# Status of ATLAS and CMS

A. Di Simone
Università & INFN Roma Tor Vergata

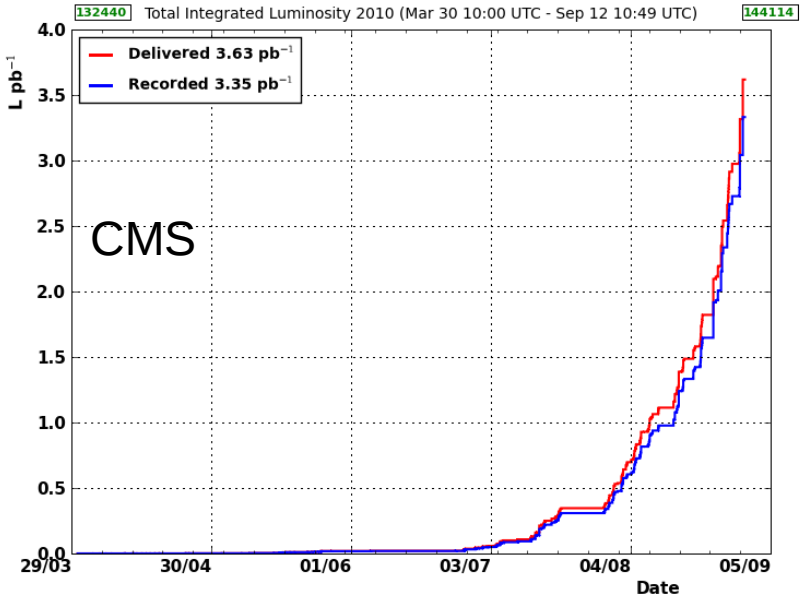
On behalf of the ATLAS and CMS collaborations

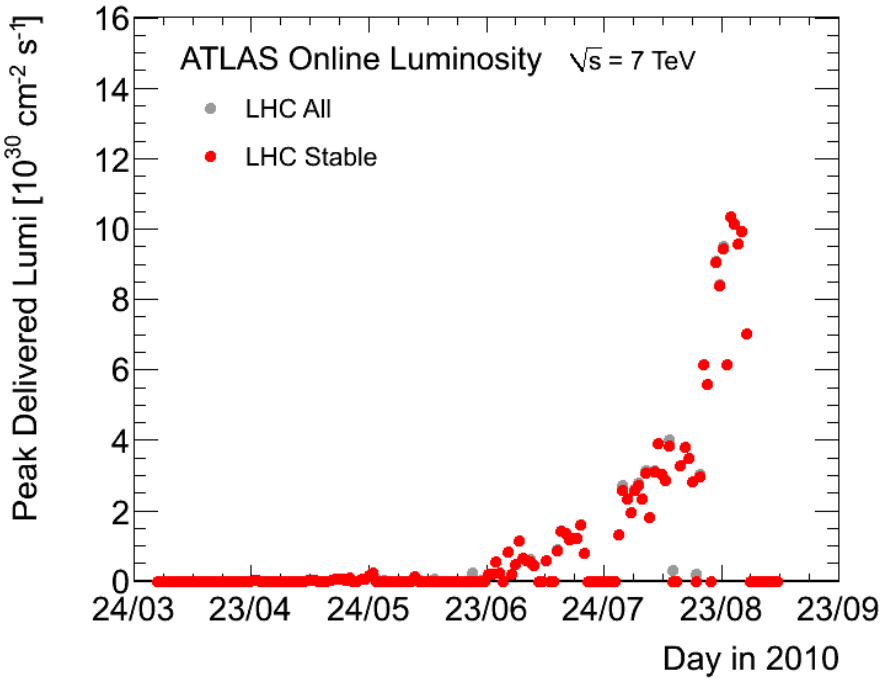
**High precision for Hard Processes at the LHC**
**GGI, Arcetri, 14-17/09/2010**

# Outline

- Introduction
- The ATLAS and CMS detectors
  - Operation
  - Performances
- Physics highlights
  - Minimum bias and UE
  - Jets
  - b/c mesons
  - EW bosons
  - Top production
  - NP searches
- Conclusions

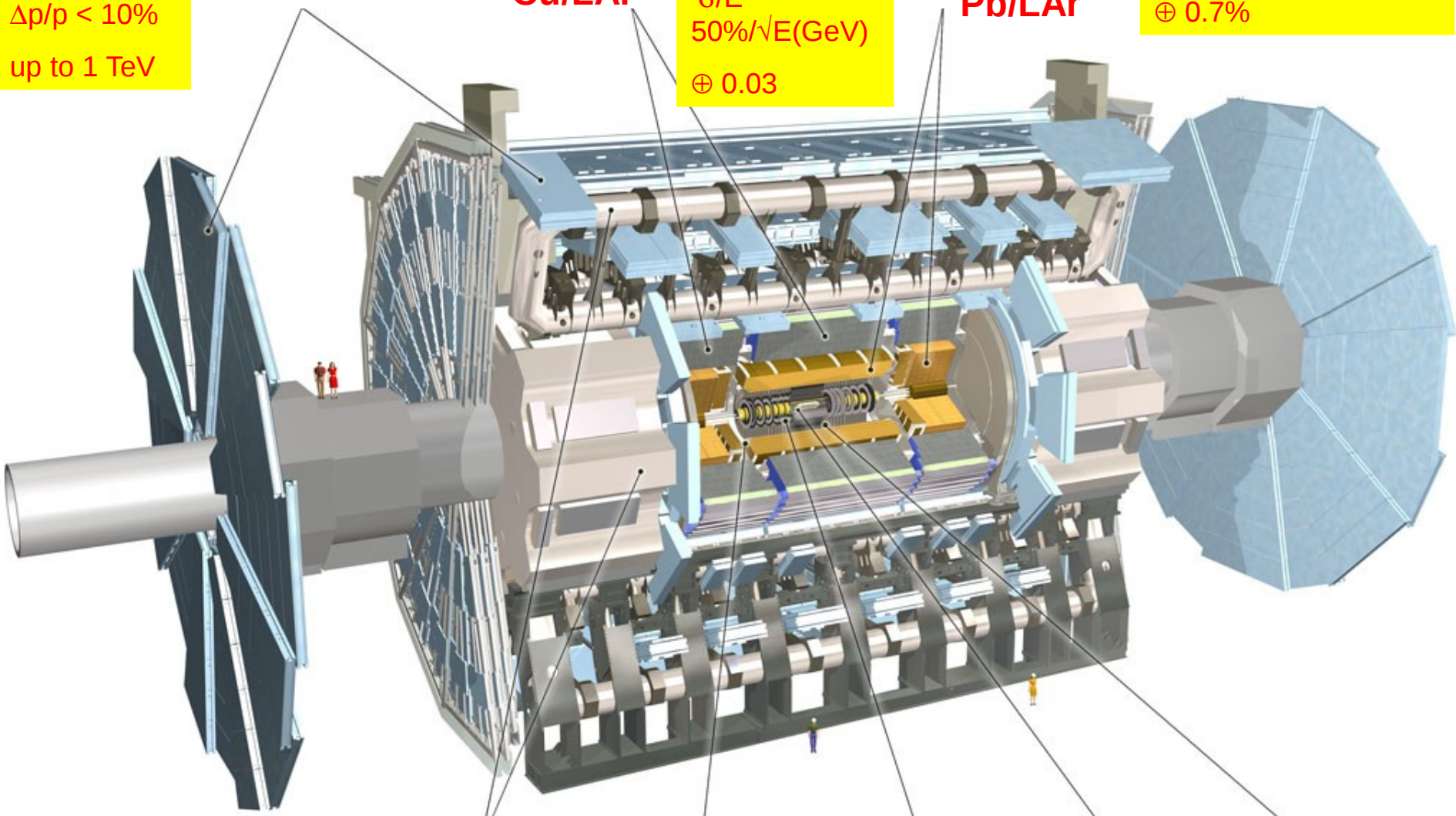
# Introduction




- LHC performance is constantly improving
  - 3.7/pb delivered up to now (~3.4/pb recorded by each of CMS and ATLAS)
  - Peak stable luminosity $1.03 \times 10^{31} cm^{-1} s^{-1}$
- Data is processed promptly, and analyses are digesting it as fast as possible (while also studying detector performance, trigger efficiencies, ...)
  - A large amount of interesting results already presented/published
  - Will give here an overview of some of the latest public results by ATLAS and CMS

# The detectors (1)



**Muon detectors: drift tubes, CSC, RPC, TGC**

$\Delta p/p < 10\%$ up to 1 TeV

**Had calo: Fe/Scintillator Cu/LAr**

$\sigma/E \sim 50\%/\sqrt{E(GeV)} \oplus 0.03$

**EM calo: Pb/LAr**

$\sigma/E \sim 10\%/\sqrt{E(GeV)} \oplus 0.7\%$

**Toroid magnets**

**Solenoid Magnet**

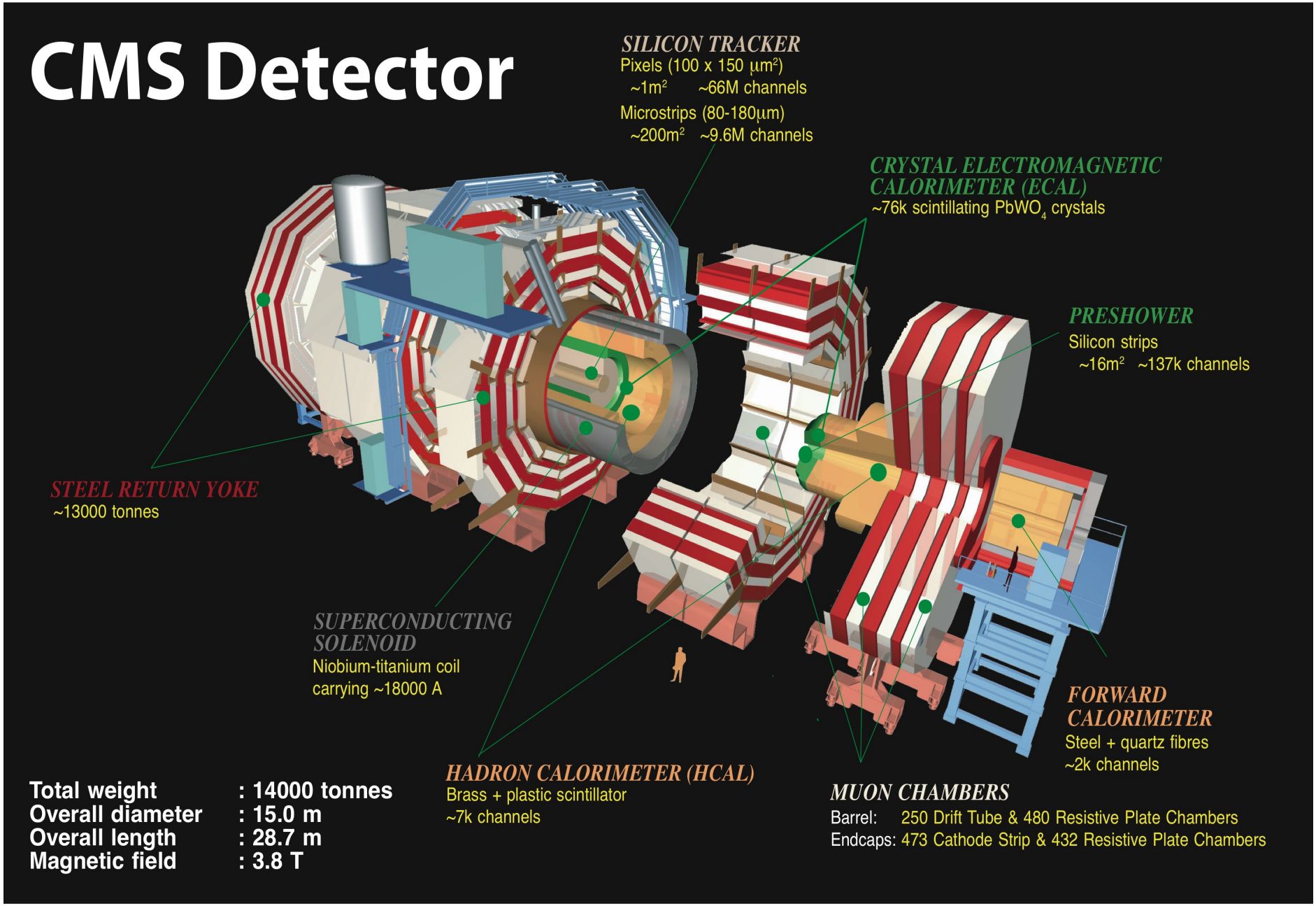
**SCT**

**Pixels**

**TR tracker**

Tracking:overall resolution $\Delta p_t/p_t <= 0.05\% \; p_T(GeV) \oplus 1\%$

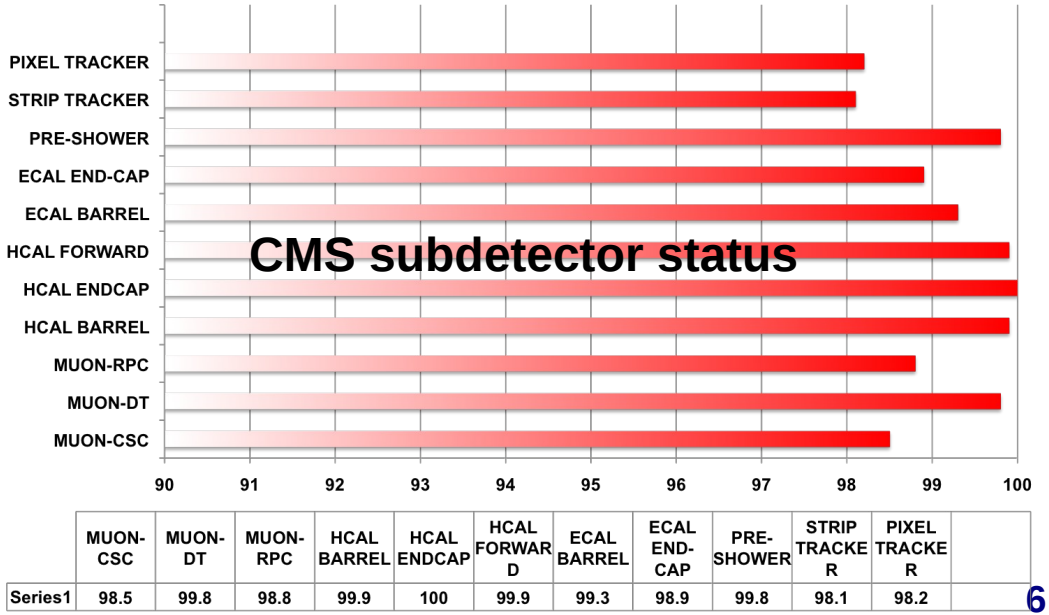
# The detectors (2)



# The detectors (3)

- The size of the detectors is reflected in the size of the collaborations designing/building/operating them and analyzing their data
  - Each has ~3000 scientists from ~170 institutes, from ~40 countries

- In spite of the intrinsic complexity, all detectors are operating very well, with sub detectors operational status close to 100%, and data taking efficiency >90%

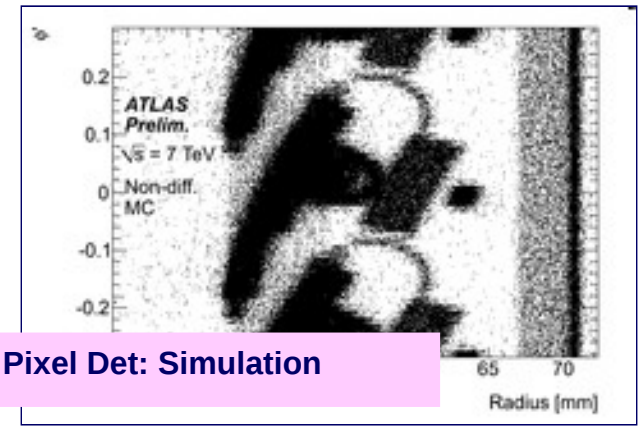




| | MUON-CSC | MUON-DT | MUON-RPC | HCAL BARREL | HCAL ENDCAP | HCAL FORWARD | ECAL BARREL | ECAL END-CAP | PRE-SHOWER | STRIP TRACKER | PIXEL TRACKER |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Series1 | 98.5 | 99.8 | 98.8 | 99.9 | 100 | 99.9 | 99.3 | 98.9 | 99.8 | 98.1 | 98.2 |

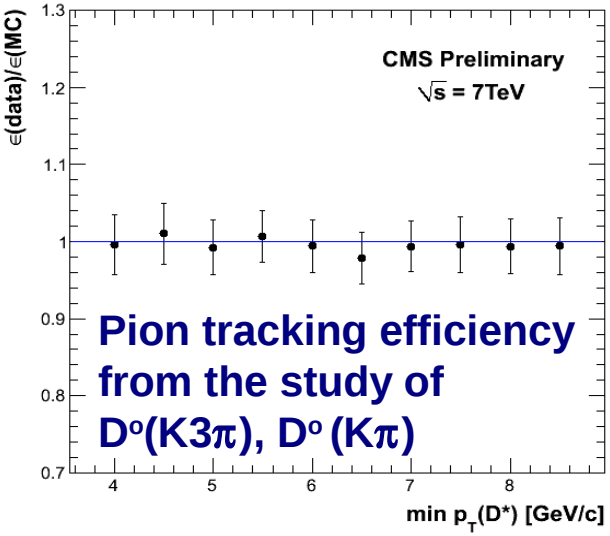
# Detector performance

- Detector material distribution already fairly well described in simulation
  - and constantly improving
- Reconstruction and tracking efficiencies as measured from data are very close to their expected value from simulation
  - "Tag&Probe" exploits invariant mass constraints on particle pairs from resonances, together with two independent tracking systems, to measure the efficiency of one tracker wrt the other

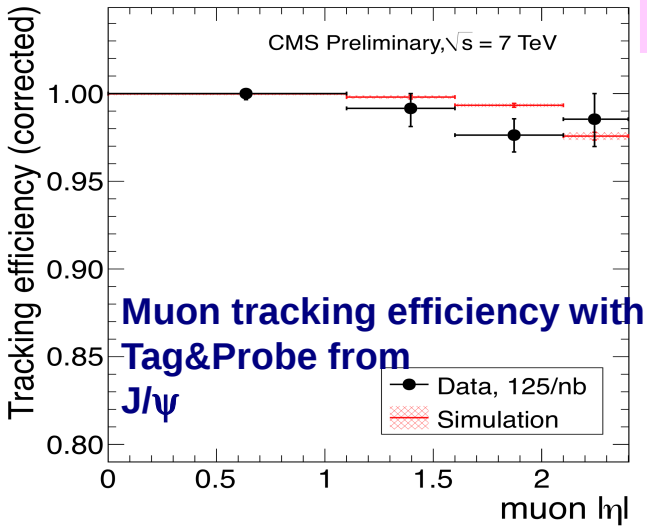
**Use γ conversions and secondary hadronic interactions for material mapping**



