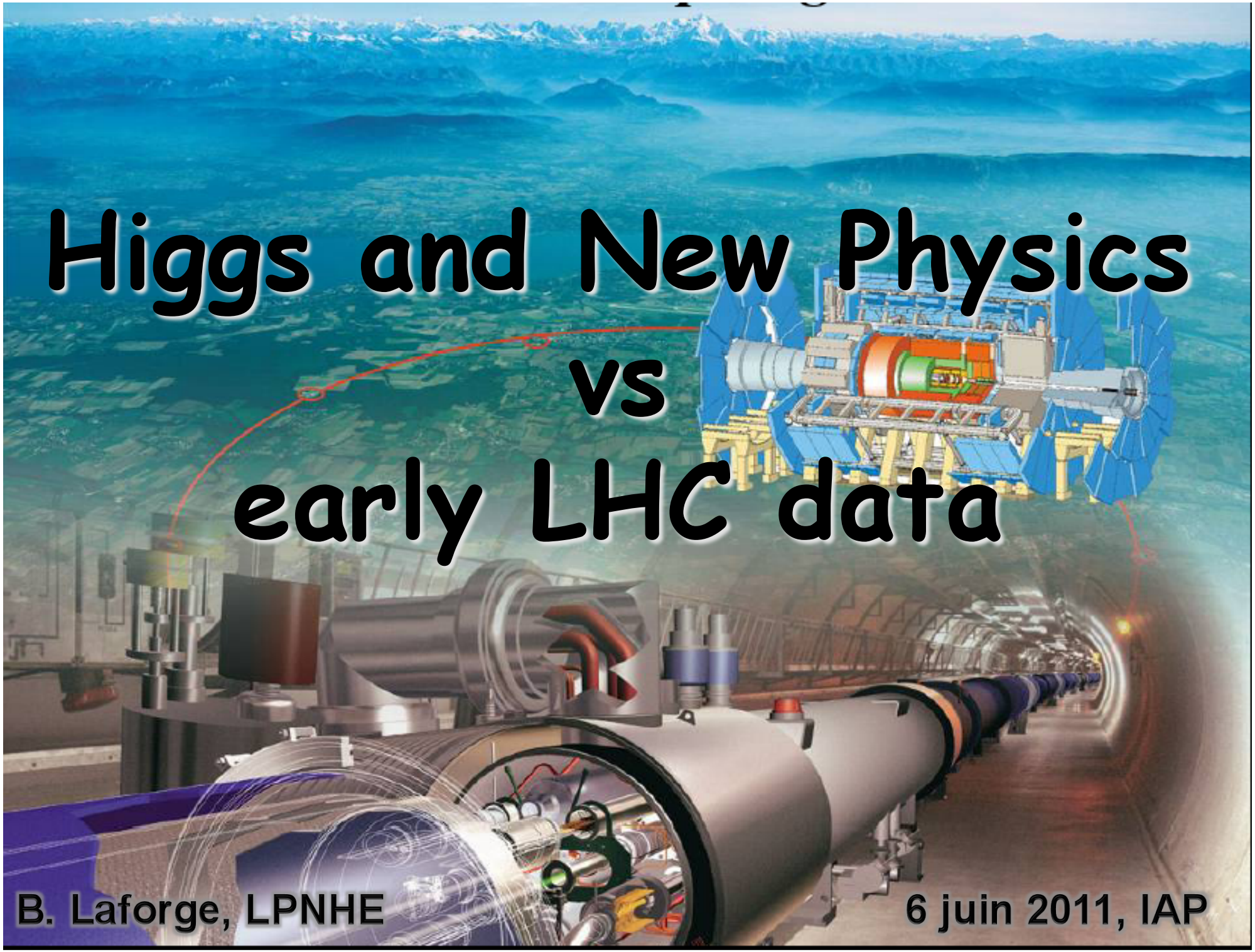
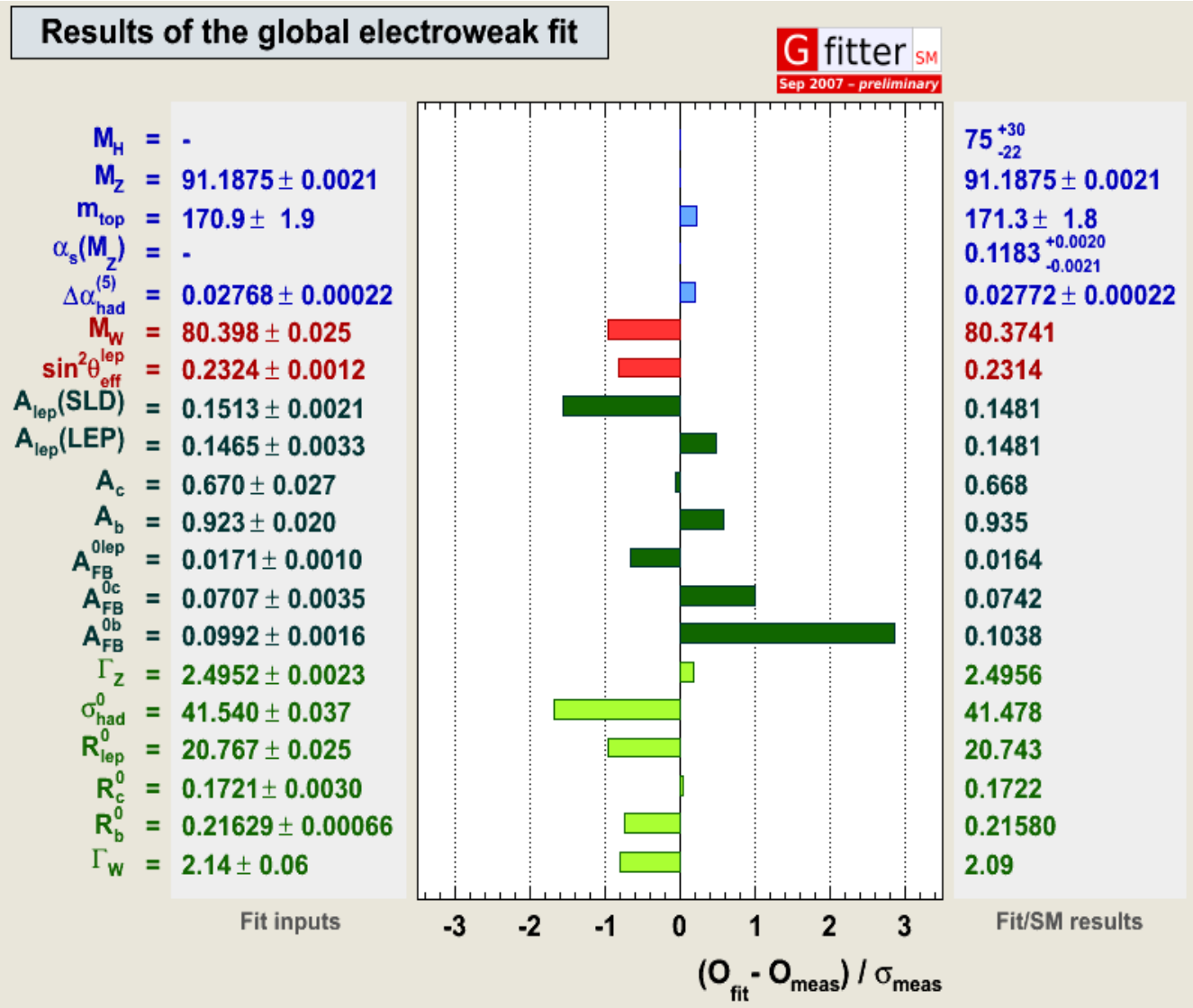

Higgs and New Physics
vs
early LHC data
B. Laforge, LPNHE
6 juin 2011, IAP

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

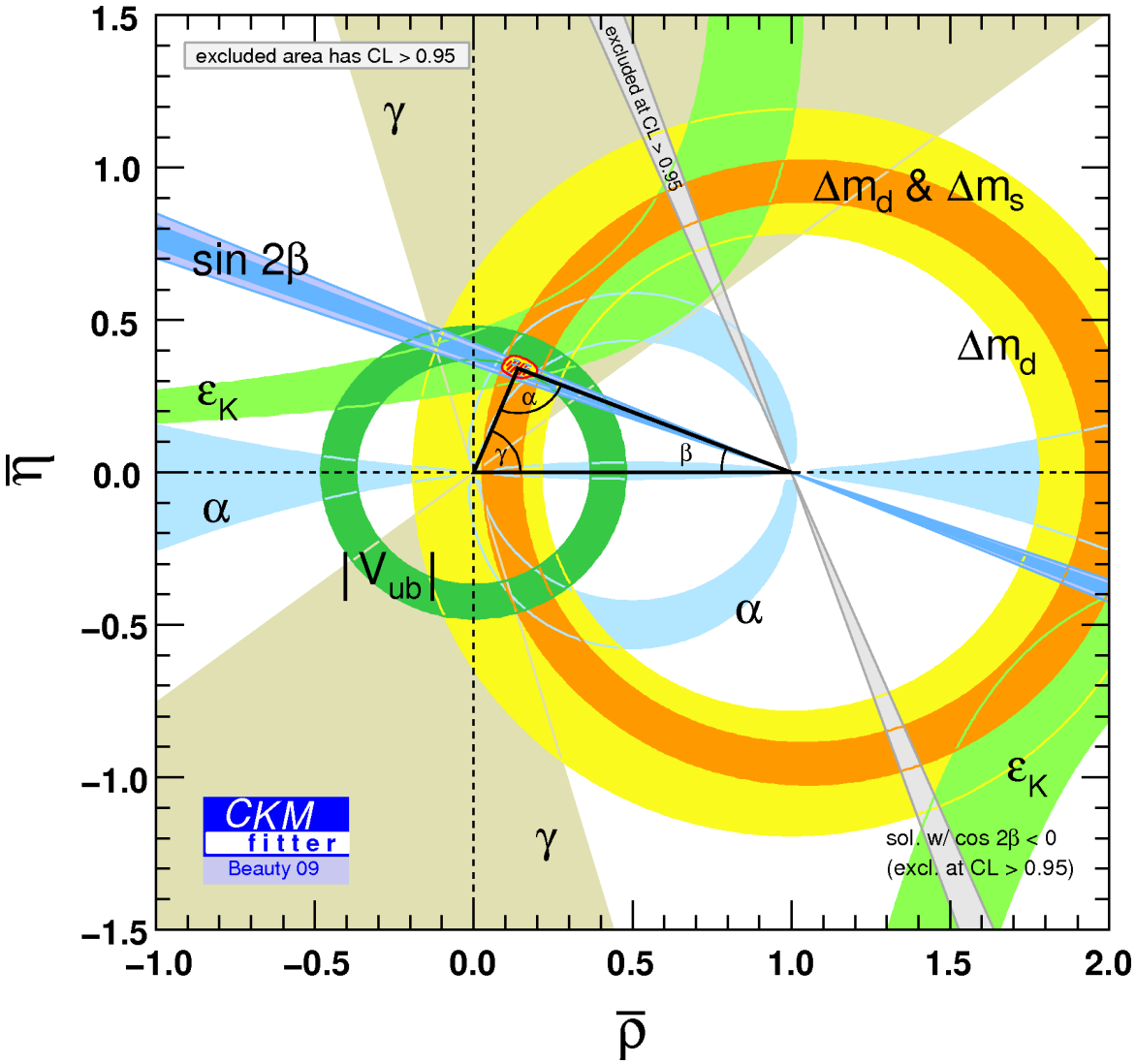
For the last 35 years, the SM has been successfully tested in experiments, with varying levels of accuracy, in many independent sectors :

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 !



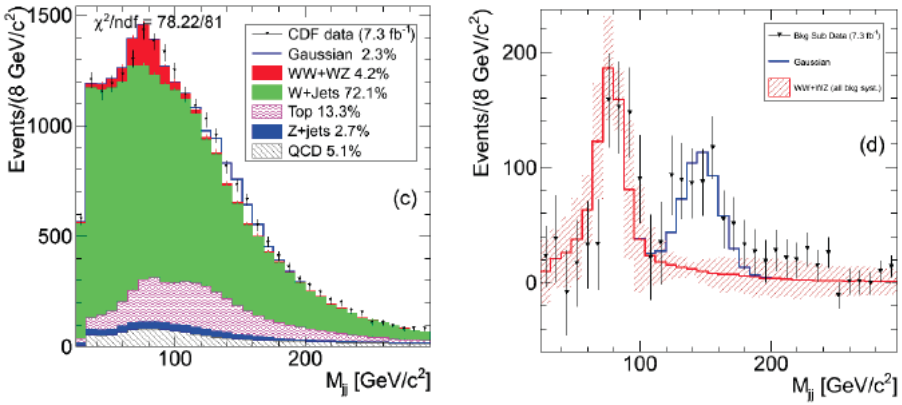
But there are still Open Questions

- 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) ?
- Is SM a effective theory of a more unified theory at high energies ?
- Why do we observe more matter than antimatter in the Universe ?
- What is dark matter ?

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 but…

Updated W-jj with 7.3fb^{-1}



CDF paper on a possible jj mass peak in W/Z + jj events

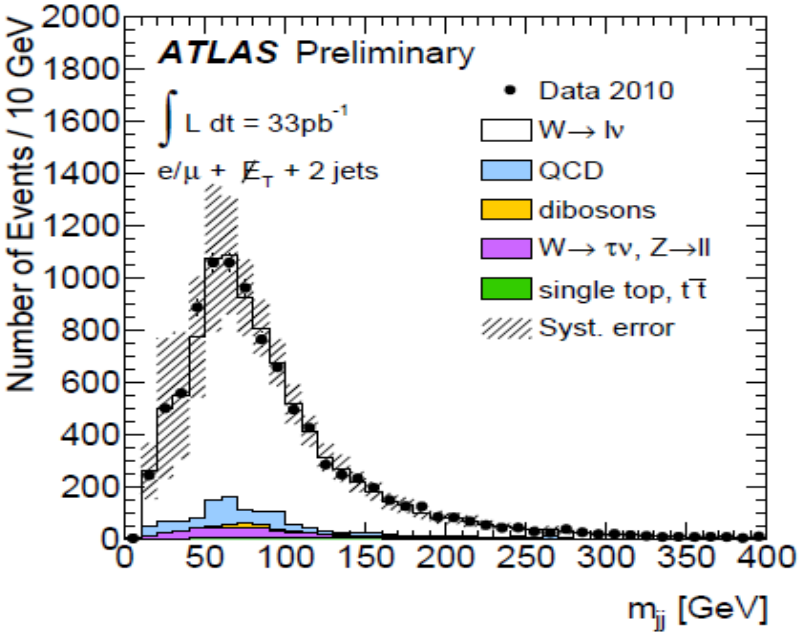
Phys. Rev. Lett. 106(2011)171801

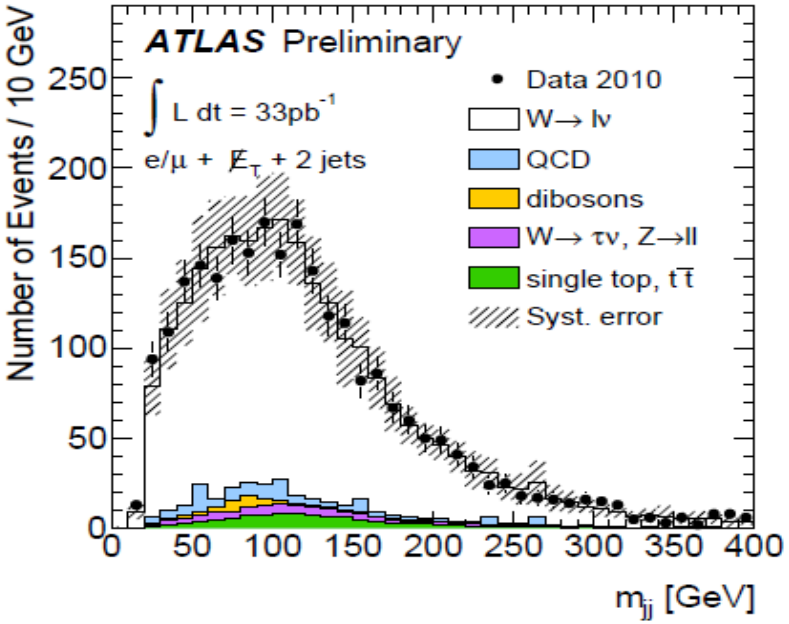
- Now closer to 5 sigma
- It was not just a statistical fluctuation
- Serious issue for CDF to understand this.
- Larger sample now allows for more detailed studies - stay tuned for updates.

Standard cuts

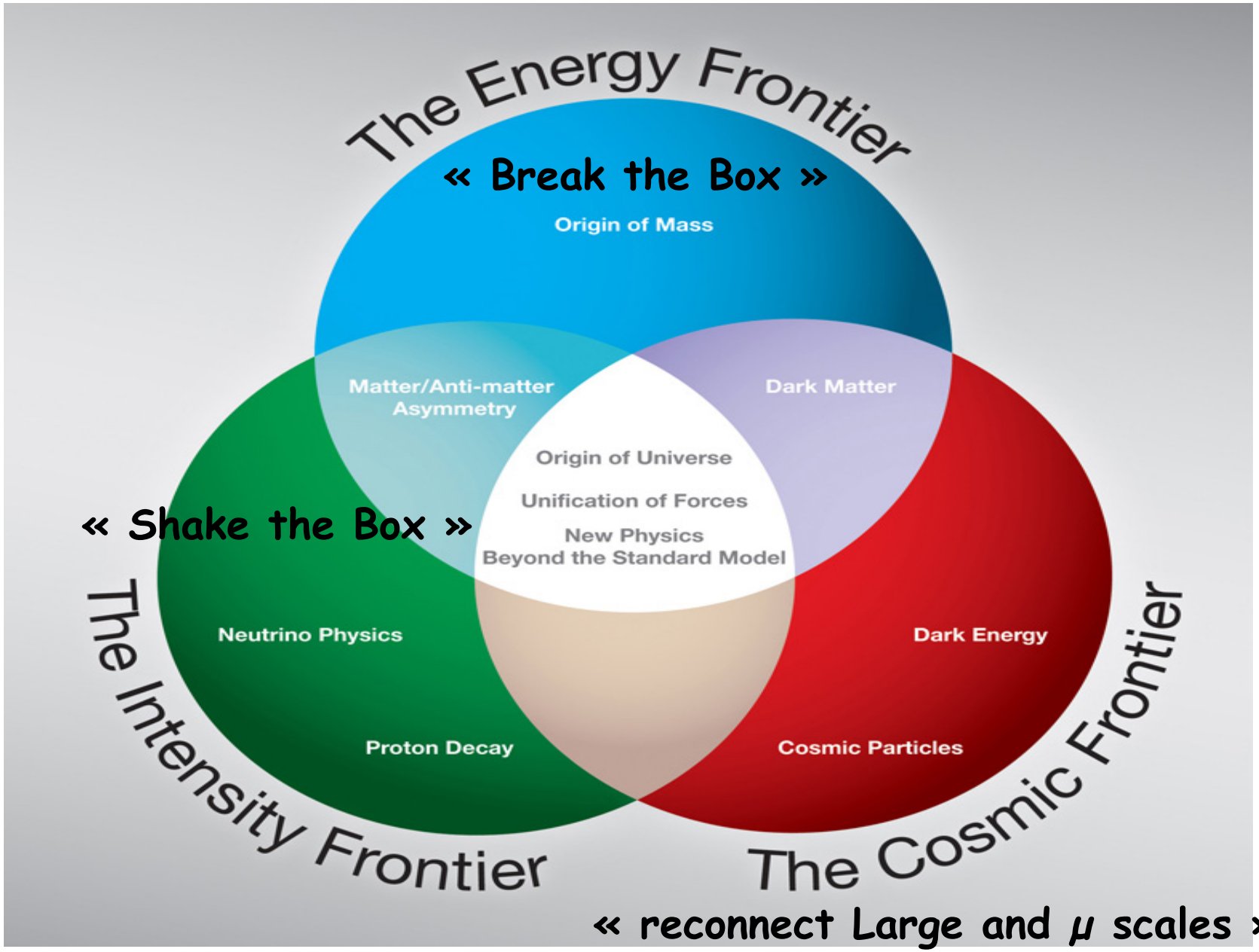
'CDF-style' cuts

ATLAS-CONF-2011-069



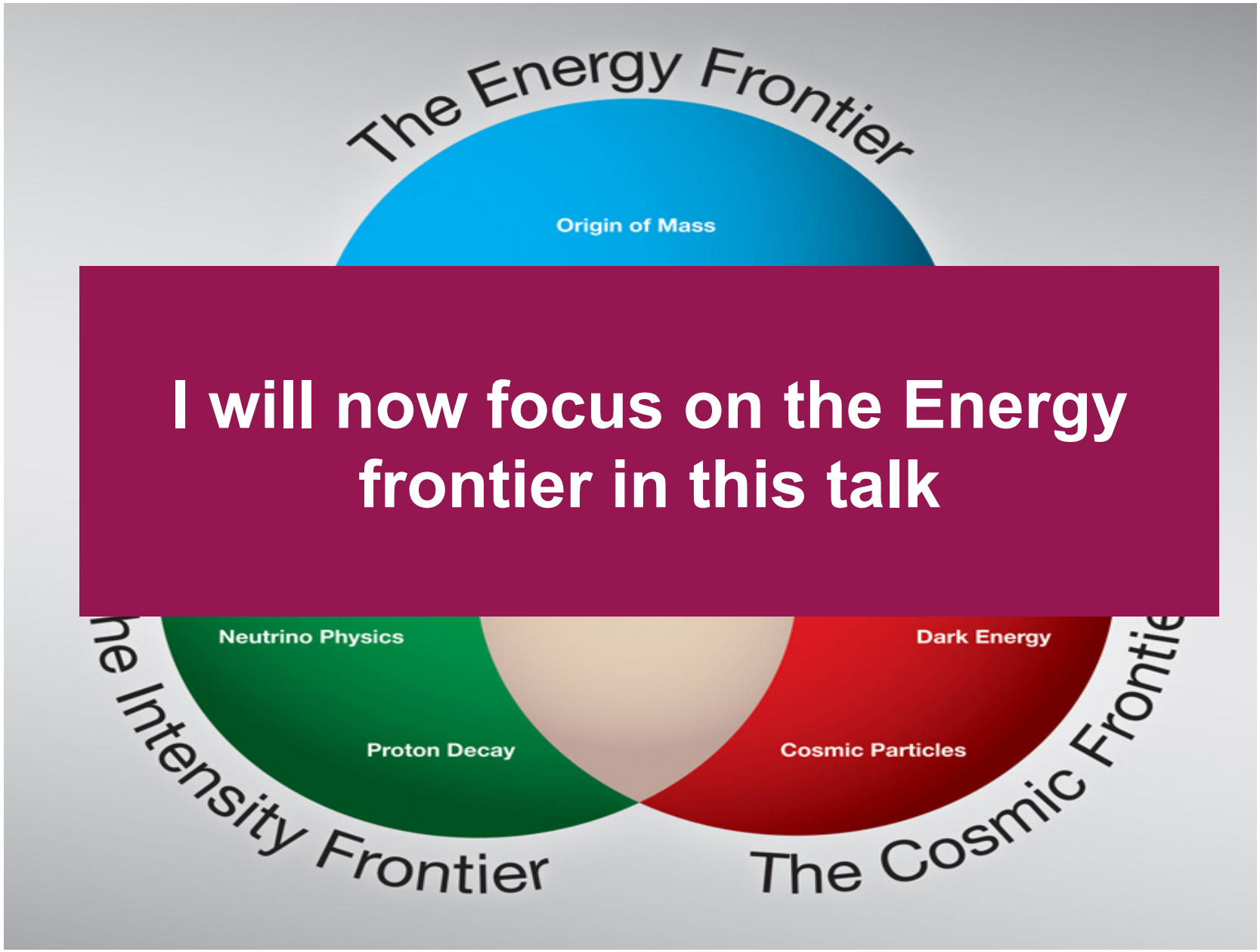


A strategy to address these questions : a 3-sided attack



« reconnect Large and μ scales »

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



I will now focus on the Energy frontier in this talk

Menu of today

LHC in action

ATLAS

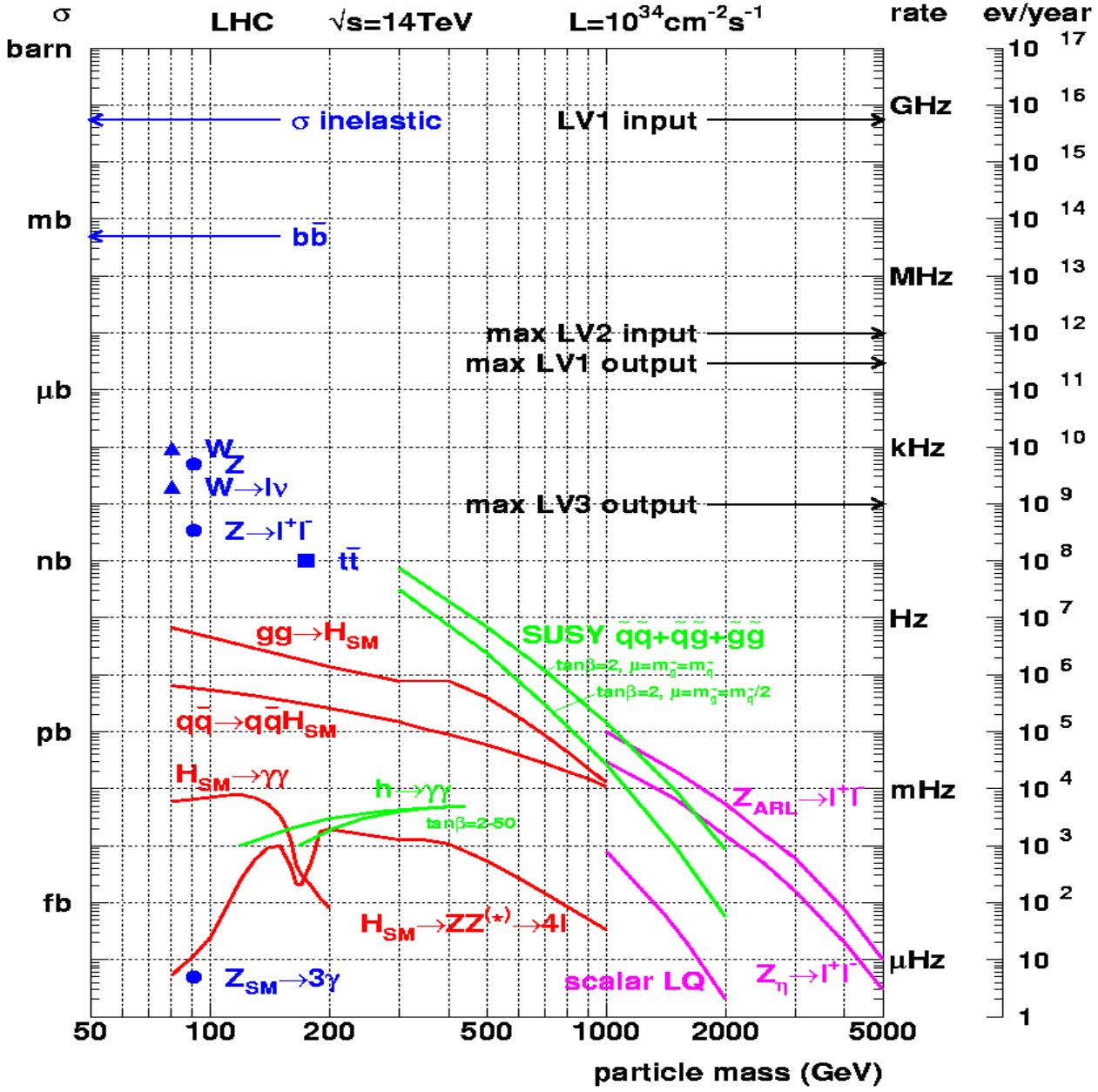
General event properties

Standard Model physics including QCD jets

Higgs searches

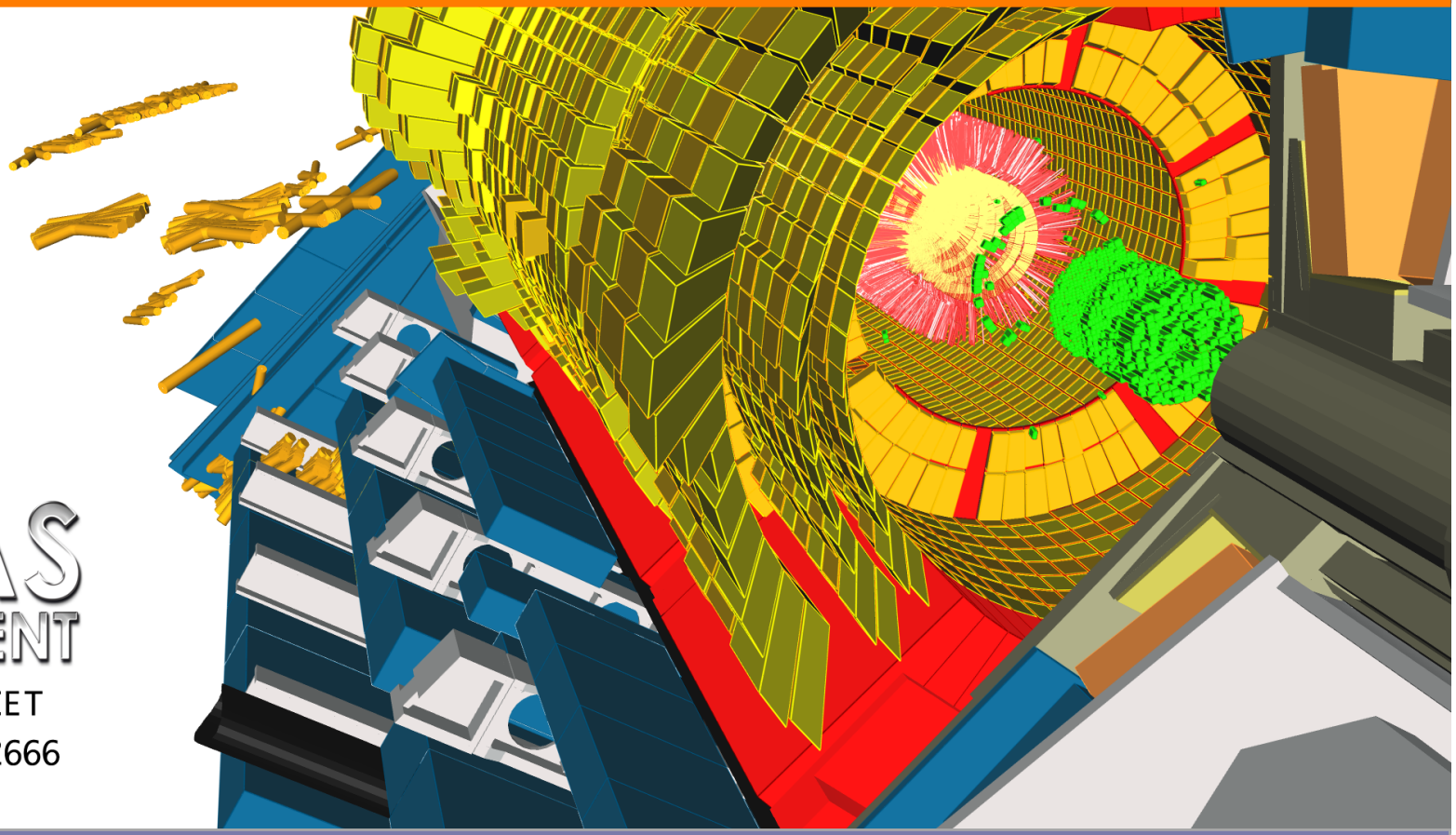
Searches for SUSY

Examples of searches for 'exotic' new physics



1st Beam Splash
from Beam-2

LHC in action !



