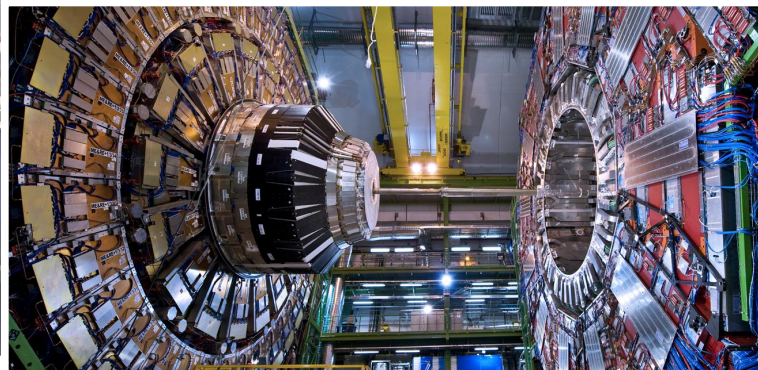
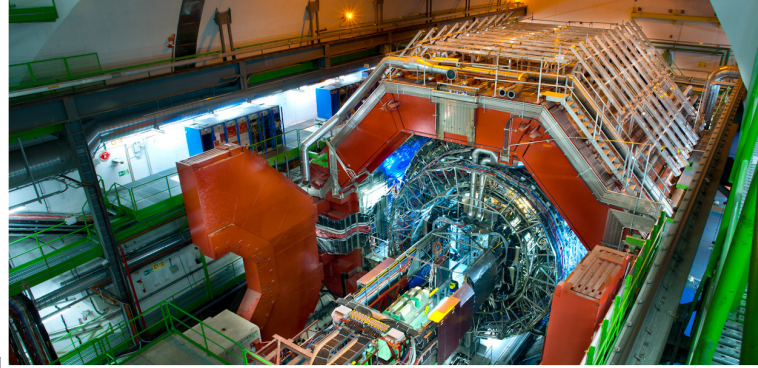
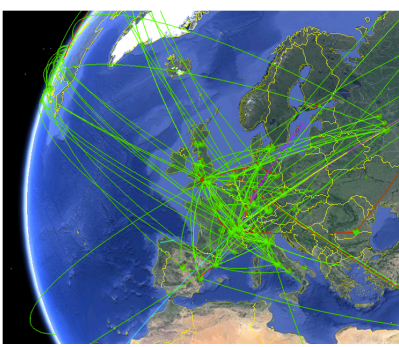
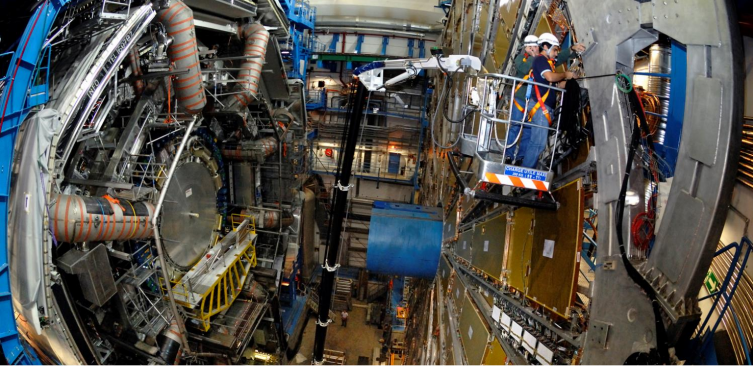




LHC Results... and how we get them

Sabine Crépe-Renaudin



MENU

Why? How? And the results

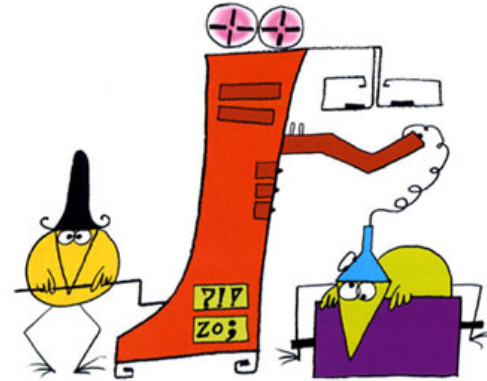
The LHC and the related experiments is a wide subject... I had to make some choices :

- Why have we built the LHC ?
- How all this complex experimental setup works ?
 - The LHC collider
 - The experiments
 - The computing
- How physicists get their results ?
- What are the main results from the ATLAS/CMS experiments

Apologize for a biased view:

- Working on the ATLAS experiment, I will mainly concentrate in ATLAS and CMS results not that ALICE and LHCb results are less interesting !

This is not a formal presentation...
please ask/discuss and don't hesitate to interrupt

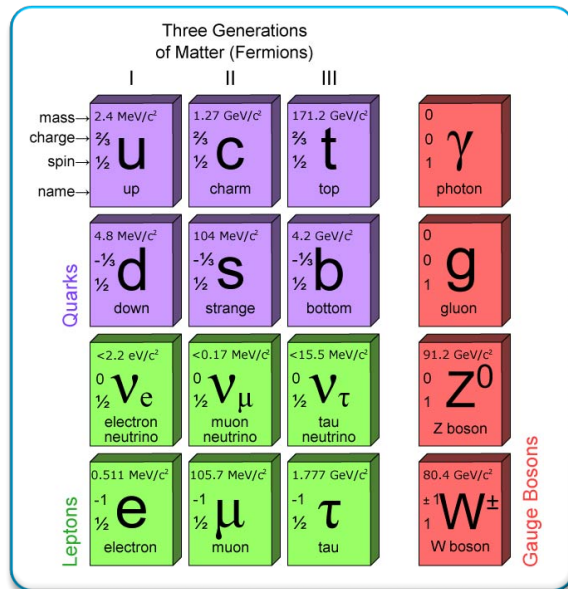


WHY ?

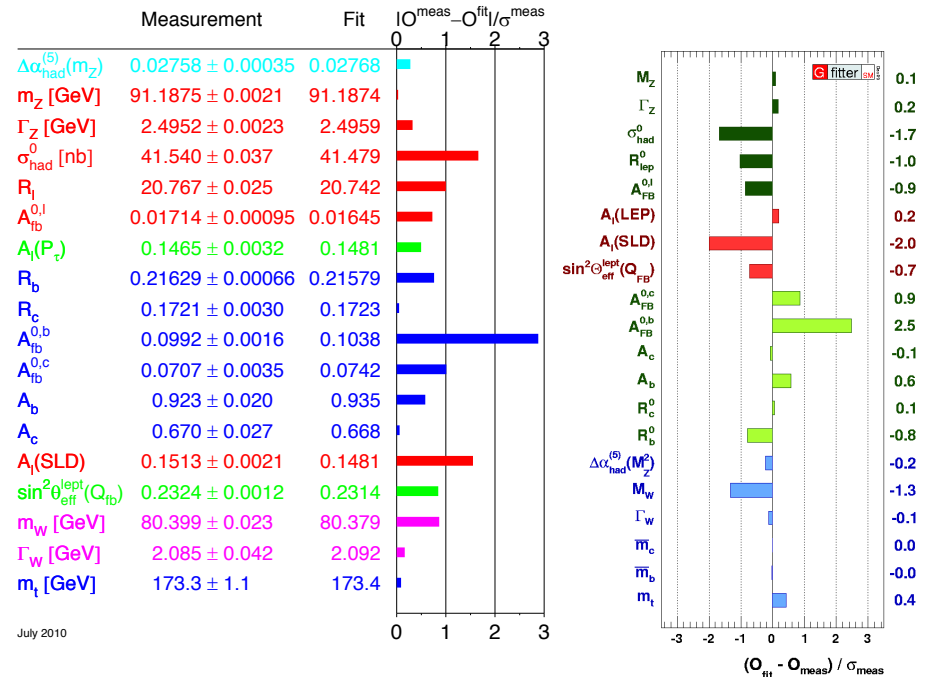
Particle physics before the LHC start

Standard Model

- Well established and comprehensive description of all known elementary particles and of 3 of the 4 fundamental interactions



Standard model parameters consistency with LEP and Tevatron measurements



<http://lepewwg.web.cern.ch/LEPEWWG/plots/summer2010/>
http://gfitter.desy.de/Standard_Model/2009_12_28_index.html

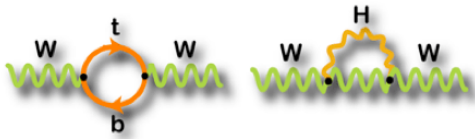
However...

- A lot of questions related to the matter
 - How these particles get their mass ? Higgs mechanism ???
 - What explains their mass hierarchy ? Why 3 families ?
 - Neutrino masses ?
 - What is the dark matter ???
 - Why don't we see as much anti-matter as matter in the universe ?
 - What was the matter state at the beginning of the universe ? Quarks-gluons plasma ?
- A lot of questions related to the interactions
 - Gravity is not included in the standard model. Can gravity be quantized ? Is there a theory that could include both the standard model and the gravity ?
 - Why gravity is so weak compared to other interactions ?
 - Is it possible to unify the interactions ?

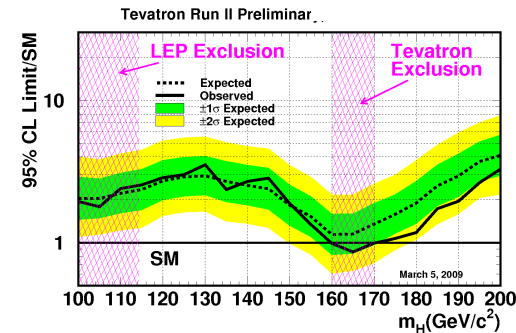
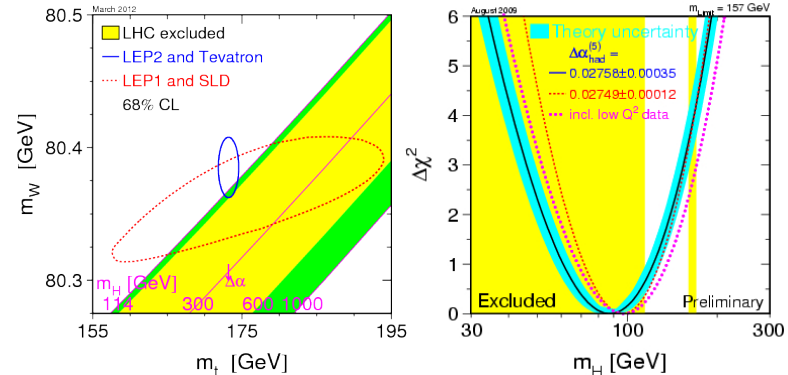
• ...

Possible answers... and possible observations

- Mass → Higgs mechanism, Brout Englert Higgs (BEH) boson (1964)
- Experimental status before LHC start



- Higgs search: LEP and Tevatron limits
→ if it exists, its mass is > 112 GeV and outside of 160-170 GeV

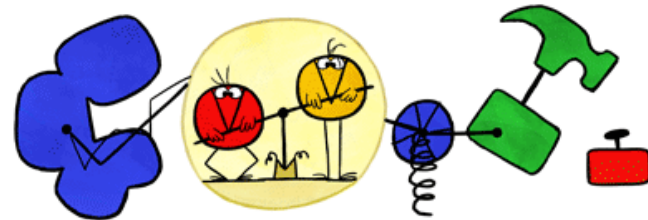


Possible answers... and possible observations

- Supersymmetry
 - Extra-dimensions
 - Compositeness
 - Higgs sector extensions
 -
- 
- New particles

LHC main goals:

- Find the Higgs or something else that should be below the TeV scale
- Search for new phenomena that can give hints on what is beyond the Standard Model



POURQUOI FAIRE SIMPLE QUAND ON PEUT FAIRE COMPLIQUÉ ?!

THE LHC AND THE EXPERIMENTS

Probing the heart of the matter

Principle:

- 1) Accelerate particles to give them a large amount of energy
- 2) Collide the particles
- 3) Look at the result

Particles: small topic to study

Big experiments

2 important parameters:

- Energy: the higher the energy, the higher the mass produced particles can have
- Luminosity: high luminosity gives access to rare processes

Important variables

Production process

- **Cross section σ** : the area transverse to the relative motion of particles within which they must meet in order to scatter from each other (! Not their transverse size) $\rightarrow$ a measure of the process production probability
 - Unity = barn = 10^{-28} m^2

Important LHC variables

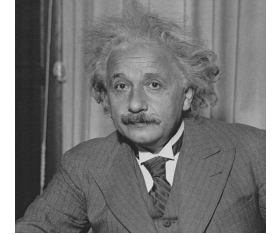
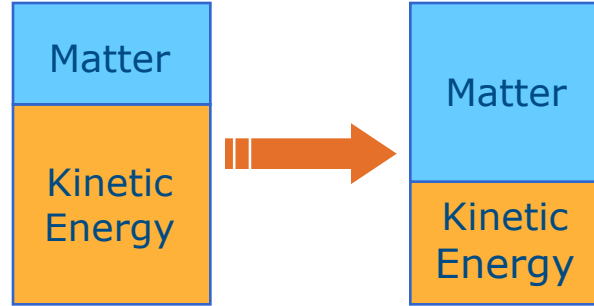
- **Energy**: collision energy = 2 times beam energy
- **Luminosity $\mathcal{L}$** $\rightarrow$ Number of produced particle $N = \sigma \mathcal{L} \rightarrow$ measures collider performance in term of collision number

Particles

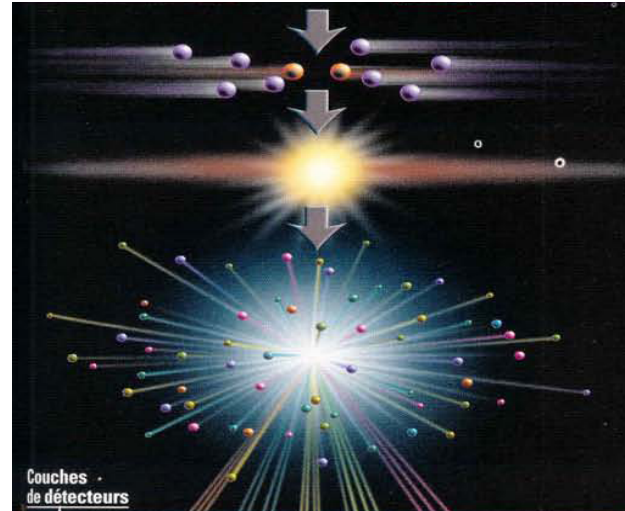
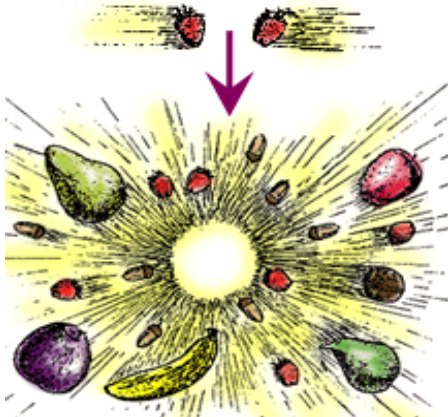
- **Energy momentum four-vector** : $P = (E, \mathbf{p})$ (natural units used $c=\hbar=1$)
- **Mass**: $m^2 = E^2 - \mathbf{p}^2$ ($m^2 = |\mathbf{P}|^2$)
- **Transverse variables**: no transverse energy in beams $\rightarrow \sum p_T = 0 \rightarrow$ using a lot transverse variables
 - **Missing transverse energy** is the transverse energy sum of all produced particles that are not detected either because they didn't interact with the detector or because detection inefficiency

Collide particles or the use of $E = mc^2$

Energy $\leftrightarrow$ Matter

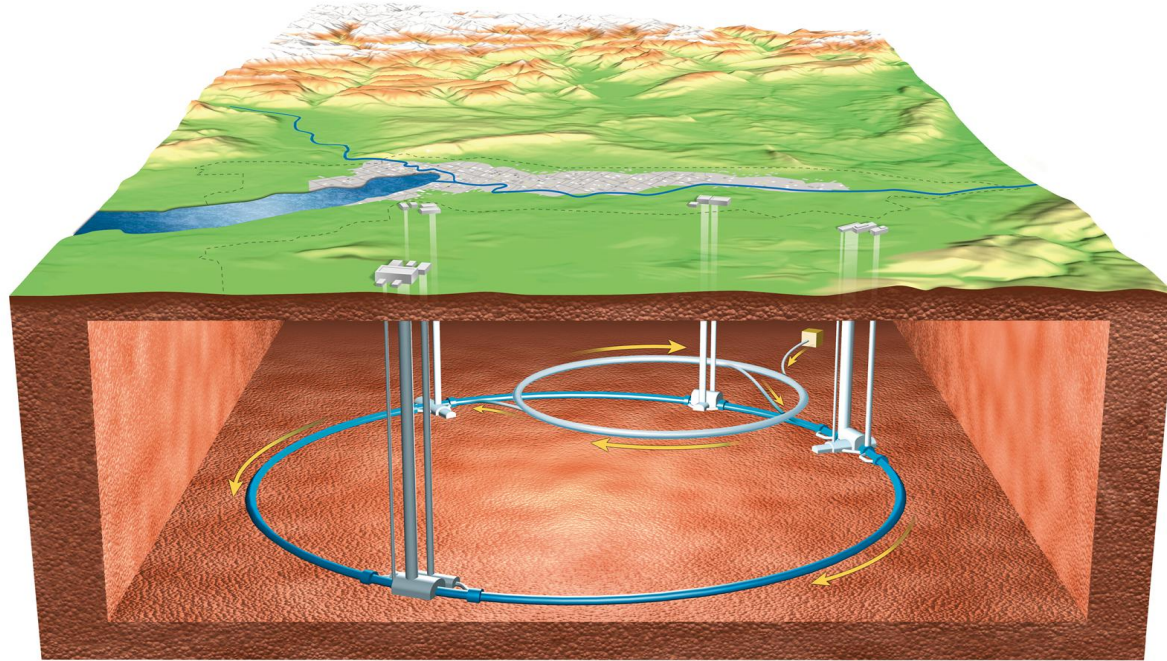


$$E^2 = m^2c^4 + p^2c^2$$

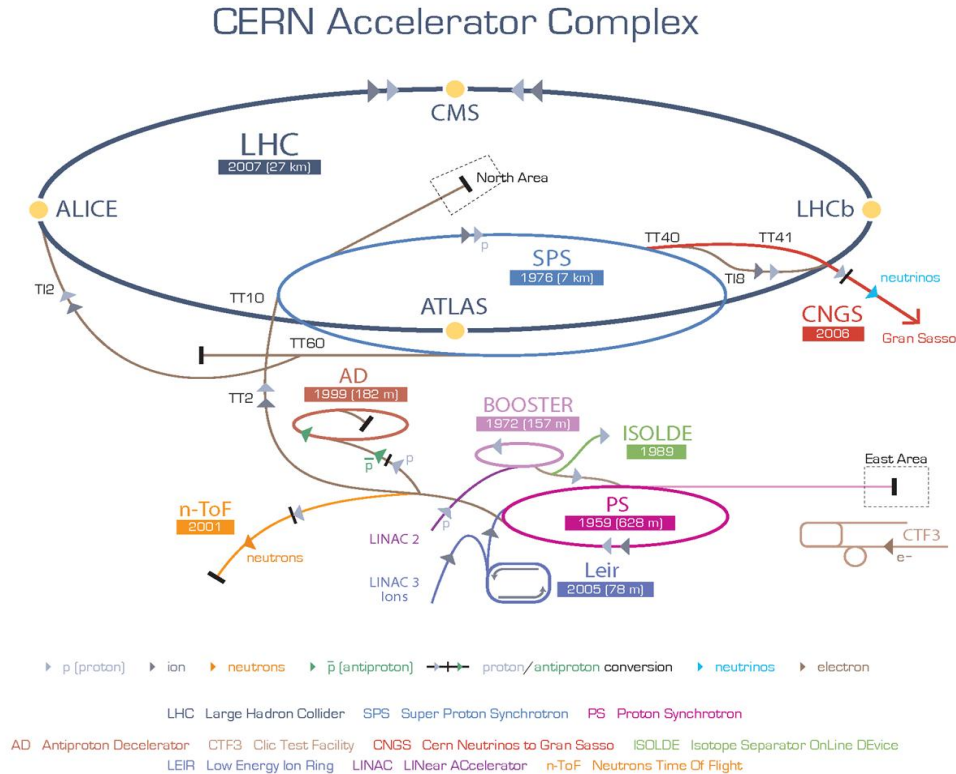


The LHC : Large Hadron Collider

- = 2 accelerators in a ring of 27 km length, at ≈ 100 m underground at the French-Swiss border
- = that collide hadrons (protons or lead ions) in 4 points where experiments register the collision products

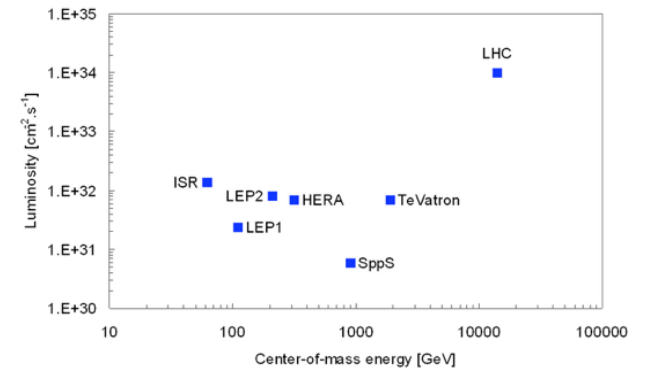
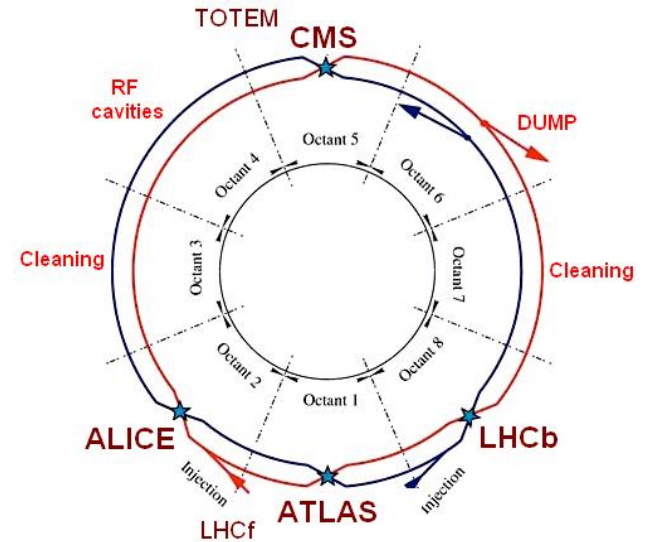
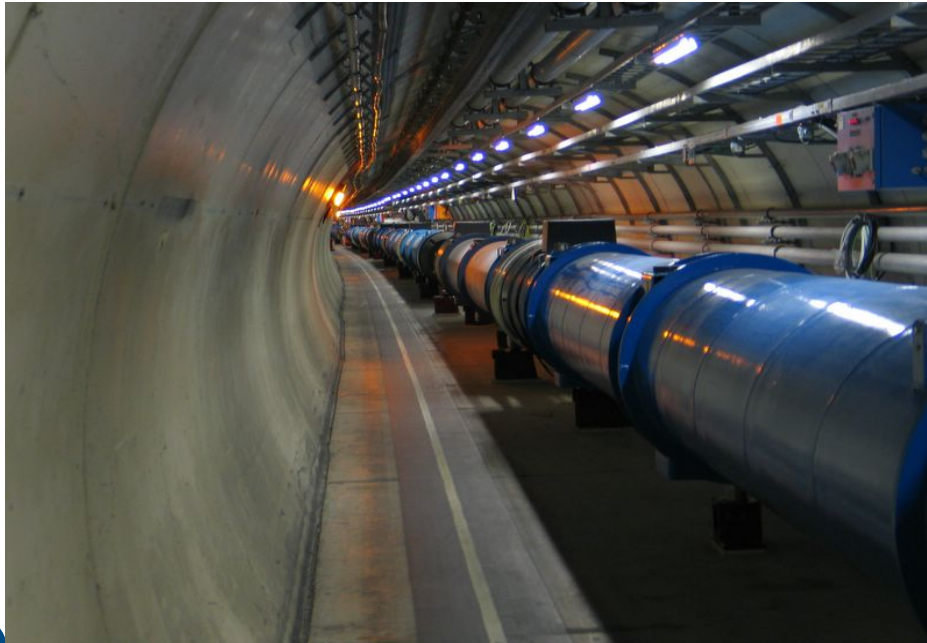


The CERN history at the service of the new challenges



The LHC

- 16 cavities for acceleration (8 per beam)
- 9600 magnets
 - 1200 dipoles to bend the beam
 - Quadrupoles, sextupoles, octupoles, decapole to focus the beam



The challenge: the dipoles

LHC beams have a circular trajectory

- It allows them to go several times through the same acceleration cavities
- It allows to collide beams: available energy in the collision = 2x beam energy

Nominal beam energy is 7 TeV ($7 \cdot 10^{12}$ eV)