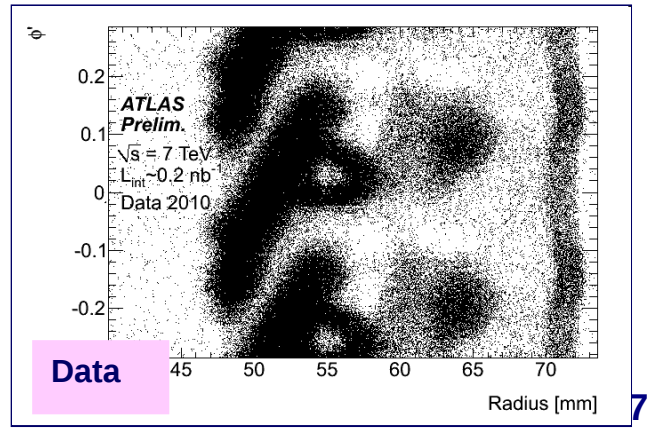

**Pixel Det: Simulation**




**Pion tracking efficiency from the study of $D^o(K3\pi)$, $D^o(K\pi)$**

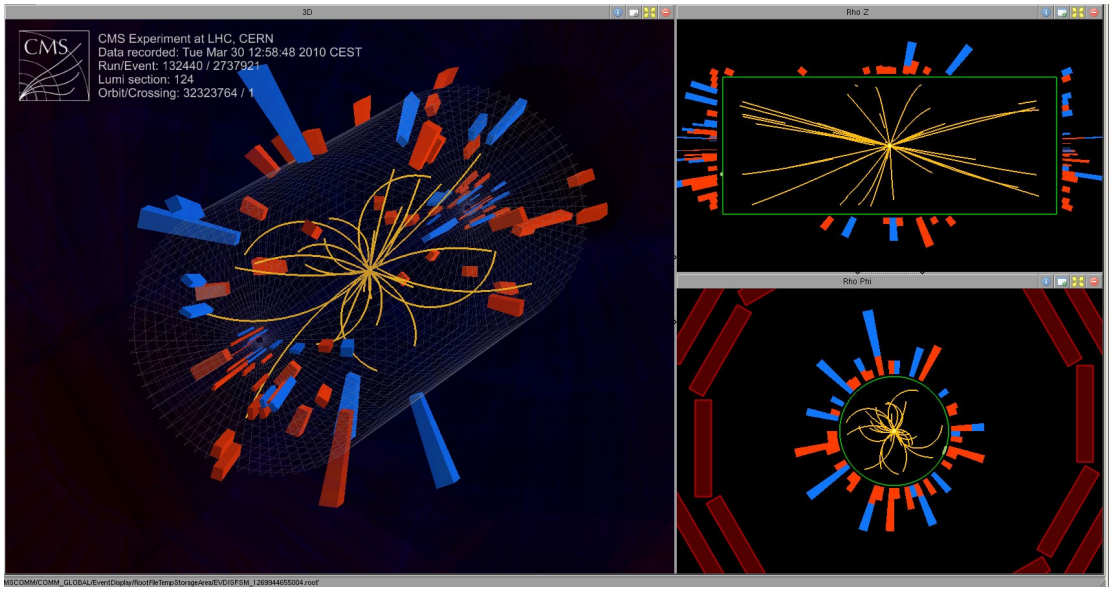



**Muon tracking efficiency with Tag&Probe from J/ψ**




**Data**

# Minimum bias and UE

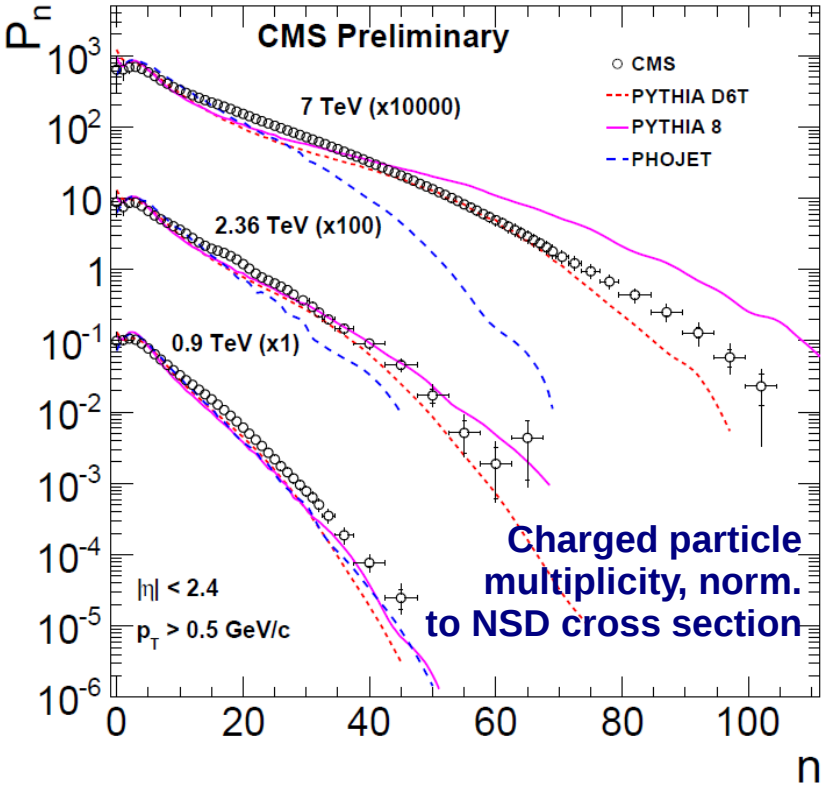


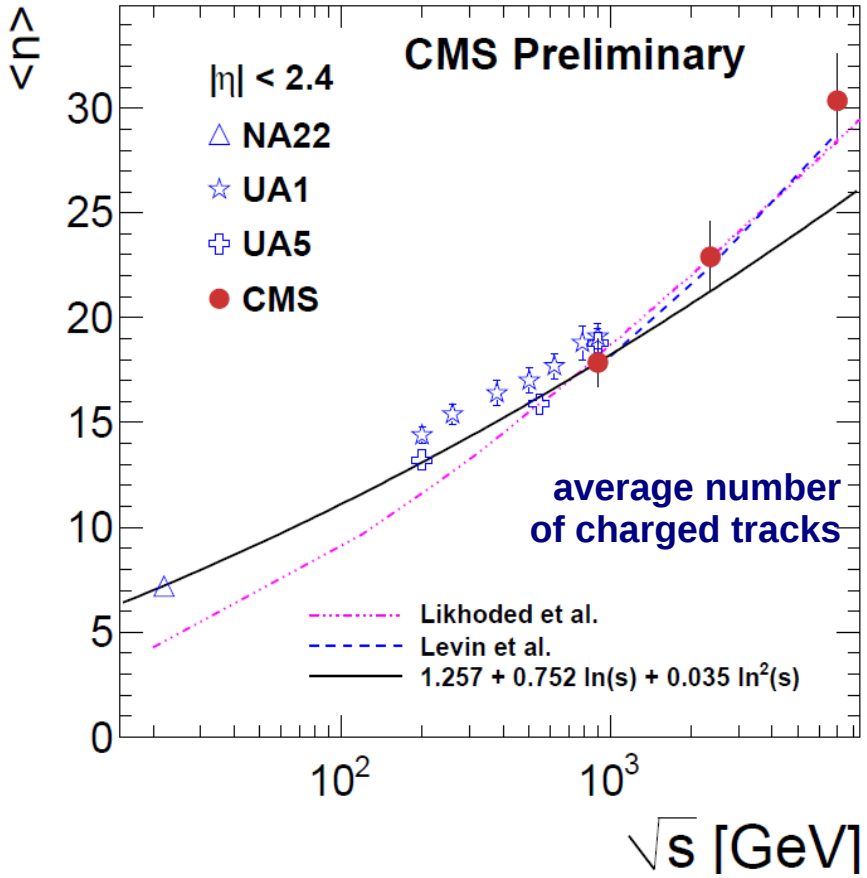


- Very first benchmark for LHC experiments
- Requires detailed understanding of tracking performances to unfold all experimental systematics
- Allows detailed tunes of MC generators at unexplored CM energies
- UE, in particular, studies the part of the final state not due to the hard scattering (BBR+MPI)
  - "Soft physics", not calculable within pQCD

# Minimum bias (1)

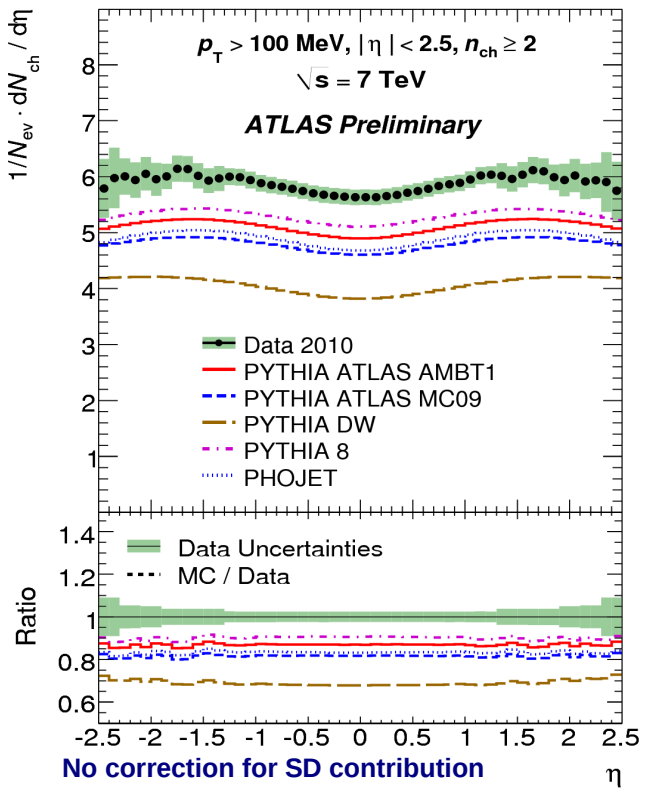
- Studies crucial for tuning of MC generators
  - Also in view of the higher luminosity phase of the LHC
- None of the existing (LEP/Tevatron) tunes reproduces correctly 7TeV measurements

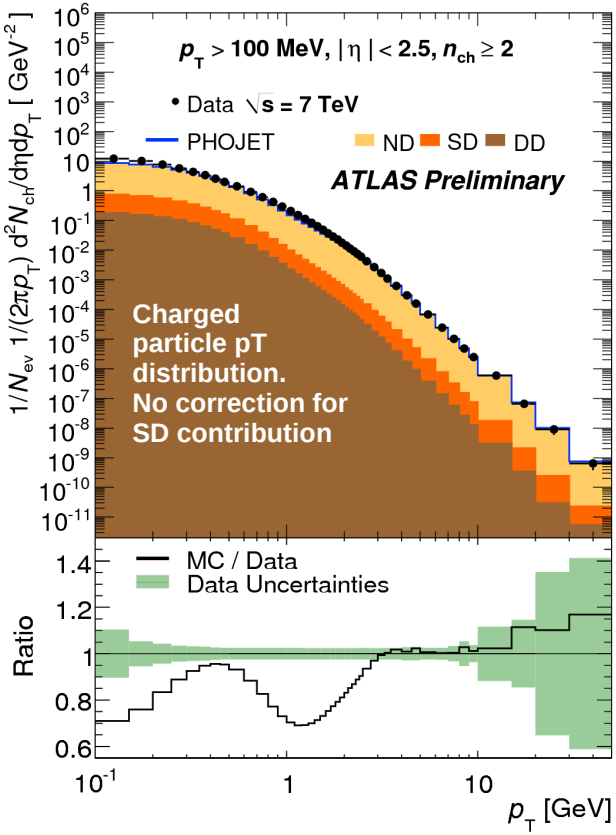


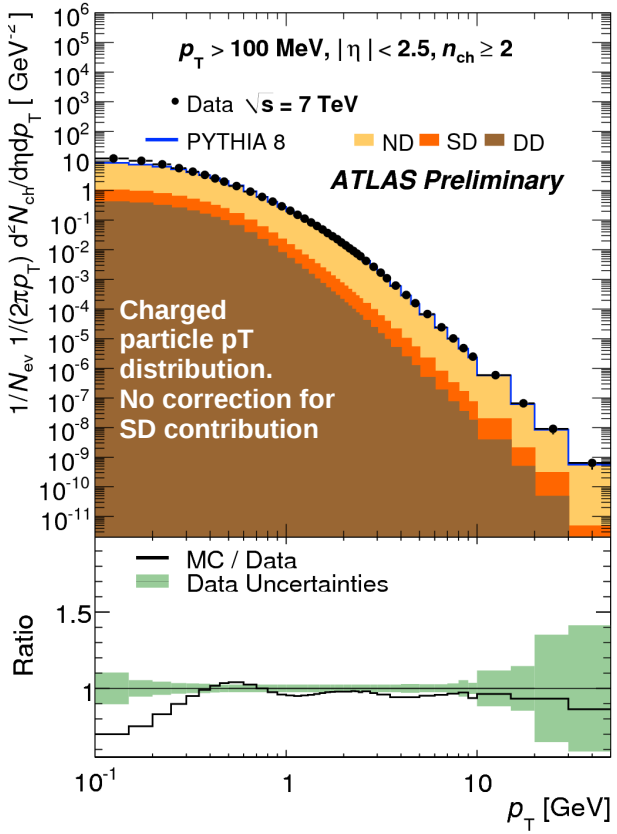



# Minimum bias (2)

- First MB results already used to produce tunes optimized for LHC (e.g. ATLAS AMBT1), including UE measurements as well (see next slide)

