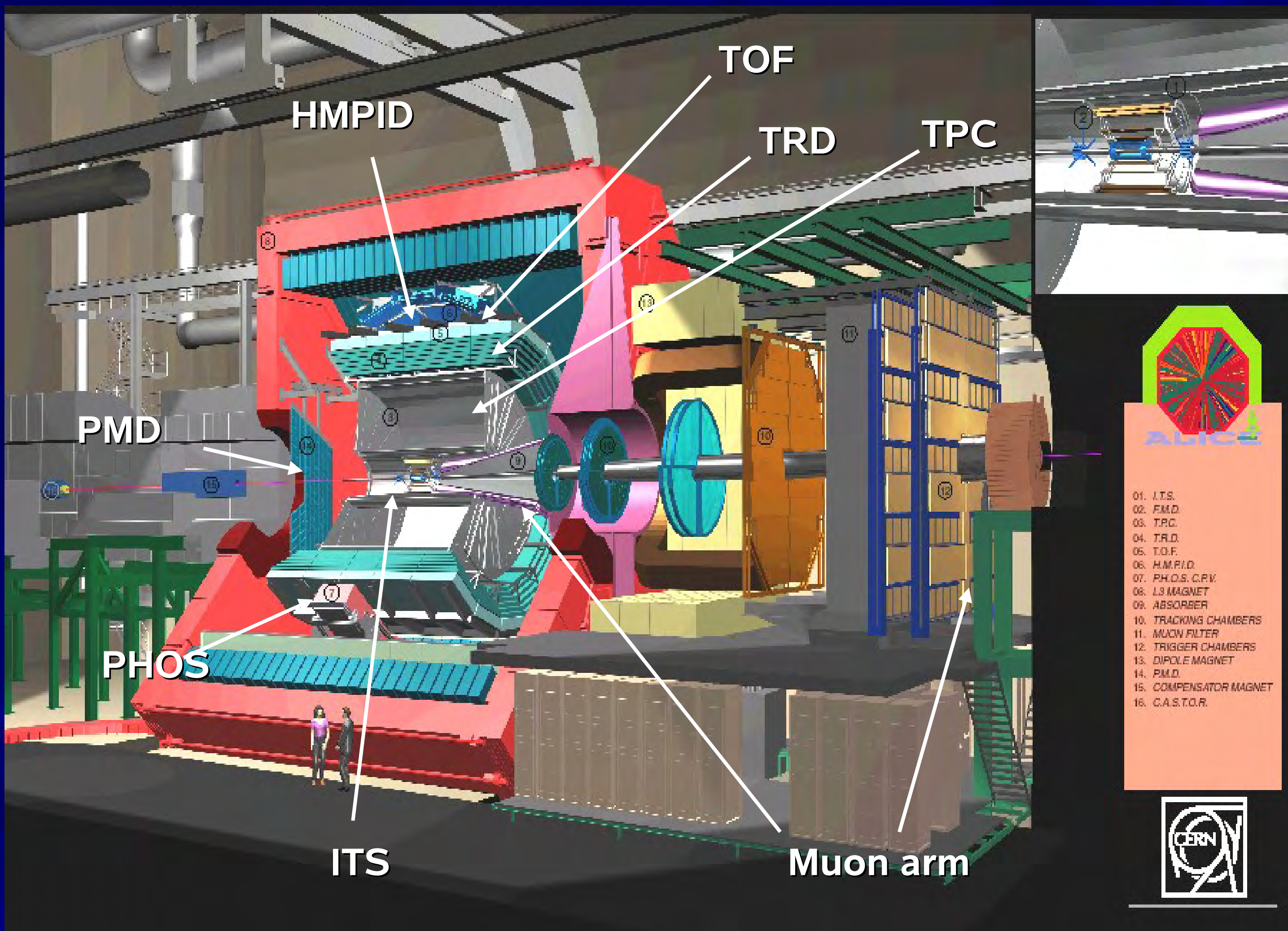
The ALICE TPC

- The ALICE experiment
  - Physics questions to be addressed
- The ALICE TPC
  - TPC introduction
  - Design and layout
- Calibrating the TPC PID at high pT
  - Test beam results
  - Model comparison
- Conclusions

The ALICE experiment at LHC



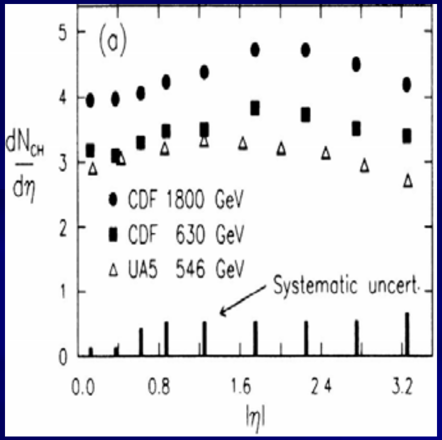
Global detectors:
V0
T0
FMD

Combines the best of STAR: TPC and full azimuthal coverage and PHENIX: Photon/lepton detectors and also has: inner tracker

Proton-proton physics with ALICE (from June 2008)

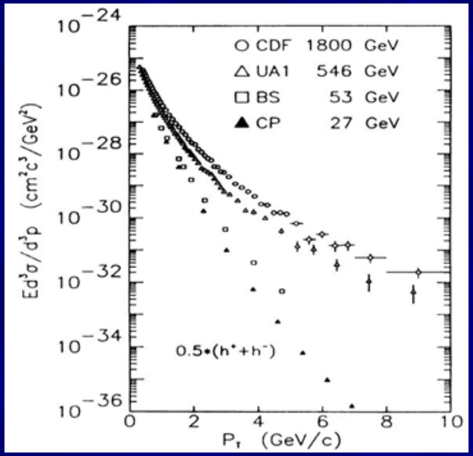
- The first physics with ALICE will be proton-proton collisions:
  - Provides "reference" data to understand heavy-ion collisions.
  - Genuine proton-proton physics where ALICE is unique or competitive
    - low momentum cutoff – due to low magnetic field and small material budget
    - particle identification – unique in central region at LHC
    - ALICE reach p_T up to ~100GeV/c, ensuring overlap with other LHC experiments
  - Proton data taking at several centre-of-mass energies (0.9 TeV?, 2.4 TeV?, 5.5 TeV? and 14 TeV)
- Physics programme: interplay of non-perturbative *vs*. perturbative physics
  - Min. bias events global properties, constraints for underlying event in high P_T signals, pileup in rare triggers
  - Multi-parton interactions (high multiplicity pp events)
  - Heavy Flavours (b and c quarks) [TRD, muon arm and TPC/ITS]
  - Jet physics
  - New physics? Rhadrons (SUSY gluinos) studied here in Lund

First p+p measurements with ALICE (and the TPC)



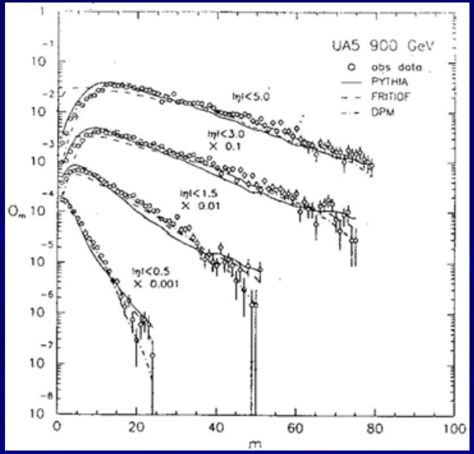
Pseudorapidity density dN/dη

CDF:
Phys. Rev.
D41, 2330 (1990)



