Some Selected LHC Physics results

Samira Hassani

CEA-Saclay, IRFU/SPP

Restricted ECFA visit of France meeting

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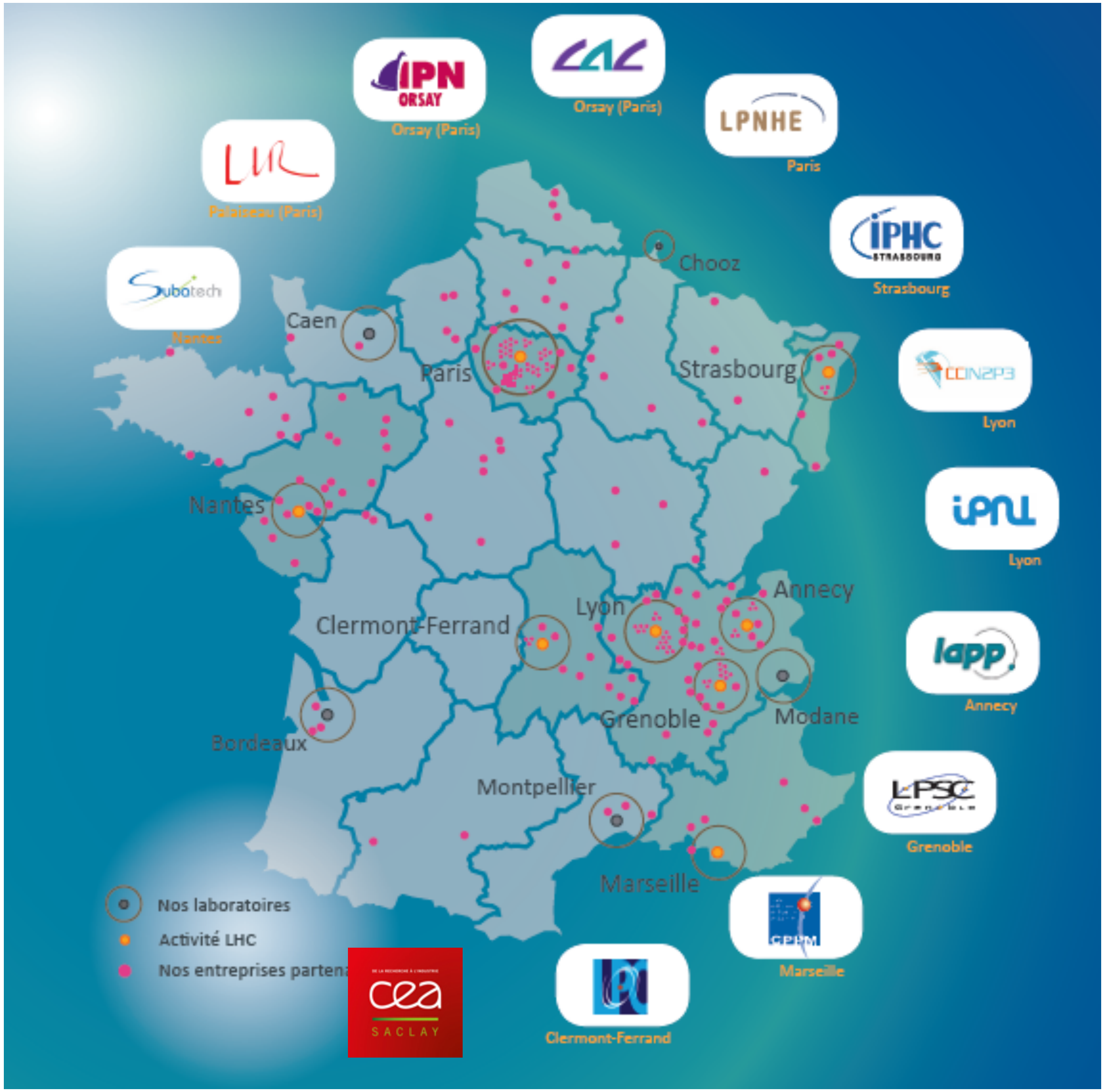
Success of 2010-2012 Run

- **Excellent collider performance** :
  - 23 fb^{-1} luminosity delivered in 2012
- **Excellent detector performance :**
  - Operational efficiency ~96%
  - Robust and high reconstruction efficiency in presence of pile-up
- **Physics highlight of the run :**
  - Discovery of a Higgs-like particle
  - We are beginning to probe its properties
- **Gigantic amount of work on searches for SUSY, extra dimensions, …**
  - Null so far
- These accomplishments are the results of the ingenuity, vision and painstaking work of the **HEP community**
- **The LHC-France community** has brought a fundamental contribution to the success of the experiments in all their components thanks to its effort, continuous support, and major role in all past, present and future activities of the LHC

The Context of LHC in France

- **Early and strong support to LHC in the French community** (since Lausanne workshop 1984) and also strong support at the government level
- **Contributions to the conception, design and technological choices of LHC experiments**
- **Continuous efforts, strong involvement and extreme dedication by the French teams in**:
  - 20 years of detector and physics simulations (historical contributions to the Higgs studies)
  - 15 years of test beams
  - 8 years of world-wide computing data challenges
  - 3 years of detectors commissioning
- **Participation to the physics coordination of the LHC experiments**: project leaders, performance convenors, physics group convenors, …
- **A total of 210 physicists and 230 engineers and technicians** from CNRS and the CEA are involved in the LHC program. About 20 PhD thesis/year

LHC-France map



LHC-France Labs

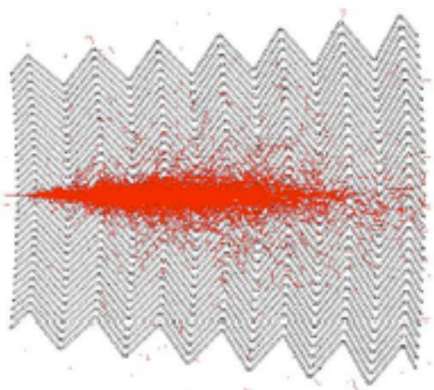
- **11 labs of IN2P3** :
  - le Centre de physique des particules de Marseille (CPPM)
  - l'Institut pluridisciplinaire Hubert Curien à Strasbourg (IPHC)
  - l'Institut de physique nucléaire de Lyon (IPNL)
  - l'Institut de physique nucléaire d'Orsay (IPNO)
  - le Laboratoire de l'accélérateur linéaire à Orsay (LAL)
  - le Laboratoire d'Annecy le Vieux de physique des particules à Annecy (LAPP)
  - le Laboratoire Leprince-Ringuet à Palaiseau (LLR)
  - le Laboratoire de physique corpusculaire de Clermont-Ferrand (LPC Clermont)
  - le Laboratoire de physique nucléaire et de hautes énergies à Paris (LPNHE)
  - le Laboratoire de physique subatomique et de cosmologie à Grenoble (LPSC)
  - le Laboratoire de physique subatomique et des technologies associées à Nantes (Subatech)
- **CEA-DSM :**
  - l'Institut de recherche sur les lois fondamentales de l'Univers à Saclay (Irfu)
  - l'institut nanosciences & cryogénie à Grenoble (Inac)
- **Centre de Calcul de l'IN2P3/CNRS (CC-IN2P3)**

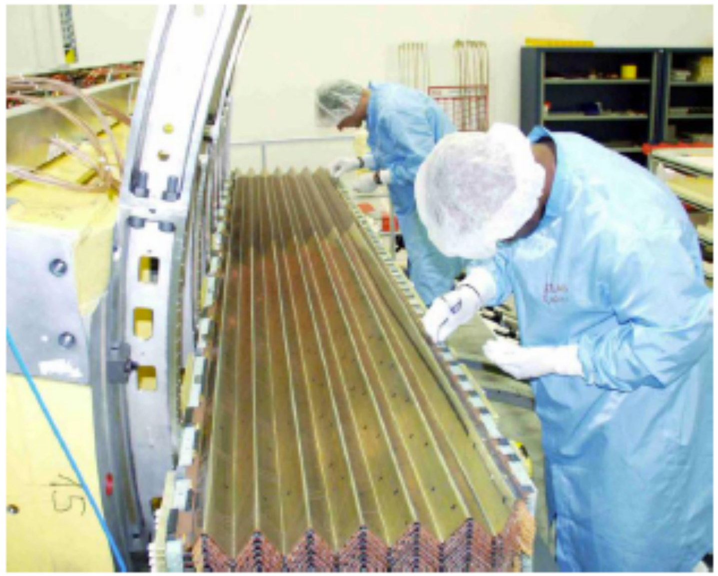
LHC-France People

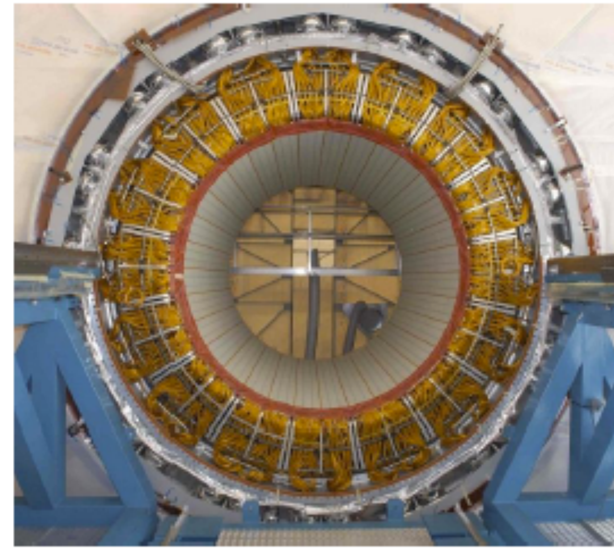
- ATLAS : 180 physicists and engineers, 43 PhD, 6 labs
  +IRFU : 21 physicists+ 60 engineers and technicians , 16 PhD, 7 post-docs
  - ATLAS IN2P3 : I. Wingerter Seez (LAPP)
  - ATLAS IRFU : C. Guyot (SPP)
- CMS : 67 physicists and engineers, 26 PhD, 3 labs
  +IRFU : 16 physicists+20 engineers , 3 PhD, 2 post-docs
  - CMS IN2P3 : Y. Sirois (LLR)
  - CMS IRFU : M. Dejardin (SPP)
- LHCb : 57 physicists and engineers, 13 PhD, 6 labs
  - LHCb : R. Le Gac (CPPM)
- ALICE : 57 physicists and engineers, 10 PhD, 8 labs
  + IRFU 20 physicists and engineers
  - ALICE IN2P3: Y. Schutz (Subatech)
  - ALICE IRFU : A. Baldisseri (SphN)

