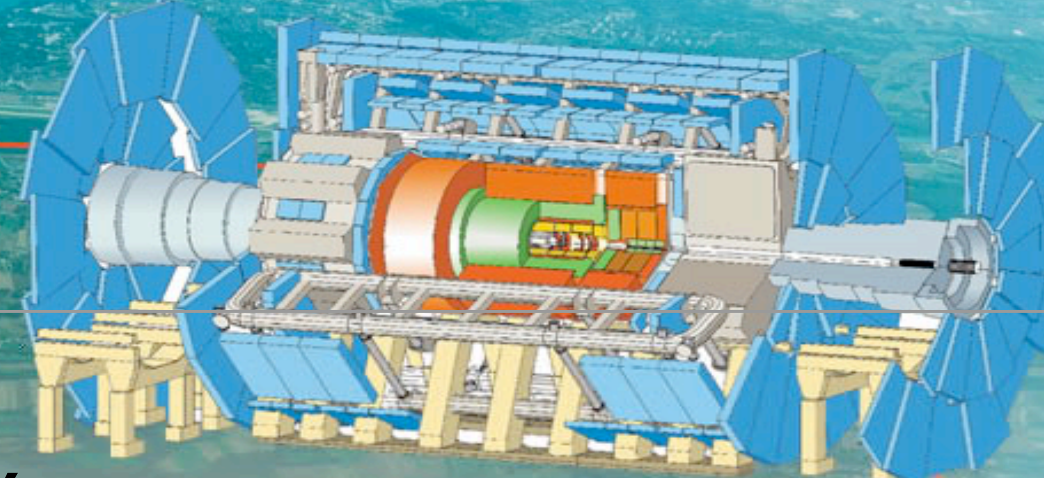
Top Quark physics with ATLAS @ LHC

LPSC, Grenoble, 31st March 2011



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Outline

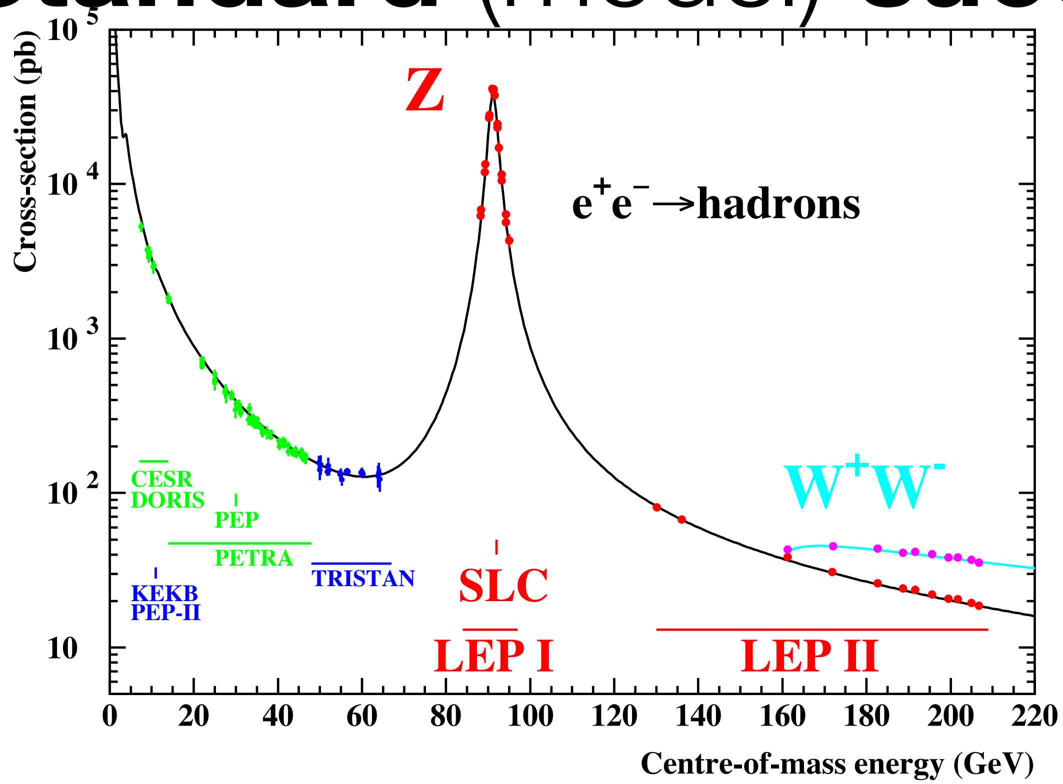
- **Why top quark?**
- **The LHC is back:** a top factory at work
- **The ATLAS detector**: a top observer
- Measuring **top quark production** (and **mass)**
- Towards new physics with top quark

Data results: hot off the press!

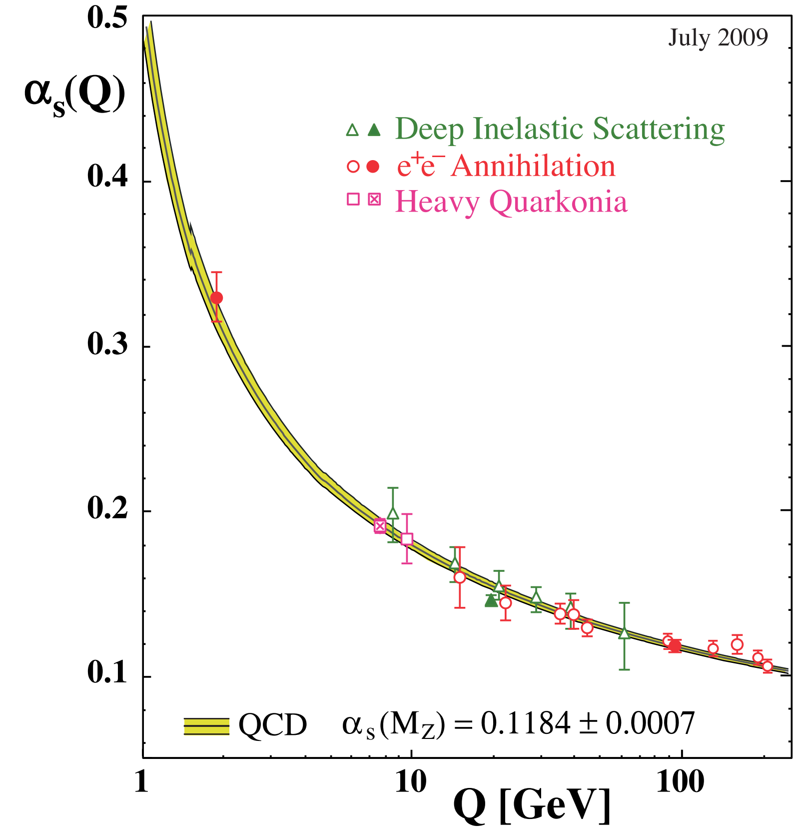
Most recent: approved 9 days ago. Oldest ~ 2 weeks.

Disclaimer: wide field, concentrate on selected topics

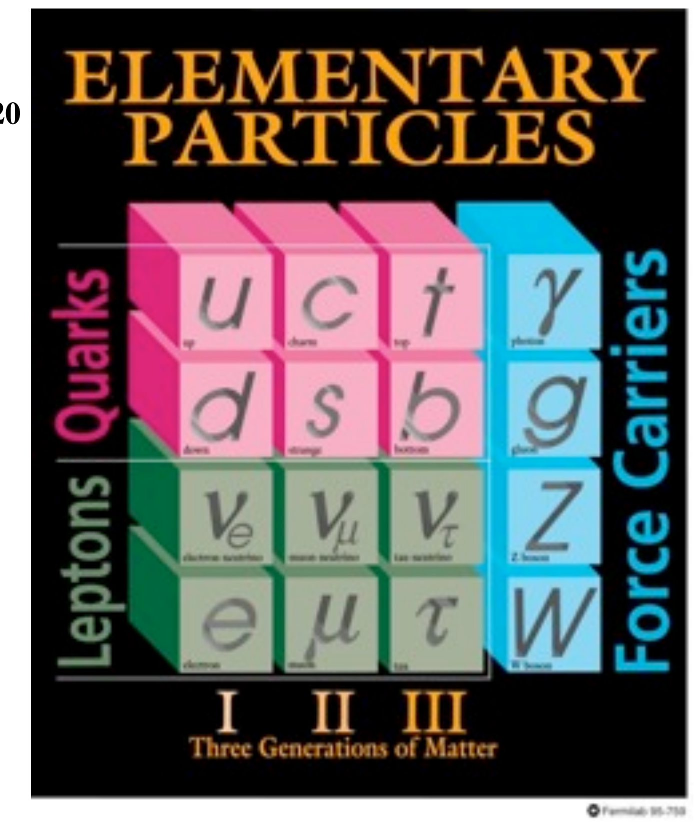
Standard (model) **successes**

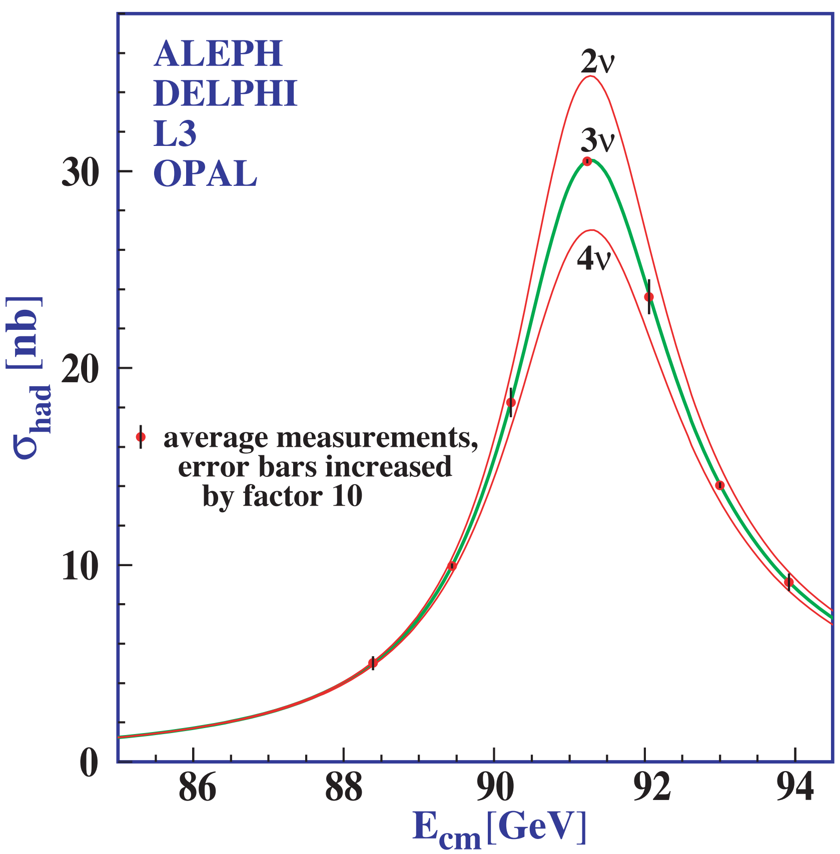


W, Z, bosons unify Electro-weak force

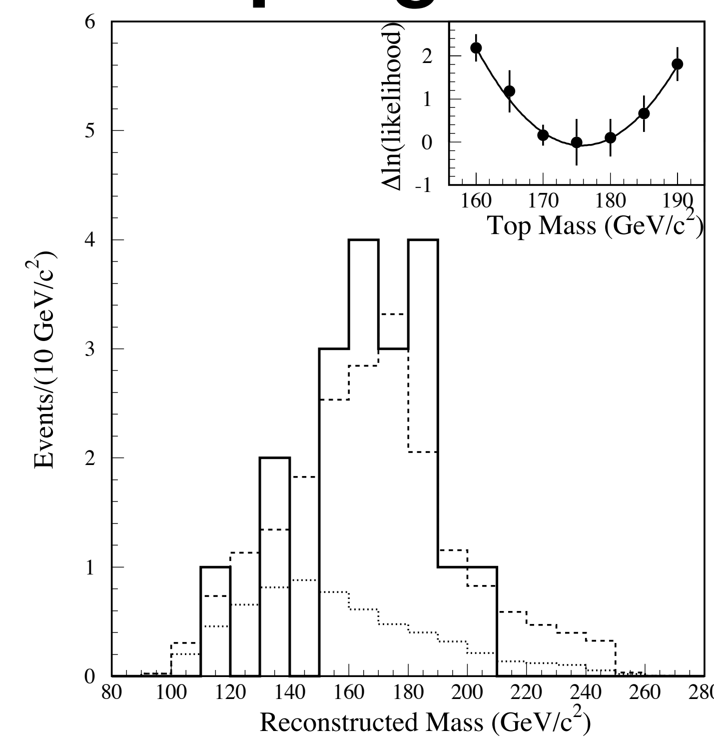


Strong coupling runs





only 3 standard neutrinos

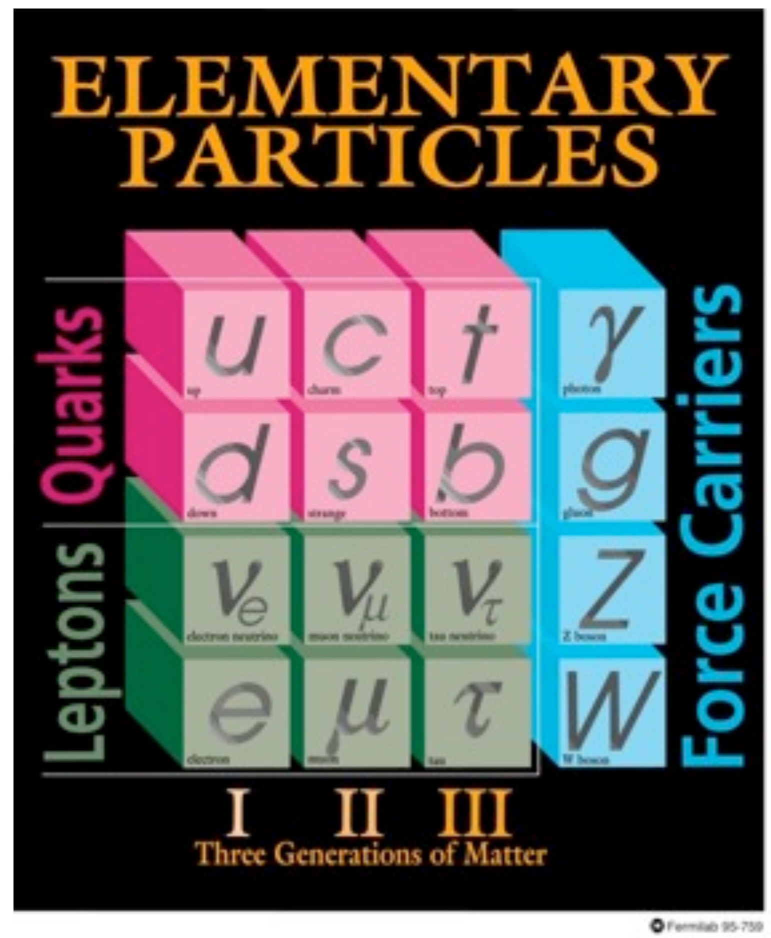


a quick (biased) selection..

Top quark is found

Standard (model) **questions**

- ***How is gravity incorporated?***
- **What is the origin of mass?**
- ***Why 3 generations with different quantum numbers ?***



- ***Why different forces (ranges, strengths)?***
- ***What accounts for the energy balance of the universe?***

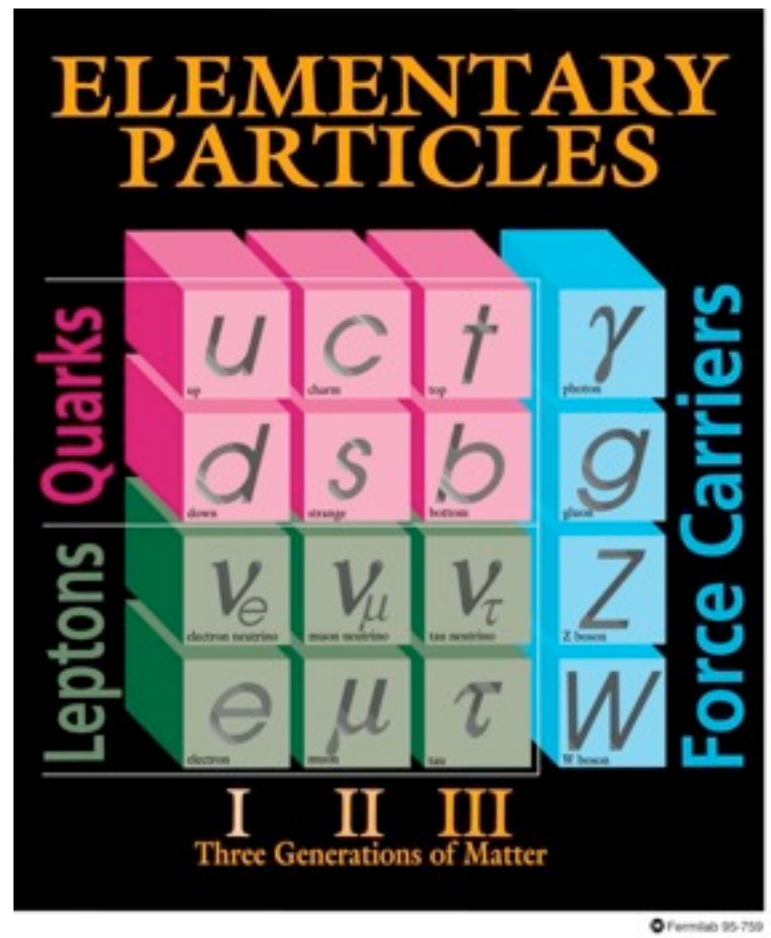
Standard (model) **questions**

- ***How is gravity incorporated?***

Quantum gravity
Extra dimensions...

- **What is the origin of mass?**

Higgs, SuperSymmetry, New Strong forces..



- ***Why 3 generations with different quantum numbers ?***

4th generation...?

- ***Why different forces (ranges, strengths)?***

String theory..

- ***What accounts for the energy balance of the universe?***

Dark matter, Dark energy...

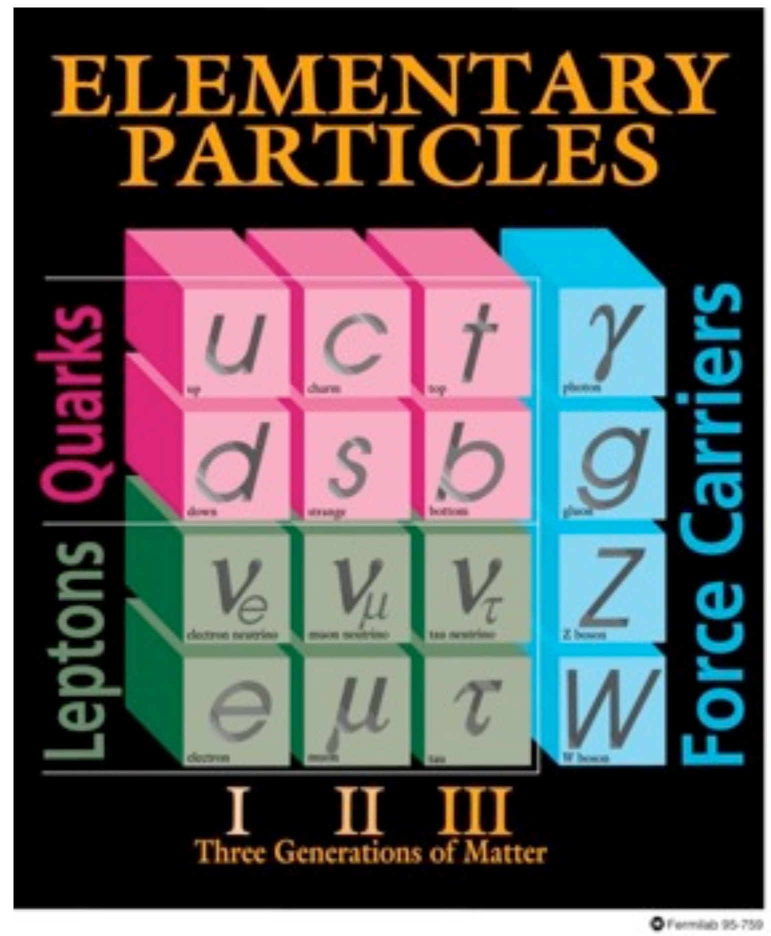
Standard (model) **questions**

- ***What is the origin of mass?***

Higgs, SuperSymmetry, New Strong forces..

- ***How is gravity incorporated?***

Quantum gravity
Extra dimensions...



- ***Why 3 generations with different quantum numbers ?***

4th generation...?

- ***Why different forces (ranges, strengths)?***

String theory..

- ***What accounts for the energy balance of the universe?***

Dark matter, Dark energy...

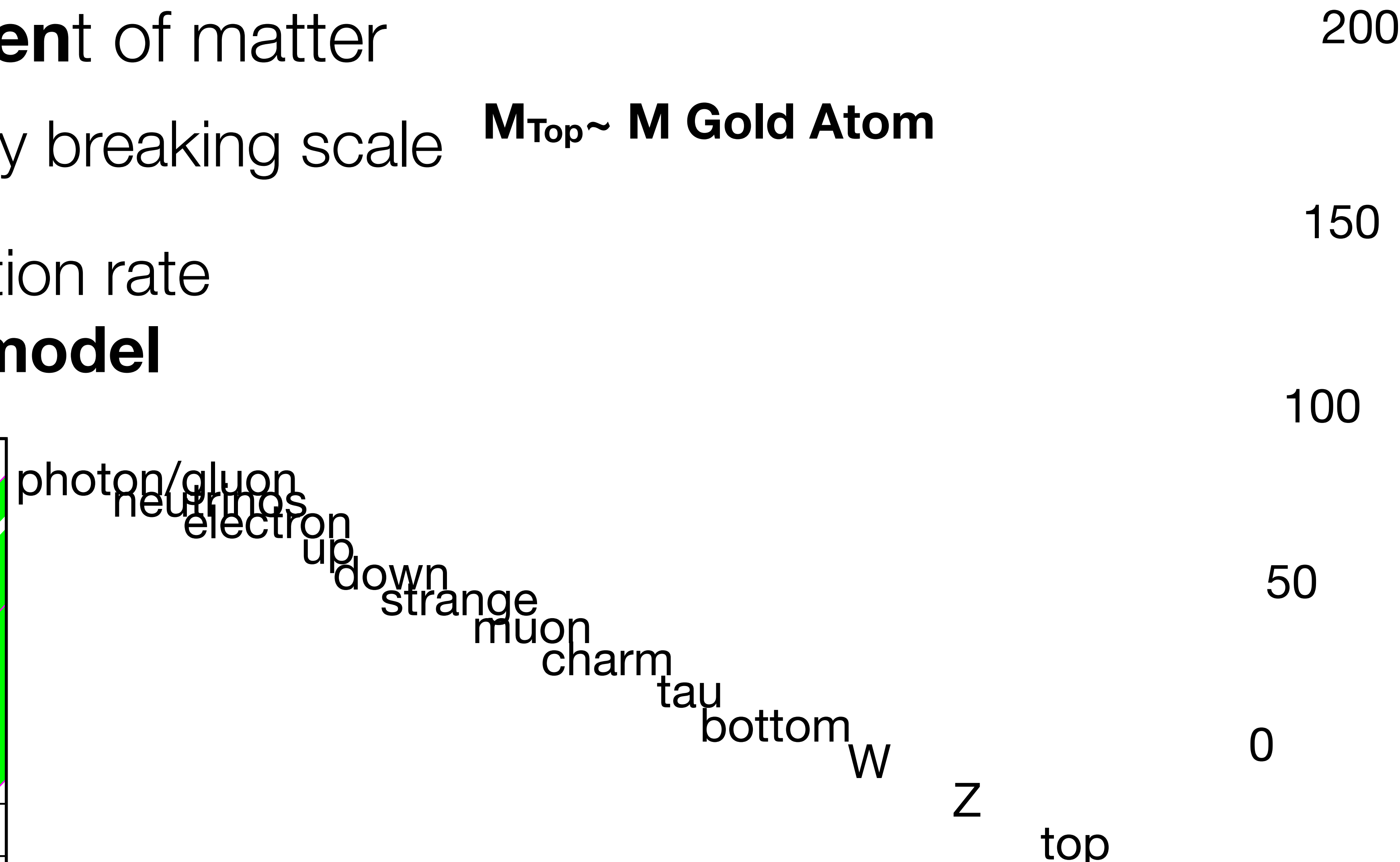
Why Top (quark)?

Most massive constituent of matter

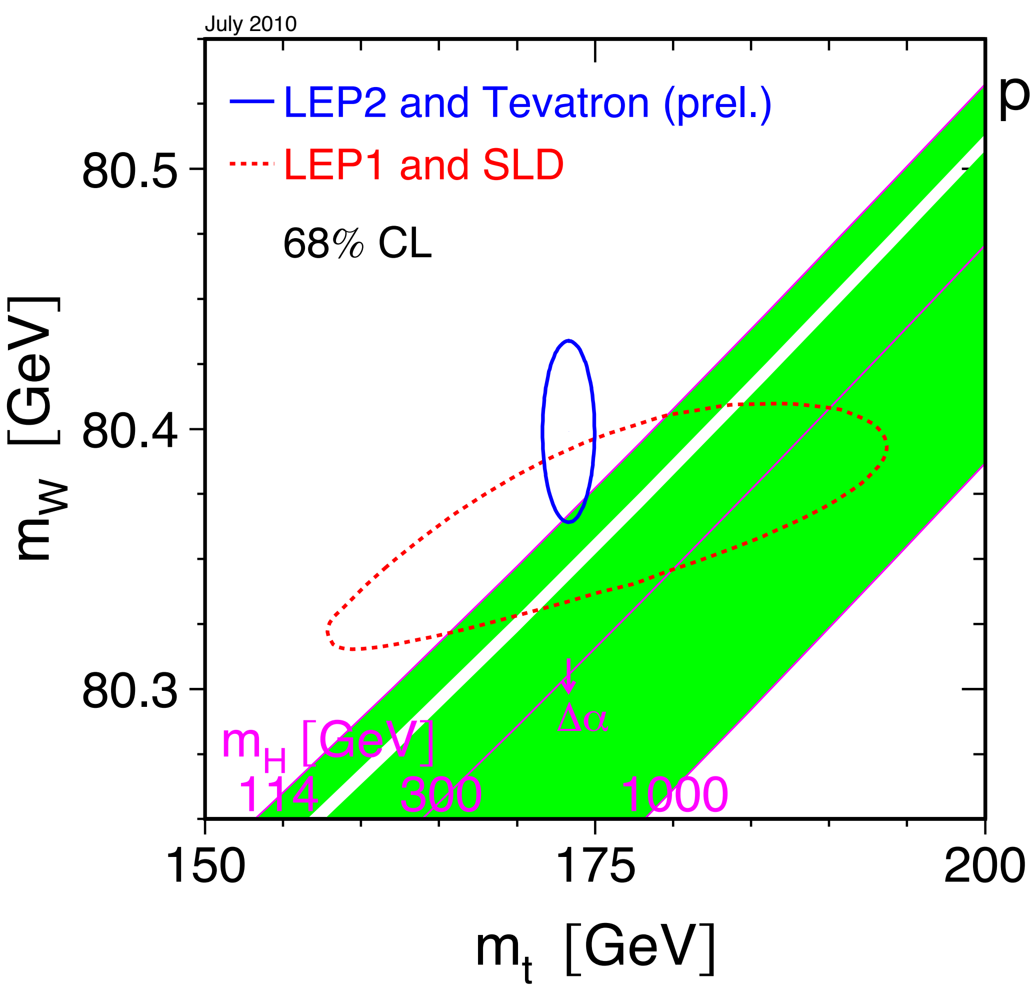
M_{top}~ electroweak symmetry breaking scale

M_{Top}~ M Gold Atom

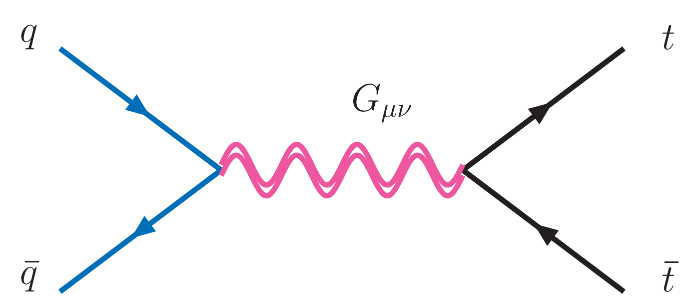
Masses of known fundamental particles

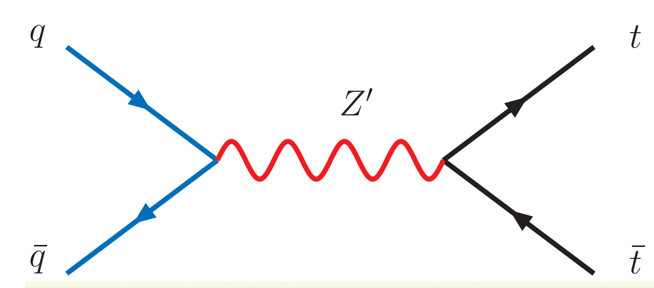


Decay and strong production rate are **tests of standard model**



Various scenarios with **direct/indirect coupling to new physics:** from extra dimensions to new strong forces



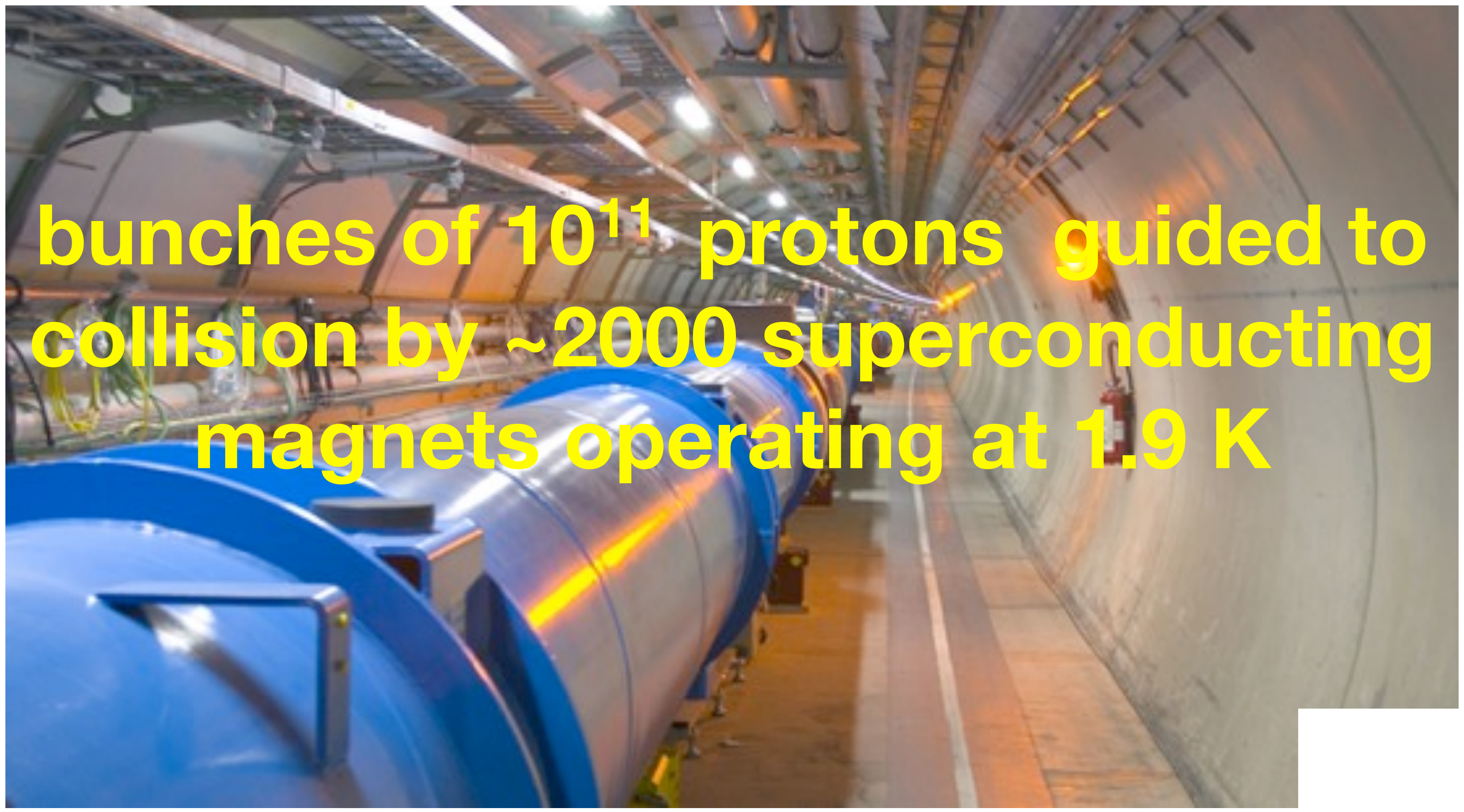


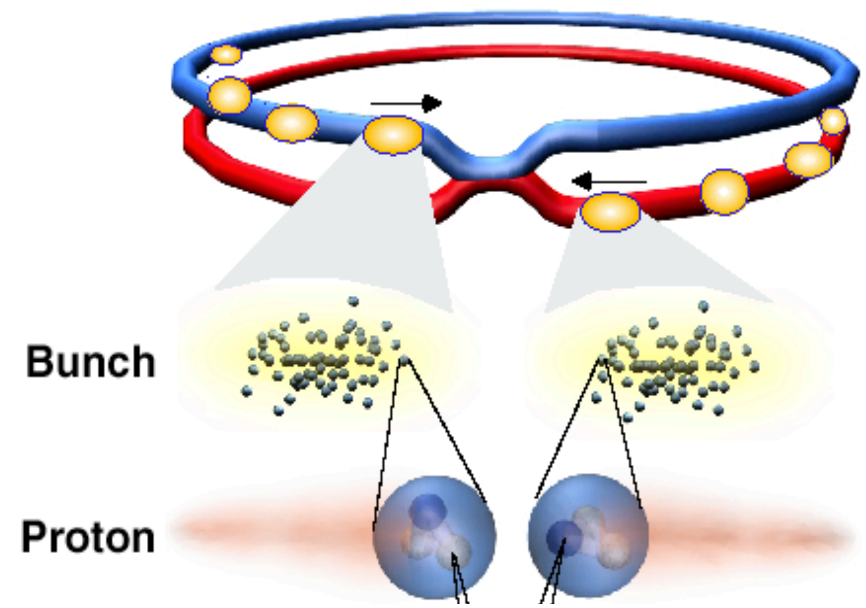
Background to possible **new physics** (Higgs, SUSY)

LHC : a *Top* producer

counter-rotating high intensity proton bunches colliding at center of mass energy (E_{cm}) = 7 TeV in 27 Km tunnel

eventually: E_{CM}=14TeV (7 TeV per beam, design value)





$$\mathcal{L} \propto \frac{N_1 N_2 n_b}{\sigma^2}$$

Key parameters:

- N_i = bunch intensity
- n_b = number of bunches
- σ = colliding beam size

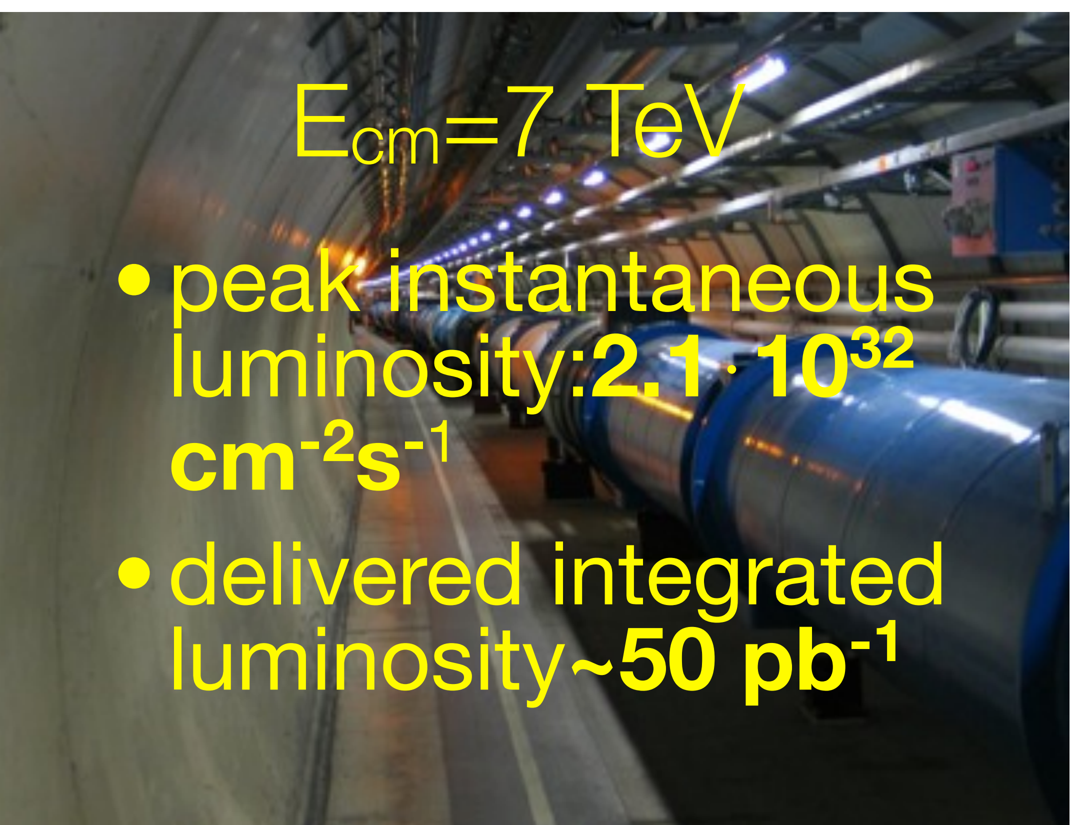
dN_{events}/dt = ***Luminosity*** * cross section

$N_{events}(\Delta t) = \int_{\Delta t} L dt$ * cross section

LHC : a *Top* producer

Ad maiora..

2010



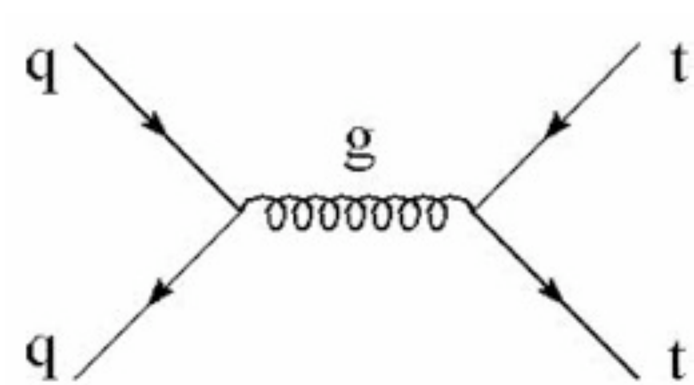
design lumi ***10^{34}cm^{-2} s^{-1}***

(30 times Tevatron p$\bar{p}$ collider)

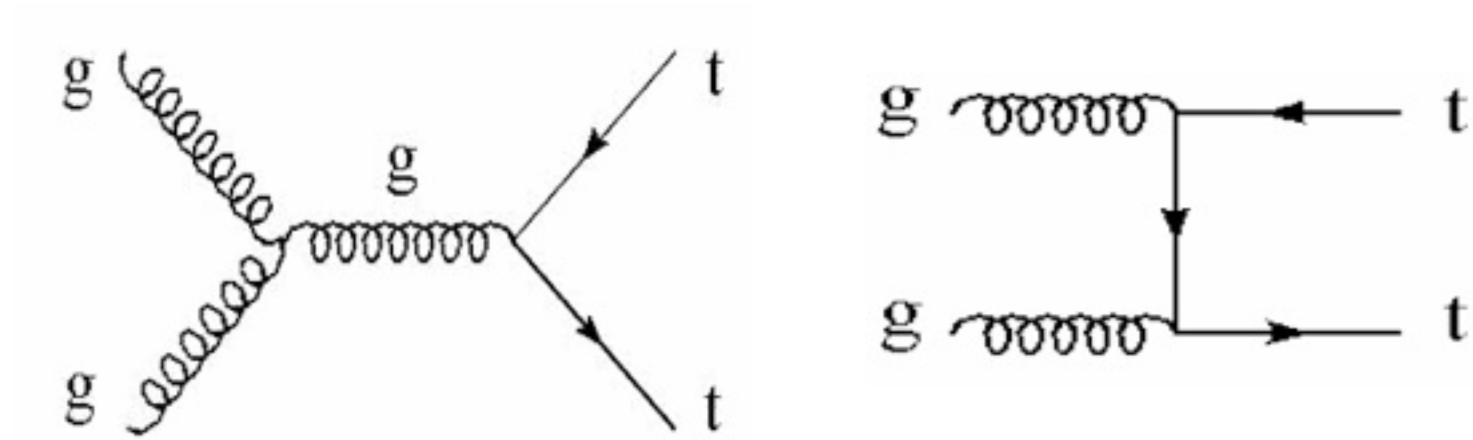
Top quark (pair) production @ E_{CM} = 7 TeV LHC

proton-proton collisions

qq annihilation



gluon fusion



~30%

~70%

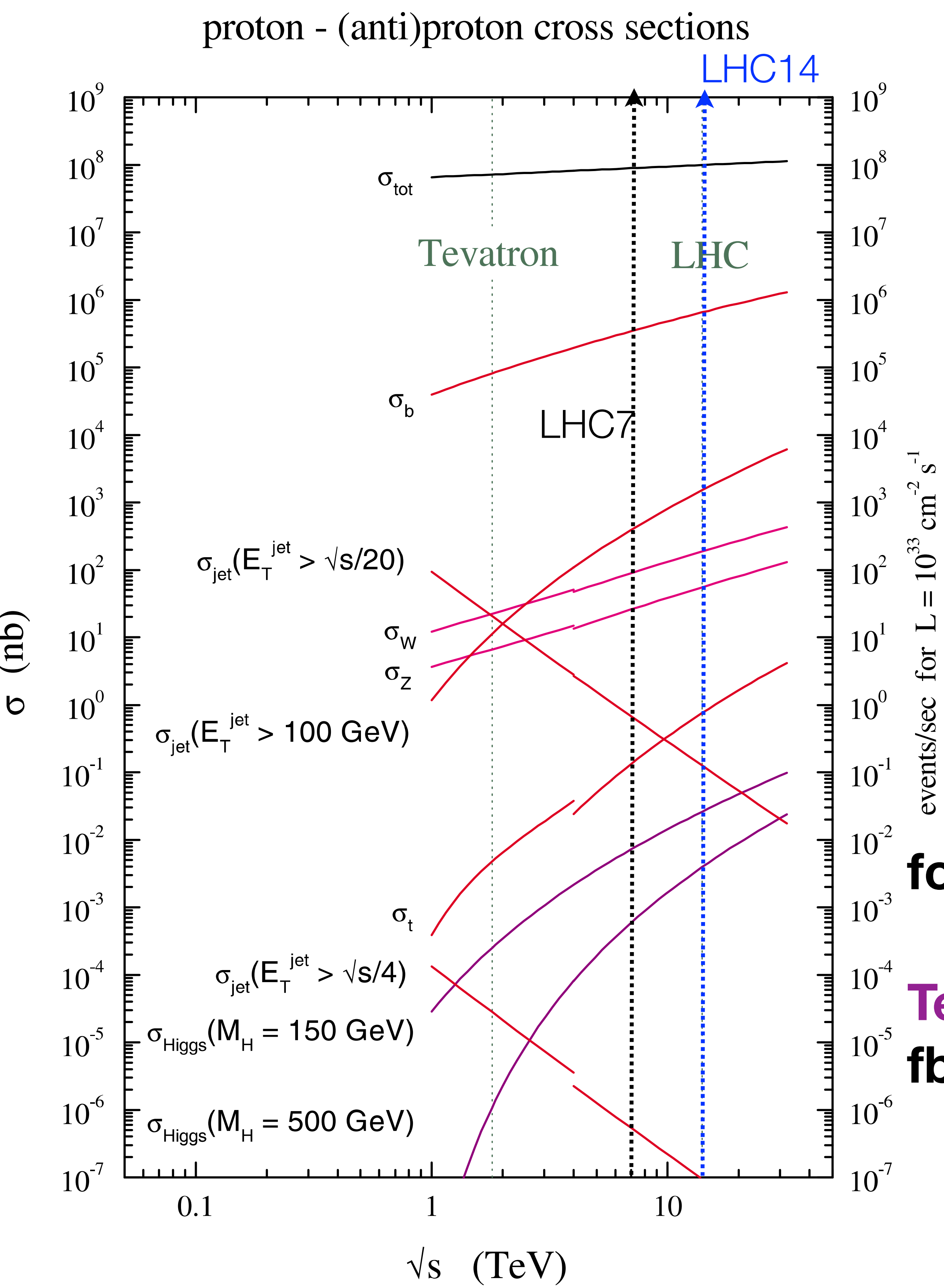
total cross section $=165^{+11}_{-11}$ pb

Aliev et al 2011
Beneke et al 2010
Langefeld Moch Uwer 2009
Moch,Uwer 2008

@ 14 TeV : qq~10%, gg ~90%

top is also singly produced, but ***focus on dominant pair production***

Top @ LHC: in the context



$t\bar{t}$ cross section

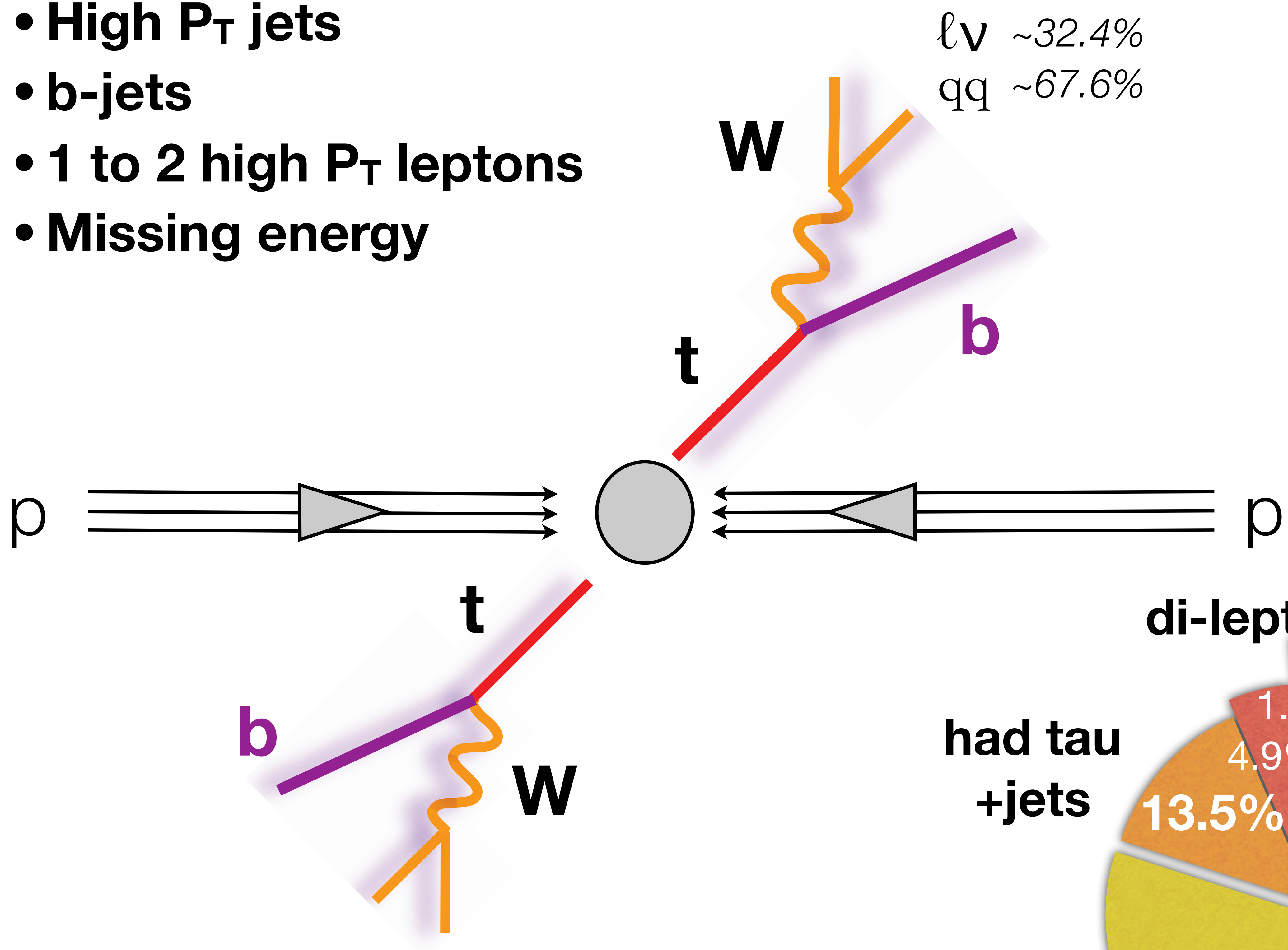
√s(TeV)	xsec (pb)	Rate at L= 10^{33}cm^{-2} s^{-1}
1.96 ($p\bar{p}$)	~7	
7 (pp)	~165	0.2Hz
14 (pp)	~900	0.9Hz

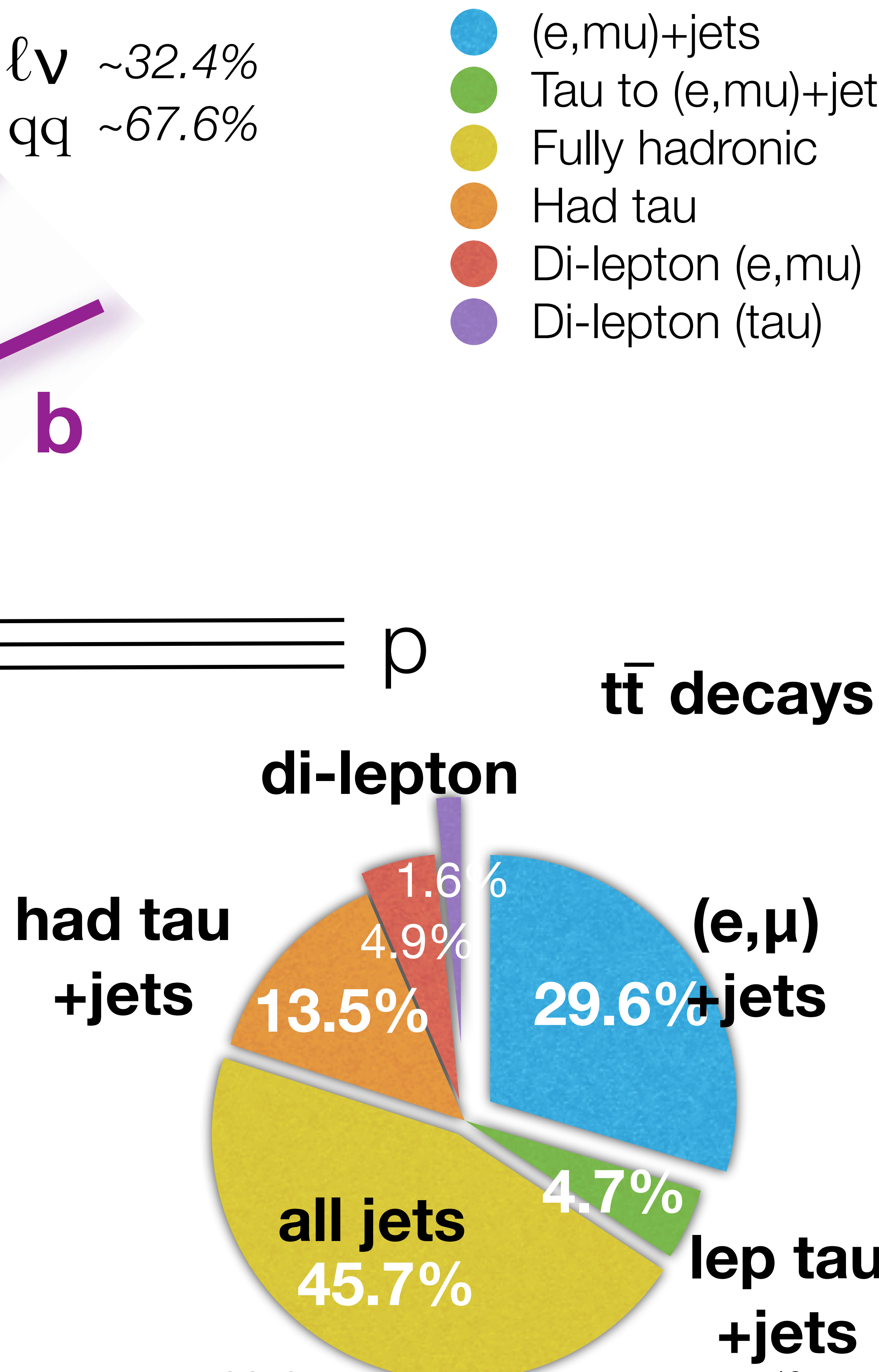
for $\int L dt$ =1 fb^{-1} @ 7TeV, expect $16 \cdot 10^4$ events

Tevatron (lower energy collider): $\int L dt$ =9.4 fb^{-1} on tape, expect ~ $6.6 \cdot 10^4$ events

