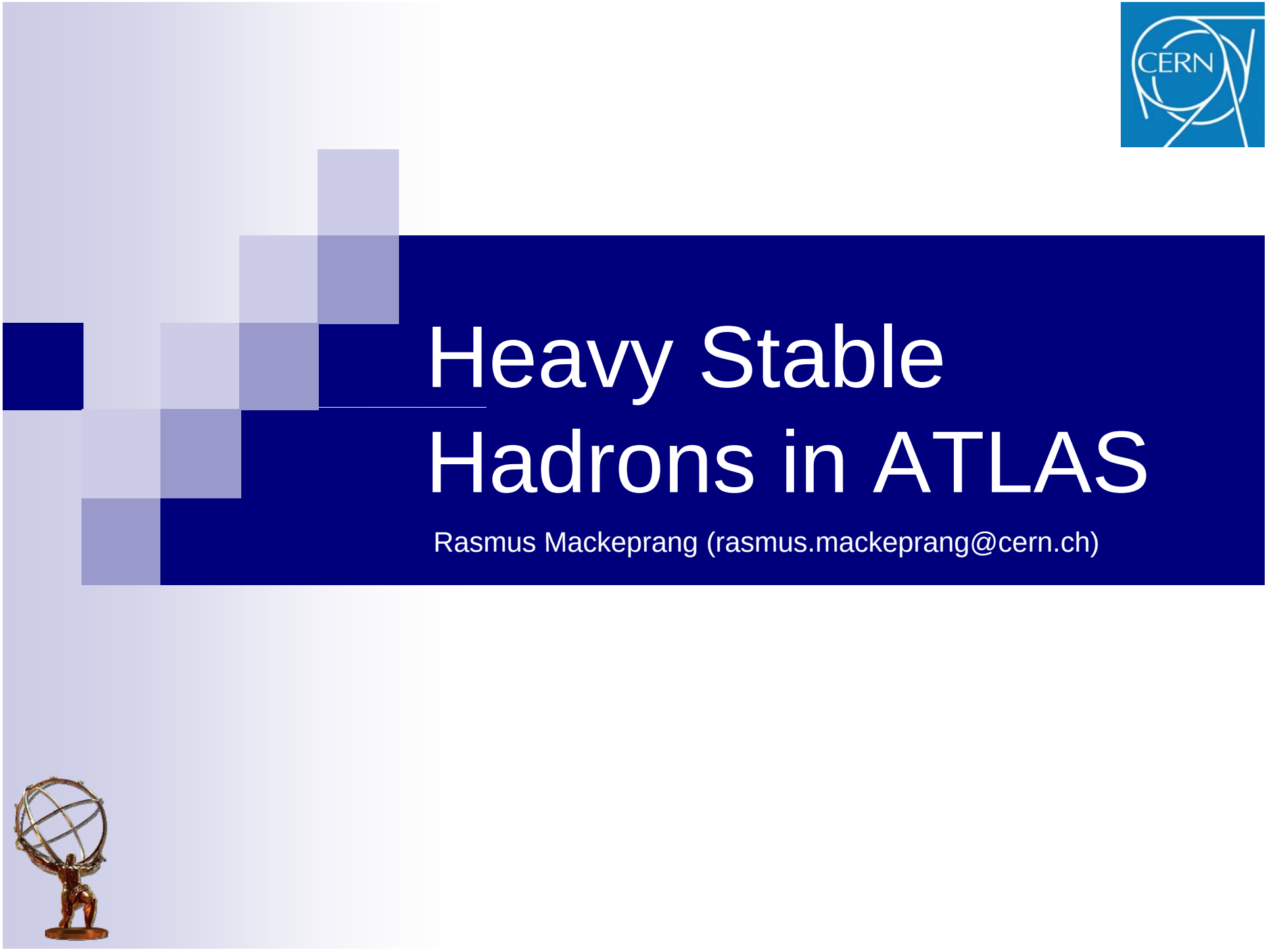


Heavy Stable Hadrons in ATLAS

Rasmus Mackeprang (rasmus.mackeprang@cern.ch)

Outline

- Heavy stable hadrons in BSM physics
- The R-hadron example
- Geant4 simulation of R-hadrons in matter
- An overview of an ATLAS analysis

Split Supersymmetry

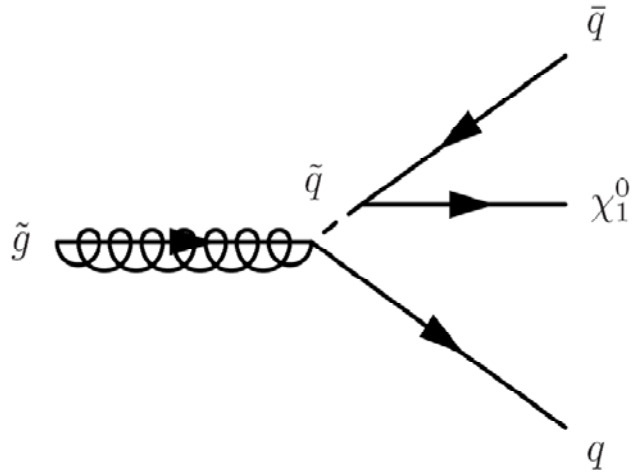
- One of many paradigms floating around these days claiming to be ”natural”.
- SSUSY abandons the hierarchy problem while aiming for the CDM density and gauge coupling unification.

hep-ph/0406088

- *Two* SUSY scales:
  - Low scale (gauginos and Higgsinos)
  - High scale (scalars)

SSUSY Phenomenology

- Gluino is NLSP and squark is **heavy**:



- Life time is linked to the squark mass:

$m_S \gg 1000$ TeV

$$c\tau_{\tilde{g}} \approx 2.4 \times 10^9 \text{ m} \times \left(\frac{m_S}{10^9 \text{ GeV}}\right)^4 \times \left(\frac{1 \text{ TeV}}{m_{\tilde{g}}}\right)^5$$

- Not unreasonable to consider the gluino (effectively) stable.

hep-ph/0408248

Large Extra Dimensions

- KK-excitations a common feature in LED:

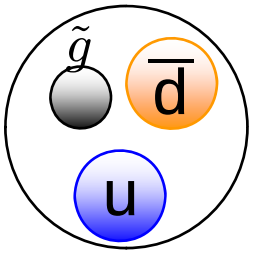
$$E^2 = p^2 + m^2 = \sum_{i=1}^{3+d} p_i^2 + m^2 = |\vec{p}|^2 + \sum_{i=4}^{3+d} p_i^2 + m^2$$

Addition to the effective mass

- Momentum conservation along extra compactified dimensions might imply (quasi-)stable KK states.
- Some models suggest the KK-gluon as the lightest state.