ATLAS Electromagnetic calorimeters

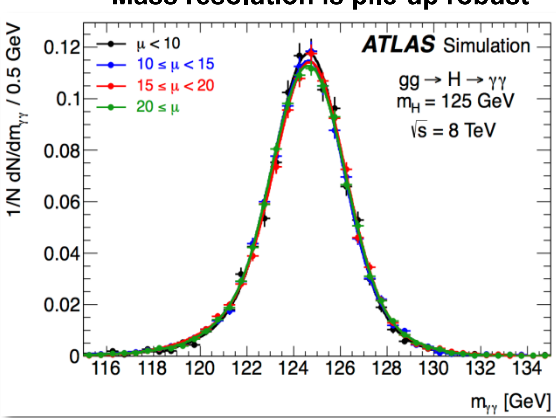
Conception	Construction	Installation



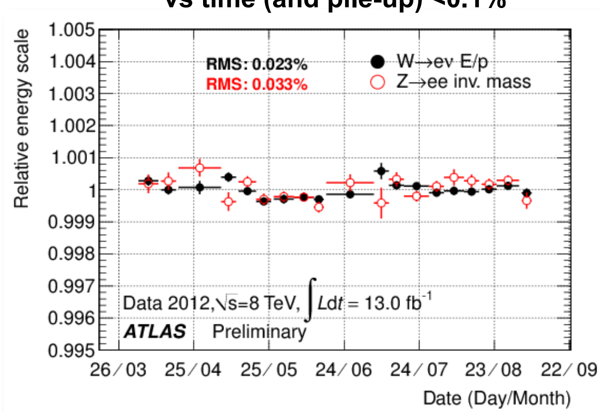




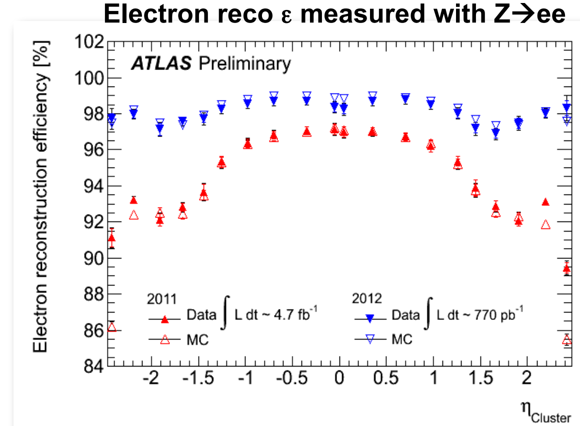
Mass resolution is pile-up robust



Stability of EM calorimeter response vs time (and pile-up) <0.1%

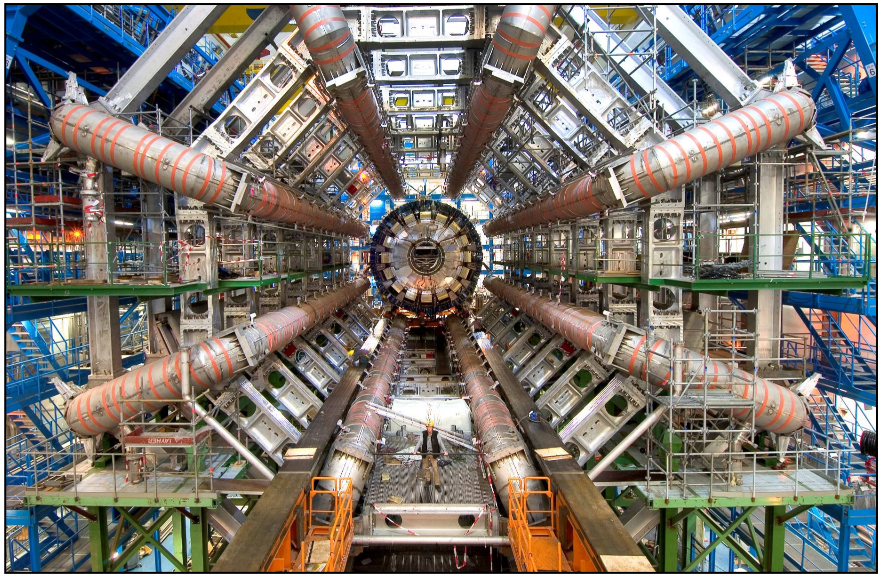


Electron reco ε measured with Z→ee



ATLAS muon spectrometer

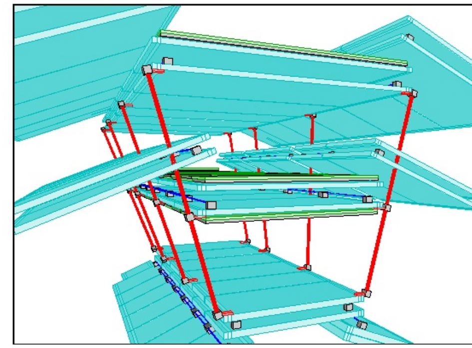
Toroidal magnet

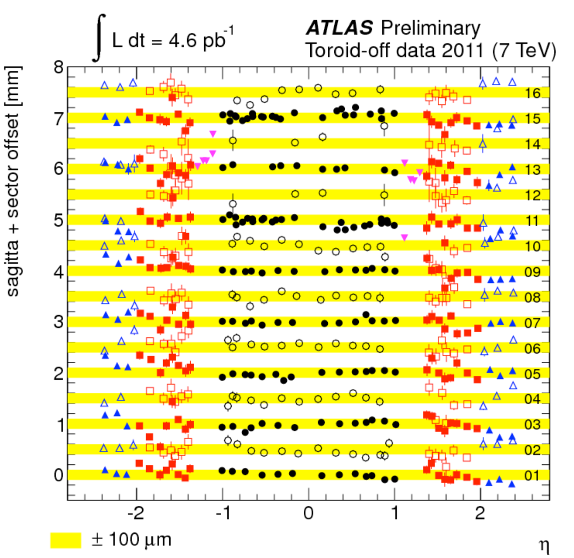


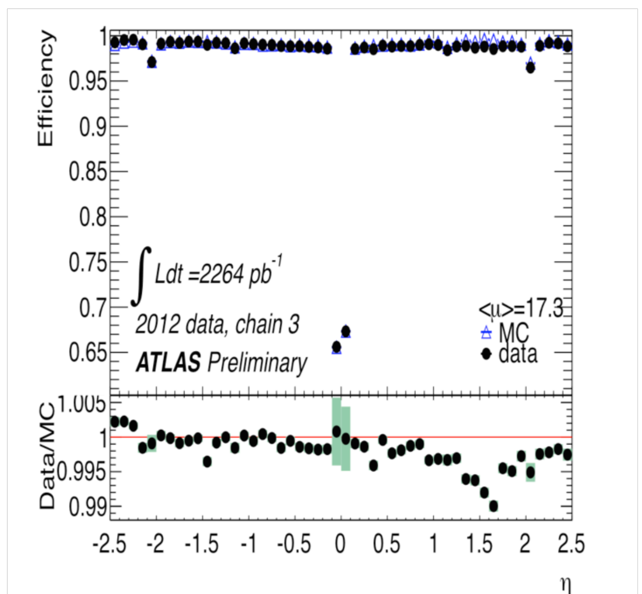
Muon chamber alignment system

Barrel: 1300 beams

50 μ over 3000m^2



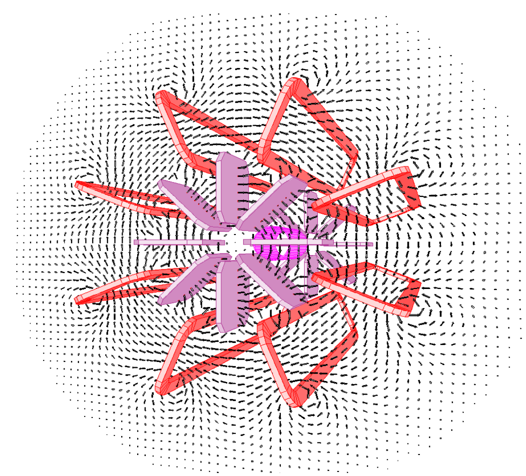




Magnetic field

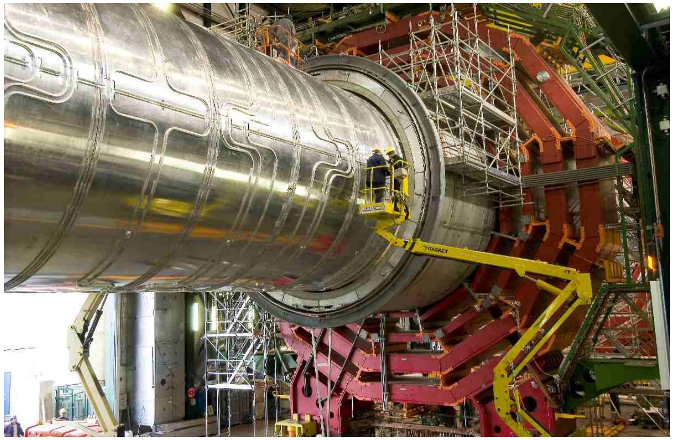
Hall probes positioning

& Reconstruction

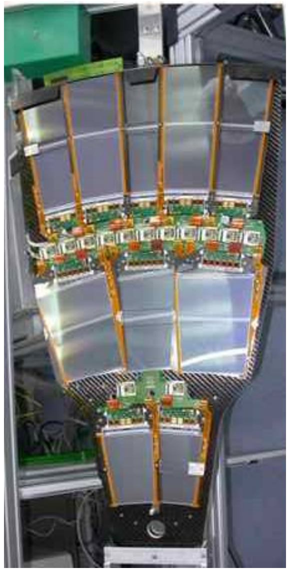


CMS detectors

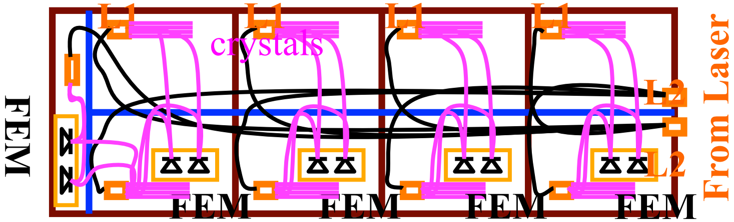
Solenoid (4T, 14x6m)

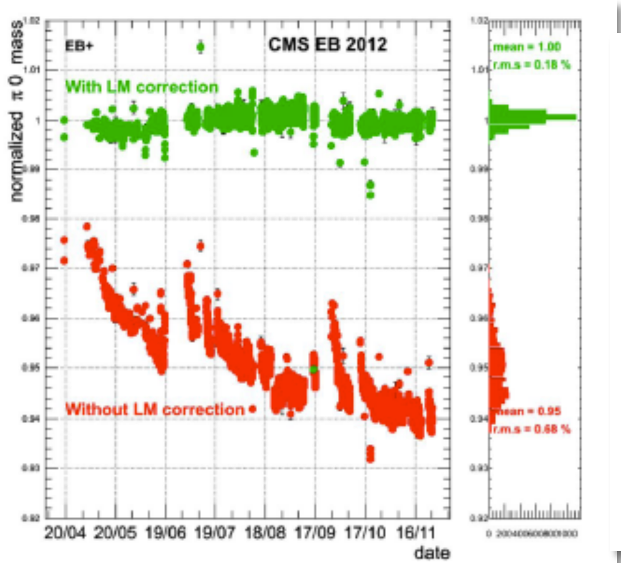


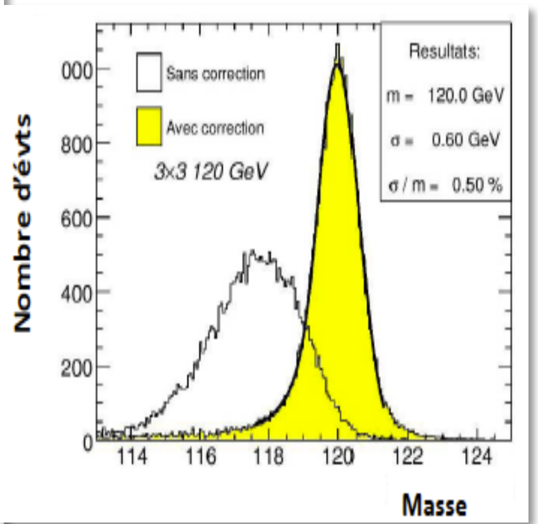
Tracker End Caps (petals)