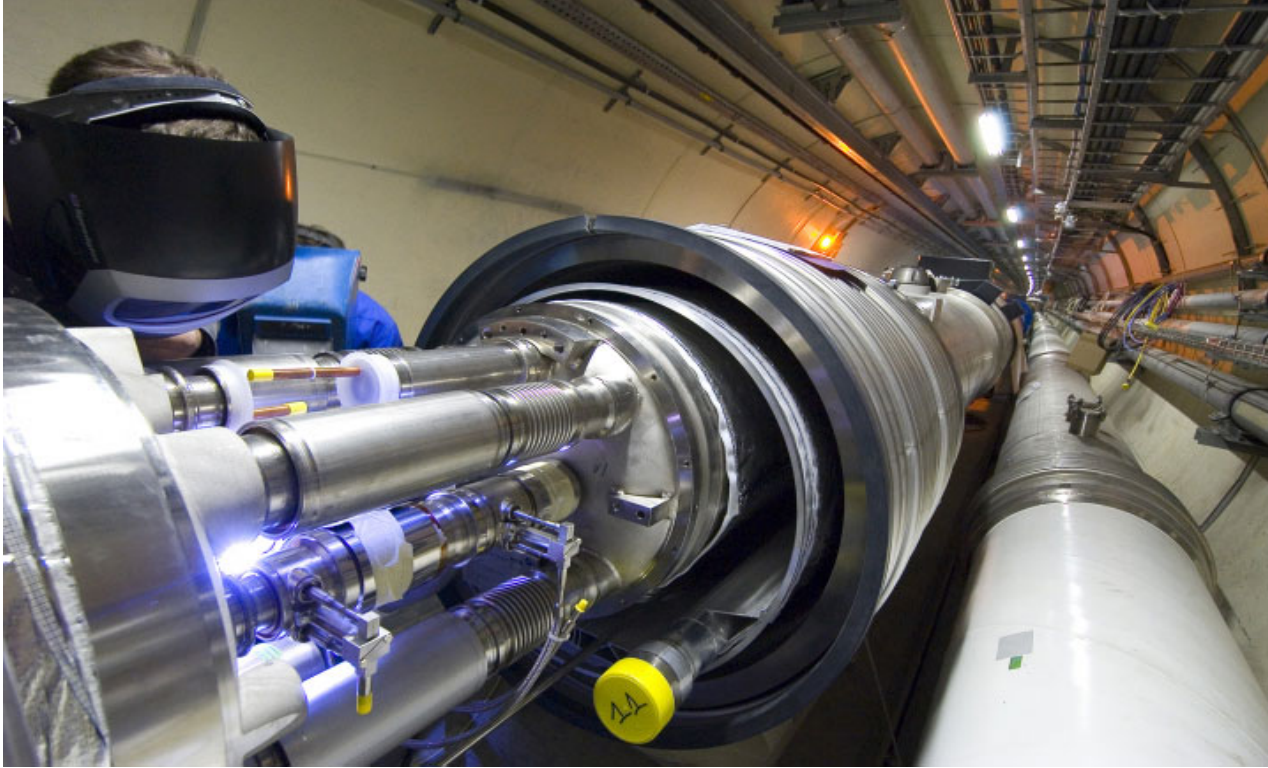
- To bend this beam superconducting magnets are needed

LHC dipoles

- Niobium-titanium cables, superconducting at 10K, operated at 1.9K with a current of 11 850 A
- Dipole field is 8.33 T



The machine of superlatives

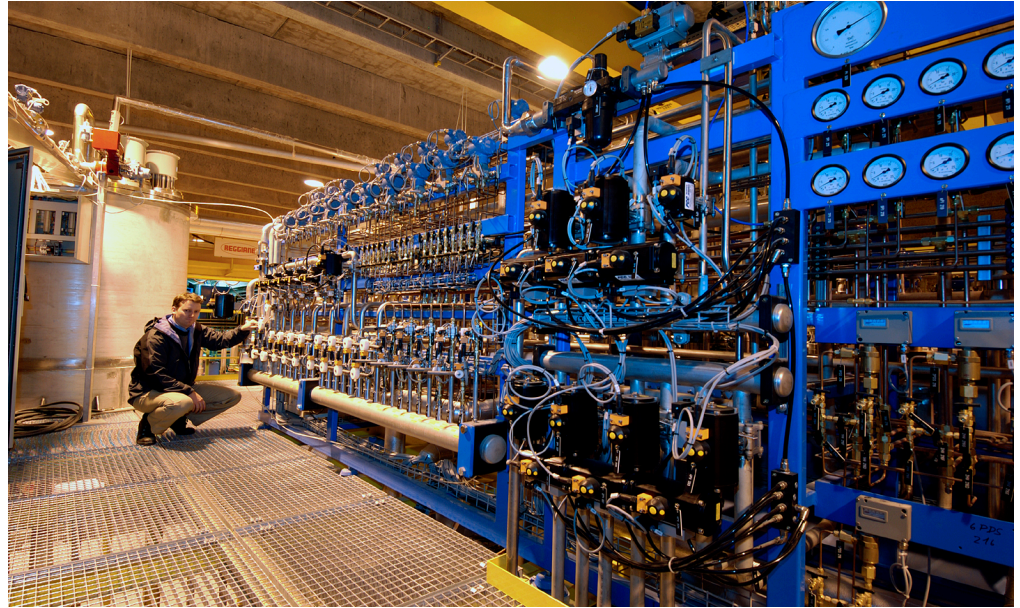


- Beams circulate in a vacuum of 10^{-13} atm
 - Ultrahigh vacuum ~ atmosphere of the moon
- Vacuum also used for insulation of cryomagnets and helium lines
 - 9000 m³ to pump down (10^{-9} atm) for cryomagnets,
 - 5000 m³ for helium lines

The machine of superlatives

The dipoles are cooled down with superfluid helium

→ Temperature $\approx 1,9\text{K}$, colder than space ($2,7\text{ K}$)



The machine of superlatives



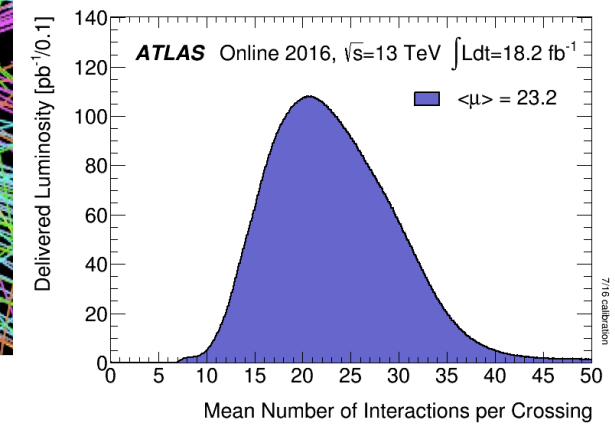
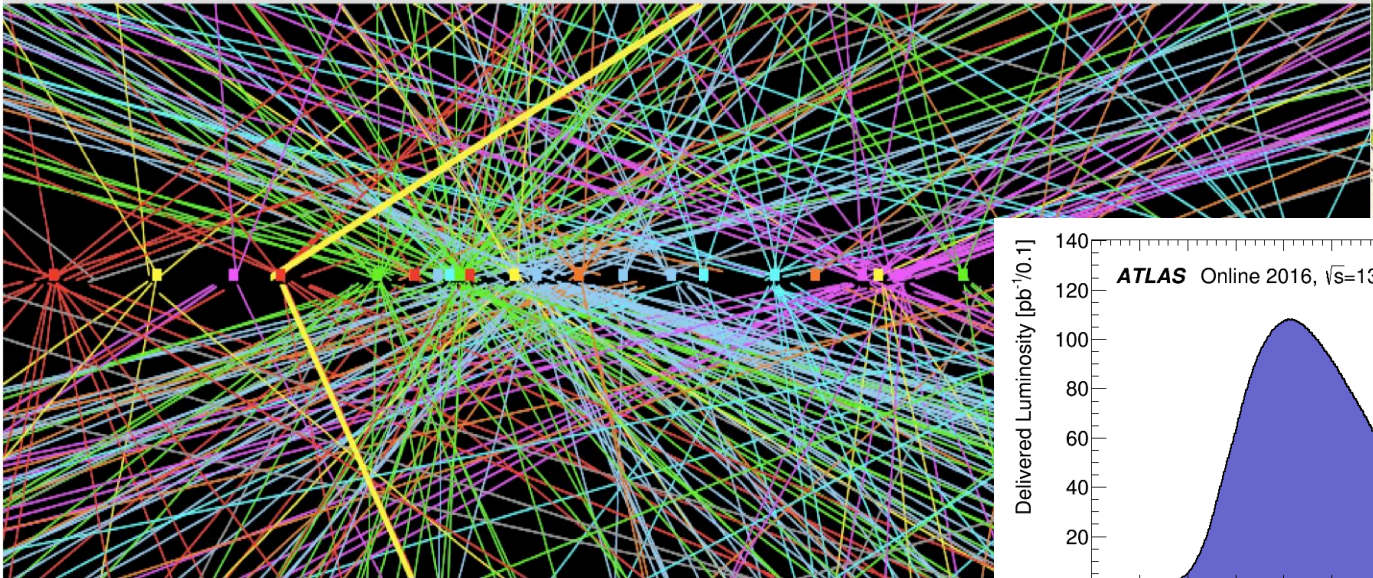
Beams are made of 2808 bunches of 10^{11} protons each

Protons travel around the LHC at 99,9999991% of c

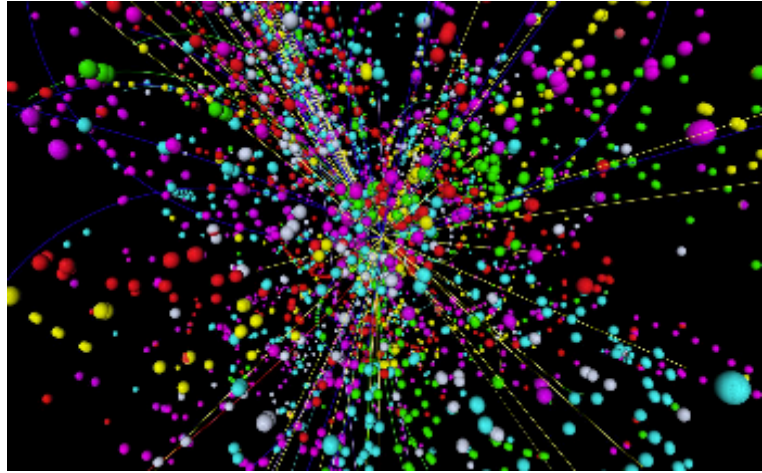
→ they do more than 11 000 LHC 27km turn/s and there is a collision every 25 ns

Collisions

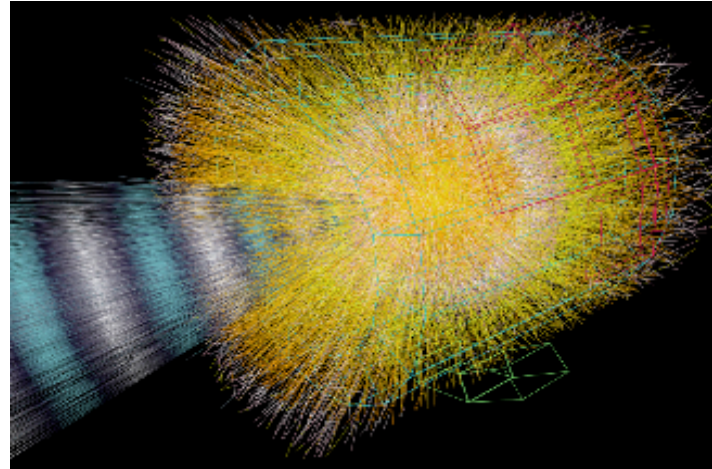
At each beam crossing, several proton collisions occur at the same time:
this is called the pile-up



Collisions



CMS



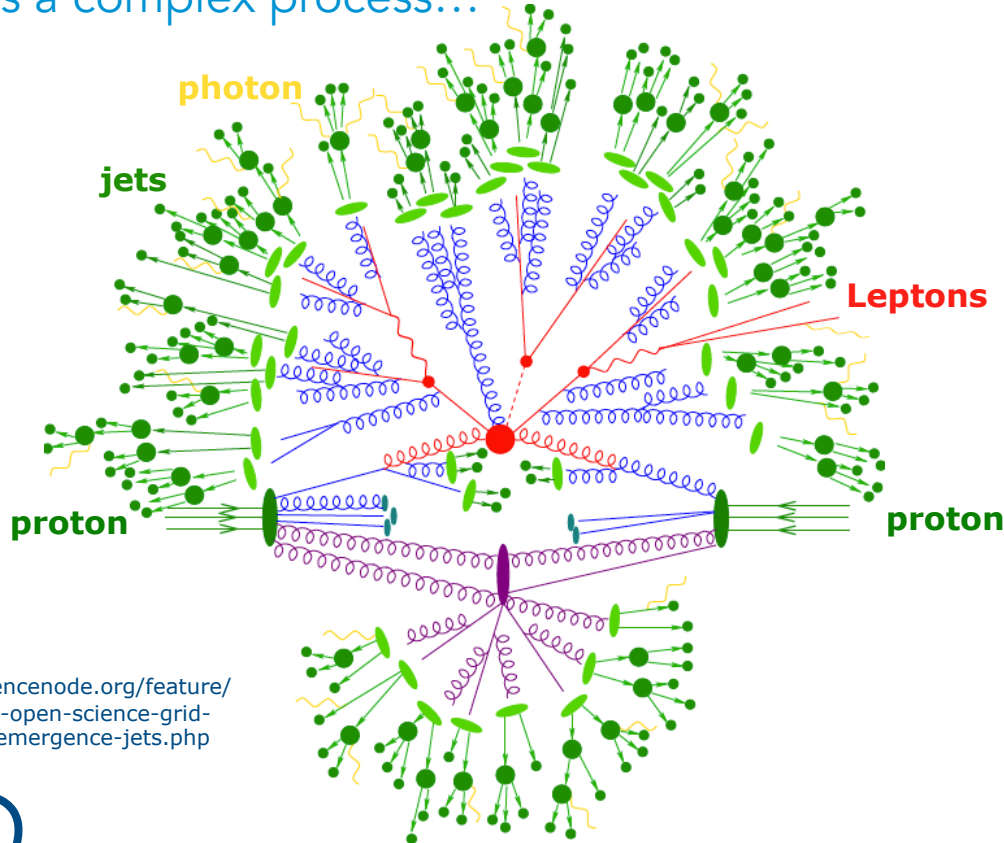
ALICE

Each hard proton collision produces hundreds of particles that we have to identify and measure (position, energy)

This has to be fast: there are 40 million collisions per second (1 every 25 ns)

Each collisions in reality

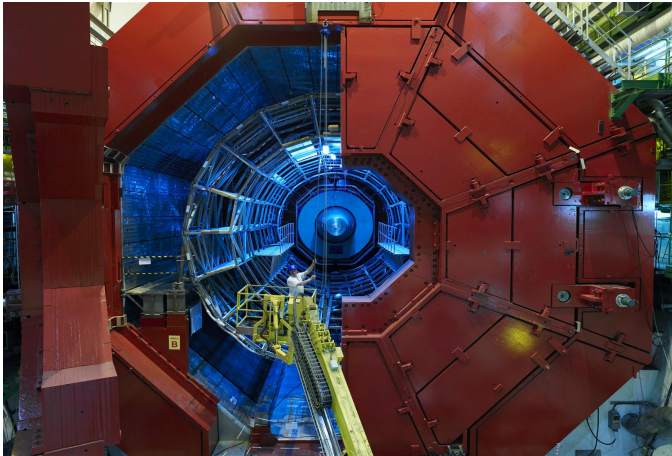
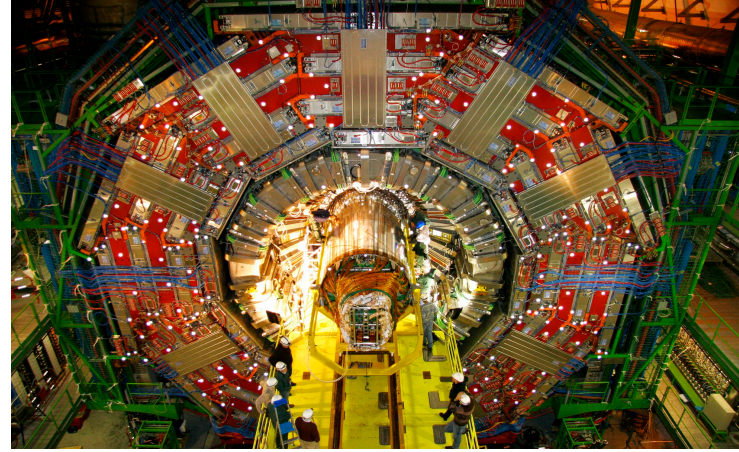
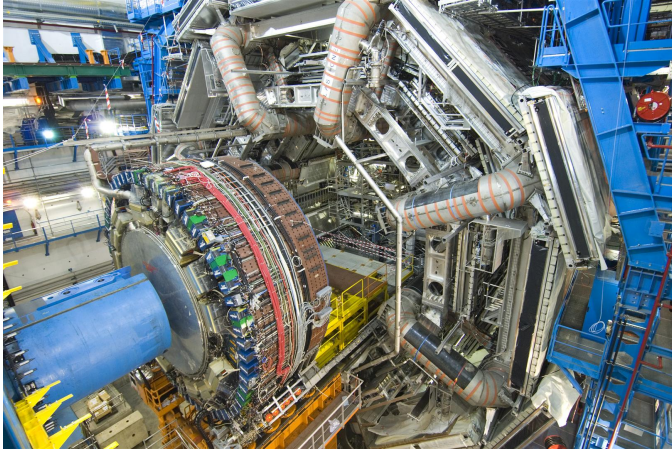
... is a complex process...

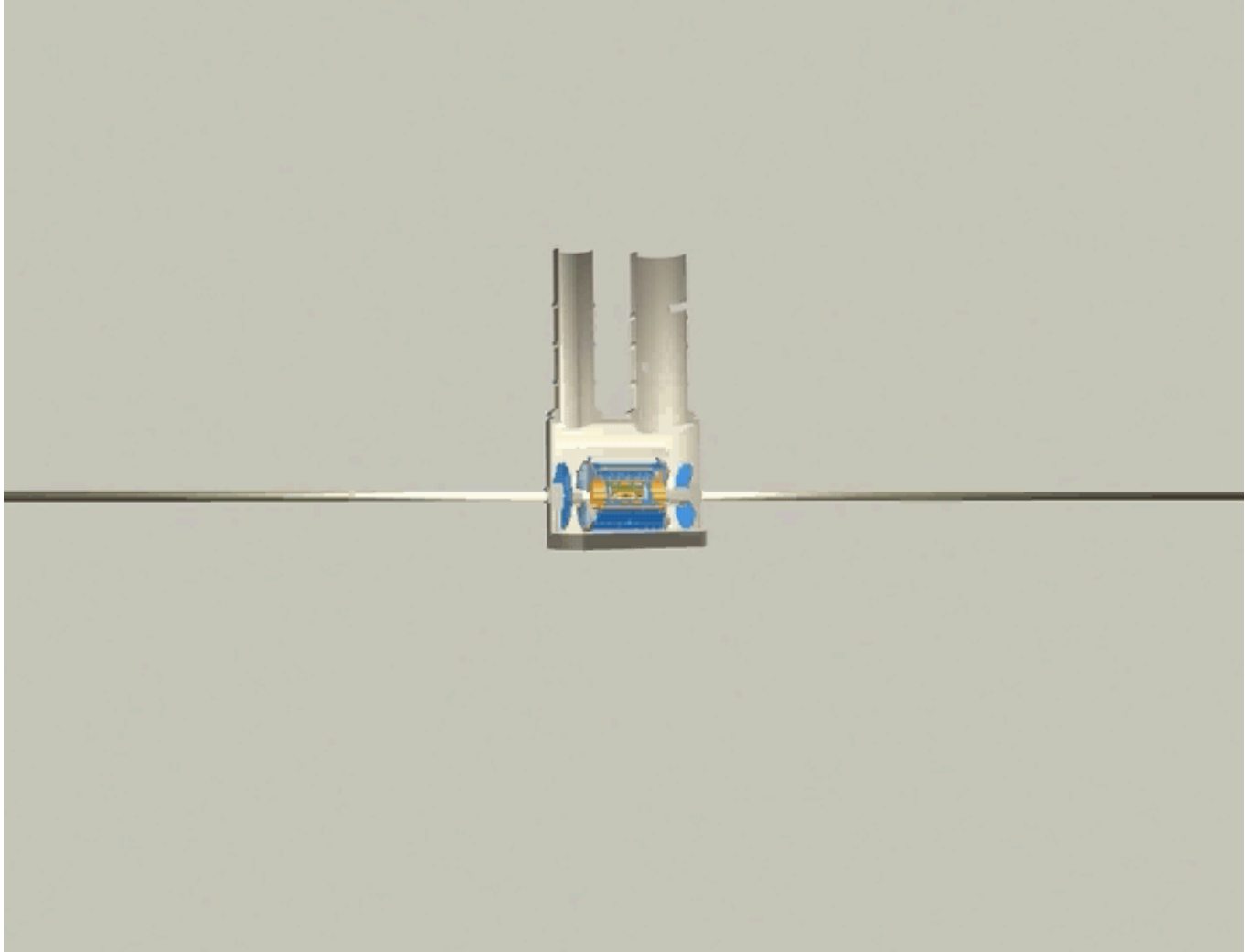


- Partons (quarks, gluons in the proton) collisions
 - Hard collision
 - Underlying events (softer parton collisions)
- Parton showering, QED bremsstrahlung
- Hadronization
- Decays

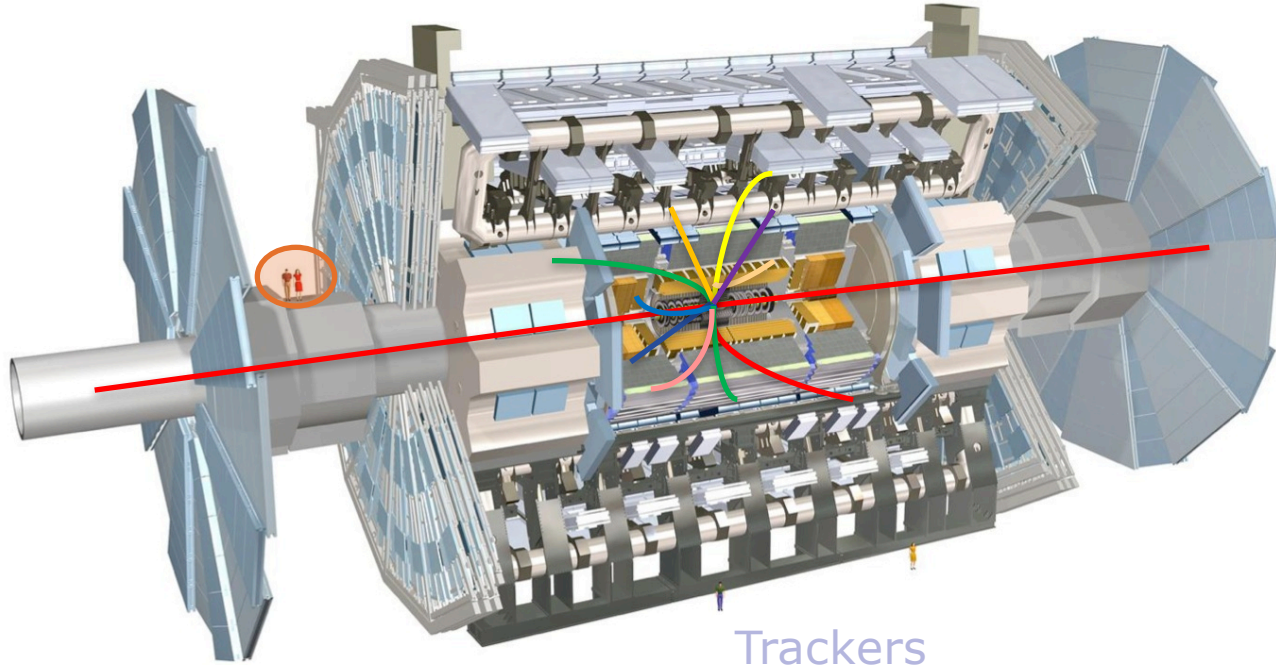
<https://sciencenode.org/feature/sherpa-and-open-science-grid-predicting-emergence-jets.php>

The four giant experiments



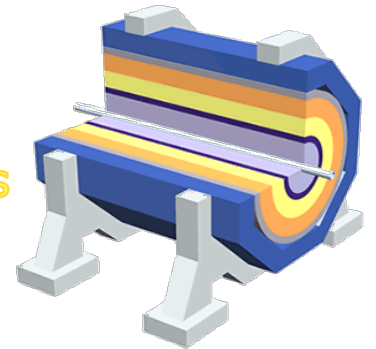


Measure particles with a giant: the ATLAS detector

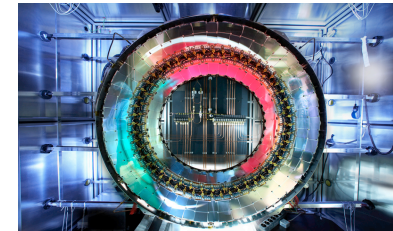
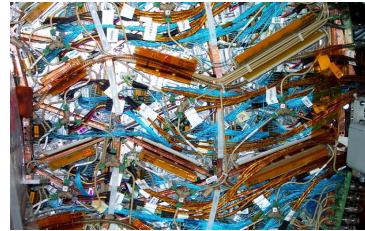
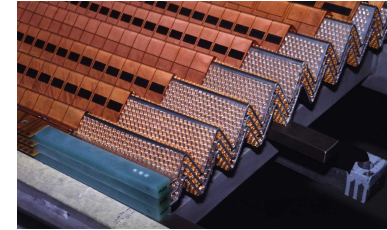
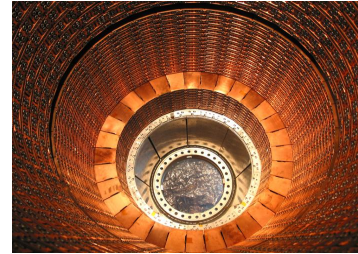
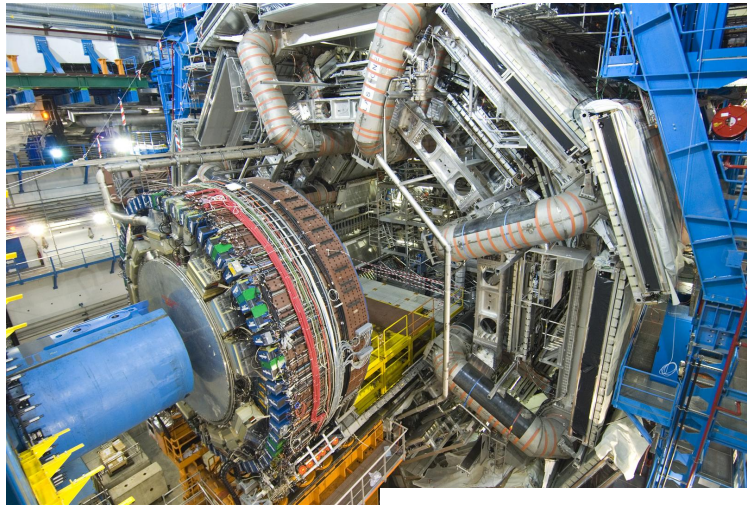