ATLAS EXPERIMENT

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

ocariz@in2p3.fr

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

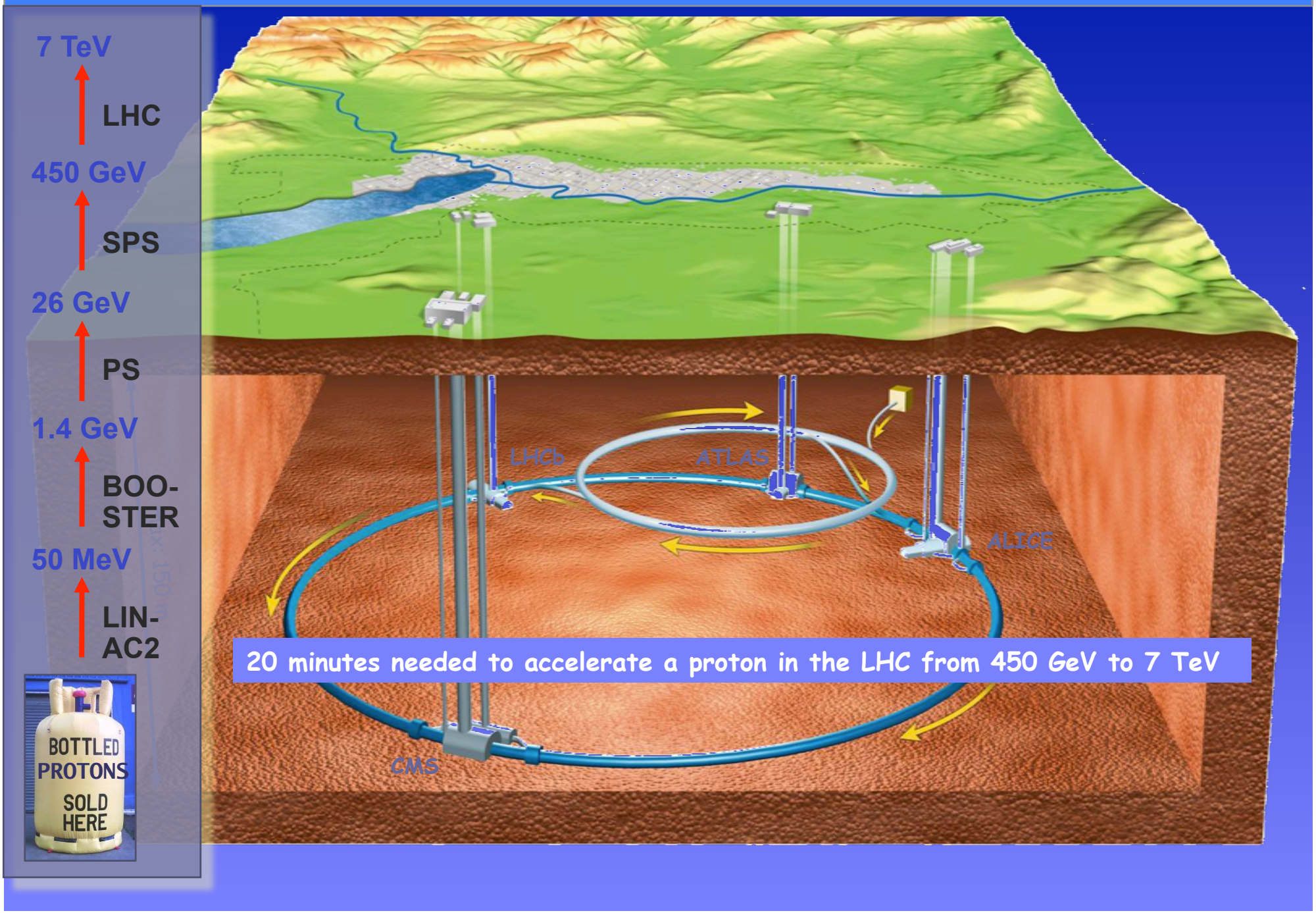
- Physics at LEP
- preparation, construction of LHC and its detectors (lot of R&D)

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

automne 2008: 1st LHC startup

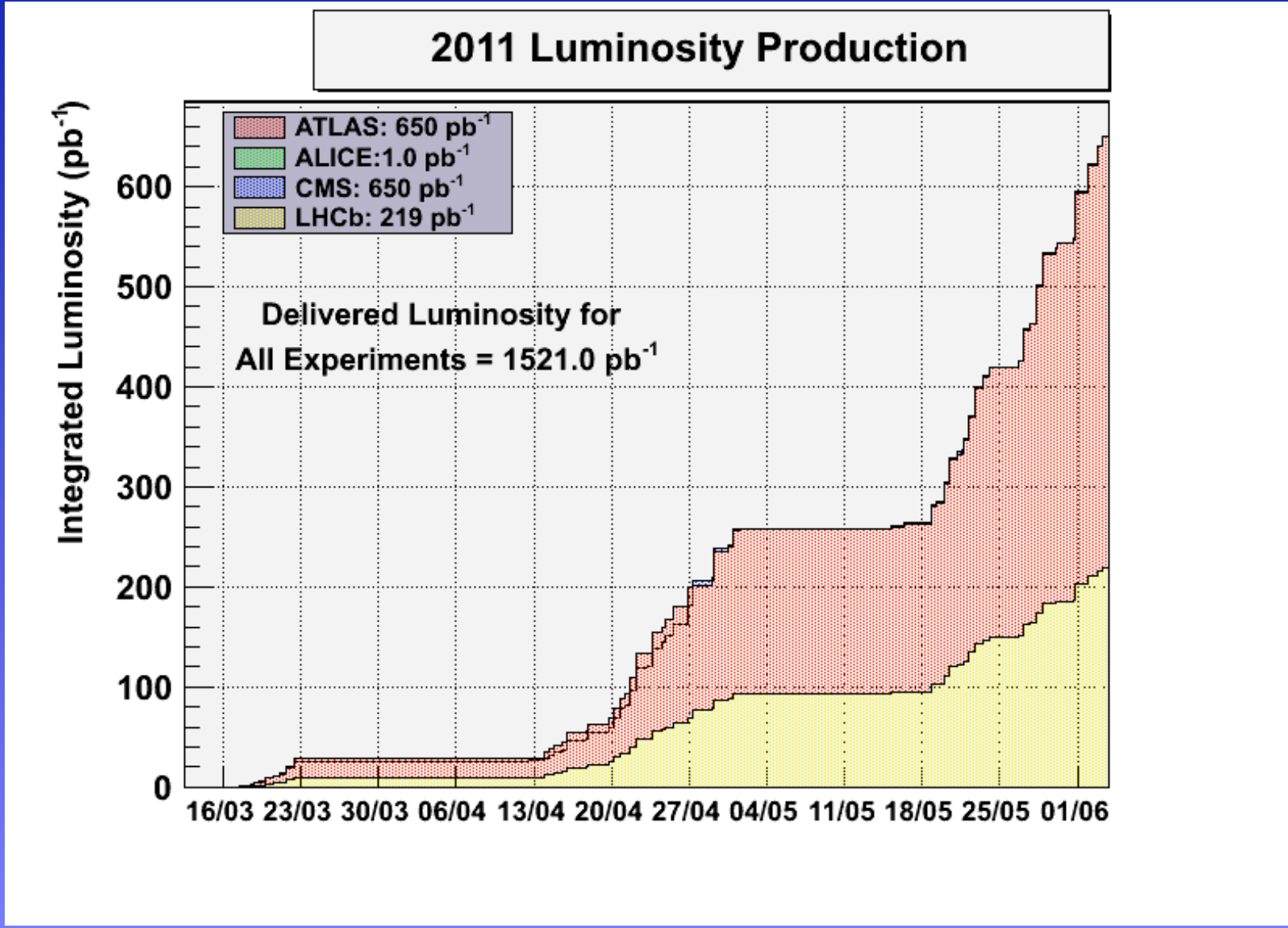
Automne 2009: Energy 2.36 TeV
2010 : LHC at 7 TeV, $2.10^{32} cm^{-2}.s^{-1}$
2011 : LHC at 7 TeV, $1.3.10^{33} cm^{-2}.s^{-1}$

LHC : a pipeline of accelerators, 4 large experiments



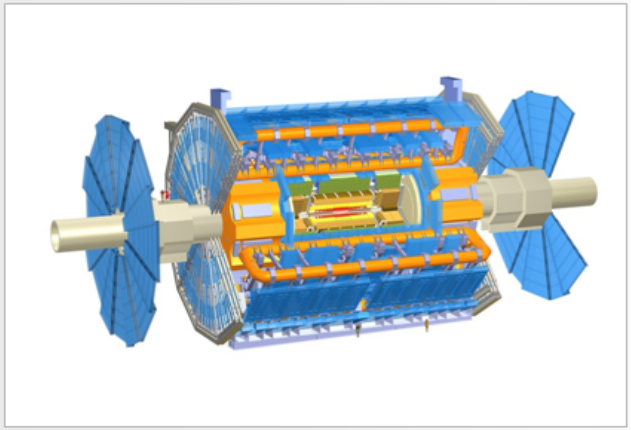
Present Integrated Luminosity @ LHC

LHC in very good shape this year

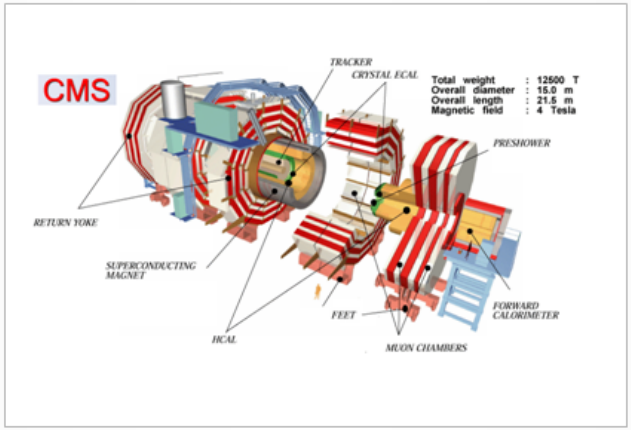


The four large LHC experiments

ATLAS



CMS

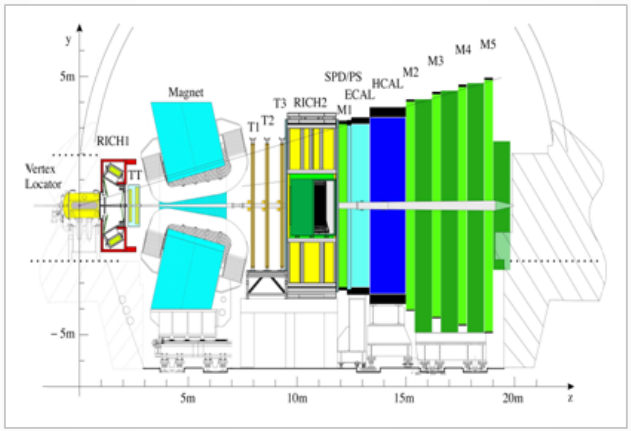


ALTAS and CMS have same physics goals: concentrate on "high-p_T" discovery physics

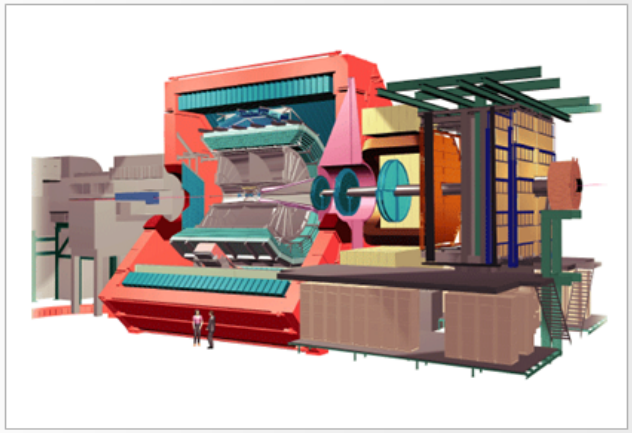
The detector concepts are however different: this provides necessary redundancy and fruitful competition

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

LHCb



ALICE

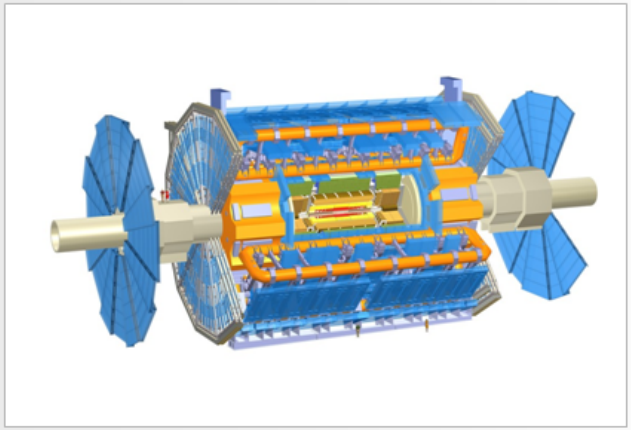


There are two more (much smaller) experiments at the LHC: TOTEM (measuring elastic and diffractive processes), and LHCf (testing cosmic shower models)

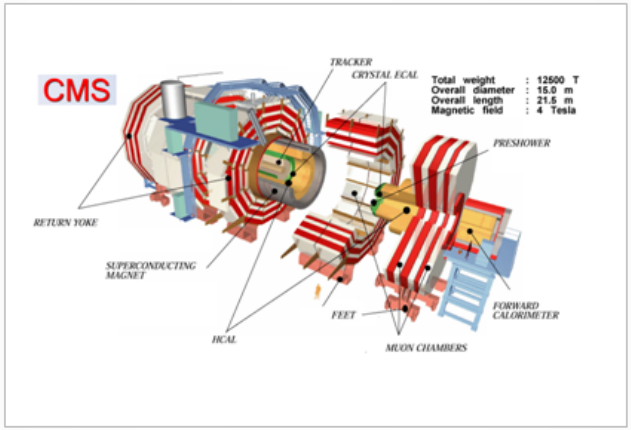
ALICE will exploit high-energetic nucleus-nucleus ("heavy-ion") collisions

The four large LHC experiments

ATLAS



CMS



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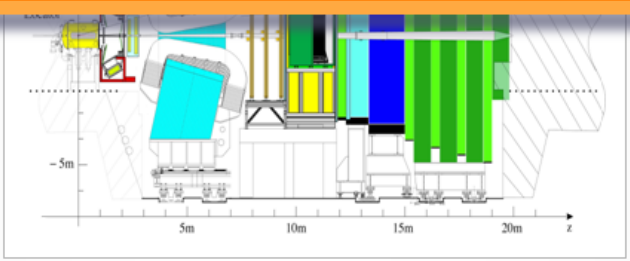
LHCb



ALICE

I will concentrate on high-p_T physics and on ATLAS (CMS)

low-p_T *B* physics

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

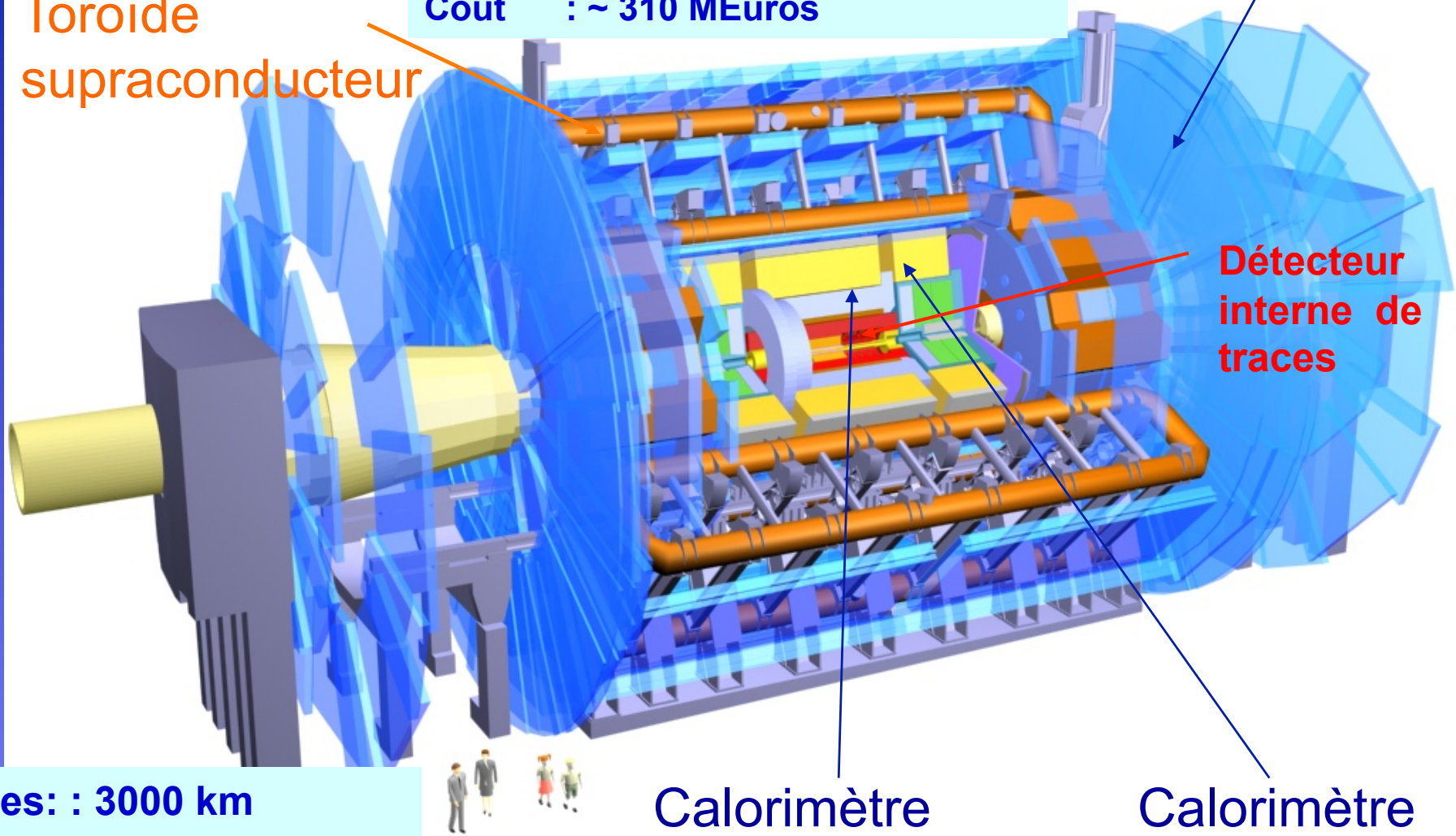
ALICE will exploit high-energetic nucleus-nucleus ("heavy-ion") collisions

The ATLAS detector at the LHC

Longueur : ~ 46 m Diamètre : ~ 25 m

Poids : ~ 7000 tonnes

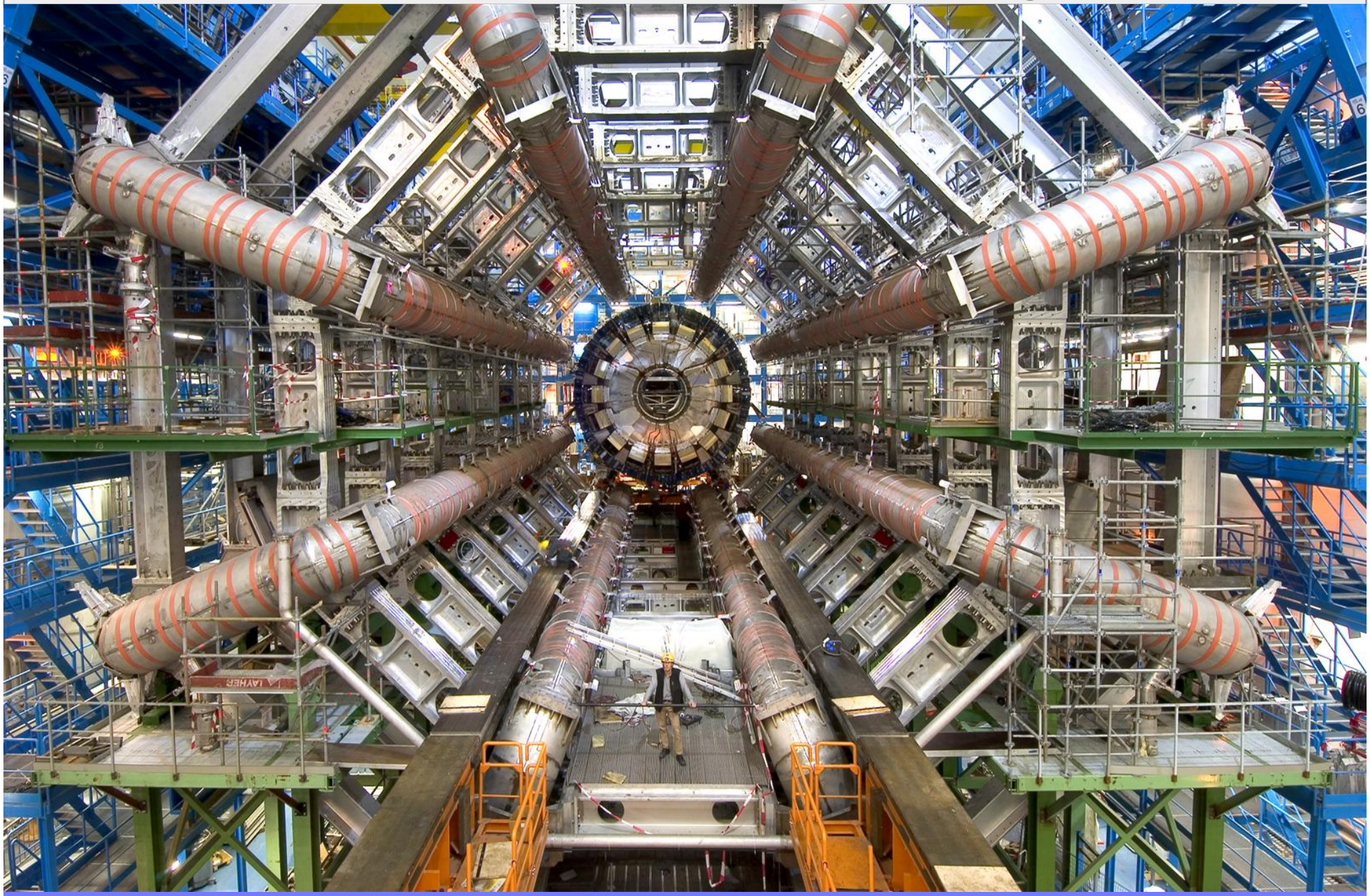
Coût : ~ 310 MEuros



Câbles: : 3000 km

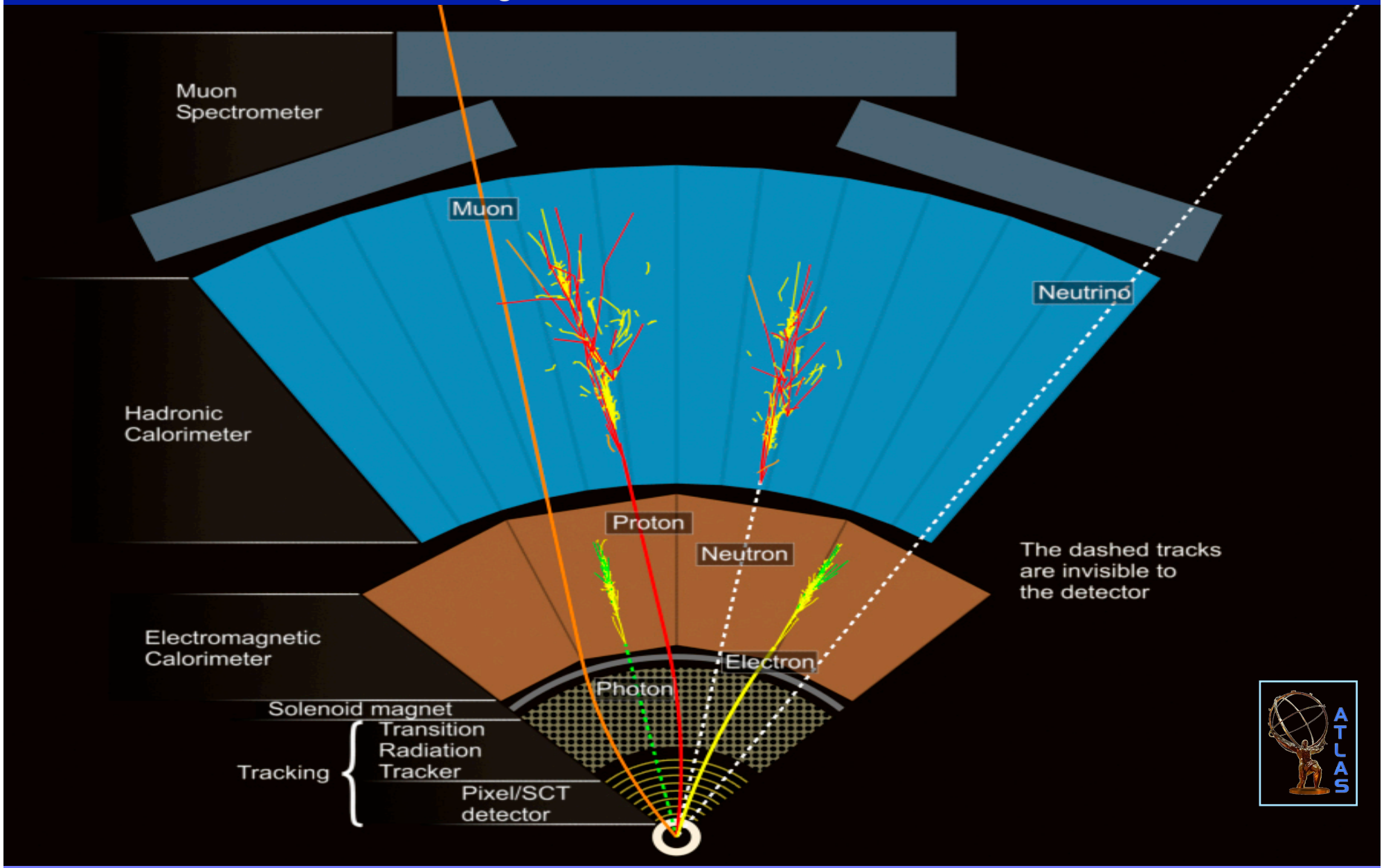
Voies électronique : 10^8

ATLAS : Air Toroidal Lhc Apparatus System



ATLAS Detector Layers

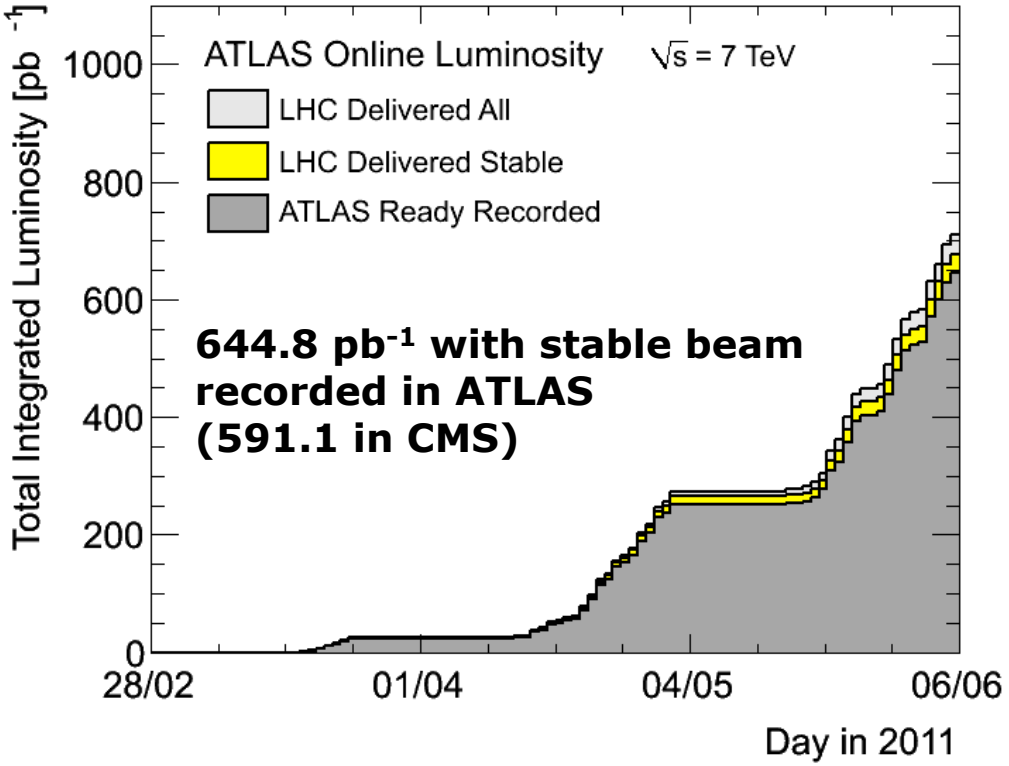
Particles are detected through their interaction with active detector materials

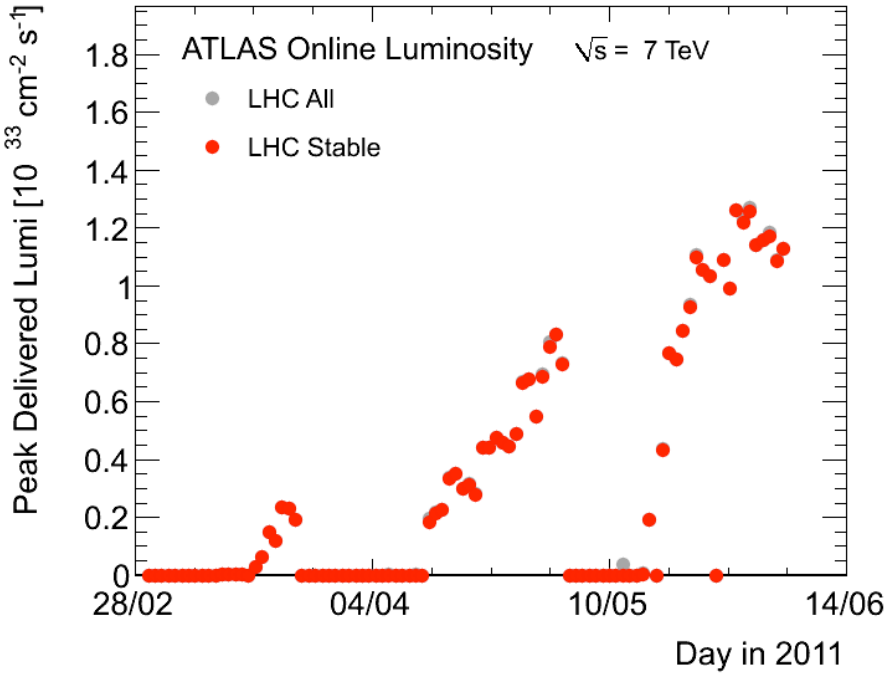


Present Integrated Luminosity @ ATLAS

$N = \sigma L$

ATLAS experiment is 95% efficient



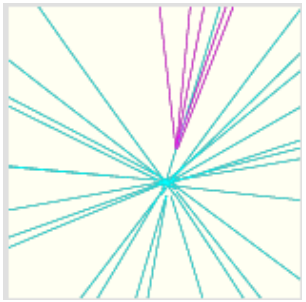


Expect 1 fb^{-1} for EPS and ~2 fb^{-1} in 2011 !
(to be compared to 45 pb^{-1} in 2010)

This year we already took more data in one day than in 2010 !

