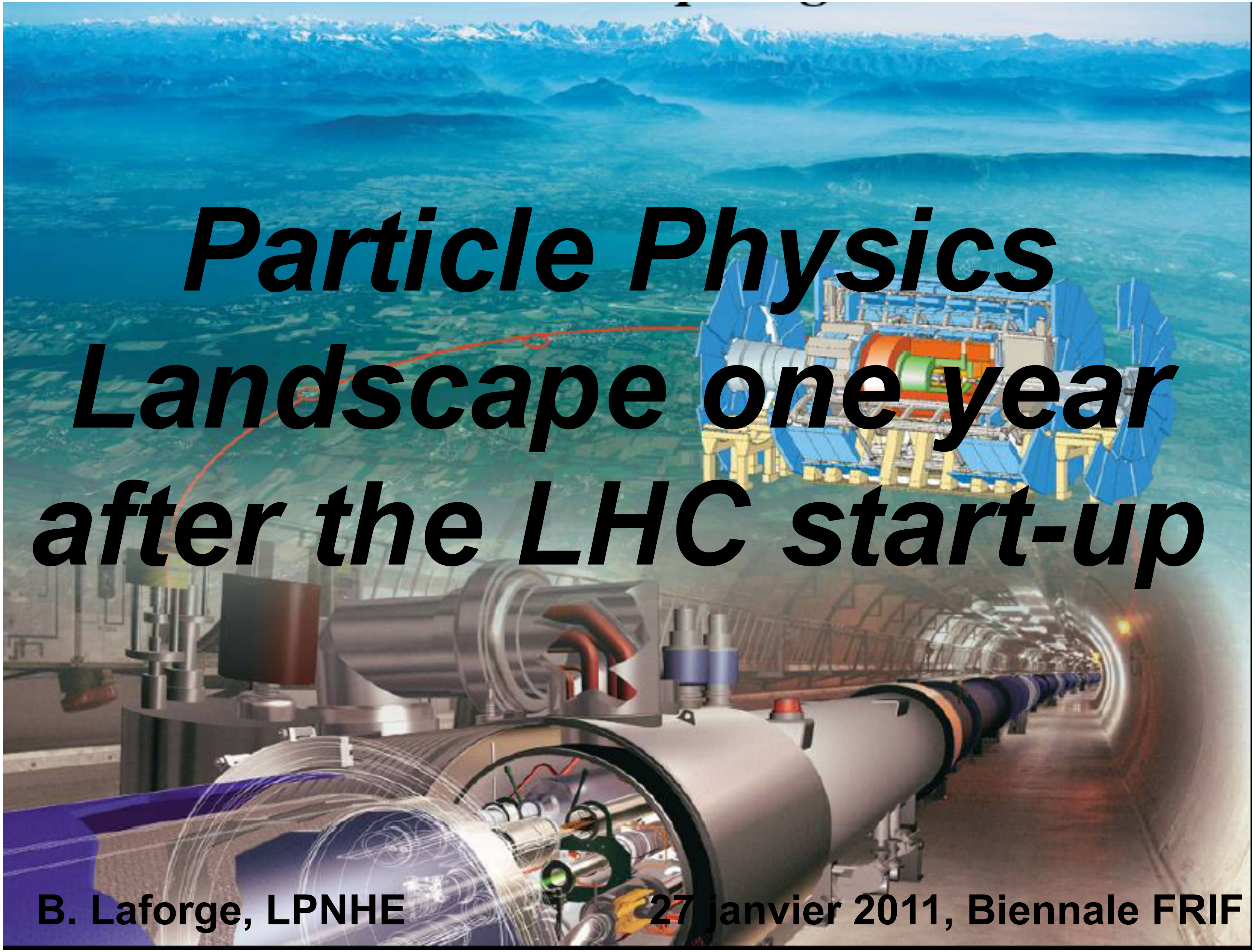
Particle Physics Landscape one year after the LHC start-up



B. Laforge, LPNHE

27 janvier 2011, Biennale FRIF

Today's talk :

- The Standard Model of particle physics :
  - Reminder : how the SM is built
  - Open issues
- LHC in action :
  - recent results from the ATLAS (and CMS) experiment

The Standard Model of Particle Physics

• aims at describing matter with the minimal of elementary constituants (quantum fields)

• aims at describing fondamental interactions between constituants using gauge theories

3 families of particles

4 interactions

Bosons $W^{+/-}$, Z^0

massifs ~ 100 GeV

+ Higgs Mécanism

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2				Quarks spin = 1/2		
Flavor	Mass GeV/c²	Electric charge		Flavor	Approx. Mass GeV/c²	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0		u up	0.003	2/3
e electron	0.000511	−1		d down	0.006	−1/3
ν_μ muon neutrino	<0.0002	0		c charm	1.3	2/3
μ muon	0.106	−1		s strange	0.1	−1/3
ν_τ tau neutrino	<0.02	0		t top	175	2/3
τ tau	1.7771	−1		b bottom	4.3	−1/3

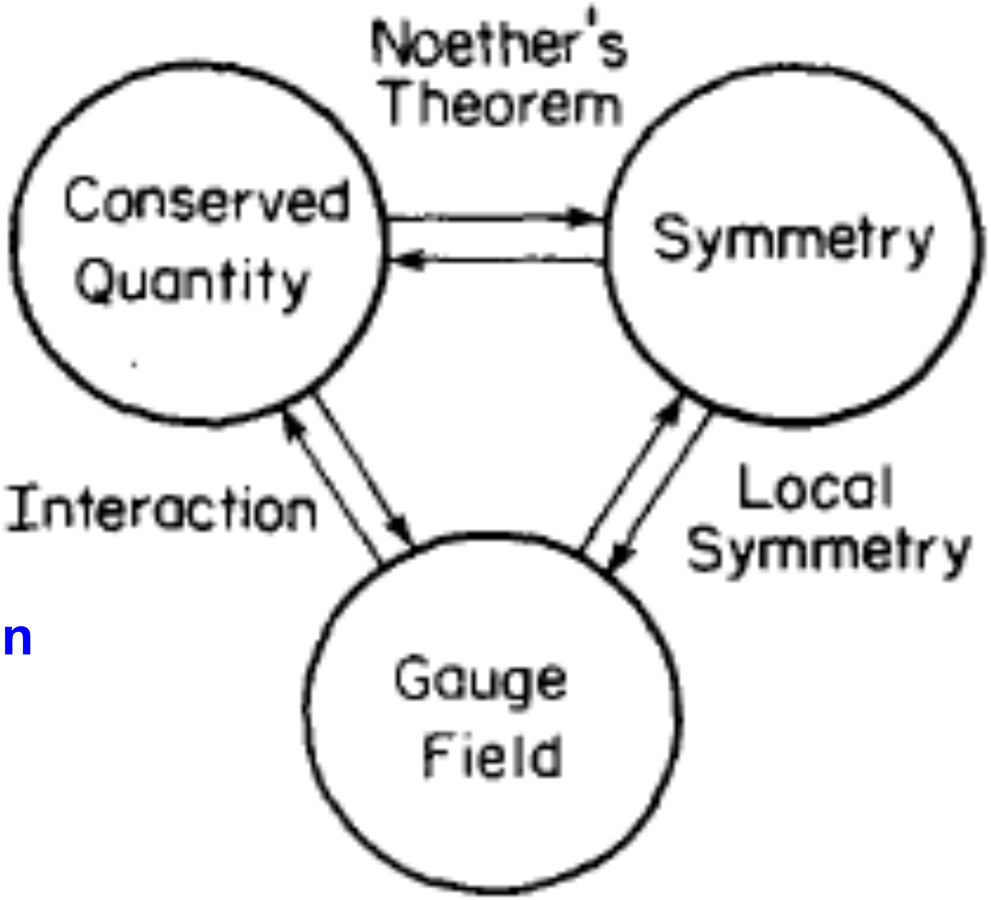
Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
3×10^{-17} m	10^{-41}	10^{-4}	1	60	

The framework behind the Standard Model

Use quantum Field theory to describe free motion and Interactions.

-Interactions result from local gauge symetries of the Lagrangian

-Conservation laws arise from the symetries of the Lagrangian through the Noether theorem



Works for strong, electroweak interactions not for gravity !

The problem of Masses in the Standard Model

~~$M_W^2 W_\mu^a W^{\mu a}$~~ → **Gauge symmetry**

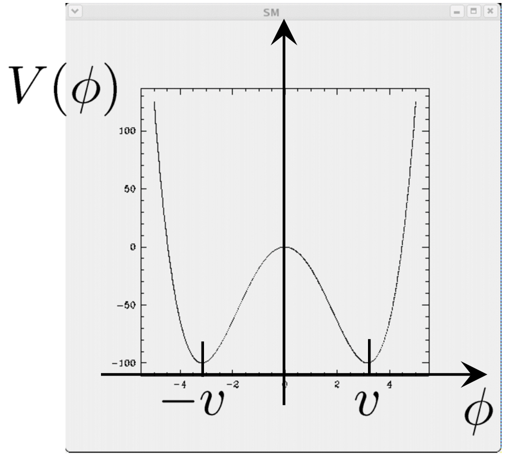
$-m\bar{\Psi}\Psi = $ ~~$-m(\bar{\Psi}_L\Psi_R + \bar{\Psi}_R\Psi_L)$~~ → **Chiral gauge symmetry**

A solution is a dynamical mechanism : Higgs mechanism with Yukawa couplings to give masses to the W, Z and fermions.

The Higgs Mechanism in the Standard Model

- A scalar field is introduced with a potential of the type:

$$V(\phi) = -\mu^2\phi^2 + \lambda\phi^4$$



$$\phi \rightarrow -\phi$$

- The lagrangian is symmetric but the minimum of the potential does not share the same symmetry
- When the scalar field stays in one of the minima of the potential, the symmetry is spontaneously broken

$\langle 0|\phi|0\rangle = v$ **is not symmetric** $v = \sqrt{-\mu^2/(2\lambda)}$

Higgs in the Standard Model

Further reading : The Higgs boson in the standard model. hep-ph/0503172, A. Djouadi

$$\mathcal{L} = \mathcal{L}_{gauge} + \mathcal{L}_{Yukawa} + \mathcal{L}_{Higgs}$$

$$\begin{aligned}
\mathcal{L}_{gauge} &= -\frac{1}{4}G^a_{\mu\nu}G^a_{\mu\nu} - \frac{1}{4}W^i_{\mu\nu}W^i_{\mu\nu} - \frac{1}{4}B_{\mu\nu}B_{\mu\nu} \\
&+ i\overline{L}_\alpha\gamma^\mu D_\mu L_\alpha + i\overline{Q}_\alpha\gamma^\mu D_\mu Q_\alpha + i\overline{E}_\alpha\gamma^\mu D_\mu E_\alpha \\
&+ i\overline{U}_\alpha\gamma^\mu D_\mu U_\alpha + i\overline{D}_\alpha\gamma^\mu D_\mu D_\alpha + (D_\mu H)^\dagger(D_\mu H)
\end{aligned}$$

$$\mathcal{L}_{Yukawa} = y^L_{\alpha\beta}\overline{L}_\alpha E_\beta H + y^D_{\alpha\beta}\overline{Q}_\alpha D_\beta H + y^U_{\alpha\beta}\overline{Q}_\alpha U_\beta \tilde{H} + h.c.$$

$$\mathcal{L}_{Higgs} = -V = m^2 H^\dagger H - \frac{\lambda}{2}(H^\dagger H)^2$$

$$\begin{aligned}
G^a_{\mu\nu} &= \partial_\mu G^a_\nu - \partial_\nu G^a_\mu + g_s f^{abc} G^b_\mu G^c_\nu, \\
W^i_{\mu\nu} &= \partial_\mu W^i_\nu - \partial_\nu W^i_\mu + g\epsilon^{ijk} W^j_\mu W^k_\nu, \\
B_{\mu\nu} &= \partial_\mu B_\nu - \partial_\nu B_\mu, \\
D_\mu L_\alpha &= (\partial_\mu - i\frac{g}{2}\tau^i W^i_\mu + i\frac{g'}{2}B_\mu)L_\alpha, \\
D_\mu E_\alpha &= (\partial_\mu + ig' B_\mu)E_\alpha, \\
D_\mu Q_\alpha &= (\partial_\mu - i\frac{g}{2}\tau^i W^i_\mu - i\frac{g'}{6}B_\mu - i\frac{g_s}{2}\lambda^a G^a_\mu)Q_\alpha, \\
D_\mu U_\alpha &= (\partial_\mu - i\frac{2}{3}g' B_\mu - i\frac{g_s}{2}\lambda^a G^a_\mu)U_\alpha, \\
D_\mu D_\alpha &= (\partial_\mu + i\frac{1}{3}g' B_\mu - i\frac{g_s}{2}\lambda^a G^a_\mu)D_\alpha.
\end{aligned}$$

$$\tilde{H} = i\tau_2 H^\dagger$$

$$SU_{colour}(3) \otimes SU_{left}(2) \otimes U_{hypercharge}(1)$$

Gauge sector: spin 1

gluons	G^a_μ	$SU_c(3)$	g_s	$(a = 1, 8)$
intermediate weak bosons	W^i_μ	$SU_L(2)$	g	$(i = 1, 3)$
abelian boson	B_μ	$U_Y(1)$	g'	

Fermion sector: spin 1/2

$$\begin{aligned}
L_{\alpha L} &= \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L, \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L, \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L \\
E_{\alpha R} &= e_R, \quad \mu_R, \quad \tau_R,
\end{aligned}$$

$$\begin{aligned}
Q^i_{\alpha L} = \begin{pmatrix} U^i_\alpha \\ D^i_\alpha \end{pmatrix}_L &= \begin{pmatrix} u^i \\ d^i \end{pmatrix}_L, \begin{pmatrix} c^i \\ s^i \end{pmatrix}_L, \begin{pmatrix} t^i \\ b^i \end{pmatrix}_L \\
U^i_{\alpha R} &= u_{iR}, \quad c_{iR}, \quad t_{iR}, \\
D^i_{\alpha R} &= d_{iR}, \quad s_{iR}, \quad b_{iR},
\end{aligned}$$

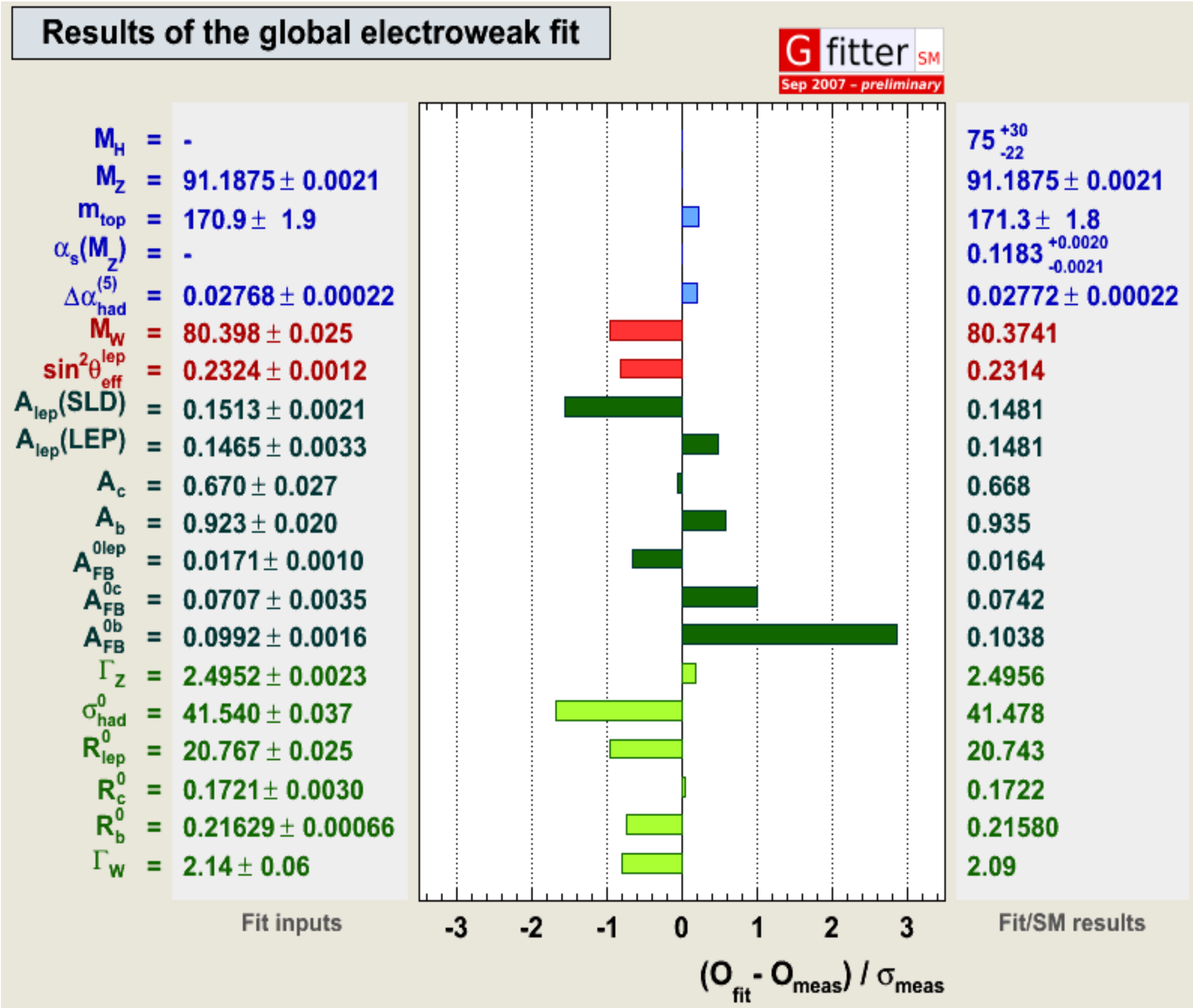
$i = 1, 2, 3$

Higgs sector: spin 0

$$H = \begin{pmatrix} H^0 \\ H^- \end{pmatrix}$$

The Standard Model (SM) of fundamental interactions

For the last 35 years, the SM has been successfully tested in experiments**, with varying levels of accuracy, in many independent sectors :**



Constraints on the Electroweak sector :

Compare many direct measurements and theoretical preds.

Up to ~10ppm precision measurements : Large SM success !

The Standard Model (SM) of fundamental interactions

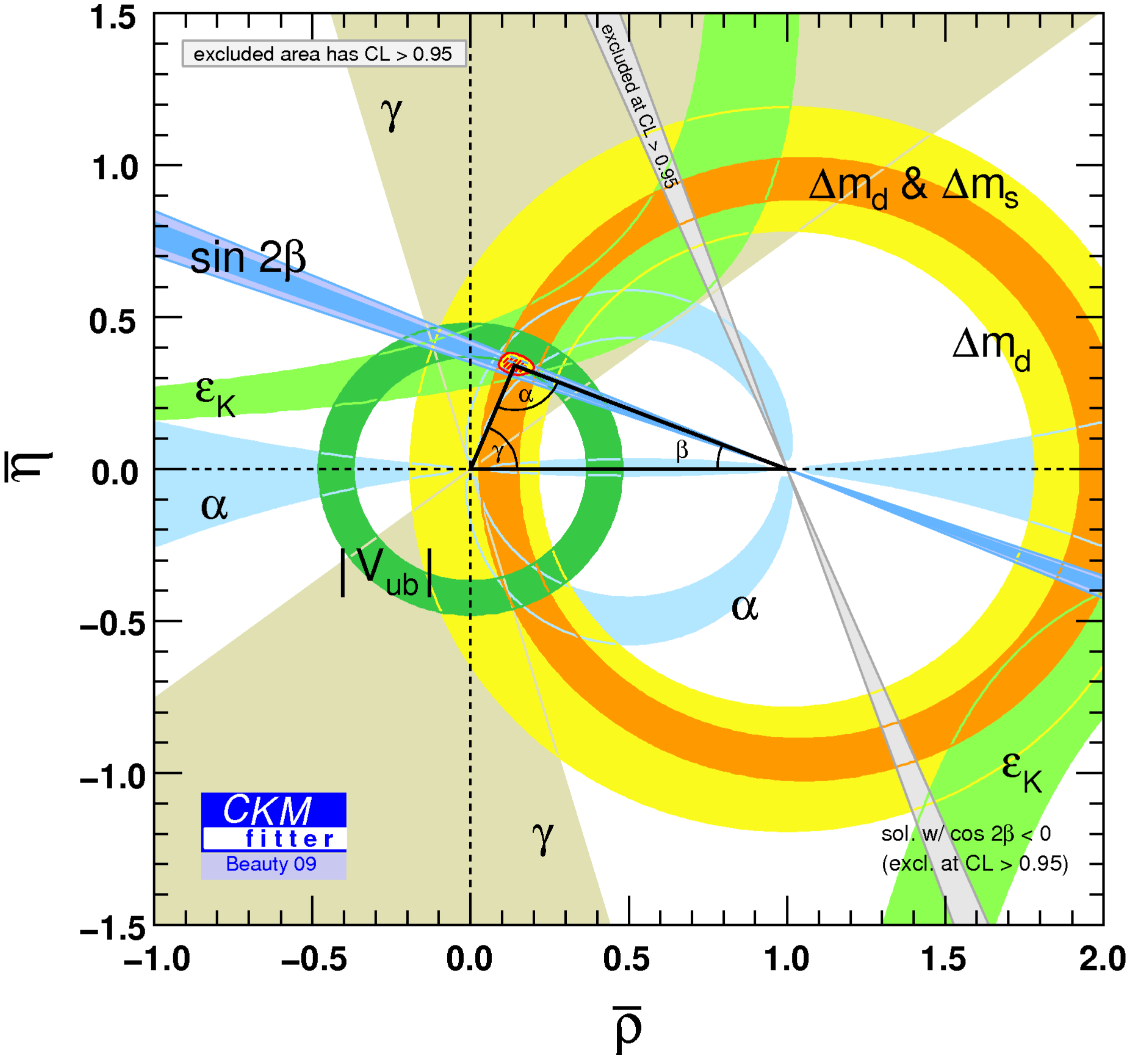
For the last 35 years, the SM has been successfully tested in experiments, with varying levels of accuracy, in many independent sectors :

Constraints on the "quark mixing" (flavour) sector :

Compare many direct measurements and theoretical preds.

All measurements compatible With CKM mixing mechanism :

Another impressive SM success !



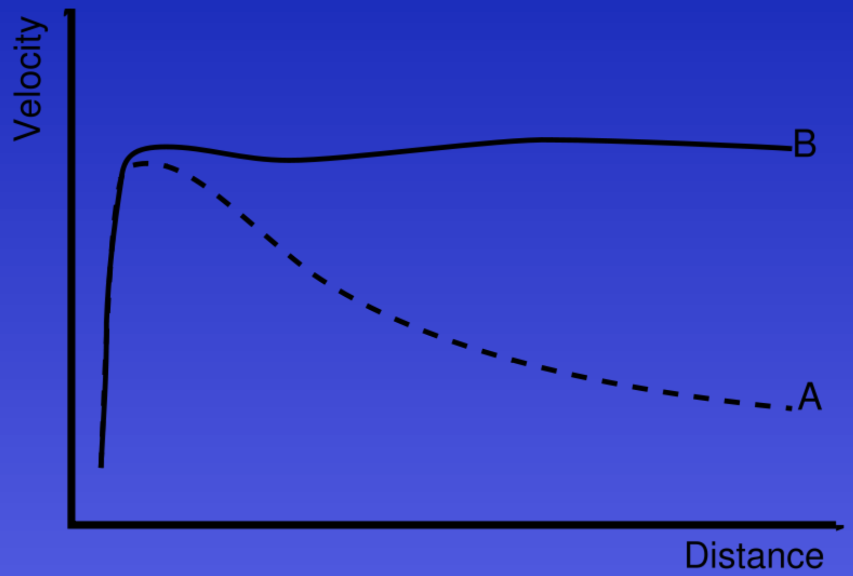
But there are still Open Questions

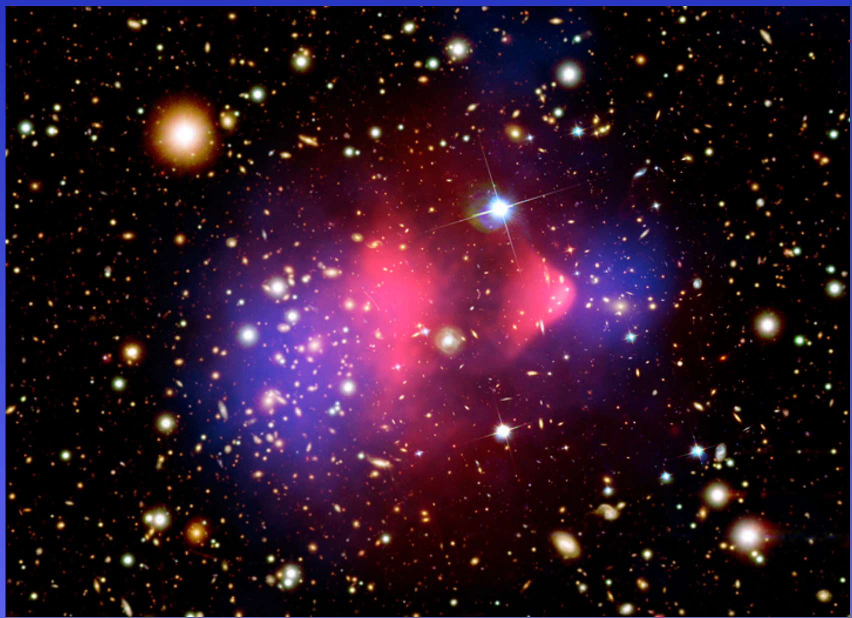
- What is the mass of a particle ?
  - Dynamical mechanism : Where are Higgs bosons ?
- Why 3 families ?
- Why so many free parameters in the SM Lagrangian ?
- Why do observe a so large mass hierarchy between the various quarks and leptons (especially neutrinos) ?
- Why do we observe more matter than antimatter in the Universe ?
- Is SM a effective theory of a more unified theory at high energies ?

