Experimental Summary: Personal Impressions
LHC's First Year of Operation

- Introduction
- Performance of the LHC and the Experiments
- Physics Highlights, especially from the 1st Year of Running at the LHC
- Outlook

Tejinder S. Virdee,
Imperial College

Acknowledgements:
Speakers at this Conference

Sergio da Vittorio Veneto

Prologue

G. Altarelli: 2009 Lepton-Photon Conference

Top physics priorities at the LHC (ATLAS&CMS):

- Clarify the EW symmetry breaking sector
- Search for new physics at the TeV scale
- Identify the particle(s) that make the Dark Matter in the Universe

Also:

- LHCb: precision B physics (CKM matrix and CP violation)
- ALICE: Heavy ion collisions & QCD phase diagram

⊕ At this point, fresh input from experiment is badly needed

First the Summary !

- **Accelerator and experiments have worked, and are working, very well**
  70Hz March 2010 to 10 MHz in Nov 2010 to 100MHz last week

- **Experiments – knew would work reasonably well from cosmics data taking** but is still very pleasing to see the whole operation (from hardware up-time, data-taking to offline/computing and distributed analysis) working so seamlessly and well, and close to the desires of the conceivers and the builders
  Level-1 and HLT have kept pace with ever increasing luminosity.

- Wide range of measurements have shown that **SM predictions for known physics have been essentially spot on** – this is a tribute to a large amount of work done by our theory colleagues along with the results from the other collider experiments at LEP, Tevatron, b-factories etc.

- There are **no indications yet of new physics** though the LHC experiments are now exploring new territory almost across the board.

But still very exciting times ahead.

LHC Accelerator : 2010 Summary

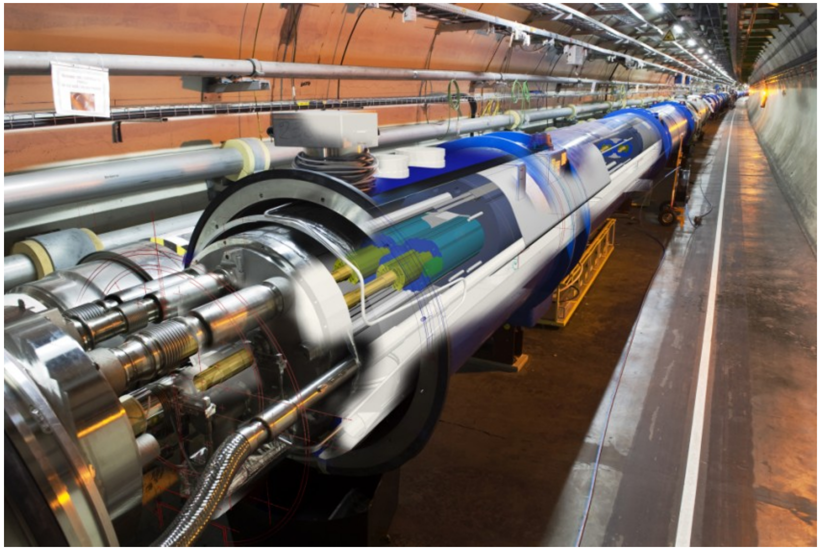
G. Arduini

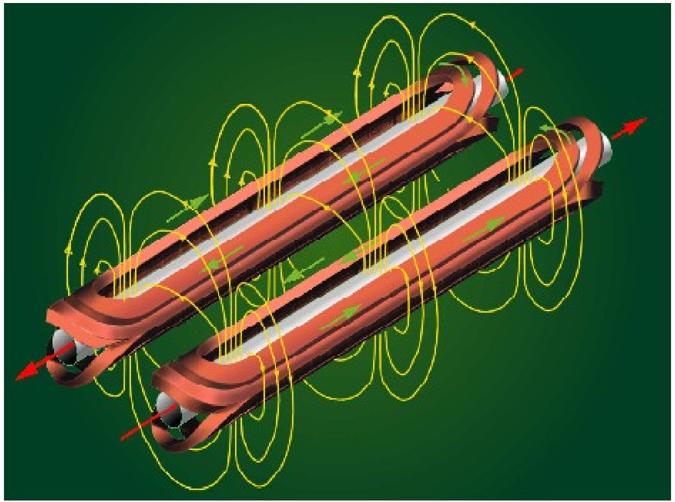
- **Excellent single beam lifetime**
- **Ramp & squeeze essentially without loss**
  - No quenches with beam above 450 GeV
  - Excellent performance of Machine Protection
- **Accelerator is magnetically and optically well-understood**
- **Excellent reproducibility**
- **Aperture (at least) as expected**
- **Better than nominal from injectors**
  - Emittances, bunch intensity
- **Beam-beam: can collide nominal bunch currents**
  - With smaller that nominal emittances

And surprisingly good availability…
Much praise to the Machine Folks (construction and operation)

Challenges for the LHC Accelerator

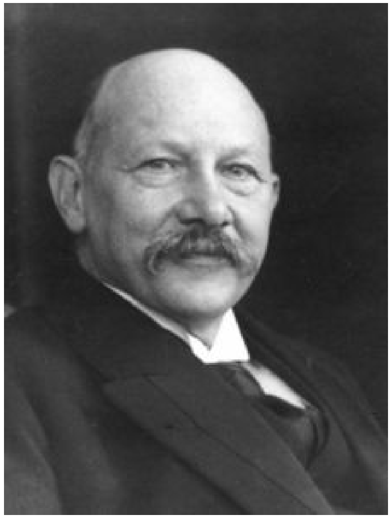
"Two in One" s.c. Magnets





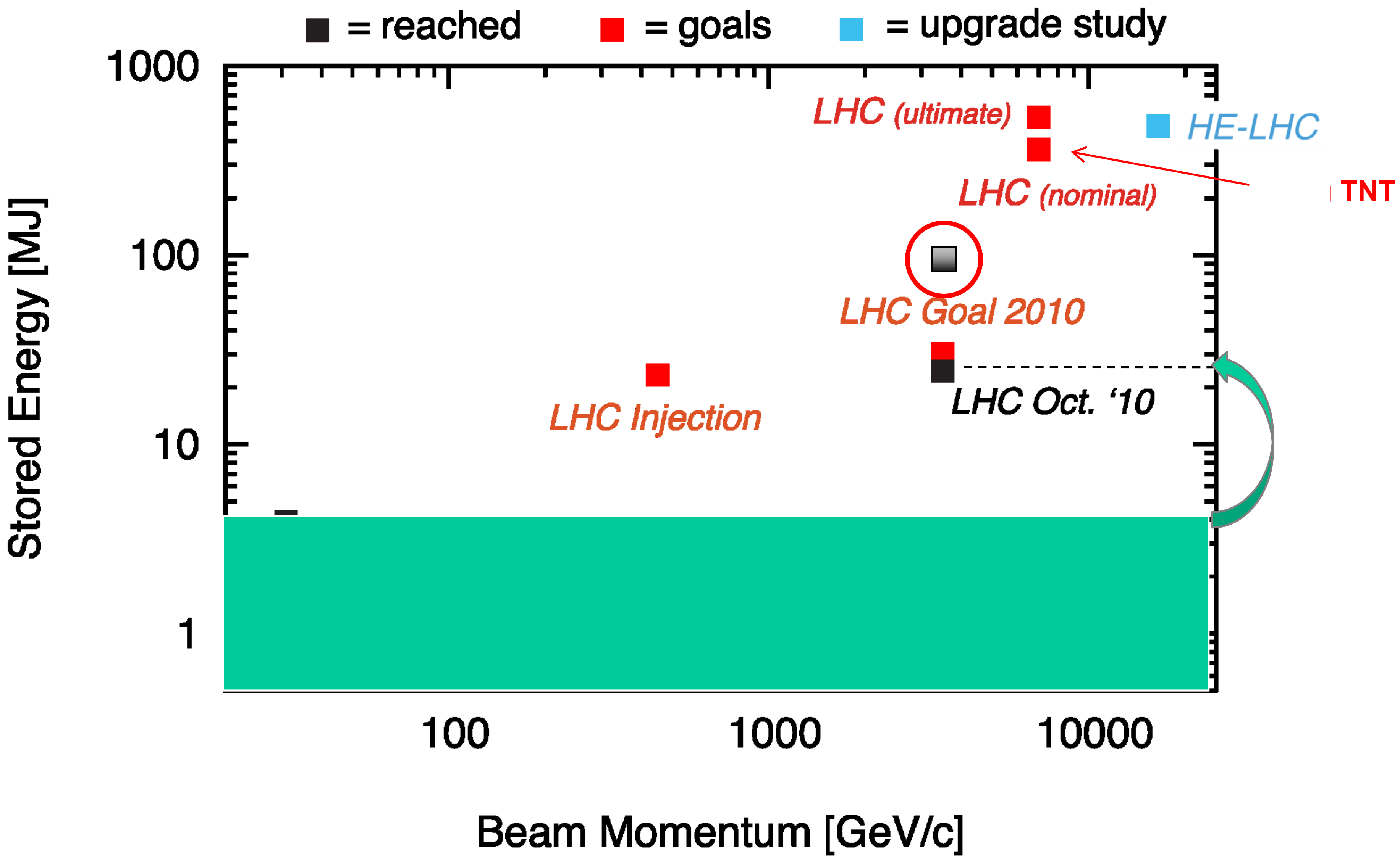
Liquid helium displays two phenomena which are both pillars in the design of LHC: superconductivity and superfluidity

Kamerlingh Onnes first **liquefied helium** in 1908 (60 ml in 1 hr)
In 1911 he discovered **superconductivity**



LHC today: 32000 liters of He liquefied per hour by eight big cryogenic plants

LHC is on its own in terms of stored energy



Imperial College London

PLHC 2011

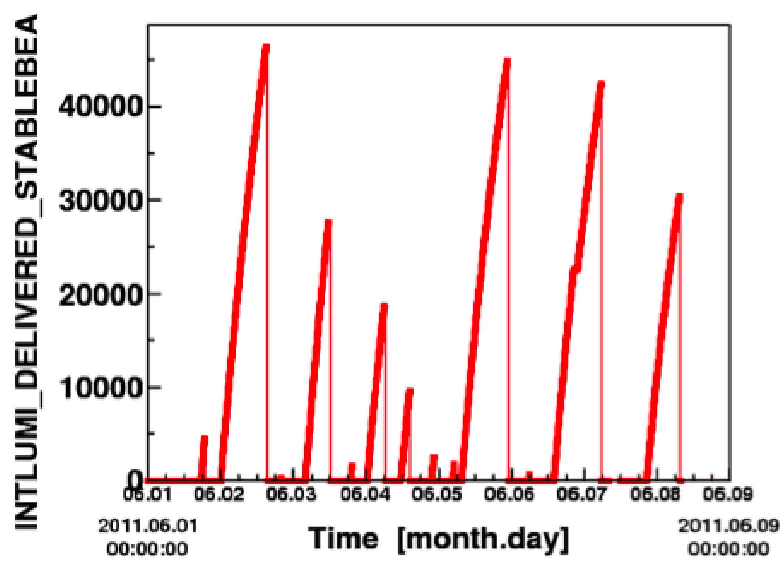
Current Performance of the LHC

- **Issues dealt with in 1st half of 2011:** electron cloud (scrubbing at 50ns led to SEY going from 2.5 to 1.8), Luminosity leveling for LHCb, bunch trains.
- **Potential issues in 2nd half of 2011:** UFO and SEU

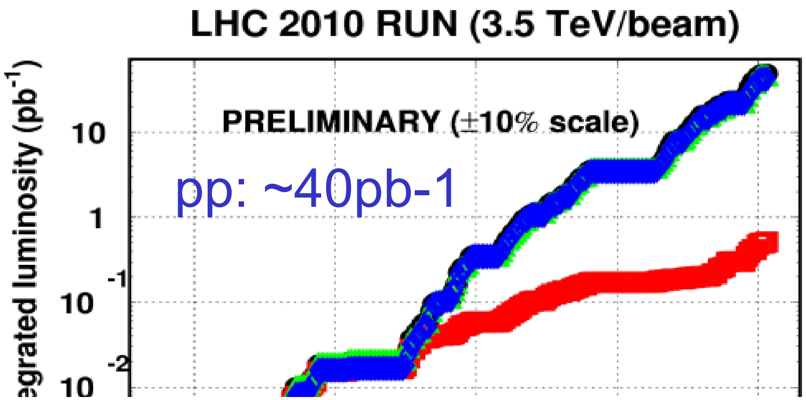
G. Arduini

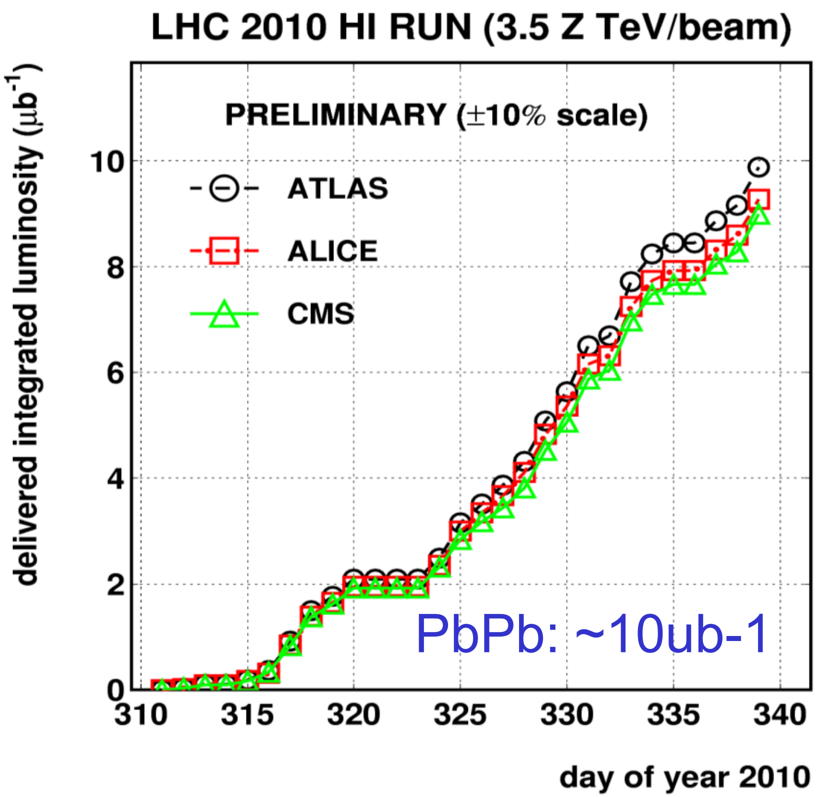
	2011 so far	Nominal
Energy [TeV]	3.5	7
β^* [m]	1.5	0.55
Emittance [μm]	2.5	3.75
Transverse beam size at IP [μm]	40	16.7
Bunch population	1.2×10^{11} p	1.15×10^{11} p
Number of bunches	1092/IP	2808
Stored energy [MJ]	100	360
Peak luminosity [$cm^{-2}s^{-1}$]	1.6×10^{33}	1×10^{34}

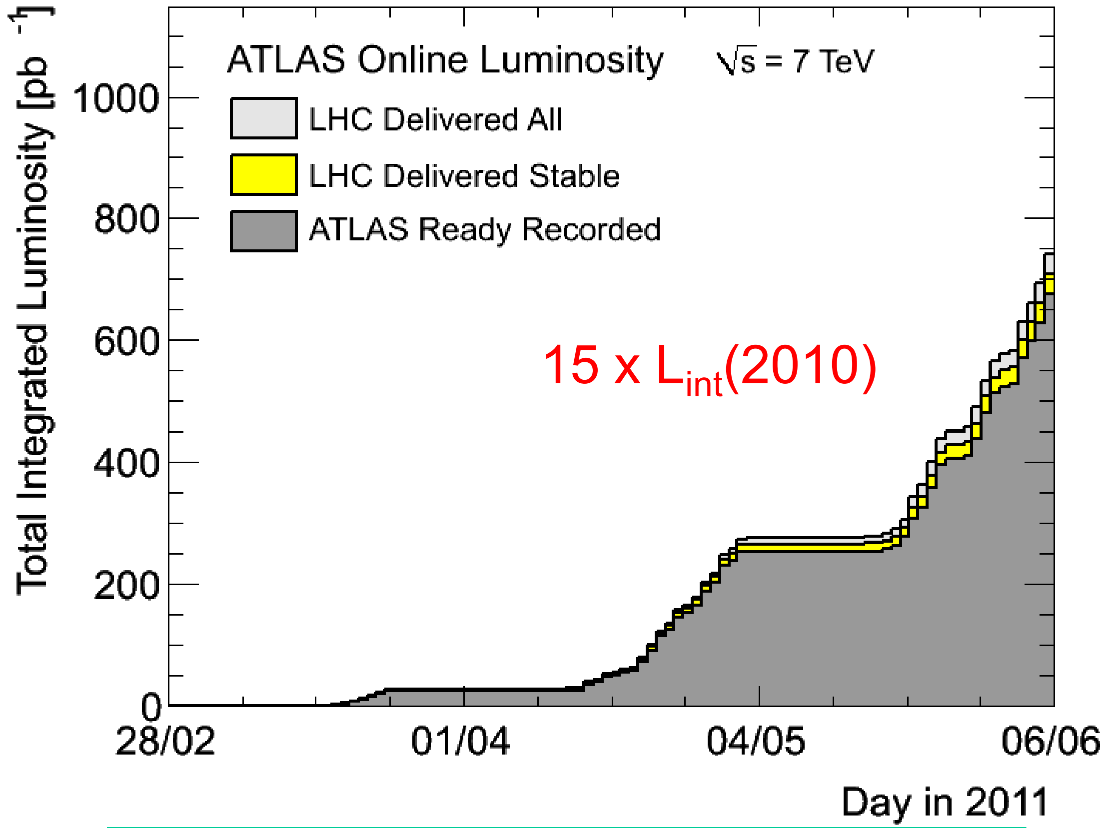
Last week delivered 200pb^{-1}



The Data Samples







Tevatron approaching 10 fb^{-1}/expt.

LHC: 2011

Realistic chance of getting several fb^{-1}

PbPb integrated luminosity 30-50ub^{-1}

Challenges for the Experiments

It was not at all obvious that the detectors could be built!

1 billion proton-proton interactions per second

Large Particle Fluxes

➪ large number of channels (~ 100 M ch)
➪ ~ 1 MB/25ns i.e. 40 TB generated/sec

High Radiation Levels

➪ radiation hard (tolerant) detectors and electronics

CMS-LOI/92-LF

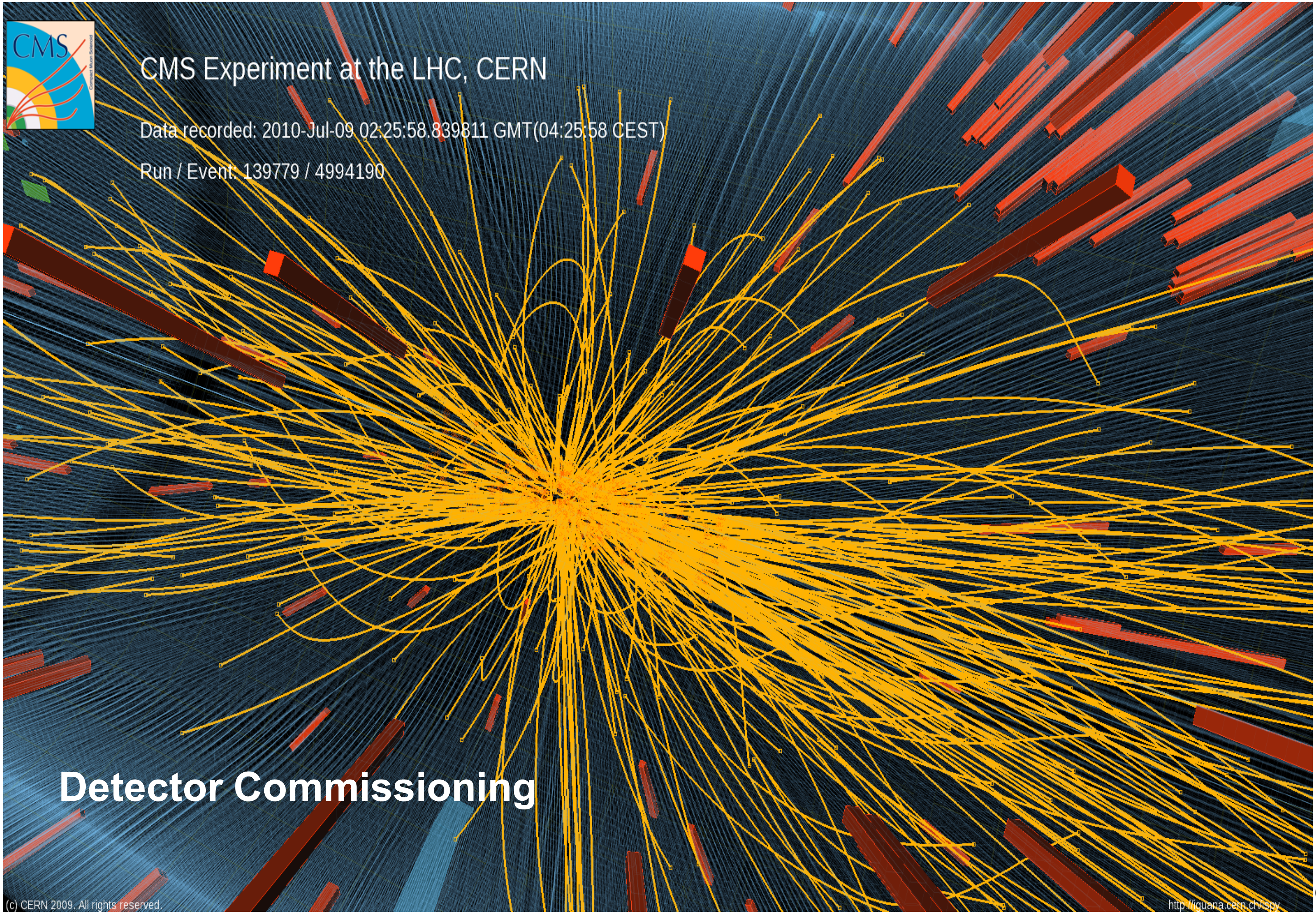
ANSWERS TO PROFESSOR LORENZO FOA

QUESTION 0

General question that concerns all experiments: What can your e.m. calorimeter do in a "stand alone" mode, I mean if you have to switch off your inner tracking because of excessive rate?

PLHC 2011

Collisions at the LHC !

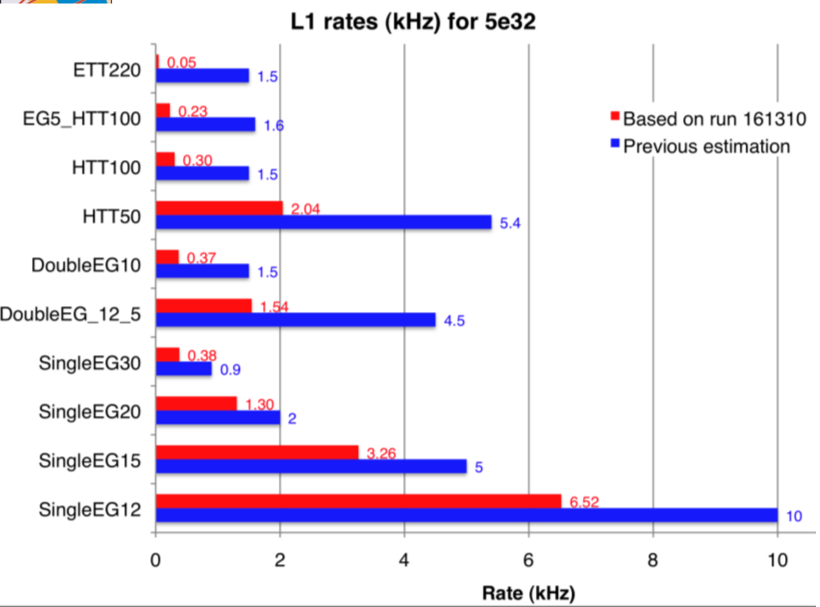


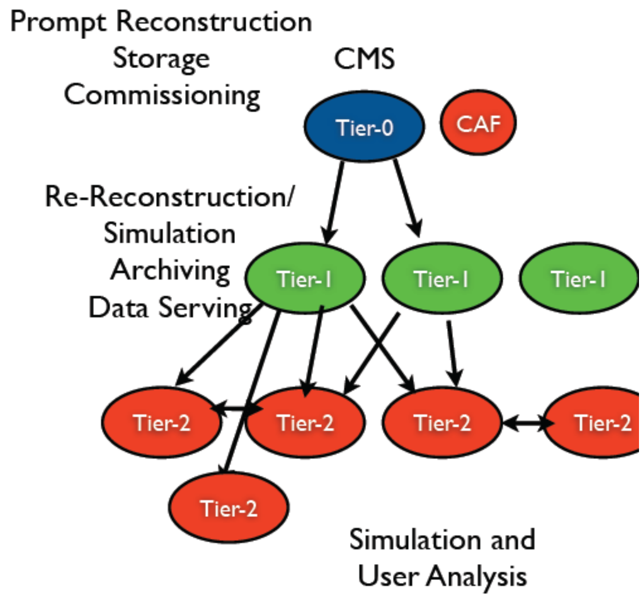
Performance of LHC Experiments

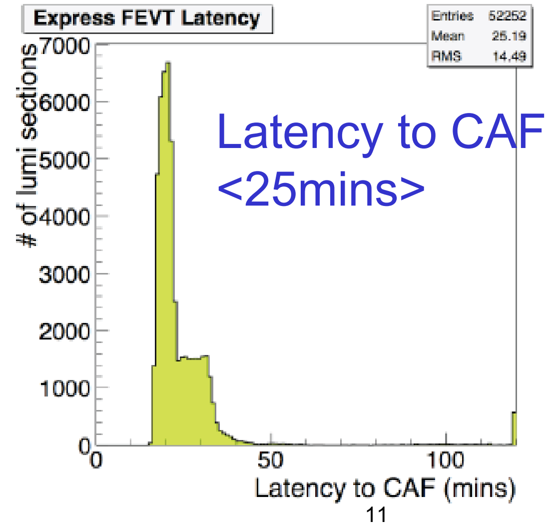
Good operational status: ~ 99% of channels working!
Overall data taking efficiency ~ 95%
~85% with all sub-detectors fully operational

Examples

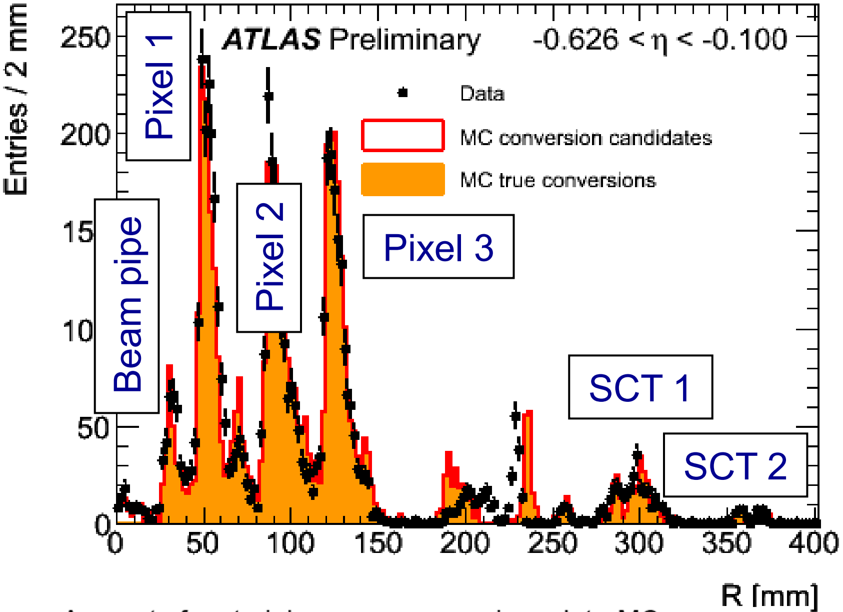
Inner Tracking Detectors			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.5	99.4	100	87.5	92.4	94.5	100	100	99.0	99.9	99.8	96.8	95.1

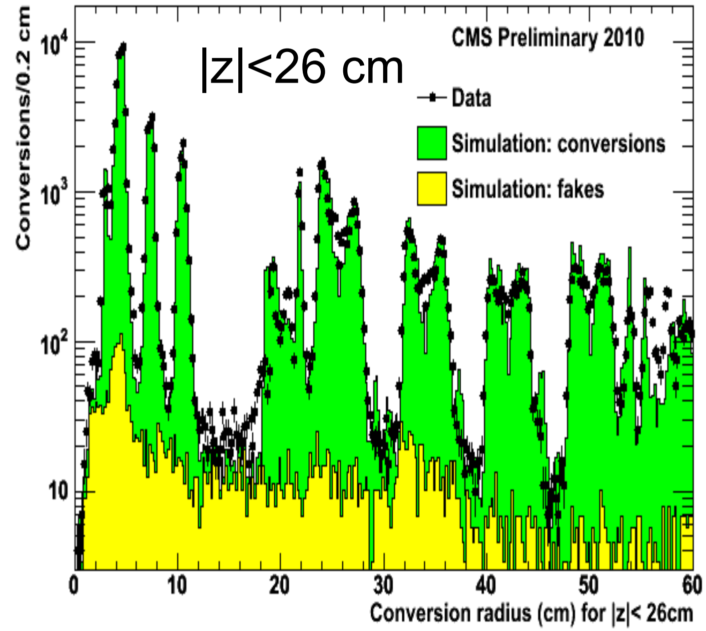




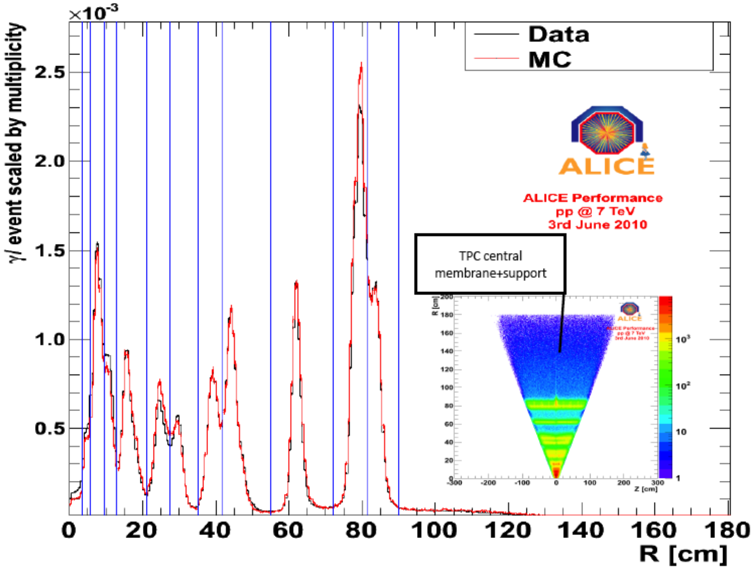


Experiments are well-described in simulation e.g. Material Budget of Trackers





Amount of material gamma conversions data-MC



E.g. Monte Carlo samples are usually generated with PYTHIA (bkg) and with a matrix-element generator (signal) interfaced with PYTHIA. After generation step the events were passed through the full detector simulation with GEANT4 and analysed with the same analysis code.

Experiments software is in good shape ! (simulation, reconstruction and analysis)

Physics Objects Essentially Commissioned

Electrons, photons, muons, jets, b-jets, neutrinos (E_T^{miss})

Physics Objects

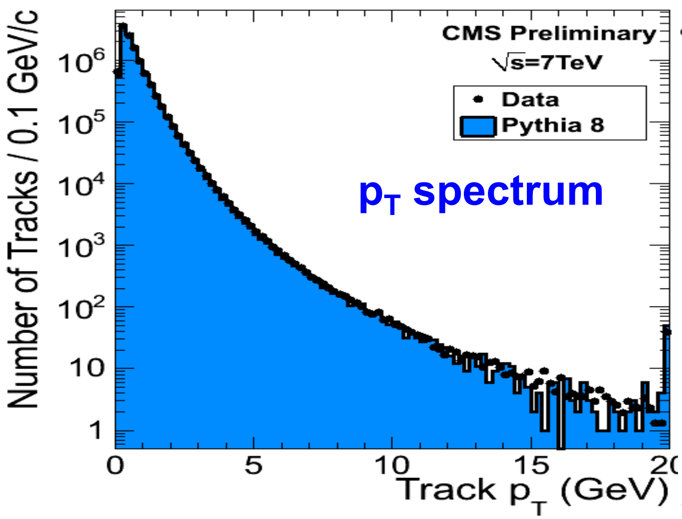
- **Charged track reconstruction, electrons, photons, muons and taus**
- **Jets & MET**
  - Refine noise filters, cleaning algorithms
  - Optimization of jet algorithms for resolution, scale, lepton and γ fakes, etc.
- **Commission higher level algorithms**
  - B tagging
  - Particle Flow (CMS)

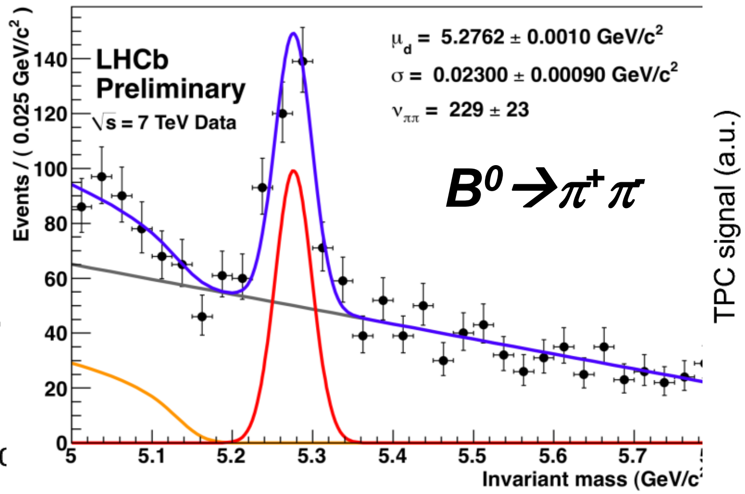
Also calibrate with known objects

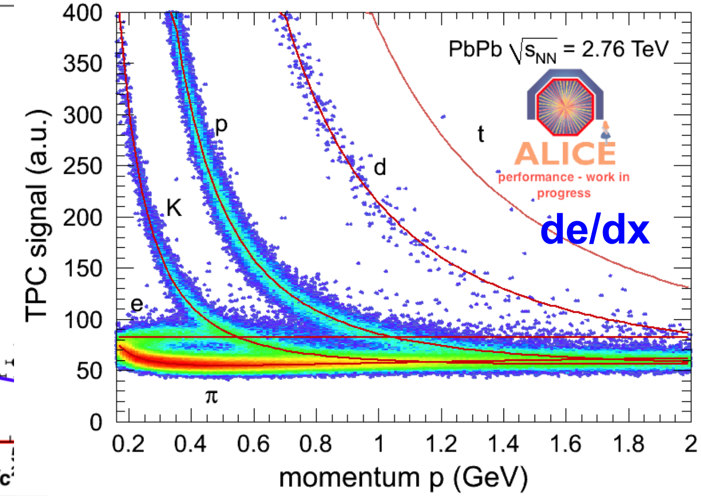
- Study candles for leptons and photons
  - $\pi^0, \eta, .. \Upsilon, \psi, ...$ initially to understand the detector, tracking, object id's
  - Extended to W, Z $\rightarrow$leptons

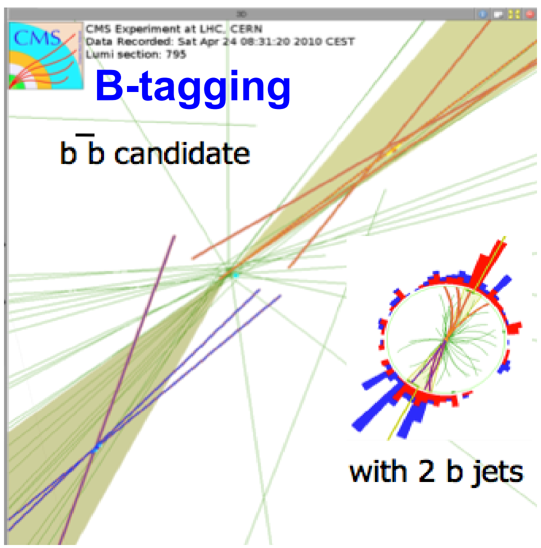
Imperial College London

Detector Performance: Tracks & Jets

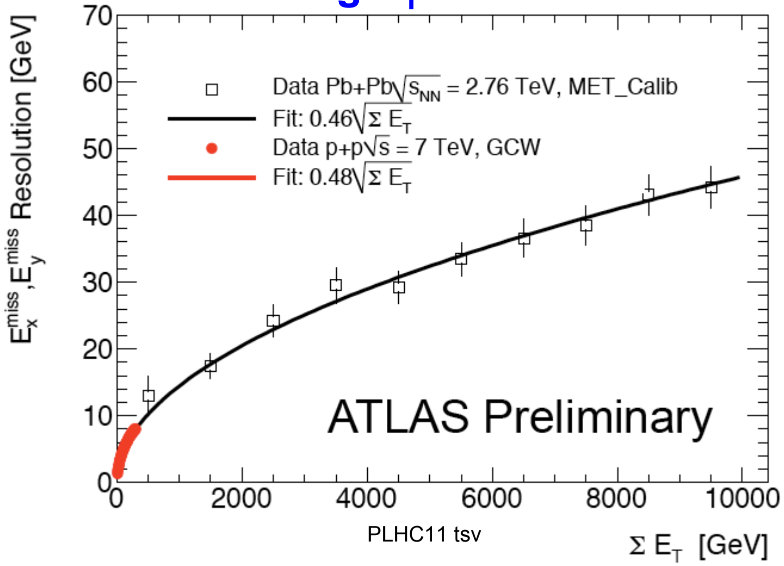


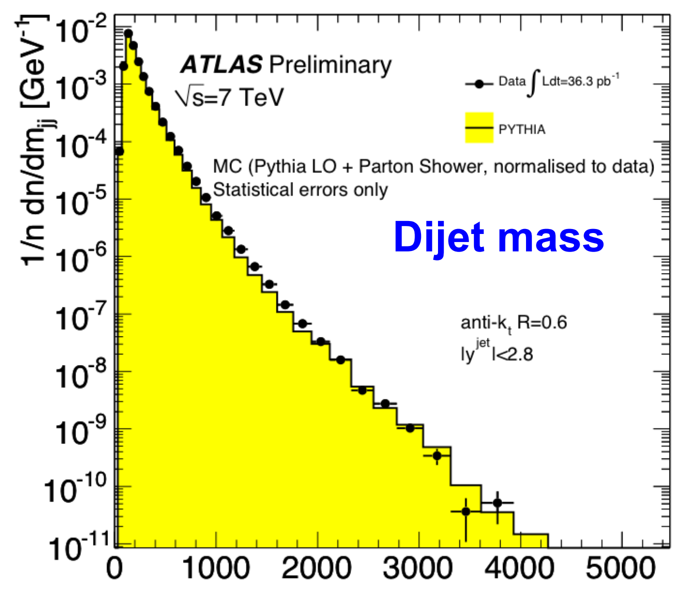






Missing E_T Resolution

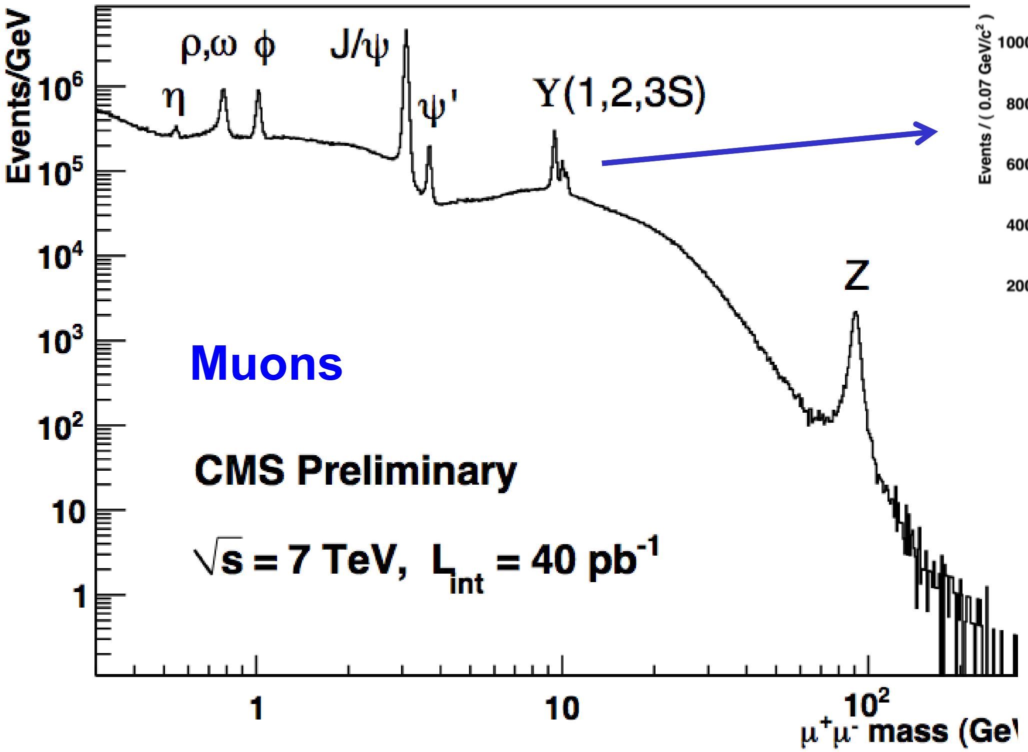


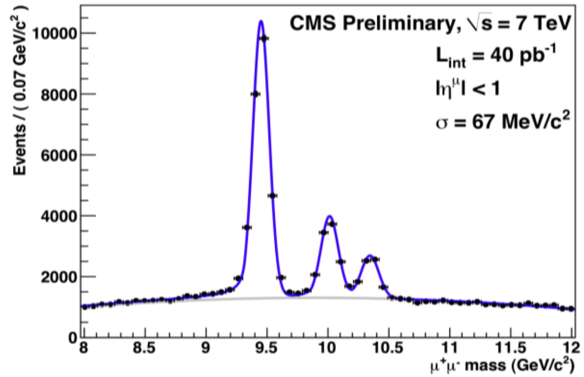


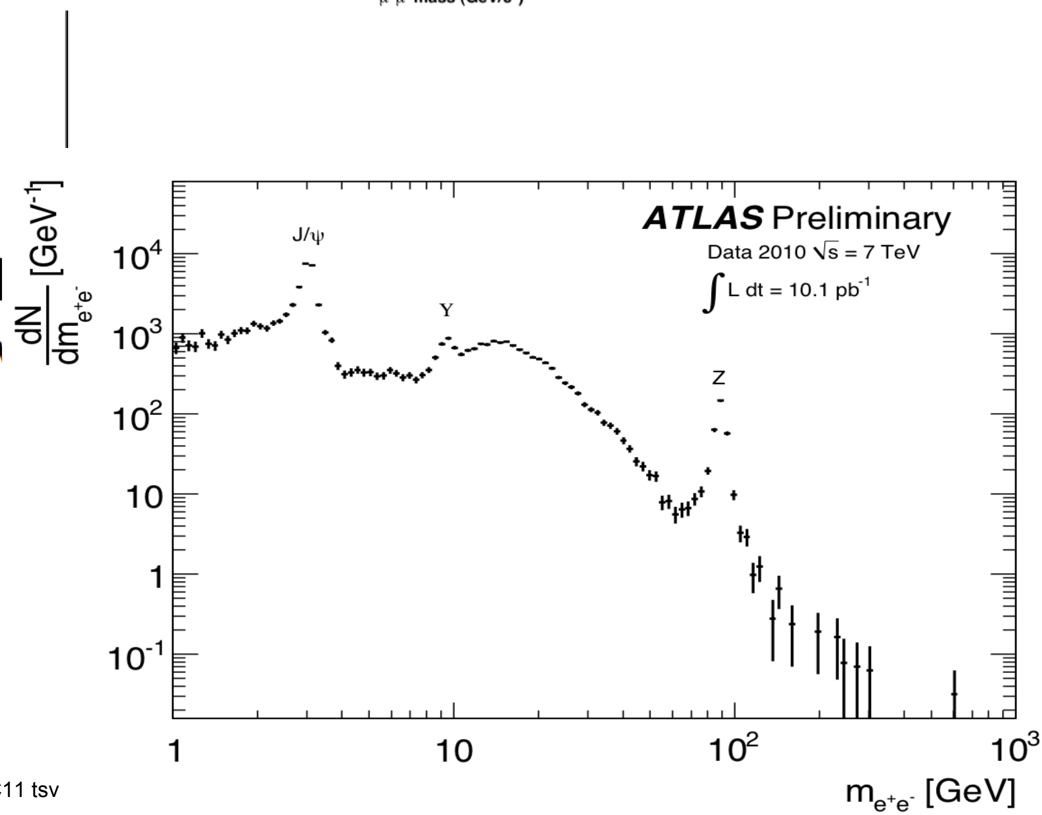
Imperial College London

PLHC 2011

Detector Performance: Electrons and Muons



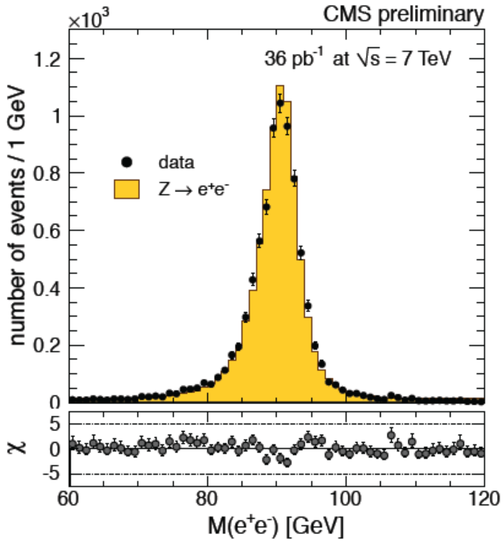


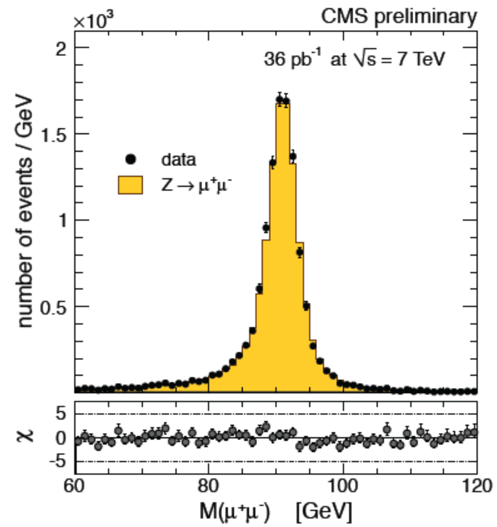


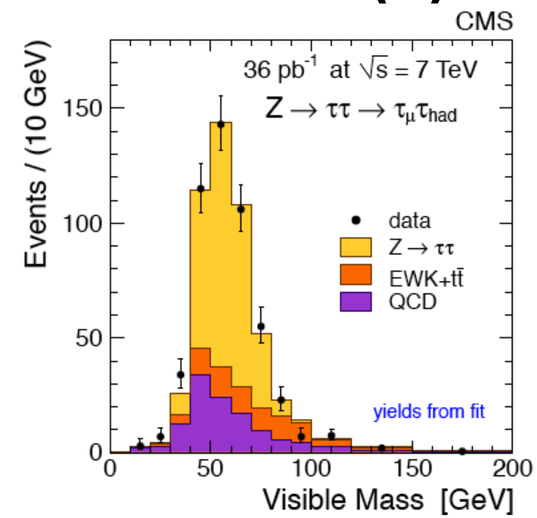
$W^{\pm}$ and Z^0 Bosons as Standard Candles!