25 m high
46 m long,
7000 tons,
~ 100 million channels
~ 3000 km of cables

Trackers
Electromagnetic Calorimeters
Hadronic Calorimeters
Muons chambers



The tools : ATLAS detector

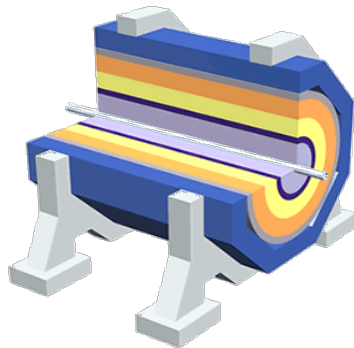


Tracking chamber

Electromagnetic calorimeter

Hadron calorimeter

Muon detector



photons



electron positron



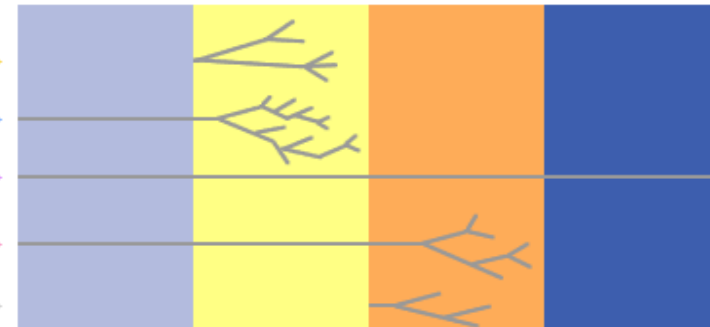
muons



pions proton



neutron



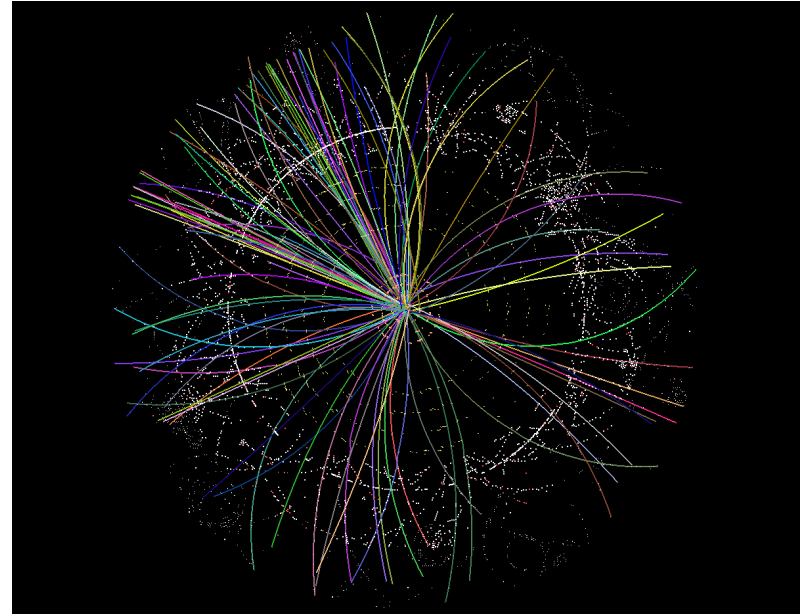
The computing challenge

Data

- Collision rate: 40 MHz
 - Impossible to register everything → In line selection: trigger
 - ~ 1000 collisions/s registered (1 Go/s)
- 50 PB of data produced per year

Software:

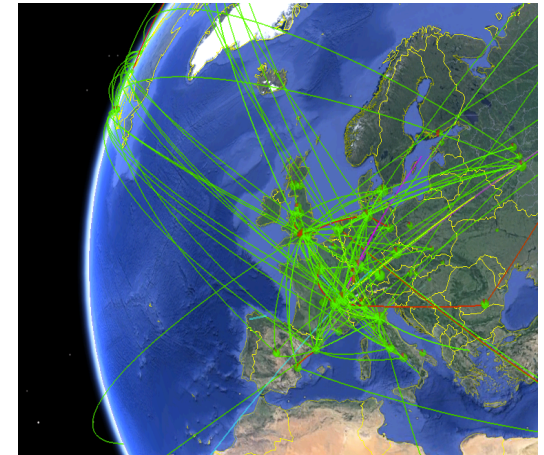
- In line with the detector complexity
 - Ex: ATLAS software is composed of 4 million code lines
- Used for data reconstruction, MC simulation and data analysis



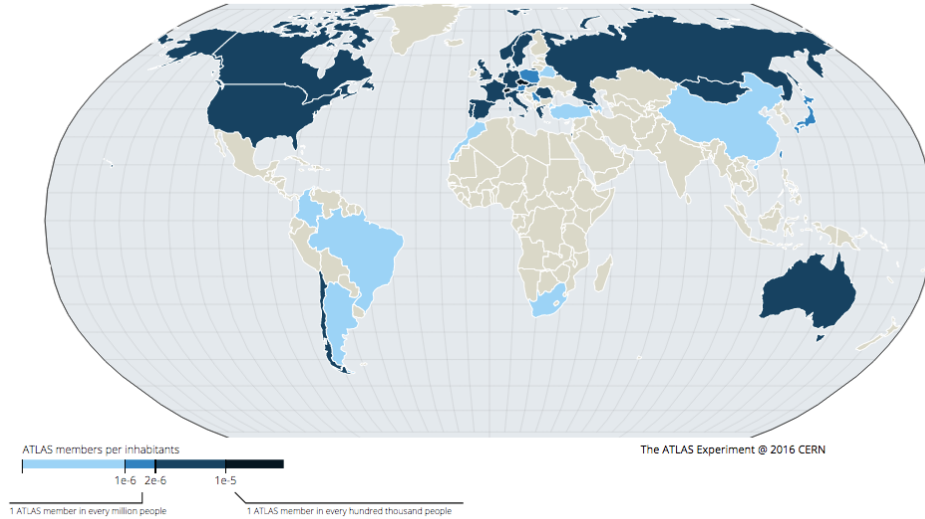
The computing challenge

Computing grid:

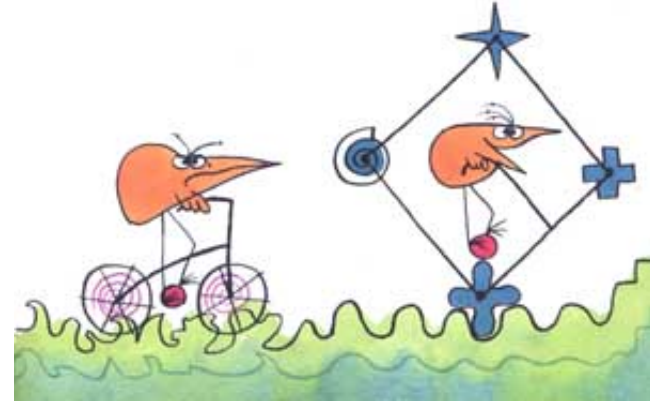
- ~170 sites from 42 countries interconnected through the network (10 to 100Gb links)
- Store data and execute programs in a transparent way for the user
 - Analysis: user program is sent automatically in the site where the data he needs is lying
 - Reconstruct LHC data and do MC simulation
- Size
 - ~ 750 000 jobs running in parallel
 - 600 PB of storage



Big experiments, big collaborations



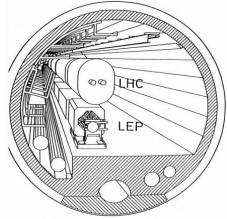
ATLAS collaboration is composed by 3 000 scientists (1 200 students)
from 180 institutes and 38 countries



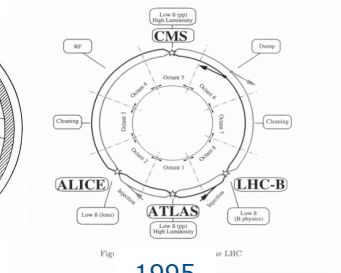
THE WAY TO THE RESULT

The way to physics results

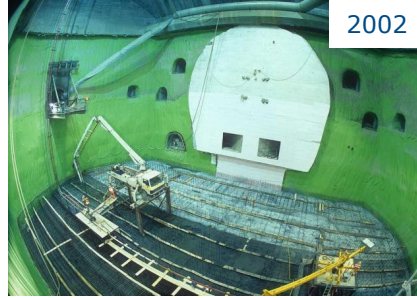
From experiment design to detector building and assembly



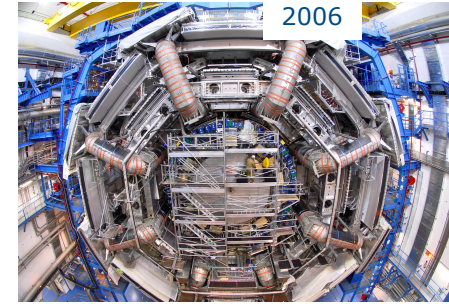
1984



1995



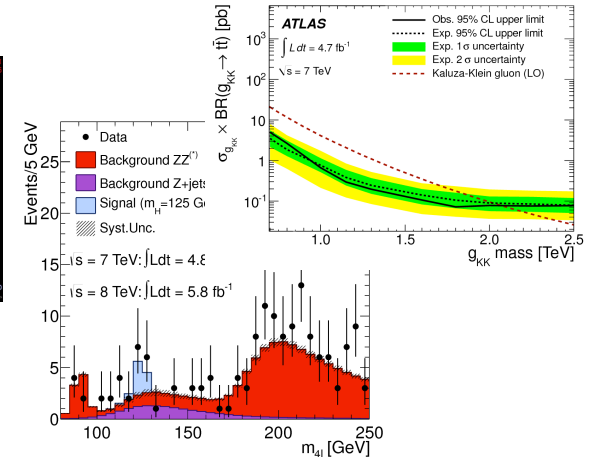
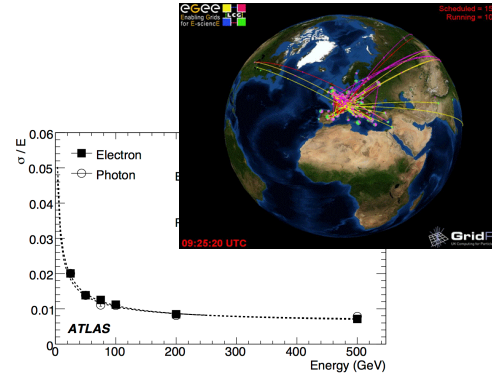
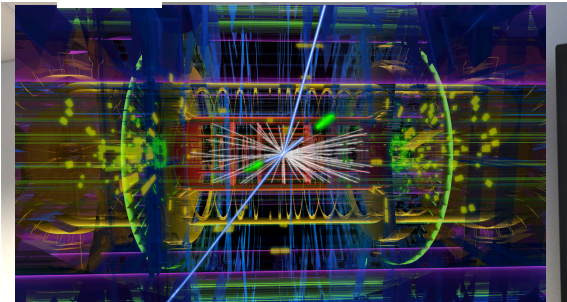
2002

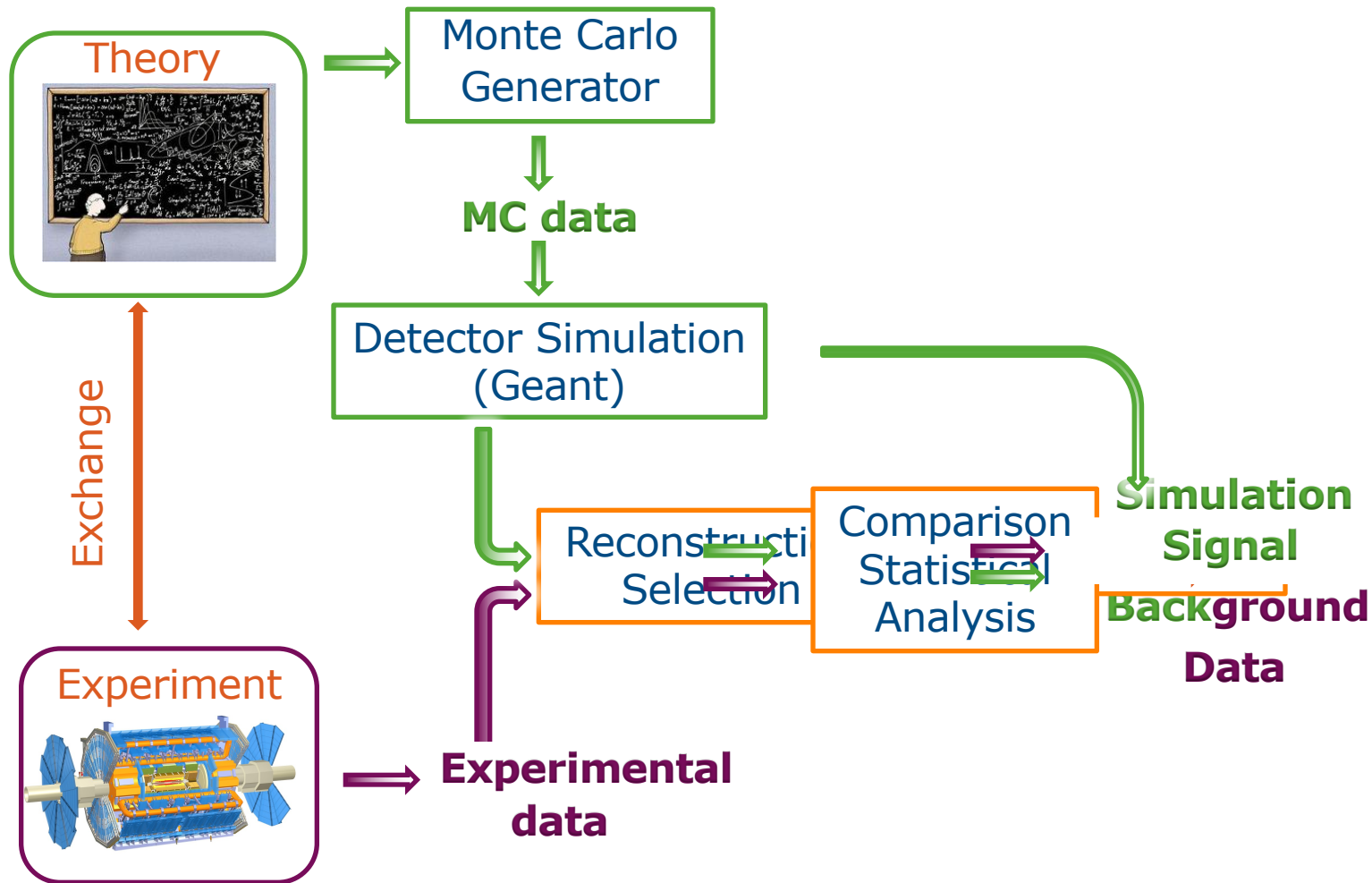


2006

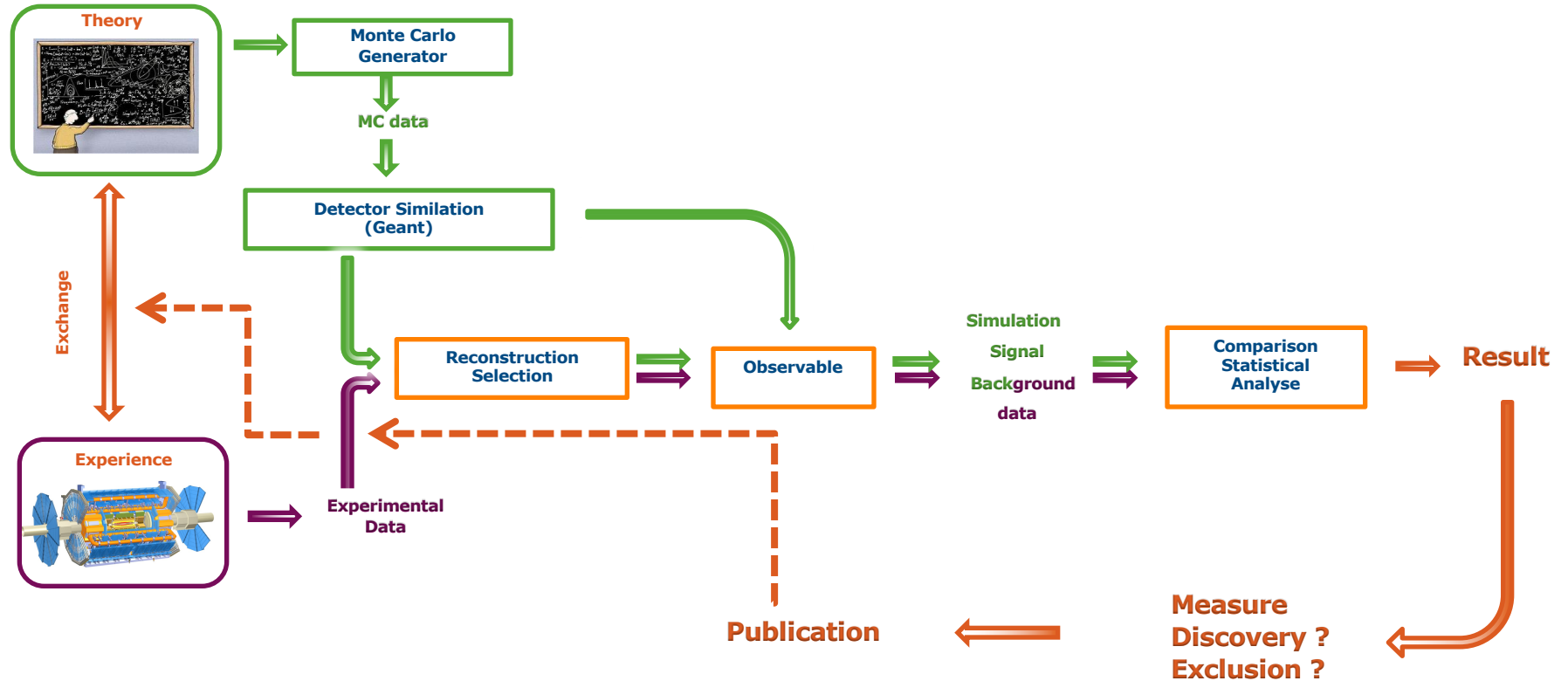
From collisions to physics result

2012

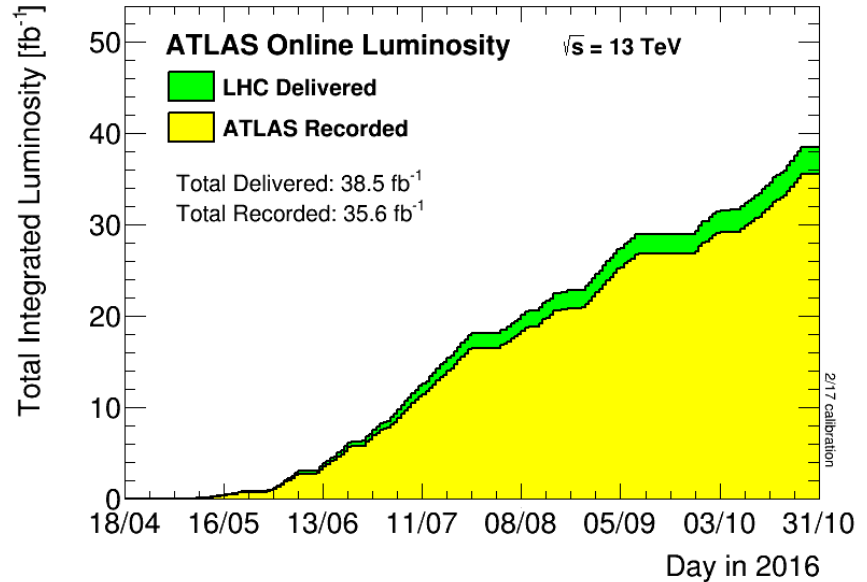
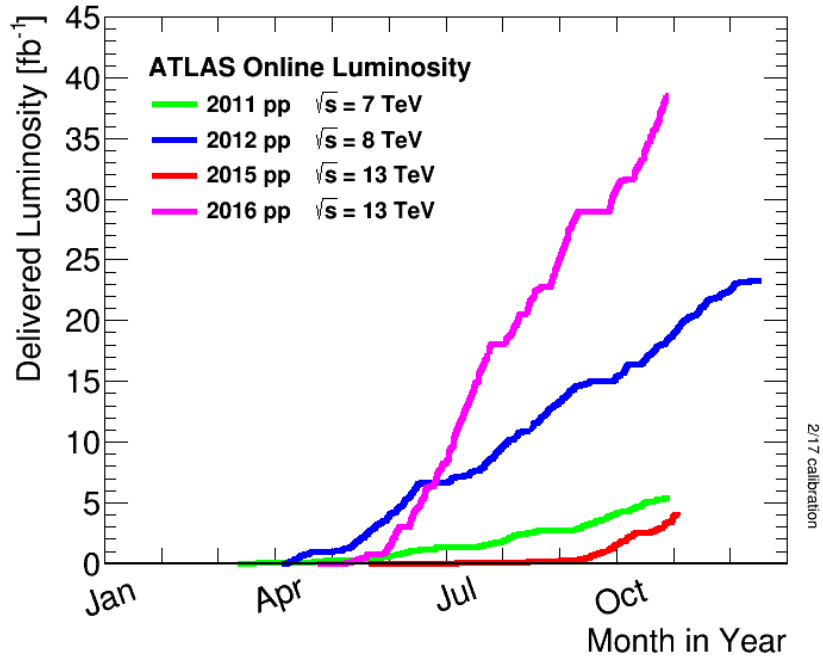




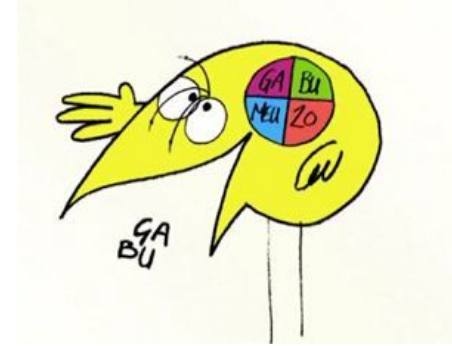
Global analysis scheme



LHC running periods



92.5 % efficiency !



REVISITING THE STANDARD MODEL

Revisiting the Standard Model

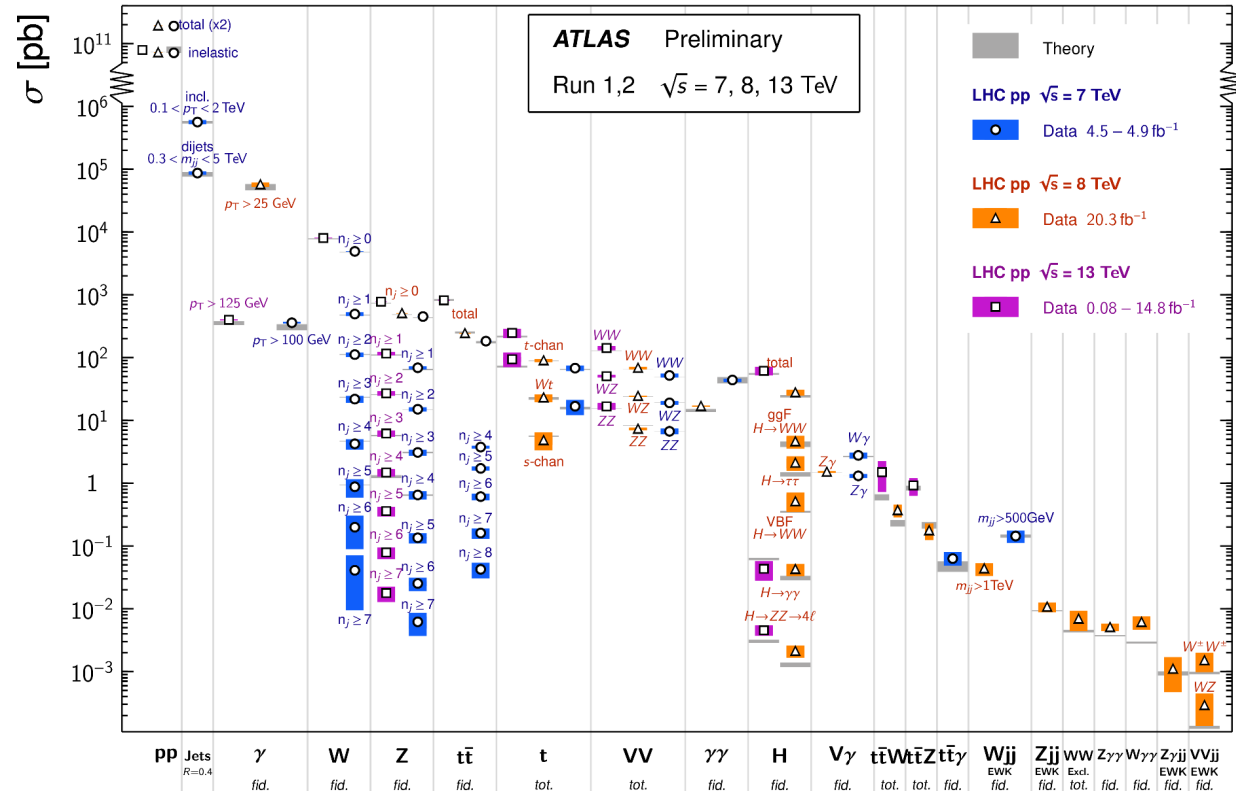
Measurements of known standard model processes are important

- **Detector commissioning and calibration:** first measurements of precisely known processes allows to commission the detectors and are used to calibrate all parts of the experiments and of the reconstruction techniques
- Comparison with theory: **is the Standard Model still valid at the TeV scale ?**
- Can we measure very seldom process that we could reach before ?
- All standard model processes represent the **backgrounds for new phenomena searches**
 - We need to know them as precisely as possible
 - Some can't be simulated (complex non perturbative QCD processes for instance), we rely on data
- **Precise measurements of standard model processes**, if not in agreement with calculation will give insight on new phenomena

Standard Model Cross Sections

Standard Model Production Cross Section Measurements

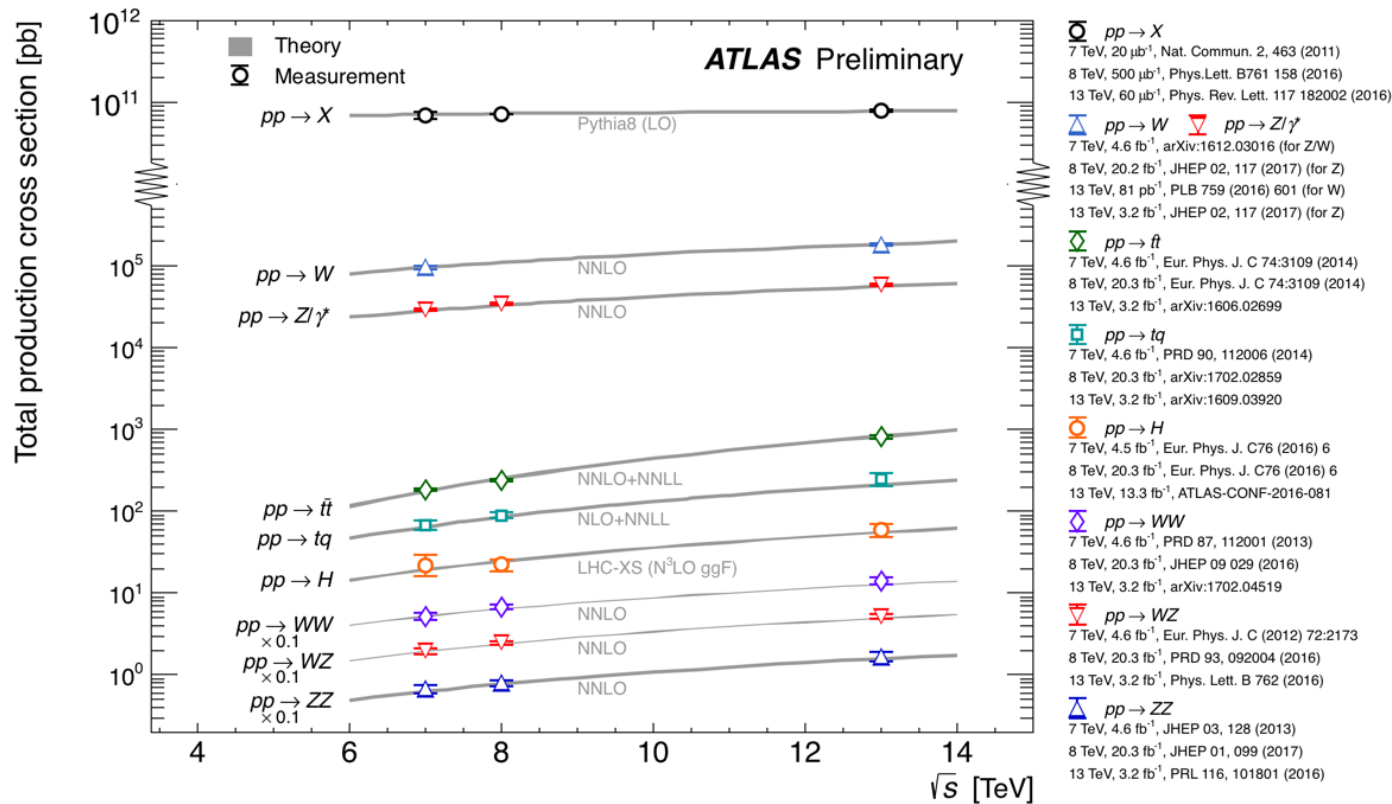
Status: March 2017



Cross sections measured over many orders of magnitude

Each point is an analysis
→ a summary of the work
of many people...

