LHC:2010-2011: Standard model

Ian Hinchliffe

Things have moved fast

- I was amazed that
  - The detectors worked “out of the box”
  - The software worked “out of the box”
  - The data and the simulation agreed amazingly well
- First Collision data taken November 20 2009
- ATLAS, CMS had published by March 15 2010
- First 7 TeV data taken March 30 2010
- First 7 TeV result shown at conferences April 19
- So much for the naysayers who claimed “it will take years to understand the LHC detectors”

Outline

- How much data?
  - Running conditions
- Types of measurements
  - Things we are sure we know (W cross section)
  - Things we might know (Psi cross section)
  - Things we don't care about but need to know (MC tunings)
- Examples of physics
- Next run in 2013: comments
- I know nothing about the heavy ion program

How much data?

- **900 GeV**
  - **“ million” events**
  - **Unlikely to be much more**
  - **“min bias” physics only**
- **2.34 TeV**
  - **Very small data set**
  - **Unlikely to be more**
  - **“min bias” only**
- **7 TeV**
  - **Today ~ 10 inverse μb**
  - **Goal 100 inverse pb in 2010, 1 inverse fb in 2011**
  -

About 1 nb-1 collected to date:

- ~65 million inelastic events
- Jets to a few 100 GeV
- Handful of W candidates

Summary of expected event rates

- **High pt is limited by**
  - **Luminosity**
  - **Detector performance**
- **Low pt is limited by trigger**
  - **Total output ~200 Hz**
  - **Prescales apply to cross-sect**
  - **10Hz of min bias**
  - **10's Hz of jets (staggered thresholds)**
  - **Inclusive muons pt>4 GeV (?)**
  - **Trigger prescales now operating**

Expected # SM Events in 1 fb-1
(after trigger and selection)

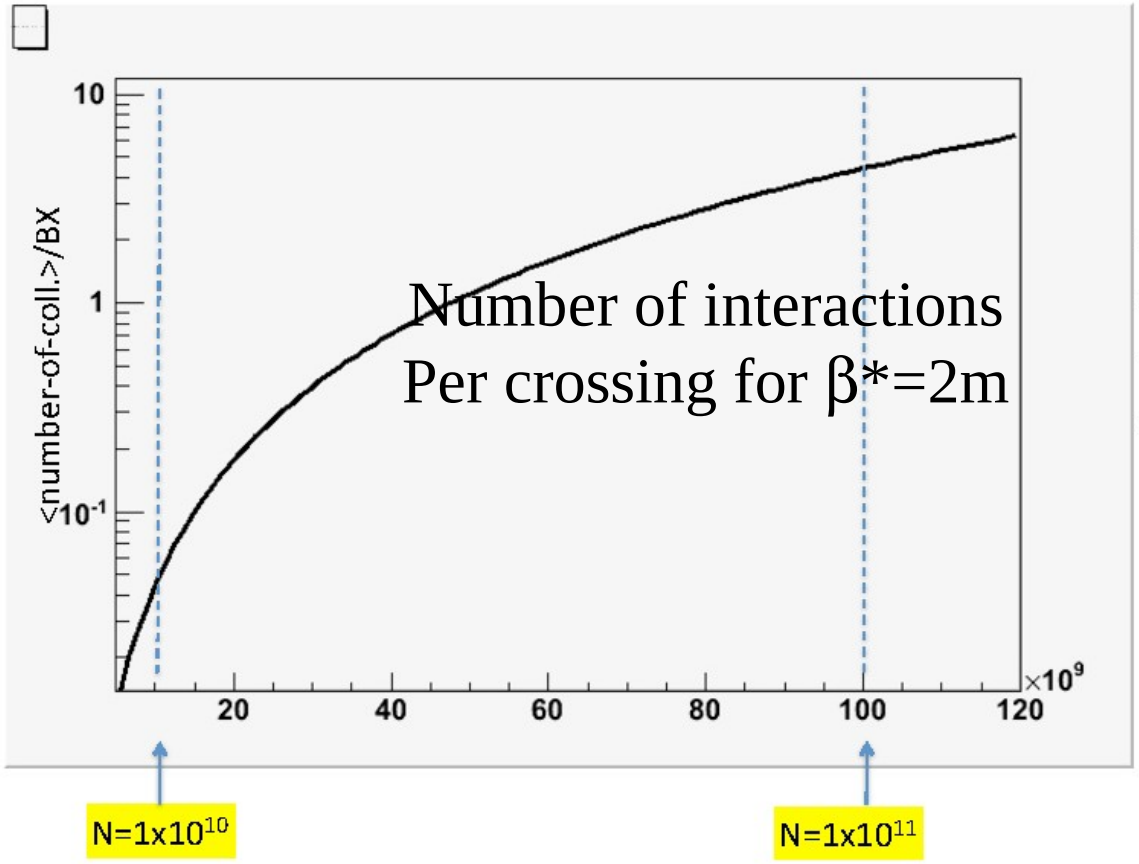
Process	Number Events
$W^{\pm} \rightarrow l^{\pm}\nu$	4M
$Z^{0} \rightarrow l^{+}l^{-}$	400k
ttbar l+jets	6000
ttbar dilepton	2500

Running conditions

- **Two variables relevant to physics**
  - **Integrated luminosity**
  - **Number of interactions per crossing (in-time pile-up)**
- **Protons per bunch (Nb), number of bunches (M) and β* (beam focusing) are variables**
  - **Lumin ~ MN_b^2/β^***
- **Total stored energy ~ total current in machine**
  - **MN_b**
- **Max luminosity for given safety means large N_b**

Running conditions II

- **Published results are from data without**
- pileup



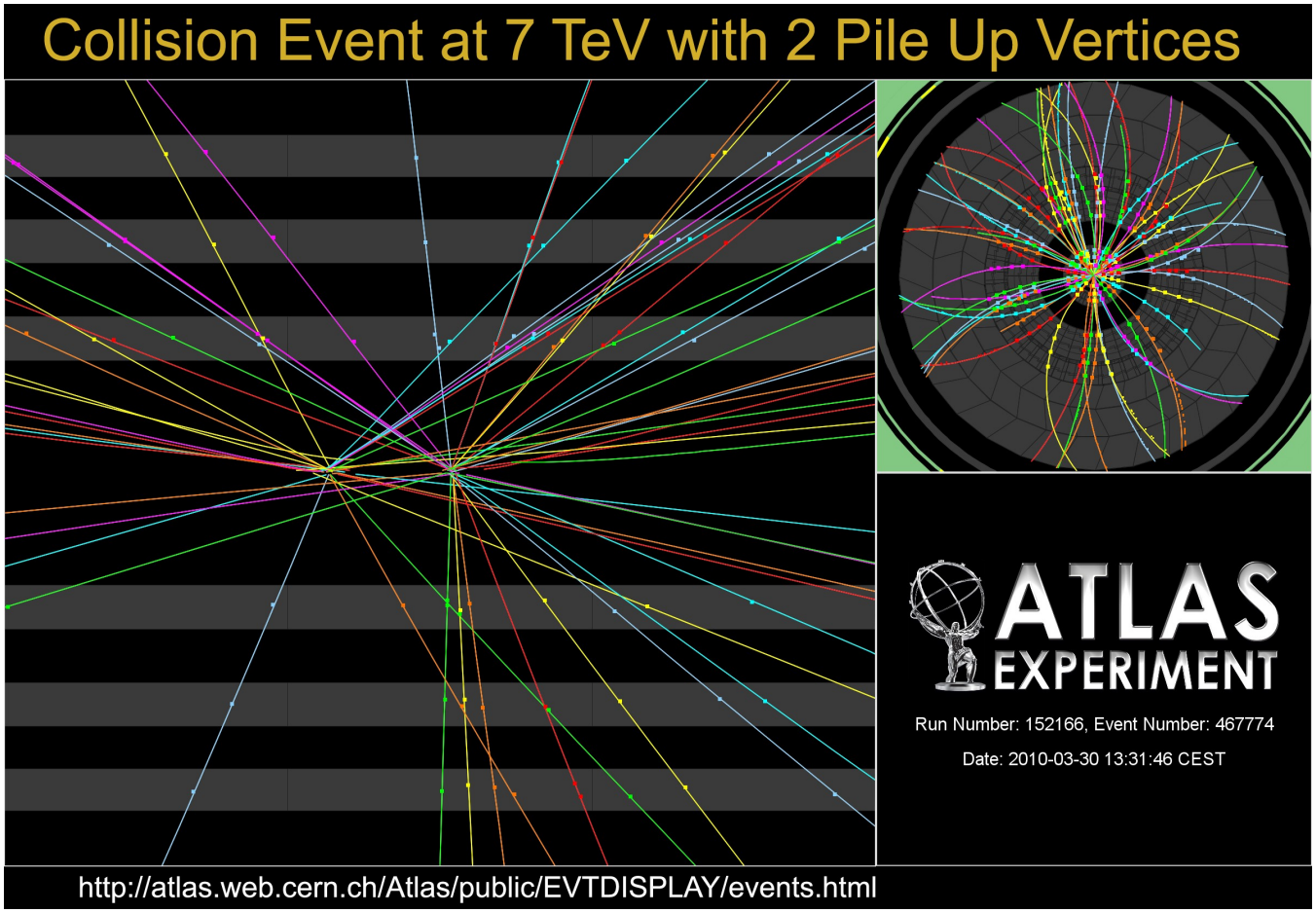
$\sigma_x = \sigma_y = 30\ \mu m$

$\sigma_{MB} = 50$ mb (just the NSD cross section)

Running conditions III

- This weeks state
  - Testing 10^{11} per bunch
  - Have reached $\beta^*=2m$
  - Together would give 10^{30} luminosity with 4 bunches
- Pressure to deliver luminosity is likely to result in most data taken with ~5 interactions per crossing
  - Not expected in earlier planning
- Caveat: this is my opinion.
  - LHC operations plans fluid

Clean pile-up events seen



Running conditions IV

- **Why does this matter?**
- **Low pt physics**
  - **All events are the same**
  - **Must assign all particles to unique vertex**
  - **Misasignment compromises measurements**
  - **ATLAS 7 TeV min bias paper vetoed any pileup events (about 0.5%)**
  - **Data sets may be limited in size**
- **High pt physics**
  - **Less impact: mostly on jet resolution**

