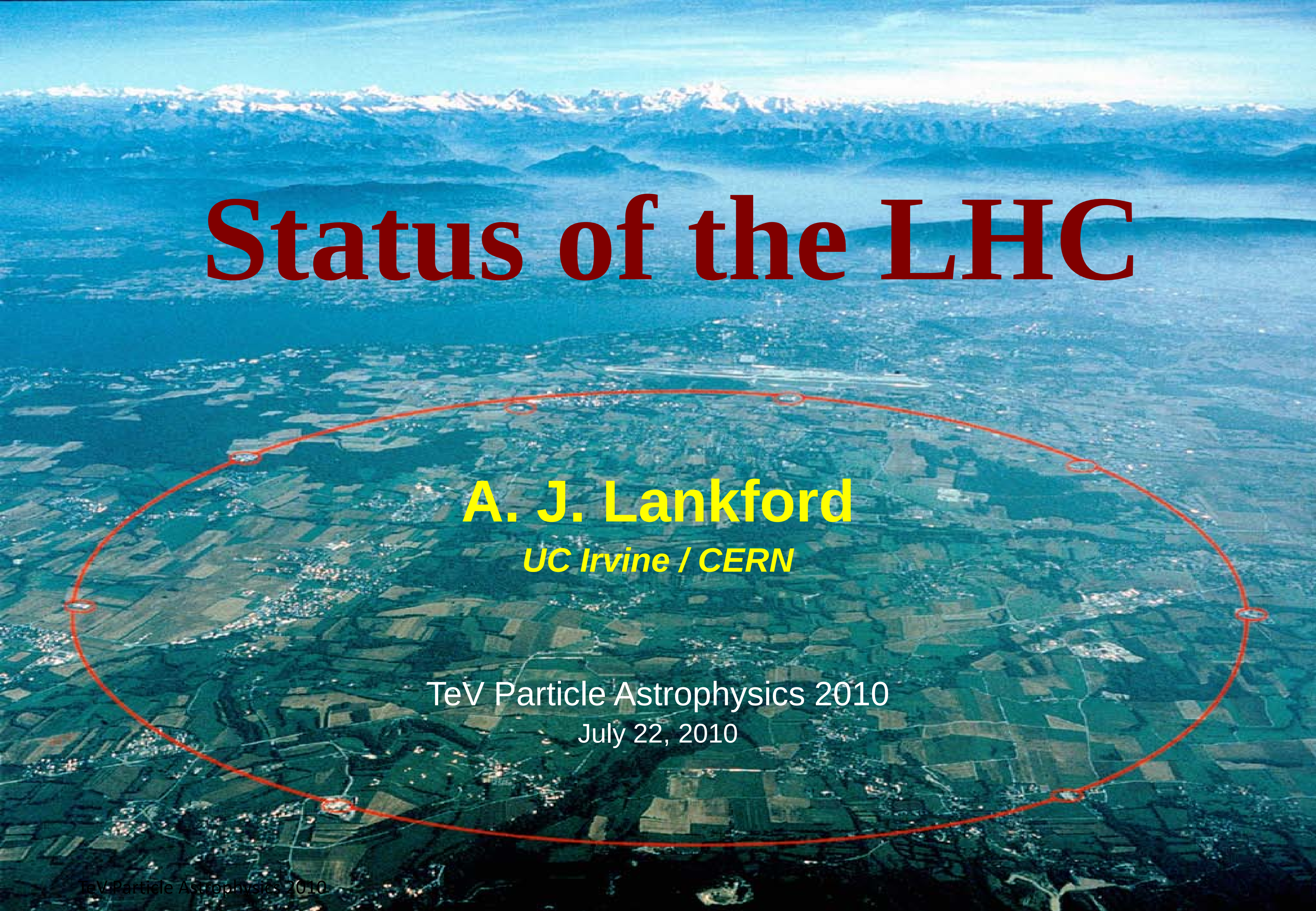


Status of the LHC

A. J. Lankford

UC Irvine / CERN

TeV Particle Astrophysics 2010

July 22, 2010

Status of the LHC - Outline

- Introduction
  - The Large Hadron Collider and experiments
- LHC commissioning
  - Machine performance to date
  - Physics expectations for 2010-11
  - Commissioning the LHC experiments
- First physics results and perspectives
  - Mainly showing ATLAS/CMS
  - Basic event properties, QCD jets
  - Initial B-physics
  - W, Z and top
  - Into the future – Higgs, SUSY and beyond
- Summary/outlook

The long road to the LHC

- 1984: First LHC workshop (Lausanne)
  - Use of the 27km LEP tunnel for protons
- 1992: ‘Expressions of interest’ for expts
- 1996: First experiments approved
- 1998: First full-size magnet tested
- 2006: Last magnet produced
- 2008/10: LHC startup and ‘incident’
- 2009/11: LHC restart
- 2010/03: First 7 TeV collisions
- Some vital statistics
  - Tunnel circumference 27 km
  - 1232 main magnets, 8 Tesla field
    - Another 7000 smaller magnets
  - Operating temperature 1.9K
  - Cost: ~4700 MCHF (incl. manpower)
  - Experiments cost: ~500 MCHF each for ATLAS & CMS (excl. manpower)

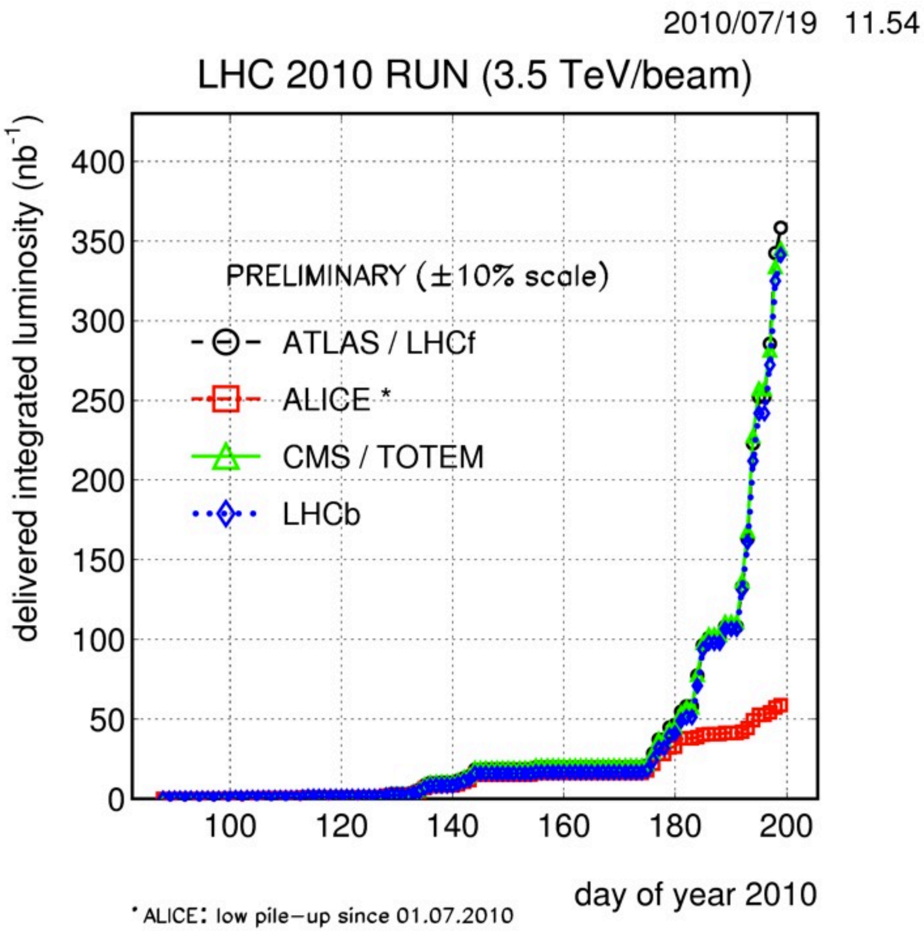
Current LHC plans

- **2010 – 2011 - 3.5 TeV/beam operations**
  - **with safe currents for magnet splices**
  - **Integrated luminosity goal: 1 fb^{-1}; requires 10^{32} instantaneous by end 2010**
- **2012 - Shutdown**
  - **Superconducting magnet splice consolidation**
    - **to enable nominal ~7 TeV/beam**
  - **Also complete collimation system for nominal luminosity – phase 1**
- **2013 – 2015 - → 7 TeV/beam operations** (~~30 fb^{-1} ??)
- **2016 – Shutdown**
  - **Improvements to injection complex; phase-2 collimation**
  - **Experiment upgrades for "ultimate" luminosity**
- **2017 – 2019 - 7 TeV/beam operations; → $2x10^{34}$** (~300-600 fb^{-1} ??)
- **2020 – 2021 - Shutdown**
  - **LHC – High-luminosity LHC (HL-LHC); upgrade experiments**
- **2022 – 2030 - → $5x10^{34}$ "leveled" luminosity** (~1500-3000 fb^{-1} ??)
- Beyond 2030: A high-energy LHC (HE-LHC) with double energy ???

LHC commissioning in 2010

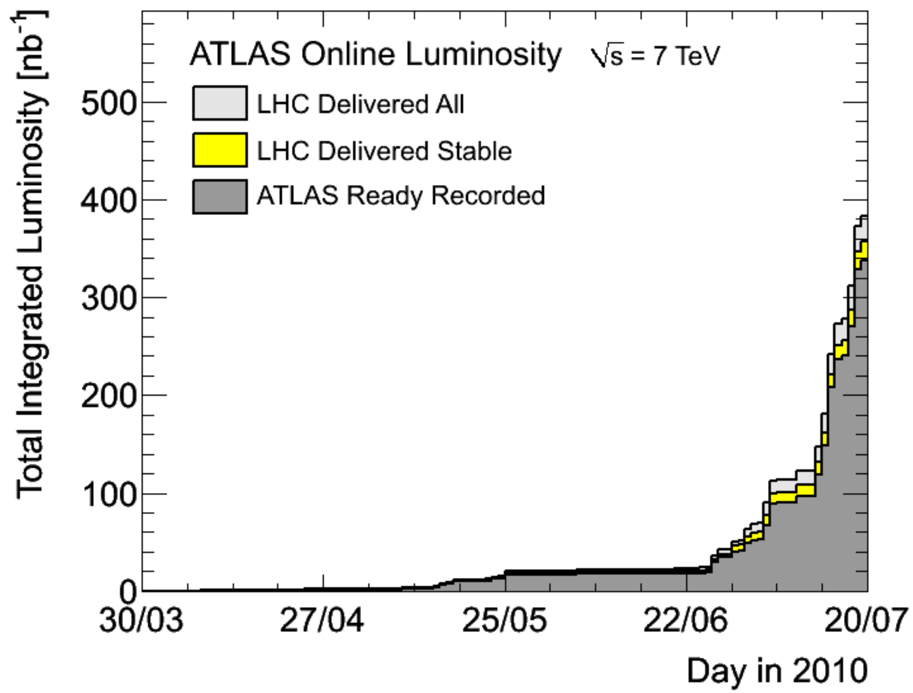
- Main LHC goals for 2010
  - Commission machine at 7 TeV step-by-step
    - Key parameter is stored energy in beam
    - Already approaching 1 MJ – limit of other machines (HERA, Tevatron) and potential for damage if beam is lost in uncontrolled way
  - Deliver data to experiments – commissioning detectors & first physics results
  - Aim to get to $L=10^{32}\ cm^{-2}s^{-1}$ by end 2010
    - This is essential to realise 1 fb^{-1} by end 2011
- Alternating periods of machine commissioning work and physics data taking
  - Started with collisions with 2×10^{10} p/bunch
  - Squeezed beams, increased # bunches to 13 per beam
  - Commissioned nominal bunch of 1×10^{11} p
    - With 3, 6, … 25 bunches per beam (> 1MJ) - most recently 13, w/ 8 colliding/expt
  - Next – commission 'bunch trains' to bring ~all into collision
    - gradually increase number of bunches
      - monitoring closely machine protection system
      - **100s bunches** (nominal LHC 2808/beam)

LHC luminosity delivery



Recent LHC progress has been excellent.

- **Peak luminosity 1.6 x 10^{30}**
- **Best fill ~70 nb^{-1}**
- **Total integrated luminosity 357 nb^{-1} (7 TeV)**
- **"Exponential" growth in luminosity**
  - **Most luminosity integrated in last few days**



Experiments are taking data efficiently.

Experiments at the LHC

- **4 large detectors in caverns ~ 100m underground**

ATLAS and CMS

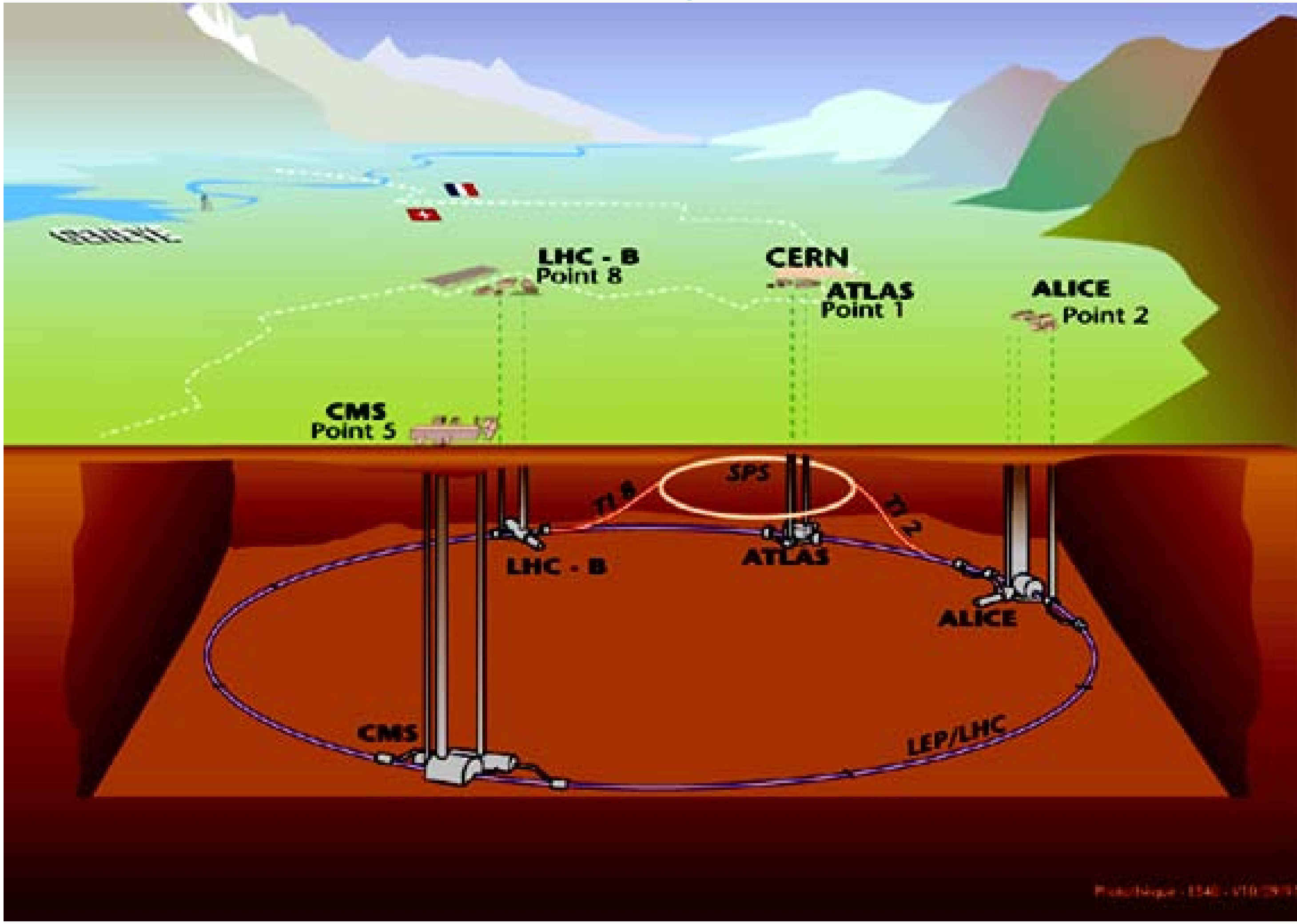
- General purpose detectors for discovery and precision SM measurements
- Similar physics goals, complementary designs

LHCb

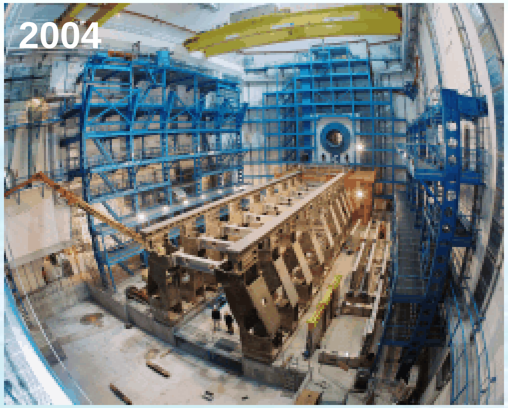
- Specialized detector for flavour physics
  - (e.g. CP violation)

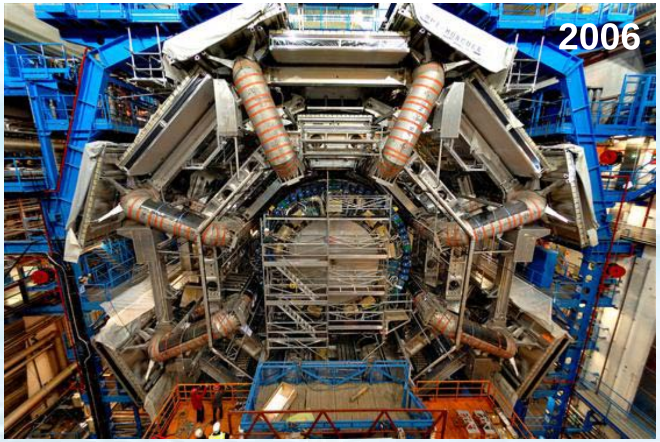
ALICE

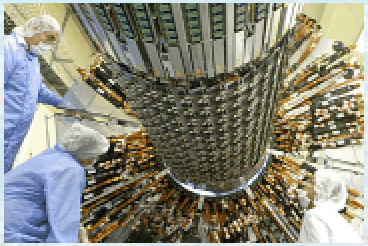
- Specialized experiment for heavy-ion physics
- First Pb-Pb ion run planned for late 2010

