Search for single-top production in the s-channel at $\sqrt{s}$= 7 TeV with the ATLAS detector

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Supervisors: Annick Lleres, Arnaud Lucotte

Séminaire de doctorants 14/5/2013

Outline

0 What is single top and why is it interesting?

SEARCH FOR AN ELECTROWEAK PRODUCTION MODE OF TOP QUARK AT LHC:
S-CHANNEL ANALYSIS STRATEGY

1 Preselection of lepton+jets events with the ATLAS detector

2 Background estimates

3 Extremely low signal purity and big overlap with backgrounds distributions

- ➡ Multivariate analysis: Boosted Decision Trees
  - control region
  - signal region
  - fit of the output distribution for cross section determination

4 Systematic uncertainties

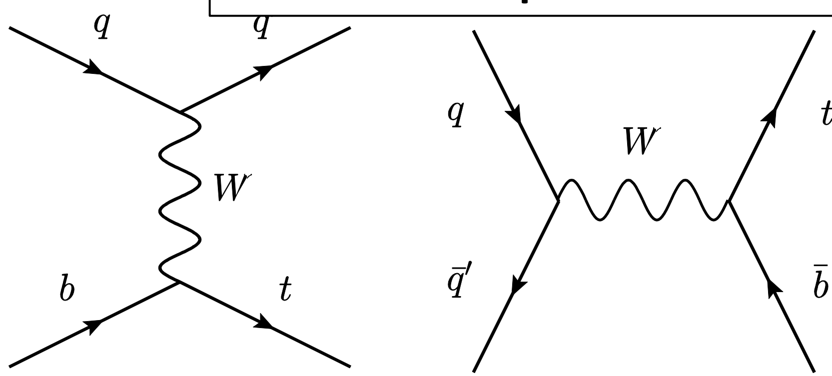
5 Statistical data analysis

- ➡ Limit drawing
- ➡ Significance

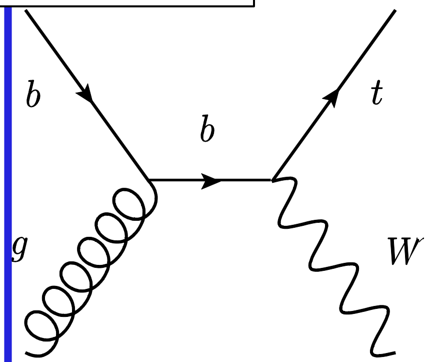
6 Conclusion

Single top discovery

Electroweak production mode of top quark



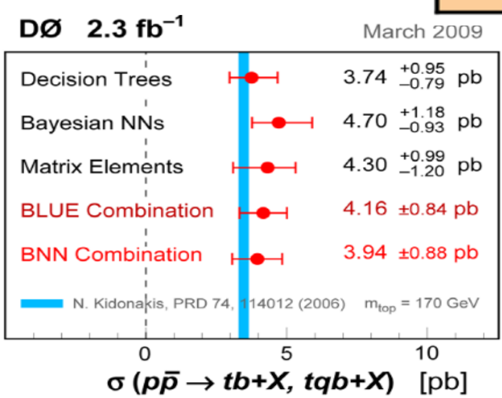
t-channel s-channel

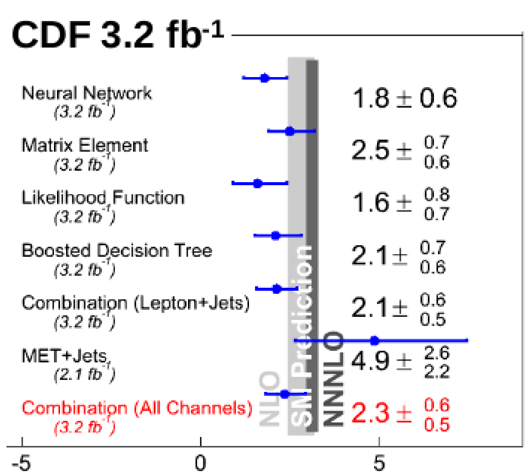


Wt channel

2009

Single Top Cross Section	Signal Significance Expected	Signal Significance Observed
DØ PRL 103, 092001(2009) m_{top}=170 GeV		
3.94 ± 0.88 pb	4.5 σ	5.0 σ
CDF PRL 103, 092002(2009) m_{top}=175 GeV		
2.3 $^{+0.6}_{-0.5}$ pb	>5.9 σ	5.0 σ





2012

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Evidence for the associated production of a W boson and a top quark in ATLAS at $\sqrt{s} = 7$ TeV ☆

ATLAS Collaboration *

LPSC:

Thomas Delemontex

Arnaud

Annick

Motivations for the single top analyses

- Top mass ≈ 173 GeV ⟺ EWSB scale v≈ 246 GeV
- Lifetime (10^{-25}s) < hadronization time scale ⇒ assess top polarization via its decay products
- Direct measurement of V_{tb} without the assumption of CKM unitarity
- Investigations on physics beyond SM:

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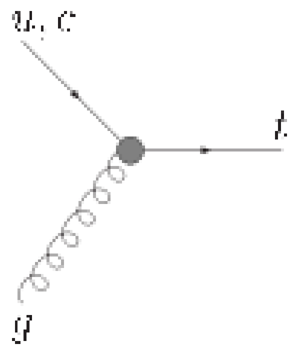
t-channel sensitive to:

Flavour Changing Neutral Currents

A search for the process

gq → t →W(→l,ν)b

show no evidence



Anomalous couplings

Work in progress

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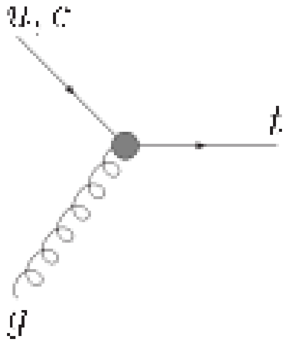
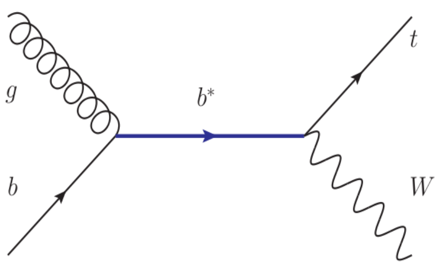


Wt production:

shares the same final state of an excited b quark decay.

b* with masses<870 GeV excluded @ 95% C.L



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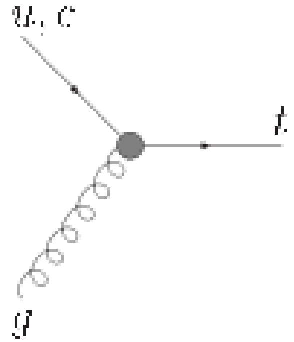

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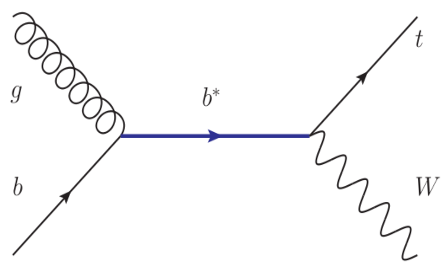


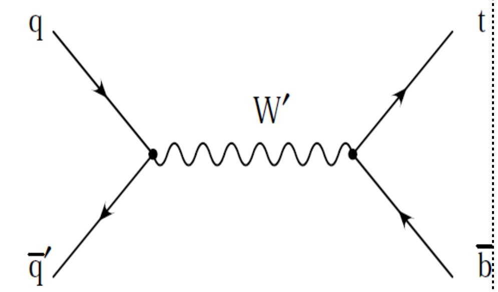
Deviations in **s-channel** XS may be caused by new resonances:

Composite models (top-pion): scalar bosons (bound states of tb) appearing in the EWSB mechanism

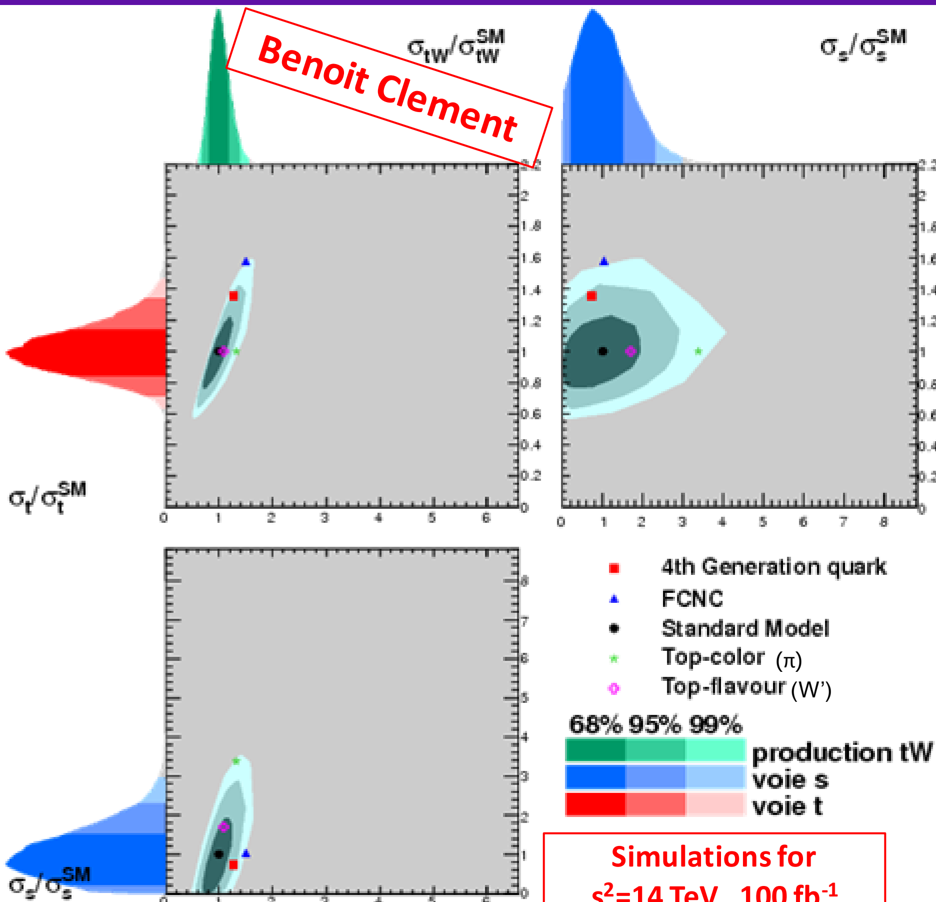
Charged W -like bosons (W’):

model independent analysis of the W'→tb decay

No excess found in m_{tb} spectrum @ 95% C.L ($0.5<m(W_{L/R})<3$ TeV)



Cross section measurements @ LHC

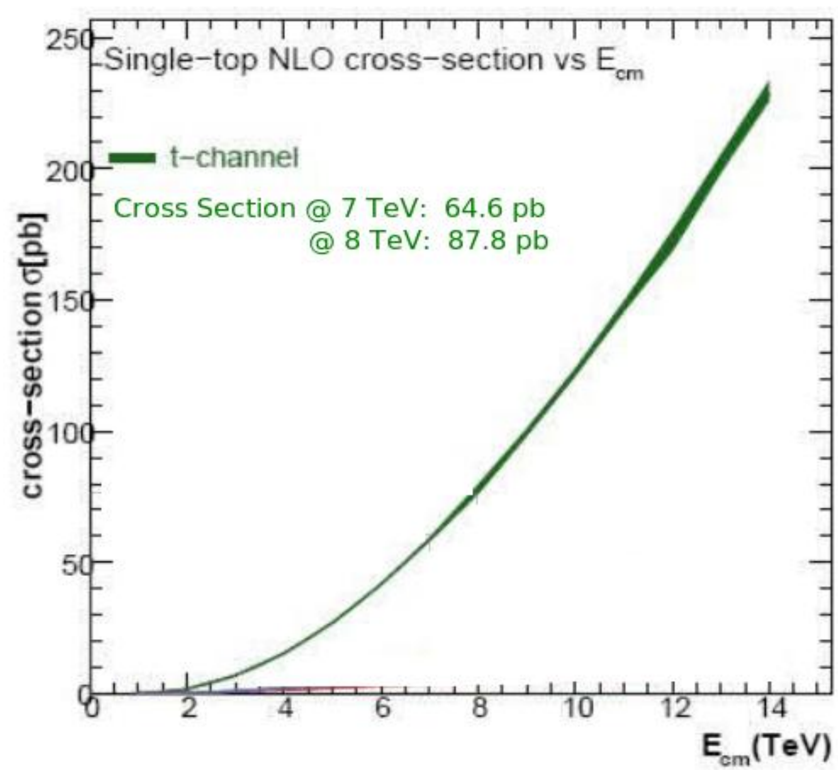


Simulations for
s^2=14 TeV, 100 fb^{-1}
data

The 3 single top production modes are separately susceptible to different types of physics

combined measurement of the three channels
- provides evidence for new phenomena
- sheds light on the nature of the underlying theory