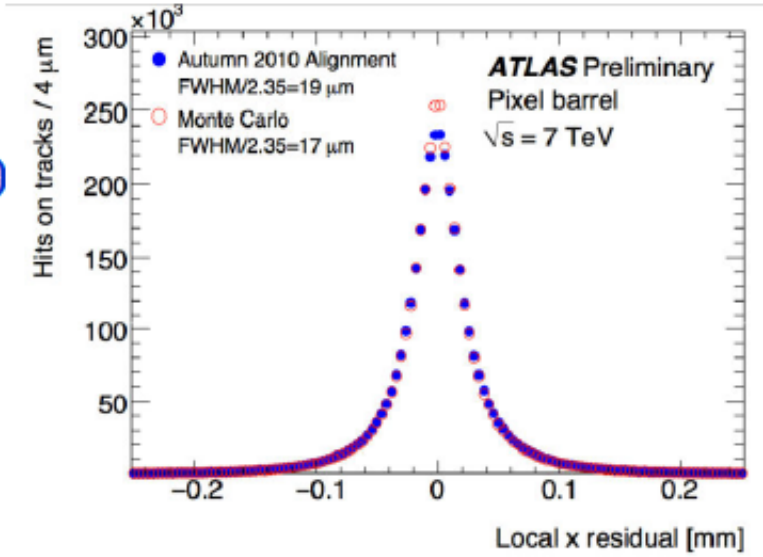
Illustration of the present detector response understanding

B-tagging

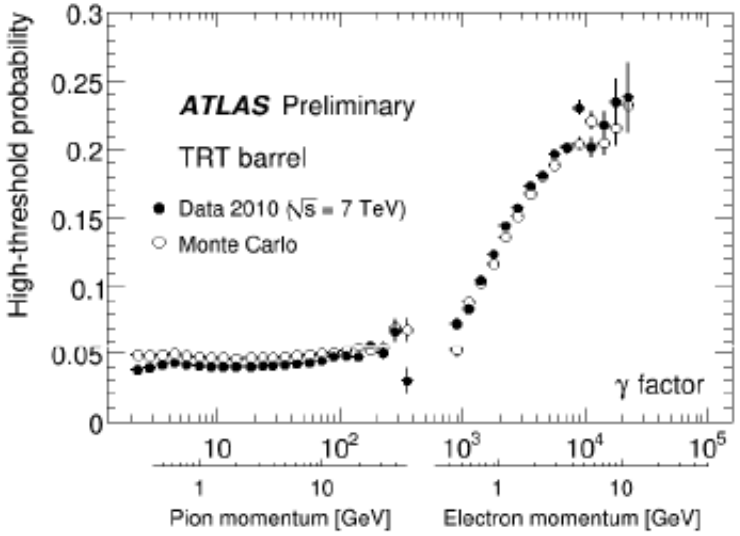


Pixel detector alignment

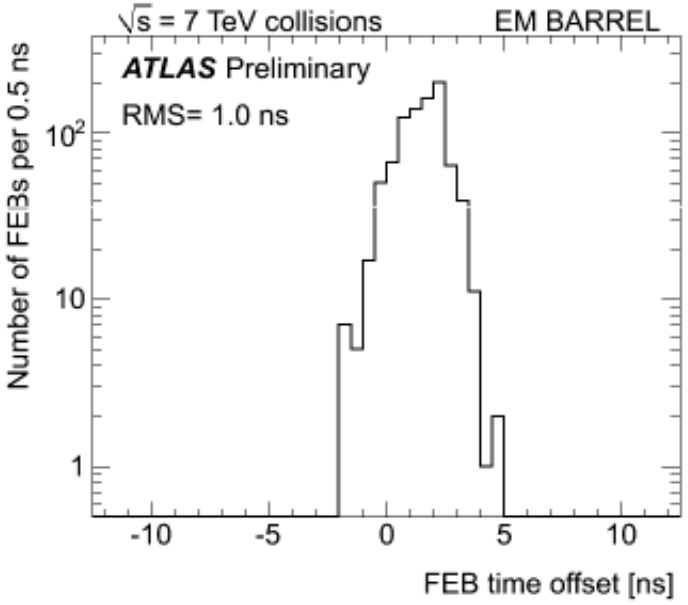
(transverse plane, autumn reprocessing)



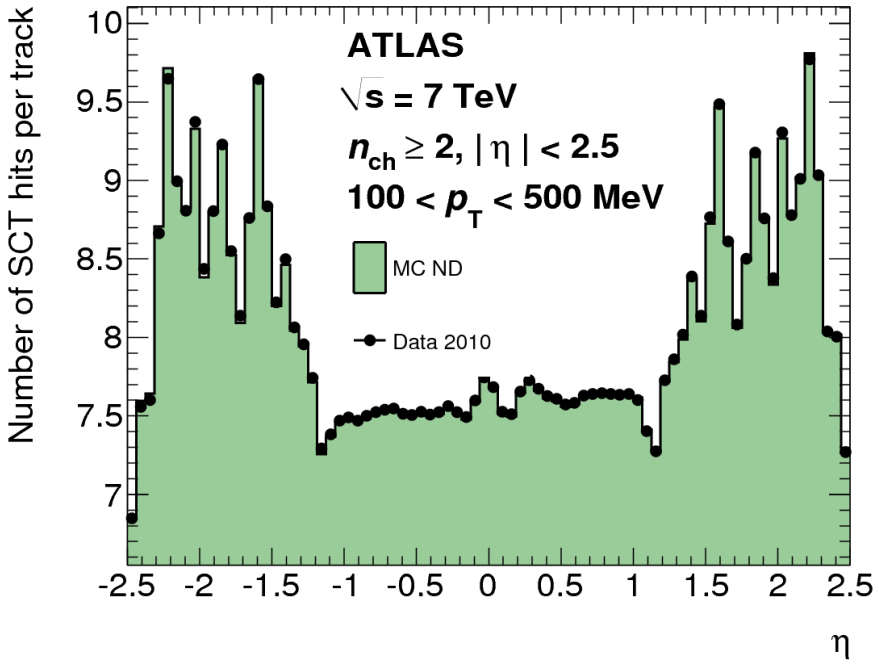
- **Transition Radiation threshold**

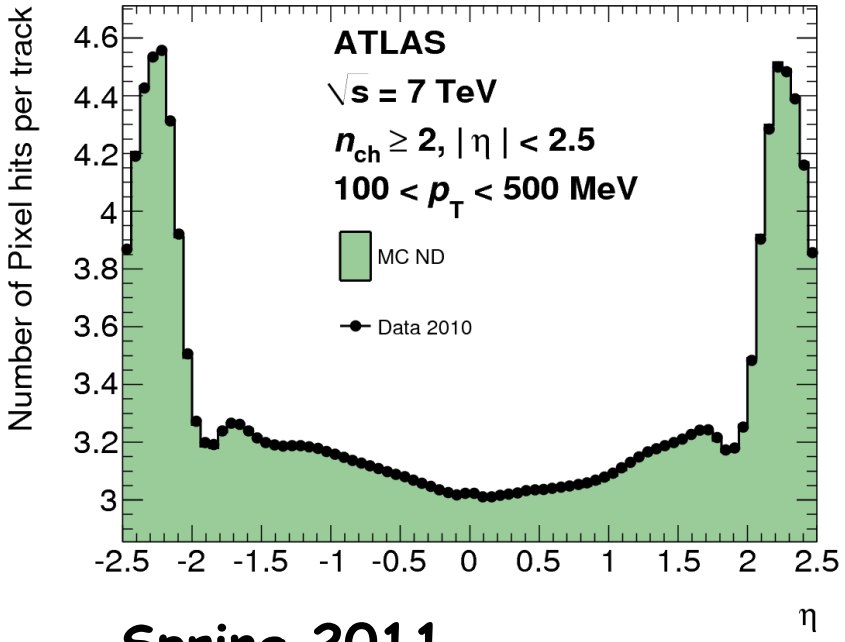


- **EM calorimeter: timing**



Dec. 2010



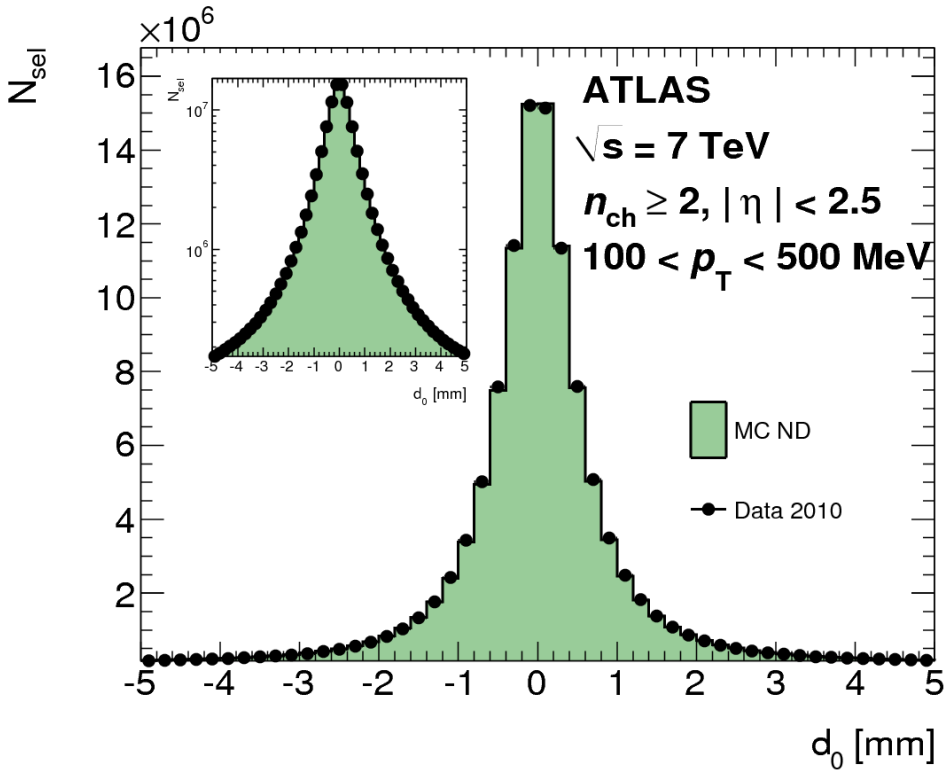


Spring 2011

The tracking detector simulations are in a mature state, charged track measurements are well understood

Example shows the ATLAS description of minimum bias tracks (silicon and pixel hits, transverse impact parameter)

Acc. by New J. Phys.
arXiv:1012.5104[hep-ex]



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 papers

https://twiki.cern.ch/twiki/bin/view/AtlasPublic
http://cdsweb.cern.ch/collection/CMS%20Papers?ln=en

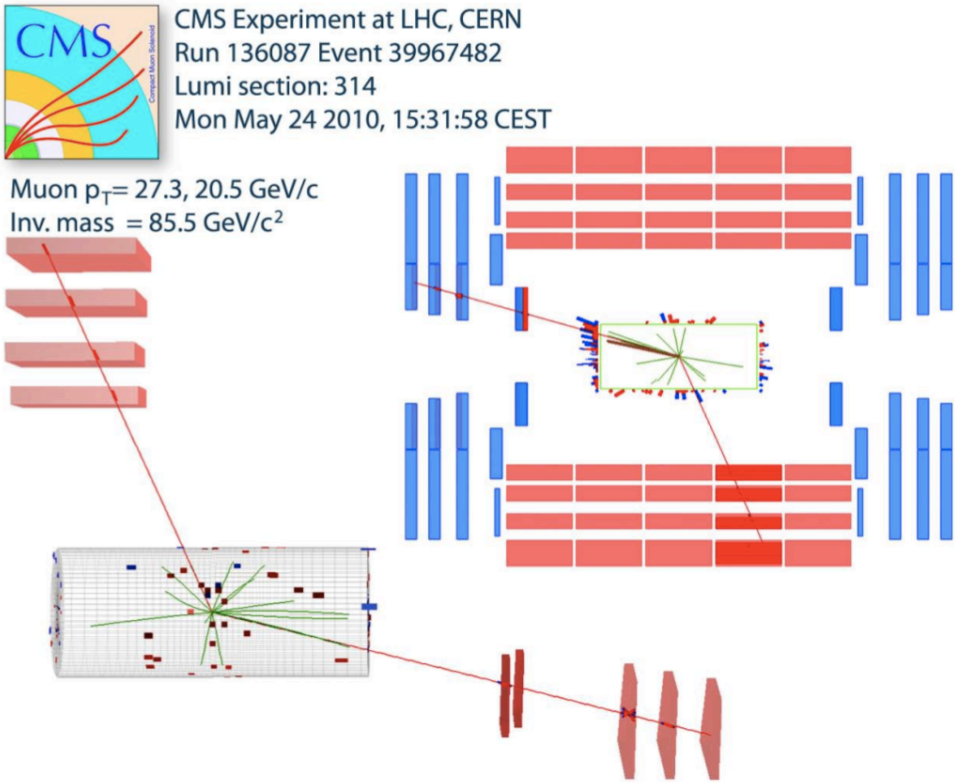
Scientific publications made in different forms :

ATLAS conference notes:
102 in 2010
89 in 2011

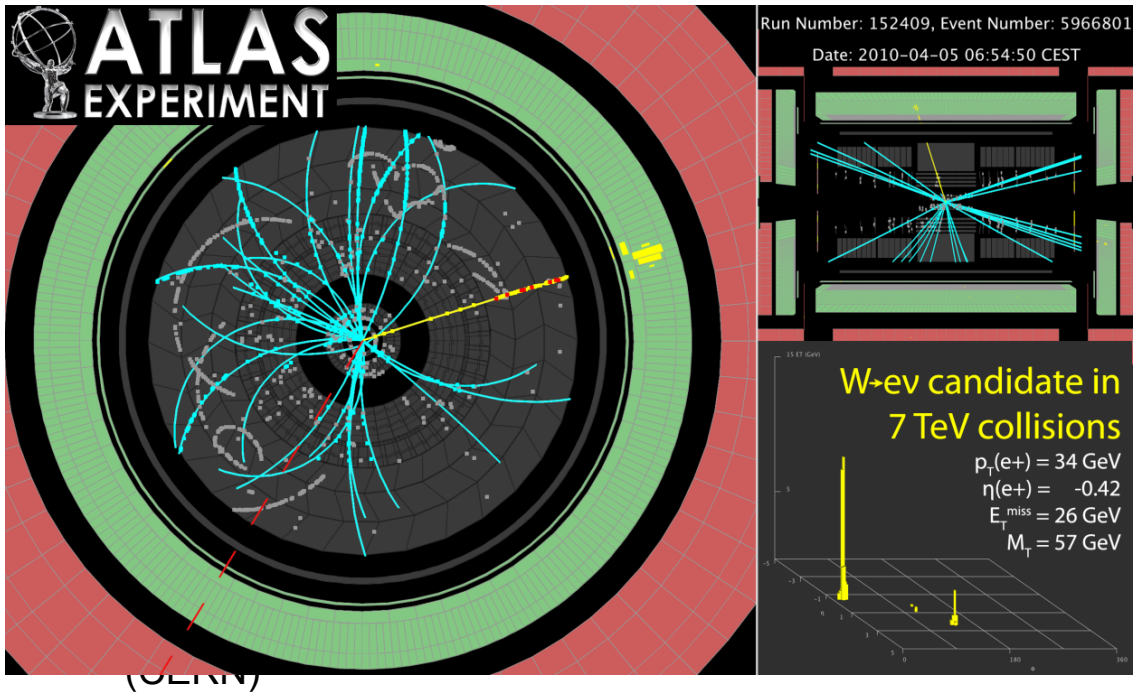
(for CMS Physics Analysis Summaries)

Published papers :
ATLAS : 44 papers
CMS : 78 papers

Standard Model Physics



CMS candidate Z → $\mu^+\mu^-$

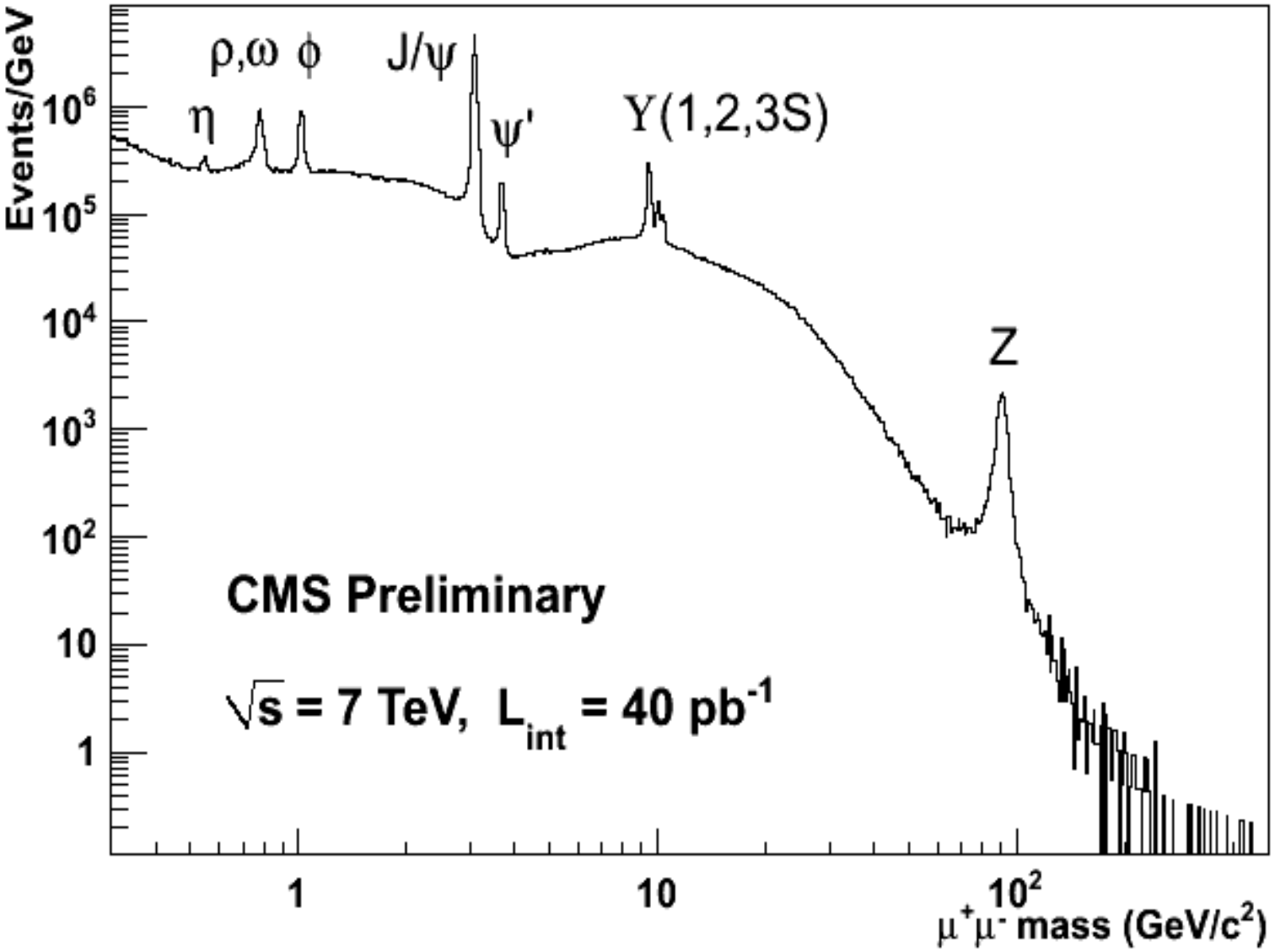


ATLAS W → eν candidate

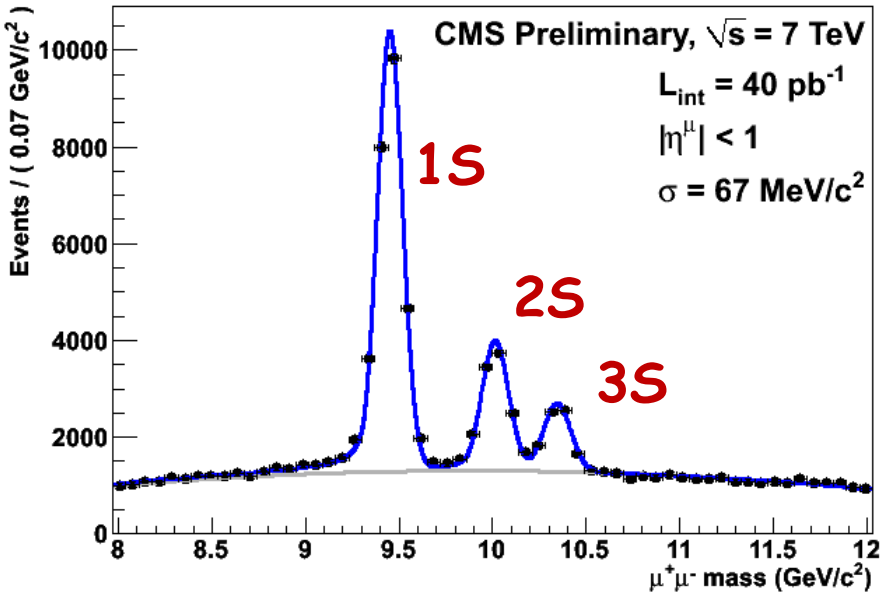
(CERN)

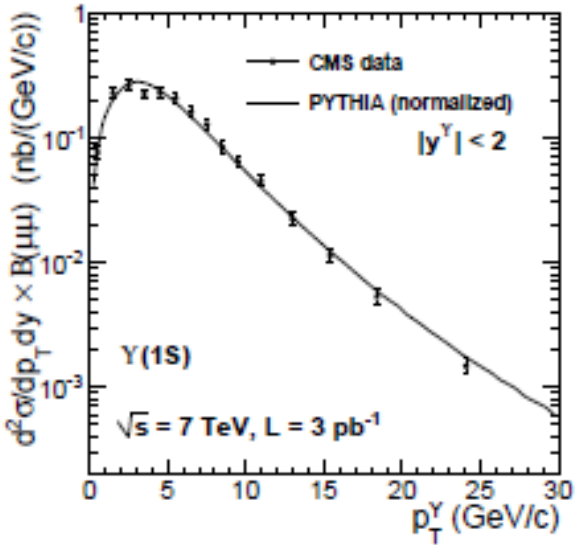
Di-lepton invariant mass spectra

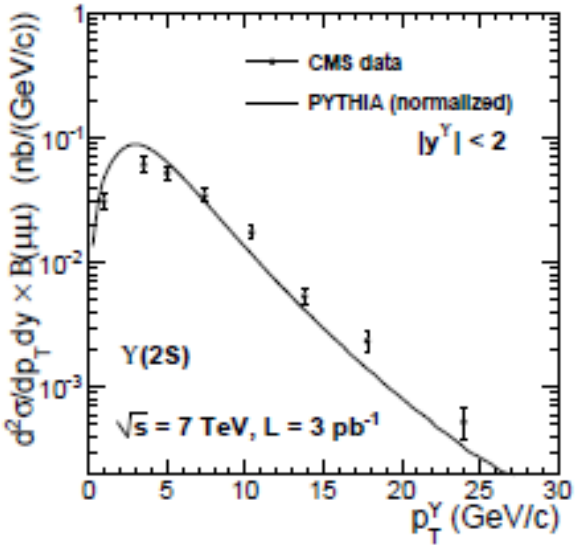
The di-muon spectrum recalls a long period of particle physics:

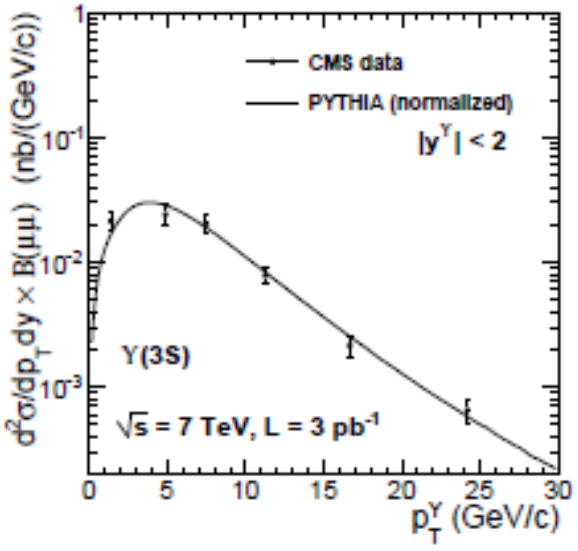


Observation, and differential cross-section measurements of the Υ - family



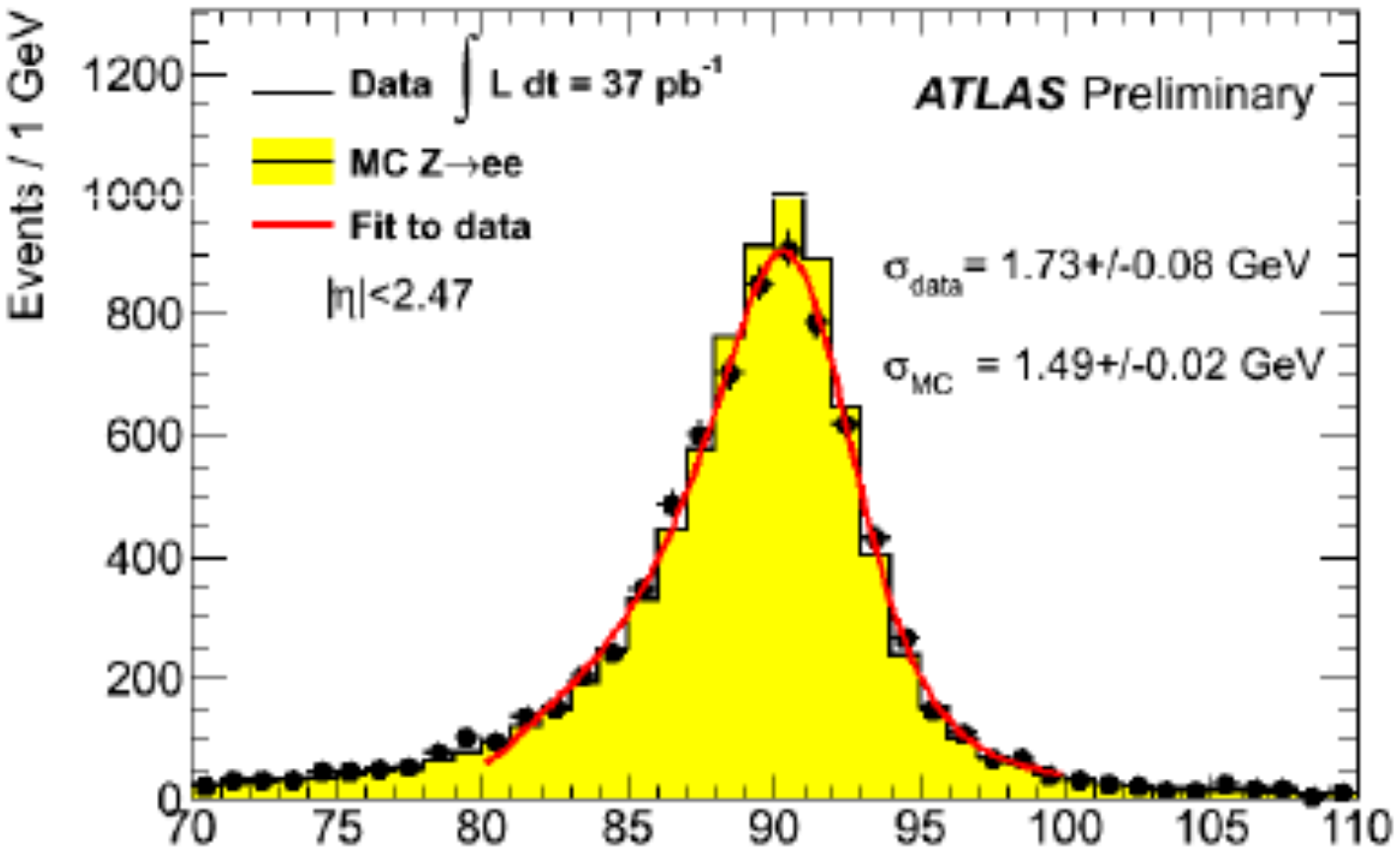






Sub. to Phys. Rev. D
arXiv:1012.5545[hep-ex]

Z in ATLAS with 2010 data

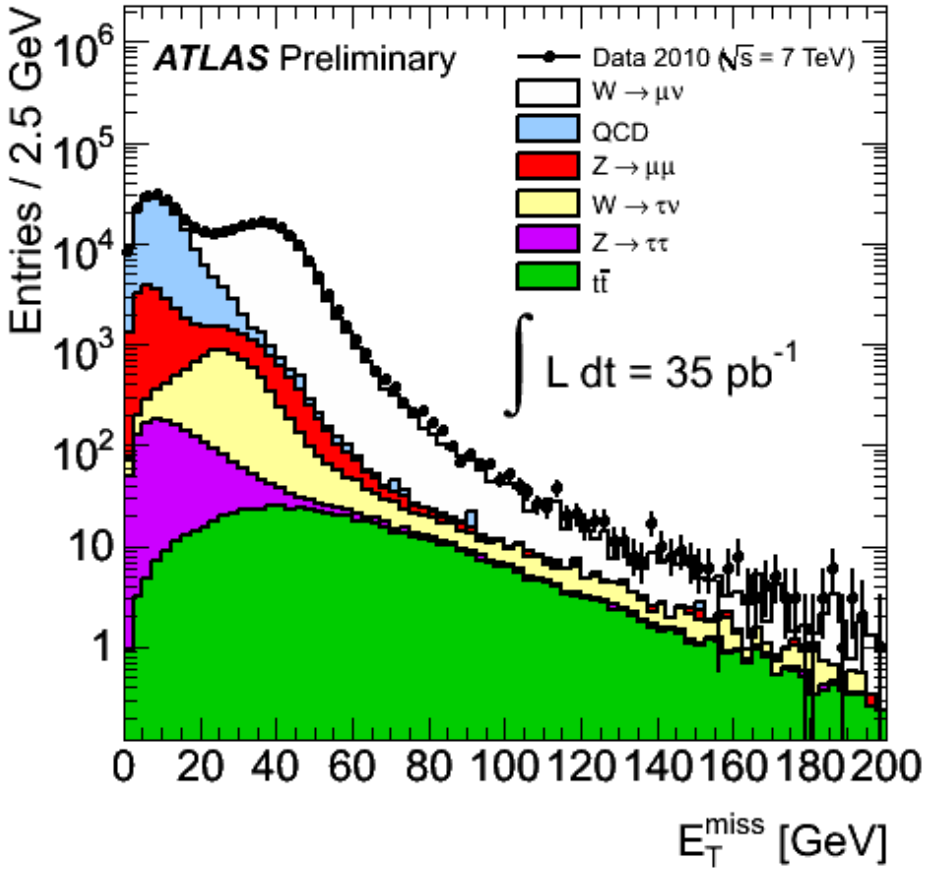


Z peak with full 2010 data

- **All EM calorimeter**
- **Autumn reprocessing**
- **Fit : Breit-Wigner ⊗ Crystal Ball**

σ quoted : Crystal Ball right

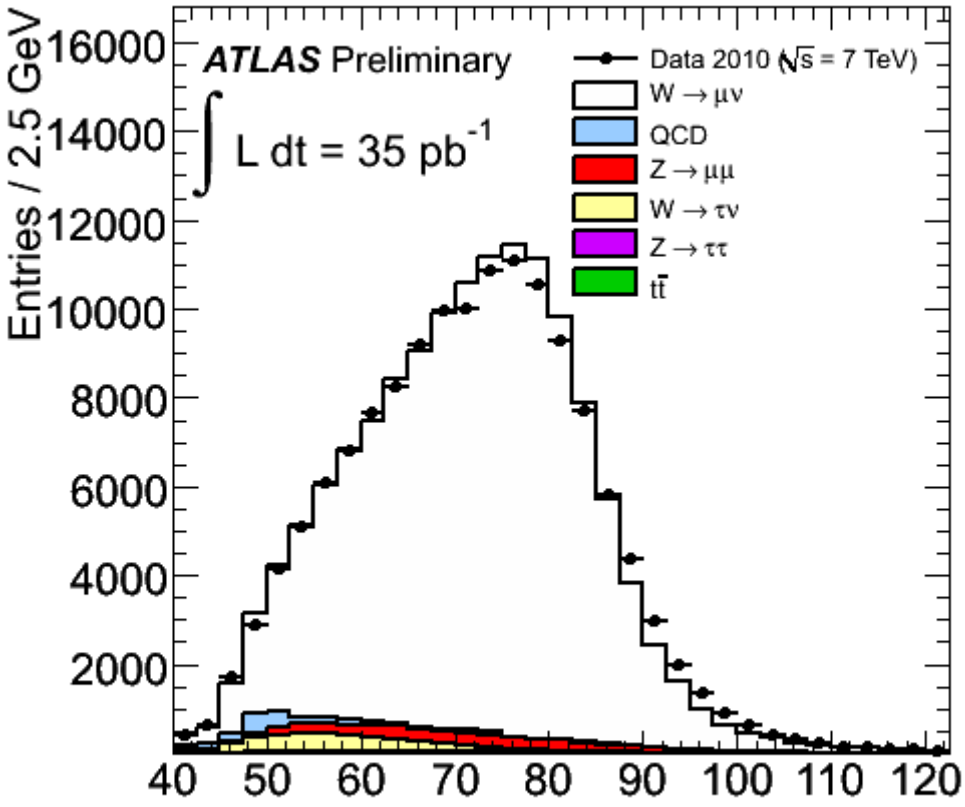
W in ATLAS with 2010 data



Missing transverse energy from the W → μ + ν decays

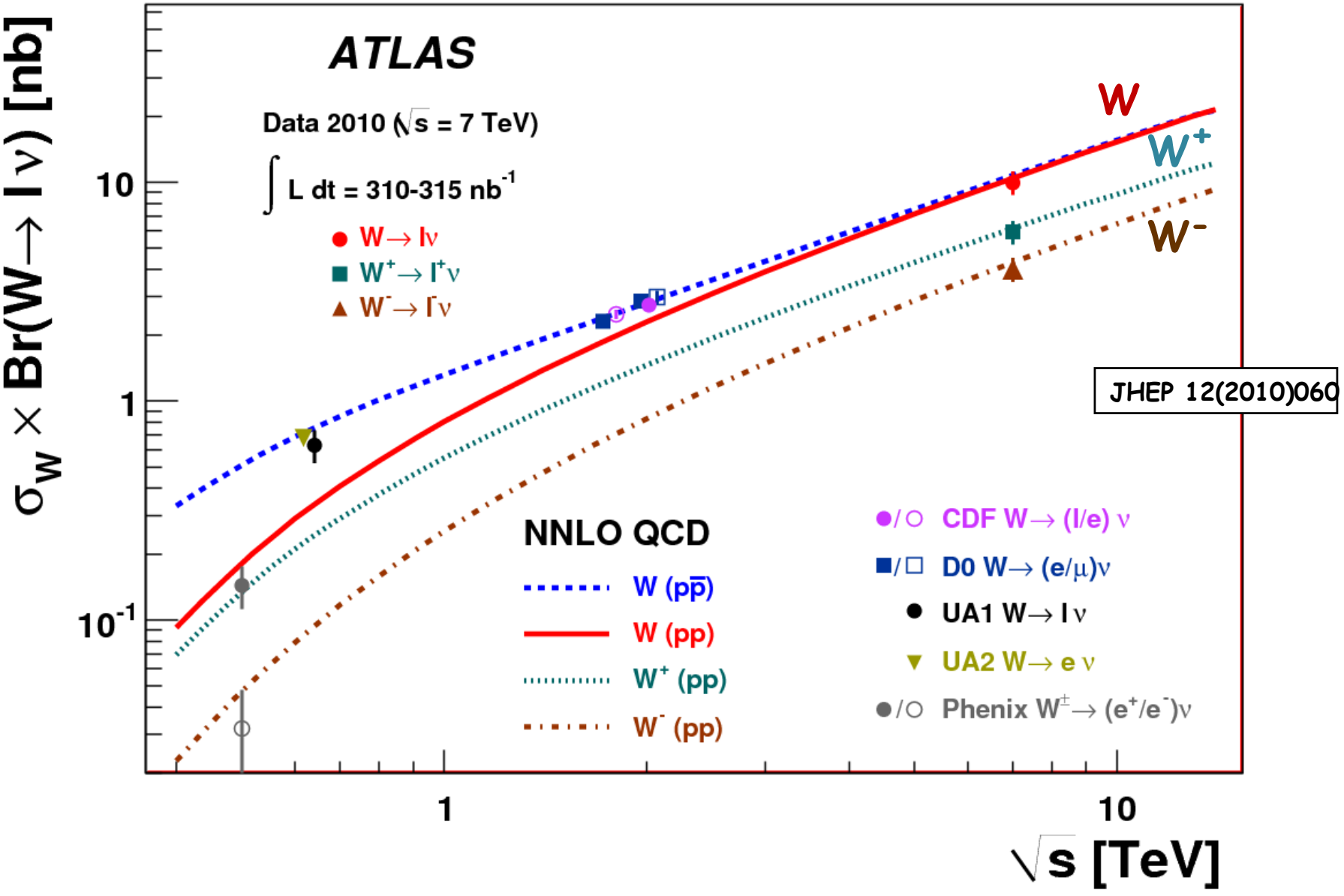
W transverse mass

μ with p_T>20 GeV, E_T^{miss}>25 GeV

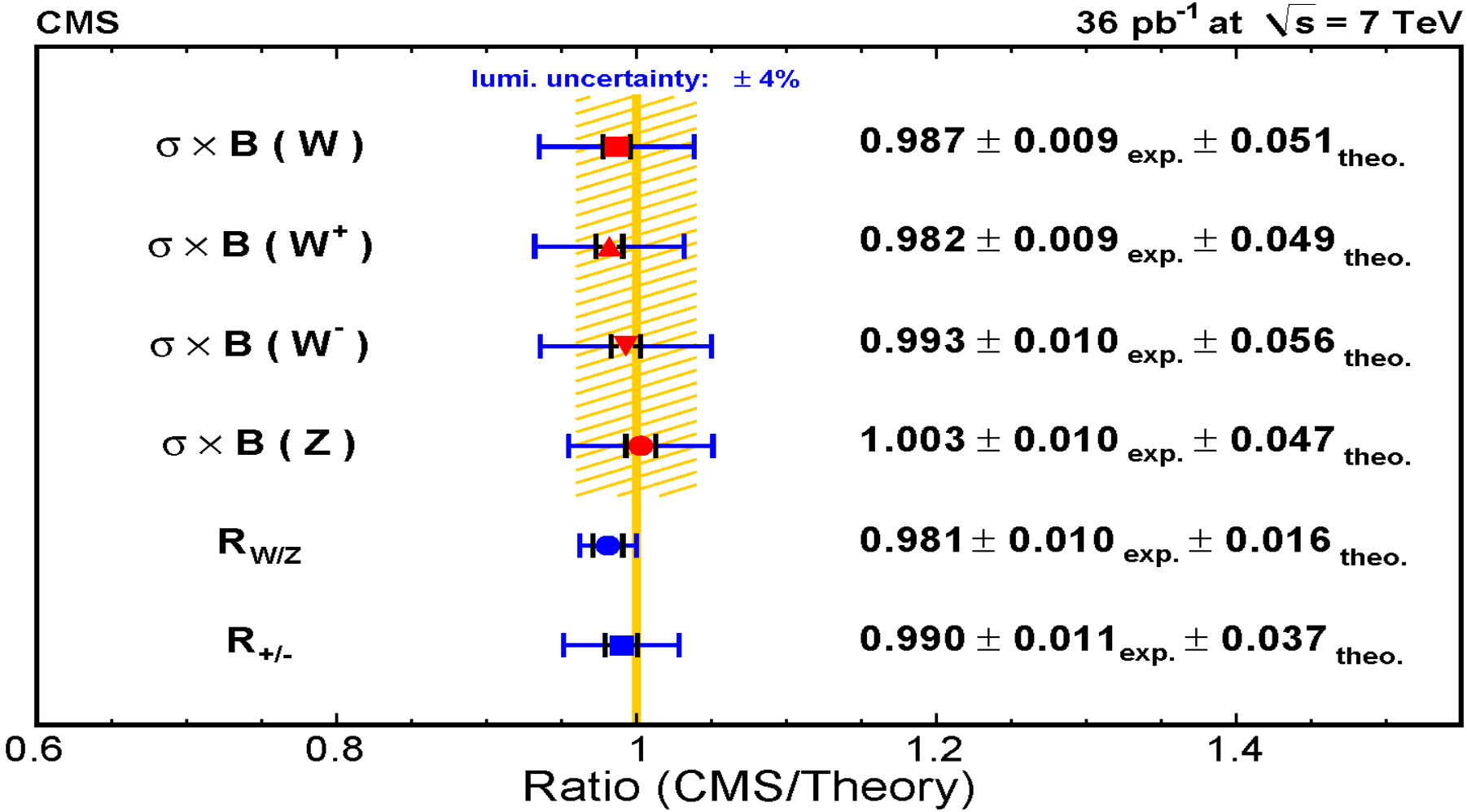


$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} p_{\mathrm{T}}^{\nu} (1 - \cos(\phi^{\ell} - \phi^{\nu}))}$$