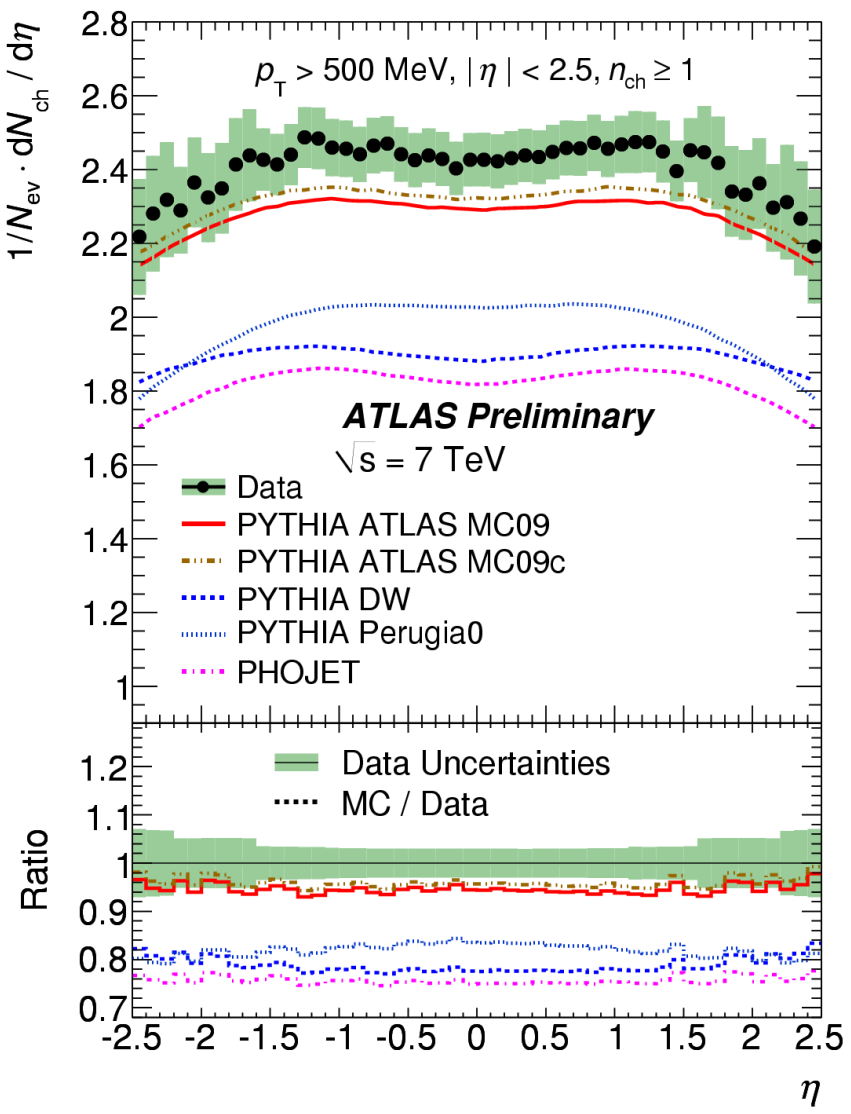
Strong interactions: Low pt

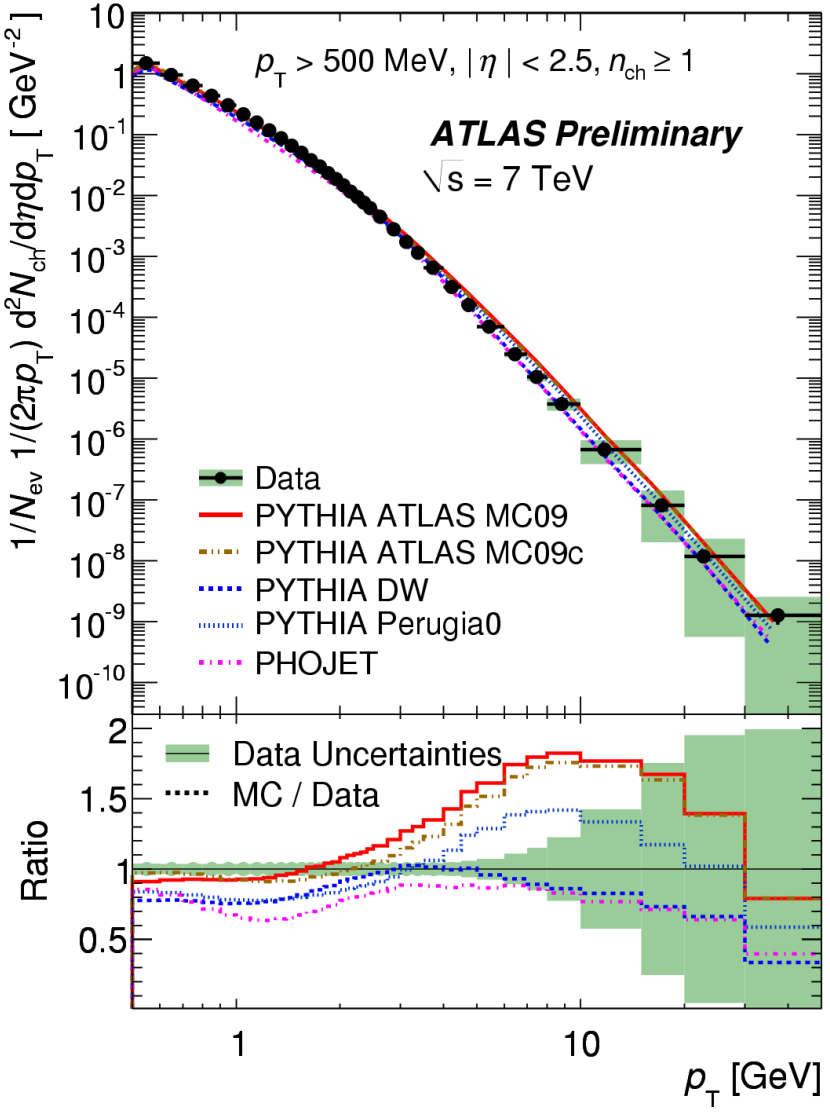
- None of this is calculable
  - "Engineering measurements" vital for future
  - Needed for calibrating luminosity
- Min bias
  - Needed for pile up
  - Measurements: dN/dη,
  - SD/DD/ND comments
- Underlying events
  - Jet energy scale
  - Additional low pt jets (tagging and vetoing)
- Needs running without pile-up
- People will move on from this shortly

“Min bias”

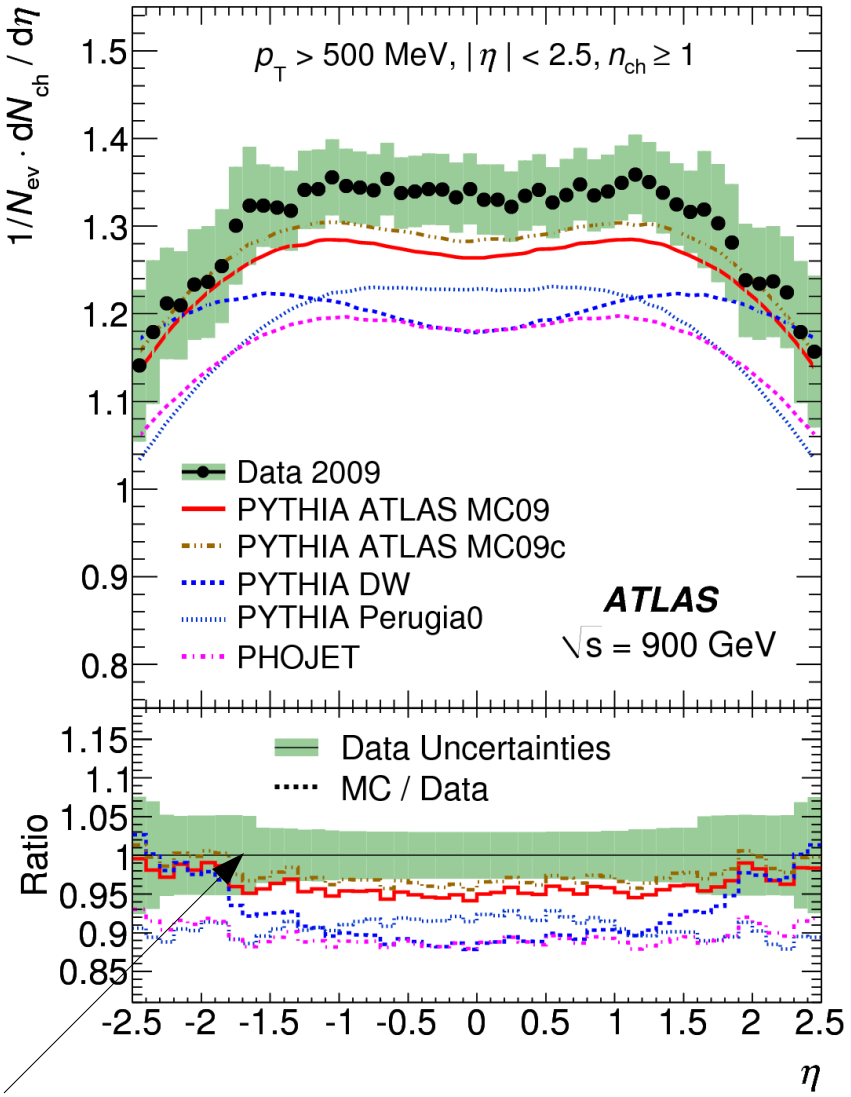
- **People talk about “min bias”**
  - **Misnomer**
  - **Baised (some kind of trigger or event selection)**
  - **Unbaised (bunch crossing trigger)**
- **Results can be difficult to compare to MC**
  - **Bias must be modeled/corrected**
  - **Correction can depend on MC model**
  - **Traditionally results are “corrected” to allow comparison with non-diffractive MC**
    - **Depends on diffractive contributions (SD/DD)**
      - Not well modeled or clearly defined

