Prospects of SUSY observation with ATLAS detector. Process $gg \rightarrow \tilde{g}\tilde{g}$ in the EGRET point

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LHC Operation

CERN announced that LHC will run through to the end of 2012 with a short technical stop at the end of 2011. The beam energy for 2011 will be 3.5 TeV.

- **2010 has been terrific !**
  Demonstrated the excellence of the LHC and of the people who built/commissioned/operated it.

- **2010 in numbers:**
  - ➔ **1074 h** of stable beams - out of ~6600h
  - ➔ **147 injections** with stable beams
  - ➔ **2010 peak luminosity ~ 2e32 Hz/cm^2**
  - ➔ **Integrated luminosity: ~ 45 pb^{-1}**

- **2011 could be the year of discovery**
  Call is Physics only with >2e32 Hz/cm^2 peak luminosity and several tens of pb^{-1} have been collected!
  → Go up quickly to 2e32, then gradually increase to ~e33

The challenge (2011 – 2012): >5 fb^{-1}

SuperSymmetry (SUSY)

- **SUSY** is the theory about a symmetry between bosons and fermions and it is the mostly believed/expected candidate theory for Grand Unification.

- **Motivations for SUSY:**
  - It is locally invariant gauge theory and therefore Gravitation can be included by the natural way
  - Unification of gauge coupling constants into an universal one at very high energies ($10^{15} \div 10^{16}$ GeV) , what is not possible within Standard Model
  - It solves the problem of hierarchy and vanishes radiation corrections to boson masses, which are very big at large energy scale because of the contribution of very massive particle loops
  - Radiation breaking of electro-weak symmetry. This spontaneous symmetry breaking is naturally caused by radiation corrections to the mass parameters of Higgs potential
  - SUSY lightest neutral stable particle is good candidate for “Dark Matter” in the Universe

Minimal SuperSymmetry Model (MSSM)

- In MSSM with using universality principle for all boson and fermions masses we can significantly reduce the number of free SUSY parameters. This model is called **mSUGRA** – minimal supergravity. Free parameters are:

  m_0 - universal mass for all bosons

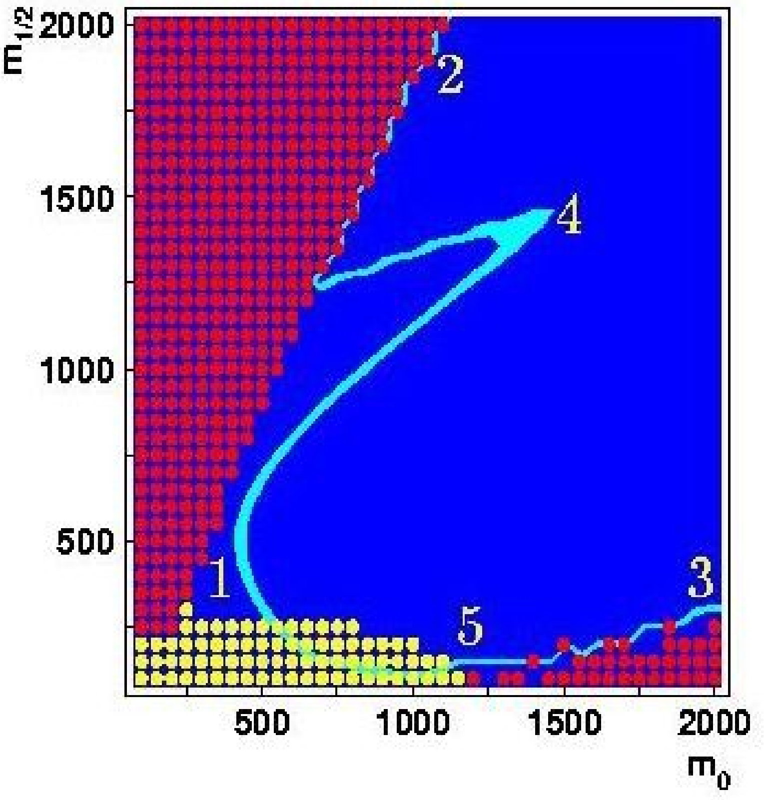
  $m_{1/2}$ - universal mass for all fermions

  A - parameter of soft supersymmetry breaking

  sign(μ) – sign of mixing parameter of two Higgs fields

  tanβ – ratio of vacuum expectation values of Higgs fields

- Plot on the right shows the mass parameters space with excluded regions (red and yellow dotted areas) due to the different experimental restrictions



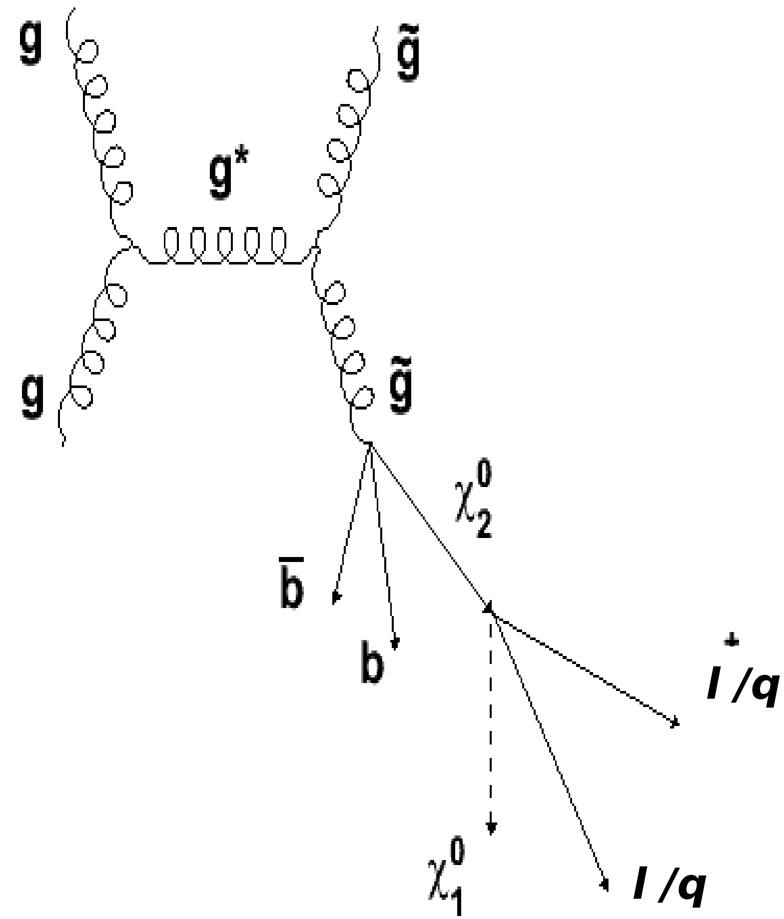
gg → ğğ in ATLAS

Cross-section of 2gluons → 2gluino for **$s^{1/2}$=14 TeV** is estimated to be of the order of **17 pb** (PDF=CTEQ6L1)

We selected the following values for free parameters (“Fixed point” – region in allowed parameter space):

- **m_0 = 1400 GeV**
- **$m_{1/2}$ = 180 GeV**
- **A = 0**
- **sign(μ) = +1**
- **tanβ = 50**
- **FSR and ISR were switched ON**

In this case gluino has large branching ratio for the decay mode shown on the right diagram giving 2 b-jets + 1 OS (oppositely signed/charged) lepton pair + large missed transverse energy (lepton = e or μ). This channel has quite good signature in SUSY searching.



$$gg \rightarrow \breve{g}\breve{g} \rightarrow 4\ b\text{-jets} + 2\ OS\ lepton\ pairs + E_T^{miss}$$

Also hadronic branch decay of gluino was added:

$$gg \rightarrow \breve{g}\breve{g} \rightarrow 4\ b\text{-jets} + 1\ OS\ lepton\ pair + light\text{-}quarks\ pair + E_T^{miss}$$

For event generation we used **Pythia** generator within **ATHENA** framework

Dependence of cross-section of process from different PDF models

Branching with 4 b-quark and 2 ($\mu^+\mu^-$) - pairs in final state

($gg \rightarrow \breve{g}\breve{g} \rightarrow$ 4 b-jets + 2 OS muon pairs + E_T^{miss})

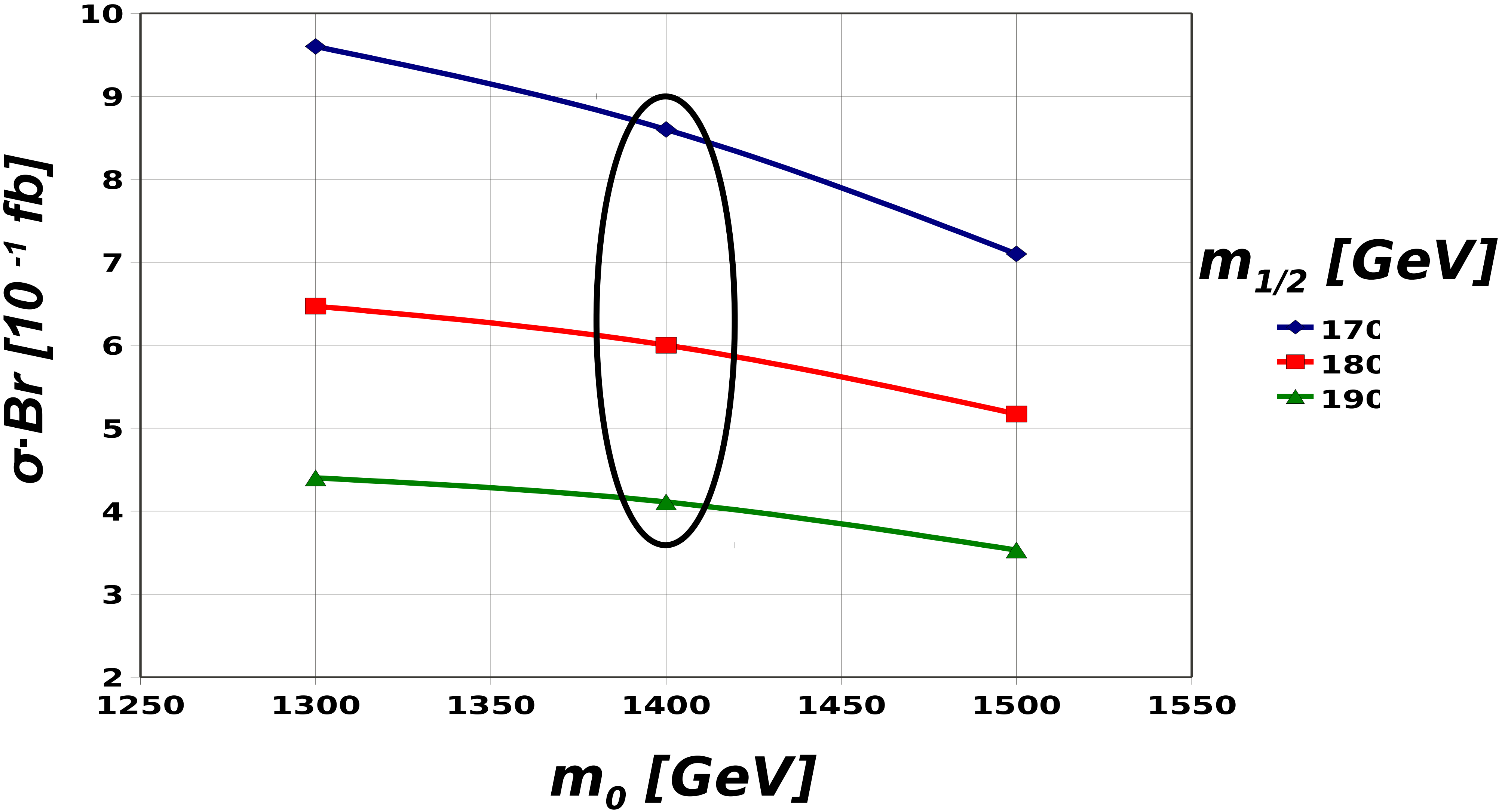
	PDF model					
	CTEQ6L1 (ATLAS DEFAULT)	MRST_2001_nlo	MRST_2004_nnlo	Fermi_2002_1000	Alekhin_1000	Botje_1000
σ·Br, [mb]	$5.993*10^{-13}$	$8.509*10^{-13}$	$9.908*10^{-13}$	$7.23*10^{-13}$	$8.77*10^{-13}$	$5.4*10^{-13}$

