The ALICE Potential for Discovering new Physics at LHC in pp Collisions

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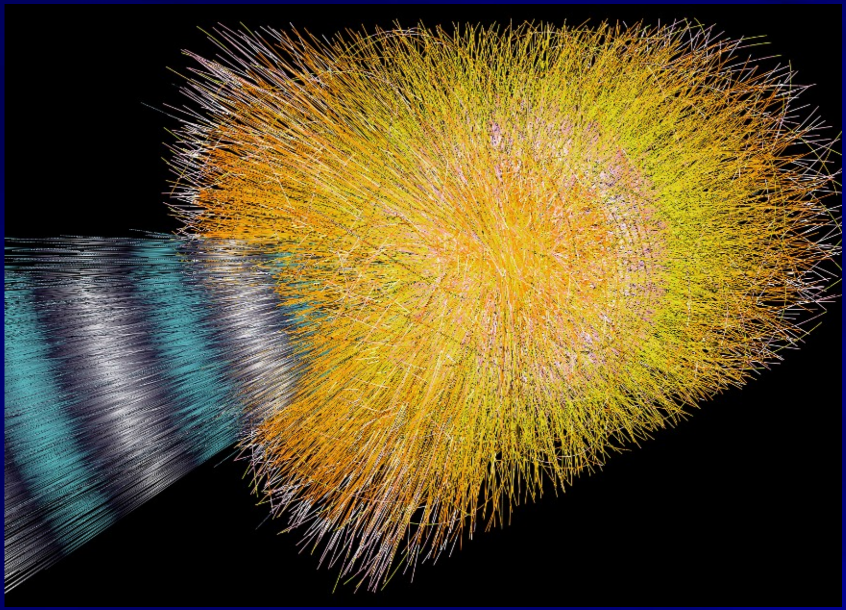
- The ALICE experiment
  - The TPC and the ITS
  - ALICE vs ATLAS
- Searching for Heavy Stable Hadrons with ALICE
  - Pythia simulations for R-hadrons
  - R-hadrons in ALICE
- Summary

ALICE design Challenge: Tracking in central Pb+Pb events



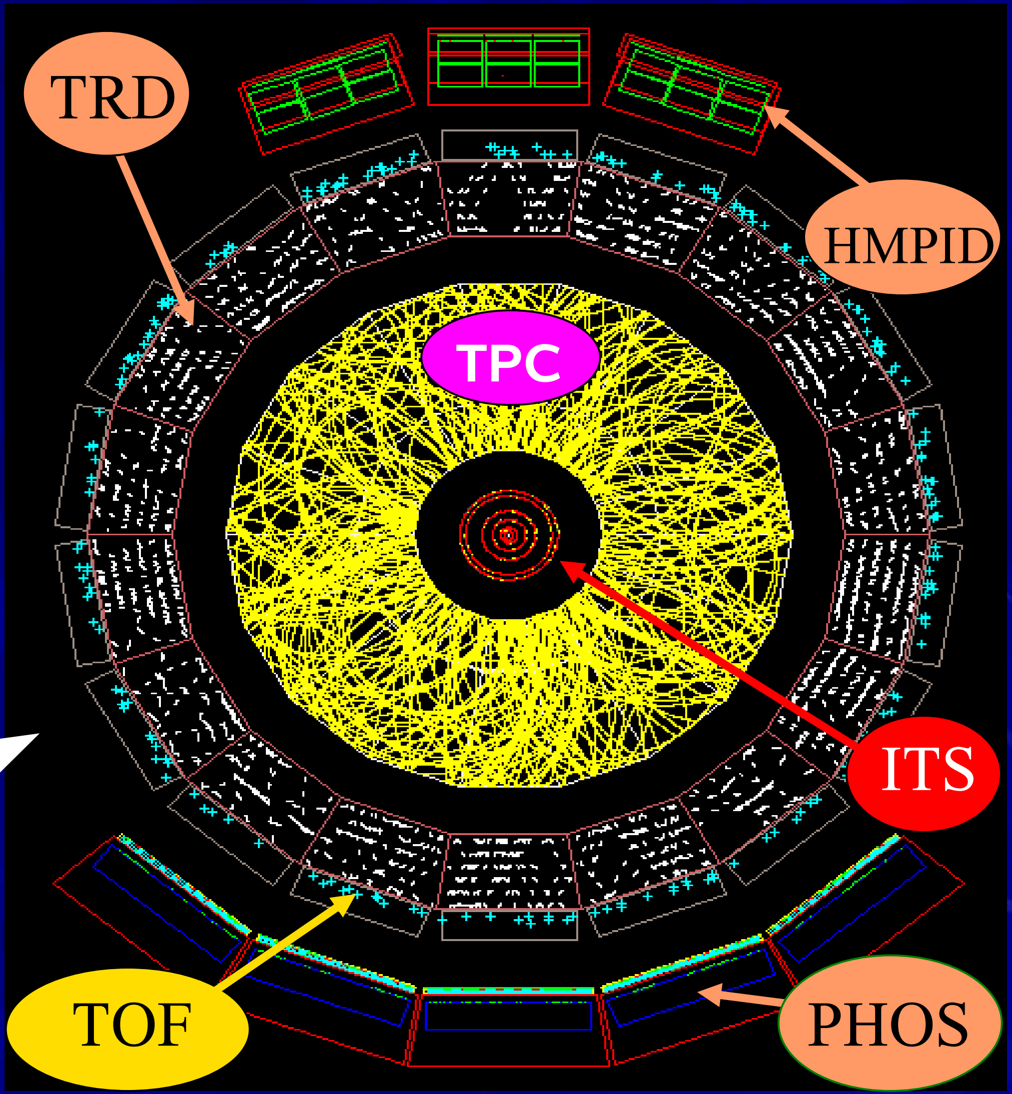
Pb+Pb simulated event

(dN/dy = 8000)

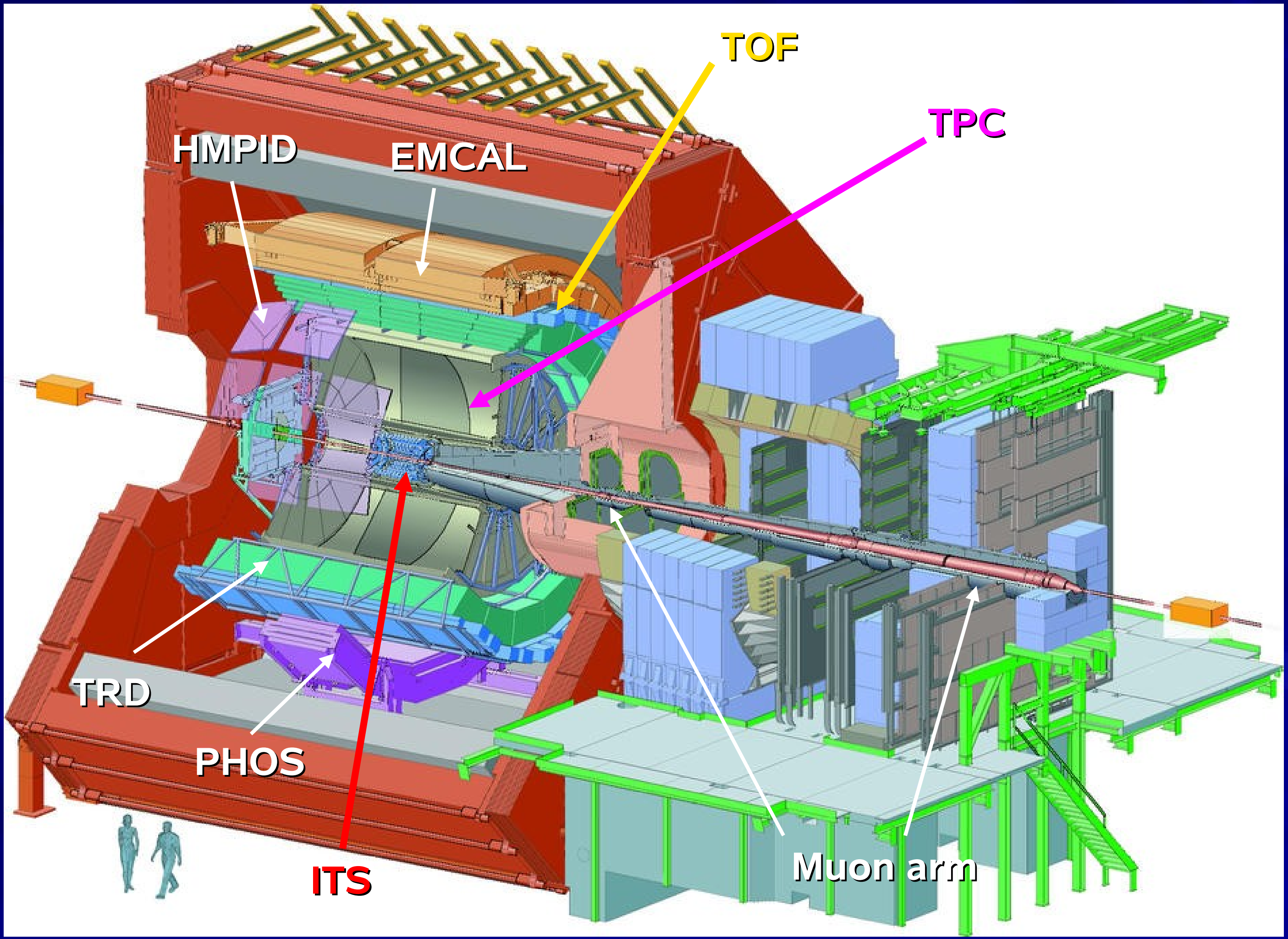
Δθ = 2° slice only!

