Prospects for detecting long-lived particles with ATLAS

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OUTLINE

- Introduction
- Some Supersymmetry models predicting long-lived particles
- Searches for long-lived particles:
  - ✳long-lived neutralinos
  - ✳long-lived sleptons
  - ✳R-Hadrons
- Conclusions

INTRODUCTION

• Many scenarios beyond standard Supersymmetry predict the existence of particles whose lifetime is long enough to be directly detected in the ATLAS detector: long-lived particles.

Ex. GMSB can give rise to a long-lived neutralino, slepton
Split-SUSY can give rise to long-lived $R_{\tilde{g}}$-hadrons
gravitino LSP/stop NLSP can give rise to long-lived $R_{\tilde{t}}$-hadrons
some RPV scenarios can give rise to, e.g., long-lived stops

LSP = Lightest Supersymmetric Particle
NLSP = Next LSP

• These particles will not necessarily be detected within the general SUSY searches (high-pT jets + missing transverse energy):

- ✳ non-pointing photons
- ✳ high-pT muon-like tracks, with longer time-of-flight than muons.

• Many searches can be made with small Standard Model background and current exclusion limits (Tevatron) point that they are ideal first-data searches.

• Their observation (or not) can put hard constraints on the SUSY breaking scenarios.

• This talk is a review on the following notes on long-lived particles:

• **ATLAS Collaboration, Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008, to appear.**
• **Trigger and Reconstruction for a heavy long lived charged particles with the ATLAS detector, Tarem, S ; Bressler, S ; Nomoto, H ; Dimattia, A ; SN-ATLAS-2008-071**

SUSY EXAMPLES

- ## GMSB: (gauge mediated SUSY breaking)

✳ SUSY breaking takes place in a hidden sector and it is transmitted to MSSM fields through a messenger sector (number of messenger generators = N_5).

✳ The LSP is always the gravitino with $M_{\tilde{G}} << 1GeV$.

✳ For $N_5 = 1$ the NLSP is the $\tilde{\chi}^0_1 \longrightarrow \tilde{G}\,\gamma$.

✳ For $N_5 \geq 2$ the NLSP is a $\tilde{\ell} \longrightarrow \tilde{G}\,\ell$

✳ If the coupling is soft the neutralino or slepton will be long-lived.

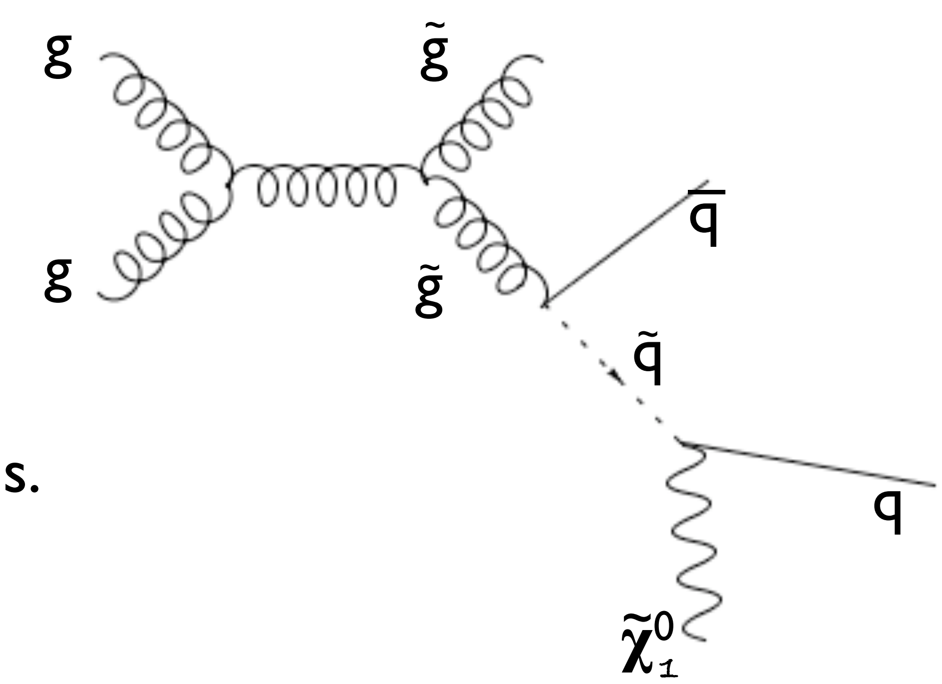
- ## Split -Supersymmetry

✳ Big difference between scalar masses (except for the ordinary Higgs), and gaugino and higgsino masses.

✳ Gluino decay proceeds via internal squark line, so it is meta-stable. It hadronizes and forms R_g-hadrons.

✳ $M_{\tilde{g}} \approx$ weak scale

✳ $M_{scalars} \approx$ near GUT scale



- ## gravitino LSP / stop NLSP

✳ NLSP is the $\tilde{t}_1$, which forms bound states called $R_{\tilde{t}}$-hadrons.