Top signatures

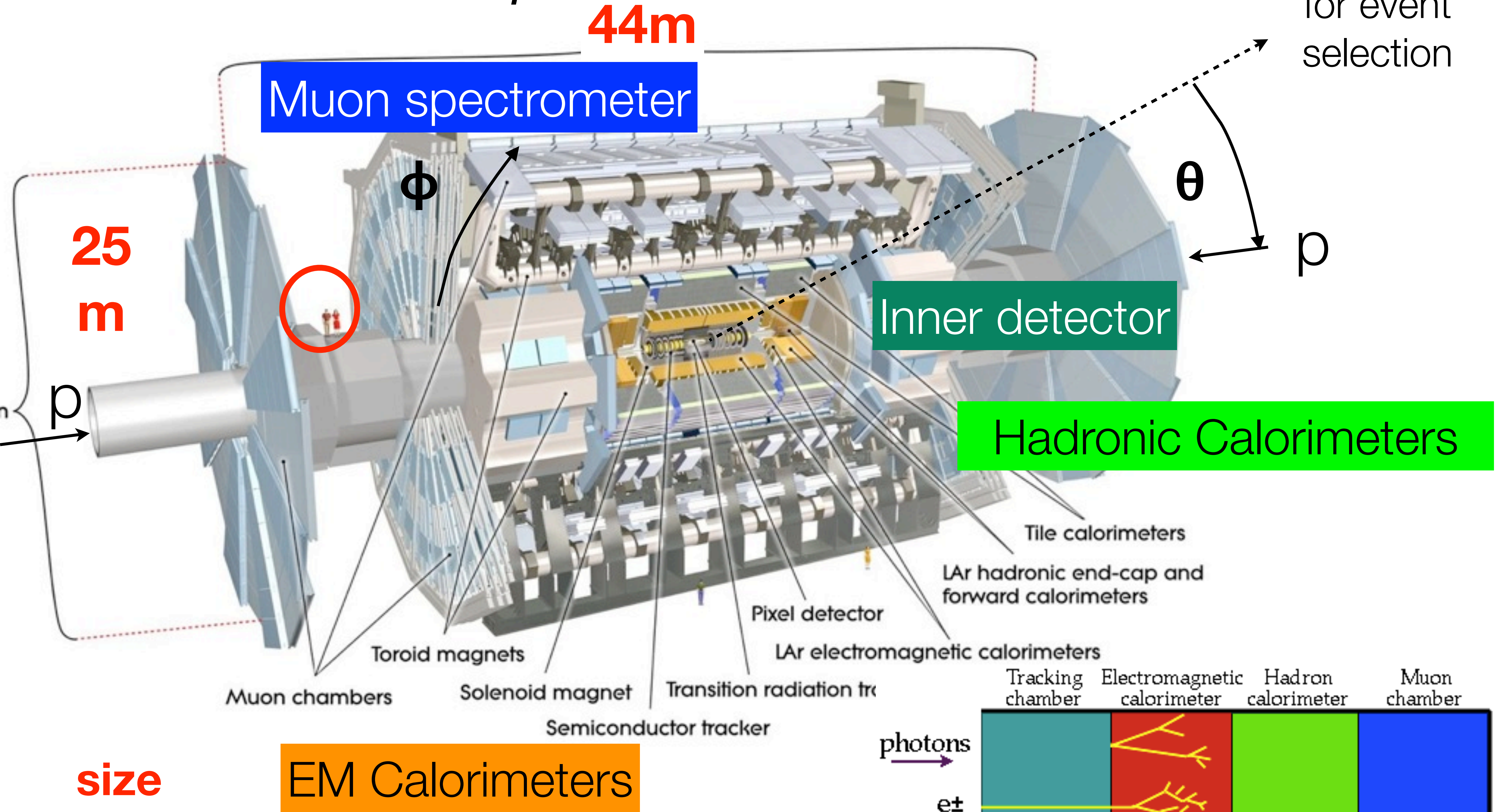
- **High P_T jets**
- **b-jets**
- **1 to 2 high P_T leptons**
- **Missing energy**





bkgs_tt̄: W/Z(+jets), single top, QCD, Di-bosons

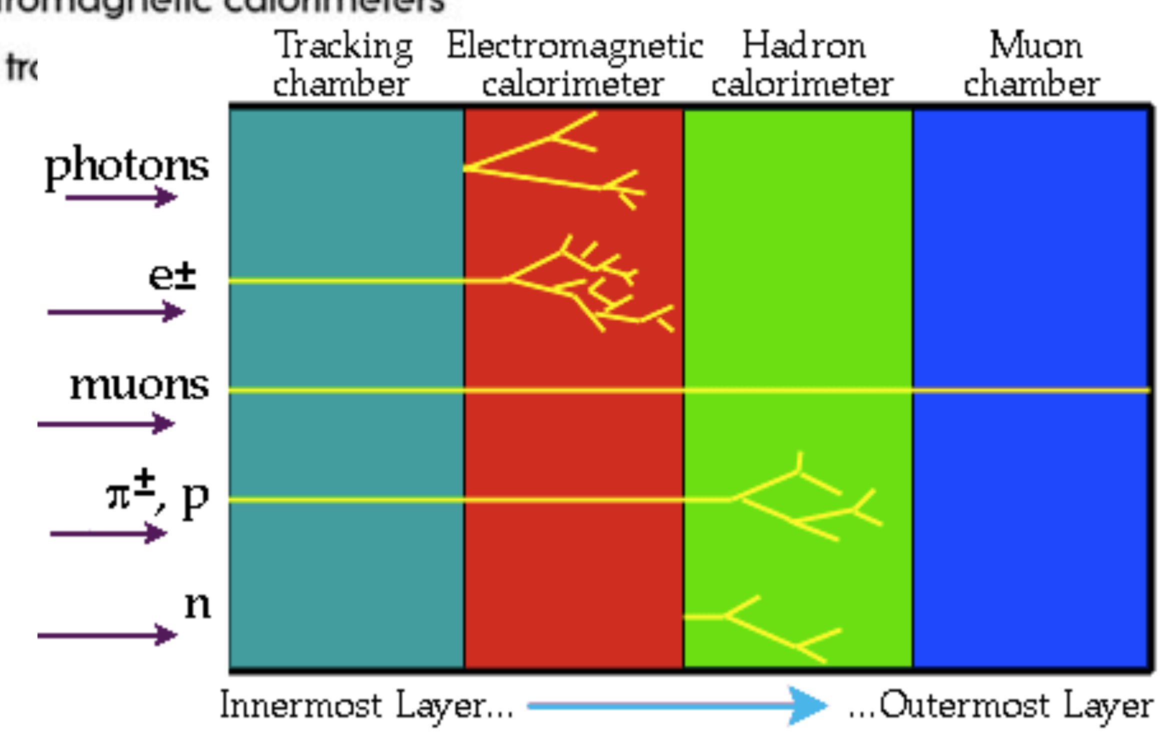
ATLAS : a *Top* observer



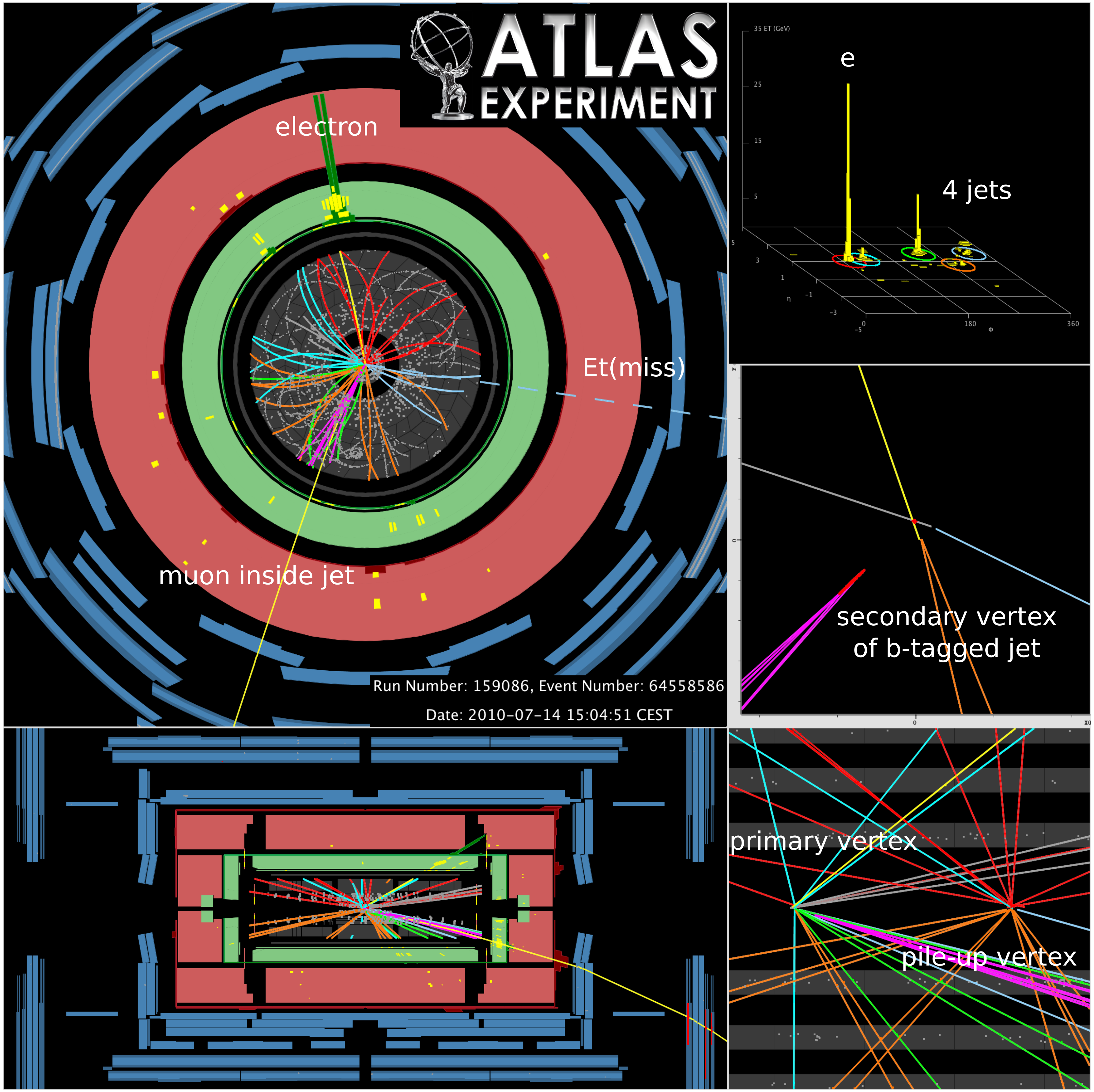
3 trigger levels for event selection

size matters

η = pseudorapidity =-ln (tan(θ/2))



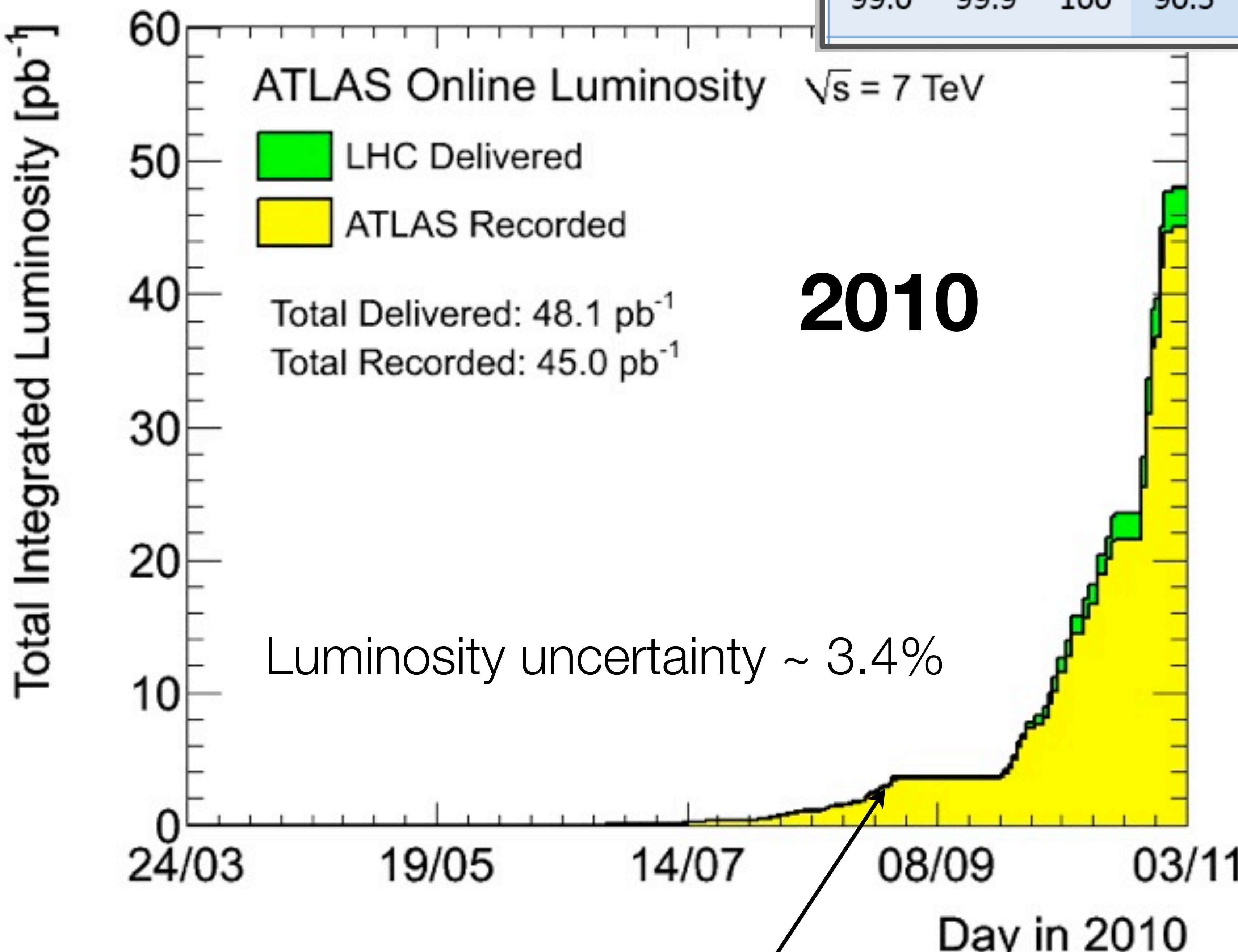
ATLAS : a *Top* observer.....



Top events are real commissioning tool: full detector at play

...with excellent data taking performance

Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC
99.0	99.9	100	90.5	96.6	97.8	94.3	99.9	99.8	96.2	99.8



Data sample for first top paper~3 pb^{-1}

For top analyses using 35 pb^{-1}

expect ~5700 $t\bar{t}$ events

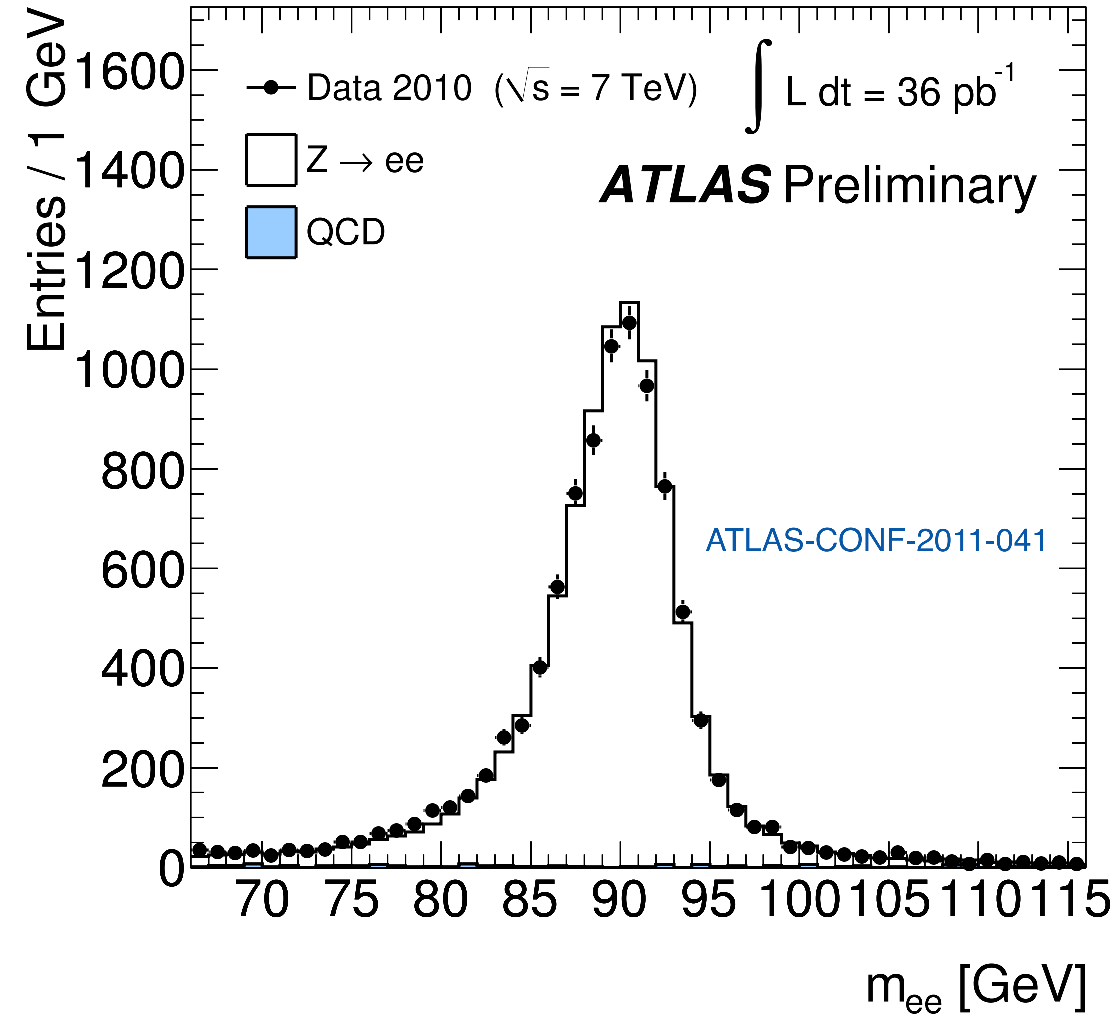
2011

Already collected ~ O(20) pb^{-1}

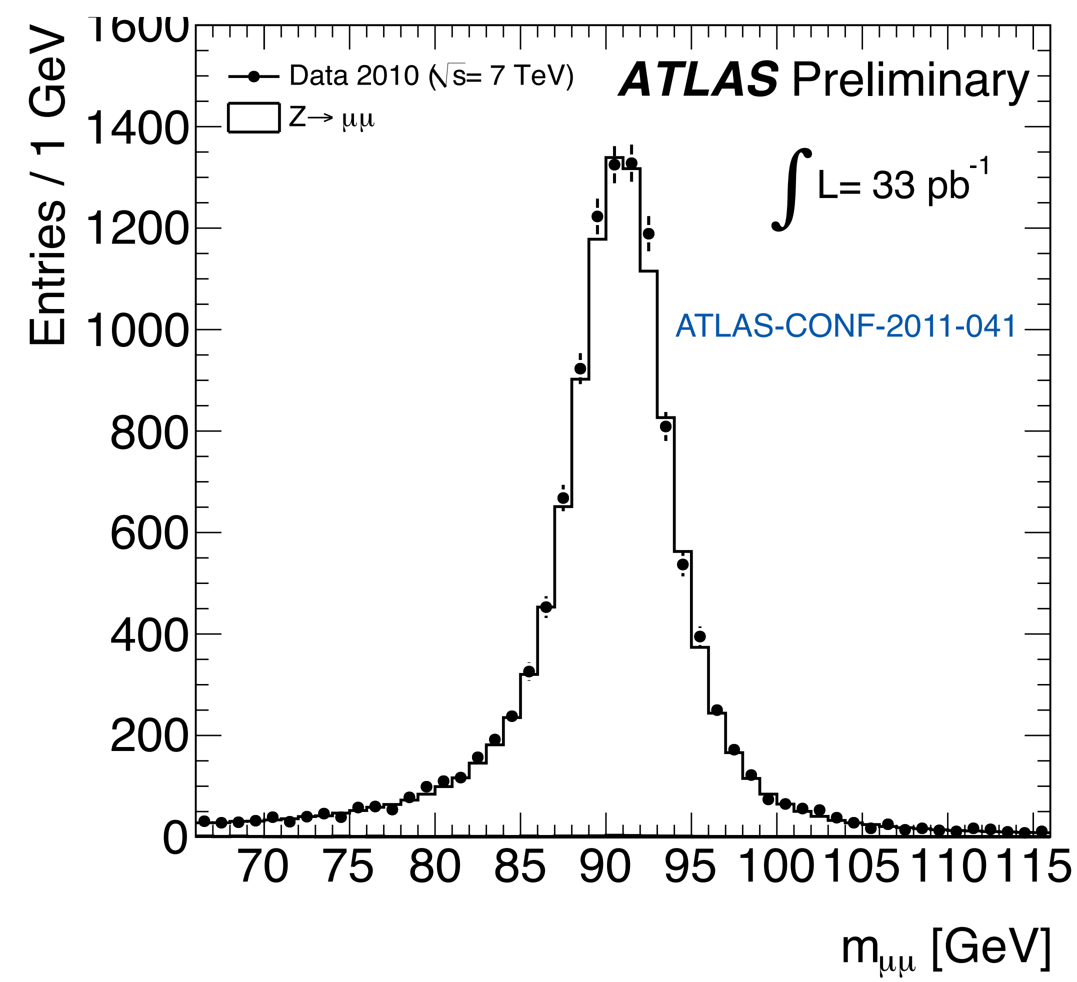
Ingredients I : leptons

* $|\eta_{cluster}| \notin$ [1.37,1,52]

- Electrons
  - **tight definition** using shower shape variables, track quality, track-cluster matching, E/p, transition radiation
  - **isolated**
  - **central***: $|\eta_{cluster}|<2.4$, $p_T>20$ GeV
  - remove close-by duplicate jets



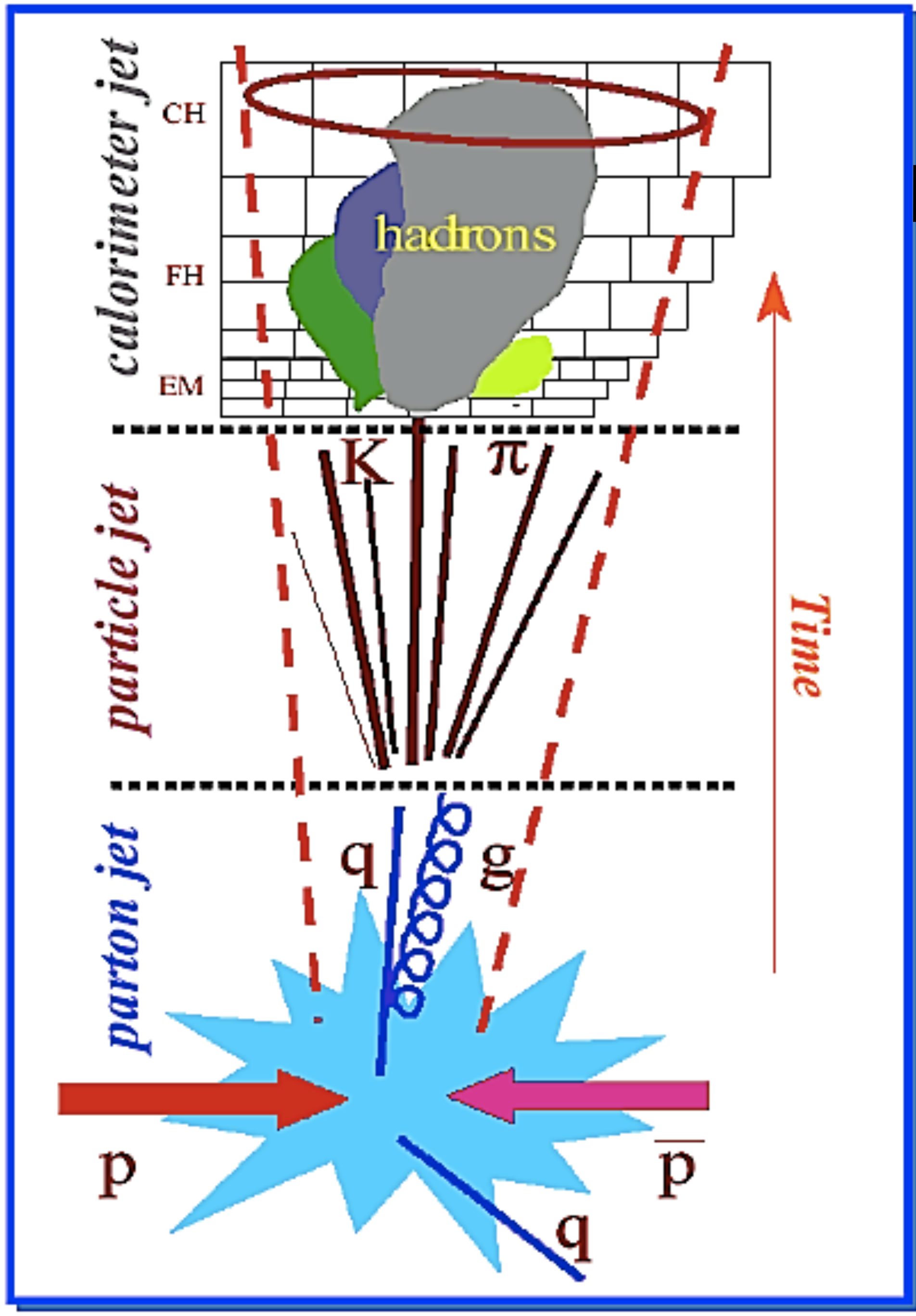
- Muons
  - **combined** fitted **track**
  - **isolated**
  - **central** $|\eta_{track}|<2.5$, $p_T>20$ GeV
  - **suppress heavy flavour decays**: no muon within DR< 0.4 of a jet



scale factors to correct small data/MC mismatch

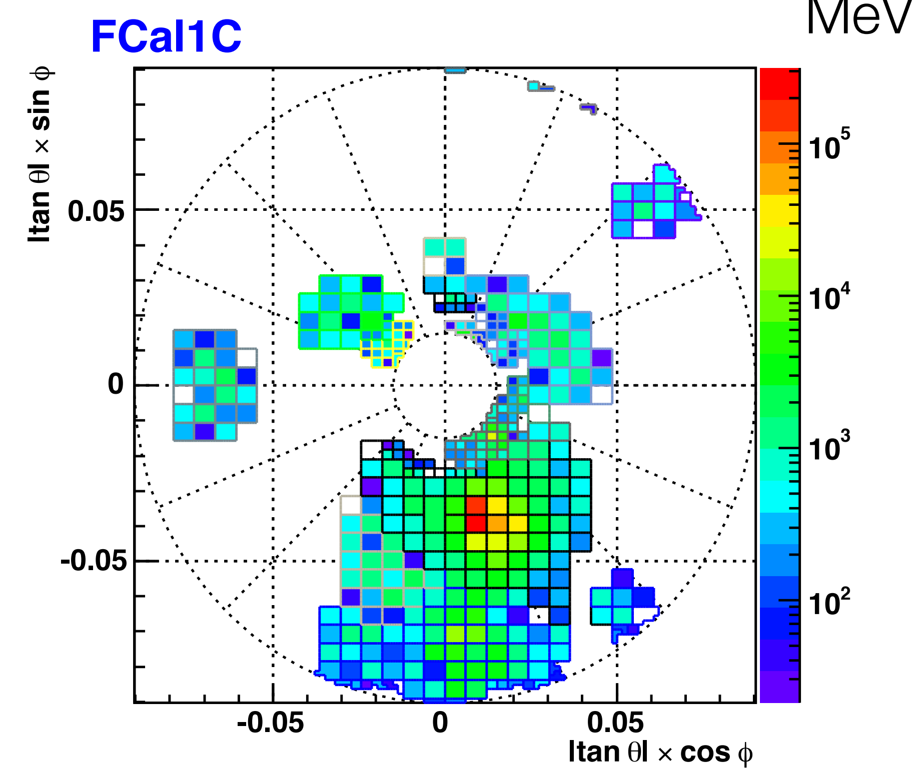
Ingredient: jets

- set of colour-less particles “remembering” momentum/colour flow from parton interaction



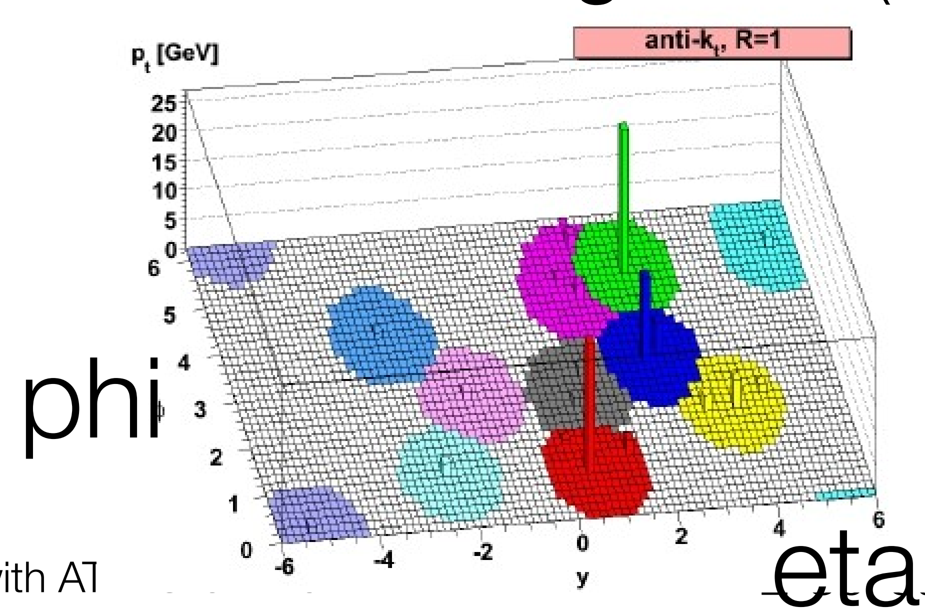
Cluster significant (E_{cell} / exp_noise_{cell}) energy deposits in calorimeters

Simulated QCD di-jet



clusters → jet

with **anti-k_T algorithm**(R=0.4) *(Cacciari,Salam, Soyez,2008)*

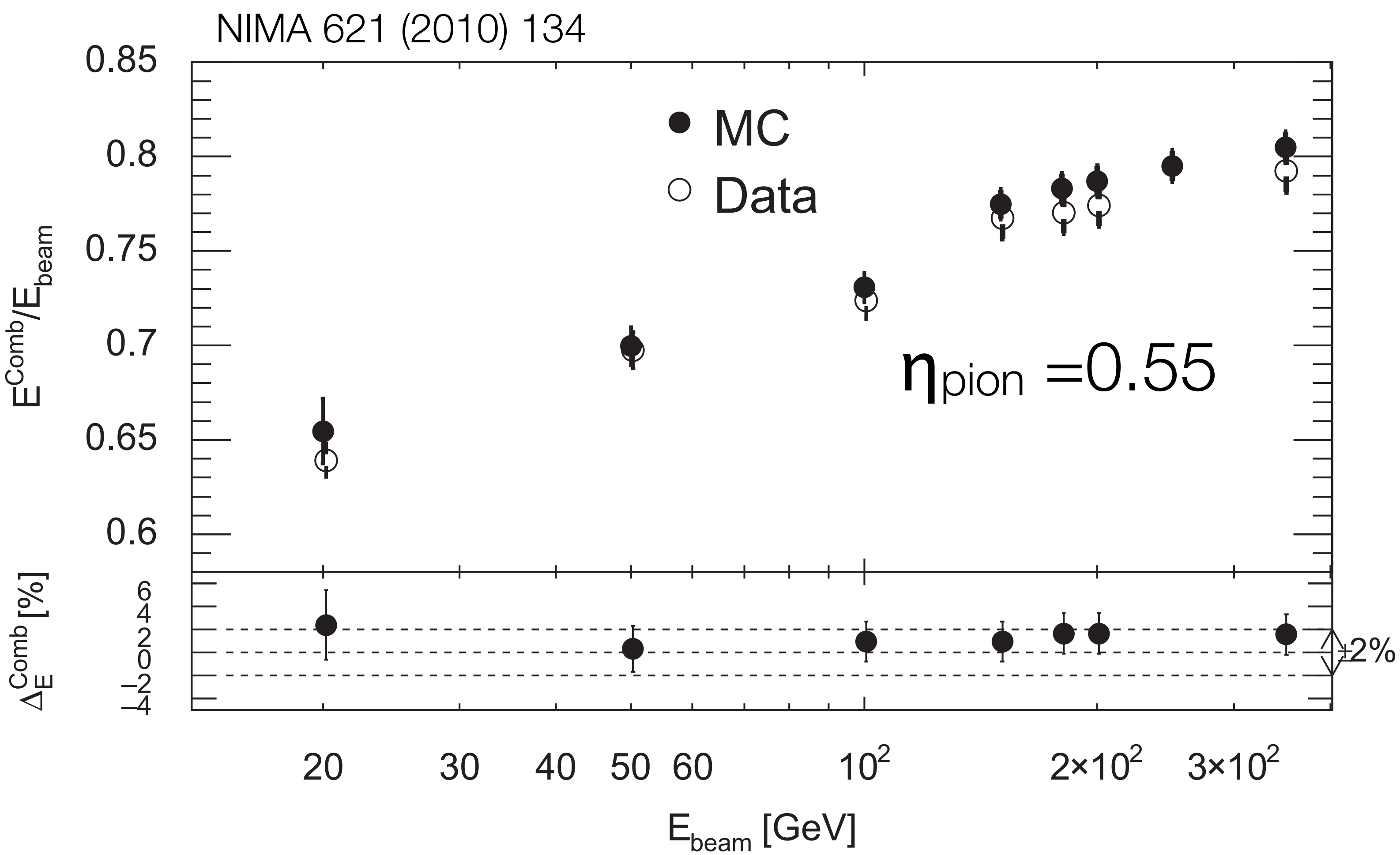


“hard stuff clusters with nearest neighbour”

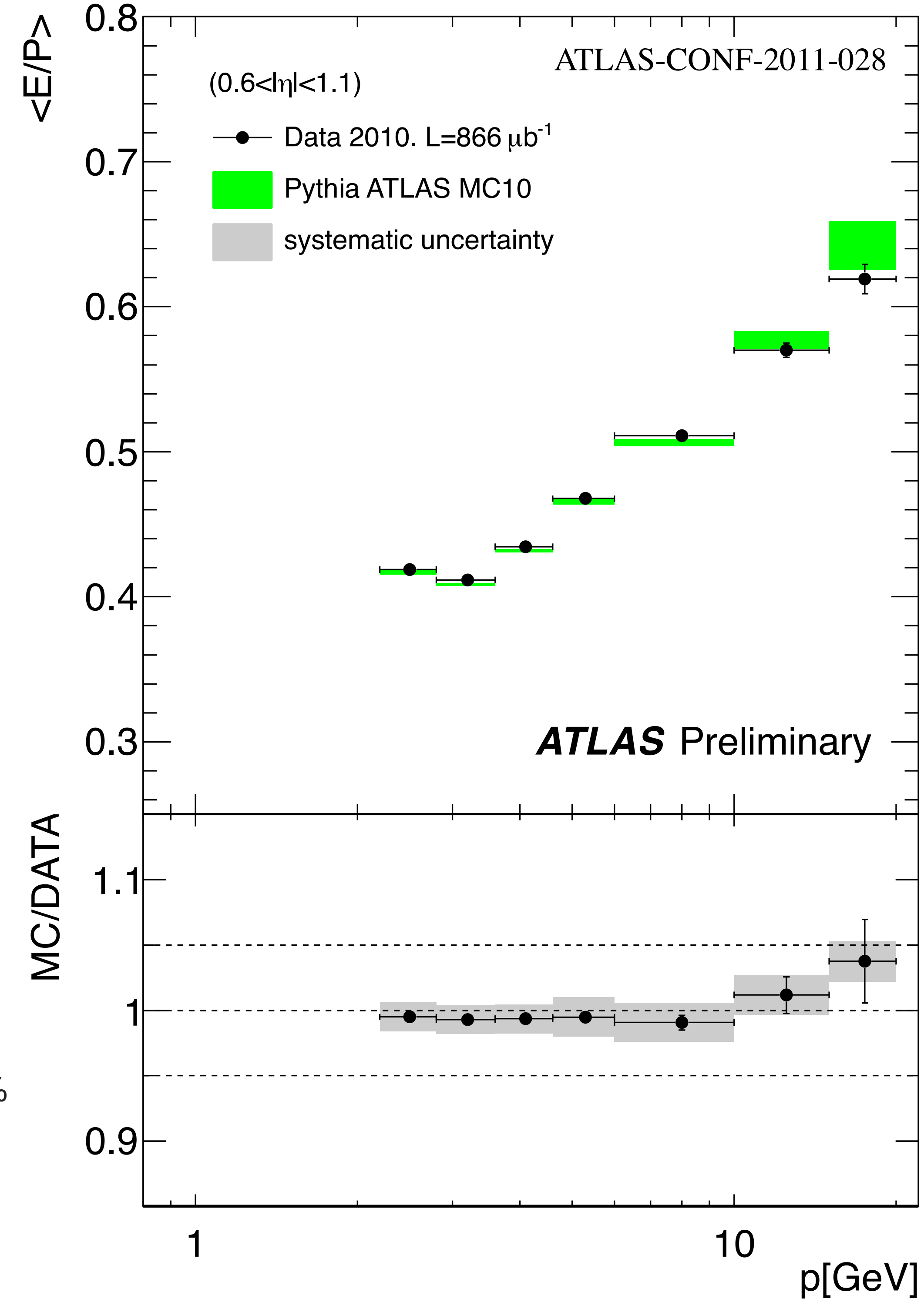
Ingredients II : jets (in the making)

Extensive validation of simulation in test-beam data →good collision data description

ATLAS test beam 2004



ATLAS colllisions 2010



Linearity within ~2%

single pion response for known beam energy

Data/MC within 2% for p<10 GeV

single isolated charged hadron response vs track momentum

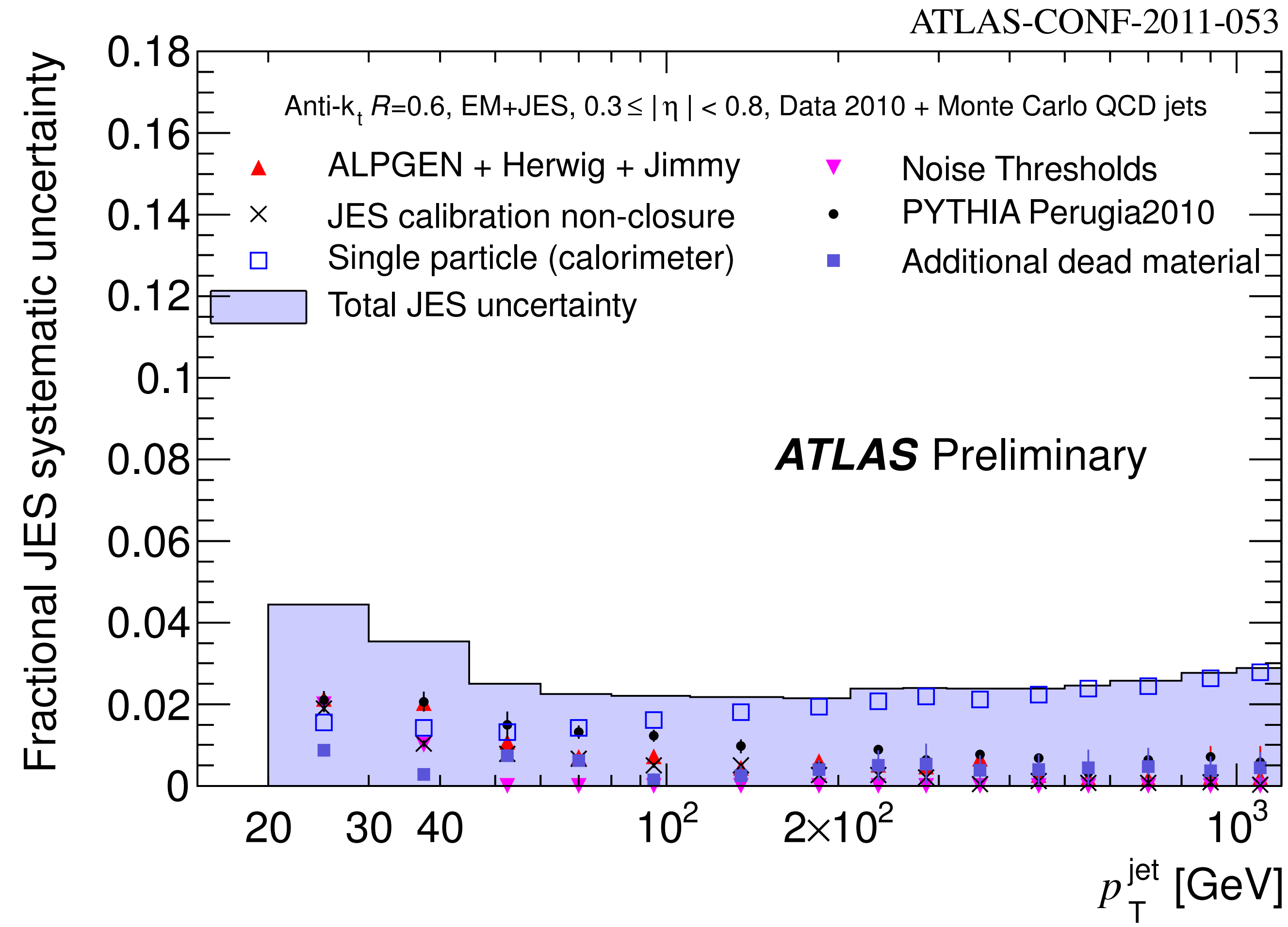
Ingredients II : jets (scale)

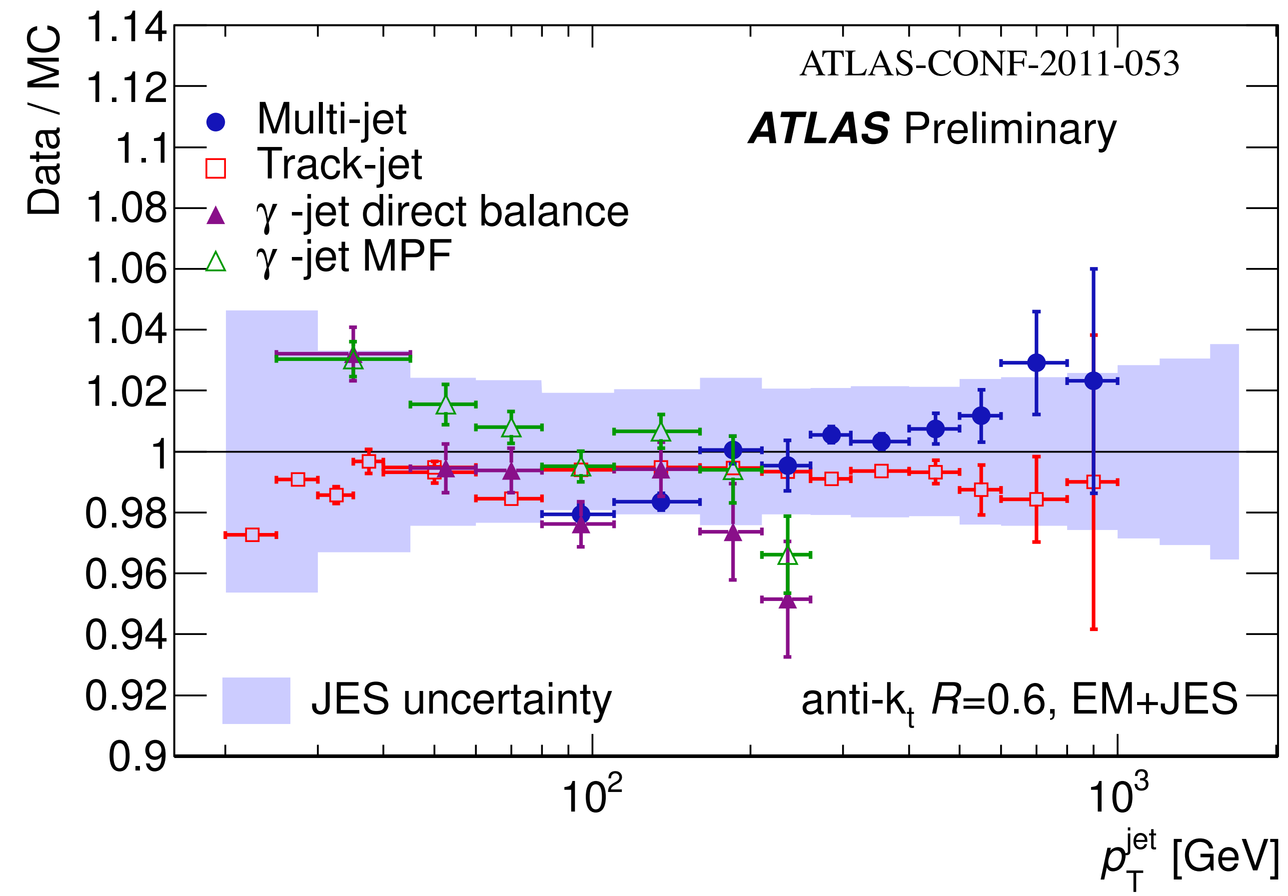
- **Calibrate jet energy scale** with (η, p_T) dependent weight ***from simulated "true" jet kinematics***

- **Scale uncertainty:** range between 2% to 8% in $\mathbf{p_T}$ and η

- Contributions from
  - Physics models for generation and hadronization
  - Calorimeter response: collision single particle data, test beam
  - Detector simulation

- Validation in control samples





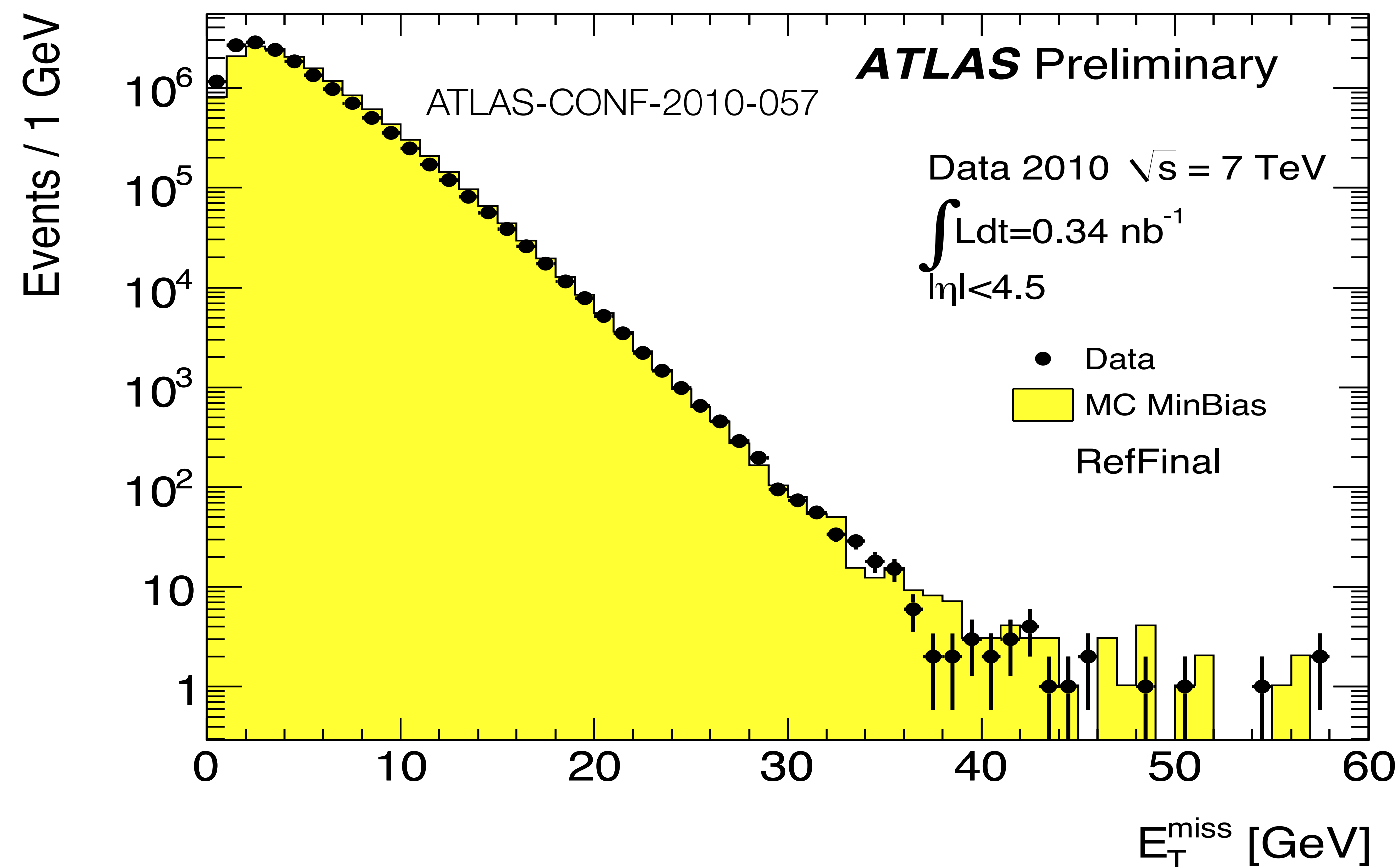
Ingredients III: missing transverse energy (E_T^{miss})

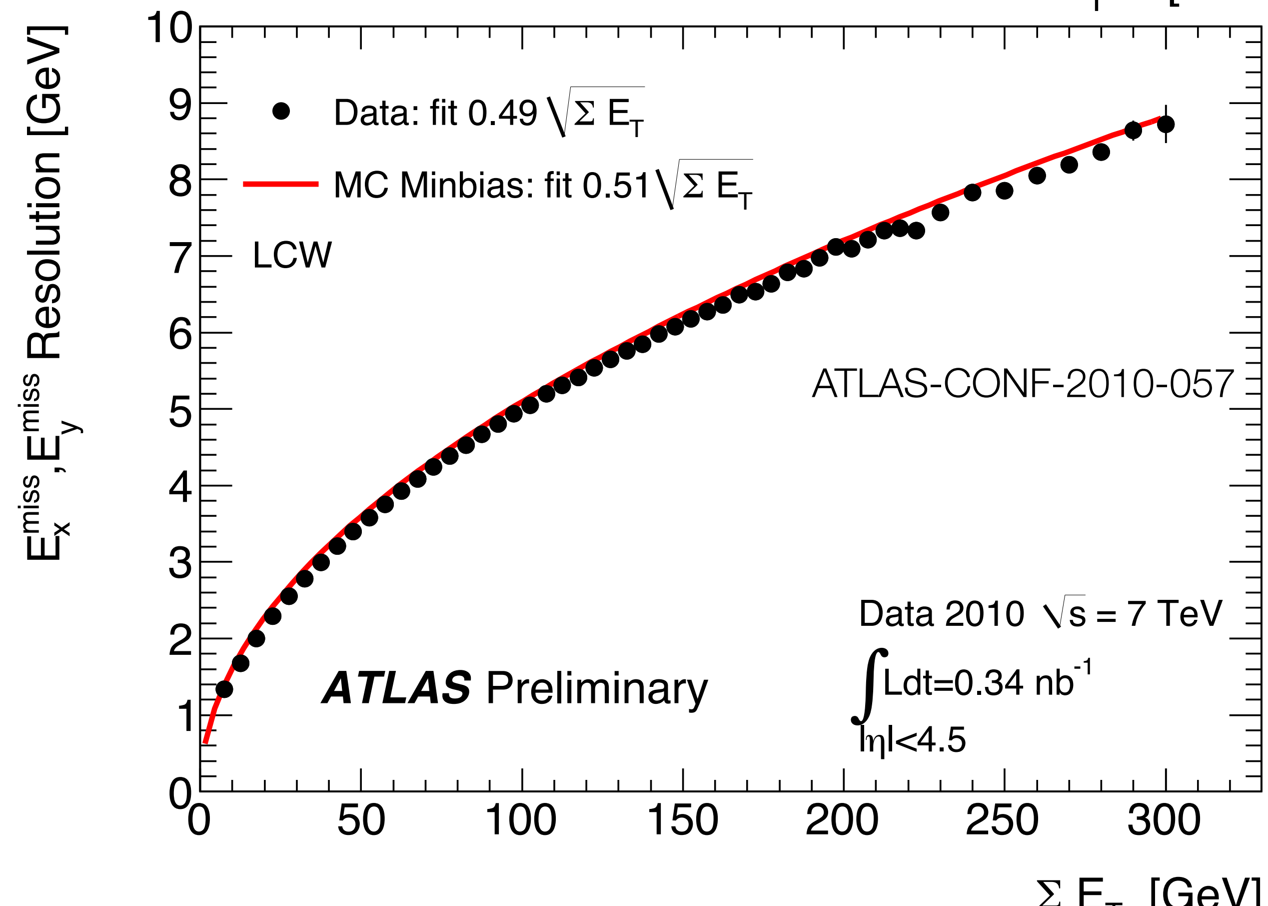
- **Negative vector sum** of
  - **energy in calorimeter cells**, projected in transverse plane **associated with high pt object**
  - **muon** momentum
  - ***dead material loss***

  projected in transverse plane

- Cells are **calibrated according to association** to high p_T object (electron, photon,tau, jet, muon)

- Remove overlapping calo cells involving jets and electrons



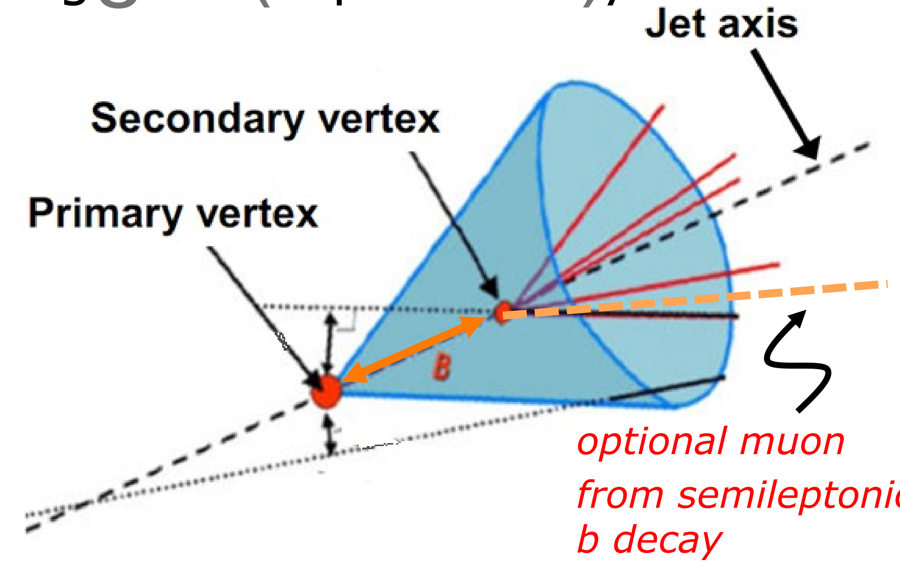


Ingredients IV : enter b-jets

- B-hadrons have long lifetime ~observable flight (few mm)

Tagging

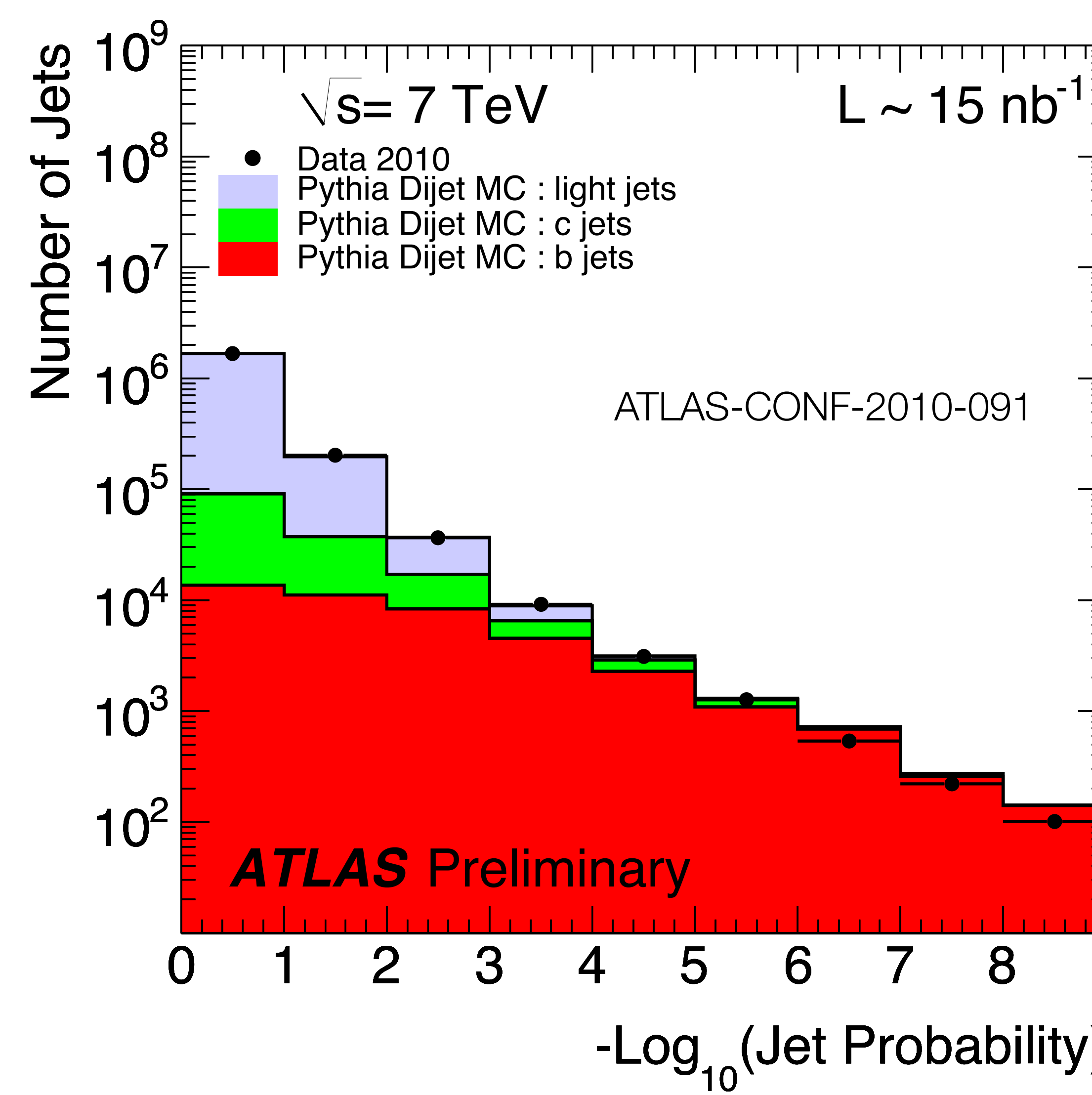
d_0/σ_{d_0}



- track impact parameter resolution d0/ σ_{d0} → **different probability for jet origin** for b-jets

Performance in data

- Fit fraction of b-jets in sample with muons in jets, *count how many are b-tagged*
- Mis-tag rate: from secondary vertex properties (*invariant mass of tracks, rate of negative decay length significance)*



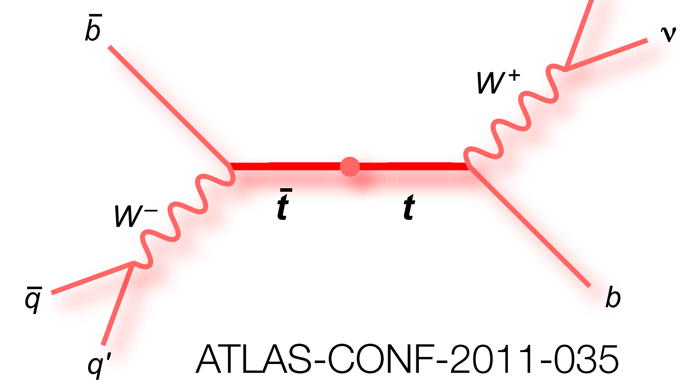
p_T dependent scale factors to correct MC

Selecting top pairs - single lepton

- **Trigger on** high p_T **single lepton**
- Good collision and good quality for jets
- **only one** high p_T central **lepton** *matching the trigger object*
- **high E_T^{miss}** *> 20 (35) GeV for e (μ) channel*
- **Large transverse leptonic W mass*** *> 25 GeV(60GeV - E_T^{miss}) for e (μ) channel*
- **≥ 1 central** high p_T **jet**

  p_T> 25 GeV

$\int L dt$ =35 pb^{-1}



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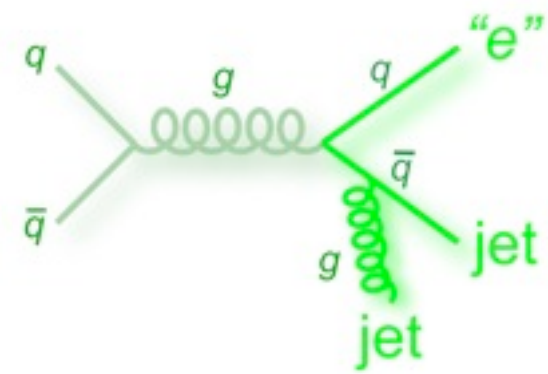
data-driven

	e		μ	
	3jets	≥4jets	3jets	≥4jets
tt	116	193	161	273
QCD	***62***	***21***	***121***	***50***
W+jets	**580**	**181**	**1100**	**320**
Z+jets	32	18	69	25
Single t	22	11	32	15
WW,WZ,ZZ	9	3	16	4
Total Exp	**830**	**431**	**1500**	**680**
Data	**781**	**400**	**1356**	**653**

$$^{*}= \sqrt{2 p_T^{\ell} p_T^{\nu} (1 - \cos(\phi^{\ell} - \phi^{\nu}))}$$

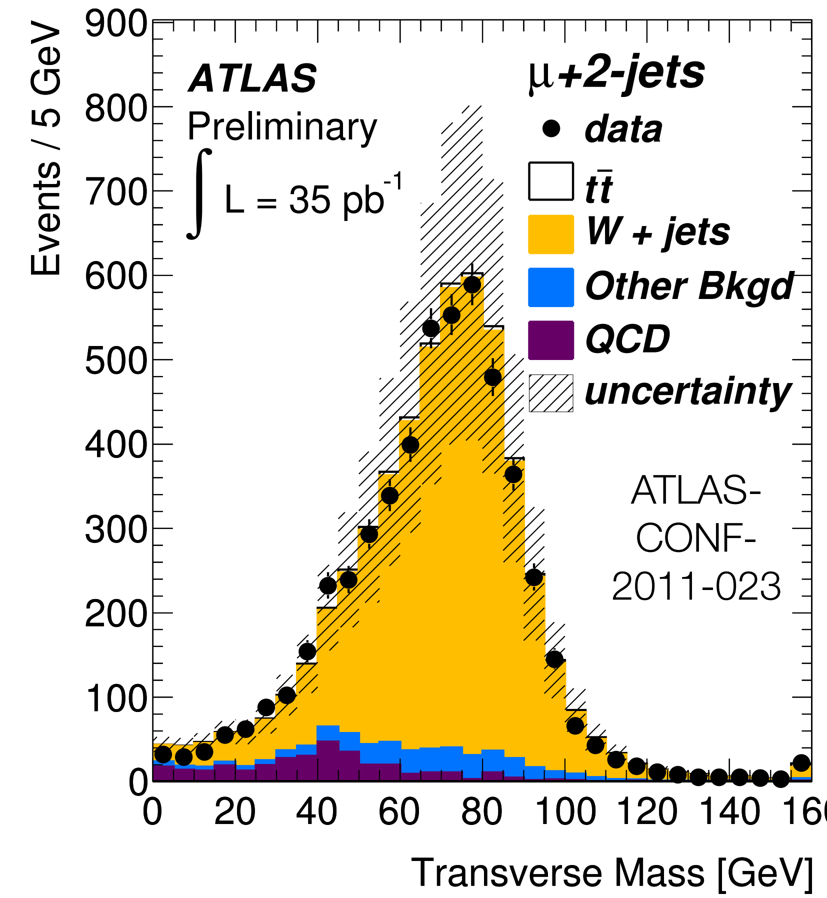
Background estimates: QCD multi-jet -single lep *with btag*

