Long-lived particle searches in ATLAS

Philippe Mermod (Stockholm University)
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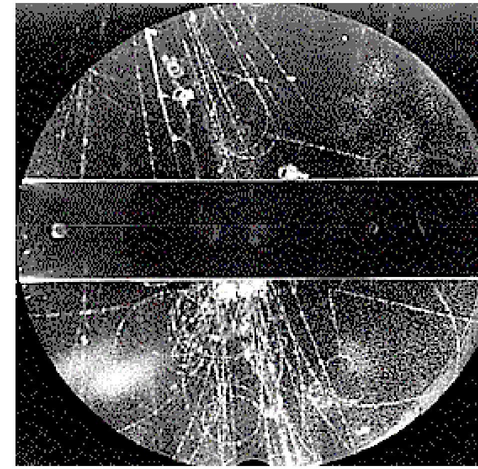
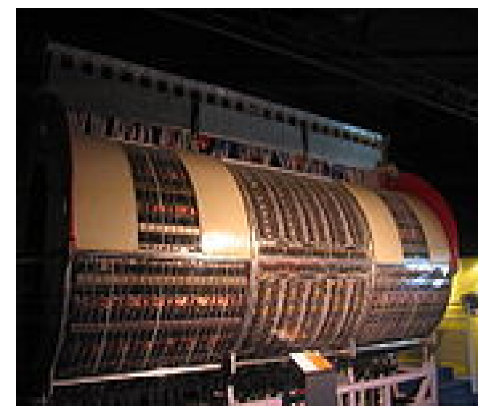
- Why look for them ?
- How to look for them ?
- What's been done ?
- What's being done and what should be done ?

History

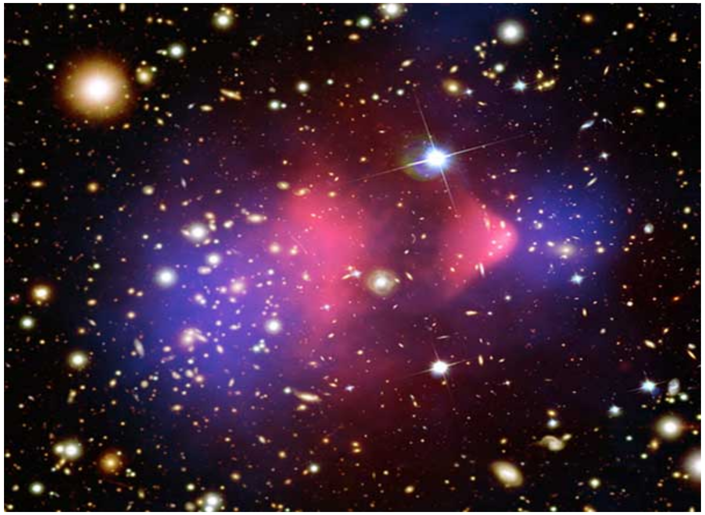
- Discovery of long-lived particles
  - muon, pion, kaon, neutrino... none of them at colliders !
- Collider discoveries
  - tau, heavy quarks, *W* and *Z*... none of them long-lived !
- New particles tend to be heavy and short-lived
  - Why should we look for new long-lived particles at high-energy colliders ?





Long-lived particles at colliders : motivations

- LHC physics
  - New energy regime : large discovery window
  - Standard model incomplete : new phenomena expected
  - Generic signatures : Missing ET, jets, leptons, **long-lived charged particles**



- Dark matter
  - Supposing **long-lived neutral particles** solves the puzzle !

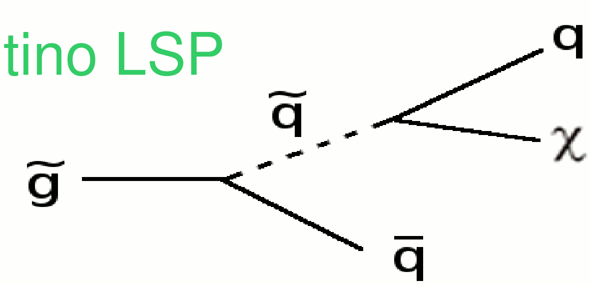
Long-lived particles in SUSY and Extra-dimensions

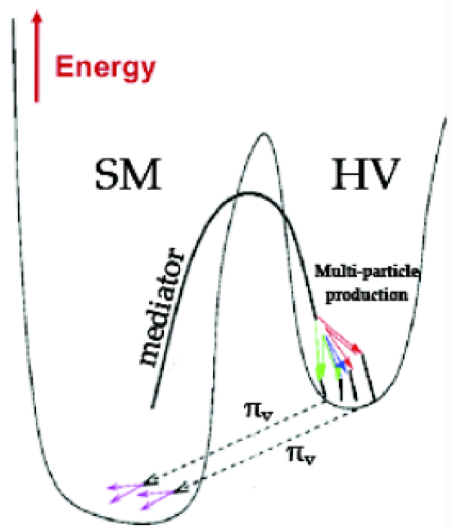
- Extensions of SM
  - Cure hierarchy problem
  - Unification of forces
  - Dark matter candidate
- Frameworks with many models and parameters
  - Dark matter particle → missing energy
  - **Quantify** → measure properties of new charged particles (most are unstable)

- SUSY (R parity) :
  - Stable neutralino or gravitino
  - Long-lived gluino (split-SUSY)
  - Long-lived stop (MSSM)
  - Long-lived stau (GMSB)
  - Long-lived chargino (AMSB)
- UED (KK number) :
  - Stable KK photon or graviton
  - Long-lived KK gluon
  - Long-lived KK quark

Possible mechanisms to suppress heavy decays

- Conservation of a new quantum number
  - R-Parity (SUSY), KK number (UED)
  - Partial conservation : RPV SUSY
- Extra weak coupling to decay products
  - GMSB with gravitino LSP
  - Split-SUSY
  - Leptoquarks
  - Hidden Valley

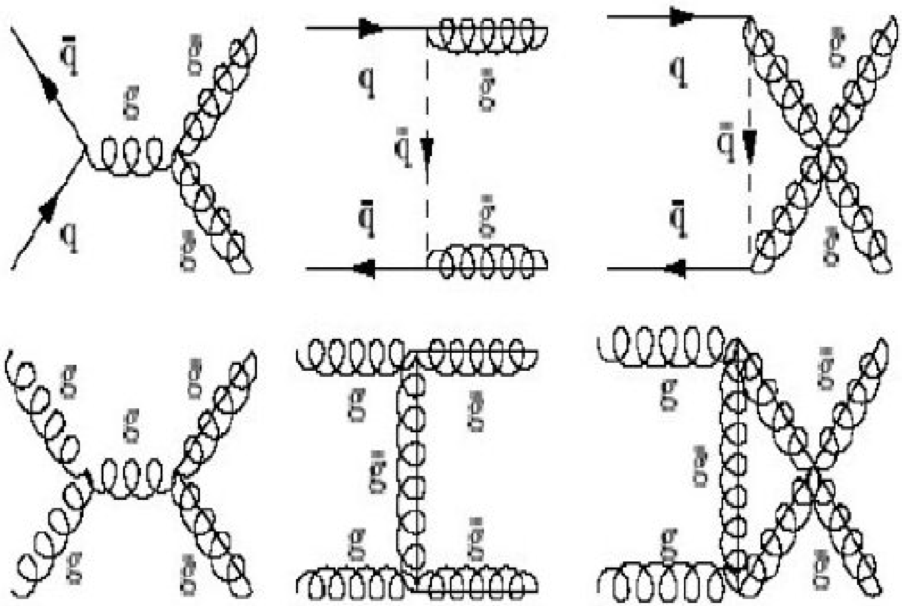


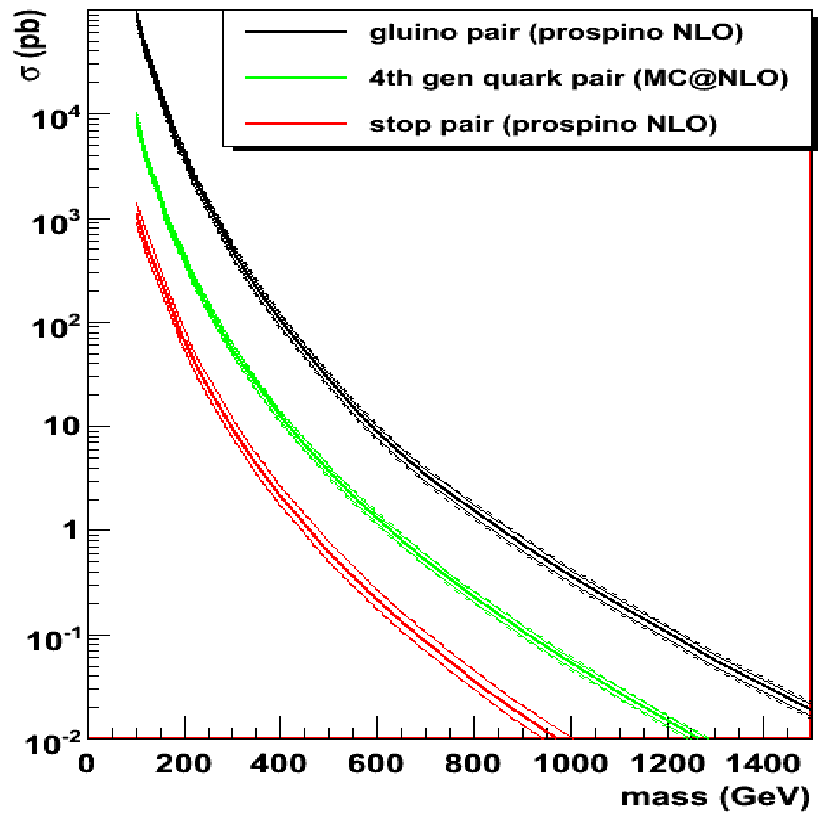


- Small mass difference to decay products
- Charge conservation
  - Exotic fractional charges
  - Magnetic Monopoles

