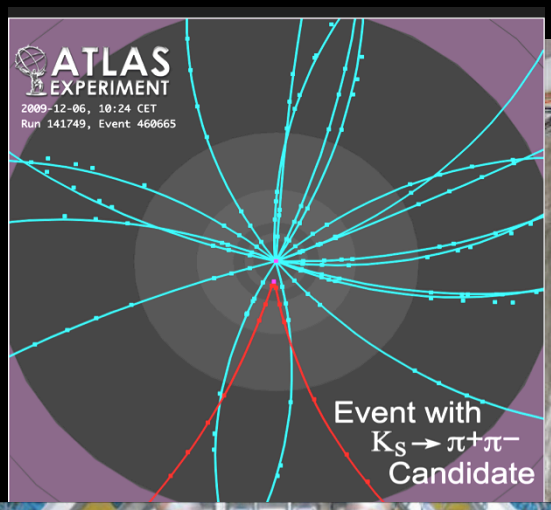
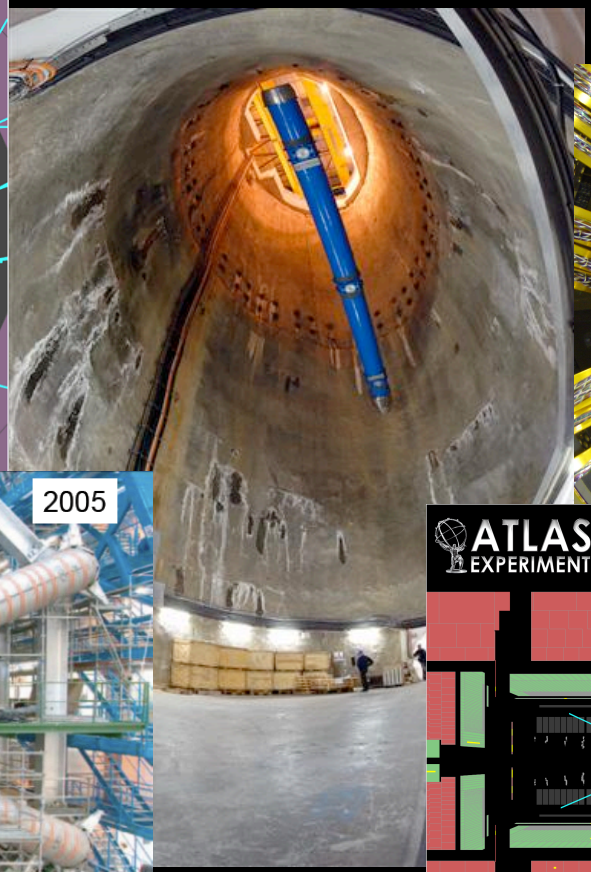
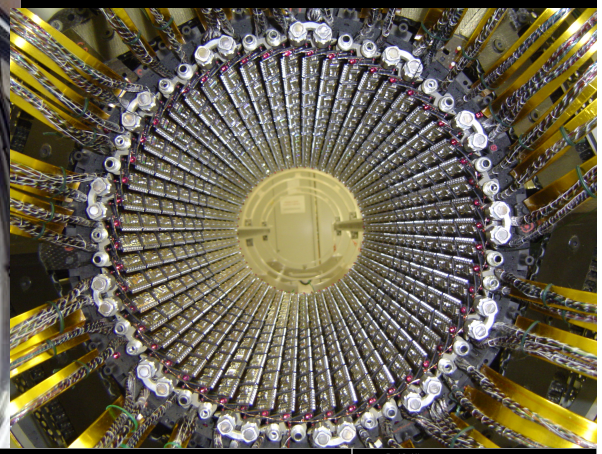
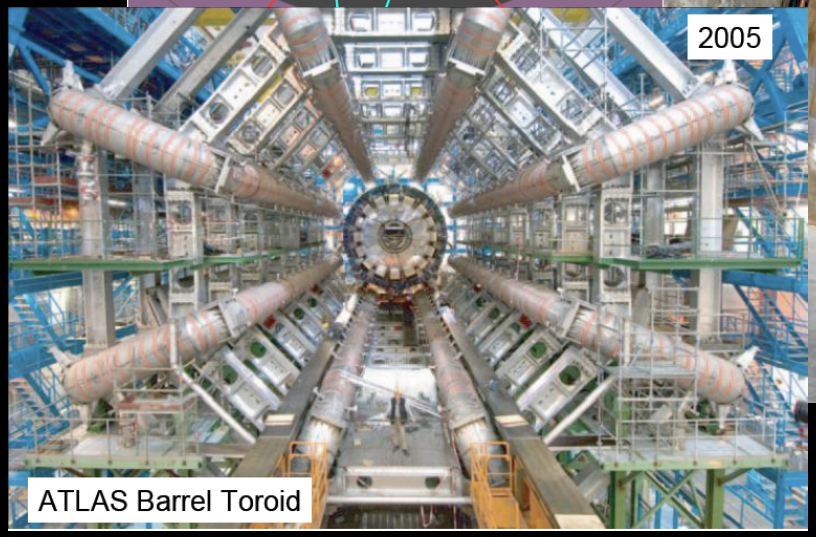
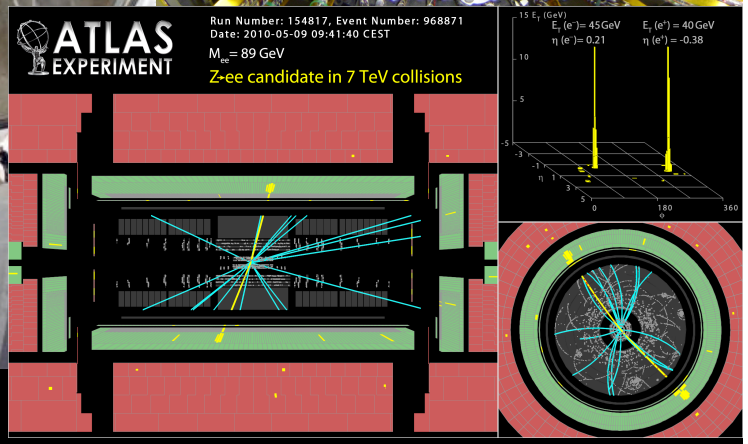
The LHC and ATLAS: Status and First Results











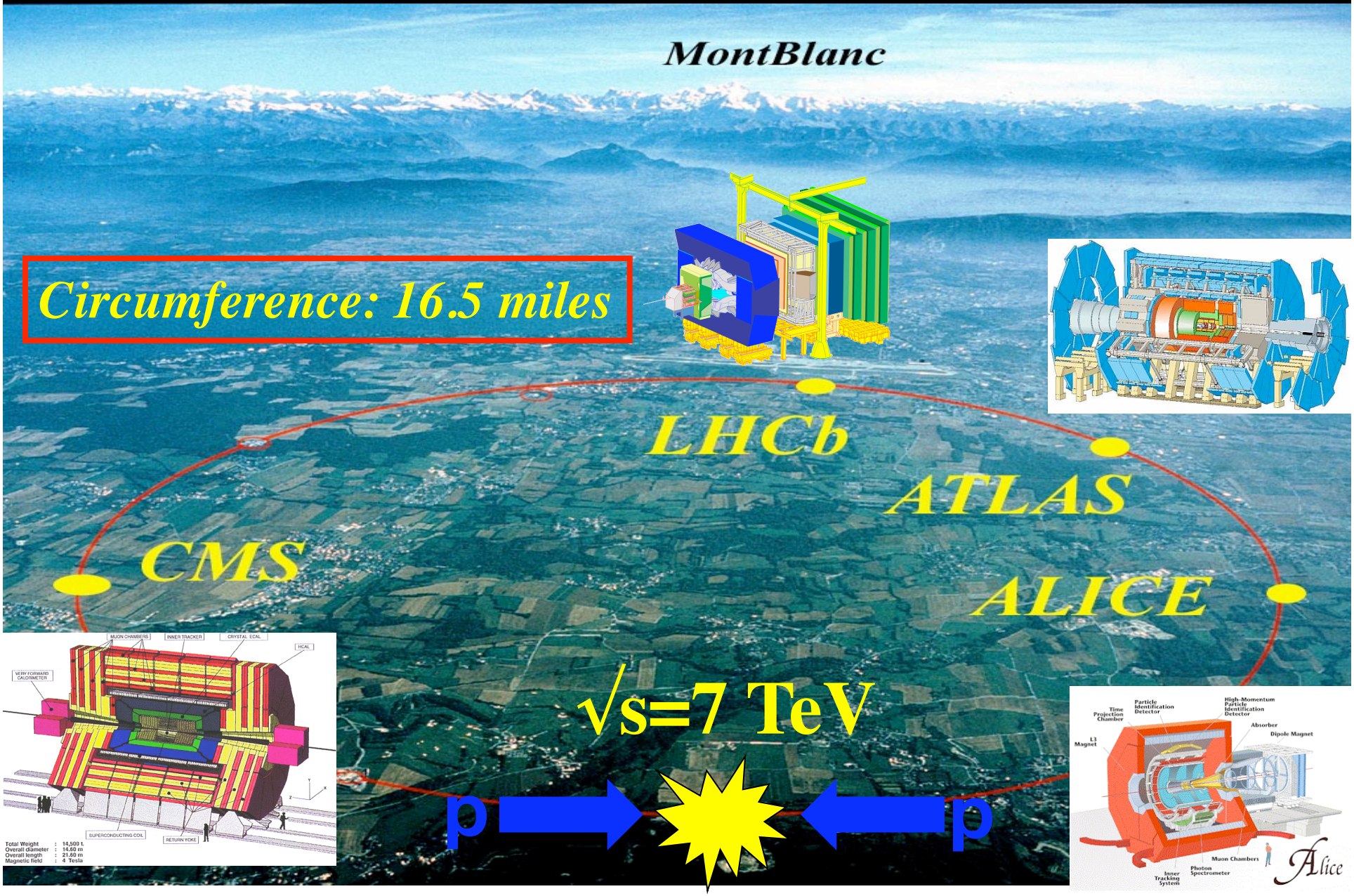
Beate Heinemann, UC Berkeley and LBNL

RPM Seminar, LBNL, August 2010

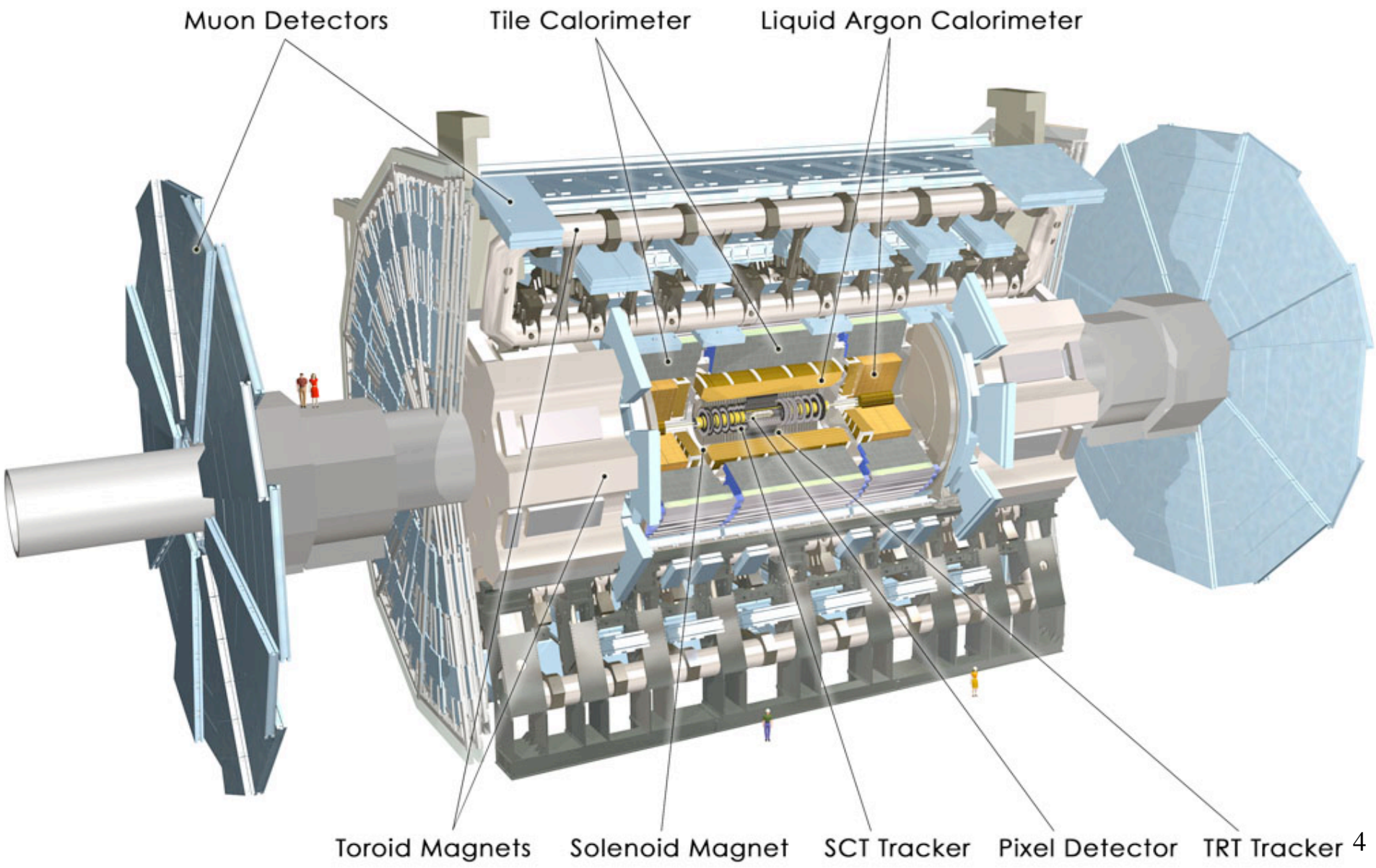
Outline

- **Introduction**
  - LHC and ATLAS
  - Data Taking, Luminosity and Trigger+DAQ
- **First Physics Results**
  - Minimum Bias
  - J/psi and Upsilon
  - Jets
  - W's and Z's
  - Towards Top
  - New Physics
- **Conclusions and Outlook**

The Large Hadron Collider (LHC)

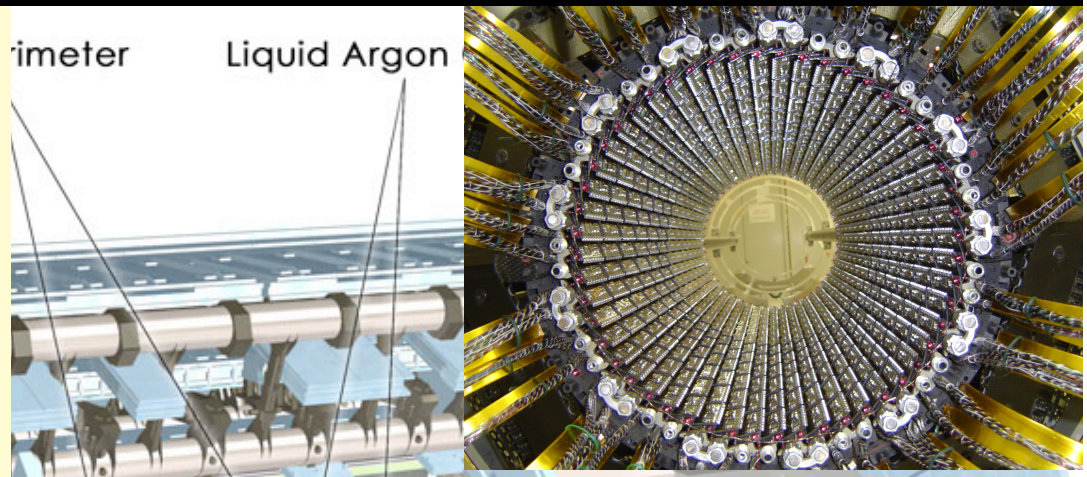


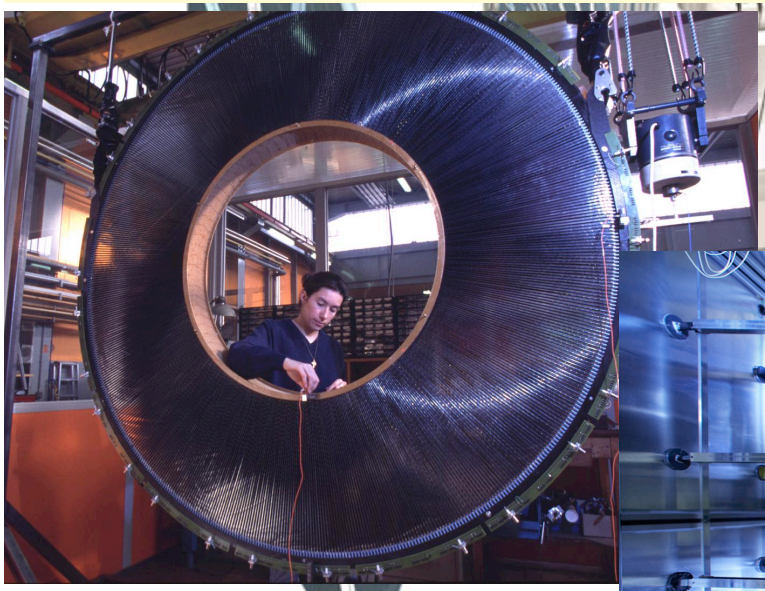
ATLAS Detector

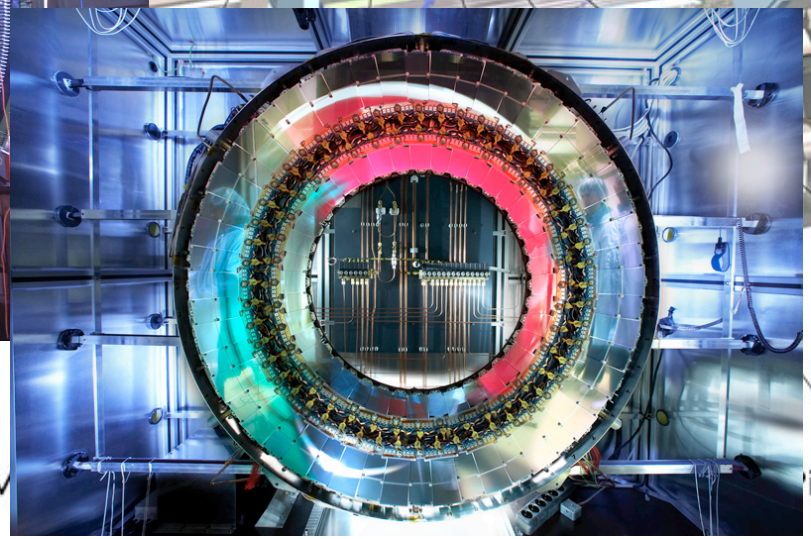


ATLAS Detector

Inner Detector: |η|<2.5
- Si Pixels: 40x800 μm
- Si Strips: 80 μm
- Transition Rad. Tracker
- Solenoid: B=2 T
- $\sigma/p_T = 3.8 \times 10^{-4}\ p_T/\text{GeV} \oplus 0.015$ (e.g. 4% at 100 GeV)



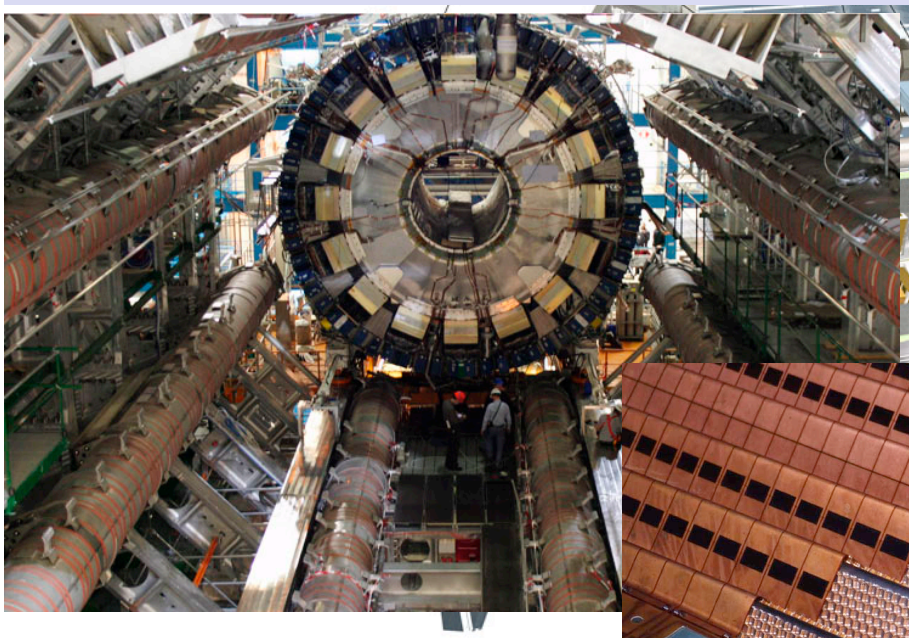


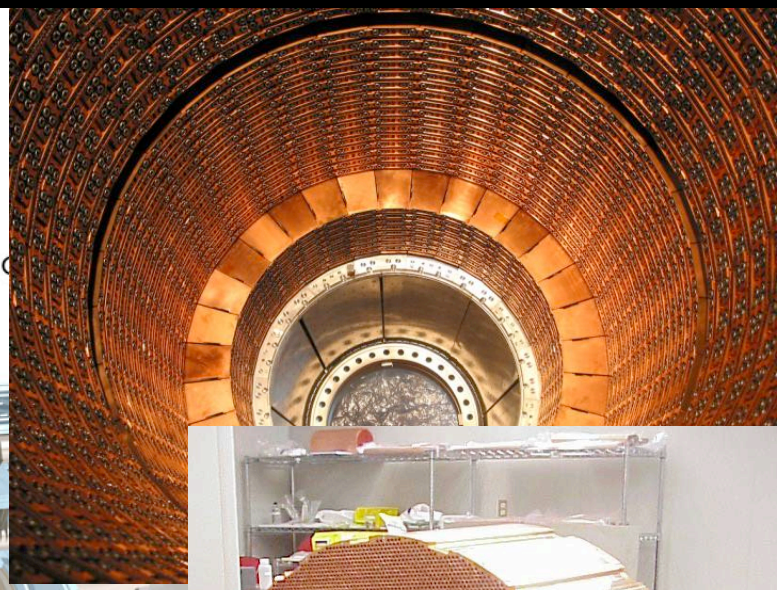


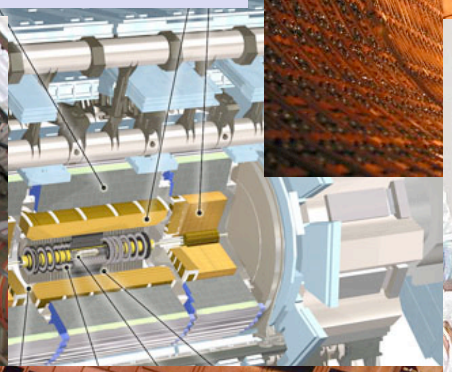
ATLAS Detector

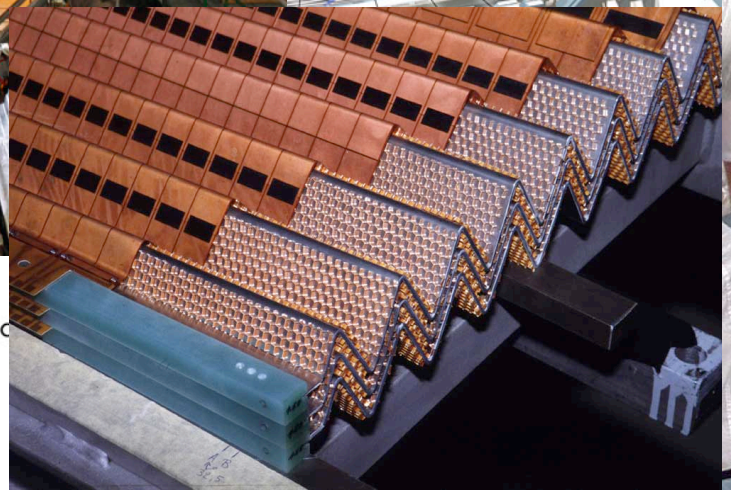
Calorimeters: |η|<4.9

- Lead/LAr : Electromagnetic
- Cu/LAr : Hadronic Endcap
- Tile (steel/plastic scintillator): Hadronic Barrel
- EM: $\sigma/E = 10\%\sqrt{E}$ (e.g. 1% at 100 GeV)
- HAD: $\sigma/E = 50\%\sqrt{E} \oplus 3\%$







