Scattering of Heavy Exotic Hadrons

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Exotic heavy particles

- Many theories of BSM physics accommodate stable massive particles (SMP).
- Eg, within SUSY
  - Gluino (octet) (Split-SUSY)
  - Stau (colourless) GMSB
  - Stop (triplet) GMSB/5-D SUSY
- If nature grants us a SMP at the LHC/HERA challenge is to detect and extract quantum numbers.
- Heavy coloured particles hadronise to form R-hadrons/H-hadrons
- Hadronic scattering useful discriminating observable

Non-SUSY scenarios

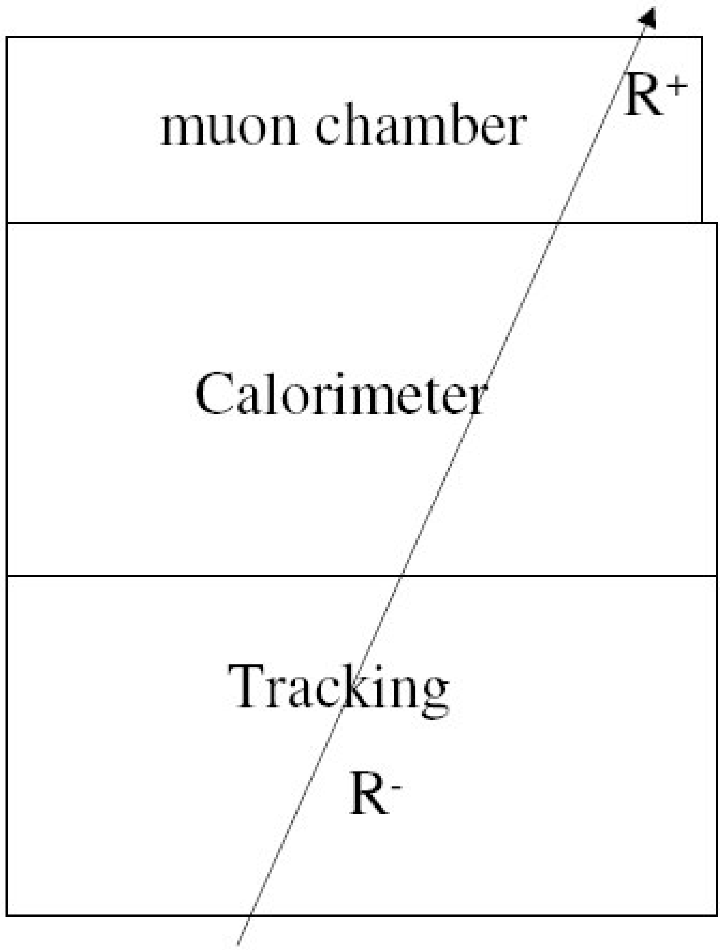
Q_{em}	C_{QCD}	S	Model(s)
0	**8**	1	Universal Extra Dimensions (KK gluon)
± 1	**1**	$\frac{1}{2}$	Universal Extra Dimensions (KK lepton)
			Fat Higgs with a fat top (ψ fermions)
			4th generation (chiral) fermions
			Mirror and/or vector-like fermions
		0	Fat Higgs with a fat top (ψ scalars)
$\pm\frac{4}{3}$	**3**	$\frac{1}{2}$	Warped Extra Dimensions with GUT parity (XY gaugino)
		0	5D Dynamical SUSY-breaking (xyon)
$-\frac{1}{3},\frac{2}{3}$	**3**	$\frac{1}{2}$	Universal Extra Dimensions (KK down, KK up)
			4th generation (chiral) fermions
			Mirror and/or vector-like fermions
			Warped Extra Dimensions with GUT parity (XY gaugino)
$\epsilon < 1$	**1**	$\frac{1}{2}$	GUT with $U(1) - U(1)'$ mixing
			Extra singlets with hypercharge $Y = 2\epsilon$
			Millicharged neutrinos
?	?	$0/\frac{1}{2}/1$	"Technibaryons"

Table 2
Examples of possible SMP states in a variety of models beyond the MSSM (for MSSM SMPs, see Tab. 1). Classified by electric charge Q, colour representation CQCD, spin S, and scenario.