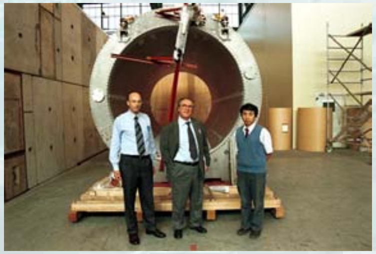


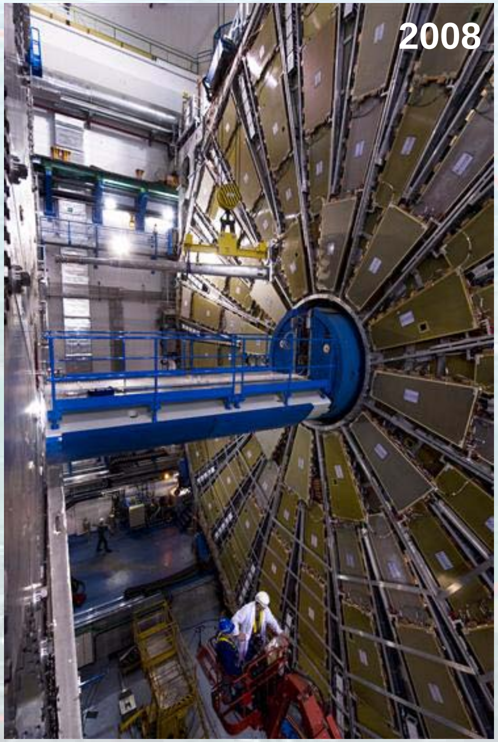

1999


2004


2006



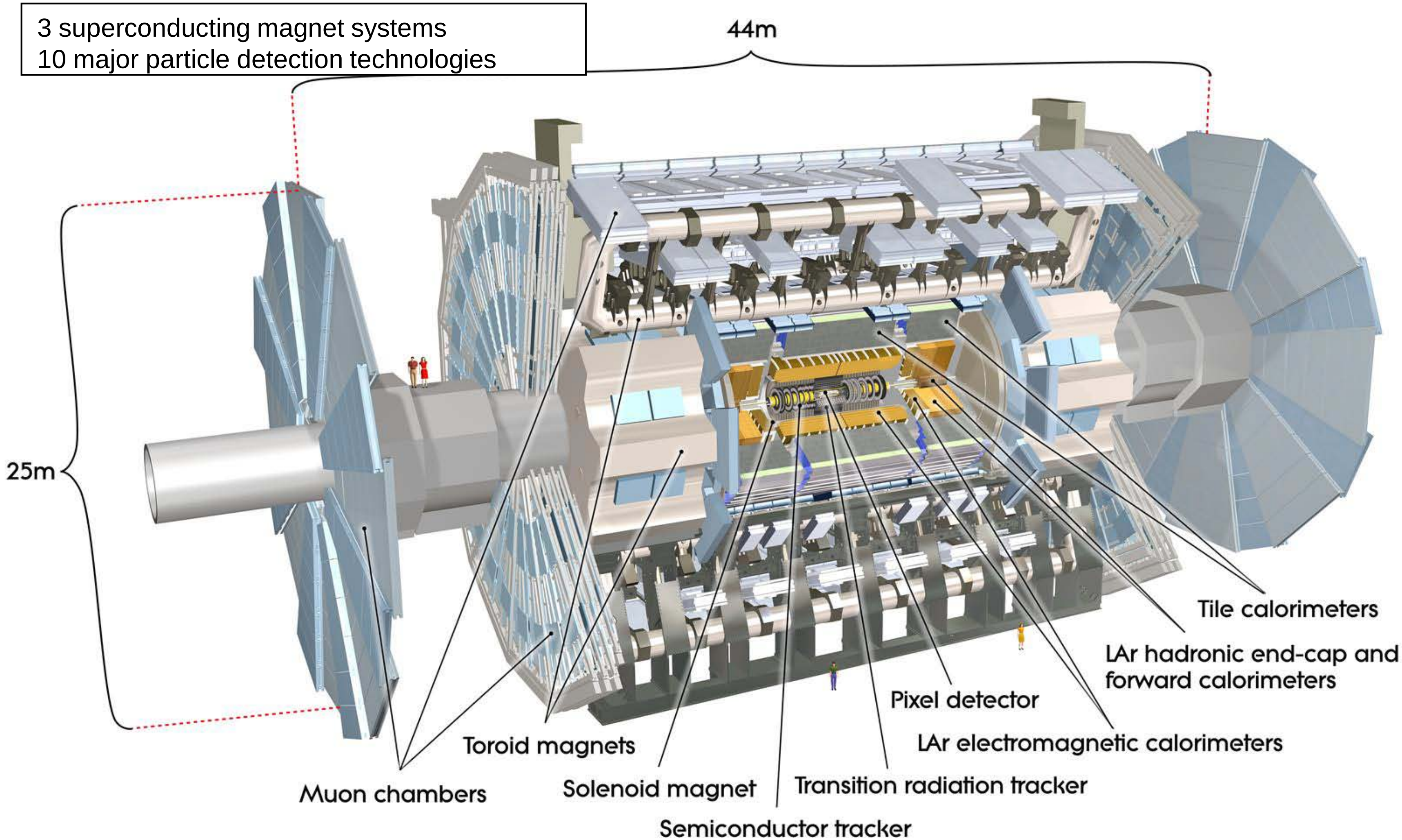



2008


2008

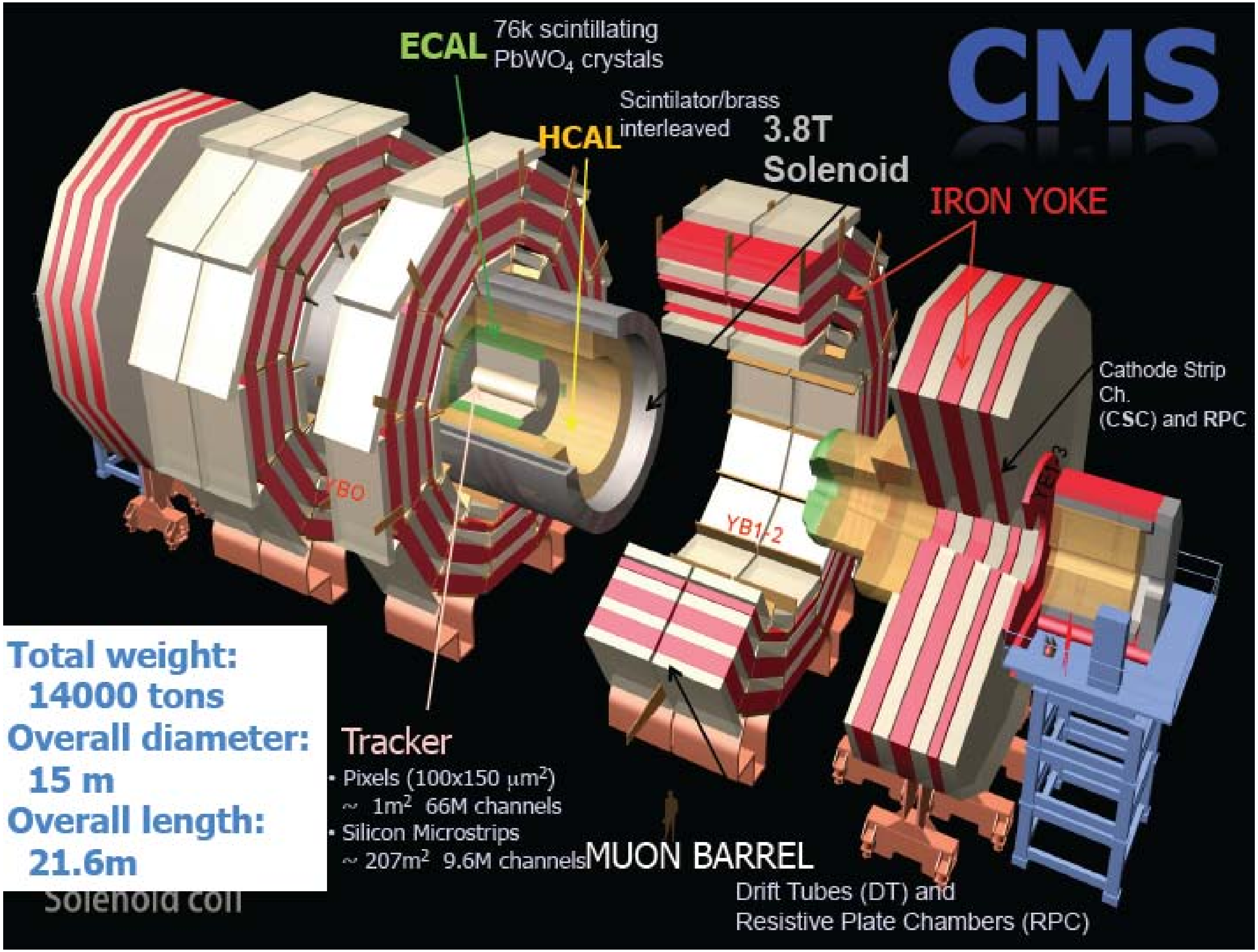
ATLAS - A Toroidal LHC Apparatus

3 superconducting magnet systems
10 major particle detection technologies

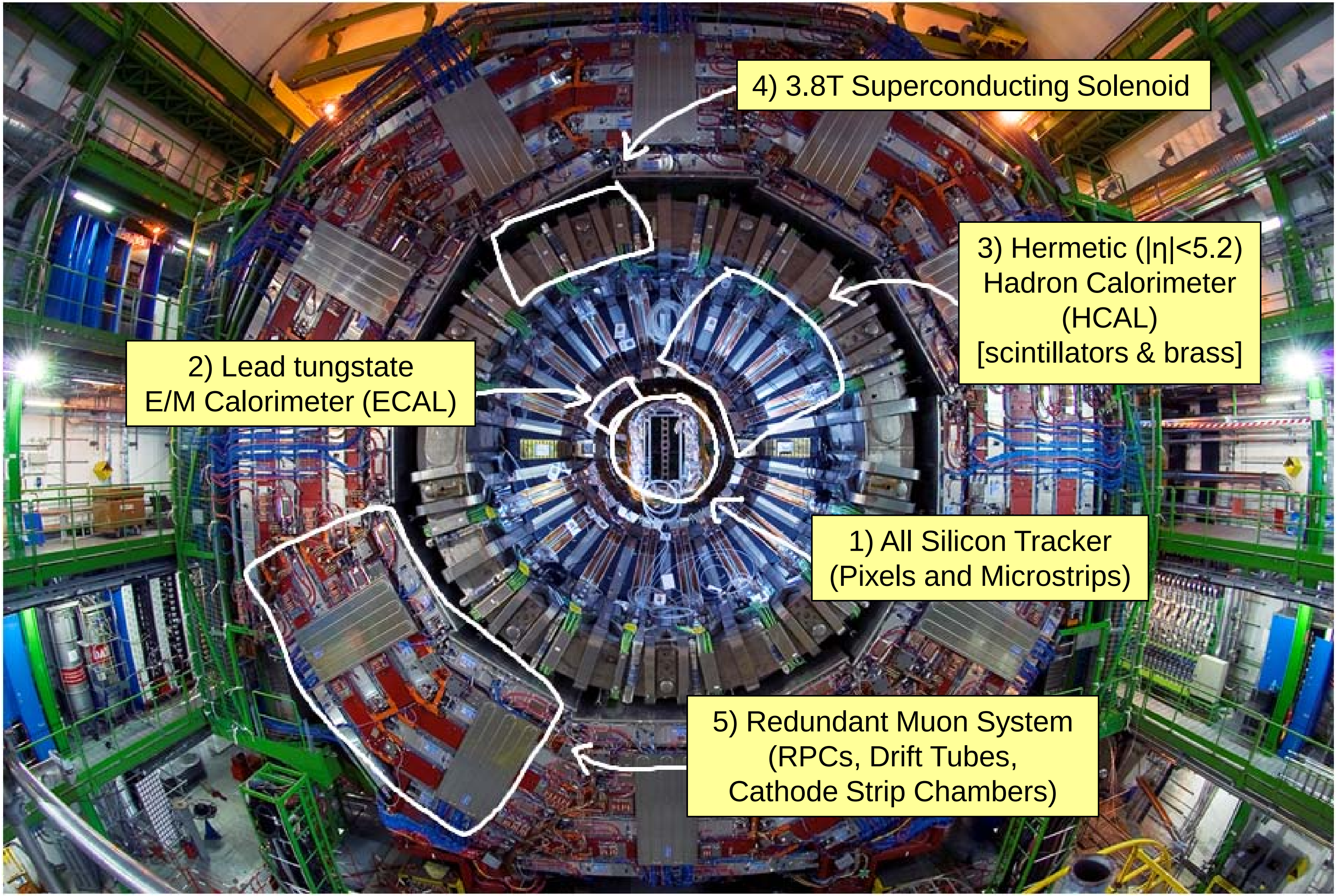


application-specific (rad-hard/tolerant) electronics
advanced IT solutions for control, data acquisition & processing

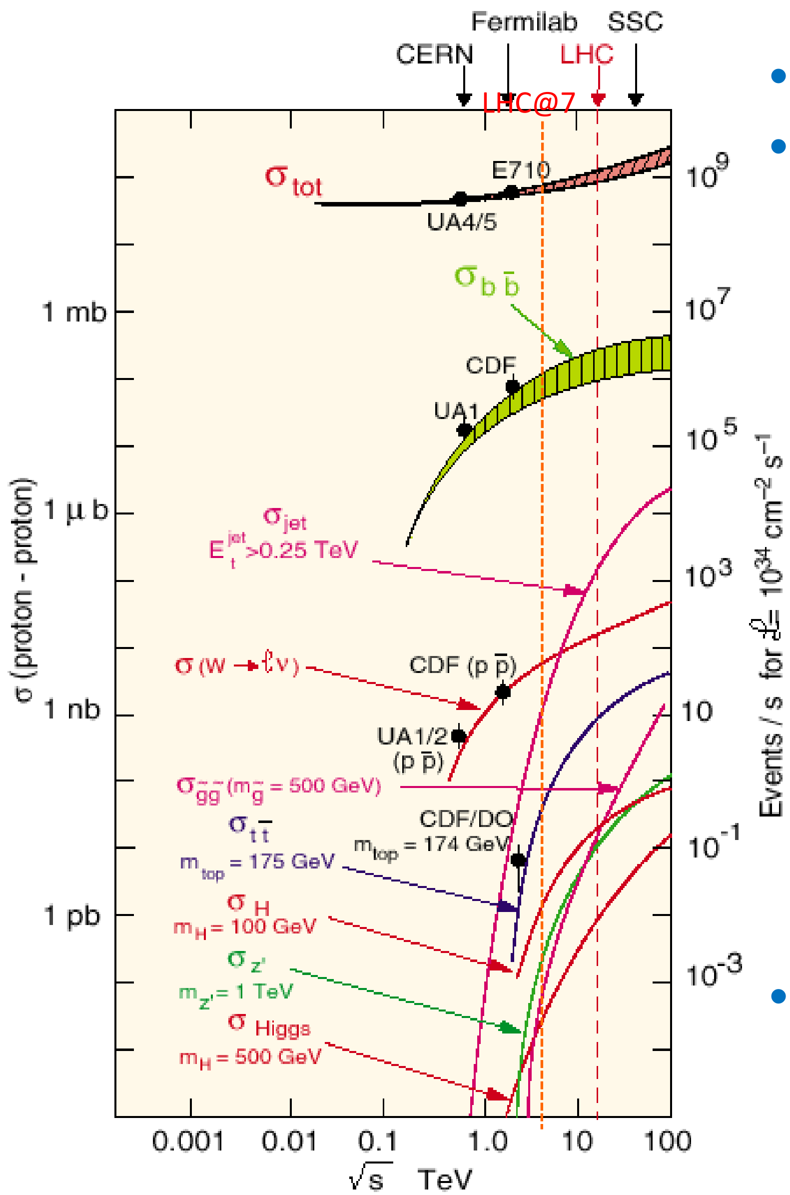
CMS - Compact Muon Solenoid



CMS - Compact Muon Solenoid



The LHC physics landscape



- LHC detectors looking for needles in haystacks
- Rare processes hiding in an overwhelming background of 'bread and butter' physics
  - o Rates for some SM processes at nominal LHC performance – 14 TeV and $L=10^{34}\ cm^{-2}s^{-1}$

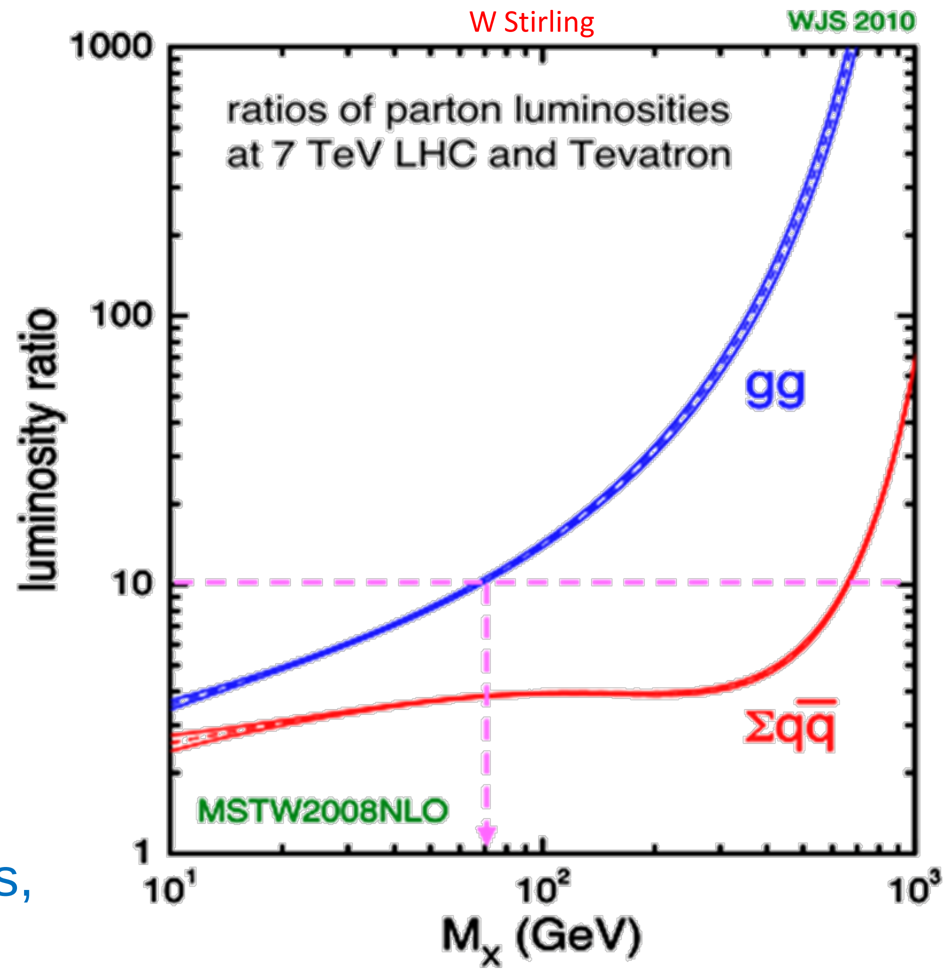
Process	Rate @14TeV
Inelastic pp collision	10^9 Hz
b-quark pair production	10^6 Hz
Jet production, E_T>250 GeV	10^3 Hz
$W \rightarrow l\nu$	10^2 Hz
Top-quark pair production	10 Hz
Higgs (m_H=100 GeV)	0.2 Hz

Integrated luminosity / time

- Early work: understanding these 'backgounds'
  - o Many interesting things to be learned on the way
  - o Important for calibrating detectors

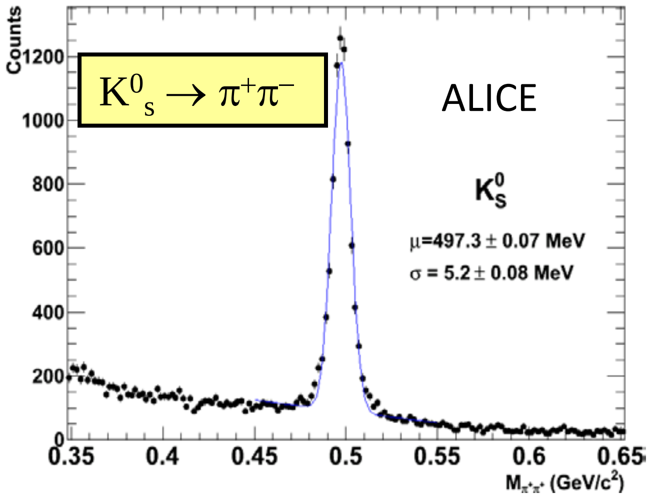
Initial LHC running compared to Tevatron

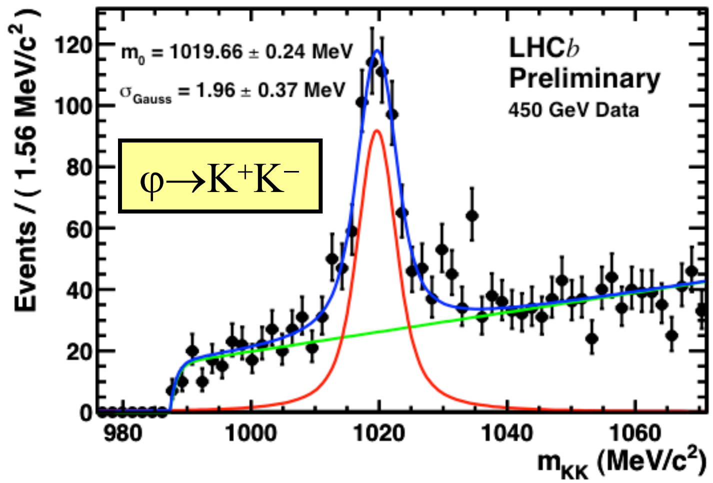
- Much early 'discovery potential' also exists
  - o Rather than comparing with ultimate LHC performance, compare with Tevatron
    - Searches typically ~5 fb^{-1} at E_{cm}=1.96 TeV
  - o Gain in energy (2→7 TeV) …
  - o Loss in int. L (5-10 → 0.1-1 fb^{-1} in 2010-11)
- Gain depends on initial state (gg or qq) and required invariant mass M_X
  - o e.g. H→WW at 160 GeV, gains factor ~15 from increased E_{CM} (gg dominated)
  - o e.g. ttbar production (X=2×175 GeV) gains a factor ~20, becomes gg dominated
  - o e.g. 1 TeV Z′ (qq) gains factor ~100
- Plenty of potential for new physics surprises, even in the 2010 run

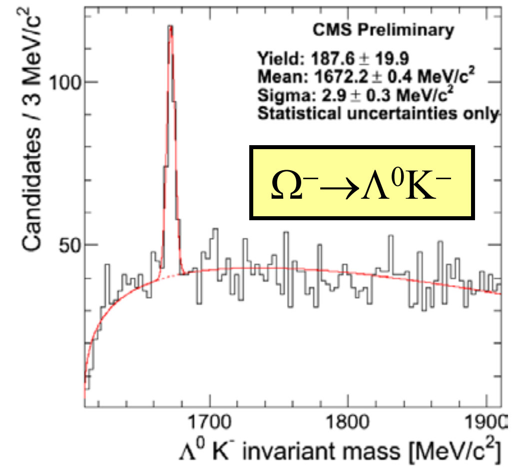


Commissioning the experiments - I

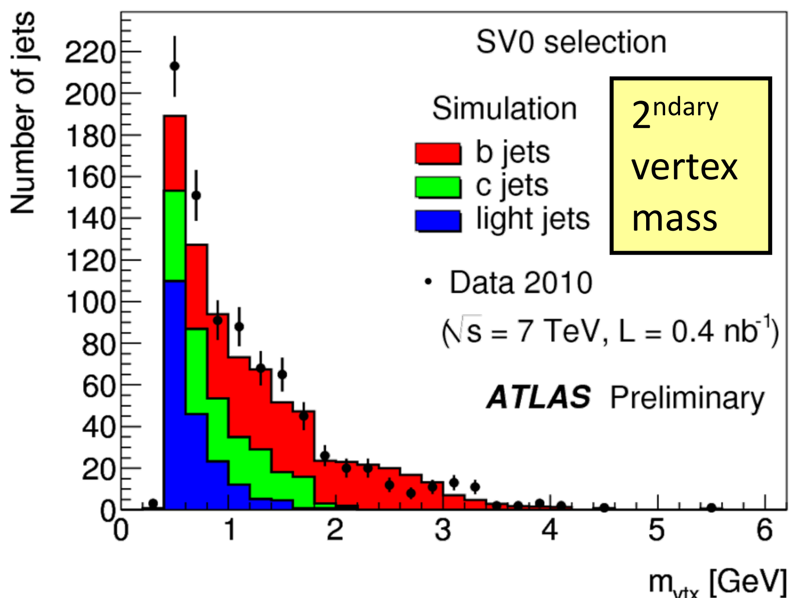
- Tracking detectors saw the 'zoo' of SM resonances from the first runs …

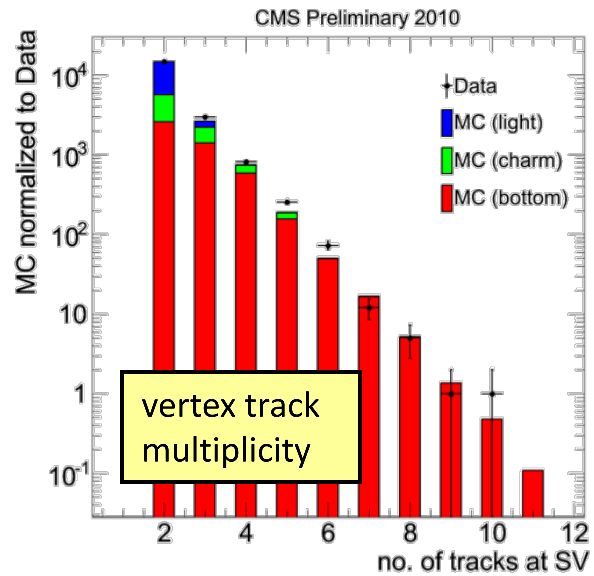






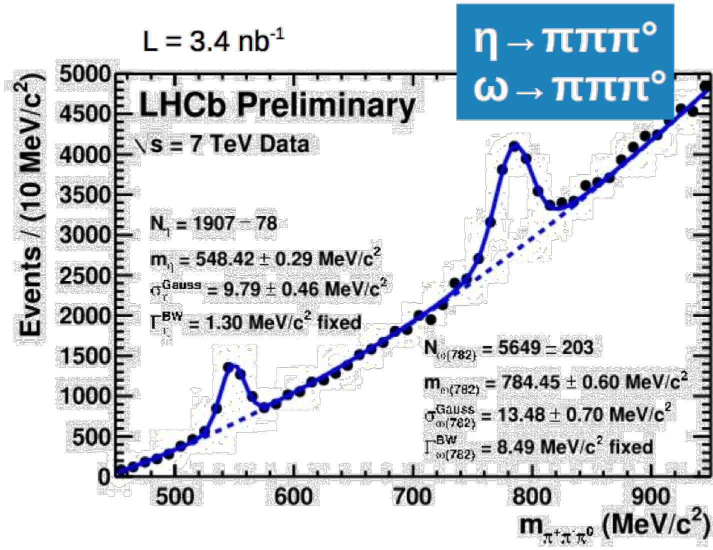
- B-tagging distributions
  - With understanding of tracking resolution and alignment, start to identify b-hadrons
  - Tracks inconsistent with primary vertex
  - Explicit 2^{ndary} vertex

