Discriminating between Charged Massive Stable Particles

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Some motivation for stable, massive particles

Stable gluino sensitivity at the Tevatron

Distinguishing between sparticles using colour and charge

Models for CMSPs

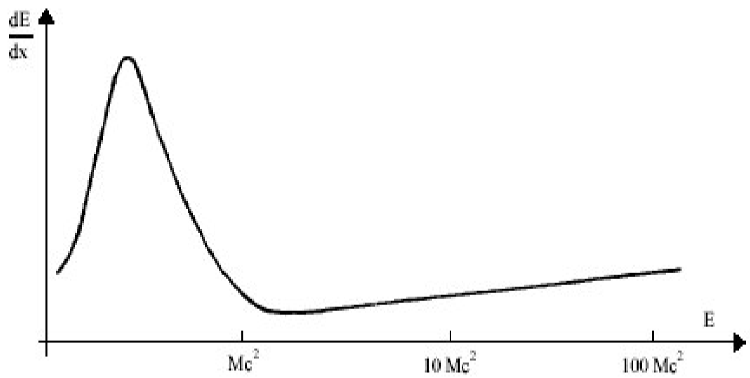
SUSY examples

Particle	Colour	Scenario
Gluino	octet	Split-SUSY
Stop	triplet	GMSB SUSY-5D
Stau	colourless	GMSB

+universal extra dimension
+ new fermion theories
+ leptoquarks
+ Dirac monopoles
+…..

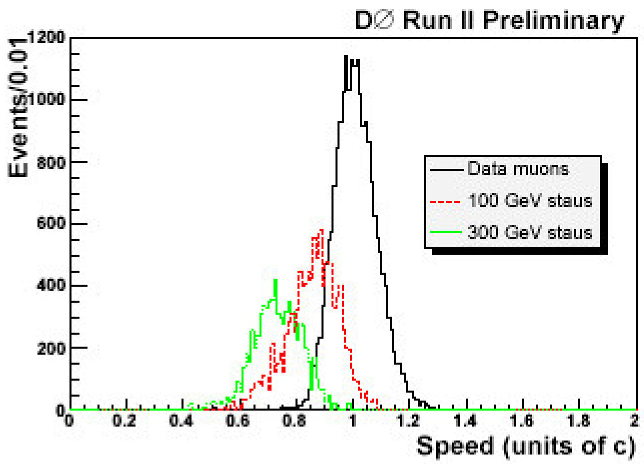
Need a strategy to determine the quantum numbers of any heavy exotic particle.

Common CMSP Signatures



$$\frac{dE}{dx} = -K\frac{Z}{A}\frac{\rho}{\beta^2}\left(\ln\frac{2mc^2\beta^2E_M}{I^2(1-\beta^2)} - 2\beta^2\right)$$

High ionisation energy loss



Slow time of flight
To muon system
(>20 ns)

Observables based on electric charge and mass

R-hadrons and their interactions

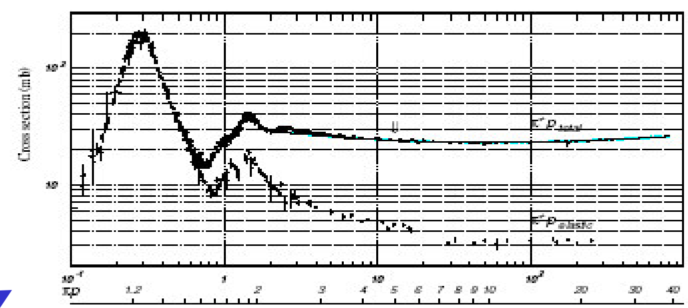
Hadronic bound states from meta-stable sparticles (R-hadron)

R-meson:	$\tilde{g}qq$	$\tilde{q}\bar{q}$
R-baryon:	$\tilde{g}qqq$	$\tilde{q}qq$
R-gluino ball:	$\tilde{g}g$	

Many approaches to modelling hadronic interactions:
H. Baer et al. – hep-ph/9806361, A. Mafi, S. Raby – hep-ph/991236
A. C. Kraan, hep.ph/0404001

$\sigma(\tilde{q},\tilde{\bar{q}} - p)$ - $1/M^2$
The sparticle is a spectator
valence quarks + 'brown' muck
Interact

$K.E._{quarks} = (\gamma - 1)m_{qq} \approx 0.5$ GeV)



Low energy hh scattering

Expected Scattering Behaviour

$$R^- + p \to S^+ + \pi^-$$

Baryon Formation

$$S^+ + \pi^- \not\to R^- + p$$

Prohibited by phase space and absence of π

$$R_{\tilde{g}}^{\ -} + p \to S_{\tilde{g}}^{\ +} + \pi^-$$

Gluino R-hadrons can flip charge

$$R_{\bar{\tilde{t}}}^{\ -} + p \not\to S_{\bar{\tilde{t}}}^{\ +} + \pi^-$$

Stop, anti-stop R-hadrons cannot

$$R_{\tilde{b}}^{\ -} + p \to S_{\tilde{b}}^{\ +} + \pi^-$$

Sbottom R-hadrons can flip

$$R_{\bar{\tilde{b}}}^{\ +} + n \to S_{\bar{\tilde{b}}}^{\ -} + \pi^+ + \pi^+$$

Antisbottom can flip followed by annihilation

$$S_{\bar{\tilde{b}}}^{\ -} + p \to R_{\bar{\tilde{b}}}^{\ +} + \pi^-$$

Nuclear Interaction Model A. Kraan (hep-ex/0404001)
No explicit resonances.
Constant cross-section at all energies
Only u, d quarks
Only 2-2, 2-3 processes, distinguished by phase space
Geant 3