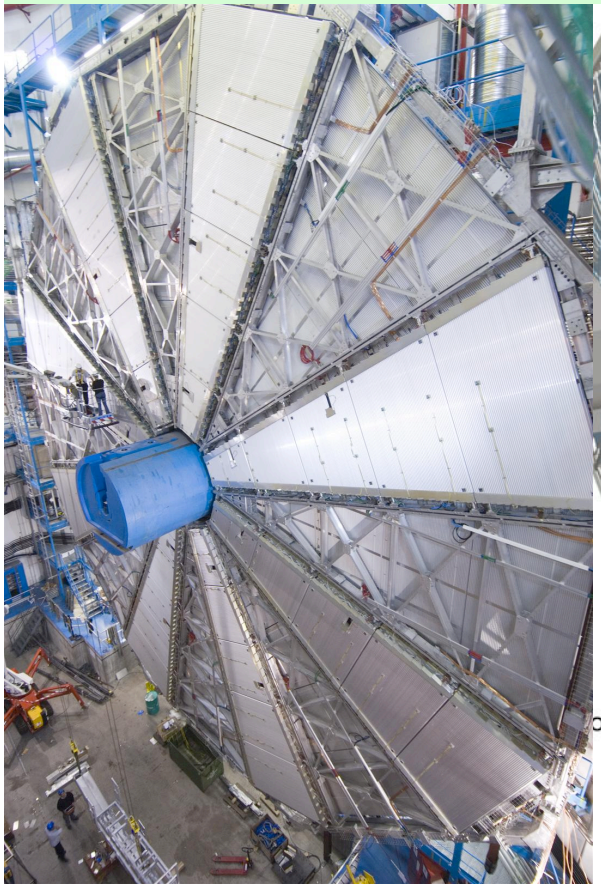


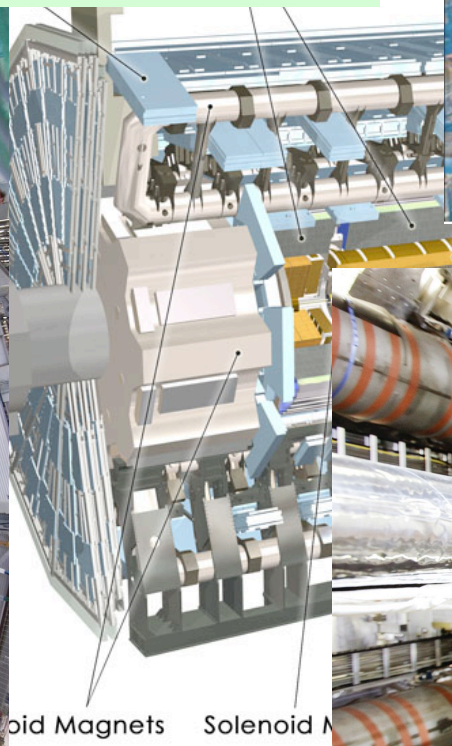
Toroid

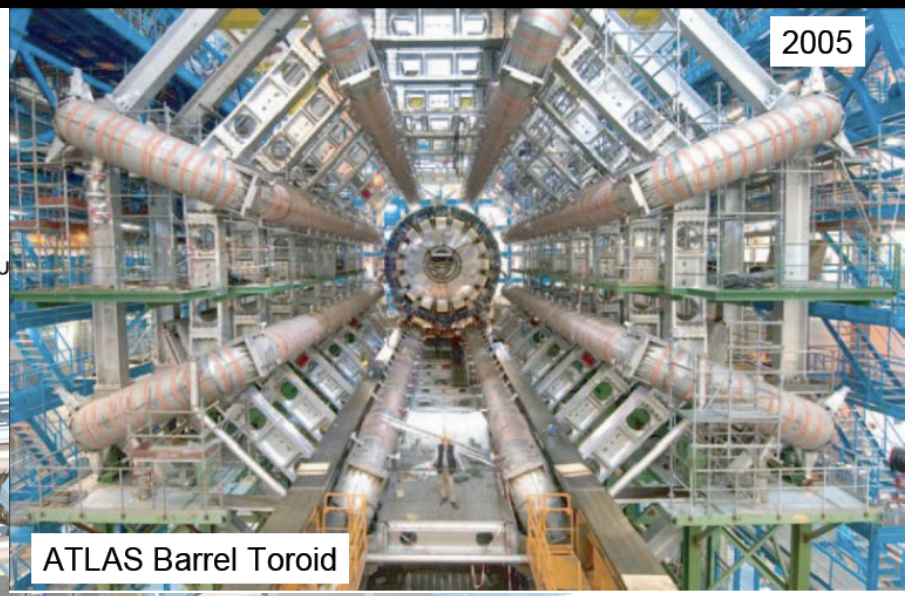
ATLAS Detector

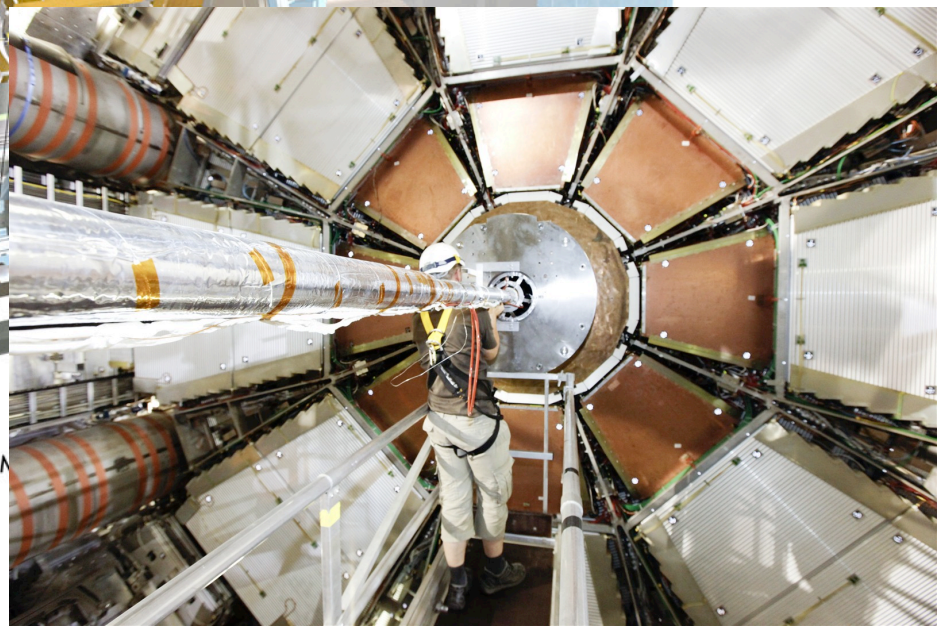
Muon System: |η|<2.5

- Precision chambers (MDT and CSC)
- Trigger chambers (RPC and TGC)
- Air-core toroid magnet (∫BdL=1-7.5 Tm)
- 10% p resolution at 1 TeV



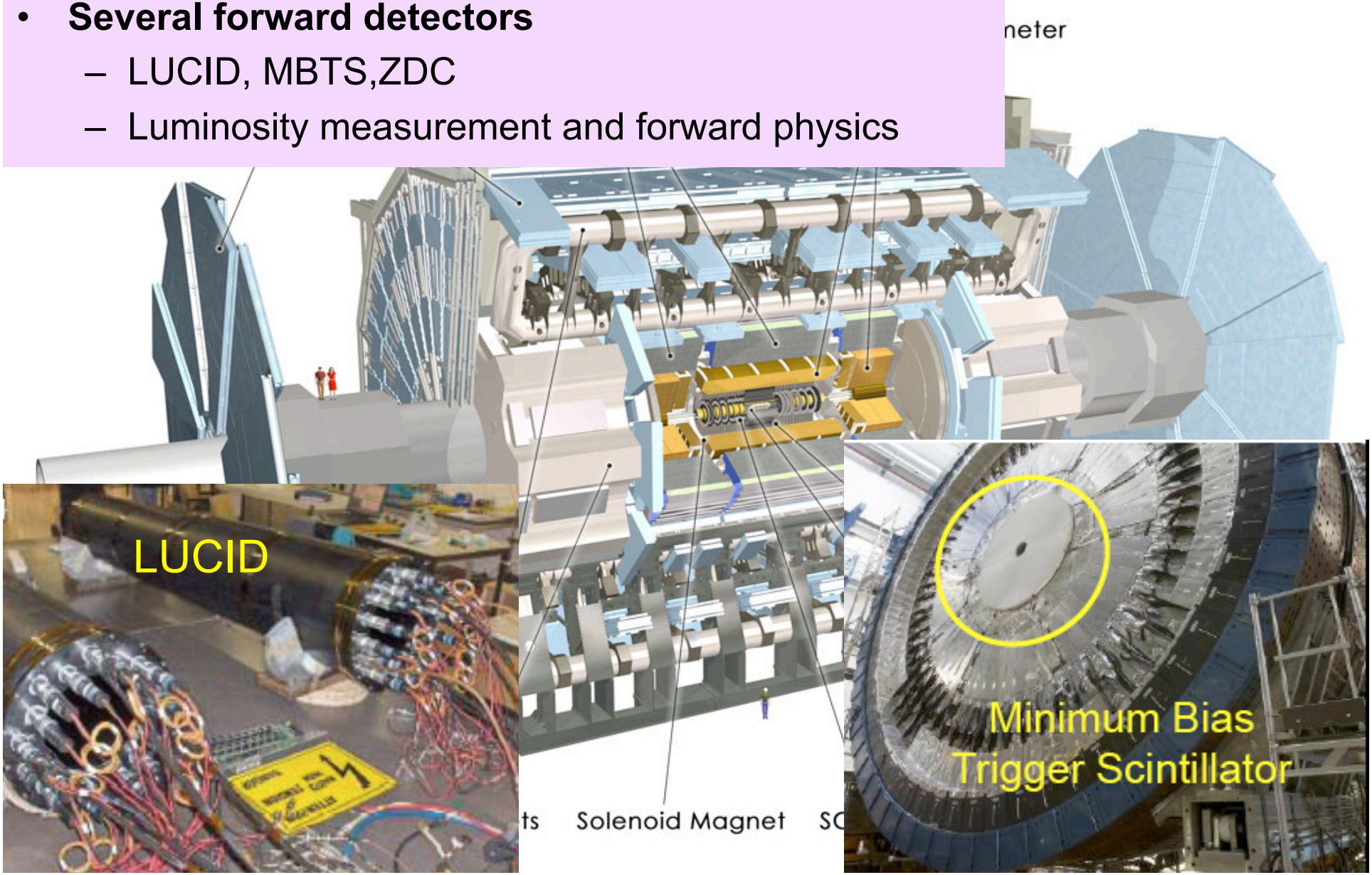




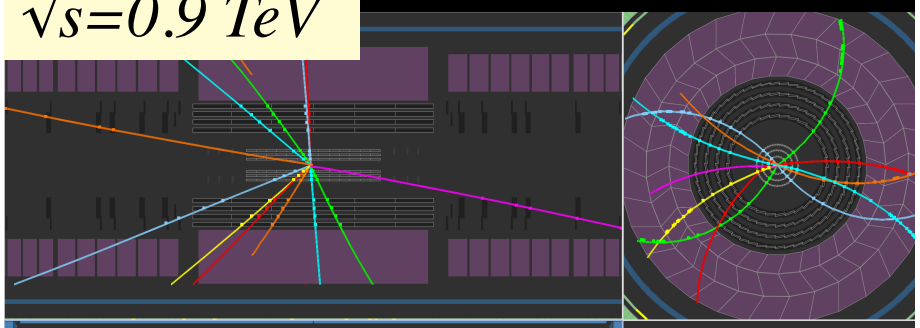


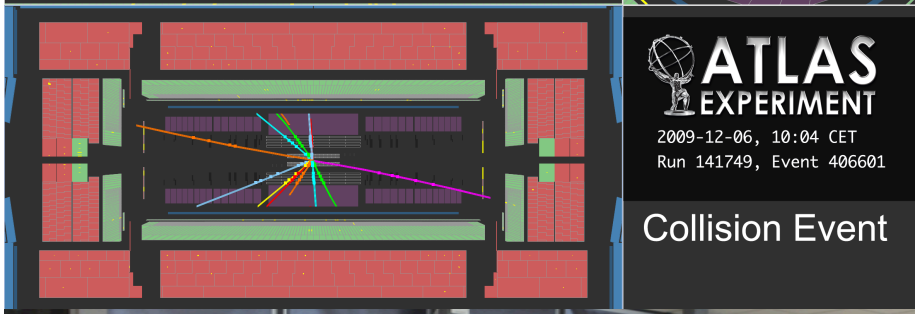
ATLAS Detector

- **Several forward detectors**
  - LUCID, MBTS,ZDC
  - Luminosity measurement and forward physics



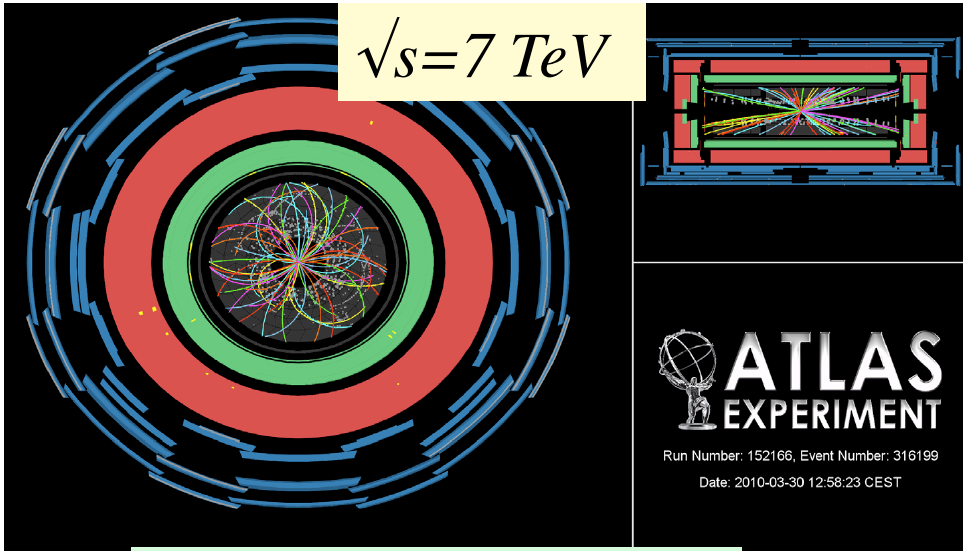
$\sqrt{s}$=0.9 TeV





Collision Event

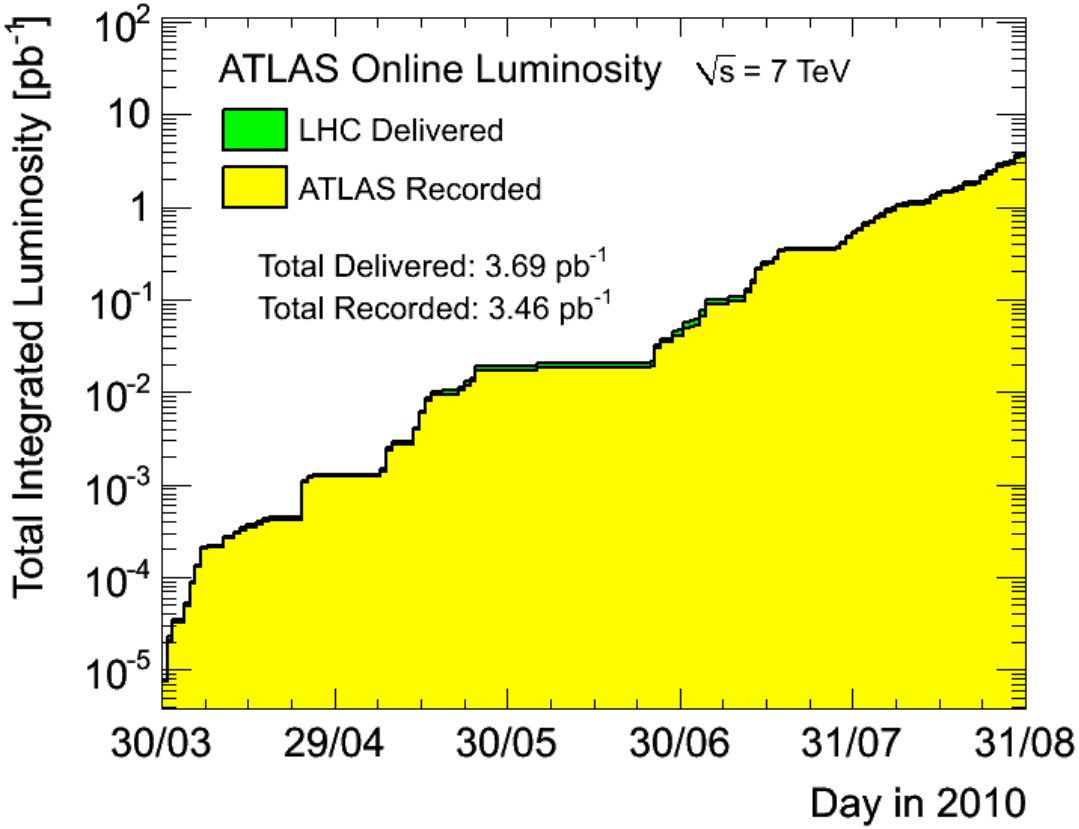
$\sqrt{s}$=7 TeV



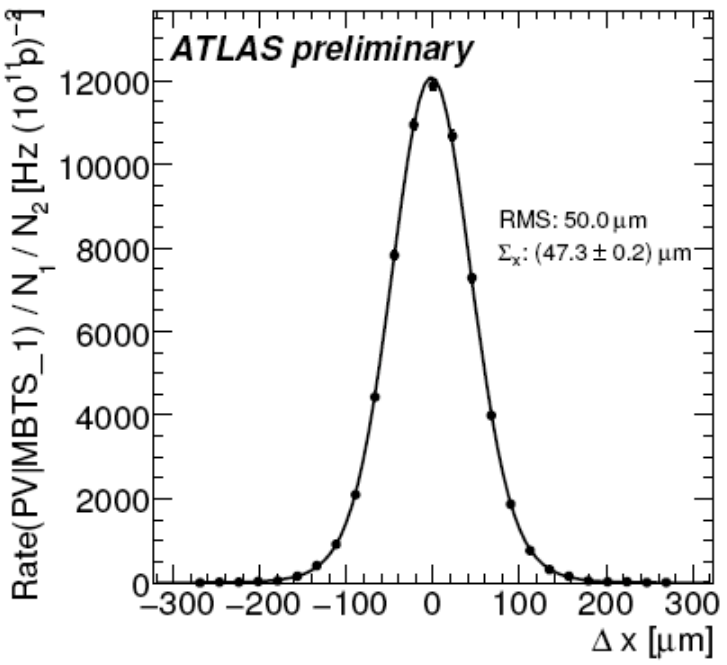
March 30th 2010: first 7 TeV Collisions

Luminosity

$$\mathcal{L} = \frac{n_b f_r I_1 I_2}{2\pi \Sigma_x \Sigma_y}$$



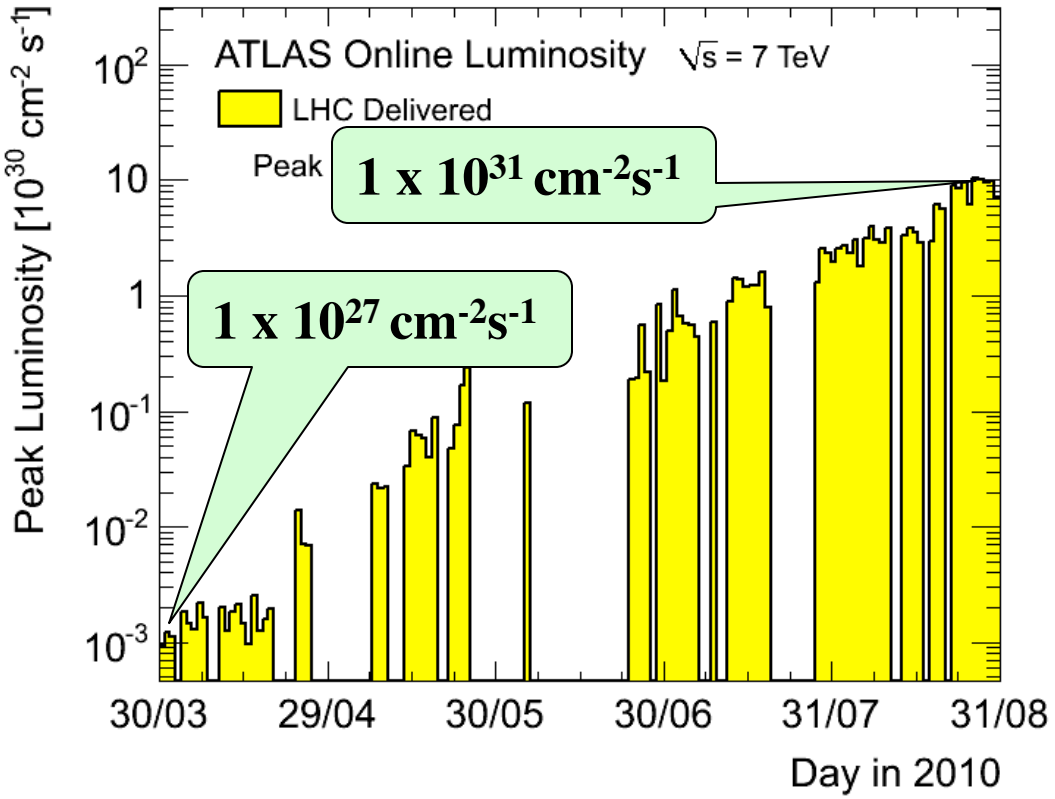
Transverse beam profile as measured in Van-der-Meer scan



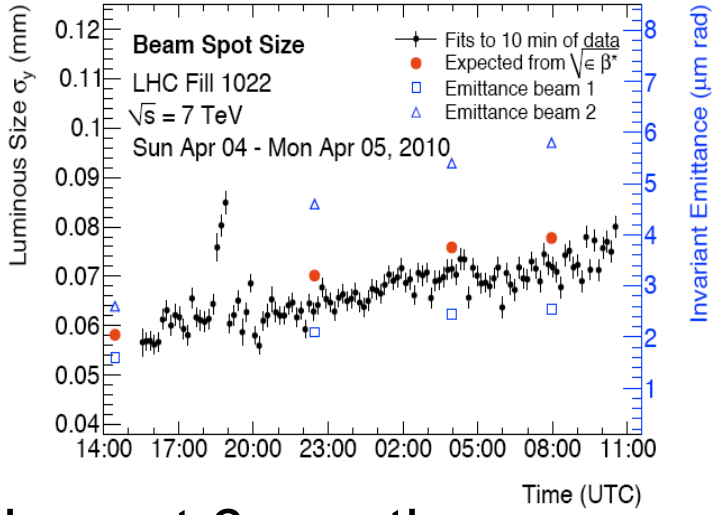
- **Delivered ∫Ldt=3.69 pb^{-1}**
  - calibrated using a Van-der-Meer scan to 11% precision
    - Dominated by 10% uncertainty on beam current normalization
- **ATLAS recorded 93.8% of the data on tape**

Peak Luminosity Evolution

$$\mathcal{L} = \frac{n_b f_r I_1 I_2}{2\pi \Sigma_x \Sigma_y}$$



Protons/bunch $I_1 \approx I_2$	10^{11}
# of bunches n_b	up to 36
beam size $\Sigma_x \approx \Sigma_y$	60 μm
Revolution frequency f_r	11 kHz



- LHC achieved 10,000 fold increase in past 6 months
  - increase in bunch current (factor 10^2) and number of bunches (factor 36) and decrease in beam size (factor 3)
- Aim at increase by another factor of 10 by end of Oct.
  - $L=10^{32}$ cm^{-2}s^{-1} equivalent to ~10 pb^{-1} in 24h

ATLAS Detector Operation

- **Operational Fraction:**
  - 97-100% of subdetector channels fully operational
- **Data Quality:**
  - 94-100% of data good for physics analyses

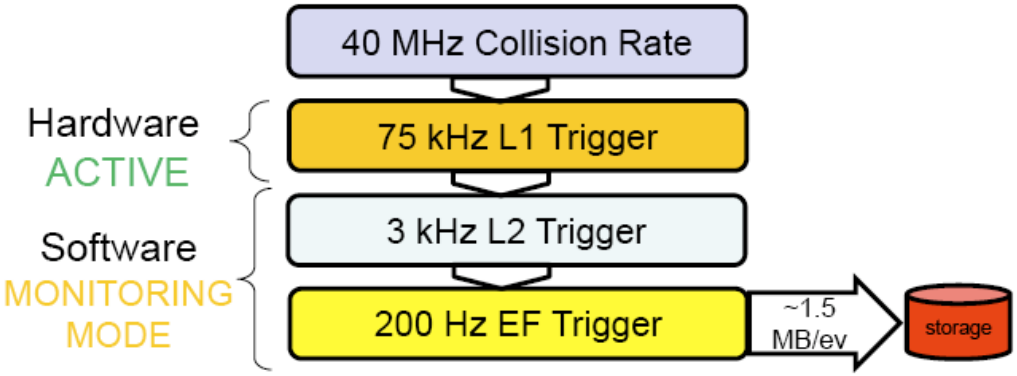
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.4%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	98.0%
LAr EM Calorimeter	170 k	98.5%
Tile calorimeter	9800	97.3%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.6%

Fraction of recorded data with subdetector *good*

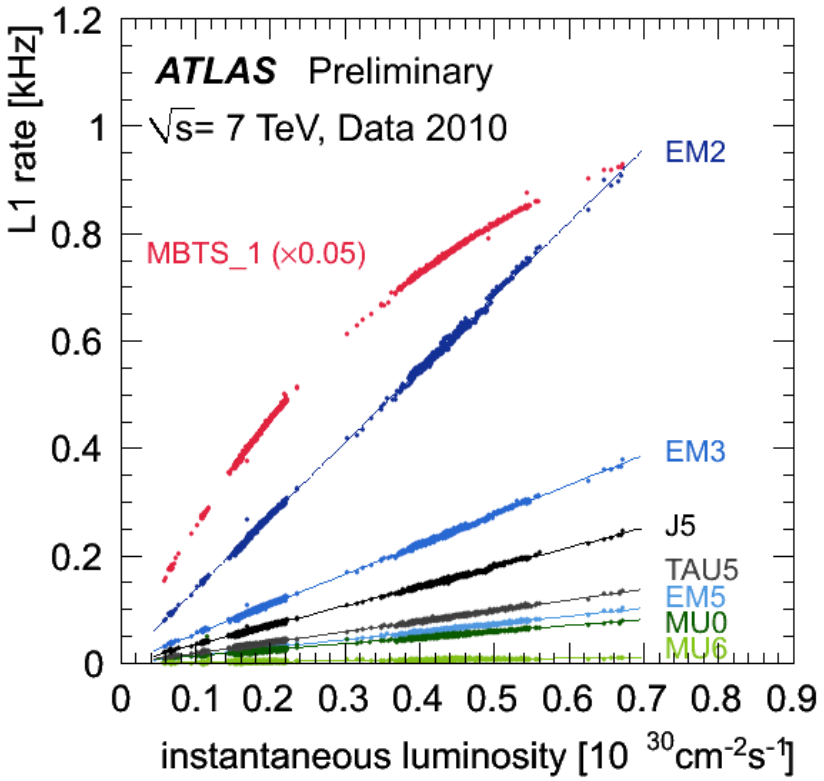
Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	TGC	CSC
97.7	96.4	100	94.4	98.7	99.3	99.2	98.5	98.3	98.6	98.3

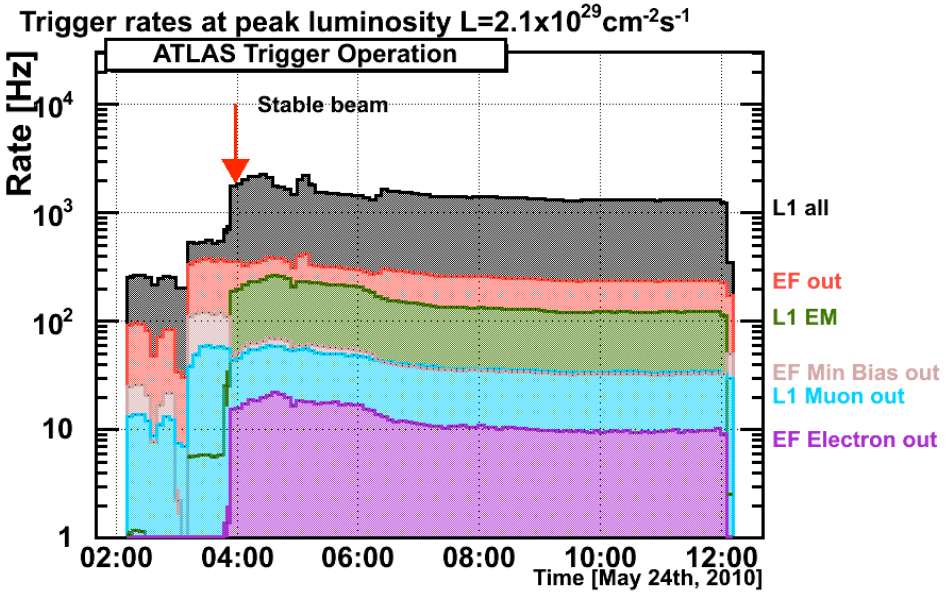
Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams at $\sqrt{s}$=7 TeV between March 30th and August 14th (in %)