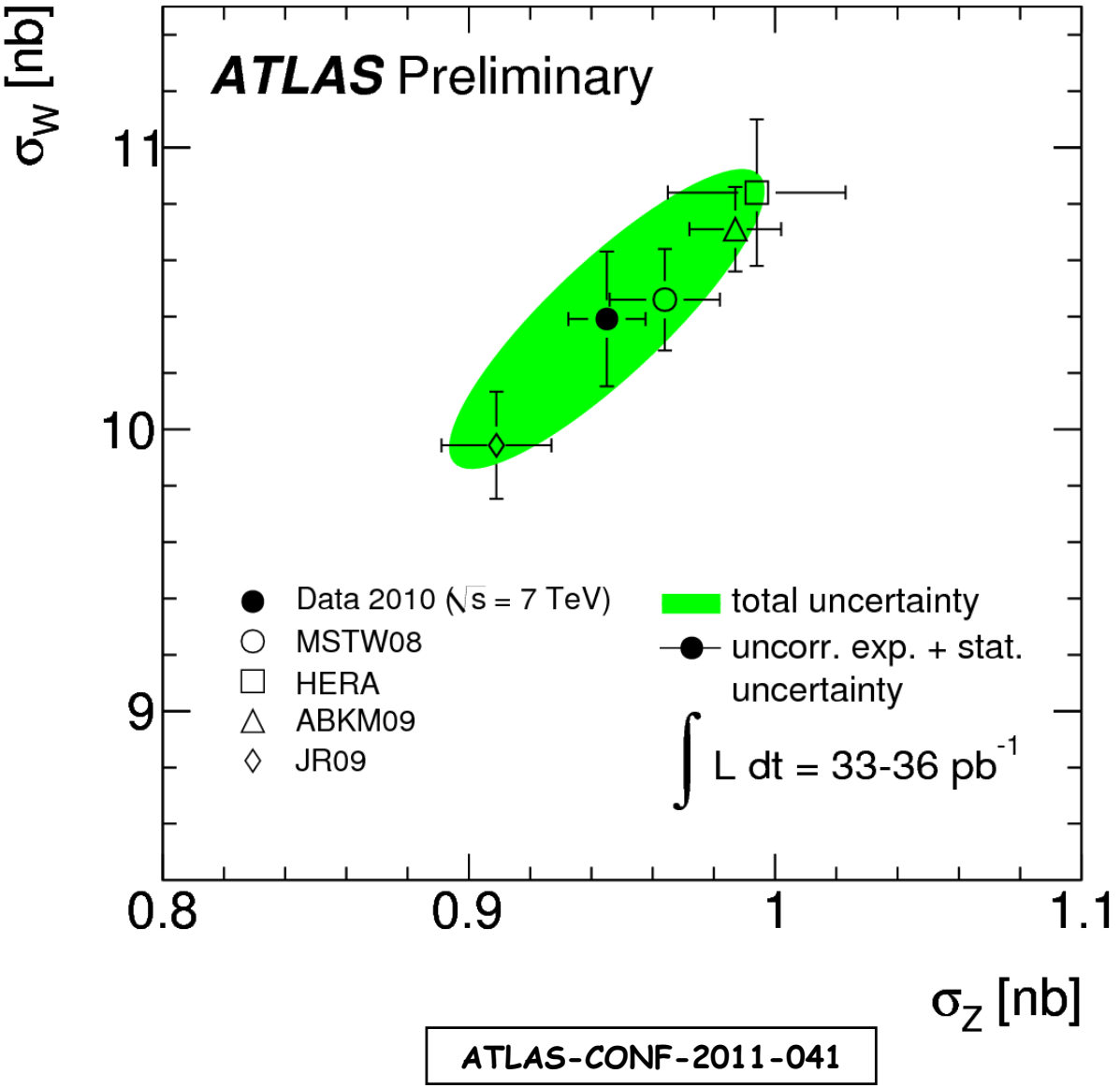
Very early W cross section measurement with e and μ



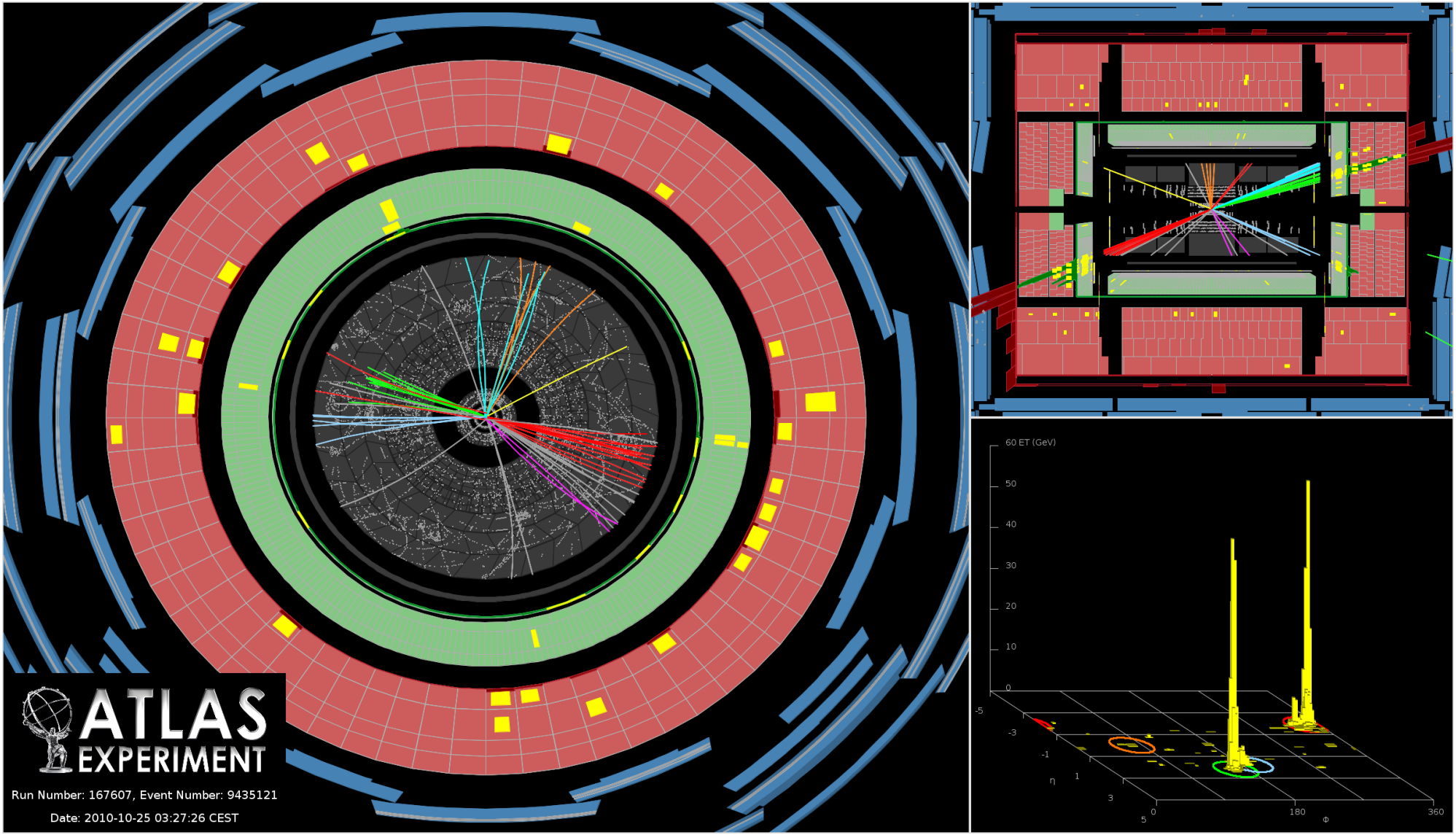
Full 2010 data set measurements from CMS



Full 2010 data set from ATLAS



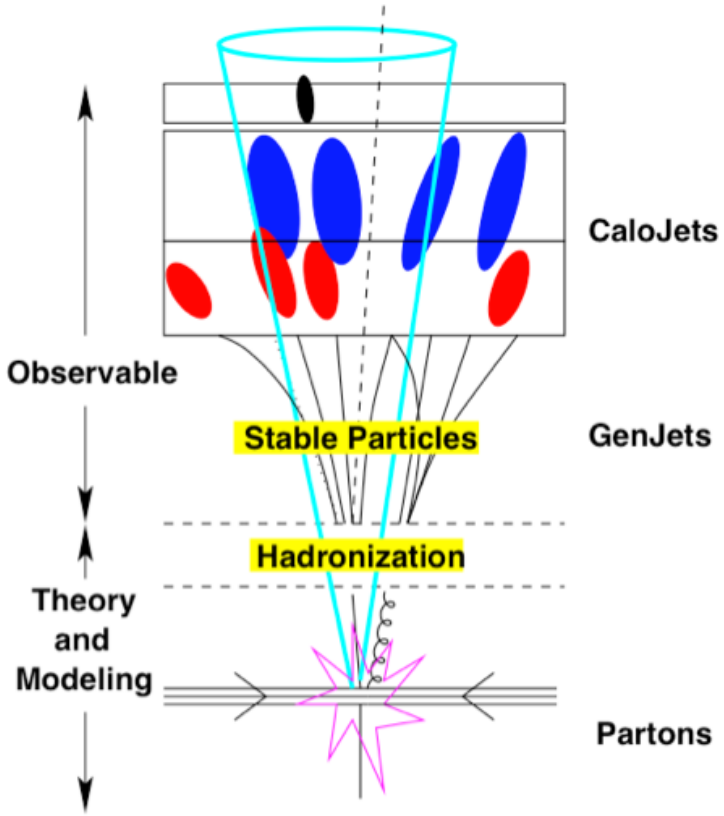
ATLAS-CONF-2011-041

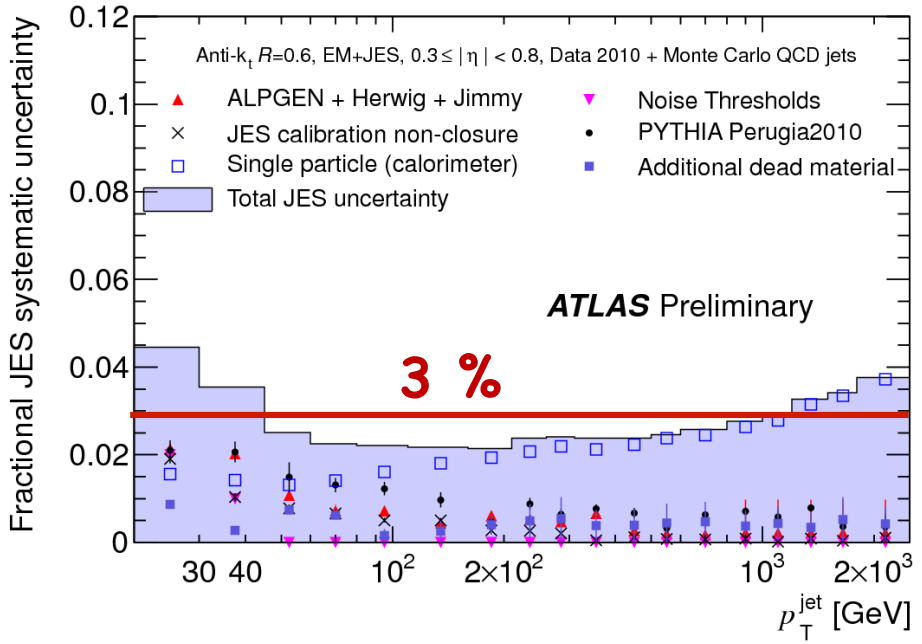


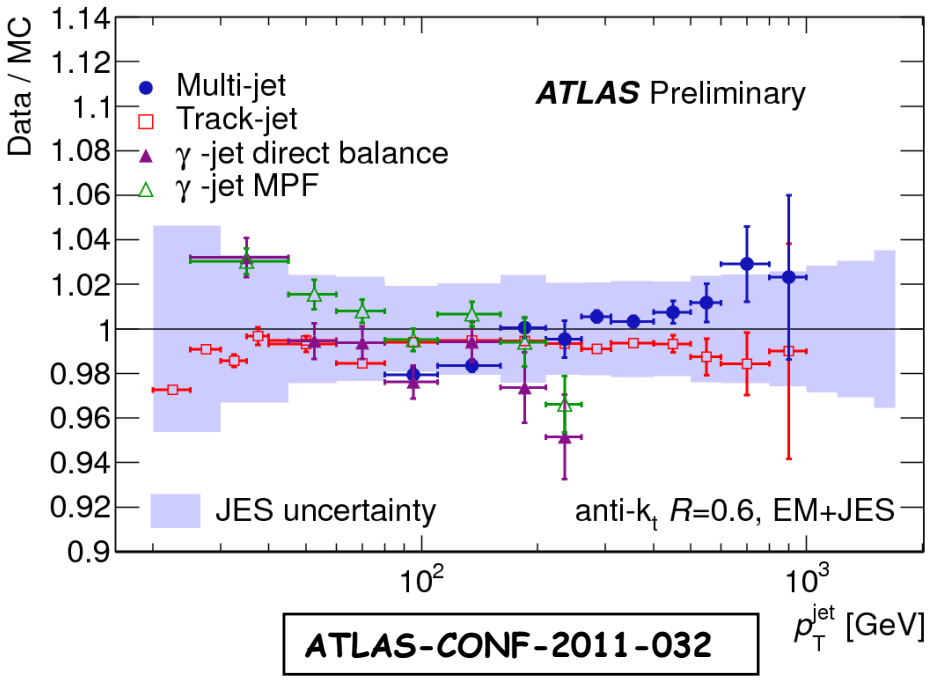
Jets

Highest-mass 2-jet event
in 2010 with mjj = 4.0 TeV
(p_T^1, y^1) = (510 GeV, -1.9)
(p_T^2, y^2) = (510 GeV, 2.2)

A considerable effort went into understanding the Jet Energy Scale (JES), the dominant source of uncertainties for most jet measurements







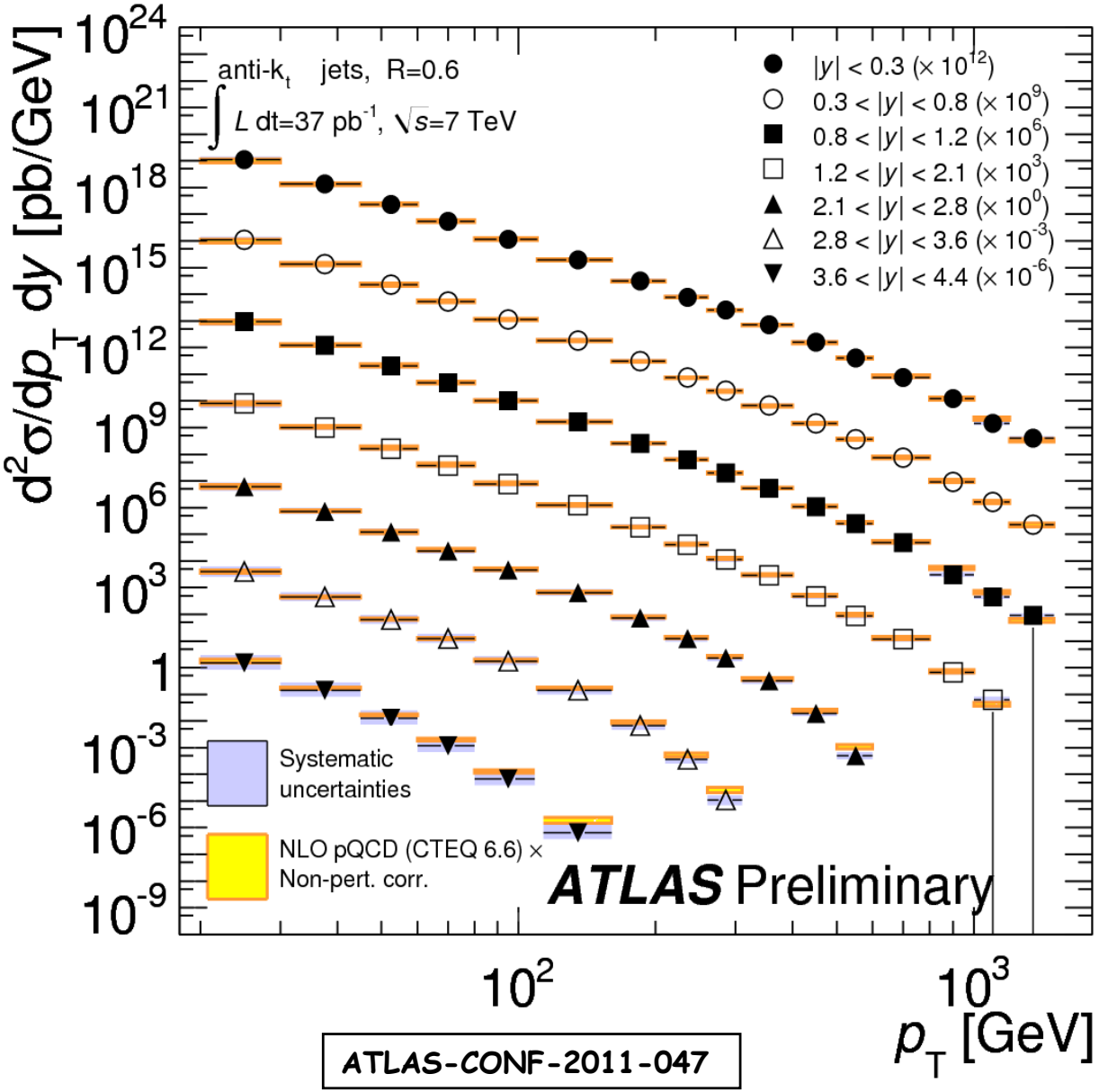
ATLAS-CONF-2011-032

Very detailed jet measurements are now available from LHC that can be compared with QCD calculations …

Inclusive jet cross sections in various rapidity intervals

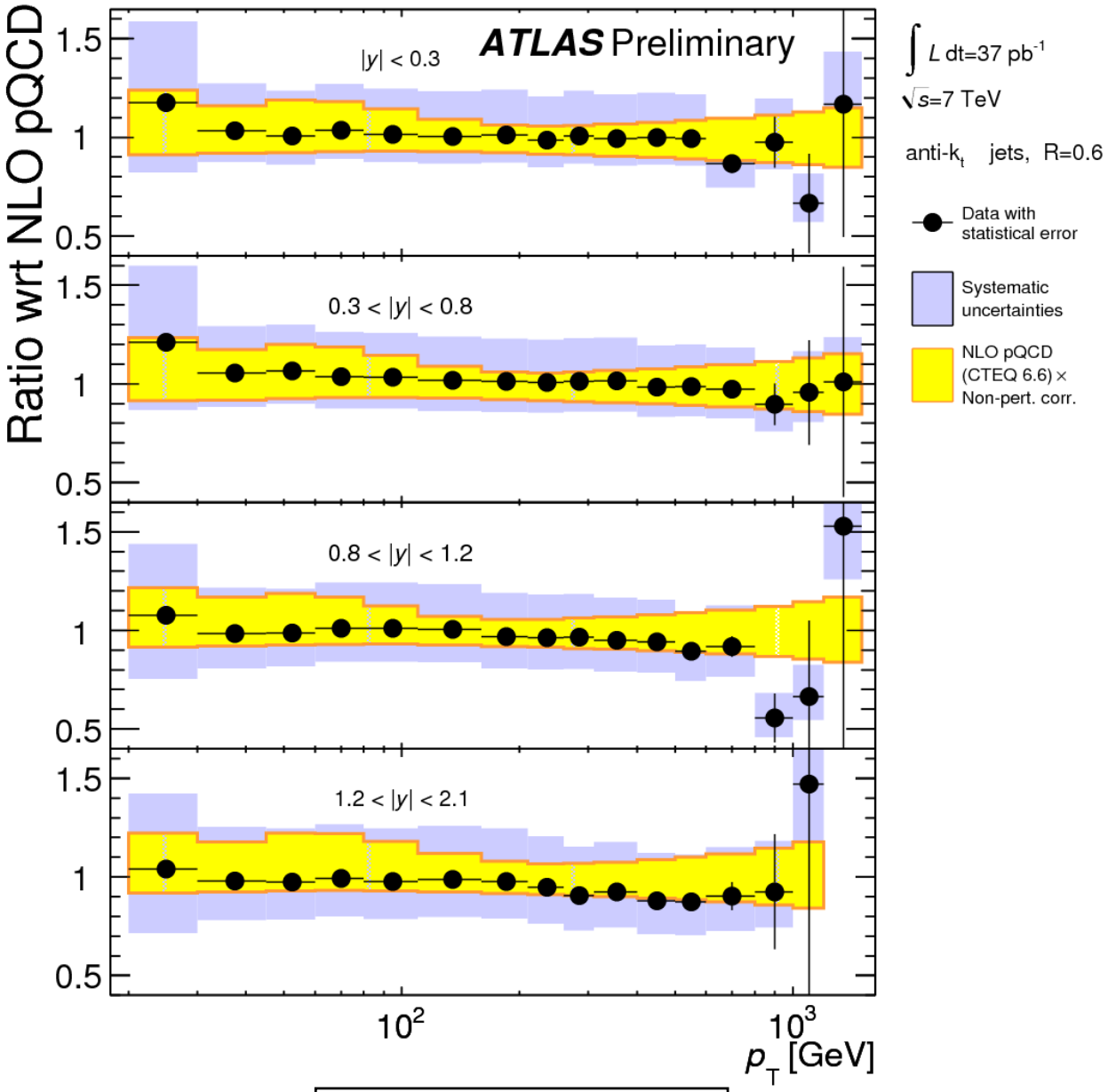
The data are spanning:

- 20 GeV < p_T < 1500 GeV
- IηI < 4.4
- Up to 12 orders of magnitudes in cross-sections



Systematic uncertainty dominated by JES

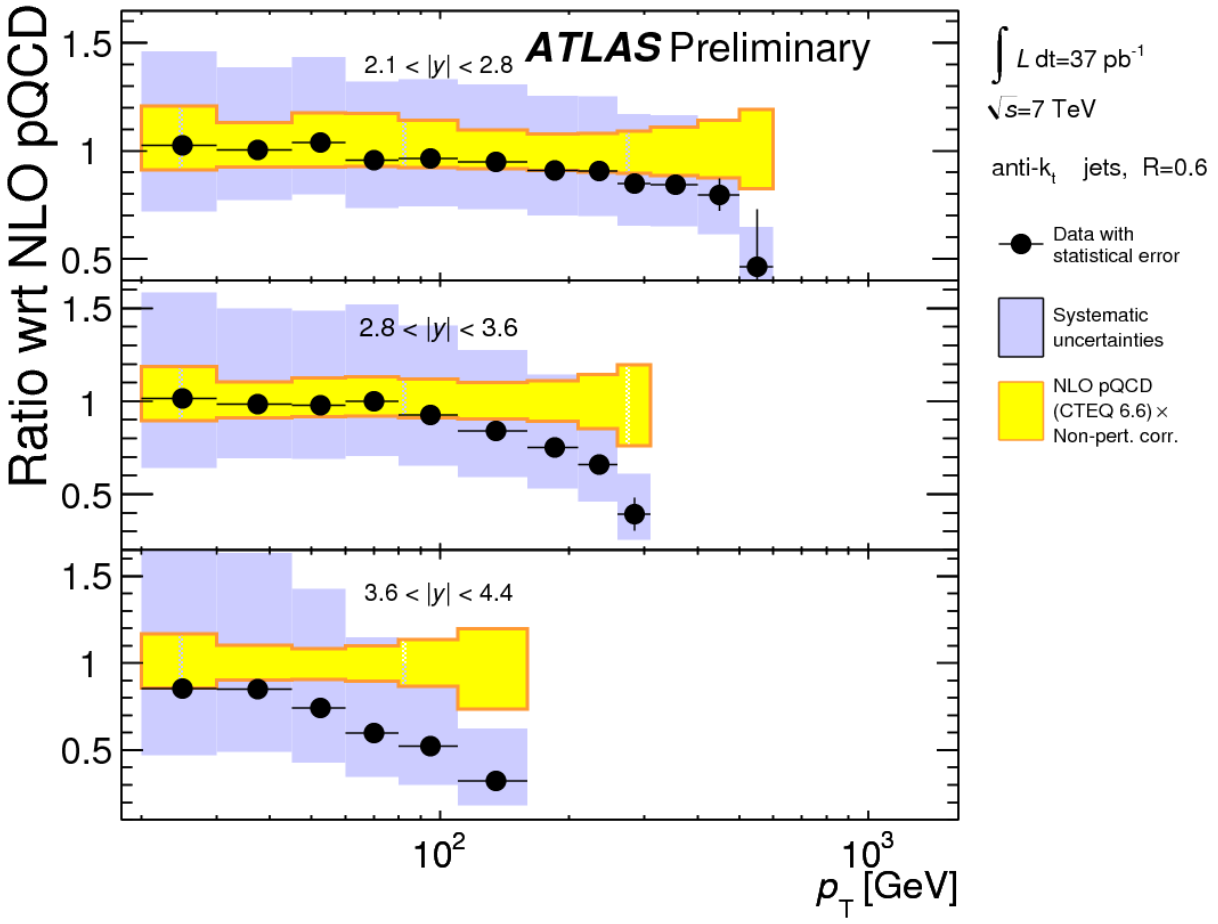
Good agreement between data and NLO pQCD with various PDFs globally…



ATLAS-CONF-2011-047

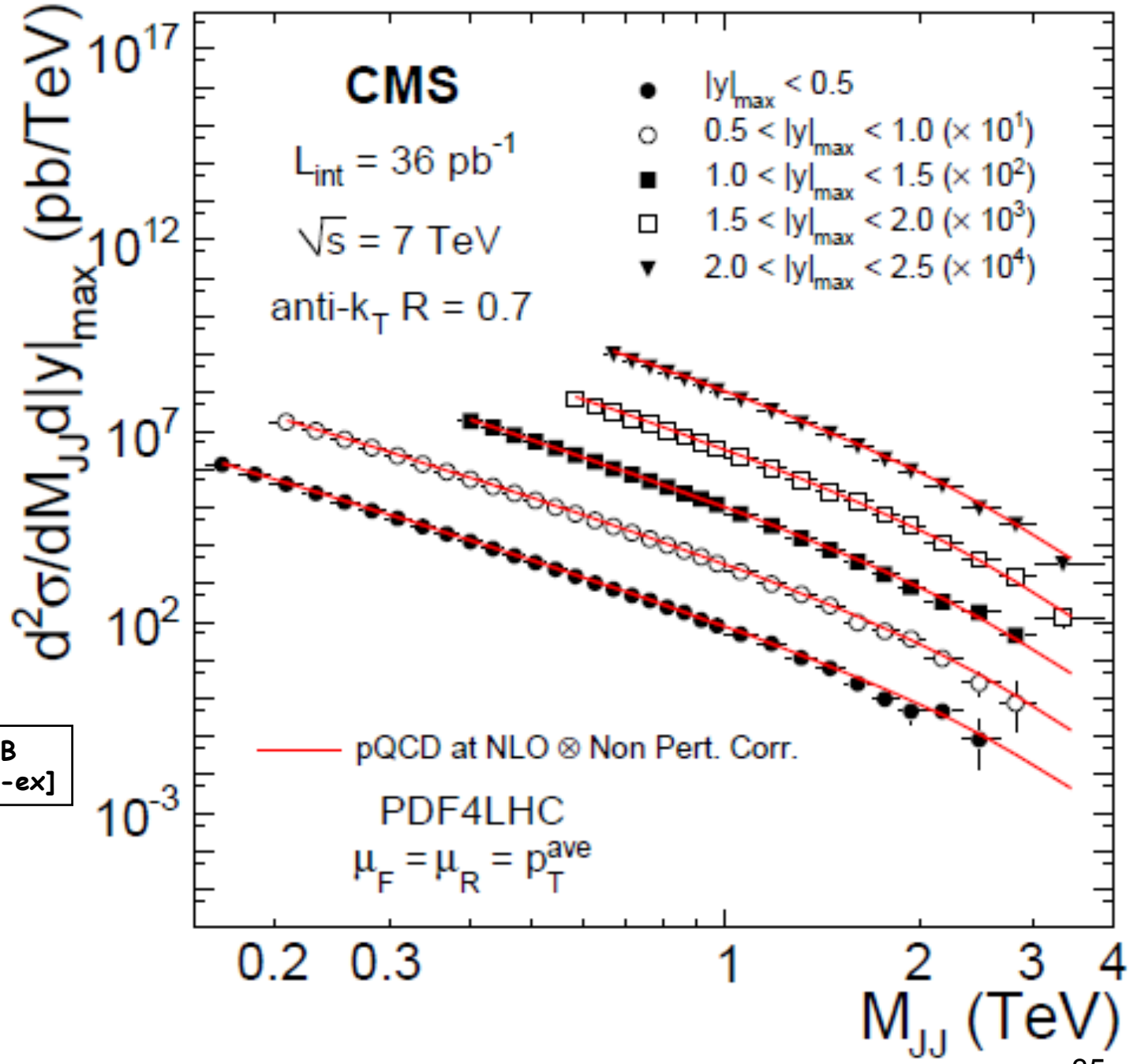
Systematic uncertainty dominated by JES

… except in some specific regions, for example in the forward directions



ATLAS-CONF-2011-047

Di-jet cross-sections in various rapidity intervals

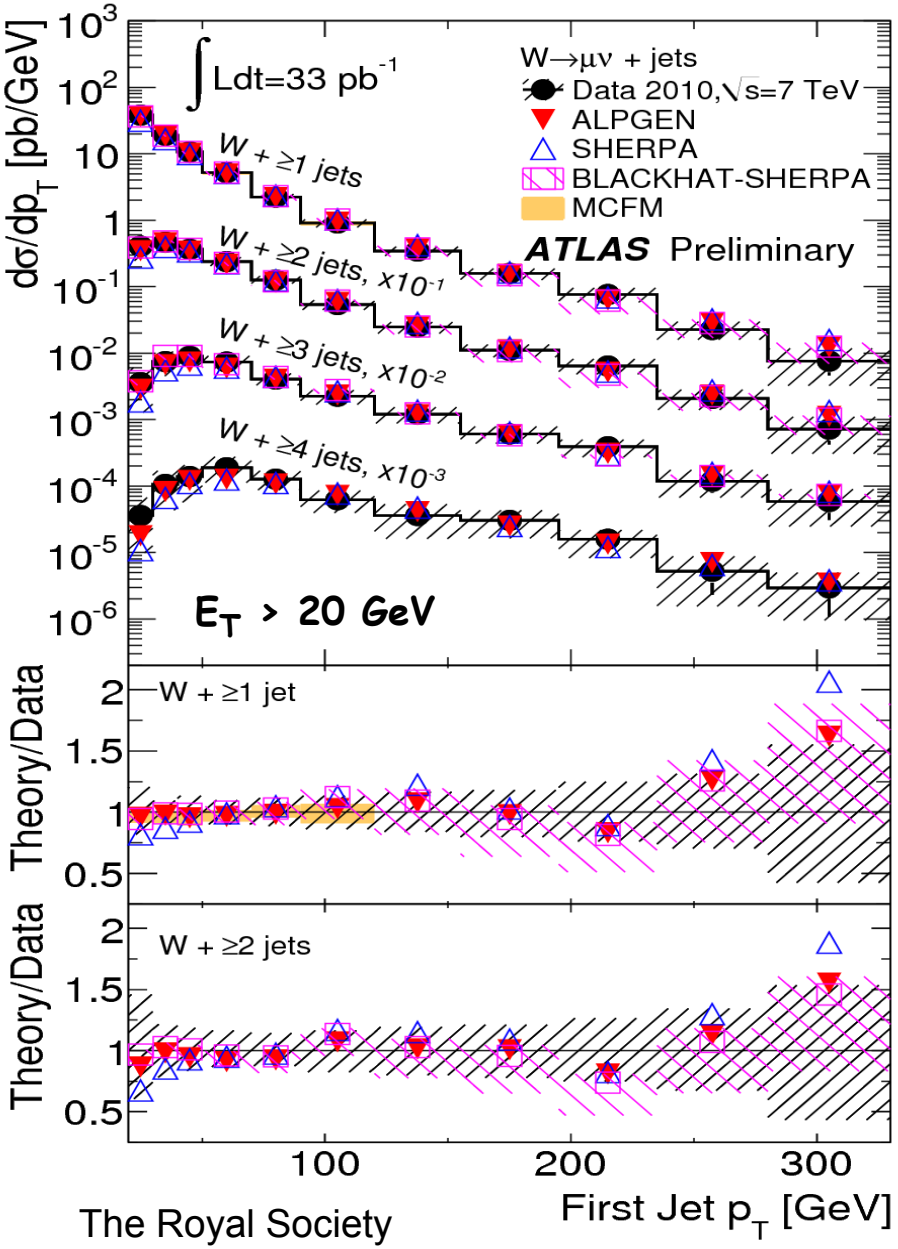


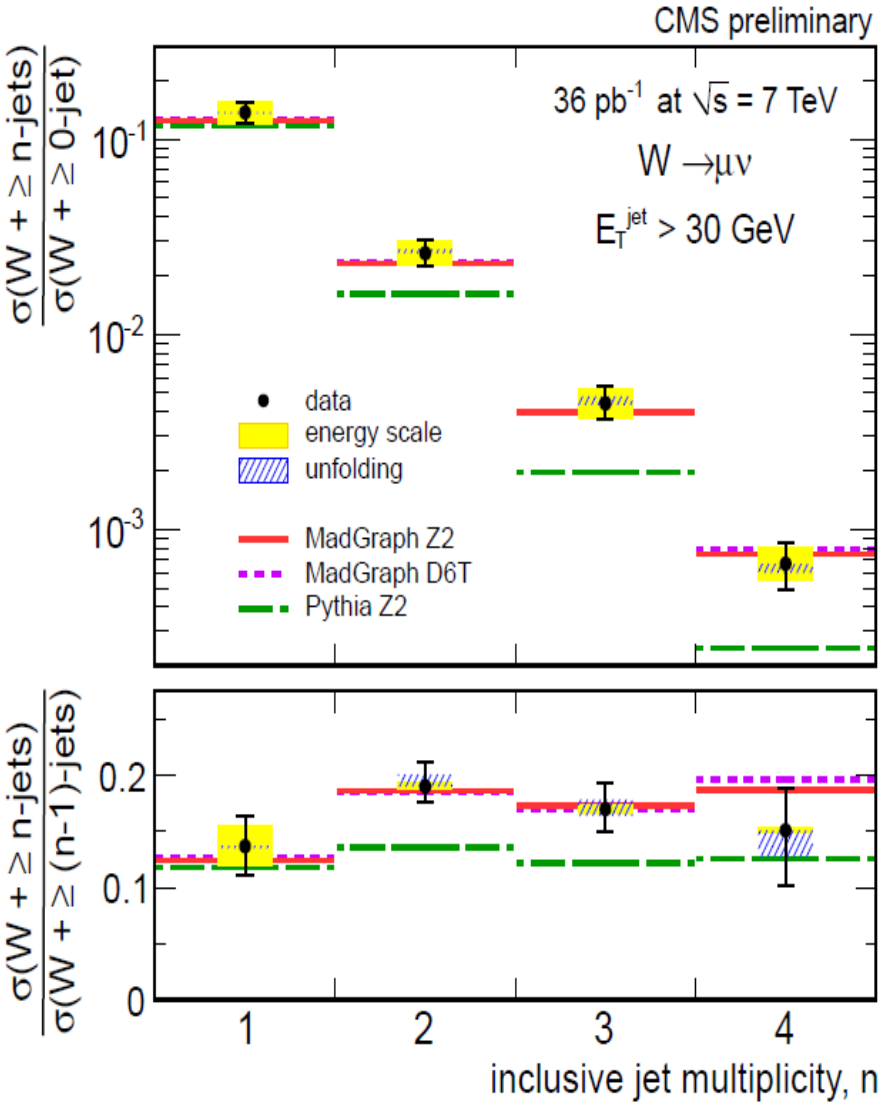
Sub. to Phys. Lett. B
arXiv:1104.1693v1[hep-ex]