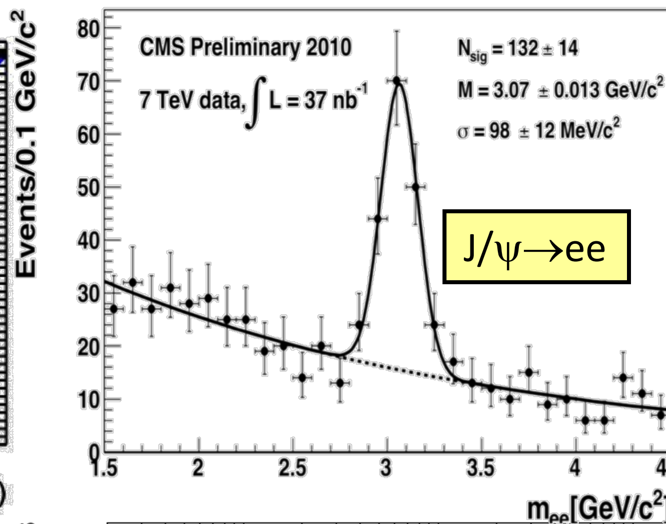


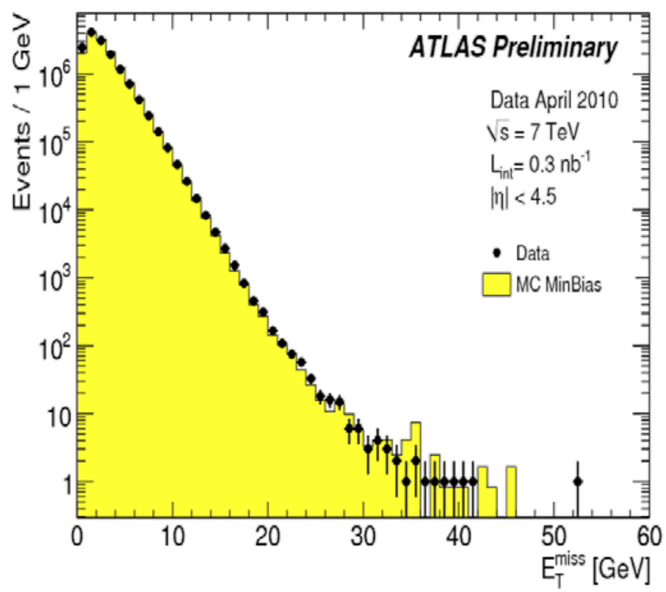


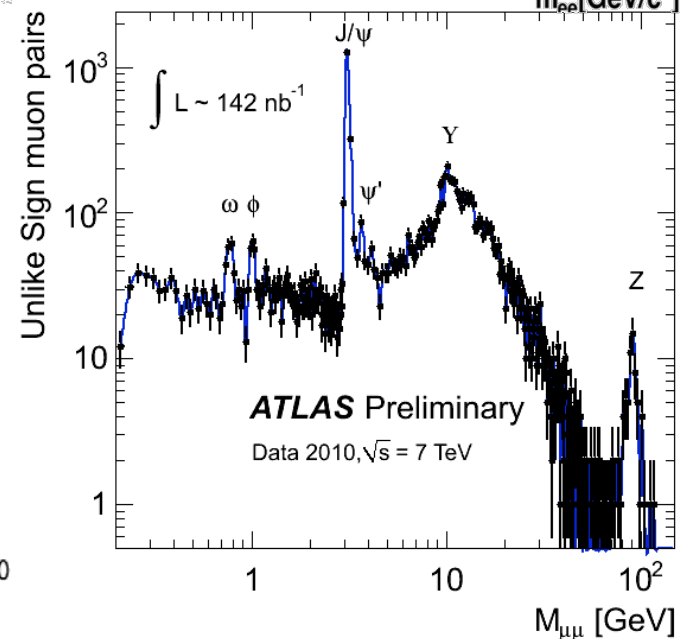
Commissioning the experiments - II

- Calorimeter studies
  - Also seeing resonances
  - E.g. $\pi^0 \rightarrow \gamma\gamma$ and related η and ω resonances
  - J/ψ→ee particularly challenging – low energy electrons, small S/B
- Missing transverse energy
  - Vector sum (E_x, E_y) to look for energy imbalance
  - Test of calorimeter coverage, noise, dead channel handling, etc. … crucial for many searches
- Muon detectors
  - Use known resonances for commissioning muons



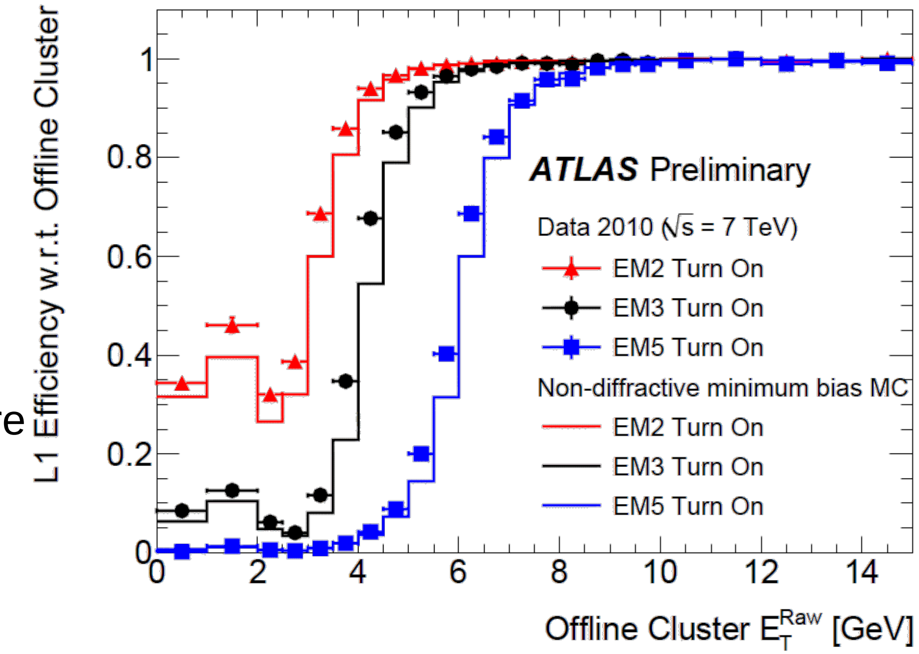


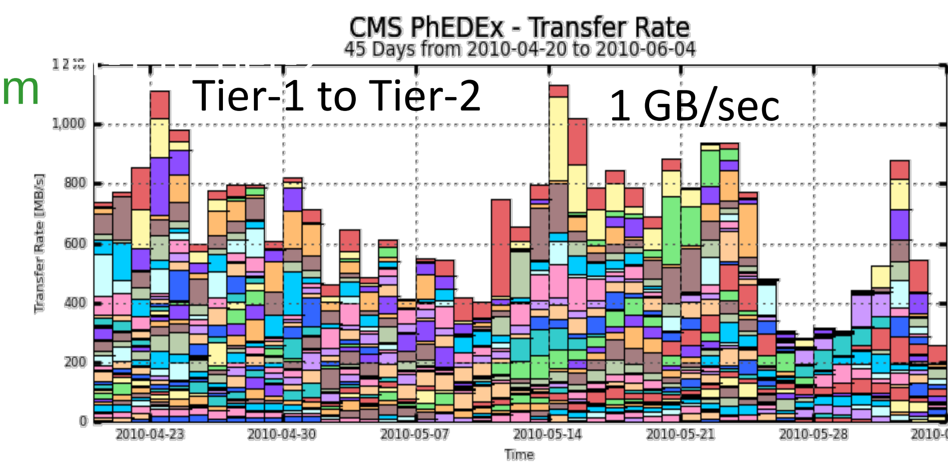




Trigger and offline computing

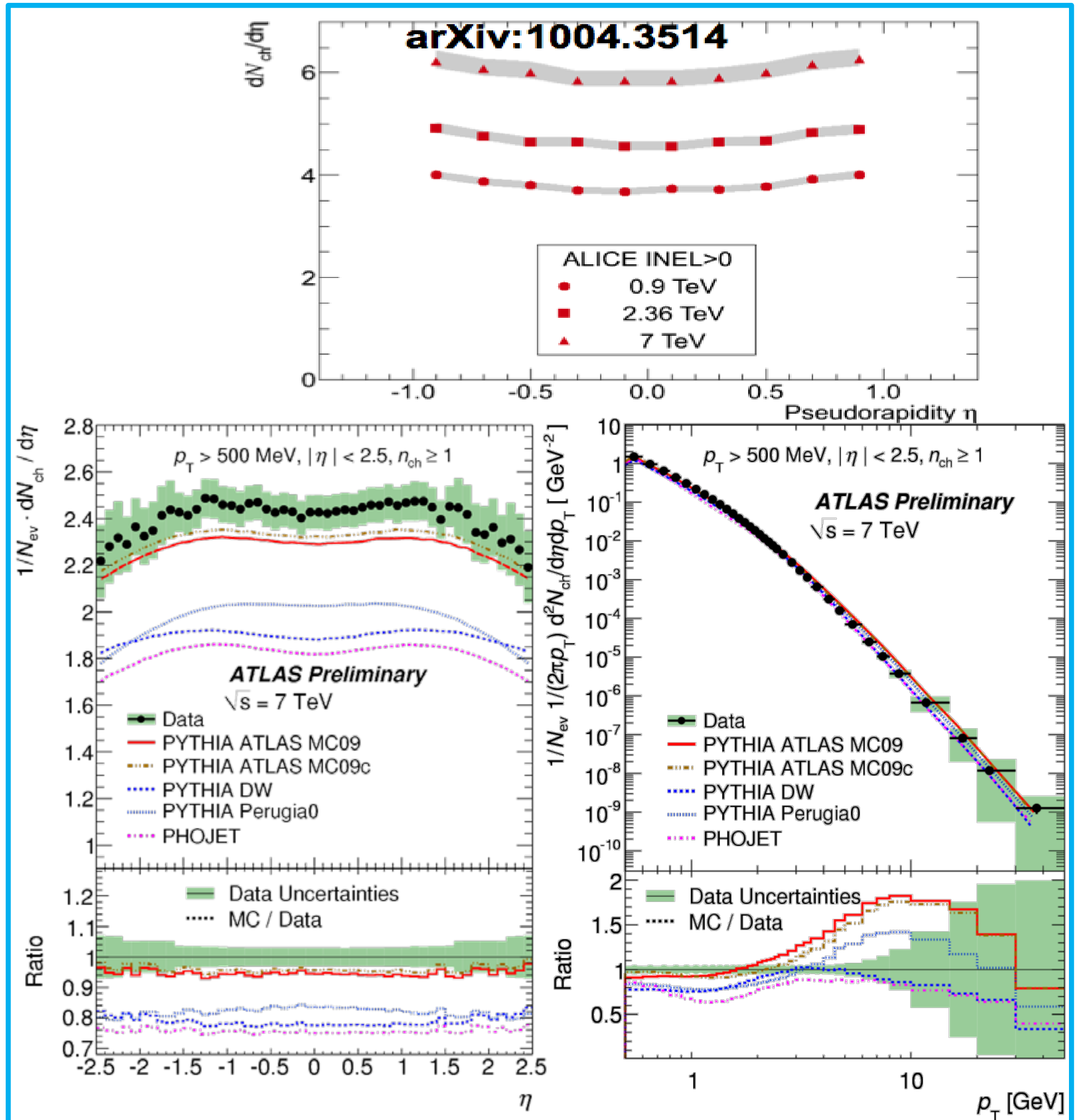
- ATLAS and CMS record data at O(200) Hz
  - o Interaction rate of pp→X exceeded this after first few runs – crucial to commission triggers
  - o L1 hardware trigger followed by multistage software-based high-level trigger on PC farms
    - Start with low L1 thresholds, HLT pass-through
    - Study effect of triggers on unbiased samples before trigger chains have to be enabled
  - o Step-by-step as LHC luminosity increases
    - Events rejected by trigger are lost forever ..
- In parallel, worldwide offline computing effort
  - o O(1GB)/sec being recorded and distributed from CERN to the >100 Tier-1/2 sites
    - Data being re-reconstructed as calibration and algorithms are improved in light of data
    - Monte Carlo simulation proceeding in parallel
  - o 1000s of users analysing data using Grid tools





Charged particle multiplicities at LHC

- Most basic inclusive process: pp→X
  - o Mix of elastic, diffractive and inelastic processes … ‘minimum bias’
    - Trigger on activity on 1 or both sides
- Measure charged particle activity
  - o N_{ch}/evt, $dN_{ch}/d\eta$, dN_{ch}/dp_T, etc
  - o Distributions have to be corrected for trigger and acceptance biases, reconstruction efficiency, …
    - Some model-dependence
- Multiplicity increases with E_{cm}
- Existing models (tuned at Tevatron):
  - o Underestimate overall multiplicity
  - o Have too hard p_T spectrum
- Work started on improving MC tunes

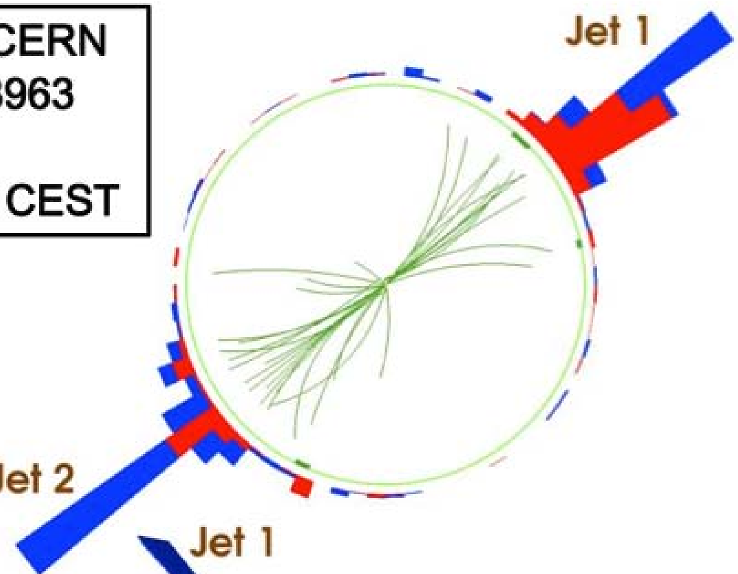


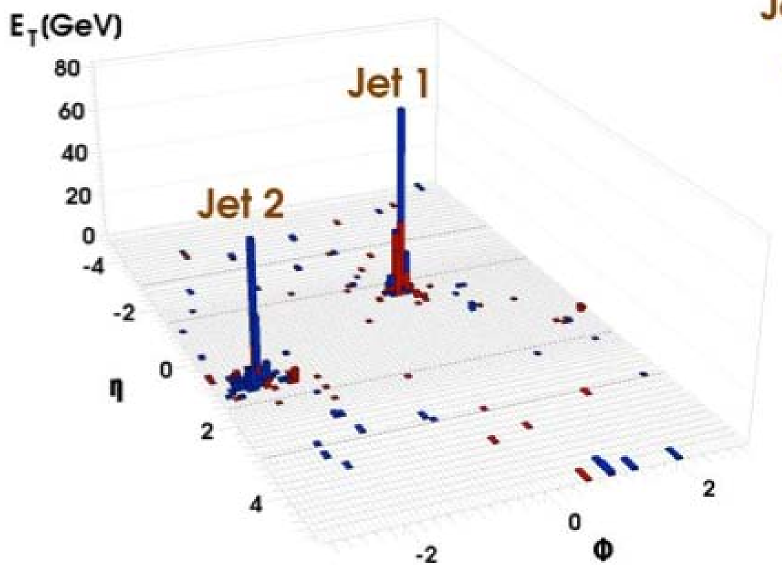
Observation of jet events

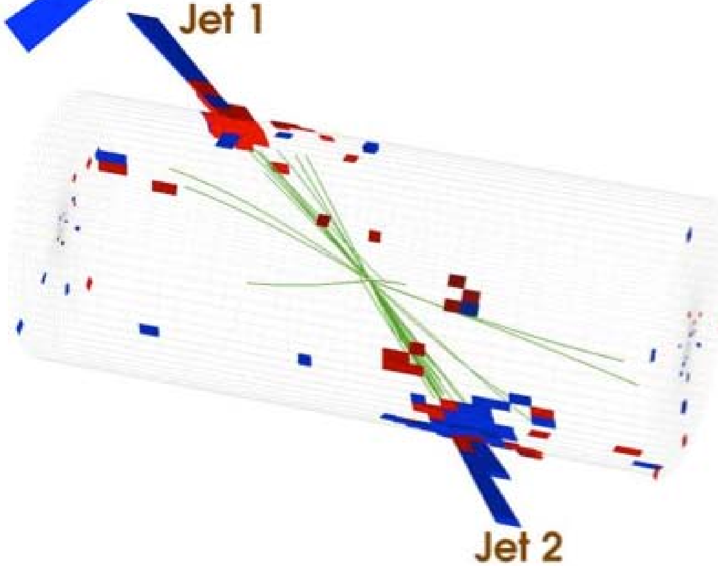
An early CMS di-jet event

CMS Experiment at LHC, CERN
Run 133450 Event 16358963
Lumi section: 285
Sat Apr 17 2010, 12:25:05 CEST

Jet1 p_T : 253 GeV
Jet2 p_T : 244 GeV
Dijet Mass : 764 GeV

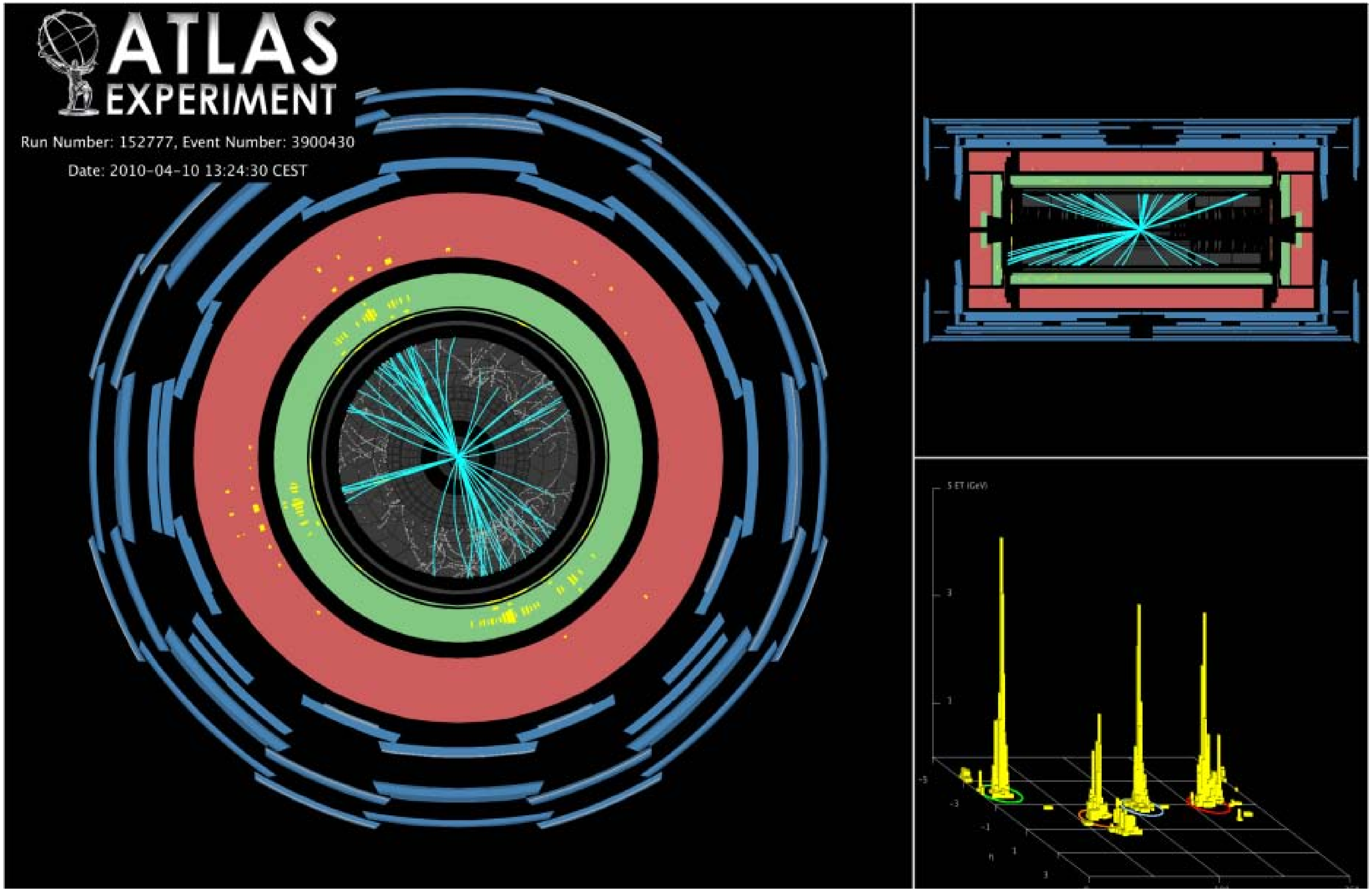






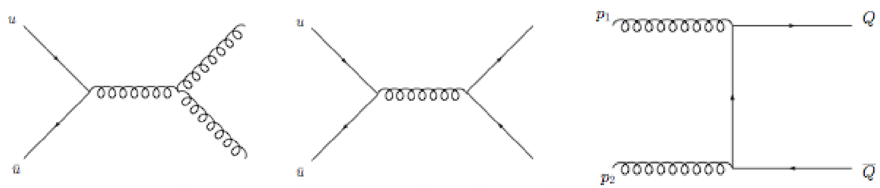
Observation of jet events

An early ATLAS multi-jet event

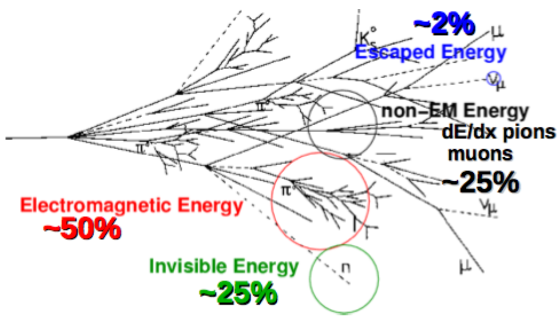


Observation of jet events

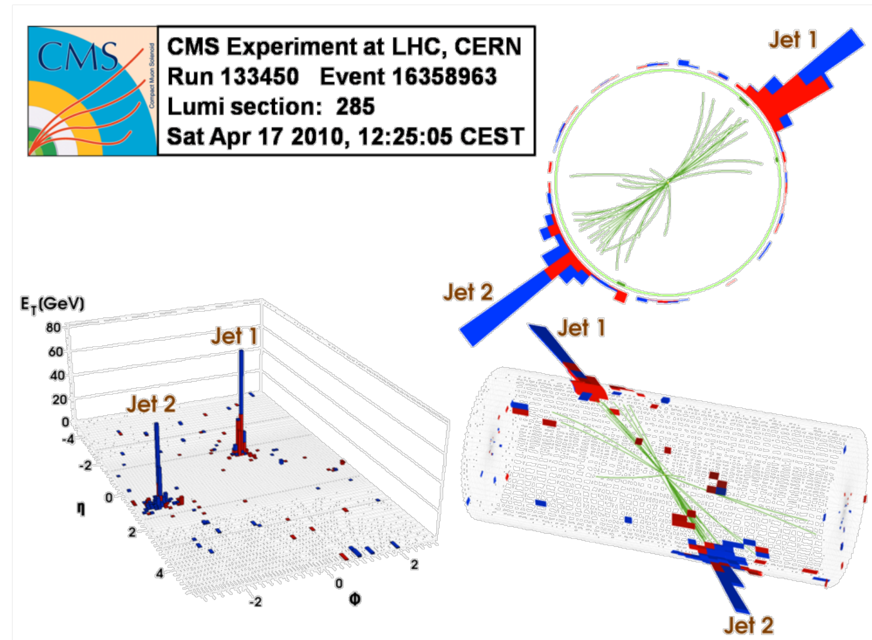
- Dominant process with high p_T final state
  - o Hard interaction of quarks & gluons leading to di-jet and multijet events