Standard Model Cross Sections Evolution with Energy

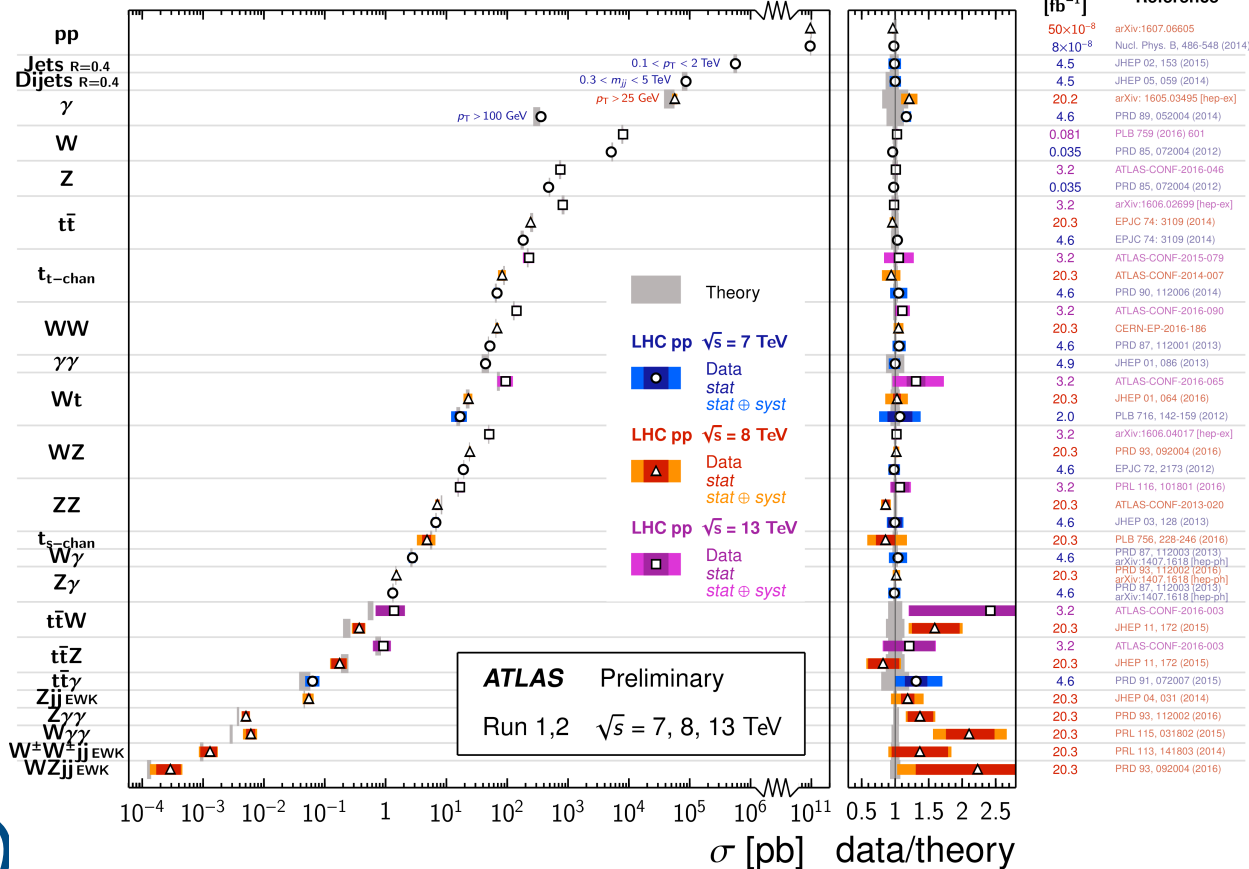


Standard Model cross sections

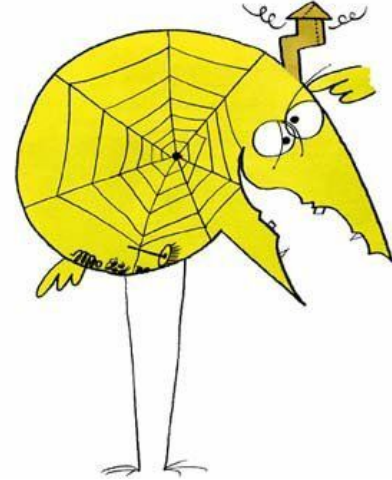
Standard Model Production Cross Section Measurements

Status: August 2016 $\int \mathcal{L} dt$

Reference



All measurements in very good agreement with Standard Model calculations



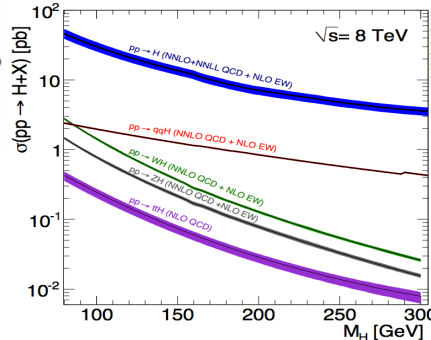
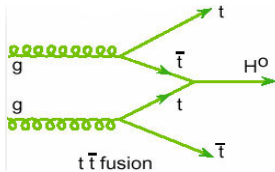
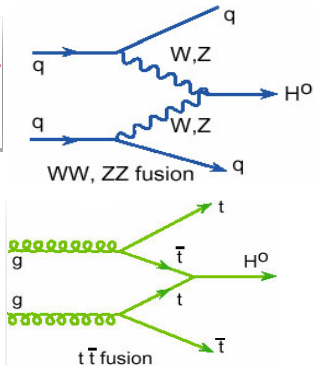
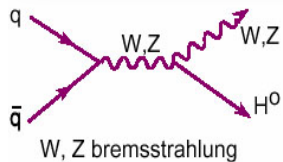
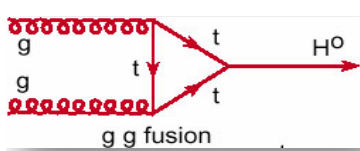
A LONG AWAITED NEW PARTICLE

BEH (Higgs) boson search

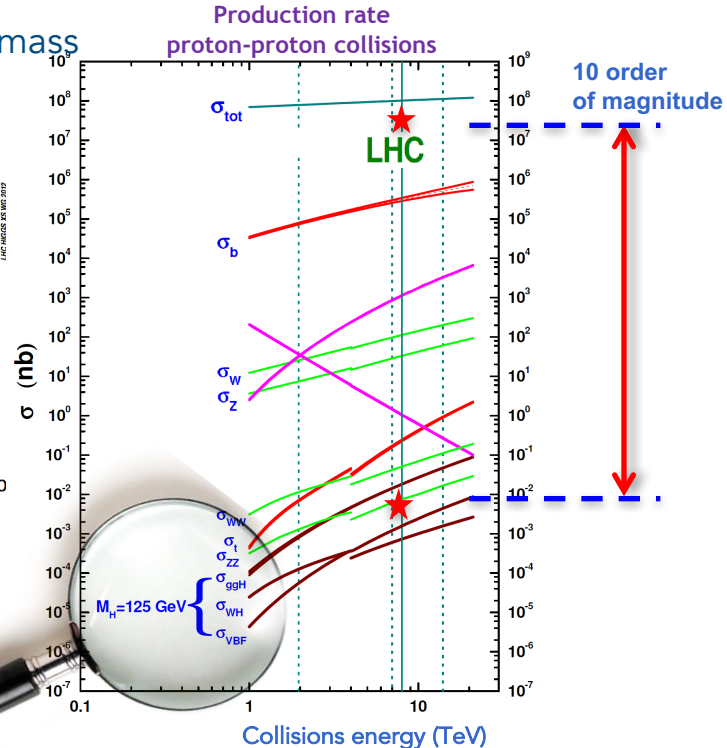
Hypothesis (theory) : mass of particles linked to a Higgs mechanism

- Higgs boson, mass not predictable
- Theory predicts production and decays as a function of Higgs mass

Production



~ 1 Higgs boson
for 5 billions of protons collisions !

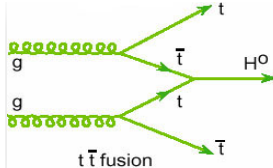
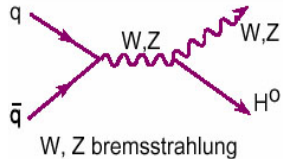
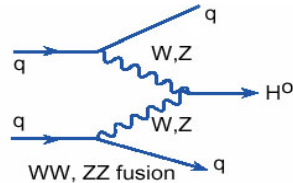
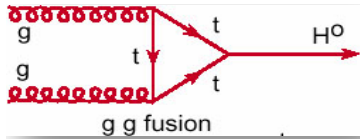


BEH (Higgs) boson search

Hypothesis (theory) : mass of particles linked to a Higgs mechanism

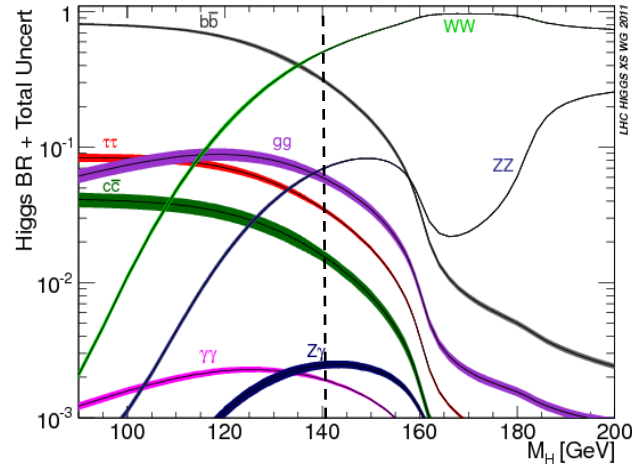
- Higgs boson, mass not predictable
- Theory predicts production and decays as a function of Higgs mass

Production



Higgs boson is not stable : it decays ...

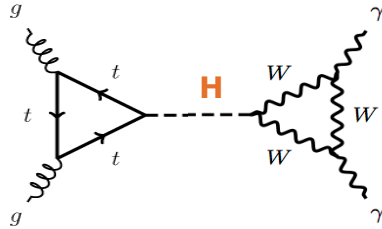
Decays probability = Branching Ratio



Exemple : Higgs in 2 photons

Signal and background:

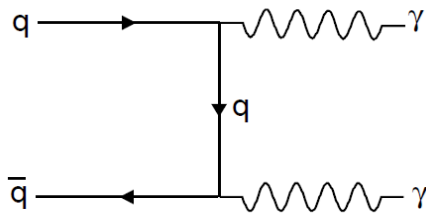
Signal : Higgs



→ Invariant mass of the 2 photons
= Higgs mass

→ $Mass^2 = 2E_1E_2(1-\cos\theta_{12})$

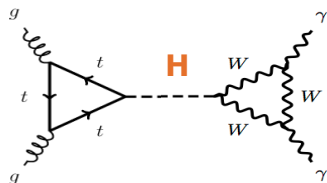
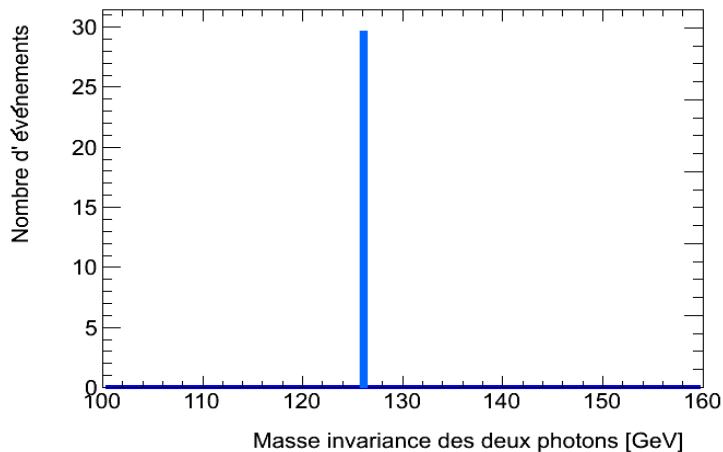
Background



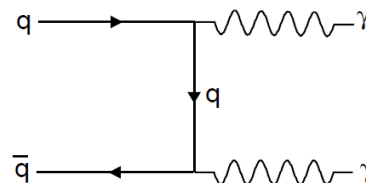
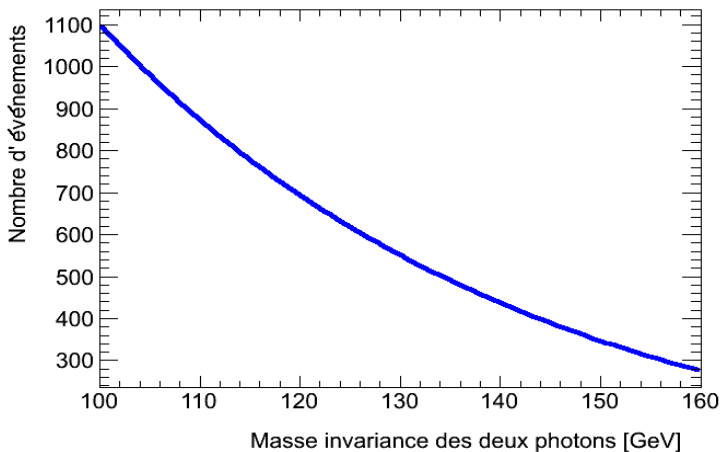
→ Invariant mass of the 2 photons
= continuum

Exemple : Higgs in 2 photons

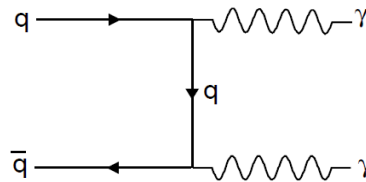
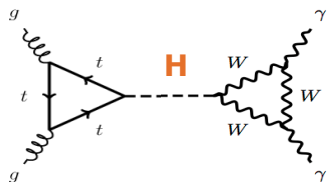
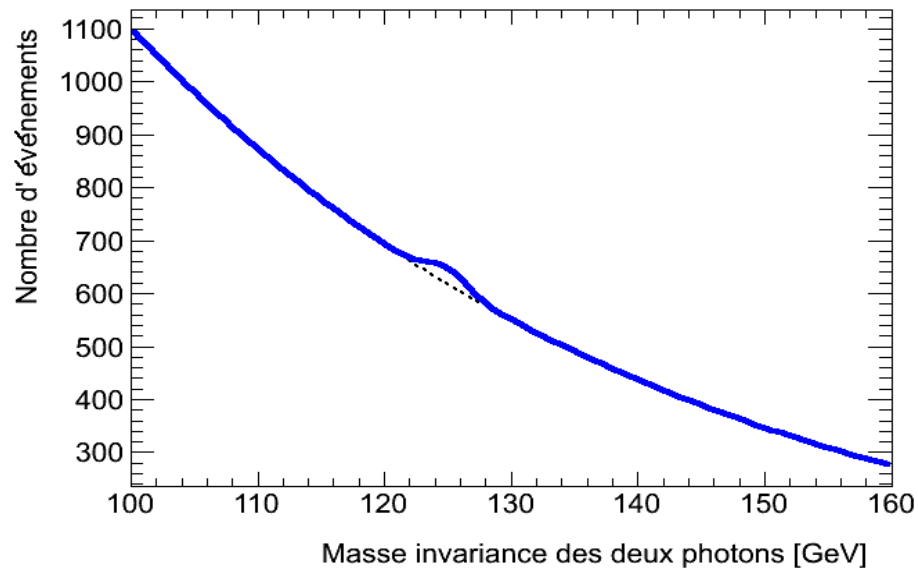
Higgs ($m_H = 125\text{GeV}$)



Background

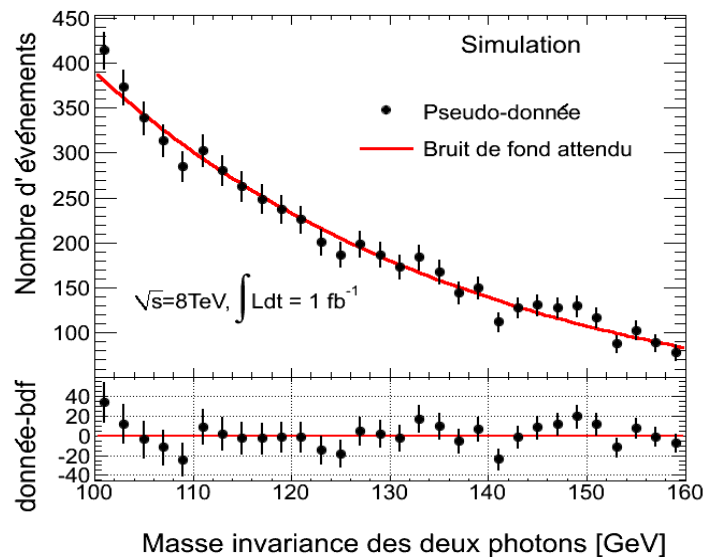
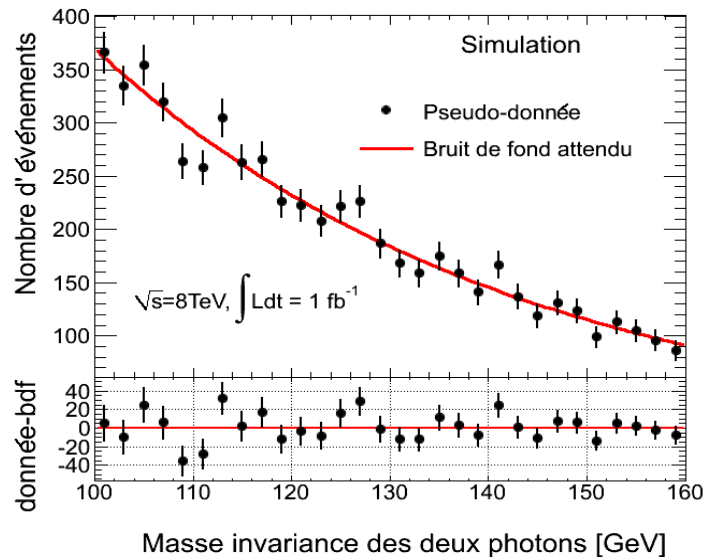


Exemple : Higgs in 2 photons



Exemple : Higgs in 2 photons

~ 100 billions of collisions

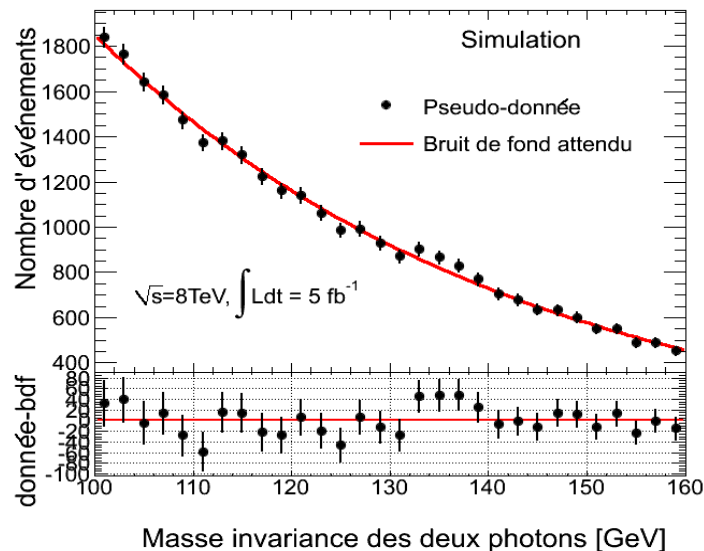
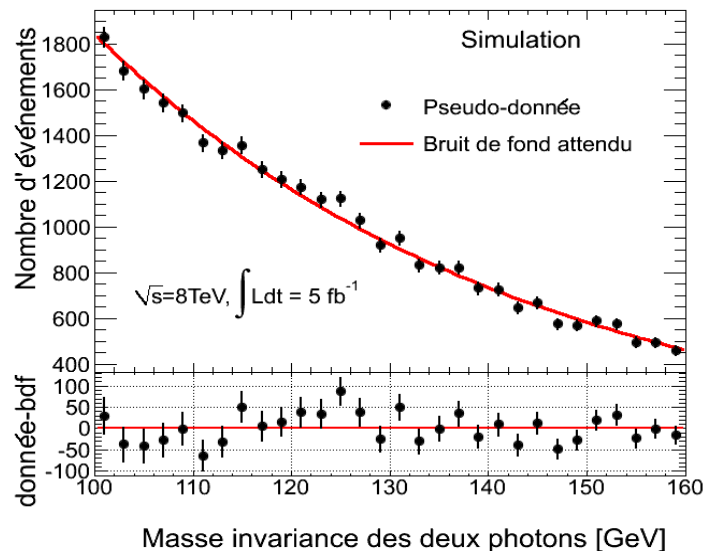


Background fluctuations !