Trigger and DAQ

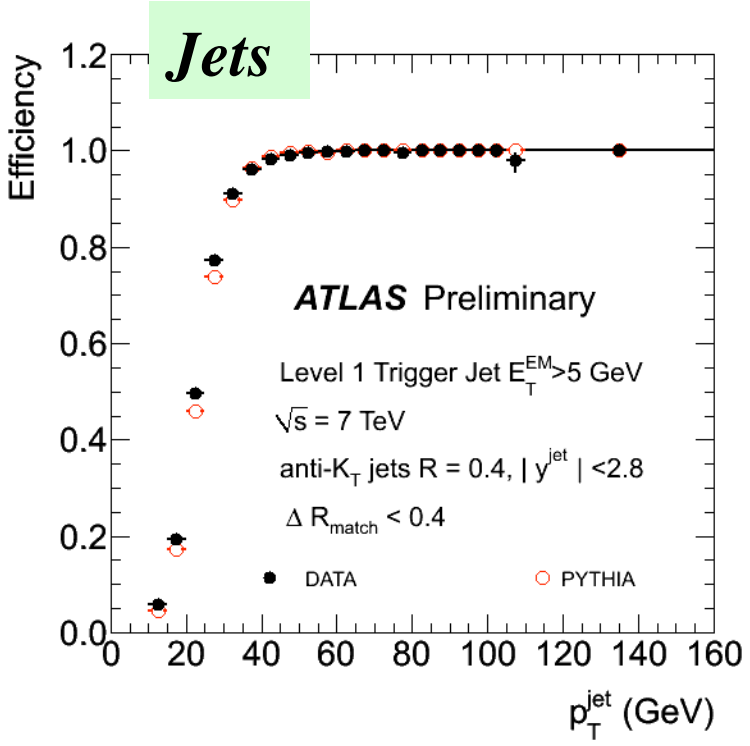


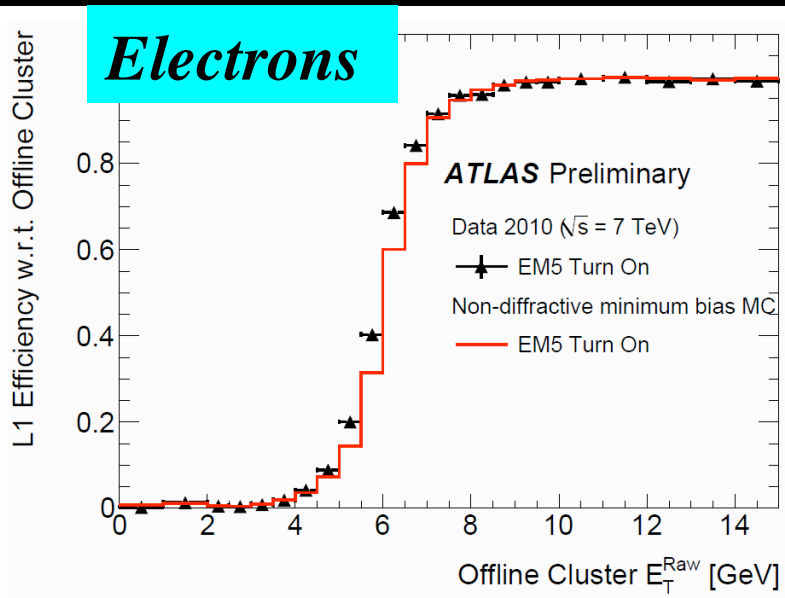
- Collision rate:
  - 1st 2010 run: 50 Hz
  - Recent runs: 200 kHz
- Trigger rate today:
  - L1 ~10 kHz
  - To tape: ~300 Hz

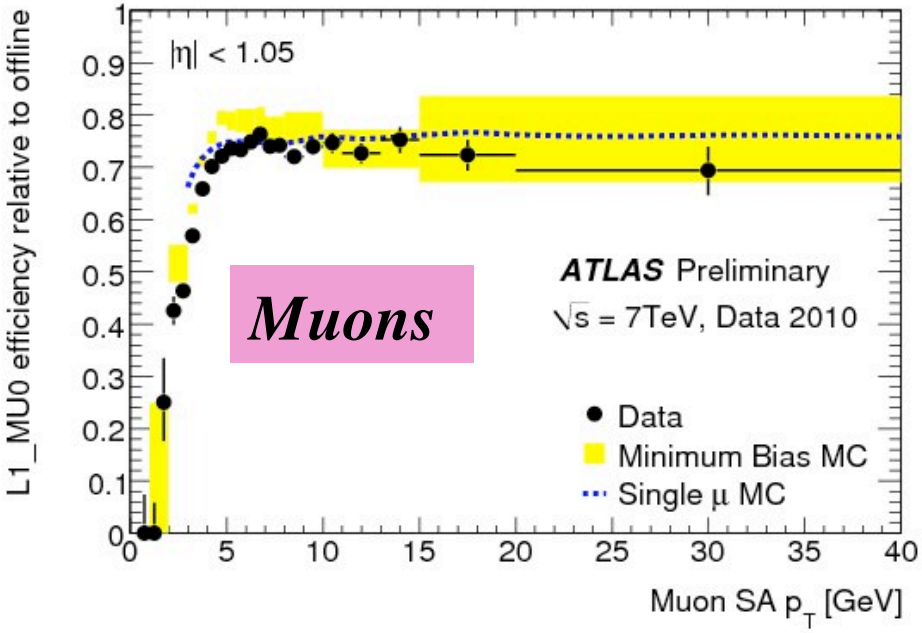




L1 Trigger



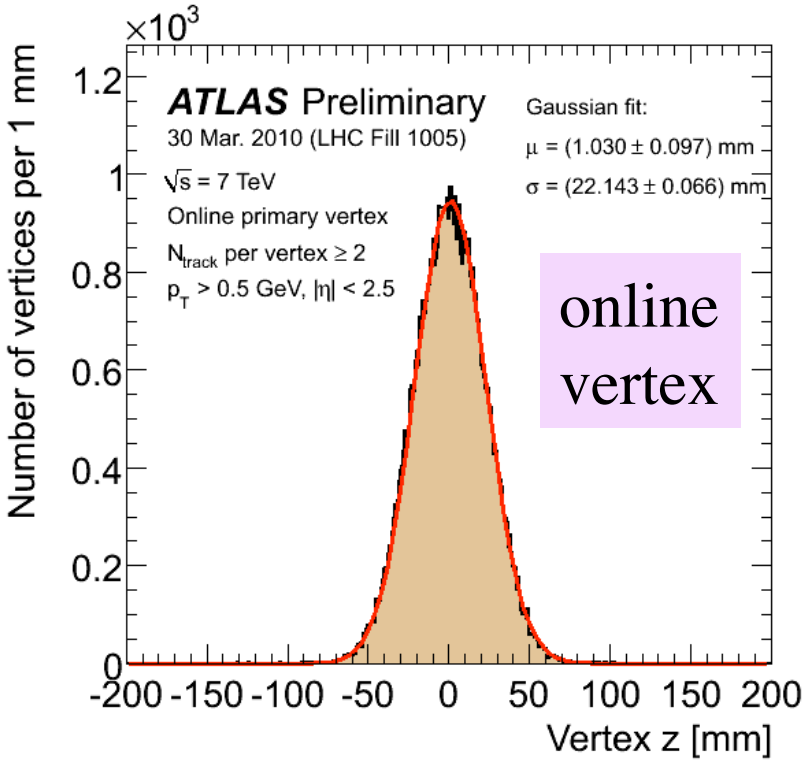




L1 Trigger well understood, agrees also with simulation

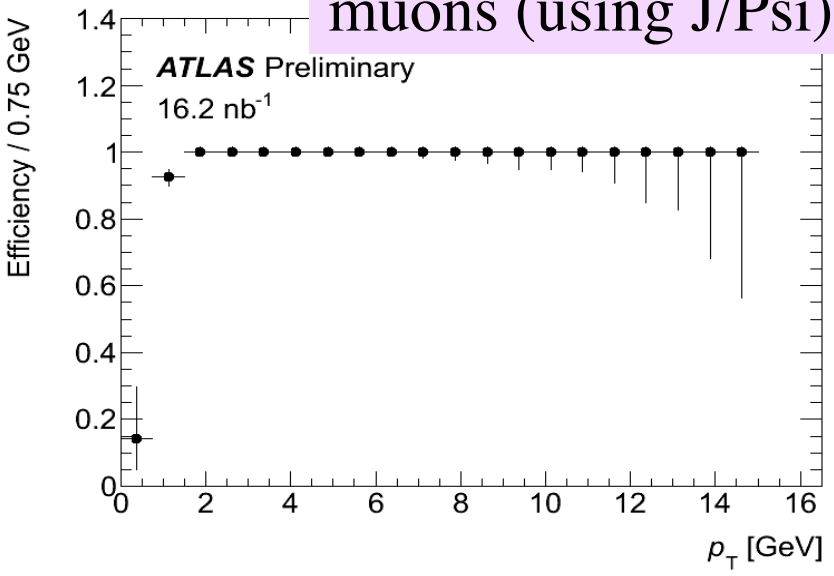
High-Level Trigger

- High-level trigger commissioned
- Used also for online beamspot measurement
  - Important e.g. for b-jet trigger

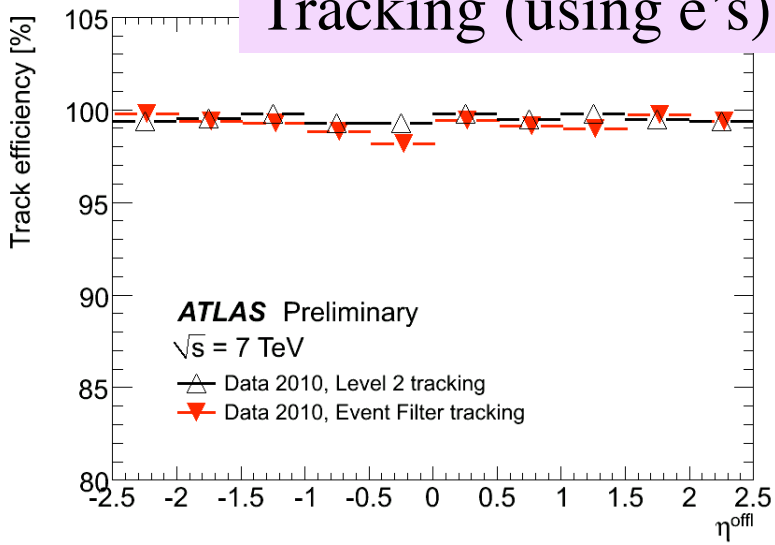


online vertex

muons (using J/Psi)

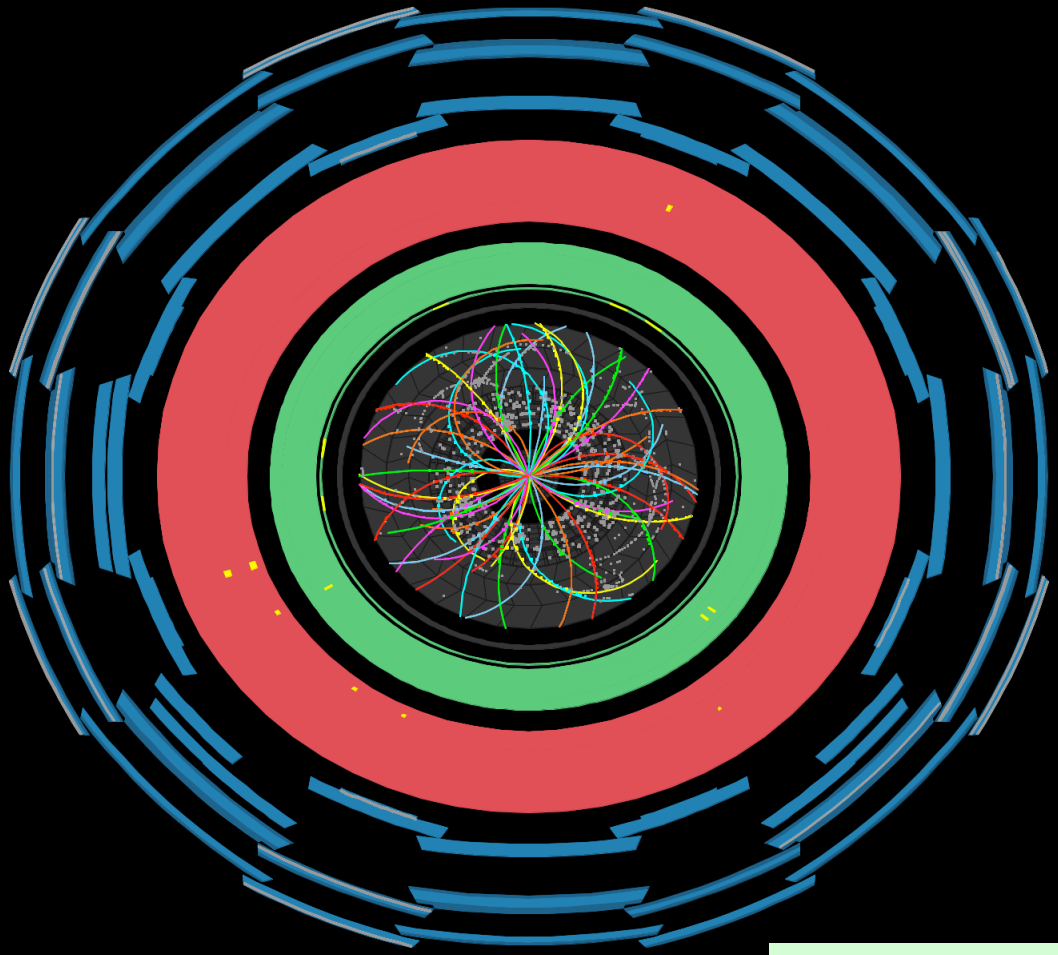


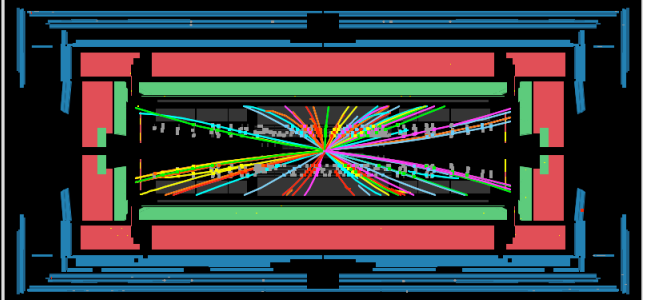
Tracking (using e's)



Minimum Bias Physics

http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html





ATLAS EXPERIMENT

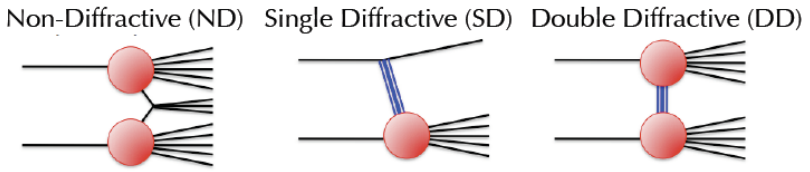
Run Number: 152166, Event Number: 316199

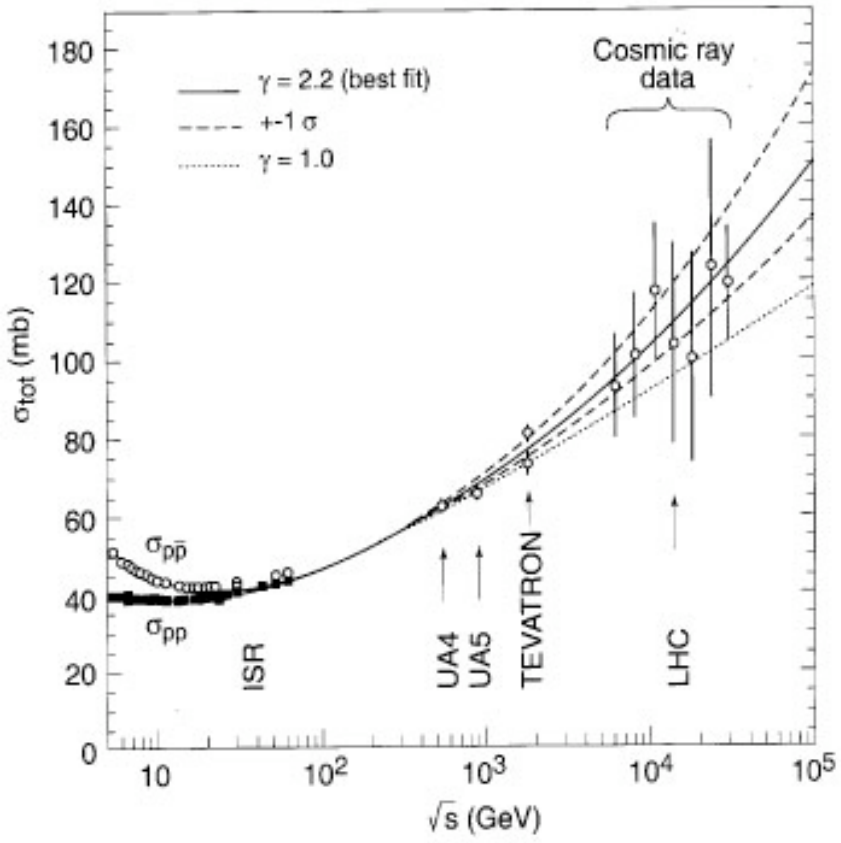
Date: 2010-03-30 12:58:23 CEST

one of the first 7 TeV collision events recorded on March 30th

Minimum Bias Physics

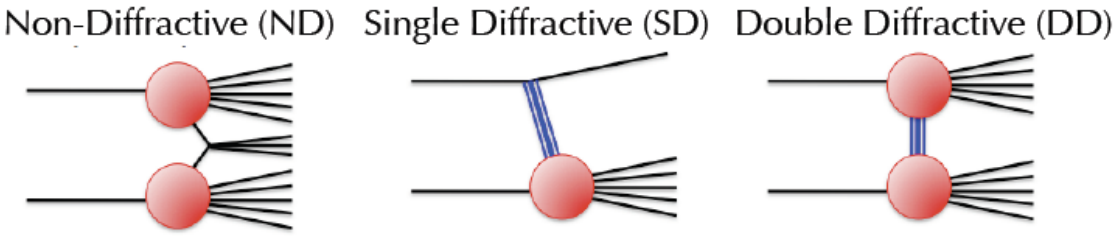
- Total cross section ~100 mb
  - ~70% inelastic
- Measurements of charged particle multiplicities in
  - Inclusive selection
  - Diffraction enhanced selection
  - Underlying event dominated regions
- Rely on understanding of low p_T tracking of charged hadrons
  - Also important for b-tagging





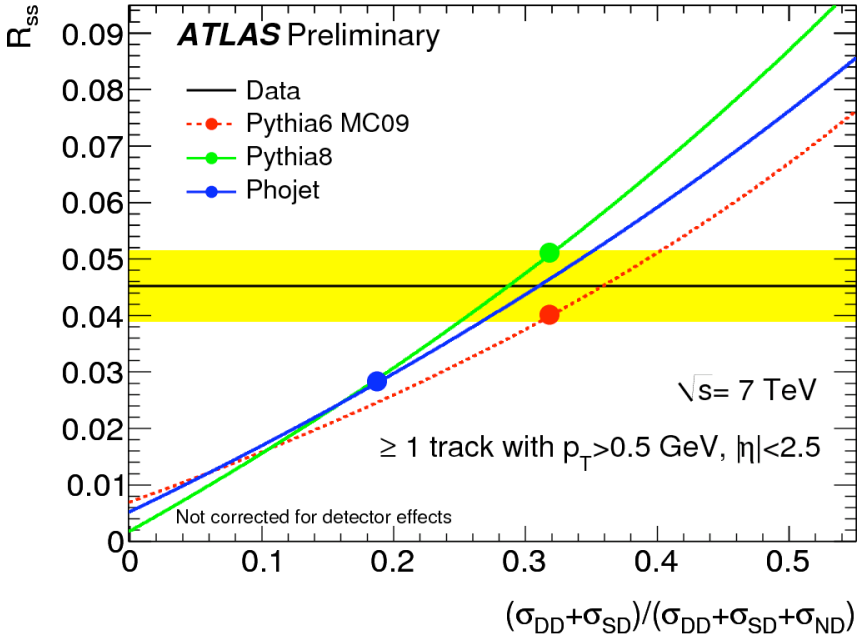
Minimum Bias Physics

- Total inelastic cross section ~70 mb
  - 20-30% diffractive
  - Not yet measured



- Assess diffractive contribution

$$R_{ss} = \frac{\text{Hits on one side of MBTS}}{\text{Hits in MBTS (one or both sides)}}$$

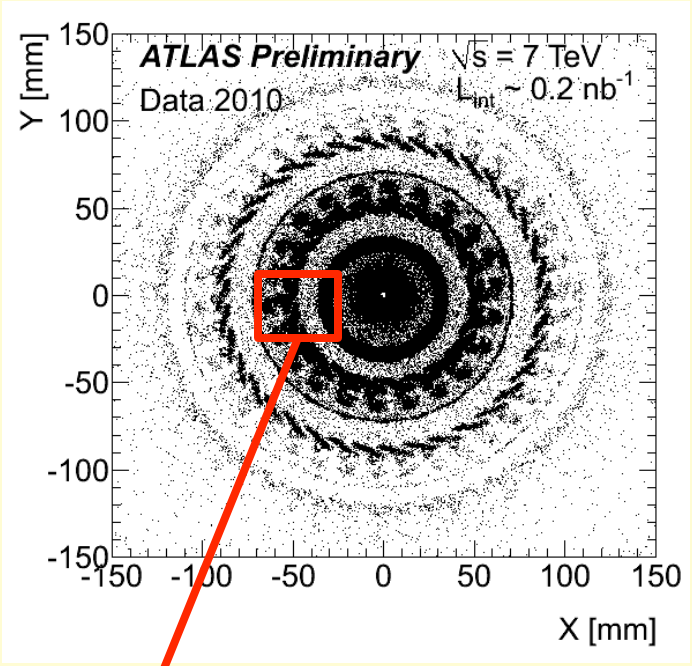


- Data prefer value around 30% for diffractive contribution

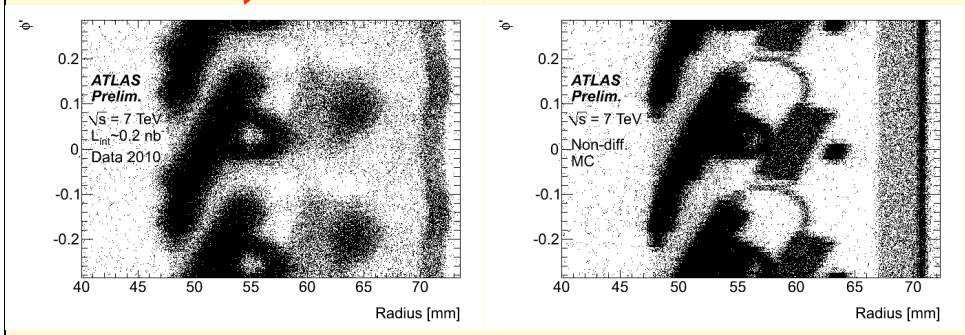
(*)MBTS covers 2.08<|η|<3.84

Inner Detector: Material

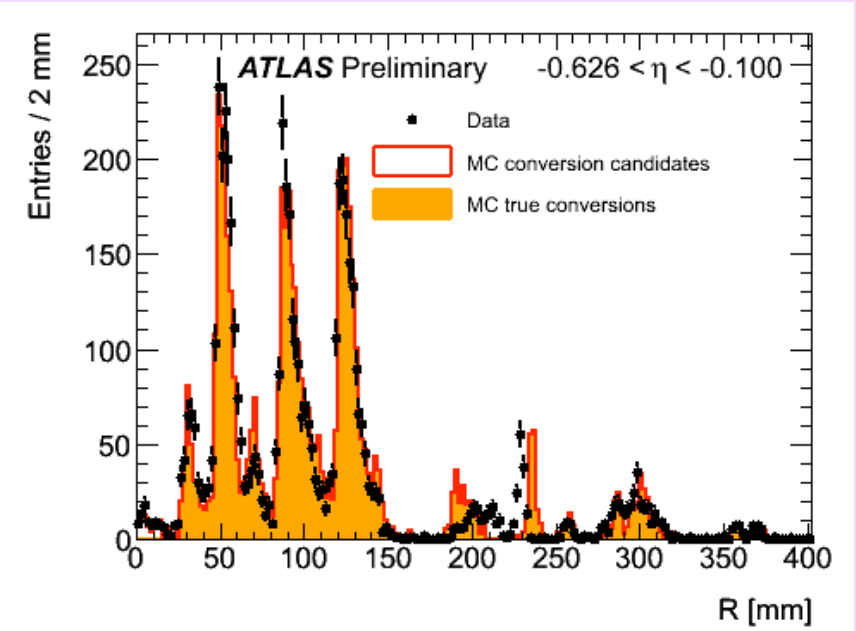
Map material using hadronic interactions



