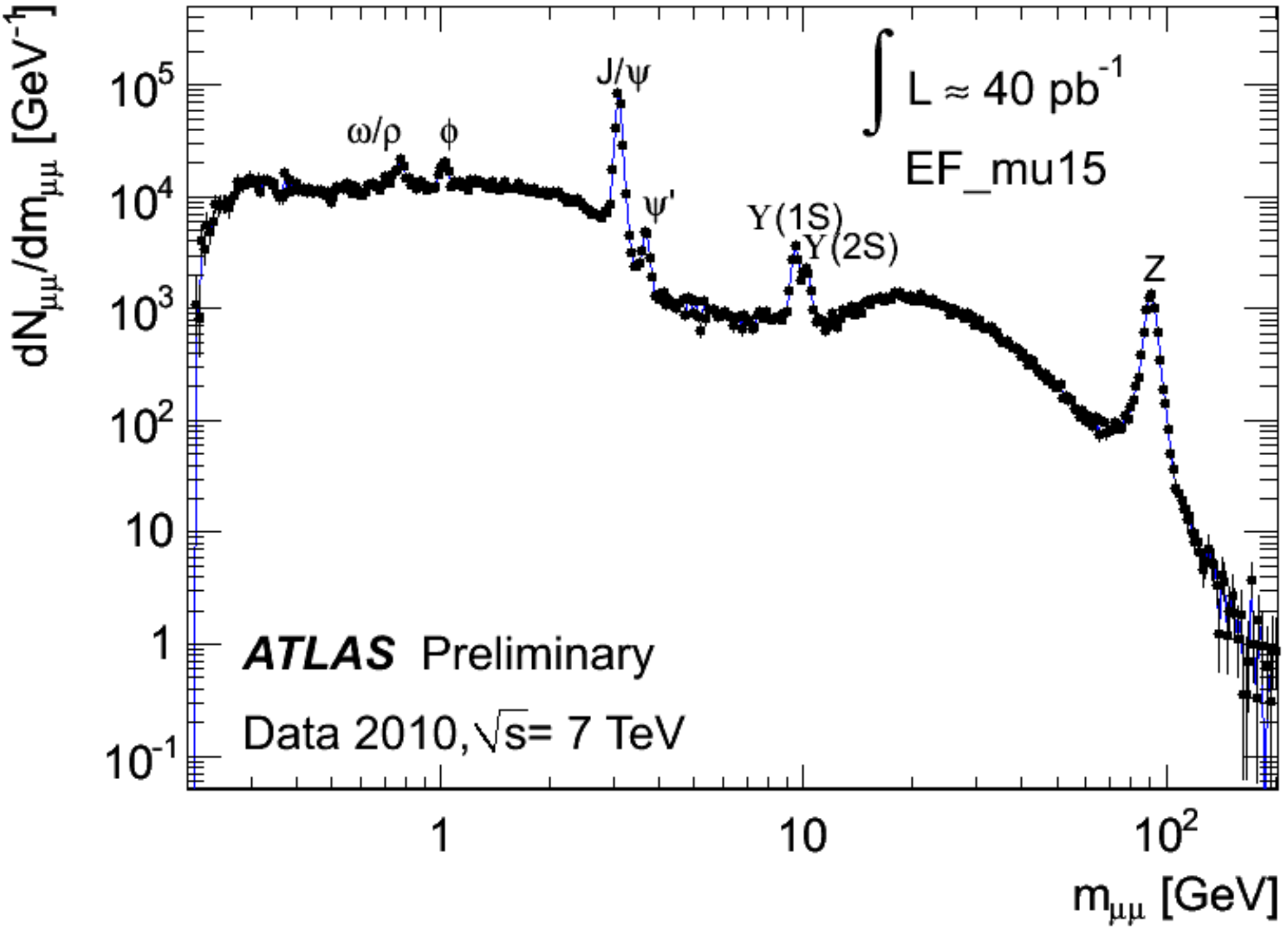
Search for W' and Z' resonances at ATLAS

Simon Viel

(University of British Columbia, TRIUMF)

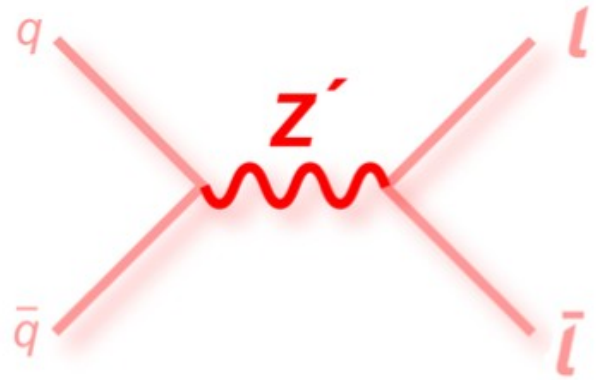
GDR Terascale Plenary Meeting, Lyon

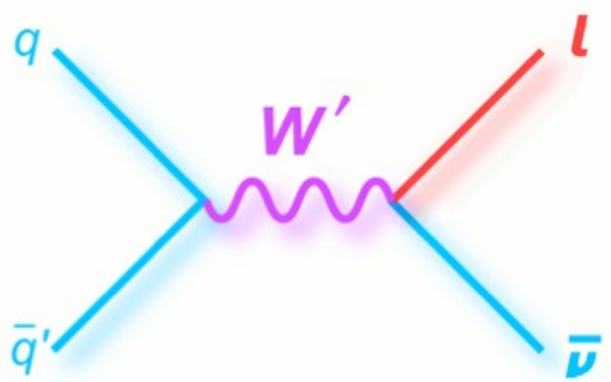
April 20th, 2011


$dN_{\mu\mu}/dm_{\mu\mu}$ [GeV^{-1}]
10^5
10^4
10^3
10^2
10
1
10^{-1}
ω/ρ
φ
J/ψ
ψ'
Υ(1S)
Υ(2S)
Z
$\int L \approx 40$ pb^{-1}
EF_mu15
ATLAS Preliminary
Data 2010, $\sqrt{s}$= 7 TeV
1
10
10^2
$m_{\mu\mu}$ [GeV]

New Resonances: Examples

- Neutral:
  - Z' bosons
    - Sequential Standard Model (SSM)
    - Superstring-motivated E_6 models
    - Left-Right Symmetric Models (Z_R)
  - Z* bosons
  - Graviton excitations
    - e.g. Randall-Sundrum models
  - Techni-mesons
- Charged:
  - W', W_R and W* bosons