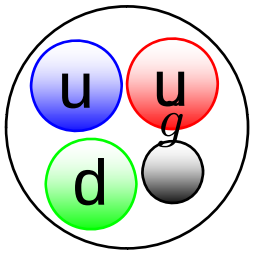
hep-ph/0201300

Heavy Hadrons

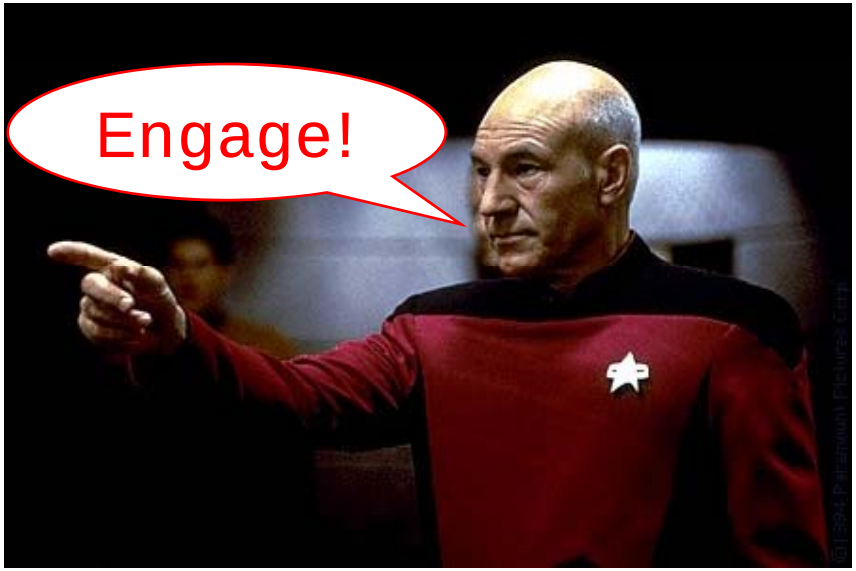


← A gluino R-meson

A gluino R-baryon →



- A variety of physics cases contain heavy stable partons.
- Gluinos, stops, KK-gluons...
- It might make sense to study these things in interaction with matter.



Disclaimer:

The author would like to emphasize the fact that any similarity to actual physics, real or imagined is purely coincidental…

(OK, maybe not quite)

- This is a simple model of complex physics
- This complex physics might indeed result in vastly different phenomenologies

- **Aim:** In using a *simple* model that is *easily applicable* to varying physics scenarios the aim is to make a *general* statement about the potential for discovery of phenomenologies containing long-lived coloured objects.

Geant4 Simulation

Basic credo:

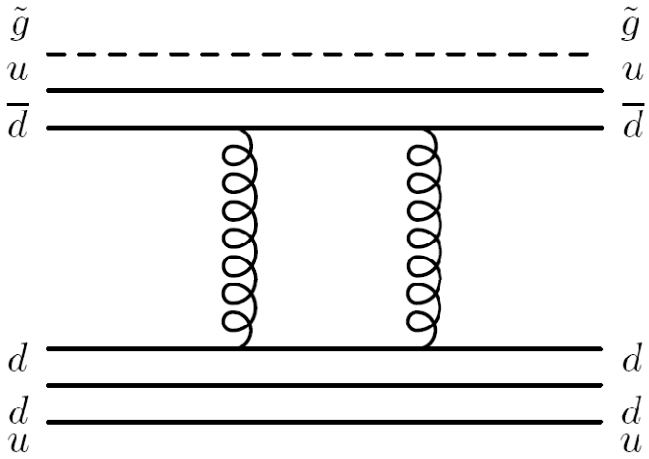
- The hadron may be modelled as a heavy parton (HP) and a light quark system (LQS)
- Hadronic interactions may be modelled as interactions between the LQS and the traversed matter.

  (motivated by the observation that the spatial extent of a wavefunction scales with $1/M^2$)
- Imposing that the LQS and the HP be comoving results in the observation that the available kinetic energy in a collision is:

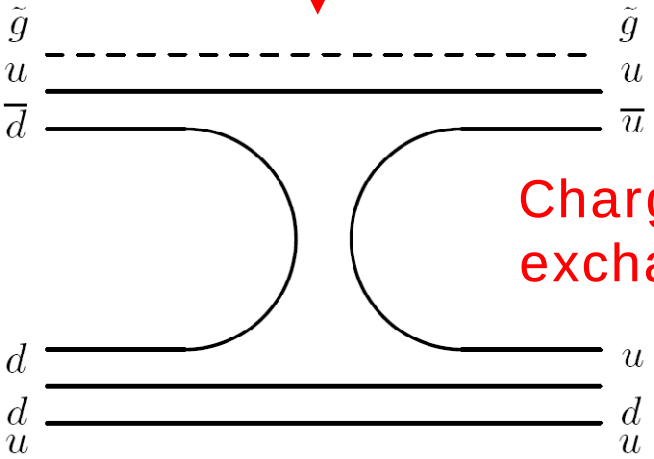
$$E_{kin,LQS} = \frac{M_{LQS}}{M_{tot}} E_{kin,tot}$$

⇒ We may view the collisions of these potentially **very** heavy particles with nuclear matter as *low-energy* collisions of the LQS with matter

