Searches Beyond the Standard Model at the LHC

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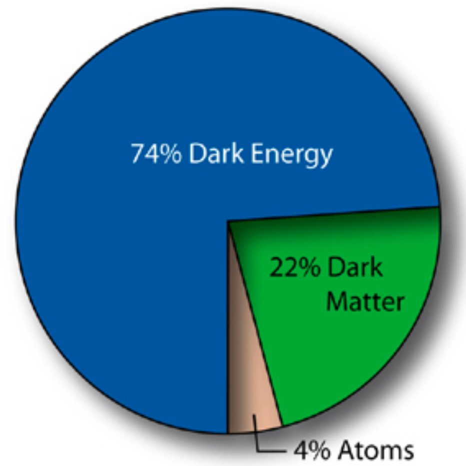
There Must Be New Physics!

- Explain low mass of Higgs
  (hierarchy problem)
- Explain Dark Matter
  - why shouldn't it be produced at colliders?
- Explain matter-antimatter imbalance in the Universe



- Explain why Yukawa couplings range more than 11 orders of magnitude from electron neutrino to top quark
- Would be nice to unify gauge forces (and incorporate gravity at some point…)

We also have ideas what this new physics could be - which lead us to believe that there is something new at energies ~ electroweak scale

- we just need to look in the right place…

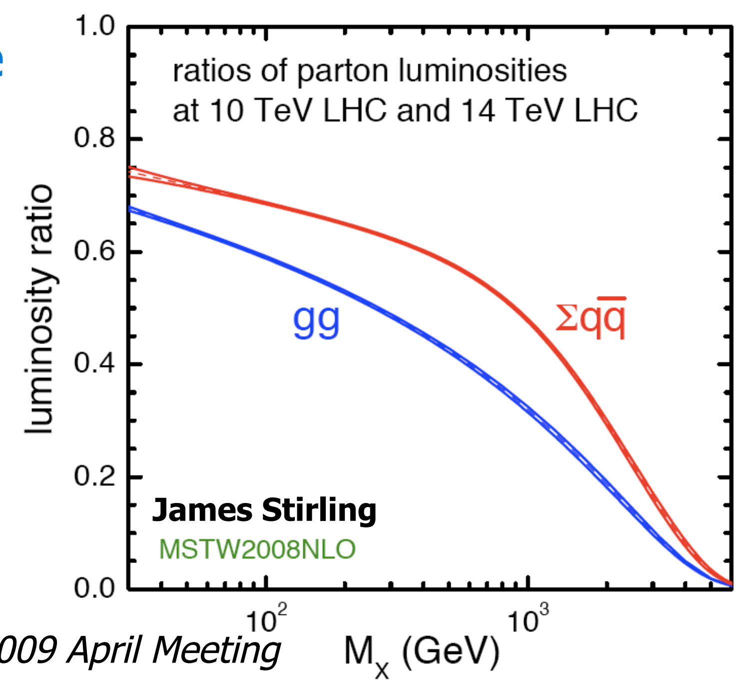
2009-2010 LHC Run

Year	2009										2010															
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Baseline	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH		SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	SH	SH	SH	SH
	24 weeks physics possible																									
Base '	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH	SH
	44 weeks physics possible																									
Delay (4W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH
Delay (8W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH

Gain 20 weeks of physics in 2010 by running during winter months

HIGH price Electricity

- Money for the operation through high price electricity period are allocated, the length of the run is ~11 months with minimum sensitivity to delays
- Energy is 10 TeV, integrated luminosity ~200 pb^{-1}
- **Dataset with real discovery potential**
  - 10 TeV is 5 times Tevatron's energy