Rather small differences!!!

Slight deviations of $m_{1/2}$ and m_0 parameters

There are possibilities to deviate $m_{1/2}$ *and* m_0 among chosen point

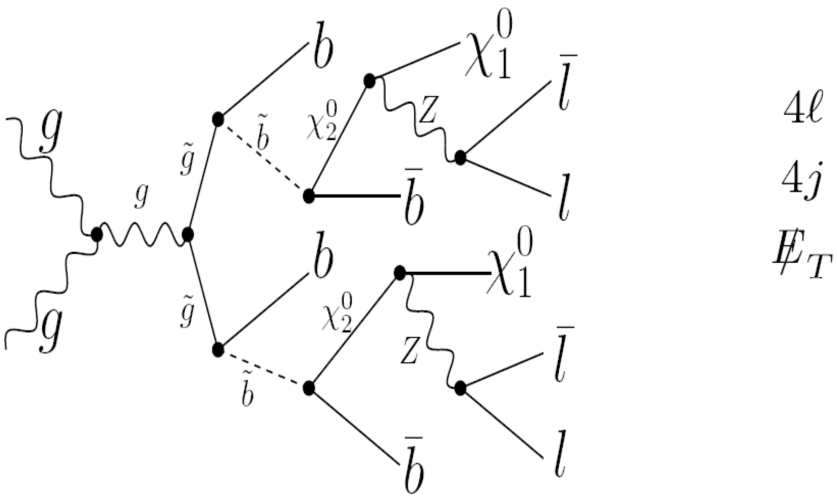
For the process $gg \to \breve{g}\breve{g} \to$ 4 b-jets + 2 OS muon pairs + E_T^{miss}



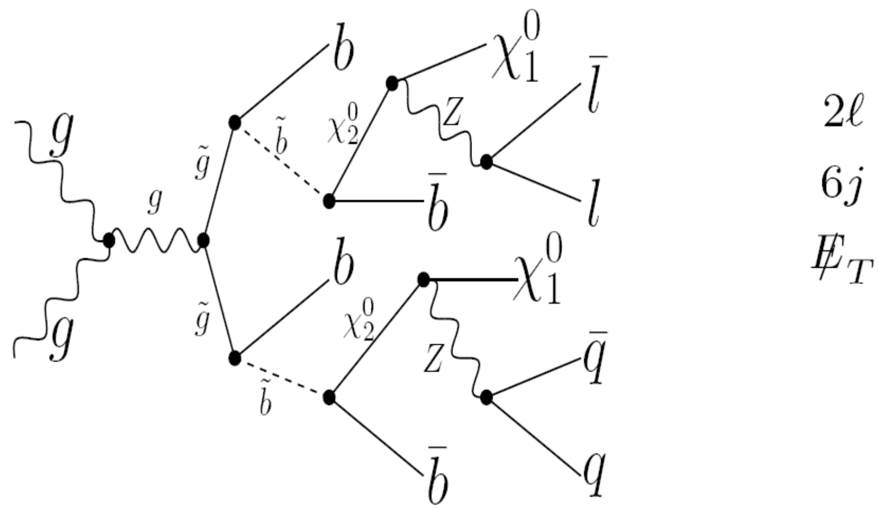
Data samples (Fast simulation)

For fixed $m_{1/2}$ = 1400 GeV and m_0= 170, 180 and 190 GeV (subpoints) samples were simulated with N events ~ 300 fb^{-1}

"Dilepton" decay channel



"Lepton+jets" decay channel



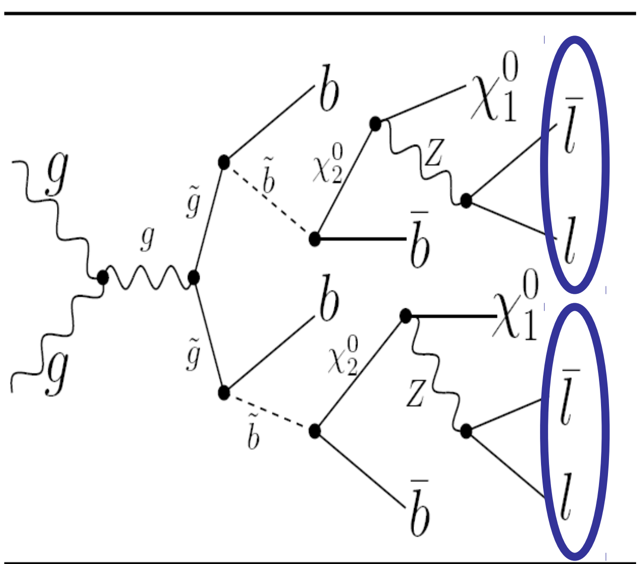
	$m_{1/2}$=170 GeV	$m_{1/2}$=180 GeV	$m_{1/2}$=190 GeV
# total events	88380	63630	43200
# "dilepton"	1057	681	529
# "lepton+jets"	17040	12339	8104

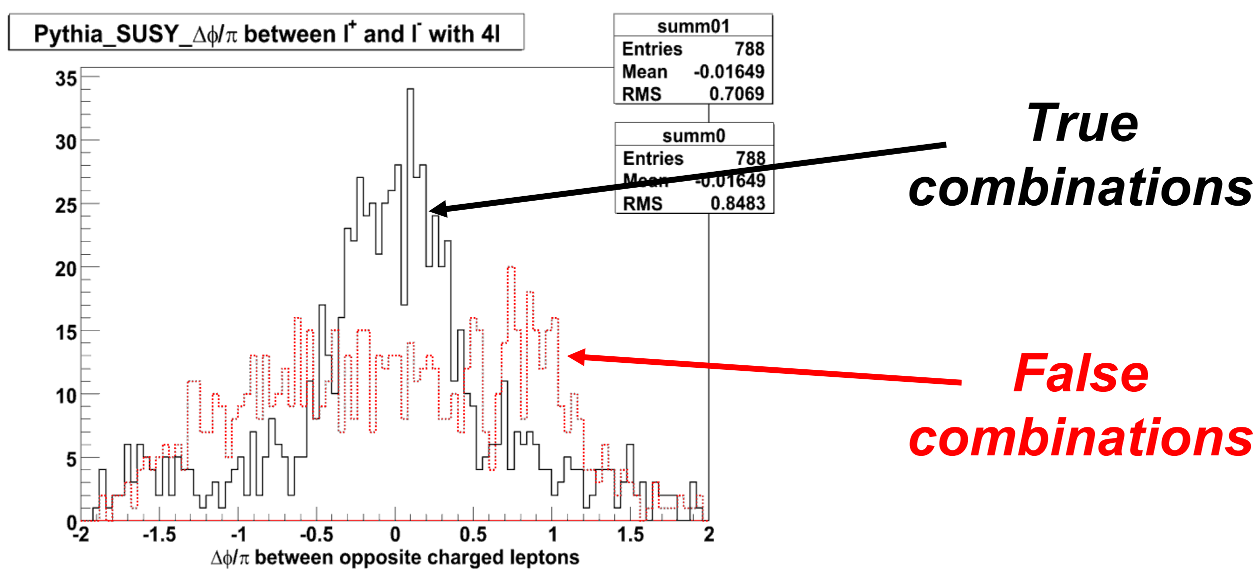
"Endpoint" method to distinguish subpoints

Since the masses of nutralinos χ_2 and χ_1 depend on $m_{1/2}$ the reconstructed invariant mass of $l^+ l^-$ pair should be less or equal than "endpoint" ($m(\chi_2)$ — $m(\chi_1)$) value.

	$m_{1/2}$ = 170 GeV	$m_{1/2}$ = 180 GeV	$m_{1/2}$ = 190 GeV
$m(\chi_2)$ GeV	114.53	125	133.91
$m(\chi_1)$ GeV	63.63	68	72.82
($m(\chi_2)$ — $m(\chi_1)$) GeV	50.9	57	61.09

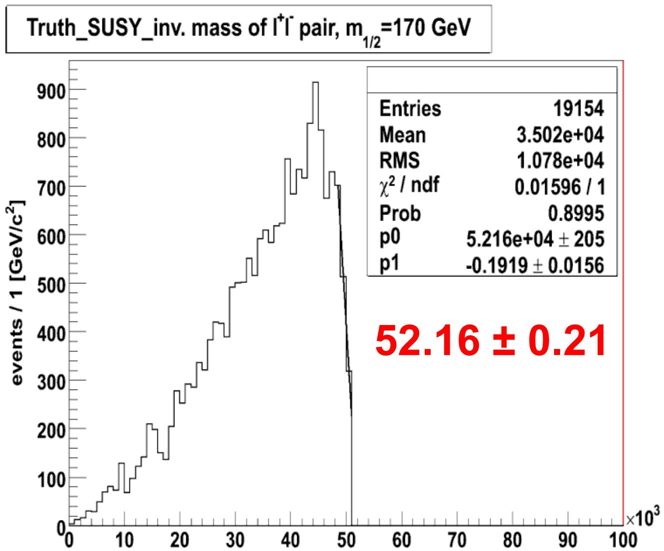
After reconstruction of invariant masses of $l^+ l^-$ pair in events with 4μ or 4e the combination having the smallest $\Delta\varphi=\varphi(l^-) - \varphi(l^+)$ of 2 pairs was chosen.

