ATLAS LAr calorimeter commissioning and search for a light stop

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Outline

- Part I: ATLAS LAr endcap commissioning
  - LAr endcap calorimeters
  - Endcap phase3 commissioning
    - Warm commissioning
    - Cold commissioning
    - Cosmic rays

  } Focus on these phases I've been involved

- Part II: SUSY searches on ATLAS
  - General introduction
  - Search for a light stop
    - Inclusive searches
    - Exclusive searches
  - Summary and outlook

Part I

LAr endcap commissioning

- LAr endcap calorimeters
- Endcap phase3 commissioning
  - Warm commissioning
  - Cold commissioning

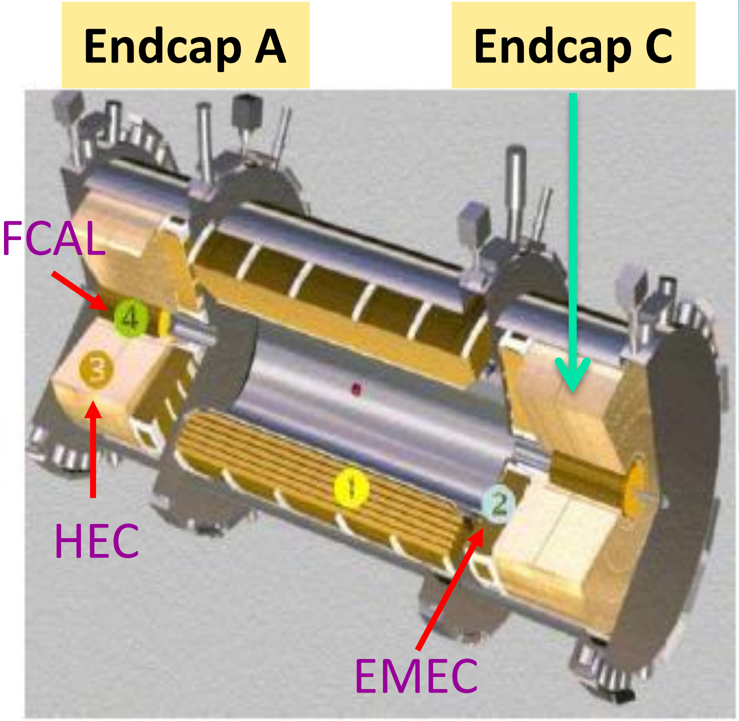
Commissioning ATLAS

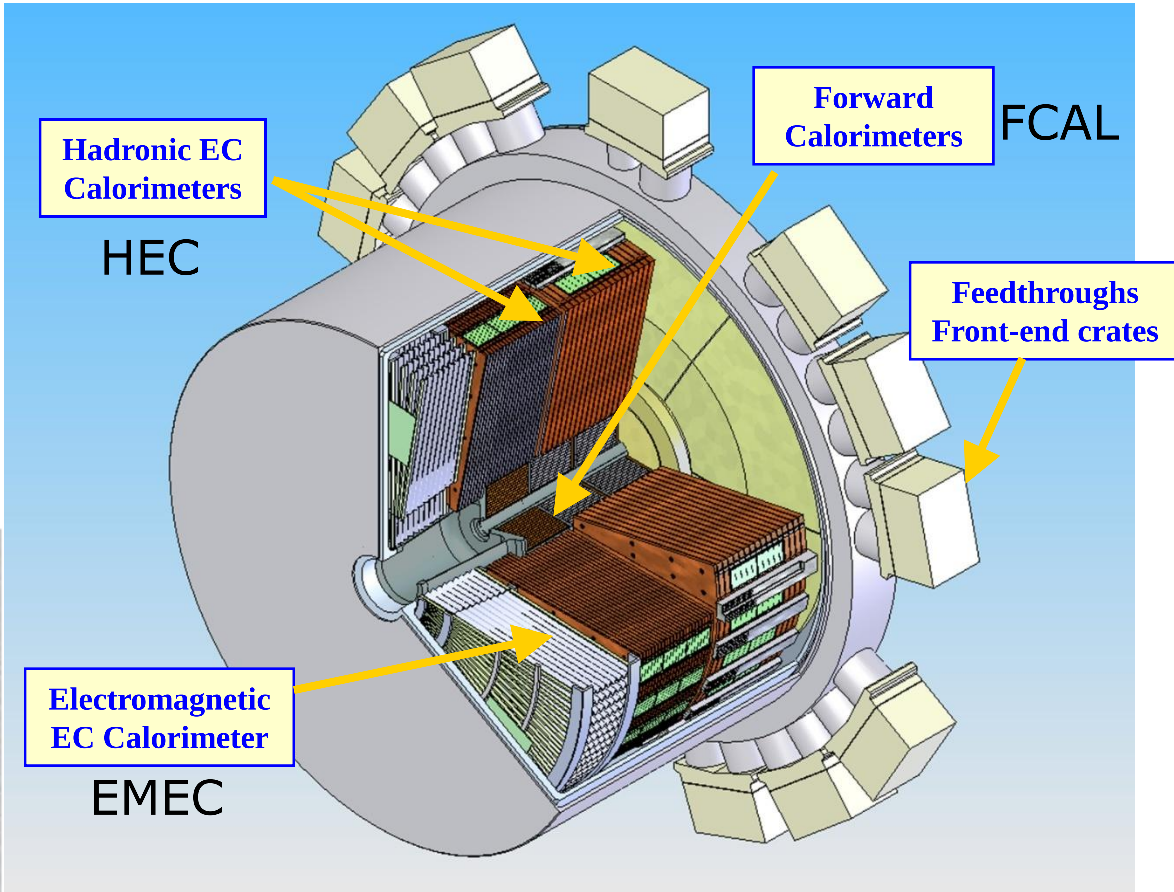
- Commissioning definition:
  - Commissioning follows and is different from installation
  - To bring the detector from the "just installed" state to an operational state.
- Commissioning phases:
  - Phase 1: commissioning each sub-system by its own.
  - Phase 2: without any particle, make ≥2 sub-systems work together. Ultimate goal is a fully integrated detector.
  - Phase 3: operate ≥1 sub-detector with cosmic particles. Ultimate goal is the global cosmic run.
  - Phase 4: same with the very first beam(s).

  Phase 1-3 and installation overlap to a large extent.
- LAr barrel started its commissioning effort since January 2006, while endcap started since May 2006.

ATLAS LAr Endcap Calorimeters

Coverage:
- EMEC:1.375<|η|<3.2
- HEC: 1.5<|η|< 3.2
- FCAL: 3.1<|η|< 4.9

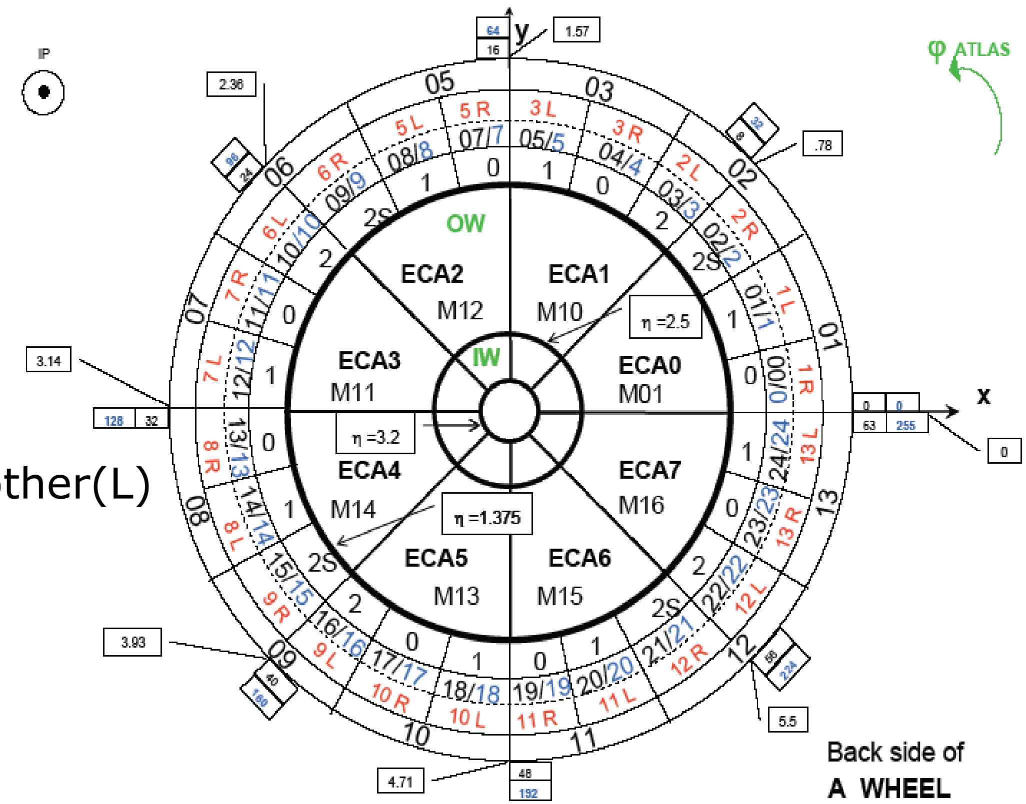




- Warm commissioning: room temperature in the ATLAS cavern
- Cold commissioning : cryostats cooled down to LAr temperature ~87K

Endcap FT mapping

- There are 3 different types of front-end crates (FECs). Each crate has 2 half crates =>25 half crates per endcap cryostat.
  - 8 Standard EMEC crates:
    - each feedthrough(FT) reads out 13 EMEC FEBs
  - 4 EMEC/HEC Special crates:
    - EMEC inner wheel and HEC share FEBs
    - 15 EMEC FEBs in one FT(R)
    2 EMEC + 6 HEC FEBs in the other(L)
  - 1 FCAL crate:
    - 14 FCAL FEBs in the sole FT.