W + jet(s) production

ATLAS-CONF-2011-060

Both an interesting QCD measurement as well as a dominat background to searches



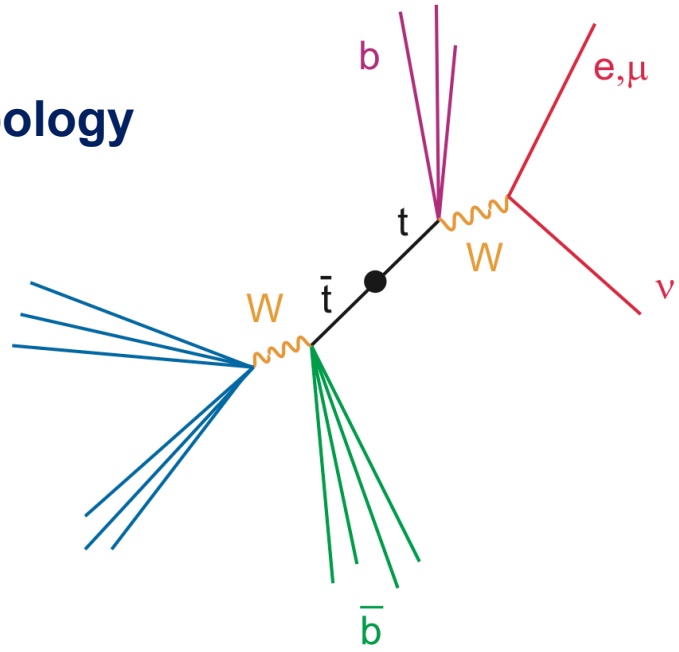


CMS PAS EWK 10-012

Early LHC measurements of the top cross section

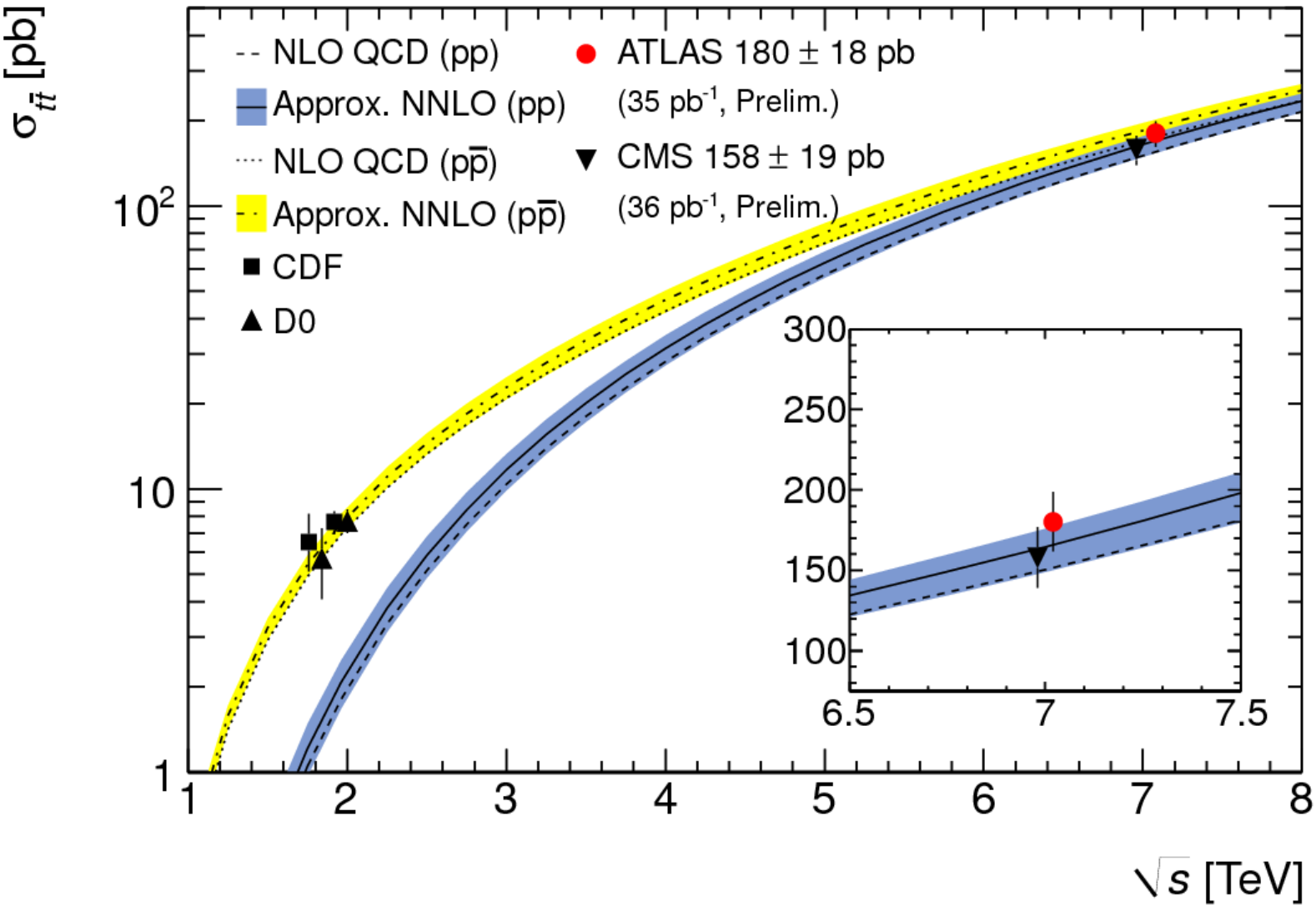
- **Complete set of ingredients to investigate production of ttbar, which is the next step in verifying the SM at the LHC:**
  - **e, μ, E_T^{miss}, jets, b-tag**

- **Assume all tops decay to Wb: event topology then depends on the W decays:**
  - **one lepton (e or μ), E_T^{miss}, jjbb (37.9%)**
  - **di-lepton (ee, μμ or eμ), E_T^{miss}, bb (6.46%)**



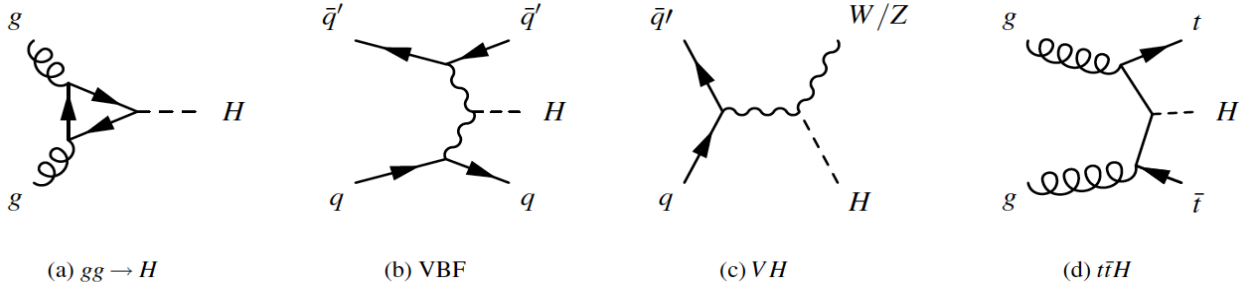
- **Data-driven methods to control QCD and W+jets backgrounds**

- **Counting experiment, with simultaneous likelihood fit to all channels to derive the combined cross section**

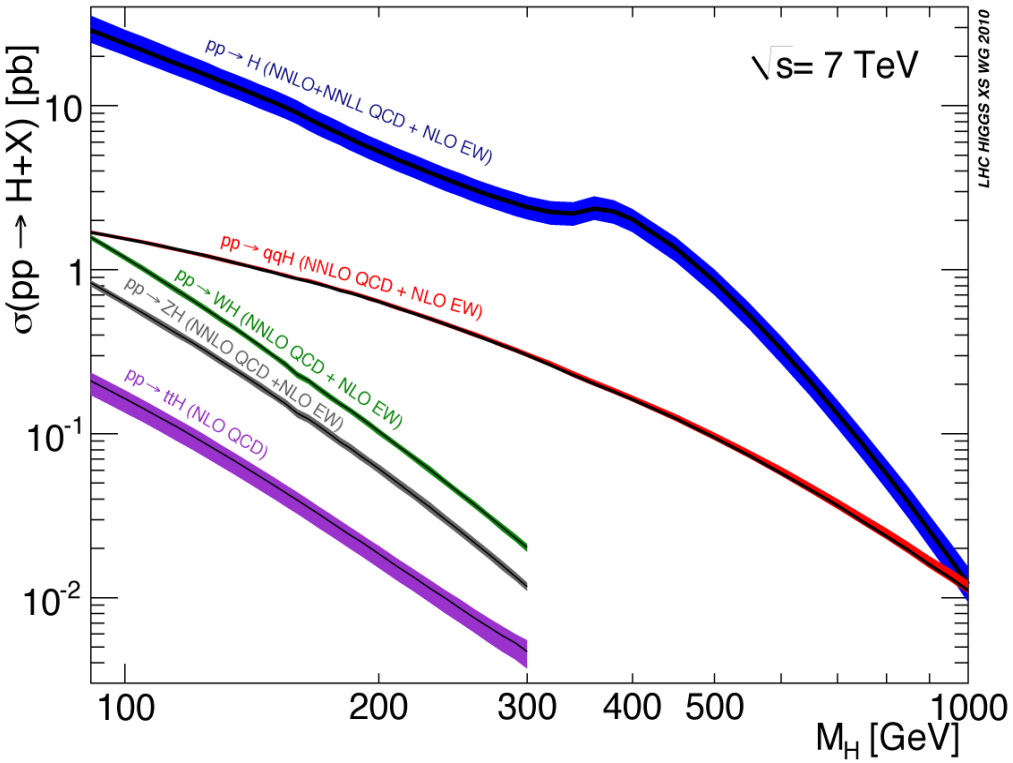


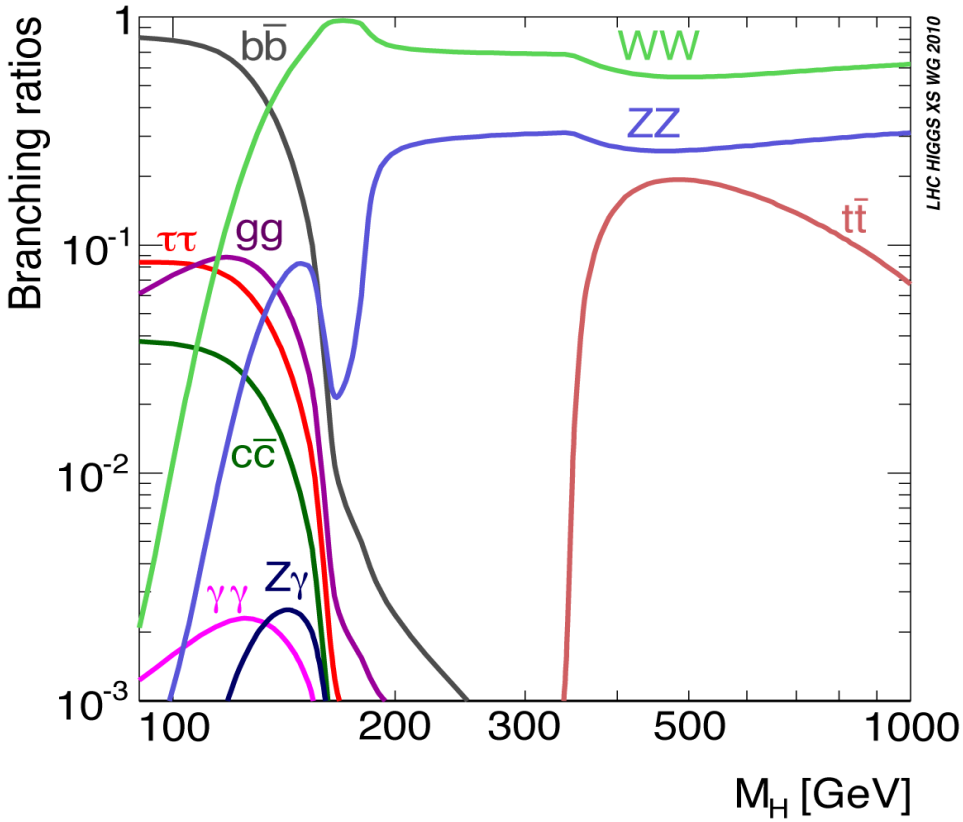
(ATLAS and CMS have also made first single top cross-section observations in agreement with NLO QCD expectations)

The Higgs Hunt at LHC



(a) $gg \to H$ (b) VBF (c) VH (d) $t\bar{t}H$



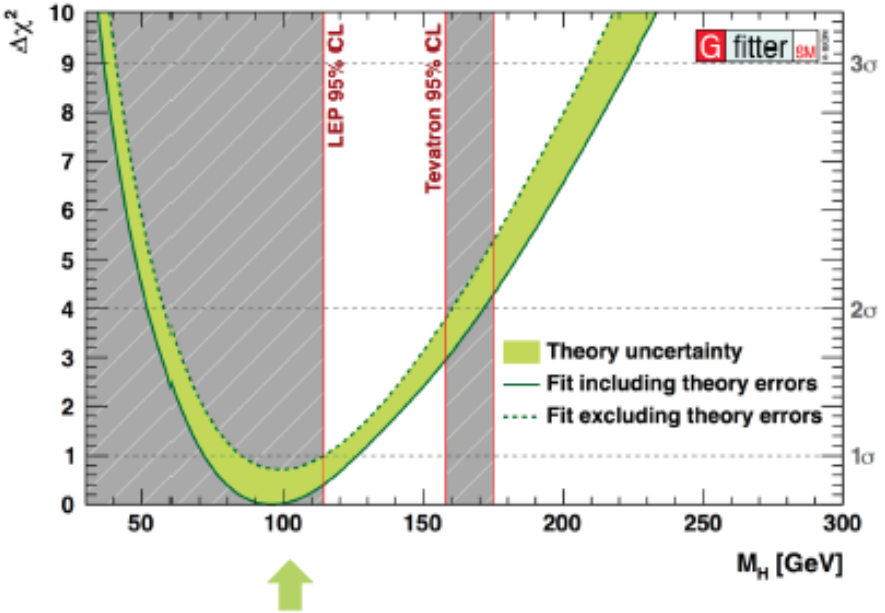


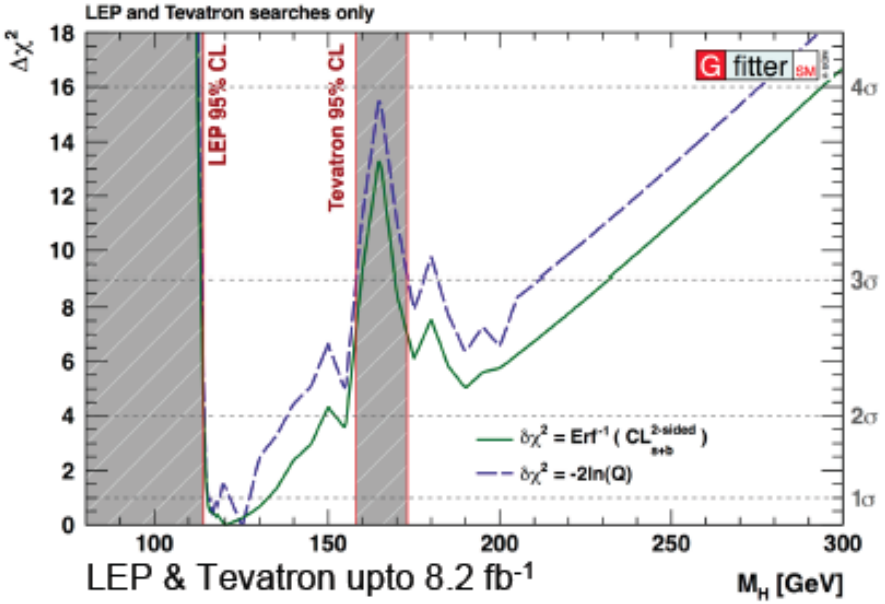
Status of Higgs boson searches without LHC data

Electroweak Fit – Tevatron Higgs Constraints

- M_H from fit w/o Higgs searches:
  - Central value ±1σ: $M_H = 95.7^{+30.3}_{-24.2}$ GeV
  - 2σ interval: [52,171] GeV

- Fit with LEP & latest Tevatron searches:
  - CL_{s+b} [2s] central value ±1σ: $M_H = 120.2^{+12.3}_{-4.7}$ GeV
  - 2σ interval:
    $CL_{s+b}^{2-sided}$: [114,149] ∪ [152,155] GeV
    $-2\ln Q$: [115,138] GeV



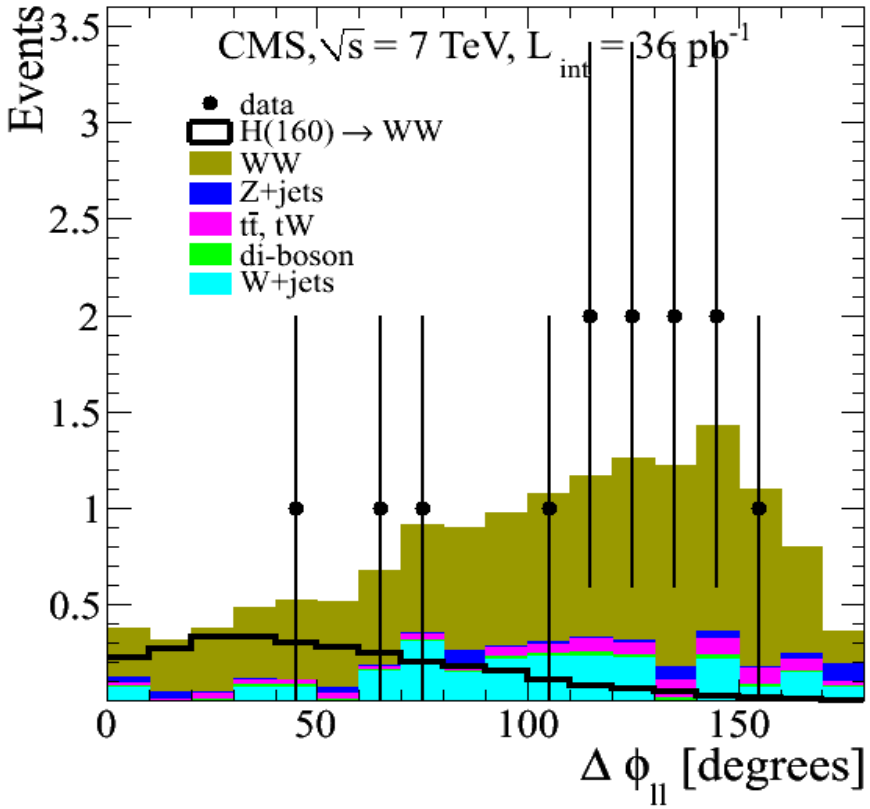


- Green error band from including / excluding theoretical errors in fit
  - Theoretical errors included in χ^2 with "flat likelihood term"

From Punzi, Blois 2011

First Higgs searches in the H → WW → lν lν channel (l = e, μ)

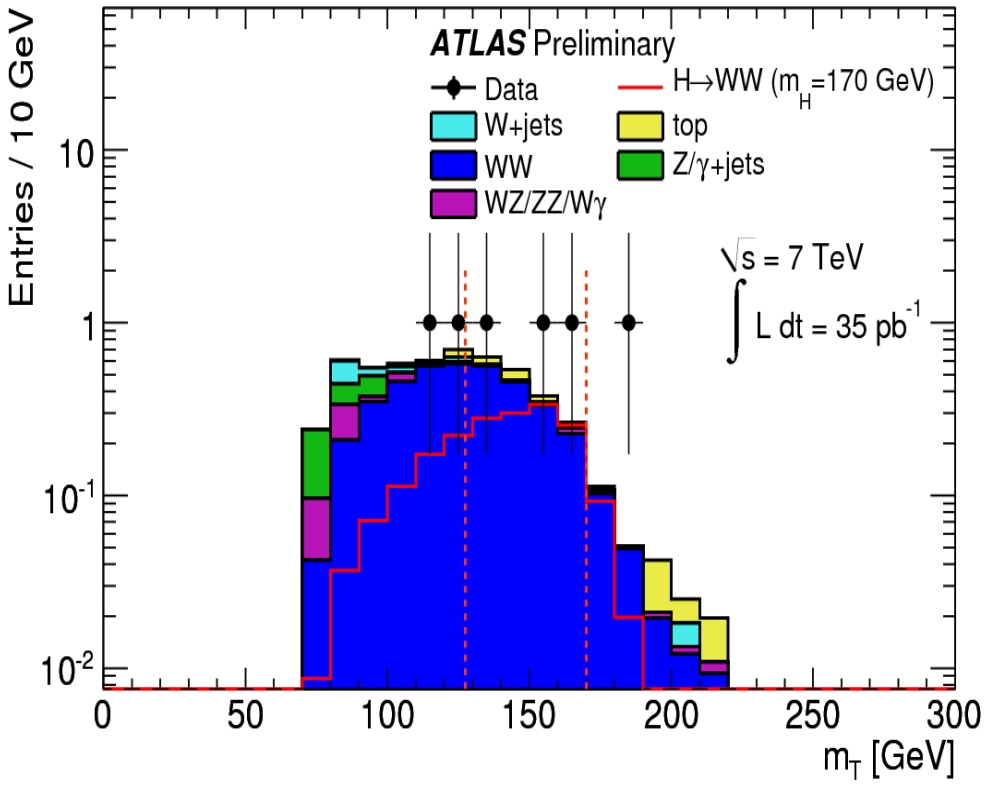
Azimuthal angular separation of the two selected leptons



Phys. Lett. B 699(2011)25

Transverse mass for H + 0 jet sample

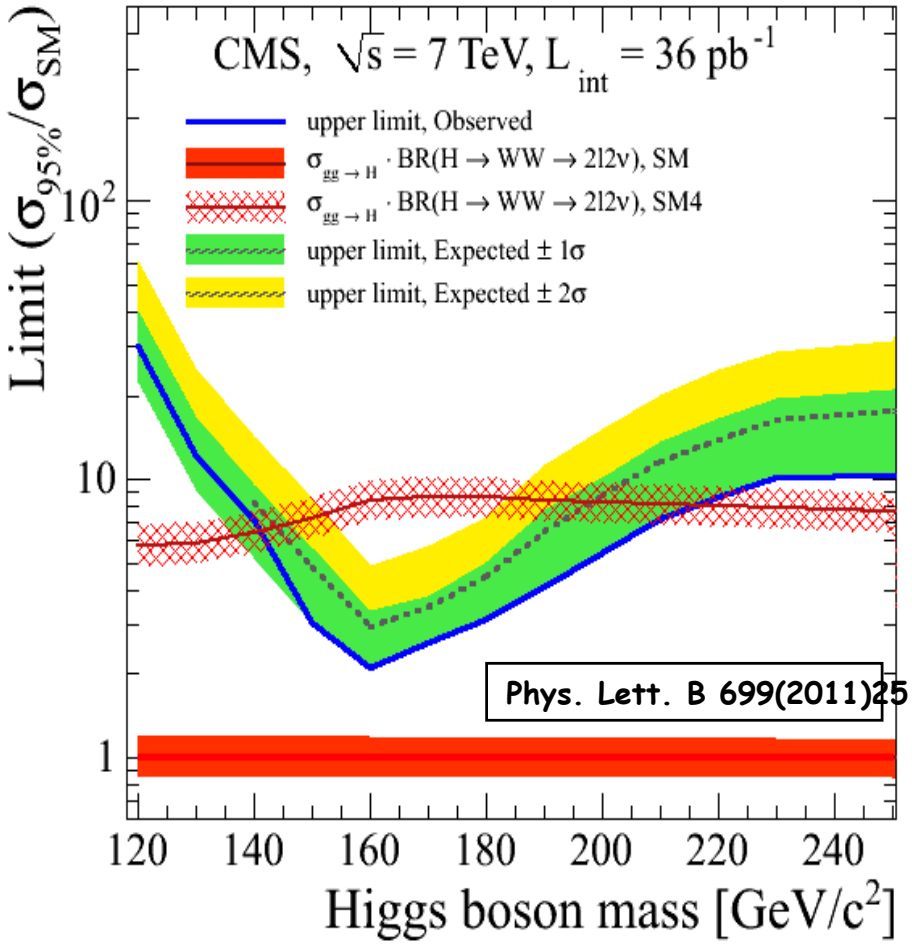
$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - (\mathbf{P}_T^{\ell\ell} + \mathbf{P}_T^{miss})^2}.$$

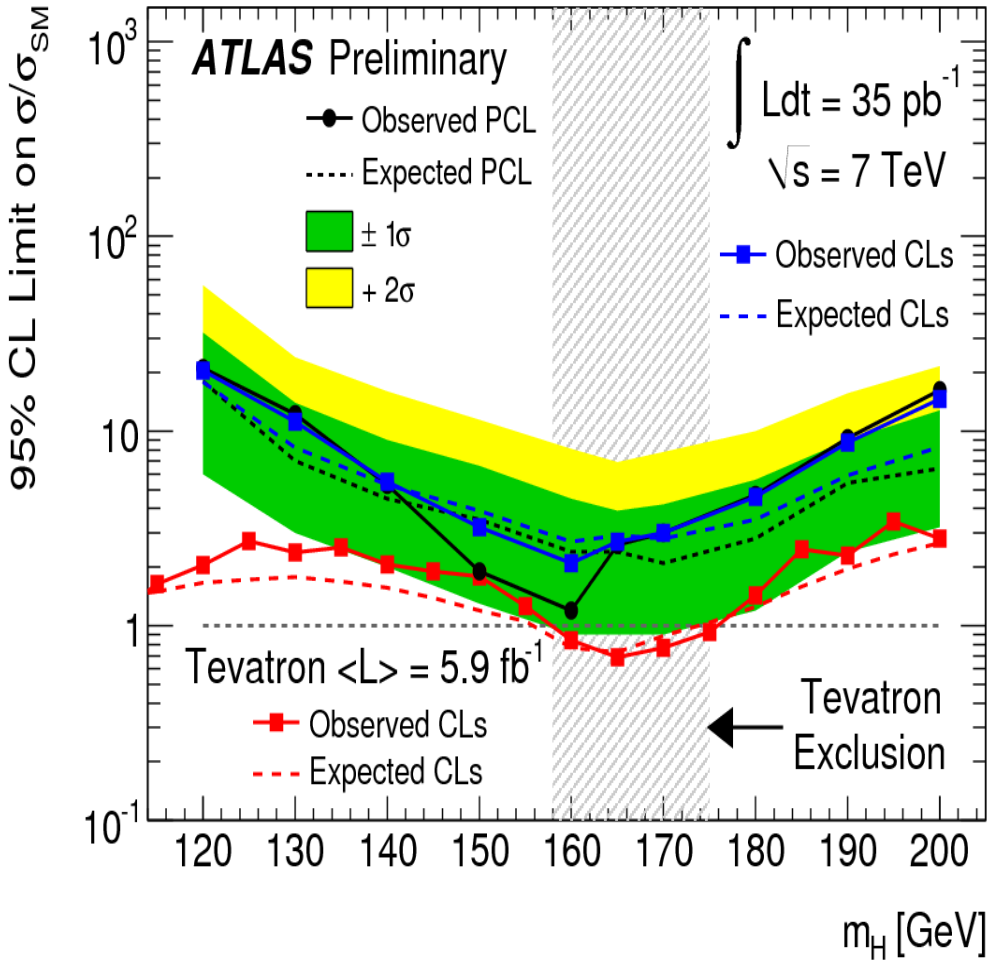


ATLAS-CONF-2011-005

ATLAS+CMS CERN SPC March 2011

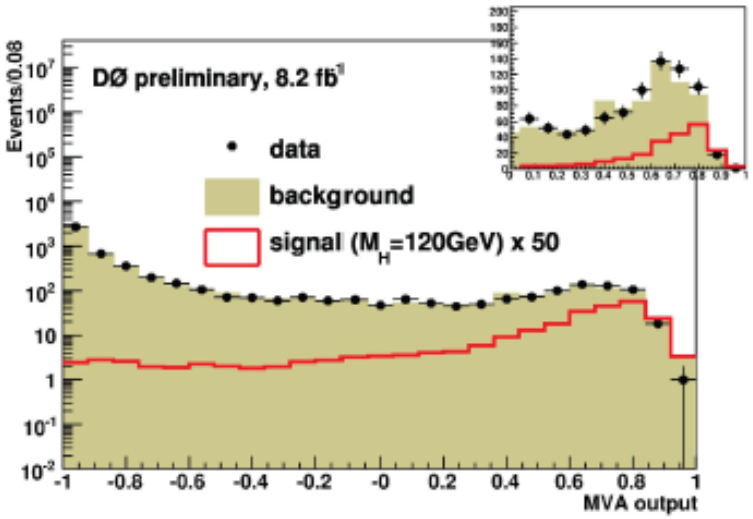
95 % CL Limit for M_H = 160 GeV	CMS Bayesian
Expected	3.0 x SM
Observed	2.1 x SM