Phys.Rept. 438:1-63,2007
Fairbairn,Kraan,Milstead,Sjöstrand, Skands, Sloan

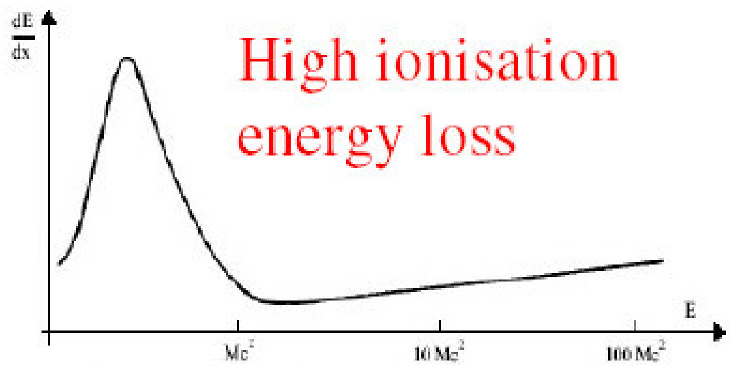
The observation or non-observation of SMPs are an important part of BSM physics program at the LHC/HERA.

Searching for R-hadrons in a generic detector!



(1) Late arriving muon
(2) 'flipped' charge

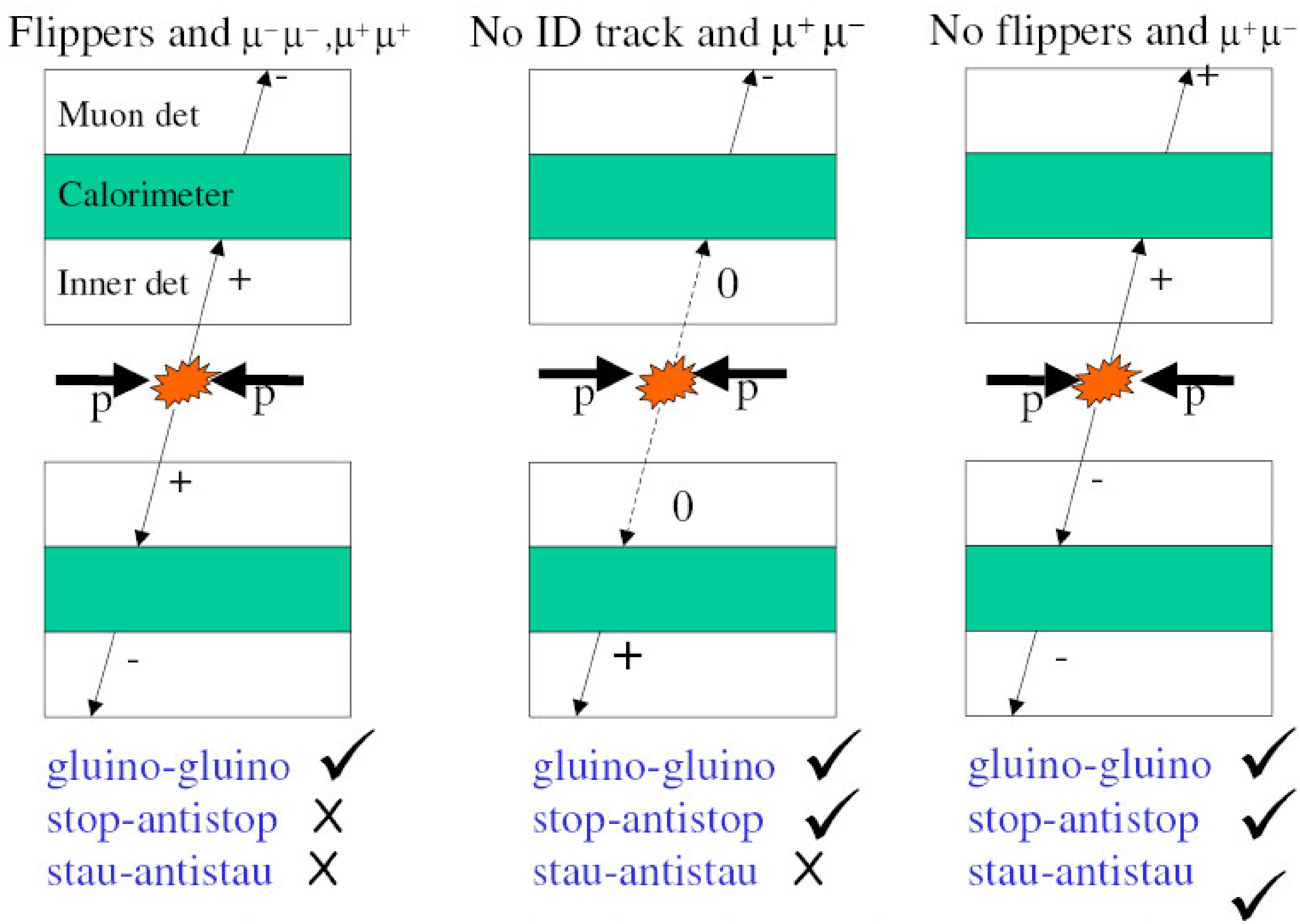
(1) E/p similar to muon
(2) 'steps' of hadronic energy deposition