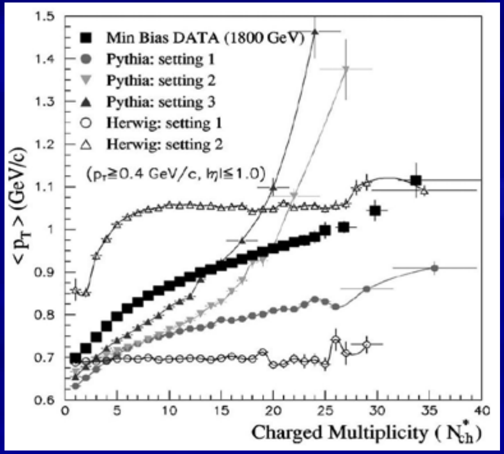
p_T spectrum Charged tracks

CDF:
Phys. Rev. Lett.
51, 1819 (1988)



Multiplicity distribution

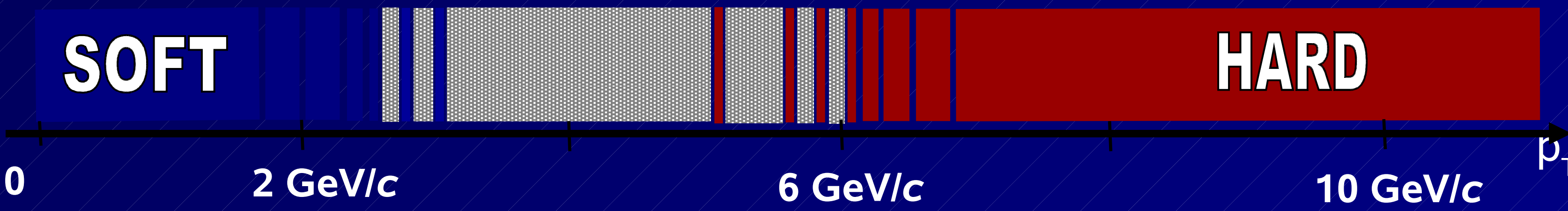
UA5:
Z. Phys
43, 357 (1989)



Mean p_T vs multiplicity

CDF:
Phys. Rev.
D65,72005(2002)

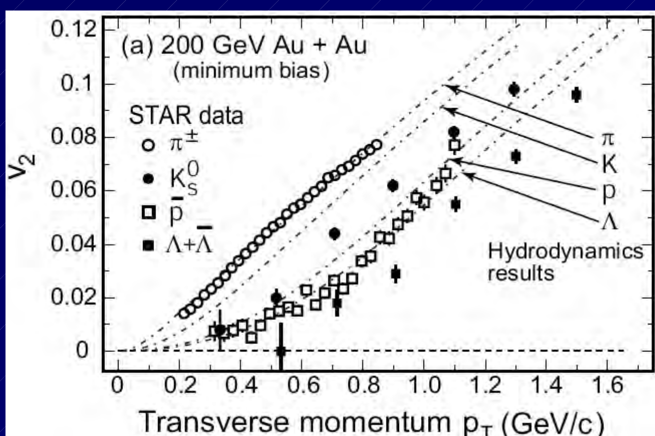
RHIC

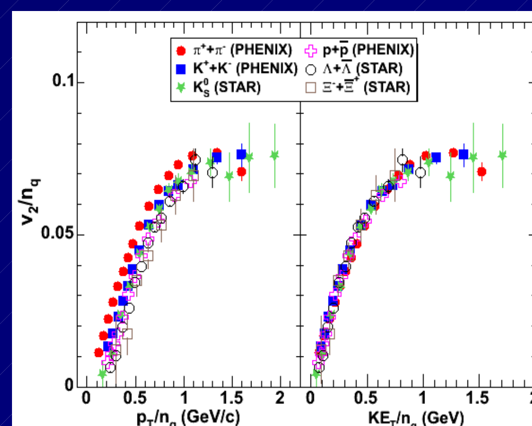


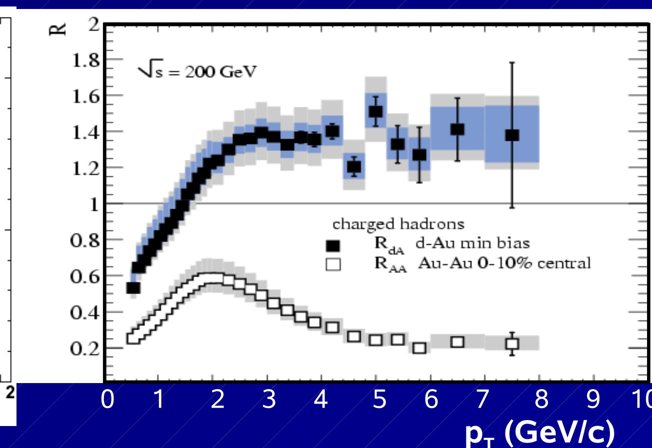
Soft
Early thermalized liquid.

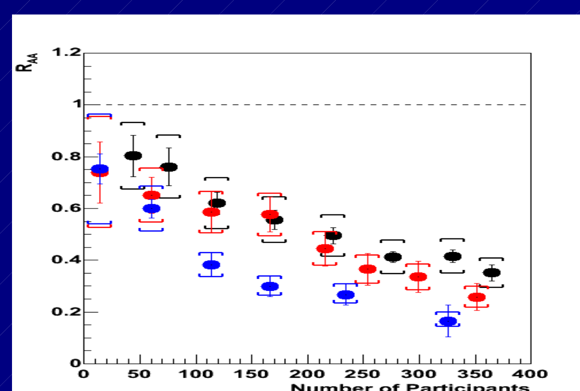
Intermediate
Quark dof?

Hard / pQCD
Dense coloured medium.









Heavy quarks / pQCD
Deconfinement.

How will these observables look at LHC?
Will there be novel effects?

