Scattering of Heavy hadrons

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New physics searches – the experimentalist's perspective

- Motivation
  - New collider energy regime about to be accessed.
  - Possible solutions to the hierarchy problem suggest new physics at TeV energies.
  - Fourth generation quarks and other heavy coloured objects.

- Need observables
  - Jets, missing Et, stable massive particles.

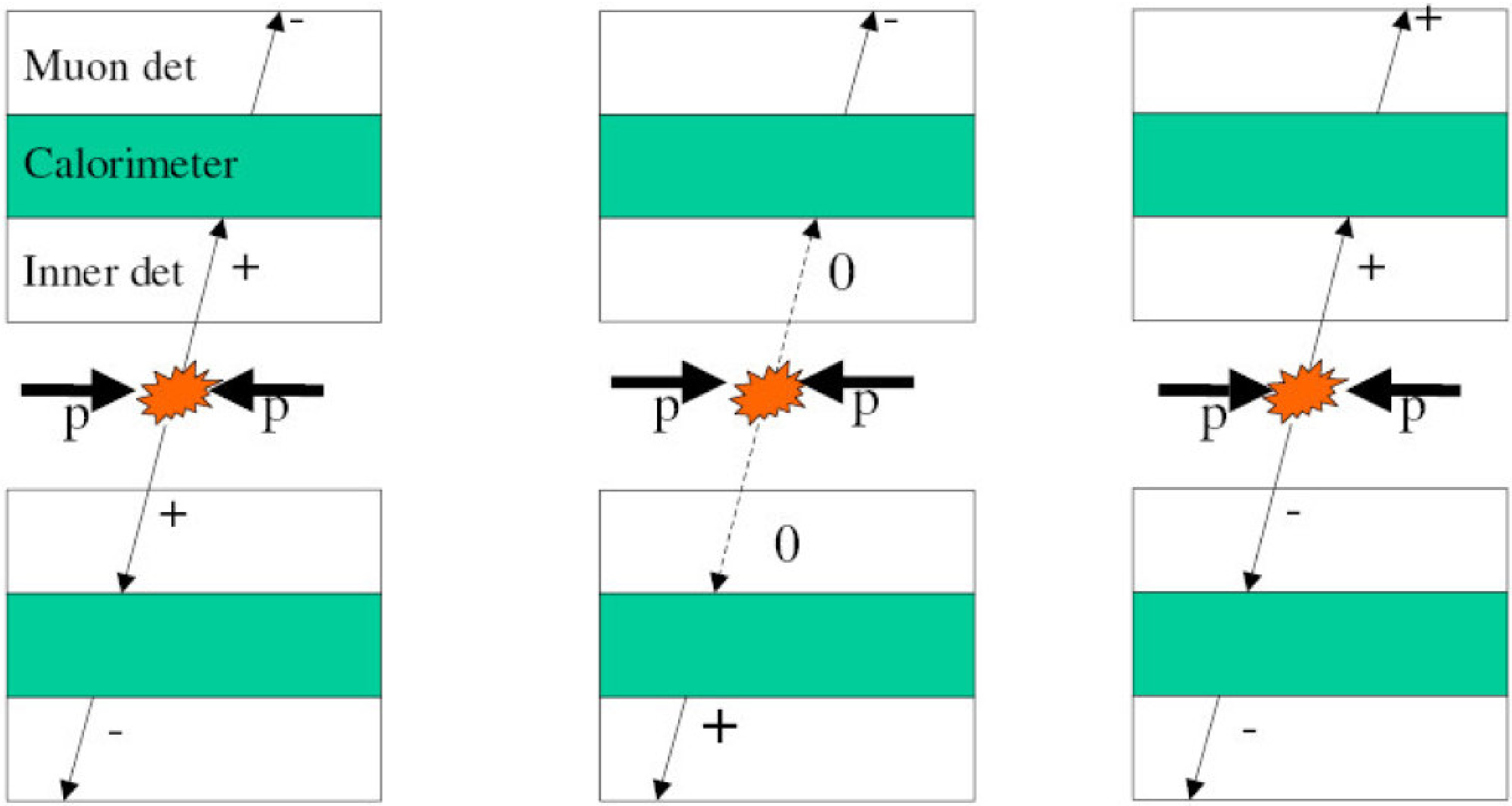
Expecting the unexpected

Assume signature of SMP as a slow muon-like object.
Is it possible to observe the SMP and extract the charge ?
Use cross section + final state expectations (where available).
Scattering/energy loss in material.