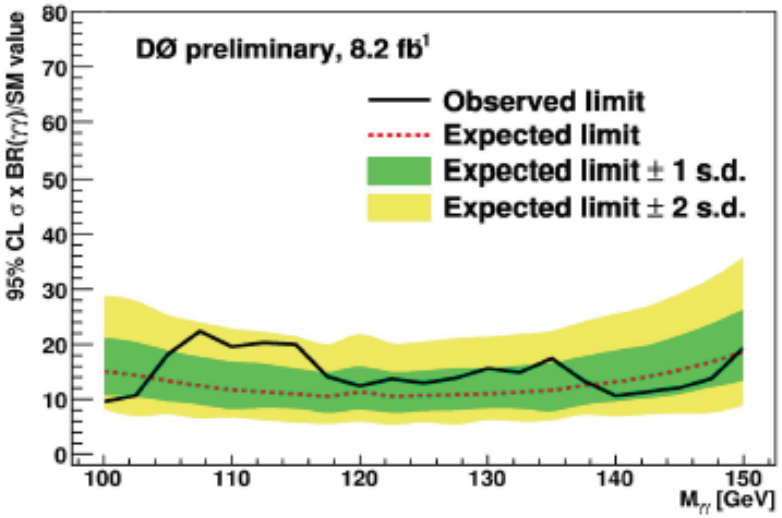


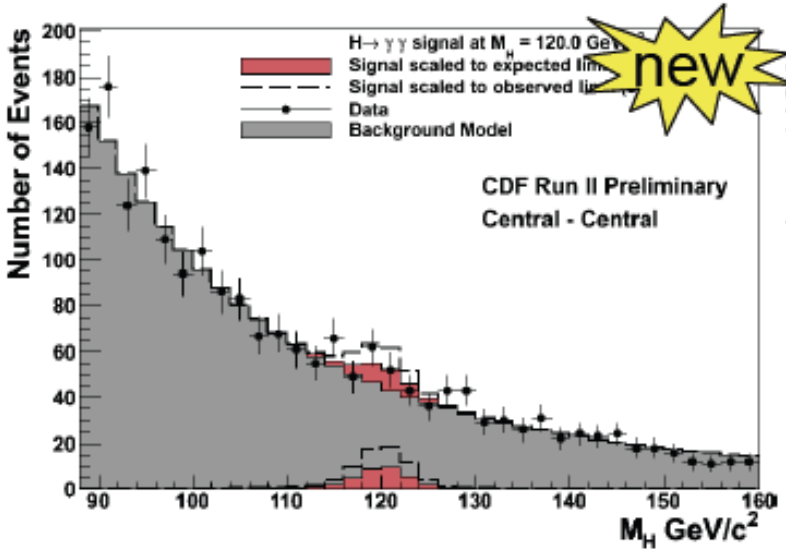


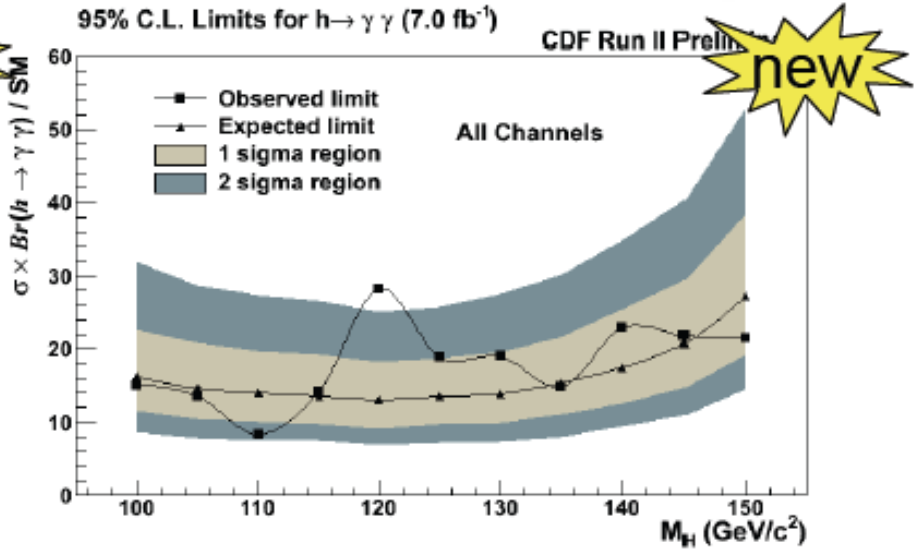
95 % CL Limit for M_H = 160GeV	ATLAS CL_S
Expected	2.7 x SM
Observed	2.1 x SM

Tevatron H→γγ searches



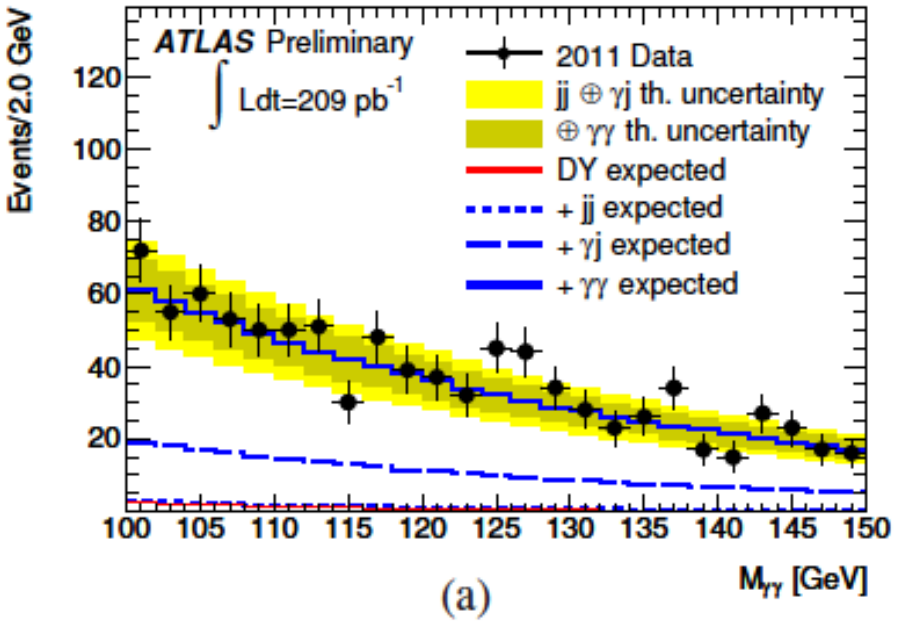


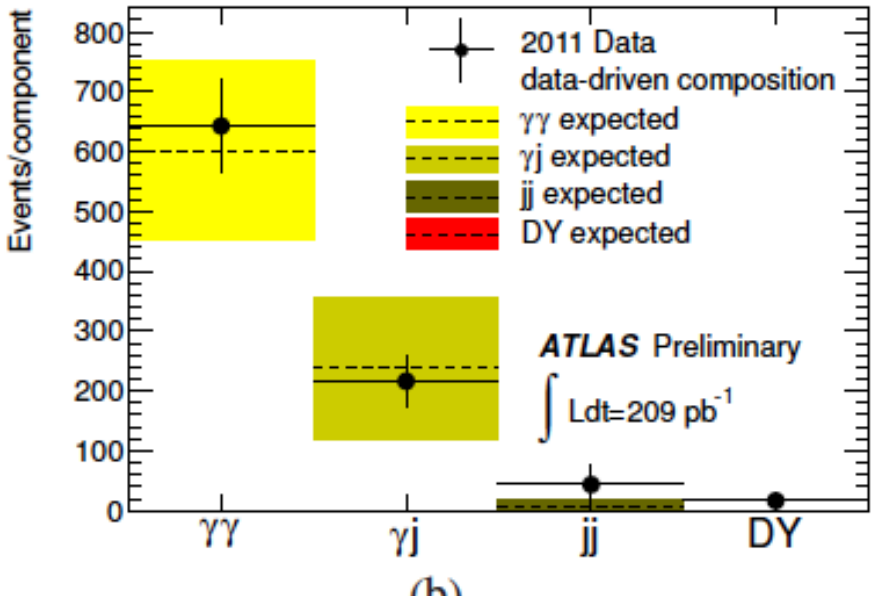


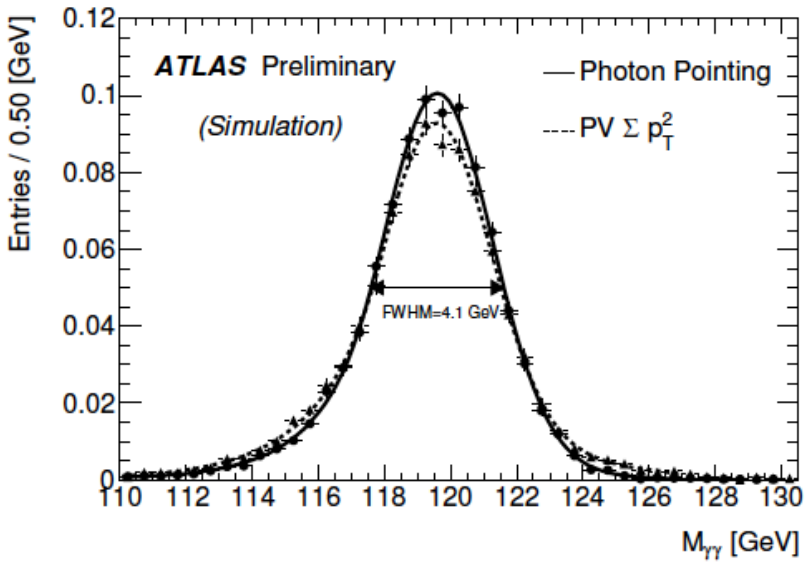


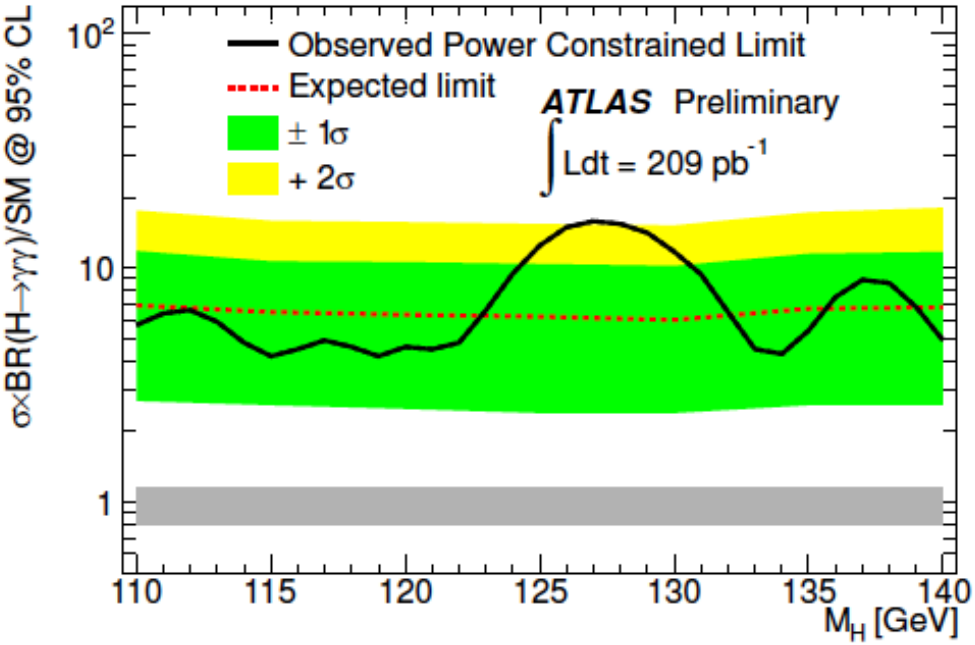
- New CDF results - no MVA yet
- Slight excess at 120GeV, but <2σ after trial factor

Higgs boson H→γγ @ ATLAS

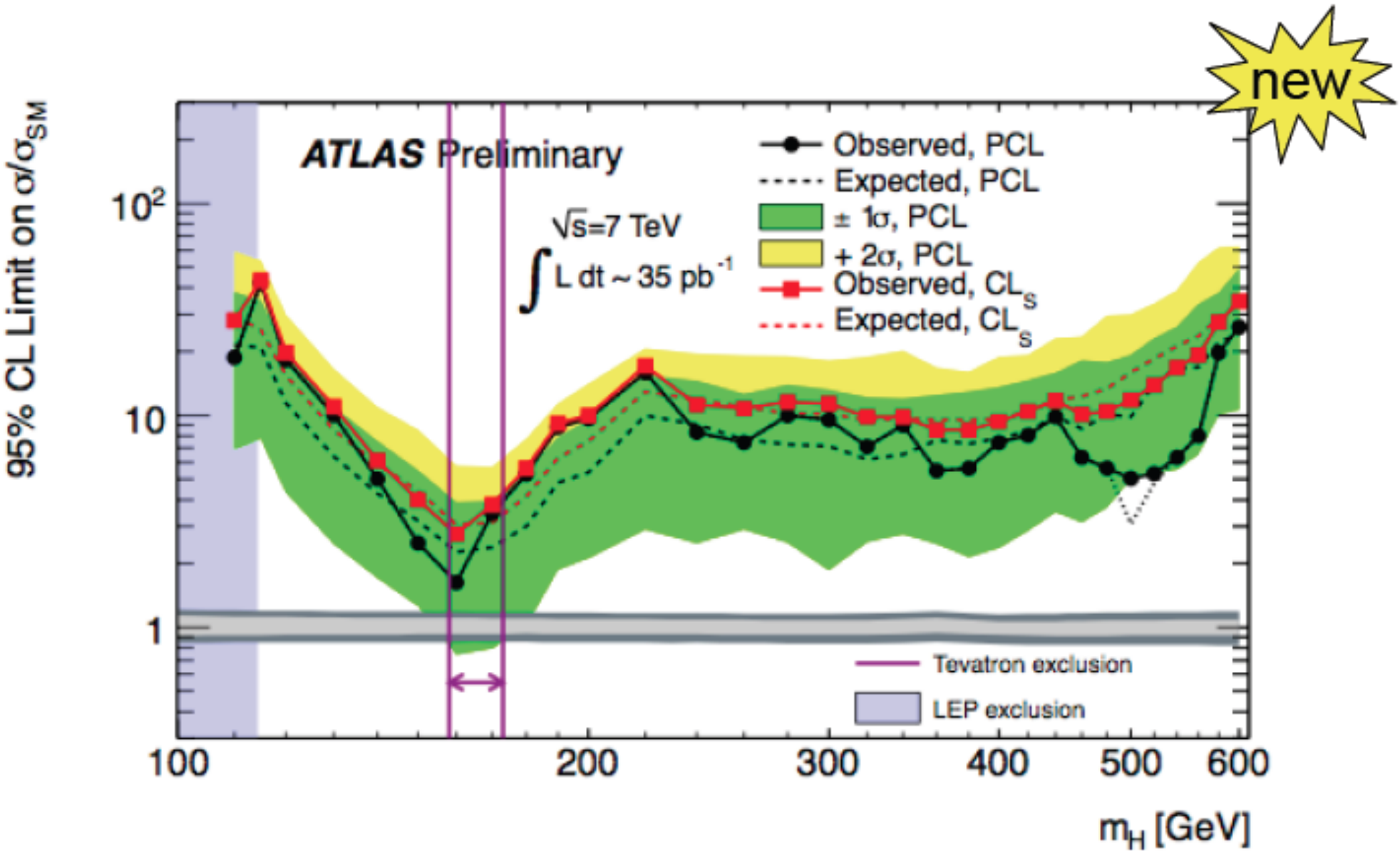






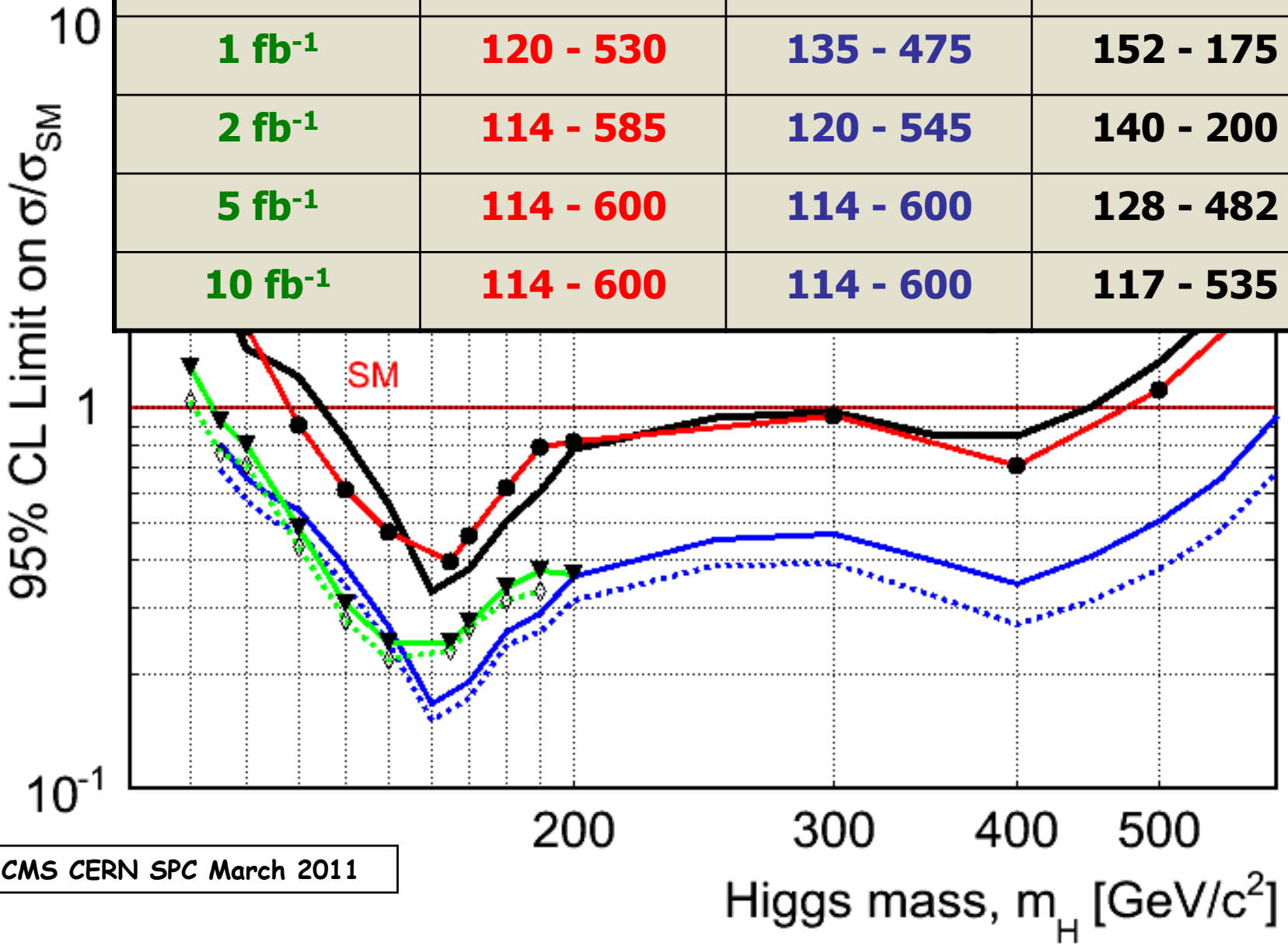


ATLAS combined limits



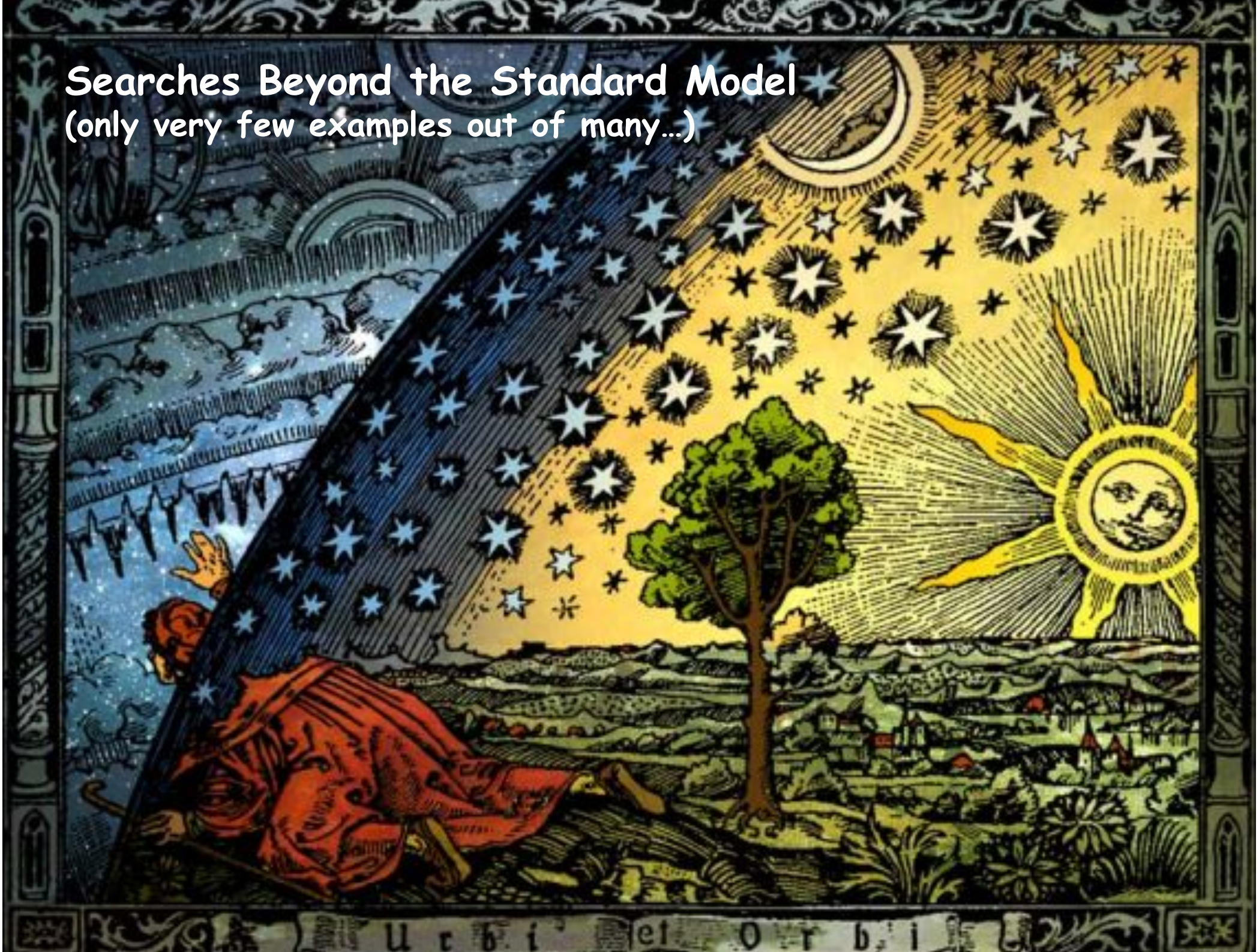
- Includes all dibosons + $\gamma\gamma$

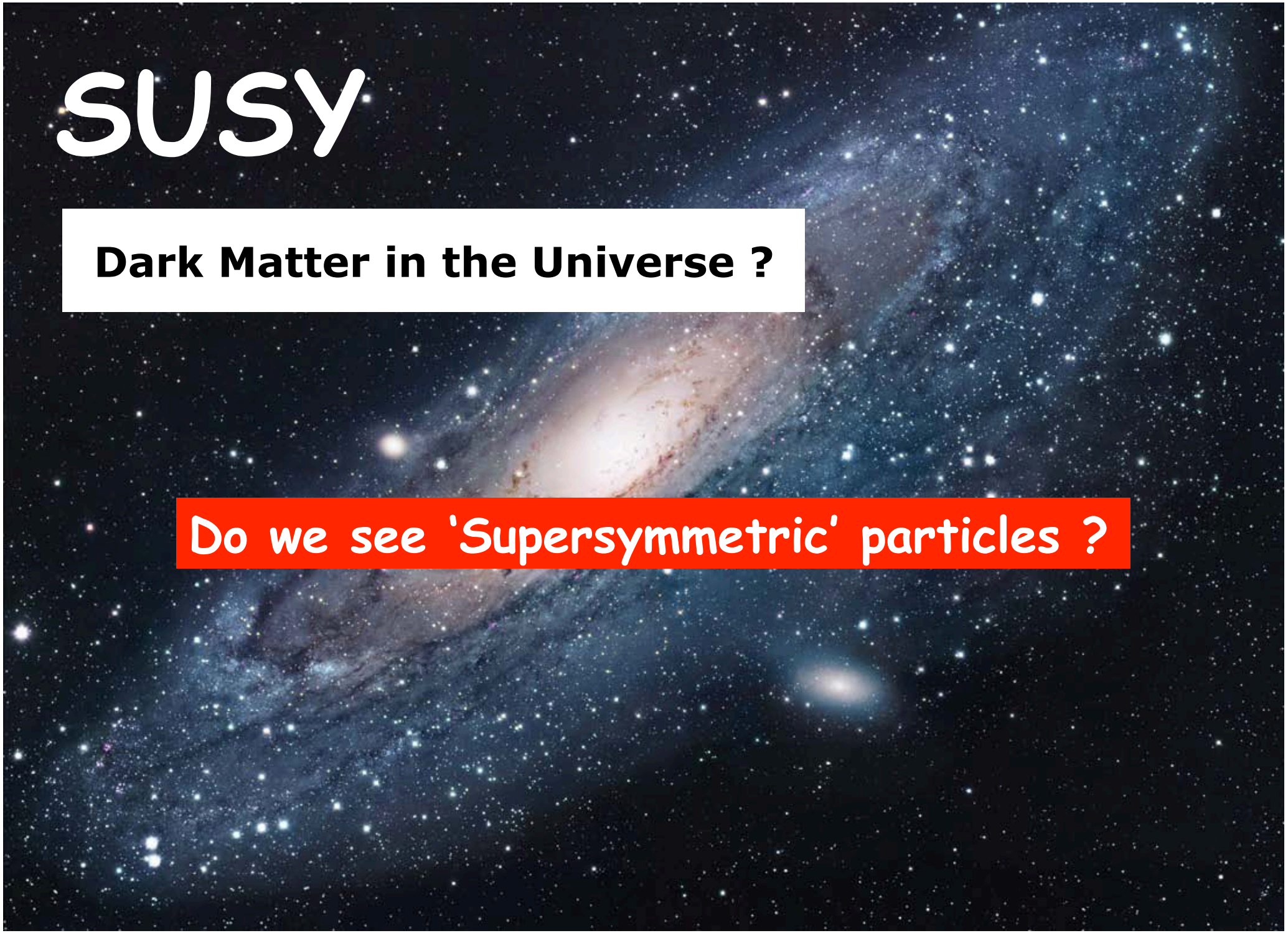
ATLAS+CMS 7 TeV	95% CL exclusion	3σ sensitivity	5σ sensitivity
1 fb^{-1}	120 - 530	135 - 475	152 - 175
2 fb^{-1}	114 - 585	120 - 545	140 - 200
5 fb^{-1}	114 - 600	114 - 600	128 - 482
10 fb^{-1}	114 - 600	114 - 600	117 - 535



ATLAS+CMS CERN SPC March 2011

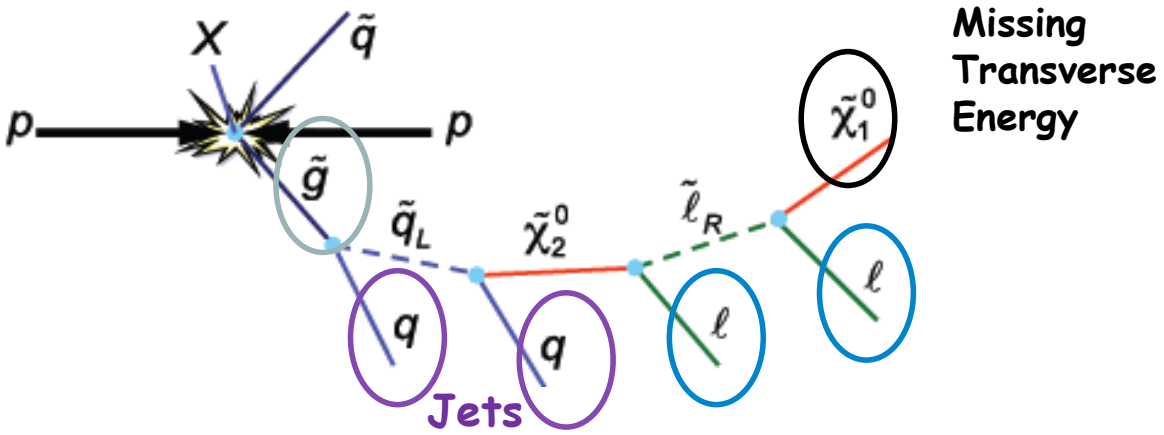
Searches Beyond the Standard Model
(only very few examples out of many…)




SUSY
Dark Matter in the Universe ?
Do we see 'Supersymmetric' particles ?

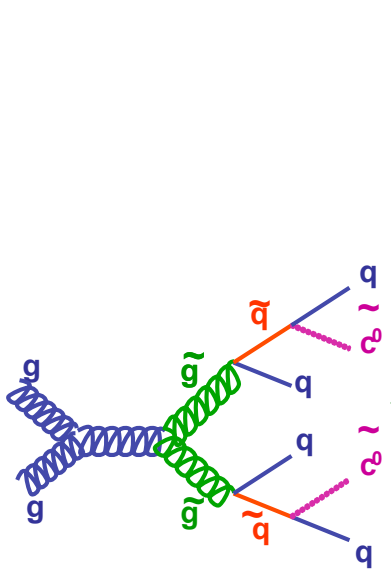
In practice the SUSY searches at LHC are rather complicated

- **Complex (and model-dependent) squark/gluino cascades**



- **Focus on signatures covering large classes of models while strongly rejecting SM background**
  - **large missing E_T**
  - **High transverse momentum jets**
  - **Leptons**
    - **Perform separate analyses with and without lepton veto (0-lepton / 1-lepton / 2-leptons)**
  - **B-jets: to enhance sensitivity to third generation squarks**

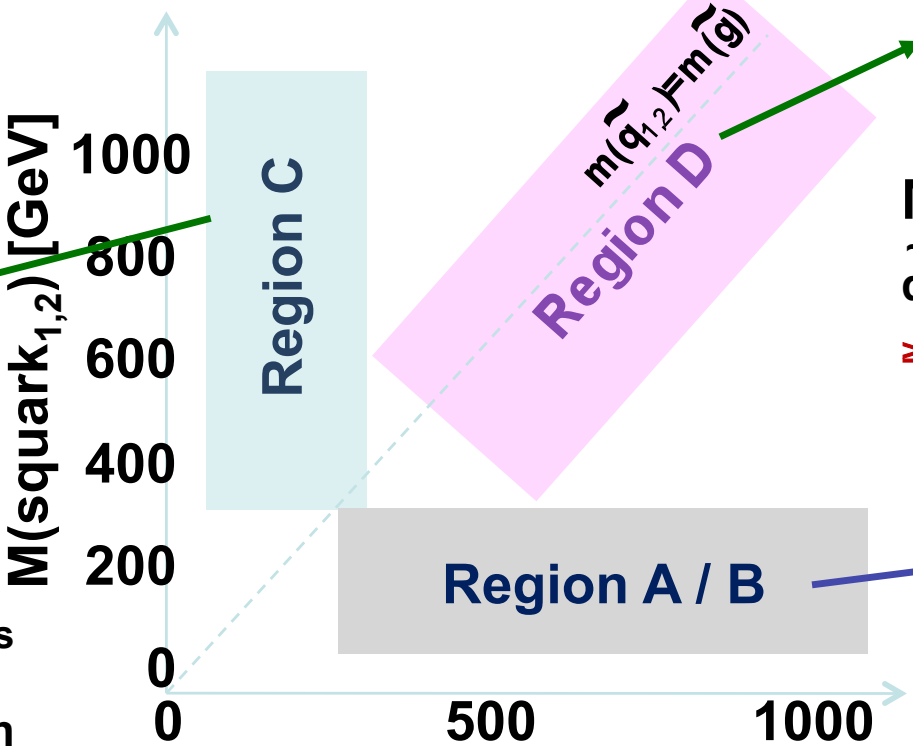
Signal regions sensitivity

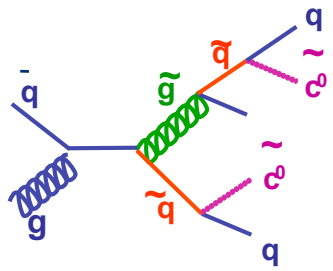


$M_{\tilde{q}} > M_{\tilde{g}}$

$\tilde{g}\tilde{g}$ production dominates

≥4 jets expected, 1 can be soft, selection in m_{eff}

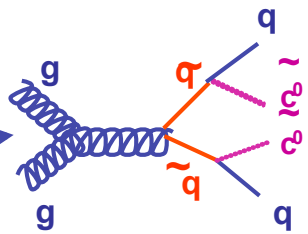




$M_{\tilde{q}} \sim M_{\tilde{g}}$

qg production dominates

≥ 3 jets expected, high m_{eff}



$M_{\tilde{q}} < M_{\tilde{g}}$

$\tilde{q}\tilde{q}$ production dominates

≥ 2 jets expected

m_{eff} or m_{T2} selection

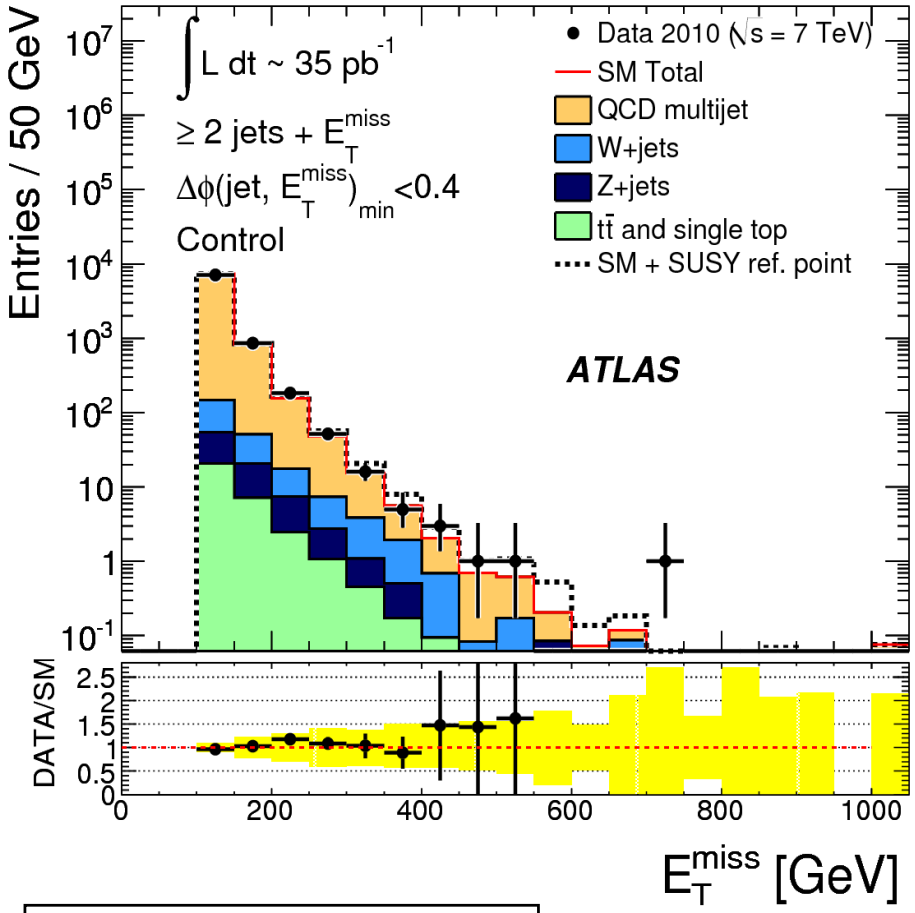
→ for high(B) / low(A) masses

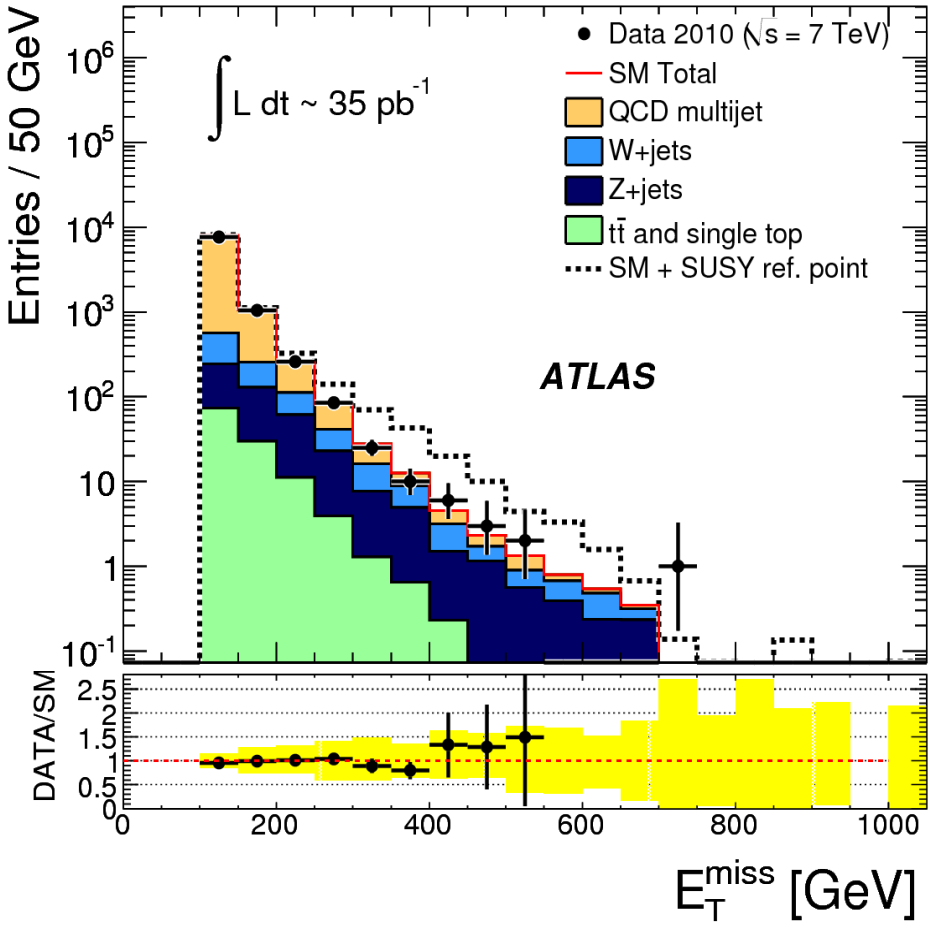
→ exploit dependence in DM($q_{1,2}$-c_0^1)

m_{eff} scalar sum pT

m_{T2} transverse mass variable

Examples of data in a background control region (enhanced with QCD multi-jet backgrounds) and in a signal region





Sub. to Phys. Lett. B
arXiv:1102.5290[hep-ex]

No significant signal excess observed so far...