Heavy Coloured objects at the LHC

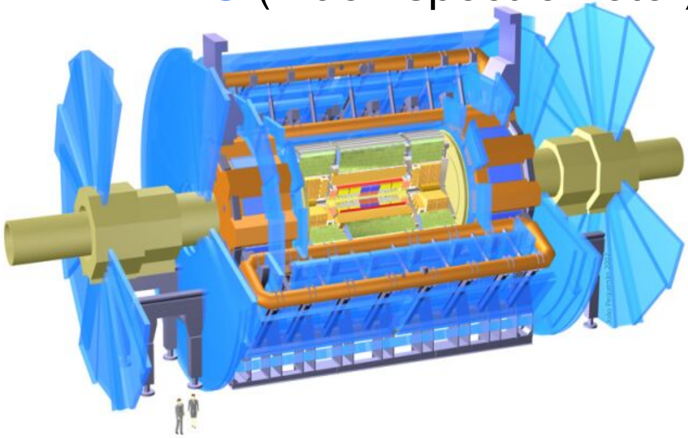
- Strong process, e.g. gluino pair production
  - Large cross section, depends only on gluino mass
  - Central and back-to-back
  - Expect more than 10^5 for mass 300 GeV for one year's running



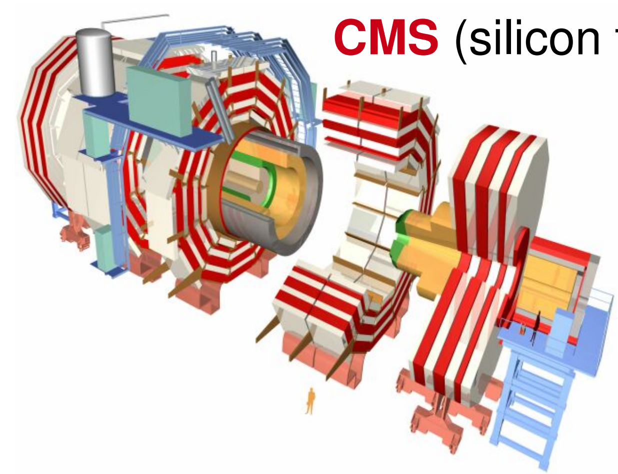


Long-lived particles at the LHC

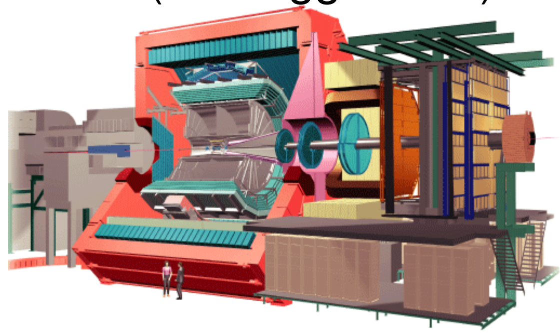
ATLAS (muon spectrometer)



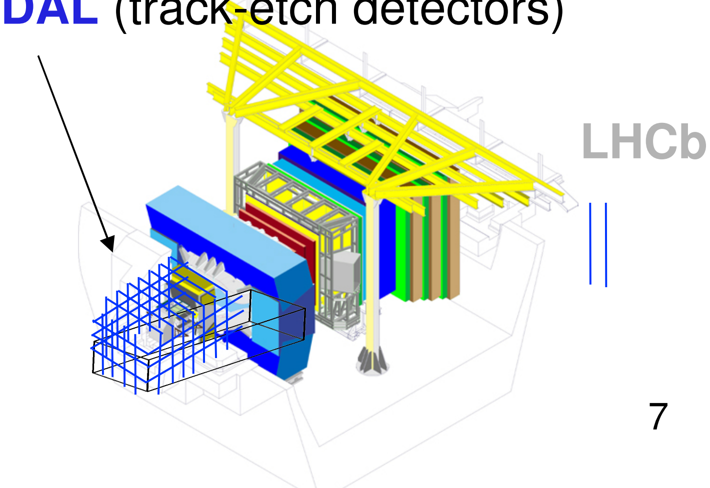
CMS (silicon tracker)



ALICE (low trigger rate)

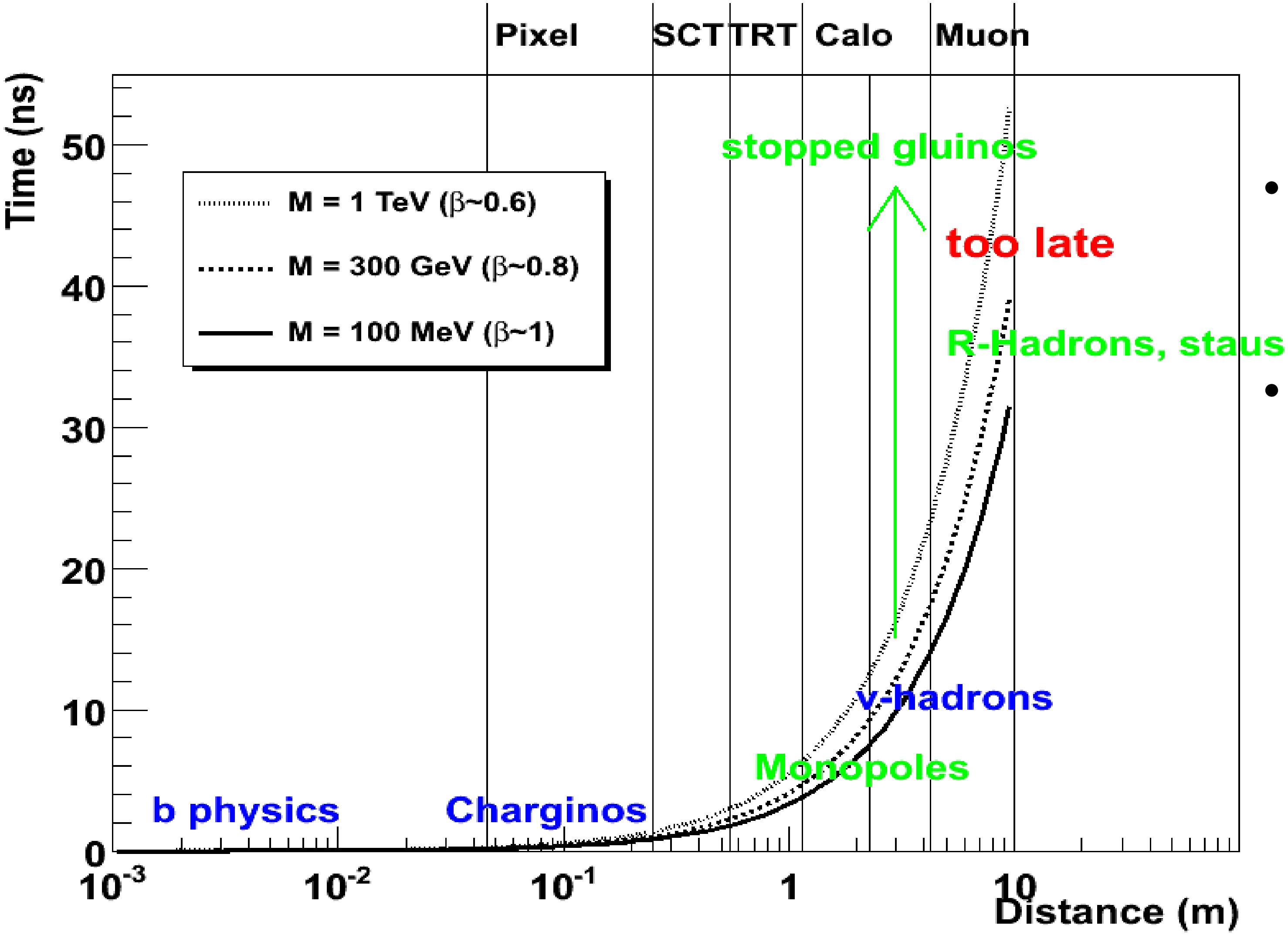


MoEDAL (track-etch detectors)



