Searching for Heavy Stable Hadrons with ALICE in pp collisions

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- Motivation
- R-hadrons
- Pythia results
- Detector response simulations of R-hadrons
- Conclusions and Outlook

Motivation

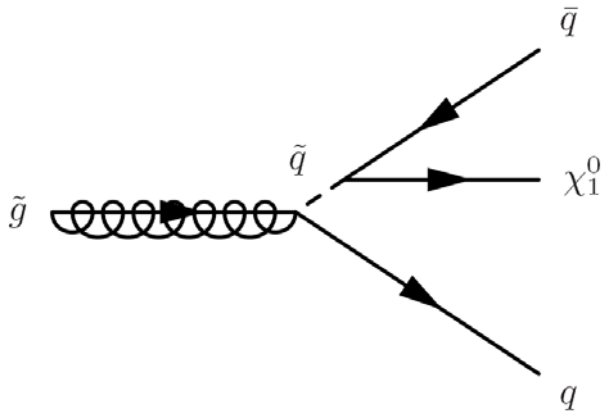
- The start-up period of LHC is also ideal for ALICE to look for new physics because of the lower luminosity
- Heavy Stable Hadrons
  - Predicted by some theories for new physics
    - SUSY-models (long lived gluino/stop/stau)
    - Universal Extra Dimensions (UED) (Stable KK excitations of the gluon)
  - Limits from previous experiments for R-hadrons(arXiv:hep-ph/0611040v2)
    - LEP: m>27 GeV at 95% CL
    - Tevatron: m>170 GeV (not explicitly considered)
- Hadrons
  - Coloured = ”large” cross sections
- ”Stable”
  - So long lived that they make it through the detector (direct detection)
- Heavy (mass > 100 GeV)
  - Slow -> Could be difficult to trigger on for ATLAS and CMS ($\beta > 0.7$)
  - Ionization different from ”normal” high momentum particles
  - TOF could give clean signal

R-hadron – Our unusual suspect

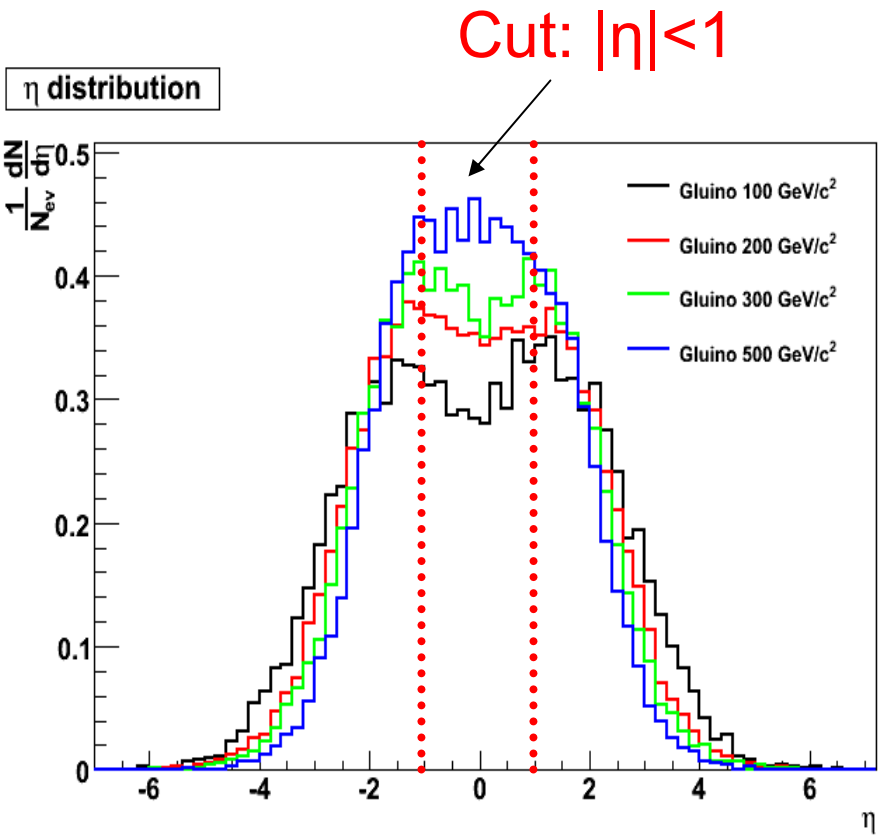
- SUSY: R-hadrons consist of a heavy gluino/squark and quarks (ignore glueballs)
  - Quark system interacts
  - Gluino is ”just” a reservoir of kinetic energy
- R stands for R-parity = number of SUSY particles is conserved
- Split-SUSY: gluino is light (mass < 1 TeV), squark is heavy (mass >> 1 TeV)
  - Because squark is heavy, the R-hadron decay to neutralino is suppressed

R-hadrons:

$$qqq\tilde{g}, q\bar{q}\tilde{g}, \ldots$$



Pythia simulations



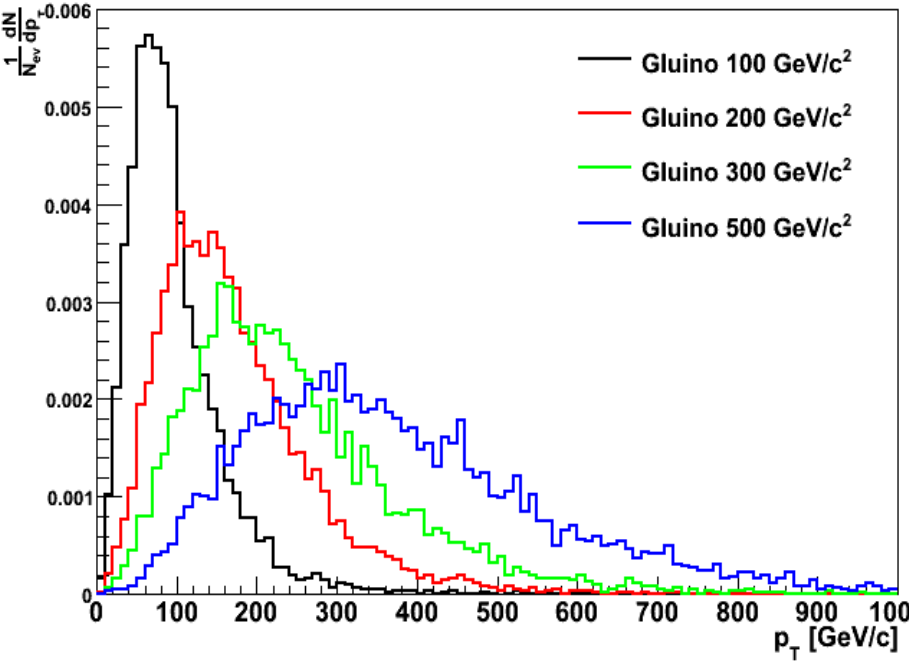
- R-hadrons are pair produced approximately back to back
- The probability for a R-hadron to be charged is ~50%
- 10000 Pythia (6.4.10) events were generated for each different gluino mass (100, 200, 300, 500 GeV)
- Used a cut in pseudorapidity: |η|<1 (to have full length tracks in the TPC)

Increasing gluino mass, the particle are produced more central

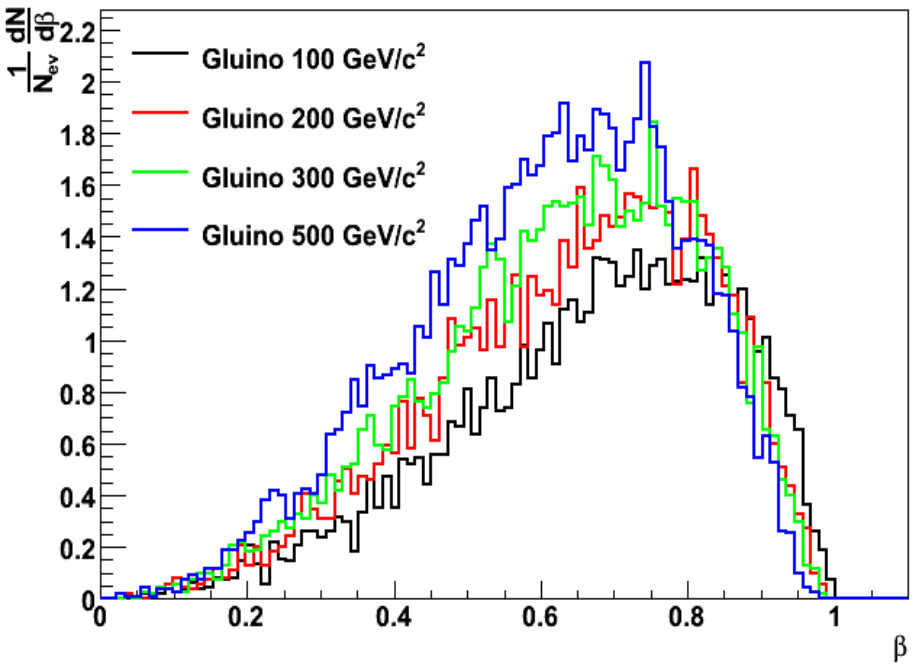
Pythia results - pT and β distributions

TPC acceptance

p_T distribution



β distribution

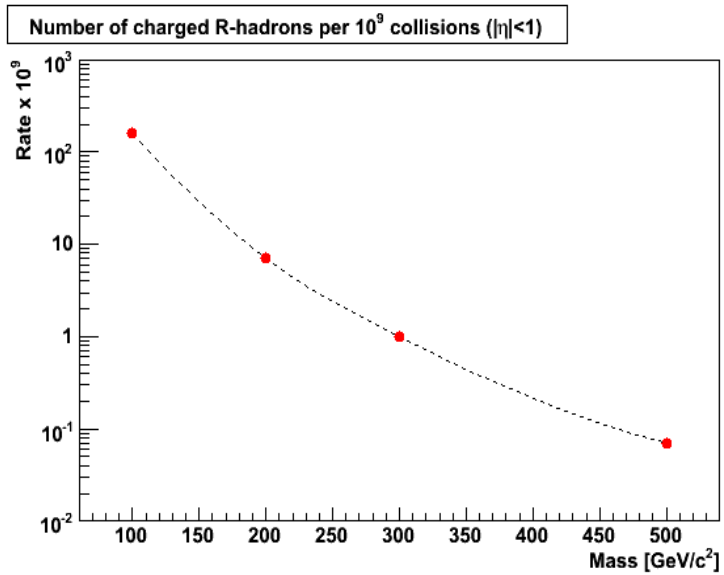


- A broad pT distribution -> Challenge for ALICE because of the low magnetic field
- After cut, gluino velocity in the range 0.3<β<0.9
  - R-hadrons are very different from ordinary particles (p, e, μ, π, K) at momenta in this range P > 50 GeV

Pythia results – R-hadrons rate

$$R \sim 2 \times \frac{\sigma_{Rhadron}}{\sigma_{pp}} \times Acc, \sigma_{pp} \sim 110 mbarn$$