SMP	charge	Scattering
lepton, free quark (fractional charge)	Electric	Ok
Colour triplet, octet (leading to H-hadron)	Colour	? (this talk)
Dirac monopole, fractional magnetic charge	Magnetic	Ok

+ combinations of above.

Some event topologies for different SMPs



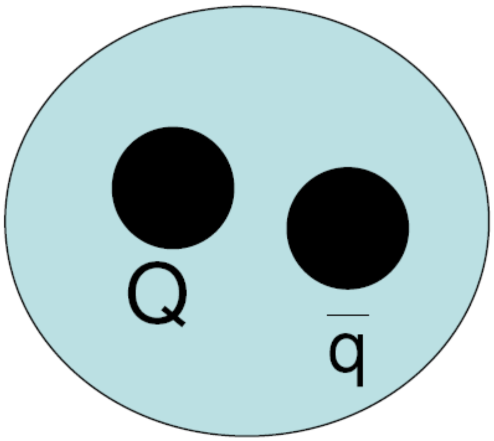
Hadron

Hadron

Hadron
Lepton

Understanding scattering in material is crucial

Heavy hadron scattering



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

$M_Q \approx M_H = 200$ GeV $E = 1$ 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)

What's on the market ?

Generic model: all 2-2 and 2-3 processes allowed.
Constant cross section
Separated by phase space.
Same Clebsch-Gordon co-efficients.
hep-ex/0404001 (A.C. Kraan)
hep-ph/0612161 (Mackeprang,Rizzi)
Geant3 and Geant 4.

Triple Regge estimates for Gluinos
hep-ph/9806361 (Baer,Chung,Gunion)
hep-ph/9912436 (Mafi,Raby)

	R^+	R^0	R^-
proton scattering: $2\to2$ 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: $2\to2$ 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: $2\to3$ 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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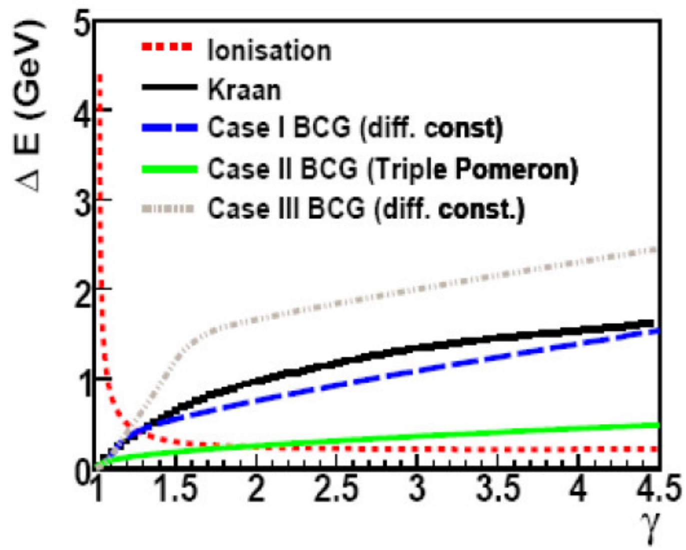
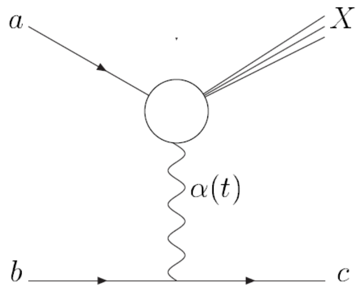
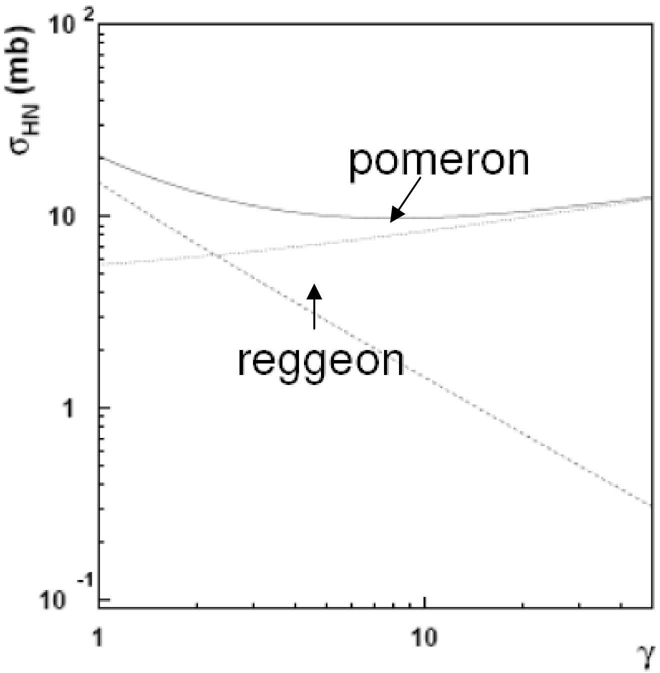