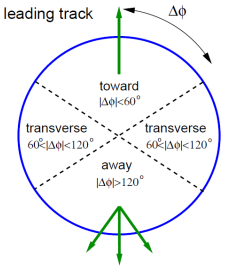


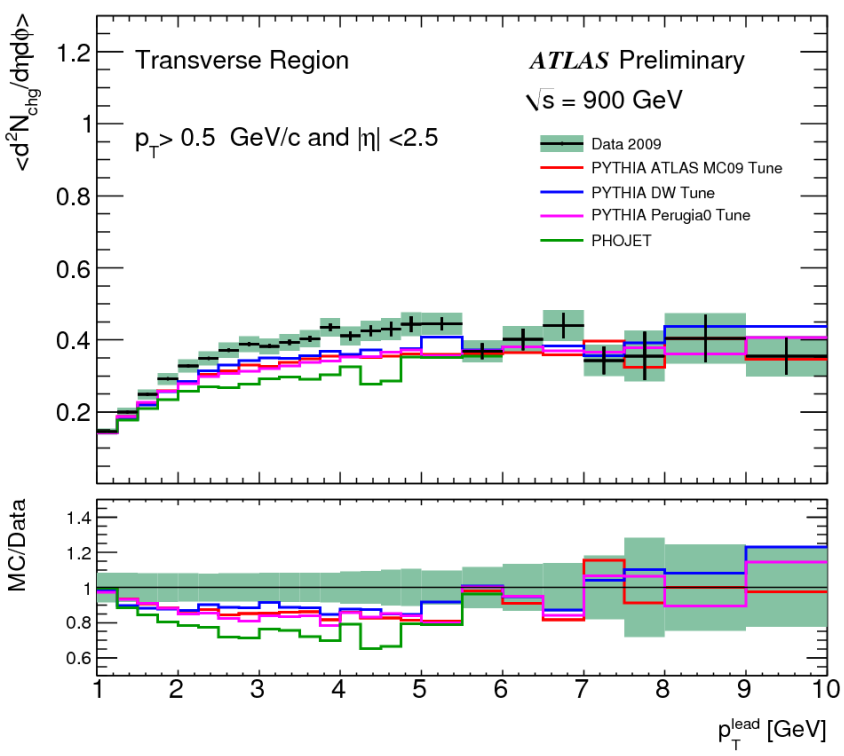



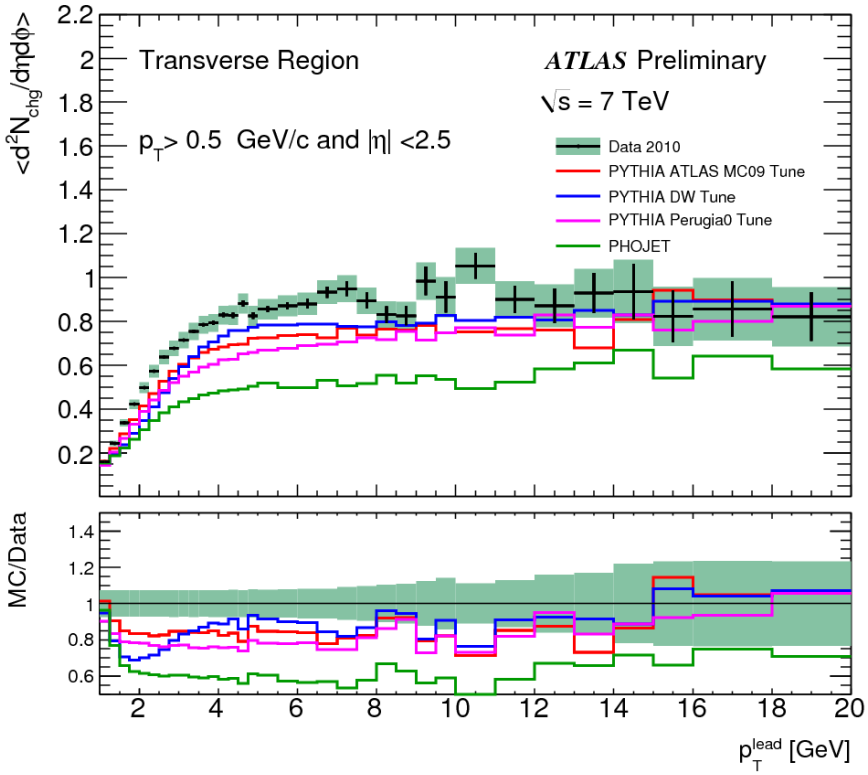



# Underlying Event

- Orient the event according to leading track

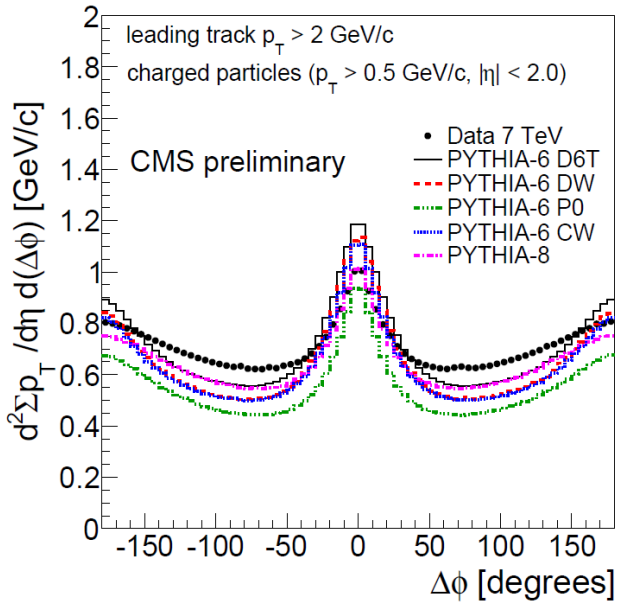


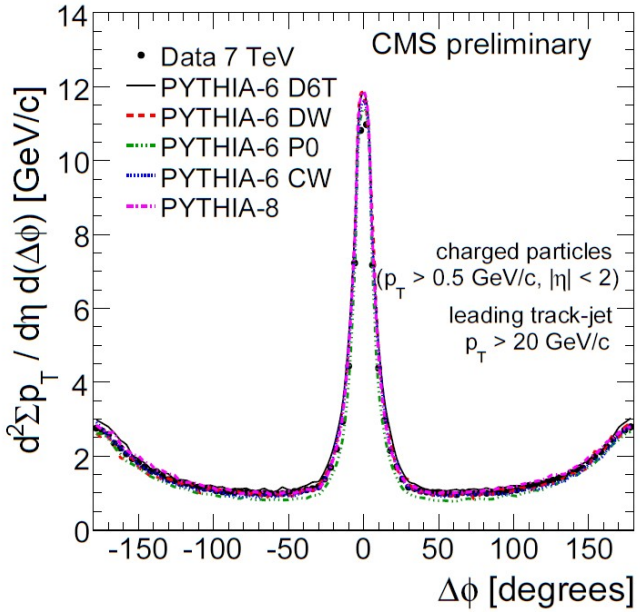



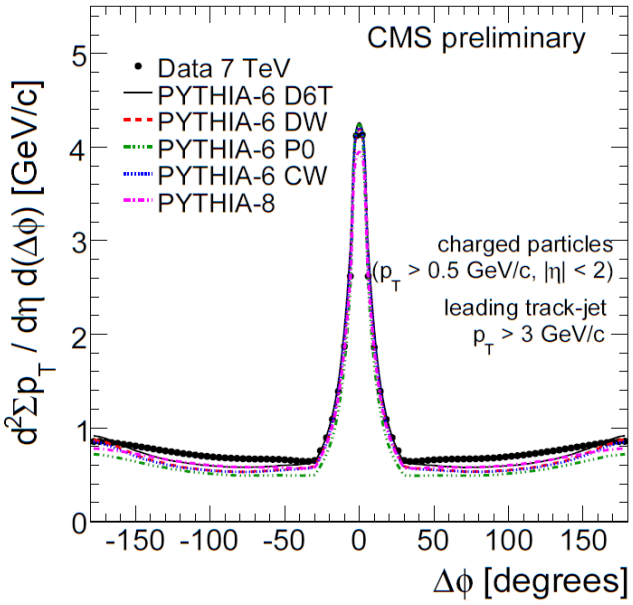

**ATLAS: corrected to particle level**

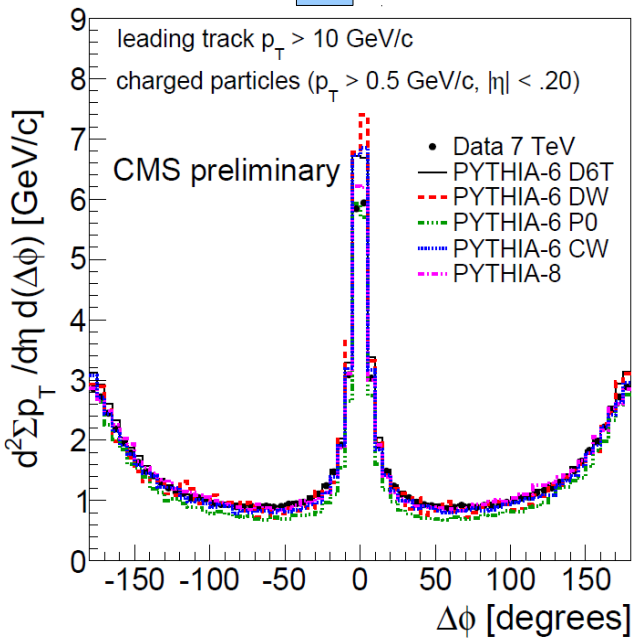
# Underlying event (2)



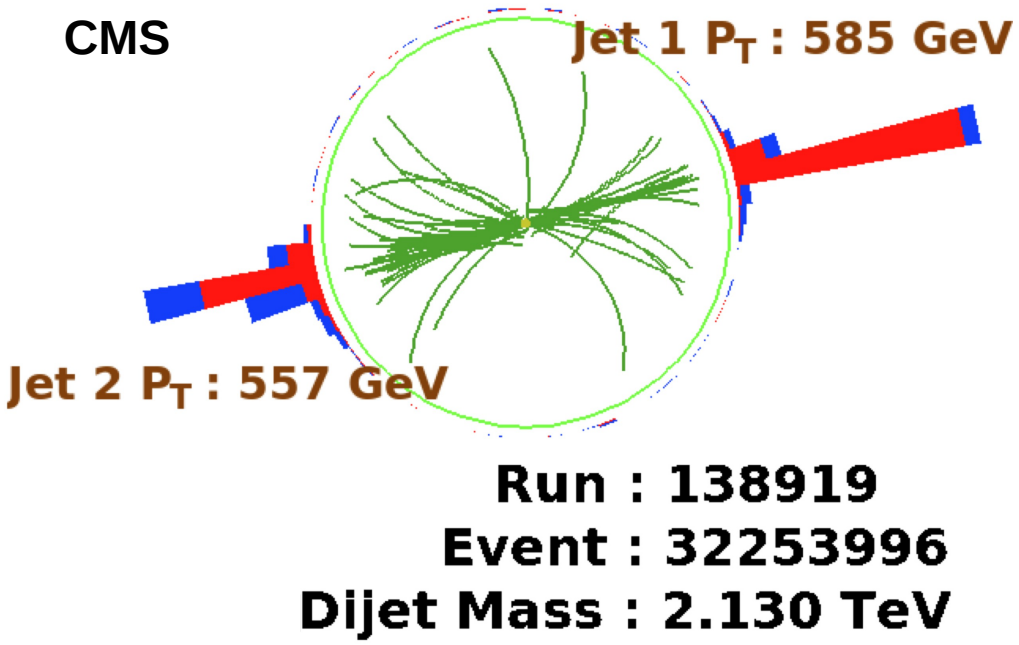



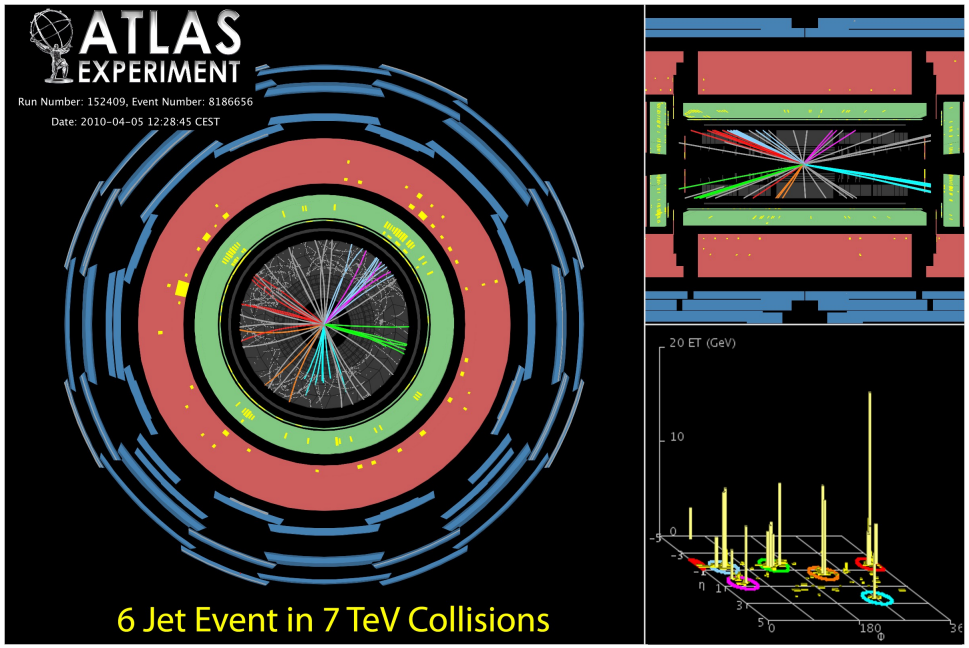

**CMS: detector level**



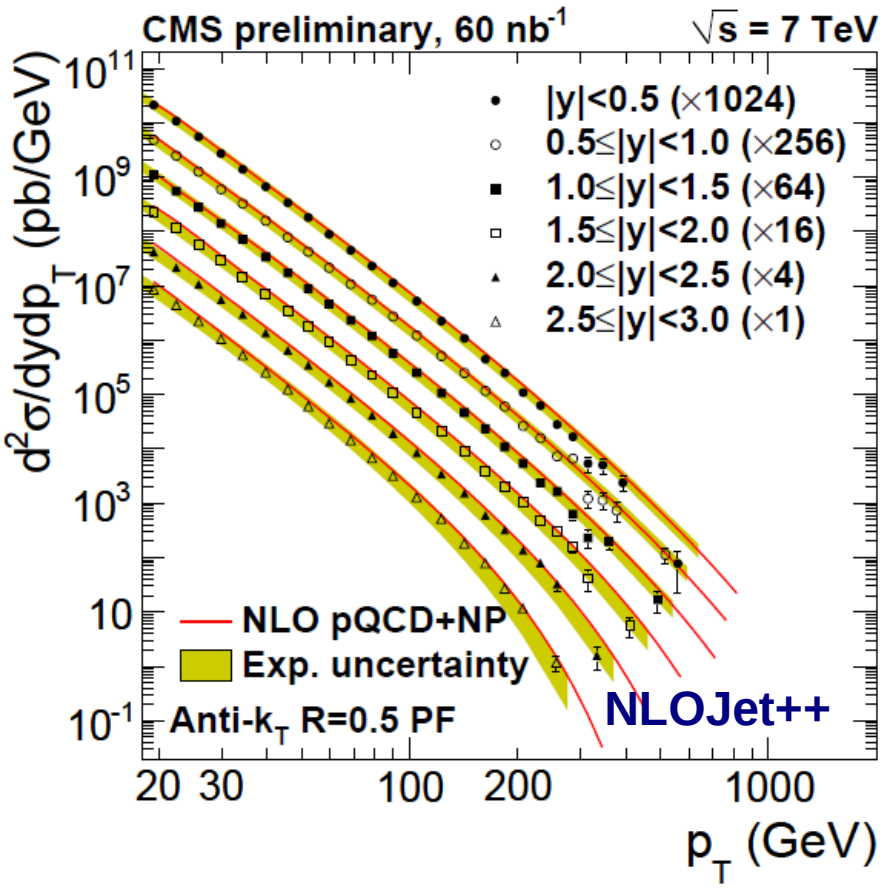
# Jets

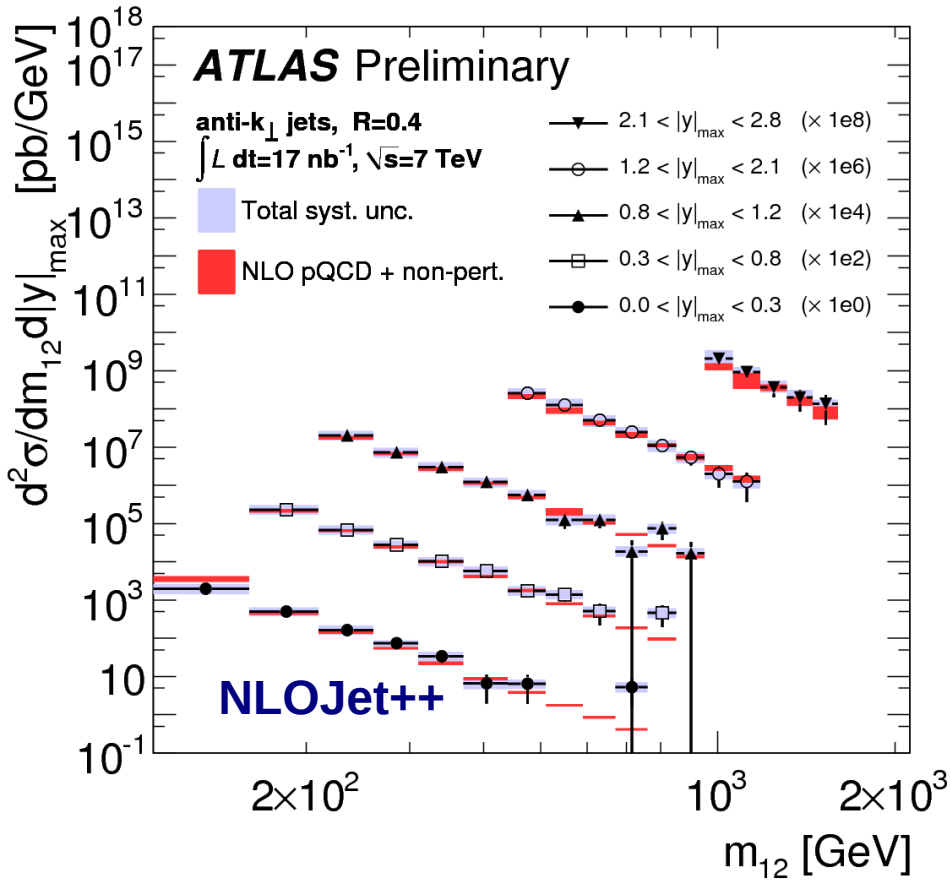



- Multi-jet events produced copiously @ LHC
- Interesting *per se*, since they are an important probe of pQCD predictions
- From the experimental point of view, crucial to study the performance of the detectors (e.g. di-jet momentum imbalance)
- They are also the main source of background for many SM and NP events
- All results shown here refer to anti-kT jet algorithm

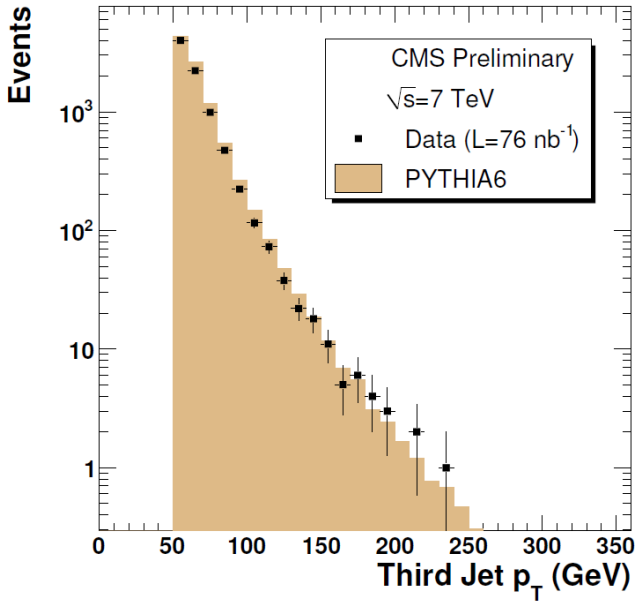
# Inclusive cross section



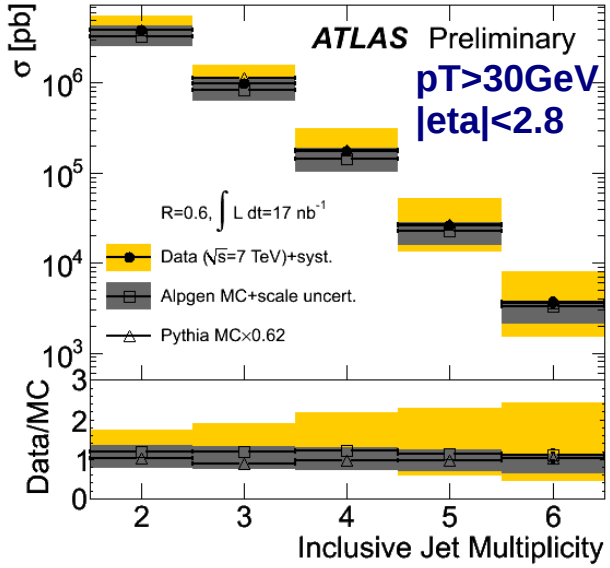



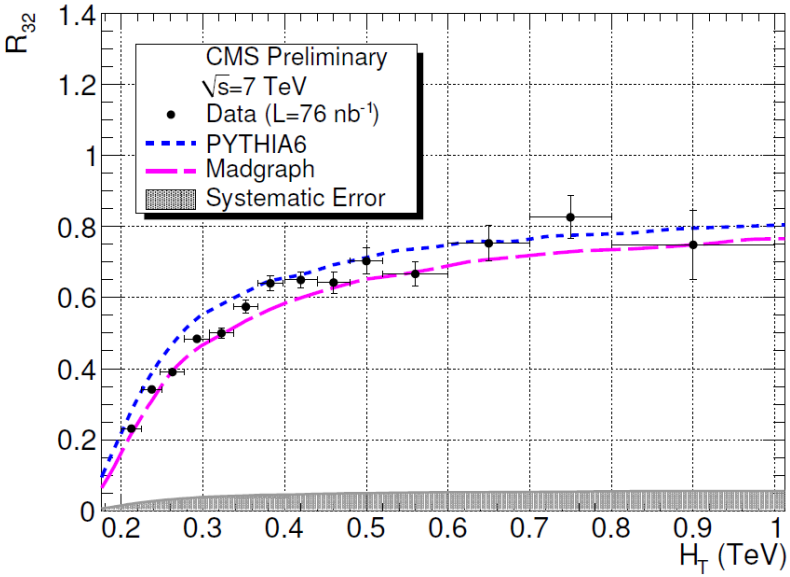

- Different jet reconstruction algorithms tested
- Agreement with NLO predictions (within exp uncertainties)