Data ***Simulation***



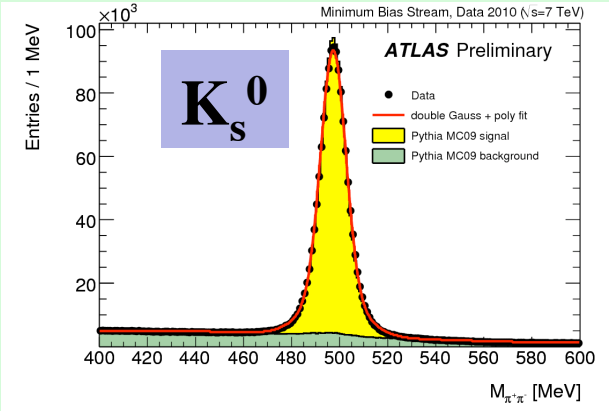
Map material with photon conversions



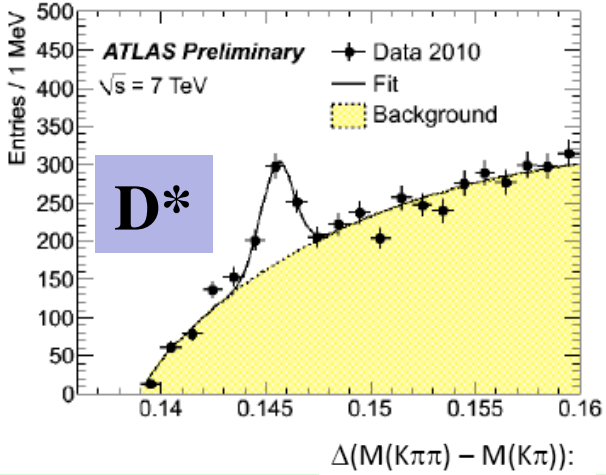
- Excellent agreement between data and simulation
  - Small discrepancies already fixed for new MC production starting now

Inner Detector: Resolution, Scale and particle ID

Resolution and Mass Scale using resonances

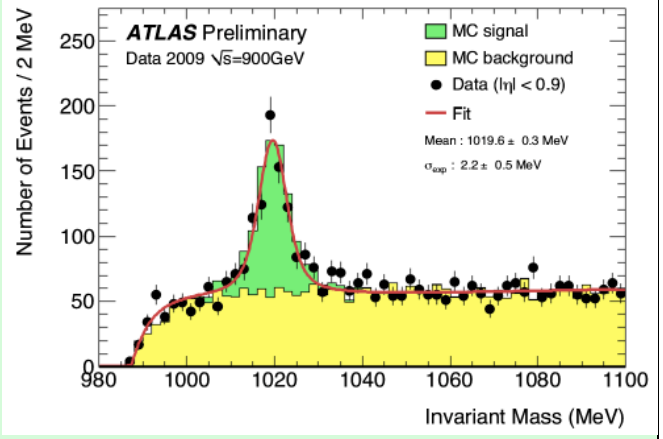


K_s^0

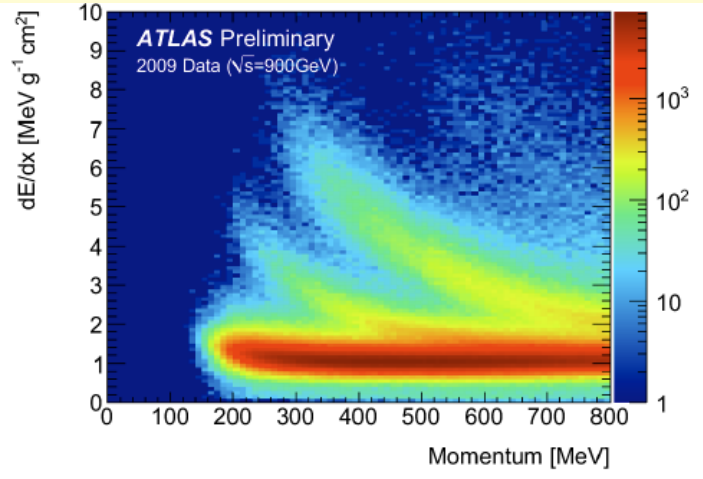


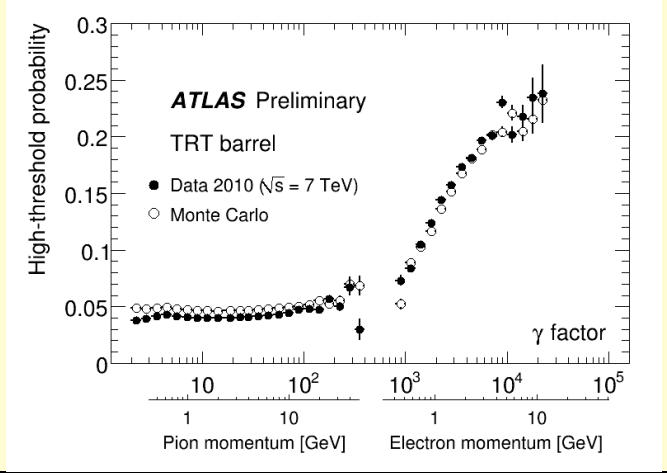
D*

$\Phi \rightarrow K^+K^-$

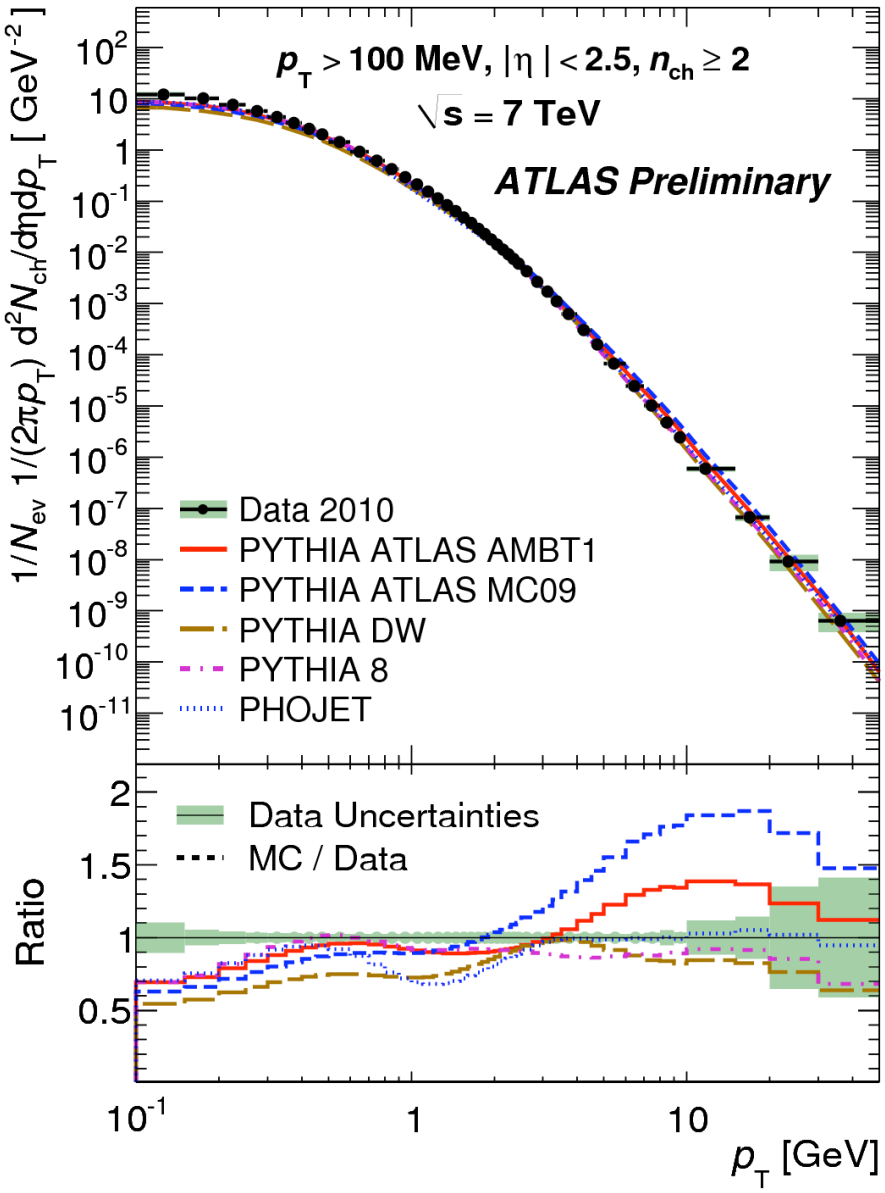


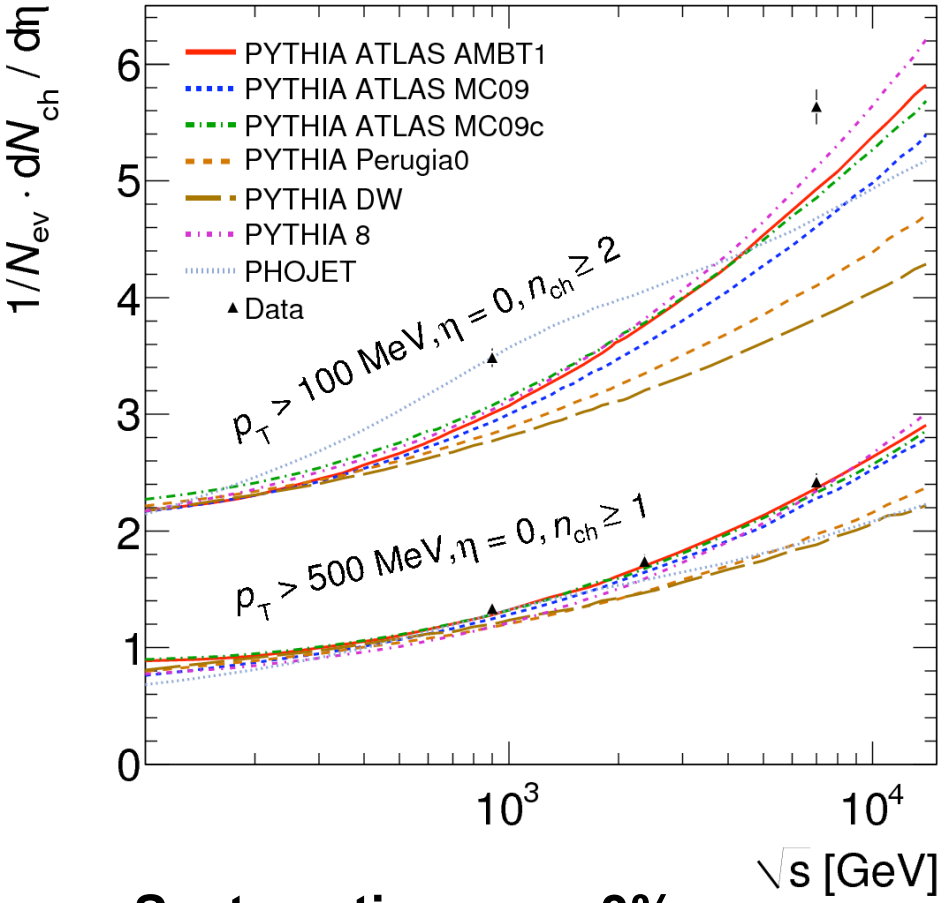
Particle identification using Pixel dE/dx and TRT transition radiation





Inclusive Charged Particle Spectra

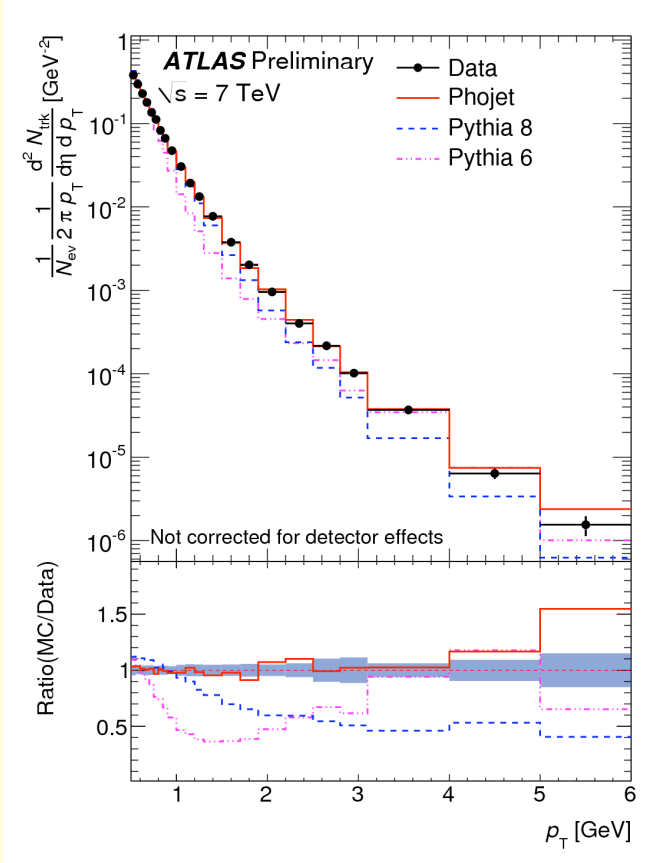




- **Systematic error ~3%**
- **MC models agree to within 50%**
  - But require further tuning
- **Multiplicity rises with energy**

Charged Particles in diffractive events, the Underlying Event and Jets

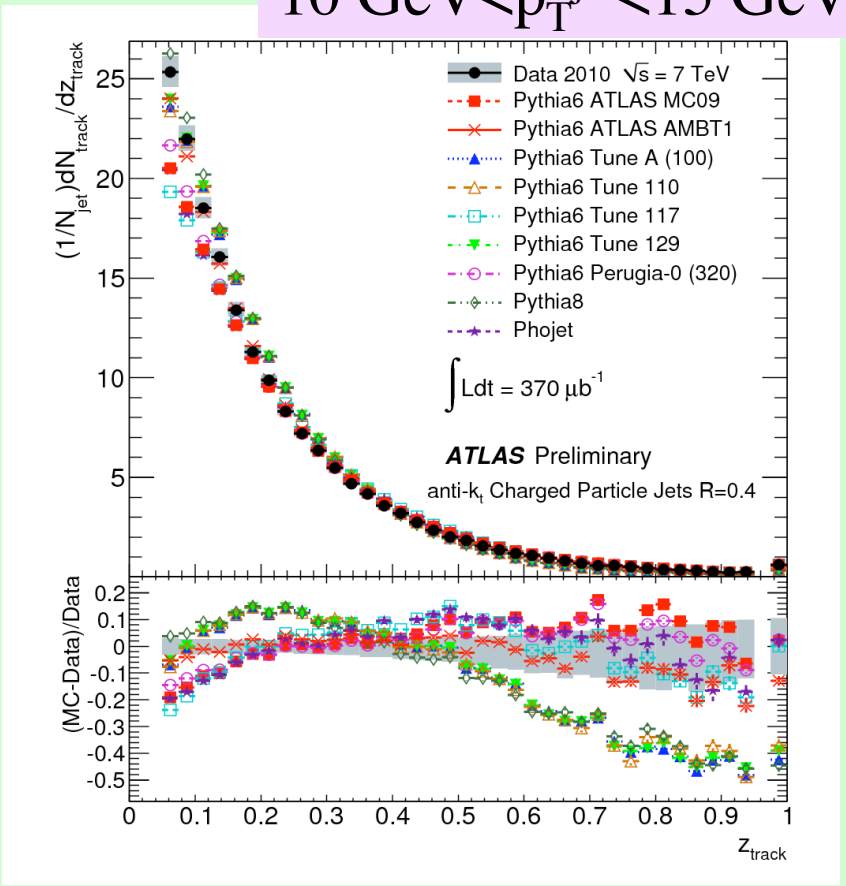
Charged particle spectra in diffractive-enhanced sample:
veto events with hits on both sides of MBTS detector



Phojet describes data best

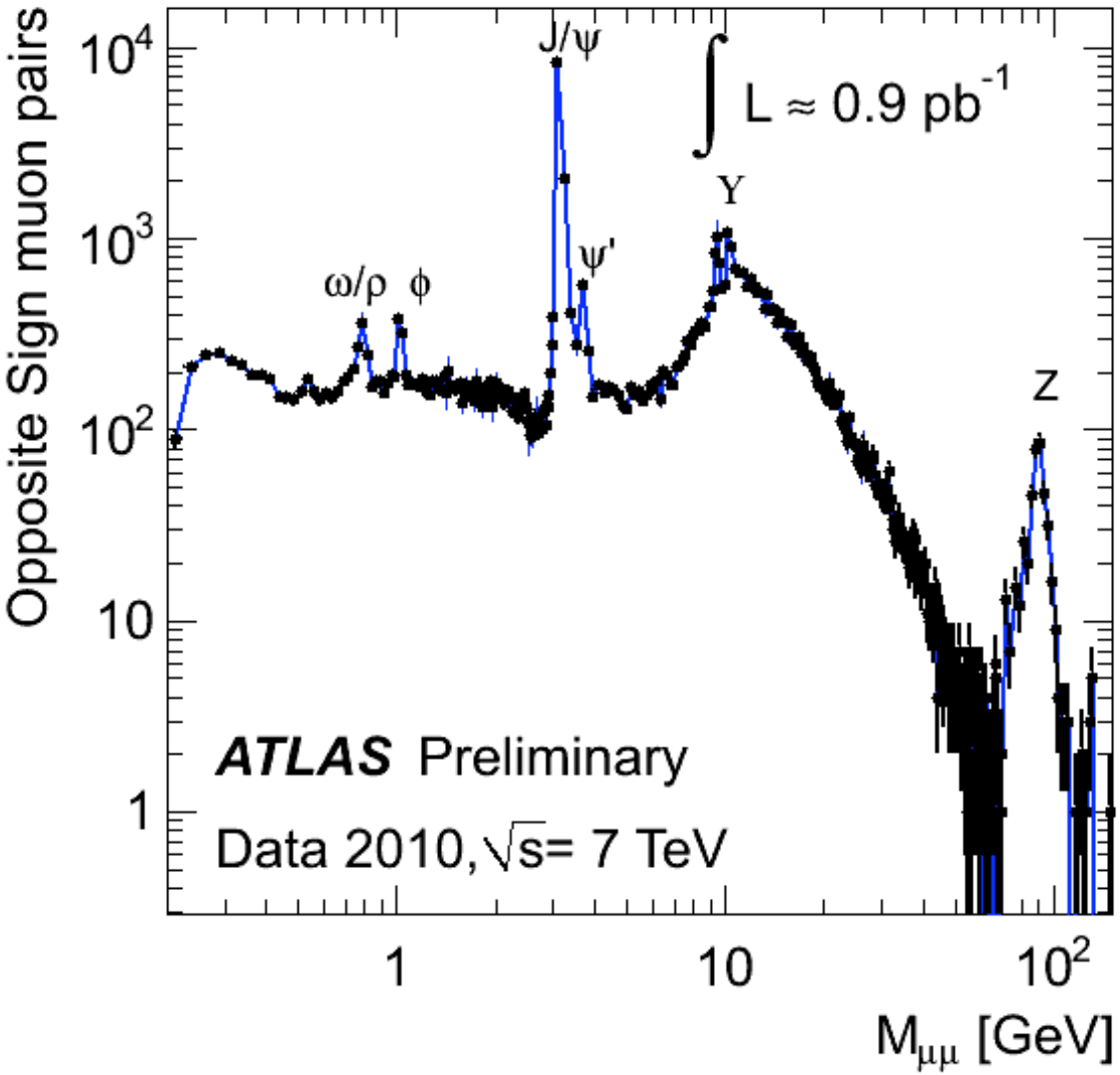
Use tracks to form jets => test fragmentation of jets

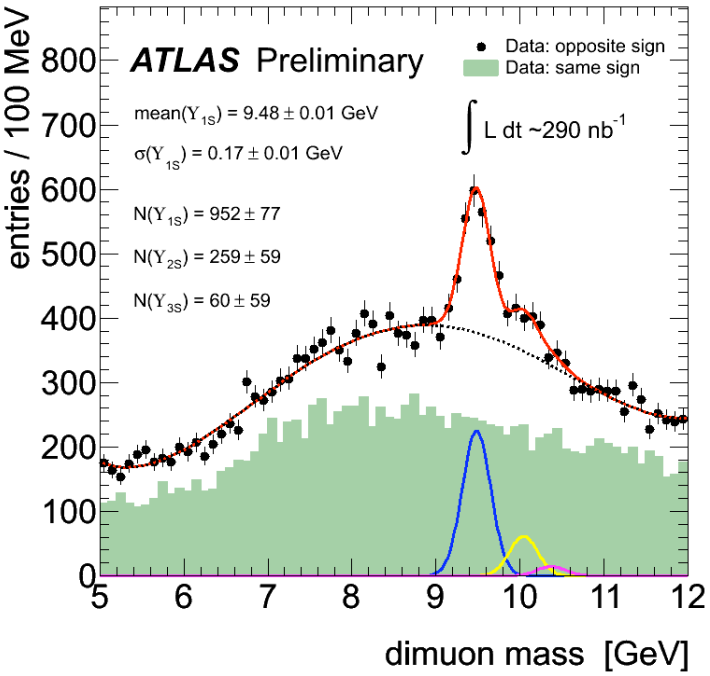
$10\ \text{GeV} < p_T^{jet} < 15\ \text{GeV}$



MC tunes have varying success in describing the fragmentation

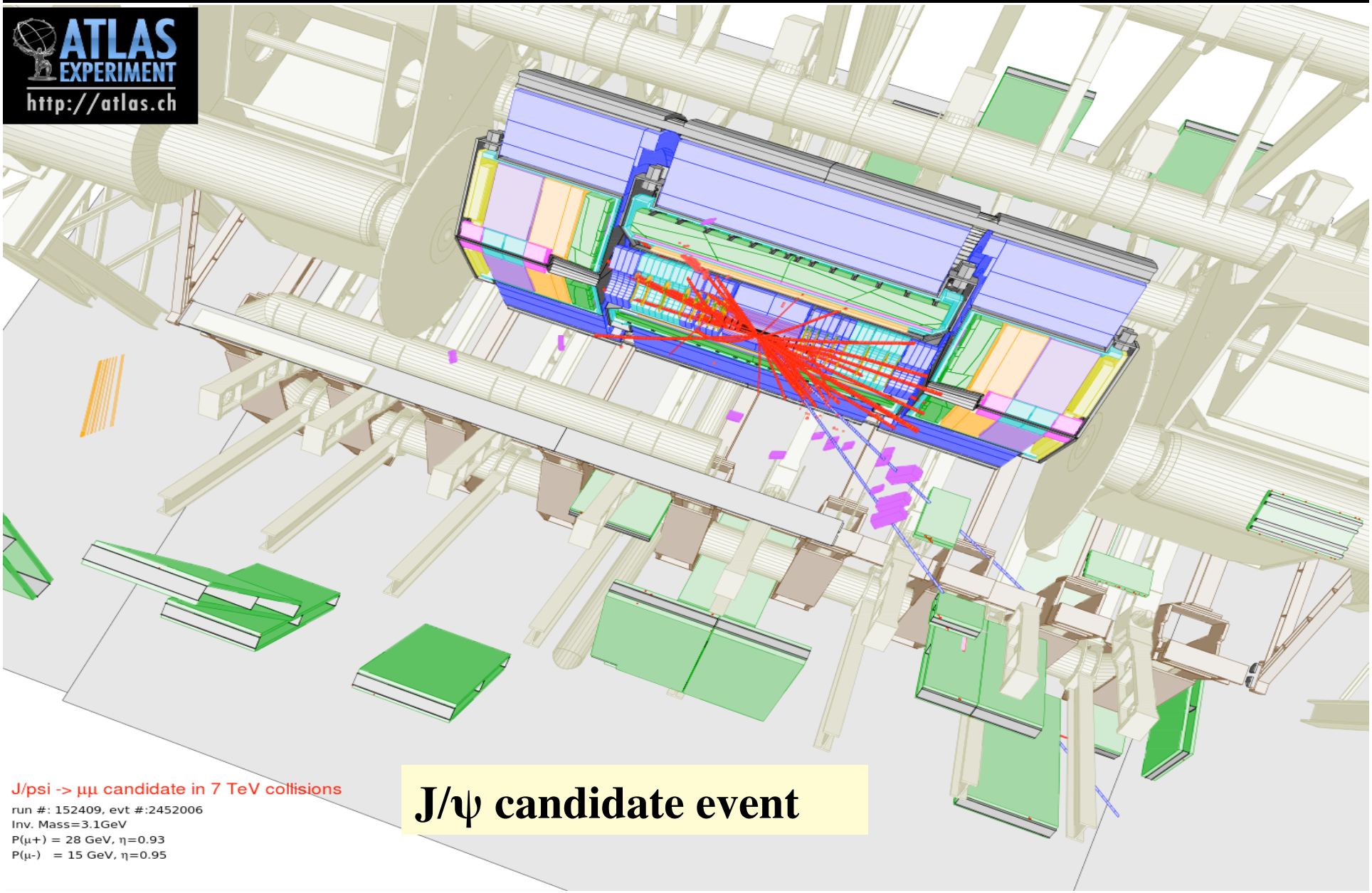
Dimuon Mass Spectrum





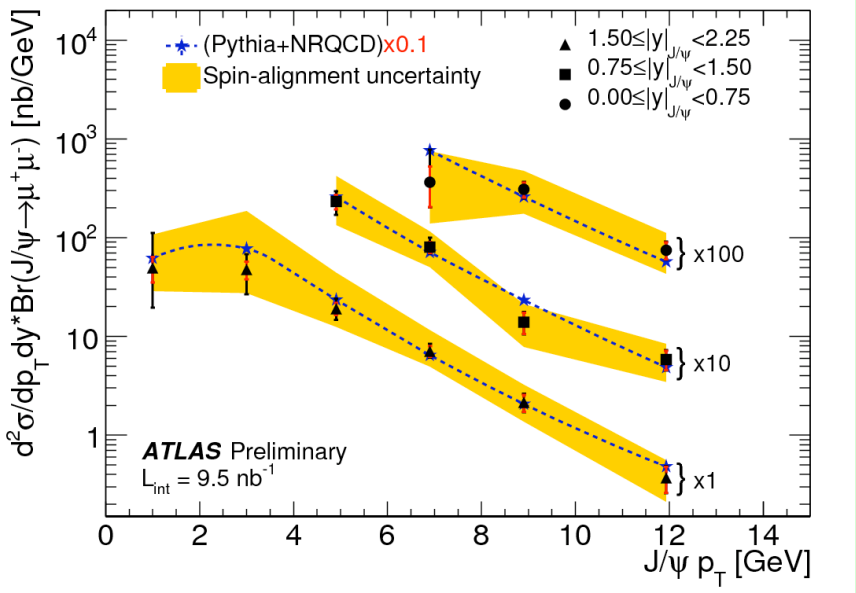
Will now also constitute excellent calibration samples

J/ψ and Υ


ATLAS
EXPERIMENT
http://atlas.ch
J/psi -> μμ candidate in 7 TeV collisions
run #: 152409, evt #:2452006
Inv. Mass=3.1GeV
P(μ+) = 28 GeV, η=0.93
P(μ-) = 15 GeV, η=0.95
J/ψ candidate event

