First LHC Results

Claus Horn (SLAC) for the CMS and ATLAS collaborations

8th International Workshop on
Identification of Dark Matter
University of Montpellier 2, 26-30 July 2010

Content

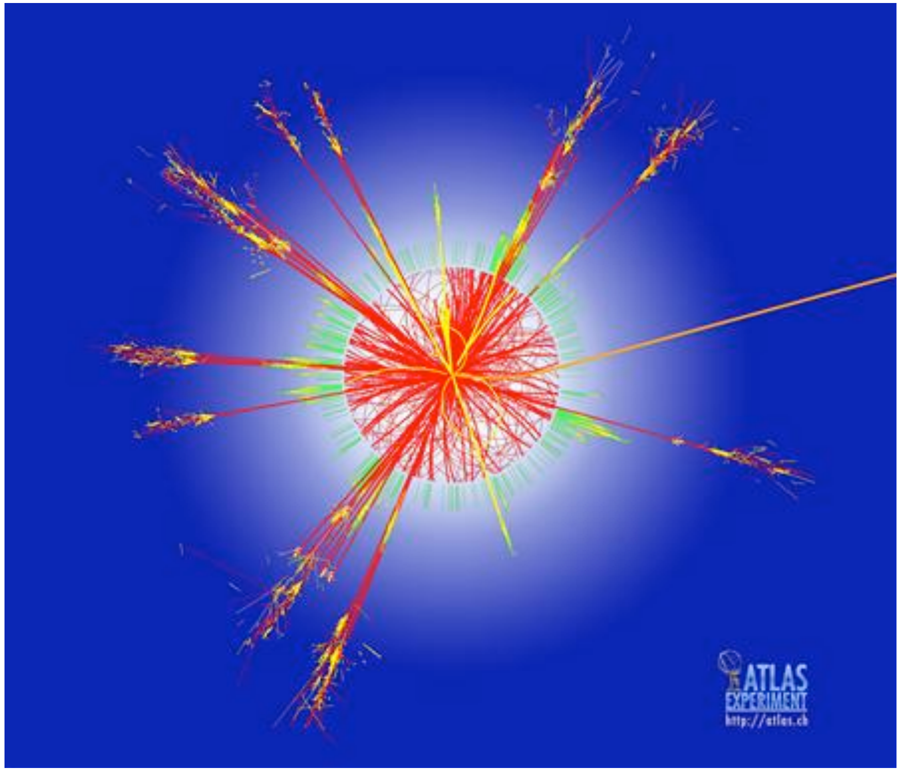
LHC performance

CMS and ATLAS detectors

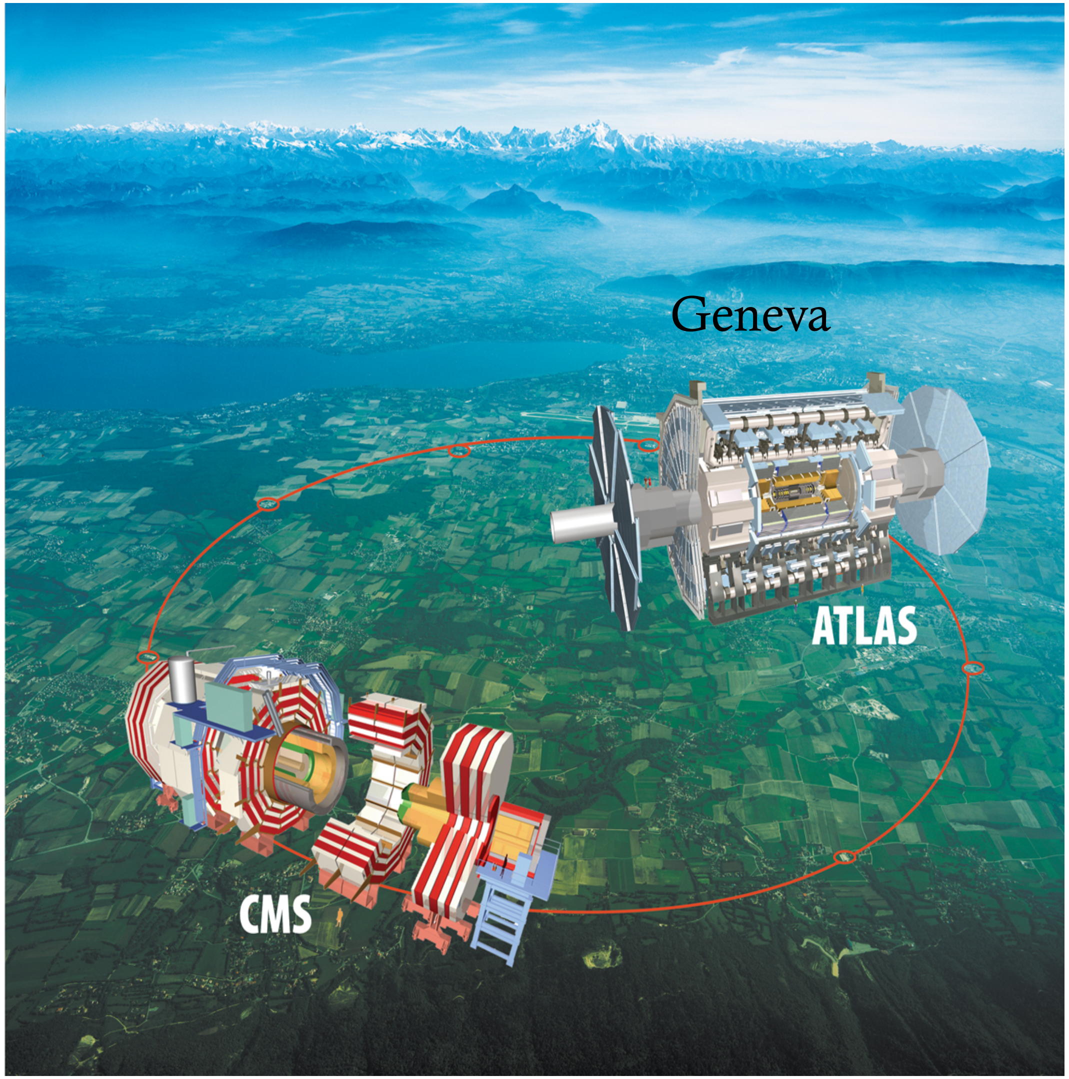
SM measurements

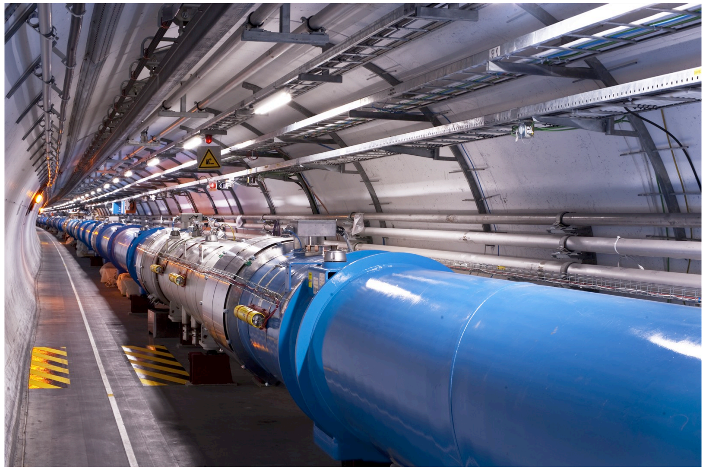
SUSY discovery potential

Status of first SUSY analyses



The Large Hadron Collider

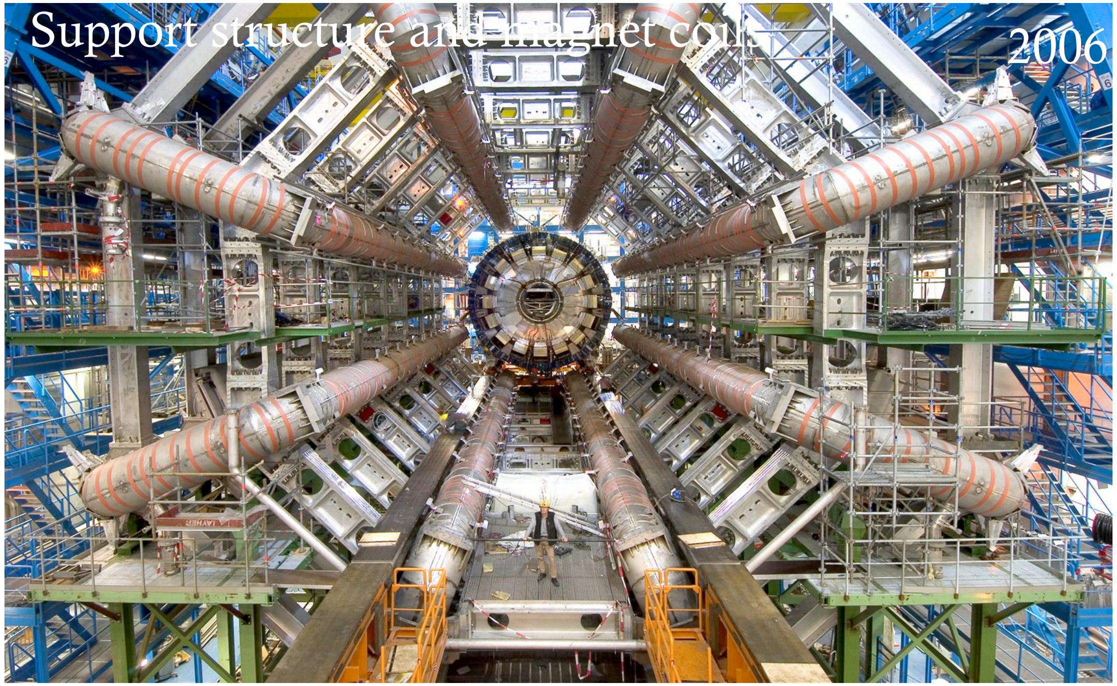


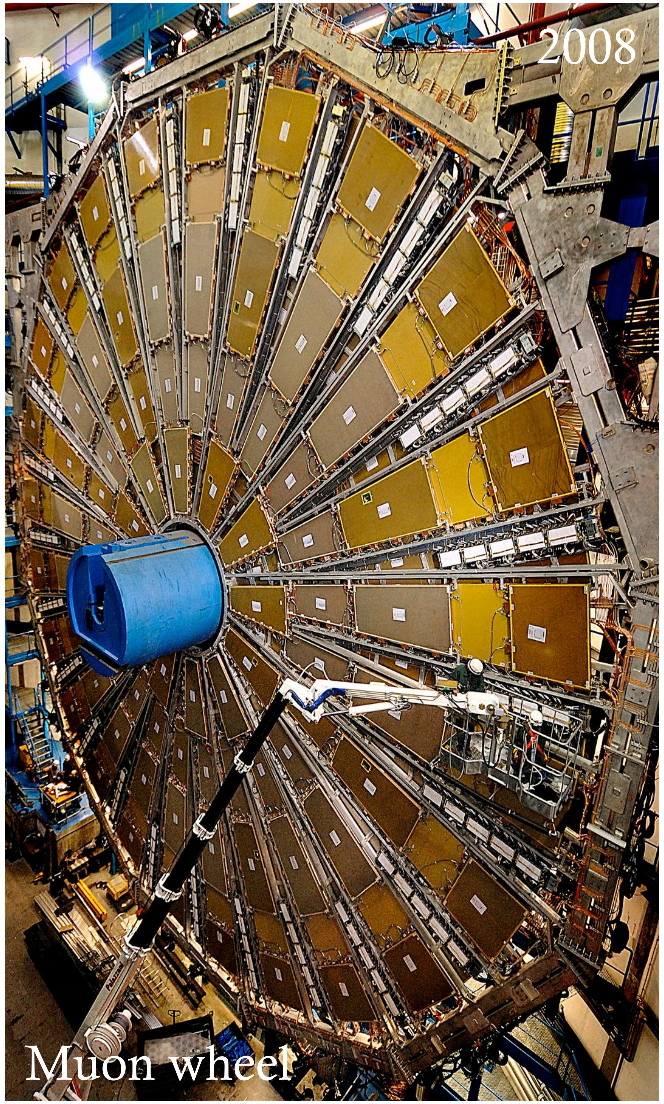


Tunnel circumference: 27 km,
~ 100m under ground.
1232 main +7000 smaller magnets,
B = 8 Tesla (@ 14TeV)
Operating temperature: 1.9K

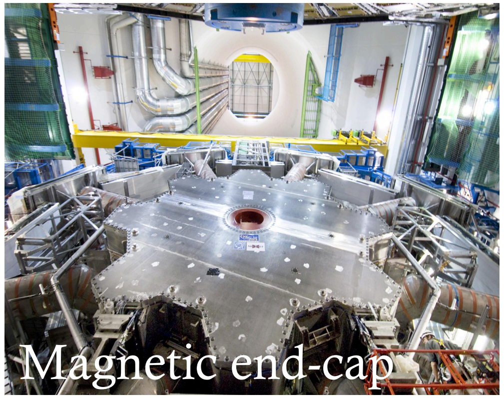
4 Experiments: ATLAS, CMS,
ALICE, LHCb.