	R^+	R^0	R^-
proton scattering: 2→2 processes	$R^+p \to R^+p$ $R^+p \to S^{++}\pi^0$ $R^+p \to S^+\pi^+$	$R^0p \to R^0p$ $R^0p \to R^+n$ $R^0p \to S^{++}\pi^-$ $R^0p \to S^+\pi^0$ $R^0p \to S^0\pi^+$	$R^-p \to R^-p$ $R^-p \to R^0n$ $R^-p \to S^+\pi^-$ $R^-p \to S^0\pi^0$
neutron scattering: 2→2 processes	$R^+n \to R^+n$ $R^+n \to R^0 + p$ $R^+n \to S^{++}\pi^-$ $R^+n \to S^+\pi^0$ $R^+n \to S^0\pi^+$	$R^0n \to R^0n$ $R^0n \to R^-p$ $R^0n \to S^+\pi^-$ $R^0n \to S^0\pi^0$ $R^0n \to S^-\pi^+$	$R^-n \to R^-n$ $R^-n \to R^0\pi^-$ $R^-n \to S^0\pi^-$ $R^0n \to S^-\pi^0$
proton scattering: 2→3 processes	$R^+p \to R^+p\pi^0$ $R^0p \to R^+n\pi^+$ $R^+p \to R^0p\pi^+$ $R^+p \to S^{++}\pi^0\pi^0$ $R^+p \to S^{++}\pi^+\pi^-$ $R^+p \to S^+\pi^+\pi^0$ $R^+p \to S^0\pi^+\pi^+$	$R^0p \to R^0p\pi^0$ $R^0p \to R^0n\pi^+$ $R^0p \to R^+p\pi^-$ $R^0p \to R^+n\pi^0$ $R^0p \to R^-p\pi^+$ $R^0p \to S^{++}\pi^0\pi^-$ $R^0p \to S^+\pi^0\pi^0$ $R^0p \to S^+\pi^+\pi^-$ $R^0p \to S^0\pi^+\pi^0$ $R^0p \to S^-\pi^+\pi^+$	$R^-p \to R^-p\pi^0$ $R^-p \to R^-n\pi^+$ $R^-p \to R^+n\pi^-$ $R^-p \to R^0p\pi^-$ $R^-p \to R^0n\pi^0$ $R^-p \to S^{++}\pi^-\pi^-$ $R^-p \to S^+\pi^0\pi^-$ $R^-p \to S^0\pi^0\pi^0$ $R^-p \to S^0\pi^+\pi^-$ $R^-p \to S^-\pi^+\pi^0$
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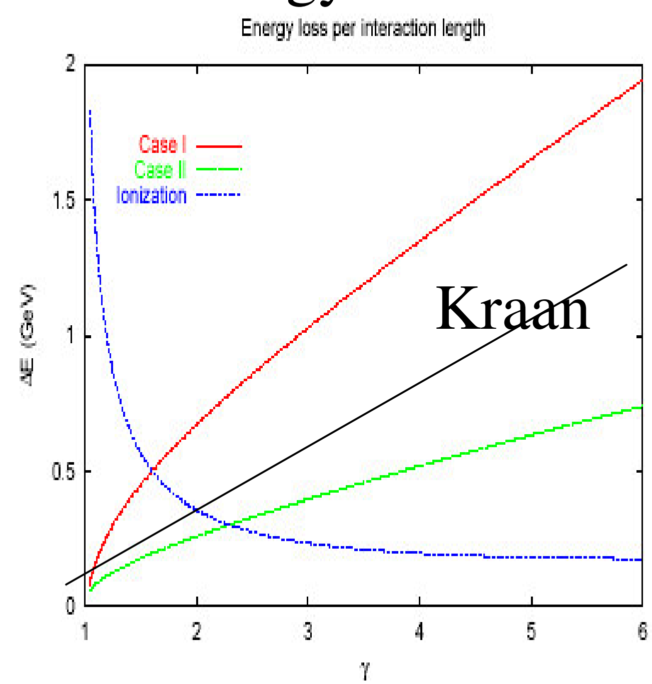
Energy Loss



GEANT-3 Implementation for gluino (+ stop, sbottom) R-hadrons

Hadronising Sparticles

Sparticle hadronisation

- PYTHIA (string)
- HERWIG (cluster)

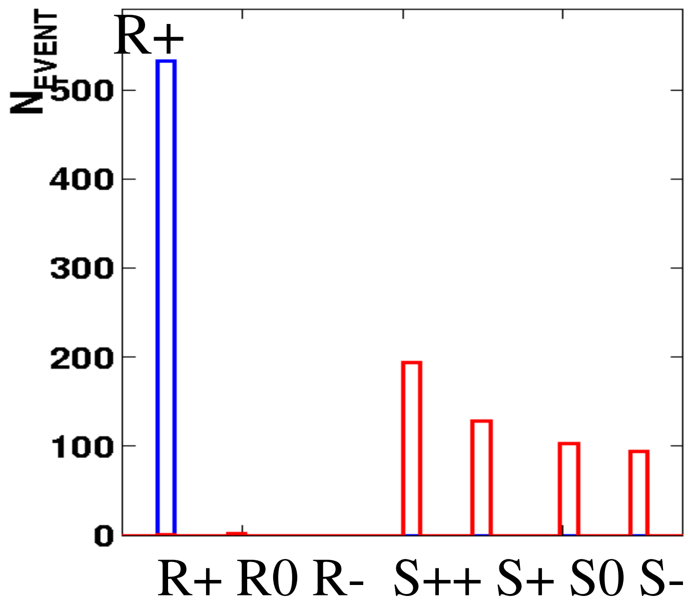
Open questions: R-hadron mass spectrum – cascade to neutrals
$(R_{meson} - R_{gluinoball} < m_{\pi}$?)
: Fraction of neutrals for gluino R-hadrons

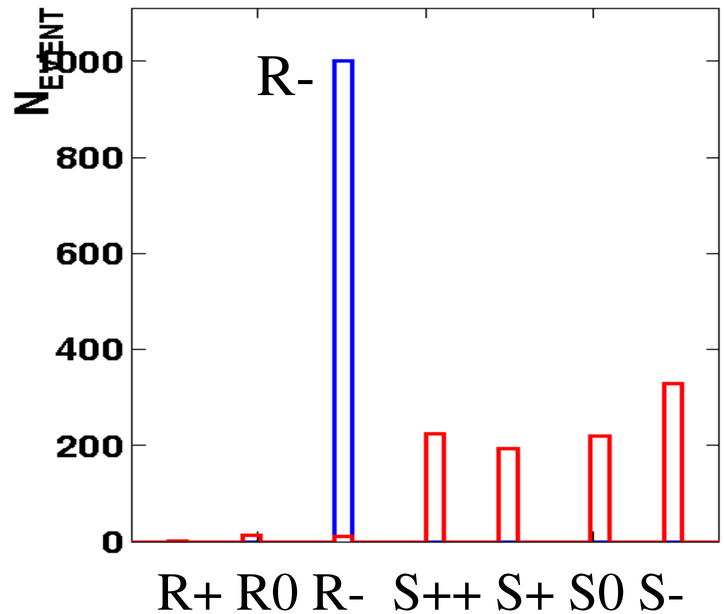
Probability of glueball formation P_{gg}=0.1 - neutral/total = 0.6

Uncertainties due to gluino constituent mass etc. expected to be small.
Set same R-meson and R-baryon masses for given sparticle.

Conversions of R-hadrons through D0 Calorimeter

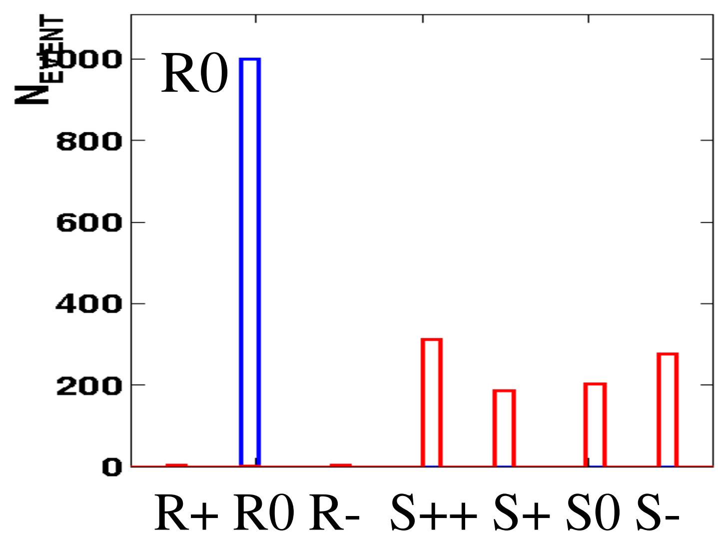
Use GEANT-3 with thickness $11\lambda_T(\pi)$