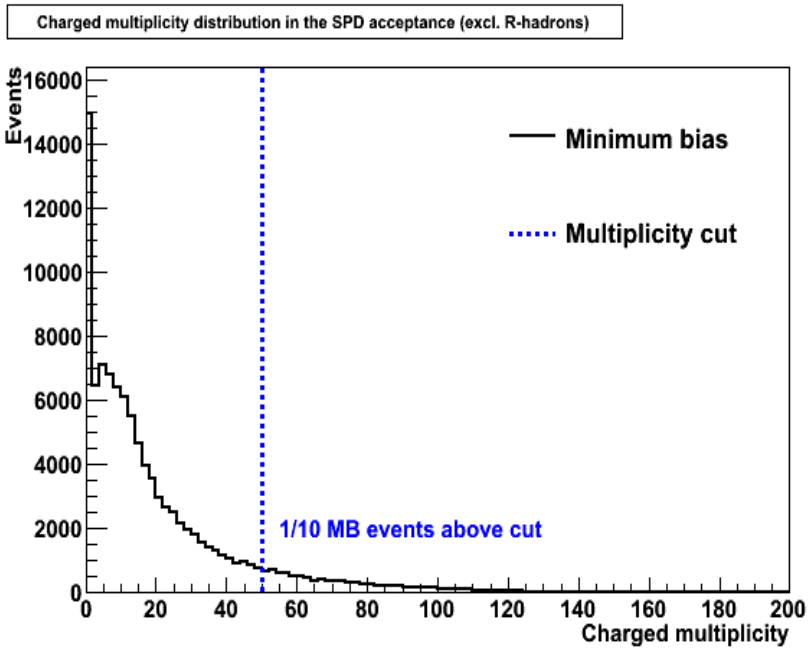
Gluino Mass [GeV]	σ [mbarn]	Acc	Rate_charged (50%)
100	5.6×10^{-5}	0.31	1.6×10^{-7}
200	2.2×10^{-6}	0.36	0.7×10^{-8}
300	2.8×10^{-7}	0.38	1.0×10^{-9}
500	1.6×10^{-8}	0.44	0.7×10^{-10}

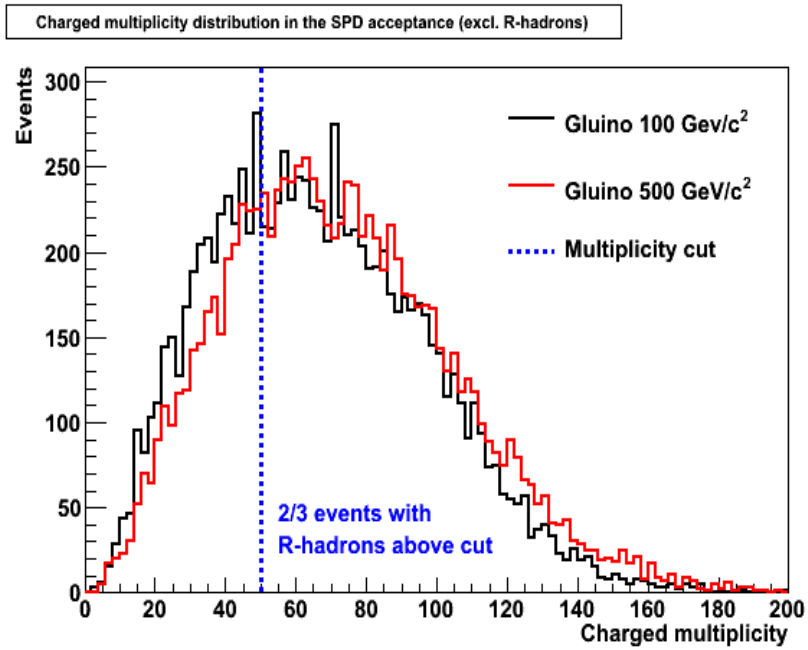


- Golden signal would be two slow back to back high momentum particles

Triggering on multiplicity to enhance the R-hadrons

Number of charged tracks in the silicon pixel acceptance (|η|<2)