High ionisation energy loss

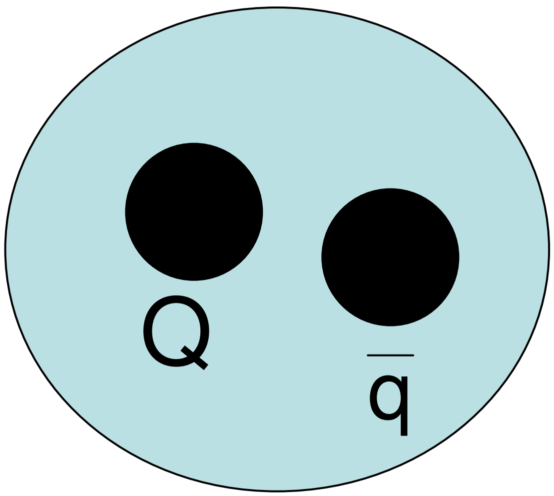
$$\frac{dE}{dx} = -K\frac{Z}{A}\frac{\rho}{\beta^2}\left(\ln\frac{2mc^2\beta^2 E_M}{I^2(1-\beta^2)} - 2\beta^2\right)$$

Different topologies for heavy hadrons



Understanding scattering processes in material is crucial.

What do we know about R-hadron scattering ?