(~500 tracks)

→ Design is different from ATLAS and CMS



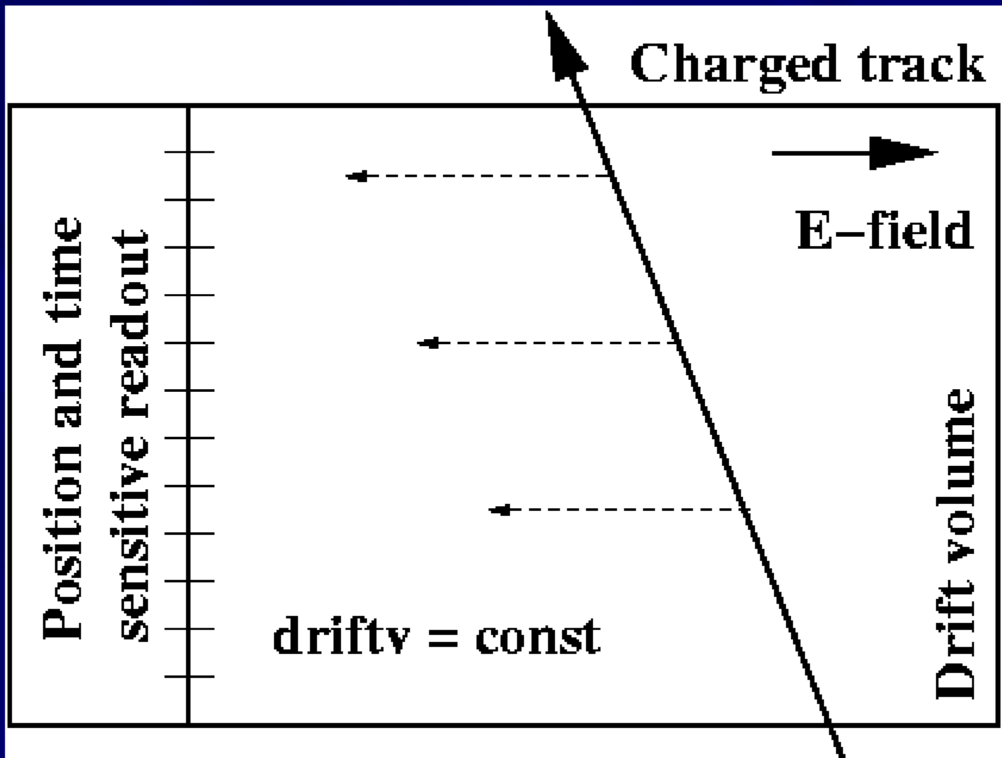
The ALICE experiment



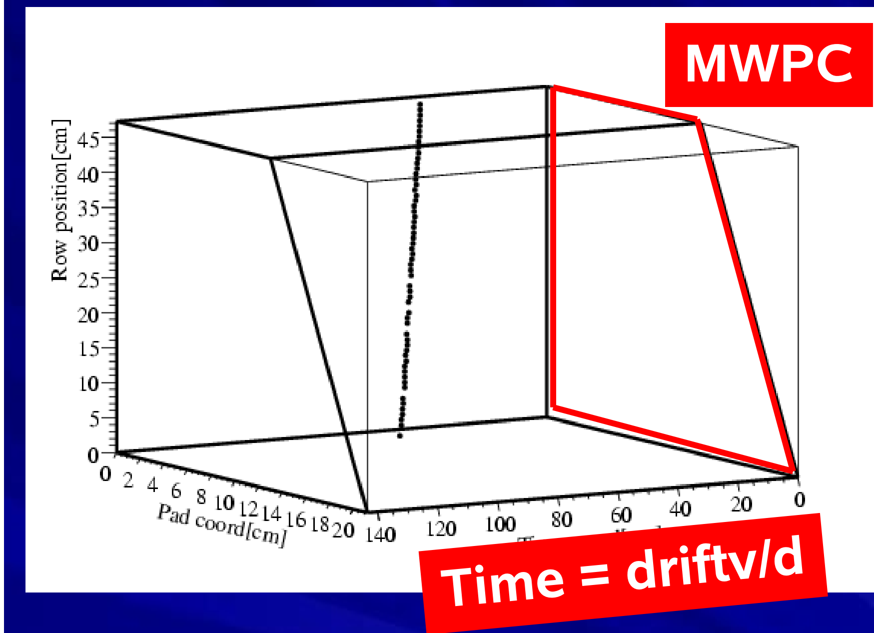
I will mention the following detectors: Time Projection Chamber (TPC), Inner Tracker System (ITS), and Time Of Flight (TOF). All these systems are fully installed and will be ready for physics from day 1.


The ALICE TPC
at the heart of ALICE

TPC Operation Principle

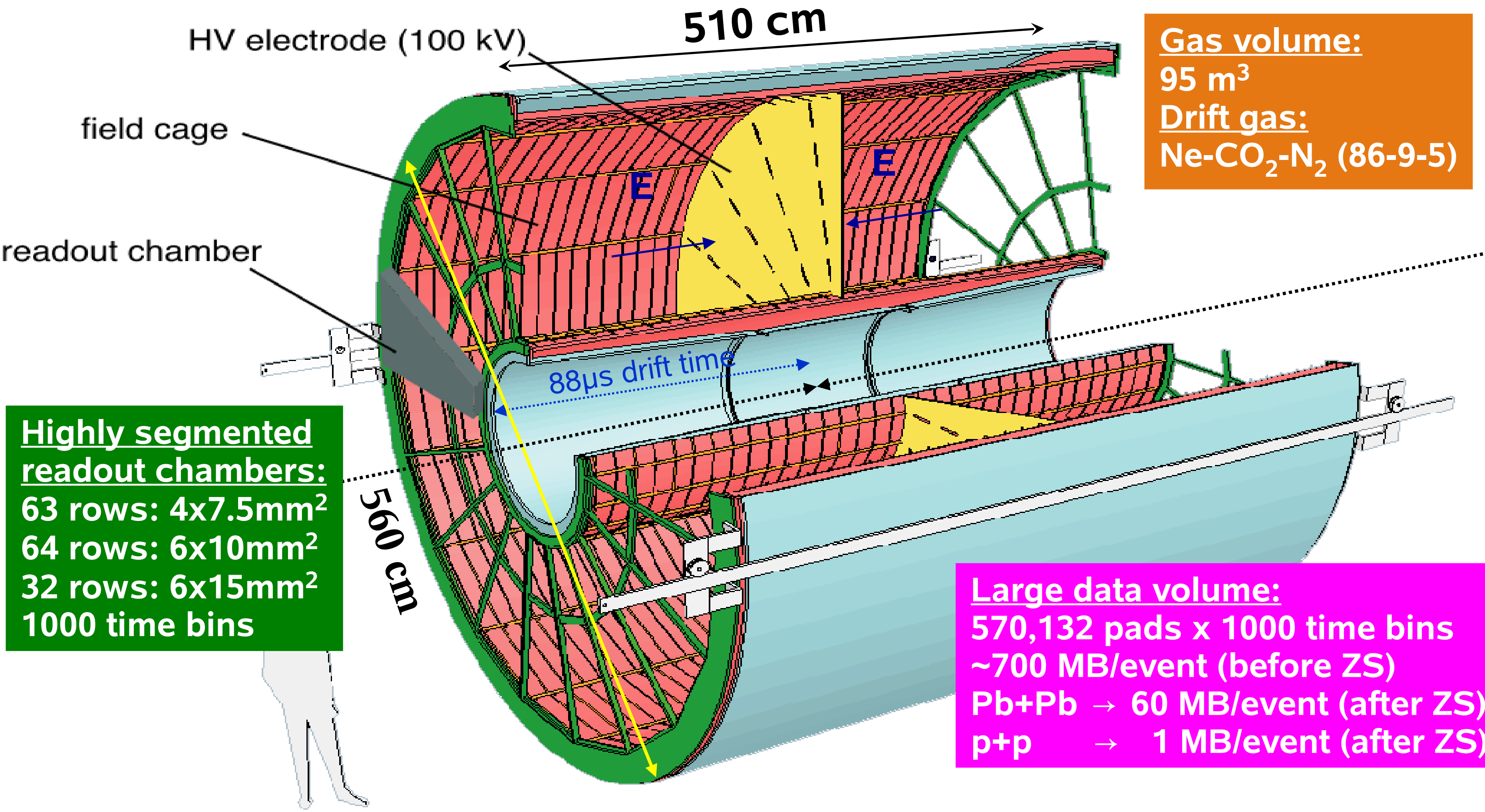


3 dimensional tracking



- Charged track ionizes gas molecules
- Ionized electrons drift (because of E-field) to readout
- Read out measures the 2d position (x,y) as a function of time (z = time*drift velocity) => 3d tracking

ALICE TPC Layout: The worlds largest TPC



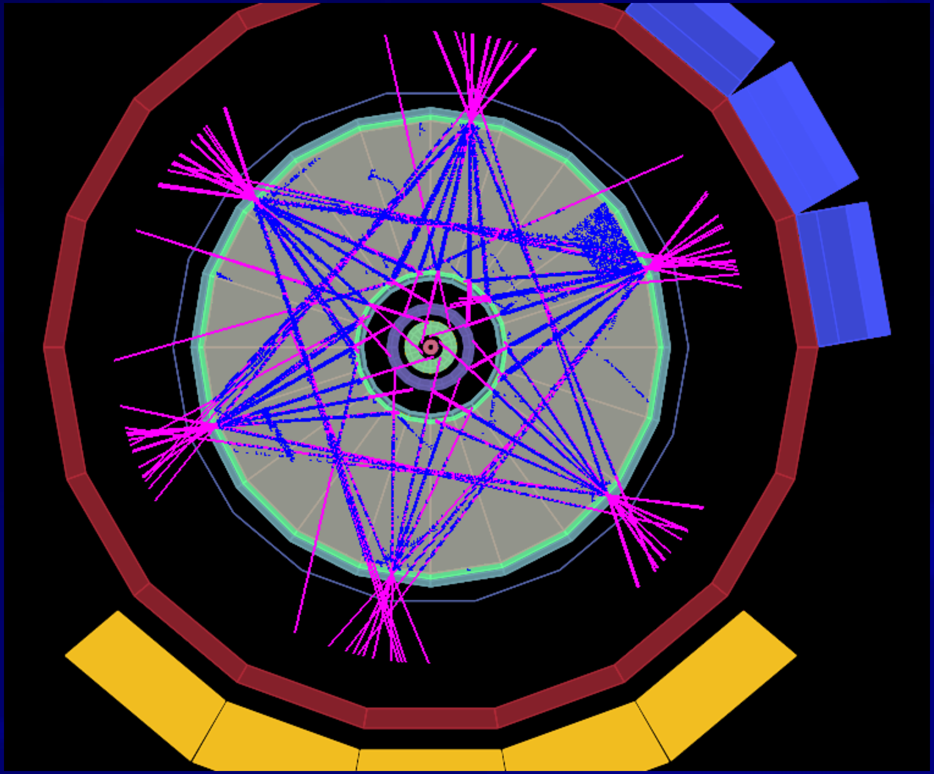
Gas volume:
95 m^3
Drift gas:
Ne-CO_2-N_2 (86-9-5)