Laser monitoring system





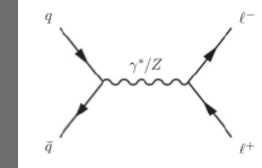


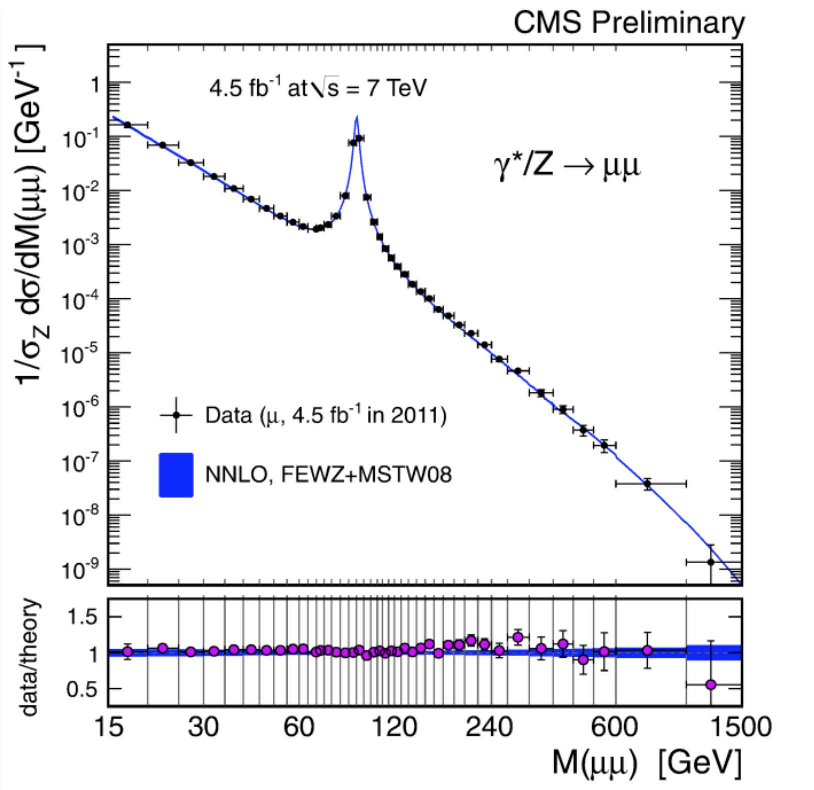
Theory and Experimental Landscape

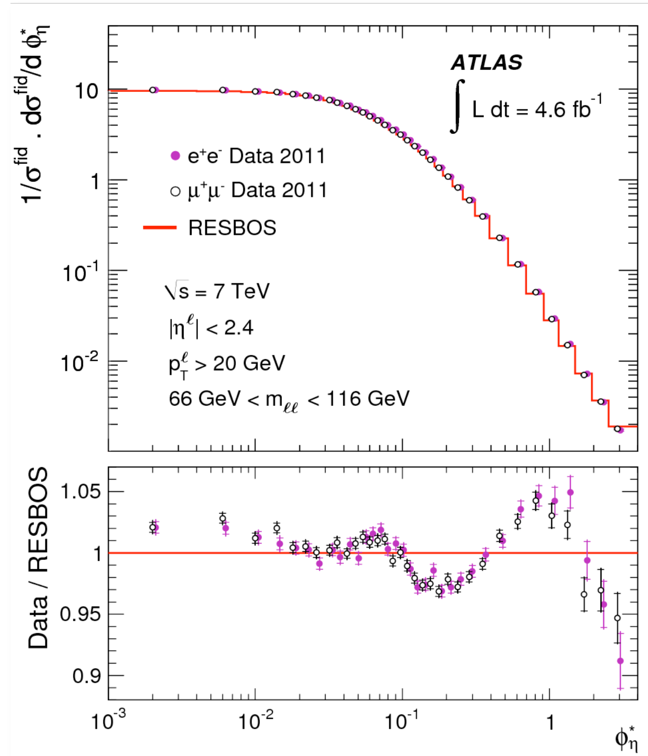
In parallel to the LHC innovative concepts and technologies, several breakthroughs in the past decade have drastically changed the theory prospective to the hadron collider processes

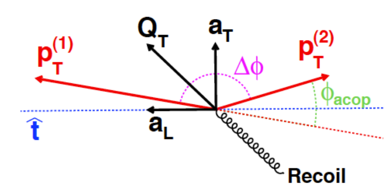
- **The “Next to…” revolution**
  - NLO, NNLO, NNLL generators
- **NNLO Particle Density Function (PDF) sets**
- **Parton Shower and Matrix Element matching improvements**
  - including description of the pile-up and the underlying event
- **The Jet revolution (Fast Jet)**
  - allowing to compute in reasonable time infrared safe k_T jets
- **Significant experimental progress**
  - Improved simulation (G4)
  - Tuning of event generators thanks to the Tevatron’s legacy

Drell-Yan cross section



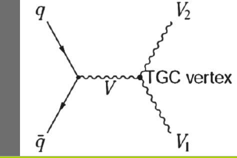


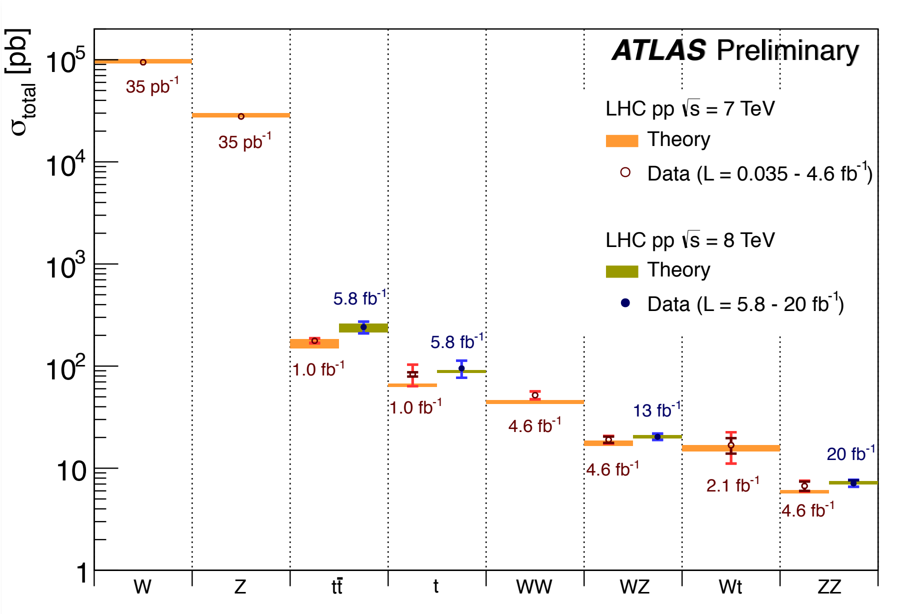


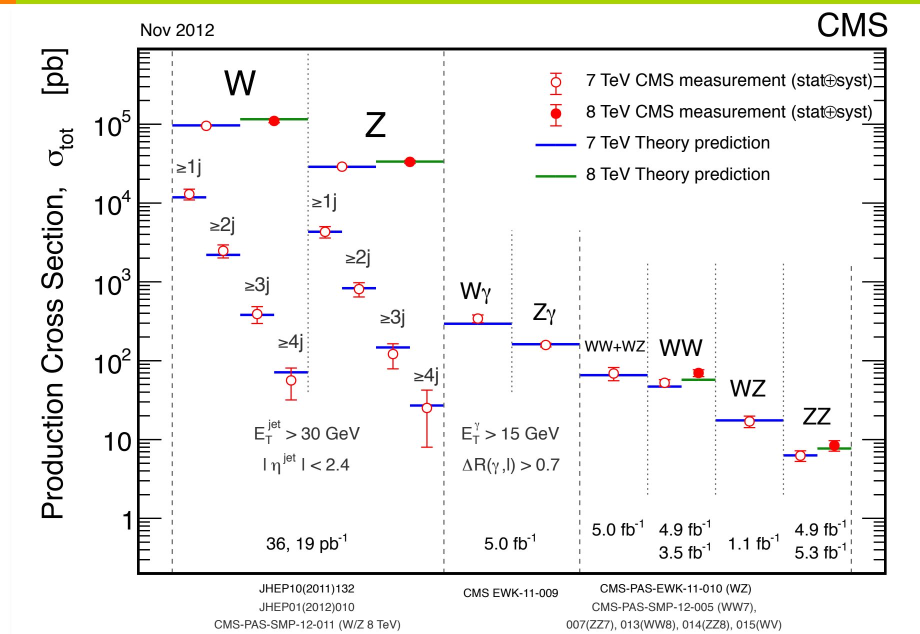


- Very good agreement on several orders of magnitude
- Use ϕ^*_η variable to probe modelling of p_T of Z boson in MC (ResBos(NNLL) and FEWZ) : **has advantage that angular resolution is better than p_T resolution**

W, Z and diboson cross sections

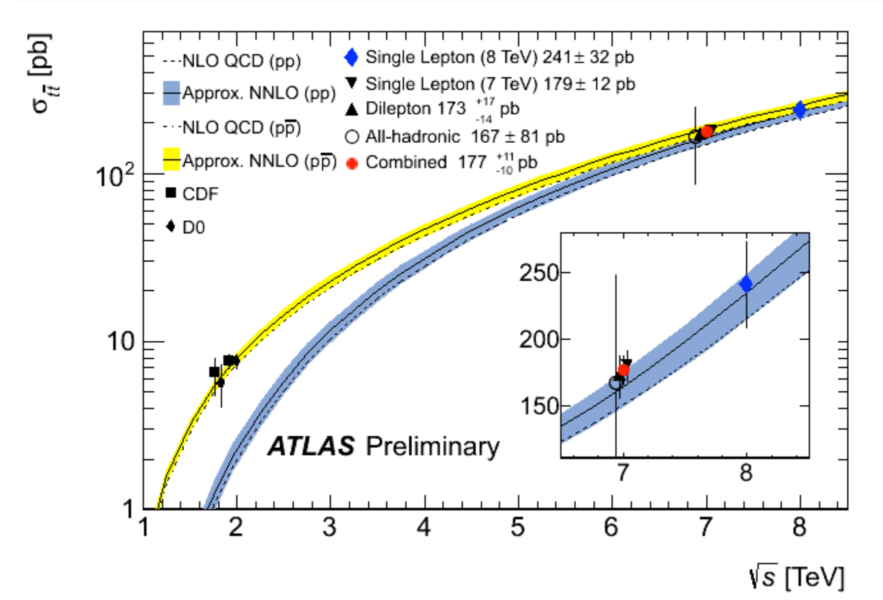


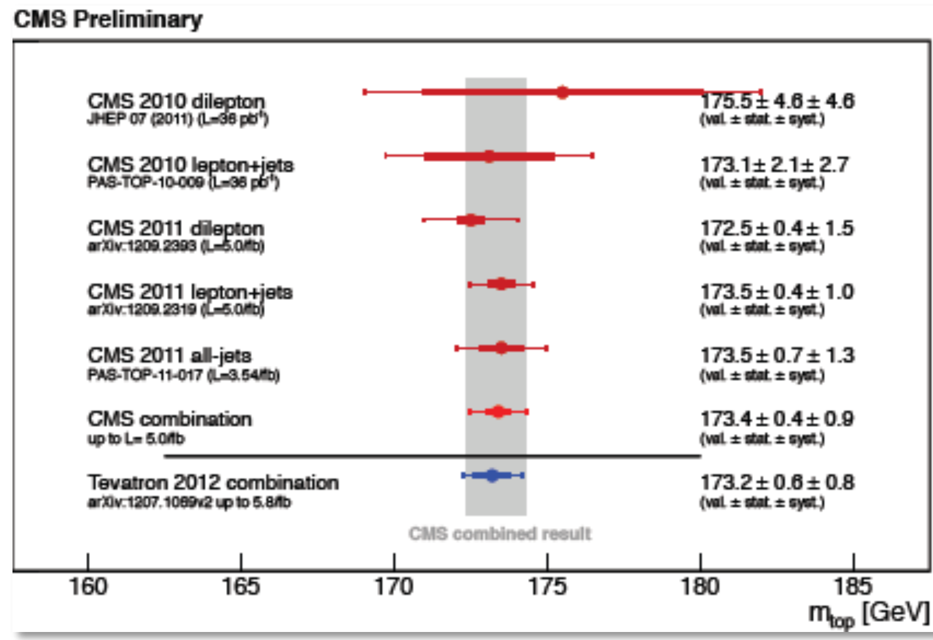




- **Major advances in ability to predict SM rates**
- **Hard work by many people allows for:**
  - Precision tests of SM production
  - Confidence in QCD calculations of production rates
    - Reduction of systematic uncertainties on background
    - Can be used in extraction of couplings (eg for Higgs)

Top studies





- As heaviest quark, top may play special role in EWSB
- Significant background for many BSM searches
- Knowledge of QCD production rate essential for many analyses
  - Cross-check with different channels and reconstruction techniques