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

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

$\Rightarrow \gamma = E/M = 4$

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

Heavy quark doesn't interact : $\sigma \approx \dfrac{k}{M_Q^2}$

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→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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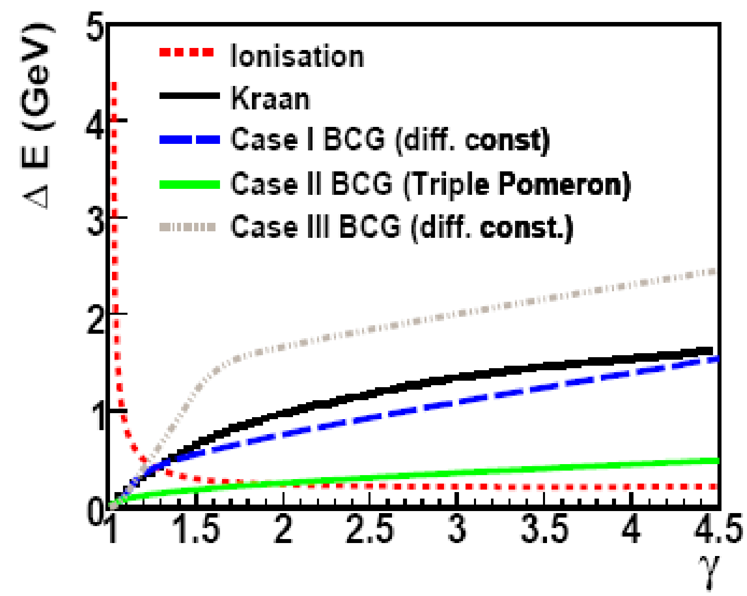
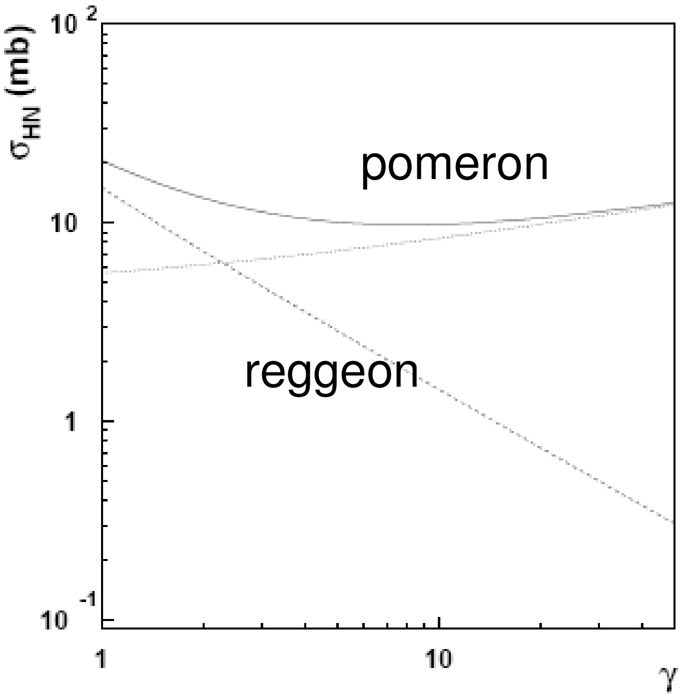


Triple Regge Approach for stable colour triplets

Talk by O. Piskounova (last HERA-LHC meeting)