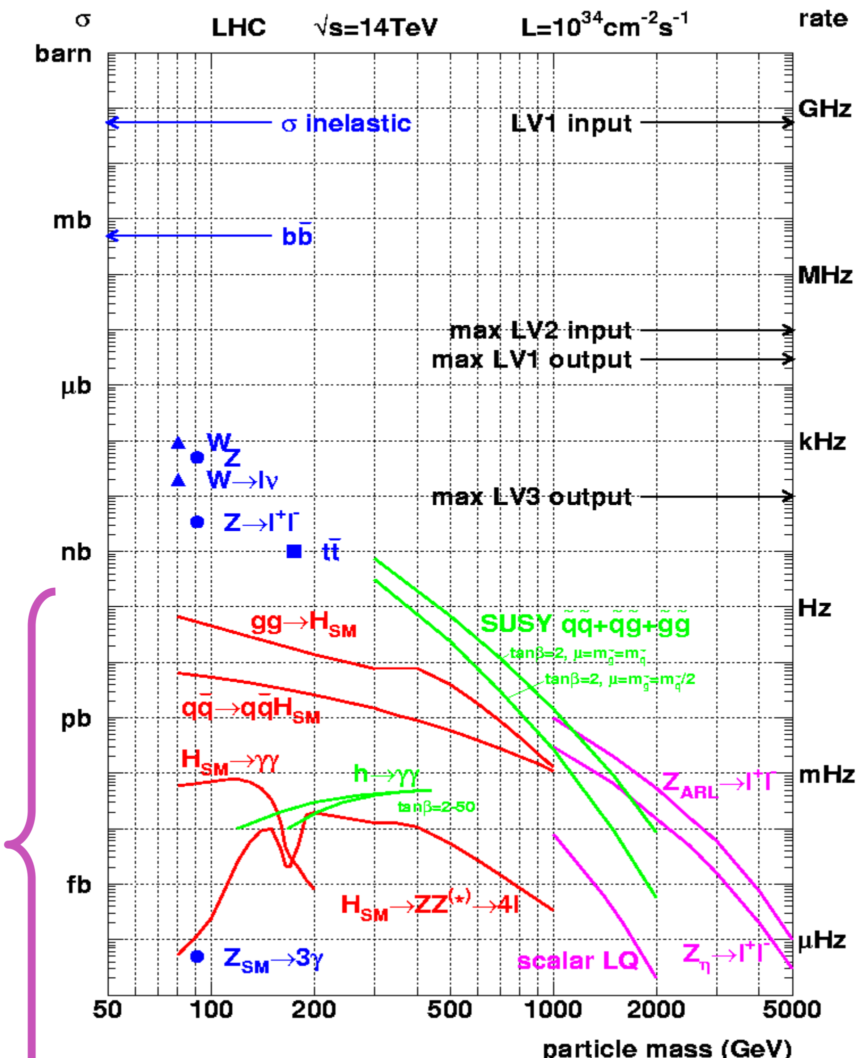


Event Counts

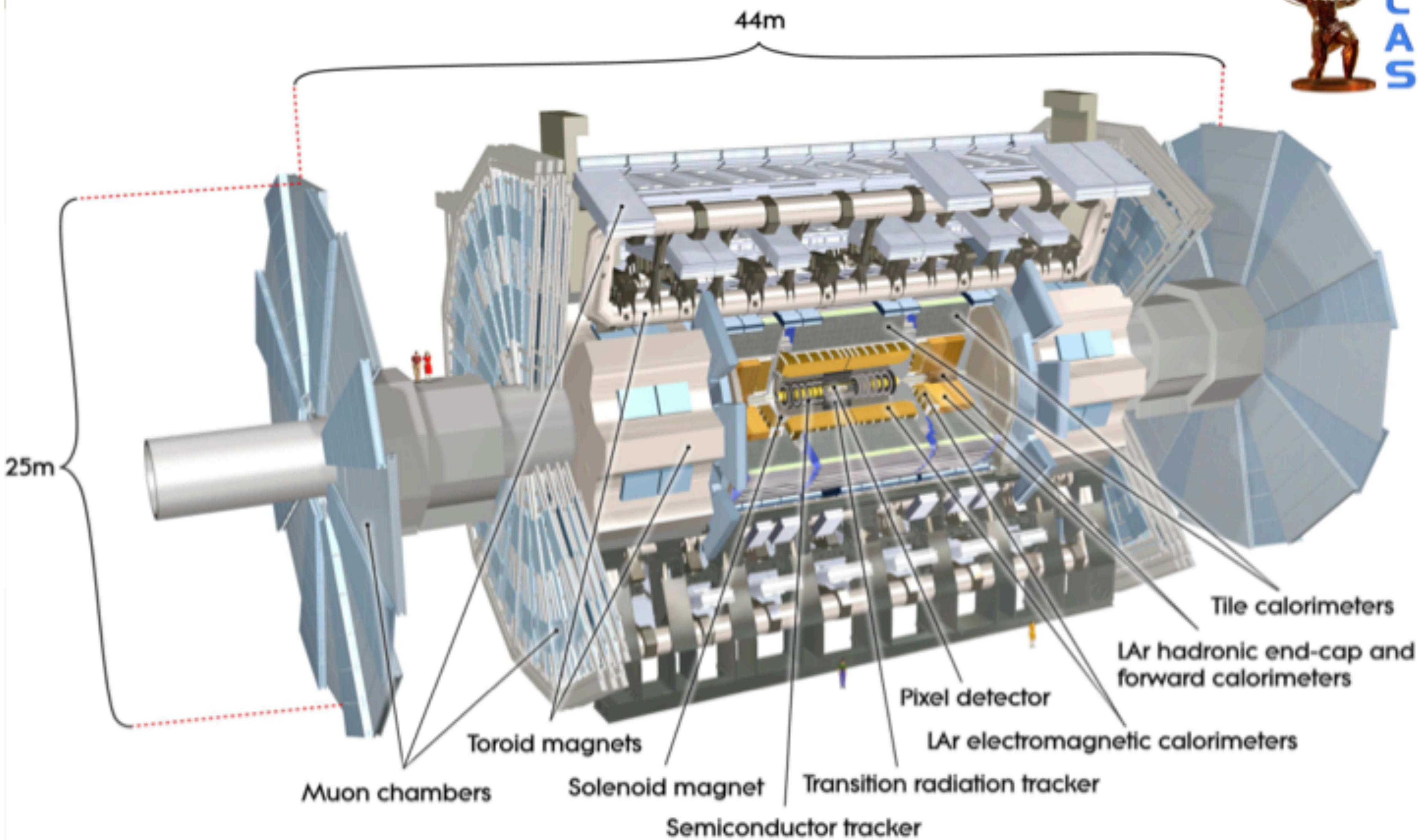
$200\ pb^{-1}$
10 TeV

Available during the 2009-2010 Run

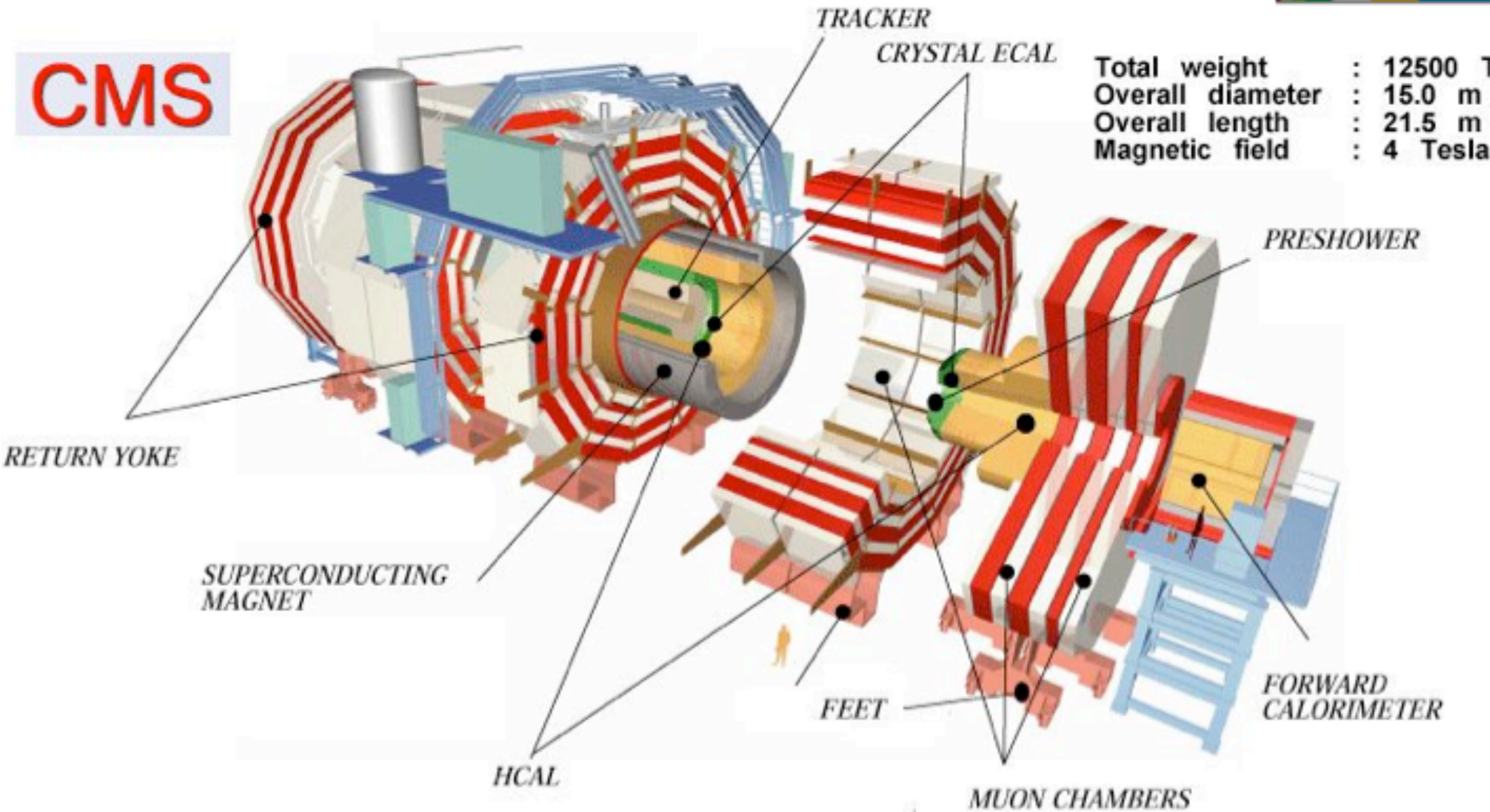
New Physics



The ATLAS detector



The CMS detector

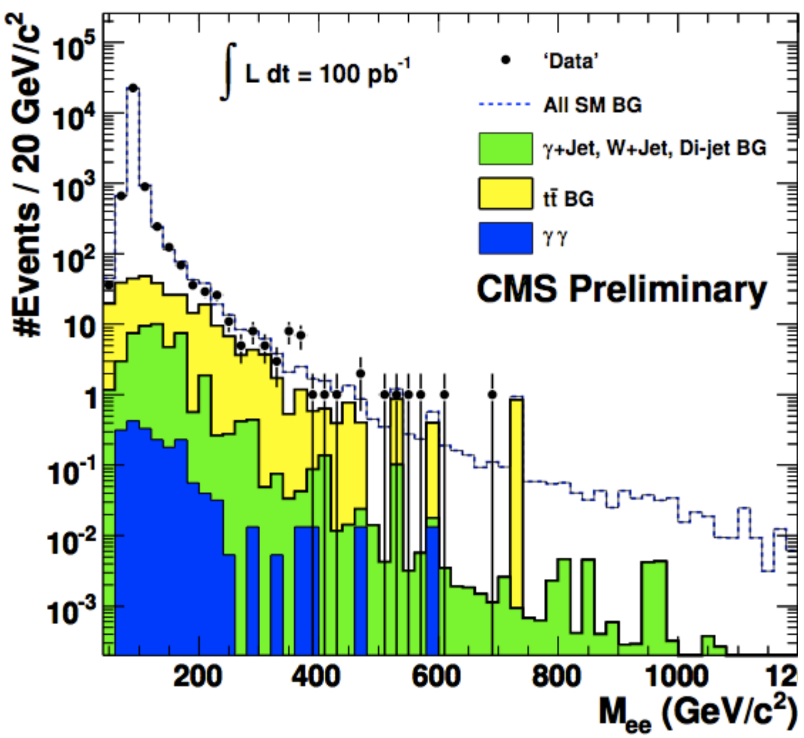


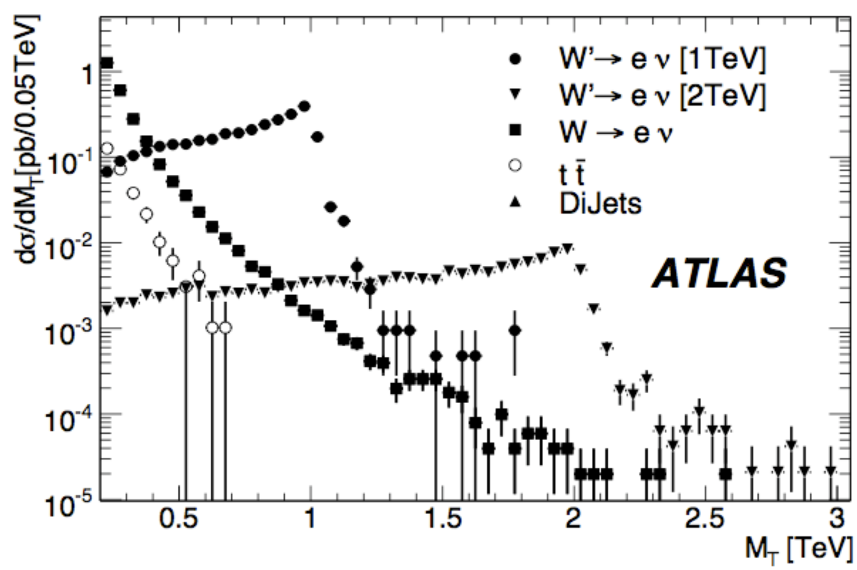
In This Talk…

- You've heard how great the LHC discovery potential is for many years now – and we keep improving our analysis methods.
- What I'll try to do in this talk is to focus on a few examples of how we think we will be able to prove to ourselves and to the world that we have made a discovery
  - topology driven searches
  - simple and inclusive methods
  - data driven background estimation
- "Supersymmetry"
  - counting experiments & shapes of distributions
  - Jets+MET
  - lepton+Jets+MET
- "Smoking gun"
  - unmistakably sharp features (almost self-calibrating…)
  - Z', W'
  - black holes
- Detector Commissioning
  - we now have real data to work with!