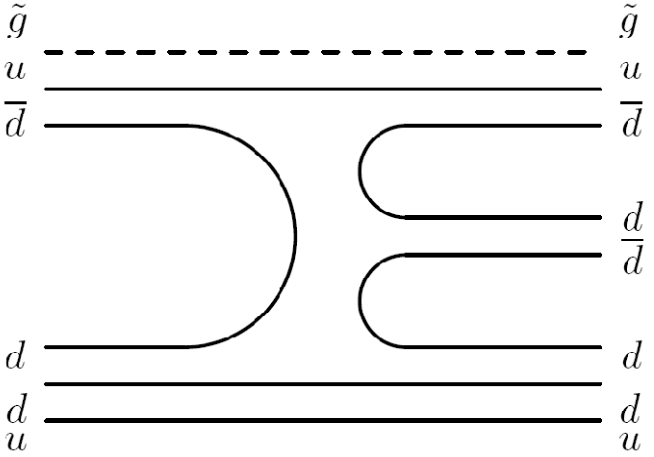
Possible nuclear reactions



Quasi-elastic scattering



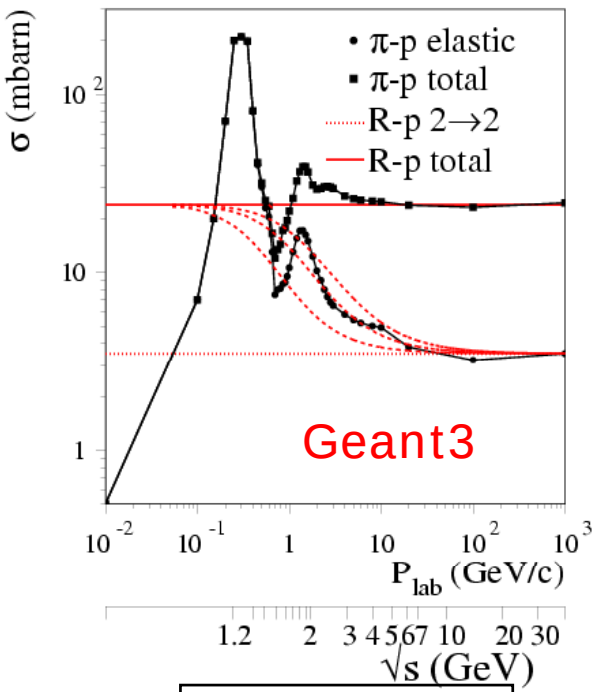
Charge exchange



2→3

Interaction Cross Section

- Cross section matched to the high energy pion cross section. Elastic / inelastic parts matched.
- Possibility of resonances added.



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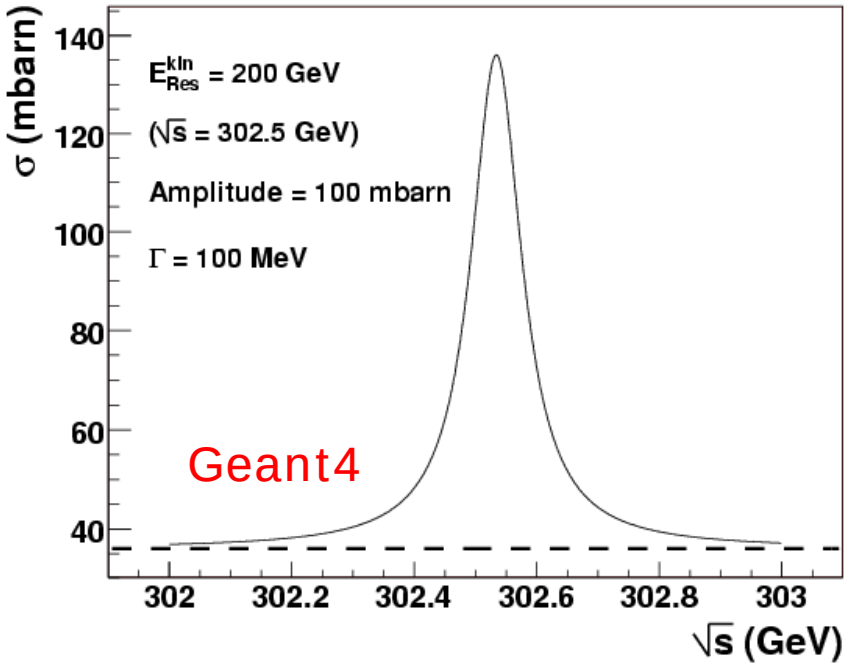
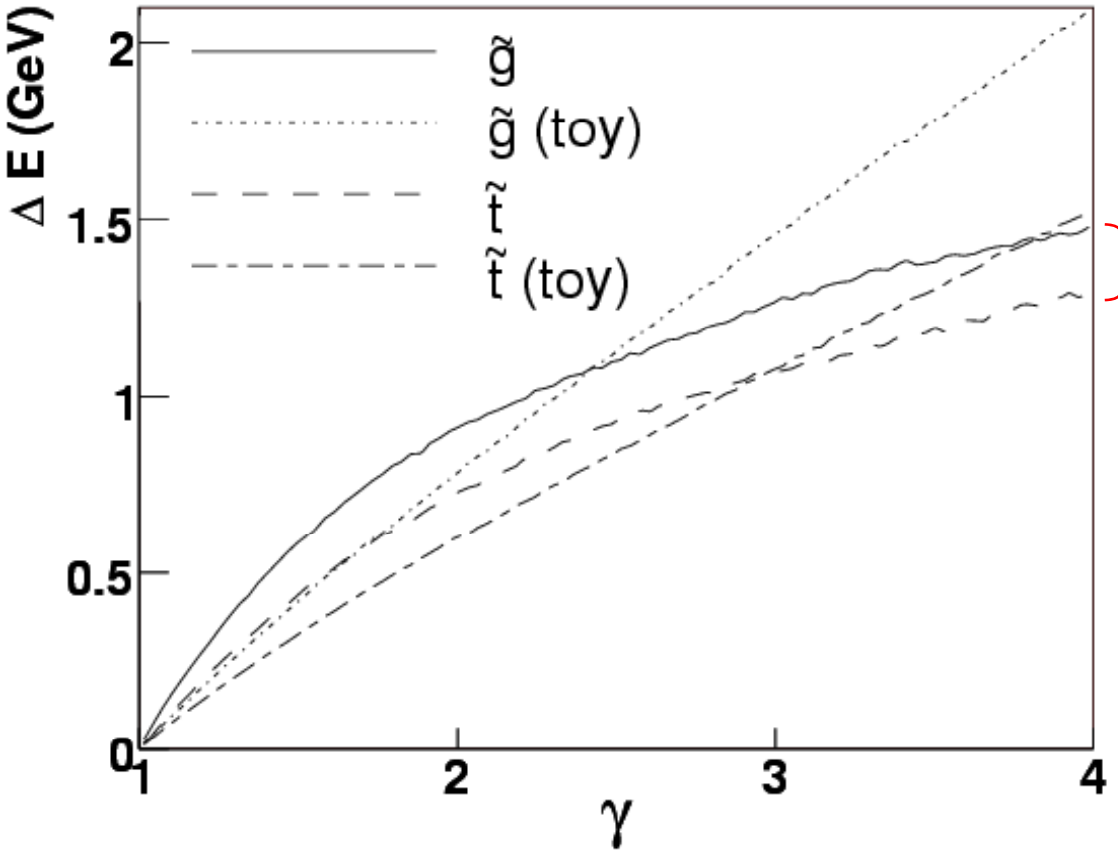