electron(s) | muon(s) | tau(s)

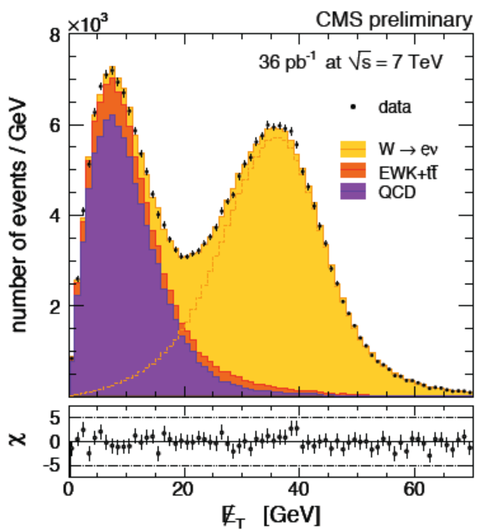
Z boson

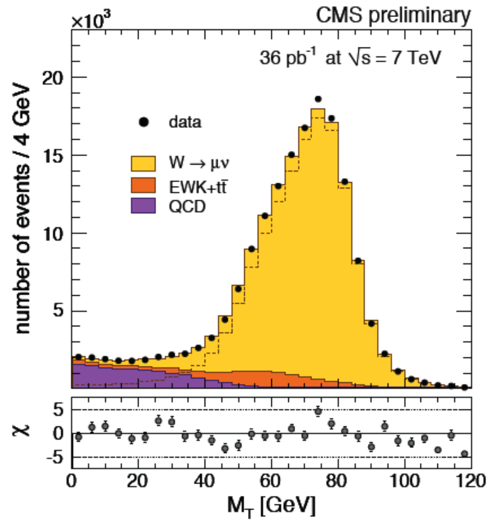


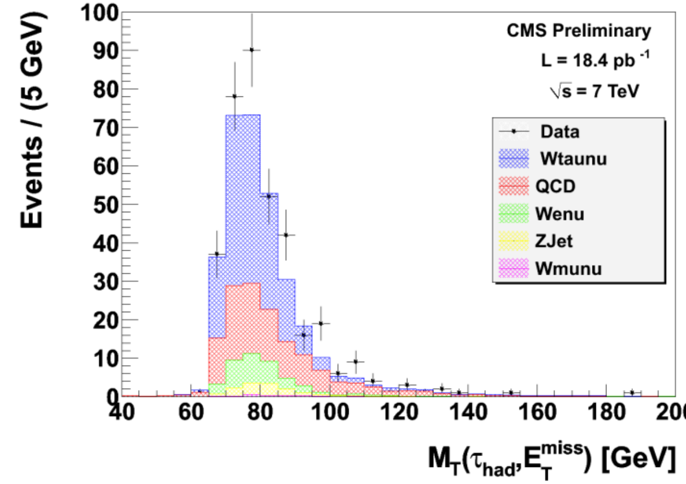




W boson

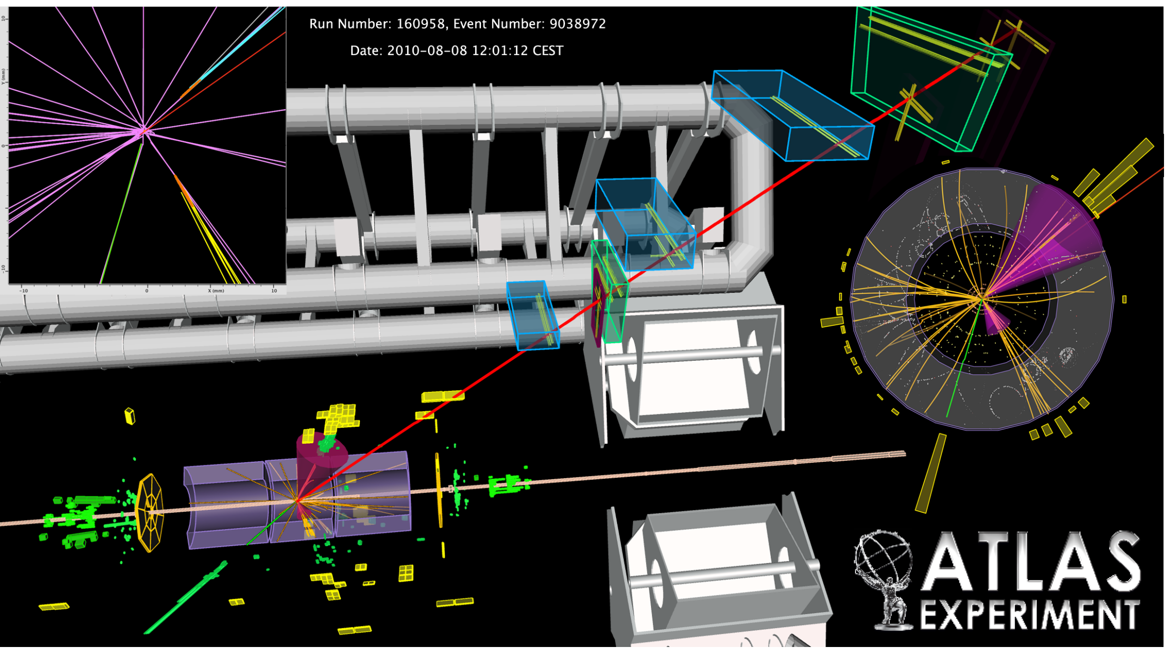


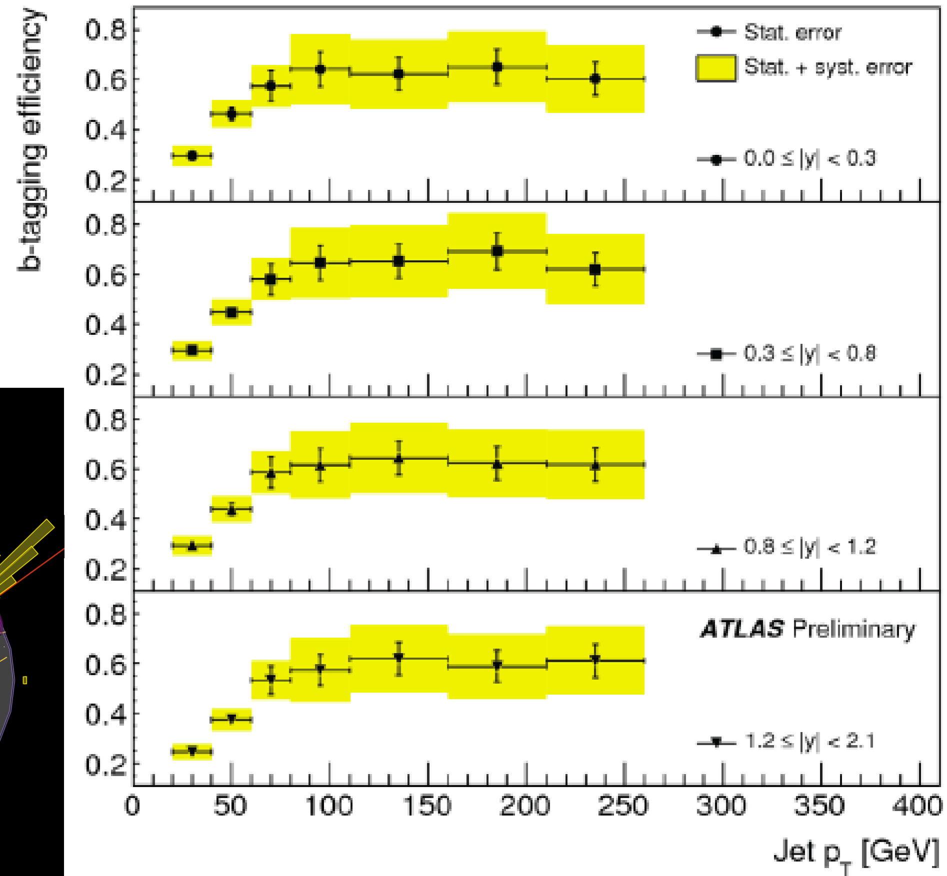




b-tagging

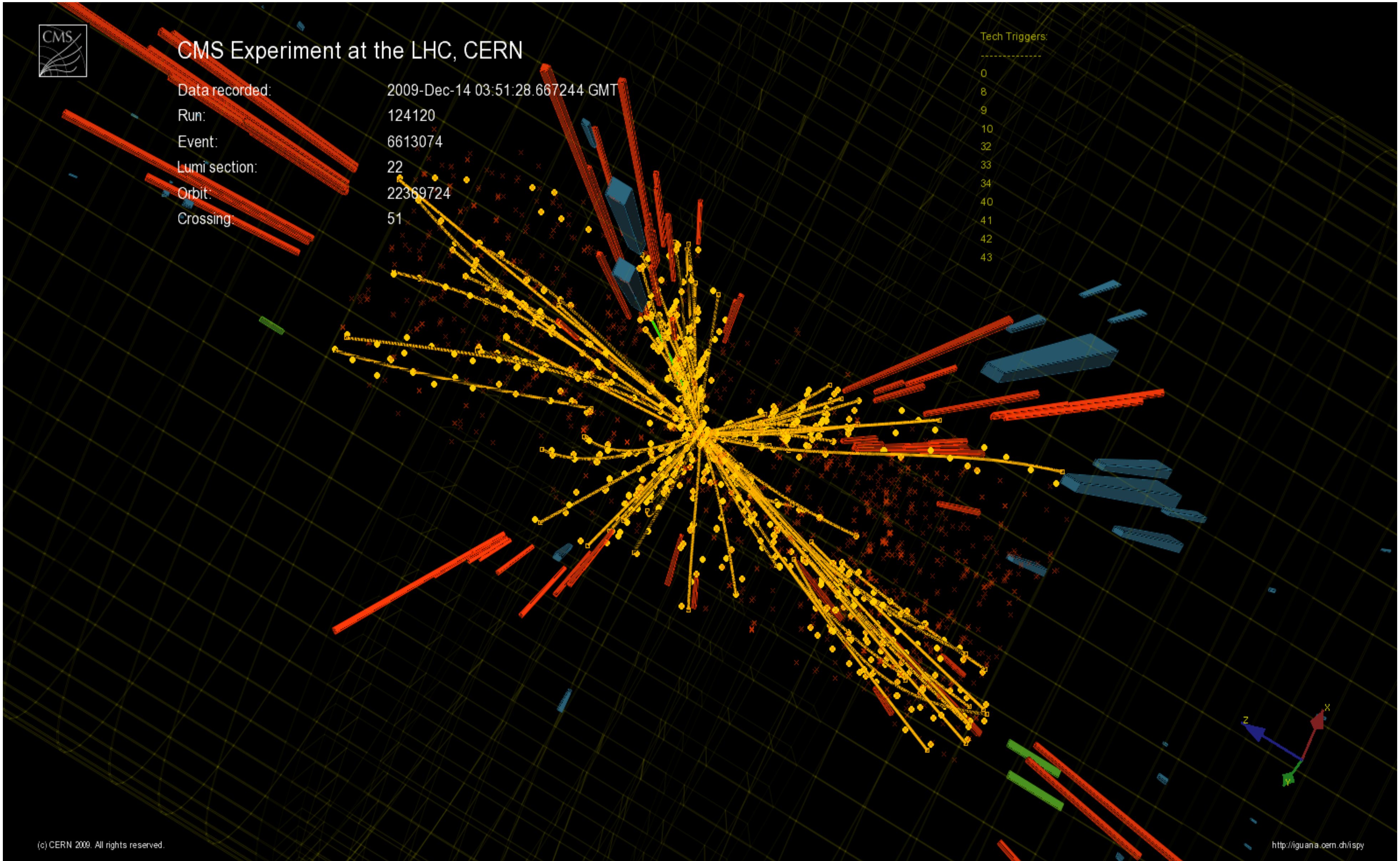
A Top Candidate Event:
eμ + 2 b-jets + MET
Ideal channel to probe detector performance





Efficiency 40-60%
Mis-tag rate : 0.2-1%

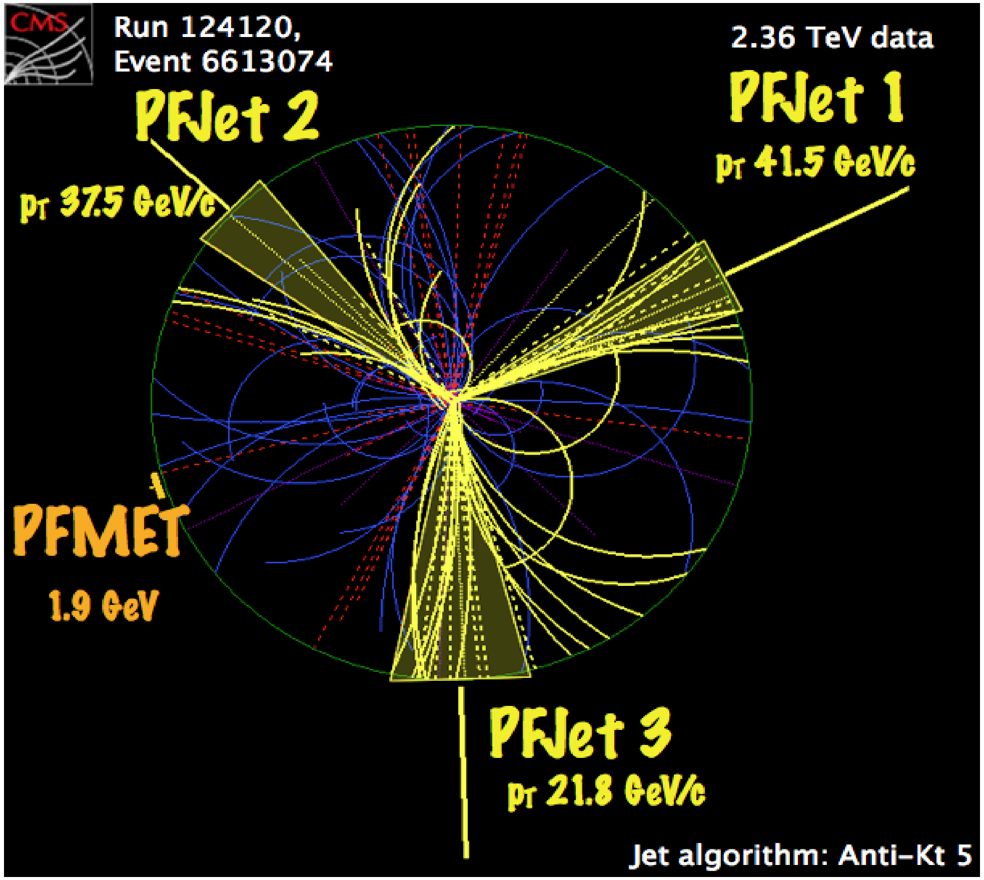
Analysing Complex Events



Combining Information from All Sub-detectors

Particle Flow aims at reconstructing all stable particles in the event, i.e., electrons, muons, photons & charged and neutral hadrons from the combined information from all CMS sub-detectors, to optimize the determination of particle types, directions and energies

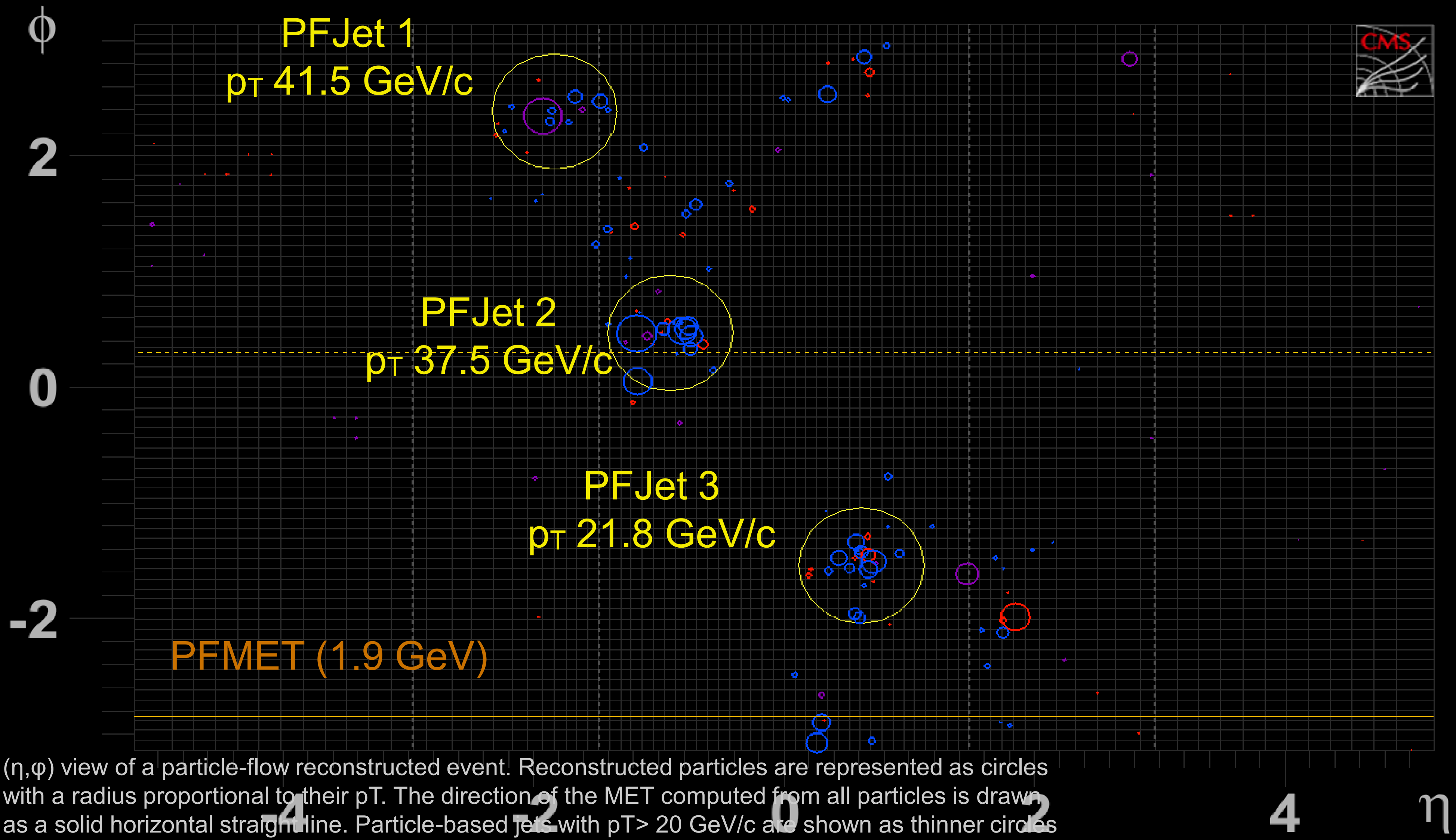
CMS is well suited for this:
- Powerful Si tracker
-EM calorimeter with fine granularity & small Moliere radius
(NB: CMS has 4T B-field & HCAL has moderate performance)



Particle Flow greatly improves CMS a performance for jets and MET

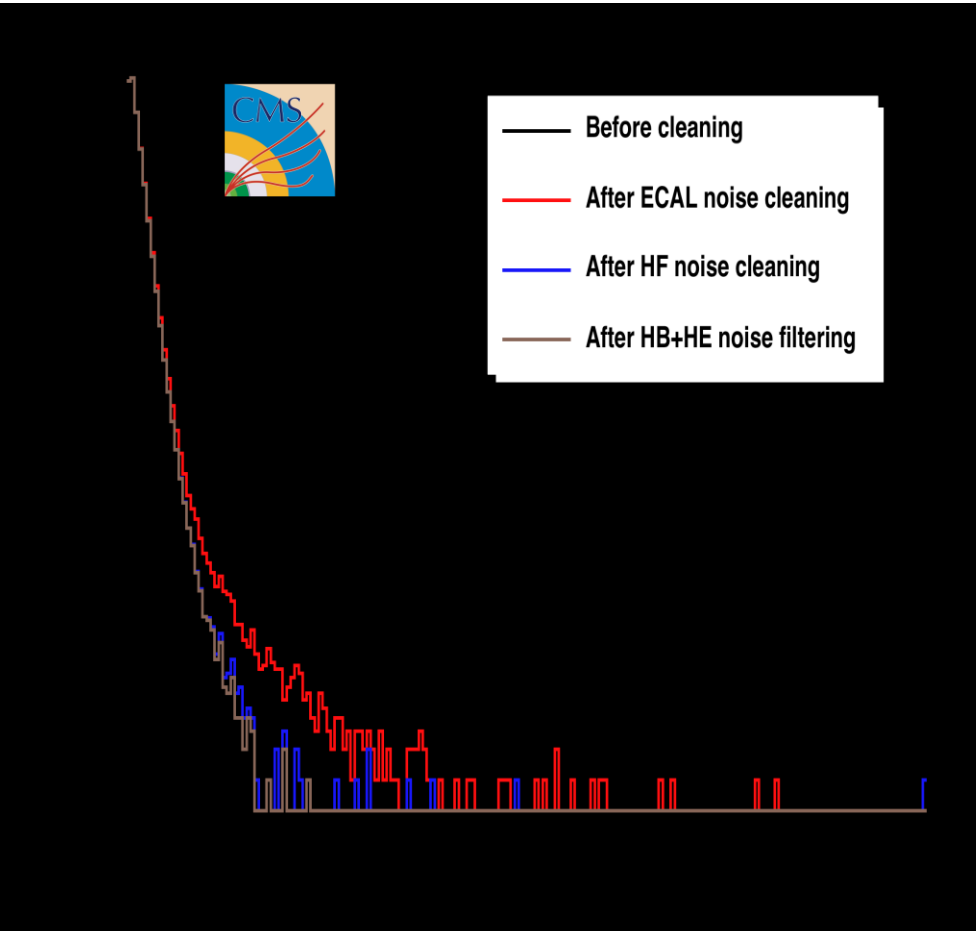
Imperial College London

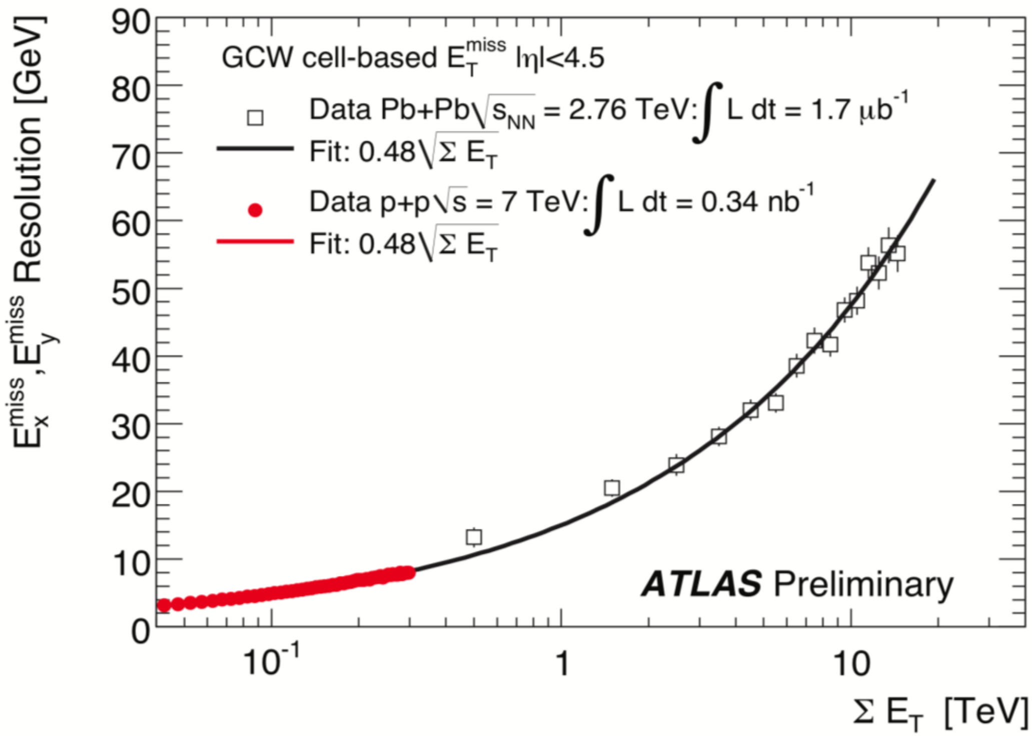
Analysing Complex Events



(η,φ) view of a particle-flow reconstructed event. Reconstructed particles are represented as circles with a radius proportional to their pT. The direction of the MET computed from all particles is drawn as a solid horizontal straight line. Particle-based jets with pT> 20 GeV/c are shown as thinner circles representing the extension of the jet in the (η,φ) coordinates.

Missing E_T Peformance





Pflow: CMS has similar MET performance

Excellent resolution and small non-gaussian tails.

Understanding all sources of erratic noise is very important for physics channels using MET.

Physics Commissioning

Standard Model Rediscovered

Soft QCD (minimum bias, underlying event, “ridge”, ..)
Production of Jets, b’s, prompt photons, J/ψ, Y, ….
W, Z production,
Top production,
….

2011 will be a year of precision SM measurements* at the LHC

* Consistent treatment of systematic and theoretical errors

The Physics

General event properties

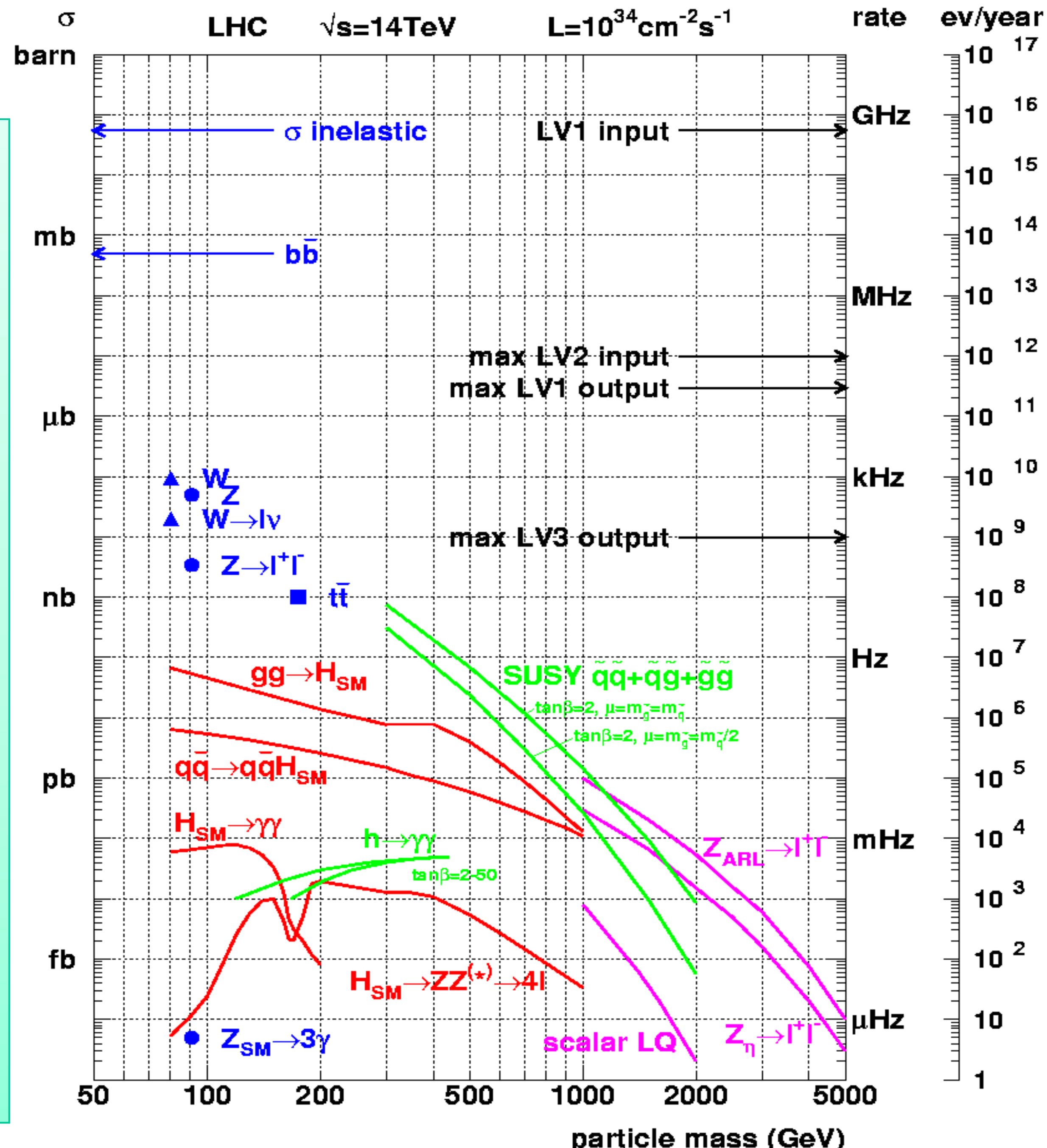
Heavy flavour physics

Standard Model physics including QCD jets

Higgs searches

Searches for SUSY

Examples of searches for ‘exotic’ new physics



Comparing Tevatron and LHC (7 TeV)

Use parton luminosties to illustrate the gain:

Example: mainly gg

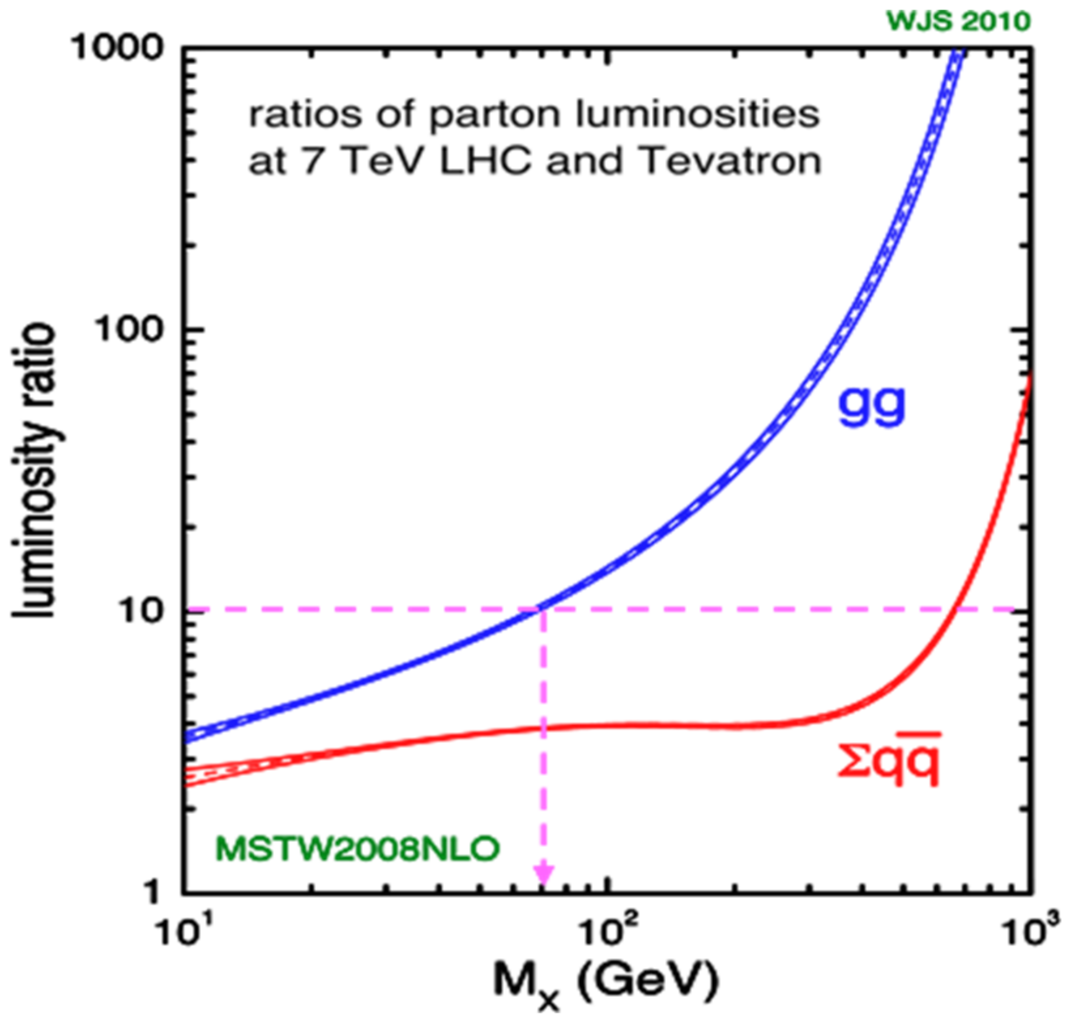
Higgs: pp → H, H→WW and ZZ
Factor ~15

Example: gg and qq

Top: (85% qq, 15% gg at Tevatron)
Factor: 0.85 x 5 + 0.15 x 100
→ ~ 20

Squarks: ~350 GeV (assume top):
Factor: 0.85 x 10 + 0.15 x 1000
→~ 150 to 200

Z′: ~1 TeV (qq)
Factor: ~ 50 to 100

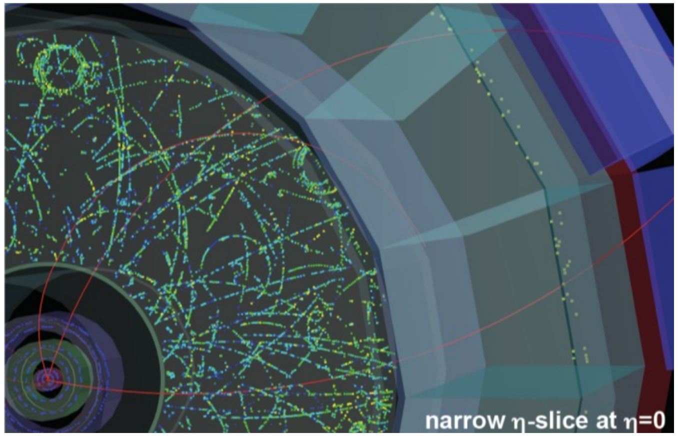


O. Buchmuller

Measurement of Charged Multiplicity: ALICE

ALICE

J. Wessels



Multiplicity and Energy density ε:

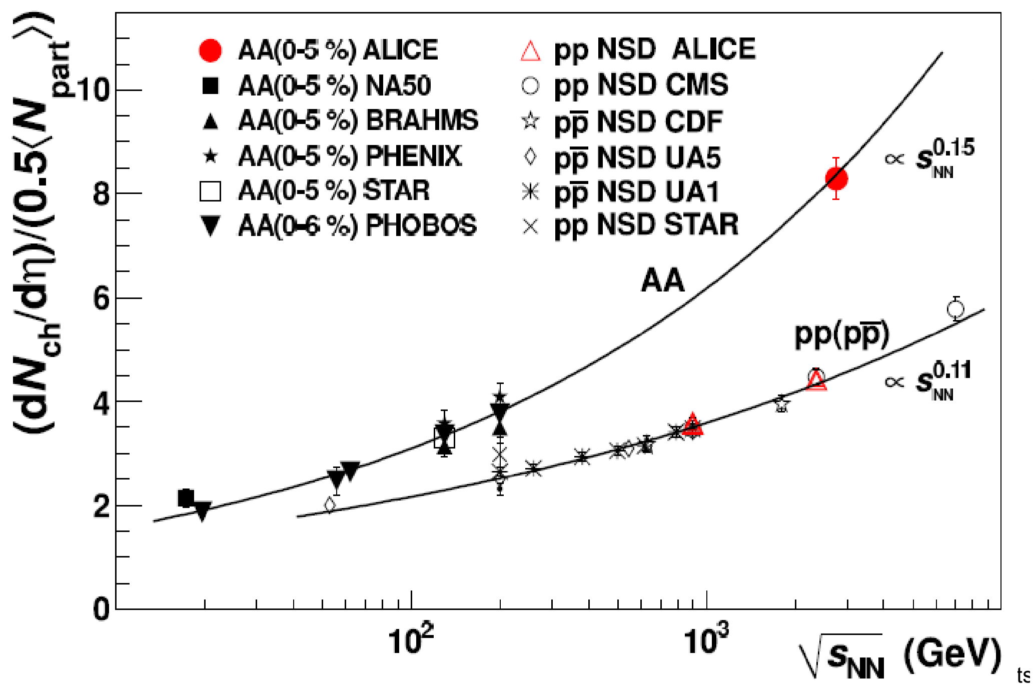
$dN_{ch}/d\eta \sim 1580 \pm 80$ (syst) for C=0-5%

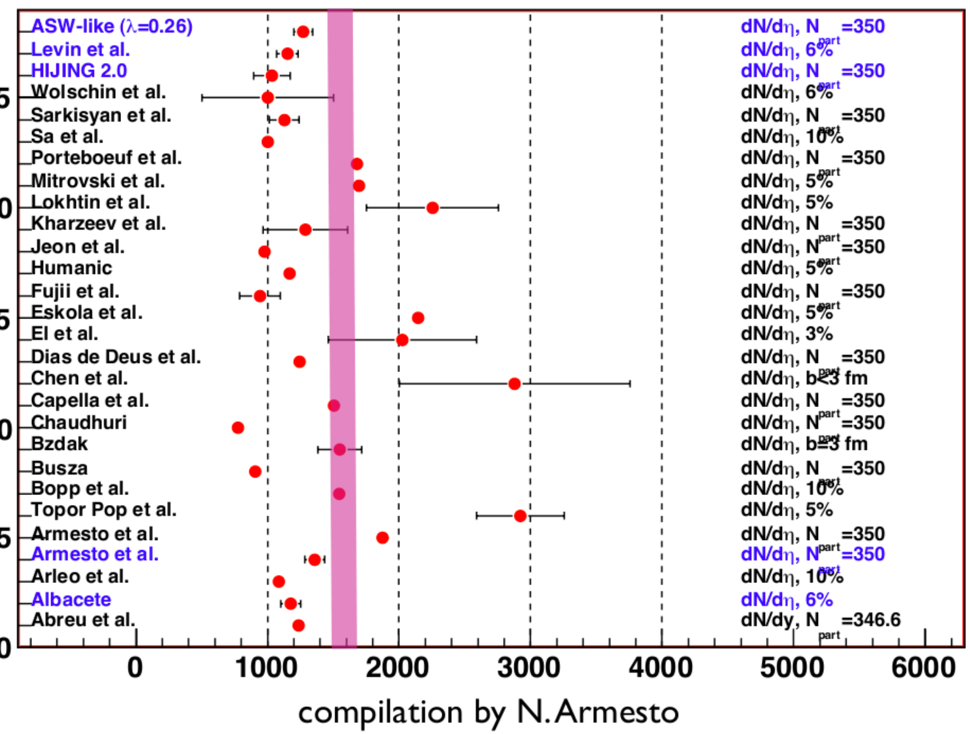
somewhat on high side of expectations

growth with √s faster in AA than pp

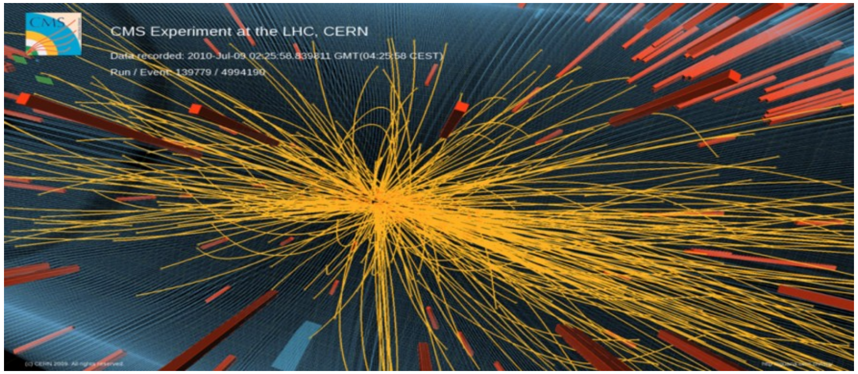
Energy density ≈ 3 x RHIC (fixed τ)

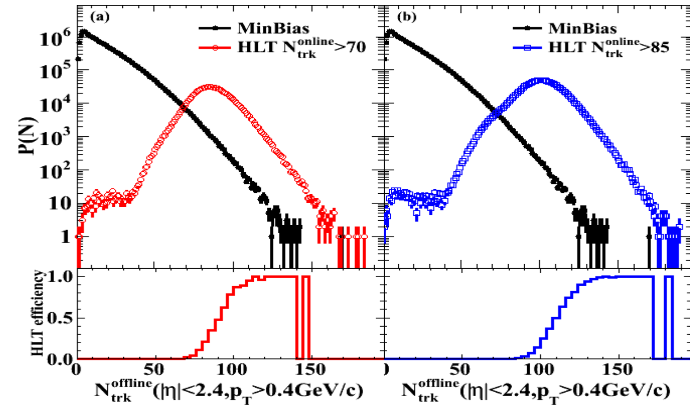
lower limit, likely τ_0(LHC) < τ_0(RHIC)

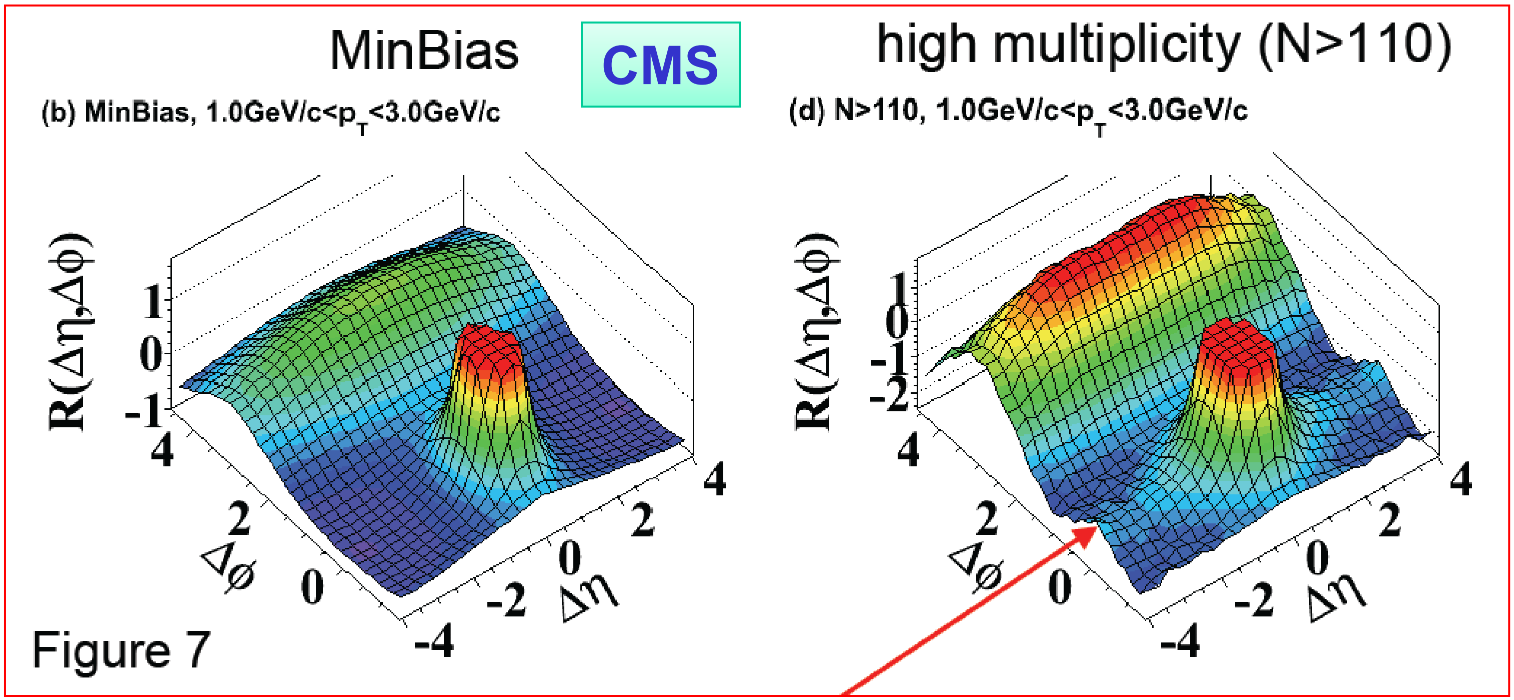




Long-range near–side angular correlations in p-p collisions: The “Ridge”