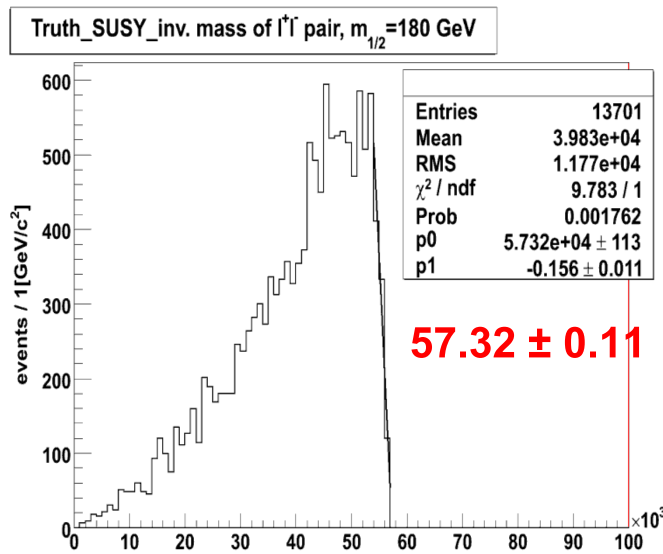


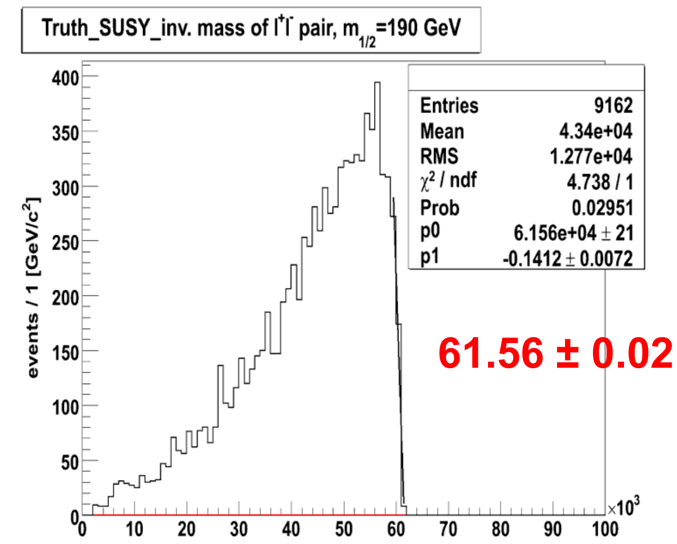


Lepton pair inv. mass (linear fit)

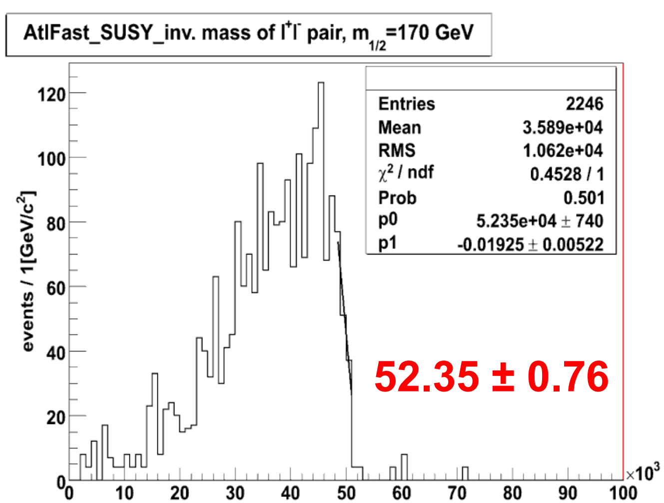
Generator level

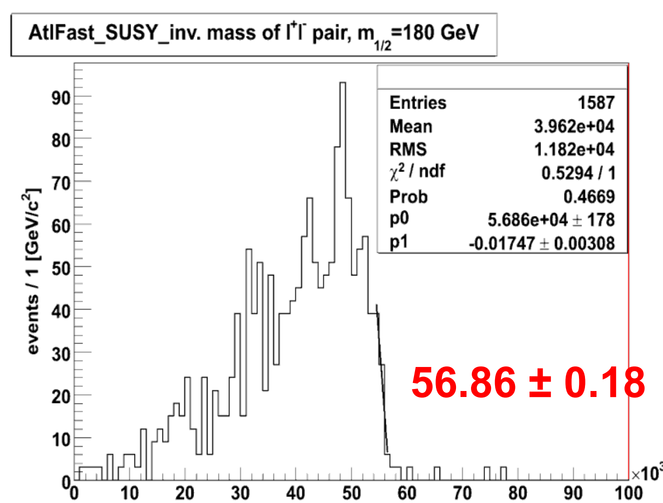


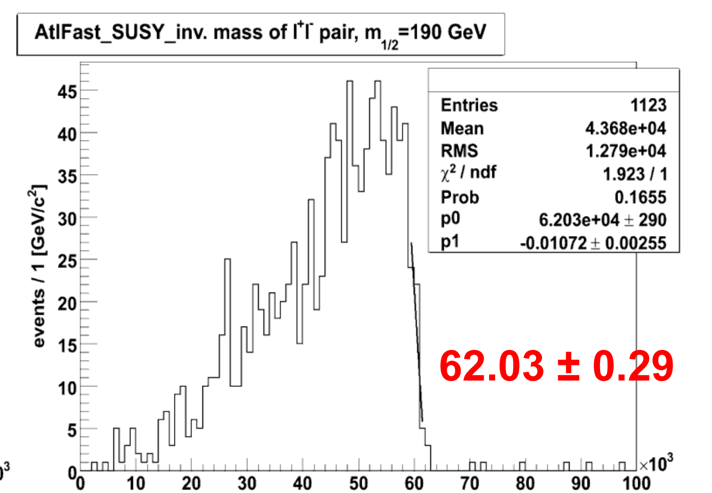




Fast simulation level



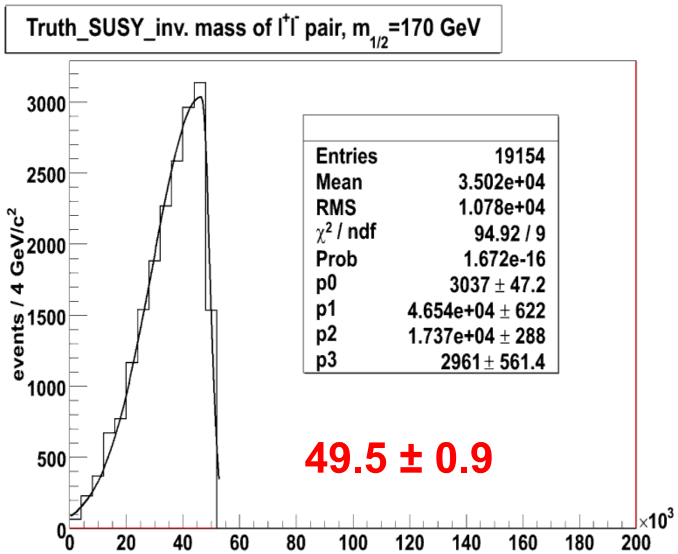


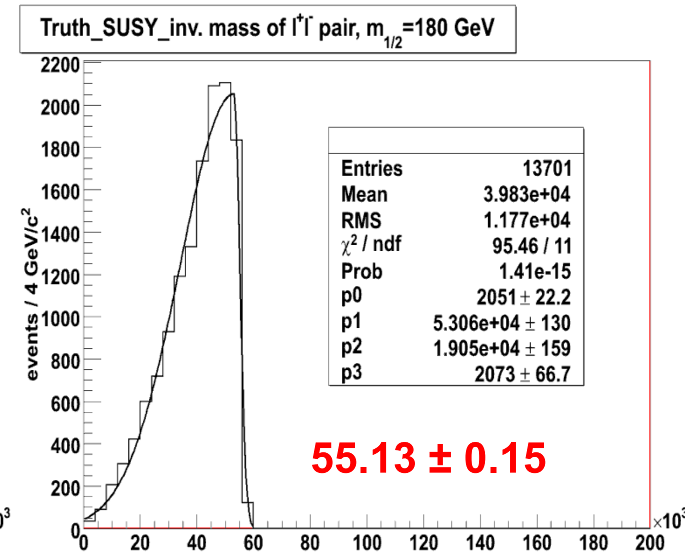


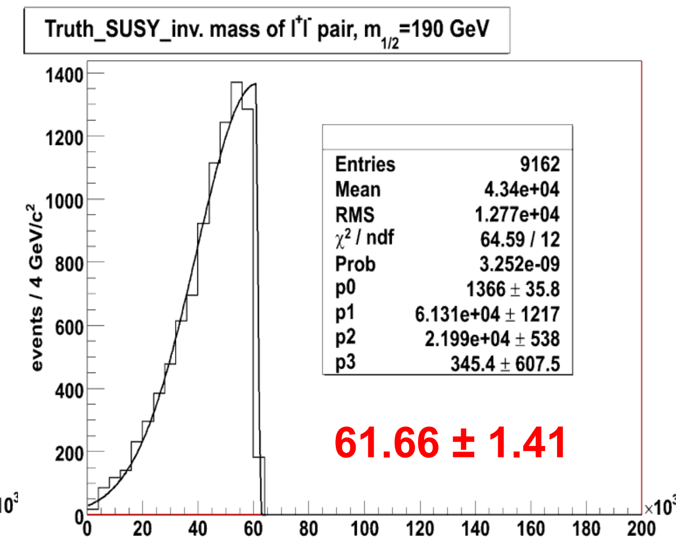
Lepton pair inv. mass (double-gauss fit)