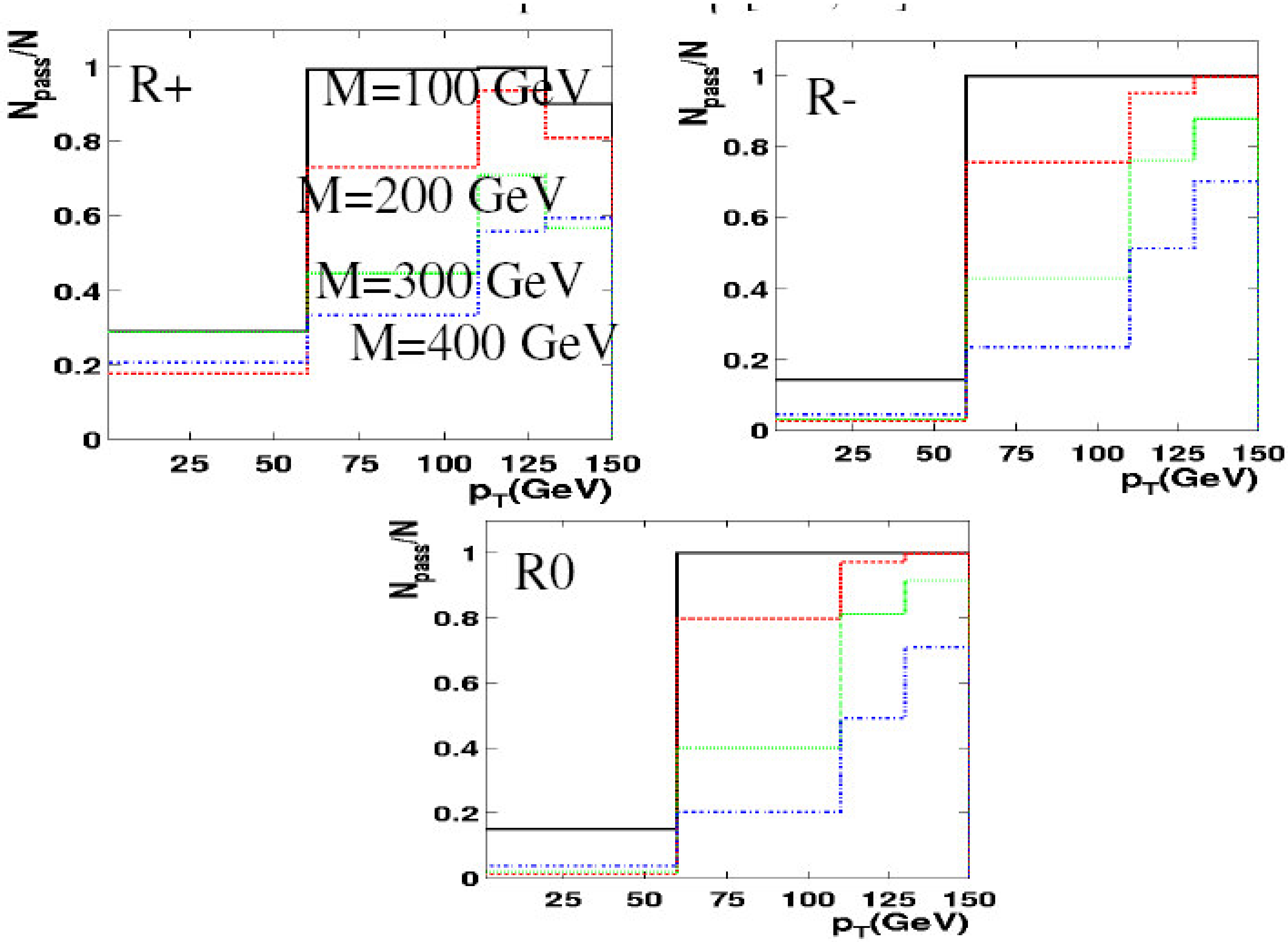


Mesons end up as baryons

Kinematics from Split-SUSY scenario
Pt>15 GeV
$|\eta|<1.5|$



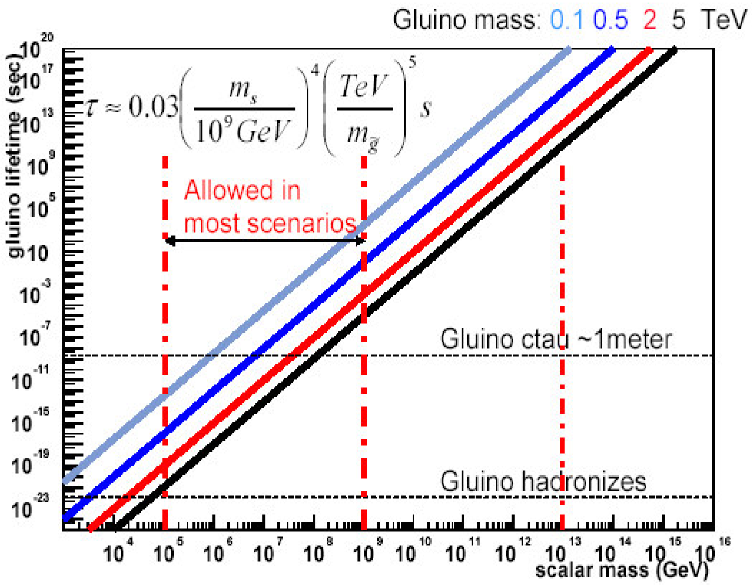
Stopping R-hadrons

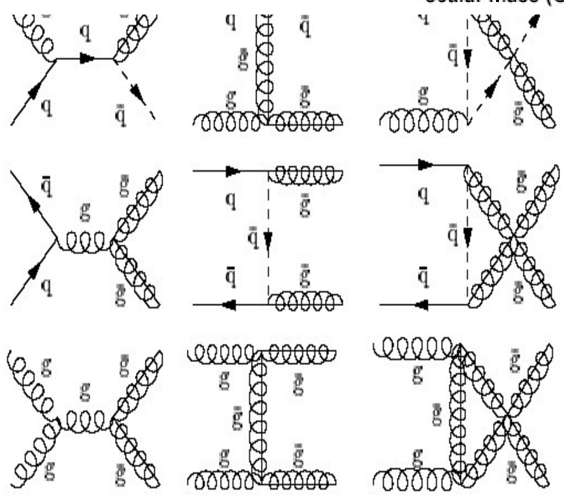


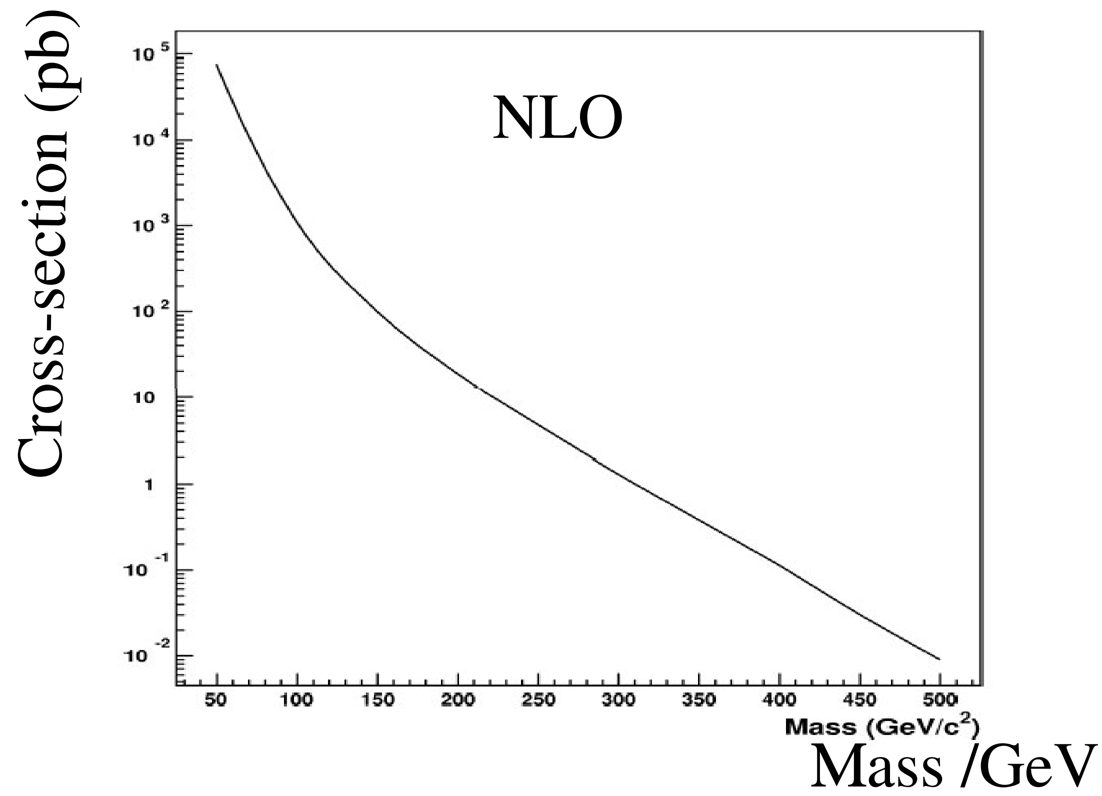
Non-negligible stopping – perhaps look for off-beam R-hadron decays (A. Arvanitaki et al., hep.ph/0506242)