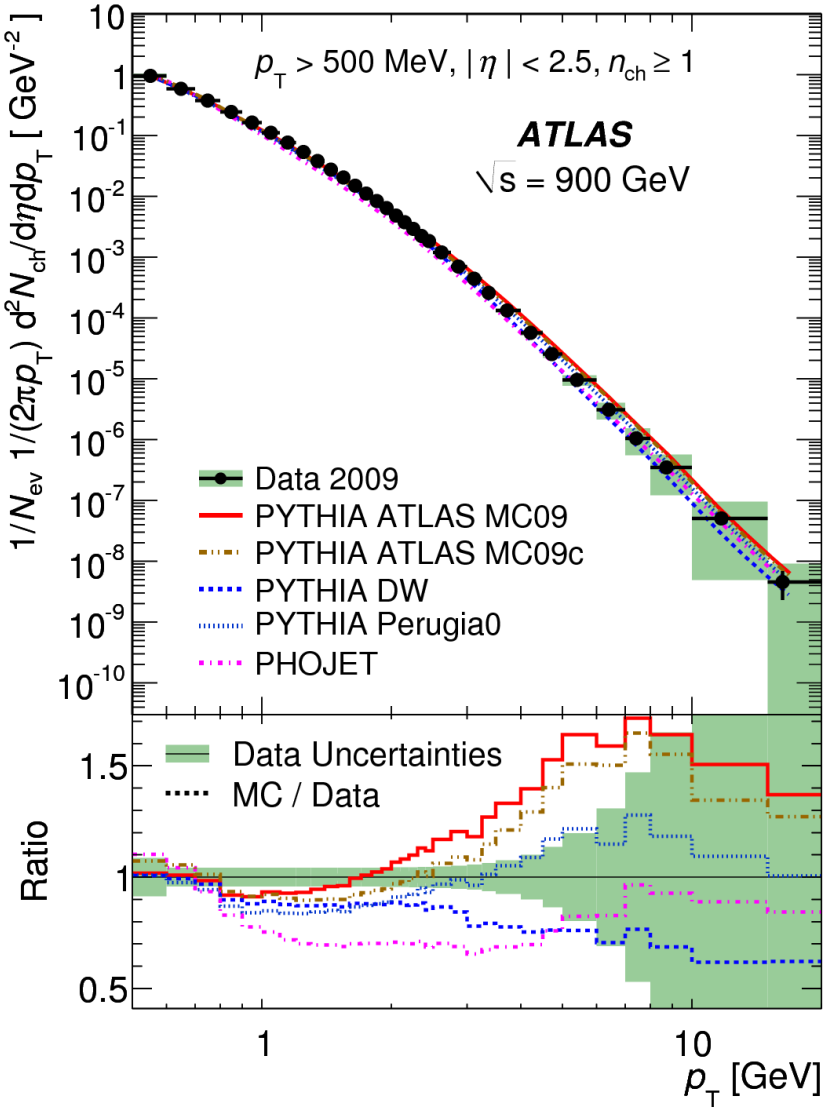
Min bias: measurements I





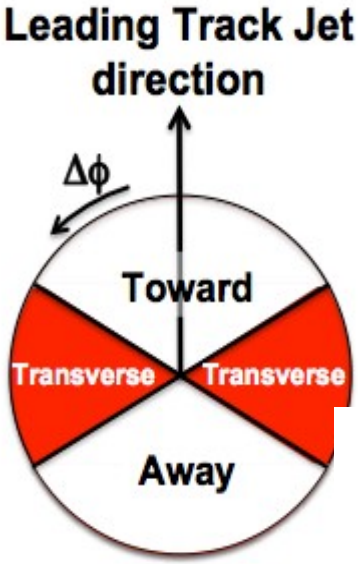
Evolution from 900 GeV not bad



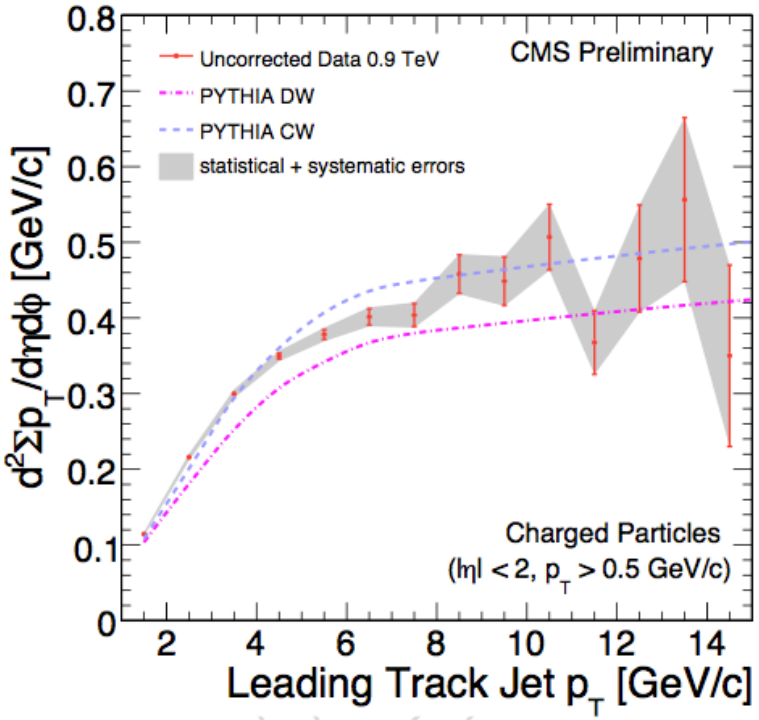


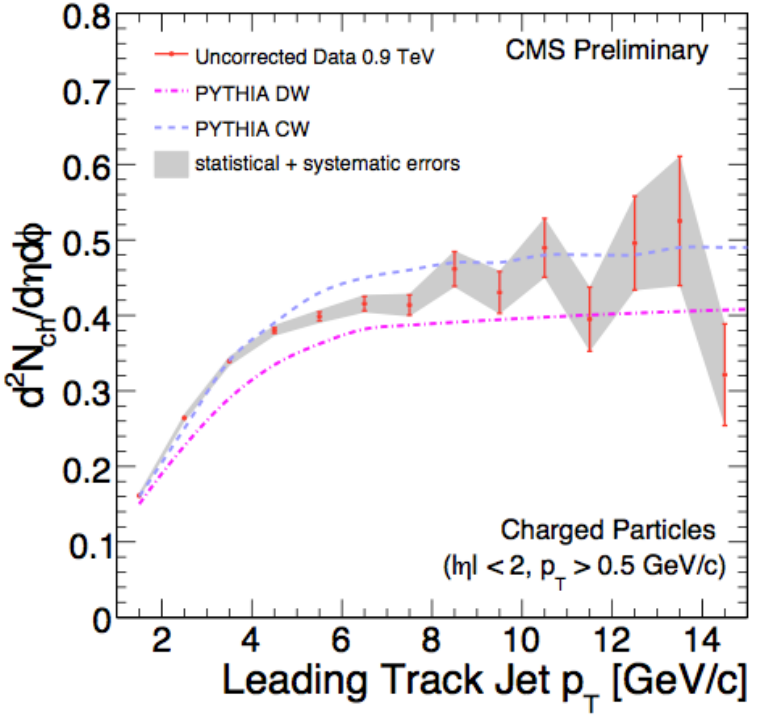
Underlying events

Energy flow



Track density





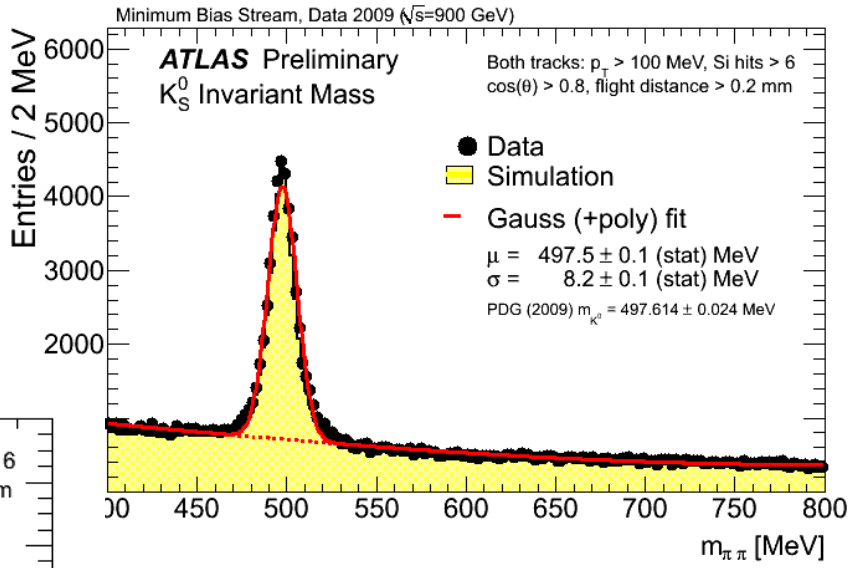
Agreement not bad

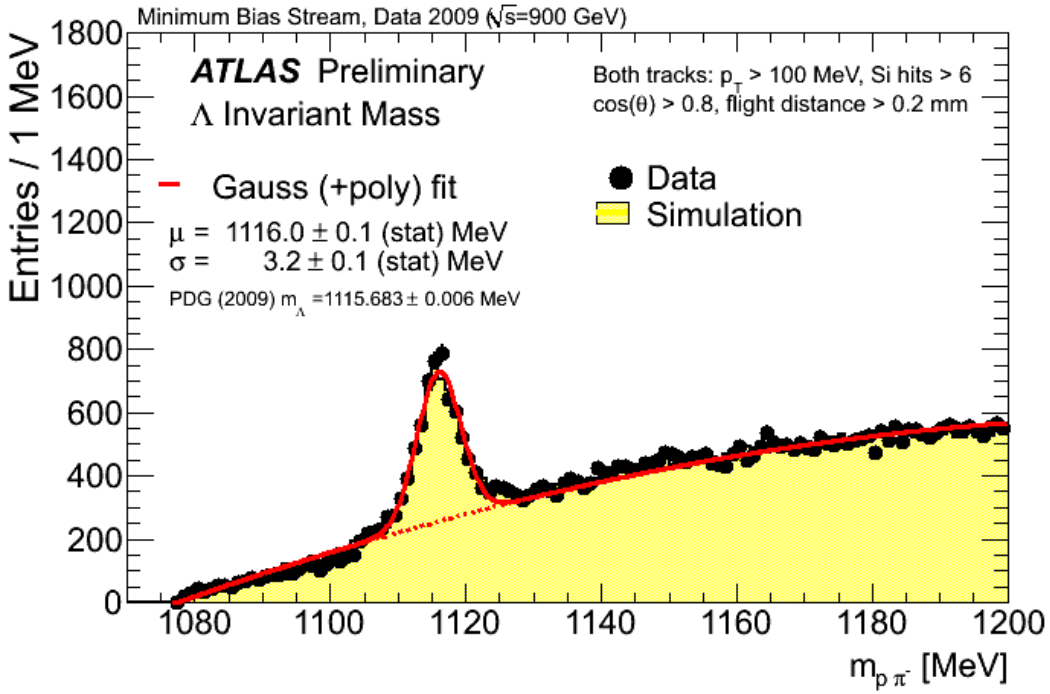
- Most preexisting tunings had too few particles and perhaps too slow energy growth
- Existing estimates of pileup effects on new physics signals unlikely to be far off
- Low pt jets emerging from these events are also OK (see later)
  - Impact on tagging and vetoing of jets in new physics signals likely to be reasonable

Other MC tuning measurements

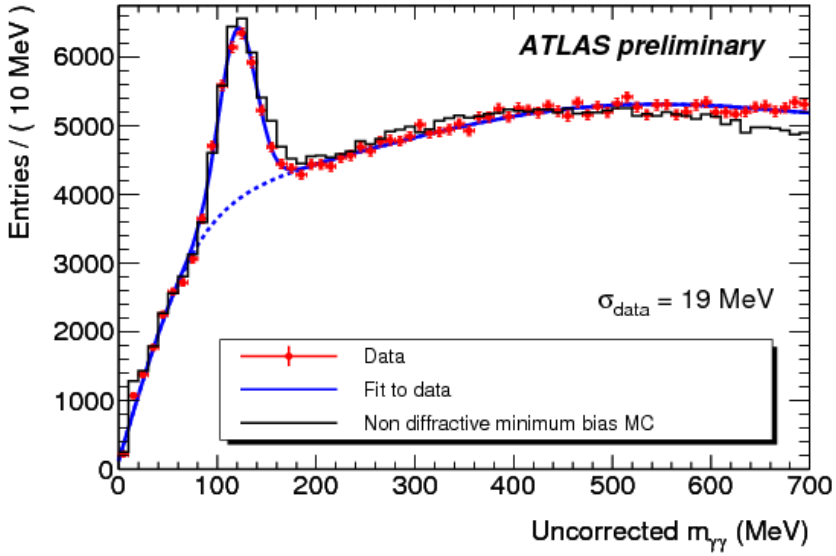
- **Detailed particle properties**
  - **Strangeness fractions**
  - **Baryon fractions**
  - **Charm fractions**
- **Expect these results at pLHC and ICHEP**
- **A few plots follow**