LHC top-factory (300 k single top events in 2011, s^2=7 TeV)
Statistics increases with center of mass energy



precise cross section determination

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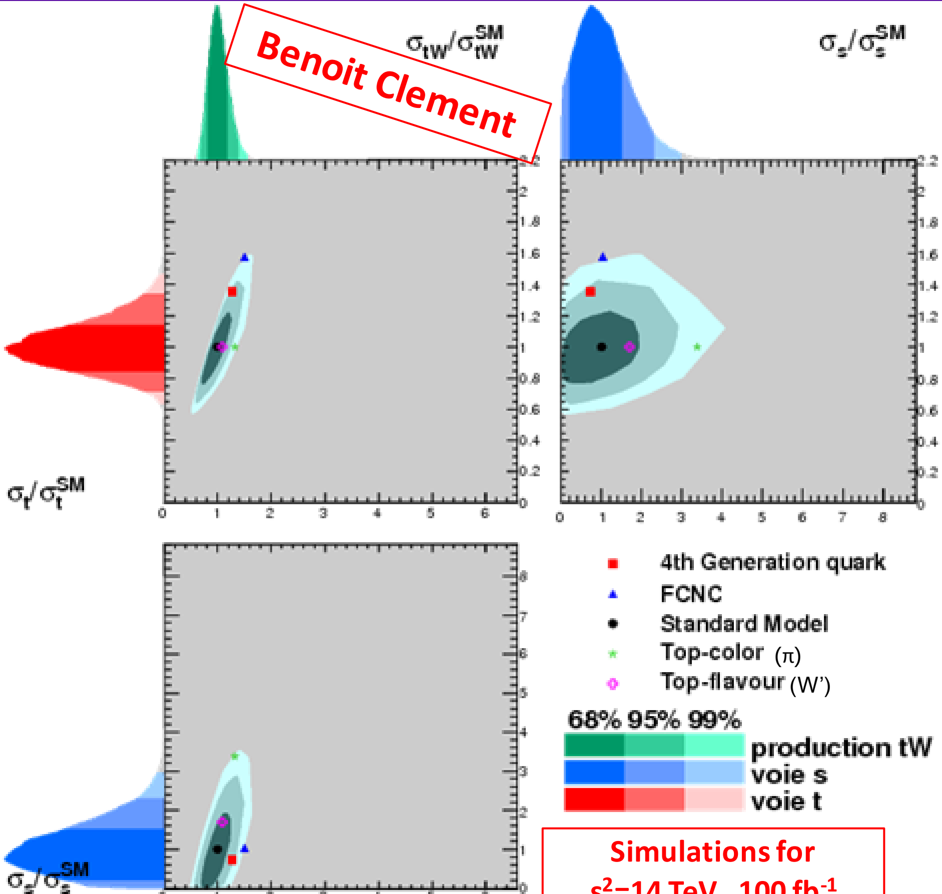

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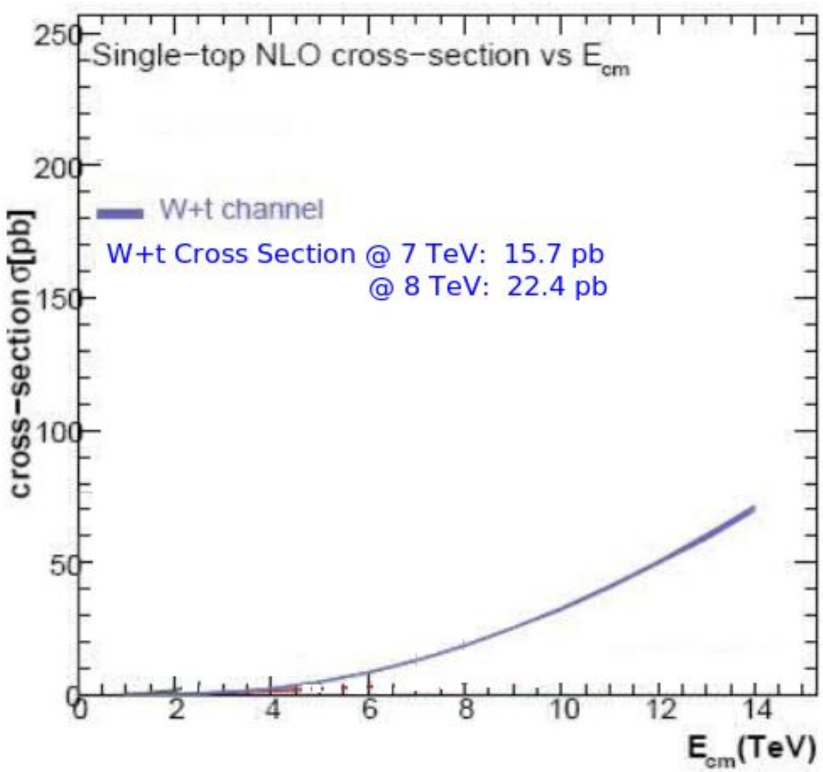

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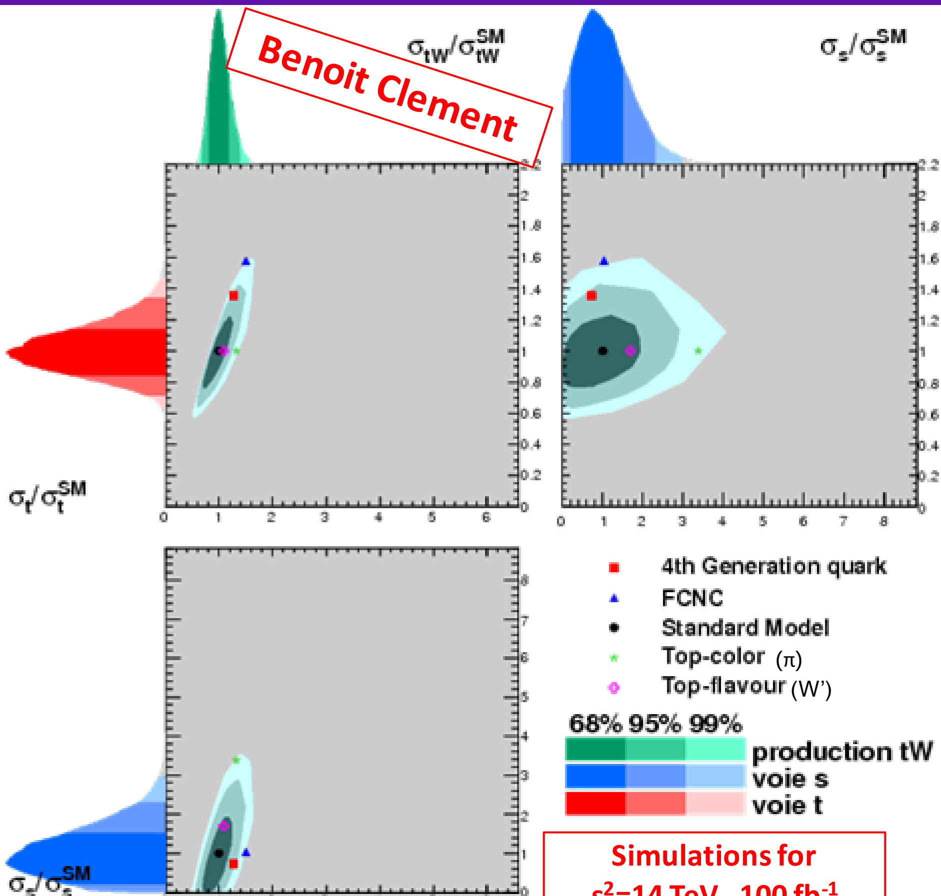

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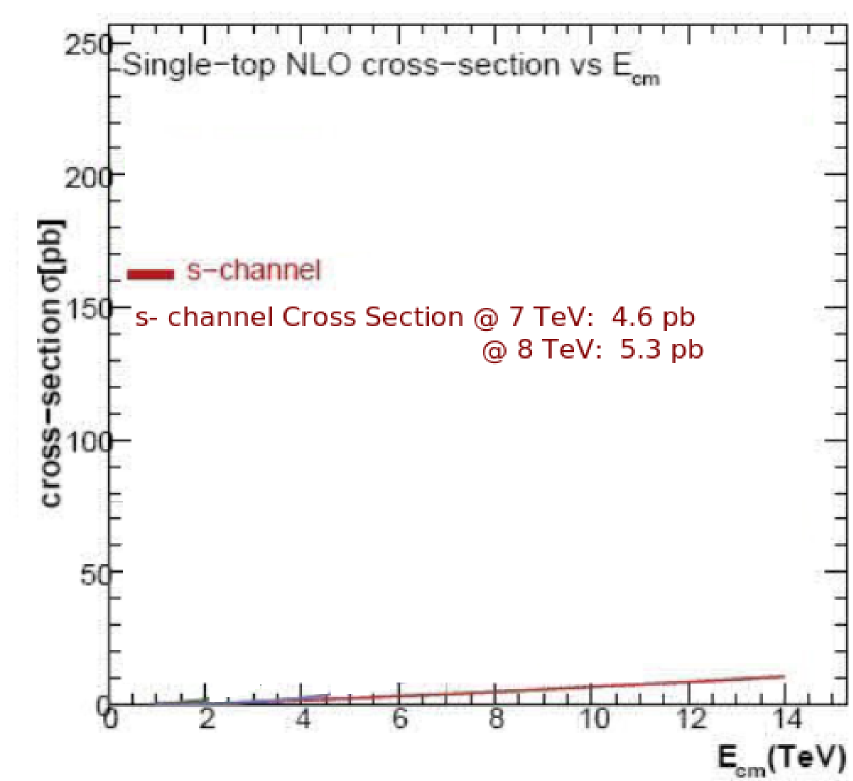
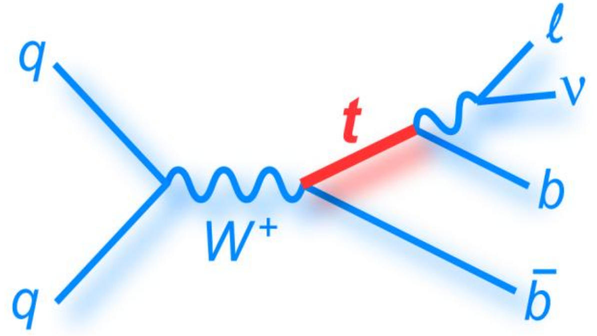
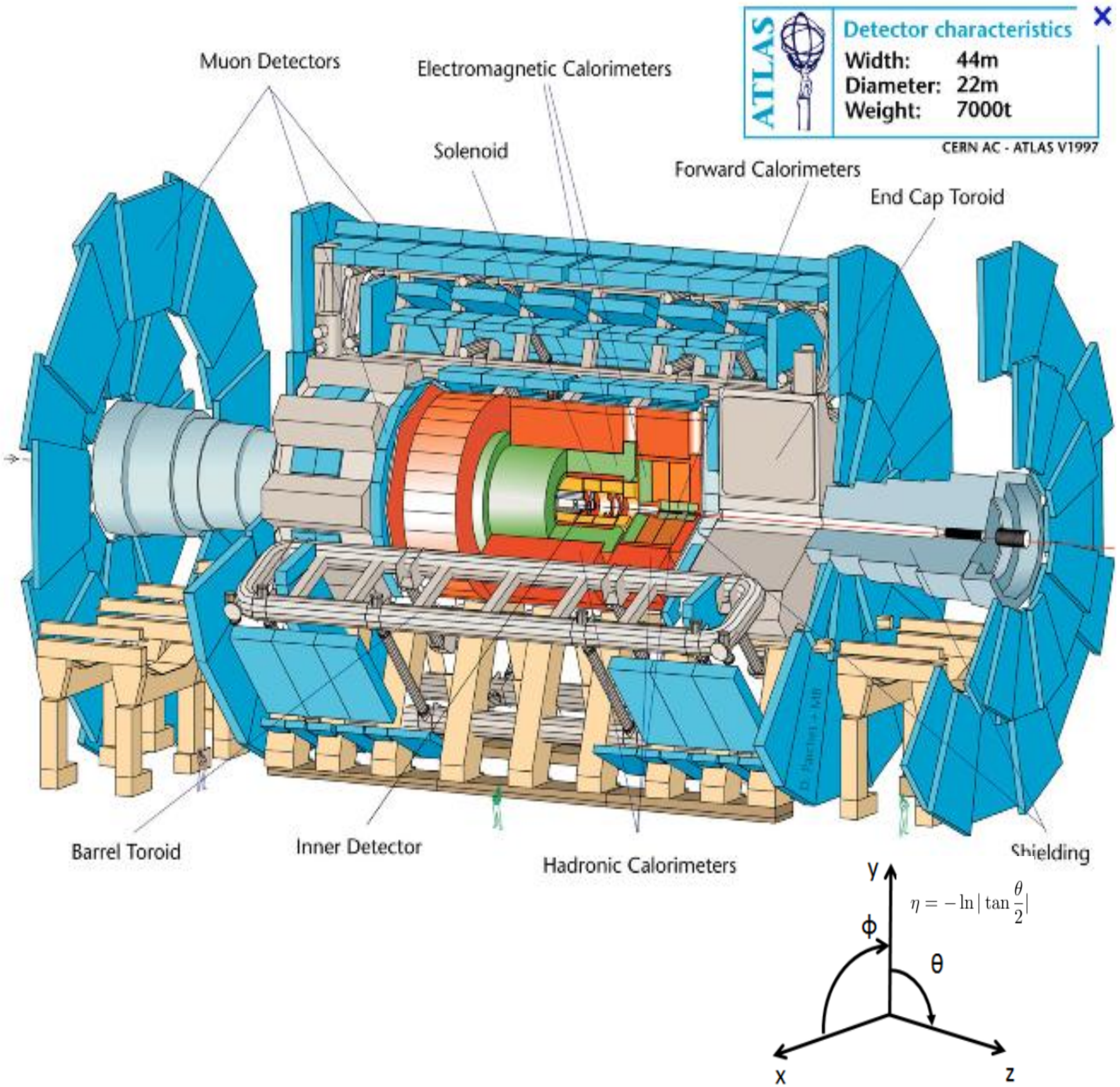


