Exotic Long-lived Particles at ATLAS

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Results based on: *Expected Performance of the ATLAS Experiment - Detector, Trigger and Physics*, ATLAS Collaboration: arXiv:0901.0512

SMPs

- SMP
  - exotic heavy particle
  - decaying away from IP
  - metastable
- Host of SUSY scenarios (RPC,RPV)
- Universal extra dimensions
- Leptoquarks…
- Primary aim
  - Inclusive search strategies with well chosen model points
  - Sufficient information to discover and extract quantum numbers of a SMP.

SMP	LSP	Scenario	Conditions
$\tilde{\tau}_1$	$\tilde{\chi}_1^0$	MSSM	$\tilde{\tau}_1$ mass (determined by $m^2_{\tilde{\tau}_{L,R}}$, μ, $\tan\beta$, and A_τ) close to $\tilde{\chi}_1^0$ mass.
	$\tilde{G}$	GMSB	Large N, small M, and/or large $\tan\beta$.
		$\bar{g}$MSB	No detailed phenomenology studies, see [23].
		SUGRA	Supergravity with a gravitino LSP, see [24].
	$\tilde{\tau}_1$	MSSM	Small $m_{\tilde{\tau}_{L,R}}$ and/or large $\tan\beta$ and/or very large A_τ.
		AMSB	Small m_0, large $\tan\beta$.
		$\bar{g}$MSB	Generic in minimal models.
$\tilde{\ell}_{i1}$	$\tilde{G}$	GMSB	$\tilde{\tau}_1$ NLSP (see above). $\tilde{e}_1$ and $\tilde{\mu}_1$ co-NLSP and also SMP for small $\tan\beta$ and μ.
	$\tilde{\tau}_1$	$\bar{g}$MSB	$\tilde{e}_1$ and $\tilde{\mu}_1$ co-LSP and also SMP when stau mixing small.
$\tilde{\chi}_1^+$	$\tilde{\chi}_1^0$	MSSM	$m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} \lesssim m_{\pi^+}$. Very large $M_{1,2} \gtrsim 2$ TeV $\gg \lvert\mu\rvert$ (Higgsino region) or non-universal gaugino masses $M_1 \gtrsim 4M_2$, with the latter condition relaxed to $M_1 \gtrsim M_2$ for $M_2 \ll \lvert\mu\rvert$. Natural in O-II models, where simultaneously also the $\tilde{g}$ can be long-lived near $\delta_{\rm GS} = -3$.
		AMSB	$M_1 > M_2$ natural. m_0 not too small. See MSSM above.
$\tilde{g}$	$\tilde{\chi}_1^0$	MSSM	Very large $m^2_{\tilde{q}} \gg M_3$, e.g. split SUSY.
	$\tilde{G}$	GMSB	SUSY GUT extensions [25–27].
	$\tilde{g}$	MSSM	Very small $M_3 \ll M_{1,2}$, O-II models near $\delta_{\rm GS} = -3$.
		GMSB	SUSY GUT extensions [25–29].
$\tilde{t}_1$	$\tilde{\chi}_1^0$	MSSM	Non-universal squark and gaugino masses. Small $m^2_{\tilde{q}}$ and M_3, small $\tan\beta$, large A_t.
$\tilde{b}_1$			Small $m^2_{\tilde{q}}$ and M_3, large $\tan\beta$ and/or large $A_b \gg A_t$.

Table 1
Brief overview of possible SUSY SMP states considered in the literature. Classified by SMP, LSP, scenario, and typical conditions for this case to materialise in the given scenario. See text for details.

hep-ph/0611040

Classification

Particle	Charge
Slepton, free quark…	electric
Gluino, squark, KK quark….	Colour (triplet, octet), electric
Magnetic monopole	Magnetic

Host of predicted long-lived exotica

+ charge combinations.

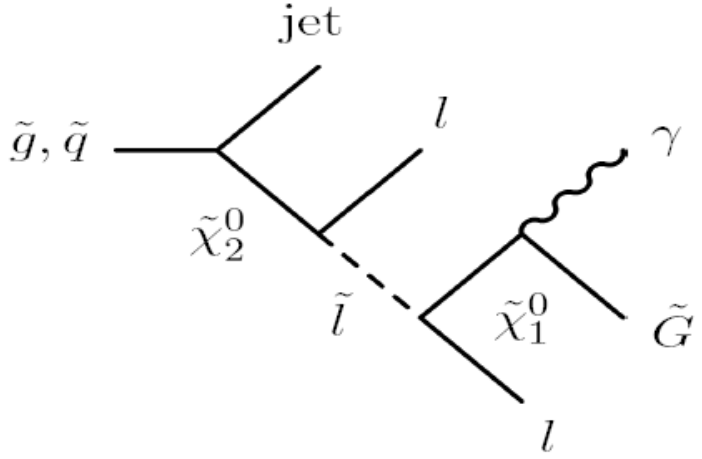
Stable: correct for detector interactions and for late response of propagating particle.