LONG - LIVED NEUTRALINOS

GMSB

LSP = $\tilde{G}$

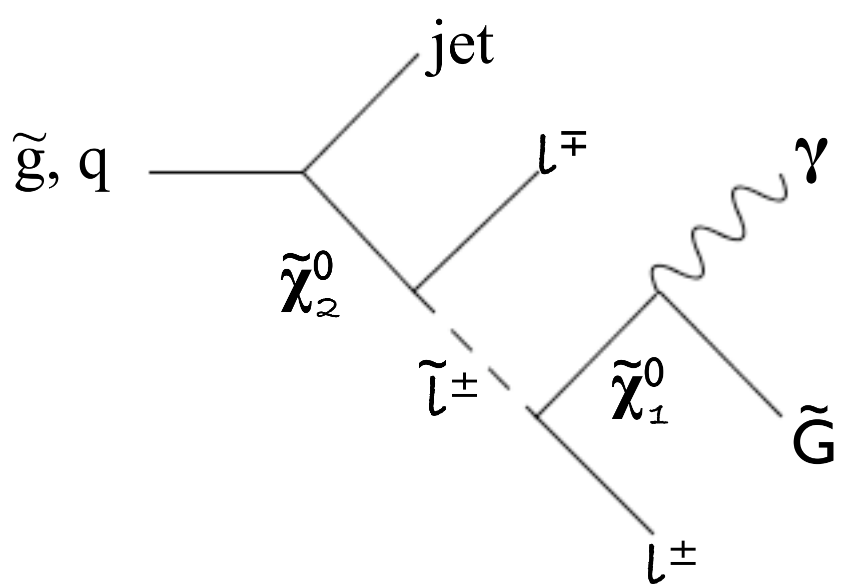
NLSP = $\tilde{\chi}^0_1$

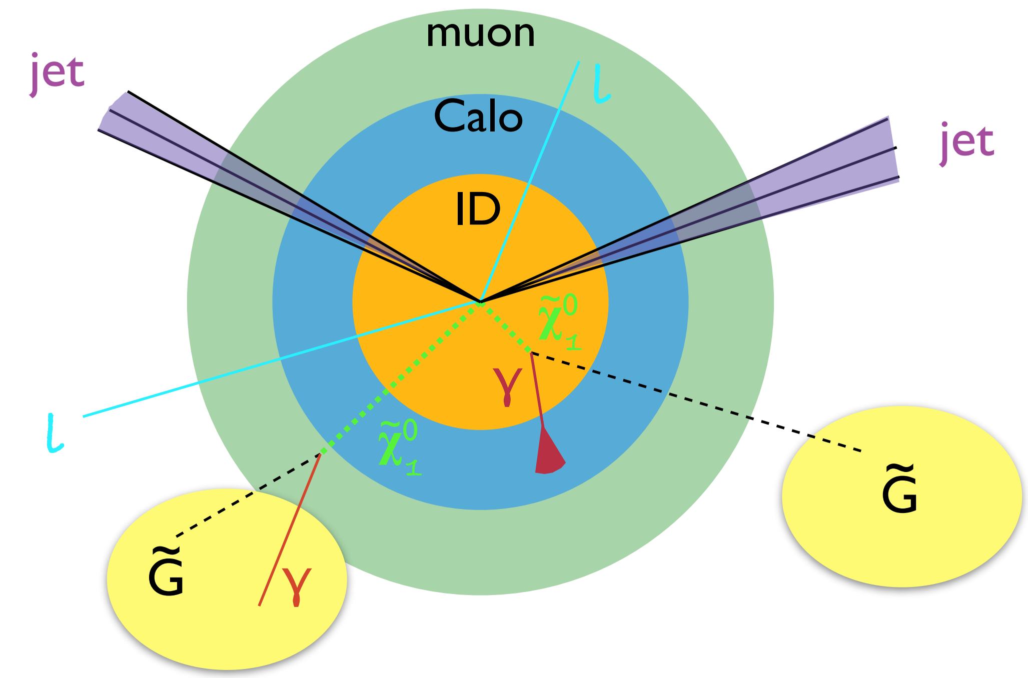
$\tilde{\chi}^0_1 \xrightarrow{97\%} \tilde{G}\,\gamma$

$\lambda_{\tilde{\chi}^0_1}$ = 3m

Λ = 90 TeV

M_{mess} = 500 TeV





photon non originated near the primary vertex: non-pointing photon

- Signature: many standard SUSY observables are useful
  - → high pT multijets
  - → E_T^{miss}
  - **+ 1 or 2 non-pointing photons**
  - **+ OSSF: opposite sign, same flavour lepton pairs**
- Good significance is obtained with 1 non-pointing photon and 1 OSSF lepton pair. L = 1 fb^{-1}

N_γ	N_{OSSF}	Signal	$\sum$ Background	Sig	N_W	N_Z	$N_{t\bar{t}}$
0	0	825.2	929.6	27.1	274.4	21.0	632.8
0	1	265.2	73.0	33.2	8.7	1.4	63.0
1	0	255.8	51.7	35.7	19.5	2.0	30.1
1	1	68.6	1.4	58.6	0.2	0.0	1.2
2	0	12.5	0.1	12.5	0.0	0.0	0.1
2	1	4.7	0.0	4.7	0.0	0.0	0.0

Sig = S / $\sqrt{B}$

GMSB: 12% 1γ (pT > 20 GeV)
0.6% 2γ (pT > 20 GeV)