# Multi-jet cross section

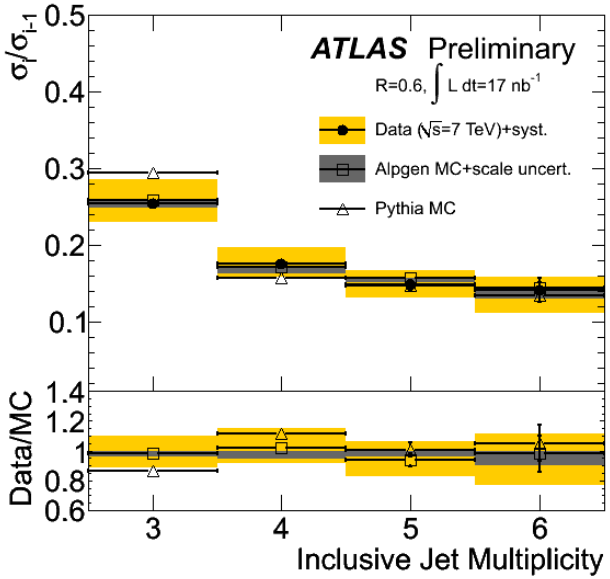



**Distributions of first and second hardest jets in good agreement with MC prediction**



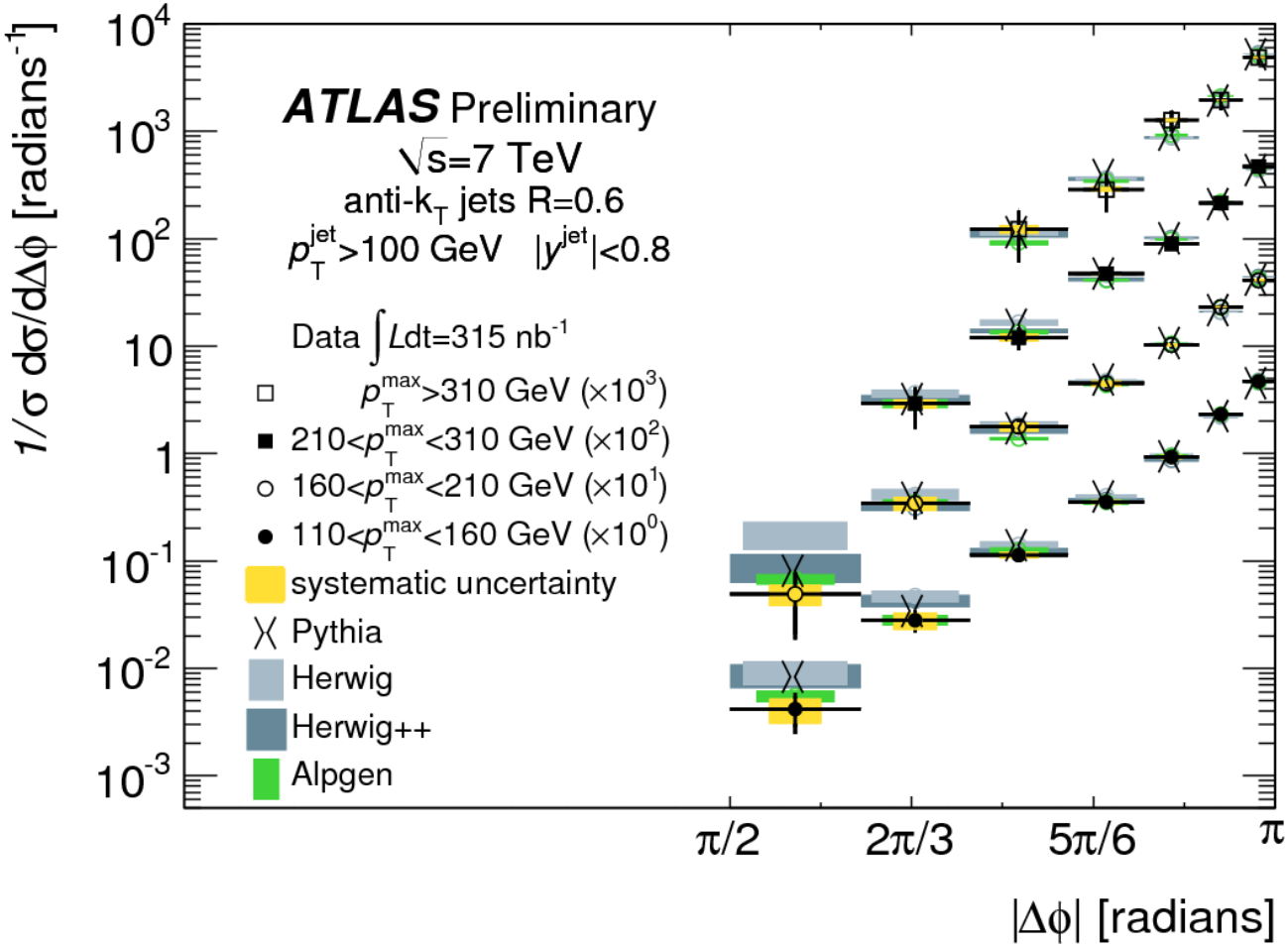




**Cross-section ratios help reducing impact of experimental and theoretical systematics**



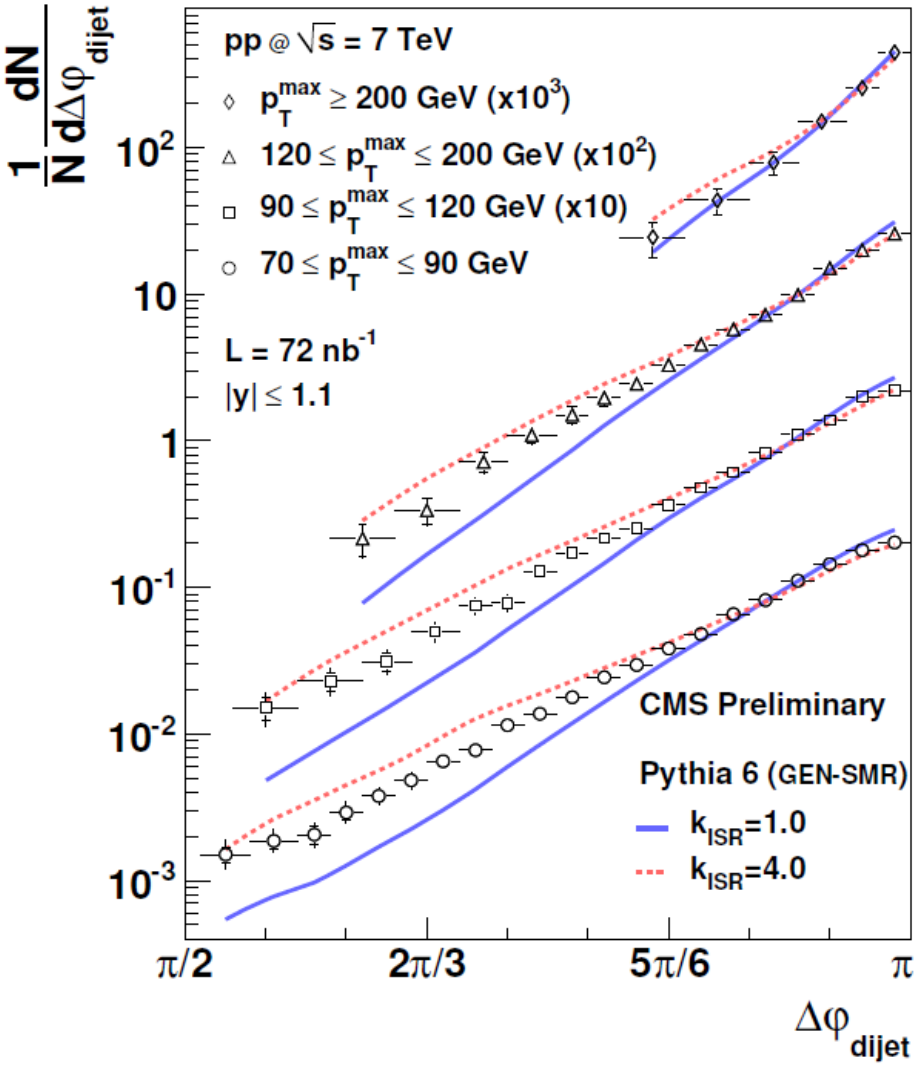
# Azimuthal decorrelation (1)

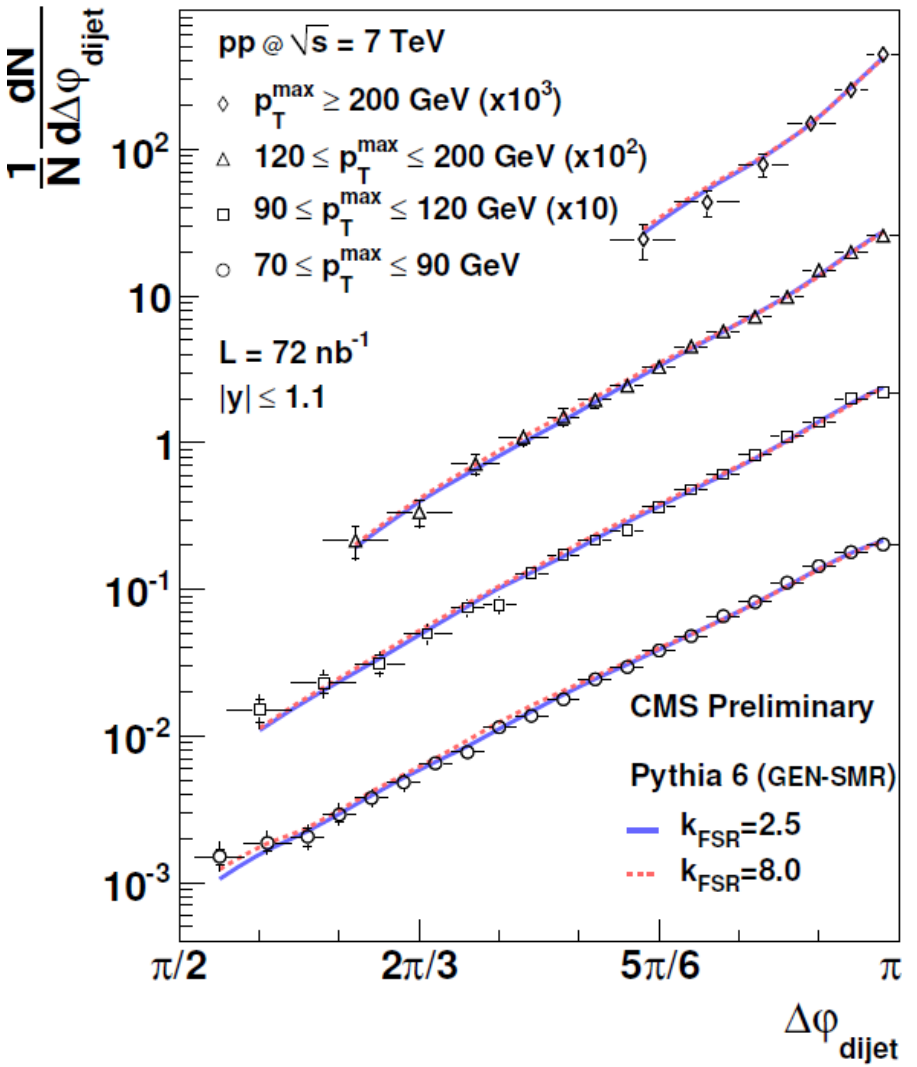
- Measure angle between the two highest-pT jets in the event
  - Allows to study higher-order QCD radiation effects without the need to explicitly reconstruct additional jets in the event



# Azimuthal decorrelation (2)

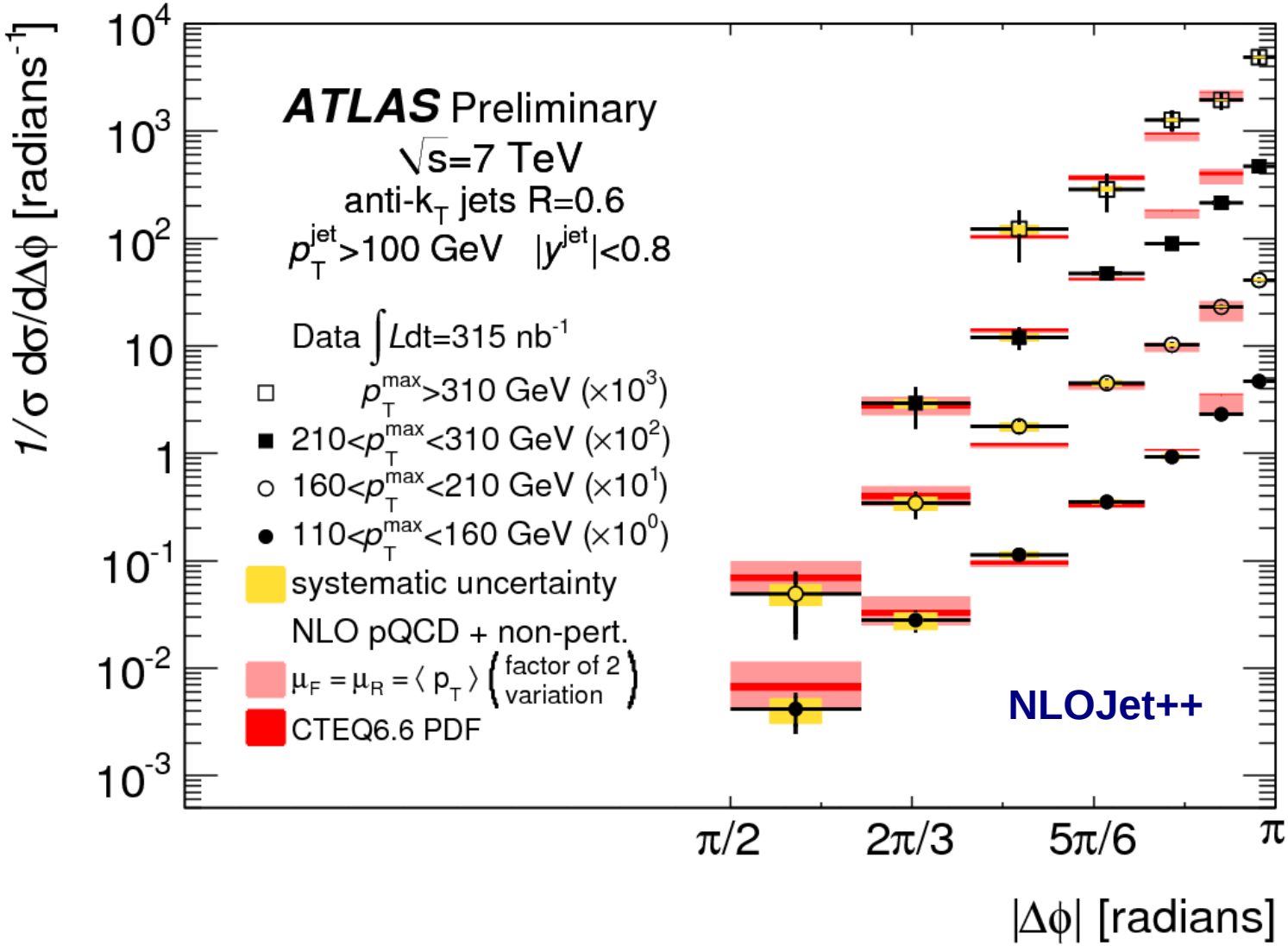
- Distributions are, to some extent, sensitive to tuning of LO generators



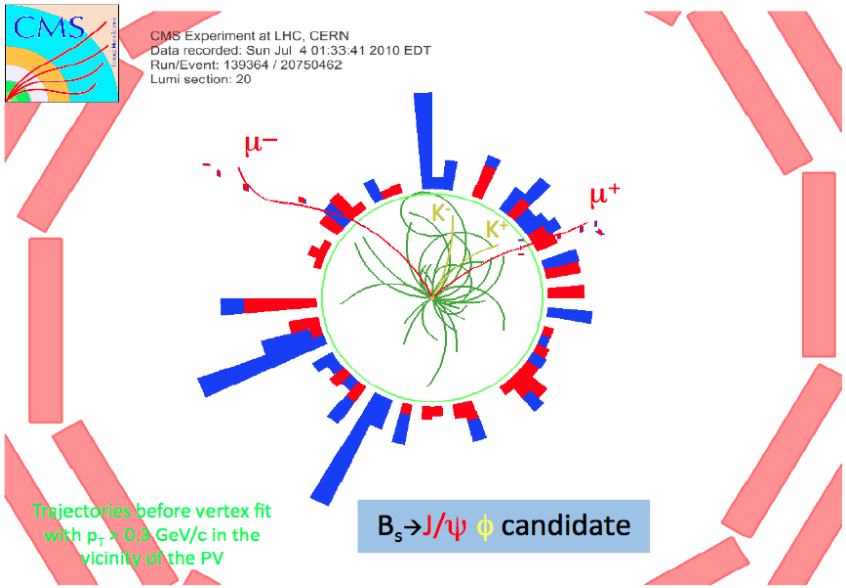



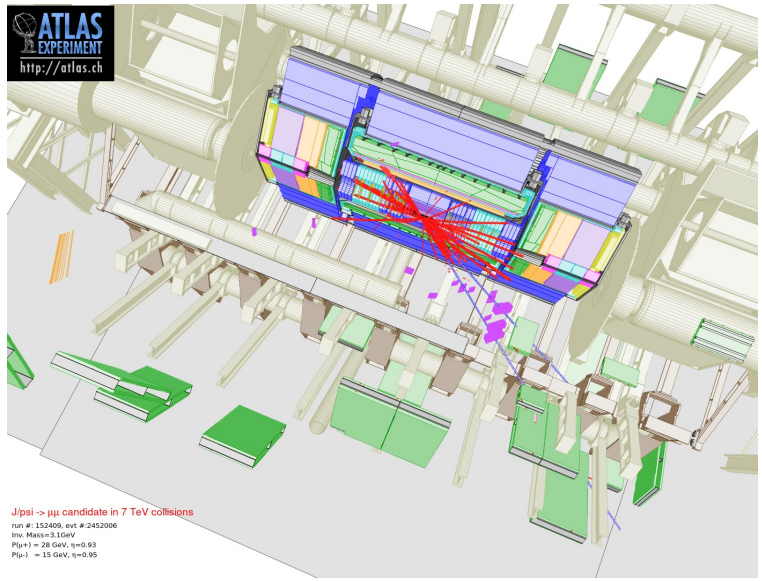
# Azimuthal decorrelation (3)