Extra Gauge Bosons

- 2 electrons
  - $p_T > 30$ GeV
  - $|\eta| < 2.5$ & fiducial cuts
  - isolated
- electron
  - $p_T > 50$ GeV
  - $|\eta| < 2.5$
  - isolated
- MET > 50 GeV
- $$\frac{\sum p_T^{leptons}}{\sum p_T^{leptons} + \sum E_T^{jets}} > 0.5$$



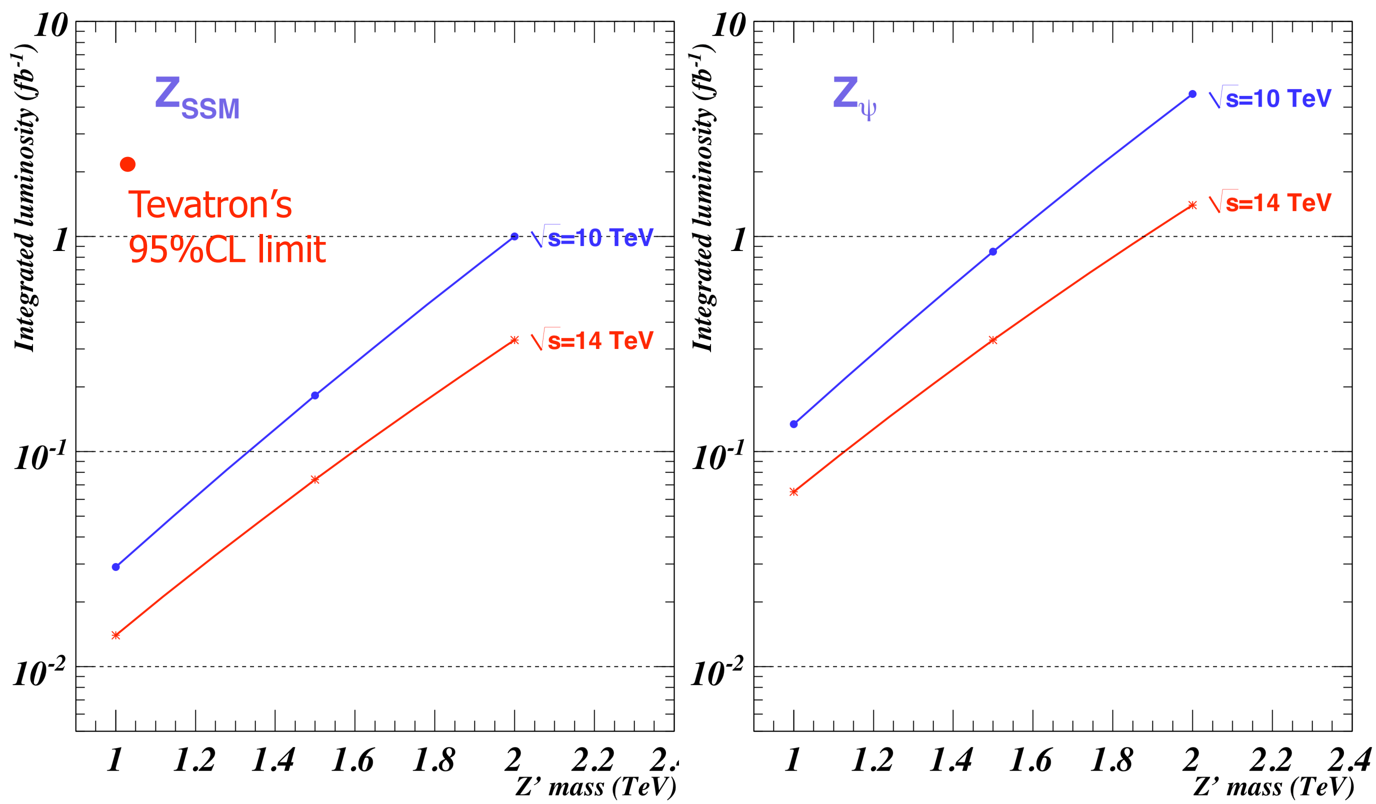


Extra Gauge Bosons

- Not very significant change in reach in 10 vs 14 GeV
  - optimization of running conditions done by physics reach, not E_{cm}!

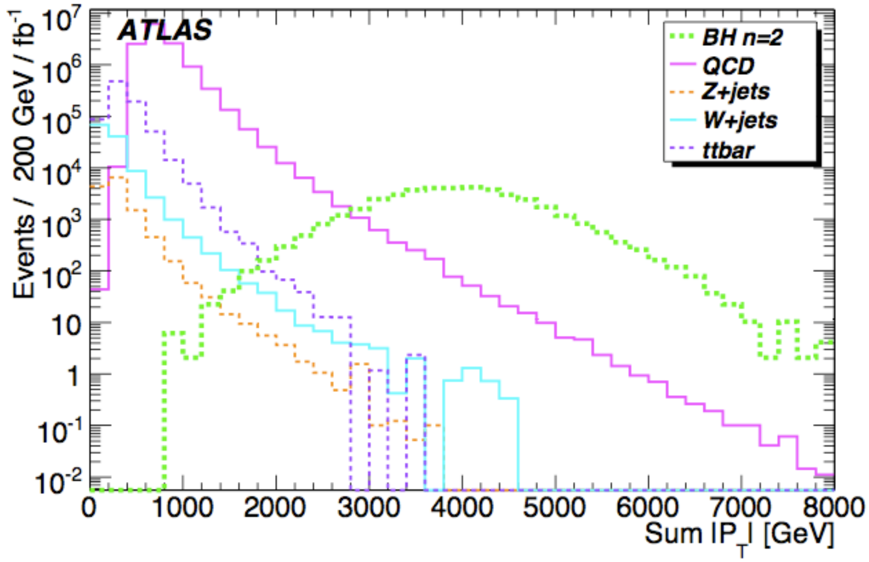
Z' mass (TeV)	σ(14 TeV)/σ(10TeV)
1	2
2	3

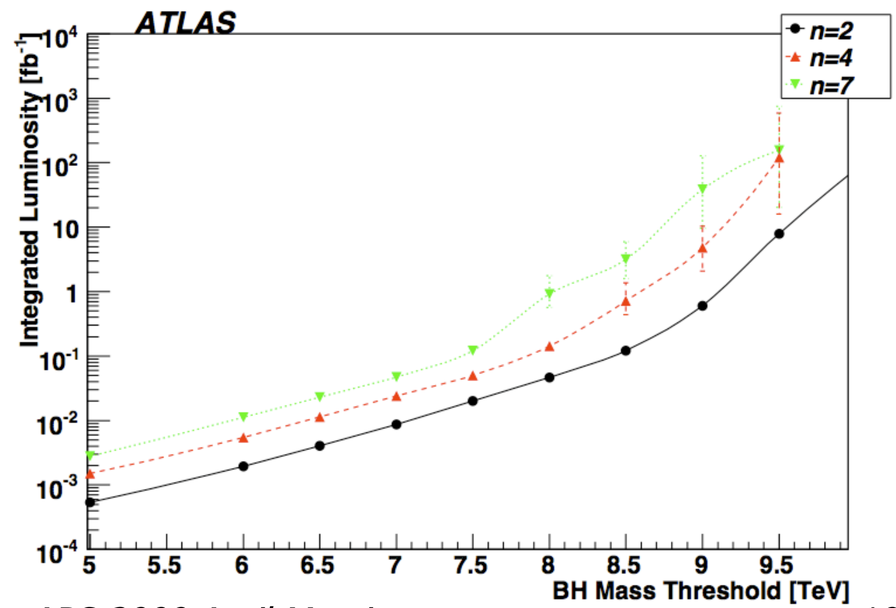
5σ discovery reach



Black Holes

- Models with Large Extra Dimensions (i.e. ADD) Black holes could be produced at the LHC if the M_{planck} is O(1-10 TeV)
- They will decay through Hawking's radiation into a large number of objects democratically
- Identify objects: muons, electrons, photons and jets
- sum up their $|p_T|$
- in addition to cut on sum $|p_T|$ require existence of one lepton above 200 GeV or, alternatively, four objects above 200 GeV