The ALICE TPC
The key detector in ALICE

The Challenge: Pb+Pb central event in ALICE

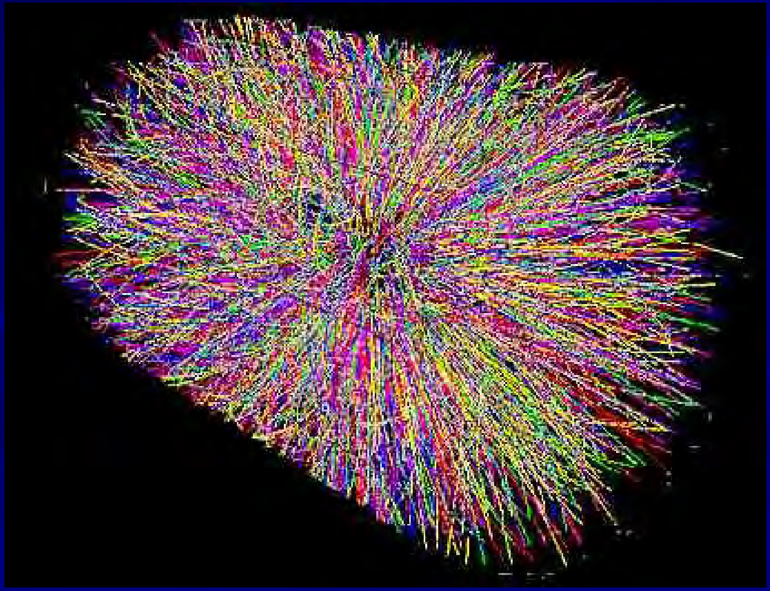
Pb+Pb event

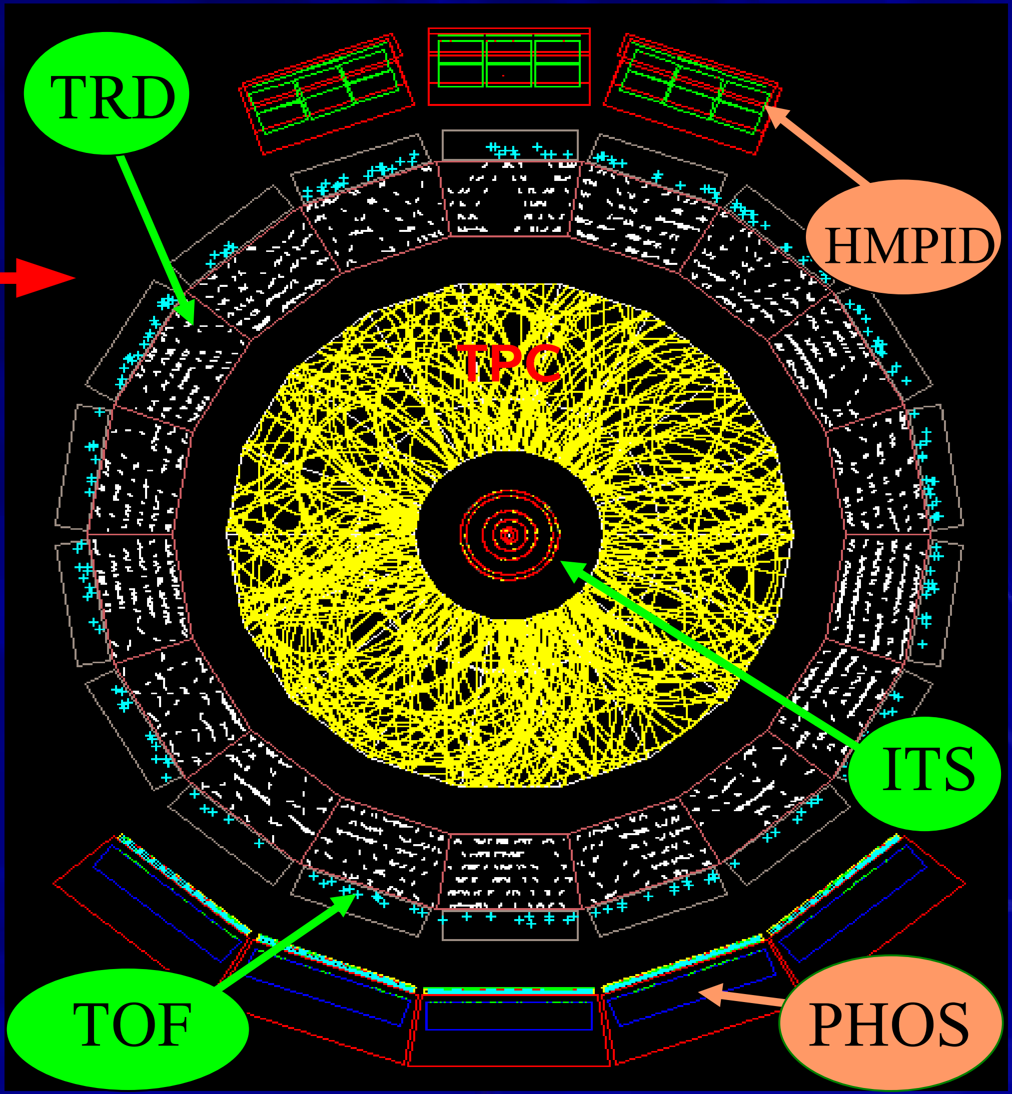
(dN/dy = 8000)

Δθ = 2° slice only!

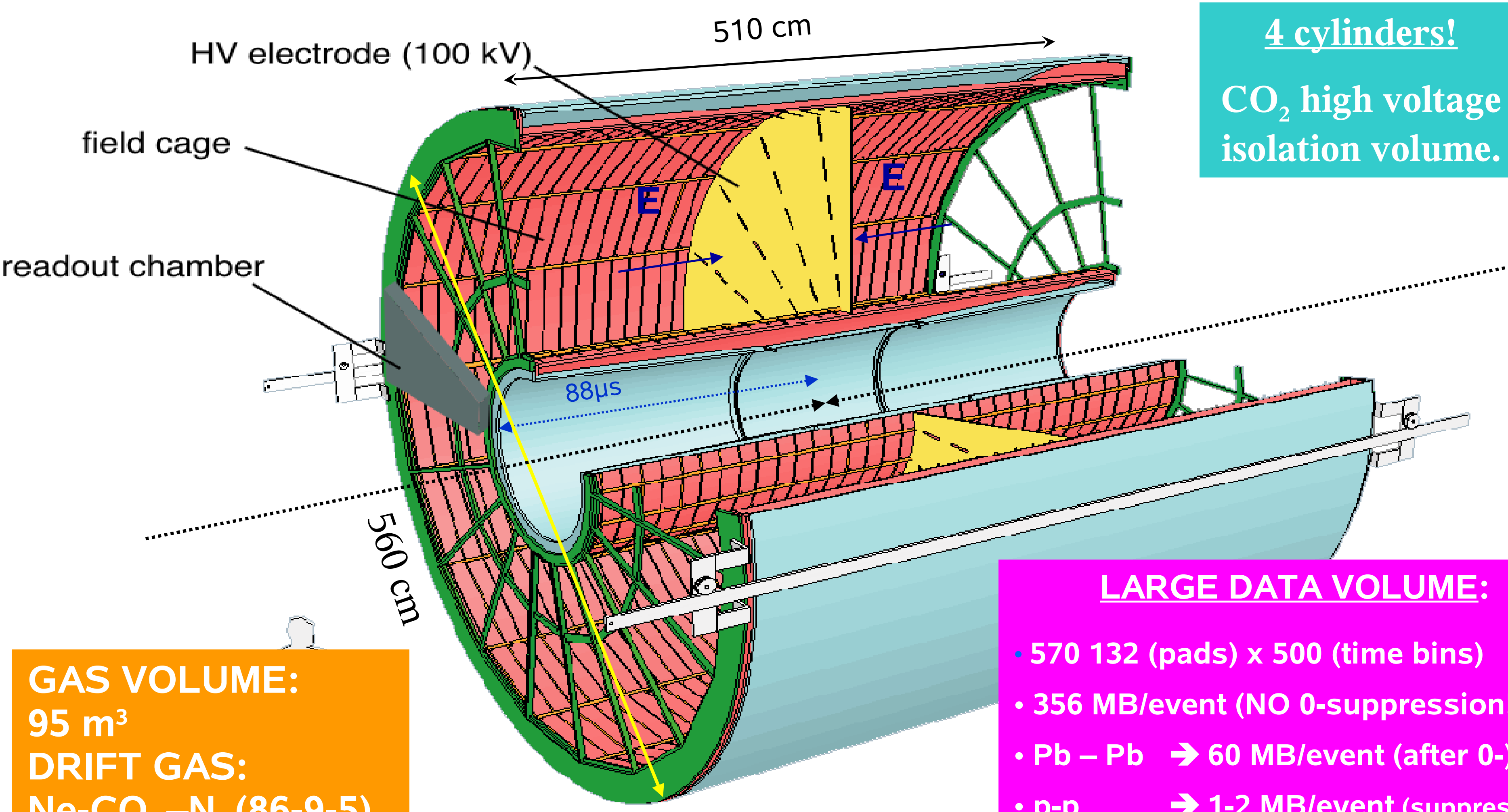
(~500 tracks)

Up to 40% occupancy (N_{ABOVE} / N_{ALL})





ALICE TPC: Layout



4 cylinders!