Gluinos at the Tevatron

Split-SUSY scenario, m_s=10^6 GeV
-> stable gluino







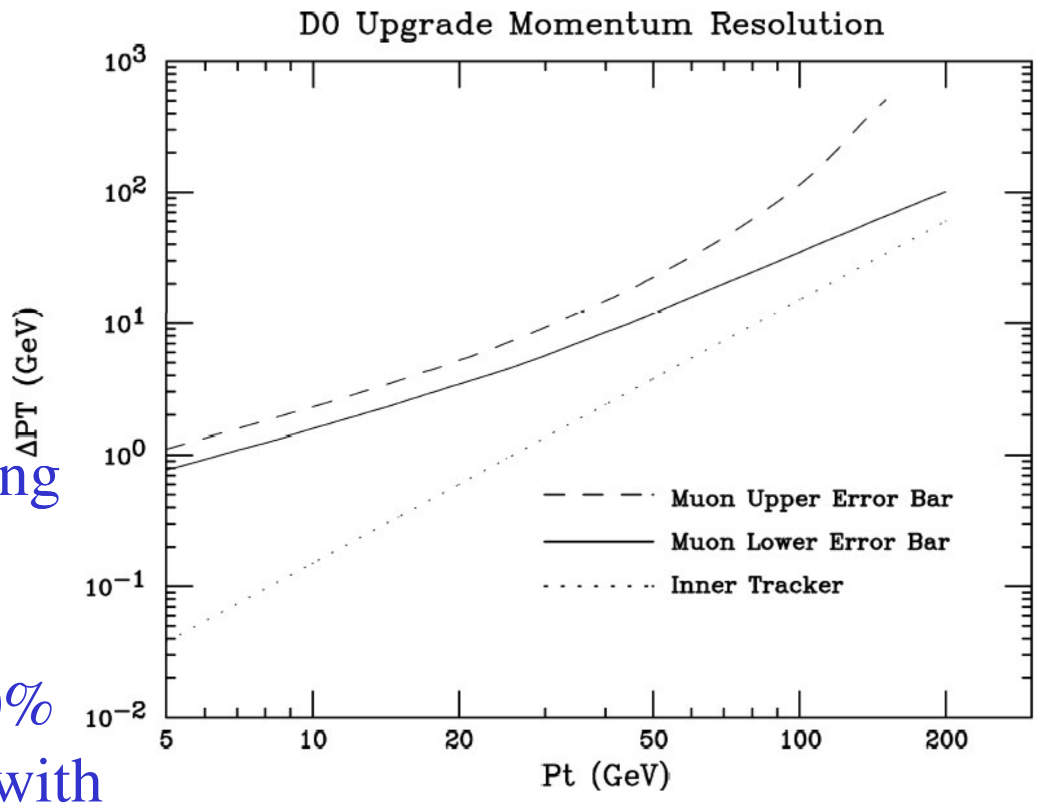
Expect - 1000 gluino pairs at 300 GeV for 1fb^{-1}

R-hadrons at the Tevatron

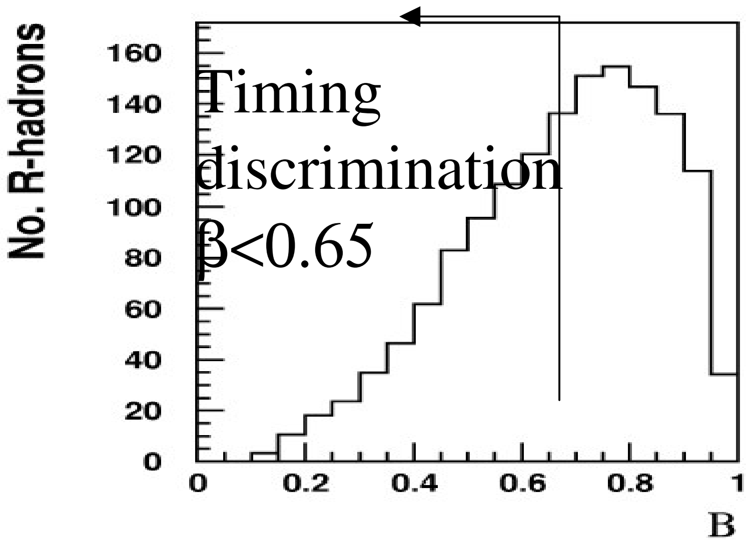
Use PYTHIA +
model for R-hadron
Scattering

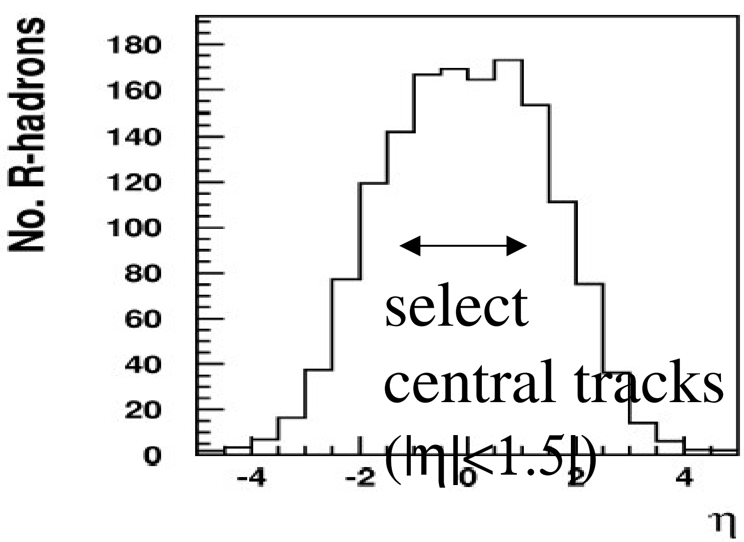
Smear with resolution of
D0 CFT and muon tracking
chambers.