Long-lived particles in ATLAS

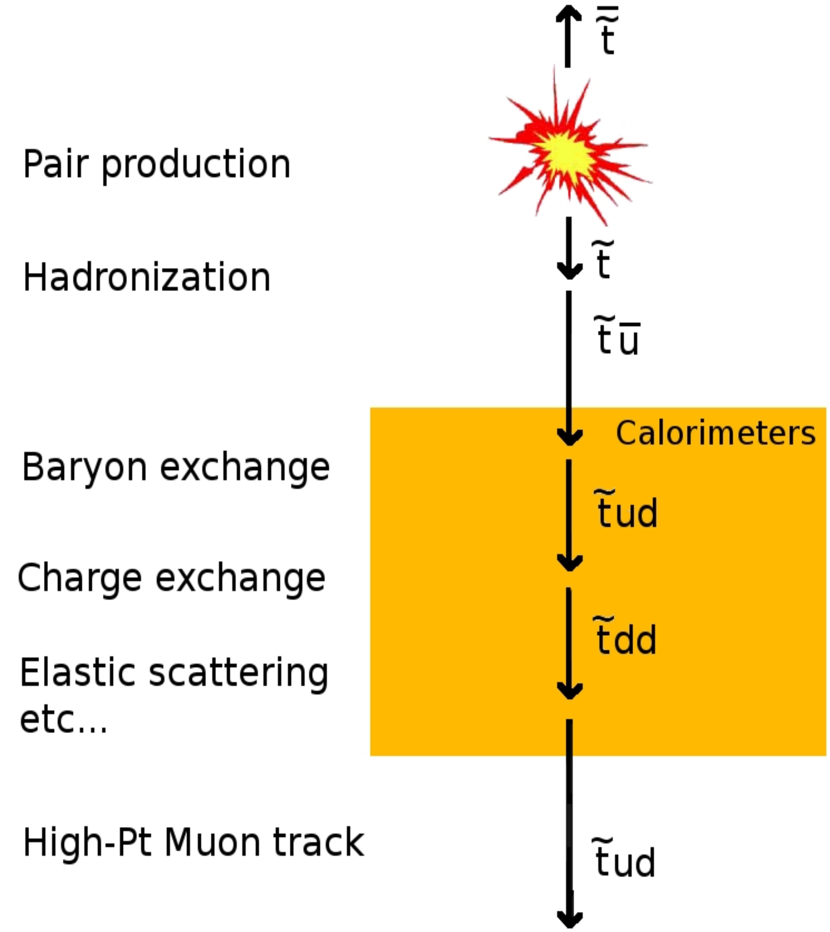
SUSY RPV/LL and Exotics LLP subgroups

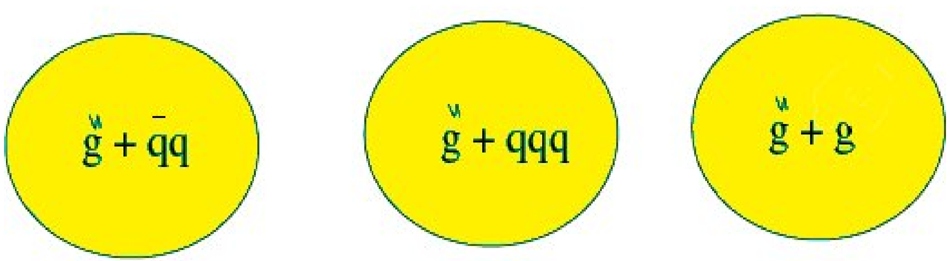


- Two classes: **decaying** and **stable**
- Many signatures are challenges for triggers

Stable Massive Particles

- *Long-lived* > 50 ns (size of ATLAS)
- **Heavy** > 100-200 GeV (LEP and Tevatron limits)
- Charged → H-Lepton
- Coloured → H-Hadron
  - Called **R-Hadron** in SUSY





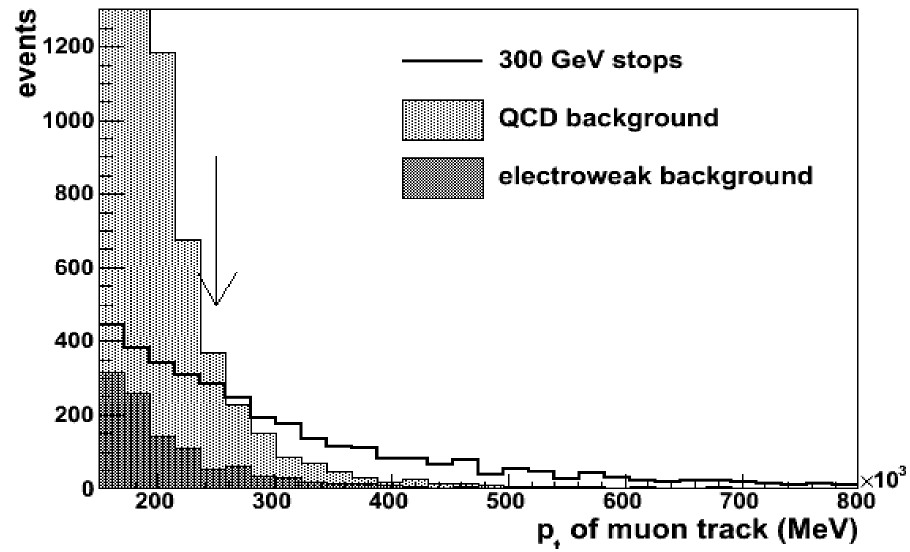
R-meson R-baryon gluino ball

Generic signature : slow-moving and high-pT

R-Hadrons : ATLAS CSC study

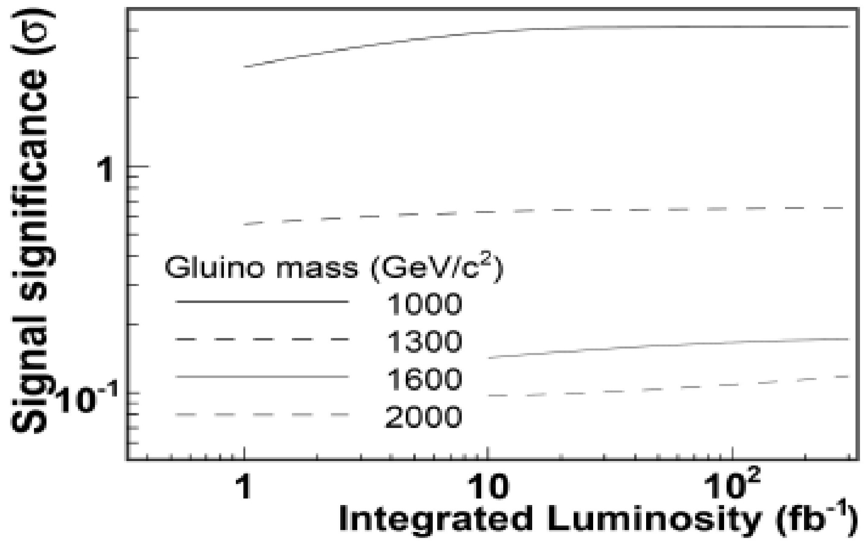
SUSY chapter in CERN-OPEN-2008-020 (arXiv:0901.0512)

- Targets : metastable gluinos and stops
- Selection : jet veto + one of the following criteria
  - Hard (p_T>250 GeV) muon track lacking ID track
  - Two hard back-to-back ID tracks with large ionization
  - Two hard back-to-back like-sign muon tracks
  - One hard muon track with ID track of opposite charge



Sample	Mass [GeV]	Event Rate / fb^{-1}
$\tilde{g}$	300	6400
	600	270
	1000	11
$\tilde{t}_1$	300	70
	600	4
BG	QCD di-jet	0.9
	$Z\to\mu\mu$	0.8

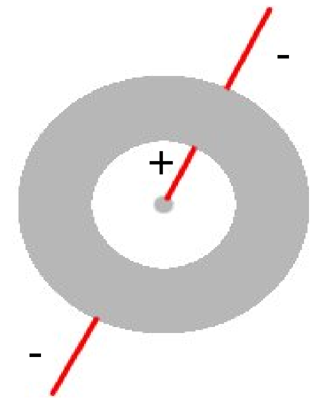
R-Hadrons CSC study : conclusions



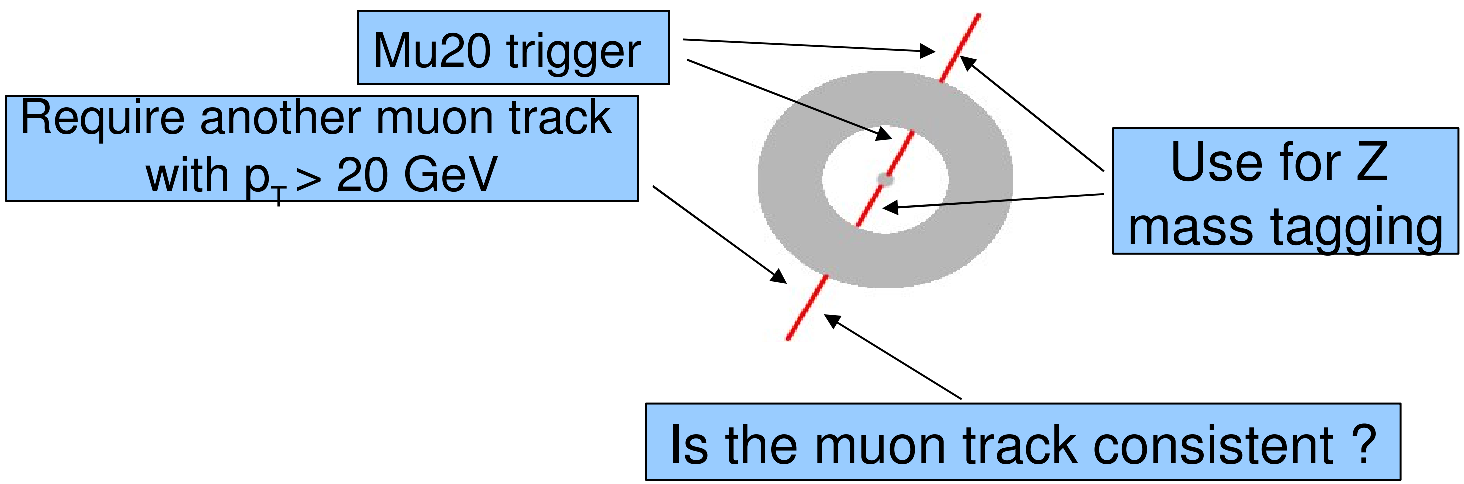
- Possible early discovery
  - 300 GeV stops
  - 600 GeV gluinos
- Limitations of the study :
  - TOF not used
  - Instrumental effects not taken into account (next slide)
  - Reconstruction efficiency not well understood
  - Model dependences
    - Fraction of charged R-hadrons
    - Scattering in material