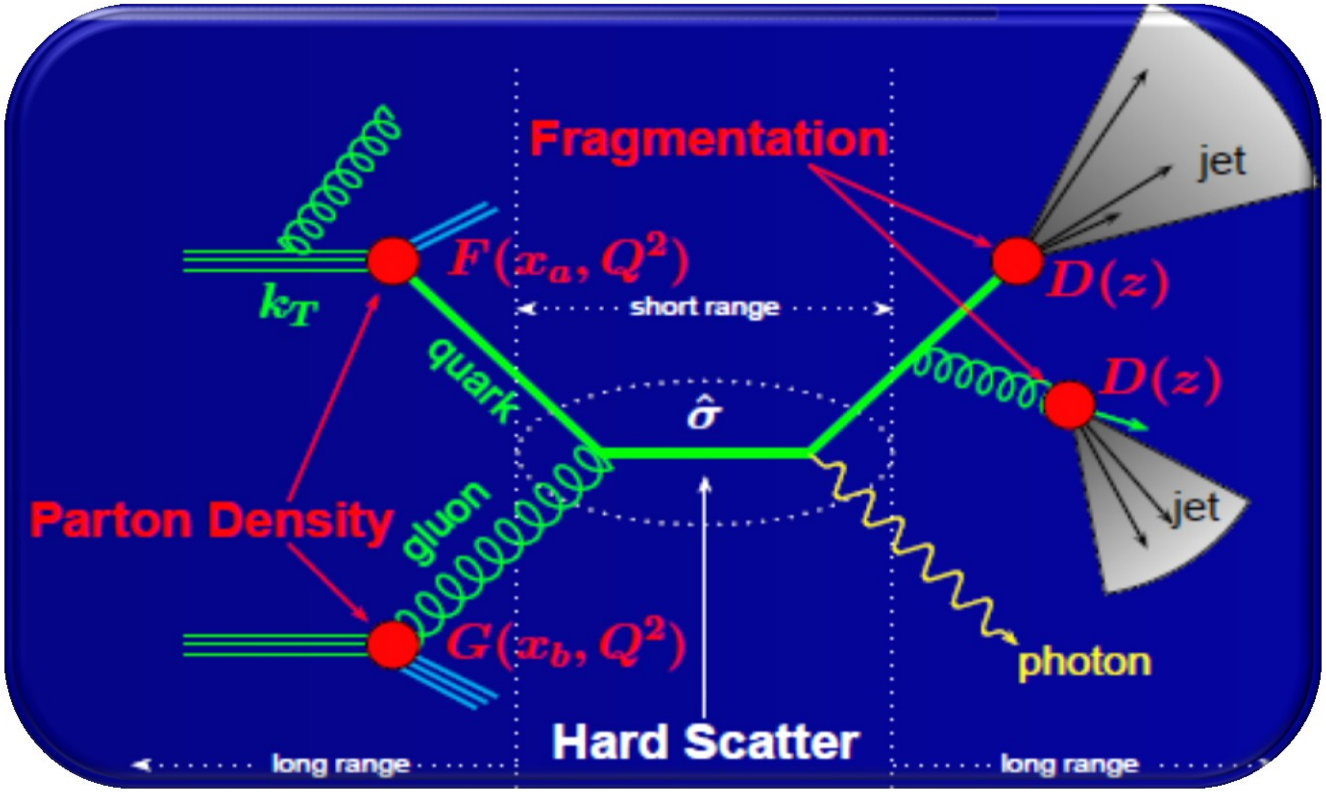






Striking “ridge” structure extending to large Δη at Δϕ ~ 0

The Hard Scatter



Jet Algorithm

Anti-k_T, R = 0.4 – 0.7

$$d_{ij} = \min(p_{ti}^{2p}, p_{tj}^{2p}) \frac{\Delta R_{ij}^2}{R^2}$$

p=-1

Typical of hard scatter

e, μ, γ : E_T > 20 GeV

Jets: E_T > 20 GeV

Isolation

E_T,p_T < thresh in cone

$$\Delta R \equiv \sqrt{\Delta\eta + \Delta\phi}$$

ΔR ~ 0.3-0.4

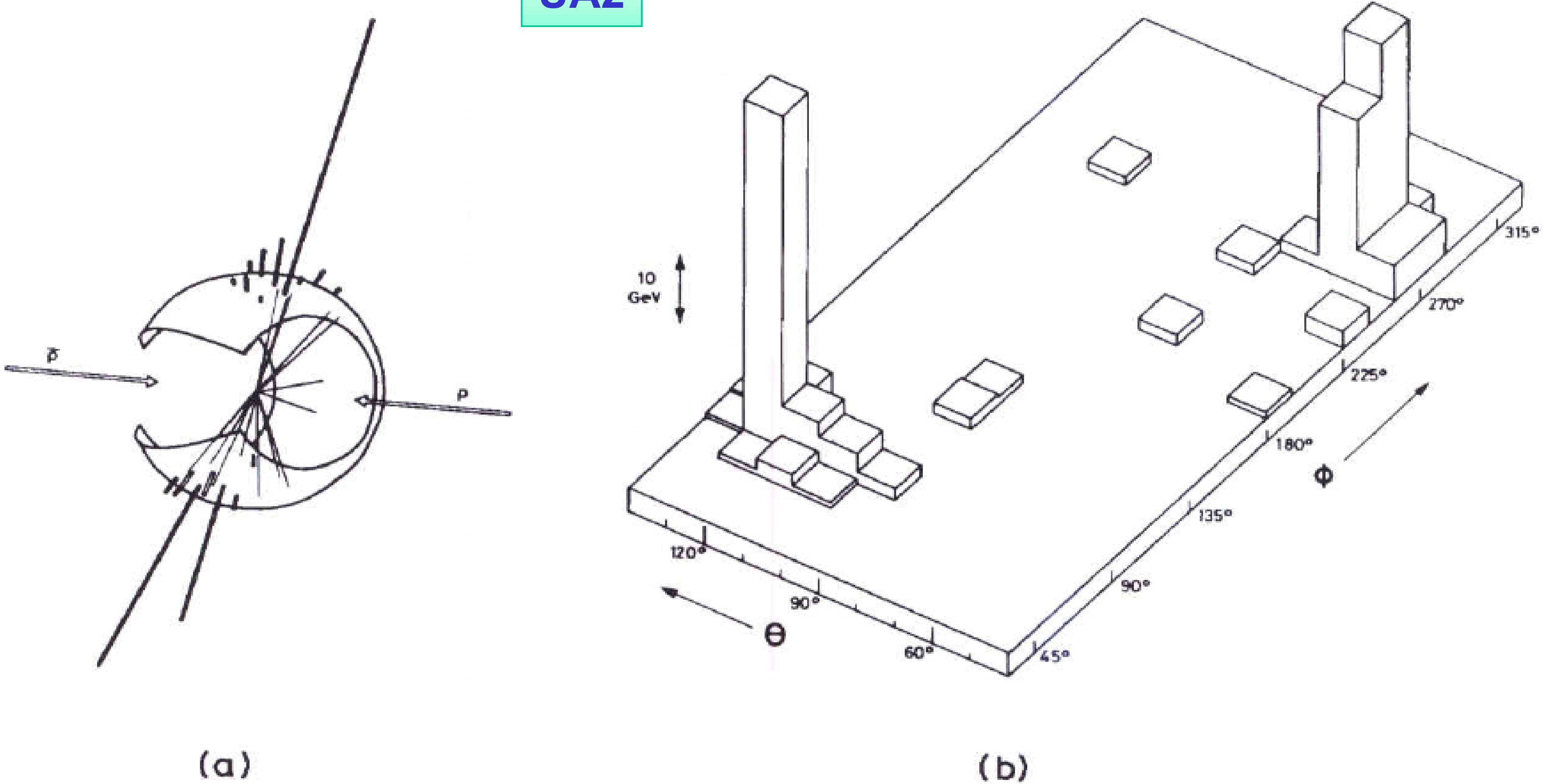
H_T - scalar sum of E_T of all jets with e.g. P_T > 30 GeV/c

S_T - scalar sum of E_T of N individual objects (jets, e, μ, γ) with e.g. E_T > 50 GeV/c

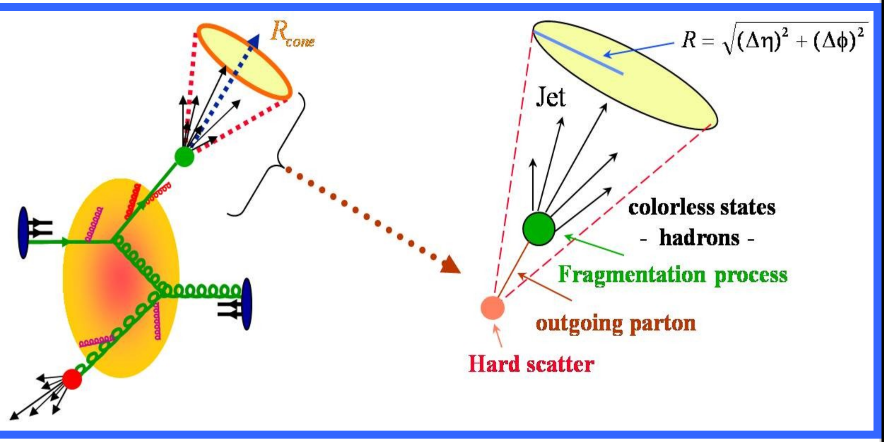
An Event Display of a first "Clear" Jet-Jet Event

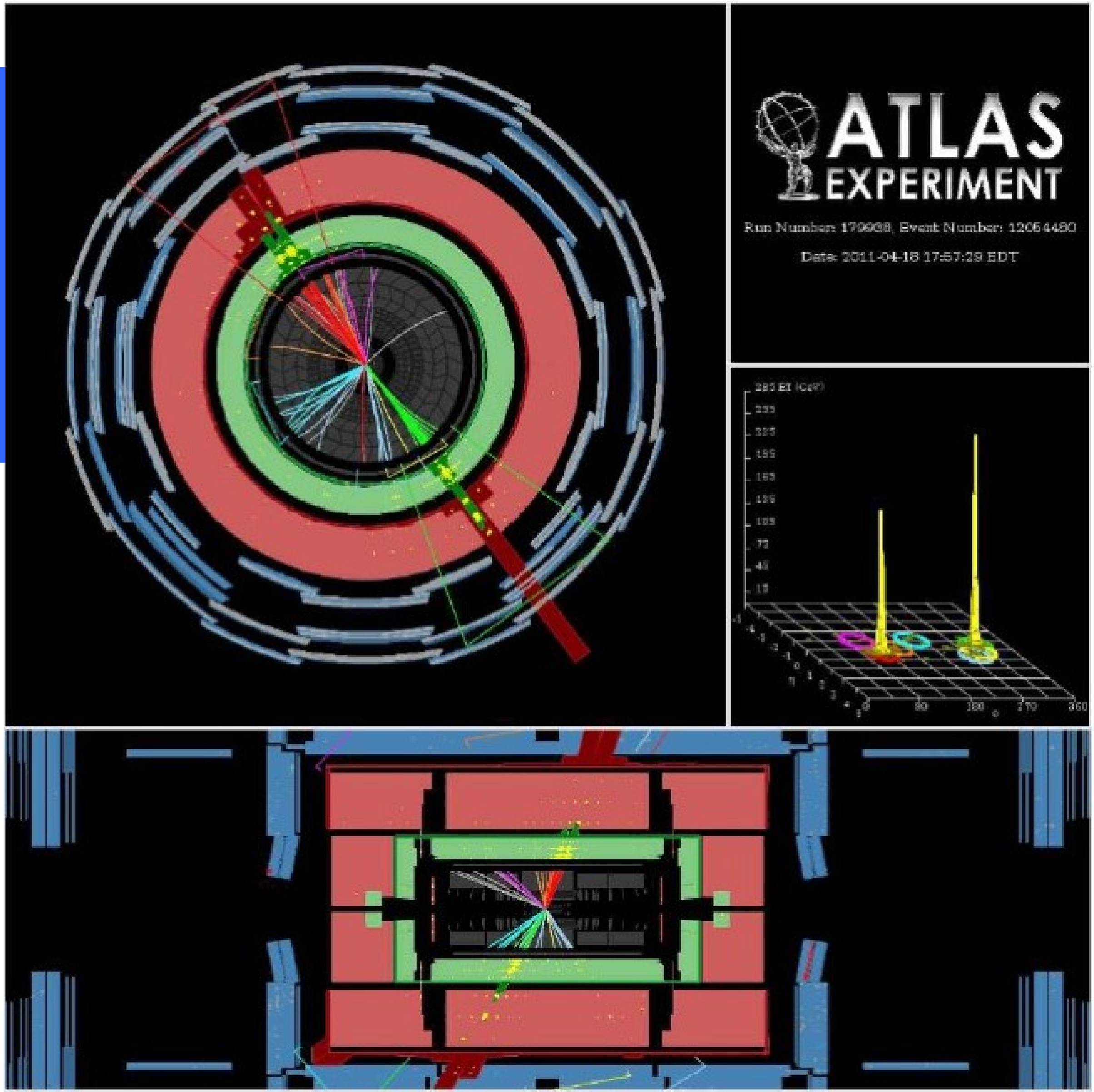
Volume 118B, number 1, 2, 3 PHYSICS LETTERS 2 December 1982

UA2



Highest Dijet Mass: M_{jj}= 4 TeV





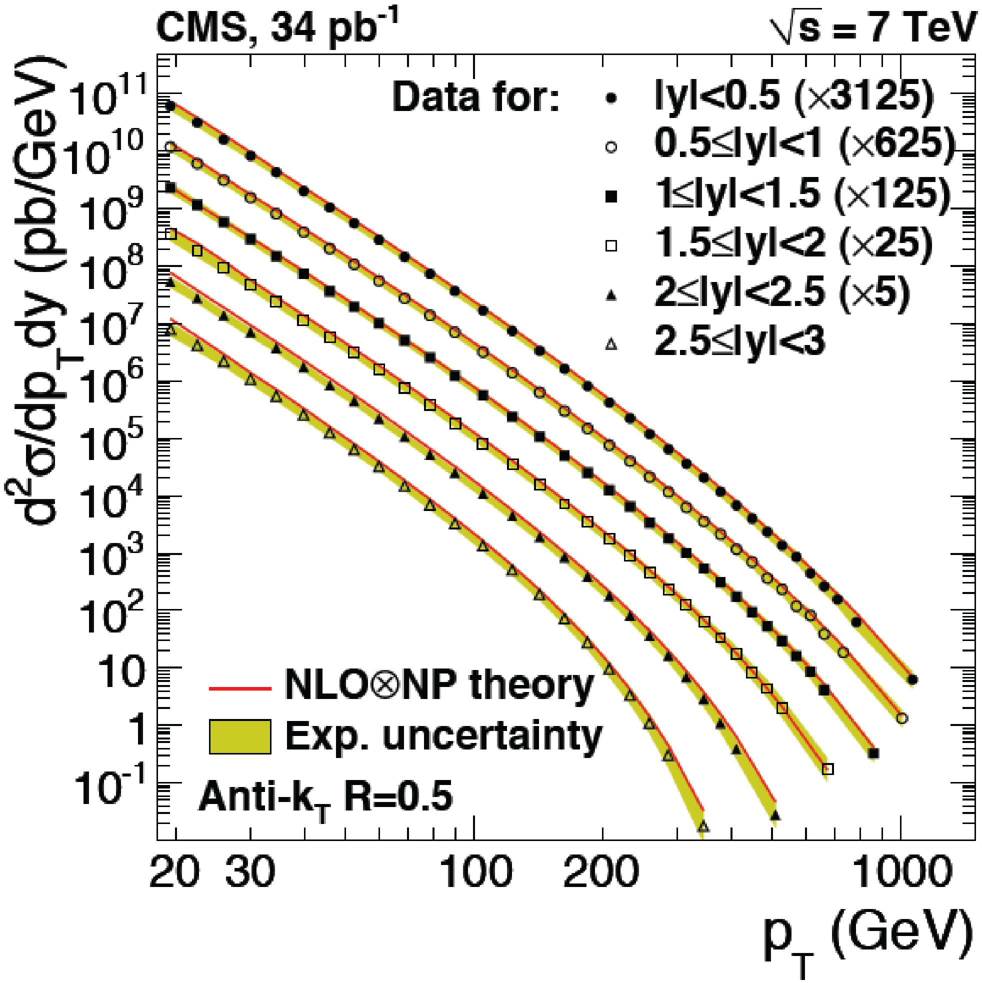
Highest Di-Jet mass in central region

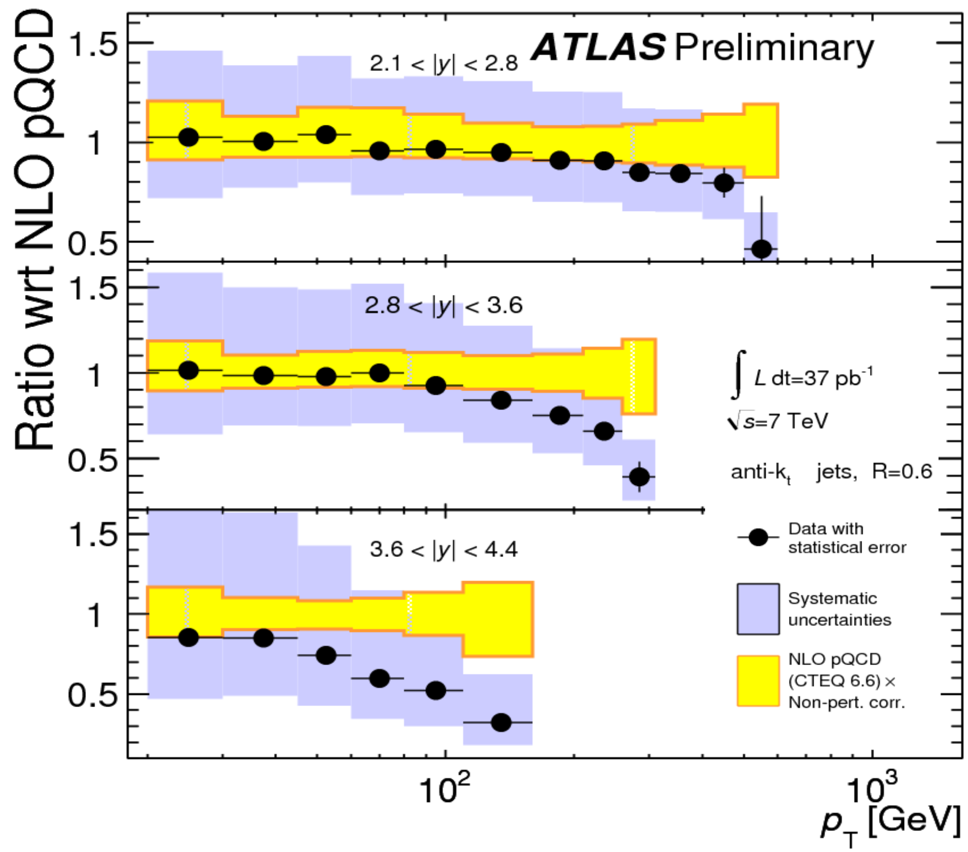
M_{jj} = 4.04 TeV

P_T^1 = 1850 GeV, η= 0.32

P_T^2 =1840 GeV, η=-0.53

Inclusive jet production





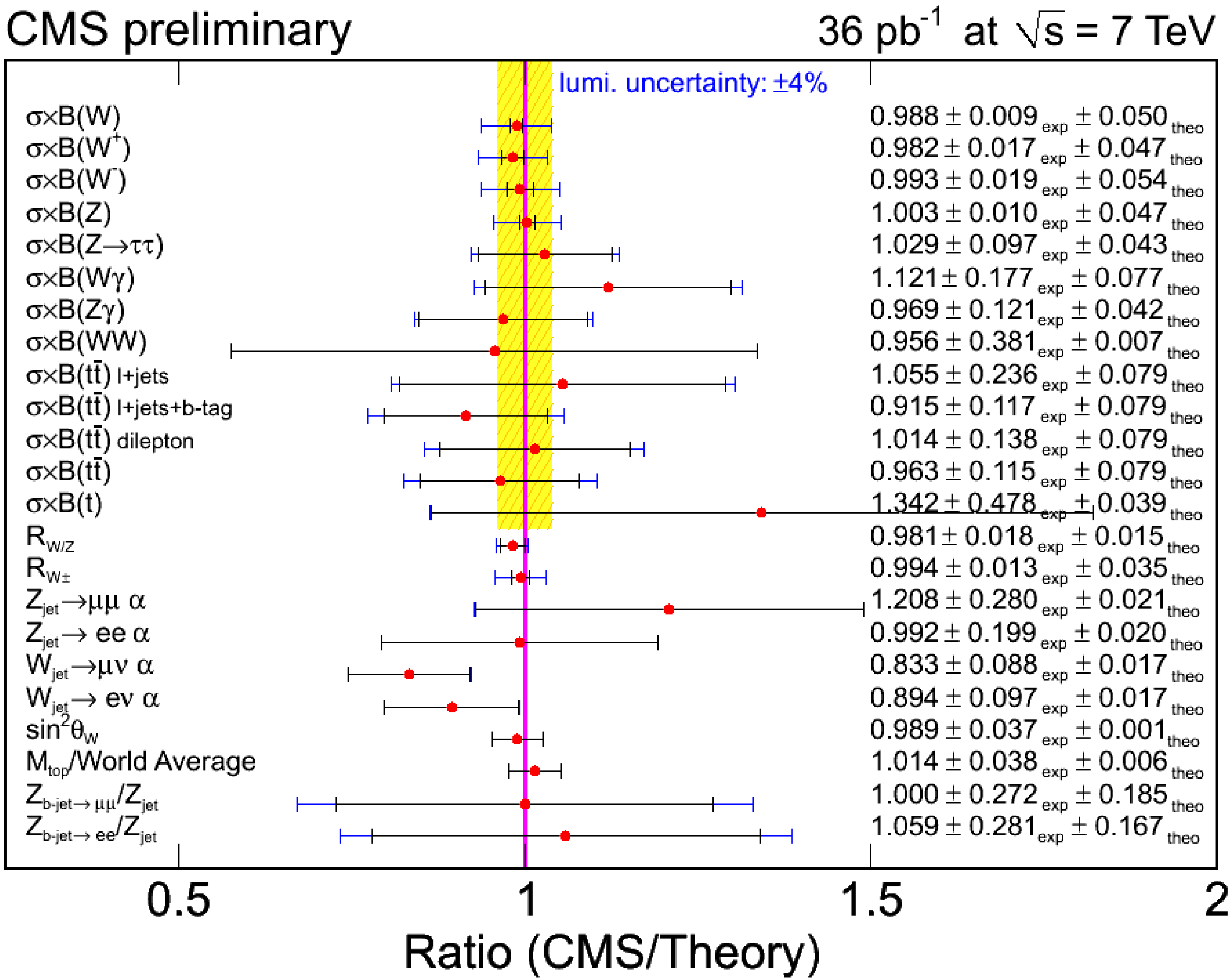
CMS: The measured jet production rate **(over 10 orders of magnitude!)** is in good agreement with pQCD predictions

ATLAS: Good agreement between data and NLO pQCD with various PDFs globally except in some specific regions, e.g. in the forward direction

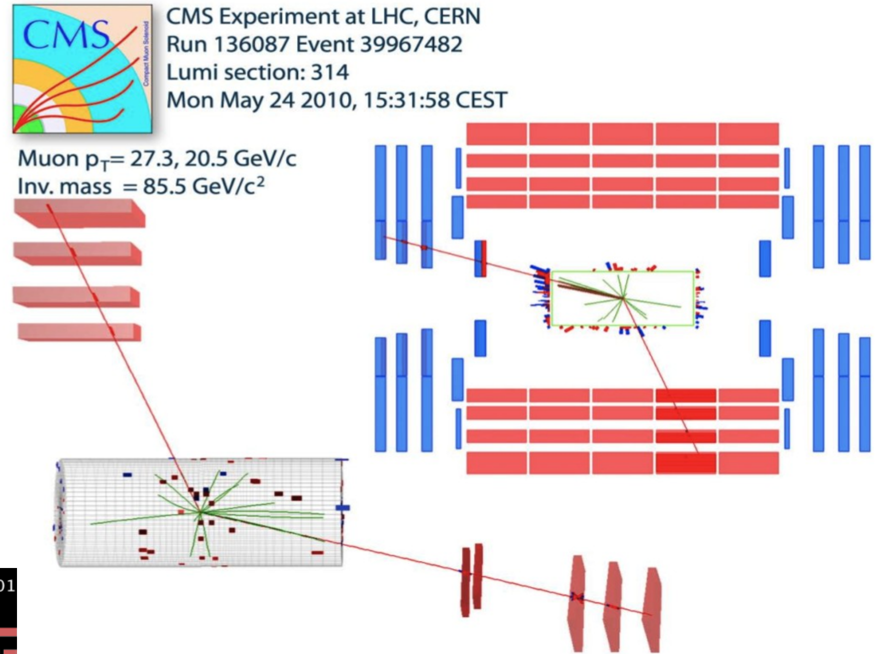
Imperial College London

PLHC 2011

SM Cross-Section Summary

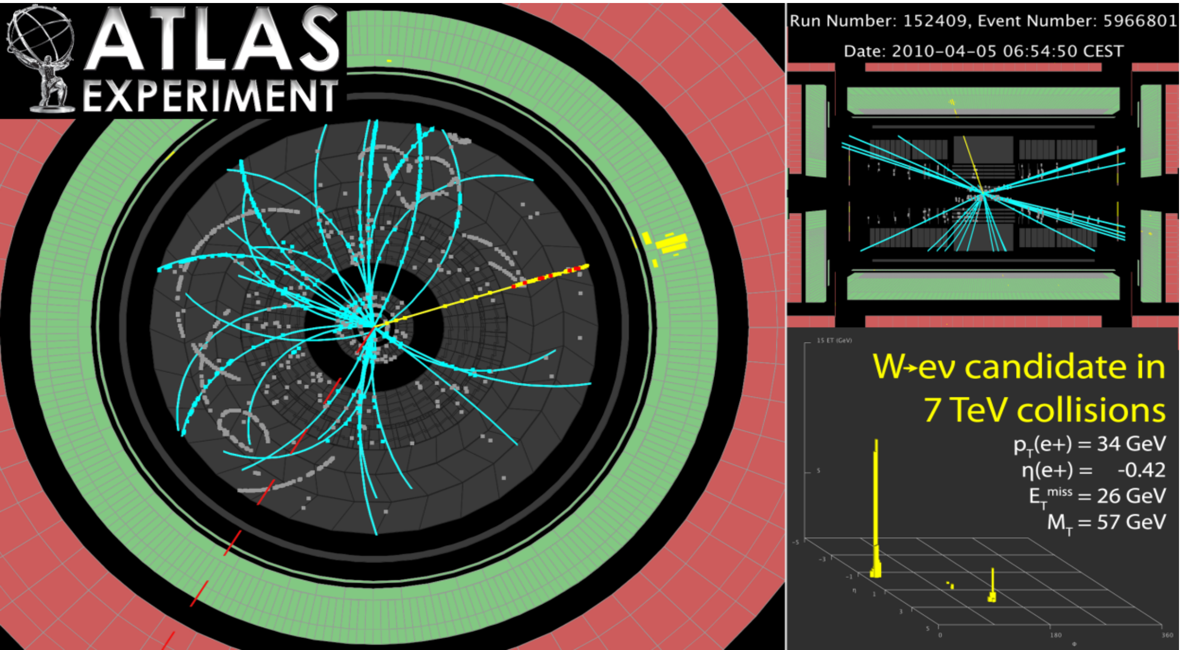


Intermediate Vector Boson Production

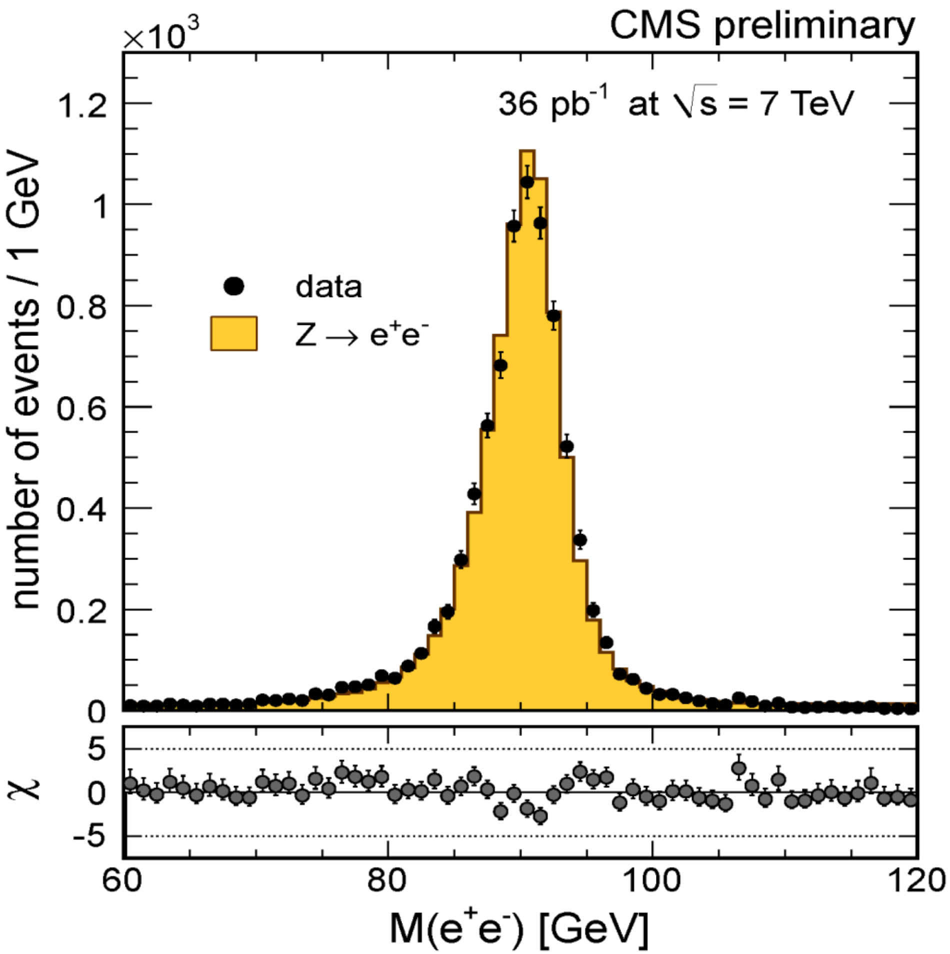


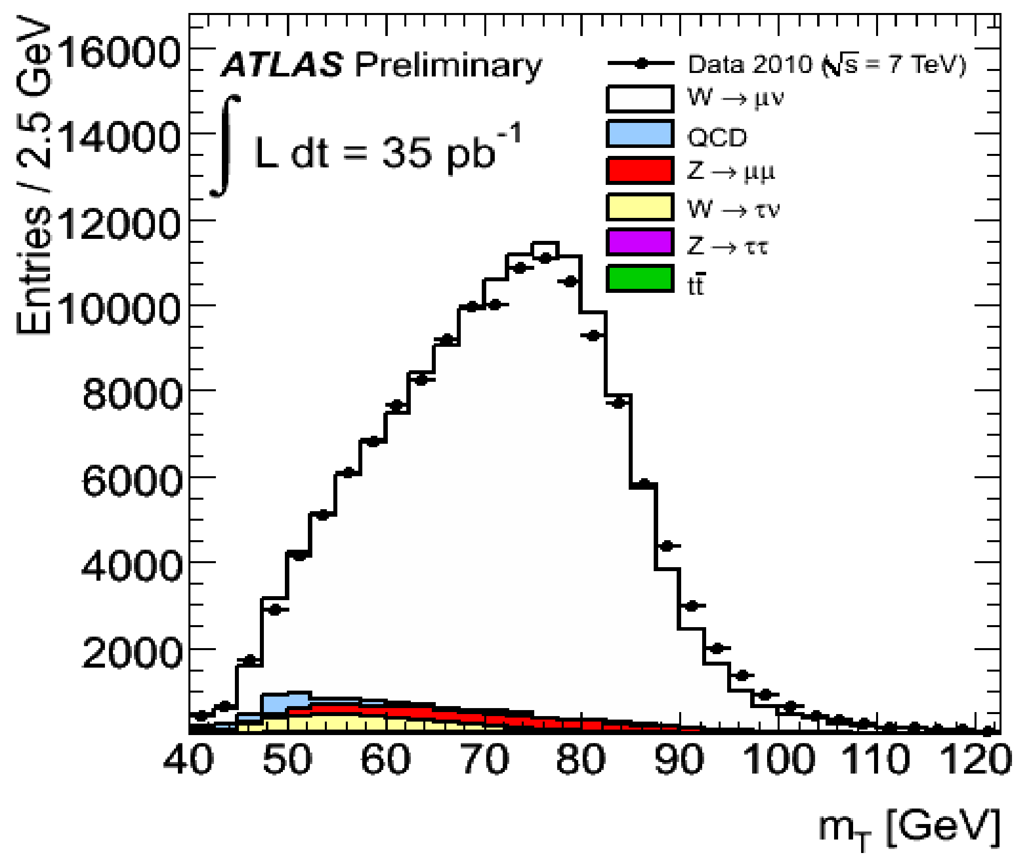
CMS candidate Z → $\mu^+\mu^-$

ATLAS W → eν candidate



Z and W production





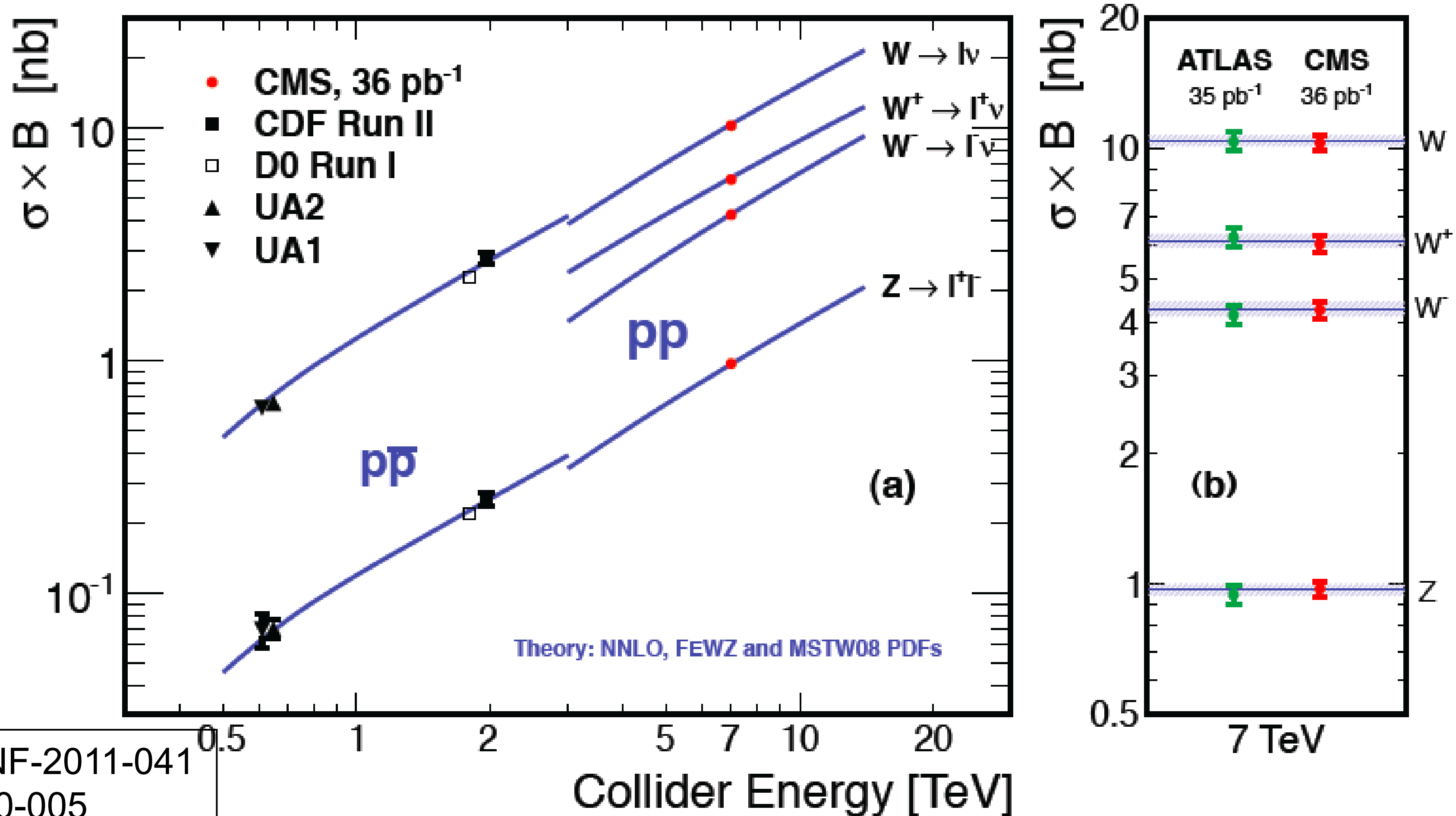
Z peak (di-lepton pair mass distributions)

$$m = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

W transverse mass

$$m_T = \sqrt{2 p_T^\ell p_T^\nu (1 - \cos(\phi^\ell - \phi^\nu))}$$

W/Z Cross-section Measurement



ATLAS-CONF-2011-041
CMS PAS 10-005

CMS: $\sigma(W+) = 6.04 \pm 0.02(stat) \pm 0.06(syst) \pm 0.08(th) \pm 0.24(lumi)$

$\sigma(W-) = 4.26 \pm 0.01(stat) \pm 0.04(syst) \pm 0.07(th) \pm 0.17(lumi)$

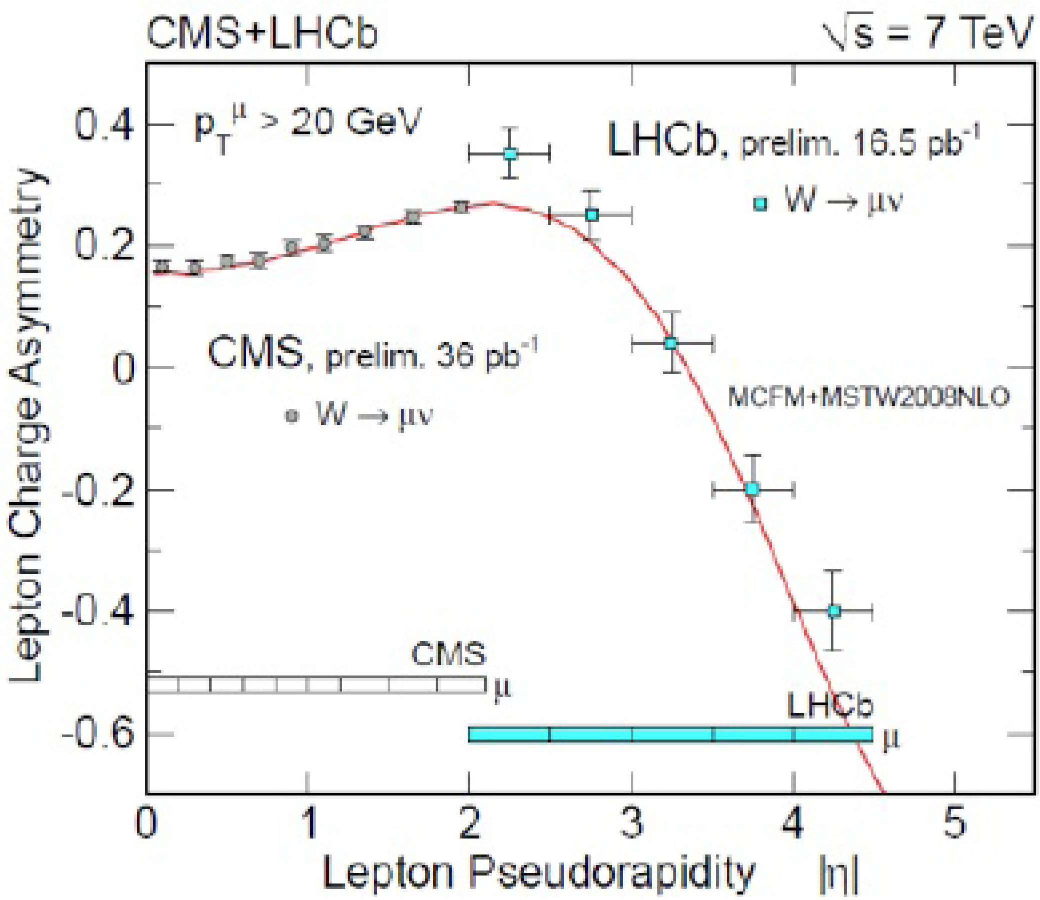
ATLAS: $\sigma(W+) = 6.257 \pm 0.017(stat) \pm 0.152(syst) \pm 0.188(acc) \pm 0.213(lumi)$

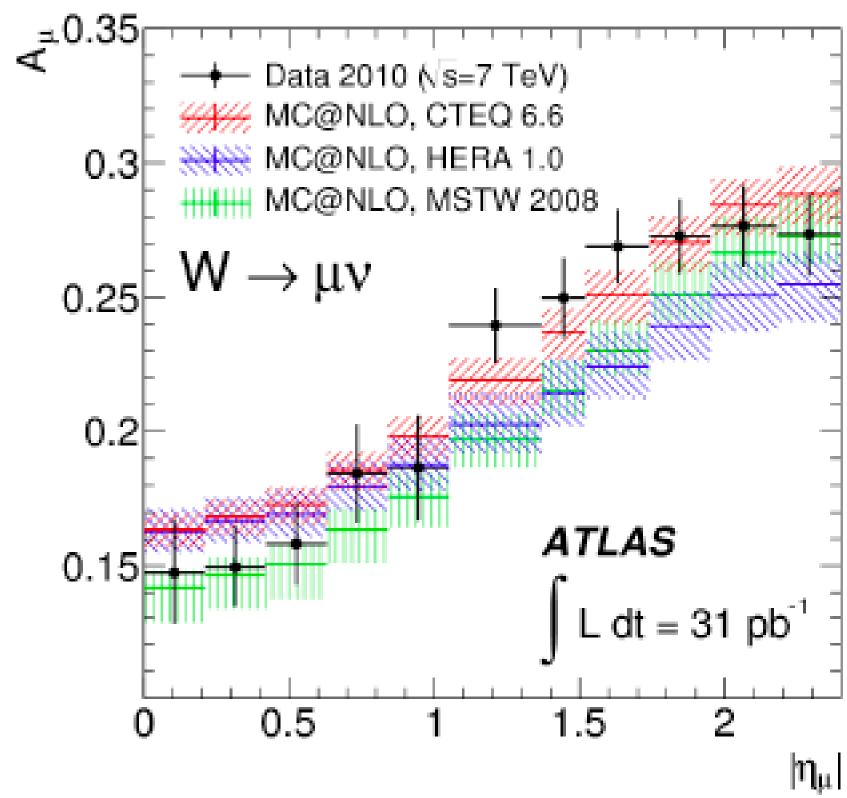
Lepton charge asymmetry from W decays

- Probes both valence and sea distributions

F. Petriello

$$A_W(y) = \frac{N_{W+}(y) - N_{W-}(y)}{N_{W+}(y) + N_{W-}(y)} \Rightarrow A_\ell(\eta) = \frac{N_{\ell+}(\eta) - N_{\ell-}(\eta)}{N_{\ell+}(\eta) + N_{\ell-}(\eta)}$$



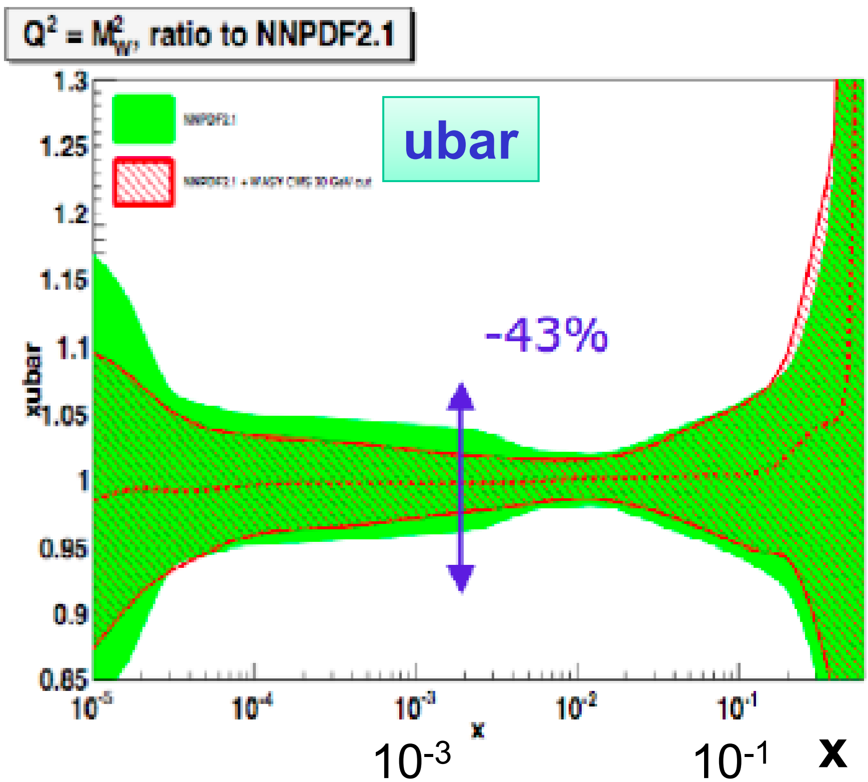


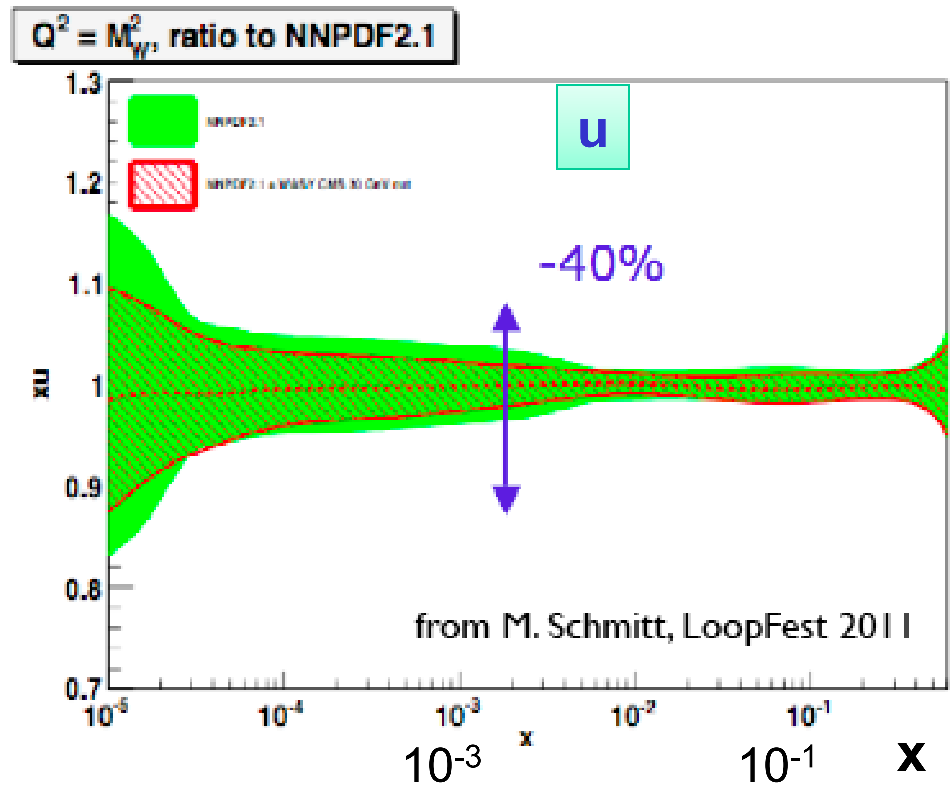
Lepton charge asymmetry from W decays

- Probes both valence and sea distributions

F. Petriello

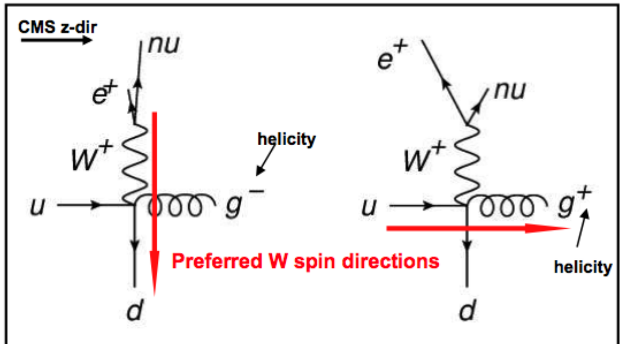
$$A_W(y) = \frac{N_{W+}(y) - N_{W-}(y)}{N_{W+}(y) + N_{W-}(y)} \Rightarrow A_\ell(\eta) = \frac{N_{\ell+}(\eta) - N_{\ell-}(\eta)}{N_{\ell+}(\eta) + N_{\ell-}(\eta)}$$



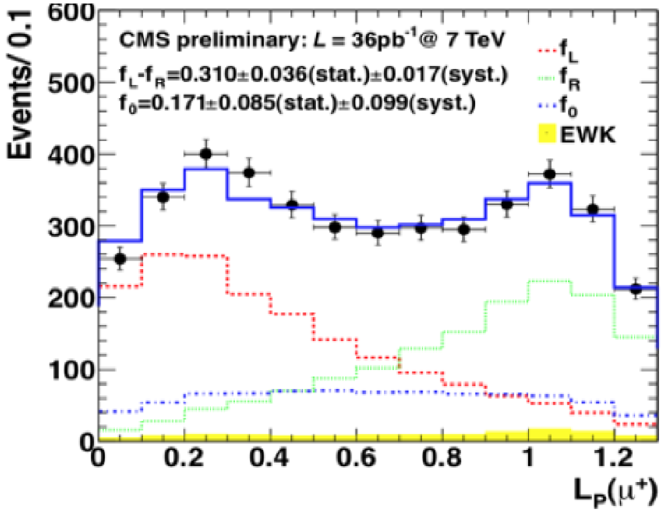


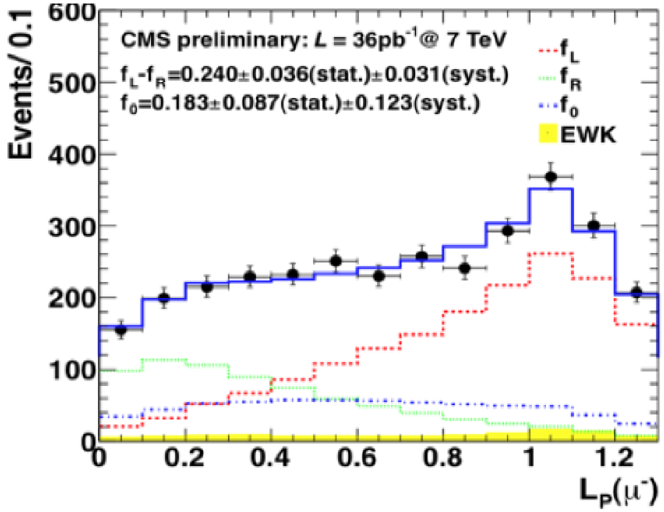
Already entering PDF determinations

Measurement of W polarization at a hadron Collider



W+1jet dominant production mechanism at LHC (not a Feynman diagram)





$$\mathrm{LP} = \frac{\vec{P}_T(\ell)\cdot\vec{P}_T(W)}{|\vec{P}_T(W)|^2}$$

comb: $(f_L - f_R)^-$	0.226 $\pm$ 0.031 (stat.) $\pm$0.050 (syst.)	***MC: 0.242***
comb: f_0^-	0.162 $\pm$ 0.078 (stat.) $\pm$0.136 (syst.)	***MC: 0.215***
Correlation (stat)	0.304 (stat.)	
comb: $(f_L - f_R)^+$	0.300 $\pm$ 0.031 (stat.) $\pm$0.034 (syst.)	***MC: 0.322***
comb: f_0^+	0.192 $\pm$ 0.075 (stat.) $\pm$0.089 (syst.)	***MC: 0.225***
Correlation (stat)	-0.660 (stat.)	