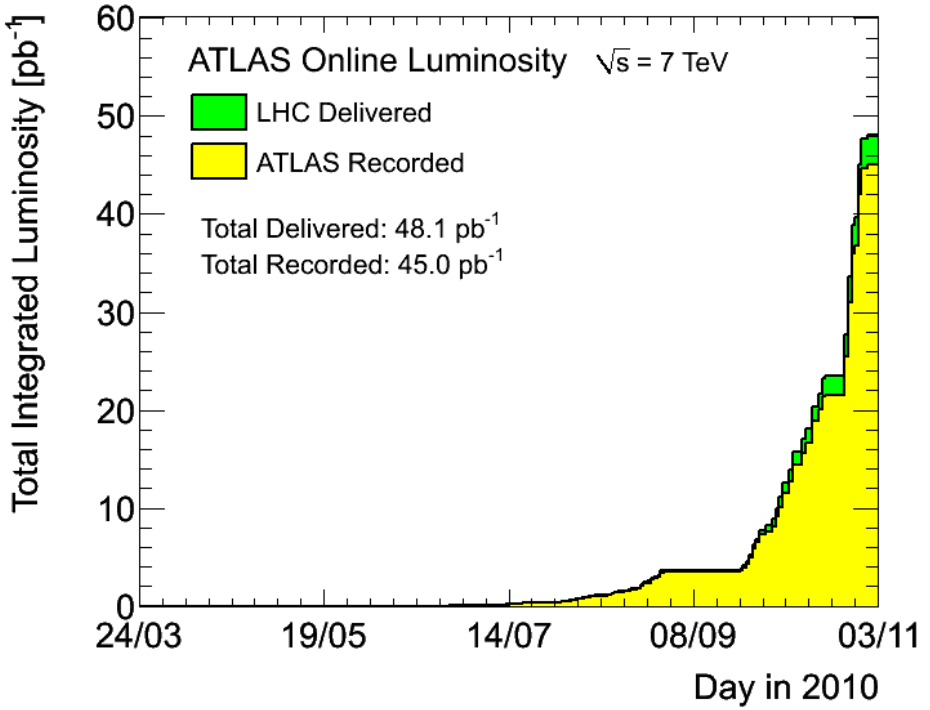


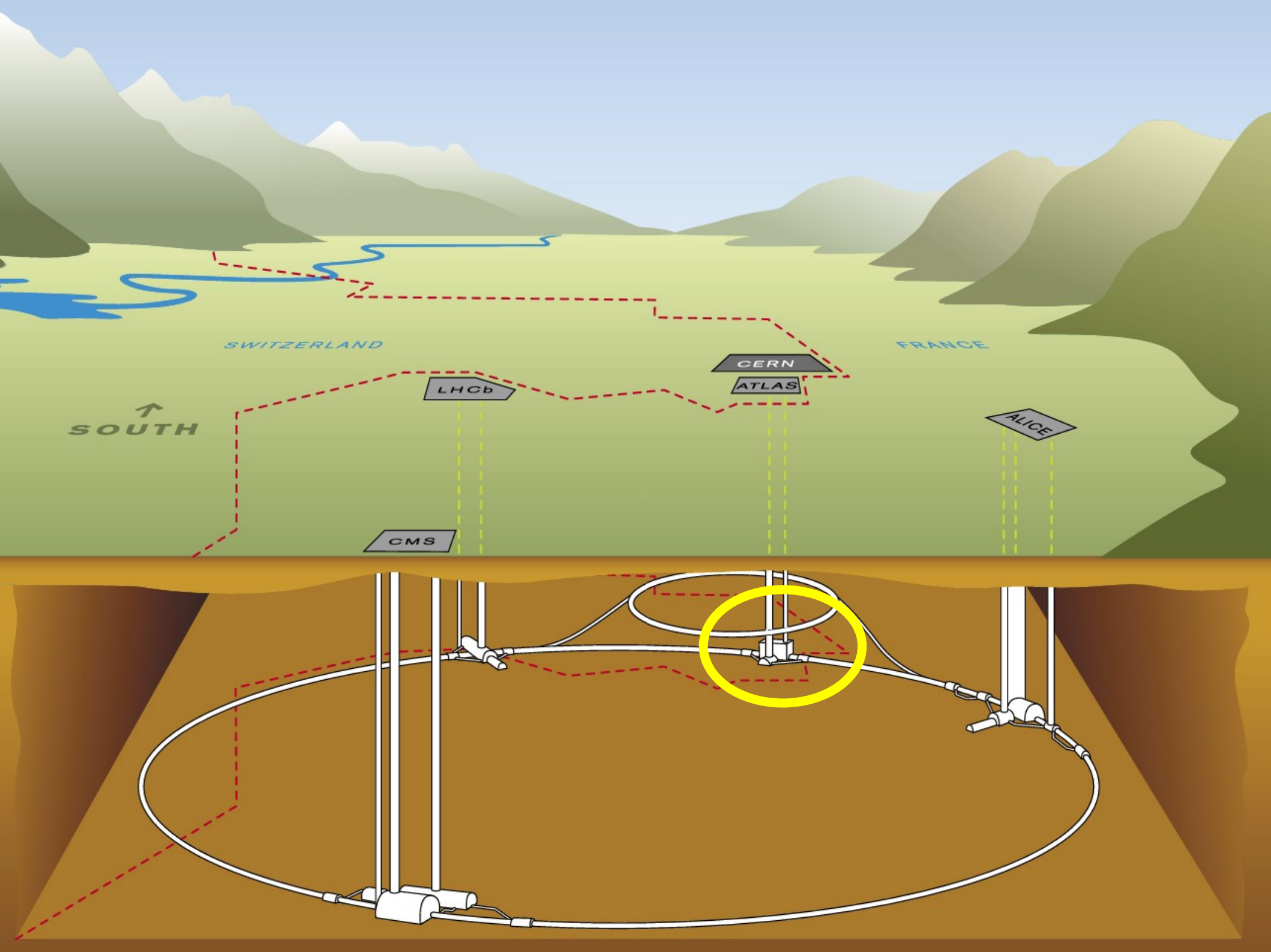


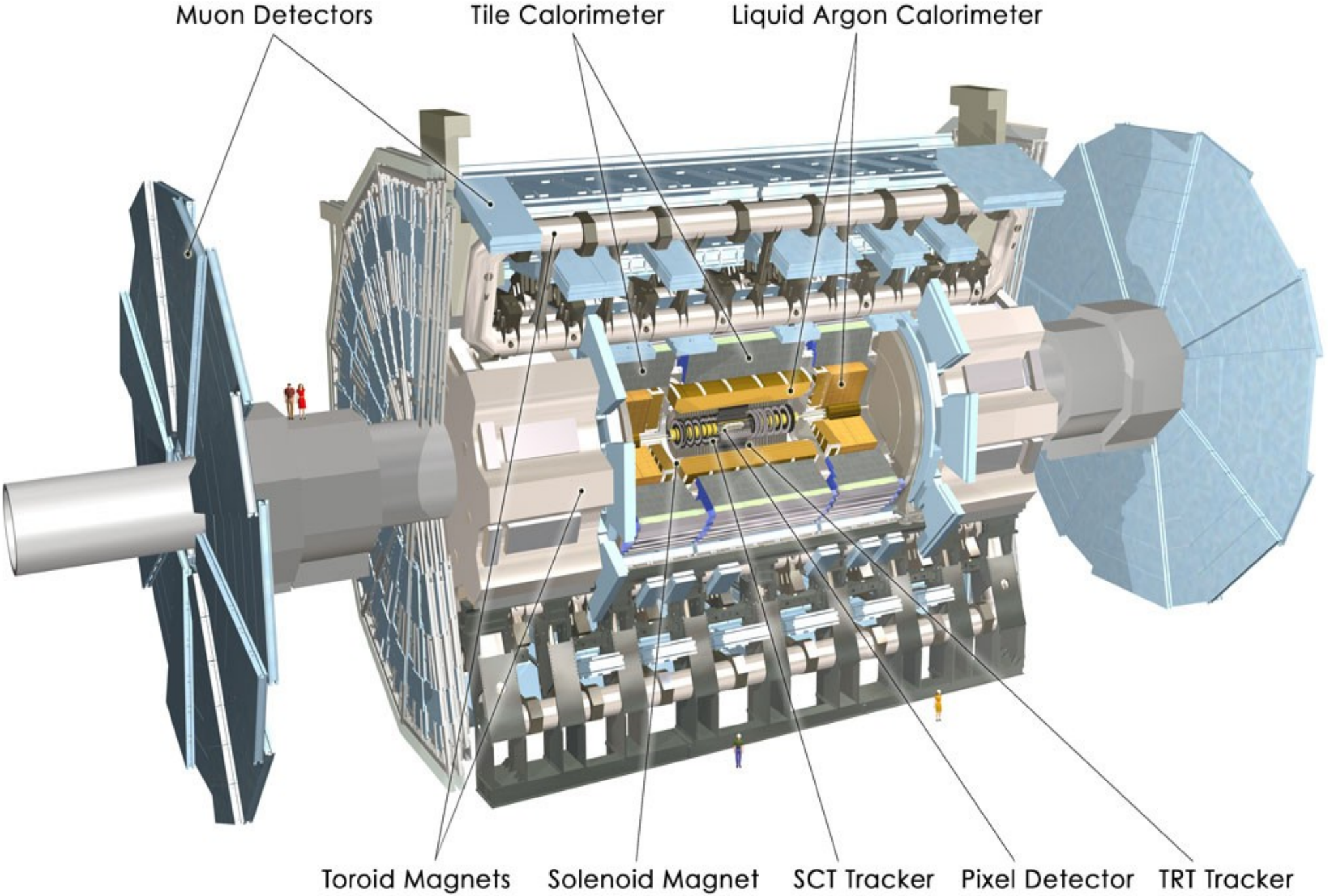
Large Hadron Collider: 2010 Data

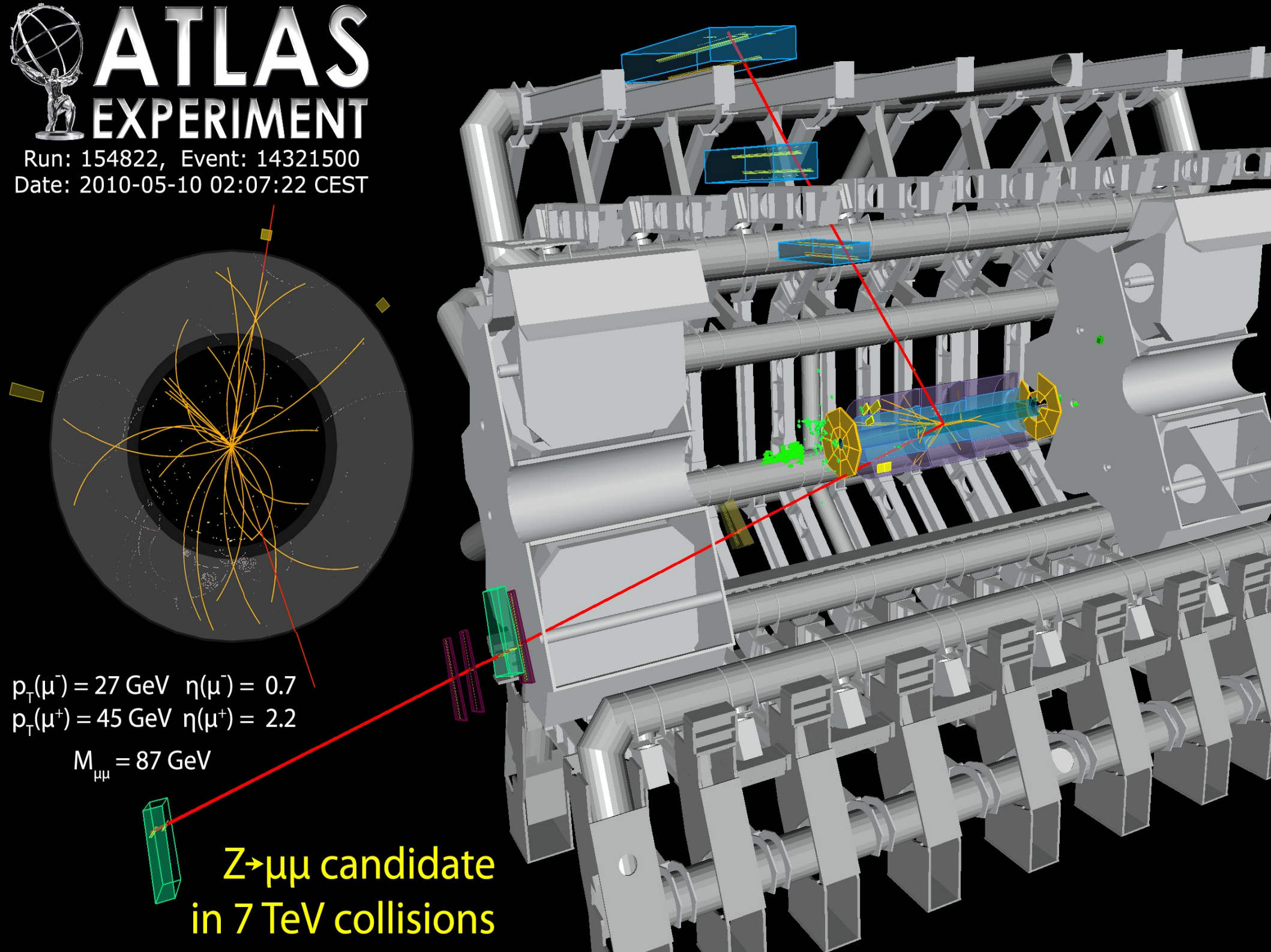
- Centre-of-mass Energy: 7.0 TeV
- Total Integrated Luminosity: 45.0 pb^{-1}

  = over 3000 billion collisions observed




SWITZERLAND
FRANCE
CERN
ATLAS
LHCb
ALICE
CMS
SOUTH


Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker


ATLAS
EXPERIMENT
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

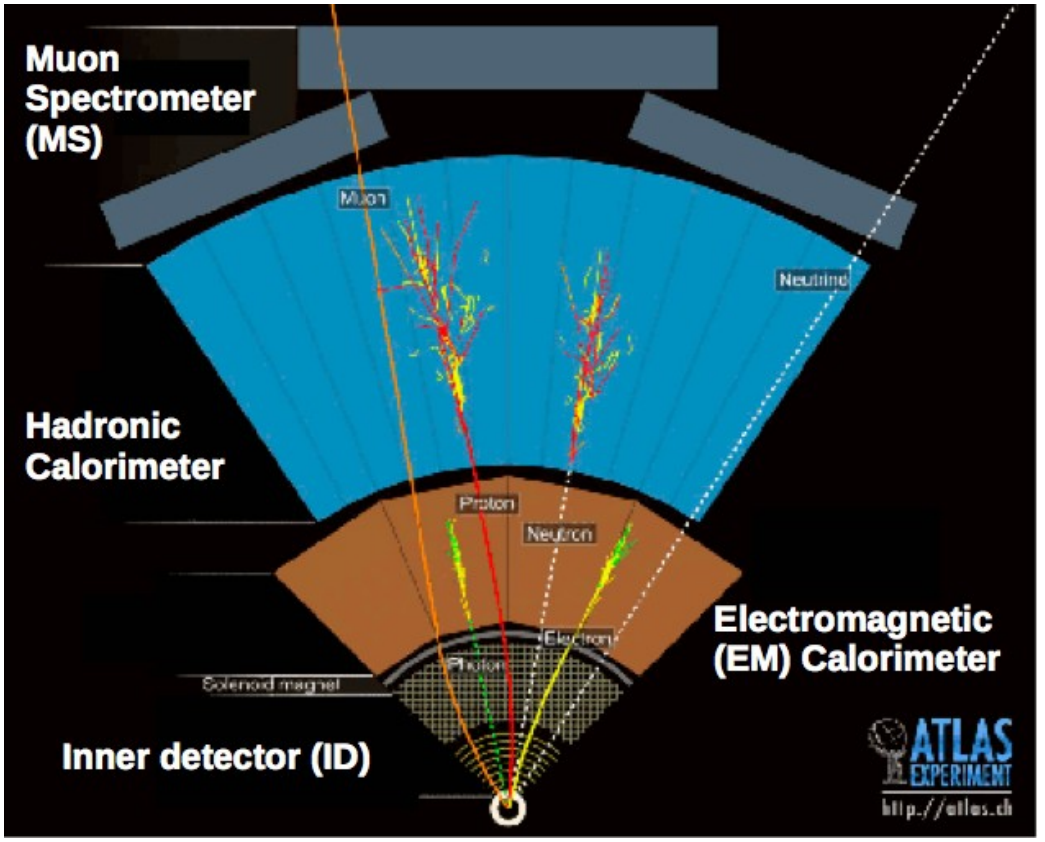
Lepton Detection at ATLAS

- Muons:
  - Combined tracks from Inner Detector and Muon Spectrometer

$$\frac{\sigma(p_T)}{p_T} = S_1 + S_2 \cdot p_T$$

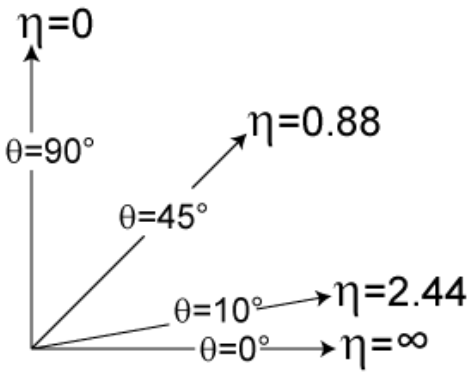
- Electrons:
  - Isolated energy deposition in the EM calorimeter associated with an ID track

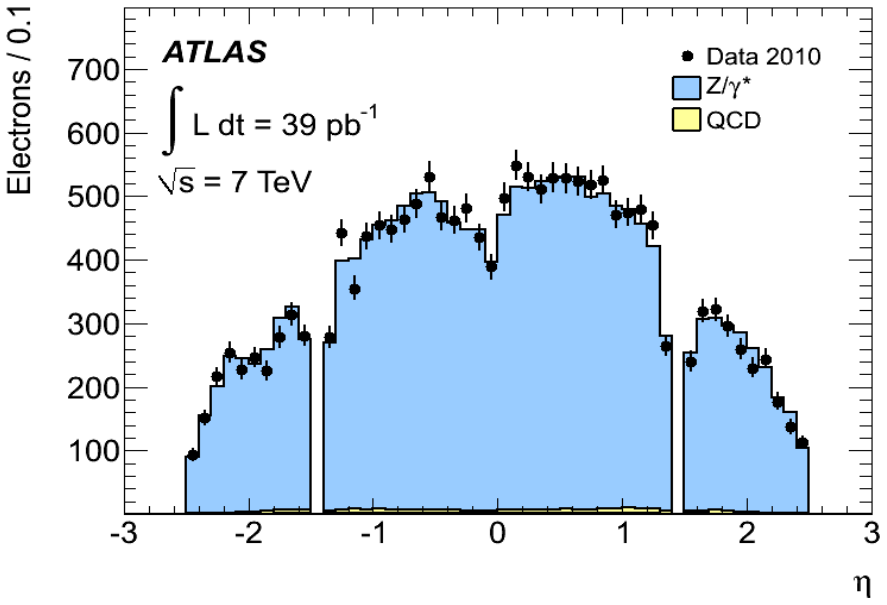
$$\frac{\sigma(E)}{E} = \frac{k_1}{\sqrt{E}} + k_2$$



Electron Selection

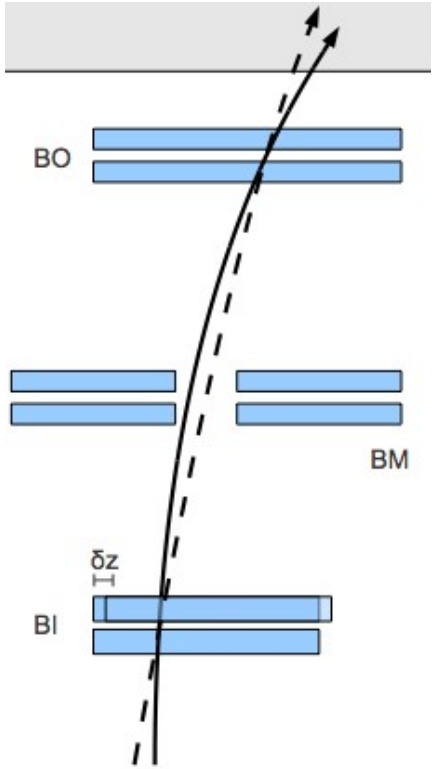
- Electrons with E_T > 25 GeV, |η| < 2.47,
  - Electron ID: Criteria on the transverse shower shape, the longitudinal leakage into the hadronic calorimeter, and the association to an inner detector track
  - Removal of transition region between barrel and endcap calorimeters
  - Hit in first Pixel layer
  - Calorimeter isolation for W' → eν



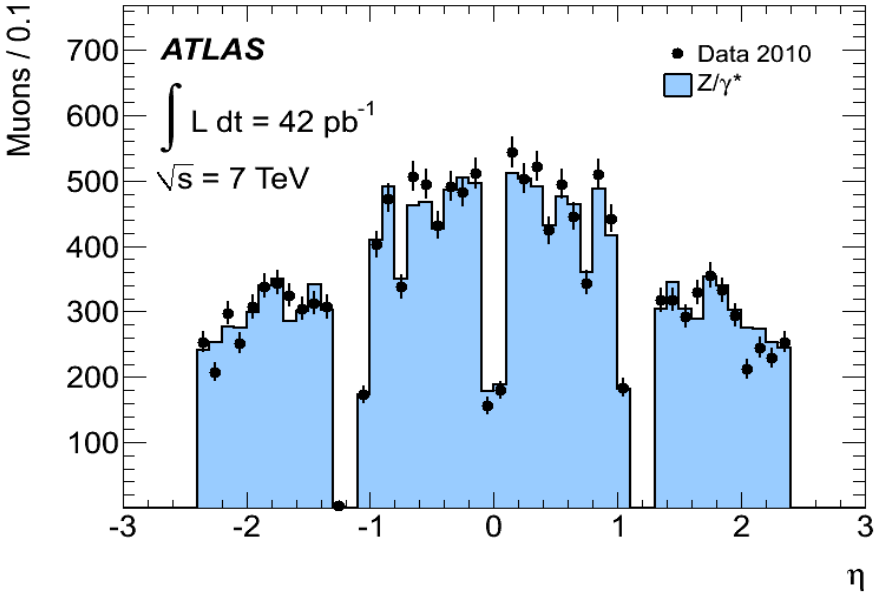


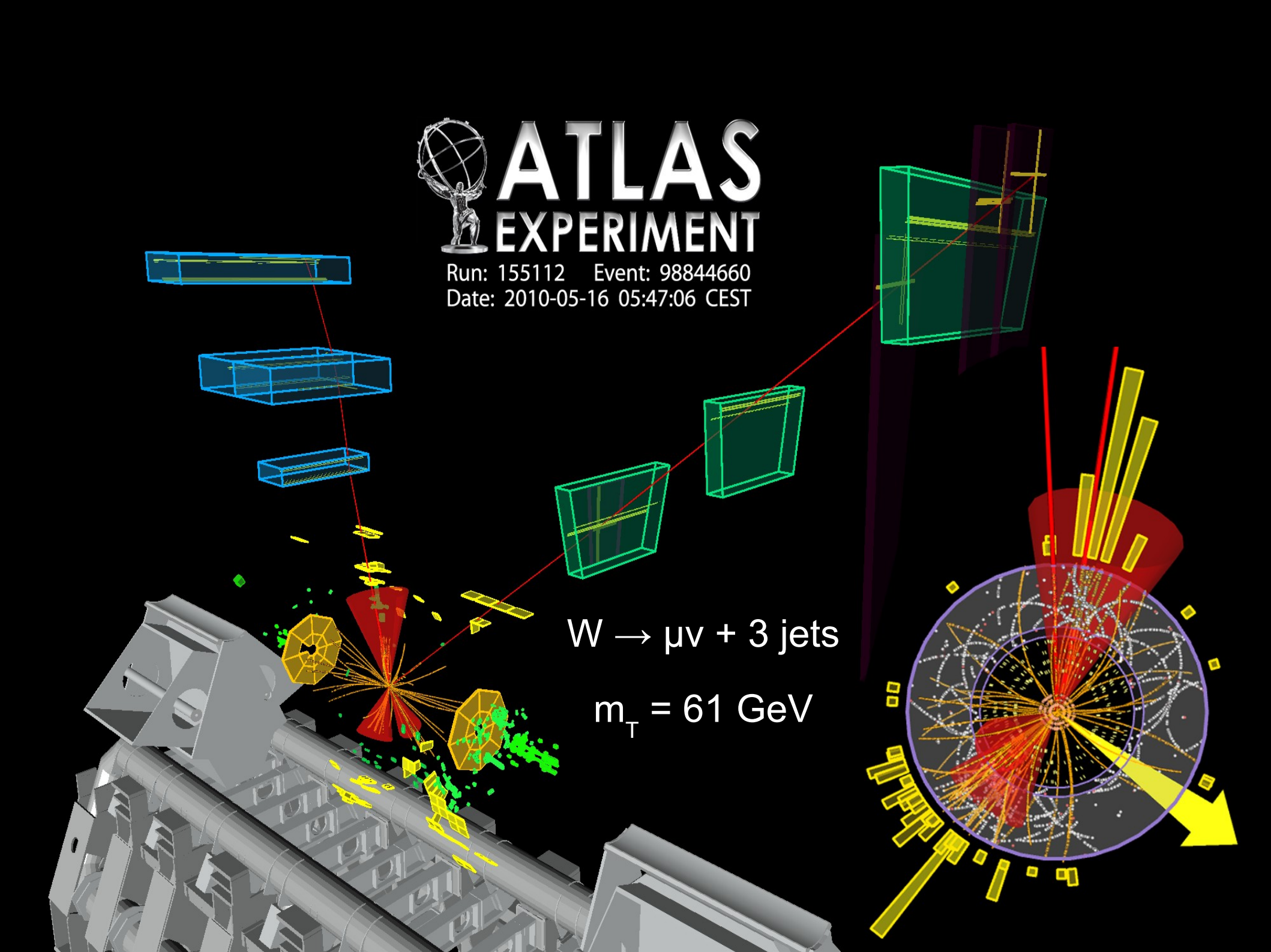
Muon Selection

- Combined muons with p_T > 25 GeV,
  - |η| < 2.4 for Z' ; |η| < 1.05 for W'
  - Hit requirements in ID and MS
  - Impact parameters: d_0 and z_0 wrt PV
  - Z': Muons of opposite charge
  - Track isolation