endpoint = mean + 2.34*σ(right gauss)/2

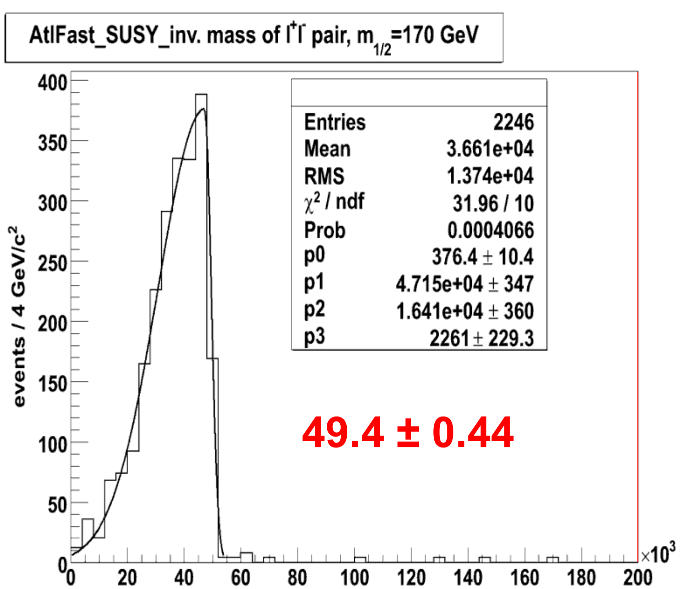
Generator level

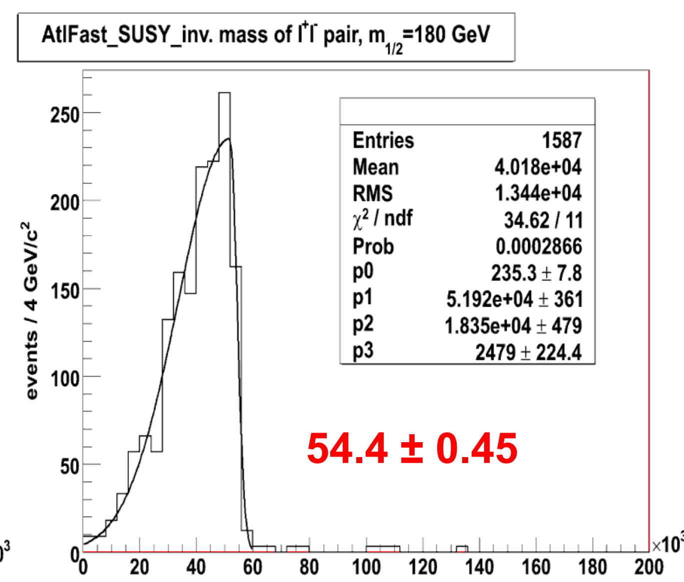


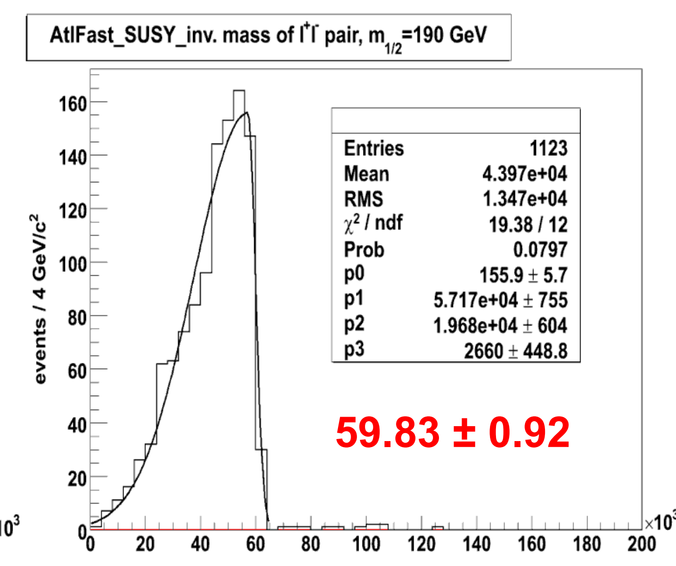




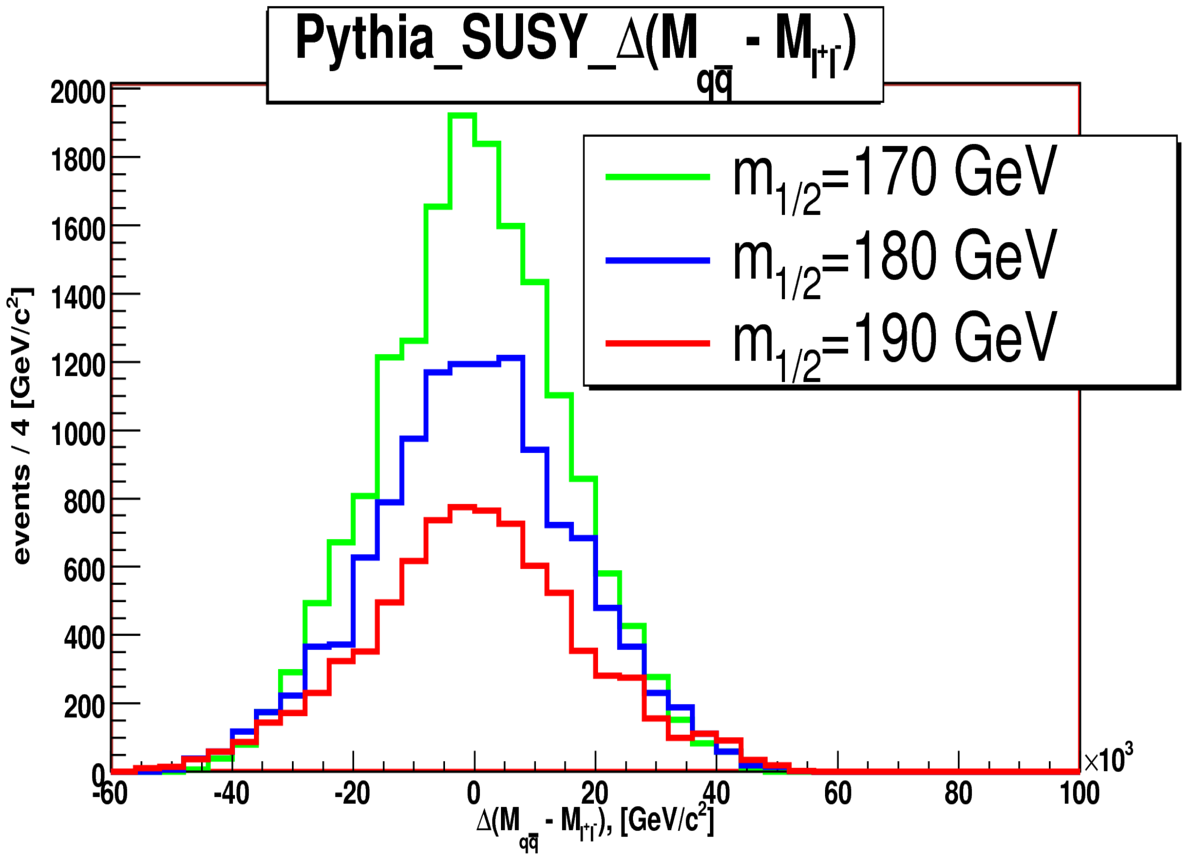
Fast simulation level



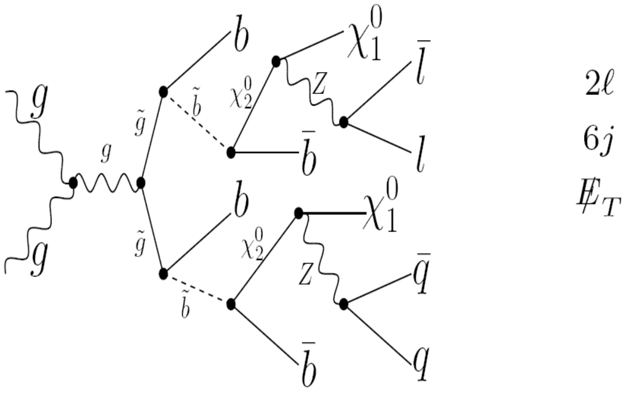




qq pair inv. mass



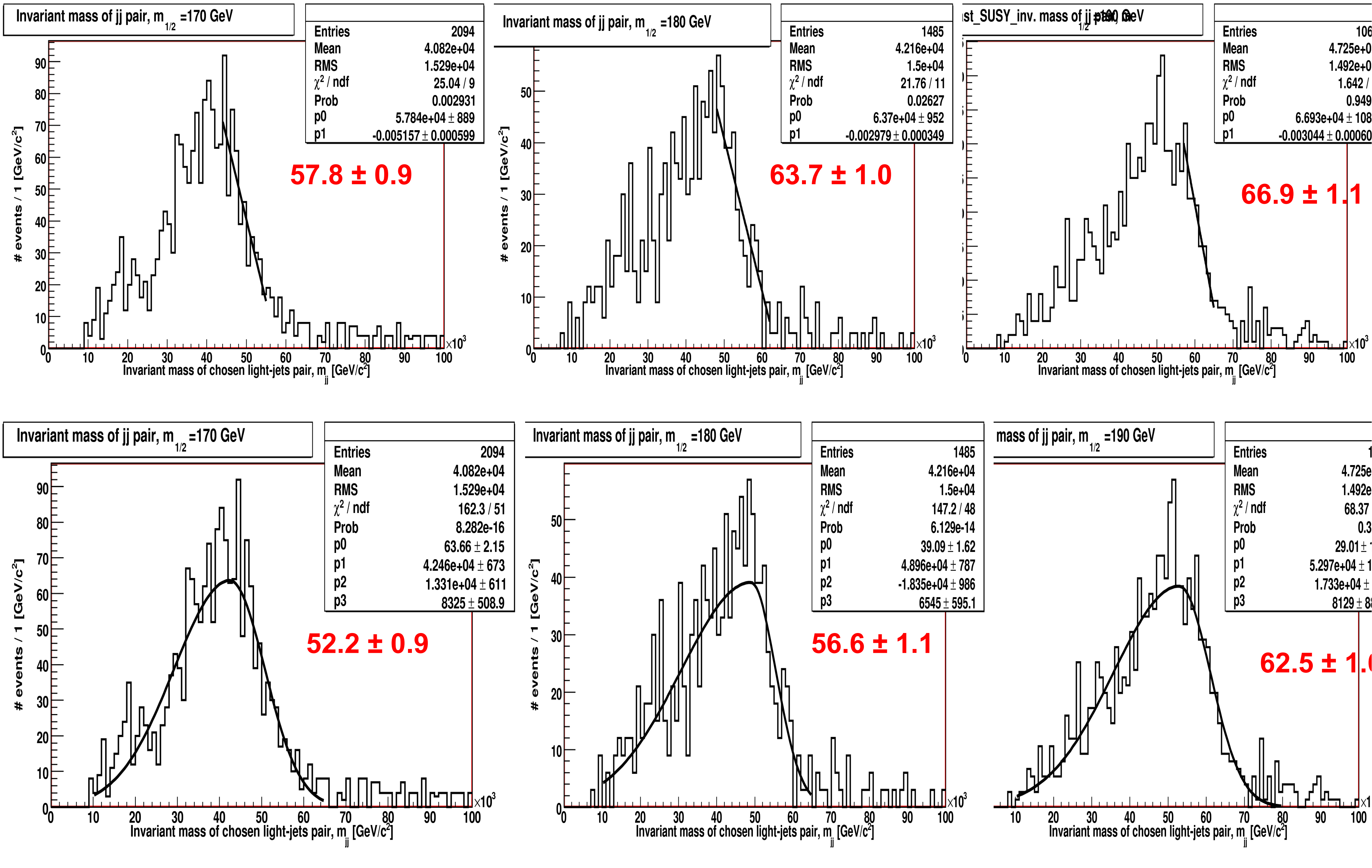
"Lepton+jets" decay channel



This method is independent on theoretical prediction of endpoint value

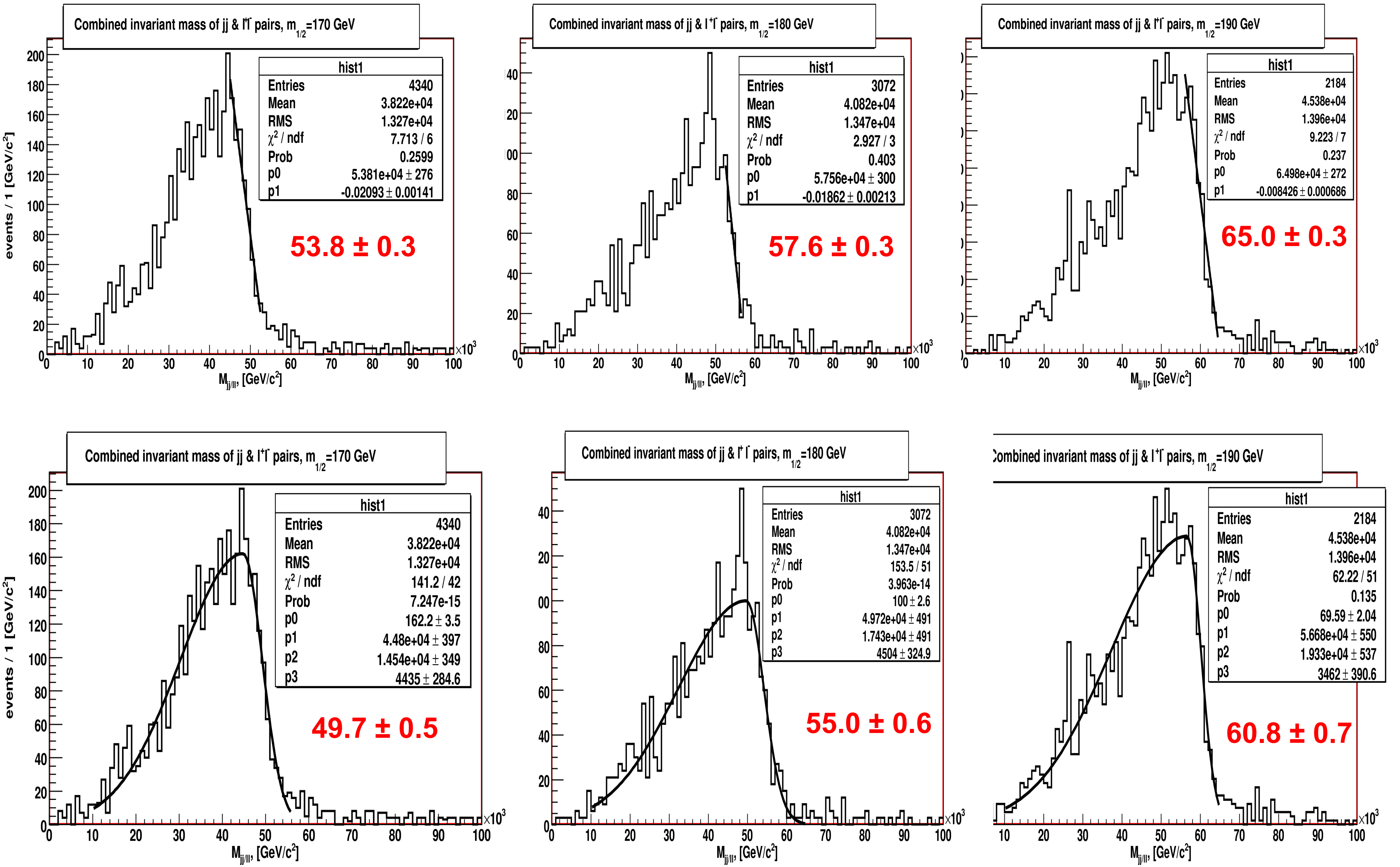
qq pair inv. mass (linear and double-gauss fit)

Fast simulation level



Combined ll & qq pair inv. mass (linear and double-gauss fit)

Fast simulation level



SM Background

- **The background processes must have 4 b-jets and 2 OS lepton pairs (or 1 OS lepton pair + light jets pair) in final state, but E_T^{miss} is expected to be far less than it is in SUSY case;**

- **Since, there is no leak of light jets after interaction of pp, the background signature without light jets pair in final state is also acceptable;**

pp → ttbar+ttbar (σ·Br ≈ $5*10^{-4}$ fb, ~ 1 events per 3 years @ H.L.)

pp → b+bbar+Z+ttbar (σ·Br ≈ $2*10^{-3}$ fb, ~ 2.7 events/3 years @ H.L.)

pp → ZZZZ → μμμμbbbb (σ·Br ≈ $3*10^{-5}$ fb, ~ 0.01 events/3 years @ H.L.)