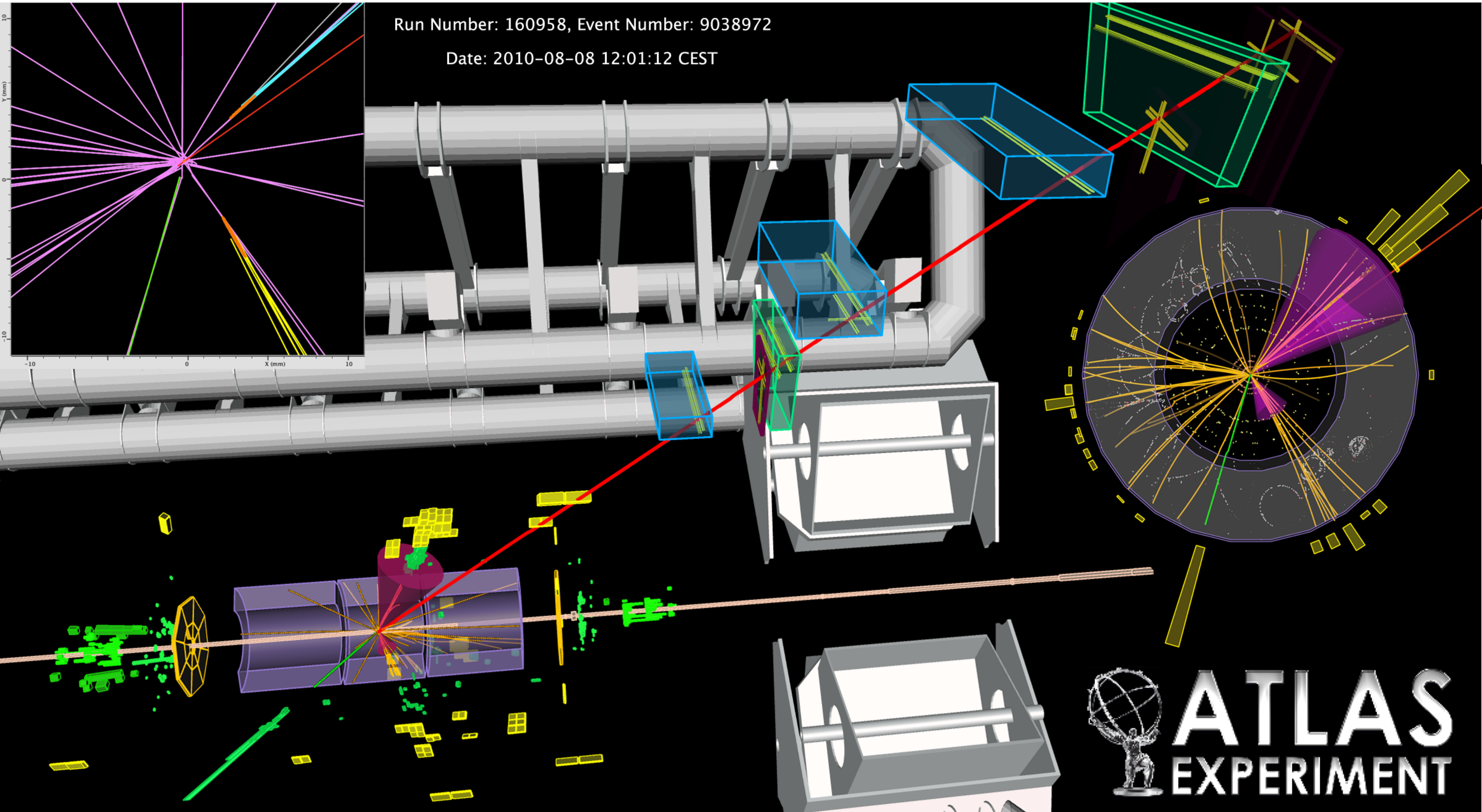
High P_T W bosons are predominantly left handed

G. Tonelli

arXiv:1103.3470 submitted to JHEP

Imperial College London

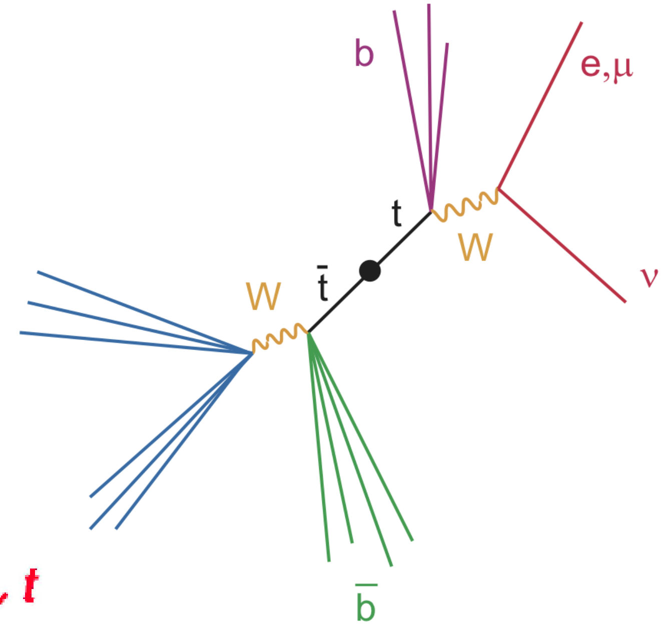
ATLAS: A Top Candidate Event: eμ + 2 b-jets + MET

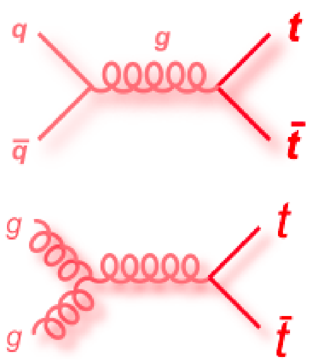


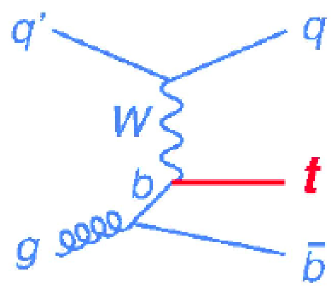
Top Production

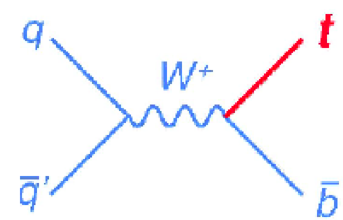
- Set of ingredients to investigate production of ttbar :
  - e, μ, E_T^{miss}, jets, b-tag
  - Good test of performance of detectors

- Of interest for top analysis:
  - one lepton (e or μ), E_T^{miss}, jjbb (37.9%)
  - di-lepton (ee, μμ or eμ), E_T^{miss}, bb (6.46%(









A. Garcia-Bellido

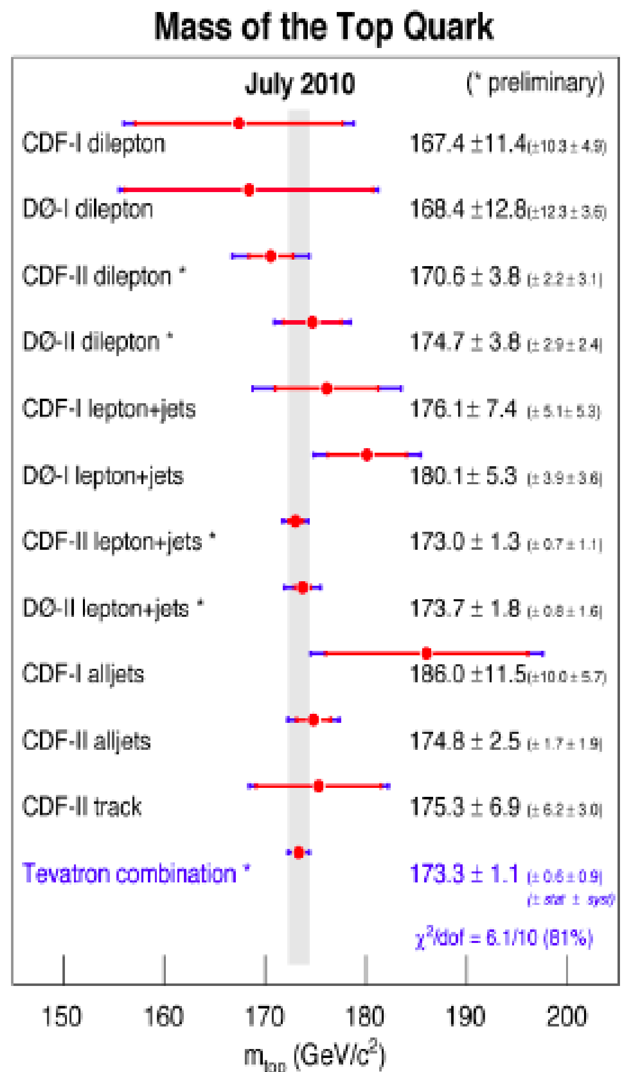
	$t\bar{t}$	t-channel	s-channel
TeV:	7.1±0.4 pb	2.1±0.1 pb	1.1±0.1 pb
LHC7:	163±11 pb	64±2 pb	4.6±0.2 pb
LHC14:	920±60 pb	243±6 pb	11.9±0.4 pb

Kidonakis NNLL m_t = 173 GeV with MSTW 2008 PDFs

Imperial College London

16 Years at the Top at the Tevatron

- Impressive list of measurements
- We know:
  - m_t = 173.3±1.1 GeV
  - $\Delta m = m_t - m_{\bar{t}}$ = 3.8±3.7 GeV
  - $\sigma(tt)$ = 7.0±0.6 pb
  - $\sigma(t)$ = 2.7 ± 0.6 pb
  - $|V_{tb}|$ = 0.88±0.07
  - Longitudinally polarized W: f_0=0.67±0.08(stat)±0.07(sys) [f_0(SM)=0.7]
  - Charge: exclude -4/3e @ 95% CL
  - Γ_t = 2.0±0.7 GeV [Γ_t(SM) = 1.3 GeV]
  - Spins in $t\bar{t}$ are correlated: C=0.57±0.31
  - $c\tau$ < 52.2 μm @ 95% CL
  - … and many limits on new physics



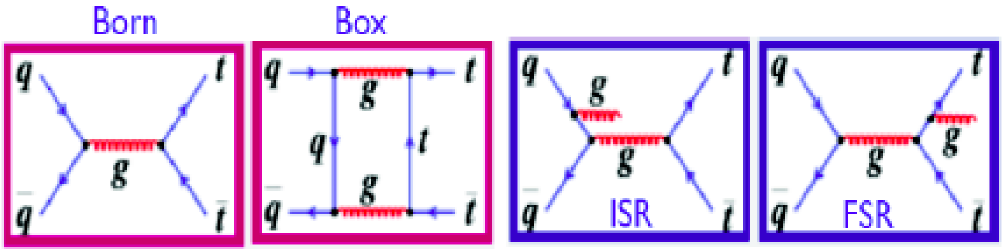
A. Garcia-Bellido

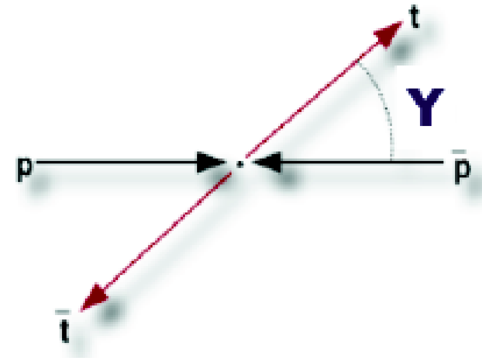
http://www-cdf.fnal.gov/physics/new/top/top.html
http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html

Top Charge Asymmetry at Tevatron

A. Garcia-Bellido

- LO: top quark production angle is symmetric wrt beam direction

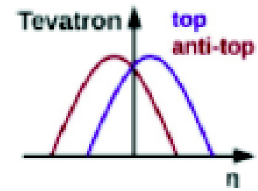




$\Delta y = y_t - y_{\bar{t}}$

- NLO: forward-backward asymmetry A_{fb}~5% due to interference effects

$$A_{fb} = \frac{N^{\Delta y>0} - N^{\Delta y<0}}{N^{\Delta y>0} + N^{\Delta y<0}}$$



D0: A_{fb} = 8±4 % A_{fb}^{SM} = 1±2 %

~2 sigma discrepancy

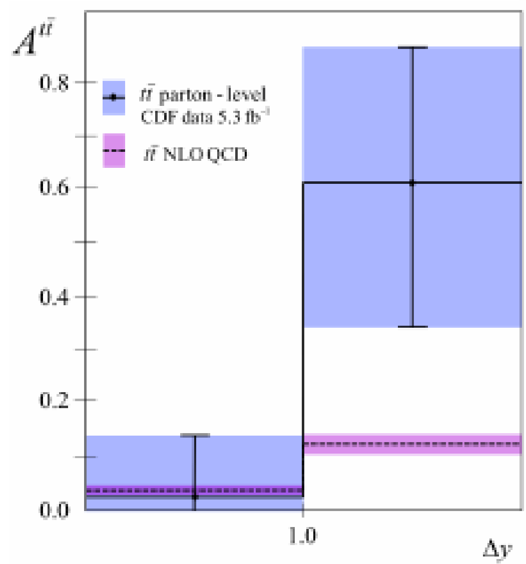
CDF: A_{fb}^{lj} = 16±7 % A_{fb}^{SM} = 6±1 %

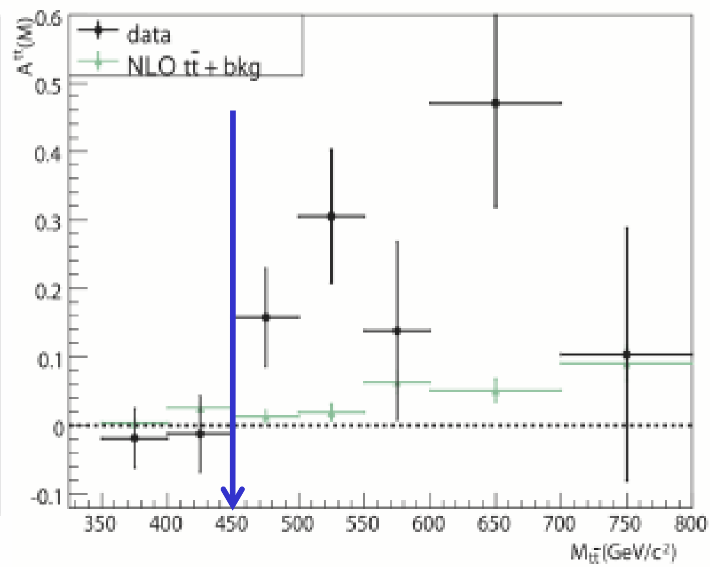
~2 sigma discrepancy

A_{fb}^{ll} = 42±16 % A_{fb}^{SM} = 6±1 %

~2.3 sigma discrepancy

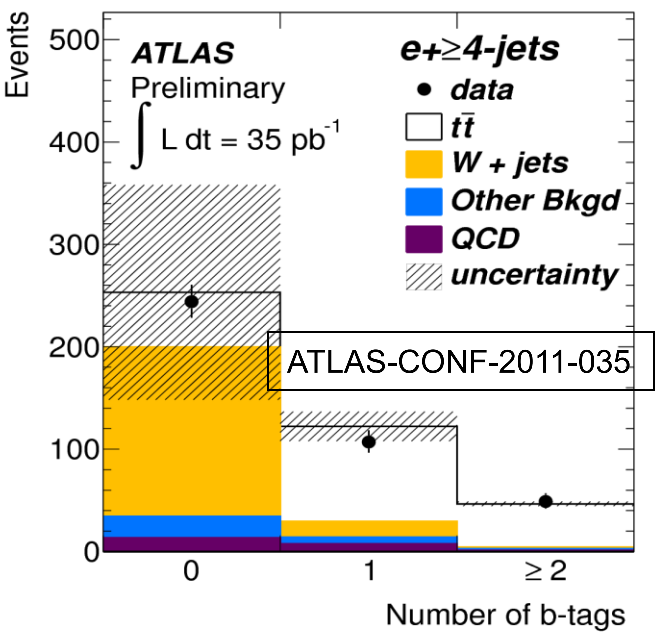
Soft QCD? New Physics?

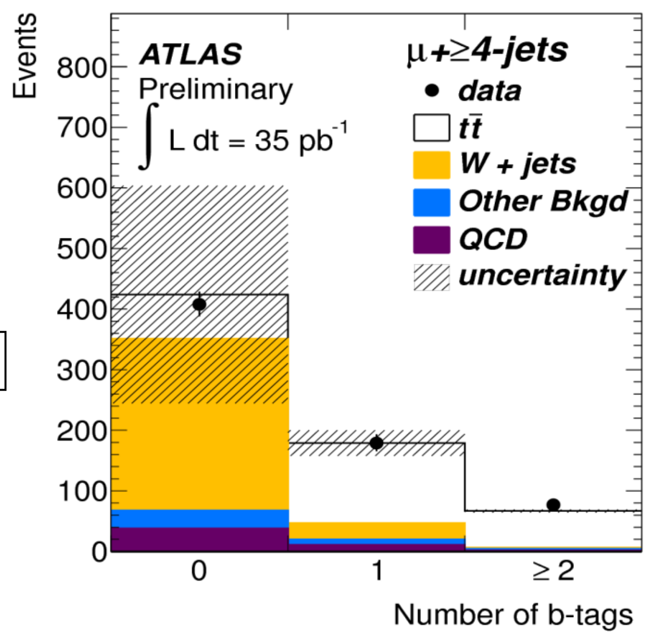




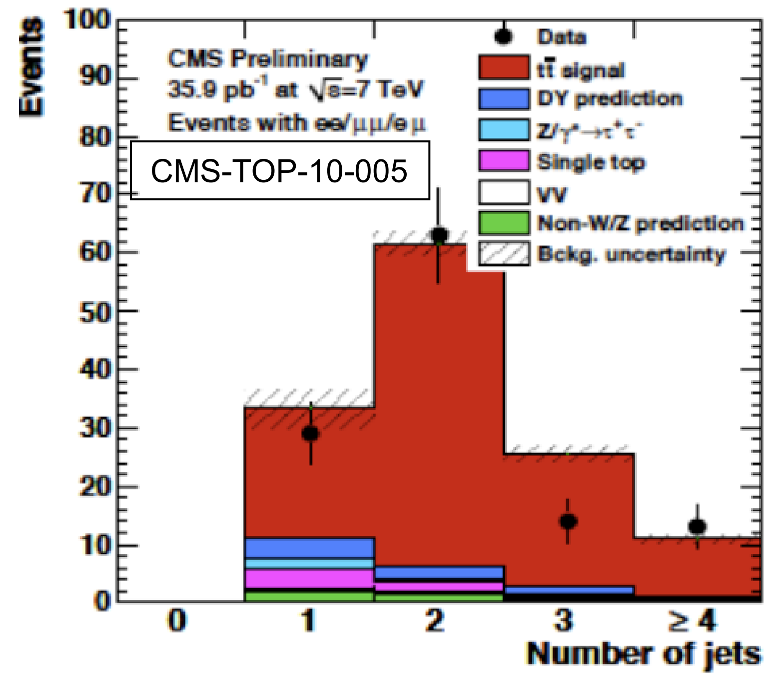
Top at the LHC !

1 lepton + 4 jets + $E_T$miss





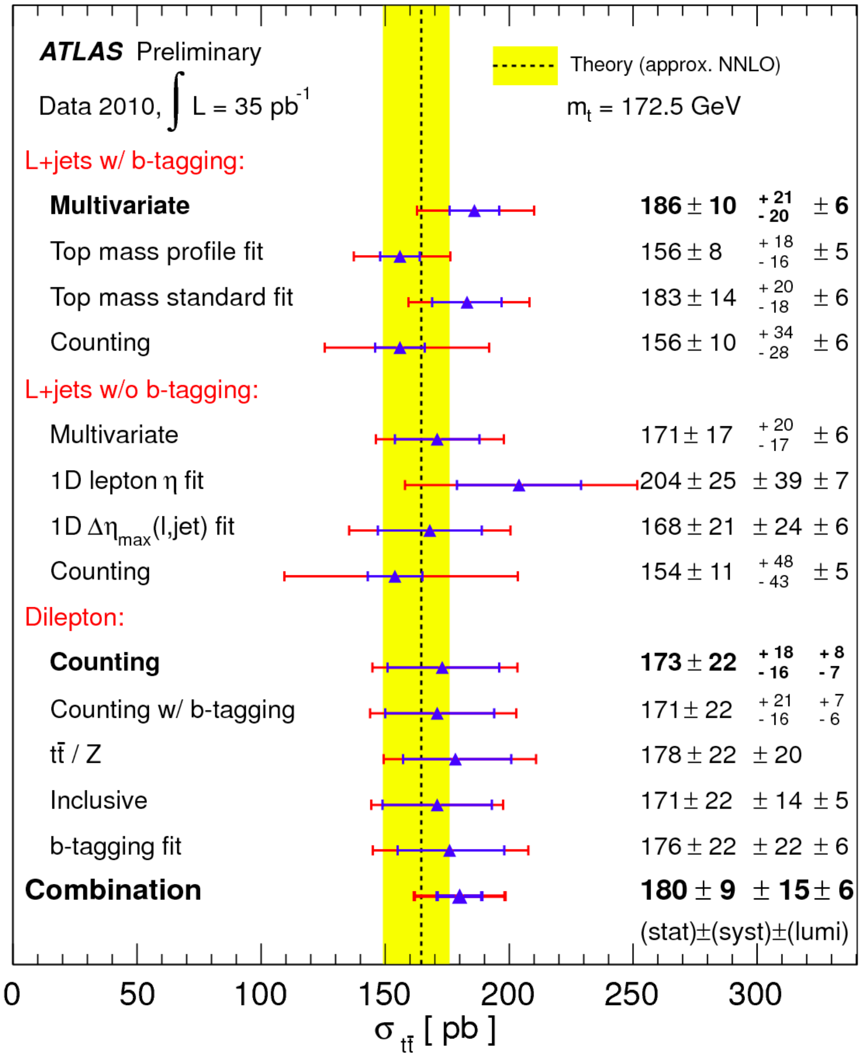
2 leptons + jets + ETmiss

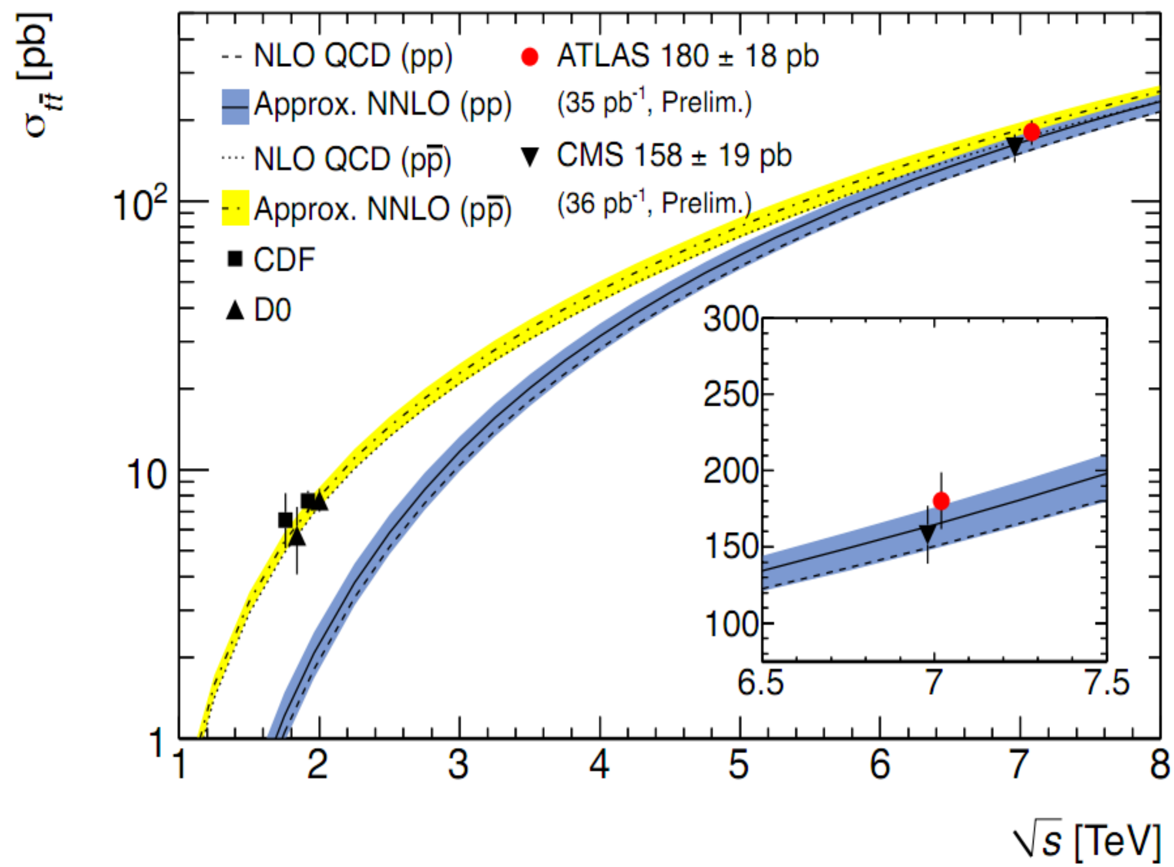


Imperial College London

PLHC 2011

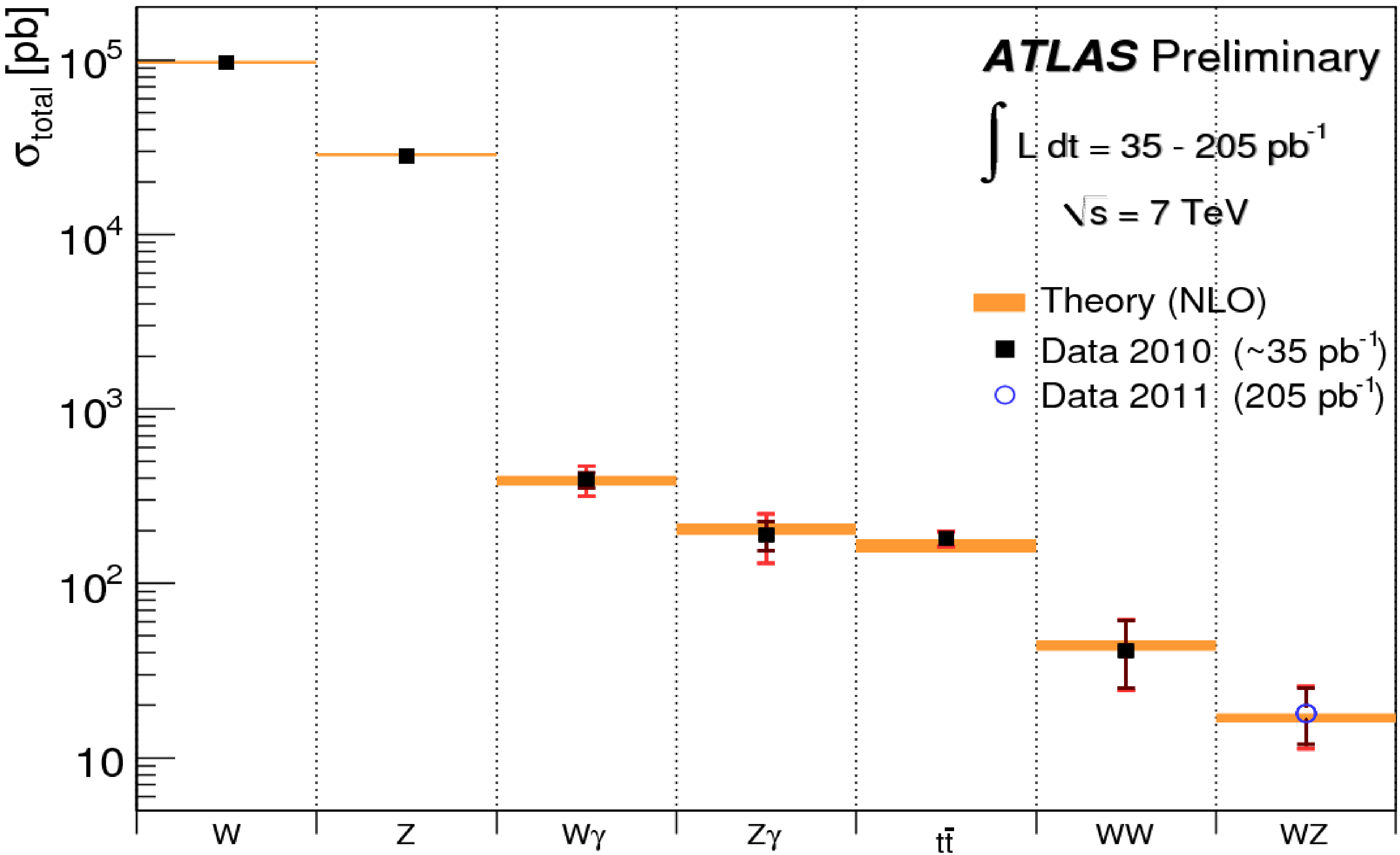
Top Mass and Cross-section at the LHC



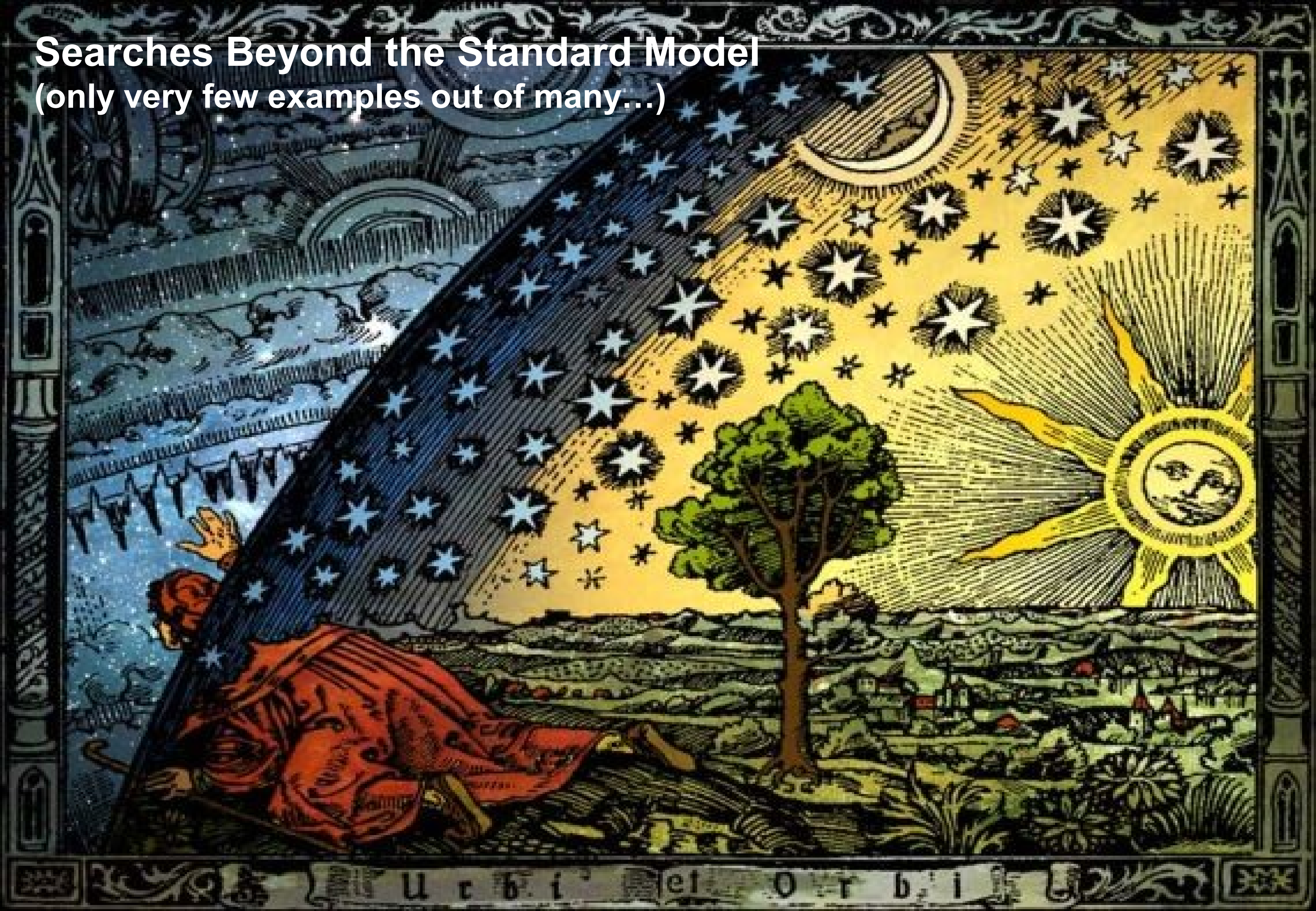


ATLAS and CMS have also made first single top cross-section observations in agreement with NLO QCD expectations

Main SM Cross-Sections: Summary

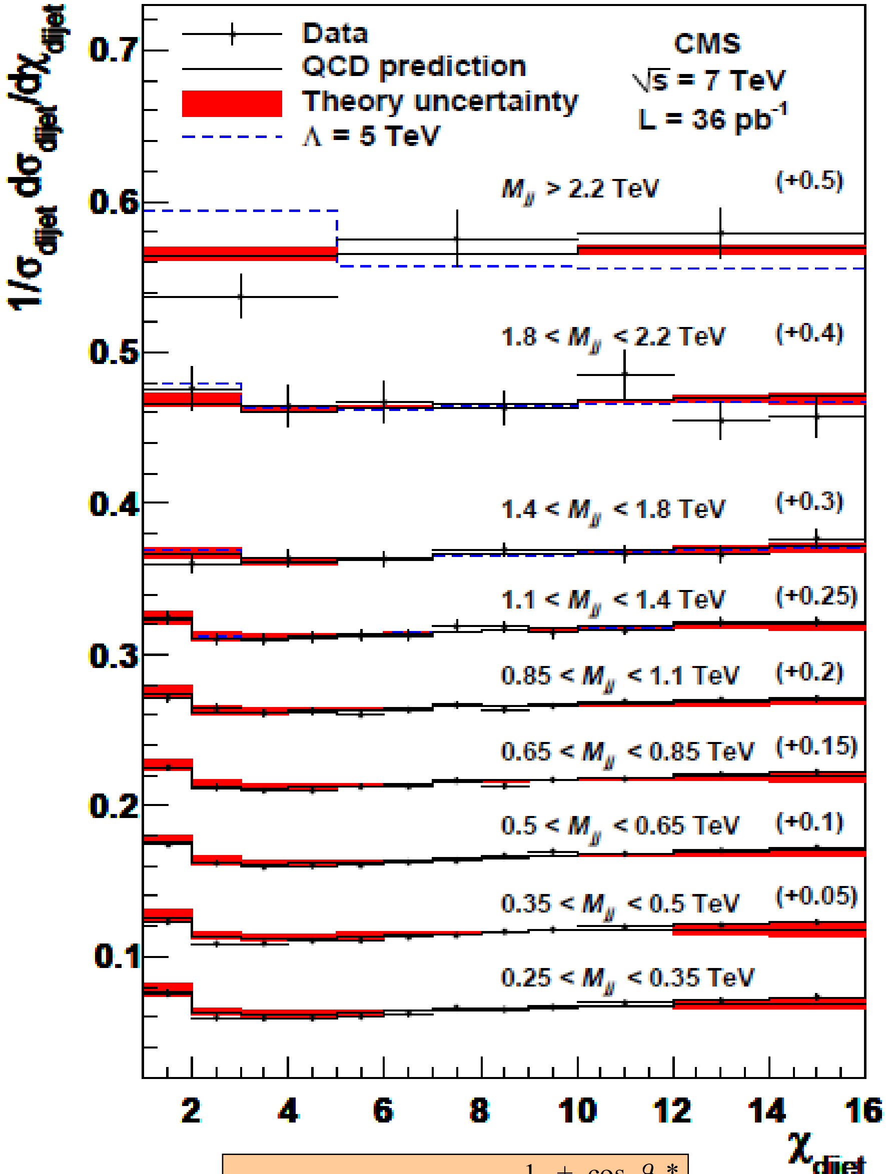


Searches Beyond the Standard Model
(only very few examples out of many…)



Deviations from QCD in di-jet angular distributions

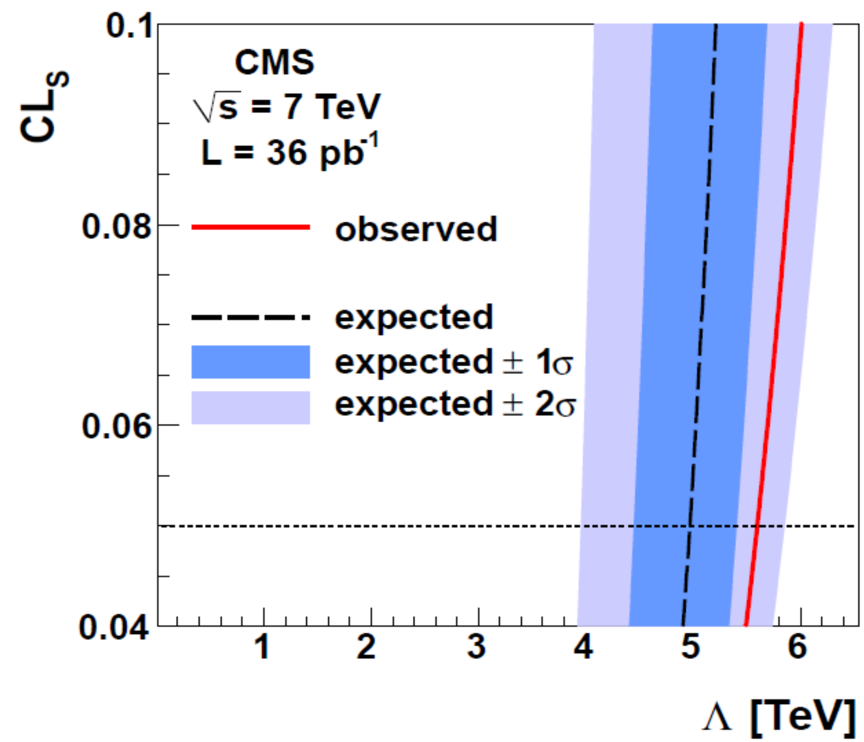
L. Sonnenschein



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

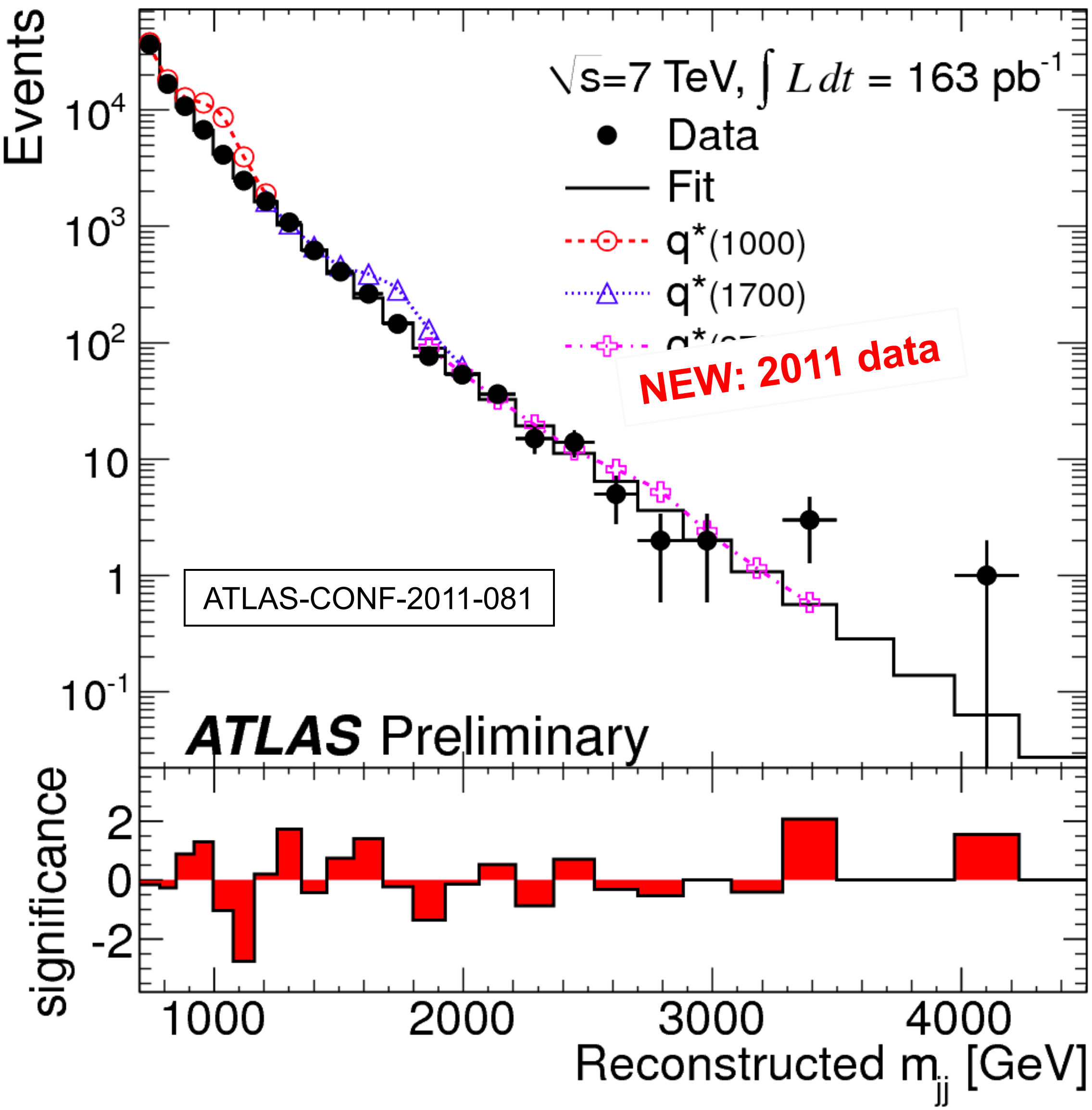
Deviations from the QCD expectation could reveal a substructure of the quarks ('compositeness' at scale Λ) in analogy to the famous Rutherford scattering 100 years ago

arXiv:1103.2020v1[hep-ex]



$\Lambda^+ > 5.6$ TeV, $\Lambda^- > 6.7$ TeV @ 95% C.L.