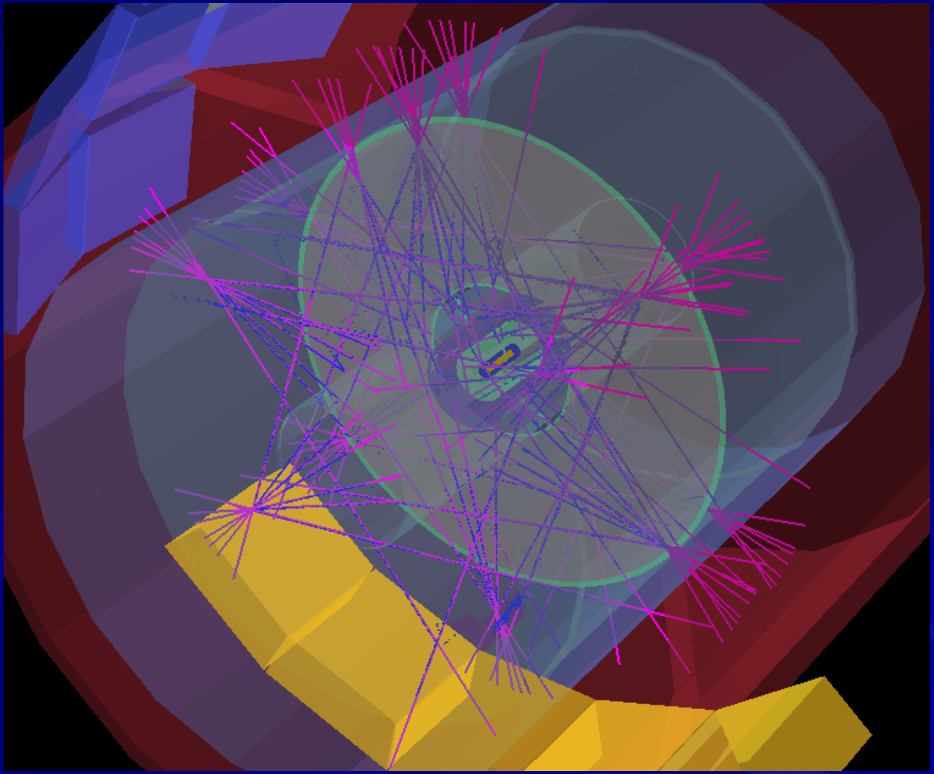
Highly segmented readout chambers:
63 rows: 4x7.5mm^2
64 rows: 6x10mm^2
32 rows: 6x15mm^2
1000 time bins

Large data volume:
570,132 pads x 1000 time bins
~700 MB/event (before ZS)
Pb+Pb → 60 MB/event (after ZS)
p+p → 1 MB/event (after ZS)

TPC Laser Event

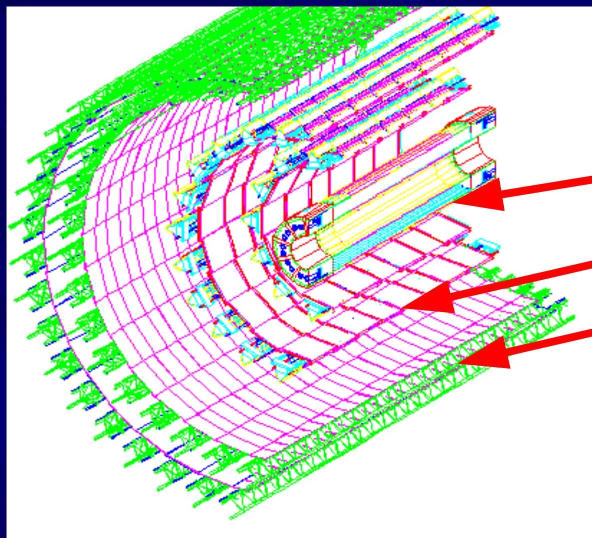
2d display **3d display**

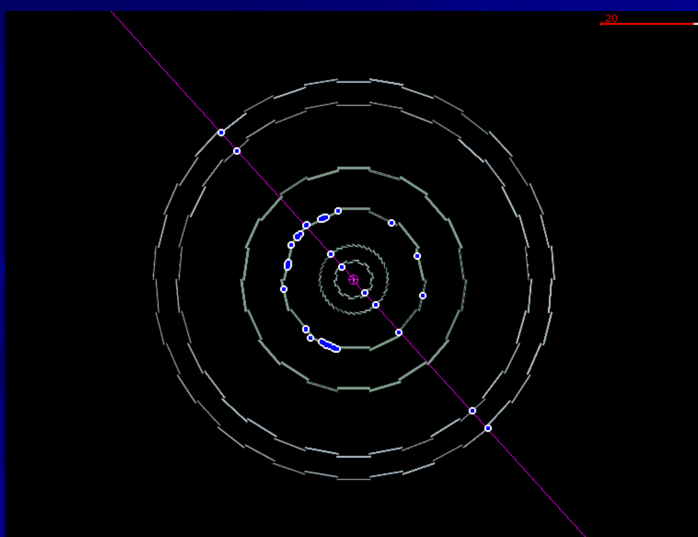




- Laser and Cosmic events are currently being analyzed to align internally the tracks in the TPC.
  - TPC will be internally calibrated for physics from day 1.

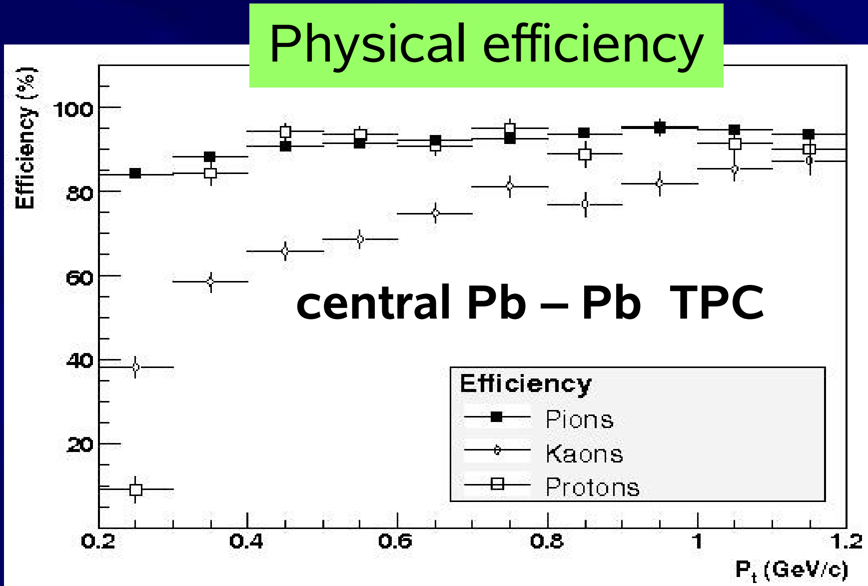
Inner Tracking System (ITS)





- 6 layers of silicon
  - 2 x Pixels (inner, r=3.9 cm)
  - 2 x Drift
  - 2 x Strips (outer, r=43.0cm)
- Spatial resolution:
  - rϕ~12-35μm, z~25-800μm
  - two tracks: rϕ~100-300μm, z~600-2400μm
- 3d reconstruction (<100μm) of primary vertex)
- Pixels provides a fast (L1) multiplicity trigger
- Cosmic tracks (left) are used to calibrate/align the 6 layers

Tracking and Particle Identification

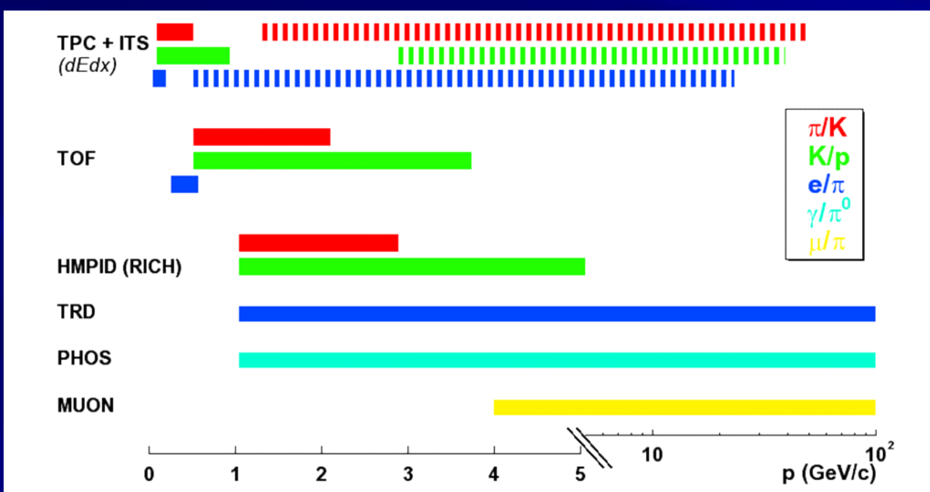


For dN_{ch}/dy = 4000 in Pb-Pb

Reconstructed / generated (|η|<0.9)
~ 90% for p_T > 1 GeV (limited by dead zones)
Protons : large absorption at low p_T
Kaons : in-flight decays

Momentum resolution:
~1% at P_T = 1 GeV/c, ~4% at P_T = 100 GeV/c

Precise vertexing (better than 100 μm)



π,K,p: dE/dx (in TPC & ITS) + TOF and RICH
→100 MeV < p < a few tens GeV

electrons: TRD → p >1 GeV

muons: p > 4 GeV (muon arm)

photons: PHOS → 1 < p < 80 GeV

ALICE vs ATLAS

- ALICE is optimized for large cross section QGP/QCD physics
  - TPC can handle 1kHz
    - optimized for Pb+Pb rates and occupancy
  - MB and multiplicity trigger (HLT after TPC is read out)
  - Moderate magnetic field, but small material budget for low pT coverage
  - 2π coverage for up to 20,000 charged tracks
  - PID detectors for individual tracks e, μ, π, K, p

- ATLAS is optimized for small cross section new physics
  - 40MHz readout
    - 25ns=7.5m between bunches
  - Sophistcated online trigger selects candidate events
  - High magnetic field and long track length for precise momentum determination
  - 4π coverage to account for full event
  - Calorimeters (EM, Hadron) and muon id

However, at the start up of LHC the pp luminosity will be significantly smaller → Ideal conditions for ALICE.
But is there anything we can discover at these low rates?

