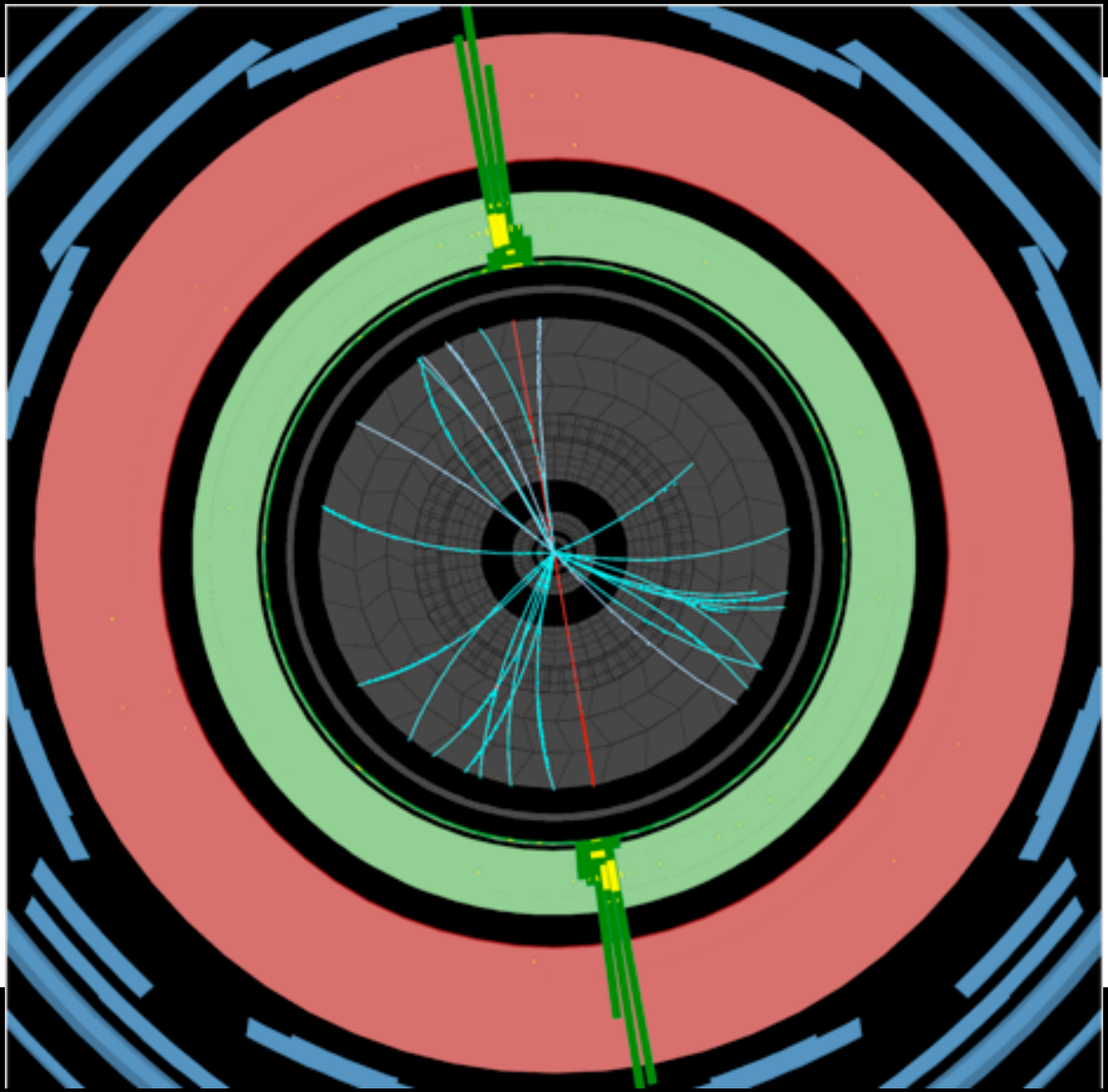
Recent results from ATLAS on W' and Z' searches



Katherine Copic
Columbia University

Experimental Particle Physics Seminar

University of Pennsylvania
April 12, 2011

LHC in the Headlines

Record Luminosity for LHC

LHC in the Headlines

Record Luminosity for LHC science 2.0

The Large Hadron Collider enters the race for supersymmetry Physics

LHC releases first Higgs search results NewScientist

LHC in the Headlines

Record Luminosity for LHC — science 2.0 JOIN THE REVOLUTION

The Large Hadron Collider enters the race for supersymmetry — Physics

LHC releases first Higgs search results — NewScientist

A melting pot of protons — Physics

LHC in the Headlines

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'Large Hadron Collider could unlock secret of time travel'
Indian Express - Mar 21, 2011

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Spurs-a-jingle boffins in America say that the Large Hadron Collider (LHC), most puissant matter-rending machine ever assembled by humanity, may also turn out to be the first time machine ever built.

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DiscoveryNews. COULD HIGGS PARTICLE BE A TIME-TRAVELING ASSASSIN?

Lots of Questions

Even if we find the Higgs, even if we find SUSY
- and especially if we don't -
questions remain

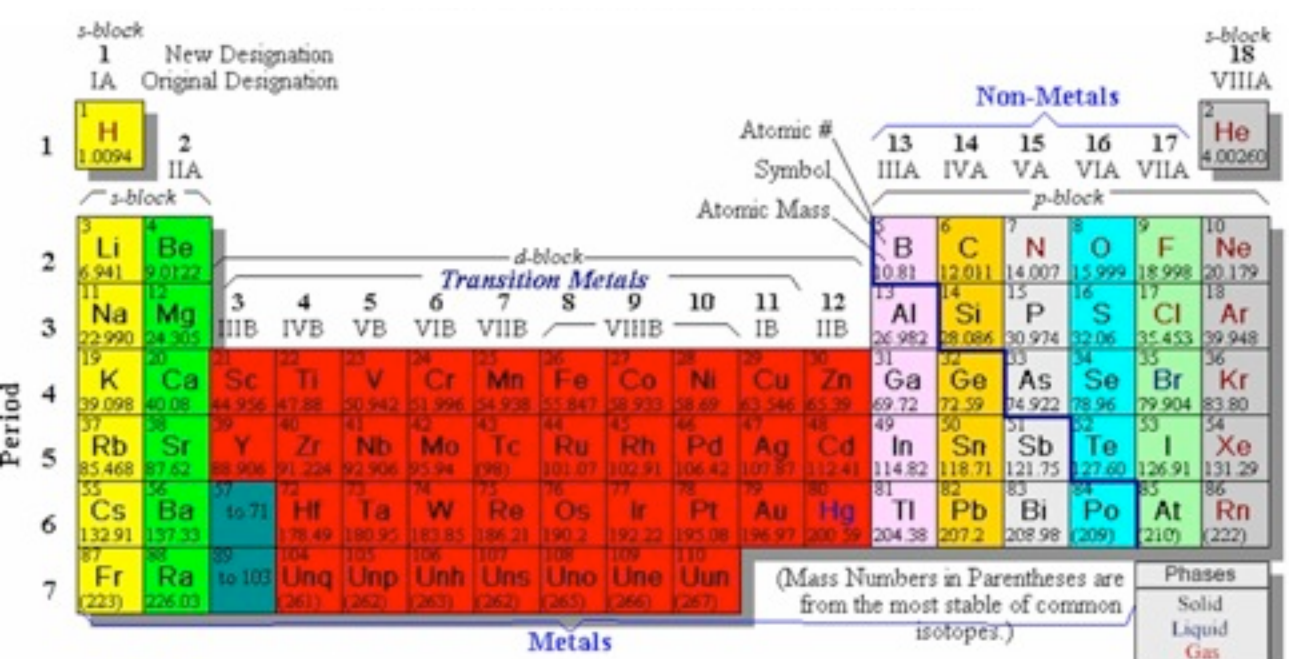
Why are there multiple copies of the same particles?

Where do the values of the masses come from?

What about gravity? and dark matter?

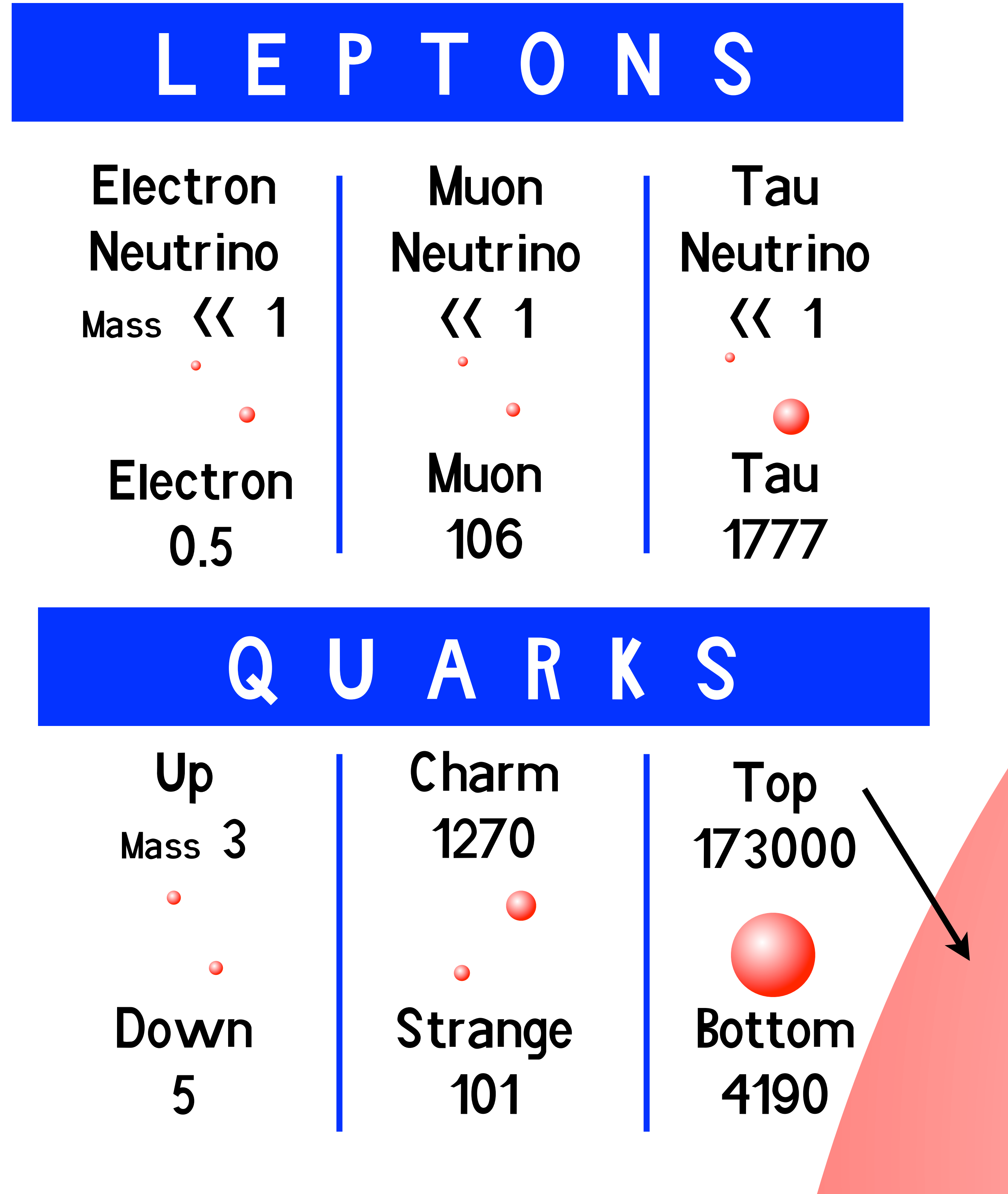
Are there more quarks, leptons or gauge bosons?

Where are we now?



Rows and columns, masses of the periodic table provide clues to underlying physics

We have yet to understand the structure and values in our own periodic table

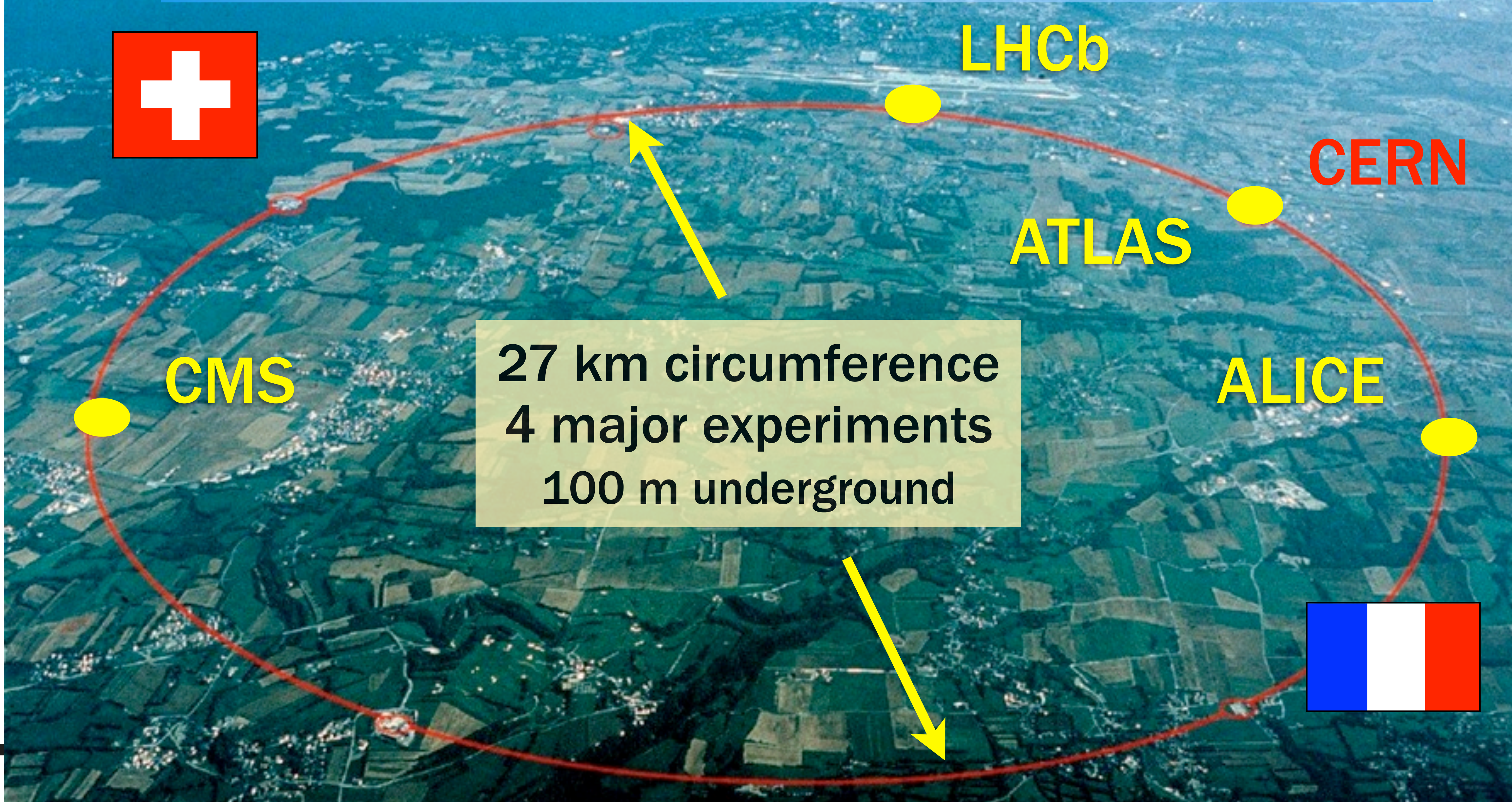


The Large Hadron Collider

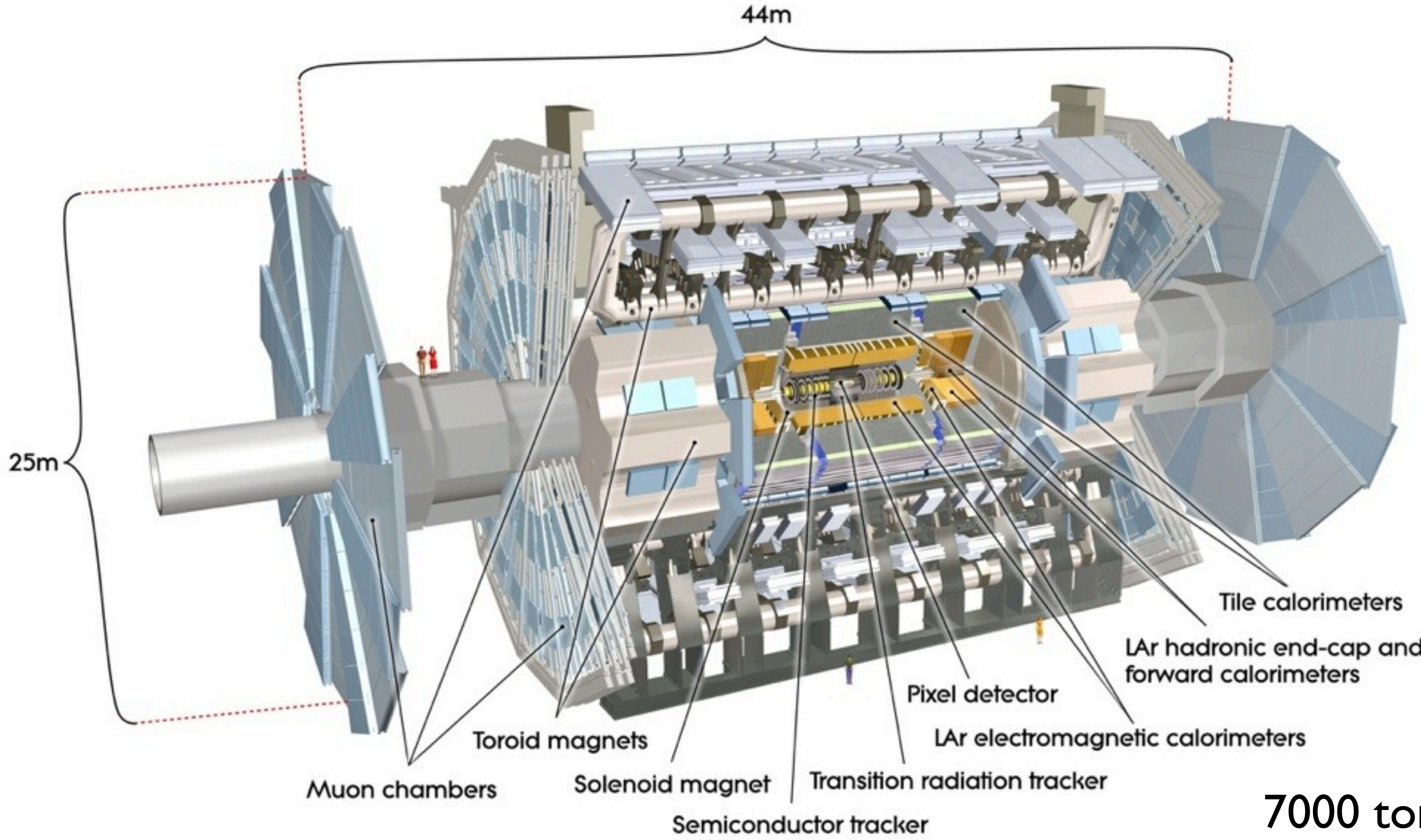
at CERN outside of Geneva, Switzerland

design: proton-proton collisions: center-of-mass energy of 14 TeV

lower energy to start - 7 TeV for 2010, 2011, 2012?

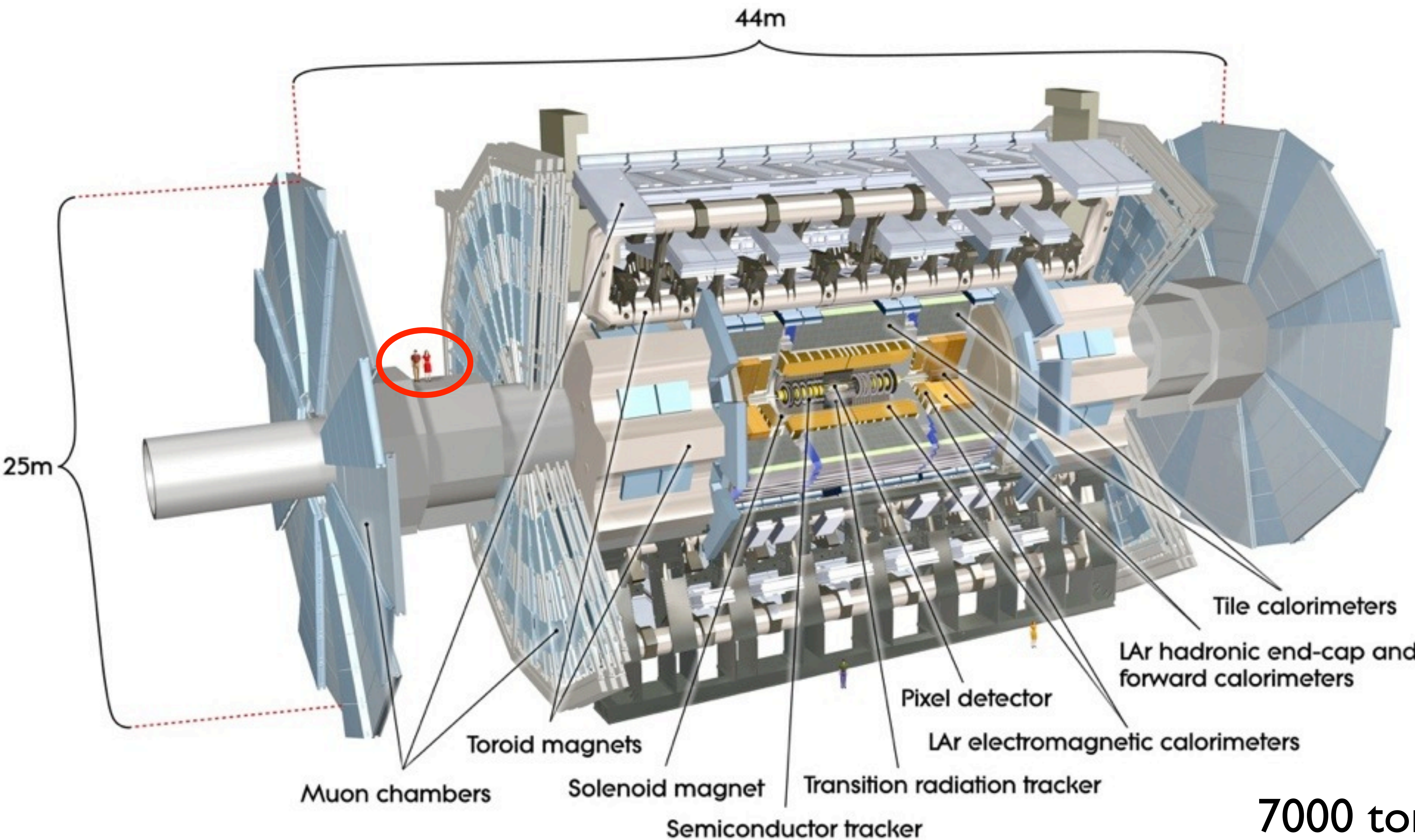


The ATLAS Experiment



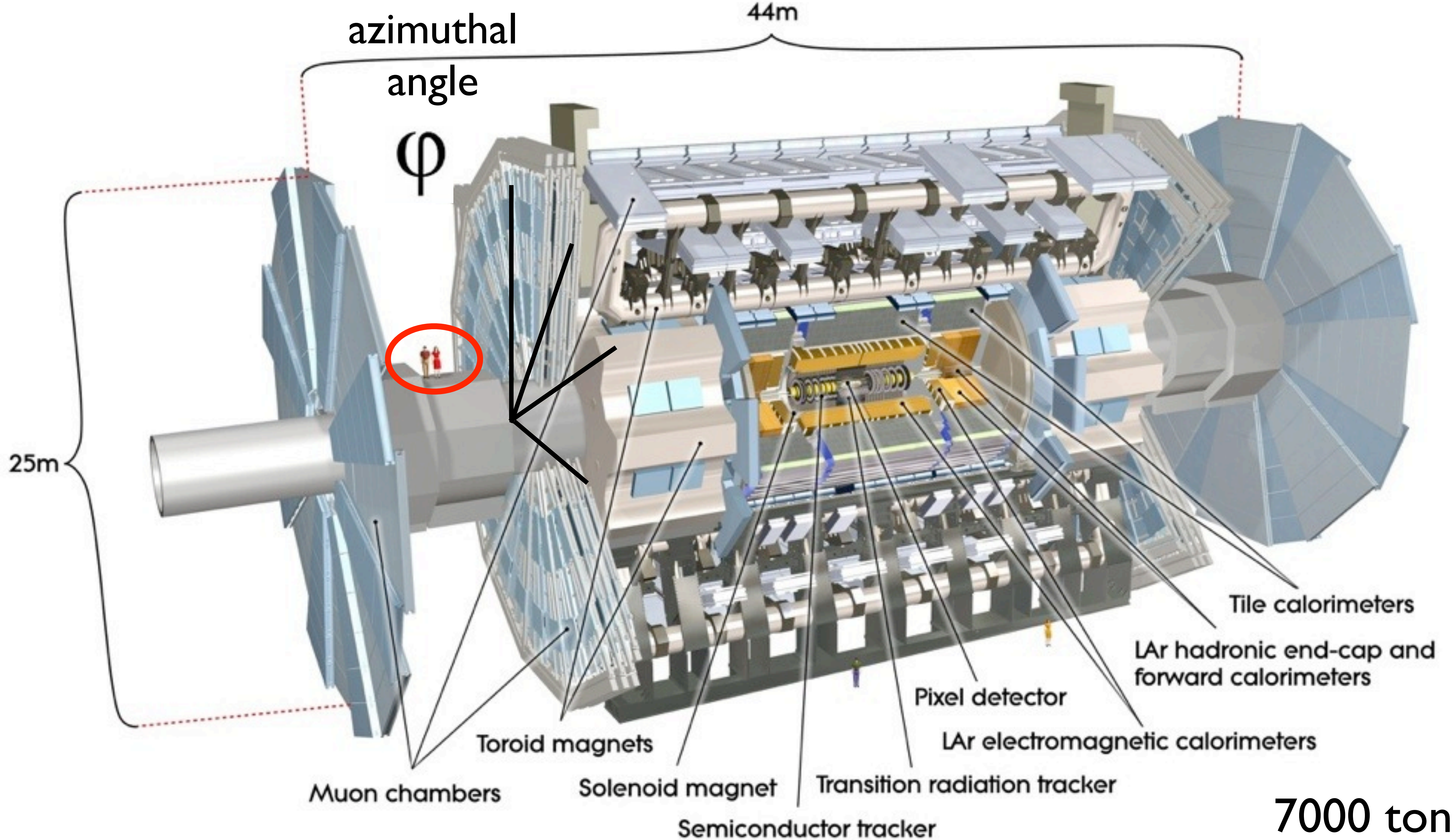
7000 tons

The ATLAS Experiment



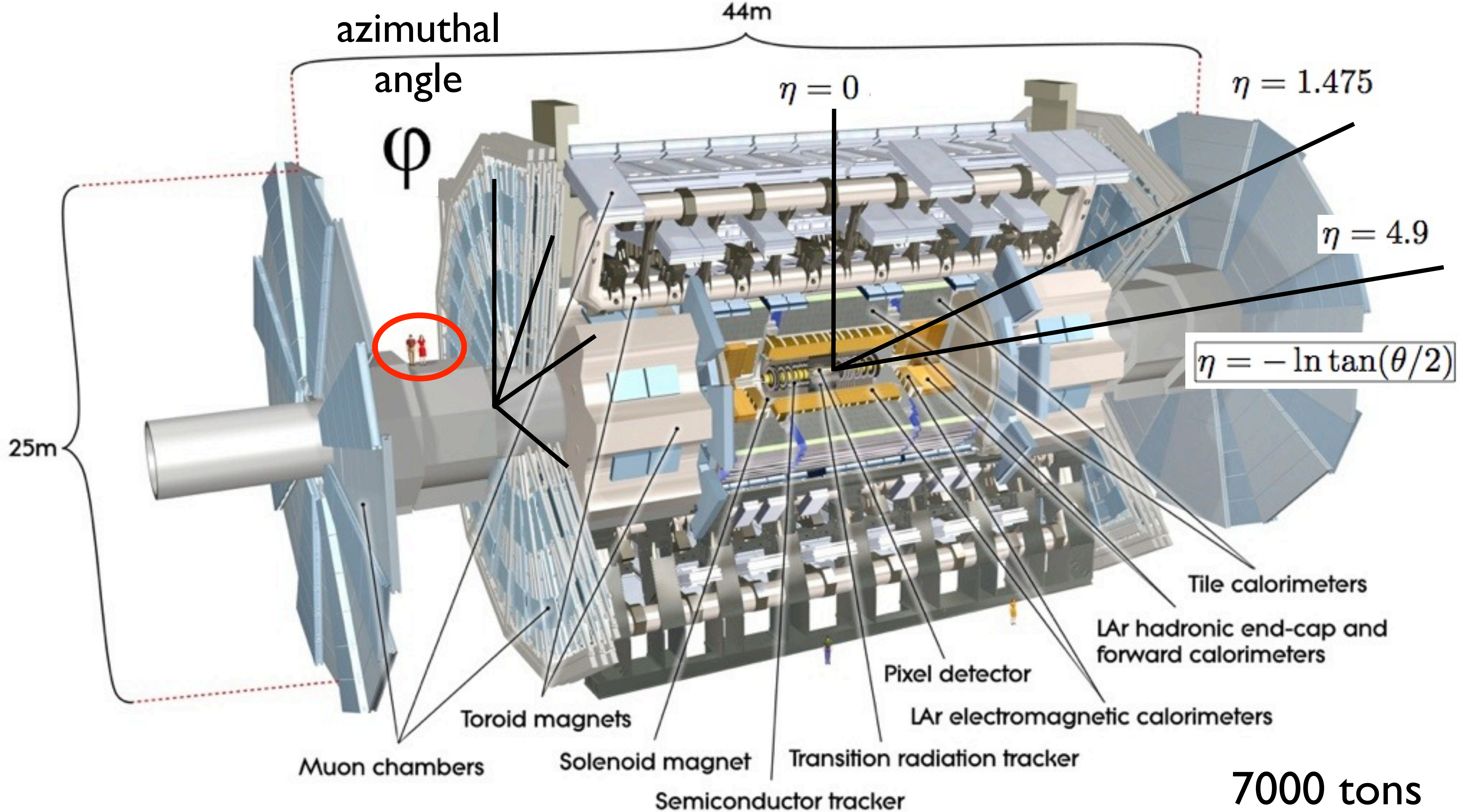
7000 tons

The ATLAS Experiment



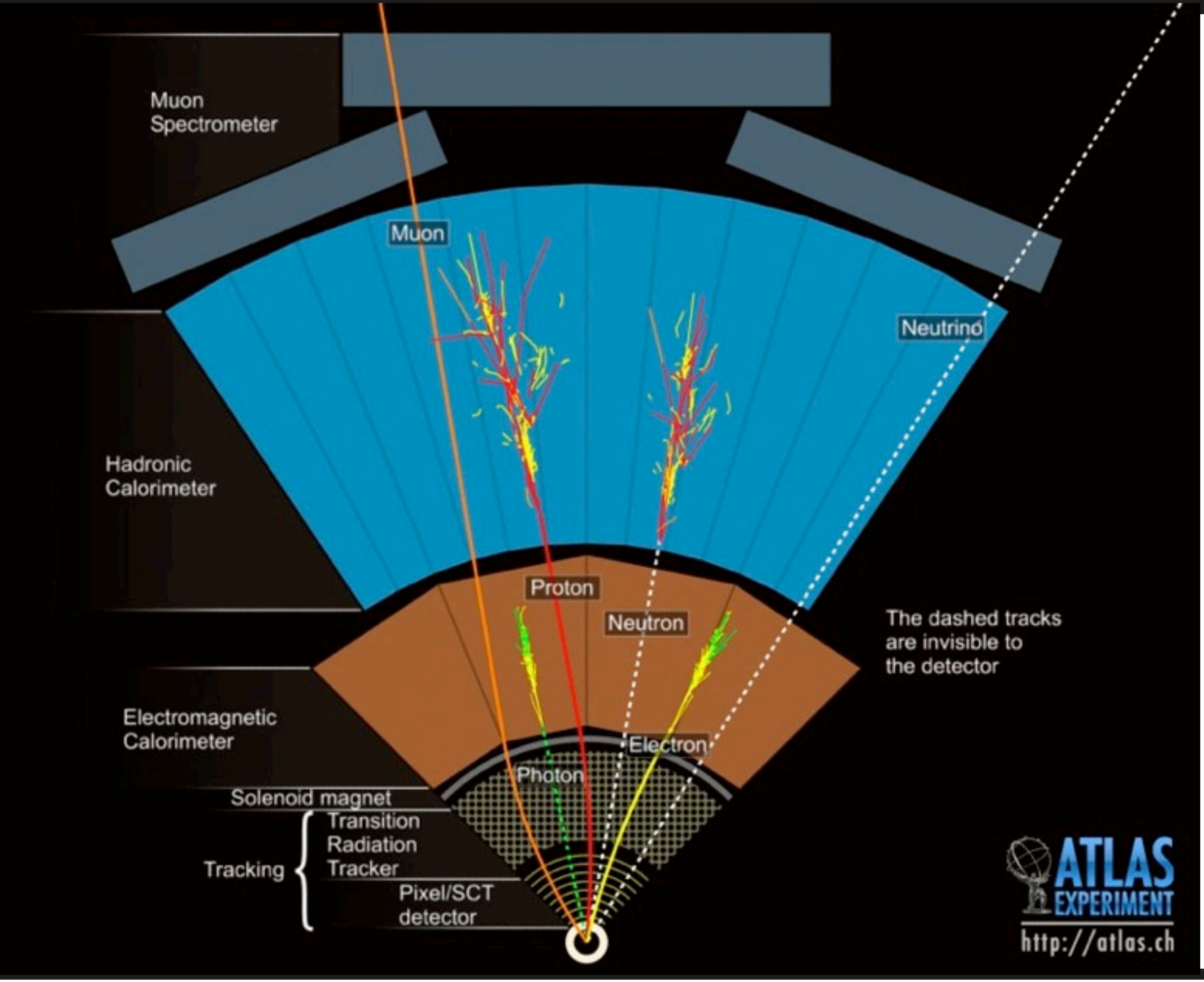
7000 tons

The ATLAS Experiment



7000 tons

Identifying final state particles

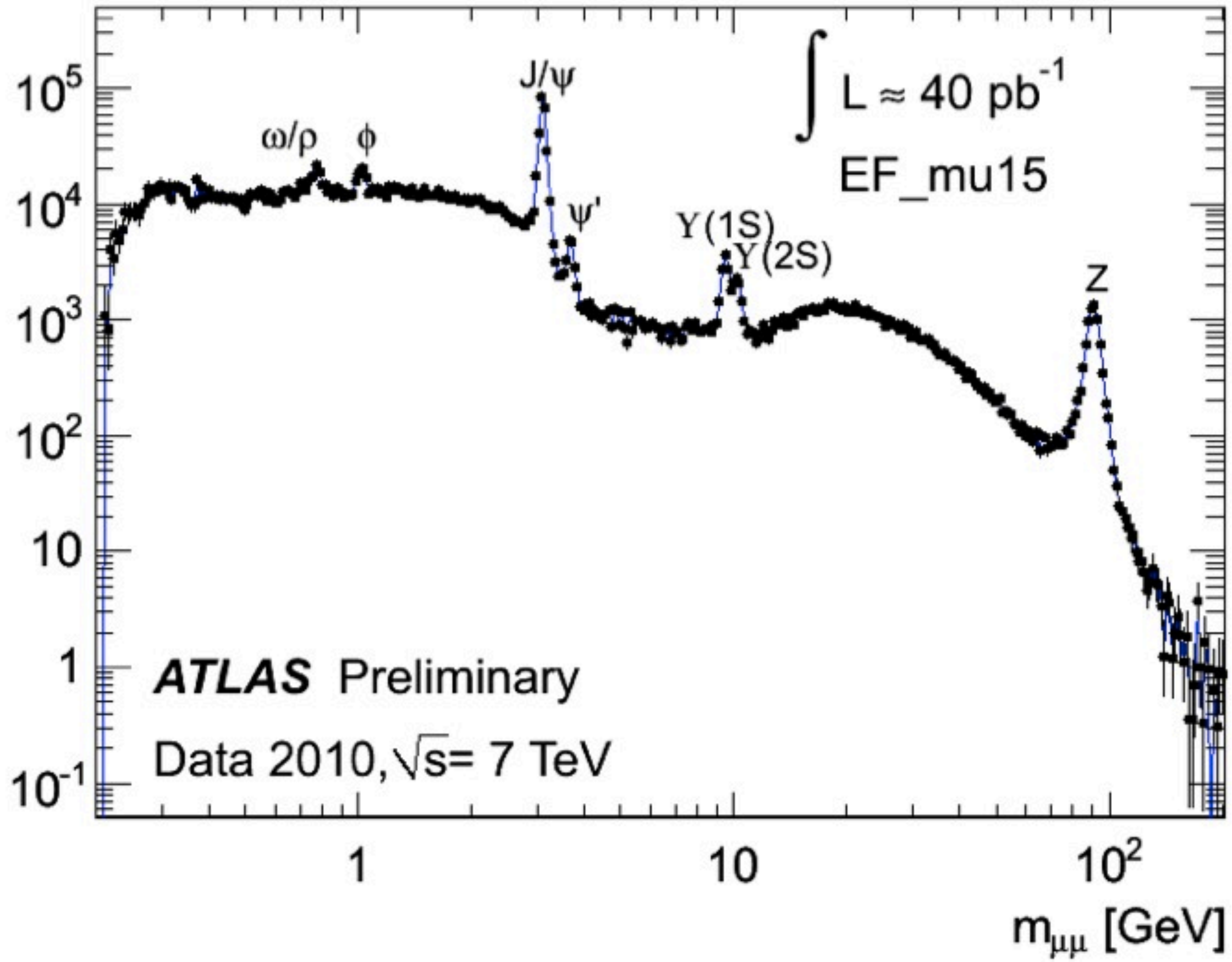


Muon Detectors

Calorimeters

Trackers

Today: Resonances



Jets

Electrons

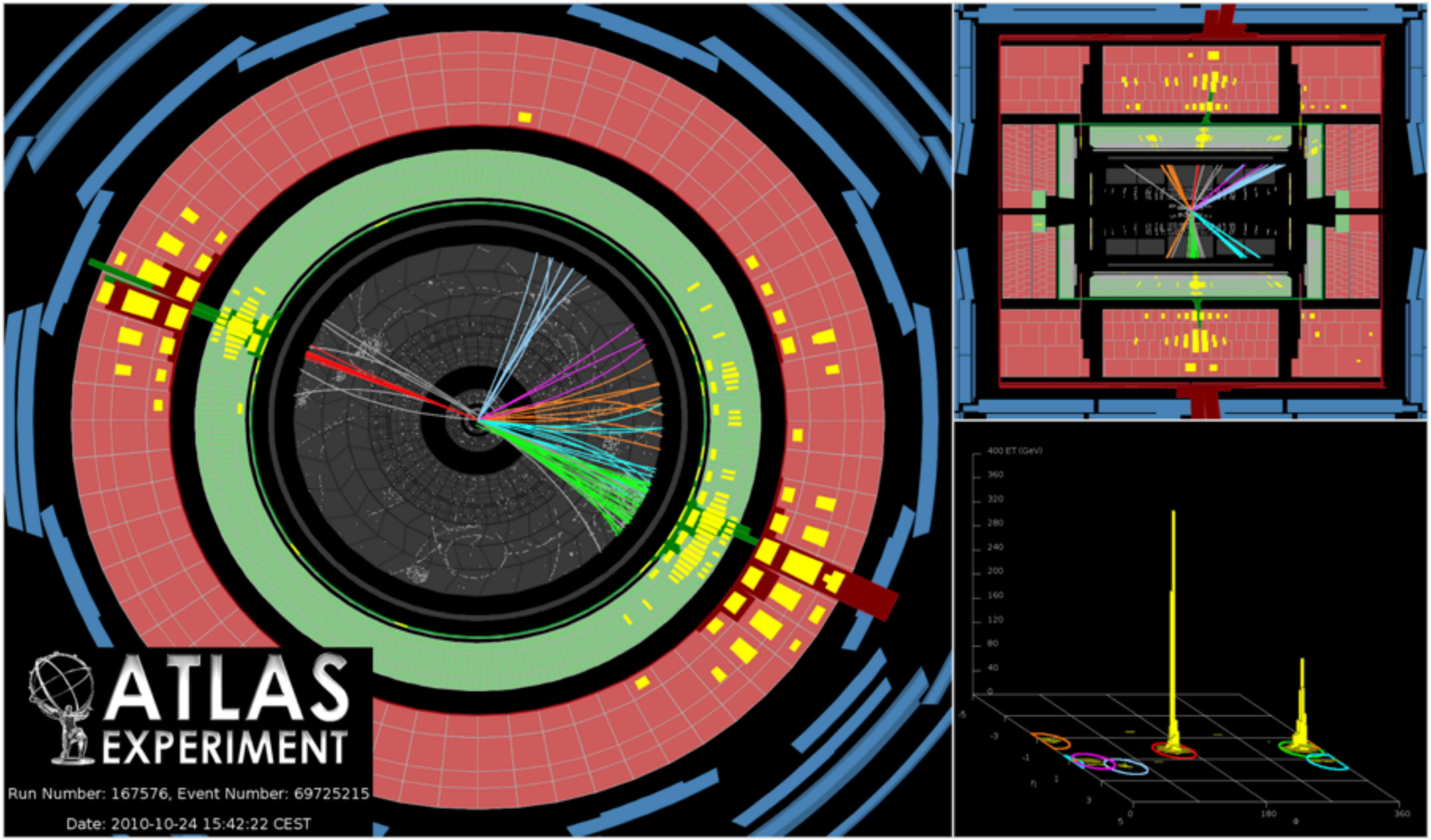
Muons

Photons

… and a few other things along the way

All results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic

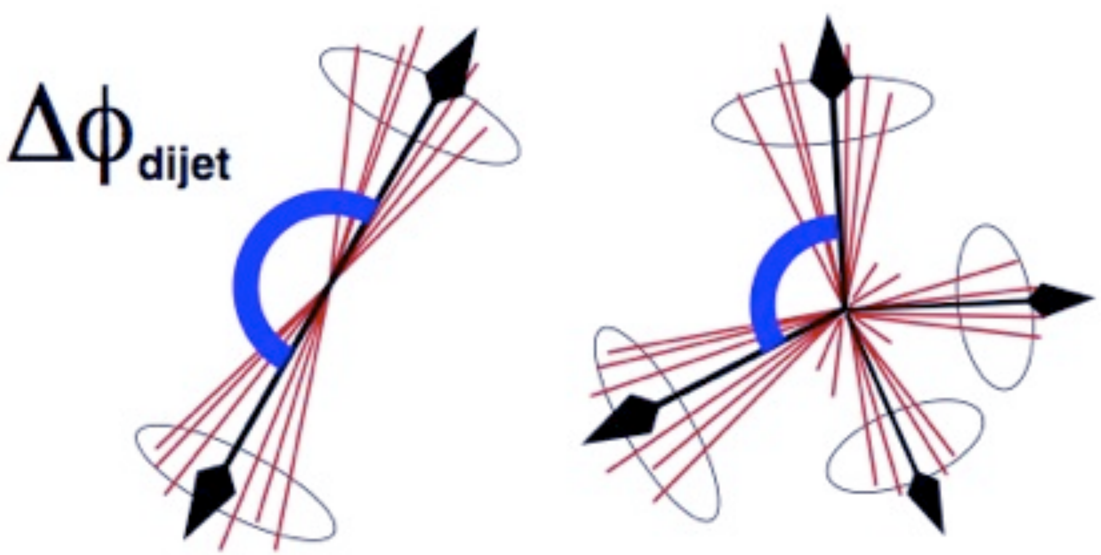
Jets!

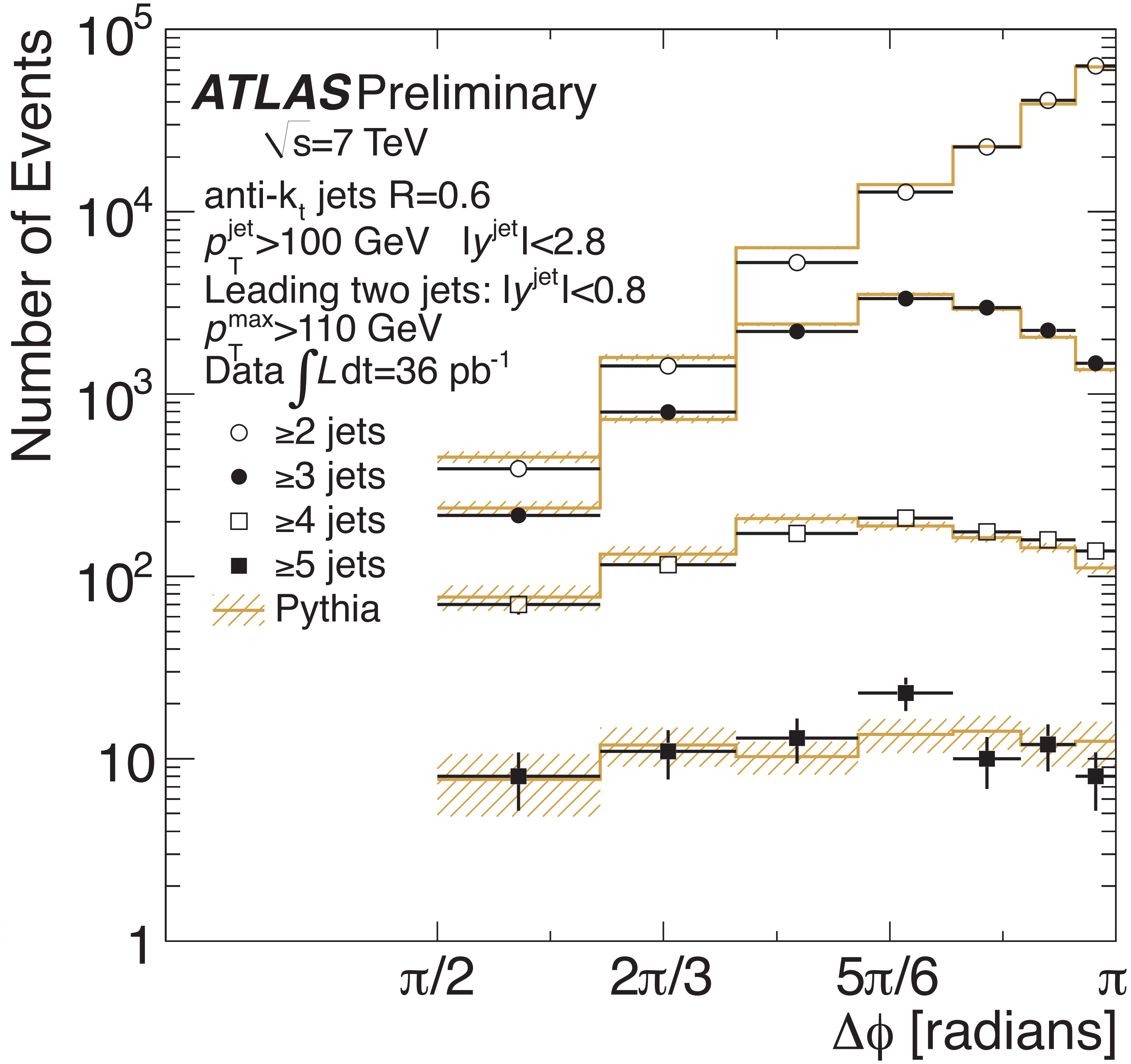


Dijet event: jets with pT of 1.2 and 1.3 TeV

Understanding jets

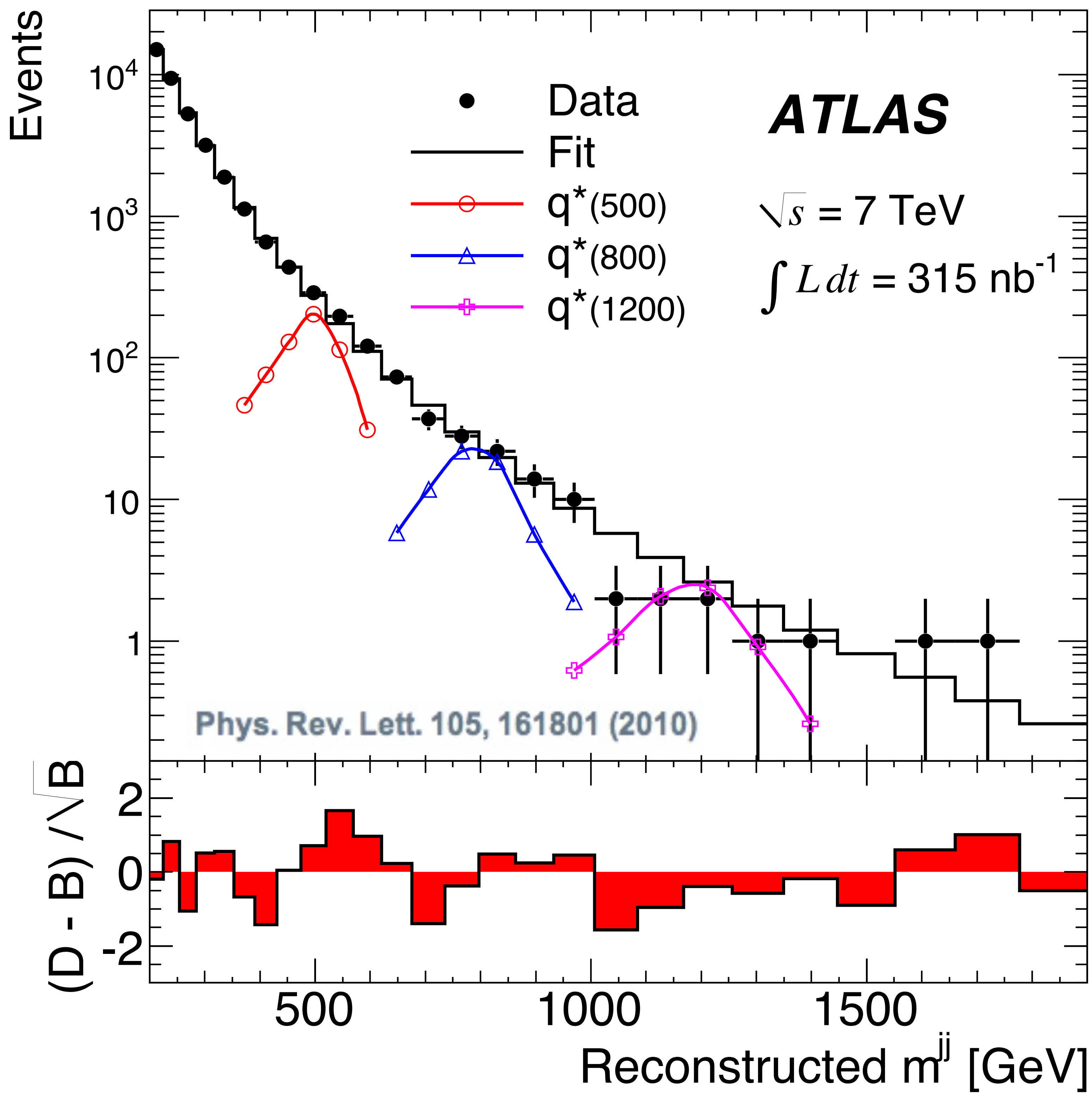
Beyond inclusive jet cross sections, we can investigate event topology to check agreement with the Standard Model





Dijet Azimuthal Decorrelations
Submitted to PRL: [arXiv:1102.2696]

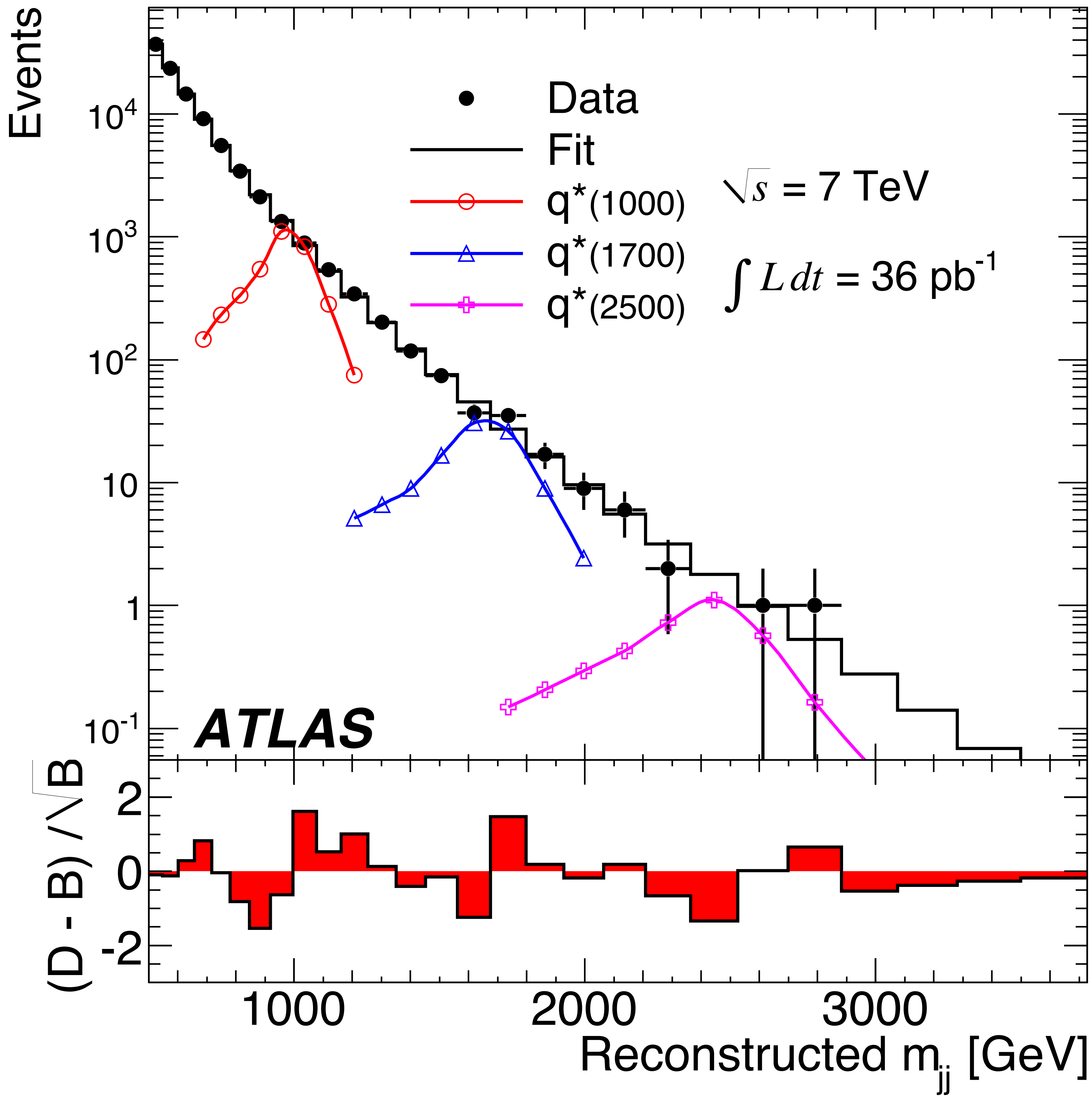
Searching for Resonances



First ATLAS Exotics results from the LHC:

Search in the dijet spectrum

Searching for Resonances



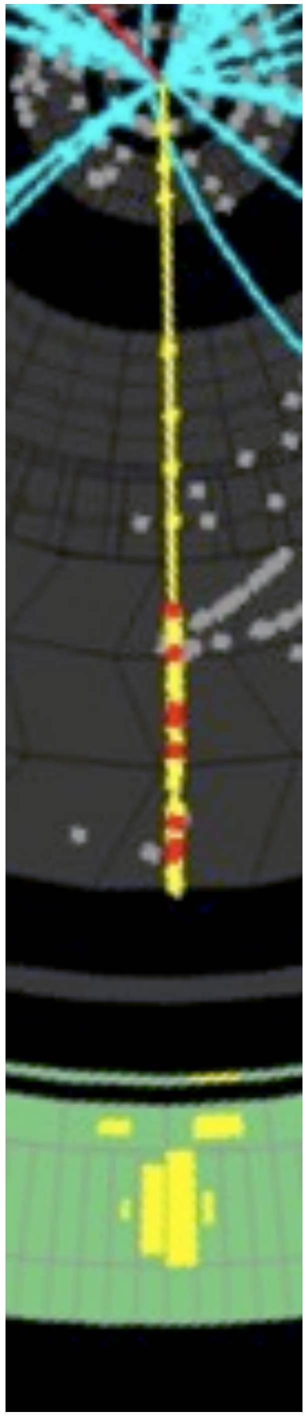
Dijet resonance search performed with 10 times more data