CMS

$$m_t^{comb} = 173.36 \pm 0.38(stat) \pm 0.91(syst)\ GeV$$
$$= 173.36 \pm 1.10\ GeV$$

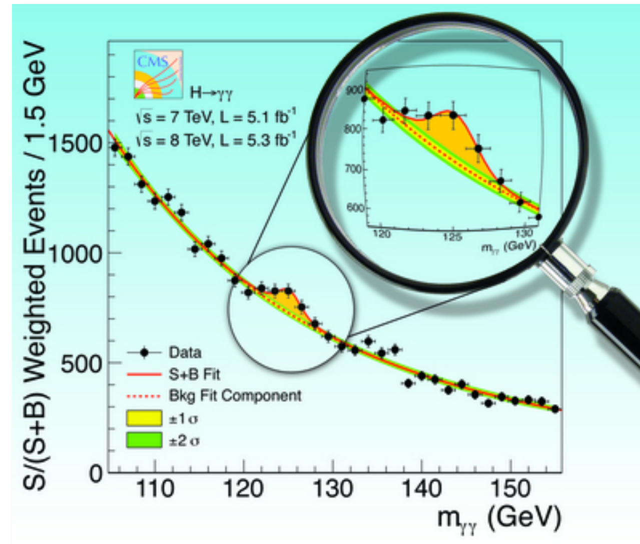
Tevatron

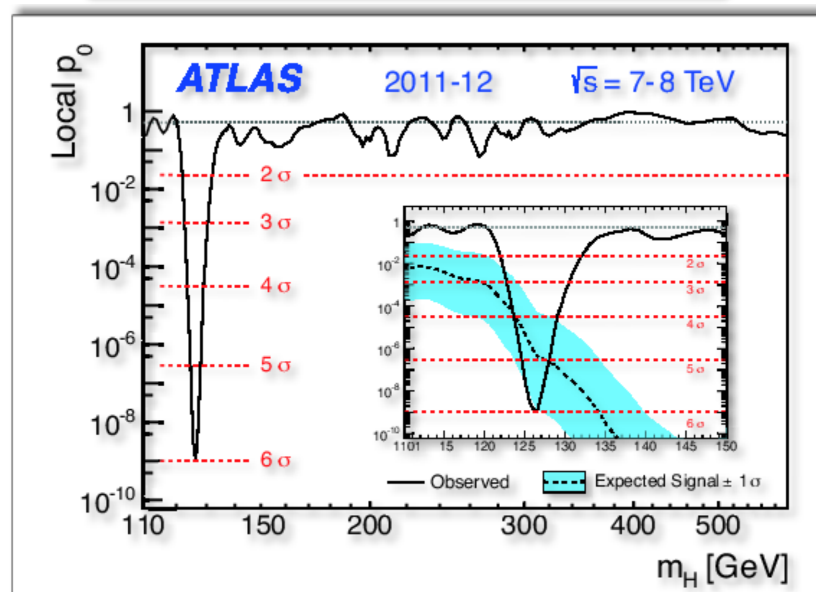
$$m_t^{comb} = 173.18 \pm 0.56(stat) \pm 0.75(syst)\ GeV$$
$$= 173.18 \pm 0.94\ GeV$$

Discovery of a Higgs-like Particle

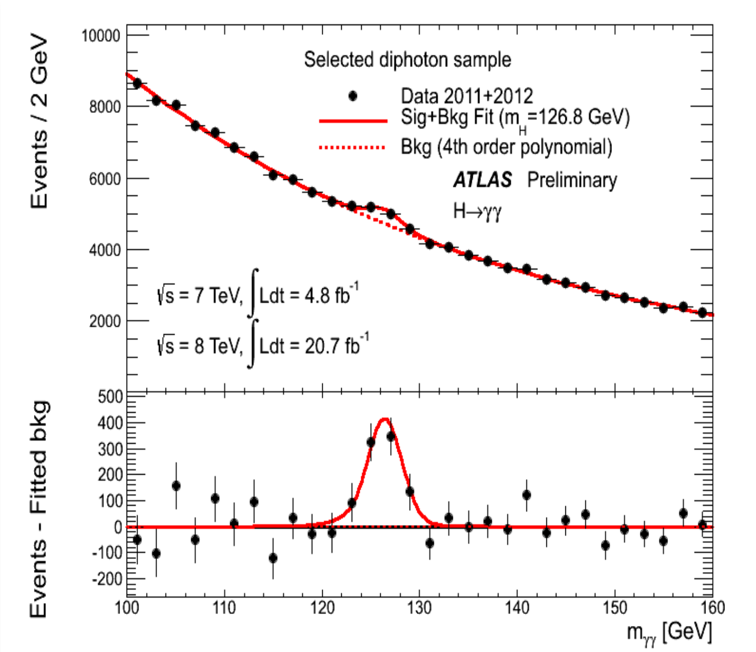
- July Revolution (1830)

- July Revolution (2012)



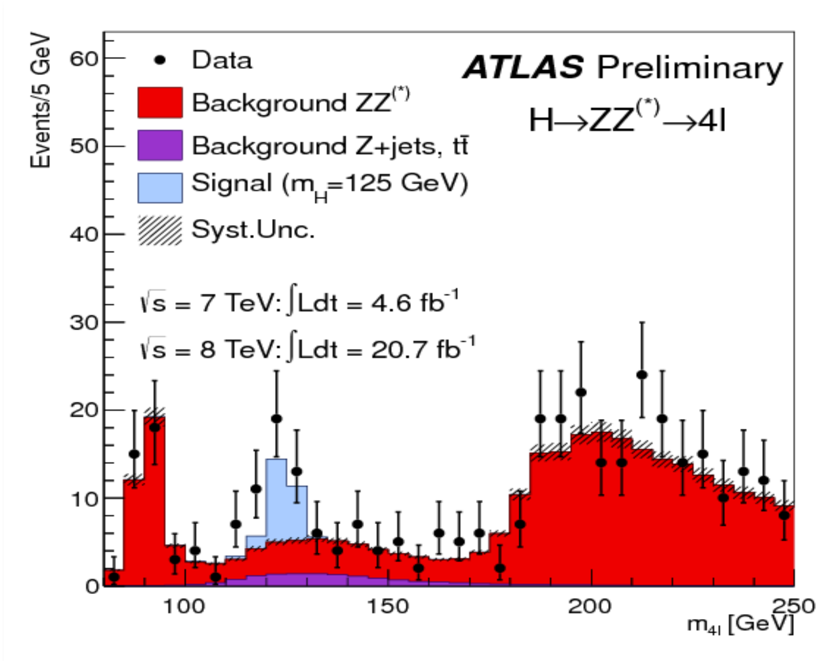


Contributions to ATLAS Higgs results



H→γγ

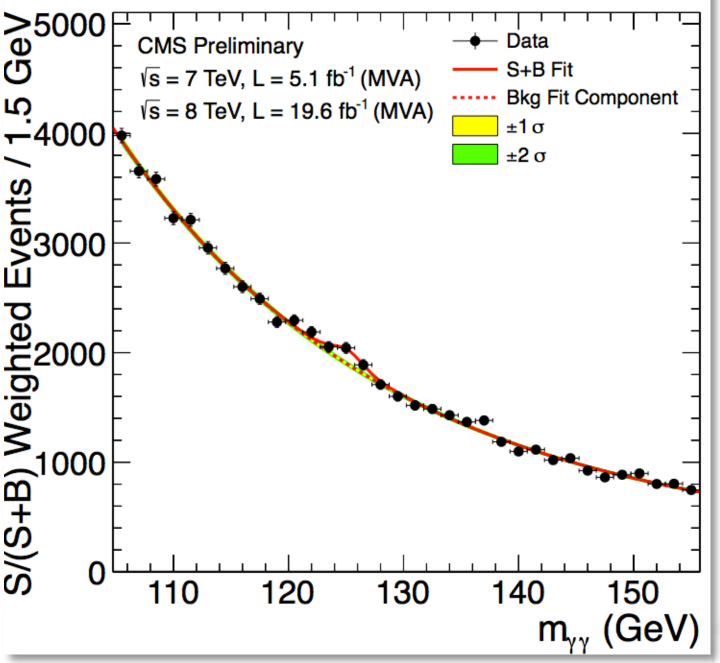
- Observed local significance of the excess: 7.4σ (4.1σ expected for SM Higgs)
- Best mass fit: 126.8 ± 0.2 (stat) ± 0.7 (syst) GeV
- Signal strength @ this mass: $\mu = 1.65^{+0.34}_{-0.30}$



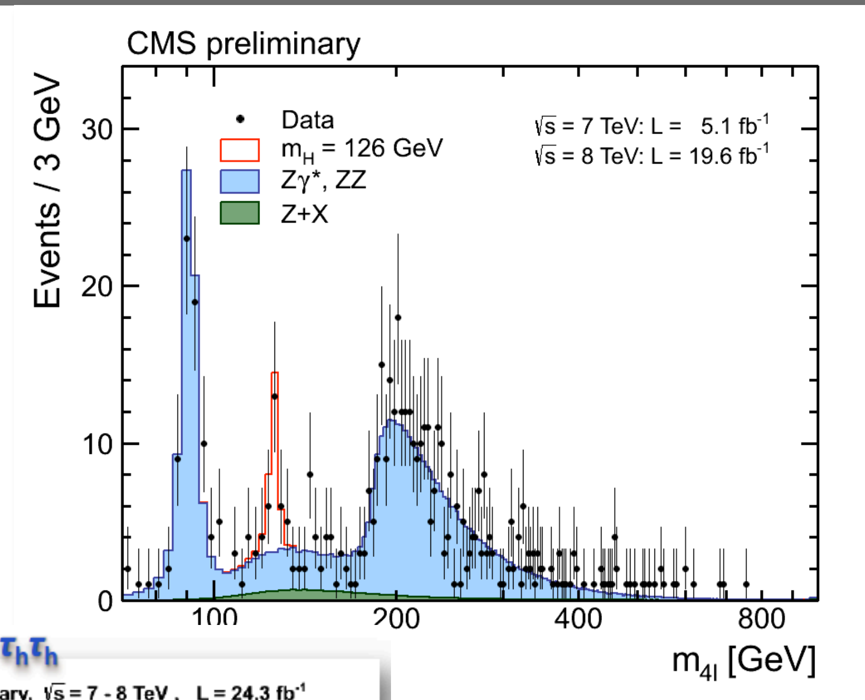
H→ZZ→4l

- Observed local significance of the excess: 6.6σ (4.4σ expected for SM Higgs)
- Best mass fit : $124.3^{+0.6}_{-0.5}$(stat) $+^{+0.5}_{-0.3}$(syst) GeV
- Signal strength @ this mass: $\mu = 1.7^{+0.5}_{-0.4}$

Contributions to CMS Higgs results

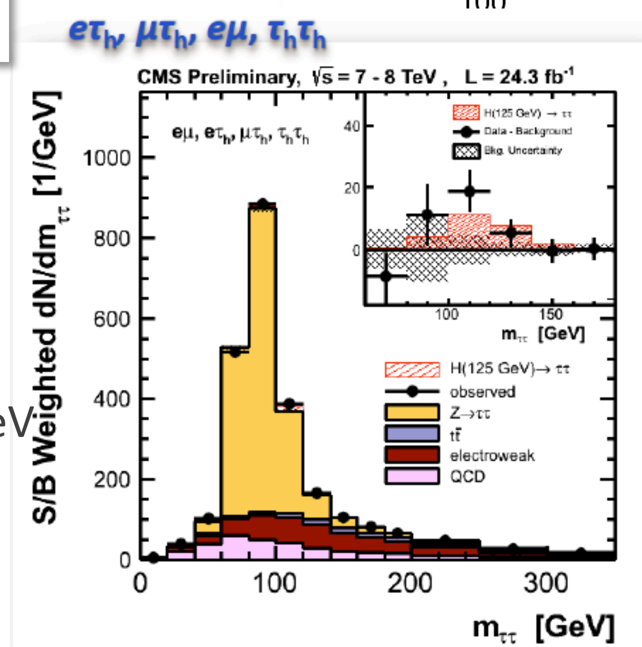


H→γγ: 3.2 σ (4.2 exp)