New theories have been proposed to address some of those questions : supersymmetry, supergravity, string theories and extra-dimensions, technicolor, …

An issue : after many years of precision tests, SM is still valid and no hint of any new physics have been found yet

Mass issue at Large scale : the DM problem



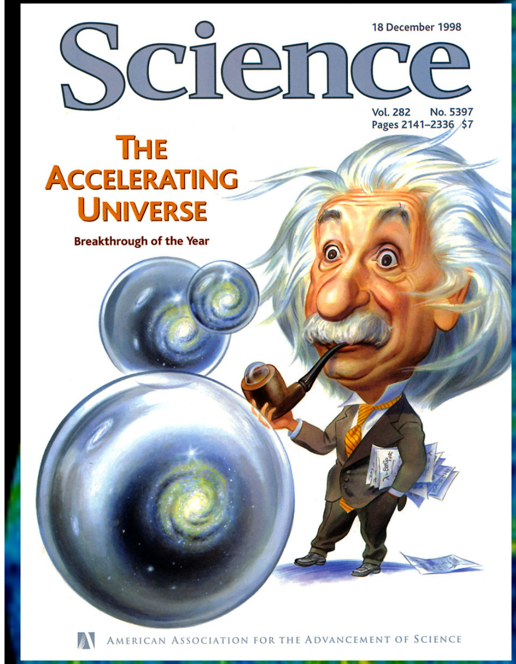


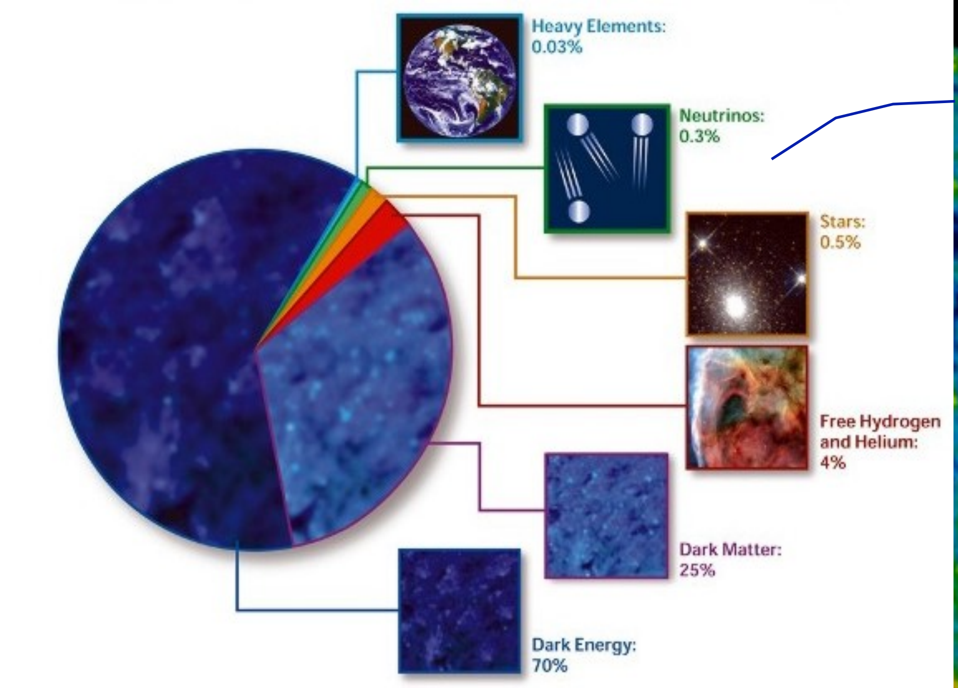
Need extra mass to explain organisation of galaxies and clusters if General Relativity holds

Need microscopic particle candidates for this weakly interacting dark matter (DM)

What's the matter with matter ?

Cosmology data : the universe contains lots of unknown matter and energy !





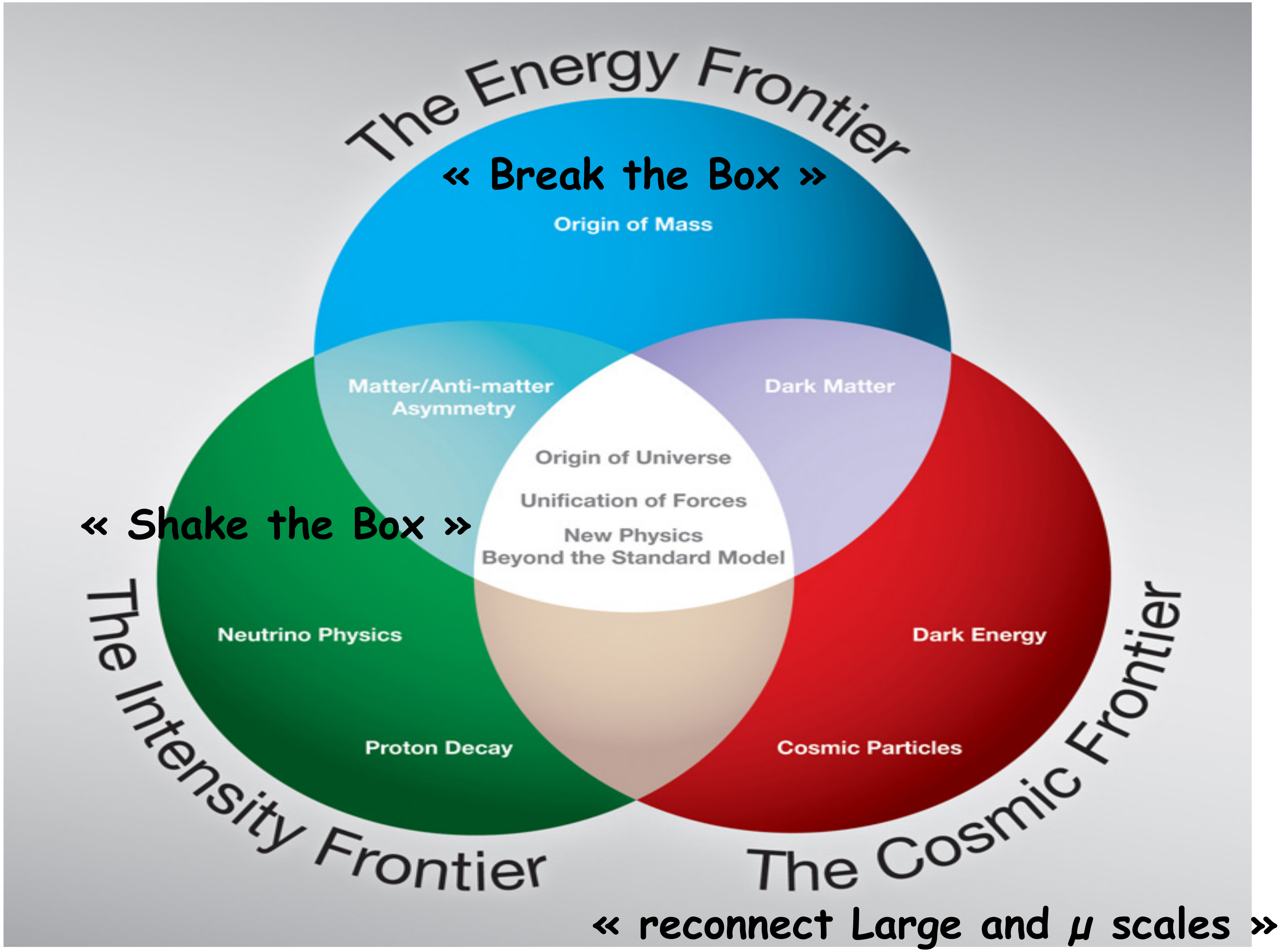
Only 5% of the Universe energy is from SM particles !

The universe is "almost" empty (in terms of ordinary, baryonic matter) and is mainly made of matter ; where did all the antimatter go ?

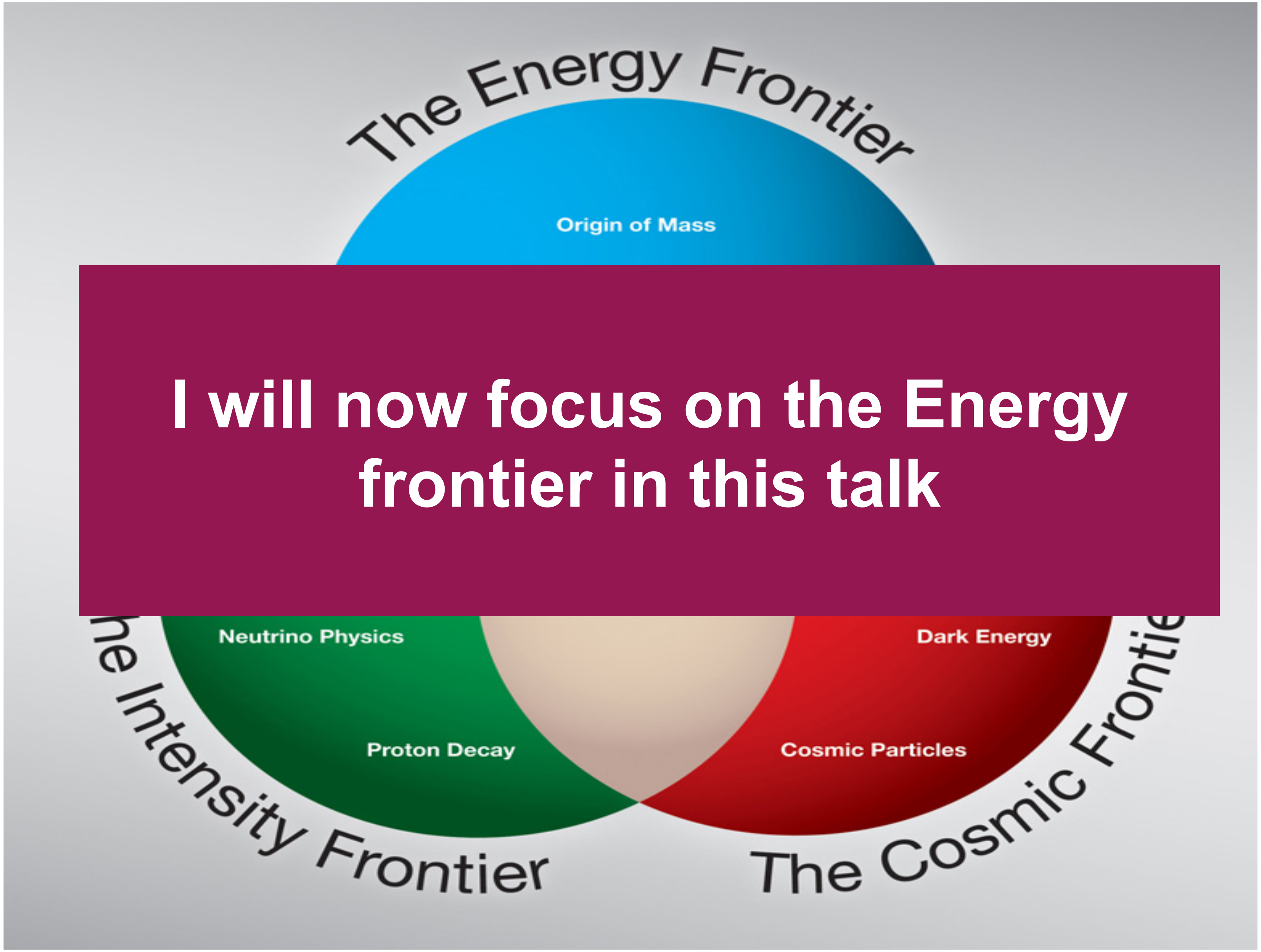
Sakharov conditions (1967) for Baryogenesis

1. Baryon number violation
2. *C* and *CP* violation
3. Departure from thermodynamic equilibrium

A strategy to address these questions : a 3-sided attack

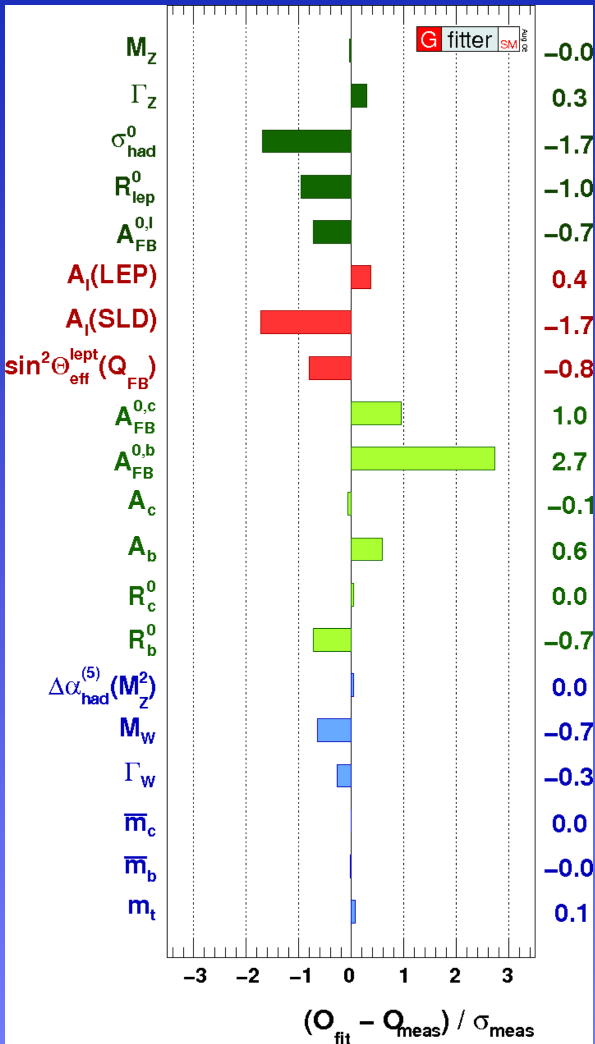


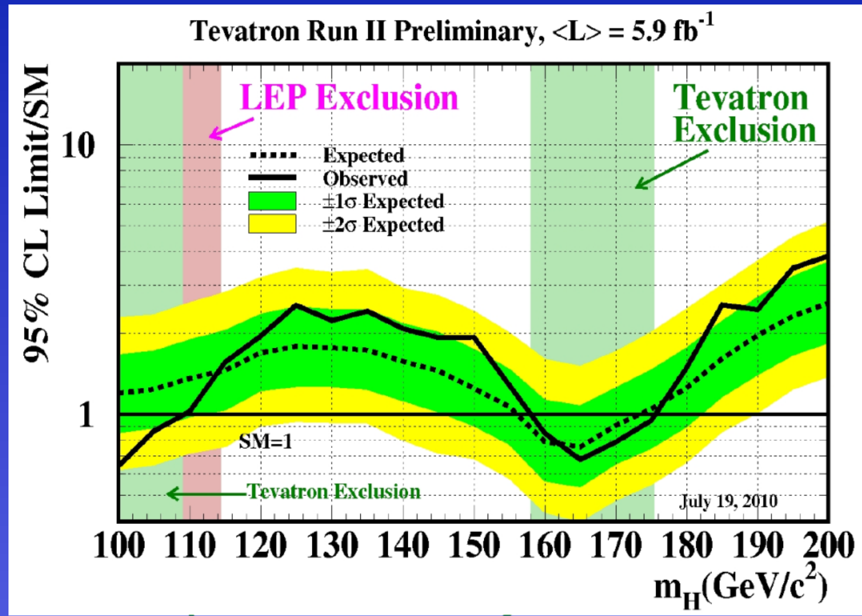
A strategy to address these questions : a 3-sided attack



I will now focus on the Energy frontier in this talk

Where to look at the Higgs boson ?

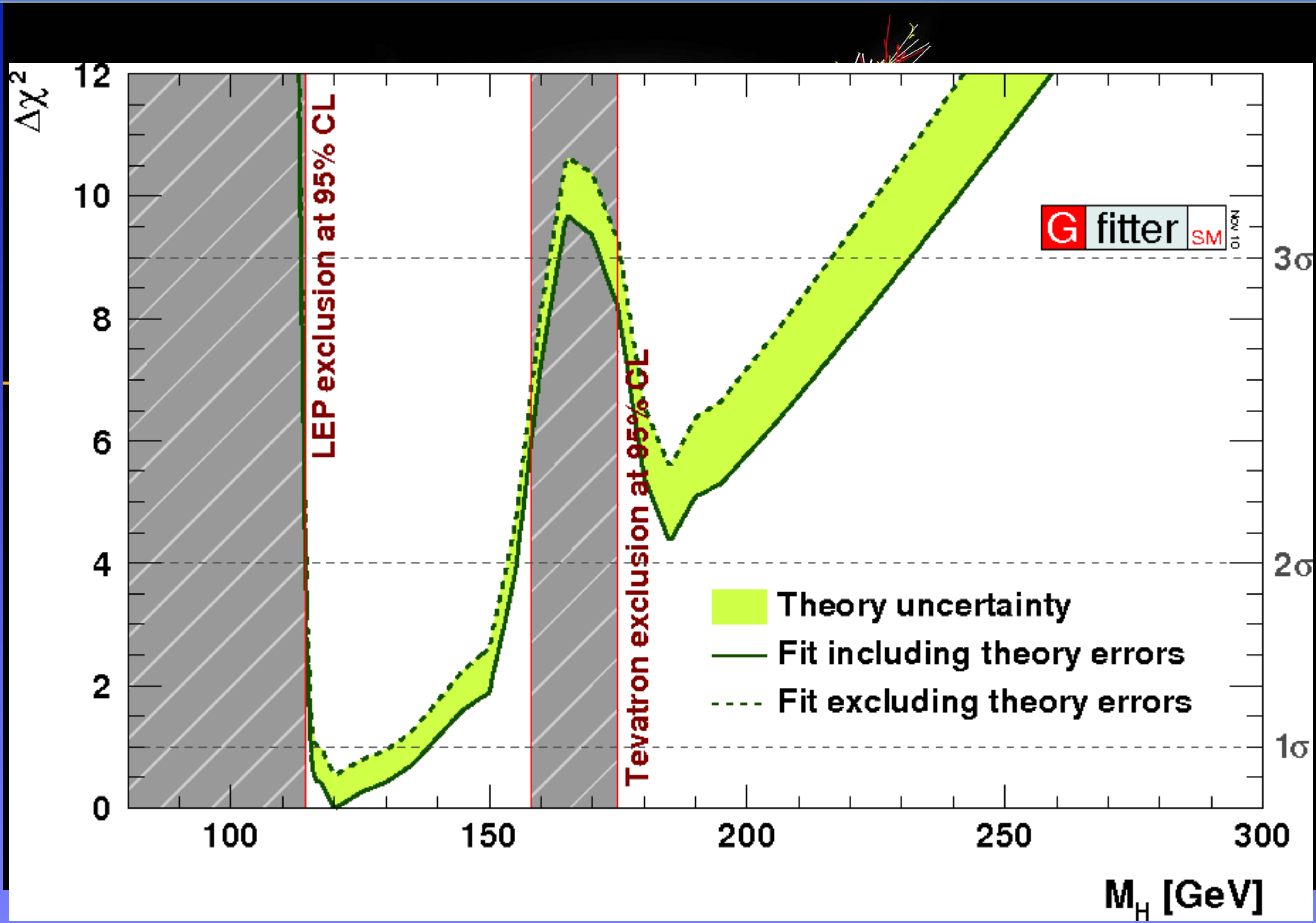




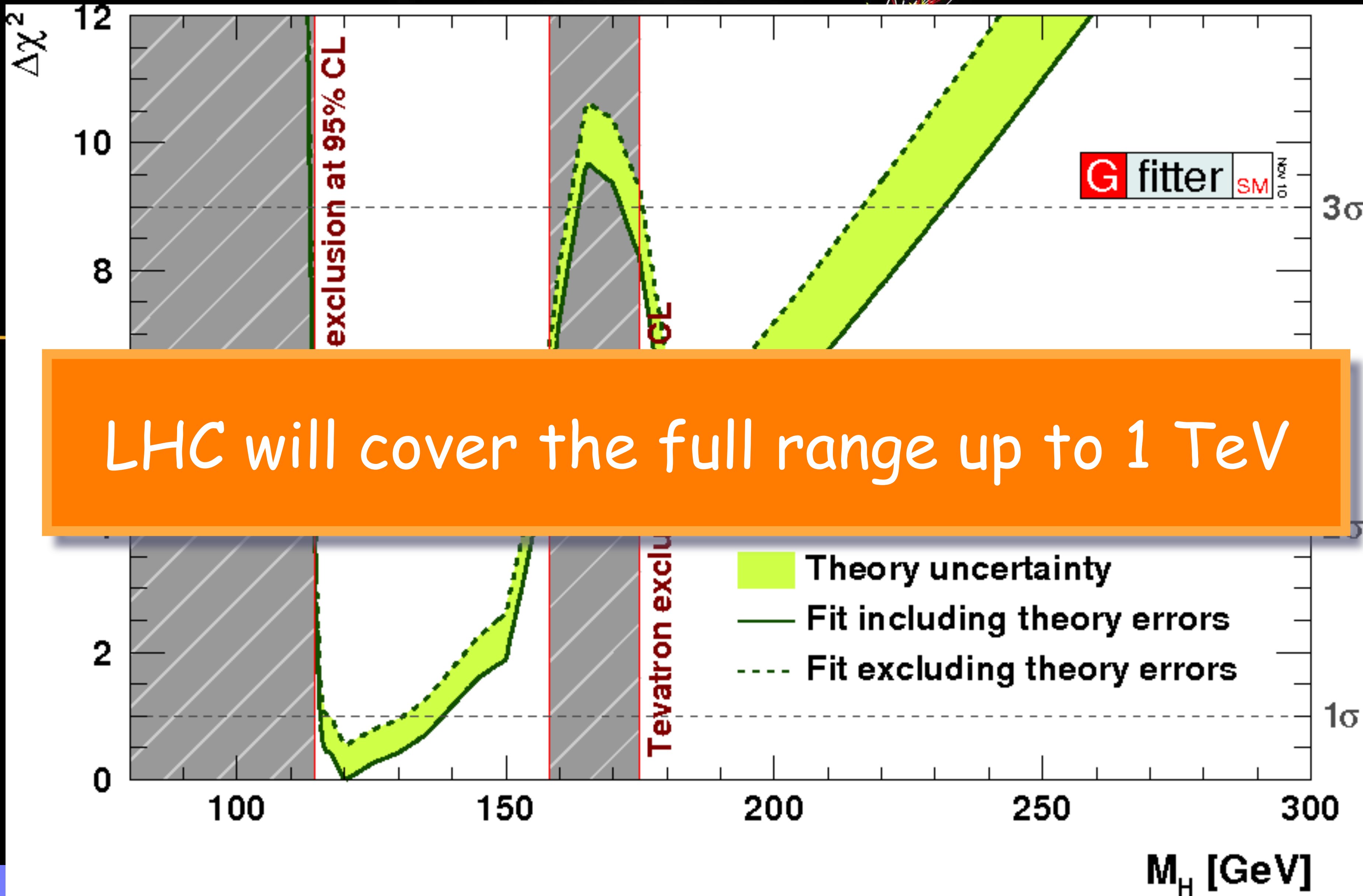
- Direct searches (LEP, Tevatron) exclude low masses
- Test of MS coherence (electroweak fit) excludes high masses
- Theoretical contraints Mh < 1 TeV

Need for pp collisions at the TeV scale (luminosity, energy)

Pre-LHC status of Higgs boson searches :



Pre-LHC status of Higgs boson searches :



LHC will cover the full range up to 1 TeV

LHC in action !