Fully simulated samples were studied:
pp → jj; pp → ttbar pair (fully hadronic excluded); pp → W(→ lν)+N partons;
pp → Z(→ ll)+N partons; pp → W(→ lν)+N partons.

Only 117 events passed criterion for 4 b-jets, and no events passed all selection criteria

Summary

- ✓ ATLAS potential to observe a SUSY-like signal from two gluinos $\tilde{g}\tilde{g}$ within a certain region of the mSUGRA parameter space was studied.

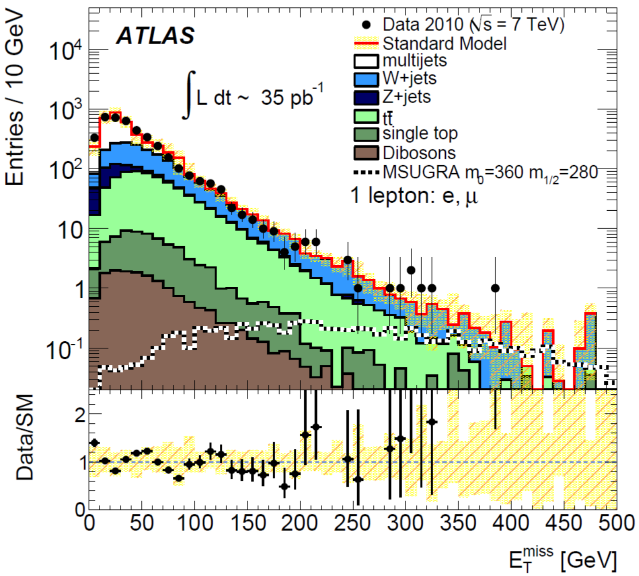
- ✓ Besides the point with $m_{1/2}$ = 180 GeV/c^2 we tried to estimate the possibility if distinguishing subpoints with different value of parameter $m_{1/2}$ = 170, 180 and 190 GeV/c^2.

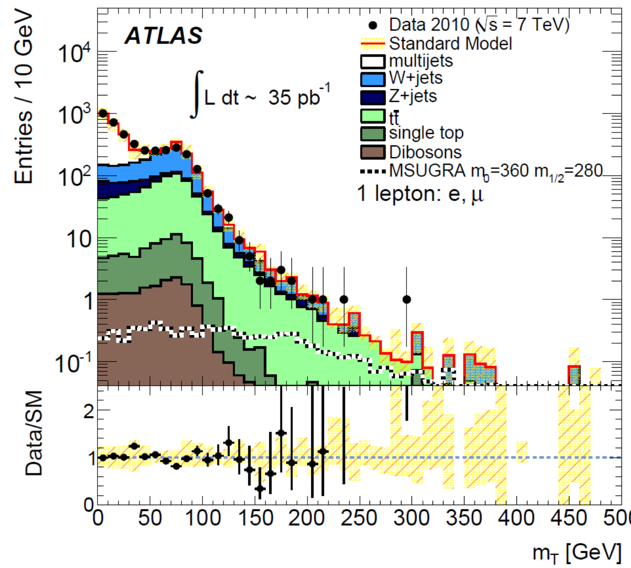
- ✓ For the chosen point in the parameter space the cross-section of $\tilde{g}\tilde{g}$ – pair production at the LHC energy is relatively high that allows to observe an excess over the Standard Model background in either leptonic or hadronic decay channels of gluino at rather high statistical significance.

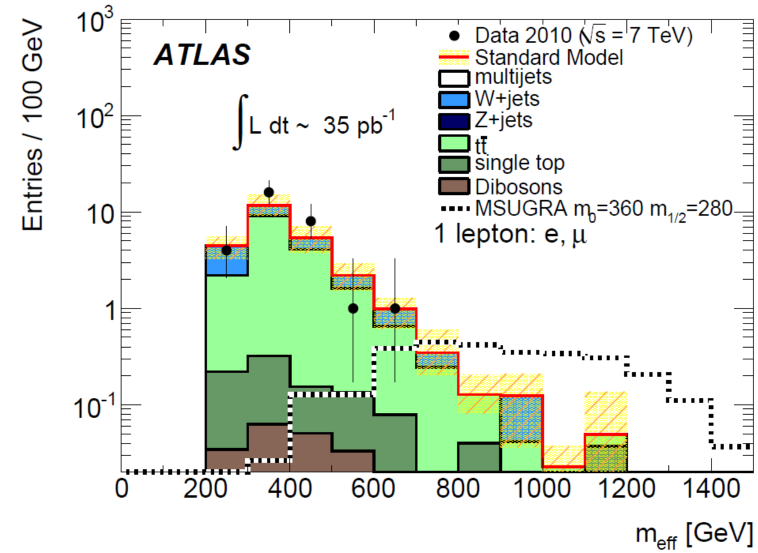
- ✓ After 3 years of the LHC operating at low luminosity ($\sim 10^{33}$ cm^{-2}s^{-1}) the subpoints can be distinguished with statistical significance of 3σ and more.