No hints of a peak

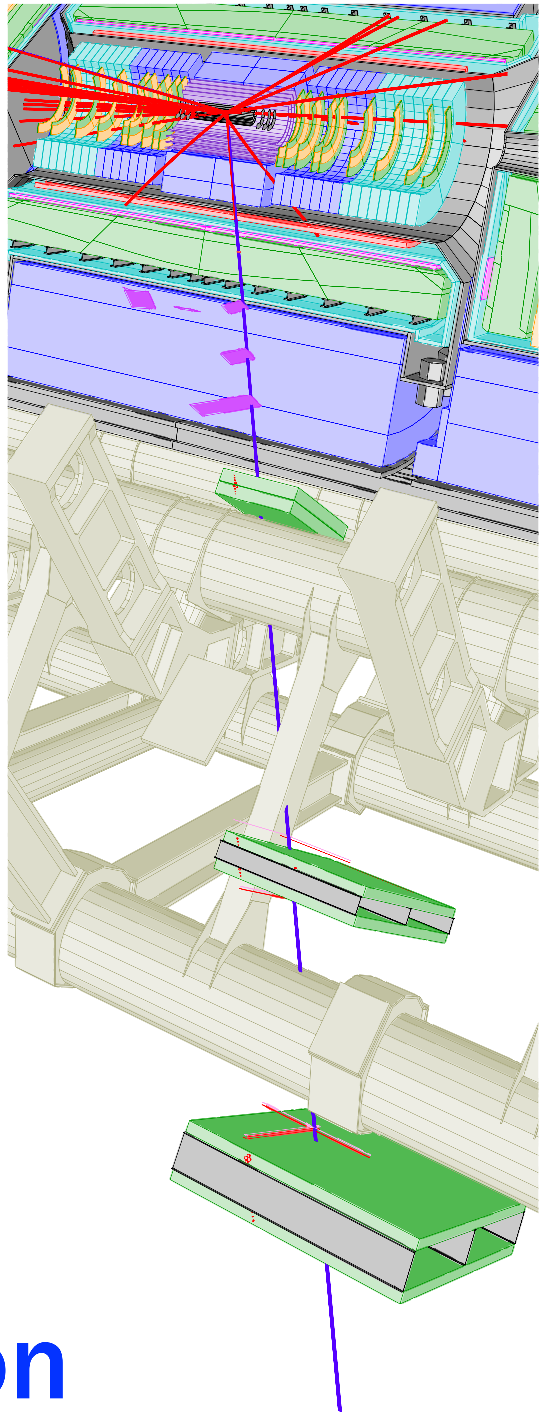
Place limits on excited quark q*: 2.15 TeV

and several other models

Electrons and Muons



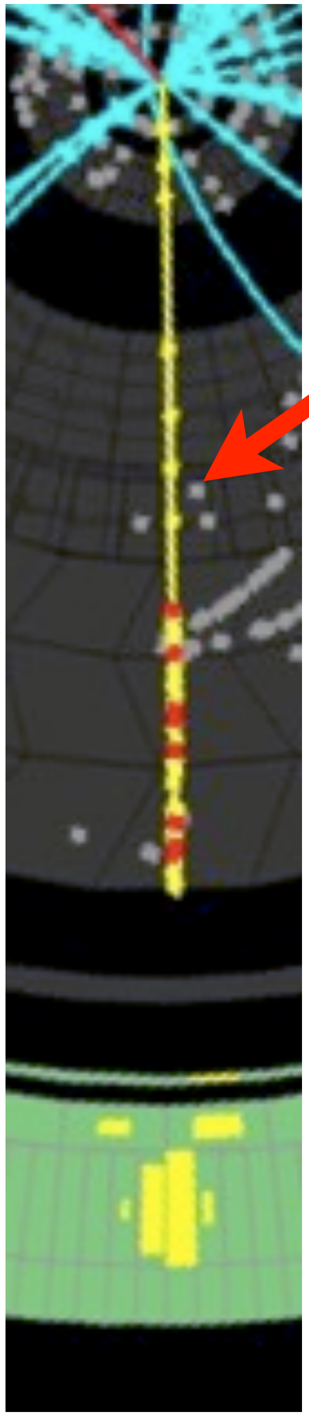
Track
in the inner
detector



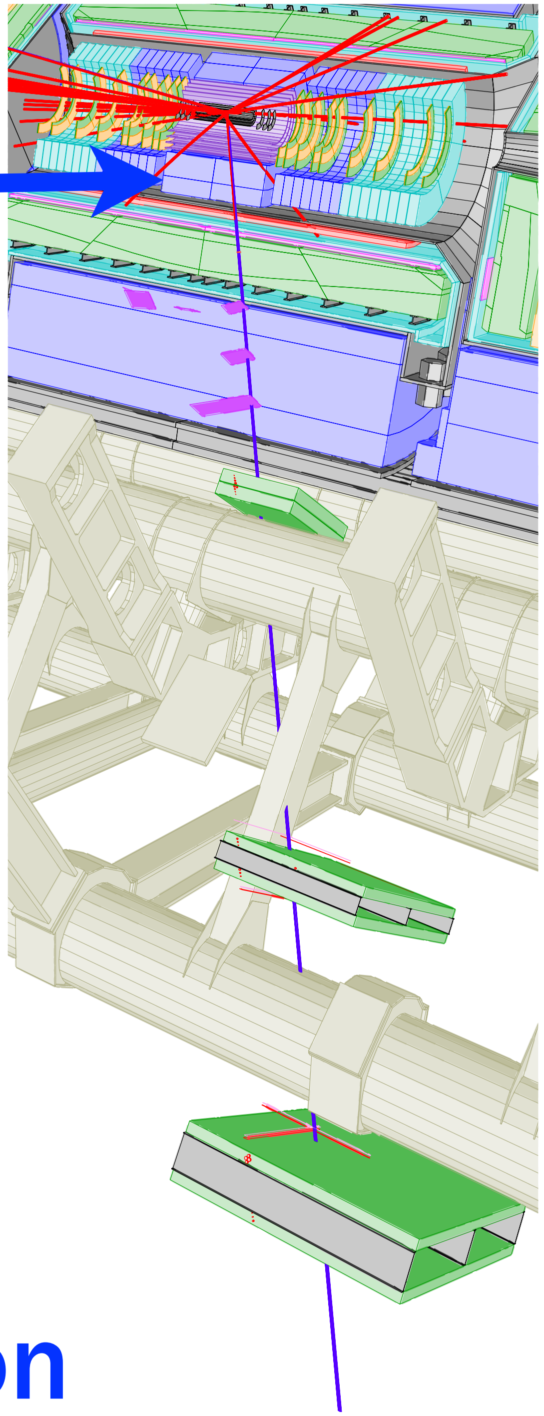
Electron

Muon

Electrons and Muons



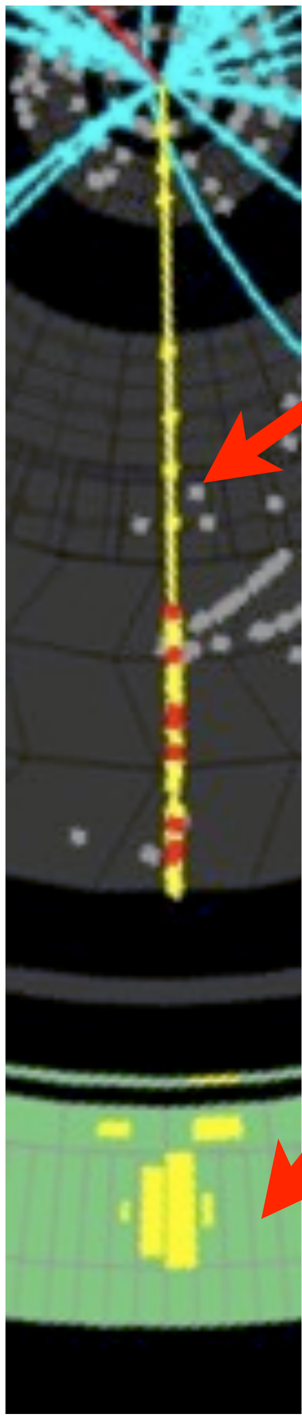
Track
in the inner
detector



Electron

Muon

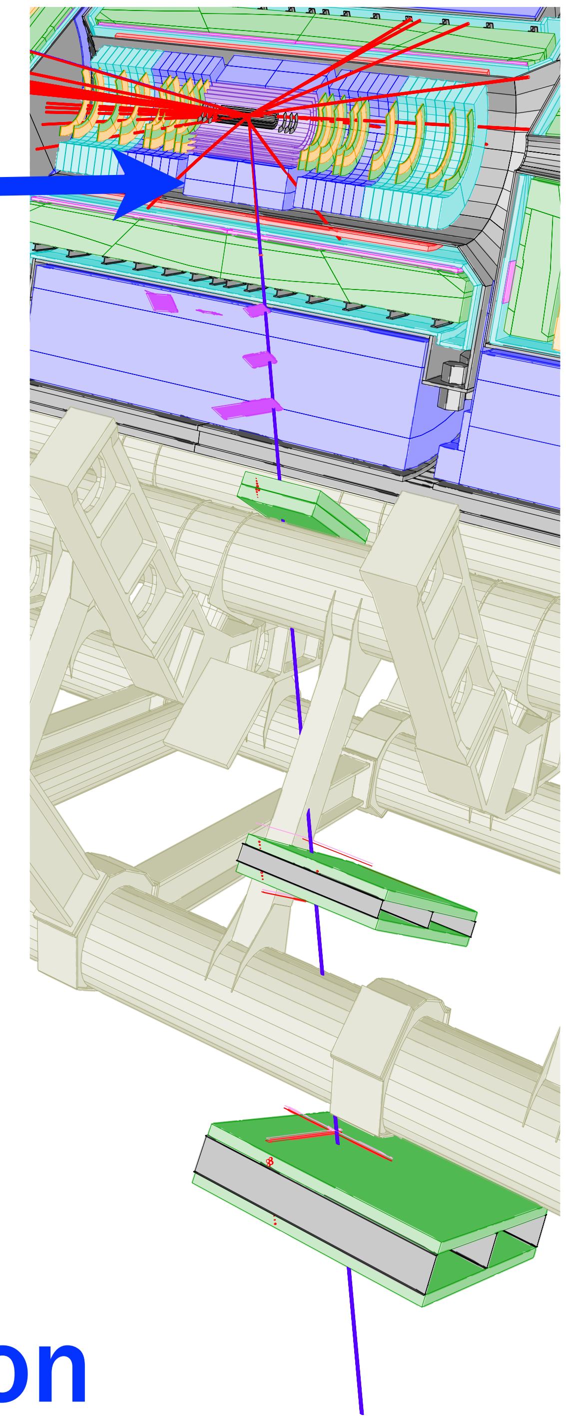
Electrons and Muons



Track
in the inner
detector

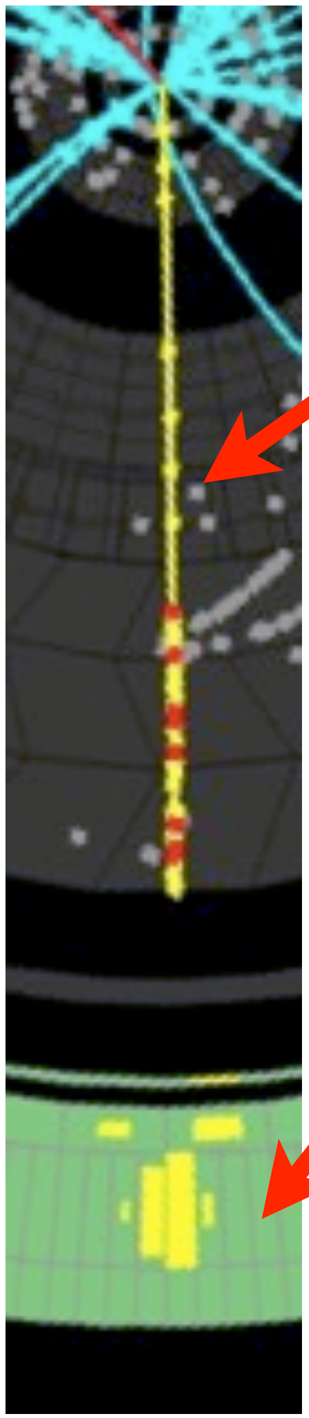
+ cluster in the
EM calorimeter

Electron



Muon

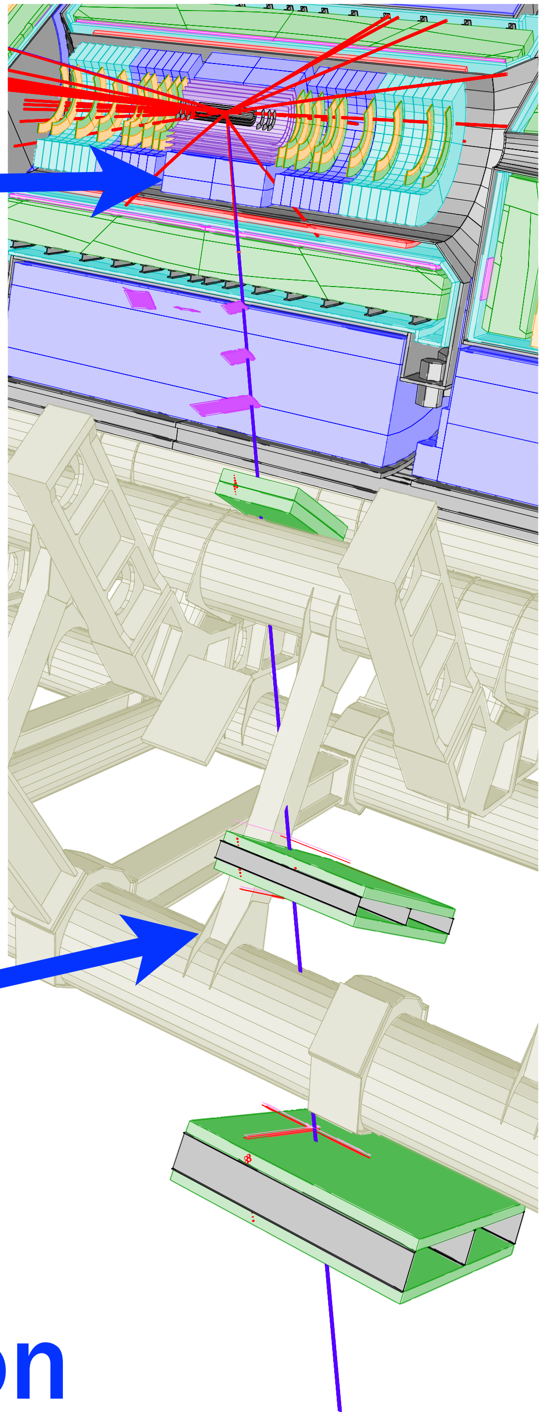
Electrons and Muons



Track
in the inner
detector

+ cluster in the
EM calorimeter

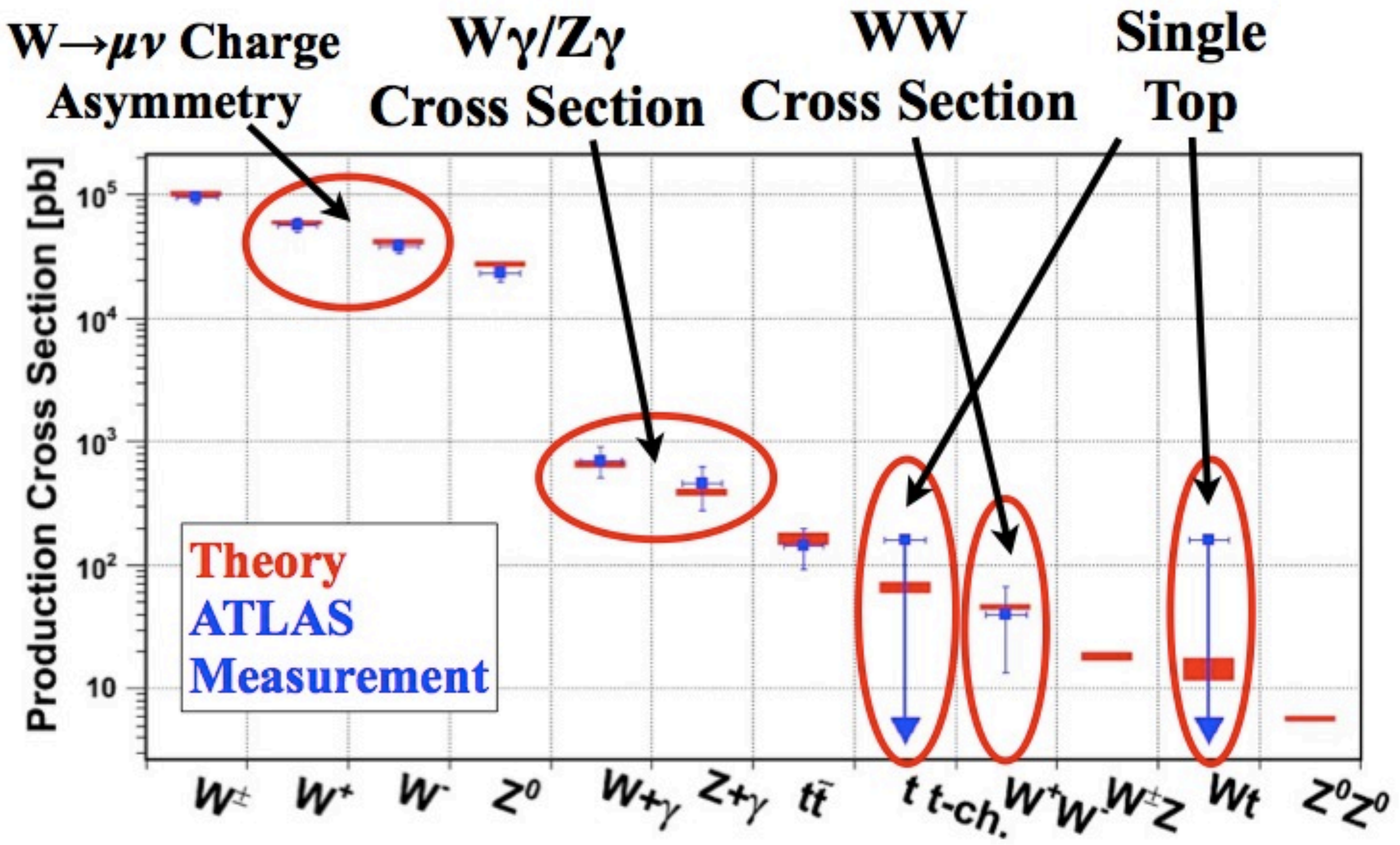
+ hits in the
muon systems



Electron

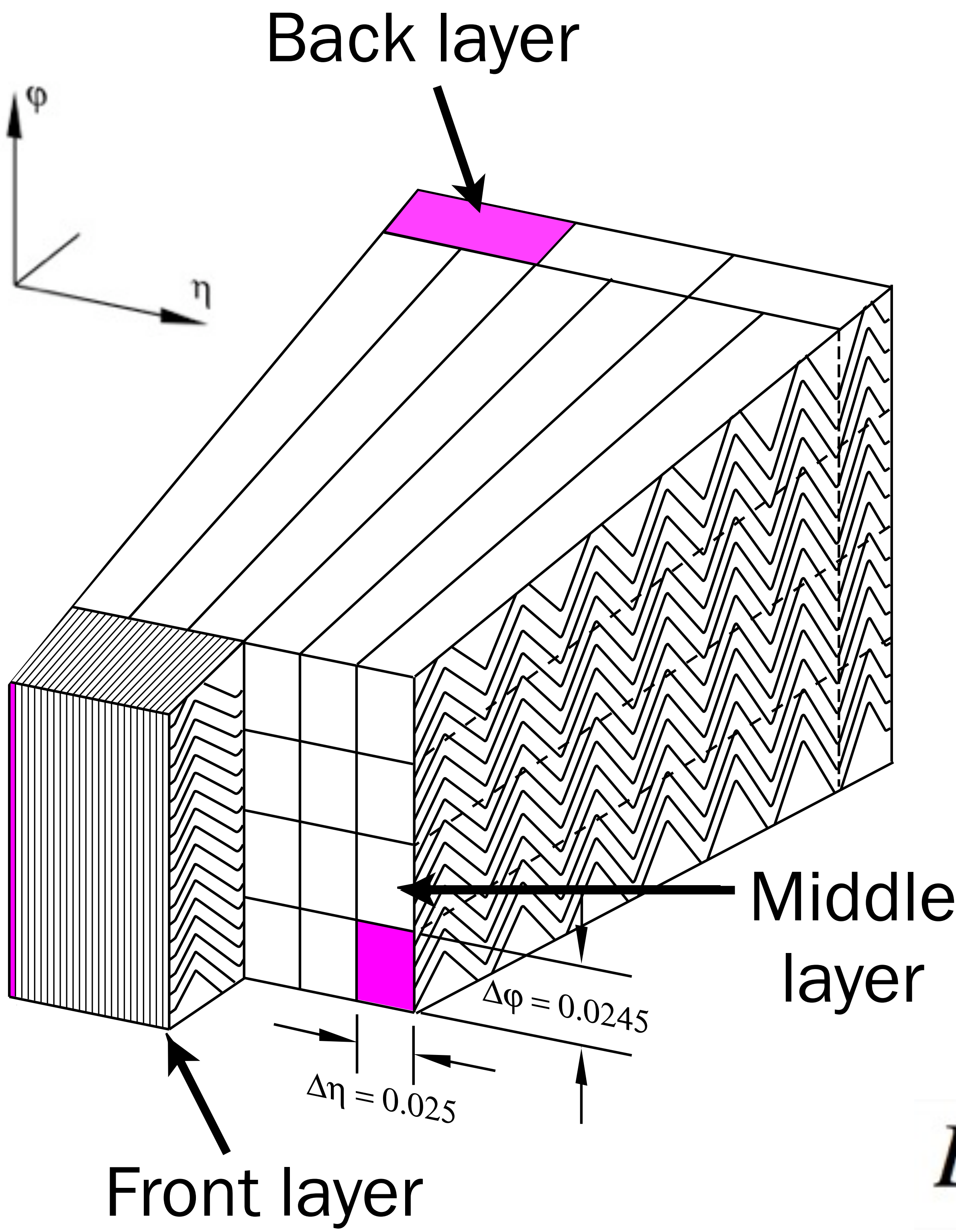
Muon

Standard Model Leptons



ATLAS results shown at Moriond covered a lot of territory with electrons and muons

Electron Identification



Electron: Track + Cluster

Shower shape variables provide discrimination

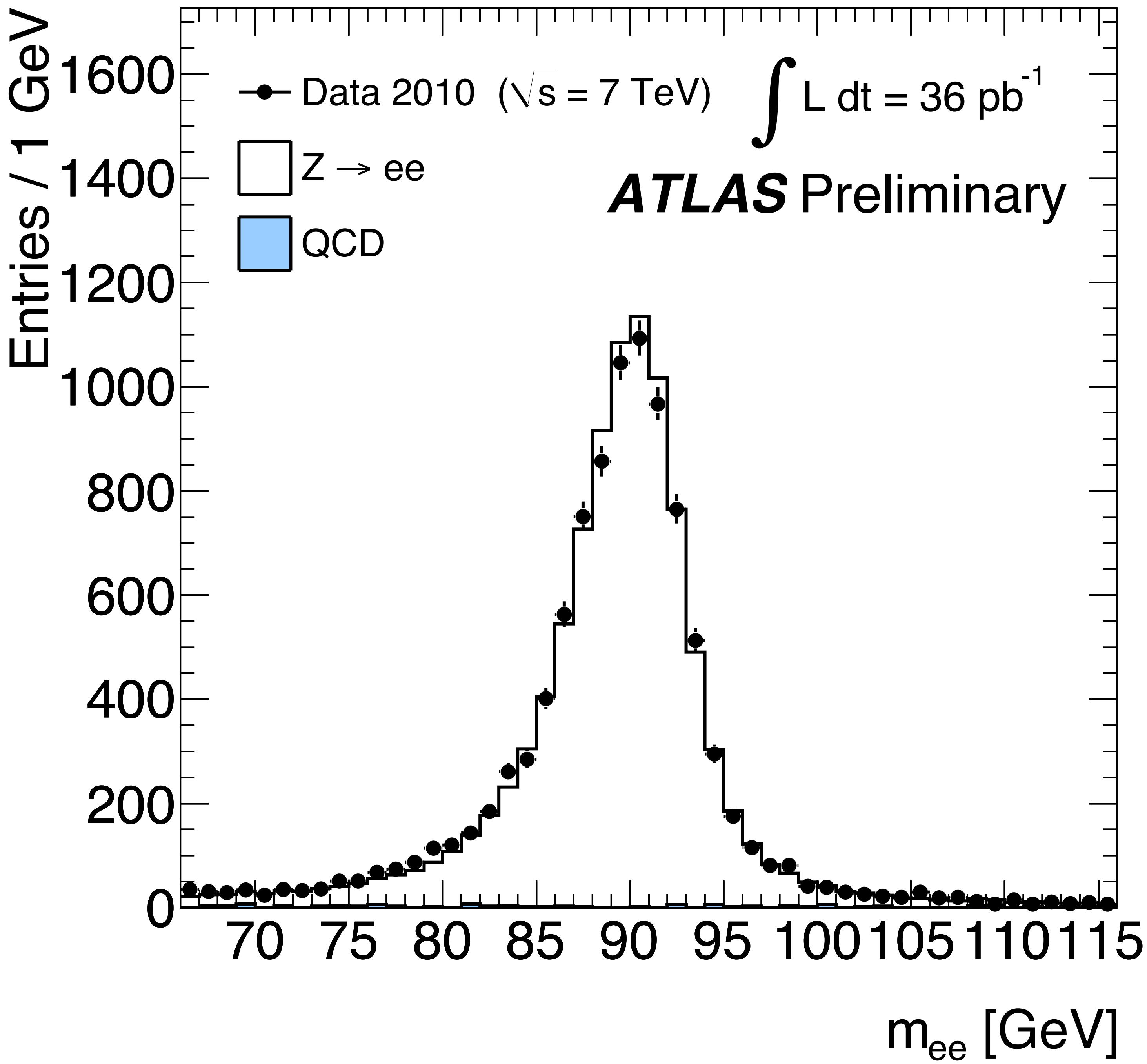
For example, in the middle layer:

$$R_\eta = \frac{3\times7}{7\times7}$$

In the front layer:

$$E_{2nd} - E_{min(E_{2nd},E_{1st})} = \Delta E_S$$

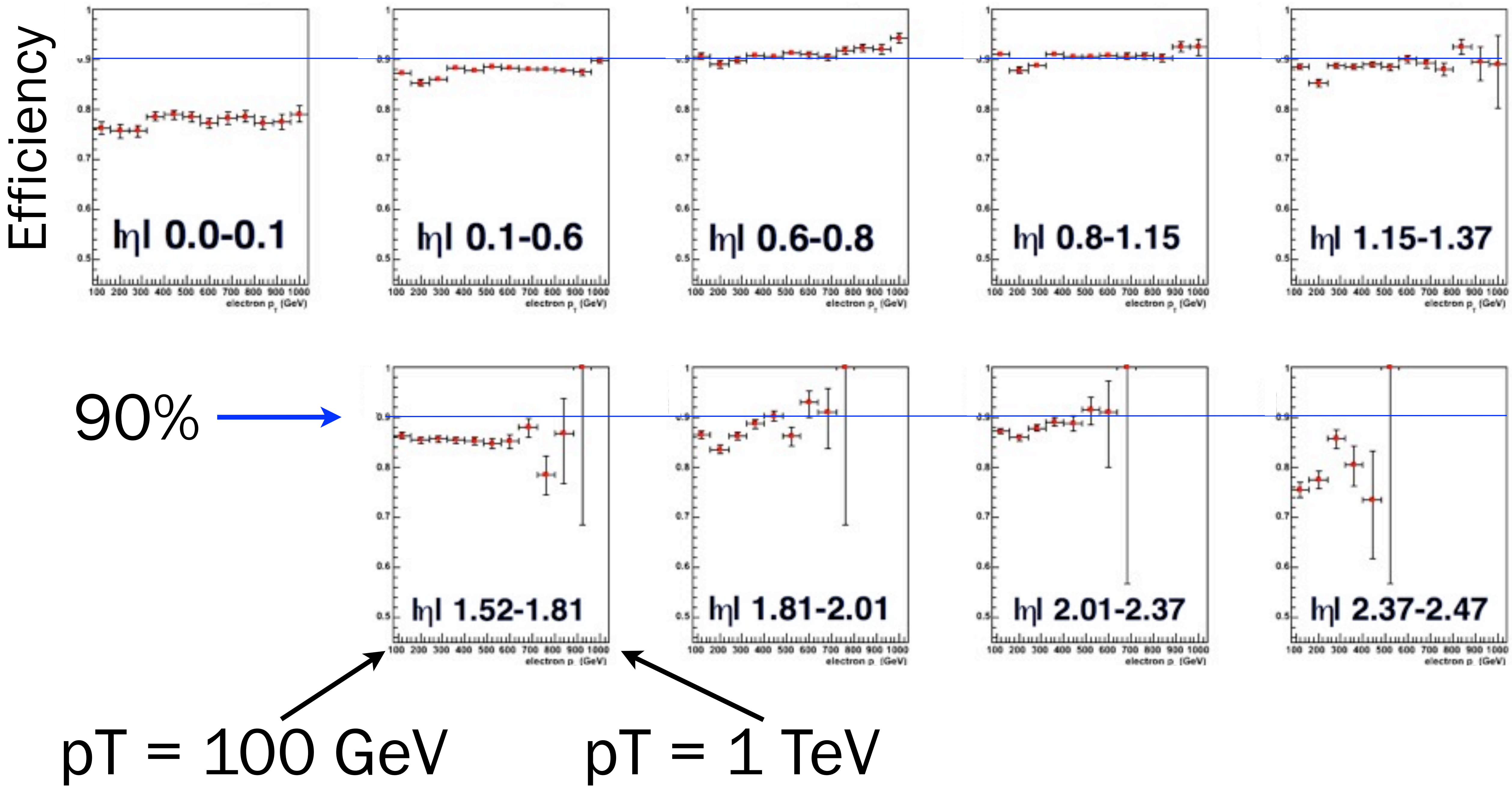
SM Z analysis



Use Z peak to understand electrons with pT of ~50 GeV

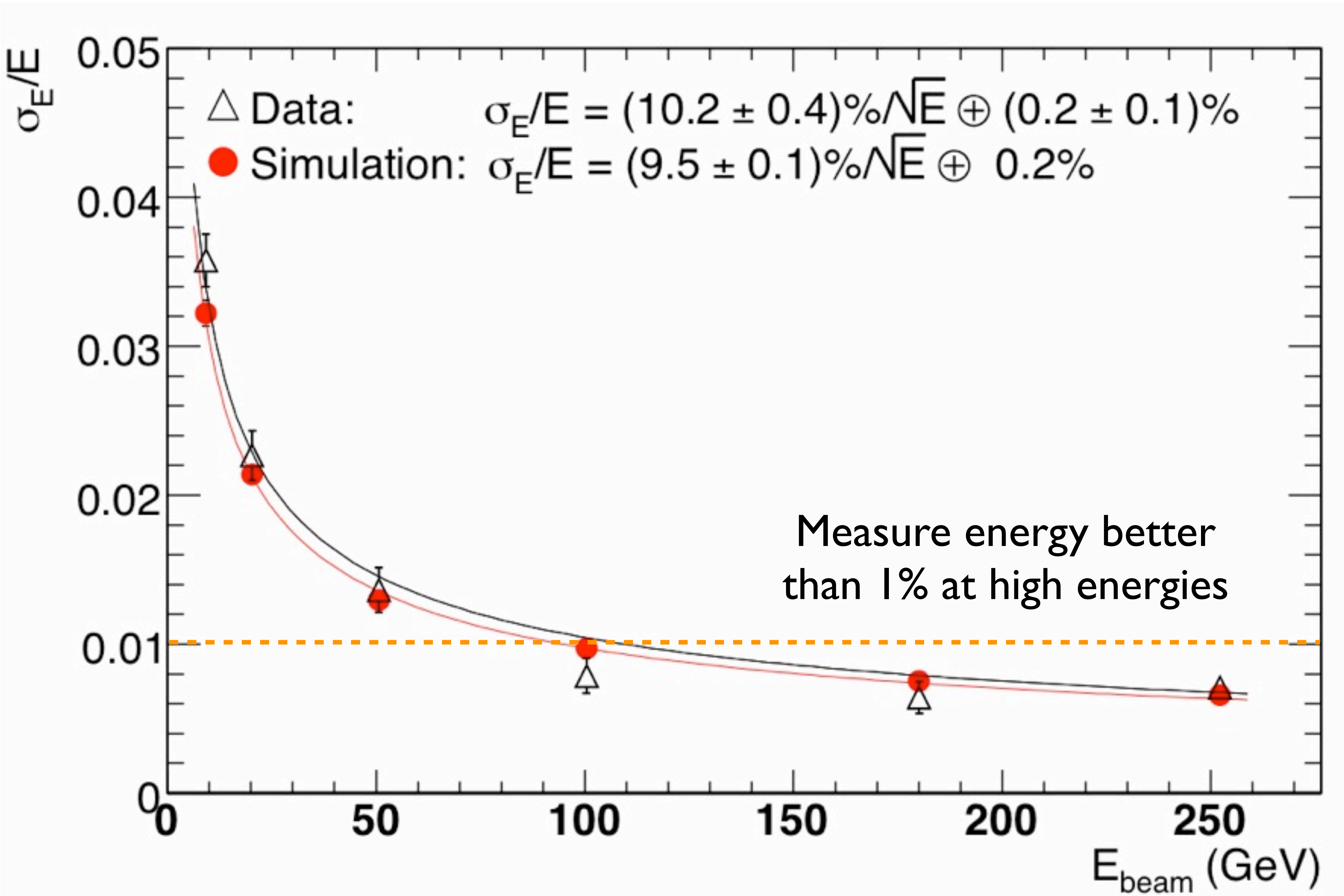
Extrapolate to 500 GeV with studies in data and MC

MC Electron Efficiency



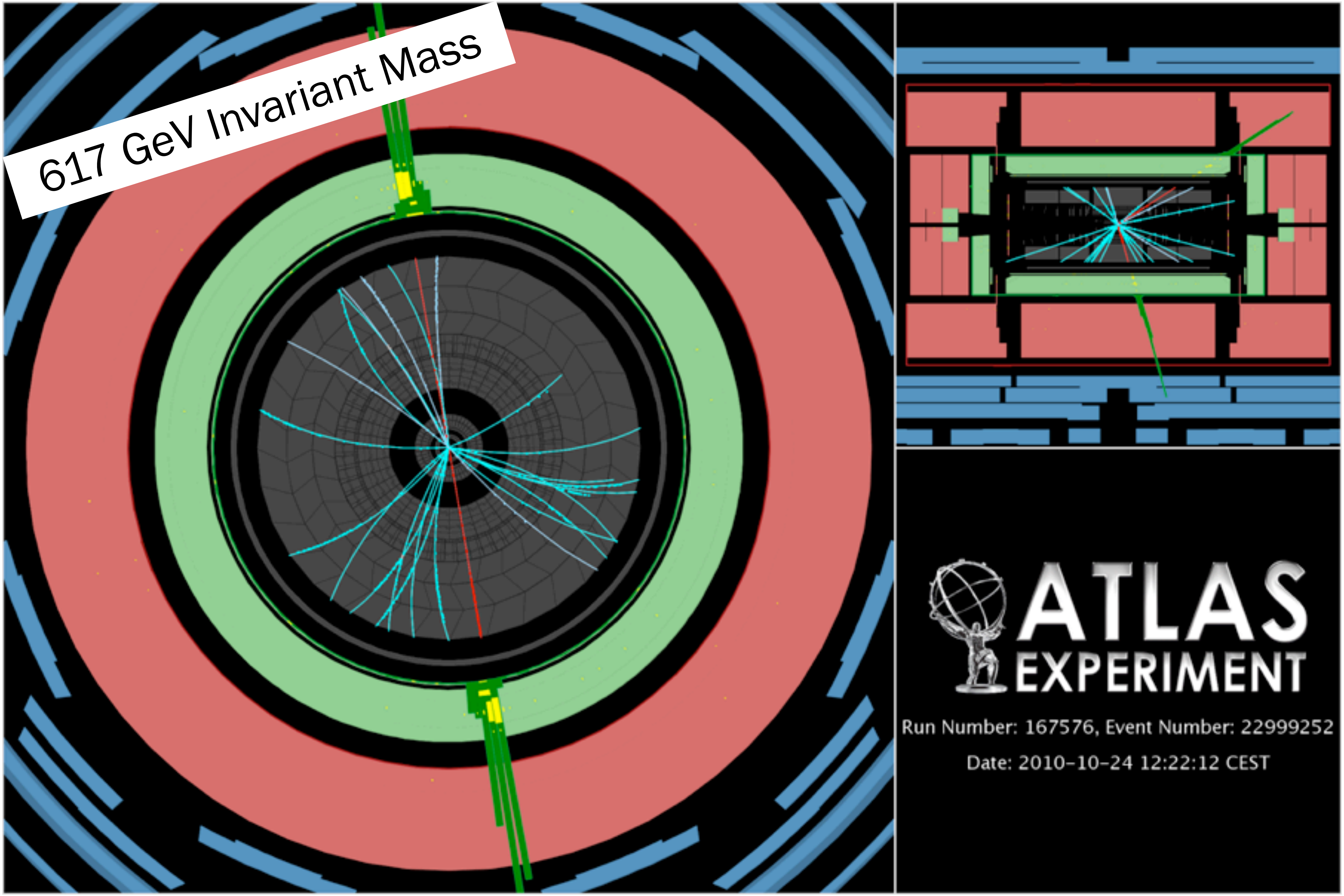
Bin electron efficiency in pT and eta

Energy Resolution for EM

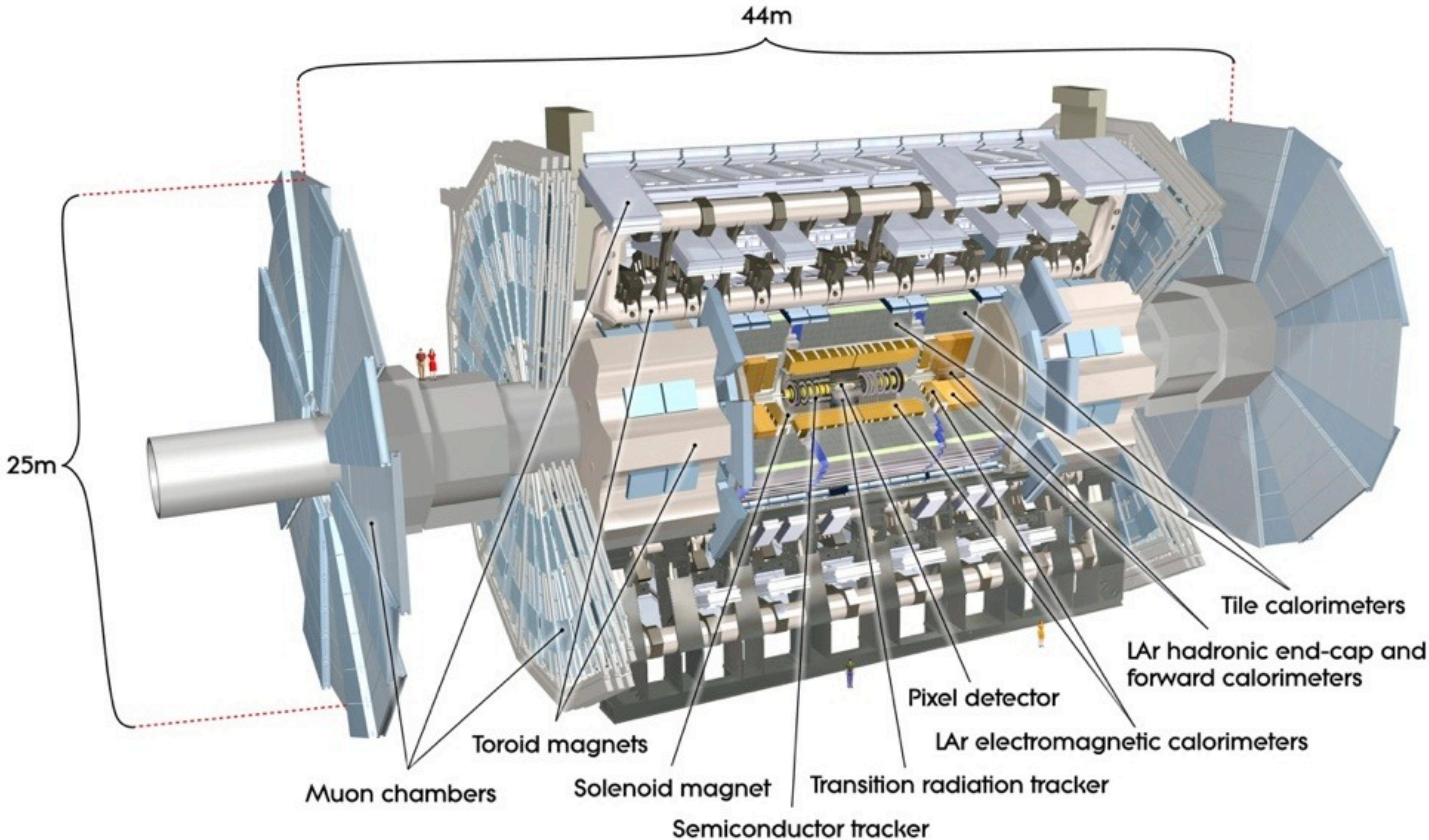


(noise subtracted)