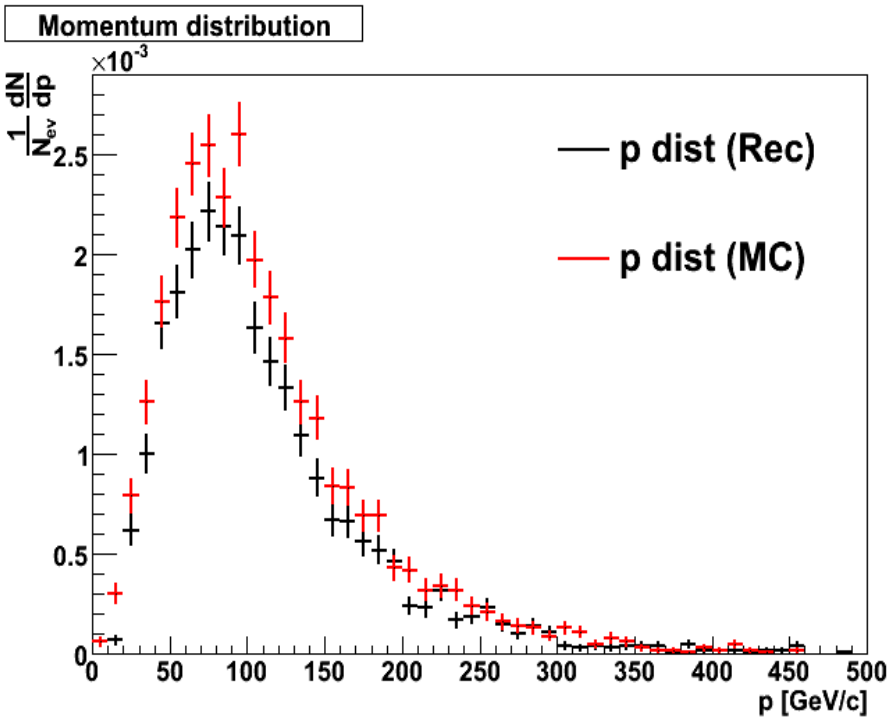


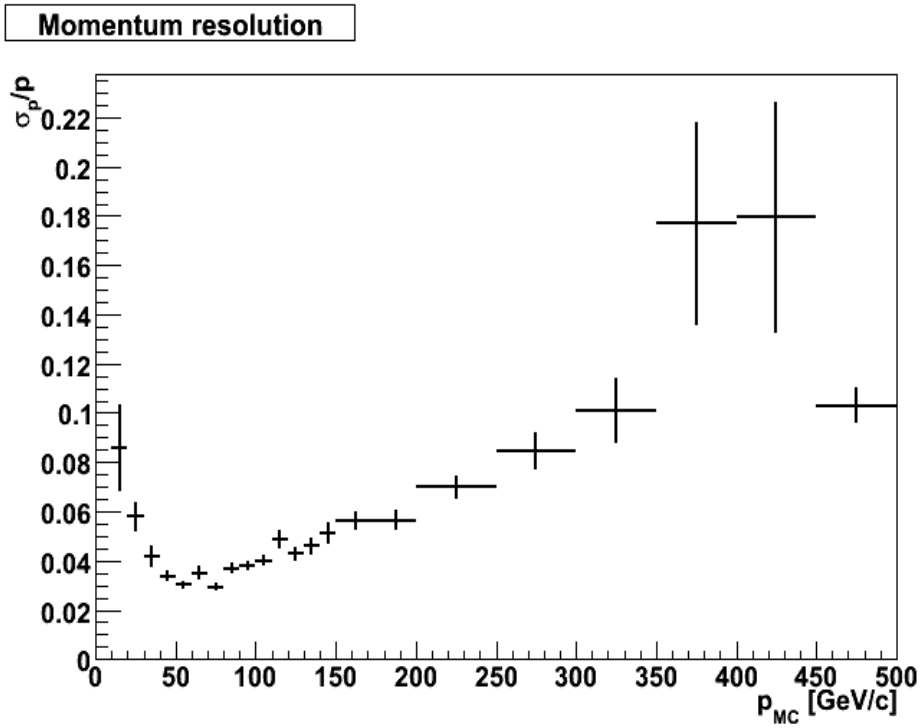
- When ALICE has to downscale the triggers, triggering on multiplicity can enhance the R-hadron sample
  - Example: Selecting the 10% events with the highest multiplicity only removes 1/3 of the R-hadrons: factor ~ 7 enhancement

Detector response simulations

- Pythia input -> ALICE (GEANT 3 based) Simulation
  - Magnetic field 0.5 T
- R-hadron quark exchange interactions are not taken into account because of the low material budget
- R-hadrons (gluino mass 100 GeV) with charge +1 are simulated and reconstructed
  - Reconstruction efficiency (ITS, TPC, TOF): ~65%
    - Tracking (ITS+TPC): ~83% (10% dead zones)
    - TOF matching: ~80% (10% loss due to η coverage)
  - Also investigated exotic charge: +2/3, +4/3, +2
- PID signals are compared to pions, protons, and muons with the same momentum distribution