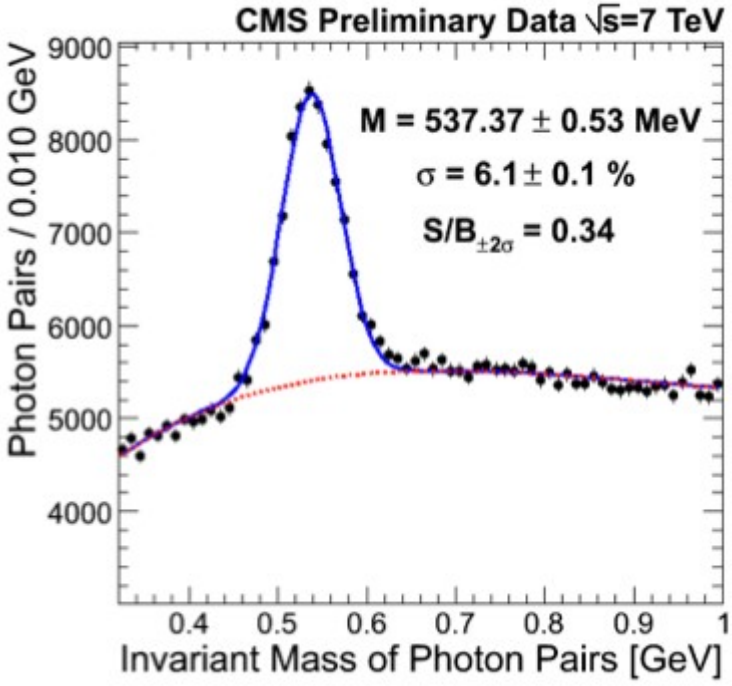
K_s and Λ


Minimum Bias Stream, Data 2009 (√s=900 GeV)
ATLAS Preliminary
K^0_S Invariant Mass
Both tracks: p_T > 100 MeV, Si hits > 6
cos(θ) > 0.8, flight distance > 0.2 mm
Data
Simulation
Gauss (+poly) fit
μ = 497.5 ± 0.1 (stat) MeV
σ = 8.2 ± 0.1 (stat) MeV
PDG (2009) m_{K^0} = 497.614 ± 0.024 MeV
Entries / 2 MeV
$m_{\pi\pi}$ [MeV]

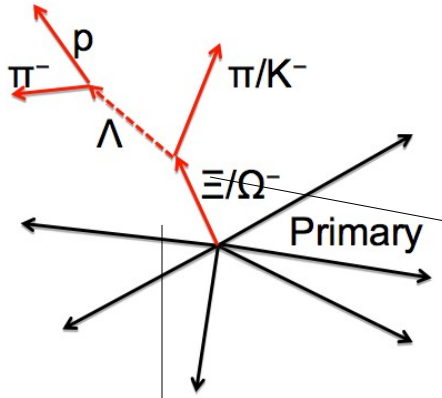

Minimum Bias Stream, Data 2009 (√s=900 GeV)
ATLAS Preliminary
Λ Invariant Mass
Both tracks: p_T > 100 MeV, Si hits > 6
cos(θ) > 0.8, flight distance > 0.2 mm
Gauss (+poly) fit
Data
Simulation
μ = 1116.0 ± 0.1 (stat) MeV
σ = 3.2 ± 0.1 (stat) MeV
PDG (2009) m_Λ =1115.683 ± 0.006 MeV
Entries / 1 MeV
$m_{p\pi^-}$ [MeV]

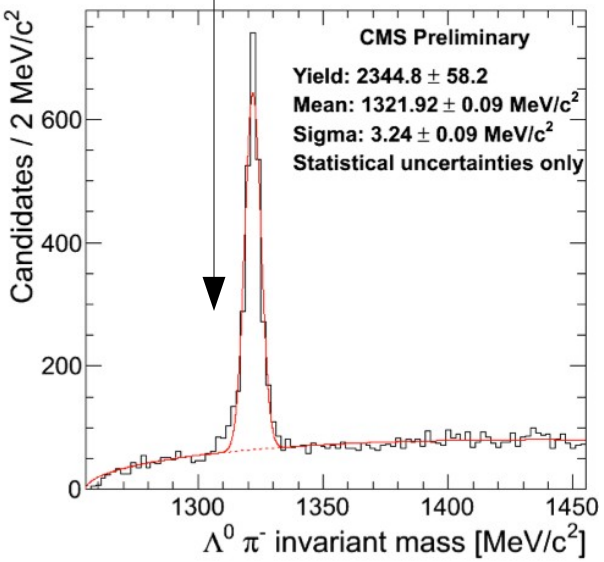
Pi0 and eta

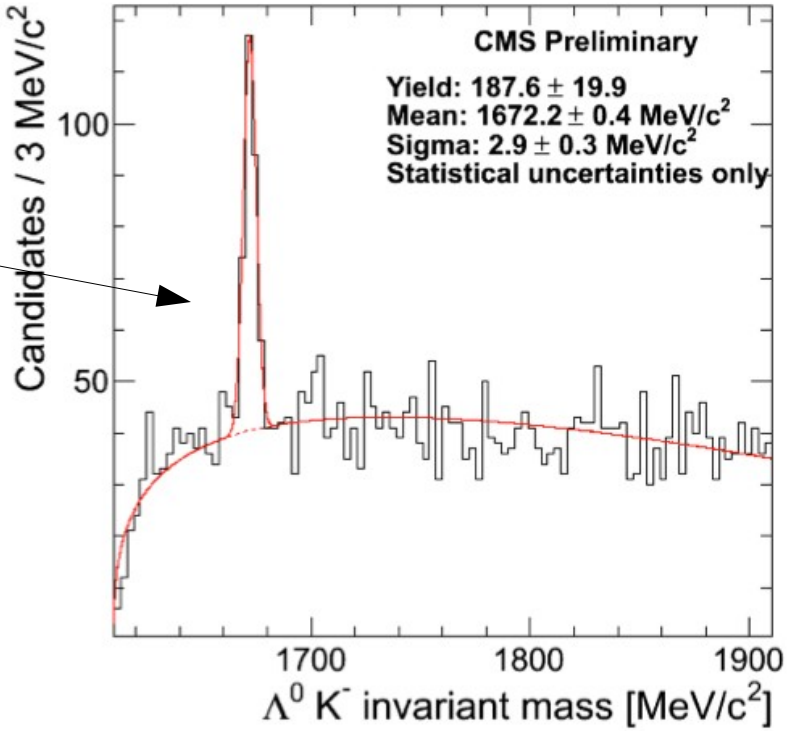

ATLAS preliminary
Entries / (10 MeV)
σ_{data} = 19 MeV
Data
Fit to data
Non diffractive minimum bias MC
Uncorrected $m_{\gamma\gamma}$ (MeV)


CMS Preliminary Data $\sqrt{s}$=7 TeV
M = 537.37 ± 0.53 MeV
σ = 6.1 ± 0.1 %
$S/B_{\pm 2\sigma}$ = 0.34
Photon Pairs / 0.010 GeV
Invariant Mass of Photon Pairs [GeV]