- "Fake" leptons: mis-id jets,$\gamma \to e^+e^-$, non-prompt leptons (b/c-decays)



μ channel: matrix method

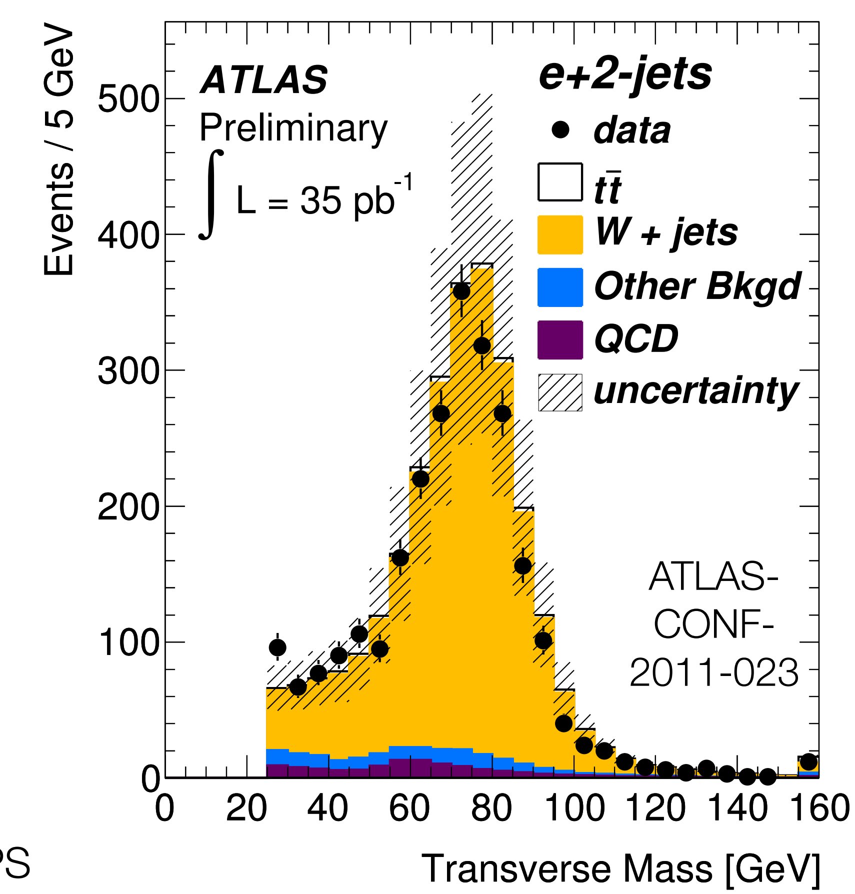
- **Derive probability of real and fake μ to be isolated** ← control region *(low E_T^{miss}, M_T^{W} and $Z \to \mu^+\mu^-$)*
- Combine with measured N(isolated μ) and N(non-iso μ) events → **find isolated fake muons**



- Do it in bins of any variable to get standard estimate

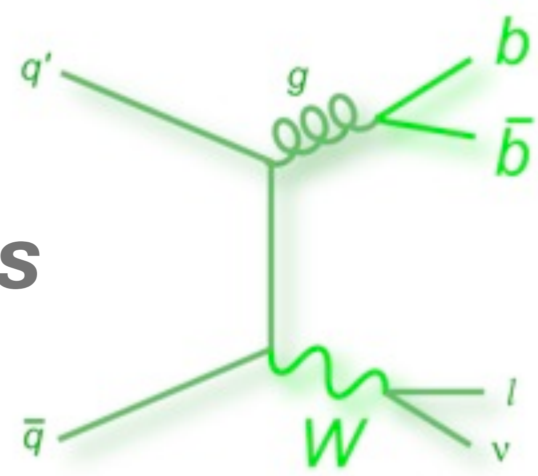
e channel: template method

- **Derive QCD template** ← control region *(electron fails one/more selection criteria)*
- **Normalize by fitting low E_T^{miss} shape** *(QCD template + MC samples)* **to data → extrapolate to** standard region



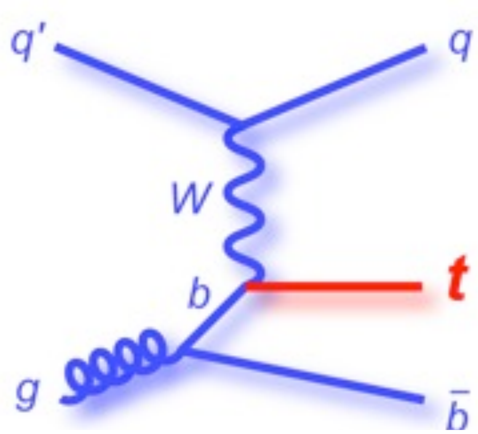
Backgrounds estimates - single lepton *with b-tagging*

- **W+jets**

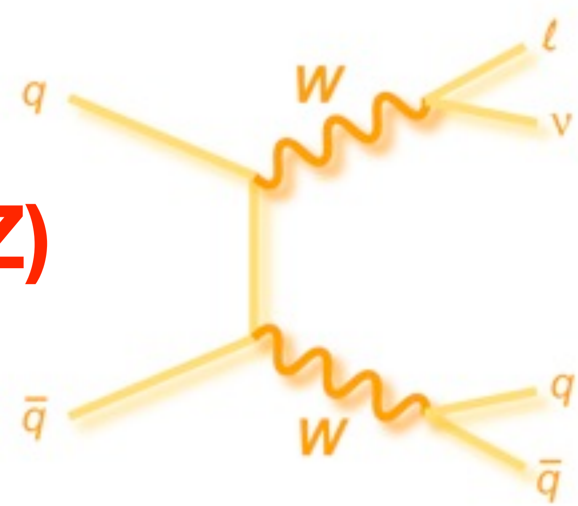


- *simulated shape*
- ***data-driven normalization*** *for high jet multiplicity bins (>=3) ←extrapolate content of 1 and 2 jet bins before tagging*

- **Single top**



- **Di-bosons (WW,WZ,ZZ)**



Simulated + rate set to SM prediction

After all cuts

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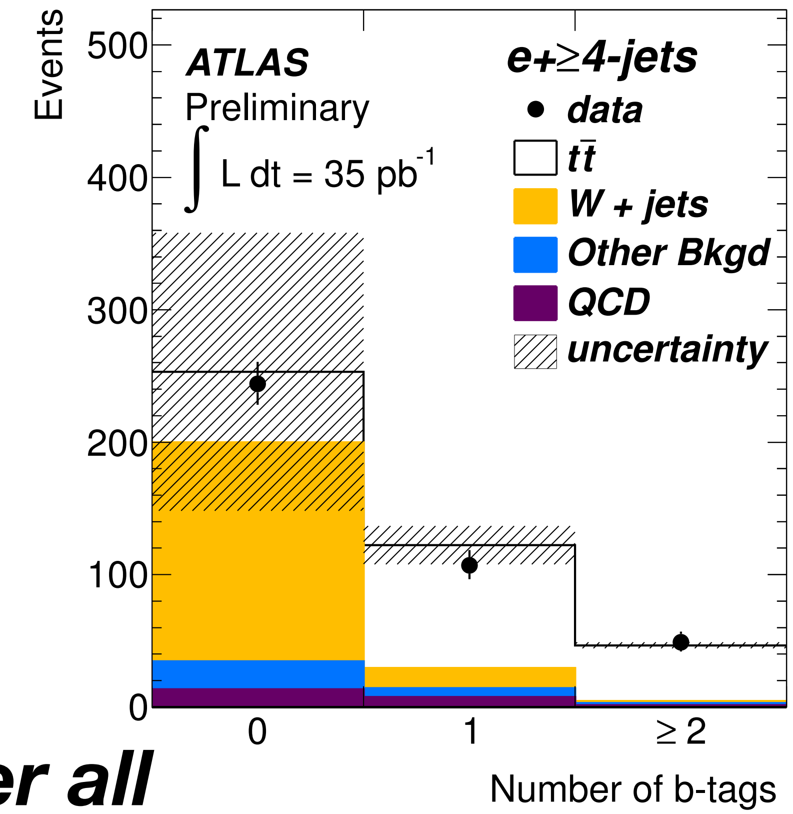

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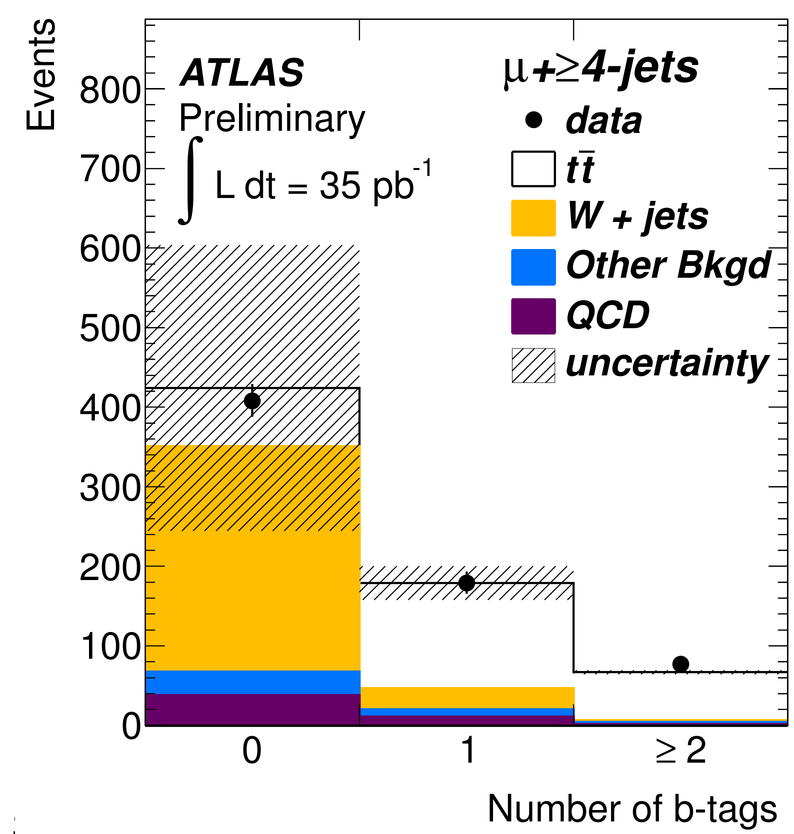

Cross section - single lepton *with b-tagging*

- Build discriminant from
  - **lepton η, aplanarity** (top is more spherical)
  - **$H_{T,3p}$** ratio of transverse to longitudinal activity ←top is more transverse
  - ***average*** of two largest **jet b-tagging** probability←top has more b-jets

- **Extract σ_{tt} from likelihood fit of discriminant** to data in 3,4 and 5 jet bins

- **Systematic uncertainties part of fit** as Gaussian nuisance parameters

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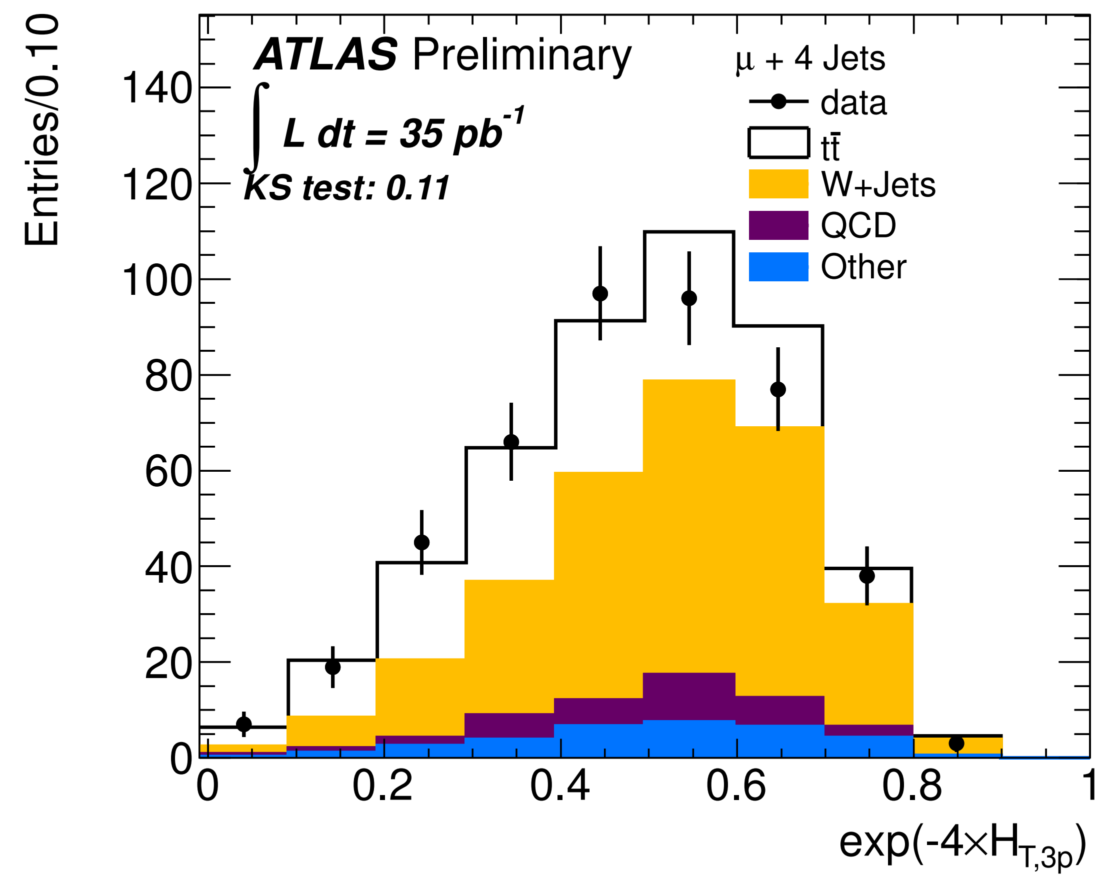

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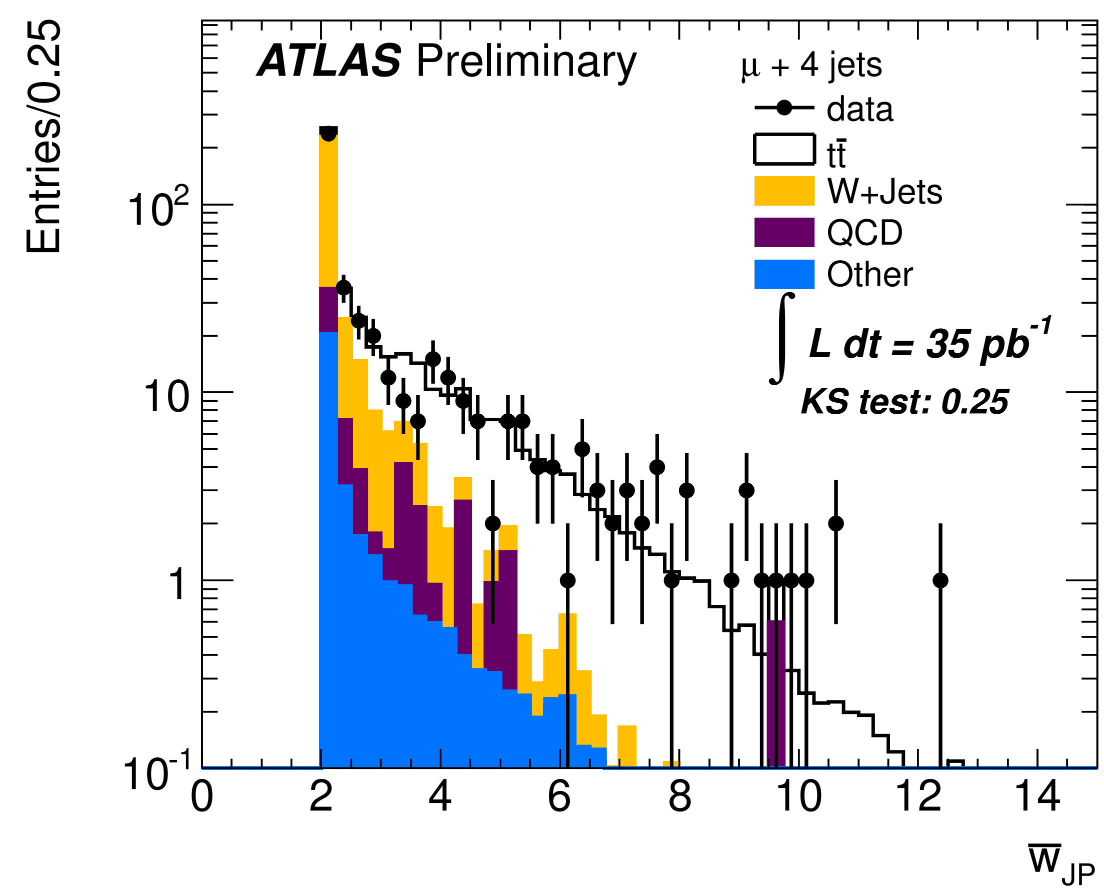

Systematic uncertainties : single lepton with b-tagging

- b-tagging efficiency jet properties (scale, multiplicity) and heavy flavour contents are the dominant contributors
- Background related and PDF uncertainty relative importance is reduced w.r.t to no b-tagging

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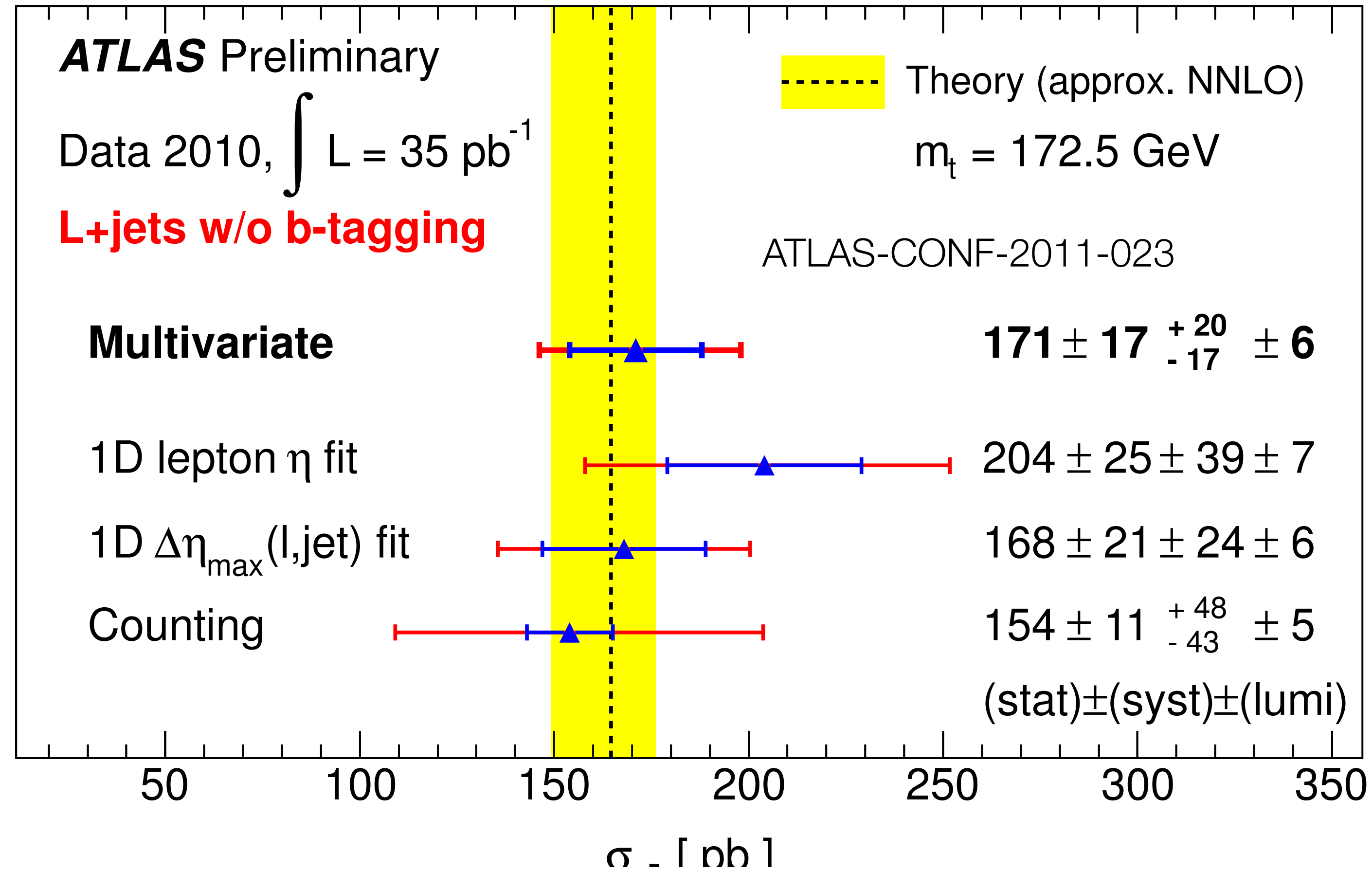
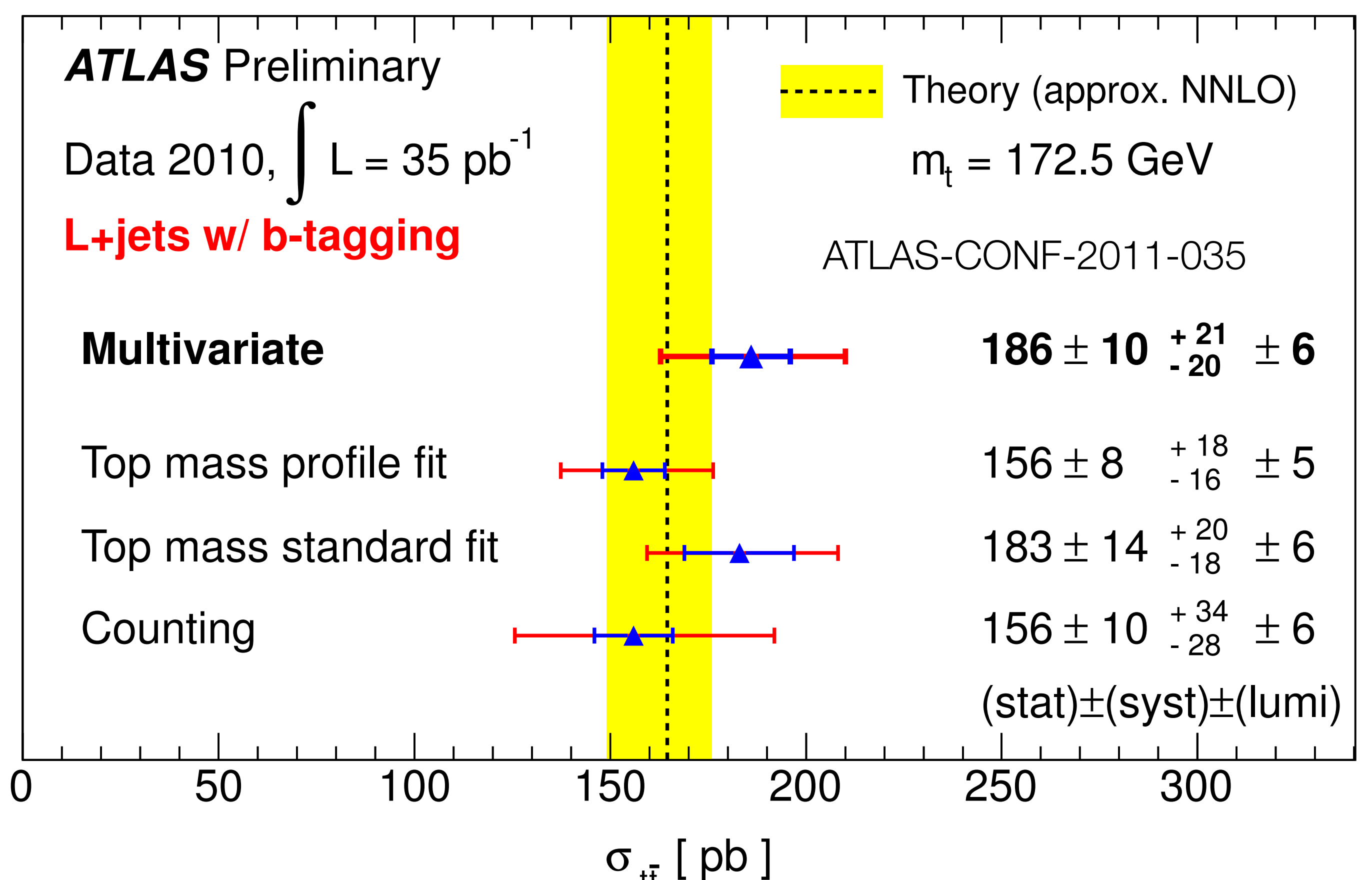
Statistical Error (%)	**+5.3**	**-5.2**
Object selection (%)		
Jet energy scale	+3.8	-2.8
Jet reconstruction efficiency	+4.2	-4.2
Jet energy resolution	+0.8	-0.2
Electron scale factor	+1.2	-0.8
Muon scale factor	+0.5	-0.6
Electron smearing	+0.3	-0.2
Muon smearing	+0.6	-0.4
Background modeling (%)		
Wjets HF content	+7.2	-6.3
Wjets shape	+1.5	-1.5
QCD shape	+1.0	-1.0
$t\bar{t}$ signal modeling (%)		
ISR/FSR	+4.0	-4.0
NLO generator	+0.5	-0.7
Hadronisation	+0.0	-0.6
PDF	+1.7	-1.7
Others (%)		
b-tagging calibration	+7.5	-6.3
Simulation of pile-up	+1.5	-0.6
Templates statistics	+1.6	-1.5
Total Systematic (%)	**+11.5**	**-10.5**

Summary for single lepton

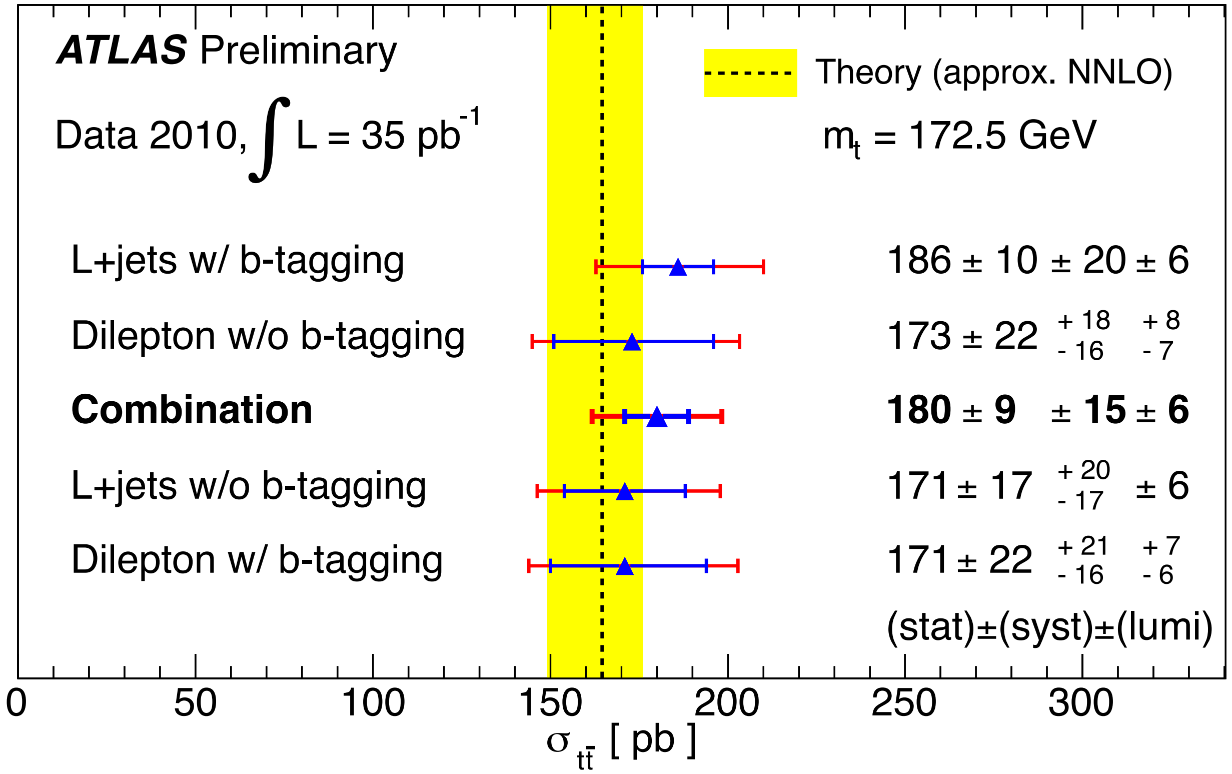
- Use of ***b-tagging improves statistical uncertainty*** (enhanced background reduction)



- Systematics are as large as statistics; already dominant ***in b-tagging case***

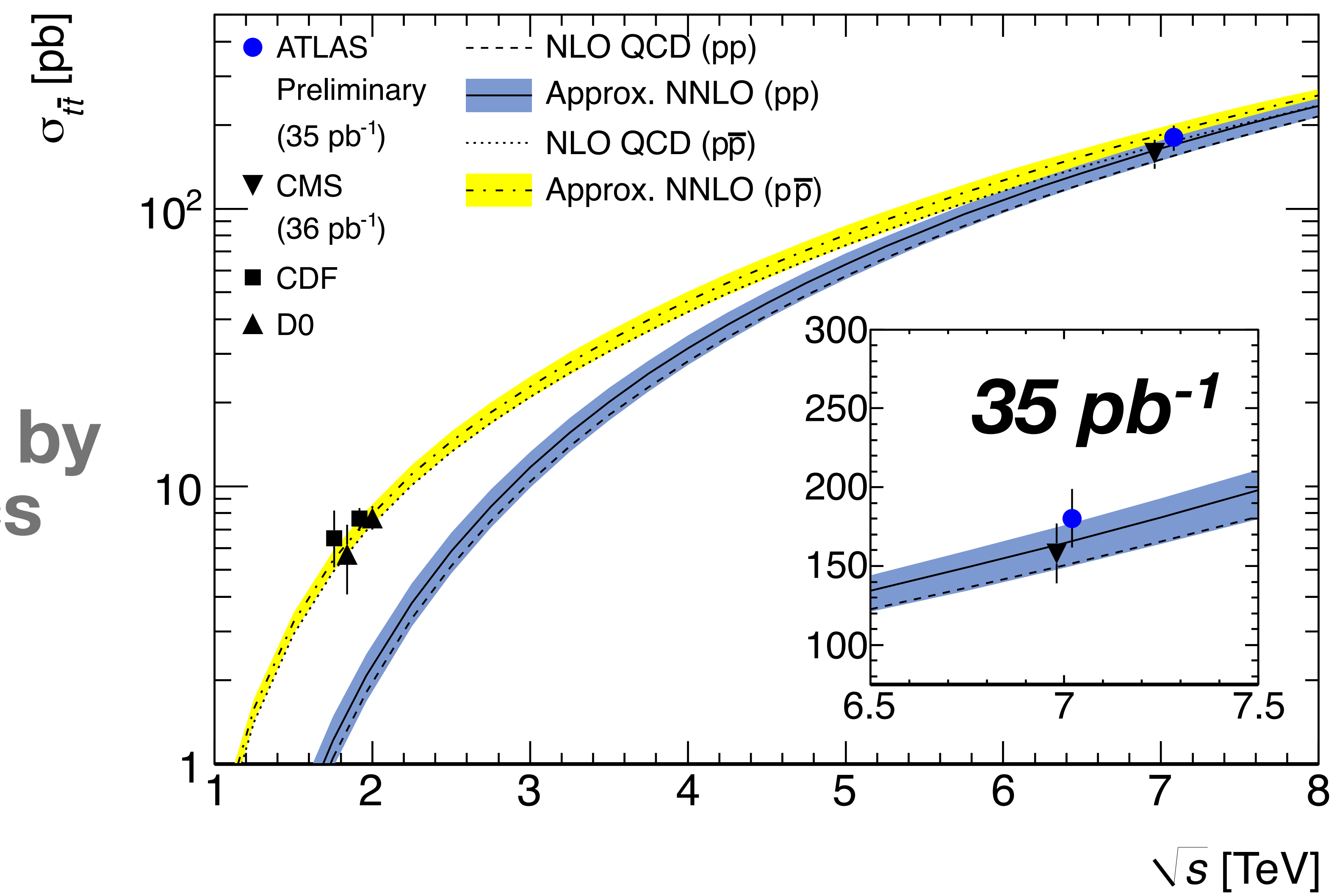


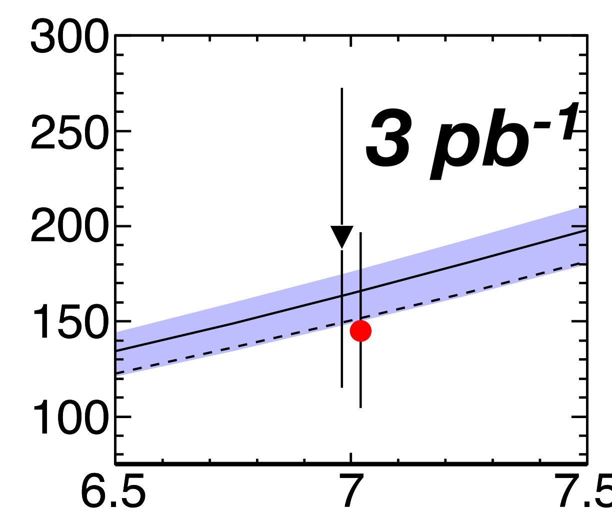
Combined cross section results



- Combined result uncertainty is **10%: comparable to theory**
  - **ATLAS:** 180 ±18 pb
  - CMS: 158±19 pb (12%)

- Uncertainty **dominated by systematics**



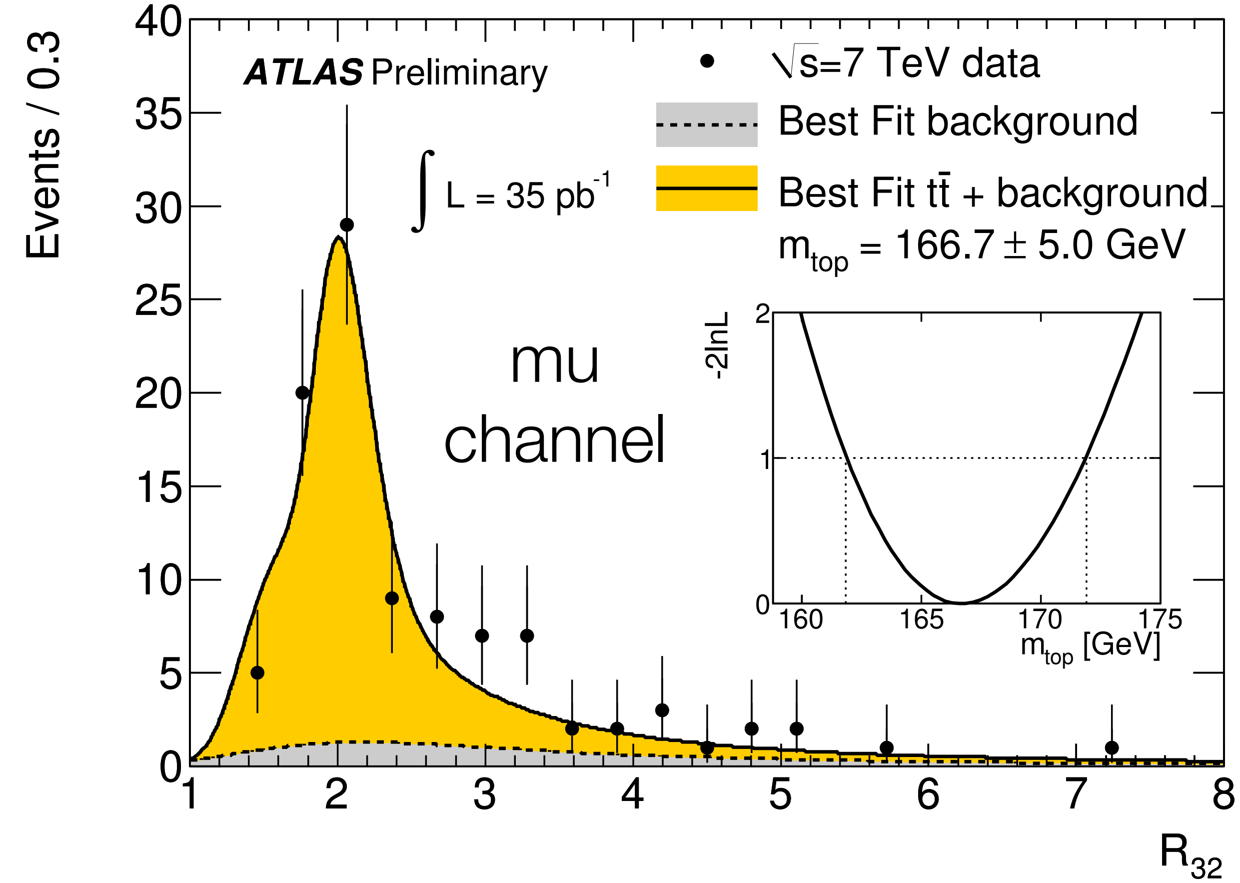


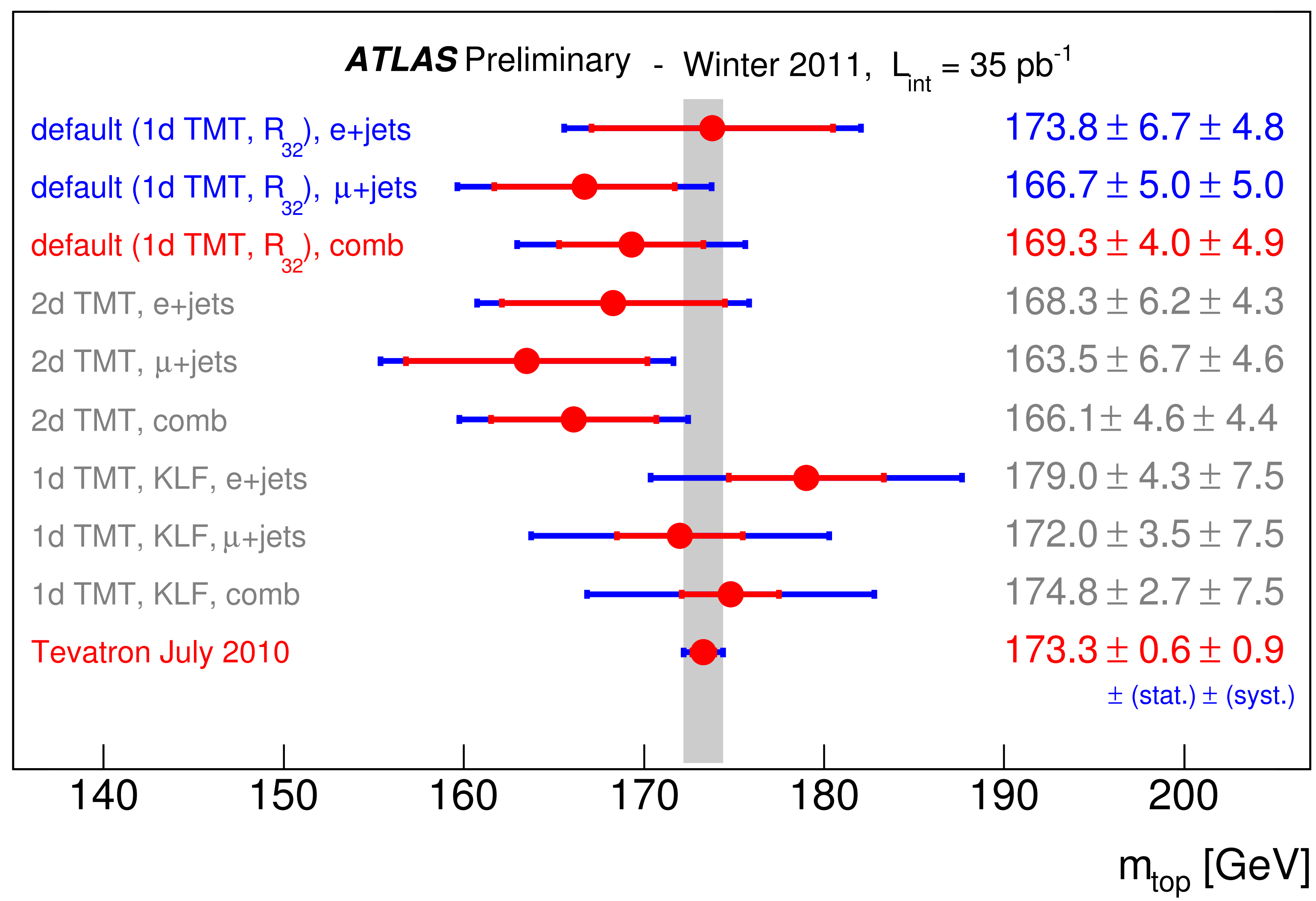
Measuring Top mass

- Same selection as cross section
- Measure mass using hadronic top
  - Jet energy scale is crucial

- Three techniques
  - **baseline: template-fit ratio of reconstructed di-jet (W) and 3-jet (top) mass**
  - *simultaneous measurement of scale and top mass*
  - *kinematic fitter based on likelihood*

- Statistics ≈ systematics
- Largest systematics (baseline): **jet energy scale, initial and final state radiation**





Looking forward: top as a window on new physics

- Larger data sample: search for new physics in differential properties

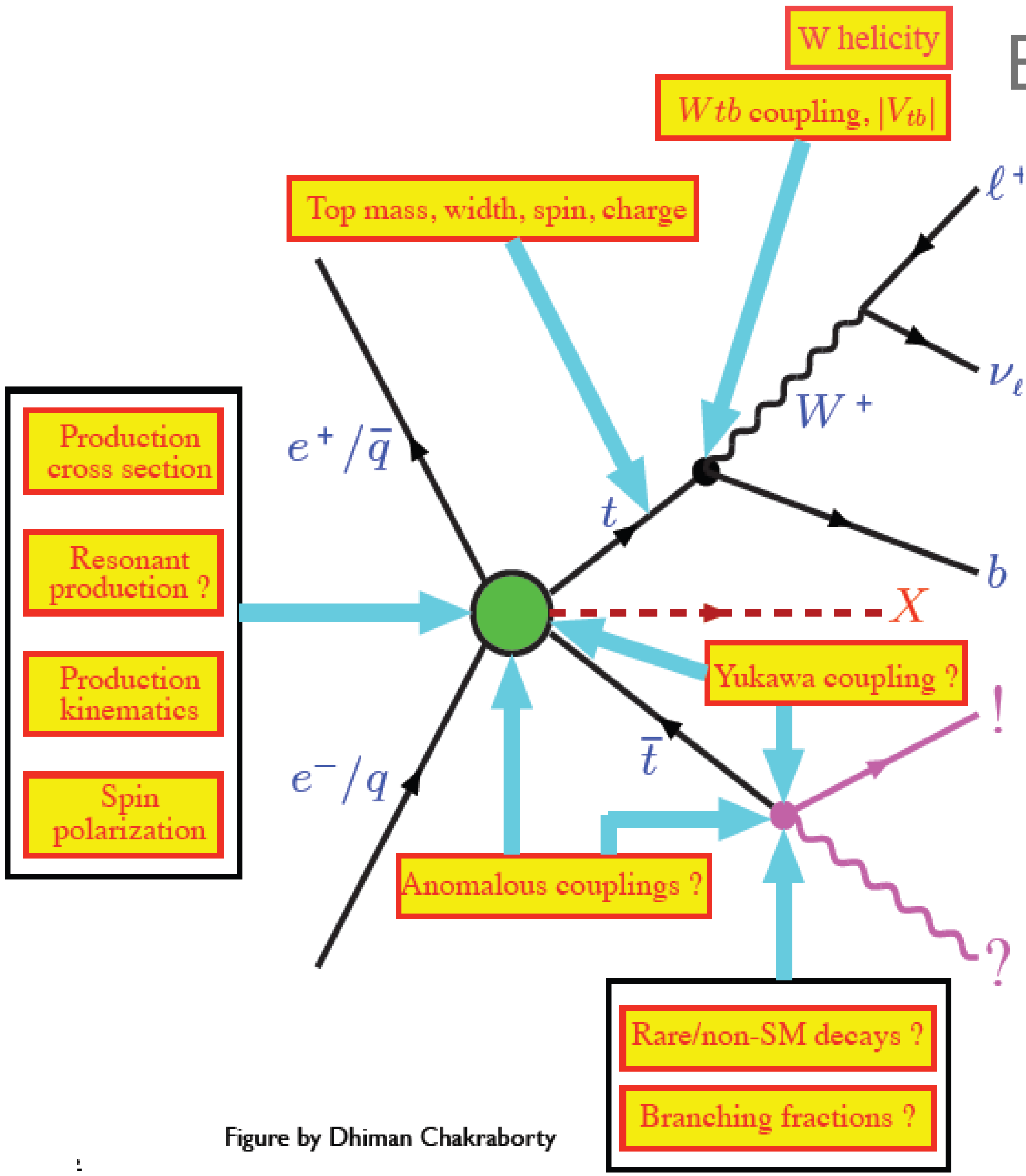
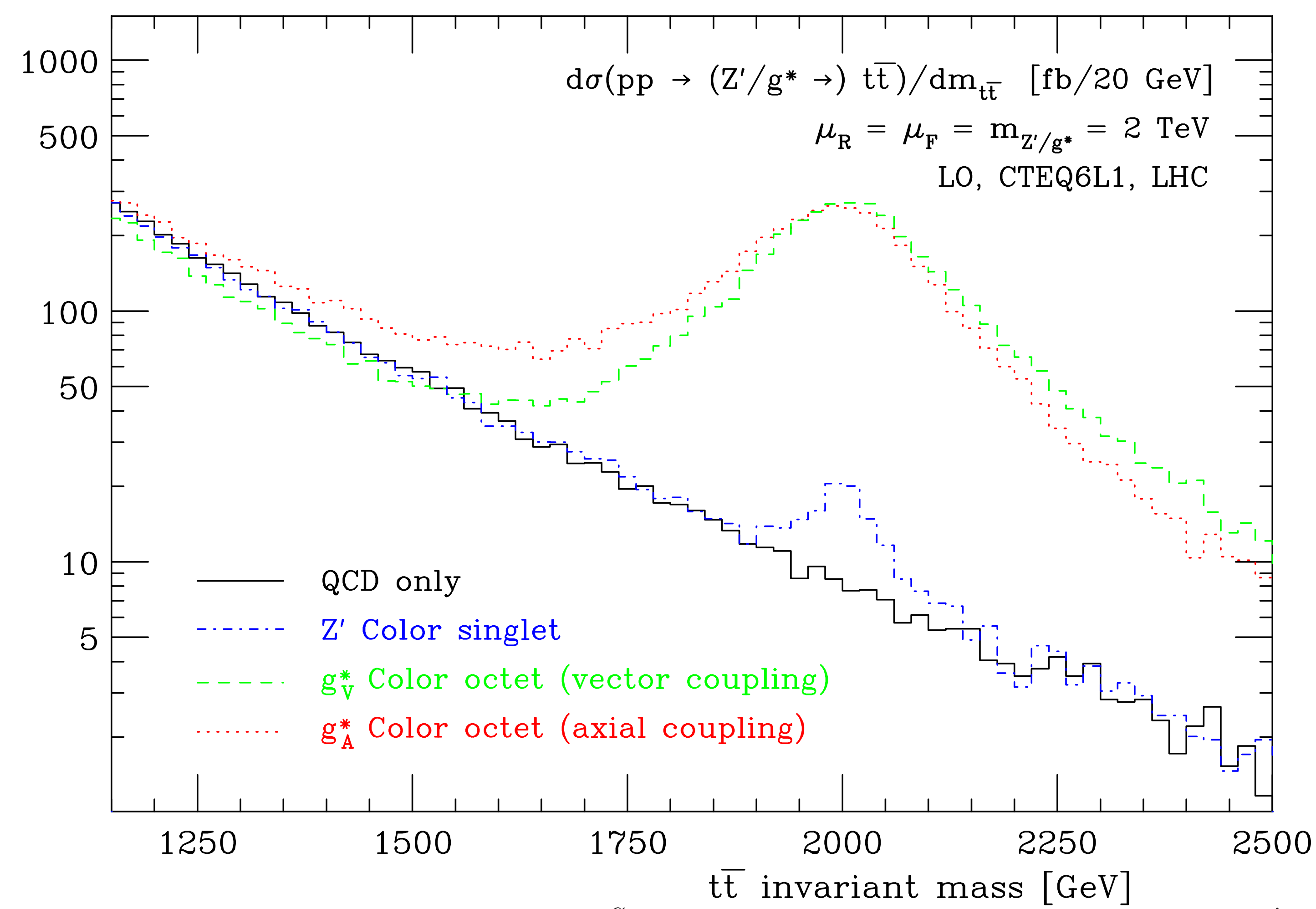
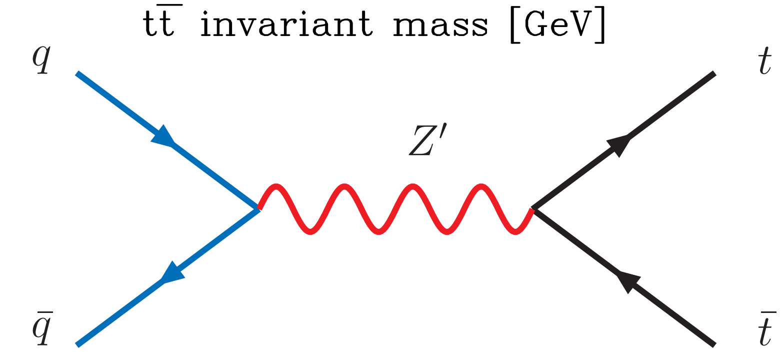


Figure by Dhiman Chakraborty

Example : resonances decaying to top

arxiv:0712.2325





Status for Z’

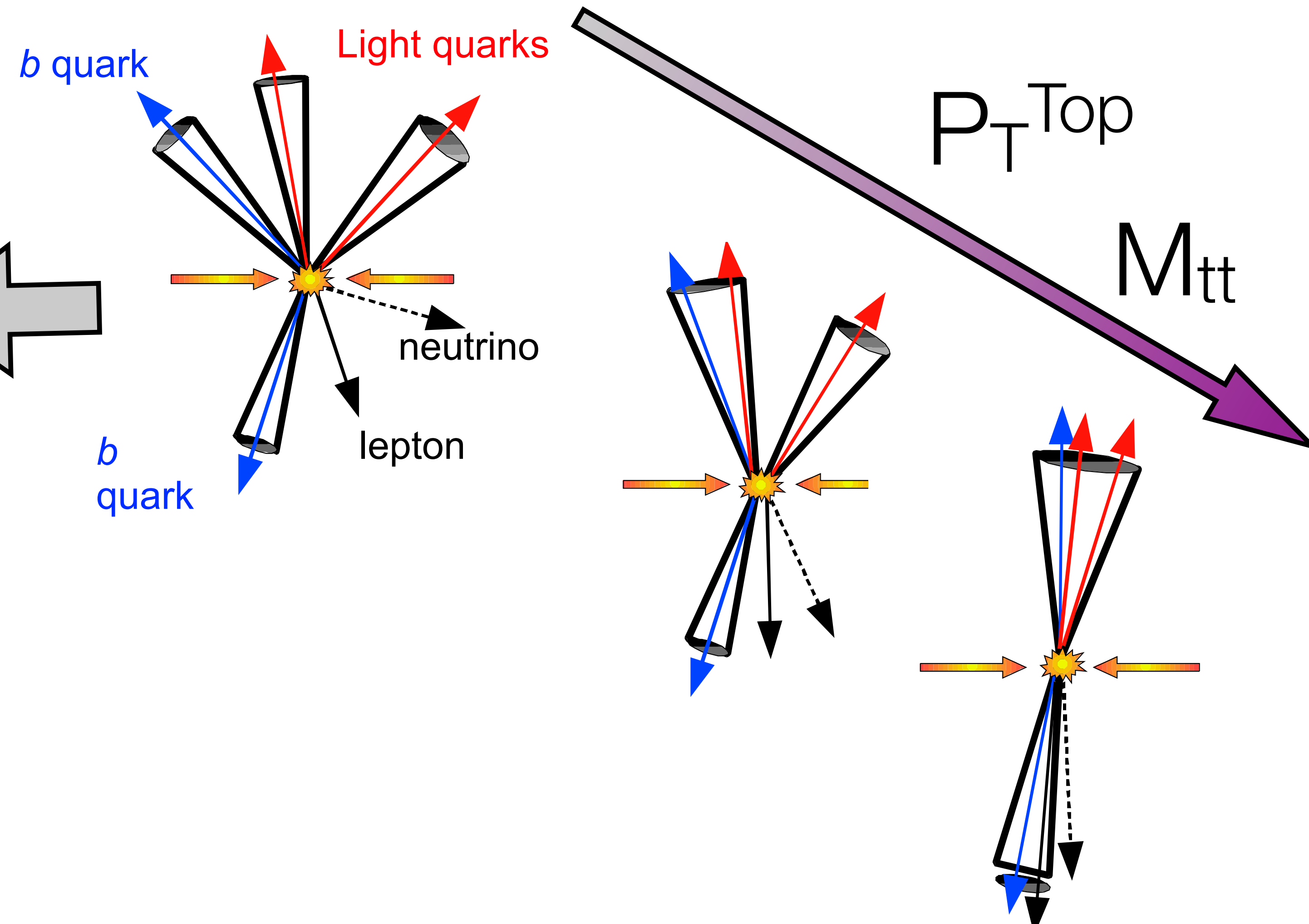
@ Tevatron: Z’mass > 850 GeV @95%CL (documented)

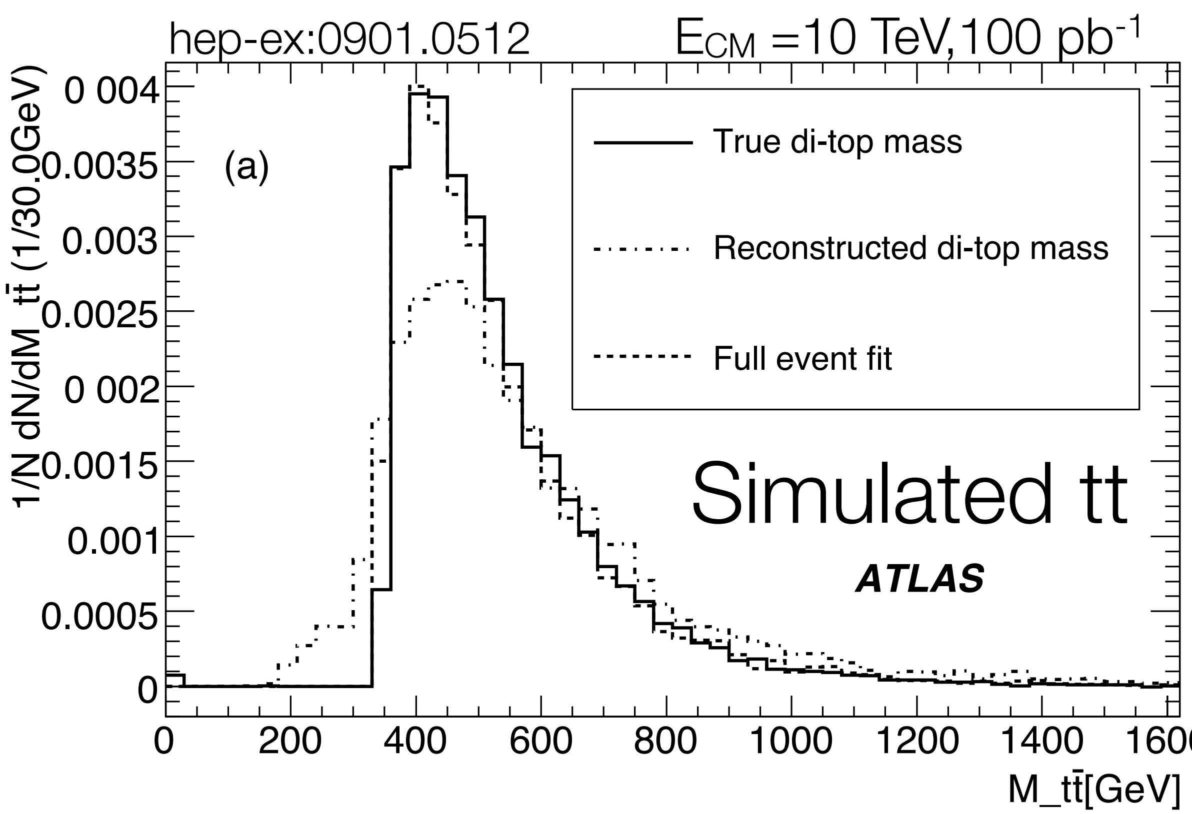
@LHC: CMS @ MoriondEWK11 showed upper limits on Z’ xsec

Top/anti-top resonances : ATLAS expectations

- Search for peaks in M_{tt} → **mass resolution is crucial**

- **At “low” M_{tt}**
  - **add final state objects** + algo to choose jets (p_T order, χ^2)
  - **perform kinematic fit** using M_W, M_{top}





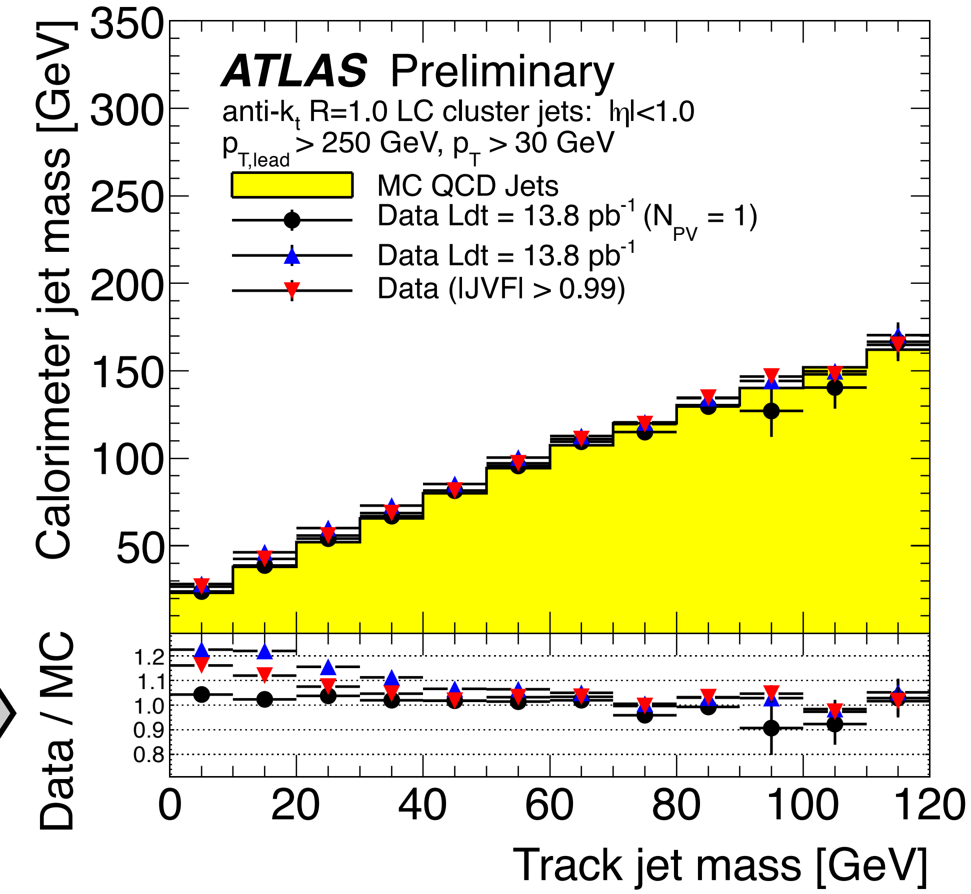
For DR=0.8 M_{tt} ~1.7 TeV, P_T ~600 GeV

- **Higher p_T^{top} (or M_{tt})** → boosted “top jet” → new reco to separate QCD, tt, possible new physics.