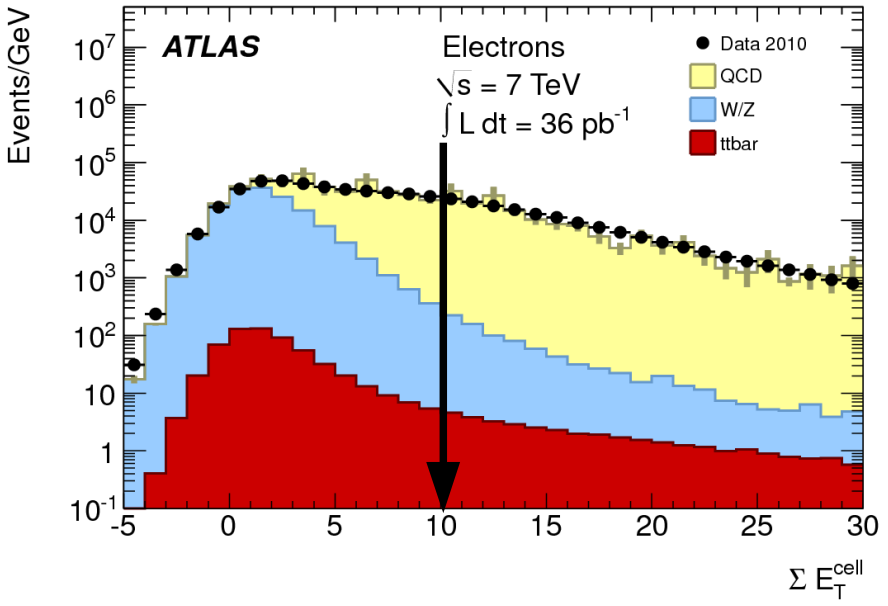
- Central hole:
  "Crack" in Muon Spectrometer
  (for read-out channels, etc)
- Side holes:
  3-station requirement



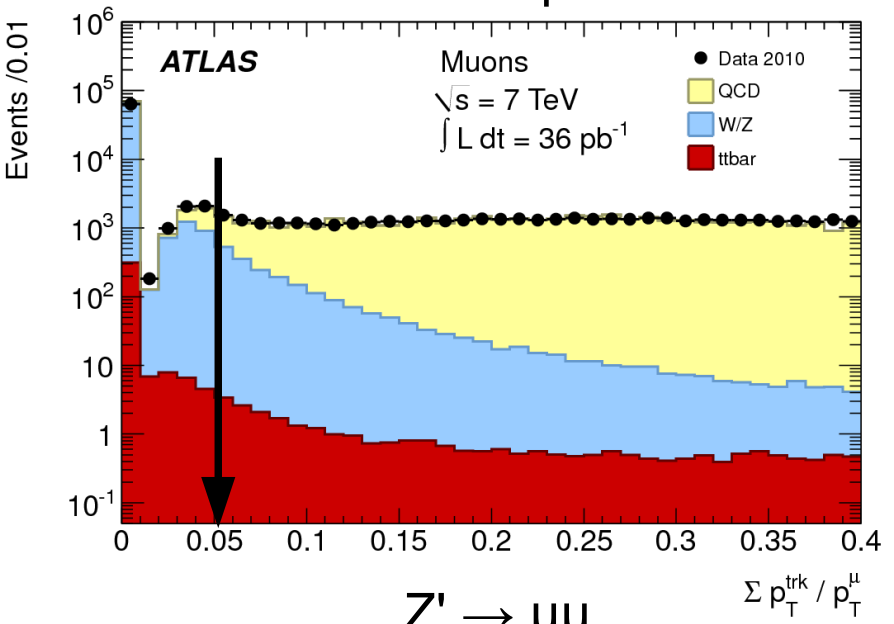

ATLAS
EXPERIMENT
Run: 155112 Event: 98844660
Date: 2010-05-16 05:47:06 CEST
W → μν + 3 jets
m_T = 61 GeV

Isolation Distributions

W' → eν



W' → μν



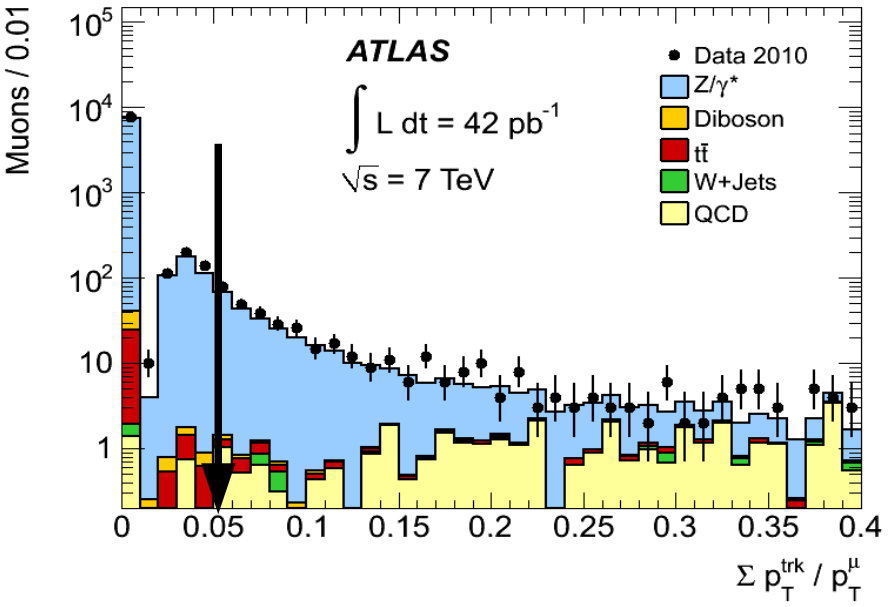
Isolation distributions, immediately before isolation cuts

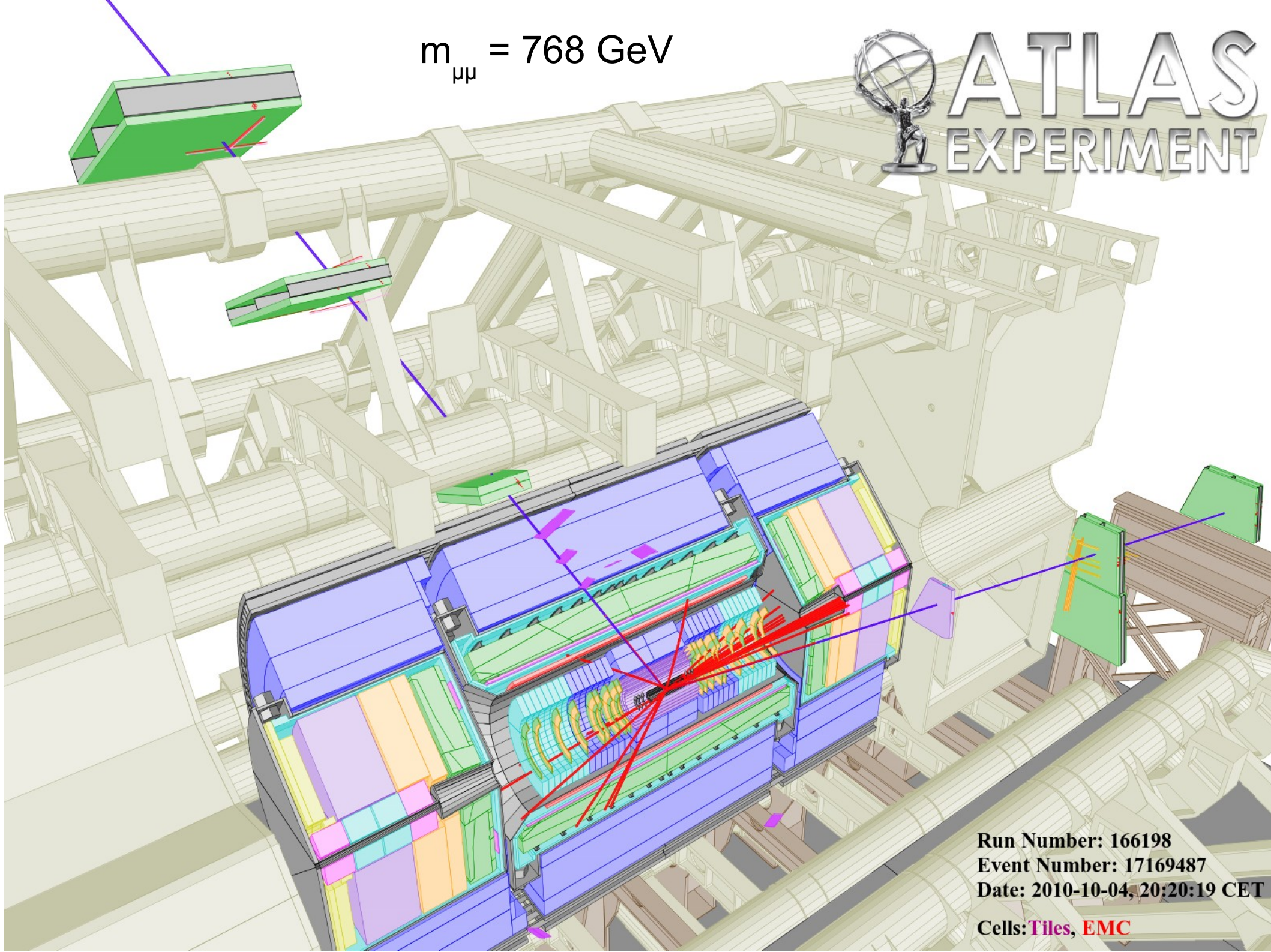
eν: $\sum_{\Delta R < 0.4} E_{\mathrm{T}} < 10\ \mathrm{GeV}$

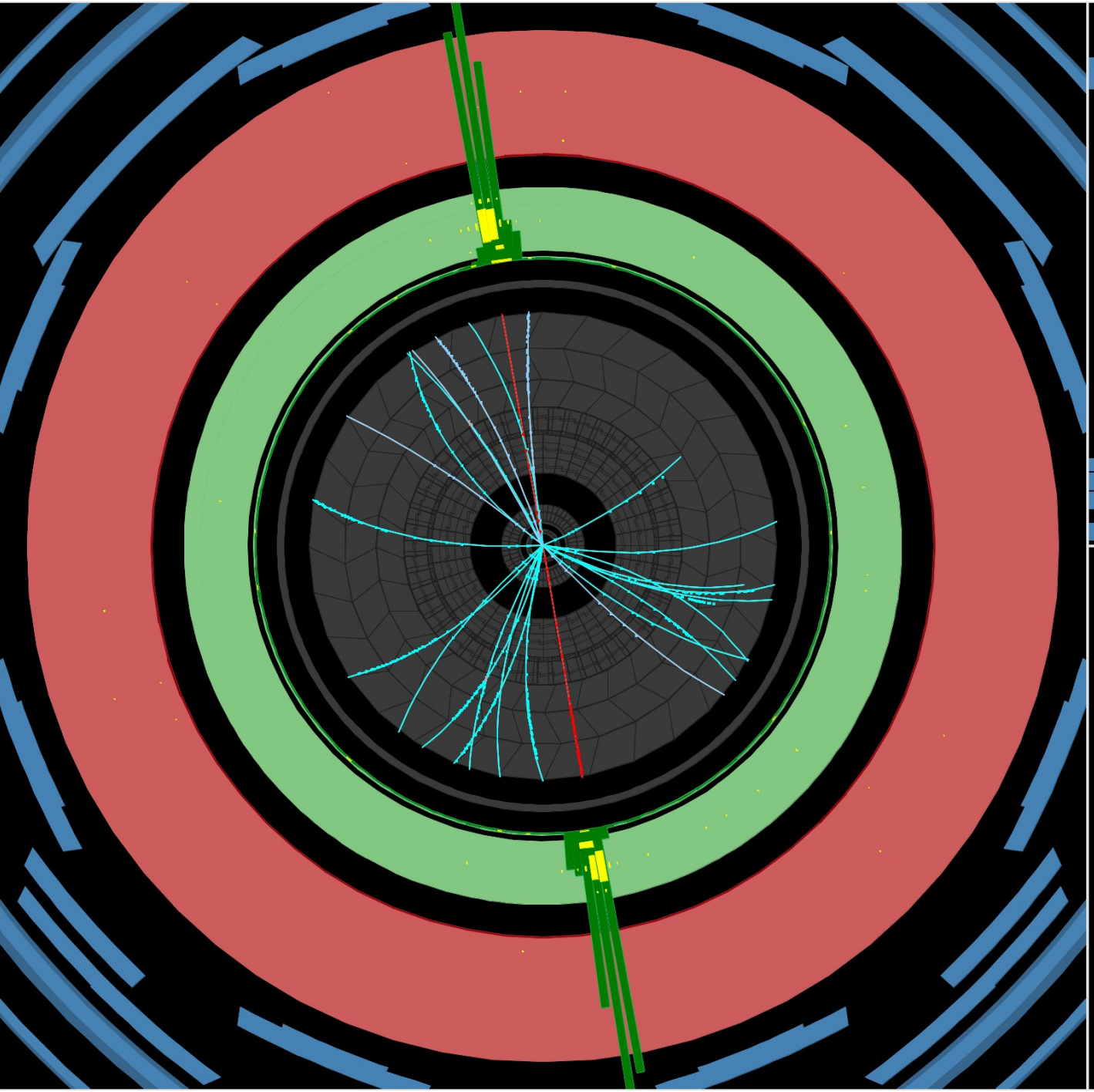
μν, μμ: $\sum_{\Delta R < 0.3} p_{\mathrm{T}}^{\mathrm{trk}} < 0.05\ p_{\mathrm{T}}$

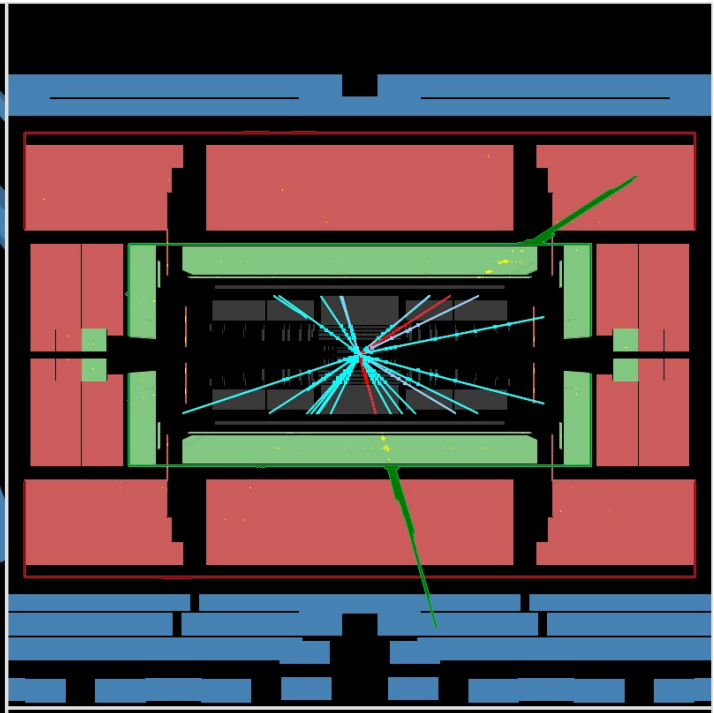
$(\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2})$

Z' → μμ




$m_{\mu\mu}$ = 768 GeV
ATLAS
EXPERIMENT
Run Number: 166198
Event Number: 17169487
Date: 2010-10-04, 20:20:19 CET
Cells: Tiles, EMC