1st Beam Splash
from Beam-2

ATLAS EXPERIMENT

2009-11-20, 23:32 CET
Run 140370, Event 2666

History of the LHC program

1984: Start of discussions on the LHC

1989: Start up of LEP 1
MS precision tests and search for Higgs boson
R&D studies for LHC détectors start

1994: LHC Collider approved
(to start in 2005)

1995: Discovery of top quark at Fermilab (Chicago) by CDF (et D0)

Precision measurements and Higgs search at LEP 2

ATLAS et CMS approved

2000: End of data taking at LEP

Apparition de la problématique Dark Matter

For more than 20 ans at CERN

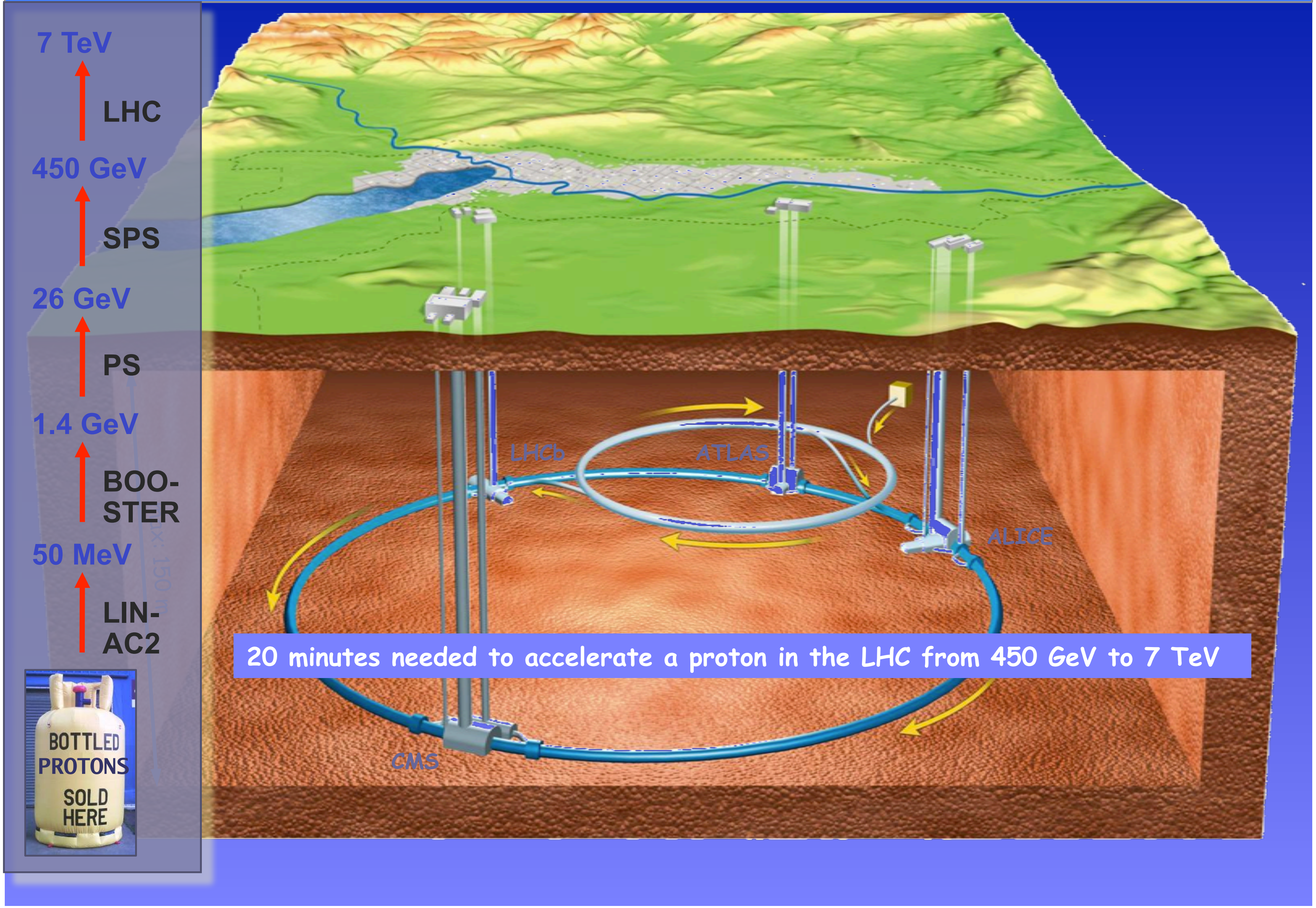
- Physics at LEP
- preparation, construction of LHC and its detectors (lot of R&D)

Aug 2008: closing of the tunnel and no access to detectors any more

automne 2008: 1st LHC startup

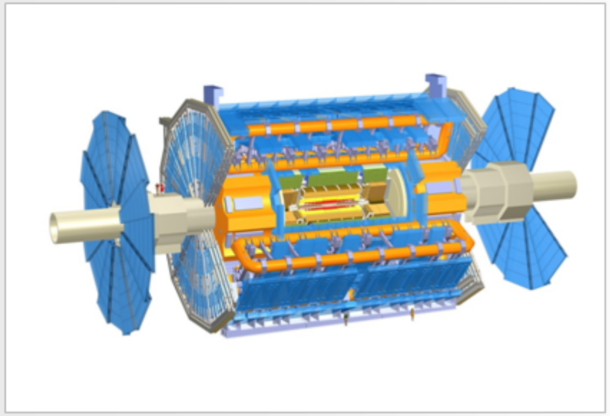
Automne 2009: Energy 2.36 TeV
2010 : LHC at 7 TeV, $2.10^{32} cm^{-2}.s^{-1}$

LHC : a pipeline of accelerators, 4 large experiments

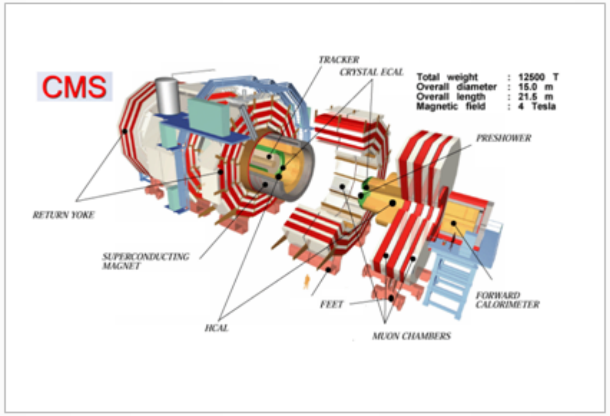


The four large LHC experiments

ATLAS



CMS

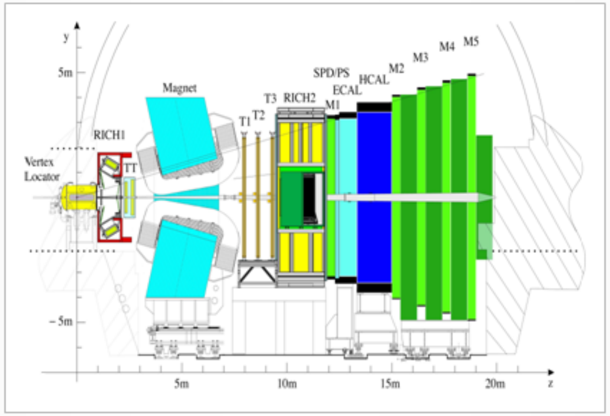


ALTAS and CMS have same physics goals: concentrate on "high-p_T" discovery physics

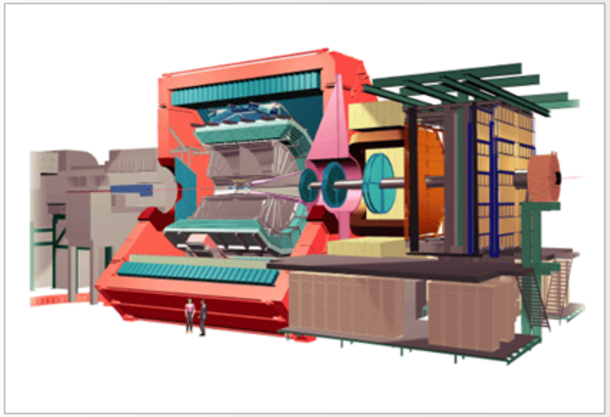
The detector concepts are however different: this provides necessary redundancy and fruitful competition

LHCb looks like a fixed-target experiment (though it is not!), because it concentrates on low-p_T B physics

LHCb



ALICE

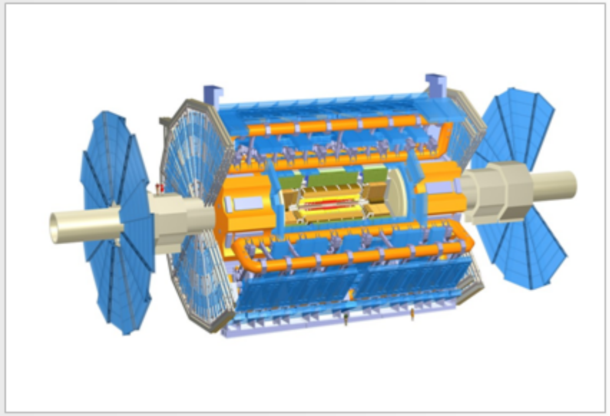


There are two more (much smaller) experiments at the LHC: TOTEM (measuring elastic and diffractive processes), and LHCf (testing cosmic shower models)

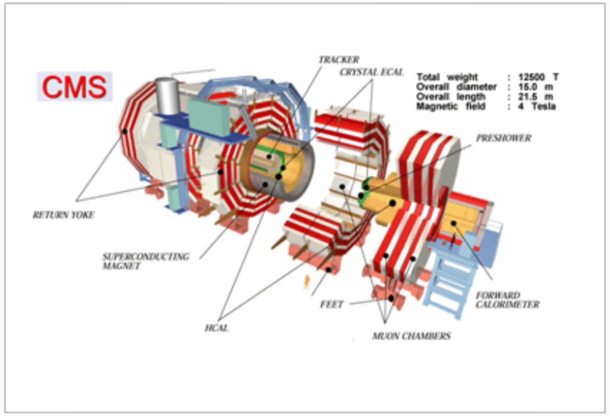
ALICE will exploit high-energetic nucleus-nucleus ("heavy-ion") collisions

The four large LHC experiments

ATLAS



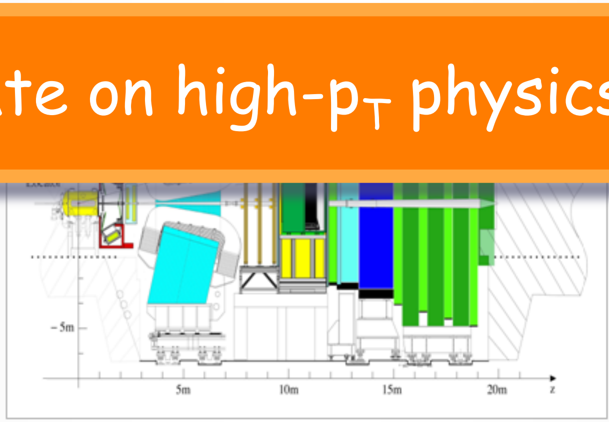
CMS



ALTAS and CMS have same physics goals: concentrate on "high-p_T" discovery physics

The detector concepts are however different: this provides necessary redundancy and fruitful competition

LHCb



ALICE

L
e
b
low-p_T *B* physics

I will concentrate on high-p_T physics and on ATLAS

There are two more (much smaller) experiments at the LHC: TOTEM (measuring elastic and diffractive processes), and LHCf (testing cosmic shower models)

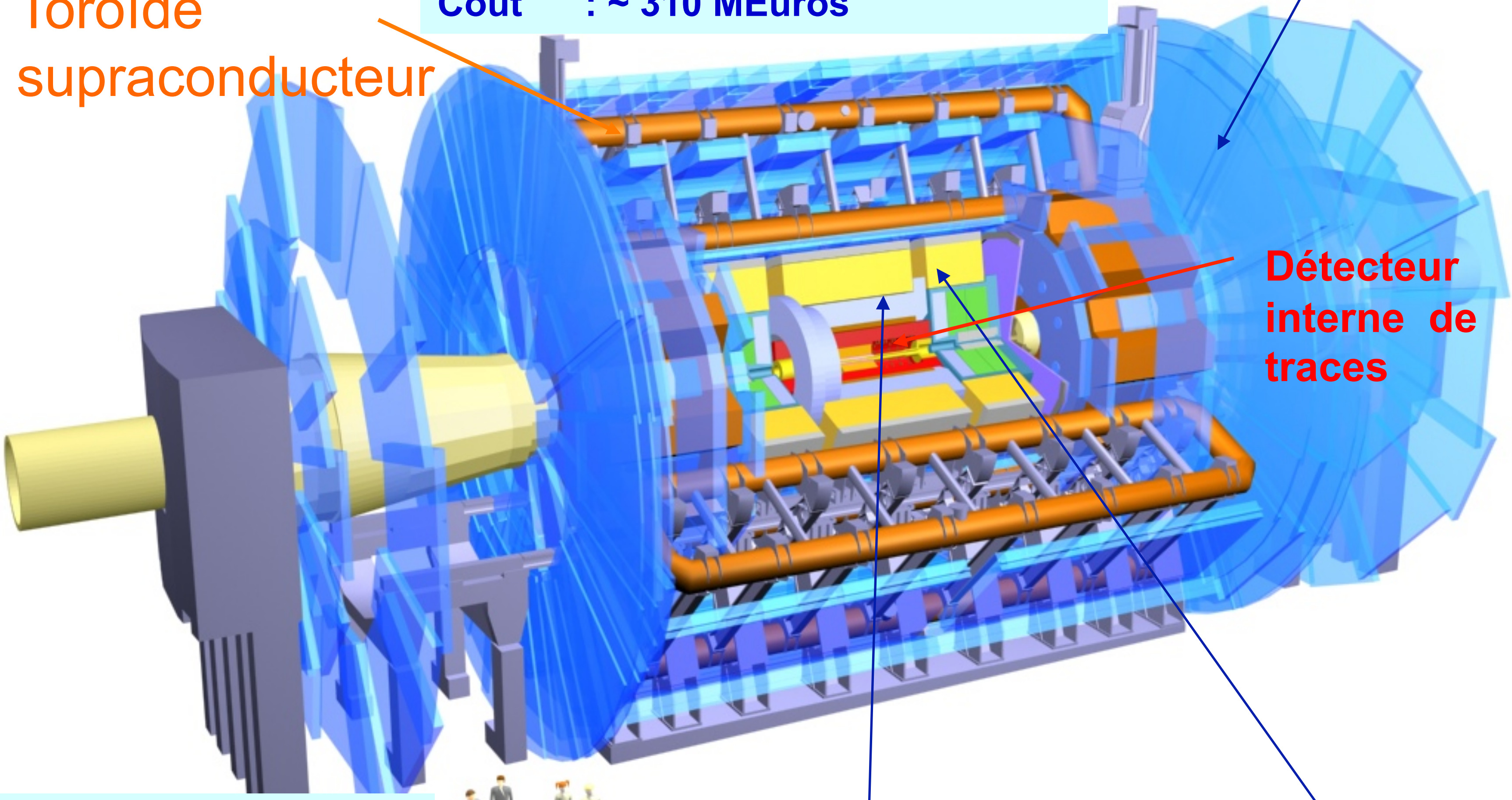
ALICE will exploit high-energetic nucleus-nucleus ("heavy-ion") collisions

The ATLAS detector at the LHC

Longueur : ~ 46 m Diamètre : ~ 25 m

Poids : ~ 7000 tonnes

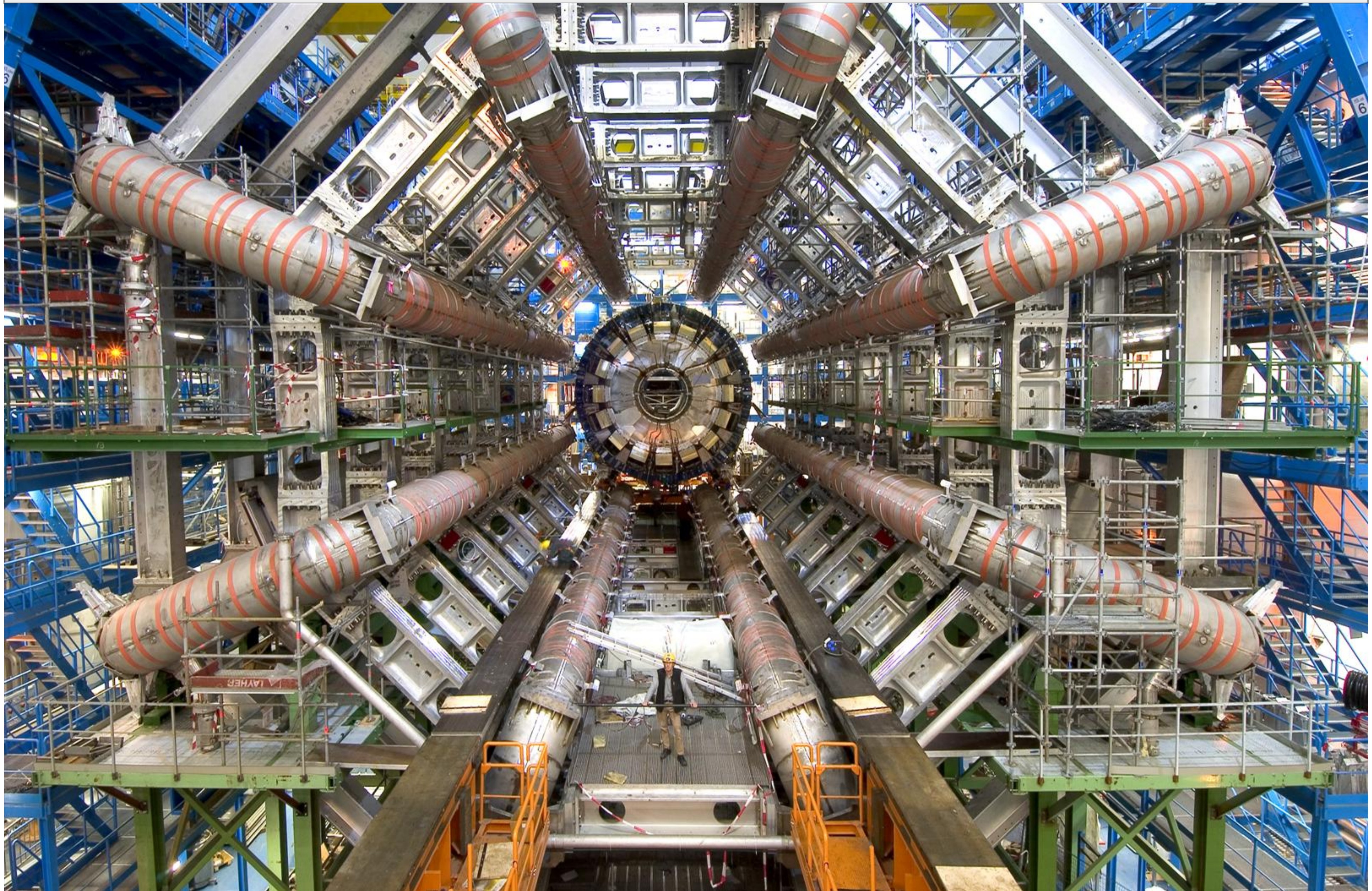
Coût : ~ 310 MEuros



Câbles: : 3000 km

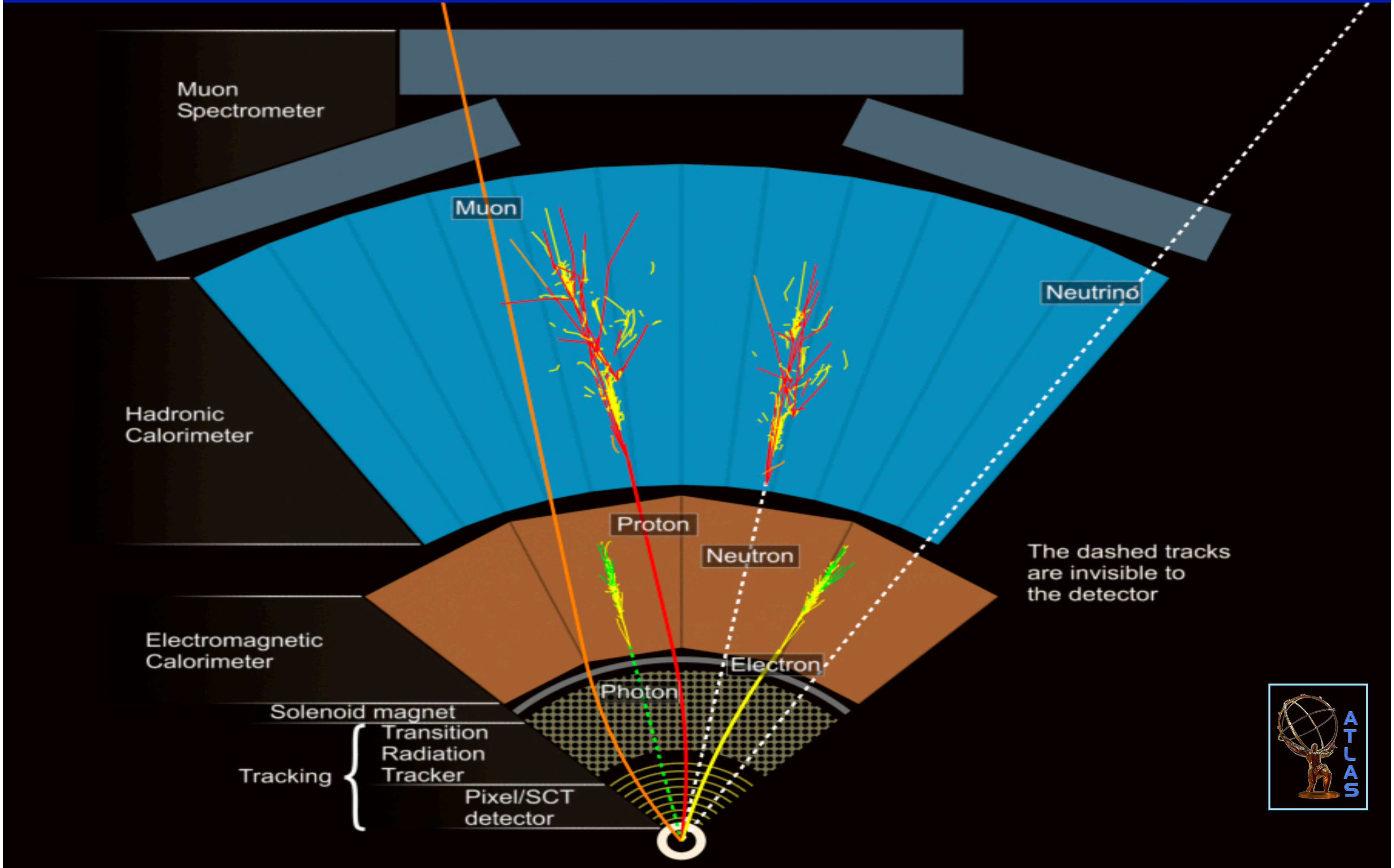
Voies électronique : 10^8

ATLAS : Air Toroidal Lhc Apparatus System

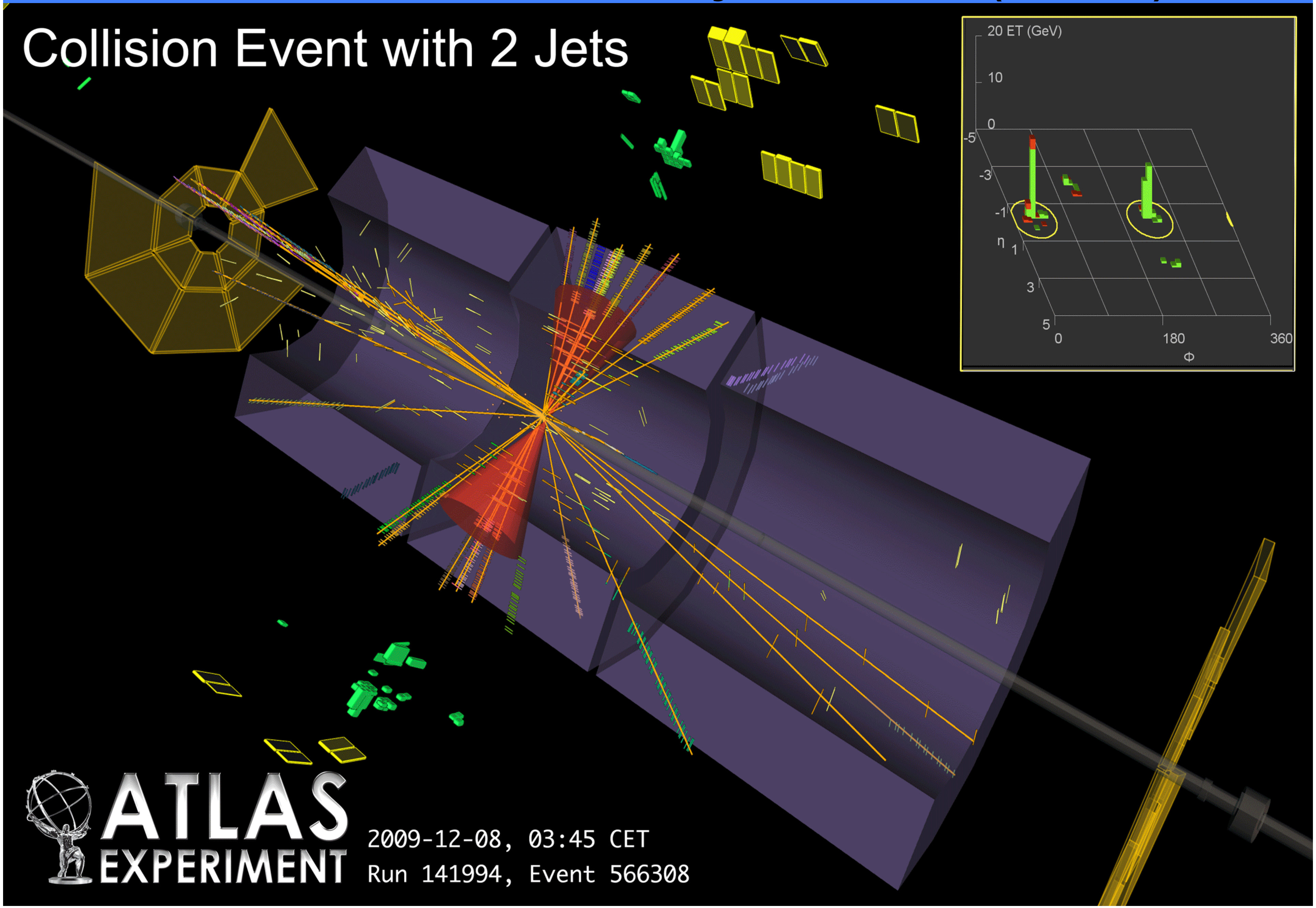


ATLAS Detector Layers

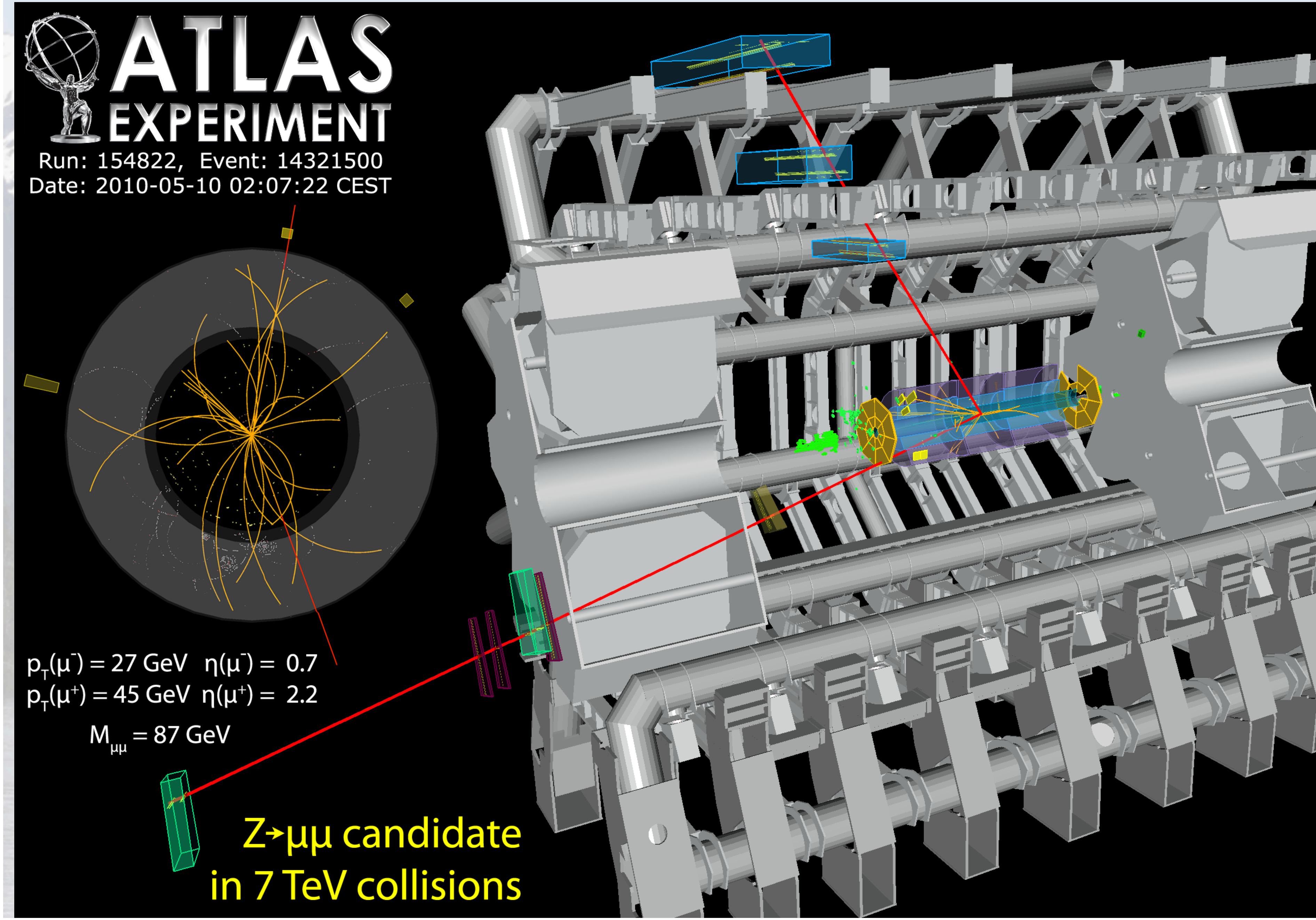
Particles are detected through their interaction with active detector materials