ATLAS

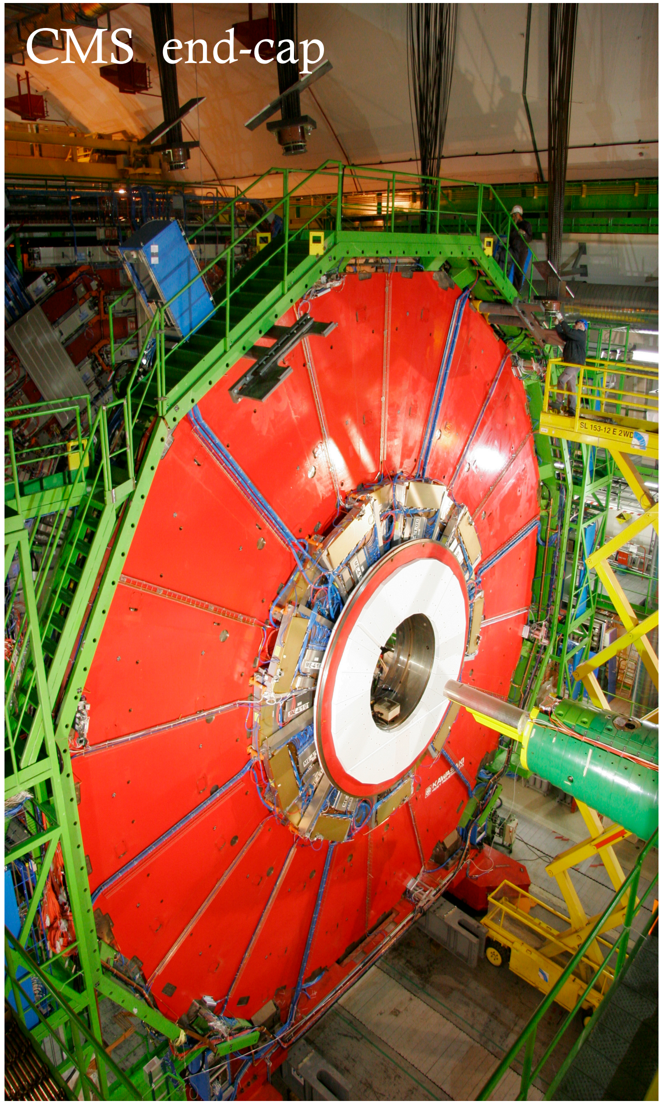

Support structure and magnet coils
2006

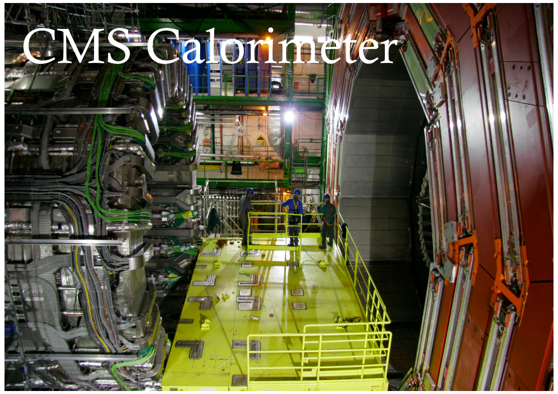

2008
Muon wheel

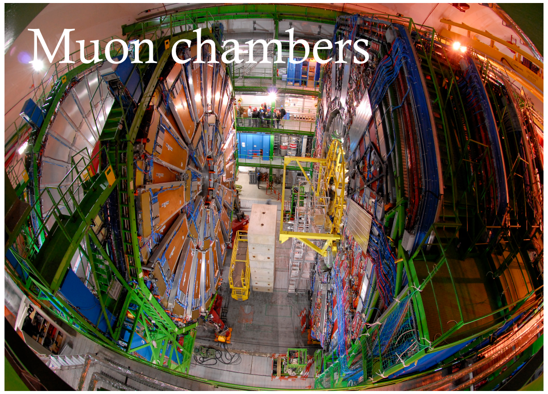

Beam pipe installation

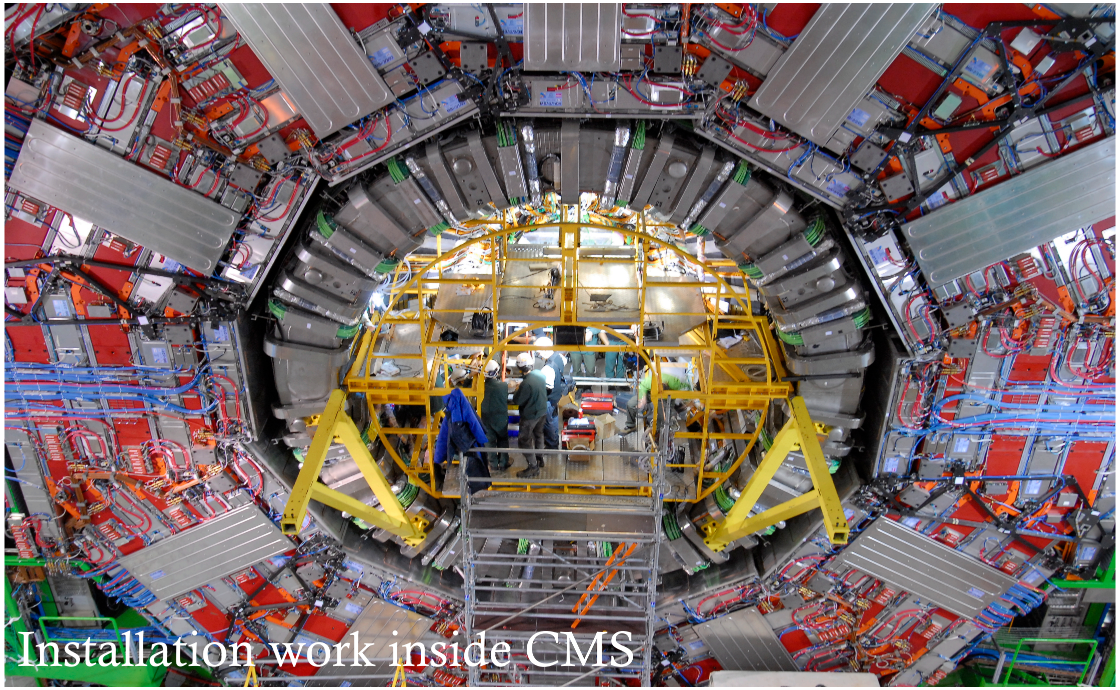

Magnetic end-cap

CMS


CMS end-cap


CMS Calorimeter


Muon chambers


Installation work inside CMS

LHC Performance

Past

LHC startup 10/2008.
Restart after incident 11/2009.
Data taking at 7TeV since 03/2010.

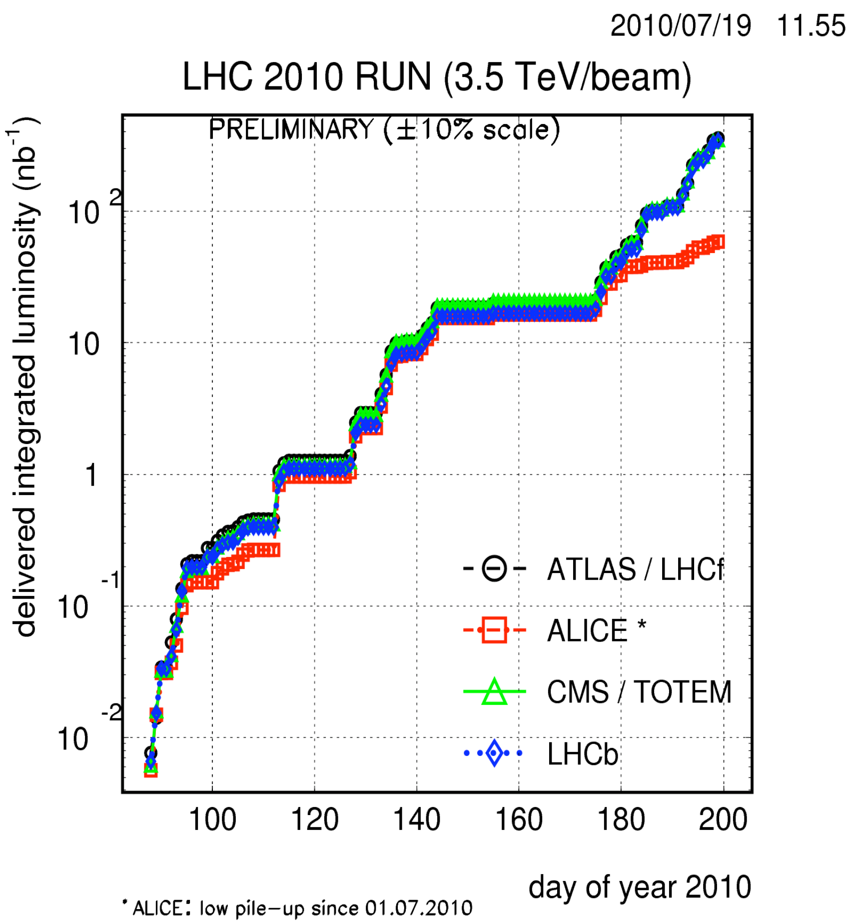
Current program

Alternating periods of machine LHC commissioning and physics data taking

- Initial collisions with 2×10^{10}p/bunch
- Squeeze, increase # bunches to 13/beam
- Commission nominal bunch of 10^{11} p with 3, 6, … 25 bunches per beam
- August 2010 –> 100s bunches (nominal LHC 2880/beam)

Future aims

$L=10^{32}$ $cm^{-2}s^{-1}$ by end 2010
I L = 1 fb^{-1} by end 2011.



Delivered luminosity increasing exponentially!

Data Taking

Current peak luminosity:
$1.6\ 10^{30}\ cm^{-2}s^{-1}$

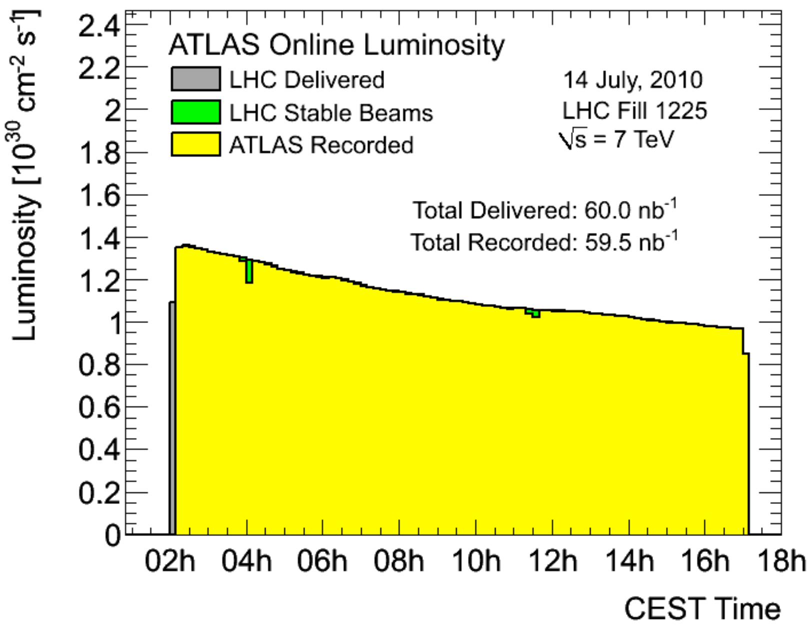
Luminosity uncertainty: 11%!

ATLAS uptimes at 7 TeV

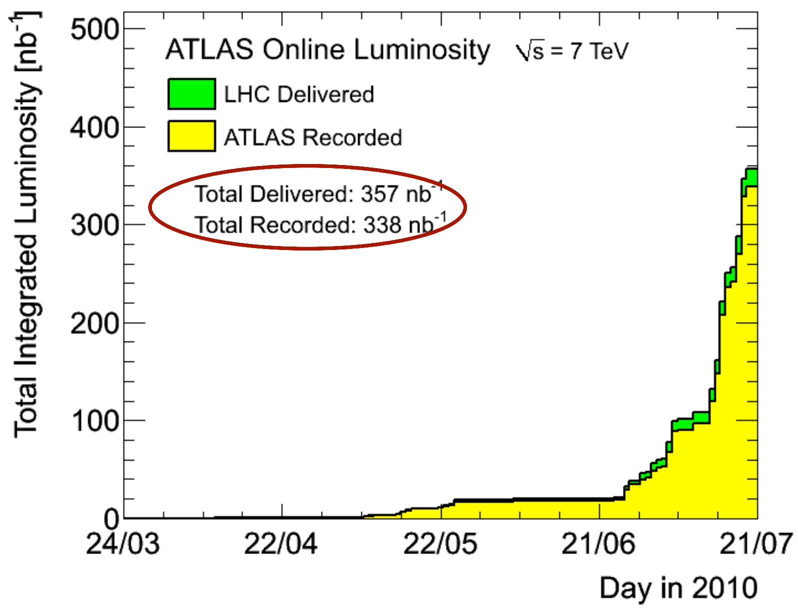
Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	TGC	CSC
97.1	98.2	100	93.8	98.8	99.1	100	97.9	96.1	98.1	97.4

Luminosity weighted relative detector uptime and good quality data delivery during 2010 **stable beams** at √s=7 TeV between March 30th and July 16th (in %)