precise cross section determination

s-channel analysis -preselection

Single top s-channel final state





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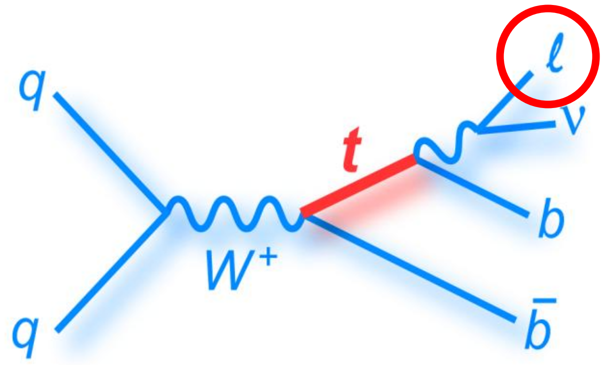
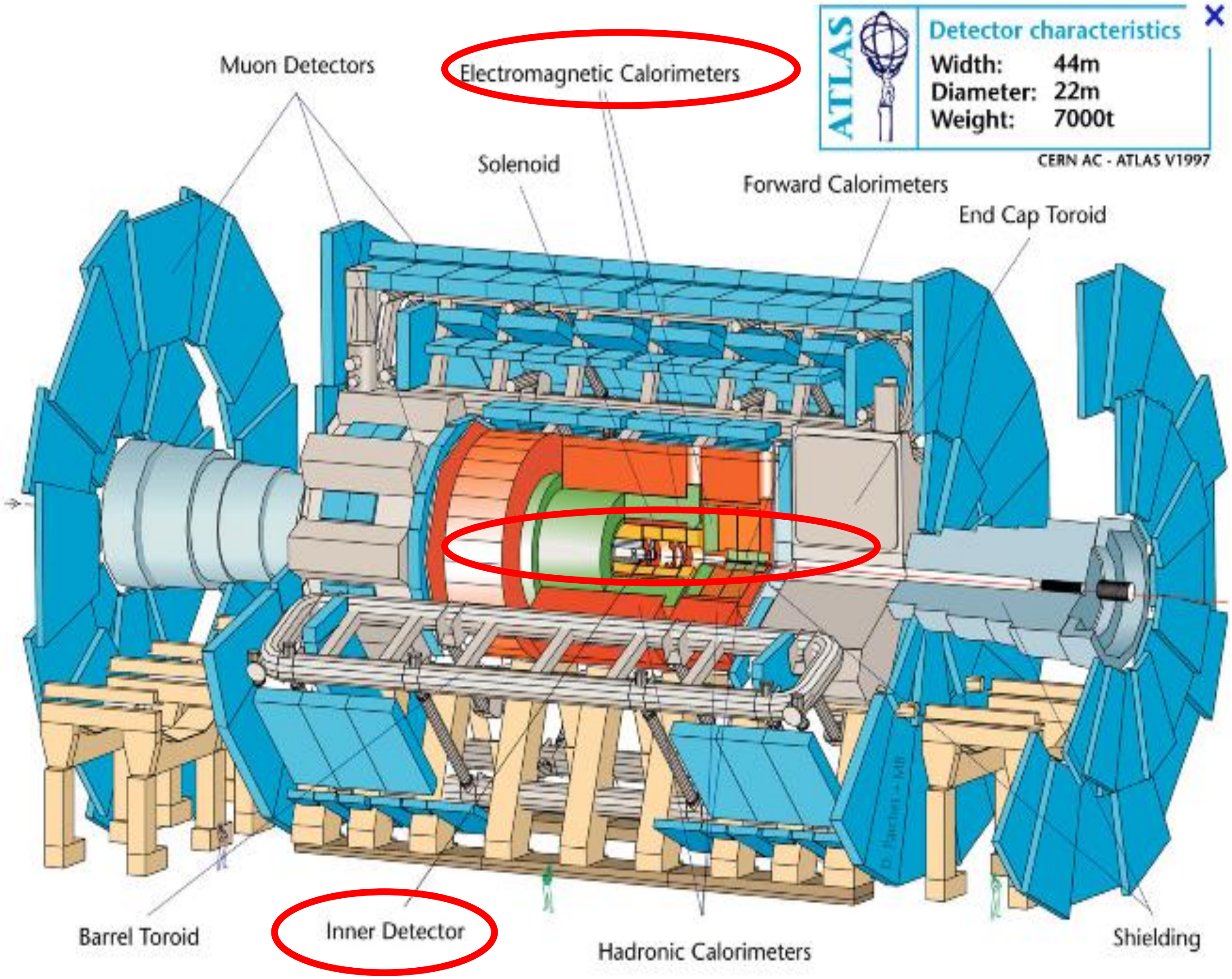


Electron

- p_T >30 GeV
- $|\eta| < 2.47$

(excluding $1.37 < |\eta| < 1.52$)



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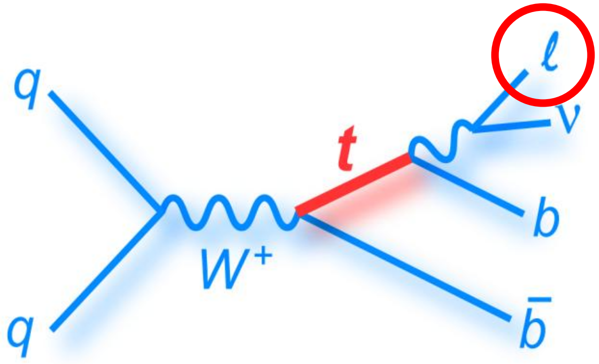

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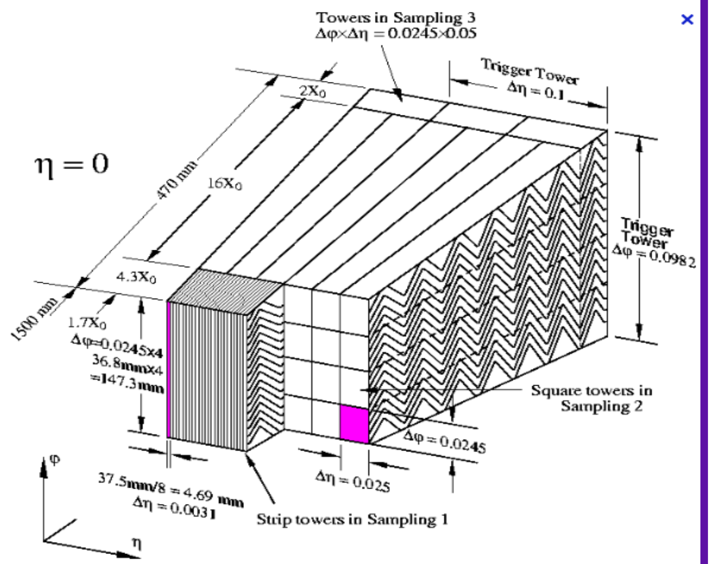
Detection & reconstruction of electromagnetic cluster



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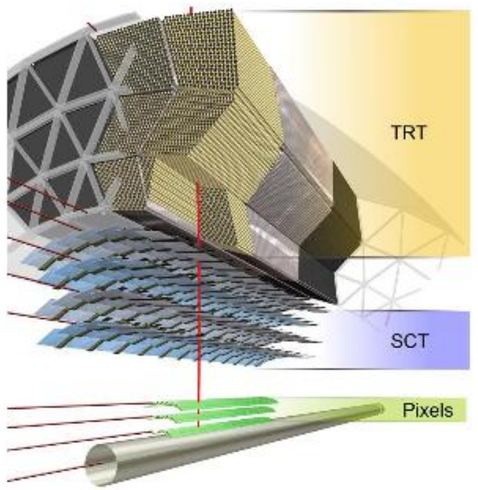
Spatial association with a Inner Detector track