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

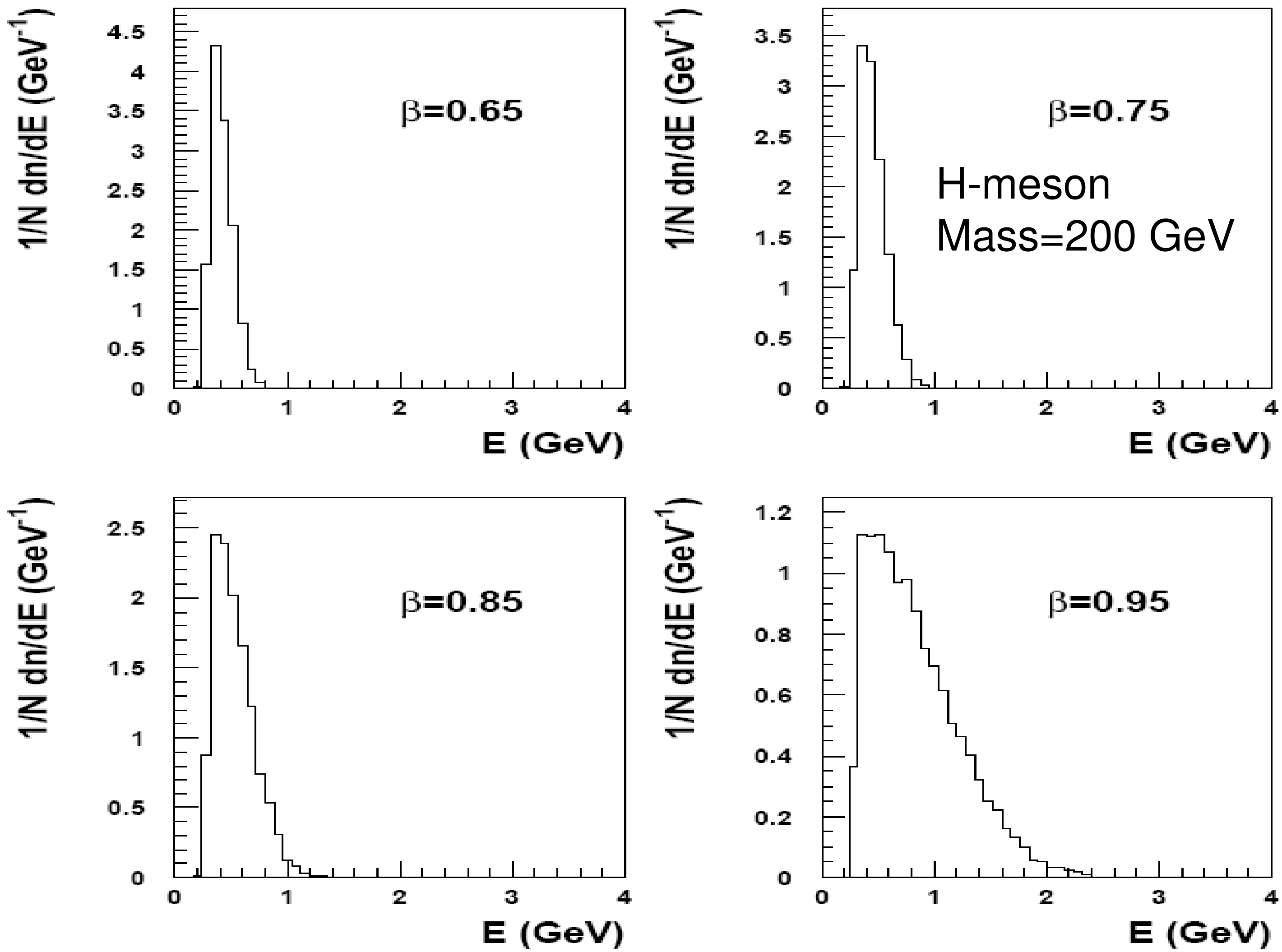
$$\frac{d^2\sigma_{RRR}}{dtdM_X^2}(\gamma, M_X^2) = \frac{1}{M_X^2}\sigma_R^2(\gamma)C_{RRR}\exp[(2B_{RH} + B_{RRR} + 2\alpha'_R\ln(\frac{2\gamma M_0^2}{M_X^2}))t]\left(\frac{M_0^2}{M_X^2}\right)^{\Delta_R} \quad (4)$$