Search for Dijet Resonance



T. Lari

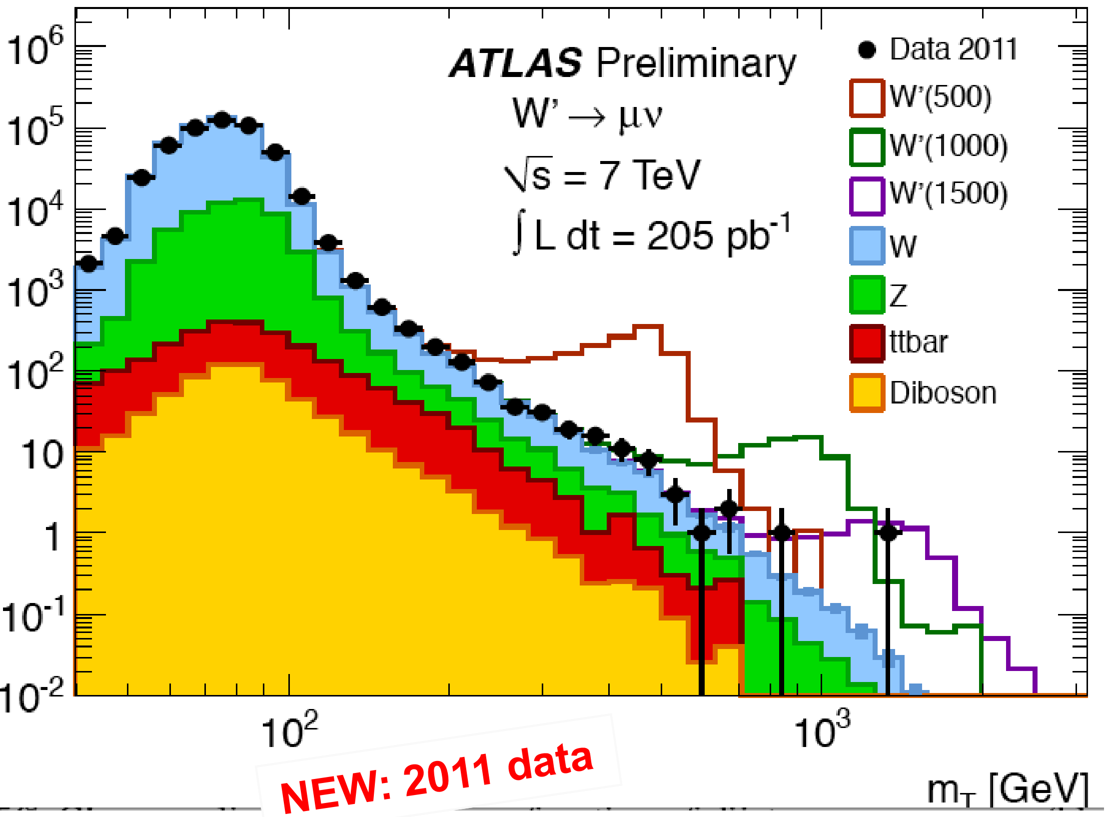
95% C.L. Limits observed (expected)

Excited quarks (q*):	M > 2.49 (2.40) TeV
Axigluons:	M > 2.67 (2.48) TeV

Search for W'/Z' SSM

T. Lari

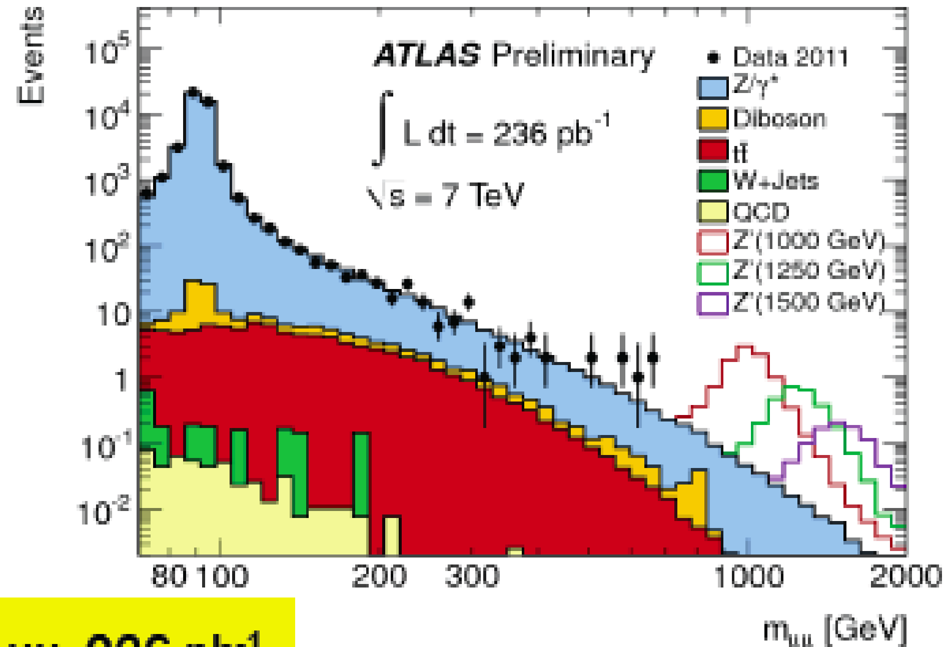
Muon + missing E_T



NEW: 2011 data

New Limit: $M_{W'} > 1.57$ TeV 95% CL
1.68 expected

Dimuons



μμ, 236 pb^{-1}

NEW: 2011 data

New Limit – ee and μμ
$M_{Z'} > 1.407$ TeV 95% CL

Microscopic Evaporating Black Holes

THE signature of low-scale quantum gravity ($M_D << M_{Pl}$)

BH formation when the two colliding partons have distance smaller than R_S,, the Schwarzschild radius corresponding to their invariant mass

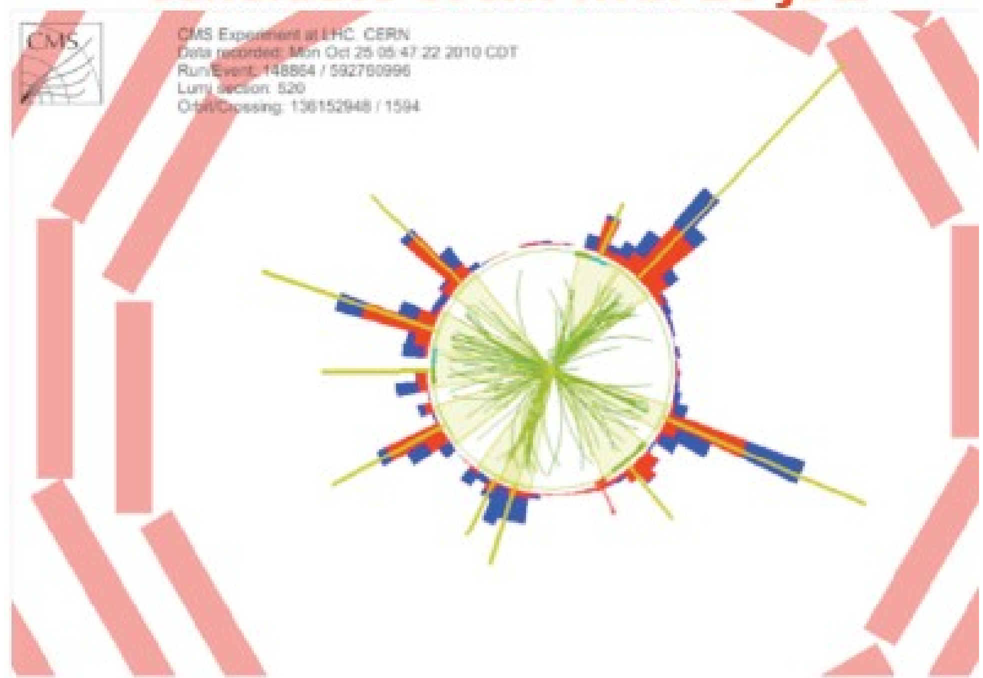
Cross section from geometry: $\sigma = \pi R_S^2 \sim TeV^{-2}$ (up to ~100 pb!)

Microscopic BHs decay instantaneously via Hawking evaporation

emitting “democratically” a large number of energetic quarks, gluons, leptons, photons, W/Z, h, etc.

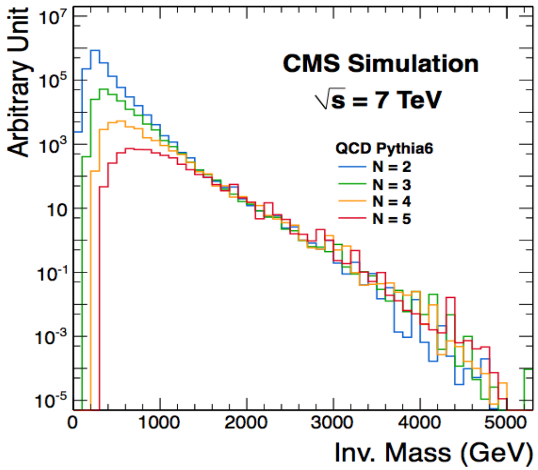
Expect lots of activity in the event, so
Use S_T = Sum E_T of all objects
(including ME_T) with E_T>50 GeV
(good for avoiding pileup)

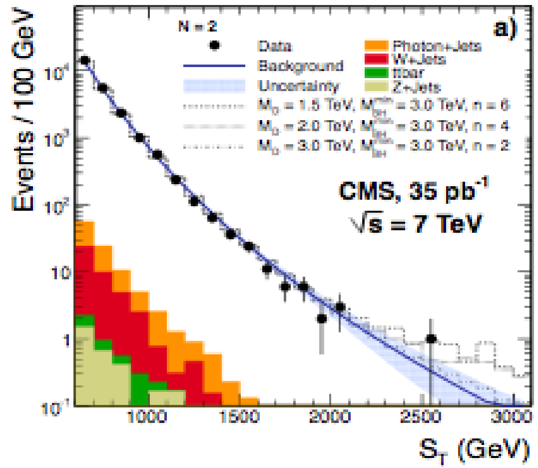
Candidate event with 10 jets

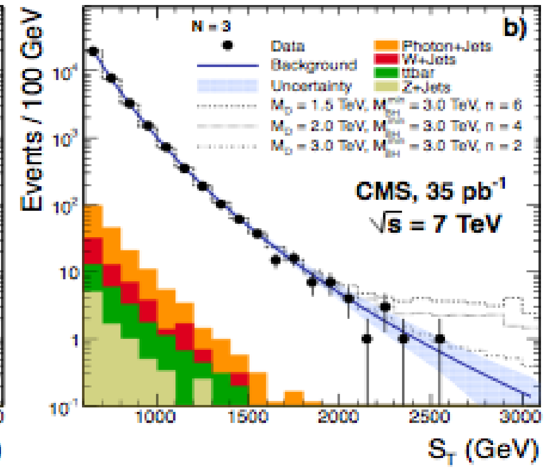


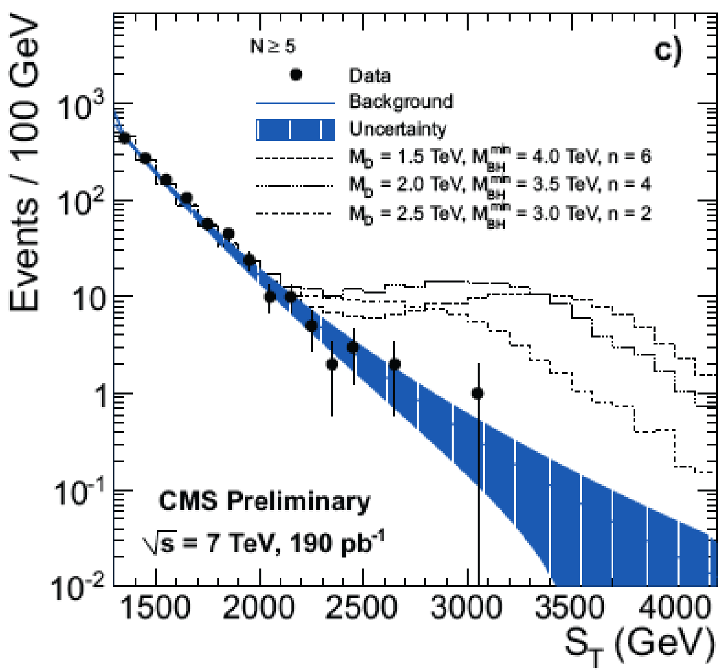
Search for Microscopic Black Holes

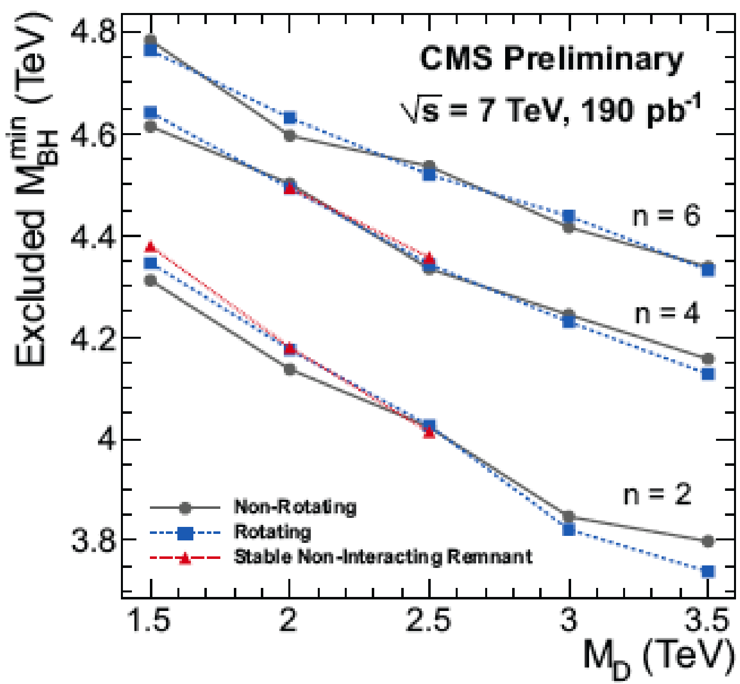
The shape of the S_T distribution is expected to be independent of event object multiplicity N











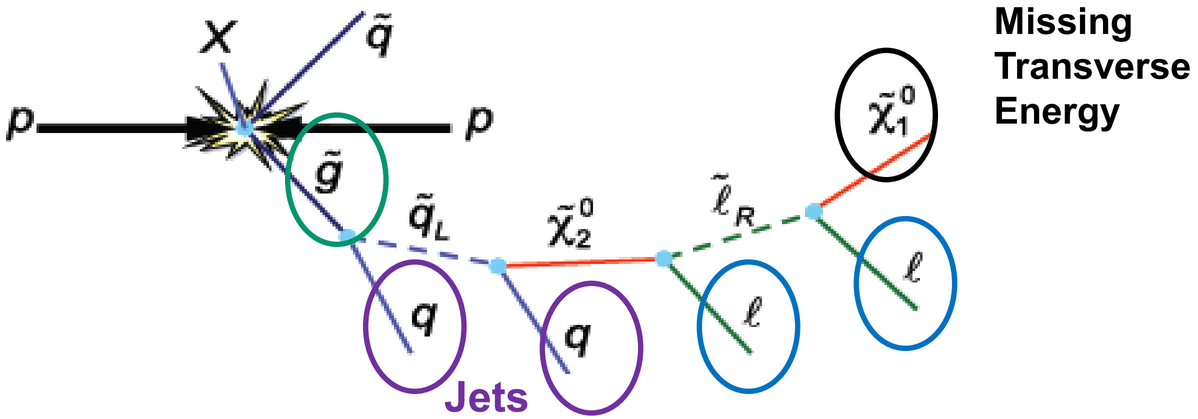
L. Sonnenschein

NEW: 2011 data

**No excess,
so set limits
M_{BH} > 3.9-4.8 TeV**

Desperately Seeking SUSY (Still!)

- **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**

Imperial College London

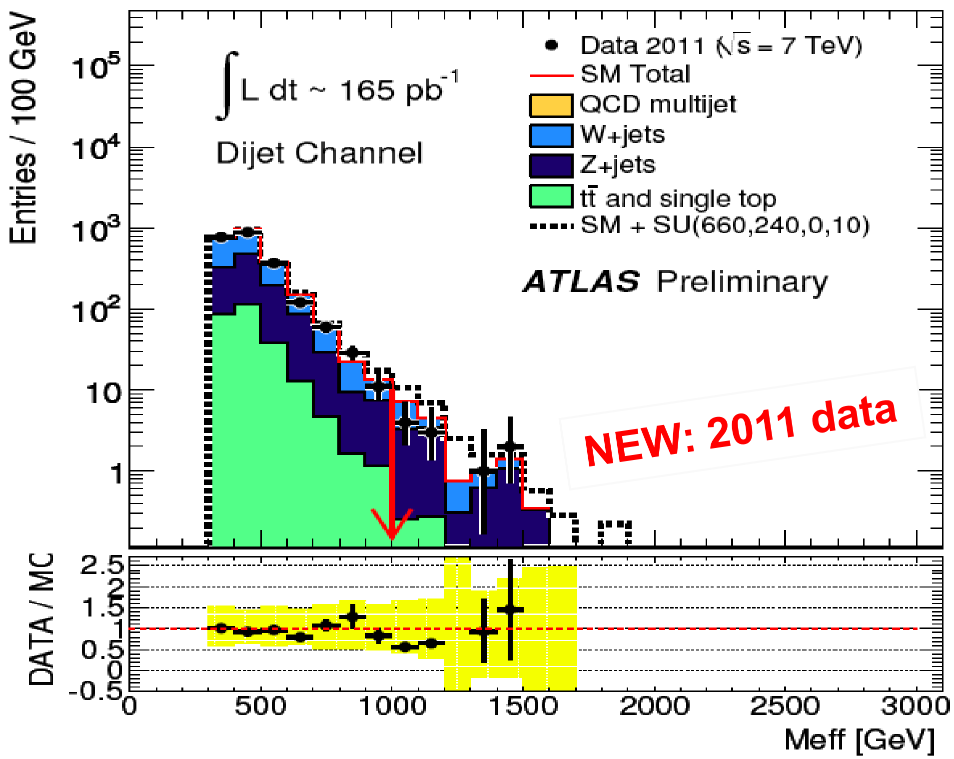
Search for SUSY: Jets+ Missing E_T

Search for Squarks and Gluinos produced in pairs (R-parity conserving models) decaying in purely hadronic final states + MET : 2, 3 , 4 Jets + MET

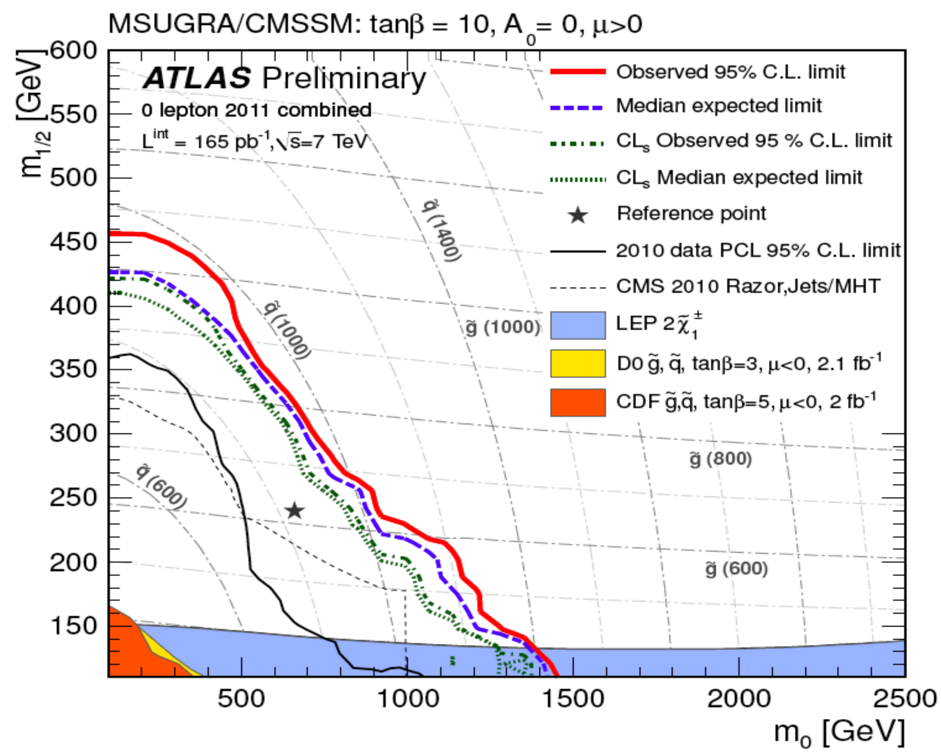
- Squark $\rightarrow q\chi^0_1$, $\tilde{g} \rightarrow qq\chi^0_1$ (χ^0_1 produces the E_{Tmiss})
- M_{eff} (= $\Sigma |p_T| + E_T^{miss}$) distributions compared with data driven BKG
- BKG: QCD, W+Jets, Z+Jets, top

T. Lari

L. Pontecorvo



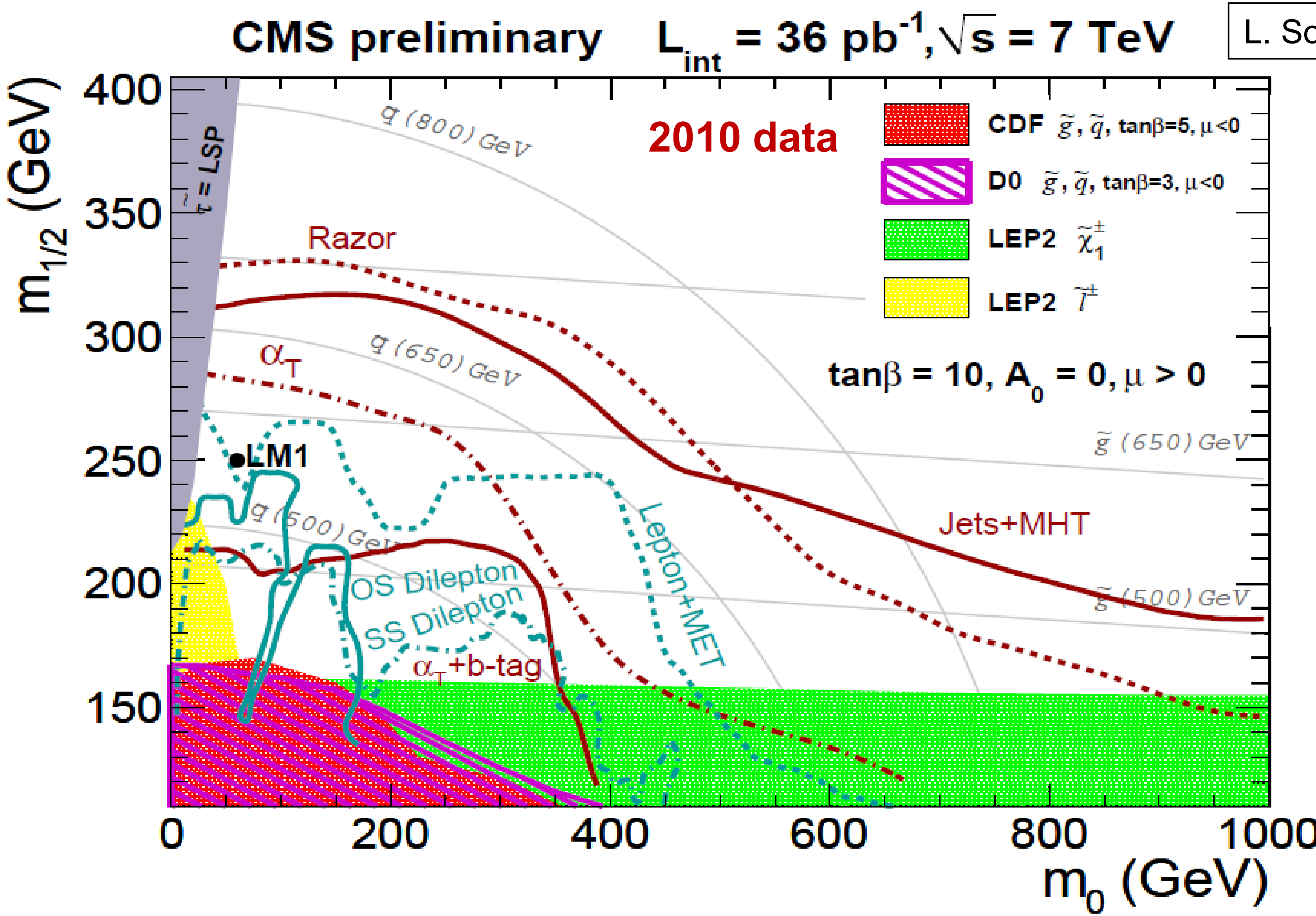
Comb. Excl. limit in m_0-$m_{1/2}$ plane



In **MSUGRA/CMSSM** Exclude $m_{1/2}$<455GeV and for $\mathbf{M_{sq}=M_g}$ $\mathbf{M_{sq}}$**< 950GeV**

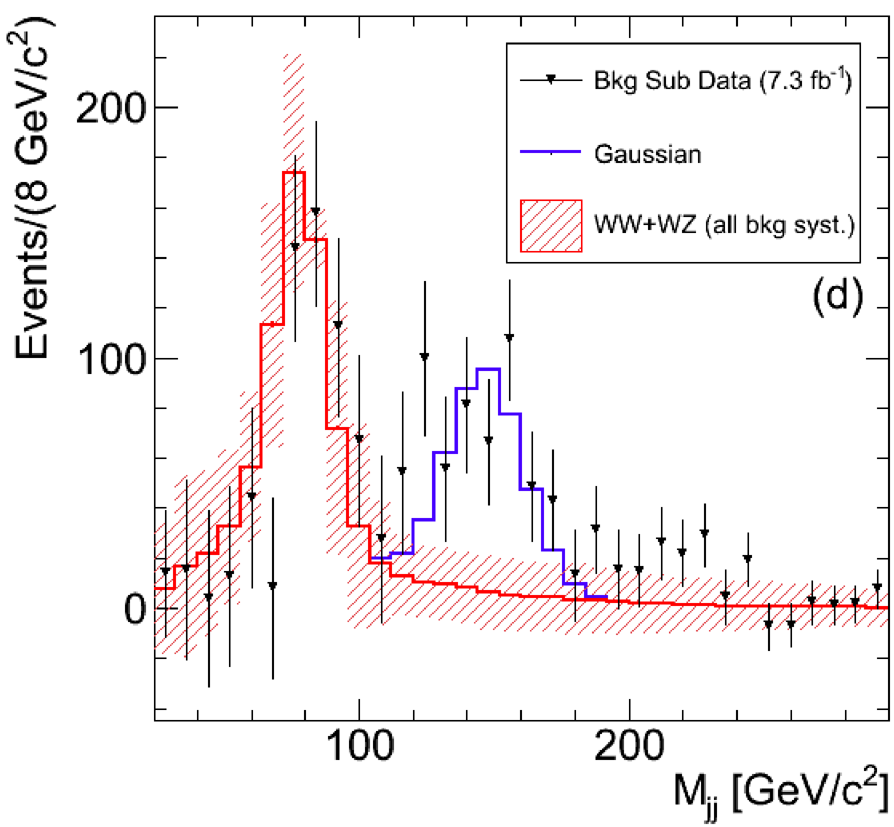
SUSY searches in CMS: Combined Limits

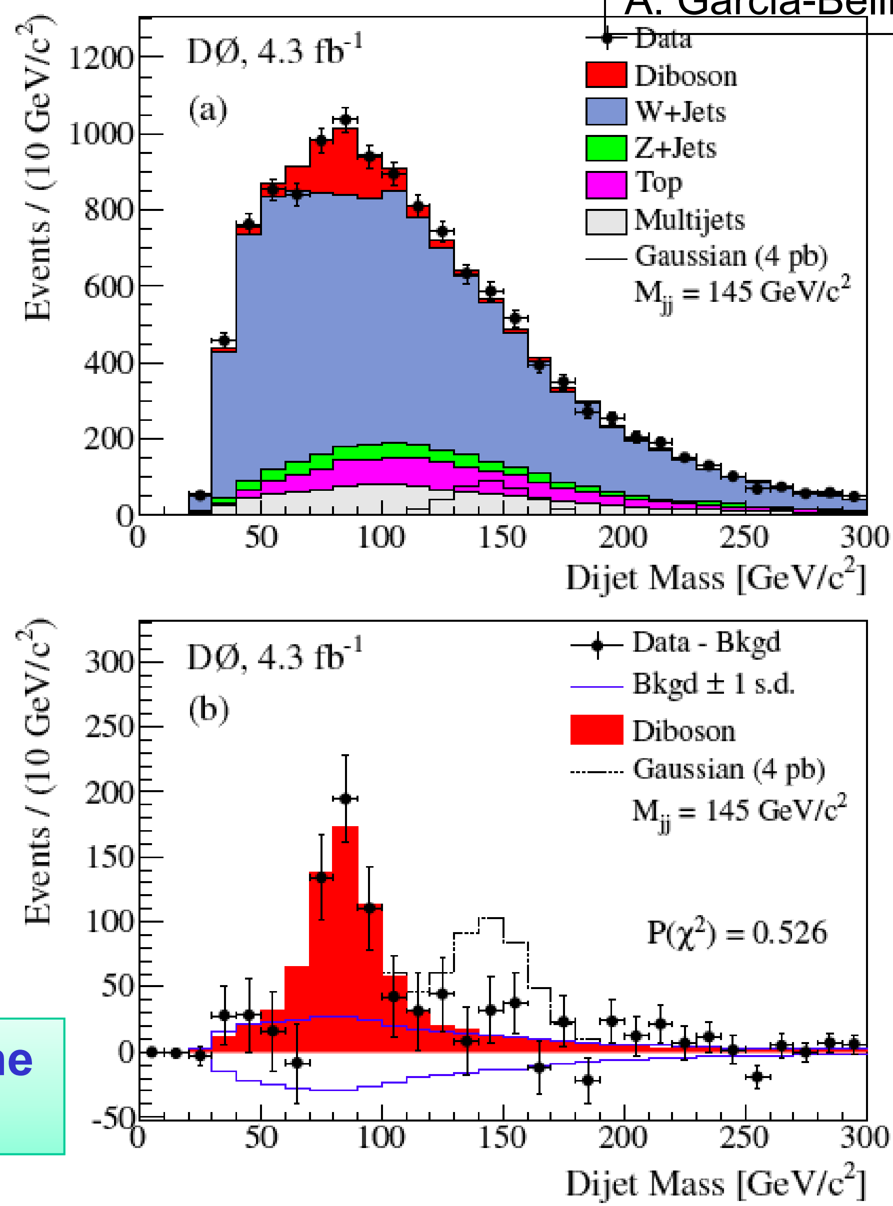
L. Sonnenschein



Jet-jet Resonance in Association with a W?

A. Garcia-Bellido



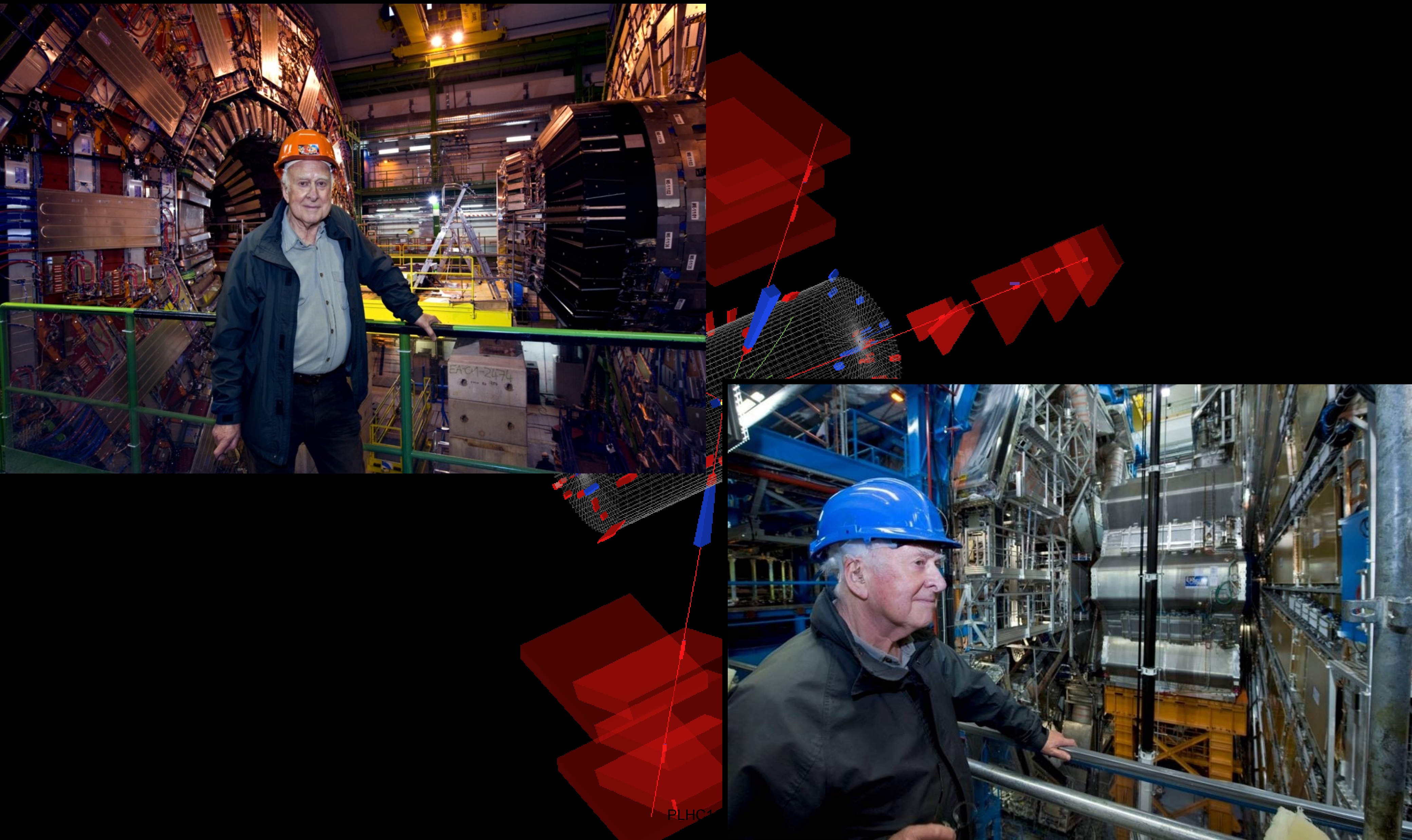


- Add additional 3 fb^{-1} of data (7.3 fb^{-1} in total)
- Significance of the bump increased to 4.1 σ

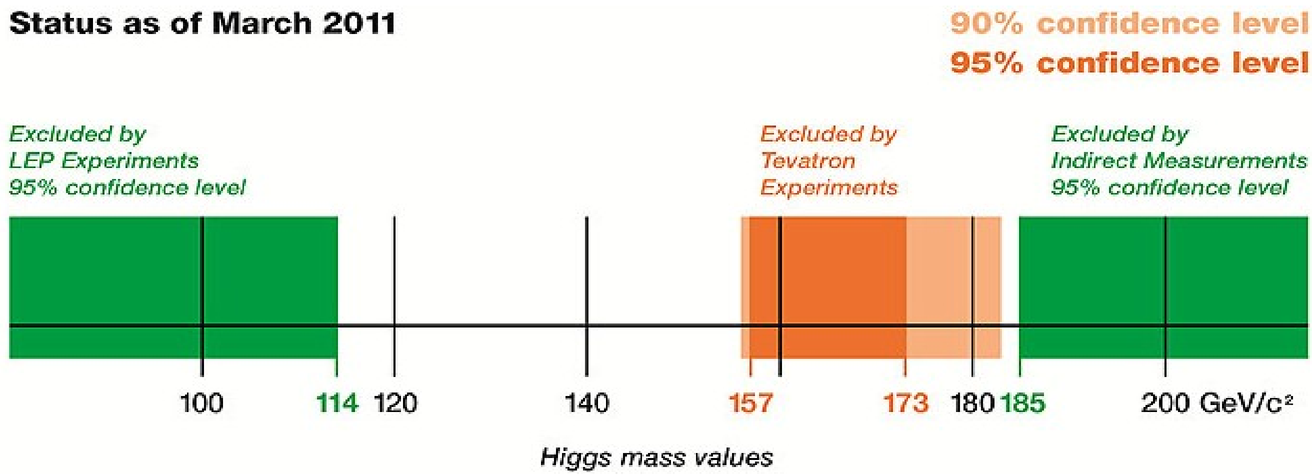
D0 data are not consistent with the excess seen by CDF

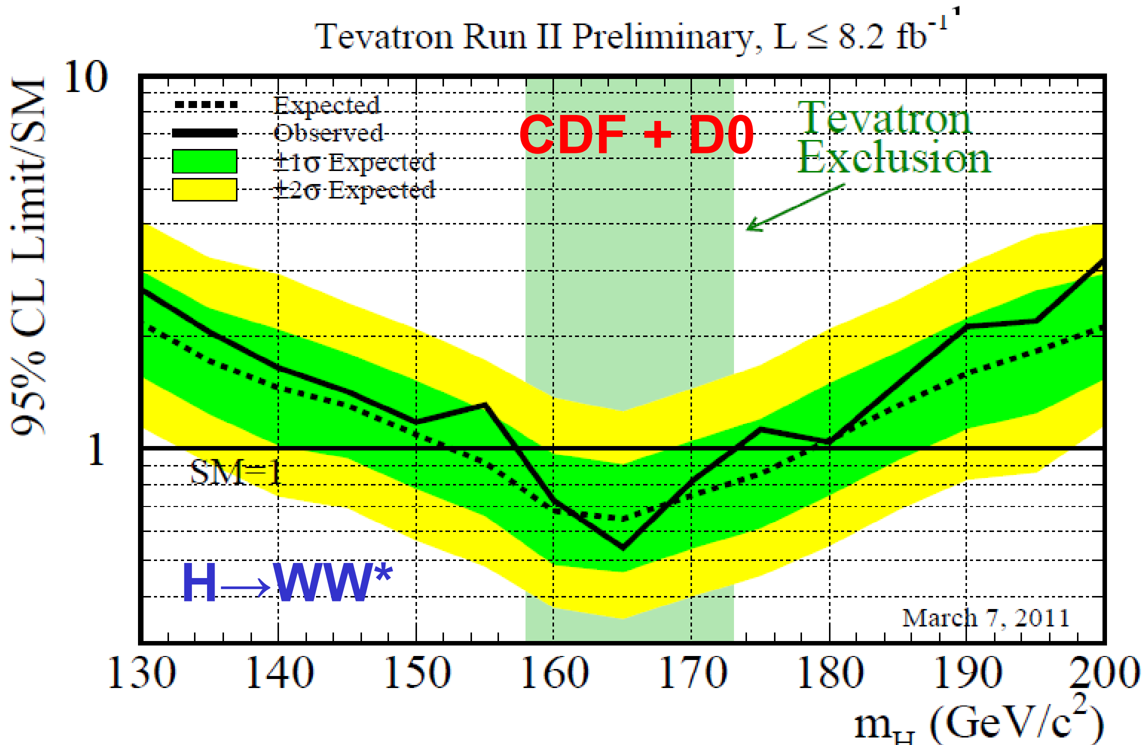
ZH57U8

Searching for the Higgs Boson



Search for the Higgs Boson at the Tevatron





M. Casarsa

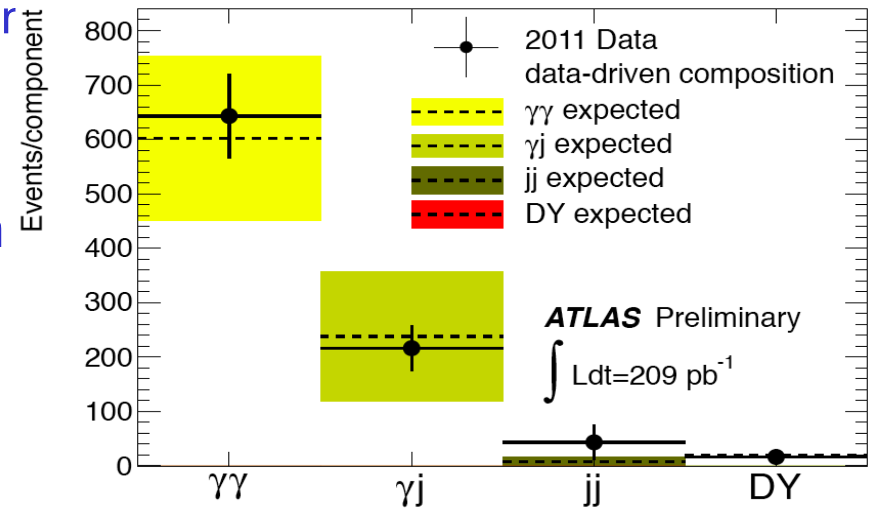
95% C.L. exclusion
M_H < 109 GeV/c^2
158 < M_H < 173 GeV/c^2