ATLAS EXPERIMENT

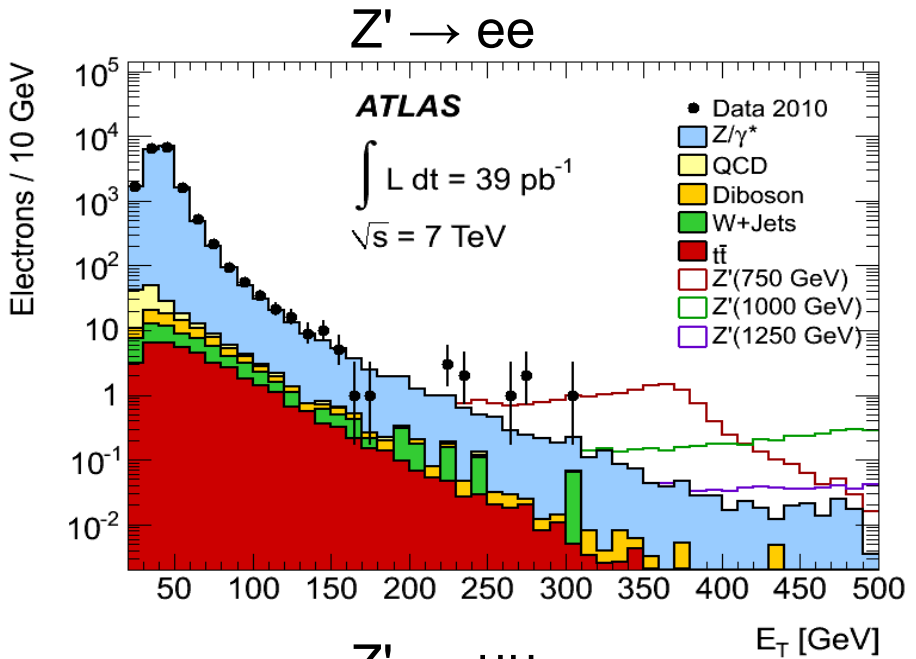
Run Number: 167576, Event Number: 22999252

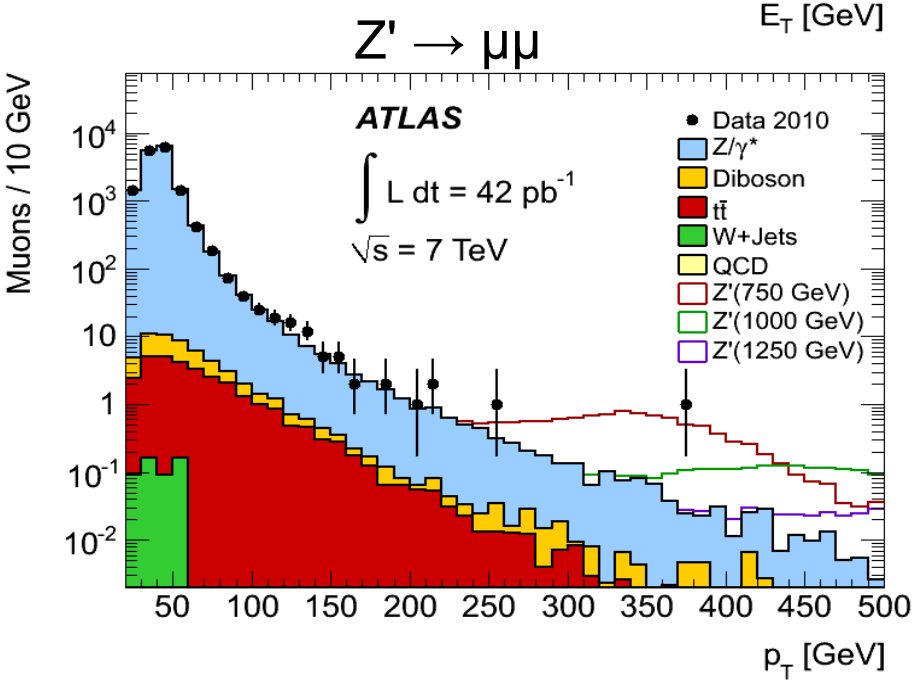
Date: 2010-10-24 12:22:12 CEST

m_{ee} = 617 GeV

Z': Analysis Strategy

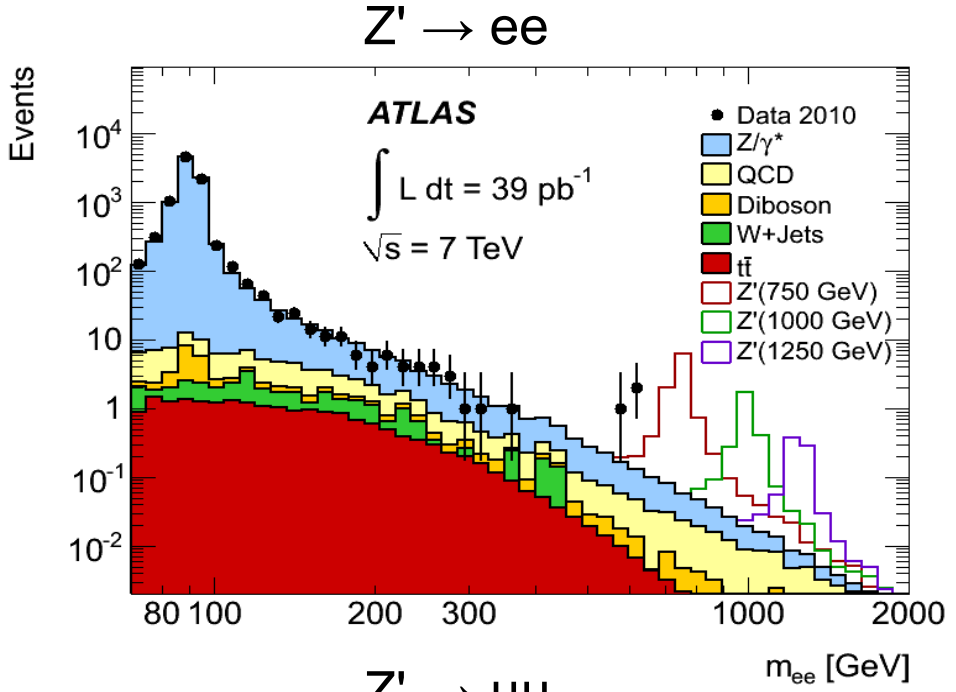
- Background and Z' signal simulated using:
  - Pythia (Z/γ*, Z')
  - Alpgen (W+Jets)
  - Herwig (WW, WZ, ZZ)
  - MC@NLO (ttbar)
- Full detector simulation using GEANT4
- Higher-order corrections to Monte Carlo cross-sections
- Data-driven backgrounds
  - QCD
  - Cosmic rays

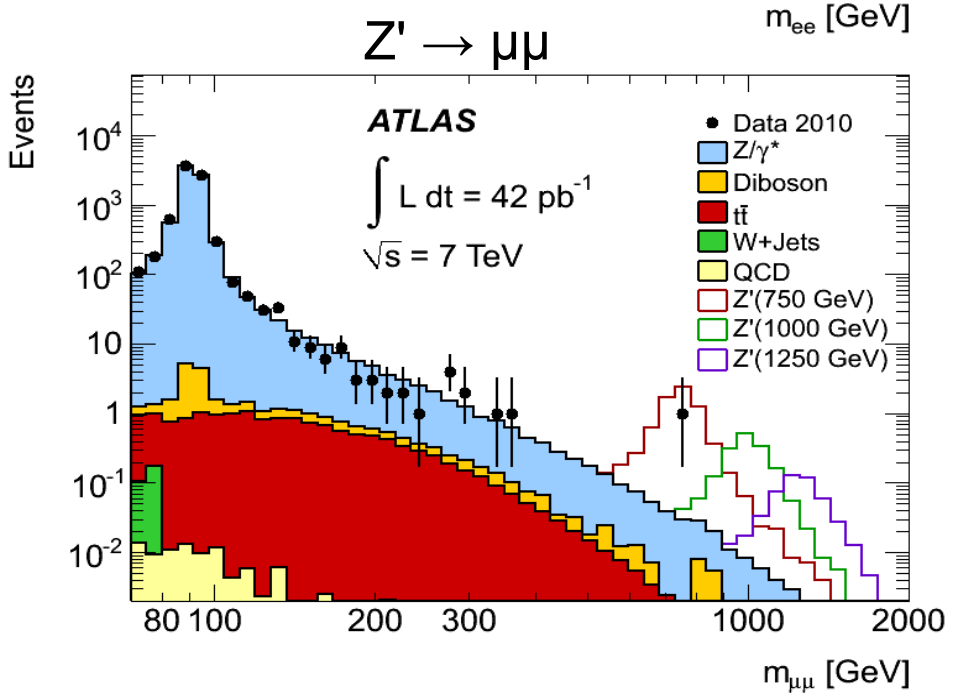




Z': Analysis Strategy

- Normalization to the Z peak in the region [70-110 GeV] in invariant mass
  - Removes mass-independent systematic uncertainties
- Remaining systematic uncertainties on:
  - Parton distribution functions
  - K-factors
  - Mass-dependent efficiencies
  - Muon resolution
- Discovery statistics: 2D maximum-likelihood fit for M(Z') and N(Z'), giving p-values: **5%** (ee) and **22%** (μμ)
- 95% CL intervals on N(Z') are then obtained for each mass bin
- These intervals are finally converted into 95% CL limits on σ·B(Z' → ll)

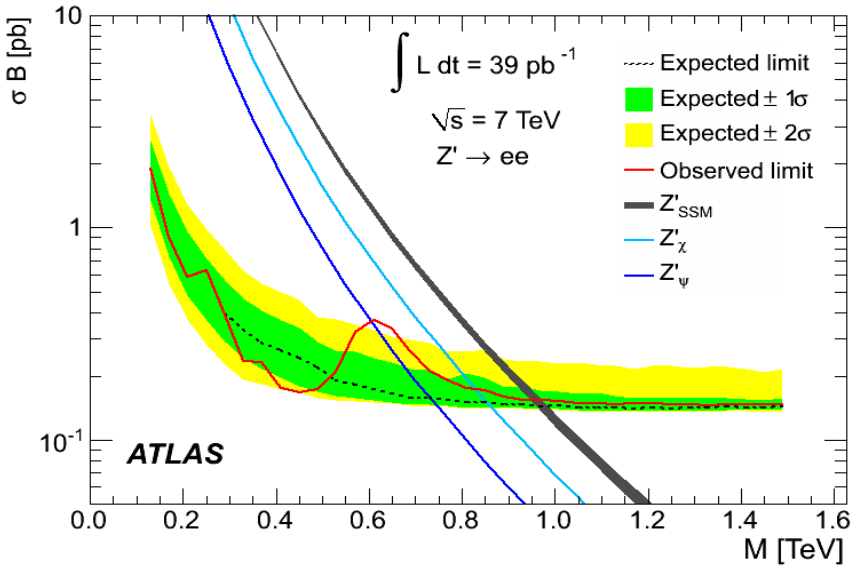




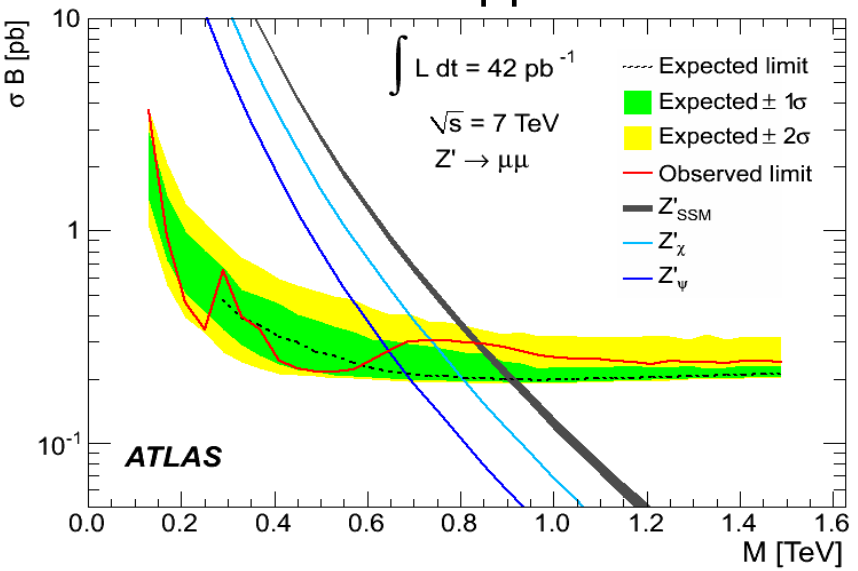
Z': Limits

arXiv:
1103.6218

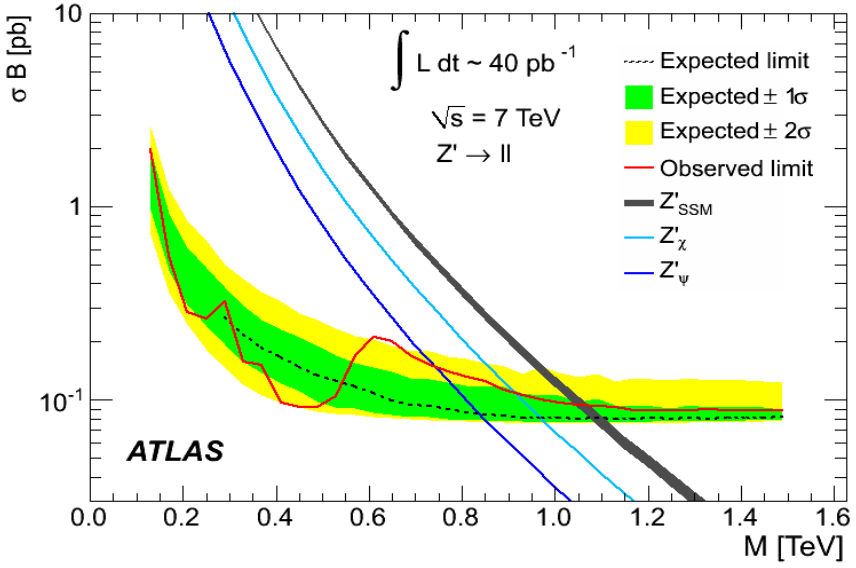
Z' → ee



Z' → μμ



Z' → ll



Combined 95% C.L. limit:

$M_{Z'SSM}$ > 1.048 TeV (1.088 TeV exp.)

Model	Z'_ψ	Z'_N	Z'_η	Z'_I	Z'_S	Z'_χ
Mass limit [TeV]	0.738	0.763	0.771	0.842	0.871	0.900

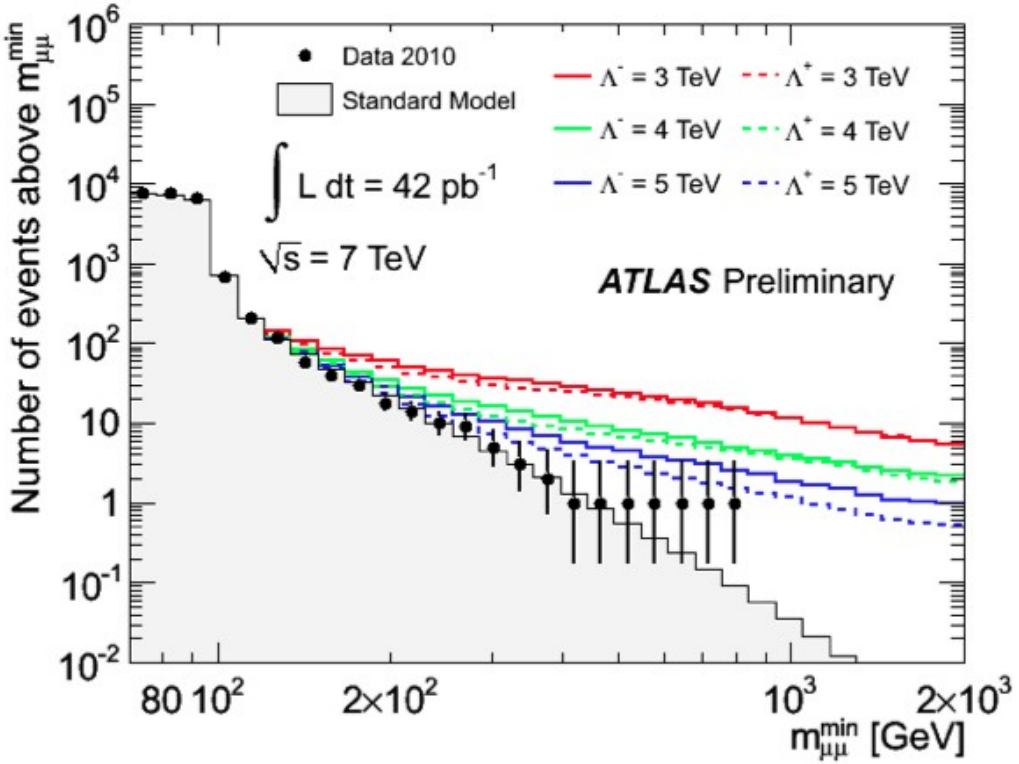
CMS: $M_{Z'SSM}$ > 1.140 TeV

Tevatron (CDF): $M_{Z'SSM}$ > 1.071 TeV

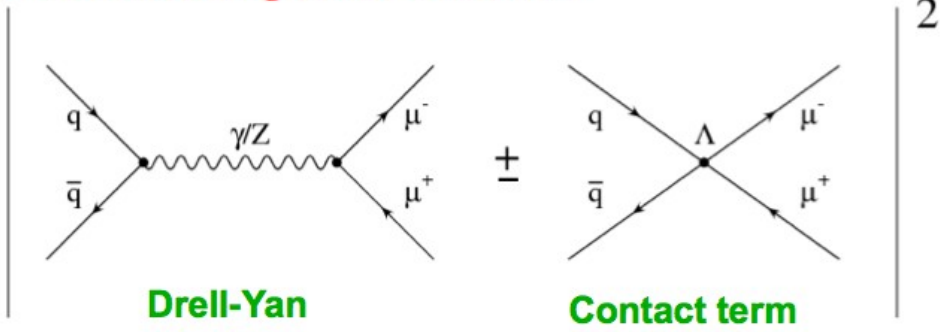
LEP combined fit: $M_{Z'SSM}$ > 1.787 TeV