Calculating energy loss



$$\Delta E = \frac{m_X^2 - m_N^2 + |t|}{2m_N}$$

$$\langle \Delta E \rangle = \frac{\int_{m_N}^{\sqrt{s}-m_{R^0}} dm_X \int_{|t|_{\min}(m_X)}^{|t|_{\max}(m_X)} d|t| \, \Delta E \frac{d\sigma}{d|t| dm_X}}{\int_{m_N}^{\sqrt{s}-m_{R^0}} dm_X \int_{|t|_{\min}(m_X)}^{|t|_{\max}(m_X)} d|t| \frac{d\sigma}{d|t| dm_X}}$$



Triple regge ansatz to estimate energy loss of H-hadron.
Separate into pomeron and reggeonic contributions.

$$\frac{d^2\sigma_{RRR}}{dt dM_X^2}(\gamma, M_X^2) = \frac{1}{M_X^2}\sigma_R^2(\gamma) C_{RRR} \exp[(2B_{RH} + B_{RRR} + 2\alpha'_R \ln(\frac{2\gamma M_0^2}{M_X^2}))t] \left(\frac{M_0^2}{M_X^2}\right)^{\Delta_R} \quad (4)$$

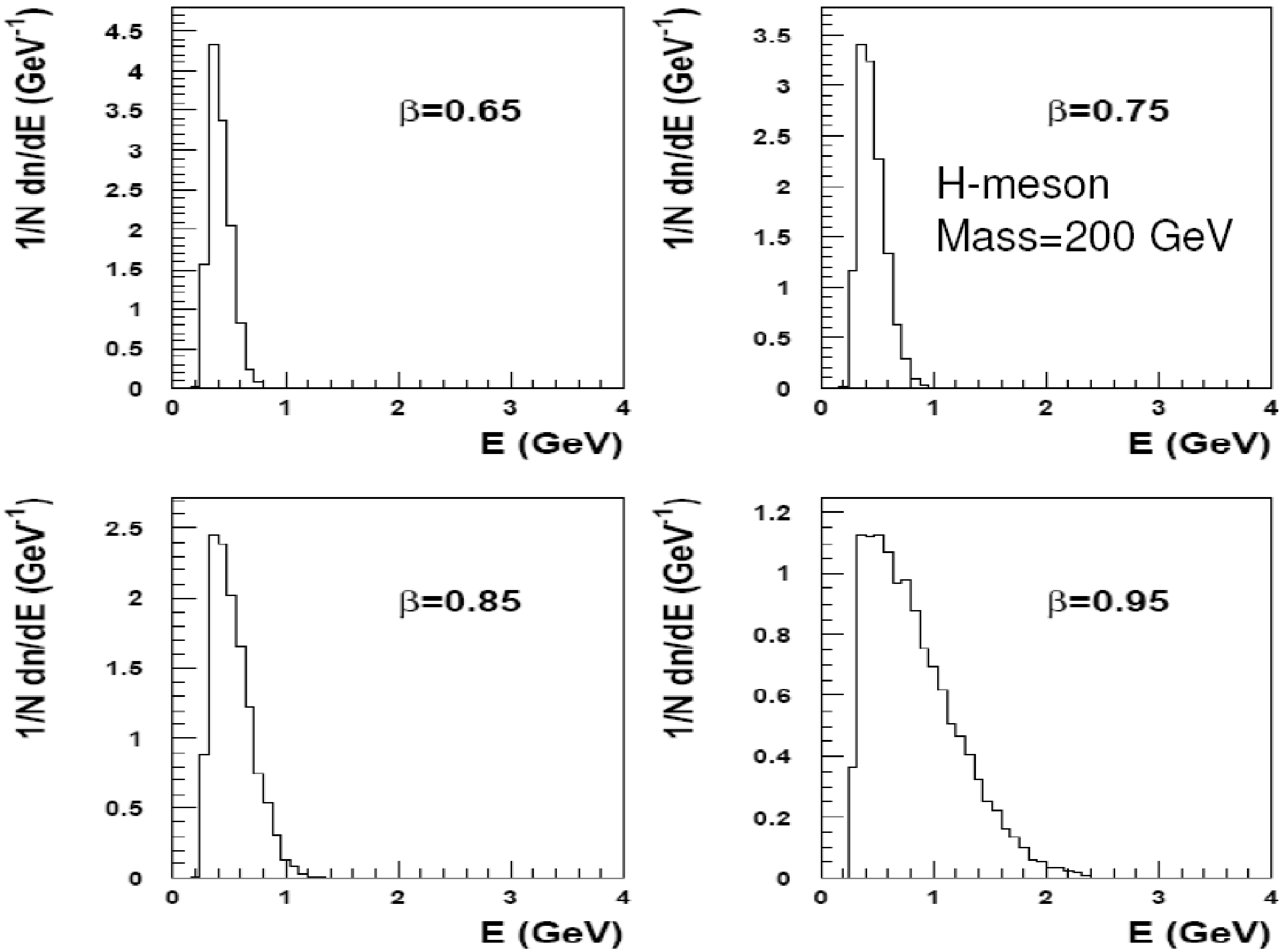