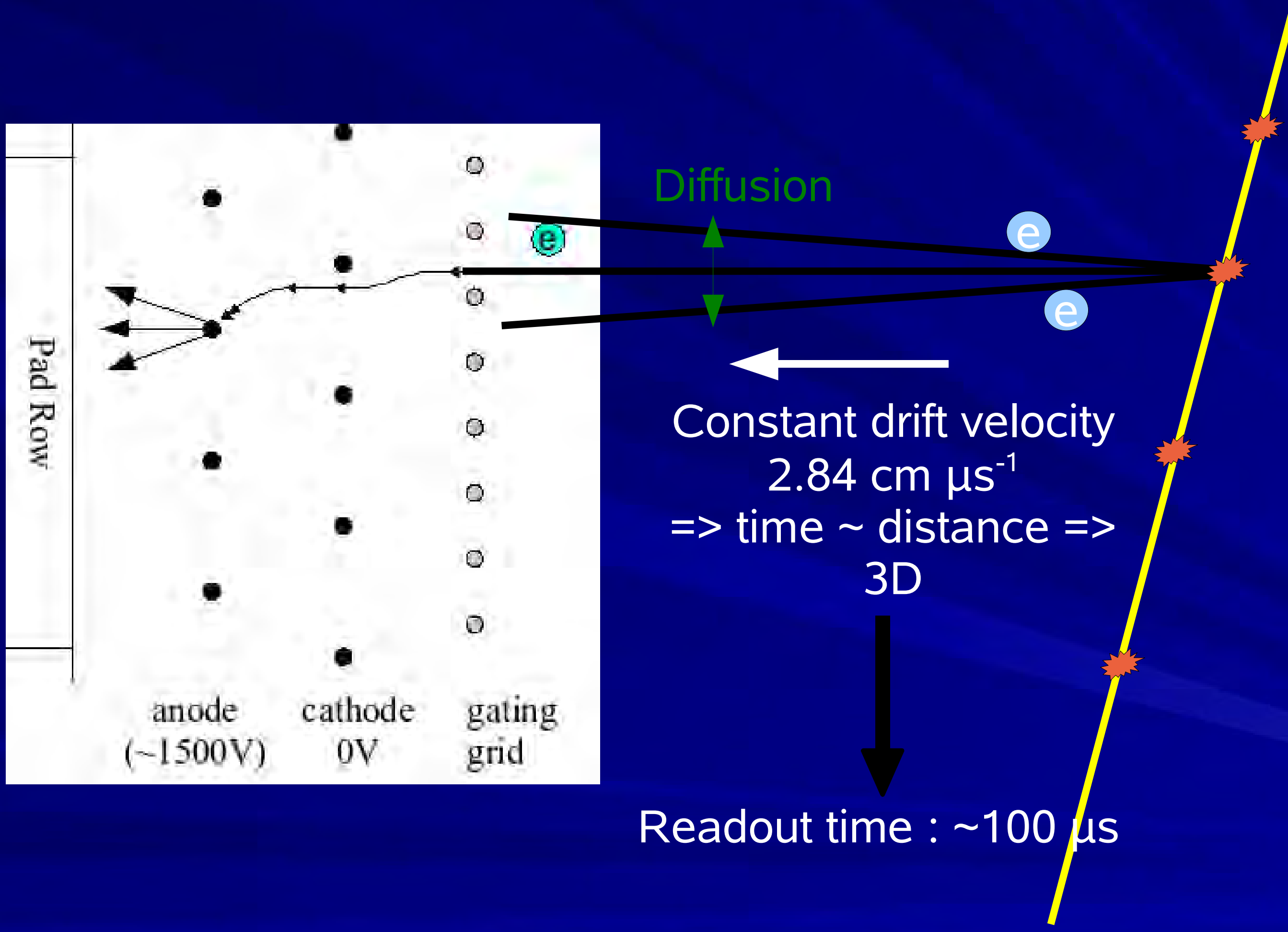
CO_2 high voltage isolation volume.

GAS VOLUME:
95 m^3
DRIFT GAS:
Ne-CO_2–N_2 (86-9-5)

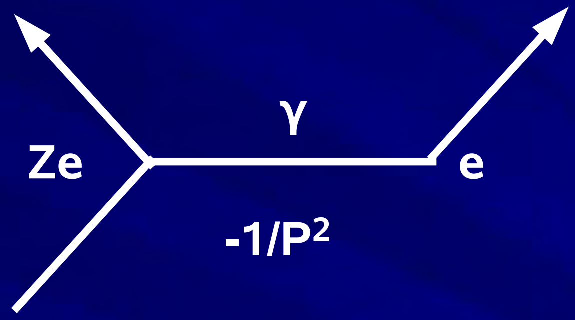
LARGE DATA VOLUME:

- 570 132 (pads) x 500 (time bins)
- 356 MB/event (NO 0-suppression!)
- Pb – Pb → 60 MB/event (after 0-)
- p-p → 1-2 MB/event (suppres.)

Operating Principle



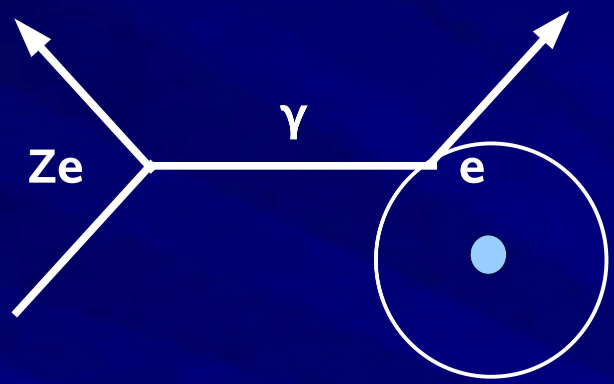
Energy loss: Free electron (Rutherford)



Electron is initially at rest

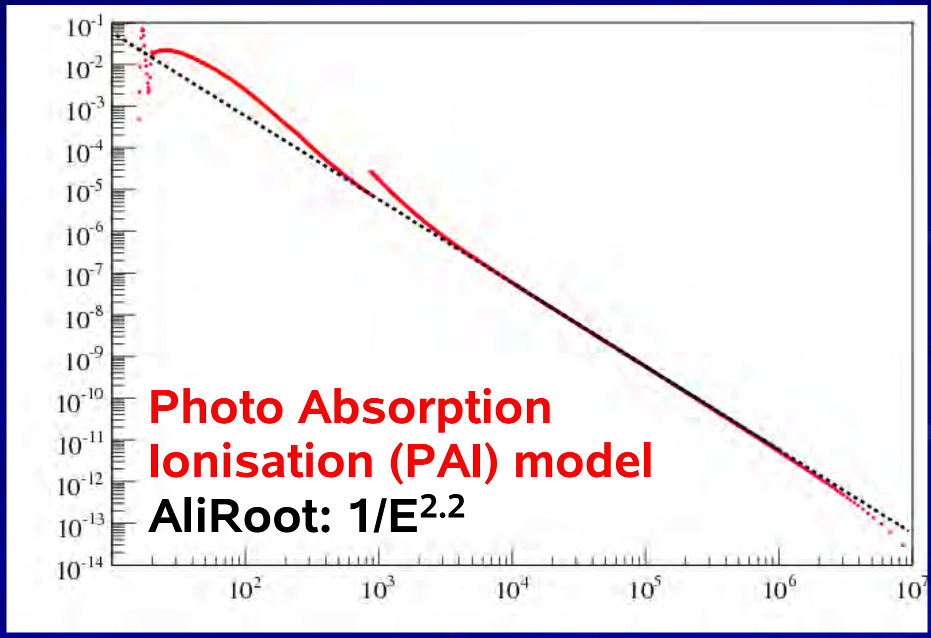
- $P \sim -Ze^2/P^2$
- $d\sigma/dE \sim Z^2e^4/P^4 \sim 1/E^2$
  - Where E is the energy loss
- σ is infinite (EM interaction has infinite range)
- For energy loss $E < m_{electron}$ the electron is scattered perpendicular to the incoming charged particle