SUSY @ LHC

- Since superpartners of quarks and gluinos carry color, they are the most abundantly produced SUSY particles at the LHC – small kinematical suppression compared to Tevatron

$\tilde{q}\tilde{\bar{q}} \rightarrow q\tilde{\chi}\ \bar{q}\tilde{\chi}$ at least two high E_T jets

$\tilde{q}\tilde{g} \rightarrow q\tilde{\chi}\ q\bar{q}\tilde{\chi}$ at least three high E_T jets

$\tilde{g}\tilde{g} \rightarrow q\bar{q}\tilde{\chi}\ q\bar{q}\tilde{\chi}$ at least four high E_T jets

- SUSY events at the LHC, even those with leptons are very jetty. Strategy is to have a grid of analyses:

	1 jet	2 jet	3 jets	4 jets
0 lepton		✓	✓	✓
1 lepton		✓	✓	✓
2 lepton SS / OS		✓	✓	✓
3 leptons	✓			
taus		✓	✓	✓
b's		✓	✓	✓

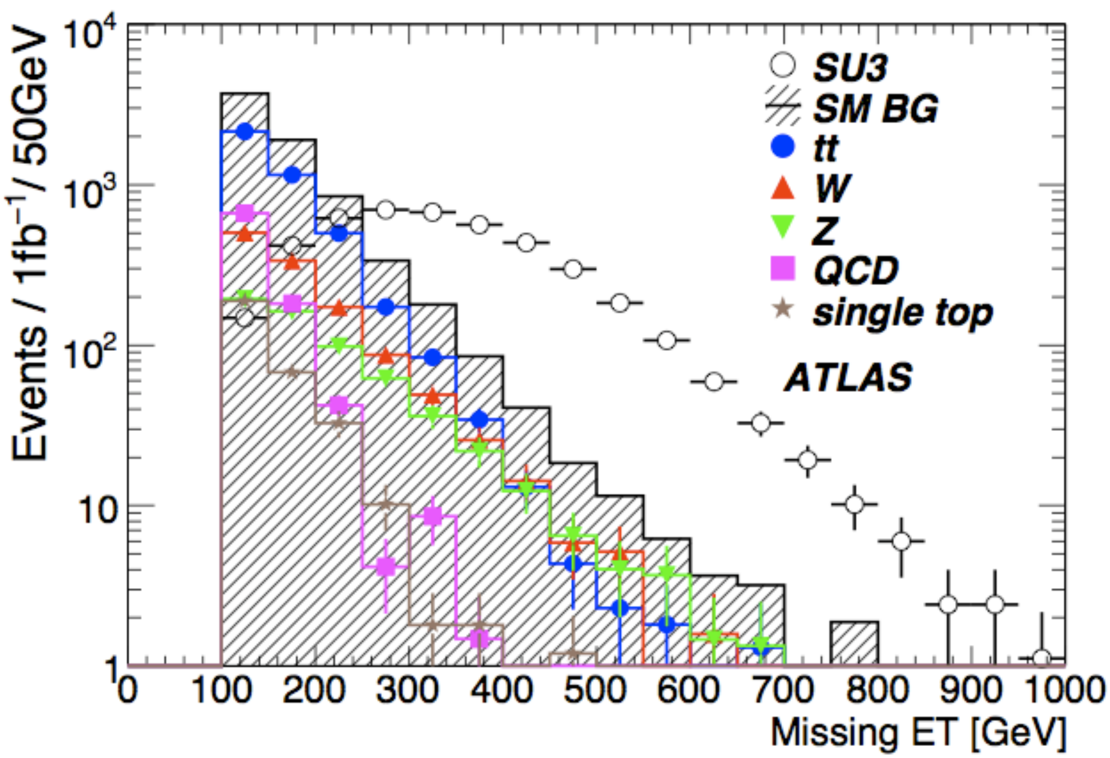
Jets + Missing Transverse Energy

- Very high probability of new physics
  - if Dark Matter particles are O(100 GeV) they will be produced by the LHC resulting in missing E_T. Since it is hadronic collider association with jets is natural
  - staple Supersymmetry search
- One of the toughest channels: instrumental background
  - Missing E_T is sensitive to all the noise, miscalibration, beam halo and hard to clean up and commission
  - Jets fluctuate and can be catastrophically under-measured in a way that is not reproduced by simulation
  - jet cross-section is humongous even small effects in jet response can look like new physics

Jets + MET

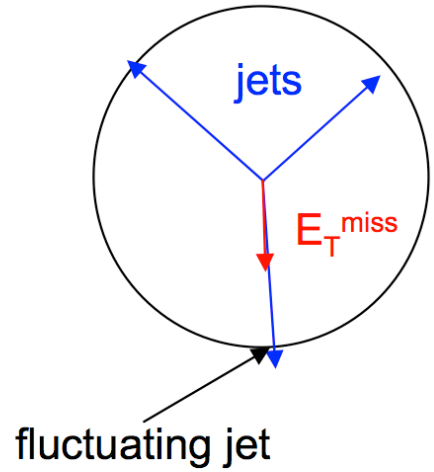
- at least 4 jets E_T>50 GeV
  - one with E_T>100 GeV
- MET > 100 GeV
- lepton veto
- sphericity
- for three leading jets
  $\Delta\phi$(jet,MET)>0.2

ATLAS: CERN-Open-2008-020



Measuring Jet Response

- Measure how often jets are mis-measured
  - Gauss + low energy tail
  - measure gaussian component from γ+jet balance
  - measure tail from "Mercedes" events
- Take events at low MET and apply the non-Gaussian part of the response to them to predict the high MET tail