- NLO shows, overall, better agreement, as expected



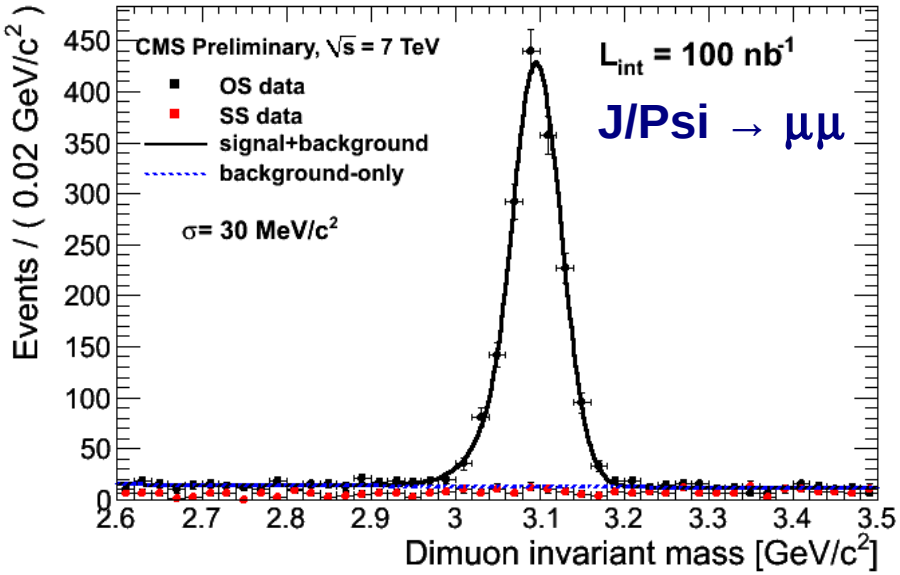
# b/c mesons

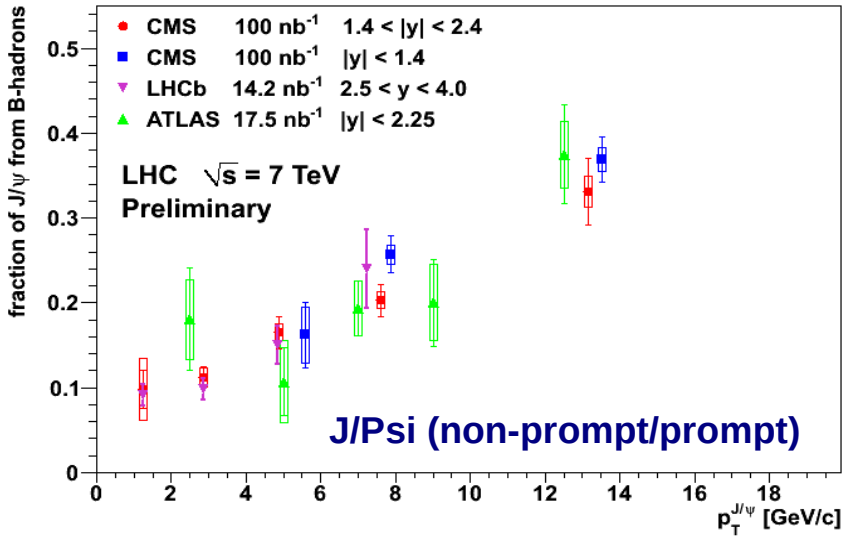


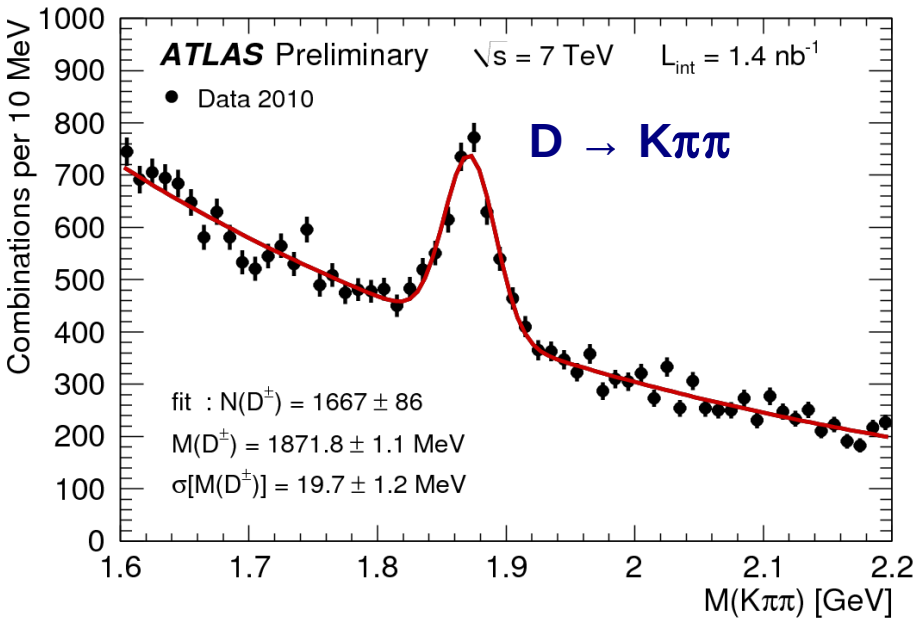



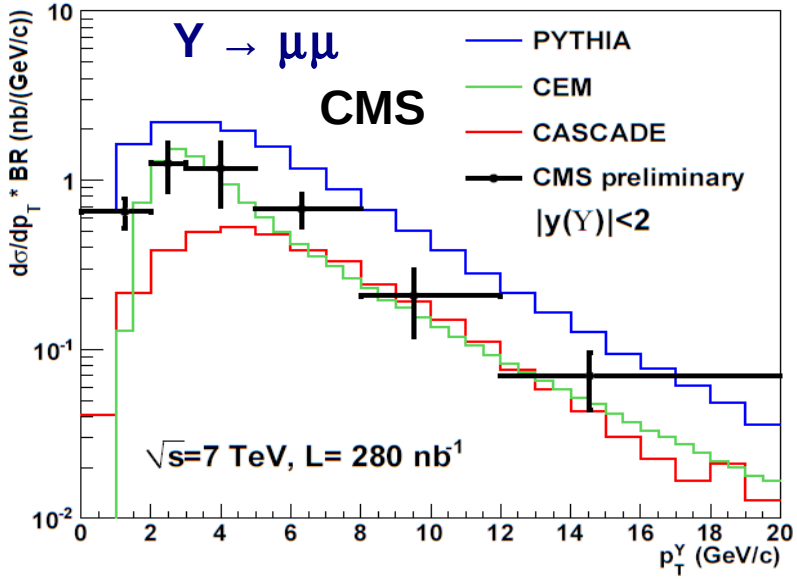

- Prompt quarkonium production extremely interesting to test models describing the observed differential pT cross section and polarization
- Non-prompt J/Psi production related to b-hadron production
- Theoretical predictions for Y more robust due to higher b mass, hence allowing more precise comparison
- From the experimental point of view, decay products can be used to assess from data the detector performance (e.g. tag & probe)

# b/c mesons (2)

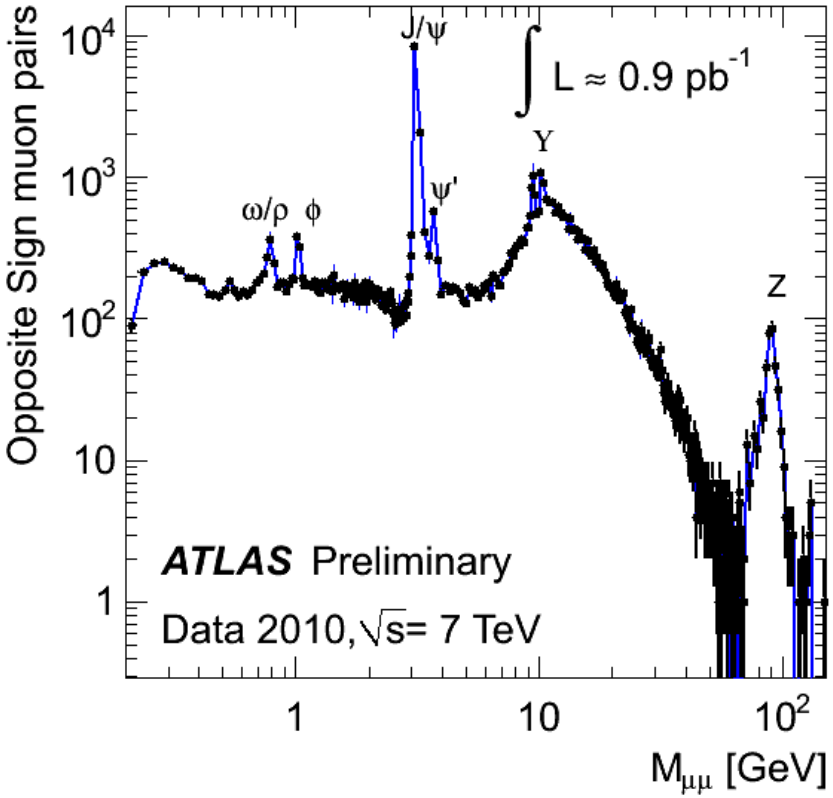

CMS Preliminary, √s = 7 TeV
L_int = 100 nb^-1
OS data
SS data
signal+background
background-only
σ= 30 MeV/c²
J/Psi → μμ
Events / ( 0.02 GeV/c² )
Dimuon invariant mass [GeV/c²]

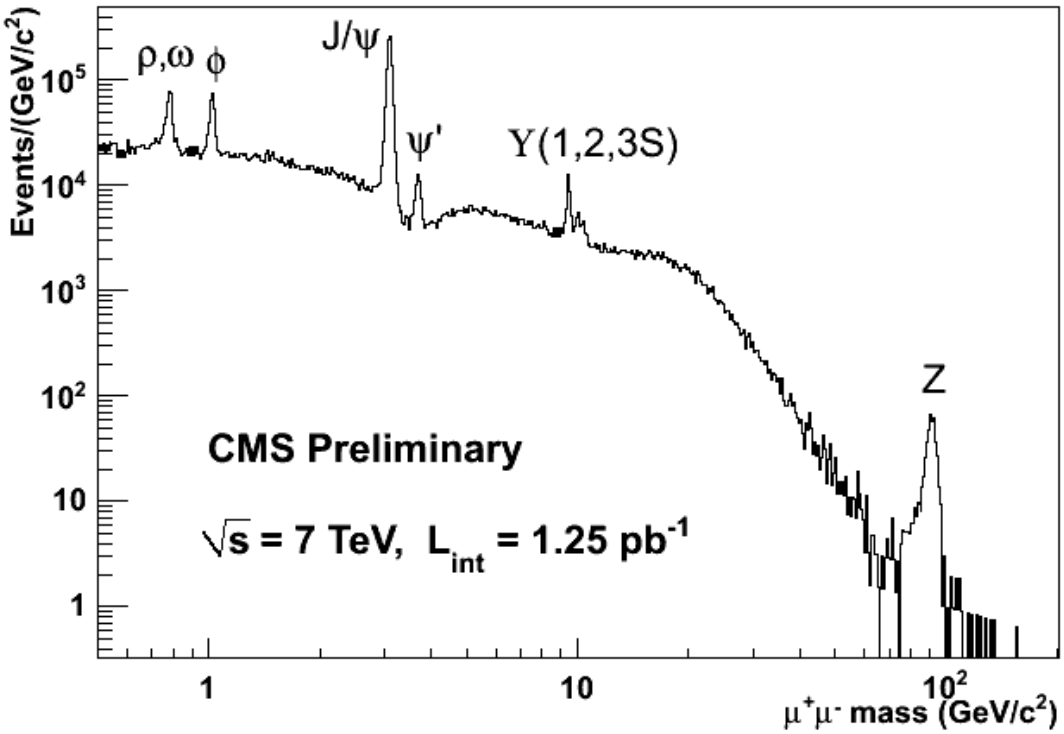

CMS 100 nb^-1 1.4 < |y| < 2.4
CMS 100 nb^-1 |y| < 1.4
LHCb 14.2 nb^-1 2.5 < y < 4.0
ATLAS 17.5 nb^-1 |y| < 2.25
LHC √s = 7 TeV
Preliminary
J/Psi (non-prompt/prompt)
fraction of J/ψ from B-hadrons
p_T^J/ψ [GeV/c]


ATLAS Preliminary √s = 7 TeV L_int = 1.4 nb^-1
Data 2010
D → Kππ
fit : N(D±) = 1667 ± 86
M(D±) = 1871.8 ± 1.1 MeV
σ[M(D±)] = 19.7 ± 1.2 MeV
Combinations per 10 MeV
M(Kππ) [GeV]


Υ → μμ
CMS
PYTHIA
CEM
CASCADE
CMS preliminary
|y(Υ)|<2
√s=7 TeV, L= 280 nb^-1
dσ/dp_T * BR (nb/(GeV/c))
p_T^Υ (GeV/c)

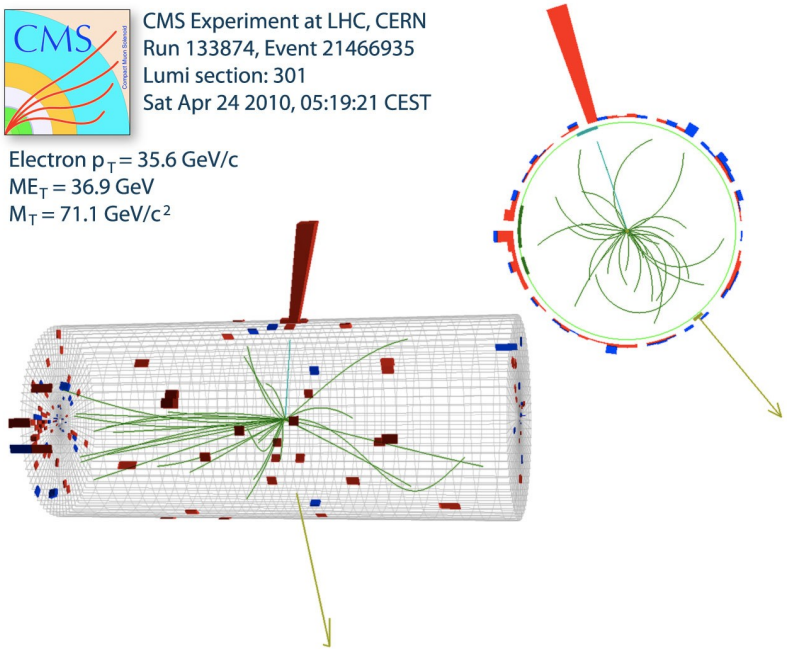
# Intermezzo: the dimuon landscape

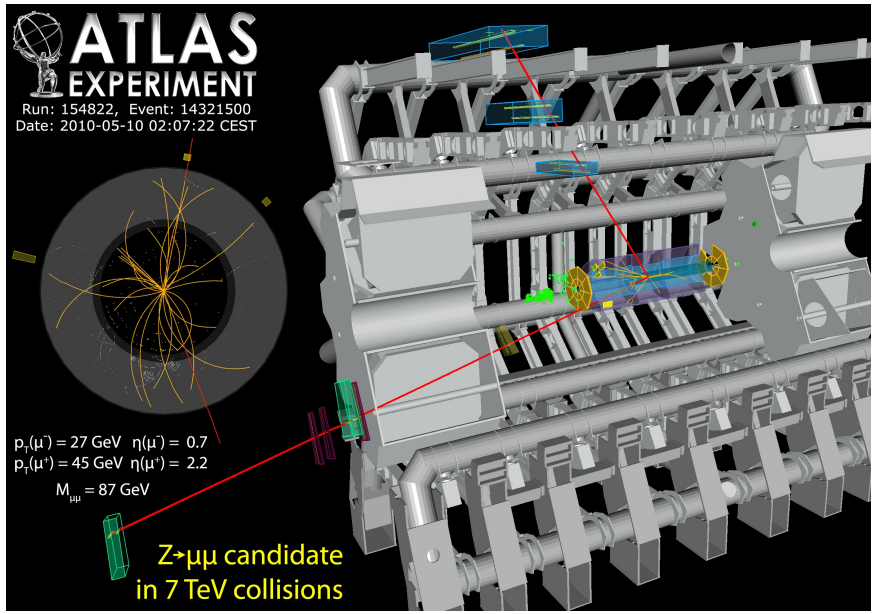



- Statistics collected in just a few months
- Already reached the point where EW bosons can be studied

# EW bosons

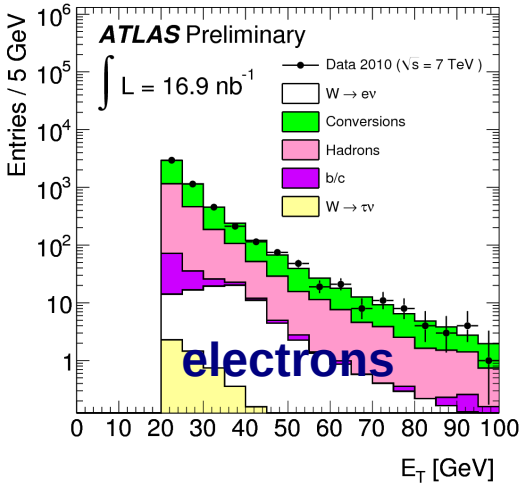


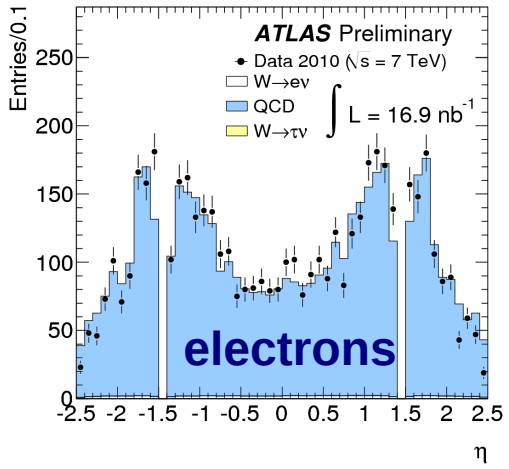



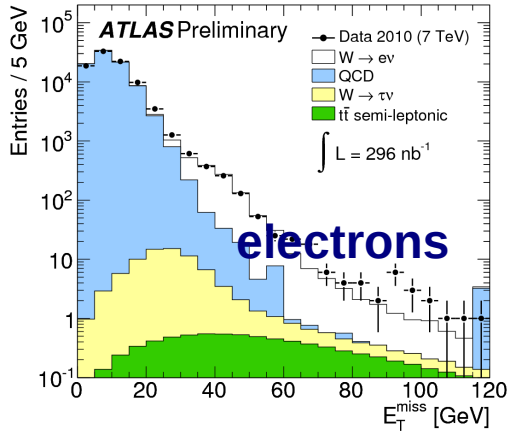

- The physics of the W and Z bosons plays a crucial role in LHC experiments
  - The clean and fully reconstructed Z leptonic final states can be used to measure from data the detector performance
  - High precision cross section calculation, including higher order corrections, allows to use these measurements as a stringent test of QCD
  - Last, but not least, these channels are important backgrounds to several new-physics studies