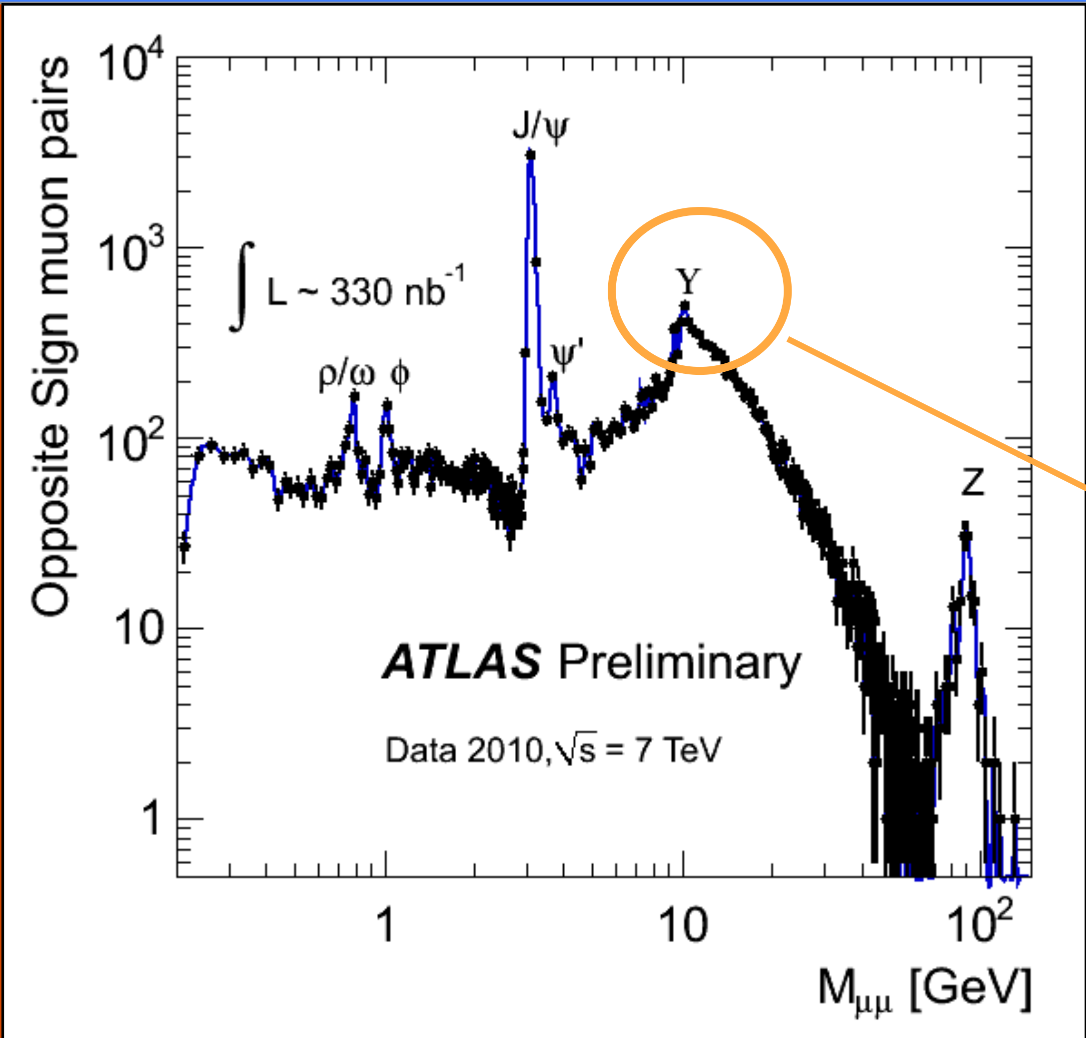
The first beautiful dijet event (2009)



Some event displays from the 2010 run



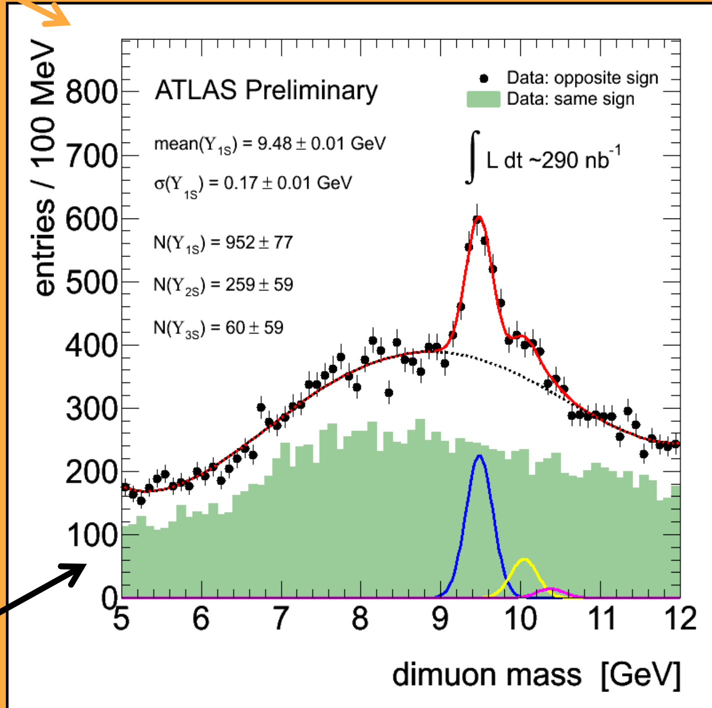
Di-muon resonances



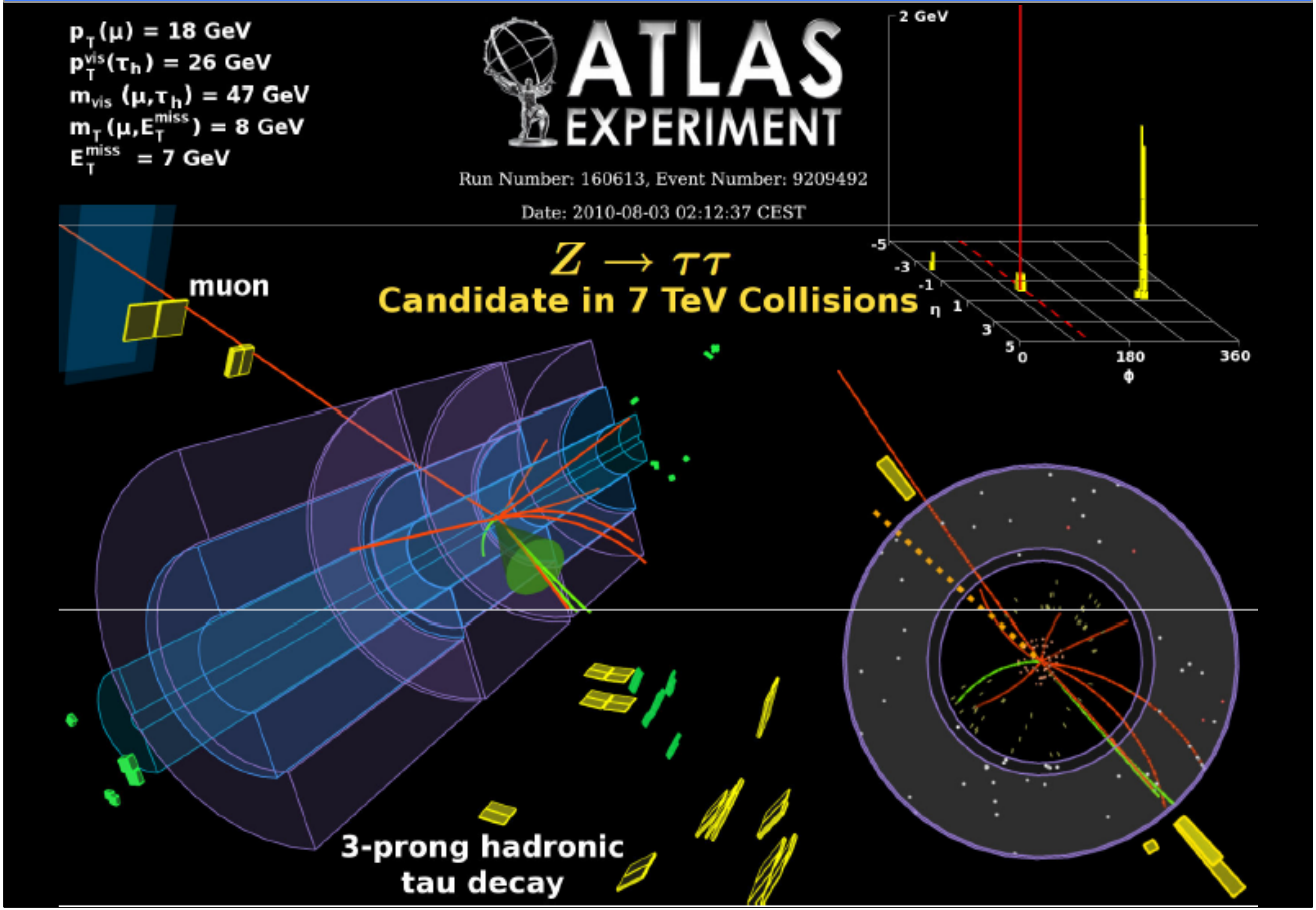
- Looser selection: includes also muons made of Inner Detector tracks + Muon Spectrometer segments
- Distances between resonances fixed to PDG values; Υ(2S), Υ(3S) resolutions fixed to Υ(1S) resolution

Simple analysis:

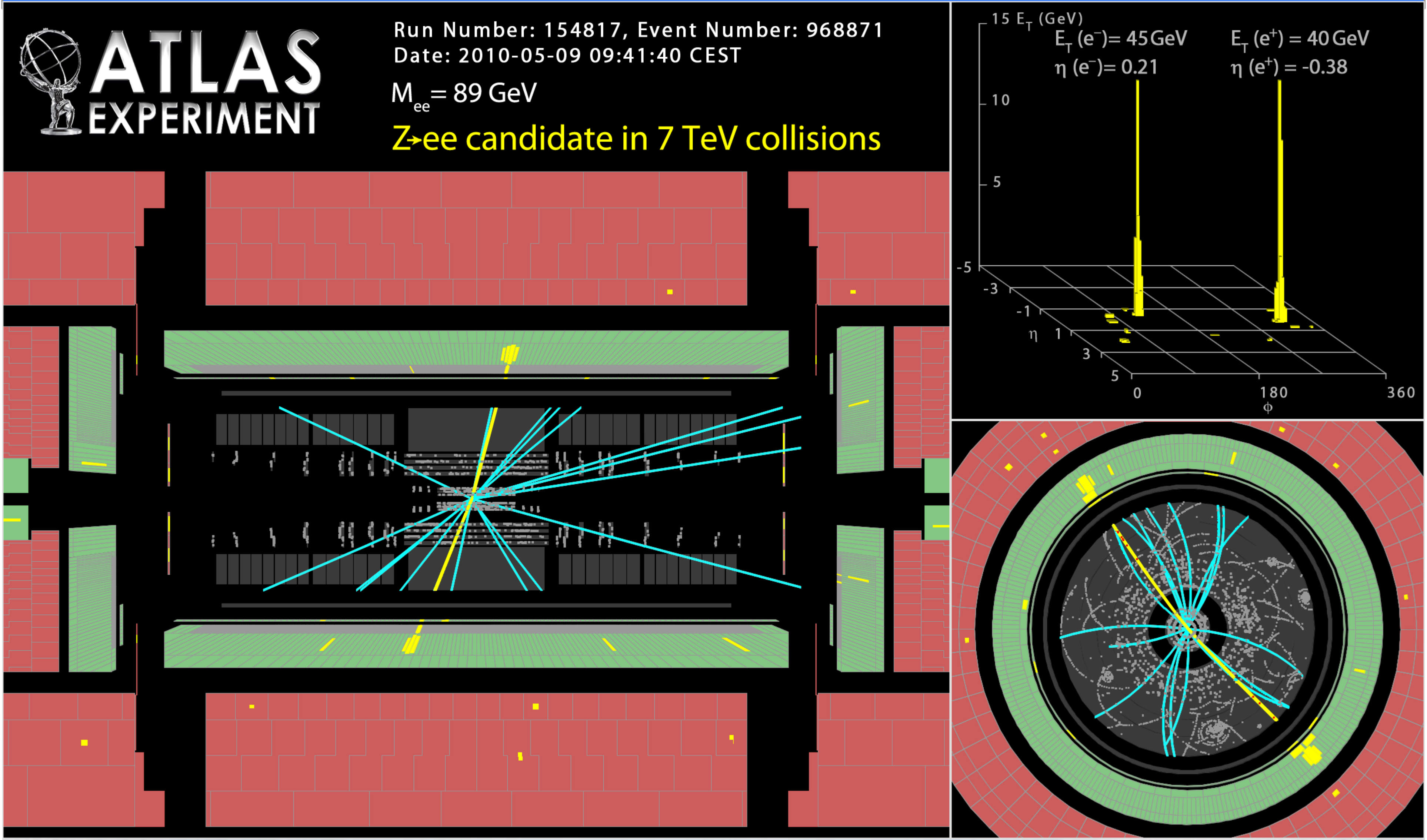
- LVL1 muon trigger with p_T ~ 6 GeV threshold
- 2 opposite-sign muons reconstructed by combining tracker and muon spectrometer
- both muons with |z|<1 cm from primary vertex



ATLAS is able to do τ physics



Some event displays from the 2010 run



ATLAS and CMS rediscover SM Physics : good start

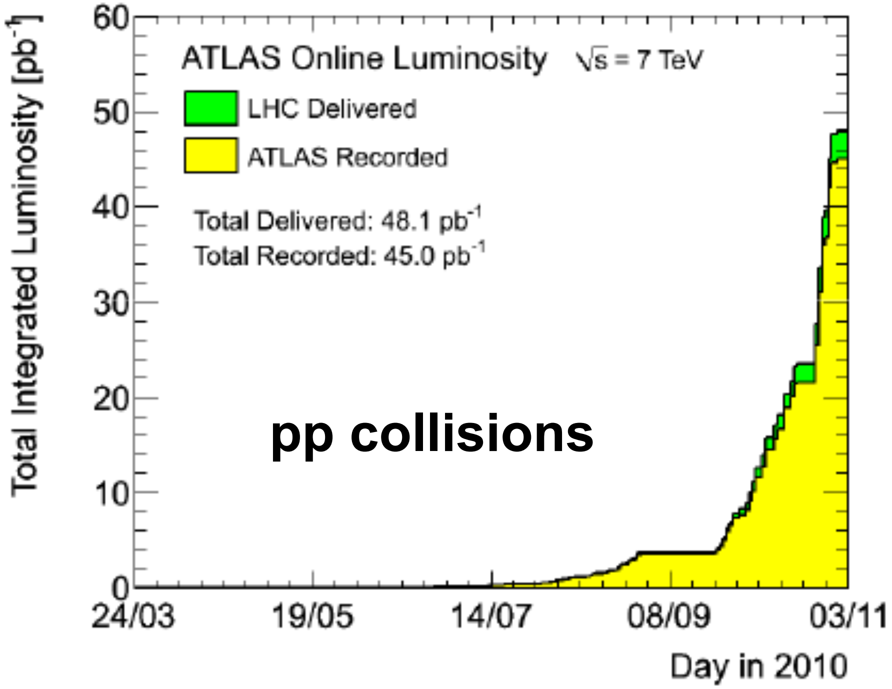
Luminosity measurement

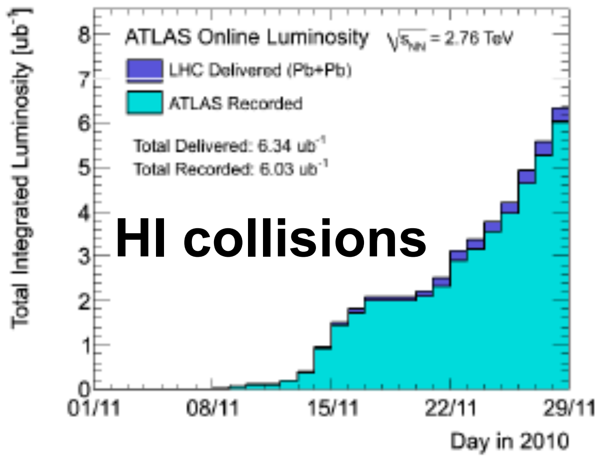
N = σ L

- **Measured by several different detectors and methods, consistency to ~2%.**

- **Present uncertainty on absolute luminosity determination (p-p): 11%**
  limited by the measurement of beam current.

- **Prospects to reduce strongly soon (5 to 6 %)**



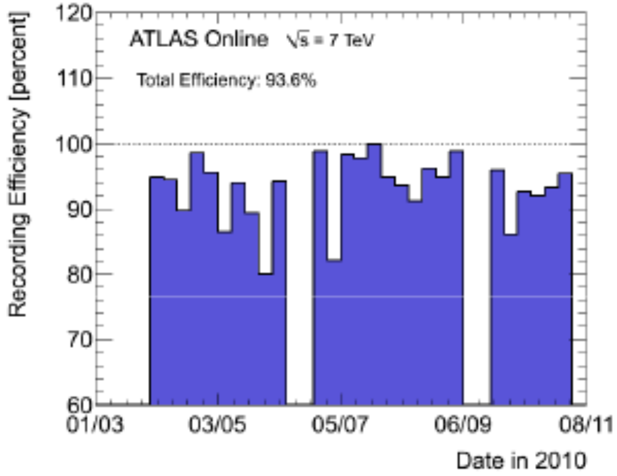


Data Taking and Data Quality

LHC Mode : pp March-Nov; Heavy Ions Nov.-Dec. 2010

- Very good recording efficiency
  - Stable beams to disk

  (includes ID voltages rise, dead time, etc.)



- And data quality
  - Disk to physics analysis
  - Latest reprocessing even better

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

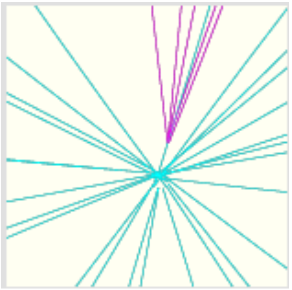
Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams in pp collisions at $\sqrt{s}$=7 TeV between March 30th and October 31st (in %). The inefficiencies in the calorimeters will largely be recovered in a future data reprocessing.

Overall data taking efficiency (with full detector on): ~94%

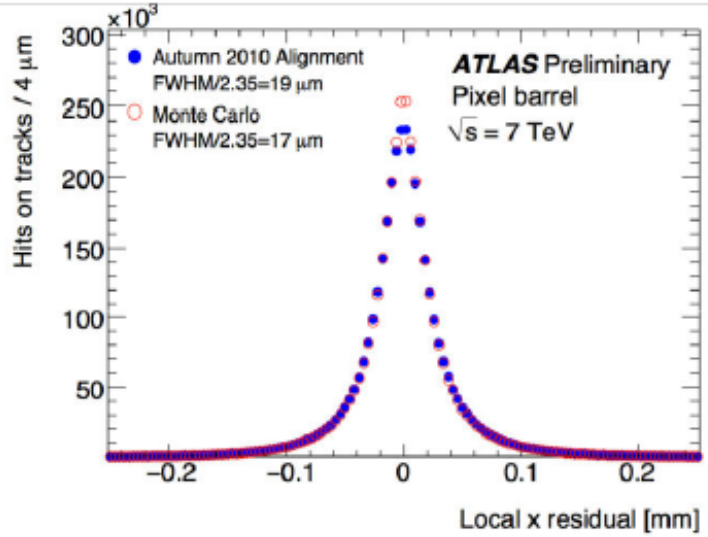
- Operational channels: 97 to 100 % depending on system

Illustration of the present detector response understanding

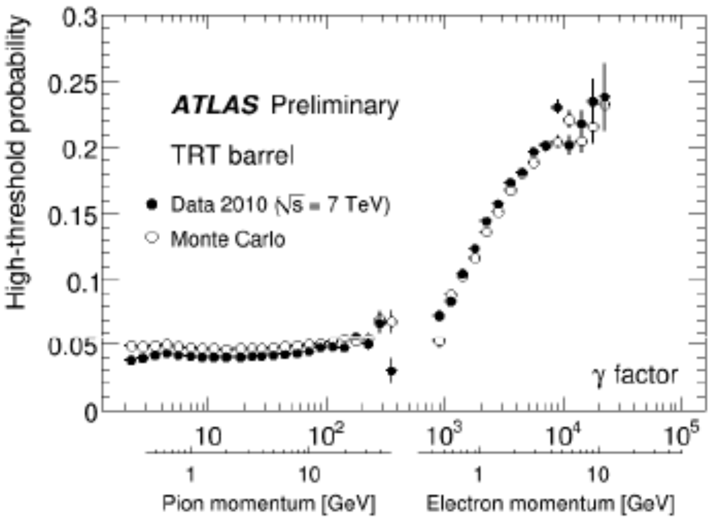
B-tagging



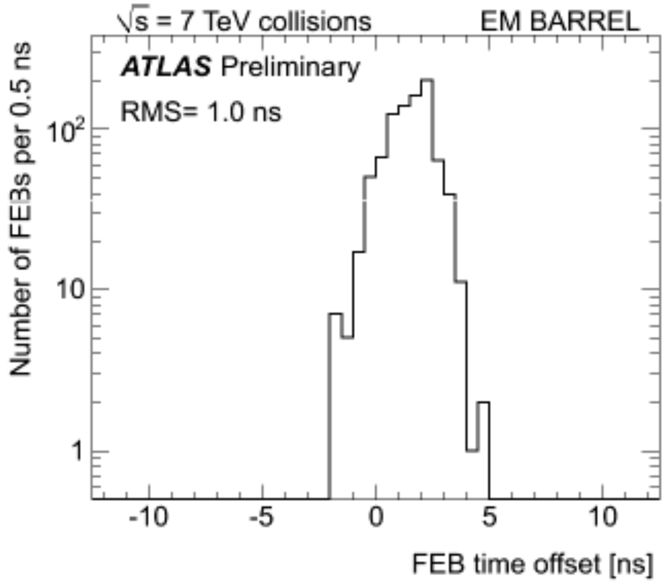
Pixel detector alignment (transverse plane, autumn reprocessing)



- **Transition Radiation threshold**



- **EM calorimeter: timing**



Physics Results

I have not the time to show all the physics results already published

Please visit ATLAS and CMS Physics results pages to get all the related papers

https://twiki.cern.ch/twiki/bin/view/AtlasPublic

http://cdsweb.cern.ch/collection/CMS%20Papers?ln=en

ATLAS released already 20 Papers showing 2010 data:

Publications of the ATLAS collaboration since Paris Workshop 15-18/12/2010

Search for Diphoton Events with Large Missing Transverse Energy in 7 TeV Proton-Proton Collisions with the ATLAS Detector, Submitted to PRL (20 Dec. 2010)
Measurement of the inclusive isolated prompt photon cross section in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector, Submitted to Phys Rev D (20 Dec. 2010)
Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC, Submitted to New J Phys (22 Dec 2010)
Measurement of the production cross section for W-bosons in association with jets in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector, Submitted to Phys Lett. B (23 Dec 2010)
Measurement of the centrality dependence of J/Psi yields and observation of Z production in lead-lead collisions with the ATLAS detector at the LHC, Submitted to Phys Lett. B (24 Dec 2010)
Study of Jet Shapes in Inclusive Jet Production in pp Collisions at $\sqrt{s}$ = 7 TeV using the ATLAS, Accepted by Phys Rev. D (submitted 30 Dec 2010)
Luminosity Determination in pp Collisions at $\sqrt{(s)}$=7 TeV Using the ATLAS Detector at the LHC

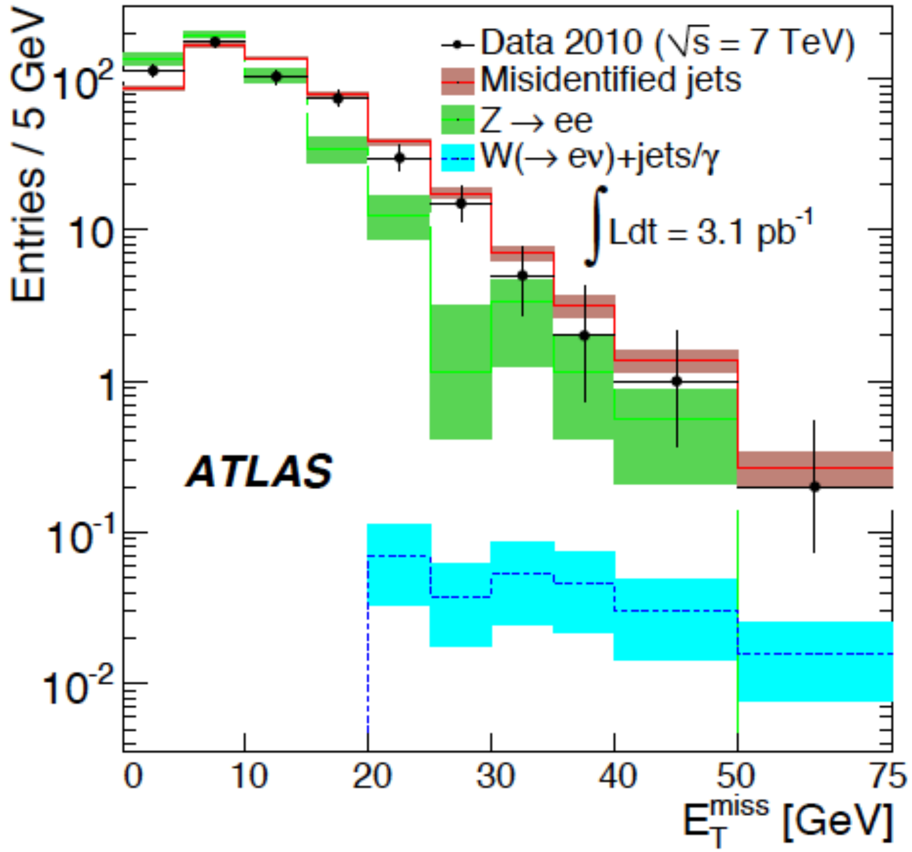
CMS released already 24 Papers showing 2010 data:

In particular, CMS is a bit earlier than ATLAS on BSM Physics (Black holes, leptoquark, Susy). Atlas will be ready on all the topics for Moriond.