Mackeprang & Rizzi,

Eur.Phys.J.C50:353-362,2007

Kinematics & Energy Loss

- Two models have been implemented, a toy model and a full parametrised model based on the G4 version of the GHEISHA code.

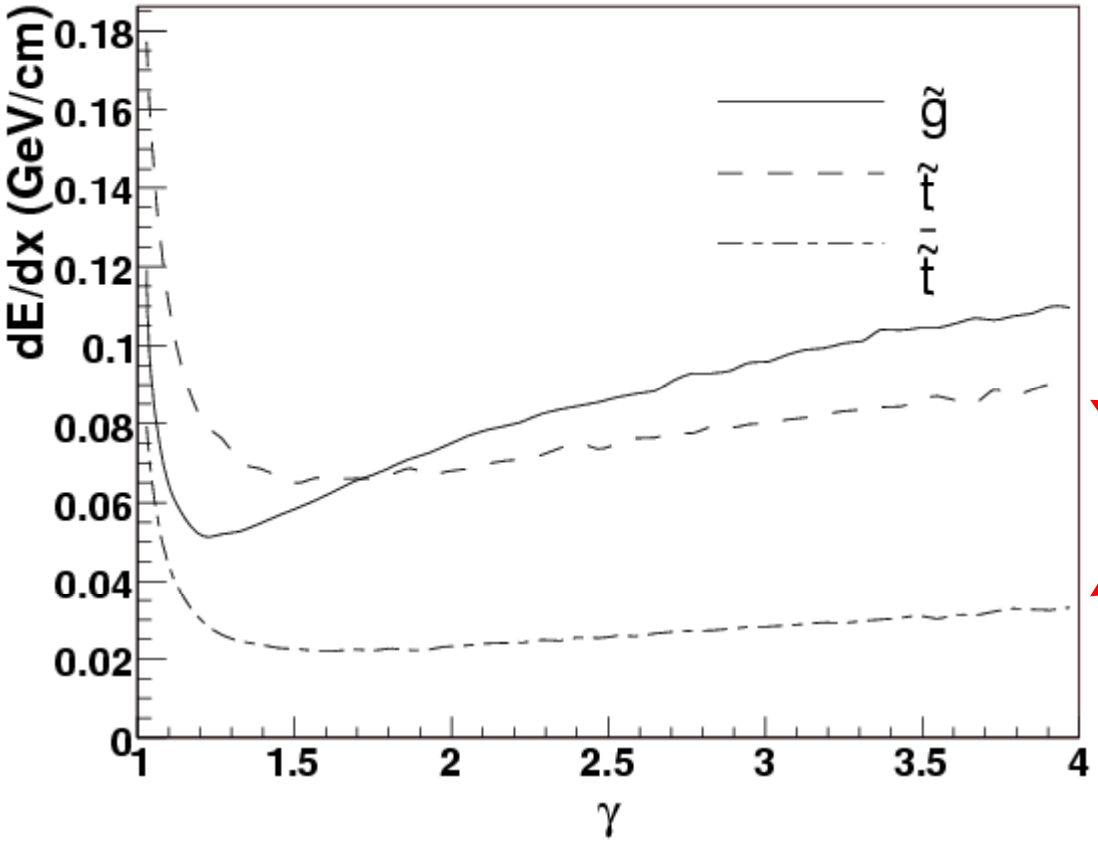


Clear effect of including nuclear effects.

Energy loss per hadronic interaction of a 300 GeV/c^2 sparticle hadron in iron

dE/dx

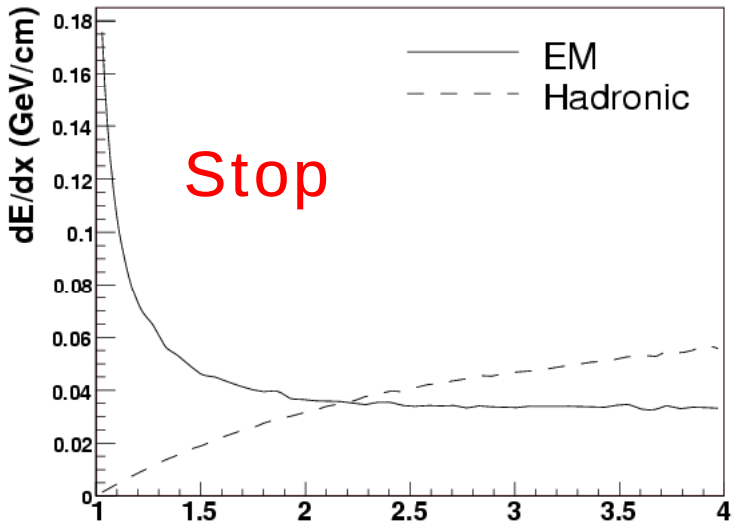
- Energy loss per unit length in iron:

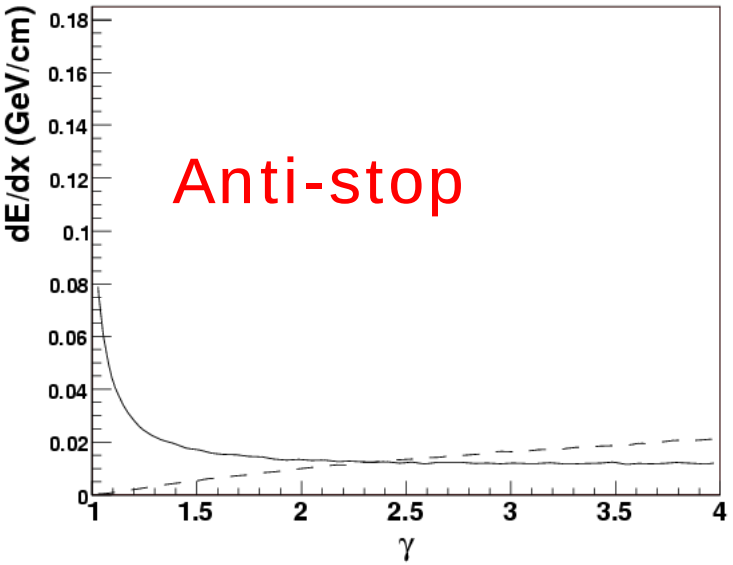


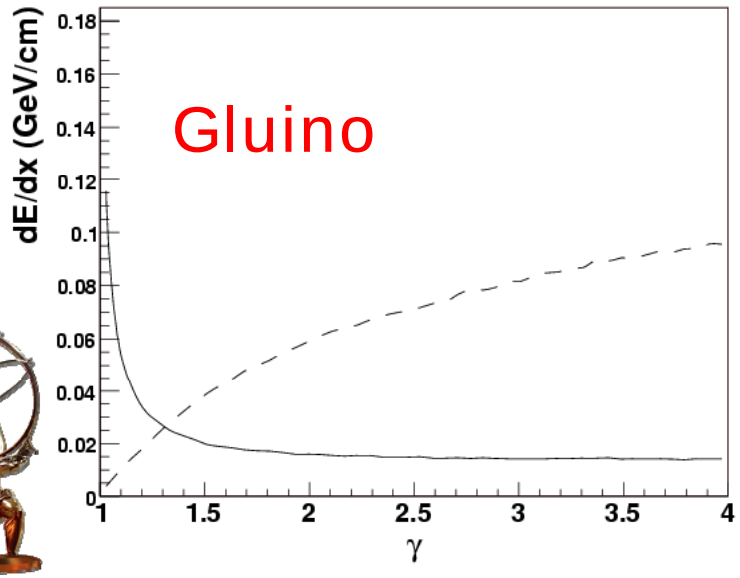
Large stop / antistop difference

- Sparticle mass is 600 GeV/c^2

dE/dx cross-over



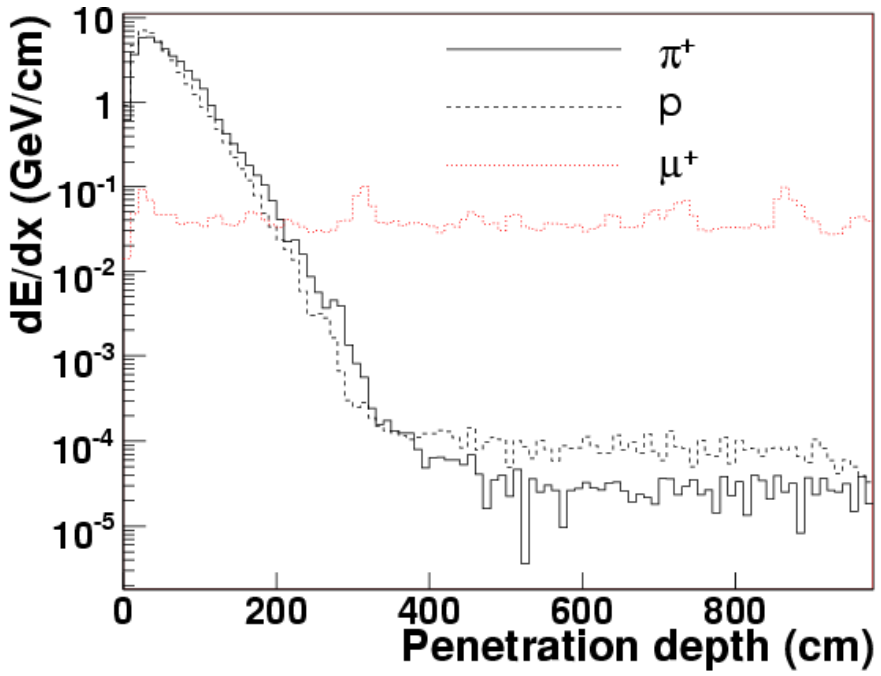


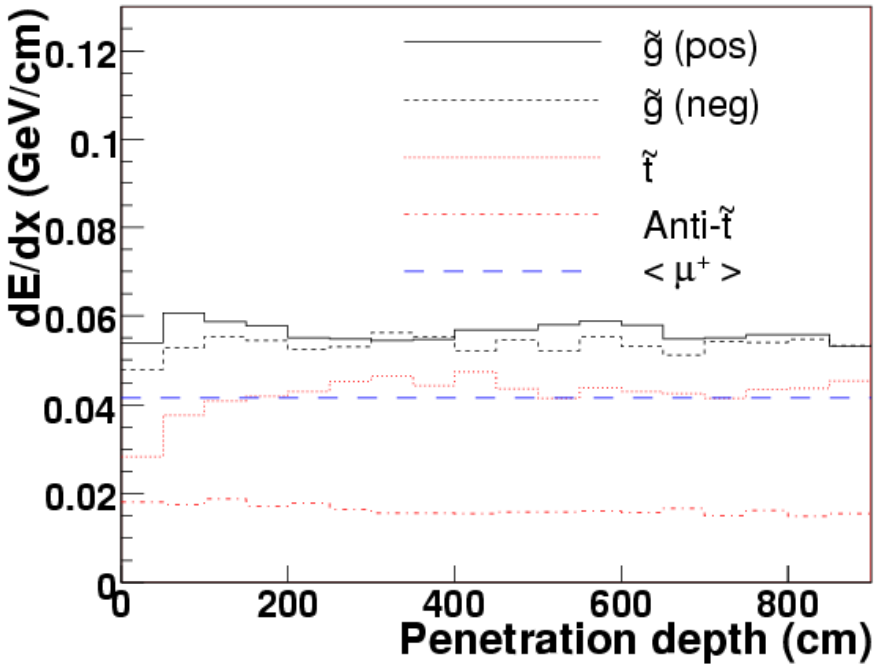


- Scale difference evident between stops and anti-stops.
- Higher ionisation loss for stops than for gluinos.
- Hadronic onset sharper for gluinos than for stops and anti-stops.