Background evaluation can come from simulation or from data

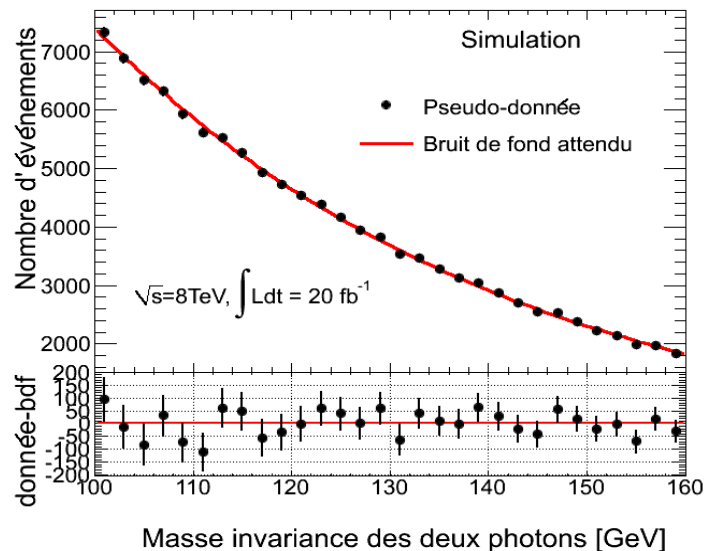
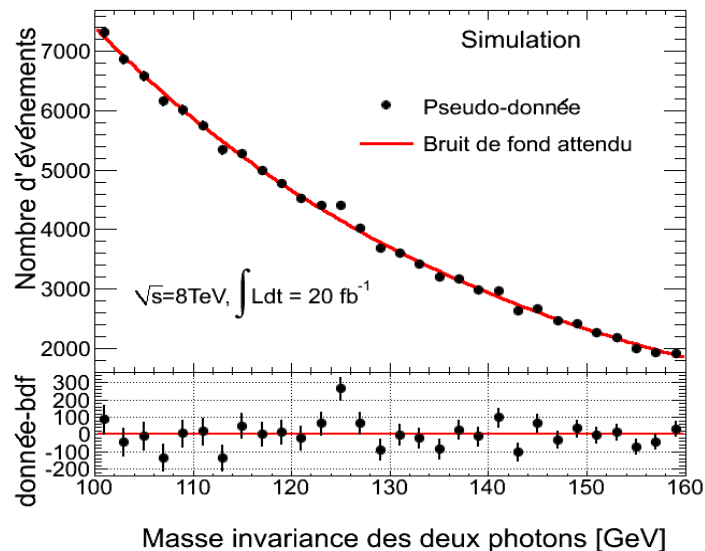
Exemple : Higgs in 2 photons

~ 500 billions of collisions

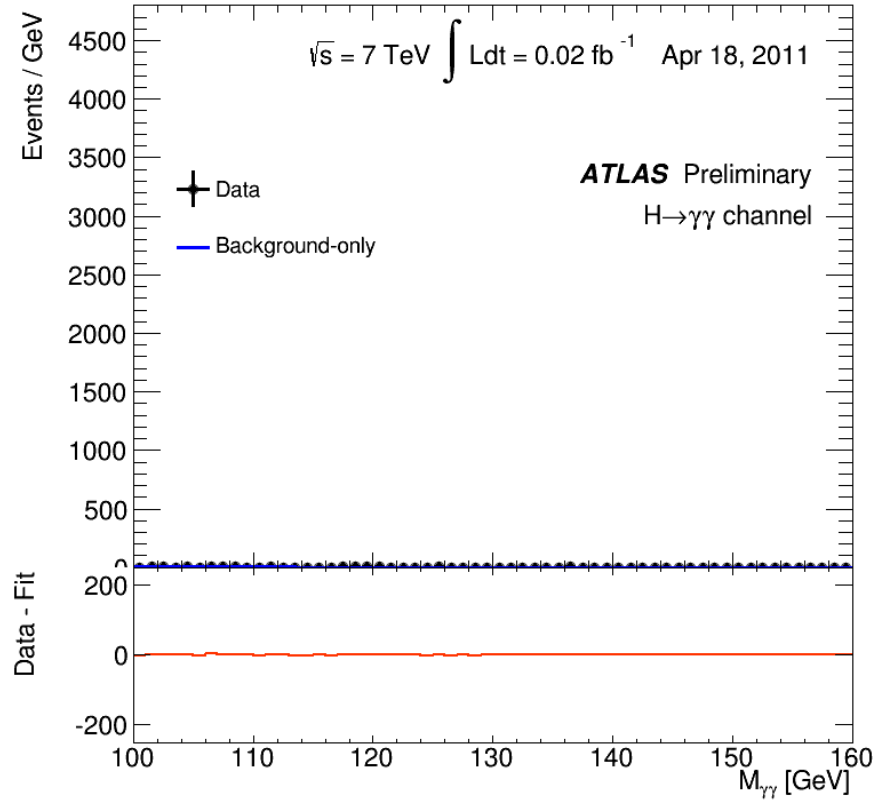


Exemple : Higgs in 2 photons

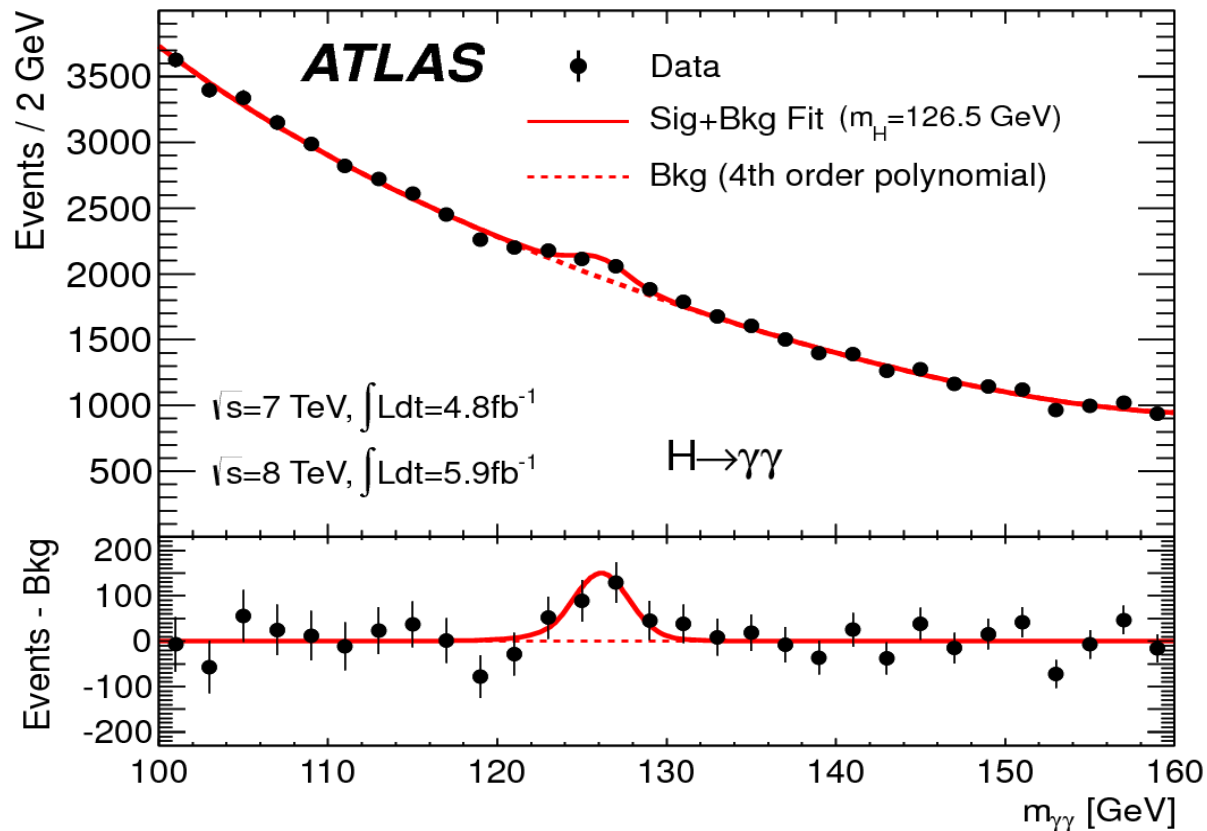
$\sim 2\,000$ billions collisions



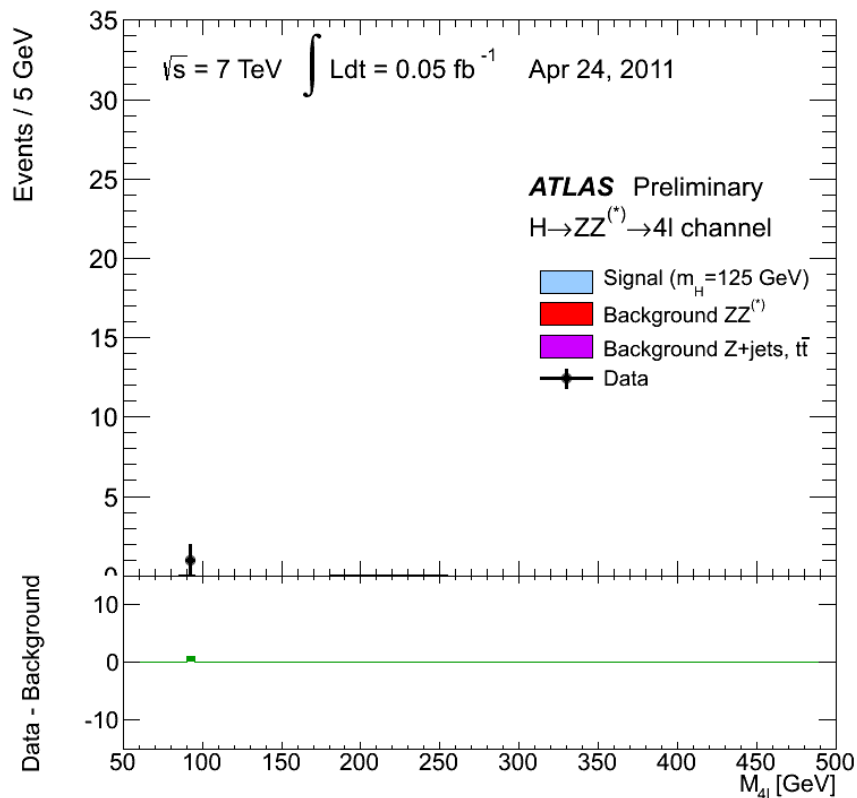
Day after day ... the real data



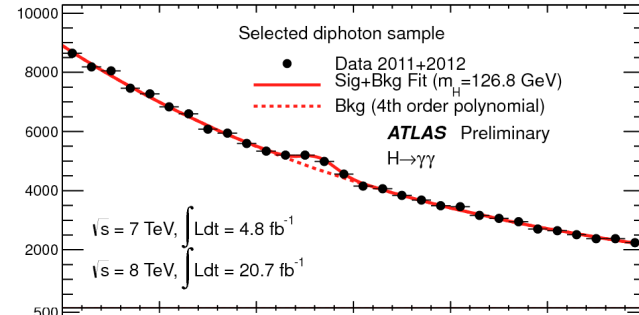
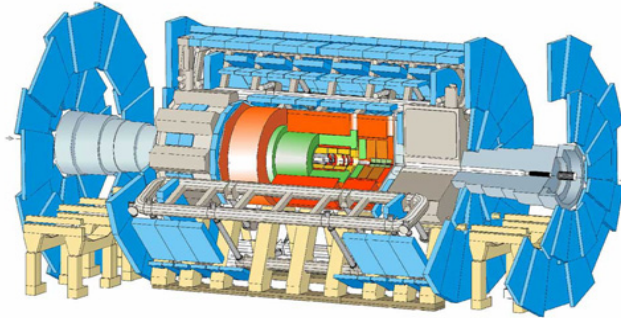
Exemple : Higgs in 2 photons



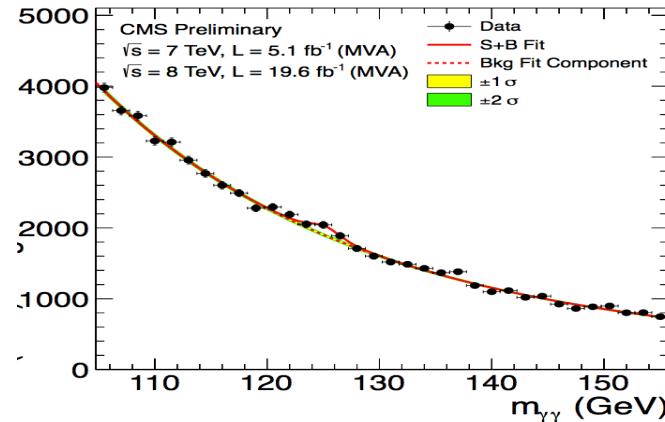
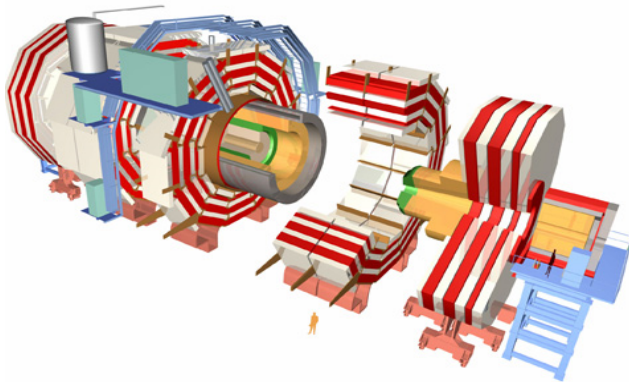
An other channel ZZ ...



2 experiments : same result



No communication



2 experiments : same result

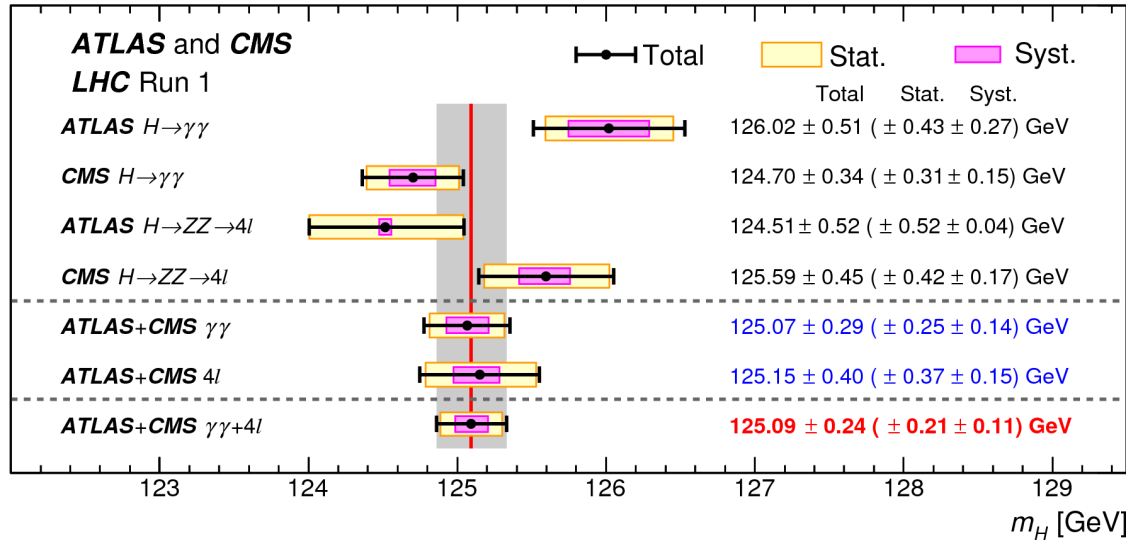




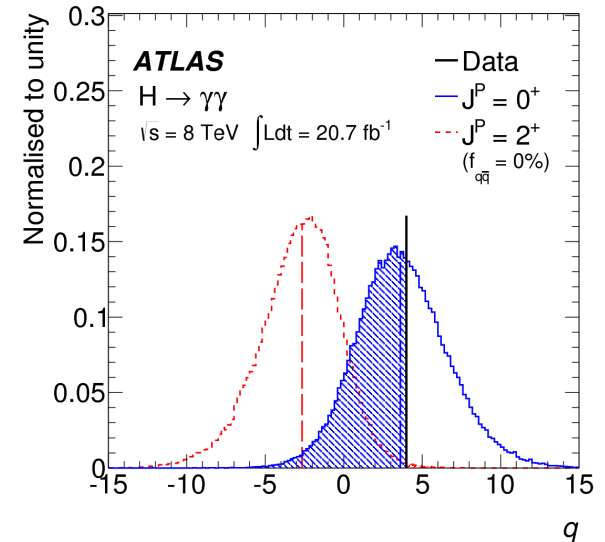
Higgs boson: measurements

New particle properties

Mass : 125.09 ± 0.24 (± 0.21 stat ± 0.11 syst)



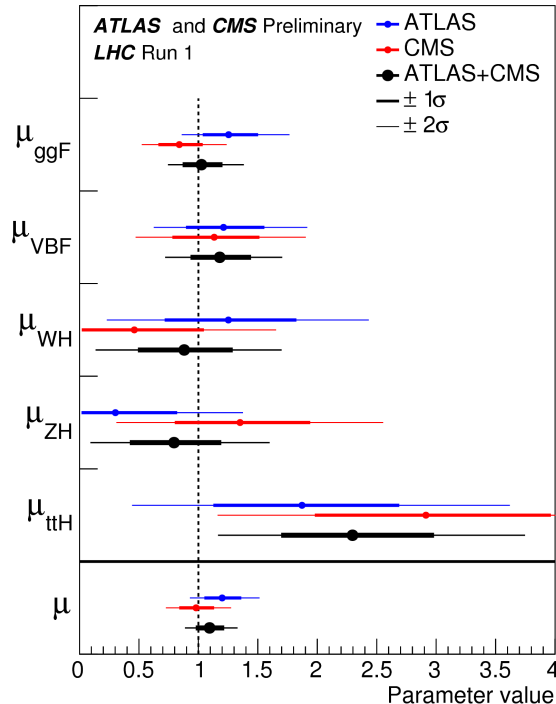
It's a Spin 0 particle



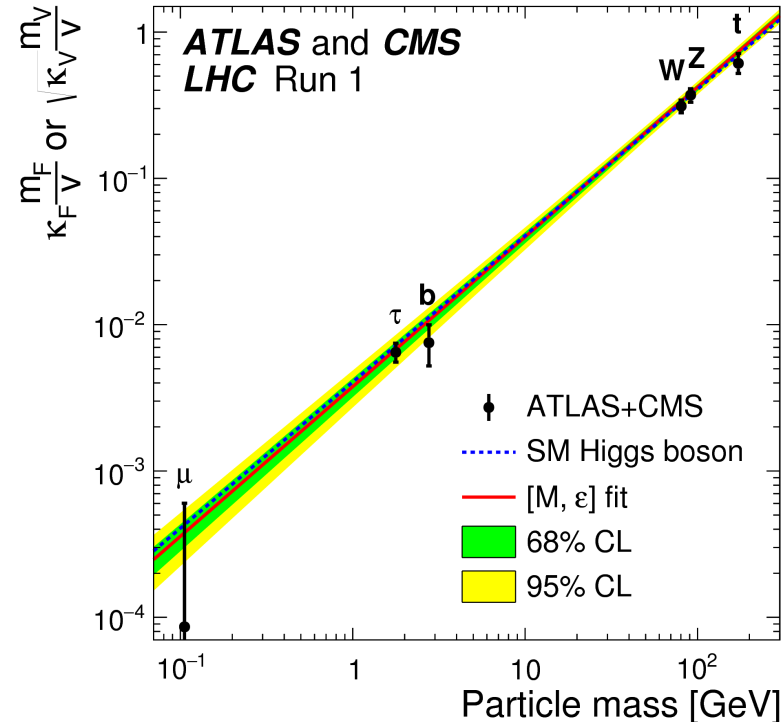
<http://cdsweb.cern.ch/record/2052552>

Is this new particle the SM Higgs boson ?

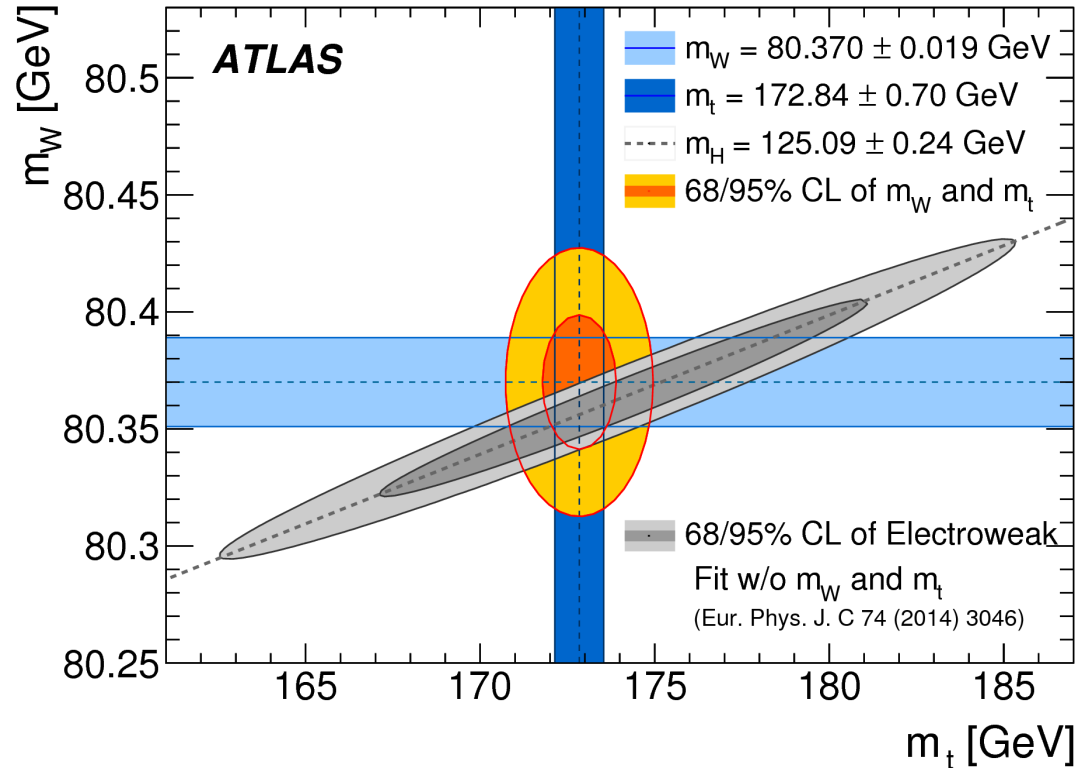
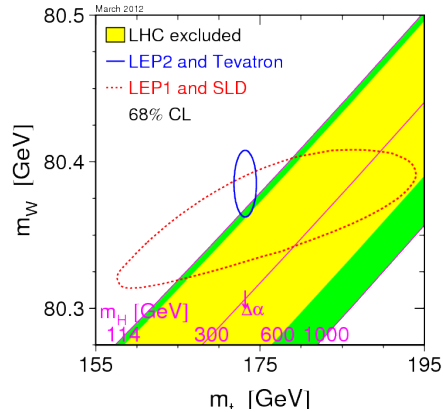
Ratio of production rate with SM predictions are close to 1



Couplings are proportional to mass



New standard Model consistency check





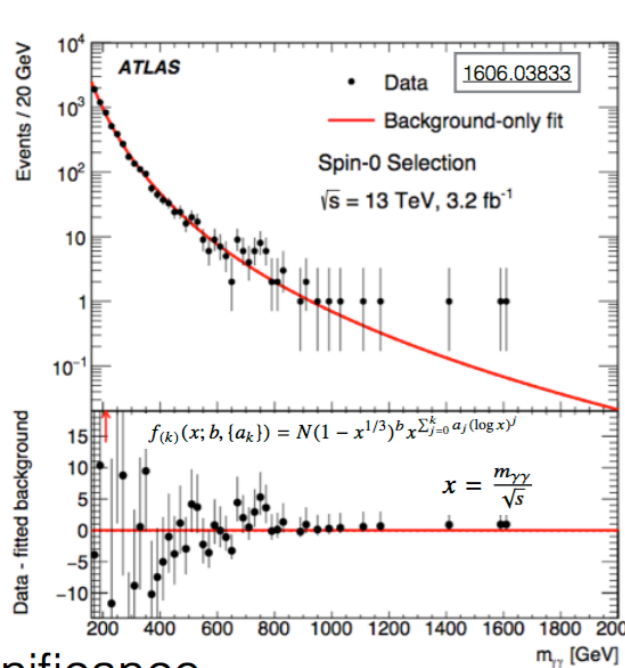
SEARCH SEARCH SEARCH

Search for new phenomena

Different strategies are followed in parallel

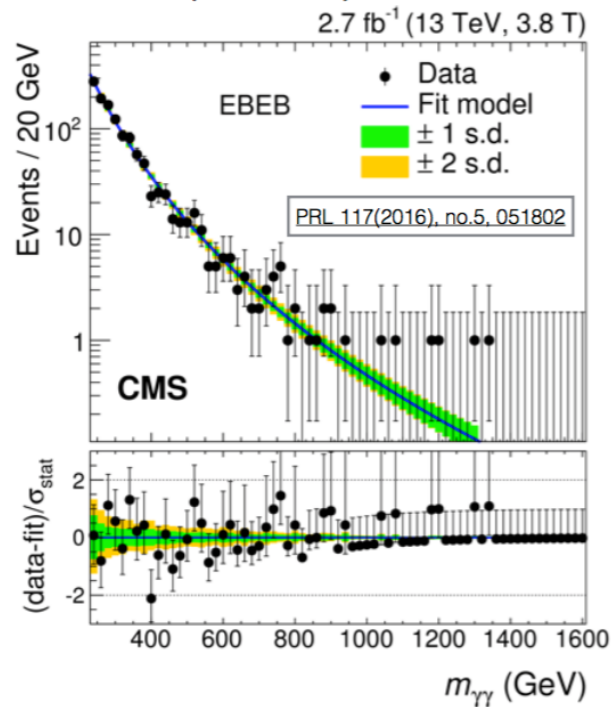
- Final state based search
 - No hypothesis done about physics model, choose a final state and compare to standard model prediction
- Search for phenomena from a given physics model
 - Typically the case for supersymmetry
- Search for simplified model or effective field theory
 - More general hypothesis, can be reinterpreted; ex dark matter search
- Analysis based search: analysis as general as possible used for interpretation with different models
 - Typically the case of “exotic” searches that predict same kind of new particles ex: Z' can be interpreted in terms of extra-dimensions models (KK gluon, graviton) or technicolor or dark matter model
- Indirect search through precision measurements
 - Typically SM measurements, LHCb for heavy flavors

2015: di-photon excess ?



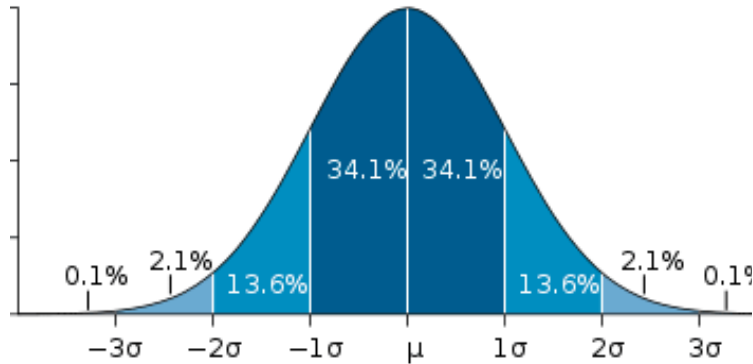
Significance

$m=750 \text{ GeV}$ (6% width)
 3.9σ (local)/ 2.1σ (global)



$m=760 \text{ GeV}$ (1.4×10^{-4} width)
 2.6σ (local)/ 1.2σ (global)

Confidence interval



$1\sigma \Leftrightarrow 68\%$
 $2\sigma \Leftrightarrow 95\%$
 $3\sigma \Leftrightarrow 99,7\%$
 $5\sigma \Leftrightarrow 99,9999\%$

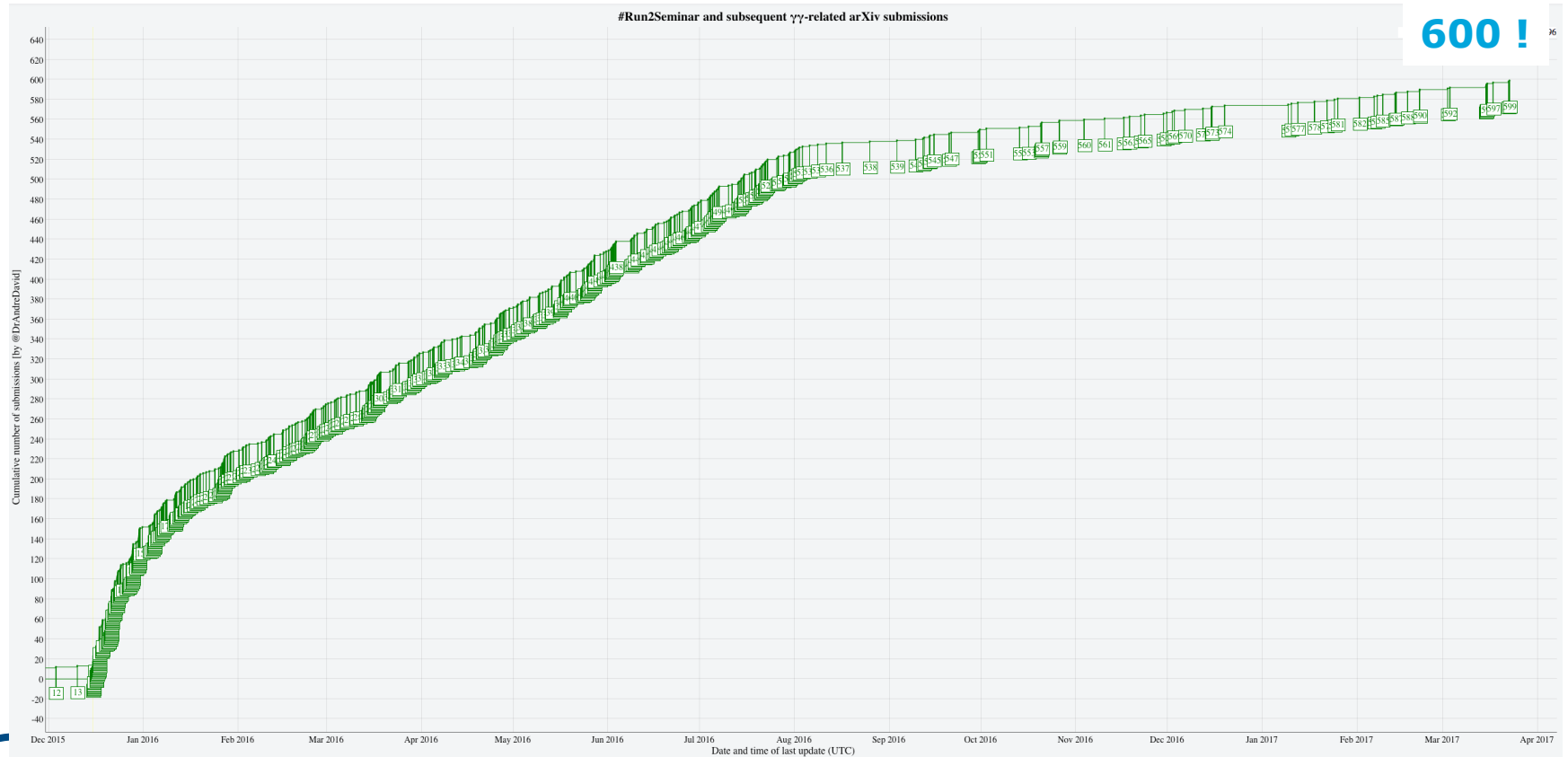
We wait for 5 σ
before claiming
for a discovery !