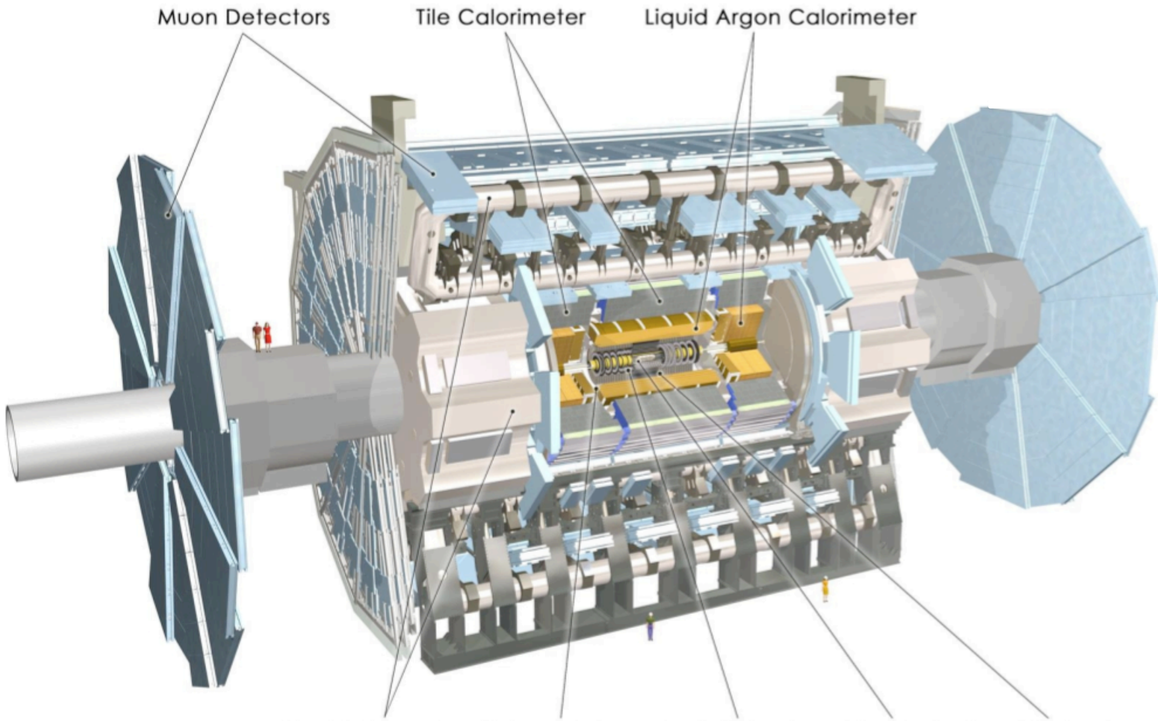
Recent fill example:



Total collected:



ATLAS Detector



Coverage in pseudorapidity

Tracking	$\|\eta\|<2.5$
Calorimeter	$\|\eta\|<4.9$
Muon spectrometer	$\|\eta\|<2.7$

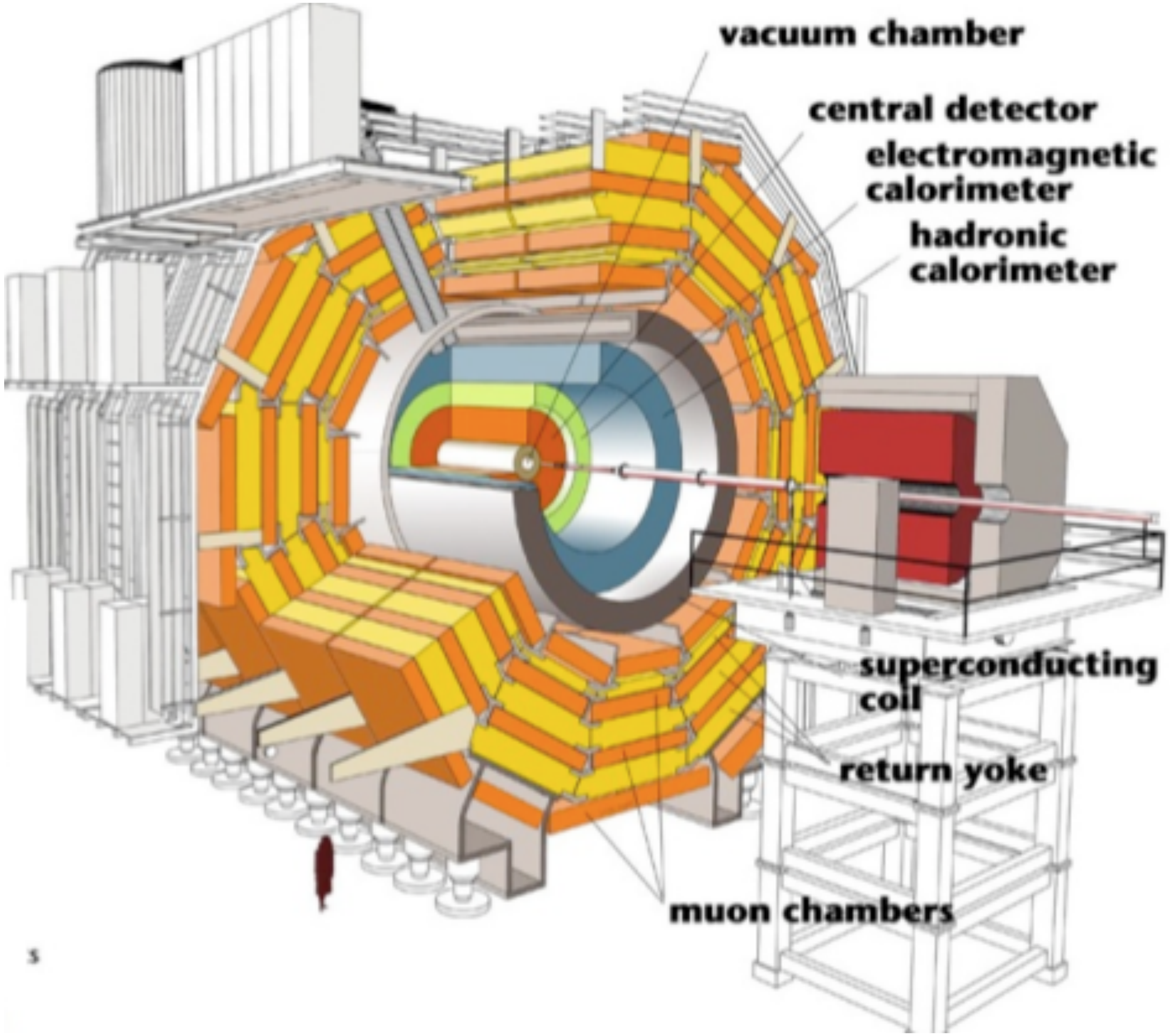
Size: 44m x 25m
Weight: 7000 tons
Readout channels: 10^8

Detector component	Required resolution
Tracking	$\sigma_{p_T}/p_T = 0.05\%\ p_T \oplus 1\%$
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$
Hadronic calorimetry (jets)	
barrel and end-cap	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$
forward	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$
Muon spectrometer	σ_{p_T}/p_T=10% at $p_T = 1$ TeV

Trigger system

Input: 40 MHz
L2: 75 kHz
Output: 200 Hz

CMS Detector



Calorimeter contained inside solenoid

Muon chambers embedded in iron return yoke.

Weight: 12500 t
Length: 12.6m
Diameter: 15m
Magnetic Field: 4 T

Detector Performance

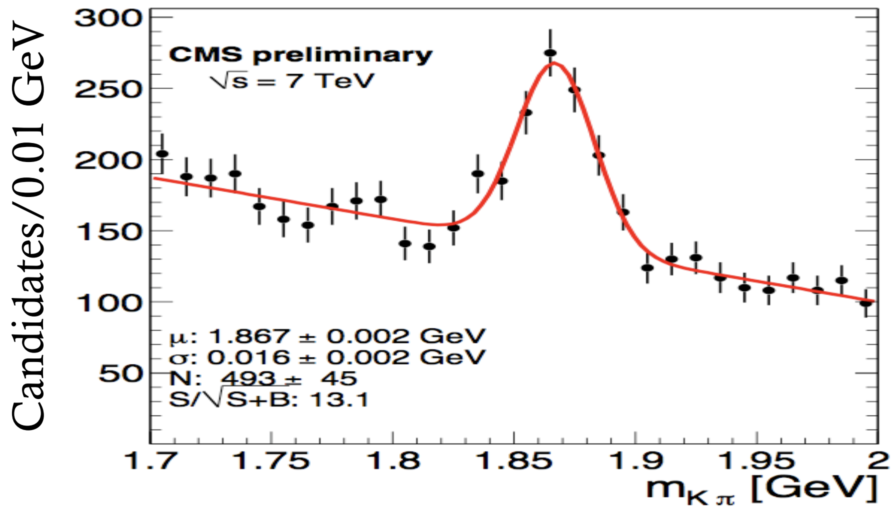
Tracking Performance

CMS observation of $D^0 \to K\pi$

$p_T(K) > 1.25$ GeV, $p_T(\pi) > 1$ GeV

good sec vertices

$\angle(\vec{p}_{D0}, \overline{PV:SV}) < 0.1$



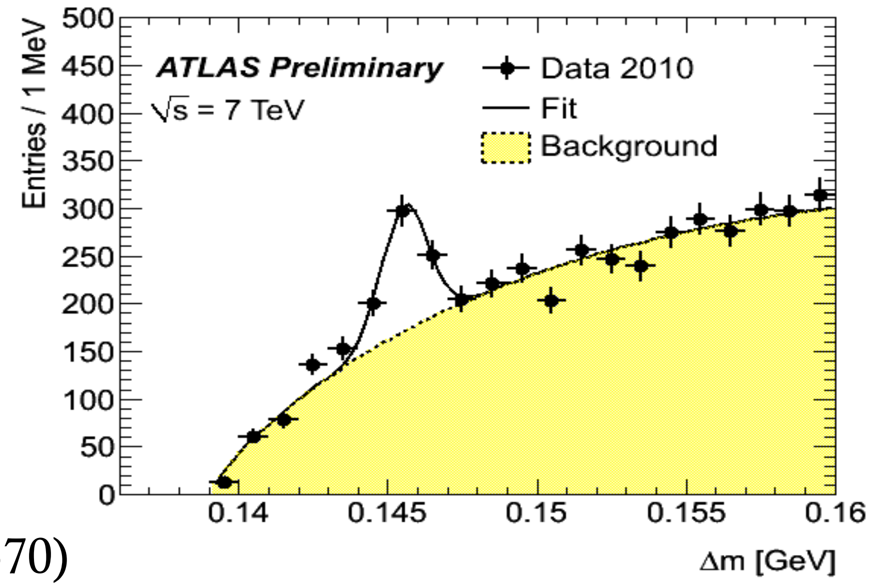
ATLAS observation of $D^* \to D^0\pi$

$|m(K\pi) - 1.865\ \text{GeV}| < 20$ MeV

p_T of $D^* > 4.5$ GeV

$m_{D*} - m_{D0} = 145.56 \pm 0.12$ MeV

(PDG: 145.436 ± 0.016 MeV)



Other observed particles:

Λ, K_s, $K^*(890)$, $\phi(1020)$, $\Xi(1320)$, $\Omega(1670)$

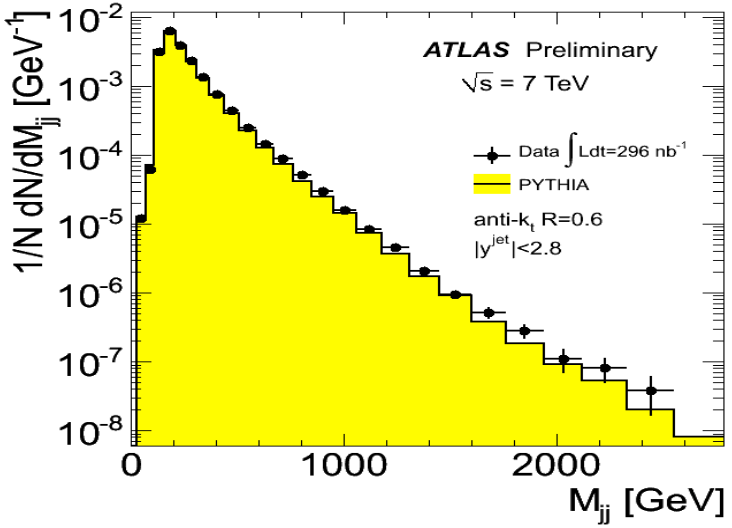
Calorimeter Performance

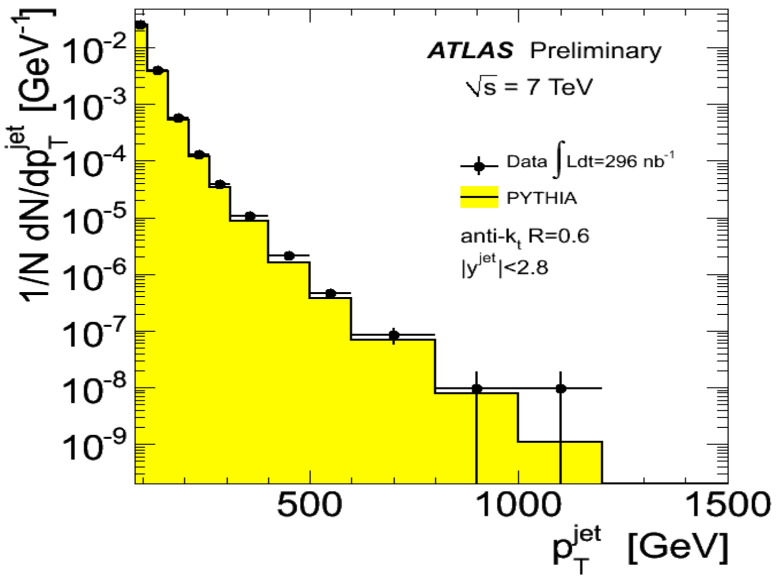
Measurement of high p_T jets

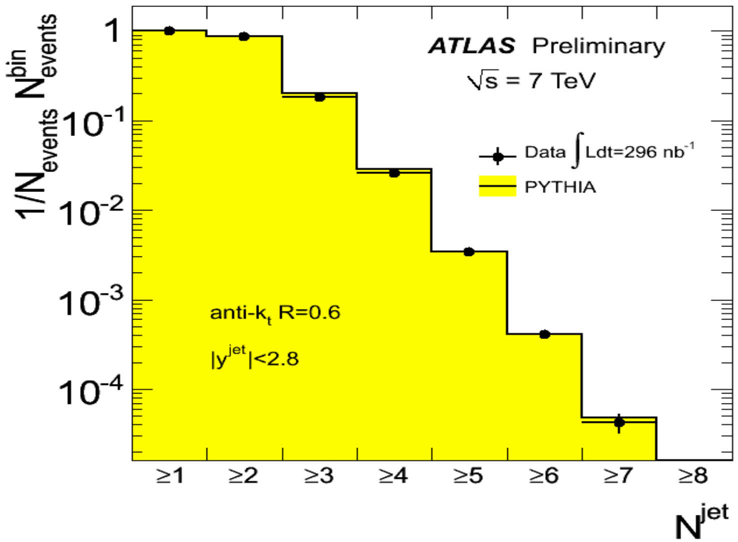
Jet distributions for jet p_T > 30 GeV

Good agreement in jet p_T spectrum over many orders of magnitude.