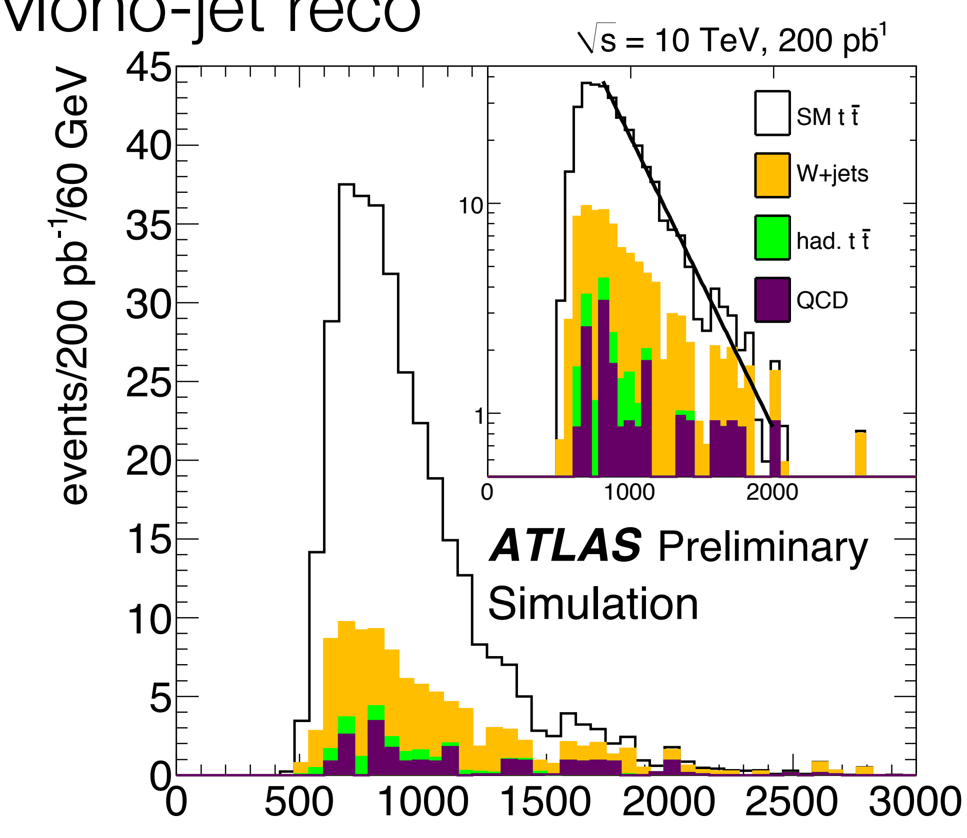
- **ATLAS analysis with 35 pb^{-1} in advanced state**. Expect results soon.

Top/anti-top resonances: ATLAS expectations

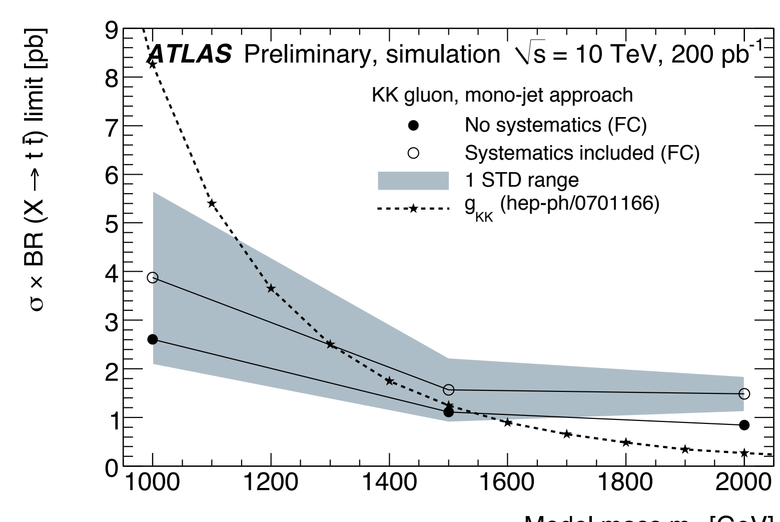
- Reconstruct top with large cone
  - techniques to tag top jets using jet substructure and shapes
- Start measuring basic properties: **jet mass** and scale for large cones, splitting scales.
- With O(1) fb^{-1} ATLAS sensitivity is expected reach resonance masses well beyond 1 TeV (ATL_PHYS_PUB_2010_008) →exciting time for searches!



Mono-jet reco



ATLAS-PHYS-PUB-2010-008



Conclusion

- **Top quarks have finally visited Europe! Signal is now established at the LHC.**

- ATLAS **$t\bar{t}$ cross section** measurements in single and di-lepton channel are in **good agreement with standard mode**l expectations. **Systematics dominated: 180±18 pb. Improvements will need to focus on reduction of systematics uncertainties.**

- ATLAS **Top mass is 169 ±4(stat)±4.9 (syst) GeV**

- If *Ldt* = 300 to 500 pb^{-1} for summer 2011 and few fb^{-1} by the end of 2011→ **exciting prospects for new physics searches with top**, ***for instance top resonances***

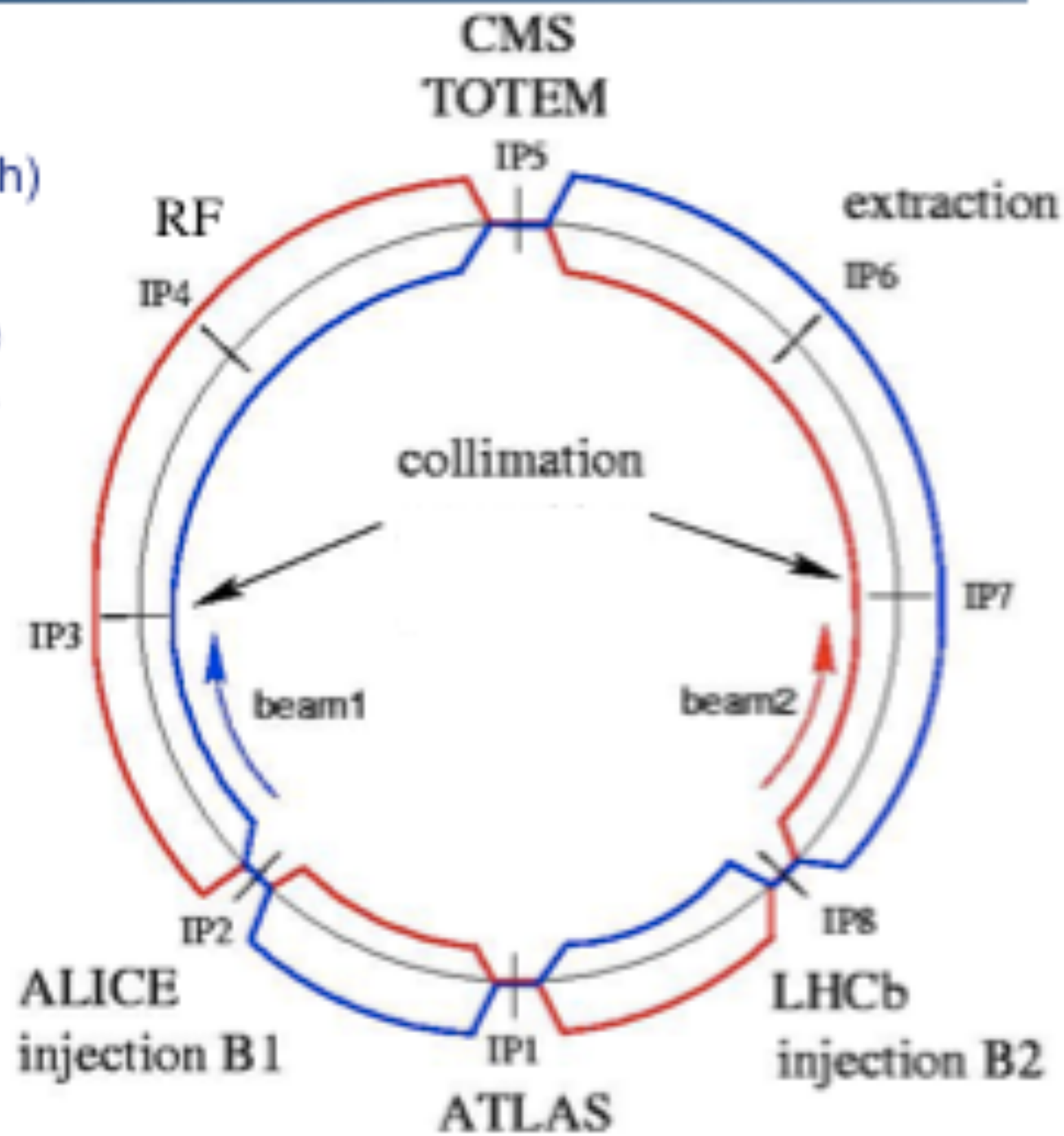
BACK-UP

LHC layout and parameters

- 8 arcs (sectors), ~3 km each
- 8 long straight sections (700 m each)
- beams cross in 4 points
- 2-in-1 magnet design with separate vacuum chambers → *p-p* collisions

Nominal LHC parameters	
Beam energy (TeV)	7.0
No. of particles per bunch	1.15×10^{11}
No. of bunches per beam	2808
Stored beam energy (MJ)	362
Transverse emittance (μm)	3.75
Bunch length (cm)	7.6

- *$\beta^* = 0.55$ m (beam size = 17 μm)*
- *Crossing angle = 285 μrad*
- *$L = 10^{34}$ cm^{-2} s^{-1}*



3

L. Ponce - Moriond EWK - 2011

LHC challenges

The LHC surpasses existing accelerators/colliders in 2 aspects :

- The energy of the beam of 7 TeV that is achieved within the size constraints of the existing 26.7 km LEP tunnel.

LHC dipole field	8.3 T
HERA/Tevatron	~ 4 T

A factor 2 in field
A factor 4 in size

- The luminosity of the collider that will reach unprecedented values for a hadron machine:

LHC	pp	10^{34} cm^{-2} s^{-1}
Tevatron	pp	$3\text{x}10^{32}$ cm^{-2} s^{-1}
SppS	pp	$6\text{x}10^{30}$ cm^{-2} s^{-1}

A factor 30 in luminosity

Very high field magnets and very high beam intensities:

- Operating the LHC is a great challenge.
- There is a significant risk to the equipment and experiments.

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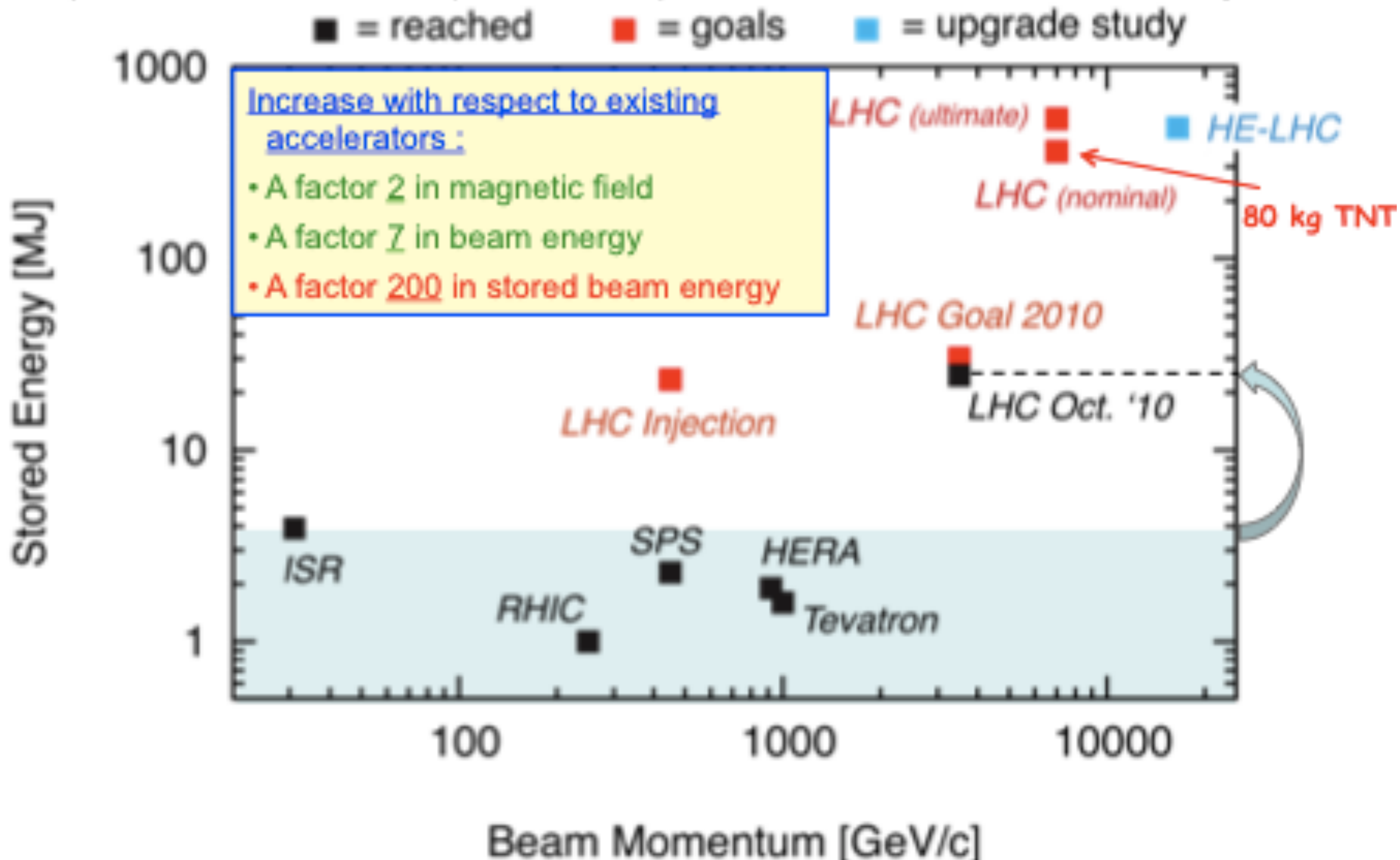
Stored energy

The present beam intensity will slice open a vacuum chamber even at injection



5

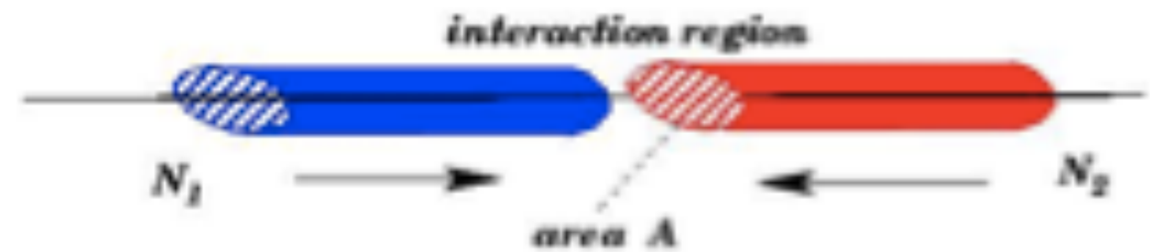
14.03.2011 LHC status – Moriond 2011

L. Ponce - Moriond EWK - 2011

Luminosity : collider figure-of-merit

The event rate N for a physics process with cross-section σ is proprotional to the collider Luminosity L:

$$N = L\sigma$$



$$L = \frac{kN^2 f}{4\pi\sigma_x^*\sigma_y^*} = \frac{kN^2 f\gamma}{4\pi\beta^*\varepsilon}$$

"Thus, to achieve high luminosity, all one has to do is make (lots of) high population bunches of low emittance to collide at high frequency at locations where the beam optics provides as low values of the amplitude functions as possible."
PDG 2005, chapter 25

To maximize L:

- **Many bunches (*k*)**
- **Many protons per bunch (*N*)**
- **Small beam sizes $\sigma^*_{x,y} = (\beta^*\varepsilon)^{1/2}$**

β^* : beam envelope (optics)

ε : beam emittance, the phase space volume occupied by the beam (constant along the ring)

High beam "brillance" N/ε (particles per phase space volume)

→ **Injector chain performance !**

Small envelope

Optics property → **Strong focusing !**

Beam property

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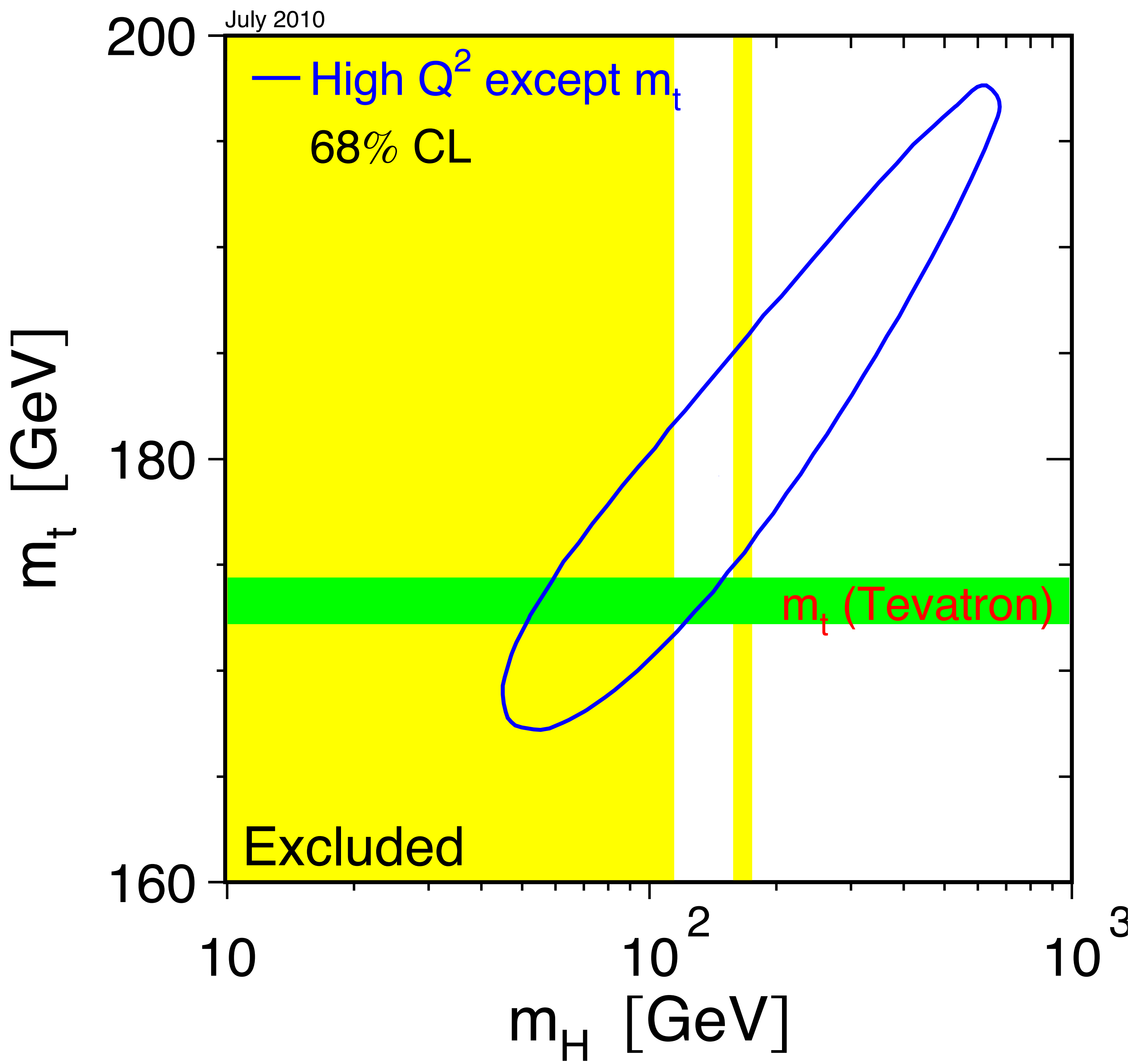
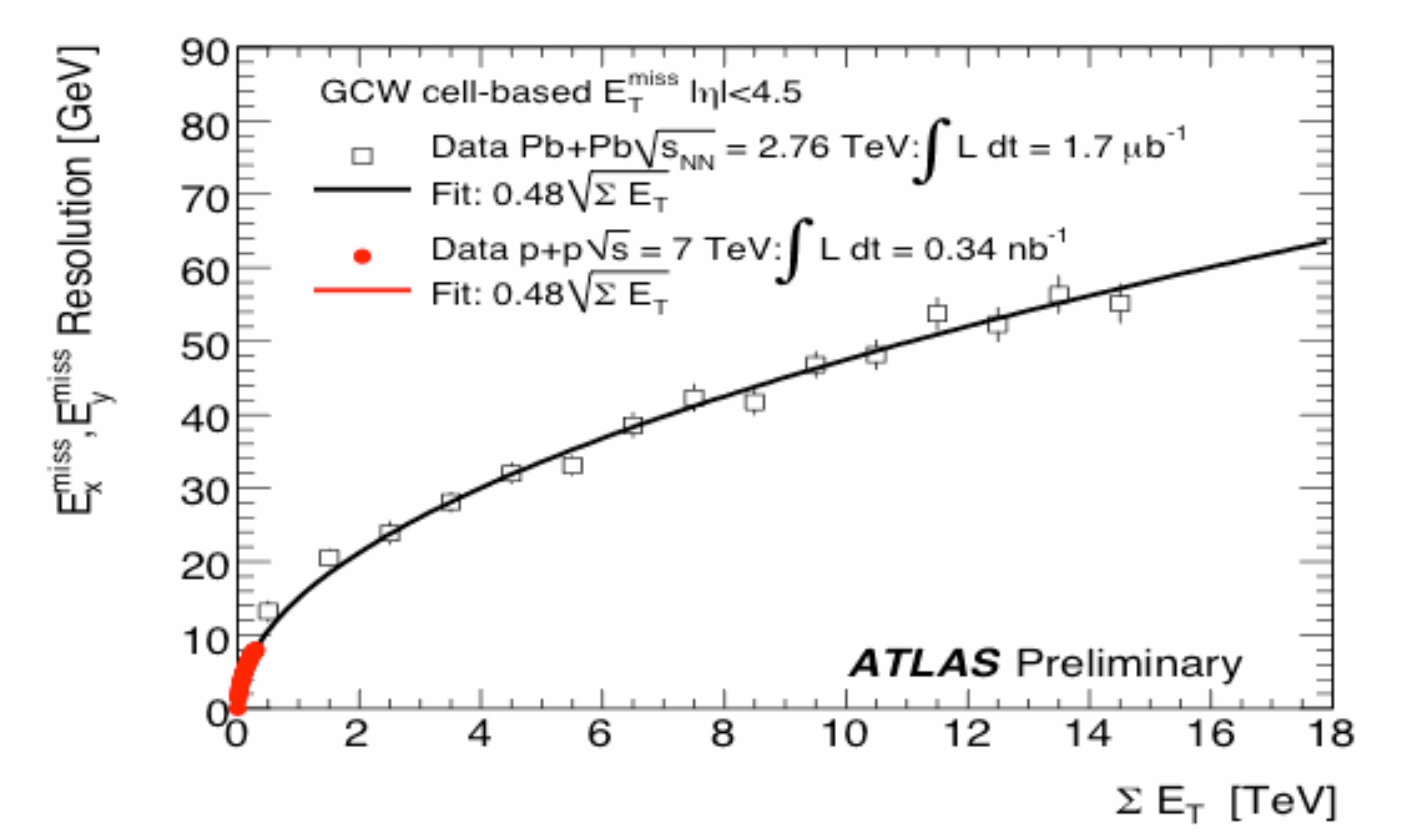
The top and the Higgs



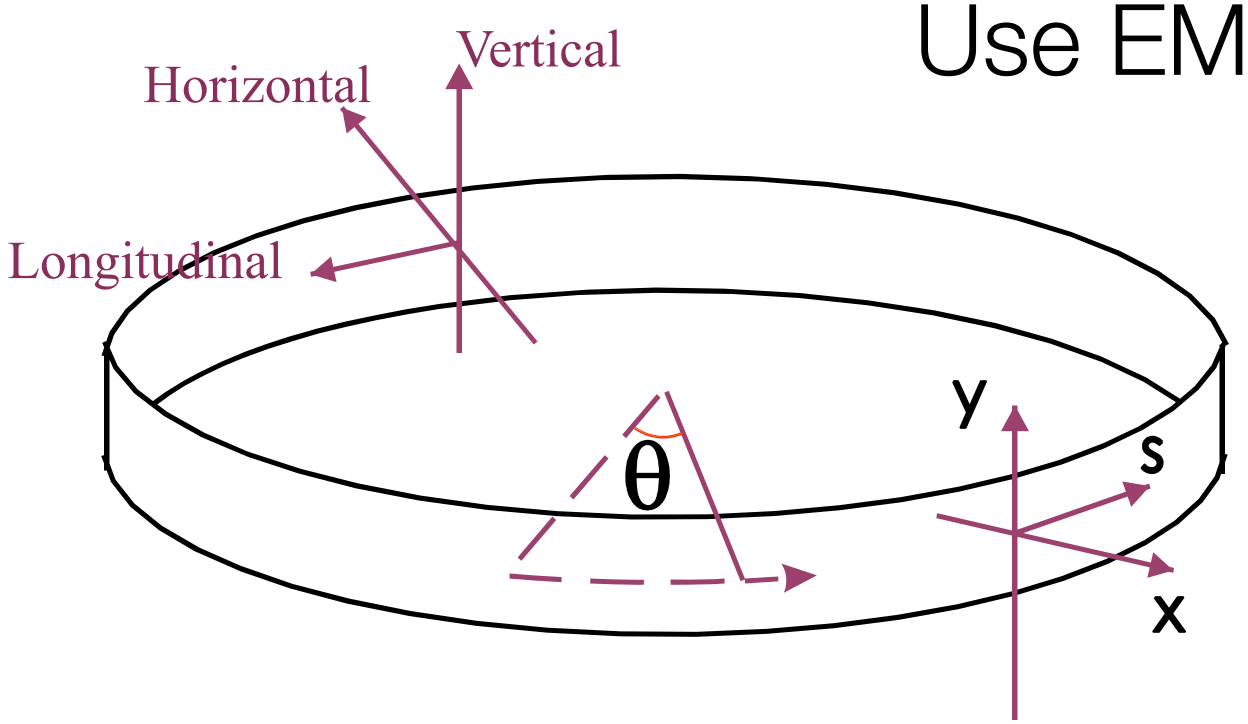
E_T^{miss} from pp and ion ion collisions



- Resolution values are RMS
- Line is indep fits to resolution in pp and PbPb data
- E_T^{miss} obtained by summming cels with E>2, with global cell weighting calibration

Accelerator's basics

Figures from R. Steerenberg -AXEL 2008 @ CERN



Use EM fields

$$\frac{d\vec{p}}{dt} = \vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

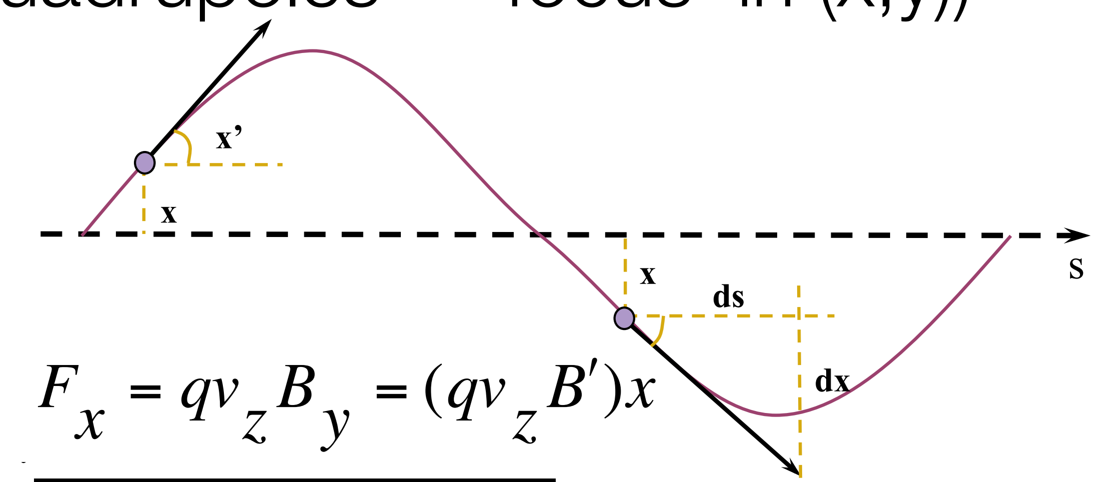
E: accelerate

$$\frac{dKE}{dt} = \vec{v} \cdot \vec{F} = q\vec{v} \cdot \vec{E}$$

B: constrain along trajectory(dipoles →circular orbit)

Transverse motion

quadrupoles→ focus in (x,y))

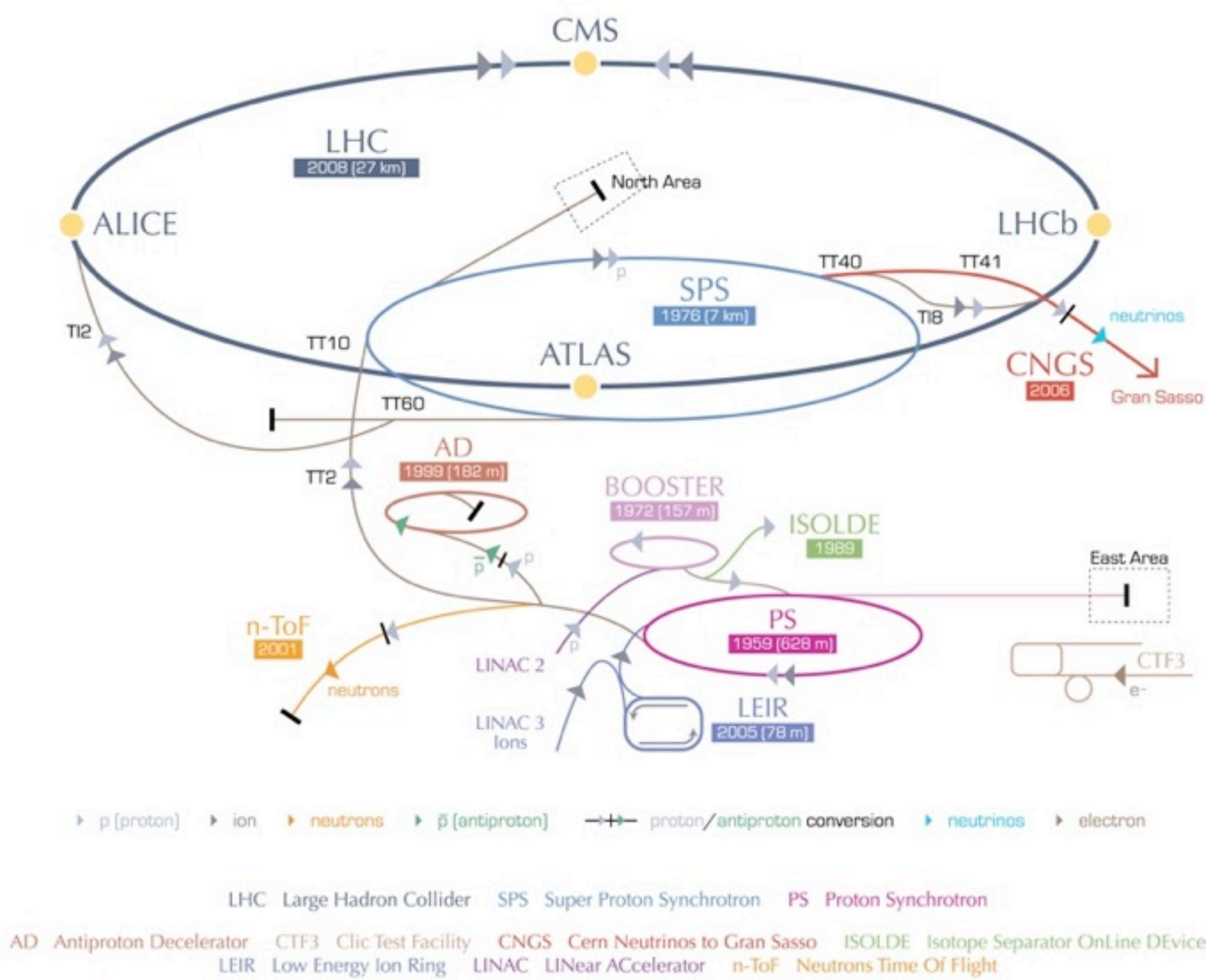


$$F_x = qv_z B_y = (qv_z B')x$$

$$\frac{d^2x}{ds^2} + k(s)x = 0$$

$$x(s) = A\sqrt{\beta(s)}\cos(\phi(s) - \phi_o)$$

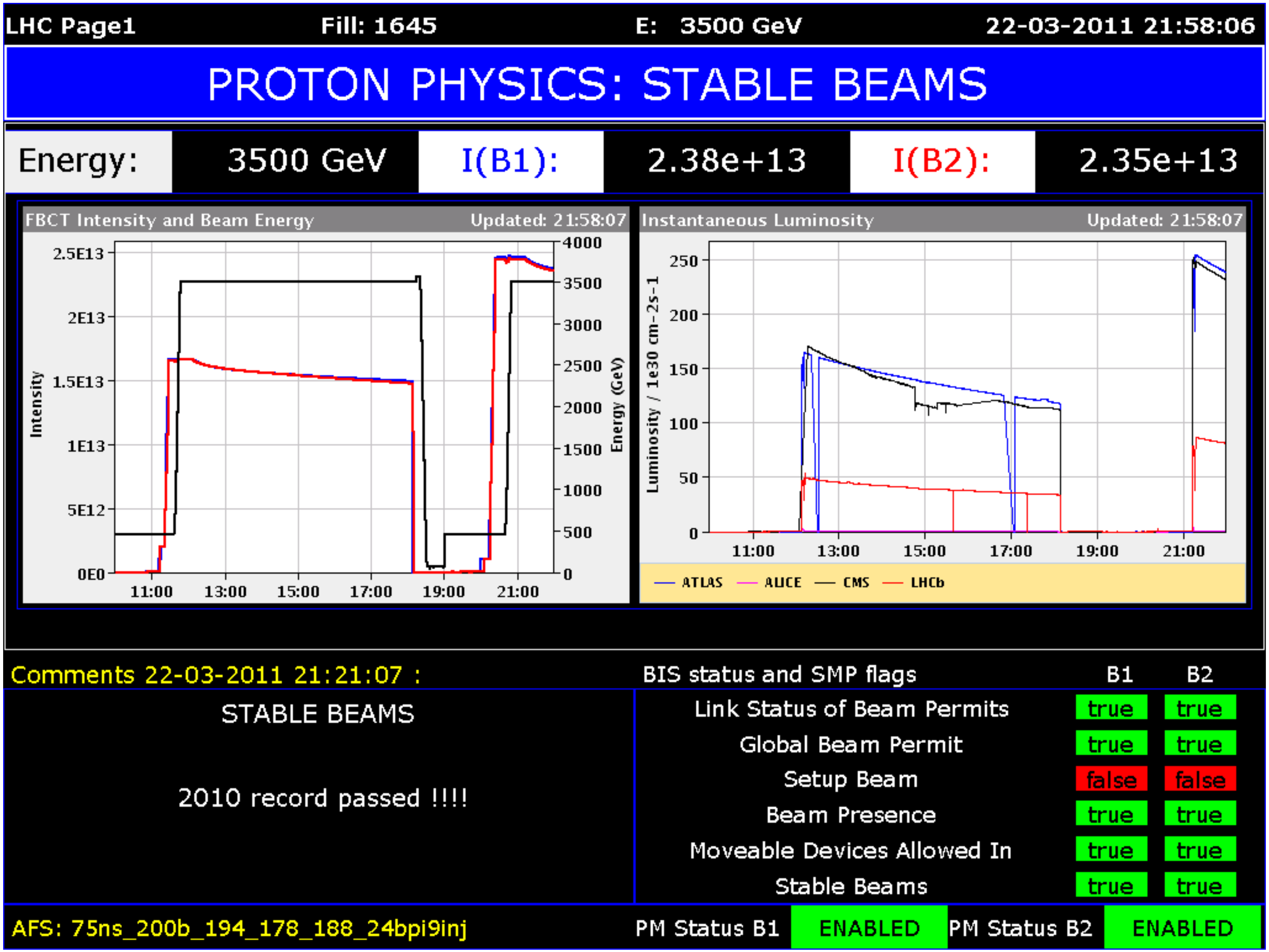
CERN's accelerator complex



European Organization for Nuclear Research | Organisation européenne pour la recherche nucléaire

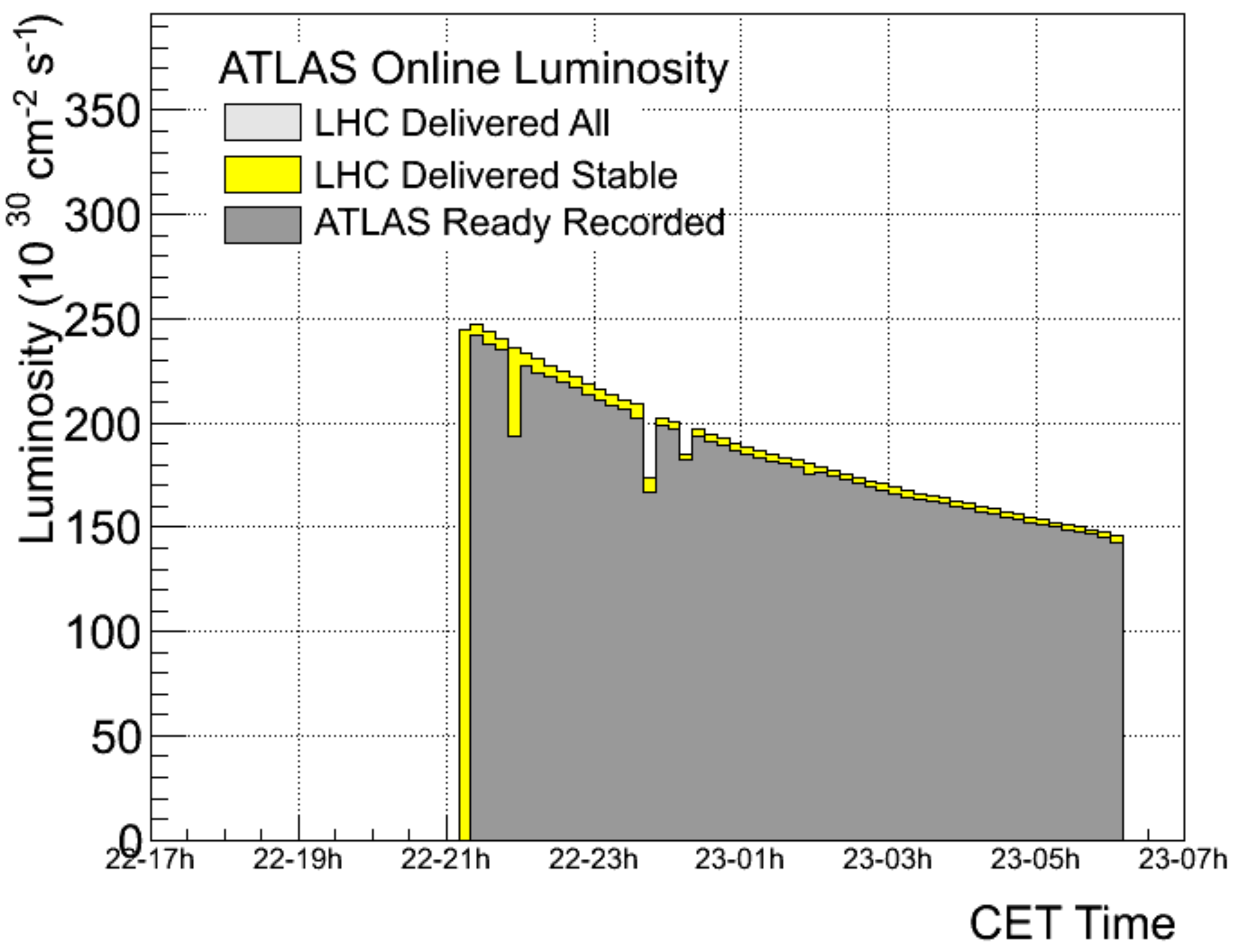
LHC record: 22nd March 2010

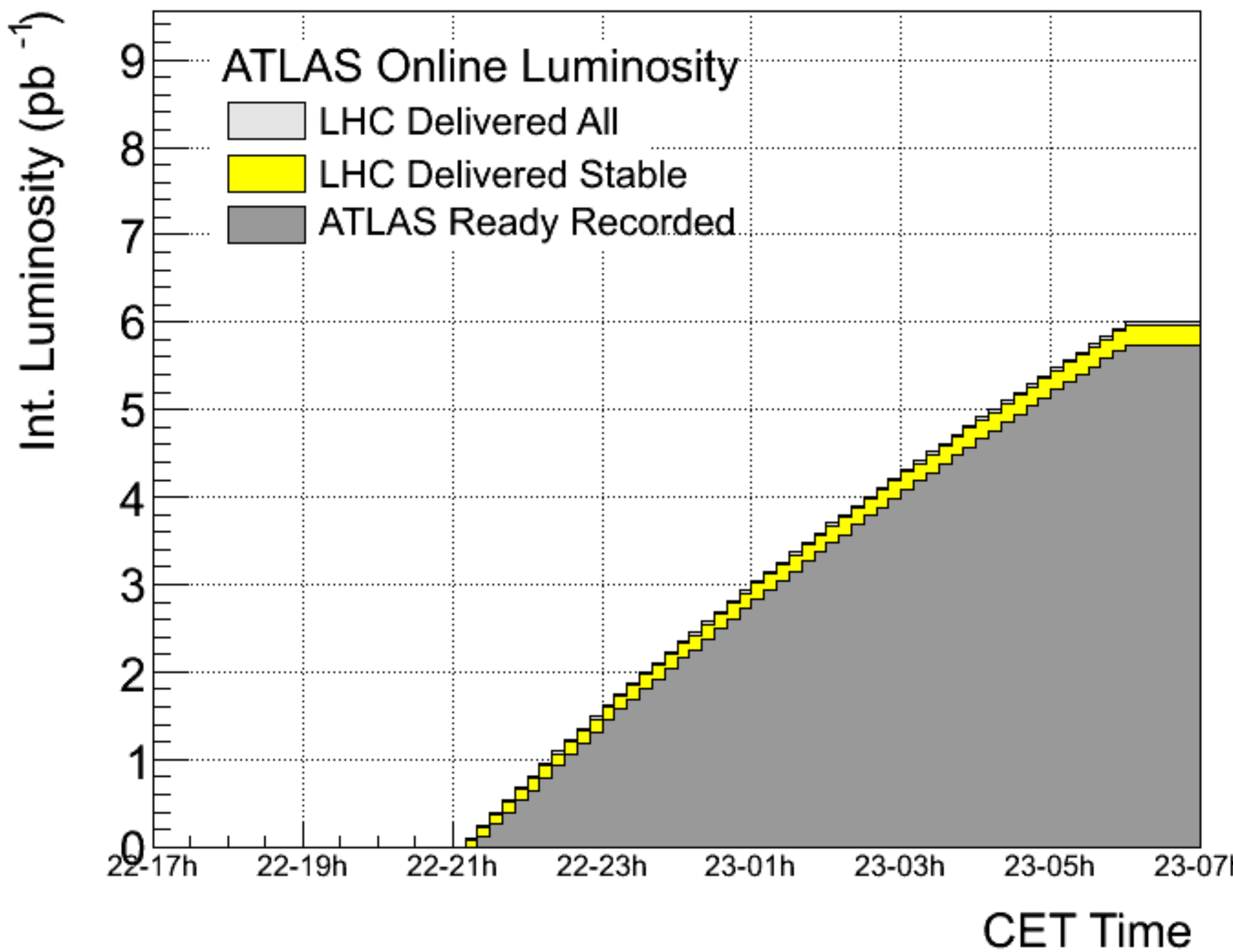
- S Meyers, 105th LHCC open Session, 23rd March 2011

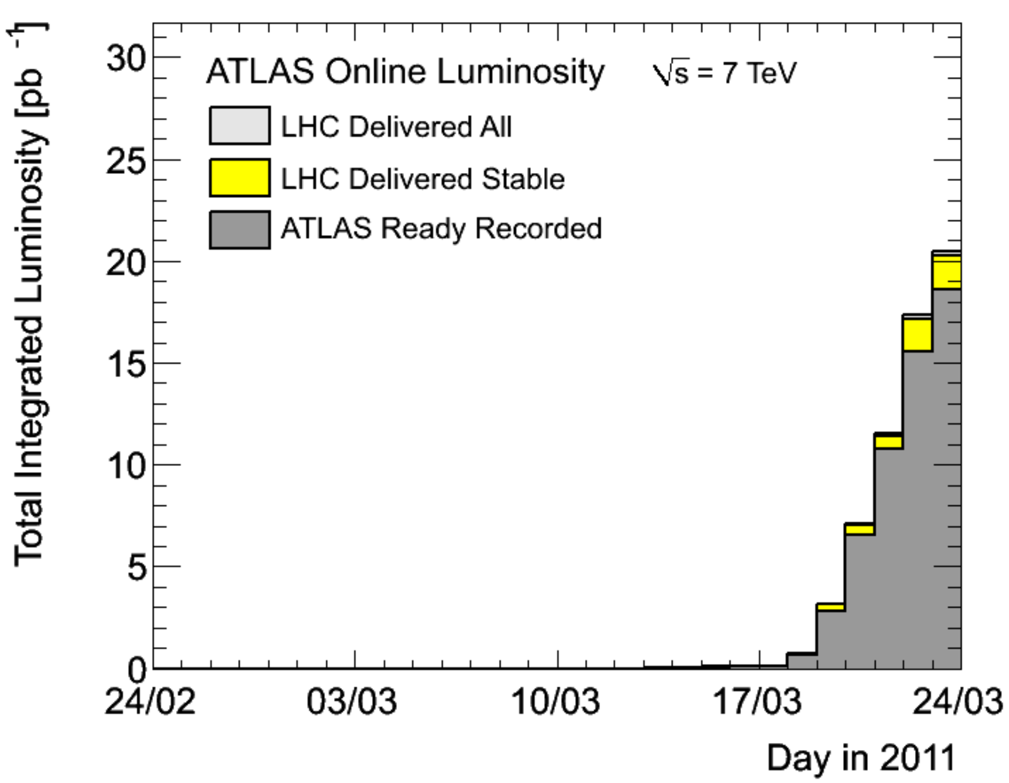


https://indico.cern.ch/conferenceDisplay.py?confId=130457

Best fill 22nd March





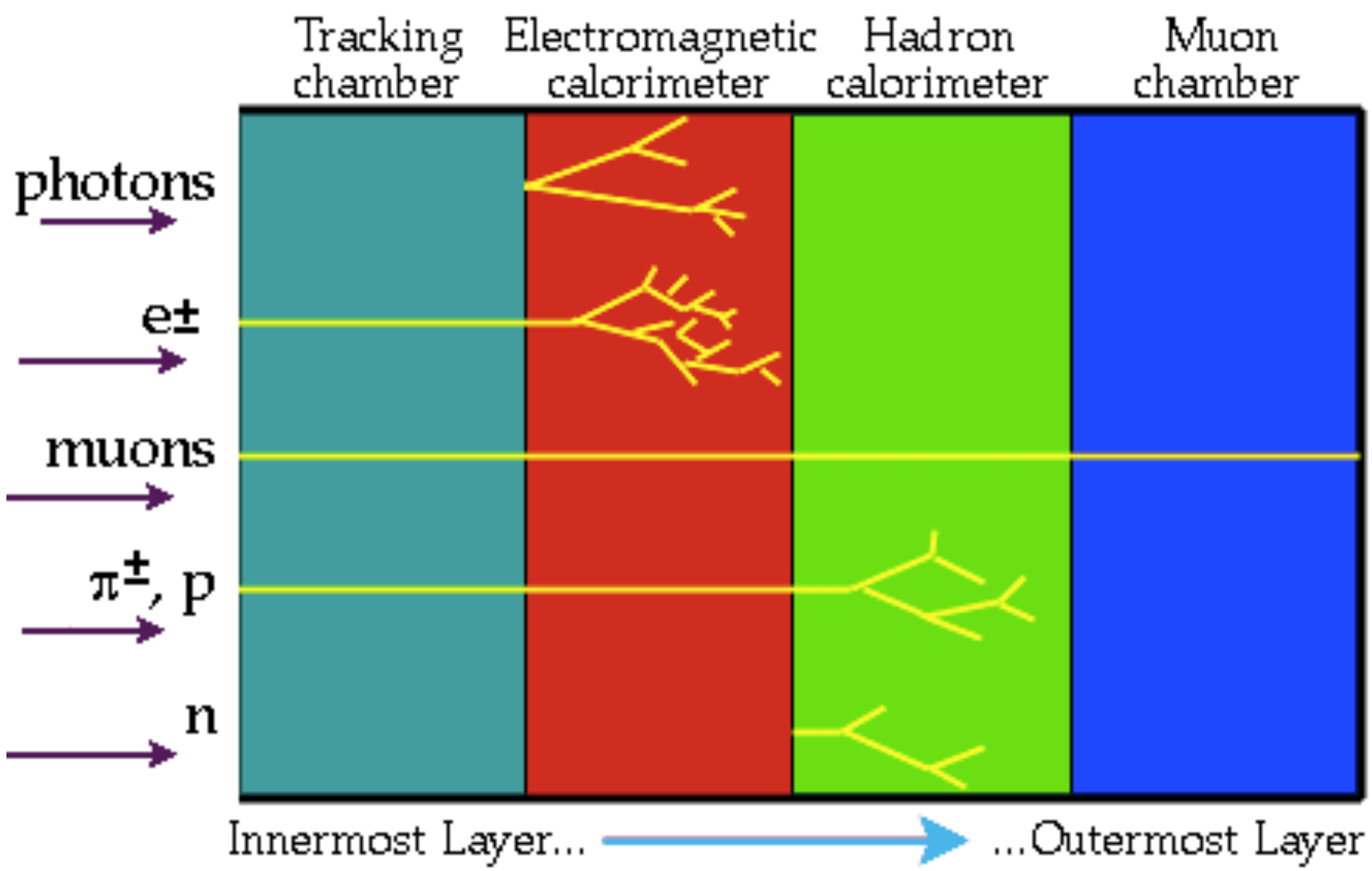


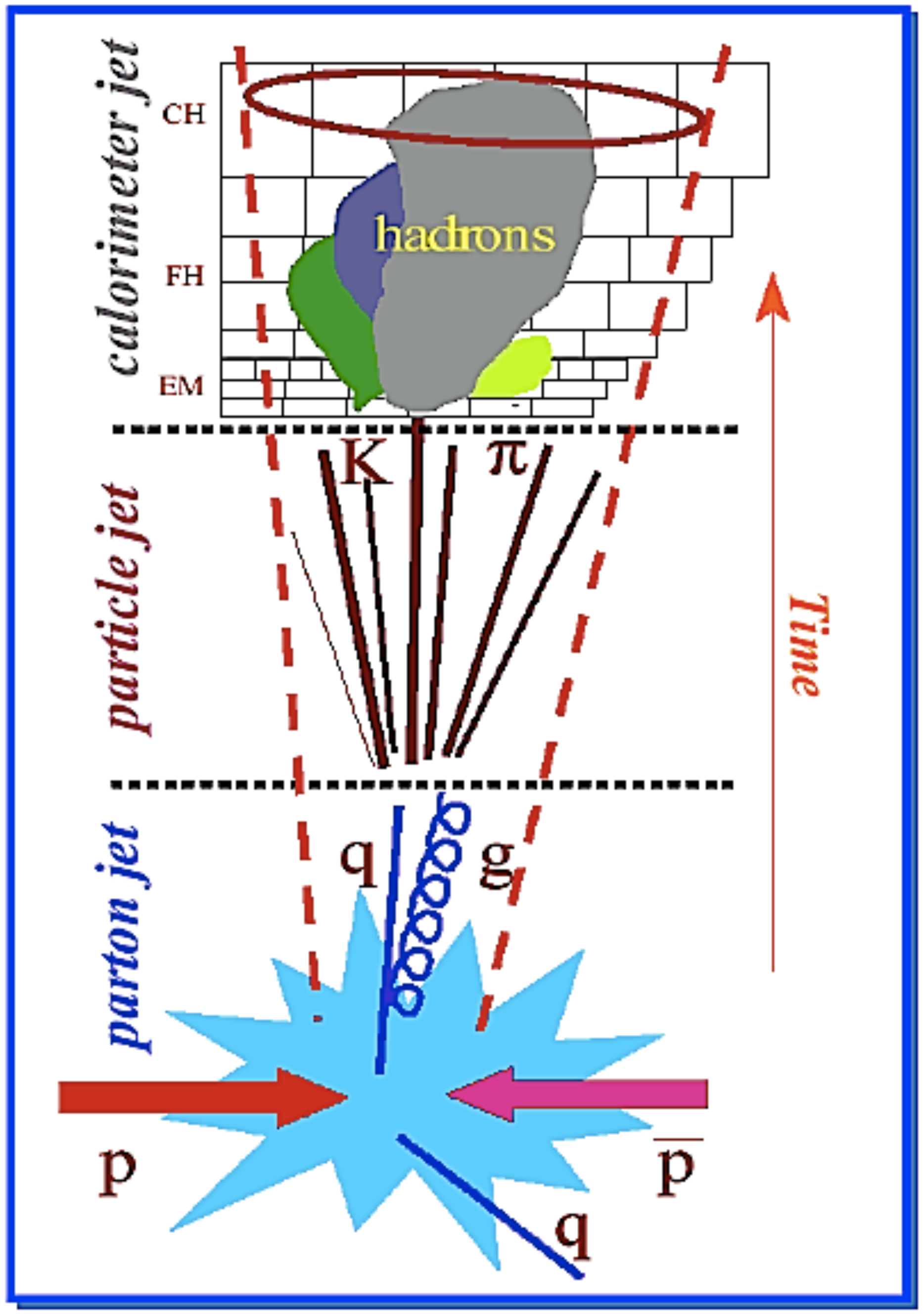
- S Meyers, 105th LHCC open Session, 23rd March 2011