J/ψ Cross Sections

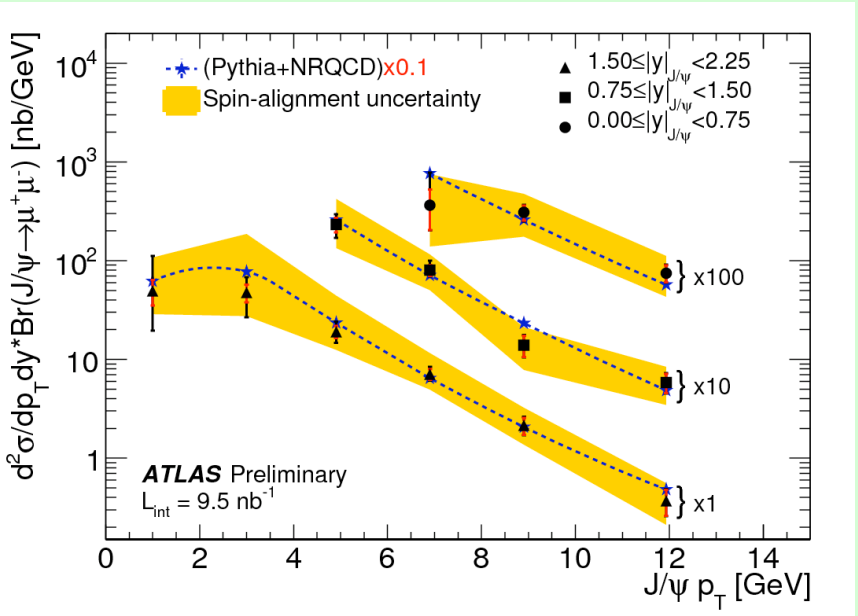
Inclusive cross section



- Kin. range: **p_T=1-12 GeV, |y|<2.25**
- Syst. Uncertainty ~30%
  - Completely dominated by polarization uncertainty
- p_T and y-dependence of σ(J/ψ) agrees with Pythia color octet model
  - Normalization off by factor 10

J/ψ Cross Sections

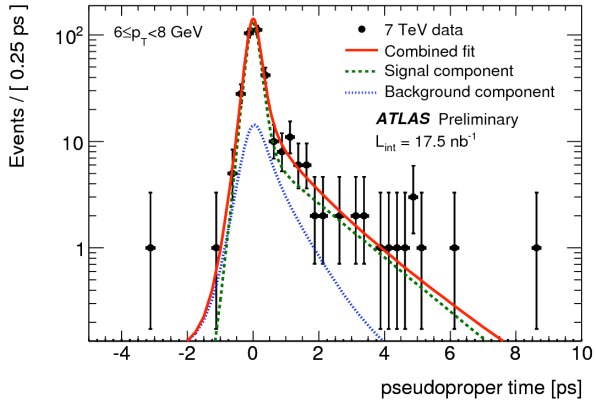
Inclusive cross section



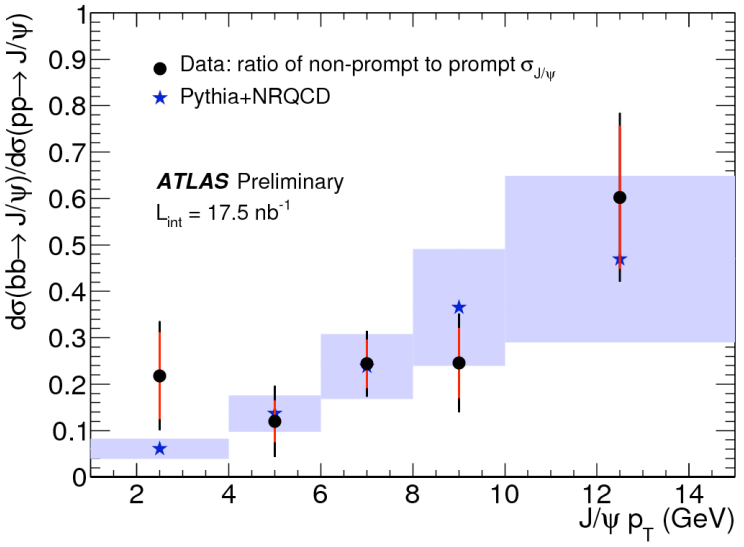
- Kin. range: **p_T=1-12 GeV, |y|<2.25**
- Syst. Uncertainty ~30%
  - Completely dominated by polarization uncertainty
- p_T and y-dependence of σ(J/ψ) agrees with Pythia color octet model
  - Normalization off by factor 10

Prompt fraction determined From pseudo-proper time distribution

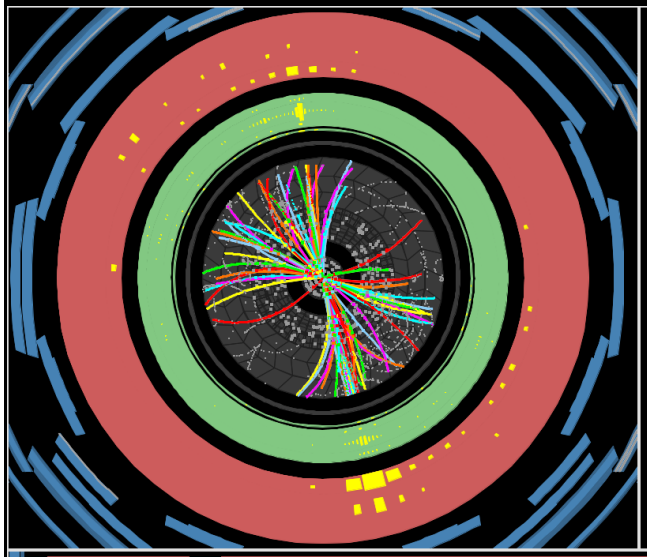
$$\tau = \frac{L_{xy}\, m(J/\psi)}{p_T(J/\psi)}$$



Non-prompt fraction



Jets

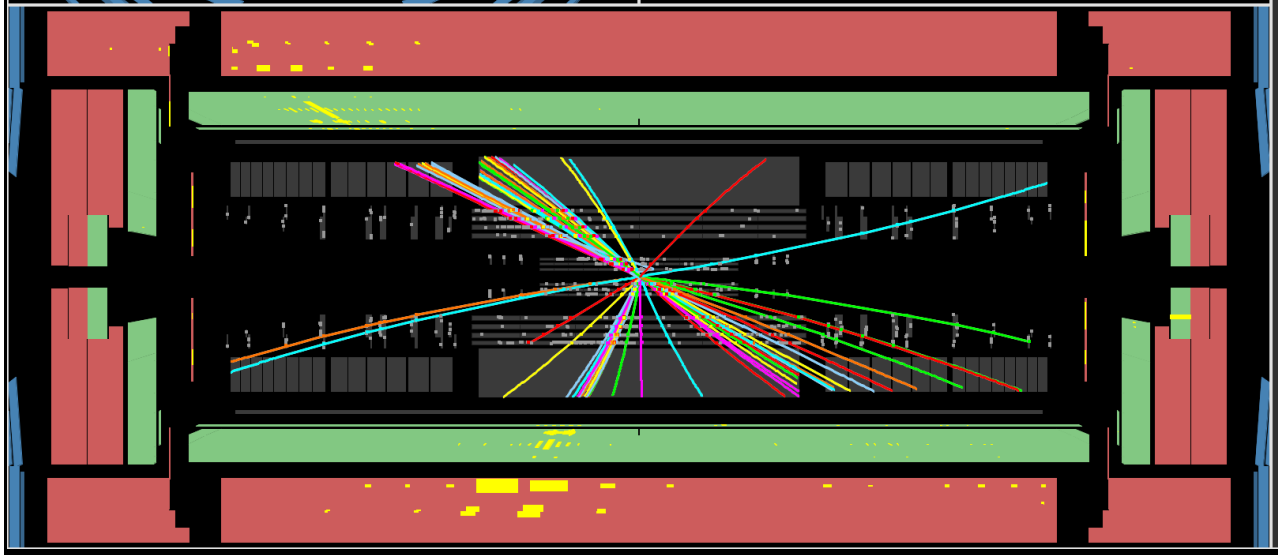


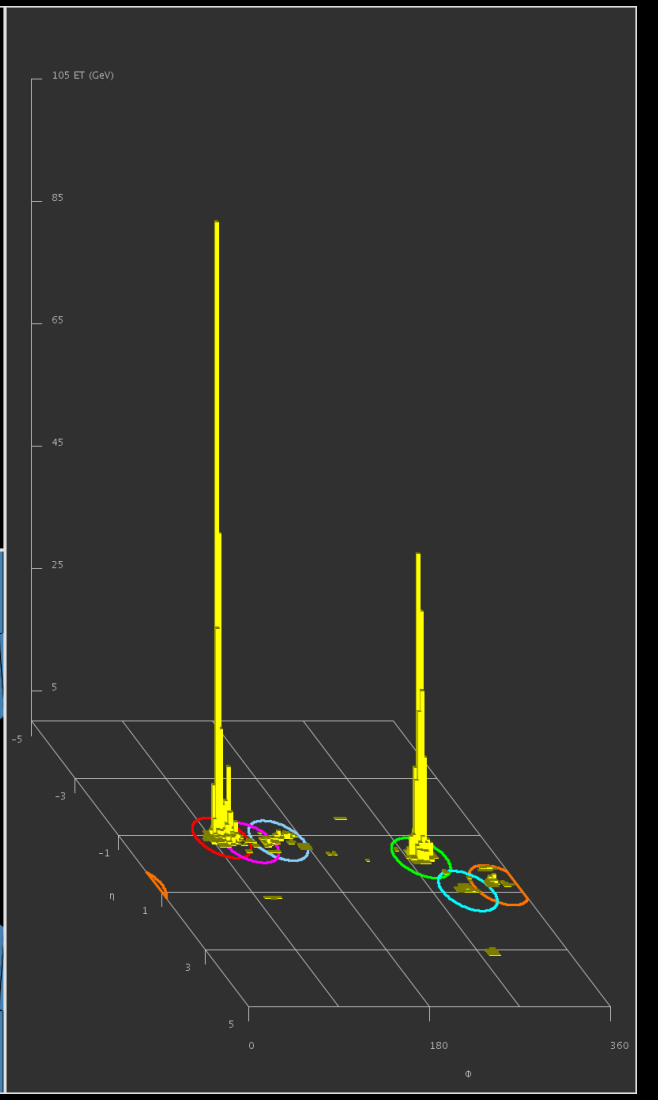
ATLAS EXPERIMENT

Run Number: 152166, Event Number: 810258

Date: 2010-03-30 14:56:29 CEST

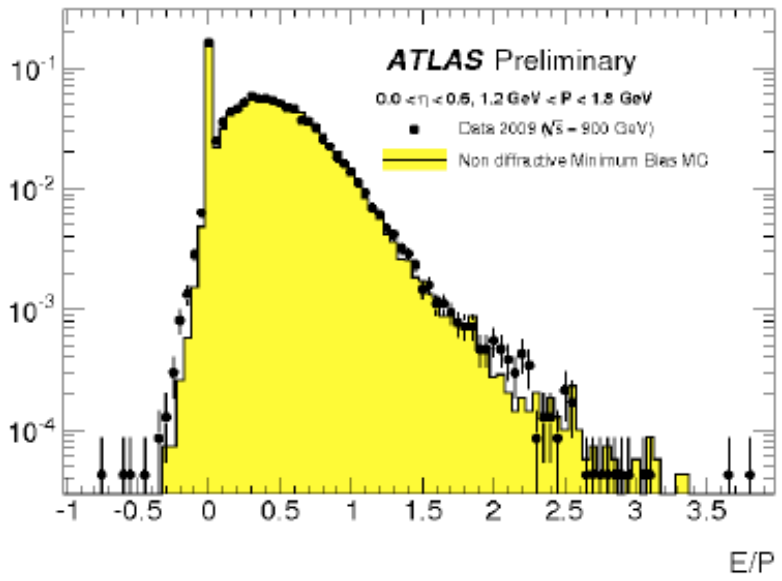
Di-jet Event at 7 TeV

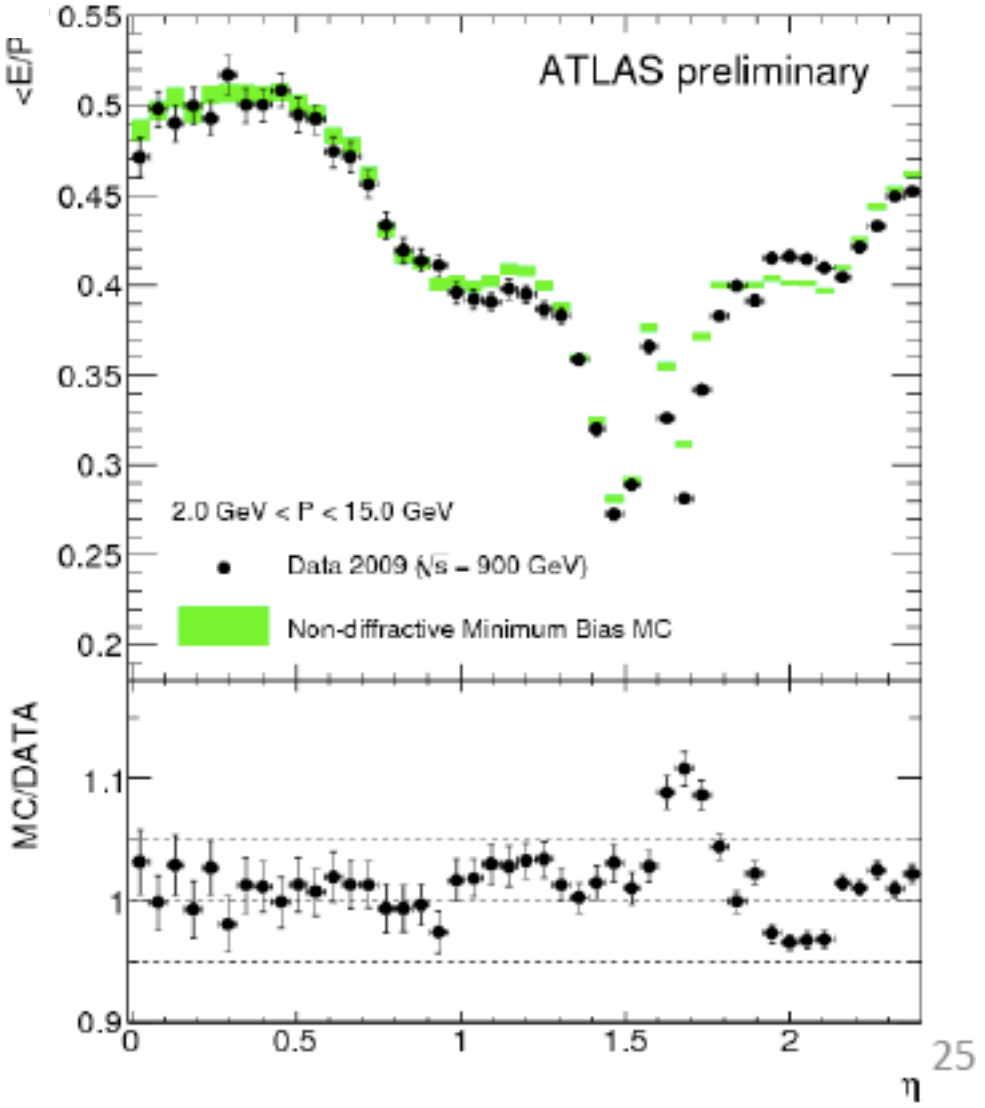




Raw measured jet energy: 300 GeV

Calorimeter Response



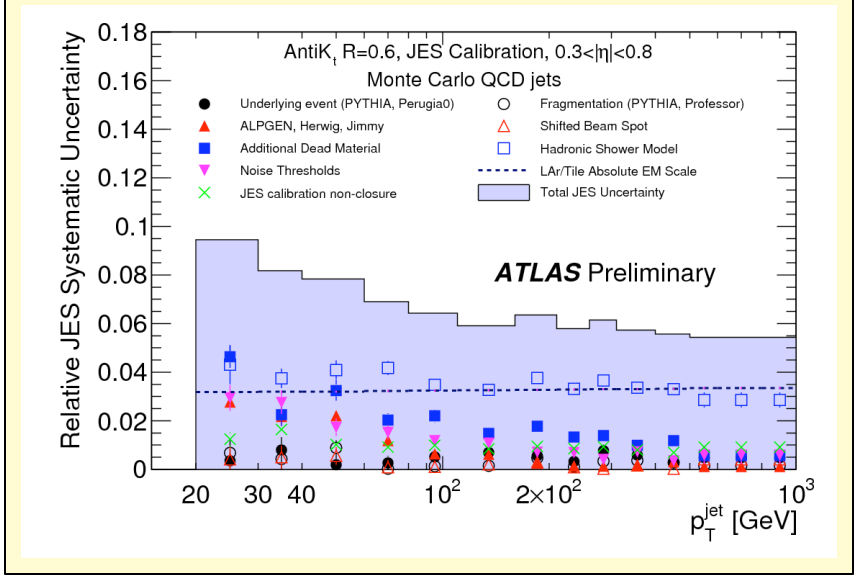


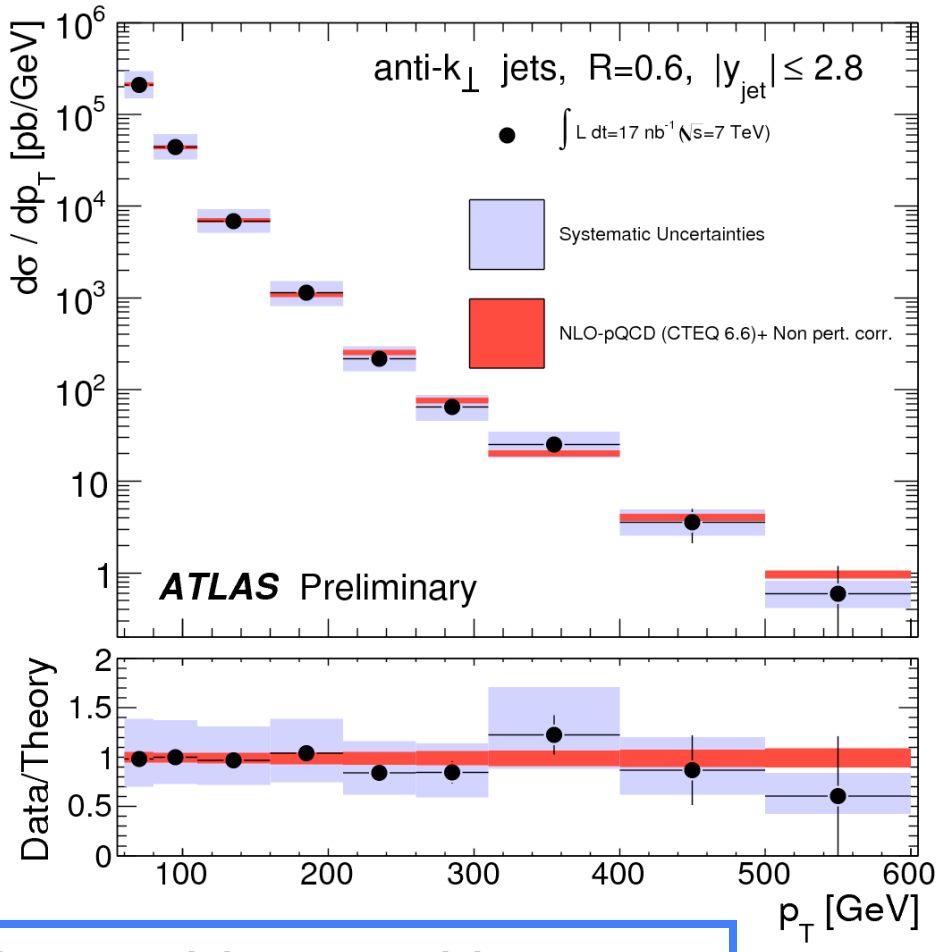
- Calorimeter energy in R=0.2 cone around track / track p
- Measures response of calorimeter to charged pions
  - Critical for jet calibration

- Data generally very well described by MC

Inclusive Jet Cross Section

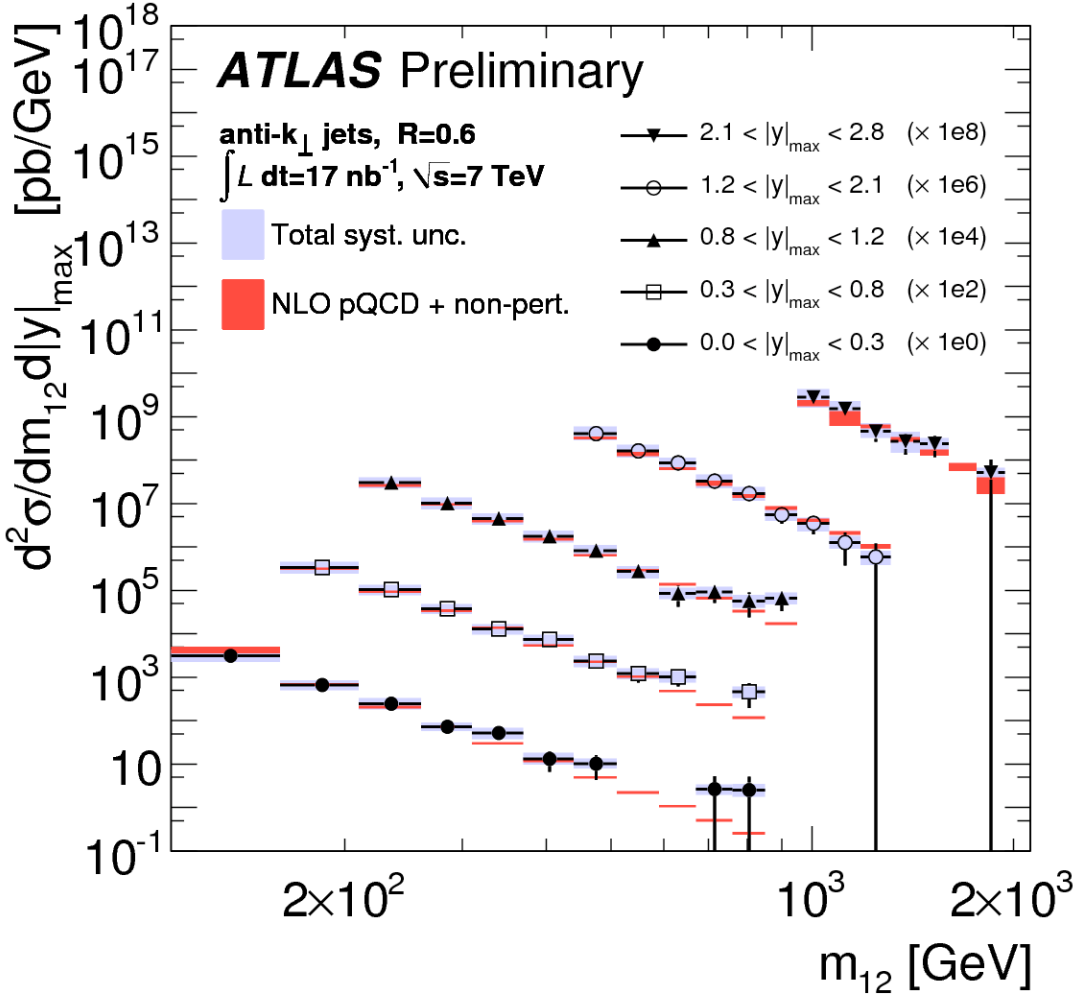
Jet Energy Scale uncertainty
6-10% depending on p_T and η
(dominated by EM scale and
hadronic shower model)

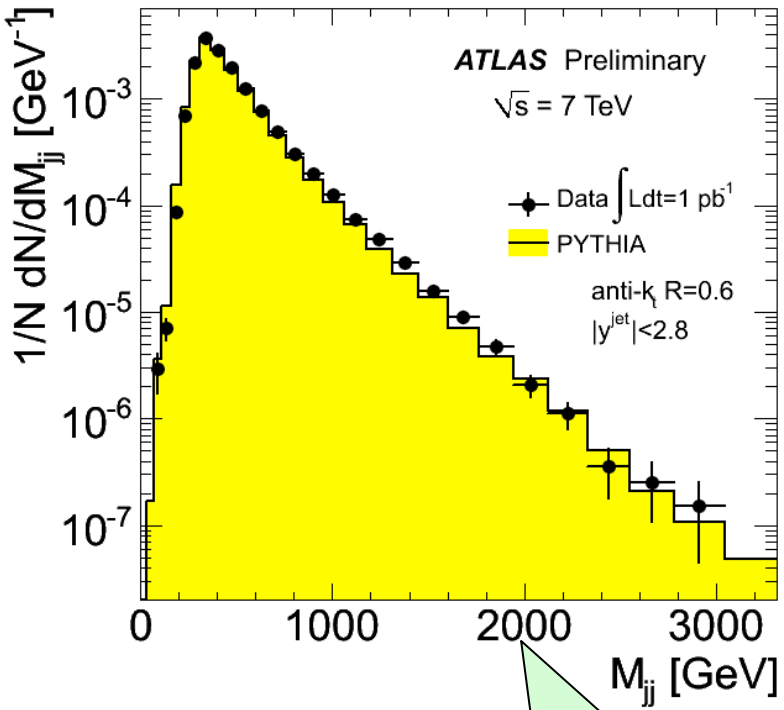




- Jet cross section measured using anti-k_T algorithm
  - Up to p_T=500 GeV (with 17 nb^{-1})
  - Dominant systematic uncertainty: jet energy scale
- Data in good agreement with QCD prediction