SLEPTONS

GMSB

LSP = $\tilde{G}$

NLSP = $\tilde{\ell}^{\pm}$

$\tilde{\chi}_1^0 \rightarrow \tilde{\ell}^{\pm} \ \ell^{\mp}$

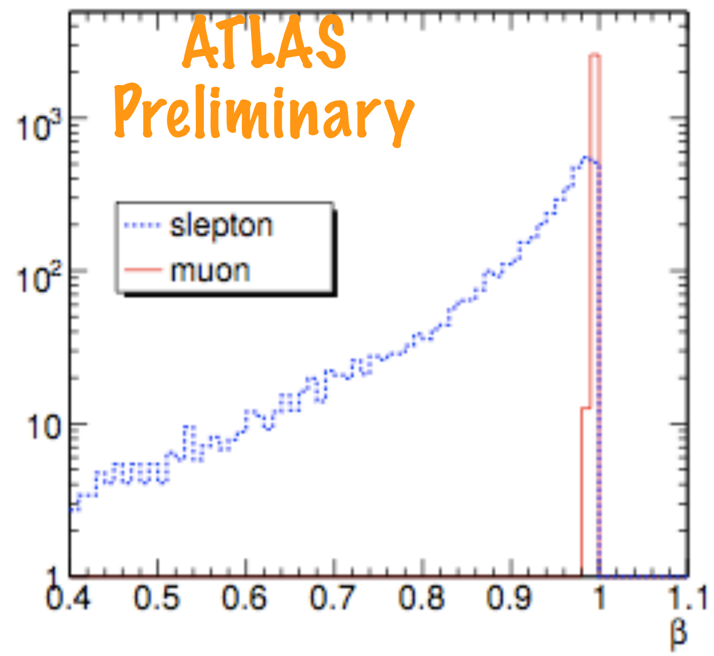
$M_{\tilde{\chi}_1^0}$ = 114 GeV

$M_{\tilde{\tau},\tilde{\ell}}$ ~ 100 GeV

Λ = 30 TeV

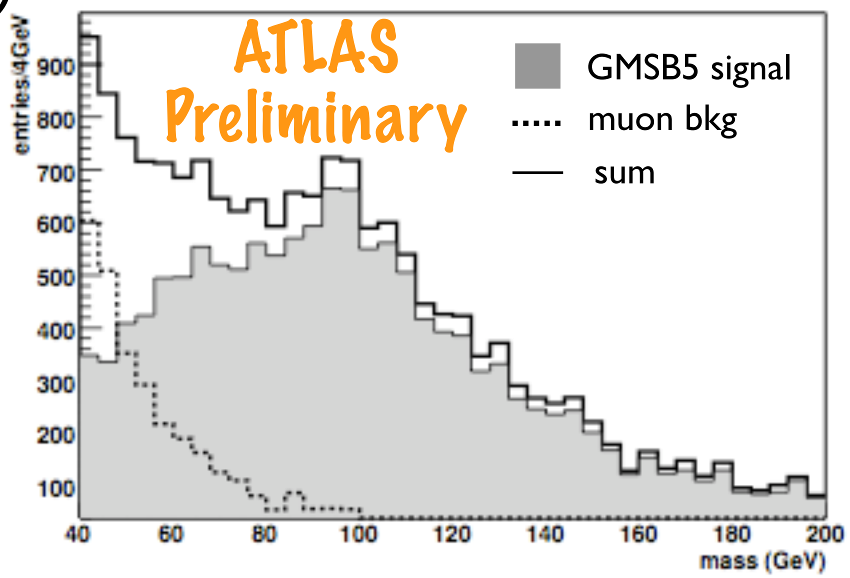
M_{mess} = 250 TeV

- $\tilde{\ell}^{\pm}$ couples weakly to gravitino.
- In principle they are detected as muons.



β ≈1 • indistinguisible from muons
β ≪1 • distinguisible, identified and mass determined

$\beta = \frac{v}{c}$

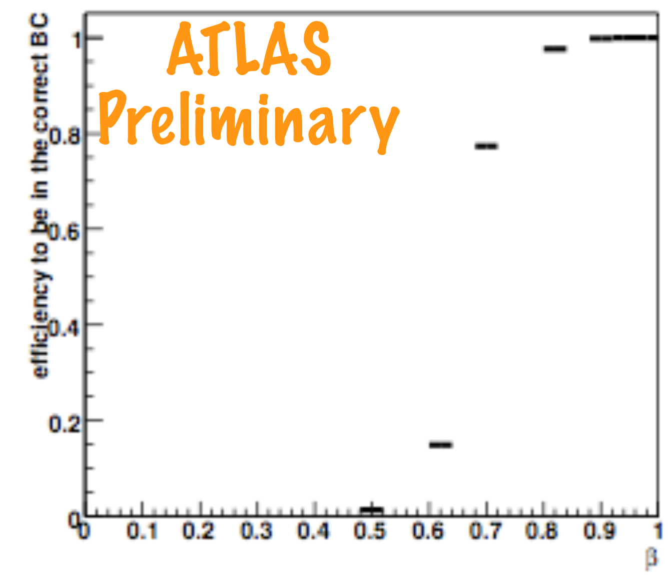


- measure of β: quick calculation with good resolution in the muon system (~3.1 ns)
- measure of pT
- preselection of slepton-like events at trigger level.