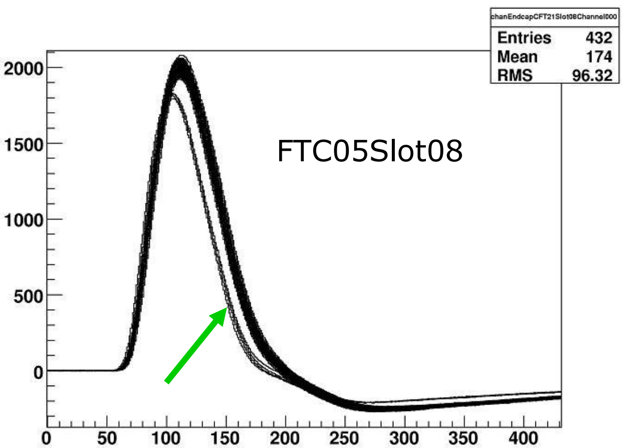
- Each FEB has 128 channels, but not all are connected to calorimeter cells.

Endcap Phase3 Commissioning

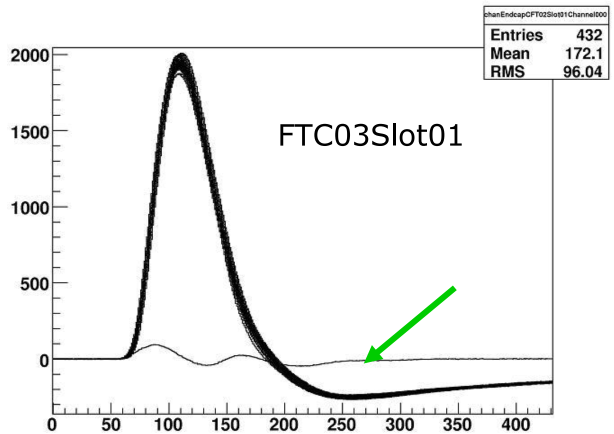
Run type	Description
Pedestal	These runs are used to monitor the noise level as well as measuring the pedestal and the autocorrelation matrix needed for determination of the OFCs.
Delay	Up to 32 samples are taken with a given input current (DAC) by changing the pulser-to-DAQ time phase. These runs are used to extract the calibration pulse shape and diagnose the detector faults.
Ramp	Runs are taken with a set of DAC values of increasing amplitude. They are used to extract the ramps for the electronic calibration and diagnose the problem channels.
Single-DAC	Runs are taken with fixed pulse height and timing. They can be used to diagnose the mapping problems especially for HEC which has many-to-many mapping.

Results from warm commissioning

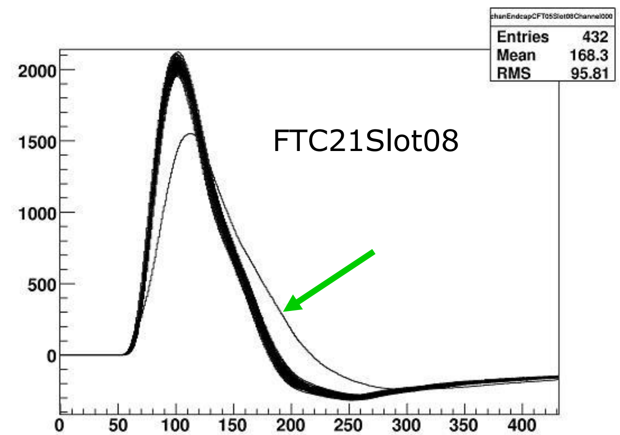
- Outstanding problems (EMEC)



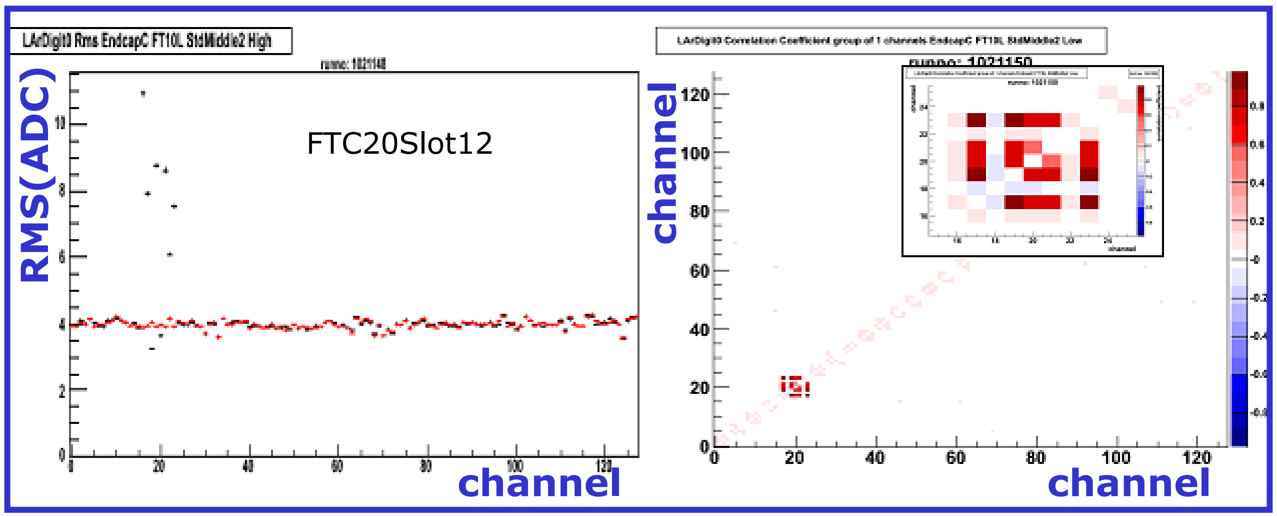
Fast Shaper



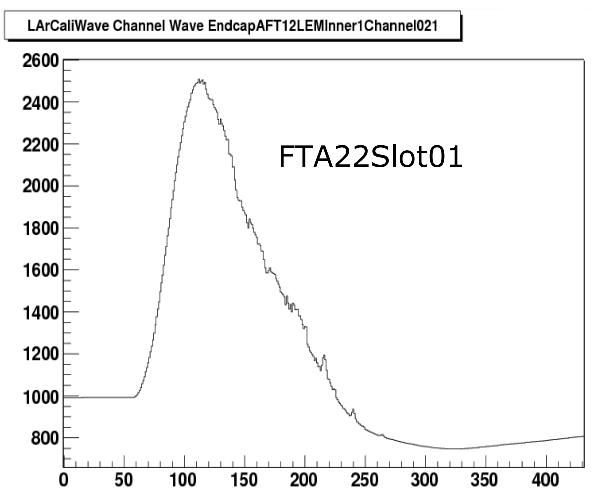
Dead Channel



Distorted



High Noise



Jitter

Results from warm commissioning

Endcap-A:

- Outstanding problems observed:
  - ***28 fast shaper*** problems
  - ***6 calibration lines*** problems
  - ***26 strongly distorted/dead channels***
  - ***4 noise*** problems
  - ***3 unknown problems,*** maybe not FEB problem
- 84 out of 195 problems which were previously found during pre-commissioning testing are ***not confirmed***

Endcap-C:

- Outstanding problems observed:
  - ***12 fast shaper*** problems
  - ***12 strongly distorted/dead channels***
  - ***5 noise*** problems
  - ***4 fast reflection*** problems (FCAL)
  - ***12 jitter*** problems
- 84 out of 132 problems which were previously found during pre-commissioning testing are ***not confirmed***

After warm commissioning, we had access to all of the crates. FEBs found to be problematic were removed and tested. Ones that could be repaired were repaired. In some cases, the FEBs were replaced with others. So in many cases, cold commissioning began with many repaired or new FEBs.