Atlas is earlier on QCD physics, especially photon physics which is so important for Higgs

Physics Results : beyond the Standard Model

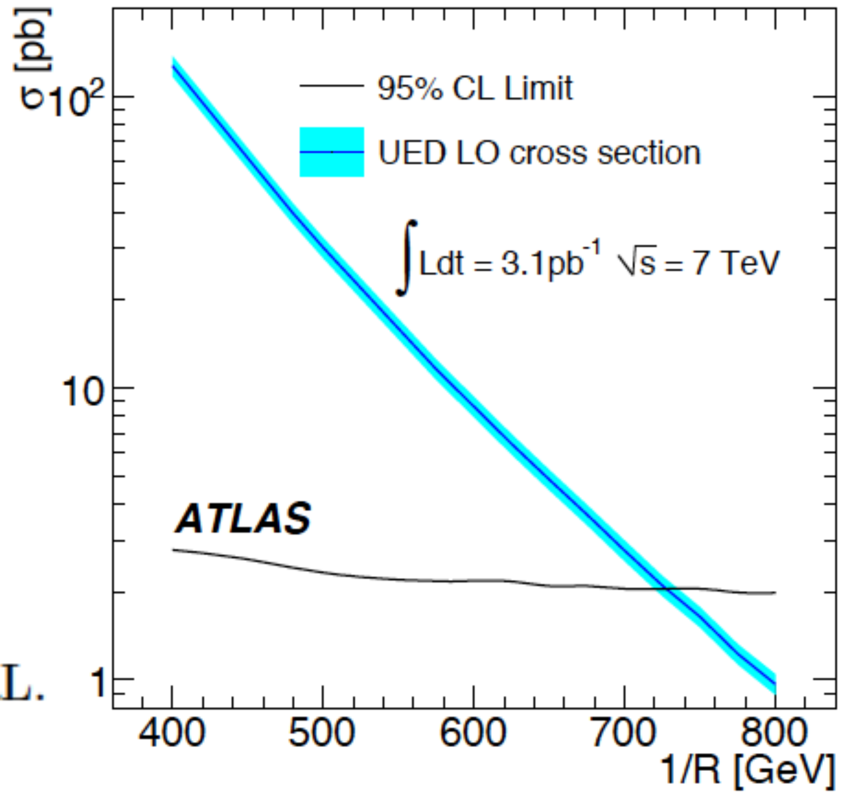
Diphoton EtMiss Spectra



CERN-PH-EP-2010-076; Submitted to PRL.

Limit extracted in the framework of Universal Extra Dimension

1/R > 728 GeV at 95% CL



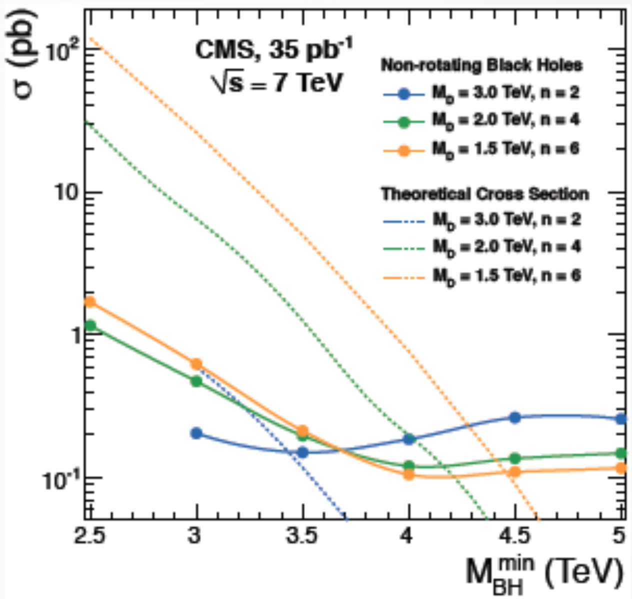
Searches for Black Holes at CMS

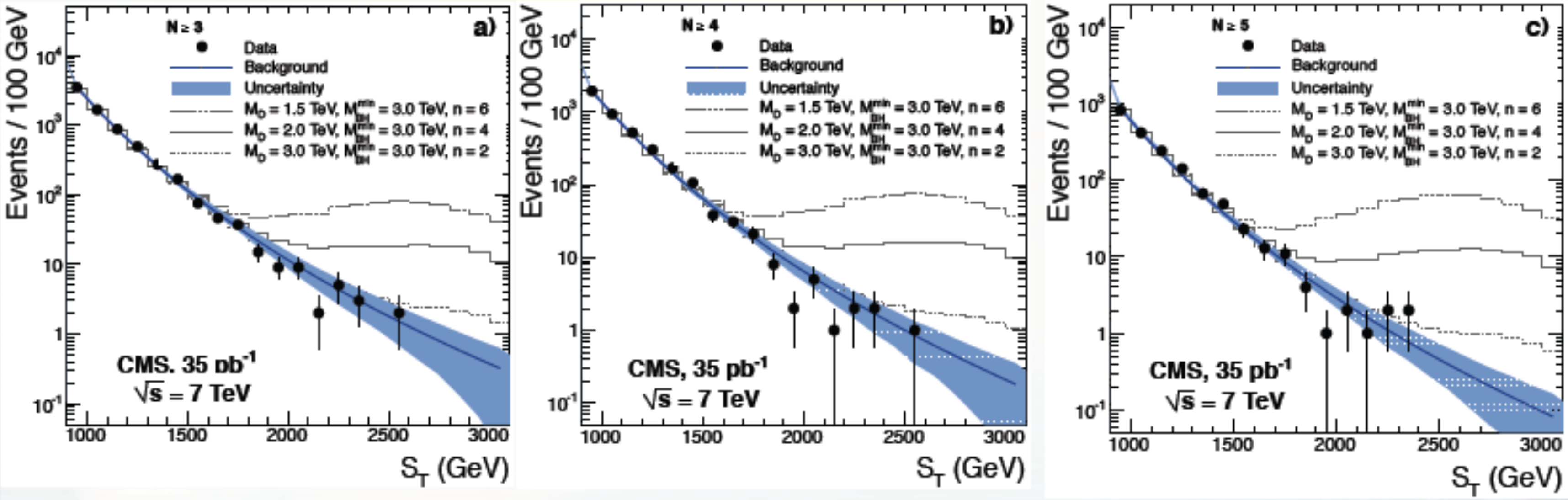
- Ultimate, smoking-gun signature of low-scale quantum gravity ($M_D << M_{Pl}$)
- Gravitational collapse is possible when the two partons from colliding beams pass each other at the distance smaller than approximately the Schwarzschild radius R_S, corresponding to their invariant mass $M = \sqrt{\hat{s}}$
- The cross section is given by the black-disk approximation, $\sigma = \pi R_S^2 \sim \text{TeV}^{-2}$ and could be as large as ~100 pb
- Black holes instantaneously decay via Hawking evaporation with an emission of large number of energetic objects, dominated (75%) by quark and gluons, with the rest going into leptons, photons, W/Z, h, etc.
- Generally, graviton emission is suppressed, so expect little MET, but this can be changed in more specific models
- Search largely based on the original papers [Dimopoulos, GL, PRL **87**, 161602 (2001) and Giddings, Thomas, PRD **65**, 050610 (2002)], with a few modifications, as captured by the CHARYBDIS 2 and BlackMax generators ([partial] grey-body factors, spinning Kerr black holes, formation of a stable non-interacting remnant, etc.)
- Caveat: rely on semi-classical approximation, which is expected to be modified for black hole masses less than ~5 x M_D

Limits on Black Holes

- Used the N=2 shape with its uncertainties, to fit higher multiplicities, where the signal is expected to be most prominent
- Given no excess, set limits on the minimum BH mass of 3.5-4.5 TeV in semi-classical approximation
- First direct limits at colliders

arXiv:1012.3375, submitted to PLB





Data driven search, N is the number of jets, $S_T = \Sigma Et$

Physics Results : Dijets

Dijet Mass Spectra

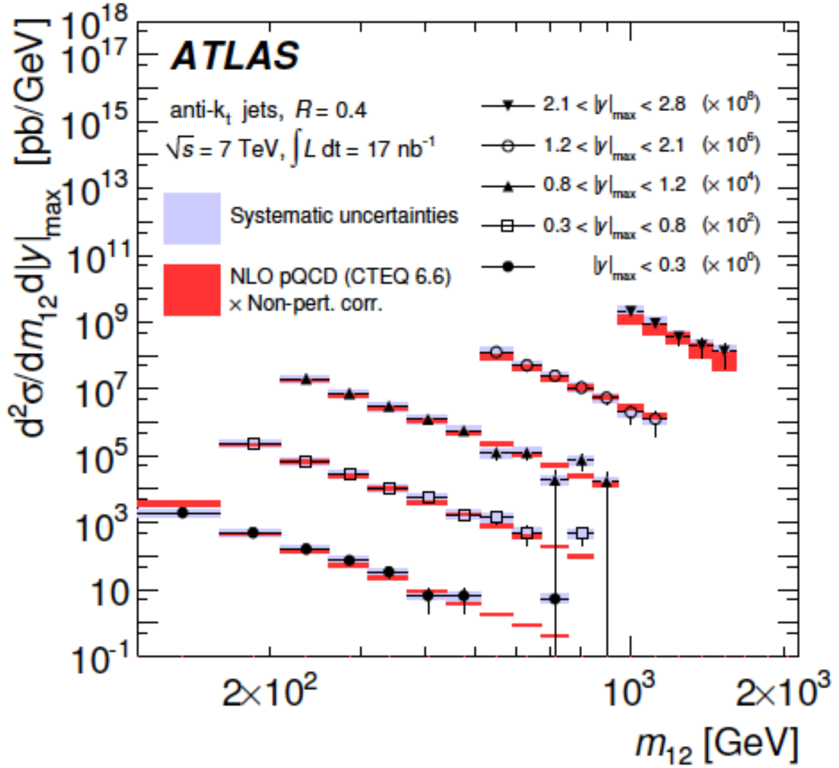
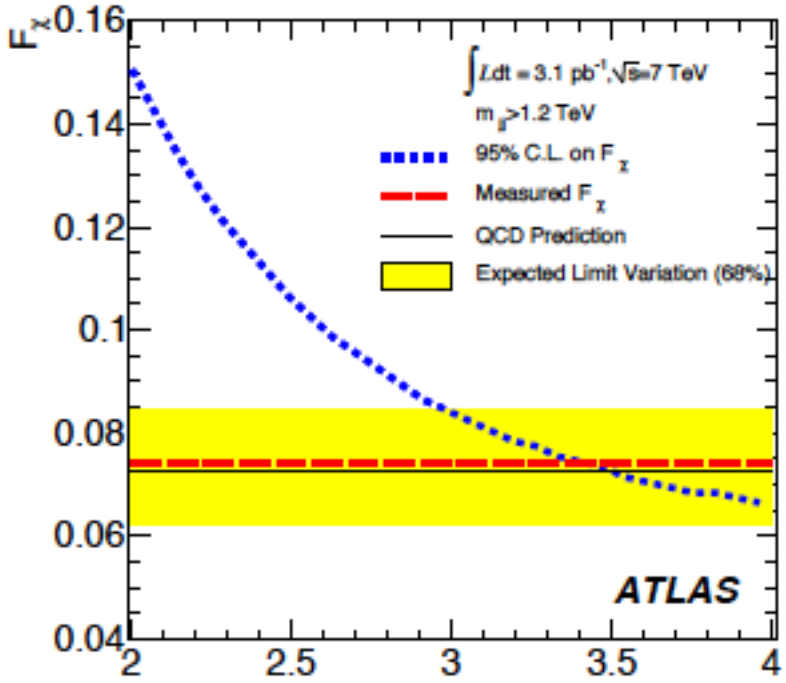


Fig. 21. Dijet double-differential cross section as a function of dijet mass, binned in the maximum rapidity of the two leading jets, $|y|_{max}$. The results are shown for jets identified using the anti-k_t algorithm with $R = 0.4$. The data are compared to NLO pQCD calculations to which soft QCD corrections have been applied. The uncertainties on the data and theory are shown as described in Fig. 13.

CERN-PH-EP-2010-034

Interpret data to look for a contact term showing up at scale Λ

$\Lambda >$ 3.4 TeV at 95% CL



CERN-PH-EP-2010-033

No obvious resonnance
pQCD seems describe the data reasonnably

Summary of the Dijet Searches

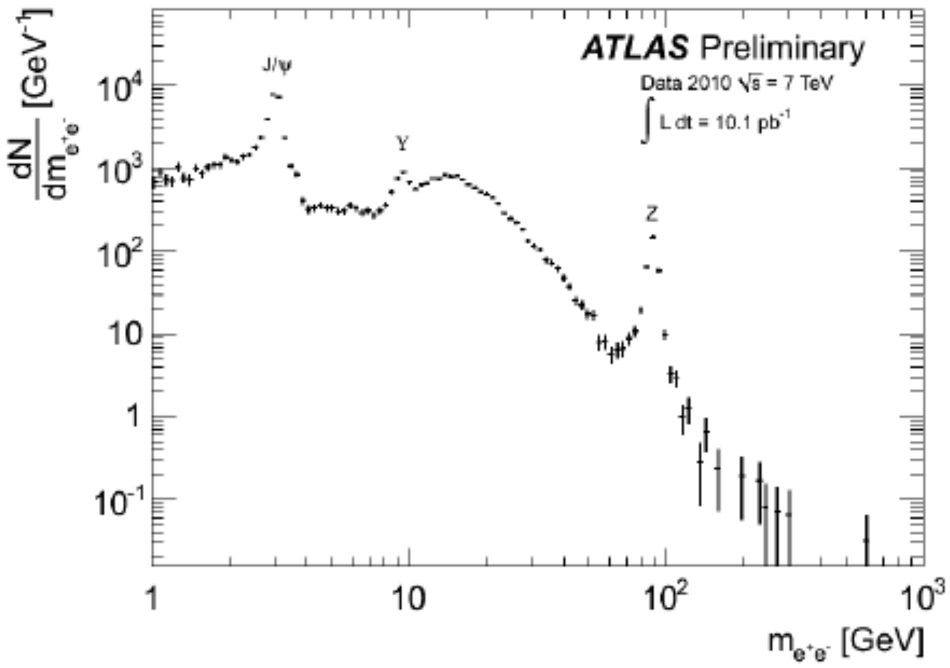
Particle	CMS, 2.9 pb^{-1} PRL **105**, 211801 (2010)	ATLAS, 0.32 pb^{-1} PRL **105**, 161801 (2010)	CDF, 1130 pb^{-1} PRD **79**, 112002 (2009)
q*	M > 1.58 (1.32) TeV	M > 1.26 (1.06) TeV	M > 0.87 TeV
S	M > 2.50 (2.40) TeV		M > 1.4 TeV (our estimate)
Axigluon/ Coloron	M > 1.17 TeV (M > 1.23 TeV) and not (1.42 < M < 1.53)		M > 1.25 TeV
E6 diquark	Exclude 0.50-0.58 & 0.97-1.08 & 1.45-1.60 TeV (M > 1.05 TeV)		M > 0.63 TeV

Quark Compositeness (left-handed quarks)		
CMS Centrality PRL **105**, 262001 (2010)	2.9 pb^{-1}	Λ > 4.0 (2.9) TeV actual (observed)
CMS Angular Distributions (to be submitted soon)	36 pb^{-1}	Λ > 5.6 (5.0) TeV
ATLAS (Angular Distributions) (Centrality) PLB **694**, 327 (2011)	3.1 pb^{-1}	Λ > 3.4 (3.5) TeV Λ > 2.0 (2.6) TeV
D0 (Angular Distriburions) PRL **103**, 191803 (2009)	700 pb^{-1}	Λ > 2.84-3.06 (2.76-2.91) TeV

CMS has set the most stringent limits to date on ALL the listed new phenomena

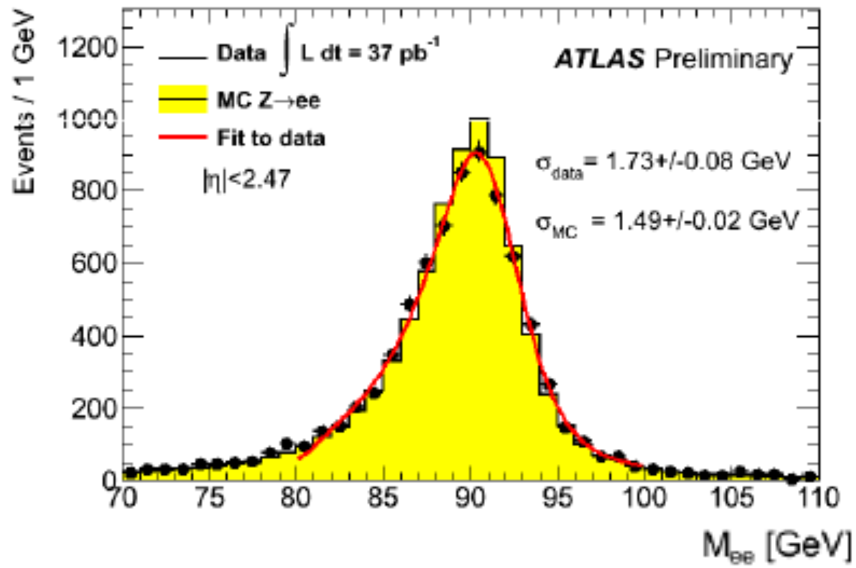
Physics Results : electrons in ATLAS

- **5 GeV di-electron trigger**
  - **prescaled in later data**
  - **produces shoulder at 15 GeV**



- **Z peak with full 2010 data**
  - **All EM calorimeter**
  - **Autumn reprocessing**
  - **Fit : Breit-Wigner ⊗ Crystal Ball**

    σ quoted : Crystal Ball right

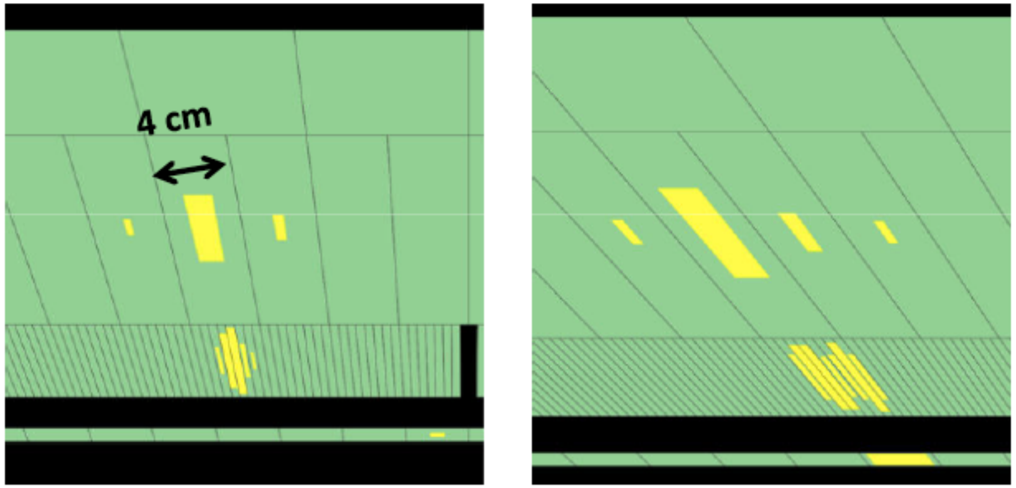


Physics Results : photons in ATLAS

- **Data: photon / π^0**

Very fine granularity first compartment in EM calorimeter

(This 21 GeV E_T π^0 would pass cuts in S2!)



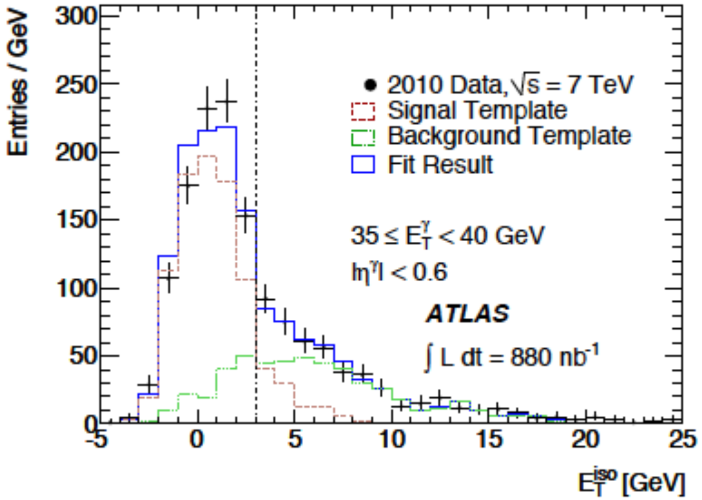
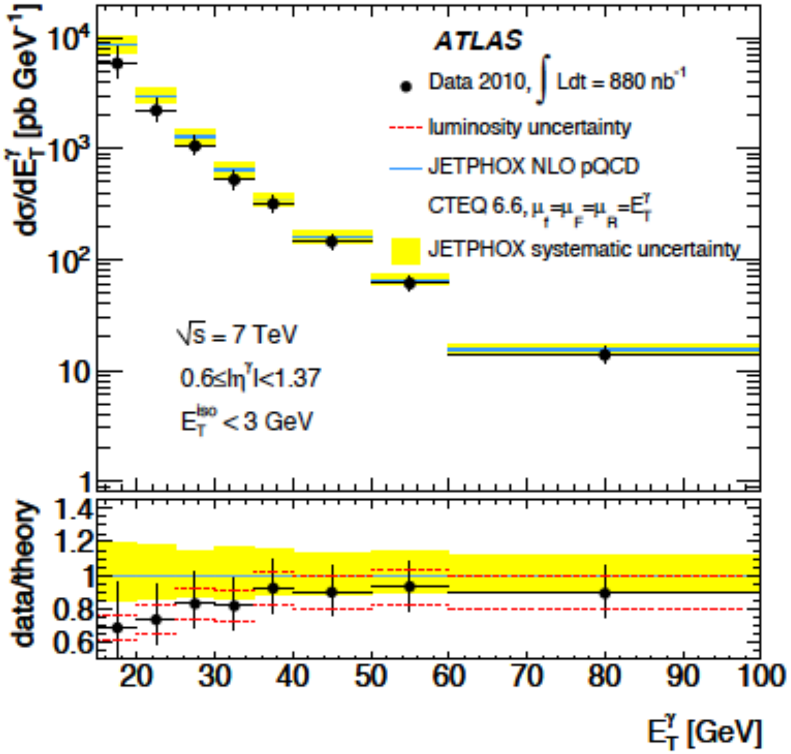


FIG. 7. Example of a fit to extract the fraction of prompt photons using the isolation template technique in the region $0 \leq |\eta| < 0.6$ and $35 \leq E_T^\gamma < 40$ GeV. The signal template is derived from electrons selected from W or Z decays, and is shown with a dashed line. The background template is derived from a background-enriched sample, and is represented by a dotted line. The estimated photon fraction is 0.85 and its statistical uncertainty is 0.01.