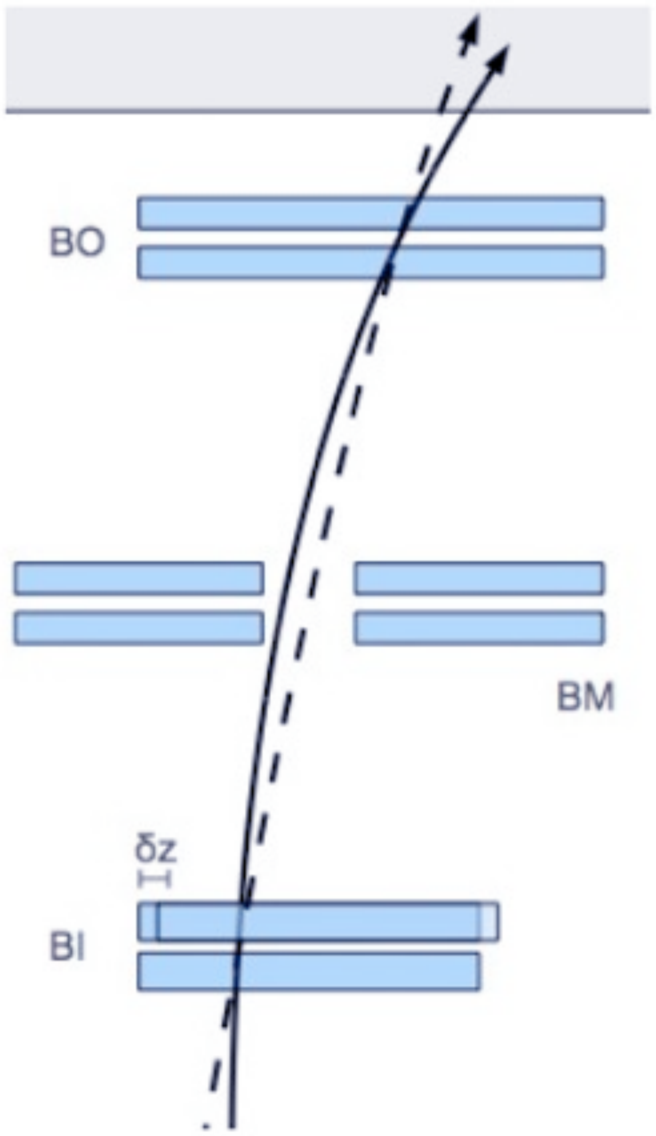
Highest ET Electrons

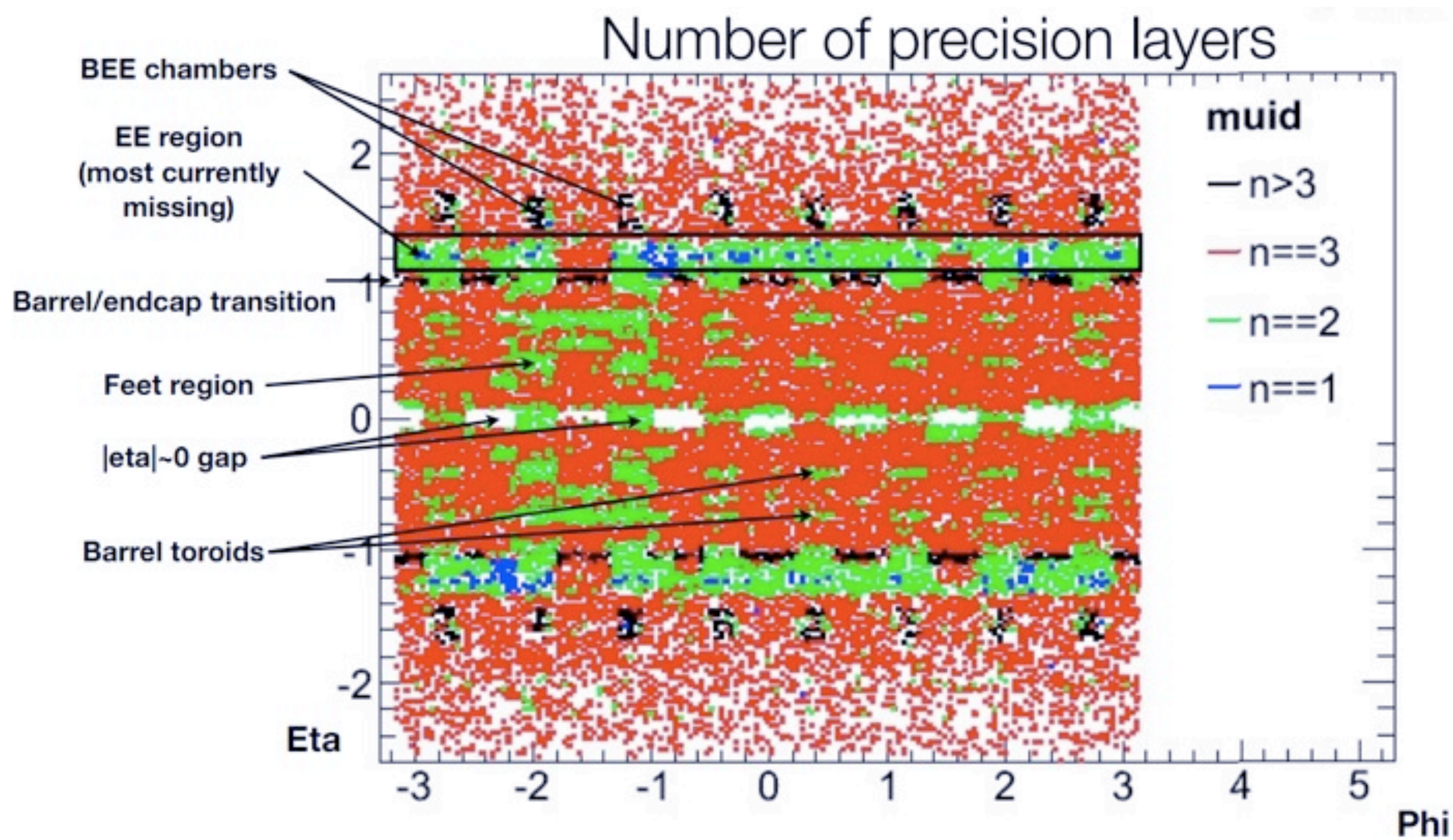


Muon Systems



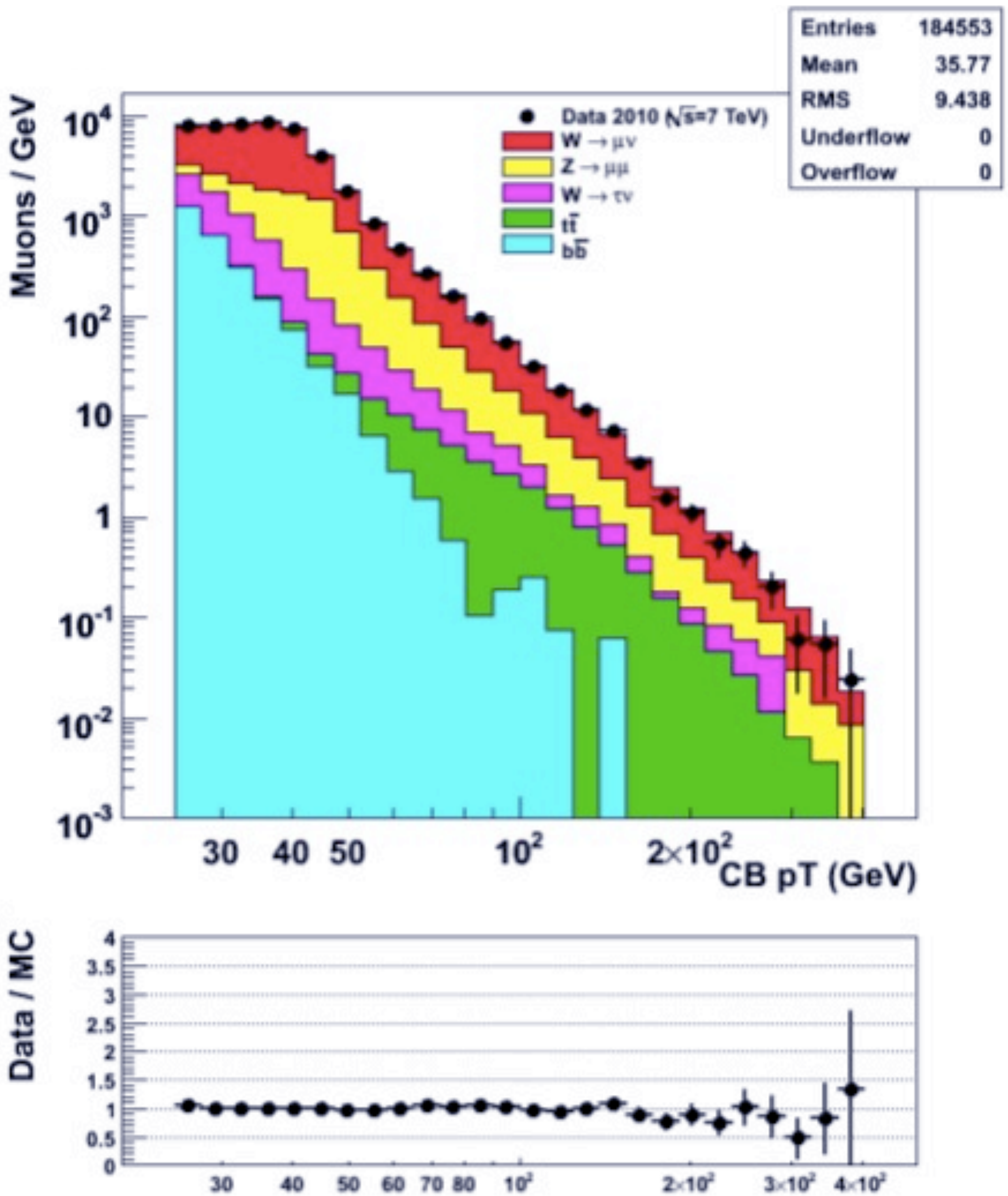
High pT Muons





Three station muons have better resolution, less acceptance

Tighter cuts for searches

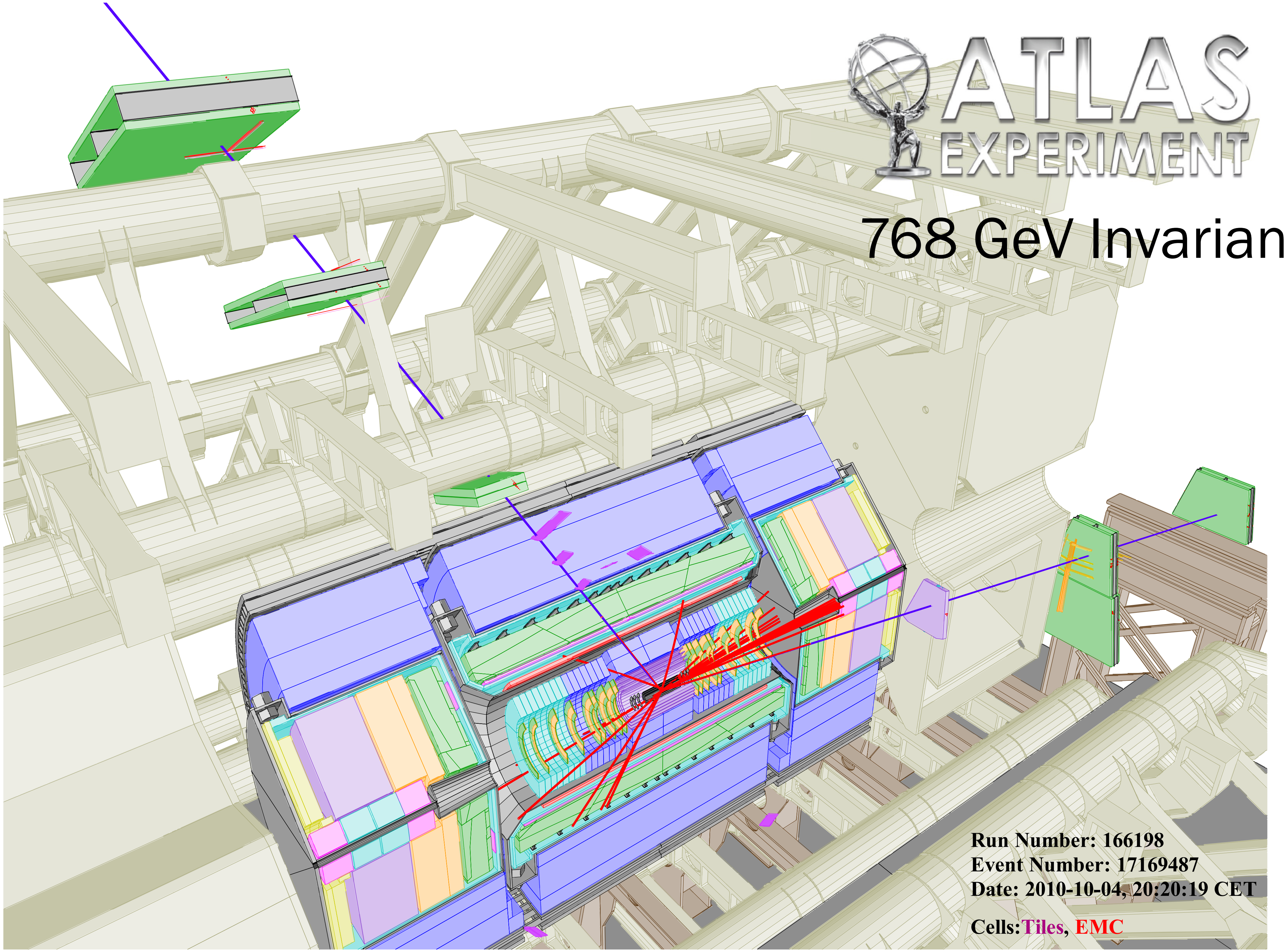


All single muon events that pass our three-station selection

All backgrounds from MC

For high-pT searches with 2010 data, use 3-station muons

Highest pT Muons



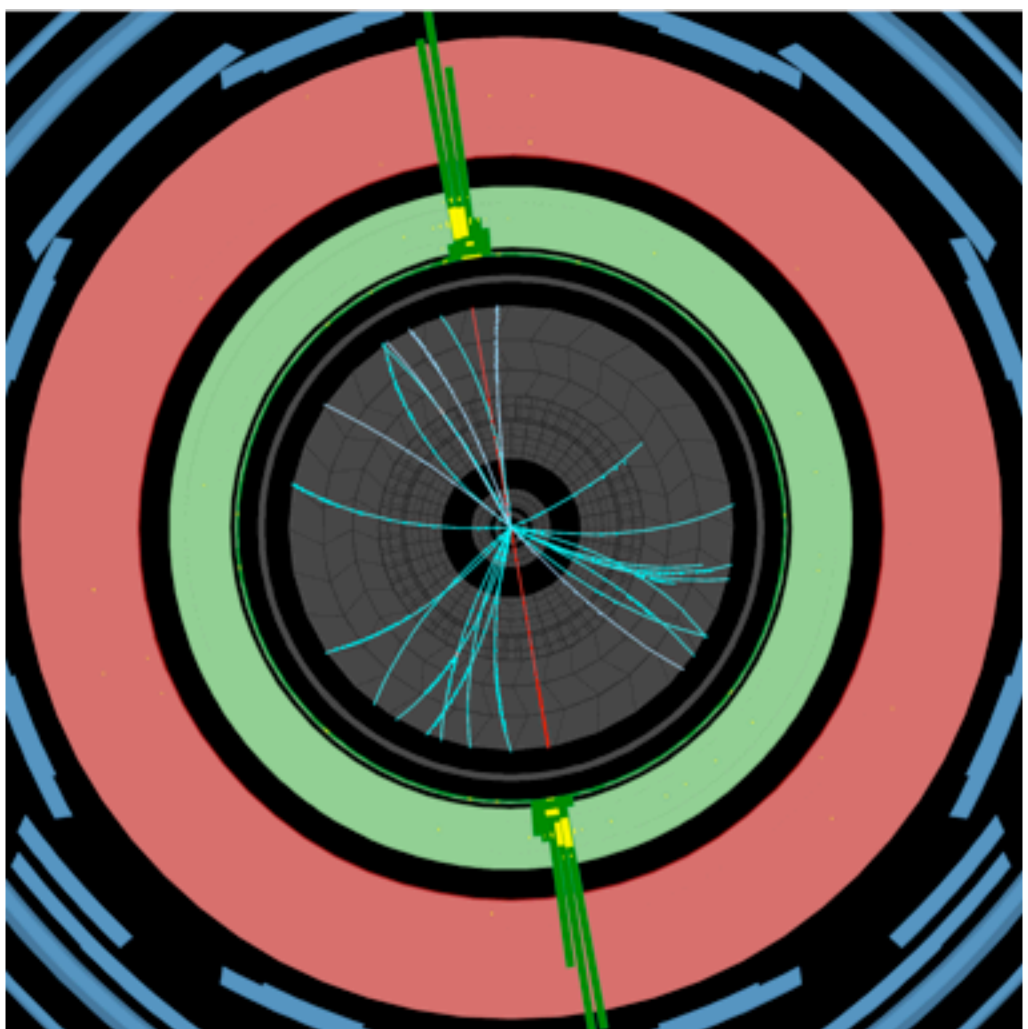
768 GeV Invariant Mass

Z' Event Selection

Two electrons

pT > 25 GeV

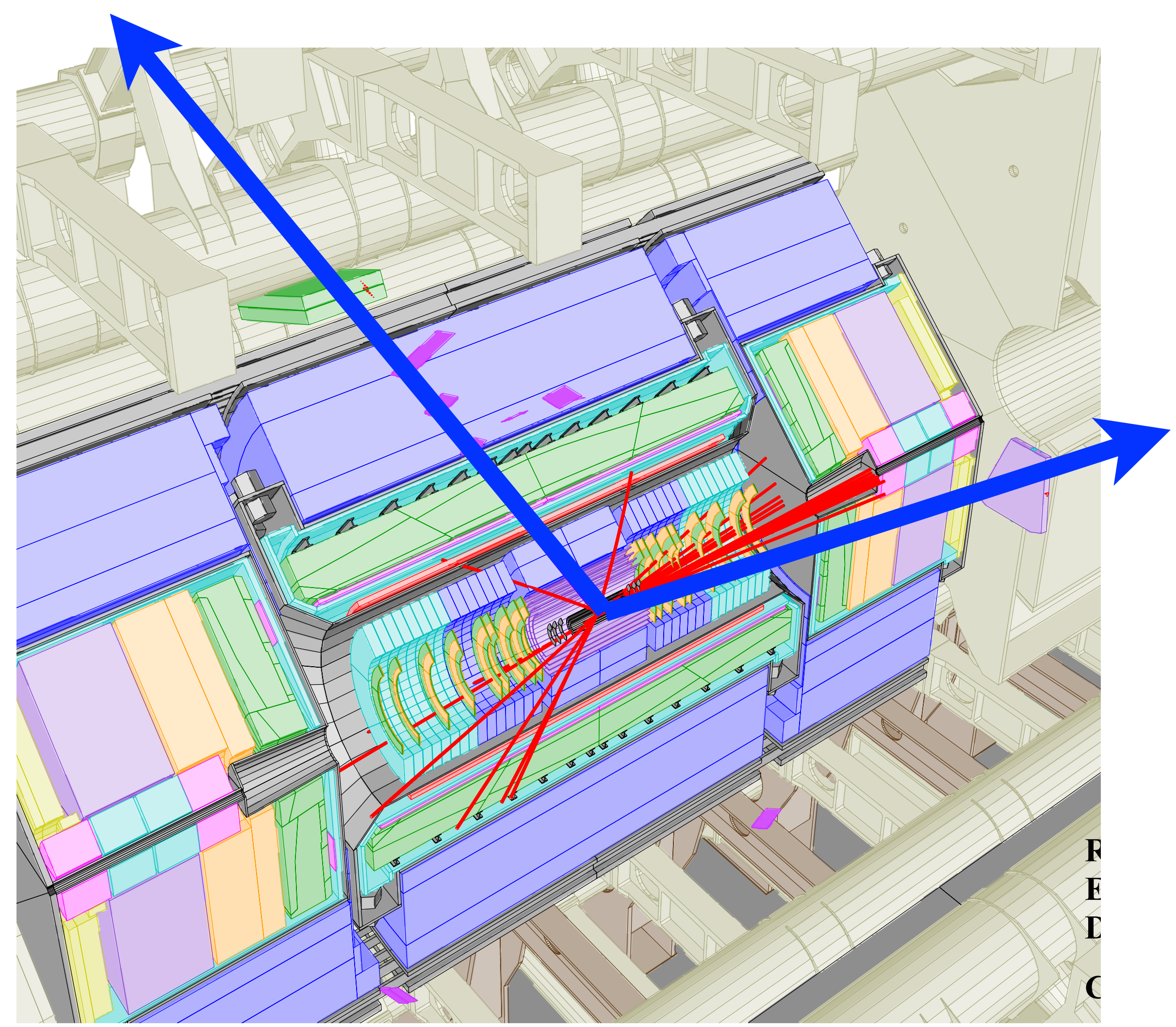
|eta| < 2.47



Two muons

pT > 25 GeV

|eta| < 2.4

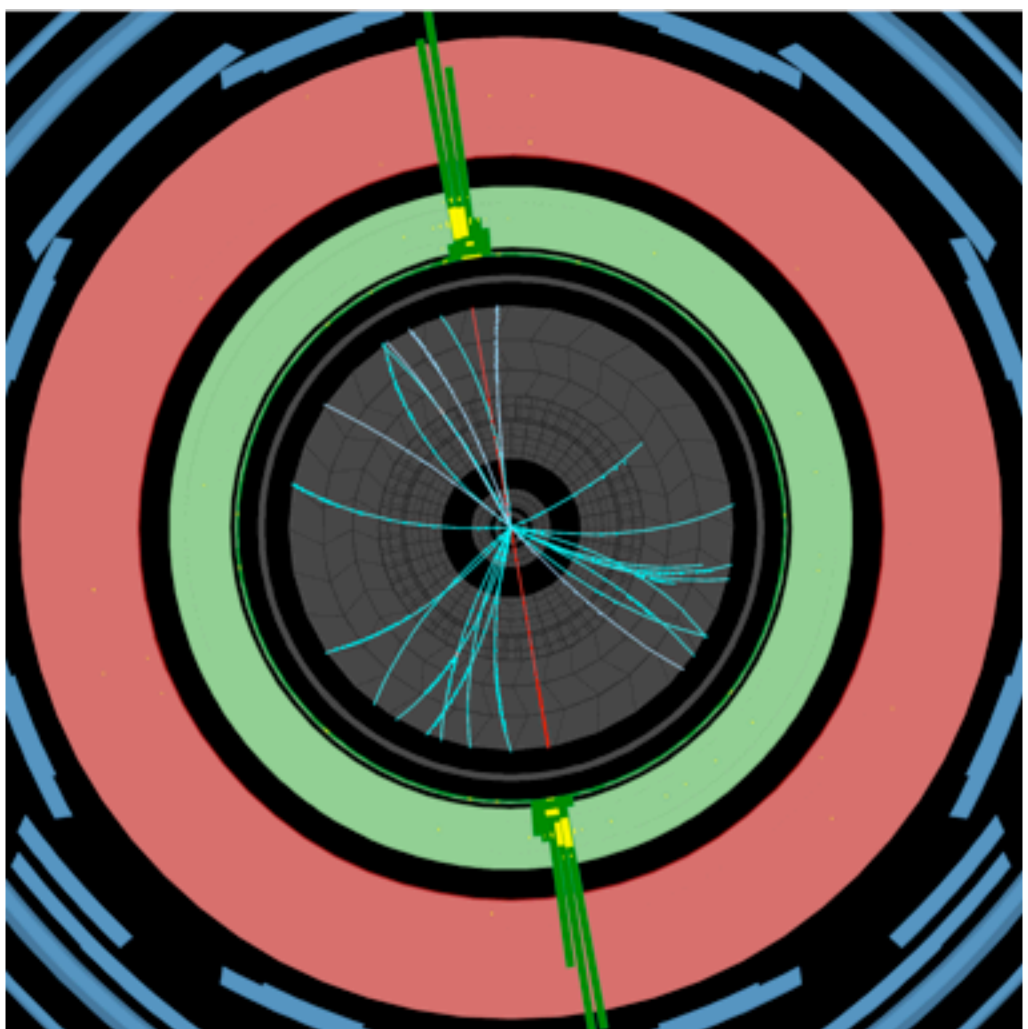


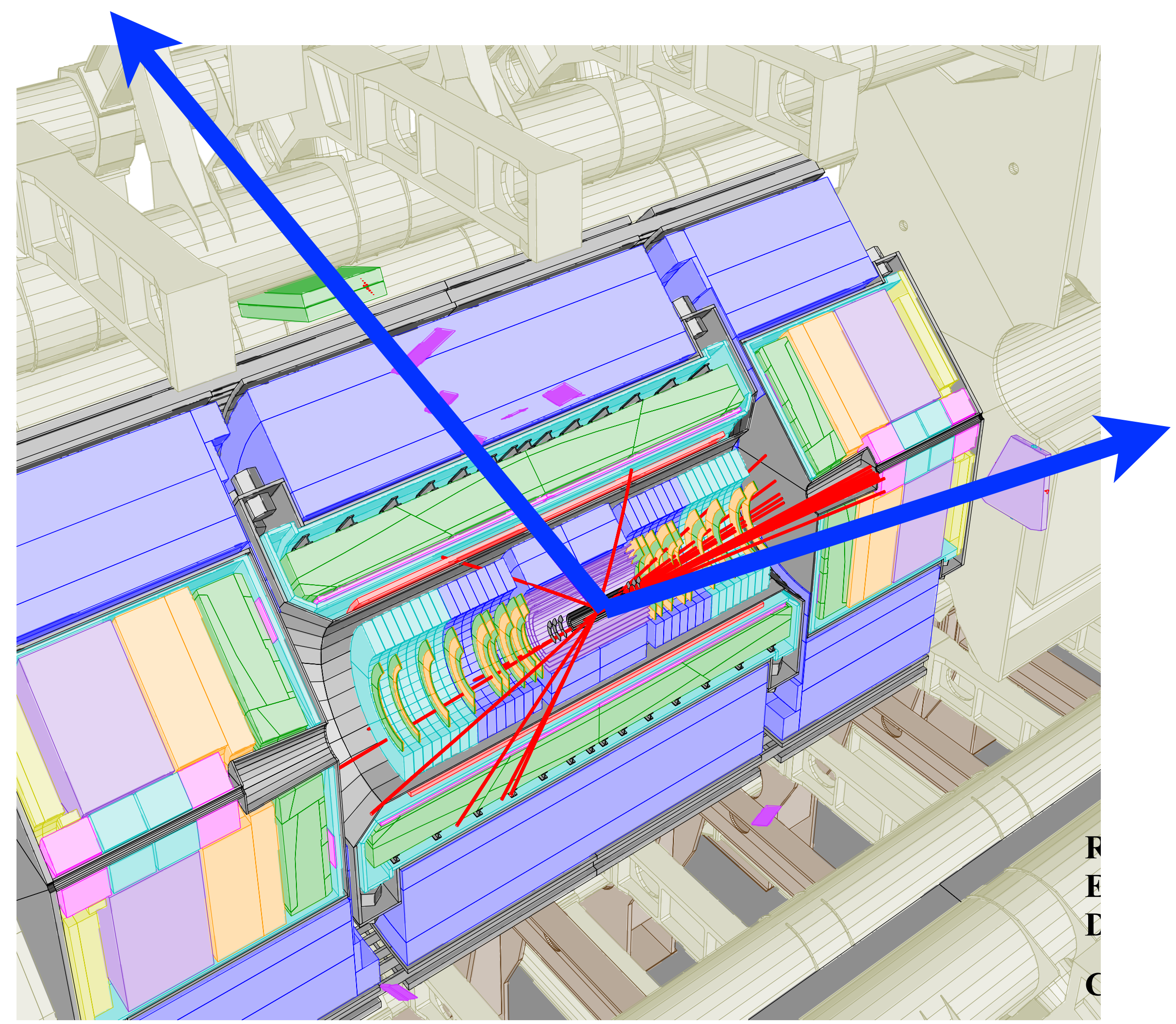
Z' Event Selection

Two electrons
pT > 25 GeV
|eta| < 2.47

Two muons
pT > 25 GeV
|eta| < 2.4

opposite charge
track isolation





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opposite charge

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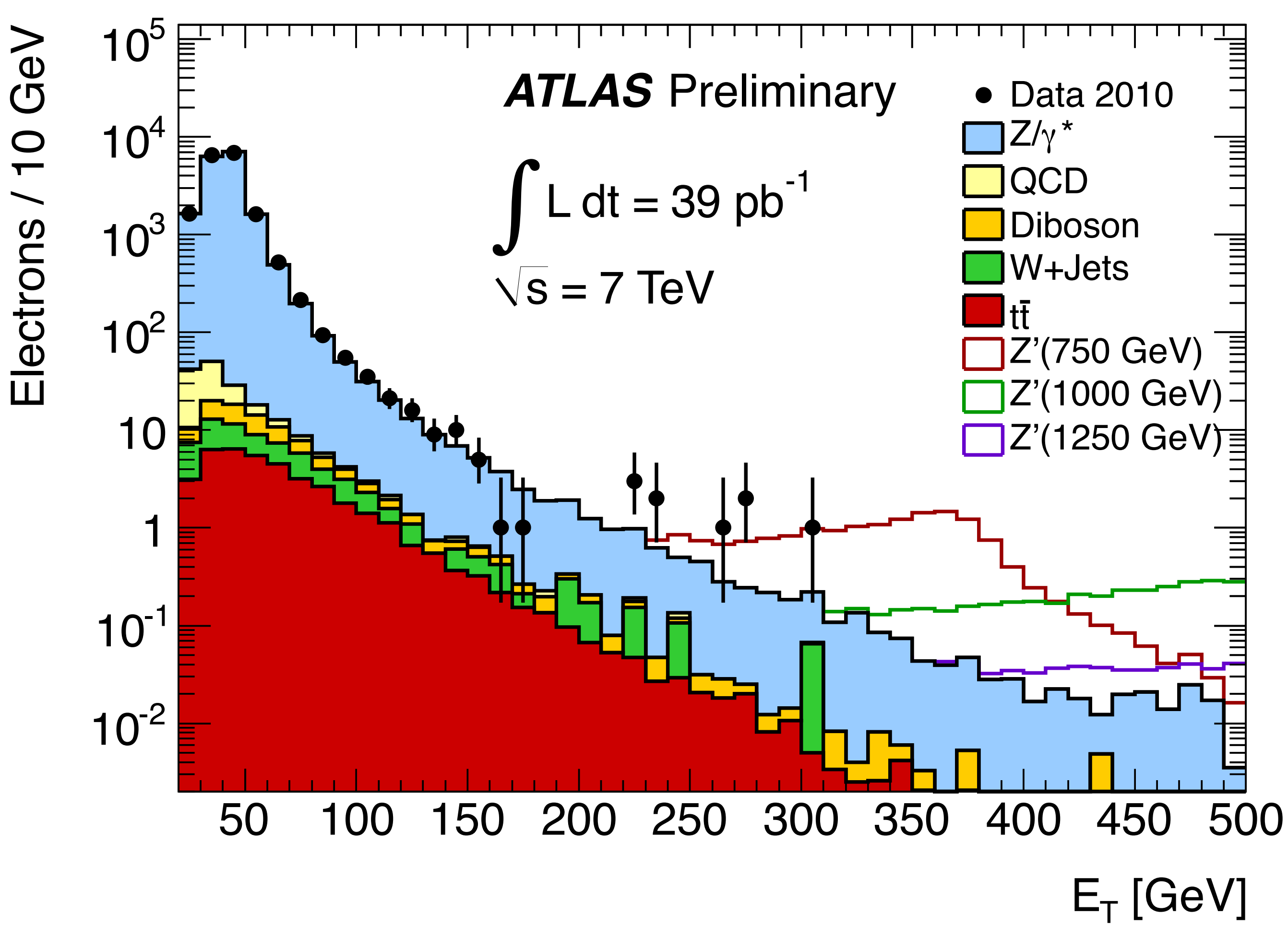
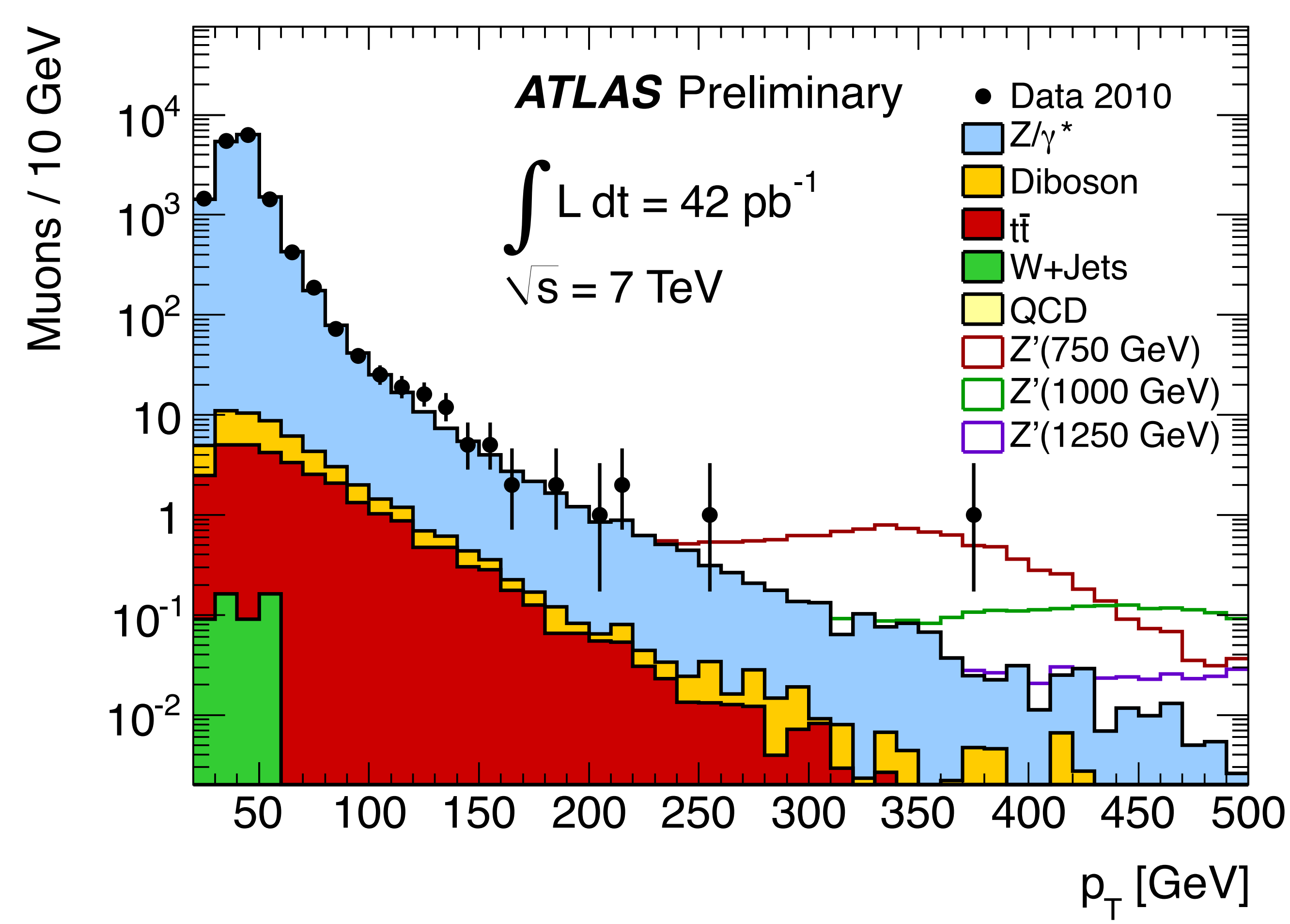


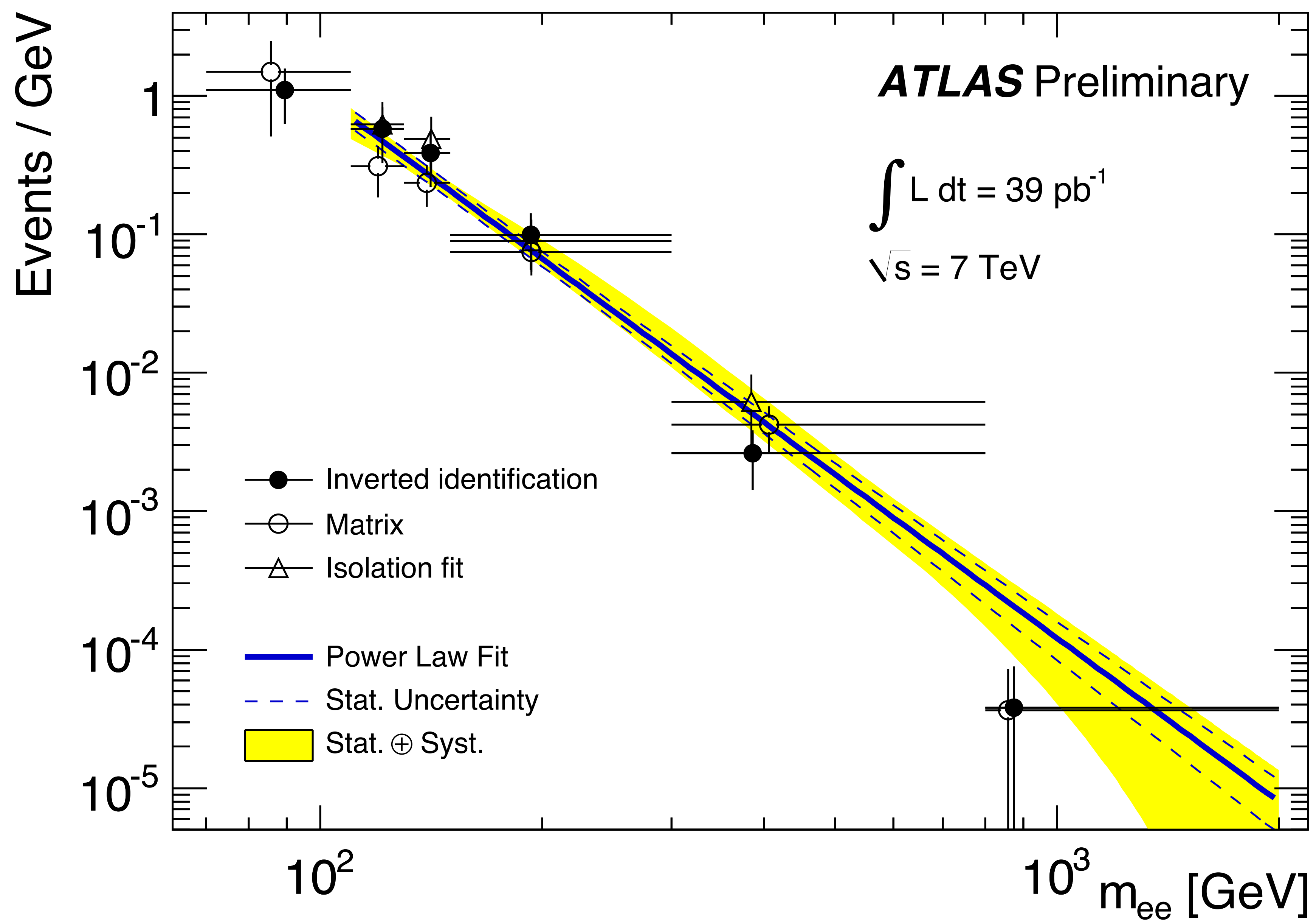


Electron backgrounds

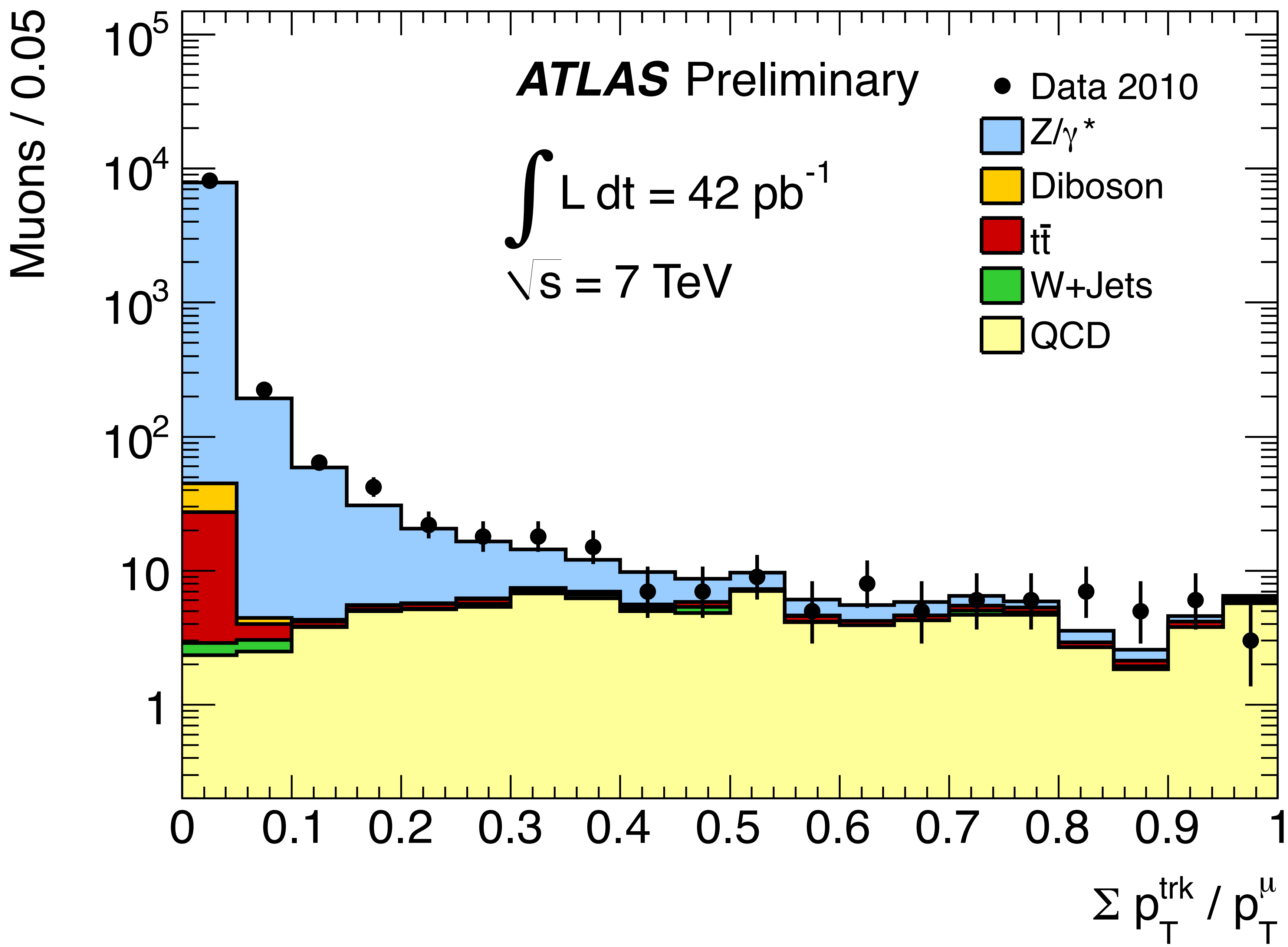
Estimate QCD background from data & extrapolate

Use three different methods with different samples:

- Inverted ID
- Matrix
- Isolation Fit



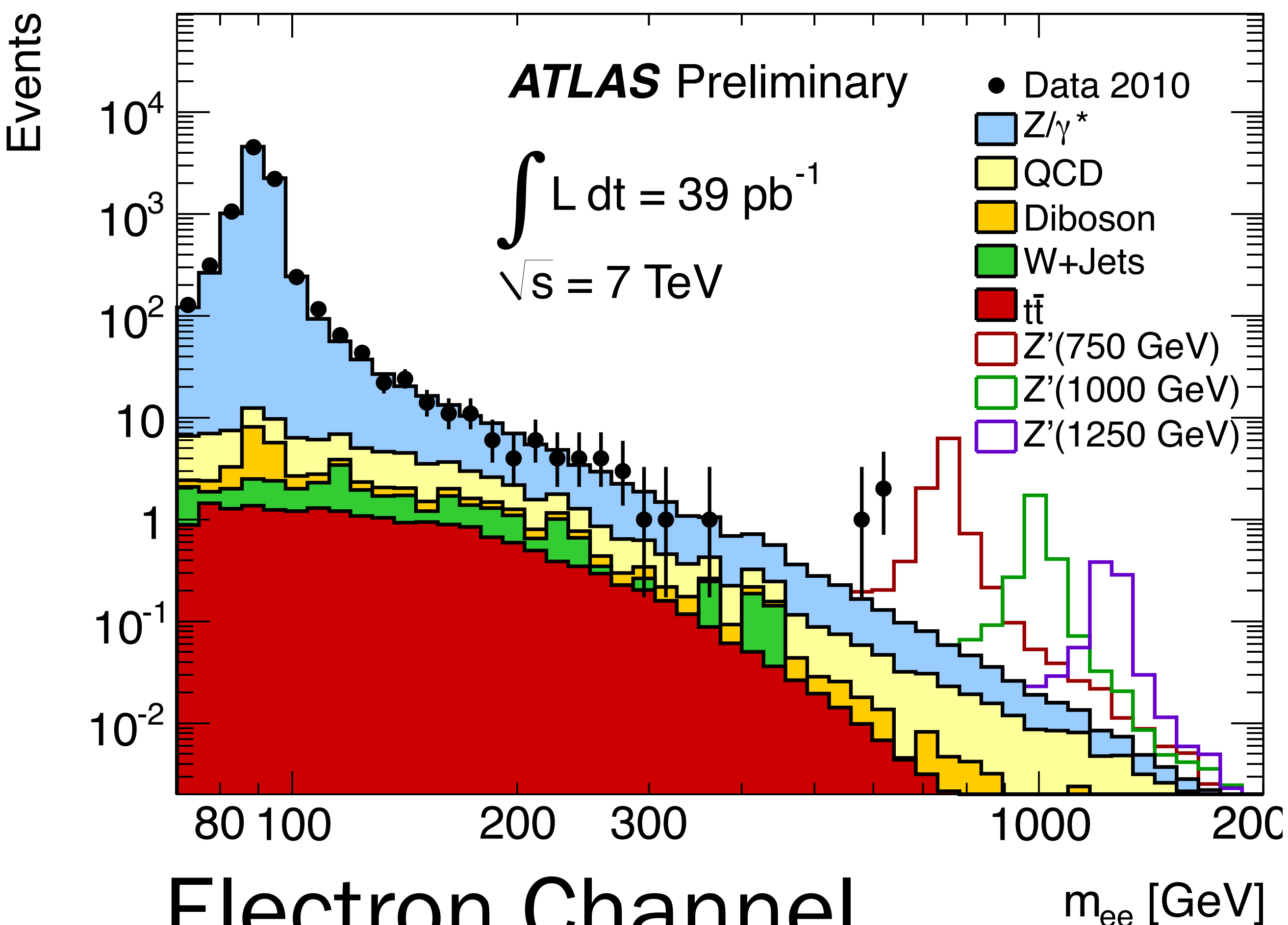
Muon backgrounds



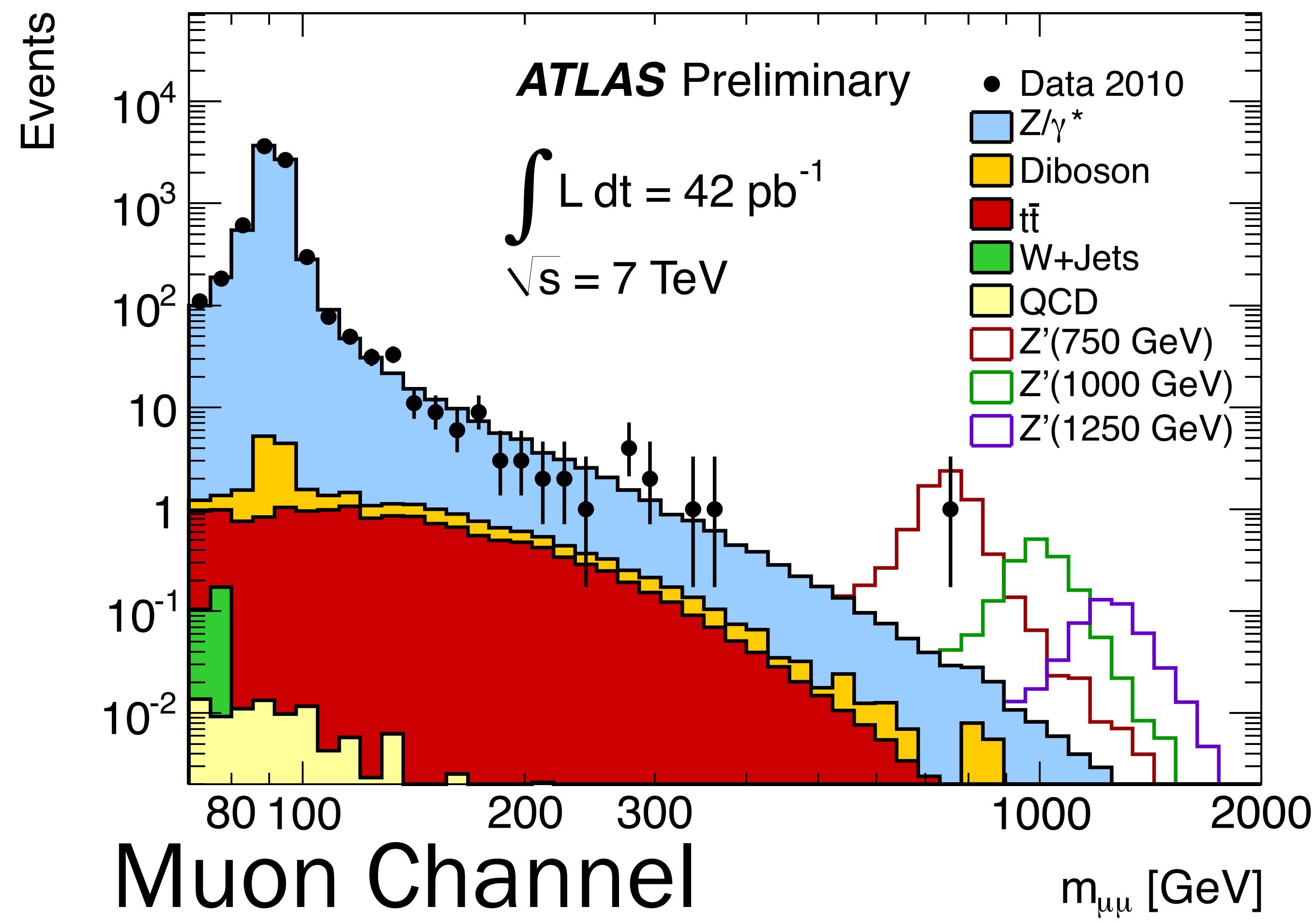
QCD background: estimate from data & MC

Cosmics: estimate from data, negligible

The Results



Electron Channel



Muon Channel

Normalize to Z Peak $\sigma B(Z') = \sigma B(Z) \frac{N_{Z'} A_Z}{N_Z A_{Z'}}$

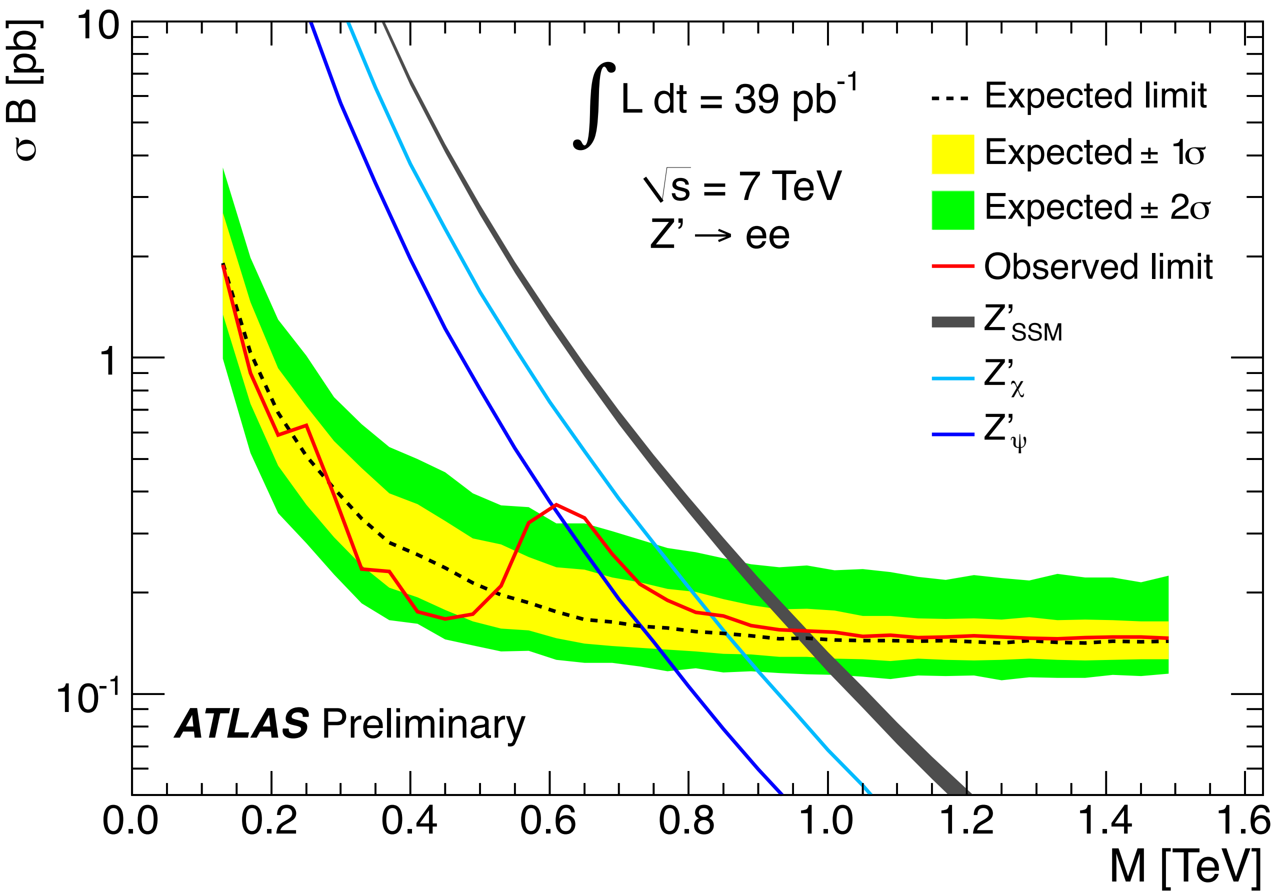
p-values of 5% for electrons, 22% for muons

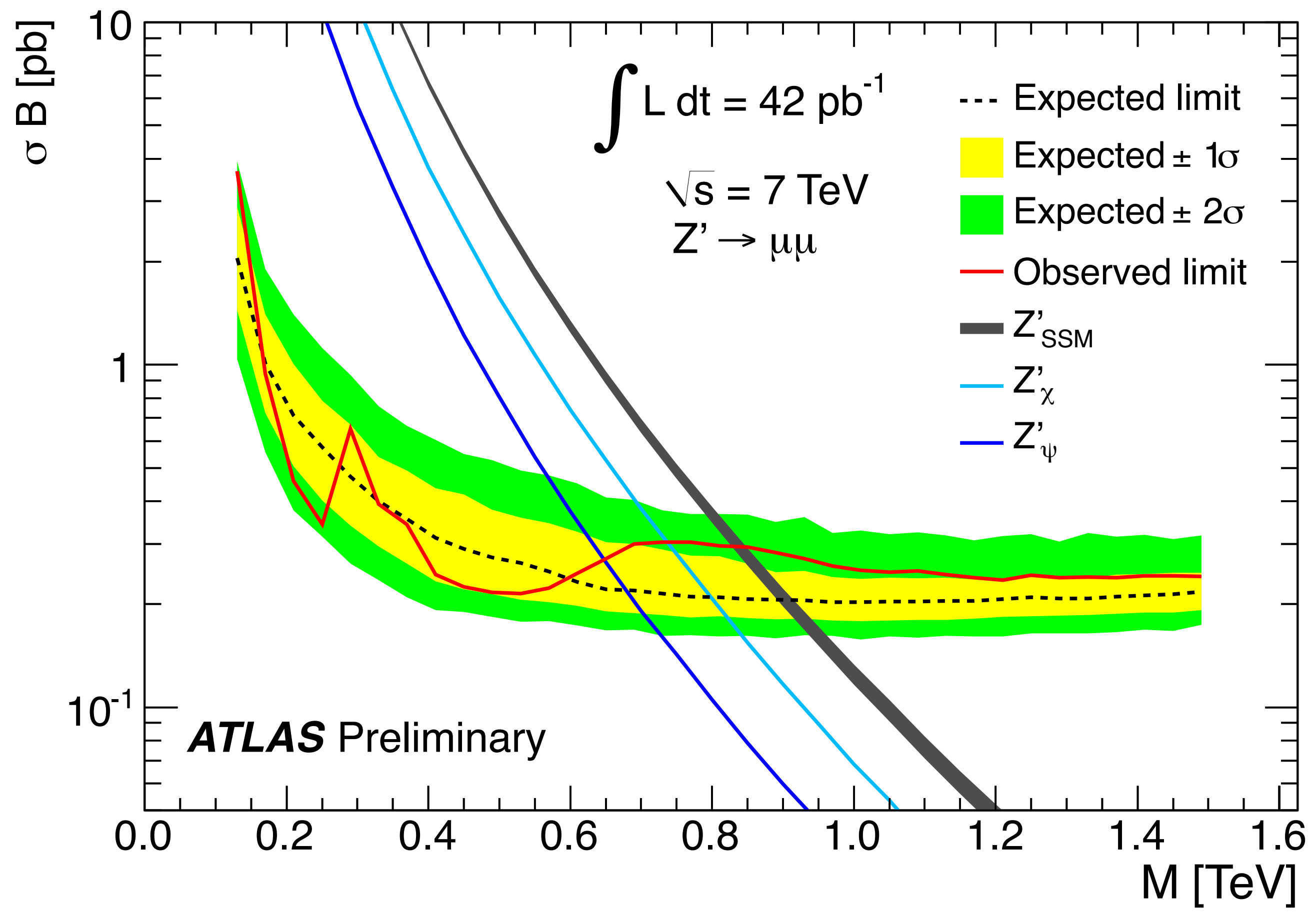
Systematics for Z’

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%

Only mass-dependent systematics matter

Limits on Models

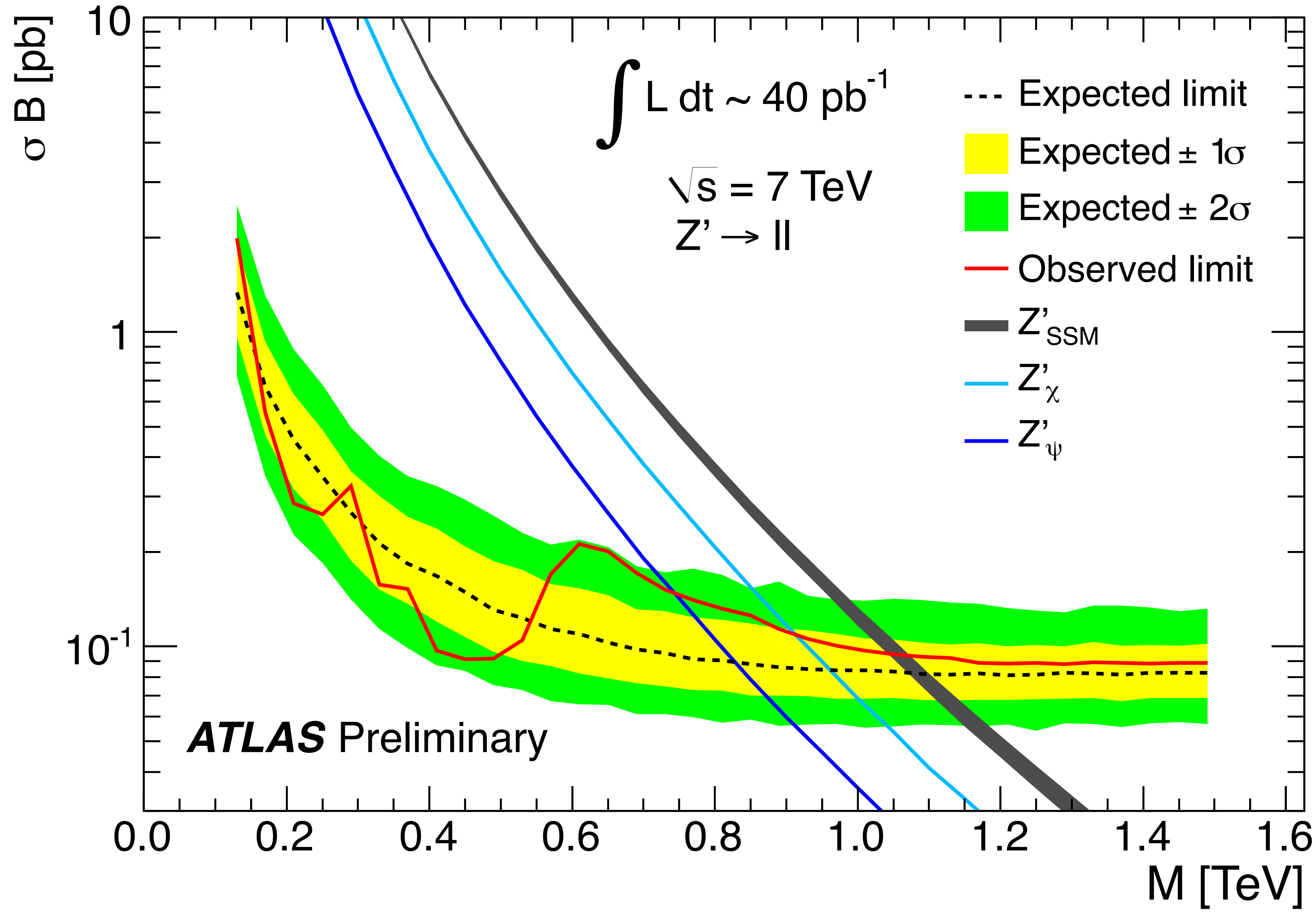




	Observed limit		Expected limit	
	mass [TeV]	σB [pb]	mass [TeV]	σB [pb]
$Z'_{\rm SSM} \to e^+e^-$	0.957	0.155	0.964	0.148
$Z'_{\rm SSM} \to \mu^+\mu^-$	0.834	0.297	0.895	0.206
$Z'_{\rm SSM} \to \ell^+\ell^-$	1.048	0.094	1.084	0.082

Use binned likelihood fit to set limits on SSM Z'

Combine Results



Also place limits on "E6" Z'

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

2011 Z' Challenges

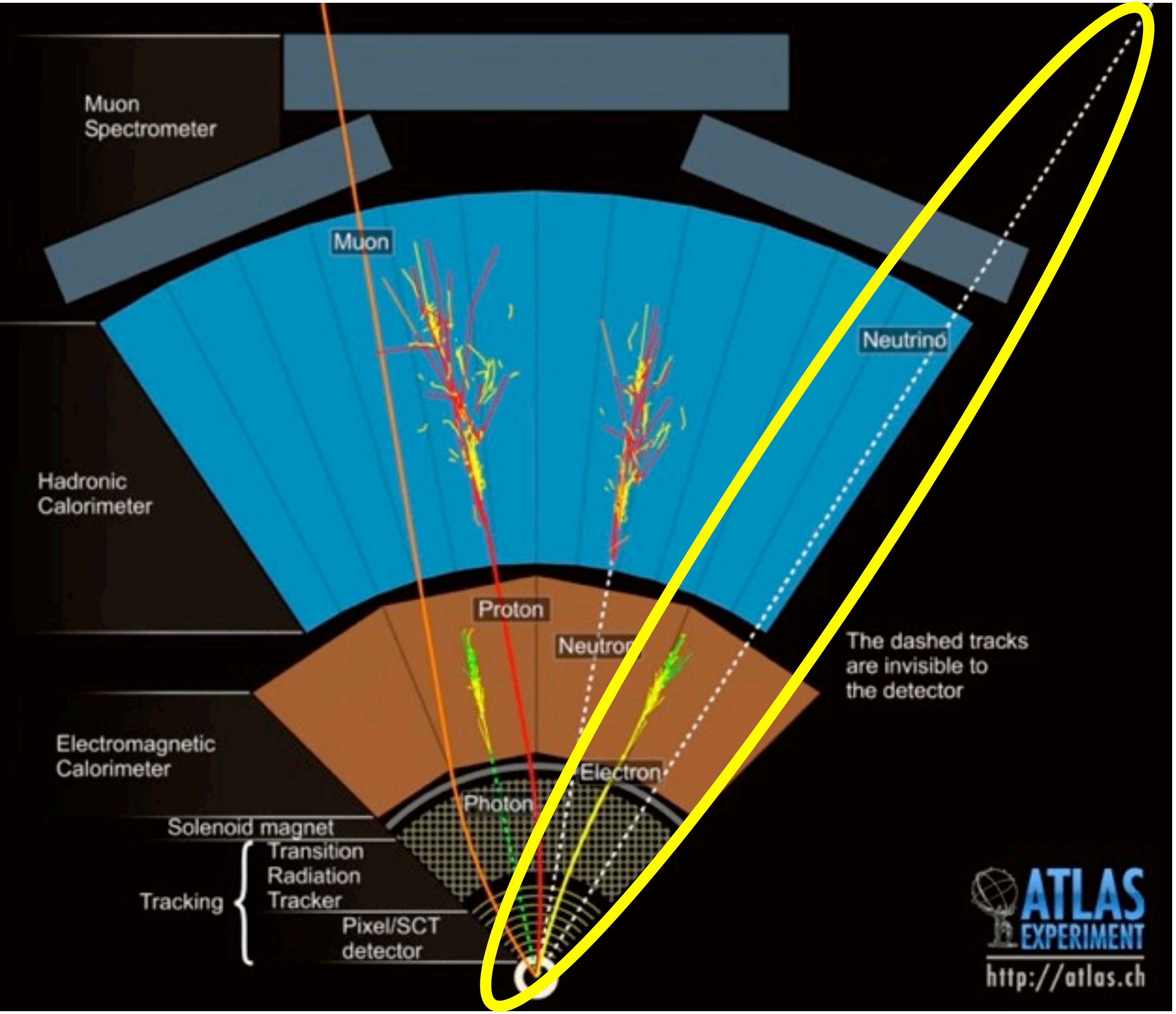
For Z', increase acceptance for electrons and muons

- As we validate more regions of the detector with data, include them
- Loosen requirements on the second lepton

More model independent presentation?

- How many/which models should we explicitly place limits on? What else is useful?

Missing Transverse Energy



Neutrinos

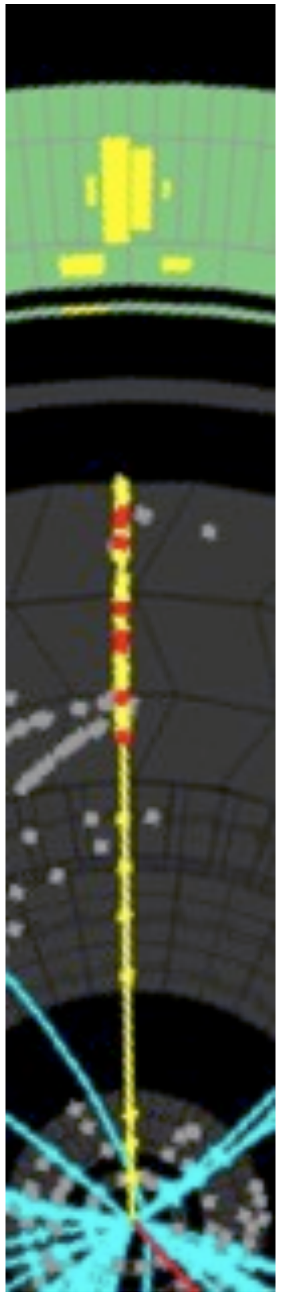
Lightest Stable Particles in new models?

Dark Matter?

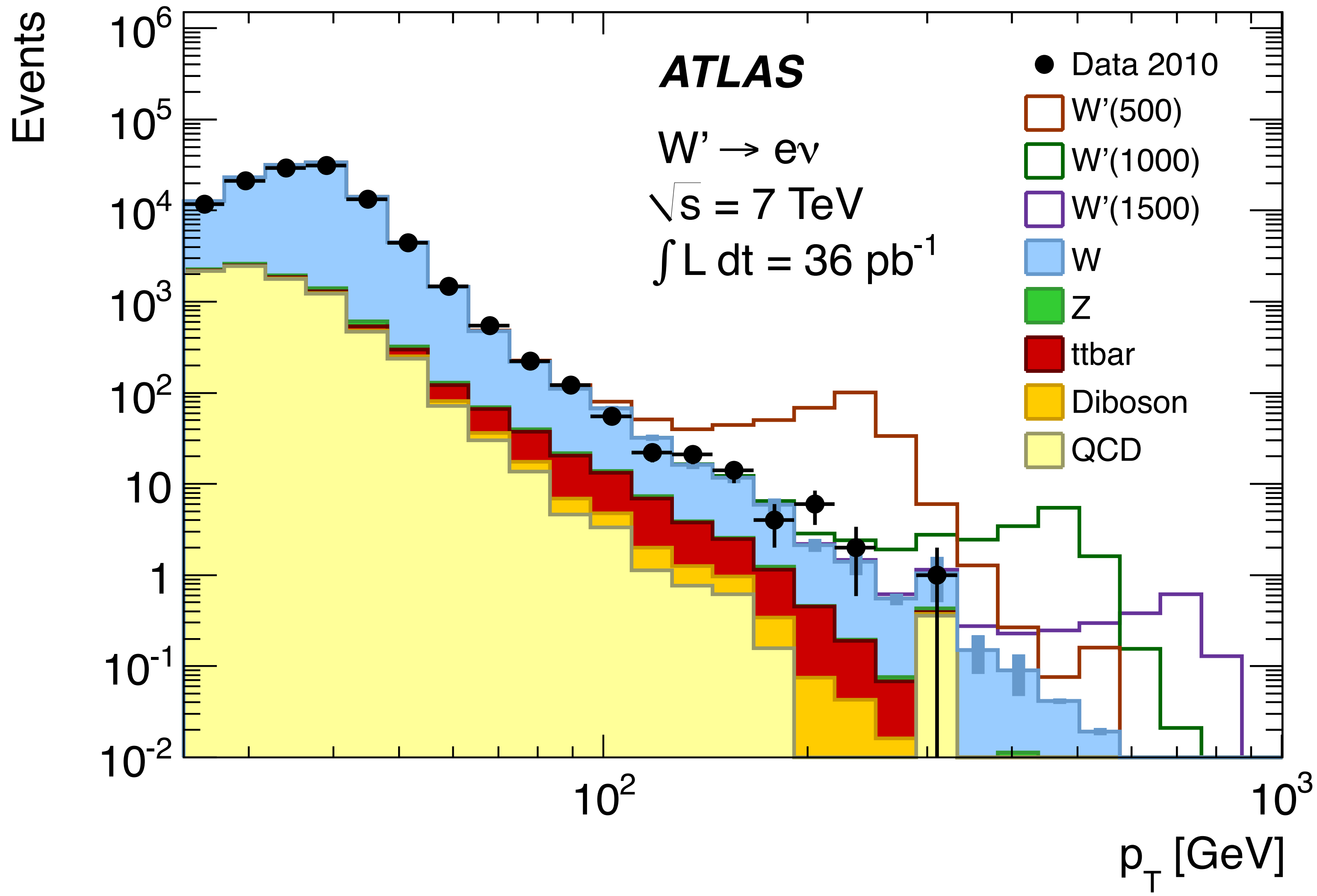
Anything that could escape detection

W' Electron Channel

Choose events with one isolated electron with pT > 25 GeV, MET > 25 GeV



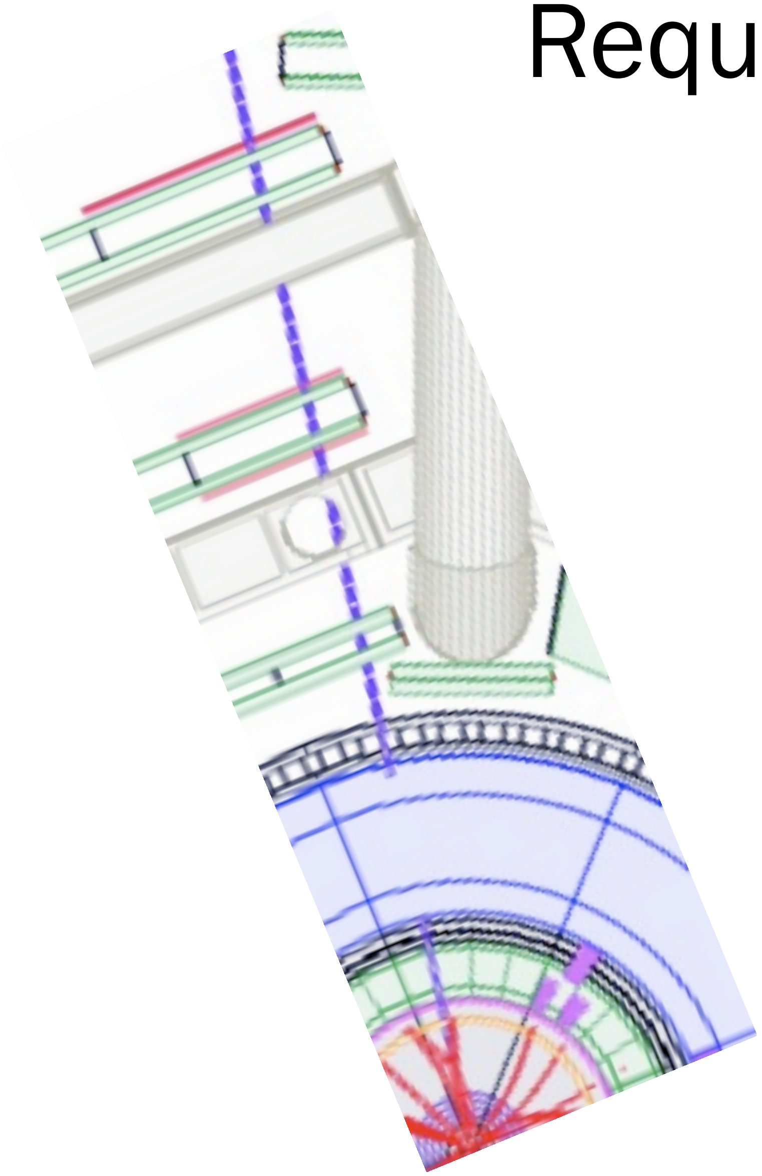
Largest backgrounds: W, ttbar, diboson events, and QCD

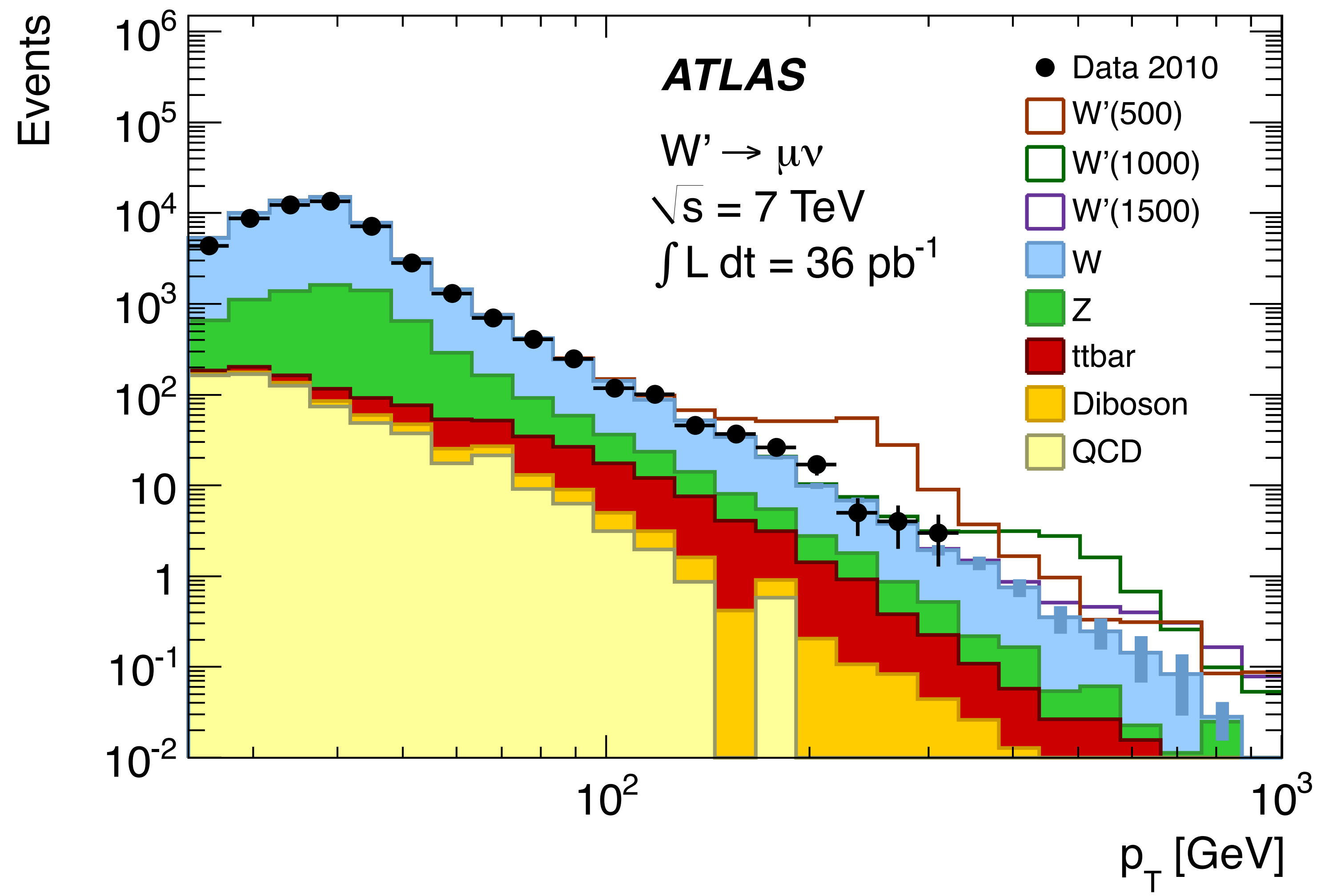


W' Muon Channel

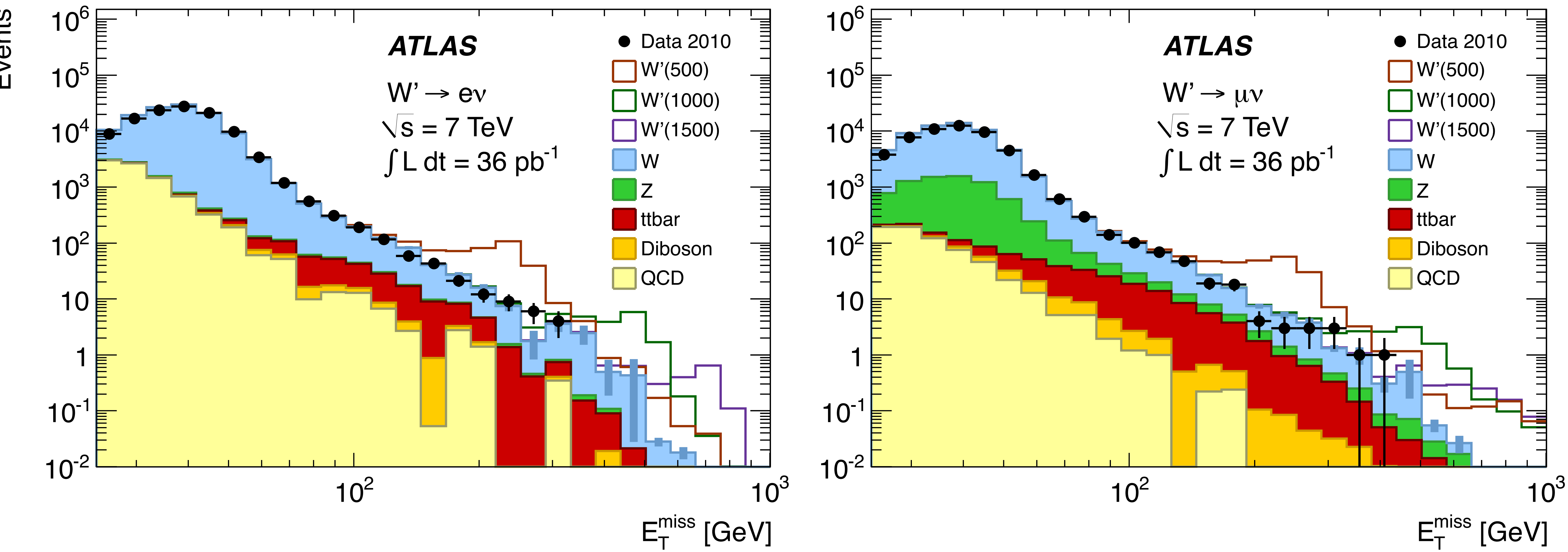
For this first data, make very strong quality cuts on the muons to ensure a well-measured pT