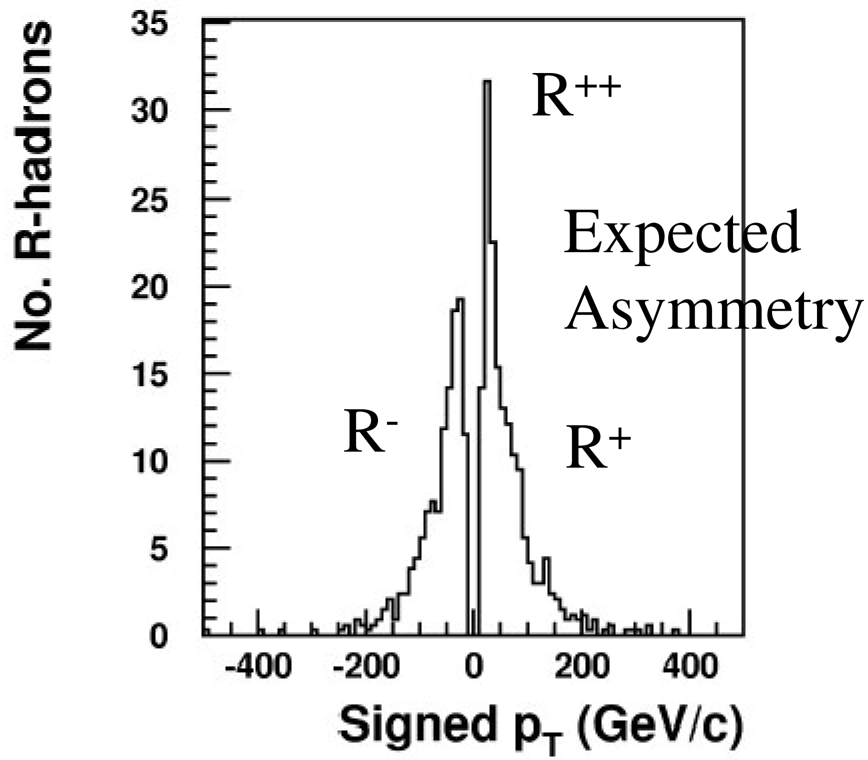
Smear to 'achieve' 25-30%
charge misidentification with
muon chamber alone



Expected Properties of 100 GeV gluino R-hadrons







Signed P_T (outer) / Signed P_T (inner)

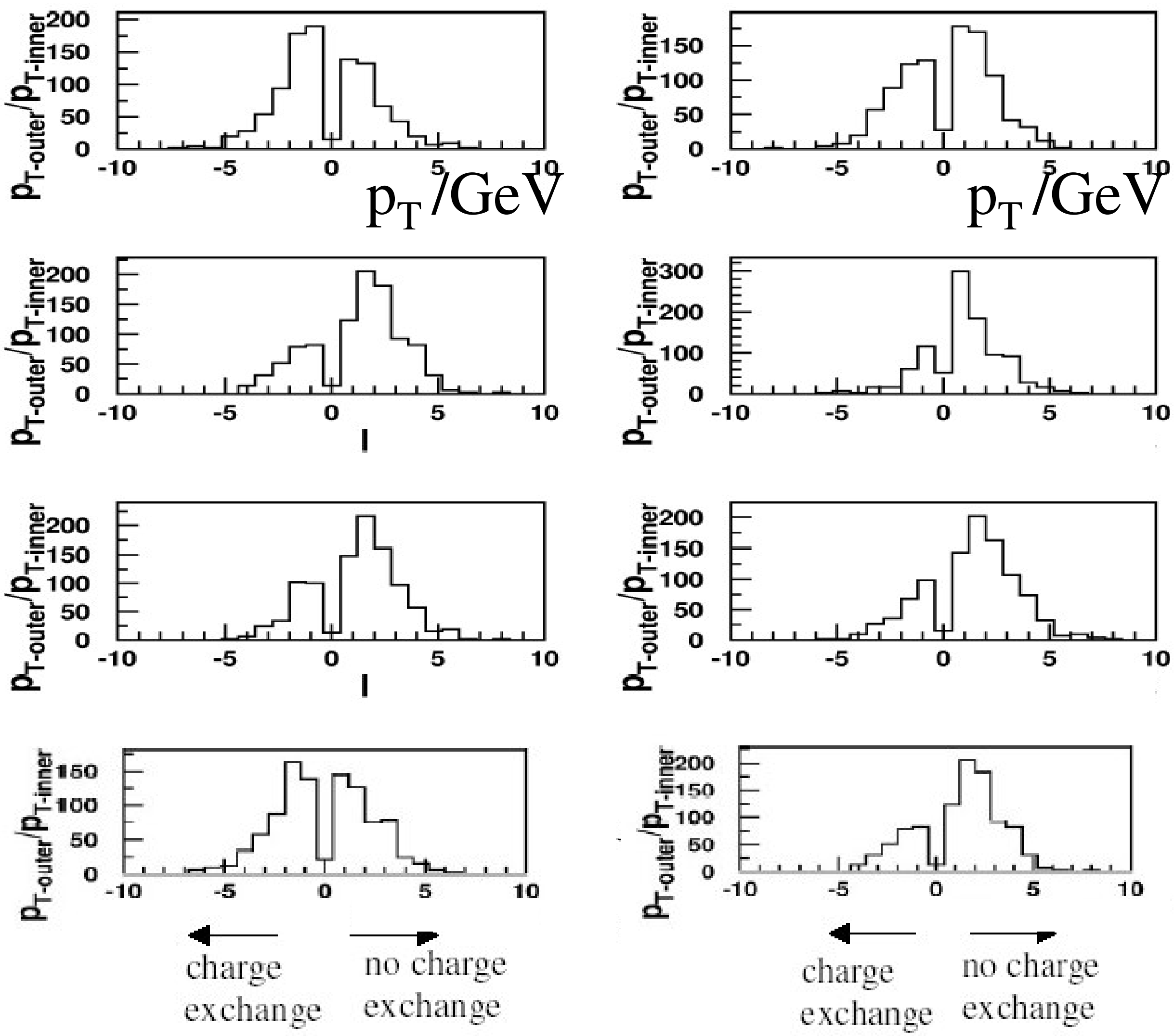
Negative Inner Tracks   Positive Inner Tracks