Tossing a coin, when do you decide the coin is rigged when you get several tails one after the other ?

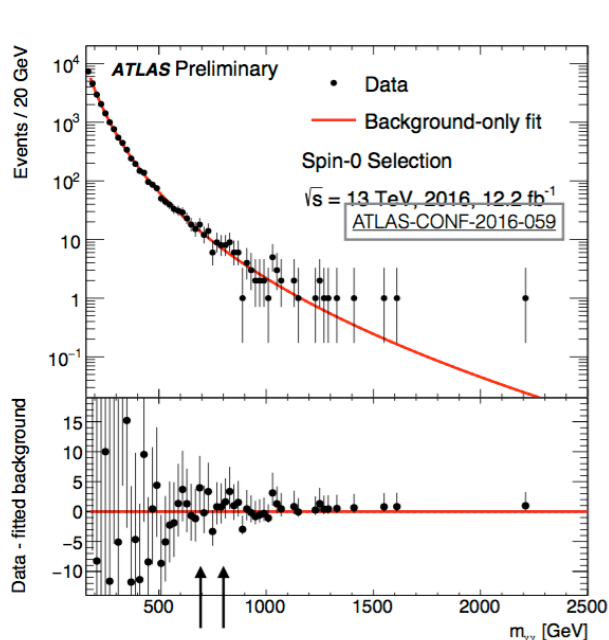
- $3\sigma \Leftrightarrow 8$ tails one after the other
- $5\sigma \Leftrightarrow 20$ tails one after the other !

The probability to be wrong is $1 / 1\,000\,000$

Number of related theory paper !

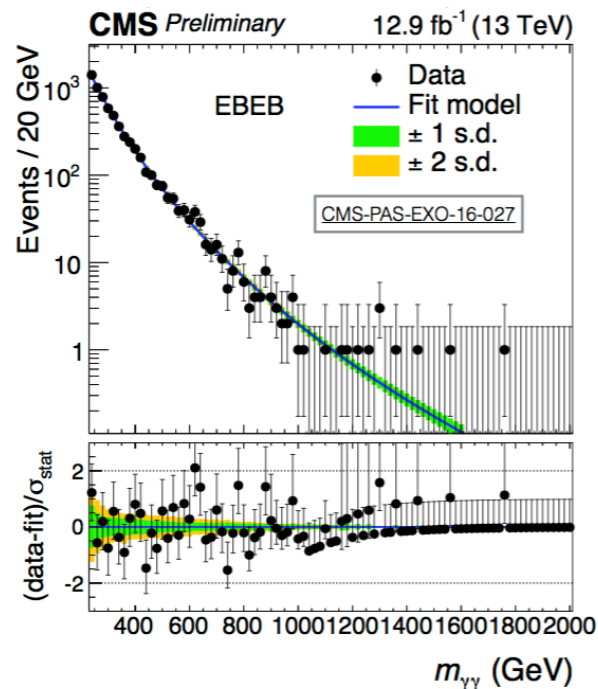


2016 results



Significance 2015+2016:

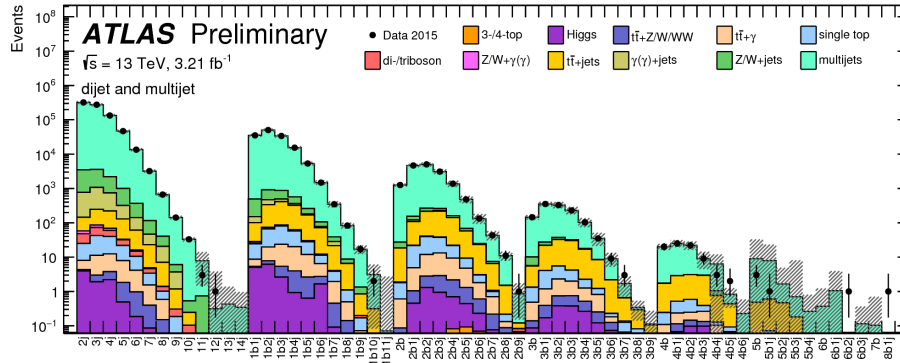
$m=710 \text{ GeV}$ (10% width)
 $2.3\sigma(\text{local}) / <1\sigma(\text{global})$



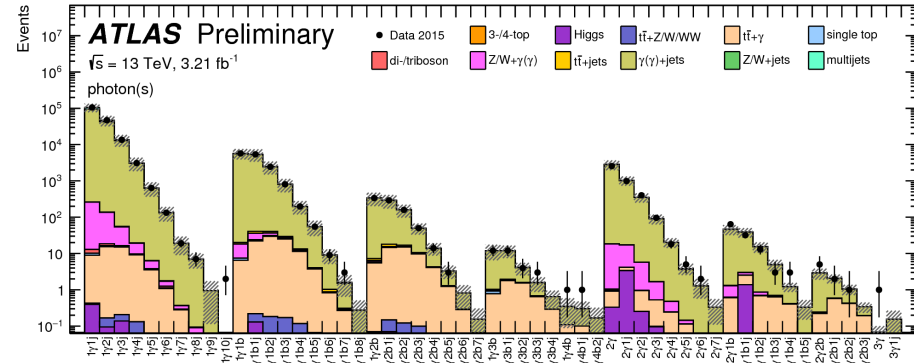
$m=760 \text{ GeV}$ (1.4×10^{-4} width)
 $<1\sigma(\text{local})$

General search

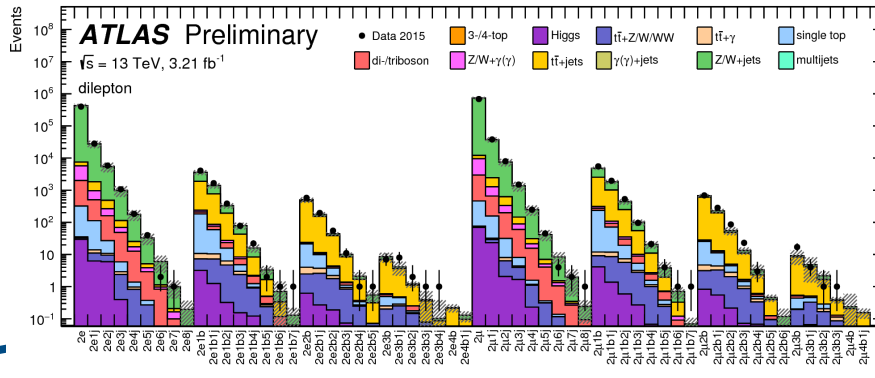
With jets



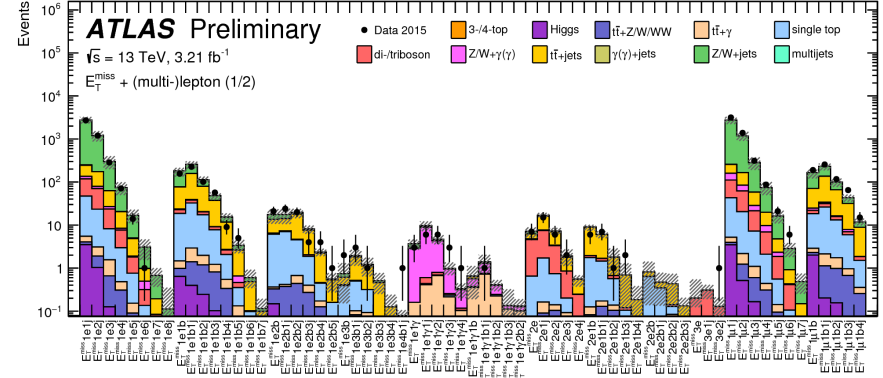
With photons



With 2 leptons



With missing E_T



New phenomena search at LHC

A wide range of signatures and models probed

- No significant deviation from SM prediction found within theoretical and experimental uncertainties
- Exclusion limits are set on model parameters, new particle masses, production cross-section...

Beware! In general, limits given for benchmark model points, or hypothesis are used to simplify the presentation

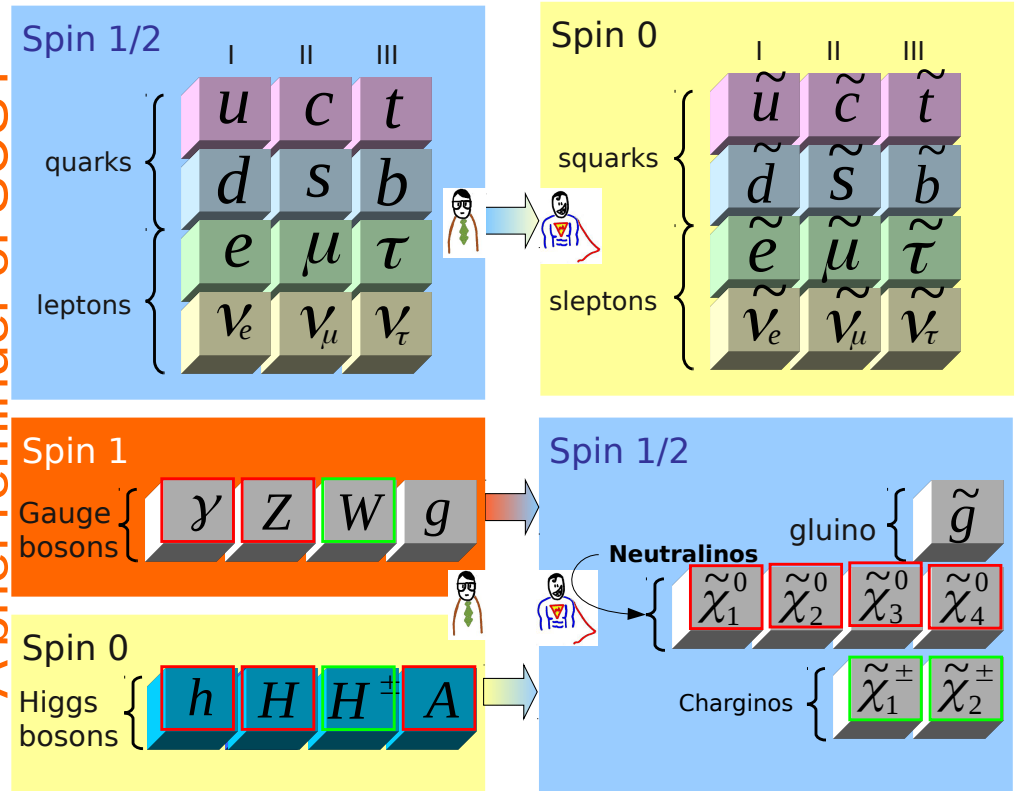
Supersymmetry

Fermion-boson symmetry

→ A lot of new parameters (on which particle mass and decays depend)

→ Very popular because it's the model that answers several questions at the same time: the lightest susy particle is a very good dark matter candidate, gauge unification, hierarchy,...

A brief reminder of SUSY



M-H Genest - Supersymmetry Searches at the LHC

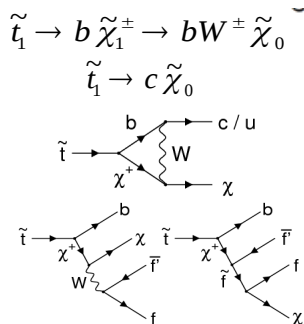
Supersymmetry

Example stop search

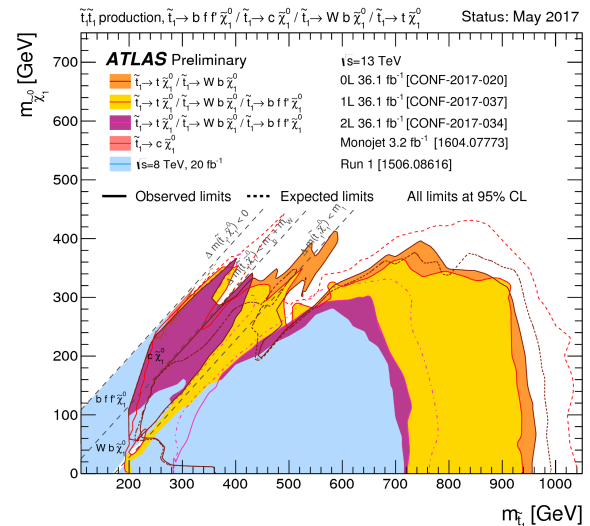
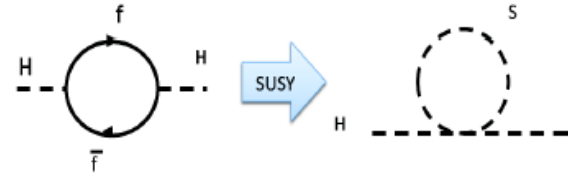
- Stop is the top quark partner
- It plays an important role to stabilize Higgs mass
- ⇒ good probability for having a quite low mass

Limits given as the functions of the lightest supersymmetric particle (partner of SM bosons and good DM candidate) and the stop mass

→ **Note:** Some regions with lower sensitivity where supersymmetric particles have mass close to each other



Light Higgs – need new physics to stabilise mass



Model		e, μ, τ, γ	Jets	$E_{\text{T}}^{\text{miss}}$	$\int \mathcal{L} d\Omega [h^{-1}]$	Mass limit	$\sqrt{s} = 7, 8 \text{ TeV}$	$\sqrt{s} = 13 \text{ TeV}$	Reference
Inclusive Searches	MSUGRA/CMSSM	$0-3 e, \mu/1-2 \tau$	2-10 jets/3 b	Yes	20.3	$\tilde{g}, \tilde{q}$	1.85 TeV	$m(\tilde{g})=m(\tilde{q})$	1507.05525
	$\tilde{q}\tilde{q}, \tilde{g}\tilde{g} \rightarrow \tilde{q}^0 \tilde{q}^0$	0	2-6 jets	Yes	13.3	$\tilde{g}$	1.35 TeV	$m(\tilde{g}) < 200 \text{ GeV}, m(\tilde{q}) \geq \text{gcm}, \tilde{q} \rightarrow \text{gcm}, \tilde{q}$	ATLAS-CONF-2016-078
	$\tilde{q}\tilde{q}, \tilde{g}\tilde{g} \rightarrow \tilde{q}^0 \tilde{q}^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{g}$	608 GeV	$m(\tilde{g}), m(\tilde{q}) < 5 \text{ GeV}$	1604.07773
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow \tilde{q}^0 \tilde{q}^0$	0	2-6 jets	Yes	13.3	$\tilde{g}$	1.80 TeV	$m(\tilde{g}) < 0 \text{ GeV}$	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow \tilde{q}^0 \tilde{q}^0$	0	2-6 jets	Yes	13.3	$\tilde{g}$	1.83 TeV	$m(\tilde{g}) < 400 \text{ GeV}, m(\tilde{q}) \geq 0.5 m(\tilde{g}) + m(\tilde{q})$	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow \ell \ell (\nu \nu) \tilde{q}^0$	$3 e, \mu$	4 jets	-	13.2	$\tilde{g}$	1.7 TeV	$m(\tilde{g}) < 400 \text{ GeV}$	ATLAS-CONF-2016-037
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow W Z \tilde{q}^0$	$2 e, \mu$ (SS)	0-3 jets	Yes	13.2	$\tilde{g}$	1.6 TeV	$m(\tilde{g}) < 500 \text{ GeV}$	ATLAS-CONF-2016-037
	GMSB ($\tilde{g}$ NLSP)	$1-2 \tau + 0-1 \ell$	0-2 jets	Yes	3.2	$\tilde{g}$	2.0 TeV	$m(\tilde{g}) < 0.1 \text{ mm}$	1607.05979
	GGM (bino NLSP)	2γ	-	Yes	3.2	$\tilde{g}$	1.65 TeV	$m(\tilde{g}) < 950 \text{ GeV}, m(\tilde{q}) < 0.1 \text{ mm}, \mu < 0$	1608.09150
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$	1.37 TeV	$m(\tilde{g}) < 680 \text{ GeV}, m(\tilde{q}) < 0.1 \text{ mm}, \mu < 0$	1507.05493
1 st gen. $\tilde{g}$ and $\tilde{q}$	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	$\tilde{g}$	1.8 TeV	$m(\tilde{g}) < 430 \text{ GeV}$	ATLAS-CONF-2016-086
	GGM (higgsino NLSP)	$2 e, \mu$ (Z)	2 jets	Yes	20.3	$\tilde{g}$	900 GeV	$m(\tilde{g}) < 430 \text{ GeV}$	1509.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$\tilde{g}^{1/2} \text{ stokes}$	865 GeV	$m(\tilde{g}) > 1.3 \times 10^{-14} \text{ eV}, m(\tilde{q}) - m(\tilde{g}) \sim 1.5 \text{ TeV}$	1502.01518
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow b\bar{b} \tilde{q}^0$	0	3 b	Yes	14.8	$\tilde{g}$	1.89 TeV	$m(\tilde{g}) < 0 \text{ GeV}$	ATLAS-CONF-2016-052
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow t\bar{t} \tilde{q}^0$	0-1 e, μ	3 b	Yes	14.8	$\tilde{g}$	1.89 TeV	$m(\tilde{g}) < 0 \text{ GeV}$	ATLAS-CONF-2016-052
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow b\bar{b} \tilde{q}^0$	0-1 e, μ	3 b	Yes	20.1	$\tilde{g}$	1.37 TeV	$m(\tilde{g}) < 300 \text{ GeV}$	1407.0600
	$\tilde{q}\tilde{q}, \tilde{q}\tilde{q} \rightarrow b\bar{b} \tilde{q}^0$	0	2 b	Yes	3.2	$\tilde{q}_1$	840 GeV	$m(\tilde{q}_1) < 100 \text{ GeV}$	1606.08772
	$\tilde{q}\tilde{q}, \tilde{q}\tilde{q} \rightarrow t\bar{t} \tilde{q}^0$	$2 e, \mu$ (SS)	1 b	Yes	13.2	$\tilde{q}_1$	325-695 GeV	$m(\tilde{q}_1) < 150 \text{ GeV}, m(\tilde{q}_2) = m(\tilde{q}_1) - 100 \text{ GeV}$	ATLAS-CONF-2016-037
	$\tilde{q}\tilde{q}, \tilde{q}\tilde{q} \rightarrow b\bar{b} \tilde{q}^0$	0-2 e, μ	1-2 b	Yes	4.7/13.3	$\tilde{q}_1$	117-170 GeV	$m(\tilde{q}_1) = 2m(\tilde{q}_2), m(\tilde{q}_1) \geq 55 \text{ GeV}$	1209.2102, ATLAS-CONF-2016-077
	$\tilde{q}\tilde{q}, \tilde{q}\tilde{q} \rightarrow W \tilde{q}^0$ or $\tilde{q}^0$	0-2 e, μ	0-2 jets/1-2 b	Yes	4.7/13.3	$\tilde{q}_1$	90-198 GeV	$m(\tilde{q}_1) \geq 1 \text{ GeV}$	1506.08816, ATLAS-CONF-2016-077
2 nd gen. squarks direct production	$\tilde{q}\tilde{q}, \tilde{q}\tilde{q} \rightarrow \tilde{q}^0 \tilde{q}^0$	0	mono-jet	Yes	3.2	$\tilde{q}_1$	90-323 GeV	$m(\tilde{q}_1), m(\tilde{q}_2) < 5 \text{ GeV}$	1604.07773
	$\tilde{q}\tilde{q}, \tilde{q}\tilde{q} \rightarrow \tilde{q}^0 \tilde{q}^0$ (natural GMSB)	$2 e, \mu$ (Z)	1 b	Yes	20.3	$\tilde{q}_1$	150-600 GeV	$m(\tilde{q}_1) > 150 \text{ GeV}$	1403.5222
	$\tilde{q}\tilde{q}, \tilde{q}\tilde{q} \rightarrow \tilde{q}^0 \tilde{q}^0 + Z$	$3 e, \mu$ (Z)	1 b	Yes	13.3	$\tilde{q}_1$	290-700 GeV	$m(\tilde{q}_1) < 300 \text{ GeV}$	ATLAS-CONF-2016-038
	$\tilde{q}\tilde{q}, \tilde{q}\tilde{q} \rightarrow \tilde{q}^0 \tilde{q}^0 + h$	$1 e, \mu$	6 jets + 2 b	Yes	20.3	$\tilde{q}_2$	320-620 GeV	$m(\tilde{q}_1) < 0 \text{ GeV}$	1506.08816
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \tilde{t}_1 \rightarrow \tilde{t}^0 \tilde{t}^0$	$2 e, \mu$	0	Yes	20.3	$\tilde{t}$	90-335 GeV	$m(\tilde{t}_1) < 0 \text{ GeV}$	1403.5294
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \tilde{t}_1 \rightarrow \tilde{t}^0 \tilde{t}^0 (\nu \nu)$	$2 e, \mu$	0	Yes	13.3	$\tilde{t}$	640 GeV	$m(\tilde{t}_1) = 0 \text{ GeV}, m(\tilde{b}, \tilde{\nu}) \geq 5 m(\tilde{t}_1) + m(\tilde{t}_2^0)$	ATLAS-CONF-2016-096
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \tilde{t}_1 \rightarrow \tilde{t}^0 \tilde{t}^0 (\nu \nu)$	2τ	-	Yes	14.8	$\tilde{t}$	580 GeV	$m(\tilde{t}_1) < 0 \text{ GeV}, m(\tilde{b}, \tilde{\nu}) \geq 0.5 m(\tilde{t}_1) + m(\tilde{t}_2^0)$	ATLAS-CONF-2016-093
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \tilde{t}_1 \rightarrow \tilde{t}^0 \tilde{t}^0 (\nu \nu), \tilde{t} \tilde{t}^0 \tilde{t}^0 (\nu \nu)$	$3 e, \mu$	0	Yes	13.3	$\tilde{t}_1^*, \tilde{t}_2^*$	1.0 TeV	$m(\tilde{t}_1) \geq m(\tilde{t}_2^0), m(\tilde{t}_1^0) \geq 0, m(\tilde{t}, \tilde{\nu}) \geq 0.5 m(\tilde{t}_1) + m(\tilde{t}_2^0)$	ATLAS-CONF-2016-096
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \tilde{t}_1 \rightarrow W \tilde{t}^0 \tilde{q}^0$	$2-3 e, \mu$	0-2 jets	Yes	20.3	$\tilde{t}_1^*, \tilde{t}_2^*$	425 GeV	$m(\tilde{t}_1) \geq m(\tilde{t}_2^0), m(\tilde{t}_1^0) \geq 0, m(\tilde{t}, \tilde{\nu}) \geq 0.5 m(\tilde{t}_1) + m(\tilde{t}_2^0)$	1403.5294, 1402.7029
	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \tilde{t}_1 \rightarrow W \tilde{t}^0 \tilde{q}^0, h, h \rightarrow b\bar{b} WW/\tau\tau/\gamma\gamma$	e, μ, γ	0-2 b	Yes	20.3	$\tilde{t}_1^*, \tilde{t}_2^*$	270 GeV	$m(\tilde{t}_1) \geq m(\tilde{t}_2^0), m(\tilde{t}_1^0) \geq 0, m(\tilde{t}, \tilde{\nu}) \geq 0.5 m(\tilde{t}_1) + m(\tilde{t}_2^0)$	1501.07110
EW direct	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \tilde{t}_1 \rightarrow \tilde{t}^0 \tilde{t}^0$	$4 e, \mu$	0	Yes	20.3	$\tilde{t}_{1,2}$	635 GeV	$m(\tilde{t}_1) \geq m(\tilde{t}_2^0), m(\tilde{t}_1^0) \geq 0, m(\tilde{t}, \tilde{\nu}) \geq 0.5 m(\tilde{t}_1) + m(\tilde{t}_2^0)$	1405.5086
	GGM (wino NLSP) weak prod.	$1 e, \mu + \gamma$	-	Yes	20.3	$\tilde{H}$	115-370 GeV	$\tau < 1 \text{ mm}$	1507.05493
	GGM (bino NLSP) weak prod.	2γ	-	Yes	20.3	$\tilde{H}$	590 GeV	$\tau < 1 \text{ mm}$	1507.05493
	Direct $\tilde{t}_1^* \tilde{t}_1^*$ prod., long-lived $\tilde{t}_1^0$	Disapp. trk	1 jet	Yes	20.3	$\tilde{t}_1^*$	270 GeV	$m(\tilde{t}_1^*) + m(\tilde{t}_2^0) > 160 \text{ MeV}, m(\tilde{t}_1^0) > 0.2 \text{ ns}$	131.03675
	Direct $\tilde{t}_1^* \tilde{t}_1^*$ prod., long-lived $\tilde{t}_1^0$	dE/dx trk	-	Yes	18.4	$\tilde{t}_1^*$	495 GeV	$m(\tilde{t}_1^*) + m(\tilde{t}_2^0) > 160 \text{ MeV}, m(\tilde{t}_1^0) < 1.5 \text{ ns}$	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	800 GeV	$m(\tilde{g}) \geq 100 \text{ GeV}, 10 \mu\text{s} < \tau(\tilde{g}) < 1000 \text{ s}$	131.03584
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	$\tilde{g}$	1.58 TeV	-	1606.05129
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$	1.57 TeV	-	1604.04520
	GMSB, stable $\tilde{t}_1, \tilde{t}_1^0 \rightarrow \tilde{t}^0, \tilde{t}^0 \rightarrow \tilde{t}^0, \tilde{t}^0 \rightarrow \tilde{t}^0$	$1-2 \mu$	-	-	19.1	$\tilde{t}_1^*$	537 GeV	$m(\tilde{t}_1^*) \geq 100 \text{ GeV}, \tau > 10 \text{ ns}$	1411.6795
	GMSB, $\tilde{t}_1^0 \rightarrow \tilde{t}^0$, long-lived $\tilde{t}_1^0$	2γ	-	Yes	20.3	$\tilde{t}_1^*$	440 GeV	$1 < \tau(\tilde{t}_1^0) < 3 \text{ ns}$, SP8B model	1409.5542
Long-lived particles	$\tilde{g}\tilde{g}, \tilde{t}_1^0 \rightarrow \text{neutrino}/\mu\nu$	displ. $\text{ee}/\mu/\mu\mu$	-	-	20.3	$\tilde{t}_1^*$	1.0 TeV	$7 < \tau(\tilde{t}_1^0) < 740 \text{ mm}, m(\tilde{g}) \geq 1.3 \text{ TeV}$	1504.05162
	GGM $\tilde{g}\tilde{g}, \tilde{t}_1^0 \rightarrow Z \tilde{q}^0$	displ. vtx + jets	-	-	20.3	$\tilde{t}_1^*$	1.0 TeV	$8 < \tau(\tilde{t}_1^0) < 480 \text{ mm}, m(\tilde{g}) \geq 1.1 \text{ TeV}$	1504.05162
	LFV $\mu\mu \rightarrow \nu_e + X, \nu_e \rightarrow \mu\mu/\text{ee}/\mu\tau$	$\mu\mu/\text{ee}/\mu\tau$	-	-	3.2	$\tilde{t}_1^*$	1.9 TeV	$\tilde{t}_{1,2} > 11, \tilde{t}_{1,2}/100\text{ps} > 0.07$	1607.08079
	Binuclear RPV CMSSM	$2 e, \mu$ (SS)	0-3 b	Yes	20.3	$\tilde{g}, \tilde{q}$	1.45 TeV	$m(\tilde{g})=m(\tilde{q}), \tau_{\tilde{g}, \tilde{q}} < 1 \text{ mm}$	1404.2500
	$\tilde{t}_1^* \tilde{t}_1^*, \tilde{t}_1^0 \rightarrow W \tilde{t}^0 \tilde{q}^0$	$4 e, \mu$	-	Yes	13.3	$\tilde{t}_1^*$	1.14 TeV	$m(\tilde{t}_1^*) > 400 \text{ GeV}, \tilde{t}_{1,2} \neq 0 (k=1, 2)$	ATLAS-CONF-2016-075
	$\tilde{t}_1^* \tilde{t}_1^*, \tilde{t}_1^0 \rightarrow W \tilde{t}^0 \tilde{q}^0, \tilde{t}_1^0 \rightarrow \tau\tau/\nu_e, \nu_e \tau/\nu_e$	$3 e, \mu + \tau$	-	Yes	20.3	$\tilde{t}_1^*$	450 GeV	$m(\tilde{t}_1^*) > 0.2 m(\tilde{t}_2^0), \tilde{t}_{1,2} \neq 0$	1405.5086
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow \tilde{q}\tilde{q}$	0	4-5 large-R jets	-	14.8	$\tilde{g}$	1.08 TeV	$\text{BR}(\tilde{g} \rightarrow \text{BR}(\tilde{q}) \rightarrow \text{BR}(\tilde{q})) < 0\%$	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow \tilde{q}\tilde{q}, \tilde{t}_1^0 \rightarrow \tilde{q}\tilde{q}$	0	4-5 large-R jets	-	14.8	$\tilde{g}$	1.55 TeV	$m(\tilde{t}_1^0) > 800 \text{ GeV}$	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow \tilde{t}\tilde{t}, \tilde{t}_1^0 \rightarrow \tilde{q}\tilde{q}$	$1 e, \mu$	8-10 jets/0-4 b	-	14.8	$\tilde{g}$	1.75 TeV	$m(\tilde{t}_1^0) > 700 \text{ GeV}$	ATLAS-CONF-2016-094
	$\tilde{g}\tilde{g}, \tilde{g}\tilde{g} \rightarrow \tilde{t}\tilde{t}, \tilde{t}_1^0 \rightarrow \tilde{q}\tilde{q}$	$1 e, \mu$	8-10 jets/0-4 b	-	14.8	$\tilde{g}$	1.4 TeV	$825 \text{ GeV} < m(\tilde{t}_1^0) < 850 \text{ GeV}$	ATLAS-CONF-2016-094
RPV	$\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow b\bar{b}$	0	2 jets + 2 b	-	15.4	$\tilde{t}_1$	410 GeV	$\text{BR}(\tilde{t}_1 \rightarrow b\bar{b}) > 20\%$	ATLAS-CONF-2016-032, ATLAS-CONF-2016-084
	$\tilde{t}_1^0, \tilde{t}_1^0 \rightarrow b\bar{b}$	$2 e, \mu$	2 b	-	20.3	$\tilde{t}_1$	450-510 GeV	-	ATLAS-CONF-2015-015
	Scalar charm, $\tilde{c} \rightarrow c \tilde{c}_1^0$	0	2 c	Yes	20.3	$\tilde{c}$	510 GeV	$m(\tilde{c}_1^0) < 280 \text{ GeV}$	1501.01325