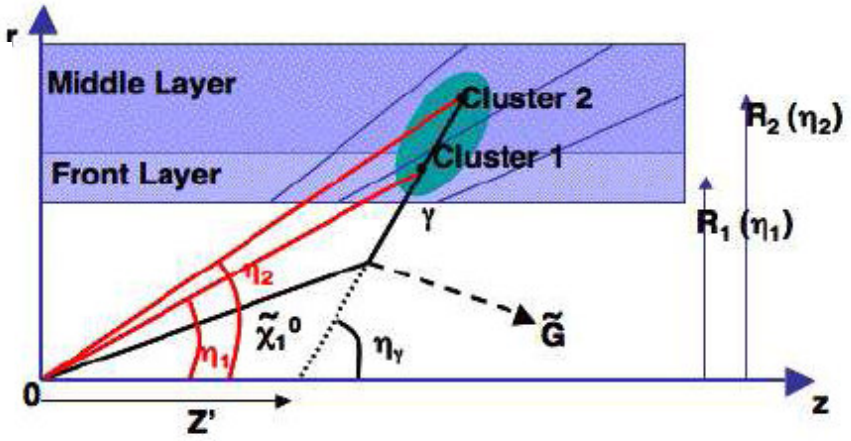
Long-lived but decaying: jet, lepton, photon topologies

Non-pointing photons

GMSB scenarios - neutralino NLSP.

name	NLO (LO) σ [pb]	Λ [TeV]	M_m [TeV]	C_G	$c\tau$ [mm]	$M_{\tilde{\chi}_1^0}$ [GeV]
GMSB1	7.8 (5.1)	90	500	1.0	1.1	118.8
GMSB2	7.8 (5.1)	90	500	30.0	$9.5 \cdot 10^2$	118.8
GMSB3	7.8 (5.1)	90	500	55.0	$3.2 \cdot 10^3$	118.8