Instrumental backgrounds

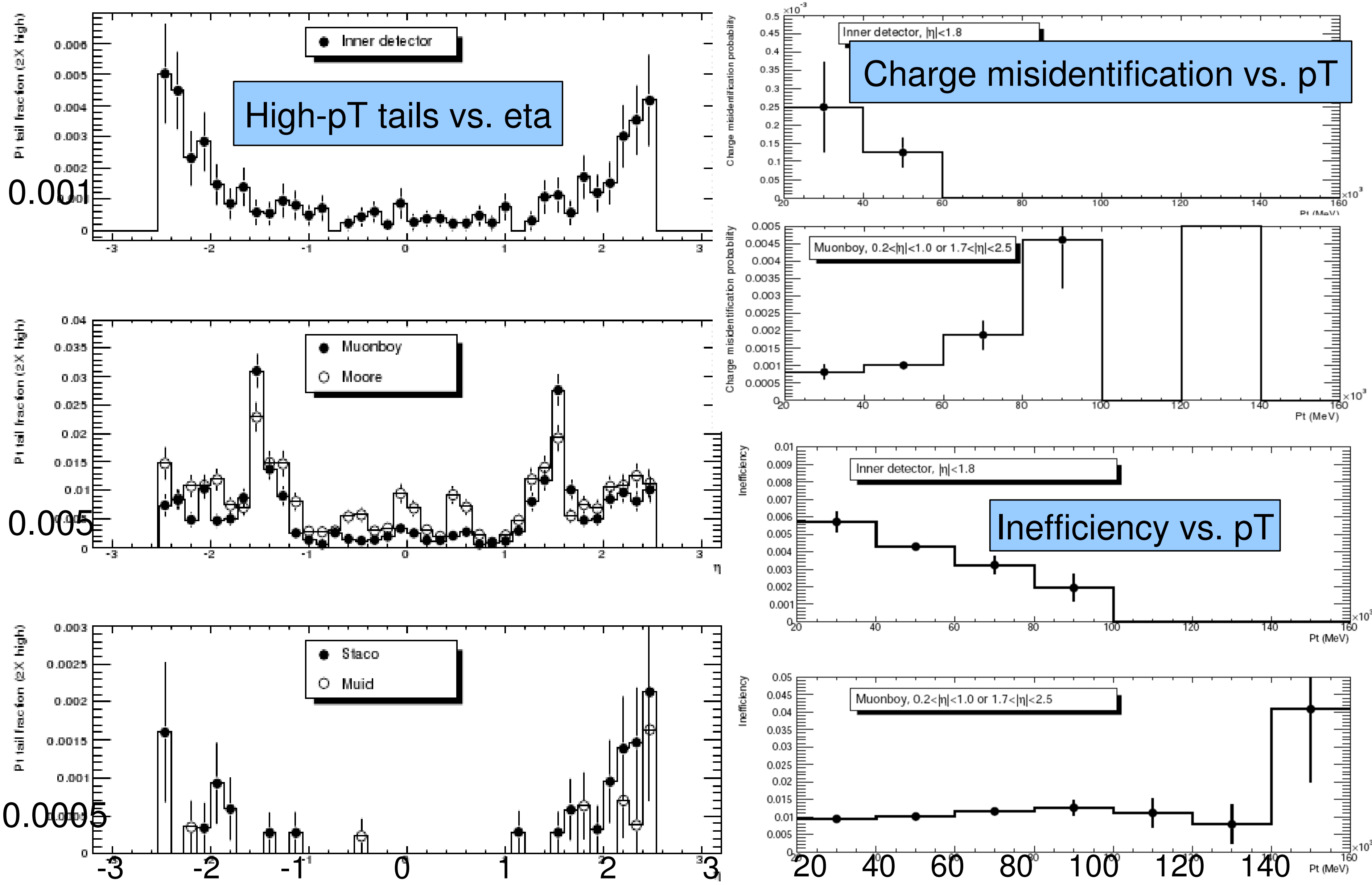
ATL-PHYS-INT-2008-040



- Use Z→μμ *tag-and-probe*
  - High-p_T tail fractions
  - Charge misidentification probability
  - Standalone track reconstruction efficiency
- *In situ* determination of both ID and muon system performances at high p_T



Data-driven method for muon performance
(Z→μμ, 250 pb^{-1})



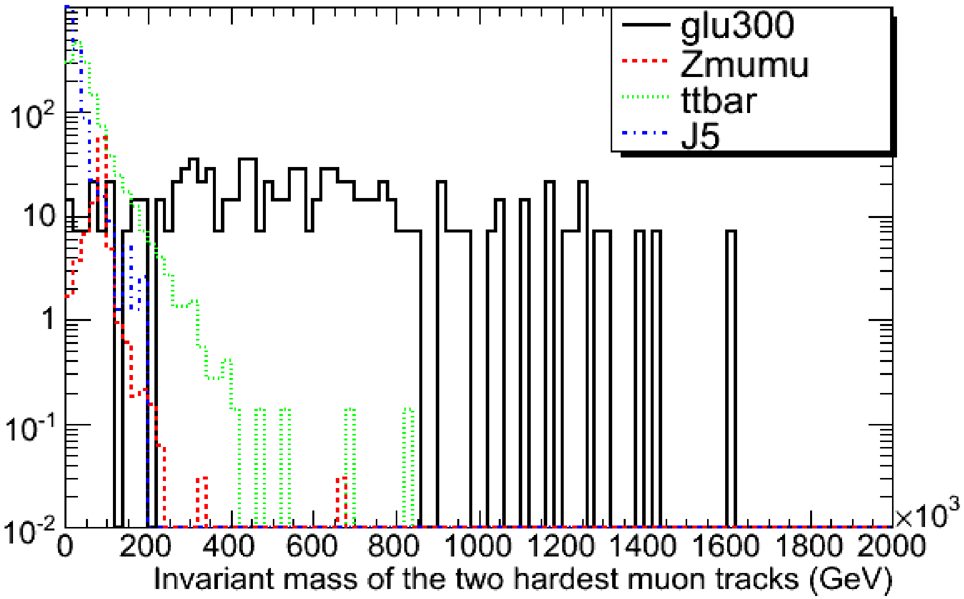
Early-data analysis

- For early data we want :
  - Data-driven control over instrumental effects
  - Generic search
- Muon-based analysis : (next slides)
  - Mu40 and stau triggers
  - Signature : two high-p_T muon tracks back-to-back
  - TOF from RPCs and MDTs
- Backgrounds :
  - QCD, ttbar, $Z \rightarrow \mu\mu$, cosmics, muon tails

- Idea :
  - Use only basic selection cuts
  - Independent analyses which can be cross-checked
- ID+Calo-based analysis : (just started)
  - J120 and J70_XE30 triggers
  - Signature : two high-p_T ID tracks back-to-back lacking high-energy associated jets
  - TOF from TileCal
  - Ionization energy loss in TRT

Muon-based analysis

1269 simulated gluino events M=300 GeV @ 10 TeV,



Two hard Muonboy tracks back-to-back

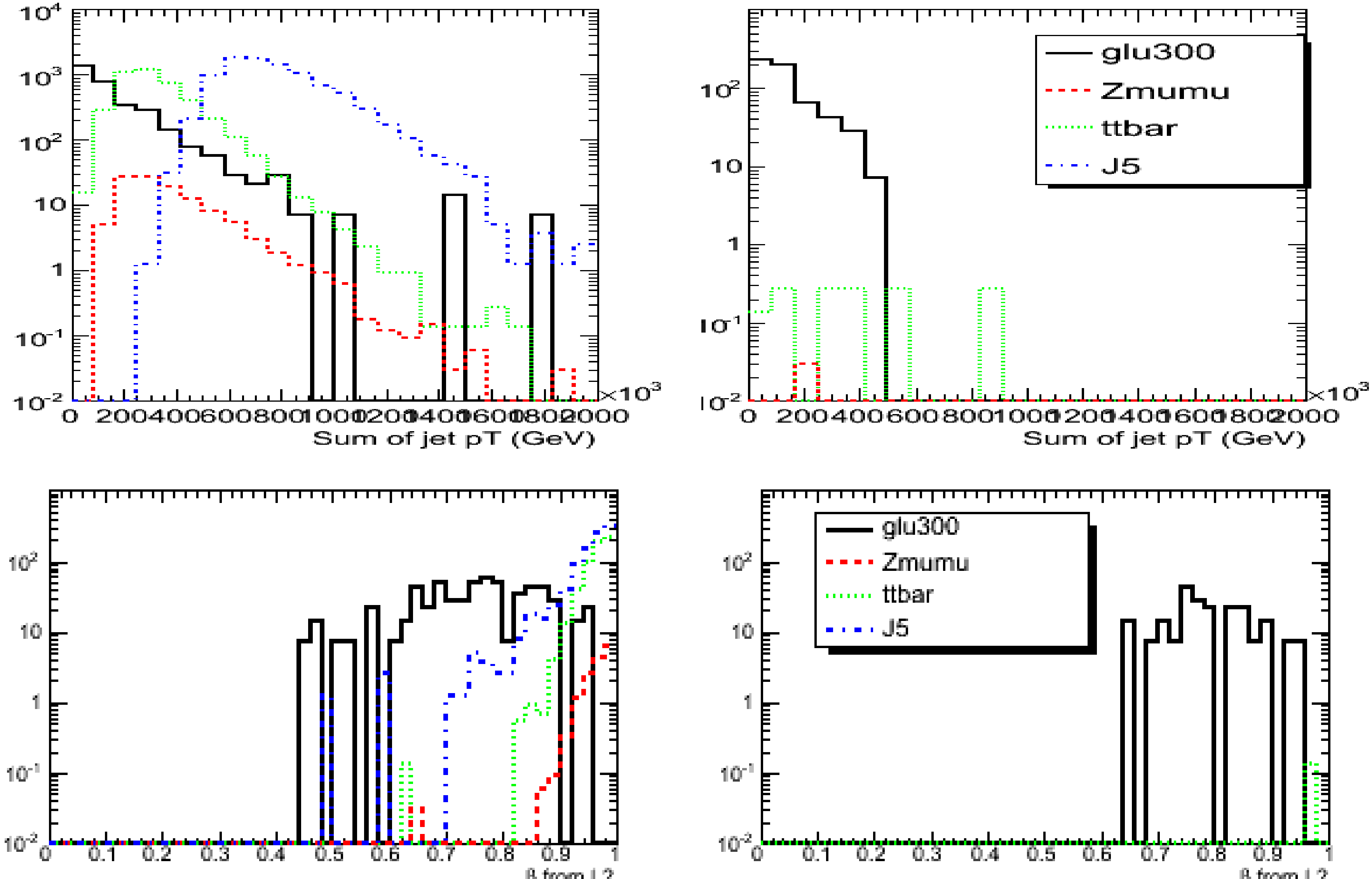
- $p_{T,1} > 200$ GeV
- $p_{T,2} > 100$ GeV
- $\cos(\Delta\Phi) < -0.5$
- $M_{\mu\mu} > 300$ GeV
- $|\eta| < 2.5$