Electromagnetic calorimeter

Accordion shape

Absorber: lead

Active detection medium: LAr

Inner Detector

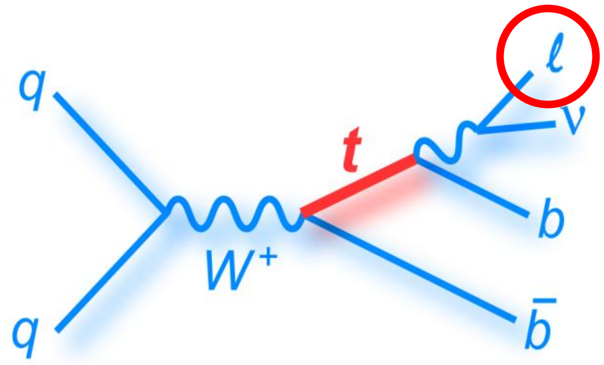
Pixel

Semi-Conductor Tracker

Transition Radiation Tracker

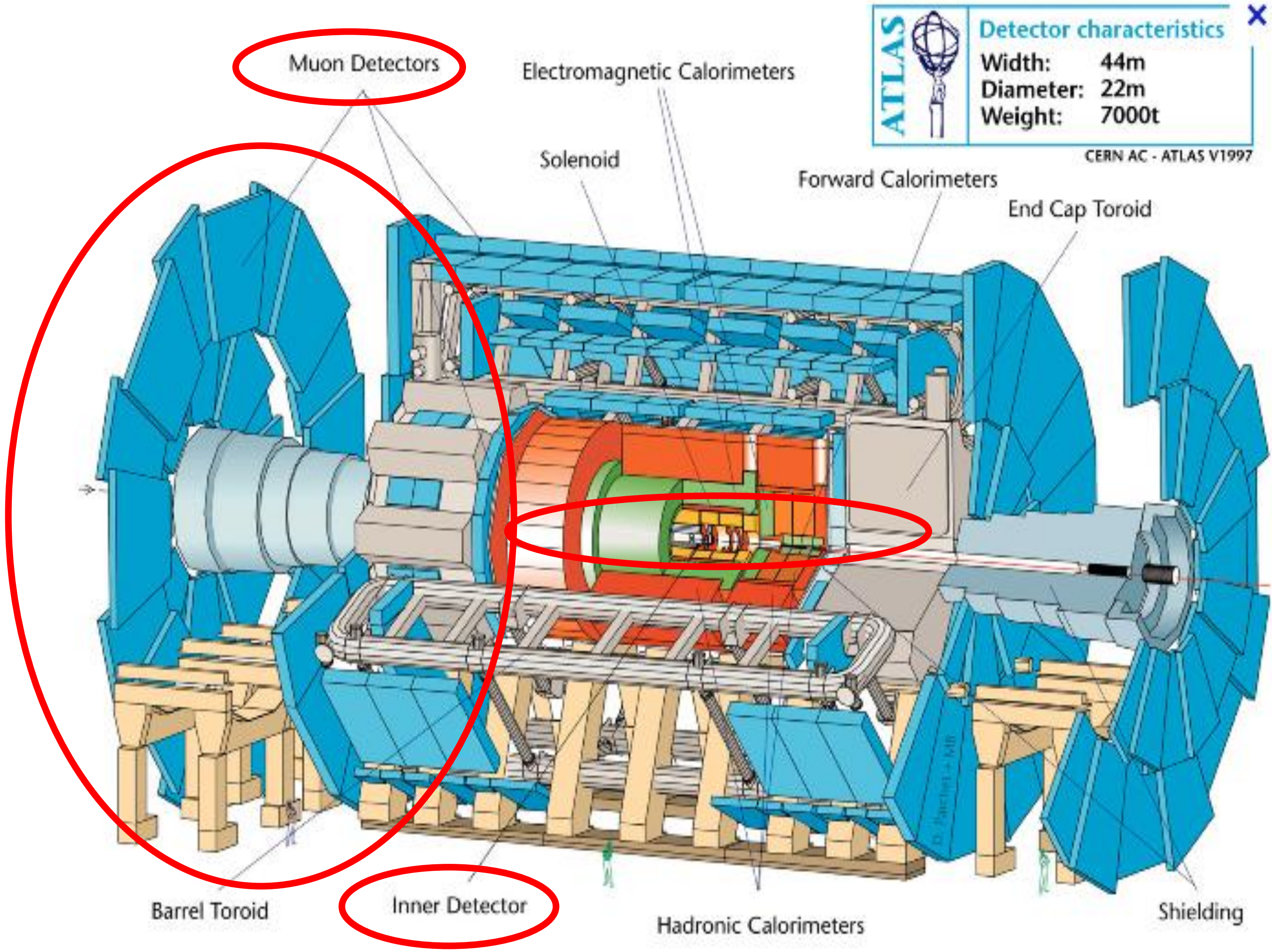
s-channel analysis -preselection

Single top s-channel final state



Muon

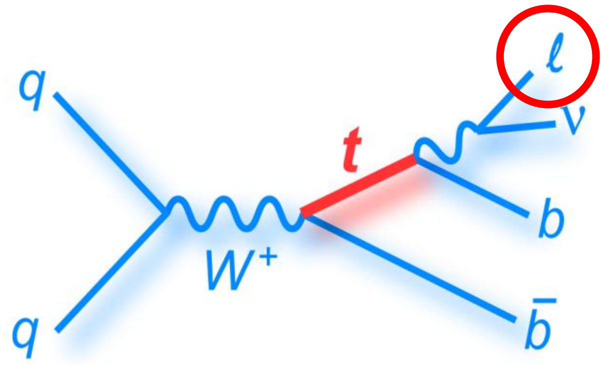
- p_T >30 GeV
- $|\eta| < 2.5$



Séminaire des doctorants

s-channel analysis -preselection

Single top s-channel final state



Muon

- p_T >30 GeV
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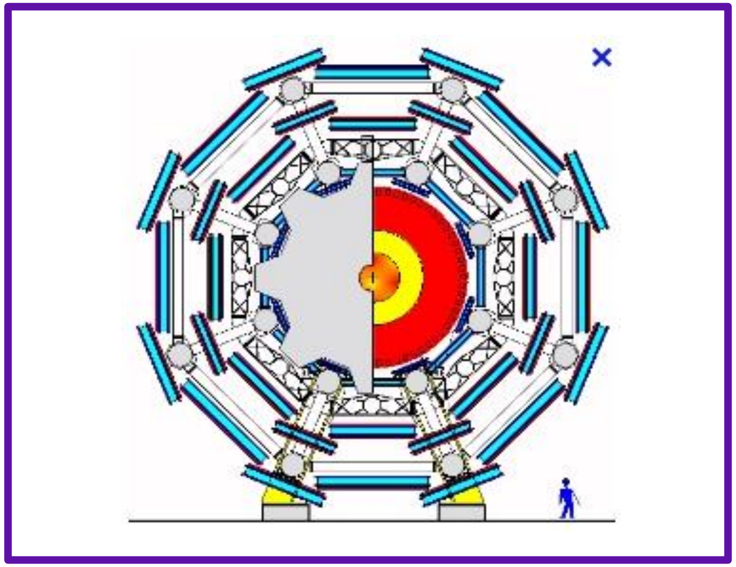
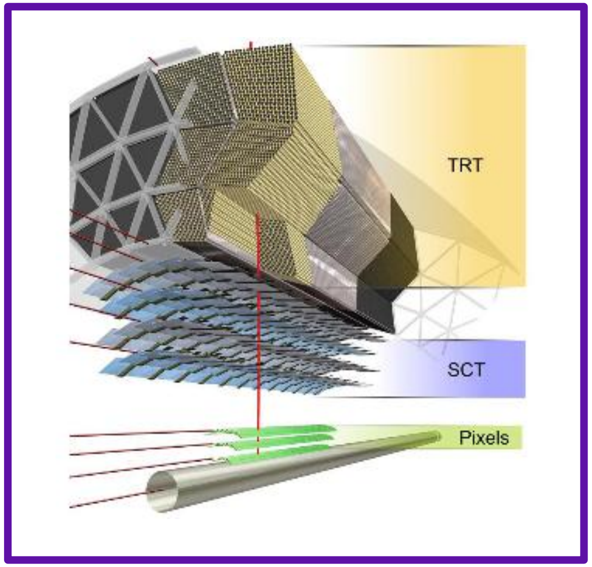
Track reconstruction



and
or

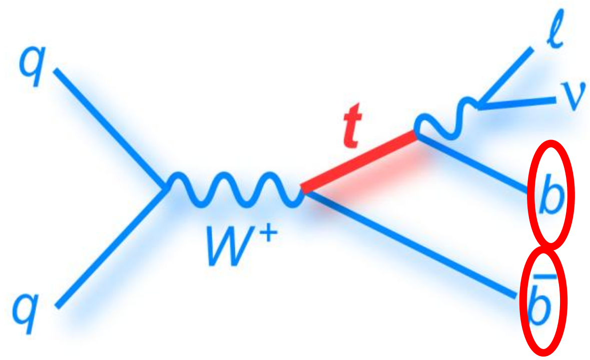


Muon spectrometer
Monitored Drift Tubes
Resistive Plate Chambers
Thin gap Chamber
Cathode Strip Chambers

Inner Detector
Pixel
Semi-Condutor Tracker
Transition Radiation Tracker

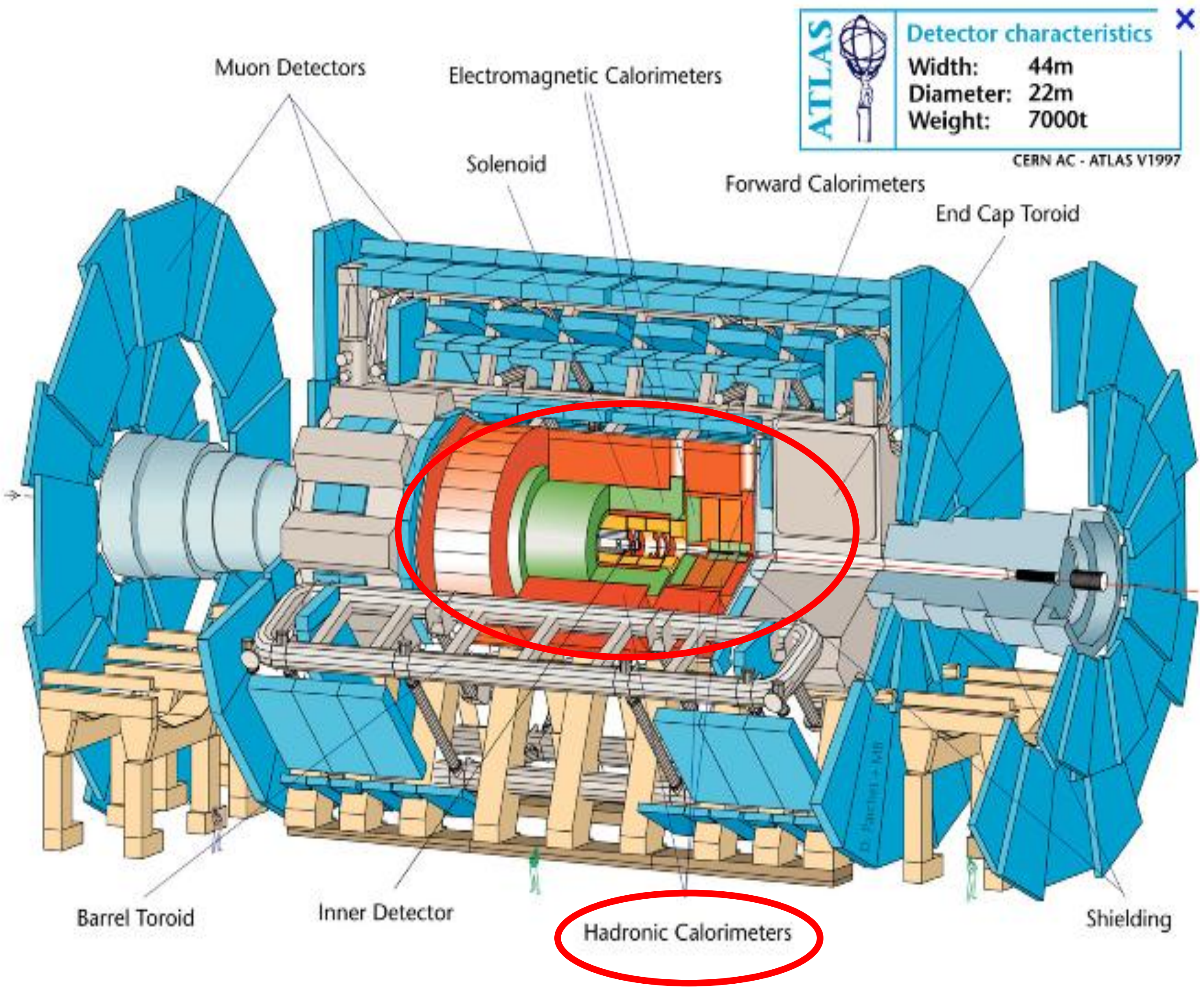
s-channel analysis -preselection

Single top s-channel final state



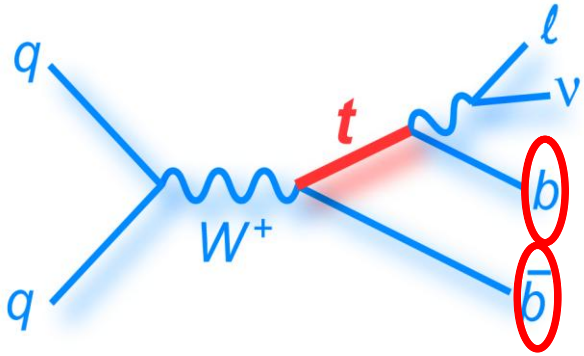
2 b-tagged jets

- p_T >25 GeV
- $|\eta| < 2.5$



s-channel analysis -preselection

Single top s-channel final state



2 b-tagged jets

- p_T >25 GeV
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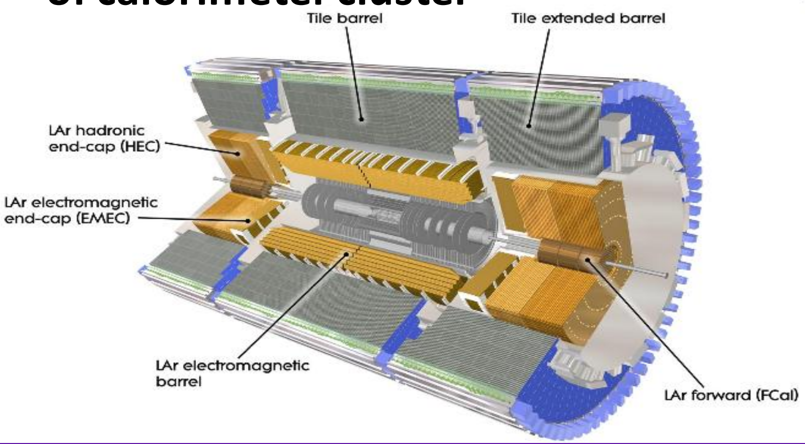
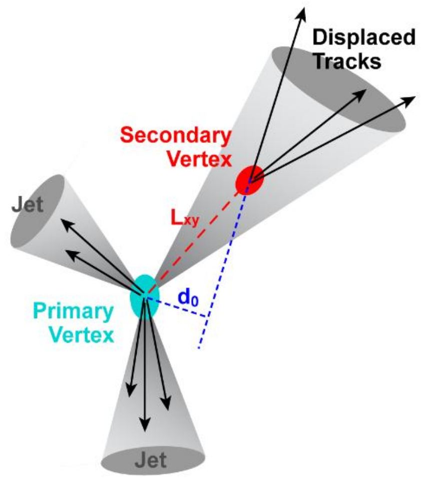
Detection & reconstruction of calorimeter cluster