CMS strangeness

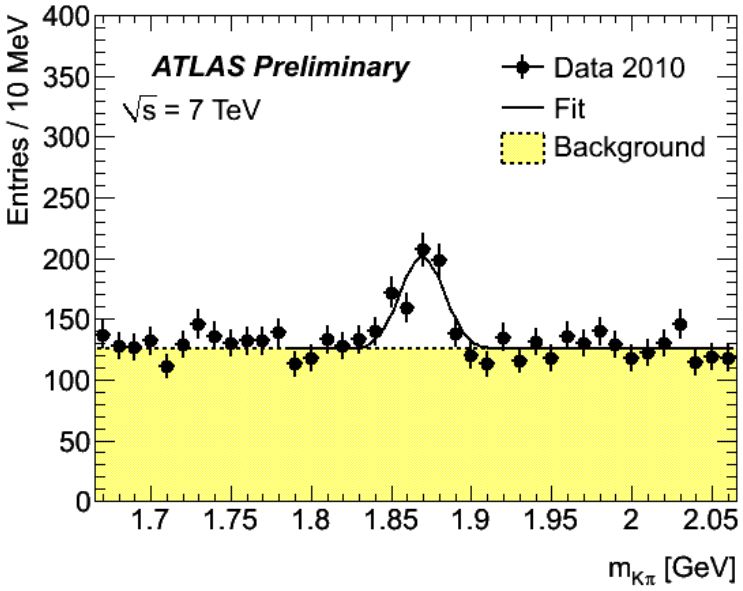




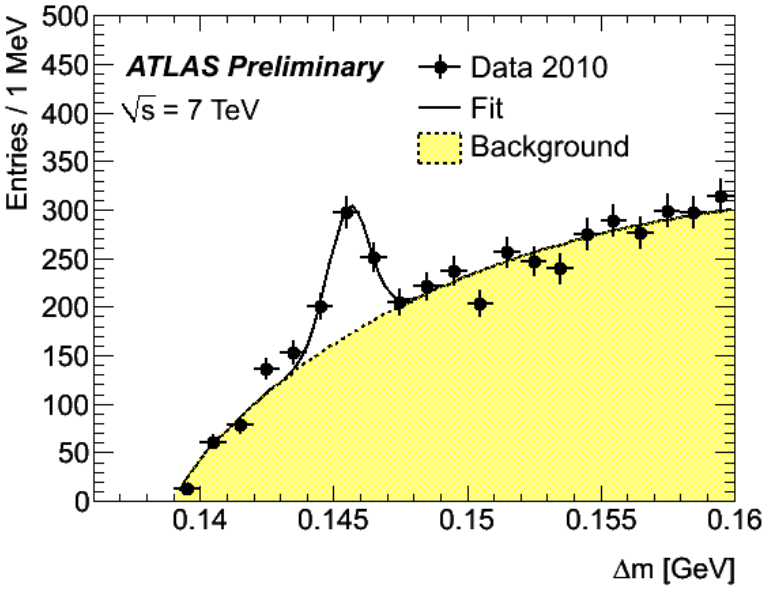


ATLAS charm

D meson



D-D* mass



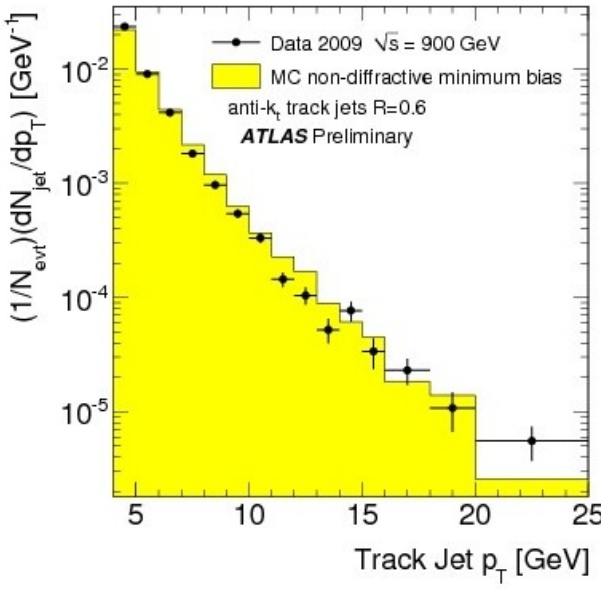
Low Pt stuff: final comment

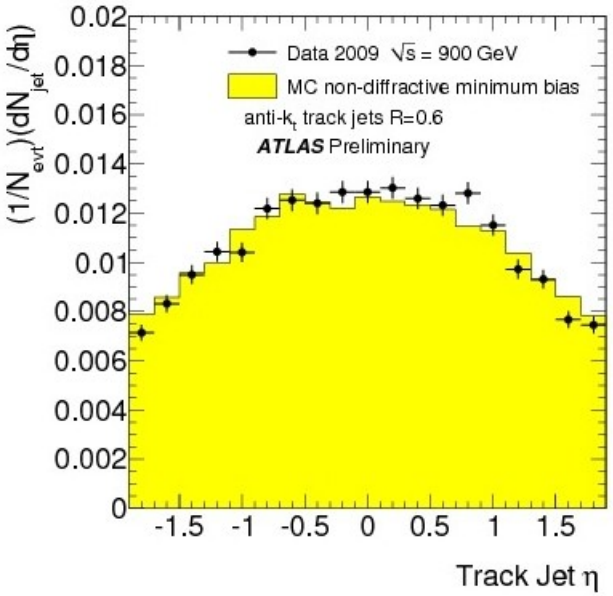
- If you care about this, now is your only chance
- Once we have more interesting data, no one will measure it any more

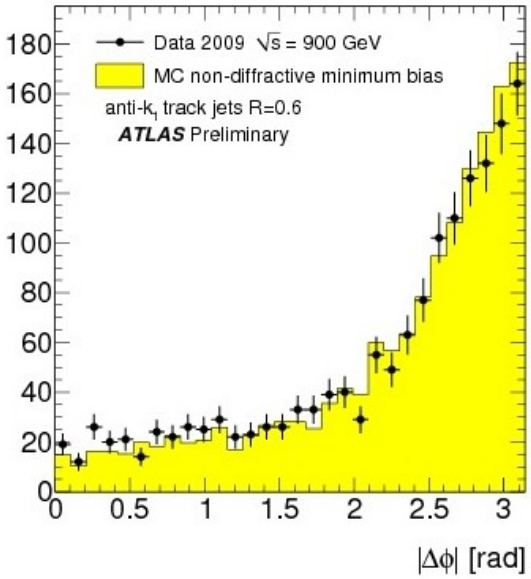
High pt QCD

- Should be calculable
  - Jet distributions
  - Direct photons
- Verify that detector works
- Check that MC have no bugs
- Validate in regions where predictions may be suspect
  - e.g Multi jet final states
- Extrapolate into new physics regions

Current jets

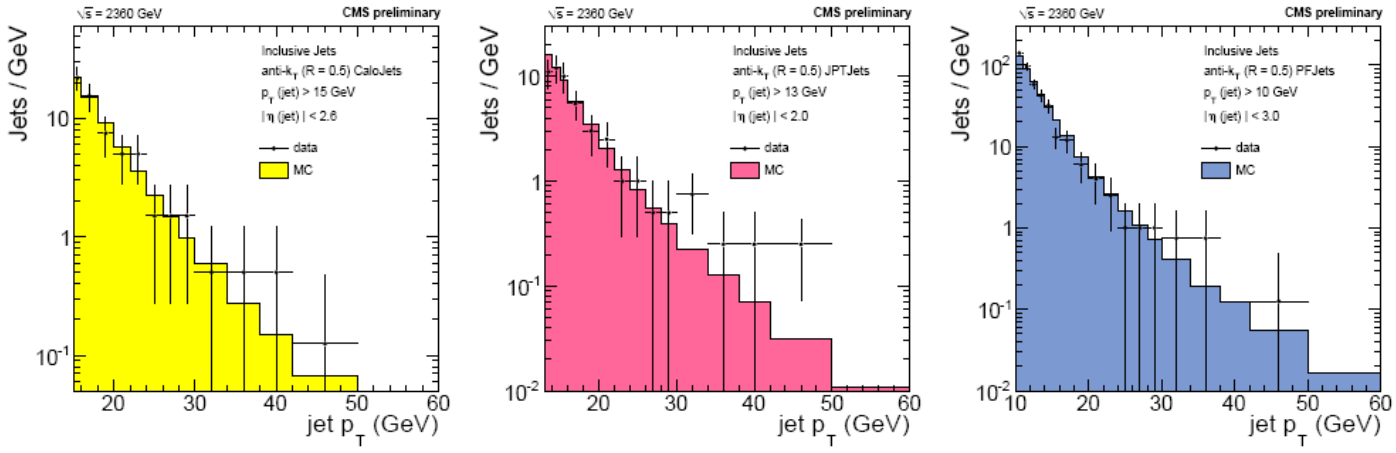




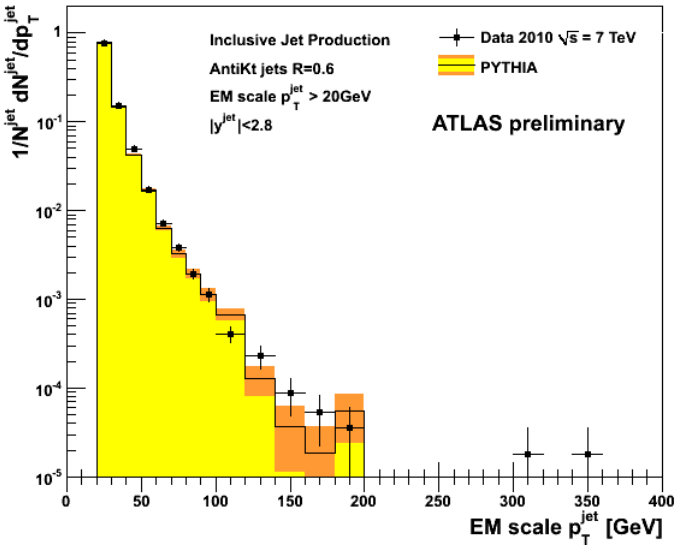


- Low pt jets emerge nicely from min bias
- Jets up to few hundred GeV seen
- Good agreement with MC: (detector simulation surprisingly good)
- Measured both in calorimeters and tracking