expected rates with 0.1 fb^{-1}

(0.1fb-1)	no trigger	stau chain
glu300	750	510
Zmumu	0.03	0
ttbar	0.2	0.1
J5	0-1	0-1

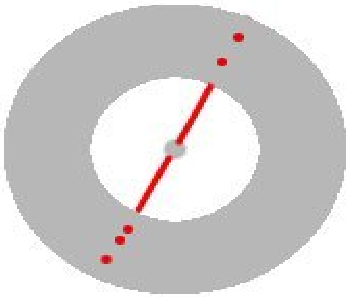
Muon-based analysis : jet activity and β

(left = before, right = after event selection)



Why we need a calo-based analysis

- Unknown systematics
  - Slow-moving particle and hadronic interactions can degrade muon-like signal : difficult to estimate
  - Muon timing performance



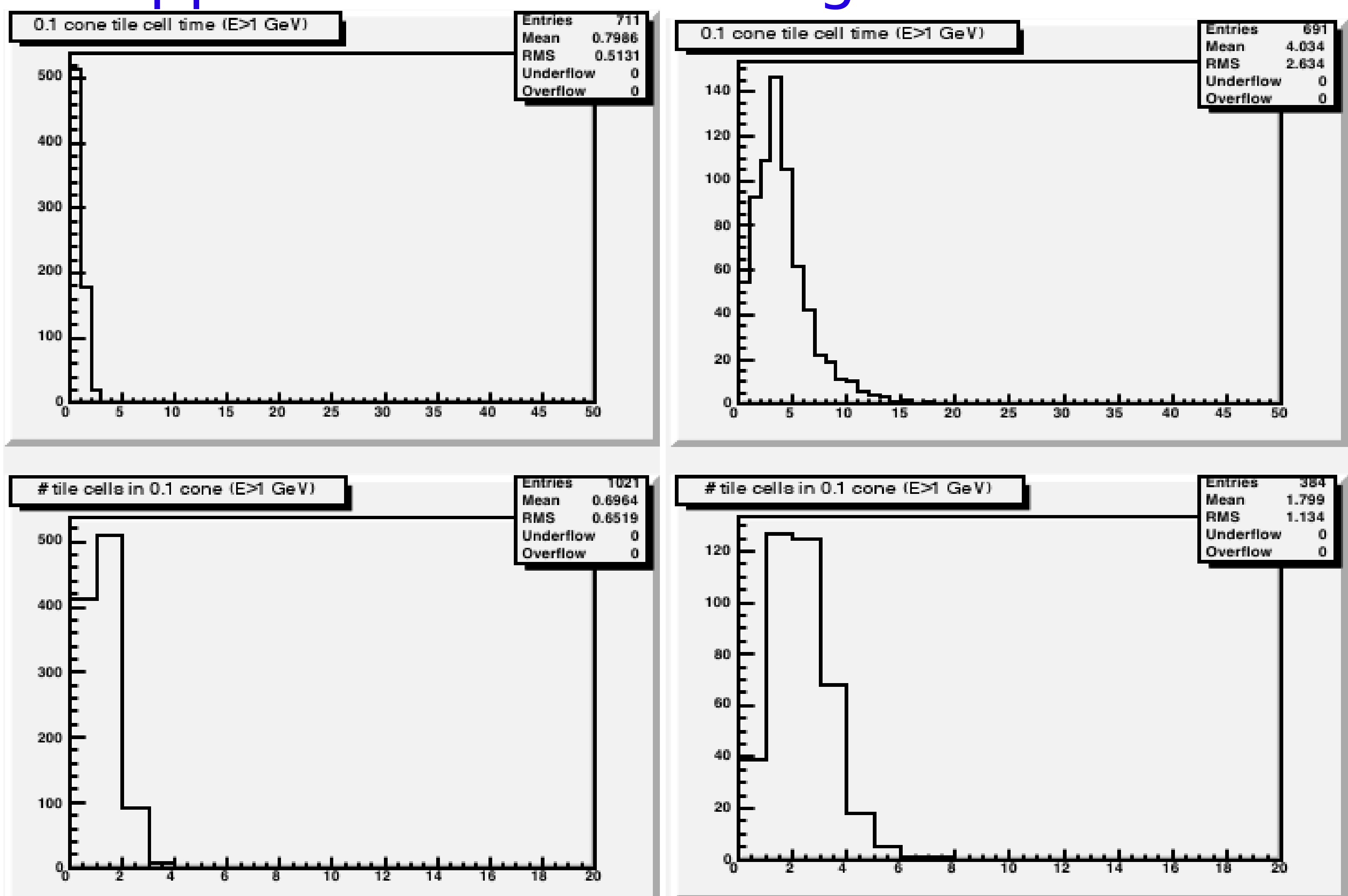
- H-Hadrons which turn neutral
  - D type neutral in muon system
- **Possible solution :** complementary calorimeter-based search
  - Efficiency studies (cross-check muon and non-muon based) assuming a signal
  - Low-β accessible
  - Timing from TileCal
  - Energy loss in ID
  - Sensitive to all long-lived charged particle types
  - More difficult background rejection → high-p_T isolated ID tracks

Calo-based analysis ingredient : TileCal cells

(here with E > 1 GeV in cone around muon track)

Z→μμ glu300

- Cell time
- #cells



Summary

- Many models of new physics predict new long-lived particles
- ATLAS searches cover a range of signatures
- Search strategies with early data have to address detector performance issues
  - Simplicity
  - Redundancy
  - Data-driven background estimations

Outlook

- Collision data are expected for this summer !
- Heavy long-lived coloured particles are expected to be produced copiously at the LHC
  - Early discovery possible !
- Muon-based search looks promising
  - High-p_T muons will be studied via the Z resonance
- Calorimeter-based search needs to be defined in more details
- Ultimately, full analysis using all available information
  - Topological signatures
  - Charge and type, model discrimination