Require 3 muon stations, |η| < 1.05





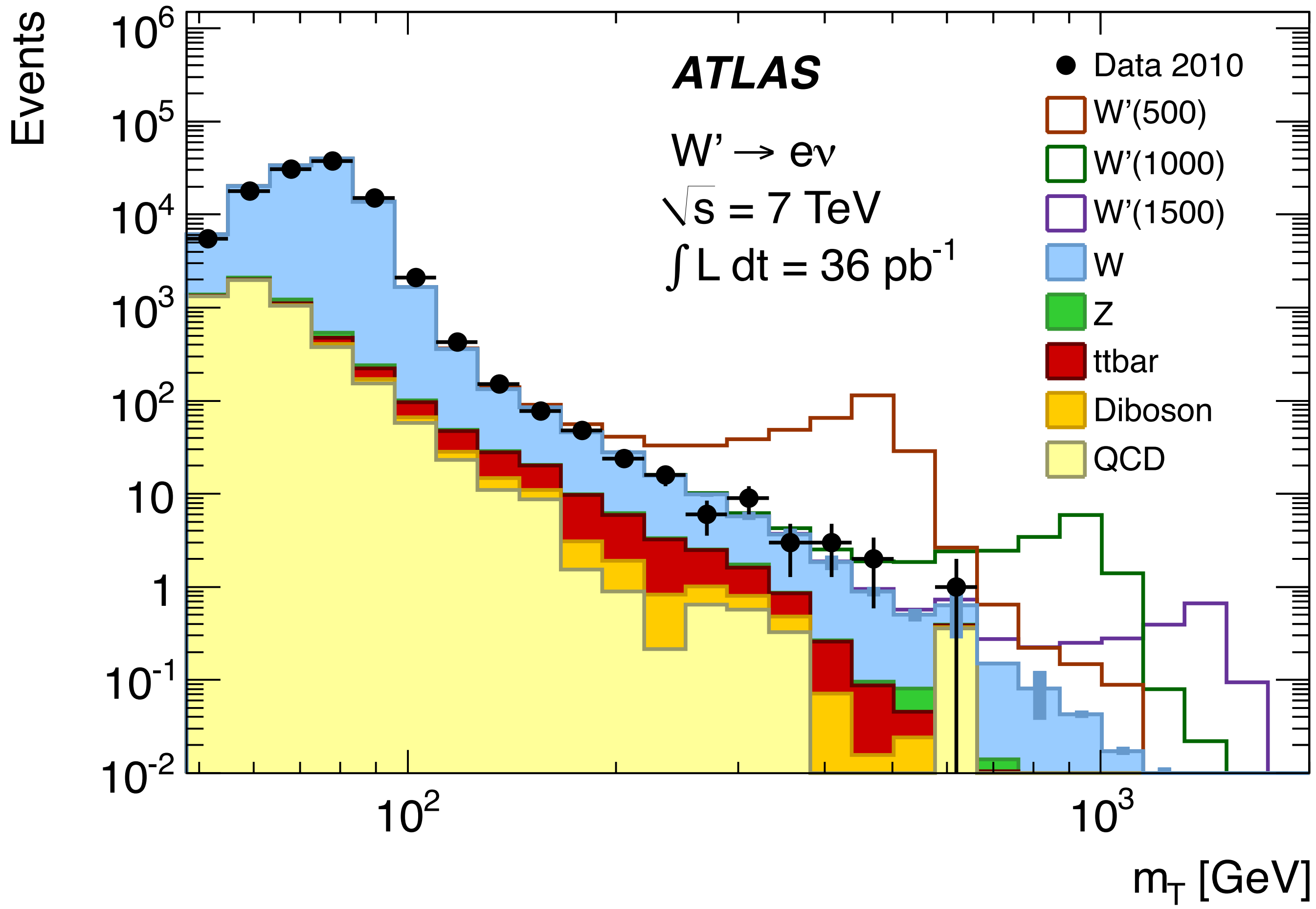
Missing Transverse Energy

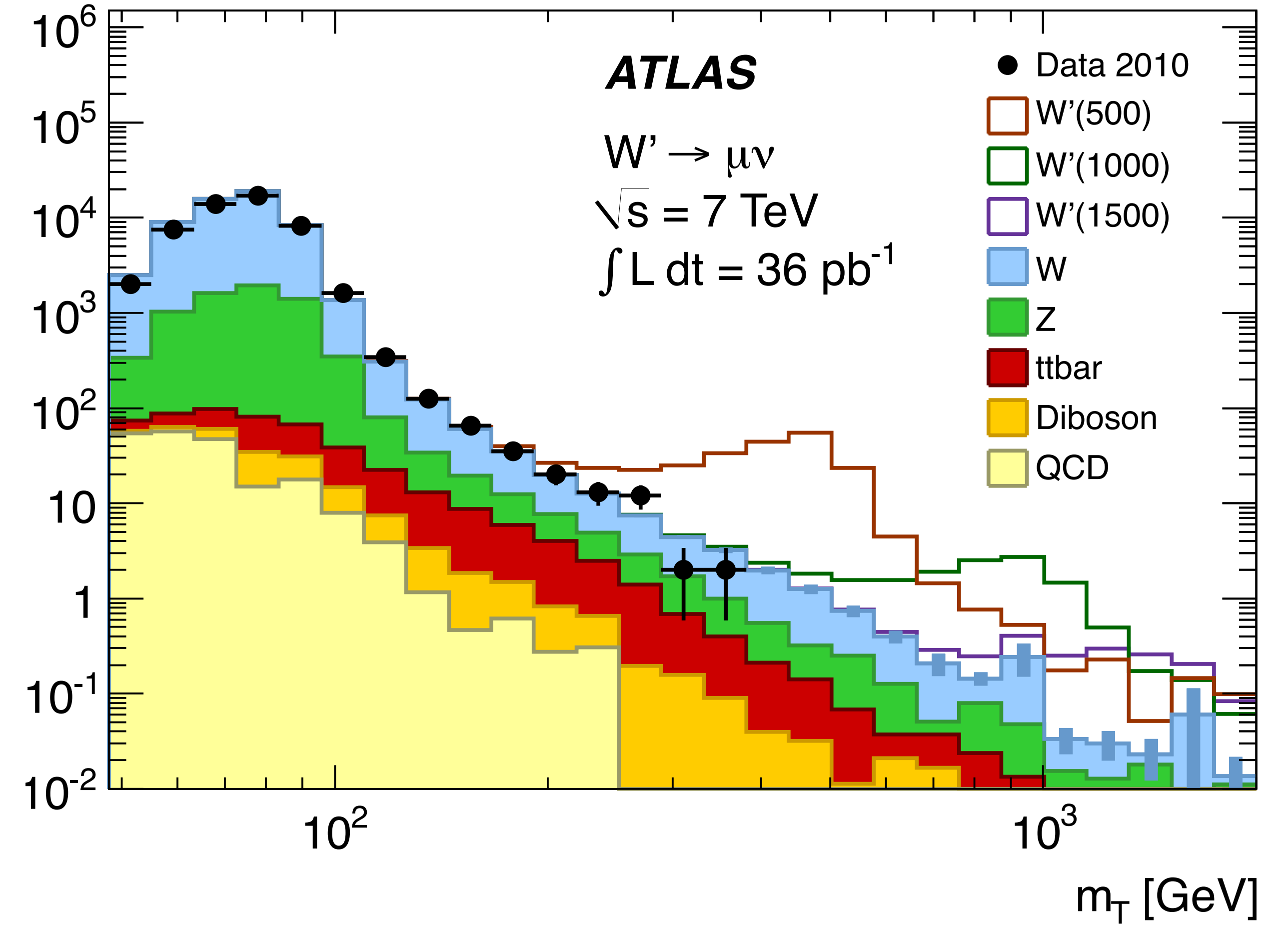


Tails of the MET distribution are also well-behaved

No hints of physics beyond the Standard Model here

Looking for Signal



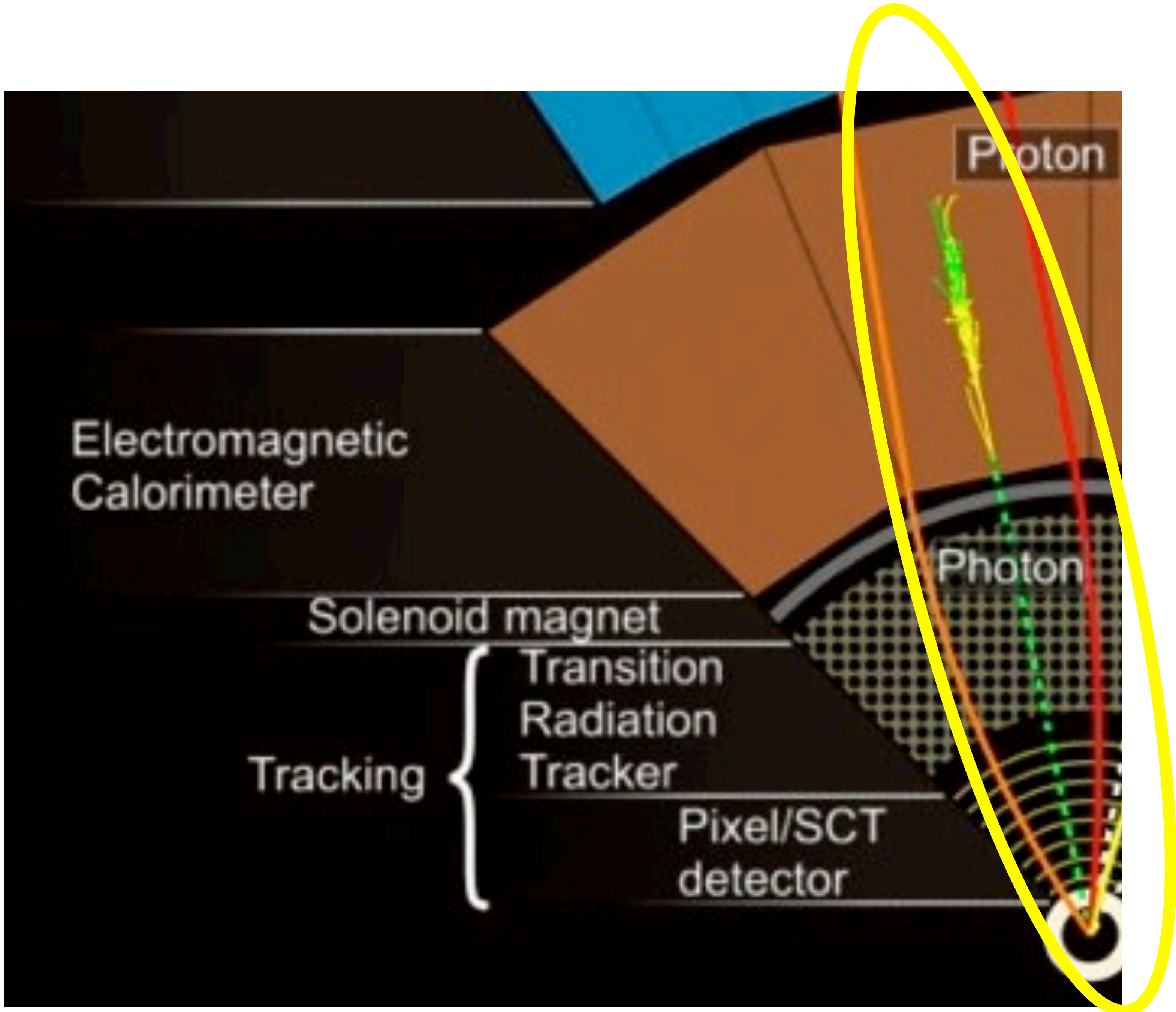


Look in the tails of the Transverse Mass distribution

Observing no signal, set limits combining the two channels: W' > 1.49 TeV at 95% confidence level

Electron channel: 1.36 TeV Muon channel: 1.29 TeV

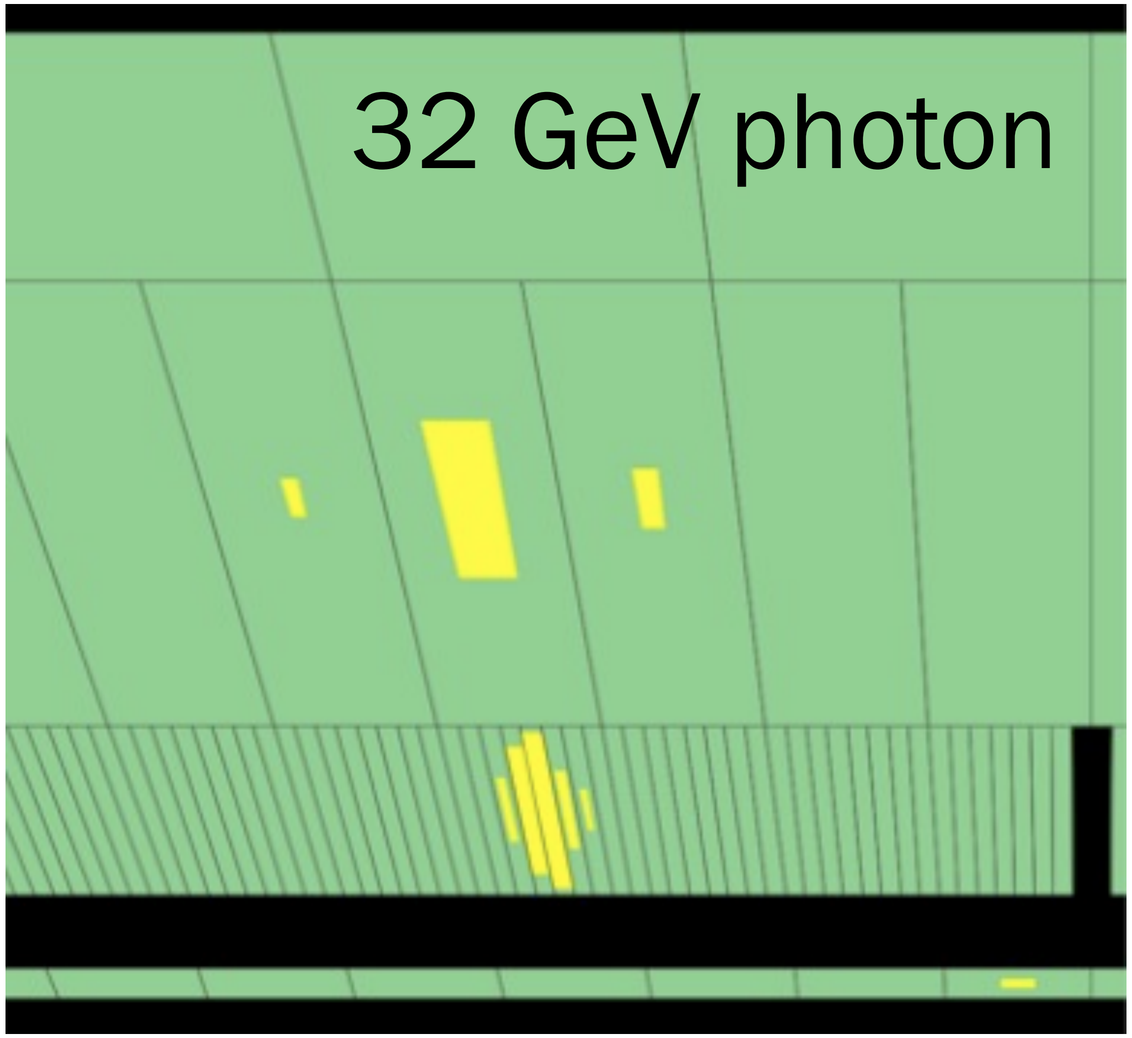
Photons at ATLAS

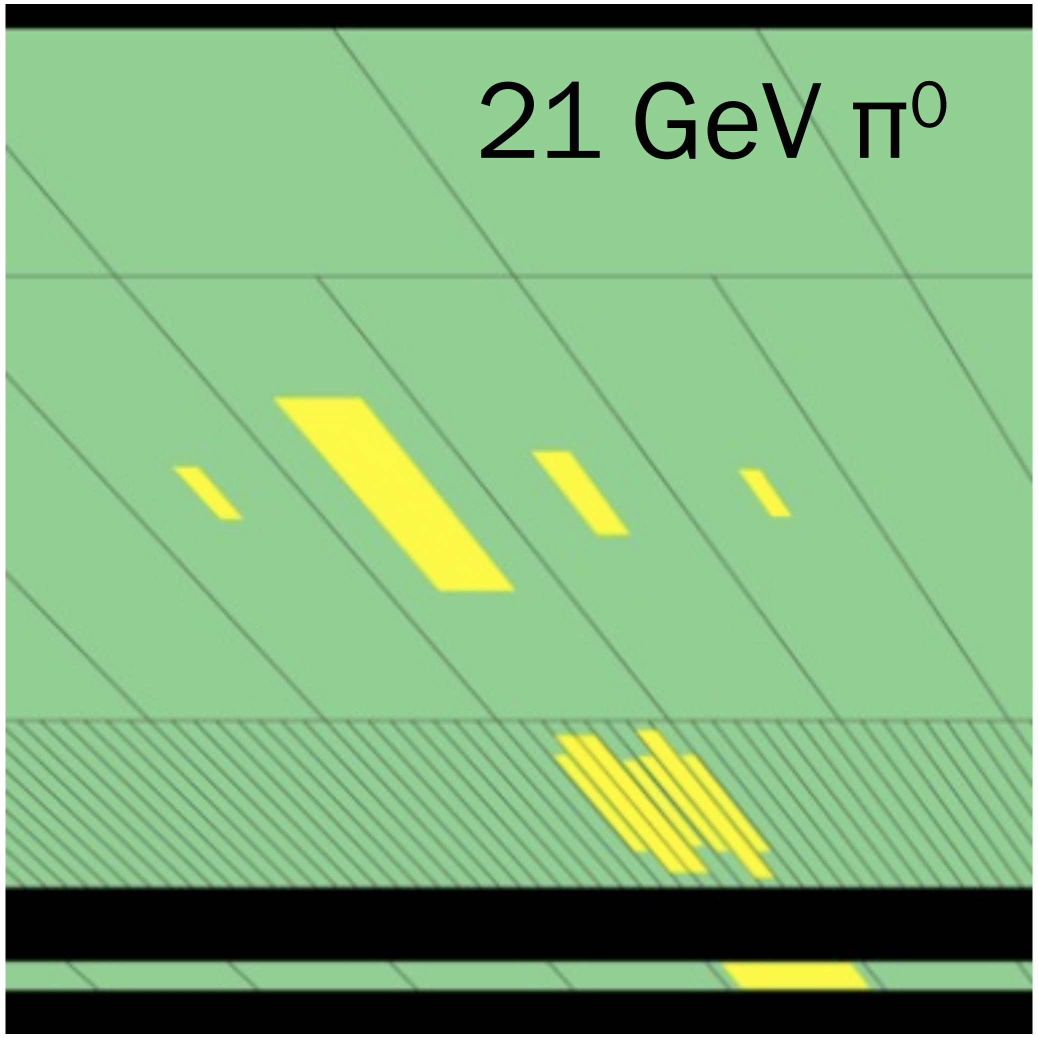


No track + EM calorimeter deposit

Also look for photons which have converted into e+e- pairs using the trackers

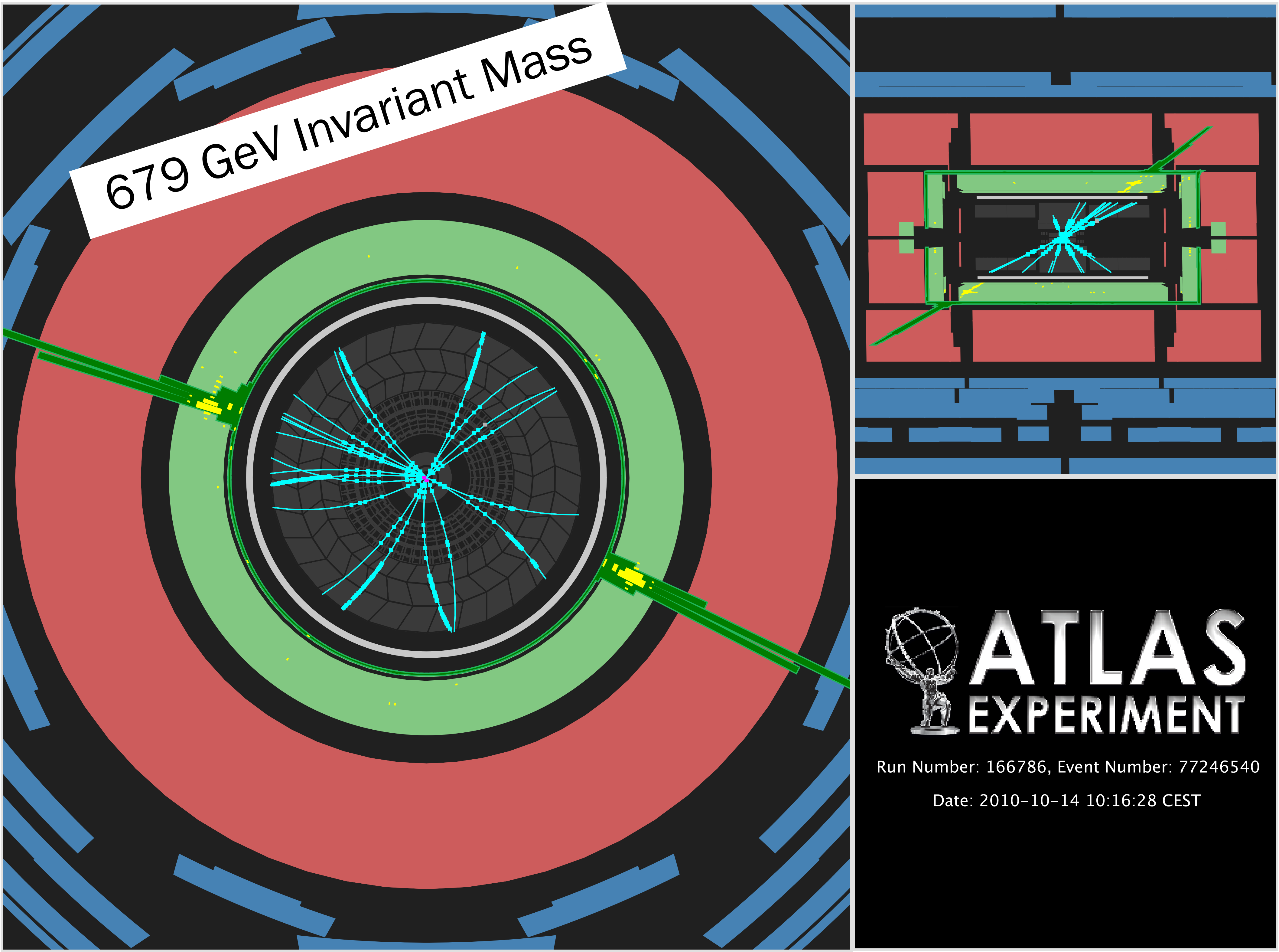
Identifying photons



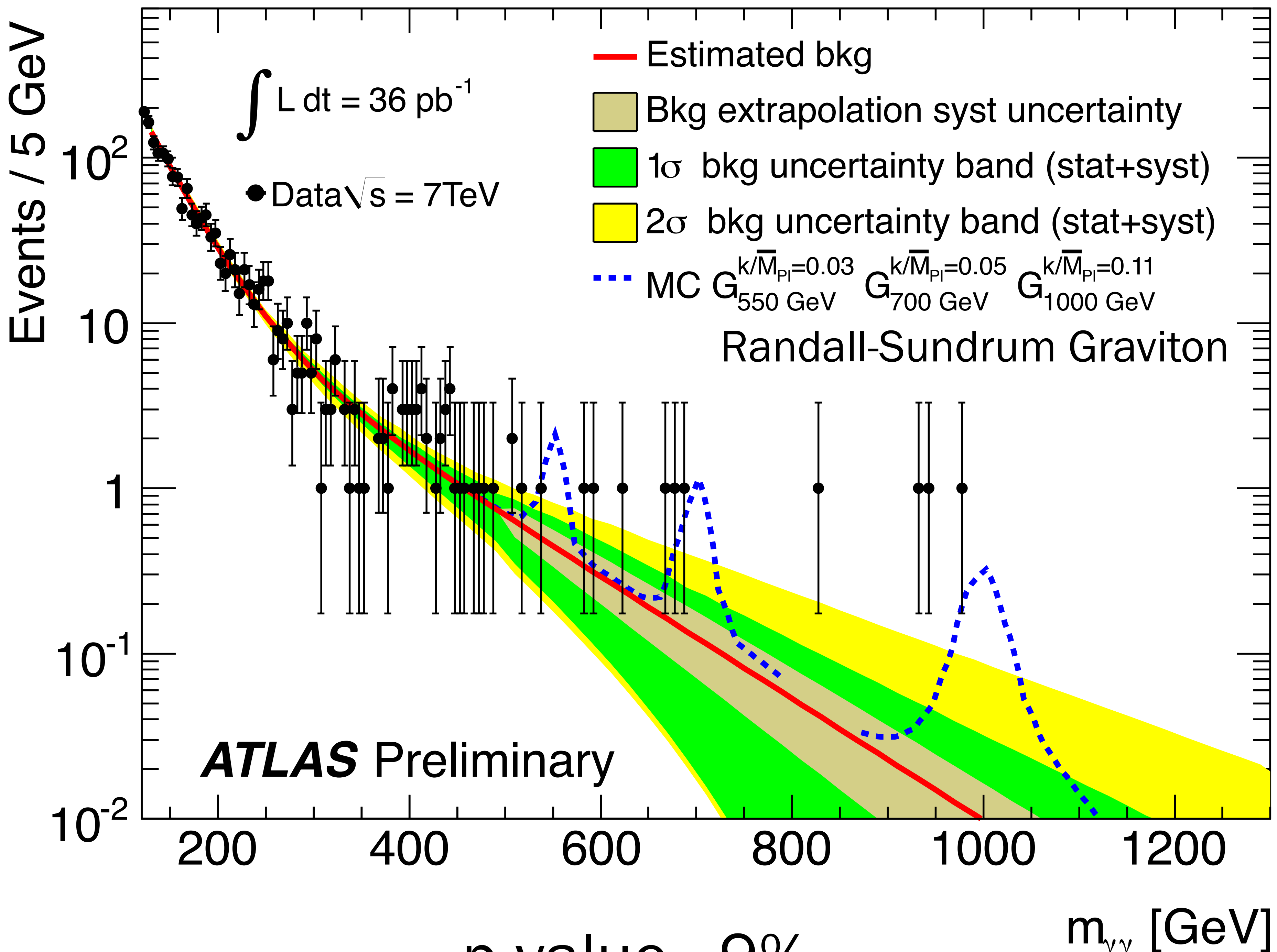


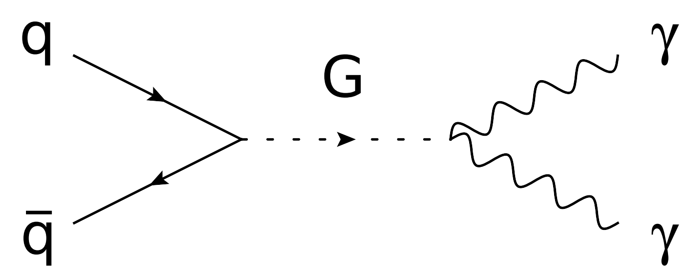
Longitudinal segmentation of the ATLAS EM calorimeter can provide good discrimination between photons and π^0

Diphoton Event



Diphoton Search



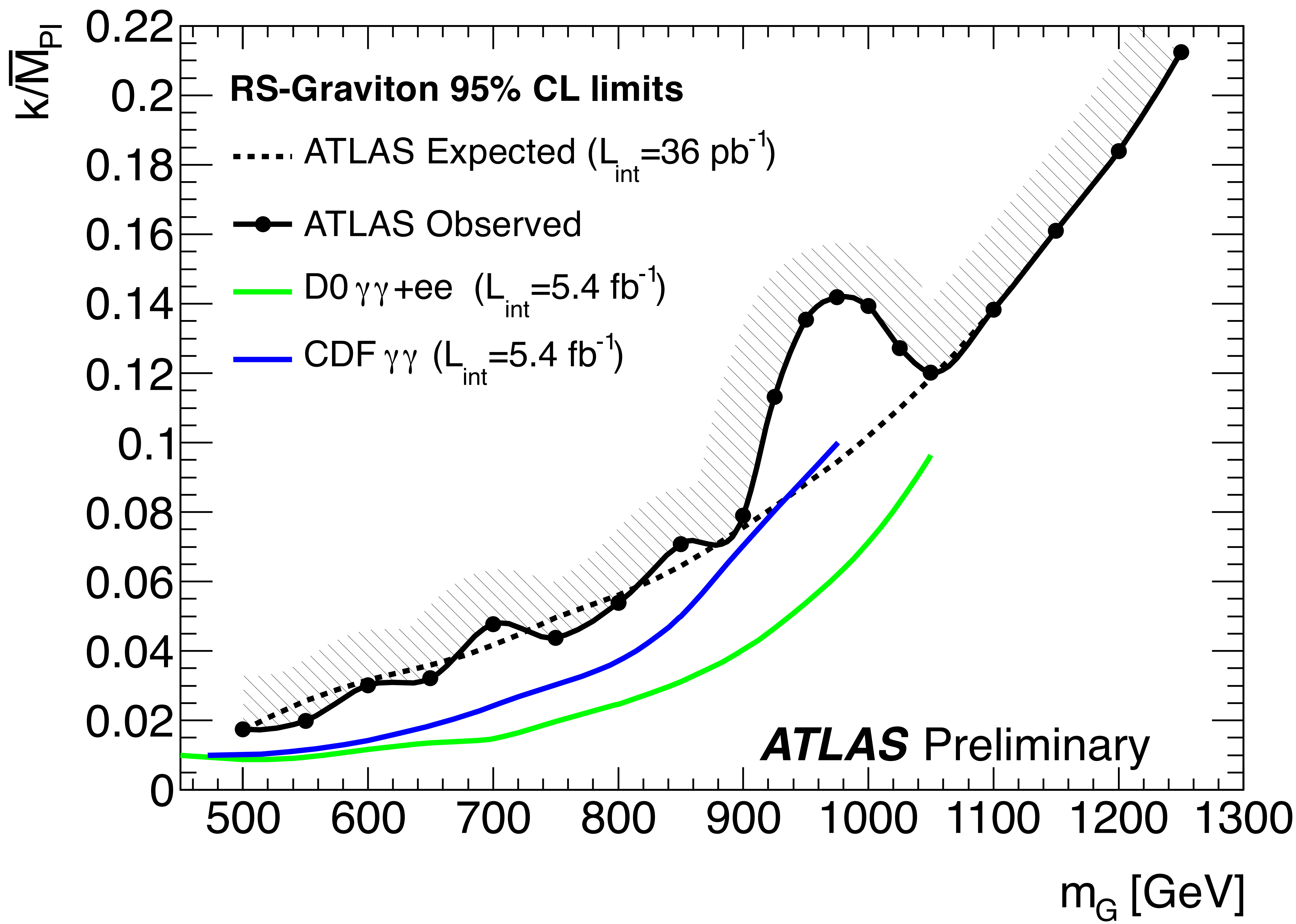


p-value - 9%

Search for resonances in the diphoton spectrum

2 photons
ET > 25 GeV

Carving out space



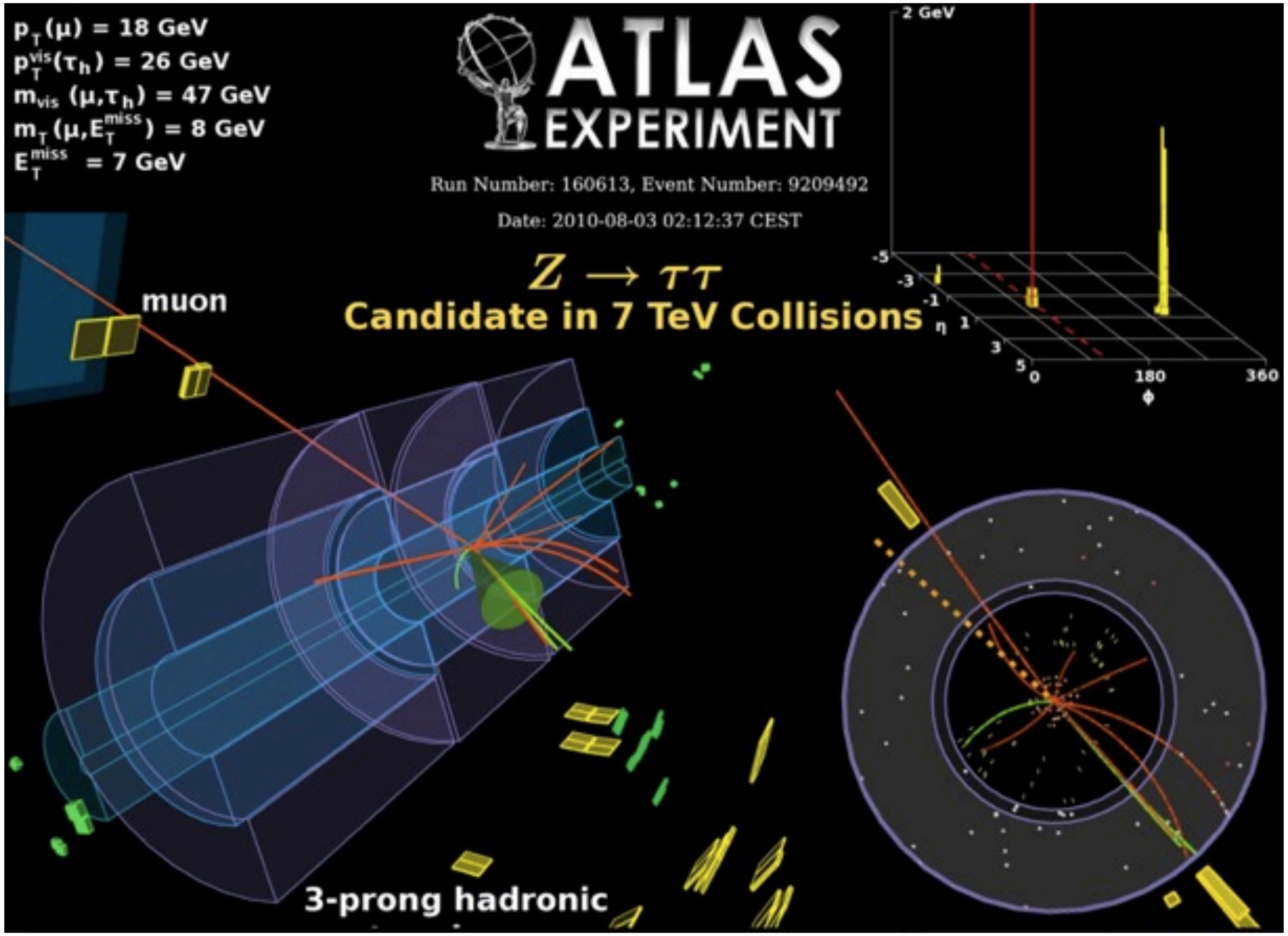
Additional Resonances

Looking towards the future:

First Z to tau tau results are out

Top Resonance searches ongoing, results soon

SM Diboson results out, searches with dibosons in 2011-12



LHC Era for Exotics

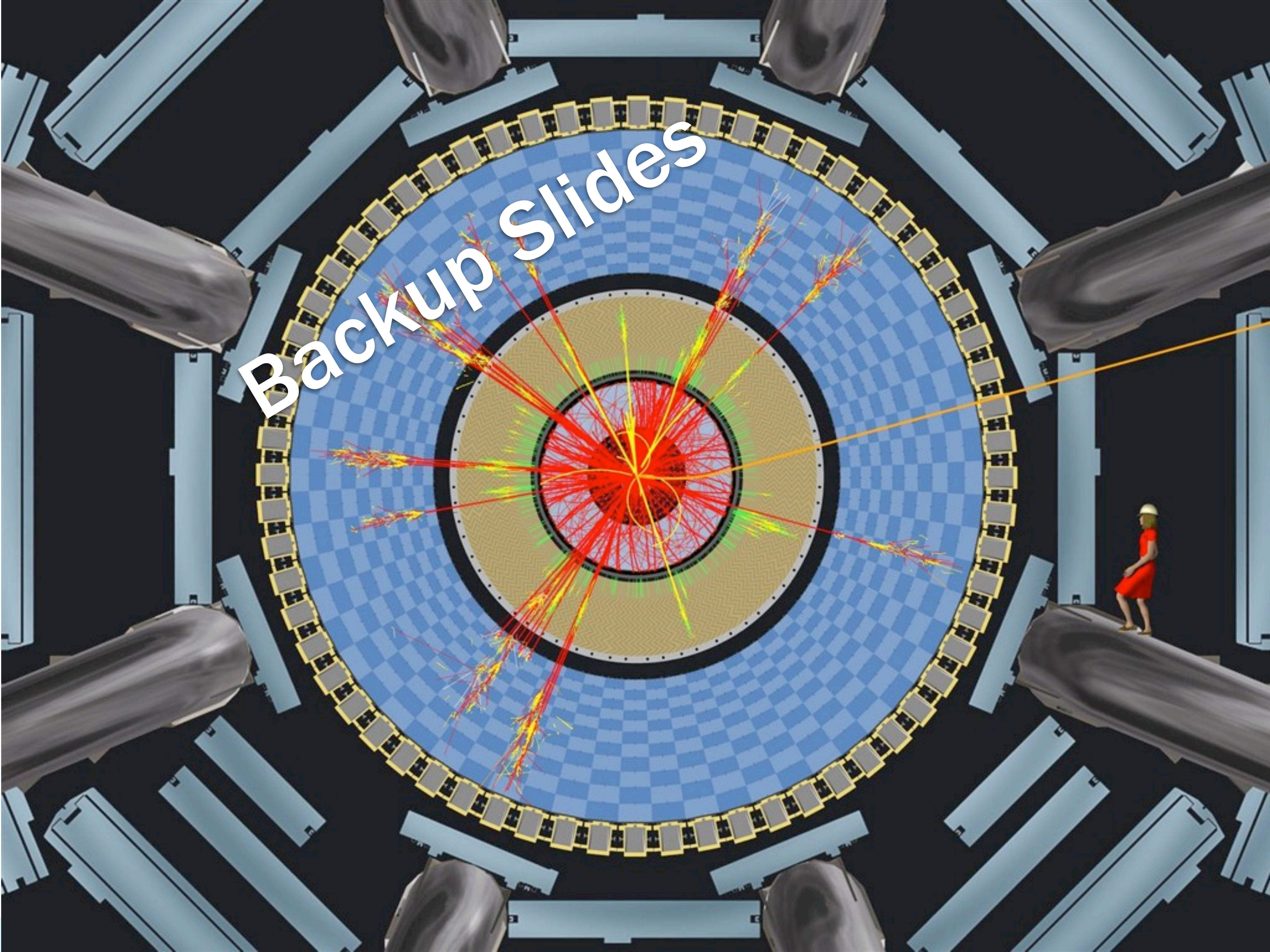
Mass limits (95% C.L.) [TeV]:

		Tevatron	ATLAS
Dijets	Excited quarks (q*)	0.87	**2.64***
	QBHs	-	**3.67***
	Axigluons	1.25	**2.10***
	Contact Int. Λ qqqq	2.9	**9.5***
Lepton +MET	W' SSM (e+μ)	1.100	**1.490**
Leptons +MET+ jets	4th gen quark Q_{u4}	0.356	0.270
	1st gen LQ (β=1.0)	0.299	**0.376**
	2nd gen LQ (β=1.0)	0.316	**0.422**

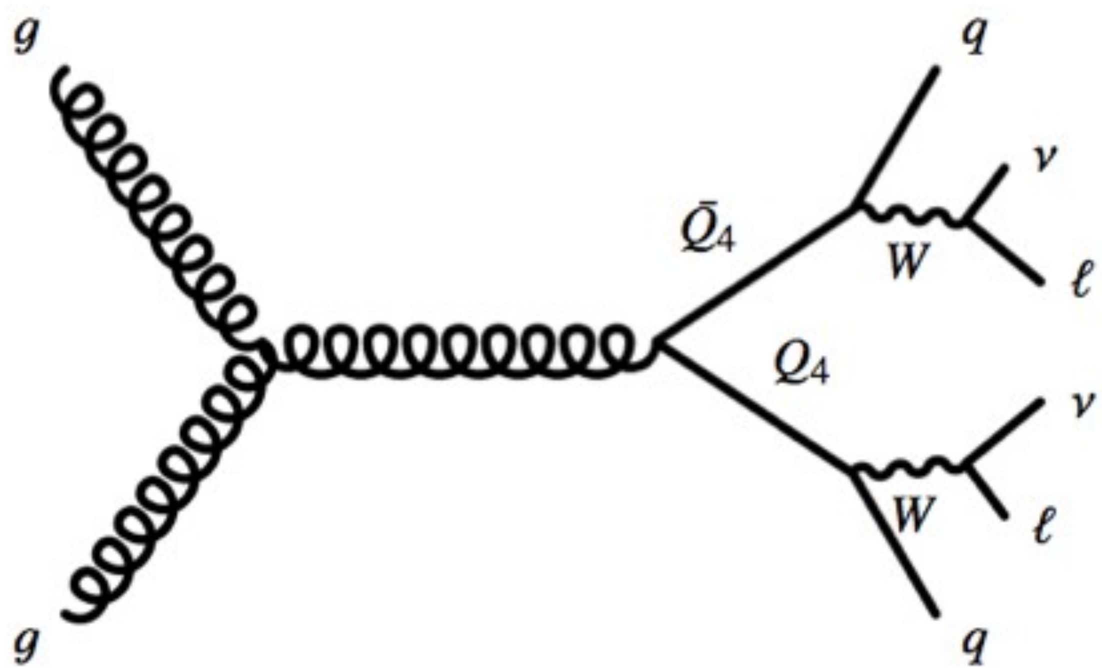
		Tevatron	ATLAS
Dileptons	Z' SSM (e+μ)	1.071	1.048
	E6 Z'_χ (e+μ)	0.930	0.900
	E6 Z'_ψ (e+μ)	0.917	0.738
	E6 Z'_N (e+μ)	0.900	0.763
	E6 Z'_η (e+μ)	0.938	0.771
	E6 Z'_I (e+μ)	0.817	**0.842**
	E6 Z'_S (e+μ)	0.858	**0.871**
γγ	RS Graviton	1.050	0.920
γγ+MET	UED (1/R)	0.477	**0.728***

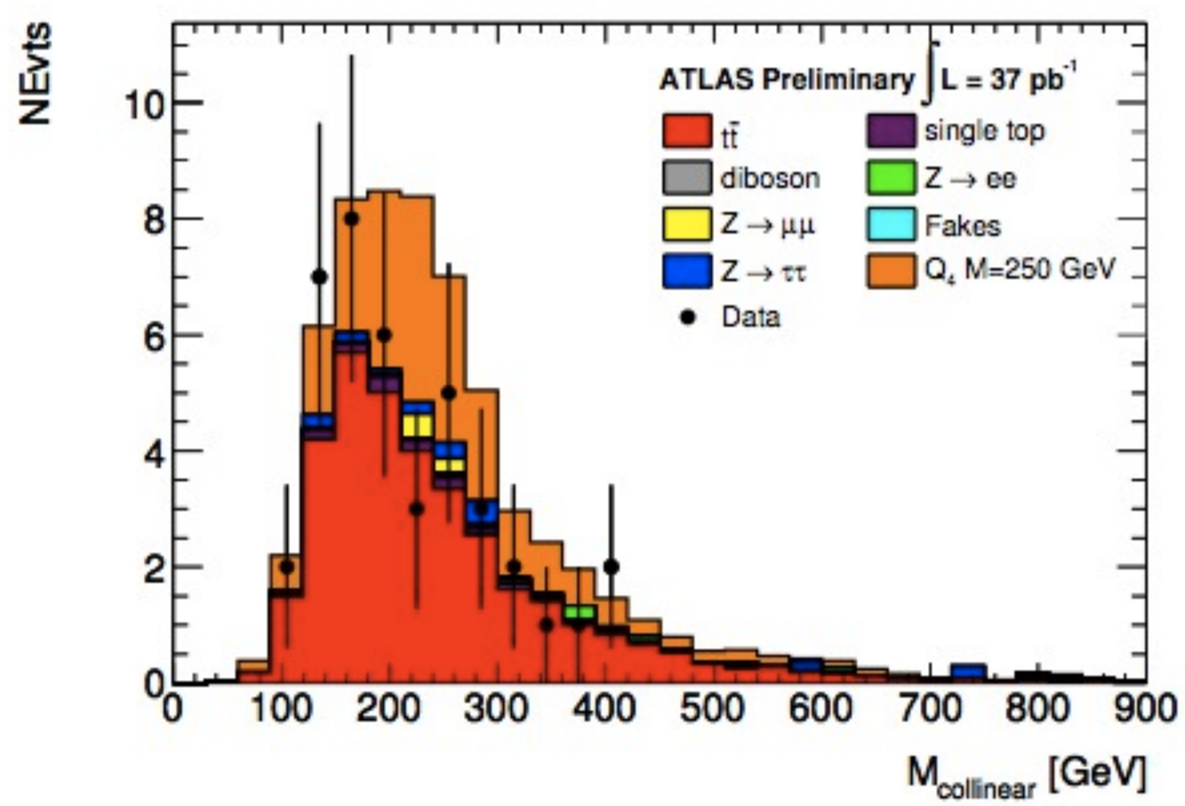
* world's best limit

With a small amount of data, get close and in some cases surpass Tevatron limits


Backup Slides

Fourth Generation Search





- Look for dilepton channel signature
- Construct collinear mass
- No excess observed, set a lower limit of m > 270 GeV

Z' MC & cross-sections

Monte Carlo:

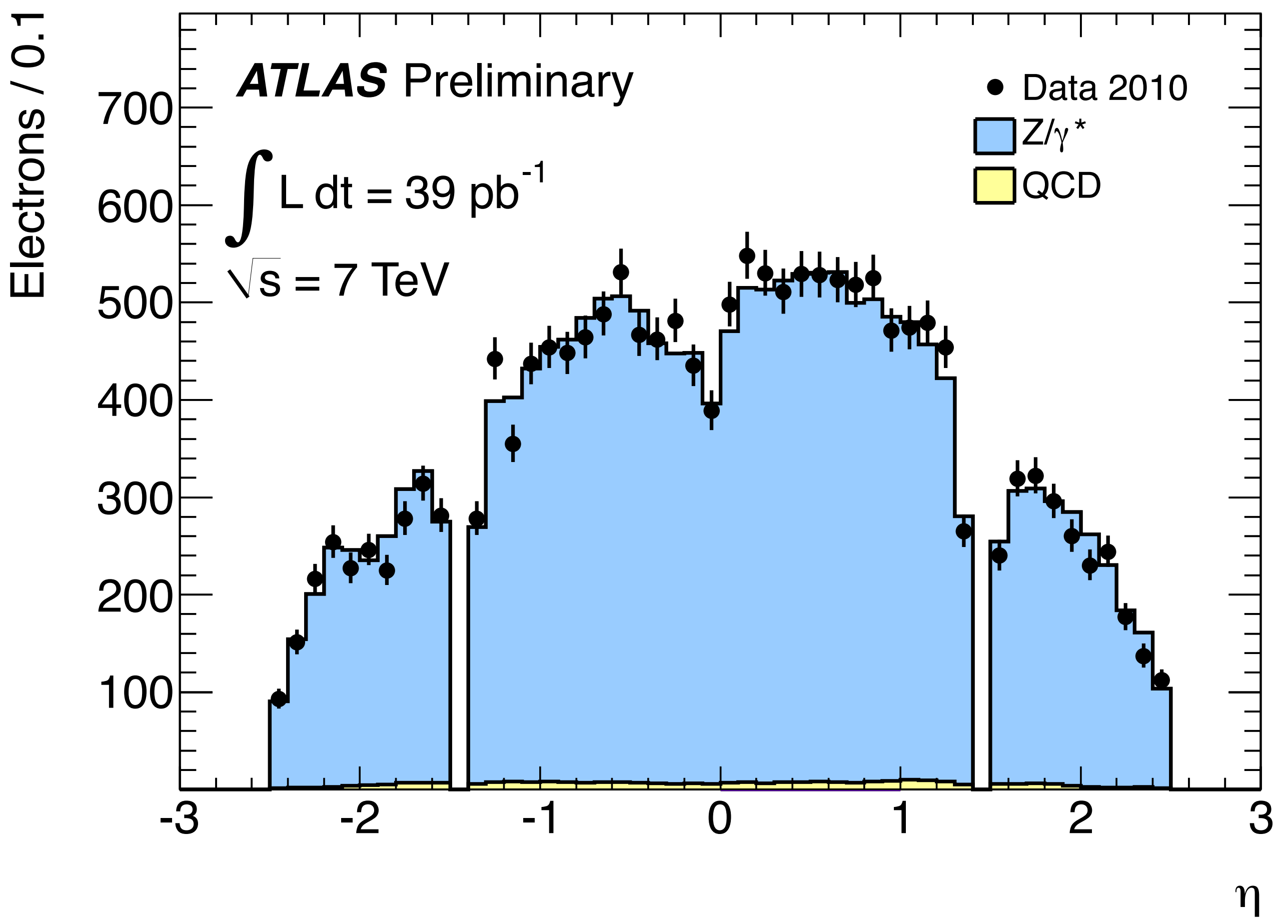
- Release 16
- SSM Z', $Z/\gamma^* \rightarrow ll$, PYTHIA, MRST2007 LO*
- W+jets: Alpgen
- ttbar: MC@NLO, CTEQ6.6

(W+jets and ttbar: Jimmy 4.31 + Herwig 6.510)

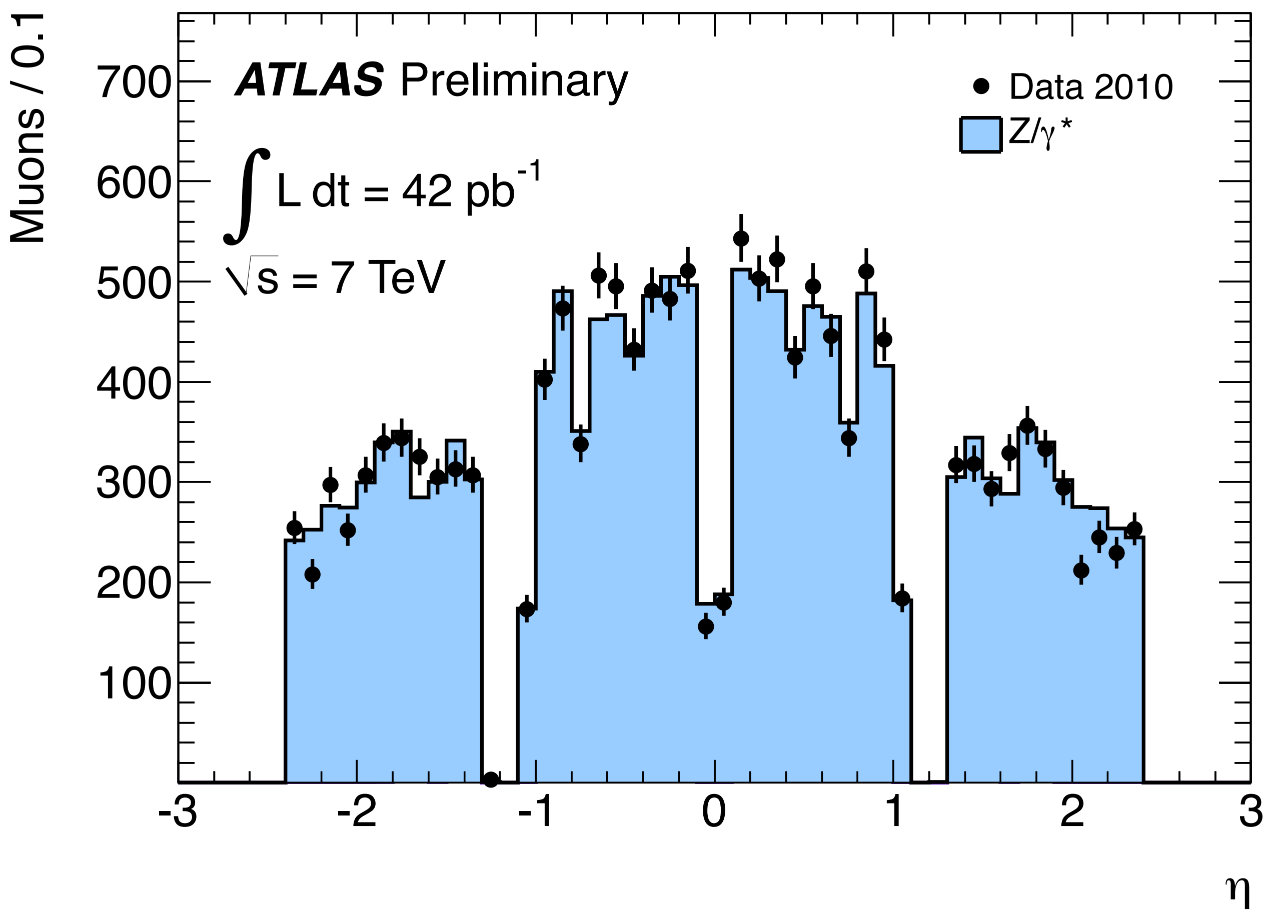
Cross sections:

- SSM $Z' \rightarrow ll$ and $Z/\gamma^* \rightarrow ll$ @ NNLO using PHOZPR + MSTW2008 PDF
  - For Z/γ^* background, higher order EW k-factor using HORACE
- W+jets: NNLO
- Diboson: NLO
- ttbar: near-NNLO (L.M.U., PRD80, 2009)

Z': Eta distributions

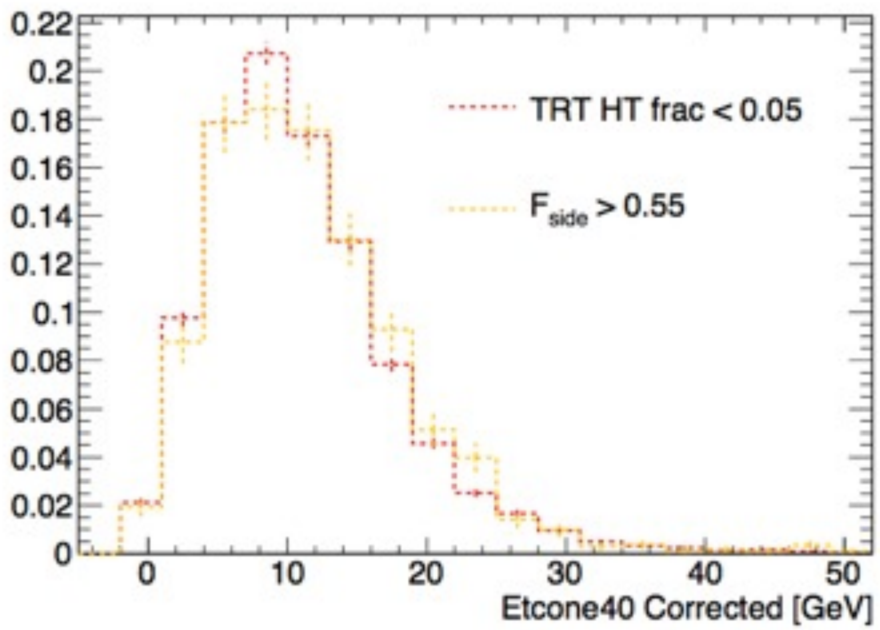


Electron Channel



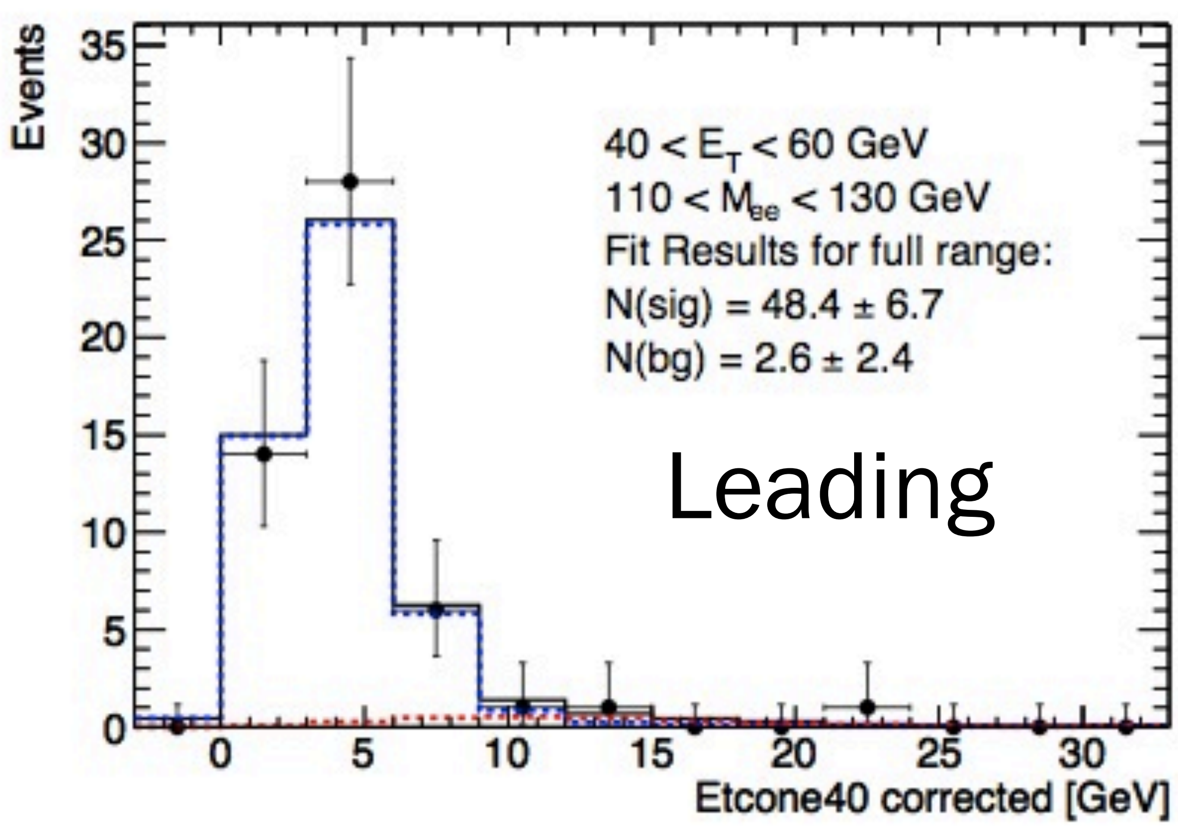
Muon Channel

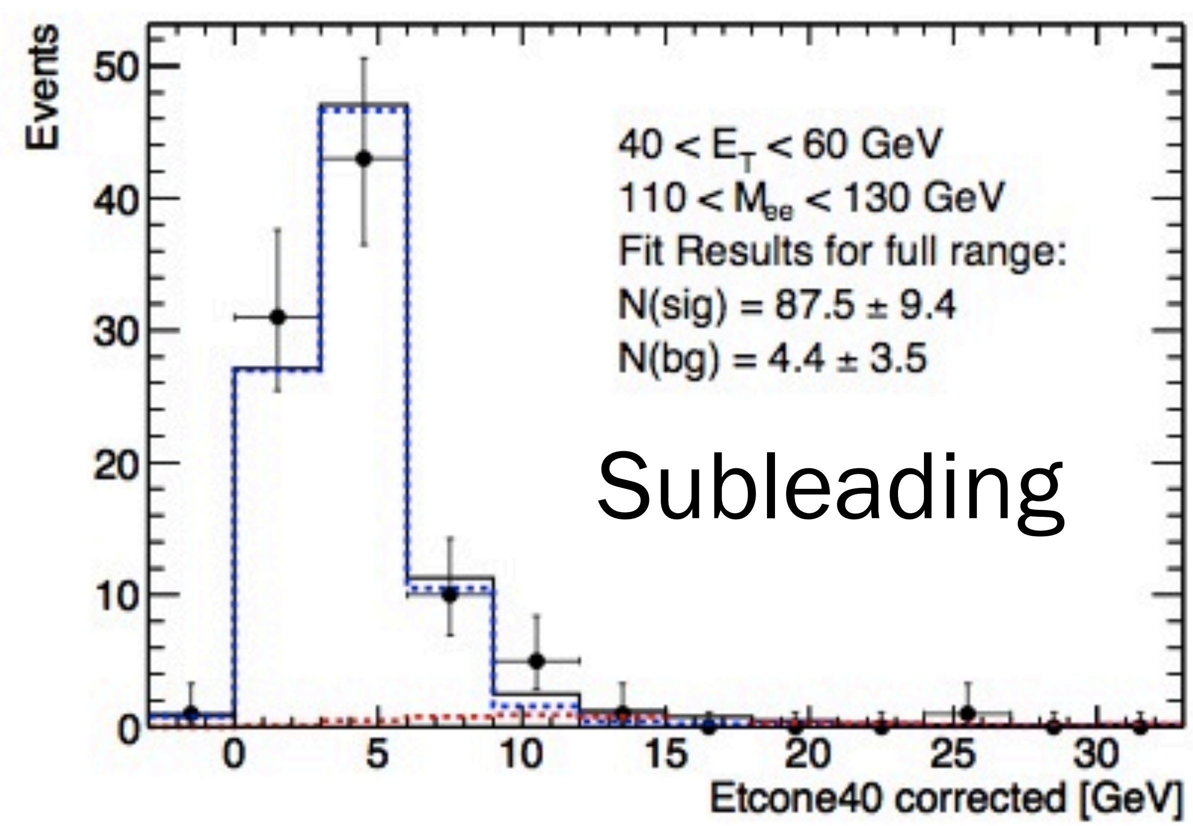
Isolation Fit



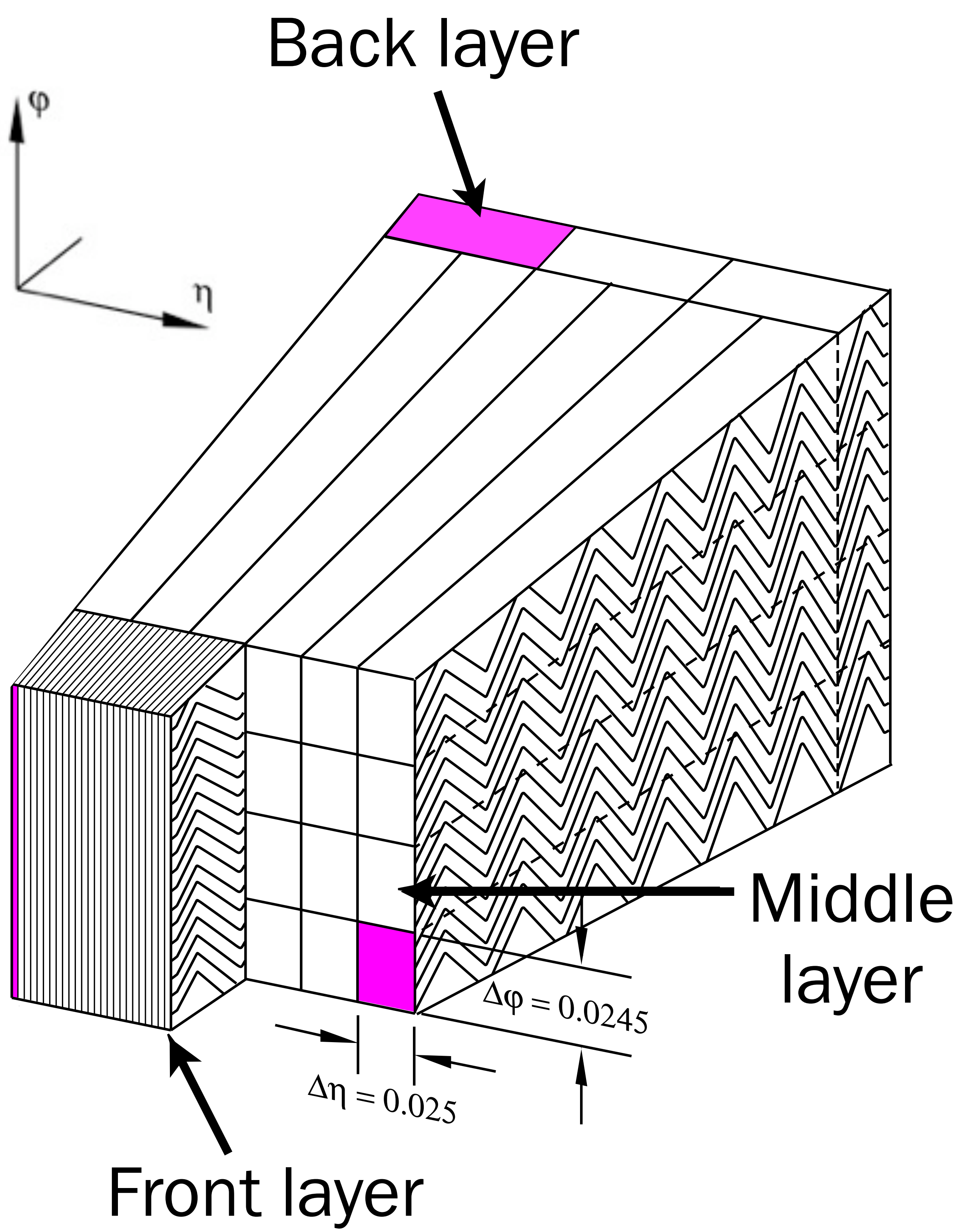
Reverse ID cuts to obtain background template