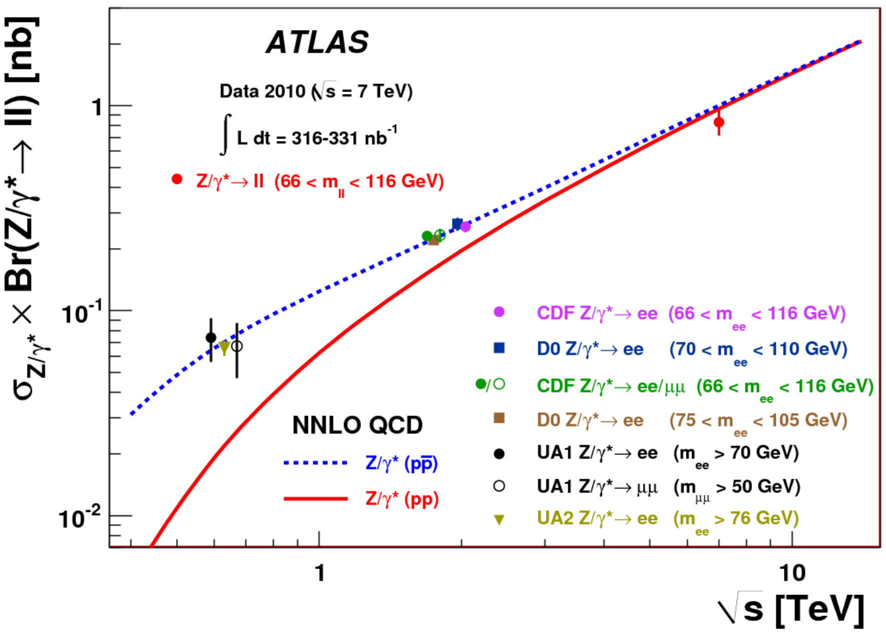


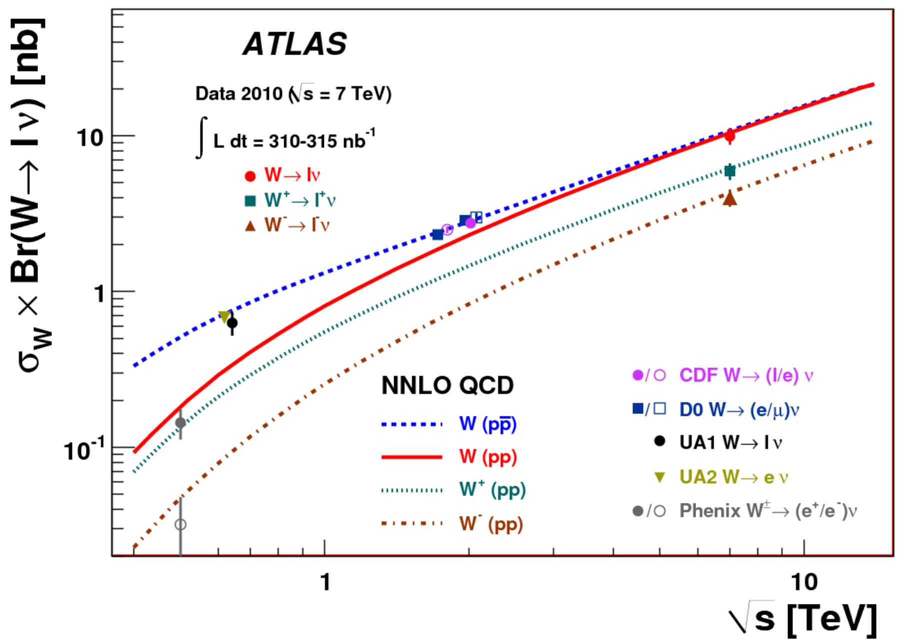
Physics Results : EW physics

Luminosité intégrée de ~300 nb^{-1}

$\sigma\ (Z \rightarrow ll) = 0.82 \pm 0.06\ (stat)\ \pm 0.05 (syst)\ \pm 0.09 (lumi)\ nb$

$\sigma\ (W \rightarrow l\nu) = 9.96 \pm 0.23 (stat)\ \pm 0.50 (syst) \pm 1.10 (lumi)\ nb$





arXiv:1010.2130, published in JHEP

Physics Results : top physics

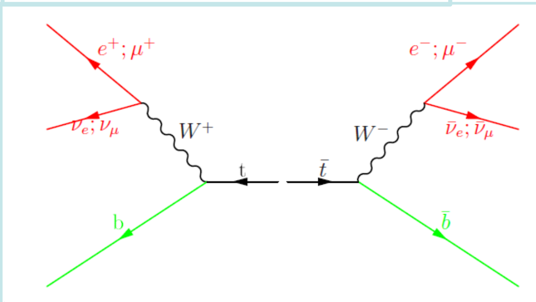
Nécessite la maîtrise des leptons, jets, énergie transverse manquante, b-tagging, bruits QCD et W/Z + jets..

σ(LHC 7 TeV) ~ 20 x σ(Tevatron) : 0.5 fb^{-1} ⇔ 10 fb^{-1}

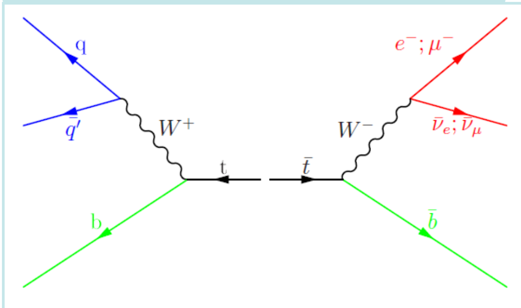
1000 di-leptons + 5000 lepton+jets

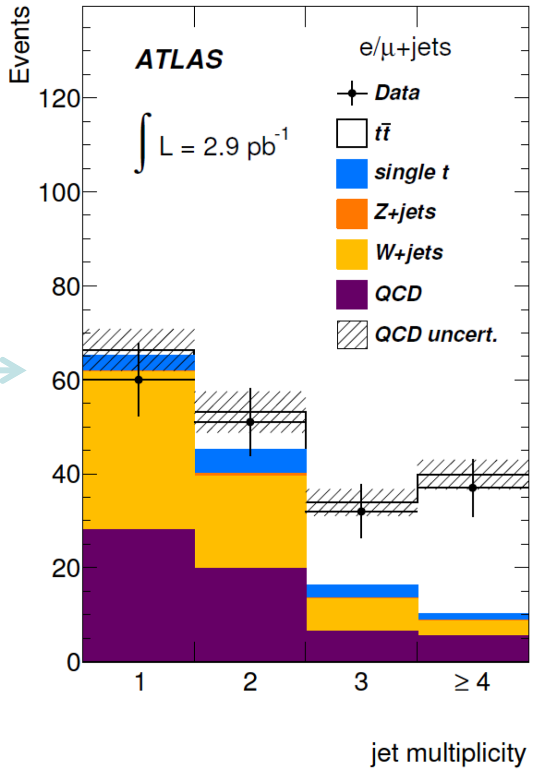
Analyse avec 2,9 pb^{-1} :

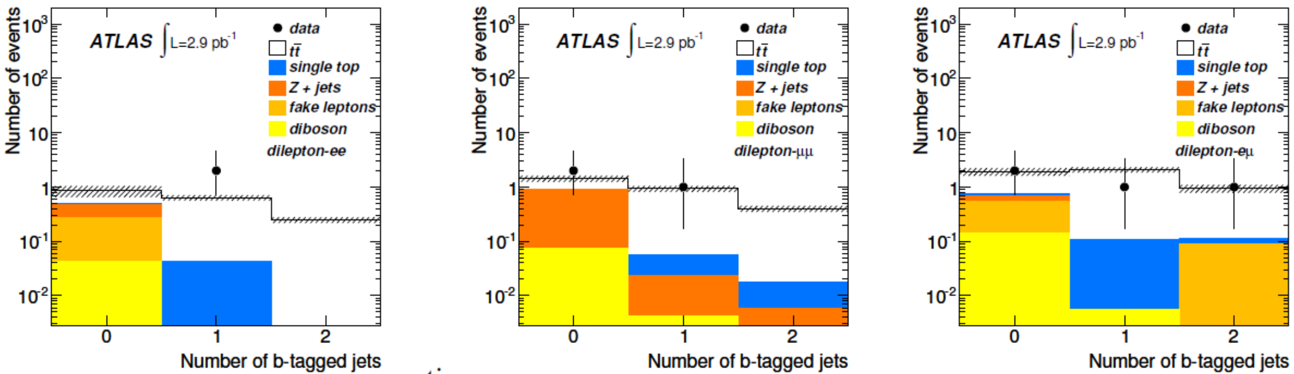
Di-leptons : 9 candidats



Jets+leptons : 20 μ + 17 e







ti

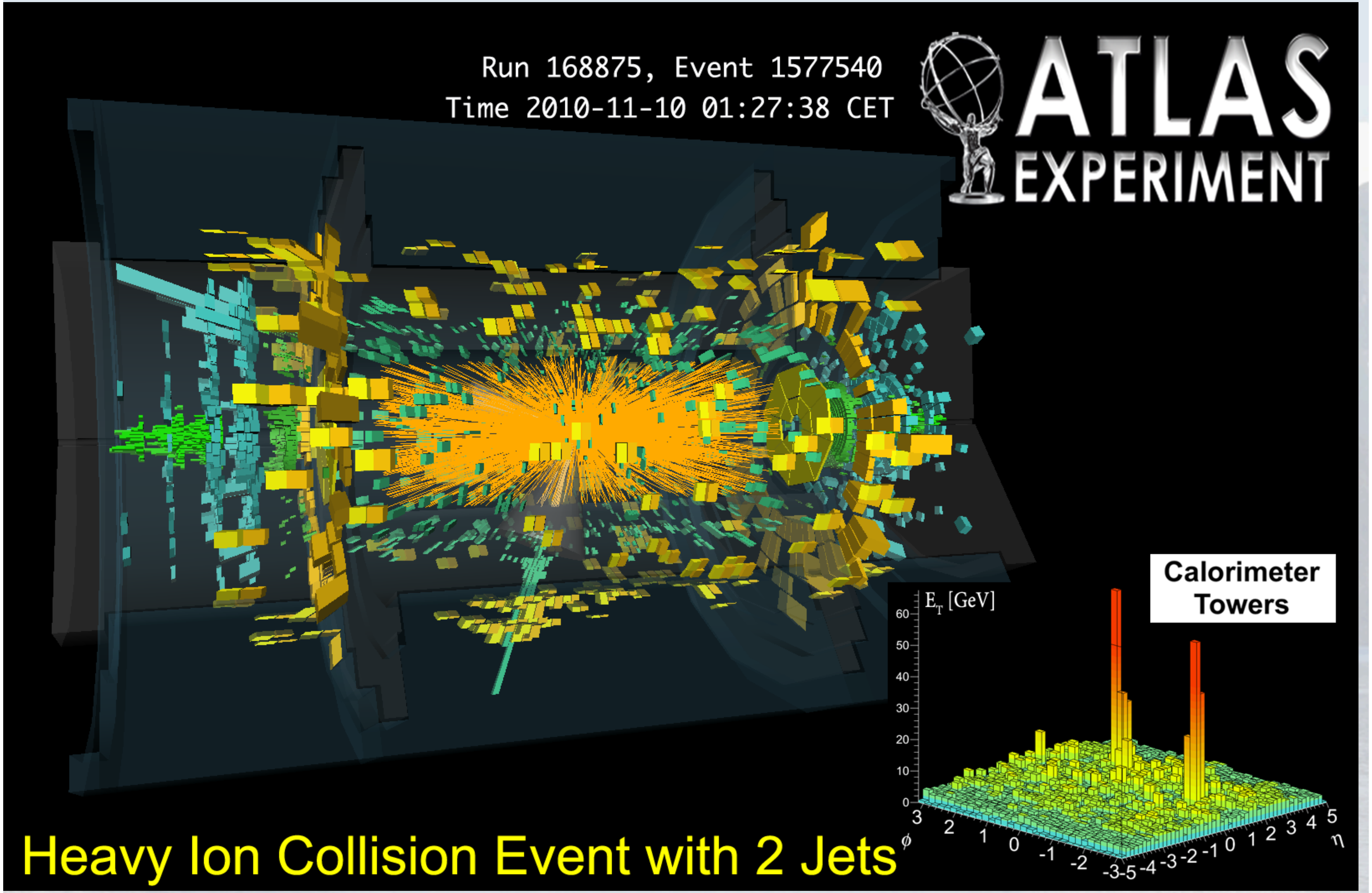
(a) N_{b-jets} in the ee channel (b) N_{b-jets} in the $\mu\mu$ channel (c) N_{b-jets} in the $e\mu$ channel

Publication en préparation avec 2,9 pb^{-1}:

$$\sigma_{t\bar{t}} = 146 \pm^{37}_{33} \pm^{49}_{30}\ \mathrm{pb}$$

Excès à ~ 4.9 σ

Heavy Ions collision from the 2010 run

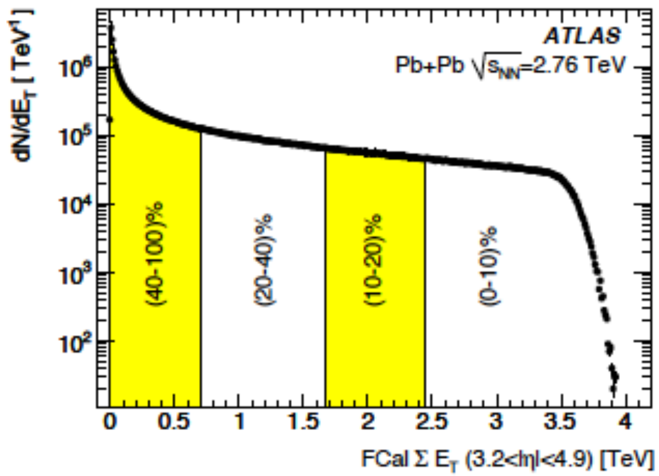


Physics Results : HI Physics

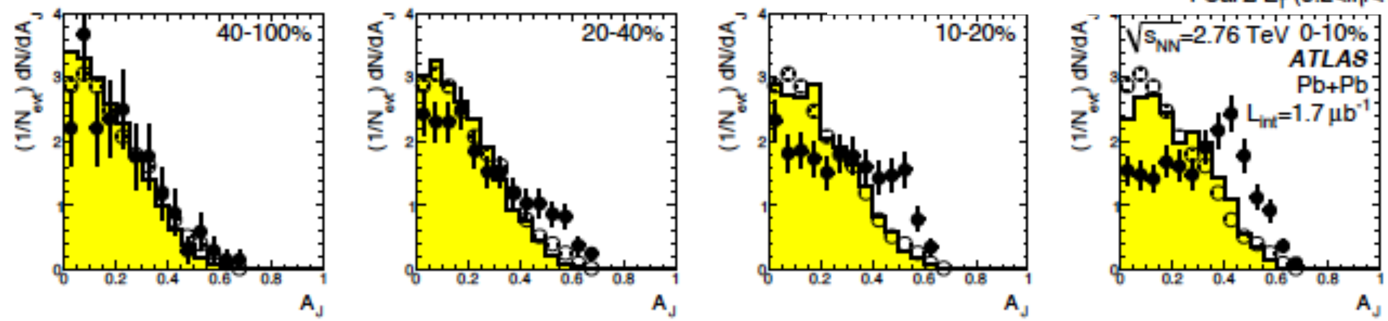
Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at sqrt(S(NN)) = 2.76 TeV

arXiv:1011.6182

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

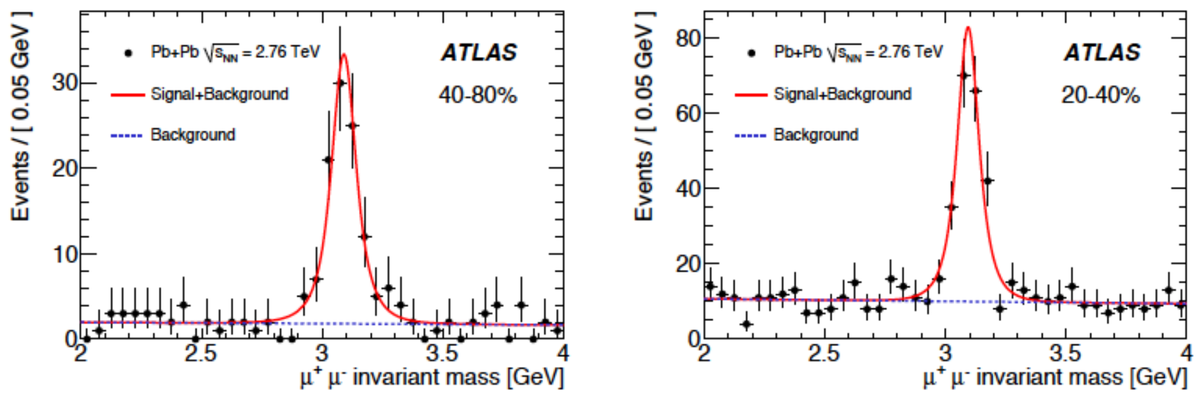


May point to an interpretation in terms of strong jet energy loss in a hot, dense medium.



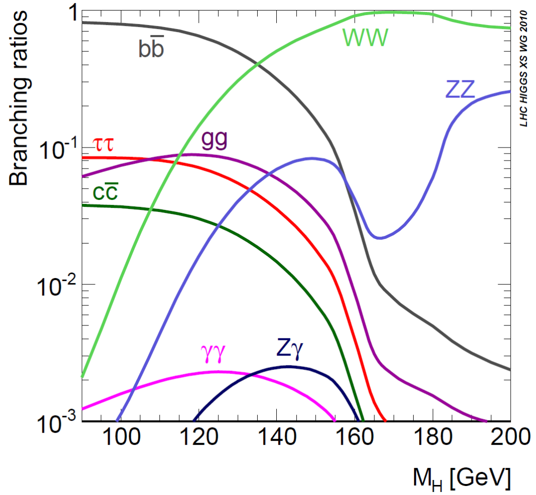
Observation of Z production in HI collisions

arXiv:1012.5419



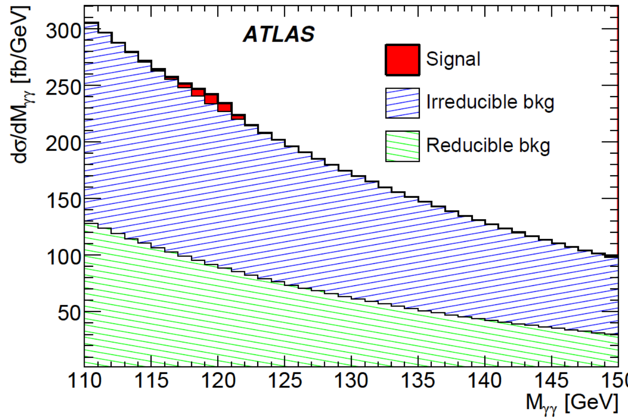
Higgs sector Beyond 2010

In the low mass region, ATLAS can benefit from various channels that give complementary information on the existence of a standard Higgs Boson.



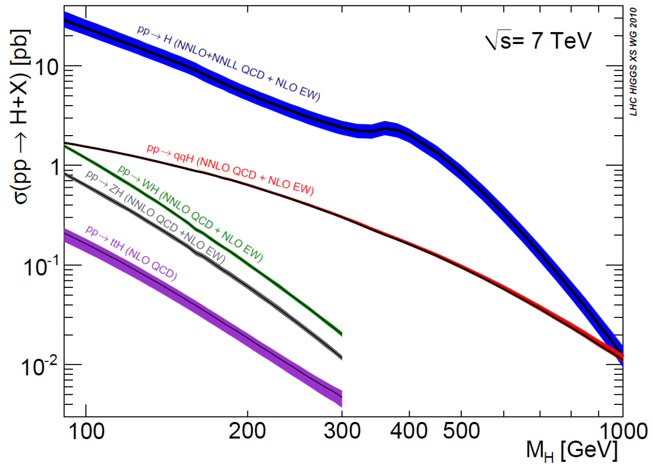
$$H \to ZZ \to l^+l^-\nu\bar{\nu}$$
$$H \to \gamma\gamma$$
$$H \to ZZ^{(*)} \to l^+l^-l^+l^-$$
$$H \to WW$$
$$H \to \tau^+\tau^-$$
$$H \to ZZ \to l^+l^-b\bar{b}$$

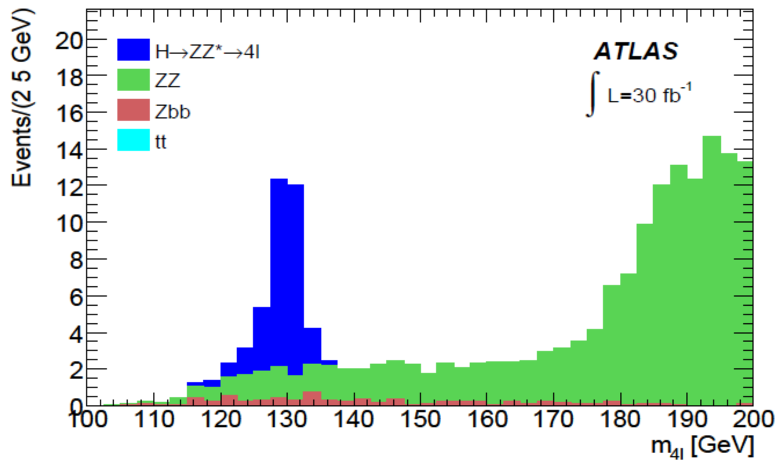
$H \to \gamma\gamma$ **(LPNHE)**



$H \to b\bar{b}$ **(LPTHE)**

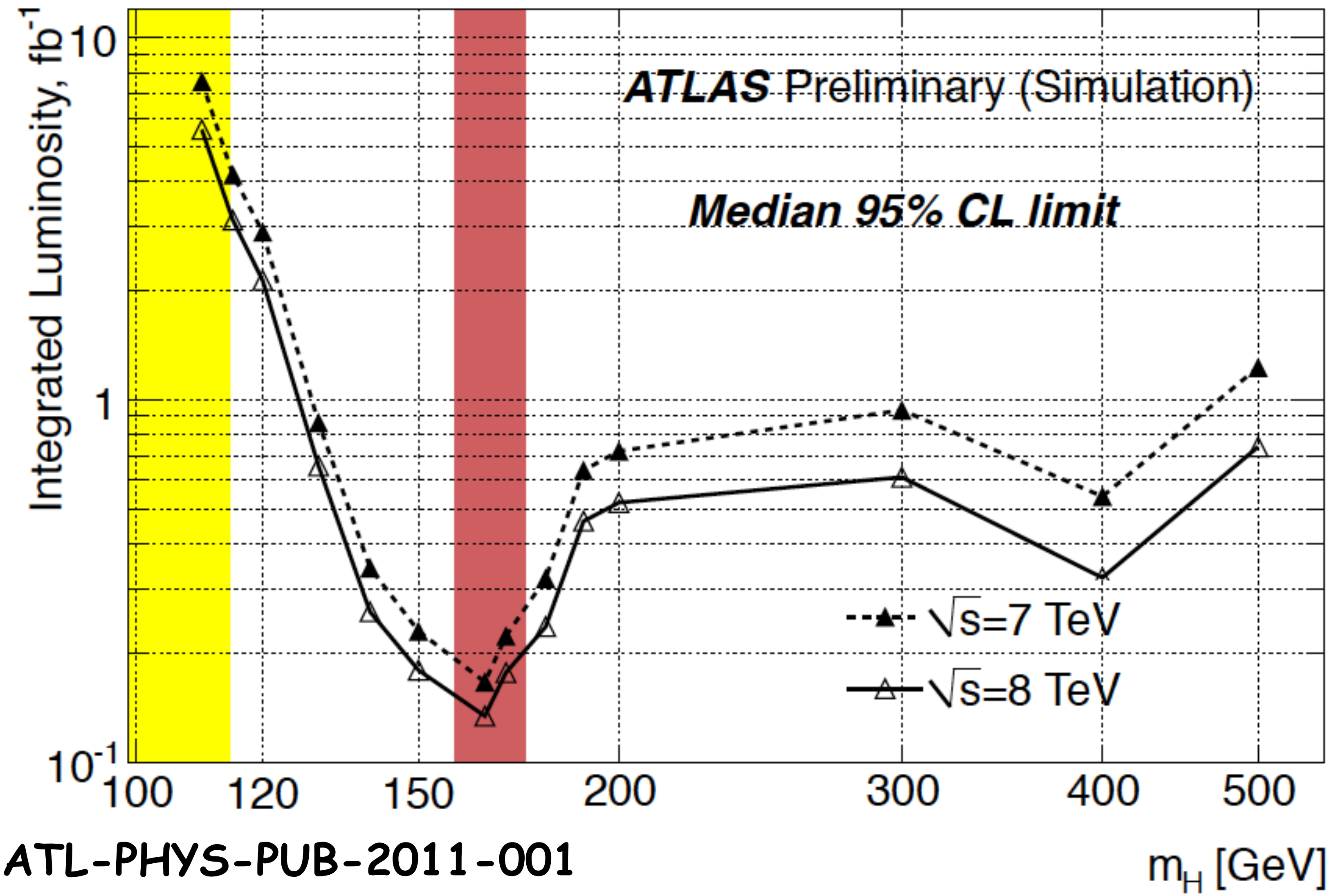
$H \to ZZ^{(*)} \to l^+l^-l^+l^-$





All these channels are considered in the next slides

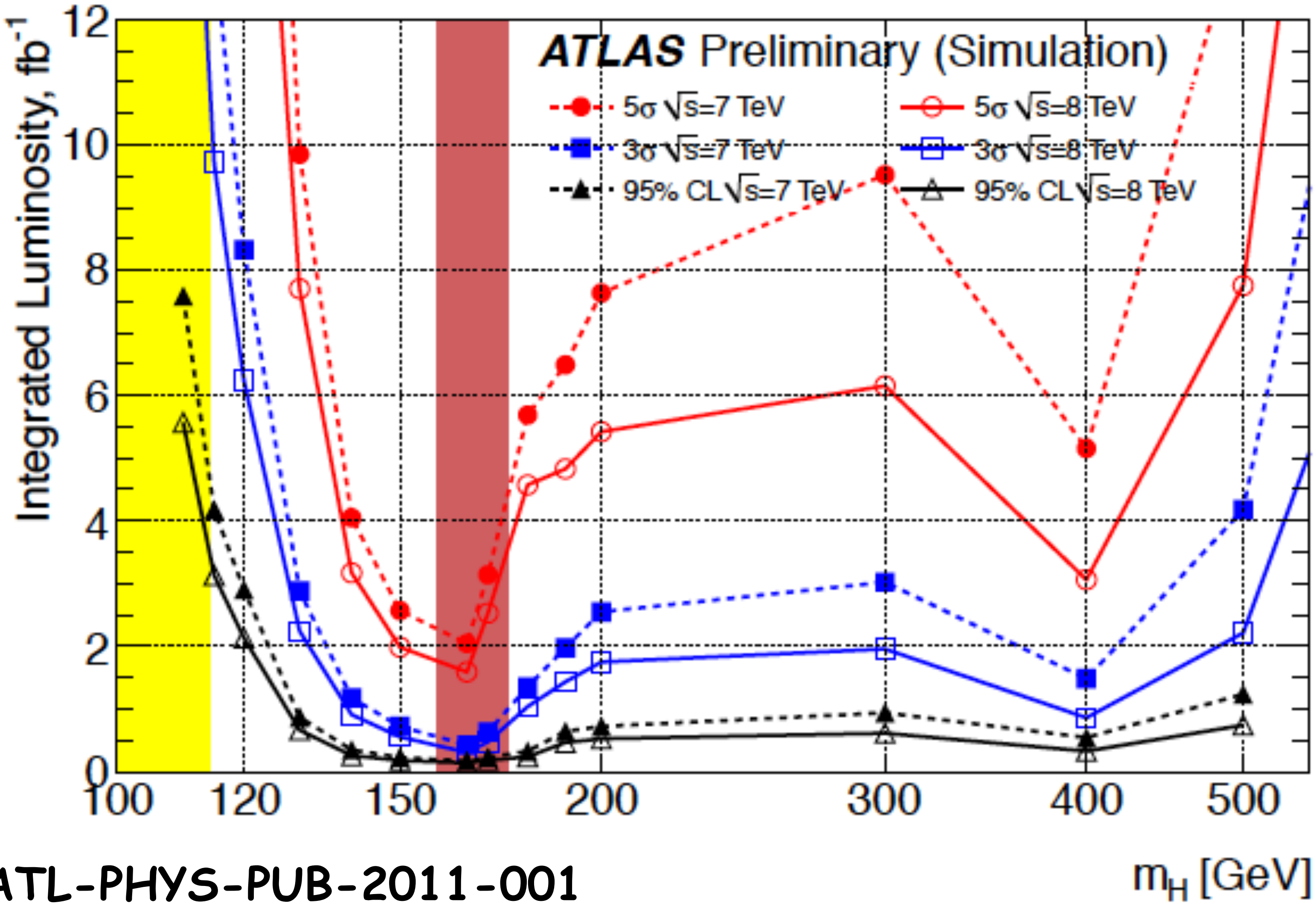
Beyond the present results : Expected lumi to reject the SM Higgs at 95% CL