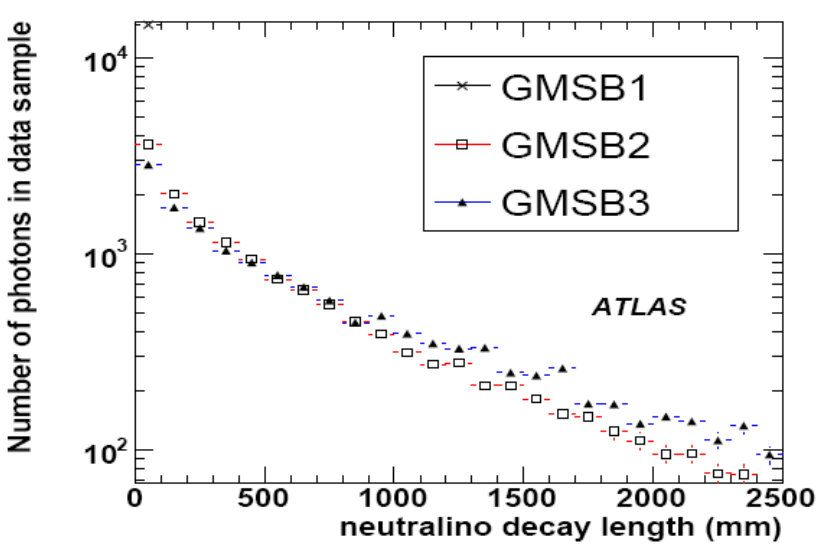


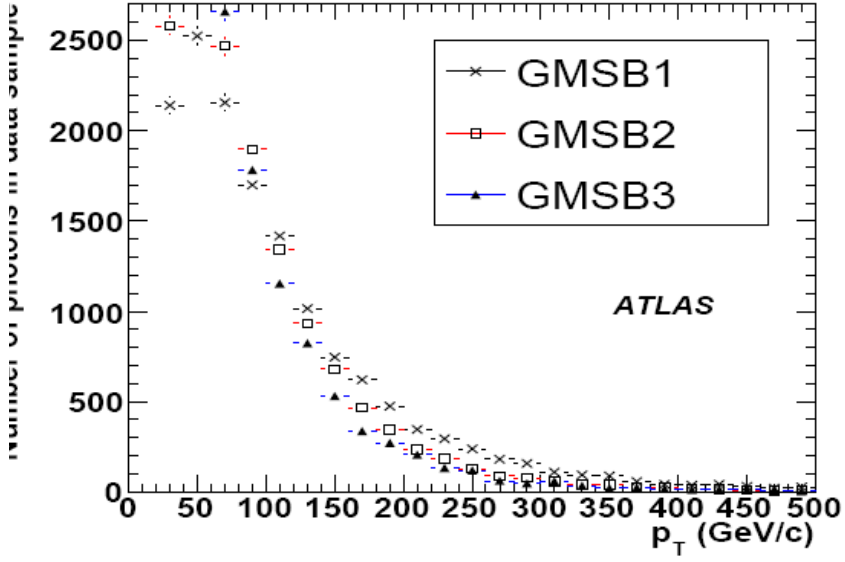
$C_{grav} > 1$

$\Rightarrow$ neutralino decays away from IP.

$\Rightarrow$ non-pointing high p_T photon.

Non-pointing photon distributions





Criteria:

Decay within inner tracking detector

$p_T > 20$ GeV ; $|\eta| < 2.5$

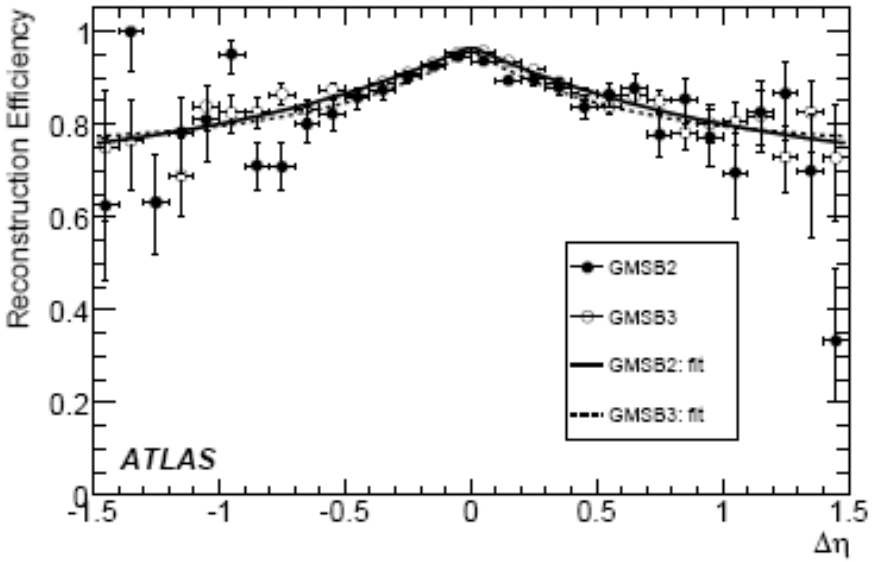
Lepton pairs of opposite and same sign (OSSF).

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

$1fb^{-1}$

Experimental issues

- Reconstruction of non-pointing objects



$\Delta\eta = \eta_{true} - \eta_{rec}$

$> 90\%$ for $|\Delta\eta| \leq 0.25$

Falls to $\sim 75\%$ for $|\Delta\eta| \sim 0.5$

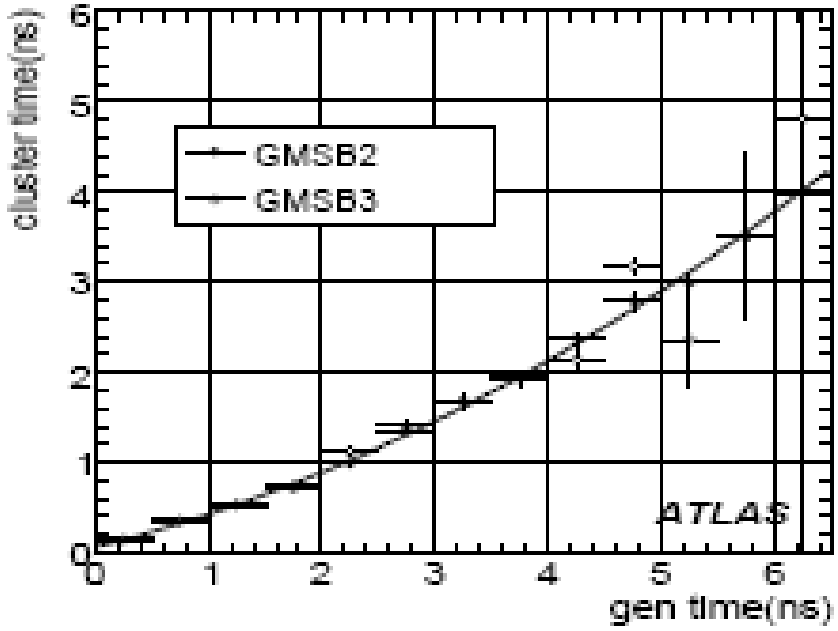
- Standard software provides good reconstruction.