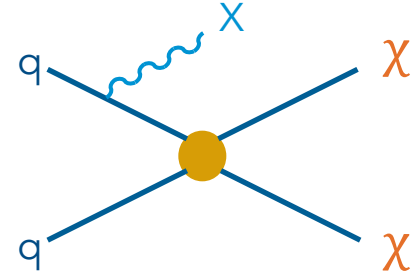
*Only a selection of the available mass limits on new states or phenomena is shown.

Mass scale [TeV]

Dark Matter search

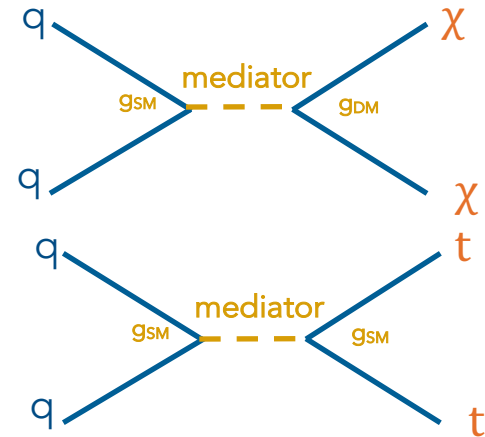
Simple approach at LHC : mono-X and EFT

- Add a single DM candidate to SM : χ
- Look for mono-X event (mono-jet, mono-photon...)
- However, only valid if $q^2 < m_{\text{med}}^2$

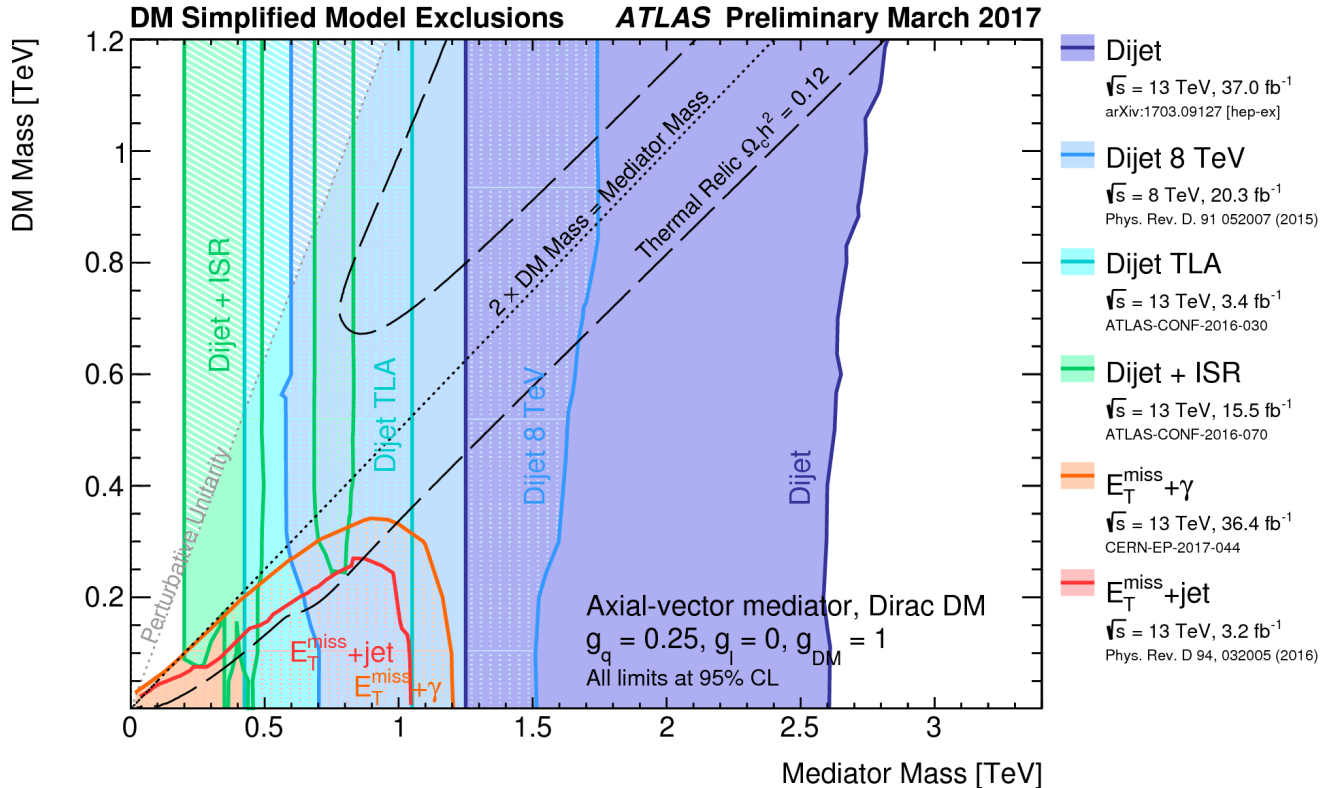


Complementary (better) approach

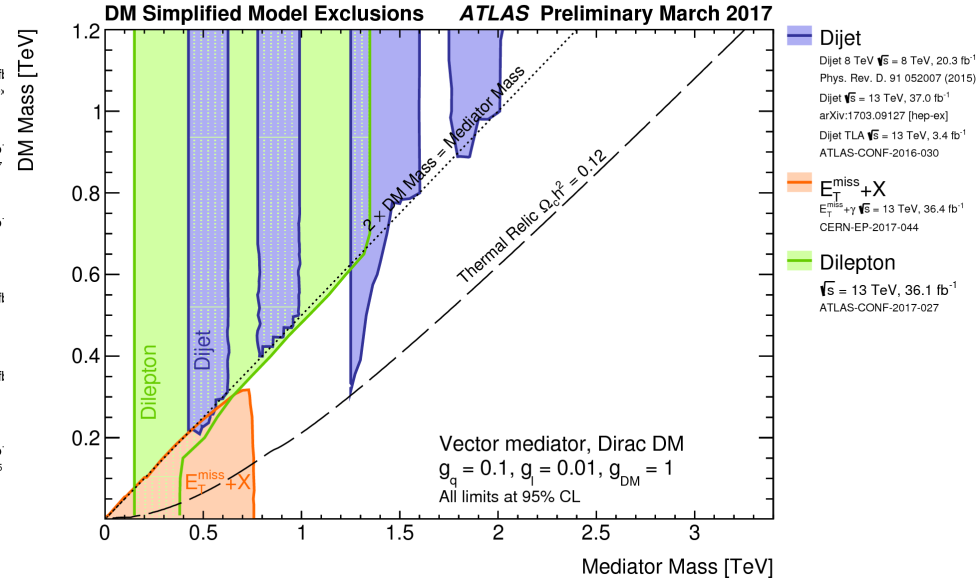
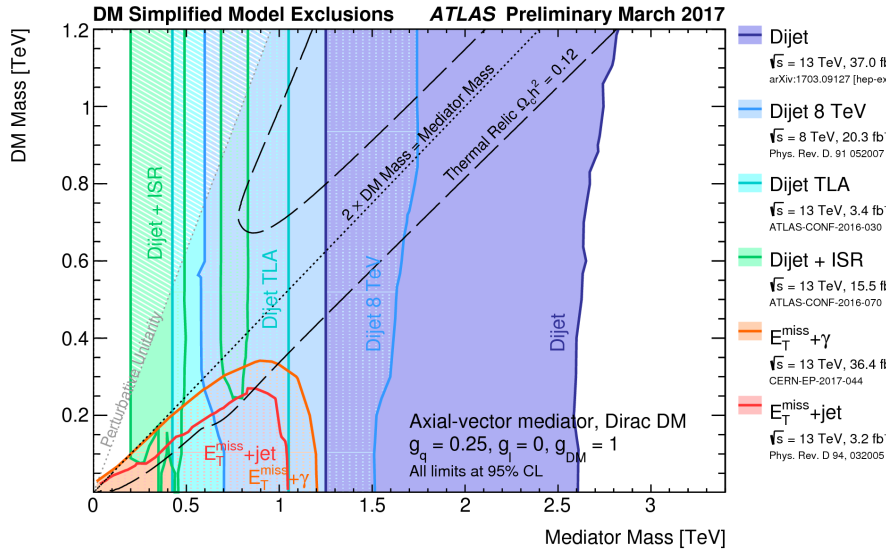
- Add a single DM candidate and a mediator
- Allow to use other signatures to probe mediator and thus constrains the model
- Relax q^2 limit but more model dependent



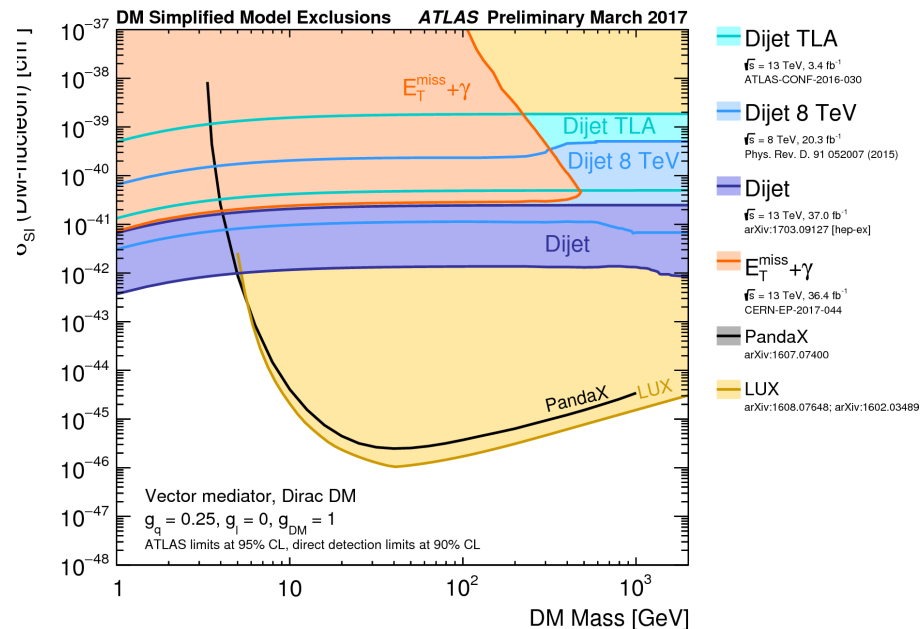
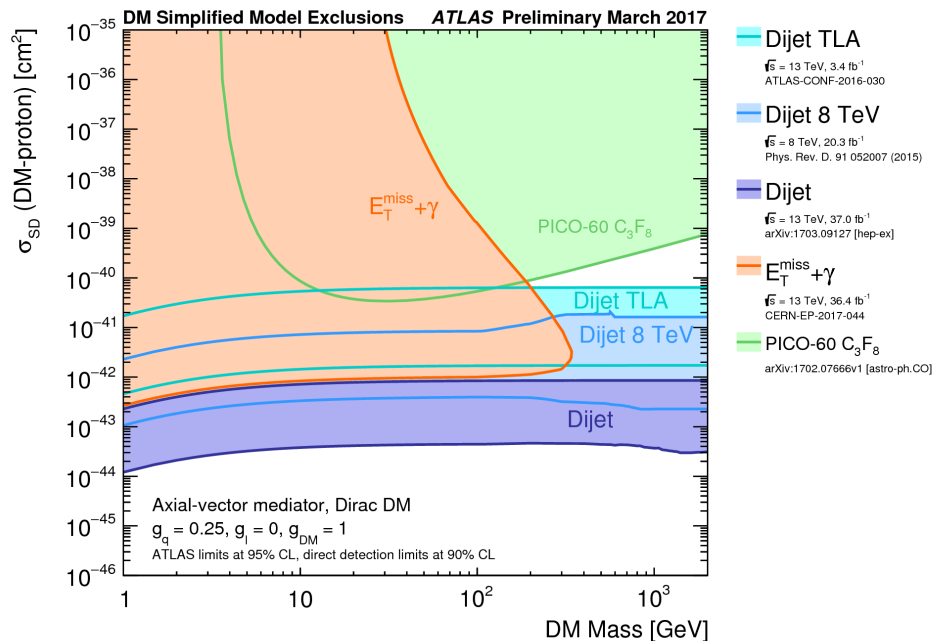
Dark Matter search



Dark Matter search



Complementarity with direct searches

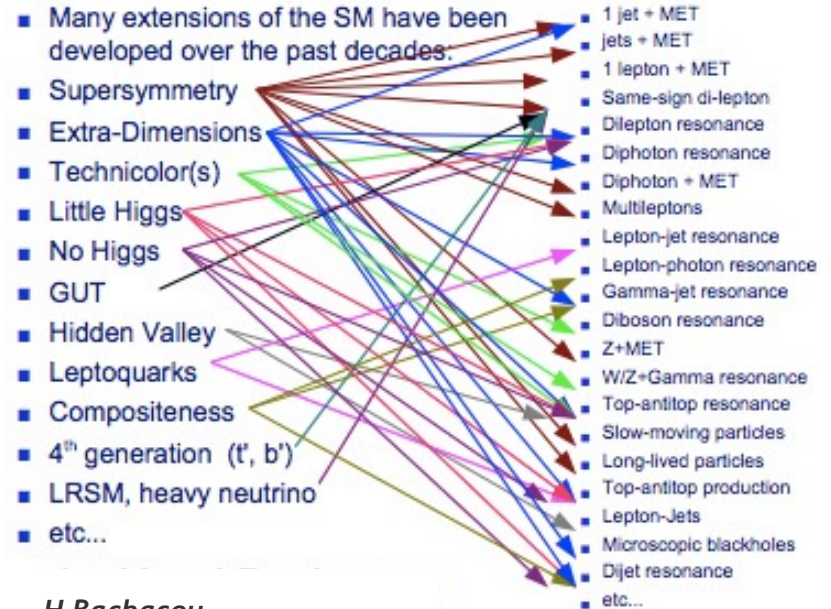


Exotics

These analyses allow to search for particles predicted by a wide range of models:

- Extra-dimensions:
 - Solve the hierarchy problem: gravity is diluted in extra dimensions
 - Compactified dimensions: signature can be Kaluza Klein excitation of particles (gluon, graviton)
- New symmetry group = New gauge bosons
- Heavy quarks, excited leptons
- Leptoquarks (particles with both baryon and lepton numbers)
- ...

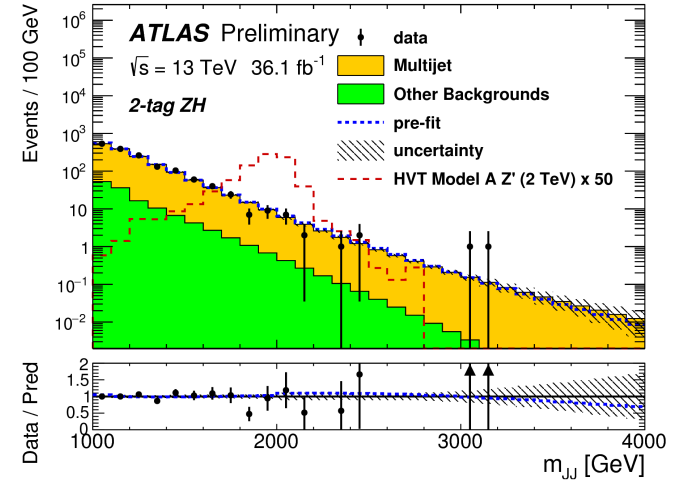
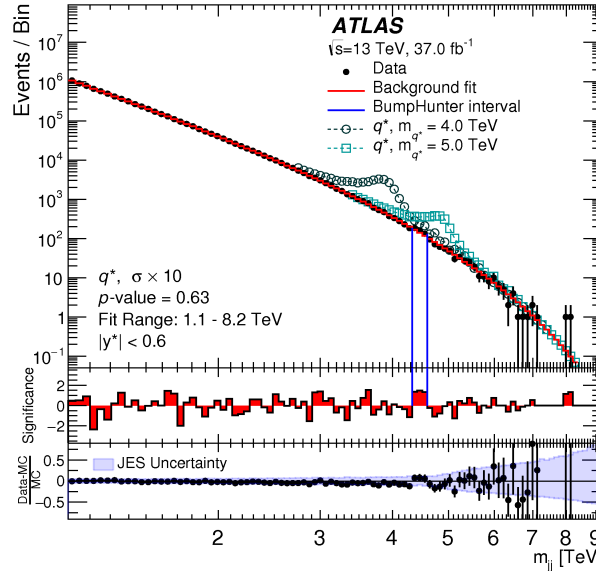
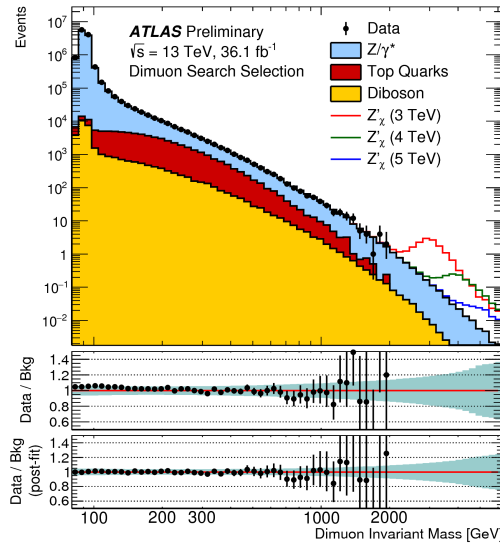
A lot of different signatures