Heavy Stable Hadrons: Candidates for ALICE searches

- Heavy Stable EM Charged Hadrons
  - Predicted by some theories of new physics e.g. SUSY and KK

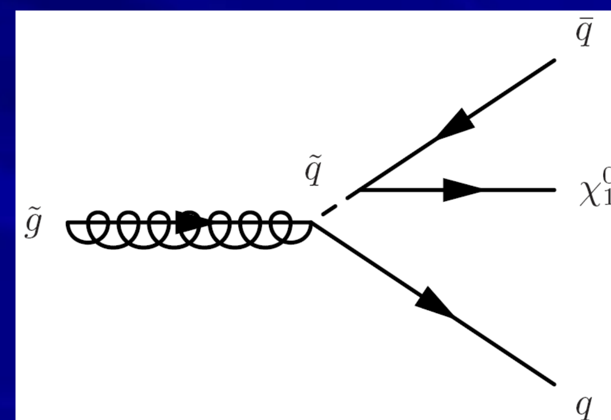
- Hadrons
  - Coloured → “large” cross sections
- Stable and EM charged
  - Can be directly measured in the detector
- Heavy (mass > 100 GeV)
  - Not observed at Fermilab and LEP!
  - Large momentum and slow (β < 0.9)
    - Does not look like a SM particle (Large momentum→fast)
    - Can therefore be directly identified by e.g. TOF
    - Could be difficult to trigger on for ATLAS and CMS

R-hadrons – Our candidate

- Consider Split SUSY where gluino light and squarks very heavy: gluino R-Hadrons (stable if R-parity is conserved)
- gluino R-Hadron = gluino + light quarks (ignore glueballs)
  - Quark system interacts
  - Gluino is reservoir of kinetic energy

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

- gluino R-Hadrons are stable because they can only decay through coloured squarks →

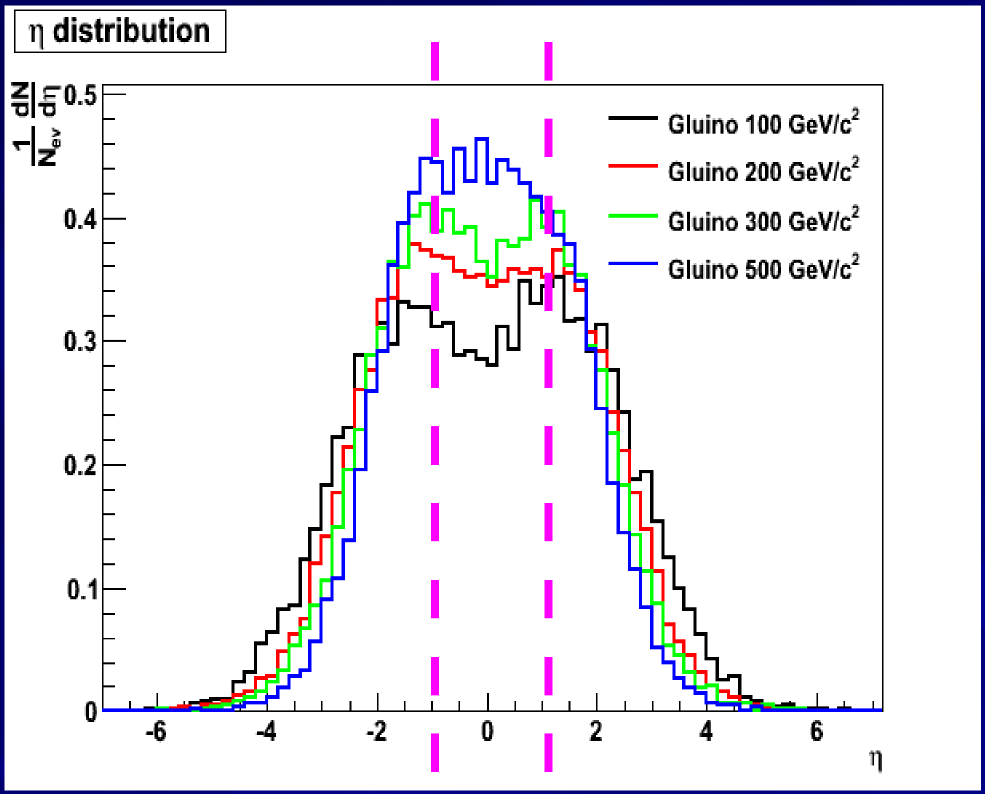


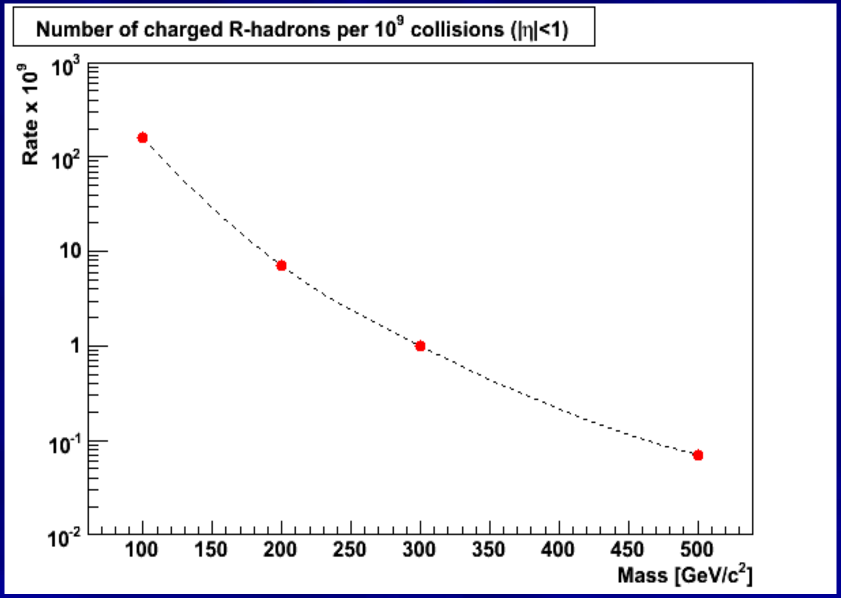
- Mass limits from prev. exp.
  - LEP (m>27 GeV)
  - Tevatron (m>170 GeV)
    - Not explicitly considered
- Detailed review (with mass limits):

(arXiv:hep-ph/0611040v2; ”Stable Massive Particles at Colliders”, M. Fairbain et all)

Pythia Simulations

ALICE ACCEPTANCE



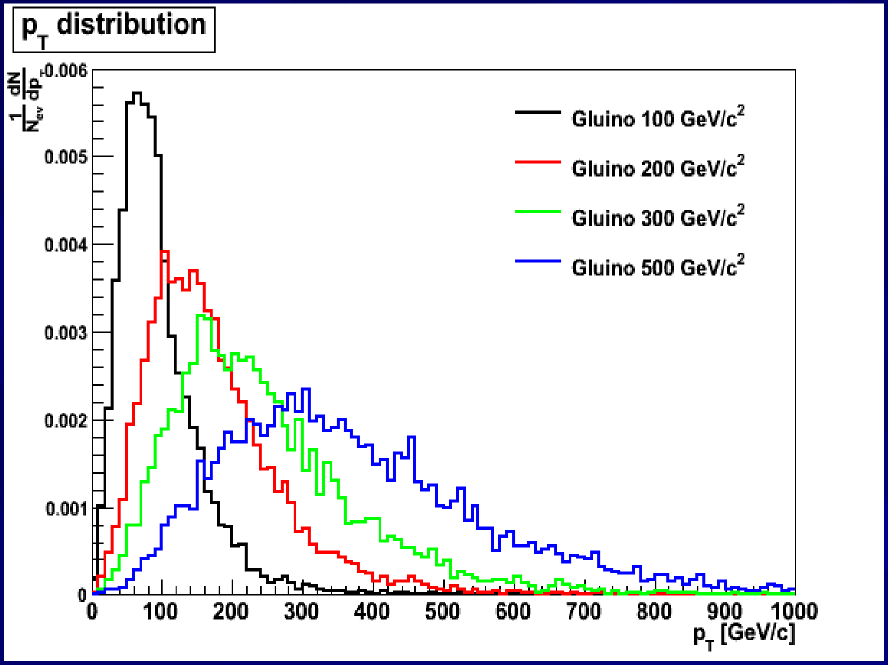


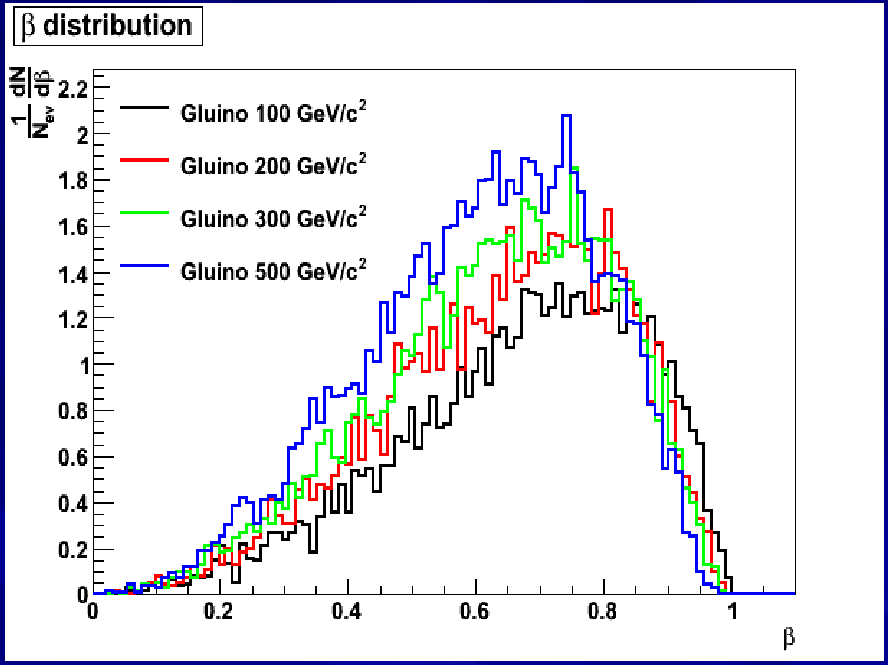
EM charged R-hadron tracks inside ALICE acceptance per 10^9 MB events as a function of gluino mass

- Gluinos are pair produced back to back
- Hadronize into EM charged hadrons ~50% of the time
  - 99% R-mesons and 1% R-baryons

p_T and β distributions ($|\eta| < 1$)

p_T distribution | **β distribution**





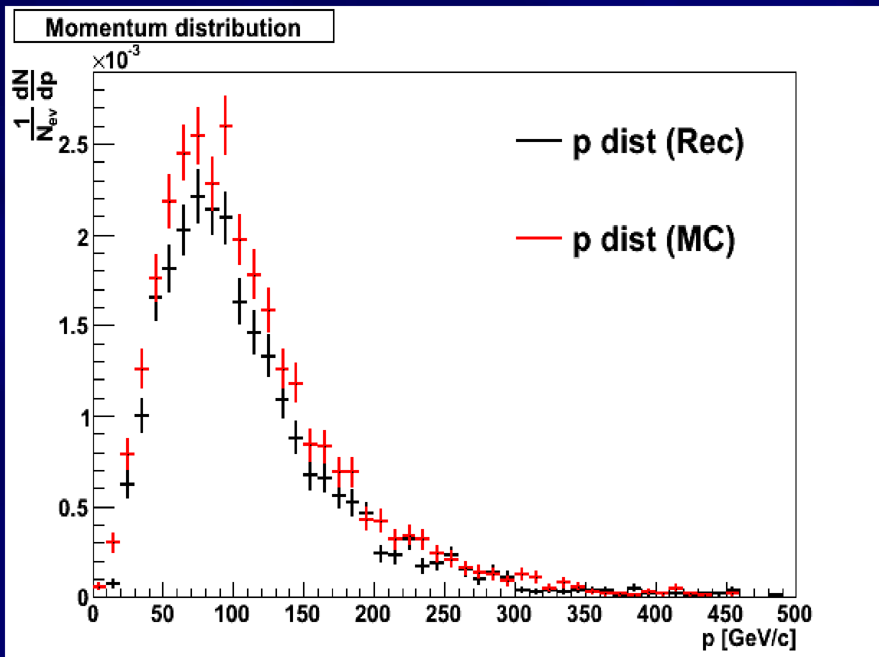
- High momentum is a challenge for precision measurements because of moderate magnetic field (0.5T)
- R-hadron velocity in the range $0.3<\beta<0.9$
  - Very different from e, μ, π, K, p for p>10 GeV/c.