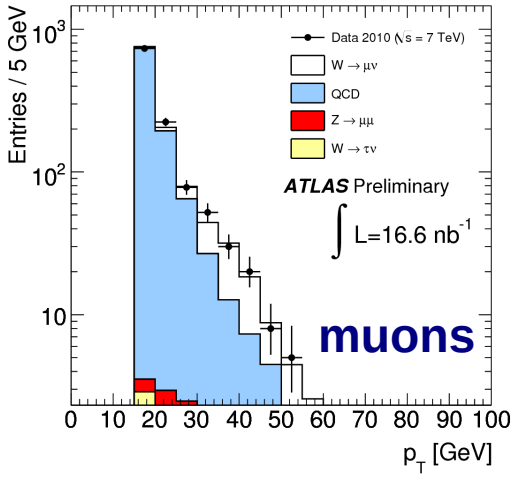
# High-pT leptons

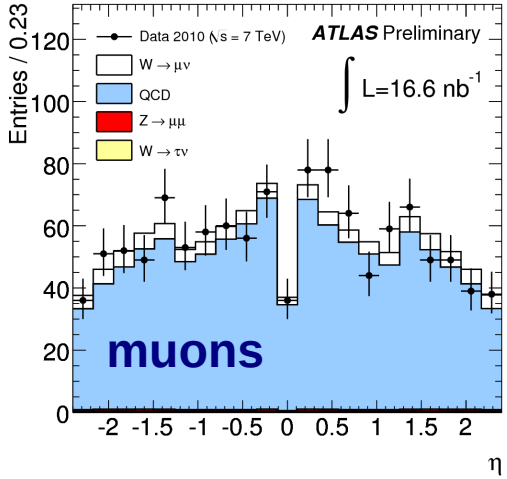
- First chance (here) to look at events with high-pT leptons
- After a loose preselection: 1 “good quality” lepton
  - muon pT>15GeV, electron ET>20GeV

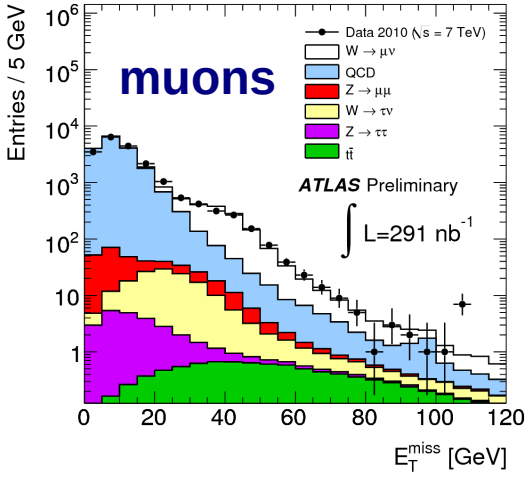


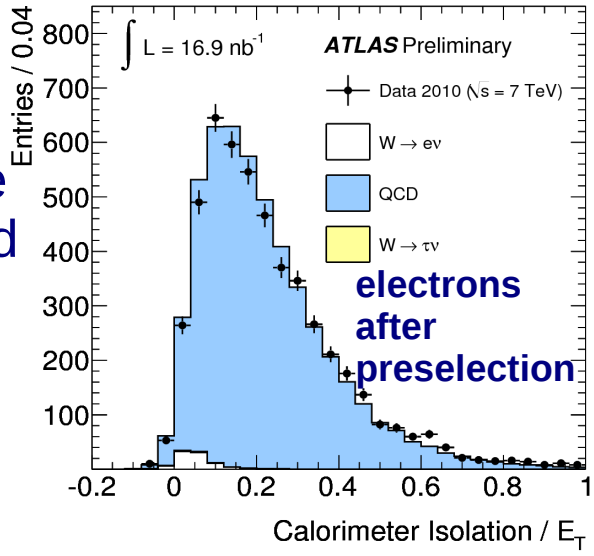



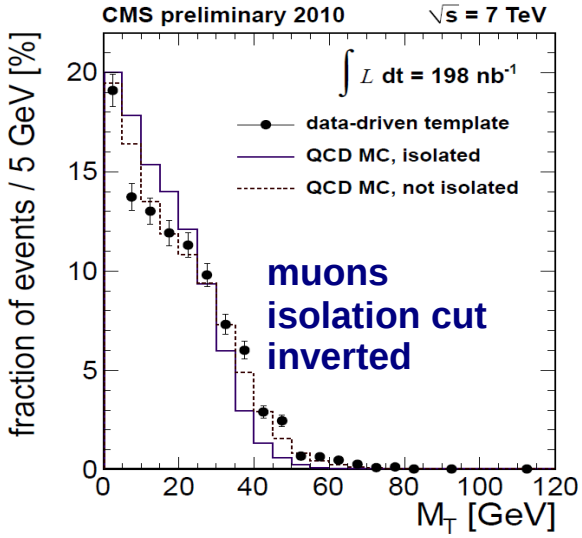



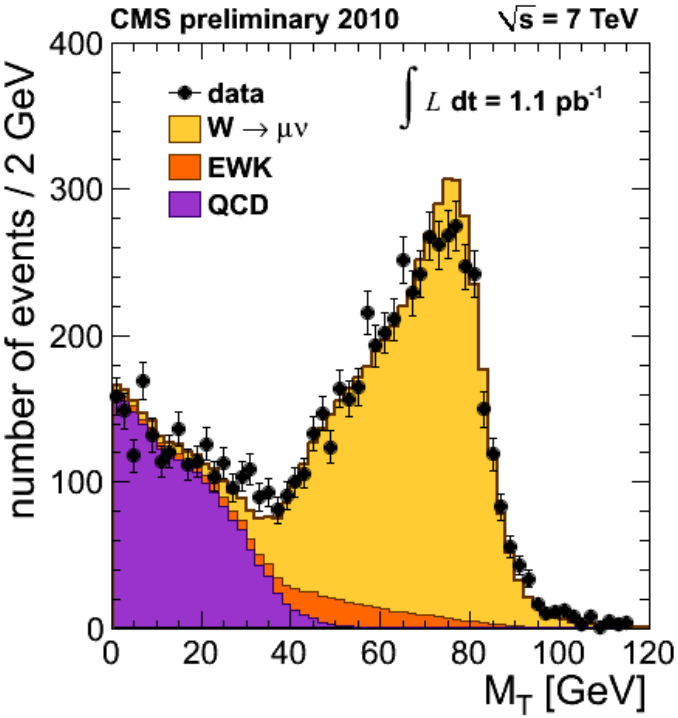

Shapes in good agreement with MC expectations, W signal already visible in the Missing Et distribution

# W signal extraction

- Tighten lepton quality, harden pT cut, require lepton isolation
- Several techniques to estimate from data the QCD background contamination
  - e.g. take shapes from bg-enriched distributions, use them in template fits

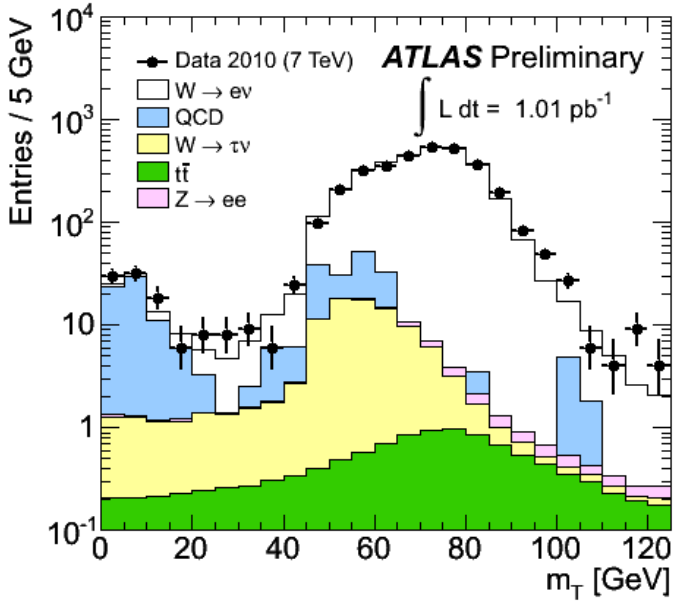


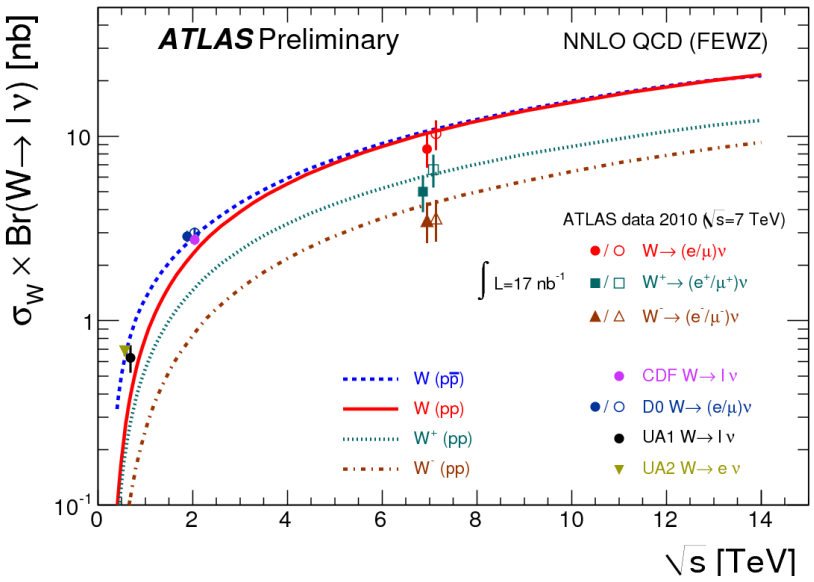

**Example: W → μν selection yields for CMS @ 198/nb**

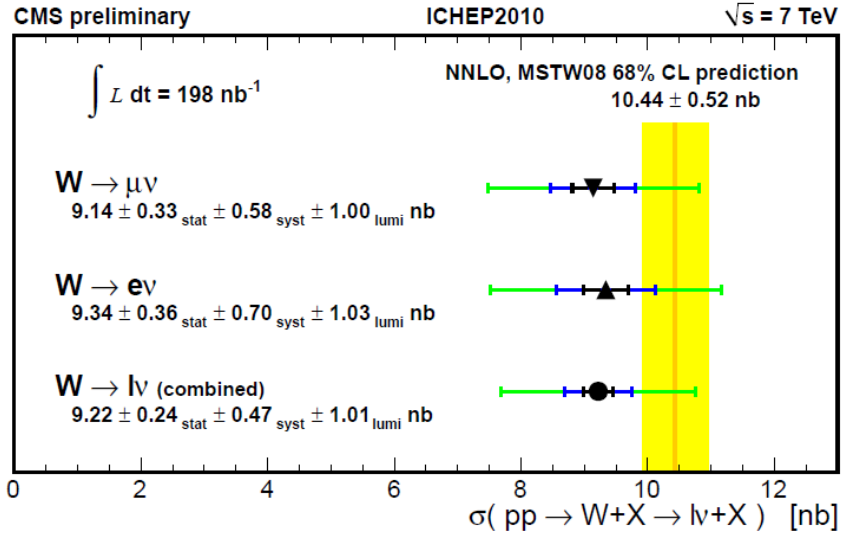
| Selection criteria | Number of events |
|---|---|
| Triggered | 16567 |
| Drell-Yan rejection | 16277 |
| Muon identification cuts | 13365 |
| $\|\eta\| < 2.1$ & $p_T > 20\,\mathrm{GeV}/c$ | 4294 |
| $I^{\mathrm{rel}}_{\mathrm{comb}} < 0.15$ | 1254 |

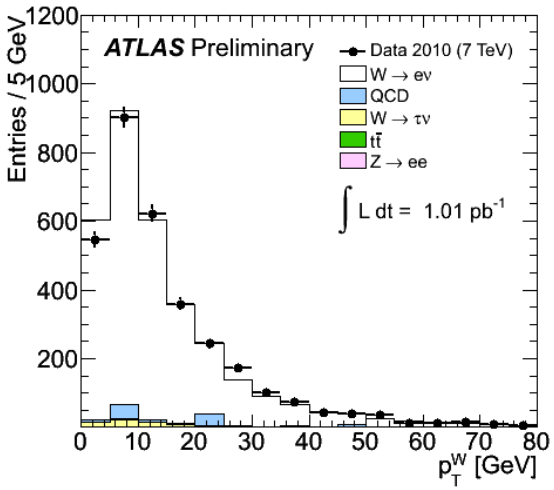


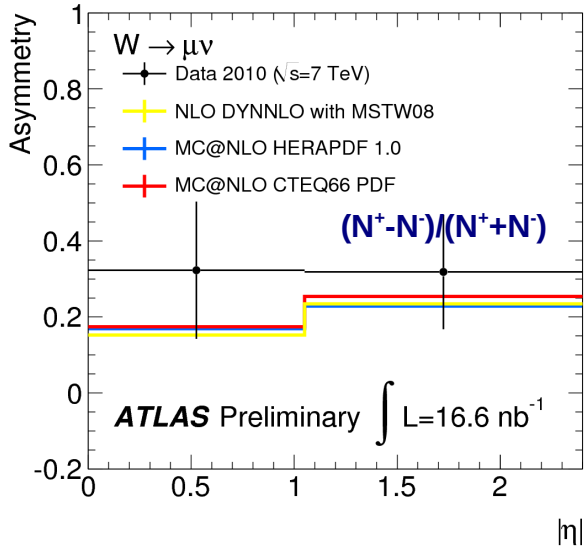
# W: results

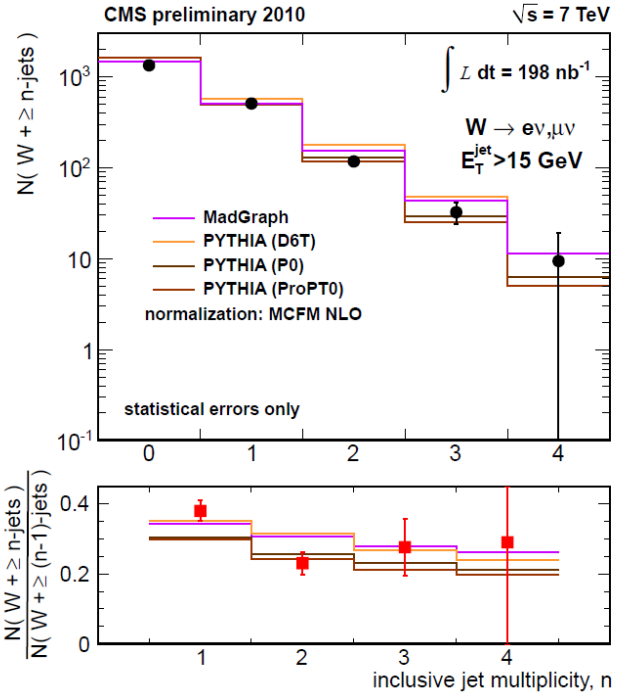
- NB: luminosity uncertainty ~11%



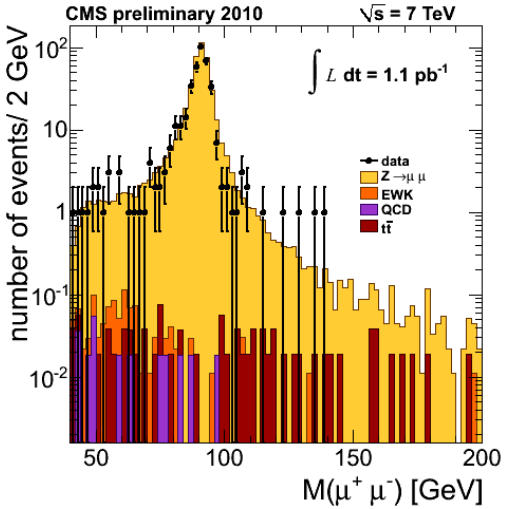



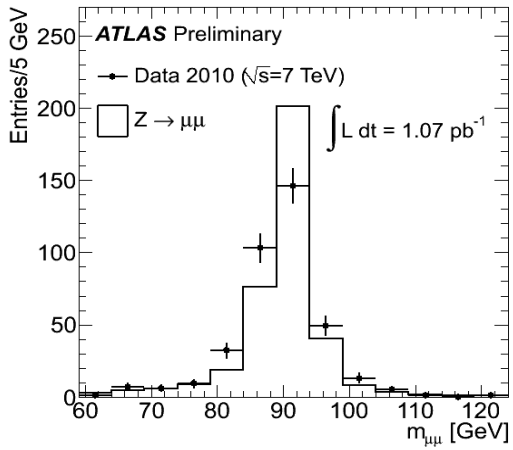



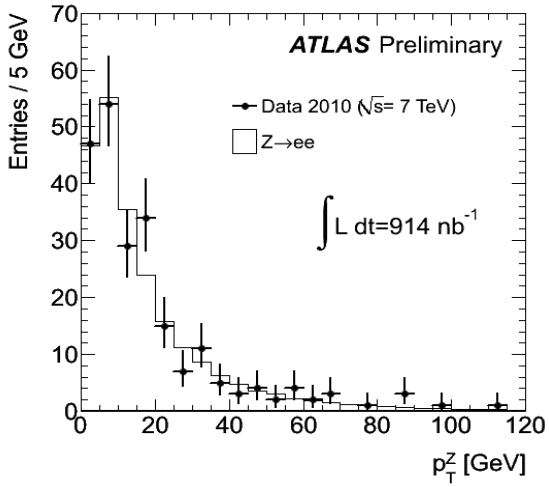



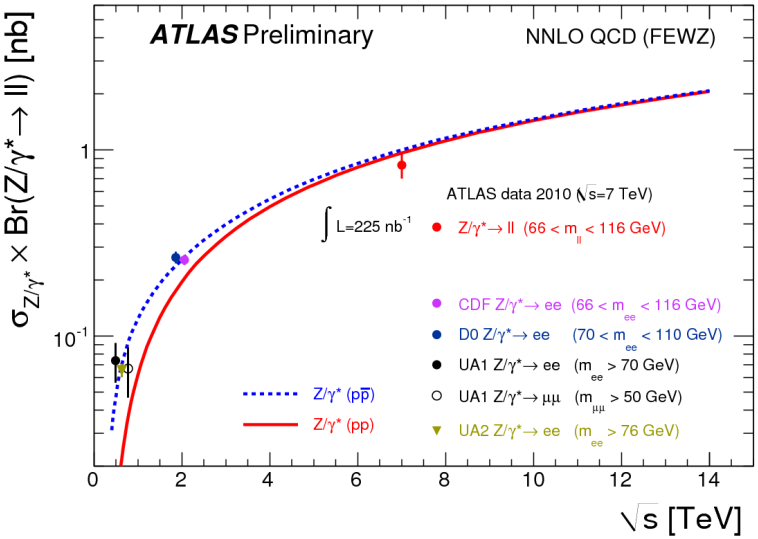
- Signal extraction similar to W, using invariant mass constraint on the two leptons
- Example: Z selection yields for ATLAS @ 219/nb (electrons) and 229/nb (muons)