Contact Interactions

- Search for constructive or destructive interference in the Drell-Yan tail, coming from new physics
- Using the exact same Z' selection

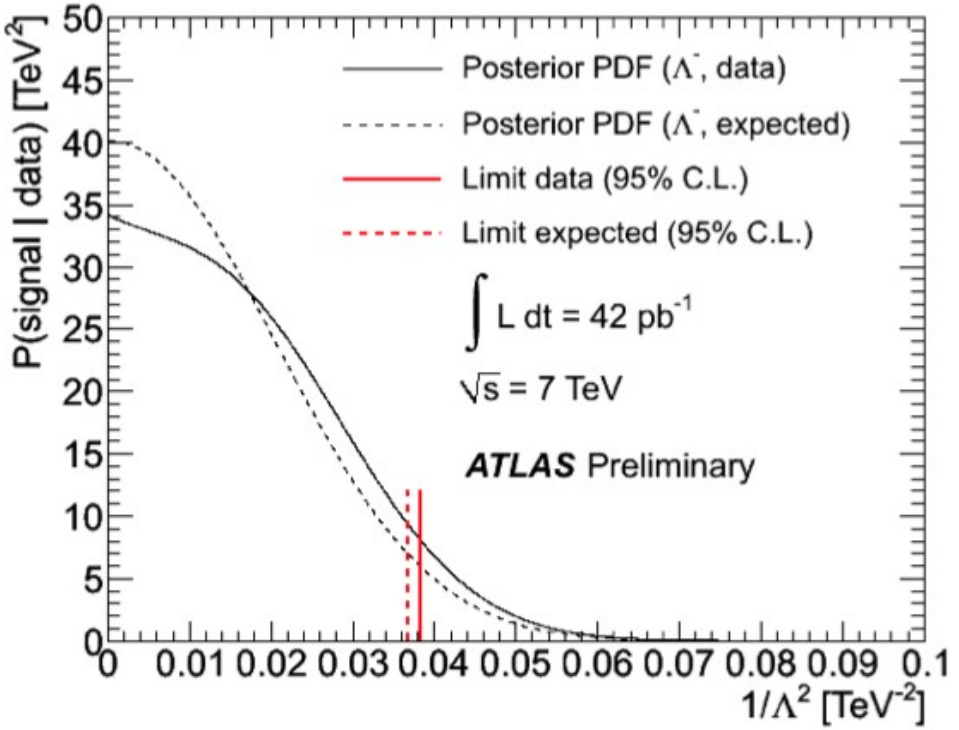


2→2 scattering cross-section:



Contact Interactions Limits

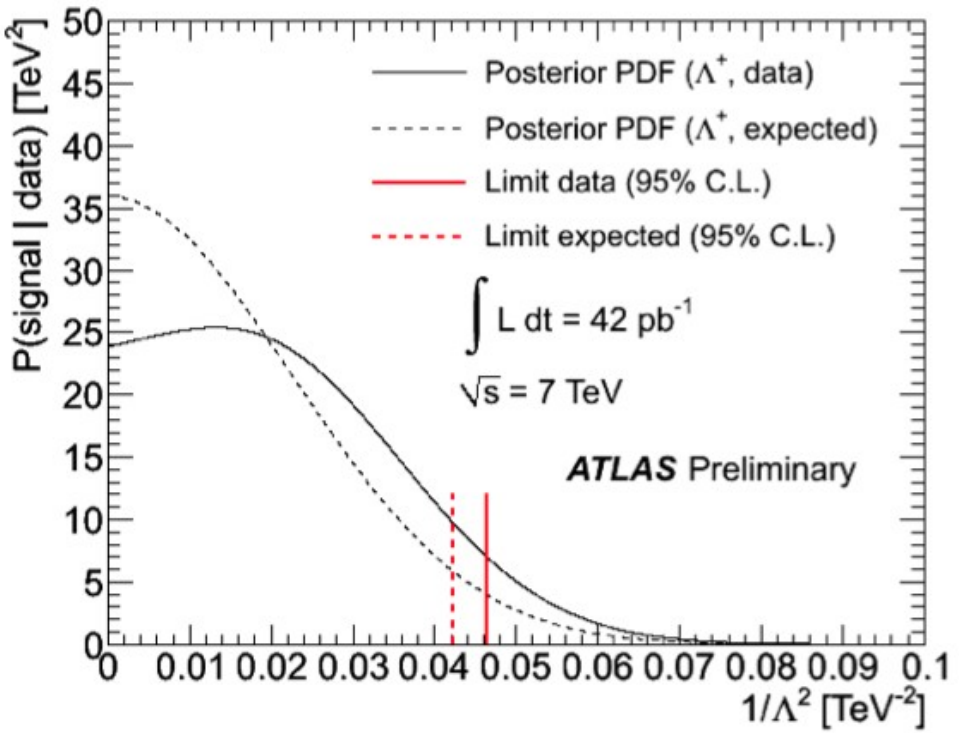
Constructive Interference



Λ⁻ data: 4.9 TeV

Λ⁻ expected: 5.1 TeV

Destructive Interference

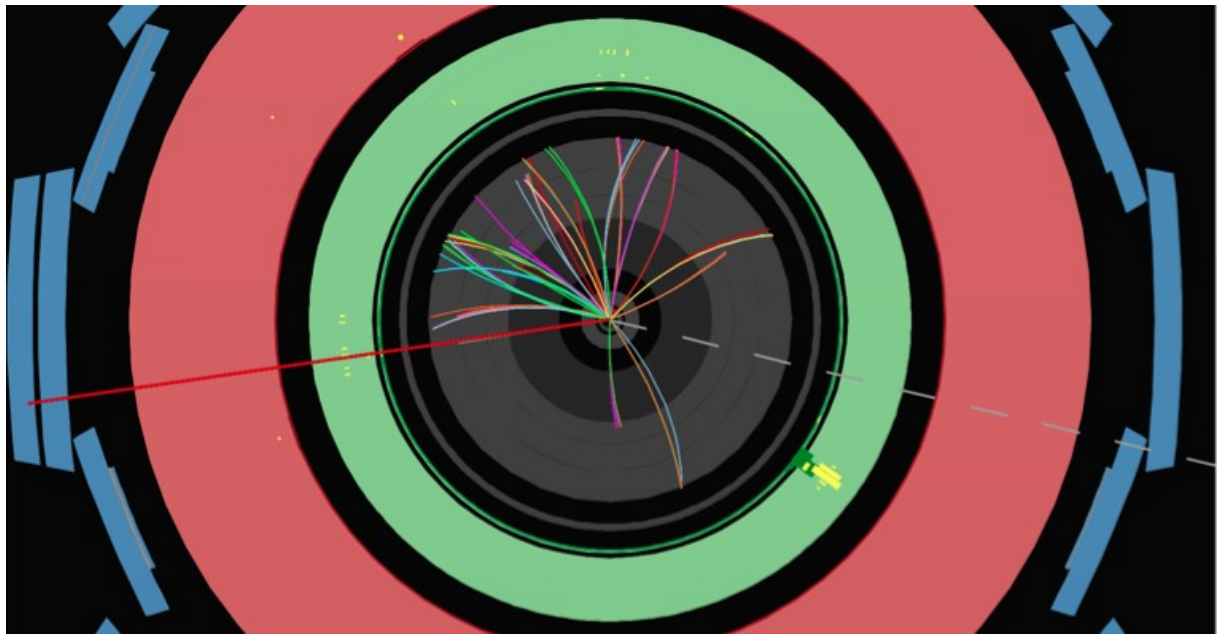


Λ⁺ data: 4.5 TeV

Λ⁺ expected: 4.8 TeV

W': Missing Energy Event Selection

- In addition to the lepton selection:
  - Requirements to remove spurious tails in missing E_T arising from calorimeter noise
  - Missing E_T > 25 GeV
  - For the electron channel: Missing E_T > 0.6*Electron E_T

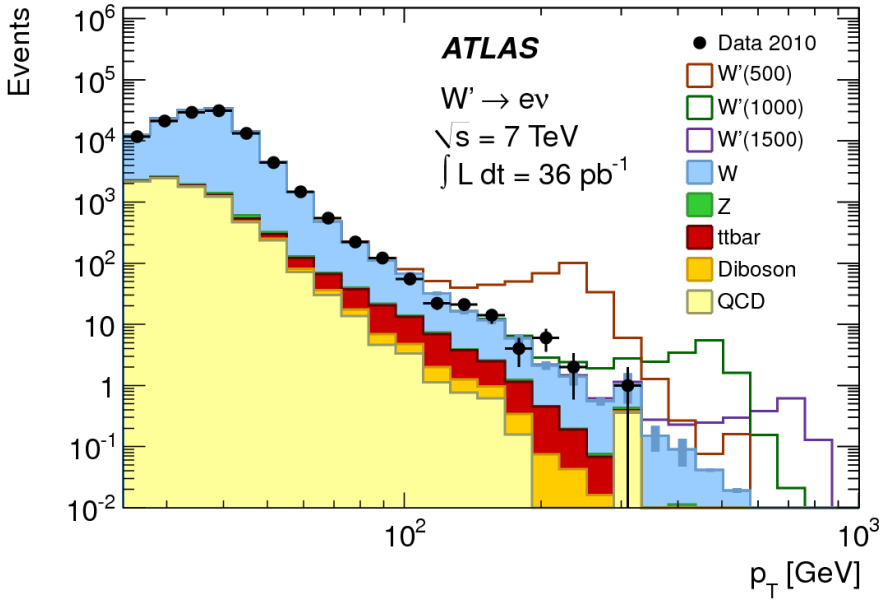


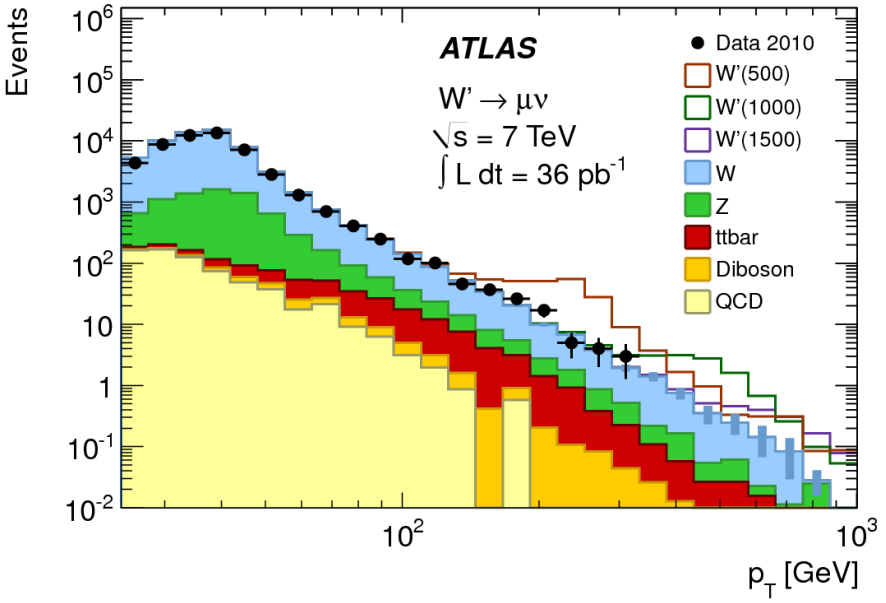
$$\mathbf{E}_{\mathrm{T}}^{\mathrm{miss}} = \mathbf{E}_{\mathrm{Tcalo}}^{\mathrm{miss}} - \mathbf{p}_{\mathrm{T}}^{\mu} + \mathbf{E}_{\mathrm{T}}^{\mu,\mathrm{loss}},$$

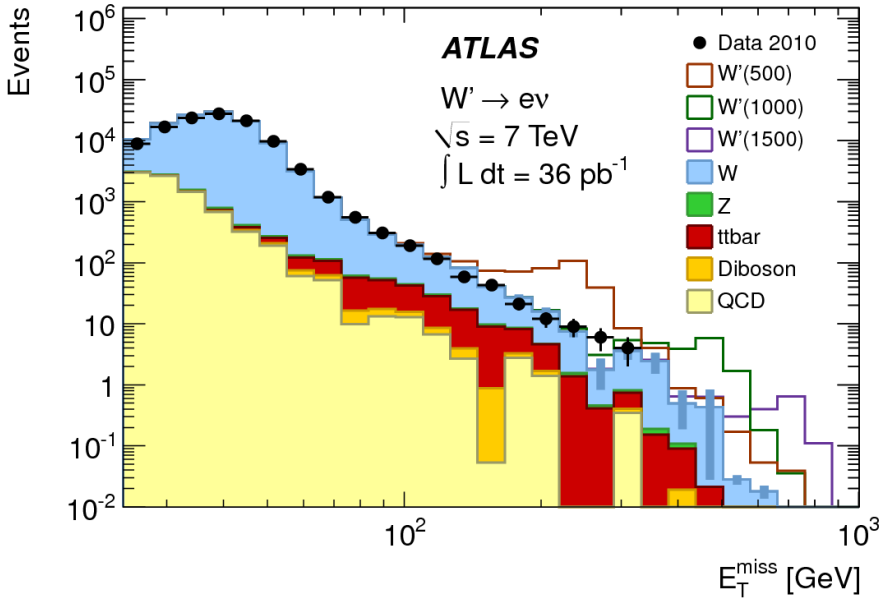
$$\mathbf{E}_{\mathrm{Tcalo}}^{\mathrm{miss}} = -\sum_{\mathrm{topo}} \mathbf{E}_{\mathrm{T}}^{\mathrm{clus}}$$

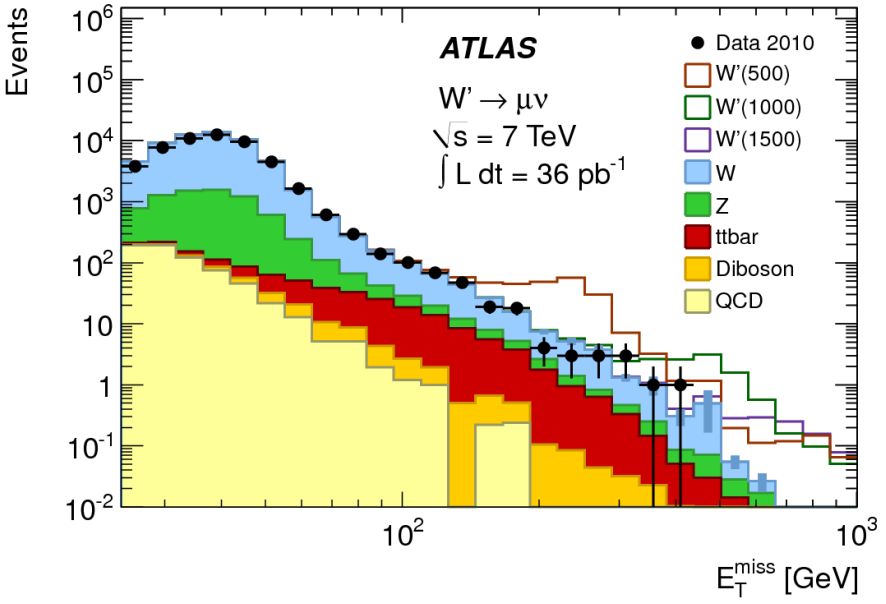
$W \rightarrow \mu\nu + \gamma$,
m_T = 65 GeV