Detector Response Simulations

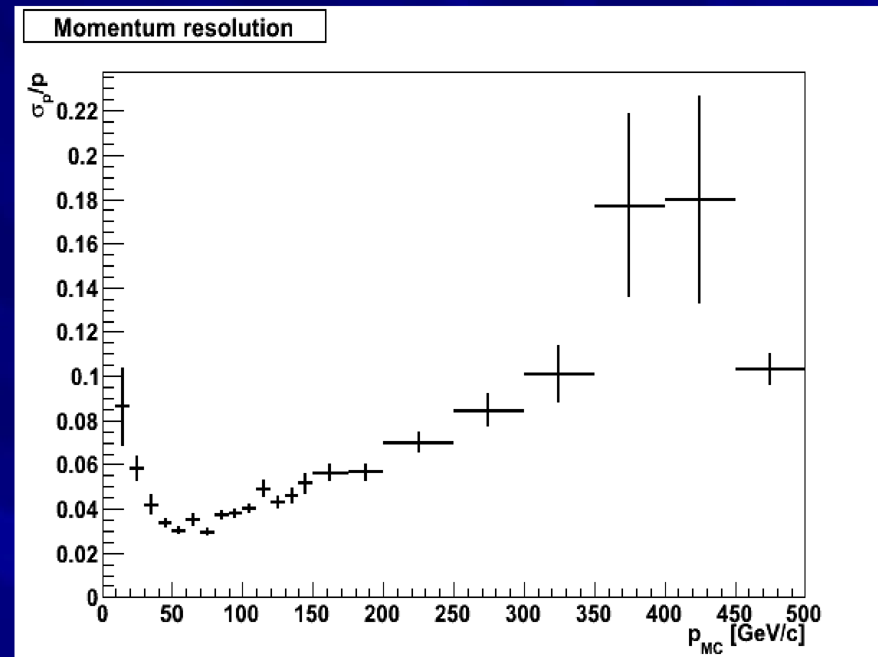
- Pythia input -> ALICE (GEANT3 based) Simulation
  - Maximum field: 0.5T
- R-hadron quark exchange interactions are not taken into account because of the low material budget
- R-hadrons (gluino mass 100 GeV) with charge +1 are simulated and reconstructed
  - Reconstruction efficiency (ITS, TPC, TOF): ~65%
    - Tracking (ITS+TPC): ~83% (10% dead zones)
    - TOF matching: ~80% (10% loss due to η coverage)
  - (Also investigated exotic charges:+2/3, +4/3, +2)
- PID signals are compared to pions, protons, and muons with the same momentum distribution

Simulation results: Momentum resolution

p: MC and Reconstructed



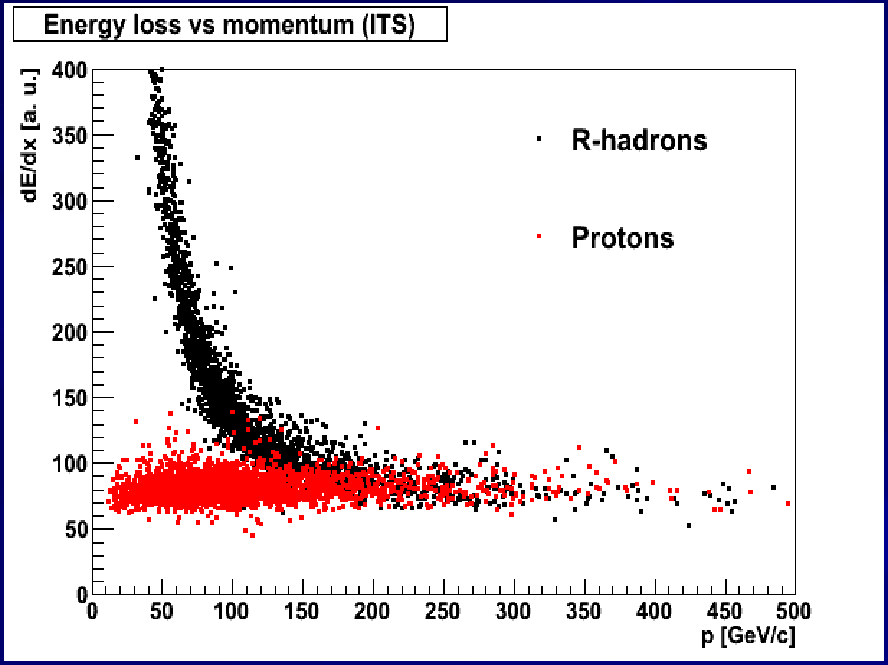
Momentum resolution



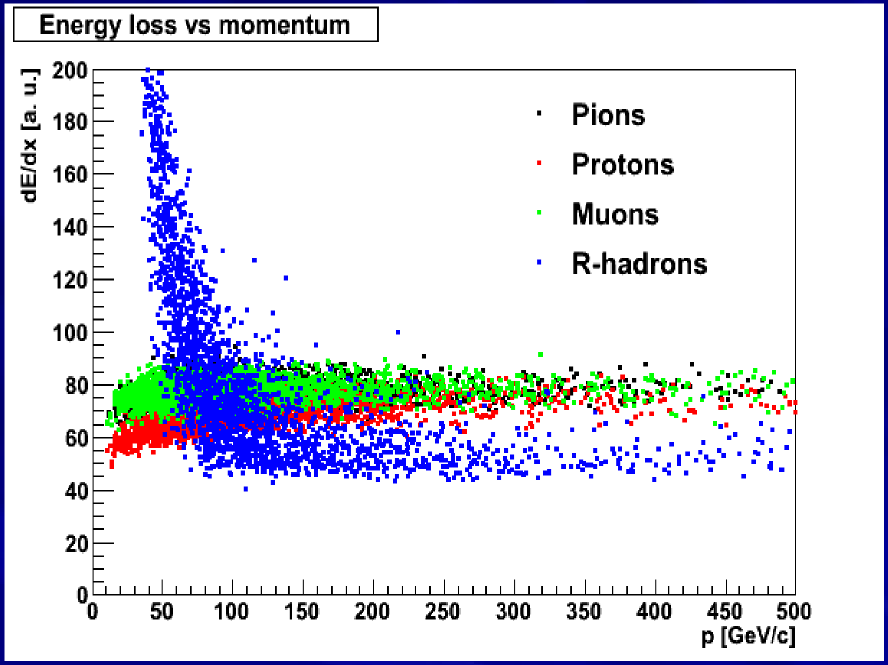
- Momentum resolution is ~4% at p=100 GeV/c
- Interesting, multiple scattering dominates for p<50 GeV/c
  - σ_p/p (MS) ~ σ_θ(MS)/θ ~ 1/(βp) / 1/p ~ 1/β

Simulation results: dE/dx in ITS and TPC

dE/dx vs p in ITS



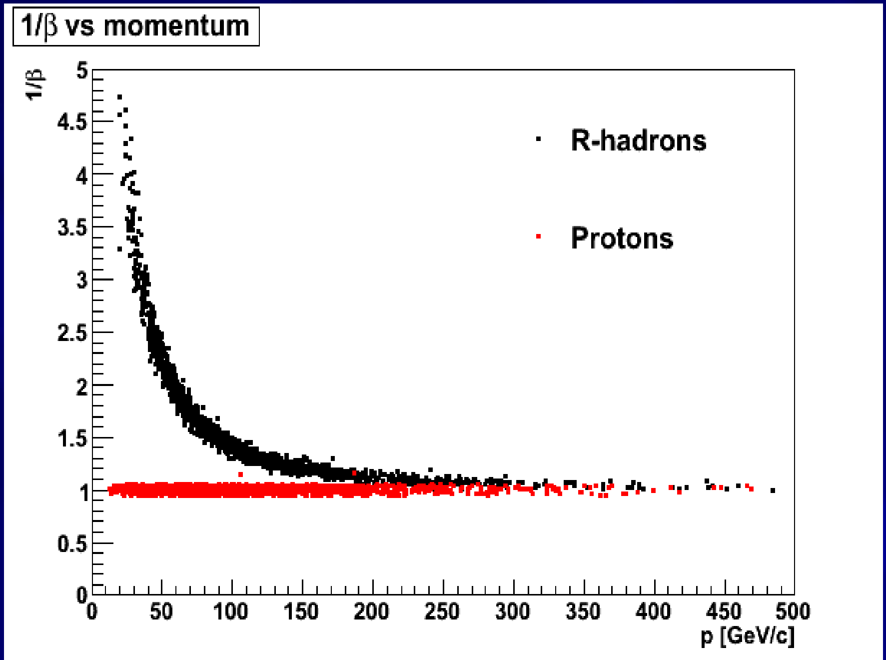
dE/dx vs p in TPC



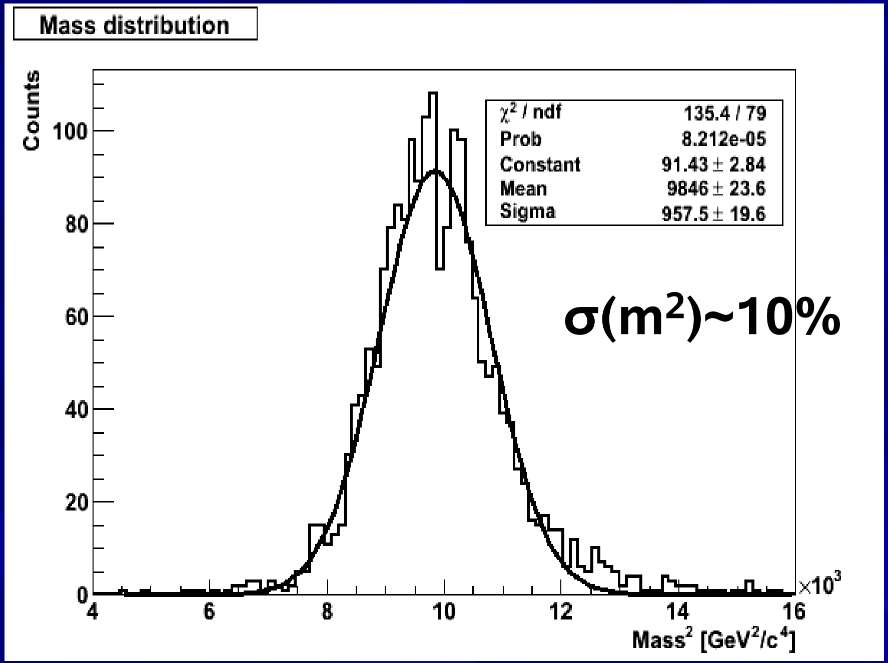
- The dE/dx for the R-hadrons is the same as for low momentum SM particles (dE/dx~1/β^2) while the dE/dx for SM particles are on the relativistic rise/plateau
- ~30% of the R-Hadrons can be identified by the large dE/dx