- In most of the events, at least one of the sleptons will have β > 0.7
- If it is labelled with the correct BCID, the triggers have a very good efficiency.
- For a low β slepton, data from next BC has to be collected.

MATCHING TO CORRECT BUNCH CROSSING

- In ATLAS event fragments from different parts of the detector are assigned to a particular bunch crossing (BC) using the BC Identifier (BCID).



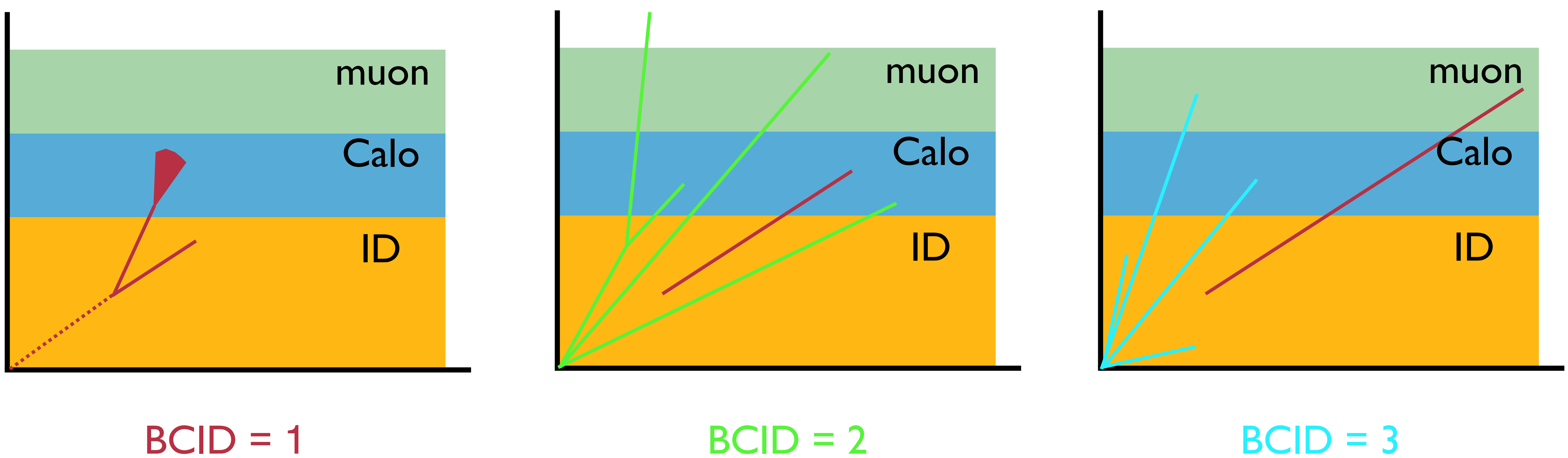
- ATLAS: max. path 20m, bunch crossing period= 25ns.

- 3 events can co-exist at the same time in the detector.

- Assumption: particles traverse the detector with $\beta \sim 1$.

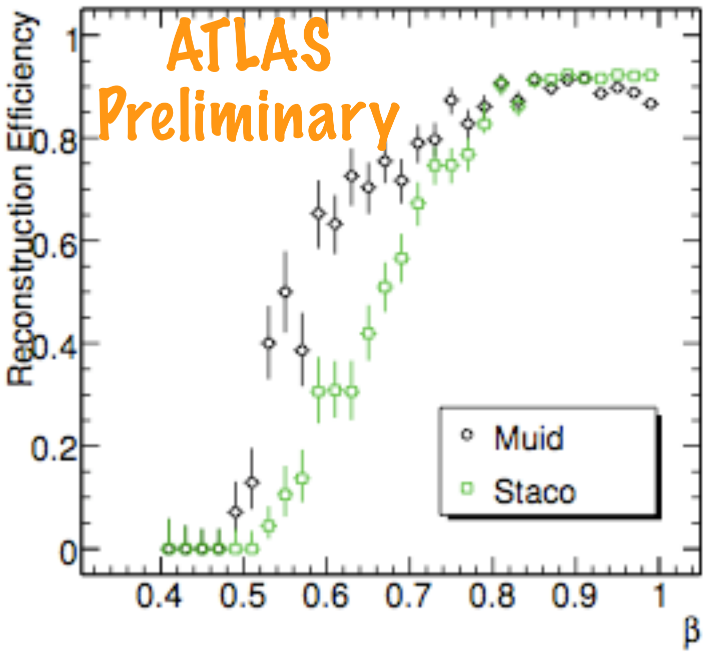
- Hits from a slower particle may be lost or labelled with the wrong BCID.