Extra slides

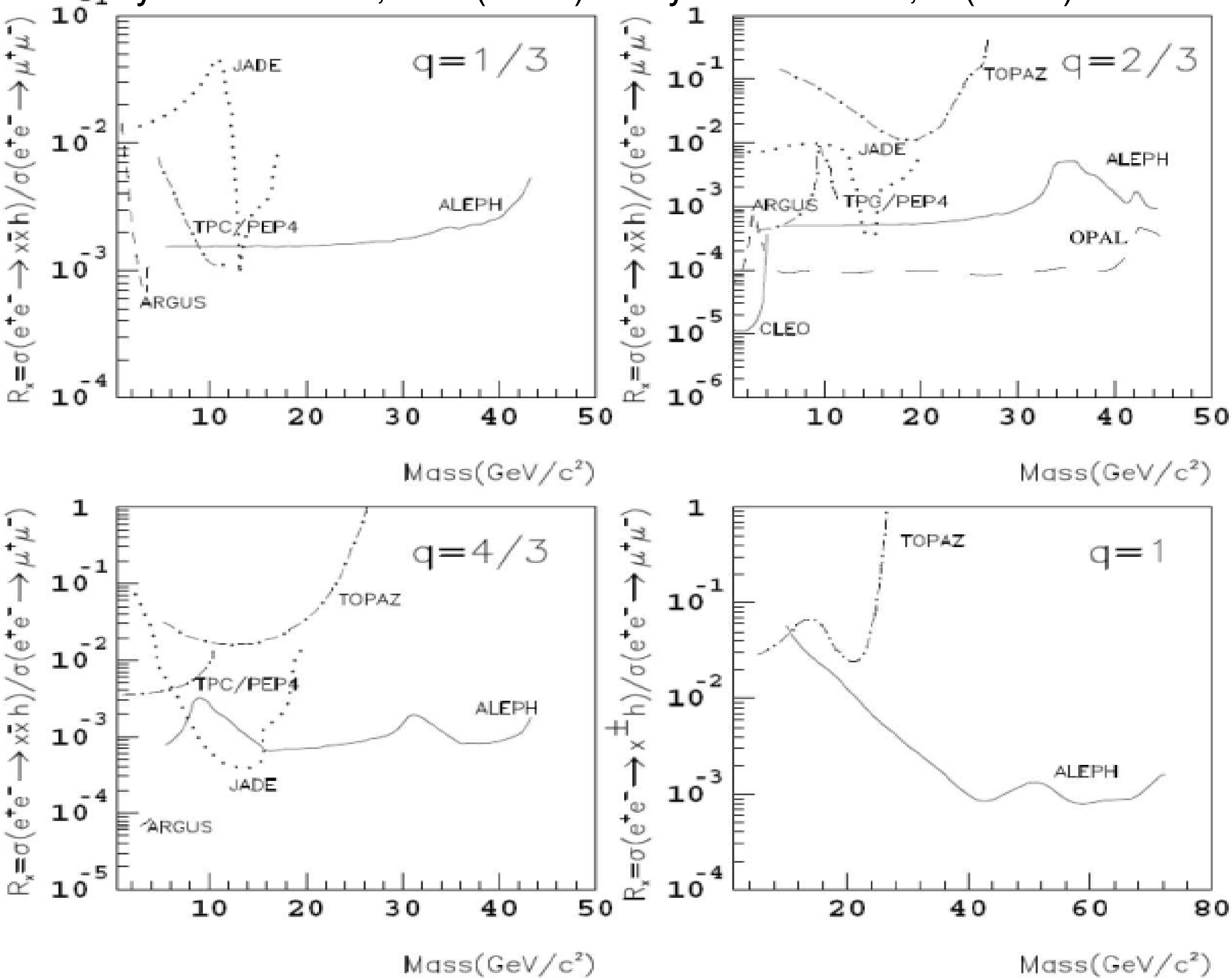
Stable massive particles : classification and scattering

- Classify according to charge : electric, colour, magnetic, and combinations thereof
- Detector interactions determine the signature

Long-lived particle	charge	scattering
lepton, free quark	electric	ionization
colour triplet, octet	colour	hadronic scattering
Dirac monopole	magnetic	large ionization

Free quarks / fractional charge objects

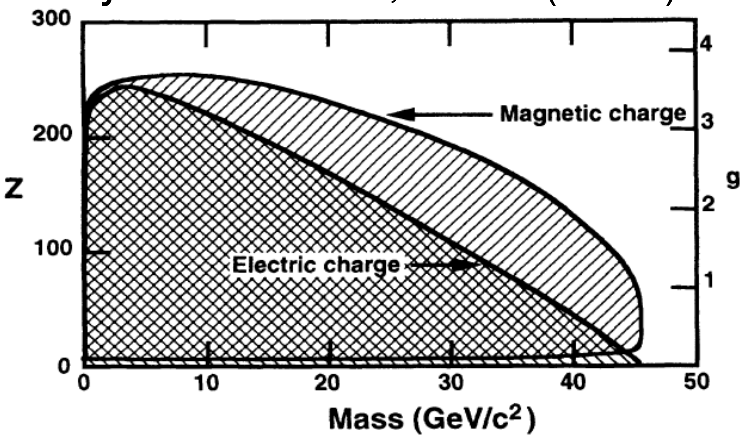
Phys. Lett. B303, 198 (1993) / Phys. Lett. B572, 8 (2003)



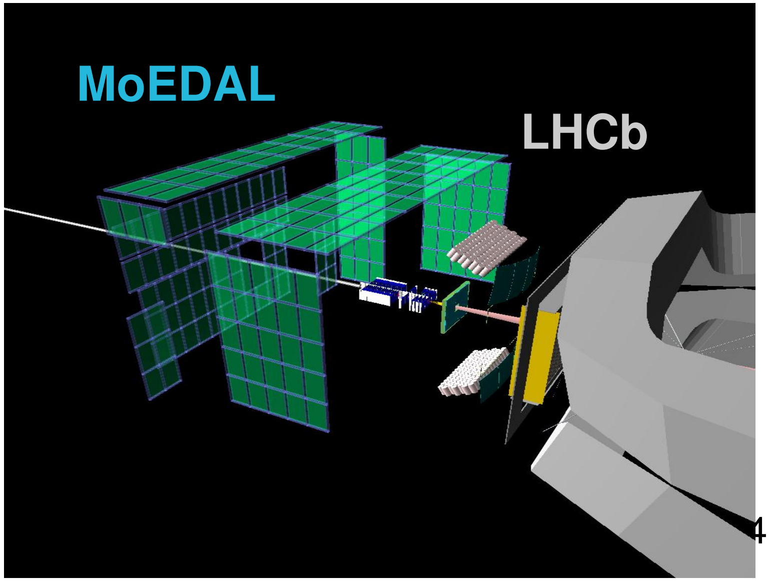
Magnetic Monopoles at colliders

- The existence of a magnetic charge would account for charge quantization ! (Dirac)
- Pair-produced, stable and highly ionizing
- MODAL (LEP)
  - Plastic track-etch detectors

Phys. Rev. D 46, R881 (1992)