Simulation results: Time-of_Flight

1/β vs momentum



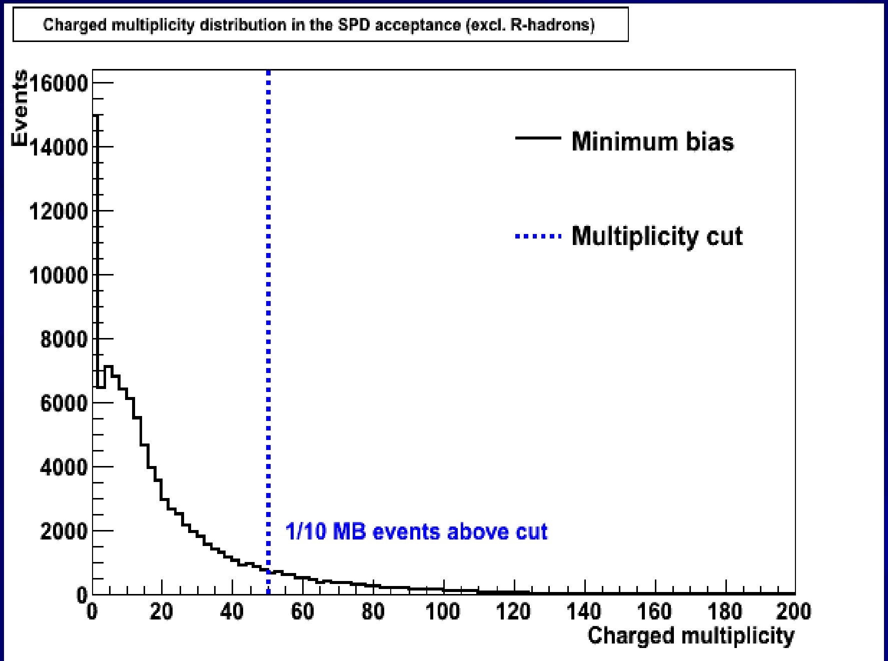
Mass² for R-hadrons

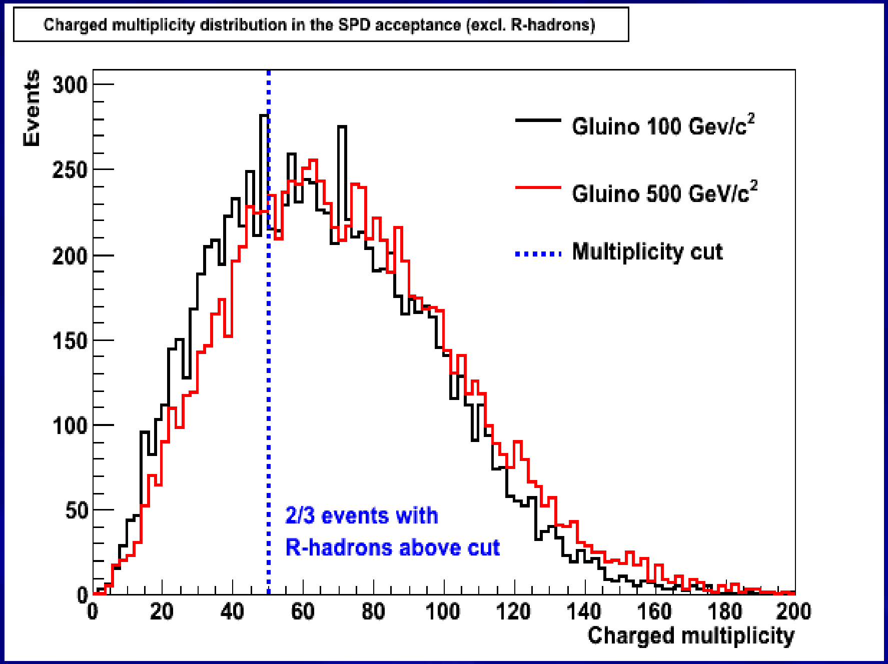


- The TOF allows separation of 99% of the R-hadrons
- Also the mass can be determined from the measurement of the momentum and the TOF
- We are currently investigating the background

Triggering on multiplicity to enhance the R-hadrons

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





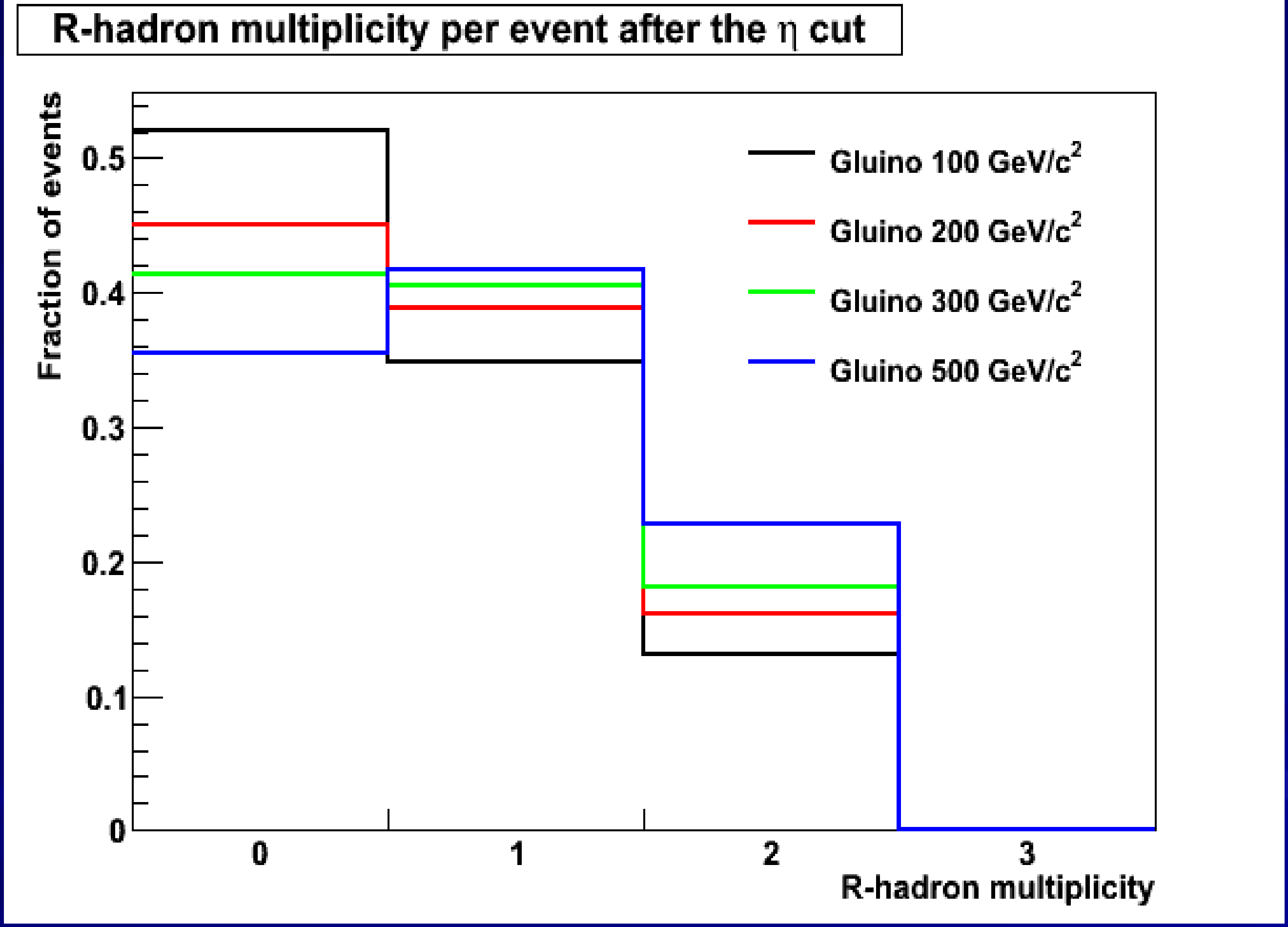
- When ALICE has to downscale the triggers, triggering on multiplicity can enhance the R-hadron sample
  - Example: Selecting the 10% events with the highest multiplicity only removes 1/3 of the R-hadrons: factor ~7 enhancement

Summary

- ALICE will be ready with the ITS, TPC, TOF and many other detector systems for the first pp collisions at LHC this year
- The startup period of LHC is ideal for ALICE because of the lower luminosity which the TPC can handle
- If there are new heavy stable EM charged particles with relative large cross section, ALICE can look for them and take advantage of the very good particle identification detectors and the simpler triggering scheme
- 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

Backup slides

Rhadrons inside acceptance per event



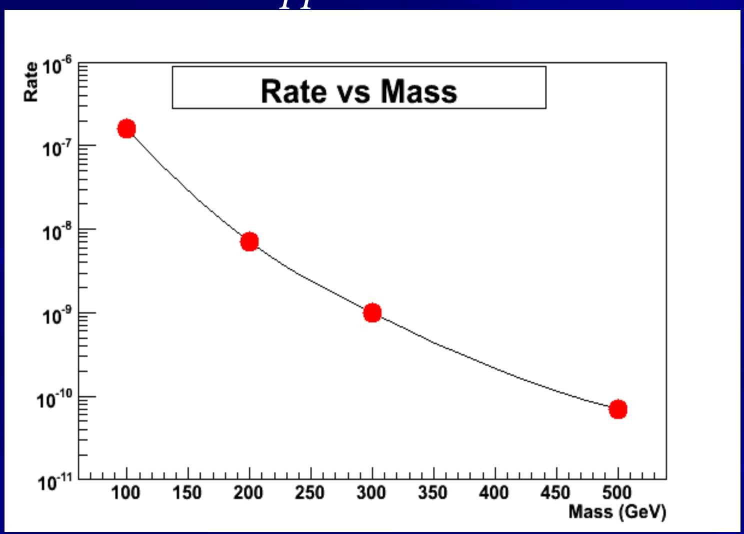
Number of Rhadrons per event after the η cut -> golden signal would be two slow back to back high momentum particles