+

b-tagging



Hadronic calorimeter

Tile calorimeter (barrel)
Absorber: iron
Active detection medium: plastic scintillator

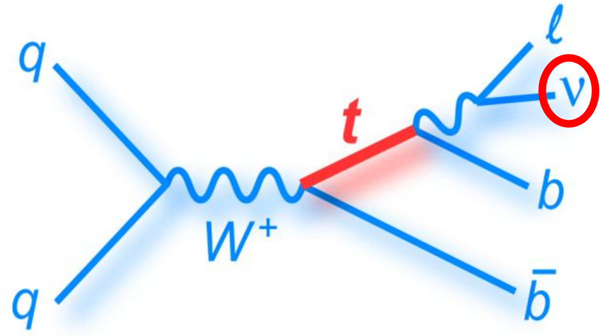
End- cap calorimeter
Absorber: lead
Active detection medium: lAr

MV1 algorithm

Neural network to combine topological variables and 3 b-tagging algorithms

s-channel analysis -preselection

Single top s-channel final state



Transverse missing energy

- E_T^{miss} >30 GeV

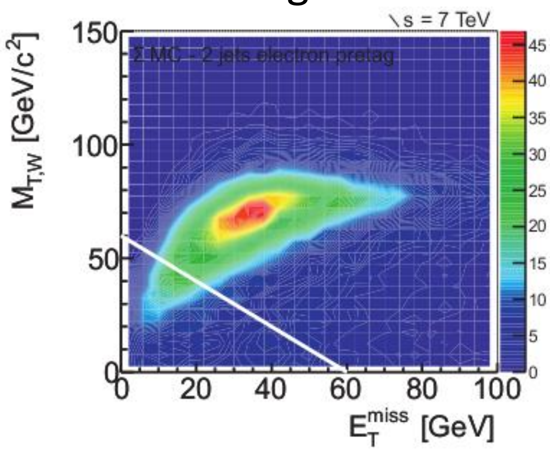
E_T not measured by the sub-detectors (total energy for particles traveling transverse to the beam axis is zero)

Triangular cut : $E_t^{miss} + M_T(W) > 60$ GeV

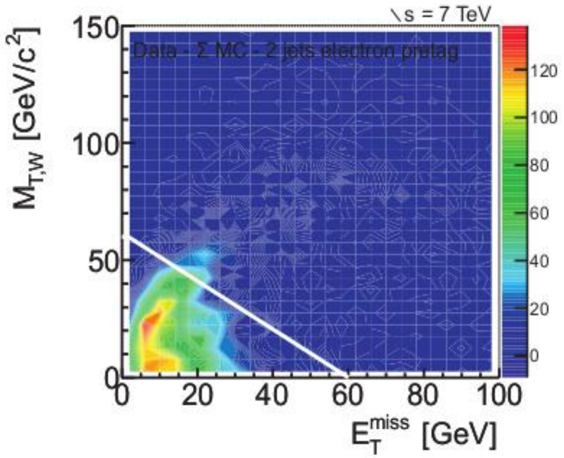
to reduce fake leptons from QCD-multijet events

Exemplar sketch for:

Signal



QCD

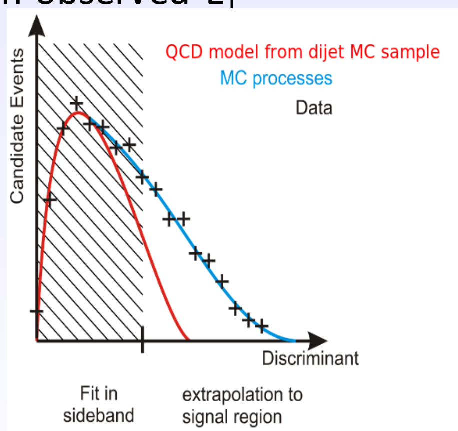


Background estimates

QCD multijet

ELECTRONS:
jet electron model

- **Shape**: MC events with 1jet faking 1 electron
- **Normalization**: binned likelihood fit on observed E_T^{miss}



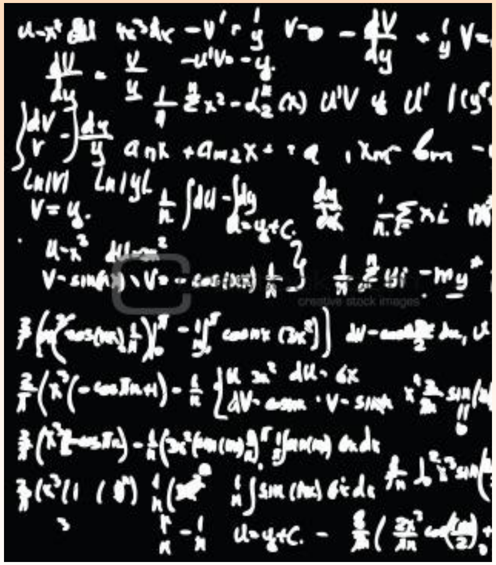
MUONS:
Matrix method

- **Shape:** loose data rescaled
- **QCD rate** expressed in terms of loose/tight lepton events, real/fake selection efficiencies

Ttbar, single top diboson, Z+jets

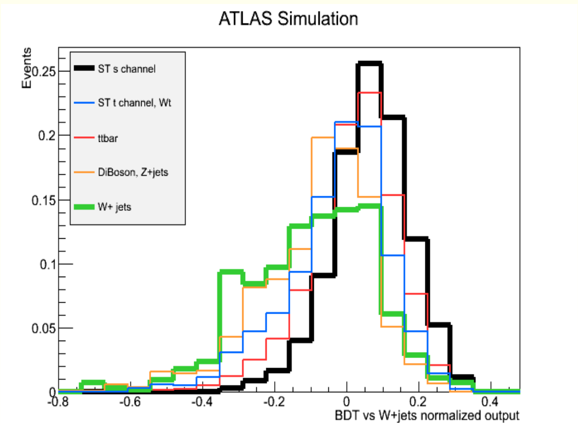
Theoretical prediction & Monte Carlo simulation

N=εσL



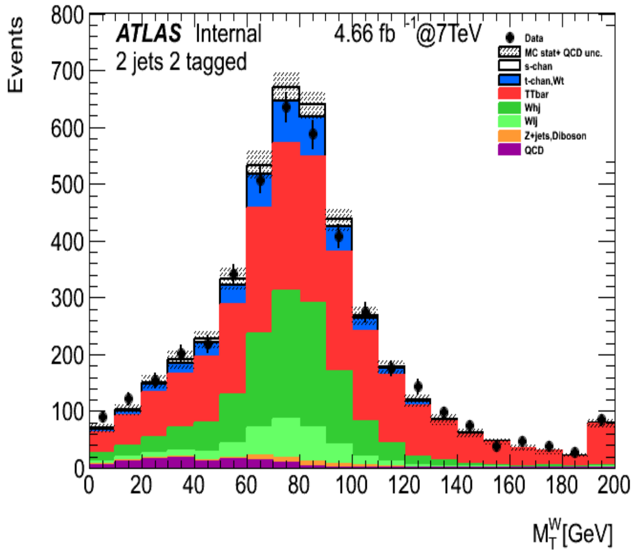
W+jets

- **Shape**: simulated events, at least 1 jet b-tagged
- **Normalization**: determined by fitting the Boosted Decision Tree output distribution in a control region (high W+jets purity)
- **Expected yields**: normalized to theory



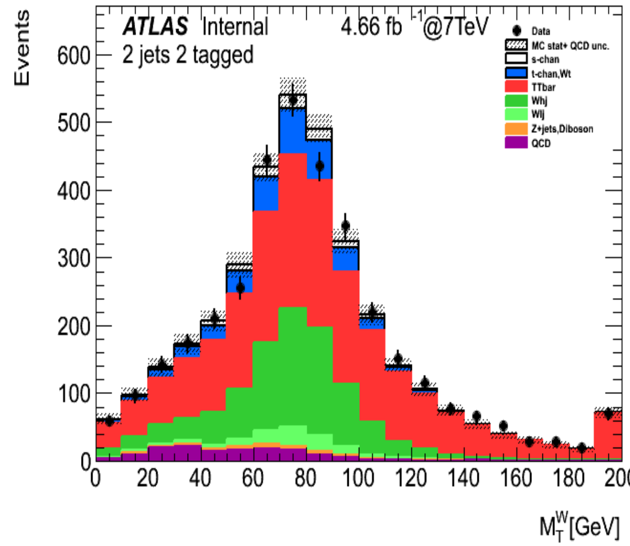
Preselected event yields

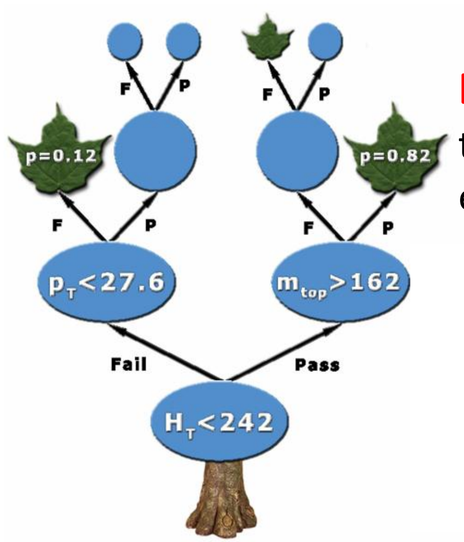
Muons



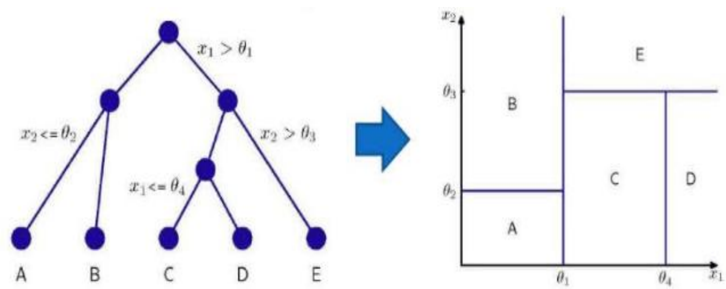
Channel	2-tagged muon	2-tagged electron
s channel	108 ± 1	90 ± 1
t channel	324 ± 4	279 ± 4
Wt	99 ± 3	84 ± 3
$t\bar{t}$	2162 ± 10	1884 ± 8
Wlight	168 ± 28	75 ± 14
Wbb	349 ± 16	291 ± 14
Wcc	104 ± 9	80 ± 8
Wc	147 ± 12	141 ± 12
Z+jets	15 ± 3	12 ± 2
Diboson	38 ± 1	33 ± 1
QCD	96 ± 19	137± 69
Total prediction	3610 ± 42	3016 ± 74
Data	4279	3526
$S/\sqrt{(B)}$	1.83	1.64
S/B	3 %	3%

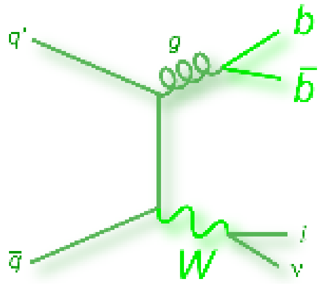
Electrons



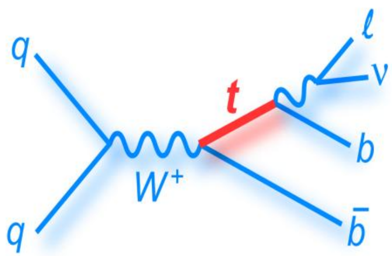


Boosted Decision Trees (BDT) classify events according to multiple cuts that define many regions in phase space, each one corresponding to a distinct signal purity.