W': Kinematic Distributions

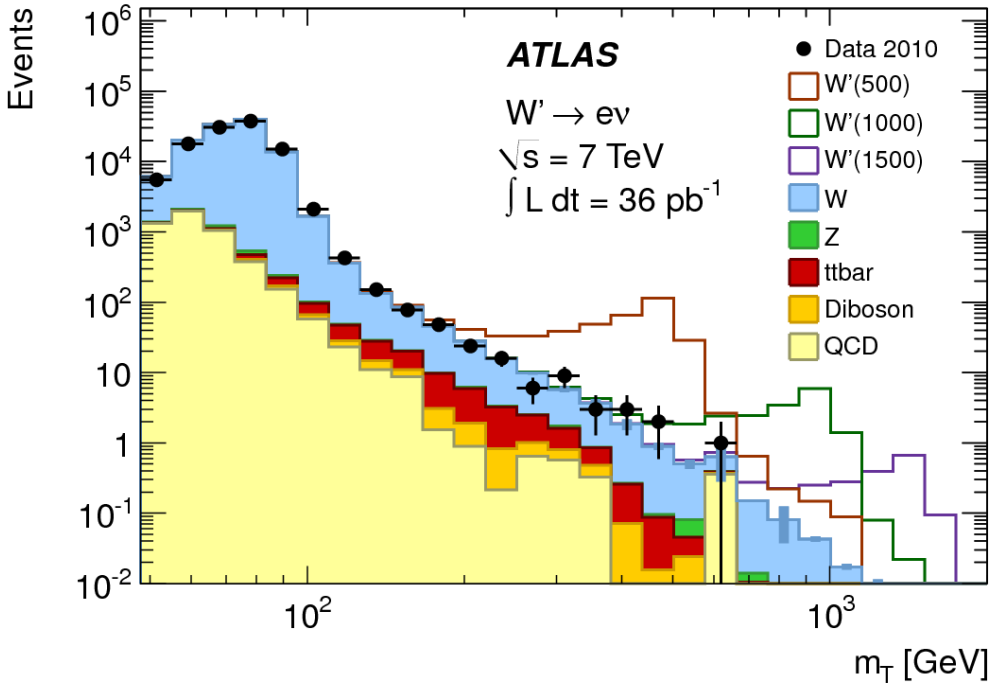


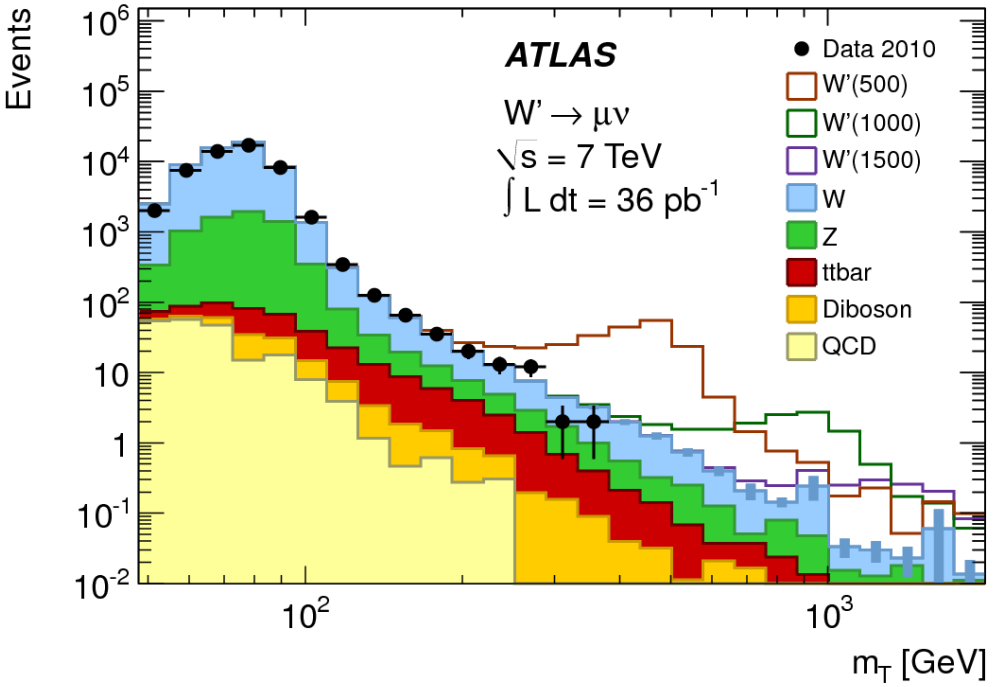






W': Transverse Mass Distributions

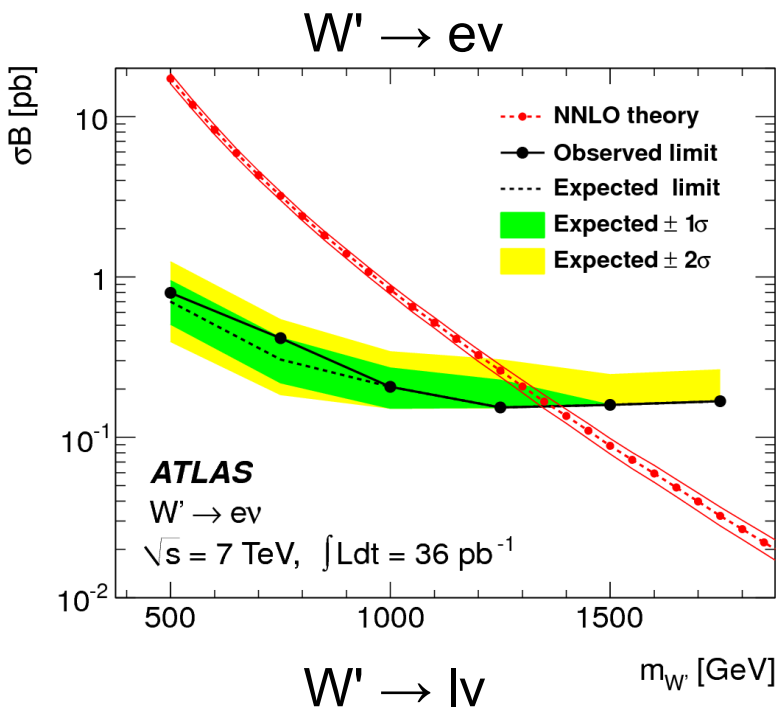


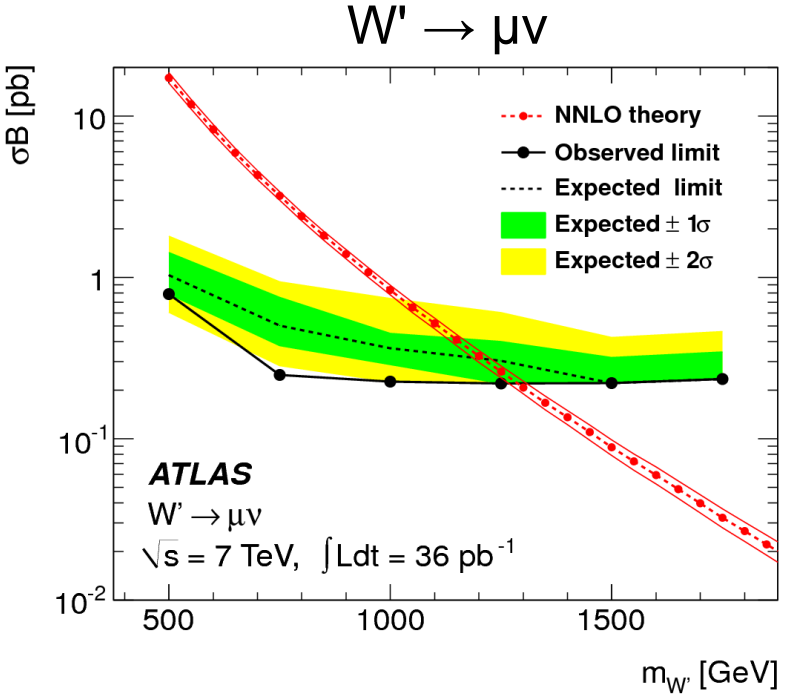


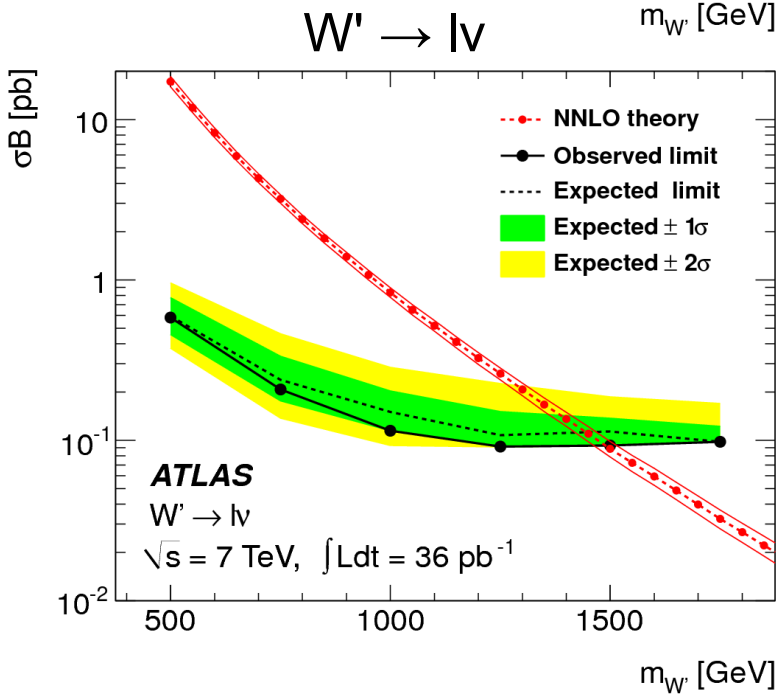
$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \varphi_{l\nu})}$$

arXiv:
1103.1391

W': Limits







Combined 95% C.L. limit:

$M_{W'SSM}$ > 1.490 TeV (1.450 TeV exp.)

CMS: $M_{W'SSM}$ > 1.580 TeV

Tevatron (CDF): $M_{W'SSM}$ > 1.120 TeV

Summary and Next Steps

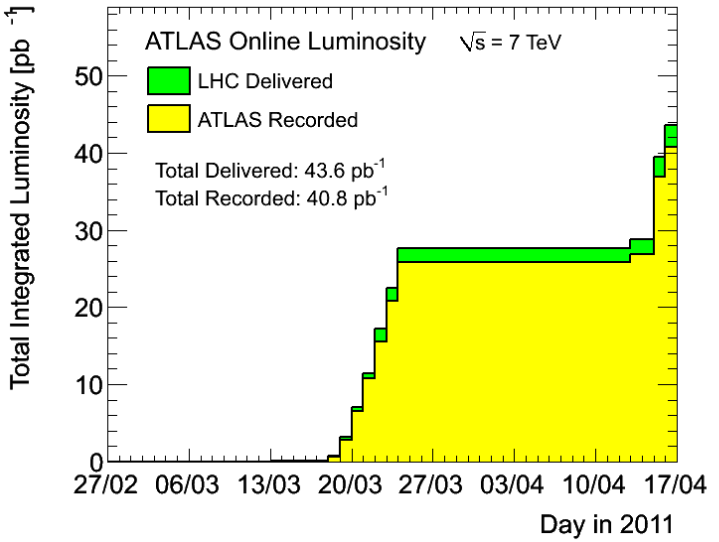
- A search for W' and Z' resonances has been performed at ATLAS
  - LHC results already compete with Tevetron results!
  - No significant excess beyond Standard Model expectations
  - Cross-section limits are set, converted into mass limits:

    $M_{Z'SSM} > 1.048$ TeV ; $M_{W'SSM} > 1.490$ TeV
- New data: Entering new territory!
  - Expected limits with 1.0 fb^{-1}:

    $M_{Z'SSM} > \sim 1.85$ TeV

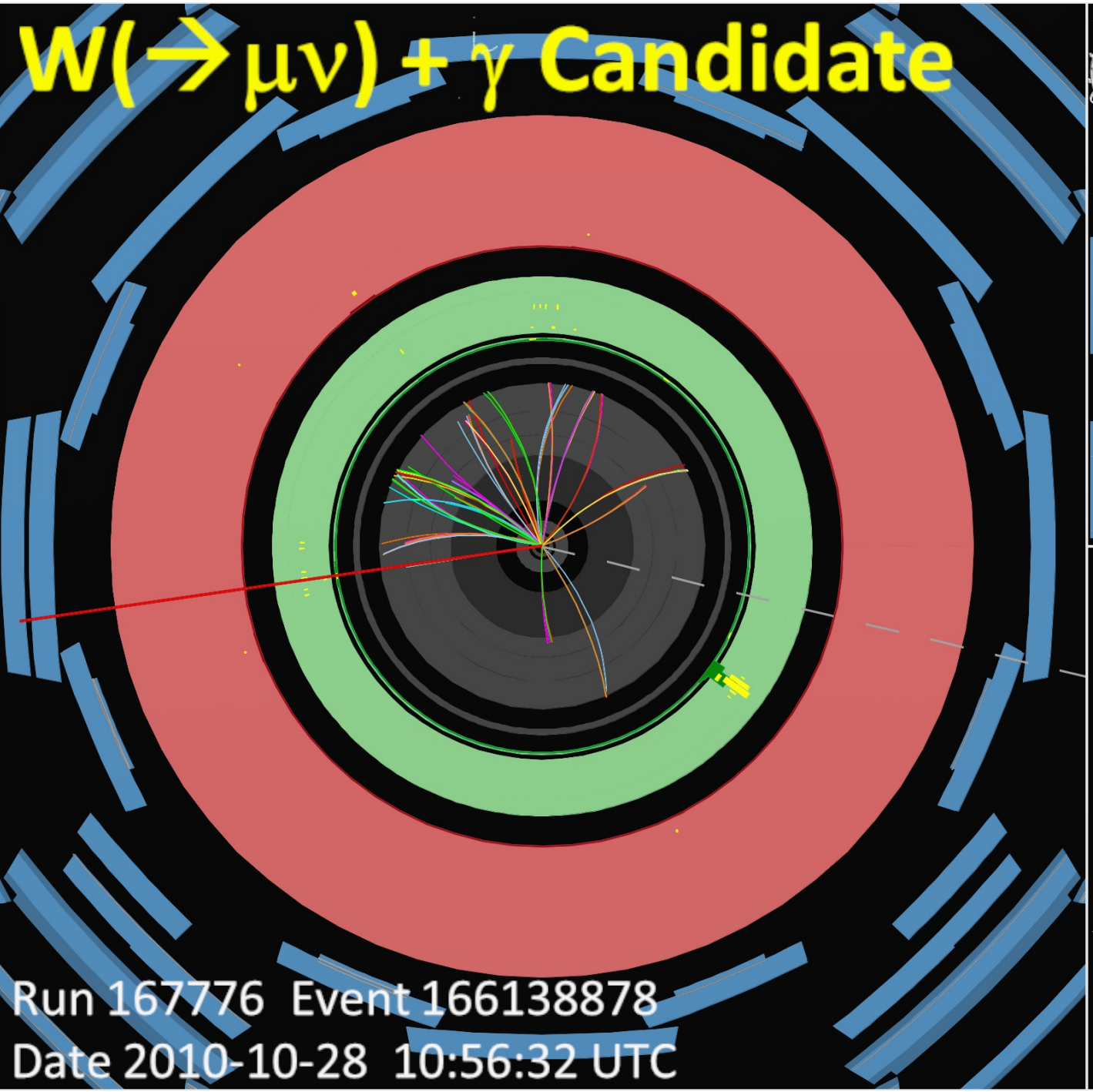
    $M_{W'SSM} > \sim 2.35$ TeV

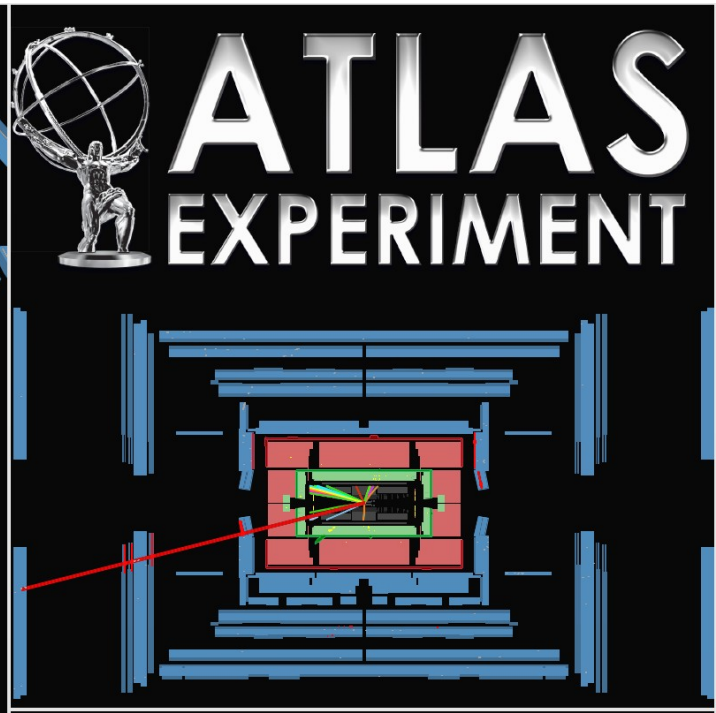
    (ATL-PHYS-PUB-2011-02)