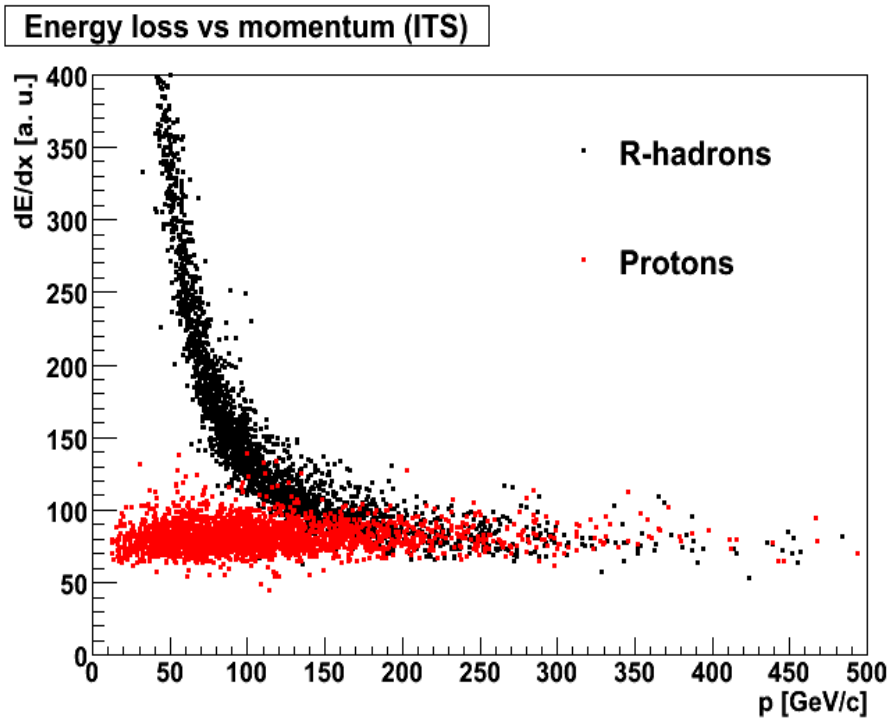
Momentum resolution

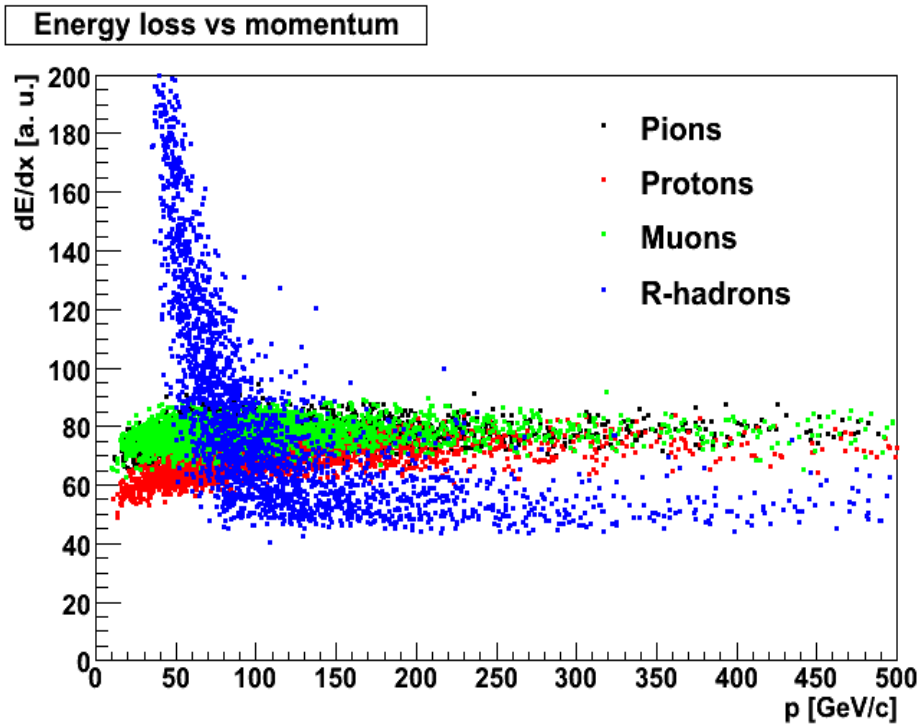




- Momentum resolution is ~4% at p=100 GeV/c
- Interesting, multiple scattering dominates for p<50 GeV/c

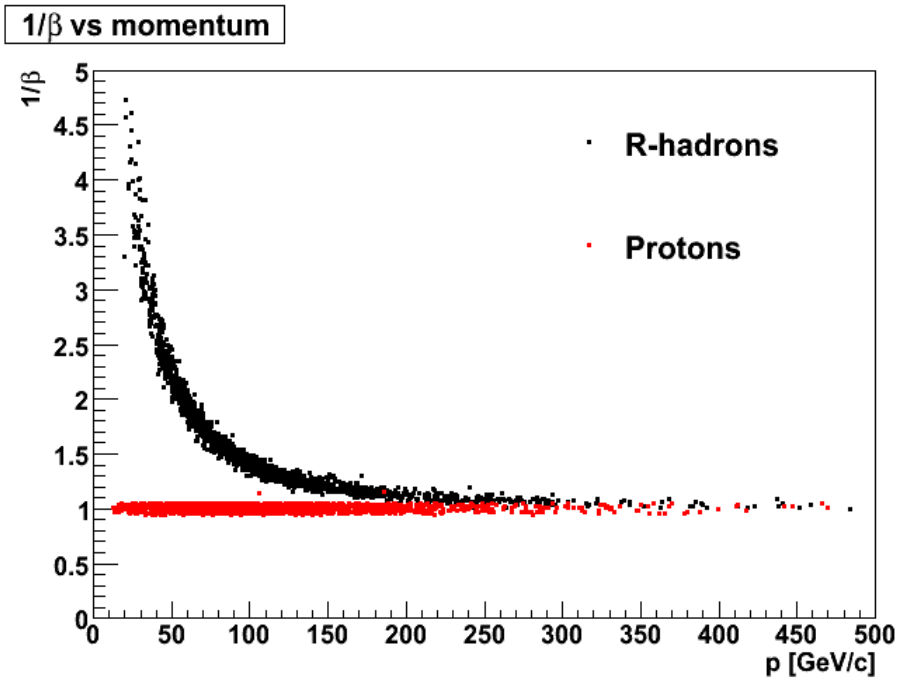
dE/dx in ITS and TPC

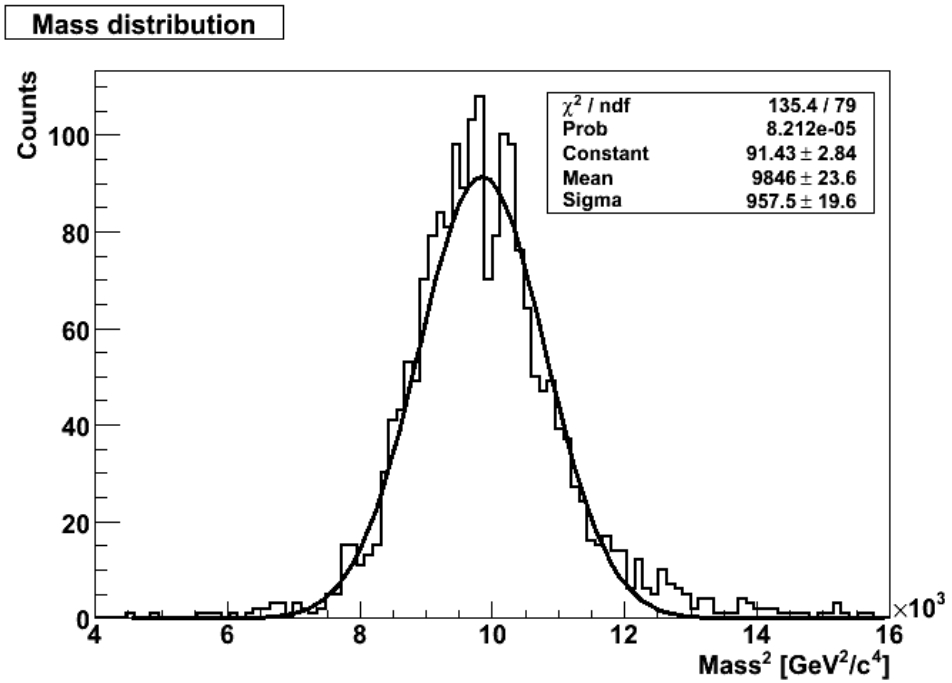




- dE/dx for R-hadrons is in the region of $1/\beta^2$ (the same as for low momentum SM particles)
- dE/dx for pions, muons, protons is on the relativistic plateau
- ~30% of the R-Hadrons can be identified by the large dE/dx