Fit Isolation in bins of invariant mass





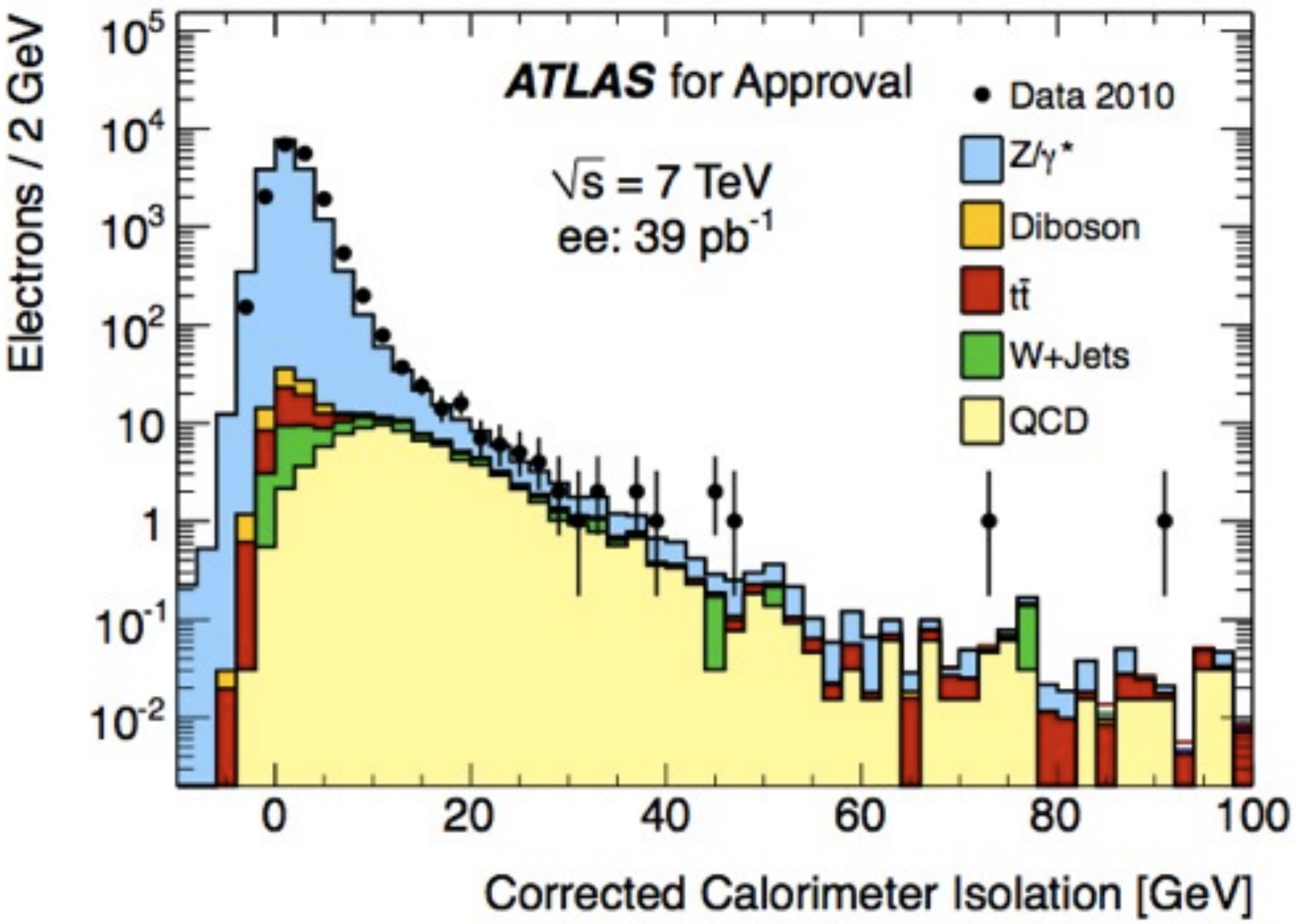
Defining Fside



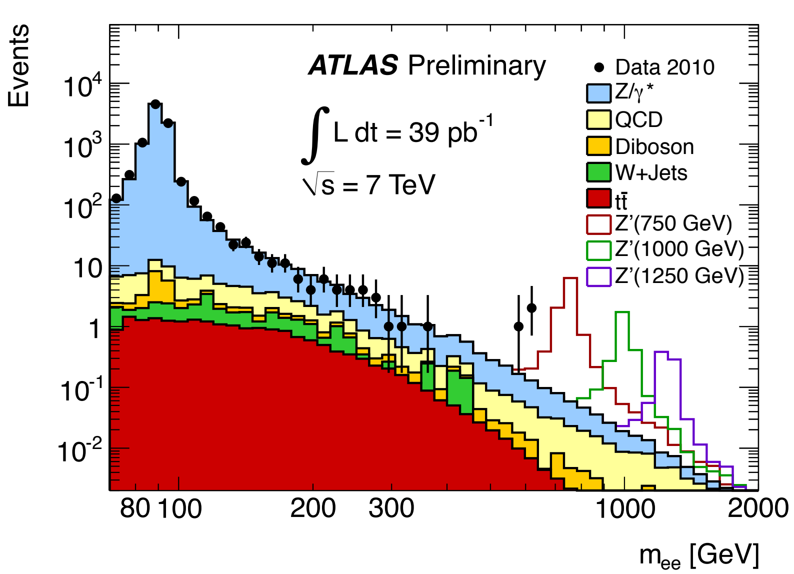
Fside = the fraction of energy outside three central strips but within seven strips

$$F_{\mathrm{side}} = \frac{\sum_{i=3}^{7} E^{i}_{\mathrm{cell}}}{E^{\mathrm{EM\,cluster}}}$$

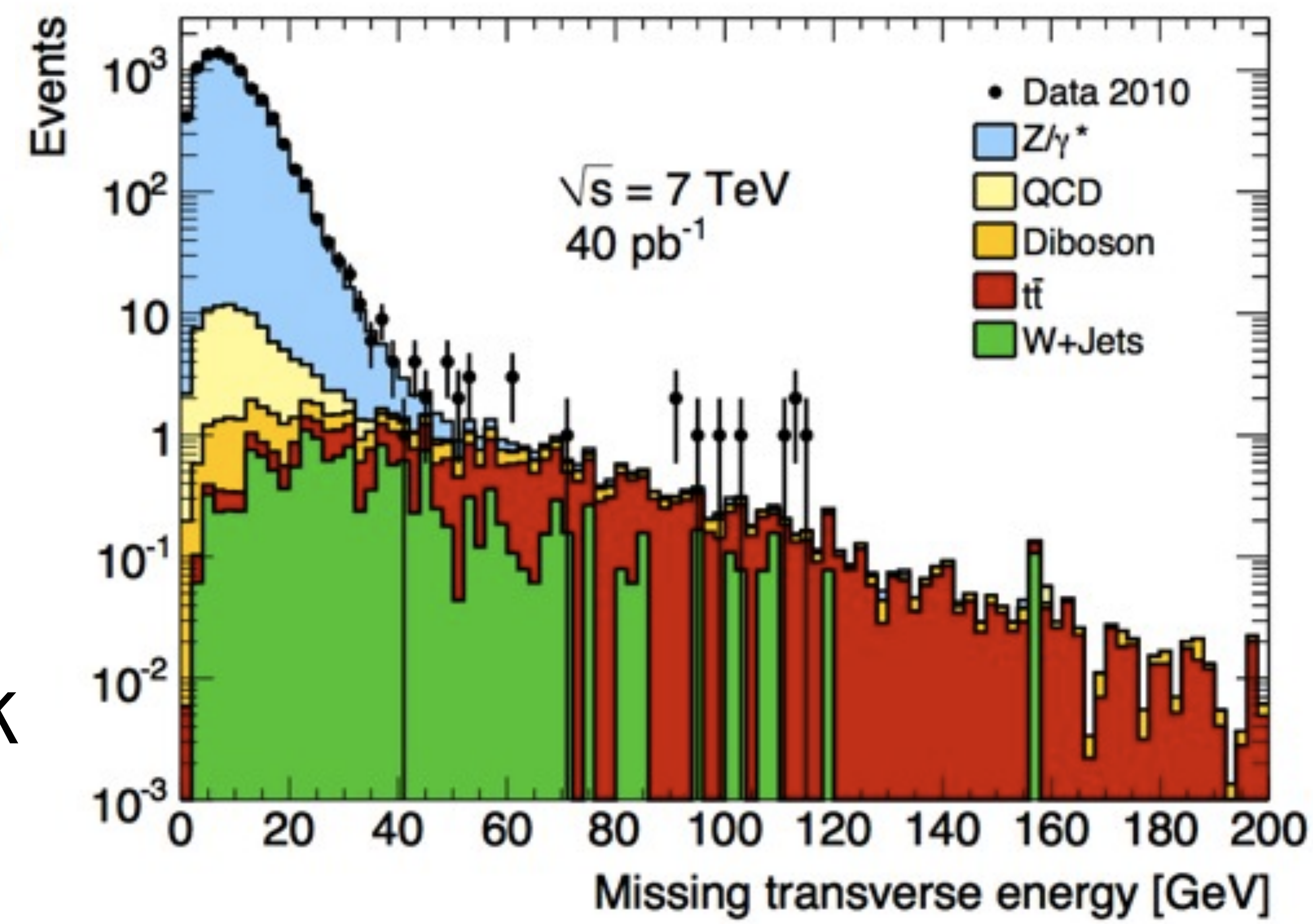
“Inverted ID”



2 electrons pass loose, fail medium ID cuts



Fit under the Z peak



Matrix Method

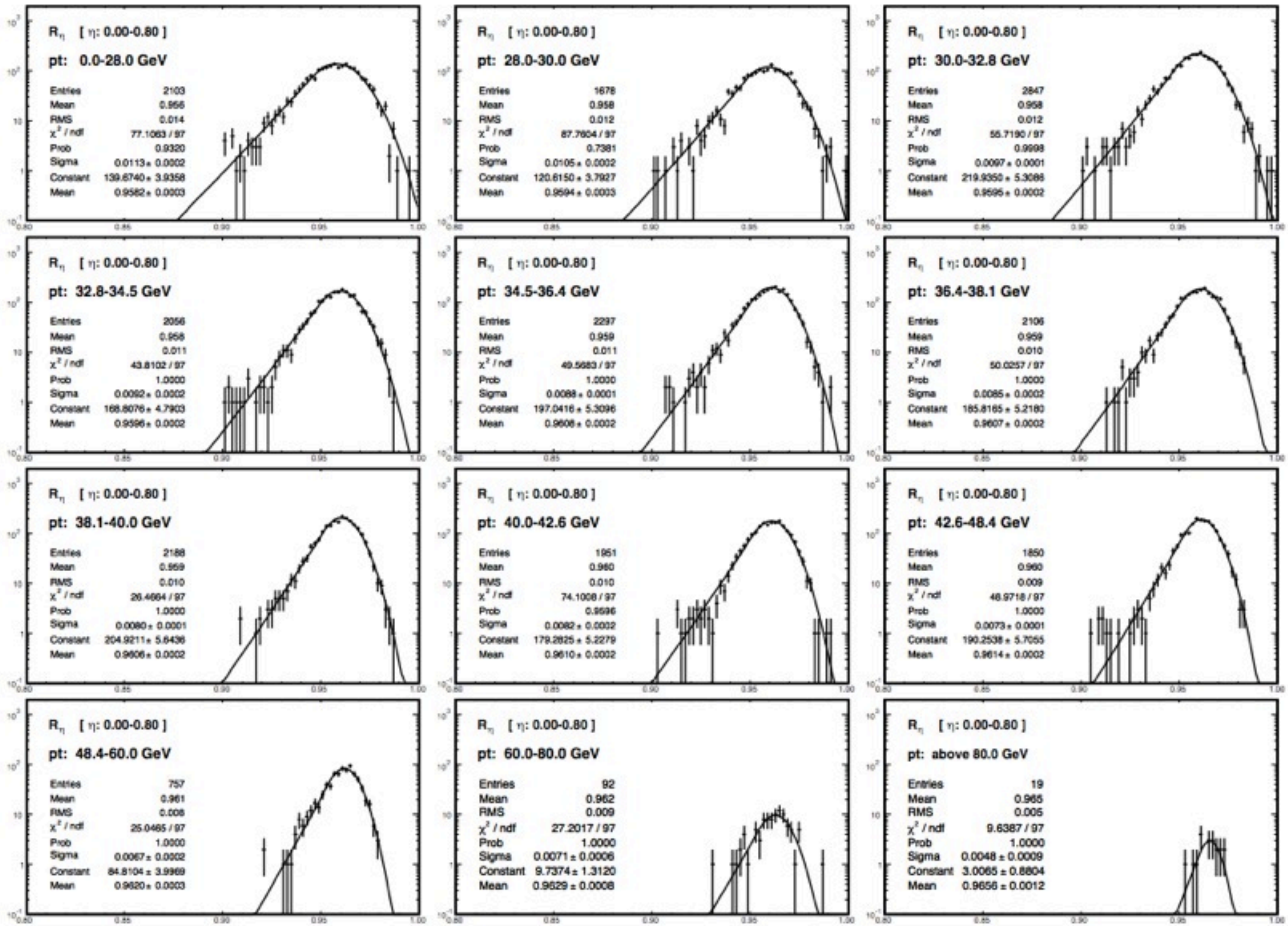
Estimate number of events with one or two “fake” electrons

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LL} \end{pmatrix} = \begin{pmatrix} rr & rf & ff \\ 2r(1-r) & f+r-2rf & 2f(1-f) \\ (1-r)(1-r) & (1-f)(1-r) & (1-f)(1-f) \end{pmatrix} \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FF} \end{pmatrix}$$

	Loose	Tight
ISEM requirement	*robust loose*	*robust medium*+ B-layer

- input:
  - efficiency r (Tight/Loose), fake rate f (from antitag cuts and same sign)
  - N_{TT}, N_{TL}, N_{LL}
- estimate for QCD+ W+jets+ttbar background: $N_{RF} + N_{FF}$

ID as a function of pT



Placing Limits

Use the Bayesian Analysis Toolkit

- For each of k bins, there are j signal and background templates (T)
- Treat systematics as nuisance parameters (θ) with Gaussian priors (G)

$$\mathcal{L}(N_j, \theta_i | data) = \prod_{k=1}^{N_{bin}} \frac{N_k^{N_k^{\text{obs}}} e^{-N_k}}{N_k^{\text{obs}}!} \prod_{i=1}^{N_{sys}} G(\theta_i, 0, 1) \quad , where \quad N_k = \sum_j N_j T_{jk}(1 + \theta_i \epsilon_{jik})$$

$$N^{bg} = N^Z + N^{WW} + N^{QCD} + N^{W+jets}$$

Z' Electron Channel

$m_{e^+e^-}$ [GeV]	70-110	110-130	130-150	150-170	170-200
Z/γ^*	8498.5 ± 7.9	104.9 ± 3.3	36.8 ± 1.3	19.4 ± 0.7	14.7 ± 0.6
$t\bar{t}$	8.2 ± 0.8	2.8 ± 0.3	2.1 ± 0.2	1.7 ± 0.2	1.7 ± 0.2
Diboson	12.1 ± 0.9	1.0 ± 0.2	0.7 ± 0.2	0.5 ± 0.2	0.5 ± 0.1
$W+$jets	6.0 ± 1.8	3.7 ± 1.2	1.2 ± 0.5	1.3 ± 0.5	1.2 ± 0.4
QCD	32.1 ± 7.1	8.4 ± 1.8	5.5 ± 0.8	3.2 ± 0.6	2.8 ± 0.8
Total	8557.0 ± 10.8	120.9 ± 4.0	46.4 ± 1.6	26.2 ± 1.1	20.8 ± 1.1
Data	8557	131	49	20	18

$m_{e^+e^-}$ [GeV]	200-240	240-300	300-400	400-800	800-2000
Z/γ^*	9.5 ± 0.4	6.0 ± 0.3	3.2 ± 0.1	1.6 ± 0.1	0.1 ± 0.0
$t\bar{t}$	1.2 ± 0.1	0.9 ± 0.1	0.5 ± 0.0	0.2 ± 0.0	0.0 ± 0.0
Diboson	0.4 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.1 ± 0.1	0.0 ± 0.0
$W+$jets	1.1 ± 0.4	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0
QCD	1.9 ± 0.8	1.3 ± 0.7	0.8 ± 0.4	0.5 ± 0.2	0.1 ± 0.1
Total	14.1 ± 1.0	8.8 ± 0.7	4.8 ± 0.5	2.7 ± 0.3	0.2 ± 0.1
Data	13	9	3	3	0

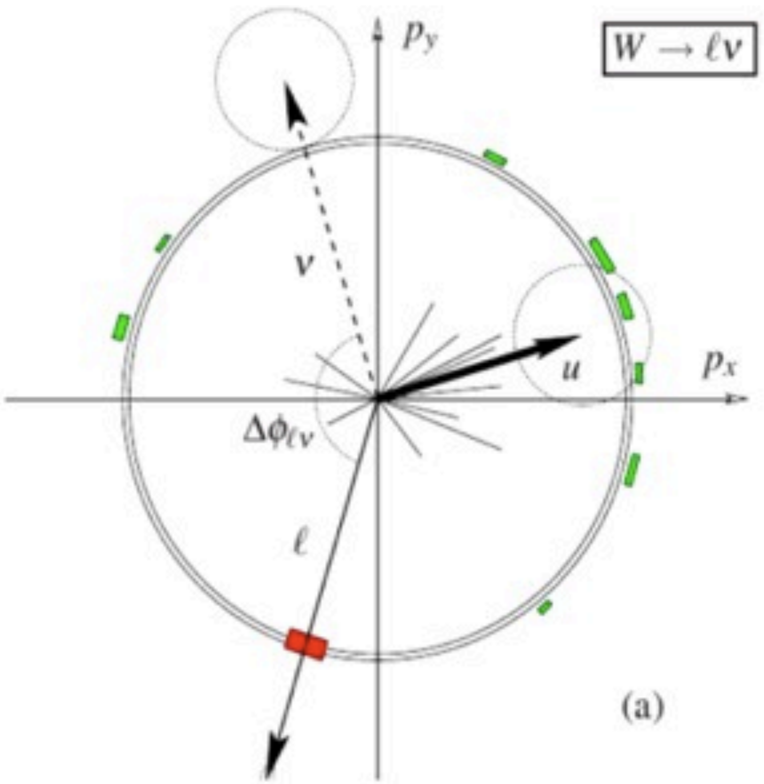
Z' Muon Channel

$m_{\mu^+\mu^-}$ [GeV]	70-110	110-130	130-150	150-170	170-200
Z/γ^*	7546.7 ± 7.1	98.4 ± 3.1	33.4 ± 1.1	17.2 ± 0.6	12.8 ± 0.5
$t\bar{t}$	6.0 ± 0.6	2.4 ± 0.3	1.7 ± 0.2	1.2 ± 0.1	1.2 ± 0.1
Diboson	10.0 ± 0.5	0.8 ± 0.1	0.6 ± 0.0	0.5 ± 0.0	0.4 ± 0.0
$W +$ jets	0.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
QCD	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Total	7563.0 ± 7.2	101.6 ± 3.1	35.7 ± 1.2	18.9 ± 0.7	14.4 ± 0.5
Data	7563	101	41	11	11

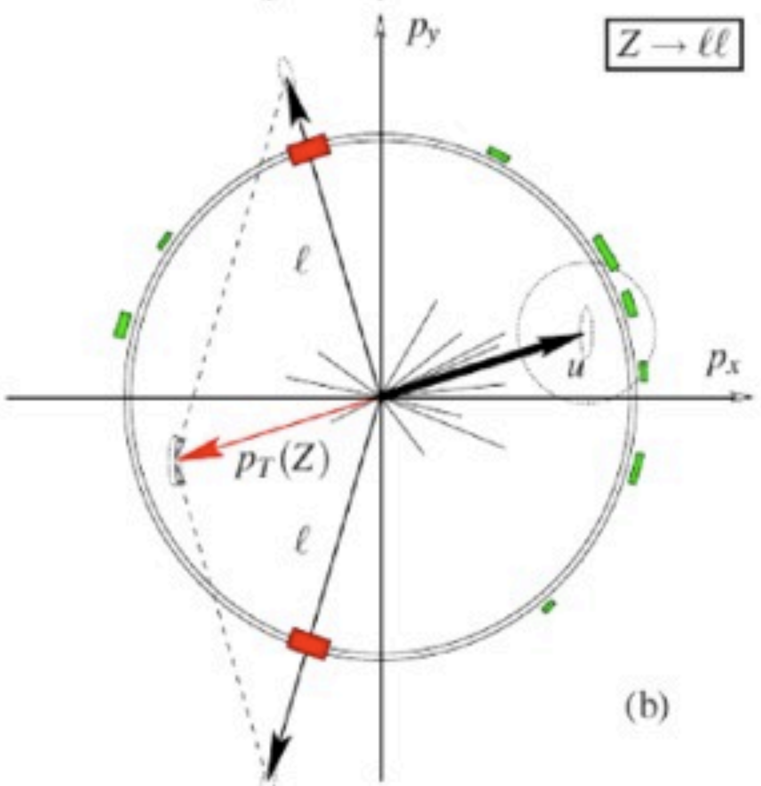
$m_{\mu^+\mu^-}$ [GeV]	200-240	240-300	300-400	400-800	800-2000
Z/γ^*	7.8 ± 0.3	5.1 ± 0.2	2.5 ± 0.1	1.3 ± 0.1	0.1 ± 0.0
$t\bar{t}$	1.0 ± 0.1	0.7 ± 0.1	0.4 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Diboson	0.3 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
$W +$ jets	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
QCD	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Total	9.1 ± 0.4	6.0 ± 0.2	3.0 ± 0.1	1.5 ± 0.1	0.1 ± 0.0
Data	7	6	2	1	0

W and Z selection

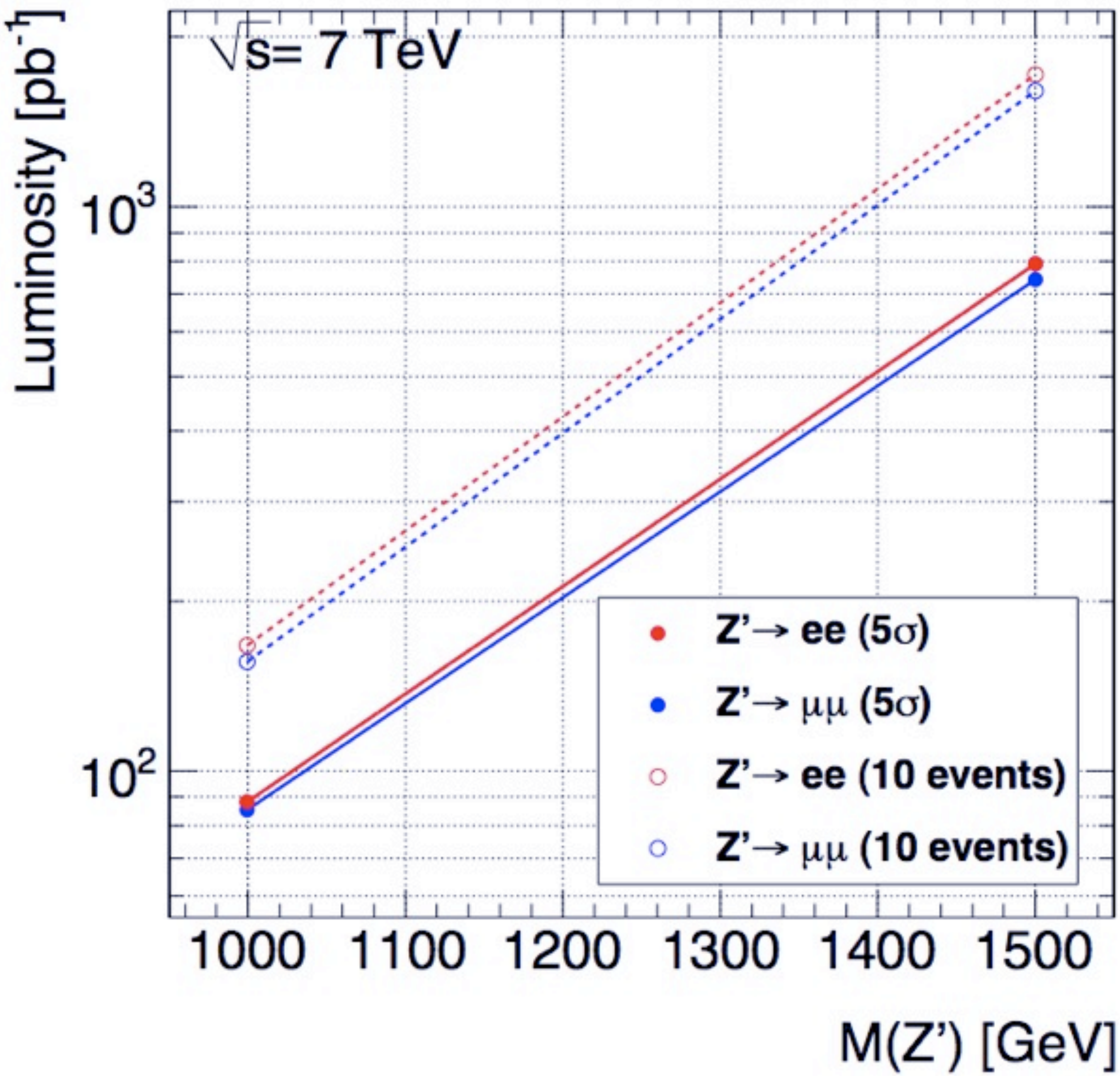
- **W→lν**
  - Pt>20GeV, |η|<2.5 (2.4 for μ)
  - Etmiss>25GeV
  - Track isolation for μ channel
  - Transverse mass>40GeV



- **Z→ll**
  - Pt>20GeV, |η|<2.5 (2.4 for μ)
  - Opposite charge
  - Track isolation for μ channel
  - 66 <M_{ll}< 106GeV

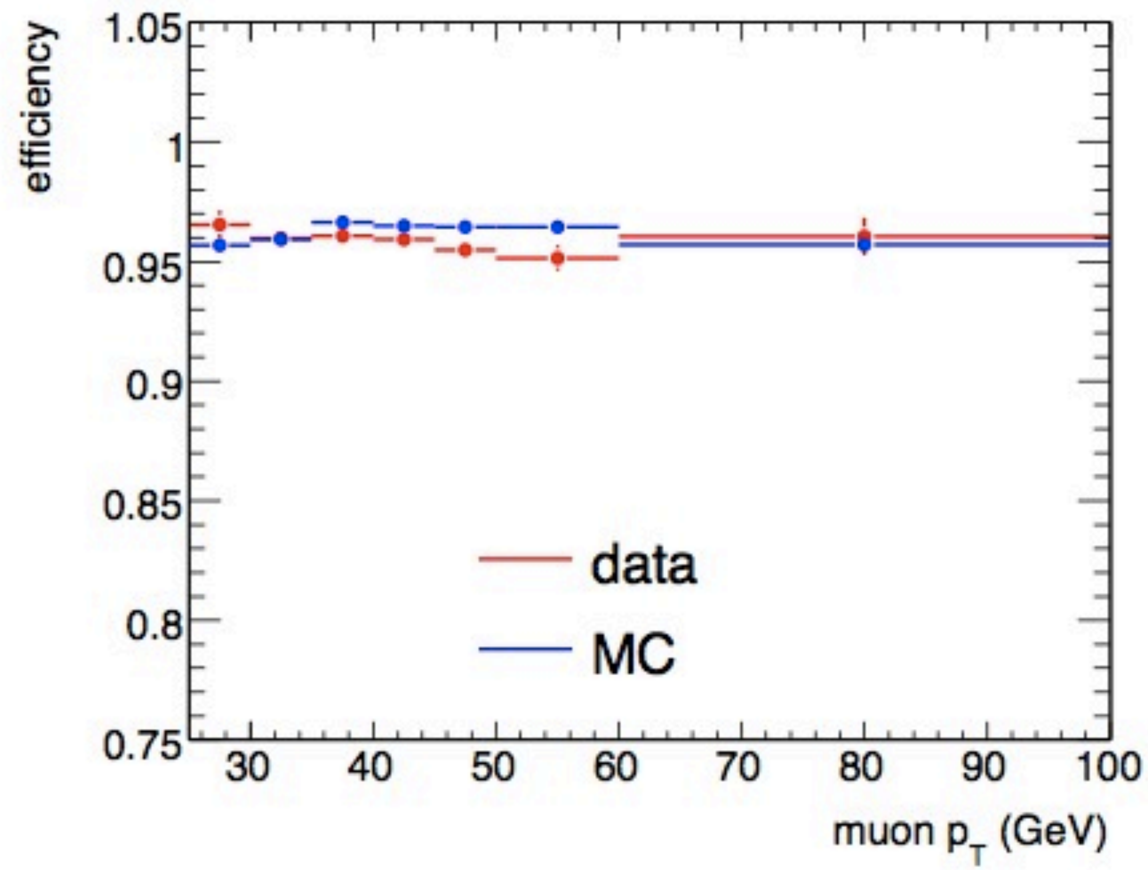


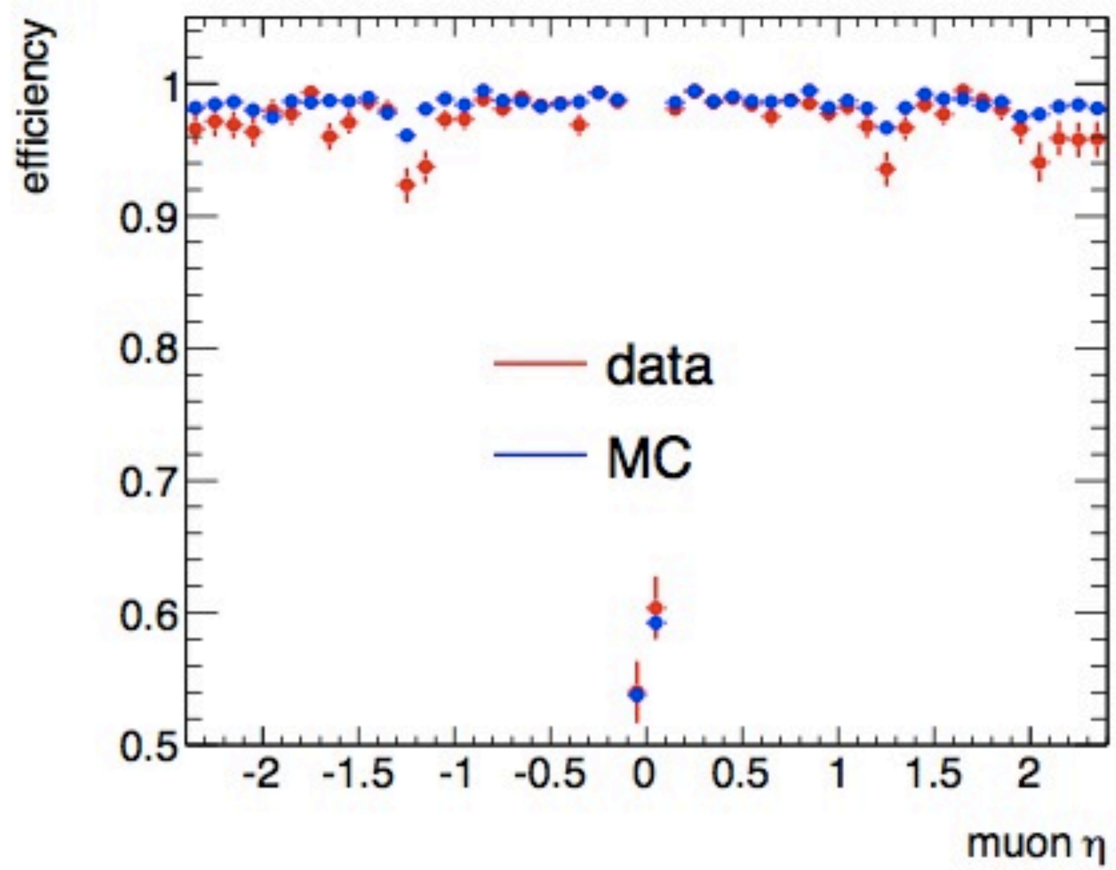
Z' Sensitivity Study for 7 TeV



ATLAS CONF note available with W' and Z' prospects

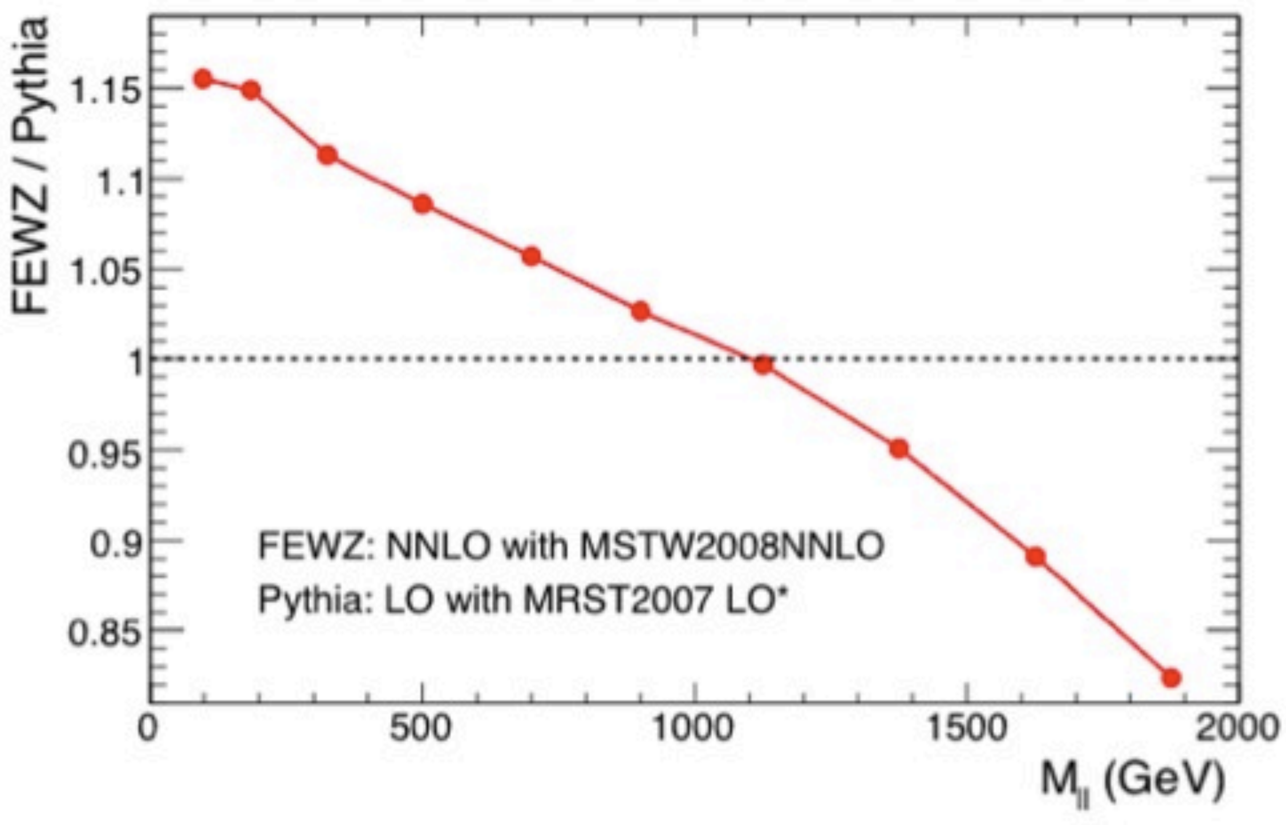
Muon Tag & Probe



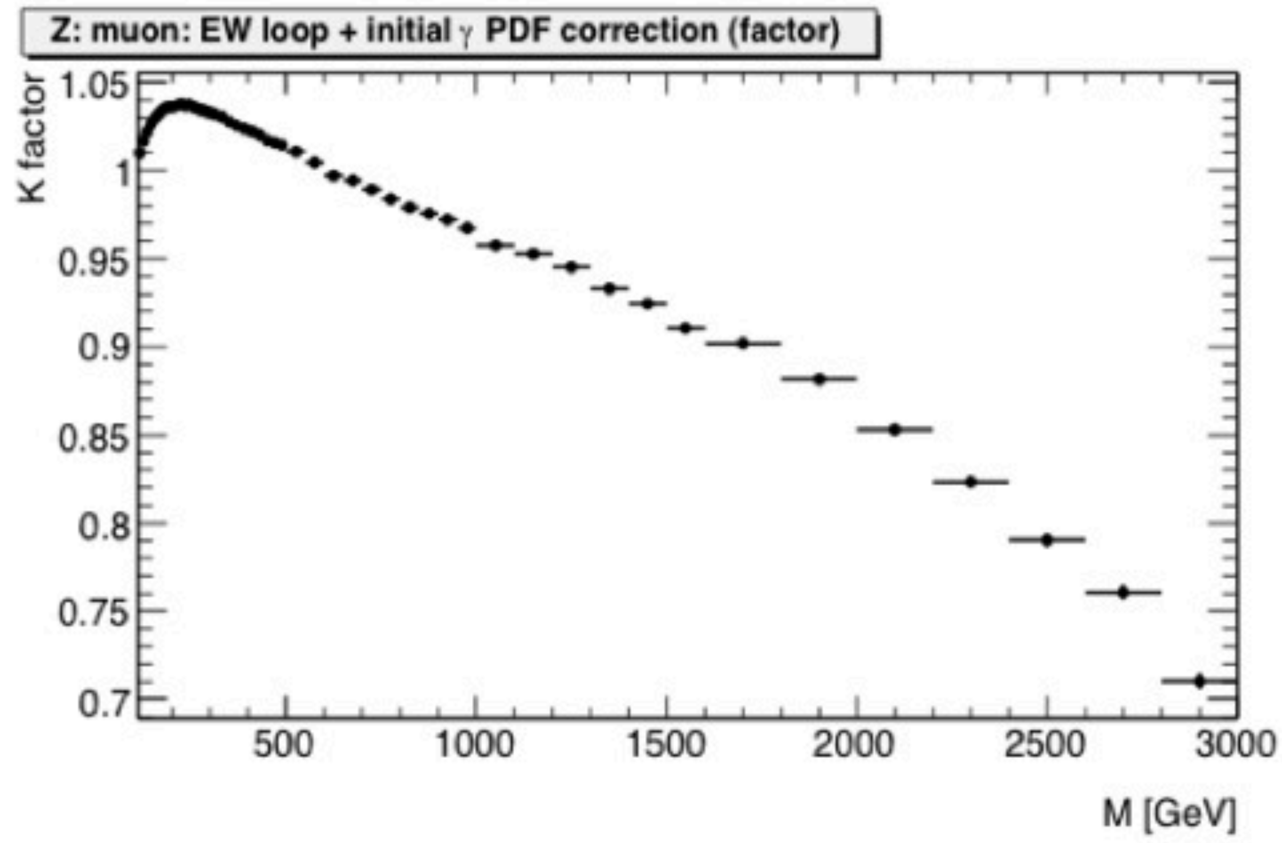


Mass-dependent k-factors

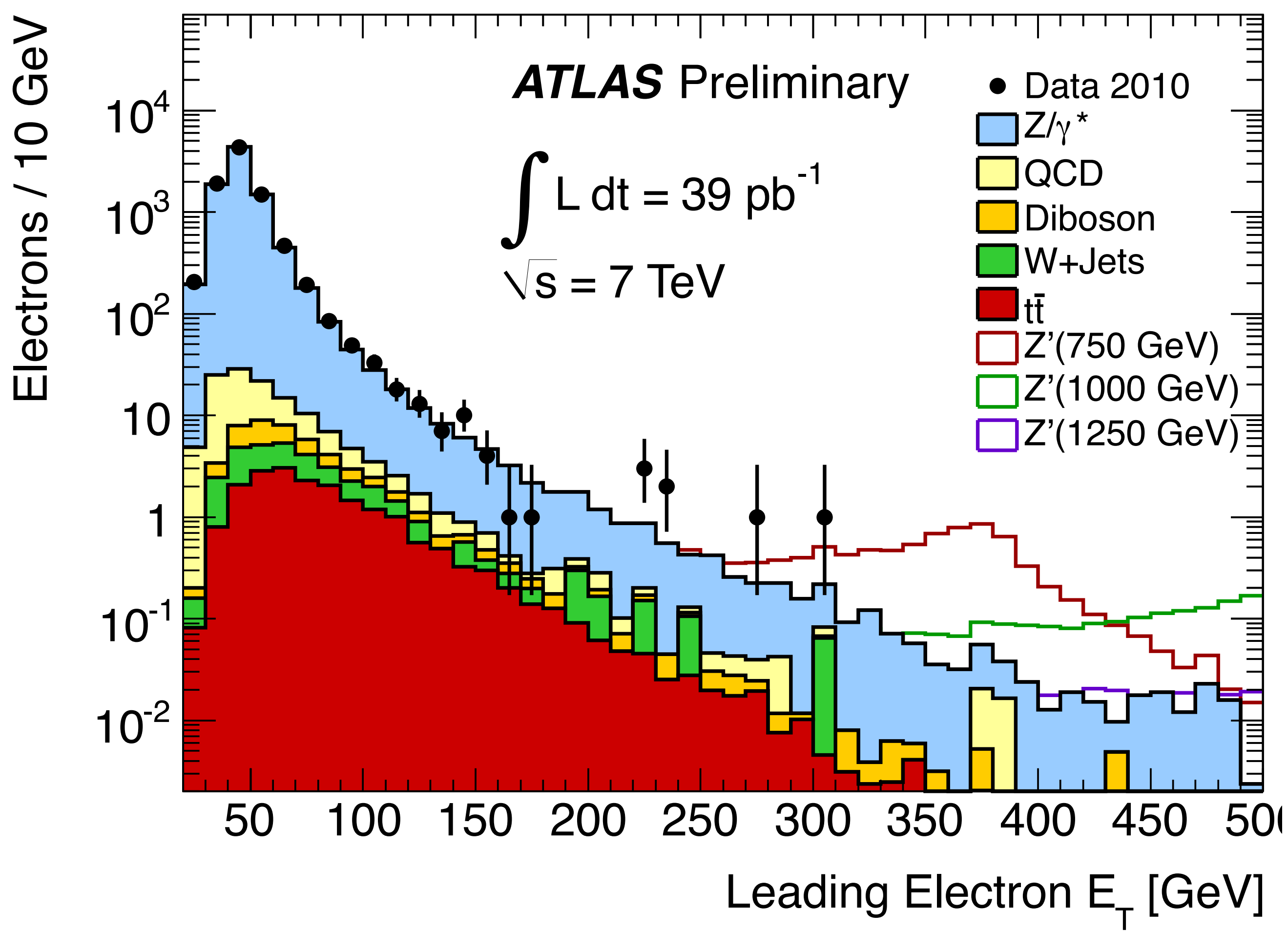
QCD

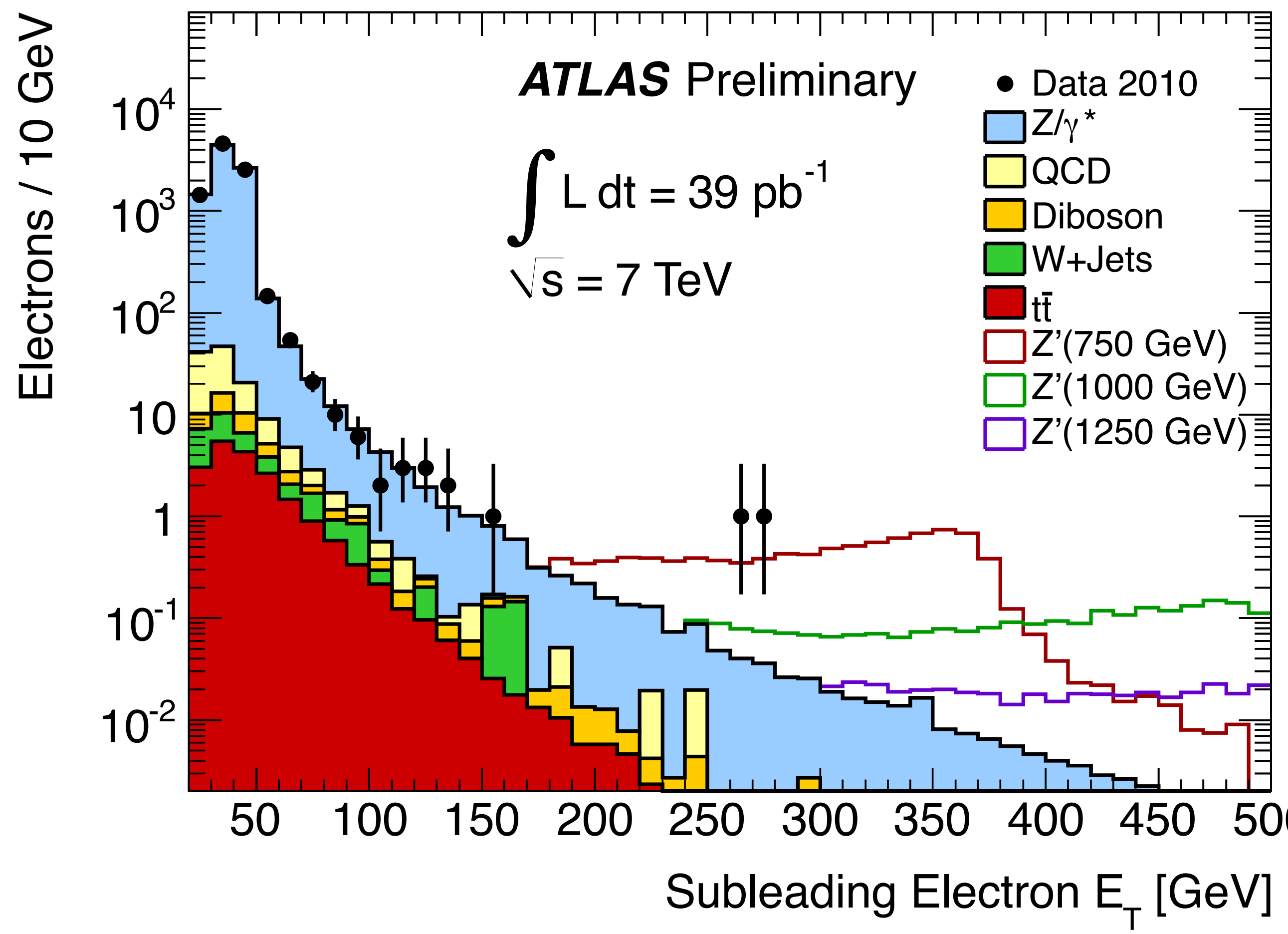


EWK



Z': Electron ET

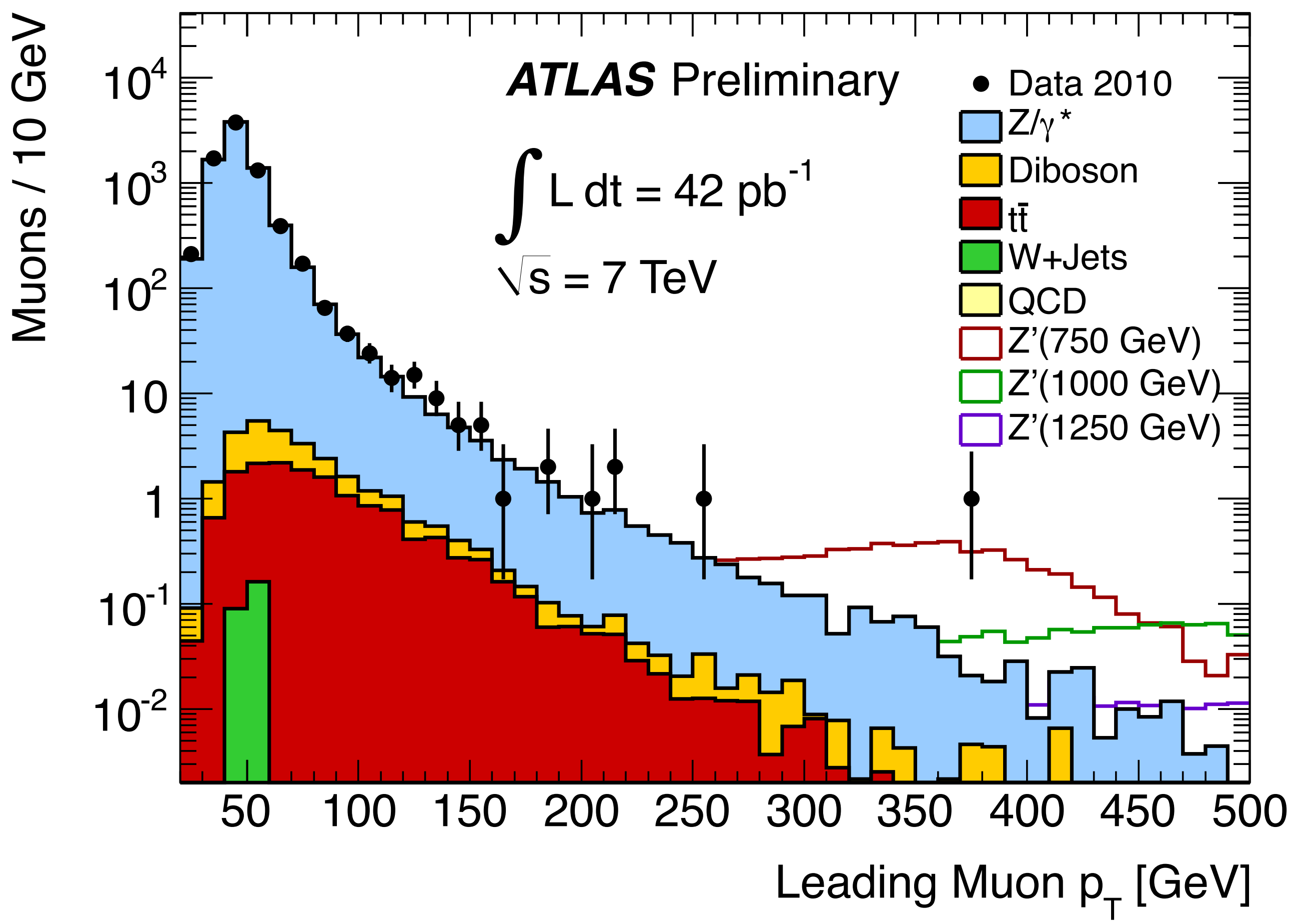


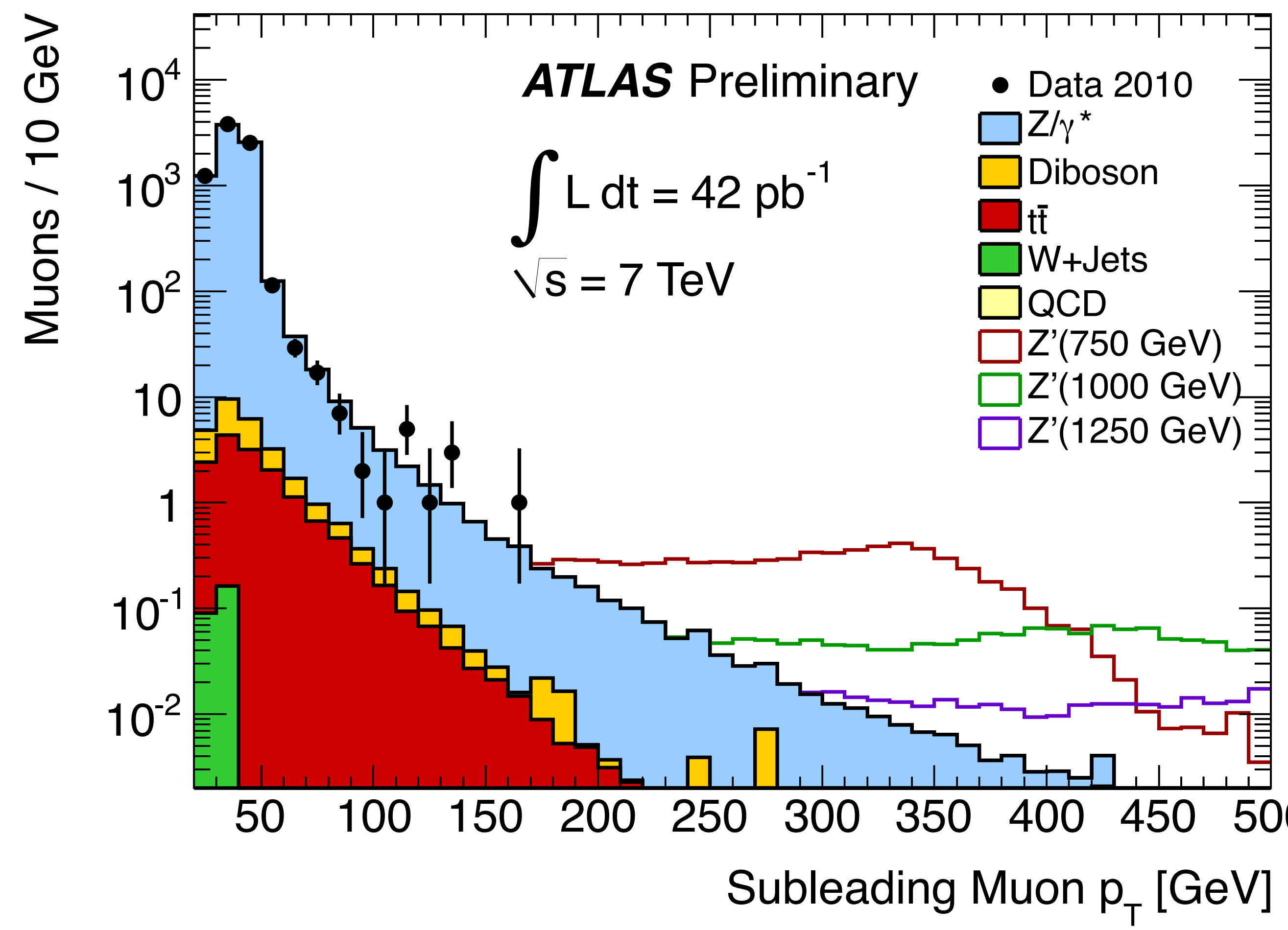


Leading Electron

Subleading Electron

Z': Muon Pt





Leading Muon

Subleading Muon

Z' Models

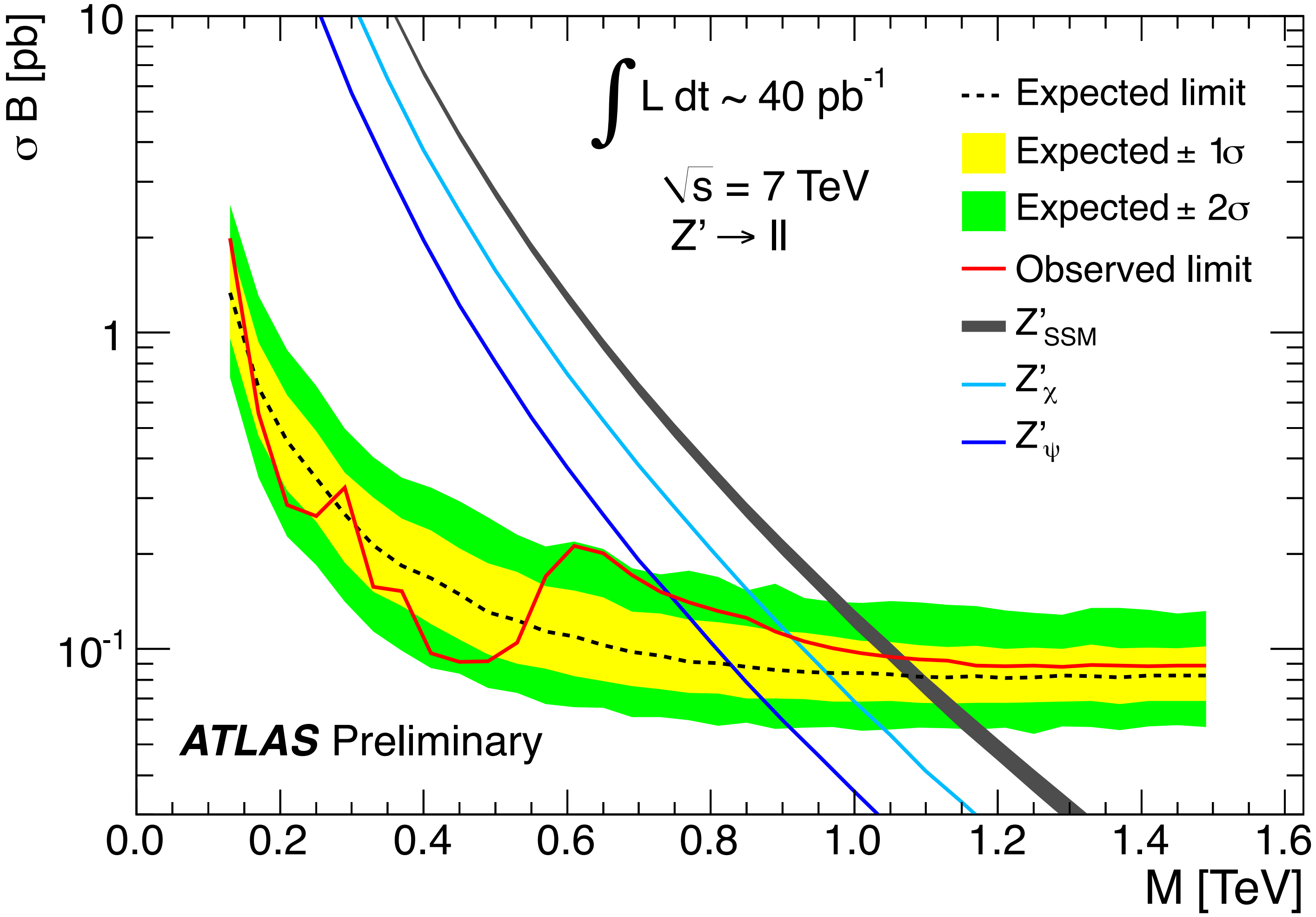
- Limits set with SM couplings (SSM) and in E6 Model (GUT inspired)

- E6 → SO(10) x $U(1)_\psi$
  → SU(5) x $U(1)_\chi$ x $U(1)_\psi$

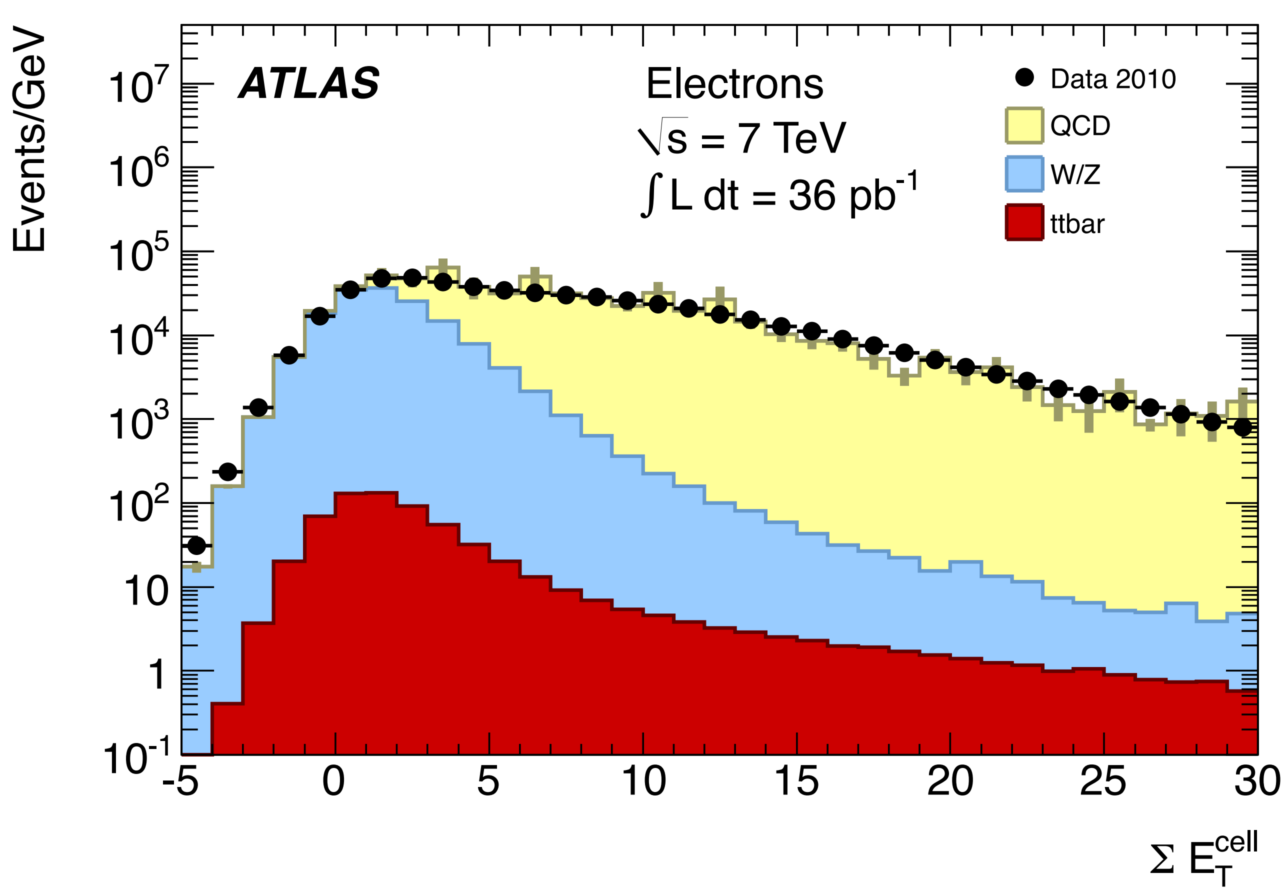
- Mass eigenstate:
  $Z'(\theta) = Z'_\psi \cos\theta + Z'_\chi \sin\theta$