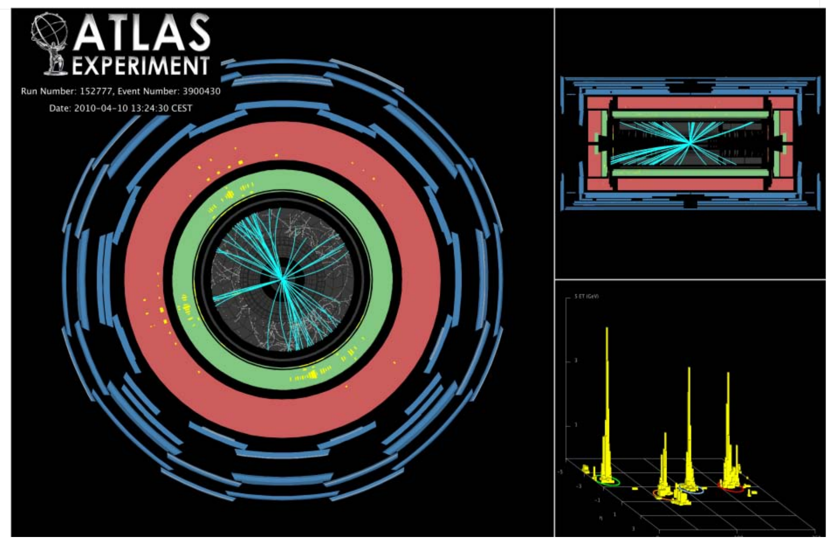


    - Seen immediately in the first 7 TeV LHC runs
- Jets measured/reconstructed in calorimeters

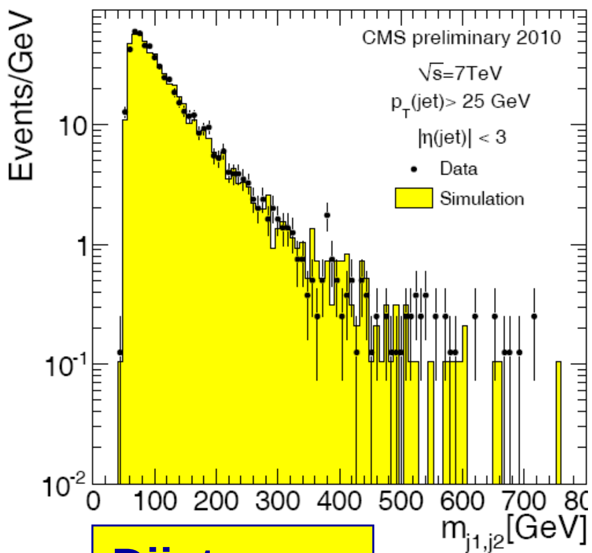


  - o Critical to understand response - energy scale and resolution
    - Testbeam, simulation and data-based methods
  - o Can also exploit complementary tracking info

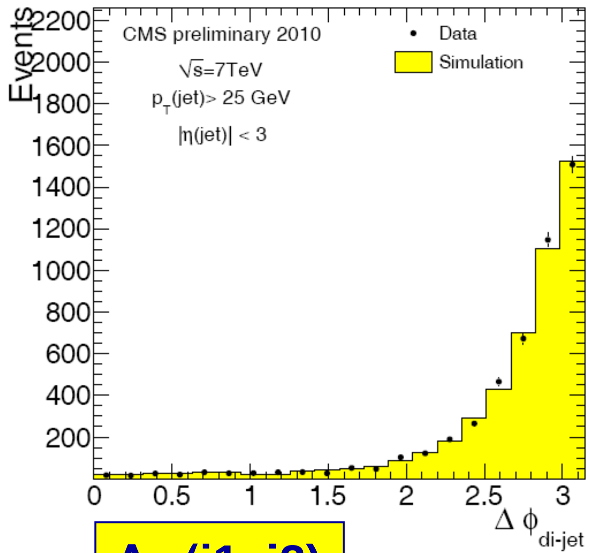




Studying jet events

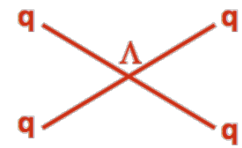


Dijet mass

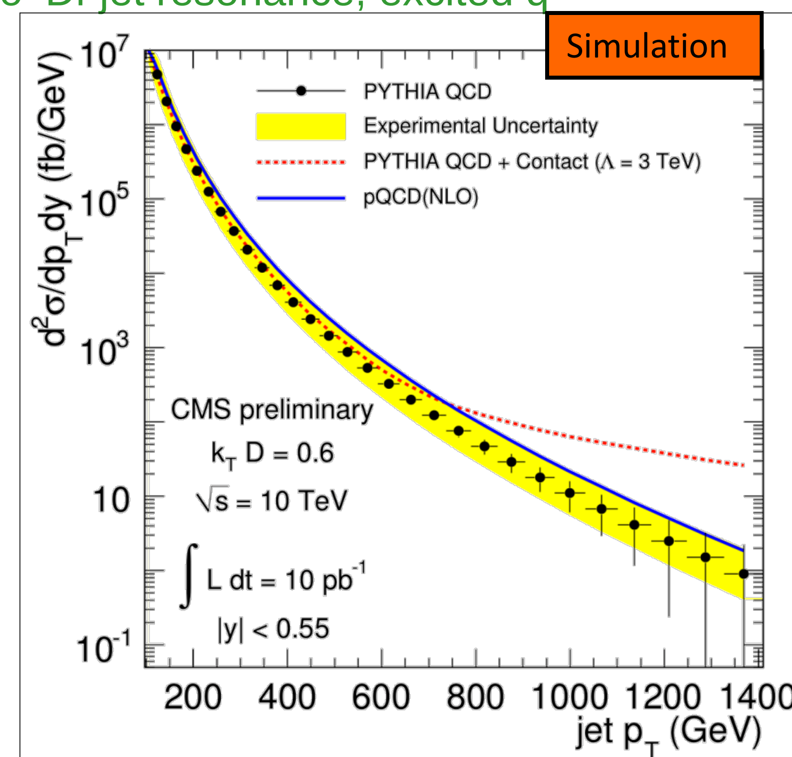


Δφ(j1, j2)

- Then look for deviations from expectation …
  - e.g. contact interactions

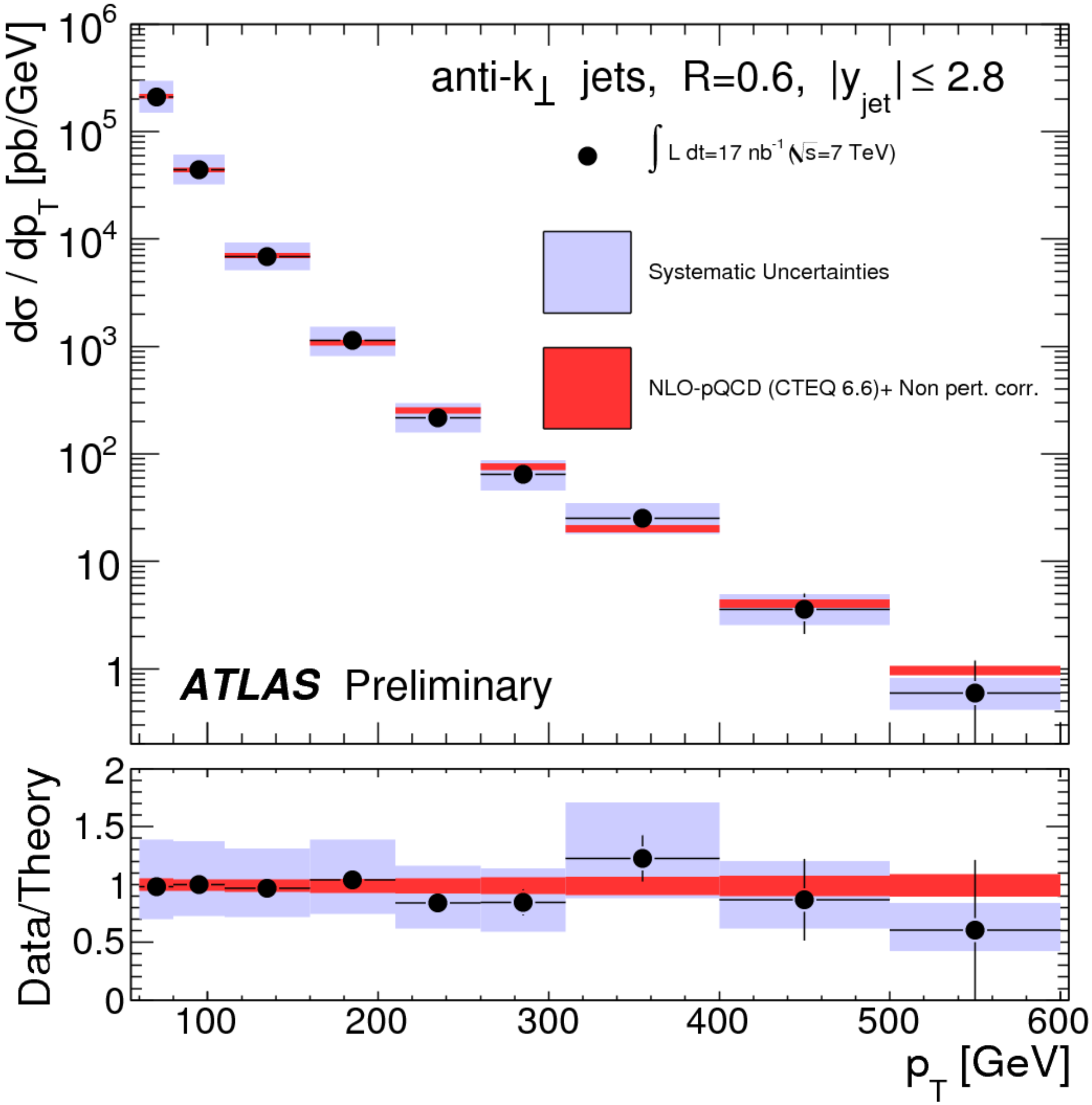


- o Interesting sensitivity already at 10 pb^{-1}
- o Di-jet resonance, excited q*



- First inclusive jet distributions being produced
  - Number of jets, jet p_T and di-jet invariant mass
  - Angular distributions, jet shape variables
  - Comparisons with LO Monte Carlo generators
    - Later, more sophisticated calculations
- Working to understand energy scale and resl^n
  - Can start to exploit di-jet and later γ-jet balance

Inclusive jet cross-section *vs.* p_T

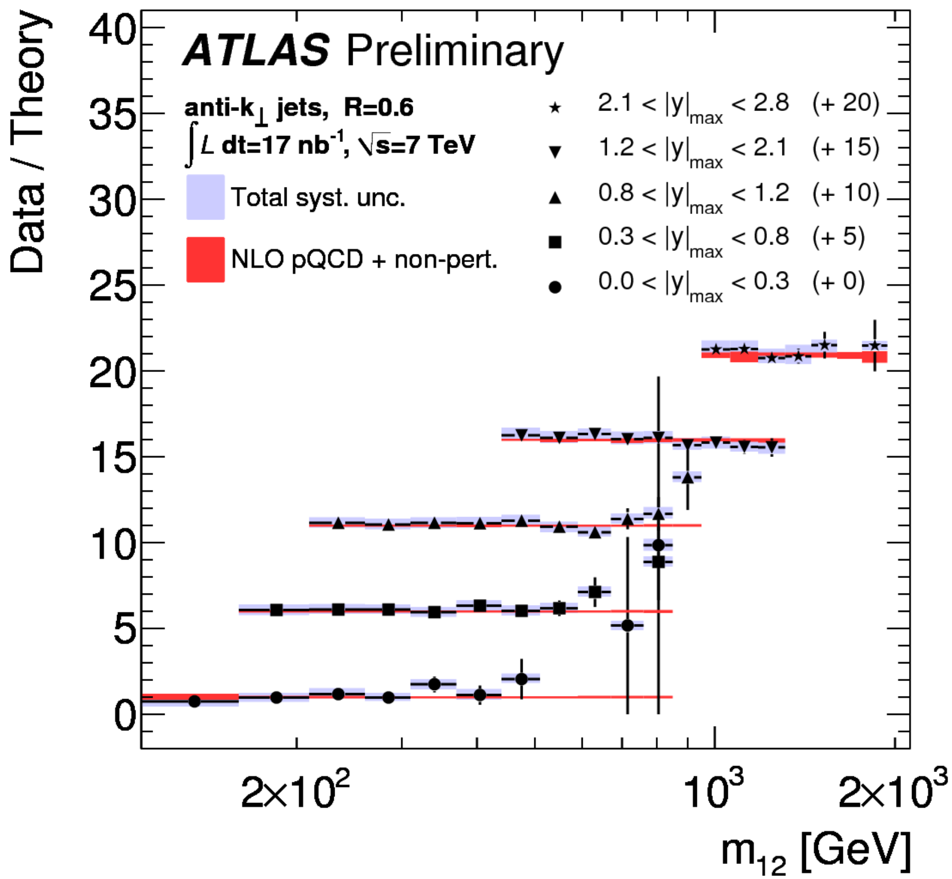


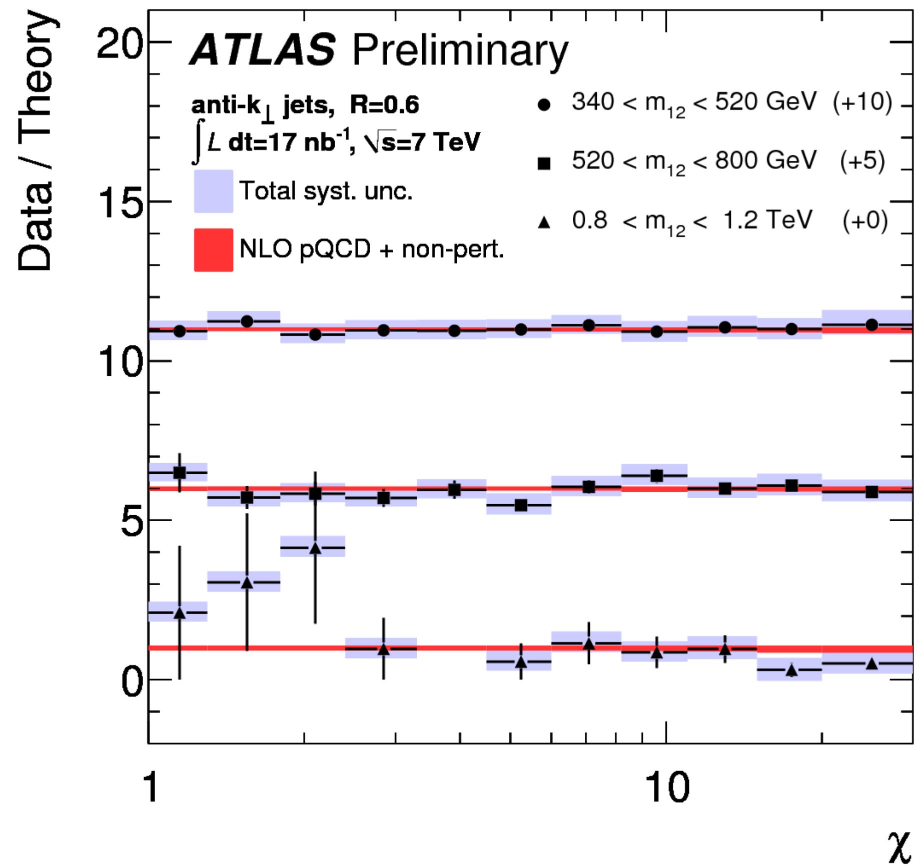
Jet energy scale uncertainty ~7%
Overall luminosity uncertainty 11%

Comparison to NLO QCD calculation
- Non-perturbative corrections from leading-log partonic showering MC
- Describes measurements well

Inclusive jet differential cross section as a function of jet pT integrated over the full region |y|<2.8 for jets identified using the anti-kT algorithm with R=0.6. The data are compared to NLO QCD calculations to which soft QCD corrections have been applied. The error bars indicate the statistical uncertainty on the measurement, and the grey shaded band indicates the quadratic sum of the systematic uncertainties, dominated by the jet energy scale uncertainty. There is an additional overall uncertainty of 11% due to the luminosity measurement that is not shown. The theory uncertainty shown in orange is the quadratic sum of uncertainties from the choice of renormalisation and factorisation scales, parton distribution functions, alpha_s(M_Z).

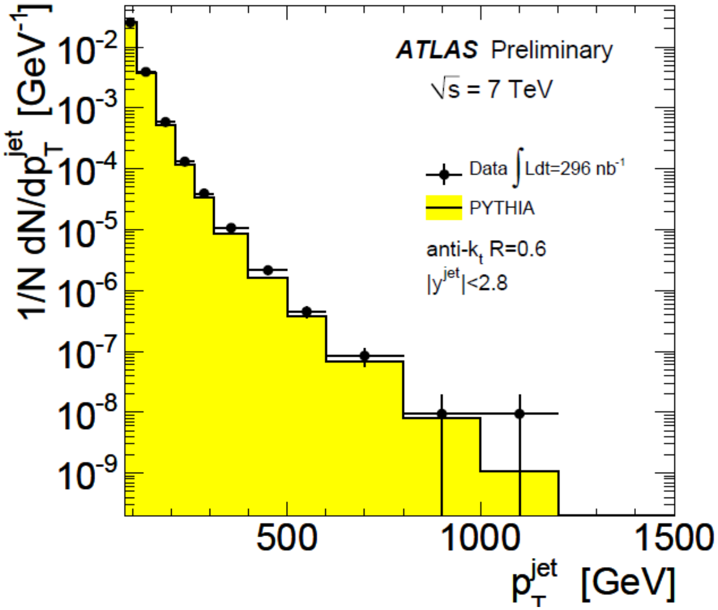
Inclusive di-jet cross-section *vs.* mass & χ





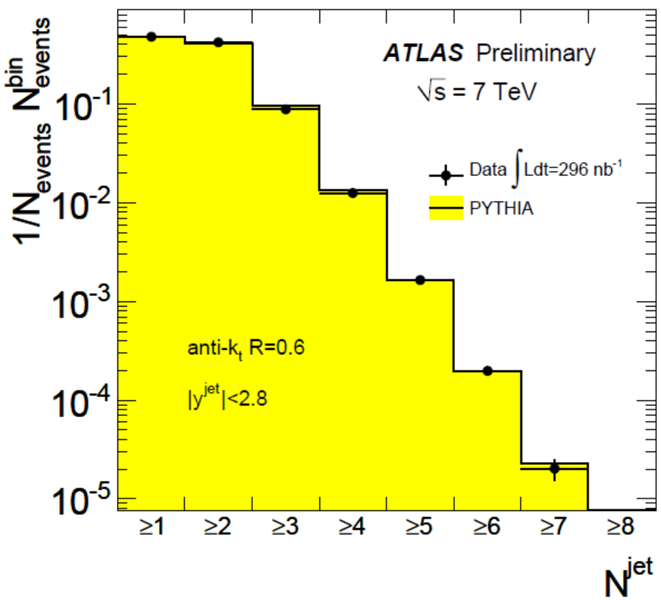
Di-jets are also well described by fixed-order NLO perturbative QCD calculations corrected for non-perturbative effects.