https://indico.cern.ch/conferenceDisplay.py?confId=130457

The ATLAS detector

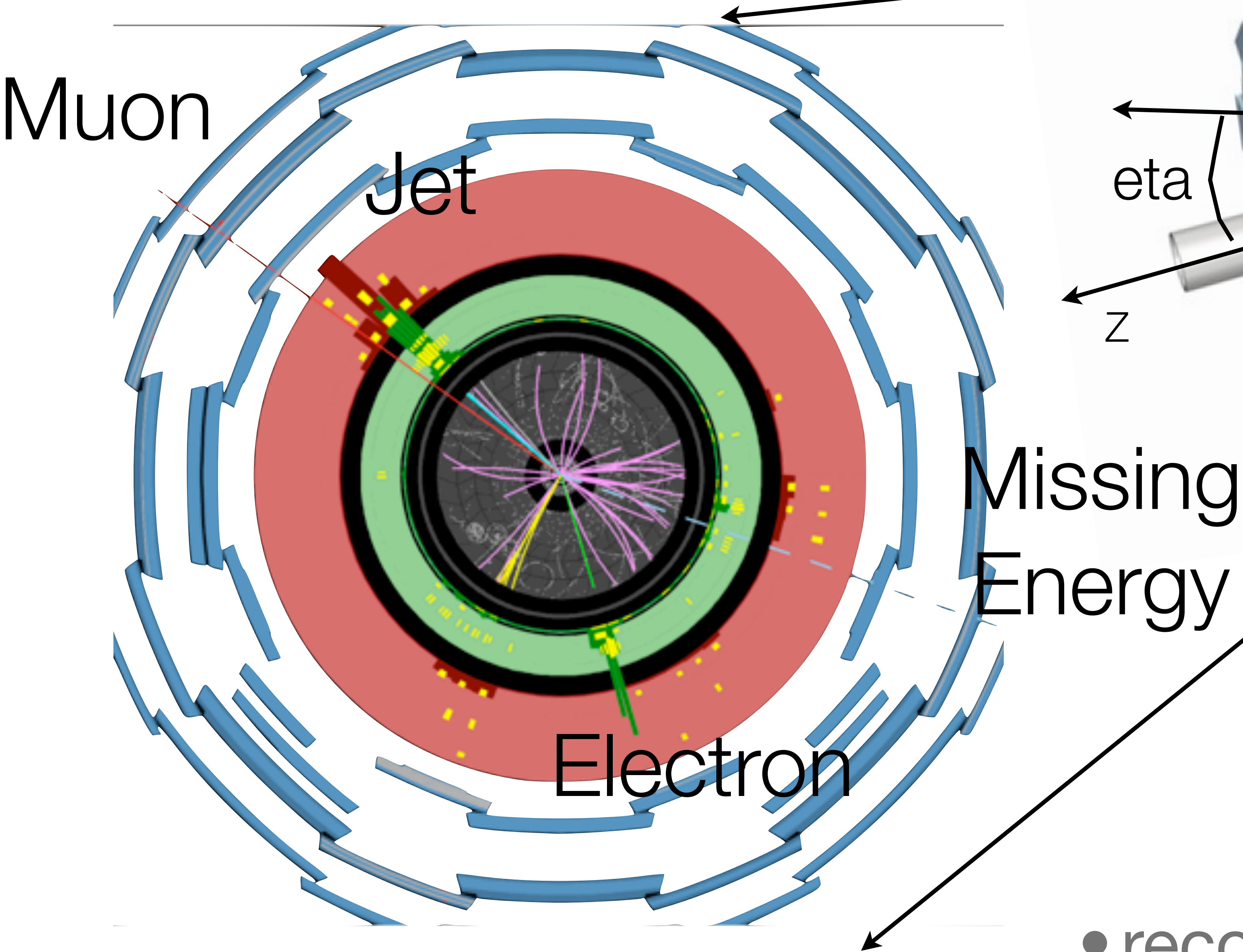
- Onion-like structure

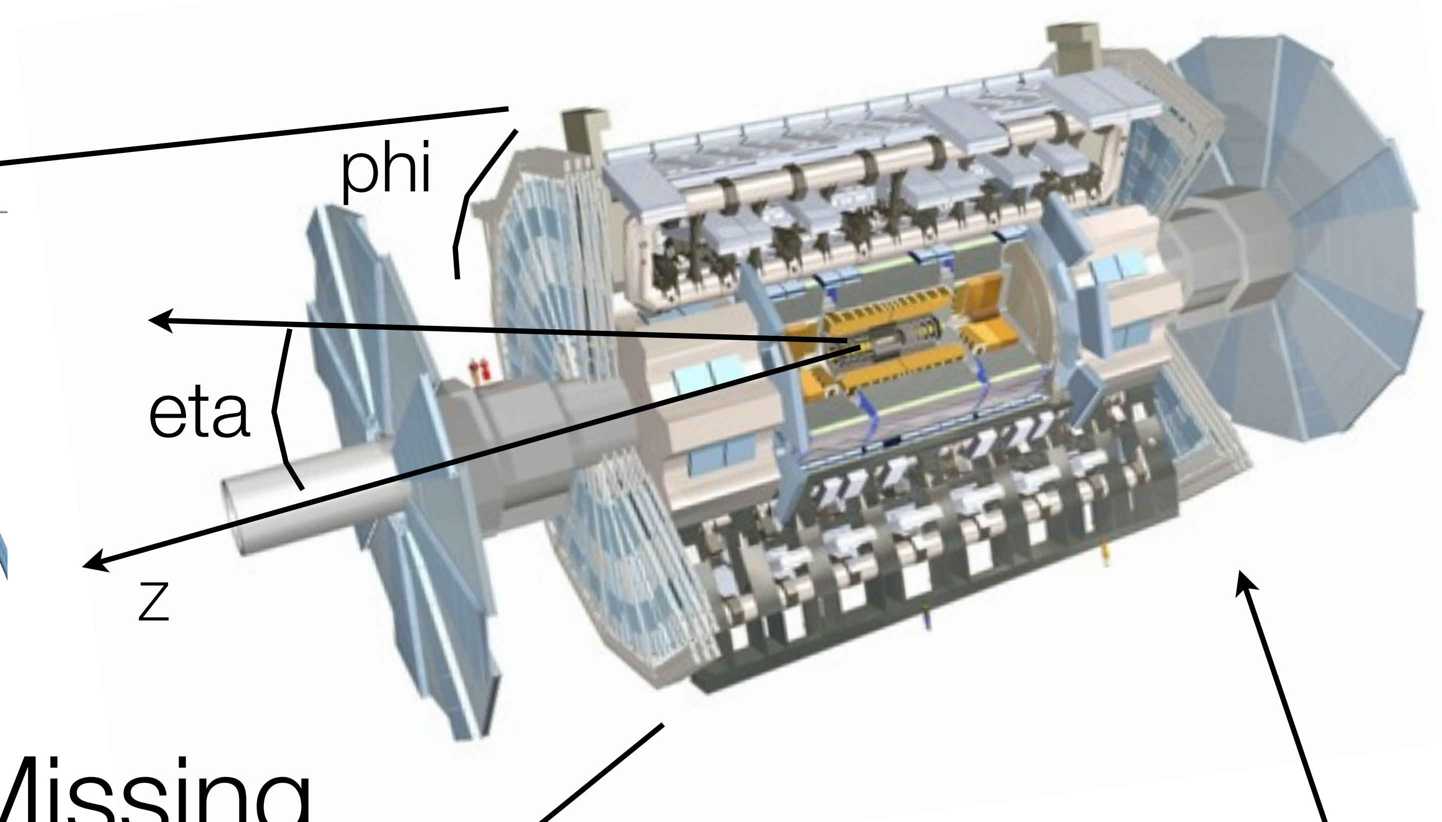




ATLAS : a *Top* observer

Top is a real commissiong tool: full detector at play



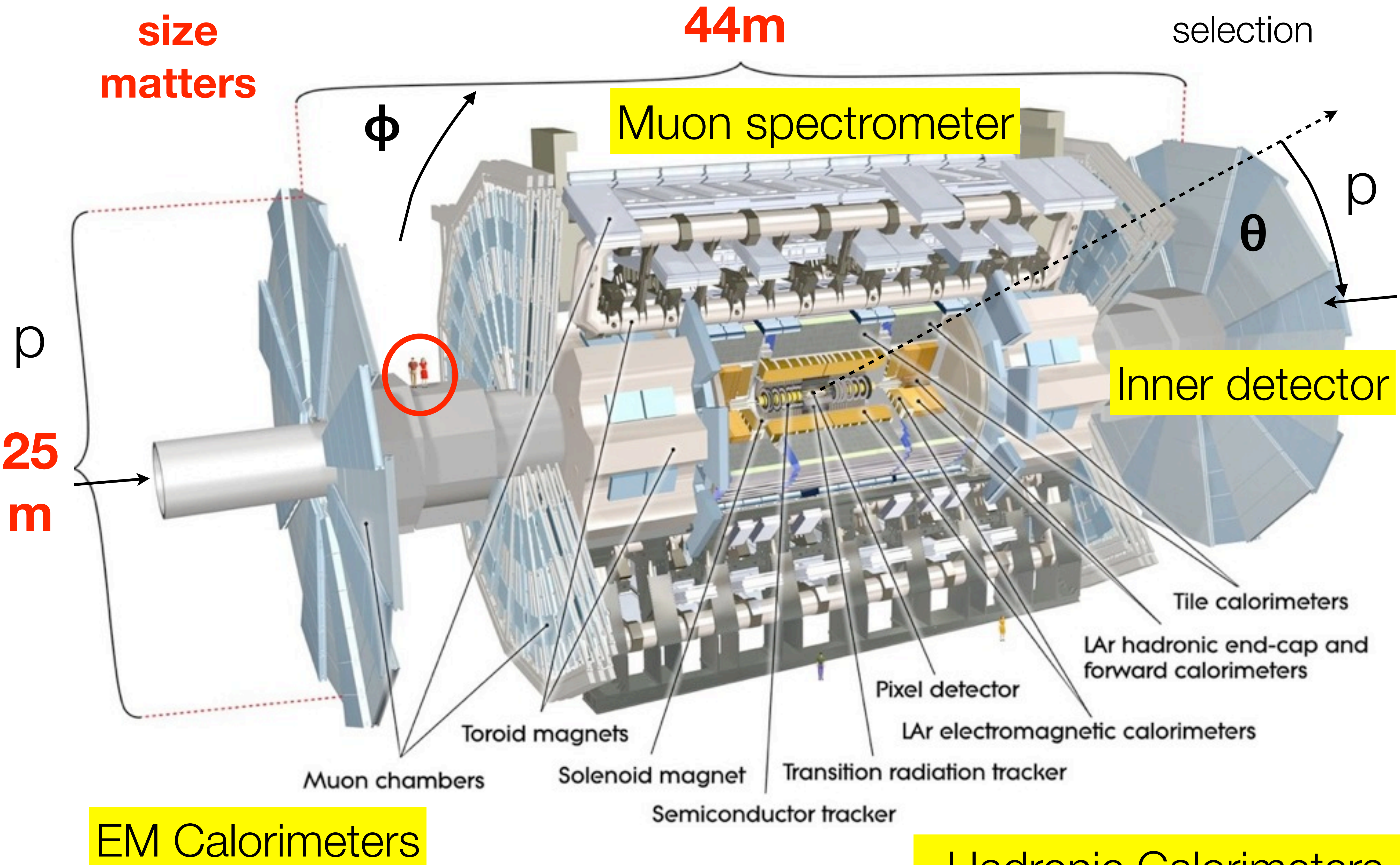


3-level trigger reducing the rate from 40 MHz to ~200 Hz

- reconstruct interaction vertex, electrons, muons, jets and missing energy

ATLAS : a *Top* observer

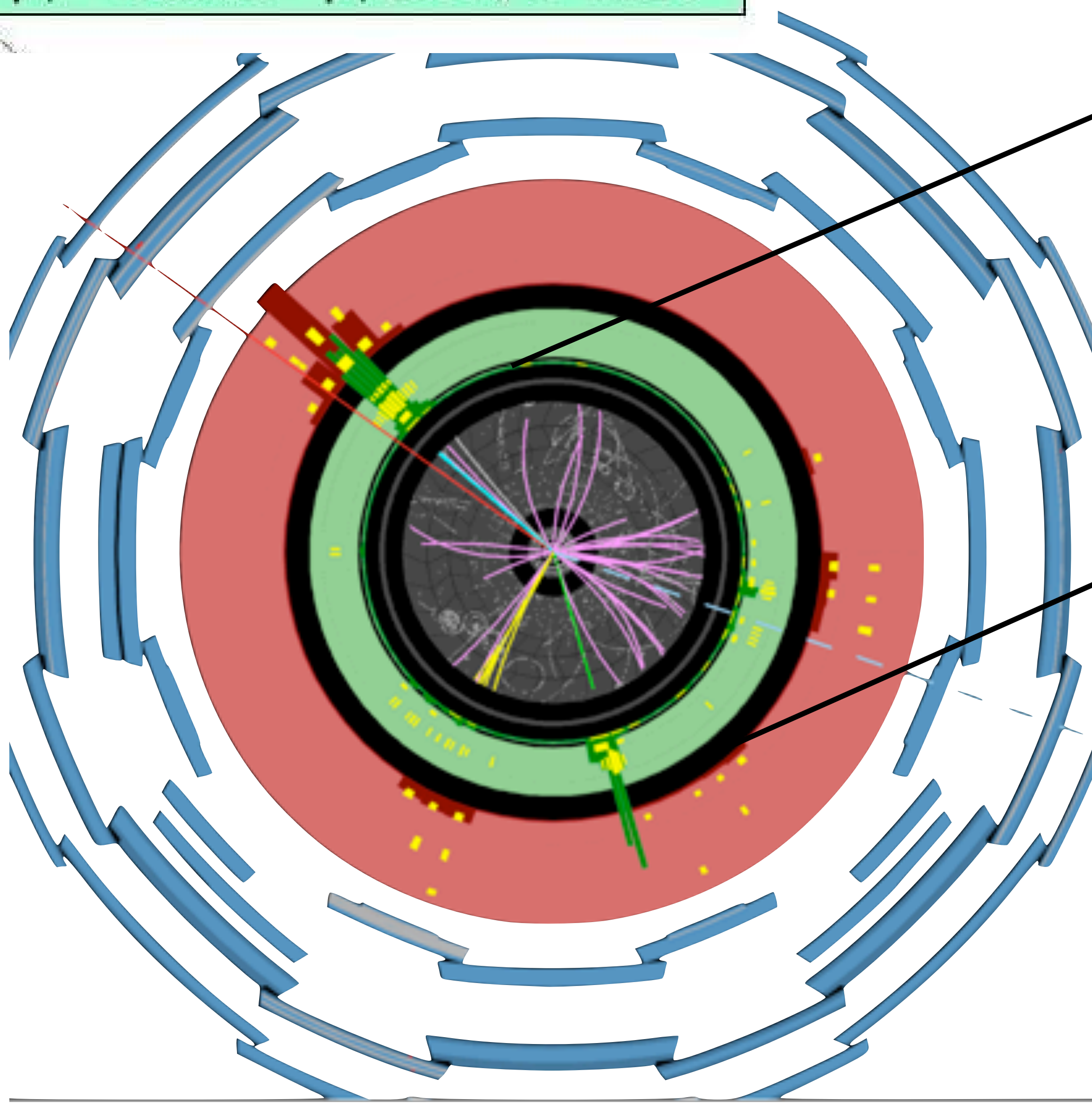
3 trigger levels for event selection



η = pseudorapidity =-ln (tan(θ/2))

ATLAS : a *Top* observer

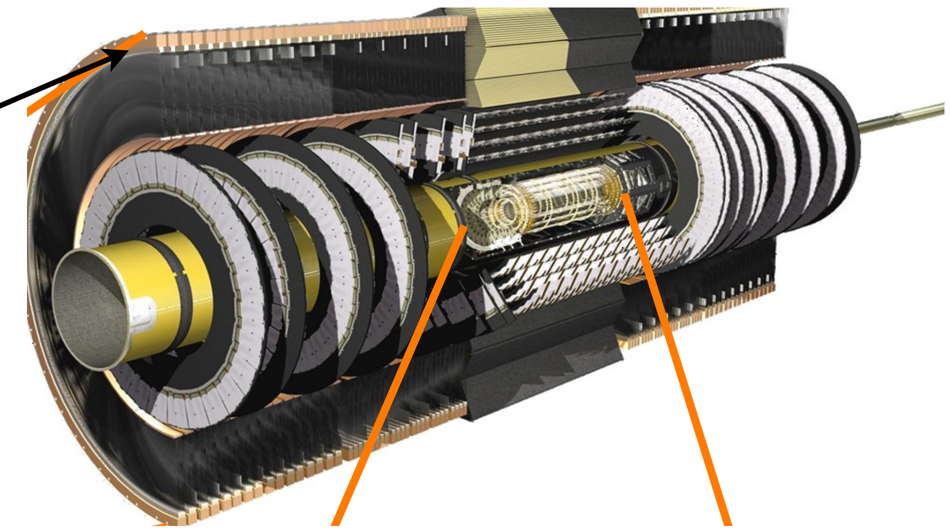
Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing, e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8 \times 10^{-4}\, p_T\,(\mathrm{GeV}) \oplus 0.015$



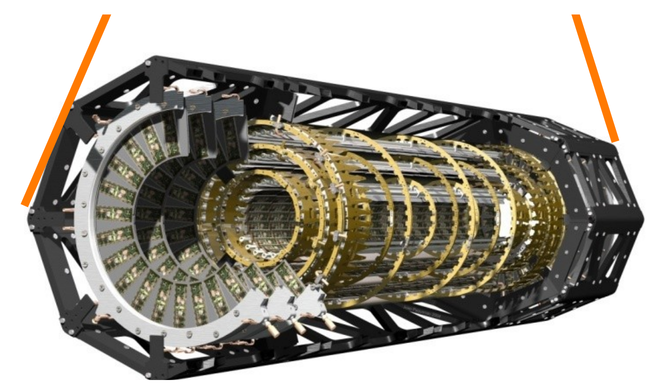
Inner detector

Transition radiation tracker

Semi conductor tracker



track, particle identifcation, pt measurement



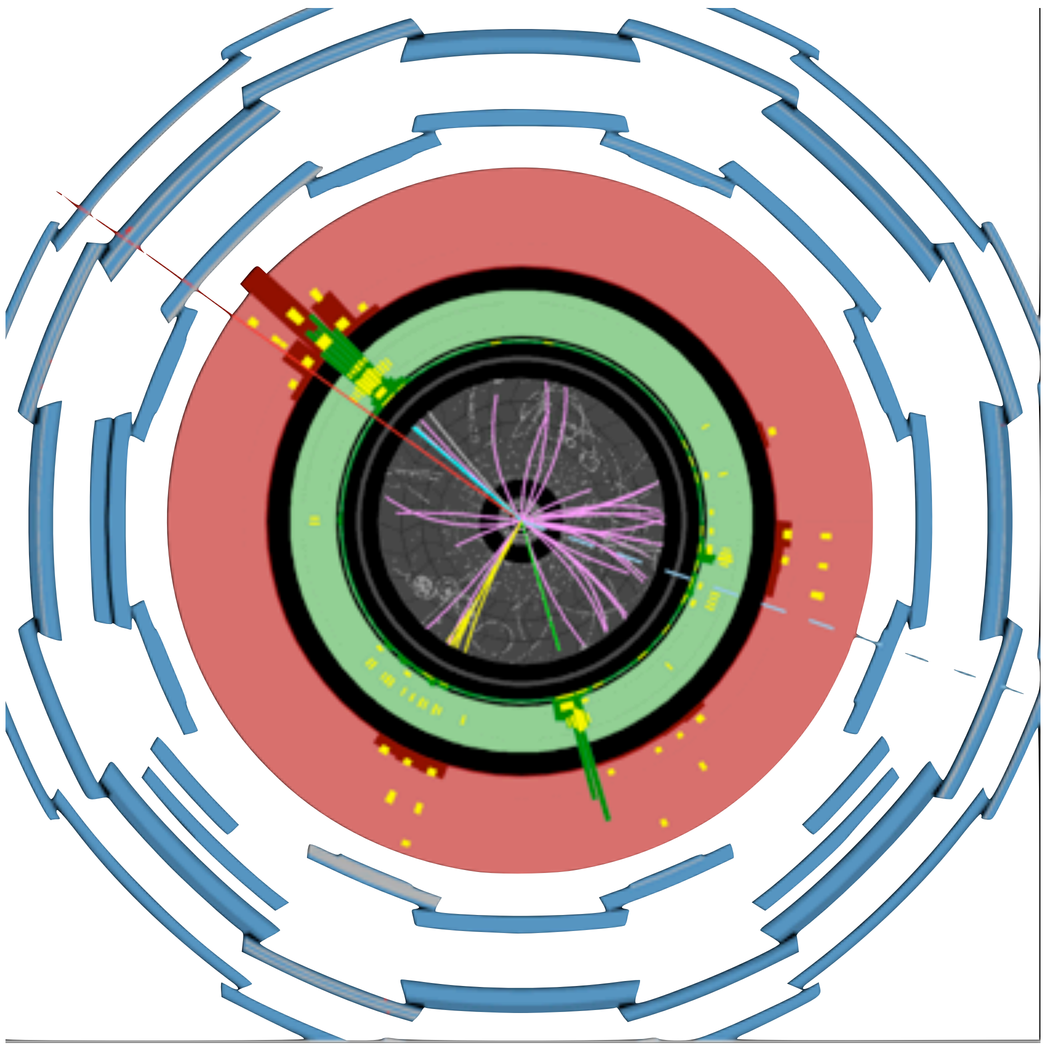
Pixel detec tor

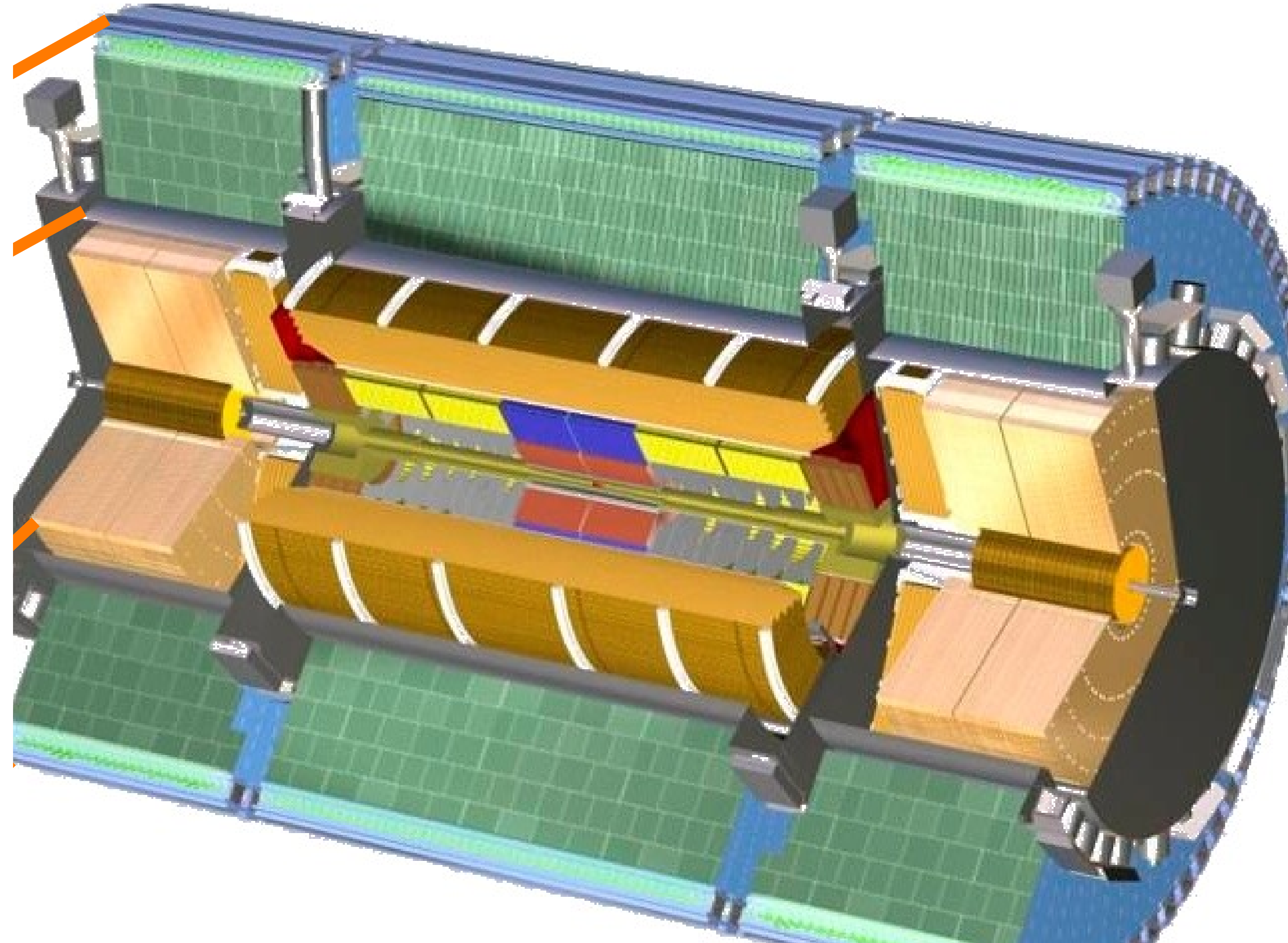
b-tagging

***ATLAS* : a *Top* observer**

Calorimeters

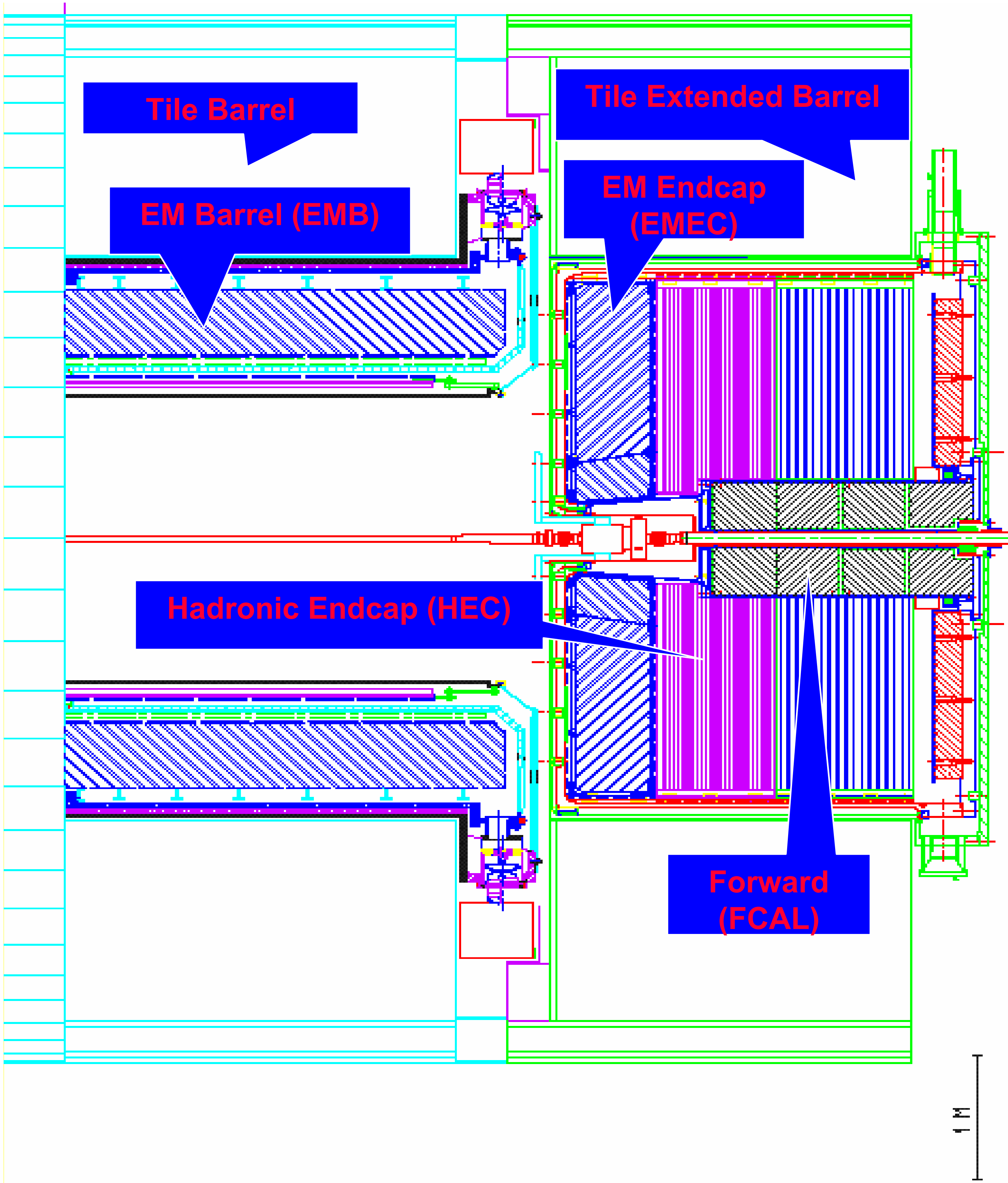
electron and jets reconstruction
Missing transverse energy





EM calorimeter: Pb-LAr Accordion
e/γ trigger, ID and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$



ATLAS Calorimetry

- EM LAr-Pb :
  - Barrel (EMB): $|\eta| < 1.5$
  - EndCap (EMEC): $1.4<|\eta|<3.2$
- Hadron Calorimeters
  - Barrel (Tile) Scintil.-Steel: $|\eta|<1.7$
  - End-Cap (HEC): LAr-Cu $1.5<|\eta|<3.2$
- Forward Calorimeter $3.2 <|\eta|< 5.0$
  - Fcal1: LAr-Cu
  - Fcal2&3: LAr-W

Variety of materials, techniques, granularity, different performances

↓

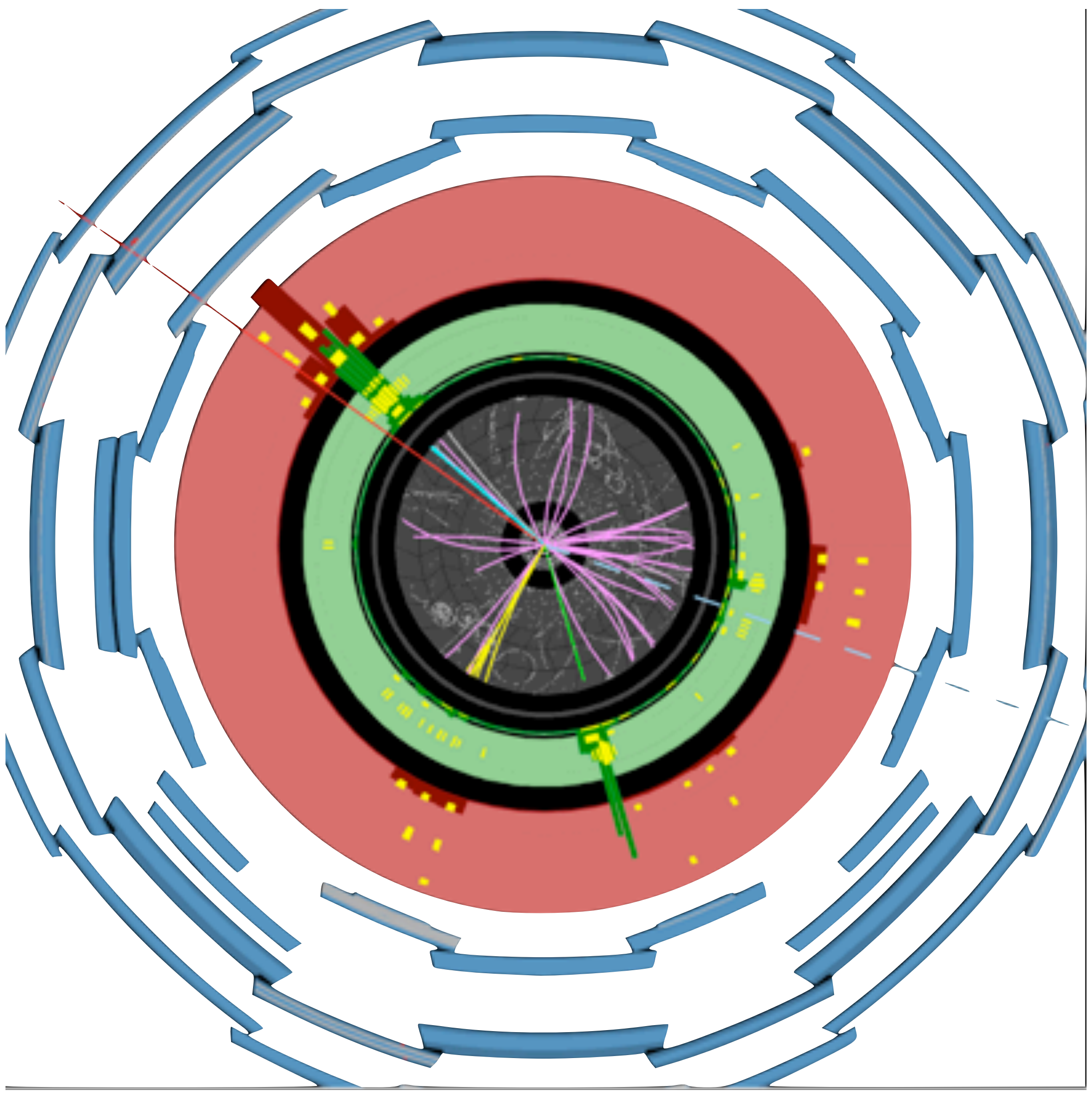
Need coherent view!

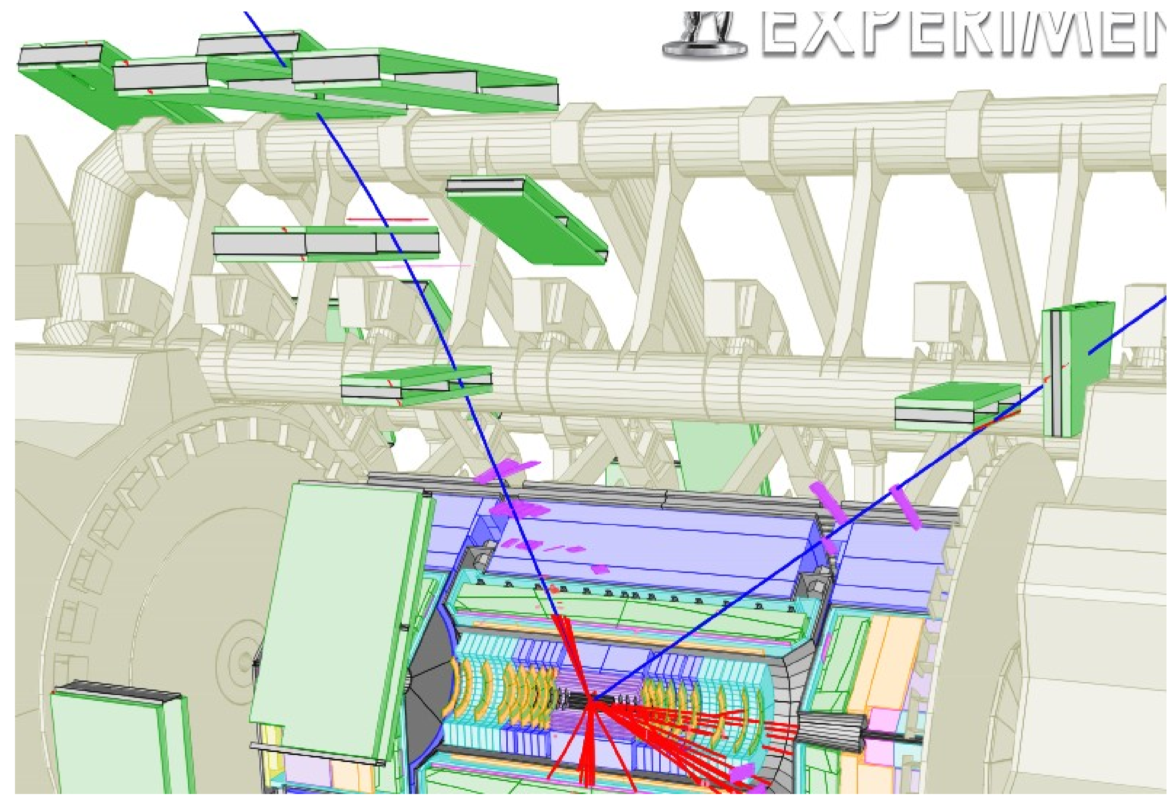
s Physics Workshop - Roma - 8th June 2005

F Spanò, Local Hadron calibration, Atlas Physics Workshop Rome 2005

ATLAS **:** a *Top* observer

Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV



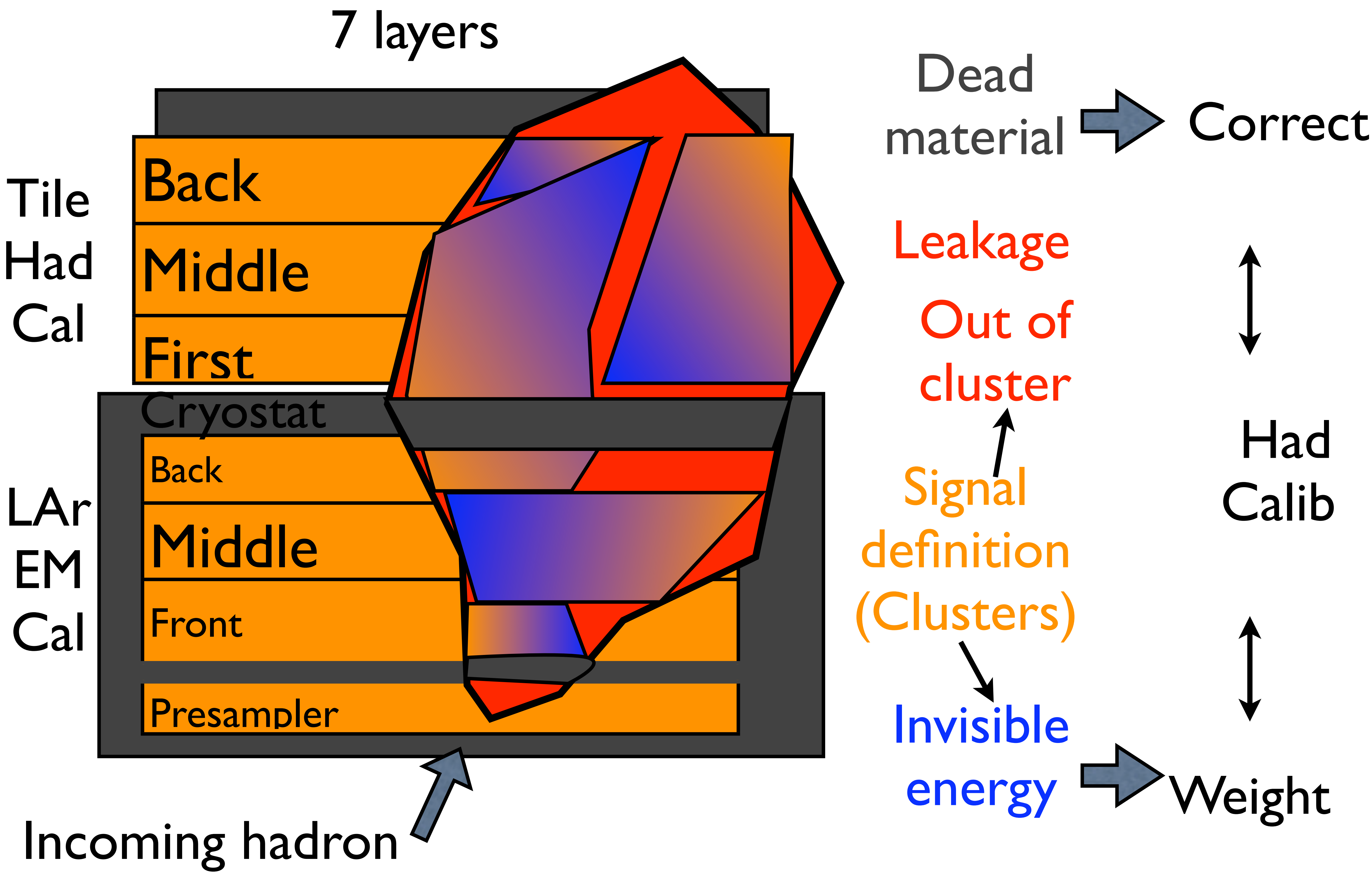


Muon spectrometer

particle identification

pt measurement

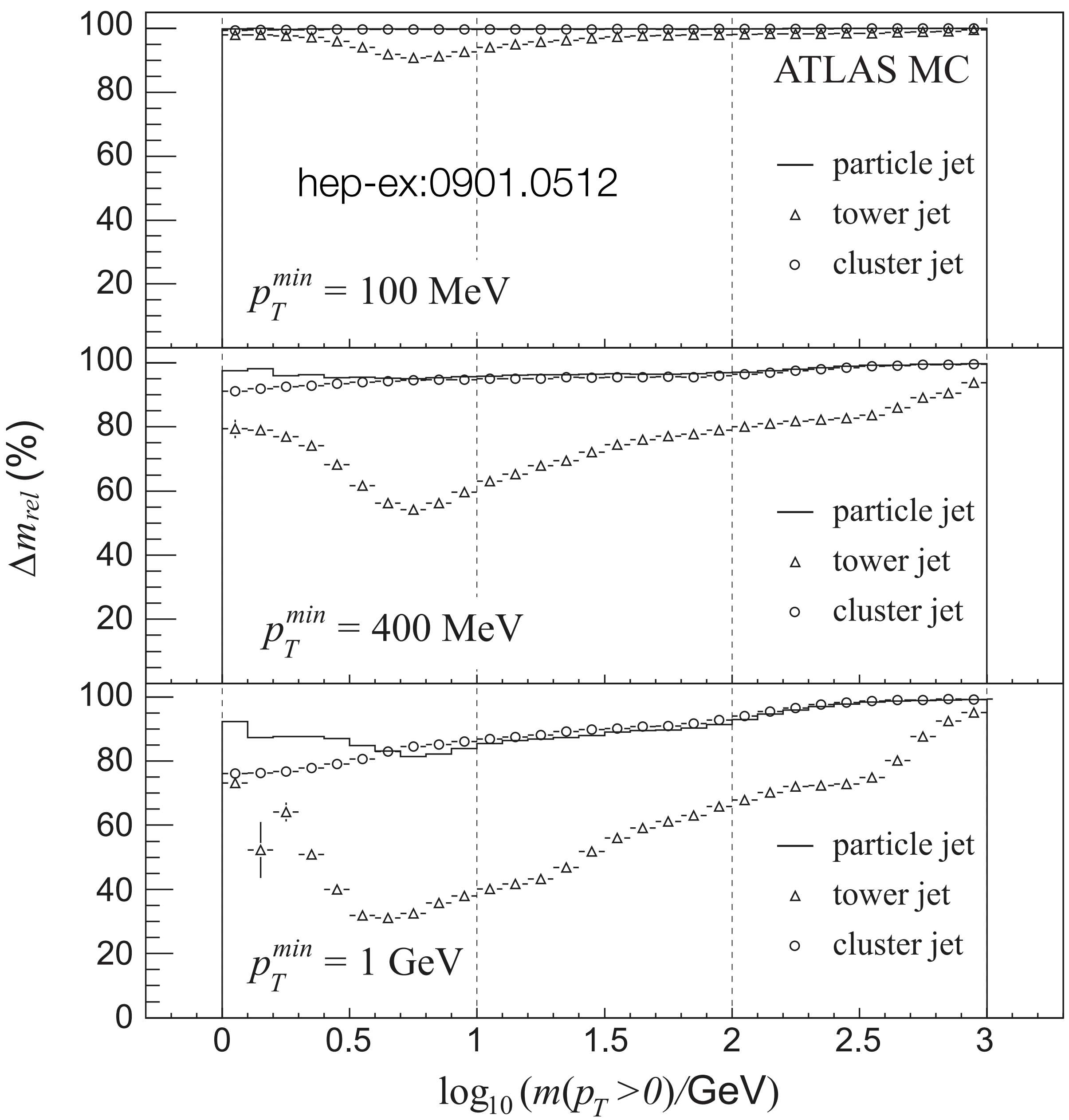
Pion in ATLAS Calo

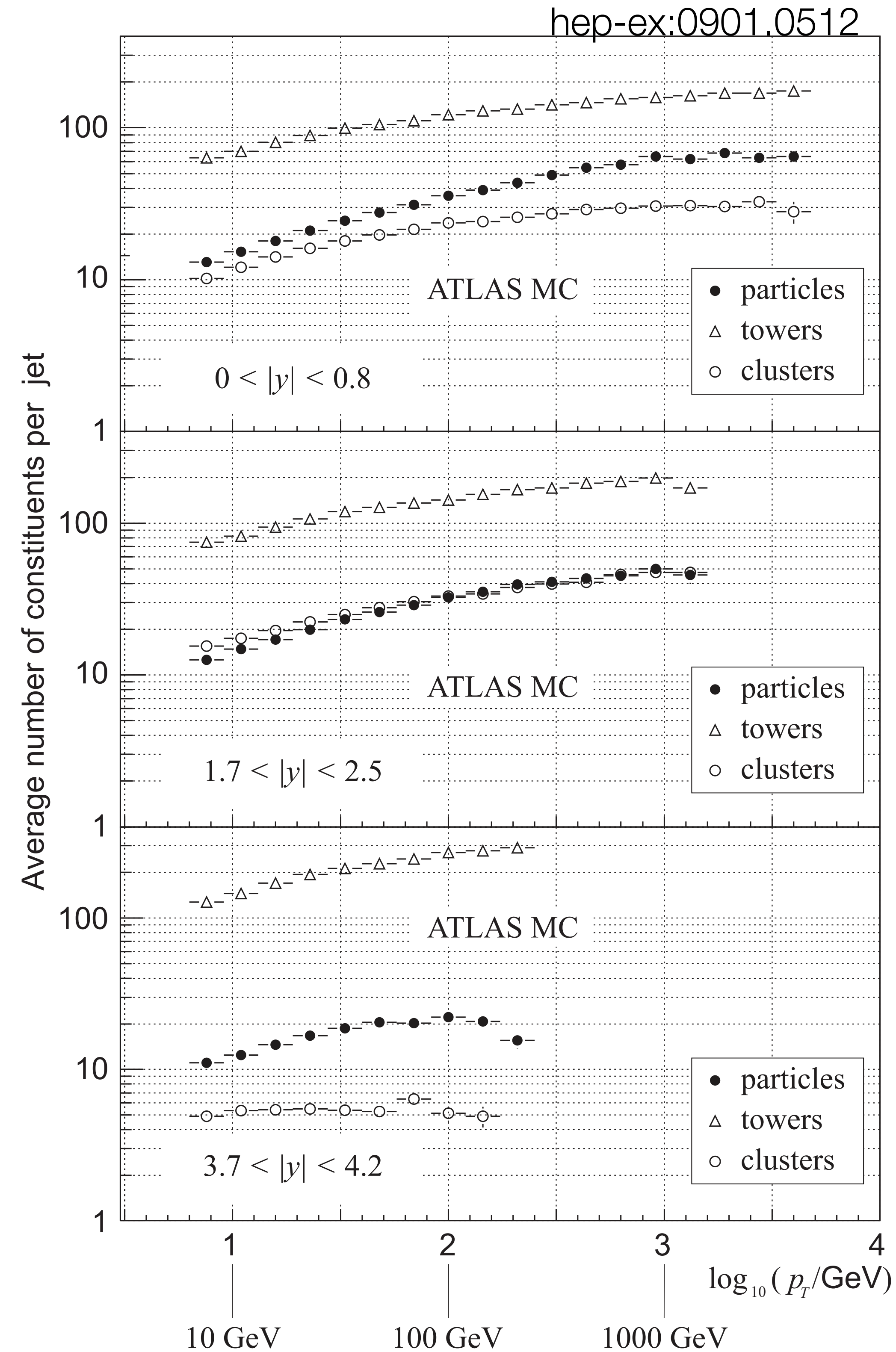


Calorimeter Clustering

di-jet simulated events, anti-k_T R=0.6

- Keep particle picture, capture shower, suppress noise
- Number of constituents per jet and jet mass closest to “true” stable particle jets





Monte Carlo used in top analyses

Generation

- Top quark : MC@NLO
  - xsec is normalized to NNLO effects
- Single top : MC@NLO
  - t, Wt and s channels
  - normalized to MC@NLO, remove Wt overlaps with $t\bar{t}$ final state
- Z/gamma+jets : PYTHIA for Z_tautau, ALPGEN (MLM matching for) Z to ee and Z to mumu NLO factor of 1.25
- Di-boson : WW, ZZ: ALPGEN normalized to NLO from MCFM
- W+jets: ALPGEN
  - W+n light partons
  - W+bb
  - W+cc
  - W+c

Hadronization

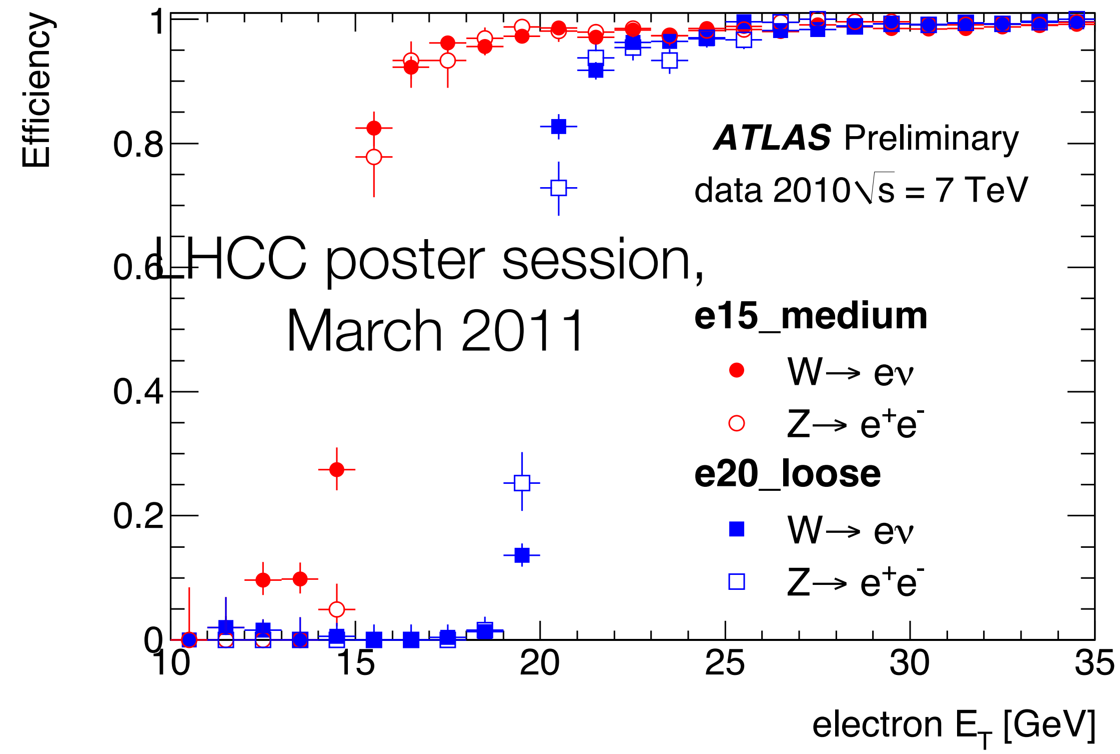
- HERWIG + JIMMY for underlying event modelling

Trigger Details

Efficiency for offline object is at plateau for p_T 20 GeV

Electron

- EM calo energy deposit with E_T between 10 and 15 GeV *at level1*
- More refined selection *at level 2*
- ***Match EM calorimeter cluster and Inner Dret track** at level3*

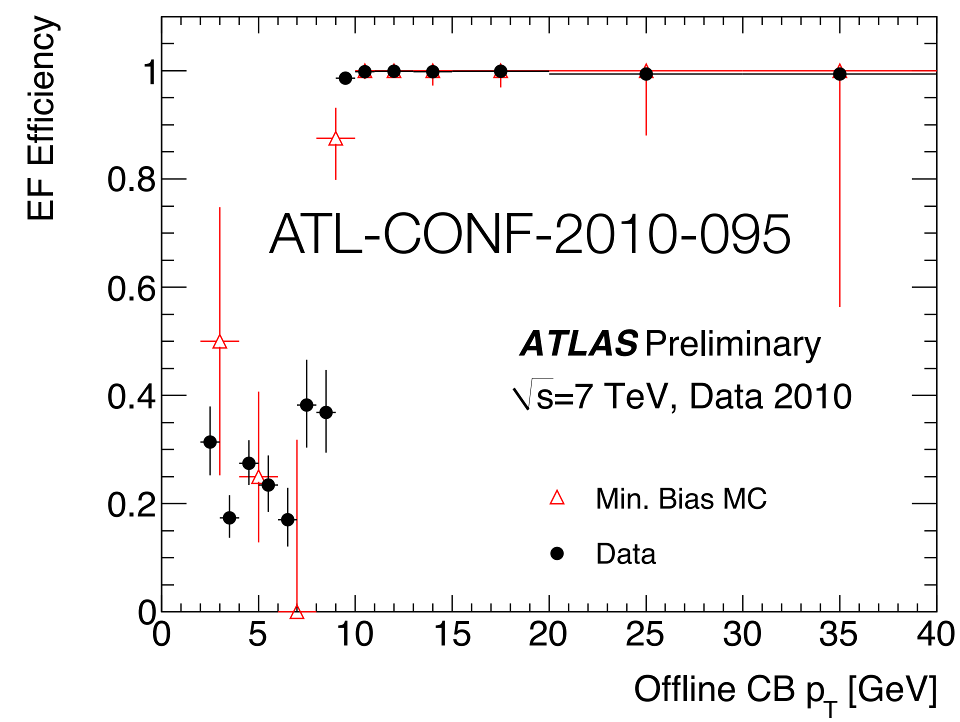


3rd level efficiency with tag and probe method for Z (in Z window), missing ET triggers for W (MET>25 GeV, isolated form Jet, MTw.40 GeV)

Muon

- Level1 track in muon chambers with p_T >10 GeV *at level 1*
- Confirm at level 2
- Match to track in inner detector . P_T threshold between 10 and 13 GeV with p_T >13 GeV muon, use precision chambers *at level 3*

$$\varepsilon_{trigger}(Z\ T\&P) = \frac{N_{matched}}{N_{probes}}$$



3rd level muon efficiency with respect to offline muon matched to level 1 and level2

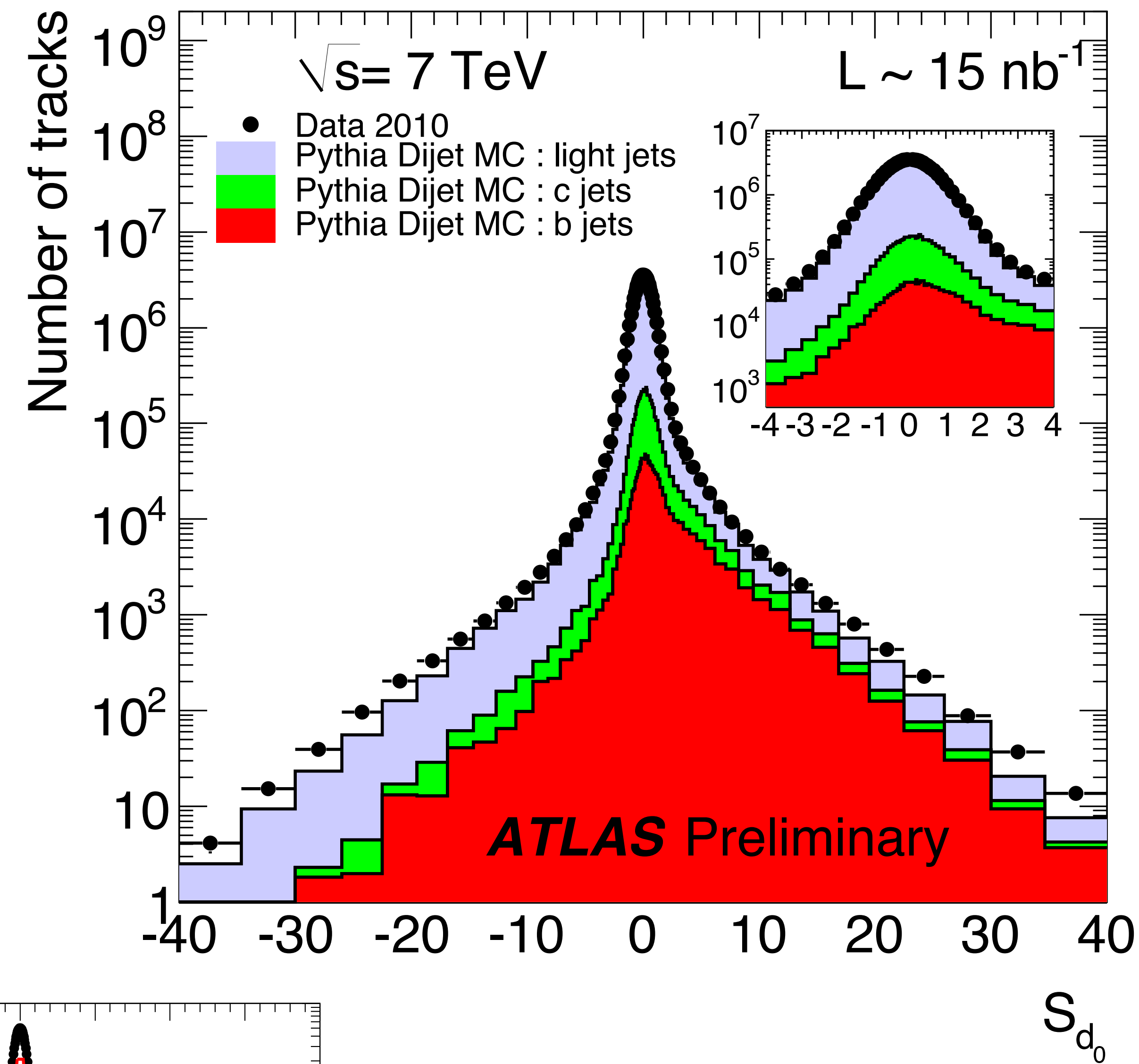
B-tagging : Jet prob algorithm

$$S_{d_0} \equiv d_0/\sigma_{d_0}$$

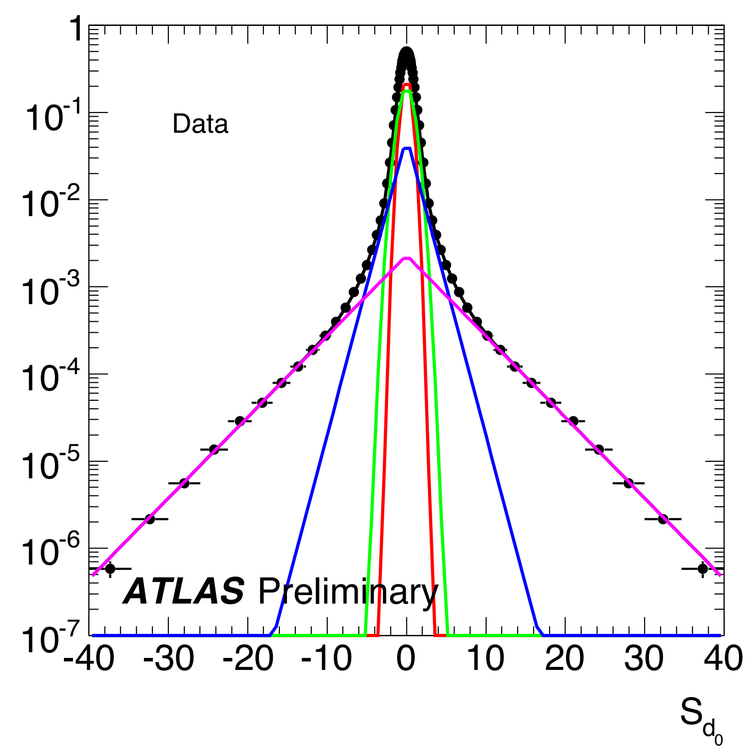
- Compare signed impact parameter significance for each track in jet to resolution function to find track prob. to originate