$$\frac{d^2\sigma_{RRP}}{dt dM_X^2}(\gamma, M_X^2) = \frac{1}{M_X^2}\sigma_R^2(\gamma) C_{RRP} \exp[(2B_{RH} + B_{RRP} + 2\alpha'_P \ln(\frac{2\gamma M_0^2}{M_X^2}))t] \left(\frac{M_0^2}{M_X^2}\right)^{2\Delta_R - \Delta_P} \quad (5)$$

$$\frac{d^2\sigma_{PPR}}{dt dM_X^2}(\gamma, M_X^2) = \frac{11}{M_X^2}\sigma_P^2(\gamma) C_{PPR} \exp[(2B_{PH} + B_{PPR} + 2\alpha'_P \ln(\frac{2\gamma M_0^2}{M_X^2}))t] \left(\frac{M_0^2}{M_X^2}\right)^{2\Delta_P - \Delta_R} \quad (6)$$

$$\frac{d^2\sigma_{PPP}}{dt dM_X^2}(\gamma, M_X^2) = \frac{1}{M_X^2}\sigma_P^2(\gamma) C_{PPP} \exp[(2B_{PH} + B_{PPP} + 2\alpha'_P \ln(\frac{2\gamma M_0^2}{M_X^2}))t] \left(\frac{M_0^2}{M_X^2}\right)^{\Delta_P} \quad (7)$$

Take free parameters from low energy hadron-hadron data.