Dijet properties well described.







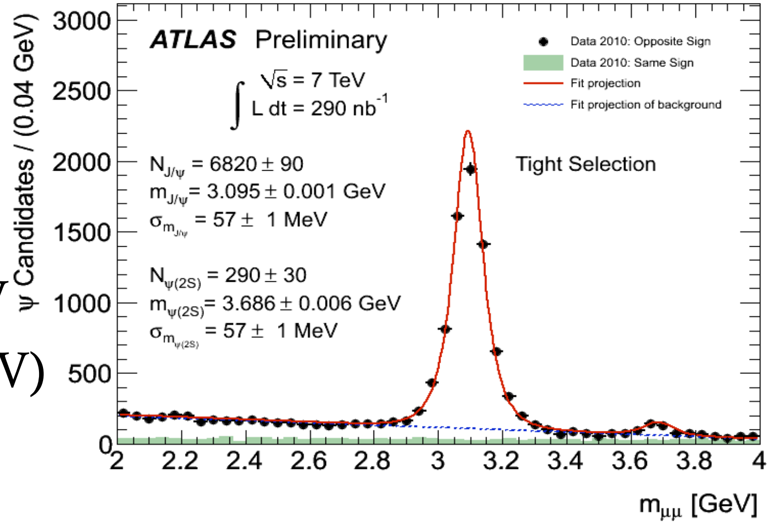
Muon Performance

Observation of J/ψ

Using combined muon+ID tracks.

Good agreement observed.

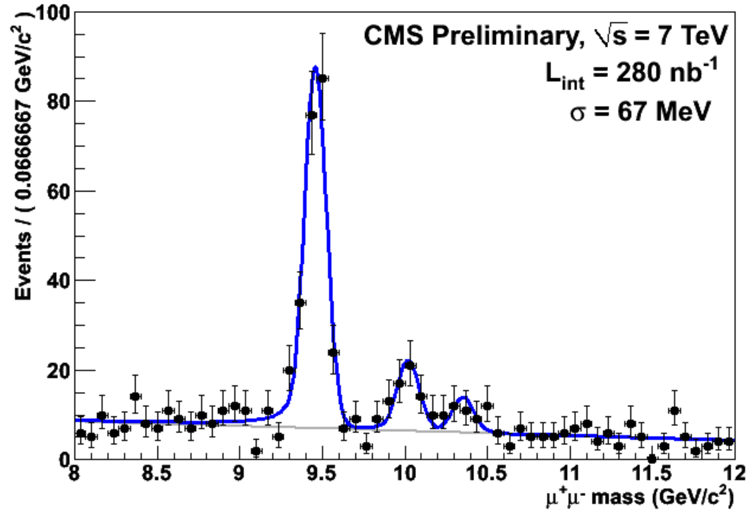
Di-muon invariant mass: 3.095 ± 0.001 GeV
(PDG: 3.09 ± 0.00001 GeV)



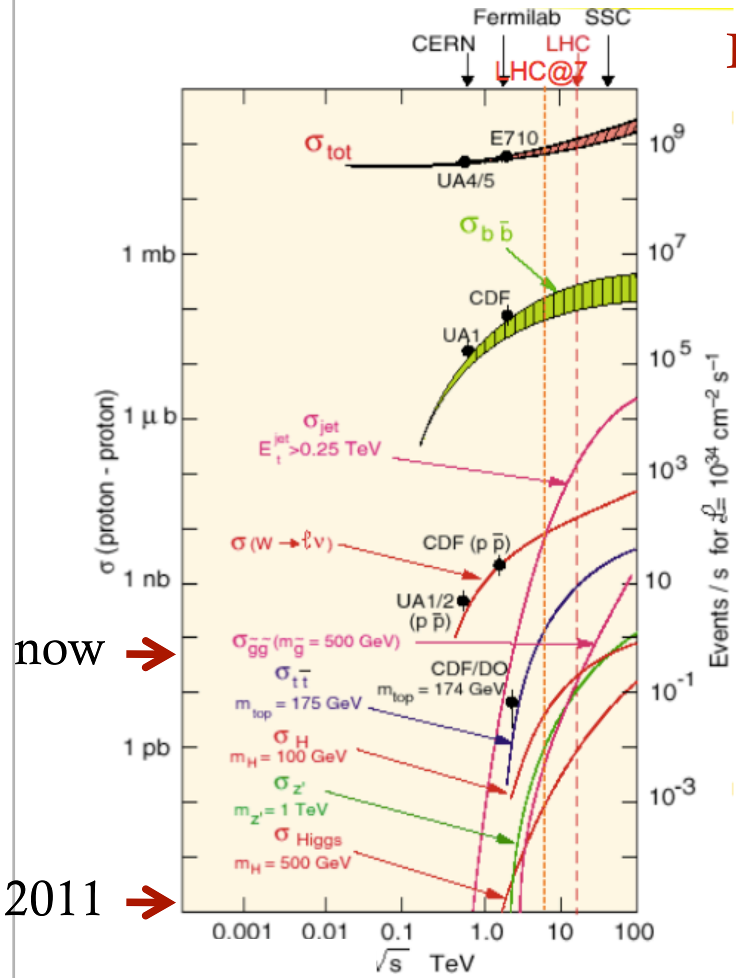
Observation of Y excited states

Selecting events with |η(Y)|<1.0

Signal events Y(1S)	218 ± 17
Signal events Y(2S)	43 ± 9
Signal events Y(3S)	22 ± 8
Background events	385 ± 24



LHC Physics Overview



Fundamental questions of particle physics:

Origin of matter: Higgs

Hierarchy problem: SUSY

Extra dimensions, black holes

Origin of dark matter: WIMPs,

Many other scenarios: 4th generation, LFV, etc.

Dark matter candidates at LHC:

Lightest SUSY particle (LSP)

Signatures

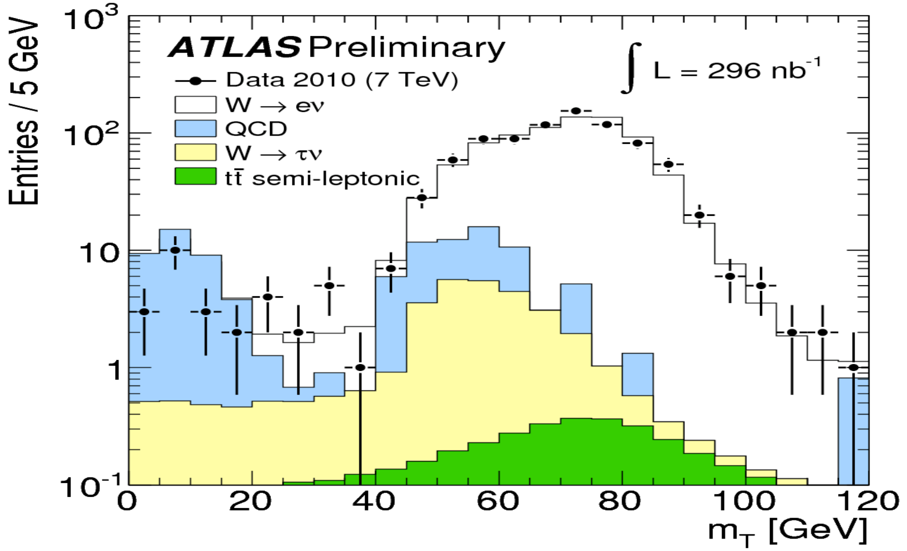
- Missing energy
- High pT jets and leptons
- Kinematic edges

Rediscovering the SM: $W^{\pm}$

W -> eν by ATLAS

Data events: 815

MC normalized to number of observed data events.



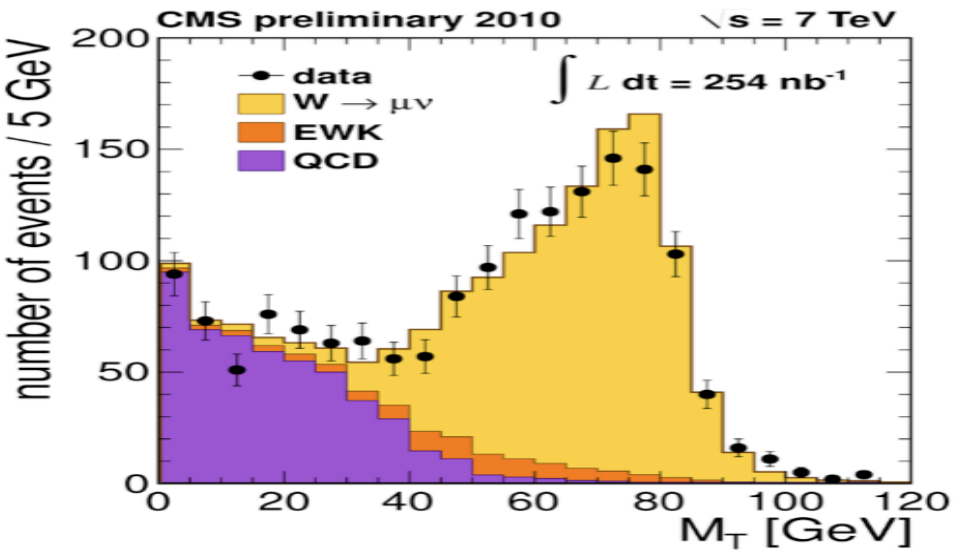
W -> μν by CMS

Data events: 940

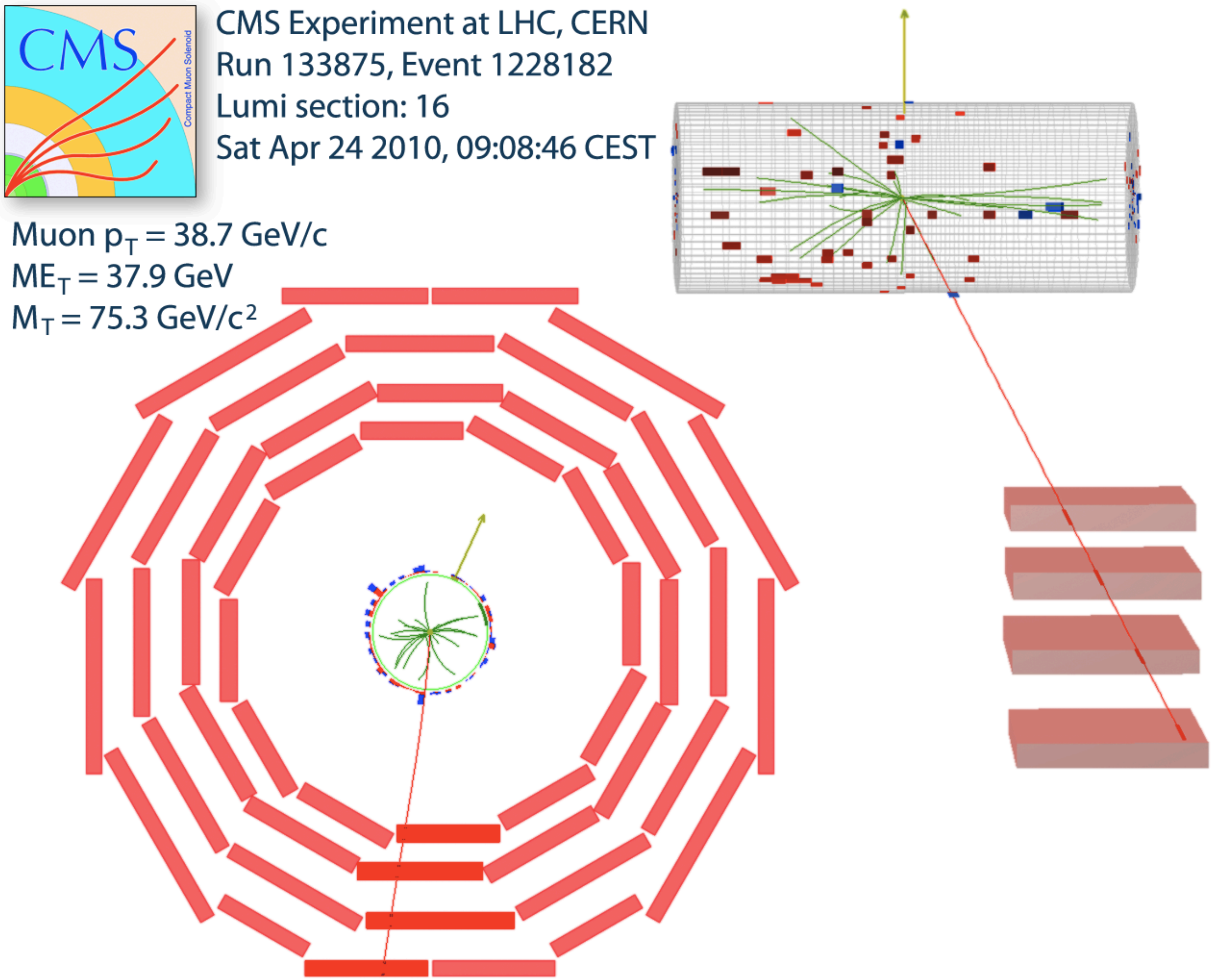
Expected in MC:

1019 signal

50 background



CMS W->μν candidate



Rediscovering the SM: Z^0

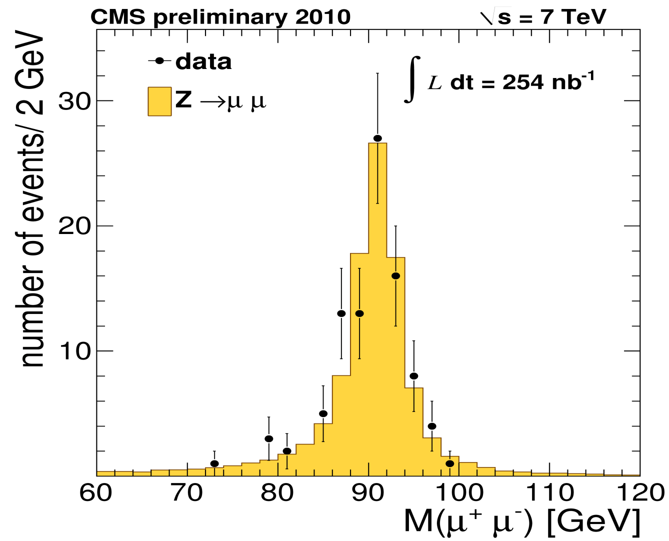
Z->μμ peak observation

Data events: 93

Expected in MC:

100.0 signal

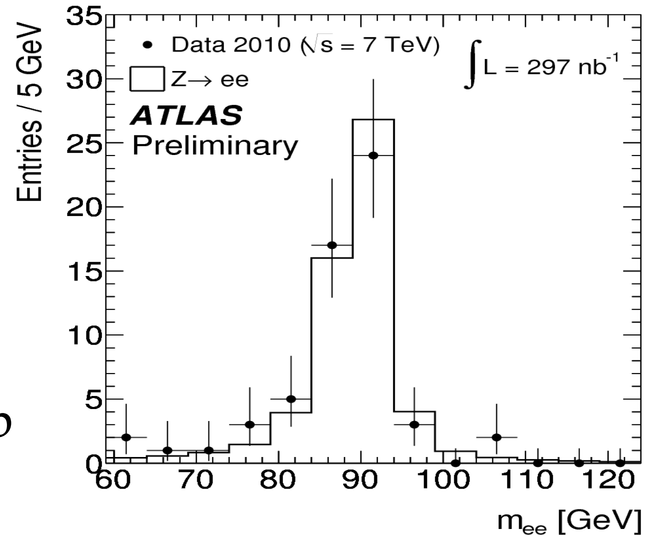
0.4 background



Cross section measurement from Z->ee + Z->μμ

Requiring $66 < m_{ll} < 116$

125 candidate events in 225 nb^{-1}



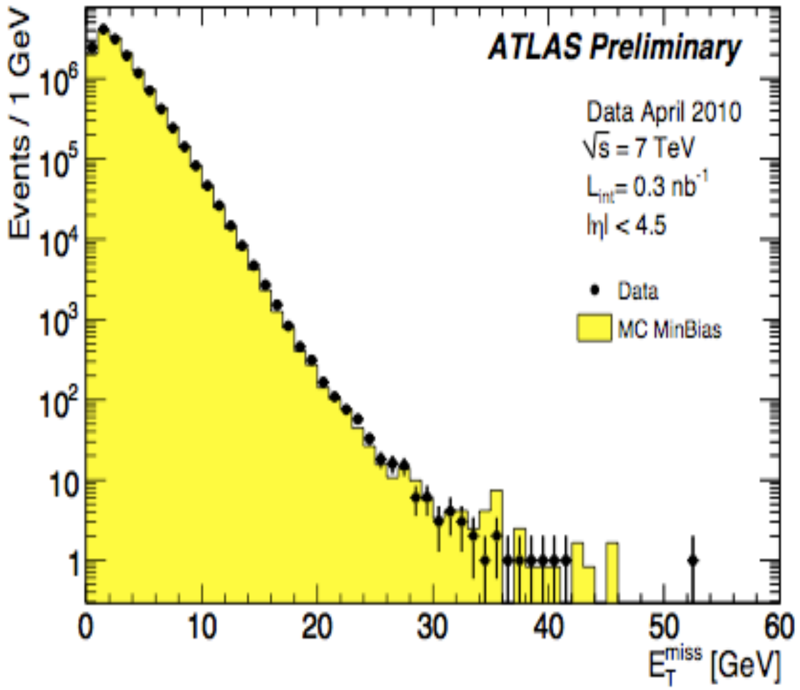
Deduced cross-section:

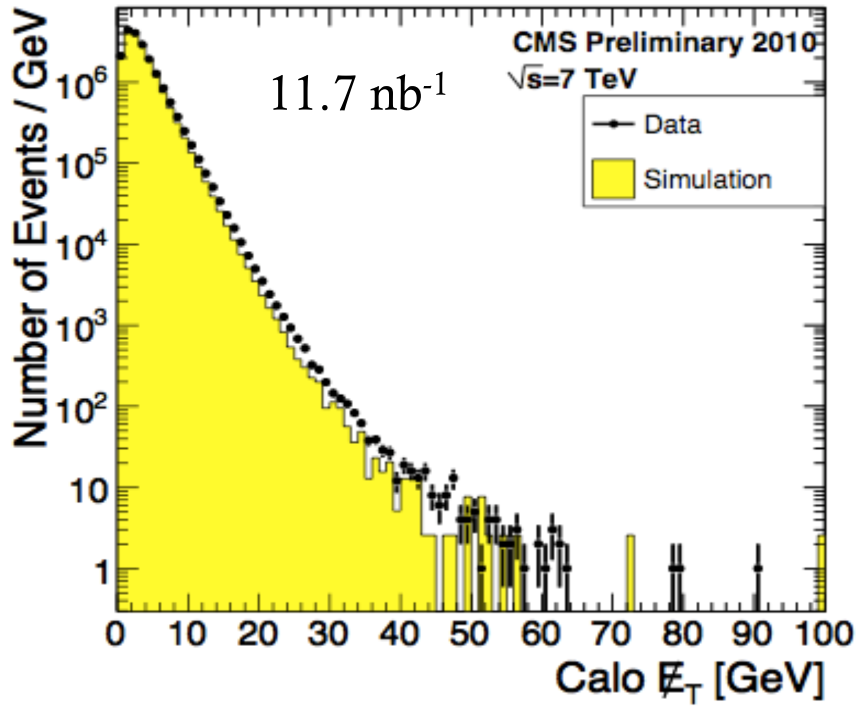
0.83 ± 0.07 (stat) ± 0.06 (syst) ± 0.09 (lumi) nb

(theoretical prediction: 0.964 ± 0.039)

Physics Performance: MET

MET in MinBias data: modeling of fake MET.





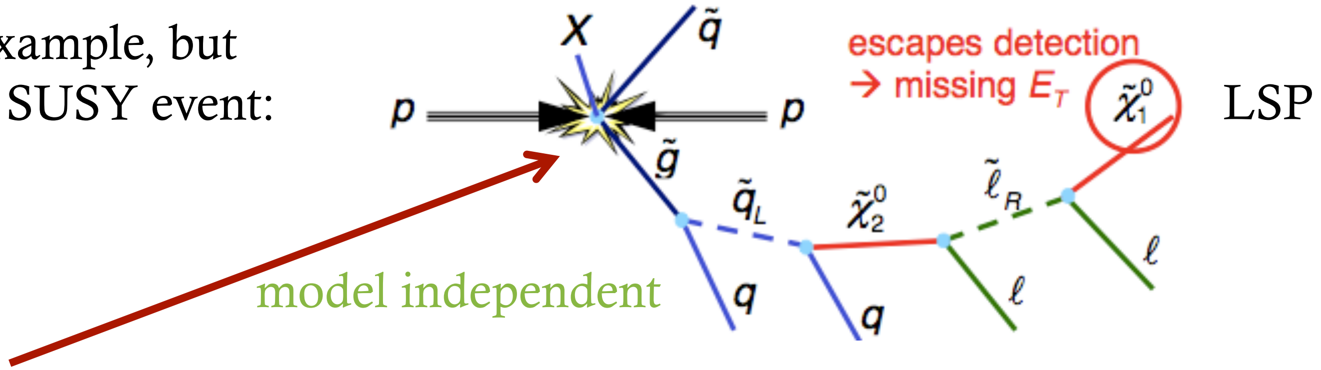
Four different algorithm give similar results.

$E_T$miss well behaved, excellent detector performance.

Even tail is well described -> we are ready to look for new physics!

SUSY processes at LHC

Typical example, but untypical SUSY event:

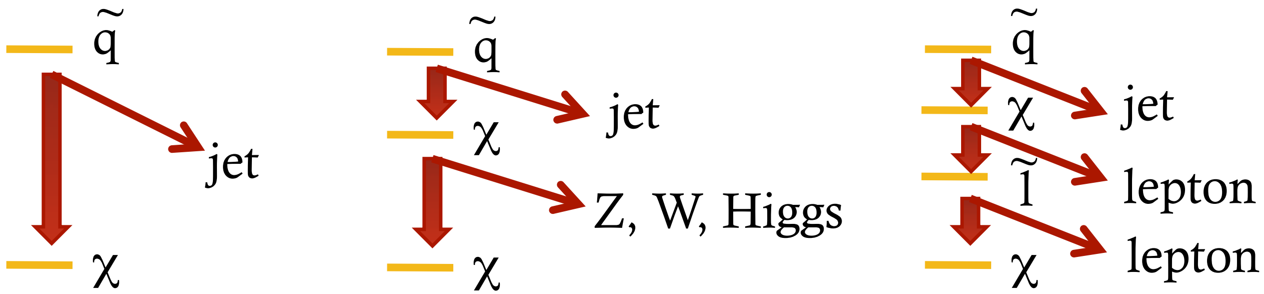


Production of two strongly interacting sparticles: squark/gluino has highest x-sect.

Three production modes: $\tilde{q}\tilde{q}$, $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$

Possible LSPs: χ, $\tilde{\nu}$, $\tilde{G}$ (model specific)

Possible decay chains (dependent on spectrum and neutralino/chargino composition):



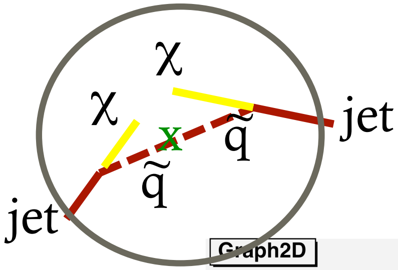
(Gauginos χ are the superpartners of the SM bosons (γ, Z^0, $W^\pm$, Higgs)).

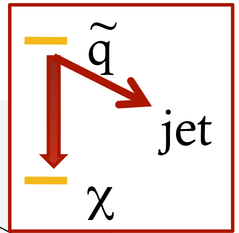
SUSY Variables

Missing transverse energy (MET)

Calculated from calorimeter cells.

Actually we only measure p_T-miss





Scalar jet p_T sum (MHT):

$$H_T = \sum_{i=1}^{N_{jets}} P_T^{jet,i}$$

If jet p_T are high

MPT

Calculated from tracks:

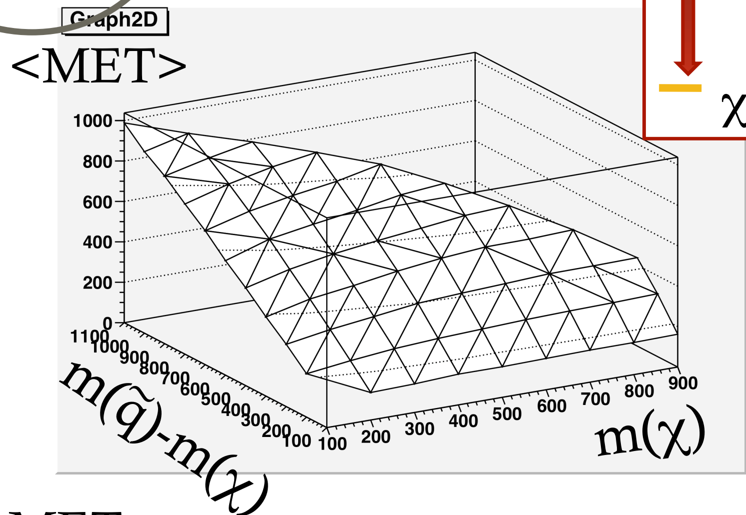
$$\mathrm{MPT} \equiv |-\sum_i \vec{p}_T(\mathrm{track}_i)|$$

M_{eff}

If jet and lepton p_T are high

$$M_{\mathrm{eff}} \equiv \sum_{i=1}^{N_{jets}} P_T^{\mathrm{jet},i} + \sum_{i=1}^{N_{lep}} P_T^{\mathrm{lep},i} + E_T^{\mathrm{miss}}$$

(but dangerous if this is not the case)



MET

- Depends on mass difference, not m_{LSP}.
- Can be small.