Cold commissioning

- One of the main goals of the cold commissioning is to look at the stability of known problems:
  - to see if we can eventually get a stable correction factor for these channels.
- Most problems observed during warm/cold testing or warm commissioning were not seen in the cold commissioning, while some new problems appeared. (see the table for example, not full version)

W/C Test: warm/cold testing
WC: warm commissioning
CC: cold commissioning

Crate A03

Location	Problem	W/C Test	WC	CC (Feb19-23)	CC (Mar6)	CC (Mar10-16)	CC (Mar28)
FT3R(FT04)/slot02/ch37	Distorted	x					
FT3R(FT04)/slot03/ch78	Dead?			x	x		
FT3R/(FT04)/slot06/ch42	Distorted	x					
FT3R(FT04)/slot06/ch43	Distorted	x	x				
FT3R(FT04)/slot06/ch44	Distorted	x	x	x	x	x	x
FT3R(FT04)/slot06/ch46	Distorted	x	x				
FT3R(FT04)/slot06/ch47	Distorted	x					
FT3R(FT04)/slot06/ch76	Distorted						x
FT3R(FT04)/slot07/ch0	Distorted	x	x				
FT3R(FT04)/slot07/ch1	Distorted	x	x	x	x	x	x
FT3R(FT04)/slot07/ch2	Distorted	x	x		x		
FT3R(FT04)/slot07/ch3	Distorted	x	x	x	x	x	x
FT3R(FT04)/slot07/ch7	Distorted	x	x				
FT3R(FT04)/slot07/ch9	Distorted	x	x				
FT3R(FT04)/slot07/ch27	Distorted	x	x	x			x
FT3R(FT04)/slot07/ch30	Distorted	x	x				
FT3R(FT04)/slot09/ch32-35	Fast shaper?		x				
FT3R(FT04)/slot09/ch119	Distorted				x		
FT3R(FT04)/slot10/ch2	Distorted		x	x	x	x	x
FT3R(FT04)/slot10/ch24-27	Fast shaper?			x	x	x	x
FT3R(FT04)/slot13/ch8-11	Fast shaper?				x	x	x
FT3R(FT04)/slot13/ch1	Distorted	x					
FT3L(FT05)/slot02/ch4-7	Fast shaper?					x	x
FT3L(FT05)/slot04/ch32	Dead	x	x	x	x	x	x
FT3L(FT05)/slot04/ch37	Distorted			x	x	x	x
FT3L(FT05)/slot04/ch48-51	Fast shaper?				x		

Summary of part I

- Continuous big effort makes great progress in the LAr endcap phase3 commissioning. Many problems have been investigated, understood and solved in order to get the detector functional for the cosmic and physics runs.
- Dead readout channels: ~0.02% channels are found to show no readout signal. No continuous dead regions are observed.
- Problematic channels: ~0.5% channels show minor problems e.g. increased noise or damaged calibration lines. No continuous problematic regions are observed.
- High-voltage status: Less than 1% HV channels are operated at reduced voltage.

Part II

SUSY searches on ATLAS

- General introduction
- Searches for a light stop
  - Inclusive searches
  - Exclusive searches
- Summary and outlook

SUSY– a broken symmetry

- Supersymmetry (SUSY) is a symmetry between fermions and bosons. Minimal Supersymmetric Standard Model (MSSM) is the minimal extension to the Standard Model that realizes supersymmetry.

- SUSY requires particles and their superpartners to have the same mass, but no sparticles have been observed: SUSY must be broken

Names		spin-0	spin-1/2
squarks, quarks	Q	$(\tilde{u}_L, \tilde{d}_L)$	(u_L, d_L)
$\times$ 3 families	$\bar{u}$	$\tilde{u}^*_R$	$u^\dagger_R$
	$\bar{d}$	$\tilde{d}^*_R$	$d^\dagger_R$
sleptons, leptons	L	$(\tilde{\nu}_L, \tilde{e}_L)$	(ν_L, e_L)
$\times$ 3 families	$\bar{e}$	$\tilde{e}^*_R$	$e^\dagger_R$
Higgs, Higgsinos	H_u	(H^+_u, H^0_u)	$(\tilde{H}^+_u, \tilde{H}^0_u)$
	H_d	(H^0_d, H^-_d)	$(\tilde{H}^0_d, \tilde{H}^-_d)$

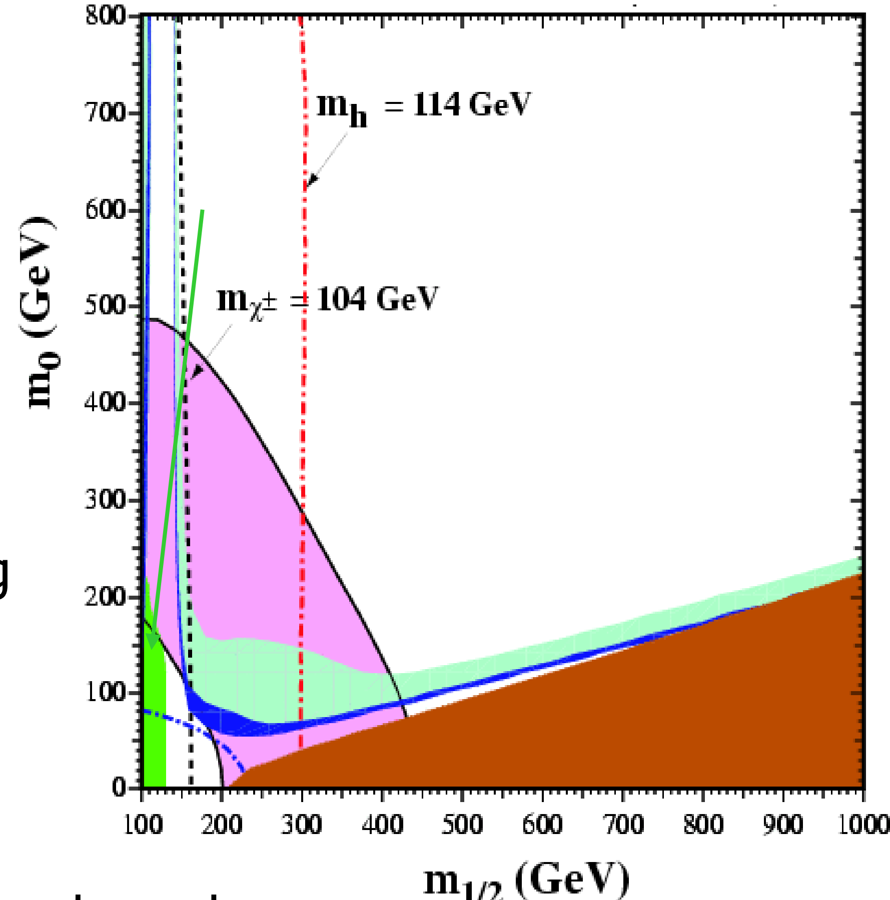
- ATLAS makes enormous effort to examine the mSUGRA model, where SUSY breaking is mediated by gravity. Also studied in detail is the GMSB model, where SUSY breaking is mediated by gauge interactions.

- R-parity conservation ($R = (-1)^{3(B-L)+2S}$) makes the lightest sparticle (LSP) stable, which forms large missing energy in the detector. Complex cascades to LSP produce large multiplicities of jets and leptons in the final states.

- If SUSY is to solve naturalness problem, need Msusy≤O(TeV): LHC can probe this energy scale.

ATLAS benchmark points

Ellis et al. hep-ph/0303043



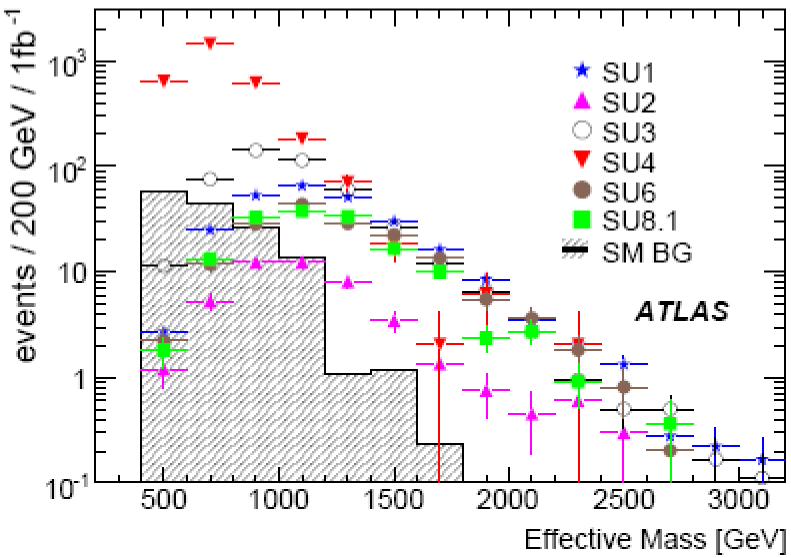
The benchmark points are chosen for regions in mSUGRA($m_{1/2}$,m_0) plane with acceptable $\tilde{\chi}_1^0$ relic density.