Longitudinal Shower Profiles

- Energy deposition per unit length (using QGSP physics list):



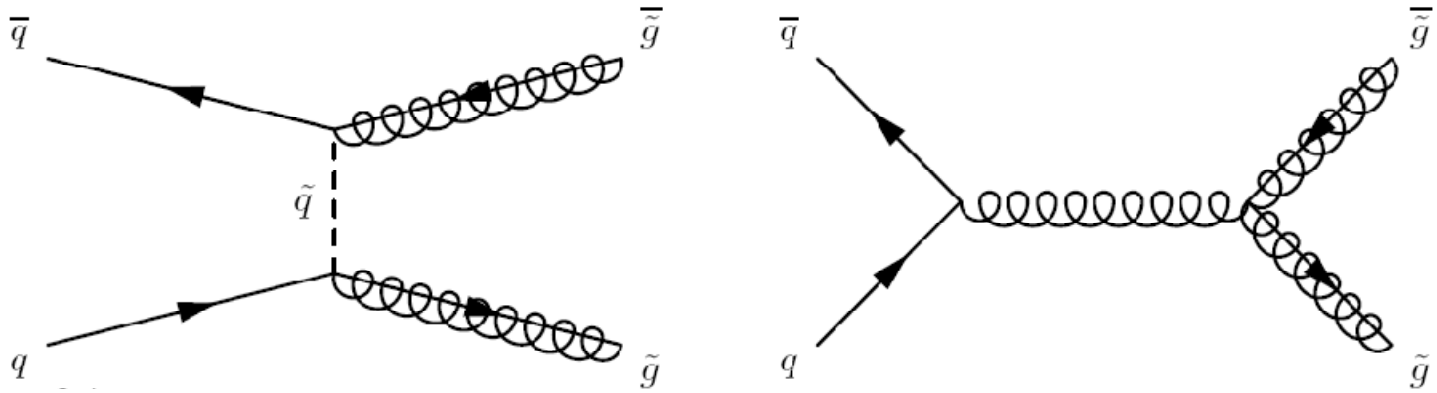


- dE/dx conclusions corroborated
- Energy deposition comparable to that of muons

➔ Signature: High p_t object changing charge while escaping the detector (possibly moving slooowly)

Split SUSY event generation

- Only $gg \to \tilde{g}\tilde{g}$ has been generated as this is independent of the squark mass.
- Diagrams *do* exist for $ff \to \tilde{g}\tilde{g}$ production, though:

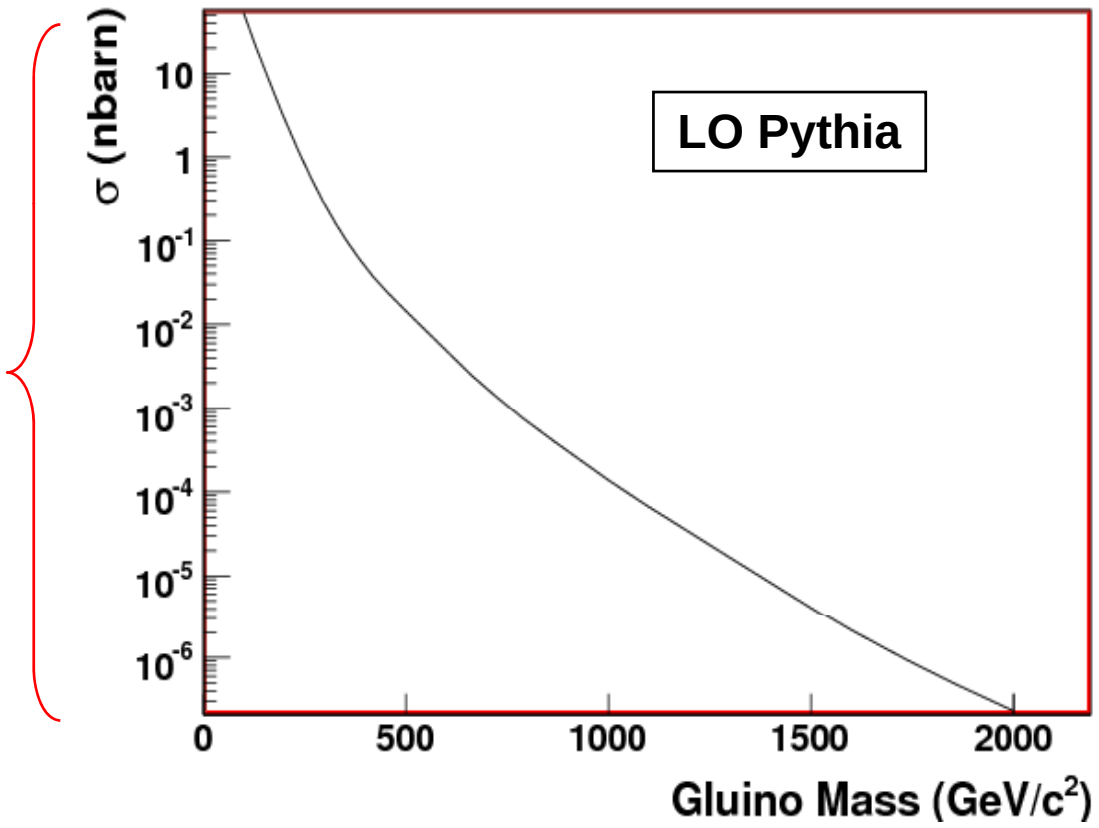


- There is significant destructive interference between the two.