Transverse mass M_T:

$$M_T = \sqrt{2(p_T^{lep} E_T^{miss}(1-\cos(\Delta\Phi(lep, E_T^{miss}))))}$$

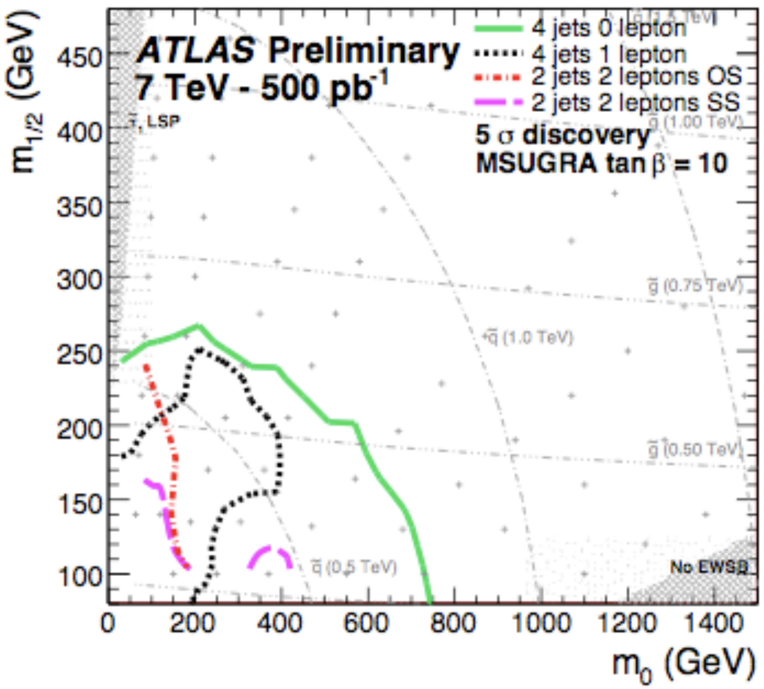
MC Studies of mSUGRA Reach (@ 7TeV)

ATLAS expected Reach

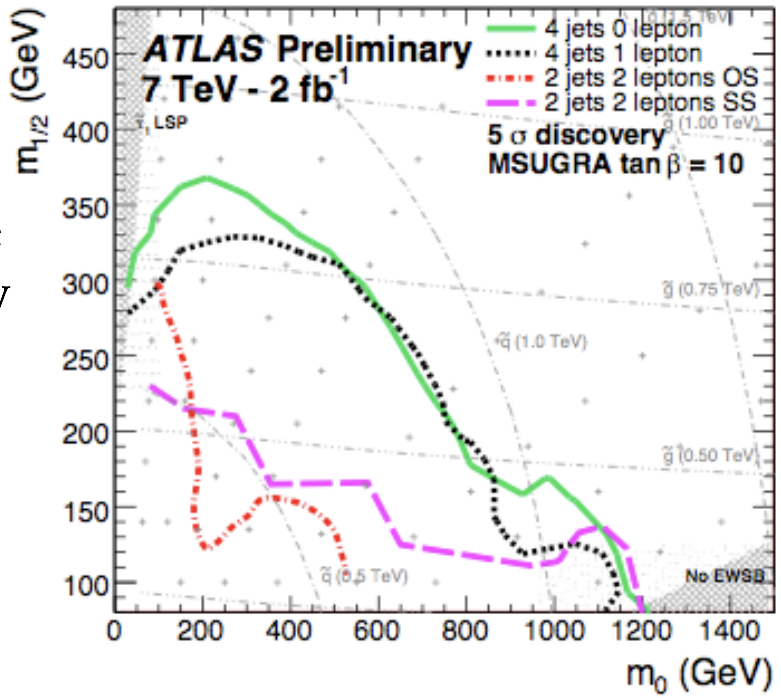
Inclusive channels: 0 lepton, 1 lepton (e,μ), 2 leptons (same-sign, opposite-sign)

Calculating 5 σ discovery reach in m_0-$m_{1/2}$ plane, $\tan\beta=10$, $A_0=0$, $\mu>0$:

Assuming conservative uncertainties (20% electroweak, 50% QCD).



with more luminosity



Gluino/squark masses up to 600 GeV.

Gluino/squark masses up to 800 GeV.

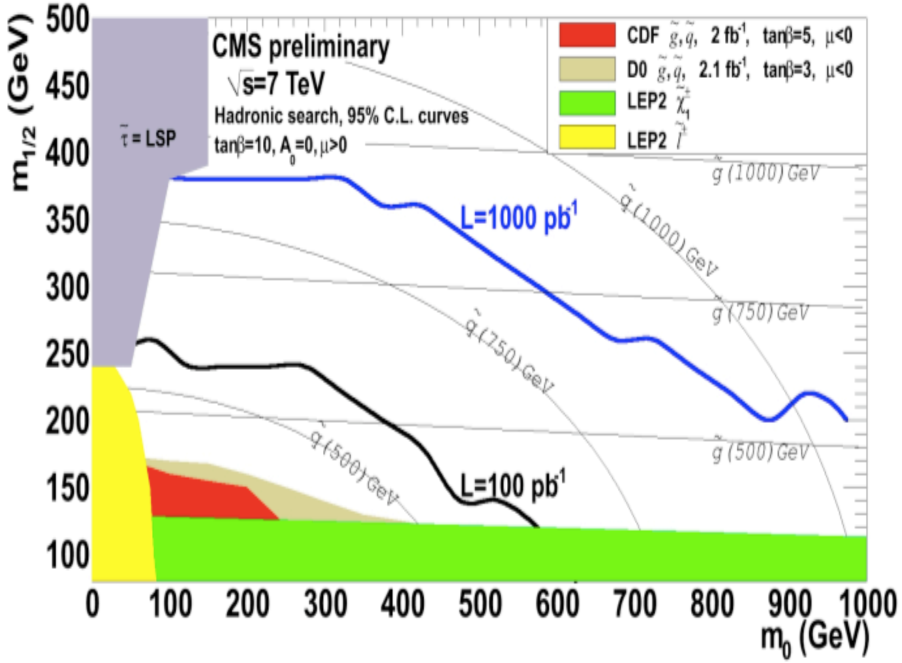
CMS expected reach

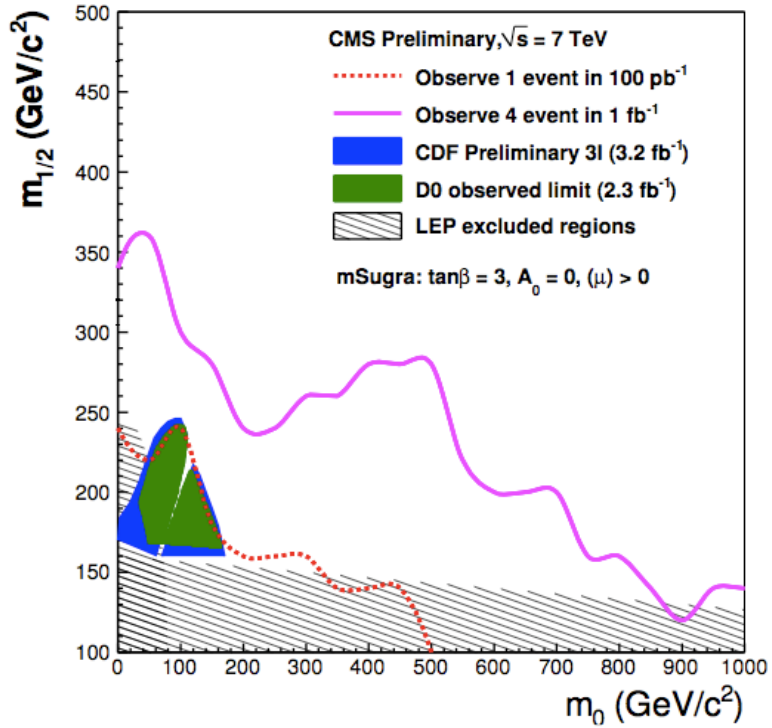
0 Lepton Analysis

Quite inclusive selection
Based on H_T and $p_T$miss
Vetoing leptons
SM Backgrounds estimated from the data.

Same-Sign Dilepton Analysis

Less inclusive, but small backgrounds.
Three channels analyzed: μμ, ee, μe
Main background from ttbar: <1 evt/100 pb^{-1}





Extension of LEP & Tevatron limits with ≤ 100 pb^{-1}.

First SUSY Studies with 7 TeV Data

Complete list of 7TeV results:

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/

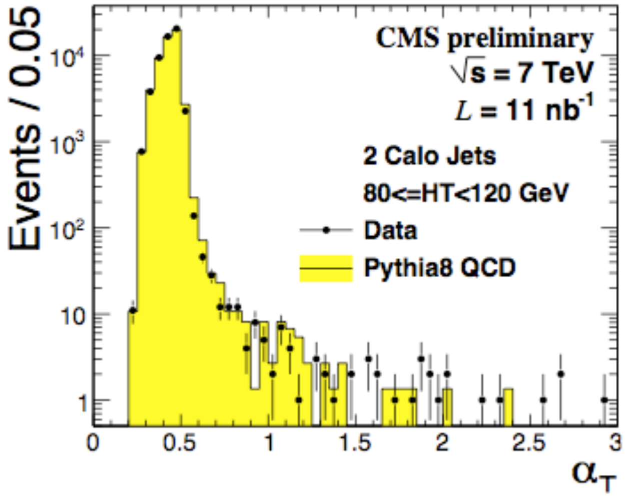
http://cms-physics.web.cern.ch/cms-physics/public/

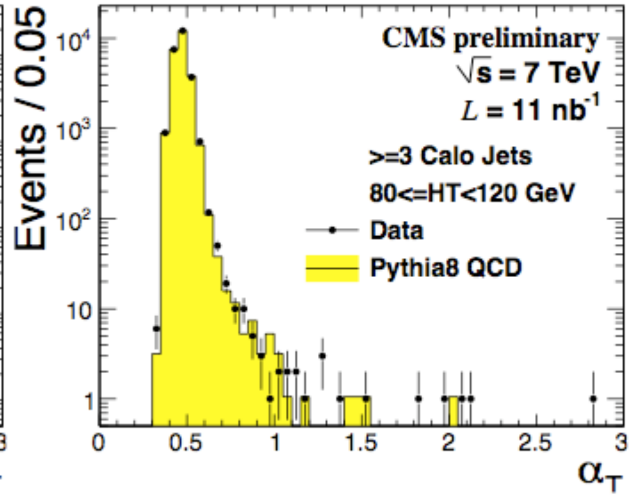
Kin. Varbles for SUSY Backg

Discrimination of fake MET from jet miss-measurement [SUS-10-001-pas]

$$\alpha_T \equiv \frac{p_{T2}}{M_T}$$

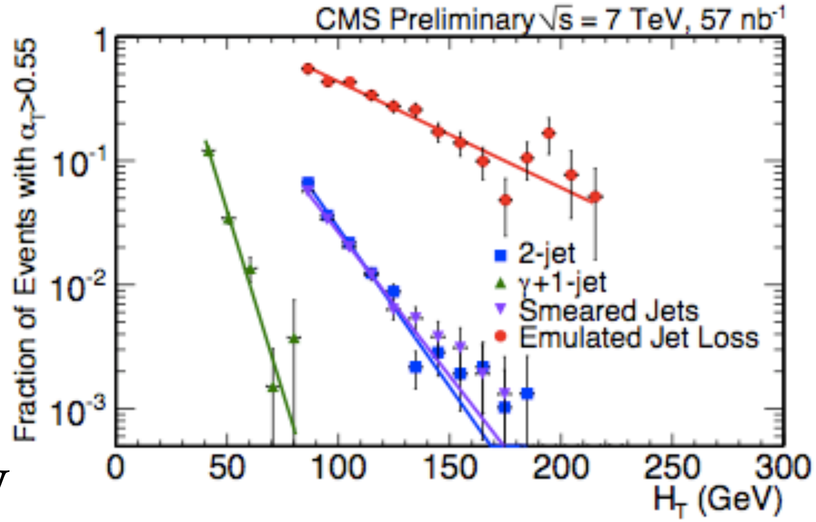
[arXiv:0806.1049v1]





SUSY signal expected at α_T>0.55

Generally good data/MC agreement observed in all cases.



Fraction of background events decreases exponentially with increasing H_T.

SUSY analysis typically require H_T>300 GeV

Data-Driven Bkg Estimation

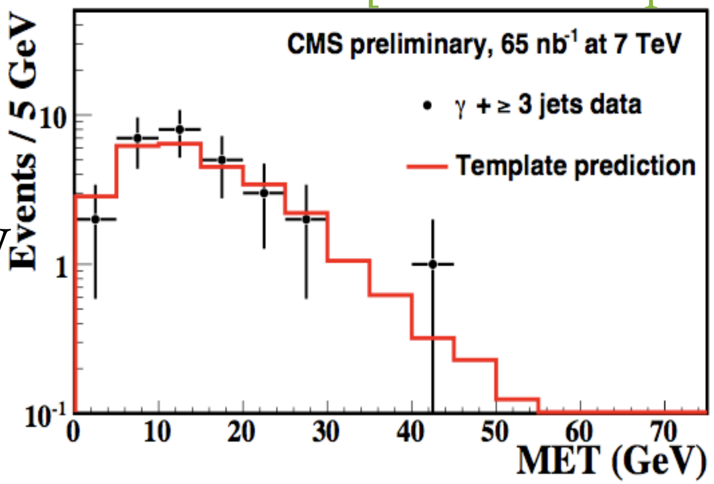
[SUS-10-001-pas]

Using QCD to predict fake MET in γ+jets events

MET measured for QCD multi-jet events in bins of #jets and H_T.

selecting γ pT > 15GeV, ≥ 3 jets with pT>40 GeV

Calculate predicted MET by looking up MET in #jets, HT bin for each γ+jets event

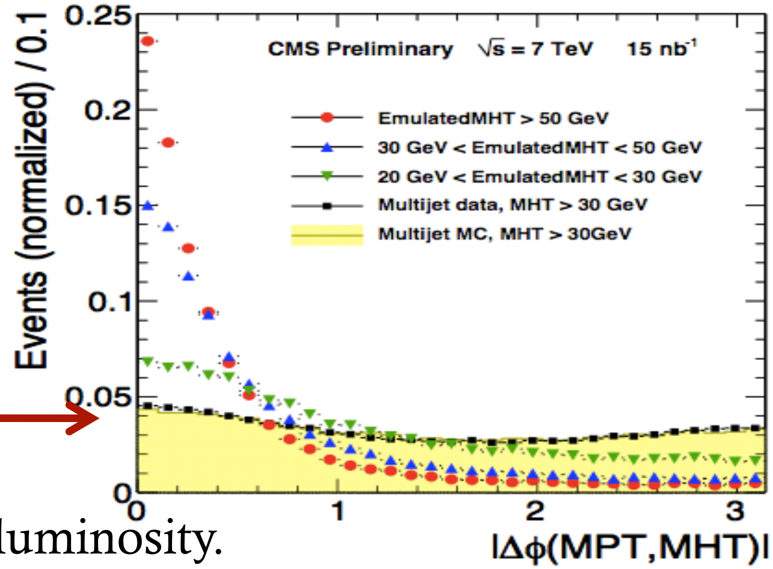


Distinguishing real and fake MET

Simulating real MET by randomly removing one jet ('EmulatedMHT').