Gluino

Stop

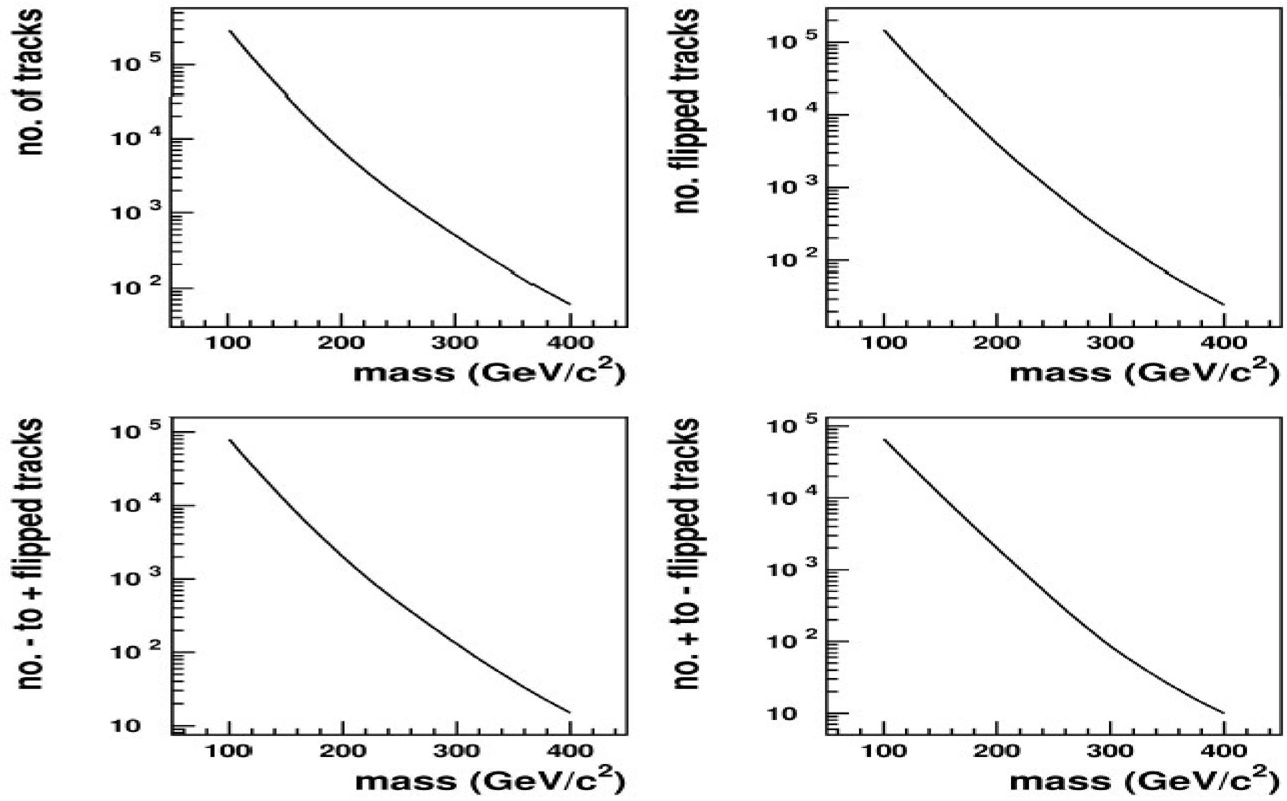
Stau

Sbottom



Toy MC with detector resolutions and charge misid.

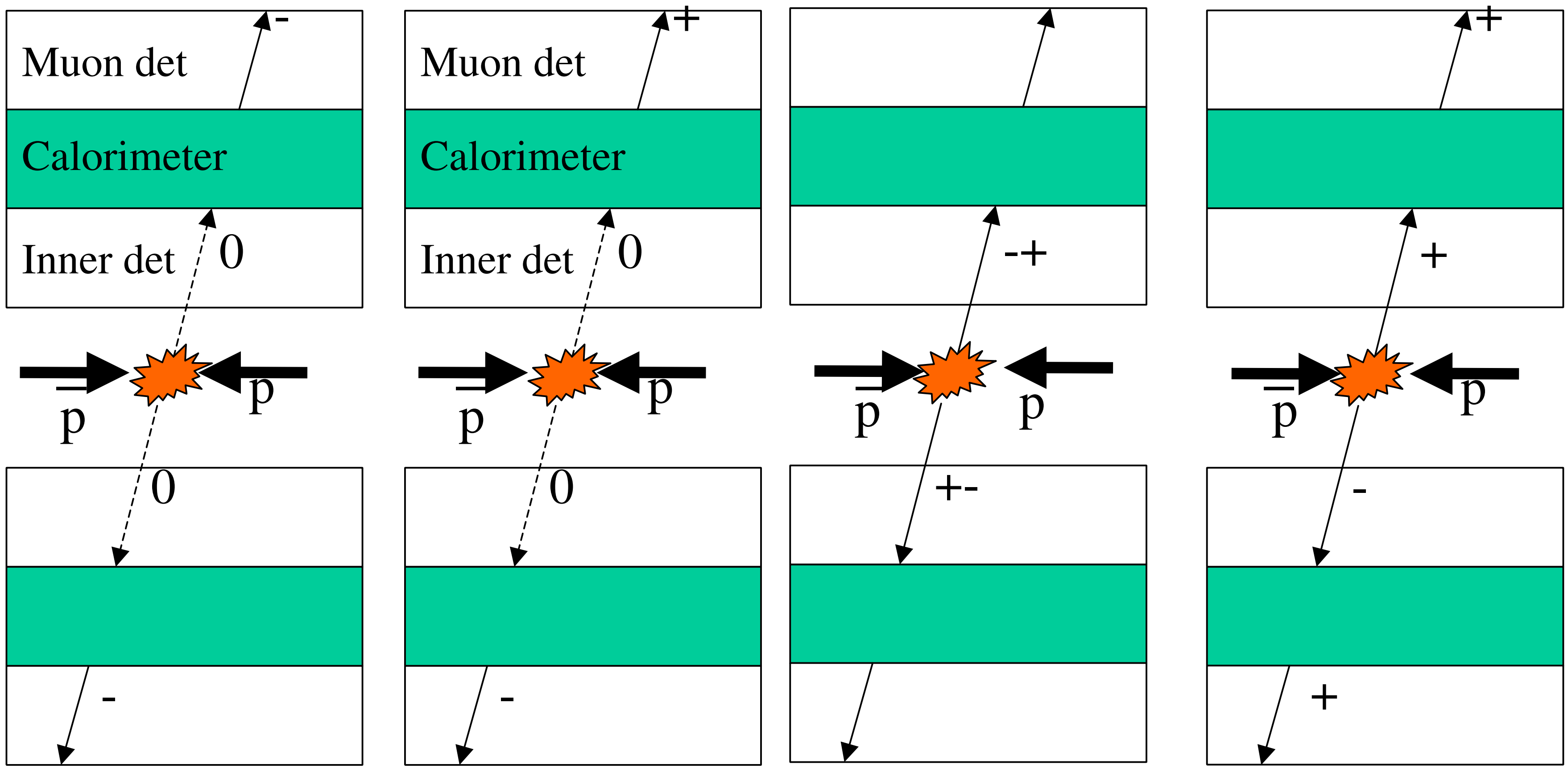
Expected number of R-hadron tracks and flippers for gluino pair production