H Bachacou

Exotics

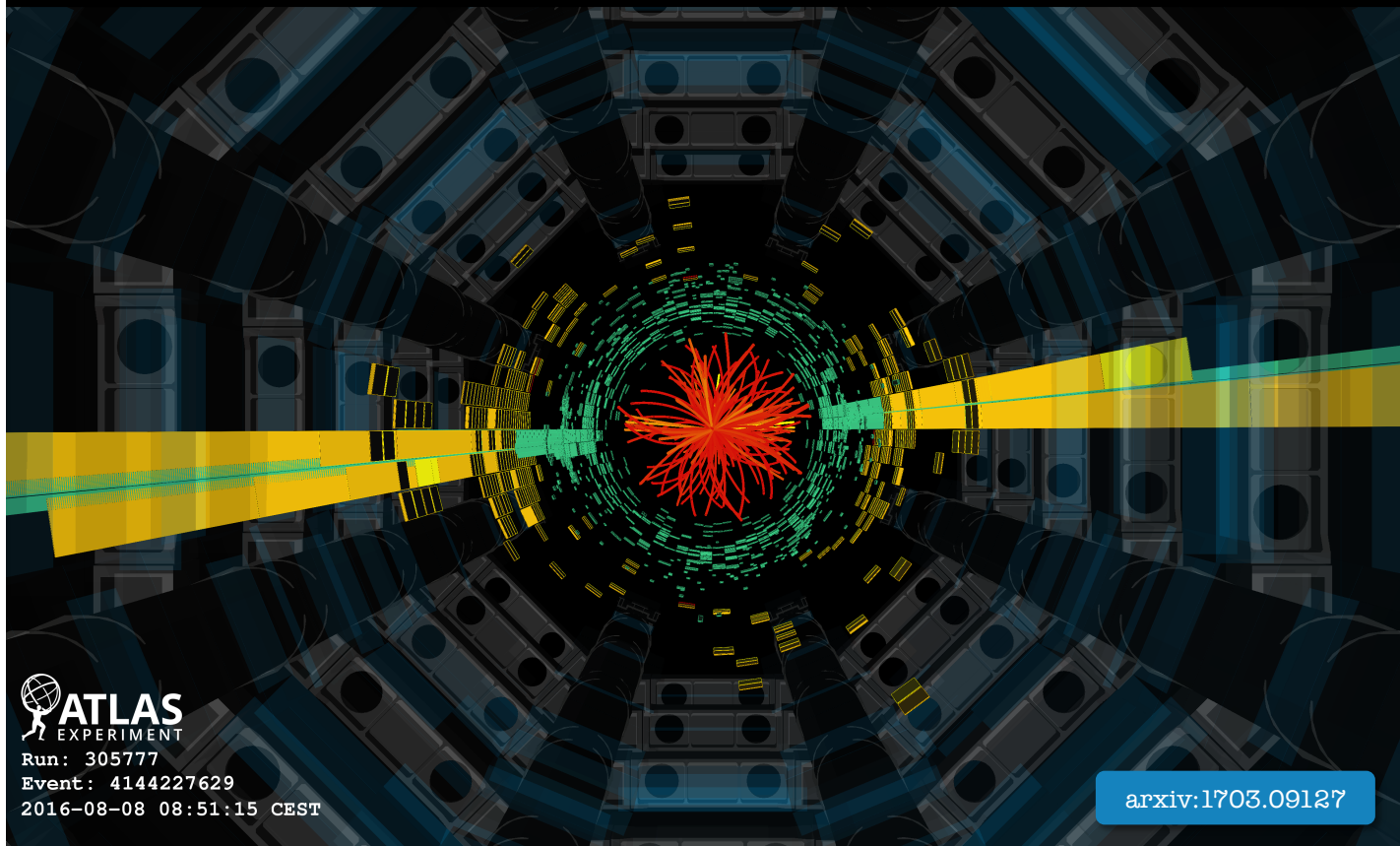
A wide range of searches



... sometimes with very exotics signatures

- Ex: long lived particles → complicated signature searches just starting

High Mass **Di-Jet** Search



 **ATLAS**
EXPERIMENT

Run: 305777

Event: 4144227629

2016-08-08 08:51:15 CEST

arxiv:1703.09127

Highest-mass dijet event: $m_{jj} = 8.12 \text{ TeV}$, $|y^| = 0.38$*

$$\int \mathcal{L} dt = (3.2 - 20.3) \text{ fb}^{-1}$$

$$\sqrt{s} = 8, 13 \text{ TeV}$$

	Model	ℓ, γ	Jets [†]	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
Extra dimensions	ADD $G_{KK} + g/q$	—	$\geq 1j$	Yes	3.2	M_D 6.58 TeV	$n = 2$ 1604.07773
	ADD non-resonant $\ell\ell$	$2e, \mu$	—	—	20.3	M_S 4.7 TeV	$n = 3 \text{ HLZ}$ 1407.2410
	ADD QBH $\rightarrow \ell q$	$1e, \mu$	$1j$	—	20.3	M_{th} 5.2 TeV	$n = 6$ 1311.2006
	ADD QBH	—	$2j$	—	15.7	M_{th} 8.7 TeV	$n = 6$ ATLAS-CONF-2016-069
	ADD BH high $\sum p_T$	$\geq 1e, \mu$	$\geq 2j$	—	3.2	M_{th} 8.2 TeV	$n = 6, M_D = 3 \text{ TeV, rot BH}$ 1606.02265
	ADD BH multijet	—	$\geq 3j$	—	3.6	M_{th} 9.55 TeV	$n = 6, M_D = 3 \text{ TeV, rot BH}$ 1512.02586
	RS1 $G_{KK} \rightarrow \ell\ell$	$2e, \mu$	—	—	20.3	$G_{KK} \text{ mass}$ 2.68 TeV	$k/M_{\text{Pl}} = 0.1$ 1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	—	—	3.2	$G_{KK} \text{ mass}$ 3.2 TeV	$k/M_{\text{Pl}} = 0.1$ 1606.03833
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	$1e, \mu$	$1J$	Yes	13.2	$G_{KK} \text{ mass}$ 1.24 TeV	$k/M_{\text{Pl}} = 1.0$ ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	—	$4b$	—	13.3	$G_{KK} \text{ mass}$ 360-860 GeV	$k/M_{\text{Pl}} = 1.0$ ATLAS-CONF-2016-049
	Bulk RS $G_{KK} \rightarrow tt$	$1e, \mu$	$\geq 1b, \geq 1J/2j$	Yes	20.3	$G_{KK} \text{ mass}$ 2.2 TeV	$BR = 0.925$ 1505.07018
	2UED / RPP	$1e, \mu$	$\geq 2b, \geq 4j$	Yes	3.2	$KK \text{ mass}$ 1.46 TeV	Tier (1,1), $BR(A^{(1,1)} \rightarrow tt) = 1$ ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2e, \mu$	—	—	13.3	$Z' \text{ mass}$ 4.05 TeV	$g_V = 1$ ATLAS-CONF-2016-045
	SSM $Z' \rightarrow \tau\tau$	2τ	—	—	19.5	$Z' \text{ mass}$ 2.02 TeV	$g_V = 3$ 1502.07177
	Leptophobic $Z' \rightarrow bb$	—	$2b$	—	3.2	$Z' \text{ mass}$ 1.5 TeV	$g_V = 3$ 1603.08791
	SSM $W' \rightarrow \ell\nu$	$1e, \mu$	—	Yes	13.3	$W' \text{ mass}$ 4.74 TeV	ATLAS-CONF-2016-061
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	$0e, \mu$	$1J$	Yes	13.2	$W' \text{ mass}$ 2.4 TeV	ATLAS-CONF-2016-082
	HVT $W' \rightarrow WZ \rightarrow qq\bar{q}q$ model B	—	$2J$	—	15.5	$W' \text{ mass}$ 3.0 TeV	ATLAS-CONF-2016-055
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel	—	—	3.2	$V' \text{ mass}$ 2.31 TeV	1607.05621
	LRSW $W'_R \rightarrow tb$	$1e, \mu$	$2b, 0-1j$	Yes	20.3	$W' \text{ mass}$ 1.92 TeV	1410.4103
CI	LRSW $W'_R \rightarrow tb$	$0e, \mu$	$\geq 1b, 1J$	—	20.3	$W' \text{ mass}$ 1.76 TeV	1408.0886
	CI $qqqq$	—	$2j$	—	15.7	Λ 19.9 TeV	$\eta_{LL} = -1$ ATLAS-CONF-2016-069
	CI $\ell\ell qq$	$2e, \mu$	—	—	3.2	Λ 25.2 TeV	$\eta_{LL} = -1$ 1607.03669
	CI $uutt$	$2(SS)/\geq 3e, \mu$	$\geq 1b, \geq 1j$	Yes	20.3	Λ 4.9 TeV	$ C_{RR} = 1$ 1504.04605
DM	Axial-vector mediator (Dirac DM)	$0e, \mu$	$\geq 1j$	Yes	3.2	m_A 1.0 TeV	$g_{\sigma}=0.25, g_{\pi}=1.0, m(\chi) < 250 \text{ GeV}$ 1604.07773
	Axial-vector mediator (Dirac DM)	$0e, \mu, 1\gamma$	$1j$	Yes	3.2	m_A 710 GeV	$g_{\sigma}=0.25, g_{\pi}=1.0, m(\chi) < 150 \text{ GeV}$ 1604.01306
	ZZ $\chi\chi$ EFT (Dirac DM)	$0e, \mu$	$1J, \leq 1j$	Yes	3.2	M_{χ} 550 GeV	$m(\chi) < 150 \text{ GeV}$ ATLAS-CONF-2015-080
LQ	Scalar LQ 1 st gen	$2e$	$\geq 2j$	—	3.2	LQ mass 1.1 TeV	$\beta = 1$ 1605.06035
	Scalar LQ 2 nd gen	$2e$	$\geq 2j$	—	3.2	LQ mass 1.05 TeV	$\beta = 1$ 1605.06035
	Scalar LQ 3 rd gen	$1e, \mu$	$\geq 1b, \geq 3j$	Yes	20.3	LQ mass 640 GeV	$\beta = 0$ 1508.04735
Heavy quarks	VLQ $TT \rightarrow Ht + X$	$1e, \mu$	$\geq 2b, \geq 3j$	Yes	20.3	T mass 855 GeV	T in (T,B) doublet 1505.04306
	VLQ $YY \rightarrow Wb + X$	$1e, \mu$	$\geq 1b, \geq 3j$	Yes	20.3	Y mass 770 GeV	Y in (B,Y) doublet 1505.04306
	VLQ $BB \rightarrow Hb + X$	$1e, \mu$	$\geq 2b, \geq 3j$	Yes	20.3	B mass 735 GeV	isospin singlet 1505.04306
	VLQ $BB \rightarrow Zb + X$	$2/\geq 3e, \mu$	$\geq 2/\geq 1b$	—	20.3	B mass 755 GeV	B in (B,Y) doublet 1409.5500
	VLQ $QQ \rightarrow WqWq$	$1e, \mu$	$\geq 4j$	Yes	20.3	Q mass 690 GeV	1509.04261
	VLQ $T_{5/3}T_{5/3} \rightarrow WtWt$	$2(SS)/\geq 3e, \mu$	$\geq 1b, \geq 1j$	Yes	3.2	$T_{5/3} \text{ mass}$ 990 GeV	ATLAS-CONF-2016-032
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1γ	$1j$	—	3.2	$q^* \text{ mass}$ 4.4 TeV	only u' and d' , $\Lambda = m(q')$ 1512.05910
	Excited quark $q^* \rightarrow qg$	—	$2j$	—	15.7	$q^* \text{ mass}$ 5.6 TeV	only u' and d' , $\Lambda = m(q')$ ATLAS-CONF-2016-069
	Excited quark $b^* \rightarrow b\gamma$	—	$1b, 1j$	—	8.8	$b^* \text{ mass}$ 2.3 TeV	ATLAS-CONF-2016-060
	Excited quark $b^* \rightarrow Wt$	$1 \text{ or } 2e, \mu$	$1b, 2-0j$	Yes	20.3	$b^* \text{ mass}$ 1.5 TeV	$f_L = f_t = f_R = 1$ 1510.02664
	Excited lepton ℓ^*	$3e, \mu$	—	—	20.3	$\ell^* \text{ mass}$ 3.0 TeV	$\Lambda = 3.0 \text{ TeV}$ 1411.2921
	Excited lepton ν^*	$3e, \mu, \tau$	—	—	20.3	$\nu^* \text{ mass}$ 1.6 TeV	$\Lambda = 1.6 \text{ TeV}$ 1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	$1e, \mu, 1\gamma$	—	Yes	20.3	$a_T \text{ mass}$ 960 GeV	$m(W_0) = 2.4 \text{ TeV, no mixing}$ 1407.8150
	LRSW Majorana ν	$2e, \mu$	$2j$	—	20.3	$N^0 \text{ mass}$ 2.0 TeV	1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow ee$	$2e (SS)$	—	—	13.9	$H^{\pm\pm} \text{ mass}$ 570 GeV	DY production, $BR(H_t^{\pm\pm} \rightarrow ee)=1$ ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3e, \mu, \tau$	—	—	20.3	$H^{\pm\pm} \text{ mass}$ 400 GeV	DY production, $BR(H_t^{\pm\pm} \rightarrow \ell\tau)=1$ 1411.2921
	Monotop (non-res prod)	$1e, \mu$	$1b$	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$ 1410.5404
	Multi-charged particles	—	—	—	20.3	multi-charged particle mass 785 GeV	DY production, $ q = 5e$ 1504.04188
	Magnetic monopoles	—	—	—	7.0	monopole mass 1.34 TeV	DY production, $ g = 1g_D, \text{ spin } 1/2$ 1509.08059

 $\sqrt{s} = 8 \text{ TeV}$ $\sqrt{s} = 13 \text{ TeV}$ 10^{-1}

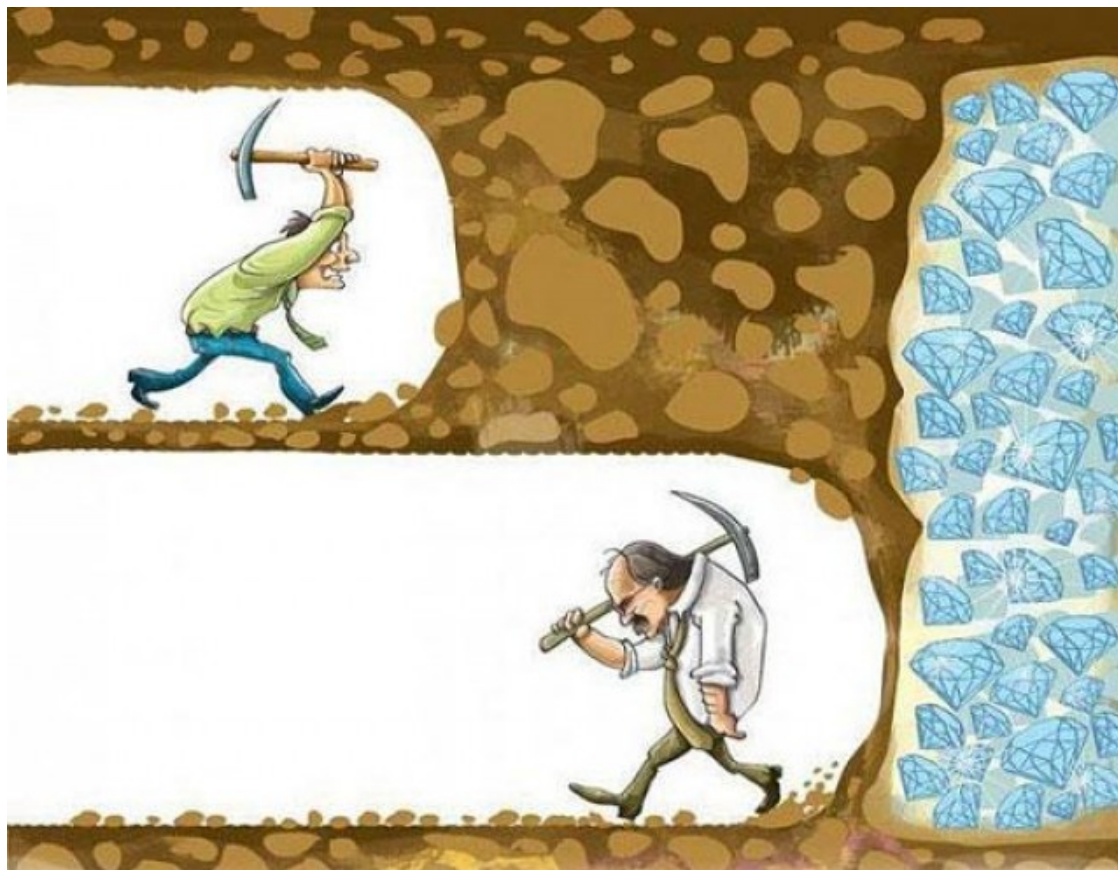
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Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

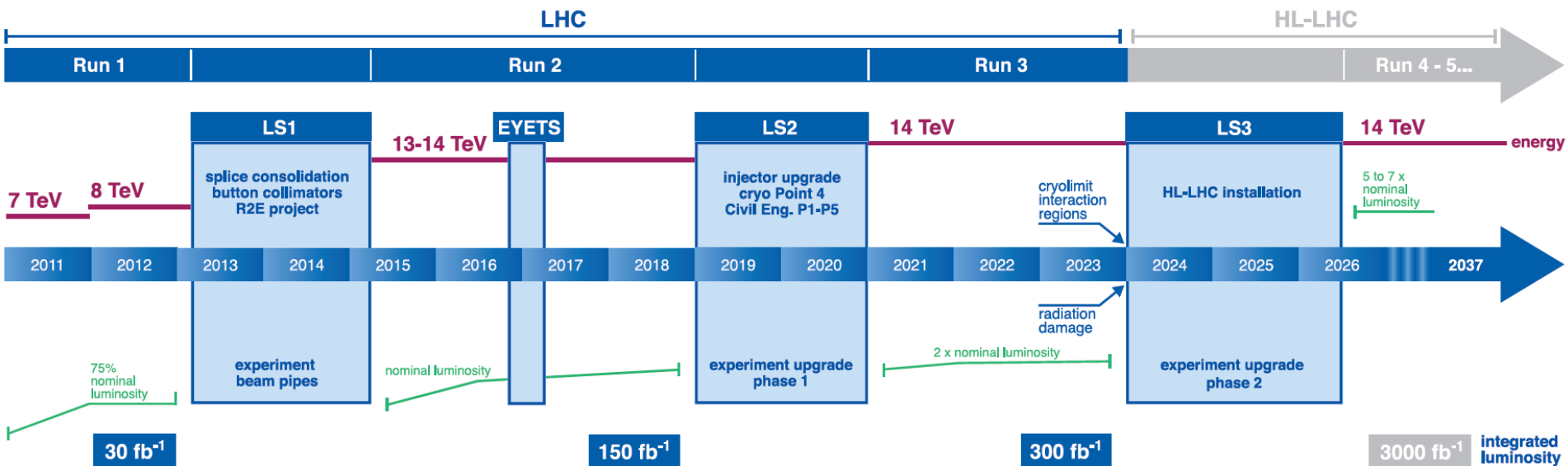
†Small-radius (large-radius) jets are denoted by the letter j (J).





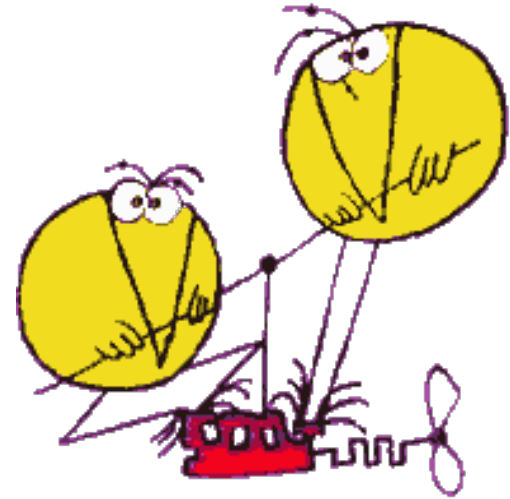
THE FUTURE

LHC / HL-LHC Plan



Program:

- Higgs measurements, in particular Higgs potential: Higgs self coupling
- Search for new phenomena



CONCLUSION

Conclusion

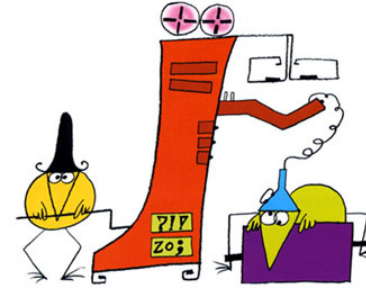
LHC collider and experiments

- Are fantastic, complex and challenging research tools
- Are operated by big international collaborations
- Are functioning extremely well

Results

- Huge amount of results produced since the start in 2011:
 - Standard Model parameters and processes measurements
 - Discovery of a spin 0 particle that has all the properties of a BEH boson
 - Wide program of search for new phenomena
 - No hint for new physics for the moment... but still unexplored territories to probe !

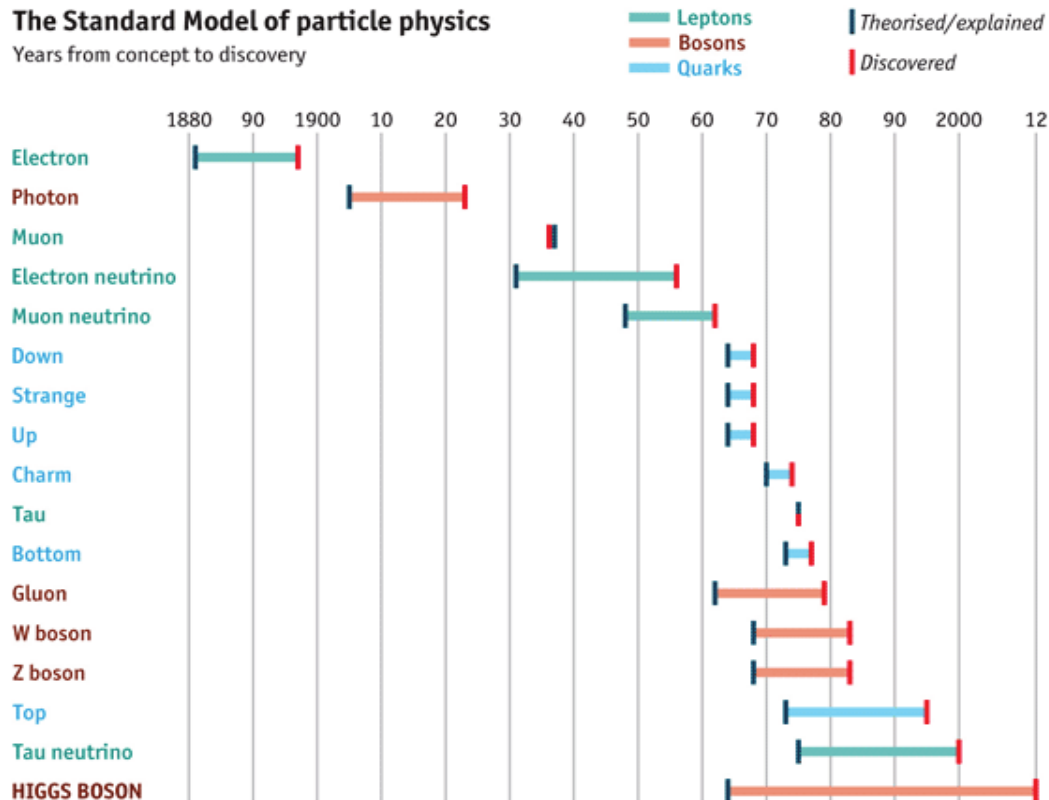




TO GO FURTHER...

The Standard Model of particle physics

Years from concept to discovery



Source: *The Economist*

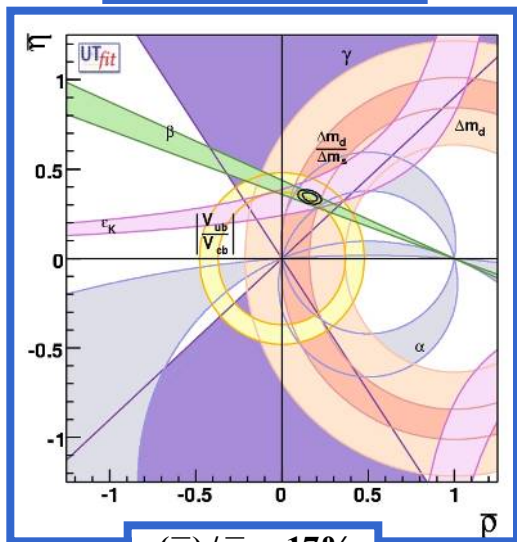
Complementarity with direct and indirect detection

	LHC	Direct Detection	Indirect Detection
scalar	low xsec, soft spectra	$:\mid$	
pseudo-scalar	low xsec, soft spectra	$:\prime($ (velocity suppressed)	$:)$
vector	large xsec	$:)$ (spin independent)	
axial-vector	large xsec	$:($ (spin-dependent: experimental issue)	

Dessin de Chappatte



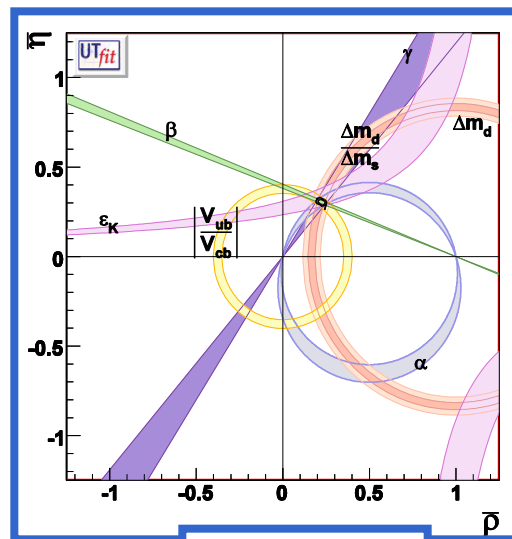
Summer
2006



$$\sigma(\bar{\rho})/\bar{\rho} = 17\%$$

$$\sigma(\bar{\eta})/\bar{\eta} = 4.7\%$$

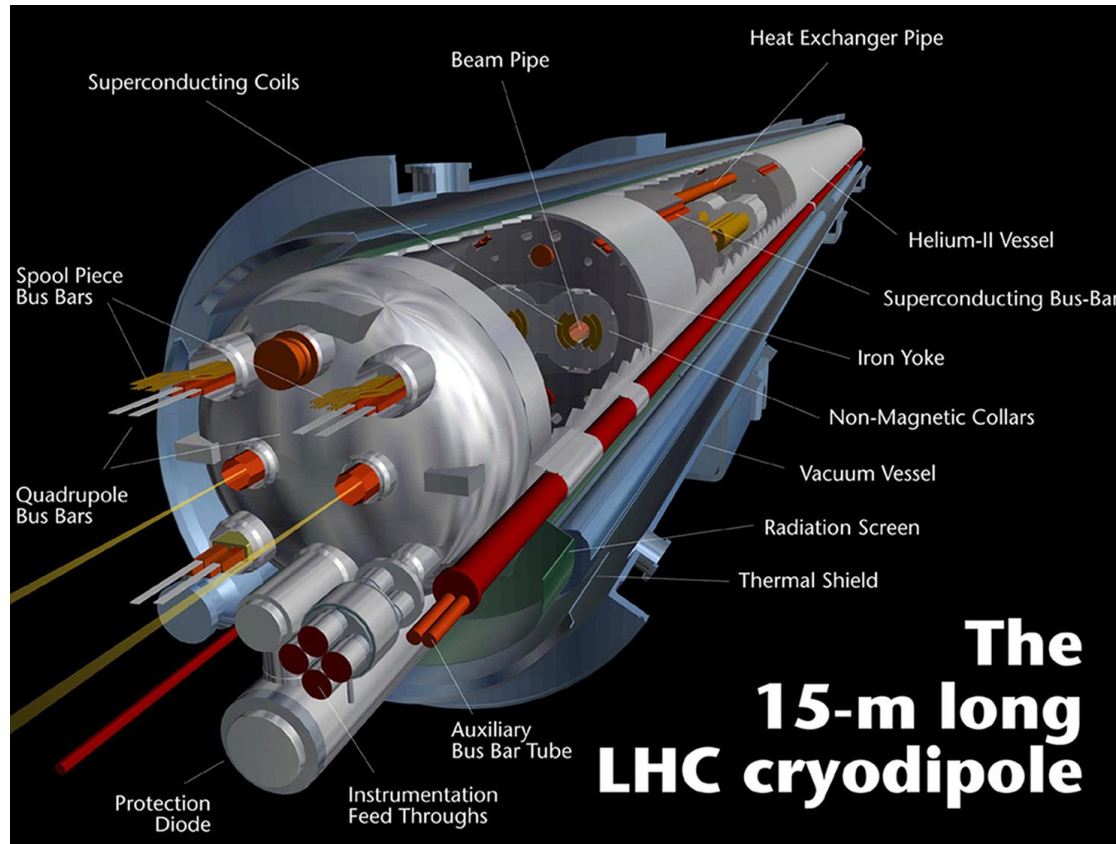
LHCb at
 $L=10\text{fb}^{-1}$



$$\sigma(\bar{\rho})/\bar{\rho} = 3.5\%$$

$$\sigma(\bar{\eta})/\bar{\eta} = 1.7\%$$

LHC Cryodipole



Un puzzle géant !