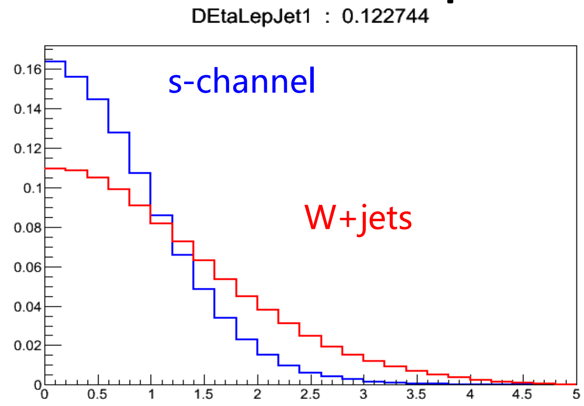


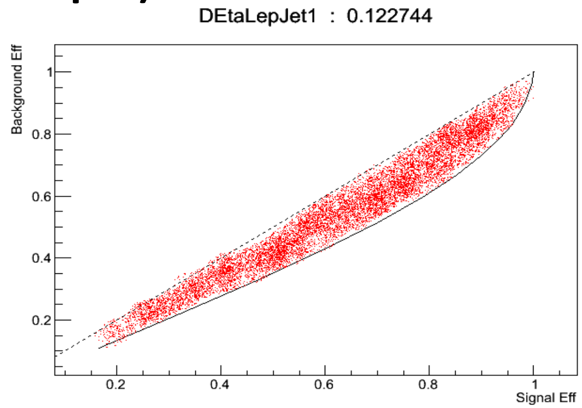


W+jets discrimination



1) Choice of the variables with separating power >0.05 (BDT input)

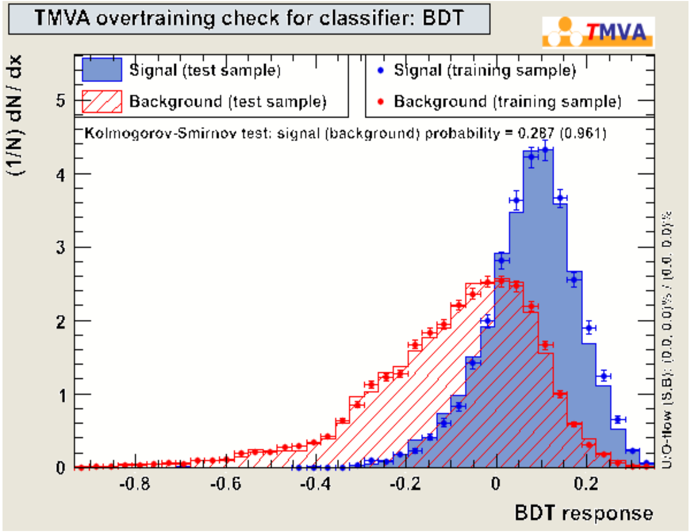


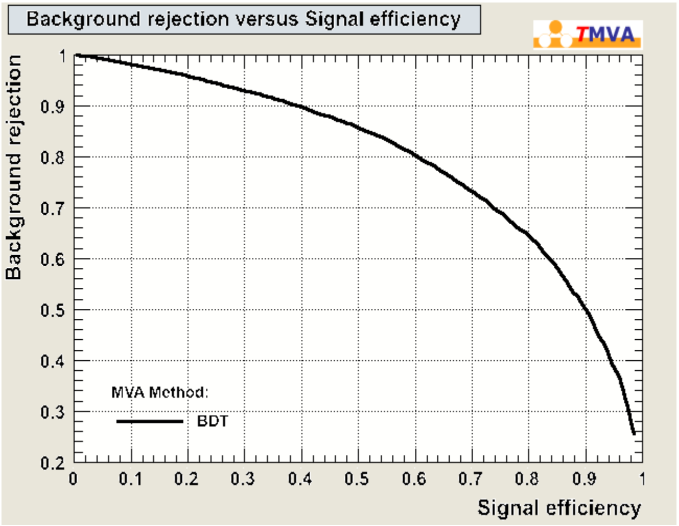


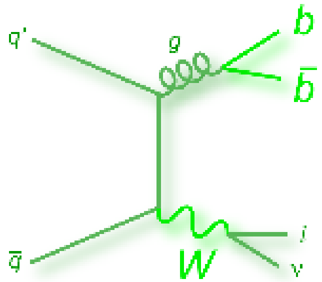
2) Classifier training

A subsample of events is used to build the algorithm

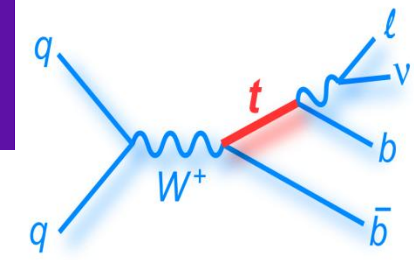
Optimization of the BDT configuration







W+jets discrimination

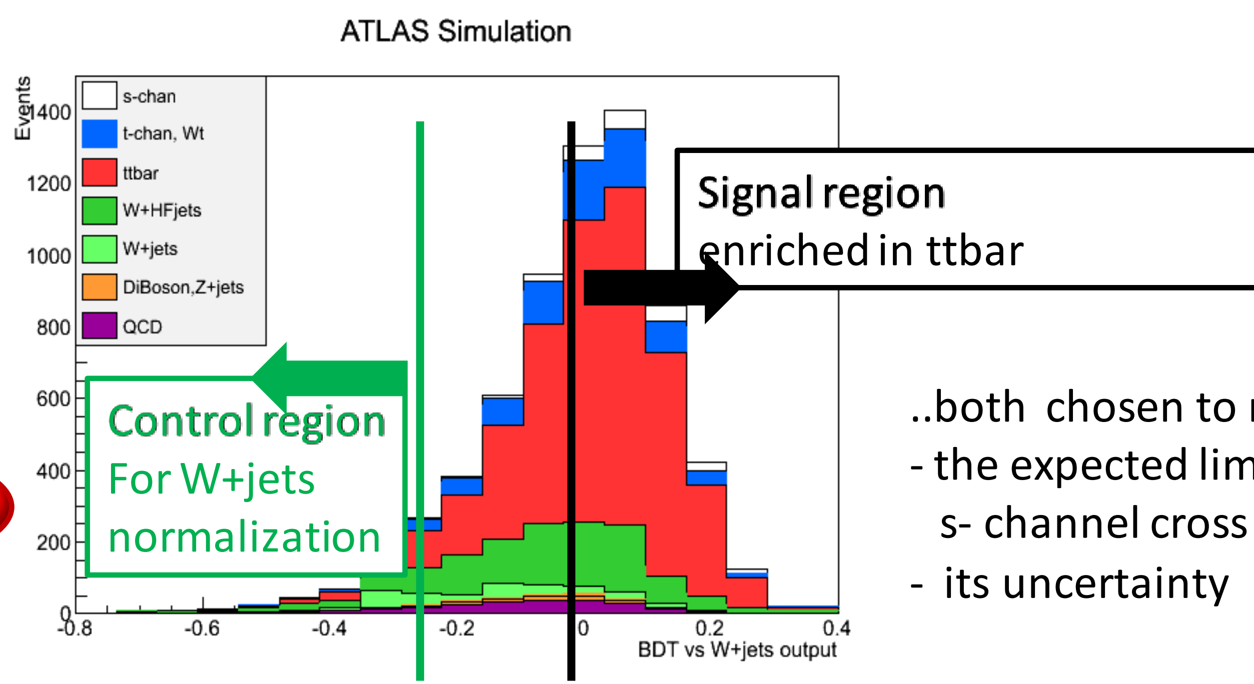


1) **Choice of the variables with separating power >0.05 (BDT input)**

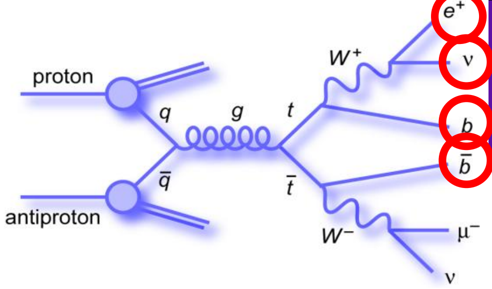
2) **Classifier training**
   A subsample of events is used to build the algorithm
   Optimization of the BDT configuration

3) **BDT testing**
   The algorithm is applied to all the MC channels and data

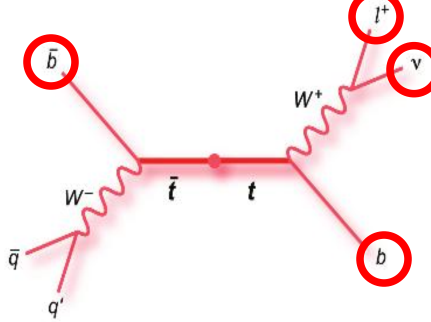
1) CUT



..both chosen to minimize:
- the expected limit on s- channel cross section
- its uncertainty



ttbar discrimination



1) **Choice of the variables with separating power >0.05 (BDT input)**

2) **BDT training**

A subsample of events (s-channel and ttbar double b-tagged) is used to build the algorithm, and optimize the BDT features

3) **BDT testing**

The algorithm is applied to all the MC channels and data

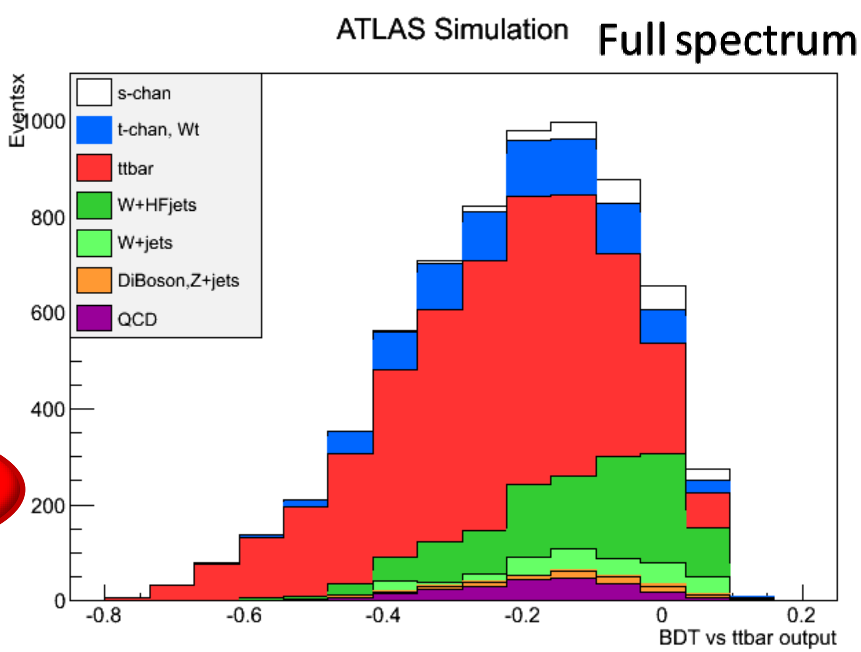
4) **Fit this distribution**

Strategy : exploit cuts on BDT vs W+jets classifier to perform a simultaneous fit on BDT vs tt distribution

- signal region -> cross section limit setting
- W+jets enriched -> normalization determination control region

2) FIT

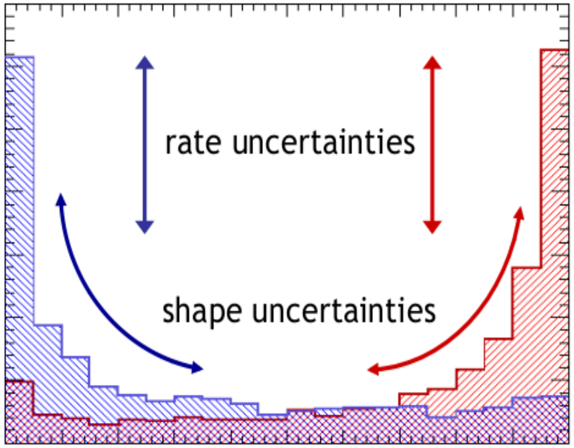
Full spectrum



Modeling systematic uncertainties

Systematic uncertainties connected to:

- Luminosity
- Cross section (theory/ data driven normalization)
- Simulation models bias (generator, parton shower, parton density functions, initial/final state radiation)
- Instrumental bias (jet energy scale, resolution, reconstruction, b-tag, lepton identification...)