Energy loss: Electron in atom



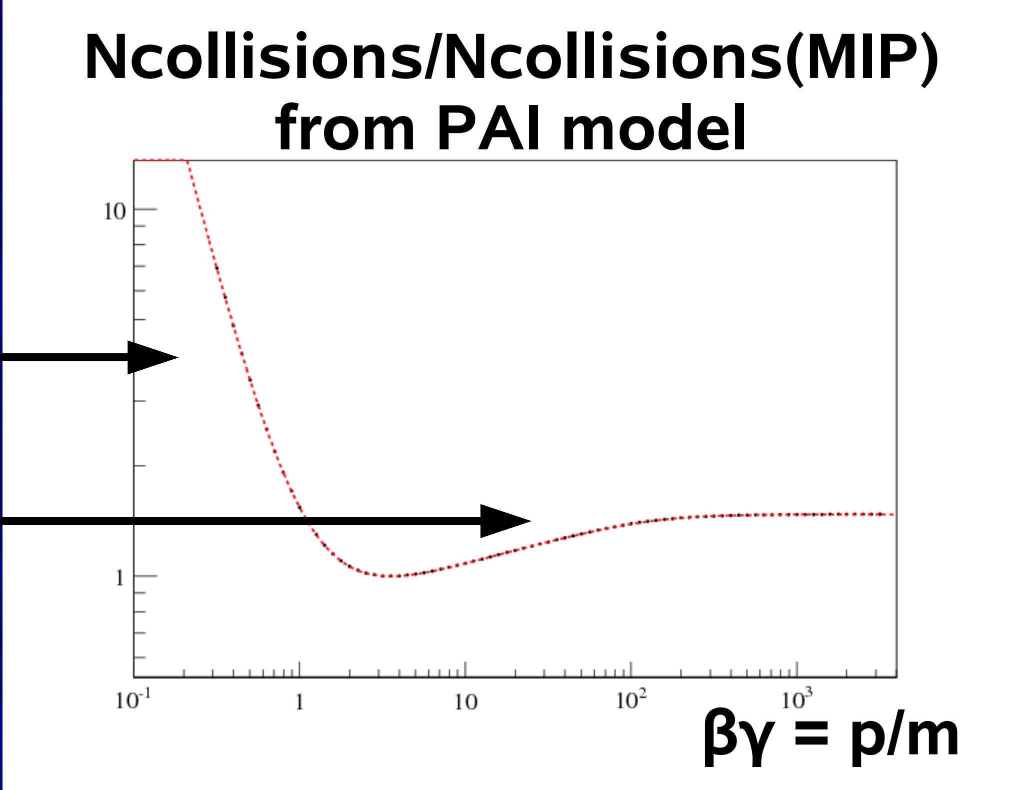
Electron is bound in atom

- Scattering from bound electrons can be approximated with "real" photon cross sections. <u>Energy levels</u> and <u>shell structure is visible</u>. Cross section is finite.