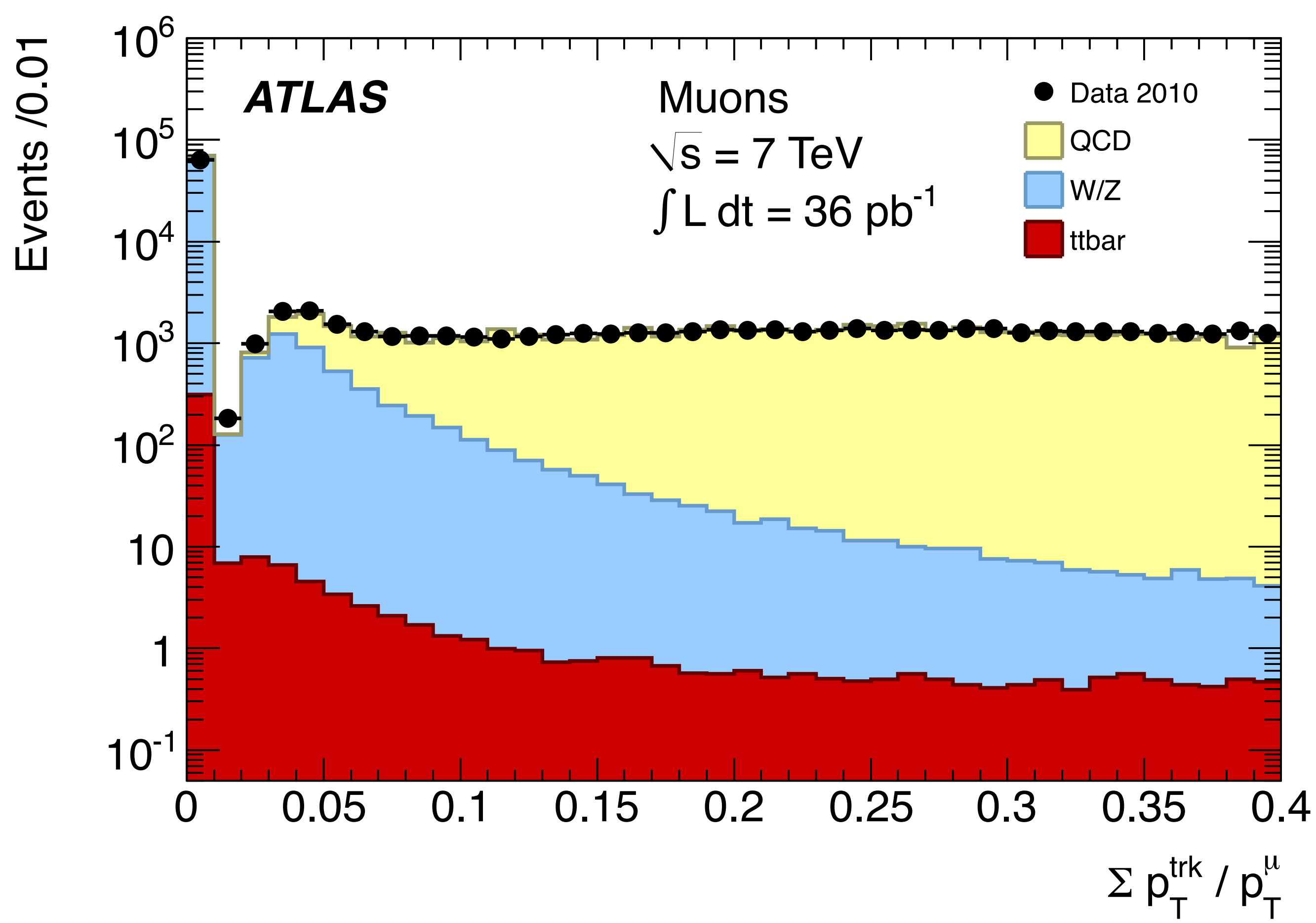
- θ: Mixing angle, determines the coupling

- Couplings for Pythia from Fermilab-fn-0773-E (July 2005)



W' Isolation

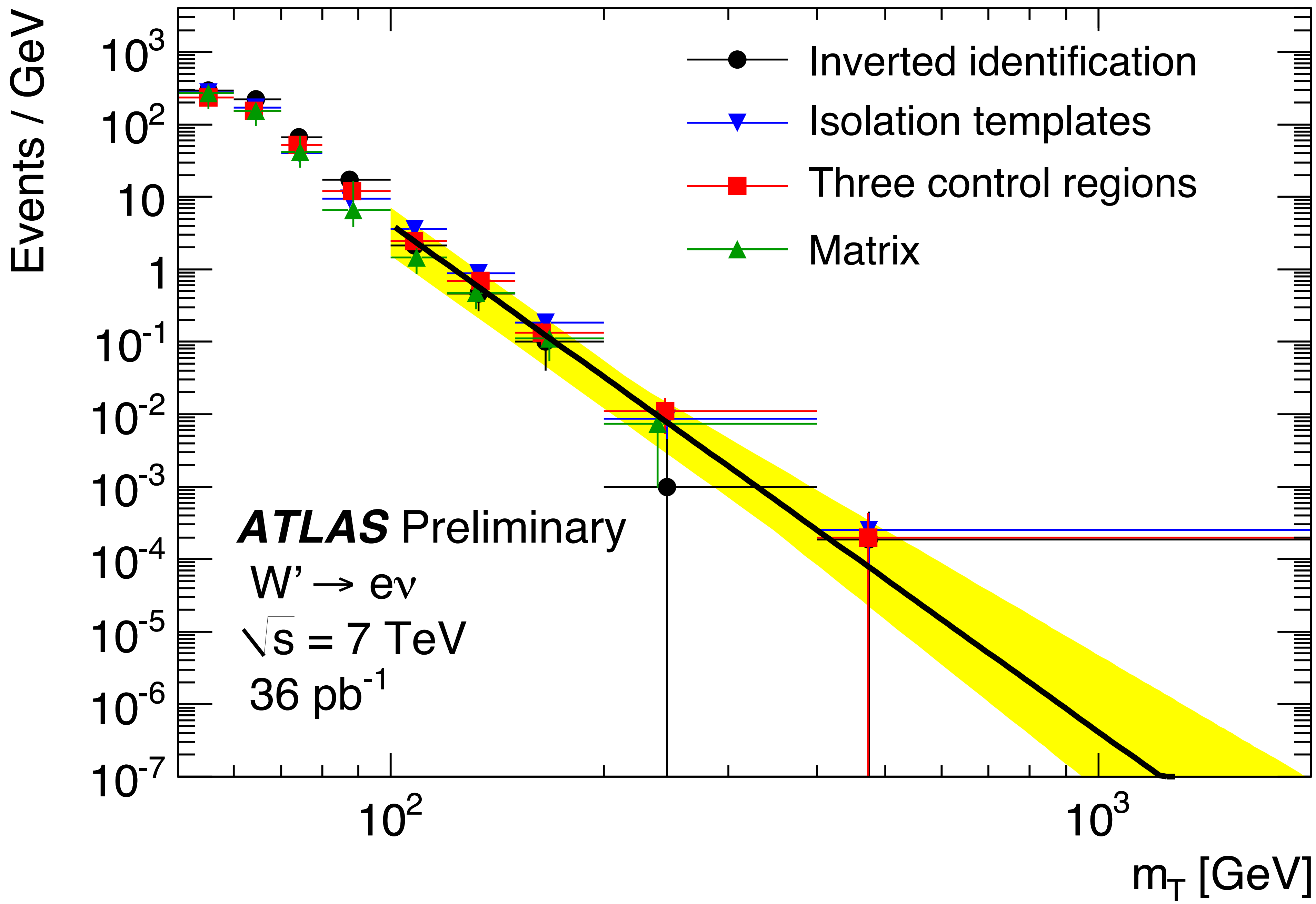




Calorimeter Isolation: Electron channel

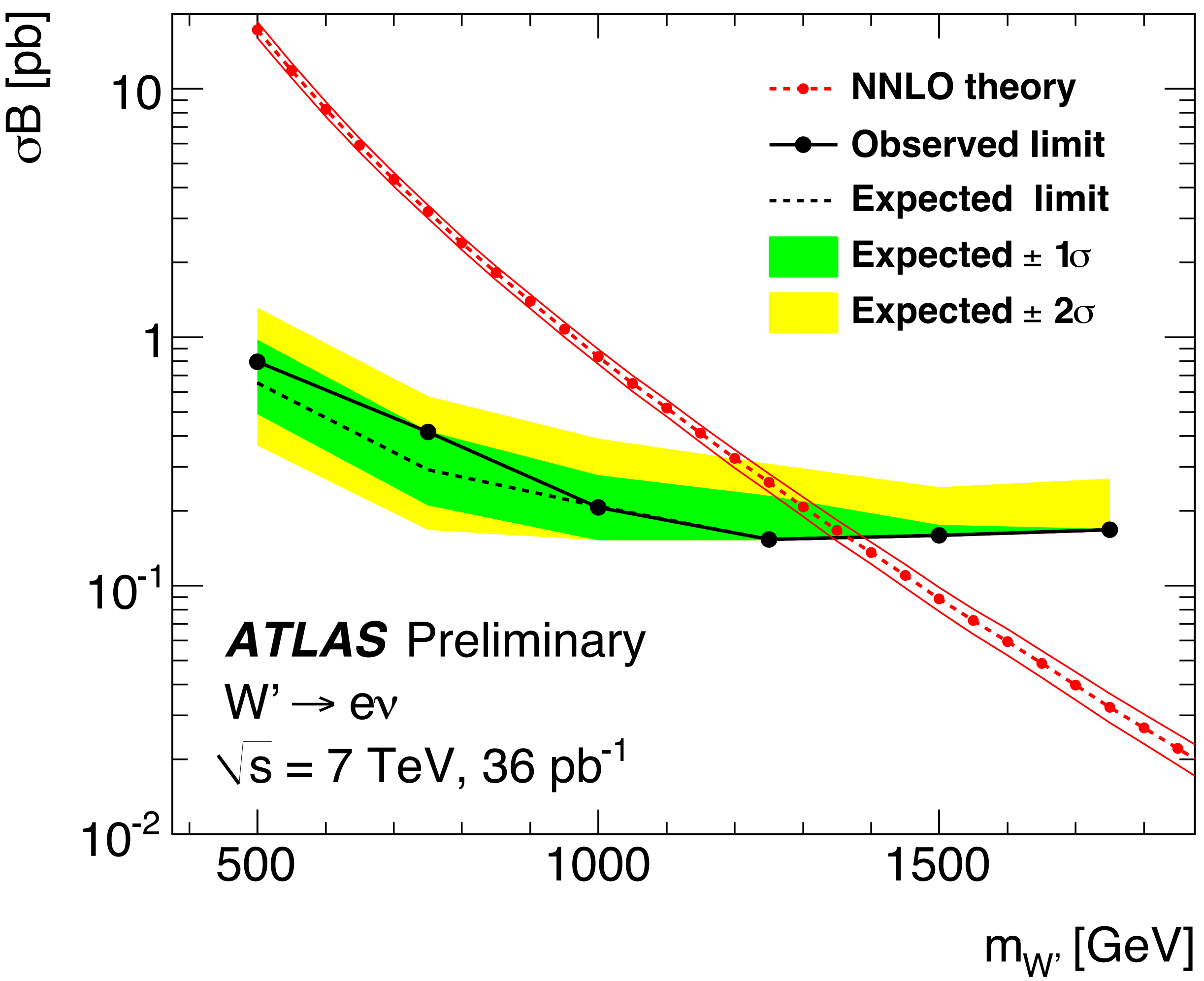
Track Isolation: Muon channel

W' backgrounds

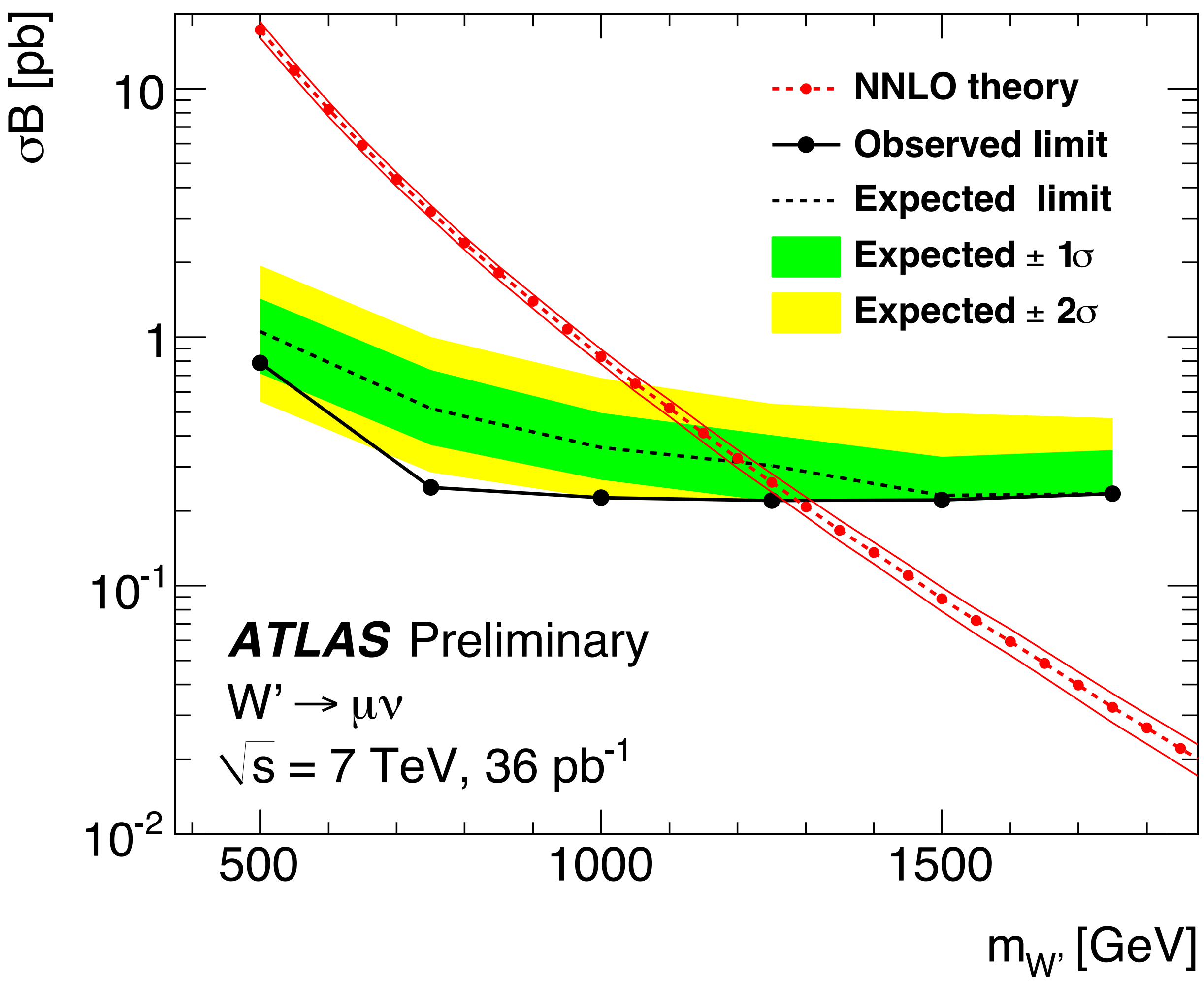


Multiple data-driven methods used for QCD

Limits for W'

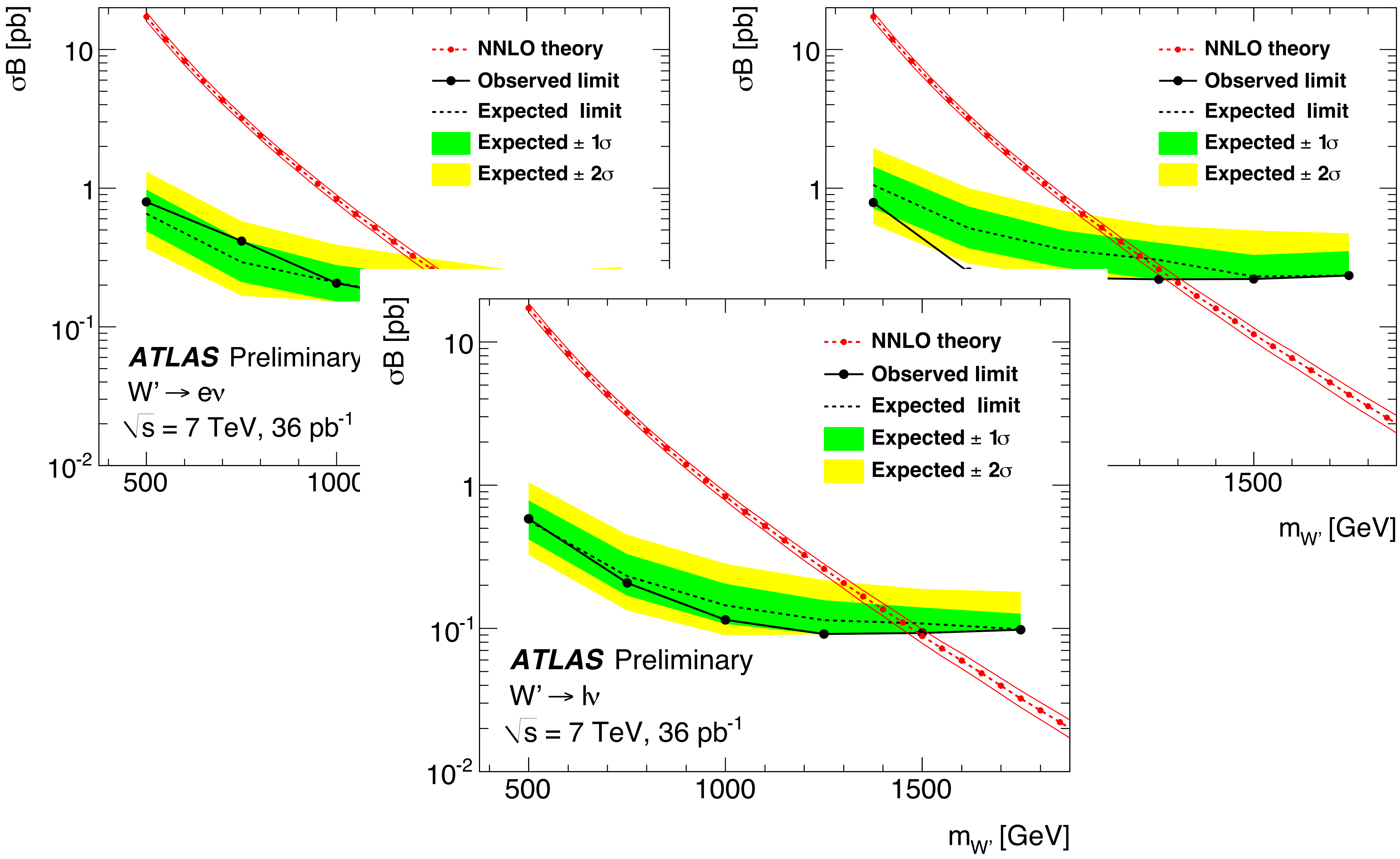


σB [pb]
10
1
10^{-1}
10^{-2}
500
1000
1500
$m_{W'}$ [GeV]
NNLO theory
Observed limit
Expected limit
Expected ± 1σ
Expected ± 2σ
ATLAS Preliminary
W' → eν
$\sqrt{s}$ = 7 TeV, 36 pb^{-1}



σB [pb]
10
1
10^{-1}
10^{-2}
500
1000
1500
$m_{W'}$ [GeV]
NNLO theory
Observed limit
Expected limit
Expected ± 1σ
Expected ± 2σ
ATLAS Preliminary
W' → μν
$\sqrt{s}$ = 7 TeV, 36 pb^{-1}

Limits for W'



σB [pb]
10
1
10^{-1}
10^{-2}
500
1000
NNLO theory
Observed limit
Expected limit
Expected ± 1σ
Expected ± 2σ
ATLAS Preliminary
W' → eν
$\sqrt{s}$ = 7 TeV, 36 pb^{-1}
σB [pb]
10
1
1500
$m_{W'}$ [GeV]
NNLO theory
Observed limit
Expected limit
Expected ± 1σ
Expected ± 2σ
σB [pb]
10
1
10^{-1}
10^{-2}
500
1000
1500
$m_{W'}$ [GeV]
NNLO theory
Observed limit
Expected limit
Expected ± 1σ
Expected ± 2σ
ATLAS Preliminary
W' → lν
$\sqrt{s}$ = 7 TeV, 36 pb^{-1}

W* and Z* Models

We will consider new spin-1 bosons with the internal quantum numbers identical to the Standard Model Higgs doublet, transforming under fundamental representation of $SU(2)_L$ and solving the Hierarchy Problem.

$$\begin{pmatrix} H^+ \\ H^0 \end{pmatrix} \leftrightarrow \begin{pmatrix} W^{*+}_\mu \\ Z^*_\mu \end{pmatrix}$$

M. V. Chizhov, V. A. Bednyakov, and J. A. Budagov, Physics of Atomic Nuclei **71**, 2096 (2008), ISSN 1063-7788.
M. V. Chizhov and G. Dvali (2009), 0908.0924v1.
M. V. Chizhov, V. A. Bednyakov, and J. A. Budagov, Nuovo Cimento **C33**, 343 (2010).

	Observed limit		Expected limit	
	mass [TeV]	σB [pb]	mass [TeV]	σB [pb]
$Z^* \to e^+e^-$	1.058	0.149	1.062	0.143
$Z^* \to \mu^+\mu^-$	0.946	0.265	0.995	0.199
$Z^* \to \ell^+\ell^-$	1.152	0.089	1.185	0.080

Dijets

Dijet Models & MC

Resonance search cuts:

$$p_{\mathrm{T}}^{j_1} > 150 \text{ GeV}$$

$$|\eta_j| < 2.5 \text{ and } |\Delta\eta_{jj}| < 1.3$$

Angular analysis cuts:

$$p_{\mathrm{T}}^{j_1} > 60 \text{ GeV}$$

$$p_{\mathrm{T}}^{j_2} > 30 \text{ GeV}$$

$$|y^*| < 1.70 \quad |y_{1,2}| < 2.8$$

$$|y_B| < 1.10$$

$$y \rightarrow y - y_B = y - \tanh^{-1}(\beta_B)$$

Fully simulated Pythia q*, RS Graviton, contact interaction + QCD samples

Pythia QCD for angular analyses (plus k factor from NLOJet++)

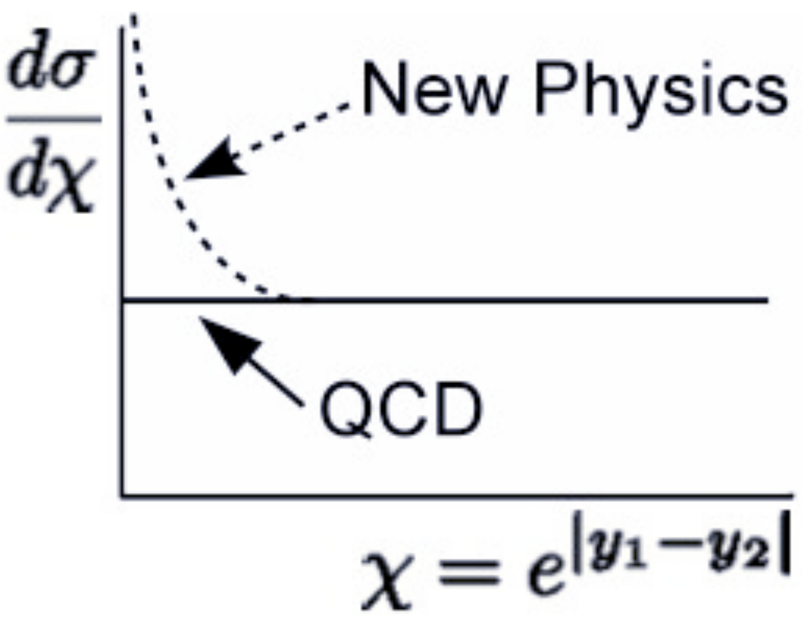
Randall-Meade low multiplicity quantum black holes from Blackmax+Pythia

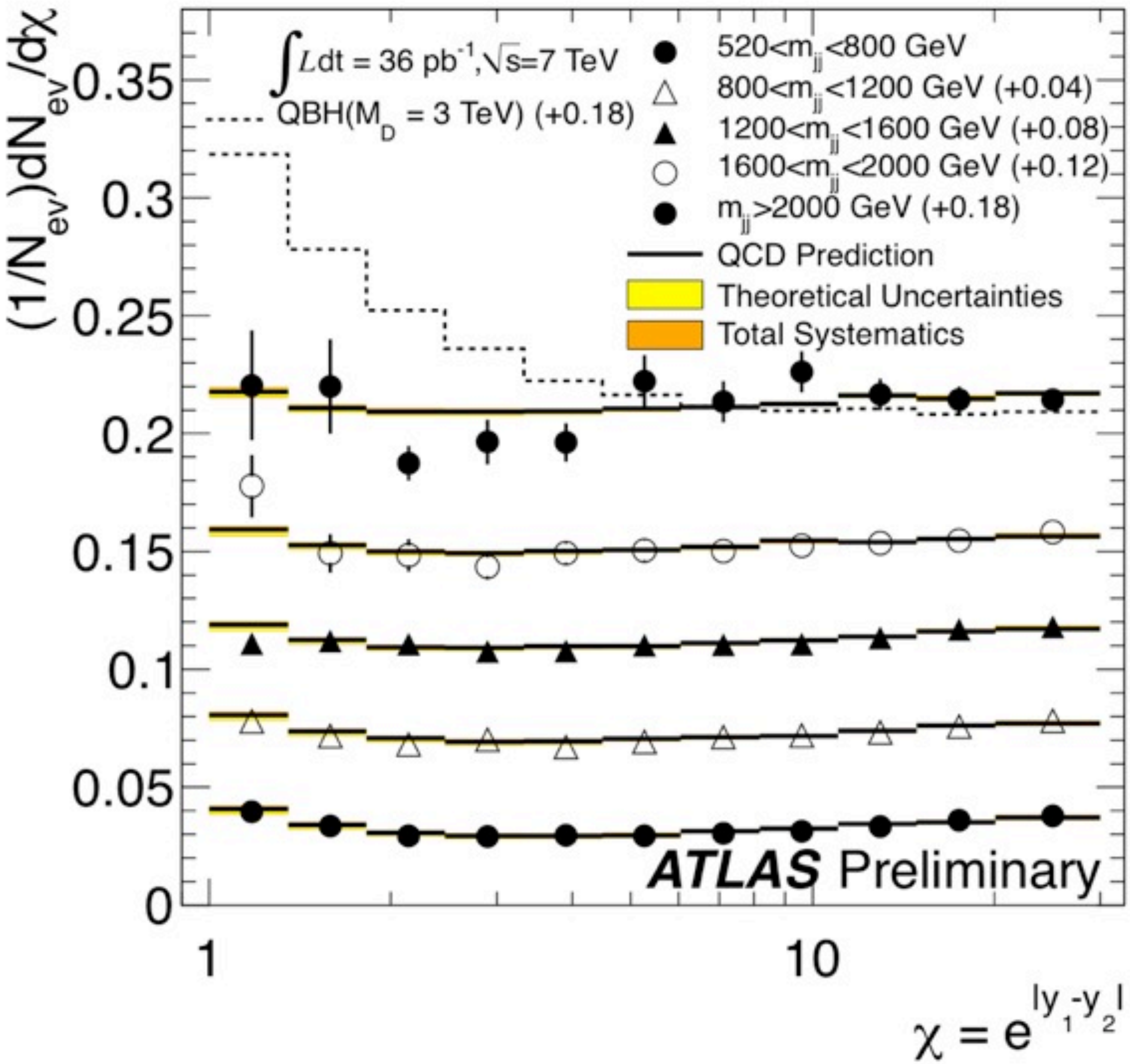
- Fully simulated for six extra dimensions

Axigluons from CalcHEP+Pythia

Going beyond resonances

Use angular information: Define X and separate into m_{jj} bins



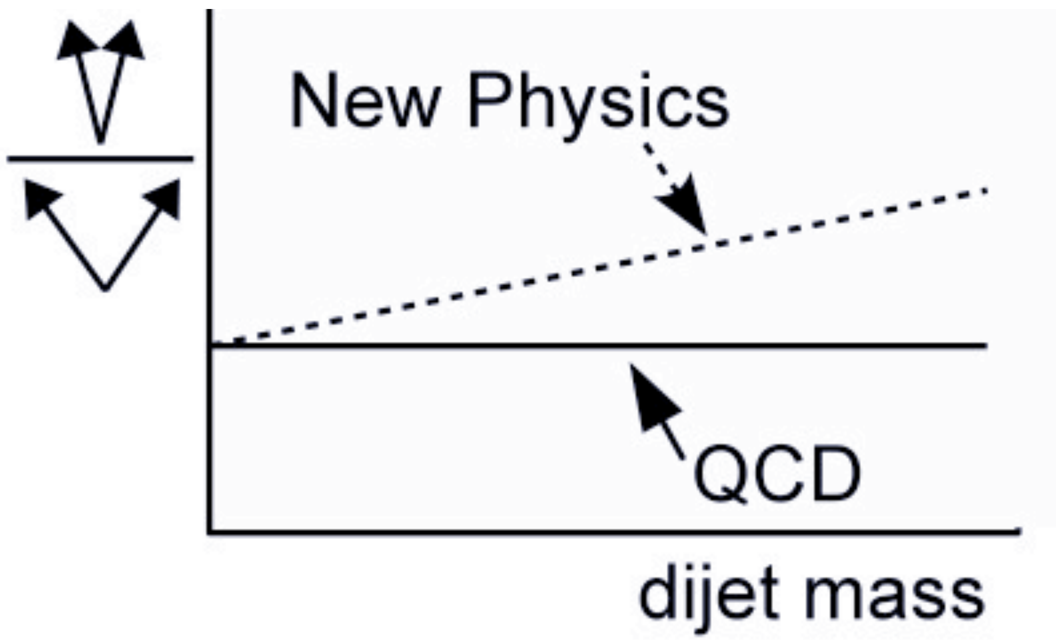


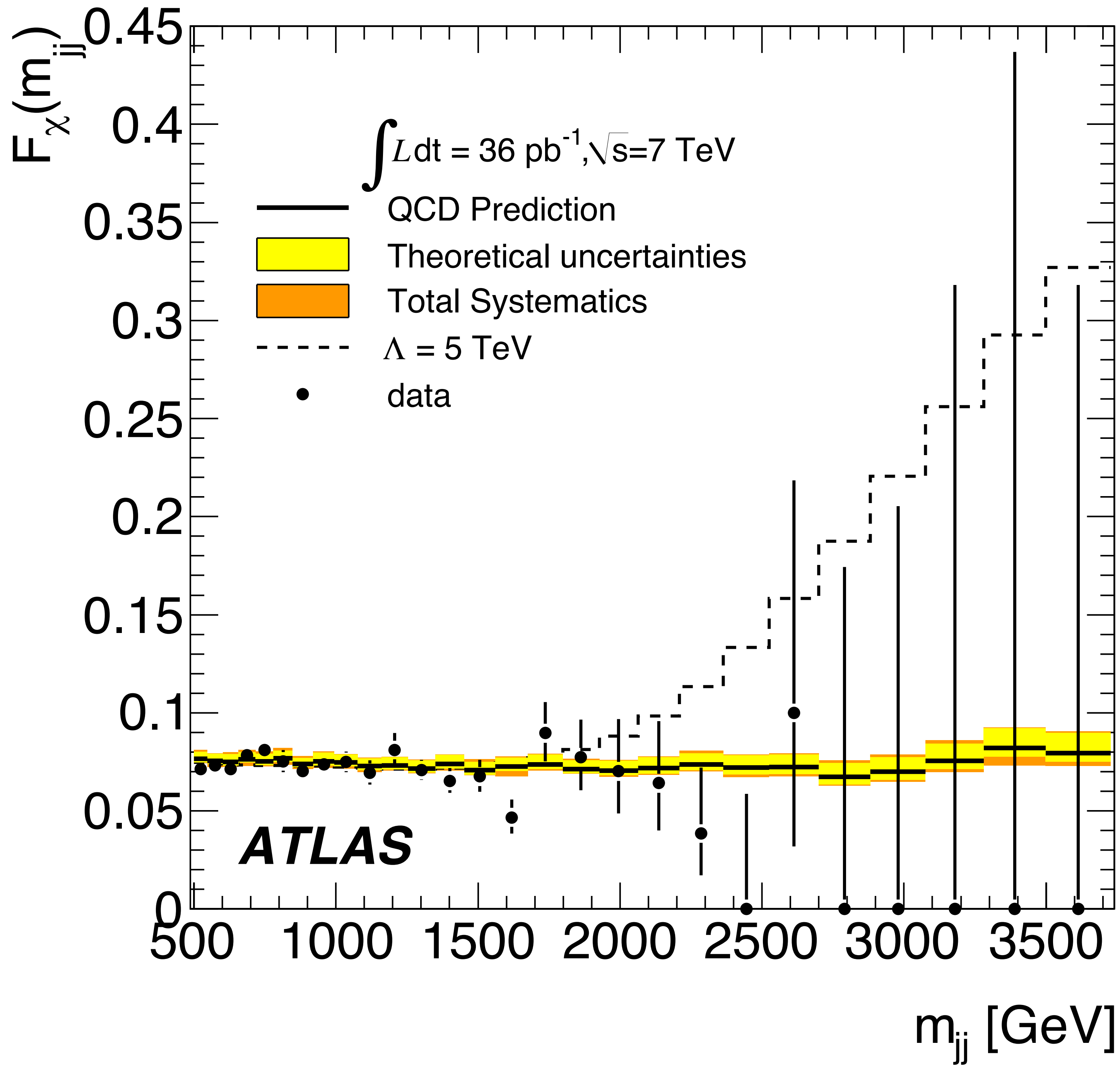
Looking for Substructure

Gain more information from the ratio:

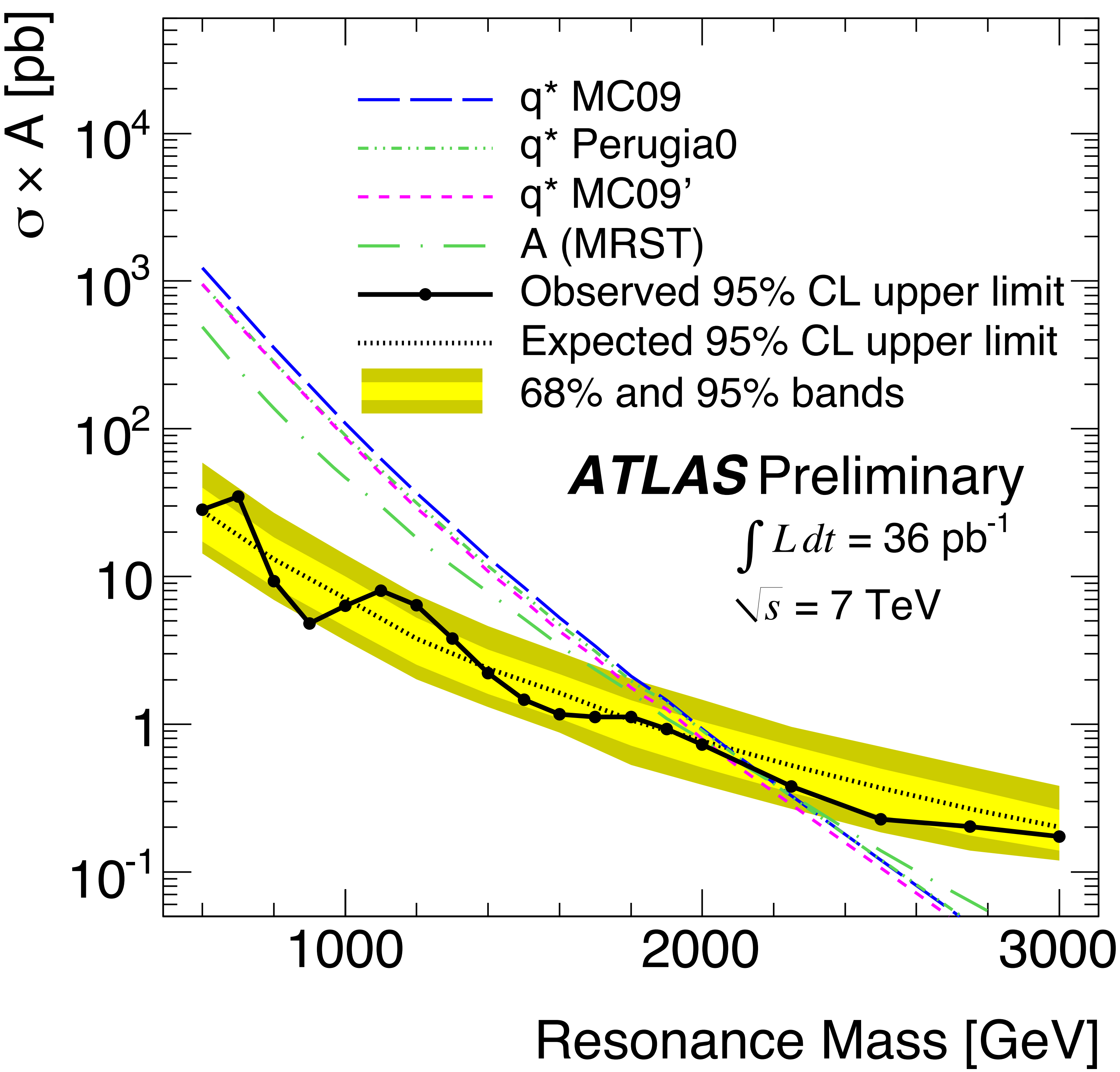
$$F_\chi(m_{jj}) = \frac{N_{events}(|y^*| < 0.6)}{N_{events}(|y^*| < 1.7)}$$

$$y^* = \frac{1}{2}(y_1 - y_2)$$





Dijet resonance limits



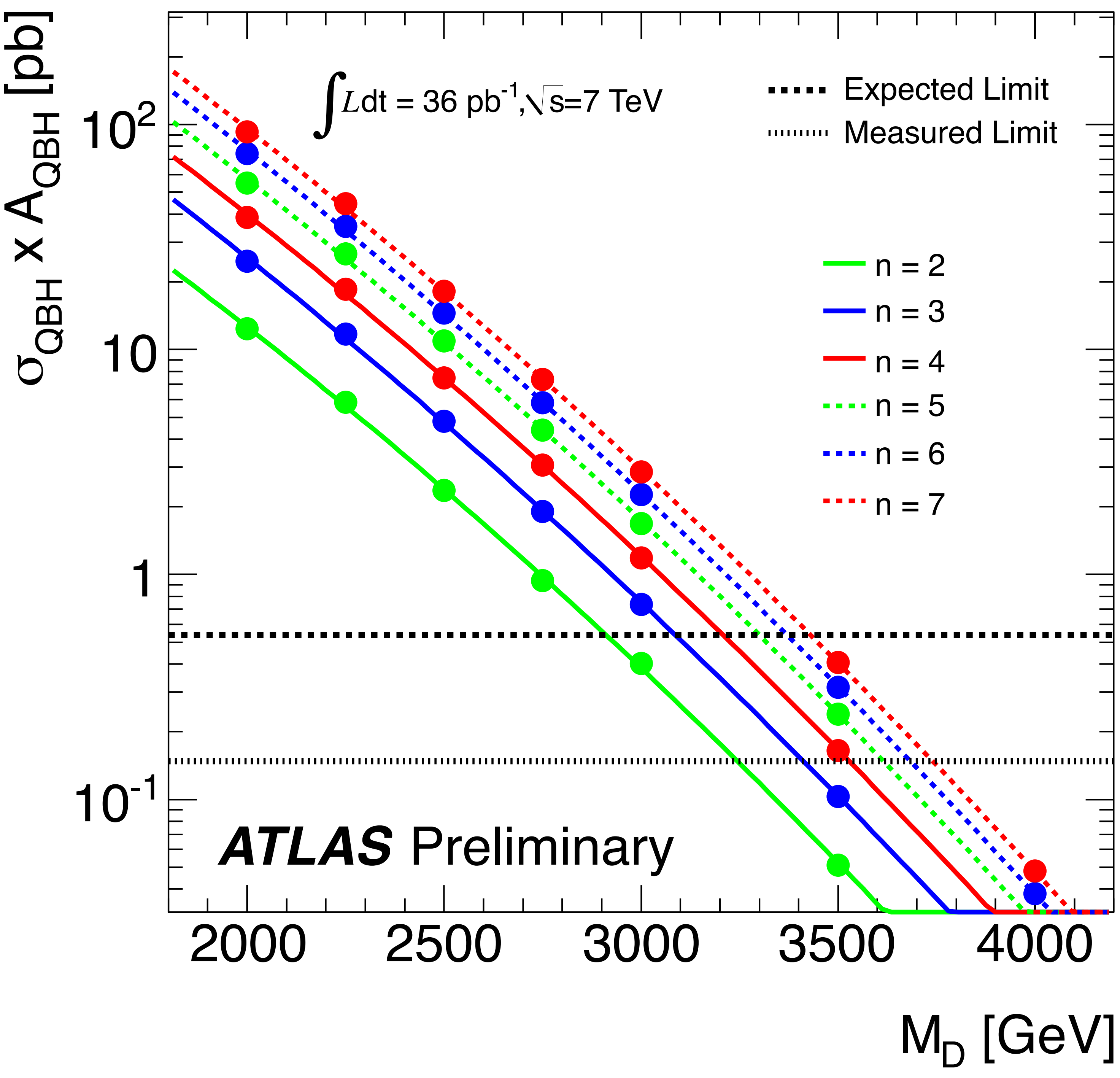
Place limits on several models:

Excited quark, q*: 2.15 TeV

Axigluon (chiral color): 2.10 TeV

Randall-Meade Quantum Black Holes: 3.67 TeV

Quantum Black Holes



Used BlackMax to simulate a simple two-body decay for a given fundamental quantum gravity scale, M_D.

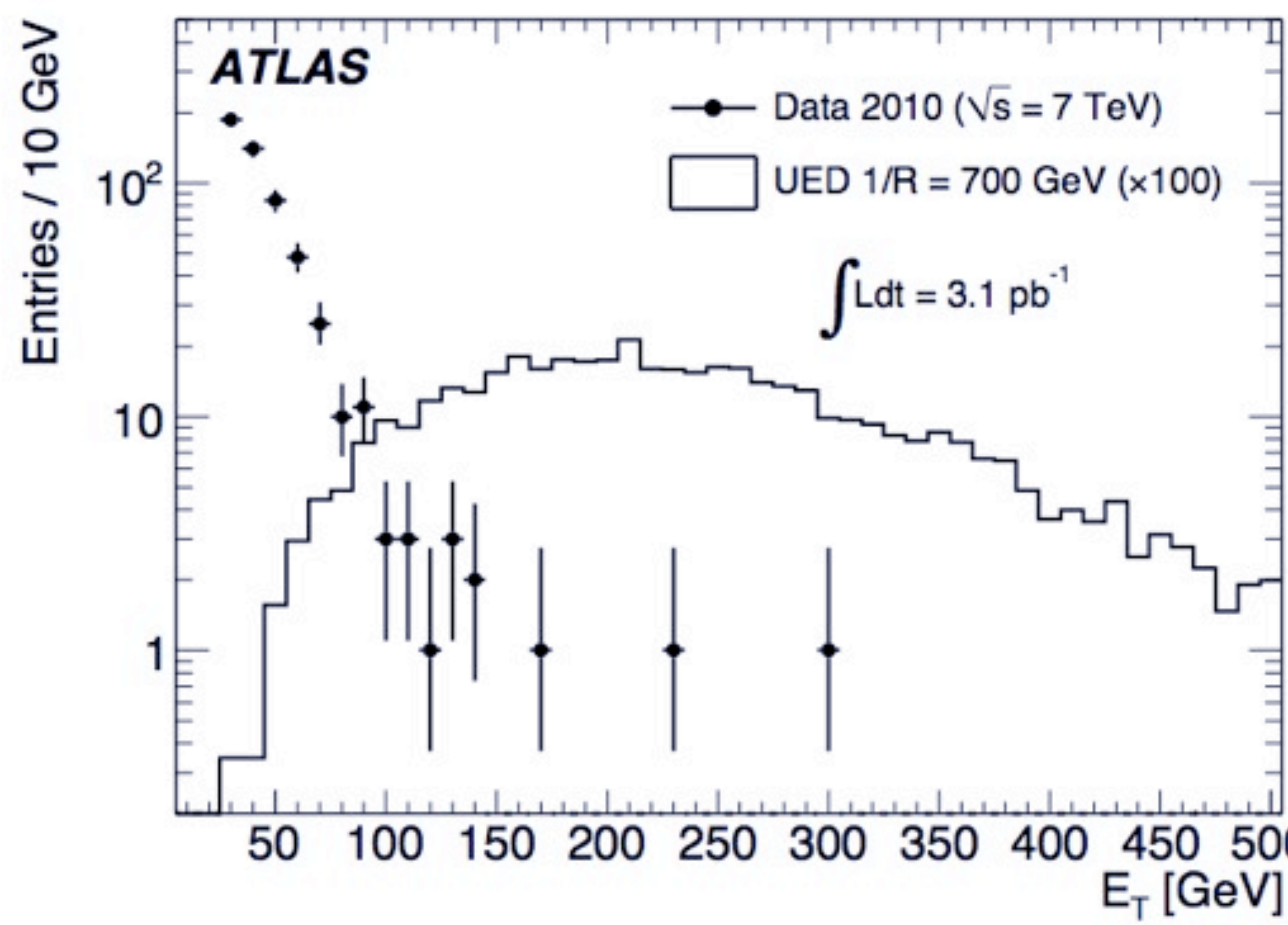
n = number of extra space time dimensions

Diphotons

Exotics with Photons

Select events with two isolated photons with ET > 25 GeV

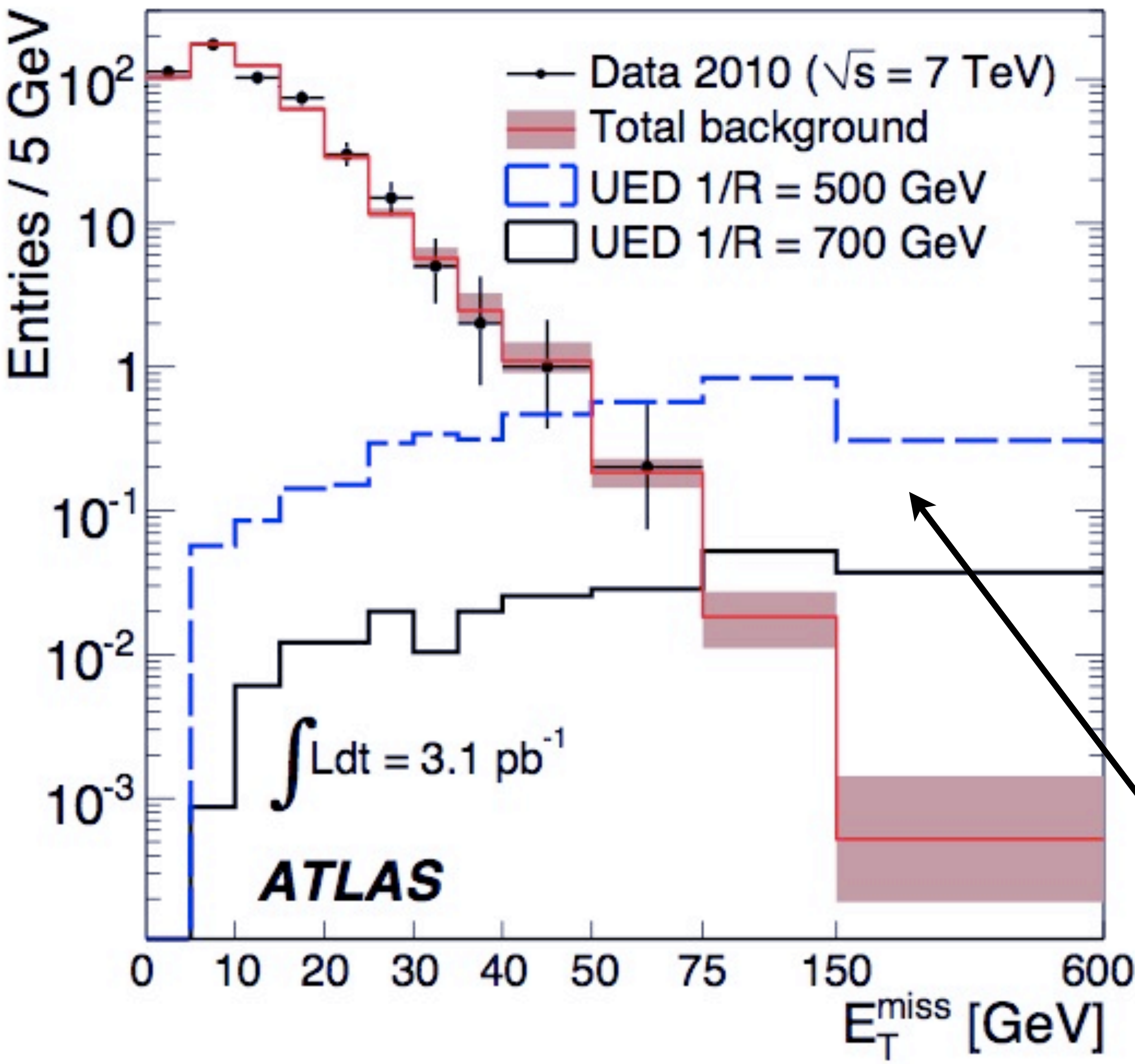
One model that could produce diphotons + MET: Universal Extra Dimensions

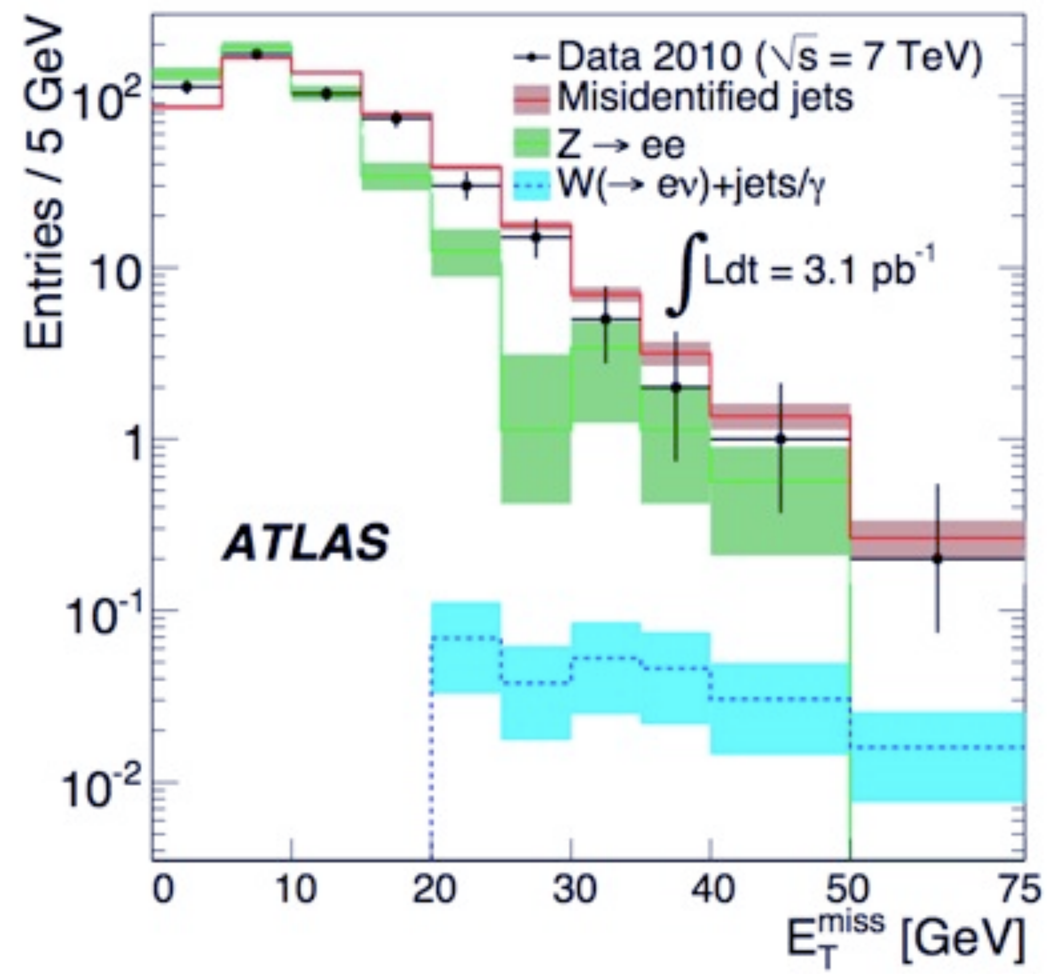


$$\gamma^* \to \gamma + G \quad \text{x 2}$$

+ other SM particles from cascade decays

Data-driven backgrounds





Zero events observed in the MET > 75 GeV signal region

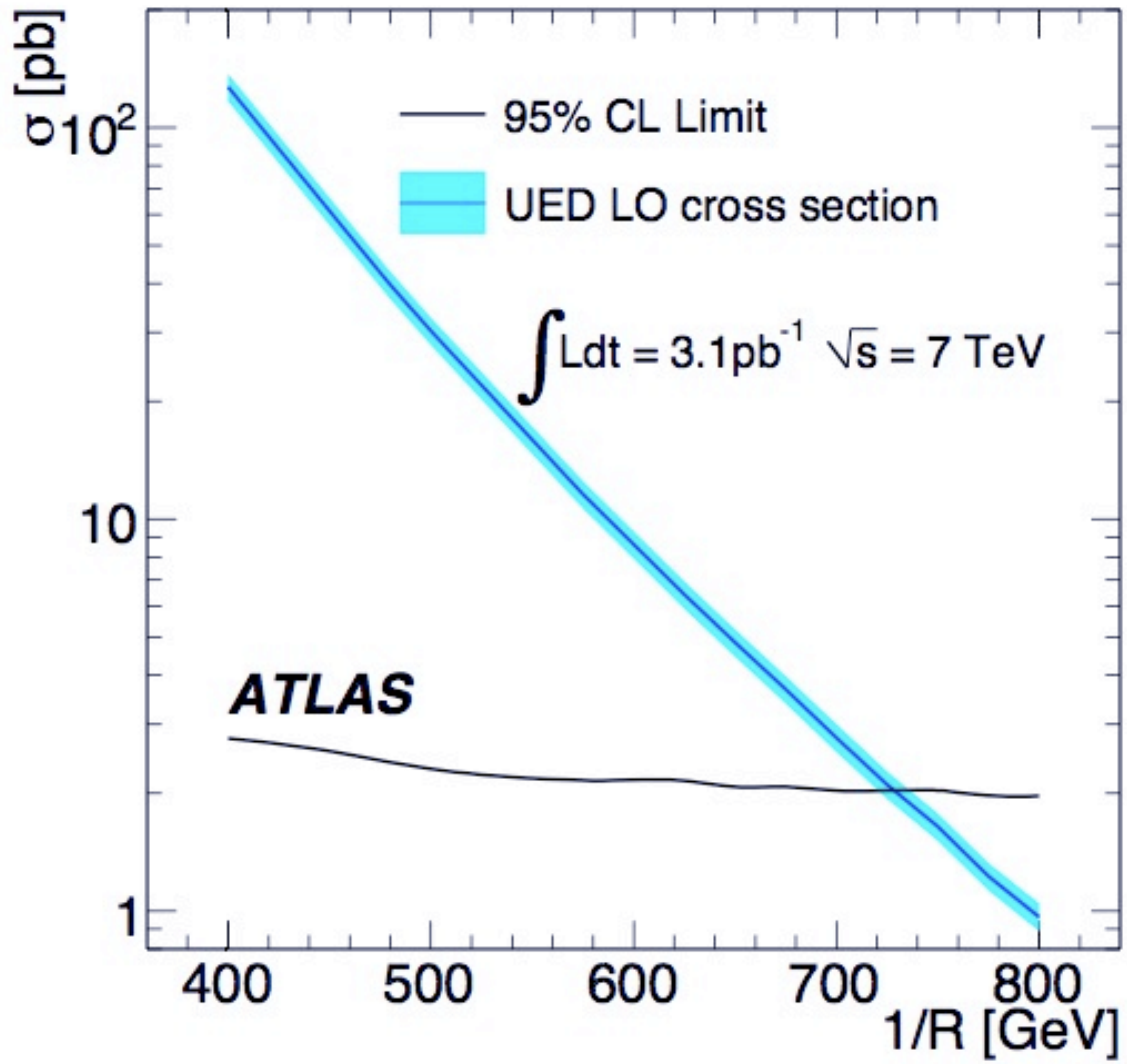
Best limit on UED

Exclude

1/R < 729 GeV at 95 % CL

Far surpassing Tevatron limits of 1/R < 477 GeV

R= compactification radius of the Universal Extra Dimension



Submitted to PRL: arXiv:1012.4272

Detectors

Resolution Requirements

Table 1.1: General performance goals of the ATLAS detector. Note that, for high-p_T muons, the muon-spectrometer performance is independent of the inner-detector system. The units for E and p_T are in GeV.