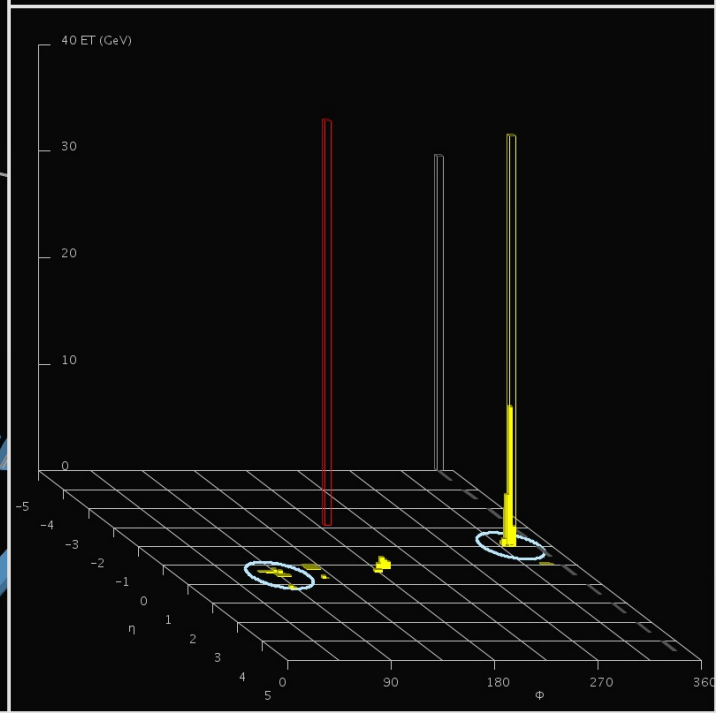


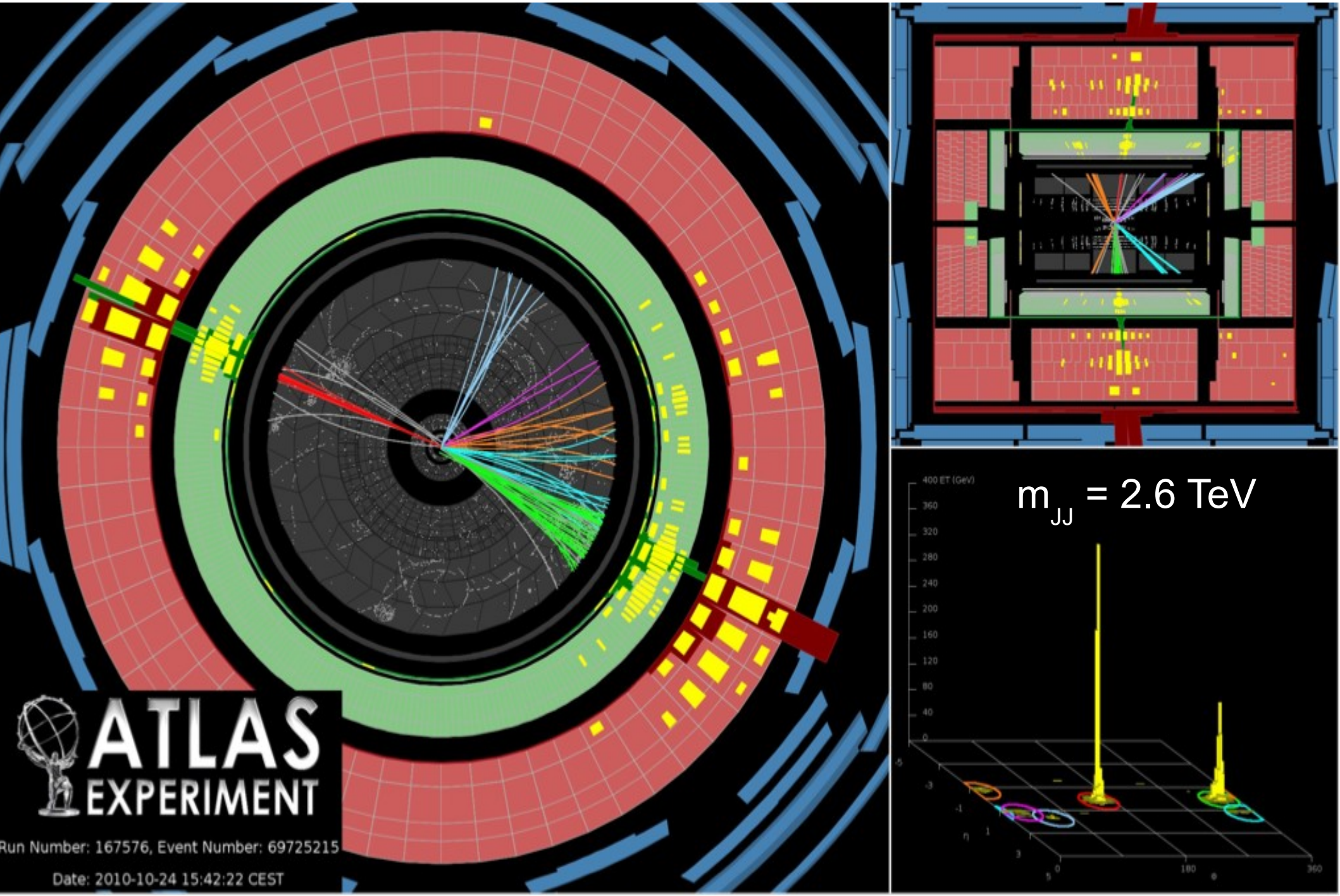
- Next objectives:
  - Increase the muon acceptance
  - Obtain mass limits for more BSM models, such as G*

Bonus Slides

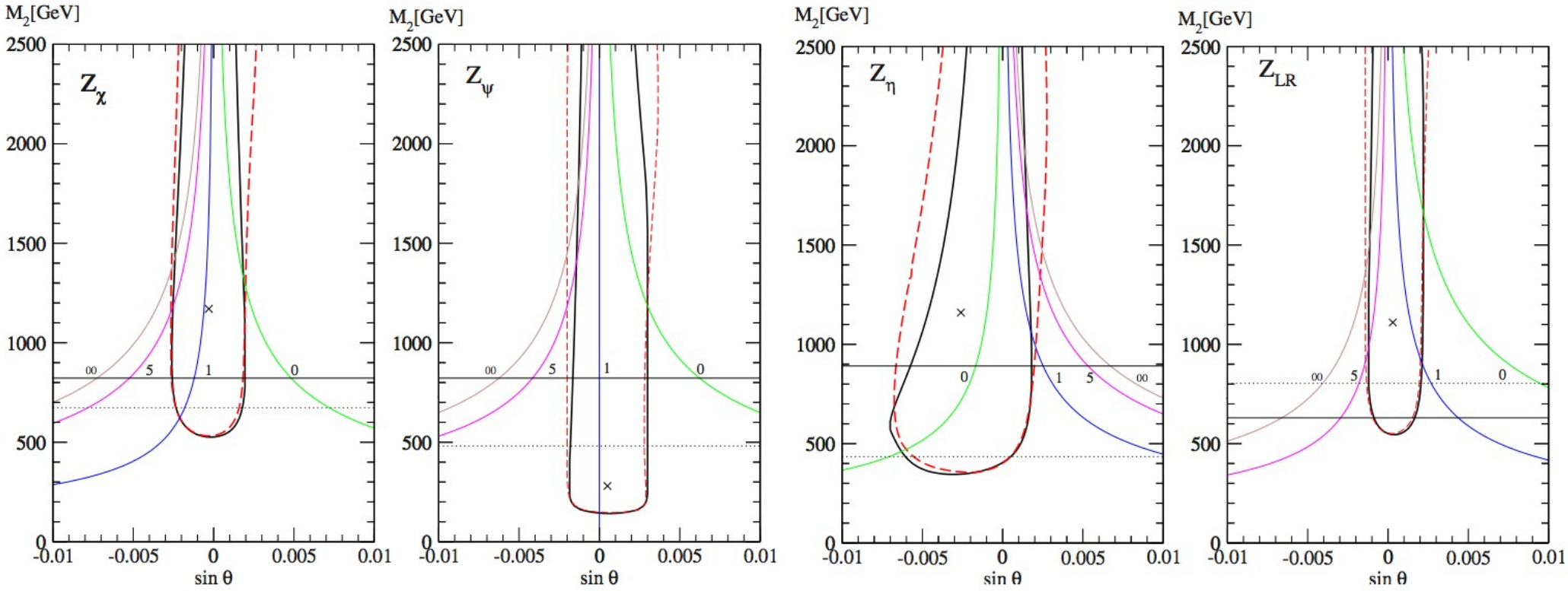

W(→μν) + γ Candidate
Run 167776 Event 166138878
Date 2010-10-28 10:56:32 UTC


ATLAS
EXPERIMENT


40 ET (GeV)
30
20
10
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
η
0
90
180
270
Φ


ATLAS
EXPERIMENT
Run Number: 167576, Event Number: 69725215
Date: 2010-10-24 15:42:22 CEST
m_{JJ} = 2.6 TeV

Z' Previous Limits



Limits on the Z' mass and the Z-Z' mixing angle.

Solid (dashed) contours are 90% C.L. exclusion contours from precision EW data, for $\rho_0 = 1$ (ρ_0 free), where $M_W = \rho_0 M_Z \cos\theta_W$

Horizontal solid (dotted) lines are 95% C.L. lower limits from the Tevatron (LEP)

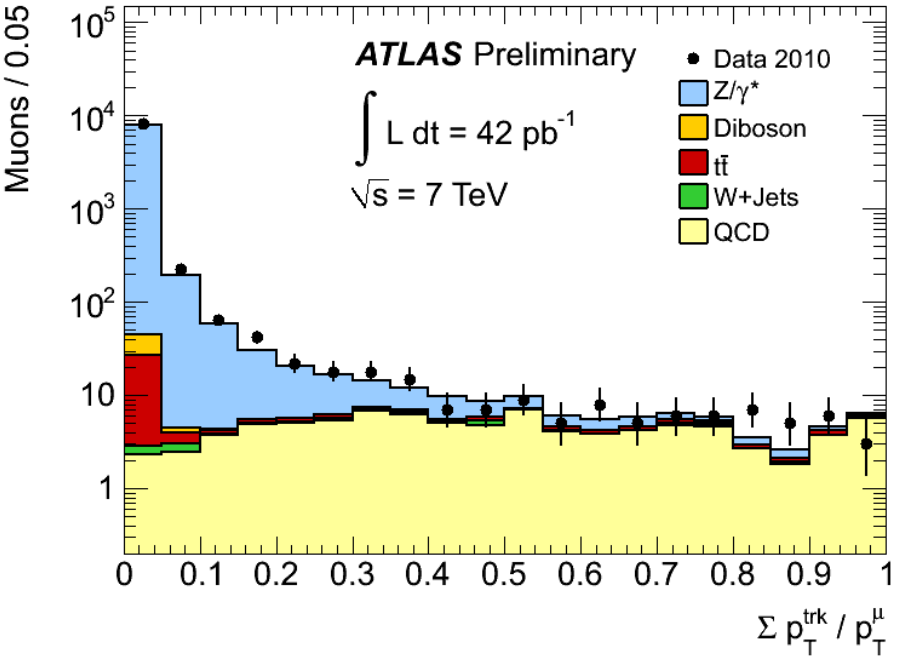
Source: Langacker (2009)

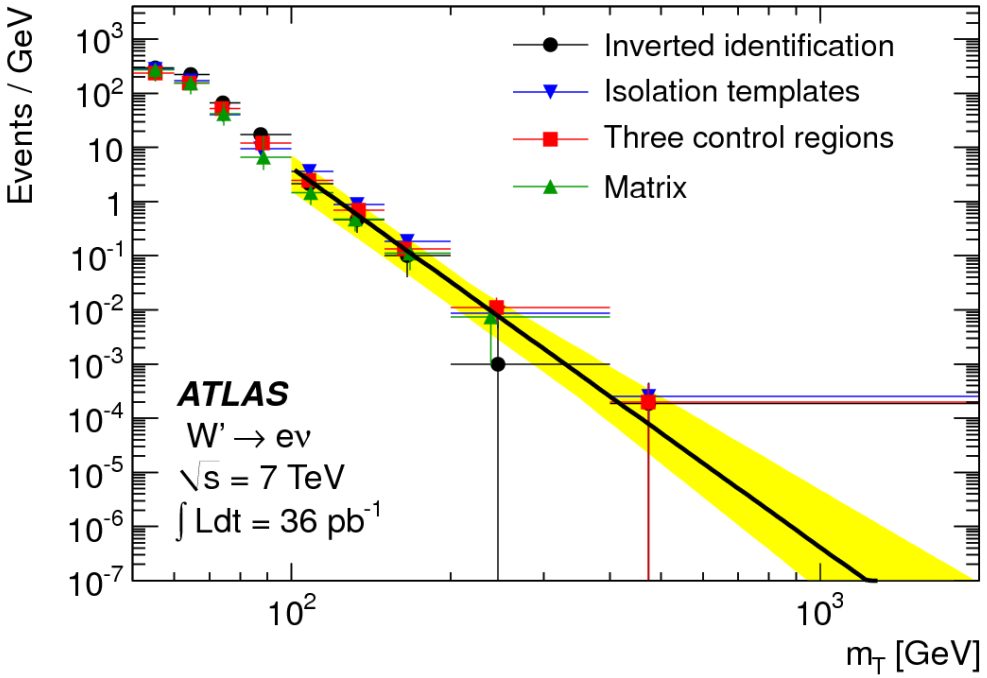
Event Selection

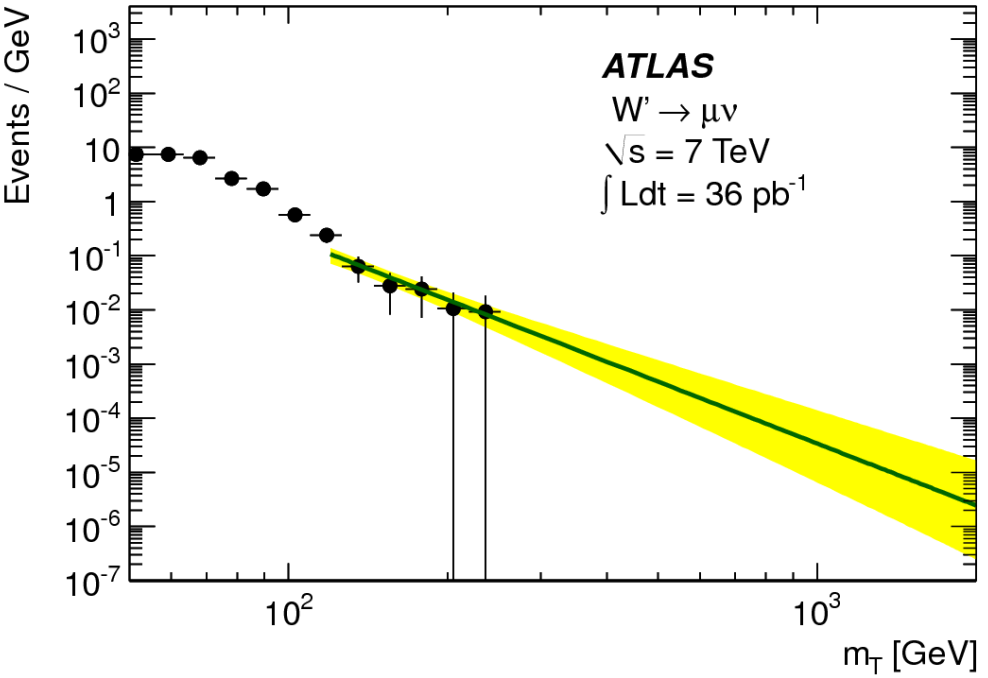
- Data Quality Requirements
- Trigger
- Primary Vertex: at least 3 tracks, $|z_{PV}| < 200$ mm
- Electron / Muon Selection
- W': Missing Transverse Energy Selection