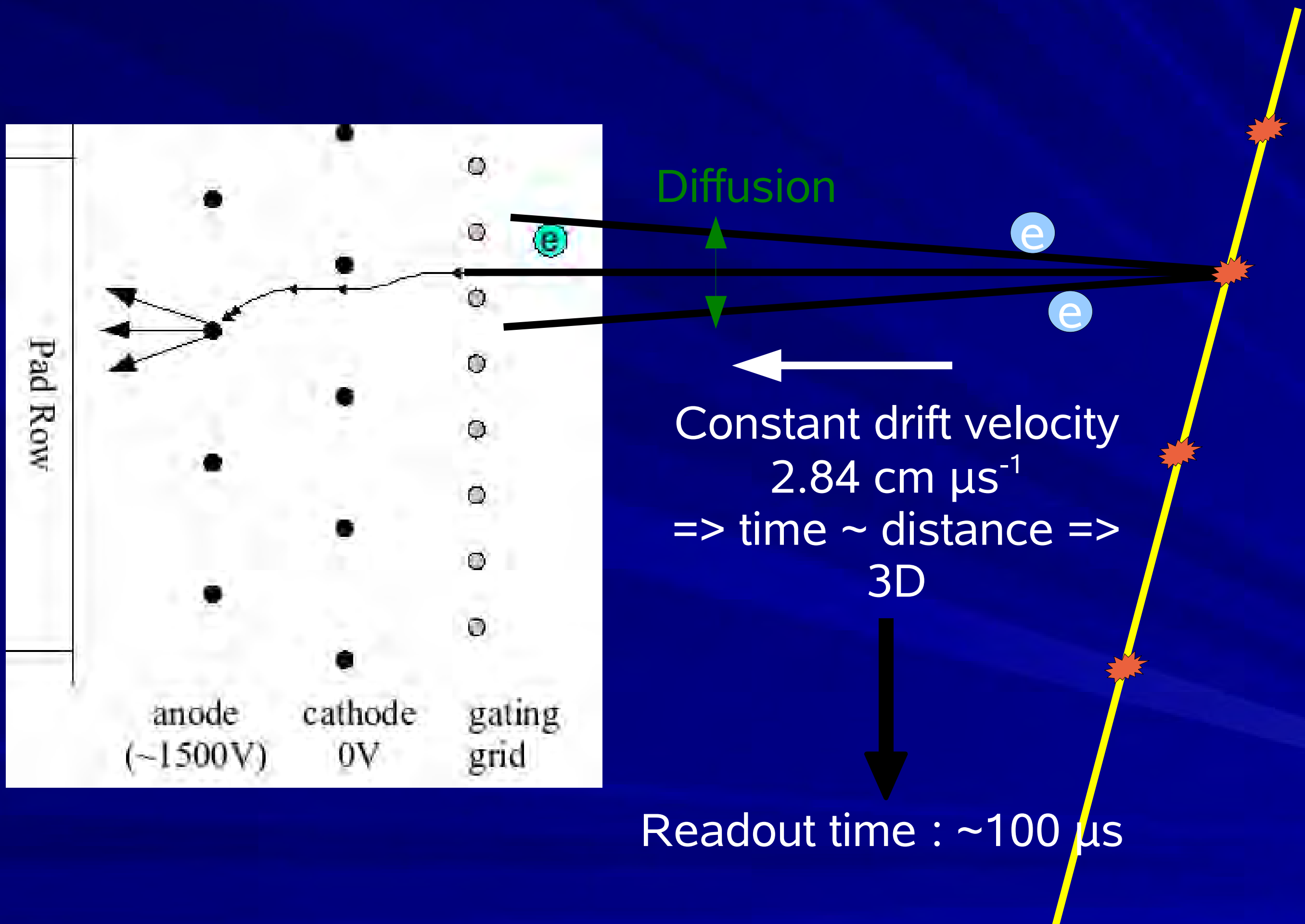


Energy loss: dE/dx in materials

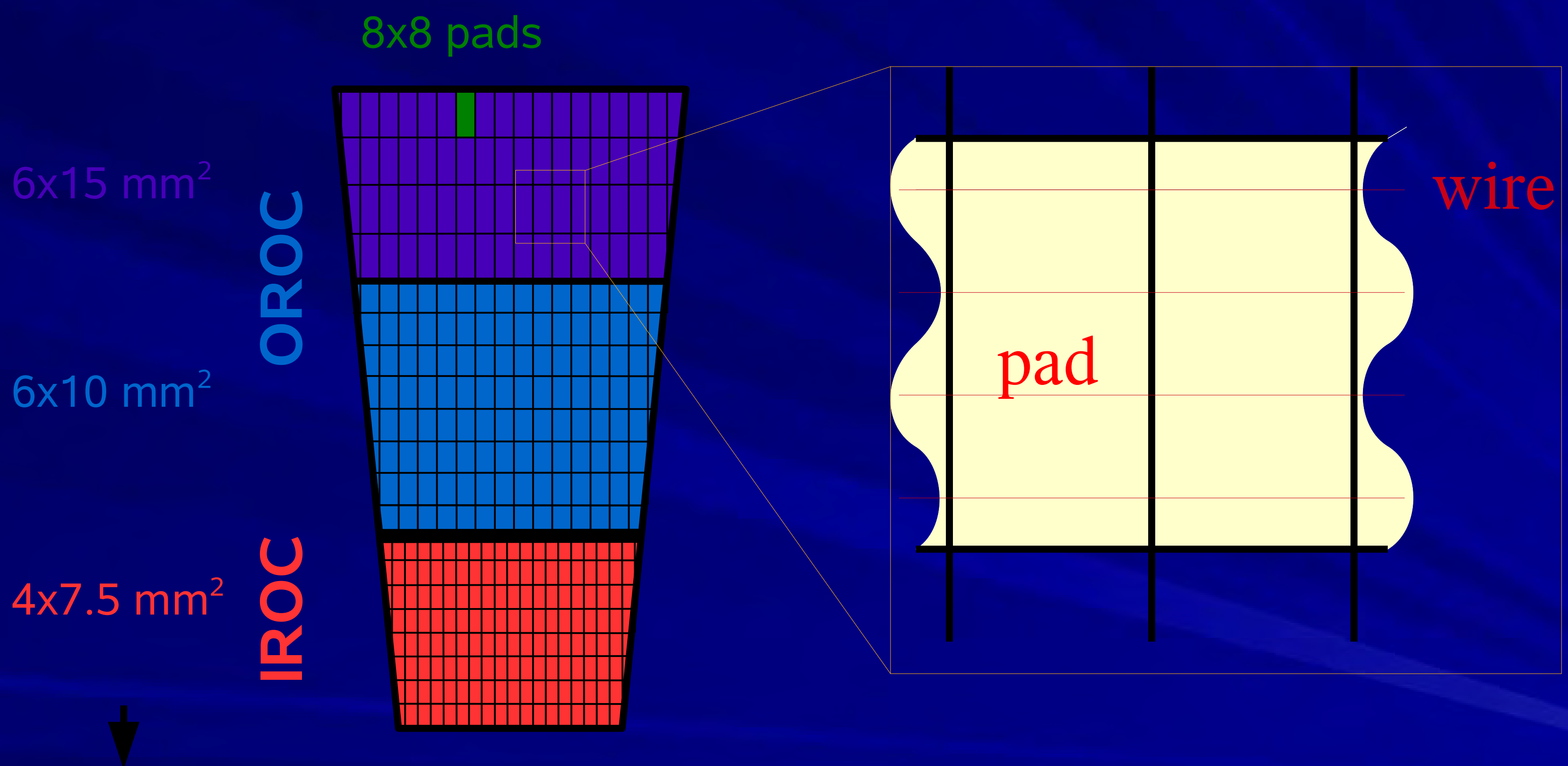
- As the charged particle traverses the gas it can make multiple collisions
  - dE/dx = folding of energy loss in each collision (previous slide) and cross-section (Poisson) ~ Landau distribution
- NB! Very weak mass dependence
- Low energies: $dt = dx/\beta$, area that we can scatter with: $A=\pi*(c*dt)^2 \sim 1/\beta^2$
- High energies: electric field (σ) grows with γ, but eventually the medium polarizes and σ saturates