- SU1: Coannihilation region. $\tilde{\chi}_1^0$ annihilate with near-degenerate slepton
- SU2: Focus point region. $\tilde{\chi}_1^0$ has a high higgisno component, enhancing annihilation of $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to WW$
- SU3: Bulk region. LSP annihilation happens through the exchange of light sleptons.
- SU4: low mass point close to Tevatron bound.
- SU6: Funnel region where $2m_{\tilde{\chi}_1^0} \approx m_A$ at high tanβ. Annihilation through resonant heavy higgs exchange.

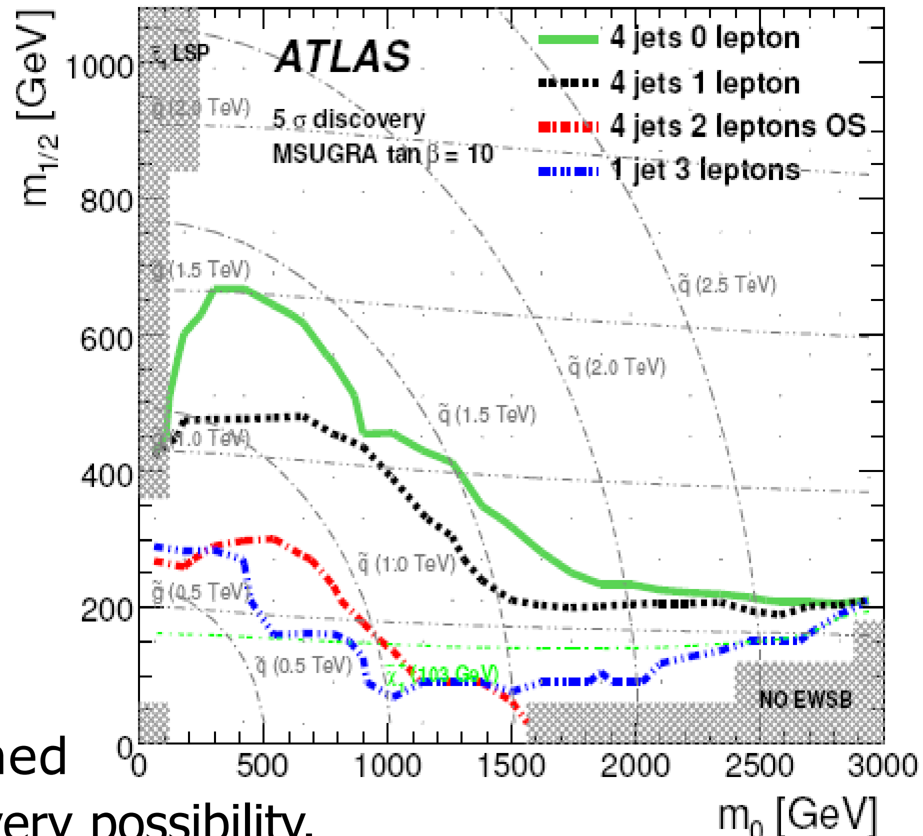
Discovery potential

- The search channels are categorized by the topology of final states, dominated by E_T^{miss} +jets

One-lepton mode



ATLAS reach for 1 fb^{-1}



- mSUGRA parameter space is scanned to represent a wider range of discovery possibility.
- Uncertainties on SM backgrounds at1 fb^{-1}:
  - 50% on QCD backgrounds
  - 20% on ttbar, W, Z+jets

Challenging task to develop data-driven techniques to estimate SM backgrounds.

Search for a light stop

Motivation: why a light stop?

- RGE running and L-R mixing can render the lighter stop $\tilde{t}_1$ much lighter than other squarks.
- Light $\tilde{t}_1$ ameliorates the fine-tuning in SUSY models.
- Baryogenesis plus higgs mass bound from LEP2 favour a light stop with $m_{\tilde{t}_1} < m_t$

In ATLAS now there are a few groups interested in the search for a light stop. Most of them are working on stop pair production. Carleton is working on light stop from gluino pair production at a new MSSM benchmark point defined in the theory paper hep-ph/0512284.

References

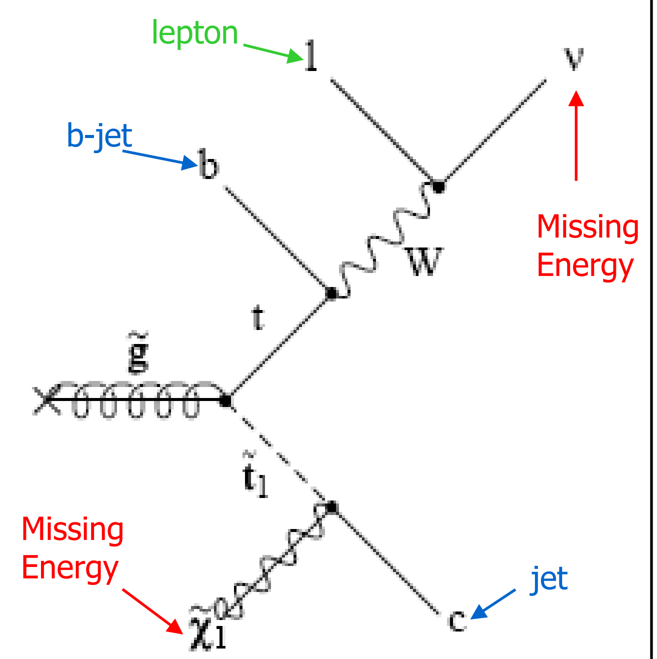
Work by theorists:

- **Same-sign top quarks as signatures of light stops at the CERN LHC**
  - S.Kraml and A.R.Raklev, Phys.Rev.D73 (2006) 075002 hep-ph/0512284
- **Same-sign top quarks as signatures of light stops**
  - S.Kraml and A.R.Raklev, Proceedings of SUSY06 hep-ph/0609293

Light stop production@LHC

- Light stop from gluino:
  - $\tilde{g}$ is a majorana particle, so $\tilde{g} \to t\tilde{t}_1^*$ or $\bar{t}\tilde{t}_1$ has equal probability.
  - Pair-produced gluinos give the signature ($\sigma \sim 5pb$):

2b-jets+2same-sign leptons +jets+ MissingEt



Half of the gluino pair production

- Search strategy:
  - Inclusive search: first step is to see if there is any excess from standard model, using effective mass.
  - Exclusive search: to extract masses by endpoint technique.

MSSM benchmark point (LST1)

- MSSM inputs for **LST1** senario:

M_1 110	M_2 220	M_3 660	μ 300	$\tan(\beta)$ 7		
m_A 250	A_t -670	A_b -500	A_τ 100			
$m_{\tilde{L}_{1,2}}$ 250	$m_{\tilde{L}_3}$ 250	$m_{\tilde{Q}_{1,2}}$ 1000	$m_{\tilde{Q}_3}$ 1000			
$m_{\tilde{E}_{1,2}}$ 250	$m_{\tilde{E}_3}$ 250	$m_{\tilde{U}_{1,2}}$ 1000	$m_{\tilde{D}_{1,2}}$ 1000	$m_{\tilde{U}_3}$ 100	$m_{\tilde{D}_3}$ 1000	
$\alpha_{em}^{-1}(m_Z)^{\overline{\rm MS}}$ 127.91	G_F 1.1664×10^{-5}	$\alpha_s(m_Z)^{\overline{\rm MS}}$ 0.11720	m_Z 91.187	$m_b(m_b)^{\overline{\rm MS}}$ 4.2300	m_t 175.0	m_τ 1.7770

hep-ph/0512284

All squark mass parameters except $m_{\tilde{U}_3}$ are set to 1 TeV

MSSM benchmark point (2)

- Sparticle mass spectrum (**LST1**)

ISAJET V7.64

Particle	Mass	Particle	Mass	Particle	Mass	Particle	Mass
$\tilde{\chi}_1^0$	104.680	$\tilde{\chi}_2^0$	190.778	$\tilde{\chi}_3^0$	306.161	$\tilde{\chi}_4^0$	340.702
$\tilde{\chi}_1^\pm$	189.083	$\tilde{\chi}_2^\pm$	339.866	$\tilde{\tau}_1$	246.985	$\tilde{\tau}_2$	260.757
$\tilde{t}_1$	148.764	$\tilde{t}_2$	1018.853	$\tilde{b}_1$	996.658	$\tilde{b}_2$	1005.328
h	113.960	H	251.612	$H^\pm$	262.179	$\tilde{g}$	660.00

- From ISAJET calculation, the light stop obtains a mass of $m_{\tilde{t}_1} \sim 150$ GeV.
- Since $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} < m_w$, it enables the decay $\tilde{t}_1 -> c\tilde{\chi}_1^0$.