ATL-PHYS-PUB-2011-001

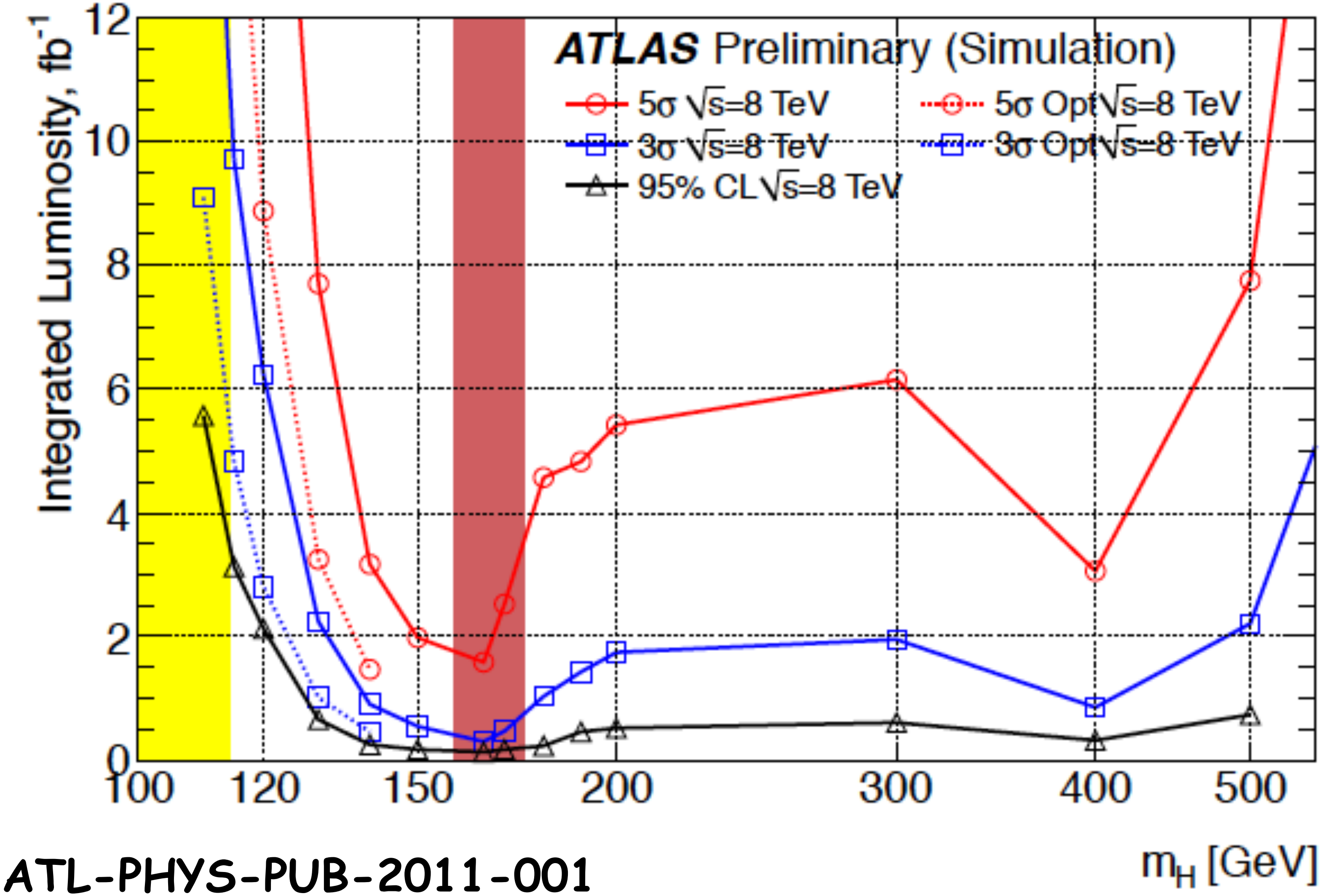
Figure 1: The luminosity required, as a function of m_H, to give a median exclusion significance of 95% CL for a SM Higgs at $\sqrt{s}$ = 7 or 8 TeV. The shaded regions are the regions excluded by LEP [11], (yellow or light) and the Tevatron [12] (brown or dark).

Beyond the present results : Discovery potential beyond 1 fb^{-1}



ATL-PHYS-PUB-2011-001

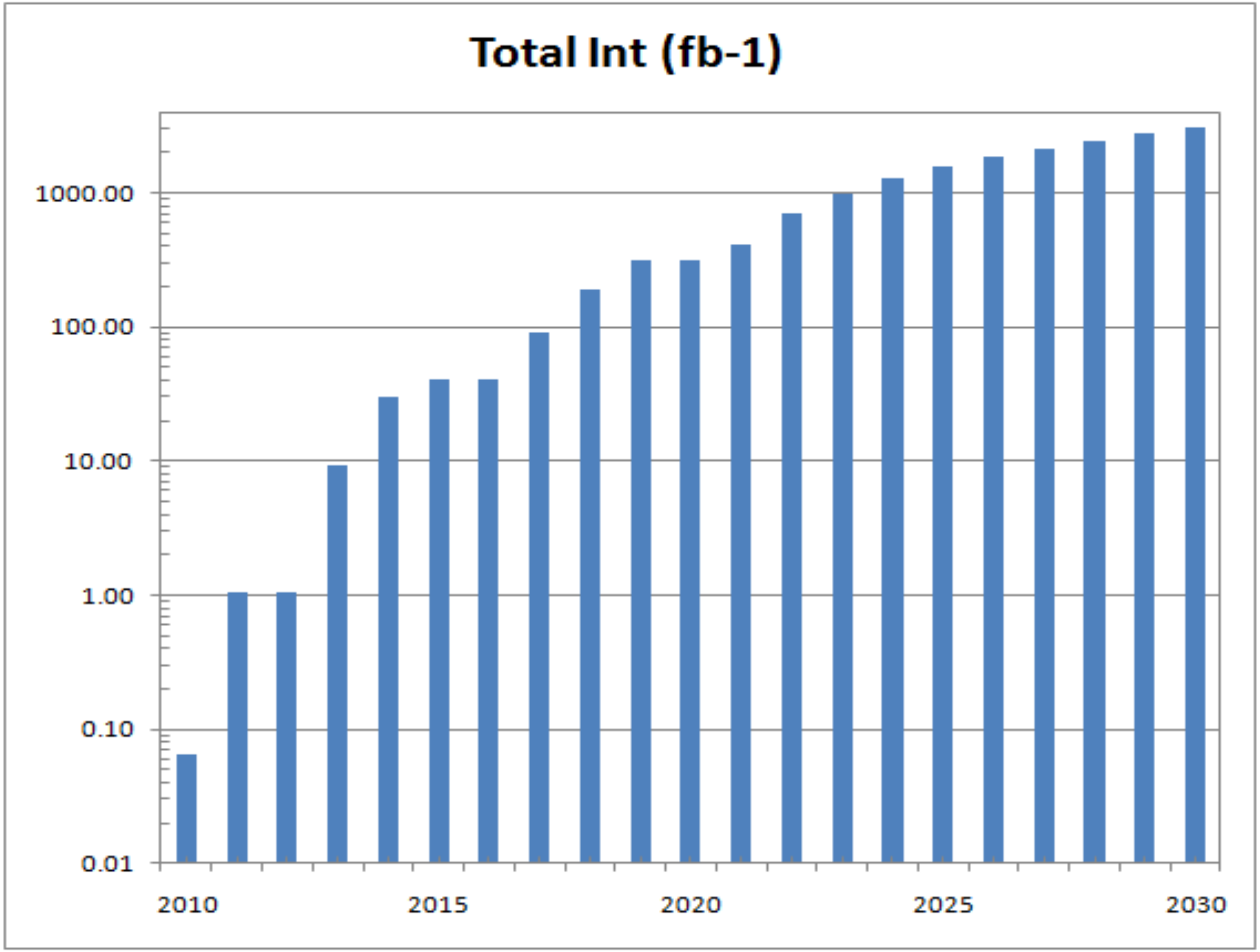
Figure 3: The luminosity required to give exclusion, evidence or discovery sensitivity for a SM Higgs with data at $\sqrt{s}$ = 7 or 8 TeV.



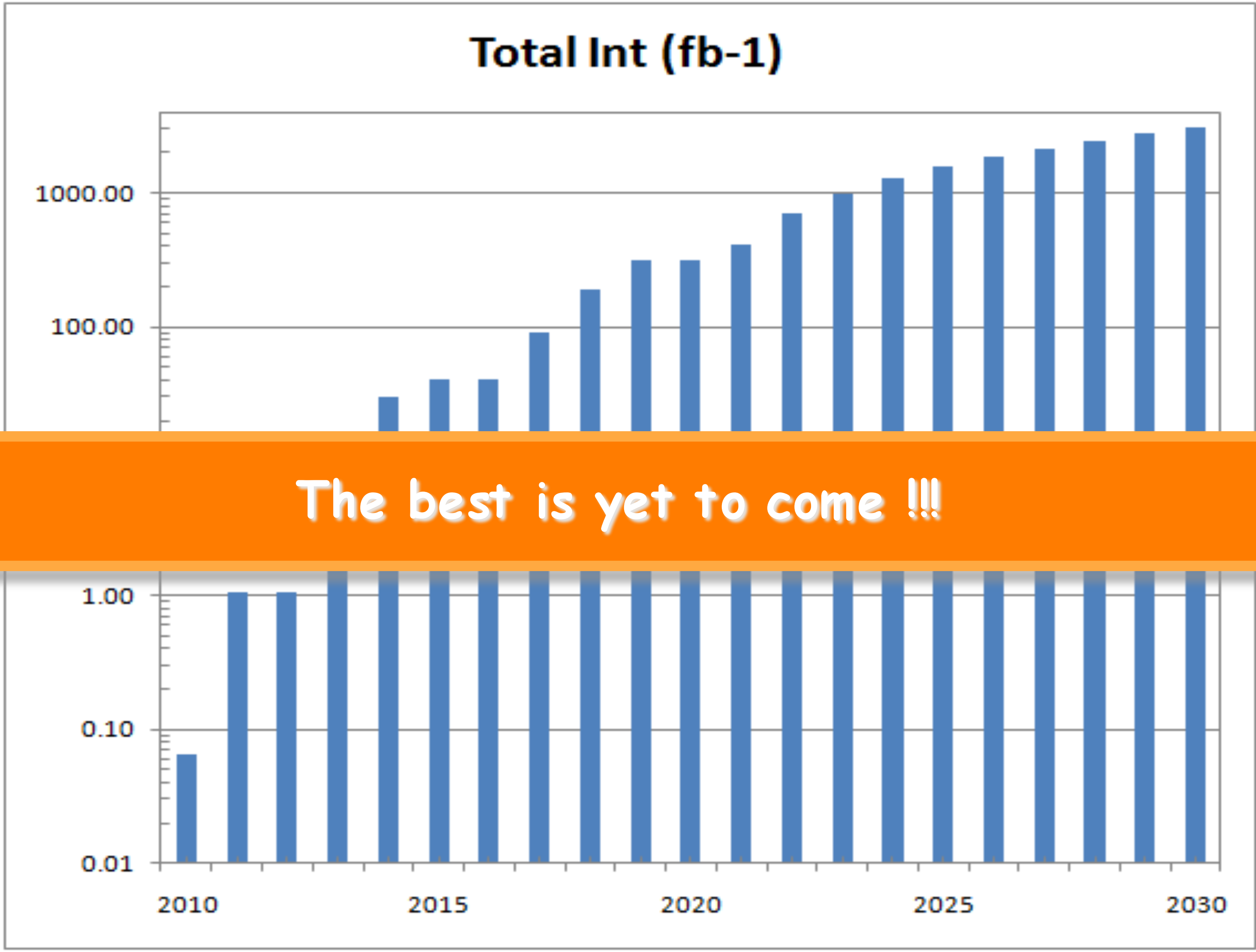
ATL-PHYS-PUB-2011-001

Figure 4: The luminosity required to give exclusion, evidence or discovery sensitivity for a SM Higgs with data at $\sqrt{s}$ = 8 TeV using the normal or optimised analysis. The latter was only run below 140 GeV.

Beyond the present results : the 20-year physics plan



The 20-year physics plan



The best is yet to come !!!

Enjoy the collisions

Thank You for your attention ☺

Backup Slides

The Standard Model of elementary particles and interactions

$$\mathcal{L} = \mathcal{L}_{gauge} + \mathcal{L}_{Yukawa} + \mathcal{L}_{Higgs}$$

$$\begin{aligned}
\mathcal{L}_{gauge} \quad = \quad & -\frac{1}{4}G^a_{\mu\nu}G^a_{\mu\nu} - \frac{1}{4}W^i_{\mu\nu}W^i_{\mu\nu} - \frac{1}{4}B_{\mu\nu}B_{\mu\nu} \\
& + i\overline{L}_\alpha\gamma^\mu D_\mu L_\alpha + i\overline{Q}_\alpha\gamma^\mu D_\mu Q_\alpha + i\overline{E}_\alpha\gamma^\mu D_\mu E_\alpha \\
& + i\overline{U}_\alpha\gamma^\mu D_\mu U_\alpha + i\overline{D}_\alpha\gamma^\mu D_\mu D_\alpha + (D_\mu H)^\dagger(D_\mu H)
\end{aligned}$$

$$\mathcal{L}_{Yukawa} = y^L_{\alpha\beta}\overline{L}_\alpha E_\beta H + y^D_{\alpha\beta}\overline{Q}_\alpha D_\beta H + y^U_{\alpha\beta}\overline{Q}_\alpha U_\beta \tilde{H} + h.c.$$

$$\mathcal{L}_{Higgs} = -V = m^2 H^\dagger H - \frac{\lambda}{2}(H^\dagger H)^2$$

$$\begin{aligned}
G^a_{\mu\nu} &= \partial_\mu G^a_\nu - \partial_\nu G^a_\mu + g_s f^{abc} G^b_\mu G^c_\nu, \\
W^i_{\mu\nu} &= \partial_\mu W^i_\nu - \partial_\nu W^i_\mu + g\epsilon^{ijk} W^j_\mu W^k_\nu, \\
B_{\mu\nu} &= \partial_\mu B_\nu - \partial_\nu B_\mu,
\end{aligned}$$

$$\begin{aligned}
D_\mu L_\alpha &= (\partial_\mu - i\frac{g}{2}\tau^i W^i_\mu + i\frac{g'}{2}B_\mu)L_\alpha, \\
D_\mu E_\alpha &= (\partial_\mu + ig' B_\mu)E_\alpha, \\
D_\mu Q_\alpha &= (\partial_\mu - i\frac{g}{2}\tau^i W^i_\mu - i\frac{g'}{6}B_\mu - i\frac{g_s}{2}\lambda^a G^a_\mu)Q_\alpha, \\
D_\mu U_\alpha &= (\partial_\mu - i\frac{2}{3}g' B_\mu - i\frac{g_s}{2}\lambda^a G^a_\mu)U_\alpha, \\
D_\mu D_\alpha &= (\partial_\mu + i\frac{1}{3}g' B_\mu - i\frac{g_s}{2}\lambda^a G^a_\mu)D_\alpha.
\end{aligned}$$

$$\tilde{H} = i\tau_2 H^\dagger$$

$$SU_{colour}(3) \otimes SU_{left}(2) \otimes U_{hypercharge}(1)$$

Gauge sector: spin 1

gluons	G^a_μ	$SU_c(3)$	g_s	$(a = 1, 8)$
intermediate weak bosons	W^i_μ	$SU_L(2)$	g	$(i = 1, 3)$
abelian boson	B_μ	$U_Y(1)$	g'	

Fermion sector: spin 1/2

$$\begin{aligned}
L_{\alpha L} &= \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L, \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L, \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L \\
E_{\alpha R} &= e_R, \quad \mu_R, \quad \tau_R,
\end{aligned}$$

$$\begin{aligned}
Q^i_{\alpha L} = \begin{pmatrix} U^i_\alpha \\ D^i_\alpha \end{pmatrix}_L &= \begin{pmatrix} u^i \\ d^i \end{pmatrix}_L, \begin{pmatrix} c^i \\ s^i \end{pmatrix}_L, \begin{pmatrix} t^i \\ b^i \end{pmatrix}_L \\
U^i_{\alpha R} &= u_{iR}, \quad c_{iR}, \quad t_{iR}, \\
D^i_{\alpha R} &= d_{iR}, \quad s_{iR}, \quad b_{iR},
\end{aligned}$$

$i = 1, 2, 3$

Higgs sector: spin 0

$$H = \begin{pmatrix} H^0 \\ H^- \end{pmatrix}$$

The hierarchy ``problem''

- Unitarity of perturbative WW scattering:

either the SM Higgs is below ~ 800 GeV or there must be new physics at the TeV scale.

- Triviality and stability:

RGE introduce a relation between $\lambda(v)$ and $\lambda(Q)$

If we request to have λ finite at Q→ infinity : $\lambda(v)=0$! (no interaction at EW scale)

Unless the SM Higgs boson lies between 100 and 200 GeV, must be new physics below Planck scale.

- Hierarchy problem ("quadratic divergences" or "high-energy sensitivity"):

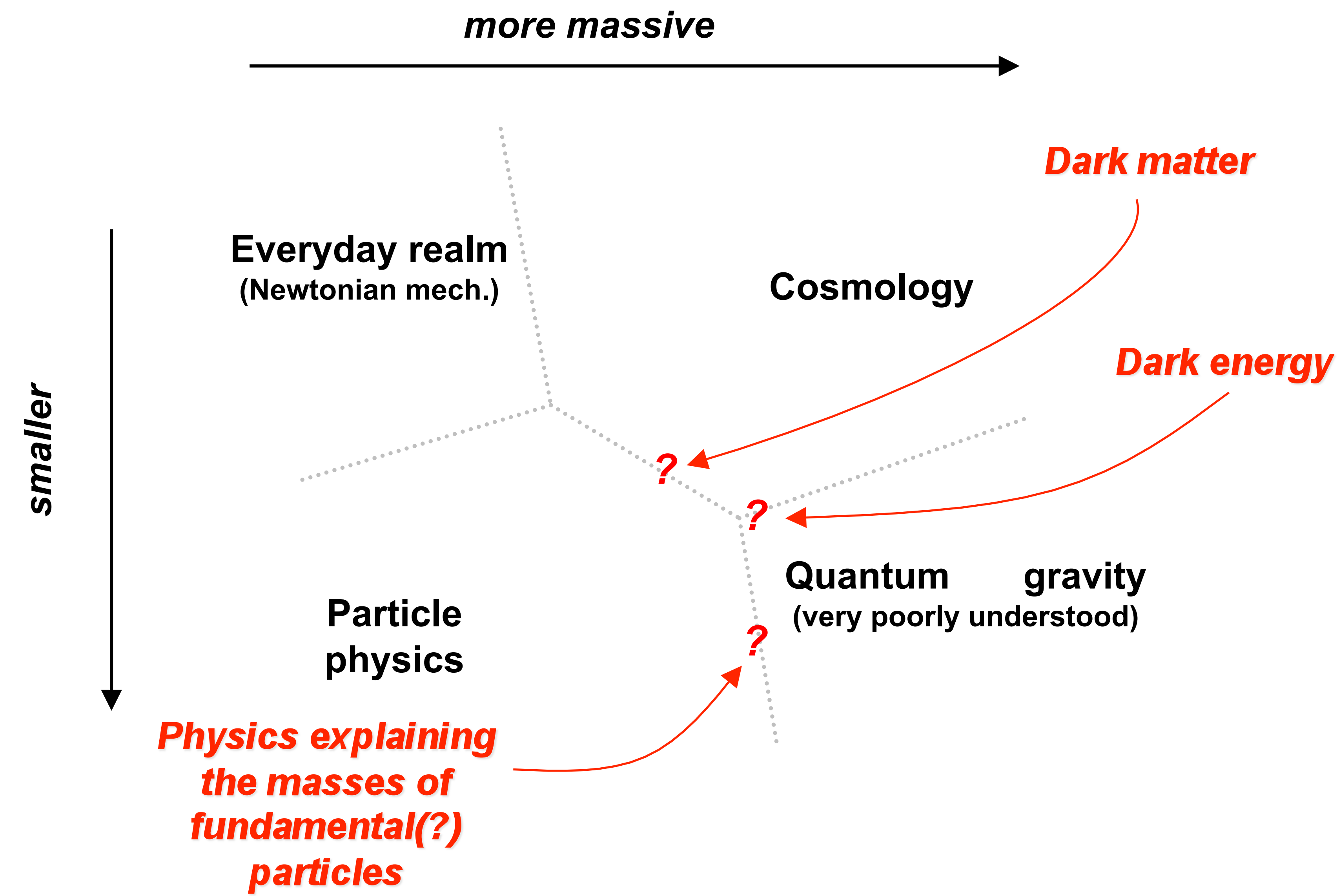
the SM with a small vev and a light Higgs is extremely ugly and ridiculously sensitive to little adjustments, so there must be new physics at the TeV scale.