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

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

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

Differential hadronic energy loss

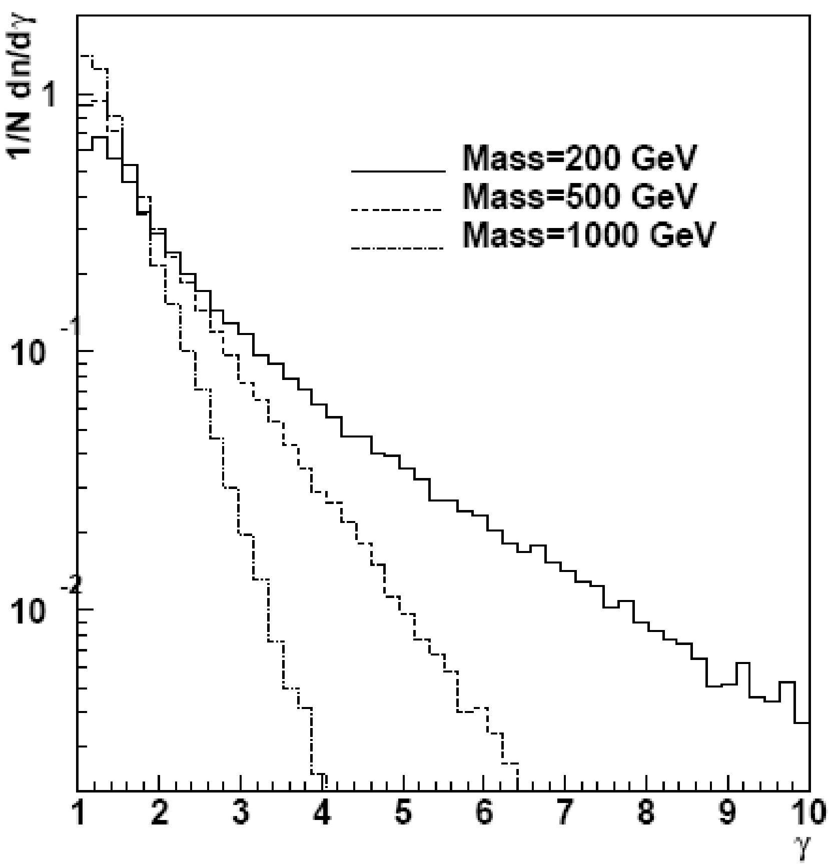


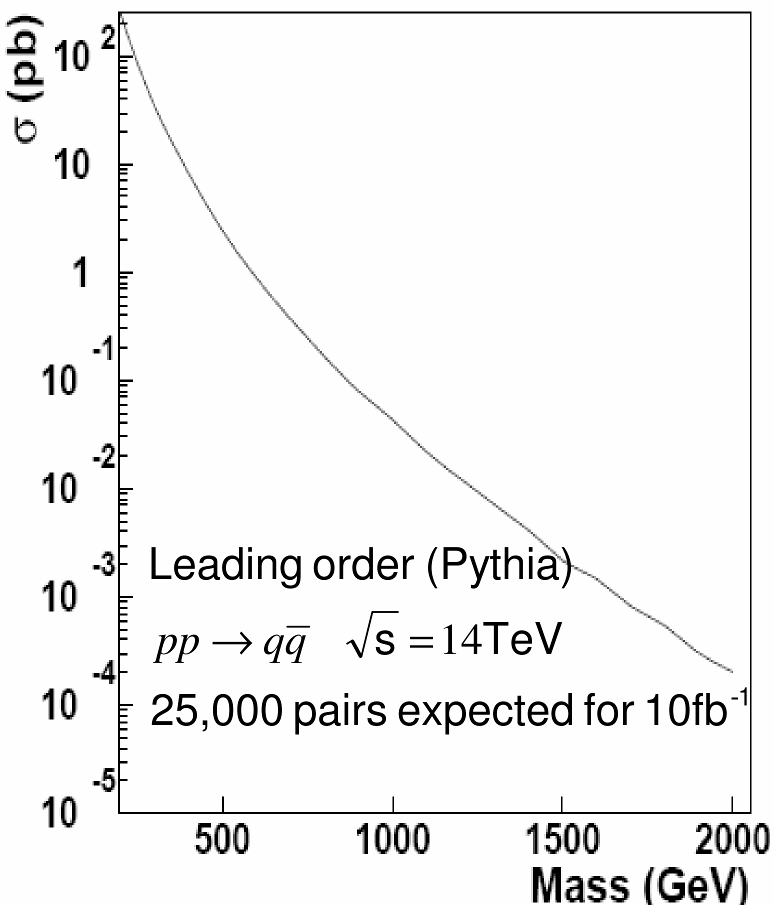
Energy loss per collision around a GeV