Dijet Mass

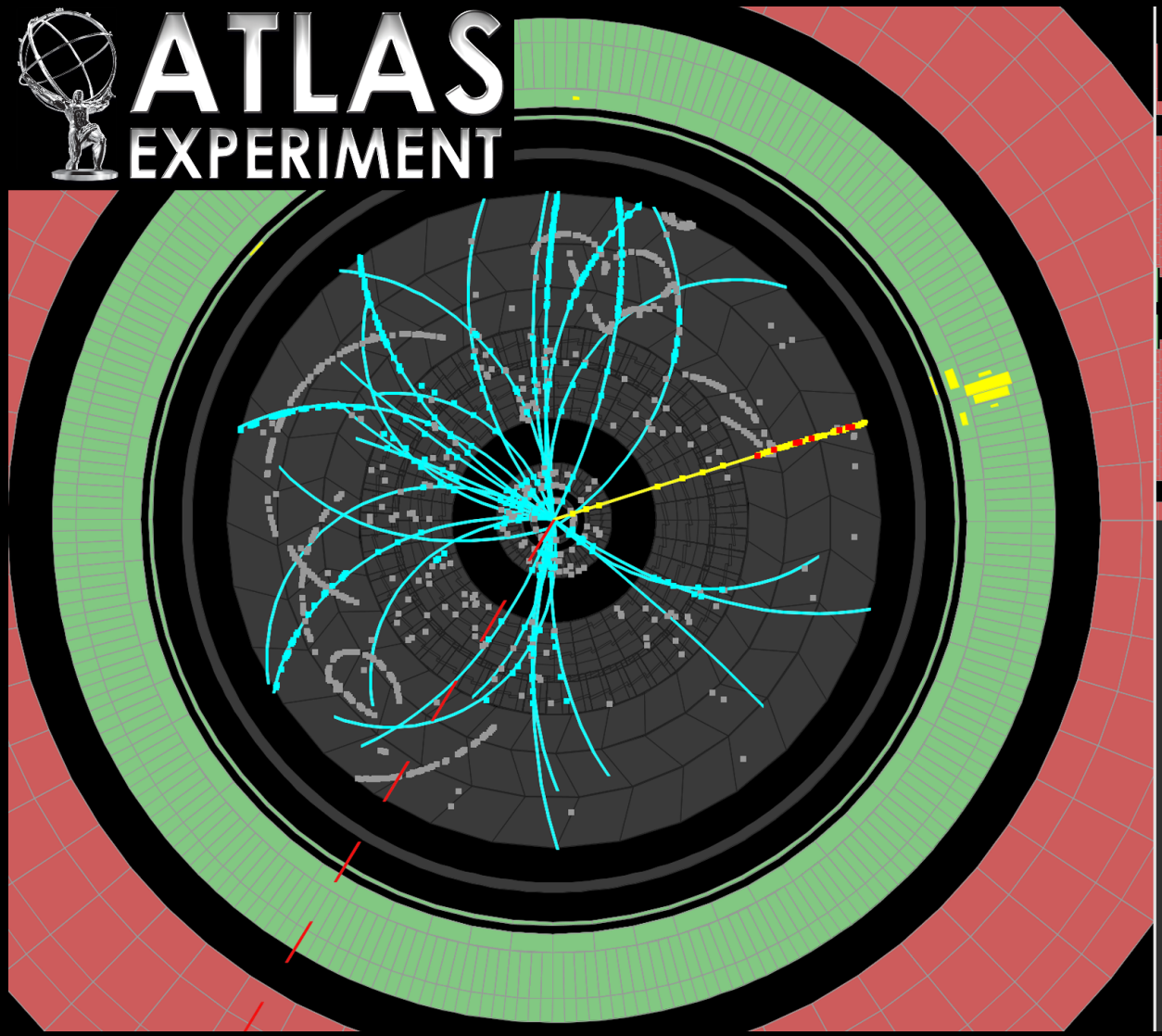


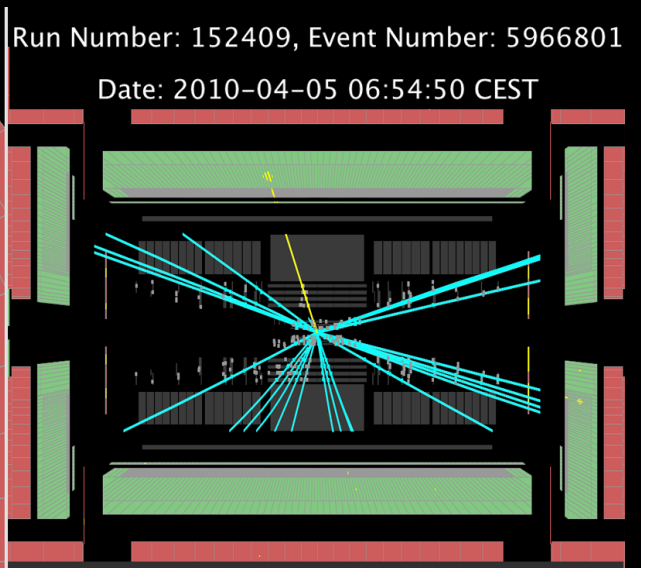


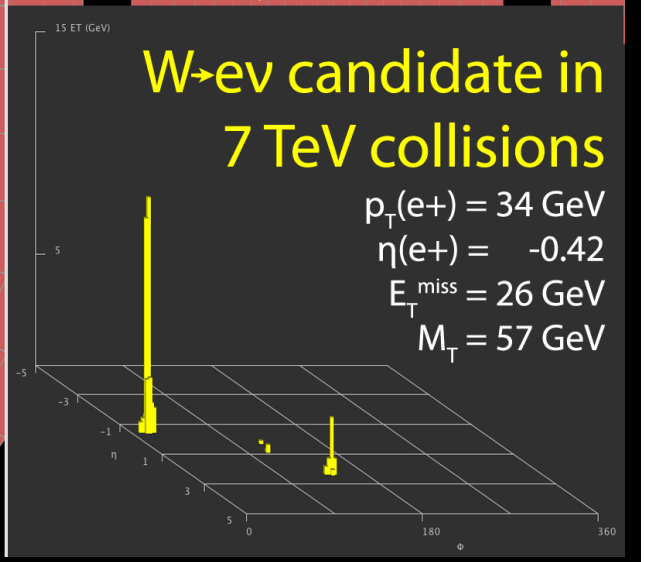
Data extend beyond Tevatron's √s

- Excellent agreement of data with QCD prediction

$W \rightarrow e\nu_e$







W→eν candidate in
7 TeV collisions

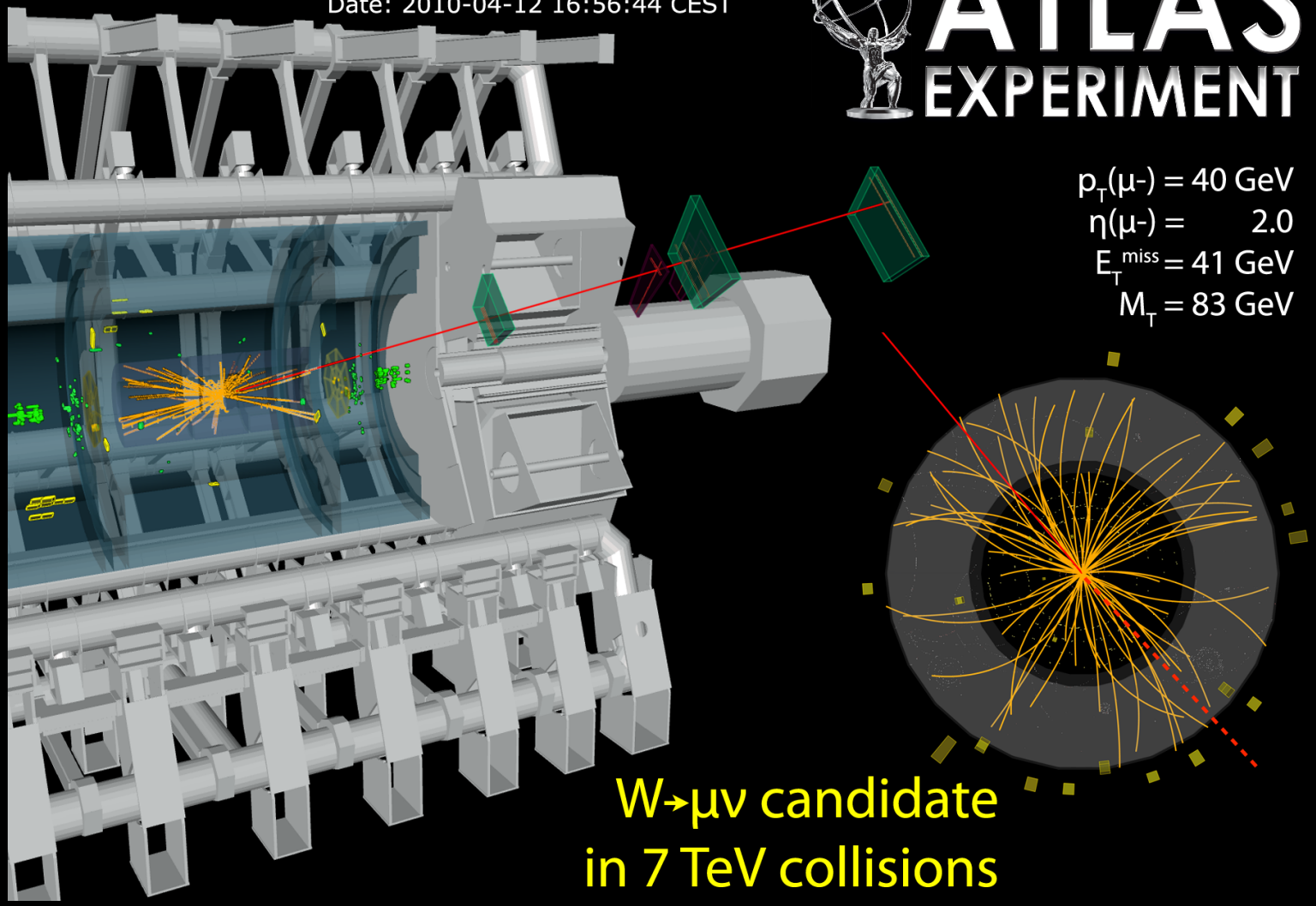
$p_T(e+) = 34$ GeV

$\eta(e+) = -0.42$

$E_T^{miss} = 26$ GeV

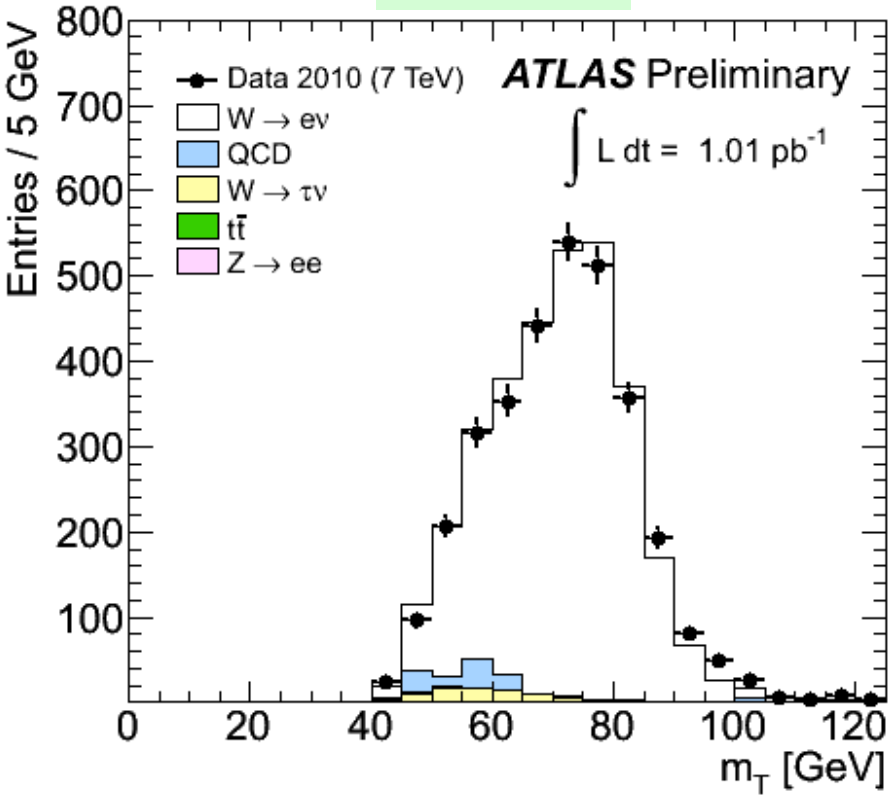
$M_T = 57$ GeV

$W \rightarrow \mu \nu_\mu$

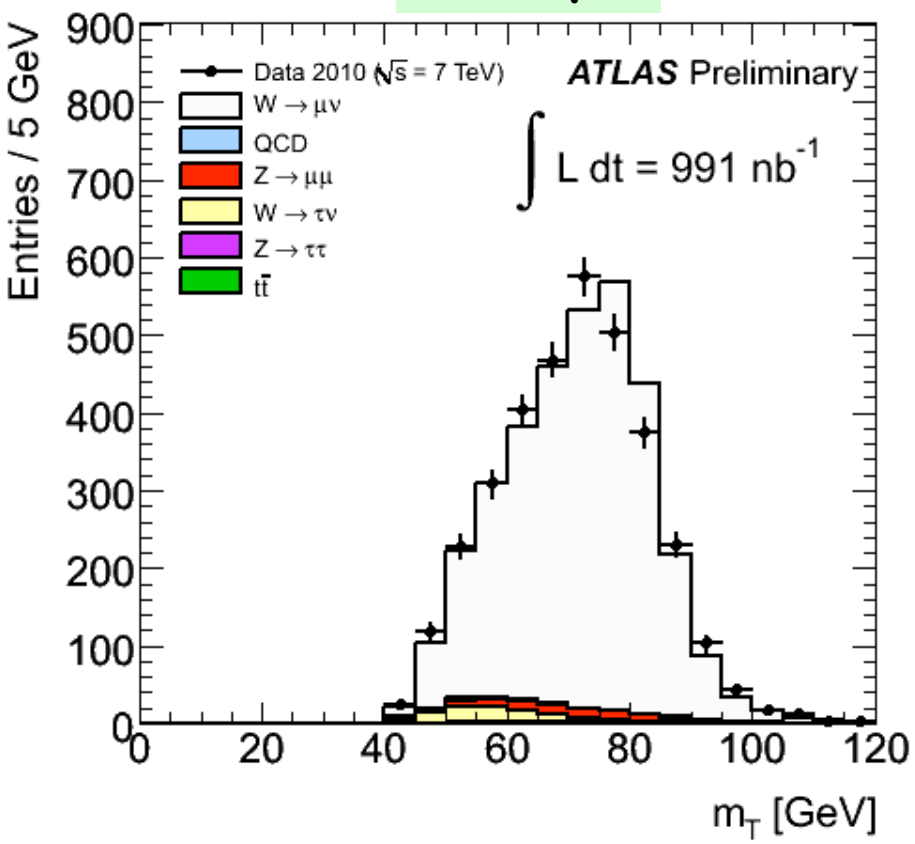


W's

W -> eν



W -> μν



- p_T(e/μ)>20 GeV (isolated), E_T^{miss}>25 GeV, m_T>40 GeV
  - about 3000 candidates/lepton type in ∫Ldt=1 pb^{-1}
- Data well modeled by simulation

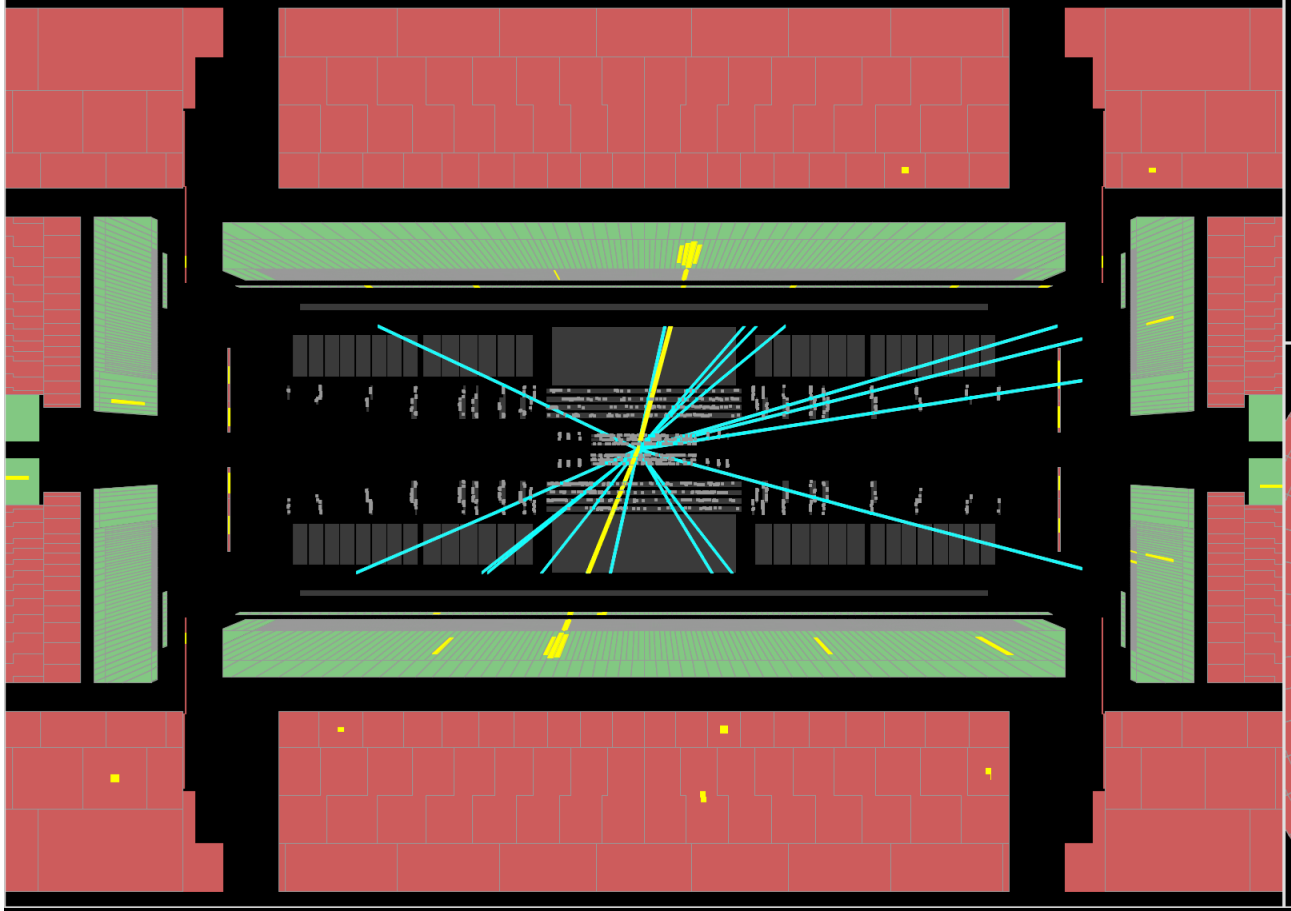
$Z \rightarrow e^+e^-$

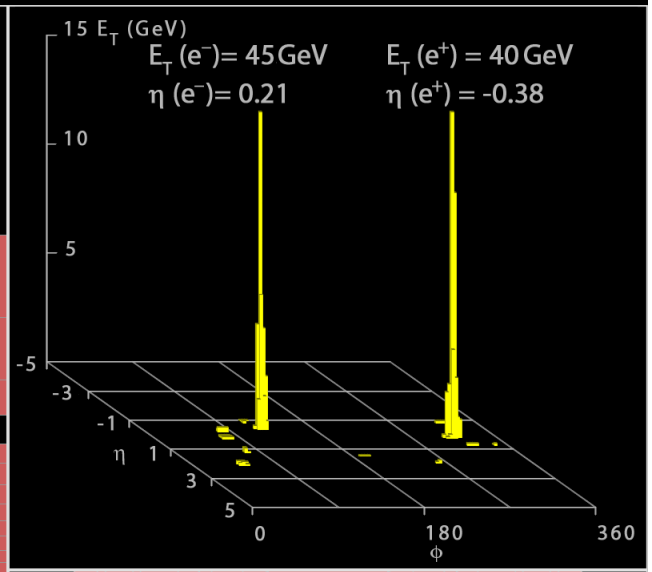
ATLAS EXPERIMENT

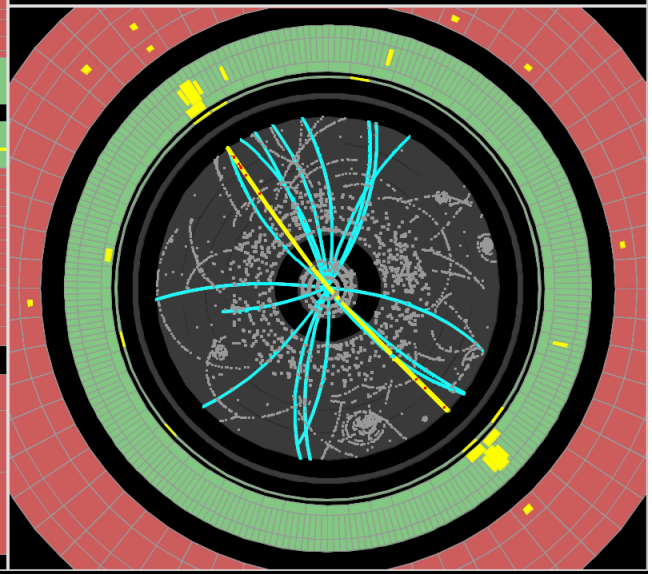
Run Number: 154817, Event Number: 968871
Date: 2010-05-09 09:41:40 CEST

M_{ee} = 89 GeV

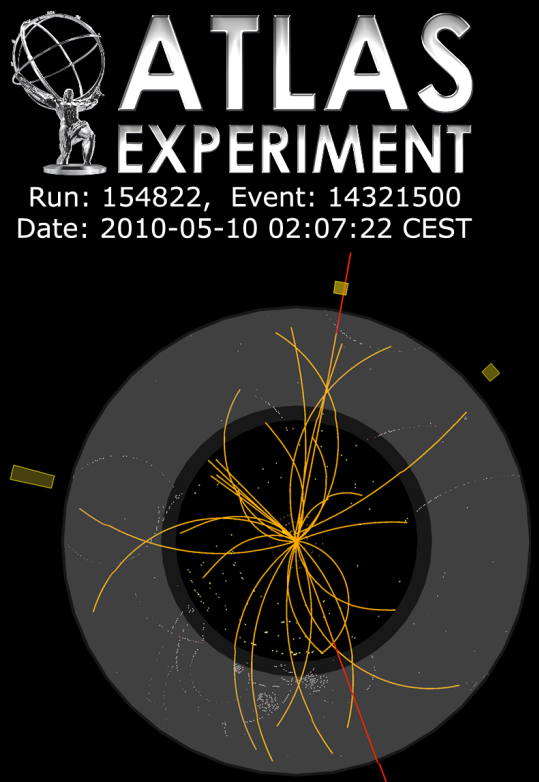
Z→ee candidate in 7 TeV collisions





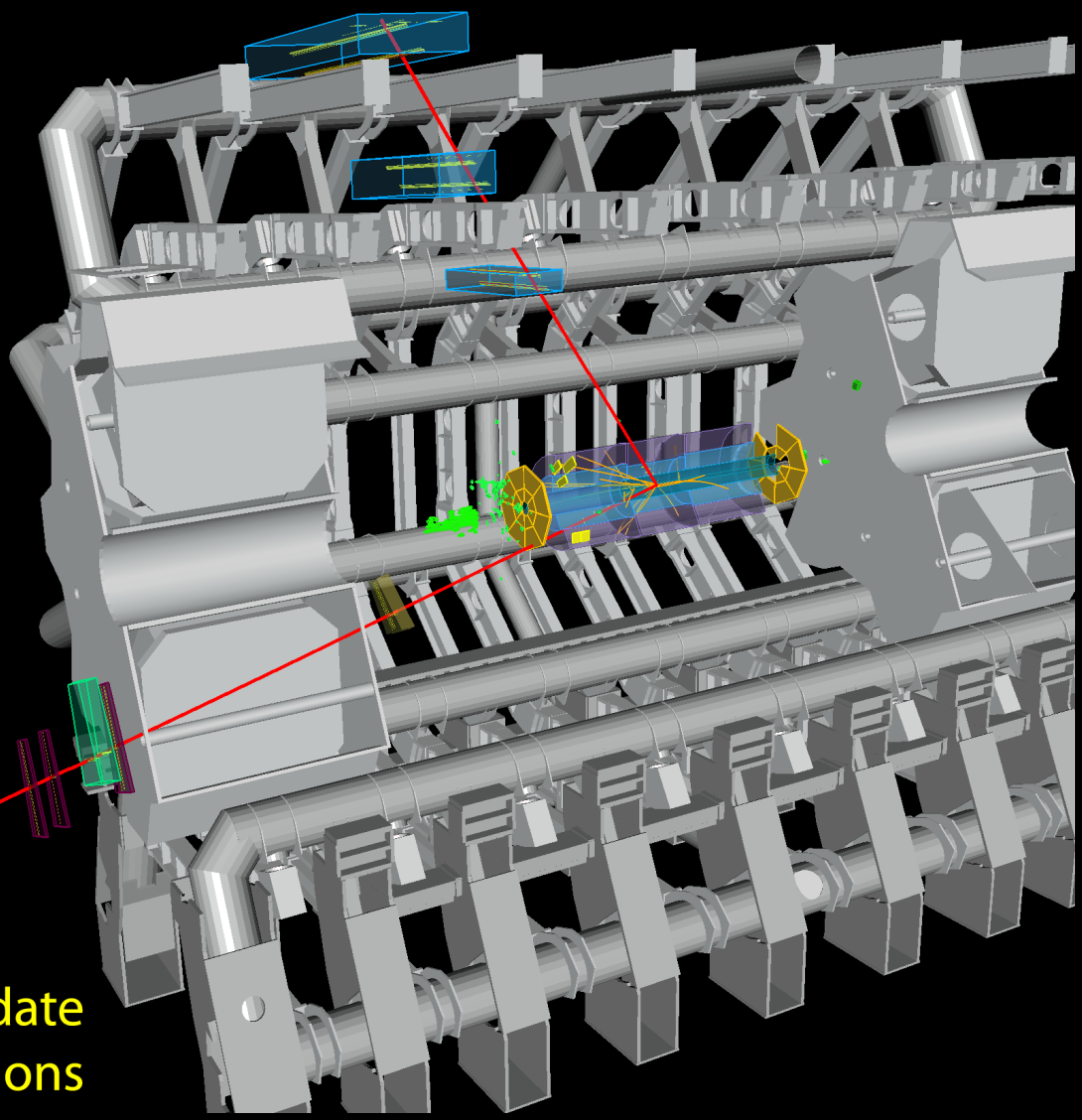


$Z \rightarrow \mu^+\mu^-$



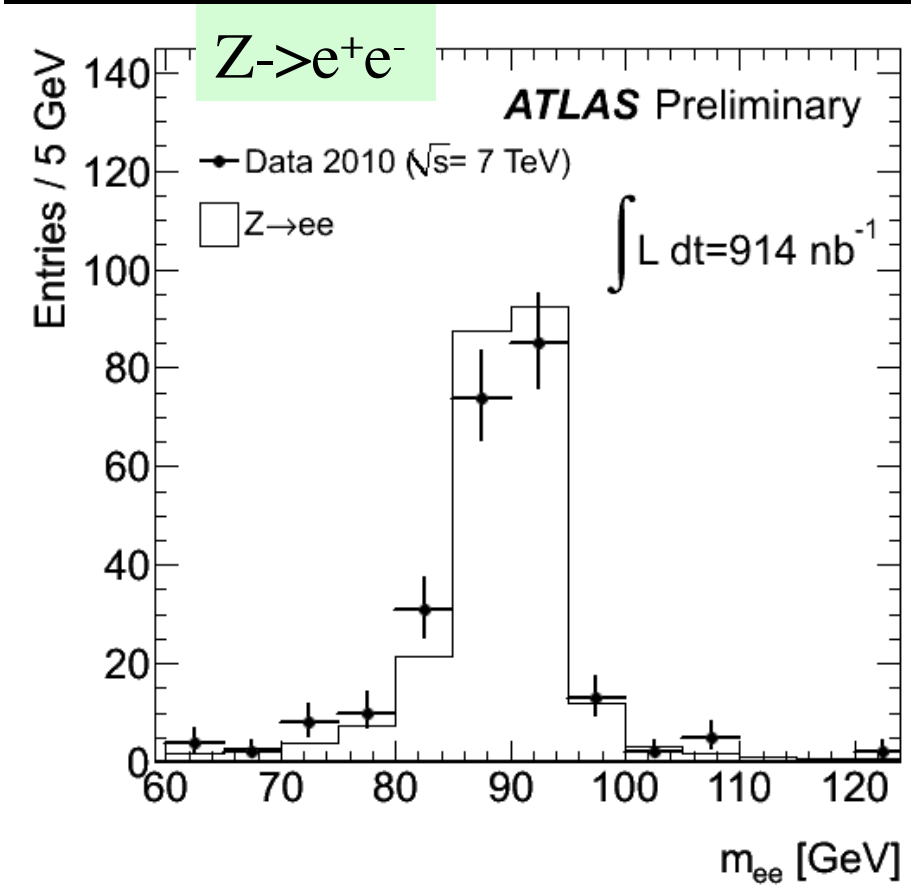
Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST

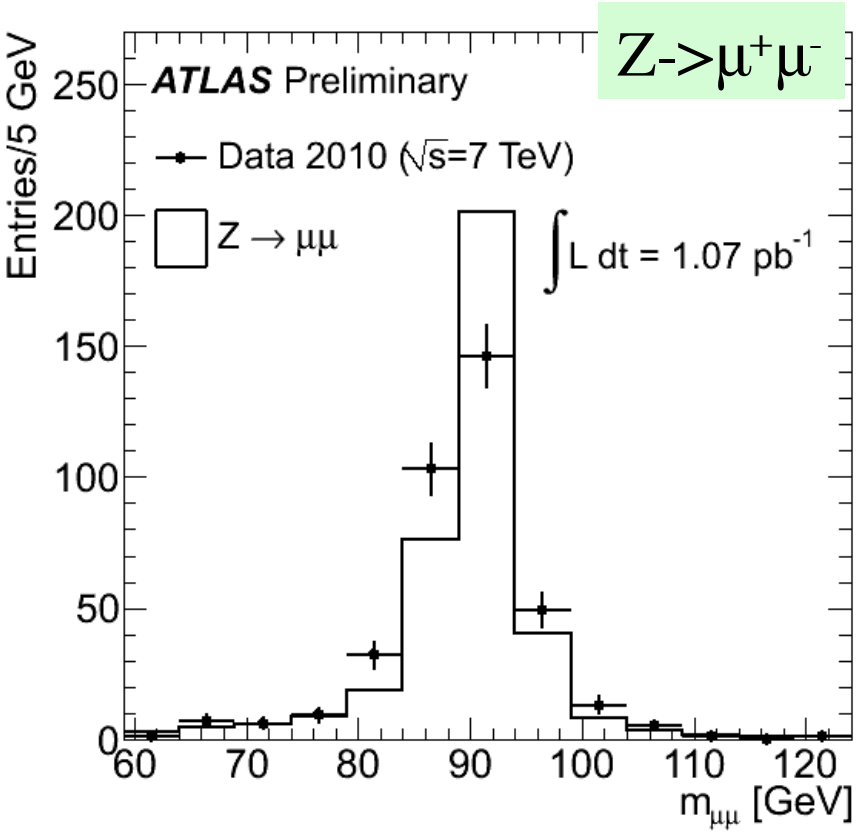
$p_T(\mu^-) = 27$ GeV $\eta(\mu^-) = 0.7$
$p_T(\mu^+) = 45$ GeV $\eta(\mu^+) = 2.2$
$M_{\mu\mu} = 87$ GeV



Z→μμ candidate
in 7 TeV collisions

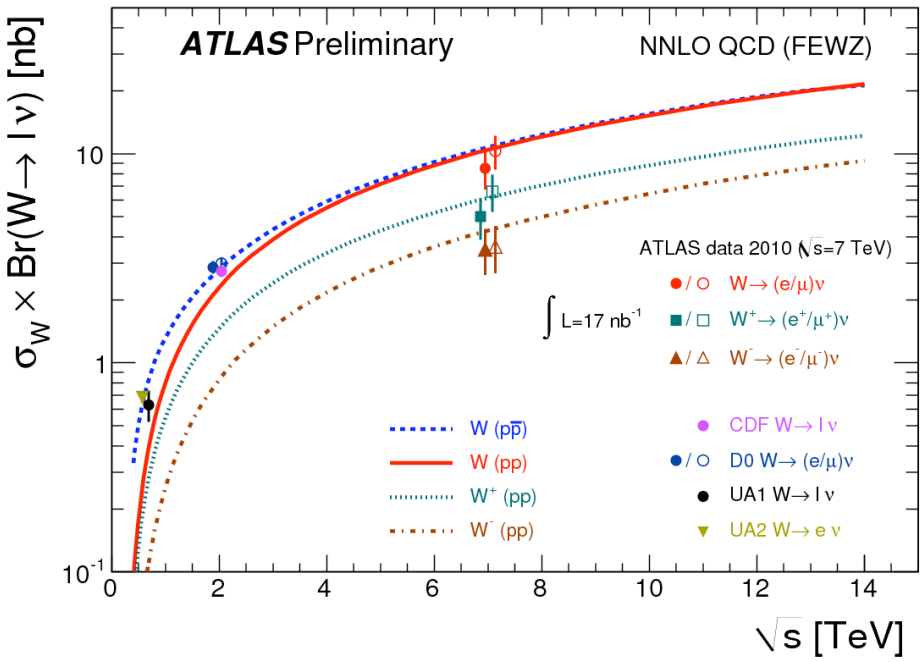
Z's

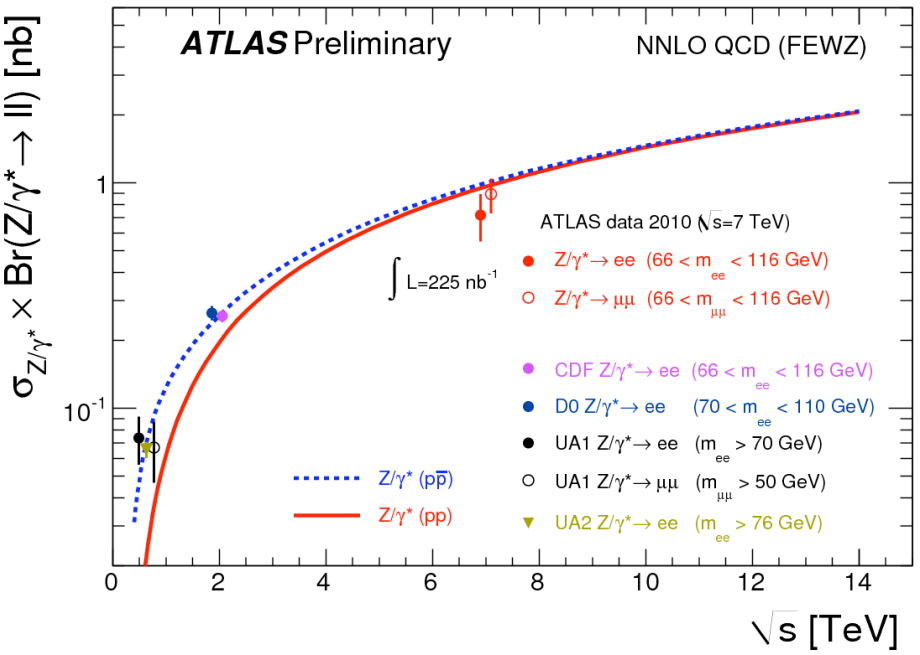




- Two leptons with p_T>20 GeV
  - About 200 (300) Z candidates in e^+e^- ($\mu^+\mu^-$) channel in ~1 pb^{-1}
  - Very precious for detector calibration
- Resolution in data slightly worse than simulation
  - Calibration and/or alignment efforts ongoing

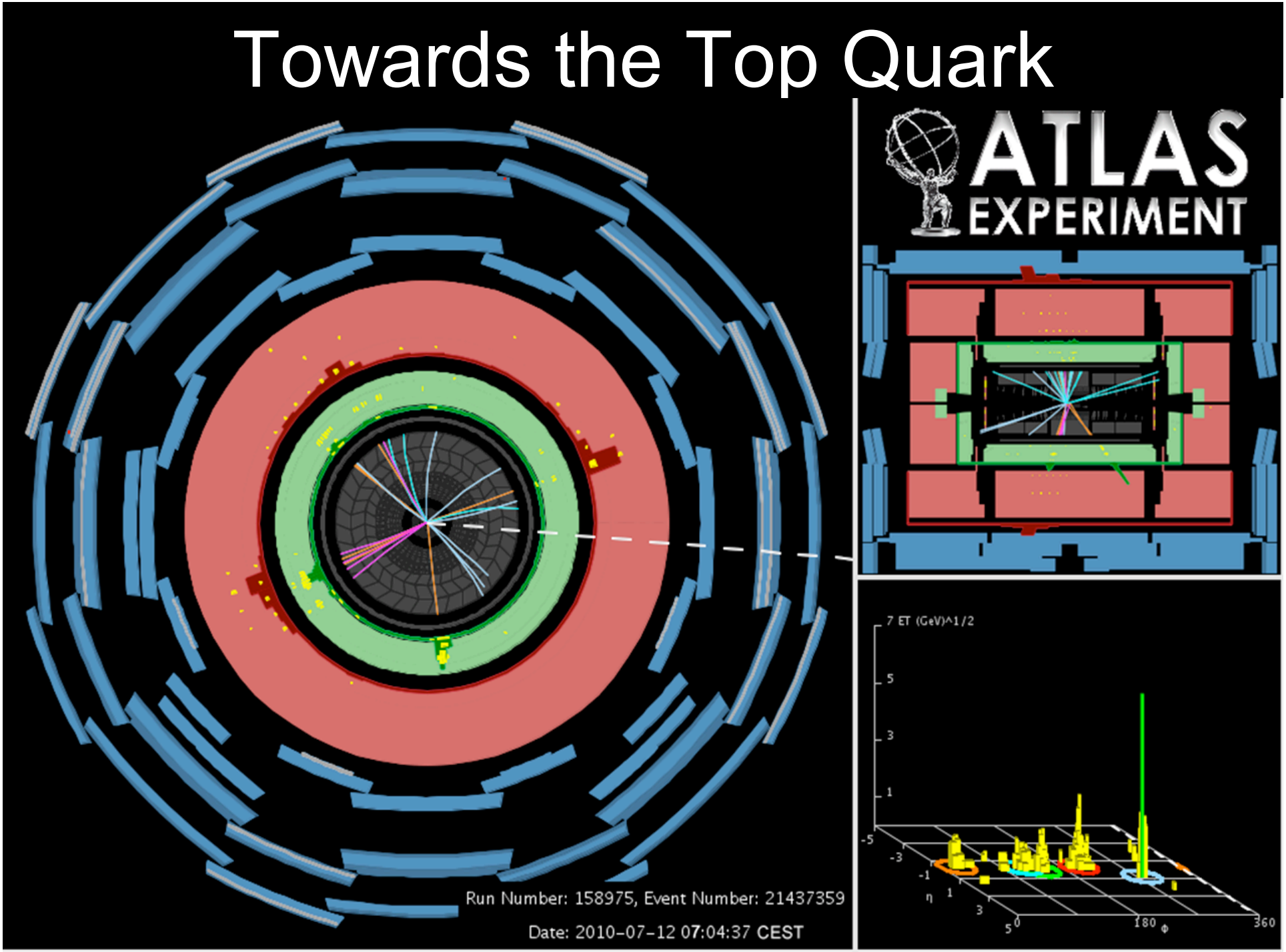
W and Z Cross Section





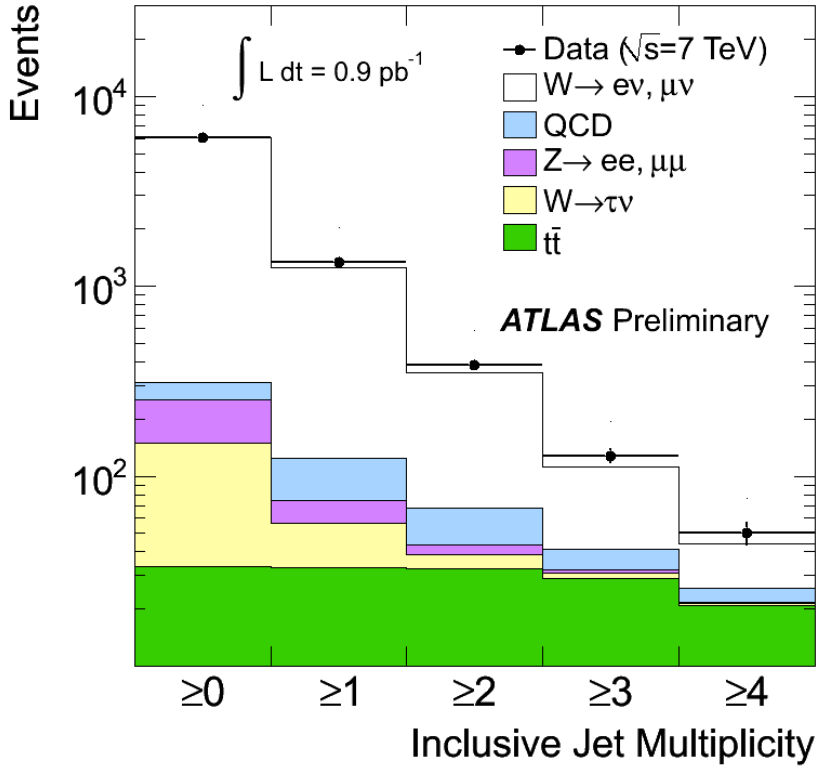
Process	Data	Background	L (nb^{-1})	Cross Section (nb)
W->eν	46	2.6±0.4	17	8.5 ± 1.3 (*stat*) ± 0.7 (*syst*) ± 0.9 (*lum*)
W->μν	72	5.3±0.7	17	10.3 ± 1.3 (*stat*) ± 0.8 (*syst*) ± 1.1 (*lum*)
Z->ee	46	0.49±0.09	219	0.72 ± 0.11 (*stat*) ± 0.10 (*syst*) ± 0.08 (*lum*)
Z->μμ	79	0.17±0.01	229	0.89 ± 0.10 (*stat*) ± 0.07 (*syst*) ± 0.10 (*lum*)

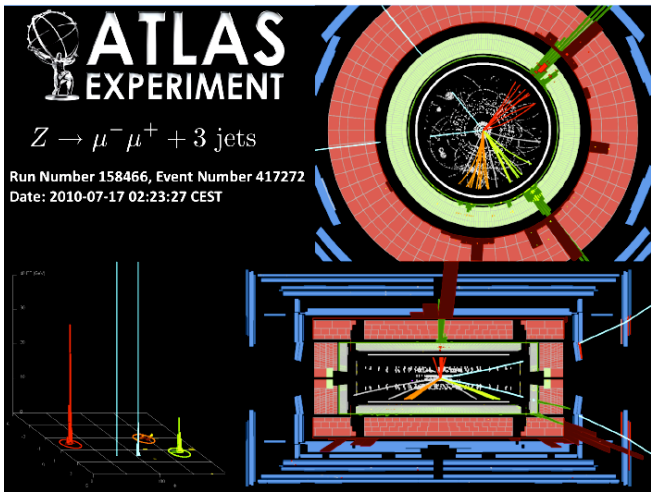
Towards the Top Quark



W and Z+jets

- Major backgrounds to top and New Physics searches (e.g. SUSY)
- Raw N_{jet} spectrum agrees well with MC (Alpgen+Herwig)
  - Already ~100 W+3-jet events in 1 pb^{-1} of data
- Looking forward to corrected cross sections to be compared with NLO QCD and Monte Carlo predictions

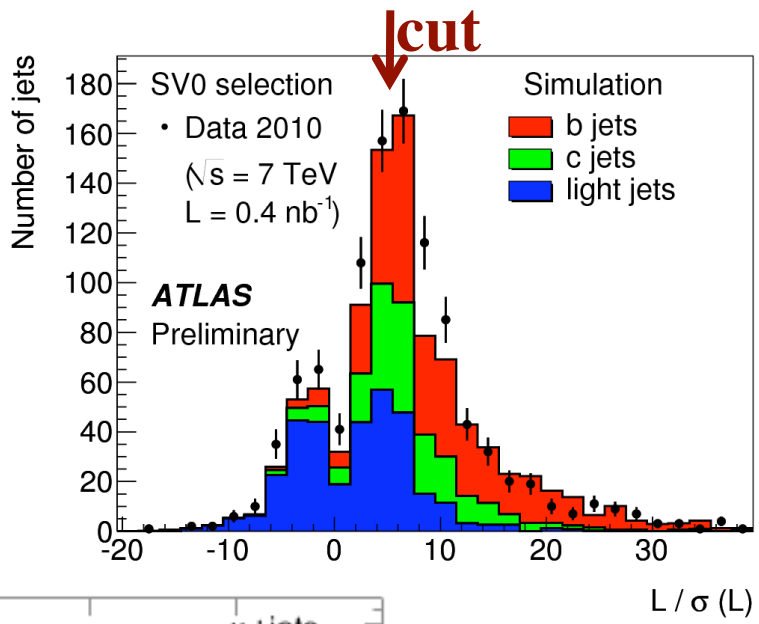


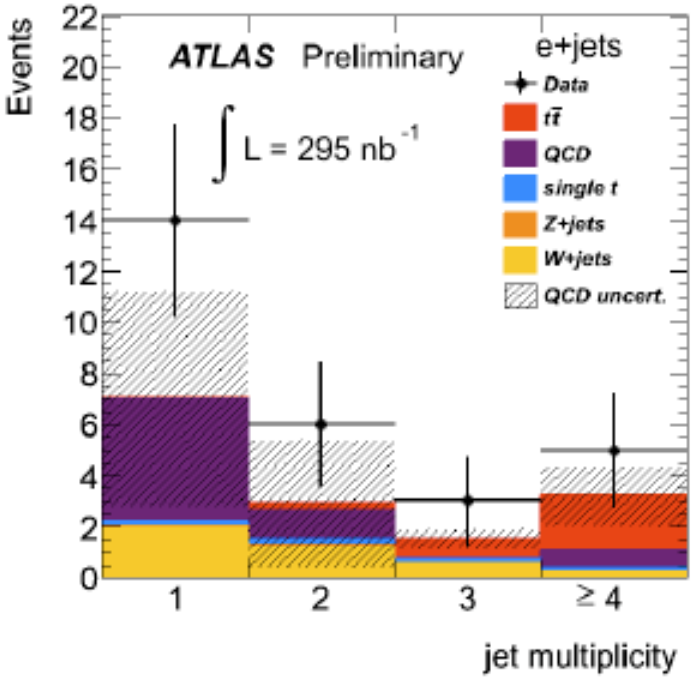


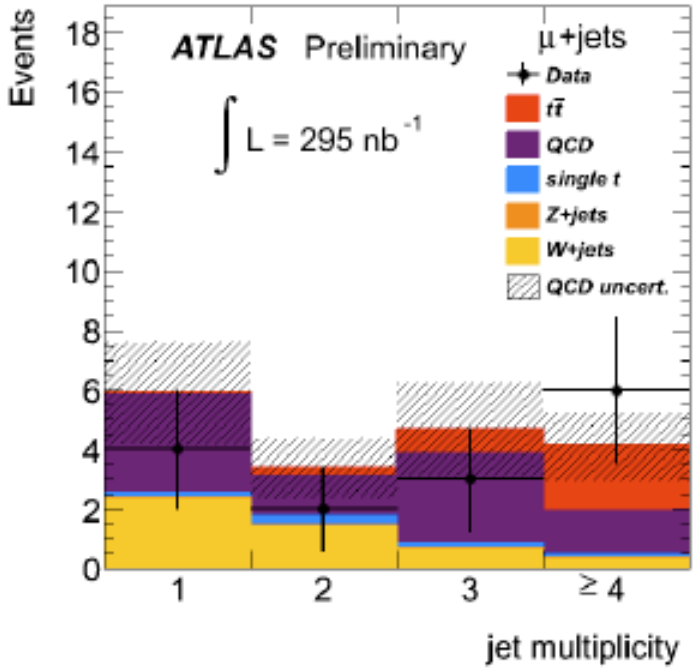
Similar result available for Z+jets

Towards the Top Quark

- Theoretical cross section: 160 pb
- $p_T(e/\mu)>20$ GeV, $E_T^{miss}>20$ GeV
- 4 jets ($p_T>20$ GeV), at least one b-tagged
  - B-tag based on secondary vertex
  - Decay length significance well modeled: require $L/\sigma(L)>5.7$
- In 0.3 pb^{-1}: observe 11 events