H→ZZ→4l

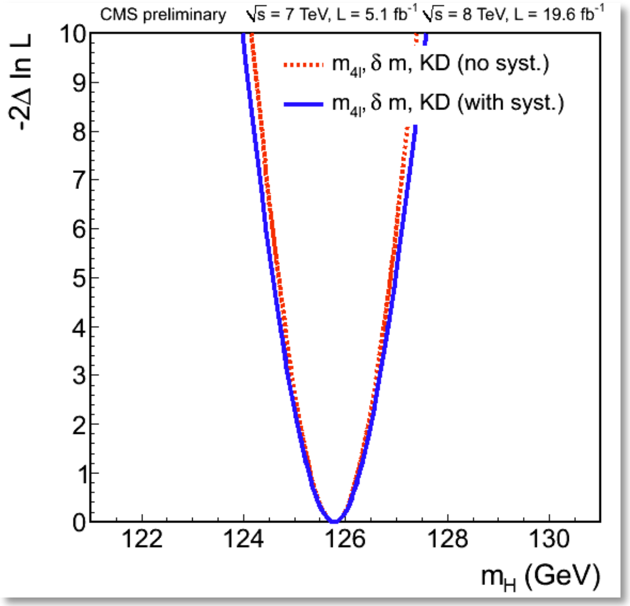
6.7 (7.2) σ obs (exp),
@125.8 GeV
μ = 0.91 +0.3 - 0.24

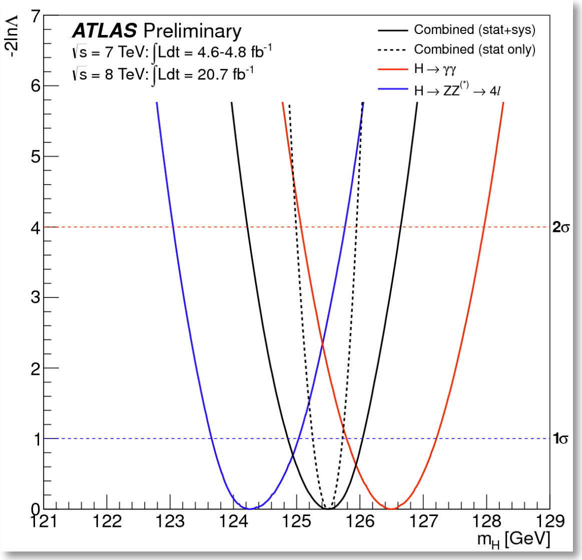


H→ττ

2.9 (2.6) σ obs (exp), @125 GeV
μ = 1.1 ± 0.4

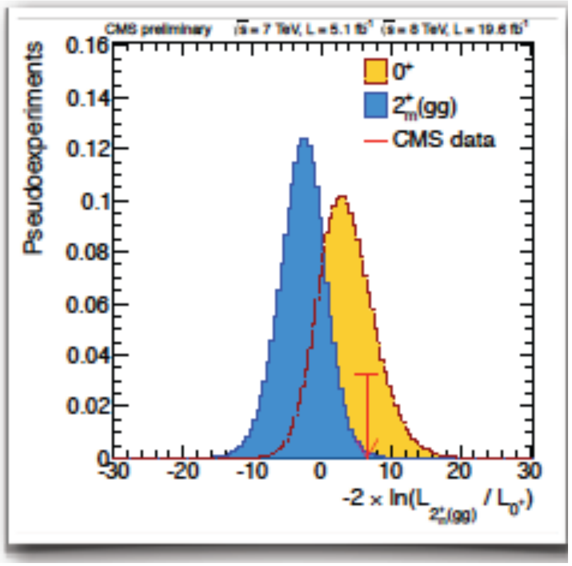
Properties of the Higgs-Like Boson: Mass, CP



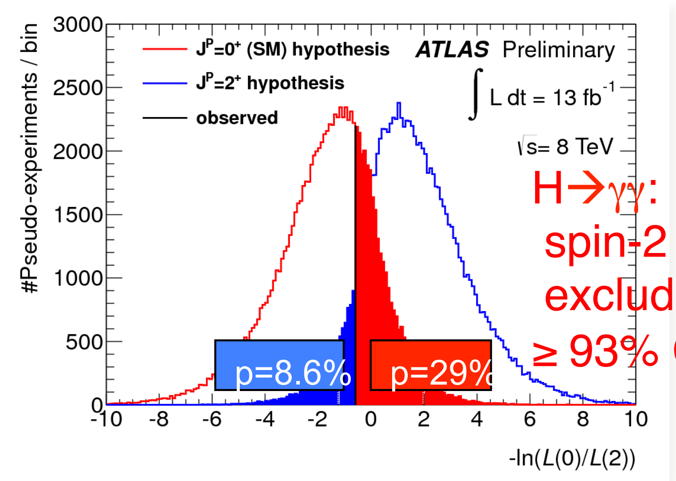


mH =125.8 ± 0.5 (stat.) ± 0.2 (syst.) GeV

mH = 125.5 ± 0.2 (stat) ± 0.6 (sys) GeV



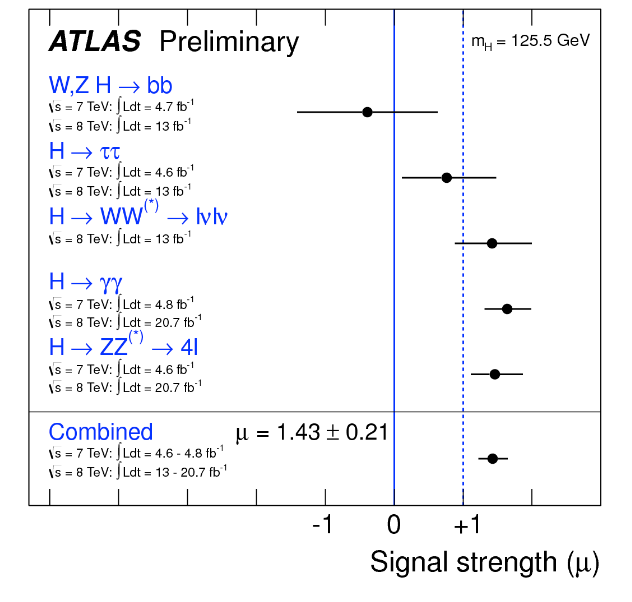
H→ZZ*→4l: pseudoscalar, spin-1 and spin-2 cases excluded at ≥ 95% CL

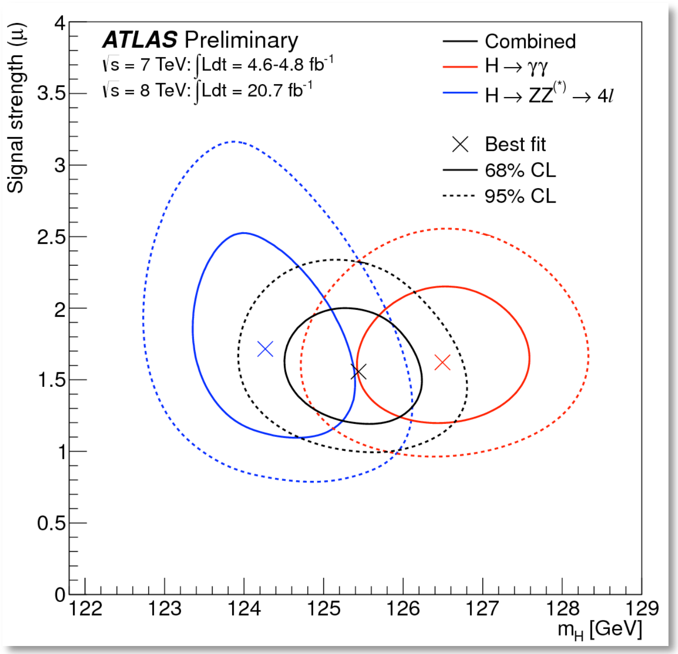


H→γγ: spin-2 cases excluded at ≥ 93% CL

Properties of Higgs-Like Particle: Signal Strength

- Global μ:
  - Full dataset for $\gamma\gamma$ and ZZ*
  - Partial 2012 for other modes
  - μ=1.43±0.16 (stat)±0.14 (sys)
- Consistency test :
  - Global μ with SM : 3%
    - 11% with rectangular QCD scale and parton distributions functions





- μ versus m_H contours for:
  - $\gamma\gamma$
  - ZZ*
  - Combined

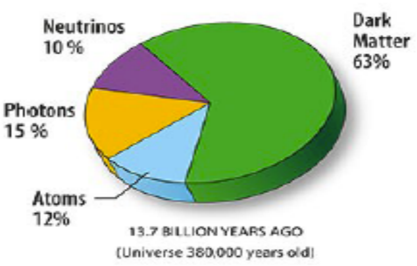
Implications of Higgs-Like Boson Discovery for SUSY and other BSM Physics

- **Higgs mass ~125 GeV excludes large regions of MSSM SUSY parameter space**
- **EW-scale SUSY still possible with** :
  - **Large mixing in the stop sector** : Either one stop light and one heavy OR both below ~1 TeV
  - **Extra matter or gauge fields in the SUSY sector**
    - Extra gauge bosons
    - More complicated Higgs sector
- **Possible paths to discovery** :
  - Exploration of Higgs properties
  - Direct observation of the new particles or phenomena
  - Precision measurements in the heavy flavour sector

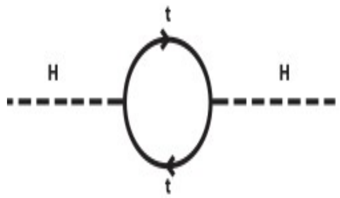
Some reasons to believe in New Physics

- **Dark Matter** :
  - cannot be explained by SM. New type of matter?
  - Natural mass scale for candidate ~100 GeV

- **Neutrinos have mass :**
  - where are the right-handed neutrinos?



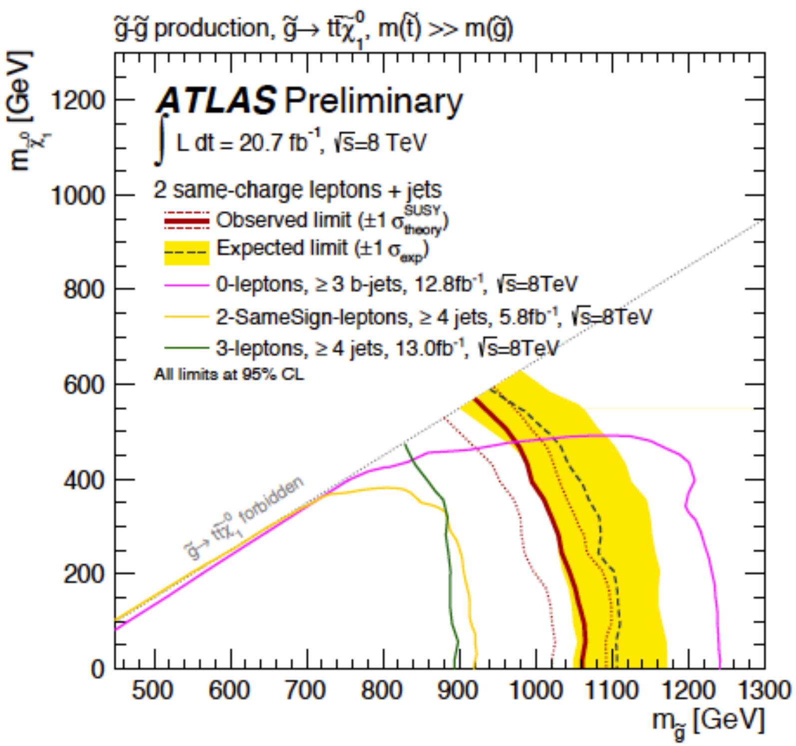
- **Naturalness and Fine Tuning :**
  - quadratic divergence of the Higgs mass, extremely fine-tuned
  - expect gauginos below ~ 1 TeV