$\Rightarrow$ High squark mass dependence of *ff* production.

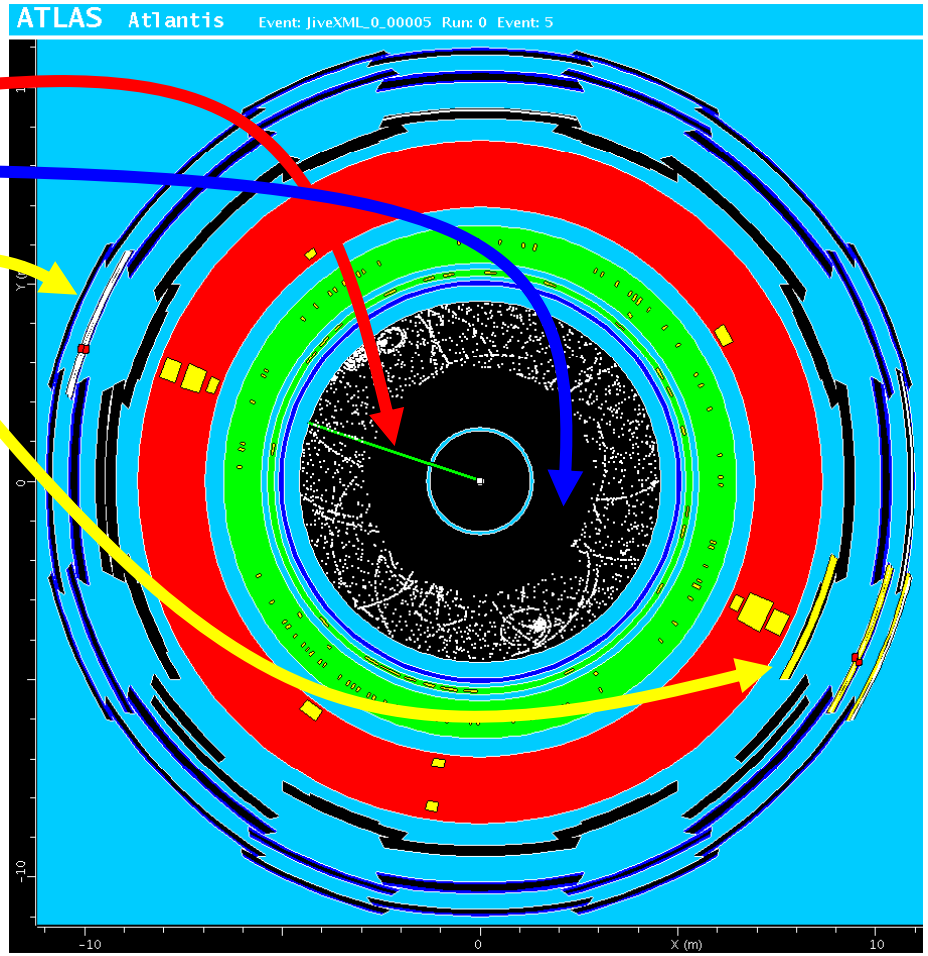
Production cross section

8 orders of magnitude…



Pretty pictures! Weeeee! ☺

- Yup, that looks like QCD
- A 10 GeV track cut does wonders
- One high-p_t track
- Nothing on the other side
- Signal back-to-back in the muon system



- Just one of the number of dead give-away signatures of these beasts.
  - Like-sign muons back to back (exclusively gluinos)
  - Factor two in momentum measurement of b2b muons
  - Charge flip between ID and muon system.
  - Missing ID track / muon track found
  - Combinations...

Types of cuts

- P_t cut: Muons with transverse momenta of 100s of GeV/c are rare
- Jet veto: R-hadron events rarely contain hard jets and these are *not* affiliated with the R-hadron.
- R-hadron likeness criteria:

Any one

1) A hard muon track with no matching ID track.
2) A hard muon track with matching ID track of opposite charge.
3) A hard muon track with matching (or back-to-back) ID track with low HT/LT fraction in the TRT.
4) Two hard back-to-back ID tracks with low HT/LT fraction.
5) Two likesign back-to back muon tracks.

Turns out to be weak → Abandoned

- Event selection was optimised for a gluino mass of 1 TeV/c^2 relative to the background.