MSSM benchmark point (3)

- Branching ratio and width (**LST1**) ISAJET V7.64

PARENT	-->	DAUGHTERS			WIDTH	BRANCHING RATIO
... ...						
GLSS	-->	W1SS+	DN	UB	0.60947E-03	0.49139E-04
GLSS	-->	W1SS-	UP	DB	0.60947E-03	0.49139E-04
GLSS	-->	W1SS+	ST	CB	0.60947E-03	0.49139E-04
GLSS	-->	W1SS-	CH	SB	0.60947E-03	0.49139E-04
GLSS	-->	W1SS+	BT	TB	0.21891E-03	0.17650E-04
GLSS	-->	W1SS-	TP	BB	0.21891E-03	0.17650E-04
GLSS	-->	Z1SS	UP	UB	0.27456E-03	0.22137E-04
GLSS	-->	Z1SS	CH	CB	0.27456E-03	0.22137E-04
GLSS	-->	Z2SS	UP	UB	0.33273E-03	0.26827E-04
GLSS	-->	Z2SS	DN	DB	0.27925E-03	0.22514E-04
GLSS	-->	Z2SS	ST	SB	0.27925E-03	0.22514E-04
GLSS	-->	Z2SS	CH	CB	0.33273E-03	0.26826E-04
GLSS	-->	Z2SS	BT	BB	0.28702E-03	0.23141E-04
GLSS	-->	TB1	TP		0.61991E+01	0.49980E+00
GLSS	-->	TP1	TB		0.61991E+01	0.49980E+00
... ...						
TP1	-->	Z1SS	CH		0.11375E-07	0.10000E+01
... ...						

~100% gluino decay

stop decay 100%

Inclusive search

Event Selection:

- 2l4j: 2 leptons and 4 jets
- l:PT: lepton PT > 20GeV
- j:PT: jet PT > 50 GeV
- MET: MissignEt > 100 GeV
- SS: 2 same-sign leptons

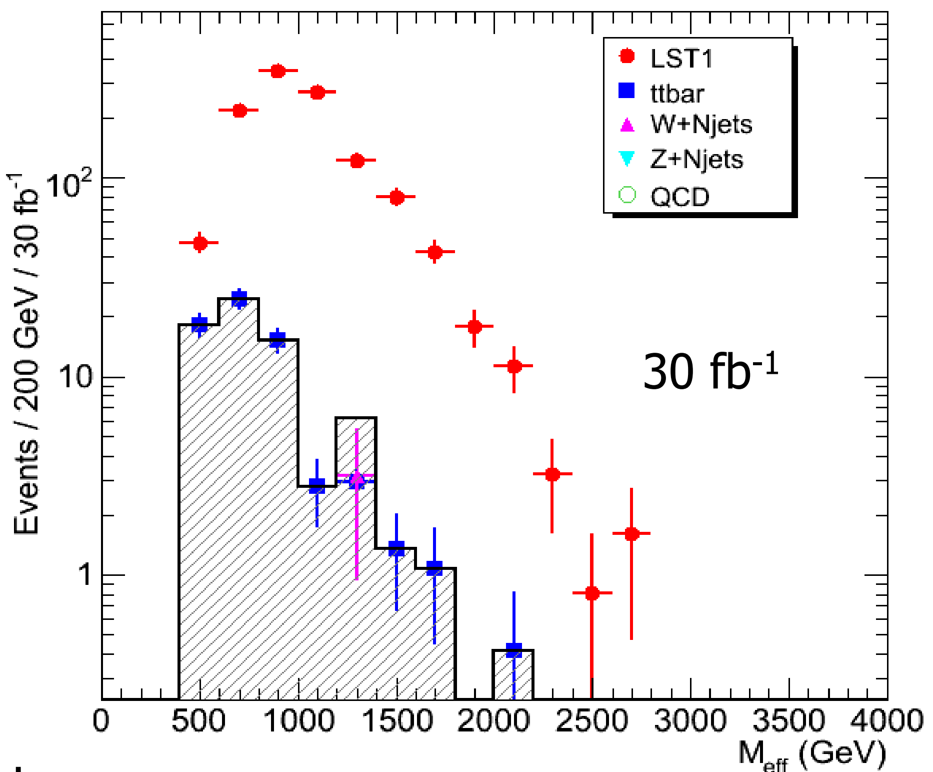
Effective mass:

$$M_{eff} = E_T^{miss} + \sum P_T^{jet}$$

Meff is a powerful quantity to discriminate SUSY from stand model, and it is also a good measurement of SUSY mass scale.

Effective mass

- SM backgrounds:
  - $t\bar{t}$
  - W+jets
  - Z+jets
  - QCD
  - WW/WZ/ZZ
- It's easy to see the event excess from standard model backgrounds even without b-tagging.
- Only ttbar, W+jets events can survive the selection. QCD don't yet have enough statistics to conclude.



Exclusive search

- Exclusive search:
  - Simple event counting
  - SUSY masses extraction
    - ✓ 4 possible endpoints: M**bc**, M**lc**, M**bl**, M**blc**
    - ✓ M**bl** only gives a relationship between W and t
    - ✓ M**bc** and M**lc** maximum are related to the masses of $\tilde{t}_1$, $\tilde{g}$, $\tilde{\chi}_1^0$

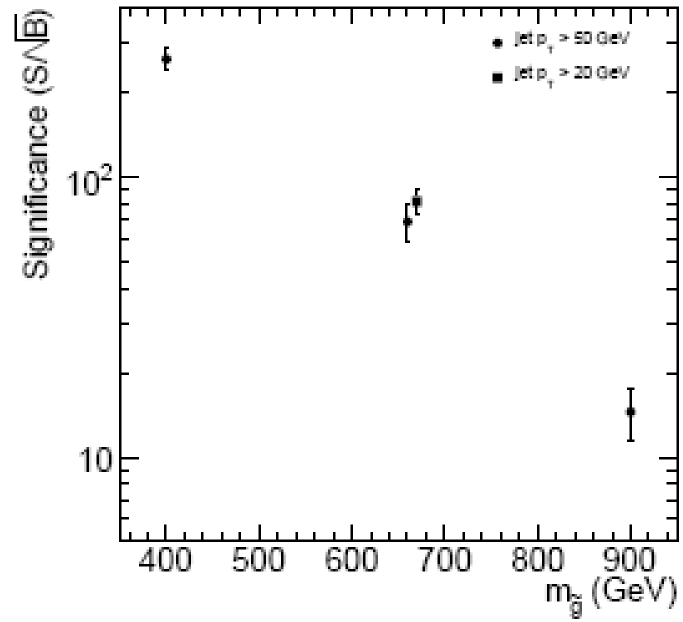
  - So there are 3 unknown masses and 2 uncorrelated endpoints. But still important to constrain models with real data.

Exclusive search

- Event selection:
  - 2l4j: 2 leptons and 4 jets
  - l:PT: lepton PT > 20GeV
  - j:PT: jet PT > 50 GeV
  - 2b: at least 2 jets are b-tagged
  - MET: MissignEt > 100 GeV
  - 2t: 2 top candidates with $M_{bl}<160$GeV
  - SS: 2 same-sign leptons
- b-tagging:
  - binary in fast simulation, only 2 values.
  - By default parameterization: 60% efficiency

Significance

- Both standard model and SUSY backgrounds are very low to the signal.
- Among SM backgrounds, only ttbar events survive all the cuts.
- The significance decreases as the gluino mass increases.