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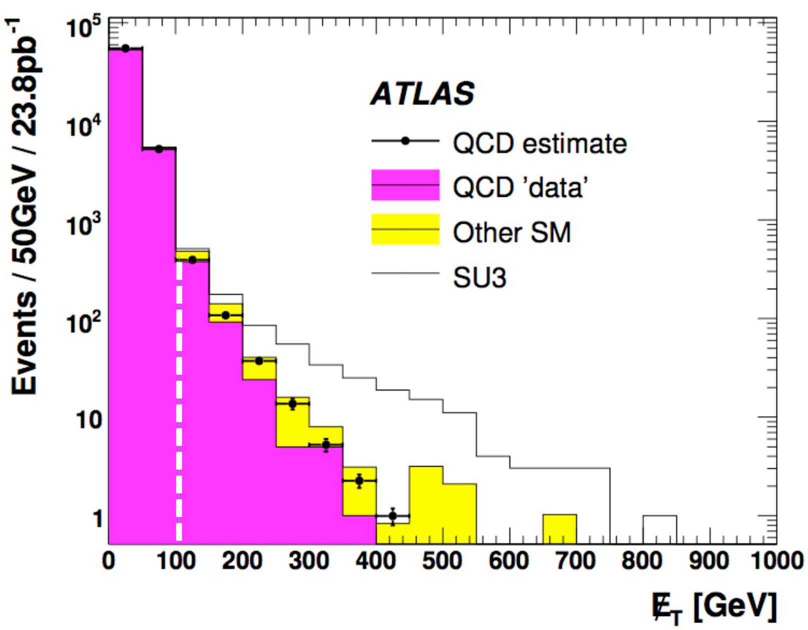
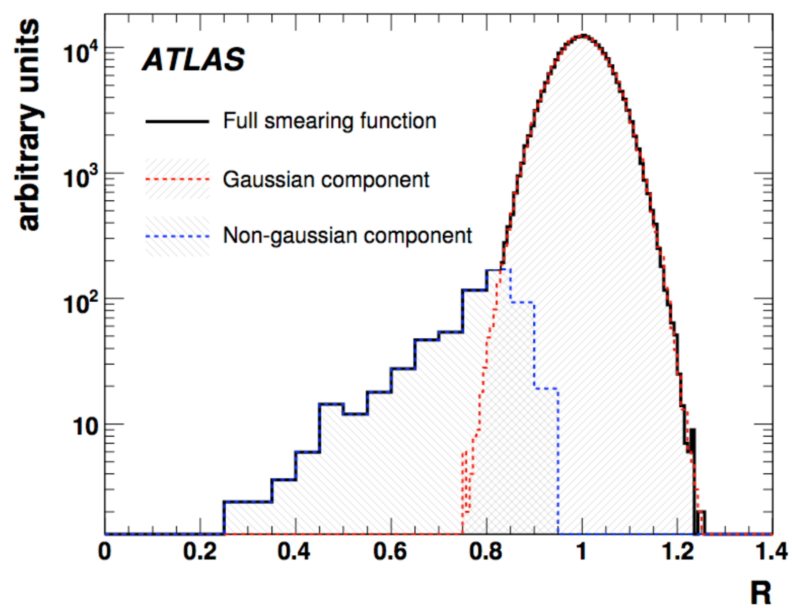
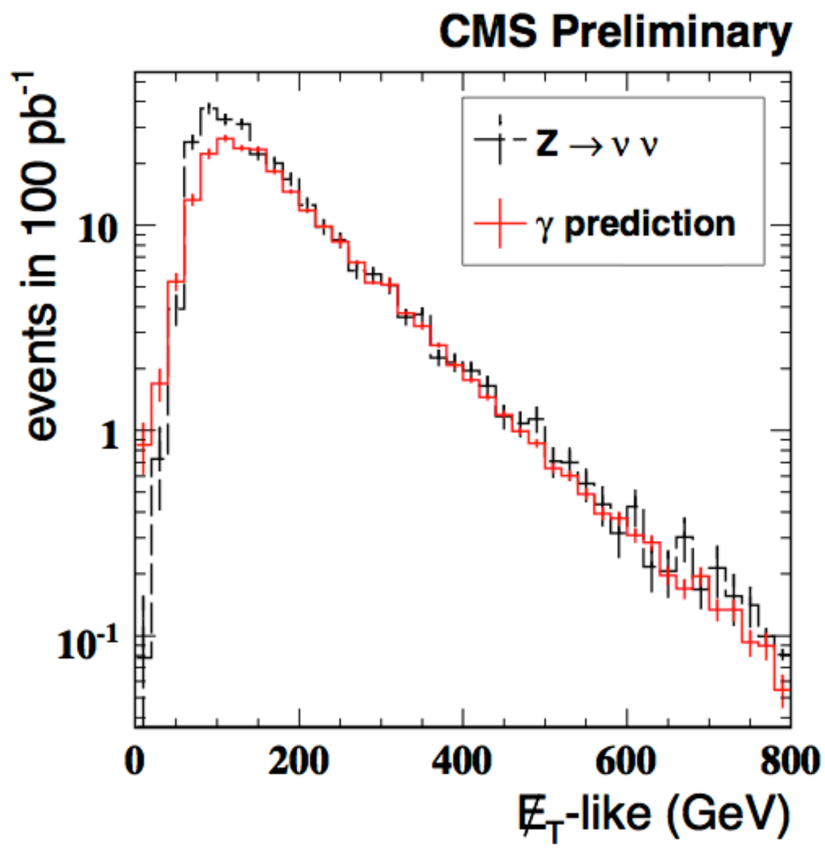




Physics Background to Jets+MET

- Irreducible background is coming from Z+jets, where Z decays into neutrinos
  - high order QCD predictions have large uncertainties
- Can be inferred by looking at Z+jets → l^+l^-+jets but this results in a large statistical error due to smallness of ee & $\mu\mu$ branchings
- Another idea: Z is just a "heavy photon" – at high Q^2 the should be little difference between Z+X and γ+X
  - use γ+jets events to predict Z+jets
  - works very well, theoretical uncertainties in the ratio of Z to γ are small



Other backgrounds from W and top involve lost leptons and are "easily" estimated from lepton+jets+MET samples

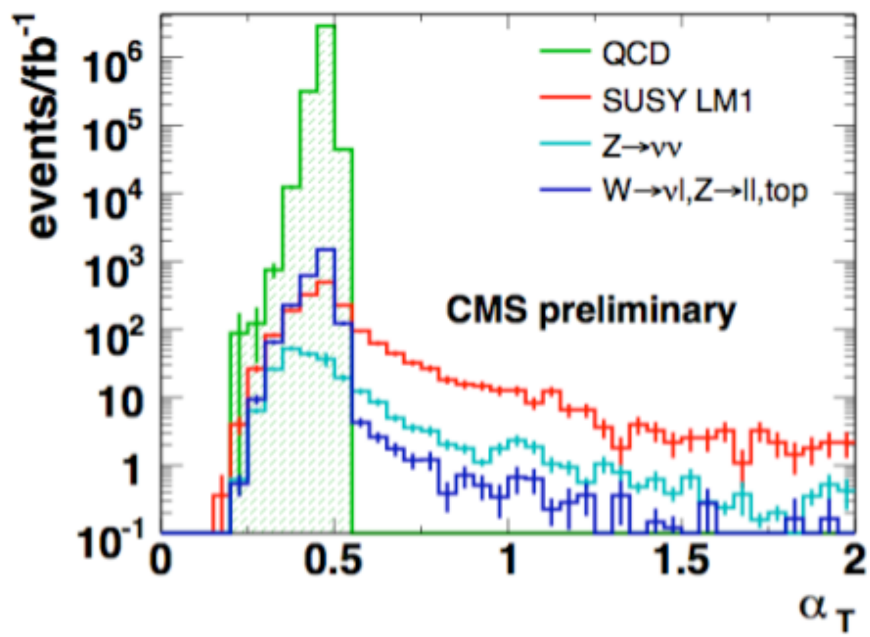
Jets+MET without MET

- For 2 jets + MET channel can avoid relying on MET altogether by devising clever topological variables

L. Randall, D. Tucker-Smith, PRL 101:221803,2008

$$\alpha_T = \frac{E_T^{j2}}{M_T^{j1,j2}} \approx \frac{\sqrt{E_T^{j2}/E_T^{j1}}}{\sqrt{2(1-\cos\Delta\varphi)}}$$

CMS PAS SUS-08-00

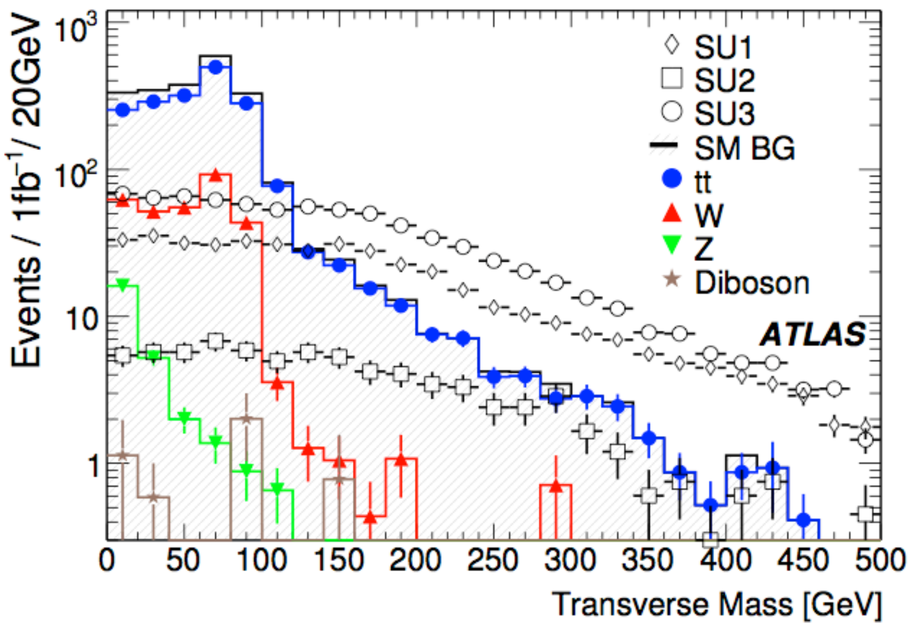


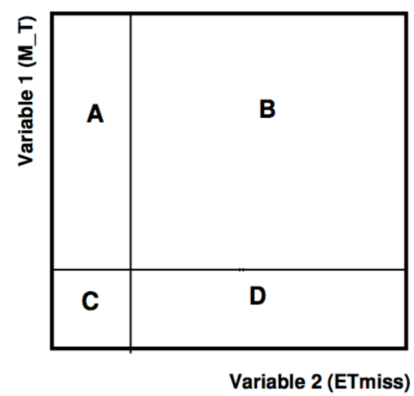
- For perfectly measured QCD di-jets α_T=0.5. If one of the jets is undermeasured, α_T decreases.
  - 2 jets, $E_T^{j1}+E_T^{j2}$>500 GeV
  - lepton veto
  - α_T>0.55

It is possible to generalize a_T variable to multi-jet case – work is ongoing…

Lepton+jets

- Requiring a lepton really helps reducing QCD
- But a new challenge arises: how to deal with W+jets and top backgrounds
  - theoretical prediction has large uncertainties. After years of running at 2 TeV, Tevatron still has to correct W+jets simulation using Z+jets
- Note, that for the largest background sources, W+jets and semi-leptonic top, MET always comes from a single neutrino from W decay creating a sharp jacobian peak
  - **use it to normalize the background predictions!**