... affect the XS measurement by varying:

Rates: predicted number of events of a certain process in a specific channel

Shapes of the normalized template histogram

Frequentist method: ensemble of pseudo-experiments including these variations (that represents our *a-priori* knowledge of nature) + maximum likelihood fit

$$L(\beta_1, \ldots, \beta_A) = \prod_{k=1}^{B} \frac{e^{-\mu_k} \cdot \mu_k^{n_k}}{n_k!} \cdot \prod_{j=2}^{A} G(\beta_j; \Delta_j)$$

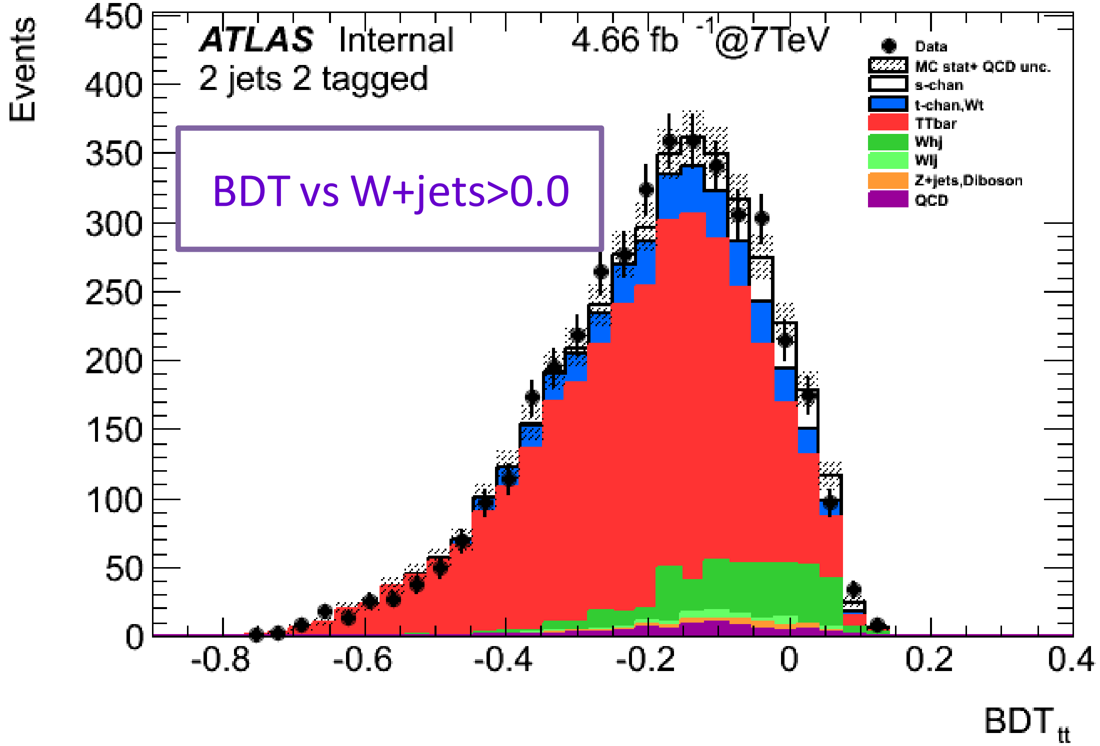
product of Poisson likelihoods for each bin

Gaussian constraints on the background cross sections

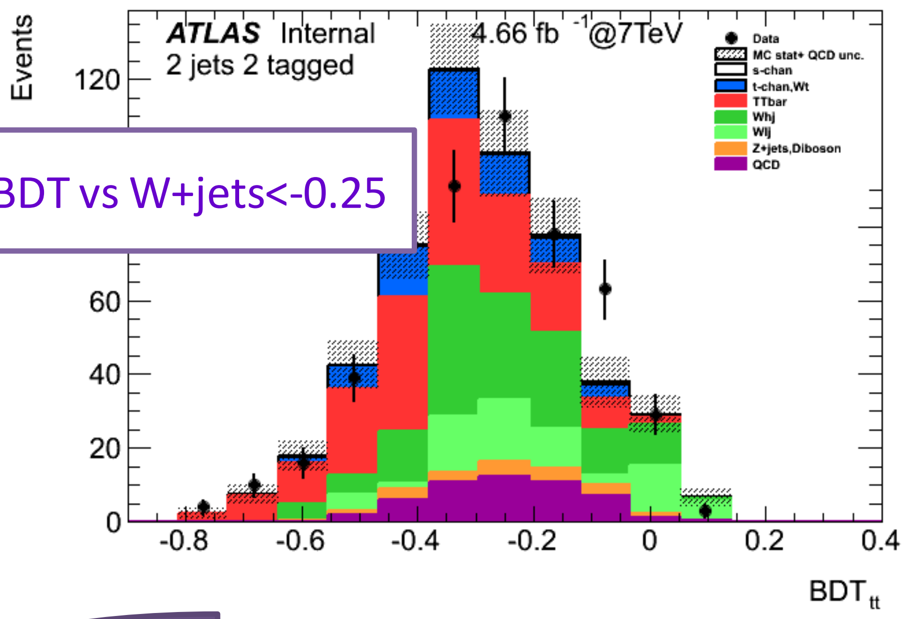
$$\beta = \frac{\sigma_{obs}}{\sigma_{SM}}$$

Fit the classifier distribution to the data

Signal region -> assess signal cross section (huge ttbar contribution)



Control region -> determine W+jets normalization



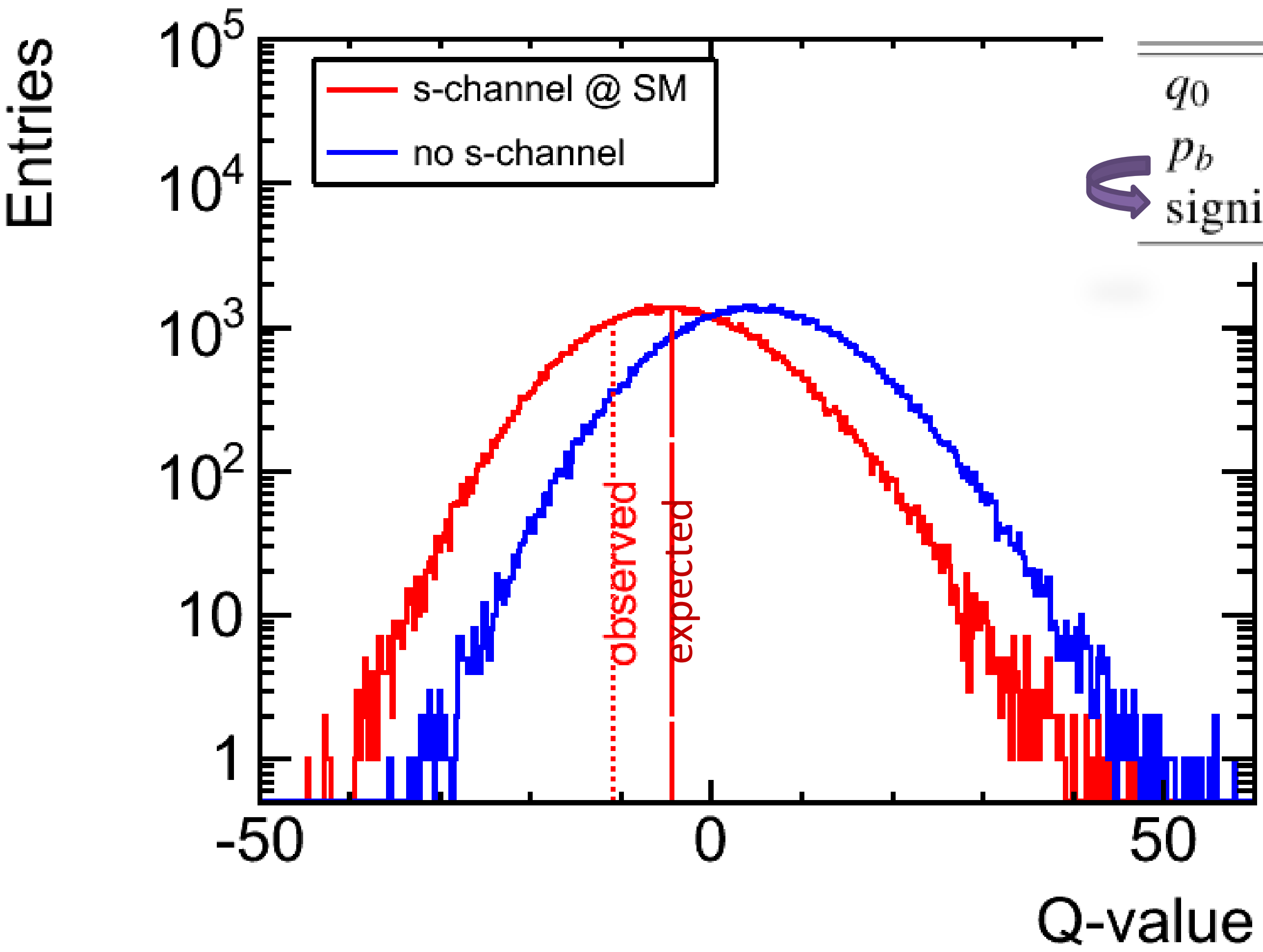
Simultaneous fit:
Observed scale factors to rescale all the processes

$$\beta = \frac{\sigma_{obs}}{\sigma_{SM}}$$

Channels	β
STs	1.59 ± 0.45
STt	1.04 ± 0.10
Wt	1.00 ± 0.08
TTbar	1.22 ± 0.03
Wjets	0.86 ± 0.09
QCD	1.00 ± 0.00
Zjets+DiBoson	1.18 ± 0.39

Cross section limit and significance

Significance:



	Expected	Observed
q_0	-4.4	-11.0
p_b	$1.62 * 10^{-1}$	$4.51 * 10^{-2}$
significance	1.4 σ	2 σ

Observed upper limit at 95% CL:

$\sigma_s \leq 3.5\ \sigma_{SM}$= 16.25 pb

(previous unique result: 26.5 pb)

Conclusions and future plans

- We analyzed the s-channel final state for the whole ATLAS 7 TeV dataset
- We built two classifiers to discriminate against the main backgrounds:
  - BDT vs W+jets:
    - -> control region (aiming at W+jets normalization)
    - -> signal region
  - BDT vs ttbar: fit of the output distribution
- We set an upper limit on the single top s-channel cross section that improves the previous result!

..but still lot of work has to be done!