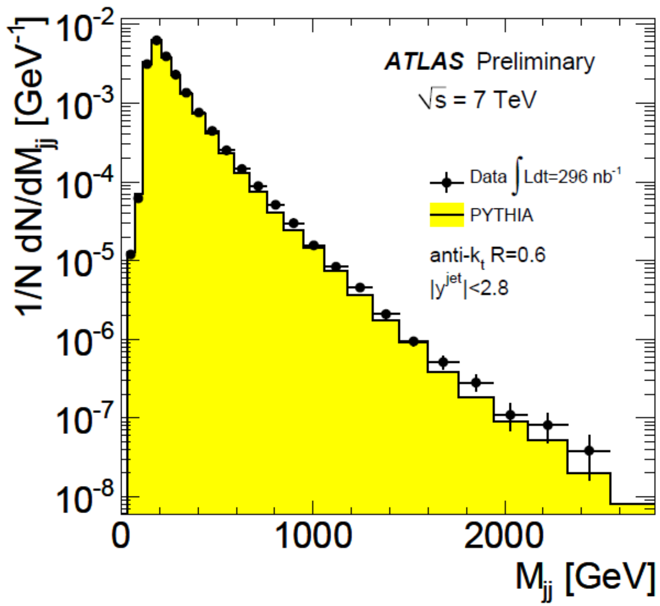
Jets – extending the reach



With increased luminosity, look at:

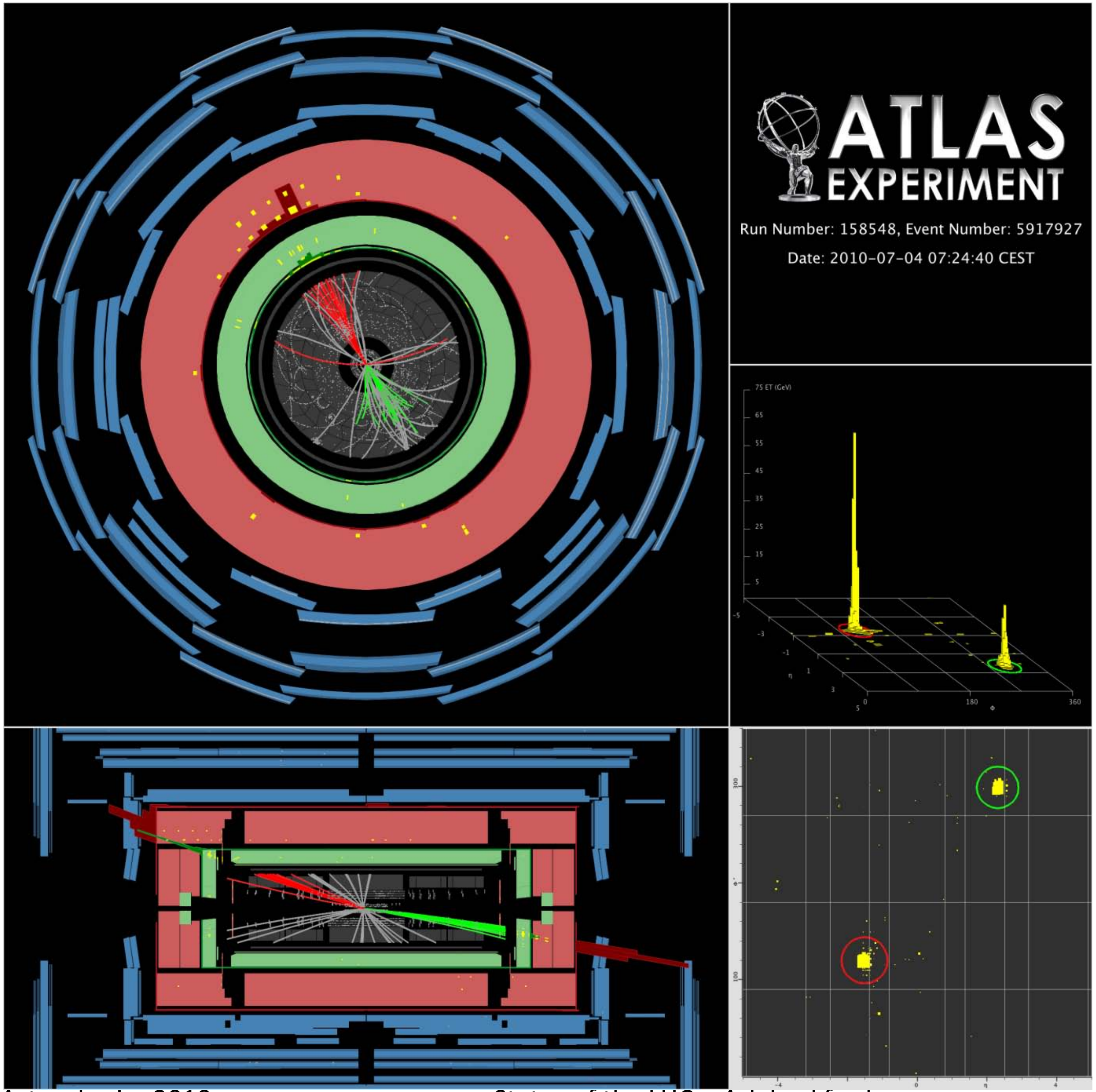
- Inclusive jet pT
- Number of jets
- Di-jet mass





p_T: 410 + 317 GeV
M_{jj} = 2550 GeV
η_1~-1.5; η_2~2.3

A di-jet event with high mass

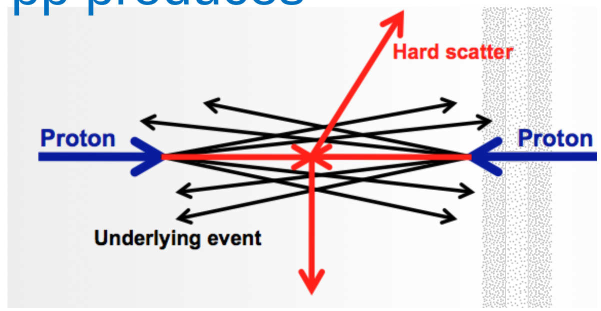


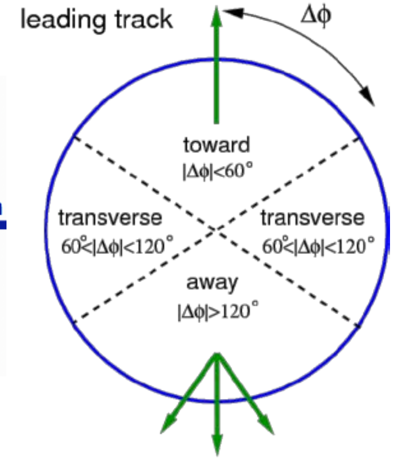
Jet p_T = 421 GeV

dijet $m_{1\,2}$ = 2.5 TeV

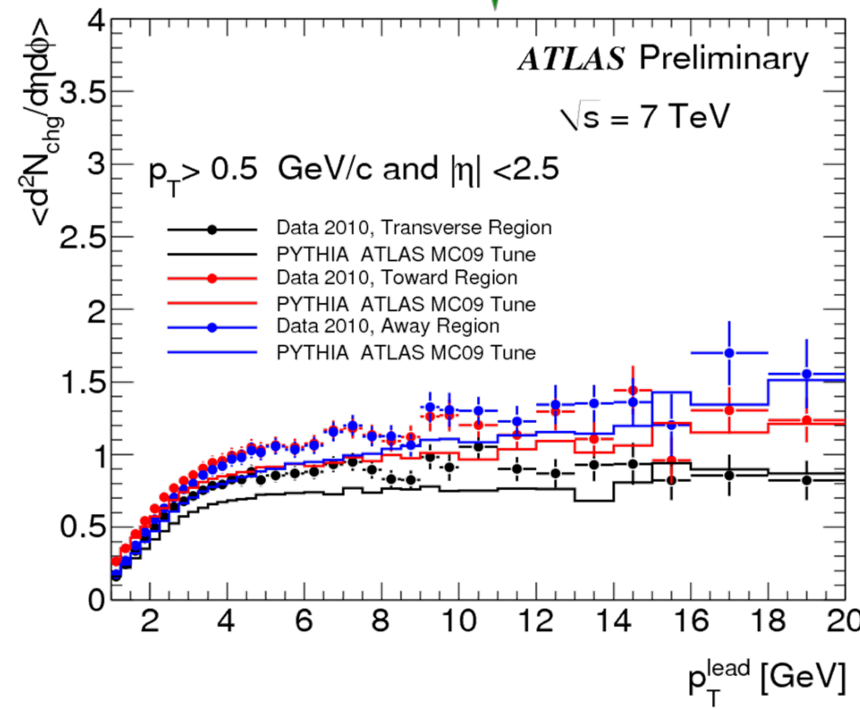
The underlying event

- As well as the hard scatter (jets), pp produces an underlying event (UE)
  - o Beam remnant
  - o Initial/final state radiation
  - o Multiple parton interactions?



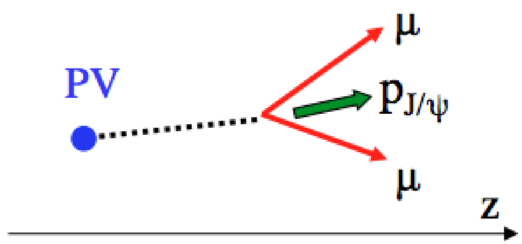


- Activity should be ~independent of hard scatter
  - o Use leading track to define event axis and towards/away/transverse (UE) regions
  - o Study track distributions in transverse regions
    - Corrects for recon+selection bias, and migration
  - o Density of particles (N_{ch}) in transverse region plateaus to become independent of p_T^{lead}
    - But larger than that in minimum bias events
  - o Other variables (e.g. p_T density) are correlated with p_T^{lead} – contrib^n other than beam remnant
- Important to understand 'background' to jets



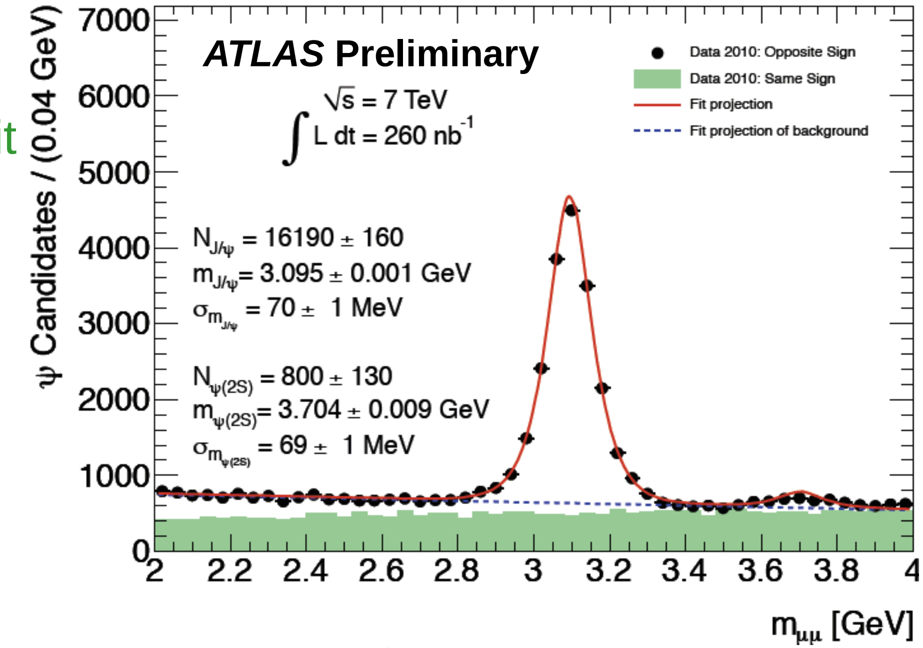
B-physics with J/ψ decays

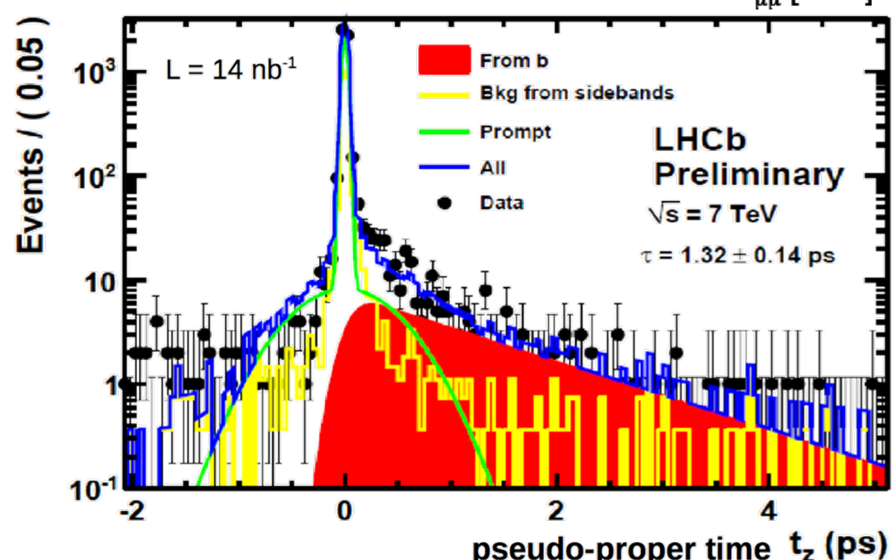
- Large b production x-sec: LHC is a b-factory
  - o Dedicated LHCb expt. optimised to fully exploit b (and c) physics potential of LHC
- Early physics topic - J/ψ(→μμ) production
  - o Mixture of 'prompt J/ψ' and b→J/ψ+X
    - Quarkonium production, spectroscopy and polarization (poorly understood)
    - b-physics with inclusive and exclusive modes
    - Detector calibration, alignment, B-field
- Exercise vertexing to separate components



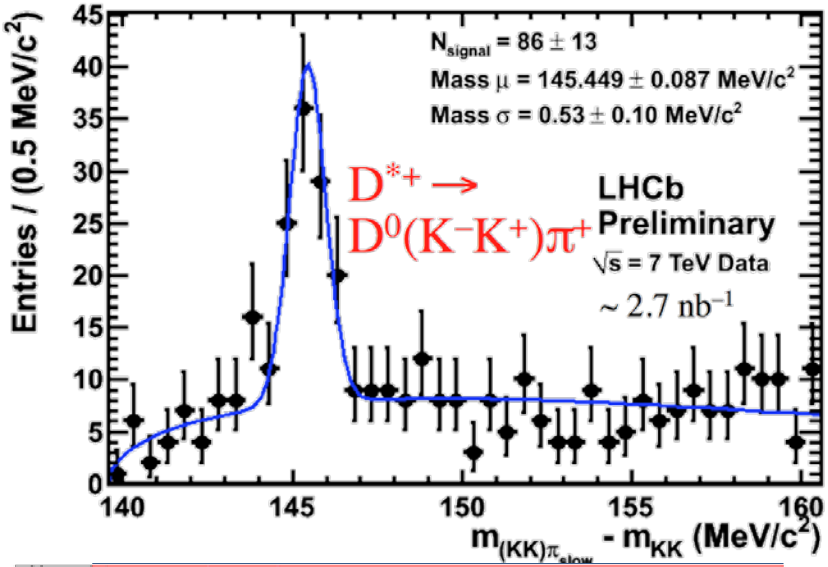
$$t_z = \left(z_{J/\psi} - z_{PV}\right)\frac{m_{J/\psi}}{p_{z,J/\psi}}$$

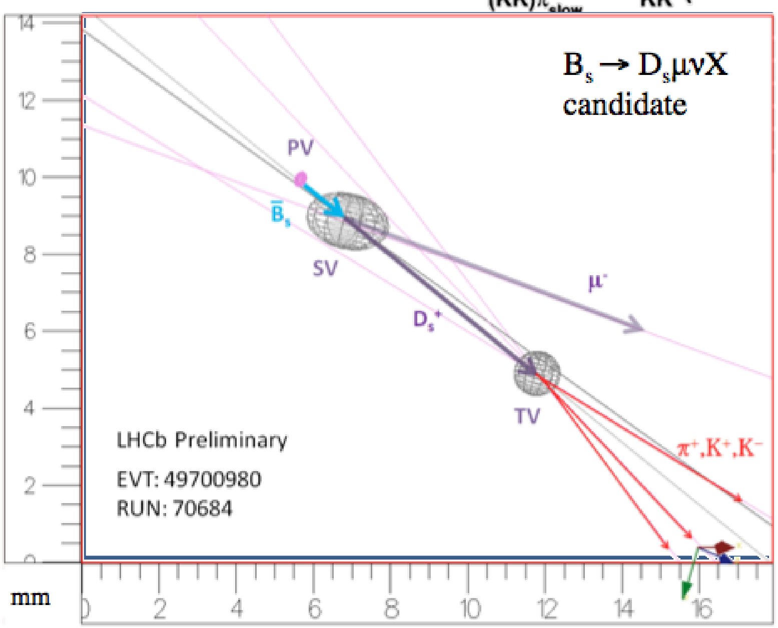
  - o Clear signal of lifetime component
  - o Start to measure b-fraction and tune Monte Carlo description of b production





D and B hadron decays



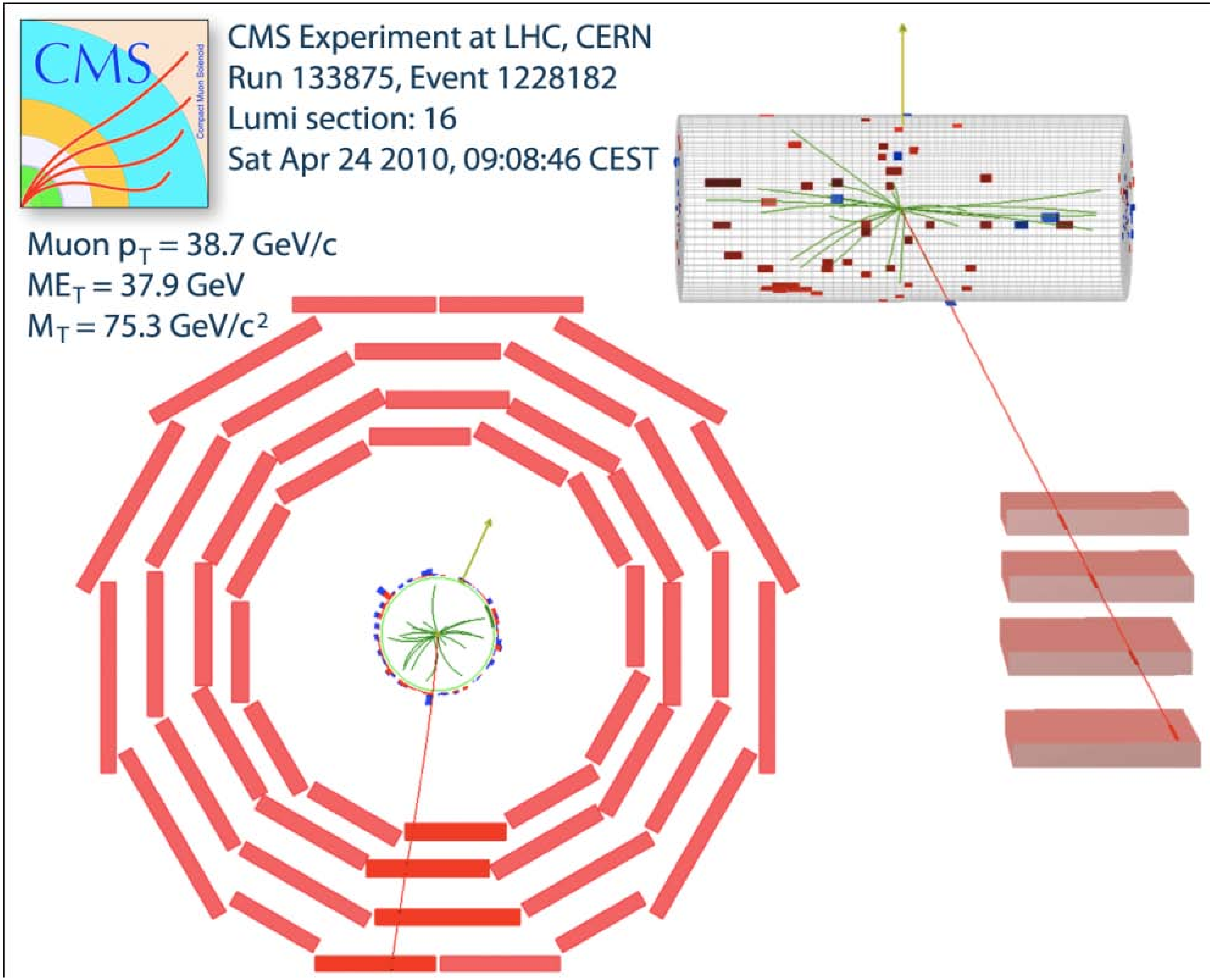


- Start to reconstruct exclusive charm decays
  - o E.g. $D^{*+} \rightarrow D^0\pi^+$; $D^0 \rightarrow K^-\pi^+$ or rarer K^-K^+
    - 'Slow' pion from D* tags flavour of D^0 (Δm)
  - o Provides access to D^0 mixing and CP-violation observables via lifetime differences

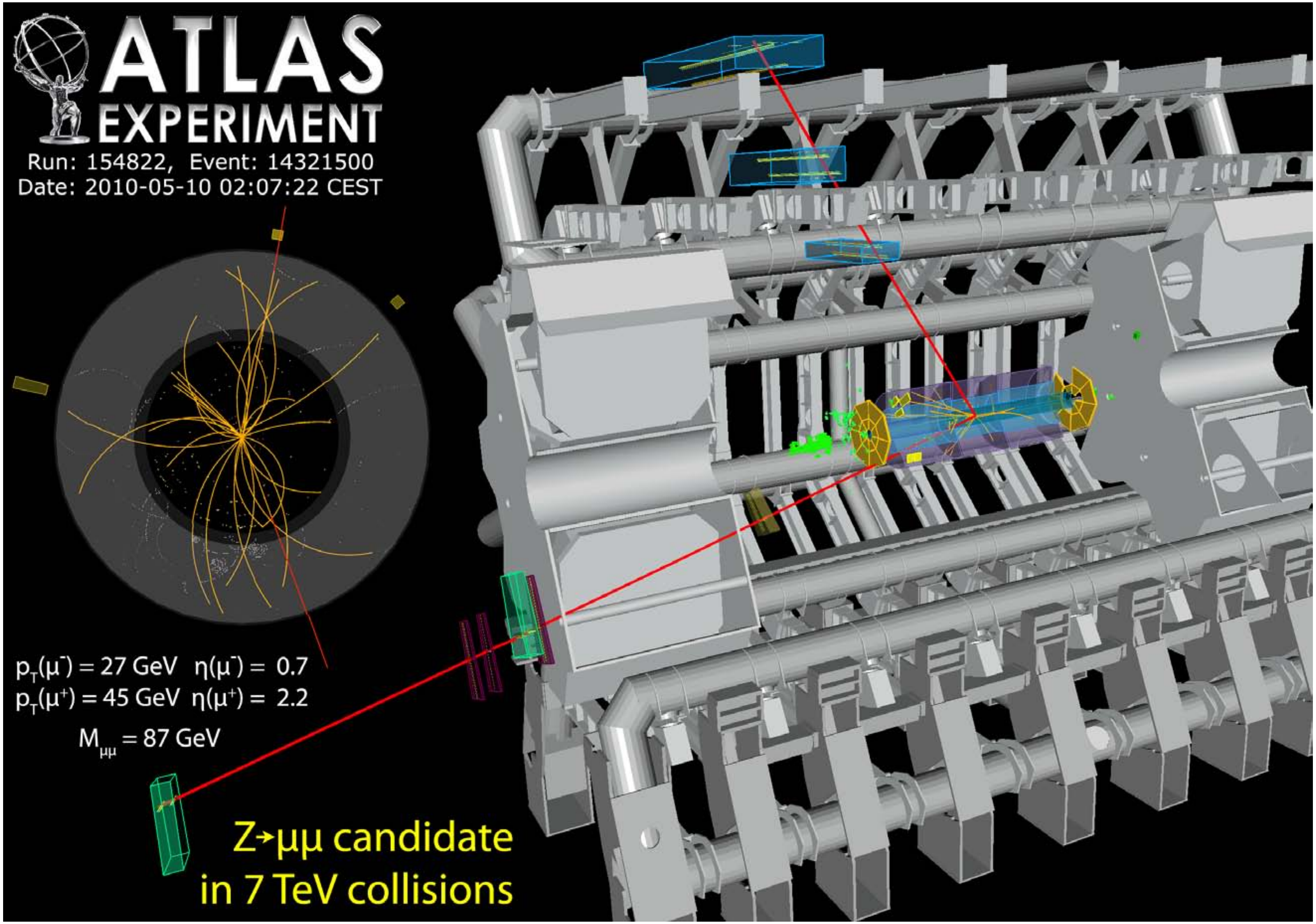
$$y_{CP} = \frac{\tau(D^0 \rightarrow K^-\pi^+)}{\tau(D^0 \rightarrow K^-K^+)} - 1 \qquad A_\Gamma = \frac{\tau(\overline{D}^0 \rightarrow K^-K^+) - \tau(D^0 \rightarrow K^+K^-)}{\tau(\overline{D}^0 \rightarrow K^-K^+) + \tau(D^0 \rightarrow K^+K^-)}$$

  - o Already seeing 100's of the rarer decay
    - With 100 pb^{-1}, expect 10x BaBar event sample
- Semileptonic b-decays $B \rightarrow D^0\mu\nu X$ and $D_s\ \mu\nu X$
  - o Already with 100 nb^{-1}, expect ~3k $B \rightarrow D^0\mu\nu X$,
    - Determine production x-sec, compare with $B \rightarrow J/\psi$
  - o Studies with B^0 and B_s semileptonic decays will provide access to B oscillations (Δm_d and Δm_s) and calibration of flavour tagging
  - o Build up to CP-violation studies
    - similar precision to D0 A_{sl}^b in ~100 pb^{-1}