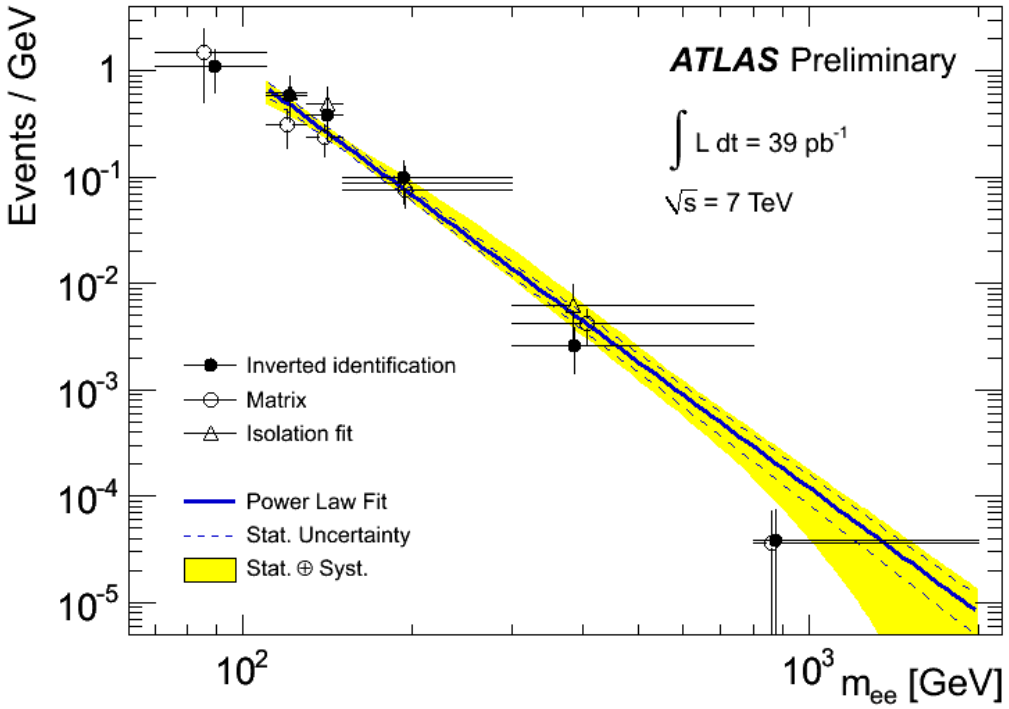
QCD Background Estimate

- Example calculation: Z' → μμ
  - Heavy-flavour QCD Monte Carlo simulated with Pythia is validated against Data in the isolation variable
  - No QCD MC event passes all cuts (very small background)
  - The ratio of "anti-isolated" (iso > 0.10) to isolated (iso < 0.05) muons is calculated
  - This ratio squared is used to scale the $m_{\mu\mu}$ distribution taken from QCD MC before the isolation cut.




Events / GeV
Inverted identification
Isolation templates
Three control regions
Matrix
ATLAS
W' → eν
√s = 7 TeV
∫ Ldt = 36 pb-1
mT [GeV]


Events / GeV
ATLAS
W' → μν
√s = 7 TeV
∫ Ldt = 36 pb-1
mT [GeV]


Events / GeV
ATLAS Preliminary
∫ L dt = 39 pb-1
√s = 7 TeV
Inverted identification
Matrix
Isolation fit
Power Law Fit
Stat. Uncertainty
Stat. ⊕ Syst.
mee [GeV]

Systematics

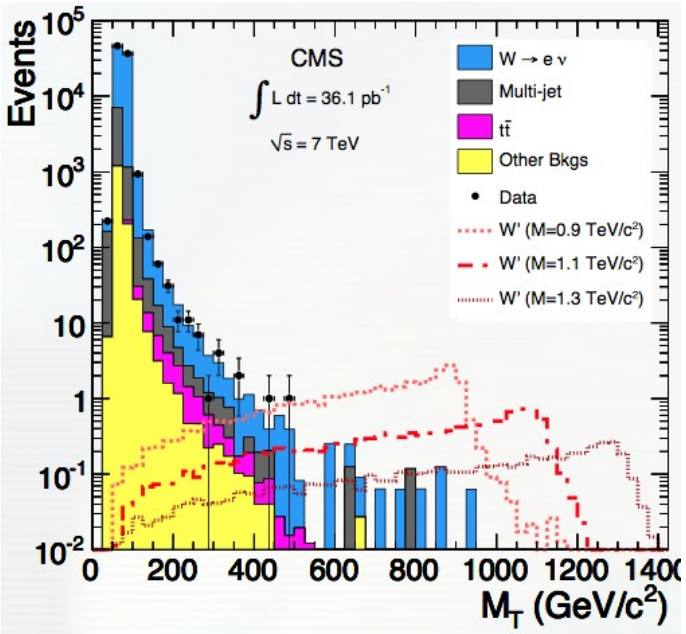
Z', 1 TeV

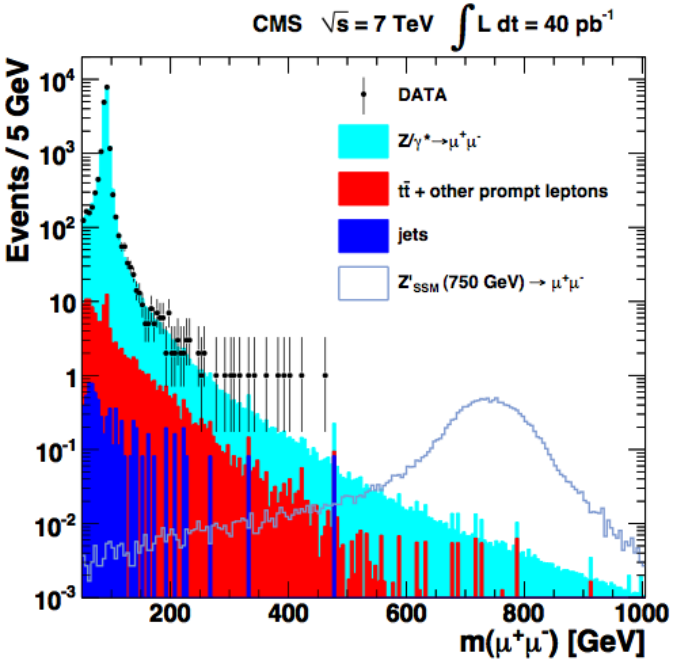
Source	dielectrons		dimuons	
	Z' signal	background	Z' signal	background
Normalization	5%	5%	5%	5%
PDFs	6%	6%	6%	6%
QCD K-factor	3%	3%	3%	3%
Weak K-factor	NA	4.5%	NA	4.5%
Efficiency	-	-	3%	3%
Resolution	-	-	3%	3%
Total	9.4%	9.5%	9.4%	10.4%

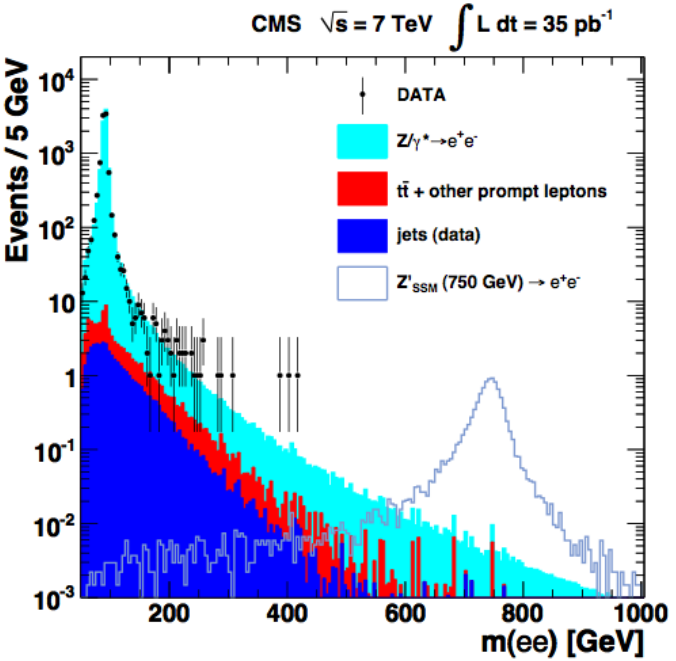
W', 1.5 TeV

Source	$\varepsilon_{\mathrm{sig}}$		N_{bg}	
	$e\nu$	$\mu\nu$	$e\nu$	$\mu\nu$
Missing E_{T} scale	0.1%	0.1%	1.1%	**3.4%**
Trigger efficiency	**1.0%**	**0.7%**	1.0%	0.7%
Reco. and id. efficiency	**3.6%**	**1.6%**	**3.6%**	1.3%
Isolation leakage	**2.7%**		**3.4%**	
Energy/momentum resolution	0.1%	0.4%	2.4%	**3.1%**
Energy/momentum scale	**0.8%**	0.1%	**6.6%**	0.1%
Correlated misalignment		0.6%		**3.3%**
QCD background			2.2%	**7.7%**
Monte Carlo statistics	**1.7%**	**1.6%**	2.2%	**16.6%**
Cross section (shape/level)	**0.7%**	**0.7%**	**8.5%**	**7.7%**
Isolation	**1.5%**	**1.5%**	1.0%	1.0%
Other	0.2%	0.4%	0.4%	0.9%
All	5.3%	3.0%	12.6%	20.7%

CMS Results

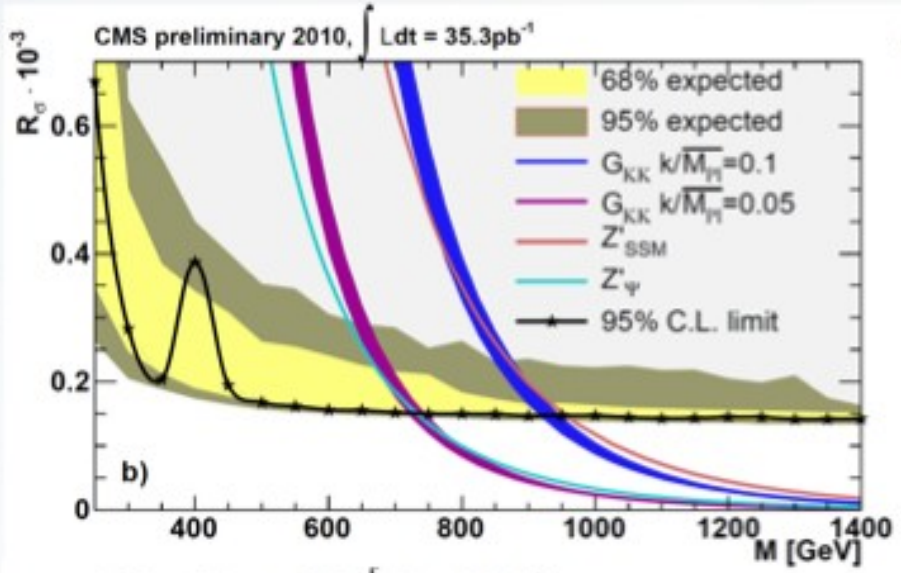

CMS
∫ L dt = 36.1 pb⁻¹
√s = 7 TeV
W → e ν
Multi-jet
tt̄
Other Bkgs
Data
W' (M=0.9 TeV/c²)
W' (M=1.1 TeV/c²)
W' (M=1.3 TeV/c²)
Events
M_T (GeV/c²)

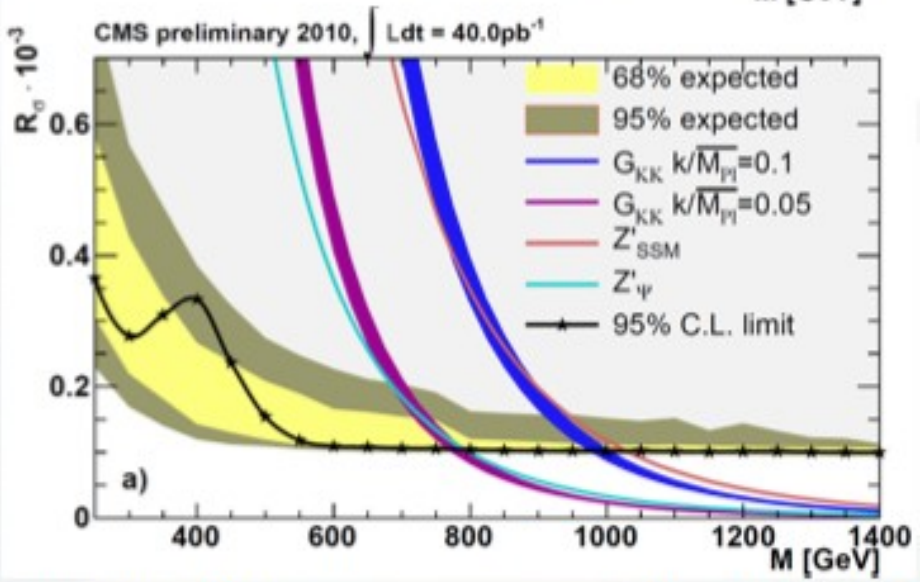

CMS √s = 7 TeV ∫ L dt = 40 pb⁻¹
DATA
Z/γ*→μ⁺μ⁻
tt̄ + other prompt leptons
jets
Z'SSM (750 GeV) → μ⁺μ⁻
Events / 5 GeV
m(μ⁺μ⁻) [GeV]

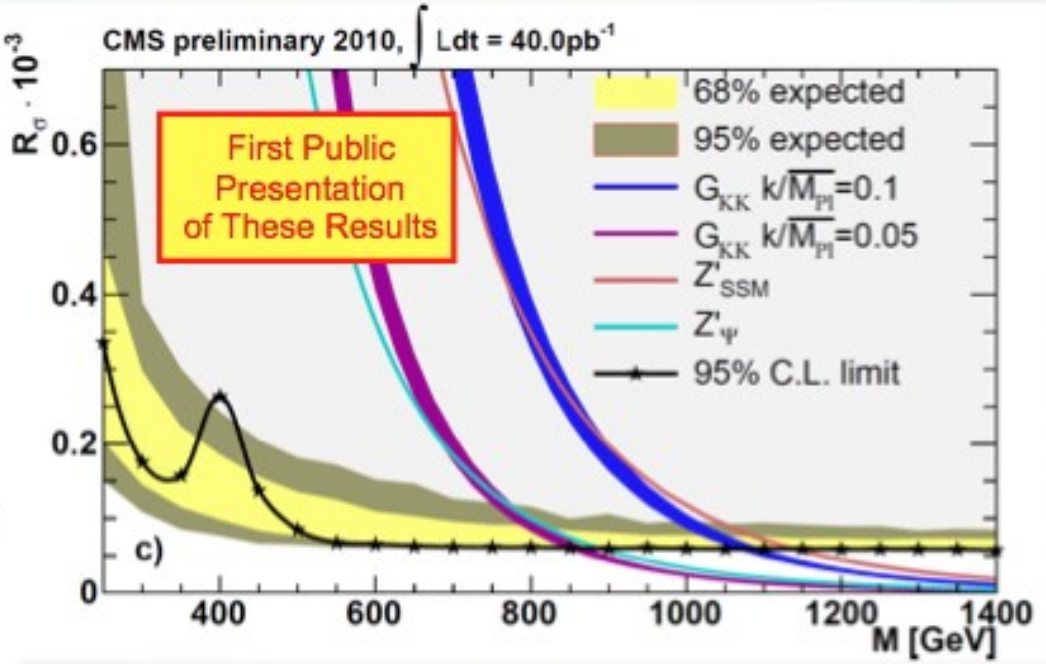

CMS √s = 7 TeV ∫ L dt = 35 pb⁻¹
DATA
Z/γ*→e⁺e⁻
tt̄ + other prompt leptons
jets (data)
Z'SSM (750 GeV) → e⁺e⁻
Events / 5 GeV
m(ee) [GeV]

Limits on the Z' and G_{KK}

- Combined limits exceed the Tevatron reach: G_{KK}, k/M_{Pl} =0.1: 1050 (ee+γγ) & 921 (μμ) GeV; Z'_{SSM}: 1023 (ee) & 1030 GeV (μμ)







Channel	μμ	ee	Combined
Z_{SSM}	1027 GeV	958 GeV	1140 GeV
Z_{ψ}	792 GeV	731 GeV	887 GeV
G_{KK}, k/M_{Pl} = 0.05	778 GeV	729 GeV	855 GeV
G_{KK}, k/M_{Pl} = 0.10	987 GeV	931 GeV	1079 GeV