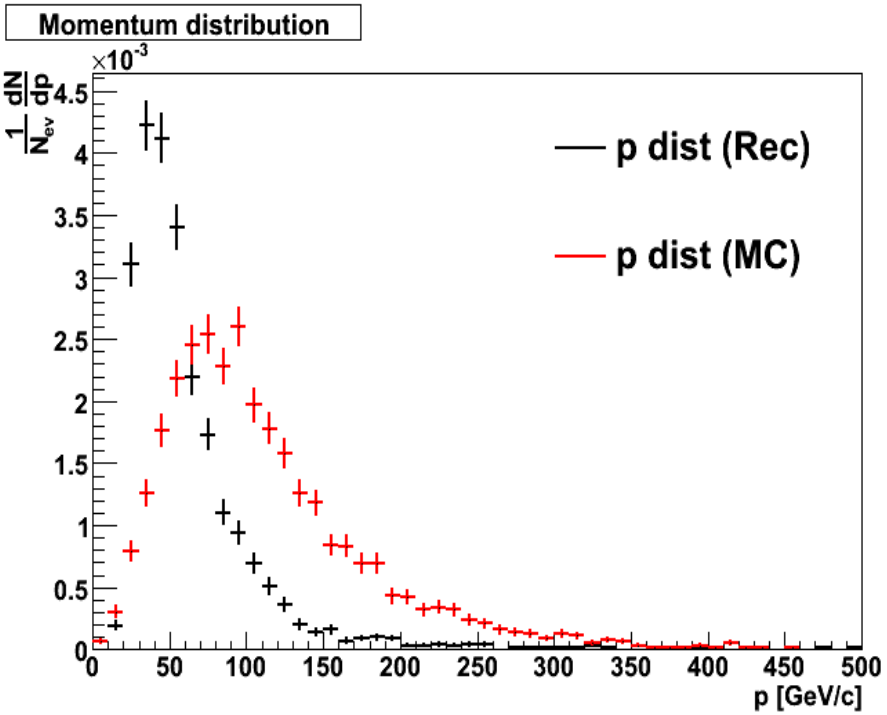
Time of Flight

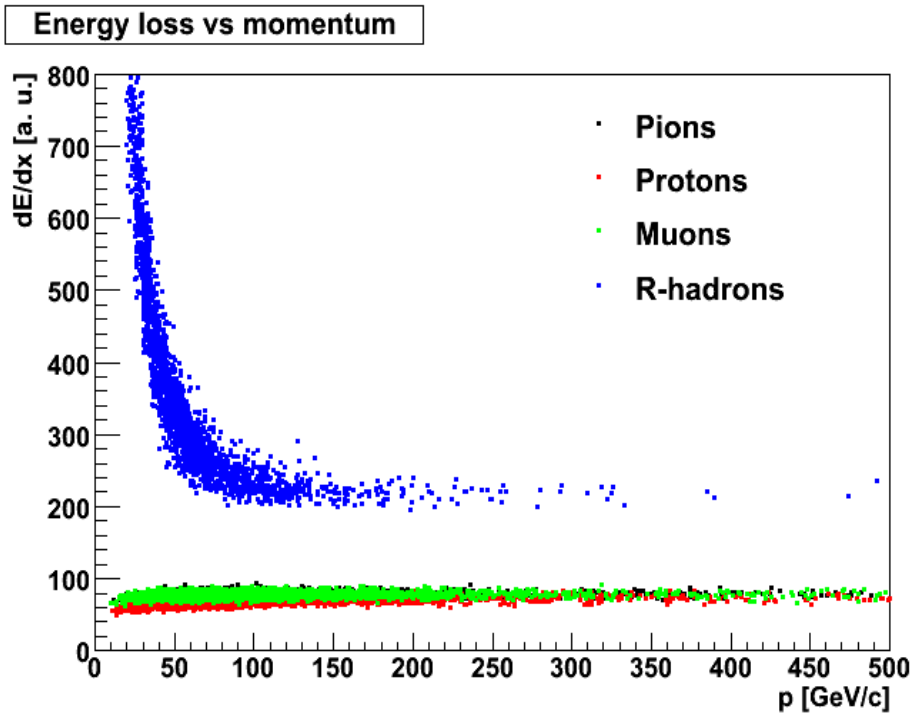




- TOF allows separation for 99% of the R-hadrons
- Also the mass can be determined from the measurement of the momentum and TOF