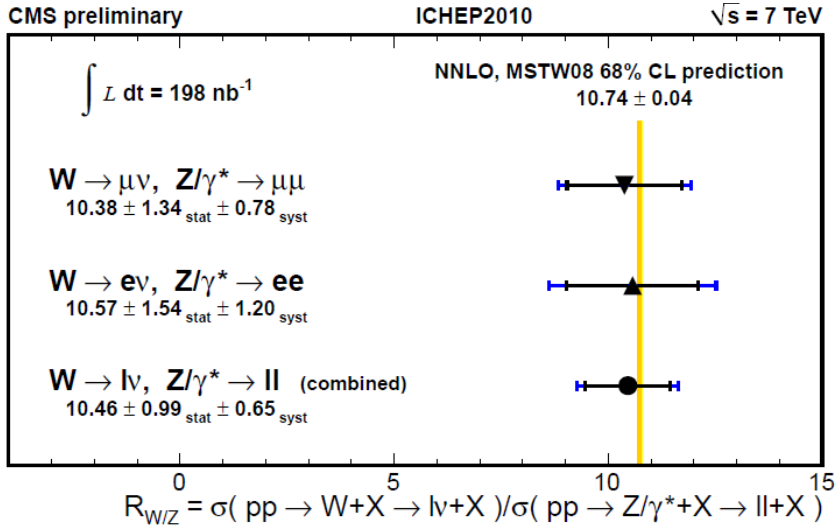
| Requirement | Electron channel Number of candidates | Muon channel Number of candidates |
|---|---|---|
| Triggered | $4.4 \times 10^6$ | $3.8 \times 10^6$ |
| $\ell^+\ell^-$ pairs | 51 | 85 |
| $66 < m_{\ell^+\ell^-} < 116$ GeV | 46 | 79 |



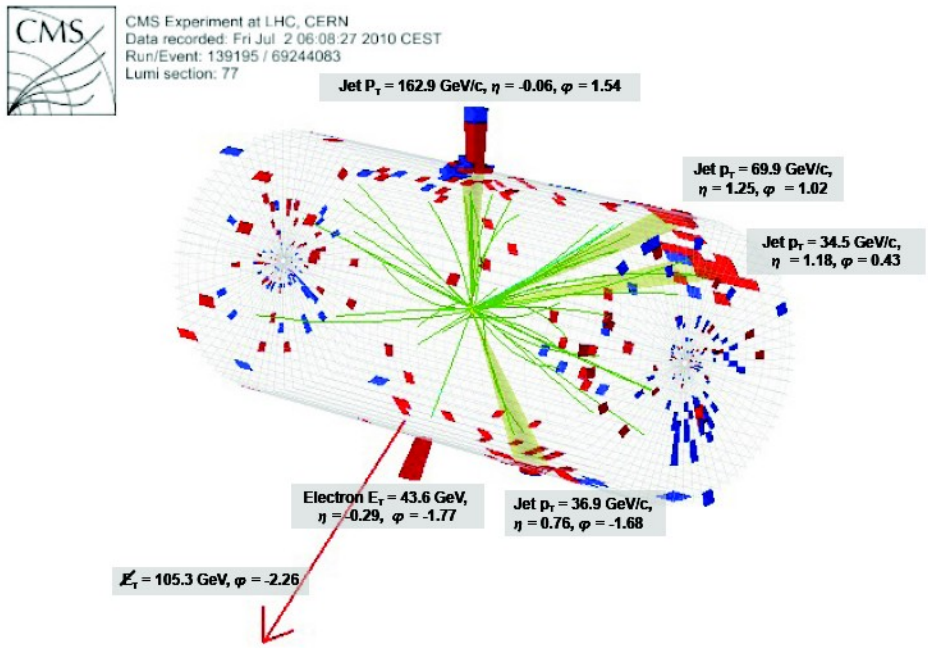



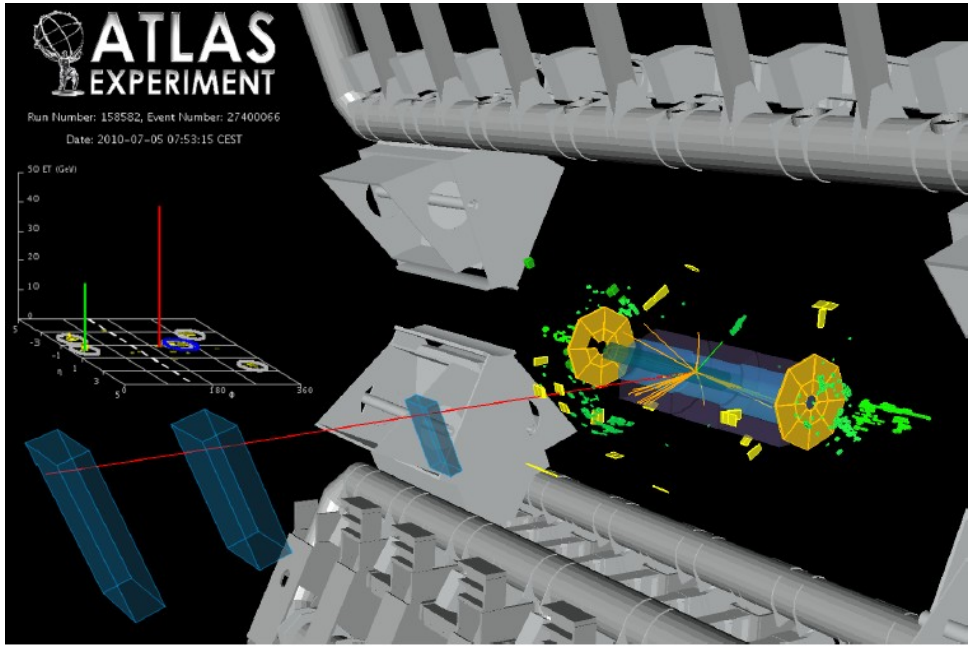



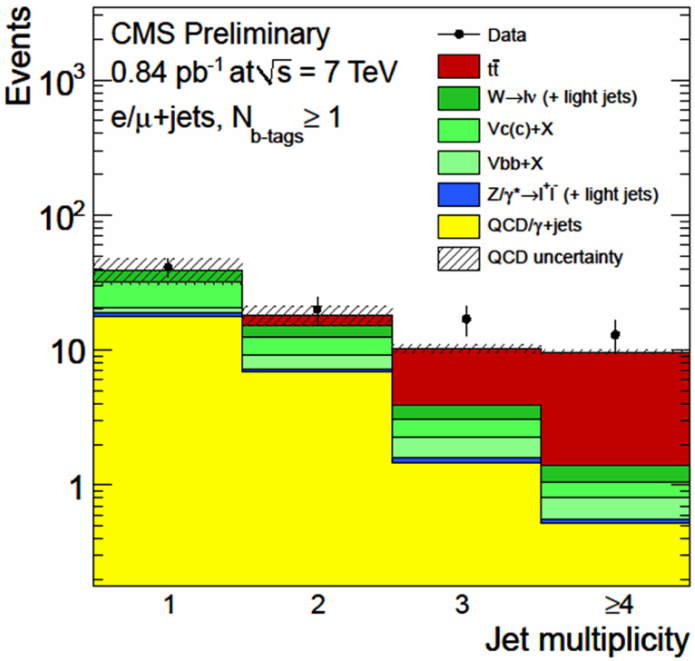
# Top physics



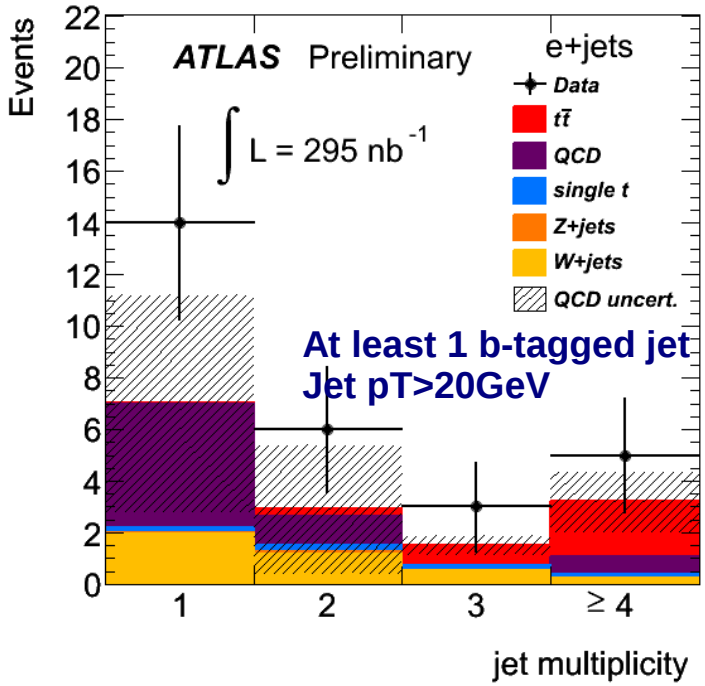



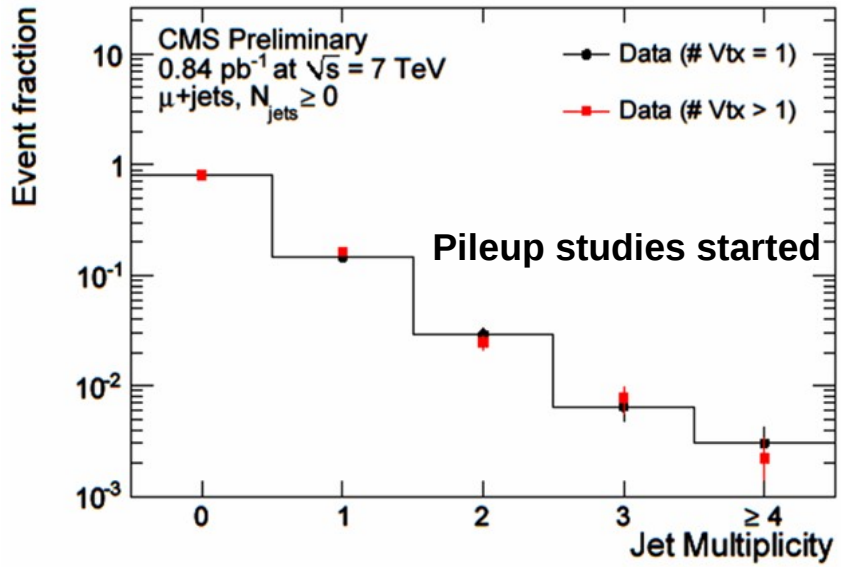

- Integrated luminosity allows by now to observe the first top-pair candidate events
  - At 7 TeV, expect production of 1 ttbar event into e/μ+jets per 20/nb and 1 ttbar into ee/μμ/eμ+jets per 110/nb
- Studies ongoing in both the di-lepton and lepton plus jets channel
- Selections require high-pT isolated leptons, missing transverse energy, refine/cross check selection with b-tagging of jets