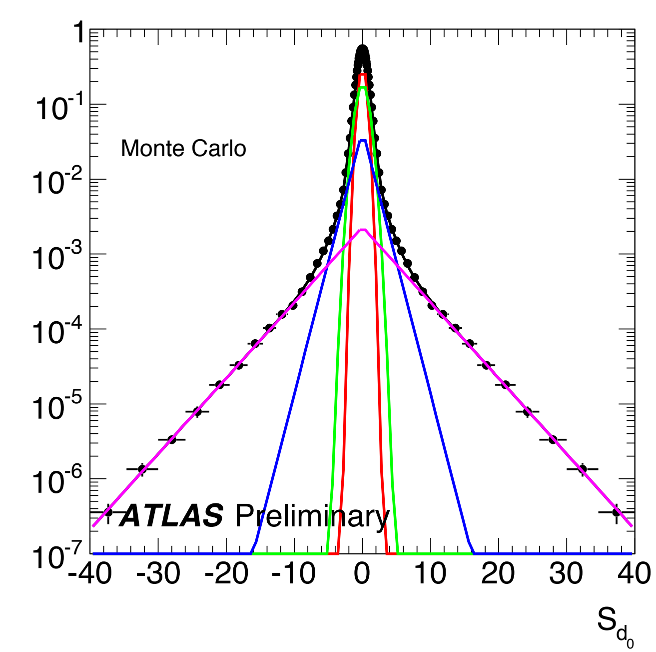
$$\mathscr{P}_{\mathrm{trk}\,i} = \int_{-\infty}^{-|d_0^i/\sigma_{d_0}^i|} \mathscr{R}(x)dx.$$

$$\mathscr{P}_{\mathrm{jet}} = \mathscr{P}_0 \sum_{k=0}^{N-1} \frac{(-ln\mathscr{P}_0)^k}{k!},$$



In sim. $t\bar{t}$ events: 70% b-tag efficiency and 5% of wrongly tagged light jets





Jet calibration : top Specific effects

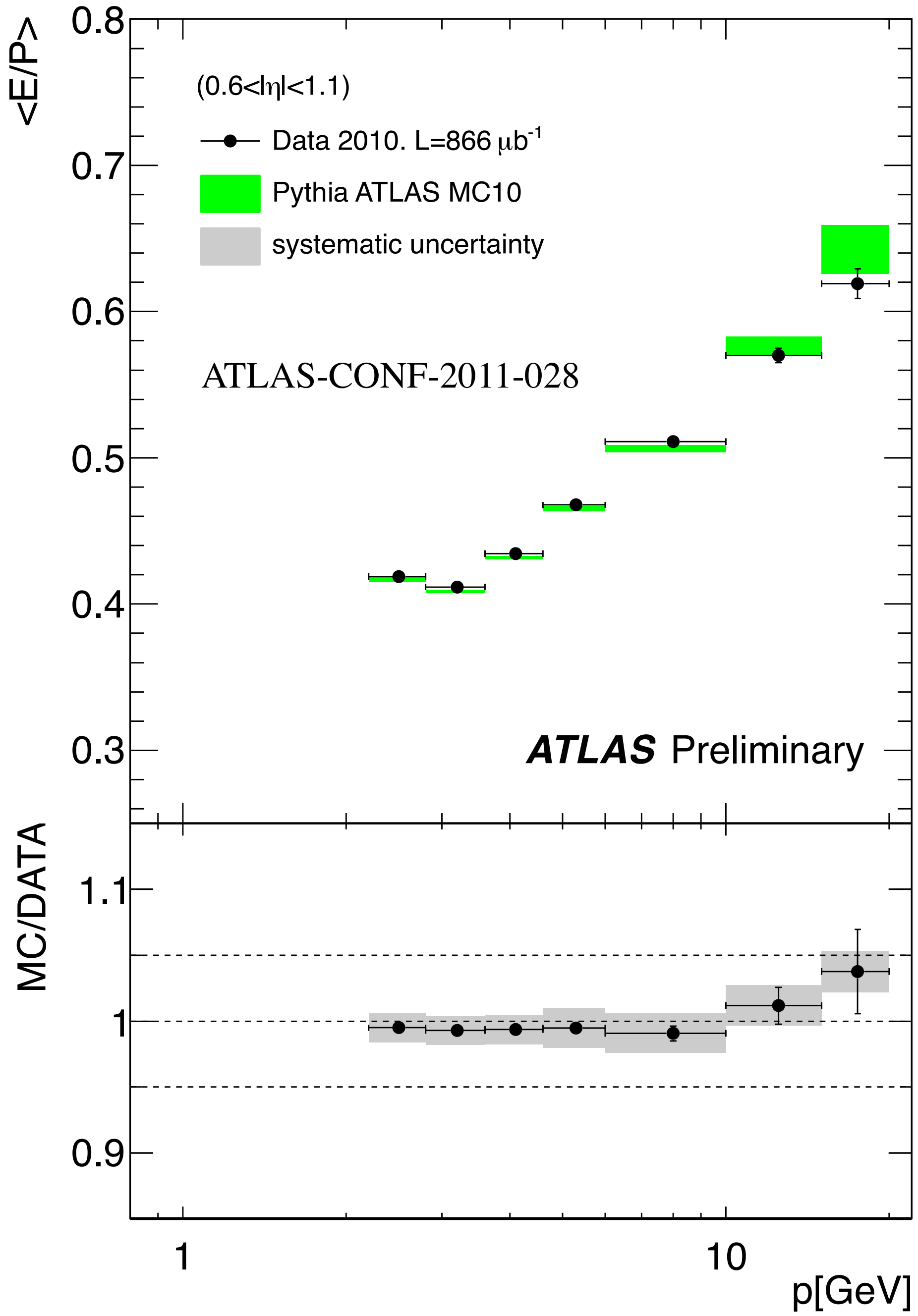
- Close by jet
  - jet splitting can bias scale
  - recover by monte carlo baed correction as a fucntion of isolation

- Gluon vs quark jets
  - different response in gluon initiated and uqark initiated jets
  - validation in di-jet (gluon) and gamma-jet (quark) samples

- B-jet
  - tag and probe method in data-MC in di-jet
  - comparison to track jets (data/MC)

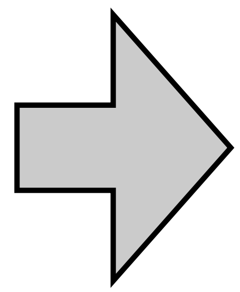
Ingredients II : jets (making and calibrating)

Extensive **validation of simulation in test-beam** data → **good collision data description**

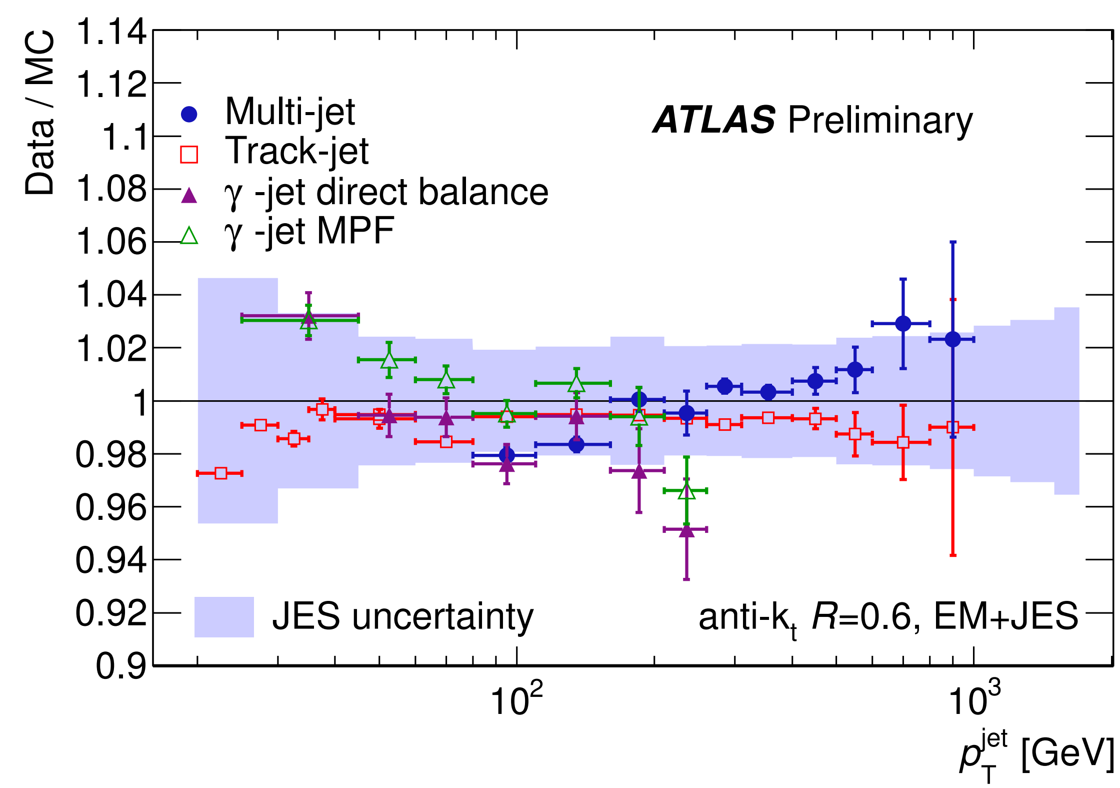


Data/MC within 2% for p<10 GeV

charged hadron response vs track momentum

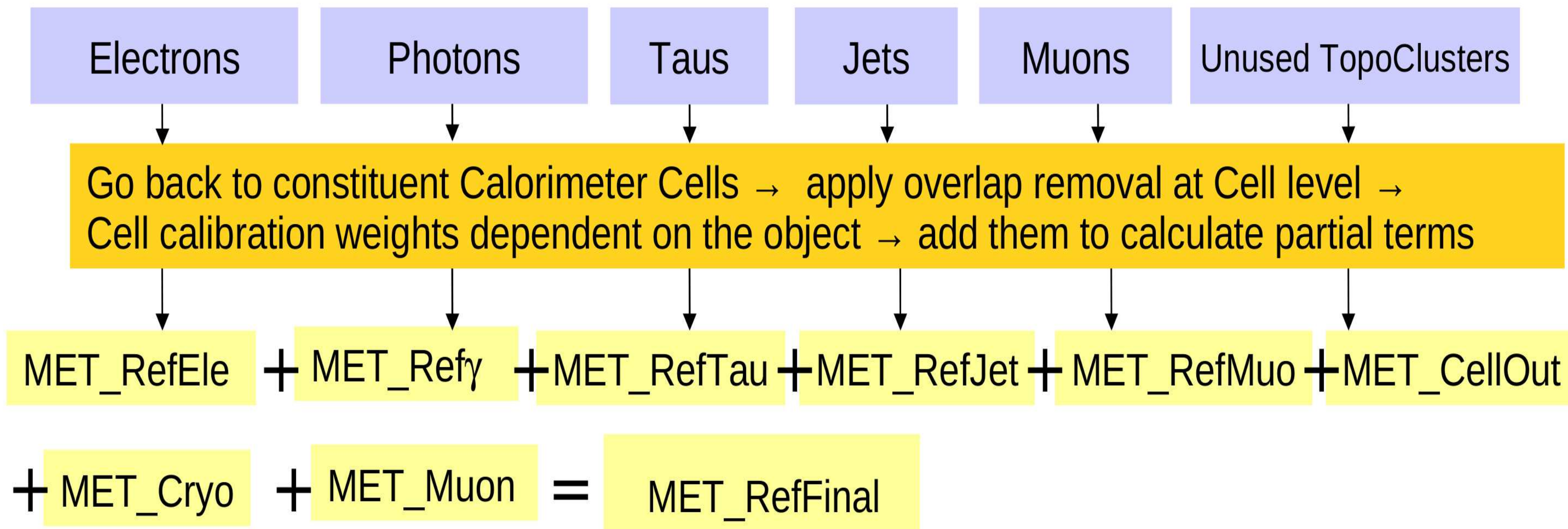


- **Calibrate jet energy scale** with (η,p_T) dependent weight ***from simulated "true" jet kinematics***
- **Scale uncertainty:** range between 2% to 8% in p_T and η
  - Contributions from physics modelling, calo response, det
  - Validation in control samples



MIssing transverse energy (I)

$$E_{x(y)}^{\text{miss}} = E_{x(y)}^{\text{miss,calo}} + E_{x(y)}^{\text{miss,cryo}} + E_{x(y)}^{\text{miss,muon}}$$



- overlap removal order is
  - electron, photon, hadronic taus, jets, muons

MIssing transverse energy (II)

- The three terms are, muons

$$E_{x(y)}^{\text{miss}} = E_{x(y)}^{\text{miss,calo}} + E_{x(y)}^{\text{miss,cryo}} + E_{x(y)}^{\text{miss,muon}}$$

$$E_{x(y)}^{\text{miss,calo,calib}} = E_{x(y)}^{\text{miss},e} + E_{x(y)}^{\text{miss},\gamma} + E_{x(y)}^{\text{miss},\tau} + E_{x(y)}^{\text{miss,jets}} + E_{x(y)}^{\text{miss,calo},\mu} + \boxed{E_{x(y)}^{\text{miss,CellOut}}}$$

$$E_{x(y)}^{\text{miss},\mu} = - \sum_{\text{selected muons}} E_{x(y)}^{\mu}$$

isolated muons

non-isolated muons

$$E_{x(y)}^{\text{miss,cryo}} = - \sum_{\text{jets}} E_{x(y)}^{\text{jet,cryo}}$$

$$E_x^{\text{jet,cryo}} = w^{\text{cryo}} \sqrt{E_{\text{EM3}}^{\text{jet}} \times E_{\text{HAD1}}^{\text{jet}}} \frac{\cos\phi_{\text{jet}}}{\cosh\eta_{\text{jet}}}$$

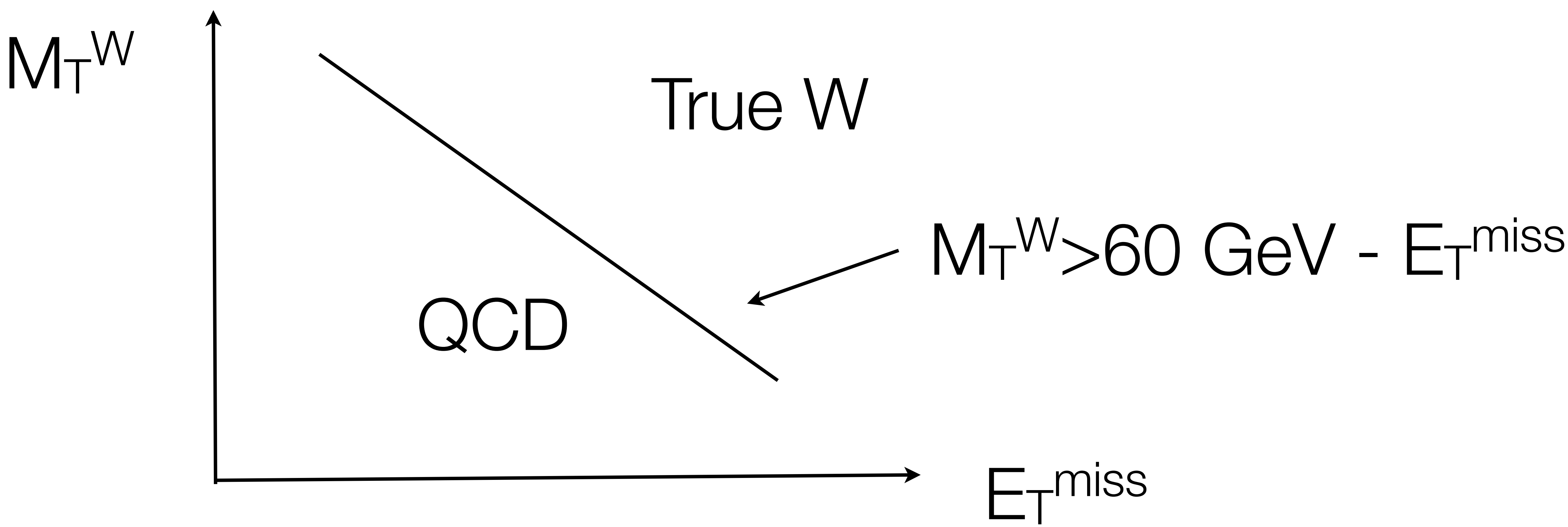
$$E_y^{\text{jet,cryo}} = w^{\text{cryo}} \sqrt{E_{\text{EM3}}^{\text{jet}} \times E_{\text{HAD1}}^{\text{jet}}} \frac{\sin\phi_{\text{jet}}}{\cosh\eta_{\text{jet}}}$$

Triangular cut

- True W leptonic decay with large missing transverse energy E_T^{miss} also have large W transverse mass M_T^W

- Mis-measured jets in QCD may have large missing transverse energy E_T^{miss}, but small transverse mass M_T^W

- Requirement on transverse missing energy and transverse mass discriminates the two



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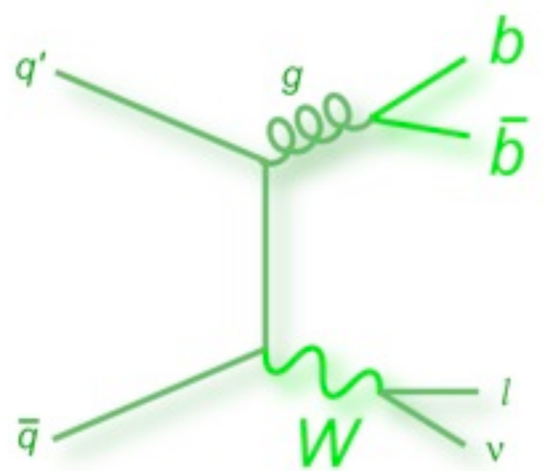
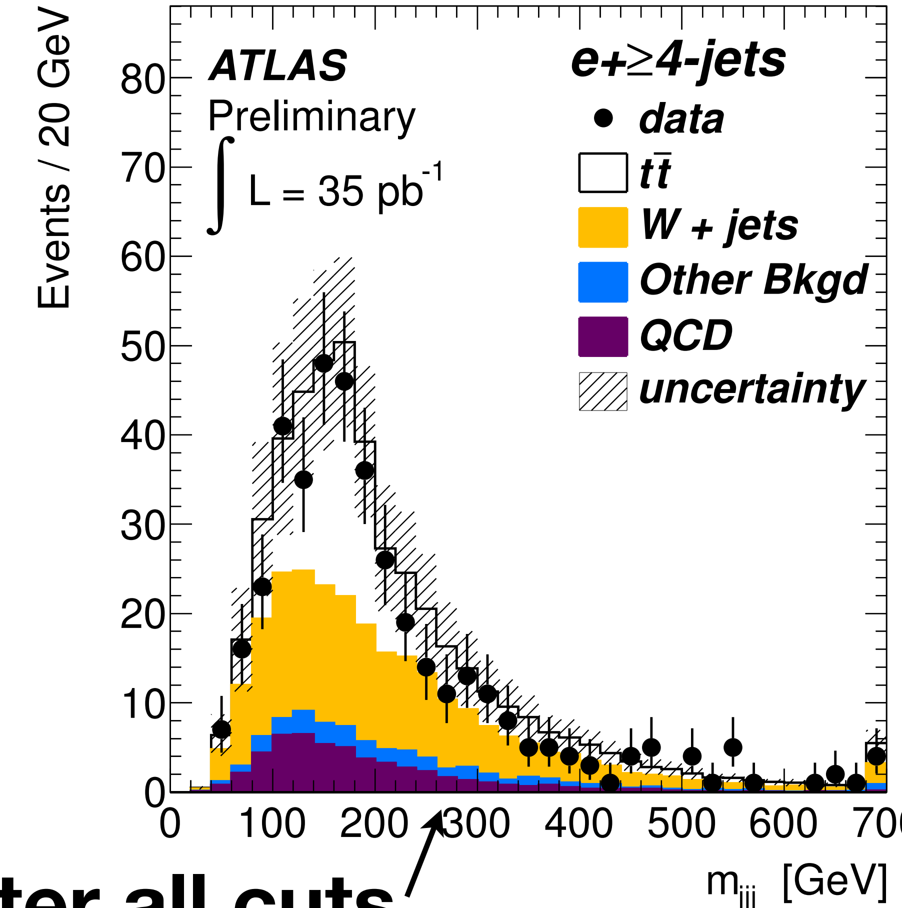
Backgrounds - single lepton

- **W(/Z)+jets**

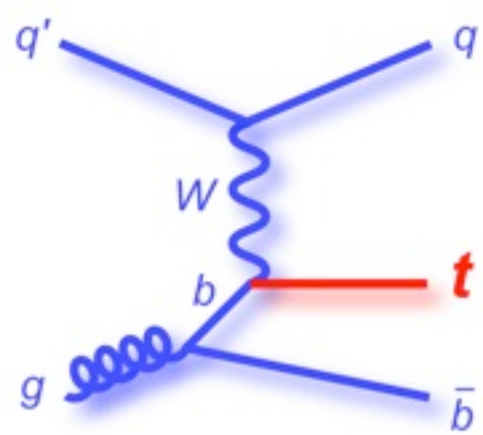


Shape from simulation rate from final fit

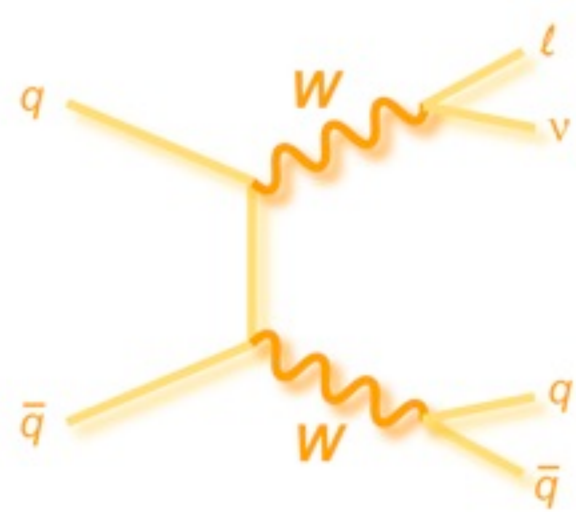


after all cuts

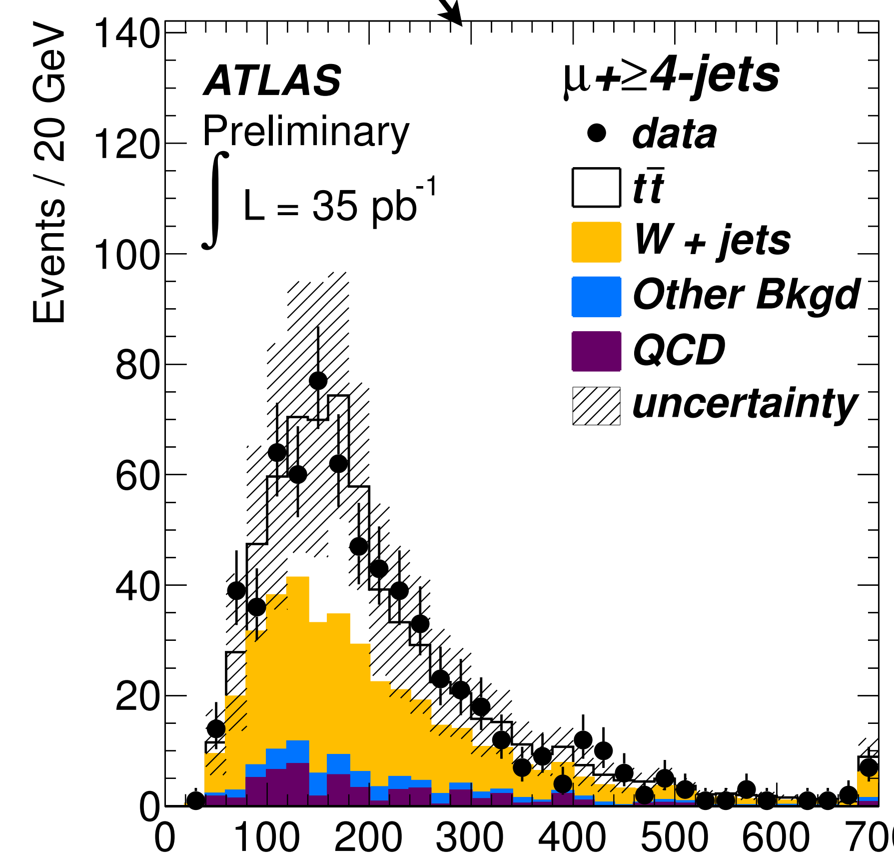
- **Single top**



- **Di-bosons (WW,WZ,ZZ)**



Simulated + rate set to SM prediction



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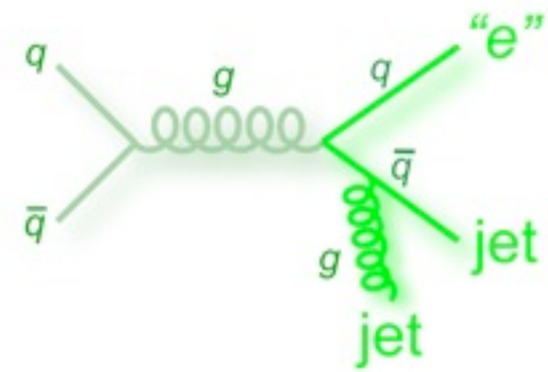
Background estimates: QCD multi-jet -single lep (*with btag*)

- "Fake" leptons: mis-id jets,$\gamma \rightarrow e^+e^-$
  non-prompt leptons (b/c-decays)



μ channel: matrix method

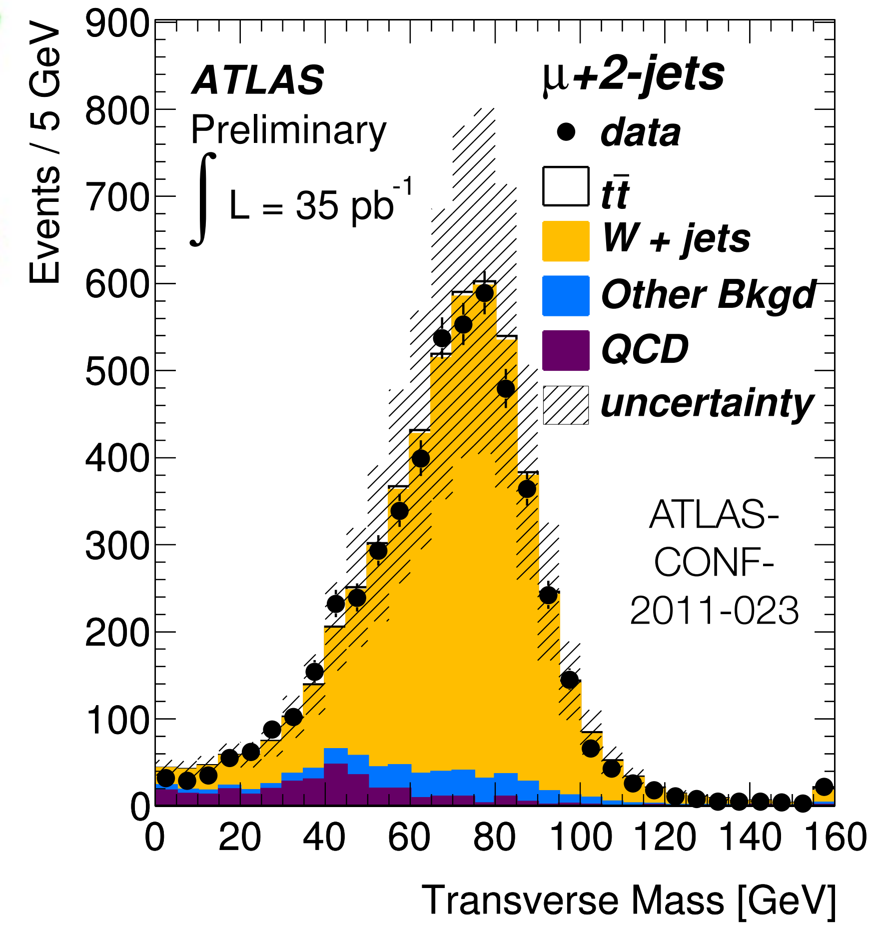
- Measure $N^{standard}$ (isolated-μ) and N^{loose}(non-iso-μ) events and **find standard fake muons** from

$$N^{loose} = N^{loose}_{fake} + N^{loose}_{real}$$

$$N^{standard} = \varepsilon_{fake}\, N^{loose}_{fake} + \varepsilon_{real}\, N^{loose}_{real}$$

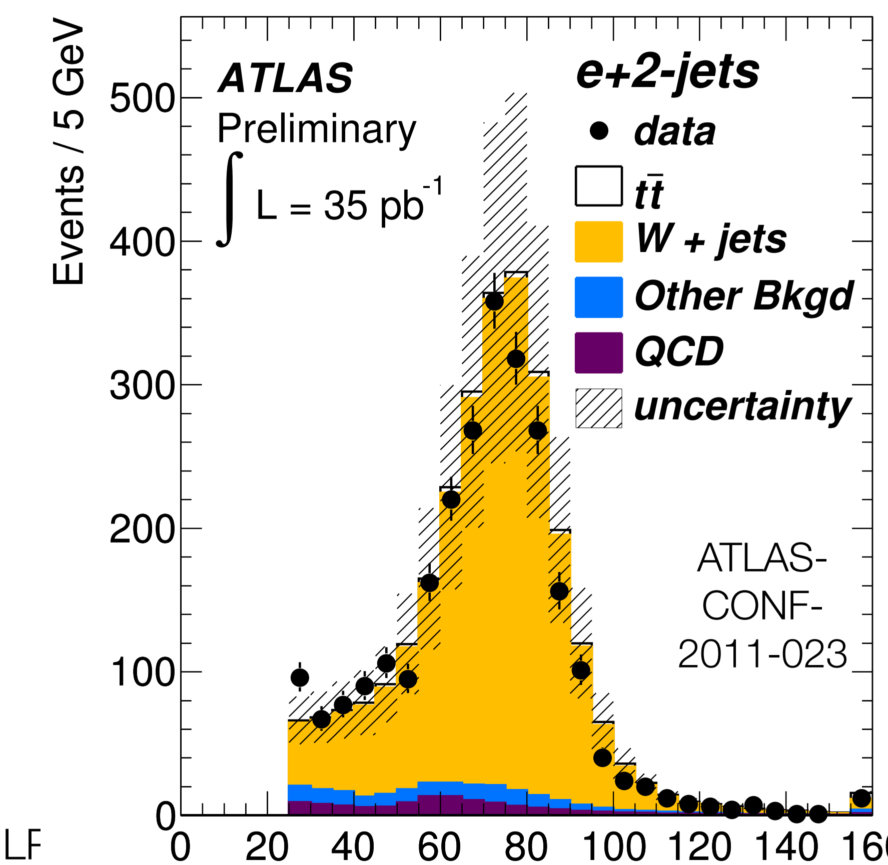
ε_{fake} from low E_T^{miss} ,M_T^W and ε_{real} from $Z \rightarrow \mu^+\mu^-$

- Do it in bins of any variable to get proper estimate



e channel: template method

- **Derive QCD template** from control region (electron fails one/more selection criteria)
- **Normalize by fitting low E_T^{miss} shape** *(QCD template + MC samples)* **to data→extrapolate to** standard region



W+jets estimate with ratio method

Estimate pre-tagged amount of W+jets in 4-jet bin then **correct it** to tagged sample

$$W^{\geq 4\text{-jet}}_{\text{tagged}} = \boxed{W^{\geq 4\text{-jet}}_{\text{pre-tag}}} \boxed{f^{\geq 4\text{-jet}}_{\text{tagged}}} \cdot$$

- Assume W+jets amounts in jet bin multiplicity are such that

$W^{n+1\text{-jets}}/W^{n\text{-jets}} \sim$ constant (Berends ,Giele)

$W^{n\text{-jets}}/W^{2\text{-jets}} = W^{n\text{-jets}}/W^{n-1\text{je}}$ * $(W^{n\text{-jets}}/W^{n-1\text{jet}}$....

$$W^{\geq 4\text{-jet}}_{\text{pre-tag}} = W^{2\text{-jet}}_{\text{pre-tag}} \cdot \sum_{n=2}^{\infty} \left(\boxed{W^{2\text{-jet}}_{\text{pre-tag}} / W^{1\text{-jet}}_{\text{pre-tag}}} \right)^n,$$

Measured by subtracting simulated nonW bkg in 1,2 jet bin, before b-tagging

good agreement data/MC in control region

$$f^{\geq 4\text{-jet}}_{\text{tagged}} = \boxed{f^{2\text{-jet}}_{\text{tagged}}} \cdot \boxed{f^{\text{corr}}_{2\rightarrow\geq 4}}$$

Subtract MC in content of 2jet bin bef and after tagging. Take ratio (only in mu, less QCD)

$$f^{\text{corr}}_{2\rightarrow\geq 4} = f^{\geq 4\text{-jet}}_{\text{tagged}} / f^{2\text{-jet}}_{\text{tagged}}$$

from simulation

Extract top cross section (I) - single lepton

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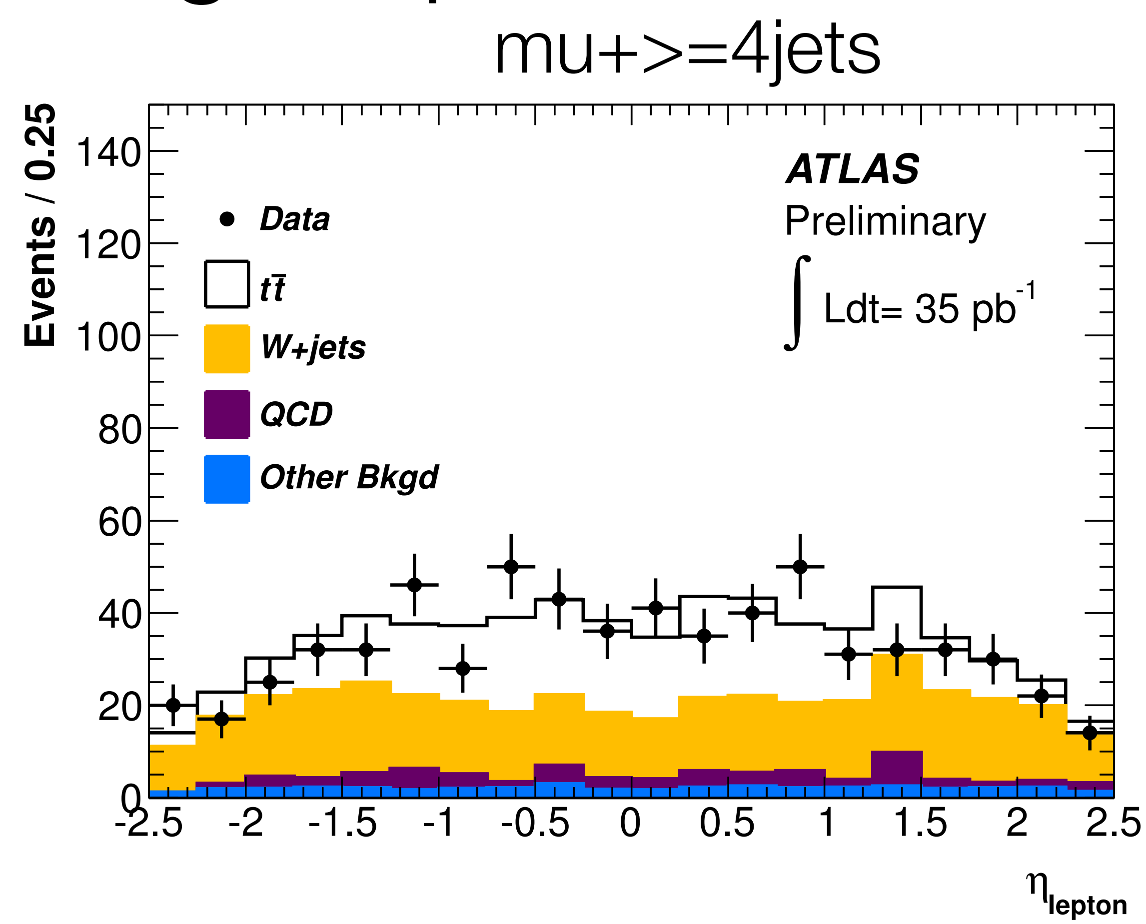
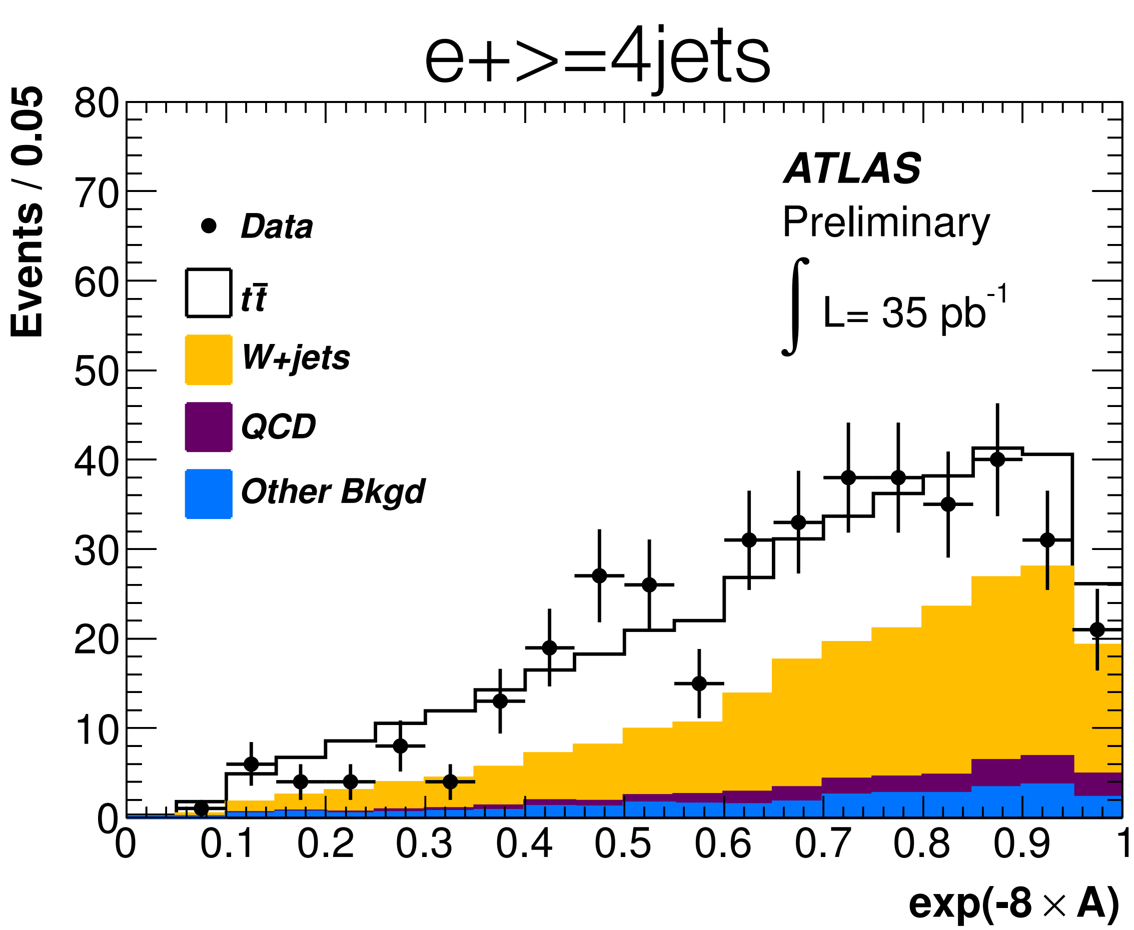
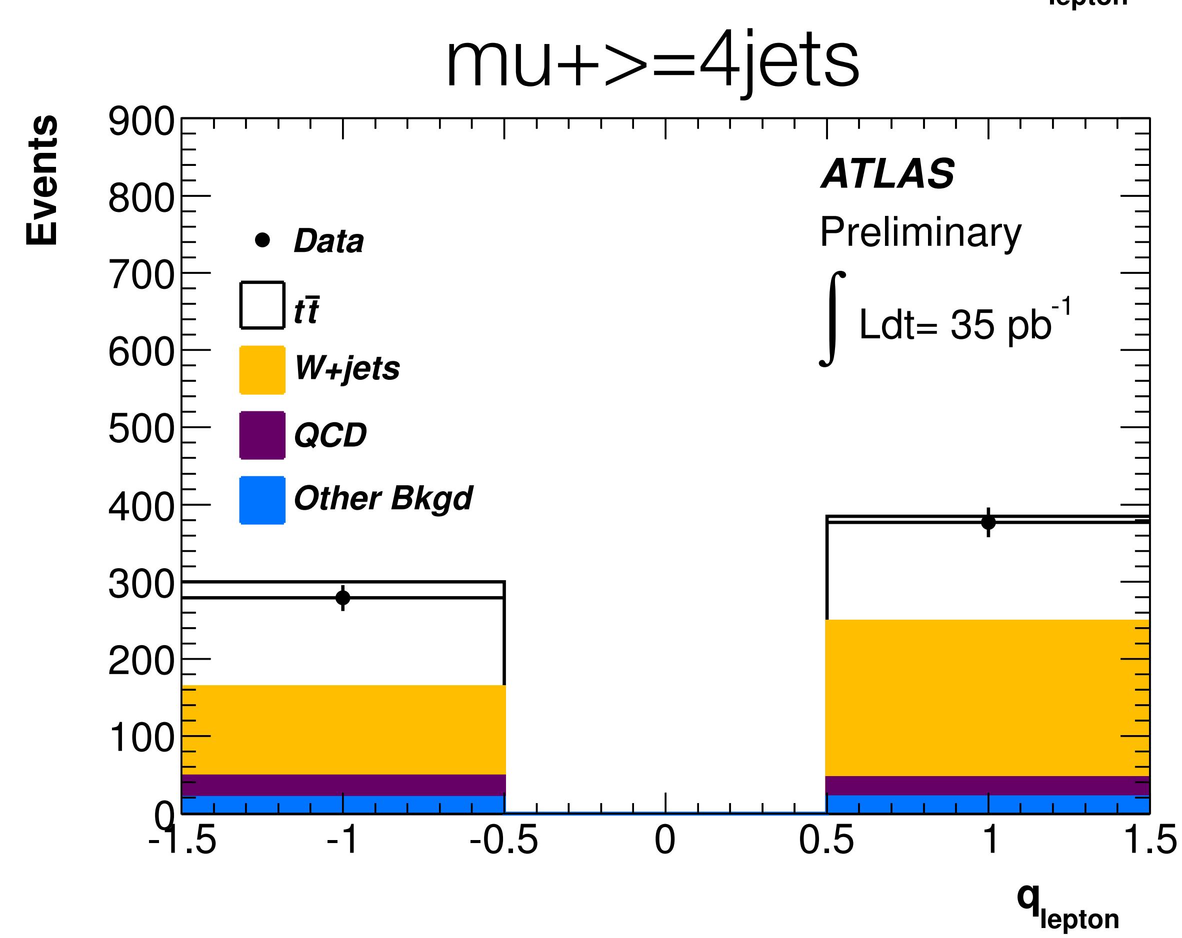
- For Njets=3, 4 an 5 , build discriminant from distributions of
  - ***lepton pseudorapidity*** ←top is more central
  - ***lepton charge*** ←top is symmetric,W+jets isn't
  - ***aplanarity*** ←top is more spherical





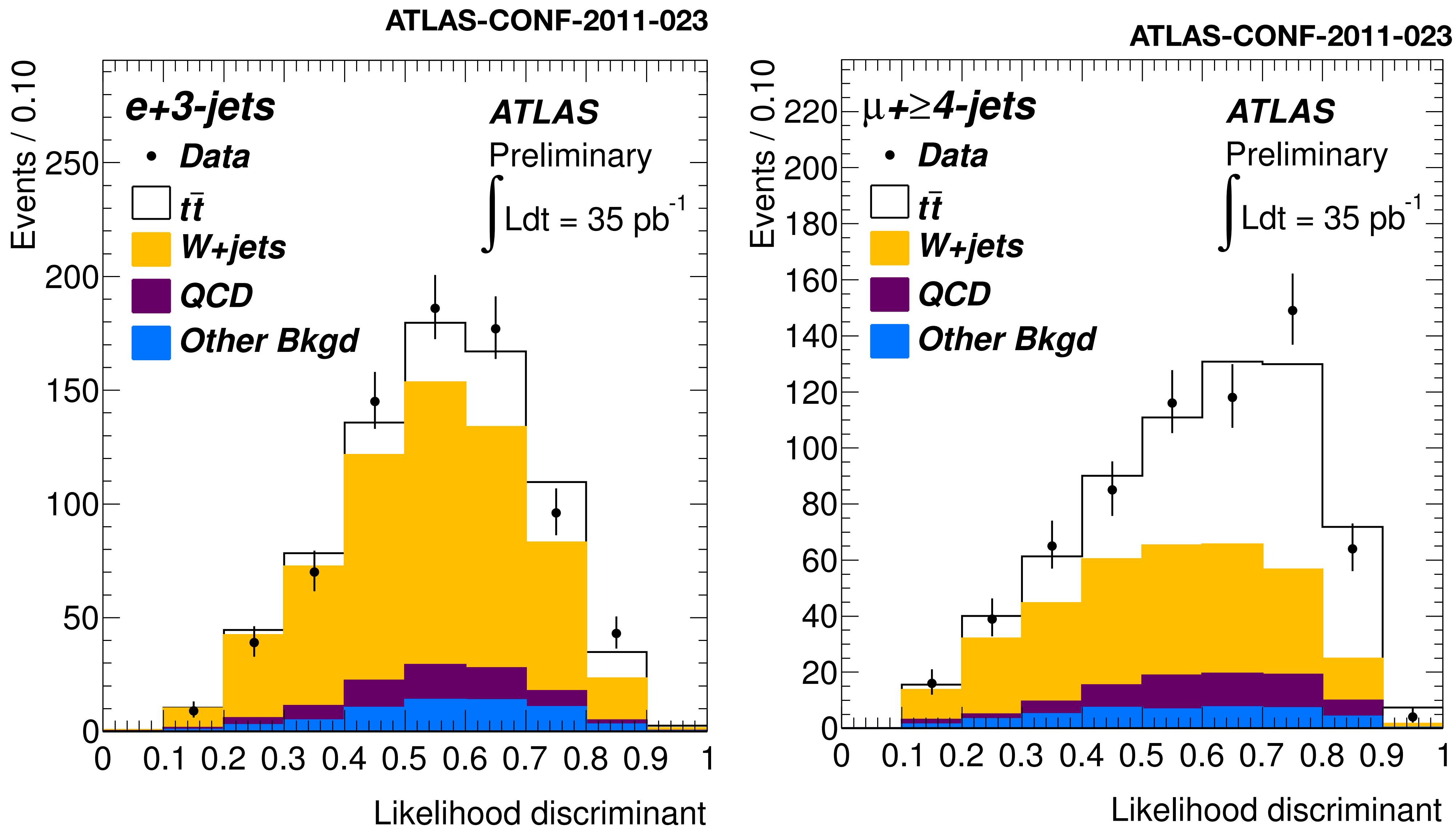


Extracting cross section (II) - single lepton

- **Perform maximum likelihood fit** to discriminant in 3,>=4 jet bin for both channels. Fix QCD and smaller bkg, **fit top and W+jets contrib**

- Cross section found as

$$\sigma_{t\bar{t}} = \frac{N_{sig}}{\int \mathcal{L}dt \times \epsilon_{sig}},$$



where

ϵ_{sig} signal acceptance, efficiency and branching ratio from simulation + data/MC scaling factors

Systematic uncertainties - single lepton

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Source	Relative cross-section uncertainty [%]
Object selection	
Lepton reconstruction, identification, trigger	-1.9 / +2.6
Jet energy scale and reconstruction	-6.1 / +5.7
Background rates and shape	
QCD normalisation	±3.9
QCD shape	±3.4
W+jets shape	±1.2
Other backgrounds normalisation	±0.5
Simulation	
Initial/final state radiation	-2.1 / +6.1
Parton distribution functions	-3.0 / +2.8
Parton shower and hadronisation	±3.3
Next-to-leading-order generator	±2.1
MC statistics	±1.8
Pile-up	±1.2
Total systematic uncertainty	-10.2 / +11.6

jet properties (scale, multiplicity) and background normalization are the dominant contributors

Cross section summary - single lepton

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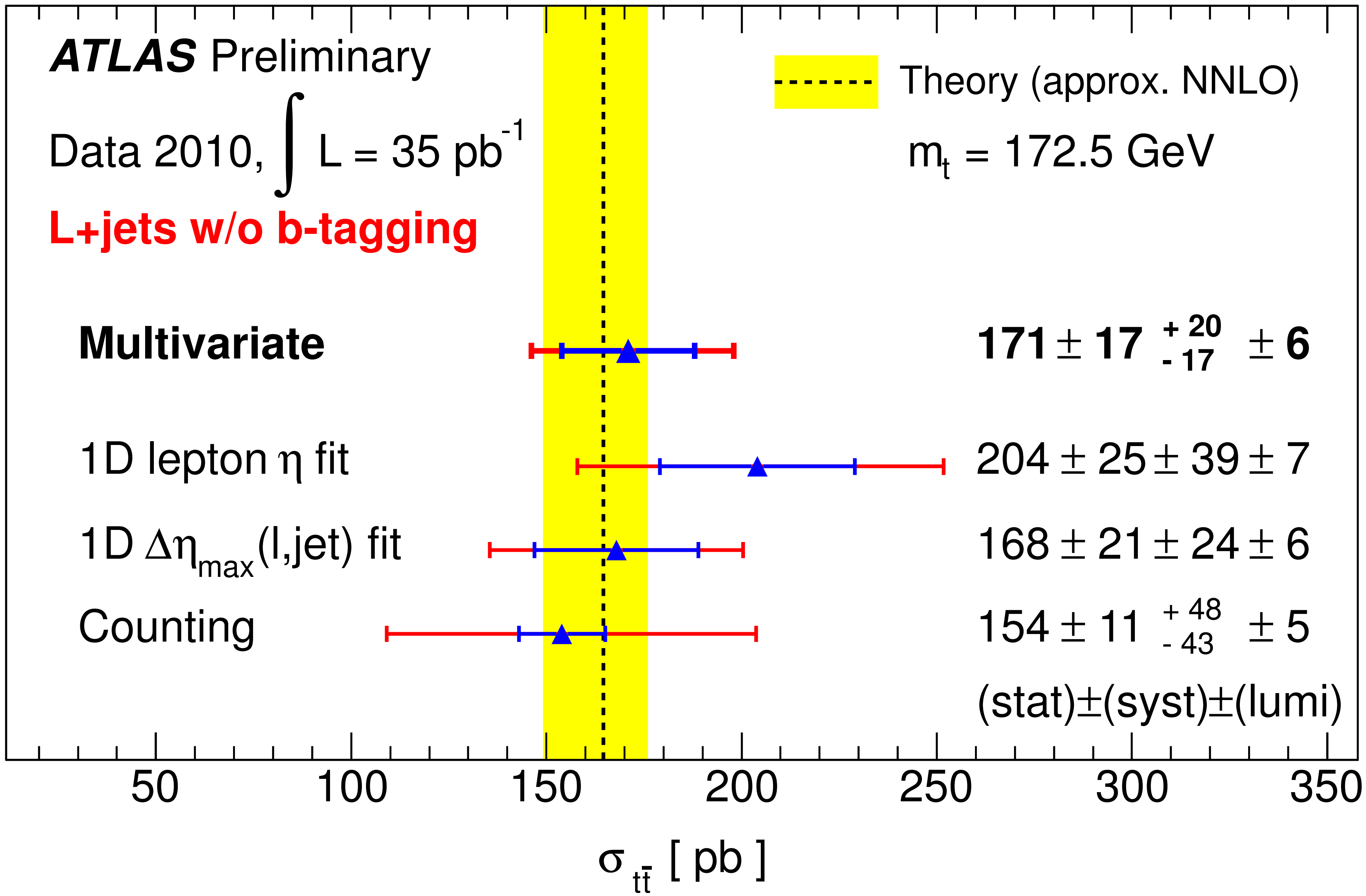


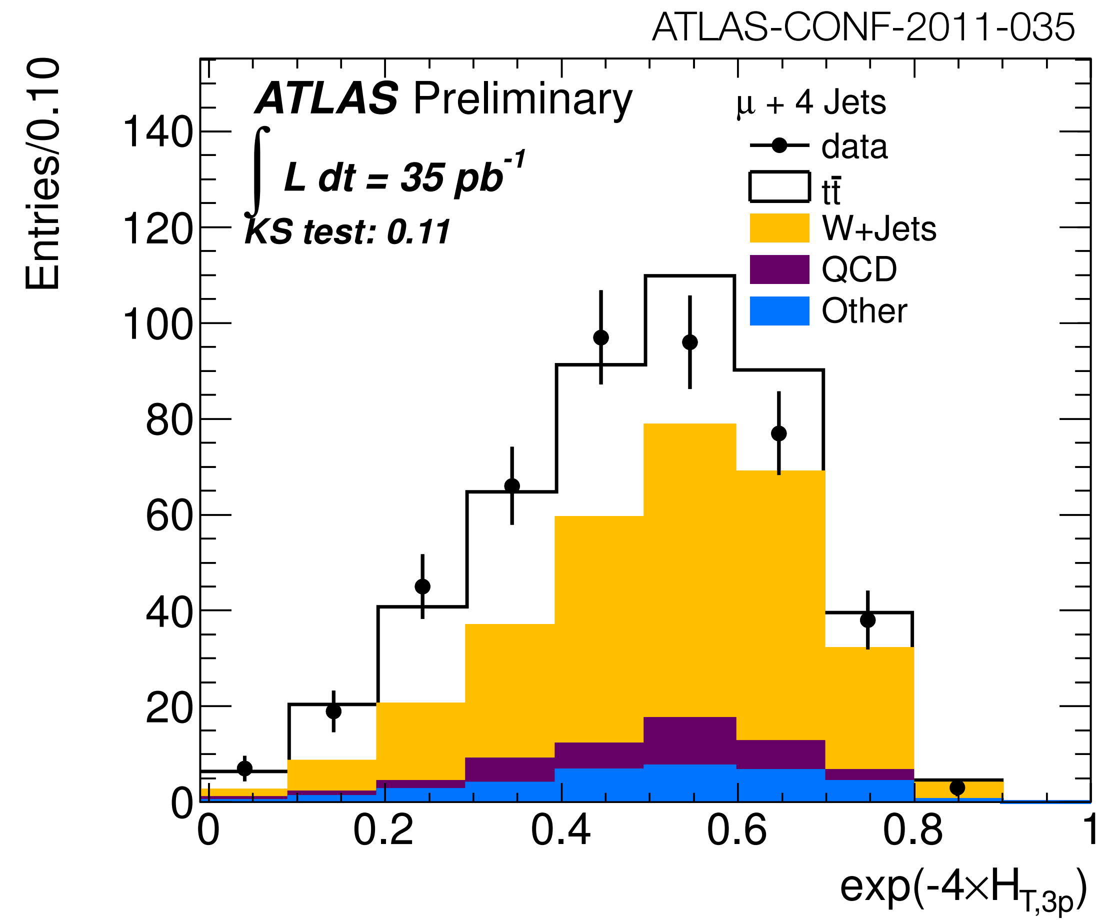
- **Consistency** with SM prediction and amongst techniques
- Statistical (10%) and systematic (11%) uncertainties have the same order of magnitude