Current measurements

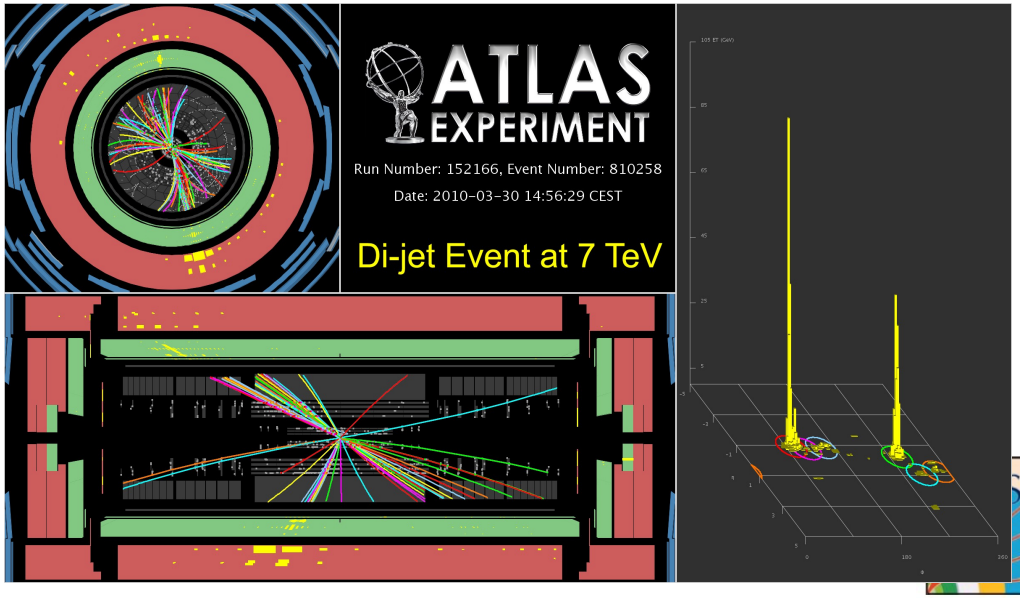


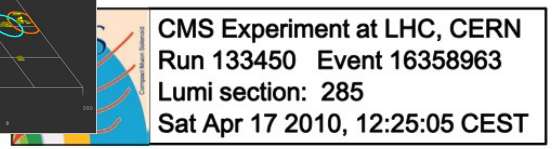
CMS



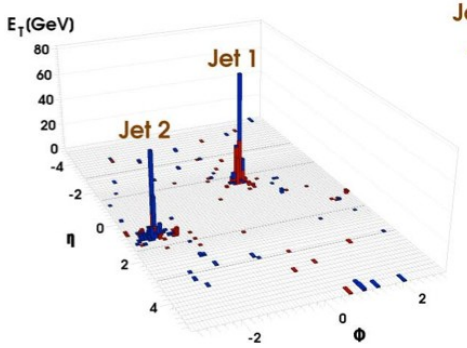
ATLAS

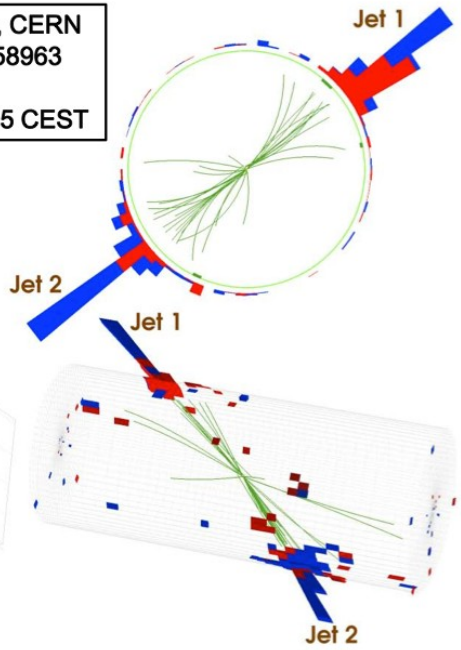
7 TeV jets





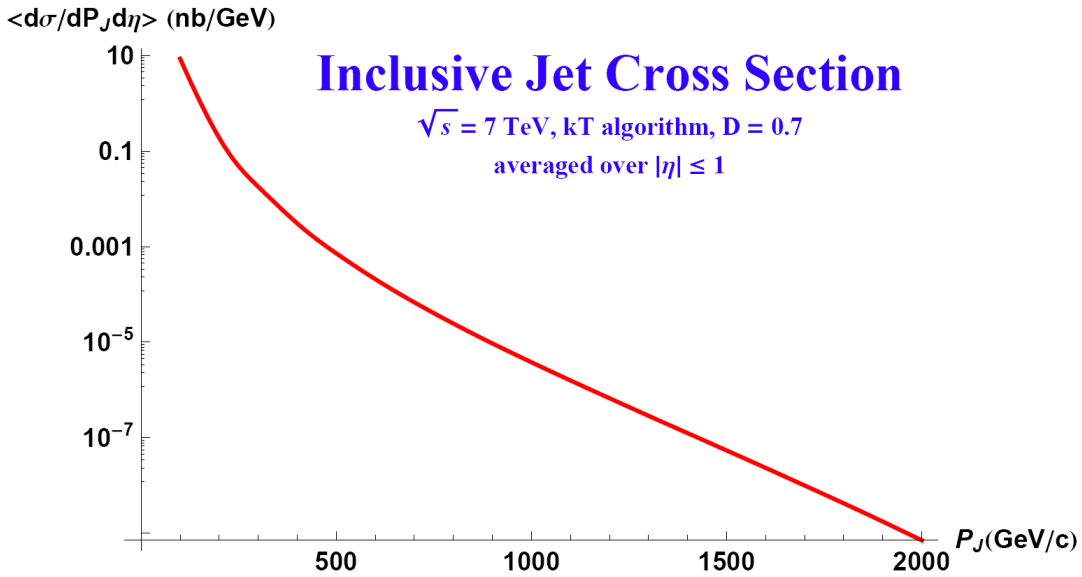
Jet1 p_T : 253 GeV
Jet2 p_T : 244 GeV
Dijet Mass : 764 GeV





Reach of jets

- 1 inverse pb : 900 GeV
- 100 inverse pb: 1.4 TeV
- 1 inverse fb: 1.7 TeV
- First new physics limit?



Steve Ellis NLO spectrum

Partial list of possible results this summer

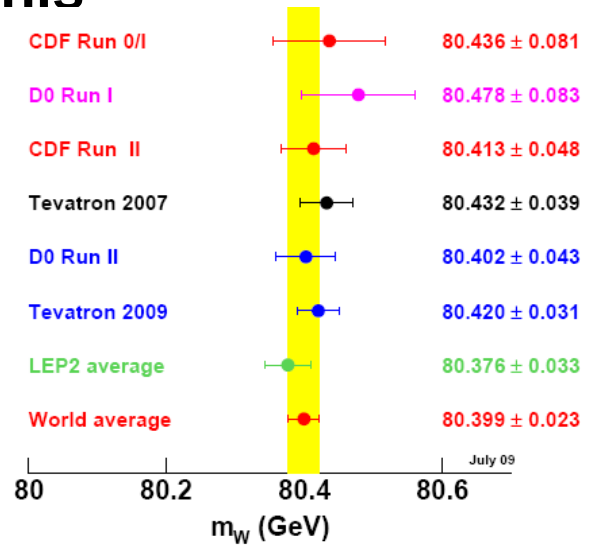
- Pt spectrum
- Fragmentation function
- Angular correlation
- Multi-jet events

W and Z

- 25K Z and 250K W per 100 inverse pb
- Properties well predicted by QCD
  - Production rate, pt and rapidity distributions
- Properties less well predicted
  - Associated jet multiplicity
    - Important for new physics
- W and Z will be used for calibration

W/Z masses

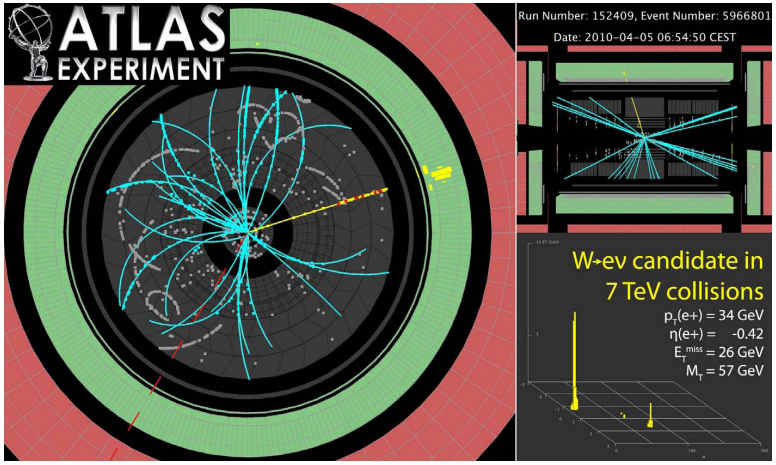
- Z is a “standard candle”: LHC cannot improve on LEP
- W mass from CDF/D0 used 500K W's
  - LHC will have more by 2011
  - But dominant issue is systematic errors
    - Often scale with statistics as you get more control events
    - LHC may be able to exploit this
- A very hard measurement
- Is there something more interesting?

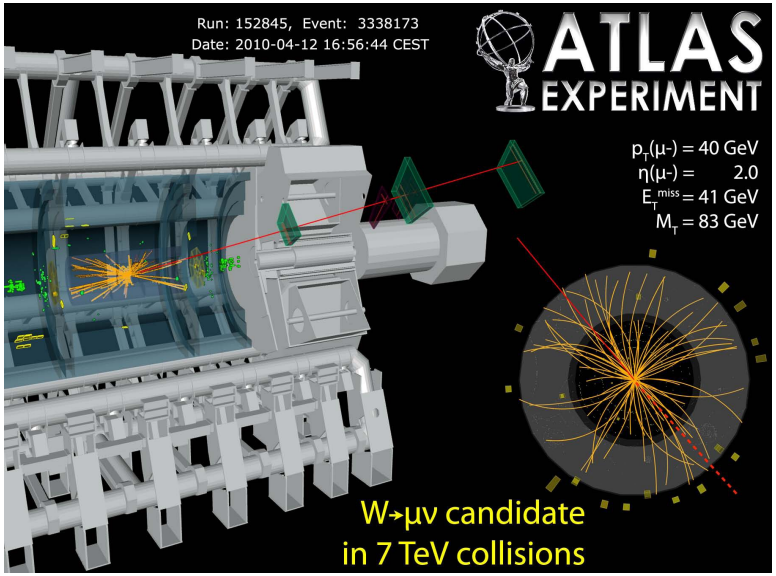


W production

- First few events look OK
- PP machine so more W+ than W-
- Expected results
  - Pt and rapidity
  - Rapidity distribution probes PDF's beyond HERA range