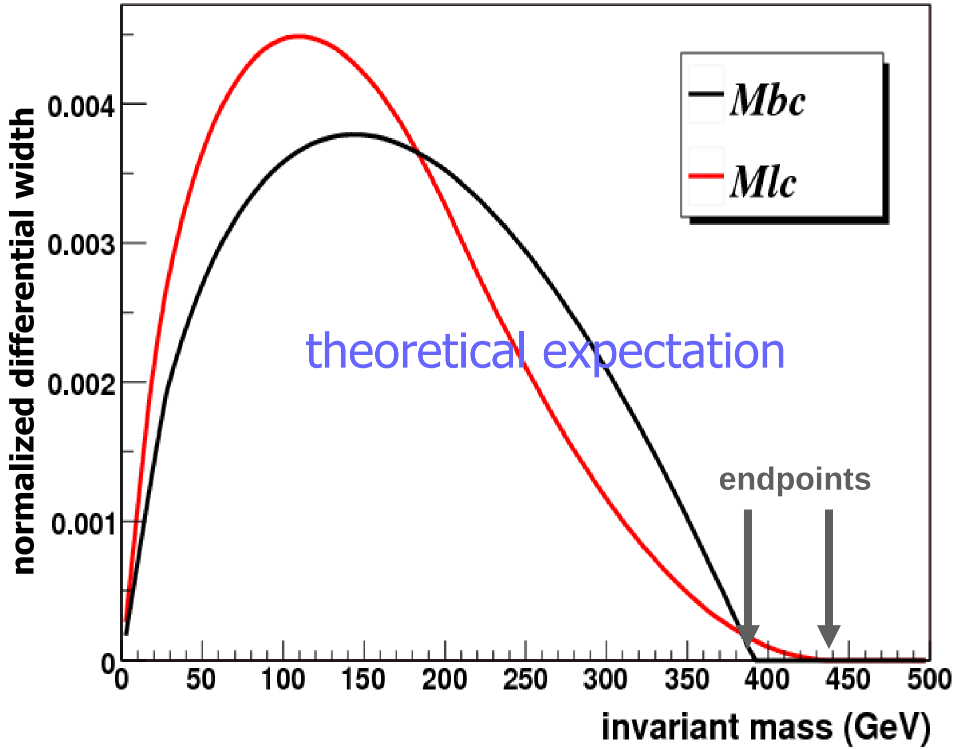


		Cut						
		$2l$,4jet	l_{PT}	jet$_{PT}$	$2b$	$\not{E}_T$	$2t$	SS
Signal	$\tilde{g}\tilde{g}$	5114	4440	2783	647	520	382	189
Background	SUSY	742	668	240	36	29	11	6
	$t\bar{t}$	68739	56758	11064	2587	1209	1101	1.5
	W + jets	150	29	15	2	2	0	0
	Z + jets	2	1	0	0	0	0	0

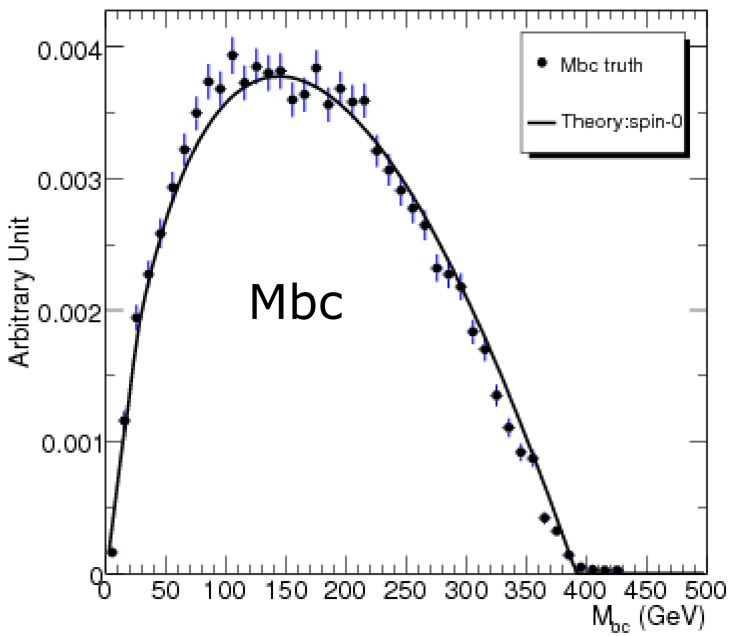
Invariant masses

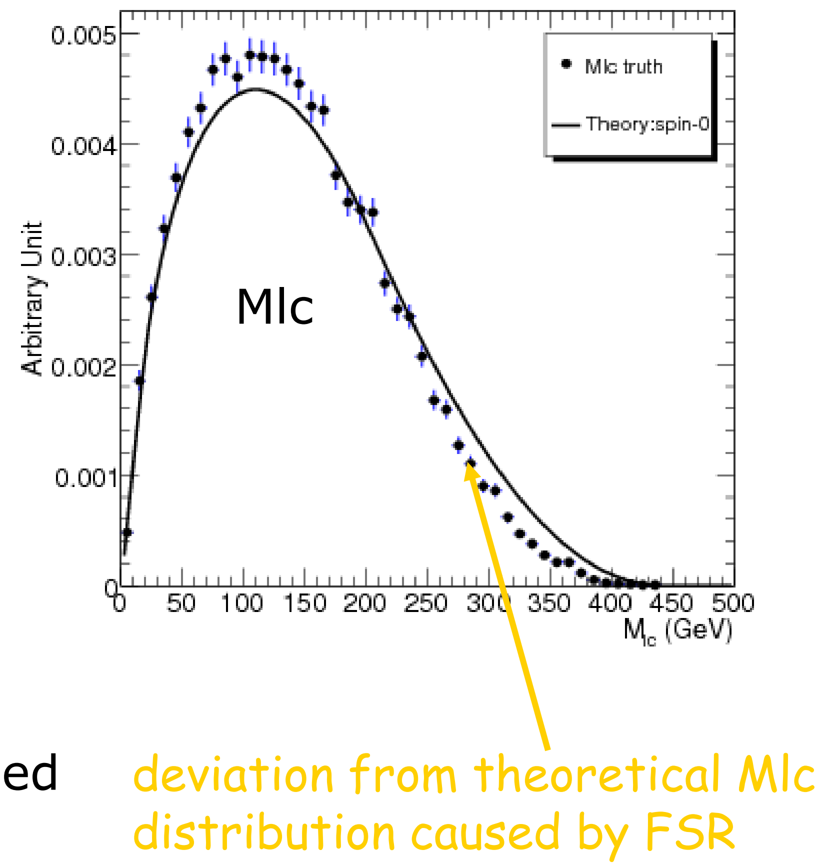
- Analytic formulas exist for Mbc, Mlc (without spin correlation)
- Two parameters to fit: a and M_{bc}^{max}

which relates the masses of $\tilde{g}$, $\tilde{\chi}_1^0$, $\tilde{t}_1$ (formulas omitted here)



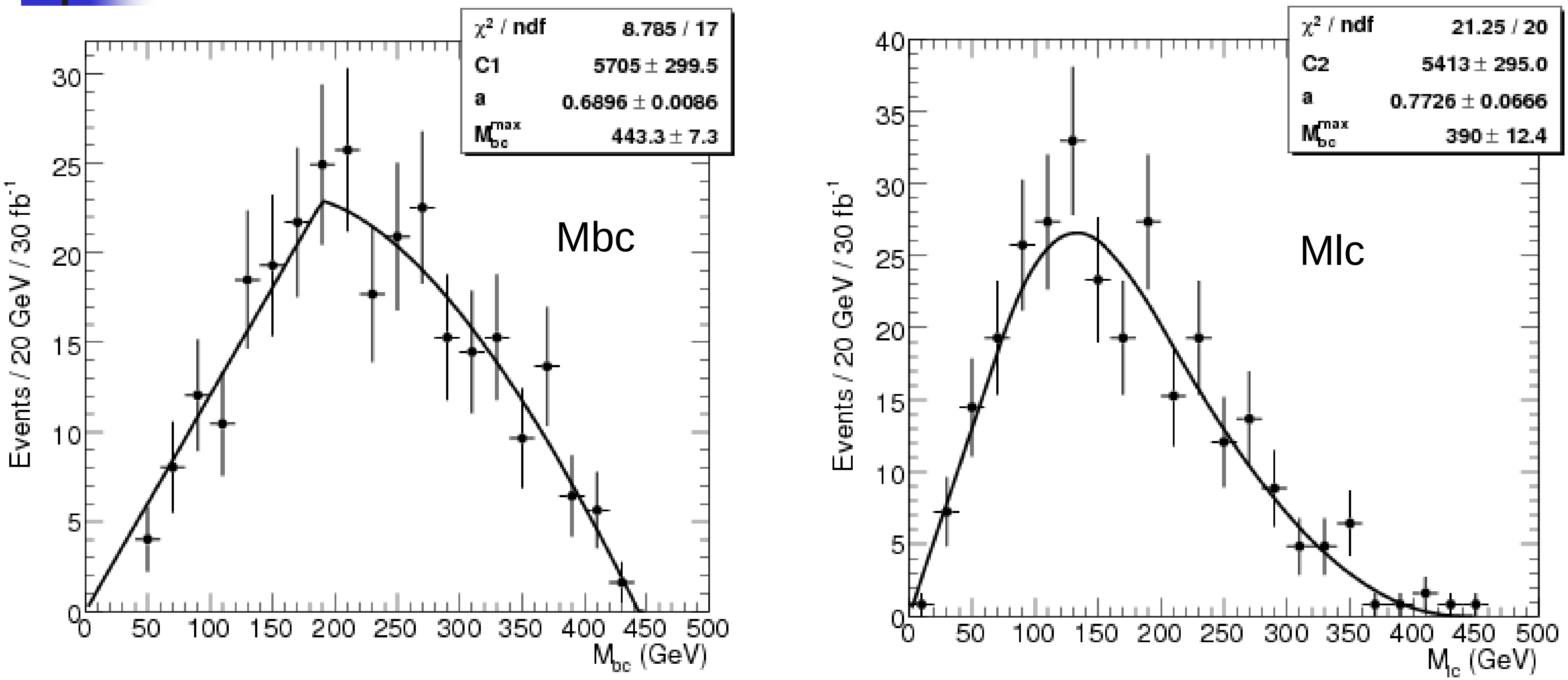
Invariant masses (truth)