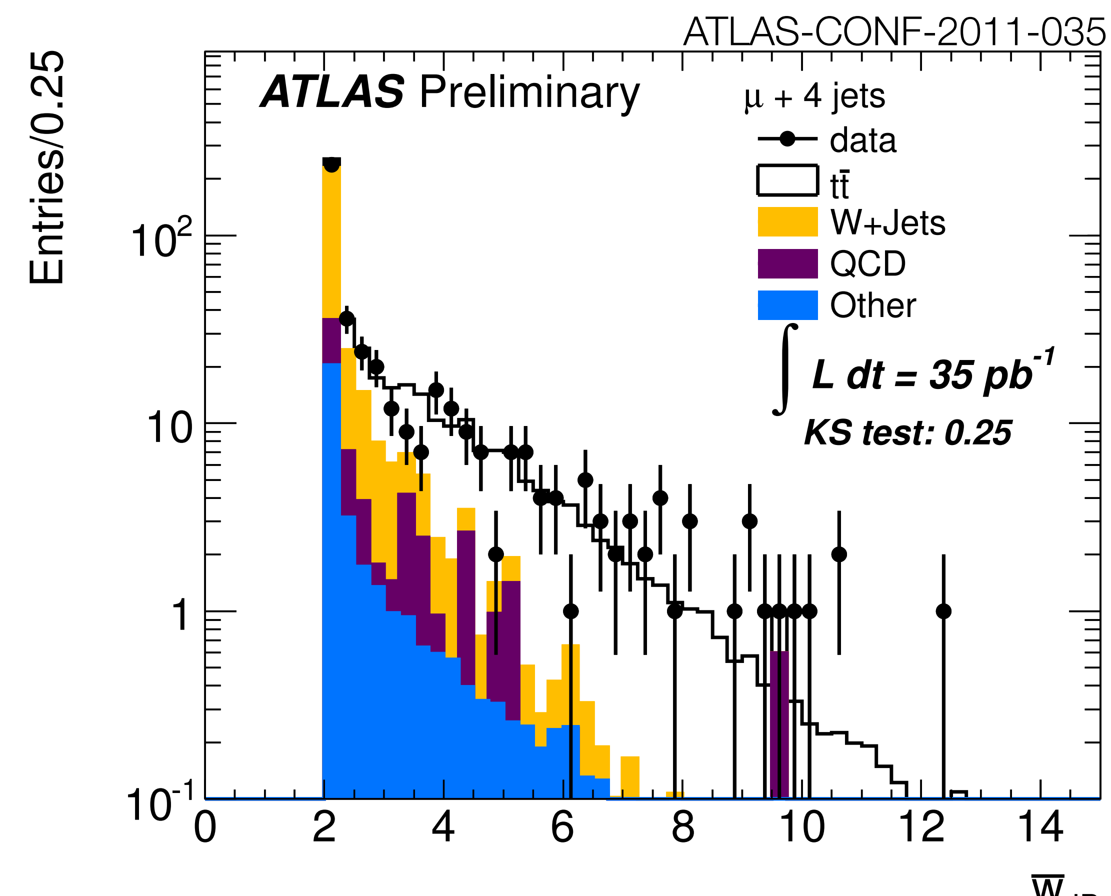
Cross section - single lepton *with b-tagging*

- Build discriminant from
  - **lepton eta, aplanarity**
  - **$H_{T,3p}$** ratio of transverse to longitudinal activity ←top is more transverse
  - **average** of two largest **jet b-tagging** probability←top has more b-jets

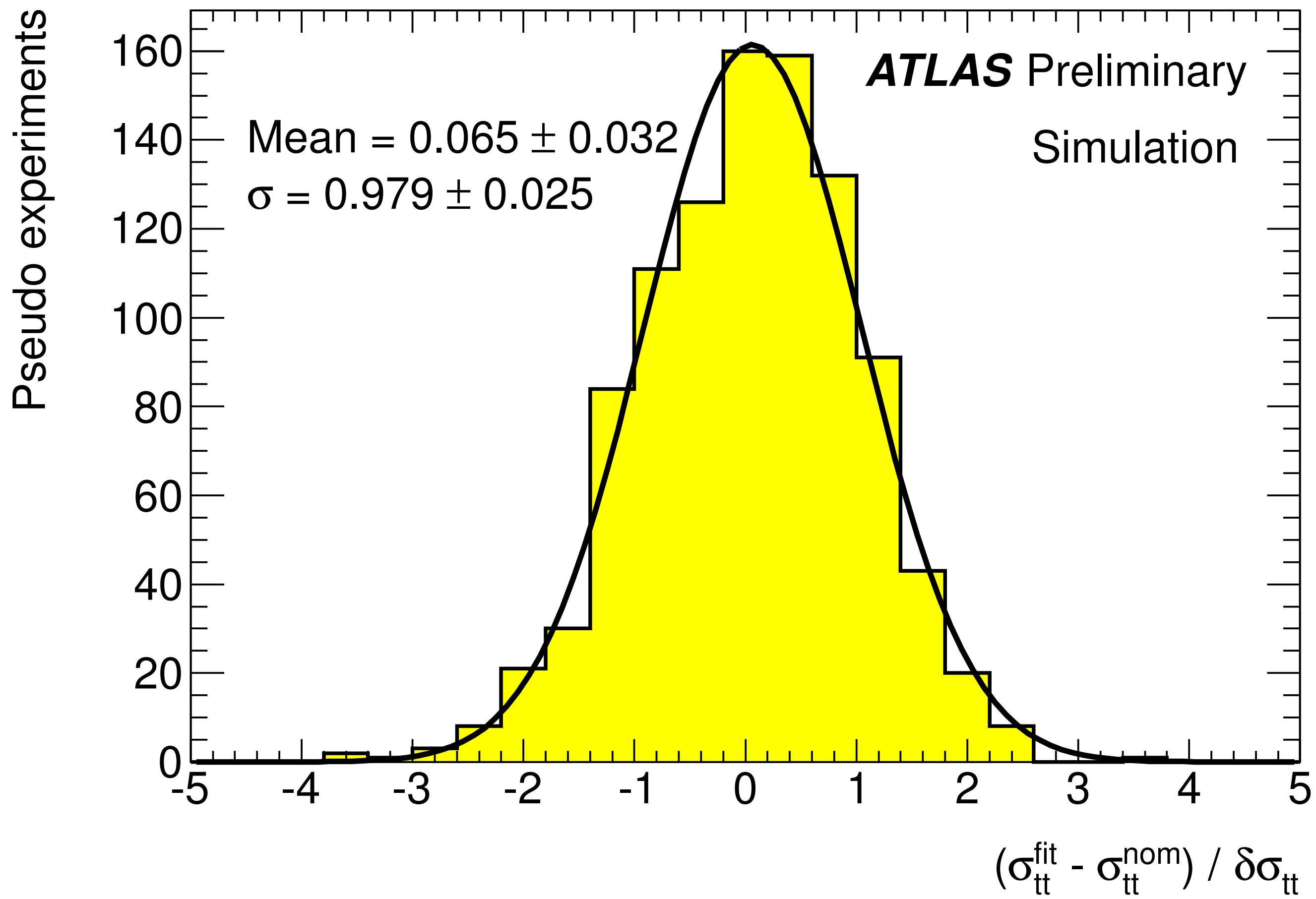
- **Extract σ_{tt} from likelihood fit of discriminant** to data in 3,4 and 5 jet bins

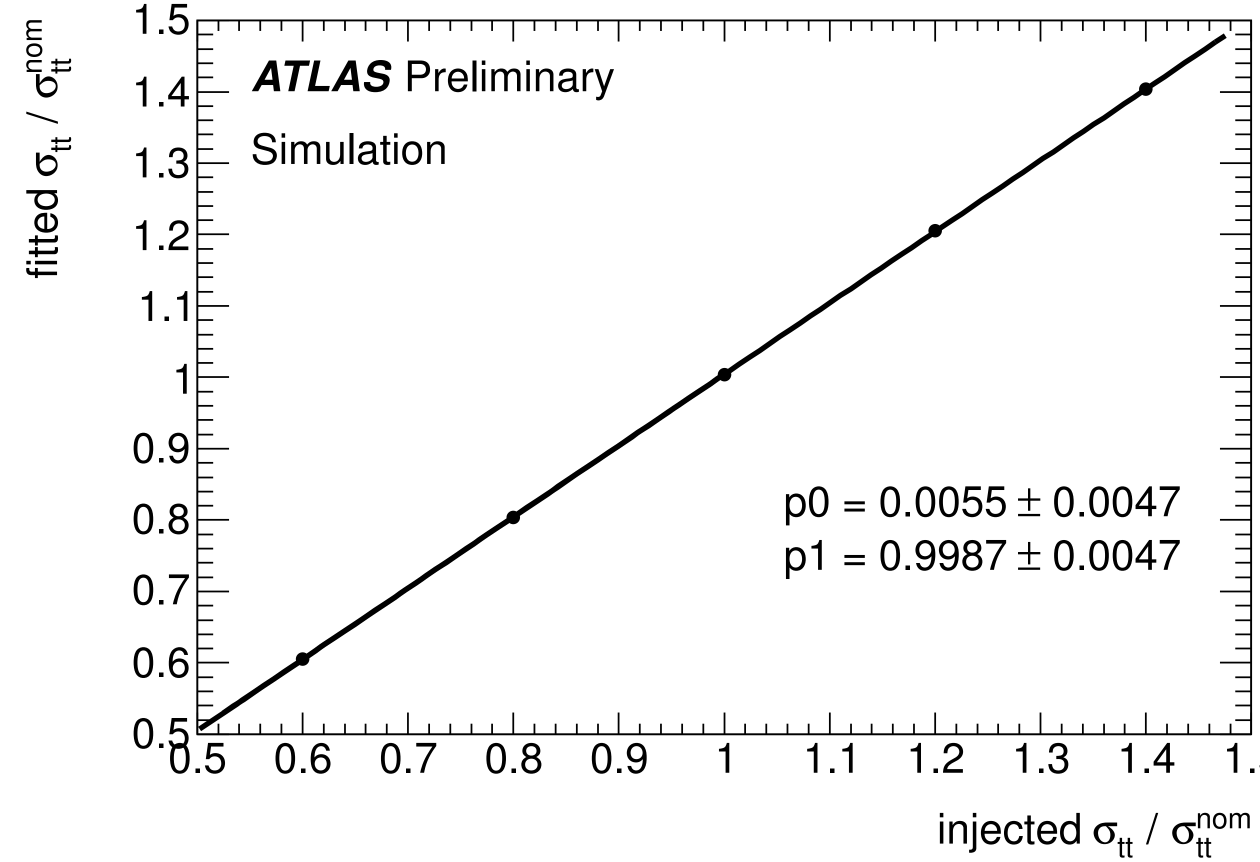
- **Systematic uncertainties part of fit** as Gaussian nuisance parameters





Extracting cross section - single lepton

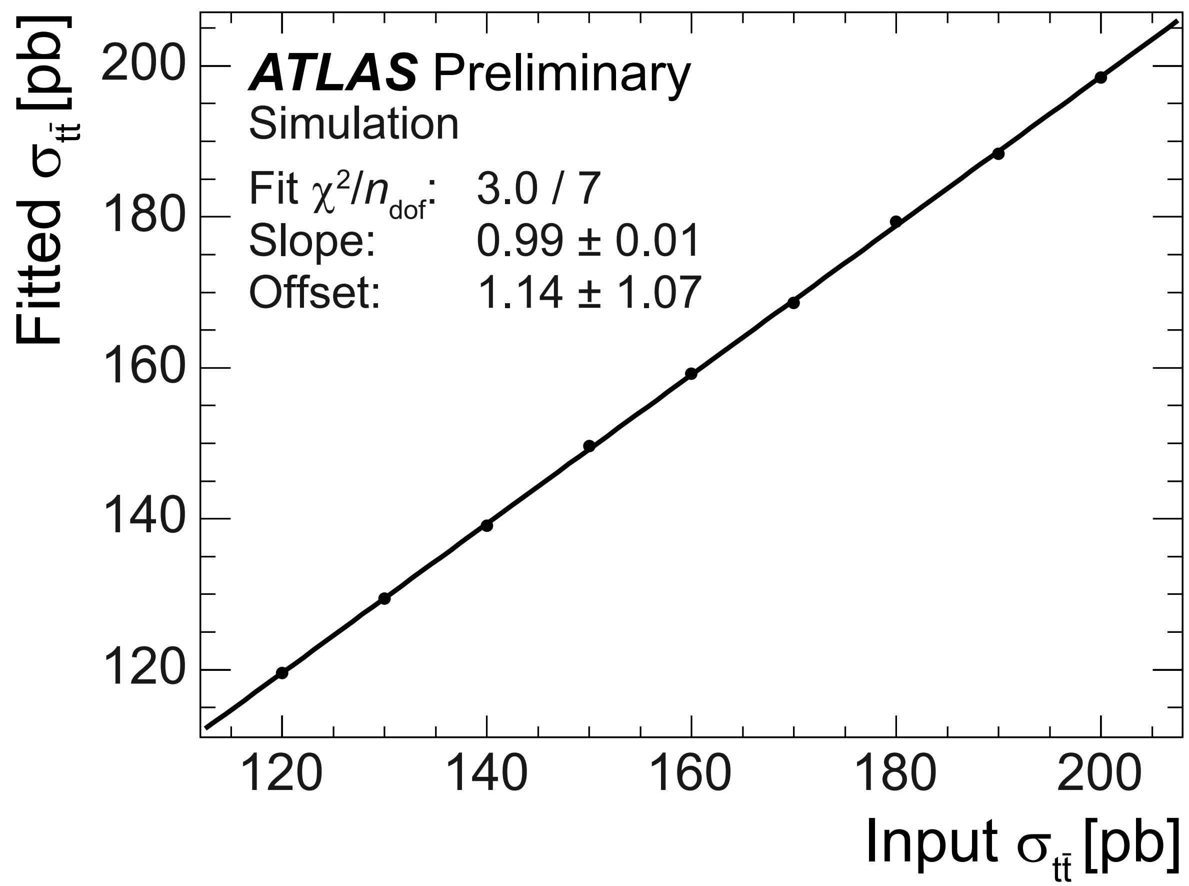


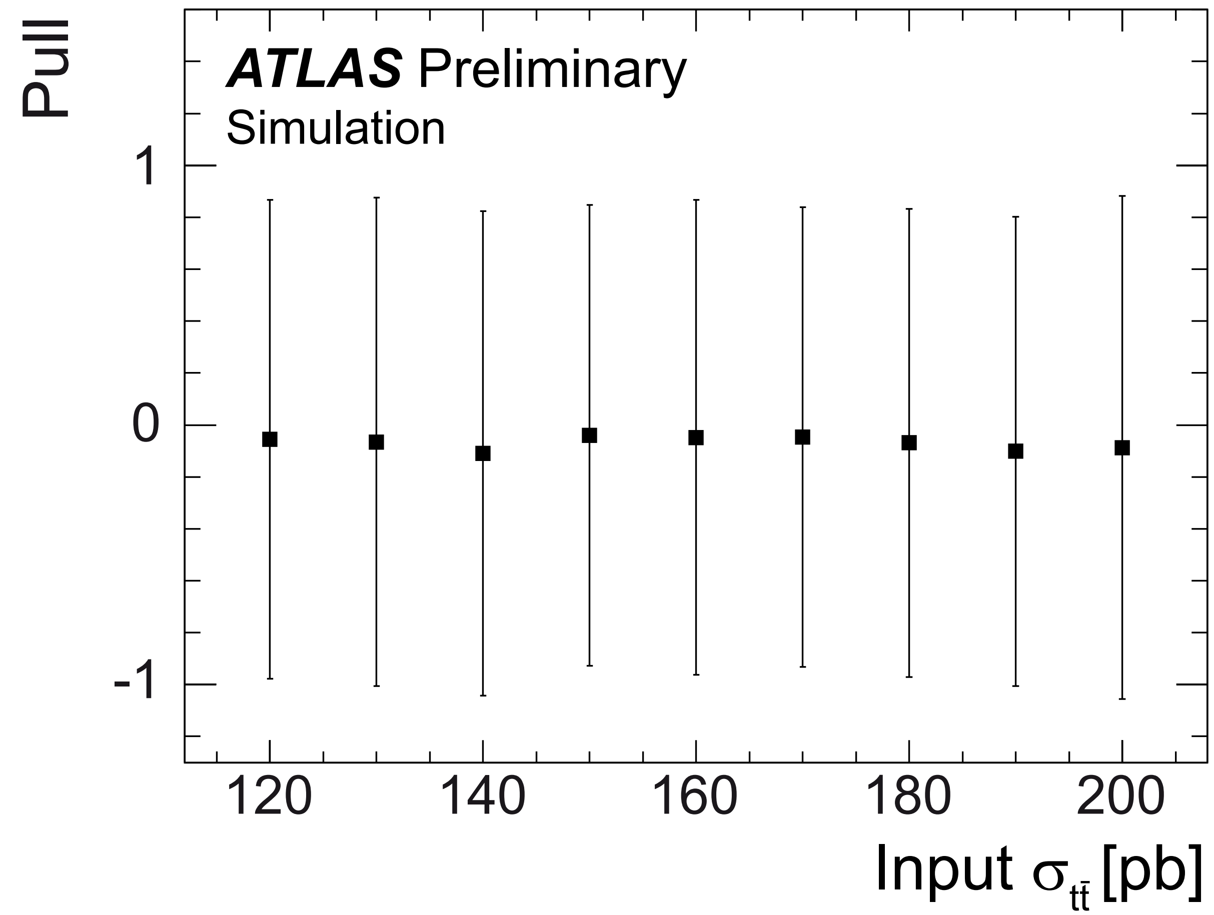


- Pseudo experiments used to test bias and uncertainty
- Bias and pull consistent with zero and 1

expected stat uncertainty is 9.7%

Extracting cross section - single lepton *with b-tagging*





- Simulated Pseudo experiments used to test bias and uncertainty
- Bias and pull consistent with zero and 1

Cross checks - single lepton *with b-tagging*

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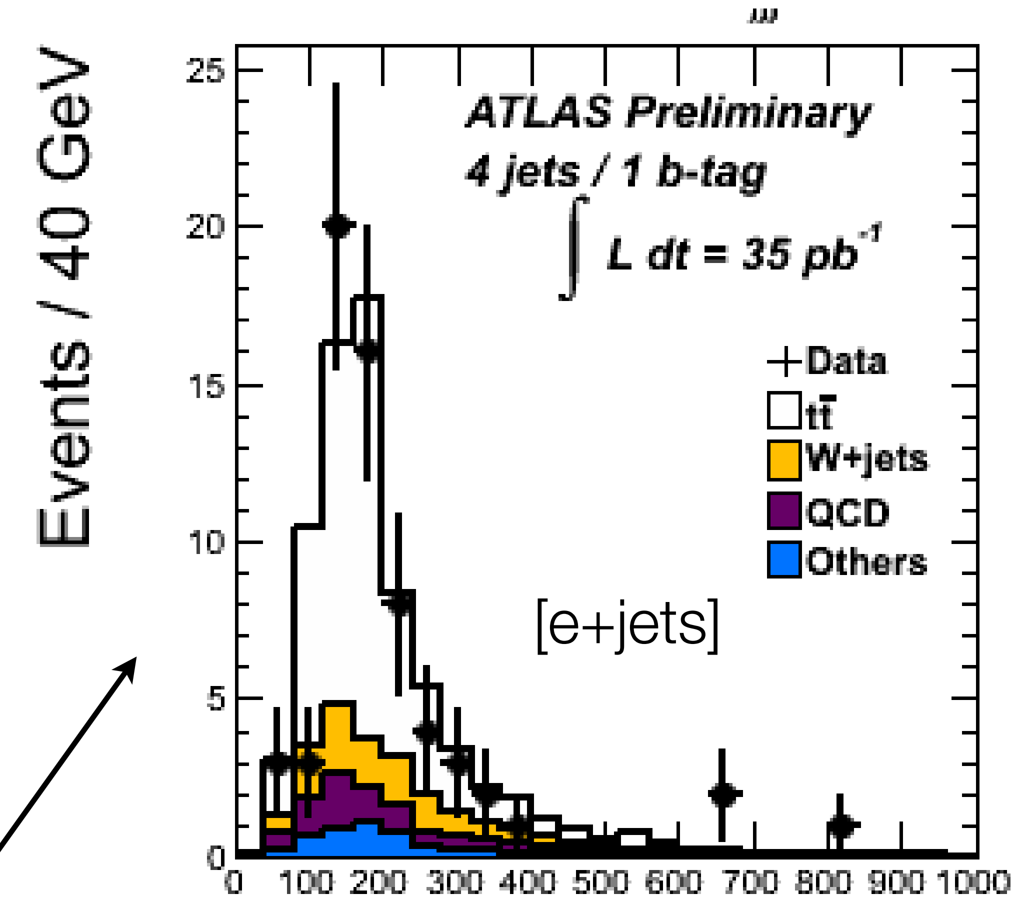
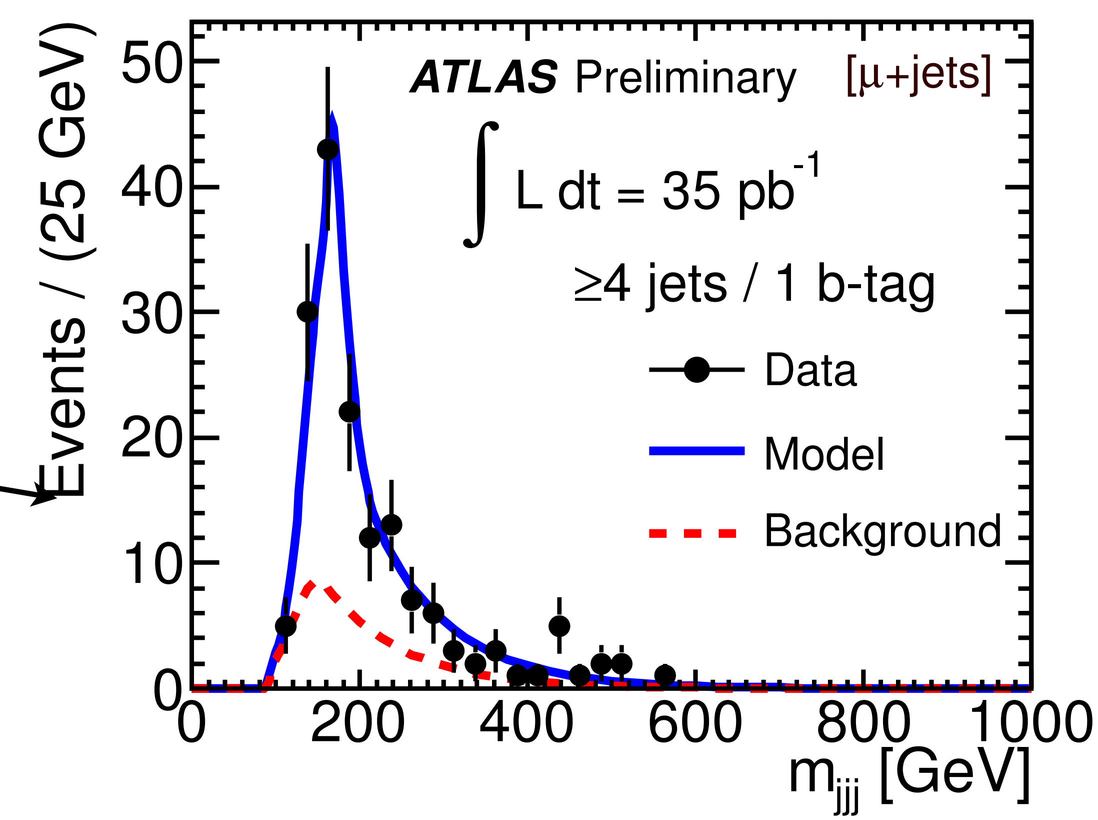
Require >= 1 b-tagged jet

- **Cut and Count**

$$\sigma(t\bar{t}) = \frac{N_{sig}}{L \times \epsilon} = \frac{N_{obs} - N_{bkg}}{L \times \epsilon}$$

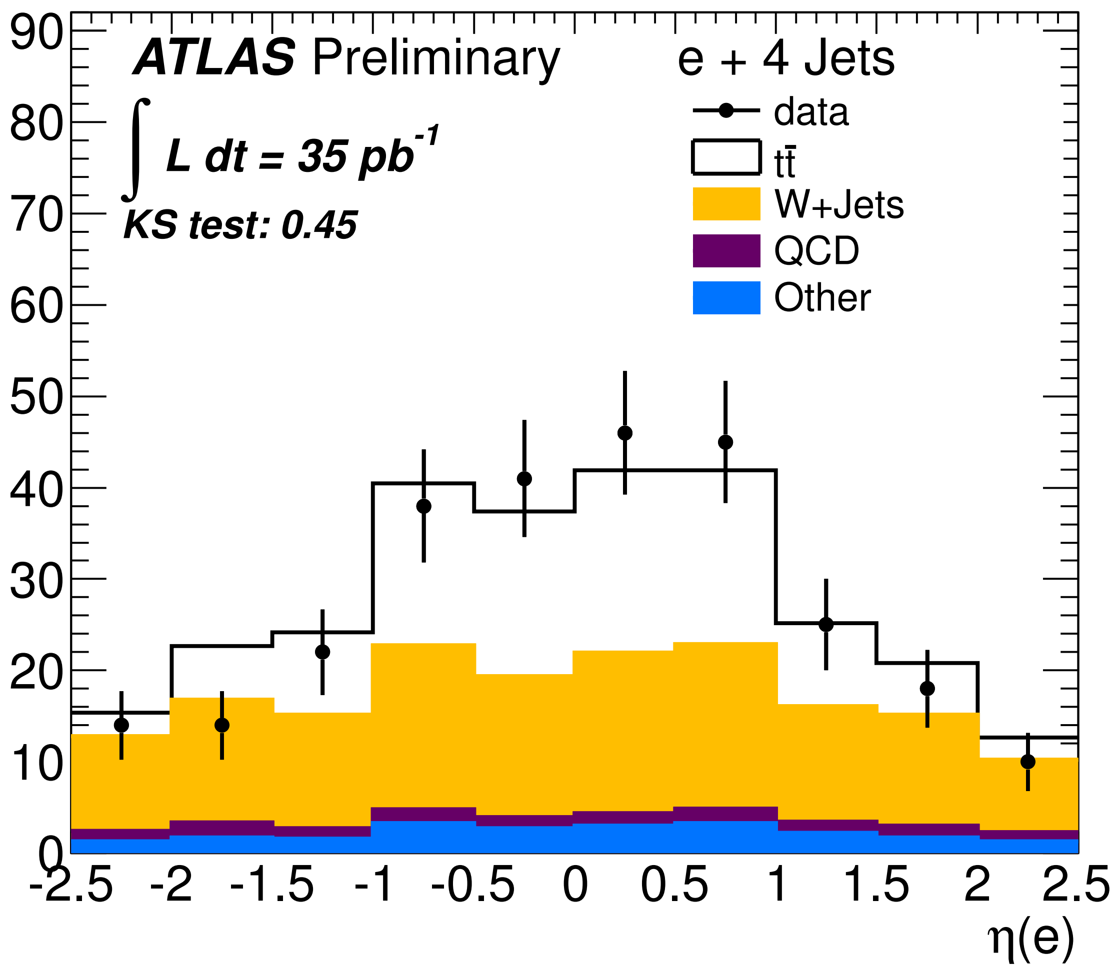
- **Likelihood fit of the 3-jet mass** to weighted sum of templates (in 3, 4, 5 jet bin) **in two ways**
  - ***including systematics*** as nuisance parameters ***in fit***
  - ***standard fit, no nuisance par***; vary parameters to assess systematics



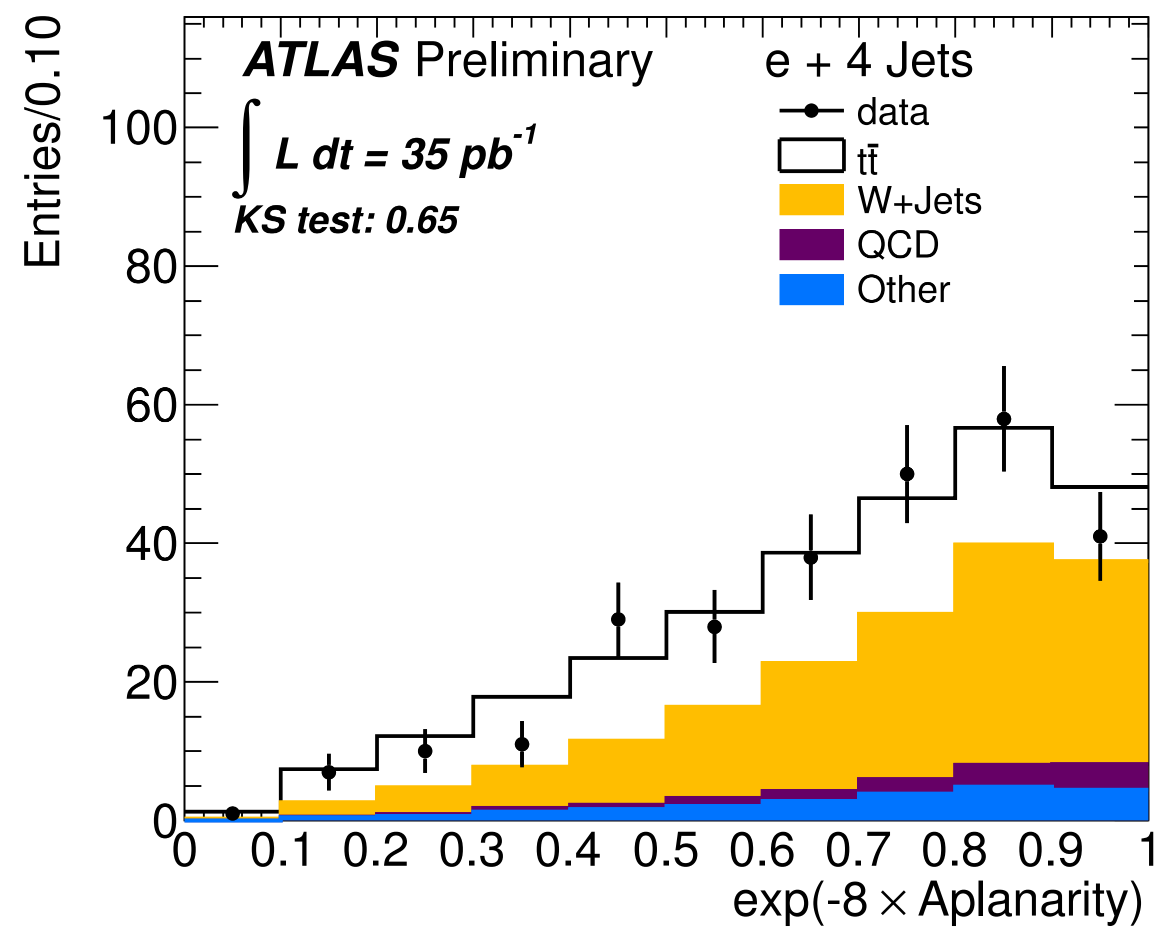


Variables for discriminant - single lepton *with b-tag*

- The aplanarity, defined as 1.5 times the smallest eigenvalue of the momentum tensor $M_{ij} = \sum_{k=1}^{N_{\text{objects}}} p_{ik} p_{jk} / \sum_{k=1}^{N_{\text{objects}}} p_k^2$, where p_{ik} is the i-th momentum component and p_k is the modulus of the momentum of object k. To smooth the aplanarity distribution $\exp(-8 \times \text{aplanarity})$ is used as input to the discriminant.



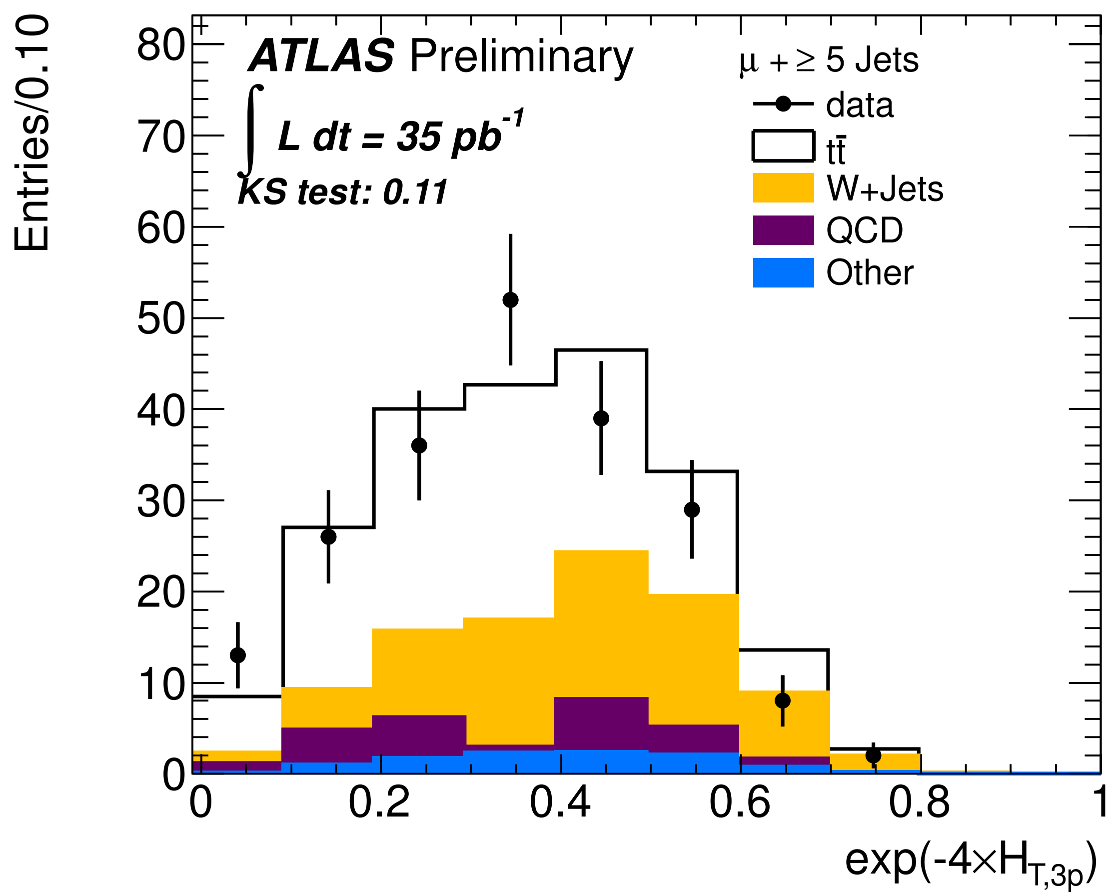
pseudorapidity



aplanarity

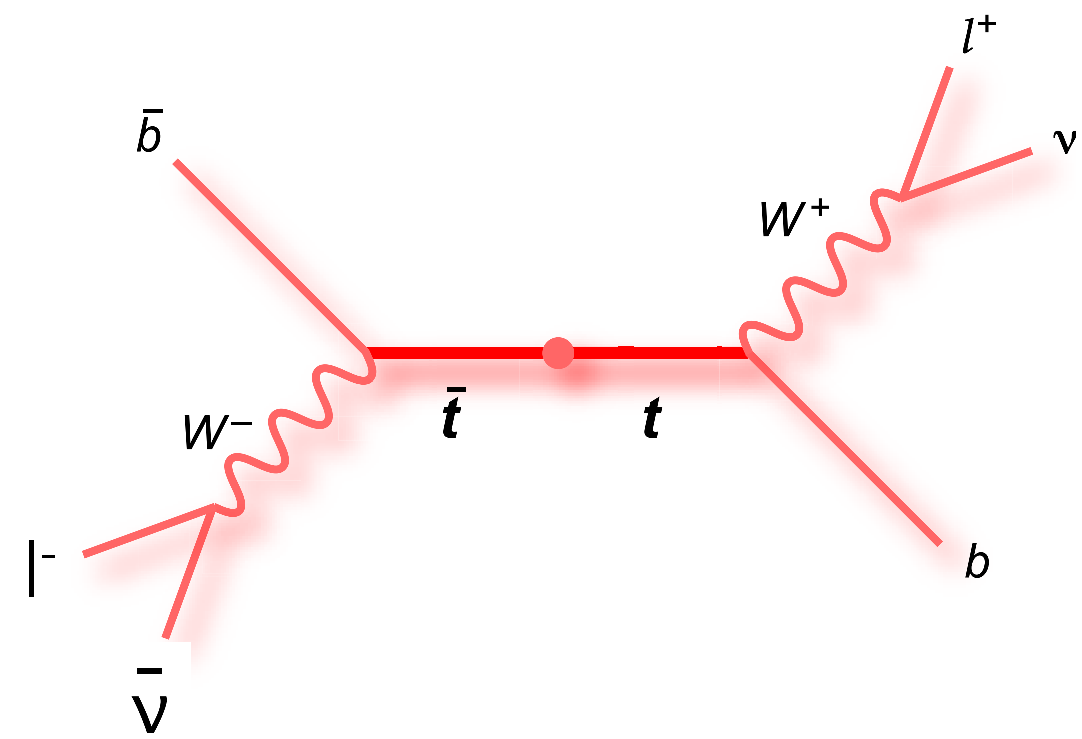
Ht,3p variable - single lepton *with b-tag*

- The variable $H_{T,3p}$, given by the transverse energy of all jets except the two leading ones, normalized to the sum of absolute values of all longitudinal momenta in the event, $H_{T,3p} = \sum_{i=3}^{N_{\mathrm{njets}}} |p_{\mathrm{T},i}^2| / \sum_{j=1}^{N_{\mathrm{objects}}} |p_{z,j}|$, where p_{T} is the transverse momentum and p_z the longitudinal momentum. The sum over all objects includes the charged lepton, the neutrino and all jets. The longitudinal momentum of the neutrino is obtained by solving the event kinematics using the W mass constraint and taking the smaller neutrino p_z solution. To smooth the $H_{T,3p}$ distribution $\exp(-4 \times H_{T,3p})$ is used as input to the discriminant.



Selecting top pairs : di-lepton

- After single lept trigger, **exactly two opposite sign** high p_T central **leptons (ee, eμ, μμ)** *and* ≥ **2 central** high p_T **jet**
- High E_T^{miss} **or trasverse activity**
- **veto Z-like events**



Backgrounds

Z/γ^*+jets
QCD, Di-bosons
single lepton

Selecting top pairs : di-lepton

Common

- **Trigger on** high p_T **single lepton**
- Good collision and good quality for jets
- **exactly two opposite sign** high p_T central **leptons (ee, e,mumu)** *matching the trigger object*
- **≥ 2 central** high p_T **jet**

  p_T> 20 GeV
- **M_{ll} >15 GeV** against b-decays and vector mesons
- **exclude cosmic rays candidates** ***mu pairs*** *with large opposite sign impact par + back to back in r/phi*
- **reject** events with **overlapping muon and electron** tracks

ee, mumu

- **$|M_{ll}$ -M_Z |<10 GeV** *against Z/gamma*
- **high E_T^{miss}** *> 40 GeV against QCD*

+

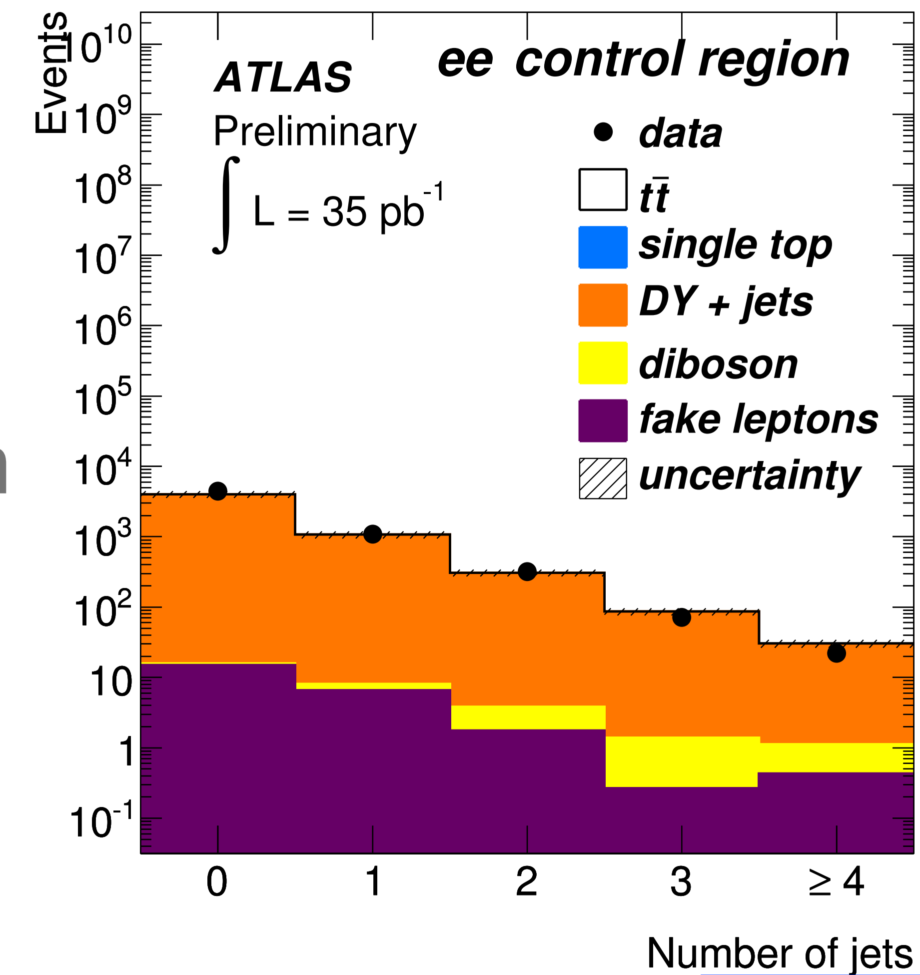
e,mu

- **H_T >130 GeV** *, H_T is sum of all transverse momenta*

Cuts optimized for significance of signal over bkg

Data Driven estimate of Non-Z bkg - di-lepton

- Define tight (standard) and loose lepton samples relaxing
  - calo and track isolation for μ
  - calo isolation, TRT hits, E/p cuts for **e**
- Express measured (tight,loose) samples in terms of unknown (**real**, ***fake***) and estimated probabilities **r** (***f***): for **real** (***fake***) leptons passing loose also to pass tight cuts



- Extract ***fake*** content by matrix inversion

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

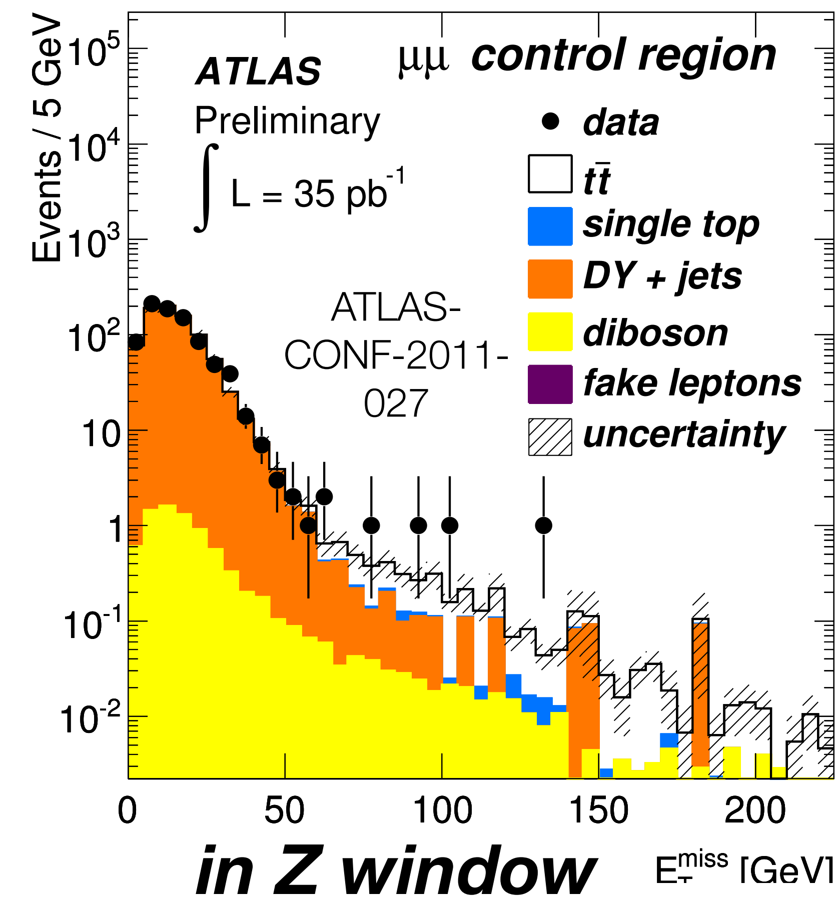
Measure **r** in Z →ll

Measure ***f*** in QCD enriched sample: single loose lepton, low E_T^{miss}

(W+jets subtracted using simulation)

Di-lepton main backgrounds

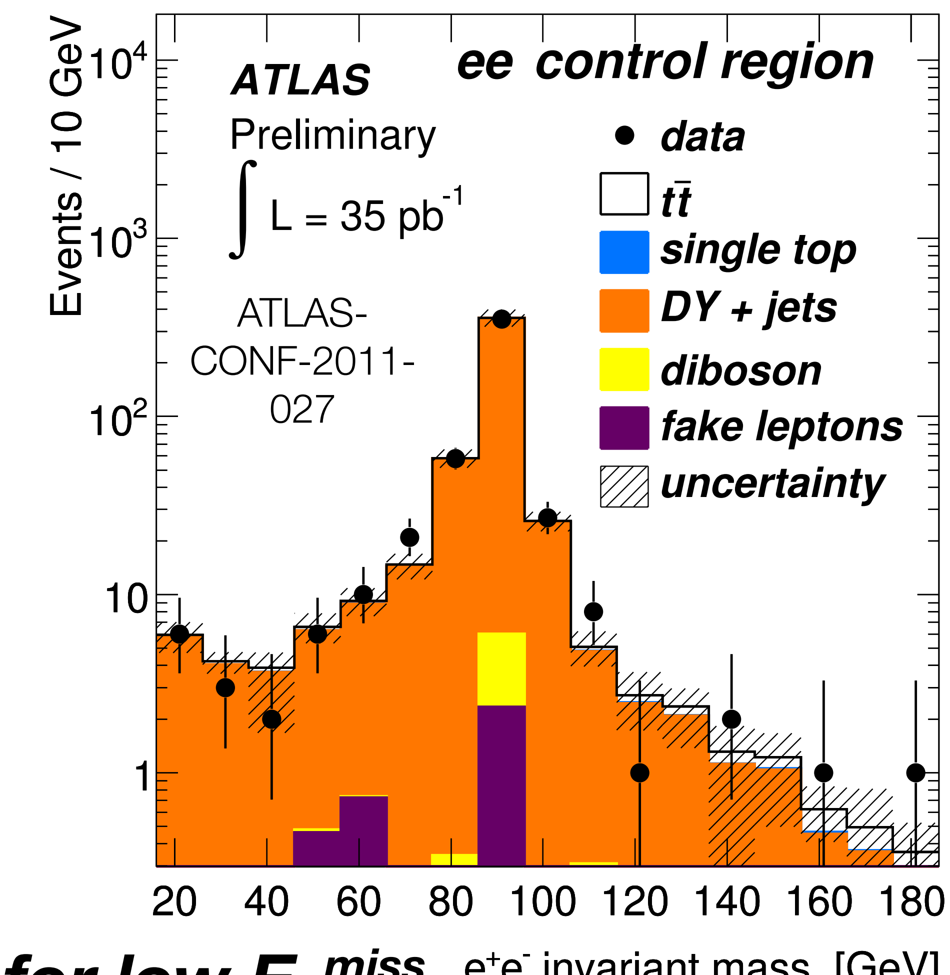
- “Fake” leptons from data (matrix method)
  - **Invert** high E_T and Z window **cuts** → **control samples** enriched with real and “fake” leptons
  - **Derive probability** for “fake” and real leptons ***to be in signal region***
  - **Estimate “fakes”** as a function of events in signal and control samples



in Z window

- Z/γ^* bkg : scale control region with simulation
  - in Z mass window, >=2 jets, E_T^{miss}>30
  - $N_{Z/\gamma}$ (SigReg) = **Data**(ConReg)-OtherMC(CR)*[$MC_{Z/\gamma}$ (SigReg)/$\mathbf{MC_{Z/\gamma}}$ **(ConReg)**]

	ee	$\mu\mu$	$e\mu$
Z/γ^*+jets (DD)	$1.2^{+0.5}_{-0.6}$	$3.4^{+1.9}_{-1.4}$	-
$Z(\to\tau\tau)$+jets (MC)	$0.4^{+0.4}_{-0.3}$	$1.2^{+0.7}_{-0.6}$	$3.2^{+1.6}_{-1.3}$
Non-Z leptons (DD)	0.8 ± 0.8	0.5 ± 0.6	3.0 ± 2.6
Single top (MC)	0.7 ± 0.1	1.3 ± 0.2	2.5 ± 0.4
Dibosons (MC)	0.5 ± 0.1	0.9 ± 0.2	$2.1^{+0.5}_{-0.3}$
Total (non $t\bar{t}$)	3.5 ± 1.1	$7.3^{+1.8}_{-1.5}$	10.8 ± 3.4
$t\bar{t}$ (MC)	11.5 ± 1.3	20.1 ± 1.7	47.4 ± 4.0
Total expected events	15.0 ± 1.7	27.4 ± 2.4	58.2 ± 5.2
Observed events	16	31	58



for low E_T^{miss}

Di-lepton results

- Subtract estimated background
- Cross section from likelihood fit combining channels and including systematics as nuisance parameters

after all cuts, except N_{jets} (notice log scale)

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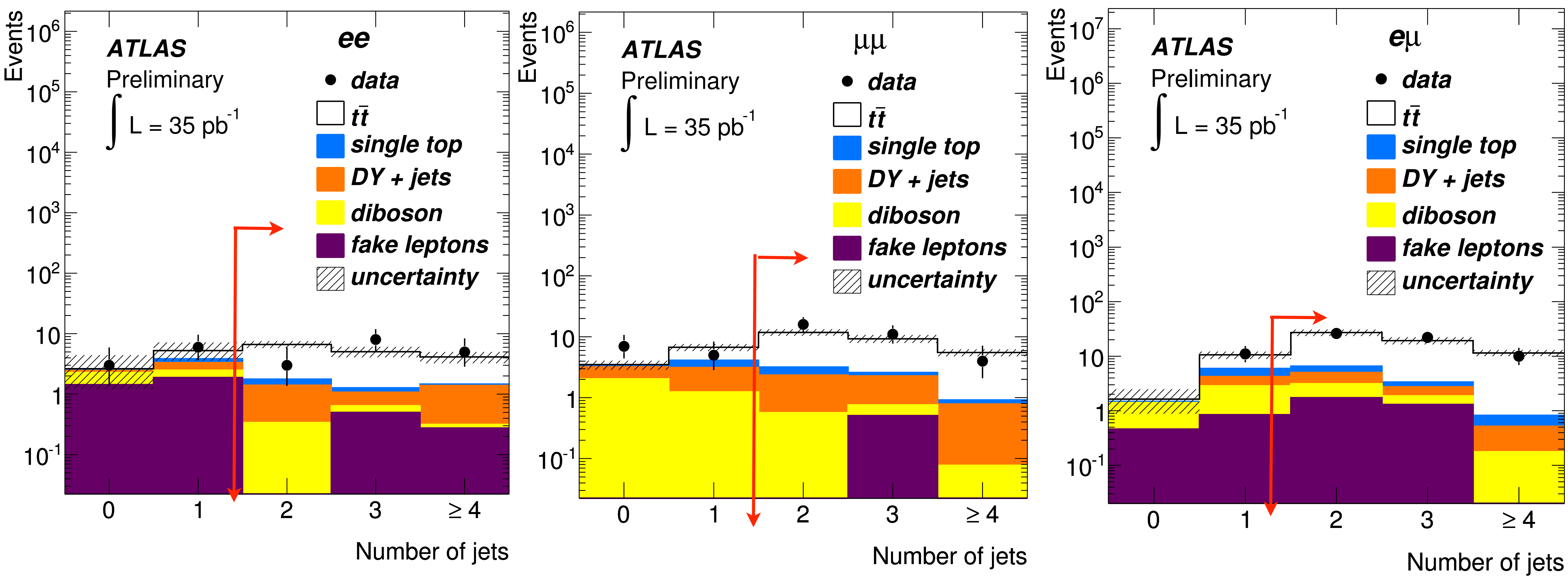
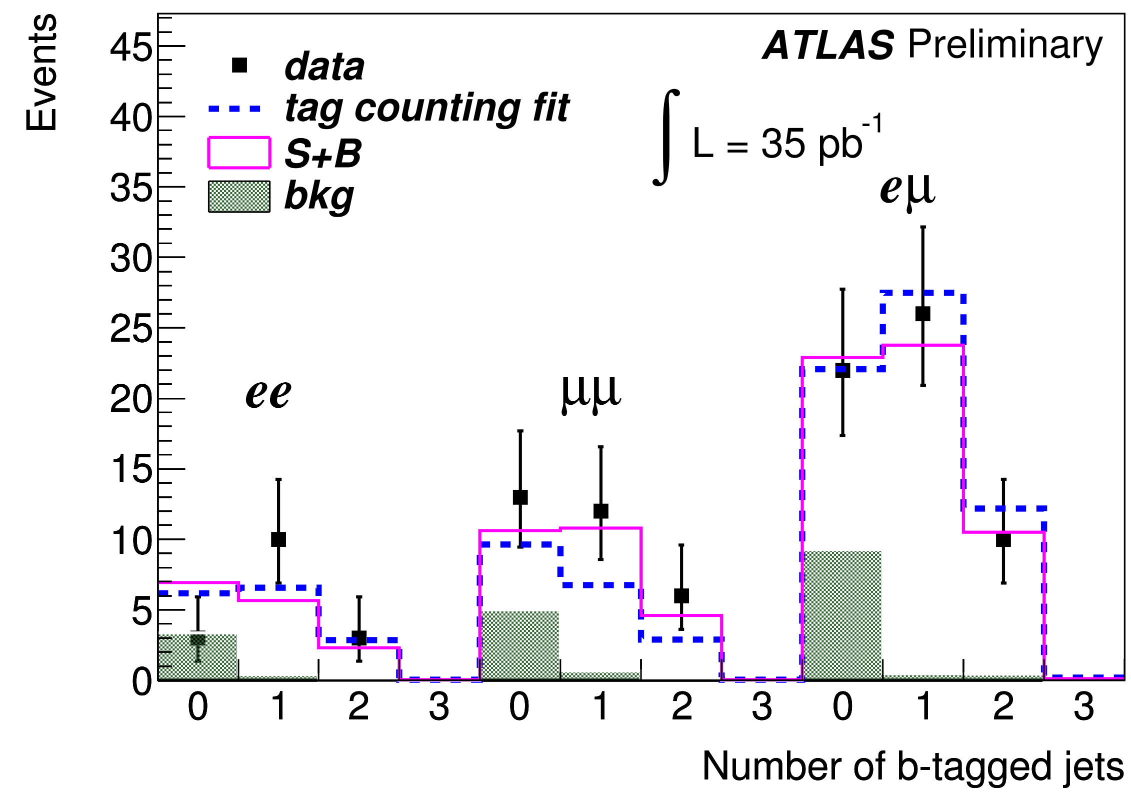


Di-lepton cross checks

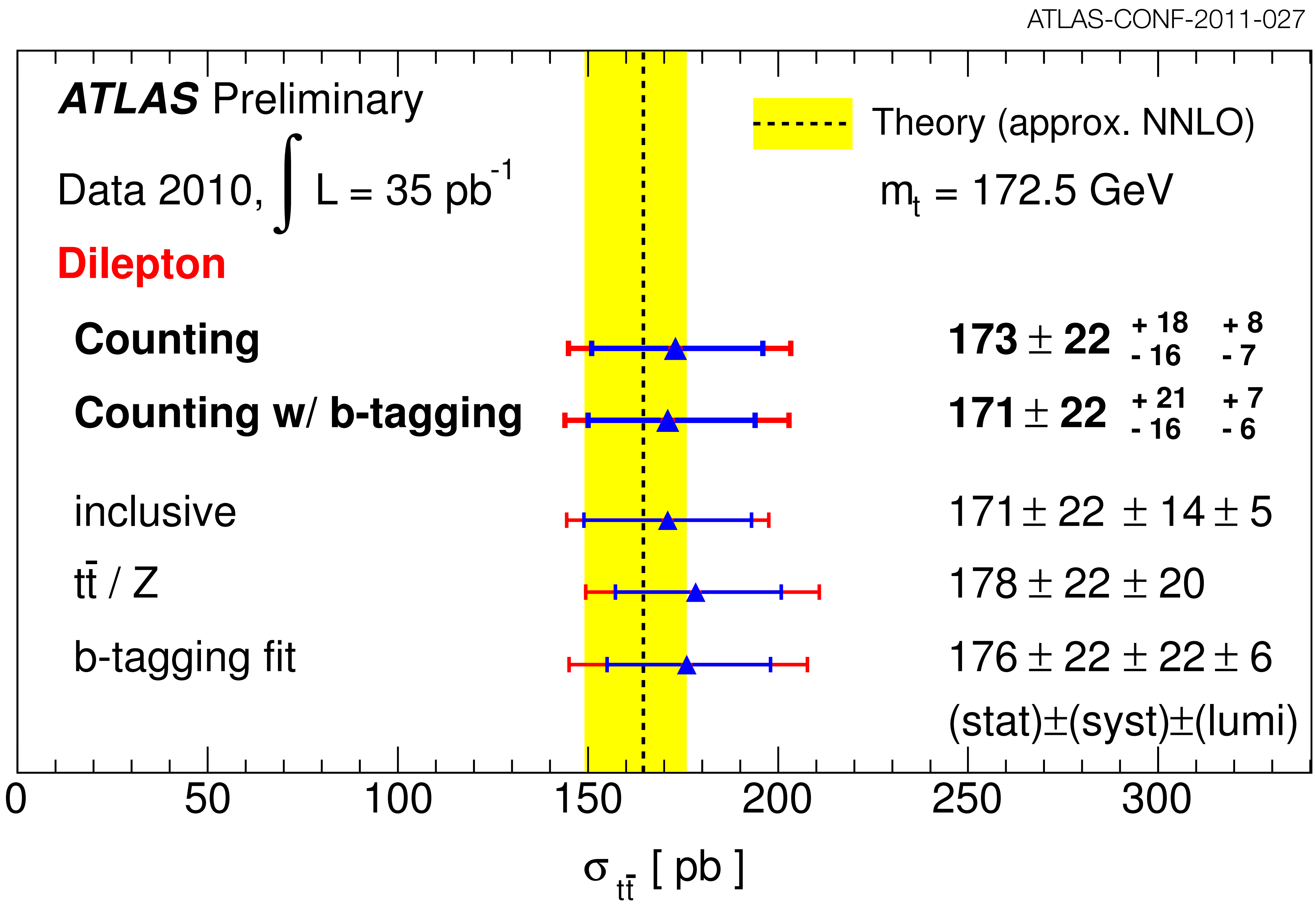
- Normalize tt signal to measured Z decay rate