normalised to $2fb^{-1}$

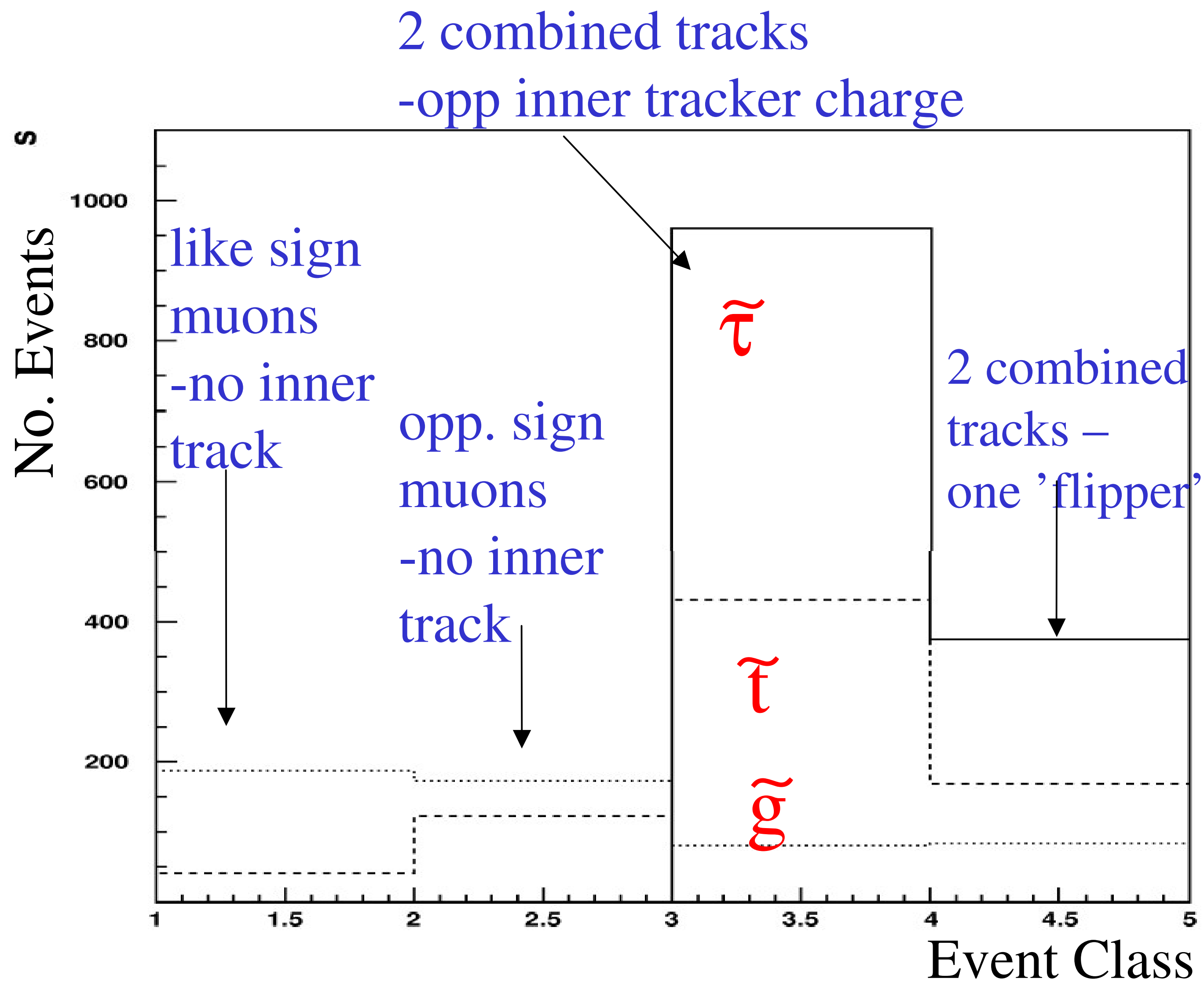
Discriminate with Event Topologies

Like sign ‘muons’ -no inner tracking link	Opp sign ‘muons’ -no inner tracking link	Opp sign inner tracks	At least one flipper



gluino-gluino ✓	gluino-gluino ✓	gluino-gluino ✓	gluino-gluino ✓
stop-antistop ✗	stop-antistop ✓	stop-antistop ✓	stop-antistop ✗
stau-antistau ✗	stau-antistau ✗	stau-antistau ✓	stau-antistau ✗

Rates of different event classes



Relative rates of different processes offer discrimination

Summary

The discovery of new stable, massive charged particles would be of fundamental significance.

The absence of such particles is of fundamental significance in developing any theory beyond the SM.

Charge exchange in hadronic interactions could allow the discovery of R-hadrons and the quantification of the sparticle colour.

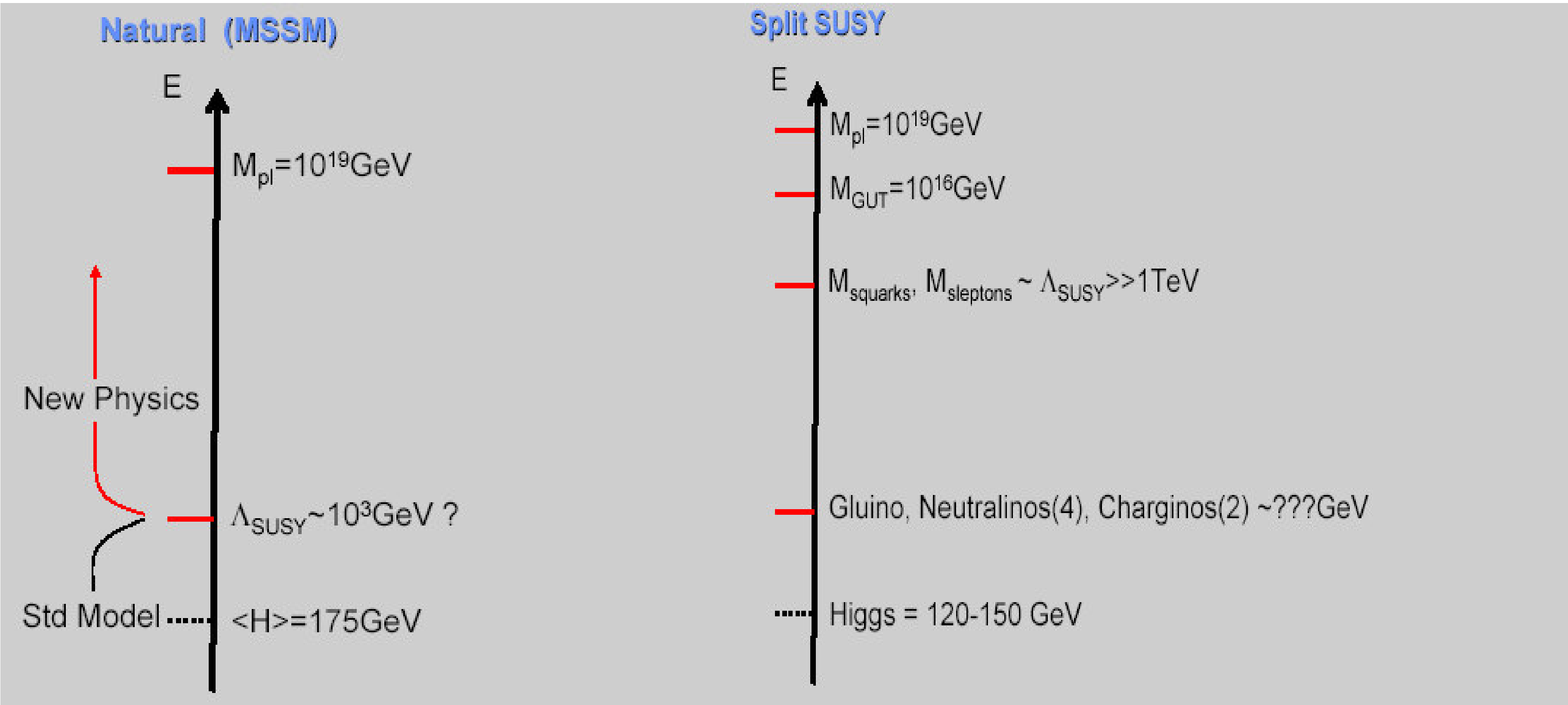
Charge exchange in hadronic interactions may have kept R-hadrons hidden in previous searches.