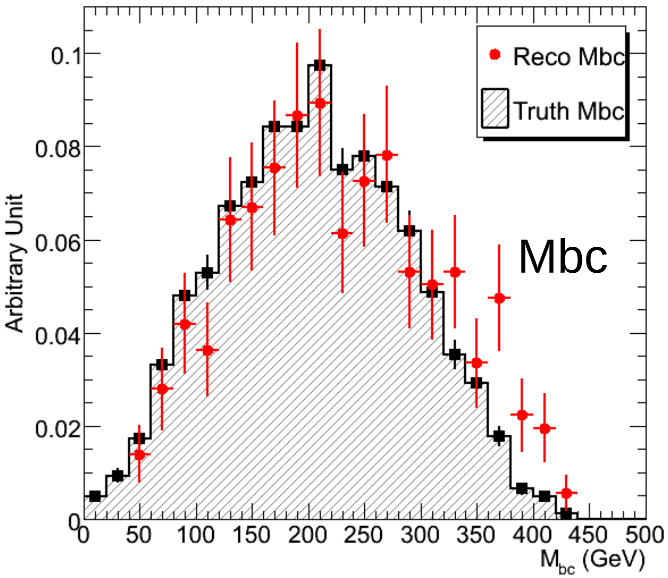
- For the comparison with analytic formulas, spin correlation was switched off in Herwig.
- FSR effect was further investigated with Pythia events.

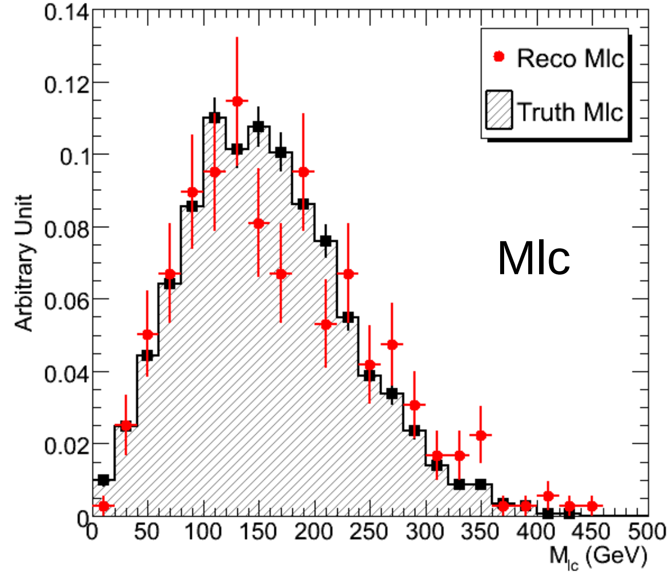
Invariant masses (reconstructed)

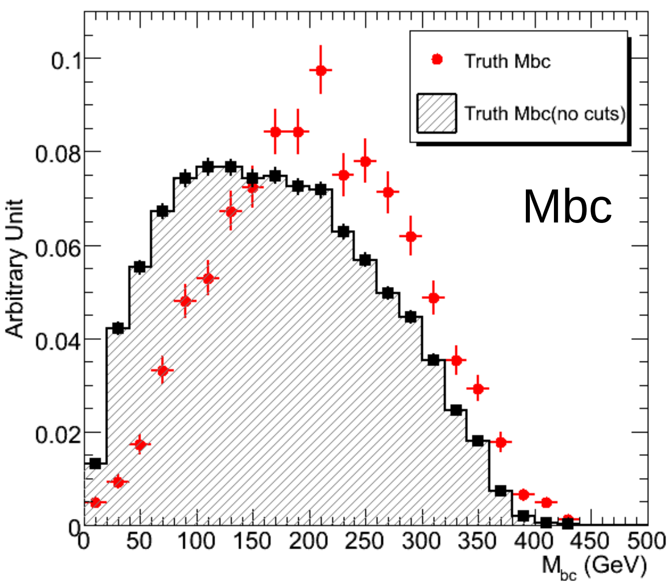


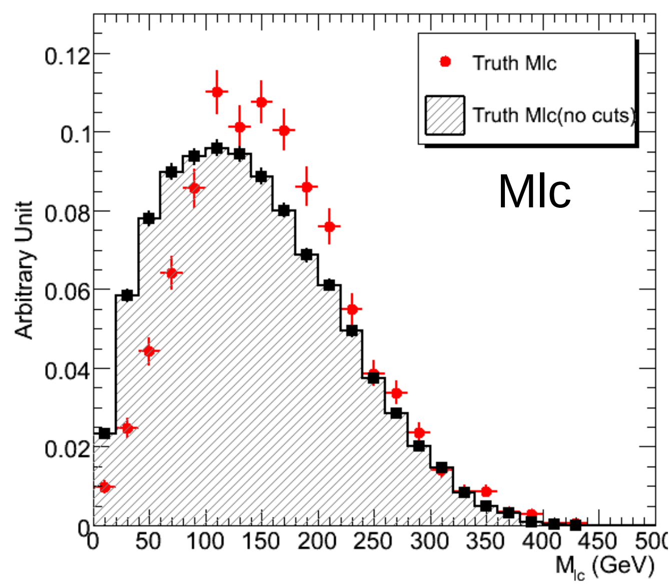
- Although the fitting converged and $M_{bc}^{\max}$ are close to correct one, fitted "a" are faraway from nominal value 0.991 (especially for Mbc). This is because the shapes are distorted at low energy end due to the cuts, mostly jet P_T cut
- The pairing algorithm gives a purity ~55%. Wrong pairing extends the tail so a larger endpoint.