- 2-d template shape fit
  - E_T^{miss} vs N_{Jets}
  - extract cross section for tt, WW and Z tauta
  - relaxed Njets and total transverse energy cuts



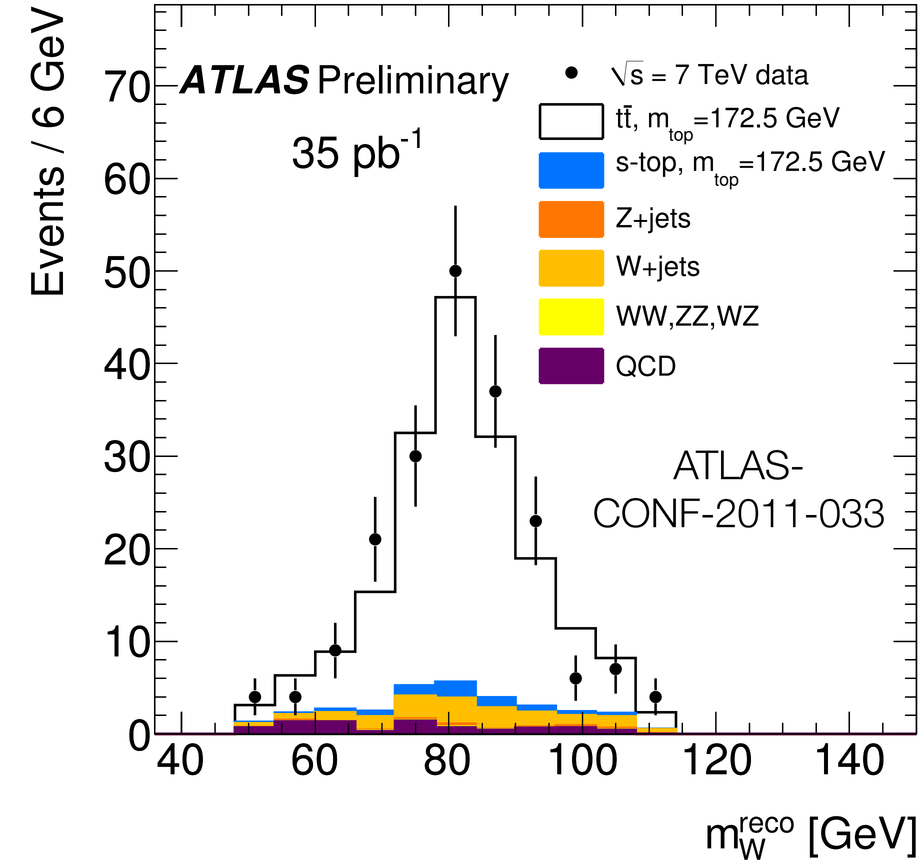
- Fit distribution of number of tagged jets to extract tt cross section and b-tagging efficiency

Di-lepton summary

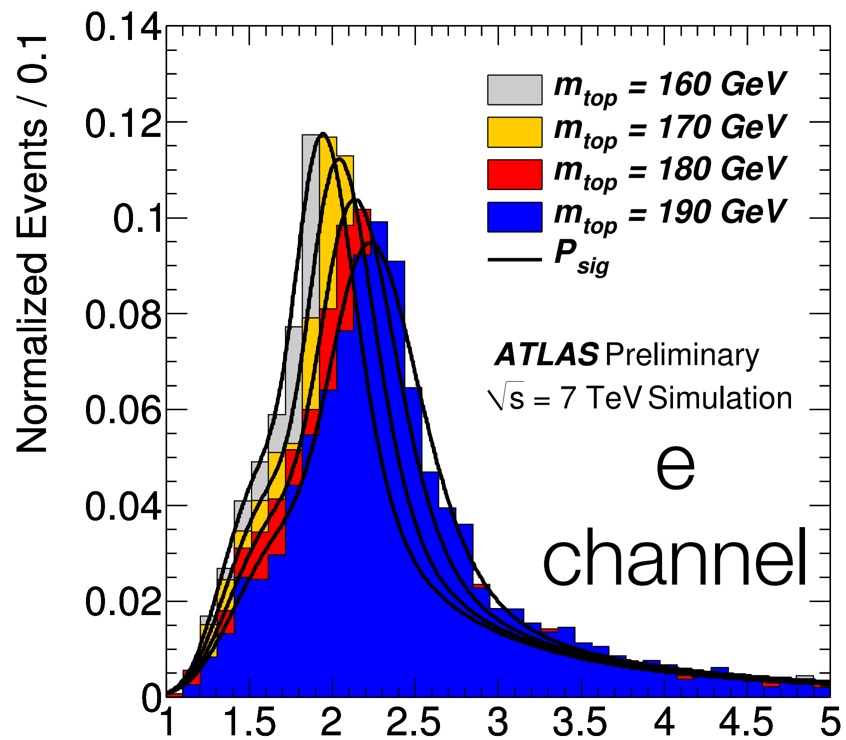


- Cross checks are **consistent** with baselines
- Systematics (10 to 12%) have similar size as statistics (~13%)

Measuring Top mass



- Same selection as cross section
- Measure mass using hadronic top
  - Jet energy scale is crucial
- Three techniques
  - baseline: fit ratio of reconstructed di-jet (W) and 3-jet (top) mass
  - simultaneous measurement of scale and top mass
  - kinematic fitter based on likelihood



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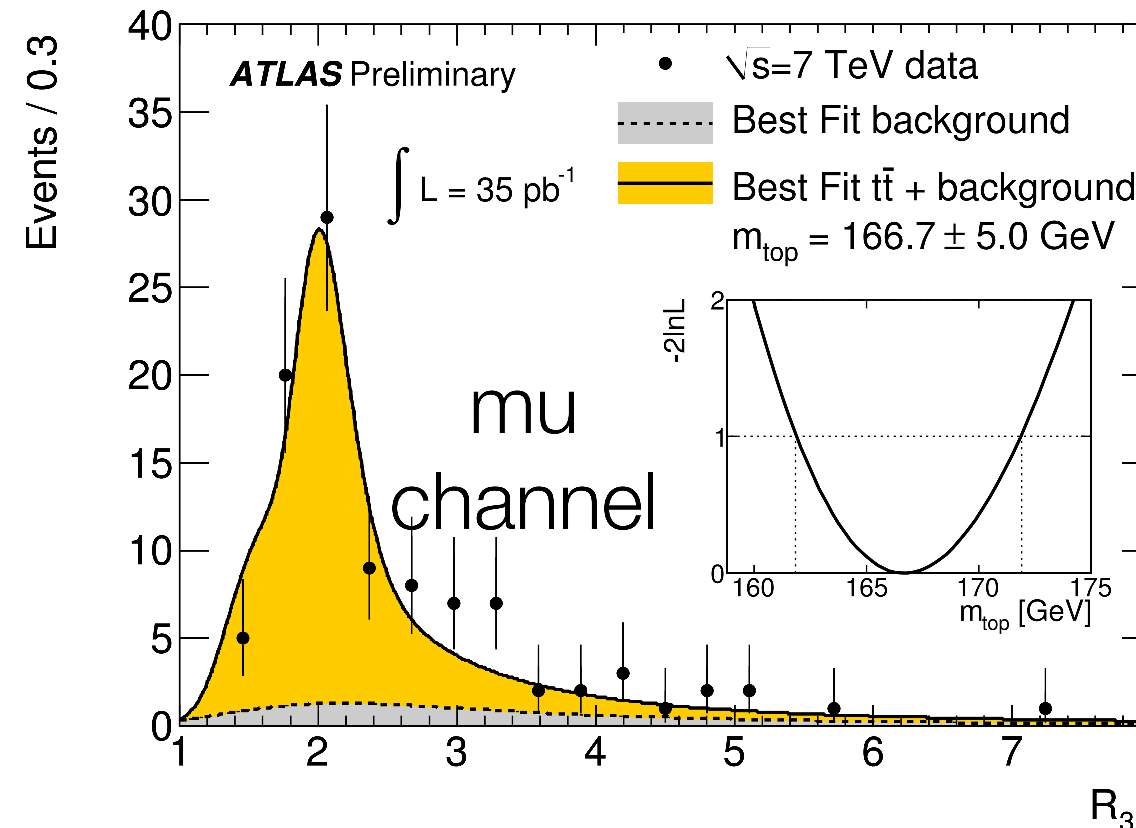
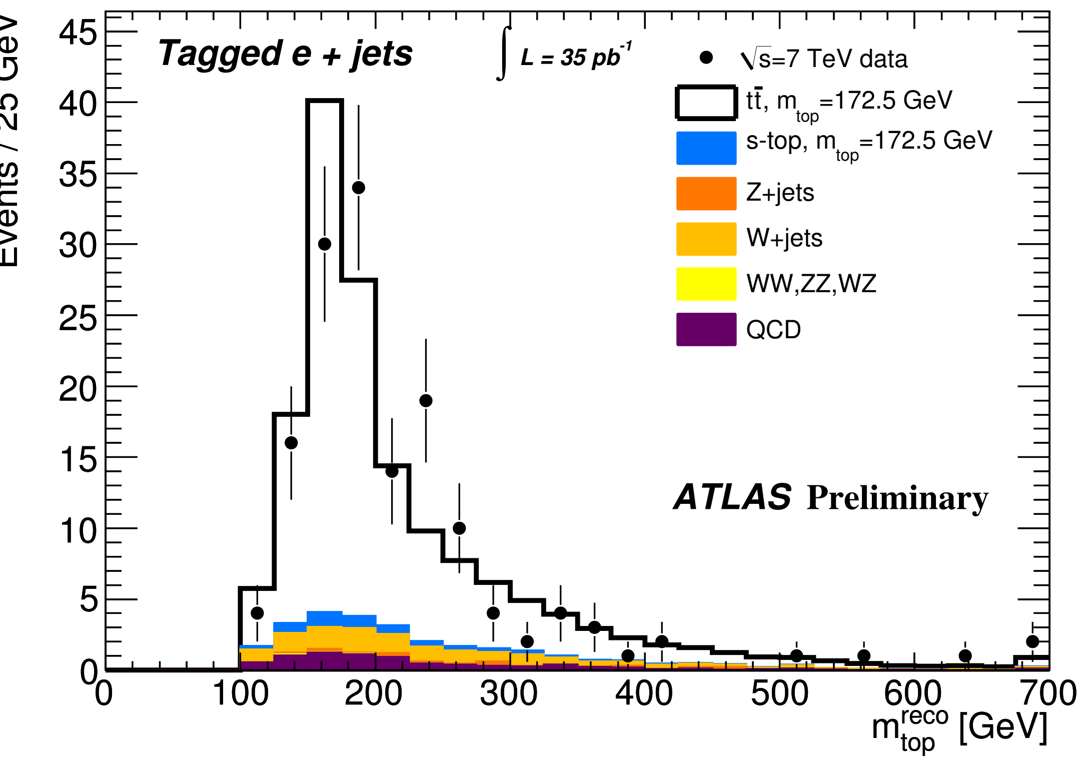
R_{32}

ATLAS-CONF-2011-033



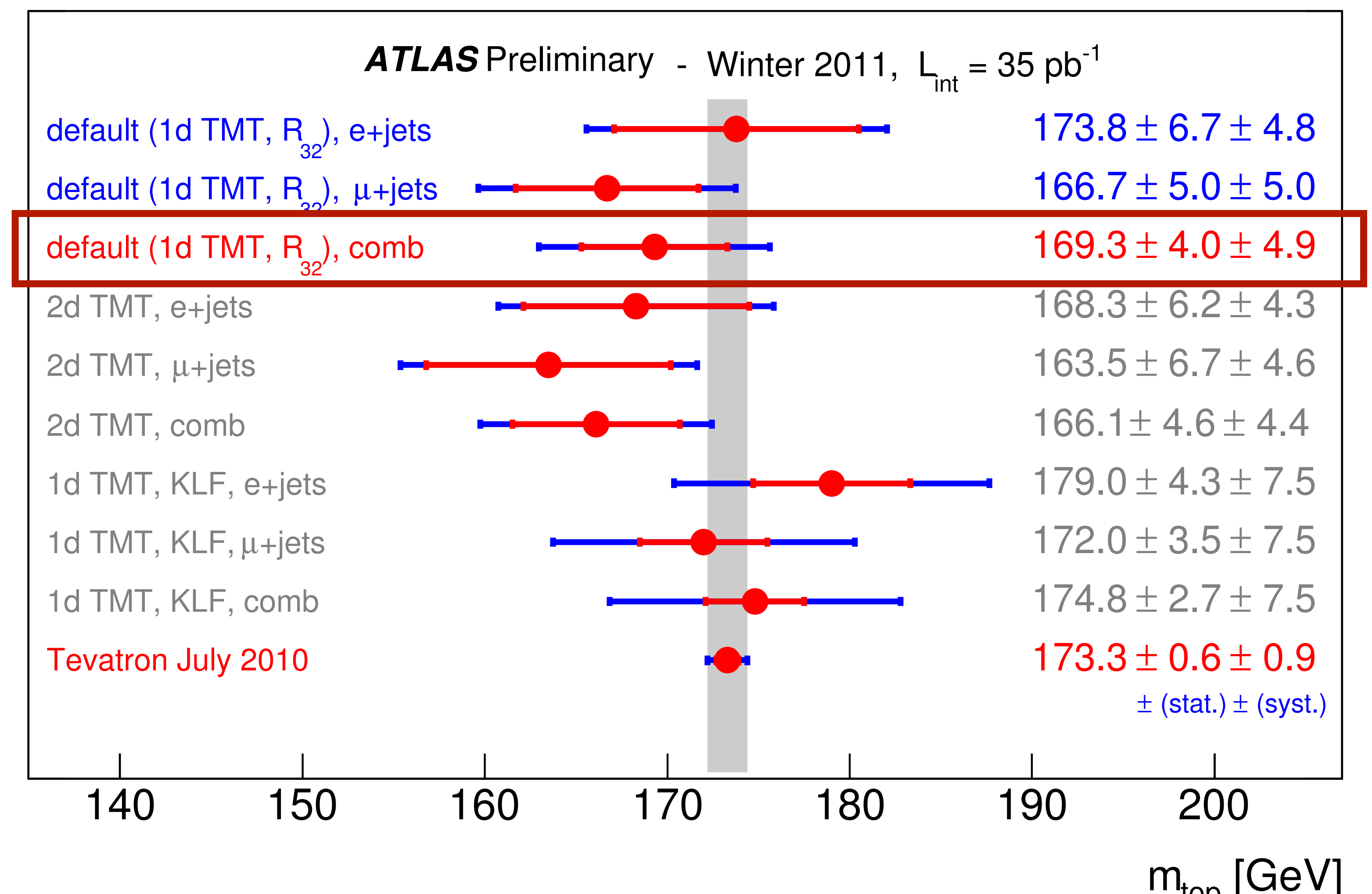
Measuring top mass

ATLAS-CONF-2011-033



top peak from kinematic fitter

ATLAS-CONF-2011-033



Stat. and syst. have the same size

- Largest systematics (baseline): jet energy scale, initial and final state radiation

CMS combined: 175.5±4.6±4.6

Top mass systematics

	Uncertainty [GeV]	
	Electron channel	Muon channel
Statistical uncertainty	6.7	5.0
Method calibration	0.7	0.5
Signal MC generator(POWHEG VS. MC@NLO)	0.7	0.6
Hadronization POWHEG (PYTHIA VS. HERWIG)	1.0	0.5
Pileup	0.6	0.8
ISR and FSR (signal only)	2.2	2.6
Proton PDF	0.6	0.5
W/Z+jets background normalization (±100%)	1.3	1.7
W/Z+jets background shape	0.6	1.0
QCD background normalization (±100%)	0.8	0.7
QCD background shape	0.6	0.5
Jet energy scale ($\pm 1\sigma$) plus 5% for close by jets	2.3	1.9
b-jet energy scale (±2.5%)	2.5	2.5
b-tagging efficiency and mistag rate	0.6	0.5
Jet energy resolution	0.6	1.1
Jet reconstruction efficiency (±2%)	0.6	0.5
Total systematic uncertainty	4.8	5.0

Single top with ATLAS

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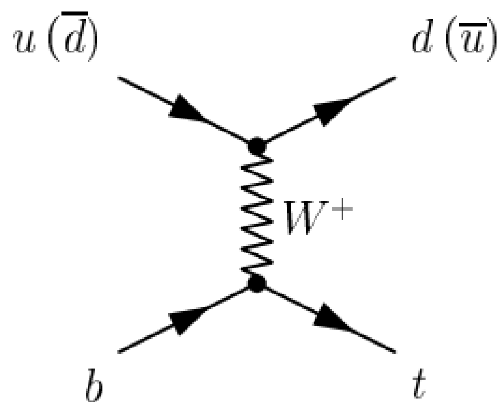
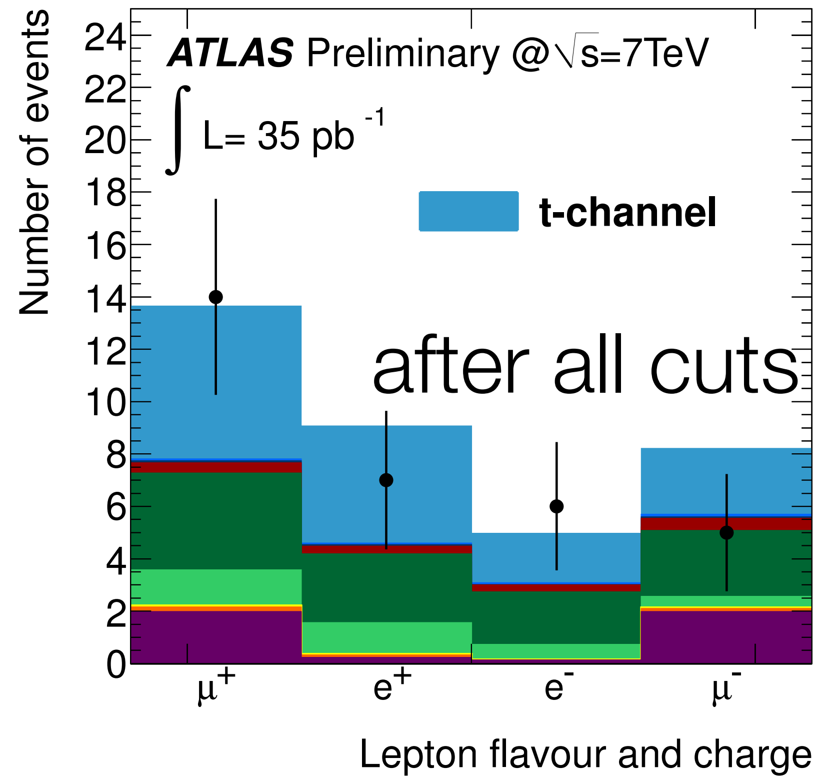
t-channel

sigma SM~ 66 pb

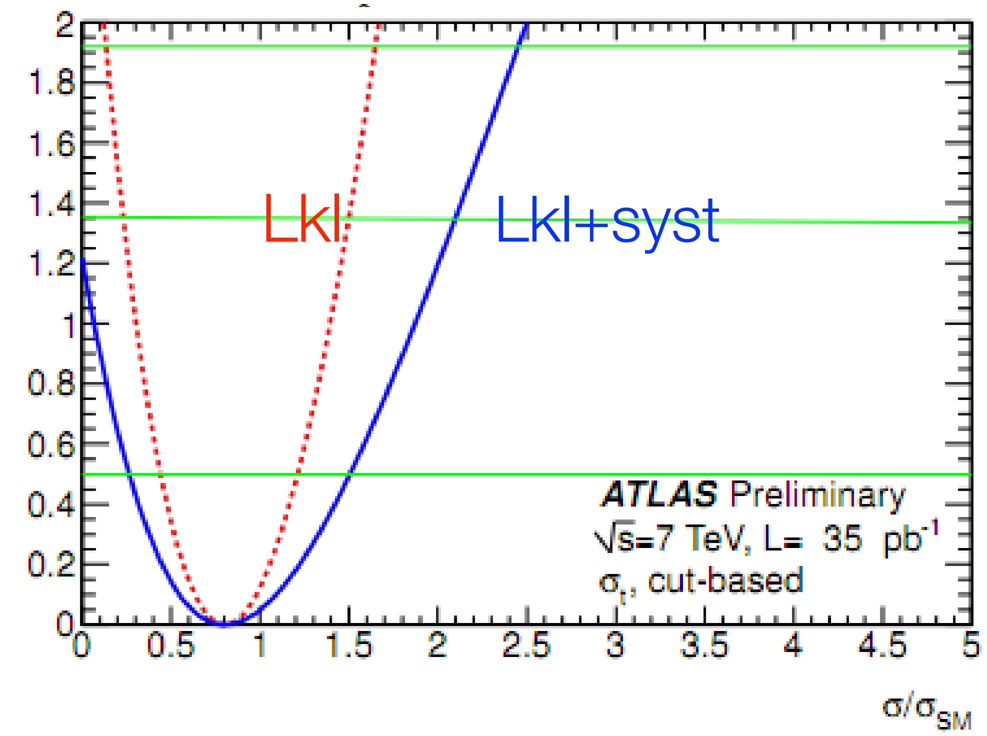


single lepton



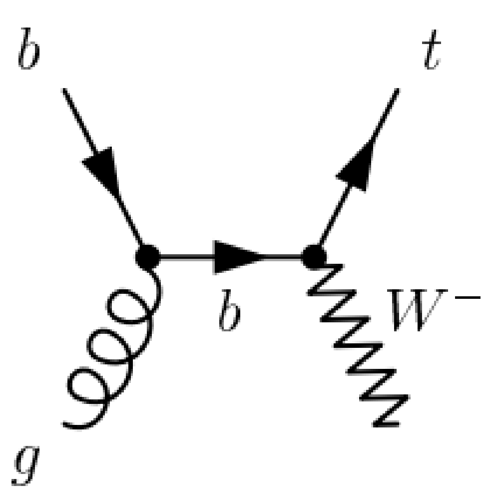
$$\sigma_t = 53^{+46}_{-36}\ \text{pb}$$

$$\sigma_t < 162\ \text{pb}$$



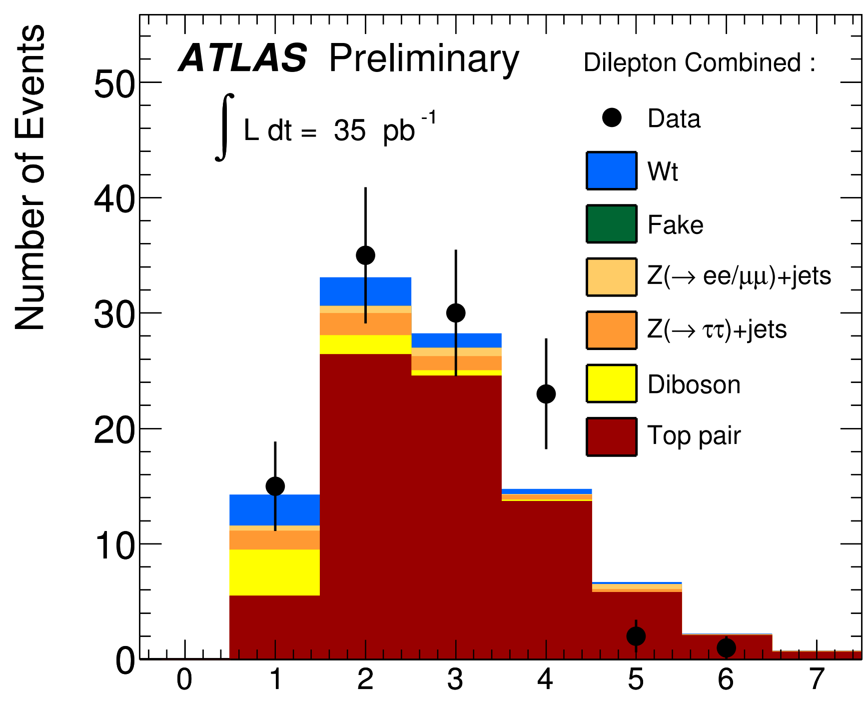
Wt channel

sigma SM~ 15 pb



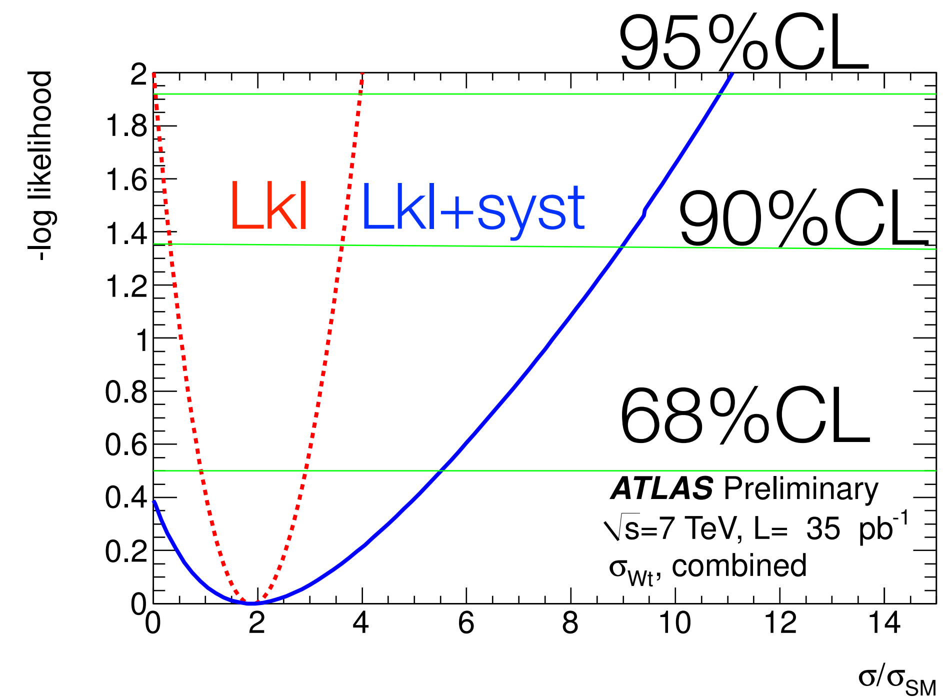
s-chan has xsec ~ 4pb

single +di-lepton



combined limit

$$\sigma_{Wt} < 158\ \text{pb.}$$

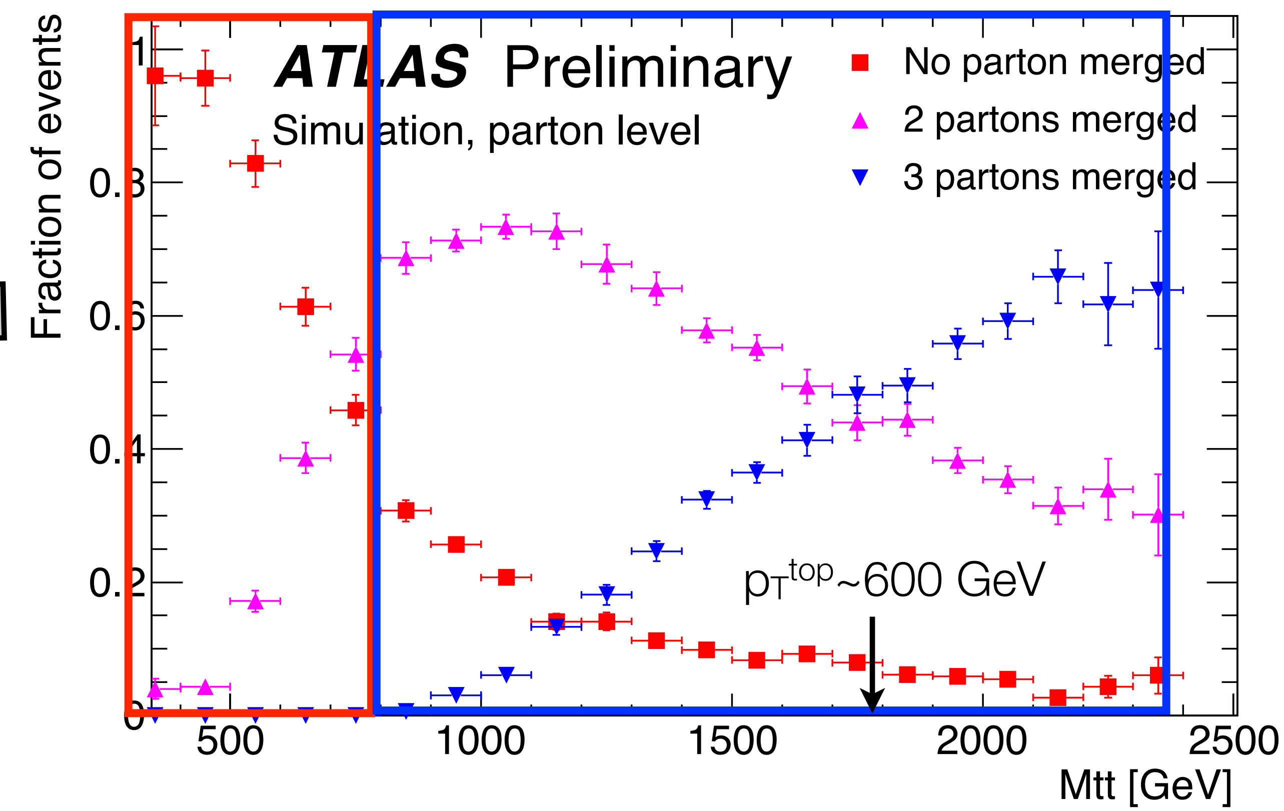


Top/anti-top resonances : ATLAS expectations

- Search for peaks in M_{tt} → **mass resolution is crucial**

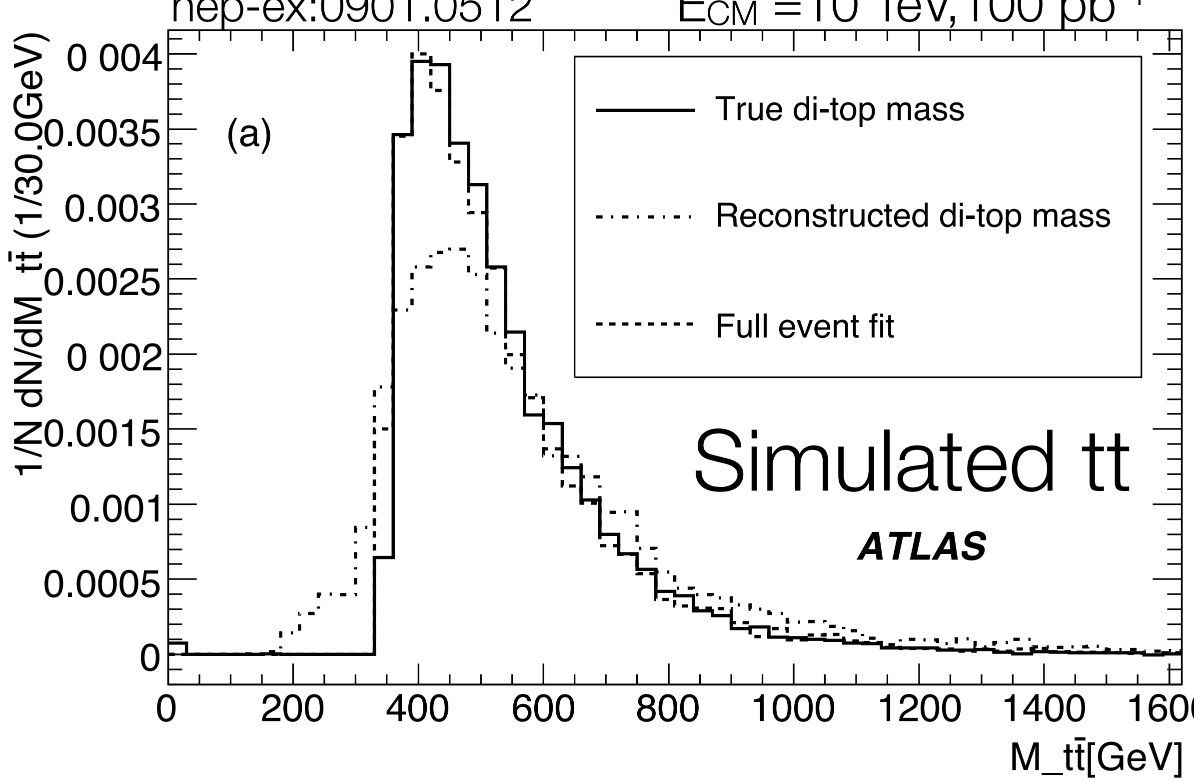
- **At "low" M_{tt}**
  - **add final state objects** + algo to choose jets (p_T order,χ^2)
  - **perform kinematic fit** using M_W, M_{top}

ATLAS-PHYS-PUB-2010-008



Probability to find partons within DR=0.8

hep-ex:0901.0512 E_{CM} =10 TeV,100 pb^{-1}



- **Higher p_T^{top} (or M_{tt})** → boosted "top jet" → new reco to separate QCD, tt, possible new physics.

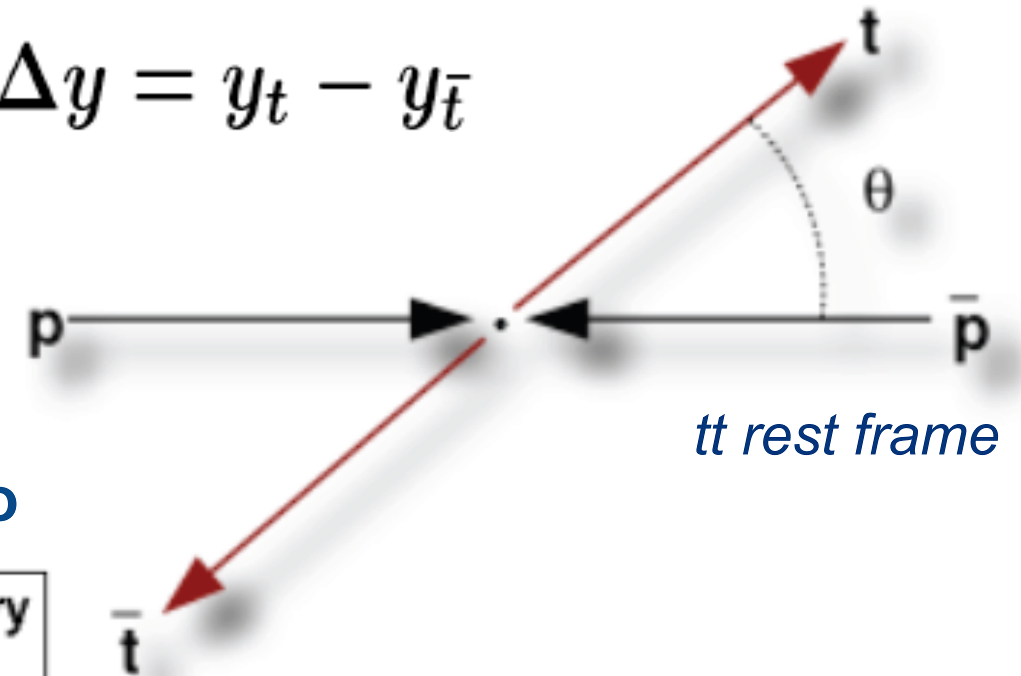
- **ATLAS analysis with 35 pb^{-1} in advanced state**. Expect results soon.

Colour Charge Asymmetry (A_{FB})

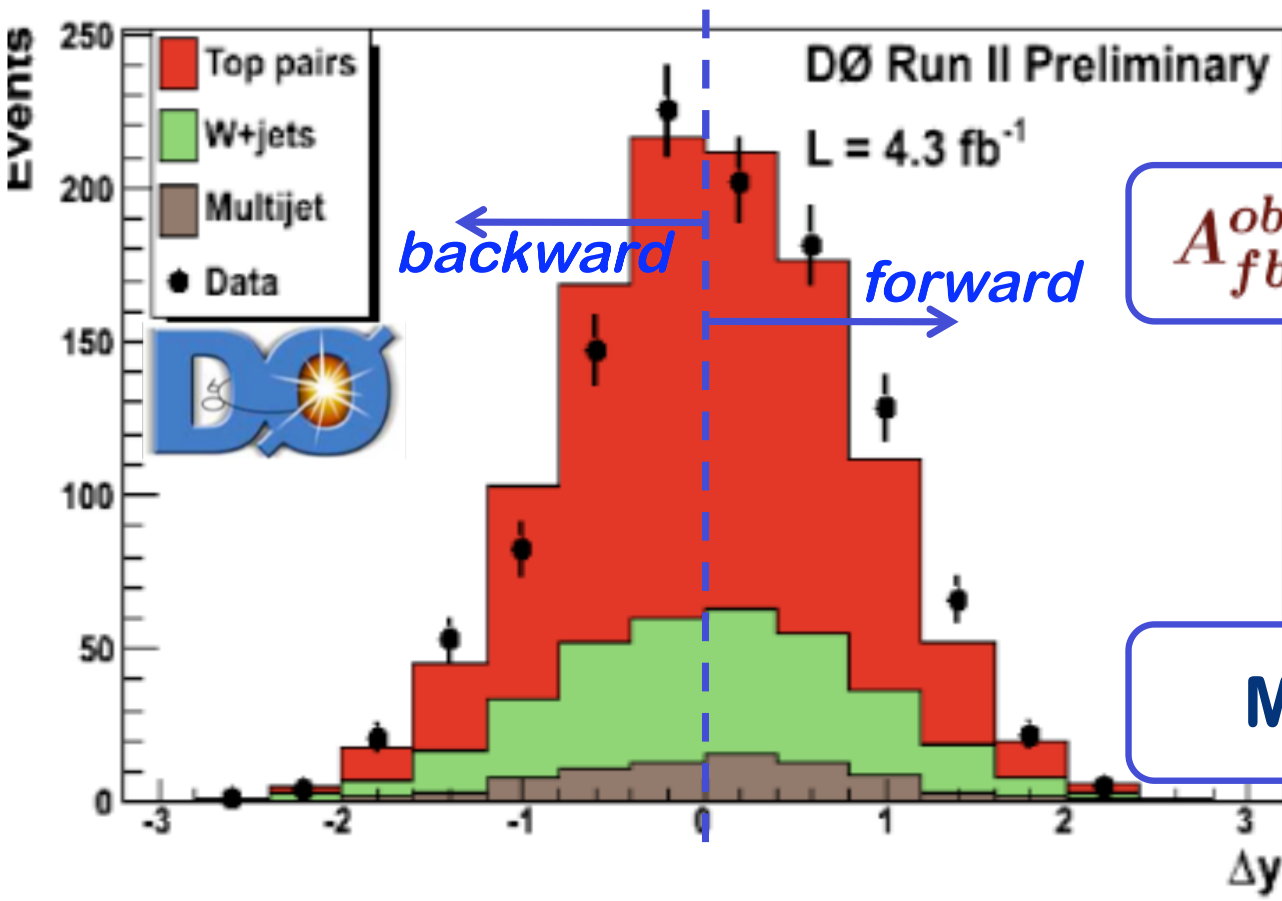
- **Form observable:**

$$\Delta y = y_t - y_{\bar{t}}$$

$$A_{fb} = \frac{N^{\Delta y>0} - N^{\Delta y<0}}{N^{\Delta y>0} + N^{\Delta y<0}}$$



  - Use b-tagged events
  - Use kinematic fitter for reco



$$A_{fb}^{obs} = 8 \pm 4(stat) \pm 1(syst)\%$$

Raw result (not unfolded)
+ description of acceptance
& detector effects allowing
comparison to any model

MC@NLO prediction: $1^{+2}_{-1}\%$

[D0 note 6062] **~2σ**

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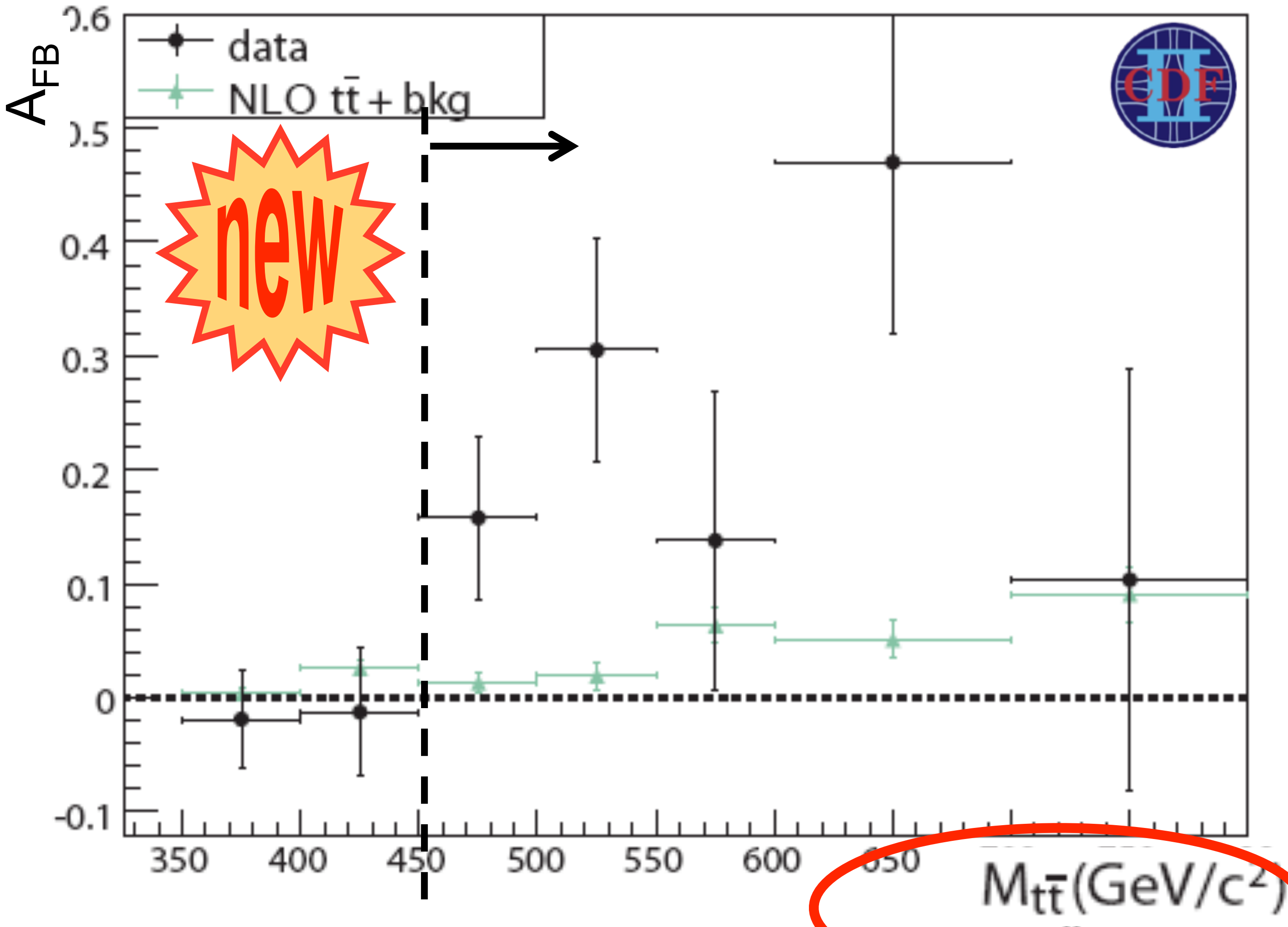
- **Look at A_{FB} as a function of M_{tt}**



Pronounced dependence of A_{FB} on M_{tt}!!!
New physics?
SM prediction at α_s^4? α_s^∞?
Soft QCD effects?

Unfolding

>3σ

selection	$M_{t\bar{t}} < 450$ GeV$/c^2$	$M_{t\bar{t}} \geq 450$ GeV$/c^2$
data parton	$-0.116 \pm 0.146 \pm 0.047$	$0.475 \pm 0.101 \pm 0.049$
MCFM	$+0.040 \pm 0.006$	0.088 ± 0.013

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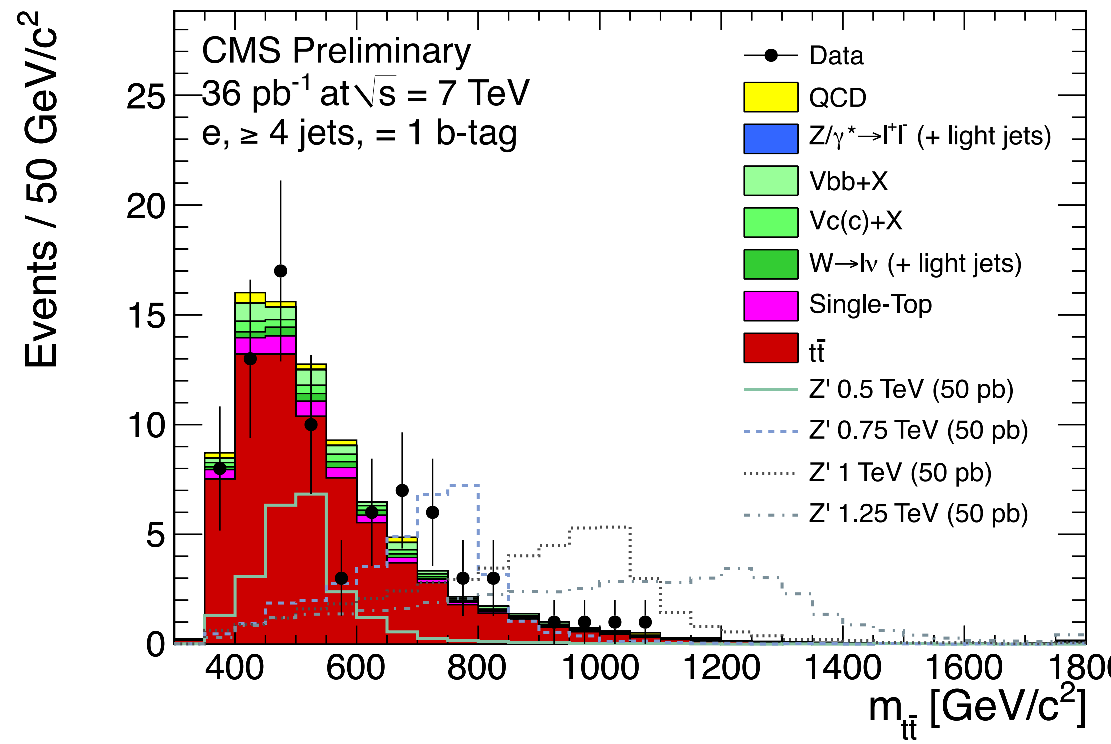
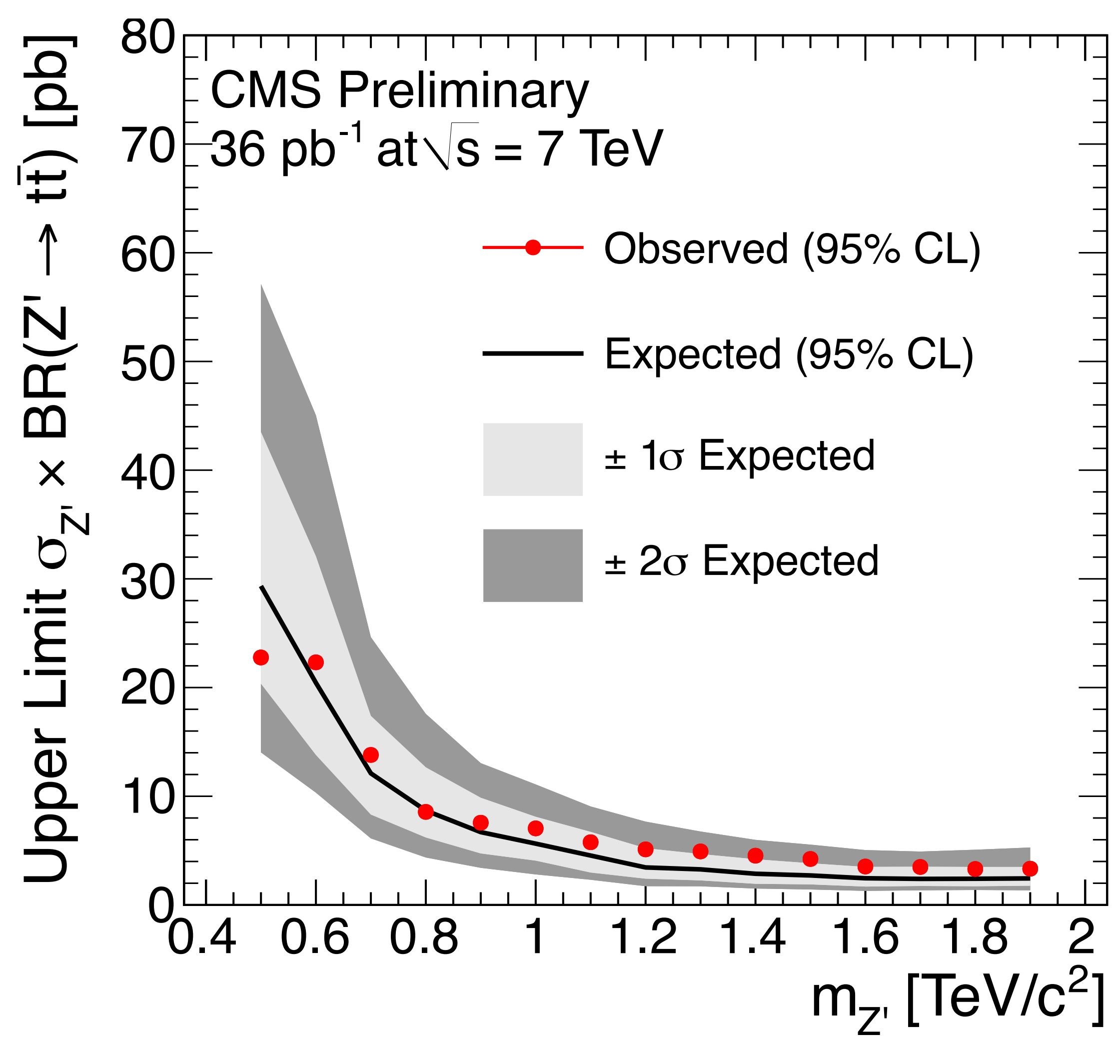
CMS top anti top resonance

TOP-10-007-PAS

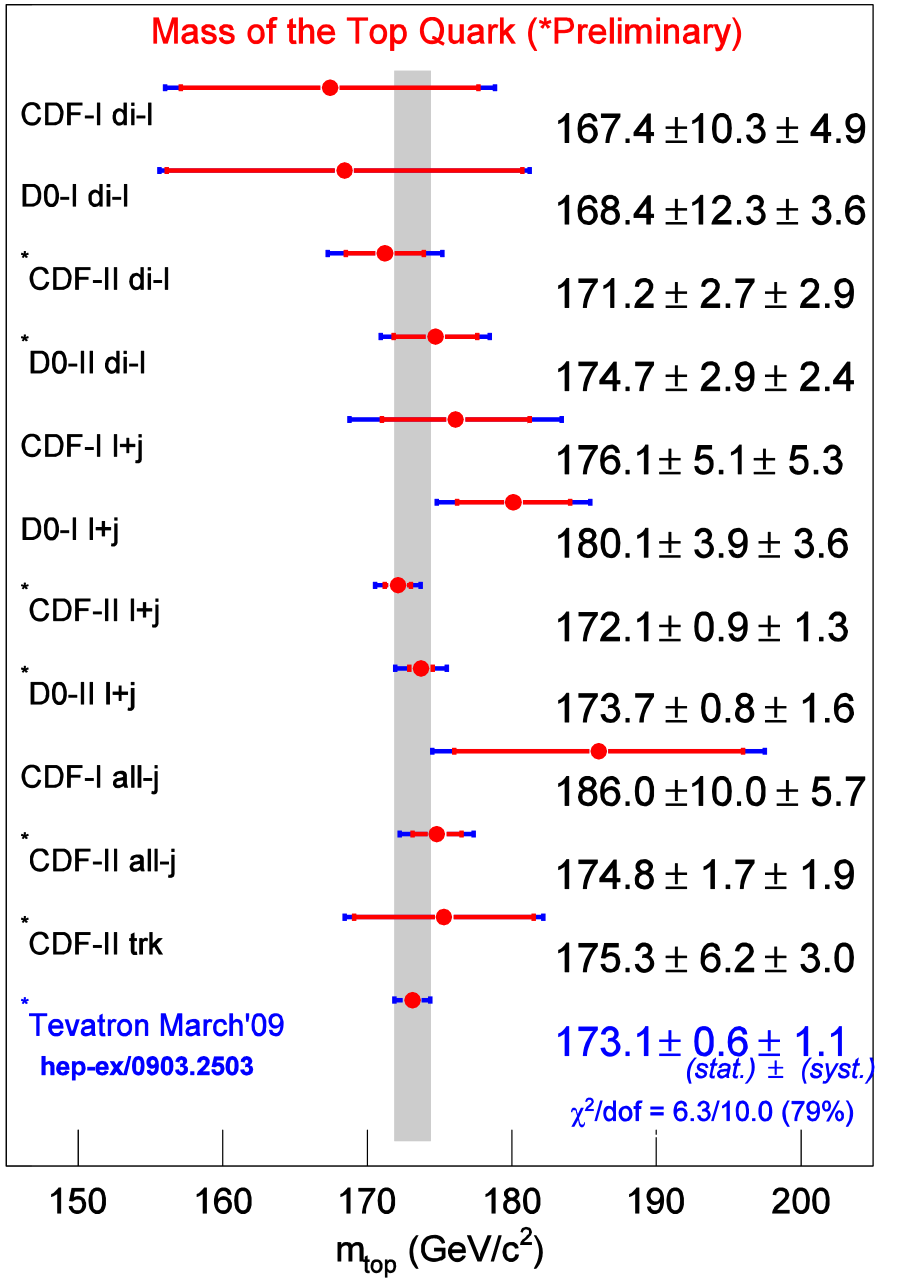
- Use b-tagged and non-b tagged events
- Least squares to choose the jets
- Kinematic fit for mass reconstruction
  - Res is about 6% at 500 GeV , 7% at 1 TeV
- Mass reach up to 1.8 TeV
- No exclusion statement, upper limit on Z prime



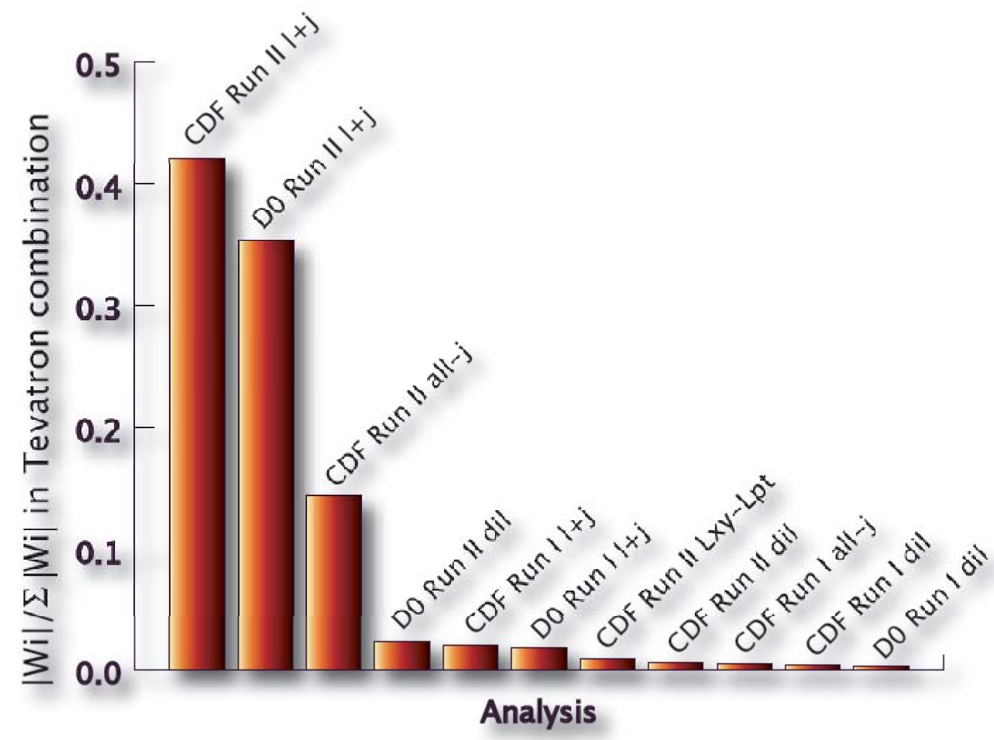


H.Lee, Moriond QCD
March 2011

Combination



$m_{top} = 173.1 \pm 1.3$ GeV/c²



New measurements

CDF LJ (ME) =172.8 ± 1.3 GeV/c^2

CDF LJ (TM) =172.1 ± 1.5 GeV/c^2

CDF DIL(TM) = 170.6 ± 3.8 GeV/c^2

Moriond QCD 2010, Hyunsu Lee, The University of Chicago 14