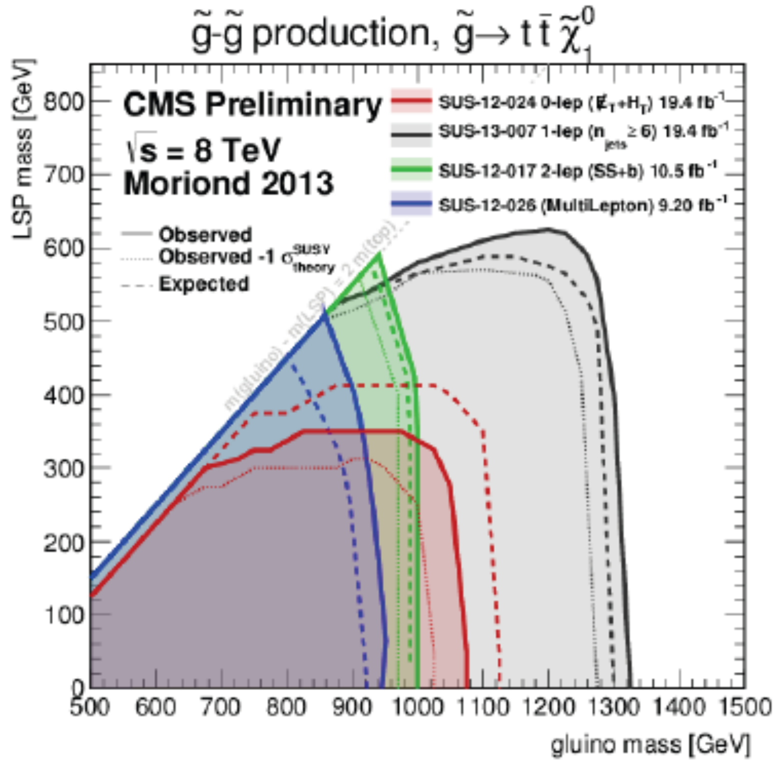
- **What this means for the experimentalist:**
  - Continue to push SUSY reach using broad search strategy
    - Special emphasis on 3rd generation and gauginos
    - Explore inaccessible corners of phase space
  - Search for new phenomena associated with EWSB
    - More Higgses, more gauge bosons, non-SM gauge boson interactions, new resonances, …

Some SUSY Searches

ATLAS gluino-induced top-squark production

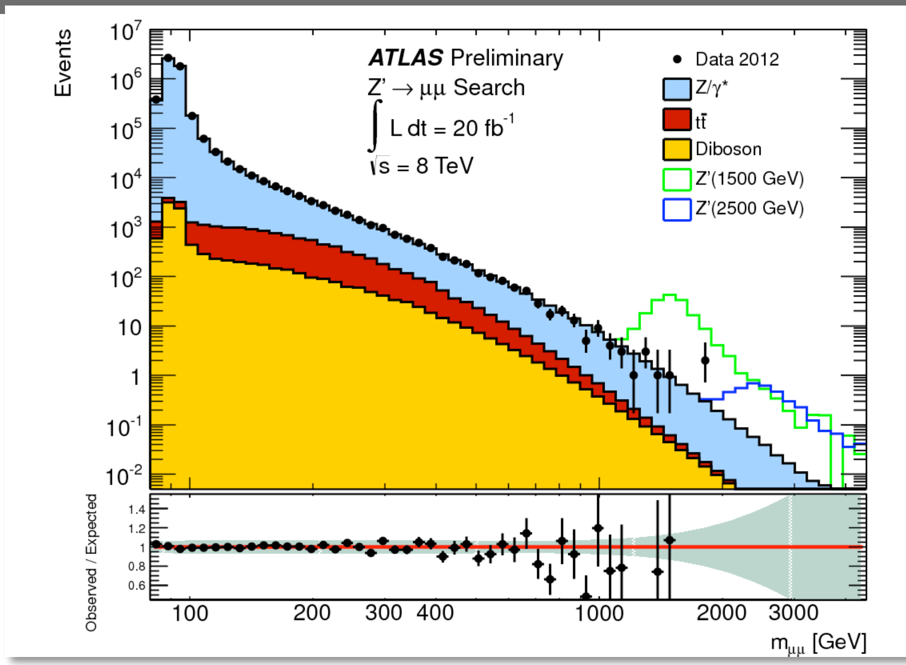


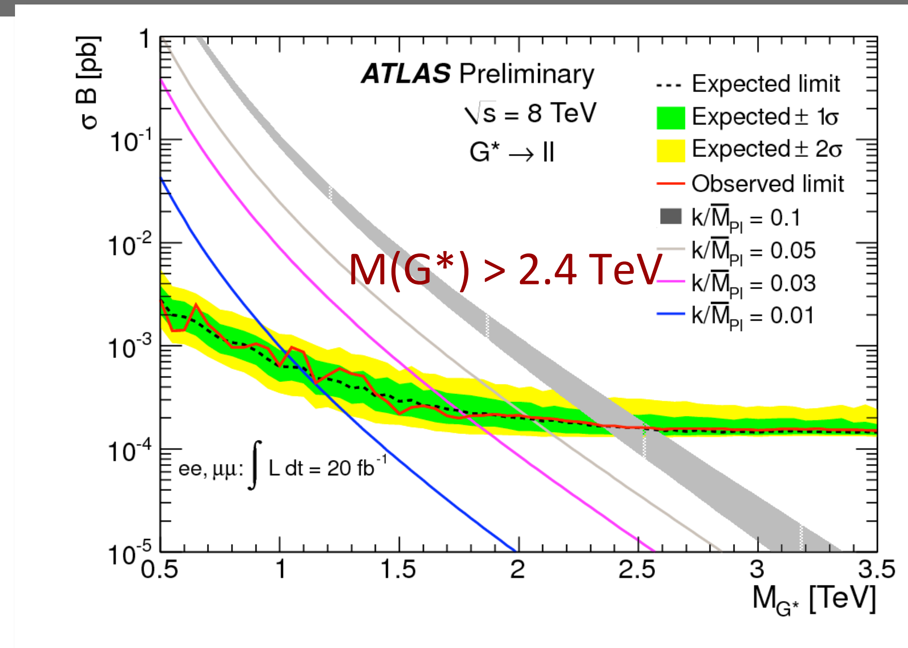
CMS gluino-induced stop production



R-Parity Conserving	Direct stop (neutralino)	Direct sbottom (neutralino)	Gluino-induced stop	Gluino induced sbottom
Best limit:	560 GeV	600 GeV	1280 GeV	1240 GeV
No limit beyond LSP:	175 GeV	300 GeV	570 GeV	650 GeV

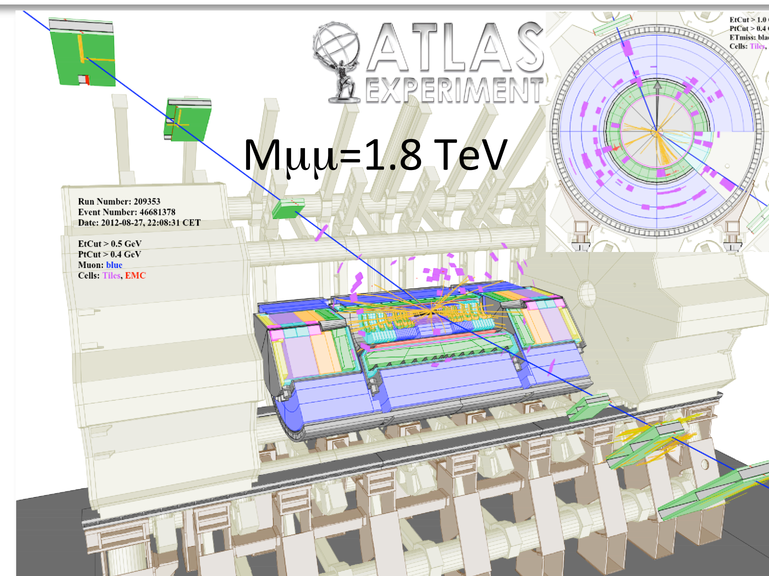
New Gauge Bosons : High Mass Dilepton Resonances





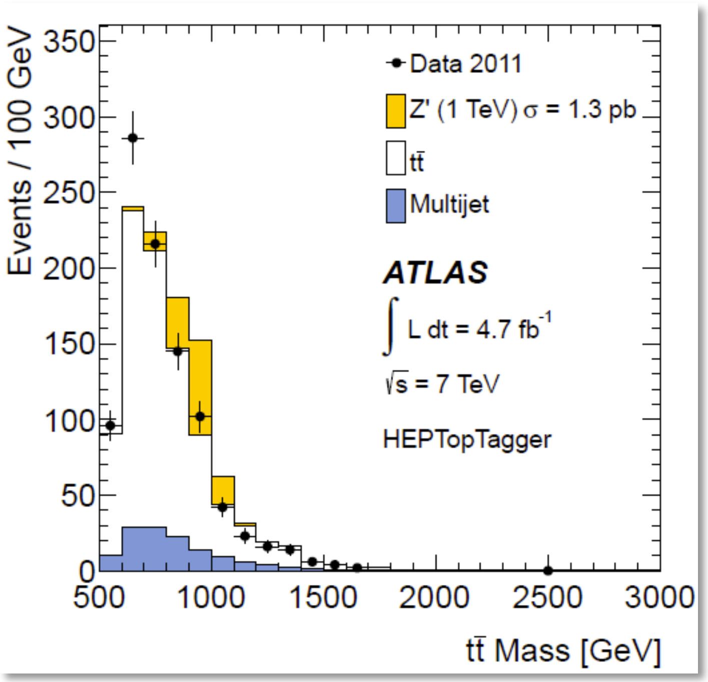
- **Classic search** for heavy narrow dilepton resonances: Z' (SSM, E6), MWT, Randall-Sundrum G*,…

- **Experimental challenge**: understand detector performance (resolution, efficiency) for a signal with (almost) no control sample at very high momentum → confidence in alignment simulation, etc...