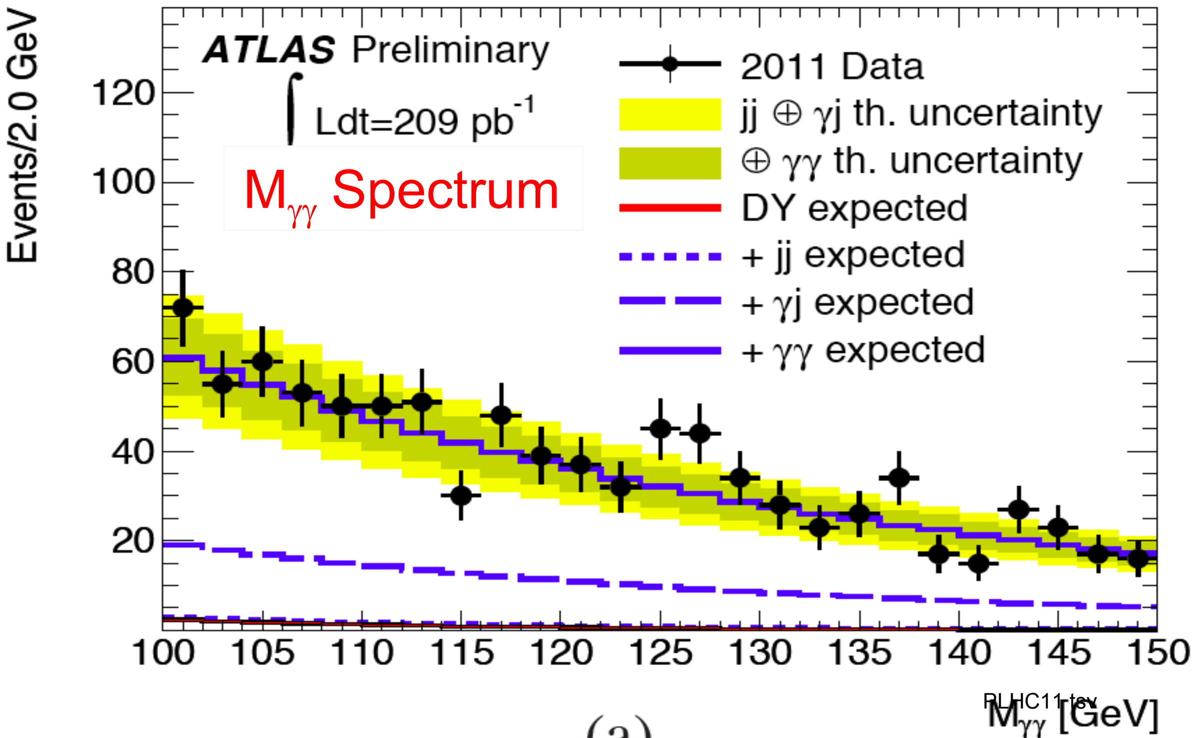
SM H->$\gamma\gamma$

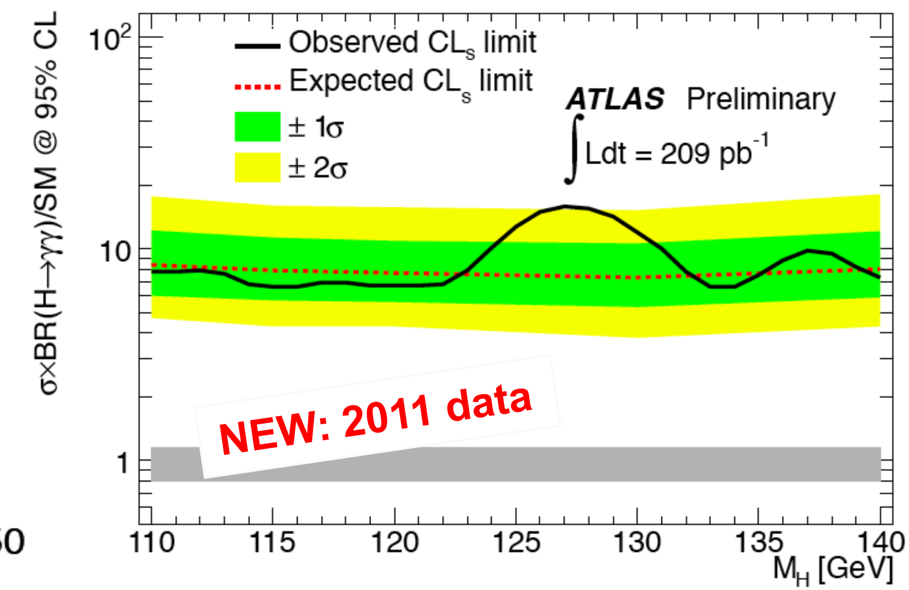
L. Pontecorvo, M. Escalier

- **Cleanest channel for very low Mass Higgs. Need**
  - Good di-photon identification and mass resolution
  - Determination of primary vertex
  - γ/Jet, γ/π^0 discrimination
- **Understand backgrounds using Data Driven techniques**
  - QCD $\gamma\gamma$ production, γ-Jet and Jet-Jet production

Background composition

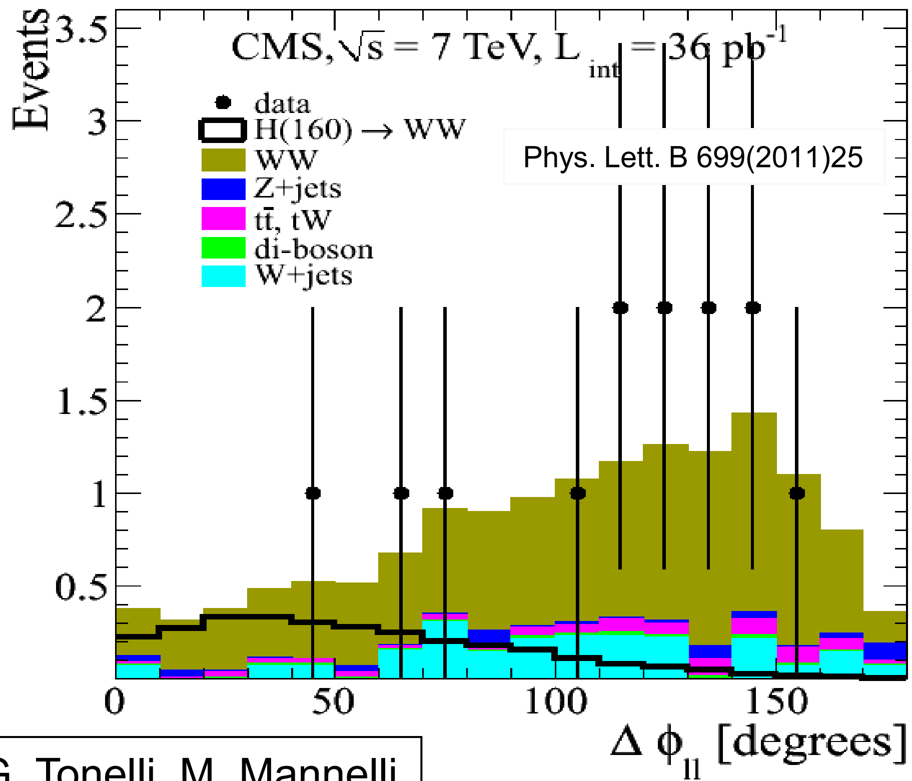


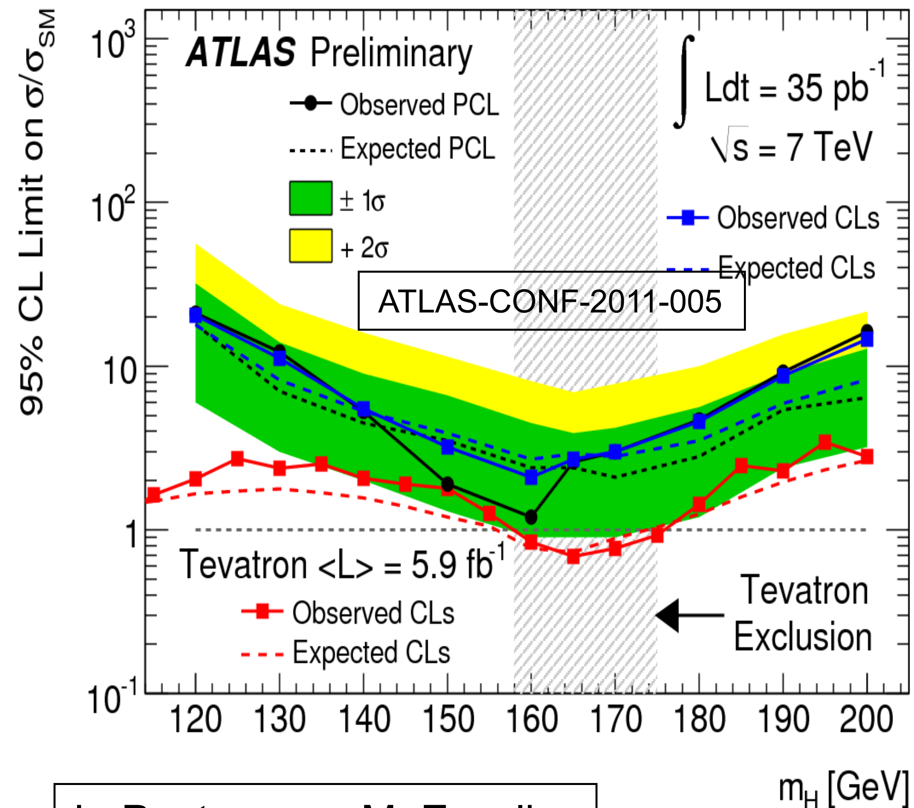




Search for $H_{SM} \rightarrow WW \rightarrow l\nu\ l\nu$ channel ($l = e, \mu$)

Azimuthal angular separation of the two selected leptons





G. Tonelli, M. Mannelli

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

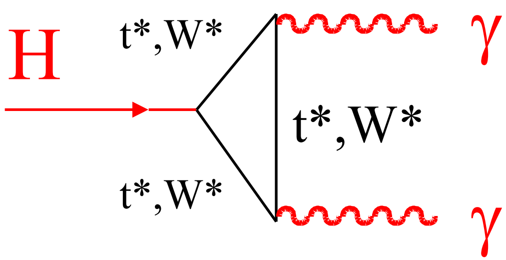
L. Pontecorvo, M. Escalier

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

Higgs Combination: ATLAS 2010 Data

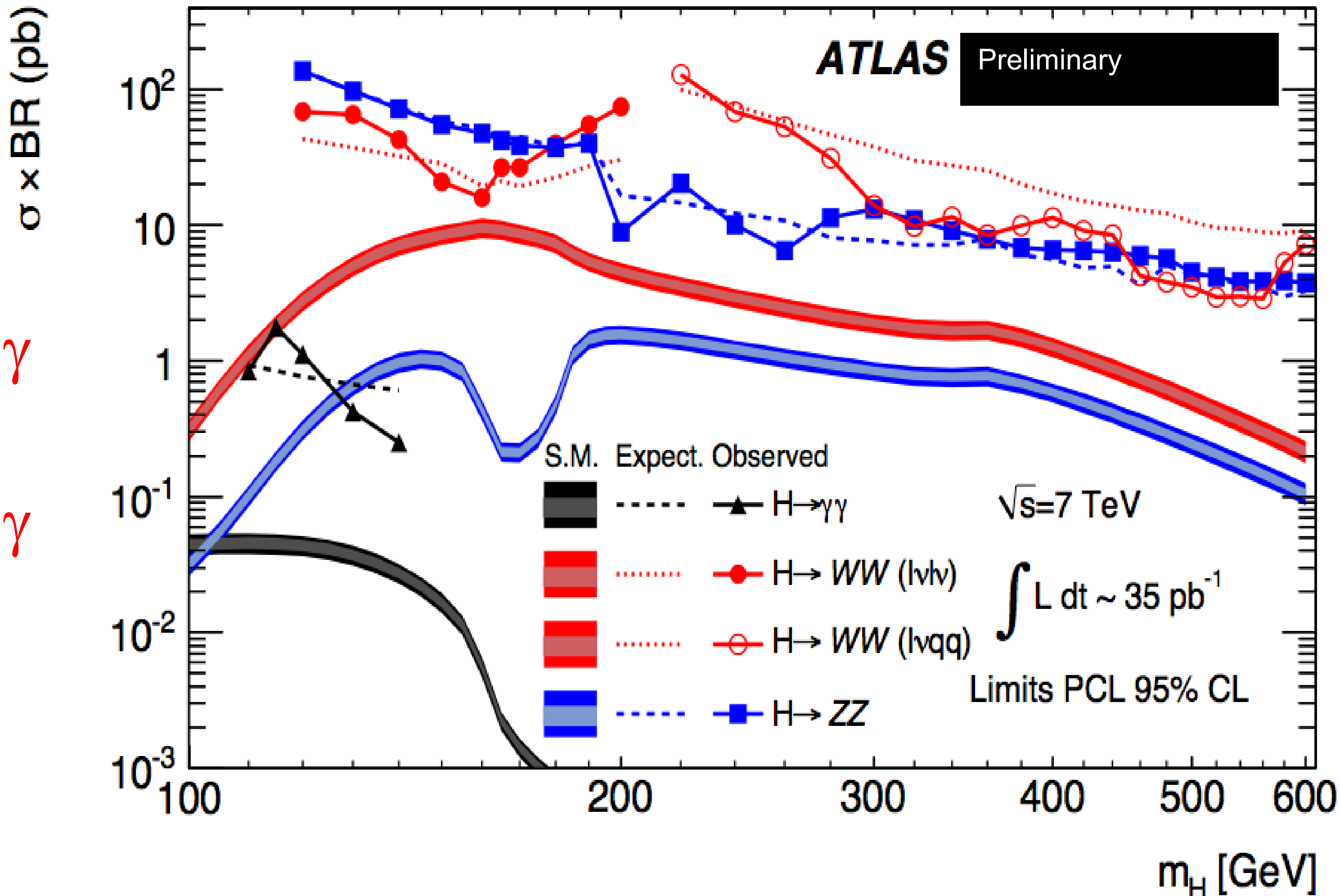
L. Pontecorvo

H → γγ,



H→WW→lνlν,lνqq,

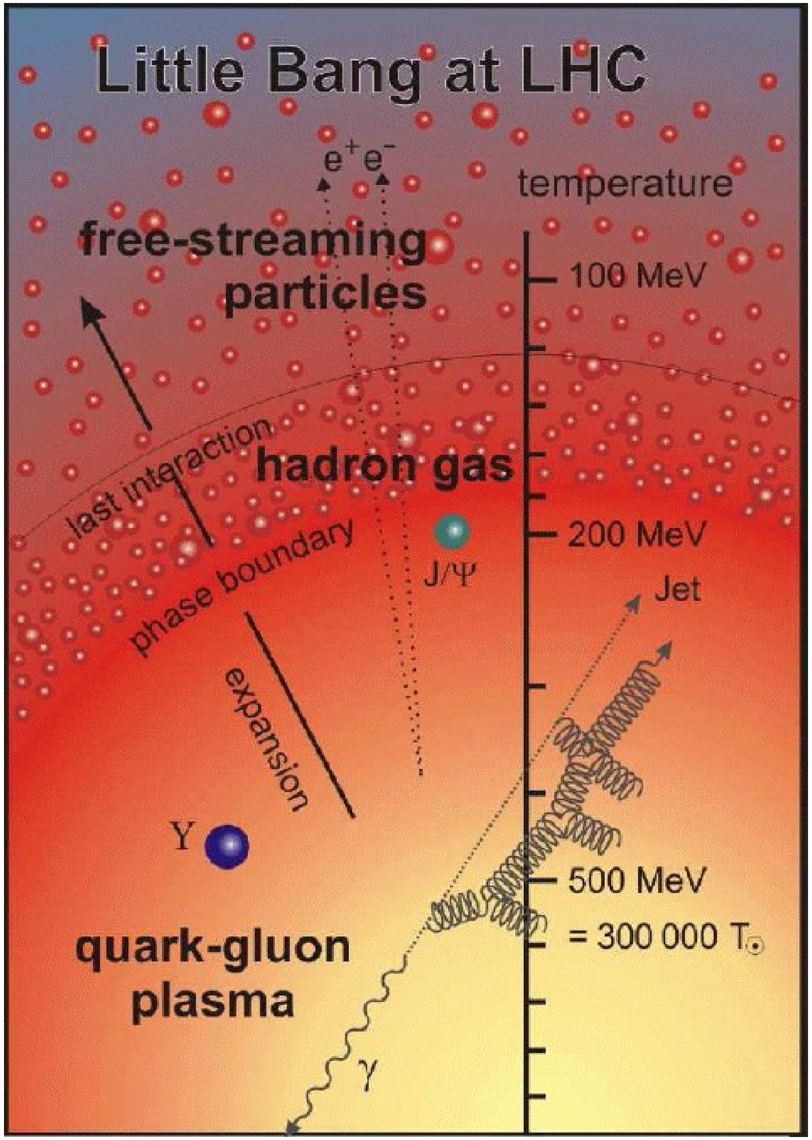
H → ZZ$^{(*)}$ → 4l,llνν



SM Higgs not yet excluded anywhere by ATLAS/CMS 2010 data
Eagerly look forward to results at EPS and later on!

Heavy Ion Collisions - Evolution of the Fireball

J. Wessels



soft

- **global observables:**
  multiplicities, rapidity distributions
- **geometry of the emitting source:**
  HBT, impact parameter via
  zero-degree energy flow
- **early state collective effects:**
  elliptic flow
- **chiral symmetry restoration:**
  neutral to charged ratios,
  resonance decays
- **fluctuation phenomena - critical behavior:**
  event-by-event particle composition and
  spectra
- **degrees of freedom as a function of T:**
  hadron ratios and spectra,
  dilepton continuum, direct photons
- **deconfinement:**
  charmonium and **bottonium spectroscopy**
- **energy loss of partons in QG medium:**
  jet quenching, high p_t spectra,
  open charm and open beauty

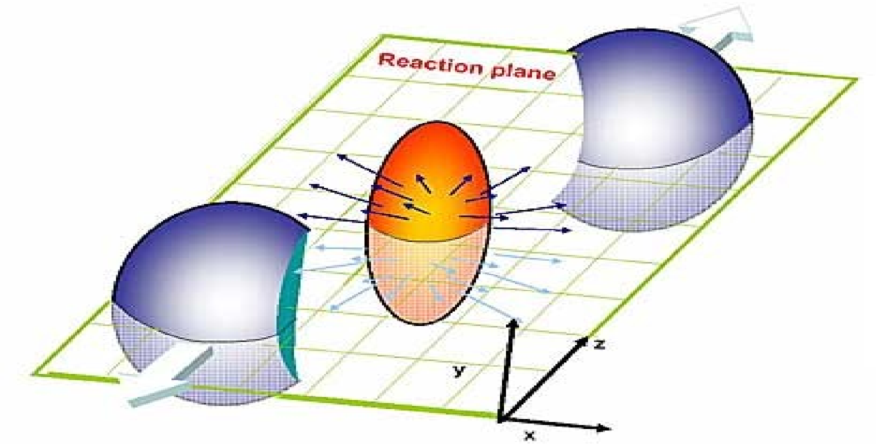
hard probes

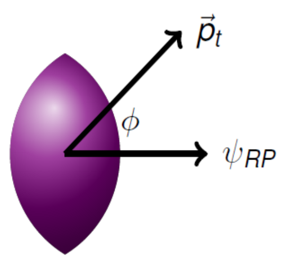
Flow in Heavy Ion Collisions

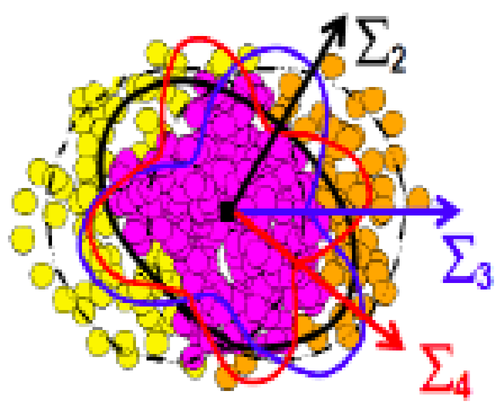
A. Morsch

$$E\frac{d^3N}{d^3p} = \frac{d^2N}{2\pi p_T dp_T dy}\left(1 + 2v_1\cos[\varphi - \psi_{RP}] + \quad + 2v_3\cos[3(\varphi - \psi_{RP})] + \ldots\right)$$

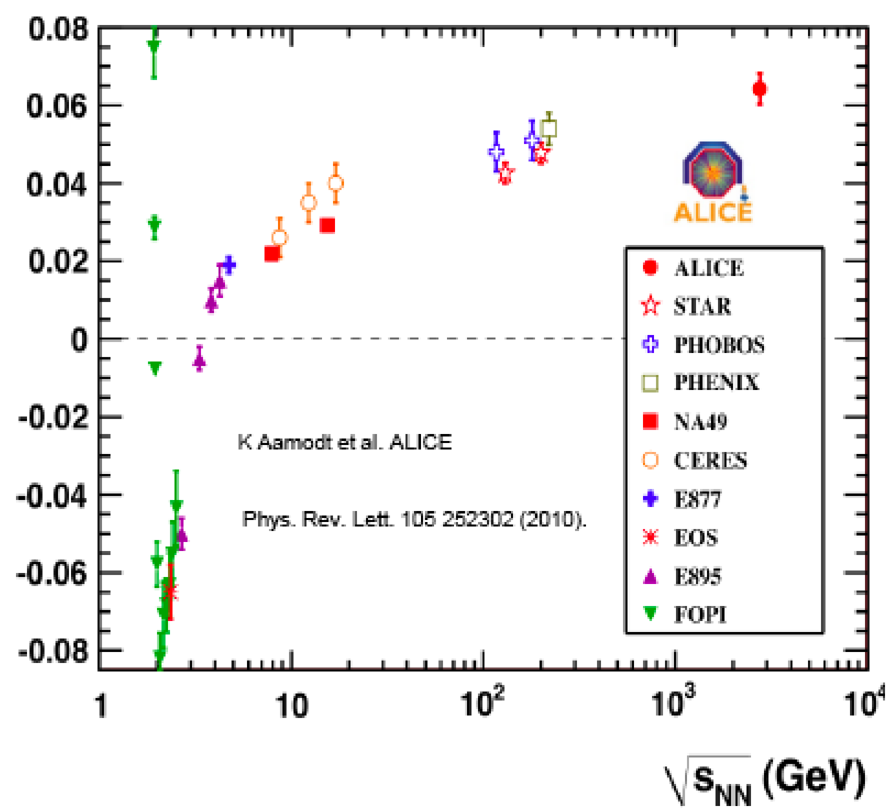
Coordinate Space Anisotropy → Interactions → Momentum Space Anisotropy

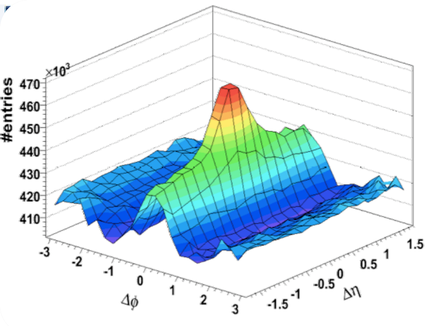






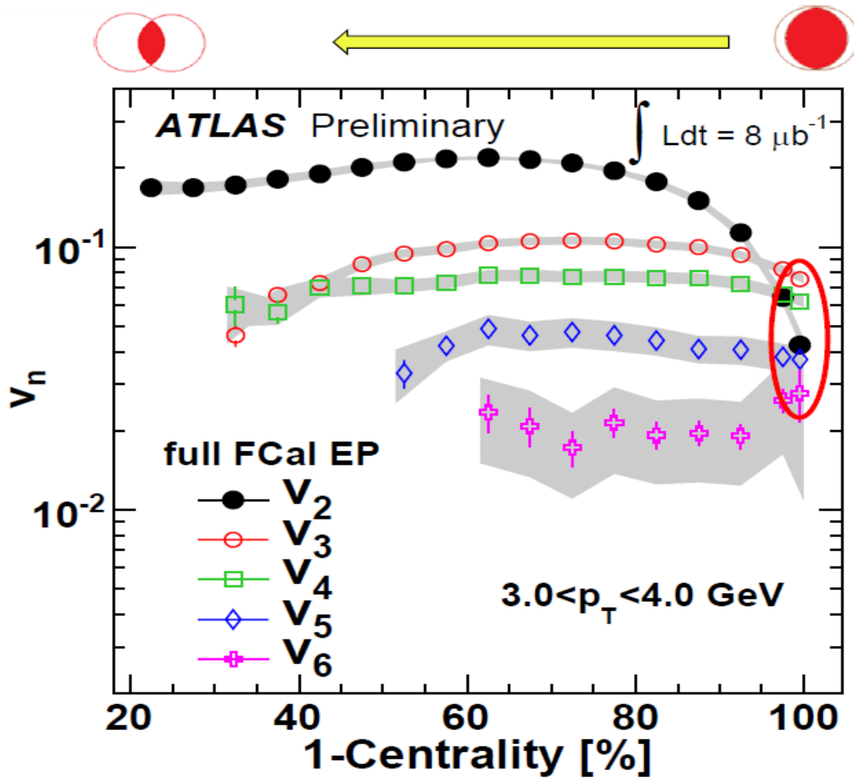
v_2



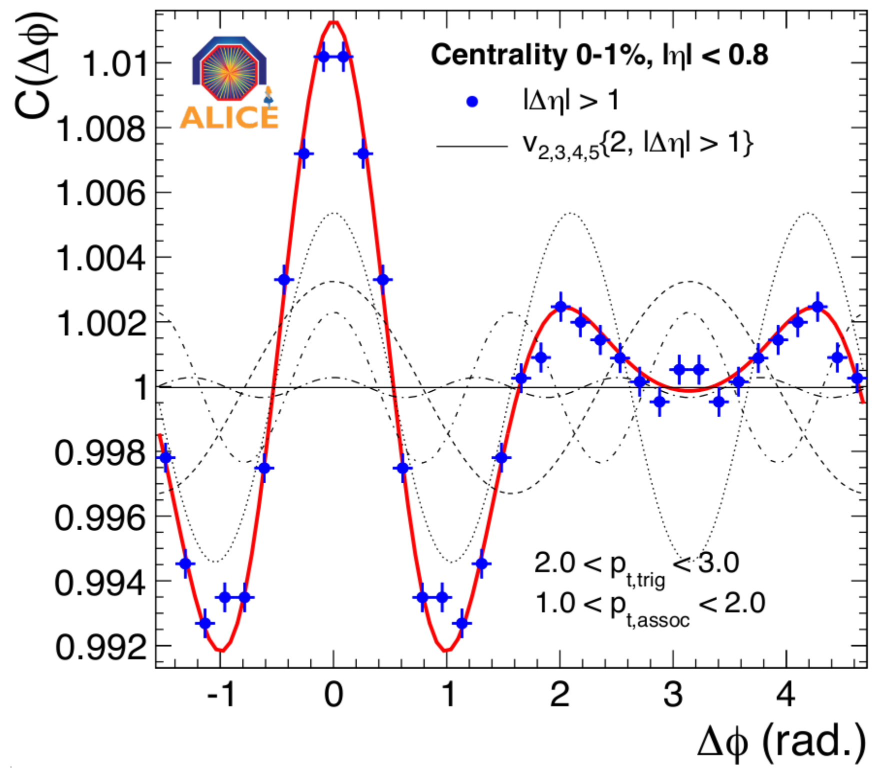


Elliptic Flow: v_i and “ridges” and “cones”

A. Morsch, G. Westfall



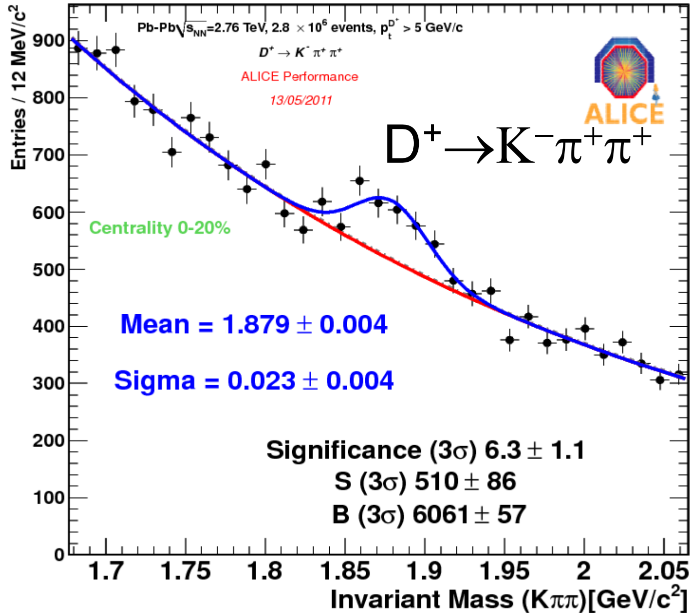
Rapidity separated di-hadron correlations

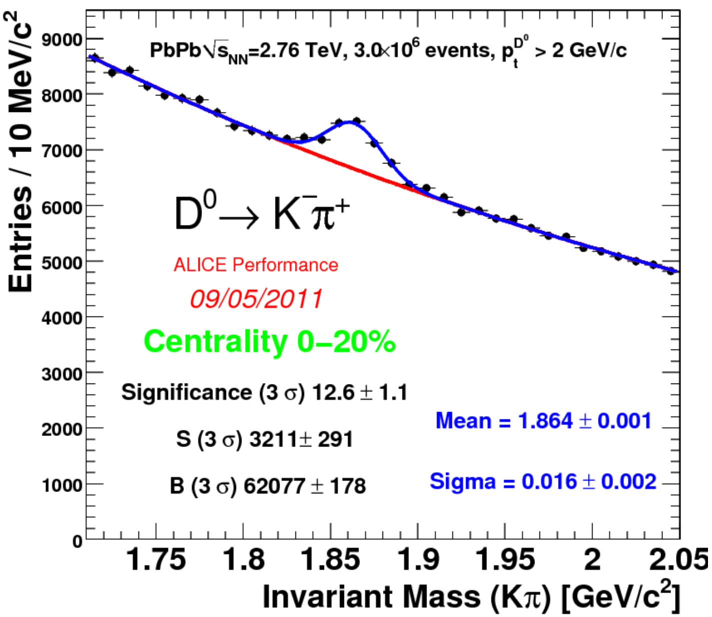


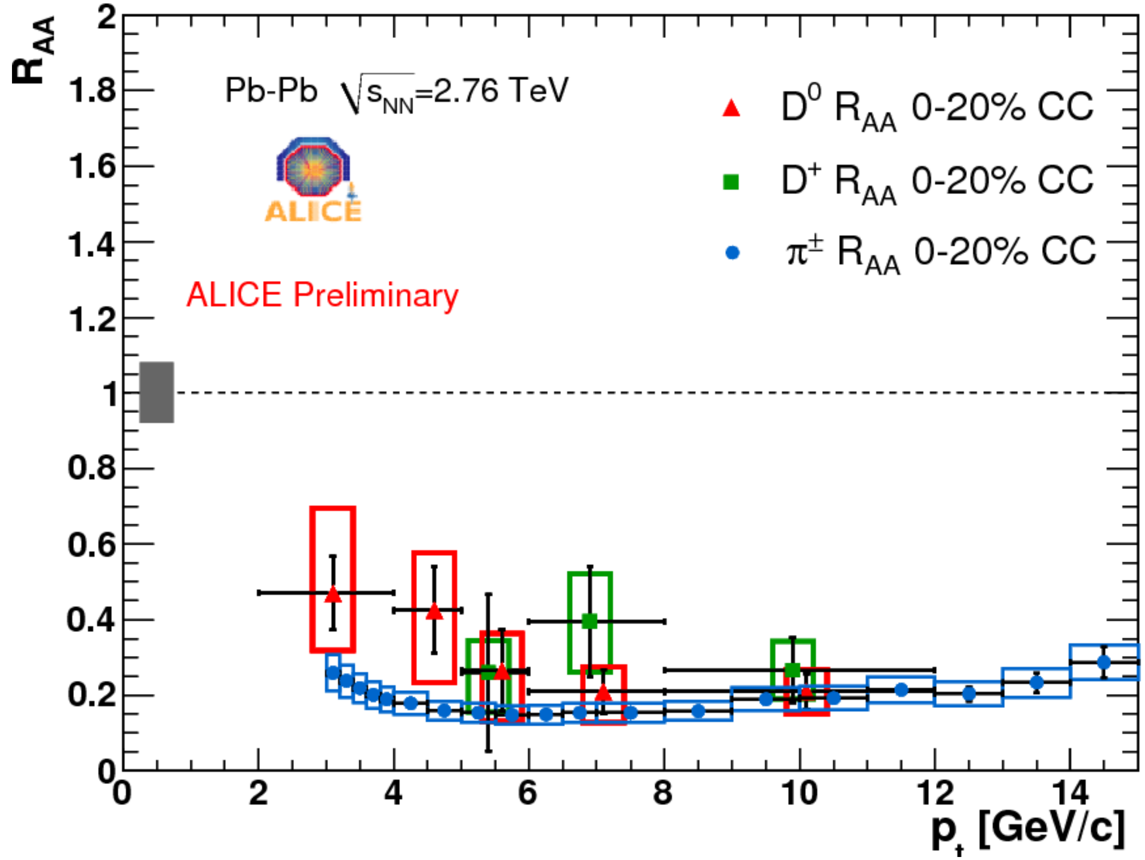
- Higher Harmonics arise from fluctuations in the initial nucleon distribution.
- The existence of high moment – indication of perfect fluid being formed.
- Structures in the di-hadron distributions, aka “ridge” and “cone”, can be explained by v_2-v_6 plus a momentum conservation term v_1.

Open Charm Suppression

A. Morsch

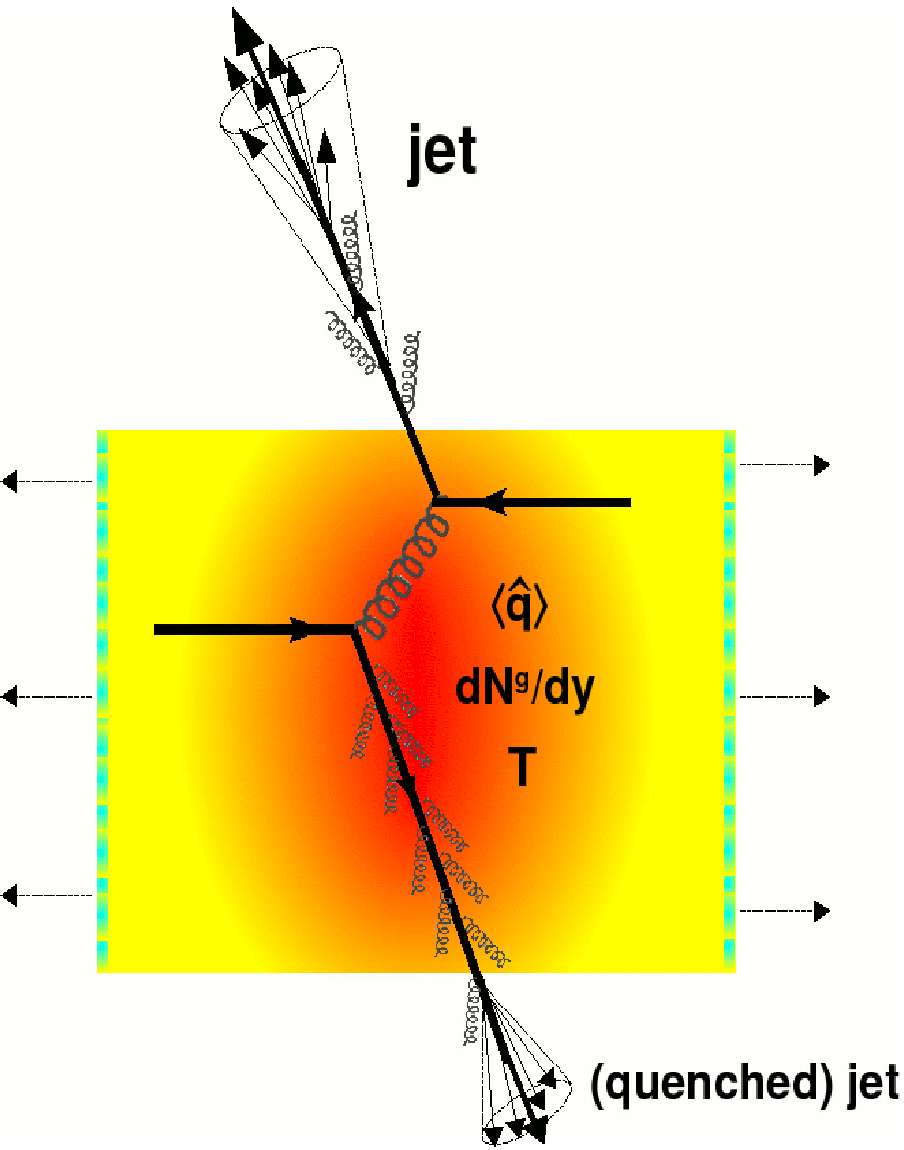


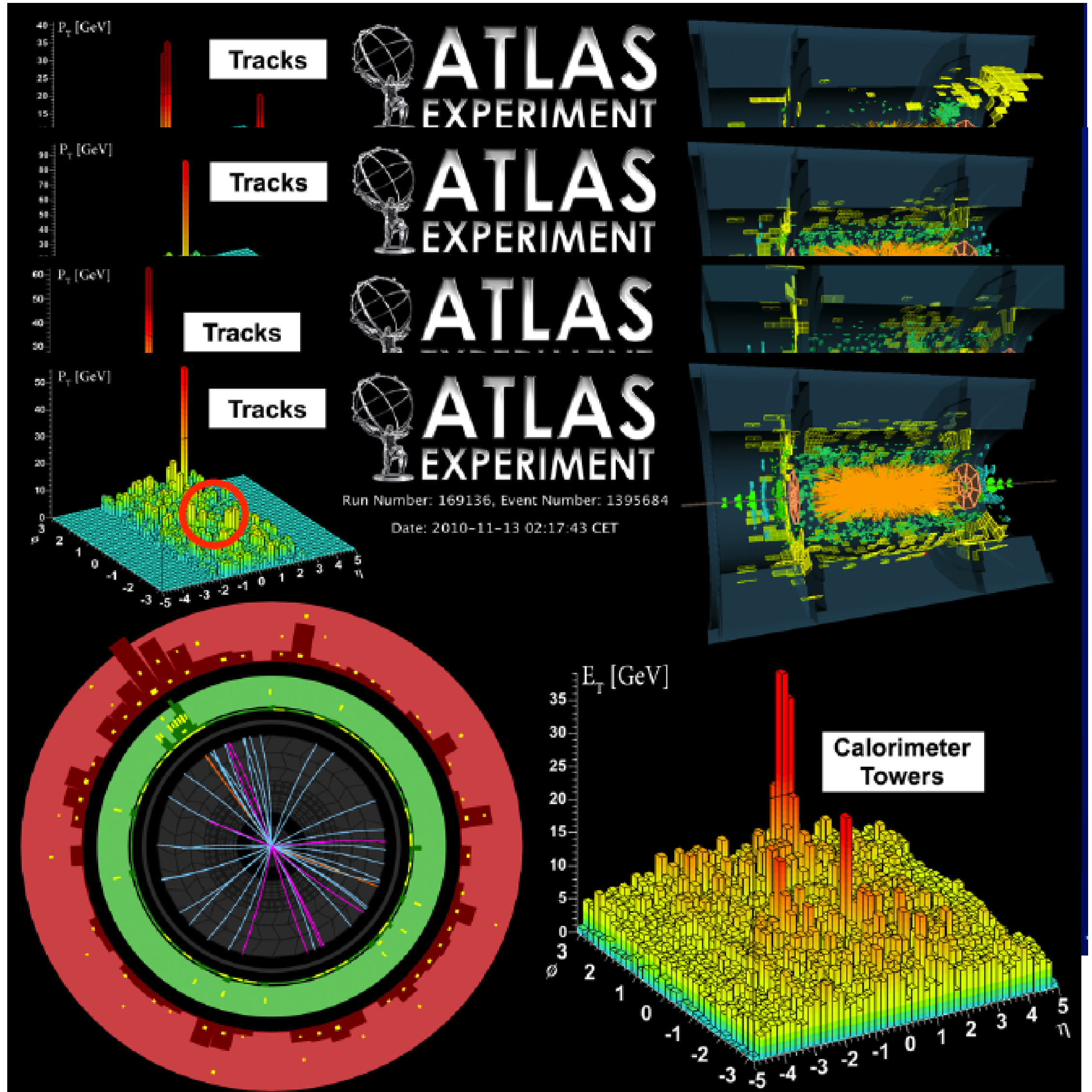




R_{AA} of prompt charm ≈ R_{AA} $\pi^{\pm}$ for p_T > 5-6 GeV
R_{AA} charm > R_{AA} $\pi^{\pm}$ for p_T < 5 GeV ?