Detector component	**Required resolution**	**η coverage**	
		Measurement	Trigger
Tracking	$\sigma_{p_T}/p_T = 0.05\%\ p_T \oplus 1\%$	± 2.5	
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$	± 3.2	± 2.5
Hadronic calorimetry (jets)			
barrel and end-cap	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$	± 3.2	± 3.2
forward	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$	$3.1 < \lvert\eta\rvert < 4.9$	$3.1 < \lvert\eta\rvert < 4.9$
Muon spectrometer	σ_{p_T}/p_T=10% at p_T = 1 TeV	± 2.7	± 2.4

Good high-pT measurements

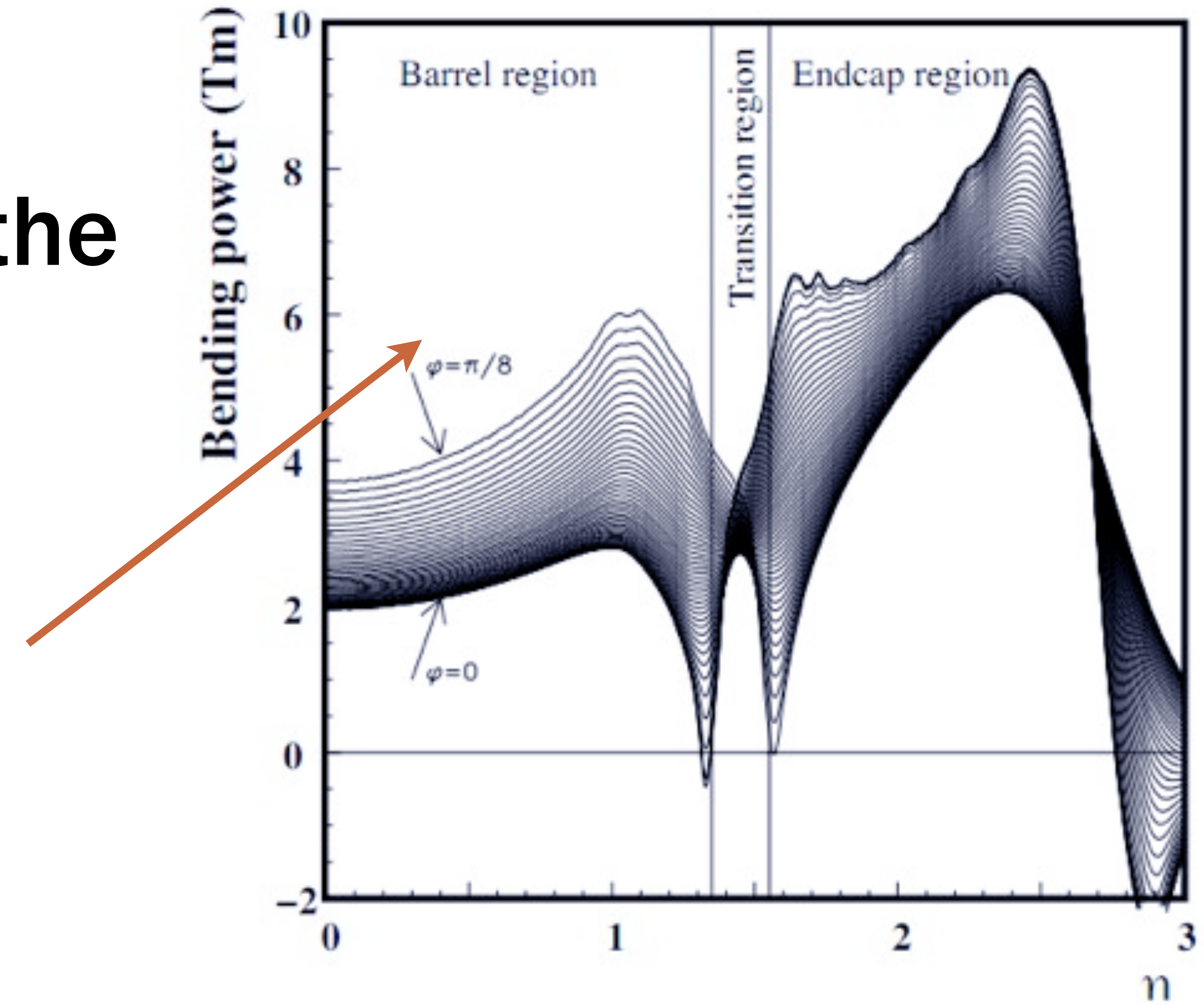
To ensure a good quality ID track, require:

Pixel hits ≥ 1, SCT hits ≥ 4, Pixel+SCT hits ≥ 6

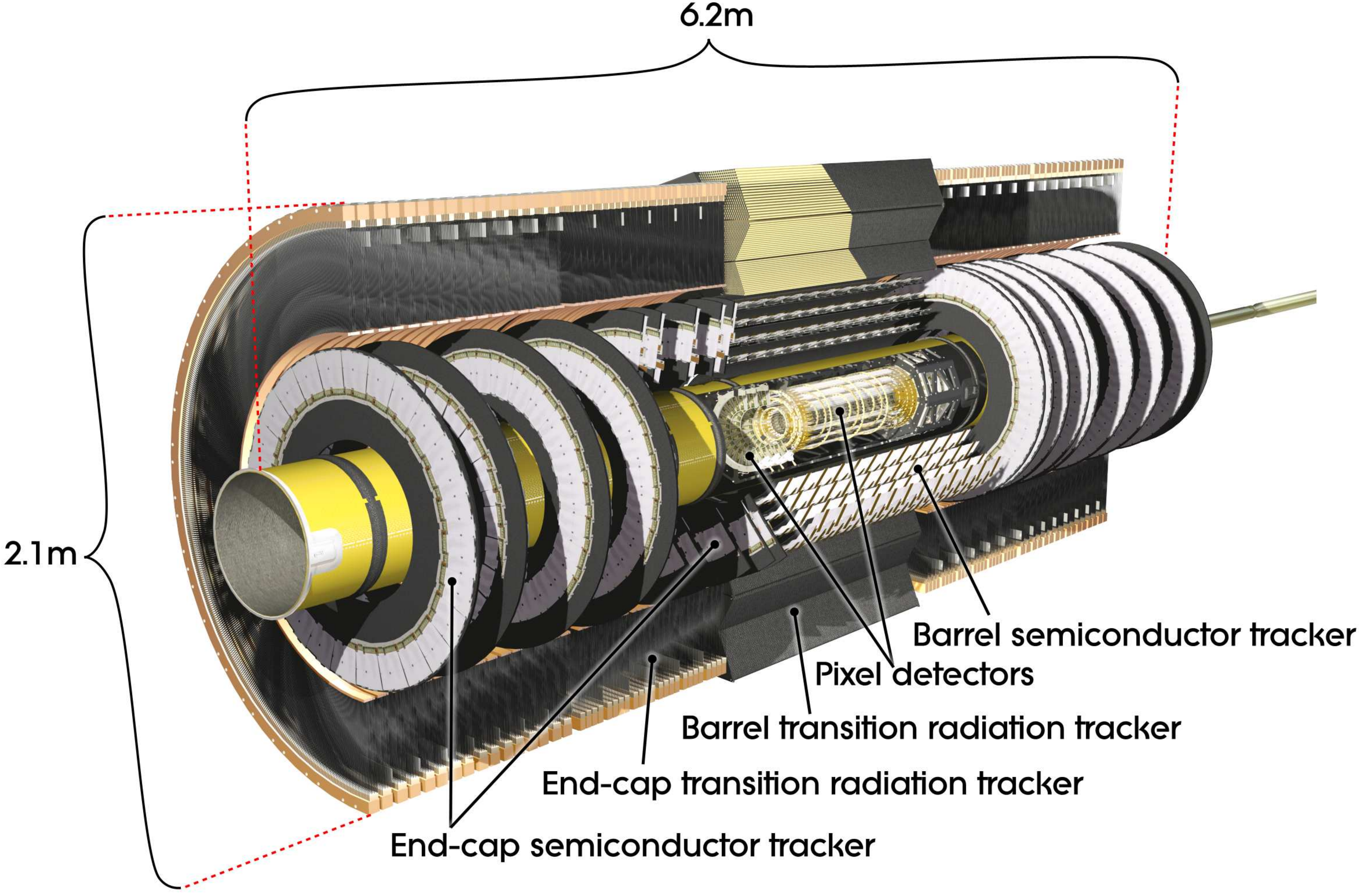
Do something similar for the muon system:

Phi hits ≥ 1

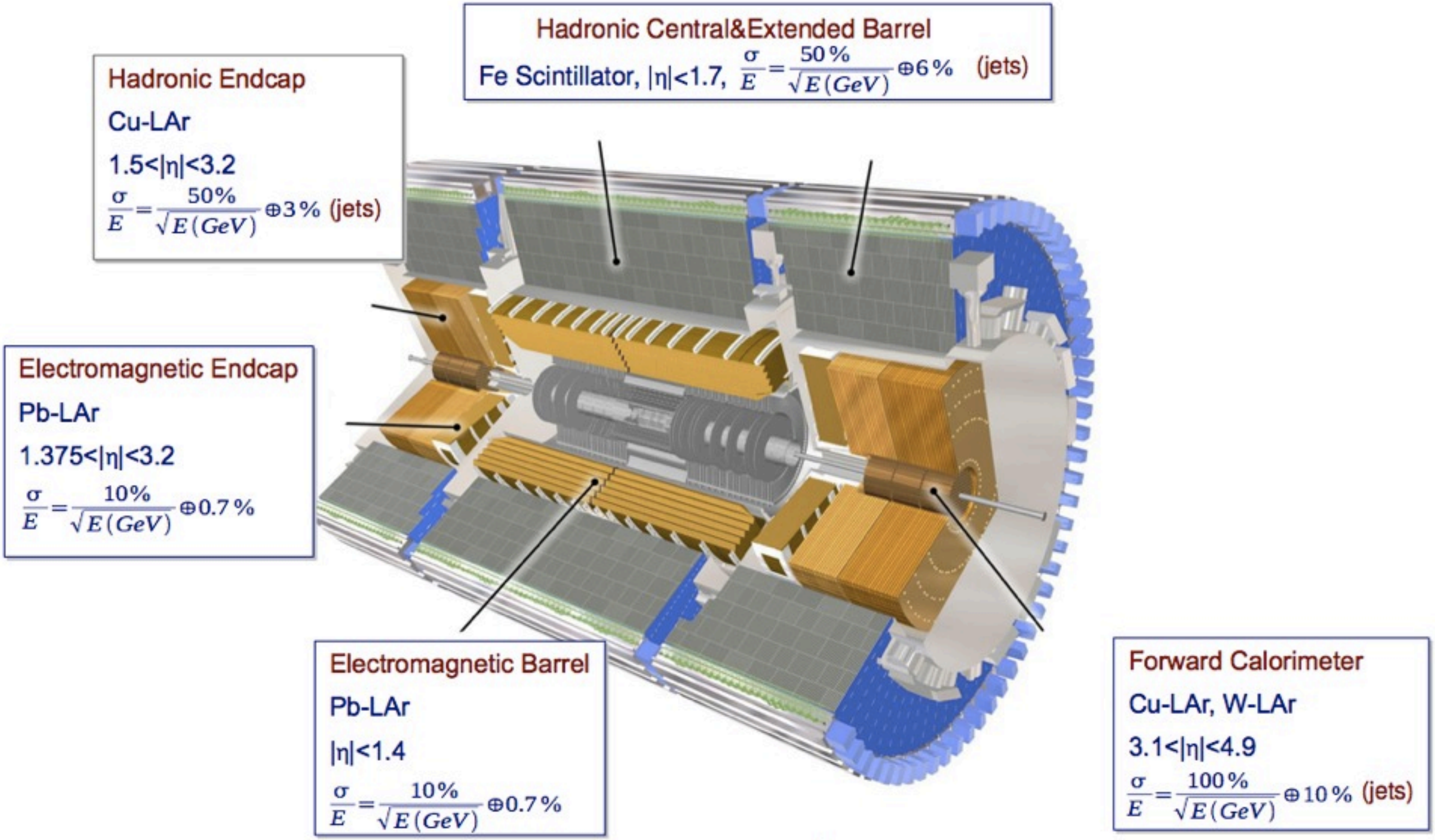
This is important as the bending power varies in phi as well as eta.



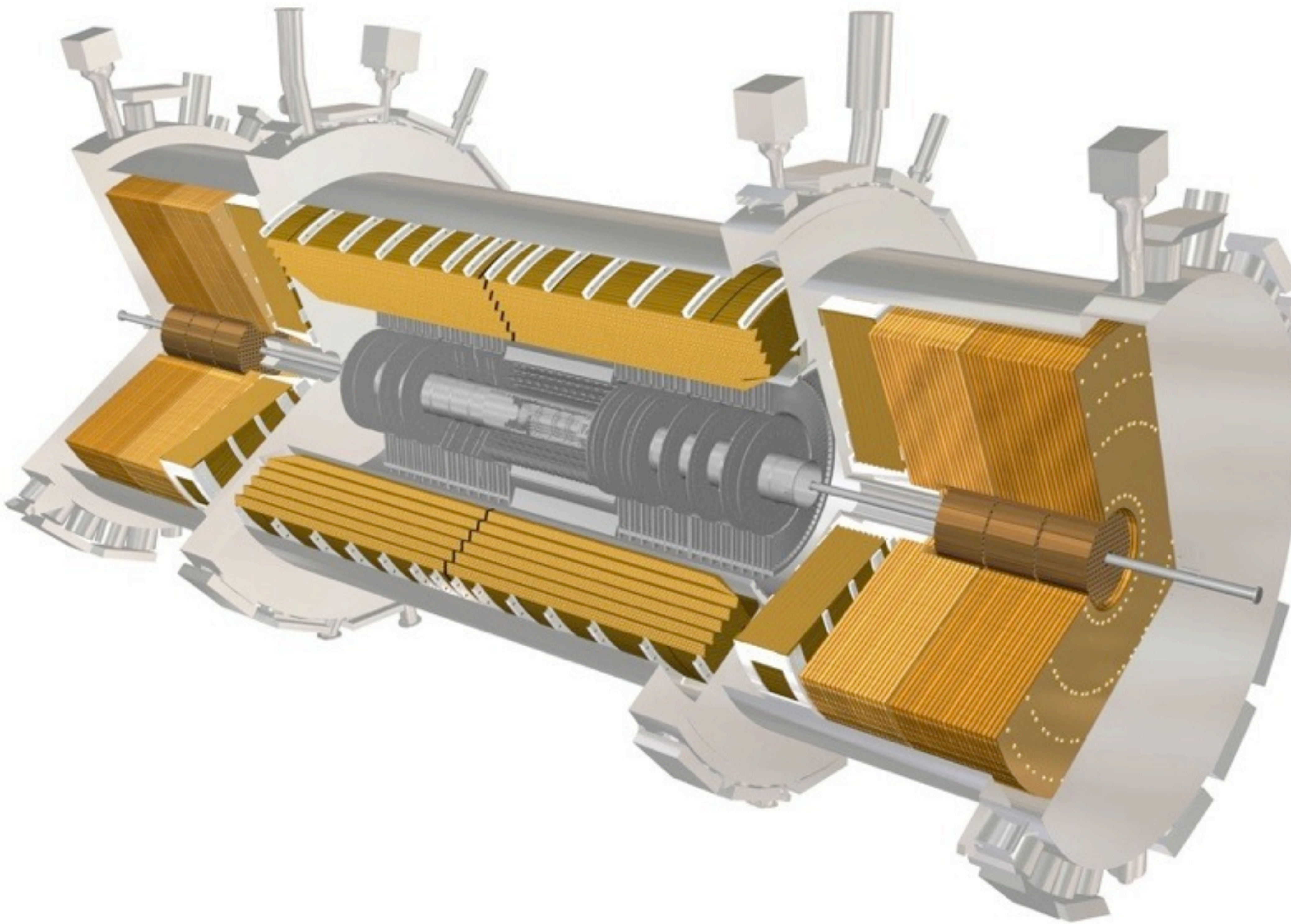
ATLAS Tracking



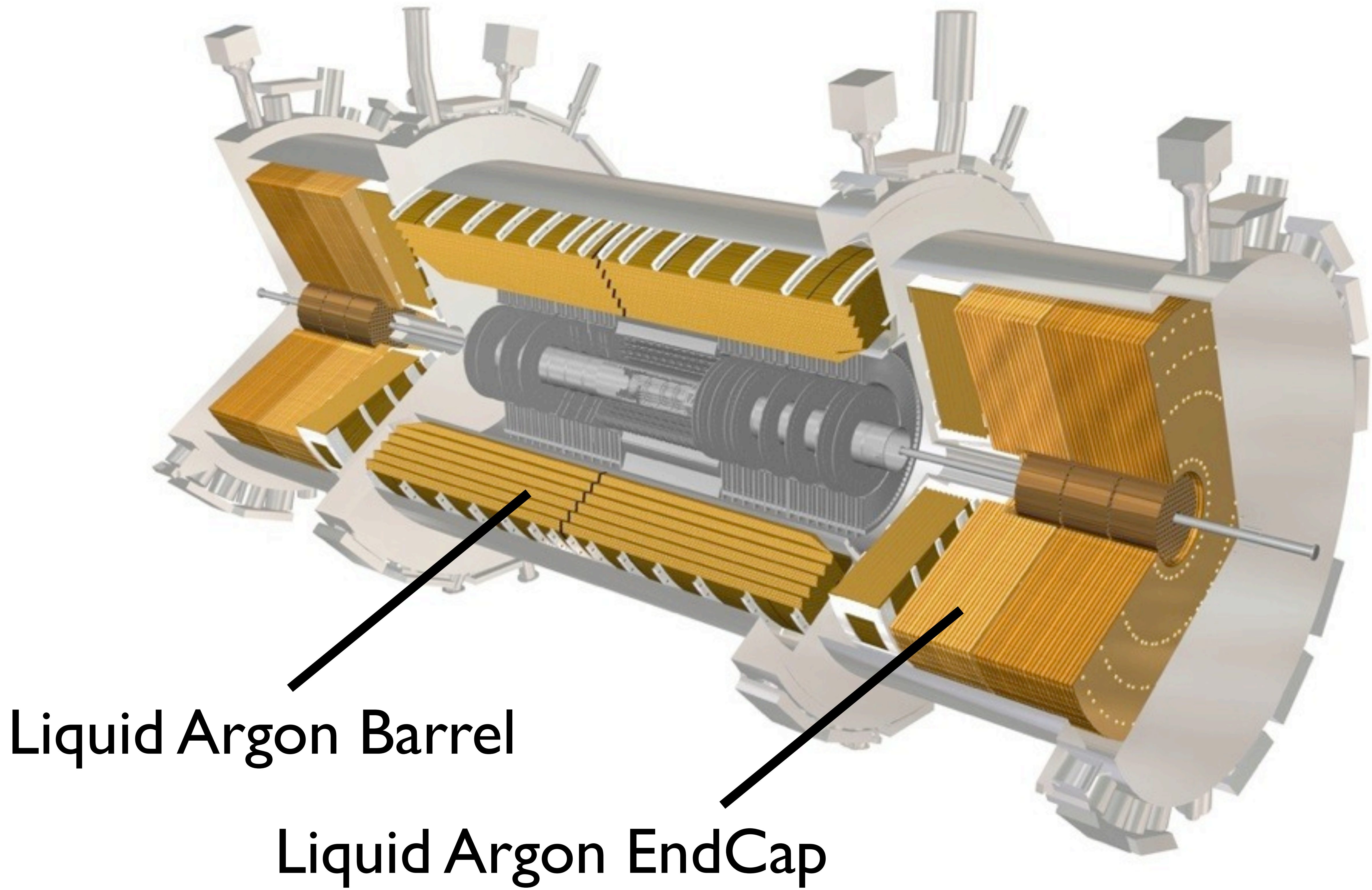
ATLAS Calorimeters



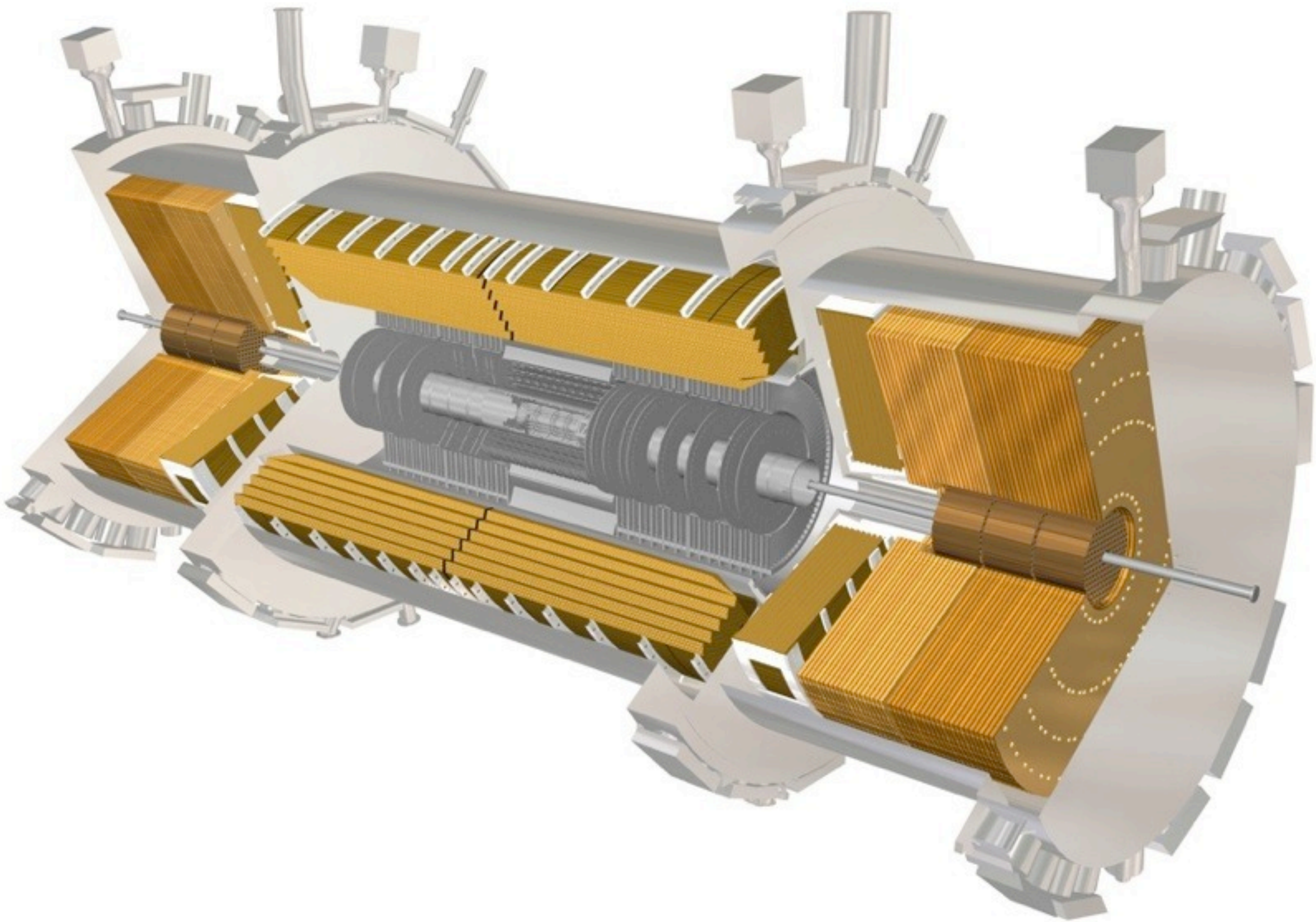
Liquid Argon Subsystems



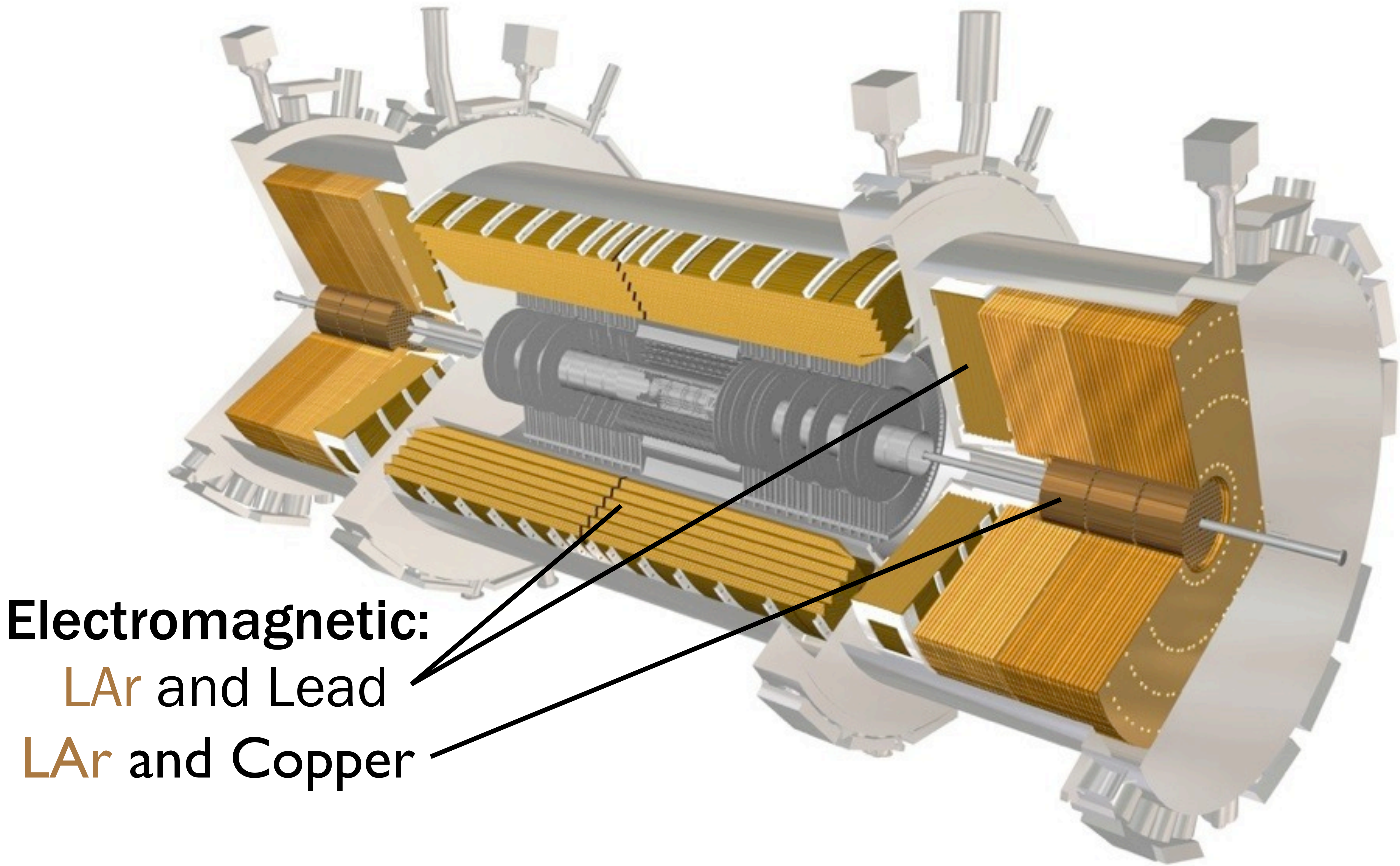
Liquid Argon Subsystems



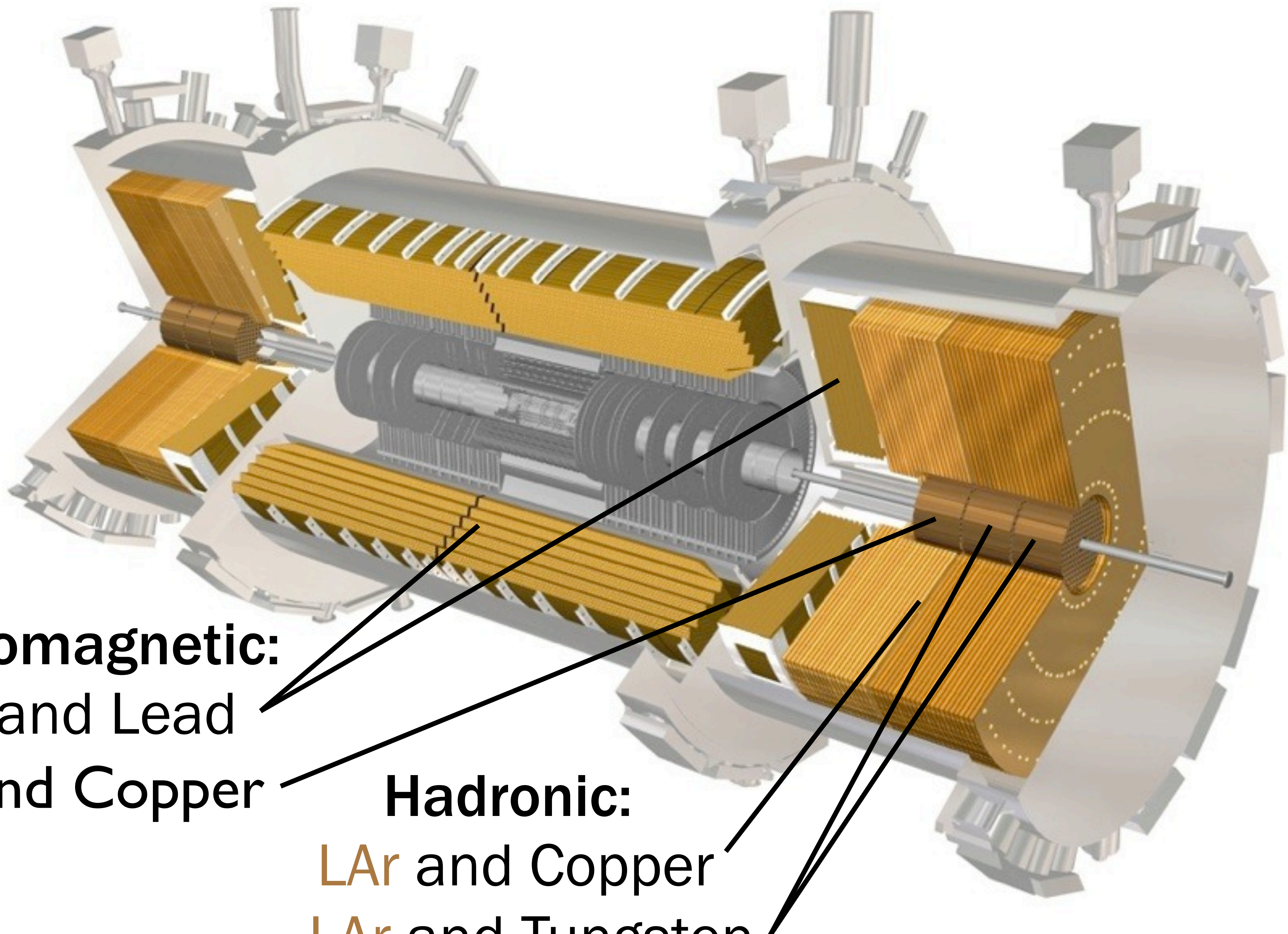
Liquid Argon Subsystems



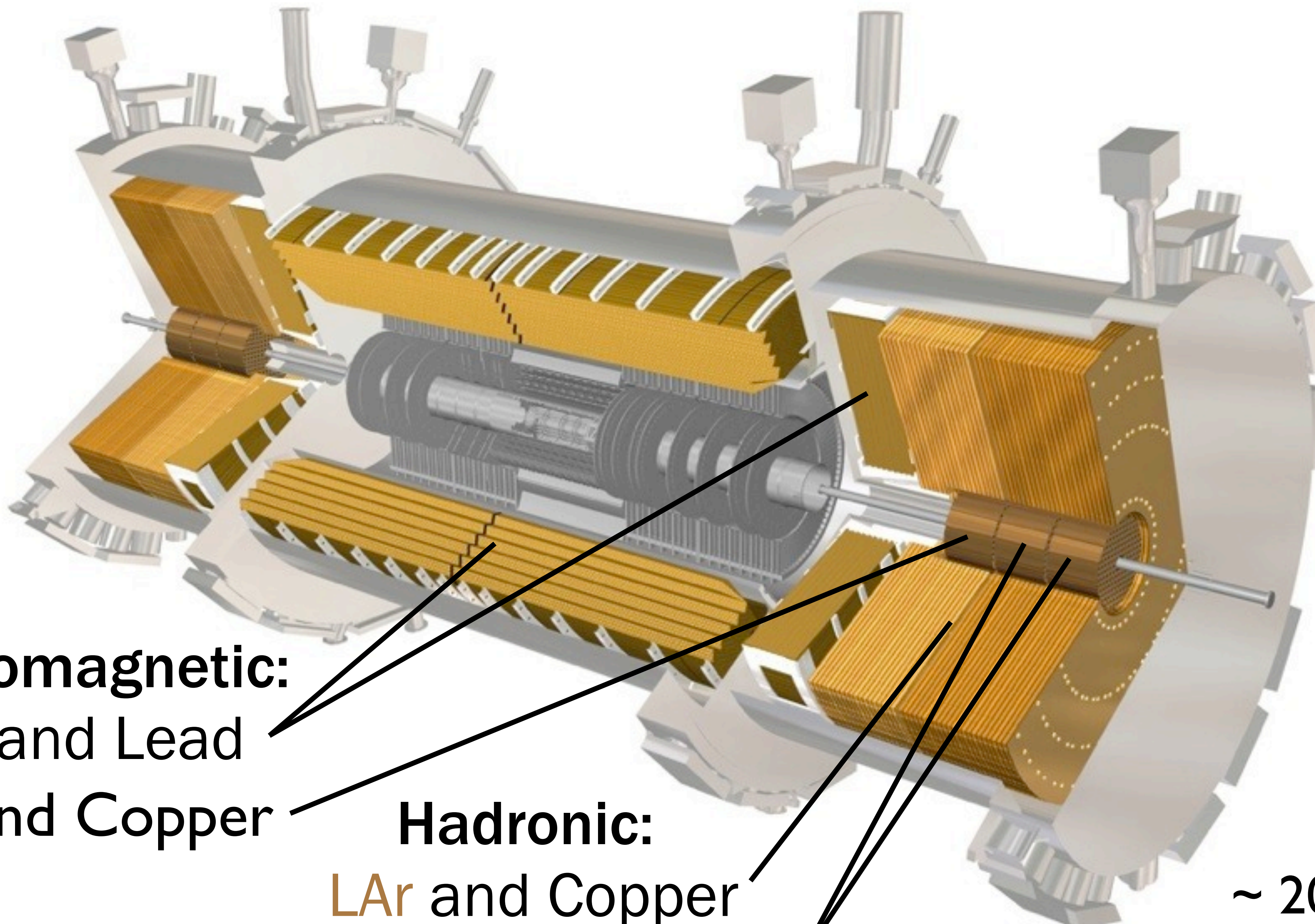
Liquid Argon Subsystems



Liquid Argon Subsystems



Liquid Argon Subsystems

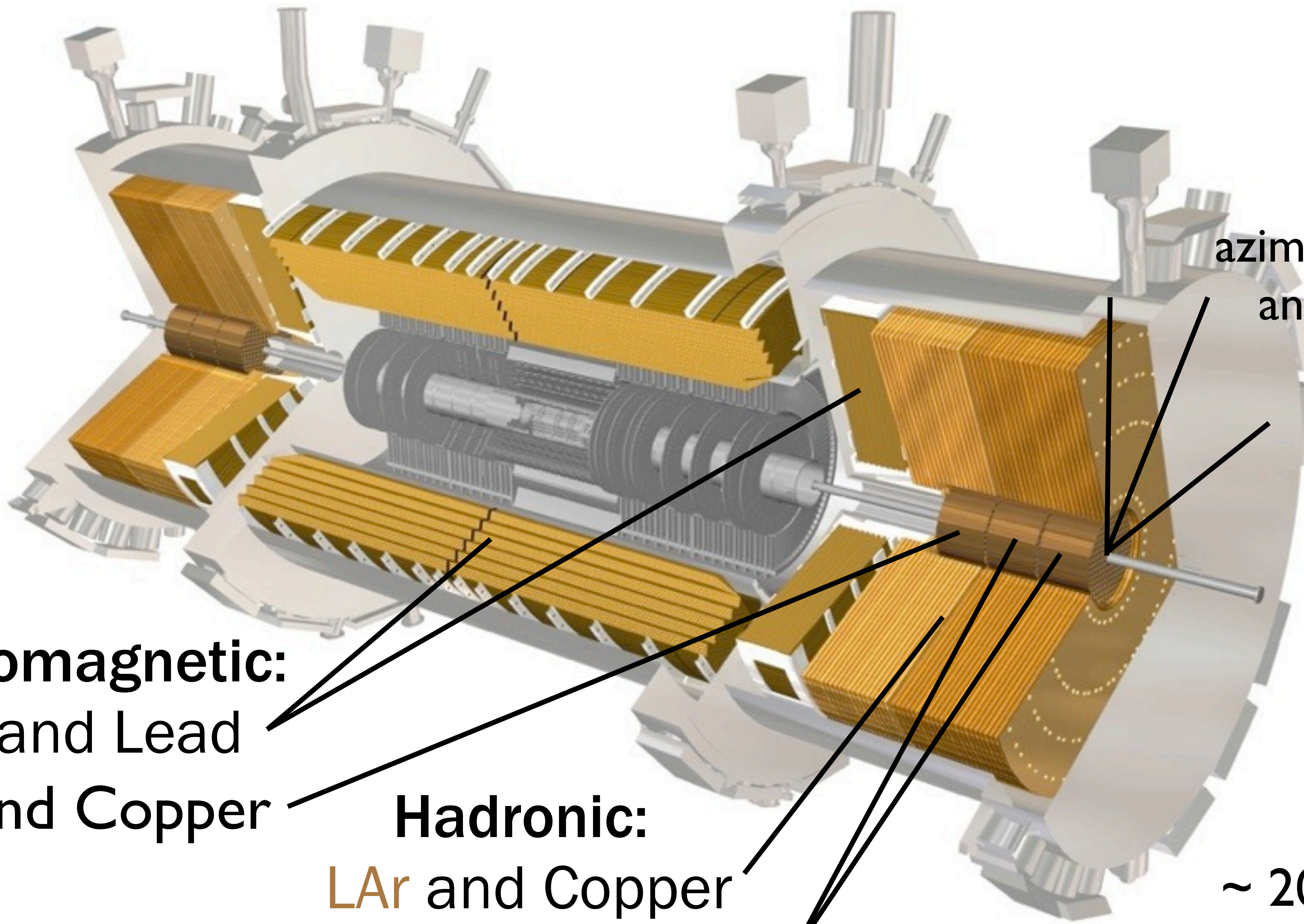


Electromagnetic:
LAr and Lead
LAr and Copper

Hadronic:
LAr and Copper
LAr and Tungsten

~ 200,000
channels

Liquid Argon Subsystems



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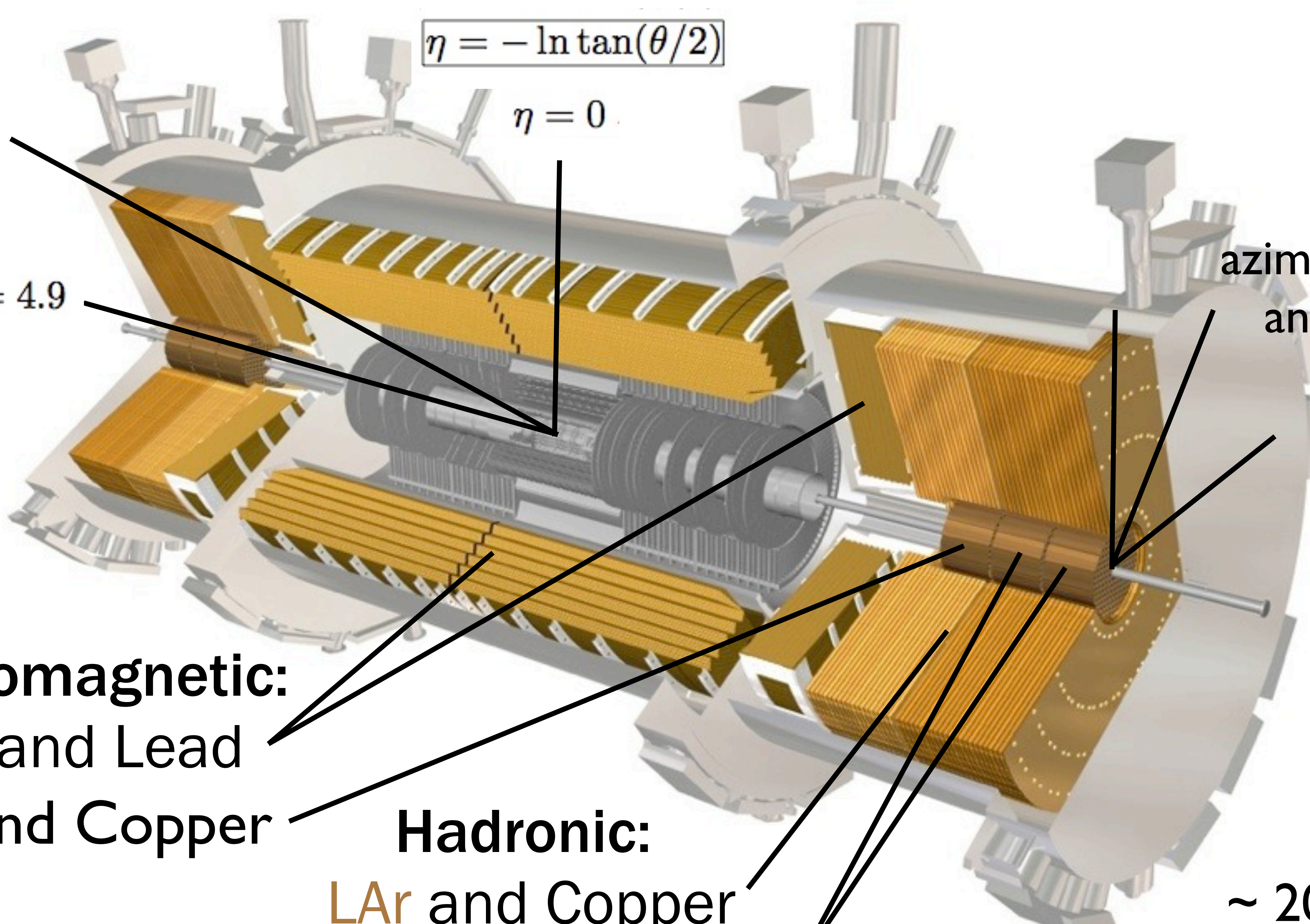
~ 200,000
channels

Liquid Argon Subsystems

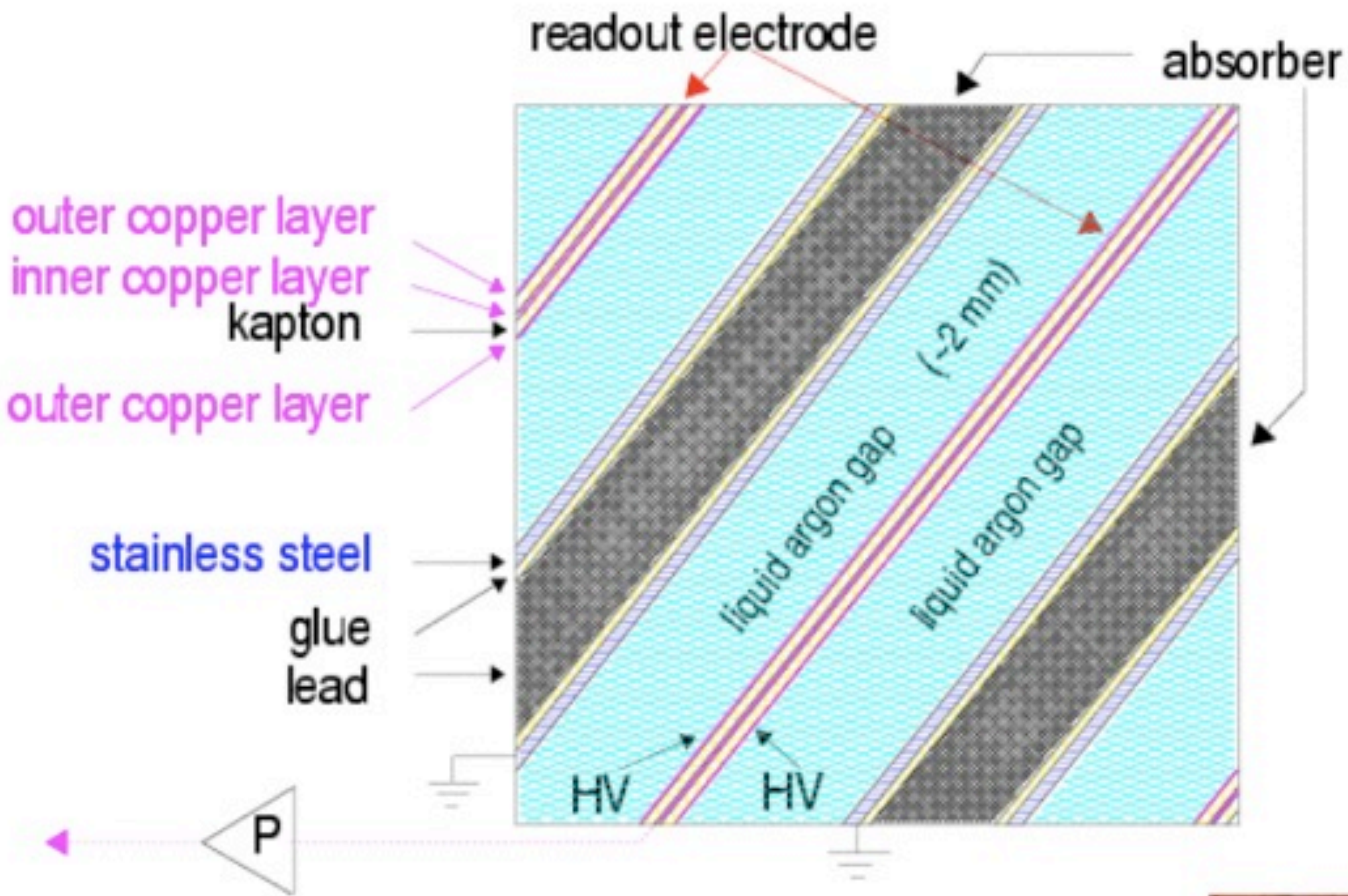


Electromagnetic:
LAr and Lead
LAr and Copper

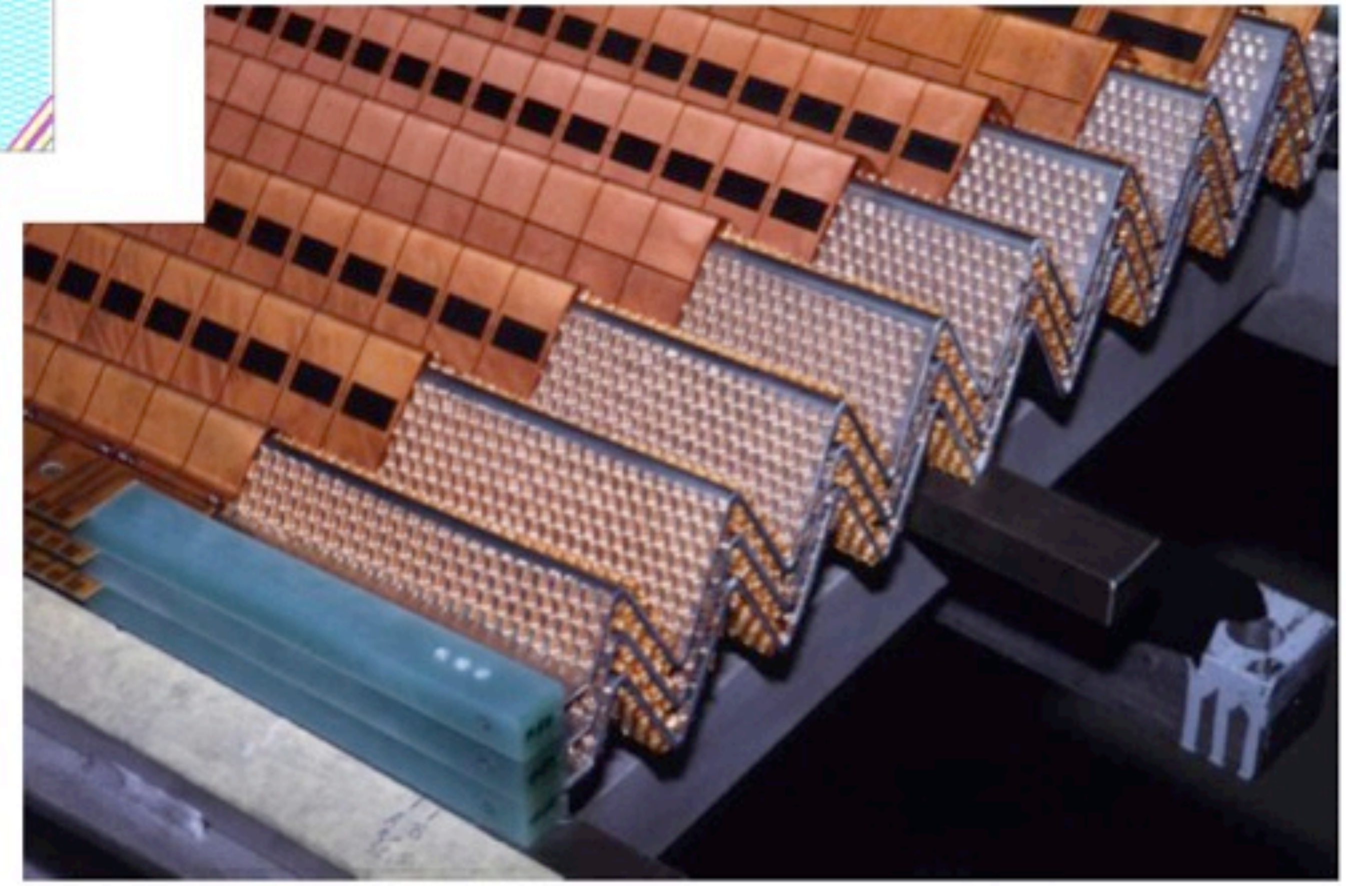
Hadronic:
LAr and Copper
LAr and Tungsten

~ 200,000 channels

How is the signal collected?

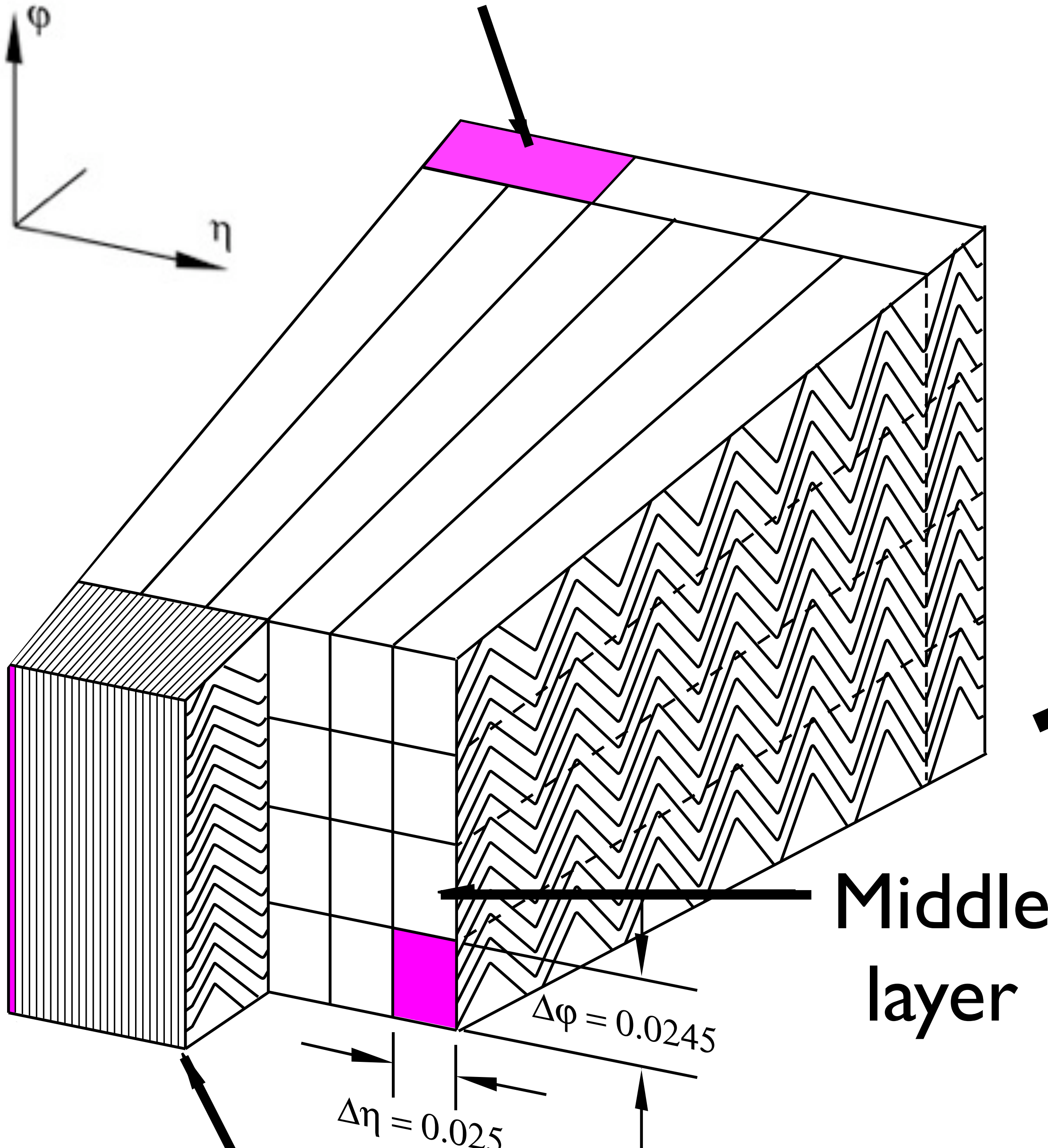


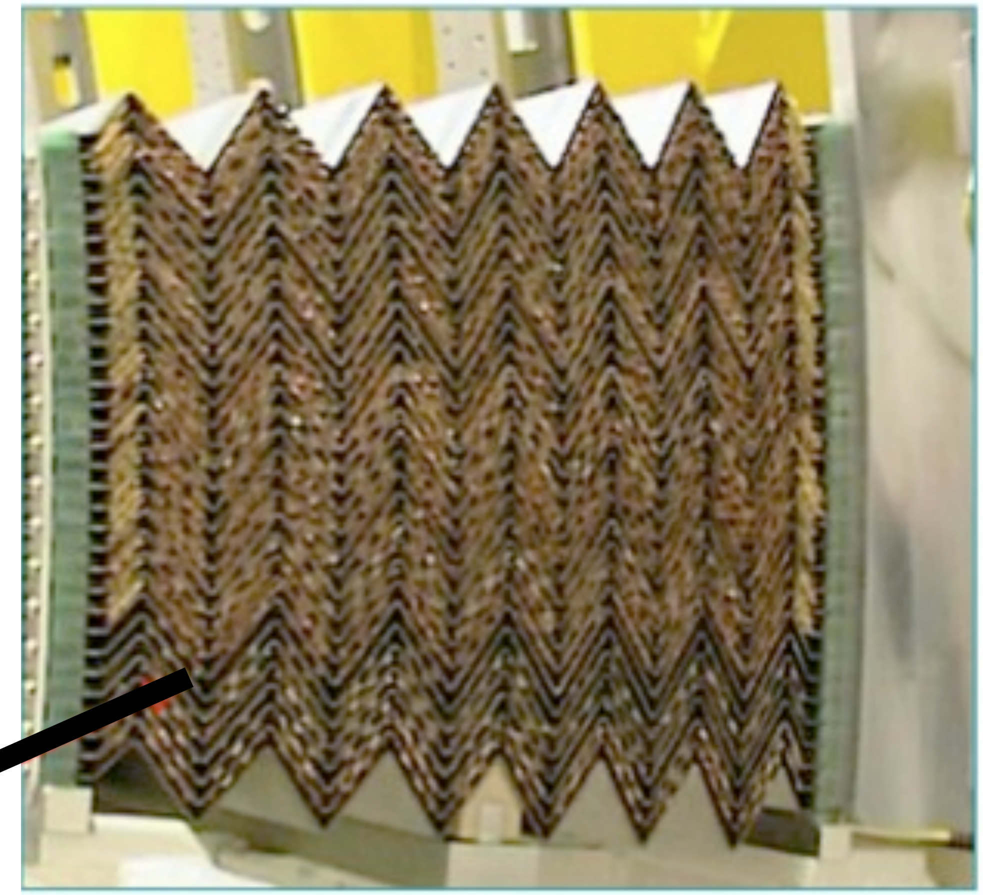
Particles ionize the Argon, signal is read out using electrodes



Precision required controlling lead thickness to ~10 microns

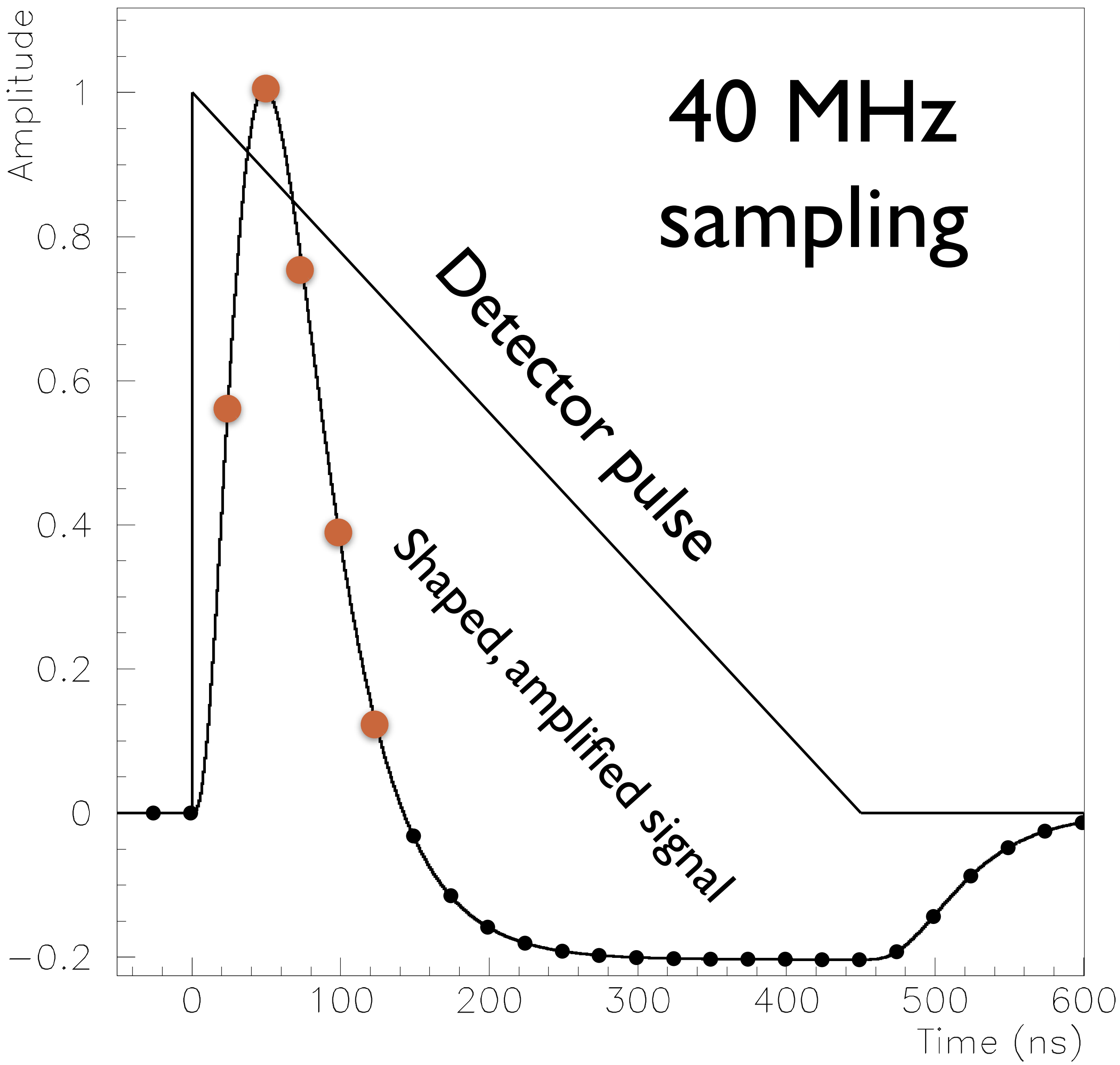
Segmentation of LAr Barrel





Accordion shaped Lead absorbers

Signal shape



$$A_{max} = \sum_{i=0}^{N_{samples}} a_i (s_i - p)$$

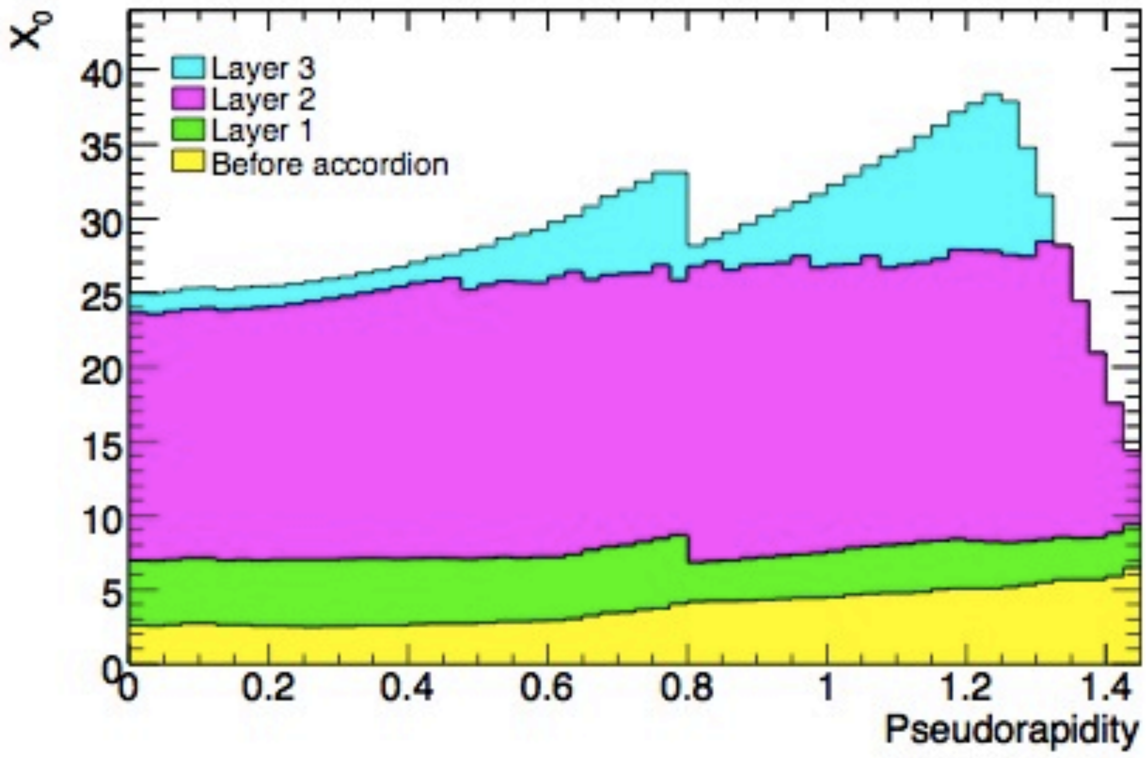
$$A_{max} \cdot \Delta t = \sum_{i=0}^{N_{samples}} b_i (s_i - p)$$

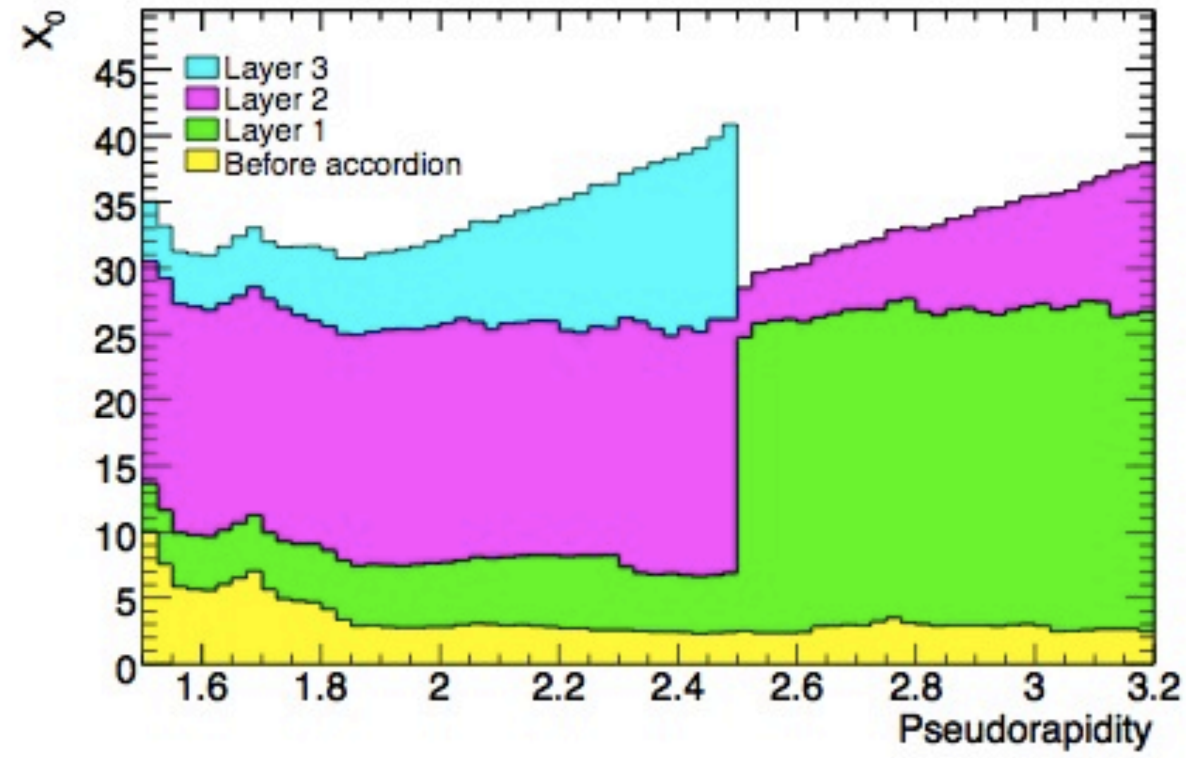
Use 5 samples s_i with pedestal values p

a_i, b_i are optimal filtering coefficients to improve precision

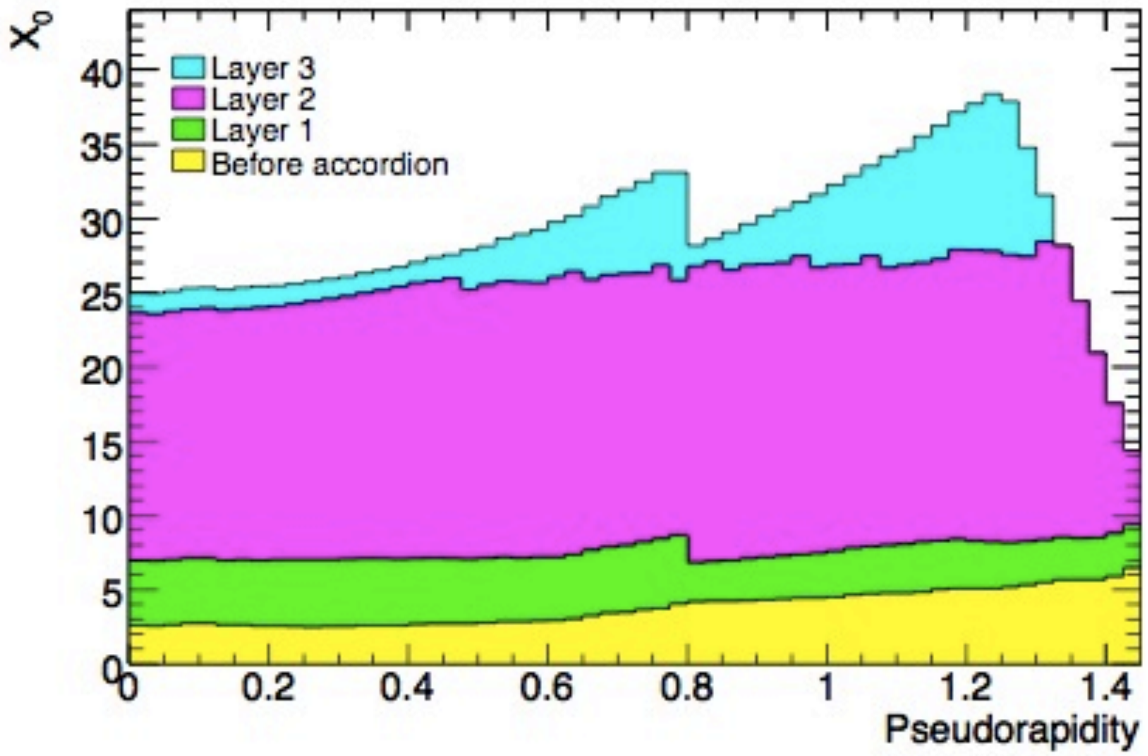
For reference: the response of the EM cal (2 mm drift gaps) to electrons results in a current of 2-3 µA/GeV, and the drift time is about 450 ns for HV = 2 kV.