Differential hadronic energy loss

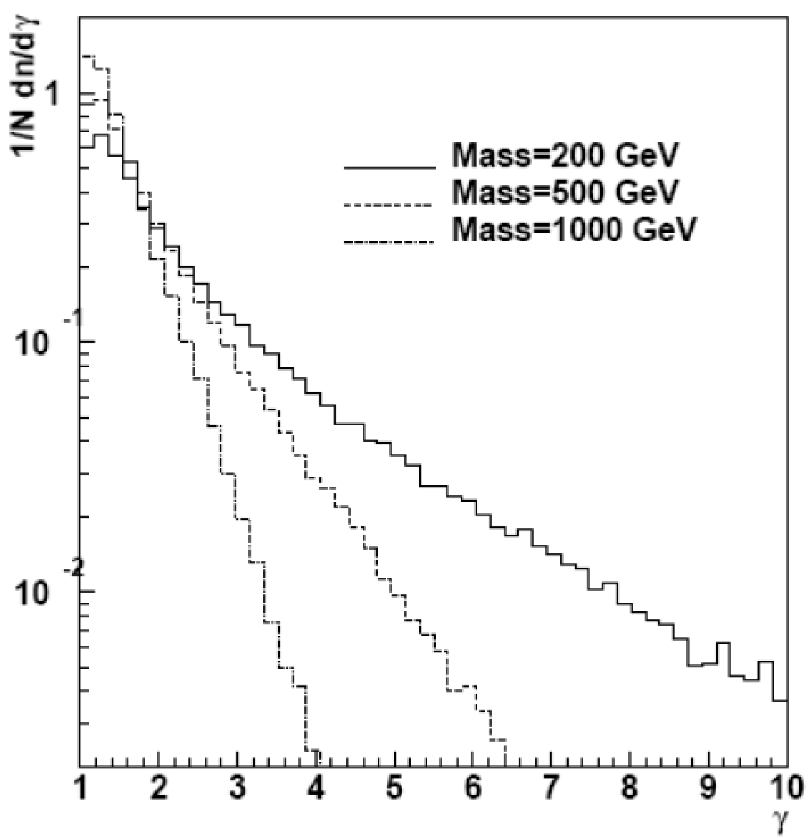


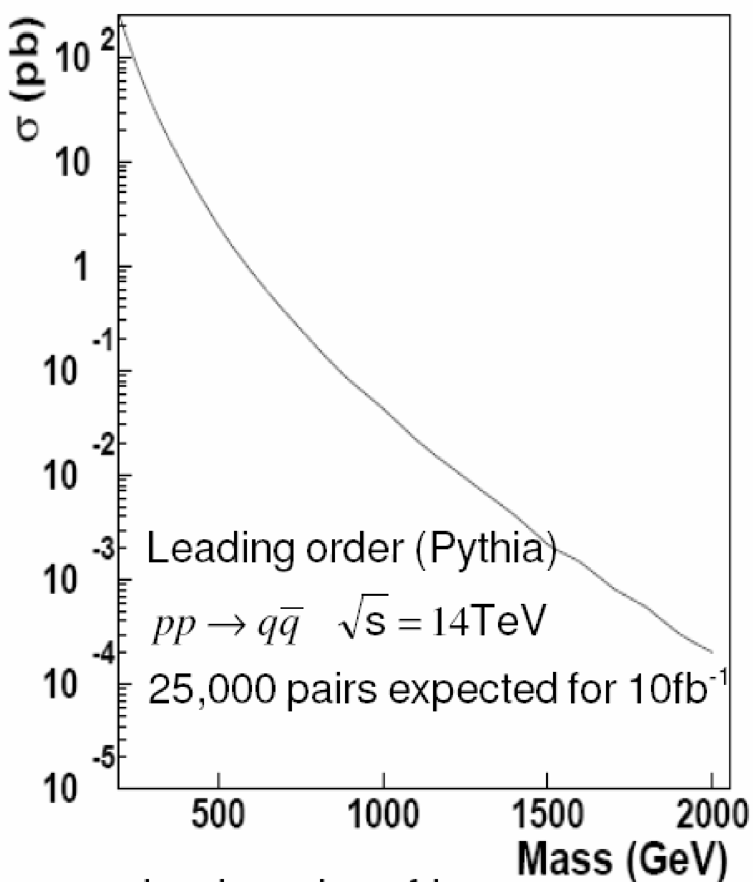
Energy loss per collision around a GeV

Exotic hadron model

Fourth generation quark model

Hadronise into H-mesons (90%) and baryons (10%)





Propagate H-mesons through – 15 interaction lengths of iron.
Use kinematic spectra for pp at cm=14 TeV.
$|\eta| < 2.5$, $\beta > 0.7$.