Observation of W - W → μν

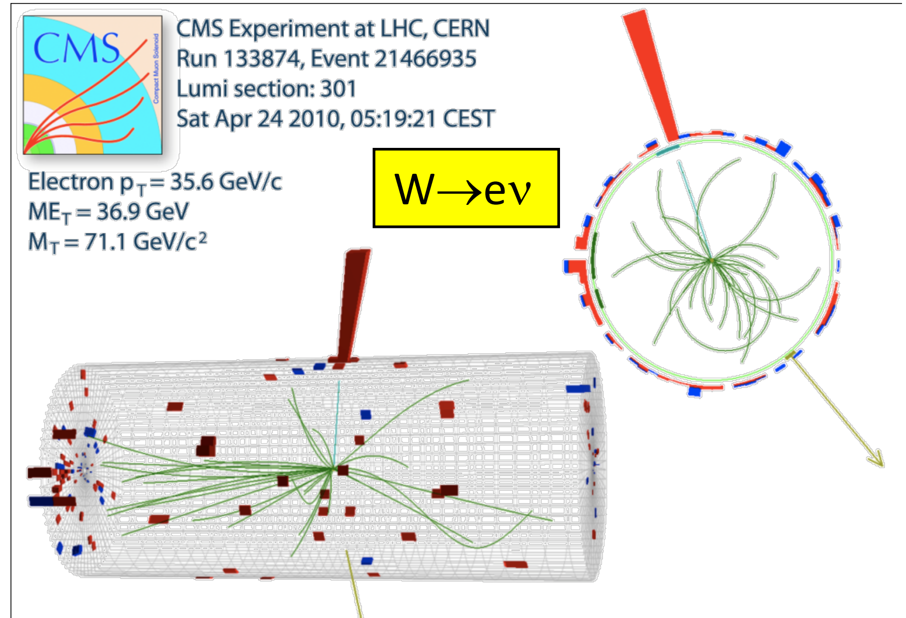


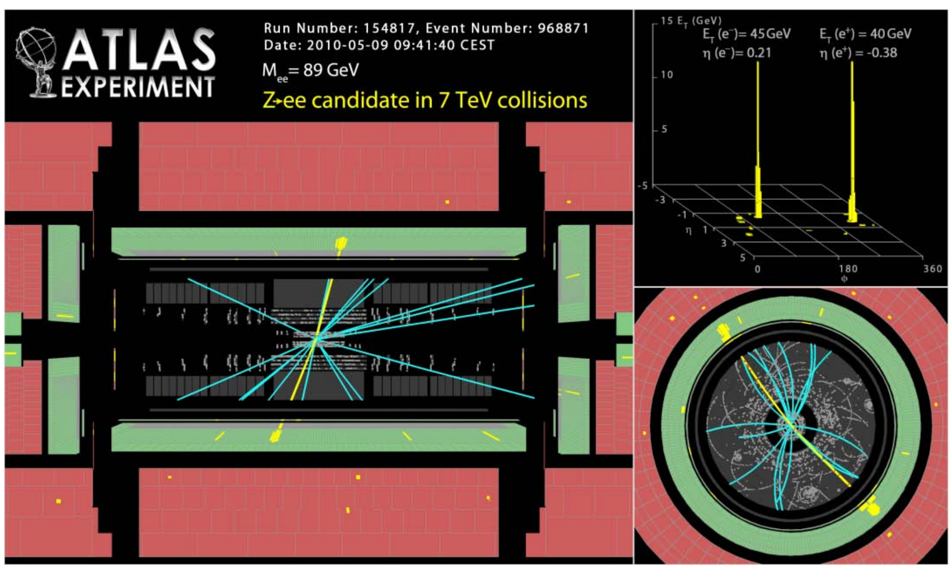
Observation of Z - $Z \rightarrow \mu\,\mu$

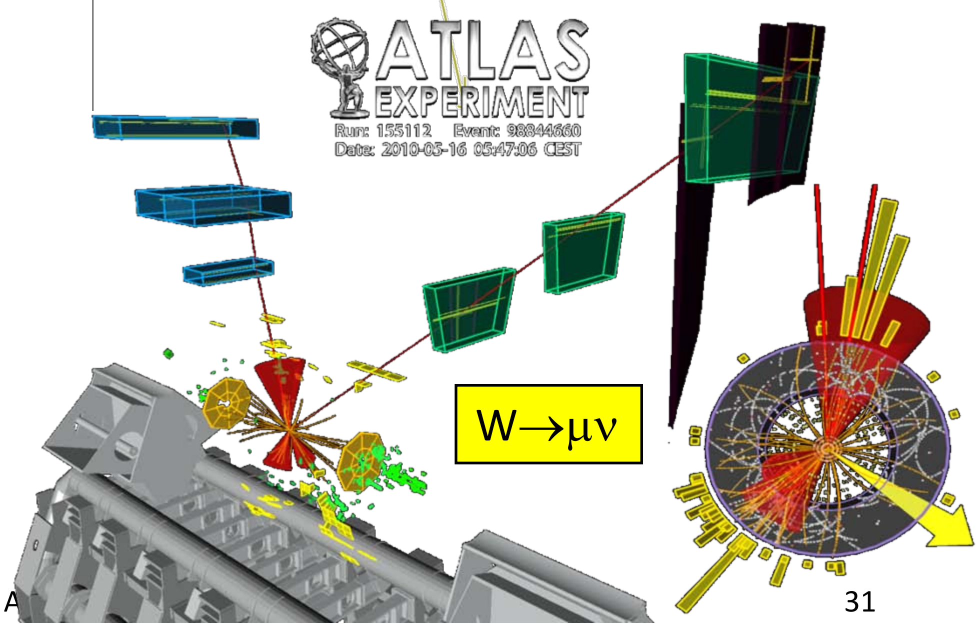


W and Z events

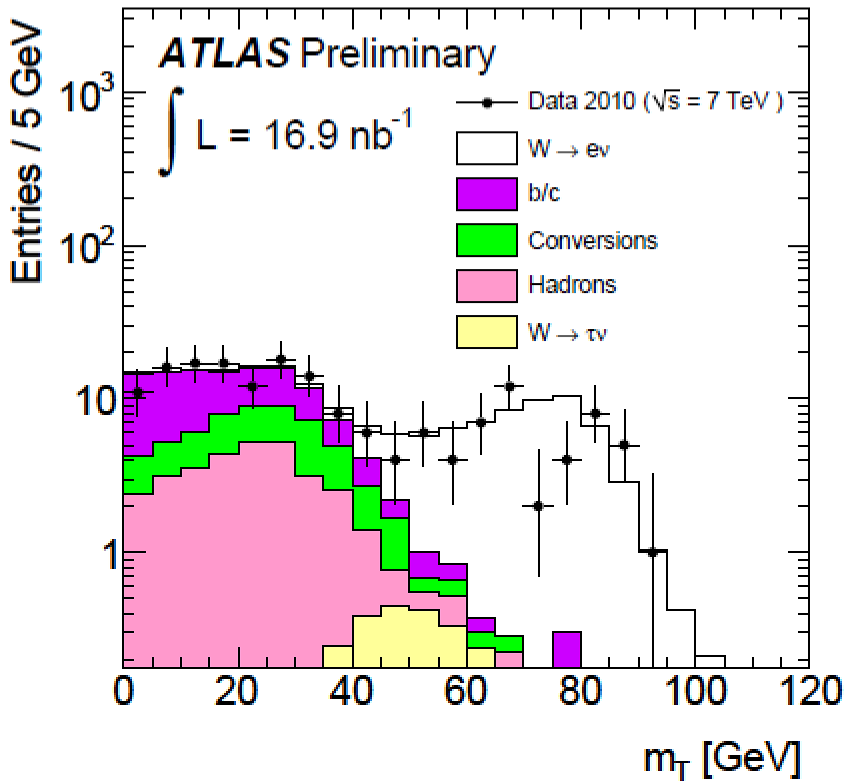
- Characterised by 1 high energy e or μ plus missing transverse energy ($W \to e\nu$, $\mu\nu$)
- Or pairs of opposite charge leptons ($Z \to ee$, $\mu\mu$)
- May be produced alone, or in conjunction with additional high-p_T jets
- Important background to more 'exotic' processes

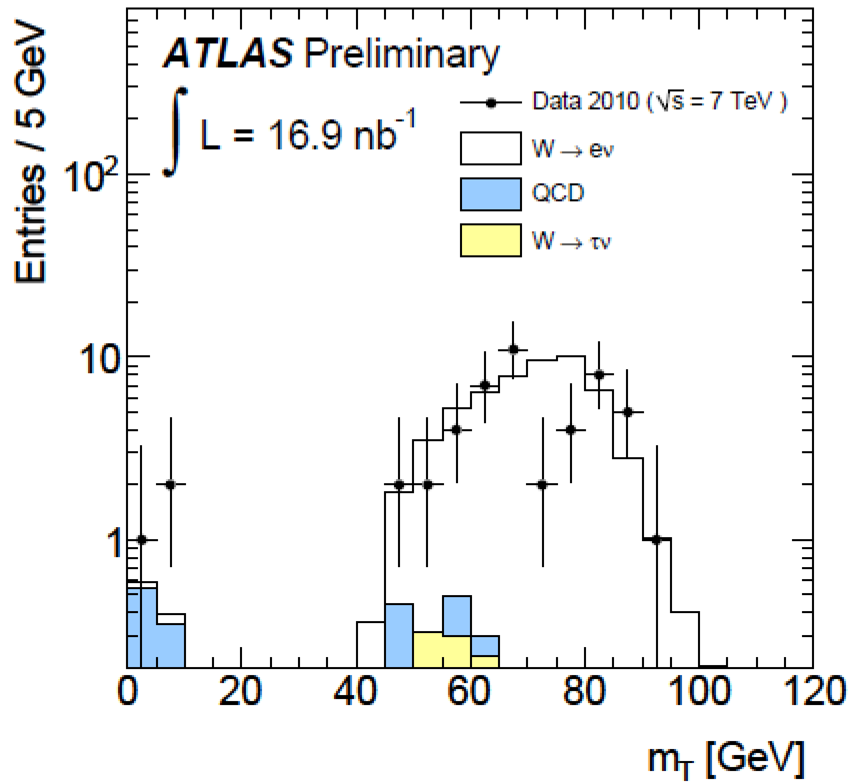






W → eν inclusive cross-section

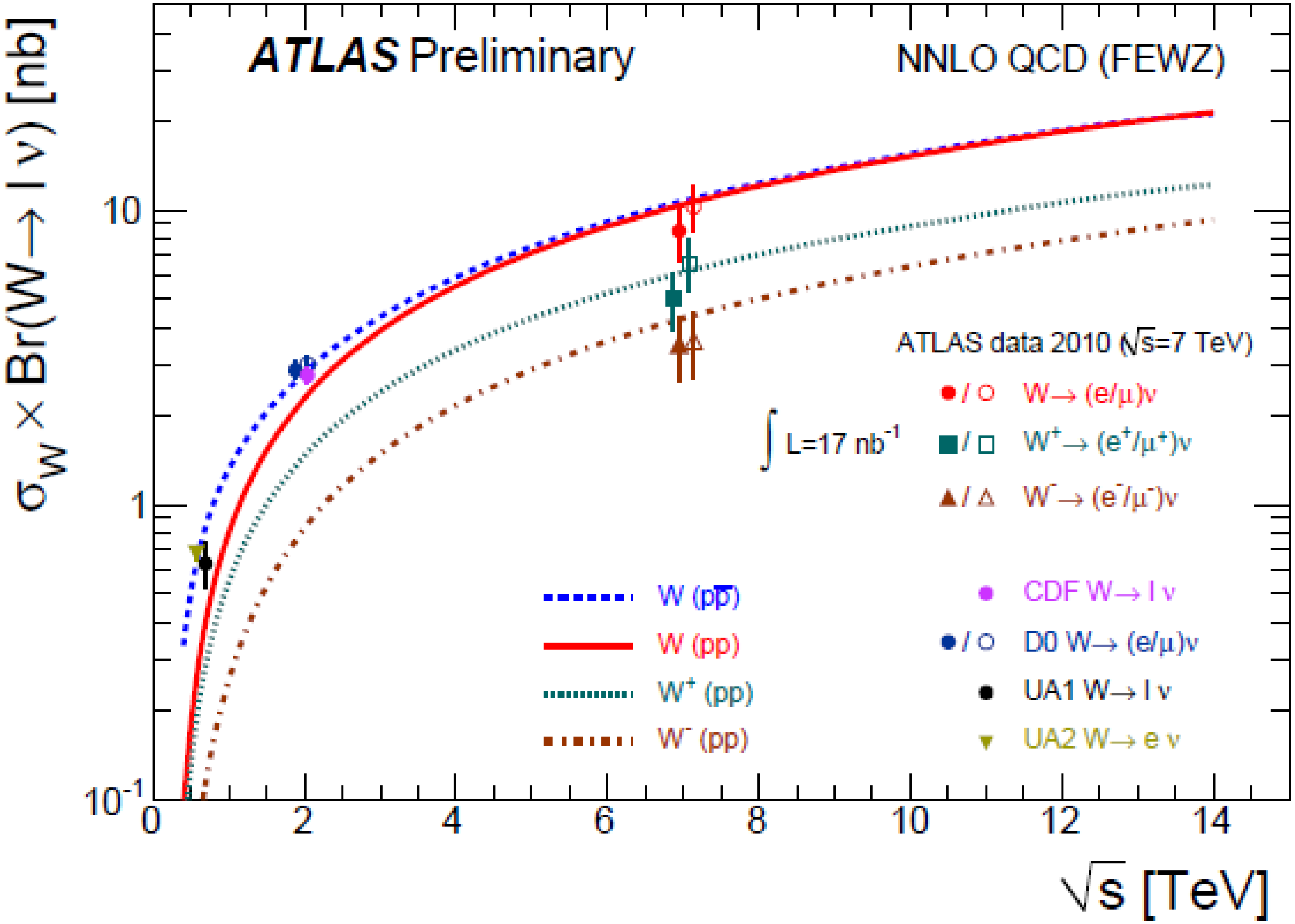




Without MET cut **With E_T^{miss} > 25 GeV**

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

$W \rightarrow \ell\nu$ inclusive cross-section & asymmetry



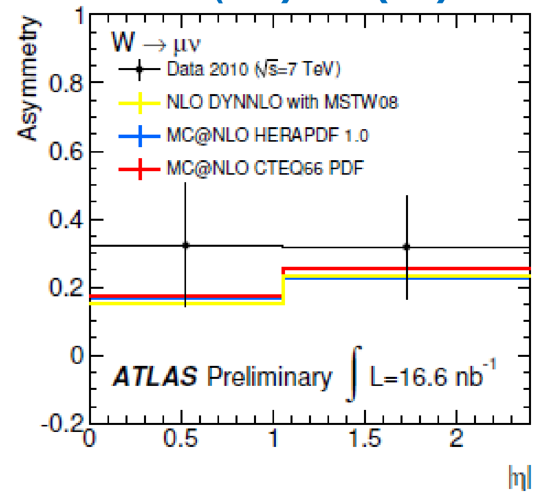
W→eν

(8.5 ± 1.3(stat) ± 0.7(syst) ± 0.9(lumi)) nb

W→μν

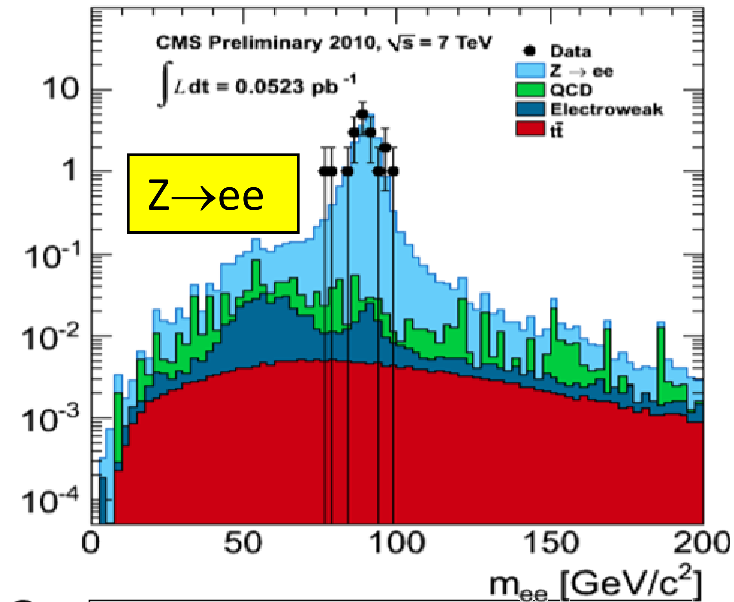
(10.3 ± 1.3(stat) ± 0.8(syst) ± 1.1(lumi)) nb

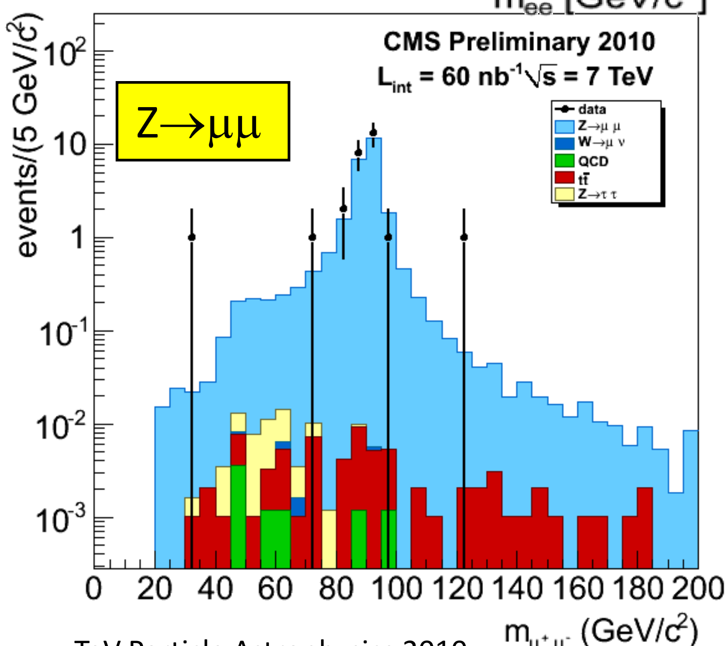
Charge asymmetry confirmed
$\sigma(W^+) > \sigma(W^-)$



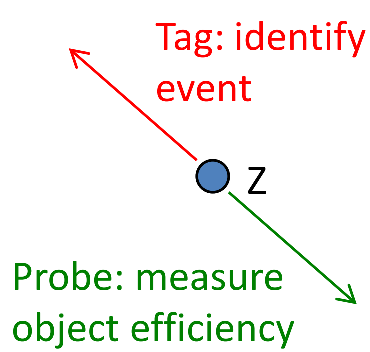
The measured values of $\sigma_W \cdot$ BR ($W \rightarrow \ell\nu$) for W^+, W^- and for their sum compared to the theoretical predictions based on NNLO QCD calculations. Results are shown separately for the electron and muon channels. The predictions are shown for both proton-proton (W^+, W^- and their sum) and proton-antiproton colliders (W) as a function of $\sqrt{s}$. The calculations are based on the FEWZ program with the MSTW2008 NNLO structure function parameterisations. In addition, measurements at previous proton-antiproton colliders are shown. The data points at the various energies are staggered to improved readability. The data points are plotted with their total uncertainty.

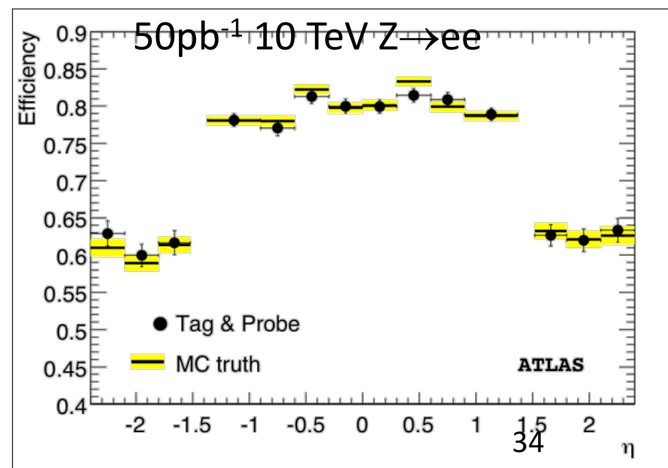
Z boson observation





- Z production rate factor 10 smaller
  - o Needs more data – first few candidates in O(10) nb^{-1} sample
  - o Two leptons – fake lepton b/g negligible
  - o Drell-Yan contribution ($qq \rightarrow Z/\gamma \rightarrow ll$)
- Z mass precisely known
  - o 'Standard candle' for detector calibration
    - Calo/muon energy scale/uniformity
- $Z \rightarrow ll$ is basis for 'tag and probe'
  - o Determination of trigger and offline identification efficiencies of leptons



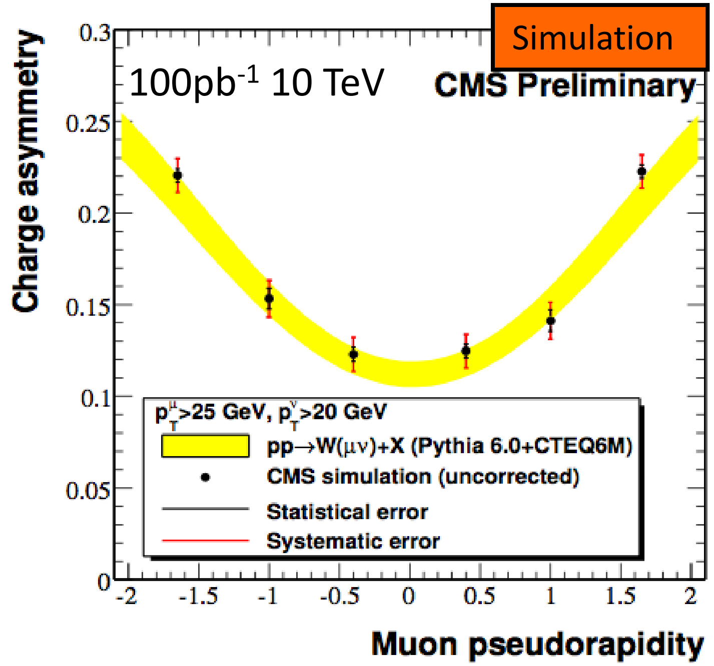


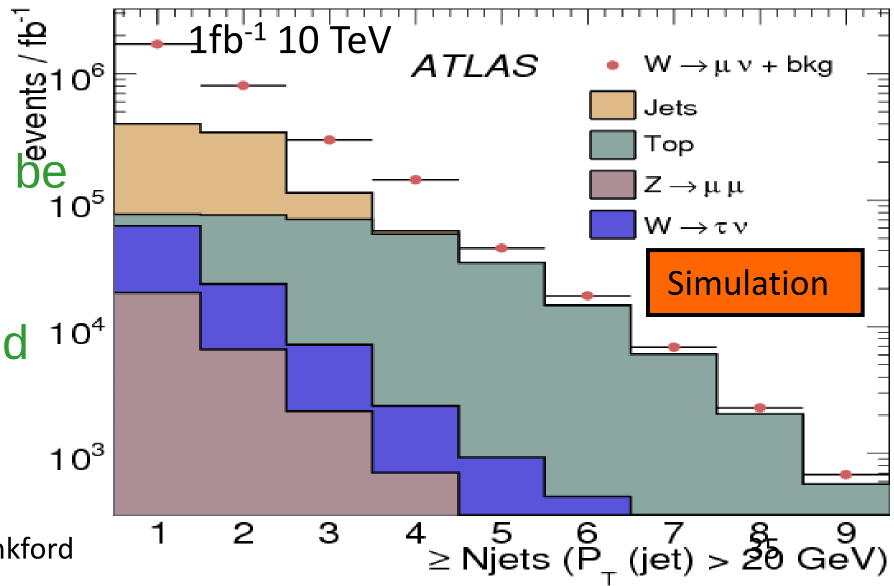
Measurements with W and Z bosons

- Expect O(3000) W and O(300) Z per pb^{-1}
  - o Many planned measurements…
- W^+/W^- charge asymmetry:

$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) - \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu)}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\nu) + \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu)}$$

  - o Ratio measurement, so many systematics cancel
  - o With ~100 pb^{-1}, can start to constrain parton density functions in proton
    - important systematic in many other measurements
- Measurements of W/Z+1, 2, 3… jets
  - o Production of each extra jet 'costs' factor α_s
    - With 1 fb^{-1}, expect 1000s events up to Z+4 jets
  - o Results for jet multiplicities and momentum can be compared to LO/NLO Monte Carlo models
    - Dominant systematics from detector jet response
  - o W/Z+multiple jets are also important background for top physics and many searches



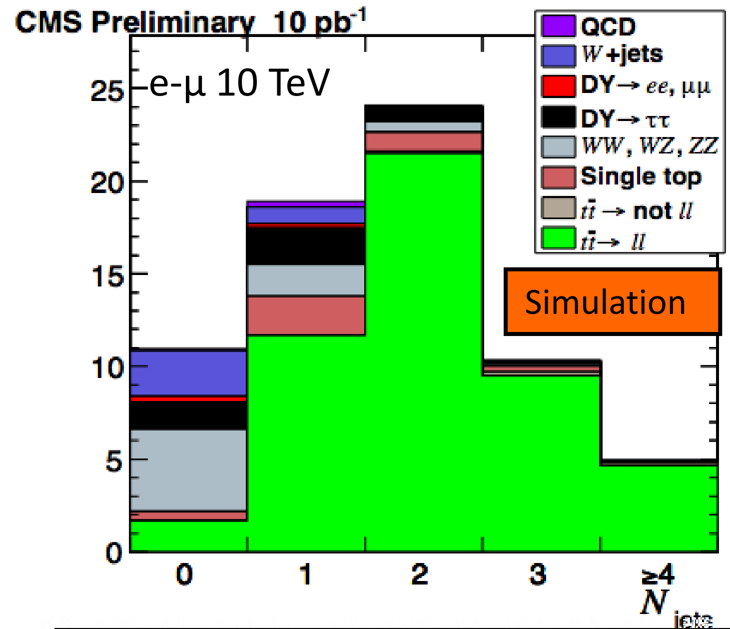


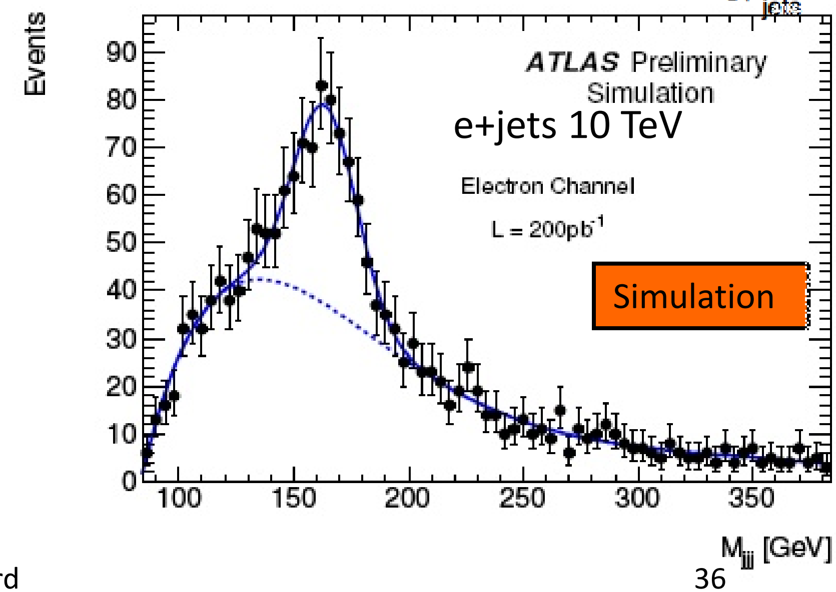
Top rediscovery

- Next milestone - ‘rediscovery’ of top quark
  - o $t \rightarrow Wb$, final state determined by W decay
  - o Dilepton: $tt \rightarrow WbWb \rightarrow l\nu b l\nu b$ with l=e or μ (5%)
  - o Lepton+4-jets: $tt \rightarrow WbWb \rightarrow l\nu bjjb$ with l=e or μ (30%)
- Events with high-p_T lepton(s), E_T^{miss} and (b)jets
  - o e+μ dilepton very clean, but low rate and no recon m_{top}
  - o e/μ+jets higher rate, recon $m_{jjj}=m_{top}$, W+jets b/g
    - b-tagging can be used in selection, or as confirmation
- Handful of events expected per pb^{-1} at 7 TeV

$1pb^{-1}$ / 7TeV	e+e	μ+μ	e+μ	e+jets	μ+jets
Signal	0.43	0.64	1.4	6	6
Background	0.11	0.19	0.24	4	4

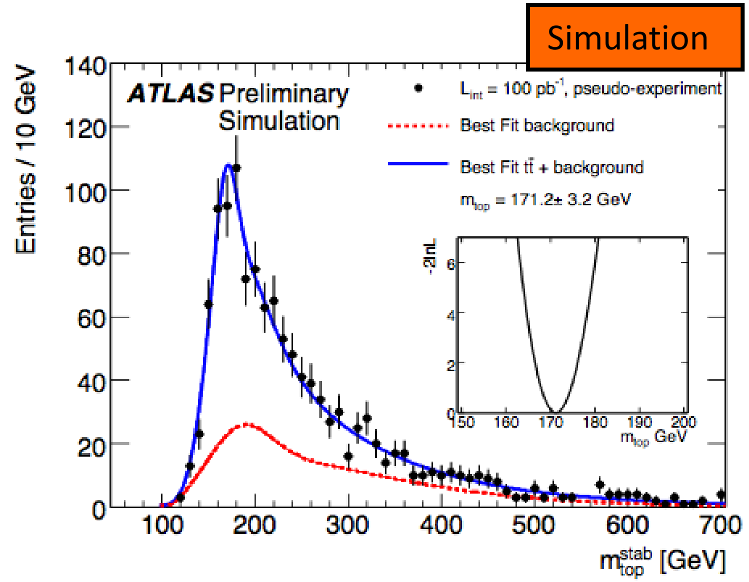
  - o First “candidates” being seen now
- Clear signal for 10 pb^{-1}
- Measure cross-sec to 10-20% with 100 pb^{-1}

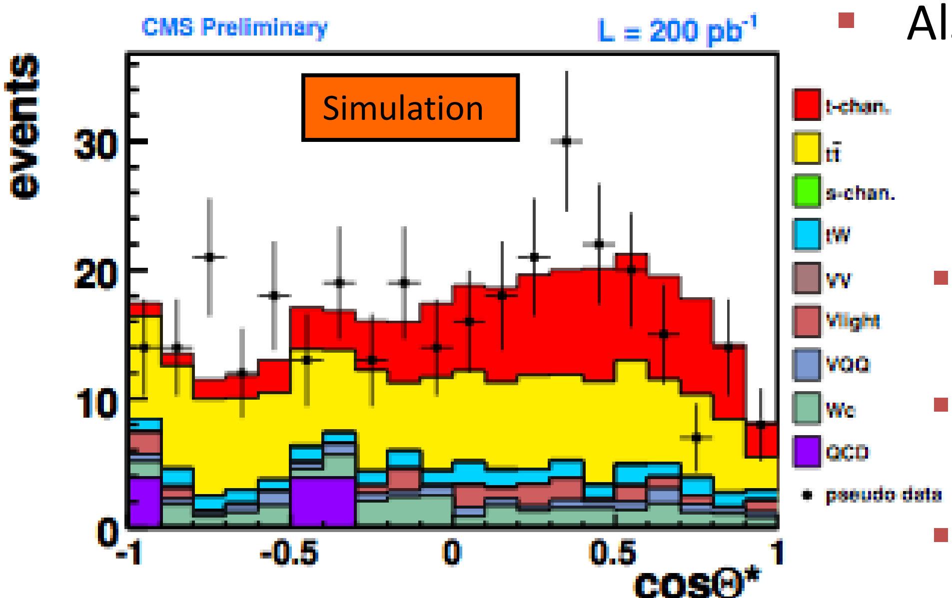




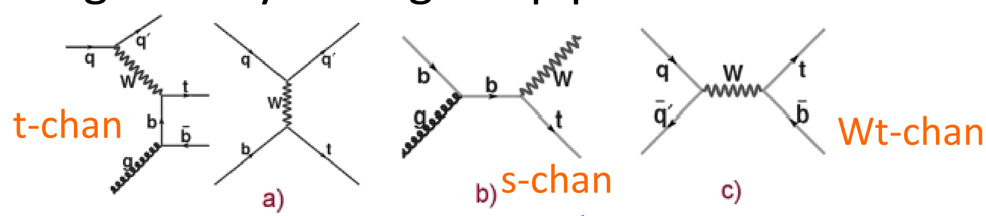
Top physics continued

- With 1000's of top pairs, start precision program
  - o e.g. top mass (Δm_{top}=1.3 GeV from Tevatron)
  - o Extract from l+jets events, using m_{jjj} or kinematic fit
    - Control jet energy scale to O(1%) with m_{jj}=known m_W
  - o Statistical error below 1 GeV for 1 fb^{-1} at 7 TeV
  - o Will take time to control systematics to same level





- Also begin study of single top production

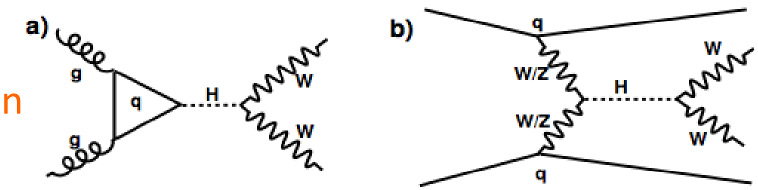


- After selection of lepton, E_T^{miss} and 2-jets, background from top-pair and W+(b)jets
- Use multivariate techniques to separate
  - CMS also uses top polarisation cosθ*
- Will take 200-1000 pb^{-1} to establish t-channel

Standard Model Higgs search

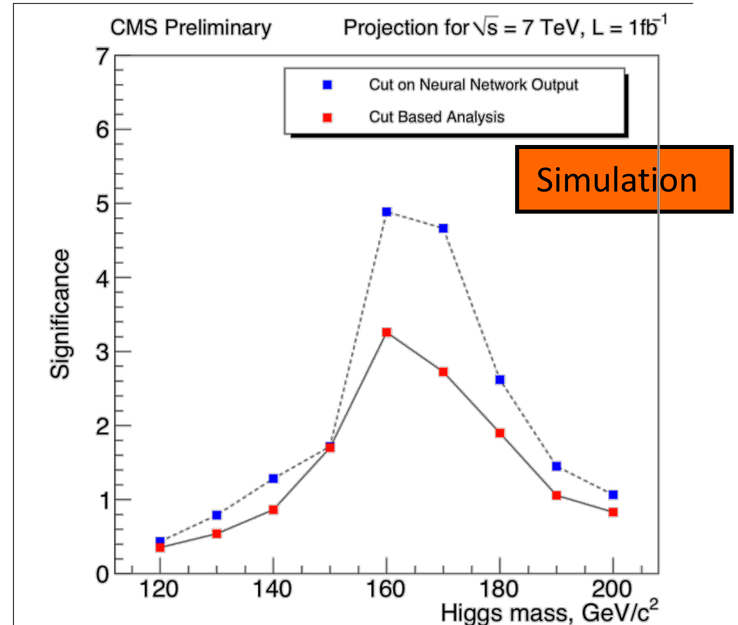
- Prospects for early discovery depend on m_H
  - o First chance for m_H=150-180 GeV, with $H \rightarrow WW$

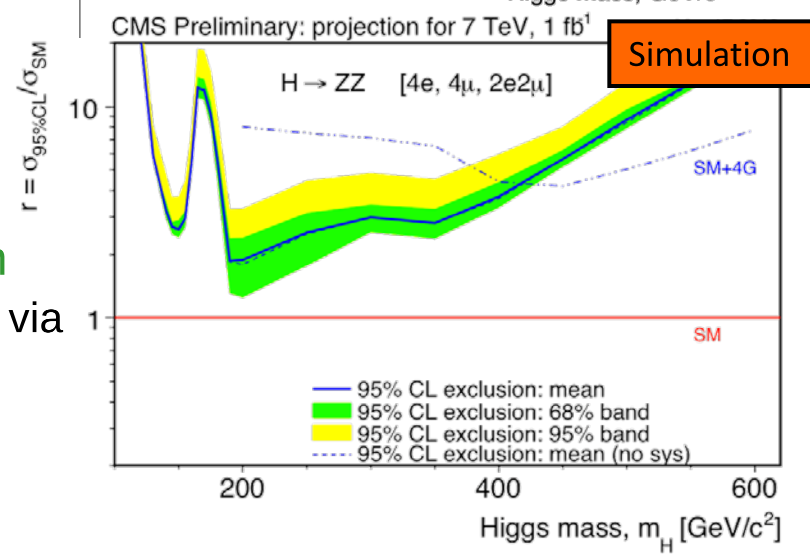
a) gluon fusion



b) VBF

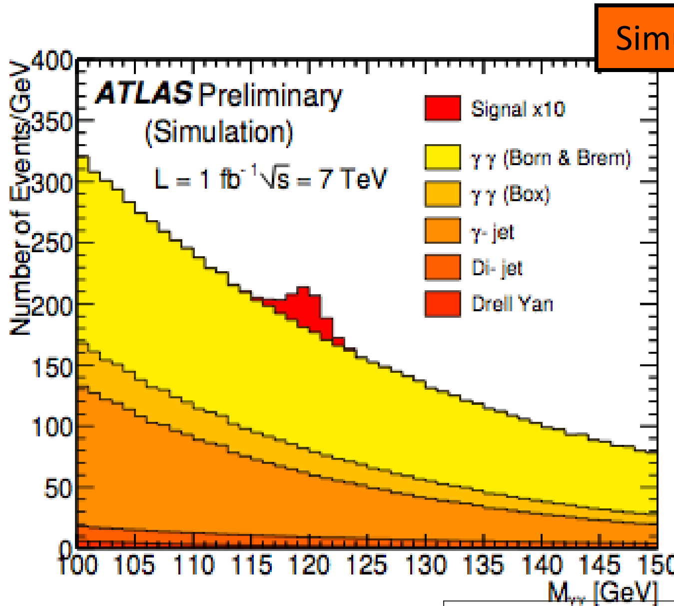
  - o Require two high pT leptons + missing energy
  - o Veto on central jets to suppress top background
    - Require forward jets in VBF fusion mode
  - o Remaining background from WW and W+jets
  - o $1fb^{-1}$ can give 3-5σ signal for m_H=150-180 GeV
- For larger m_H, $H \rightarrow ZZ \rightarrow 4l$ is most promising
  - o Rather clean signal above continuum $ZZ^{(*)} \rightarrow 4l$
    - But limited by statistics and Z mass resolution
  - o For 1 fb^{-1}, exclusion limited to few x SM expectation
    - Exotic scenario with 4th quark generation, H production via gg fusion enhanced by factor 9, could be visible

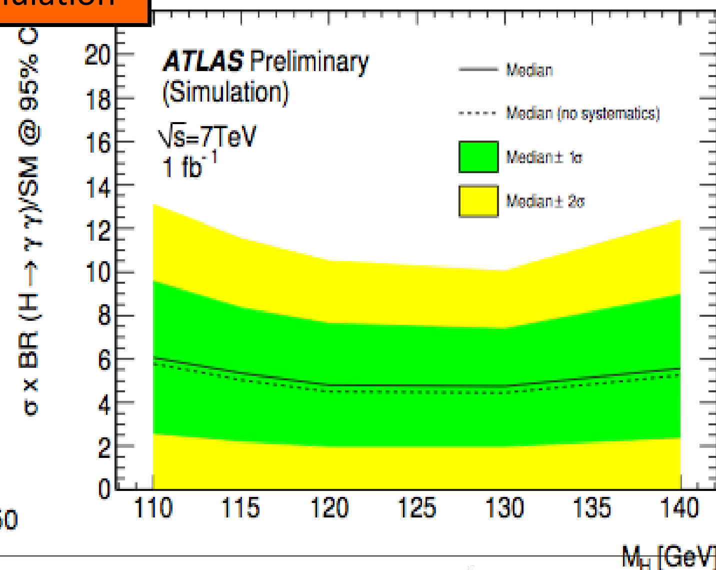




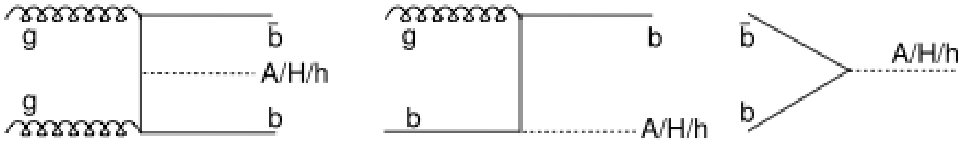
Higgs searches continued

- $H \to \gamma\gamma$ for low mass
  - o Observe peak above continuum background from $\gamma\gamma$ and γ-jet
  - o Exclude ~5xSM for 1fb^{-1}
- Combine channels and ATLAS+CMS, but cannot cover full m_H range in 1fb^{-1}

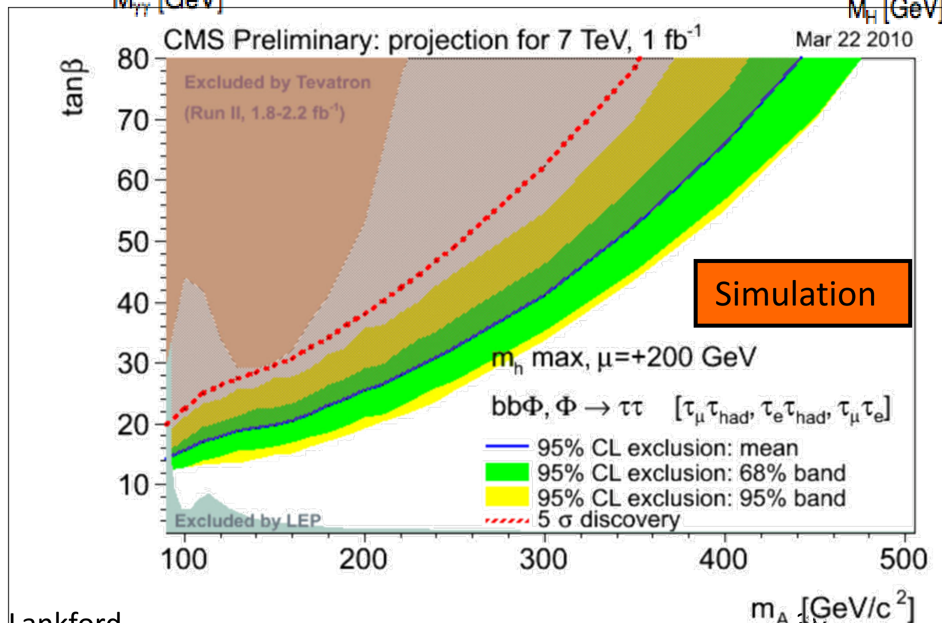




- MSSM limits for A,H,h(Φ)$\to\tau\tau$

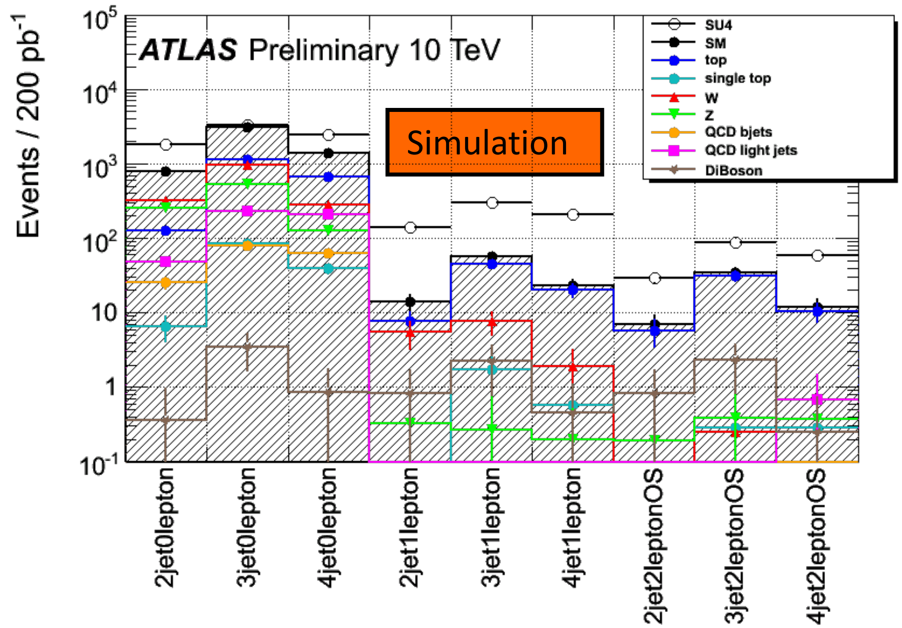


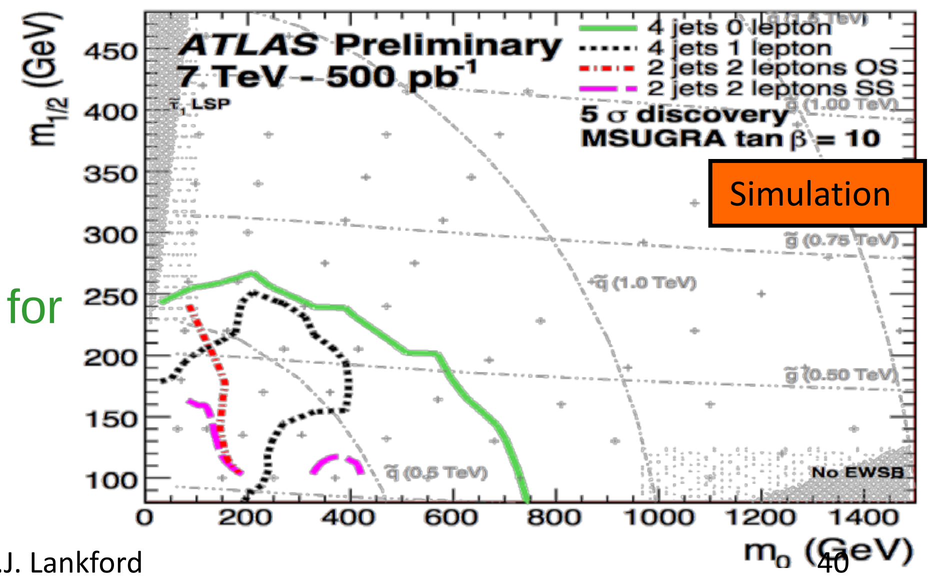
  - Production with b-quarks dominate for tanβ>10
  - Require b-jets, look for $\tau \to e, \mu, \pi$ or 3π
- Can discover down to tanβ=20 for low m_A
  - Exclusion limits down to tanβ=15