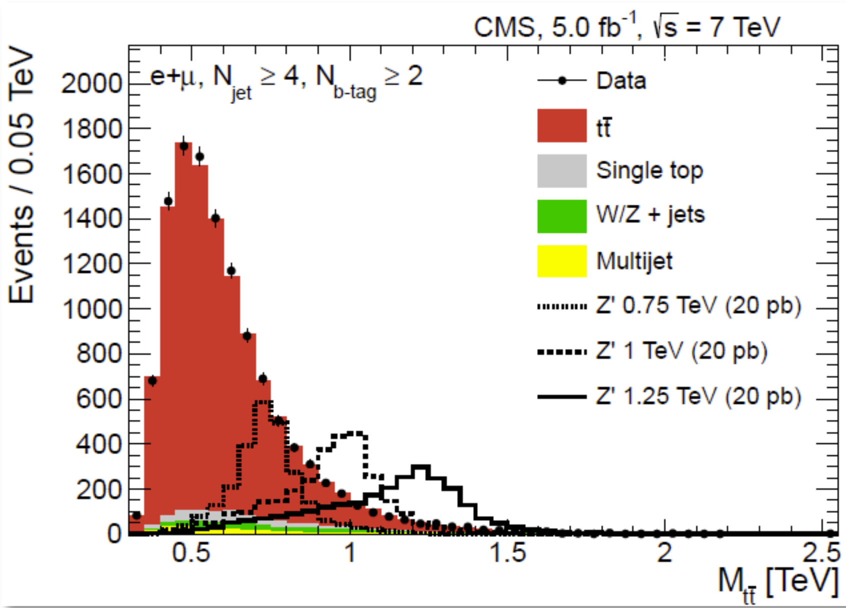


ttbar Resonance Searches

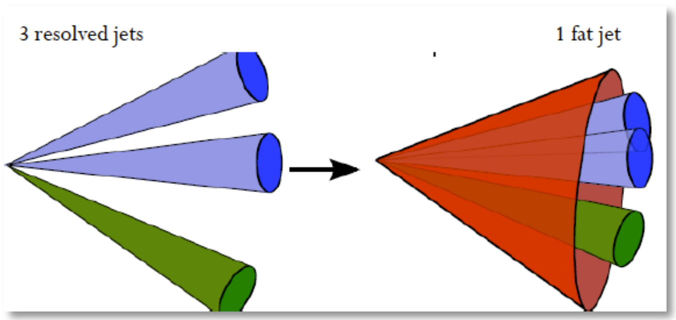
Full hadronic channel



Semi-leptonic channel

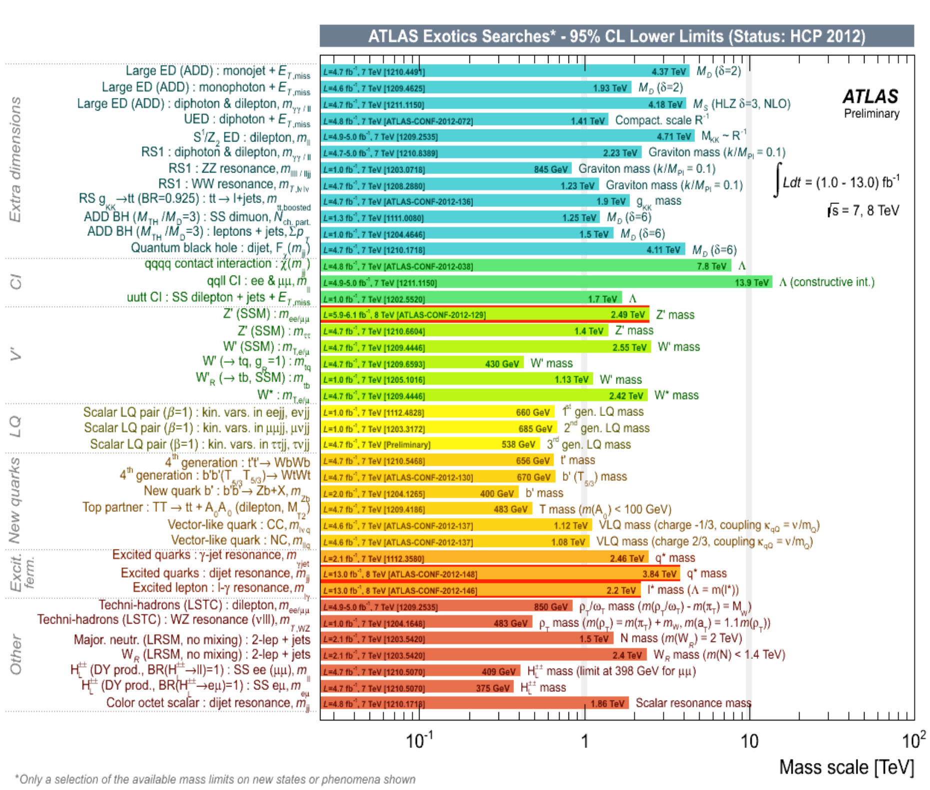


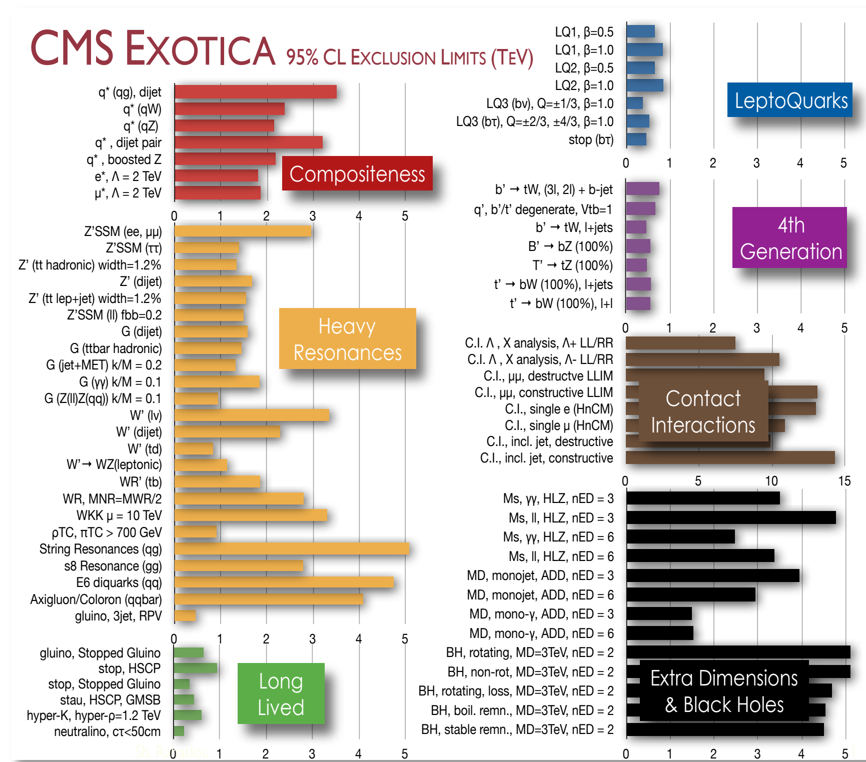
- **Tagging of boosted top jets**
  - Reconstruct a “fat” jet (pT > 200 / 400 GeV) with a large distance parameter (R=0.8 to 1.5)
    - Conditions on pairwise mass / subjet pT
    - Split the fat jet into subjets
- **Reconstruct the fat jet mass using subjets**



- Limits on Z' s.BR in mas srange 0.70-1.0 TeV and KK gluons in range 0.7-1.62 TeV

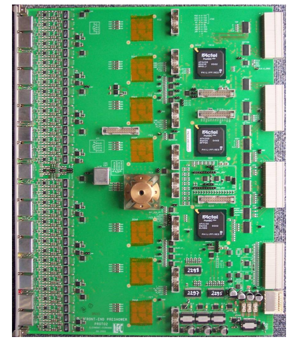
A very long list of models x signatures

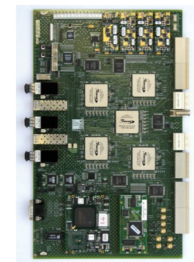


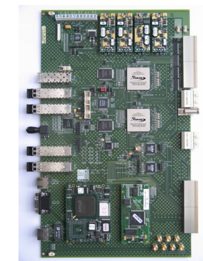


LHCb

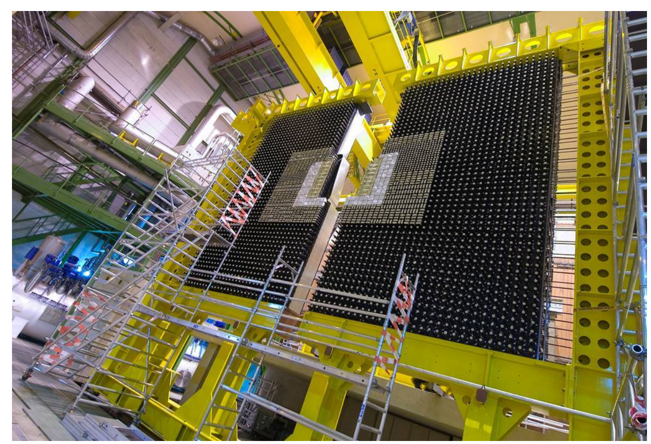
- Electronics:
  - Calorimeter readout and trigger
  - Muon Trigger and overall Level_0





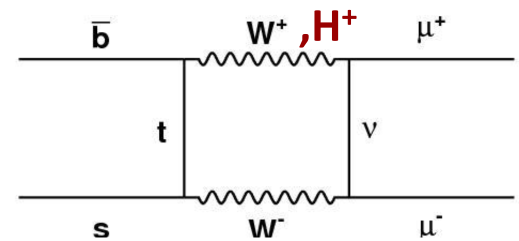


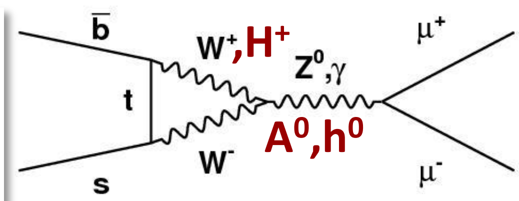
- Mechanics:
  - Ecal and Hcal support structures

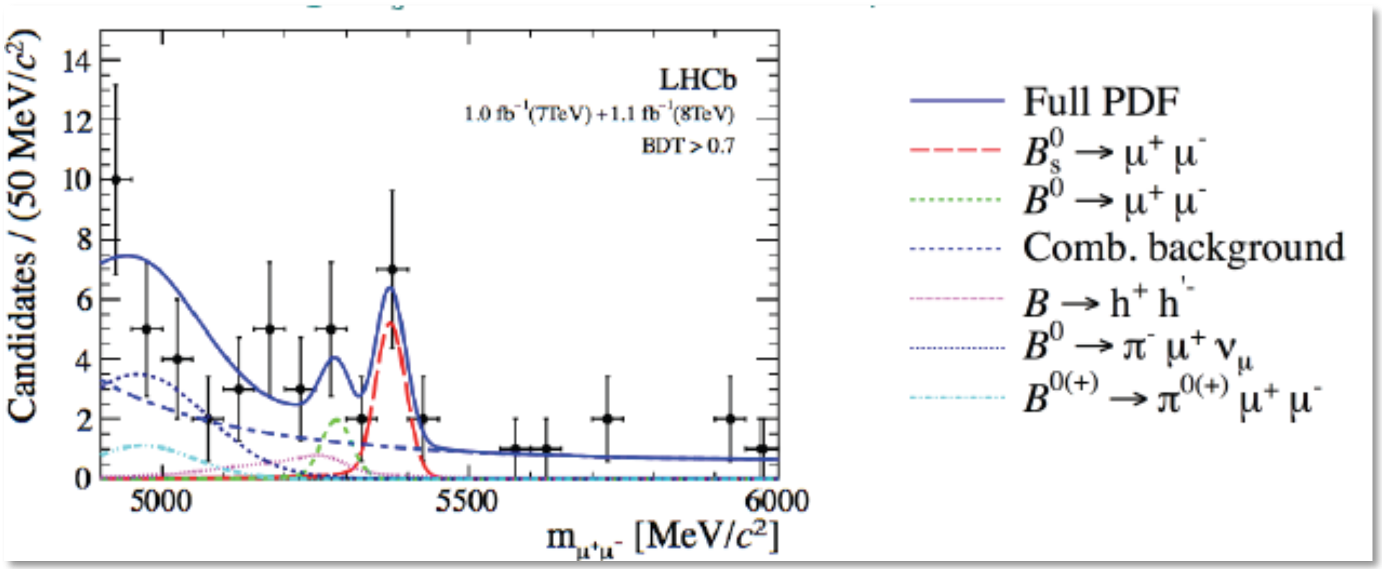


$B^o_{s,d} \rightarrow \mu\mu$ results from LHCb

- **Decay highly suppressed in the SM**
- Flavor changing neutral current restricted
- Can have enhancement or suppression of BR with BSM physics







$BR(B^0_s \rightarrow \mu\mu) = (3.5^{+1.5}_{-1.2}(stat.) \pm 0.2(syst.)) \times 10^{-9}$

Probability of background-only fluctuations : $5\times10^{-4} \rightarrow 3.5\sigma$ (first evidence)