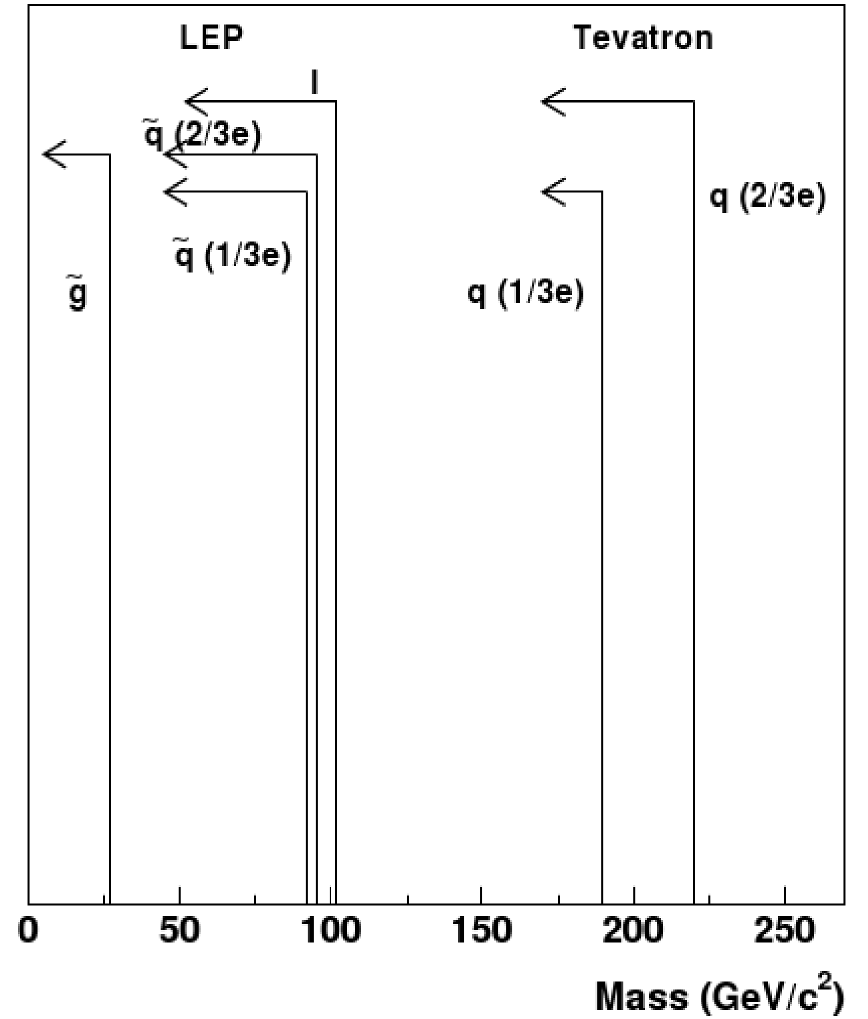


- MoEDAL (LHC)
  - Same principle
  - At Point 8
  - Run in 2010

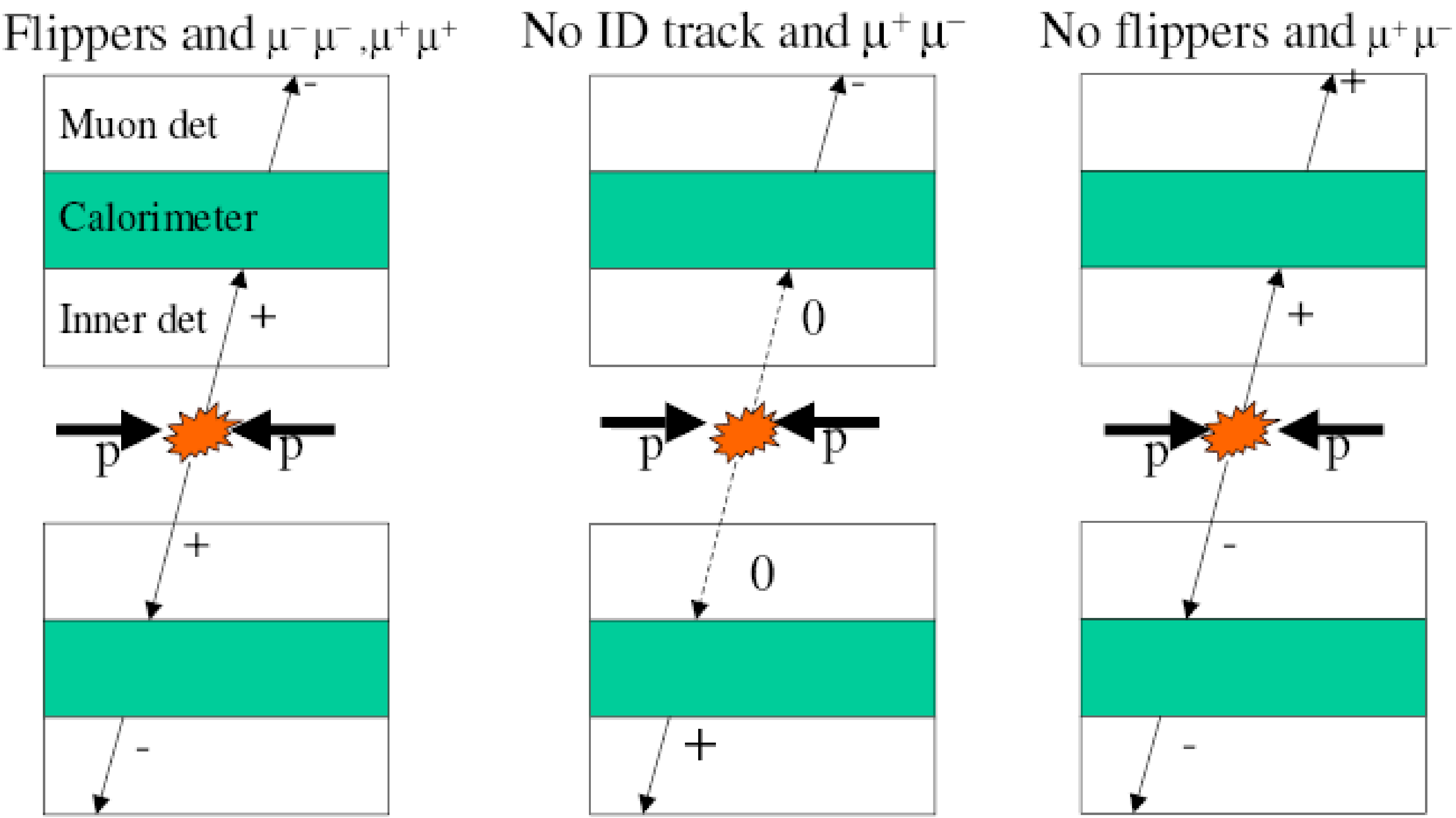


- **Leptons, gluons and U type objects**
  - Published ATLAS studies
- **D type objects**
  - New models (arXiv:0710.3930) suggest stable hadron neutral in muon system !
- **Objects with exotic charges**
  Q = 1/3, 1/2, 2/3, 4/3, 3/2, 2
  - Reconstruction efficiency issues
  - Are ATLAS searches sensitive to them ?
  - Possible signature : p/ΔE

Phys. Rept. 438, 1 (2007)

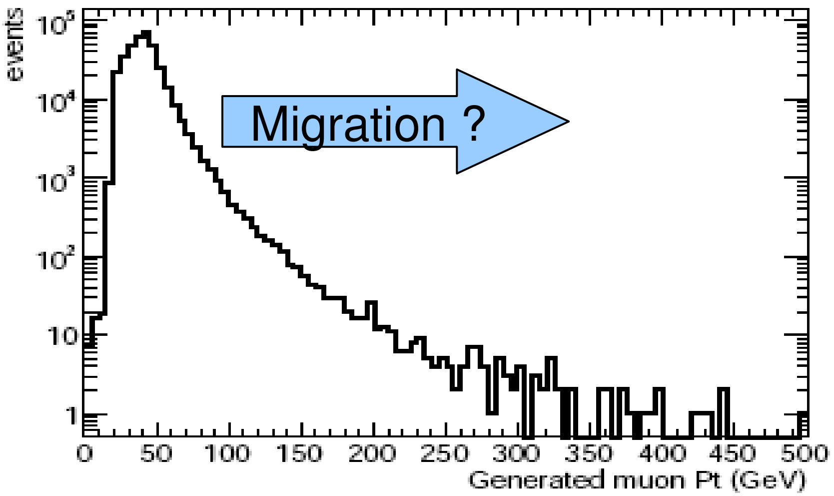


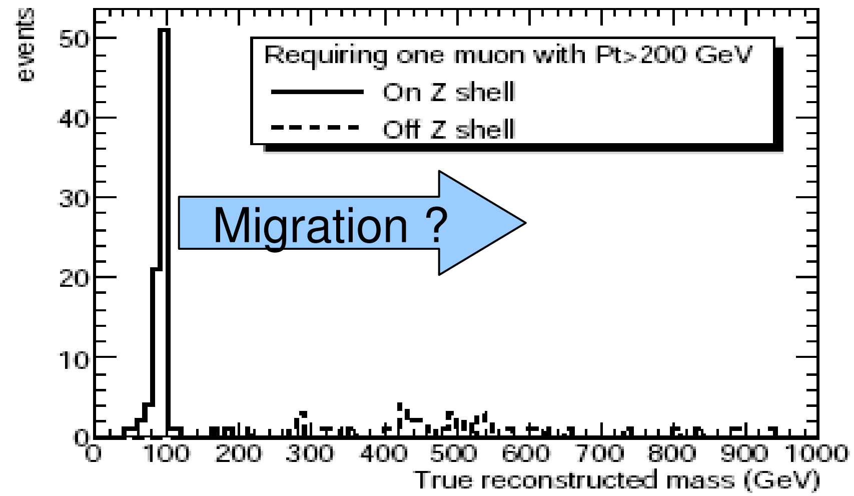
R-Hadron topological signatures

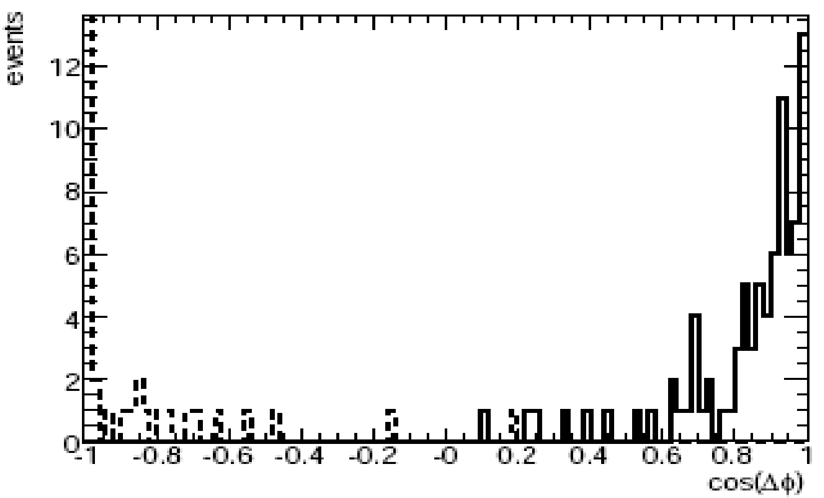


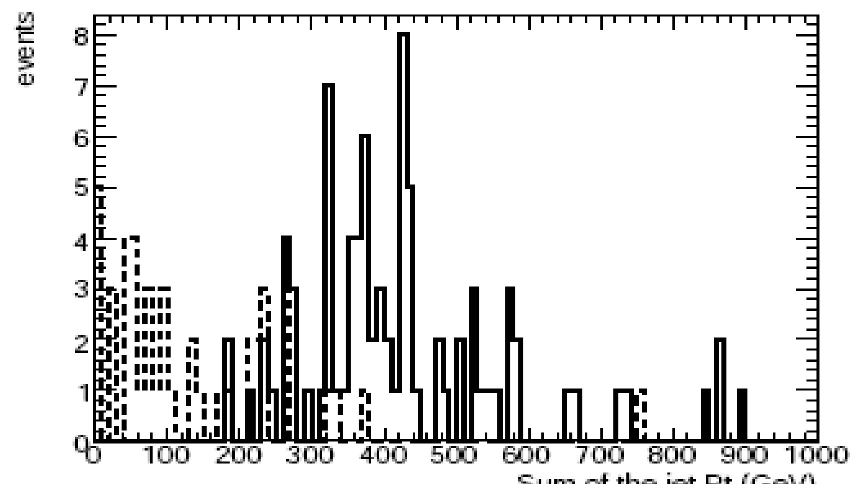
Flippers and $\mu^-\mu^-,\mu^+\mu^+$		No ID track and $\mu^+\mu^-$		No flippers and $\mu^+\mu^-$	
gluino-gluino	✓	gluino-gluino	✓	gluino-gluino	✓
stop-antistop	✗	stop-antistop	✓	stop-antistop	✓
stau-antistau	✗	stau-antistau	✗	stau-antistau	✓

Drell-Yan as both a physics background and a way to extract instrumental backgrounds