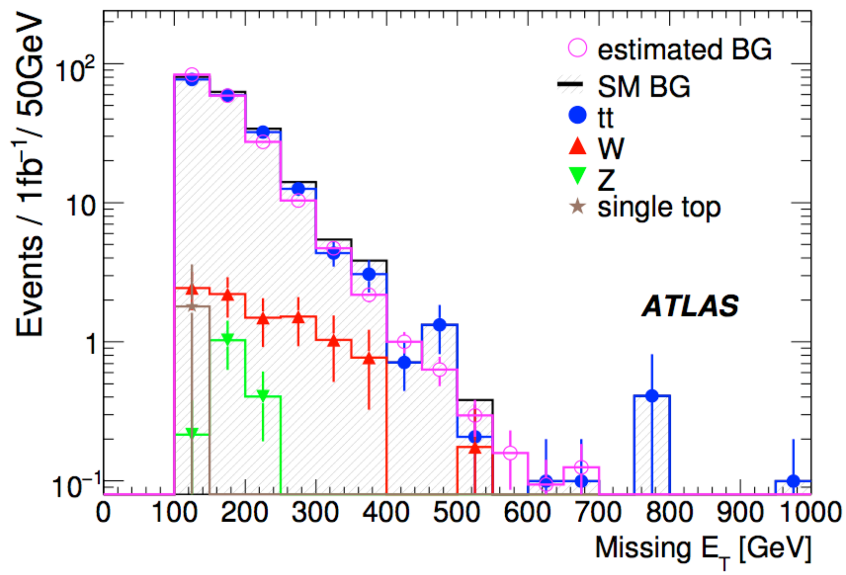


only guaranteed to work if Variable 1 and 2 are uncorrelated

Lepton+jets

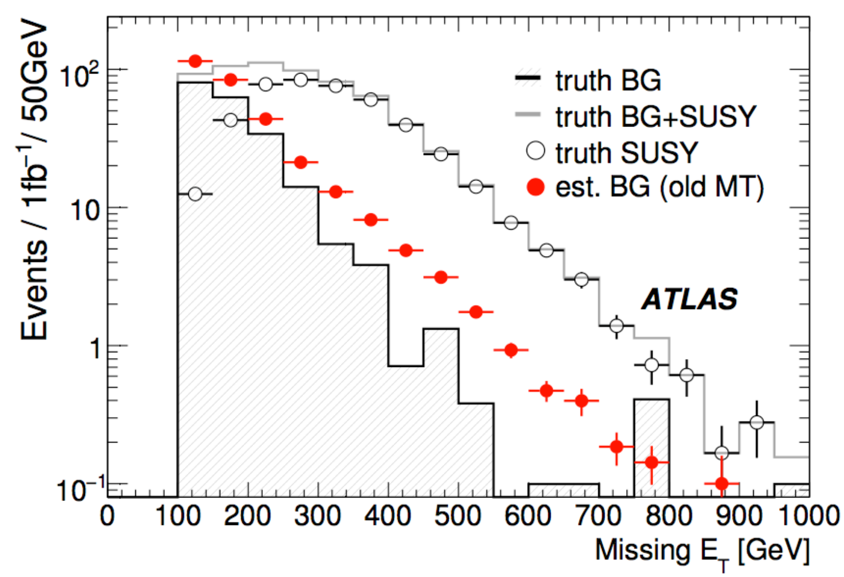
- Simulation seems to tell us that MET and M_T are not strongly correlated
- In the absence of signal the method works perfectly

	$\not\!\!E_T > 100$ GeV	$\not\!\!E_T > 300$ GeV
True BG	203 ± 6	12.4 ± 1.6
Estimated BG	190 ± 8	9.4 ± 0.7
Ratio(Est./True)	0.93 ± 0.05	0.76 ± 0.11



- The problem is that "background" samples are contaminated with signal – reduced sensitivity…

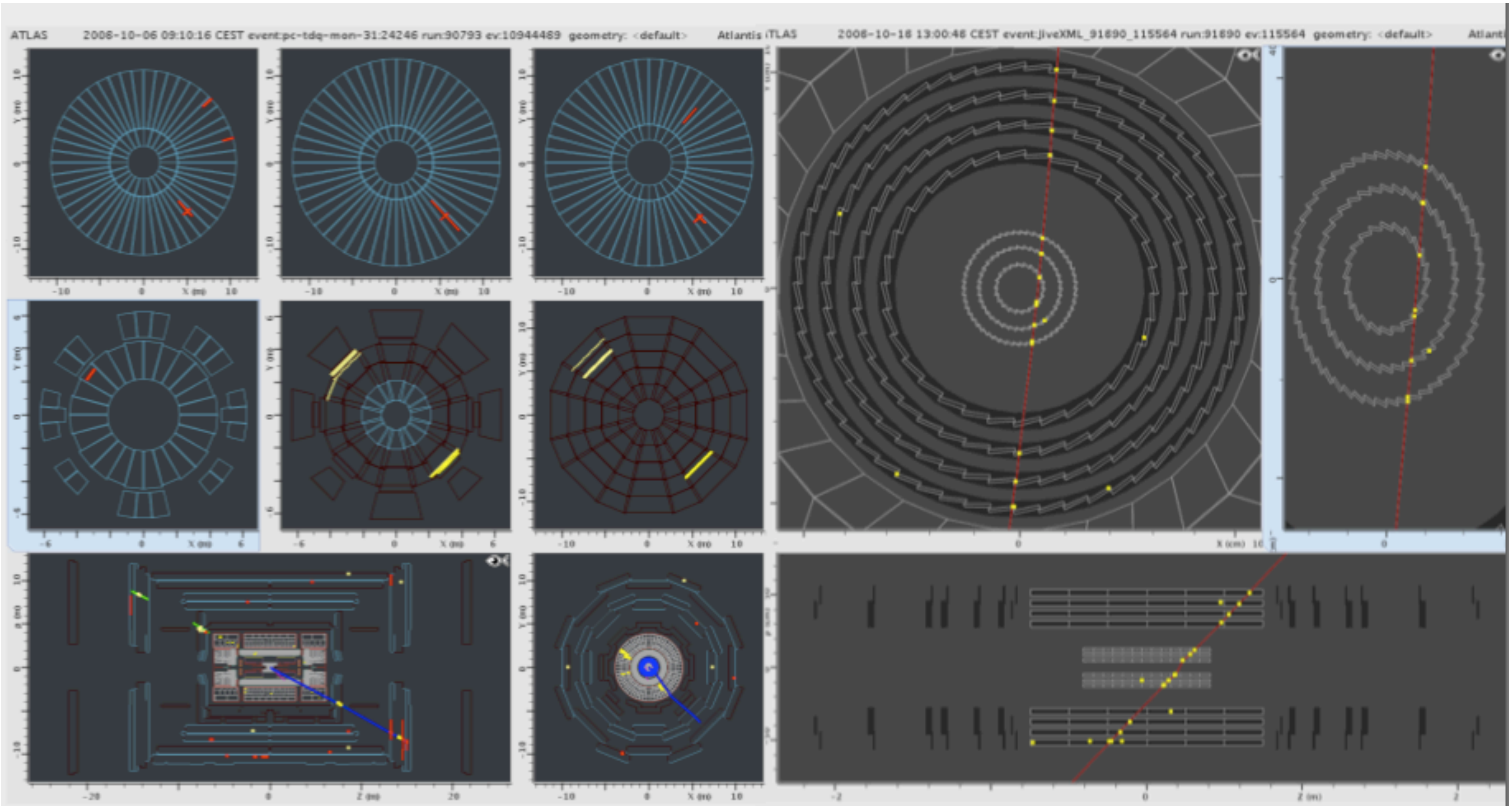
	$\not\!\!E_T > 100$ GeV	$\not\!\!E_T > 300$ GeV
True BG	203 ± 6	12.4 ± 1.6
Estimated BG	296 ± 10	33.3 ± 1.4
True BG+SUSY	653 ± 8	245 ± 4