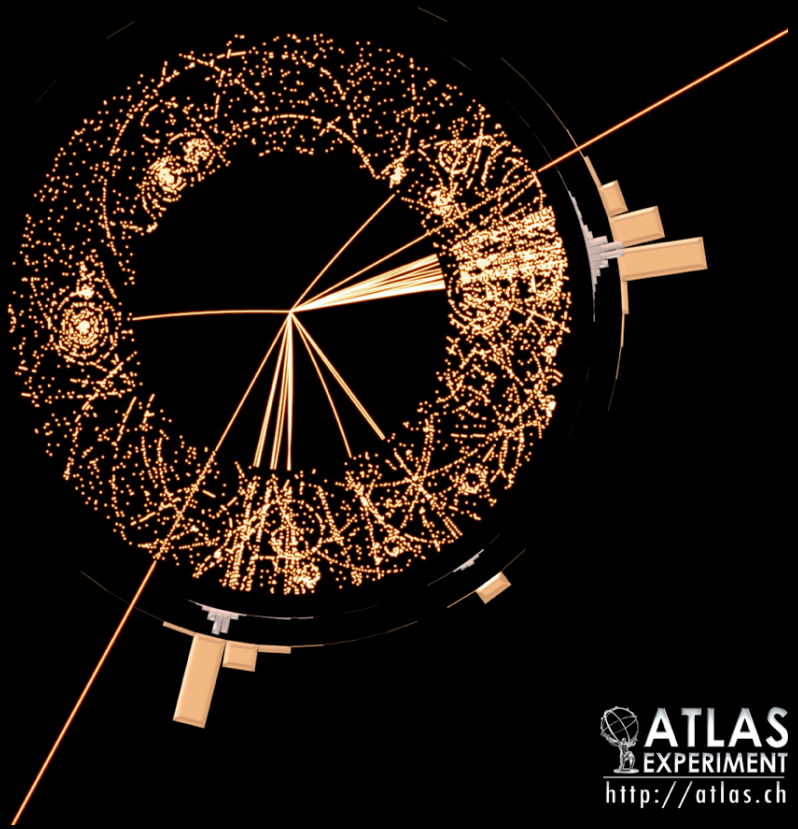






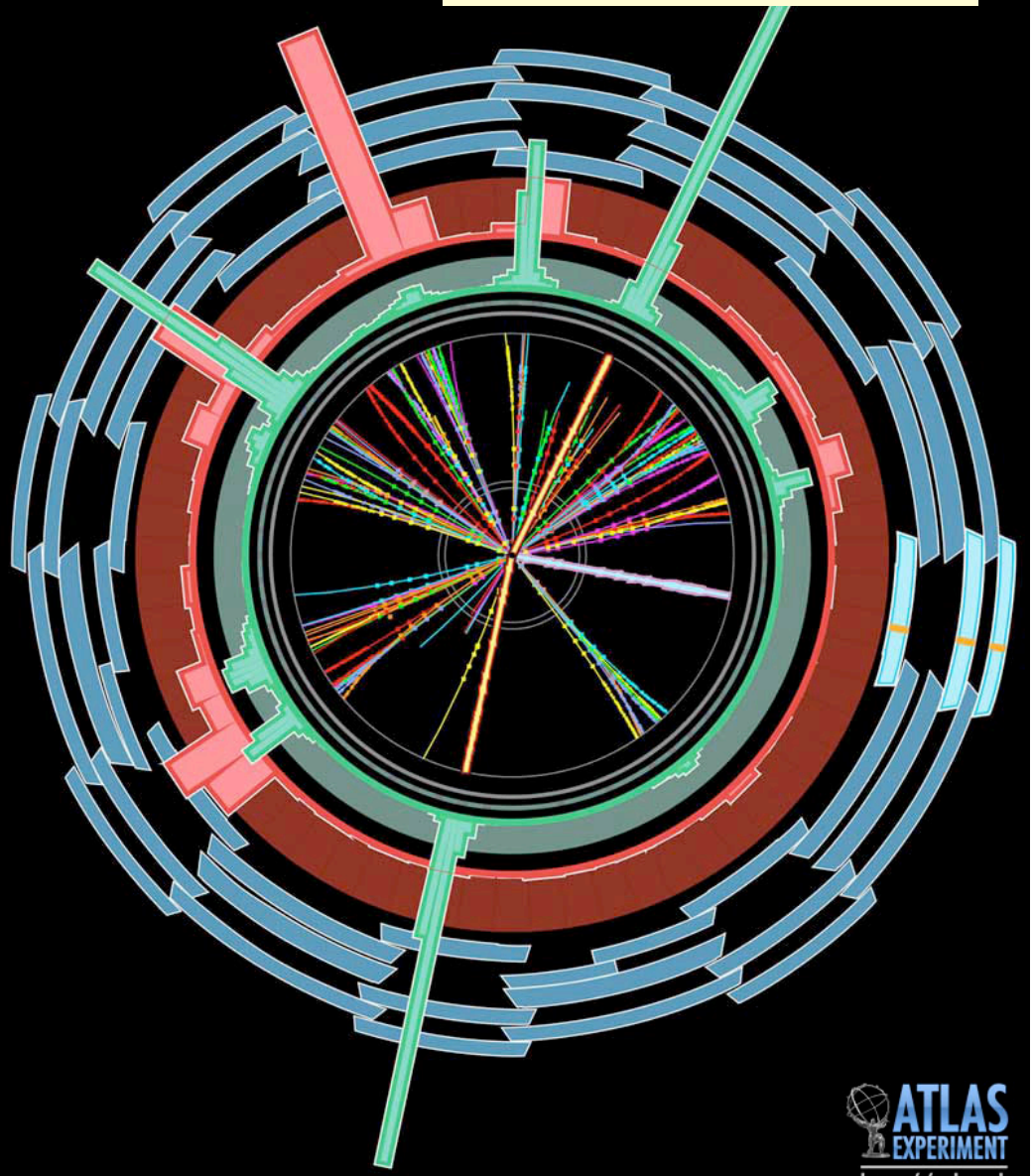
New Physics

Supersymmetry



ATLAS EXPERIMENT
http://atlas.ch

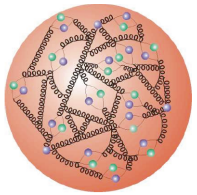
Micro Black Hole

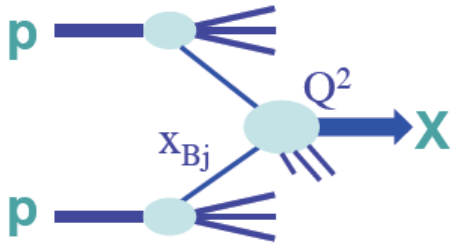


ATLAS EXPERIMENT
http://atlas.ch

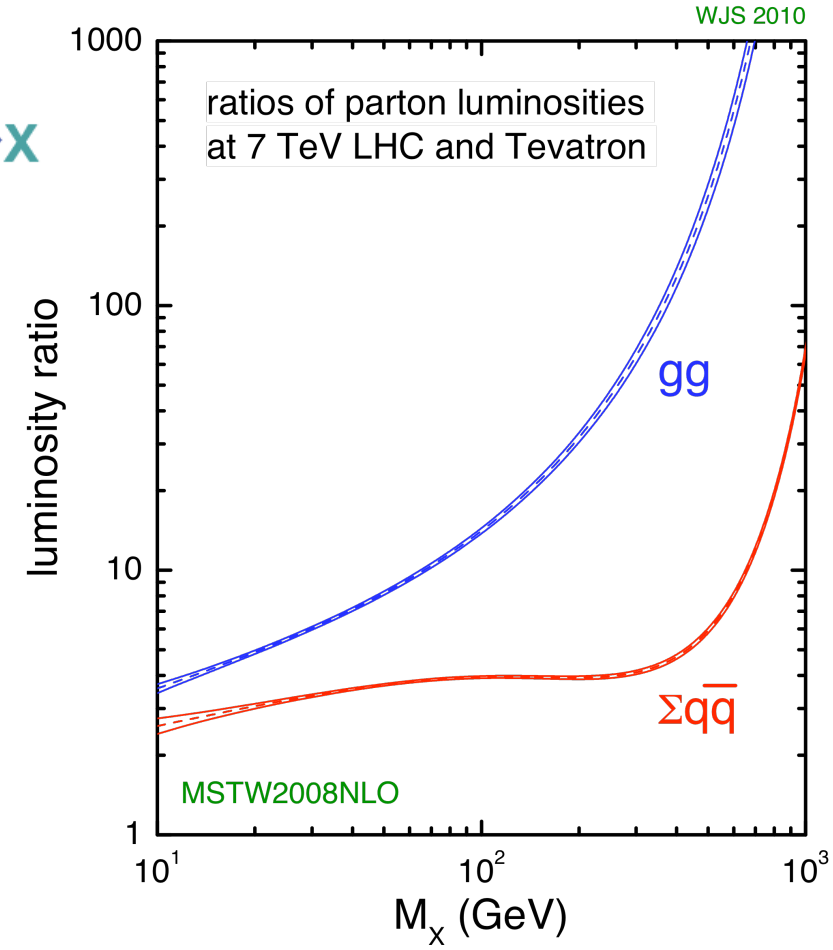
New Physics Potential

$$M_X = \sqrt{x_1 \cdot x_2 \cdot s}$$



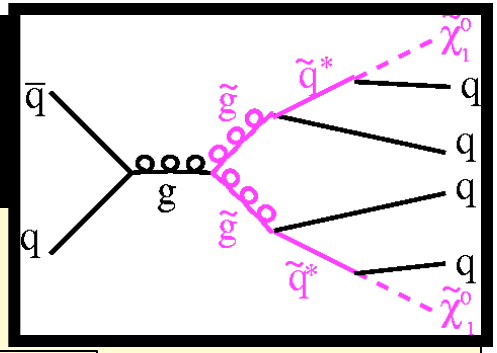


Process	M_X	σ(LHC @ 7 TeV) / σ(Tevatron)
$q\bar{q} \rightarrow W$	80 GeV	3
$q\bar{q} \rightarrow Z'_{SM}$	1 TeV	50
$gg \rightarrow H$	120 GeV	20
$q\bar{q}/gg \rightarrow t\bar{t}$	2x173 GeV	15
$gg \rightarrow \tilde{g}\tilde{g}$	2x400 GeV	1000

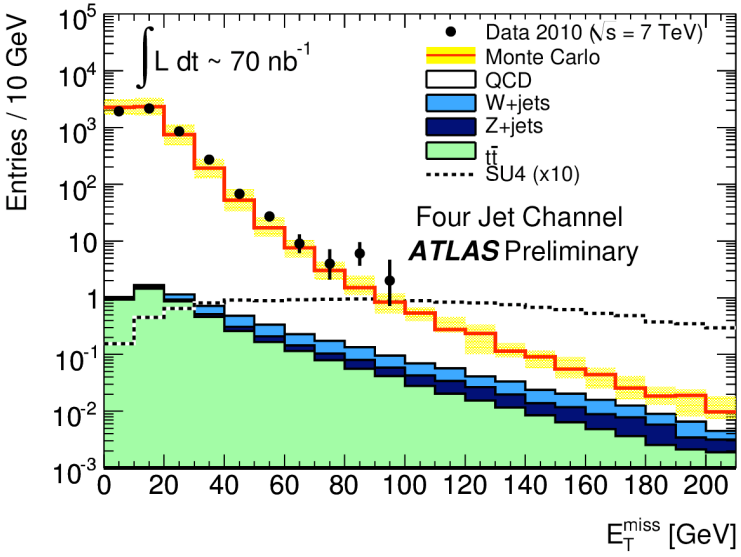


- ∫Ldt=1 fb^{-1} at LHC competitive with 10 fb^{-1} at Tevatron for many high mass processes
  - Already competing now for some new physics scenarios though!

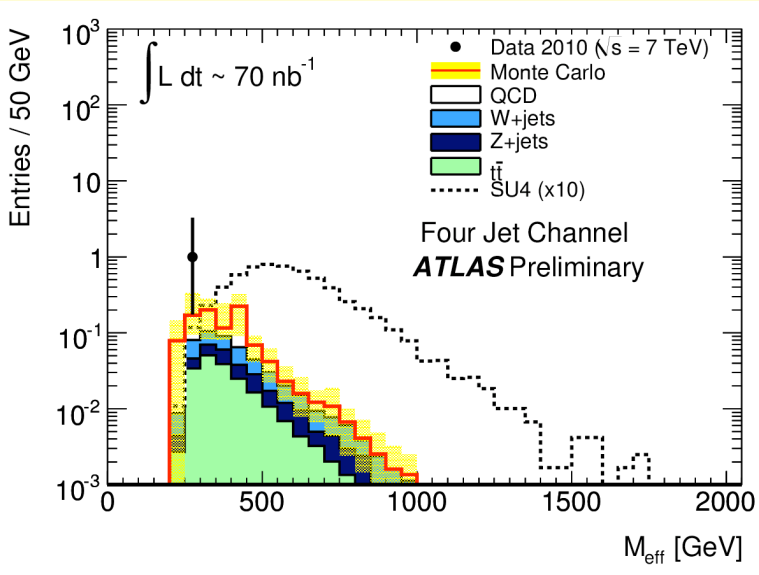
Supersymmetry Searches



4 jets+0 leptons, p_T^1>70 GeV, $p_T^{2,3,4}$>30 GeV

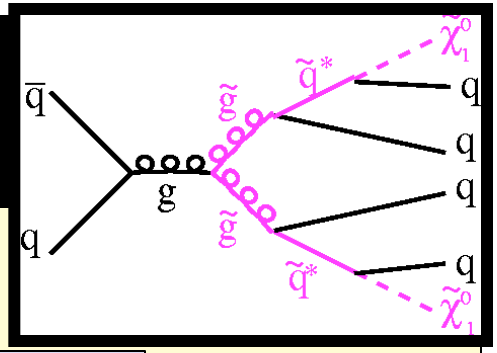


- E_T^{miss}>40 GeV
- $d\phi(E_T, p_T^{jet})$>0.2
- E_T/M_{eff}>0.2

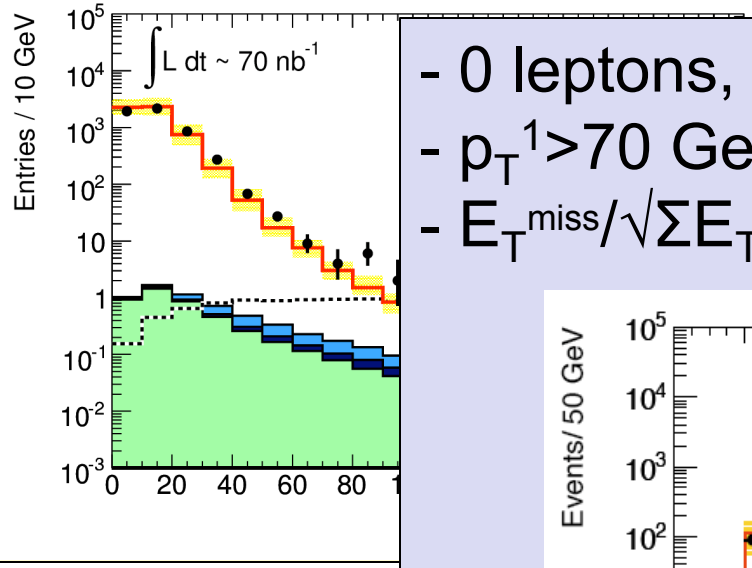


- Data consistent with background
  - Excellent control of missing E_T
- Possibly sensitive beyond Tevatron for non-mSUGRA type models already
  - Alvez, Izaguirre, Wacker: arXiv:1008.0407

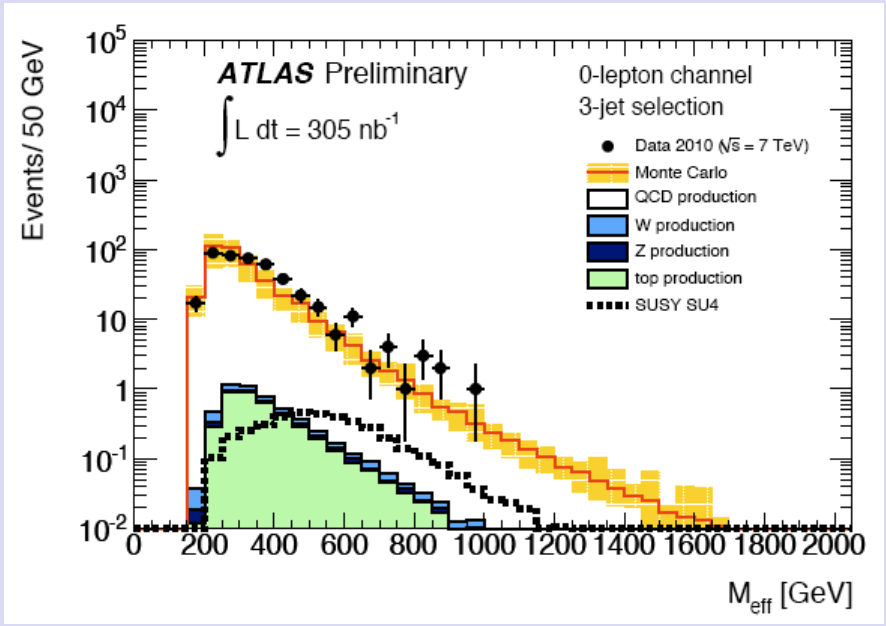
Supersymmetry Searches

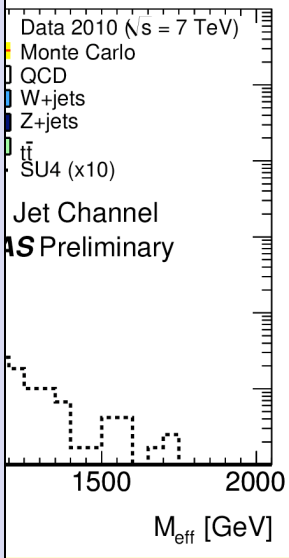


4 jets+0 leptons, p_T^1>70 GeV, $p_T^{2,3,4}$>30 GeV



- 0 leptons, 3 jets, ≥1 b-tag
- p_T^1>70 GeV, $p_T^{2,3}$>30 GeV
- $E_T^{miss}/\sqrt{\Sigma E_T}$>2 √GeV

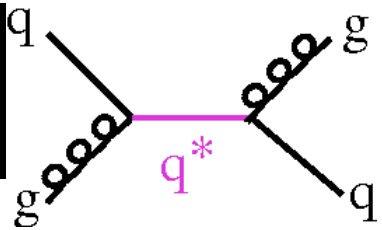


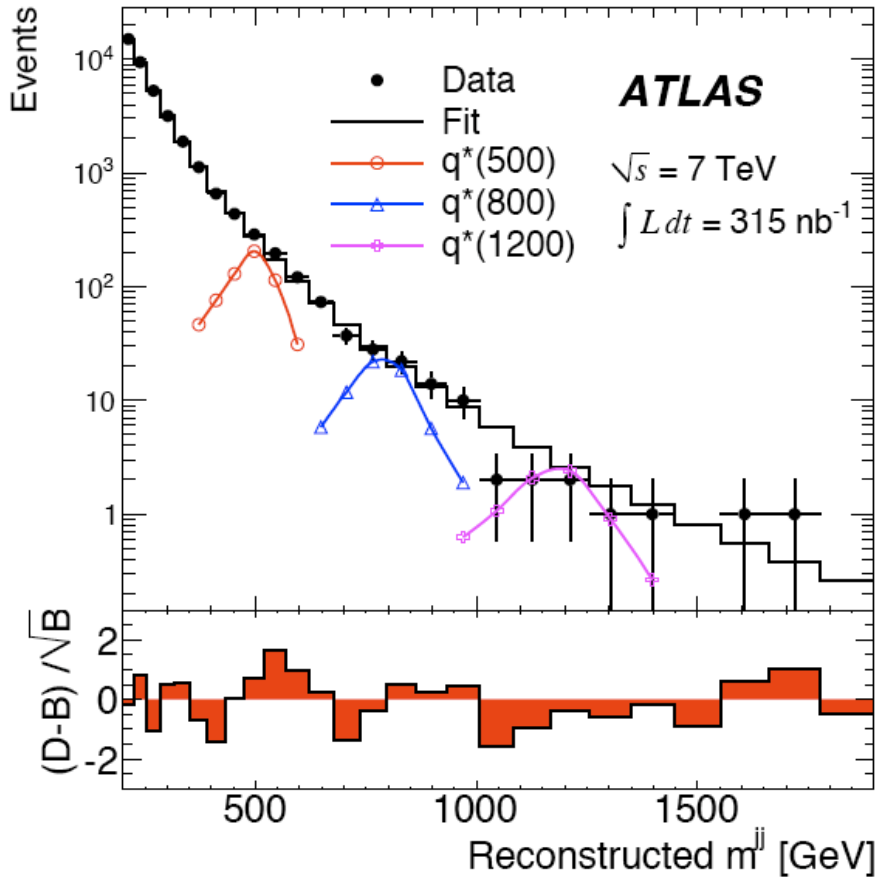


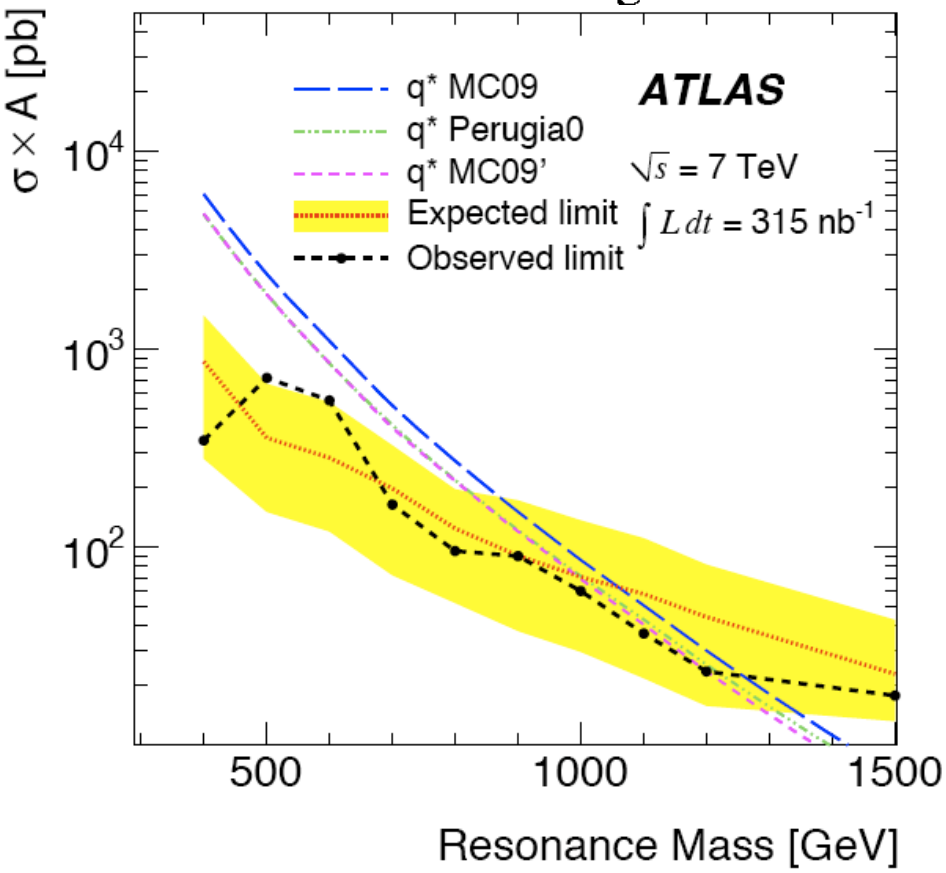
- Data consis
  - Excellent
- Possibly se
  Tevatron fc
  models alre
  - Alvez, Izagu

First steps towards 3rd generation squarks

Dijet Resonance: q*





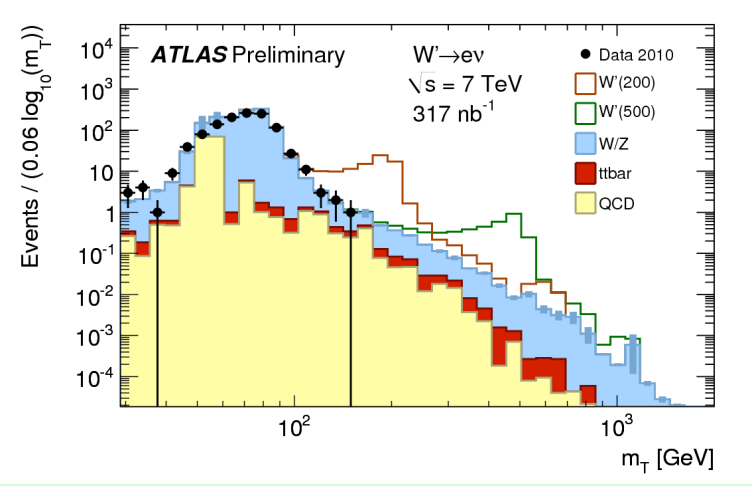


- p_T^{jet1}>80 GeV, p_T^{jet2}>30 GeV, $|\eta^{jet1}-\eta^{jet2}|$<1.3
- No evidence for peak in dijet mass spectrum
- Constrain m(q*)>1.26 TeV (0.3 pb^{-1})
  - Supersedes published CDF limit of 0.87 TeV (1 fb^{-1})

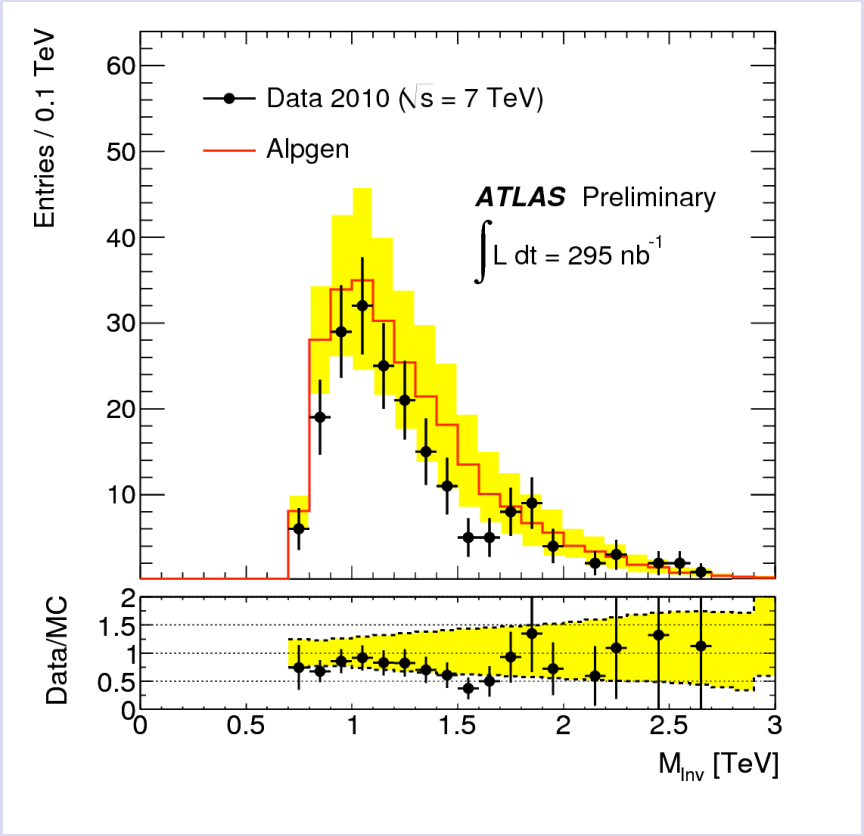
arXiv: 1008.2461
submitted to PRL

More Searches for New Physics

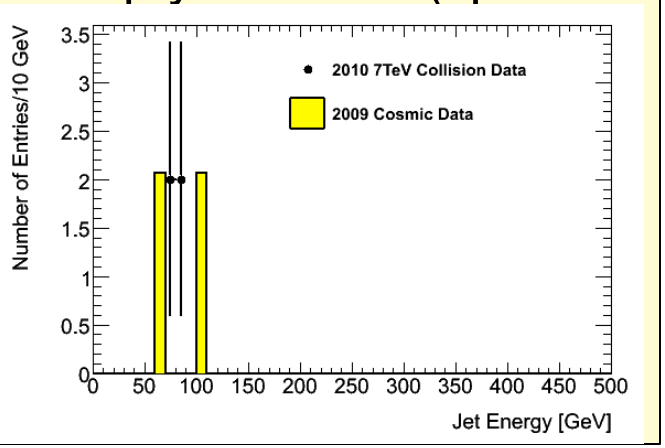
Search for W' bosons



Search for high-multiplicity events (as expected from micro-Black Hole)



Background study to search for "R-hadrons" in empty bunches (split-SUSY,..)

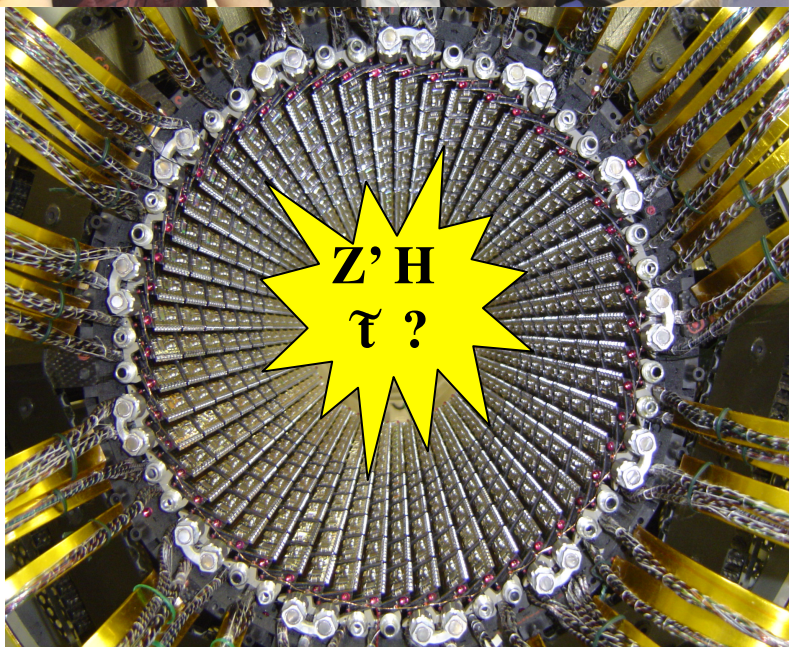


How to get to 1 fb^{-1}?

	LHC (now)	LHC (end of 2010)	LHC (design)
√s [TeV]	7	7	14
# of colliding bunches	up to 36	384	2808
Protons/bunch [10^{10}]	~9	~9	11.5
Energy stored (MJ)	2.7	21.5	362
Peak Luminosity [$cm^{-2}s^{-1}$]	$1x10^{31}$	~1 x 10^{32}	10^{34}
Integrated Luminosity	3 pb^{-1}	~40 pb^{-1} (?)	10-100 fb^{-1} /yr

(* plan constantly adjusted in reaction to what is learned)

- In following weeks
  - **Increase number of bunches each week by factor ~2**
    - Involves using "bunch trains": 150 ns separation between collisions
- 2011
  - Further focus the beam (β*: 3.5m => 2m)
  - Deliver $\int Ldt=1\ fb^{-1}$ (requires e.g. 30% LHC up-time at 1.5 x 10^{32} $cm^{-2}s^{-1}$)

Conclusions and Outlook

- **The LHC era has started**
  - LHC performance remarkable *and* improving week by week
    - On track for 1 fb^{-1} in 2011
  - ATLAS is efficiently taking high quality
- **ATLAS has made many physics measurements**
  - Thanks to excellent performance of detector, simulation, reconstruction, data distribution (grid) … and many many people!
- **If Nature is kind LHC experiments can find something in 2010/2011**