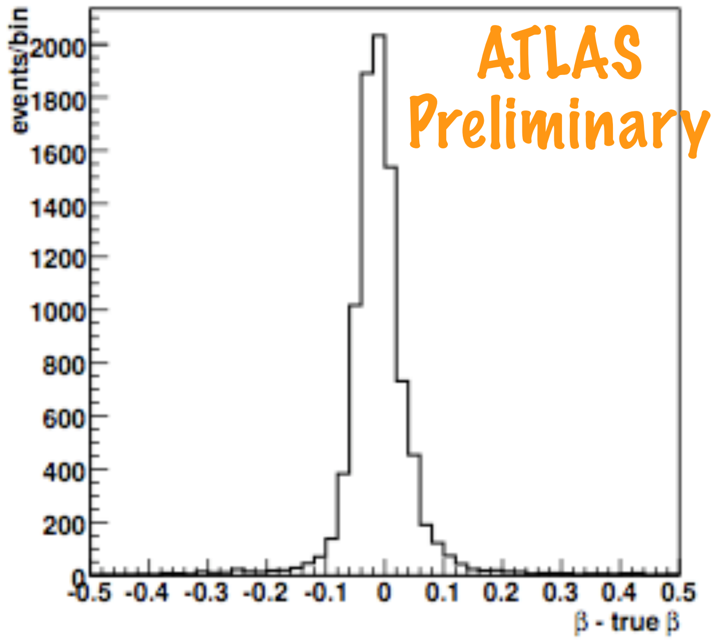
- For slow particles data from next BCs should be collected with the trigger of the first one.



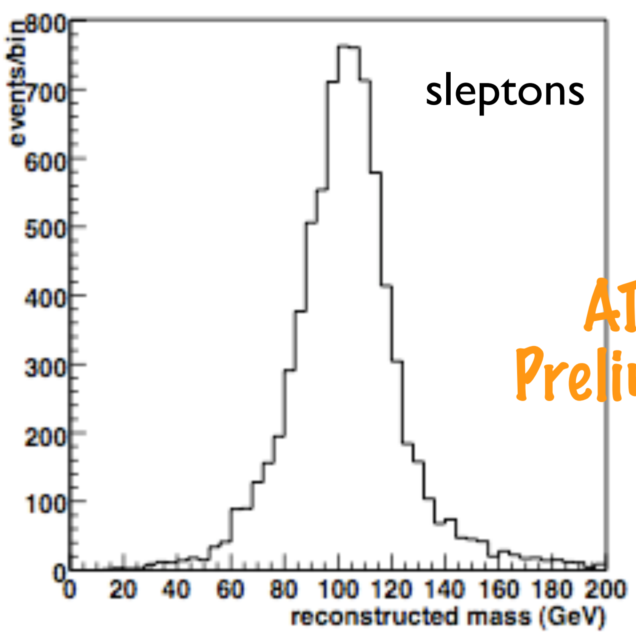
SLEPTONS

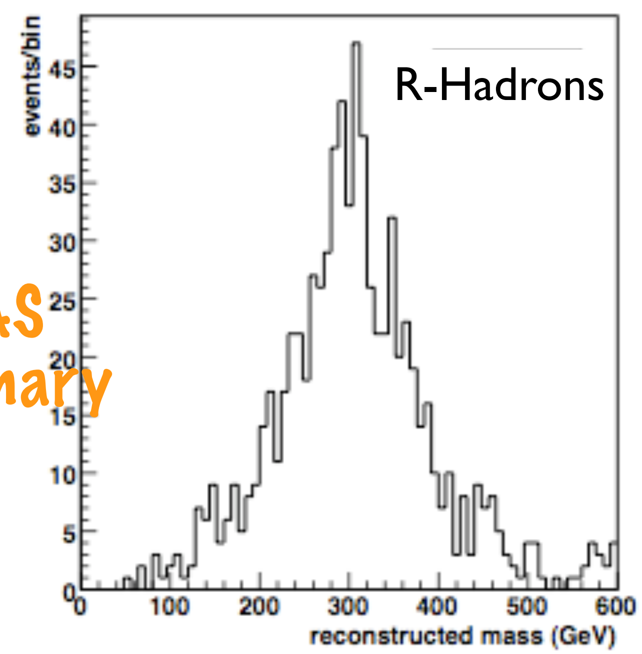
Reconstruction of sleptons:





- Efficiency of reconstructing sleptons with muon reconstruction algorithms is low for β < 0.8
- A specialized algorithm to reconstruct slow particles is needed.





- β resolution and reconstructed mass for sleptons with the algorithm muGirl: estimating the velocity and mass avoids reconstructing sleptons as muons.
- This mecanism of reconstructing slow particles is also valid for other models besides GMSB, for example Lepton Flavour Violating SUSY Kaneko et al. arXiv:0811.0703v1

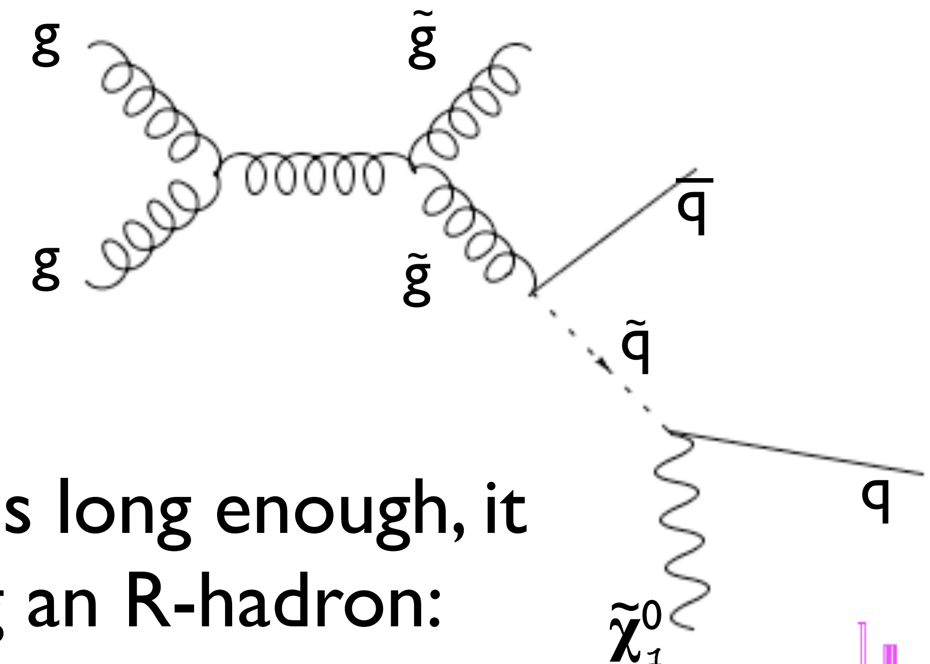
There are good muon-like recostruction tools to identify long-lived charged particles, although some of the discovery must be done in data acquisition and trigger levels.