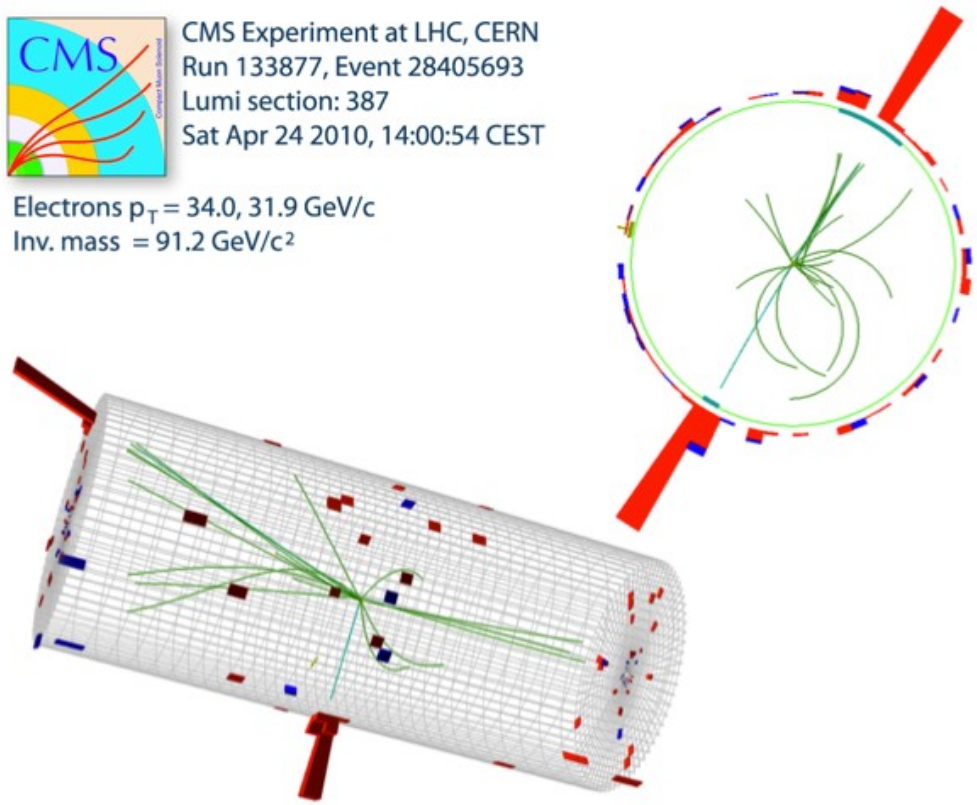
W candidates



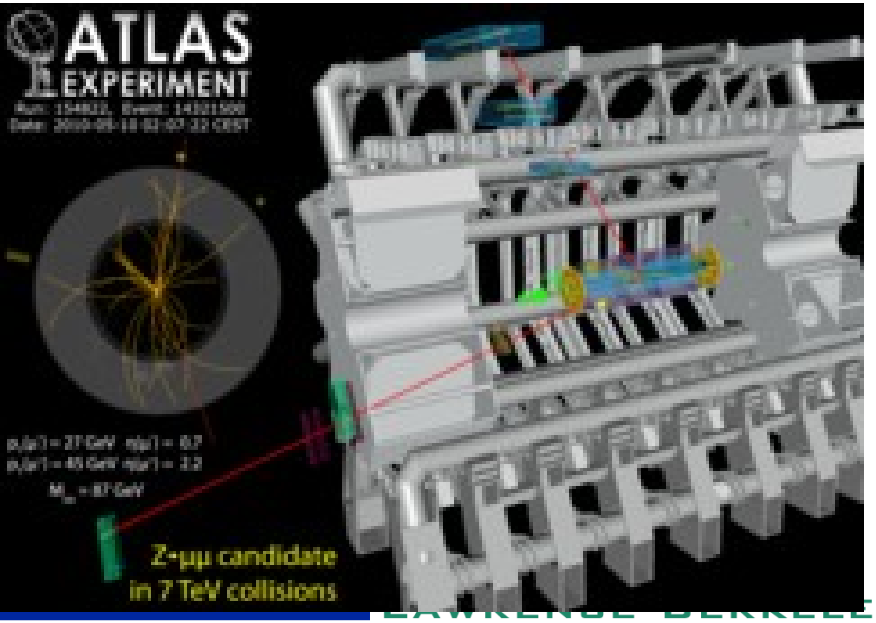


Z candidates

ee



Mu mu

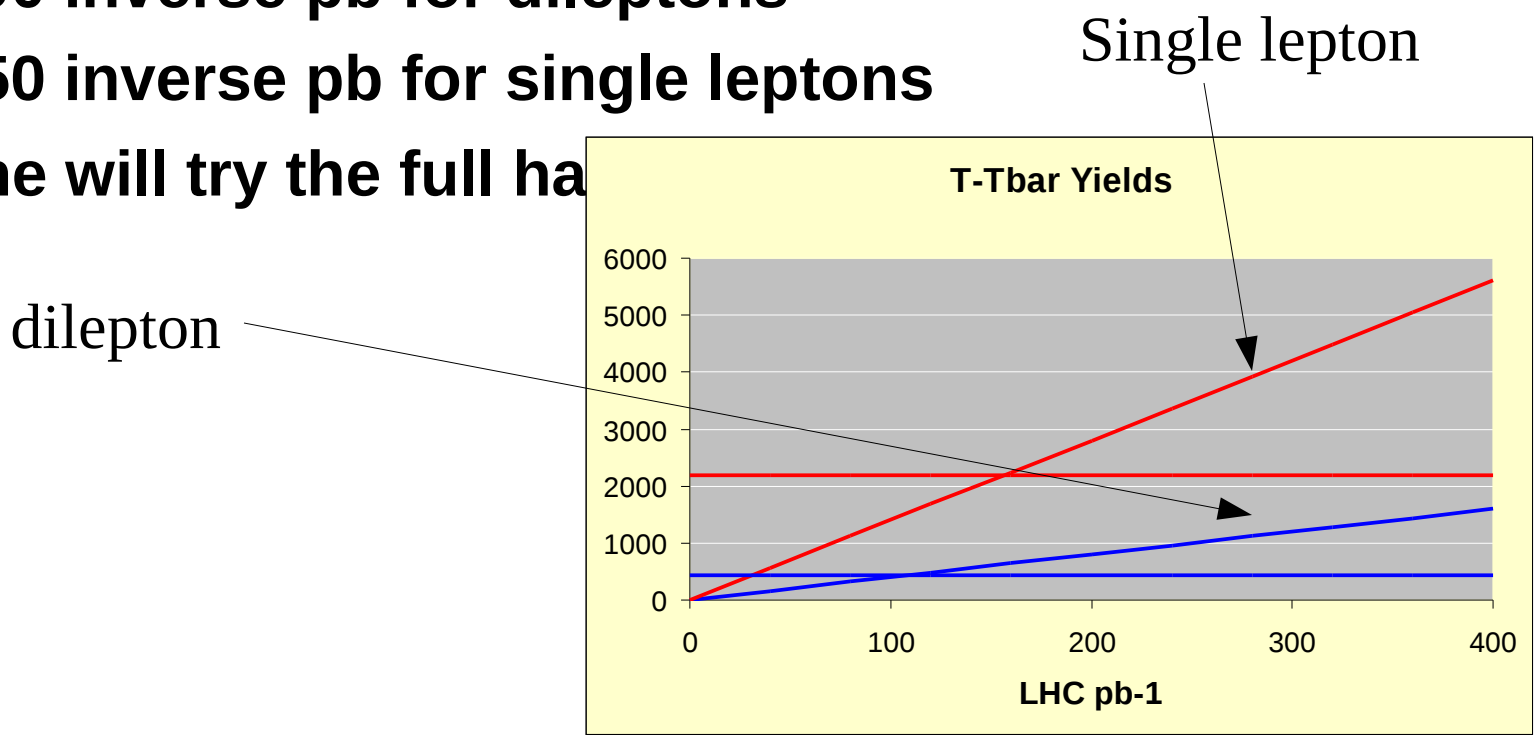


Top physics as samples increase

- **Observation this summer**
- **Cross section at 7 TeV**
  - **Well predicted by QCD**
  - **Can only be wrong in the tails**
- **Single top (hard)**
- **Top properties**
  - **Decays and production properties**

No data yet: so only MC

- **S/B better than Tevatron: Higher energy**
- **Need at least one lepton**
- **Need a few inverse fb to get started**
- **More data than Tevatron (horizontal lines)**
  - **100 inverse pb for dileptons**
  - **150 inverse pb for single leptons**
- **Someone will try the full ha**

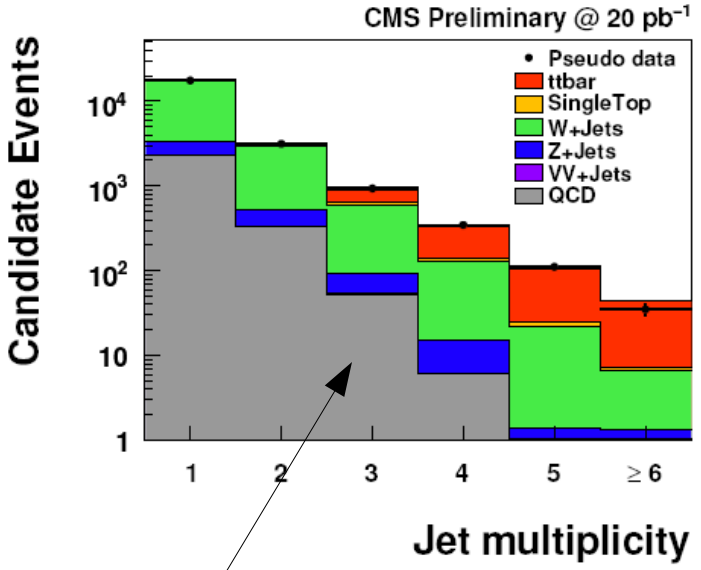


Handles to extract top: 1 lepton

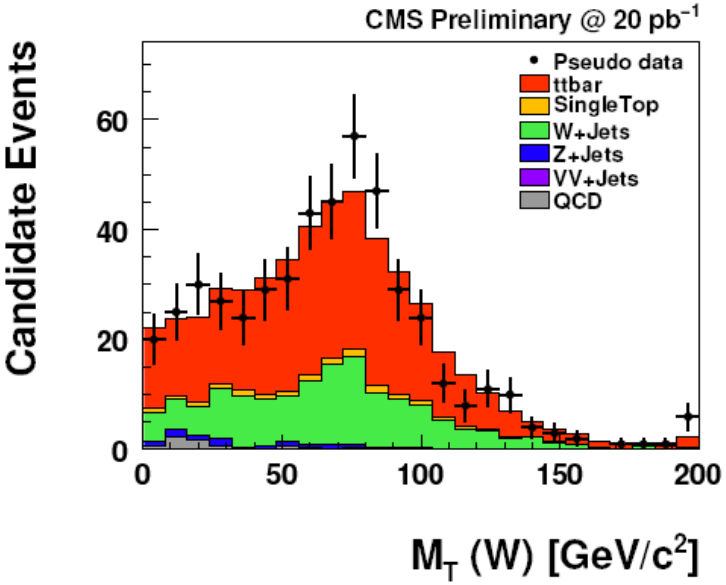
- Lepton (isolated) and etmiss distributions (must have a W)
- Many jets
- Presence of b-jets
- Top mass peak
- Same number of + and – leptons in signal not in background (not available at Tevatron)
- Backgrounds
  - W+jets
  - Charm and bottom +jets
  - Junk (fake leptons) +jets