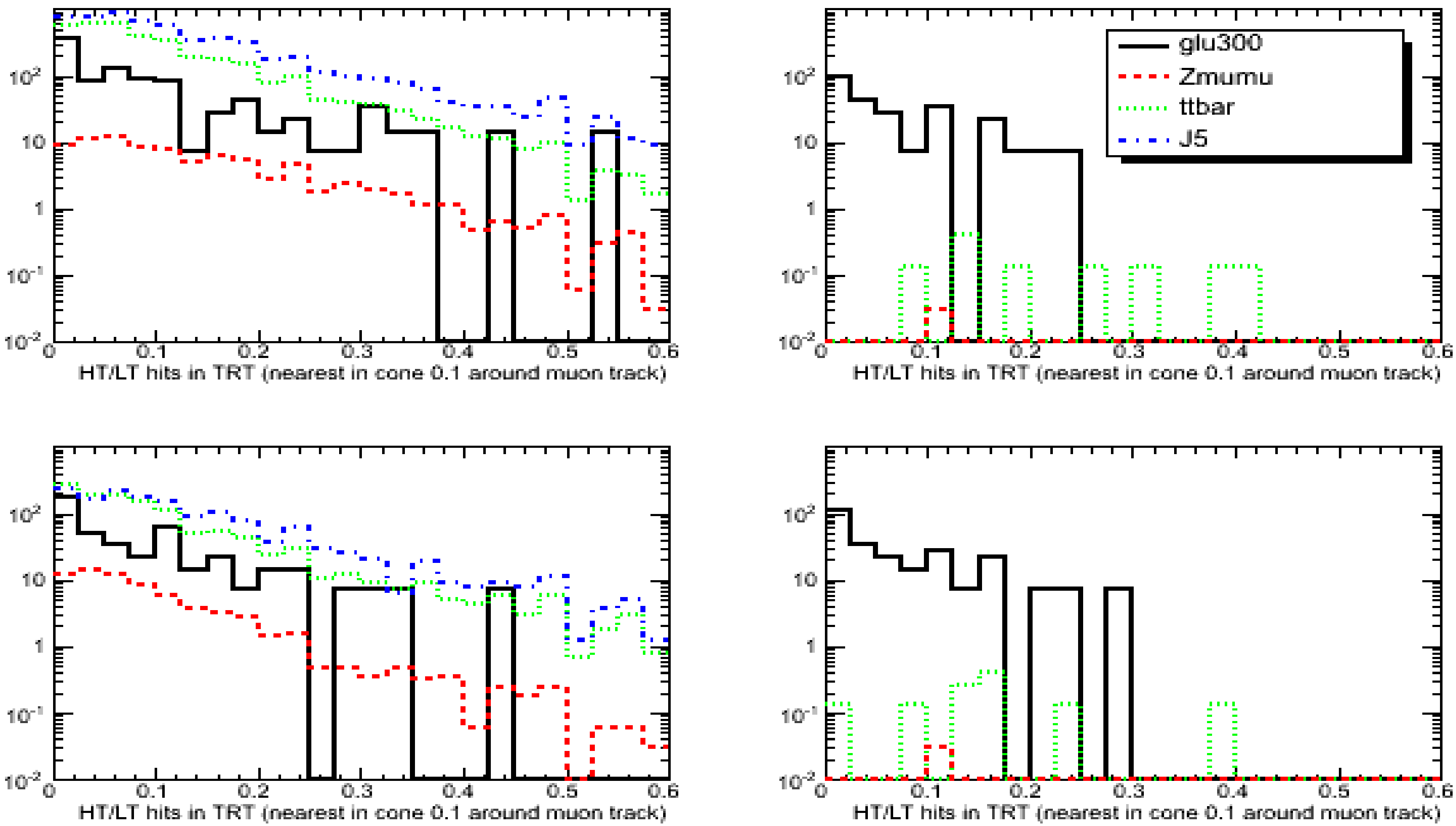




High-threshold hits in TRT

(left = before, right = after event selection)

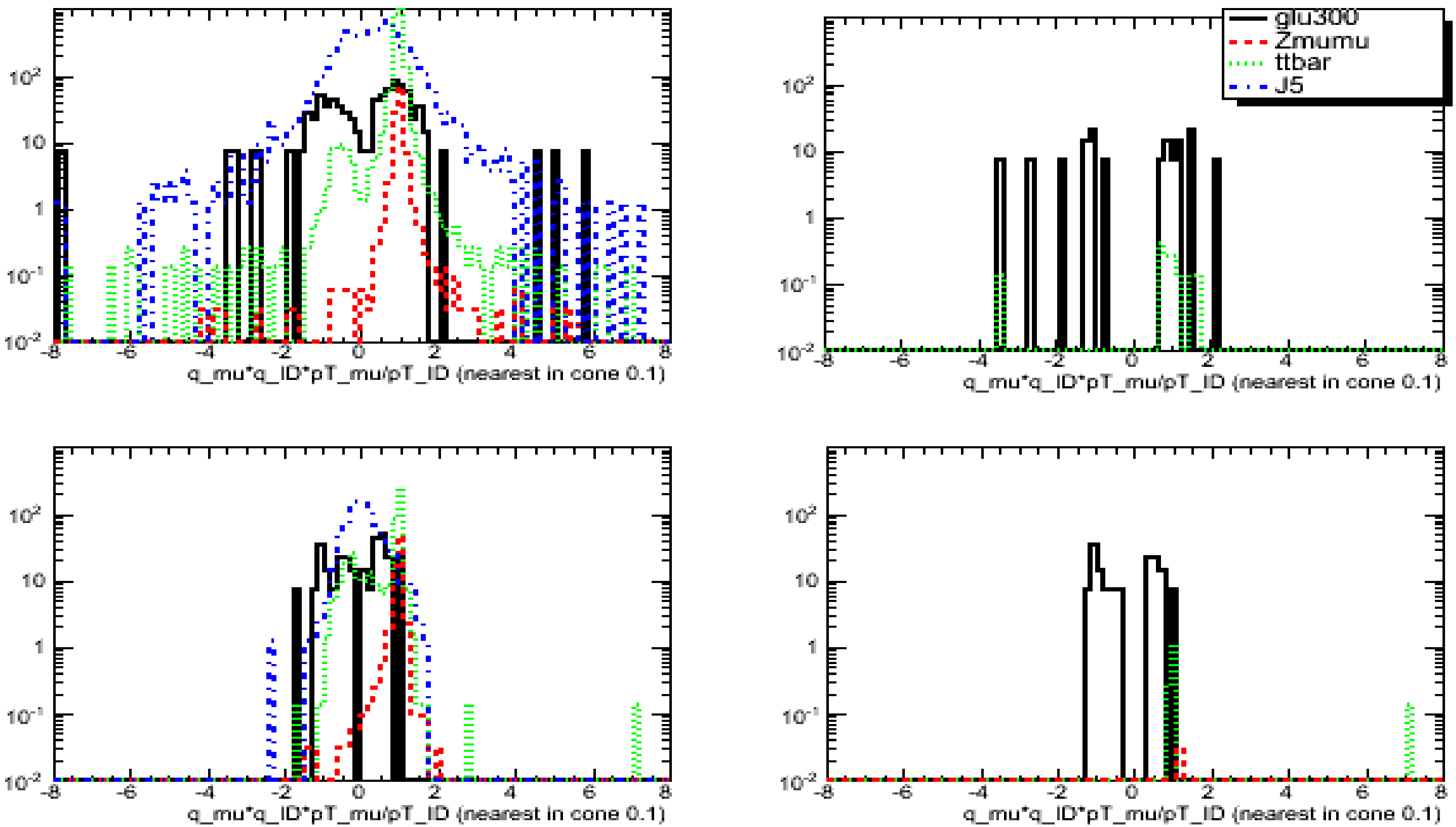
(top = leading muon track, bottom = second leading muon track)



Charge-flipping signature

(left = before, right = after event selection)

(top = leading muon, bottom = second leading muon)



Muon-based analysis : efficiencies

- Trigger efficiency : probability to pass the trigger given that it passes the analysis
  - Obtained from data using independent trigger, e.g., J120
  - Around 75% for stau trigger
- Efficiency of the analysis : probability for an underlying event to be reconstructed and selected
  - ϵ_{ANA} = N(ANA_{NOTRIG})/N(GEN) = 8.5 ± 1 % (from MC)
  - Depends on three factors :
    - Two charged H-Hadrons in muon system : 56% for gluon type (33% for U type, 0% for D type)
    - Muonboy reconstruction efficiency for two charged H-Hadrons : first estimation 32% (speed & model-dependent)
    - Efficiency of the selection cuts for two reconstructed H-Hadrons : 48% (dominated by high-p_T cut)

Trigger efficiencies

$\epsilon_{TRIG,MU} = N(ANA \ \& \ TRIG_{MET} \ \& \ TRIG_{MU}) / N(ANA \ \& \ TRIG_{MET})$

$\beta > 0.7$ requirement added by hand for L1 muon triggers

ϵ_{TRIG}	"from data"	MC prediction
L1_MU10	92 ± 6 %	97 ± 2 %
L1_MU20	88 ± 7 %	94 ± 6 %
L1_XE70	~25 %	24 ± 17 %
L1_J70_XE30	31 ± 17 %	24 ± 17 %
L2_mu10	~20 %	25 ± 17 %
L2_mu20	~16 %	24 ± 17 %
L2_stau	76 ± 11 %	68 ± 7 %
L2_stau || L2_mu10	76 ± 11 %	77 ± 5 %

- Uncertainties from MC statistics

Measuring β with calorimeters

- Calorimeter read-out every bunch crossing (25 ns)
  - Fit gives E, t
- Late arrival : in TileCal, with β= 0.7, we get 3.2 < Δt < 9.3 ns
- TileCal cell time resolution in test beam (ATL-TILECAL -PUB-2007-002)
  - $\sigma_t < 1$ ns for E > 1 GeV
  - LAr expects similar resolution