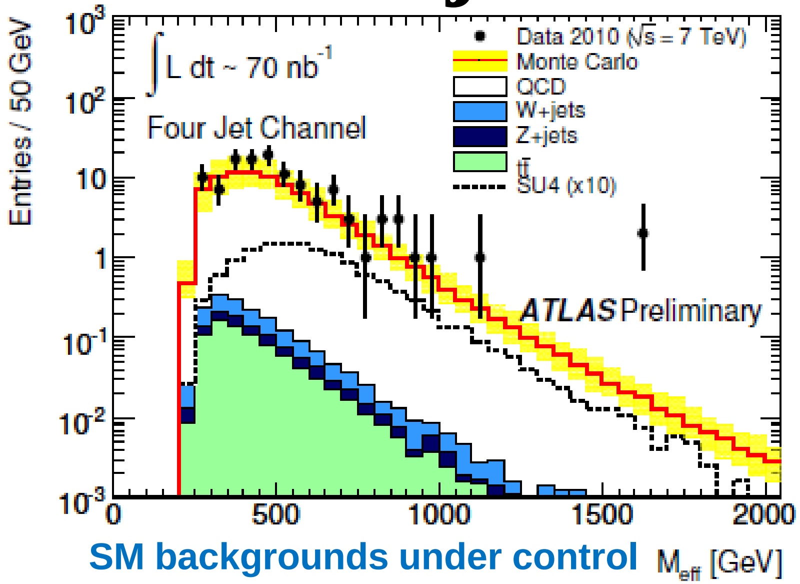
Searches for SUSY

- R-parity conserving SUSY
  - o Complex high-multiplicity cascade decays from squark/gluino pair production
- Variety of final states – topological search
  - o Characterised by missing E_T due to escaping LSP, and large $M_{eff}=\Sigma E_T^{jets}+\Sigma E_T^{lep}+E_t^{miss}$
  - o States with 0,1,2 leptons, multiple jets
- Key to early SUSY searches:
  - o Control of fake missing E_T (detector issues)
  - o Measuring SM backgrounds from data
    - In particular contributions from top and W+jets
- Early reach typically studied with mSUGRA
  - o 4 parameters (m_0,$m_{1/2}$,A_0,tanβ) + sign(μ)
- e.g. search in 0 or 1 lepton, jets +E_T^{miss}
  - o Sensitivity beyond 500 GeV squarks/gluionos for around 0.5 fb^{-1} at 7 TeV

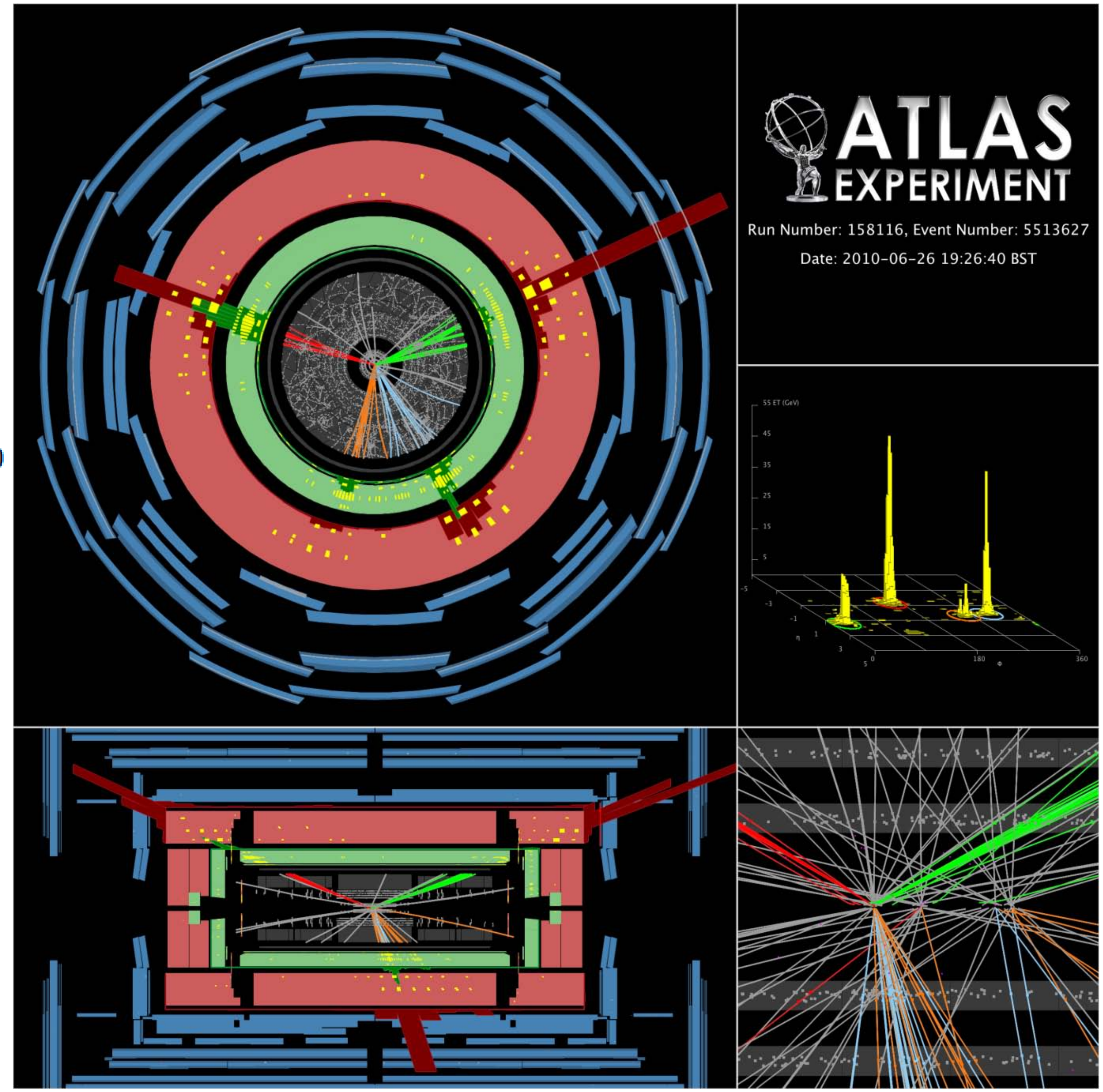




4-jet + Etmiss + 0-lepton search



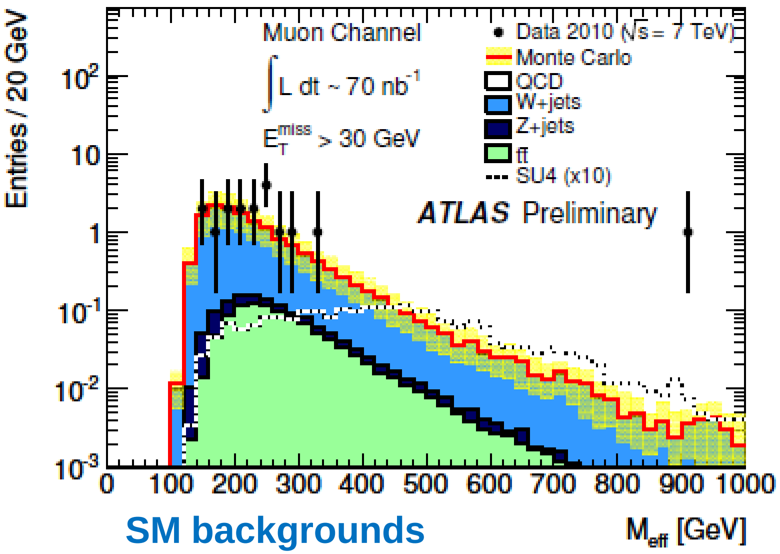
SM backgrounds under control



An outlier

Event display of the collision (run number 158116, event number 5513627) which has *Meff* of about 1.5 TeV when only the the leading three jets are included in the scalar sum increasing to about 1.65 TeV if all four high-energy jets are included. The size of the missing transverse momentum is about 100 GeV. The missing transverse momentum vector lies within the radius of a jet with a secondary vertex tag. All of the high energy jets are associated with the same primary vertex.

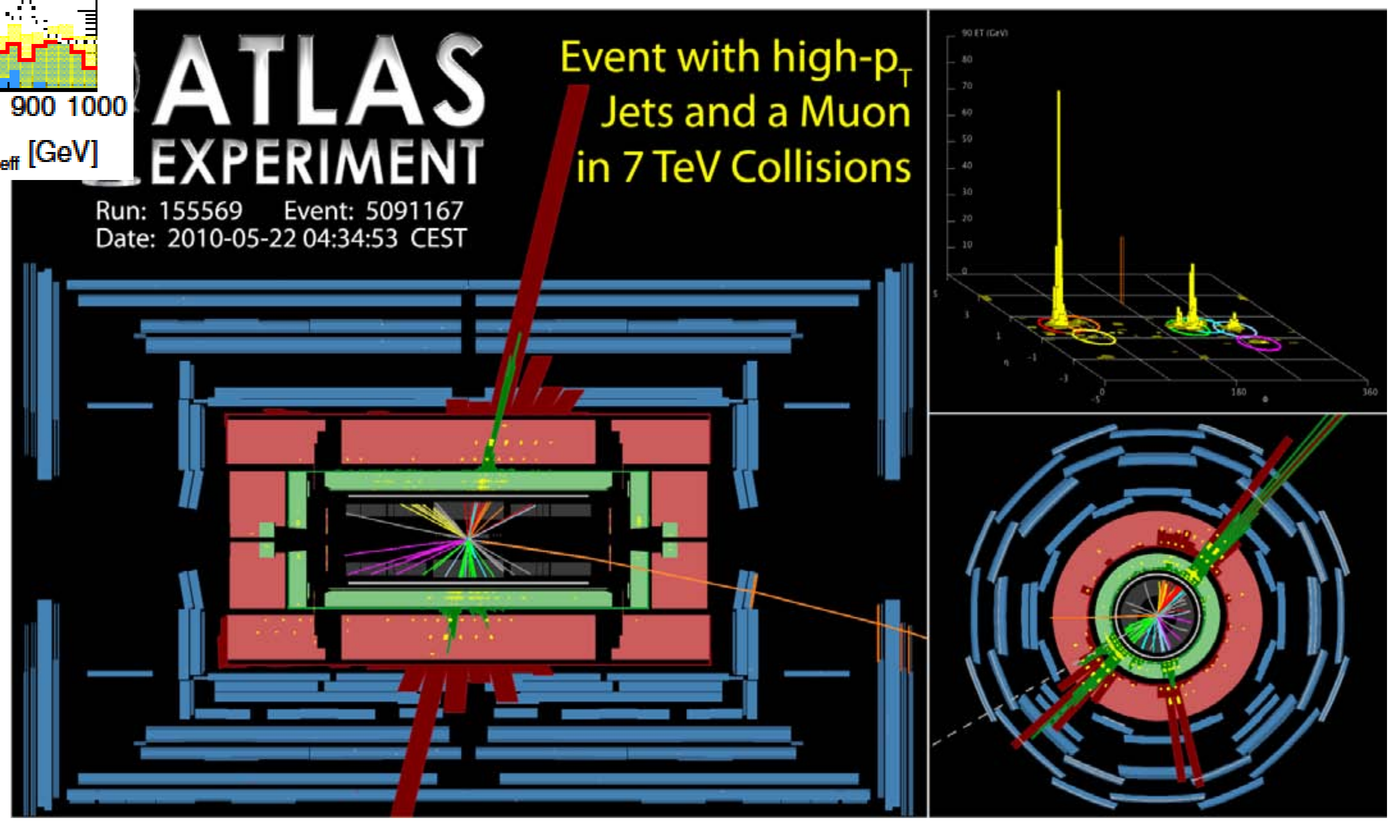
1-lepton + ≥2-jets + Etmiss search



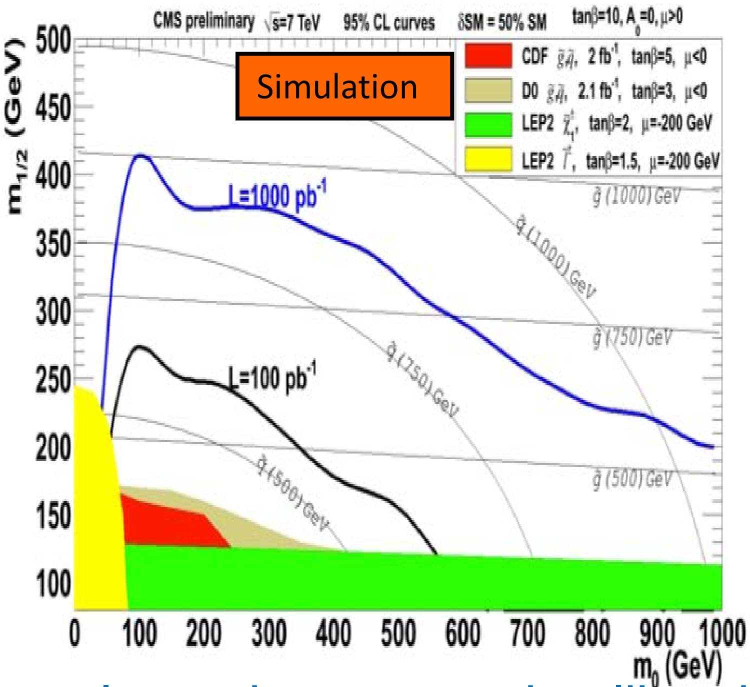
Event display of the collision (run number 155569, event number 5091167) with M_{Eff} of 915 GeV when only the the leading two jets are included in the scalar sum increasing to 1156 GeV if all jets are included. There are a total of 145 tracks associated with the primary vertex; no second vertex is reconstructed. The missing transverse momentum is 118 GeV. There is one well isolated positively charged muon with p_T of 25 GeV, and h = 2.33. That muon is cleanly selected with 11 hits on the monitored drift tubes, 6 on the cathode strip chambers, 5 pixel hits and 8 silicon strip hits.

SM backgrounds under control

An outlier

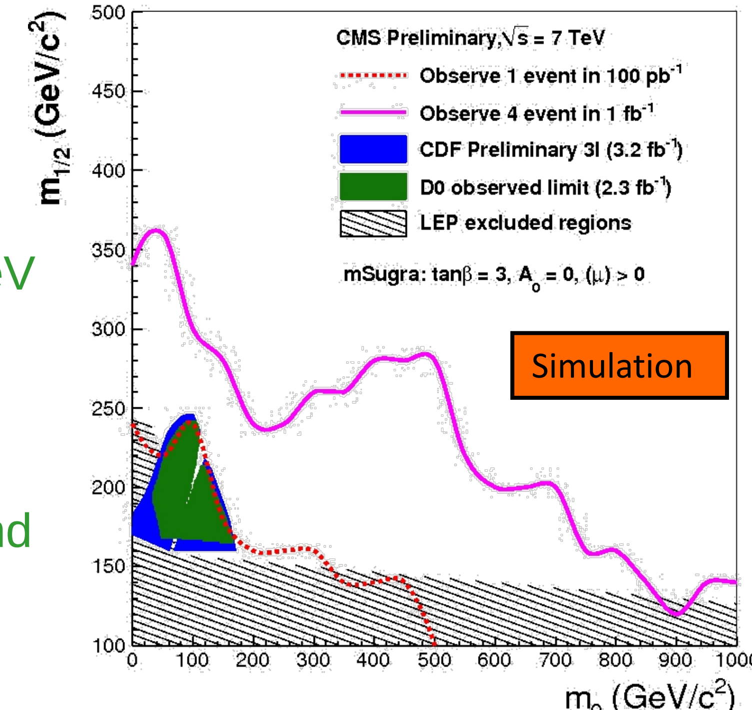


Searches for SUSY - continued



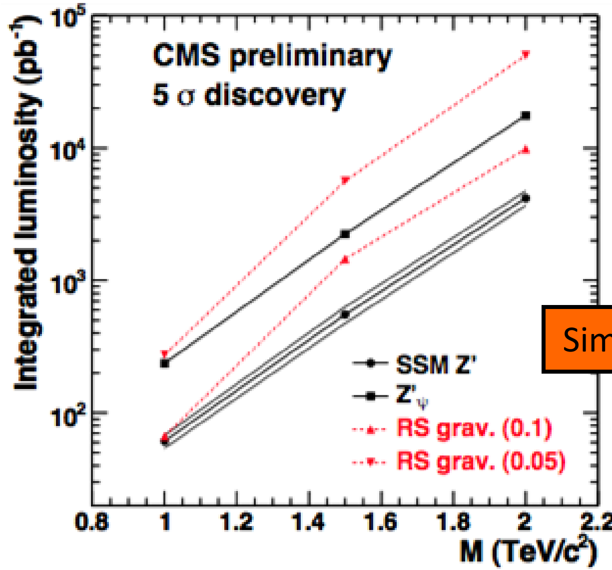
- Fully hadronic mode (with lepton veto)
  - o Require ≥3 jets, $H_T = \Sigma E_T^{jet} > 400$ GeV, $E_T^{miss} > 225$ GeV
  - o Generic requirements – high efficiency
    - But complicated mixture of SM backgrounds – determine from data
  - o Sensitive to 500 GeV squark with 100 pb^{-1}

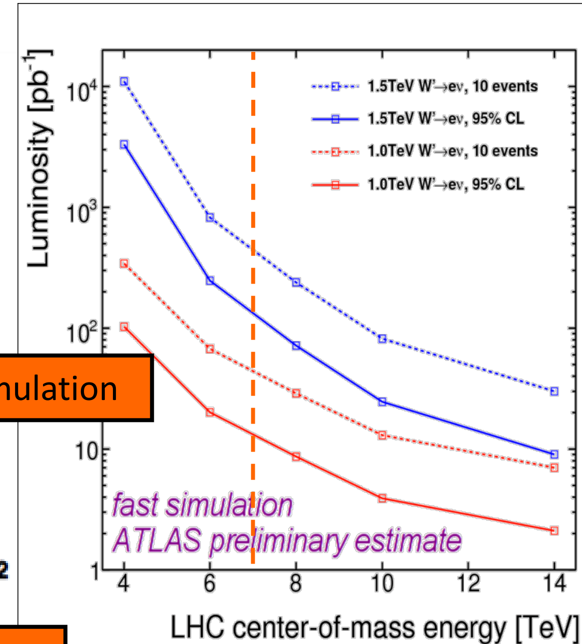
- Alternative approach – like-sign dileptons
  - o Require 2 leptons, ≥3 jets, $H_T > 200$ GeV, $E_T^{miss} > 80$ GeV
  - o Much smaller efficiency, but suppressed backgrounds, mainly from top pairs
    - Second lepton from b-decay, or fake
  - o Significant improvement on existing limits from LEP and Tevatron with 1 fb^{-1}
- But 14 TeV data needed to probe 1 TeV scale.



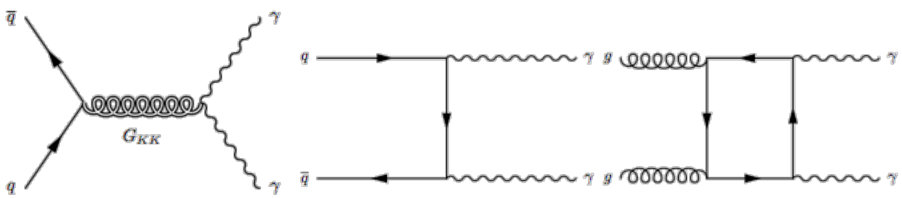
More exotic scenarios

- Dilepton resonances: Z'→ee, μμ
  - o Z-like object or RS-graviton
  - o Small Drell-Yan background
  - o Tevatron limits of ~ 1TeV on SSM Z' overtaken with ~100 pb^{-1}
- Heavy W boson: W'→eν or μ
  - o Again, Tevatron limits of ~1 TeV can be extended with ~-20 pb^{-1}

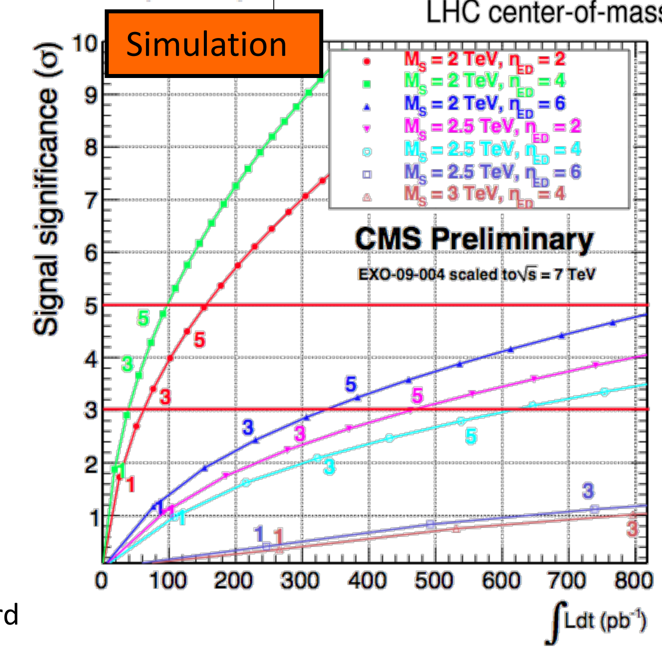




- Diphoton resonances –large extra dimensions



  - Excess of diphoton events above SM background
    - Extend Tevatron limits with 50 pb^{-1}
- Also dijet searches for compositeness, excited e and q, black holes – all accessible in first year



Summary and outlook

- The LHC era has finally begun!
  - LHC machine commissioning at 7 TeV is going well – much data already delivered
  - No major problems at 7 TeV, and clear plan towards $L=10^{32}\ cm^{-2}s^{-1}$ at end of year
    - Leading on to ~1 fb^{-1} in 2011, before a long 2012 shutdown to enable 14 TeV operation
  - Experiments are working very well, recording data with high efficiency
- Already seeing first LHC physics results
  - Basic event properties in the new energy regime at 7 TeV
    - No major surprises, but detailed description by event generators can be improved
  - A start on the b-physics and jet physics programs
  - W & Z signals established, on the verge of the top quark
  - Extend SUSY and exotica exclusion regions this year – or make a discovery?
  - Standard Model Higgs requires a little more time –beyond Tevatron reach in 2011
- Delivered luminosity profile is ~exponential – but takes time to analyze and understand the data …
  - Results shown today have used only a fraction – much more expected soon!