Handles to extract top

More jets better S/B



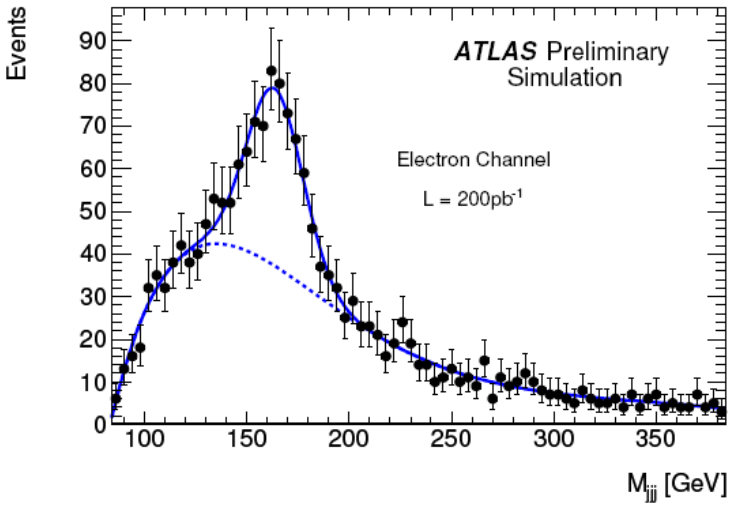
W peak: less junk Bckg

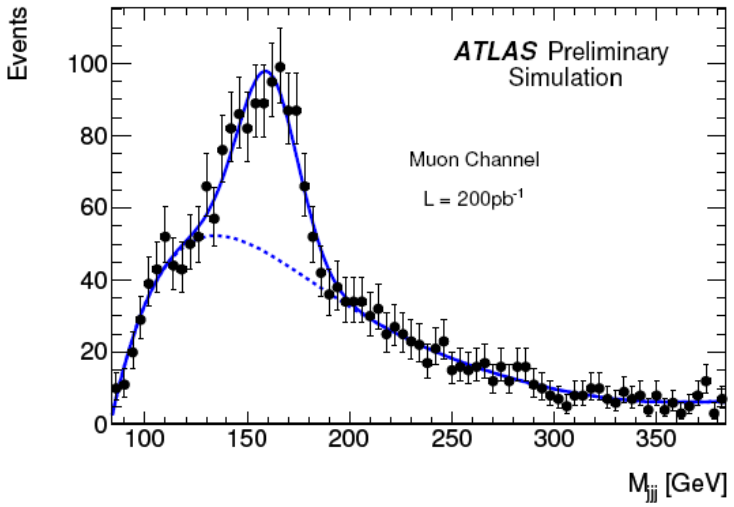


This W+jets background may not be well predicted

No b-tagging required

Top with more data



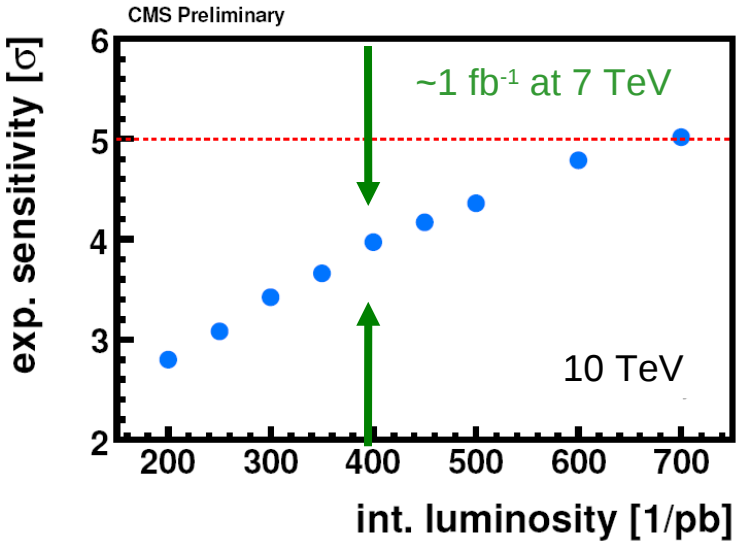


Mass peaks
Clean up background

This is a 10 TeV simulation
Approx same as 500 inverse Pb at 7 TeV

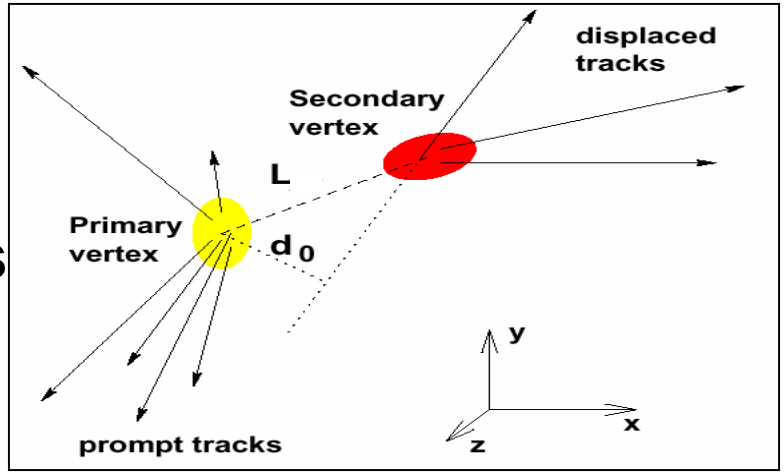
Single top

- Very hard as t tbar is dominant
- Might be possible with much data
- Cannot be sure now
- Possible MC problems?

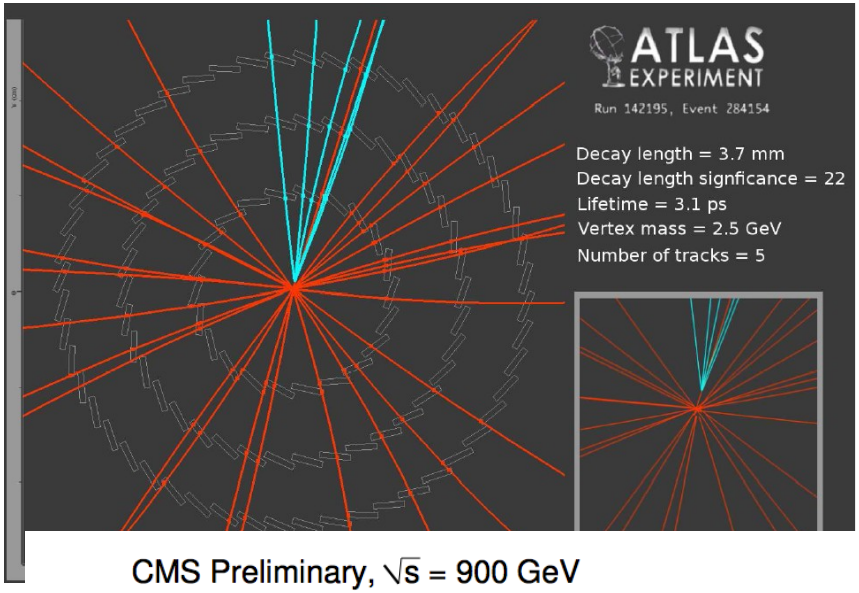


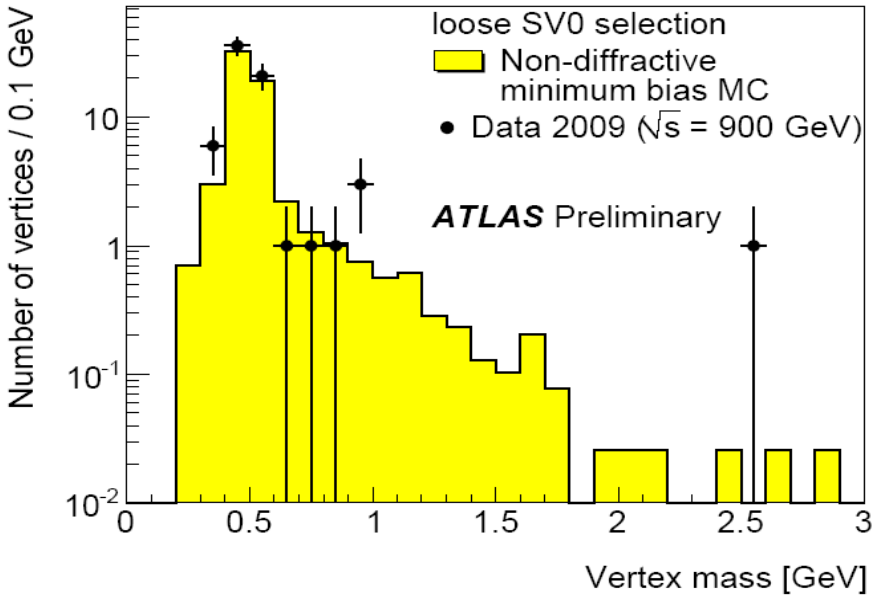
B-tagging

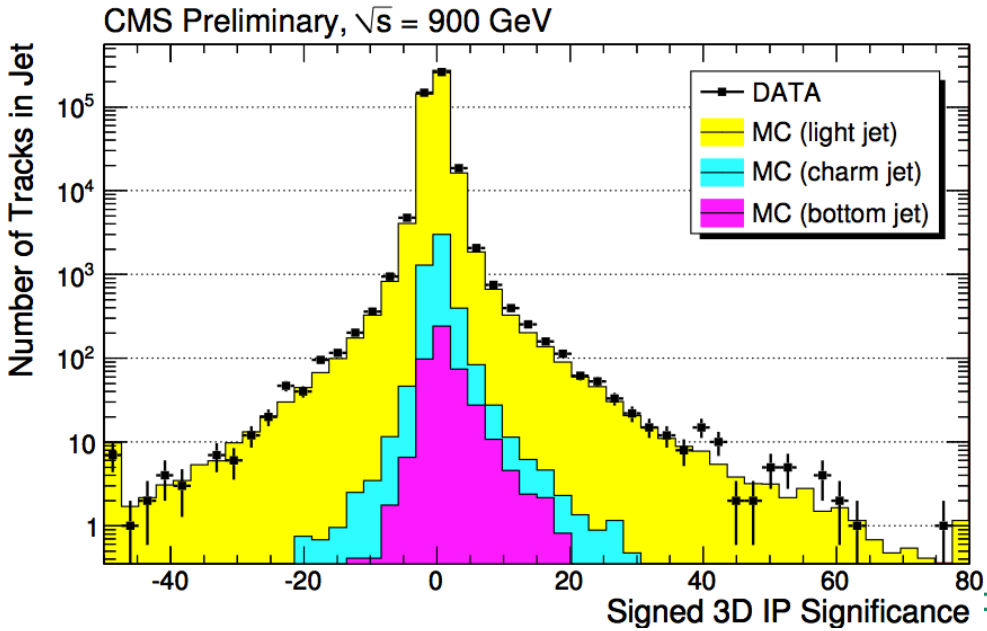
- **Aids greatly in top and new physics**
  - **Need to measure tagging efficiency and fakes**
- **Basic methods**
  - **Vertexing**
  - **Muons in jets**
- **(almost) No b's at 900 GeV**
  - **Understand fakes from K's**



Importance of flavor tagging







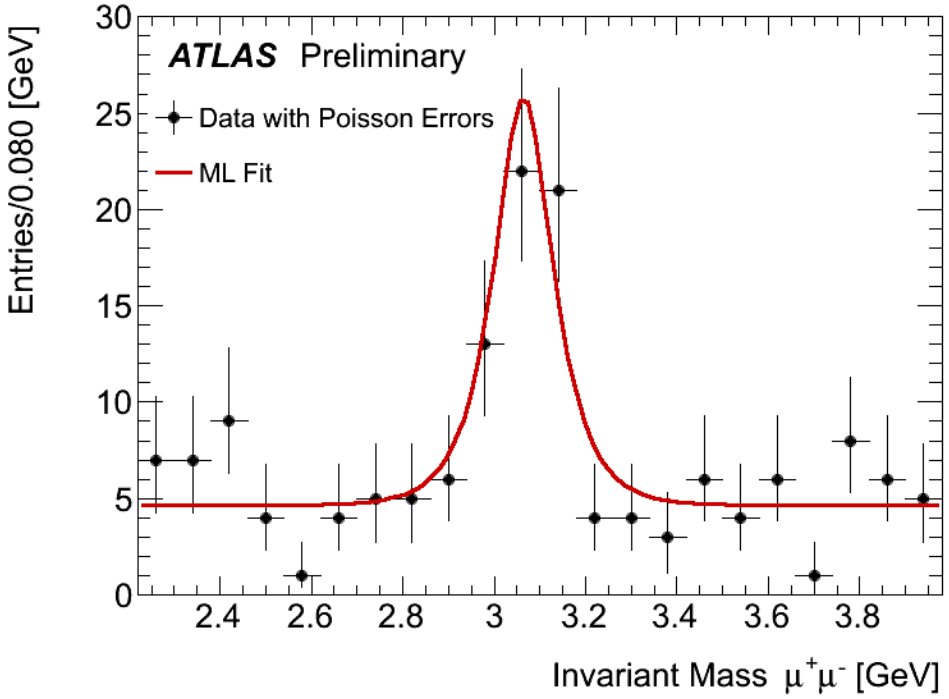
Looking good
7 TeV plots soon

Charm and bottom

- **Production properties may not be well described by "theory"**
  - **Long history of failed predictions and inadequate measurements**
- **Inclusive b-jet cross section**
  - **Needs b-tagging**
- **Inclusive charm**
  - **Use D*-D trick**
  - **Kinematics to remove bottom**
- **Psi and Upsilon rates: prompt and non prompt**

Psi have started to appear

- **Must identify muons**
- **Rates only measureable in restricted kinematic regions**



Getting ready for new physics: backgrounds

- **Some results come for free out of SM measurements**
  - **Z prime: SM dilepton mass plot**
  - **W prime: tail of transverse mass plot**
  - **Jet compositeness: jet pt distribution**
  - **Top and W+Jets backgrounds to SUSY**
- **> 100 inverse pb: New regime**

Significant Discovery Potential

- **5σ SUSY discovery above current Tevatron limit with a few 100 pb^{-1}**
- **$Z' \rightarrow \mu\mu$ up to ~1.5 TeV**
- **Higgs discovery highly unlikely: 3σ for ~145 to 180 GeV**

Next run in 2013

- **Energy will be 13? TeV**
  - **Redo all the SM measurements with first 100 inverse pb: comparable statisics to current run for top**
  - **A dedicated no pile-up run may be needed for some studies**
  - **Then on to new physics**

Min bias: what have we learned

- **Most previous MC tunings don;t work well**
  - **More particles than predicted**