Operating Principle



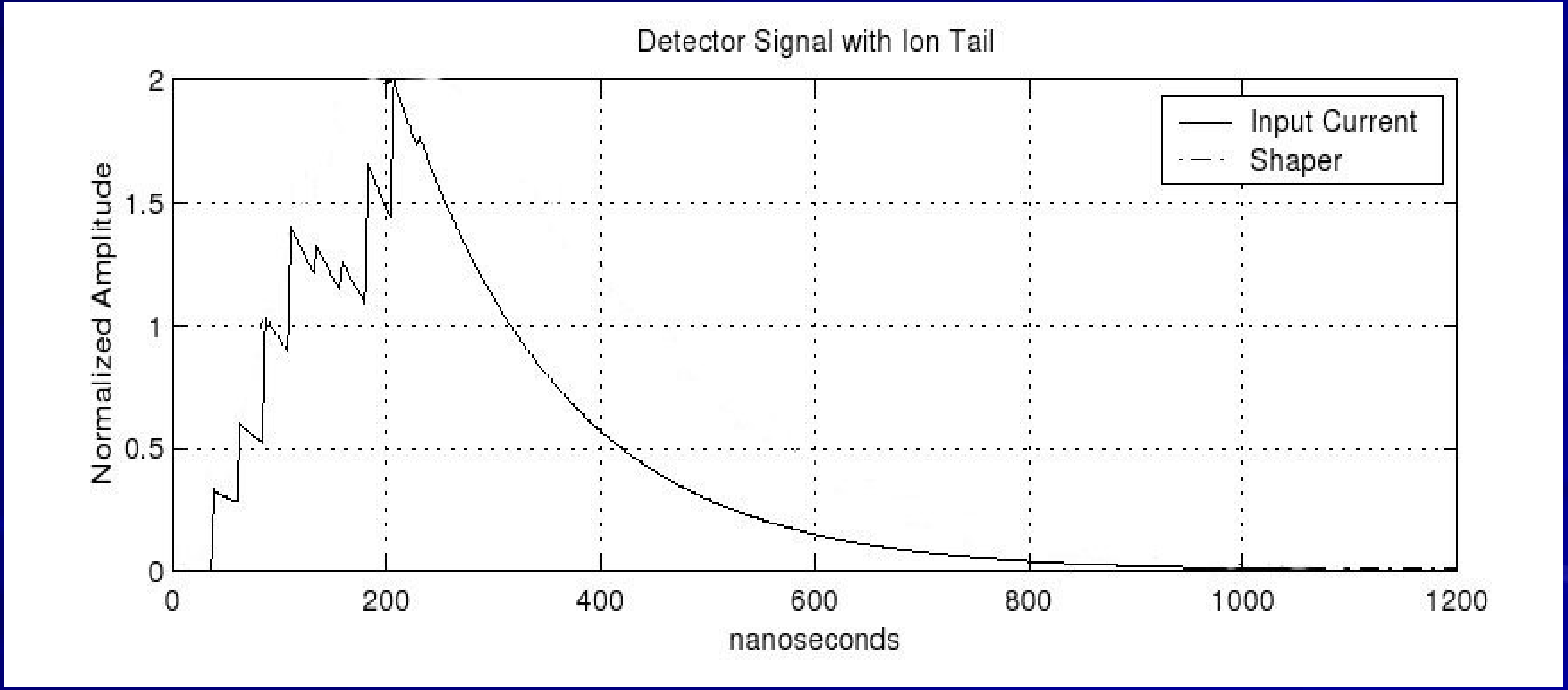
ReadOut Sectors



Total >570 000 pads (electronic channels) ← 2 x 18 sectors

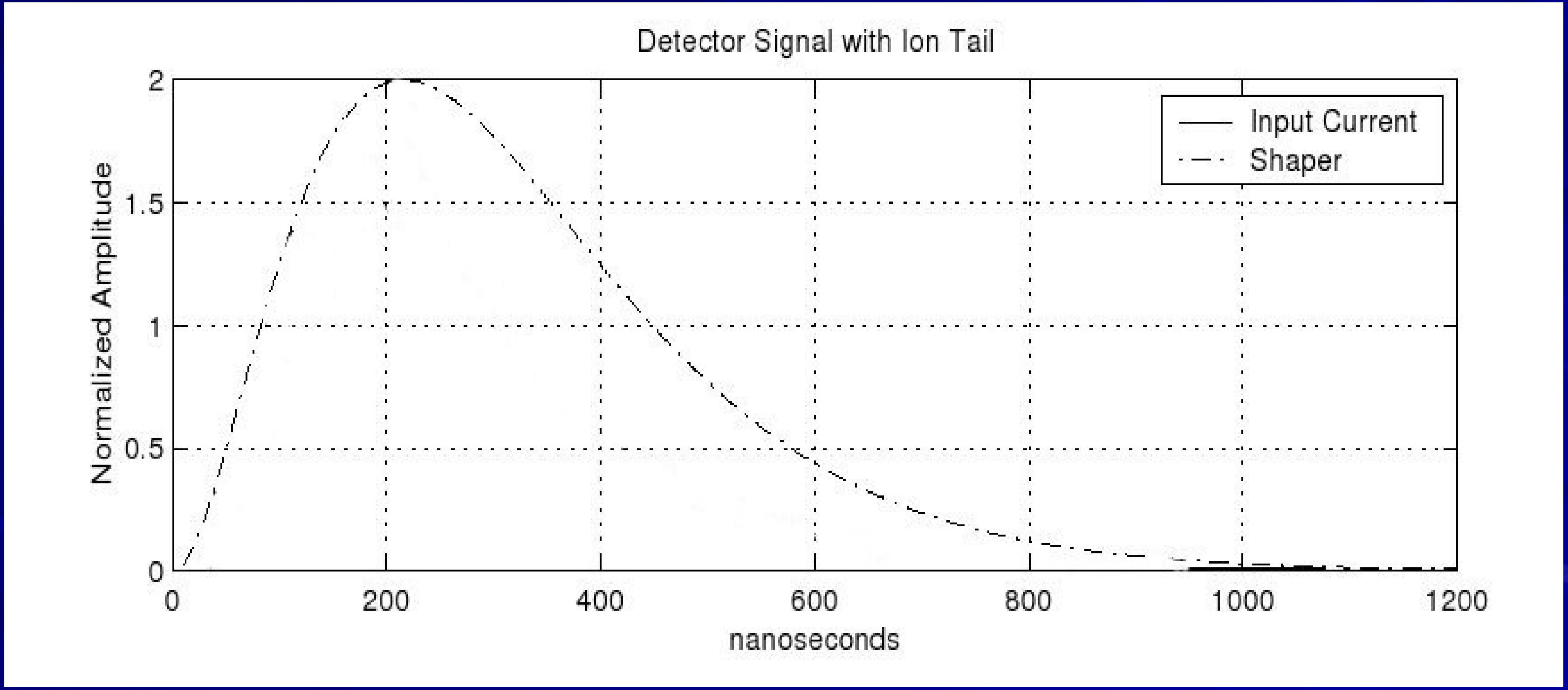
Electronics : PASA

Pad signal has a long tail due to slow drifting ions

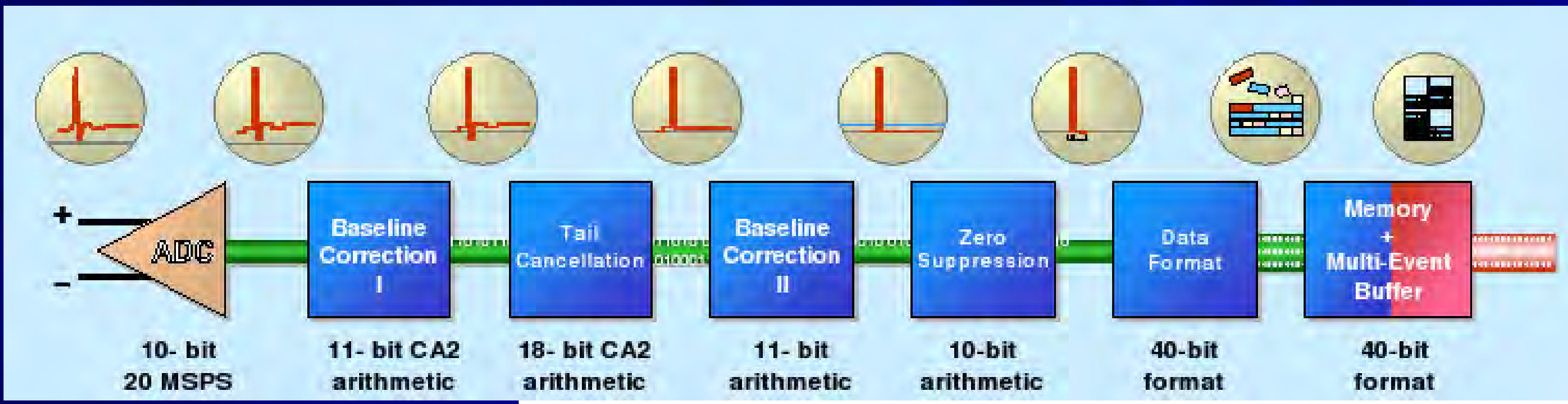


Electronics : PASA

Pad signal is amplified and shaped