Neutralino lifetime determination

Optimise photon selection.

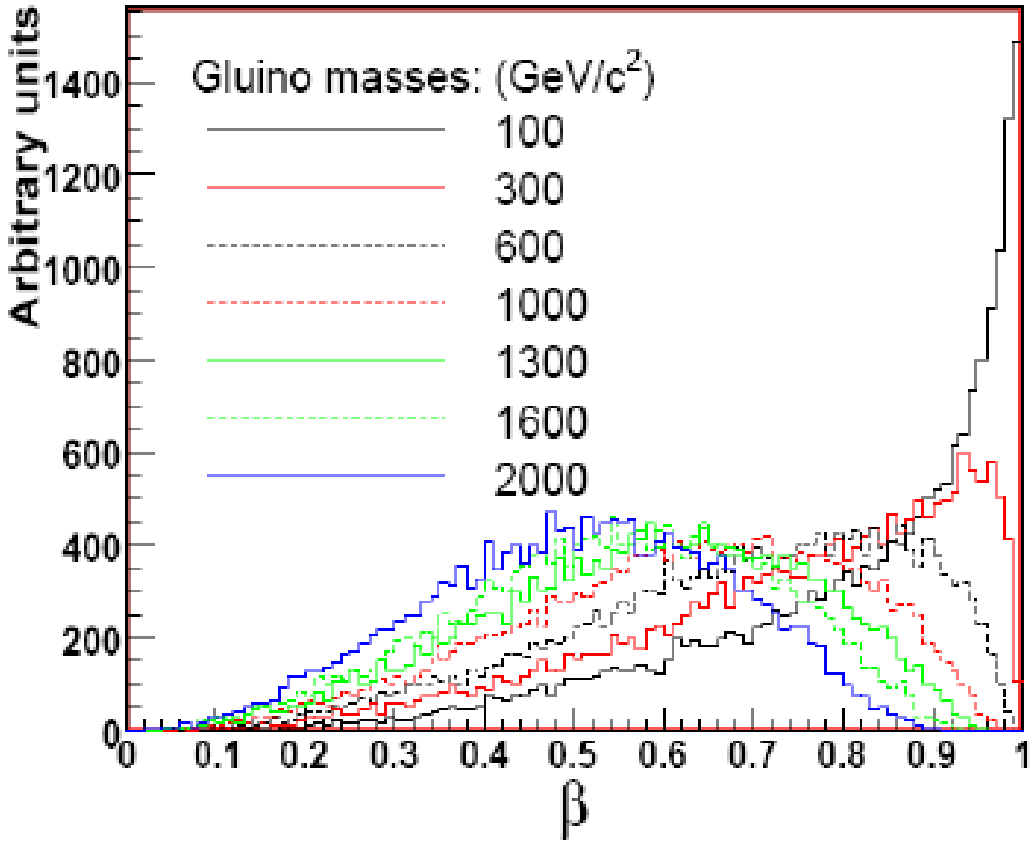
Use calorimeter timing.

Complementary approach to measure extrapolated z-displacement wrt interaction point



Stable Exotic particles

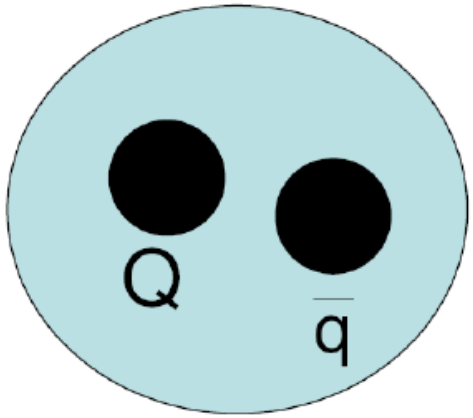
Scenarios, eg Split-SUSY ⟶ stable gluinos.
GMSB⟶ stable stops, sleptons



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

Two major experimental issues: slowness and hadronic scattering

Heavy hadron scattering



Heavy exotic meson from massive exotic colour triplet Q and SM quark $\overline{q}$.