Partons in a Dense Medium





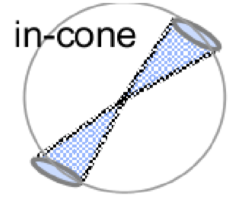
Central event, with split dijet + additional activity

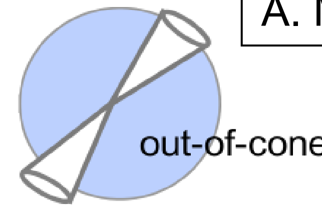
Where Did the Energy Go?

arXiv:1102.1957

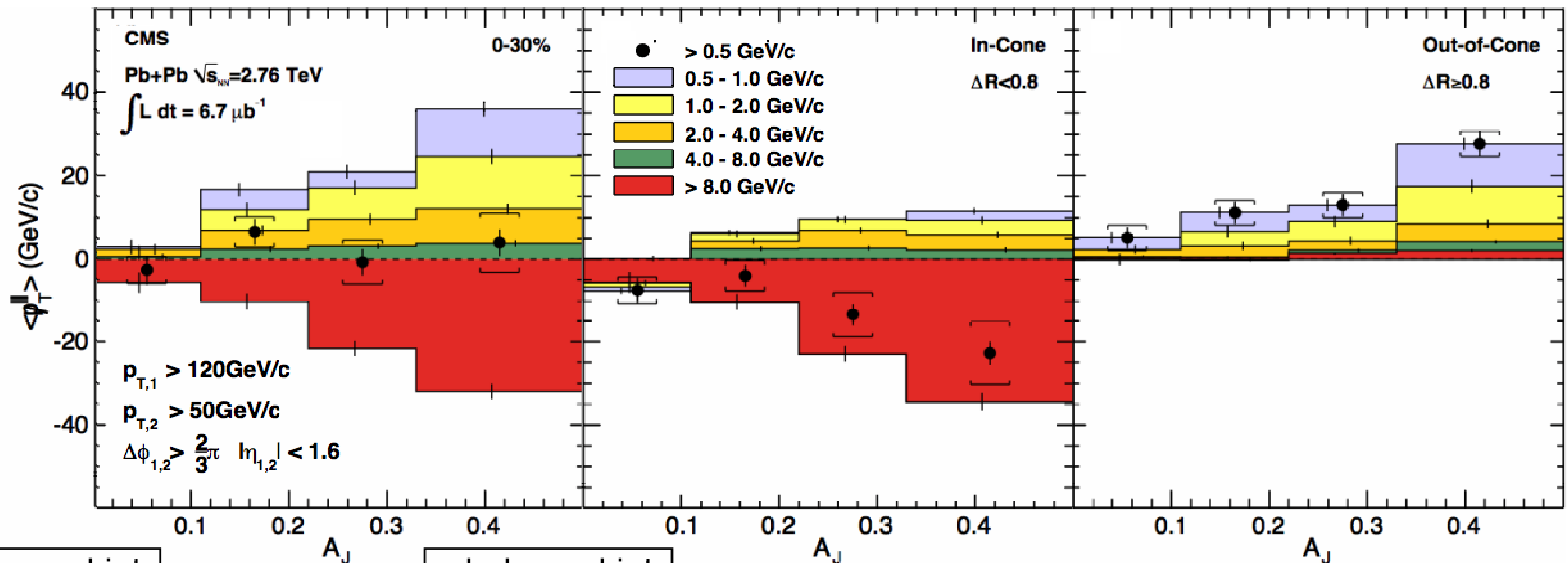
$$\not{p}_T^{\parallel} = \sum_{\text{Tracks}} -p_T^{\text{Track}} \cos\left(\phi_{\text{Track}} - \phi_{\text{Leading Jet}}\right)$$

0-30% Central PbPb





A. Morsch



balanced jets

unbalanced jets

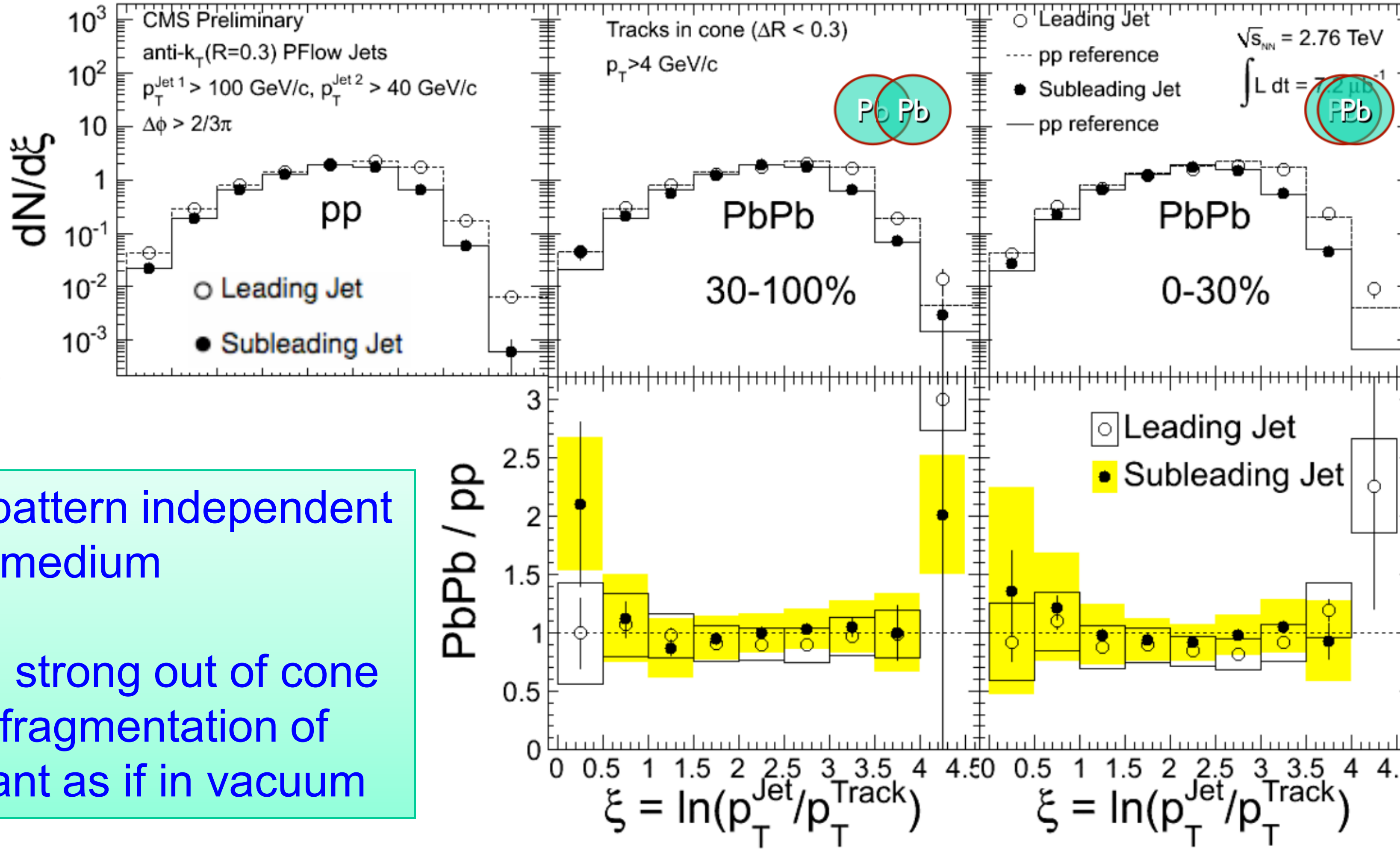
Low p_T, full acceptance
Momentum is balanced

In-cone large momentum
imbalance at high p_T
Consistent with calorimetry

Out-off-cone low p_T particles
balance the complete event

Fragmentation Function of the Jets in QG Medium

CMS-PAS-HIN-11-004

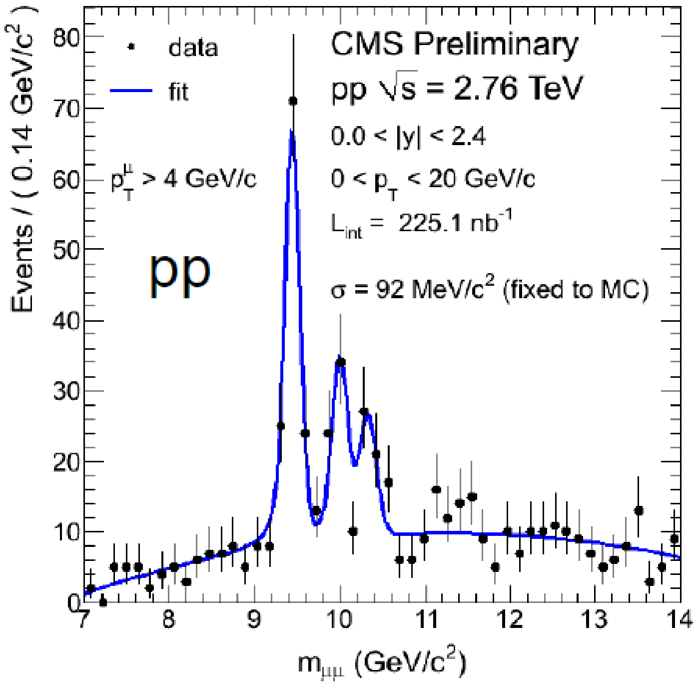


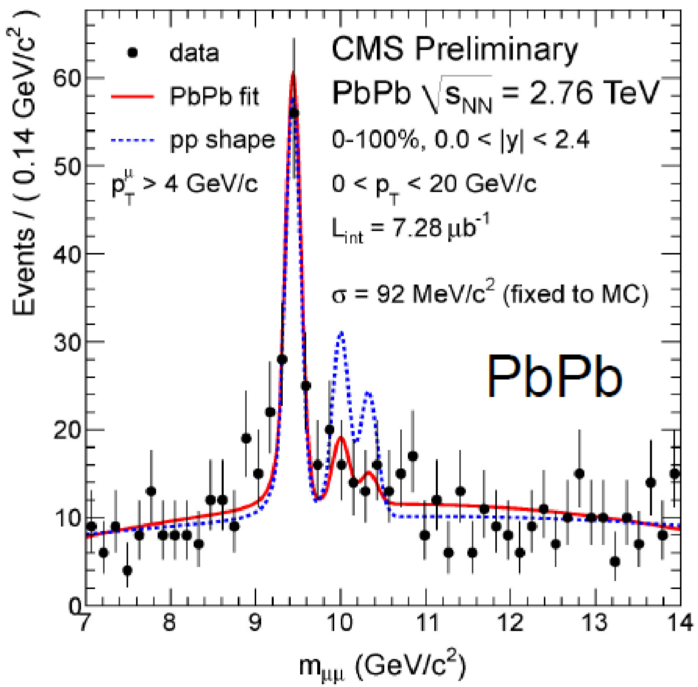
- Fragmentation pattern independent of energy lost in medium
- Consistent with strong out of cone energy loss and fragmentation of the parton remnant as if in vacuum

A. Morsch

Suppression in the Upsilon Family

CMS-PAS-HIN-10-006





$$\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp} = 0.78^{+0.16}_{-0.14} \pm 0.02 \qquad \Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb} = 0.24^{+0.13}_{-0.12} \pm 0.02$$

$$\frac{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb}}{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03$$

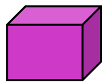
R. G De Cassagnac

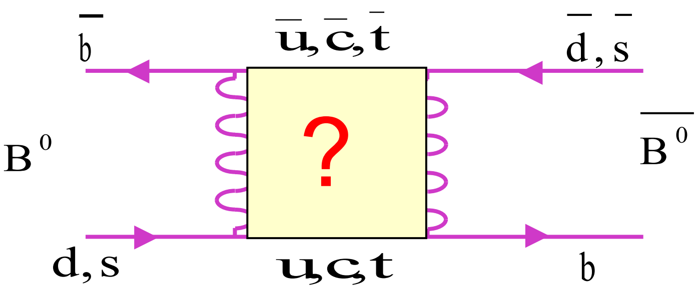
- $R_{AA}(1S) = 0.6 \pm 0.15$
- Excited states ϒ(2S,3S) relative to ϒ(1S) are suppressed.
- 2.4σ effect

LHC*b* Physics Goals

Search for deviations from Standard Model predictions due to
virtual contributions of new heavy particles in loop processes

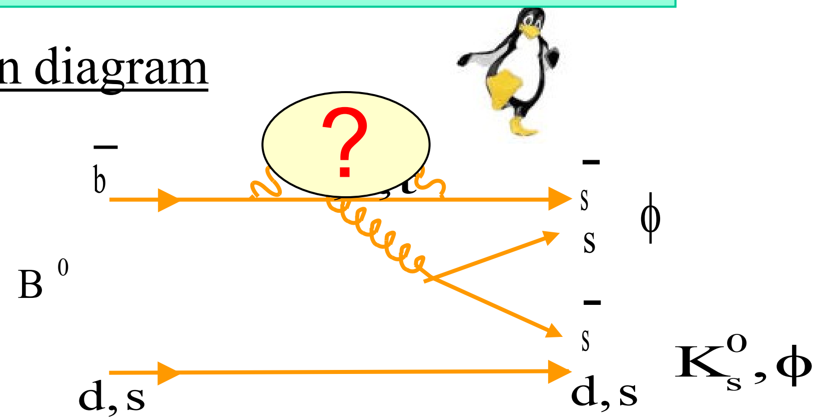
Box diagram





New Physics

Penguin diagram



Measure:

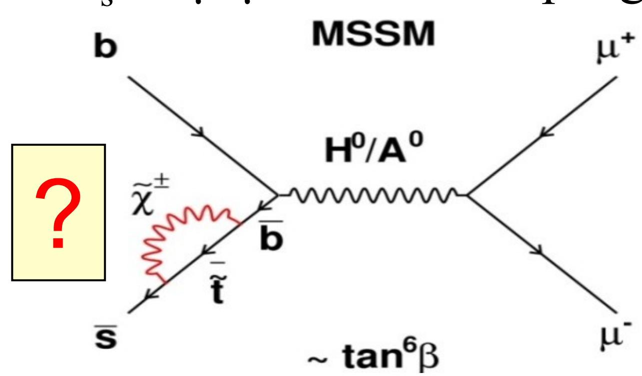
- ***CP violating phases*** in mixing and decay
- ***Rare Decays*** of heavy quarks

Compare:

- to ***very precise predictions*** of the SM

→ discovery potential for ***New Physics*** extending to mass scales far in excess of the LHC centre-of-mass energy

$B_s \rightarrow \mu^+\mu^-$ "s-channel penguin"

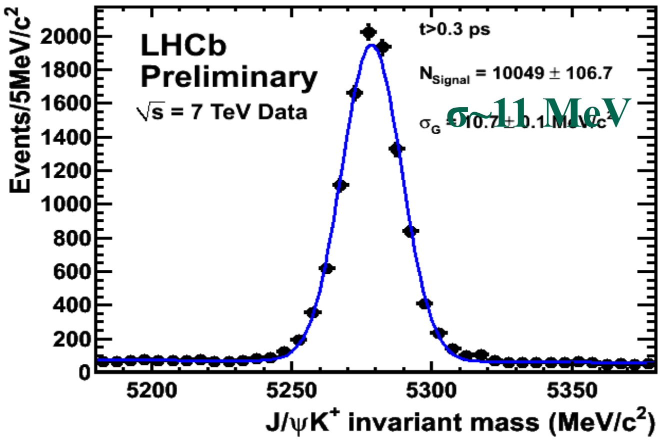


A. Schopper

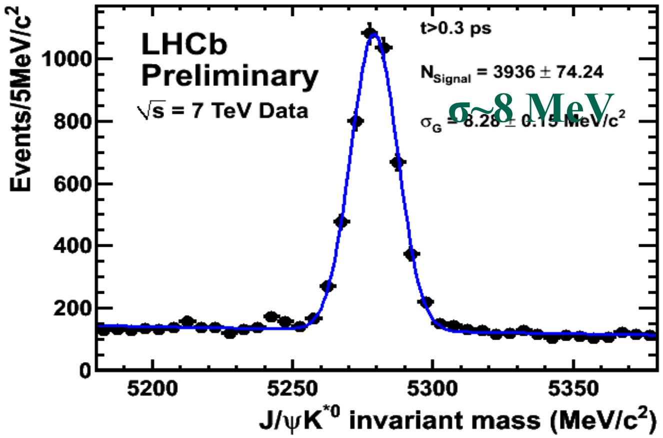
Mass and Proper Time Resolution in LHC*b*

A. Schopper

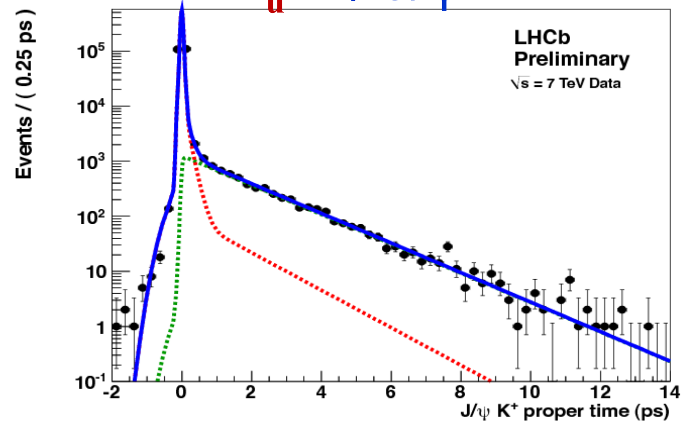
$B_u^+ \rightarrow J/\psi\, K^+$



$B_d^0 \rightarrow J/\psi\, K^*$



$B_u^+ \rightarrow J/\psi\, K^+$



- very good mass resolution
- very low background (comparable to e^+e^- machines)
- ***worlds best*** mass measurements

- excellent proper time resolution of ~50 ps

Comparison GPDs:

- **CMS: σ~16 MeV**
- **ATLAS: σ~26 MeV**

Very rare decays: search for $B_{d,s} \to \mu\,\mu$

A. Schopper

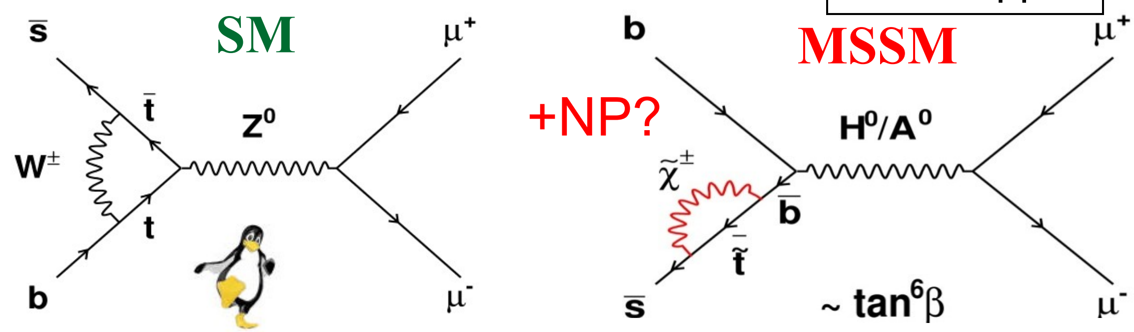
$B_{d,s} \to \mu\mu$ the super rare loop decay

In Standard Model:

$B(B_d \to \mu\,\mu) = (0.10 \pm 0.01)\times10^{-9}$

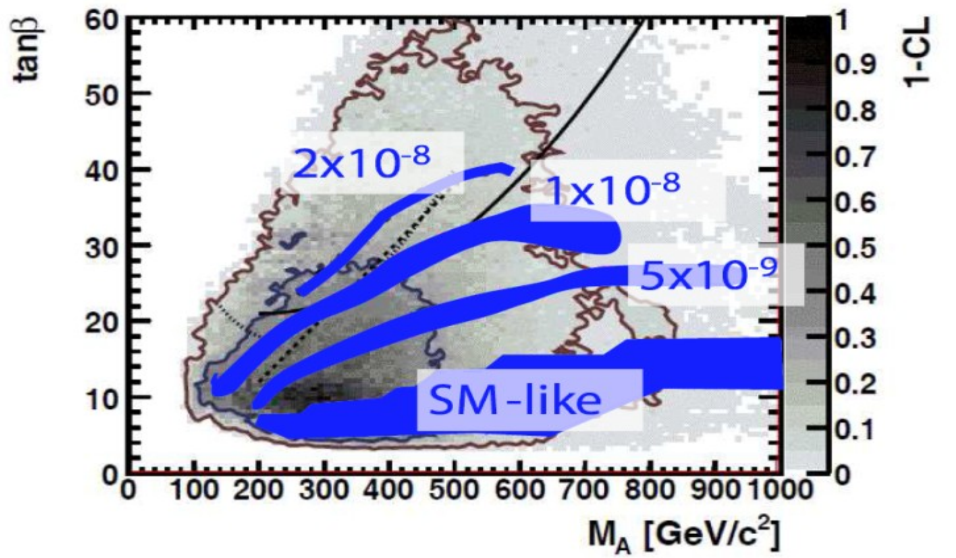
$B(B_s \to \mu\,\mu) = (3.2 \pm 0.2)\times10^{-9}$

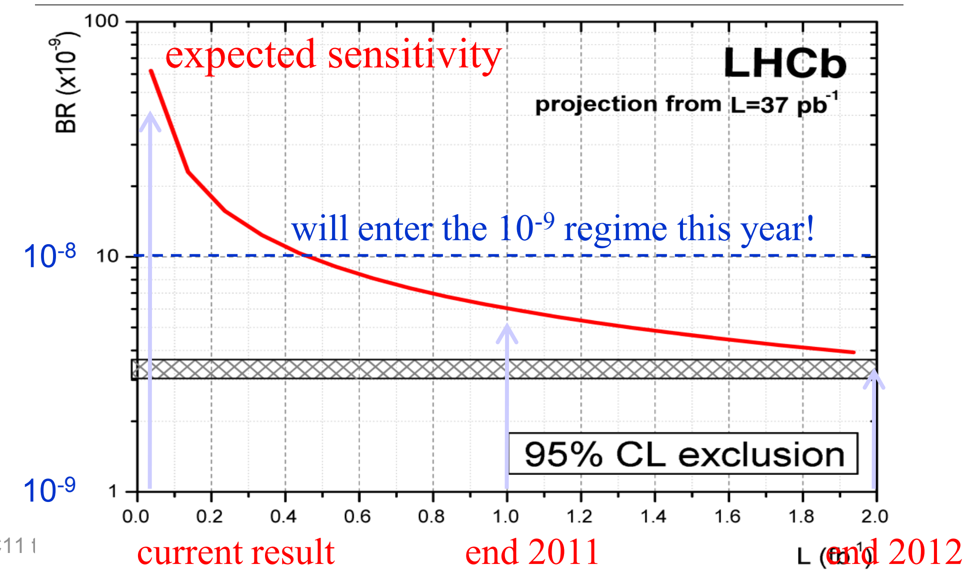
[A.J.Buras: arXiv:1012.1447]



- ✓ sensitive to New Physics, can be strongly enhanced in SUSY with scalar Higgs exchange
- ✓ sensitive probe for MSSM with large tanβ: $B(B_S \to \mu^+\mu^-) \sim \tan\beta^{\,6} / M_A^{\,4}$

$B(B_s \to \mu\mu) < 5.6\times10^{-8}$; $B(B_d \to \mu\mu) < 1.5\times10^{-8}$ (95% CL)



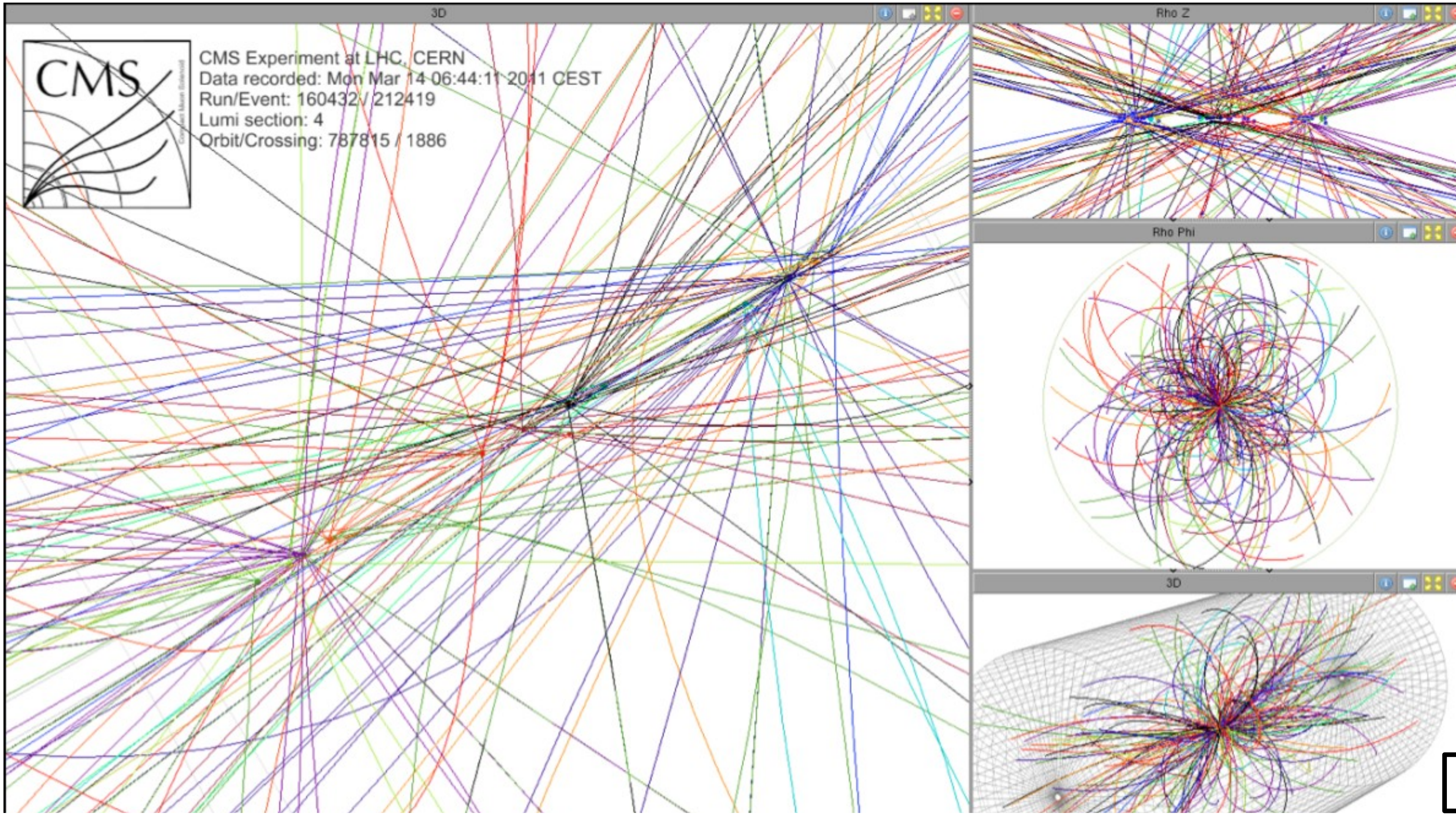


Outlook 2011-2012

Physics with several thousands of pb^{-1}

Make more precise SM measurements – confront theory
Search for the Higgs Boson
Search for Supersymmetry
Search for exotica
Look and be prepared for the unexpected

Approaching Design "Specific" Luminosity

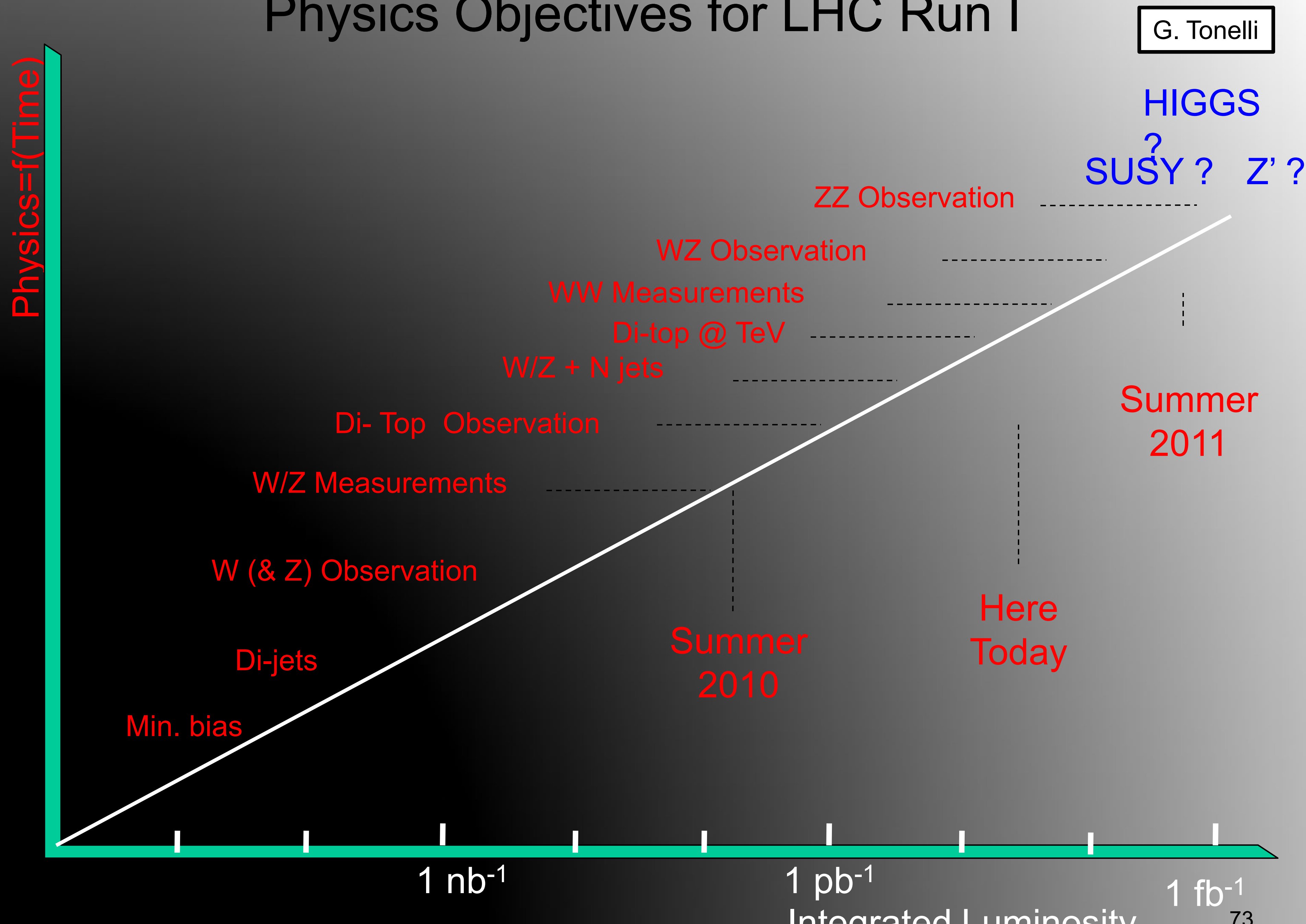


M. Mannelli

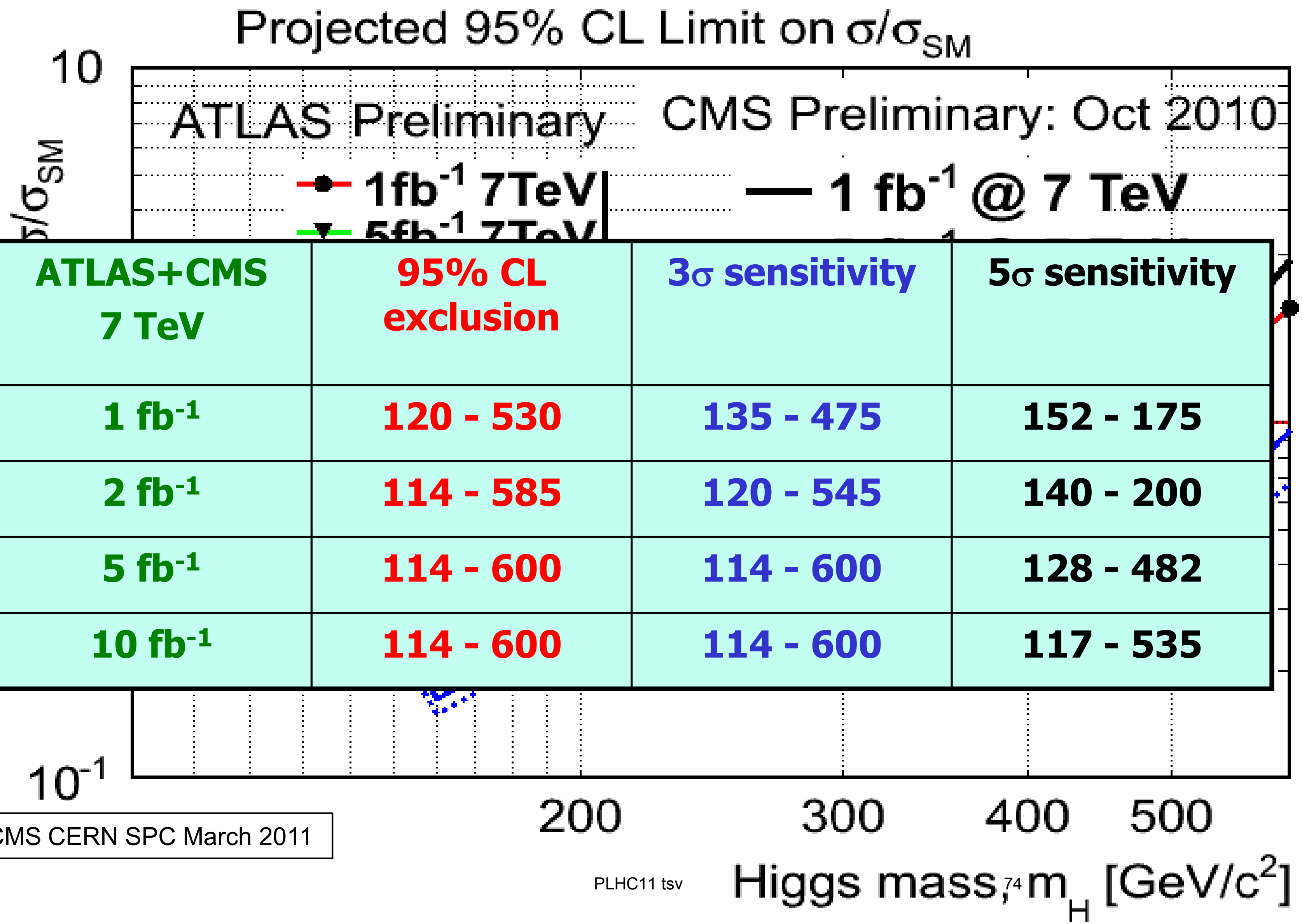
Operating at ~ $1.5x10^{33}$ with 50ns bunch structure presents many challenges
Our experience so far makes us confident that we will make effective use of these data

=> Can make useful projections for higher accumulated Luminosity

Physics Objectives for LHC Run I



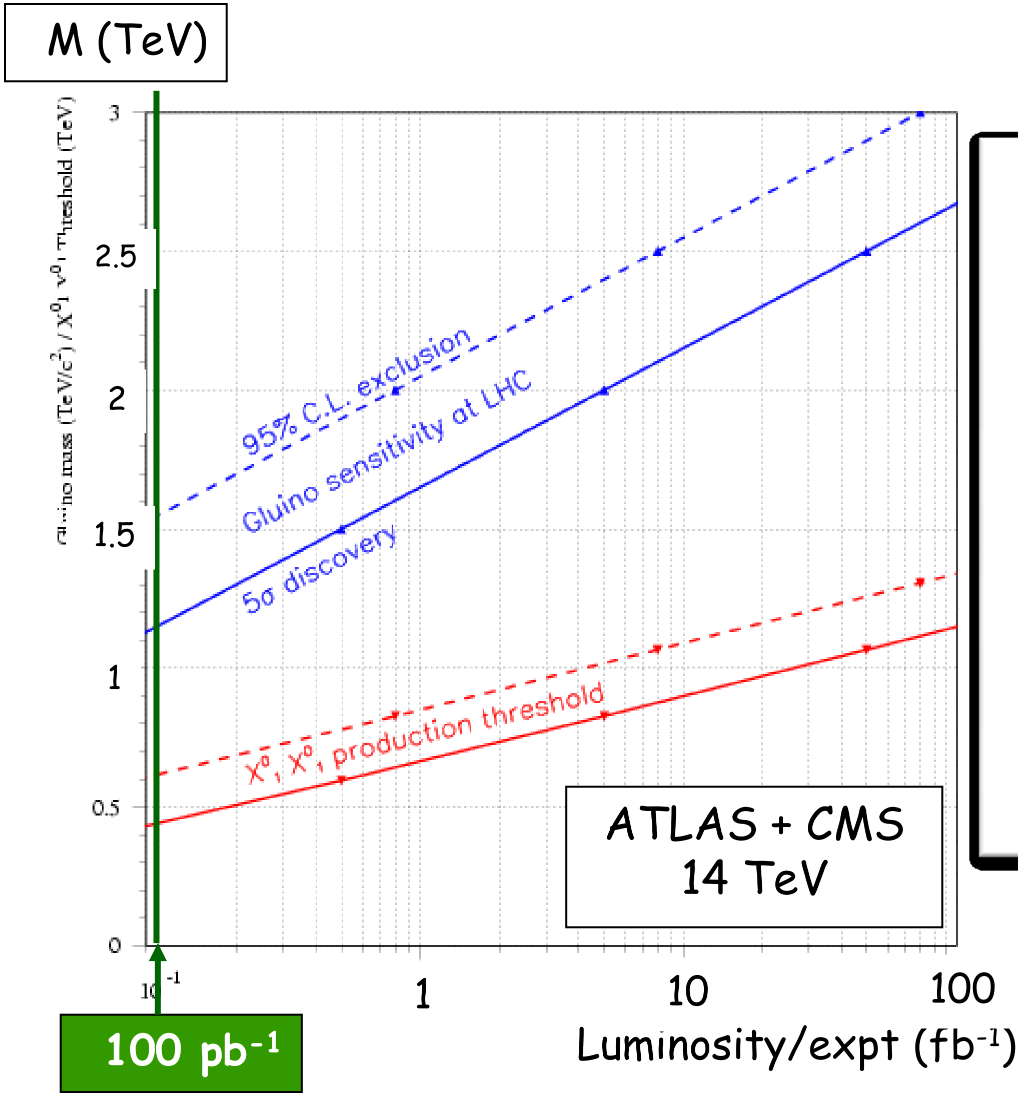
Progonosis for the Search for H_{SM}

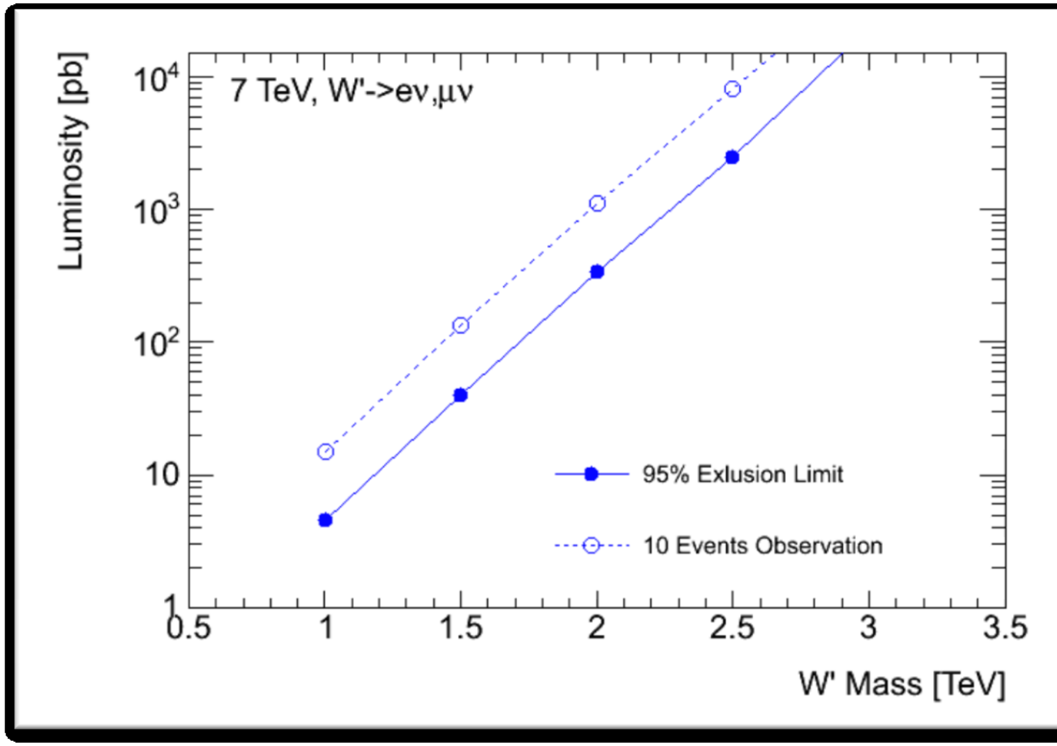


ATLAS+CMS 7 TeV	95% CL exclusion	3σ sensitivity	5σ sensitivity
1 fb^{-1}	120 - 530	135 - 475	152 - 175
2 fb^{-1}	114 - 585	120 - 545	140 - 200
5 fb^{-1}	114 - 600	114 - 600	128 - 482
10 fb^{-1}	114 - 600	114 - 600	117 - 535

ATLAS+CMS CERN SPC March 2011

Outlook: Supersymmetry and New Gauge Bosons





LHC Time-line

S. Bertolucci

2009 — Start of LHC

Run 1: 7 TeV centre of mass energy, luminosity ramping up to few 10^{33} cm^{-2} s^{-1}, few fb^{-1} delivered

2013/14 — LHC shut-down to prepare machine for design energy and nominal luminosity

Run 2: Ramp up luminosity to nominal (10^{34} cm^{-2} s^{-1}), ~50 to 100 fb^{-1}

2017 or 18 — Injector and LHC Phase-I upgrades to go to ultimate luminosity

Run 3: Ramp up luminosity to 2.2 x nominal, reaching ~100 fb^{-1} / year accumulate few hundred fb^{-1}

~2021/22 — Phase-II: High-luminosity LHC. New focussing magnets and CRAB cavities for very high luminosity with levelling

Run 4: Collect data until > 3000 fb^{-1}

2030 — ILC, High energy LHC, ... ?

Epilogue

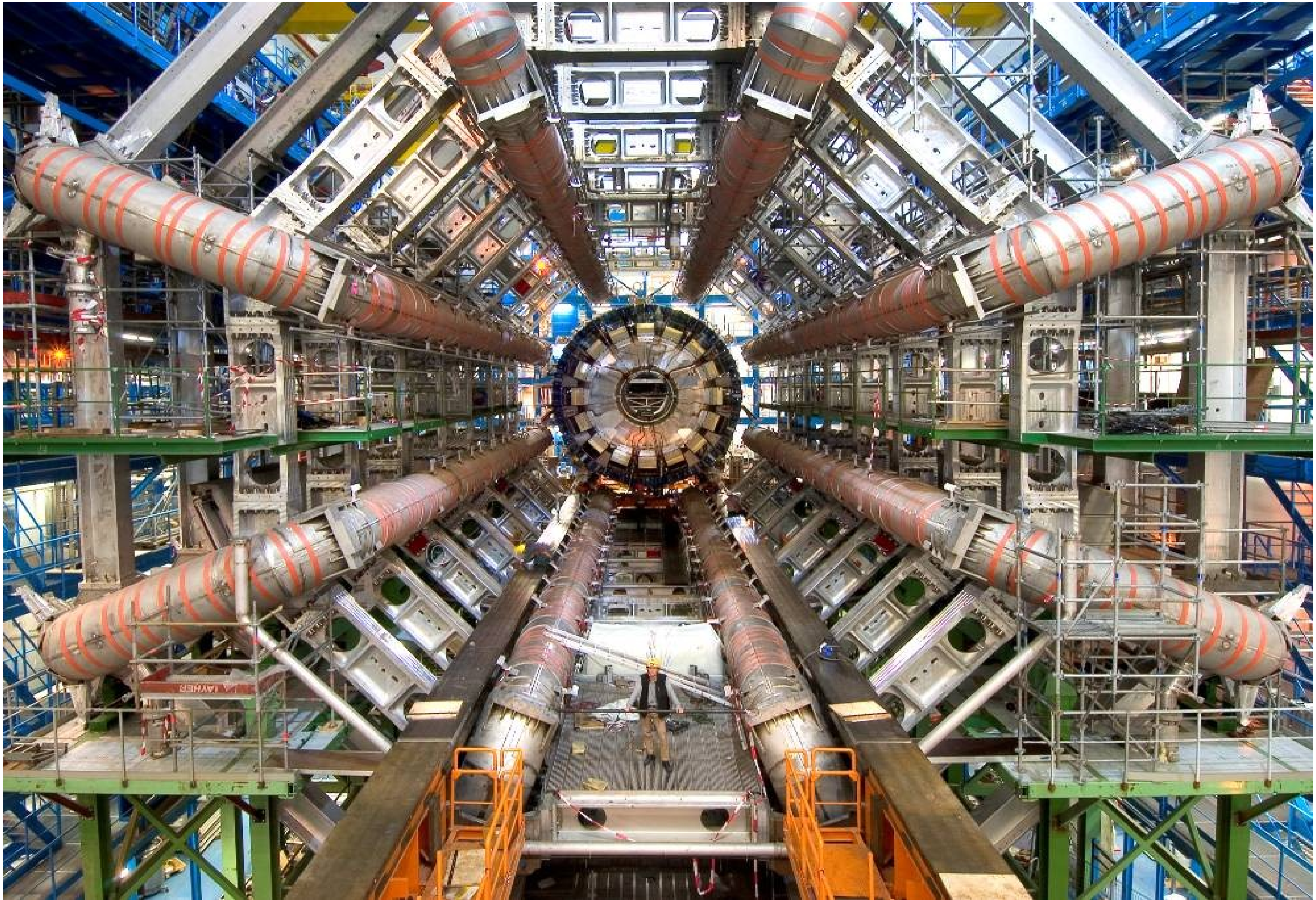
C. Llewellyn Smith at the Royal Society London May 2011

What would a Rip Van Winkle understand of a talk on fundamental micro-physics if he fell asleep/woke up 27 years later in:

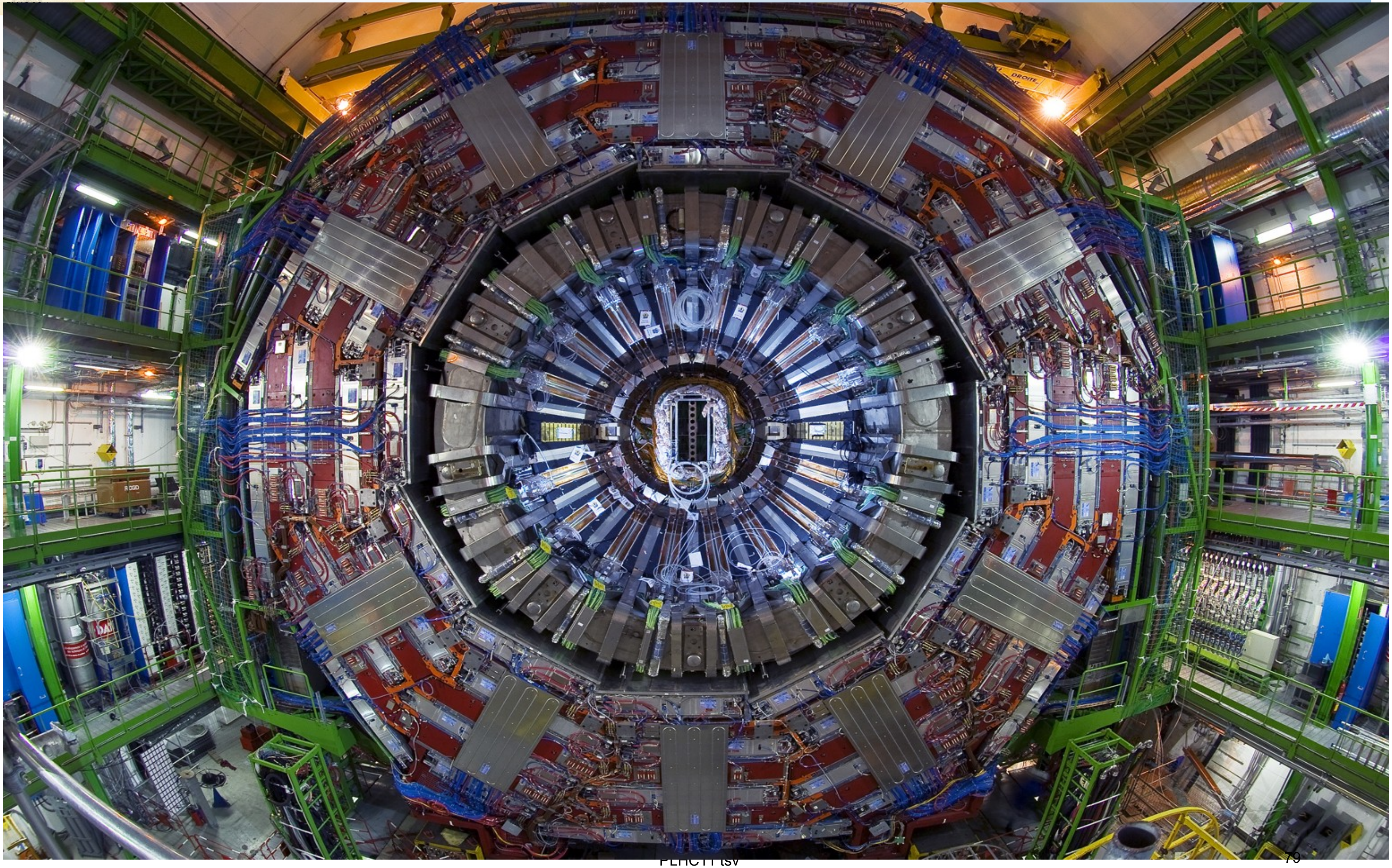
- **1903/1930** - nothing
- **1930/1957** - almost nothing
- **1957/1984** - almost nothing
- **1984/2011** - almost everything*
- *although he would have been amazed by the sophistication and performance of the LHC detectors*
- * *except about data analysis*