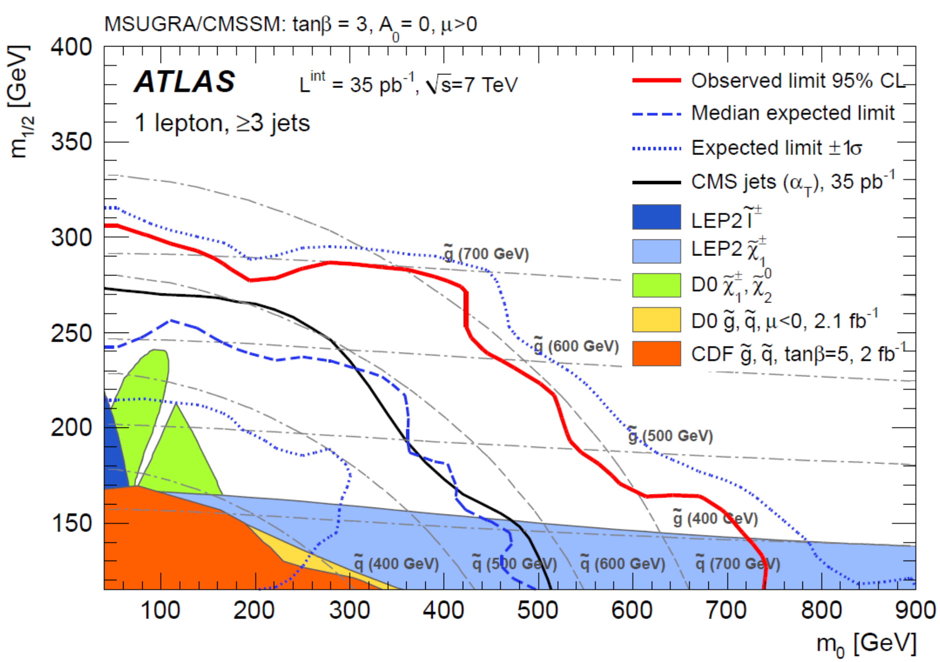
Recent results with tan(β)=3 (arXiv: 1102.2357v1)

Final states with one lepton, jets, and missing transverse momentum







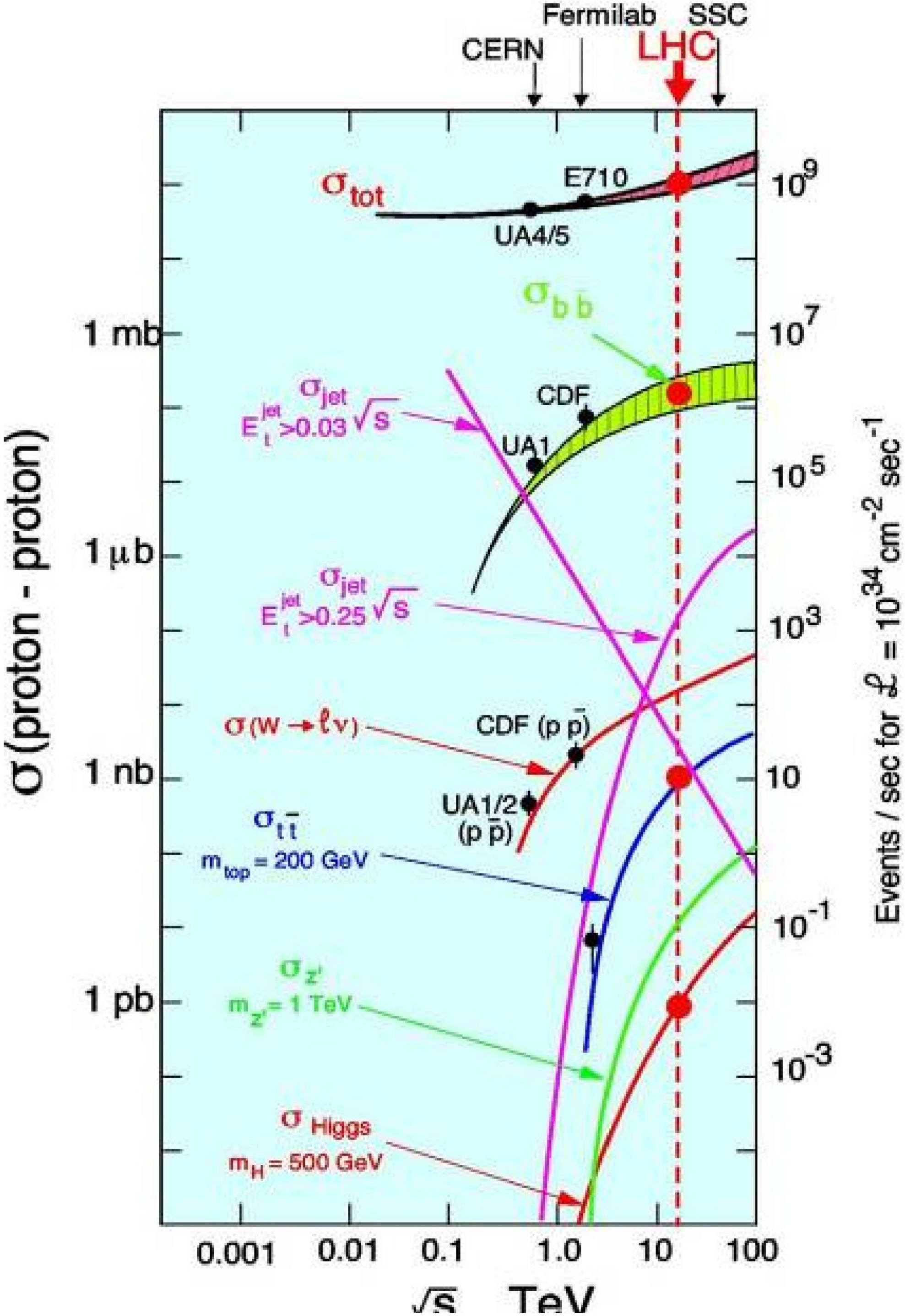


In summary, the first ATLAS results on searches for supersymmetry with an isolated electron or muon, jets, and missing transverse momentum have been presented. In a data sample corresponding to 35 pb^{-1}, no significant deviations from the standard model expectation are observed. Limits on the cross section for new processes within the experimental acceptance and efficiency are set. For a chosen set of parameters within MSUGRA/CMSSM, and for equal squark and gluino masses, gluino masses below 700 GeV are excluded at 95% CL. These ATLAS results exceed previous limits set by other experiments

Thank you for your attention!

Backup slides

Cross Sections and Production Rates



Rates for L = 10^{34} cm^{-2} s^{-1}: (LHC)

- **Inelastic proton-proton reactions: 10^9 / s**

- **bb pairs 5 10^6 / s**
- **tt pairs 8 / s**

- **W $\rightarrow$ e ν 150 / s**
- **Z $\rightarrow$ e e 15 / s**

- **Higgs (150 GeV) 0.2 / s**
- **Gluino, Squarks (1 TeV) 0.03 / s**

LHC is a factory for:
top-quarks, b-quarks, W, Z, ……. Higgs, ……

(The challenge: you have to detect them !)

SM Background (2/3) SUSY WG Fully simulated samples

Selection criteria: 1) For "dilepton" events: 4 b-jets and 2 OS lepton pairs; 2) For "lepton+jets" events: 4-bjets, 1 OS lepton pair and 1 qqbar pair. (NOTE!!! No criteria on TRANSVERSE MISSING ENERGY !!!)

Dataset	Filter	X-section, pb	# events	4 b-jets	"dilept" *	"lept+jets" **
J4 Herwig	pt: 140-280 GeV	3.08E+005	370900 (~0.0013 fb^{-1})			
J5 Herwig	pt: 280-560 GeV	1.247E+004	272000 (~0.023 fb^{-1})			
J6 Herwig	pt: 560-1120 GeV	360	286750 (~0.83 fb^{-1})	42		
J7 Herwig	pt: 1120-2240 GeV	5.71	258400 (~47.12 fb^{-1})			
J8 Herwig	pt: >2240 GeV	0.24	236900 (~1027.8 fb^{-1})			
tokyoWjetNp0	Parton CUT Pt>40GeV eta < 6, MET>10GeV	48000	9900 (~0.00022 fb^{-1})			
tokyoWjetNp1	- // -	3300	3000 (~0.001 fb^{-1})			
tokyoWjetNp2	- // -	820	9950 (~0.013 fb^{-1})			
tokyoWjetNp3	- // -	156	10050 (~0.07 fb^{-1})			
tokyoWjetNp4	- // -	30	3000 (~0.104 fb^{-1})			
tokyoWjetNp5	- // -	18.3	7500 (~0.43 fb^{-1})			
tokyoZeeNp3	Parton CUT Pt>40GeV eta < 6, PT_lep>5GeV eta < 6, Mll=50-500GeV	2.1	10800 (~5.355 fb^{-1})		0	0
tokyoZeeNp4	- // -	0.89	8850 (~10.35 fb^{-1})			
tokyoZeeNp5	- // -	0.32	6750 (~21.96 fb^{-1})	0		
tokyoZmmNp3	- // -	2.1	2050 (~1.02 fb^{-1})			
tokyoZmmNp4	- // -	0.89	1850 (~2.16 fb^{-1})			
tokyoZmmNp5	- // -	0.32	1600 (~5.21 fb^{-1})			
tokyoZnunuNp0	Parton CUT Pt>40GeV eta < 6, MET>10GeV	8902	8400 (~0.001 fb^{-1})			
tokyoZnunuNp2	- // -	168	2100 (~0.013 fb^{-1})			
tokyoZnunuNp3	- // -	33.5	5850 (~0.182 fb^{-1})			
tokyoZnunuNp4	- // -	6.4	8250 (1.34 fb^{-1})			
tokyoZnunuNp5	- // -	1.9	7080 (~3.88 fb^{-1})			