Acceptance correction

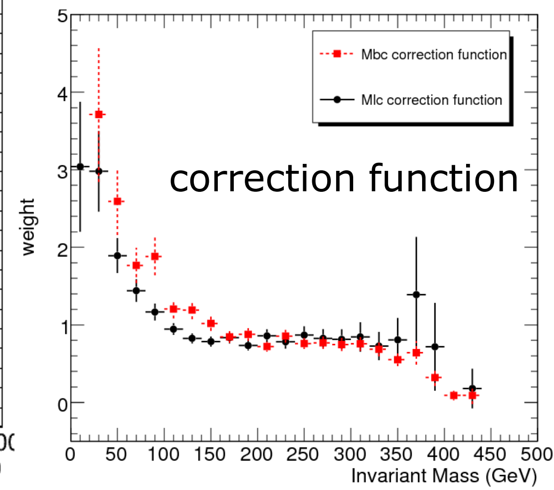






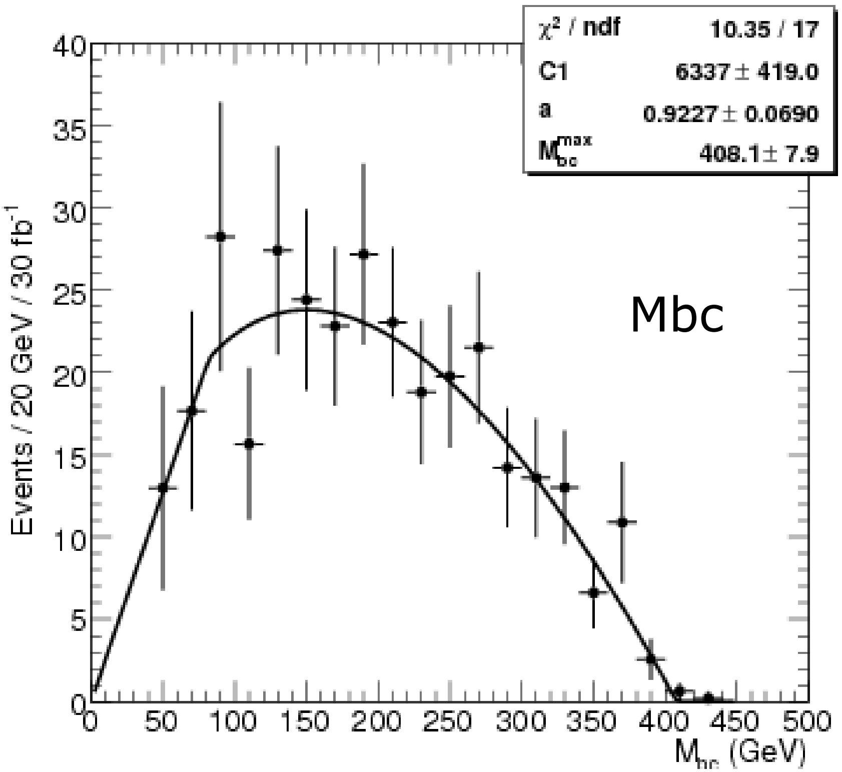


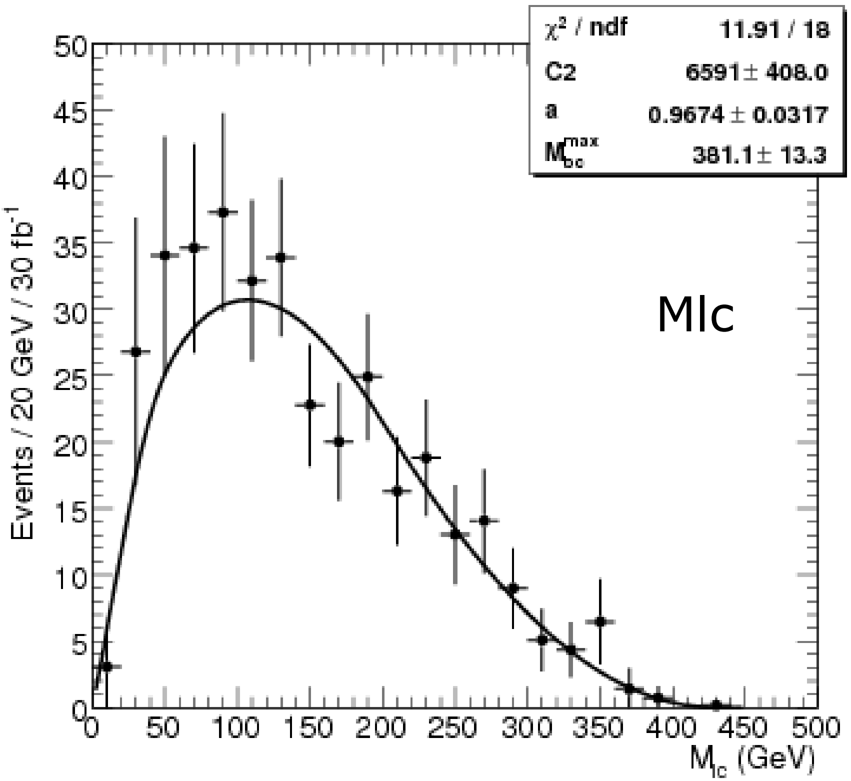
- The Mbc and Mlc distributions are comparable to the truth with similar cuts, but obviously distorted due to the acceptance
- The correction func was calculated as the ratio of all the truth events to those passing the selection criteria.



Masses after correction

- After corrections, Mbc and Mlc shape are mostly restored and results in a much better fit.





Summary

- A new light stop benchmark point LST1 was investigated with fast simulation. In addition to a thesis work, the event generation in this scenario is committed to CVS for public use.
- Using the event selection criteria proposed in Phys. Rev. D73 (2006) 075002, gluino pair events are easy to discriminate from both SM and SUSY backgrounds.
- Because only the proposed kinematics cuts were adopted, there is large improvement room to optimize these cuts and also the pairing algorithm.
- Full simulation is necessary to consider the more realistic detector performance: lepton fakes, jet energy scale, resolution and b-tagging etc.
- The conclusion from the study with fast simulation is that LST1 is a promising benchmark point to search on ATLAS.

Outlook

- Further investigation of LST1 with full simulation. It is expected that the SM backgrounds is still very low from full simulation, mainly ttbar events.
- It's meaningful to extend the work from the specific benchmark point to a more generic SUSY search using same-sign dilepton.
- Same-sign dilepton is almost background-free, but there are other non-physics backgrounds from detector performance, especially lepton fakes. So expecting more W+Njets backgrounds.

Backup Slides

Invariant mass distribution

$$\frac{1}{\Gamma_0}\frac{\partial\Gamma}{\partial M_{bc}^2} = \frac{(1+a)}{2a(M_{bc}^{max})^2} \times \begin{cases} \ln\frac{1+a}{1-a}, & \text{for } 0 < M_{bc}^2 < (M_{bc}^{max})^2\frac{1-a}{1+a} \\ \ln\frac{(M_{bc}^{max})^2}{M_{bc}^2}, & \text{for } (M_{bc}^{max})^2\frac{1-a}{1+a} < M_{bc}^2 < (M_{bc}^{max})^2 \end{cases}$$

$$\frac{1}{\Gamma_0}\frac{\partial\Gamma}{\partial M_{lc}^2} = \frac{(1+a)}{2a(M_{bc}^{max})^2} \times \begin{cases} \ln\frac{1+a}{1-a}\ln\frac{m_t^2}{m_W^2}, \\ \qquad \text{for } 0 < M_{lc}^2 < (M_{lc}^{max})^2\frac{1-a}{1+a}\frac{m_W^2}{m_t^2} \\ \ln\frac{1+a}{1-a}\ln\frac{m_t^2}{m_W^2} - \frac{1}{2}\left[\ln\left(\frac{1+a}{1-a}\frac{m_t^2}{m_W^2}\frac{M_{lc}^2}{(M_{lc}^{max})^2}\right)\right]^2, \\ \qquad \text{for } (M_{lc}^{max})^2\frac{1-a}{1+a}\frac{m_W^2}{m_t^2} < M_{lc}^2 < (M_{lc}^{max})^2\frac{1-a}{1+a} \\ \ln\frac{m_t^2}{m_W^2}\left(\ln\frac{(M_{lc}^{max})^2}{M_{lc}^2} - \frac{1}{2}\ln\frac{m_t^2}{m_W^2}\right), \\ \qquad \text{for } (M_{lc}^{max})^2\frac{1-a}{1+a} < M_{lc}^2 < (m_{lc}^{max})^2\frac{m_W^2}{m_t^2} \\ \frac{1}{2}\left(\ln\frac{(M_{lc}^{max})^2}{M_{lc}^2}\right)^2, \\ \qquad \text{for } (m_{lc}^{max})^2\frac{m_W^2}{m_t^2} < M_{lc}^2 < (M_{lc}^{max})^2 \end{cases}$$

$$(M_{lc}^{max})^2 = (M_{bc}^{max})^2\frac{m_t^2}{m_W^2}$$

NLO cross sections

- NLO cross section for gluino-pair production at the LHC

$m_{\tilde{g}}$ (GeV)	400	500	600	700	800	900	1000
$\sigma(\tilde{g}\tilde{g})$ (pb)	113	31.6	10.4	3.84	1.56	0.68	0.31

- NLO cross sections in pb for stop pair production at the Tevatron and the LHC ($m_{\tilde{g}} = 660$ GeV)

$m_{\tilde{t}_1}$ [GeV]	120	130	140	150	160	170	180
$\sigma(\tilde{t}_1\tilde{t}_1^*)$, Tevatron	5.43	3.44	2.25	1.50	1.02	0.71	0.50
$\sigma(\tilde{t}_1\tilde{t}_1^*)$, LHC	757	532	382	280	209	158	121

Effective mass

$$M_{\text{eff}} \equiv \sum_{i=1}^{4} p_T^{\text{jet},i} + \sum_{i=1} p_T^{\text{lep},i} + E_{\text{T}}^{\text{miss}}$$

- Peak of effective mass distribution as a function of Msusy