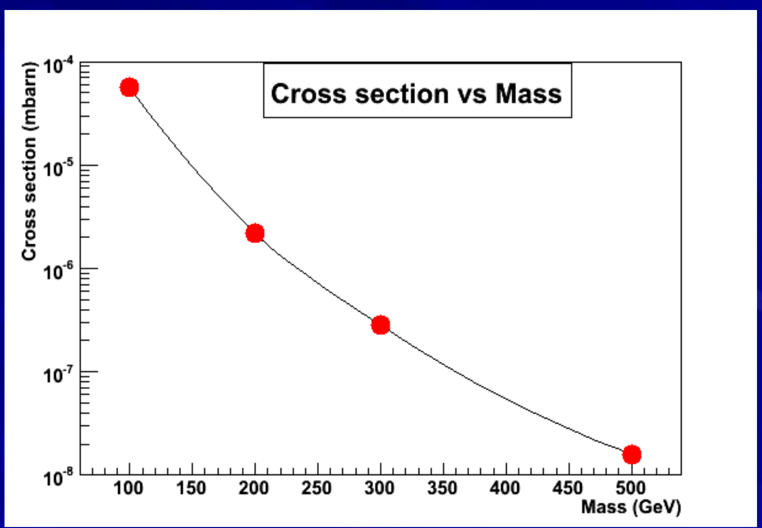
Pythia Results: R-hadrons rates

Mass [GeV]	Rh_all	Rh_cut	σ [mbarn]	Acceptance	Rate	Rate_charged
100	20000	6102	5.6×10^{-5}	0.31	3.2×10^{-7}	1.6×10^{-7}
200	20000	7116	2.2×10^{-6}	0.36	1.5×10^{-8}	0.7×10^{-8}
300	20000	7681	2.8×10^{-7}	0.38	2.0×10^{-9}	1.0×10^{-9}
500	20000	8726	1.6×10^{-8}	0.44	1.3×10^{-10}	0.7×10^{-10}

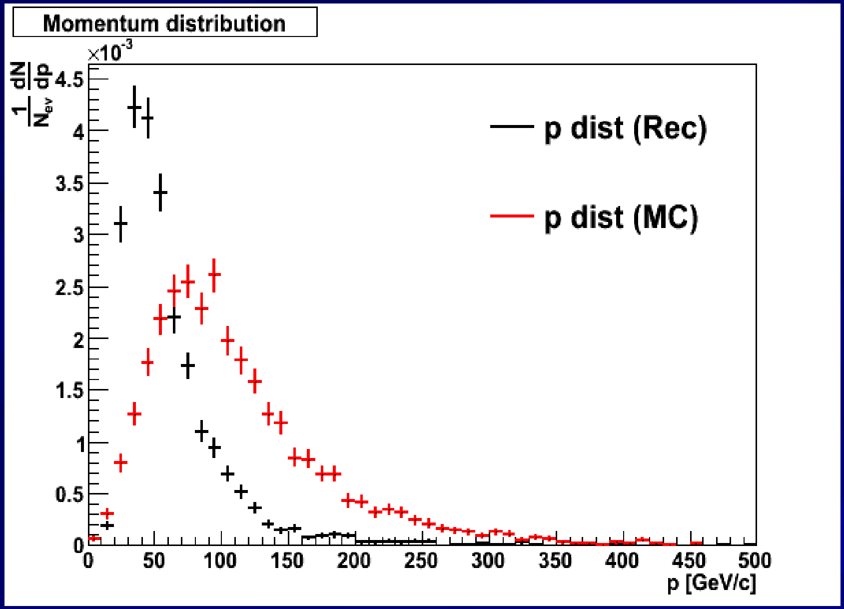
$$R \sim 2 \times \frac{\sigma_{Rhadron}}{\sigma_{pp}} \times Acc$$