$M_Q \approx M_H = 200$ GeV $\quad E = 1$ TeV

$\Rightarrow \gamma = E/M = 5$

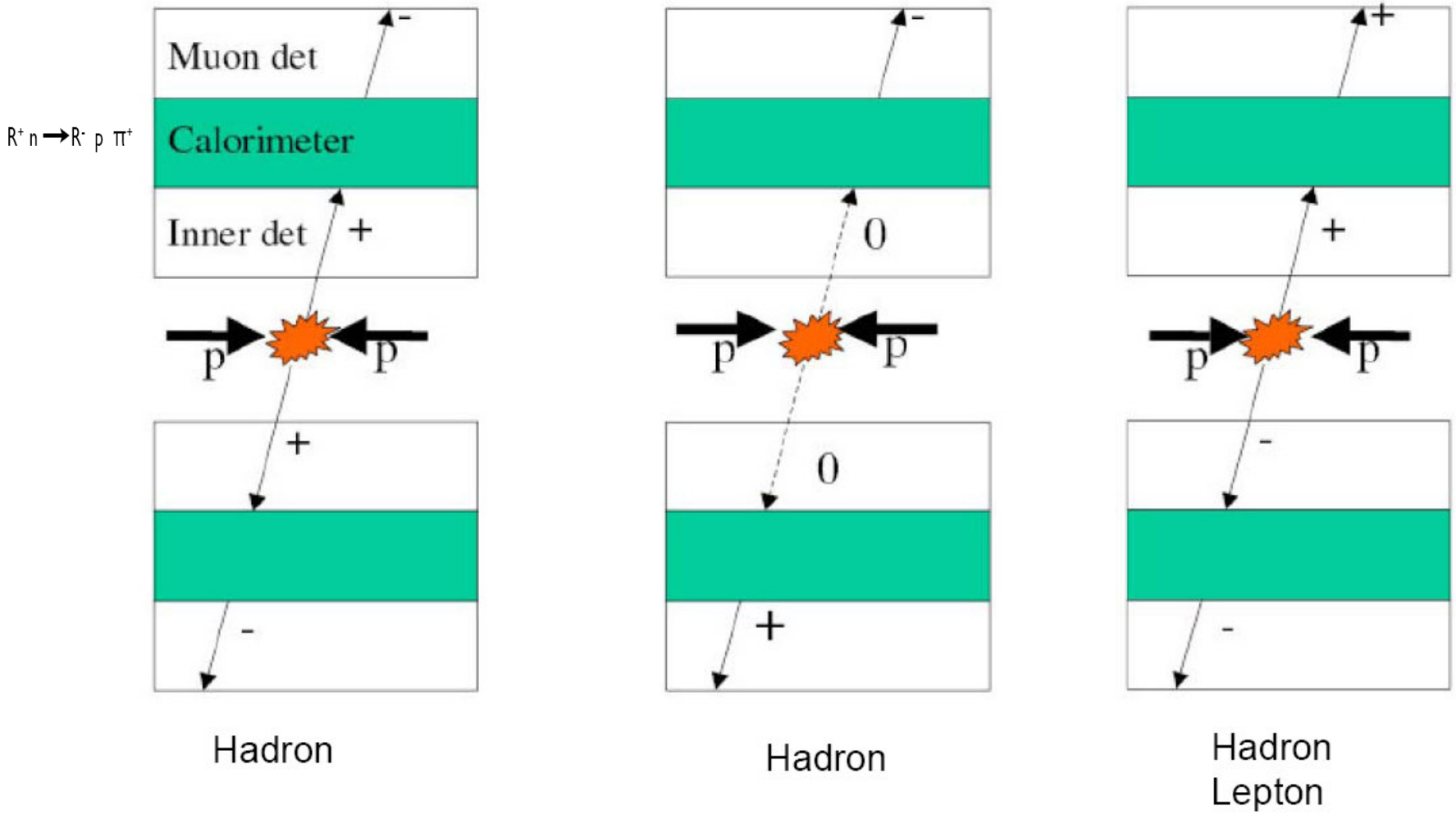
$M_q \approx 0.2$ GeV $\Rightarrow KE_q = (\gamma - 1) M_q \approx$ GeV

Heavy quark doesn't interact

Low energy collision between SM quark in material.