SM Background (3/3) SUSY WG Fully simulated samples

T1	All hadronic events rejected	461	459550 (~1.04 fb^{-1})	104		
ToplnlnNp0 (5535)	pt_j1>80GeV, pt_j4>40GeV, MET>80GeV	0.185	9100 (~51.22 fb^{-1})			
ToplnlnNp1 (5536)	- // -	1.162	47050 (~42.2 fb^{-1})			
ToplnlnNp2 (5537)	- // -	1.454	49200 (~35.23 fb^{-1})			
WenuNp2 (5223)	- // -	0.67	4000 (~6.22 fb^{-1})	1		
WenuNp3 (5224)	- // -	3.39	15200 (~4.67 fb^{-1})			
WenuNp4 (5225)	- // -	2.02	24900 (~18.84 fb^{-1})			
WenuNp5 (5226)	- // -	0.87	8000 (~9.57 fb^{-1})			
WmunuNp3 (8203)	- // -	0.695	7000 (~10.5 fb^{-1})			
WmunuNp4 (8204)	- // -	1.852	19050 (10.71 fb^{-1})			
WmunuNp5 (8205)	- // -	0.86	4000 (~4.84 fb^{-1})			
WtaunuNp2 (8208)	- // -	0.534	4000 (~7.8 fb^{-1})			
WtaunuNp3 (8209)	- // -	2.843	9700 (~3.55 fb^{-1})			
WtaunuNp4 (8210)	- // -	2.675	30500 (~11.87 fb^{-1})			
WtaunuNp5 (8211)	- // -	1.201	7750 (~6.72 fb^{-1})			
ZnunuNp3 (5124)	- // -	0.88	5000 (~5.92 fb^{-1})			
ZnunuNp4 (5125)	- // -	2.4	41350 (~17.94 fb^{-1})			
ZnunuNp5 (5126)	- // -	1.07	28800 (~28.03 fb^{-1})			

J(4-8) – pp → jj;

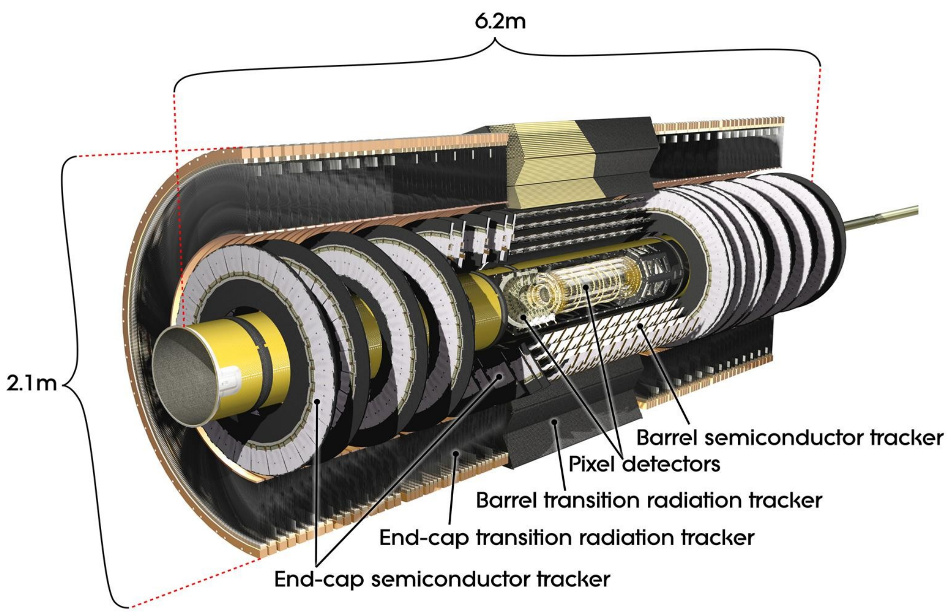
T1 – pp → ttbar pair (fully hadronic excluded);

tokyoWjetNp – pp → W(→ lv)+N partons;

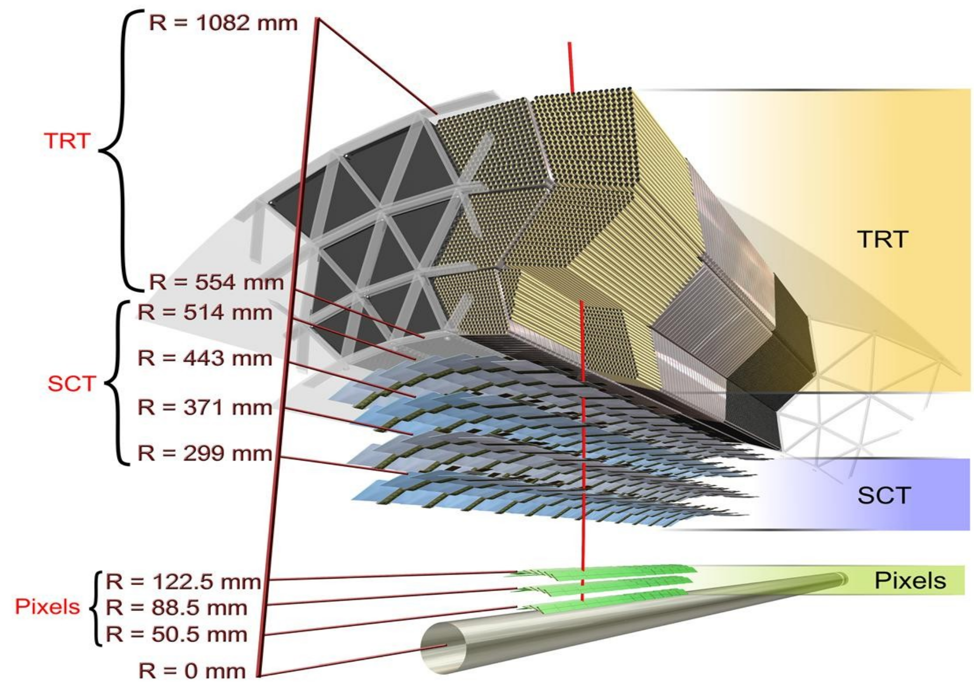
ZllNp – pp → Z(→ ll)+N partons;

WlnuNp – pp → W(→ lv)+N partons.

Inner Detector (tracker)



Covers |η|<2.5 in a solenoidal magnetic field of 2T



Silicon pixels (**Pixel**): 0.8 10^8 channels
Silicon strips (**SCT**) : 6 10^6 channels
Transition Radiation Tracker (**TRT**) :
straw tubes (Xe), 4 10^5 channels
e/π separation

$$\sigma/p_T \sim 5\times10^{-4}\, p_T \oplus 0.01$$

Pixel: each pixel is 50 μm wide in Rφ and 300 μm long. At R=4cm -- "B-layer" (good vertexing)

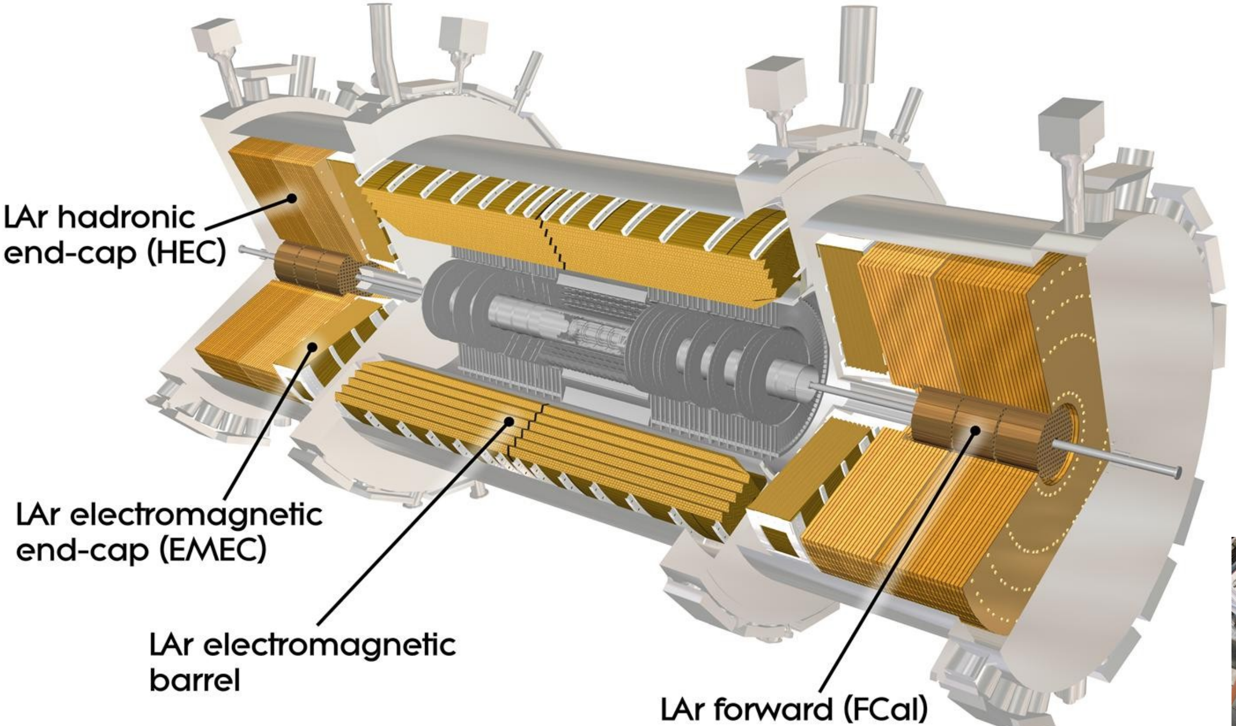
SCT: 4 double layers of silicon strips. Each double layer consists of strips aligned in the azimuthal direction and strips rotated by a 40 mrad stereo angle with respect to the first set. The strips have an 80 μm pitch and are 12 cm long.