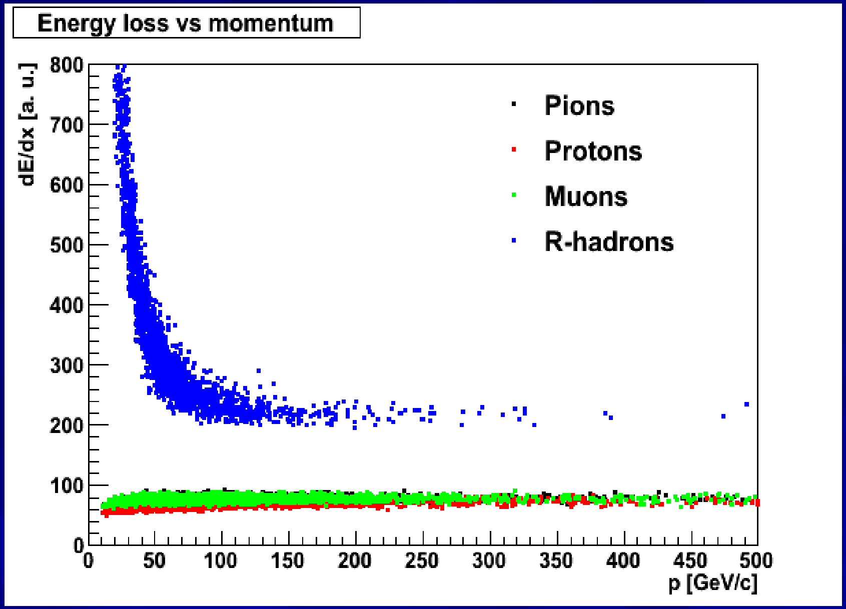
σ_{pp}~100 mbarn





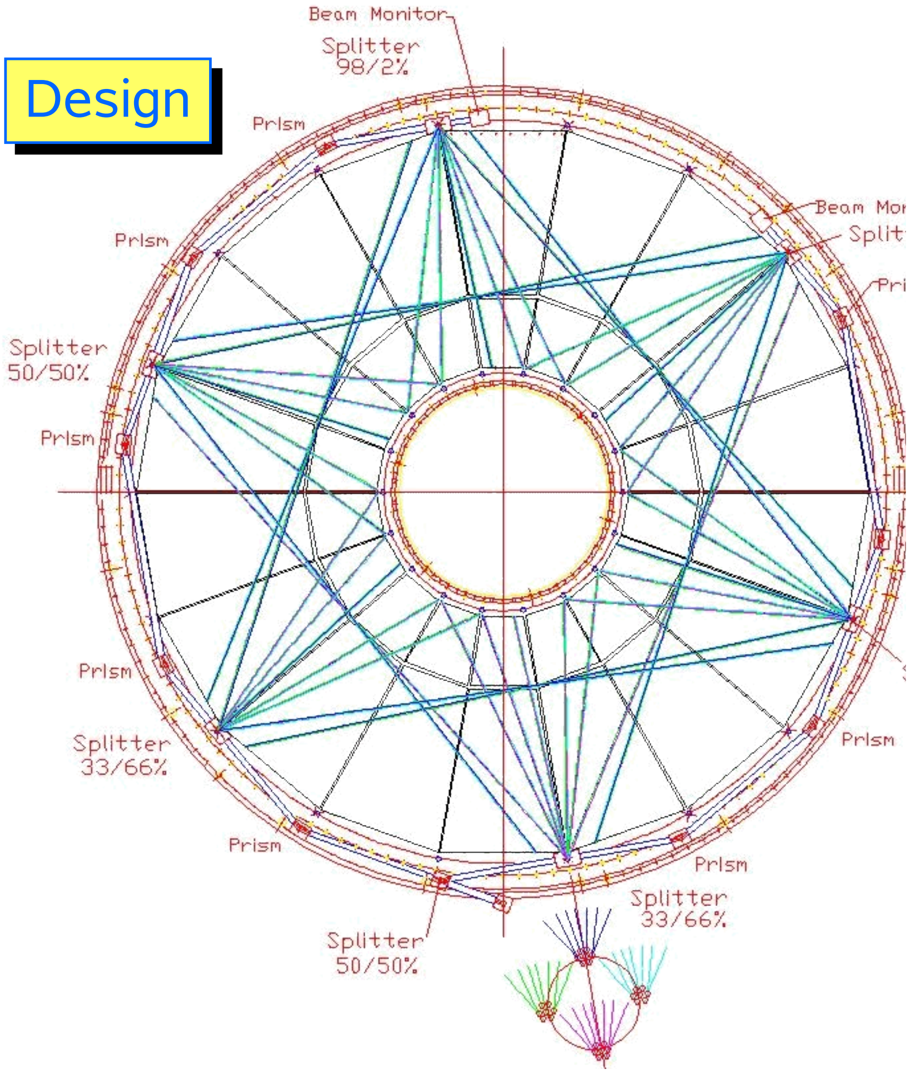
R-hadrons: Charge +2

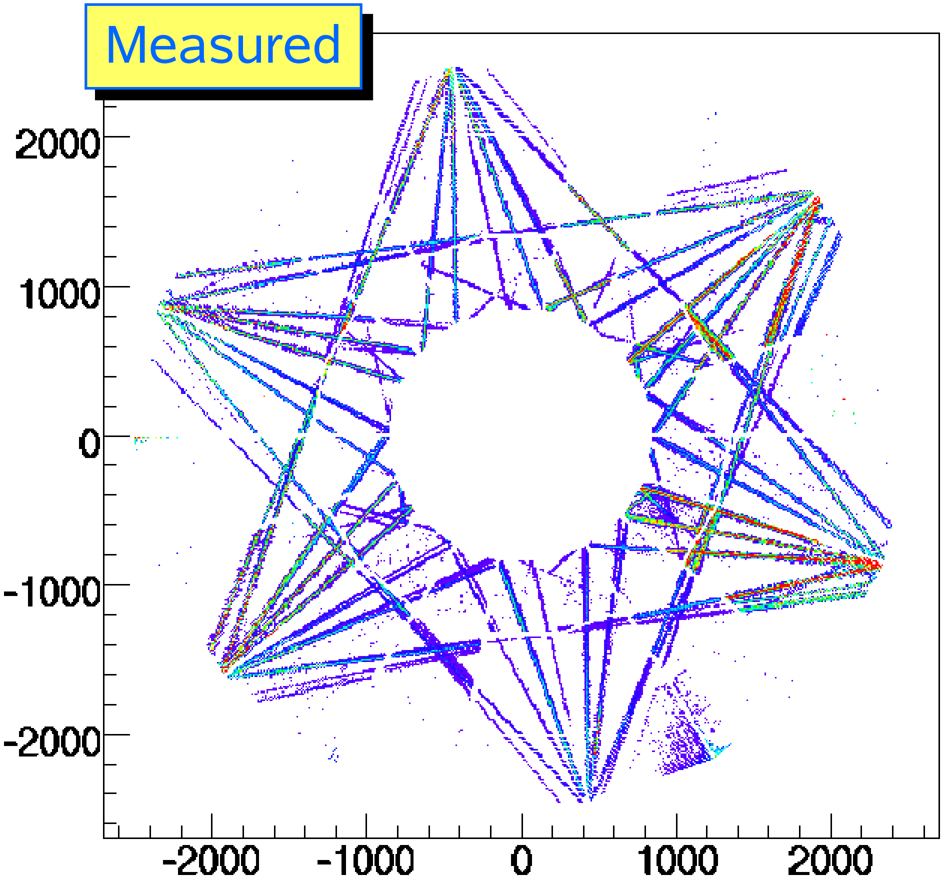




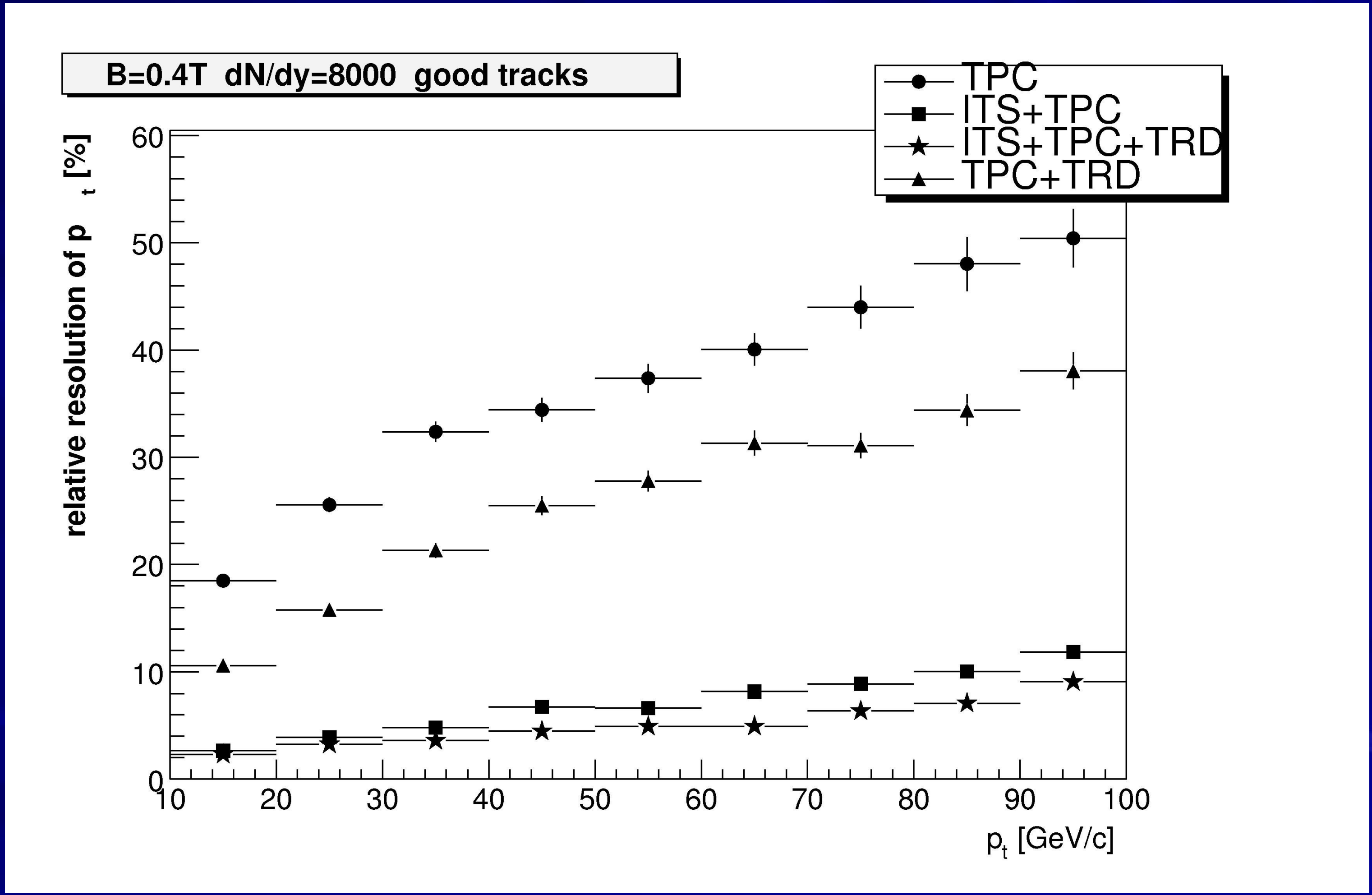
- Models: a small fraction (1%) of Rhadrons have EM charge 2 (based on low energy QCD hadronic spectrum)
- For charge 2 particles the reconstructed momentum is only half of the real (reconstruction assumes charge 1)
- $dE/dx \sim Q^2 \rightarrow$ Complete separation

Laser tracks in the TPC

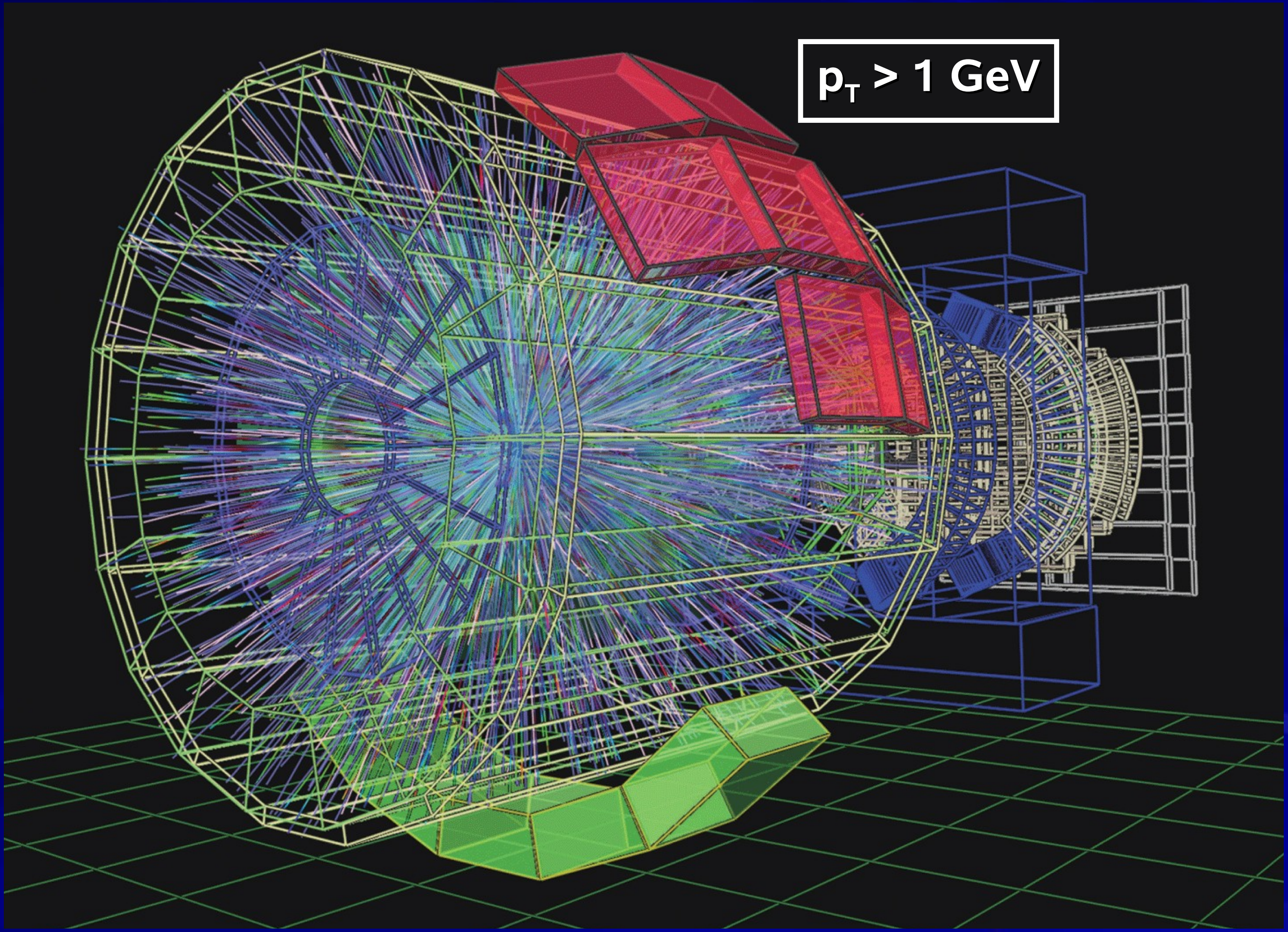




ALICE p_T Resolution for dN/dy = 8000

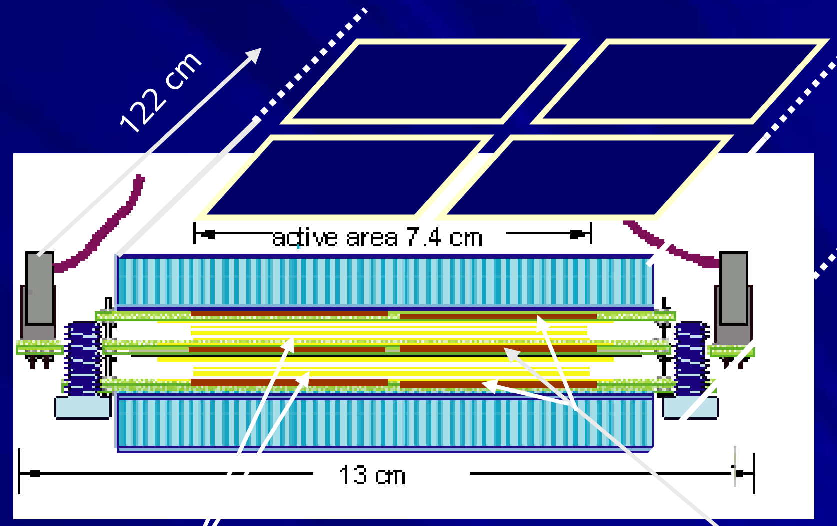


An ALICE PbPb Event



Time Of Flight (TOF)

- Large array at r~3.7m, covering |η|<0.9 and full ϕ
- Test beam results
  - Intrinsic resolution ~40ps
  - Efficiency>99%



- TOF basic element: double-stack **Multigap RPC** strip
- Occupancy < 15% (**O**(10^5) readout channels)