Perspectives for the future:

- Use new prescription for the b-tagger working point
- Include 1jet bin to constrain W+jets in the fit
- Include 3jets bin to constrain ttbar in the fit
- Re-optimize the 7 TeV analysis and then switch to 8 TeV

Backup slides

Input variables for BDT vs W+jets

Table 10: Separation Power against W+jets

Variable	Separation power	Definition
$m(Top\_j2\nu l)$	0.056	Top mass computed by using the second jet and the leptons to reconstruct the top quark
$p_T(l, j2)$	0.057	p_T of the system composed by the lepton and the second jet
$cos\theta(Top\_j2\nu l)$	0.057	Top spin correlation in helicity basis [1]
$\Delta\Phi(j1, \nu)$	0.062	$\Delta\Phi$ between the leading jet and the neutrino
$E_T(l)$	0.062	Transverse energy of the lepton
$\Delta\eta(j1, j2)$	0.063	$\Delta\eta$ between the leading the second jet
H_T	0.070	Scalar sum of the p_T of the selected jets, lepton and neutrino
E_T^{miss}	0.071	Transverse missing energy
$P_T(l, j1)$	0.073	p_T of the system composed by the lepton and the leading jet
$\Delta\eta(t1, j2)$	0.074	$\Delta\eta$ between the top quark and the leading jet
$\Delta\Phi(l, \nu)$	0.078	$\Delta\Phi$ between the lepton and the neutrino
$E(j2)$	0.078	Second jet energy
$Whelicity\_j2\nu l$	0.079	W helicity from the top quark (reconstructed through the second jet) decay [2]
$\Delta\eta(t2, j1)$	0.083	$\Delta\eta$ between the leading jet and the top quark
$p_T(Top\_j2\nu l)$	0.085	p_T of the top quark reconstructed through the second jet
$\Delta R(l, j1)$	0.086	ΔR between the leading jet and the lepton
$p_T(Top\_j1\nu l)$	0.090	p_T of the top quark reconstructed through the leading jet
$p_T(j1)$	0.093	Leading jet p_T
$p_T(j2)$	0.096	Second jet p_T
$Ht(j1, j2)$	0.101	Scalar sum of the p_T of the jets
$Whelicity\_j1\nu l$	0.117	W helicity from the top quark (reconstructed through the leading jet) decay
$\Delta\eta(l, j1)$	0.122	$\Delta\eta$ between the lepton and the leading jet

Input variables for BDT vs ttbar

Table 17: Separation Power against tt

Variable	Separation power	Definition
$p_T(l, j2)$	0.052	p_T of the system composed by the lepton and the second jet
$p_T(Top\_j2\nu l)$	0.054	p_T of the top quark reconstructed through the second jet
$p_T(l, j1)$	0.062	p_T of the system composed by the lepton and the leading jet
$p_T(j1)$	0.066	Leading jet p_T
$\eta(l, j2)$	0.066	Pseudorapidity of the system constituted by the second jet and the lepton
$p_T(j2)$	0.067	Second jet p_T
$\eta(l, j1)$	0.069	Pseudorapidity of the system constituted by the leading jet and the lepton
$p_T(l)$	0.070	Leptonp_T
$m(l, j1, j2)$	0.071	Mass of the system composed by the two jets and the lepton
$m(l, j2)$	0.073	Mass of the system composed by the second jet and the lepton
$p_T(j1, j2)$	0.074	p_T of the system composed by the two jets
$m(Top\_j1\nu l)$	0.075	Top mass computed by using the leading jet and the leptons to reconstruct the top quark
$p_T(Top\_j1\nu l)$	0.080	p_T of the top quark reconstructed through the leading jet
$m(l, \nu, j1, j2)$	0.084	Mass of the system composed by all the final particles
$m(Top\_j2\nu l)$	0.088	Mass of the top quark reconstructed through the sub-leading jet and the leptons
$H_T(j1, j2)$	0.088	The scalar sum of the p_T of the selected jets
H_T	0.090	Scalar sum of the p_T of the selected jets, lepton and neutrino
$M_T(W)$	0.102	Transverse mass of the W boson
$\Delta\Phi(t1, j2)$	0.118	$\Delta\Phi$ between the top quark and the second jet
$\Delta\Phi(t2, j1)$	0.119	$\Delta\Phi$ between the top quark and the leading jet
E_T^{miss}	0.141	Transverse missing energy
$p_T(l) + E_T^{miss}$	0.162	Sum of the lepton p_T and of the transverse missing energy
$p_T(l, \nu, j1, j2)$	0.164	p_T of the system composed by all the final particles

Analysis optimization↔ systematic uncertainties

How systematic uncertainties affect our choice of the signal/control regions?

➡ Check several combinations of cuts in order to minimize the expected cross section limit and its uncertainty

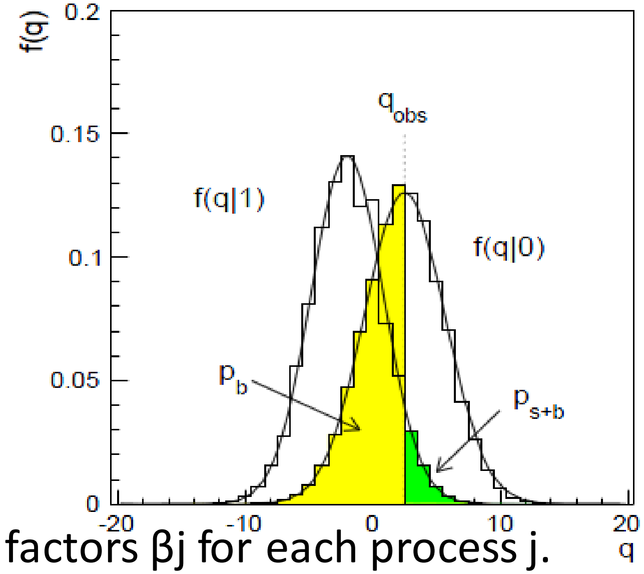
- I) Test statistics:
  Q value distribution generated with pseudoexperiments

  for background only hypothesis: $q_0 = -2ln\frac{\mathcal{L}(B|S+B)}{\mathcal{L}(B|B)}$

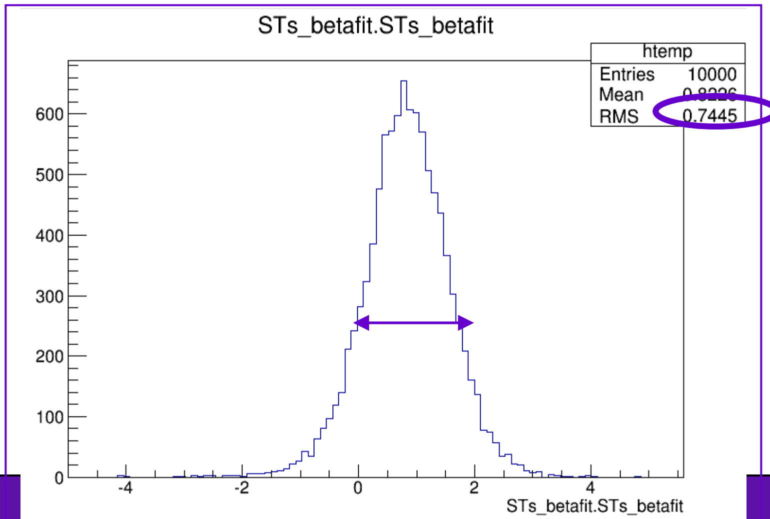
  for signal + background hypothesis: $q_1 = -2ln\frac{\mathcal{L}(S+B|S+B)}{\mathcal{L}(S+B|B)}$

  II) CLs expected limit (replacing q_{obs} with q_0)

  $CL_s = \frac{CL_{s+b}}{C_b} = \frac{p_{s+b}}{1-p_b} = 5\%$ has to be minimized



- For each pseudo experiment we fit the distribution to obtain the scale factors βj for each process j. The RMS of β signal is an estimator of the (expected) uncertainty of our measurement

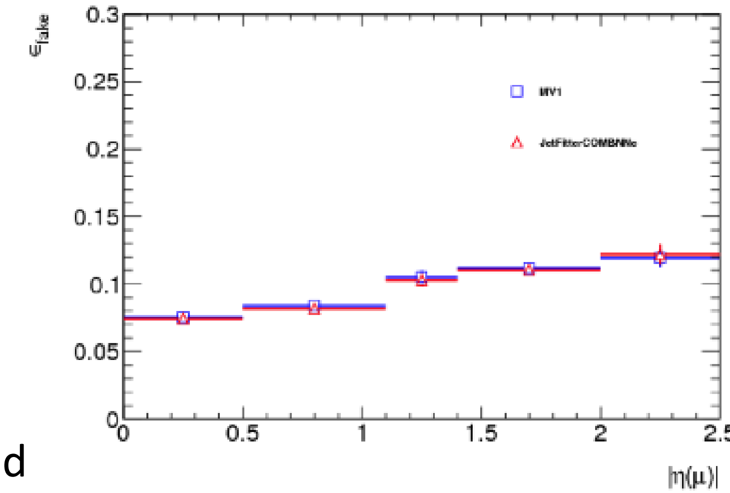


QCD ESTIMATE

MATRIX METHOD for muons

$$N^{\text{tight,loose}} = N^{\text{tight,loose}}_{\text{fake}} + N^{\text{tight,loose}}_{\text{real}}$$

$$N^{\text{tight}}_{\text{fake,real}} = \epsilon_{\text{fake,real}} \cdot N^{\text{loose}}_{\text{fake,real}}$$



- Loose: relaxed isolation
- Real efficiencies: tag and probe
- Fake efficiencies: from low Mt(W) and high d0-significance regions
- Uncertainties: should cover data/MC disagreement in QCD enriched control regions-> 50%

JET-ELECTRON MODEL for electrons

- Dijet MC sample, events with 1 jet faking 1 electron
  (same pT threshold and η acceptance as a signal electron, 80-95% of its energy deposited in the electromagnetic calorimeter, and at least 4 tracks to reduce the contributions from converted photons) .
- Binned likelihood fit of observed MET in a sideband (MET<30 GeV)
- Uncertainties: pile-up studies, fit of less sensitive variables… -> 50%

Pseudo experiments

1. For each process *j* (single top, $t\bar{t}$ ...) we have a prediction of the expectation value: $\widetilde{\nu}_j$

   Uncertainties on the cross sections are included by varying $\widetilde{\nu}_j$ according to a random number β_j^{gen} thrown from a log normal distribution

2. The acceptance uncertainties $\varepsilon_{i,j-}$ and $\varepsilon_{i,j+}$ are included by varying the expectation values accordingly for all systematic uncertainties S: Gaussian distributed random number δ_i for each process i using a mean of zero and a width of one.

$$\nu_j^{gen} = \widetilde{\nu}_j \cdot \beta_j^{gen} \cdot \left\{ 1 + \sum_{i=1}^{S} |\delta_i| \cdot (H(\delta_i) \cdot \epsilon_{i,j+} + H(-\delta_i) \cdot \epsilon_{i,j-}) \right\}$$

nuisance parameter specifying the strength of the systematic excursion

(Correlations across channels are taken into account since the same δ_i is used for all of them)

3. Interpolation between different shape histograms (relative change of the template in the different bins)

$$\alpha_{jk}^{gen} = \alpha_{jk} + \sum_{i=1}^{S} |\delta_i| \cdot \left\{ (\alpha_{jki}^{+} - \alpha_{jk}) \cdot H(\delta_i) + \cdot (\alpha_{jki}^{-} - \alpha_{jk}) \cdot H(-\delta_i) \right\}$$

Likelihood function

$$L(\beta_1, \ldots, \beta_A) = \prod_{k=1}^{B} \frac{e^{-\mu_k} \cdot \mu_k^{n_k}}{n_k!} \cdot \prod_{j=2}^{A} G(\beta_j; \Delta_j)$$

- β_1 = relative signal cross section normalized to the prediction (scale factor)
- β_2 to β_A = relative background cross sections (rates) normalized to the prediction, enter as nuisance parameters = fit parameters
- A = number of considered processes
- k = bin index
- μ_k = predicted expectation value of the number of events in bin k, includes signal and background events
- n_k = observed number of events in bin k
- B = number of bins

$$G(\beta_j, \Delta_j) = \exp\left(-\frac{1}{2}\left(\frac{\beta_j - 1}{\Delta_j}\right)^2\right)$$

Breakdown of systematic uncertainties

Process: STs

SysName	up[%]	down[%]
Data stat.	42.100	-42.100
ctag	4.853	-4.782
mu_smeared_MS	5.203	-5.203
pileup	8.867	-6.676
JVF	6.801	-6.783
iqopt3	7.322	-7.263
jet_goodReco	7.709	-7.658
lep_SF	8.073	-8.073
ptjmin10	8.238	-8.225
outsoft	9.001	-9.704
ISR_FSR	9.219	-9.148
jet_smeared_syst	9.149	-9.729
jet_scaled	10.476	-10.430
el_smeared	10.771	-10.783
xsection	11.294	-11.212
el_scaled	14.225	-15.637
ps	15.296	-15.286
ttgen	15.527	-17.394
mistag	17.636	-17.773
mu_smeared_ID	21.156	-21.258
mcstat	32.757	-32.757
btag	40.679	-40.588
Total(sys)	61.409	-63.921
Total(sys+stat)	74.455	-76.539

Beyond standard model

Extra gauge bosons
- Inspired by GUT
-Predict W' *coupled to top quark*

→ increase s-channel
~no impact in t- nor Wt channel

Extra scalar bosons
- *Top color assisted* technicolor
- Predict new scalars as bound fermionic states
(tb) pseudoscalar top-pion

→ increase s-channel
~no impact in t- nor tW channel

Fourth generation
- Fourth quark family (t',b') models
- with extended CKM matrix

→ increase t-channel (via PDF s)
decrease s-channel (via smaller V_{tb})

FCNC
-New couplings beyond EW scale via FCNC
(Ztc, γtc, gtc, Ztu,…)

→ increase t- and Wt- channel
~no impact in s-channel