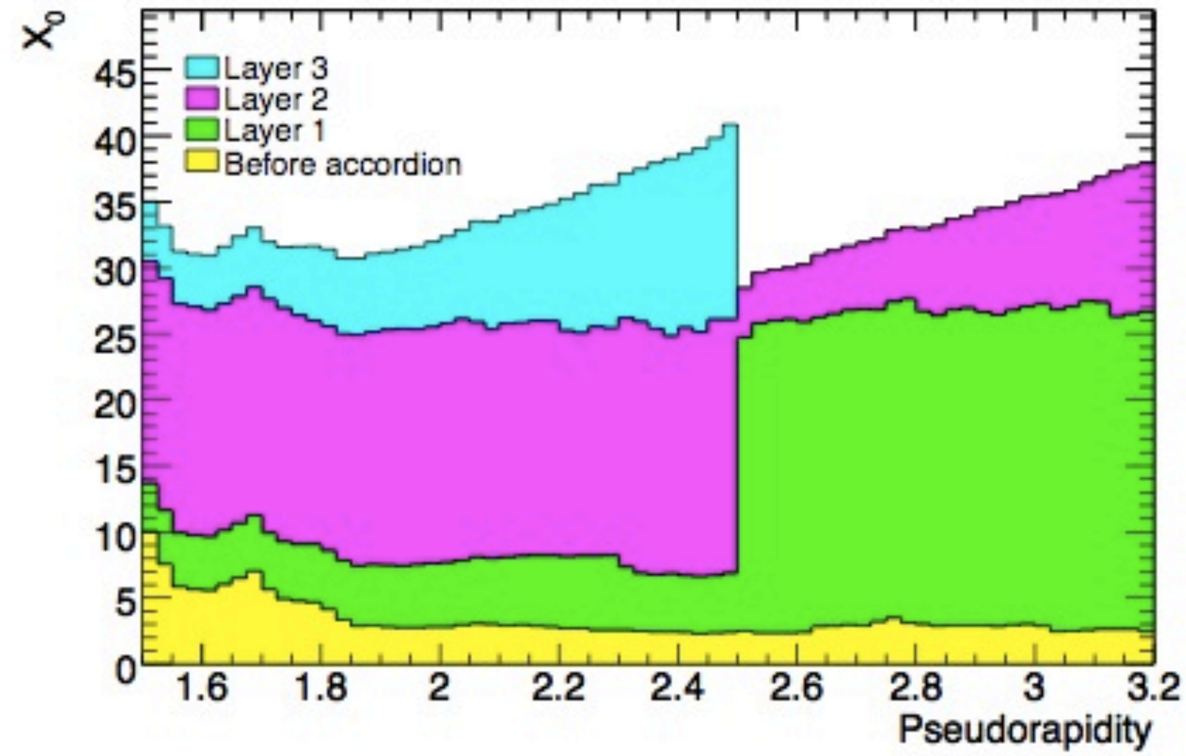
Material before/in EM

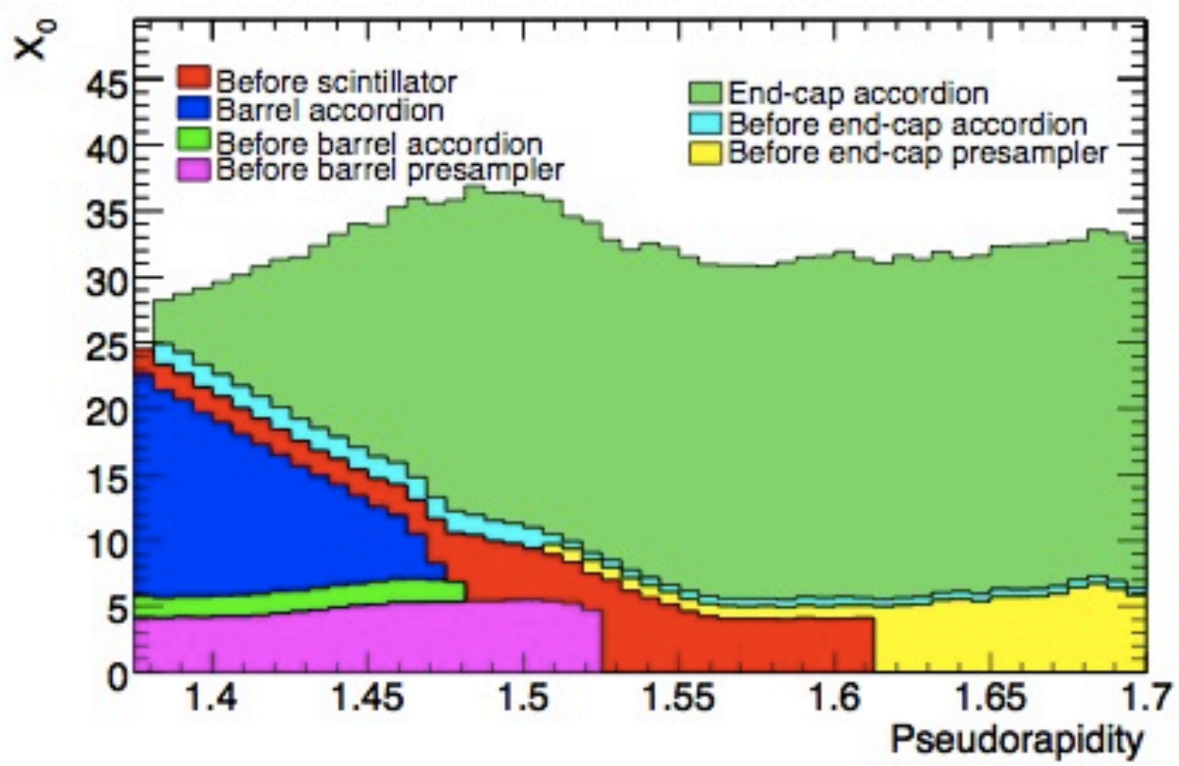




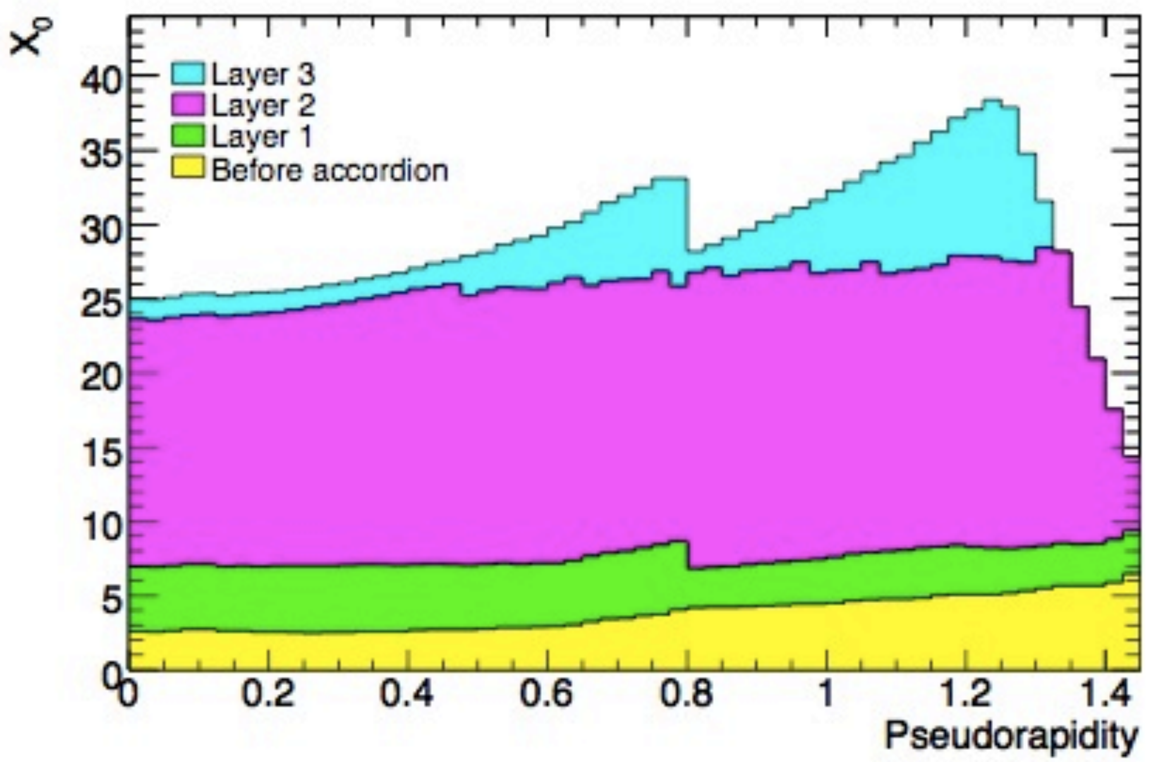
Material before/in EM

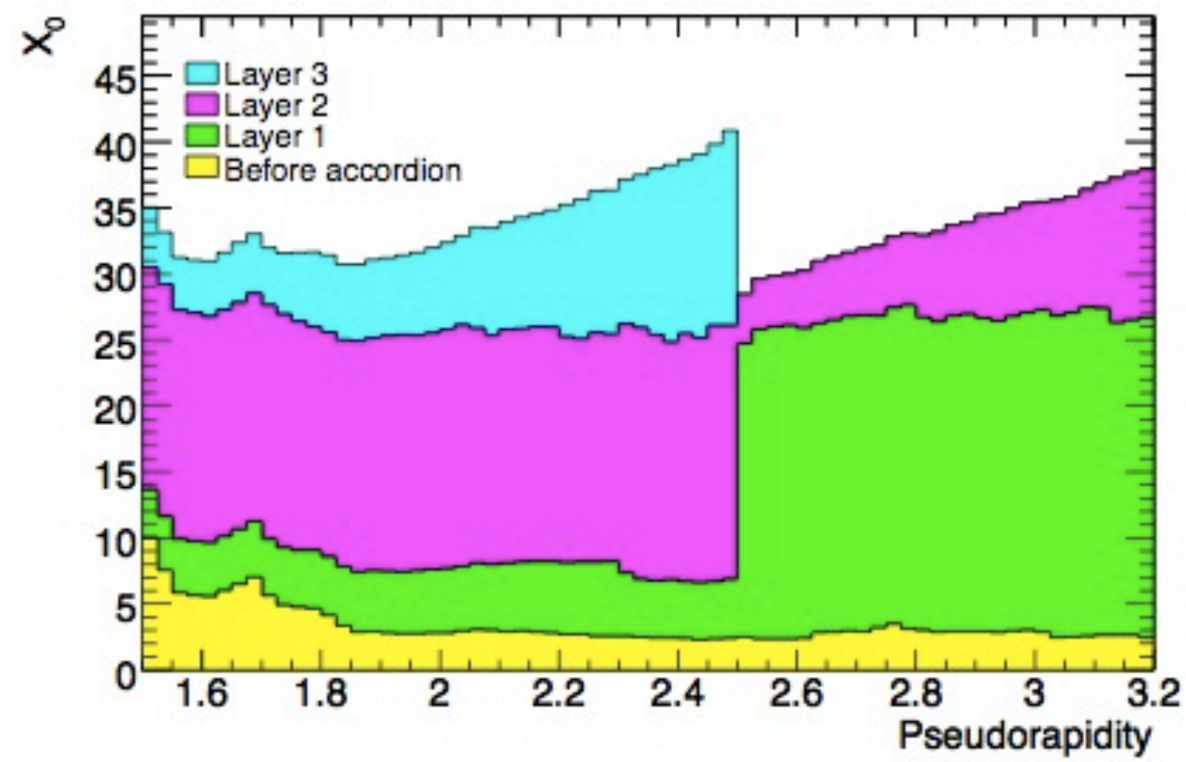


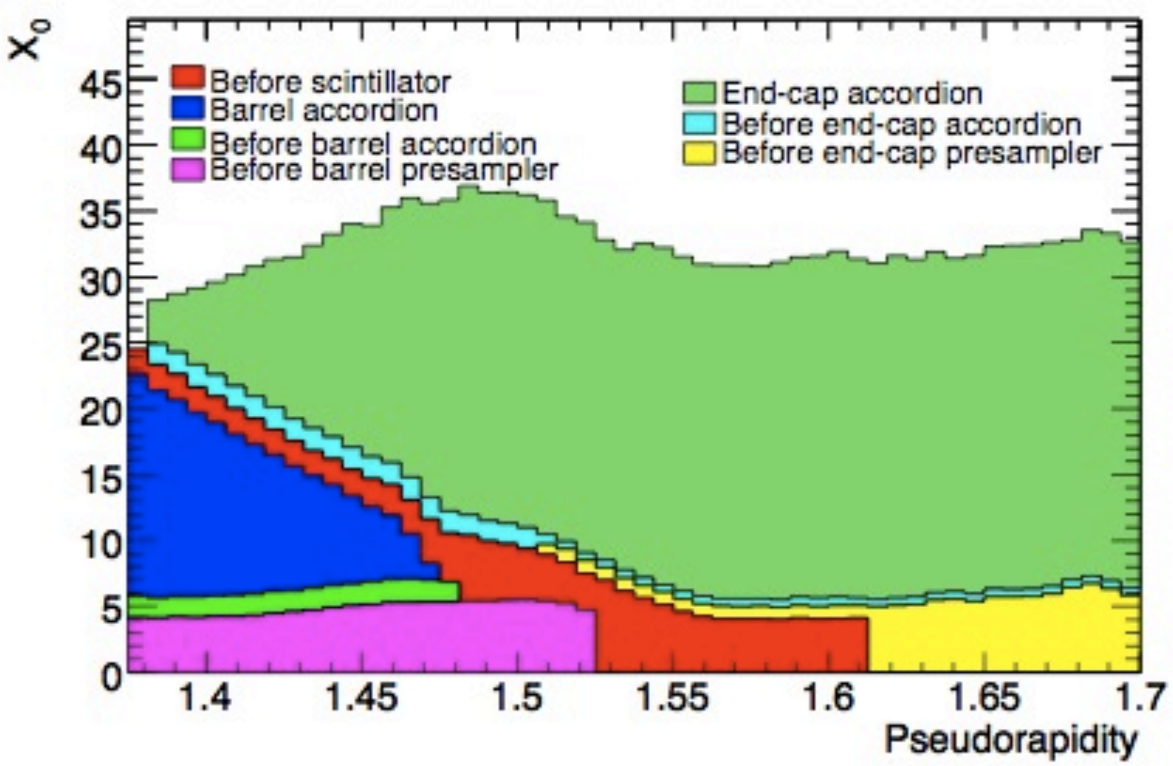




Material before/in EM

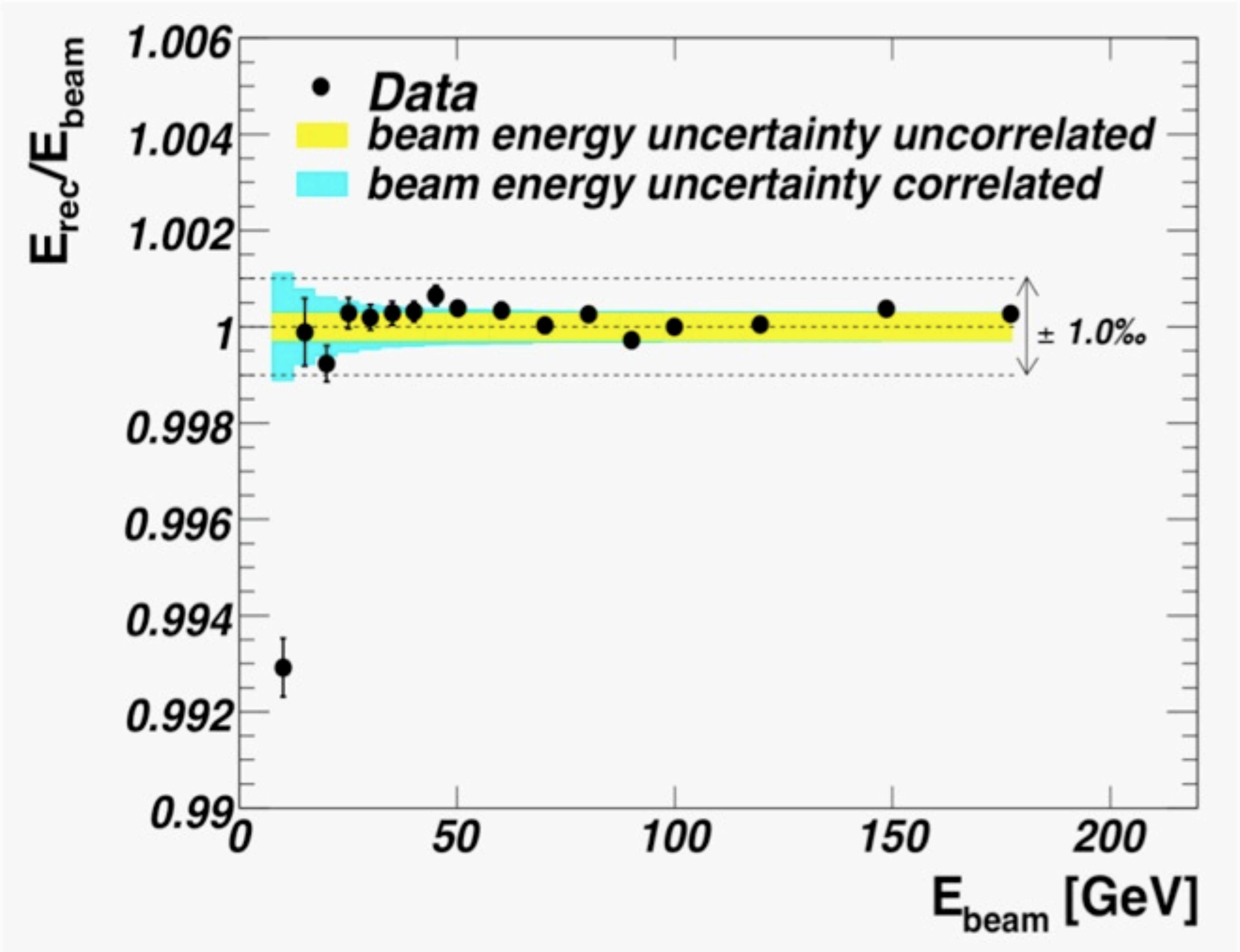






Standard electron/ photon cuts remove this area from consideration.

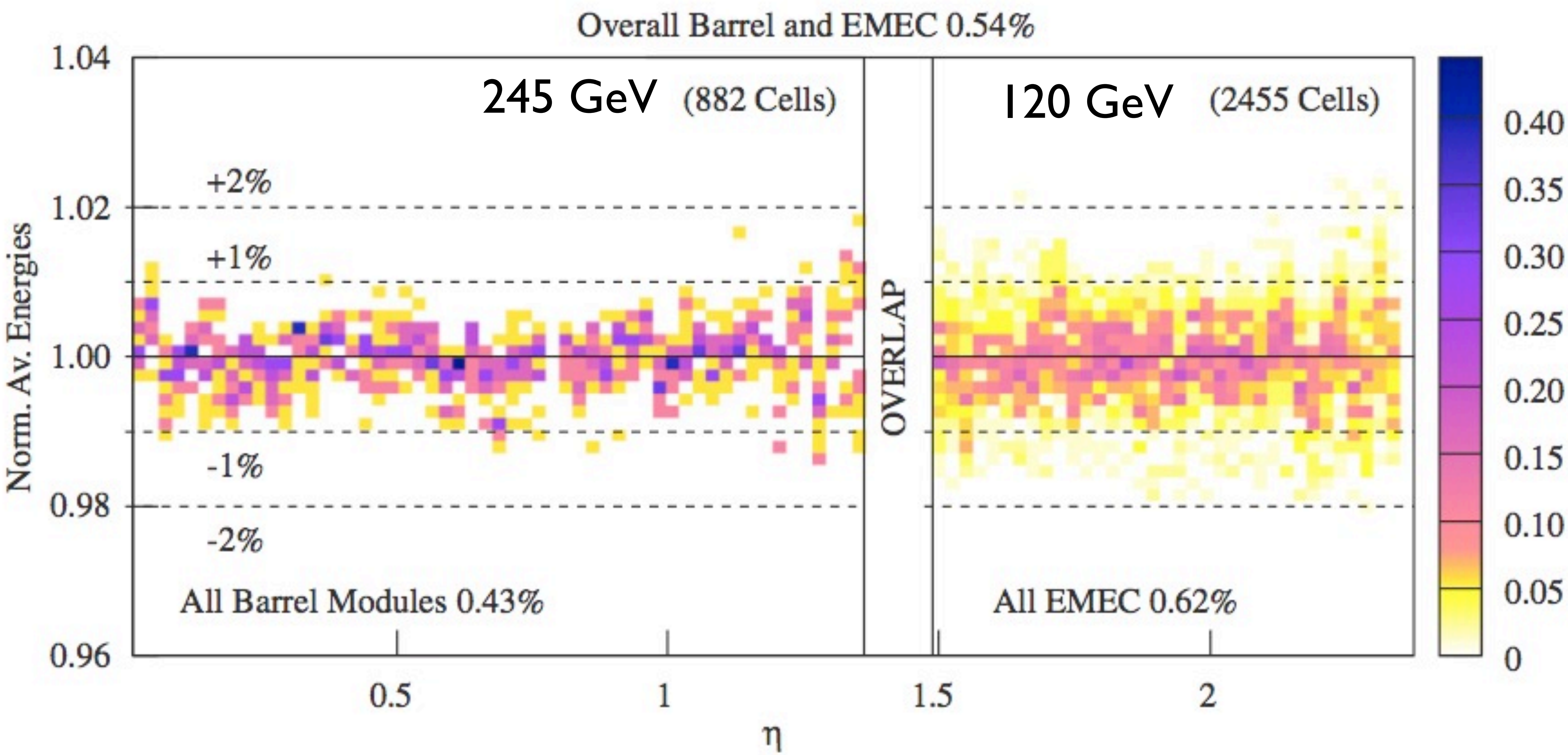
Linearity



Better than 1 per mill linearity across EM Barrel

Nuclear Instruments and Methods in Physics Research A 568 (2006) 601–623

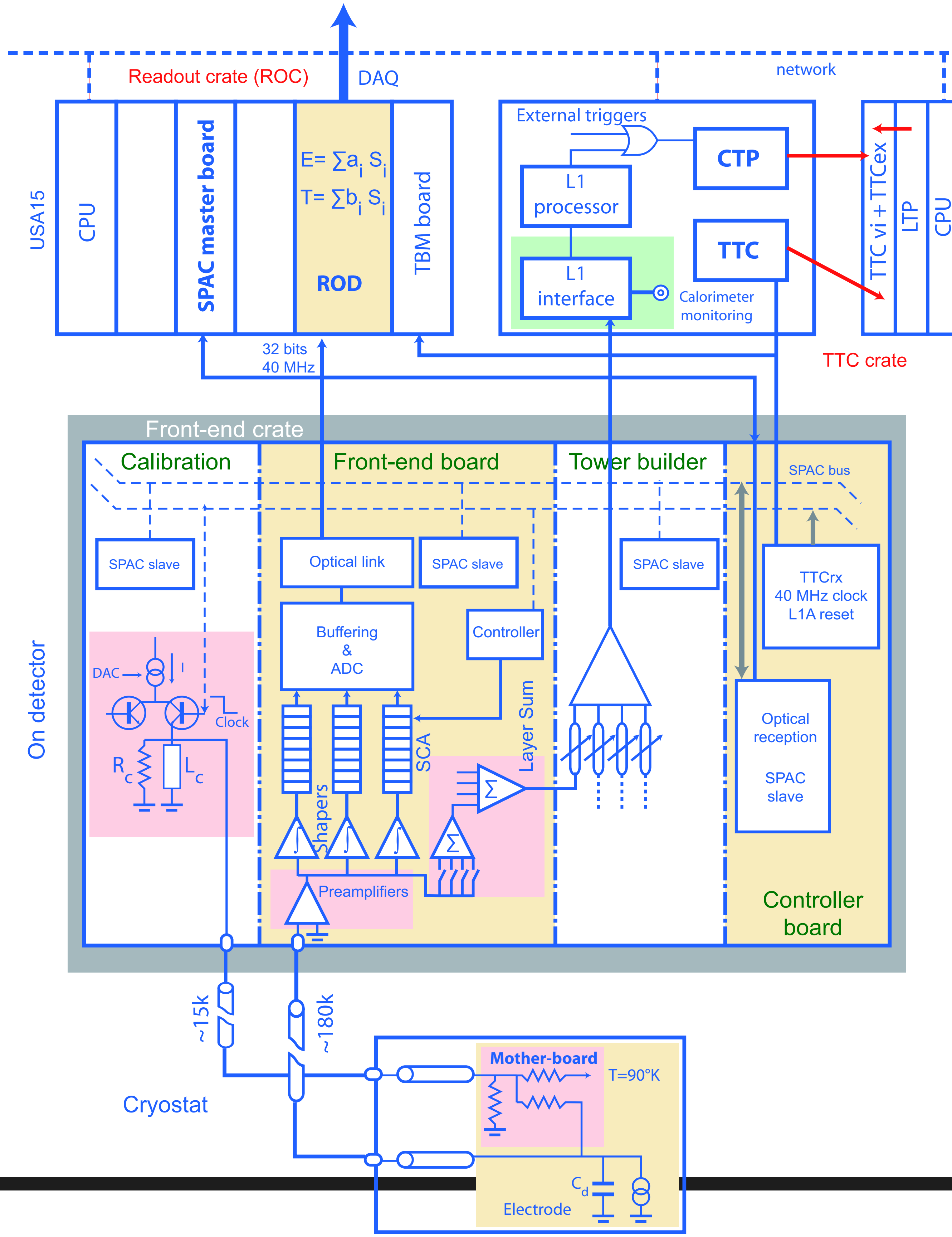
Uniformity



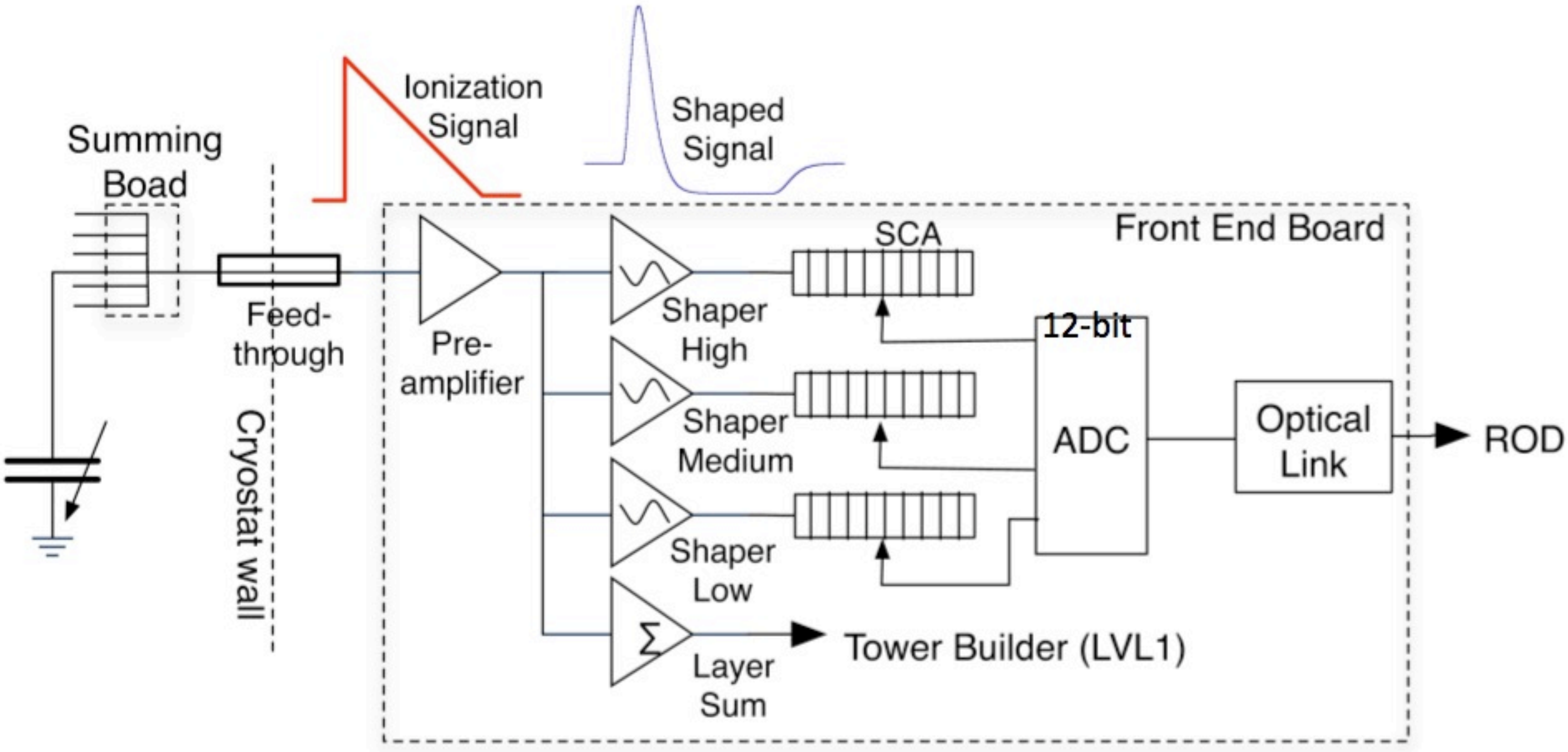
Better than 1% uniformity across EM Barrel and Endcap

Nuclear Instruments and Methods in Physics Research A 582 (2007) 429–455

LAr Readout Chain



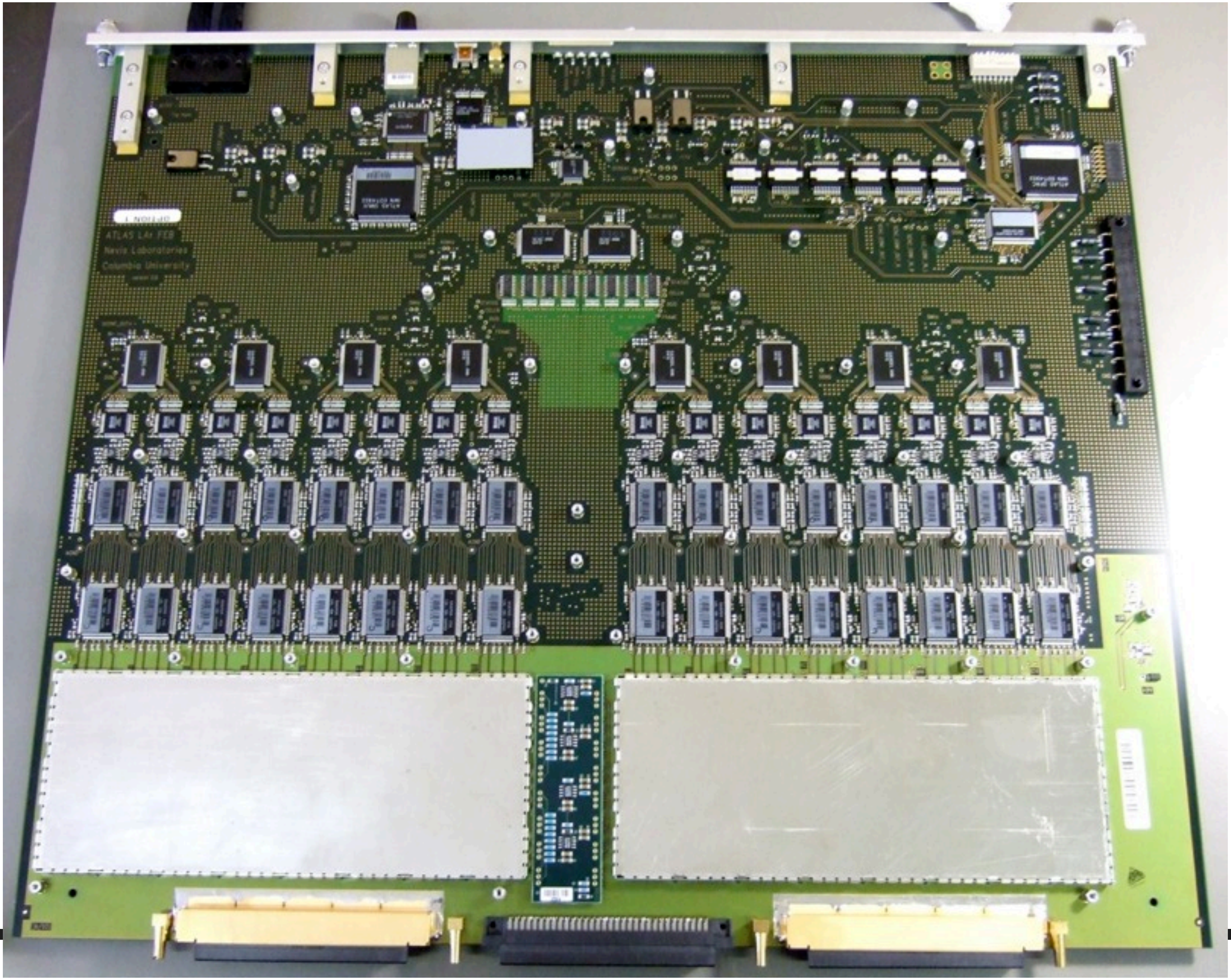
FEB schematic



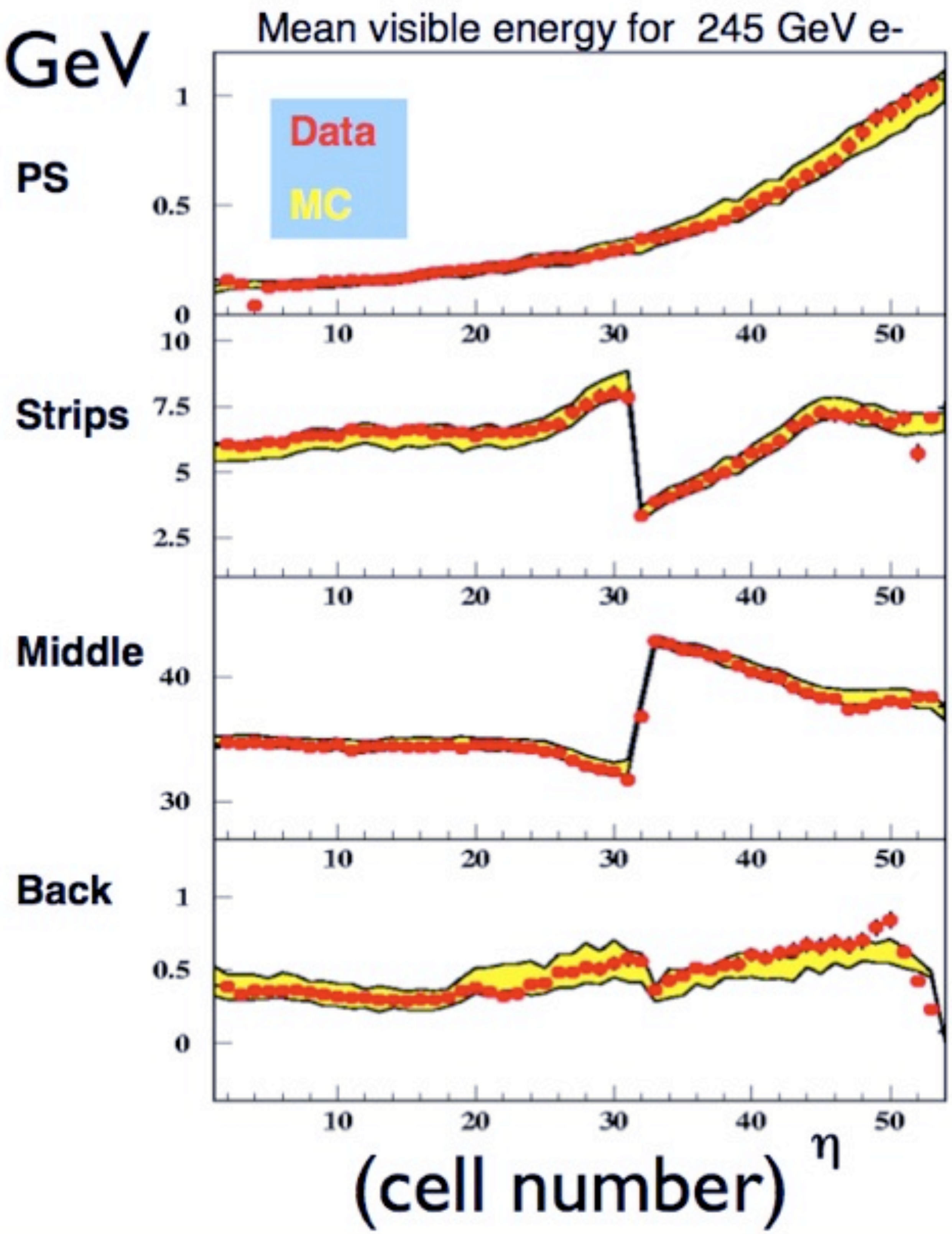
Shaper is an analog RC-$(CR)^2$ filter:

- Remove long tail, limit band-width to reduce noise

Front End Board



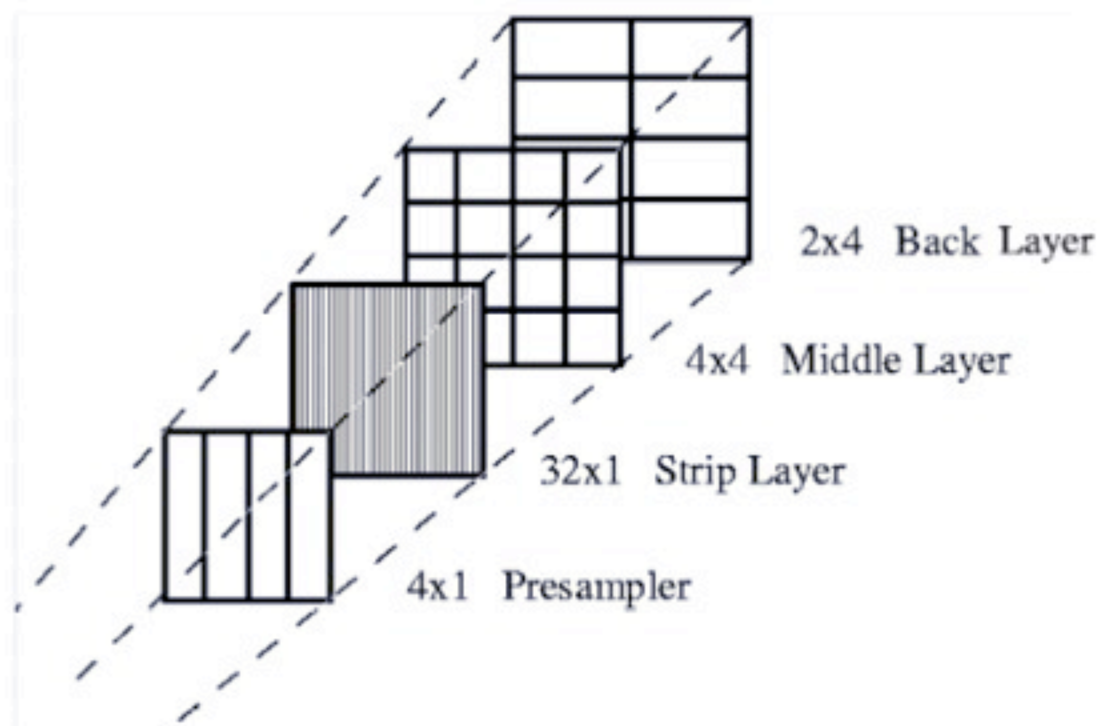
How much energy is deposited?



Deposited energies = f(η) in the PS and in the 3 calorimeter compartments before applying the correction factors

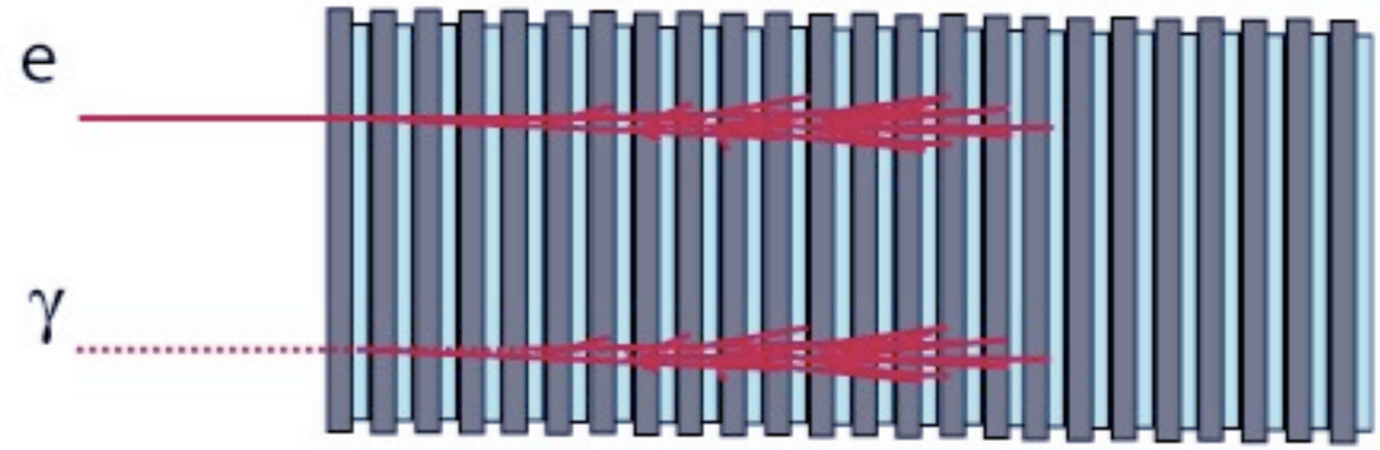
Excellent Data / MC agreement

in all samplings

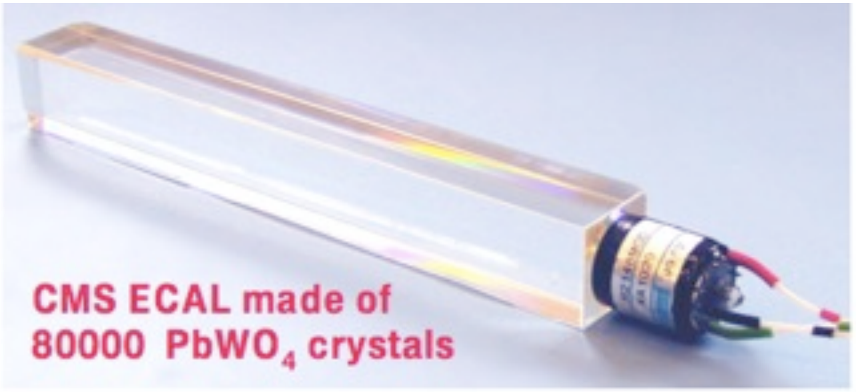


Sampling vs. Non-sampling

- "lead-scintillator sandwich" calorimeter



- exotic crystals (BGO, PbW, ...)



ATLAS vs CMS – ECAL

ATLAS EM Calorimeter	CMS EM Calorimeter
Lead/LAr sampling	PbWO4
Moliere radius 10 cm	Moliere radius 2.2 cm
Outside solenoid: more material in front	Inside solenoid: less material in front
Longitudinal segmentation	No long. segementation
Challenges: slow response time, lead must be precisely machined	Challenges: temperature and radiation sensitivity
$\sigma_E/E = (10.2 \pm 0.4)\%/\sqrt{E} \oplus (0.2 \pm 0.1)\%$	$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.8\%}{\sqrt{E}}\right)^2 + \left(\frac{0.12}{E}\right)^2 + (0.30\%)^2$

CMS Resolution

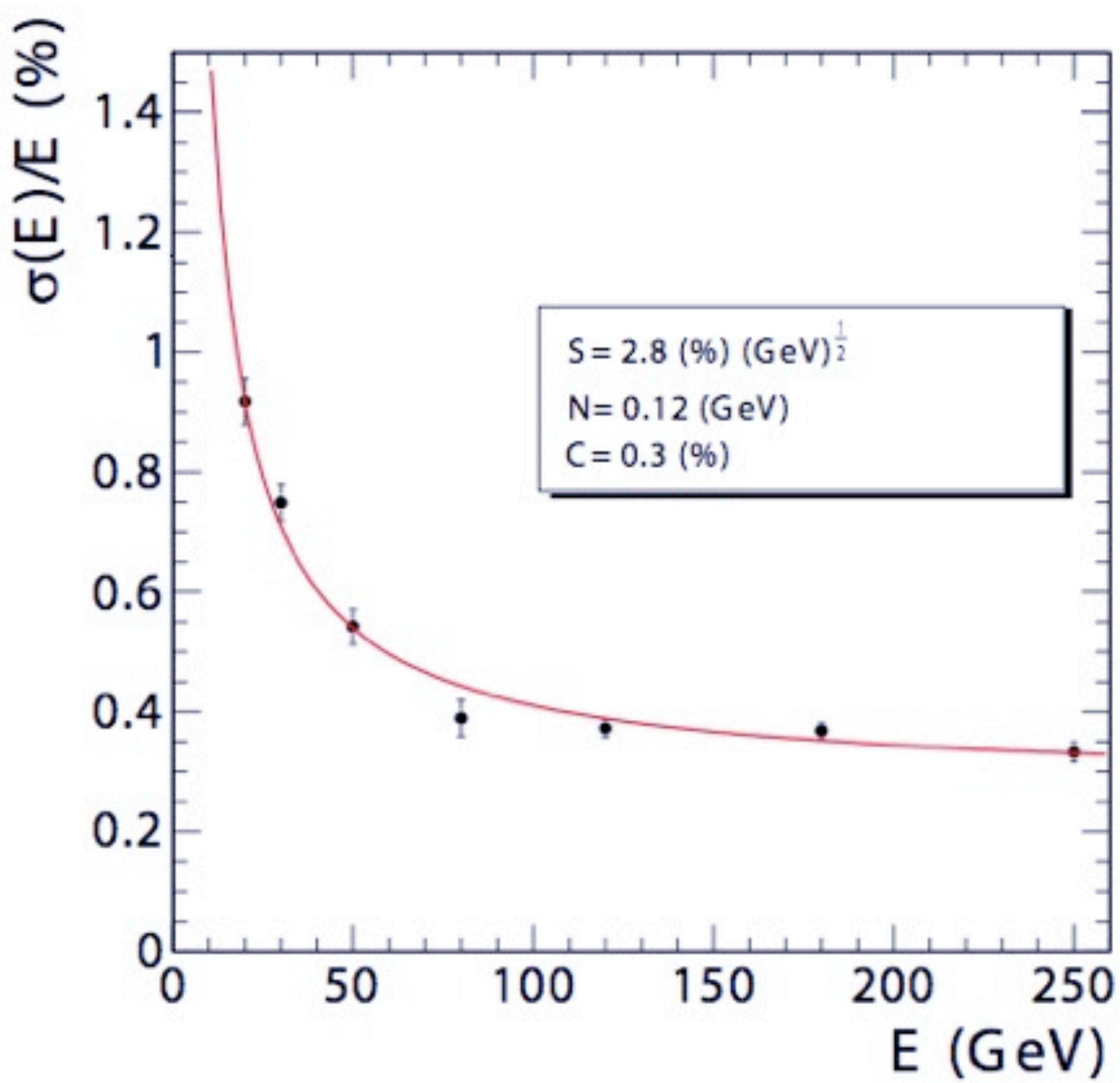


Figure 3: ECAL energy resolution, $\sigma(\mathrm{E})/\mathrm{E}$, as a function of electron energy as measured from a beam test. The energy was measured in an array of 3×3 crystals with an electron impacting the central crystal. The points correspond to events taken restricting the incident beam to a narrow ($4 \times 4\ \mathrm{mm}^2$) region. The stochastic (S), noise (N), and constant (C) terms are given.

TABLE 8 Main parameters of the ATLAS and CMS electromagnetic calorimeters

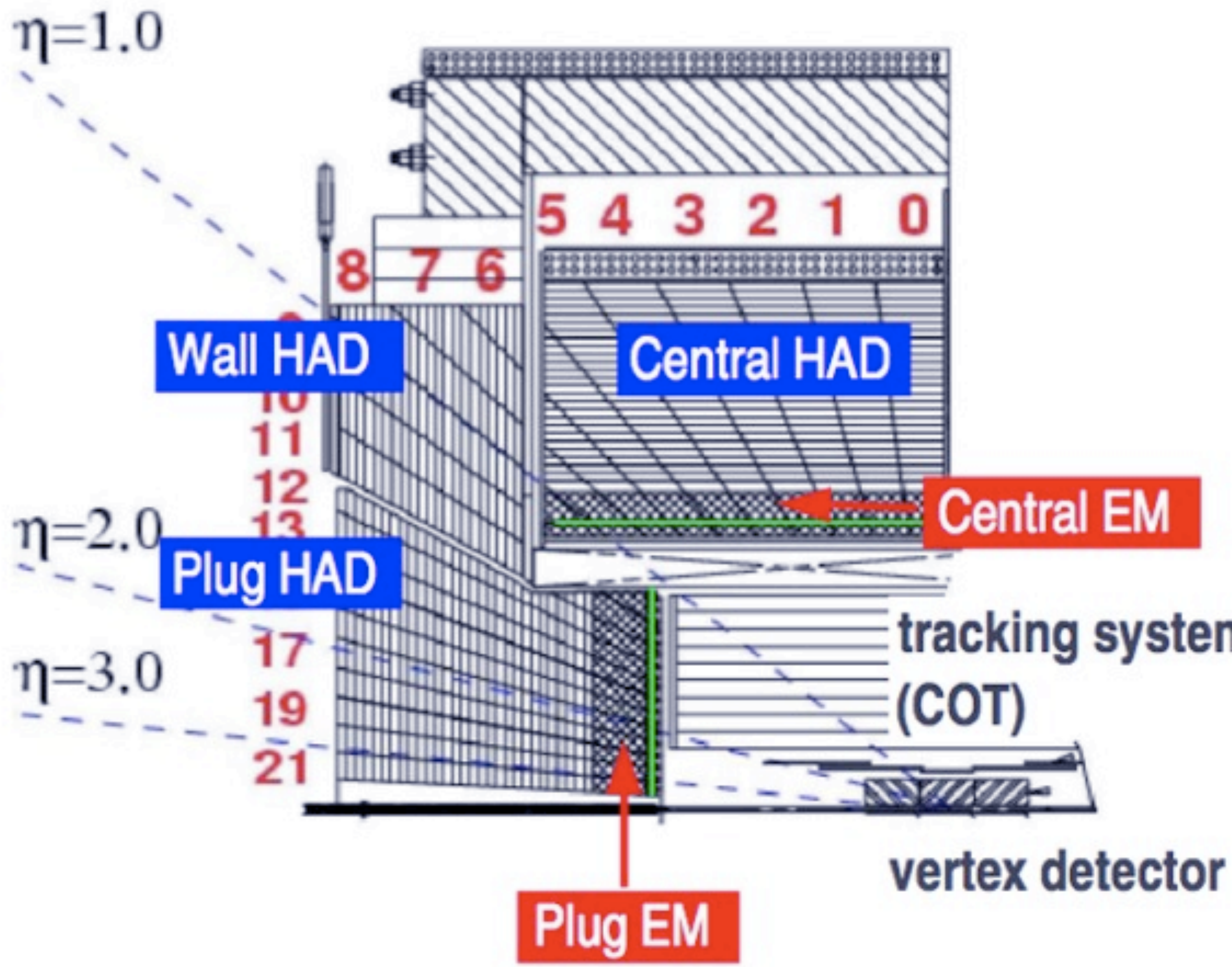
	ATLAS		CMS	
Technology	Lead/LAr accordion		$PbWO_4$ scintillating crystals	
Channels	Barrel	End caps	Barrel	End caps
	110,208	63,744	61,200	14,648
Granularity	$\Delta\eta \times \Delta\phi$		$\Delta\eta \times \Delta\phi$	
Presampler	0.025×0.1	0.025×0.1		
Strips/ Si-preshower	0.003×0.1	0.003×0.1 to 0.006×0.1		32×32 Si-strips per 4 crystals
Main sampling	0.025×0.025	0.025×0.025	0.017×0.017	0.018×0.003 to 0.088×0.015
Back	0.05×0.025	0.05×0.025		
Depth	Barrel	End caps	Barrel	End caps
Presampler (LAr)	10 mm	2×2 mm		
Strips/ Si-preshower	$\approx 4.3\ X_0$	$\approx 4.0\ X_0$		$3\ X_0$
Main sampling	$\approx 16\ X_0$	$\approx 20\ X_0$	$26\ X_0$	$25\ X_0$
Back	$\approx 2\ X_0$	$\approx 2\ X_0$		
Noise per cluster	250 MeV	250 MeV	200 MeV	600 MeV
Intrinsic resolution	Barrel	End caps	Barrel	End caps
Stochastic term a	10%	10 to 12%	3%	5.5%
Local constant term b	0.2%	0.35%	0.5%	0.5%

Note the presence of the silicon preshower detector in front of the CMS end-cap crystals, which have a variable granularity because of their fixed geometrical size of $29 \times 29\ mm^2$. The intrinsic energy resolutions are quoted as parametrizations of the type $\sigma(E)/E = a/\sqrt{E} \oplus b$. For the ATLAS EM barrel and end-cap calorimeters and for the CMS barrel crystals, the numbers quoted are based on stand-alone test-beam measurements.

The CDF Calorimeter

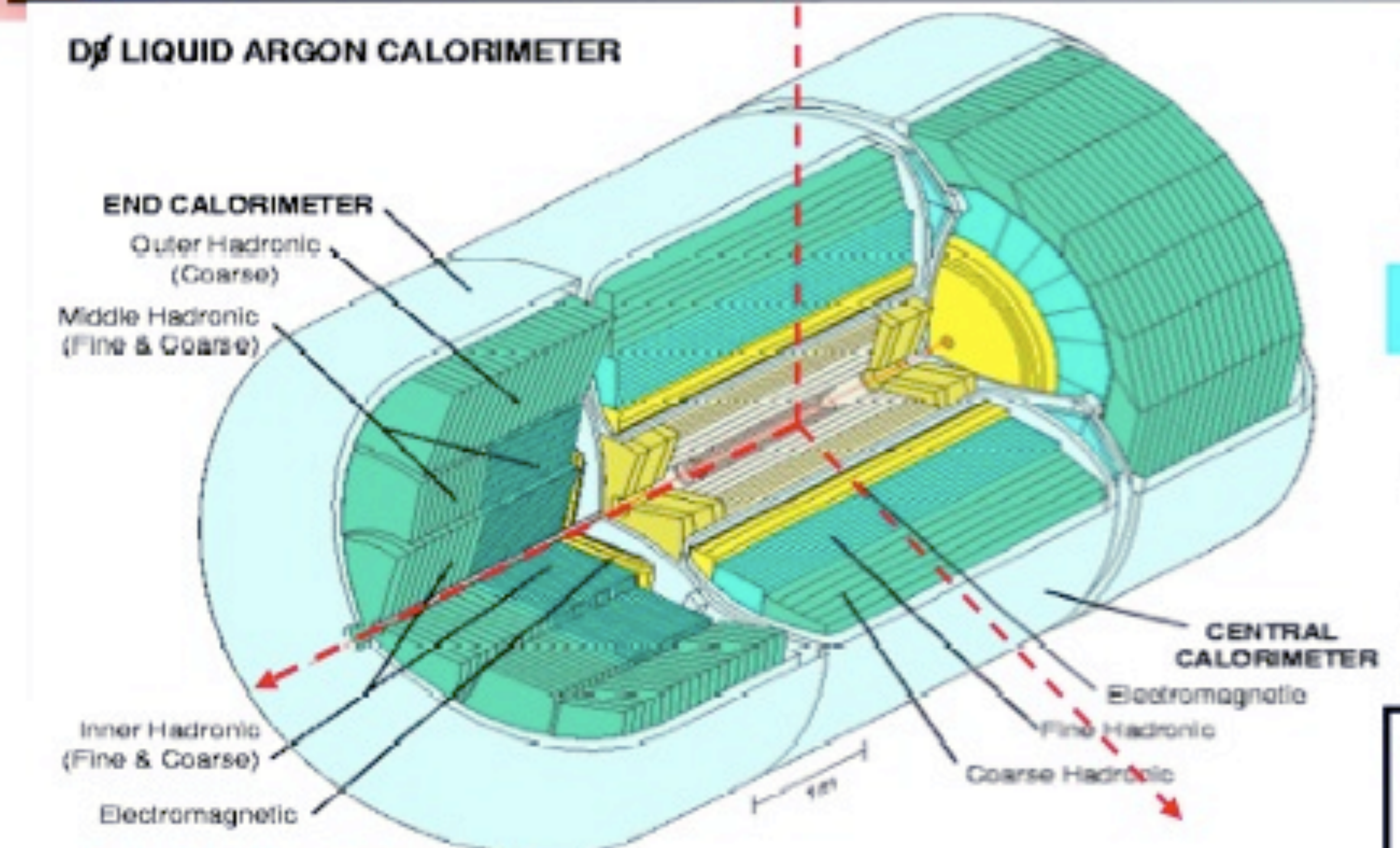
- Sampling calorimeter:
  - scintillating tiles + WLS
  - lead/iron absorbers
  - projective tower geometry
- Divided in Central / Wall / Plug part

		Central	Plug
EM	thickness	$19\,X_0,\ 1\lambda$	$21\,X_0,\ 1\lambda$
	sample(Pb)	$0.6\,X_0$	$0.8\,X_0$
	sample(scint.)	5 mm	4.5 mm
	resolution	$\frac{13.5\%}{\sqrt{E}} \oplus 2\%$	$\frac{14.5\%}{\sqrt{E}} \oplus 1\%$
HAD	thickness	$4.5\,\lambda$	$7\,\lambda$
	sample(Fe)	25-50 mm	50 mm
	sample(scint.)	10 mm	6 mm
	resolution	$\frac{50\%}{\sqrt{E}} \oplus 3\%$	$\frac{70\%}{\sqrt{E}} \oplus 4\%$



- Pseudorapidity coverage: $|\eta| < 3.6$
- Granularity: 24(48) wedges per ring

DØ Calorimeter Overview



Drift time 430 ns

Cu pad readout on 0.5 mm
G10 with resistive coat epoxy

- Liquid argon sampling
  - Stable, uniform response, rad. hard, fine spatial seg.
  - LAr purity important
- Uranium absorber (Cu or Steel for coarse hadronic)
  - Compensating $e/\pi \sim 1$, dense $\Rightarrow$ compact
- Uniform, hermetic with full coverage
  - $|\eta| < 4.2$ ($\theta \approx 2^o$), $\lambda_{int} > 7.2$ (total)
- **Energy Resolution**
  - e: $\sigma_E / E = 15\% / \sqrt{E} + 0.3\%$ π: $\sigma_E / E = 45\% / \sqrt{E} + 4\%$