Interpretation of the results (I)

A sophisticated likelihood method is used that includes correlations of uncertainties where appropriate

→ Estimate upper limits at 95% C.L. on N signal events and effective cross sections independently of new physics models (background-only hypothesis)

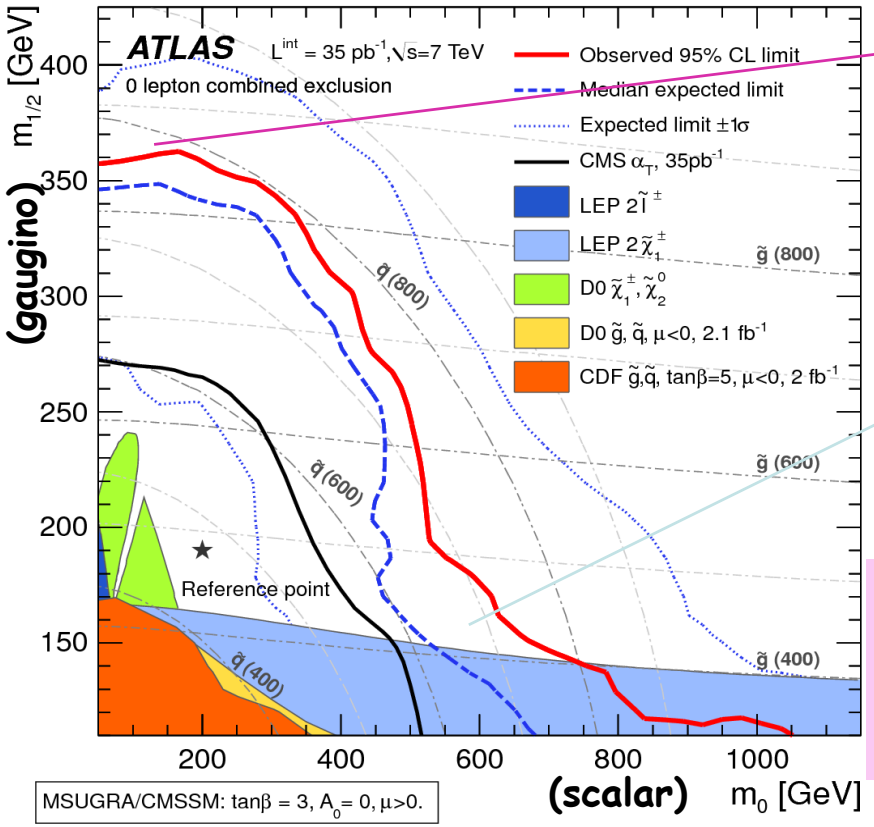
Exclude non-SM: N events 43.9 (A), 11.9 (B), 37.6 (C), 3.5 (D)
σ (pb) of 1.3 (A), 0.35(B), 1.1 (C), 0.1 (D)

Translate results in limits on MSUGRA/CMSSM (m_0, $m_{1/2}$)-plane

parameters at GUT scale
1. Unified gaugino(scalar) mass $m_{1/2}(m_0)$
3. Ratio of H_1, H_2 vevs tanβ
4. Trilinear coupling A_0
5. Higgs mass term sgn(μ)

Theoretical uncertainties on SUSY NLO cross sections included in limit calculation

Sub. to Phys. Lett. B
arXiv:1102.5290[hep-ex]



Best sensitivity
Region D
(3j, m_{eff} > 1 TeV)

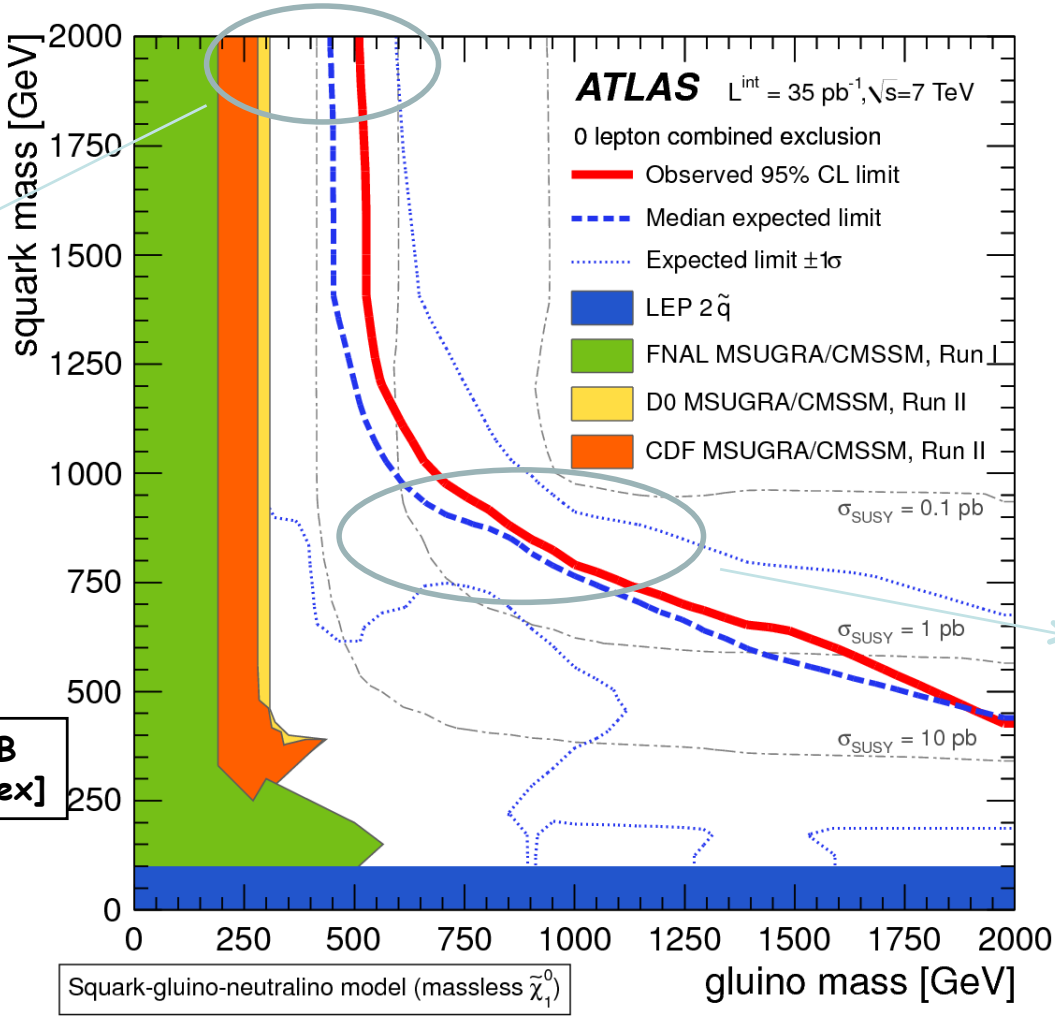
Best sensitivity
Region C
(3j, m_{eff} > 500 GeV)

If $m_{squark} = m_{gluino}$ exclude < 775 GeV at 95% CL

Interpretation of the results (II)

Consider phenomenological MSSM models containing only squarks of 1st and 2nd generation, gluino and massless neutralinos

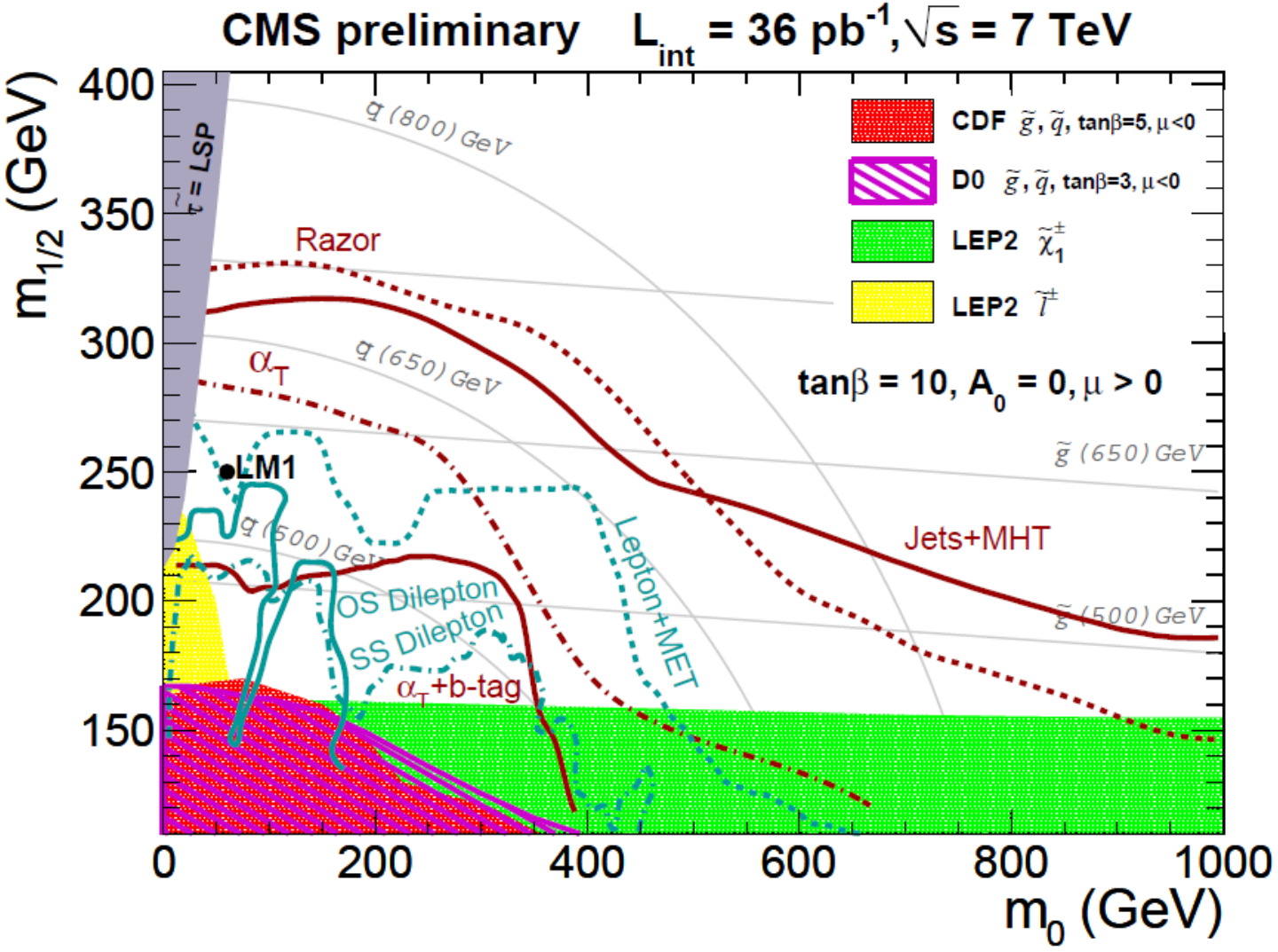
excluded gluino mass below 500 GeV



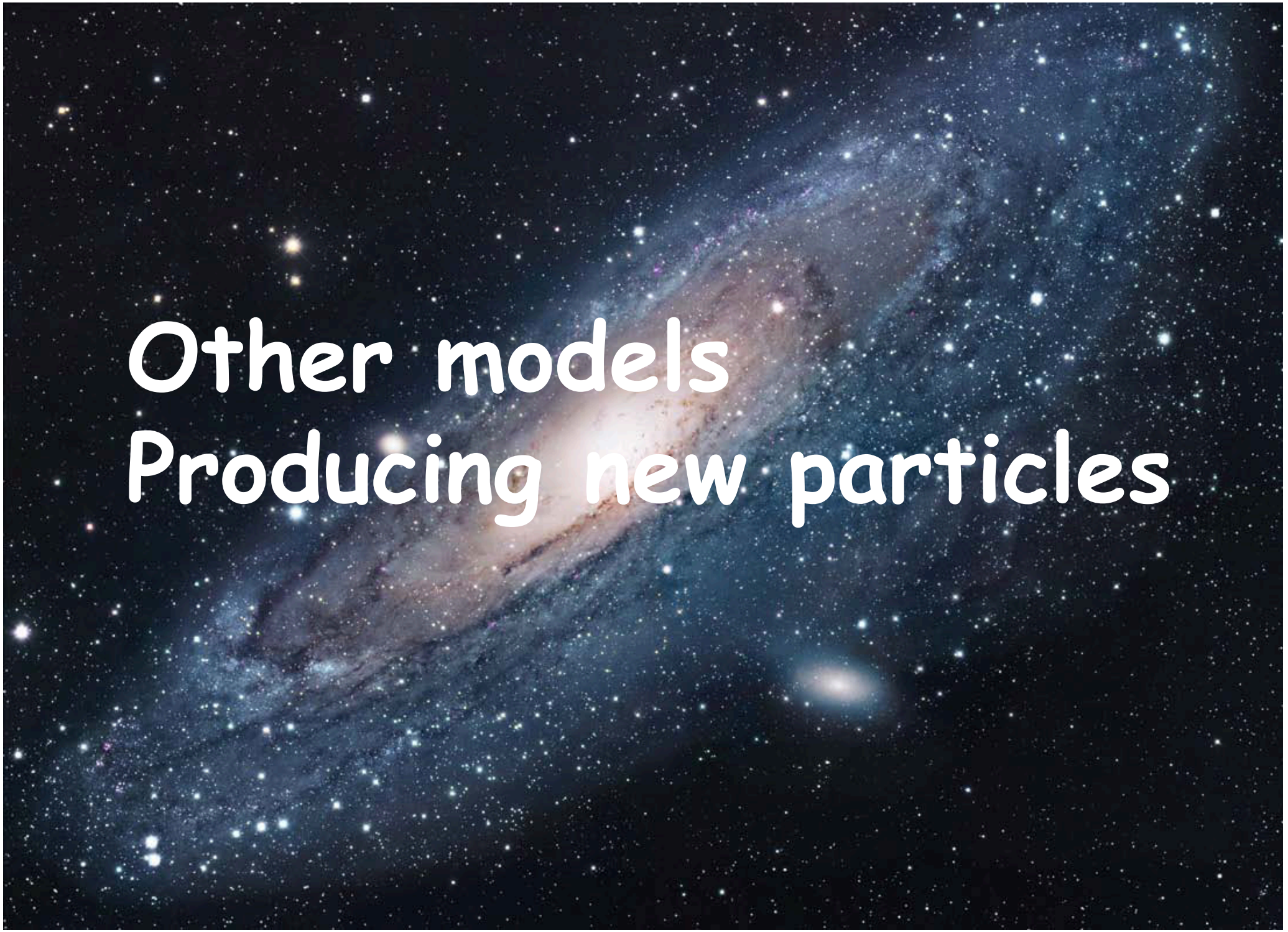
Sub. to Phys. Lett. B
arXiv:1102.5290[hep-ex]

If $m_{squark} = m_{gluino}$ exclude < 870 GeV

Combined limits from several CMS SUSY searches for the 2010 data



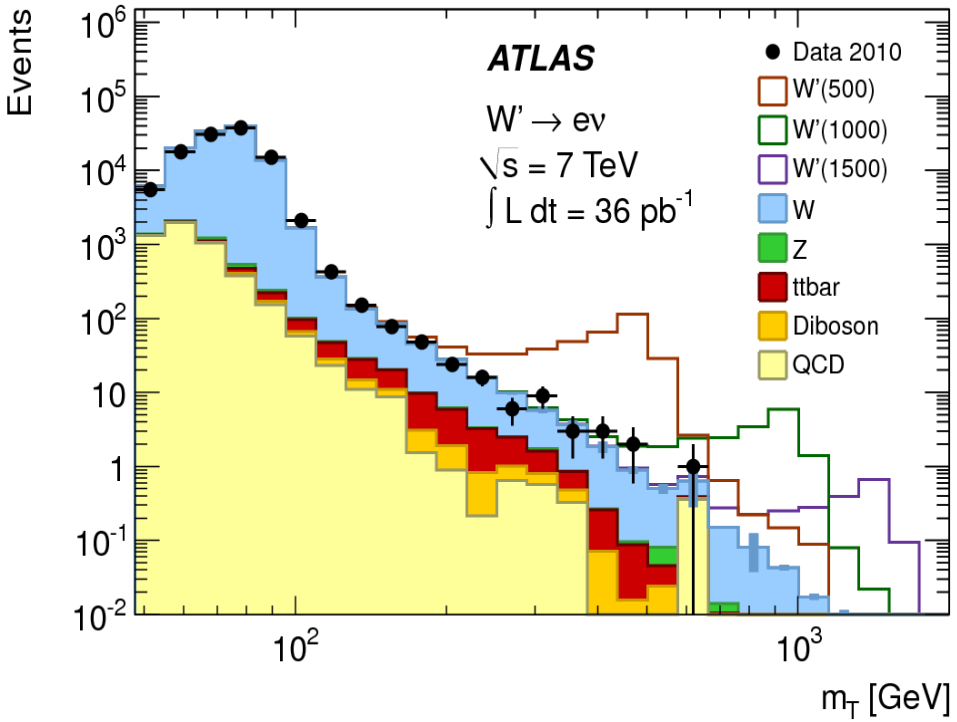
Note that many more SUSY searches have been reported, including ones related to gauge-mediated SUSY, to models with R-parity violation, with long-lived R-hadrons…

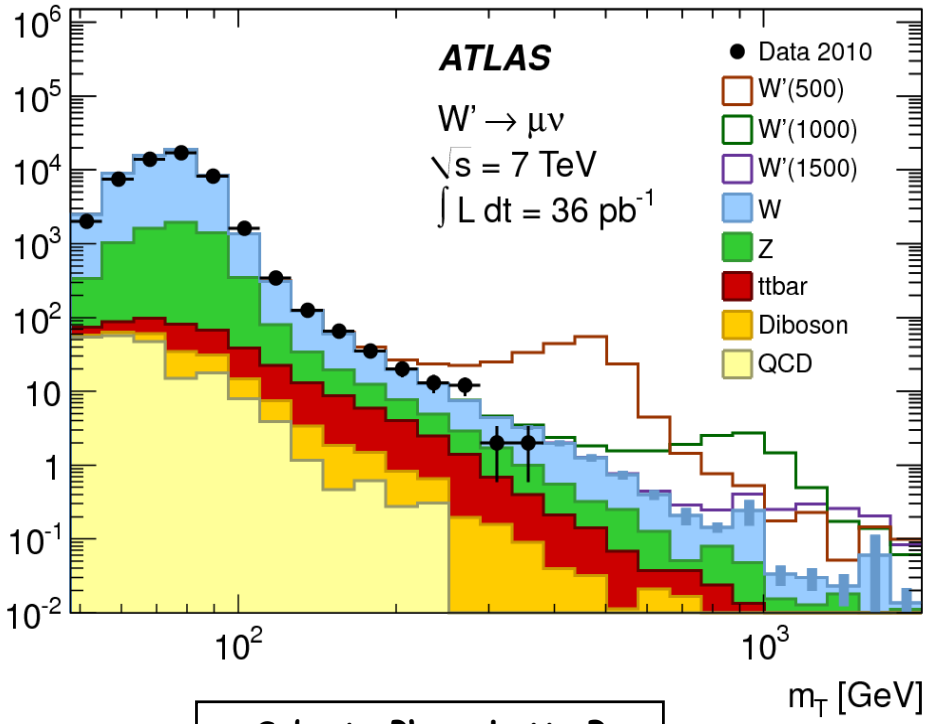

Other models
Producing new particles

Searches for heavy W and Z like particles

These searches are quite straight-forward, following basically the same analyses as for the familiar W and Z bosons

Lepton + missing E_T

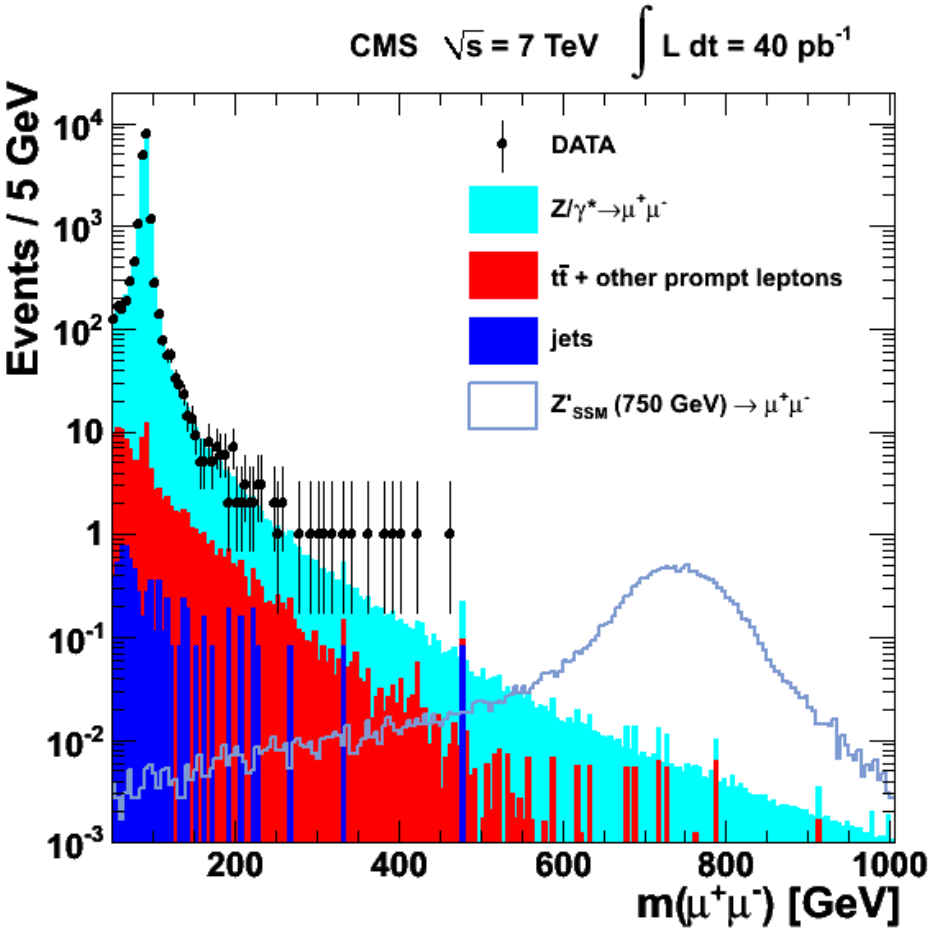


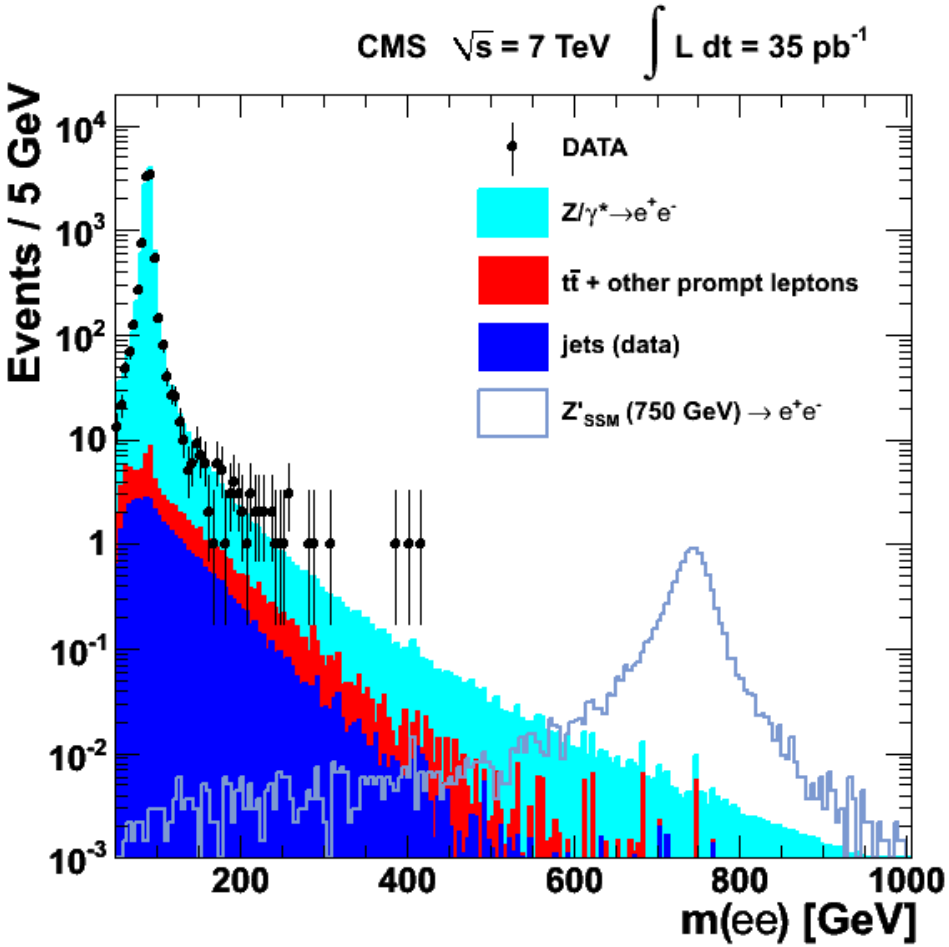


Sub. to Phys. Lett. B
arXiv:1103.1391[hep-ex]

Di-lepton pairs

Sub. to JHEP
arXiv:1103.0981hep-ex]



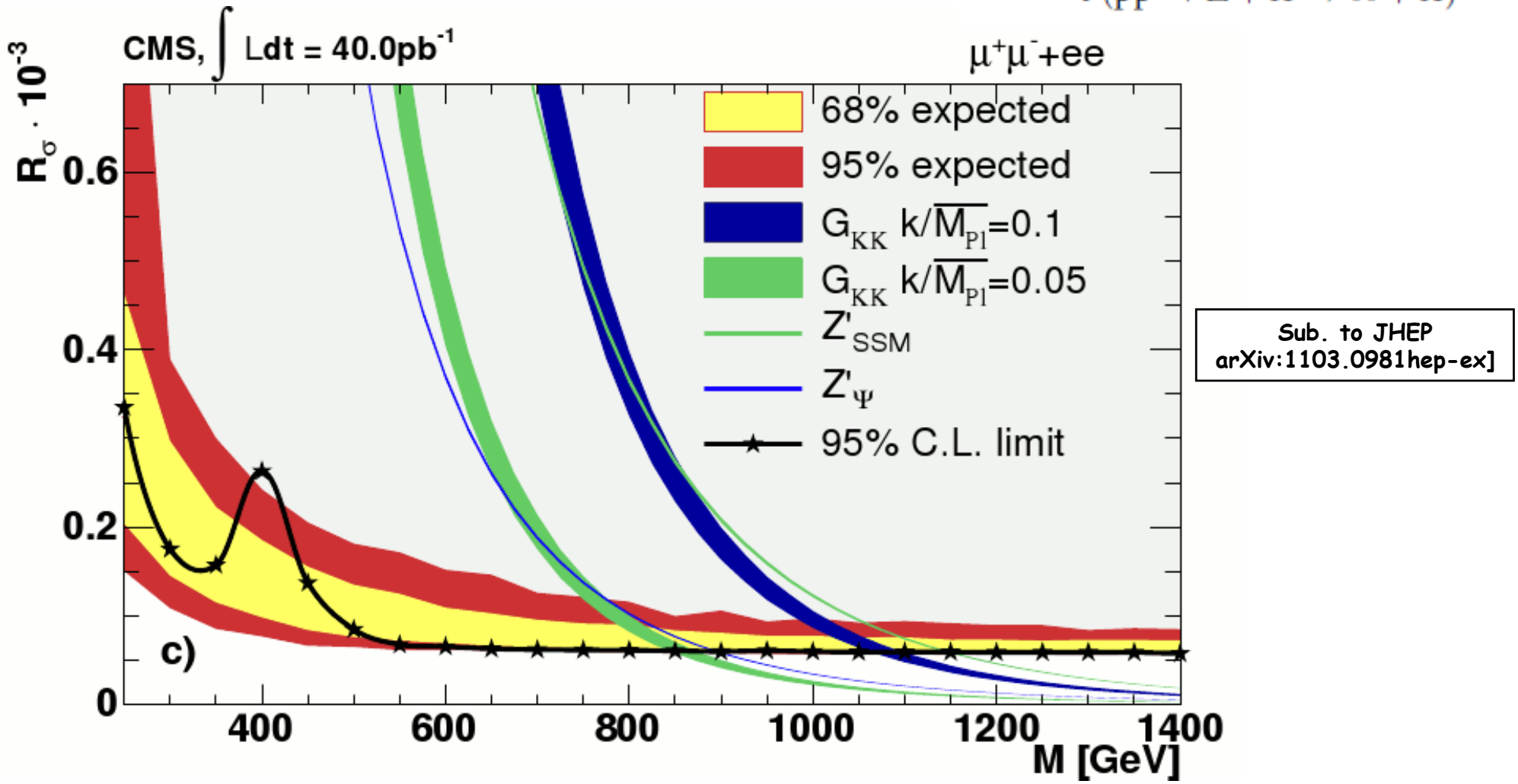


Limits can be interpreted in various models

Mass limits for various models with hypothetical heavy particles decaying into lepton pairs