***BUT I hope this will have changed by the next PLHC**

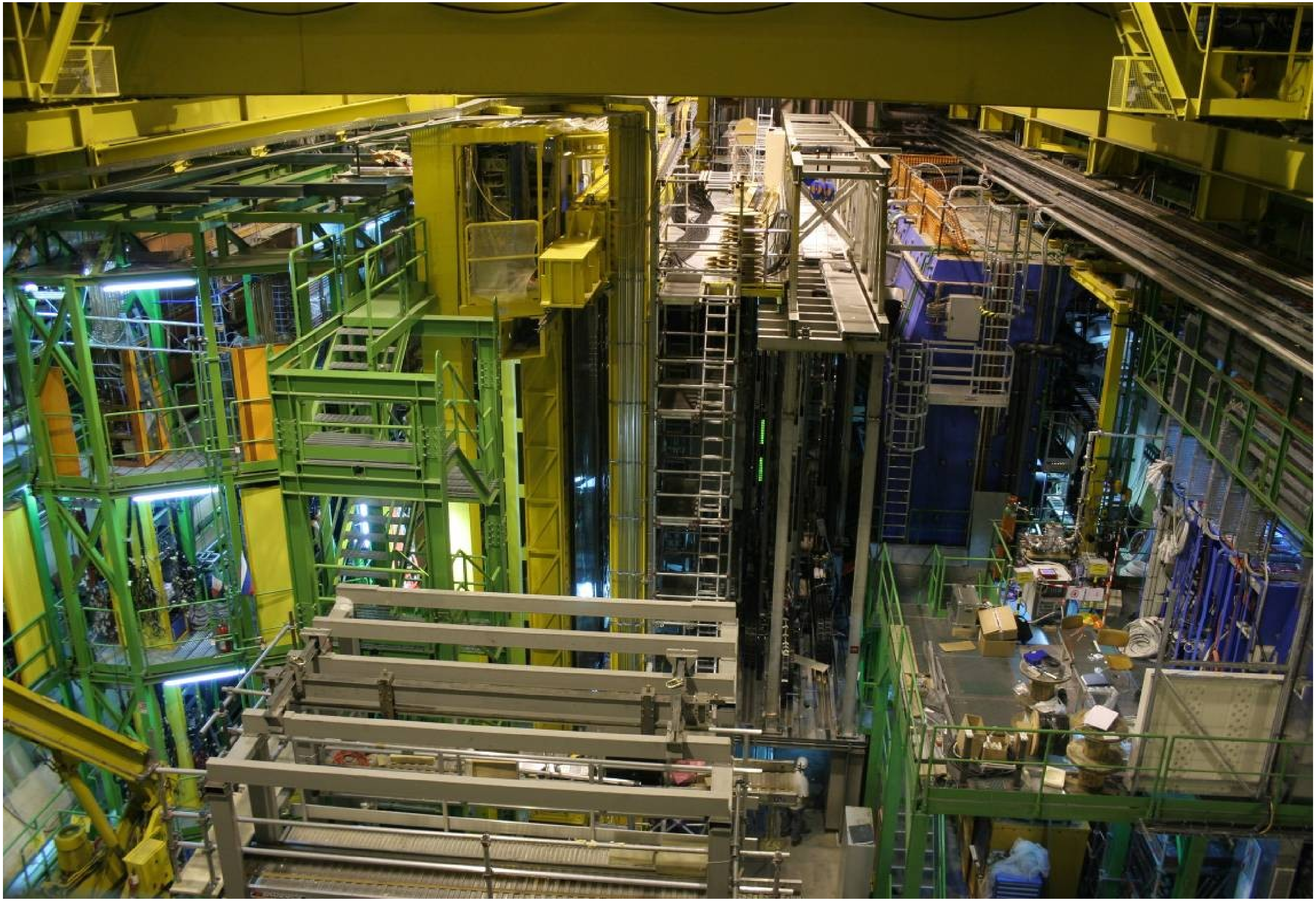
ATLAS



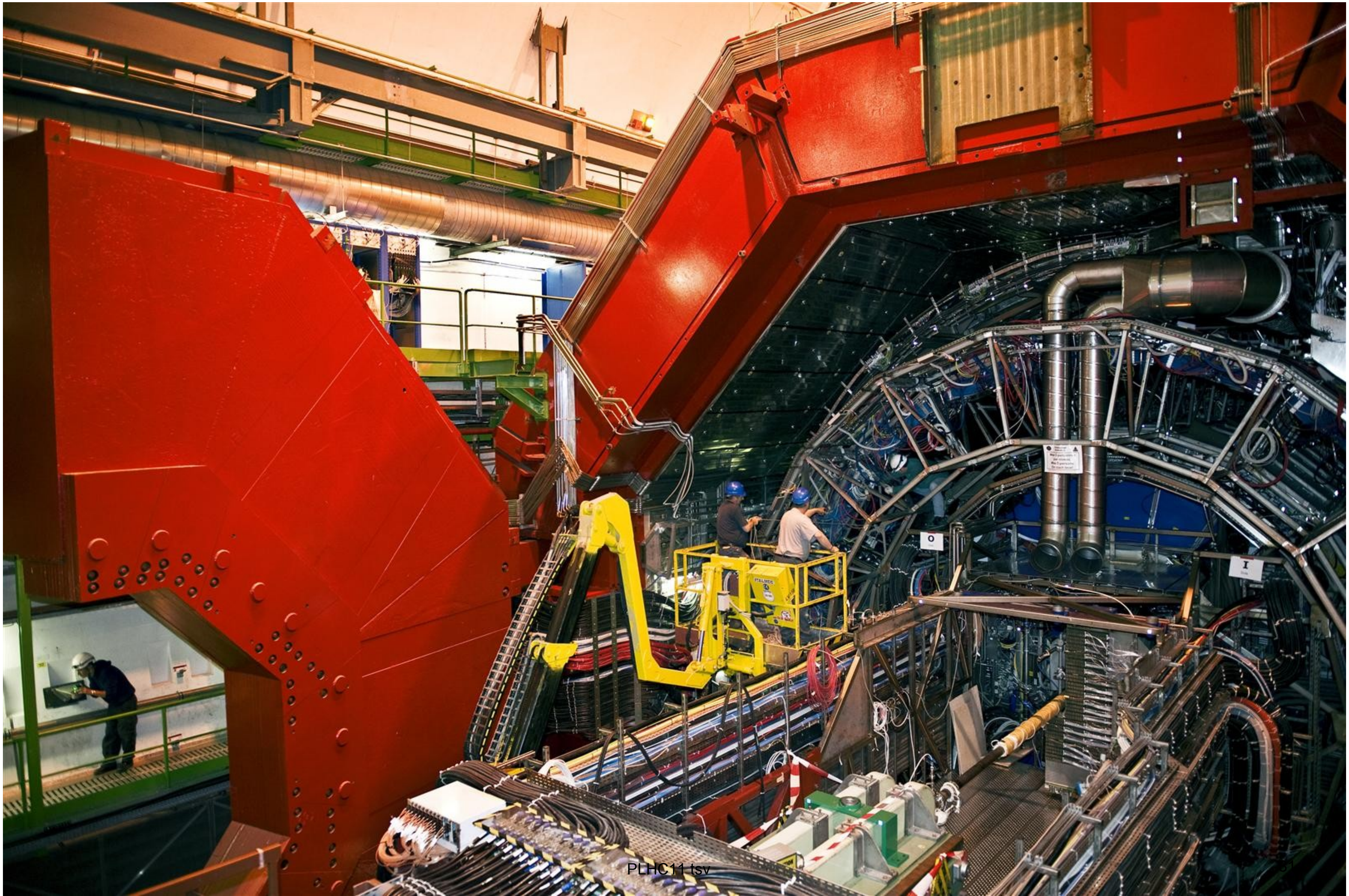
CMS Detector



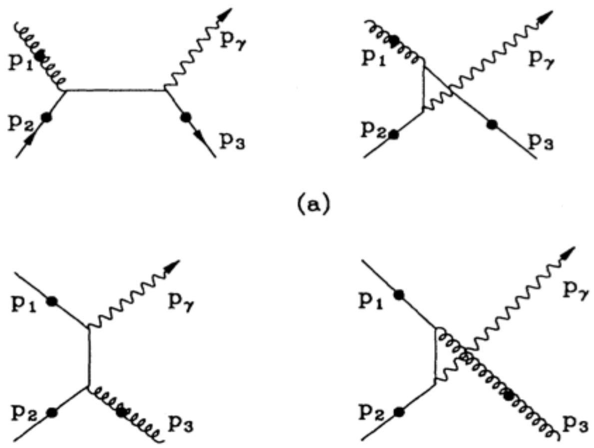
LHCb Detector

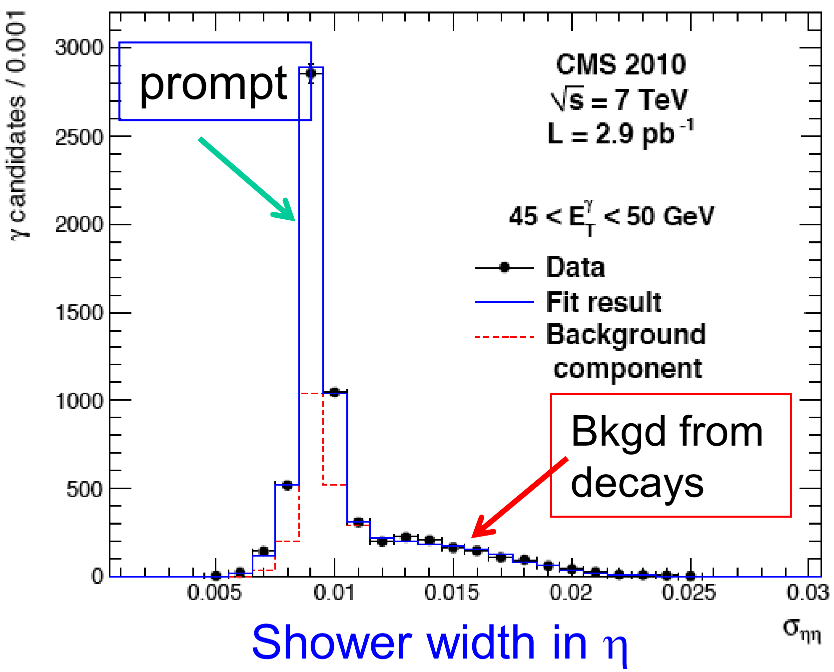


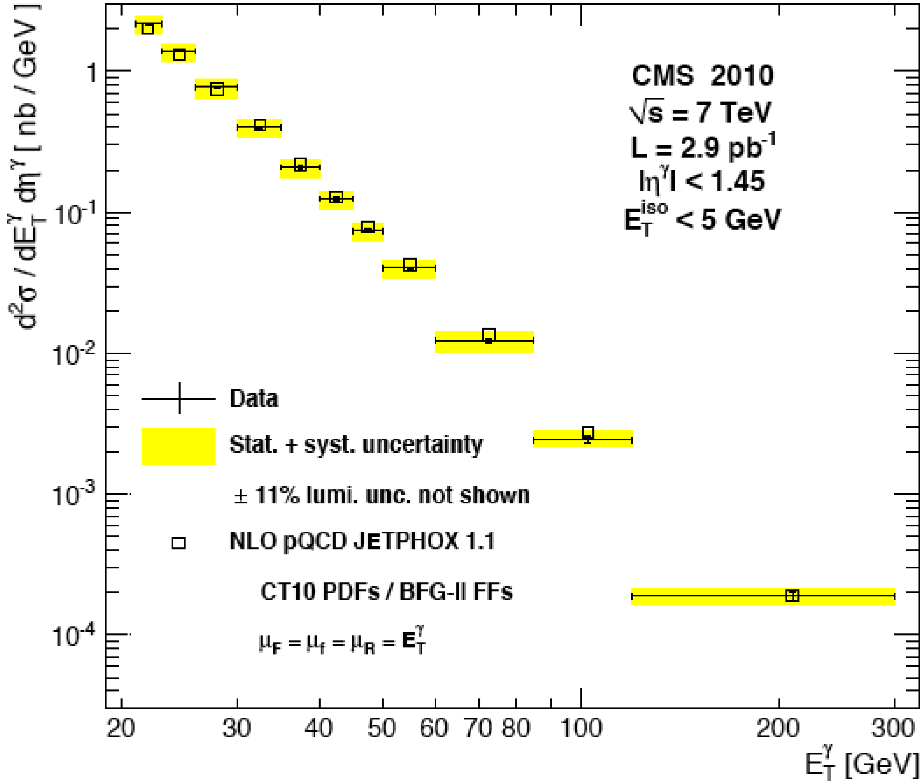
ALICE

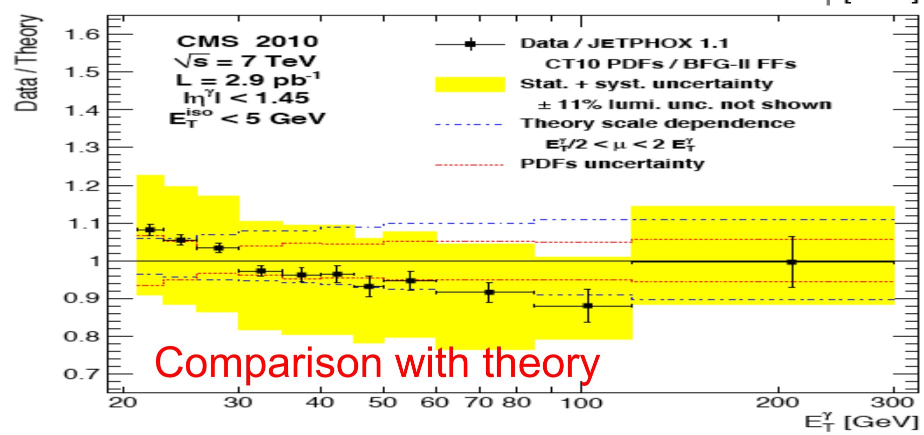


Prompt (Isolated) Photon Production

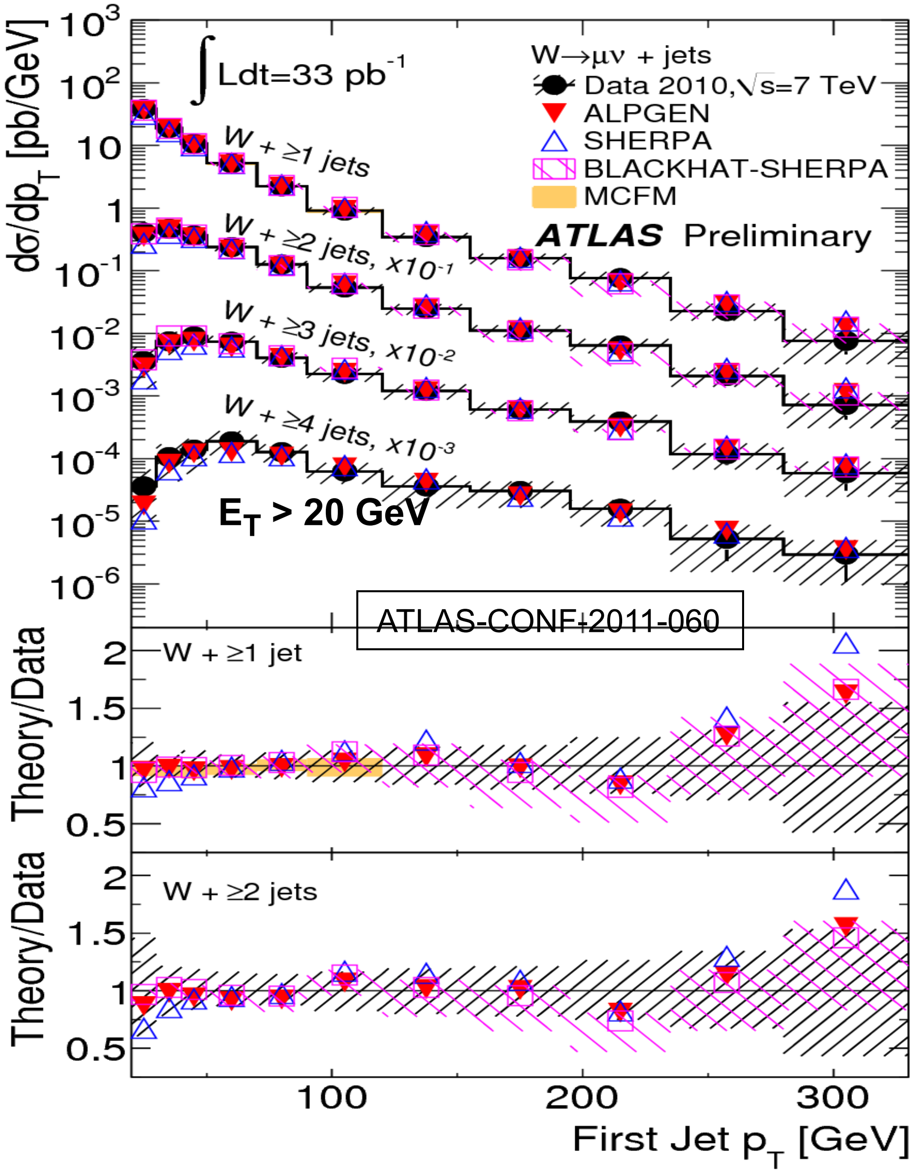




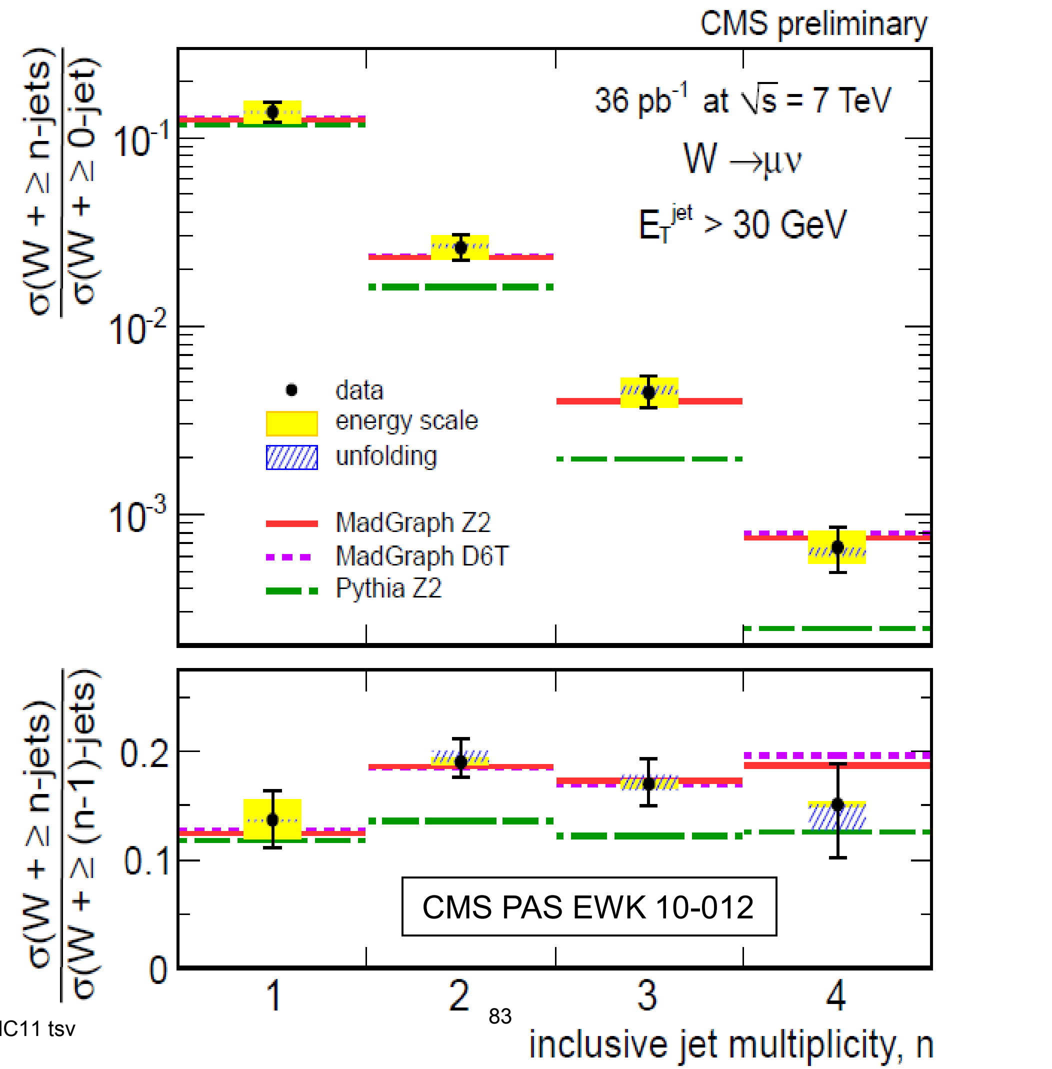




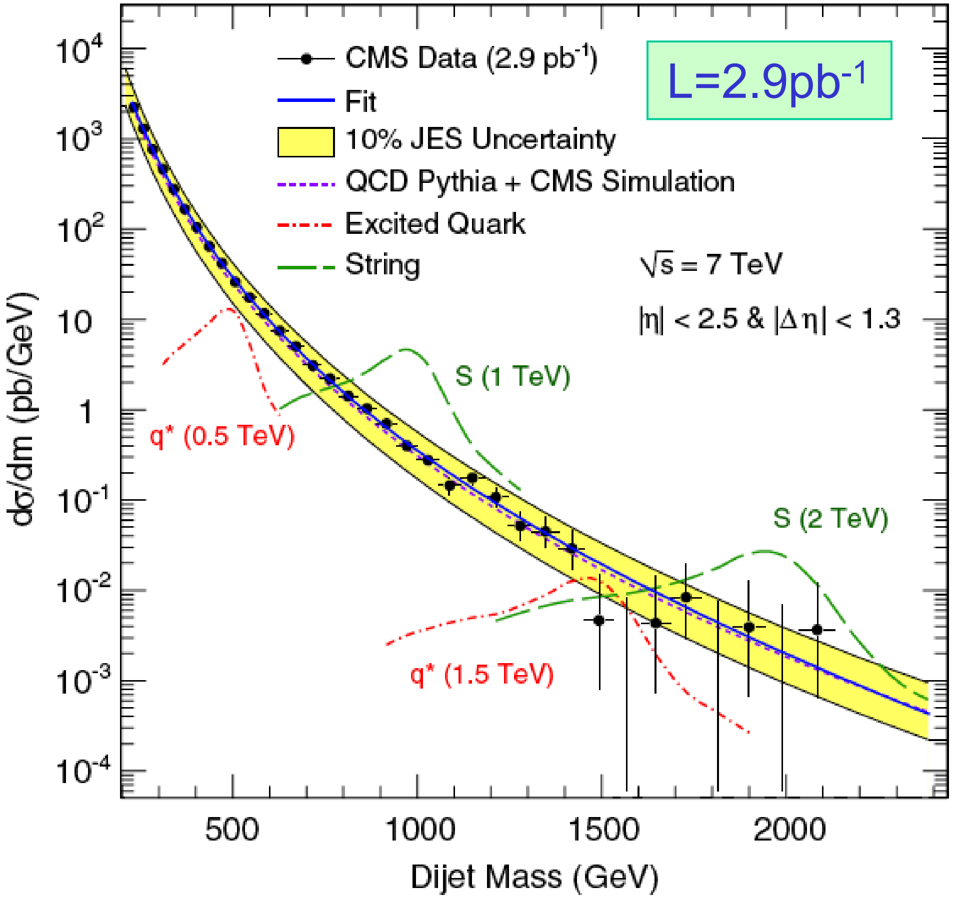
W + jet(s) production

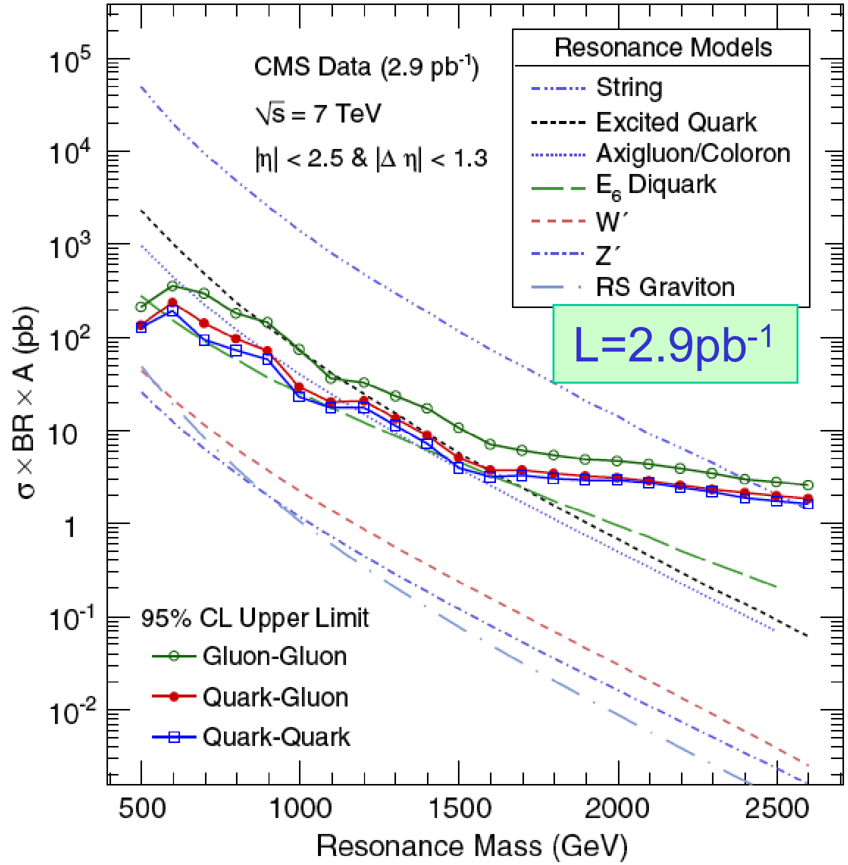


Both an interesting QCD measurement as well as a dominat background to searches



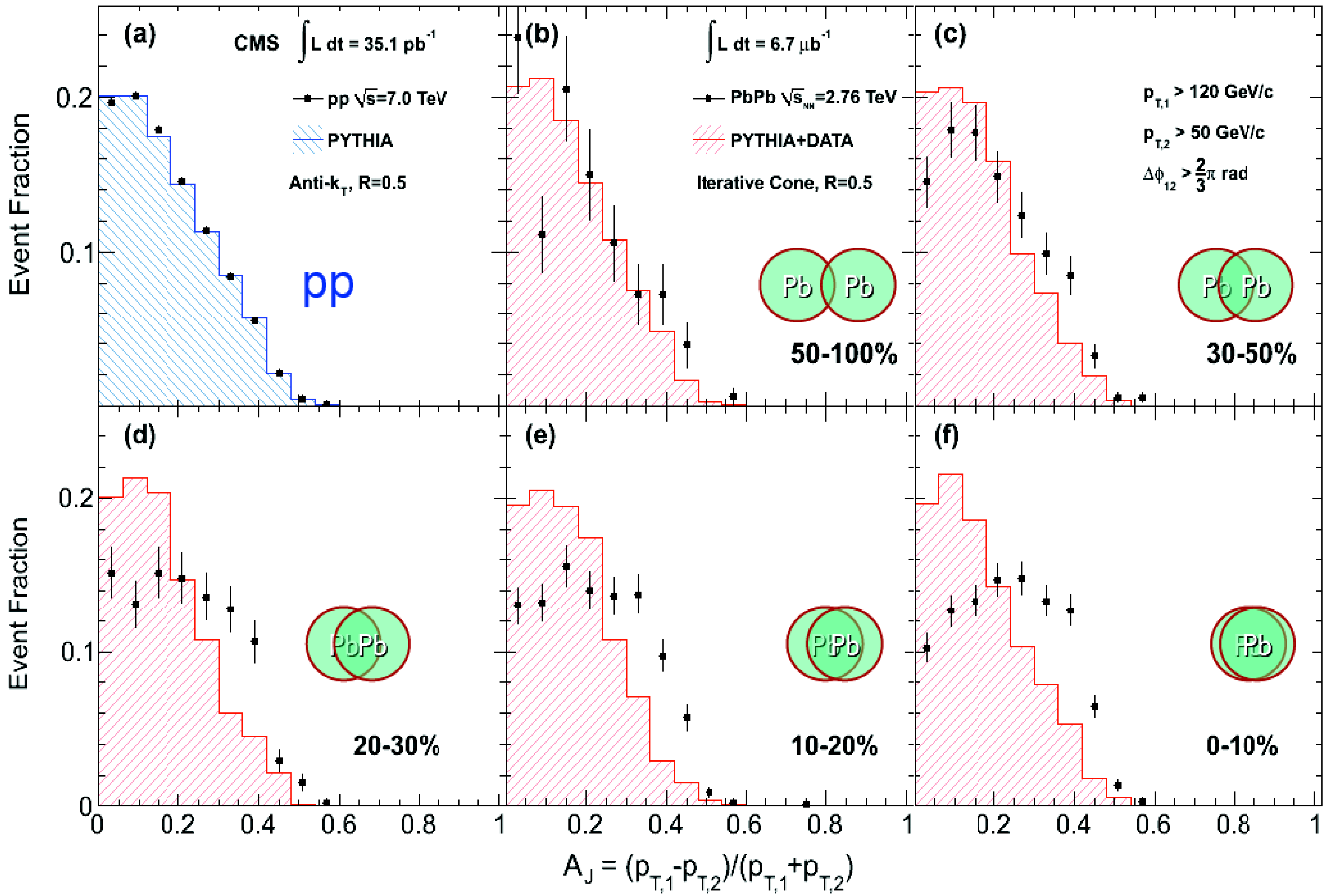
Search for narrow resonances in di-jets

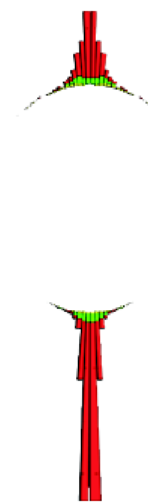




95% CL mass limits for new particles decaying to parton pairs:
String resonances > 2.4 TeV; Excited quarks >1.58TeV, axigluons or colorons >1.23 TeV, ….

"Jet Quenching": ATLAS, CMS

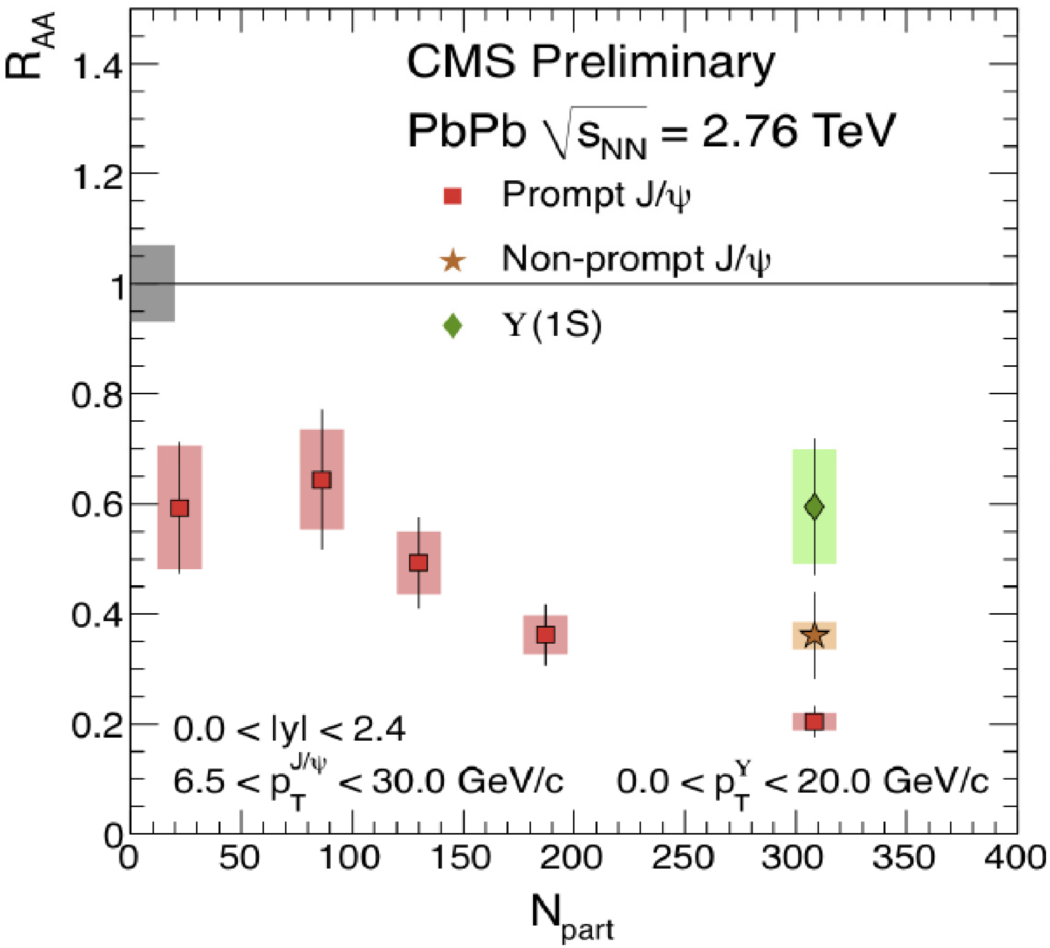


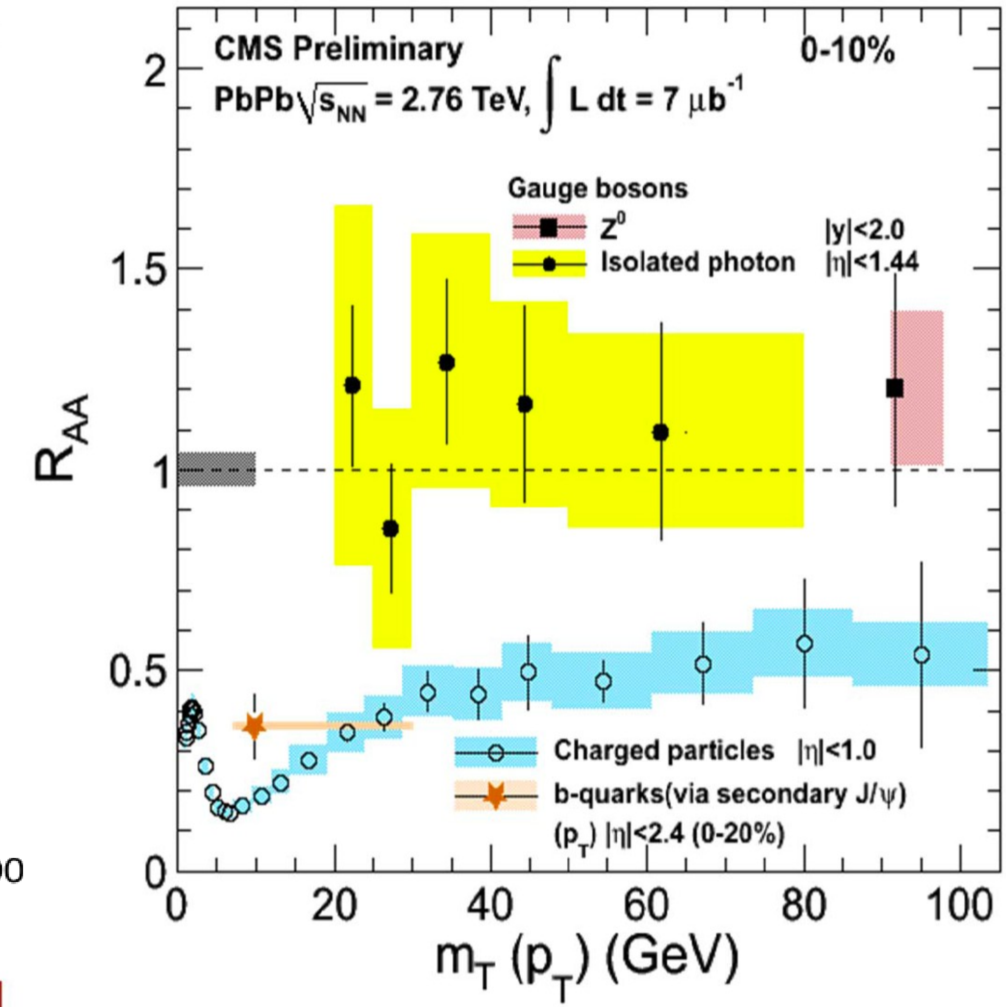


p_T (leading jet (1)) > 120 GeV,
p_T (sub-leading jet (2)) >50 GeV

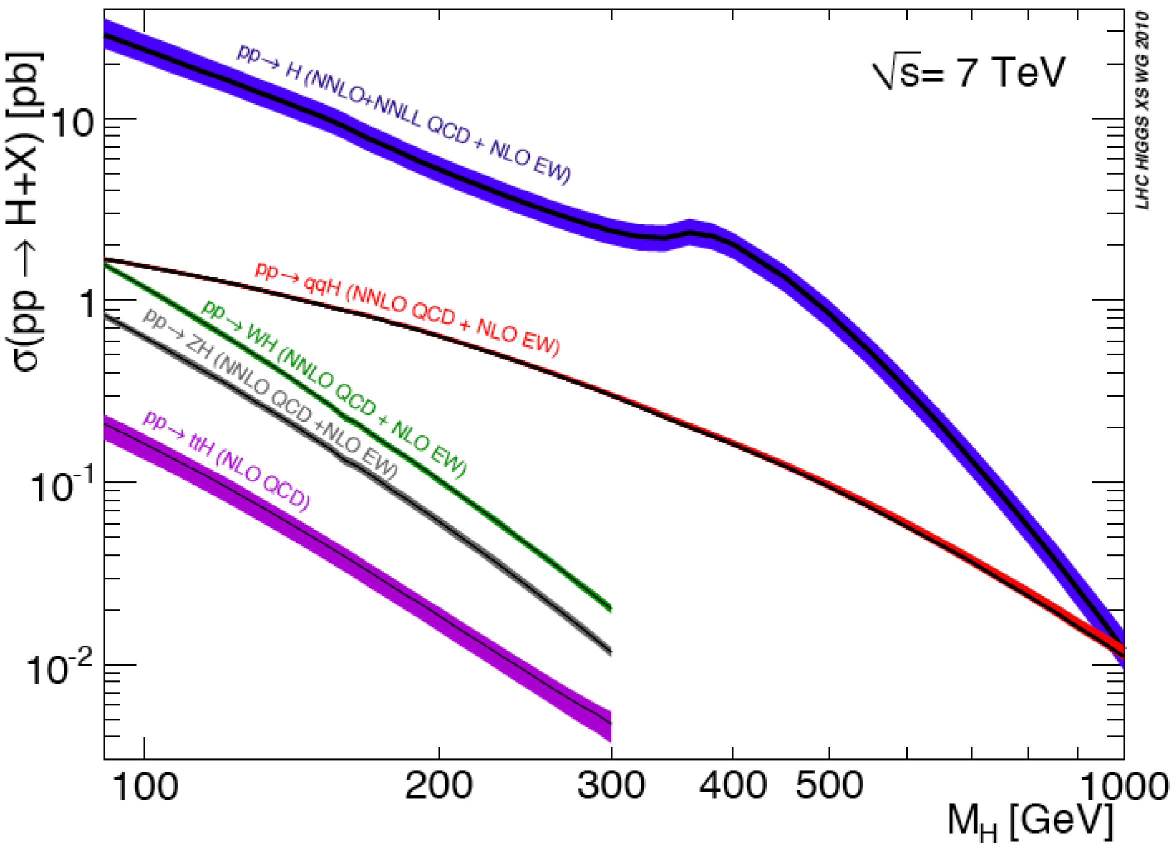
Asymmetry $$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$$

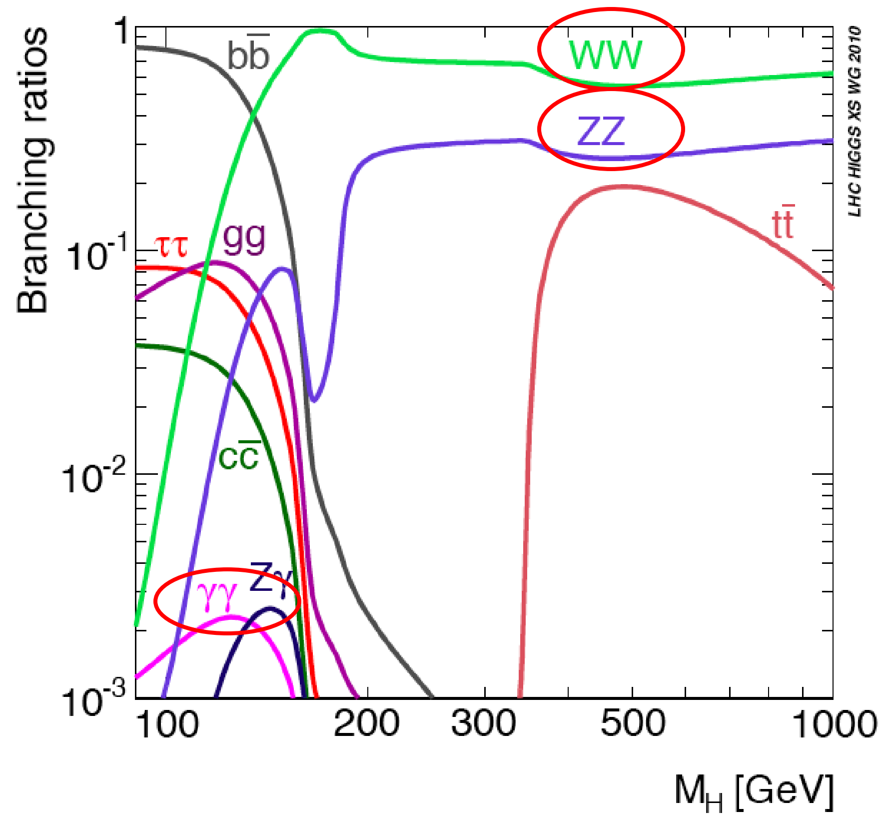
Other Suppression





The SM Higgs Boson at LHC

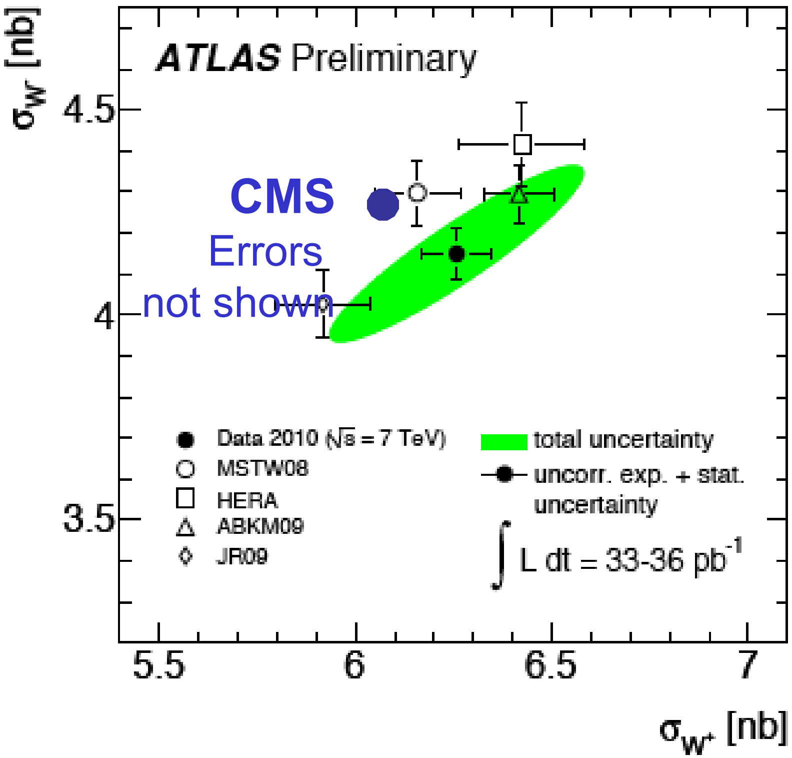


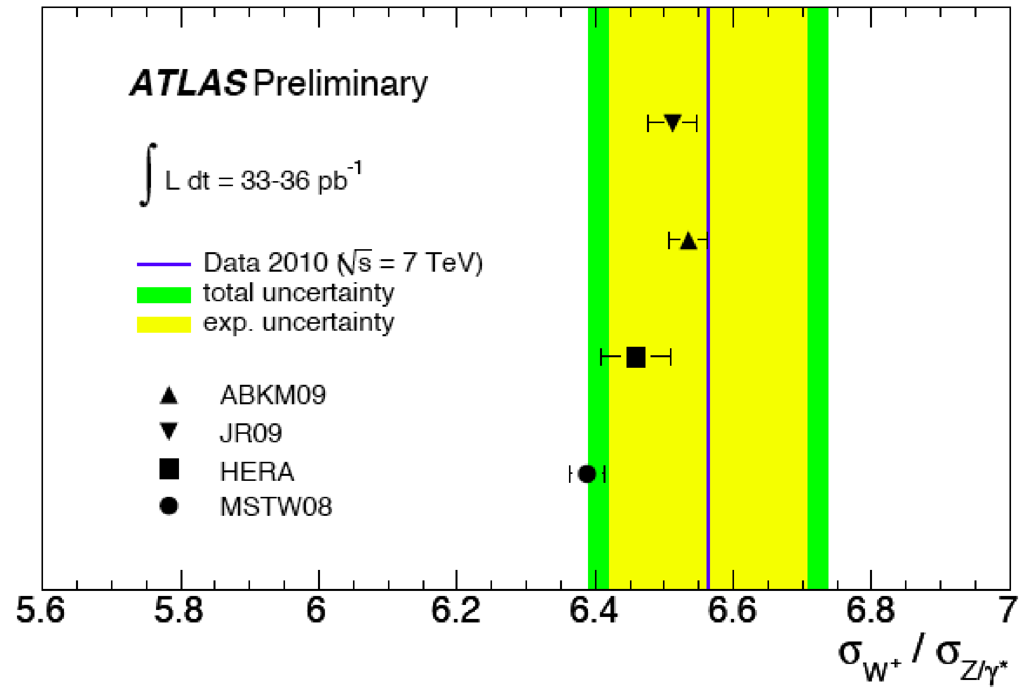


Imperial College London

PLHC 2011

More on W/Z Cross-section Measurement





MC+PDF	A_{W+}/A_{W-} e	A_{W+}/A_{W-} μ	$\sigma^{tot}_{W+}/\sigma^{tot}_{W-}$ e	$\sigma^{tot}_{W+}/\sigma^{tot}_{W-}$ μ
PYTHIA+MRSTLO*	1.02	1.02	1.50	1.51
PYTHIA+CTEQ6.6	1.05	1.05	1.46	1.47
PYTHIA+HERAPDF1.0	1.03	1.04	1.48	1.49
MC@NLO+HERAPDF1.0	1.05	1.05	1.46	1.47
MC@NLO+CTEQ6.6	1.06	1.06	1.45	1.46

$$\frac{\sigma^{tot}_{W+}}{\sigma^{tot}_{W-}} = \frac{\sigma^{fid}_{W+}}{\sigma^{fid}_{W-}} \cdot \frac{A_{W-}}{A_{W+}}$$

G. Watt

Alternative acceptance calculations move ATLAS $\sigma^{tot}_{W+}/\sigma^{tot}_{W-}$ much closer to CMS.

- Precision requires better acceptance calculations and/or data to theory comparisons at level of fiducial cross section.