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

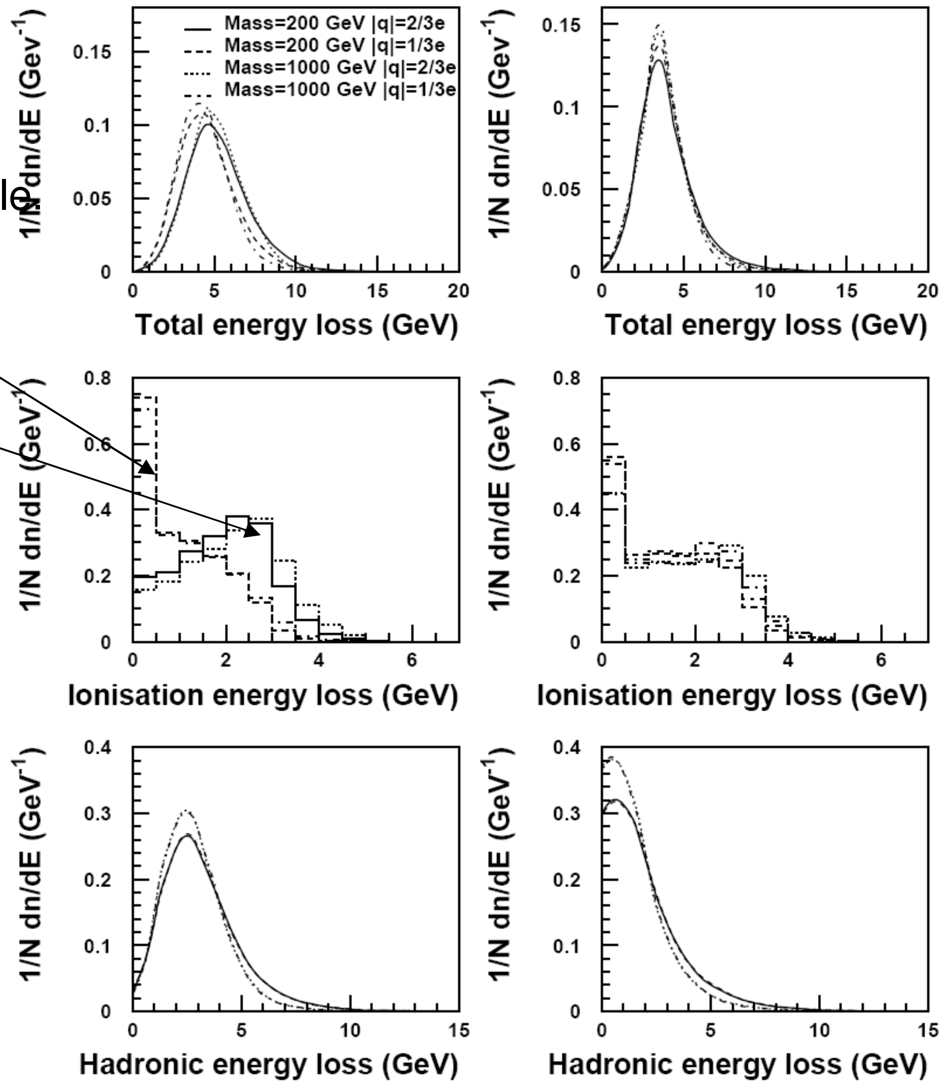
$M_{Q\bar{u}} + N \rightarrow B_{Quu} + \pi$

Reverse reaction not possible

Lowest baryon state : Qud

D - type quarks : neutral

U - type quarks : positive



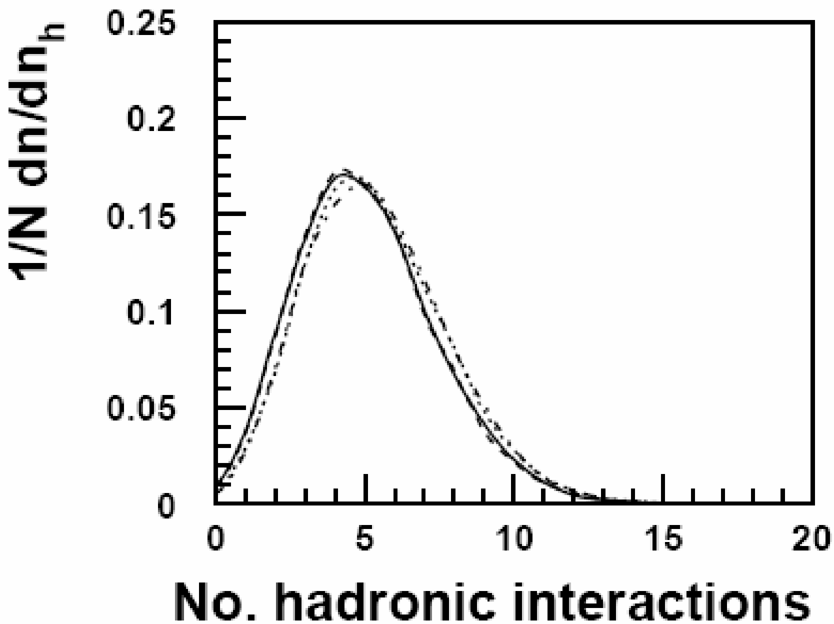
H-hadrons (Q) H-hadrons ($\bar{Q}$)