MPT and MHT are aligned for real MET, uncorrelated for QCD.

Data shows no sign of real MET.



Kinematic region will be extended with more luminosity.

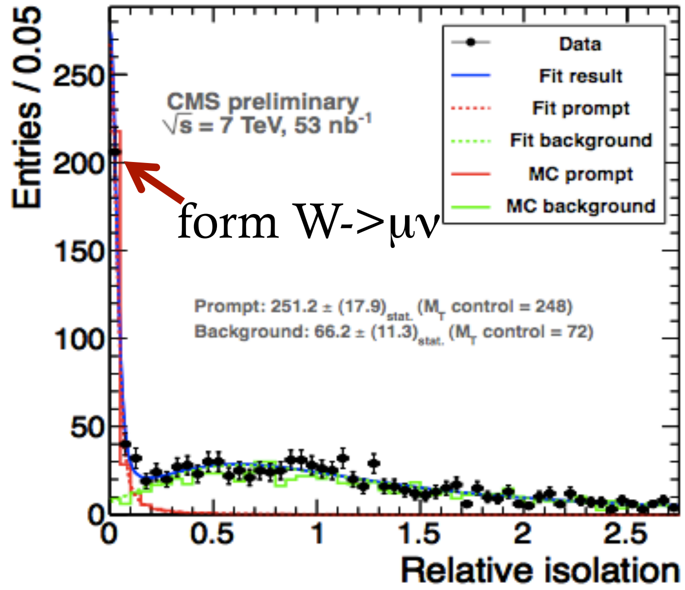
Estimation of lepton backg

[SUS-10-001-pas]

Muon background prediction with isolation fits

Determination of background from non-prompt muons to prompt muon signal.

Extrapolation from the non-isolated to the isolated muon region.



Estimating QCD backgrounds in lepton channels

Very small QCD backg expected, may be estimated by assuming factorization of selection efficiencies:

$$\epsilon_{ABC} = \epsilon_A \epsilon_B \epsilon_C$$

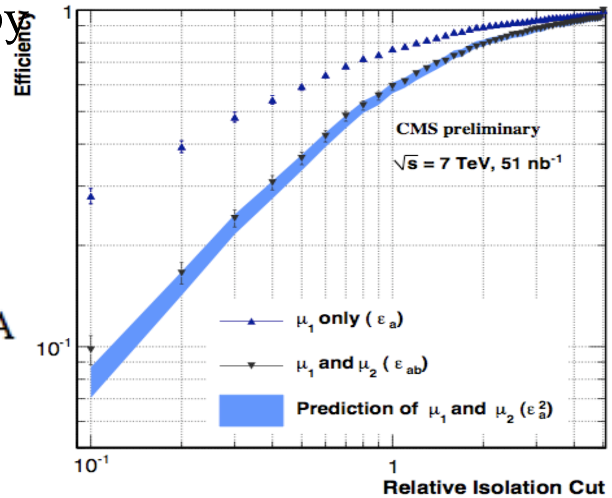
Application to same-sign di-muon search:

Cut A $\equiv$ Relative isolation of μ_1 below some value

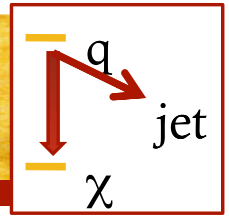
Cut B $\equiv$ Relative isolation of μ_2 below the same value as A

Cut C $\equiv$ Presence of a 3rd jet and large MET

Confirmation observed in data: $\epsilon_{AB} = (\epsilon_A)^2$



0 lepton Analysis



Final state: jet + MET [ATLAS-CONF-2010-065]

Same inclusive channels as in MC studies (+Monojet).

Selection criteria for different channels

Number of jets	Monojets	≥ 2 jets	≥ 3 jets	≥ 4 jets
Leading jet p_T (GeV) Subsequent jets p_T (GeV)	> 70 veto if > 30	> 70 > 30	> 70 > 30 (Jets 2 and 3)	> 70 > 30 (Jets 2 to 4)
E_T^{miss} $\Delta\phi(\text{jet}_i, \vec{E}_T^{miss})$	> 40 GeV no cut	> 40 GeV $[> 0.2, > 0.2]$	> 40 GeV $[> 0.2, > 0.2, > 0.2]$	> 40 GeV $[> 0.2, > 0.2, > 0.2, > 0]$
$E_T^{miss} > f \times M_{eff}$	no cut	$f = 0.3$	$f = 0.25$	$f = 0.2$

Loose selection for comparison with SM.

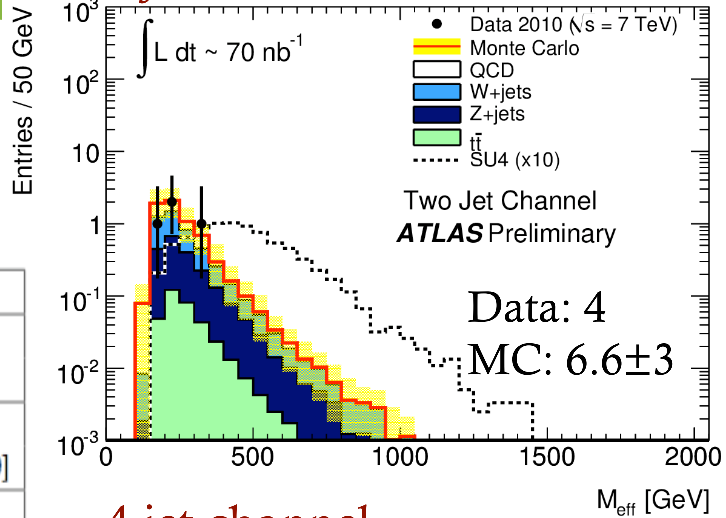
70 nb^{-1} analyzed so far.

More luminosity needed for SUSY to become visible.

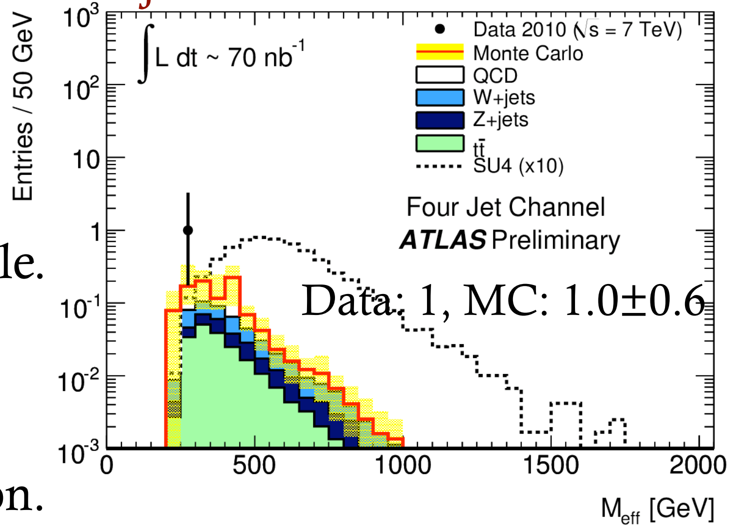
All results agree with SM expectations.

QCD normalized to data in low MET control region.

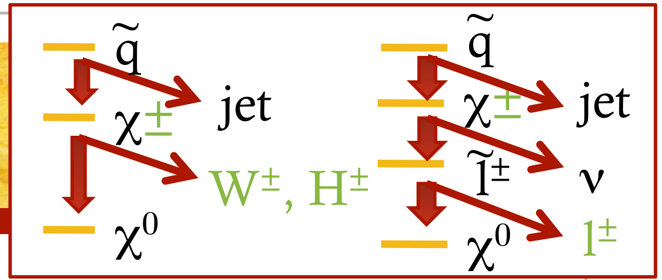
2 jet channel



4 jet channel



1 lepton Analysis

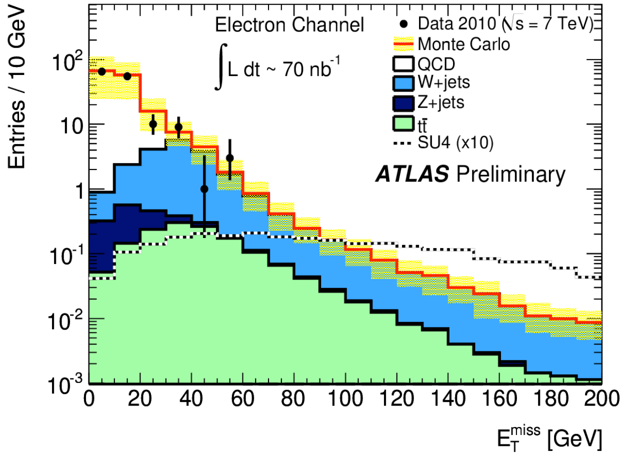


[ATLAS-CONF-2010-066]

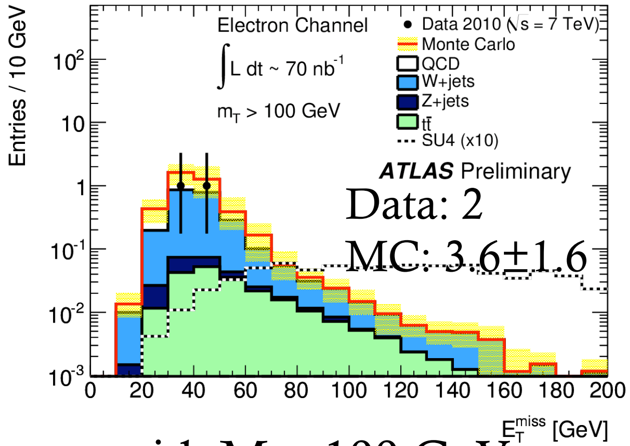
Electron Channel:

lepton pT > 20 GeV

2 jets with
p_T> 30 GeV
|η| < 2.5



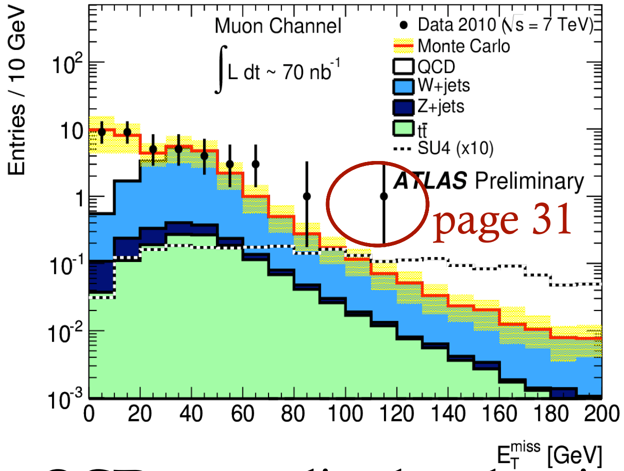
with M_T>100 GeV



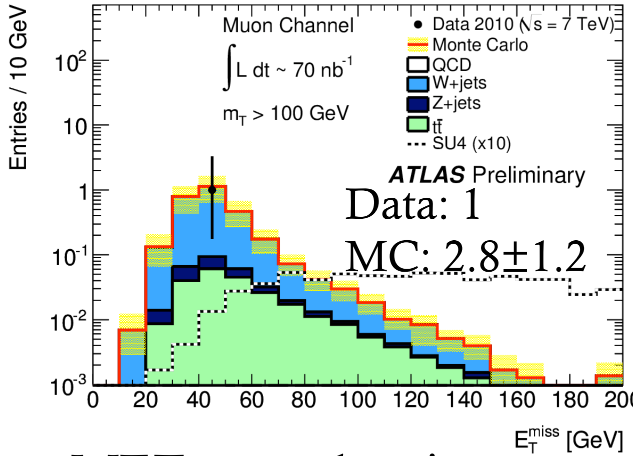
Muon Channel:

lepton pT > 20 GeV

2 jets with
p_T> 30 GeV
|η| < 2.5



with M_T>100 GeV



For all lepton channels: QCD normalized to data in low MET control region.

Dilepton Analysis

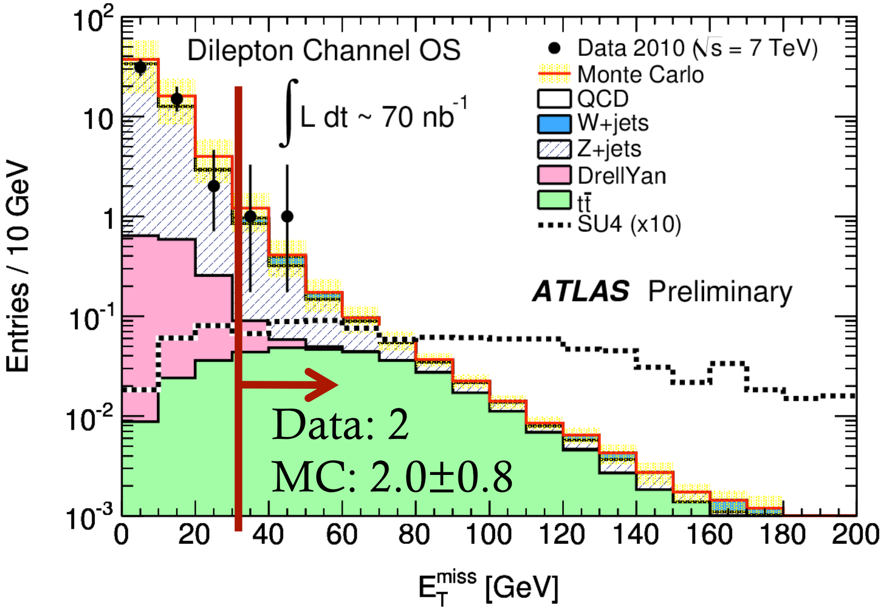
[ATLAS-CONF-2010-066]

At least 2 leptons, one with p_T>20GeV, others with p_T > 10 GeV
Dilepton invariant mass > 5 GeV

No jet requirements.