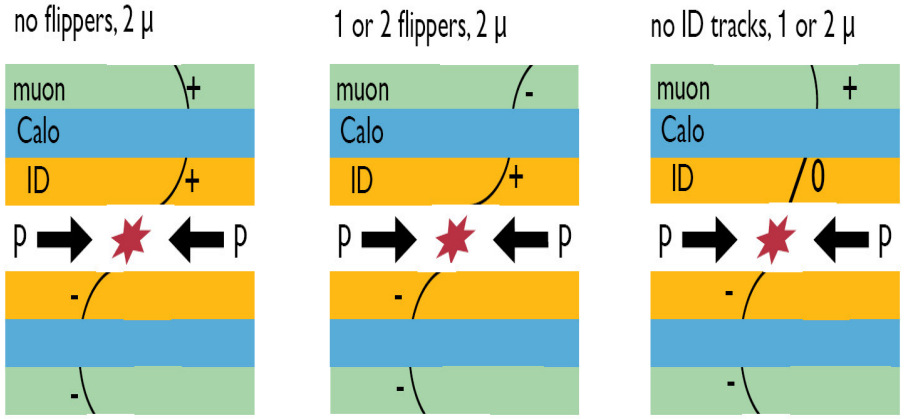
Recent ref: hep-ex/0404001 (A.C. Kraan)

Event topologies for exotic hadrons and leptons

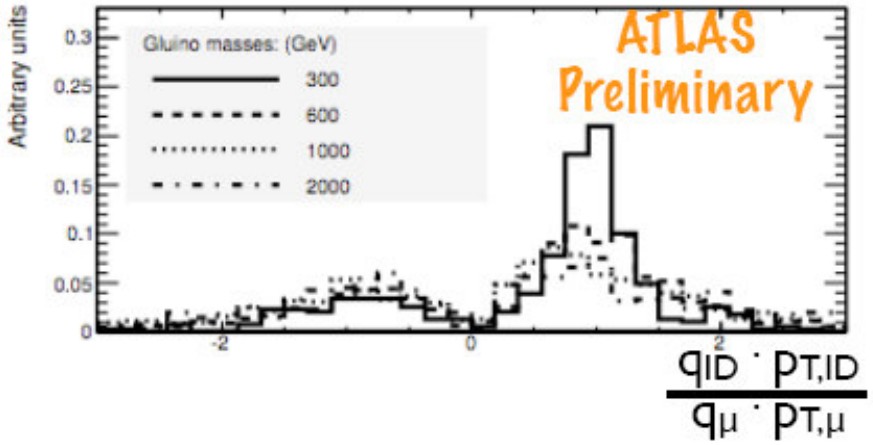


Understanding hadronisation and scattering in material is crucial

R-hadron selections



Cuts
One hard muon track with no inner tracking link.
Two back-to-back ID tracks with TRT hits satisfying high threshold/low threshold < 0.05
Two back-to-back like-sign muons
At least one hard muon track with hard matching inner track with 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

ATLAS preliminary

LHC - ATLAS

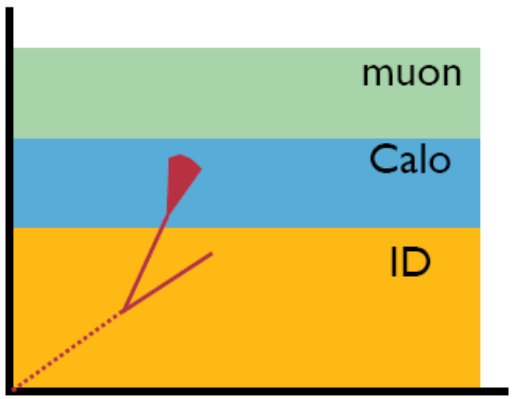
•In ATLAS event fragments from different parts of the detector are assigned to a particular bunch crossing (BC) using the BC Identifier (BCID).

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

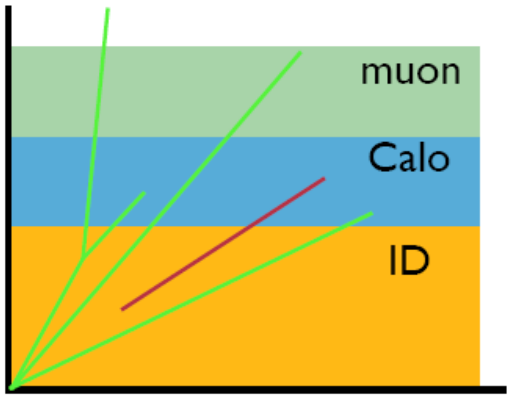
•3 events can co-exist at the same time in the detector.