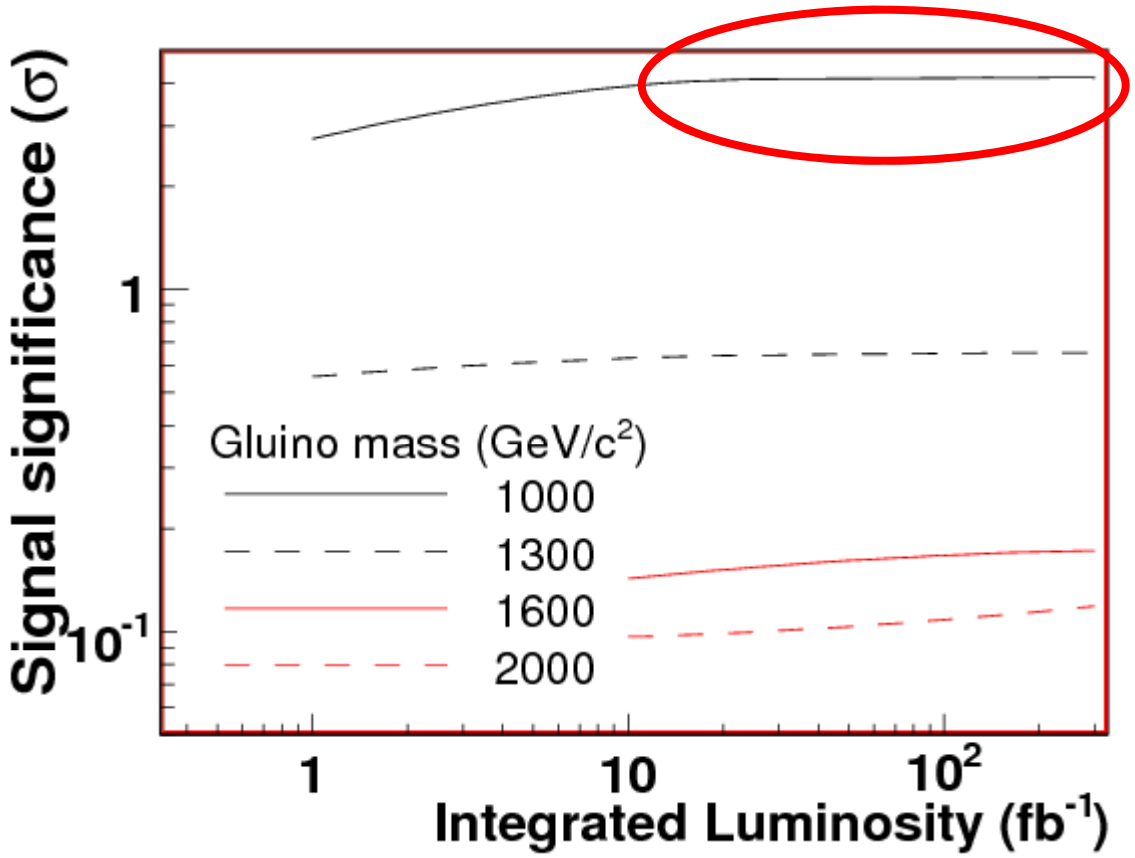
Acceptance numbers

Sample	Accepted events	Rate (Events/fb^{-1})
100 GeV/c^2 gluino	20	1.06×10^5
300 GeV/c^2 gluino	235	6.44×10^3
600 GeV/c^2 gluino	551	2.70×10^3
1000 GeV/c^2 gluino	774	10.7
1300 GeV/c^2 gluino	732	1.20
1600 GeV/c^2 gluino	685	0.147
2000 GeV/c^2 gluino	546	1.26×10^{-2}
J5	1	0.893
J8	1	2.26×10^{-3}
$Z \rightarrow \mu\mu$	1	0.776

Hard to prevent discovery...

Optimised at this mass

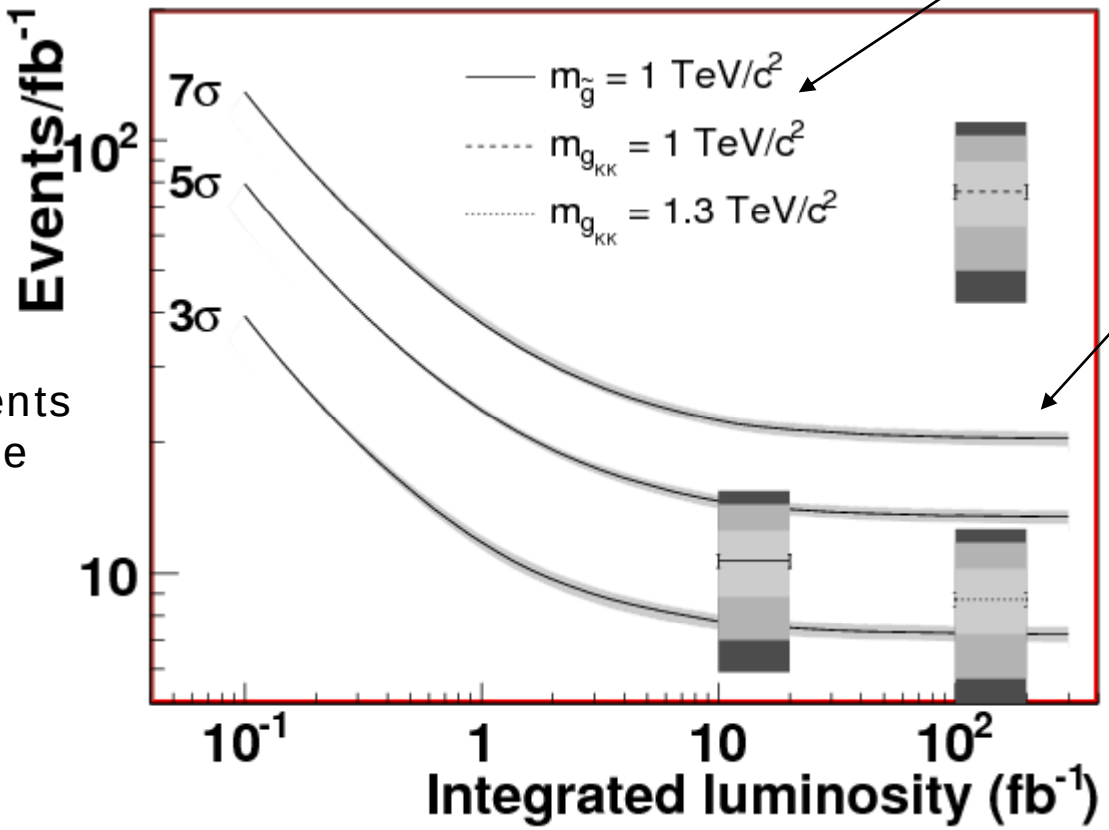
Signal Significance



If we don't know the background better, large statistics won't help…

Signal significance

KK-gluons treated by reweighting.



Signal events *Passing* the cuts

K-factors on background included as error band

Significance contours ”flatten”, as the knowledge of the background is limited

The three systematic errors added in succession to the statistical error are:

G4 parameters: 17%, PDFs + K-factors: 30%, PYTHIA parameters: 9%

Conclusions & Outlook

- A Geant4 based simulation for heavy stable hadrons has been developed and adopted by ATLAS and CMS.
- The move from G3 to G4 has obvious advantages in terms of modularity of code and run-time reconfiguration.
- This is the first full ATLAS analysis using GEANT4 simulation and a detailed background description to study discovery potential of heavy stable hadrons.
- The simulation software presented here is applicable to a broad range of physics scenarios. Should R-hadrons or the like be discovered there will be basis for a more rigorous theory-driven implementation. (Your job... :-P)