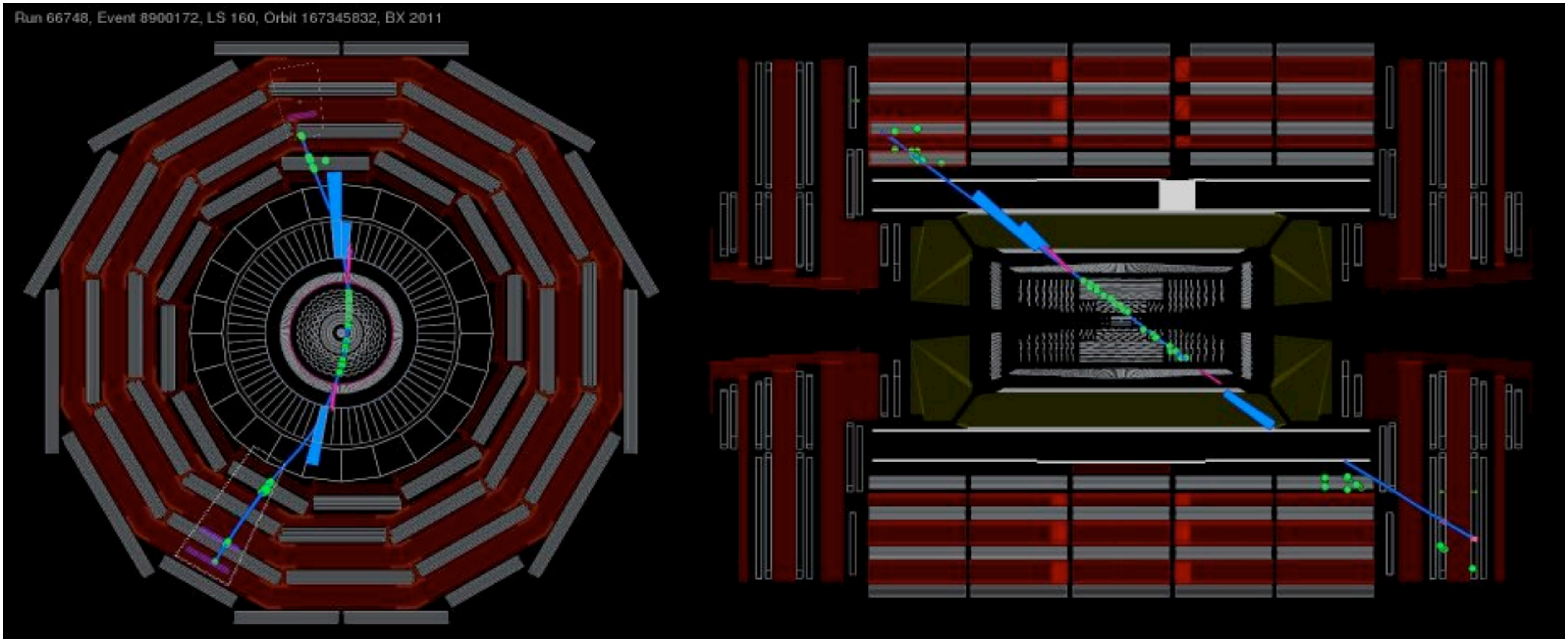
Start-up and Commissioning

- It is a large and difficult task to commission detectors like CMS and ATLAS
- But by the time the beam collisions come we will have operated the detectors for almost two years
  - system stabilities and noise measured
  - trackers partially aligned
  - magnetic fields mapped out with cosmic muons
  - billions of events acquired, reconstructed, distributed, re-reconstructed, and compared to detector simulation
  - countless problems solved
- The start-up is likely to be very different from the Run II Tevatron, where detector and accelerator were brought up ~ simultaneously