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

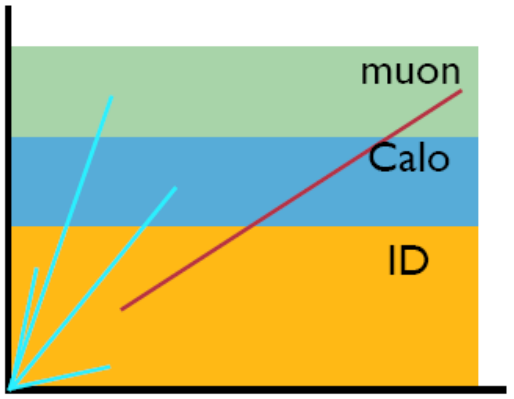
•Hits from a slower particle may be lost or labelled with the wrong BCID.



BCID = 1



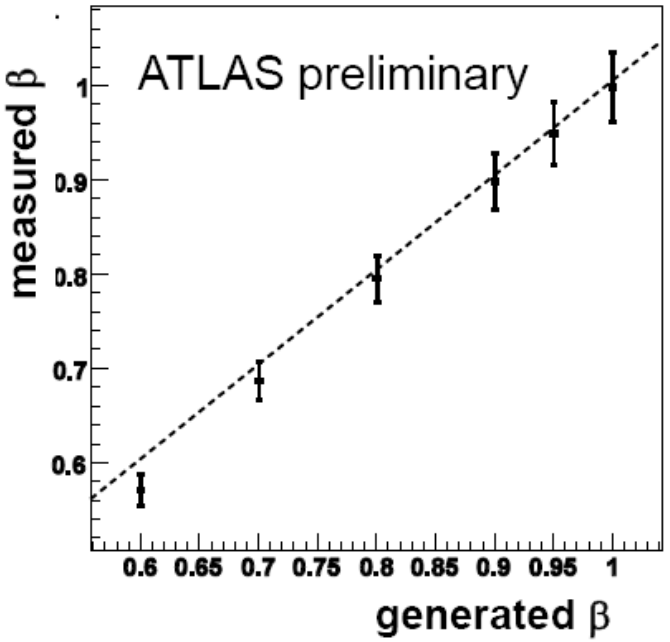
BCID = 2



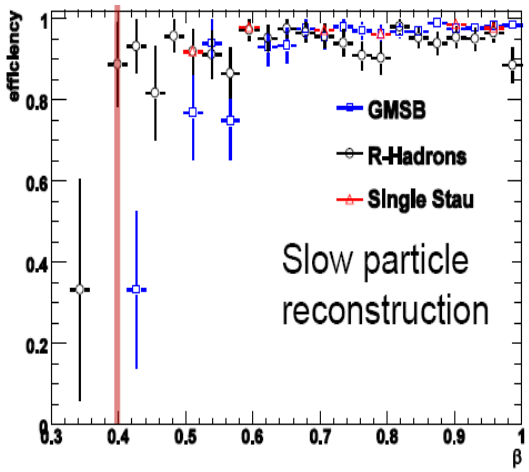
BCID = 3

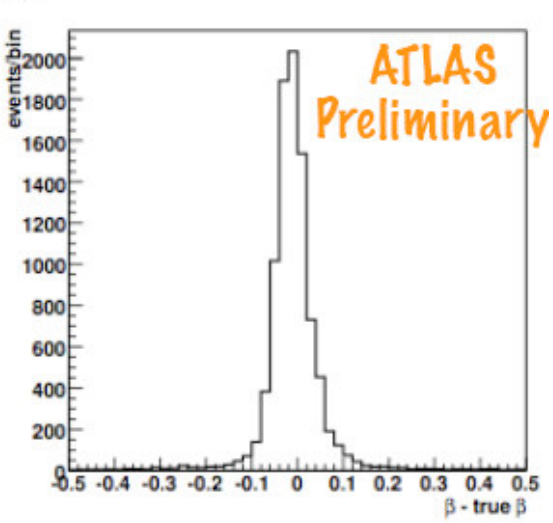
Slow particle selection

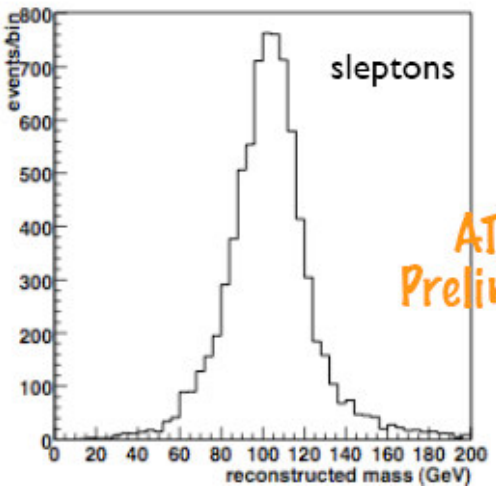
- Added TOF calculation to *L2* muon trigger
- Mass calculation
- Slow particle section based on mass and momentum
- Recover cases where no inner track link present
- Measure speed and mass in special offline reconstruction software