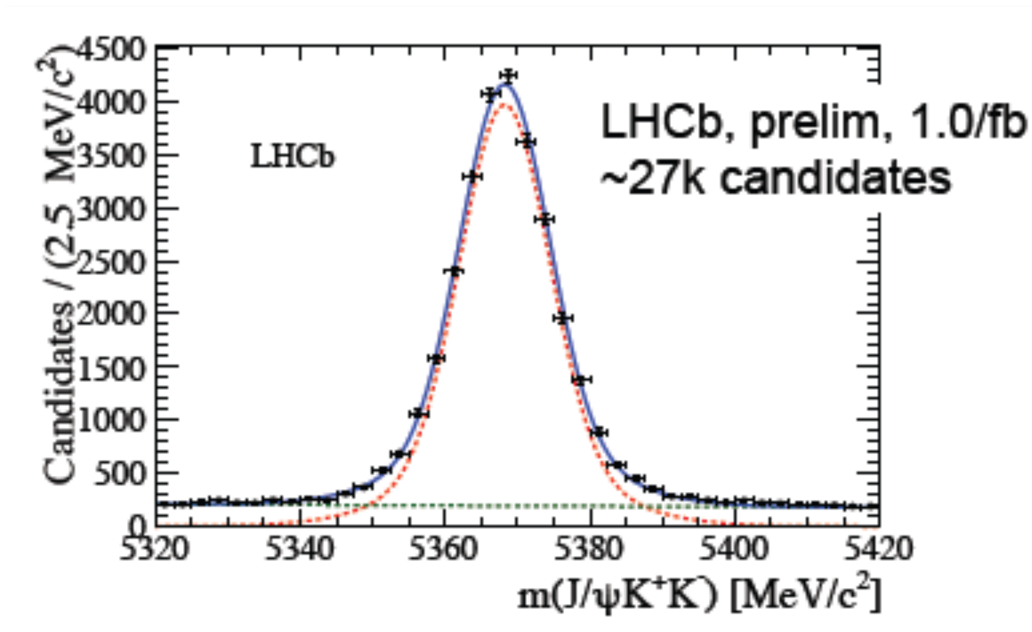
in agreement with SM expectation $(3.54\pm0.30)\times10^{-9}$

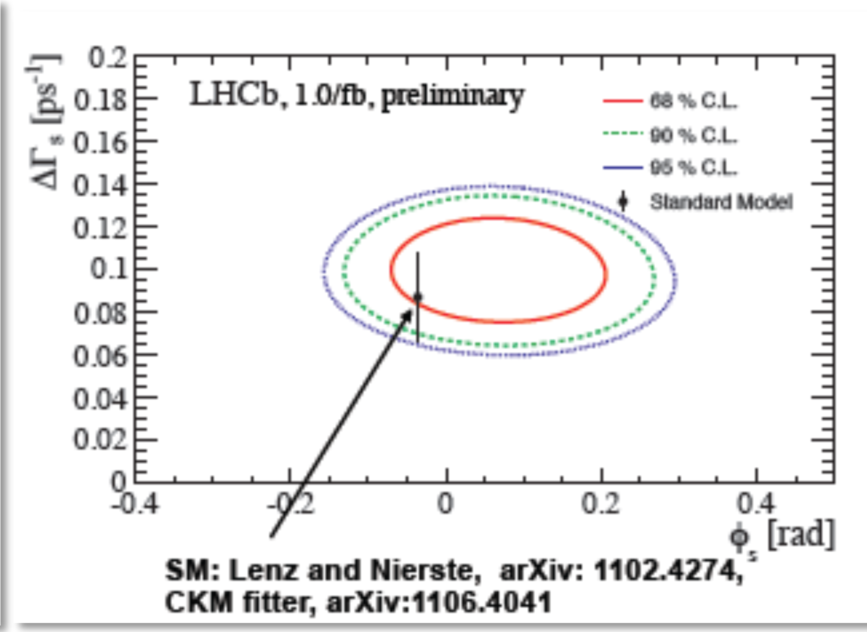
$BR(B^0_d \rightarrow \mu\mu) < 9.4\times10^{-10}$ @95% C.L

Probability of background-only fluctuations : 11% → 1.2σ

CP violation in Bs→J/ψφ

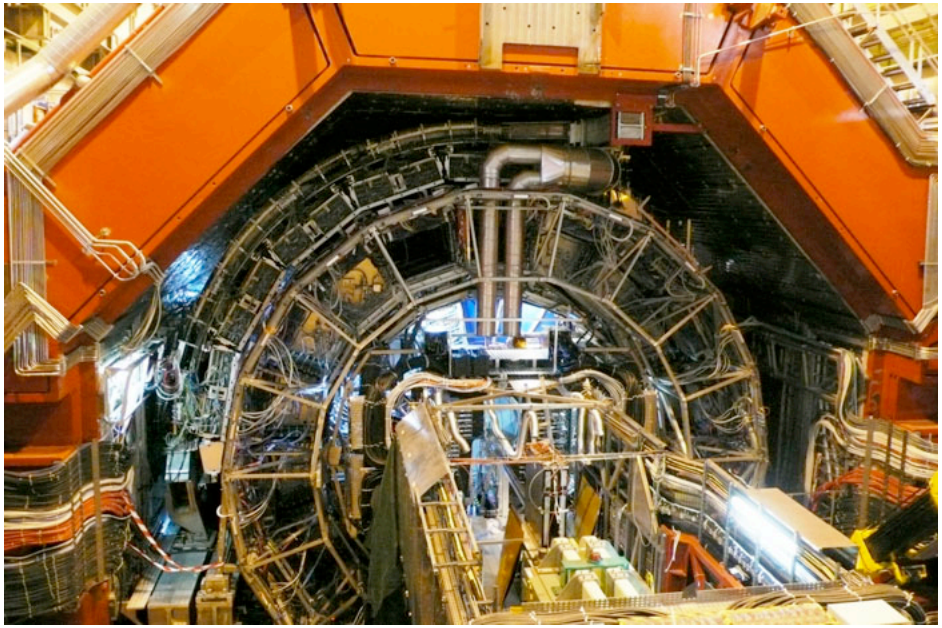
- $B_s \to J/\psi\phi$ and $B_s \to J/\psi\pi^+\pi^-$ provide measurement of ϕ_s in $b \to c\bar{c}s$ transitions
- In SM, CP violation from interference between mixing and decay in $b \to c\bar{c}s$ transitions is predicted to be: **$\phi_s = -2\arg(V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \sim -0.04$** Charles *et al.* (2011)Phys.Rev**D84**
- Full angular analysis in helicity basis is employed



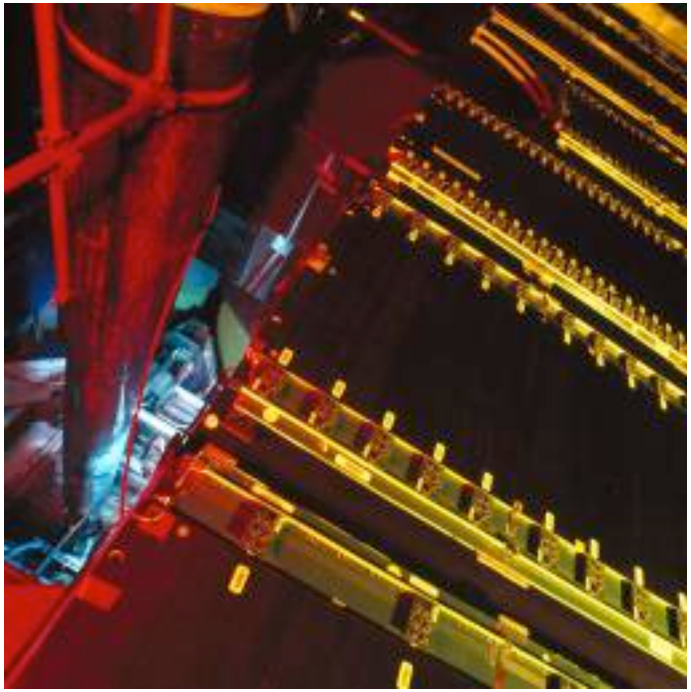


Result consistent with SM expectation

Electromagnetic Calorimeter



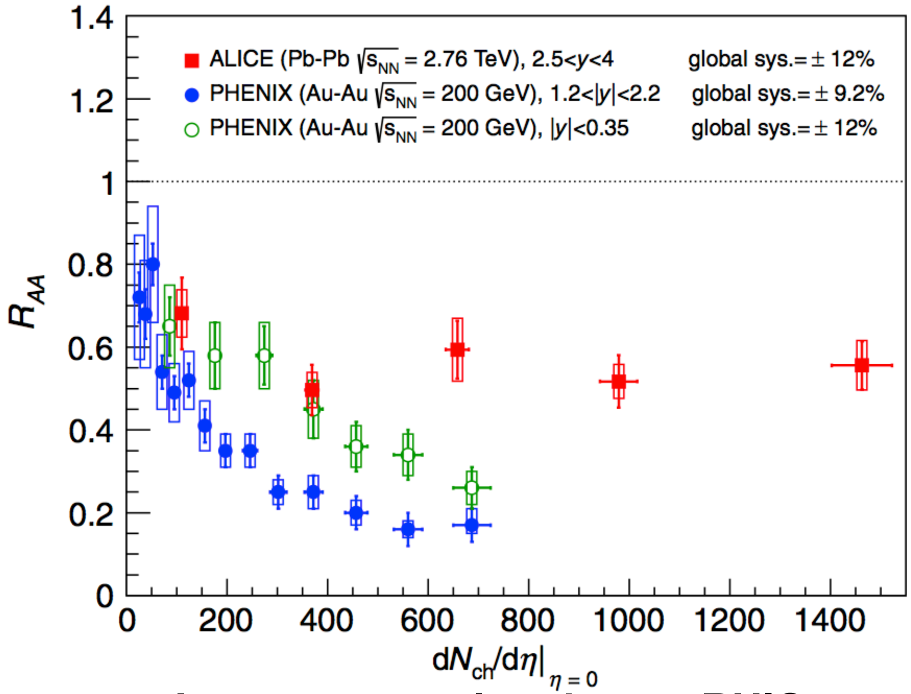
A side view of a tracking chamber



Quarkonia : Nuclear modification factor R_{AA}

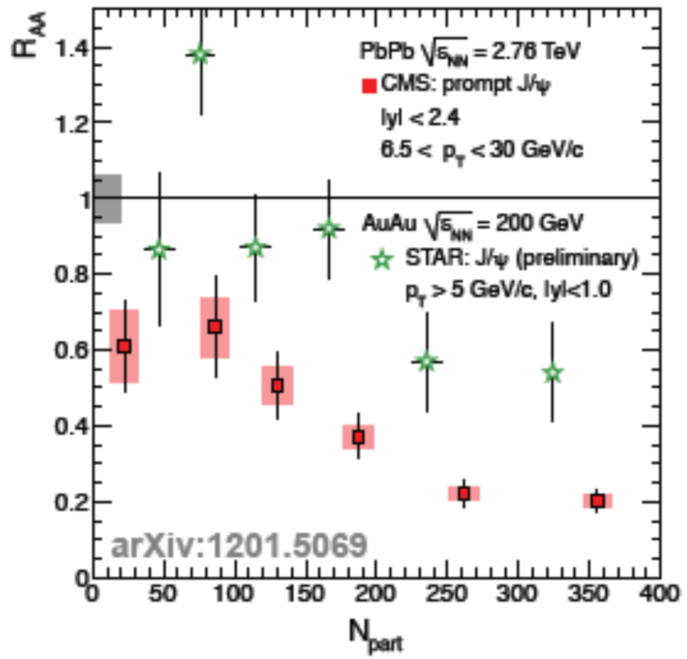
- **Nuclear modification factor R_{AA} compares Pb-Pb to p-p** : 1 means no medium effect

Inclusive J/ψ at low p_T



Less suppression than at RHIC
– ALICE (forward)
> PHENIX (forward)

Prompt J/ψ at high p_T



More suppression than at RHIC
– CMS (pT > 6.5 GeV/*c*)
< STAR (pT > 5 GeV/*c*)

- Recombination of charm quarks in the medium could be at play to produce low p_T J/ψ → Would imply that deconfined heavy quarks do evolve with the medium

Next Steps and Conclusions

- **First phase of LHC running successfully concluded**
- **Strong implication of France HEP community in the LHC physics program**
- **Analysis of full 2012 sample still in early stages**
  - Studies of the properties of the Higgs-like boson continue
  - Insightful Standard Model measurements on-going
  - Broad-based program of searches for BSM physics underway
    - No signals yet, but windows still open with current data samples
- **Looking forward to ~14 TeV running in the future**