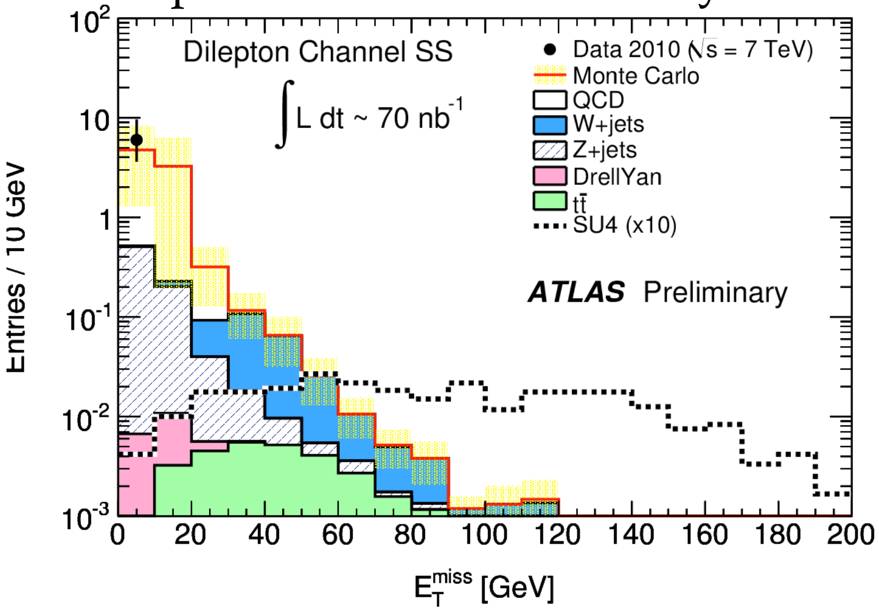
Opposite-sign channel

Leptons from Z^0,H^0 or $\tilde{l}^{\pm}$ chain



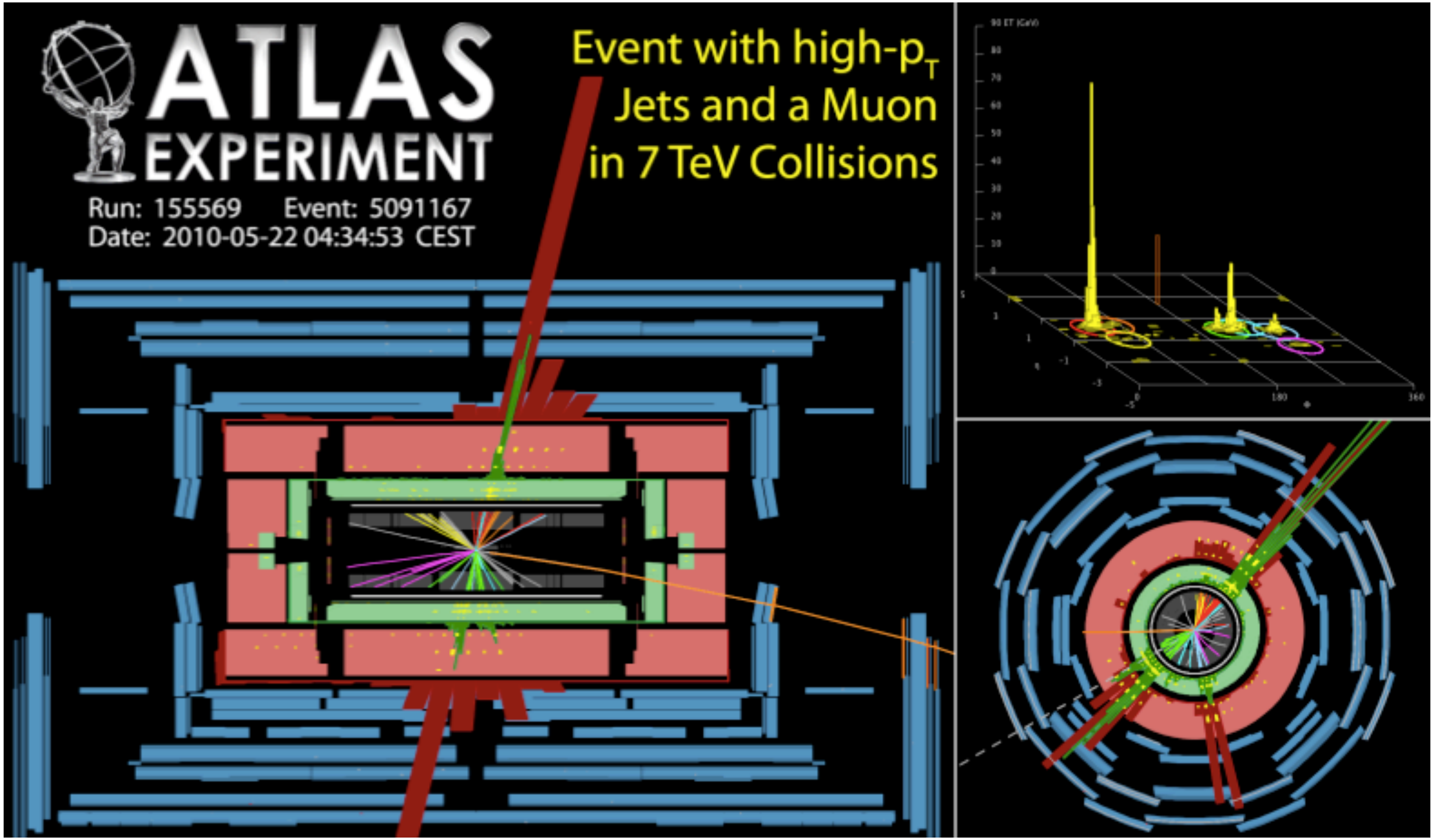
Same-sign channel

Leptons from different decay chains



General result: SM backgrounds to SUSY searches are under good control!

Interesting Event

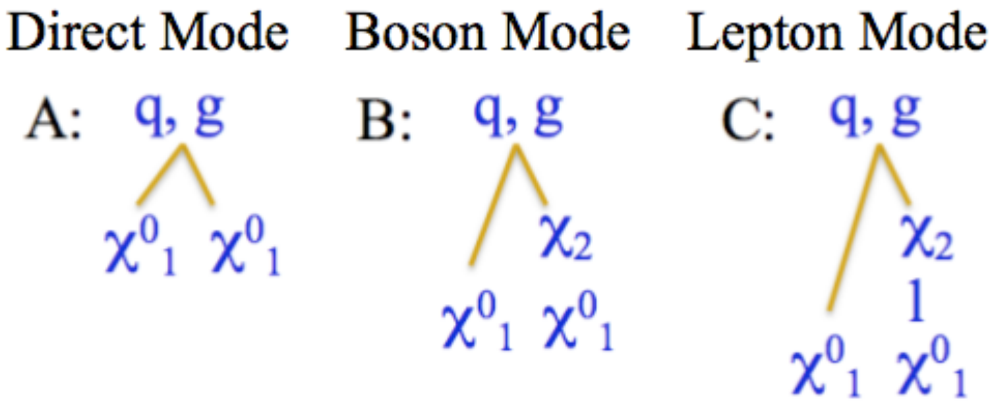


M_{eff} = 915 GeV (using two highest p_T jets); MET = 118 GeV ; muon p_T = 25 GeV

Outlook

Standard approach looks at convolution of all decays at specific SUSY point.

Future: Decay mode specific analyzes



[arXiv:0905.4497v2]

- SUSY model-independent interpretation of results
- Increased coverage of SUSY scenarios (mass constraints in special SUSY models)
- Increased sensitivity (less inclusive)
- Favors determination of sparticle properties

Conclusions

LHC is producing proton-proton collisions at world-record energies of 7TeV.

ATLAS and CMS are showing excellent performance.

Large amount of measurements let us rediscover the SM at 7 TeV.

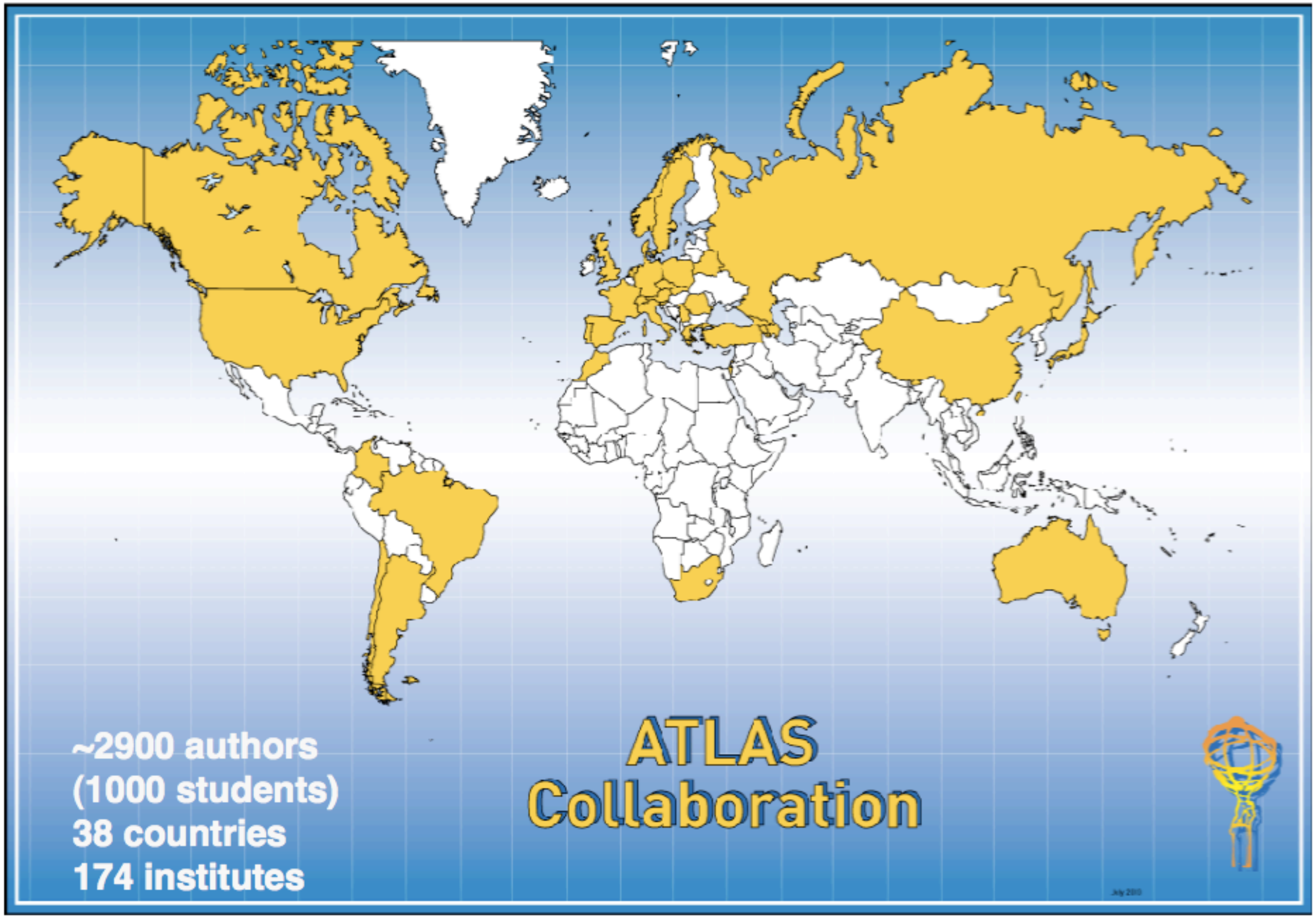
Searches for new physics phenomena have started!

Large number of SUSY and dark matter searches!

Sensitivity advantage over Tevatron, great potential for the near future.

Bonus Material

The ATLAS Collaboration



Sensitivity LHC/Tevatron

Unitary limit for scattering in the J = 0 (S-wave) partial wave:

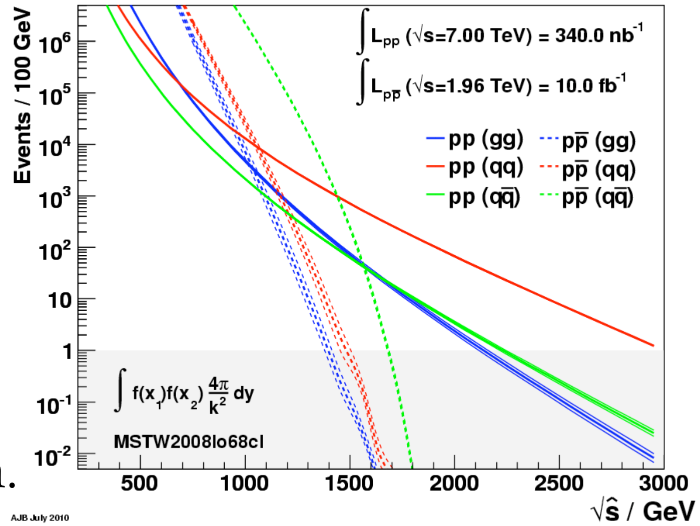
(k: wave number)

$$\hat{\sigma}_{J=0}^{\max} = \frac{4\pi}{k^2}$$

Expected events:

$$\delta N = \left(\int \mathscr{L} dt\right) \times \left(\int x_1 f(x_1) x_2 f(x_2) \frac{2}{\sqrt{\hat{s}}} \frac{16\pi}{\hat{s}} dy\right) \times (\delta\sqrt{\hat{s}})$$

Reduced by α_s^2 for strong sparticle pair-production.



[plot by A. Barr]

Already now (with factor 10^5 less luminosity)
LHC has higher sensitivity for $\sqrt{\hat{s}}$ > 1.1 TeV

Track Jets

Using tracks from charged particles for track reconstruction

Association of tracks to PVs allows for robust results under pileup
Good data/MC agreement for jets with pT > 10 GeV
Good agreement between track jets and calorimeter jets.