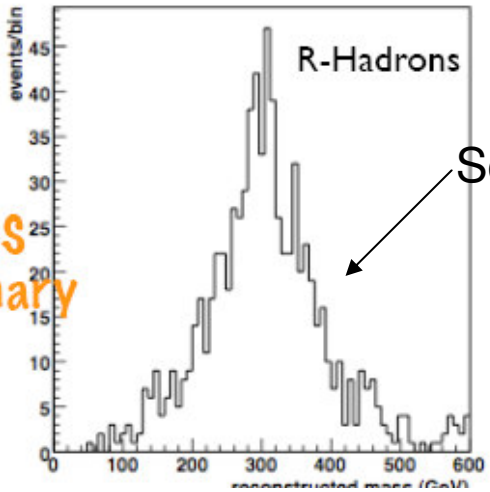


Reconstructing slow particles









ATLAS Preliminary

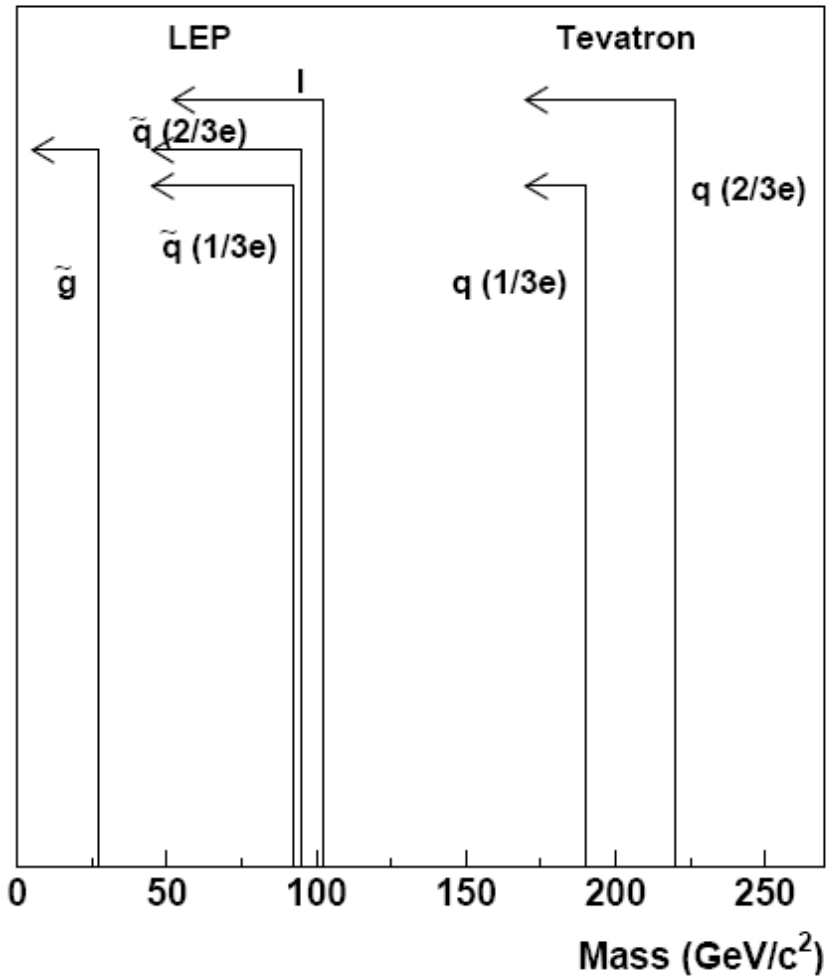
Scattering degradation

arXiv:0901.0512

Summary

- Long-lived exotic particles anticipated in many scenarios of exotic physics
  - Non-pointing photons
  - R-hadrons
  - Sleptons
- Strategy for inclusive searches allowing discovery and identification of exotic particle
- Challenge reconstruction and trigger
- Work shown is a subset of ongoing ATLAS work

Limits on stable particles



- LEP limits tend to use inner tracking info only
- Tevatron assumes a ”heavy muon-like object”
- What is the stable gluino limit ?