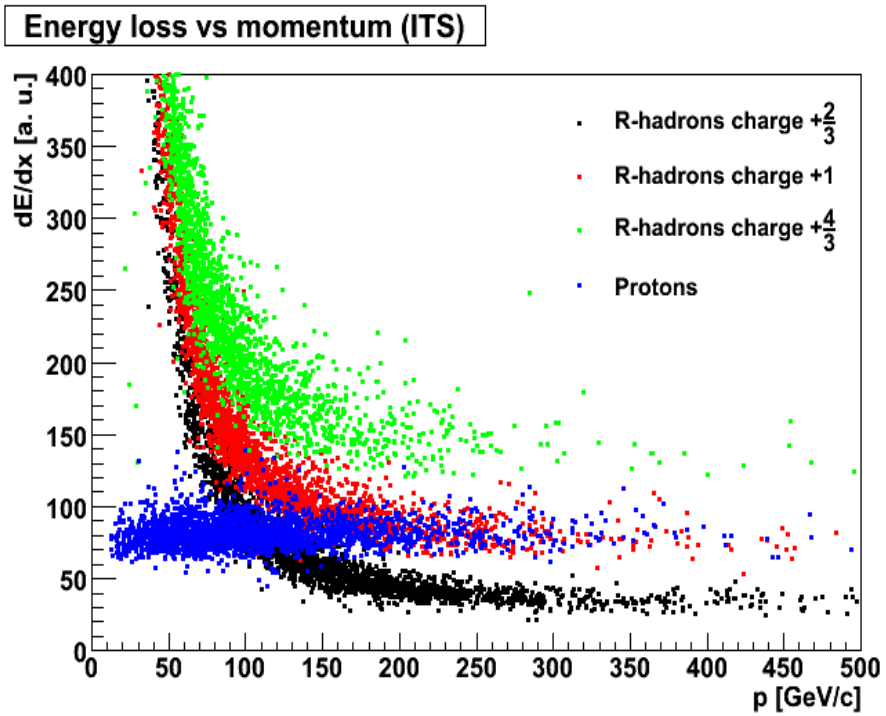
Charge +2 R-hadrons

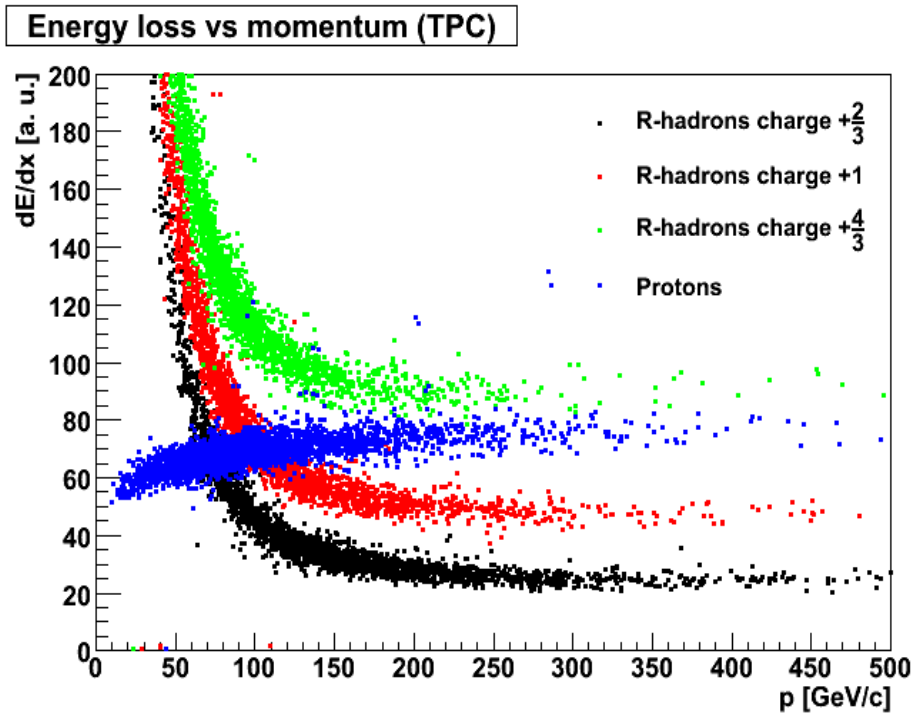




- Models: a small fraction (1%) of R-hadrons have charge +2, but this is based on the low energy QCD hadronic spectrum.
- For R-hadrons with charge +2 the reconstructed momentum is half (Reconstruction assumes charge +1)
- Complete separation for R-hadrons with charge +2 – very clean signal

Fractional charge R-hadrons

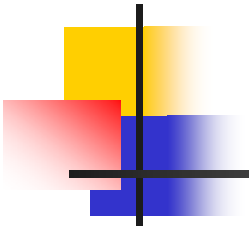




- Signature of free (heavy) quarks
- Reconstruction efficiency for charge +2/3 and +4/3 (ITS, TPC, TOF): ~62%
- dE/dx for fractional charge R-hadrons follows $dE/dx \sim q^2$