Cross sections are normalized to the measured Z production:

$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}.$$

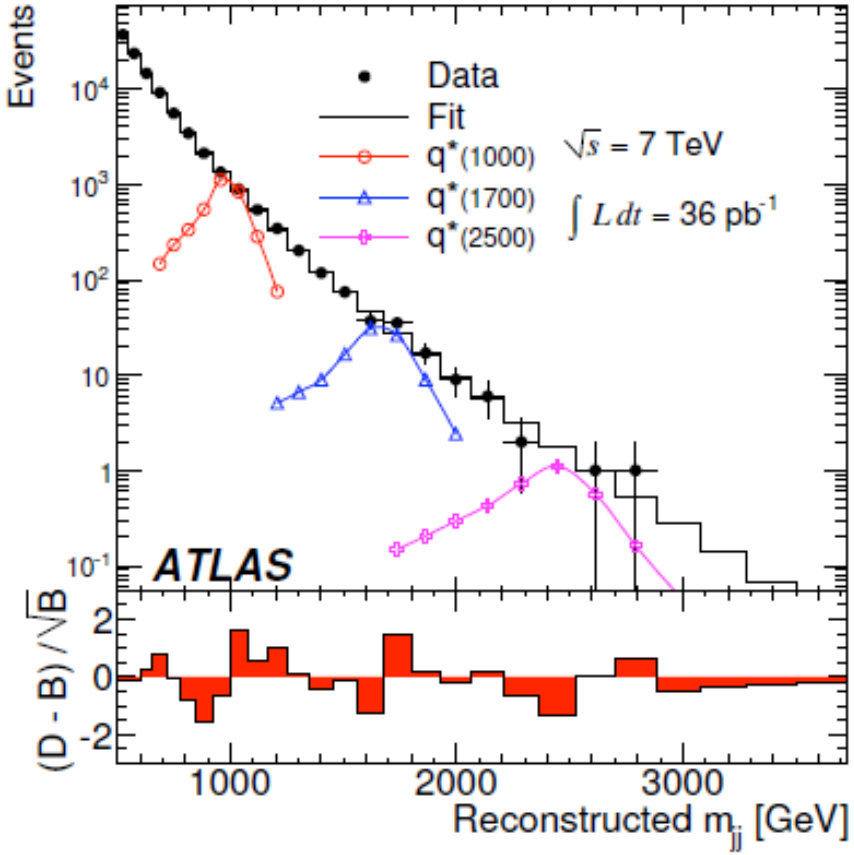


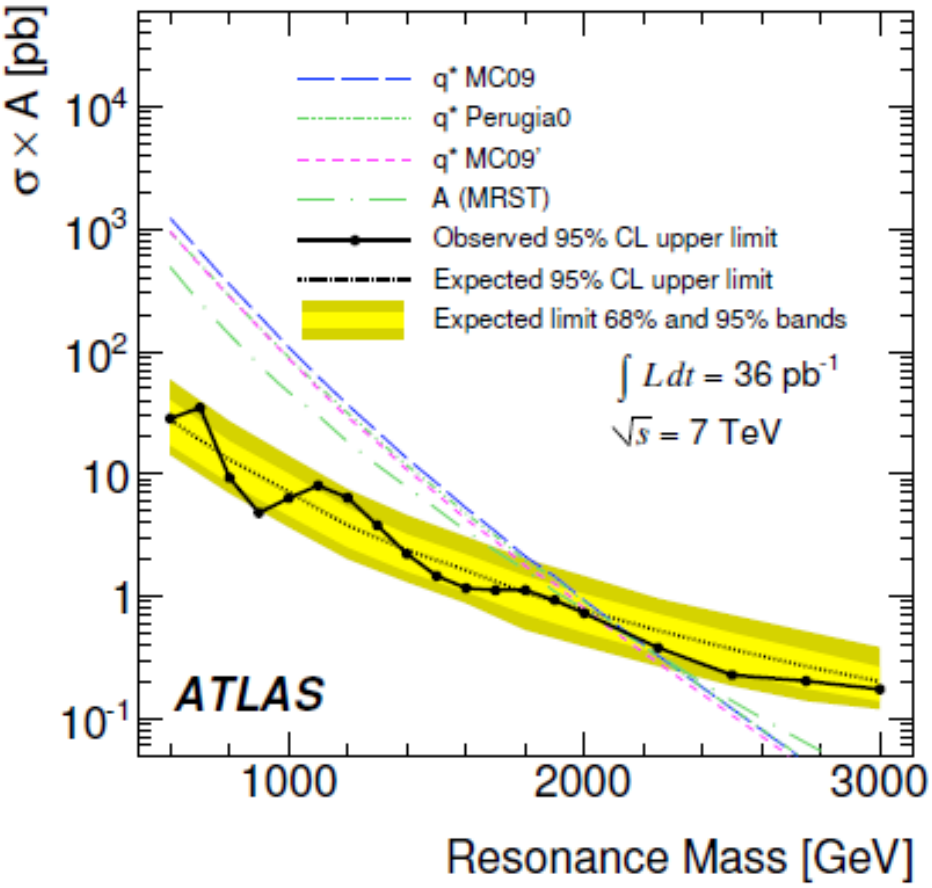
Sub. to JHEP
arXiv:1103.0981hep-ex]

Two examples of searches for New Physics as deviations from QCD behaviour of hadronic jet distributions

Search for resonances in the di-jet mass spectrum

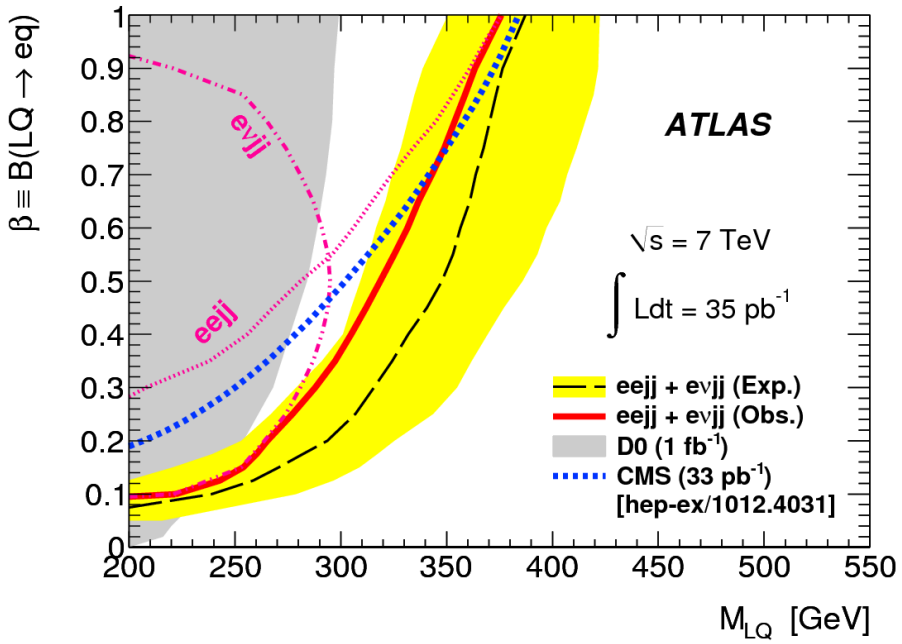
Sub. to New J Phys
arXiv:1103.3864v1[hep-ex]

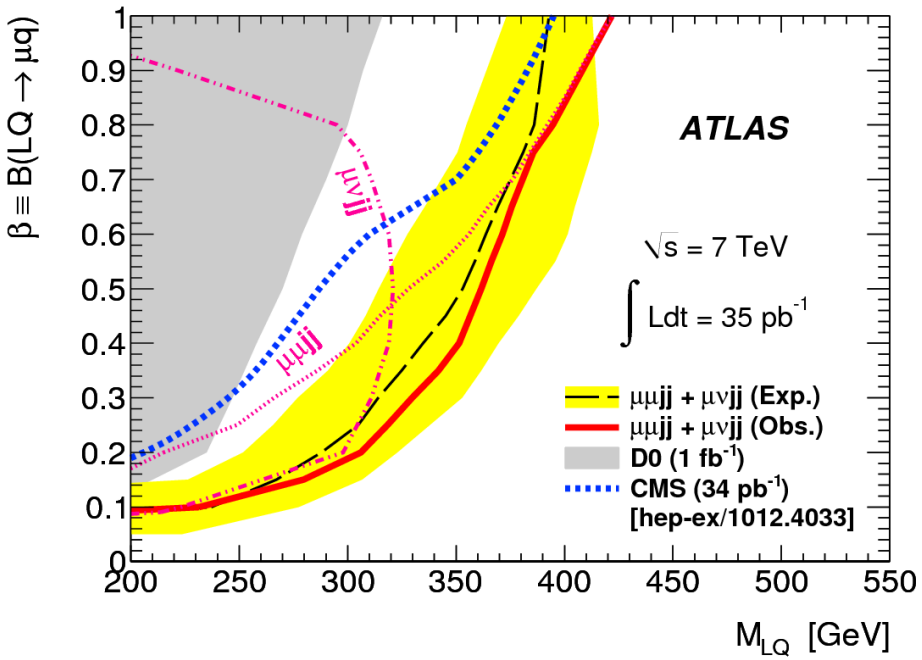




Lepto-Quarks @ ATLAS

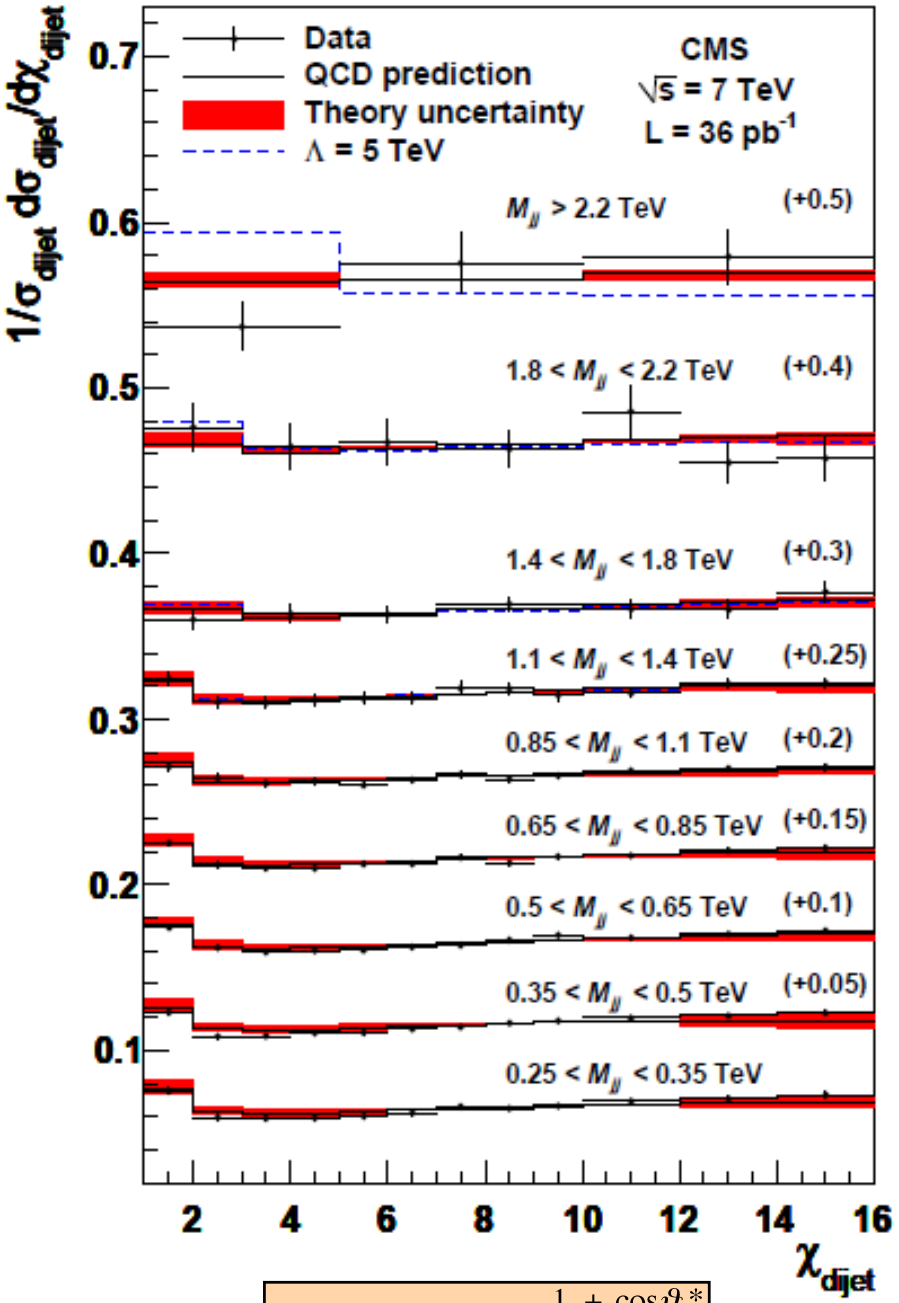
95% CL exclusion limits for Lepto-Quarks





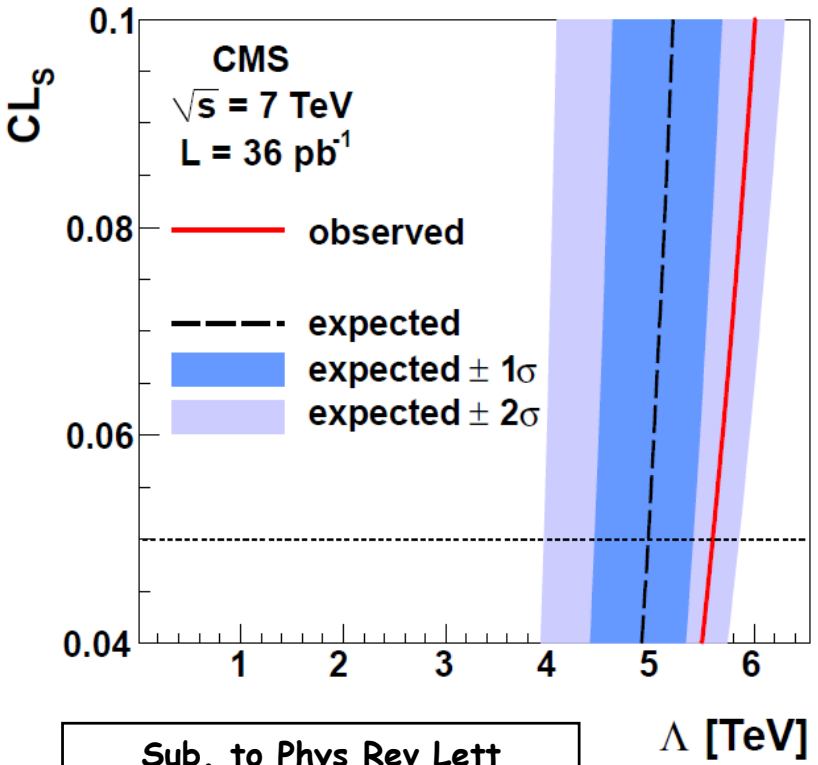
Sub. to Phys Rev D
arXiv:1104.4481v1[hep-ex]

Search for deviations from QCD in the di-jet angular distributions



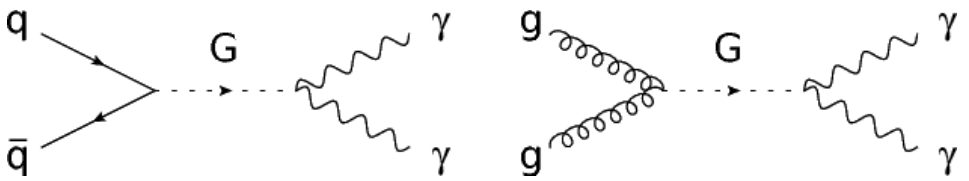
$$\chi = \exp(|y_1 - y_2|) = \frac{1 + \cos\vartheta^*}{1 - \cos\vartheta^*}$$

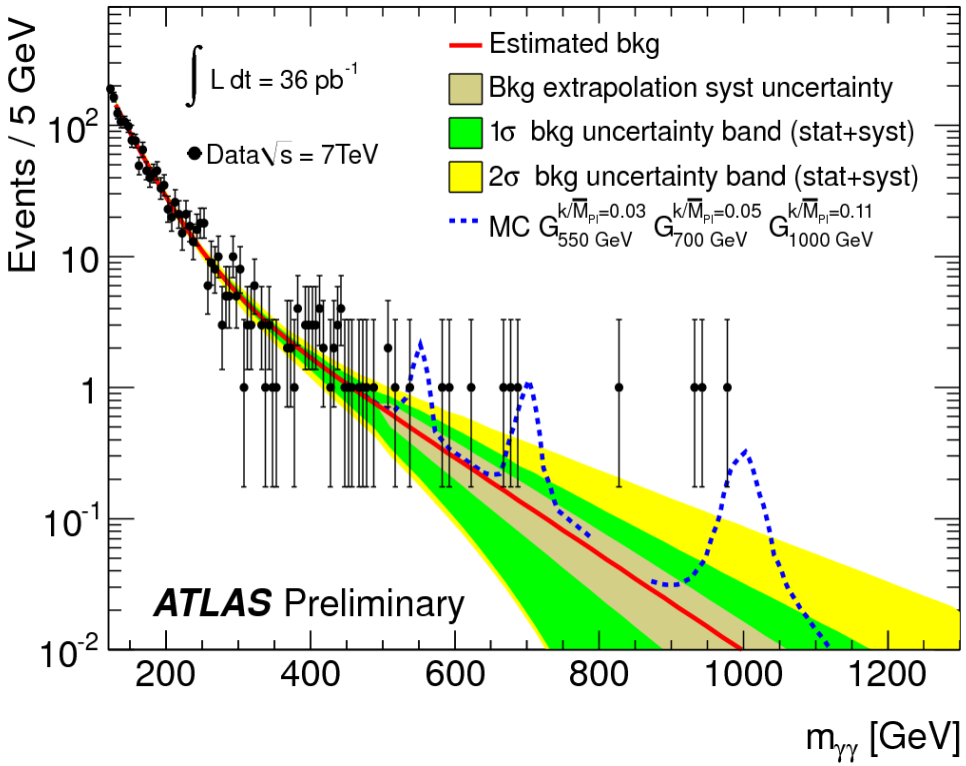
Deviations from the QCD expectation could reveal a substructure of the quarks ('compositeness' at scale Λ) in analogy to the famous Rutherford scattering 100 years ago

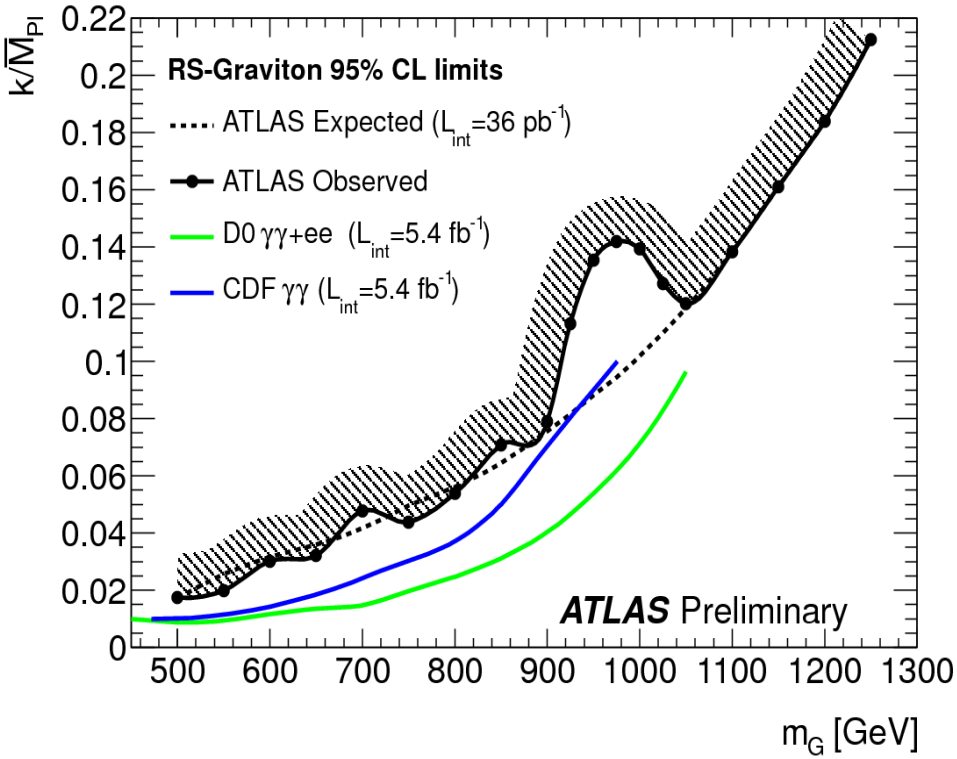


Sub. to Phys Rev Lett
arXiv:1103.2020v1[hep-ex]

Example for a search of extra dimension signals (Kaluza-Klein Graviton in the Randall-Sundrum model)







ATLAS-CONF-2011-044

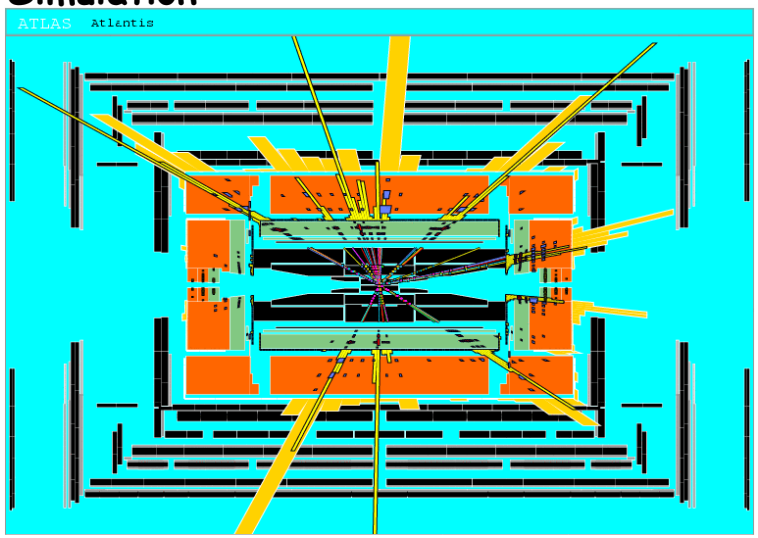
Search for Microscopic Black Hole production in models with large extra dimensions

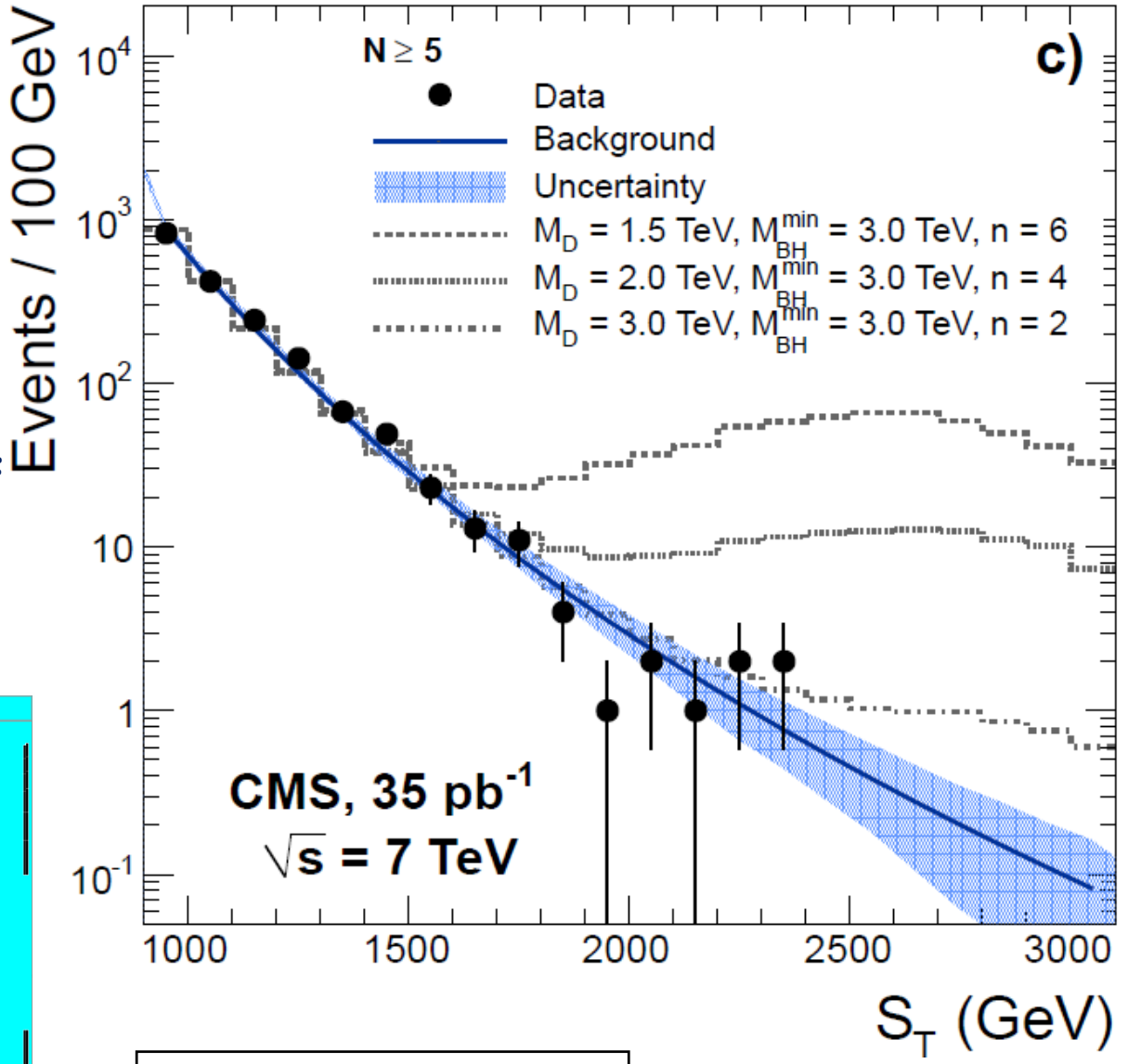
(Arkani-Hamed, Dimopoulos, Dvali)

Decay into many objects (jets, leptons, photons)

S_T : scalar sum of the E_T of the N objects in the event

Simulation





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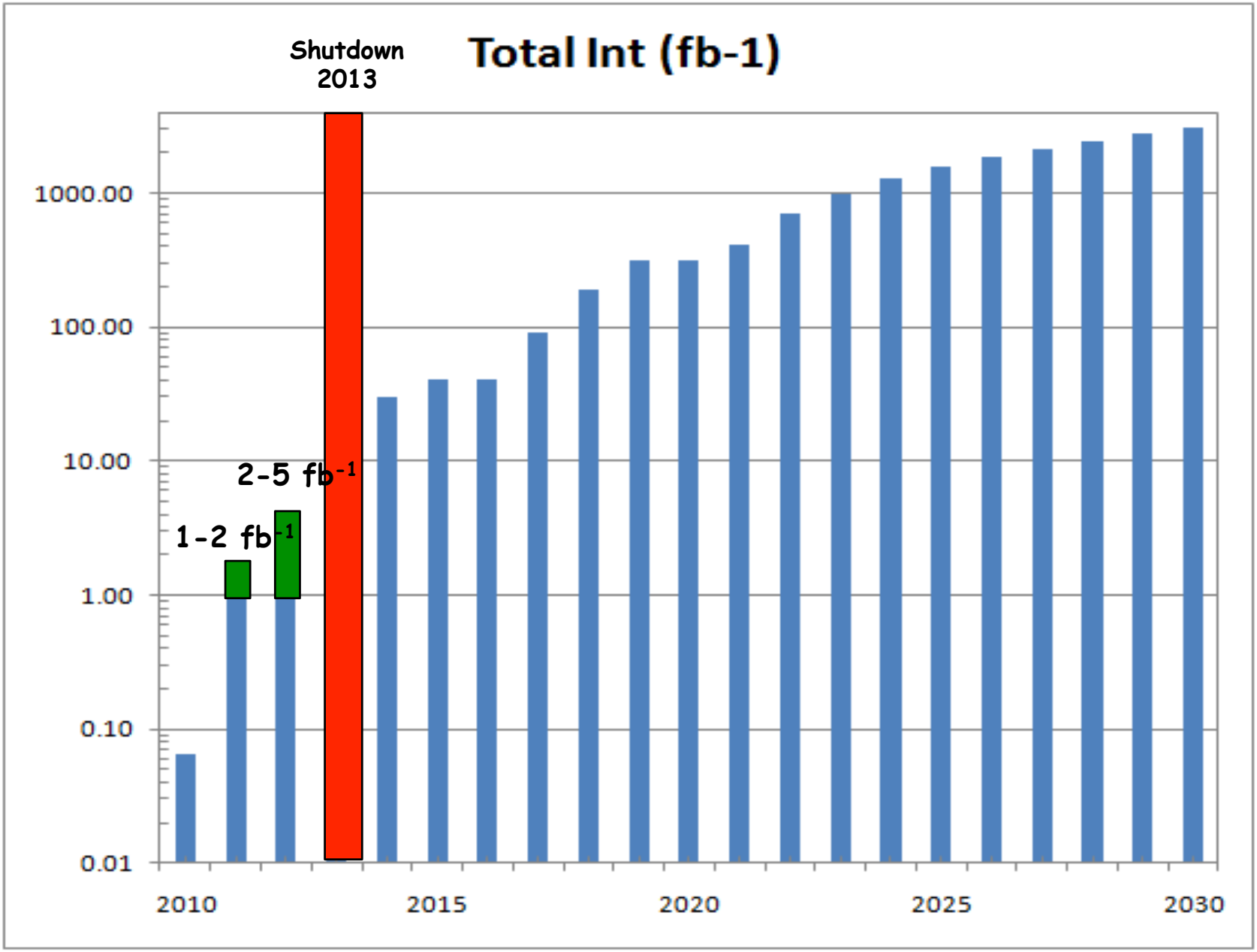
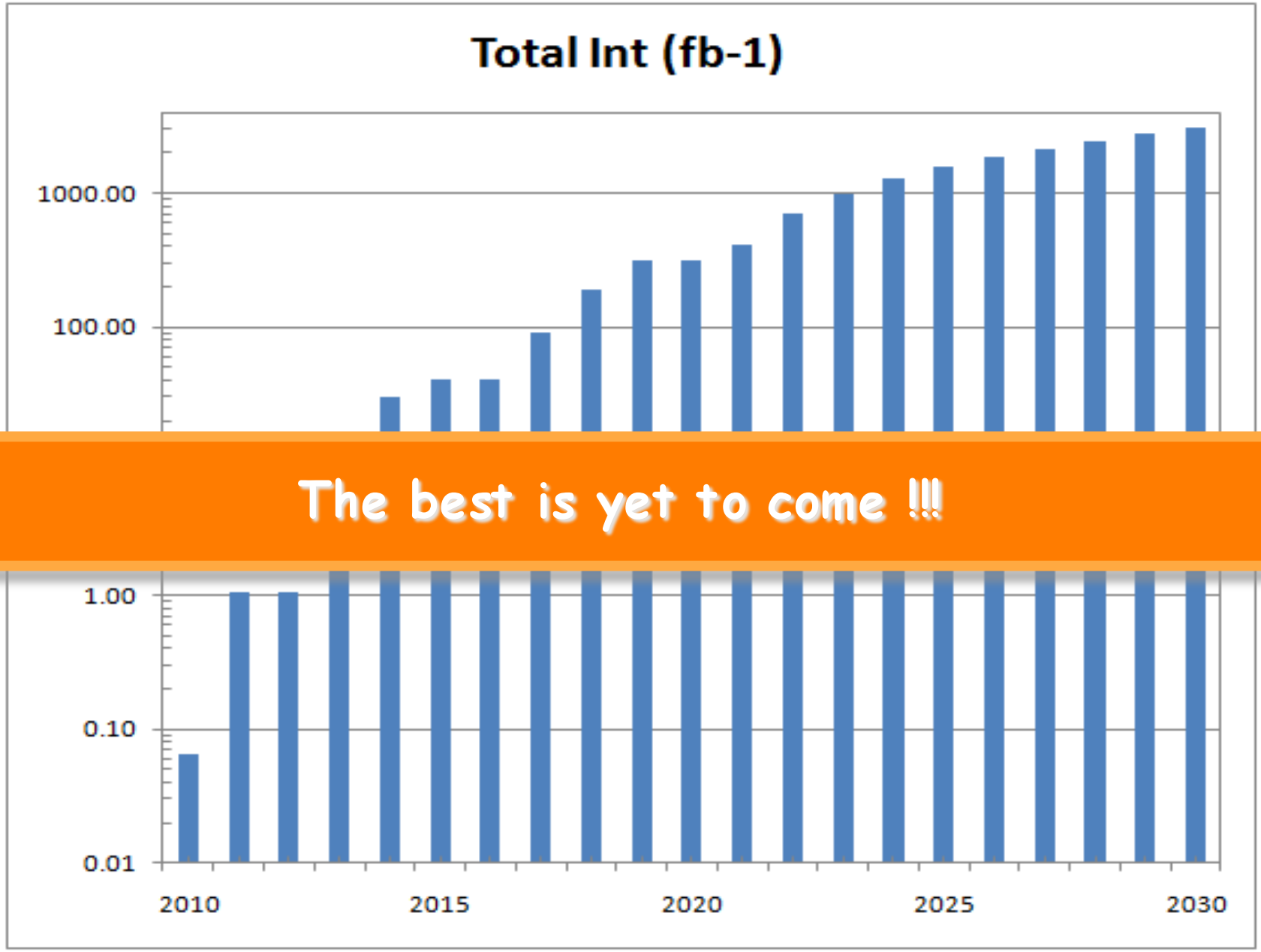
Limit 3.5 to 4.5 TeV

Beyond the present results : the 20-year physics plan



The 20-year physics plan



The best is yet to come !!!

Enjoy the collisions