R-Hadrons

Massive exotic stable hadrons, formed by meta-stable gluinos ($R_{\tilde{g}}$) or meta-stable stops ($R_{\tilde{t}}$)

Split-SUSY

meta-stable gluinos



Amplitude of the favoured decay is small: the squark is a very heavy scalar

$M_{\tilde{g}} \approx$ weak scale

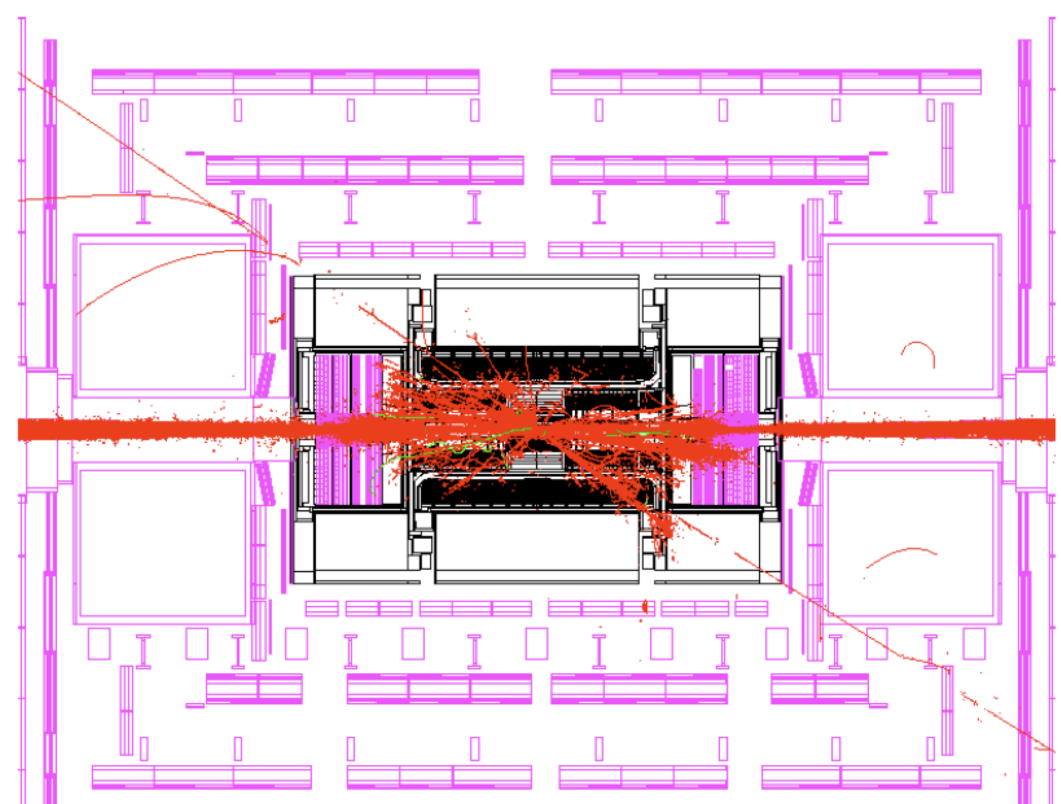
$M_{scalars} \approx$ near GUT scale

- If the gluino lifetime is long enough, it will hadronise forming an R-hadron:

R-meson: $\tilde{g}q\bar{q}$

R-baryon: $\tilde{g}qqq$

R-Gluino-ball: $\tilde{g}g$



signature: high-pt slow muon-like track

R-Hadrons

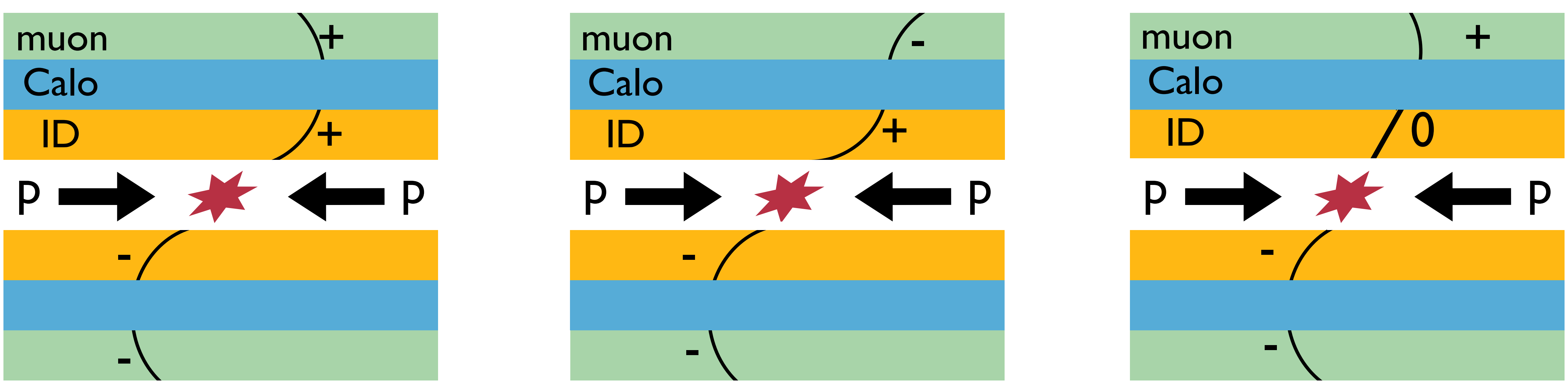
- Energy deposition in the detector is supposed to be small since only (light) quarks will interact with matter, but not heavy squarks or gluinos.
  - ✳ R-hadrons will not be stopped.
  - ✳ they will not be confused with jets

- A typical R-hadron has 10-20 nuclear interactions before escaping the detector.
- $R_{\tilde{g}}$-hadrons can flip its charge so tracks with different charge will be detected in the ID and muon system.

Interactions of coloured heavy stable particles in matter
Mackeprang and Rizzi, Eur. Phys. J. C50 (2007) 353-362

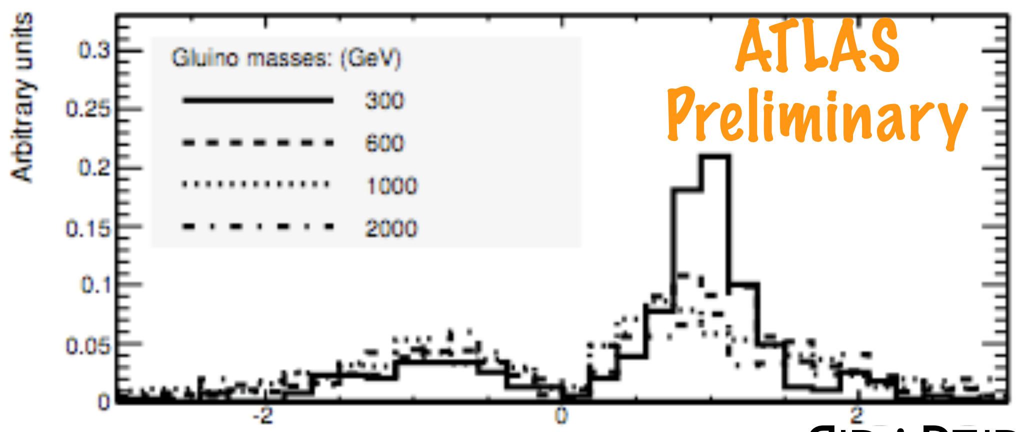
$$R^{+}\ n \longrightarrow R^{-}\ p\ \pi^{+}$$