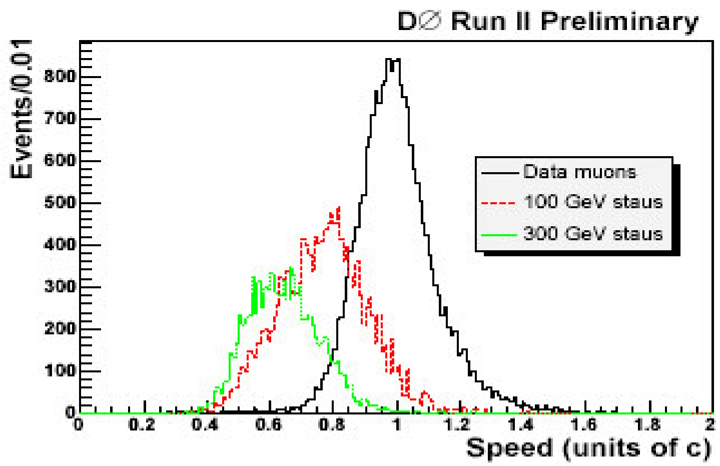
Tevatron offers chance of discovery and systematic study ahead of LHC

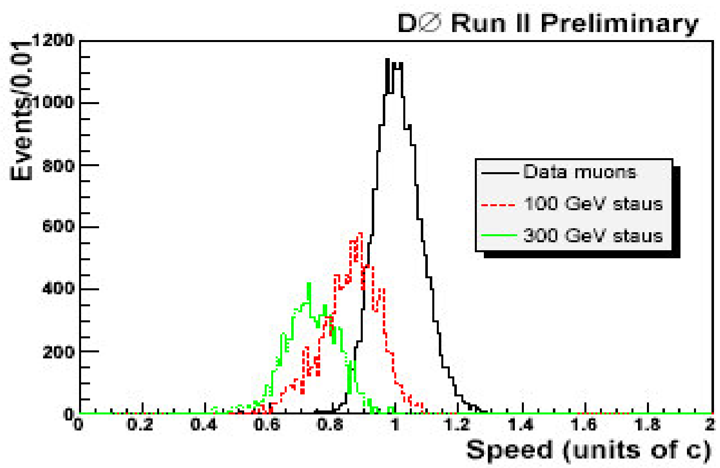
Split SUSY

Abandon the Hierarchy Problem! Arkani-Hamed, et al hep-ph/0409232

Supersymmetry breaking occurs at high scale M_s>>1000 TeV
Scalars have masses at this scale – Higgs light
Fermions light

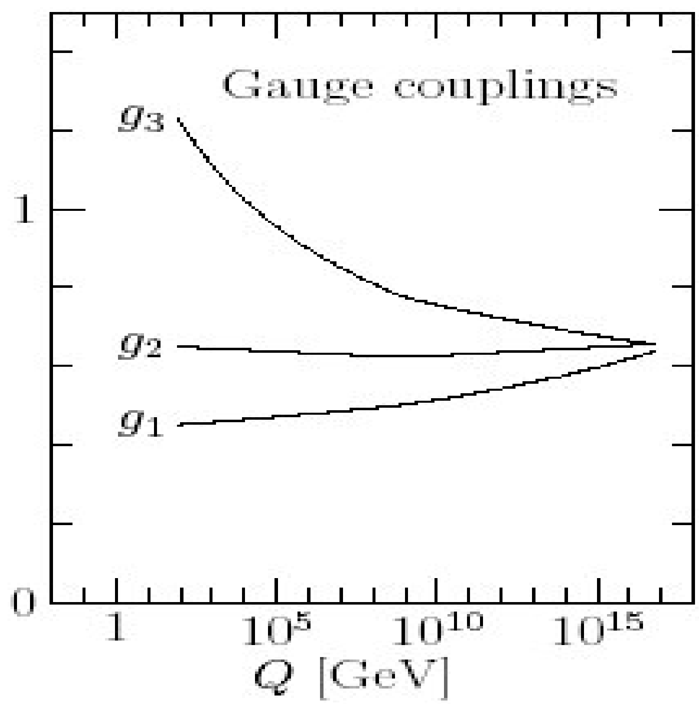



DØ Run II Preliminary
Events/0.01
Speed (units of c)
Data muons
100 GeV staus
300 GeV staus


DØ Run II Preliminary
Events/0.01
Speed (units of c)
Data muons
100 GeV staus
300 GeV staus

Some nice theoretical features of Split SUSY

Long proton lifetime
FCNC limits $M_s > 100$ TeV
EDM limit $M_s > 1000$ TeV

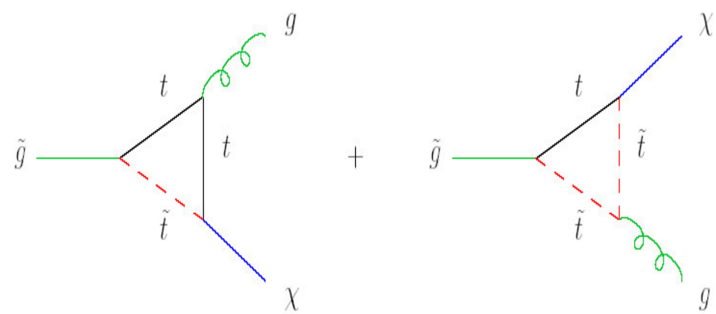


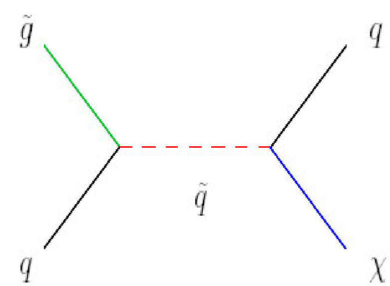
Unification of Coupling

Dark matter candidate – neutralino ?

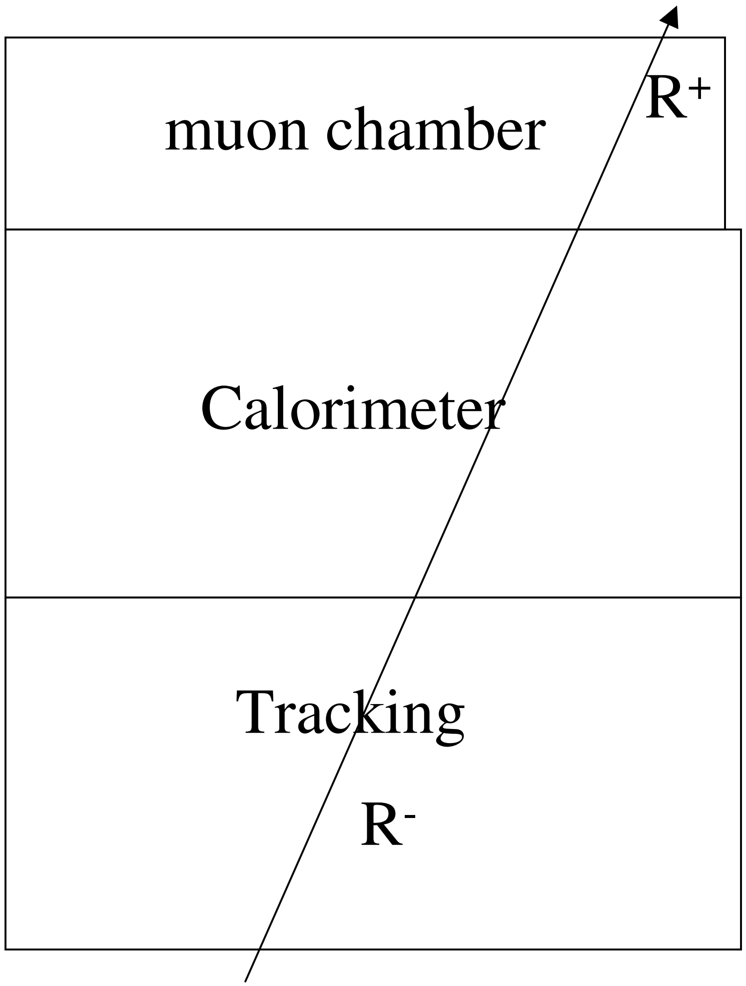
One nice experimental feature of Split SUSY

Heavy squark, light gluino -> (meta)stable gluino





Searching for R-hadrons in a generic detector!



Ionisation

Time of flight

Hadronic Interactions