# Top physics (1)



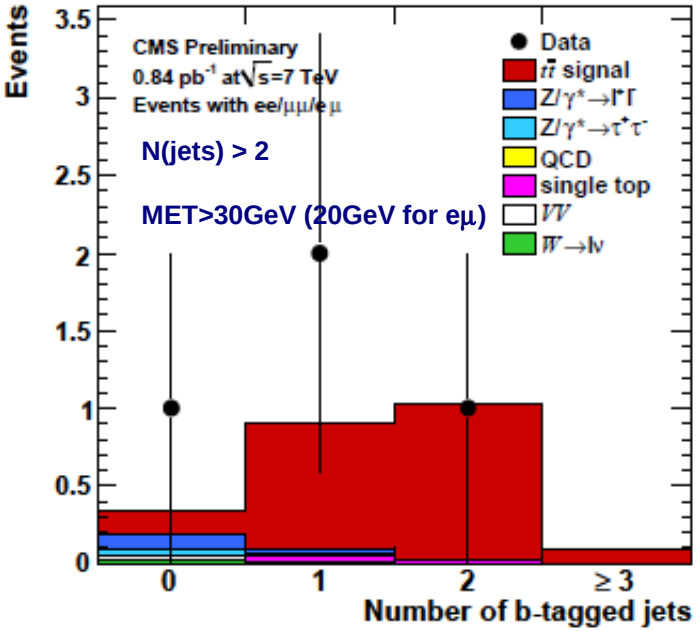

## Lepton + jets



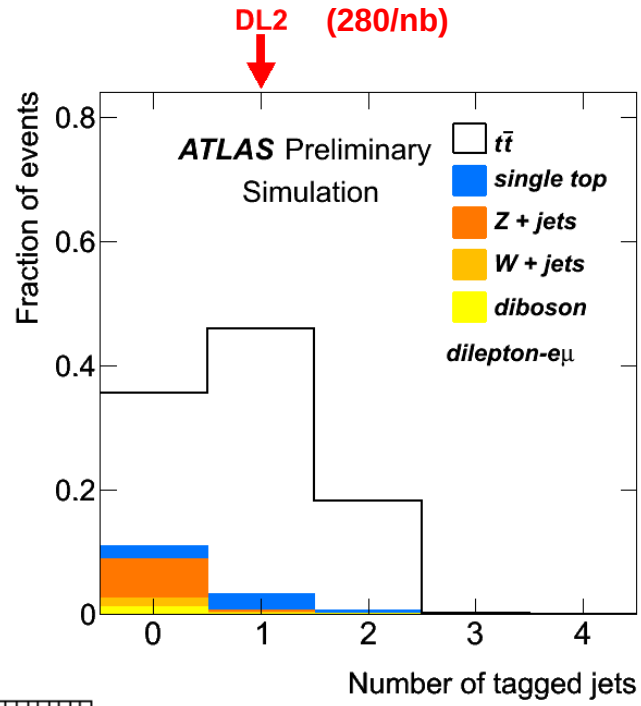



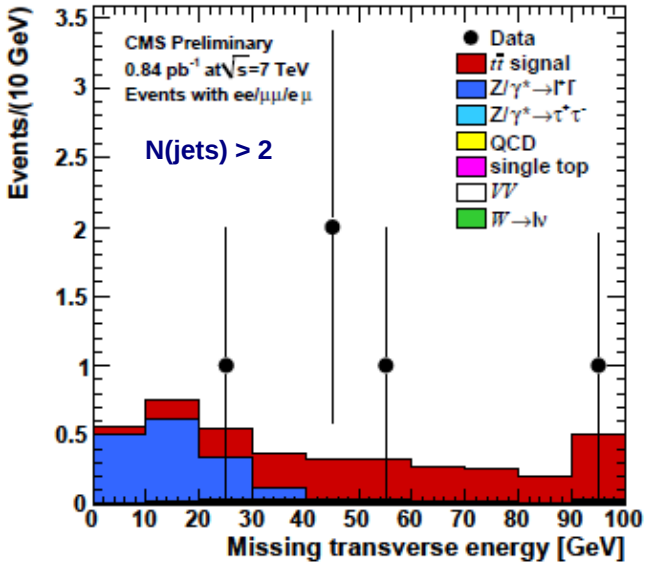

**ttbar MC:**
**ATLAS → MC@NLO**
**CMS → MADGRAPH**

# Top physics (2)



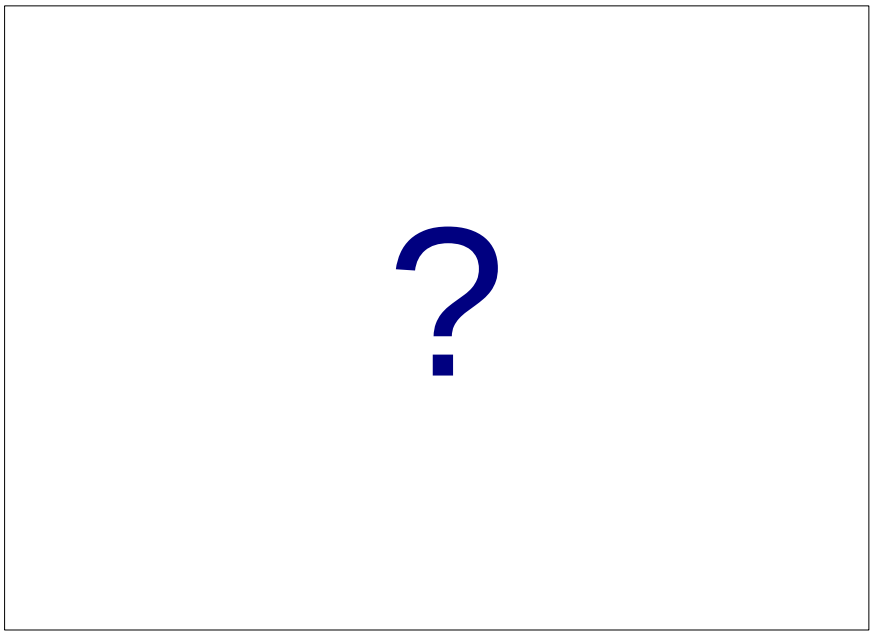

## Dilepton

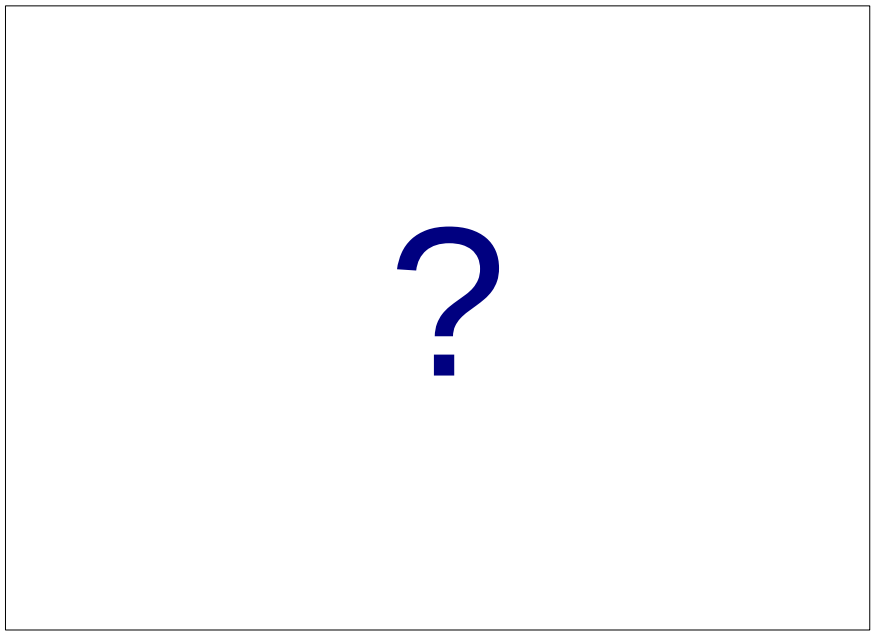



**ttbar MC:**
**ATLAS → MC@NLO**
**CMS → MADGRAPH**

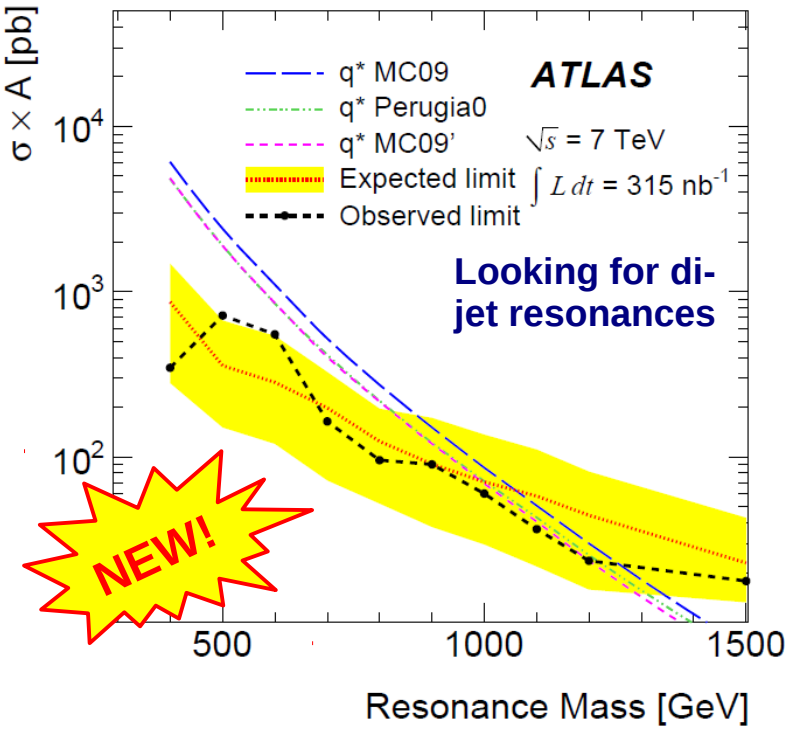
# New physics searches



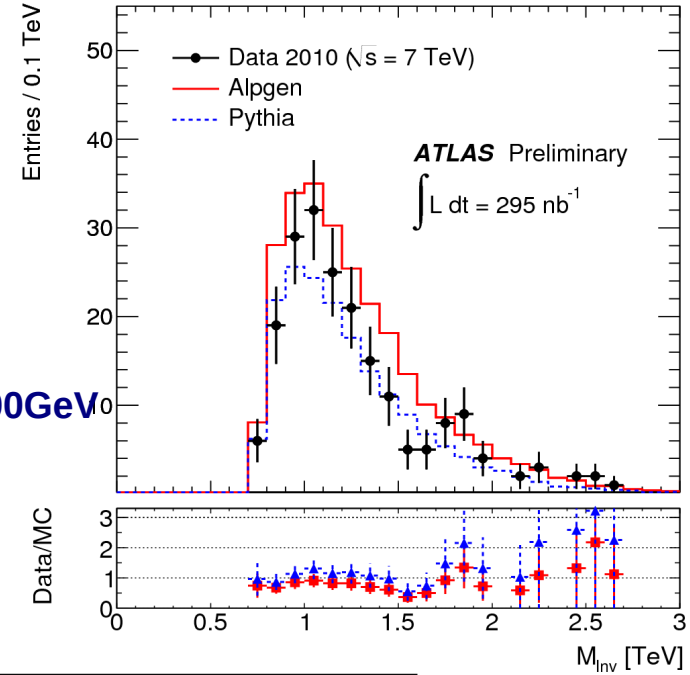



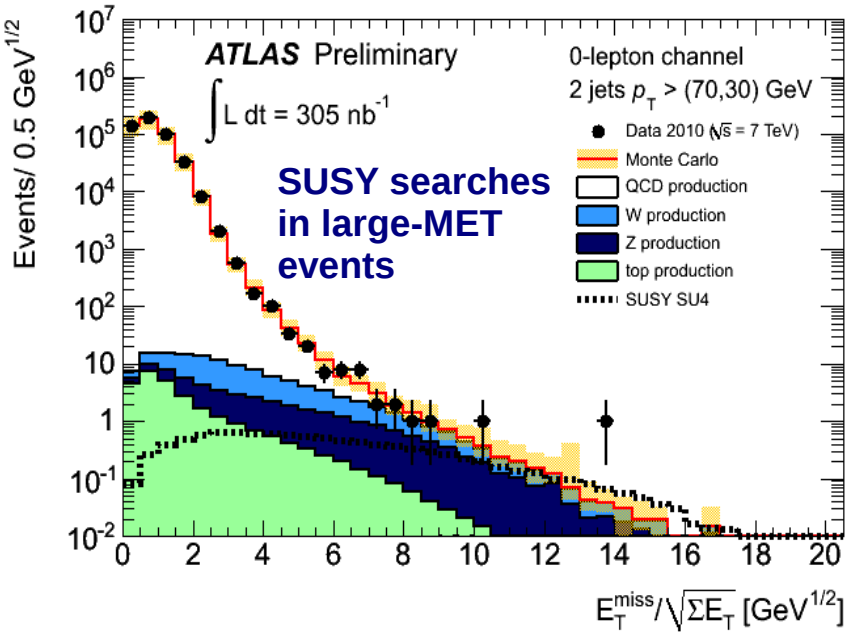

- Inclusive searches, trying to be as model-independent as possible
- Look for “anomalous” topologies
  - Unexpected mass peaks in multi-body final states
  - Extremely massive particles
  - Large missing transverse energy

# New physics searches (1)

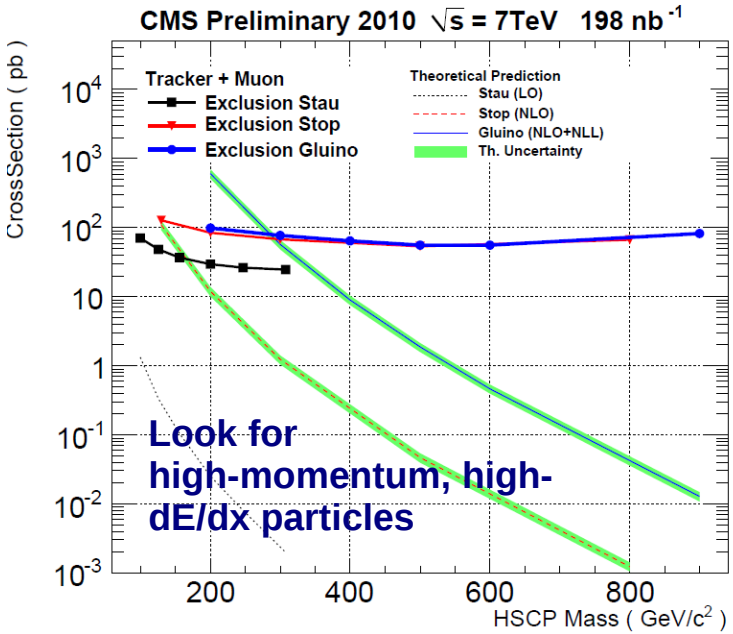


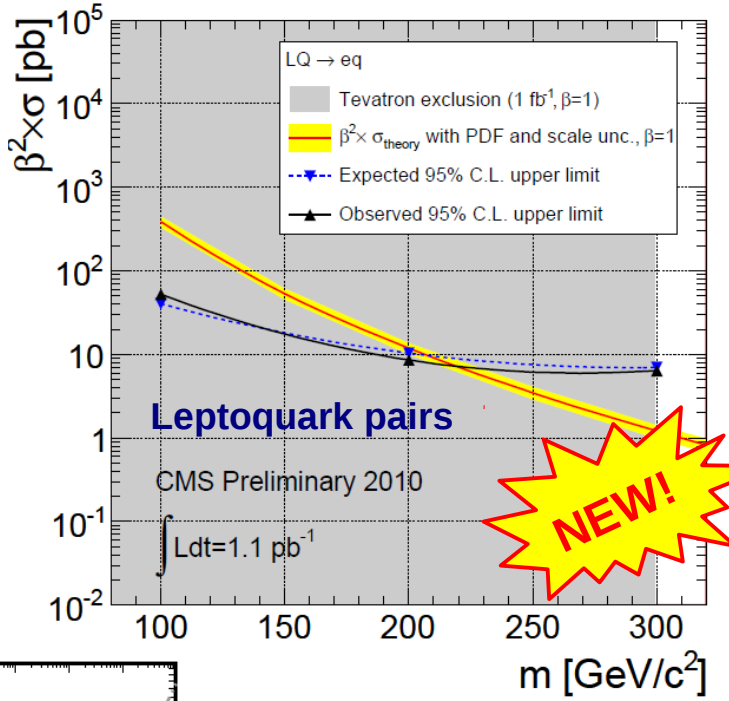

**Multi-body Inv. Mass sum(pT)>700GeV**

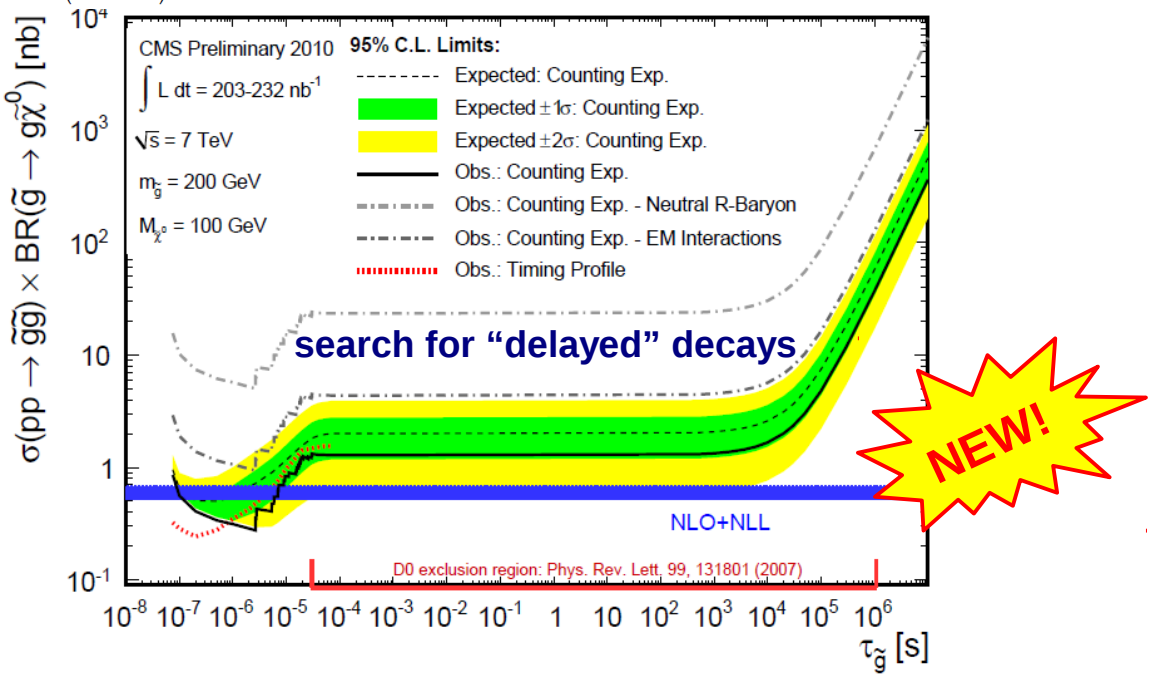


# New physics searches (2)

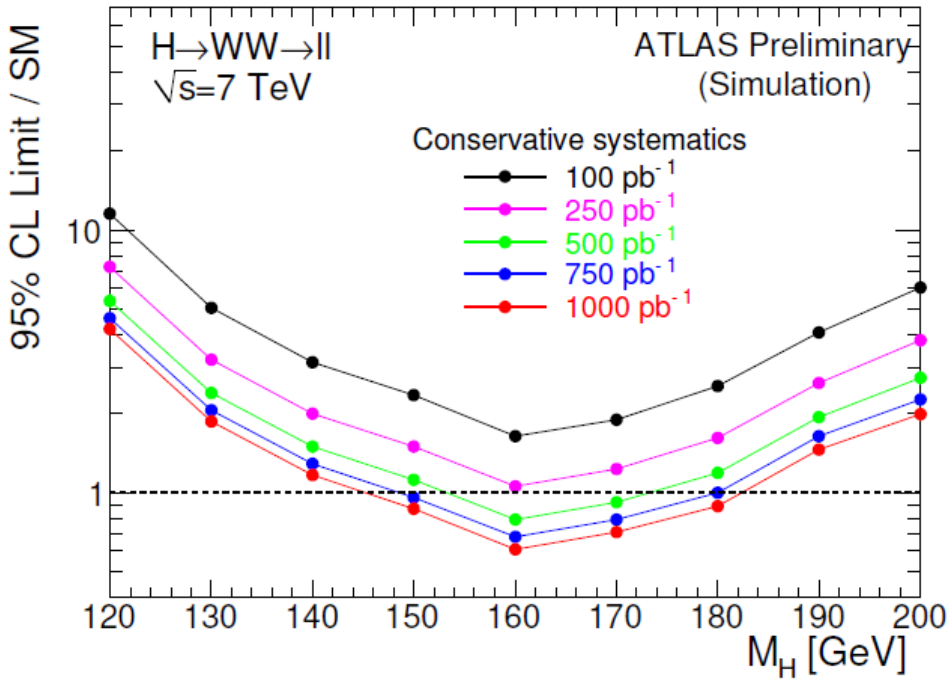


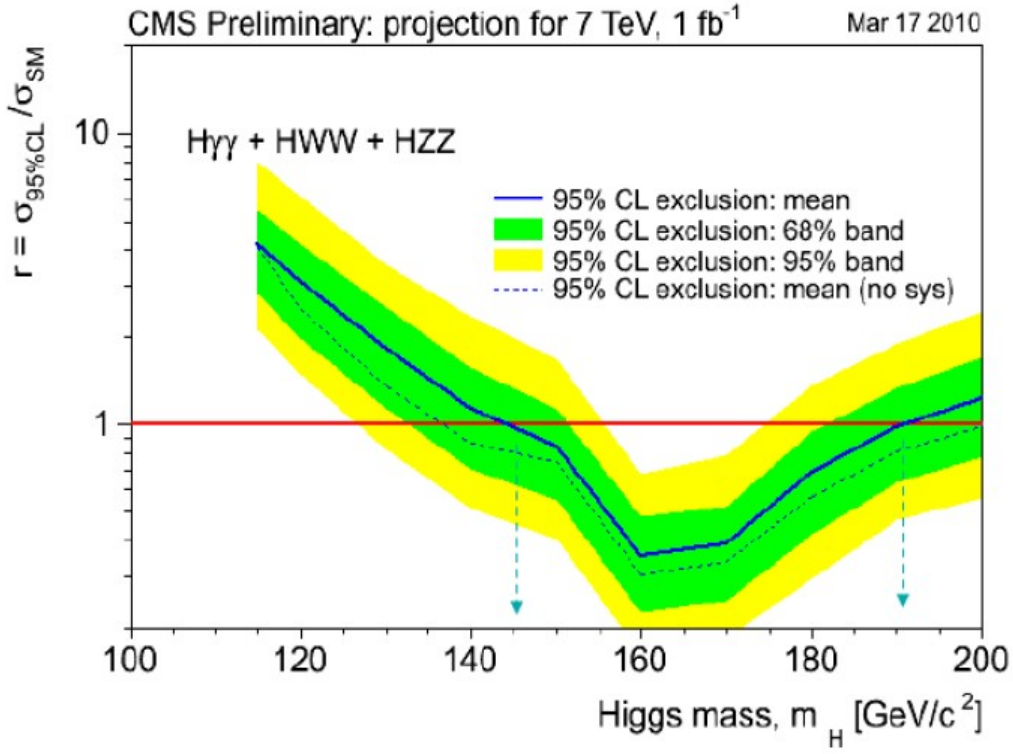



# What's next

- Further LHC performance improvements are expected
  - Aim at $1x10^{32}cm^{-1}s^{-1}$ by the end of this year
  - 1/fb by the end of 2011
    - 4 weeks HI operation starting from end october 2010
  - More NP channels become accessible for exclusion/discovery



# Conclusions

- LHC operation at 7TeV is proceeding smoothly, and the experiments are already producing many interesting results
- We are just starting to explore our vast collision physics programme
- Standard Model physics is the very first benchmark
  - At an unexplored CM energy
- Already many W and Z bosons
- Top-pair candidates are pouring-in as we speak
- Searches for new physics already started
  - Limited statistics forces analyses to be as inclusive as possible
    - Model independent!
  - Exclusion of some models already possible, in regions of phase space not yet covered by Tevatron
  - As well as close inspection of interesting events...
  - … stay tuned!

# Further reading

- Some references to notes and **papers**
  - Minimum bias, UE:
    - ATLAS-CONF-2010-081, ATLAS-CONF-2010-046, CMS-PAS-QCD-10-010, CMS-PAS-QCD-10-004, **arXiv:1003.3124 (Phys Lett B 688, Issue 1, 21-42), arXiv:1006.2083, arXiv:1005.3299 (Phys. Rev. Lett. : 105 (2010)), arXiv:1002.0621 (J. High Energy Phys. 02 (2010) 041)**
  - Jets:
    - ATLAS-CONF-2010-083, CMS-PAS-QCD-10-015, ATLAS-CONF-2010-050, CMS-PAS-QCD-10-011, ATLAS-CONF-2010-084, CMS-PAS-QCD-10-012
  - c/b mesons:
    - ATLAS-CONF-2010-062, CMS-PAS-BPH-10-002, ATLAS-CONF-2010-034, CMS-PAS-BPH-10-003
  - EW bosons:
    - ATLAS-CONF-2010-051, CMS-PAS-EWK-10-002, ATLAS-CONF-2010-076
  - Top physics:
    - ATLAS-CONF-2010-063, ATLAS-CONF-2010-087, CMS-PAS-TOP-10-004
  - New physics:
    - ATLAS-CONF-2010-079, ATLAS-CONF-2010-080, ATLAS-CONF-2010-088, CMS-PAS-EXO-10-002, CMS-PAS-EXO-10-003, CMS-PAS-EXO-10-004,CMS-PAS-EXO-10-005, CMS-PAS-EXO-10-010, ATLAS-PHYS-PUB-2010-009, **arXiv:1008.2461 (accepted by PRL)**