TRT: consists of ~36 layers of 4 mm diameter straw tubes with resolutions ~200 μm

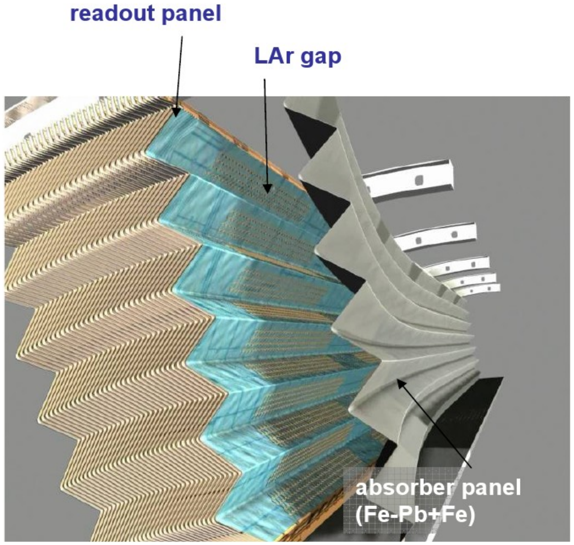
LAr EM Calorimeter

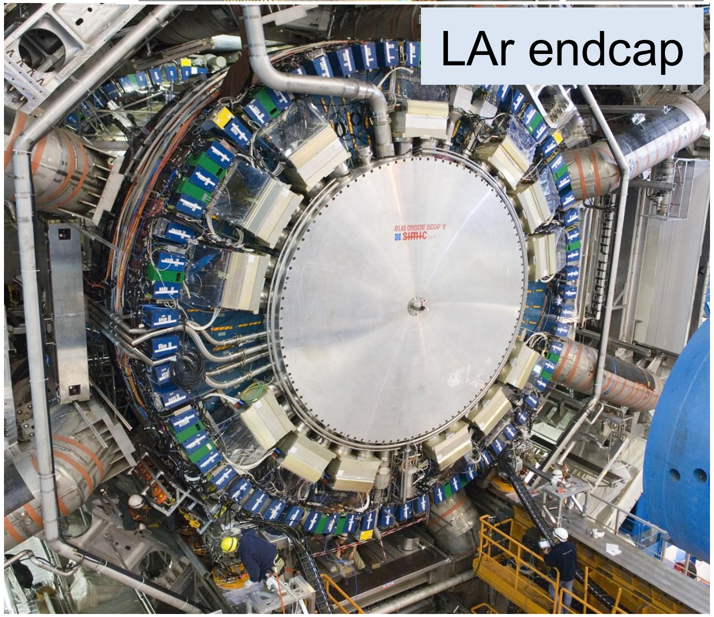
Barrel coverage |η|<3.2

Total coverage |η|<4.9



High granularity accordion geometry





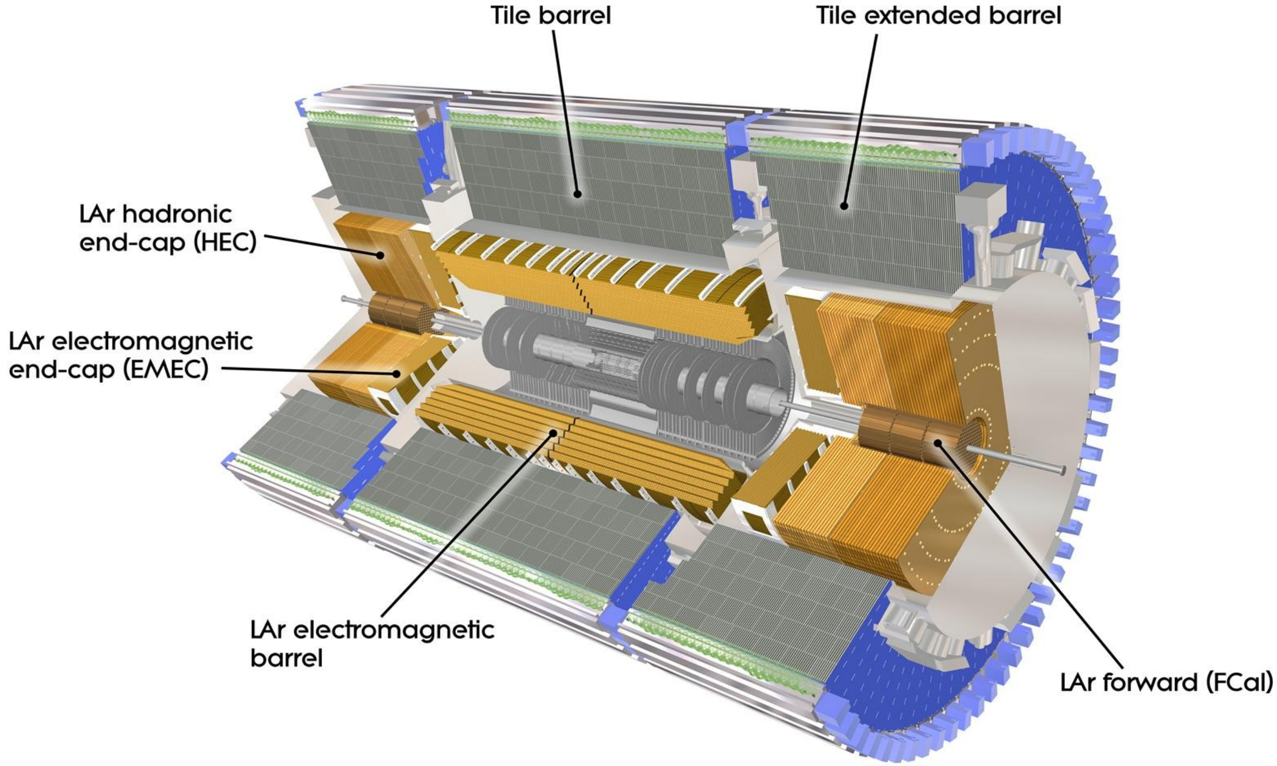
Outer radius of 2.25 m and half-length 6.65 m

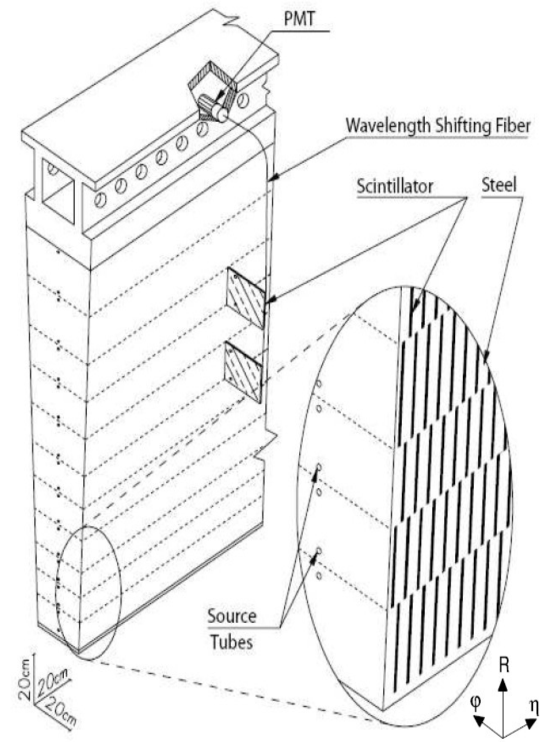
Electromagnetic Calorimeter
Barrel,Endcap: Lead-LAr
FCal: Copper/Tungsten-LAr
~10%/√E energy resolution e/γ
180000 channels: longitudinal segmentation
Trigger for e/**γ**

Hadronic calorimeter

Barrel coverage |η|<1.7

Total coverage |η|<5





Outer radius of 4.25 m and half-length 6.10 m

Hadron Calorimeter

barrel: Iron-Tile; HEC: Copper-LAr; (~20000 channels)

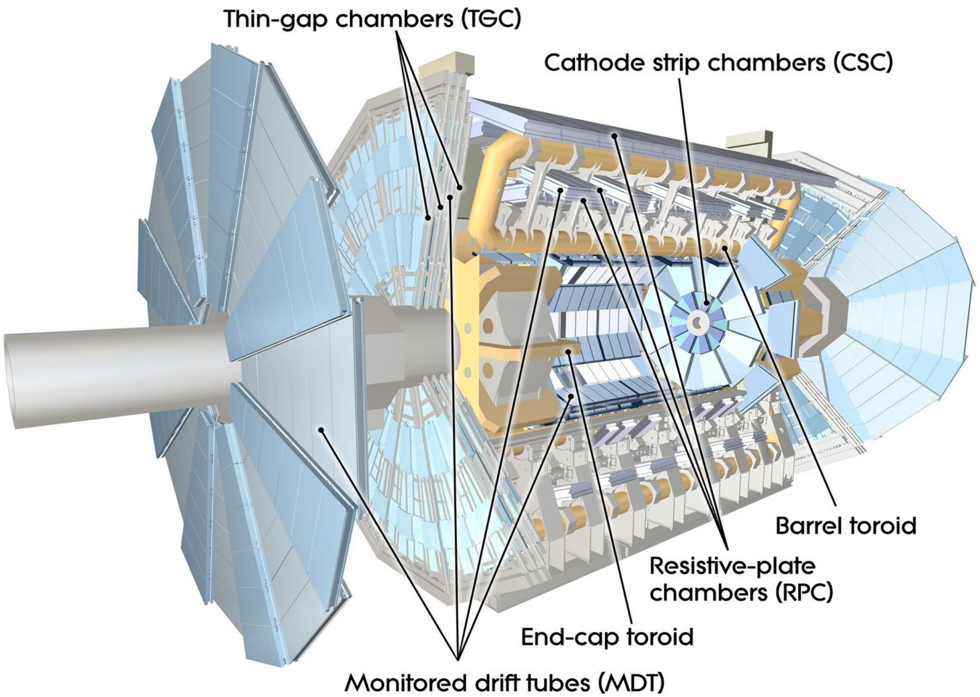
$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$ pion (at η≈10λ (λ-interaction length))

Trigger for **jets, Missing E_T**

The total weight of the Calorimeter System is ~4000 Tons

Muon System (Spectrometer)

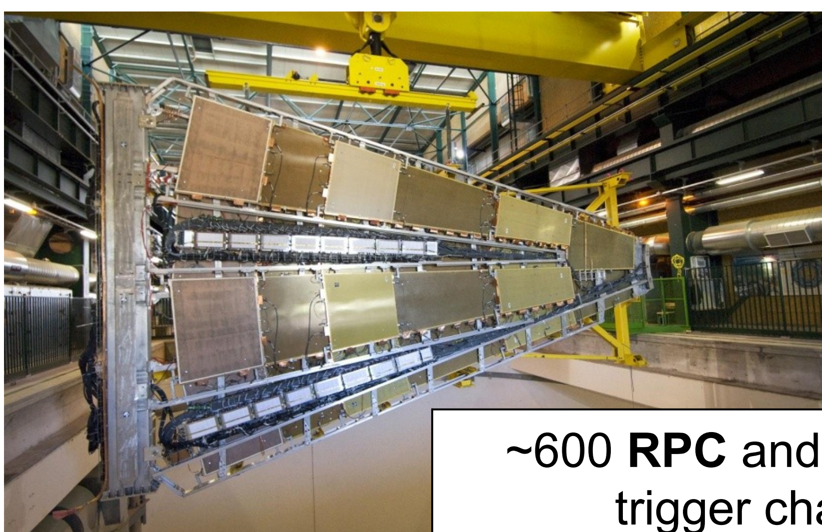
Outer radius of 11 m and half-length 12.5 m



Stand-alone momentum resolution Δpt/pt < 10% up to 1 TeV

2-6 Tm |η|<1.3   4-8 Tm 1.6<|η|<2.7

~1200 **MDT** precision chambers for track reconstruction (+ **CSC)**



~600 **RPC** and ~3600 **TGC** trigger chambers