no flippers, 2 μ — 1 or 2 flippers, 2 μ — no ID tracks, 1 or 2 μ



challenge for reconstruction - useful observables for discovery

R-Hadrons

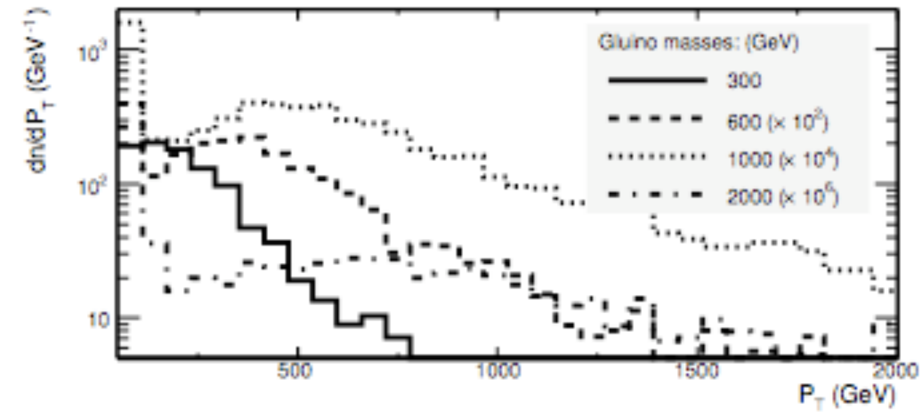


$$\frac{q_{ID} \cdot p_{T,ID}}{q_{\mu} \cdot p_{T,\mu}}$$

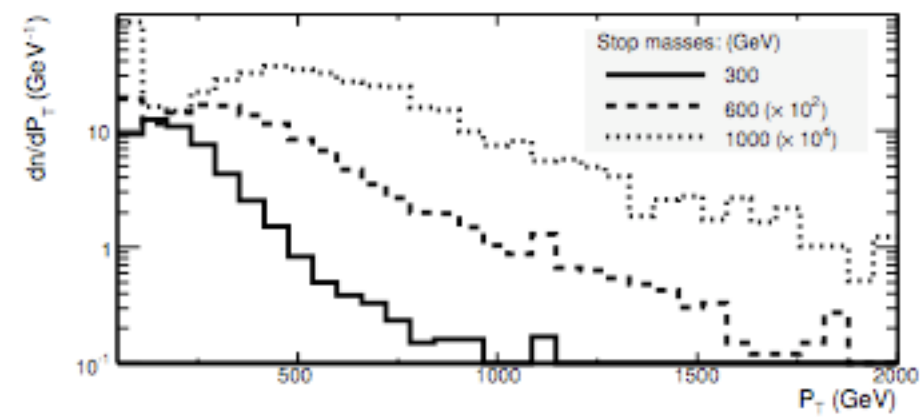
R_g-hadrons:
charge and p_T measured in the Inner Detector divided by charge and p_T measured in the muon system.
The peak in the negative section means one track in the ID corresponding to a track in the muon system with the opposite sign of the charge.

Distribution of transverse momenta of hard tracks reconstructed in the muon system

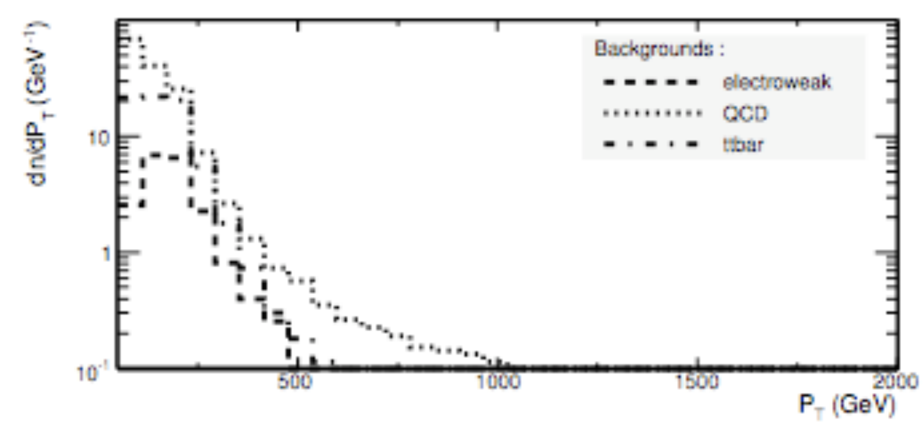
$R_{\tilde{g}}$



$R_{\tilde{t}}$



backgrounds



ATLAS Preliminary

R-Hadrons

R-hadron selection criteria:

- ➡ one hard muon track no linked to any ID track.
- ➡ one hard muon track with a hard matching ID track of opposite charge

Sample	Rate (Events/fb^{-1})
300 GeV gluino	6.44×10^3
600 GeV guino	2.70×10^3
1000 GeV guino	10.7
1300 GeV guino	1.20
1600 GeV guino	0.147
2000 GeV guino	1.26×10^{-2}
300 GeV stop	70.0
600 GeV stop	3.9
1000 GeV stop	0.1
J5	0.893
J8	2.26×10^{-3}
$Z \rightarrow \mu\mu$	0.776

Discovery window open with low luminosity searches for stop and gluino R-hadrons with masses greater than several hundred GeV.

CONCLUSIONS

- Some search strategies have been developed at ATLAS for a range of long-lived particles within Supersymmetry: neutralinos, sleptons and R-hadrons.

- For an integrated luminosity of about 1 fb^{-1} of LHC data, a discovery window is opened in ATLAS for the above particles:

    - long-lived neutralinos within GMSB with non-pointing photons signature.

    - R-hadrons with muon-like and charge exchange signature.

- Enhanced reconstruction algorithms make possible reconstruction and mass determination of slow particles as sleptons and R-Hadrons.

- Although these studies have been performed within Supersymmetry, the techniques used can be applied to other searches.

Backup

R-Hadrons

Sample	Accepted events	Rate (Events / fb^{-1})
300 GeV gluino	235	6.44×10^3
600 GeV gluino	551	2.70×10^3
1000 GeV gluino	774	10.7
1300 GeV gluino	732	1.20
1600 GeV gluino	685	0.147
2000 GeV gluino	546	1.26×10^{-2}
300 GeV stop	78	70.0
600 GeV stop	134	3.9
1000 GeV stop	170	0.1
J5	1	0.893
J8	1	2.26×10^{-3}
$Z \rightarrow \mu\mu$	1	0.776

sparticle	Mass (GeV)	Events/fb^{-1}	$\mathscr{L}$ (fb^{-1})
$\tilde{g}$	300	2.69×10^5	3.72×10^{-2}
$\tilde{g}$	600	4.84×10^3	2.07
$\tilde{g}$	1000	138	72.5
$\tilde{g}$	1300	16.4	610
$\tilde{g}$	1600	2.12	4.72×10^3
$\tilde{g}$	2000	0.230	4.35×10^4
$\tilde{t}$	300	7.82×10^3	1.12
$\tilde{t}$	600	1.76×10^2	35.2
$\tilde{t}$	1000	6.4	1.5×10^3