Claim: it is a problem that the weak and gravitational scales are so different:

$$v / M_{pl} \sim 10^{-16}$$

Need for pp collisions at the TeV scale (luminosity, energy)

The Frontiers of Our Knowledge



Interactions: gauge invariance

Case of the electromagnetic interaction: a fermion interacting with an EM field:

From the free lagrangian $\mathcal{L} = \bar{\psi}(i\gamma^\alpha \partial_\alpha - m)\psi$ **with** $i\partial_\alpha \rightarrow i\partial_\alpha - eA_\alpha$ **(minimal coupling)**

Impose Lagrangian invariance under:

- ✓ Lorentz transformations
- ✓ Local gauge transformations

$$\begin{array}{lcl} \psi(x) & \longrightarrow & \psi'(x) = \mathrm{e}^{-i\epsilon(x)}\psi(x) \\ A_\alpha(x) & \longrightarrow & A'_\alpha(x) = A_\alpha(x) + \frac{1}{e}\partial_\alpha \epsilon(x) \end{array}$$

$$\boxed{\mathcal{L} = \bar{\psi}(i\gamma^\alpha \partial_\alpha - m)\psi - (e\bar{\psi}\gamma^\alpha\psi)A_\alpha - \frac{1}{4}F^{\alpha\beta}F_{\alpha\beta}}$$

$$F_{\alpha\beta} = \partial_\alpha A_\beta - \partial_\beta A_\alpha$$

The Higgs Mechanism in the Standard Model

$$H = \begin{pmatrix} H^0 \\ H^- \end{pmatrix}$$

charged scalar doublet under weak isospin

4 scalar fields

3 enter as longitudinal polarizations of the W and Z bosons therefore they become massive (while the photon remains massless)

$$m_W = \frac{1}{\sqrt{2}} g v$$

$$\tan\theta_W = g'/g$$

$$m_Z = m_W / \cos\theta_W$$

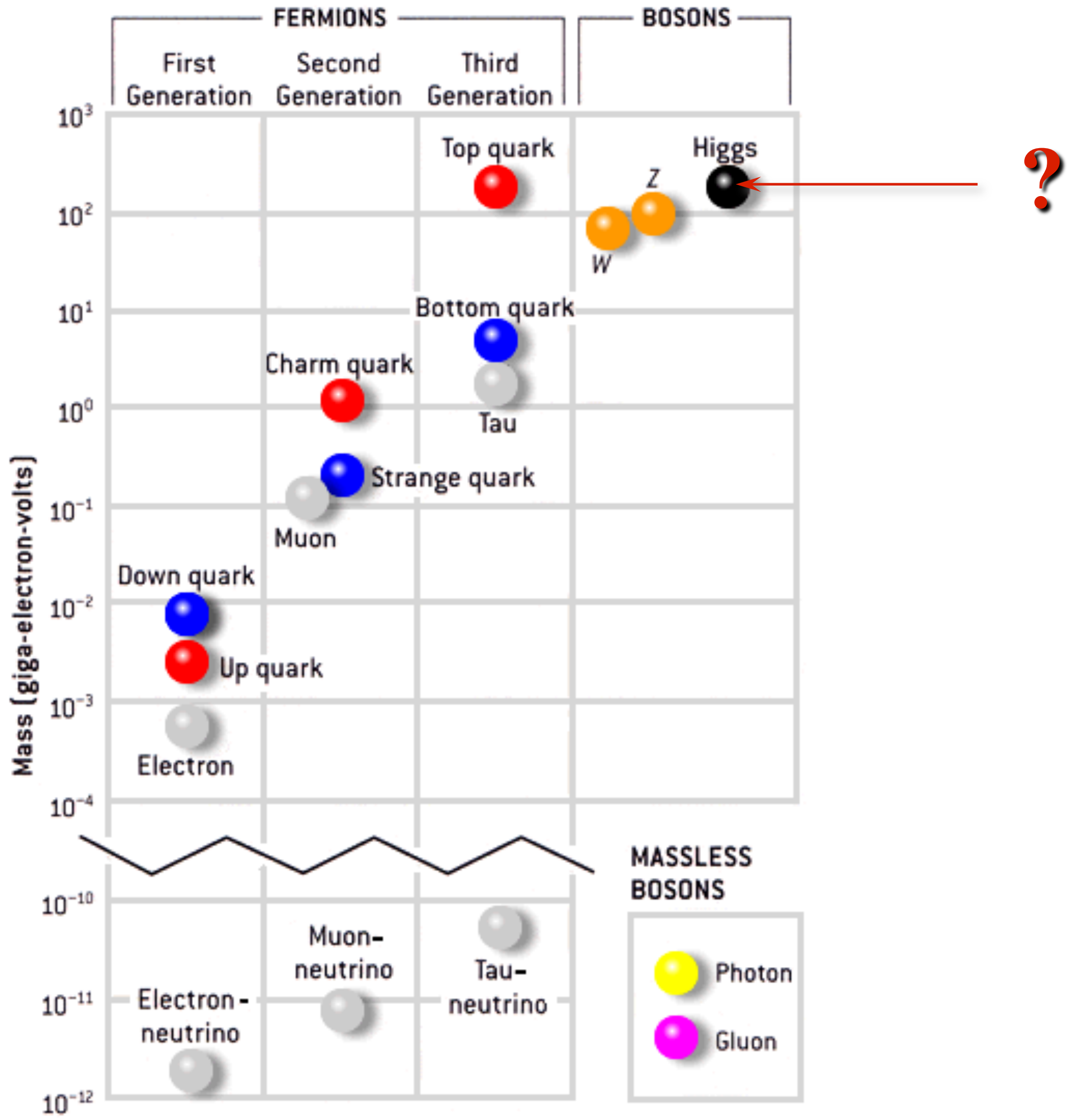
1 remains as a physical particle

H Higgs boson

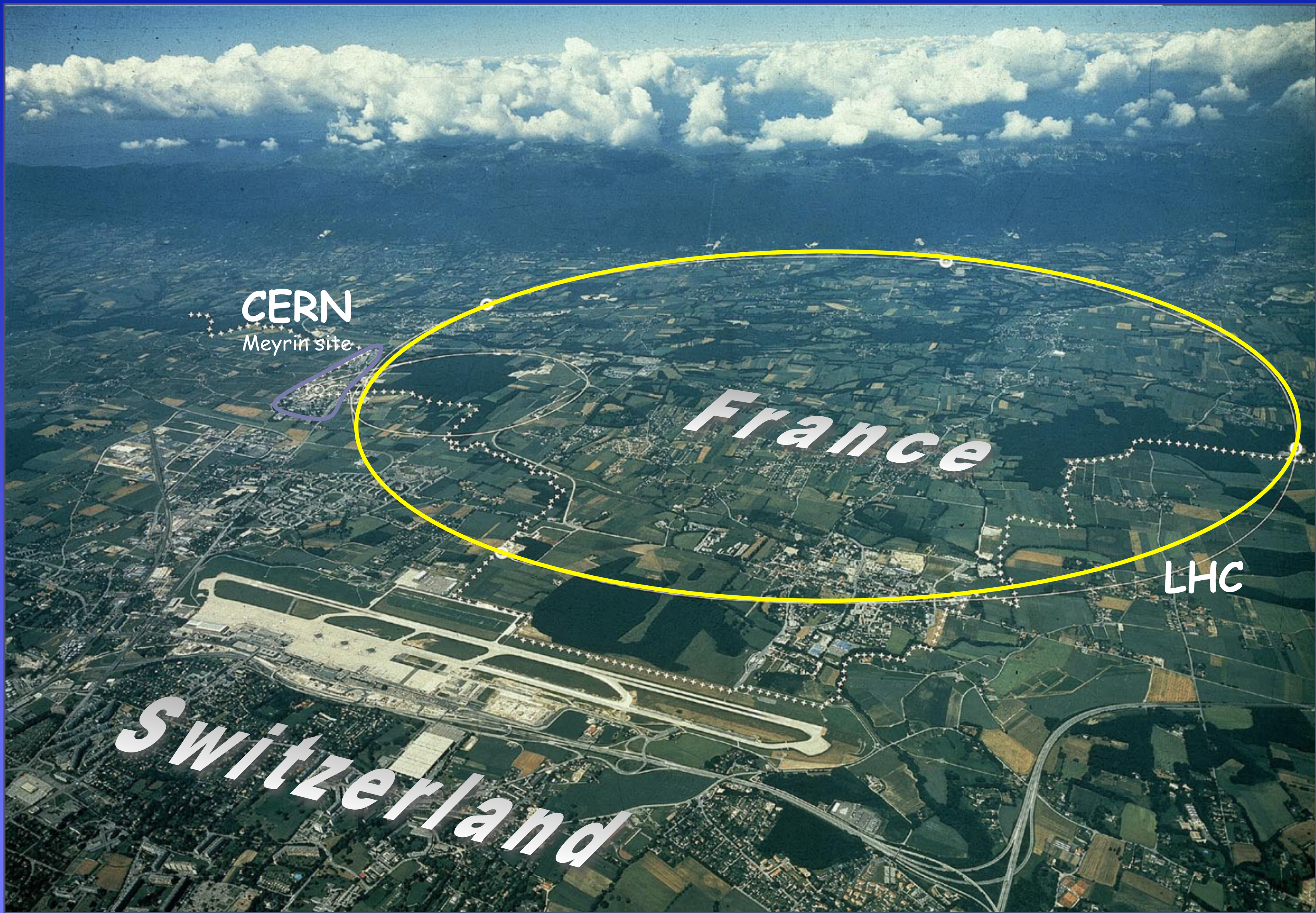
$$s = 0$$

$$m_H = ?$$

Mass spectrum of the Standard Model



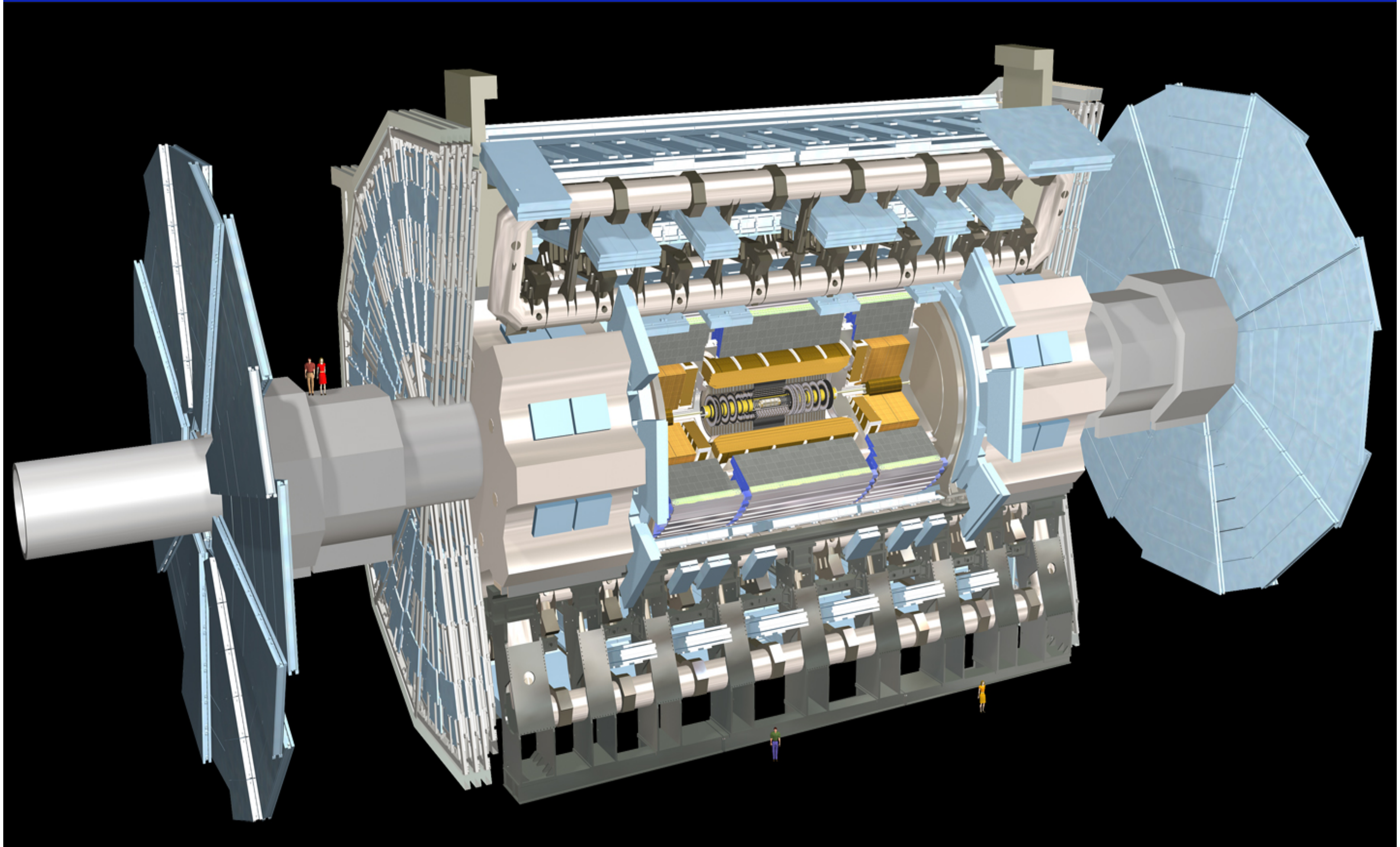
LHC : 1 Collider, 4 large experiments



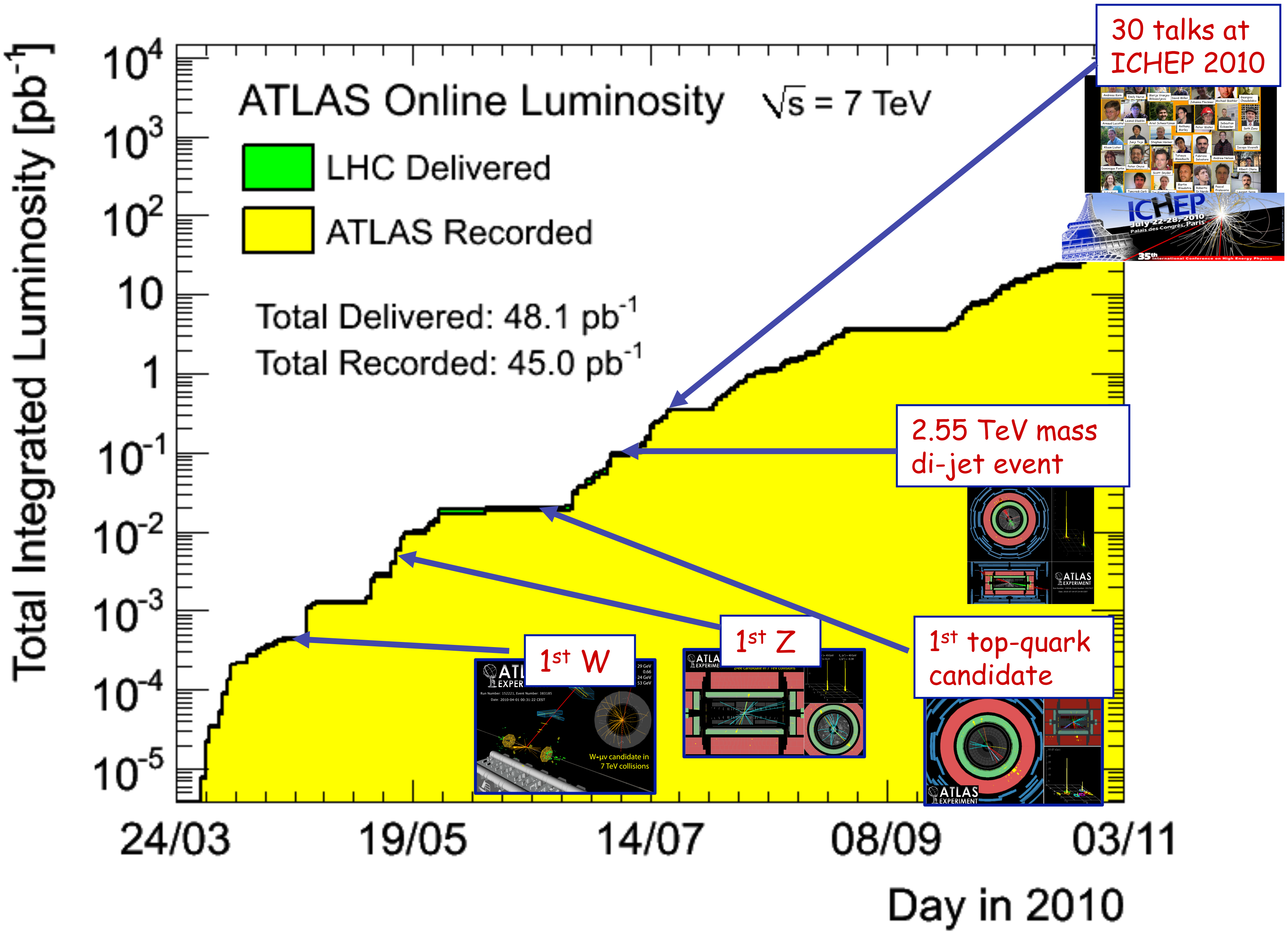
LHC: Some Technical Challenges

Circumference (km)	26.7	100-150m underground
Number of superconducting twin-bore dipoles	1232	Cable Nb-Ti, cold mass 37million kg
Length of Dipole (m)	14.3	
Dipole Field Strength (Tesla)	8.4	Results from the high beam energy needed
Operating Temperature (K) (cryogenics system)	1.9	Superconducting magnets needed for the high magnetic field Super-fluid helium
Current in dipole sc coils (A)	13000	Results from the high magnetic field 1ppm resolution
Beam Intensity (A)	0.5	$2.2.10^{-6}$ loss causes quench
Beam Stored Energy (MJoules)	362	Results from high beam energy and high beam current 1MJ melts 1.5kg Cu
Magnet Stored Energy (MJoules)/octant	1100	Results from the high magnetic field
Sector Powering Circuit	8	1612 different electrical circuits

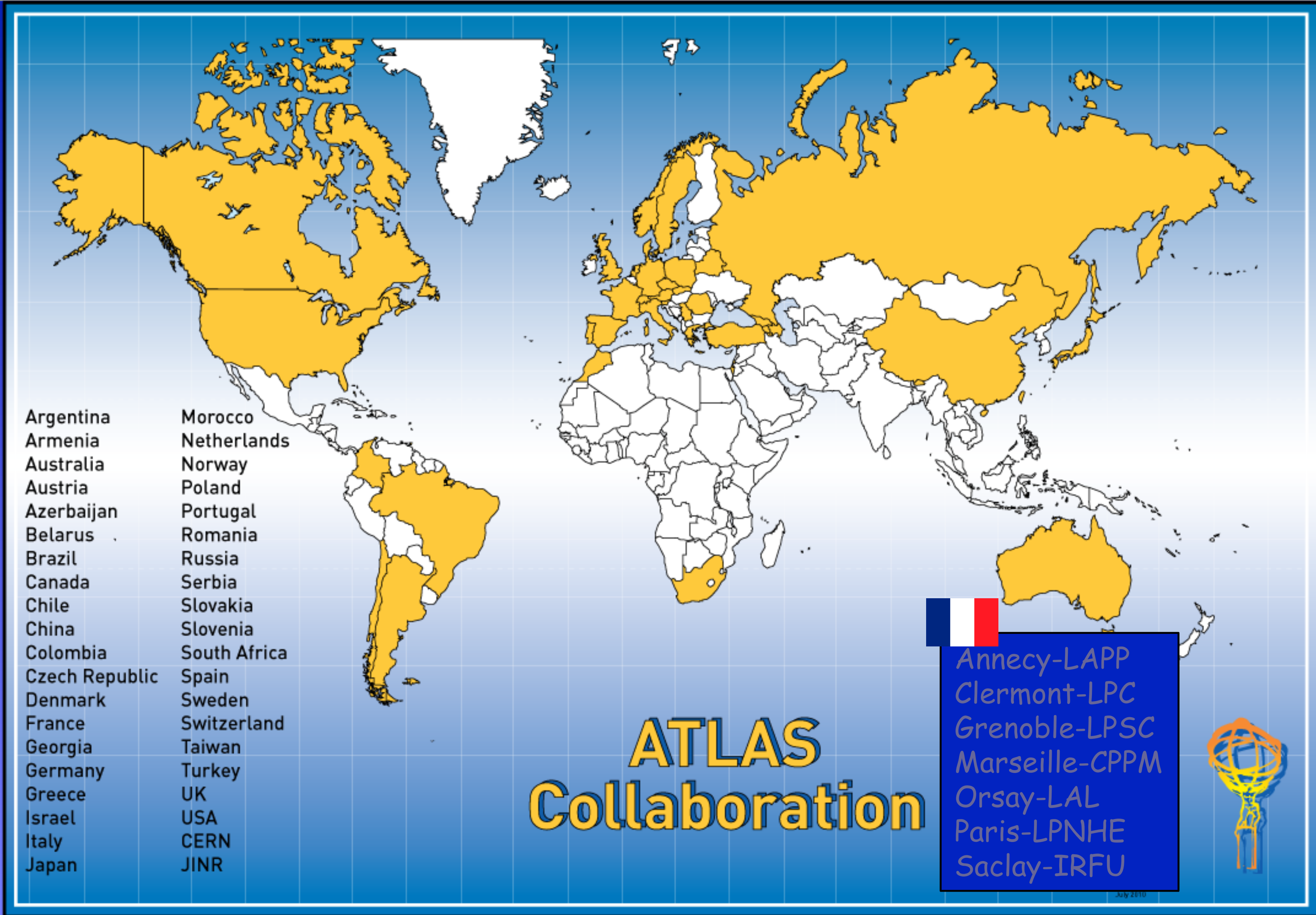
The ATLAS detector at the LHC



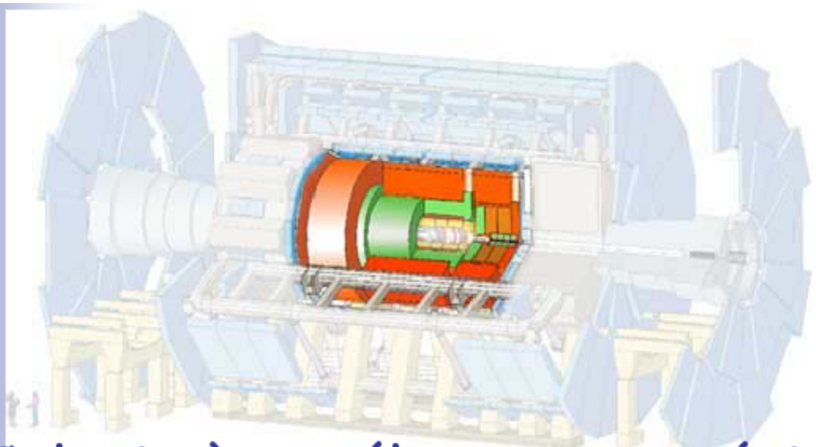
ATLAS data-taking in pp mode 2010 – 7 TeV



~3000 scientists from 174 Institutions and 38 Countries

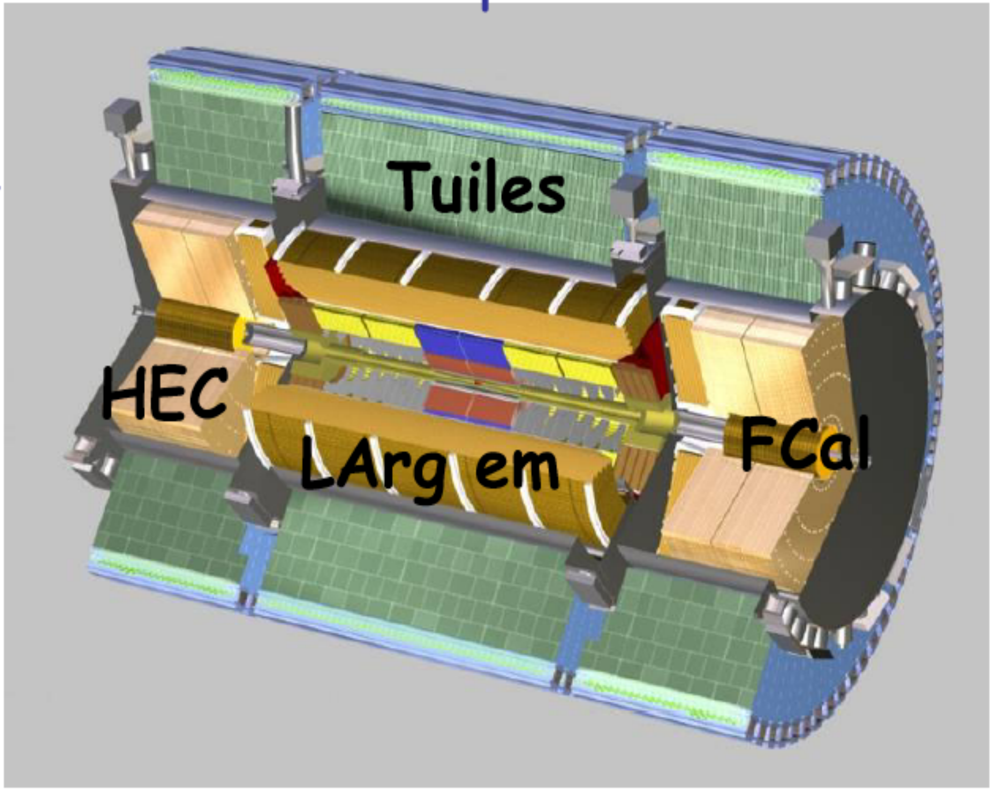


Calorimétrie d'ATLAS



Mesurer l'énergie des électrons, des photons et des hadrons

Discriminer les particules



Calorimètre électromagnétique

170000 cellules

$$\frac{\sigma_E}{E} = \frac{0,1}{\sqrt{E}} \oplus \frac{0,25}{E} \oplus 0,007$$

Calorimètre hadronique

10000 + 9000 cellules (tuiles + HEC/FCAL)

$$\frac{\Delta E}{E} = \frac{50\%}{\sqrt{E}} \oplus 3\% \text{ pour } |\eta| < 3$$

$$\frac{\Delta E_T}{E_T} = \frac{100\%}{\sqrt{E}} \oplus 10\% \text{ pour } 3 < |\eta| < 5$$

Systématiques W et Z

électron

Parameter	$\delta C_W/C_W(\%)$	$\delta C_Z/C_Z(\%)$
Trigger efficiency	<0.2	<0.2
Material effects, reconstruction and identification	5.6	8.8
Energy scale and resolution	3.3	1.9
E_T^{miss} scale and resolution	2.0	-
Problematic regions in the calorimeter	1.4	2.7
Pile-up	0.5	0.2
Charge misidentification	0.5	0.5
FSR modelling	0.3	0.3
Theoretical uncertainty (PDFs)	0.3	0.3
Total uncertainty	7.0	9.4

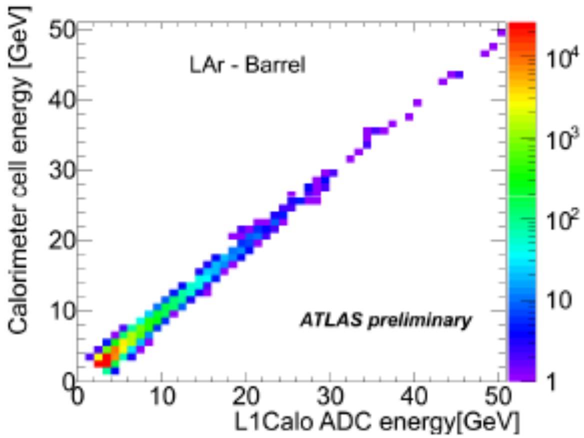
muon

Parameter	$\delta C_W/C_W(\%)$	$\delta C_Z/C_Z(\%)$
Trigger efficiency	1.9	0.7
Reconstruction efficiency	2.5	5.0
Momentum scale	1.2	0.5
Momentum resolution	0.2	0.5
E_T^{miss} scale and resolution	2.0	-
Isolation efficiency	1.0	2.0
Theoretical uncertainty (PDFs)	0.3	0.3
Total uncertainty	4.0	5.5

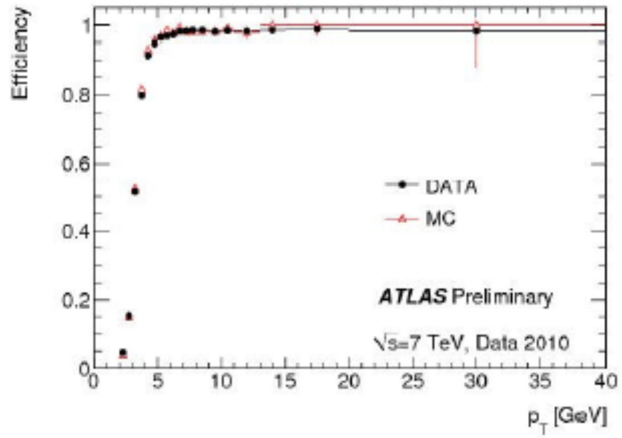
Trigger

- **Good understanding of trigger primitives, thresholds…**

  – **EM level 1 calorimeter Trigger vs Readout**



  - **Muon level 2 Trigger threshold (4 GeV)**



- **Good control of rates, evolution with luminosity…**

3 level trigger

– **L1**

– **L2**

– **Event Filter**