Energy loss

Q

Mesons convert to baryons

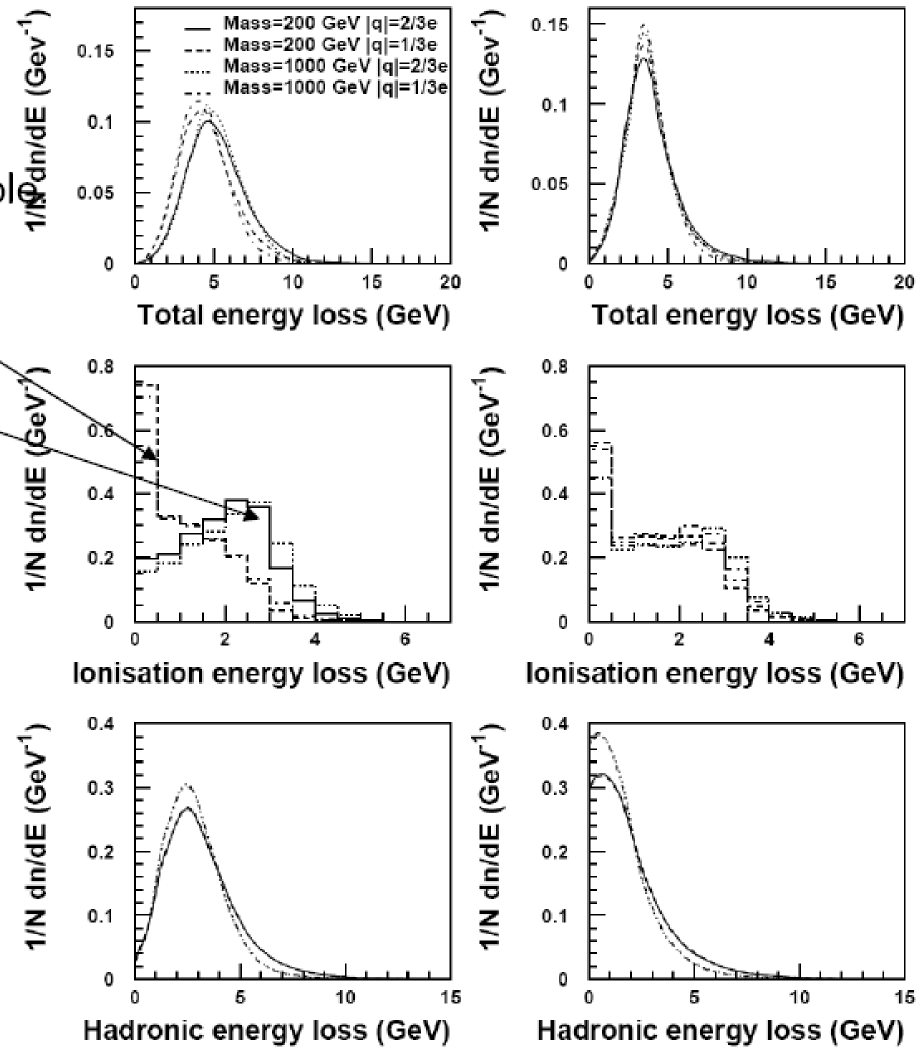
$M_{Q\bar{u}} + N \rightarrow B_{Quu} + \pi$

Reverse reaction not possible

Lowest baryon state : Qud

D - type quarks : neutral

U - type quarks : positive



H-hadrons (Q) H-hadrons ($\overline{Q}$)