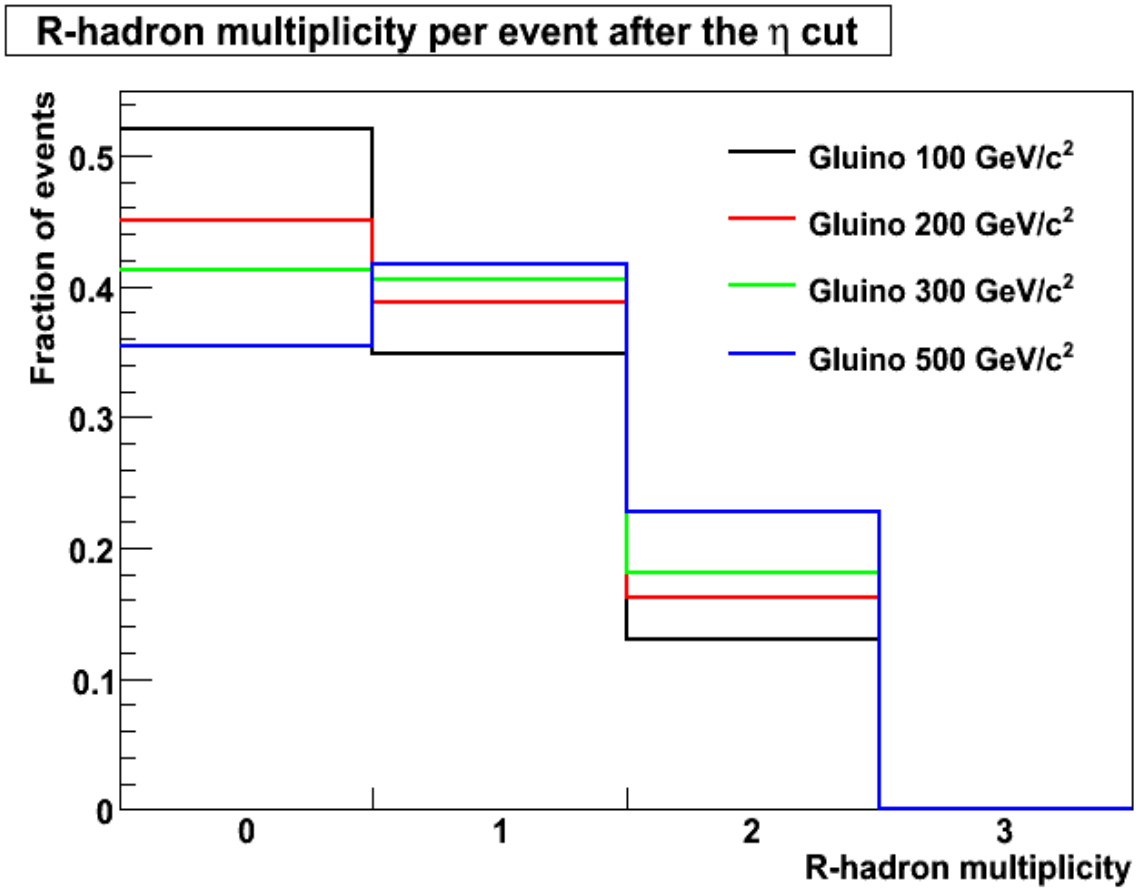
Conclusions and outlook

- Heavy stable charged particles provide good candidates for ALICE searches because the trigger and the detector system is simpler and optimized for PID of charged particles
  - dE/dx gives a good separation of the new integral/fractional charge particles from the SM particles
  - TOF separates these particles from slow SM ones and gives an estimate for their mass
- For gluino R-hadron one expects around 80 (0.5) reconstructed R-hadron tracks for a gluino mass of 100 (300 GeV/c) in a nominal ALICE year (10^9 MB events)
  - this can be increased by a factor 7 using the multiplicity trigger



BACK-up slides

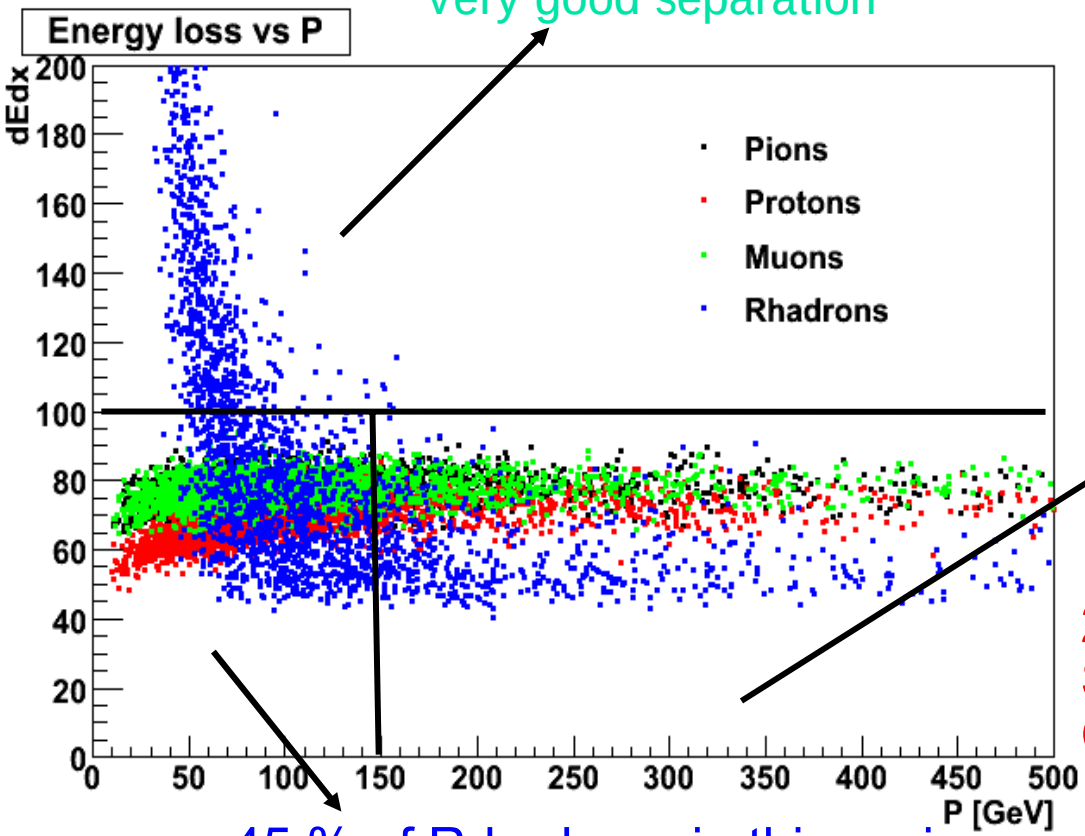
Pythia results – R-hadrons distribution

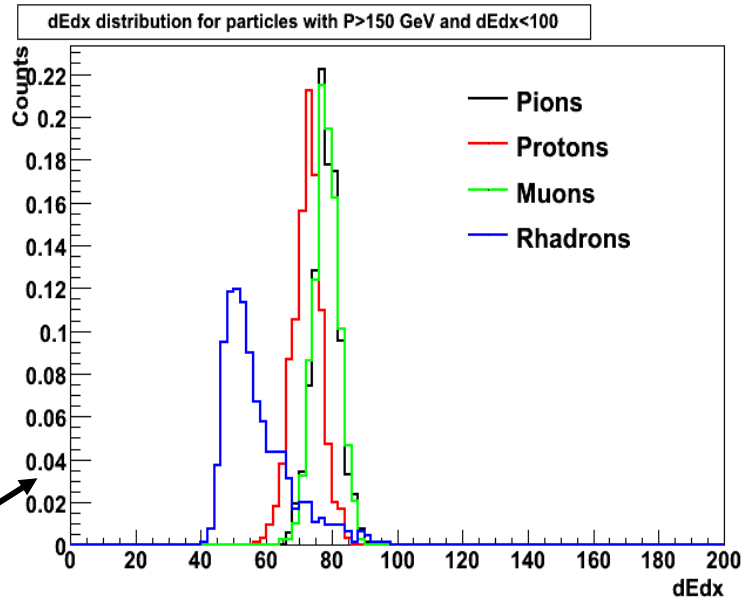


Number of R-hadrons per event after the η cut -> golden signal would be two slow back to back high momentum particles

TPC: dE/dx for pi, p, mu and R-hadrons

30% of R-hadrons in this region
Very good separation





25% of R-hadrons in this region
Separation is not clean
Cut: dE/dx < 100 and P > 150 GeV

45 % of R-hadrons in this region
Not well separated by TPC
Cut: dE/dx<100, P>10 GeV and P<150 GeV