$\bar{Q}$

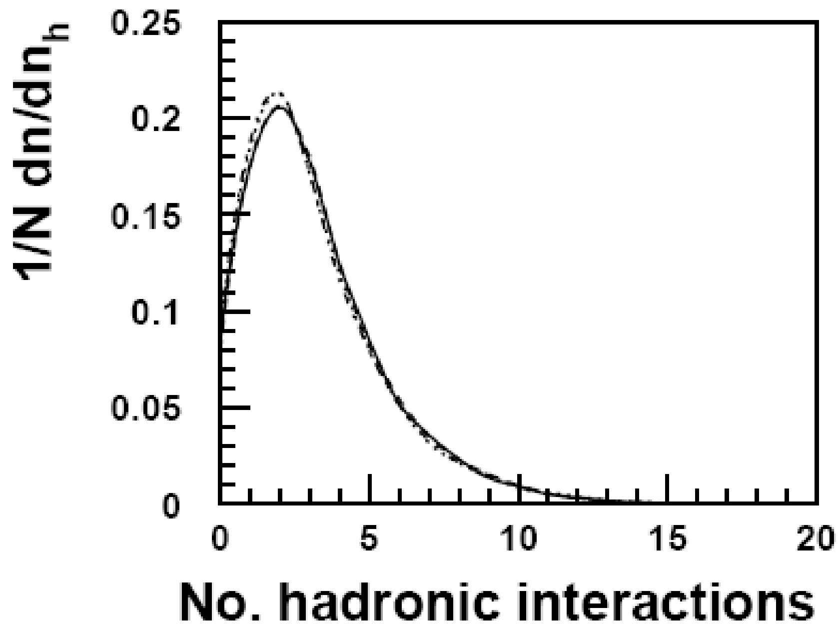
Mesons stay as mesons

Baryon number annihilation.

$\bar{Q}u$ 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

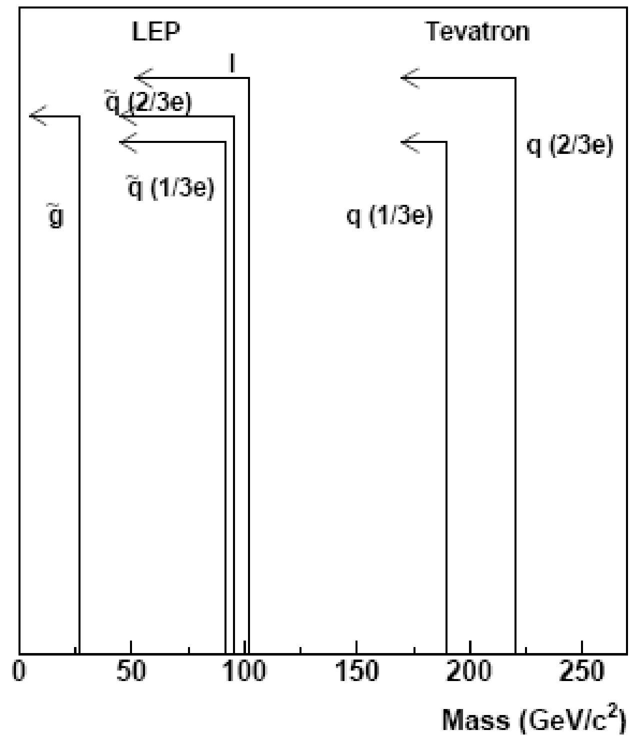
Mixing: neutral H-meson states can oscillate into their anti-particles.

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

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

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

Previous searches



Mostly Tevatron and LEP. HERA makes generic searches for
highly ionising particles. Could be fruitful to also include hadron channel.

Summary

- Stable massive particles predicted in a variety of scenarios of BSM physics.
- Possibility to observe SMPs and extract their quantum numbers.
- Hadronic interactions can hinder and aid a search strategy.
- New approach for quark-like exotic objects.