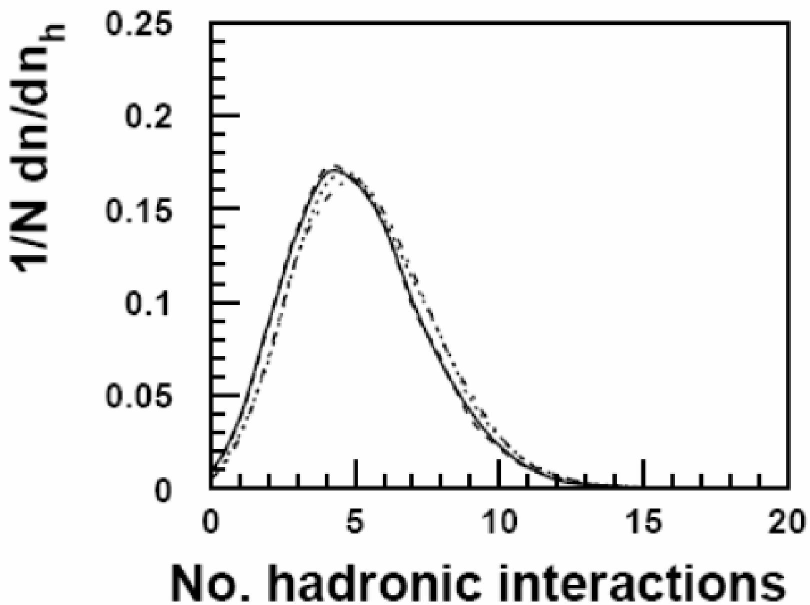
$\overline{Q}$

Mesons stay as mesons

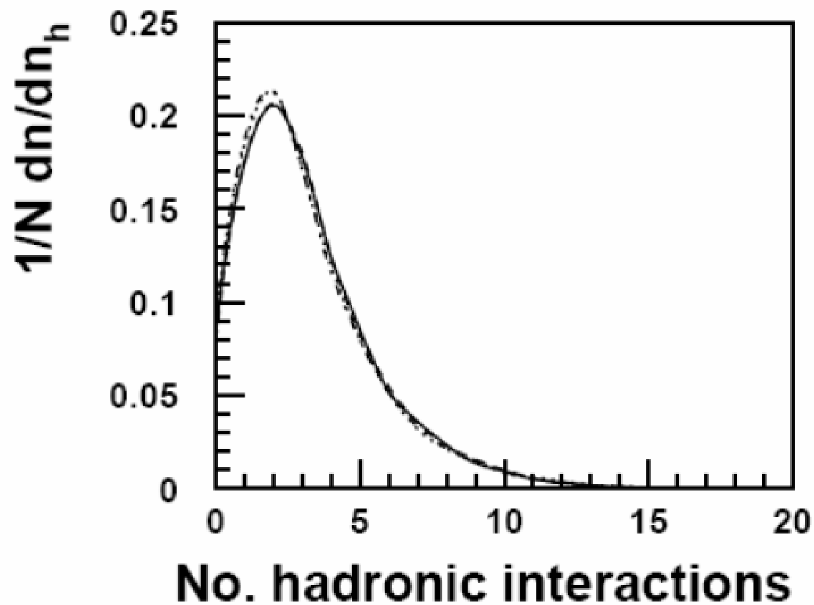
Baryon number annihilation.

$\overline{Q}u$ quark annihilation with nucleon quarks not possible.

(pomeron)



($Q\bar{q}$) – quark annihilation with nucleon quarks



($\bar{Q}q$) – no quark Annihilation with nucleon quarks.

Topologies

Detector with inner tracking and muon tracking chambers enclosed by calorimeter for scattering..

1	One H-hadron produced with non-zero charge which doesn’t change
2	Both particles produced with non-zero charge which don’t change.
3	Both particles produced with non-zero charge. One changes to neutral.
4	One partice produced with zero and the other with non-zero charge. The zero charge particle converts to a charged state.
5	Both particles are produced with non-zero charge but convert to zero charge particles.
6	At least one particle leaves the detector material with non-zero charge of opposite sign to the charge it was produced with.

Expected rates for various topologies for $10fb^{-1}$

Topology	No mixing Mass (GeV)			Maximal mixing Mass (GeV)		
	200	500	1000	200	500	1000
1	4.9×10^5	4.3×10^3	57	4.1×10^5	3.5×10^3	48
2	3.0×10^4	2.6×10^2	3	2.2×10^4	1.9×10^2	2
3	9.6×10^4	8.3×10^2	9	8.2×10^4	6.8×10^2	8
4	6.0×10^4	5.2×10^2	6	4.8×10^4	4.0×10^2	5
5	6.4×10^4	5.3×10^2	6	6.3×10^4	5.5×10^2	6
6	0	0	0	8.1×10^4	7.2×10^2	9

Mixing: neutral H-meson states can oscillate into their anti-particles.

$$H^+(\tilde{u}\bar{d}) + n \rightarrow H^0(\tilde{u}\bar{u}) + p$$

$$H^0(\tilde{u}\bar{u}) \rightarrow \bar{H}^0(\bar{\tilde{u}}u)$$

$$\bar{H}^0(\bar{\tilde{u}}u) + n \rightarrow \bar{H}^-(\bar{\tilde{u}}d) + p$$

Summary

- Observation (or even non-observation) of stable massive particles important in BSM physics at the LHC
- Understanding scattering is critical for any search
- Hadronic scattering model for colour triplets (arXiv:0710.3930) .
- Quantify experimental uncertainties