Cosmics Event Example: ATLAS

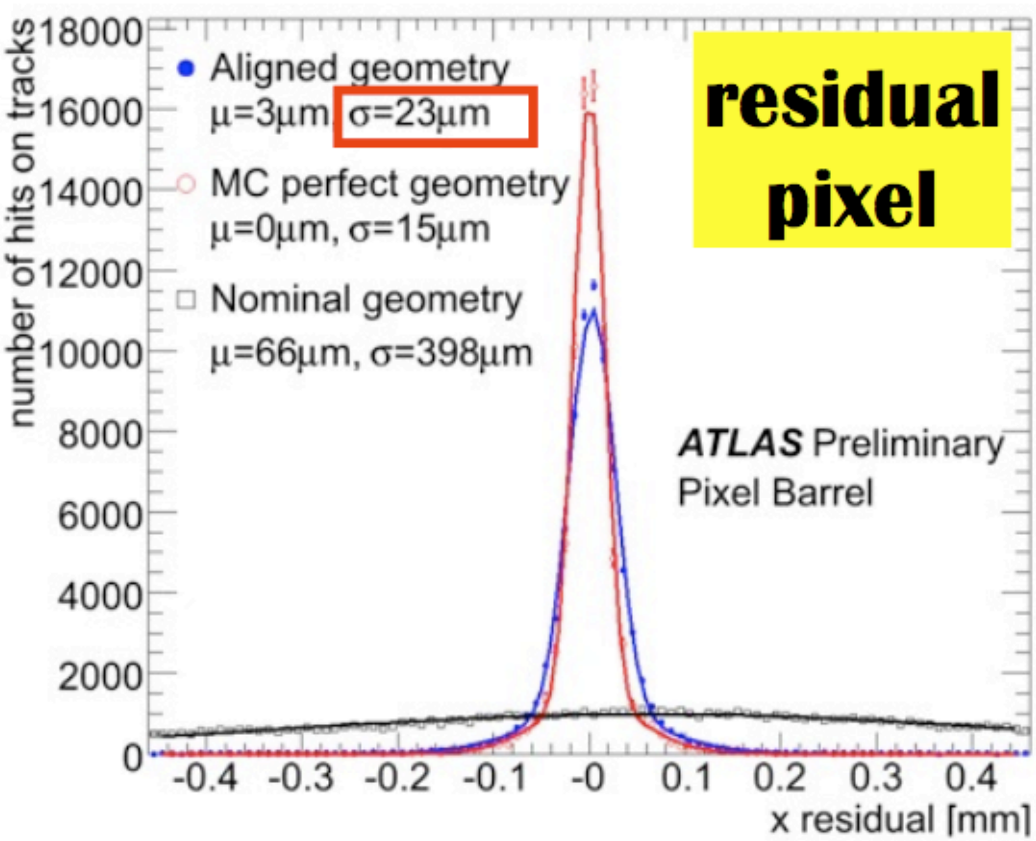


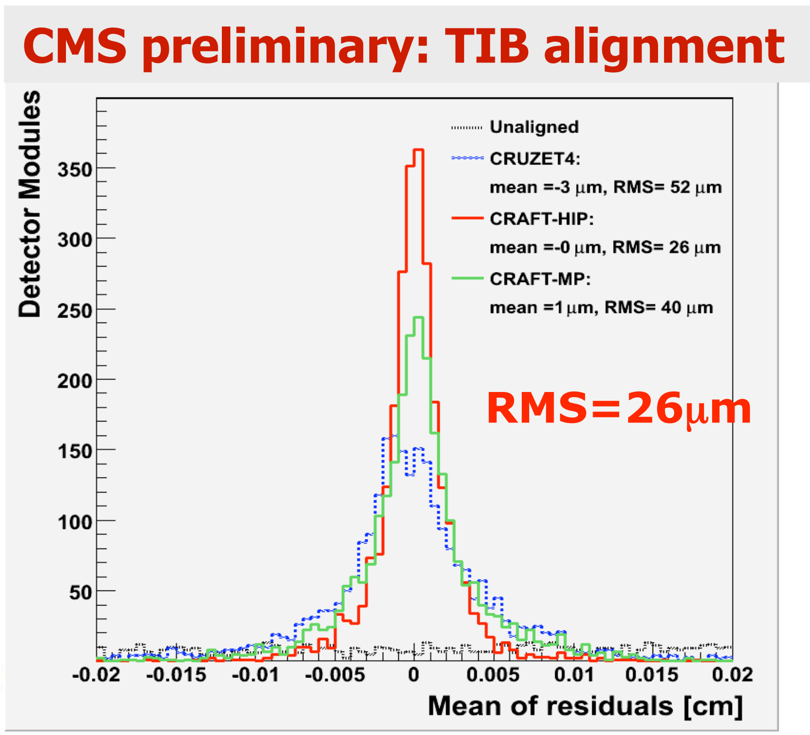
Cosmics Event Example: CMS



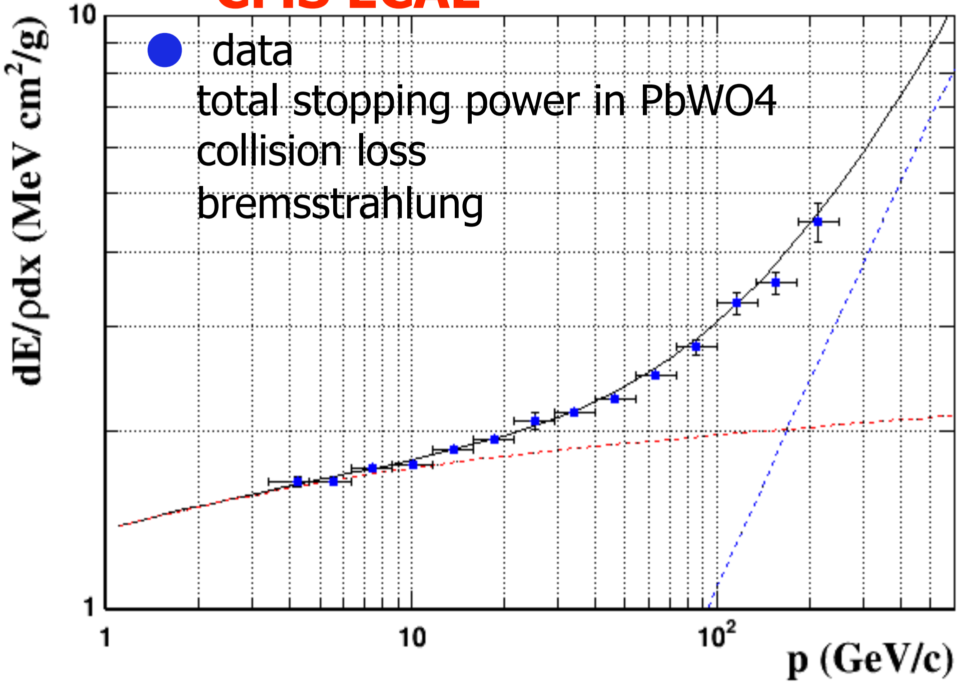
Tracker Alignment

- alignment algorithms work
- achieved precision is already better then considered MC scenario after 10 pb^{-1} of data





CMS ECAL



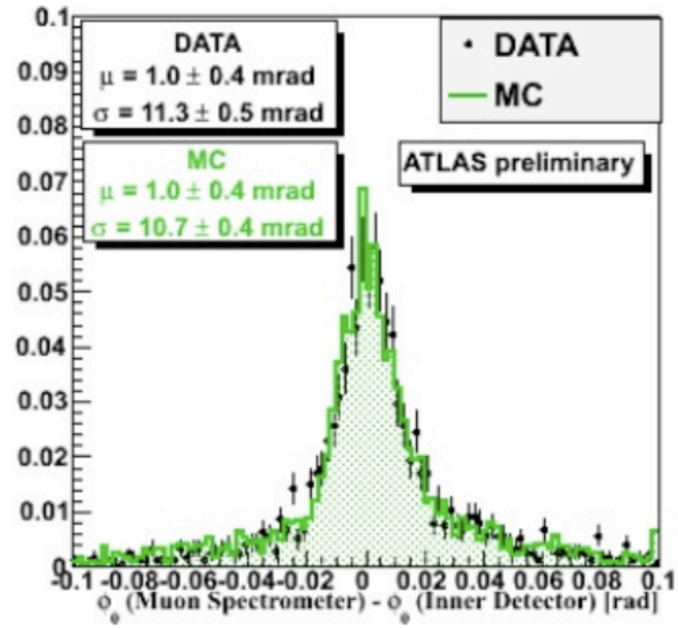
Measured stopping power (corrected for containment) of muons in ECAL

Note – the lines are not fits, but absolute predictions

ATLAS muons

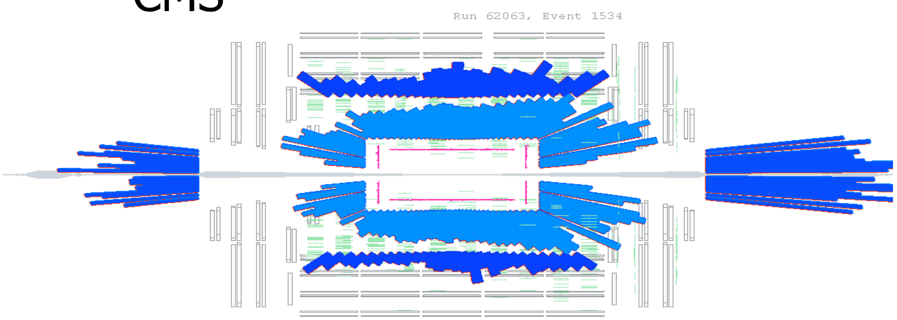
consistency of direction in the azimuthal angle between Muon and Inner Tracker

- good agreement with MC



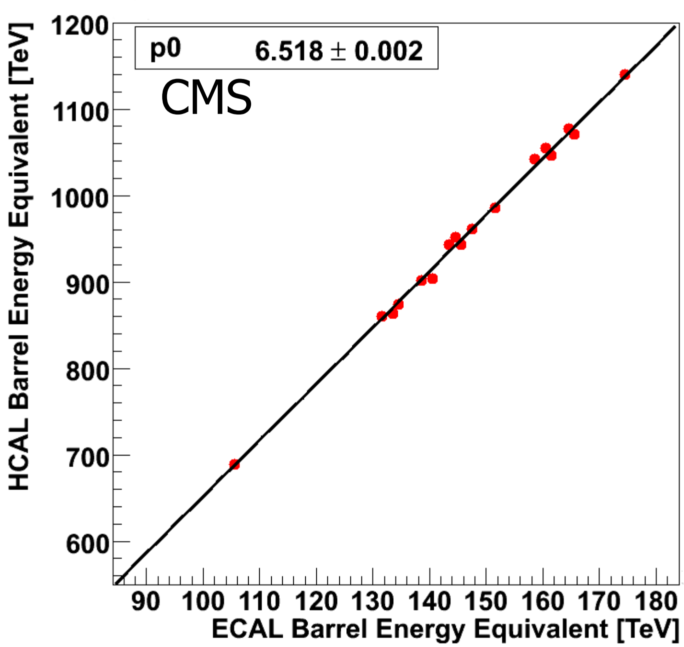
One Beam

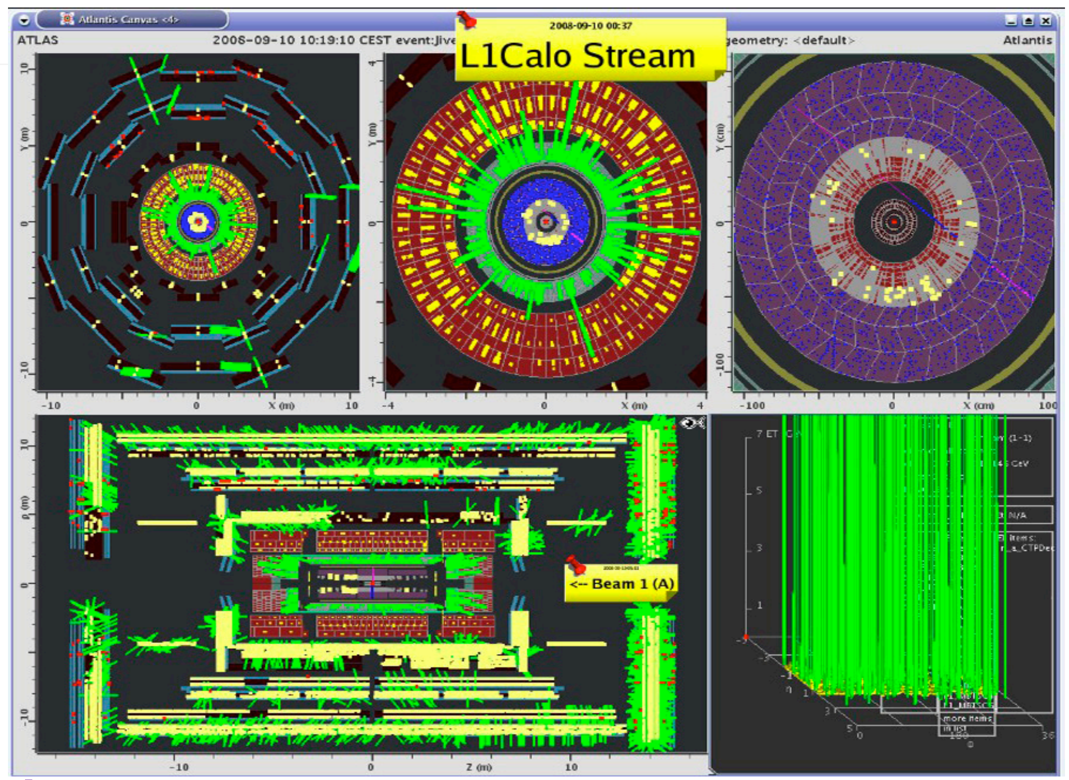
CMS



~2x10⁹ protons on collimator
~150 m upstream of CMS

ATLAS





Energies >100 TeV!!

Hundreds of thousands muons/event

Summary

- LHC operations with two beams will start this year!
- Detectors had more then a year to iron out problems – may be able to produce physics grade results soon after collisions
- Methods for early analysis are improving

Stay tuned!!