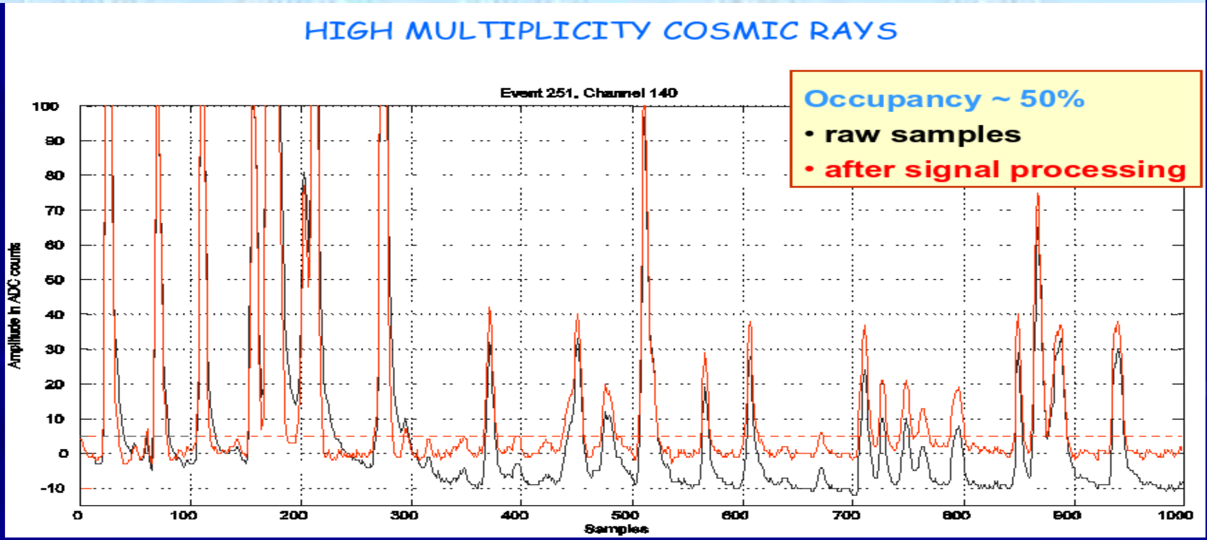


Electronics : ALTRO

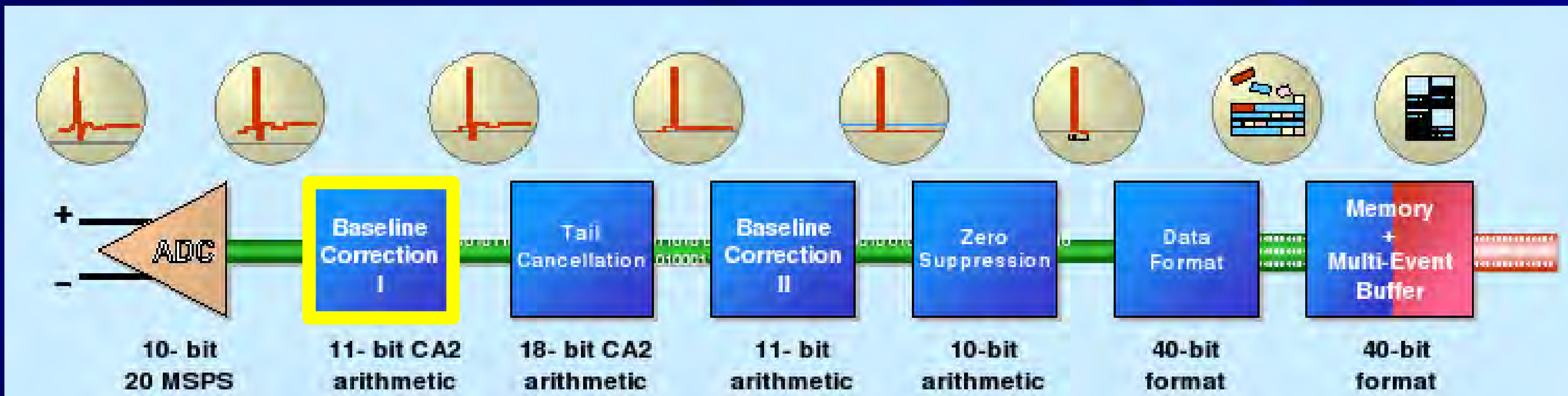


~digital oscilloscope

Total data in one event:
~ 1 GByte

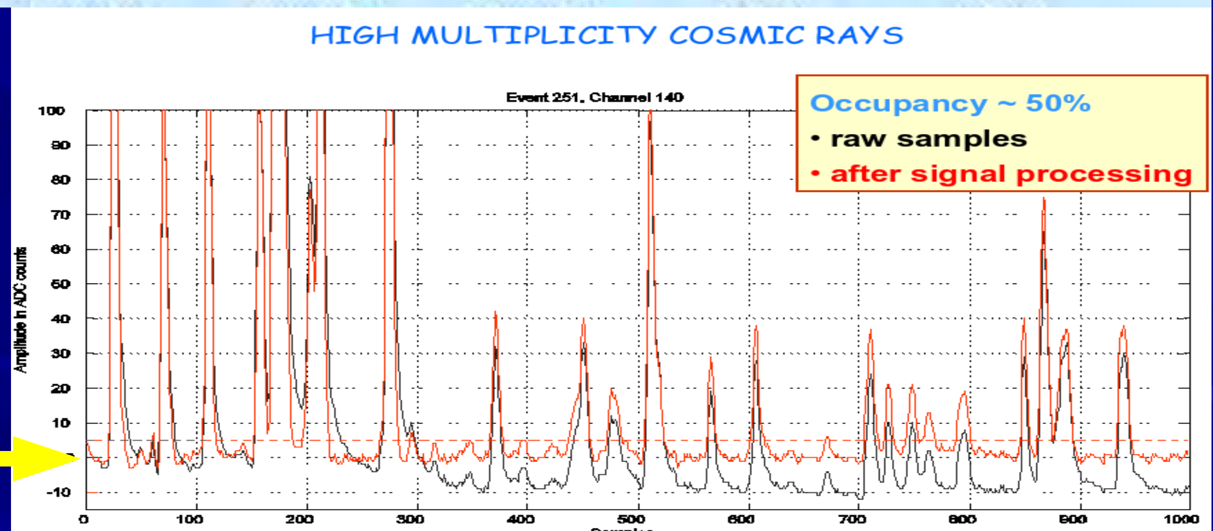


Electronics : ALTRO

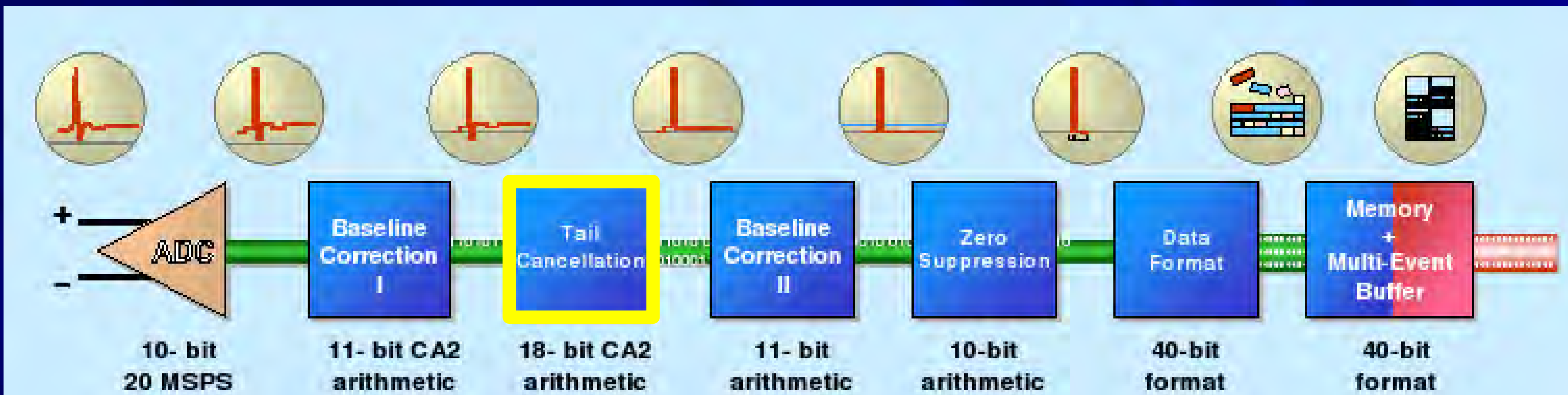


~digital oscilloscope

Total data in one event:
~ 1 GByte

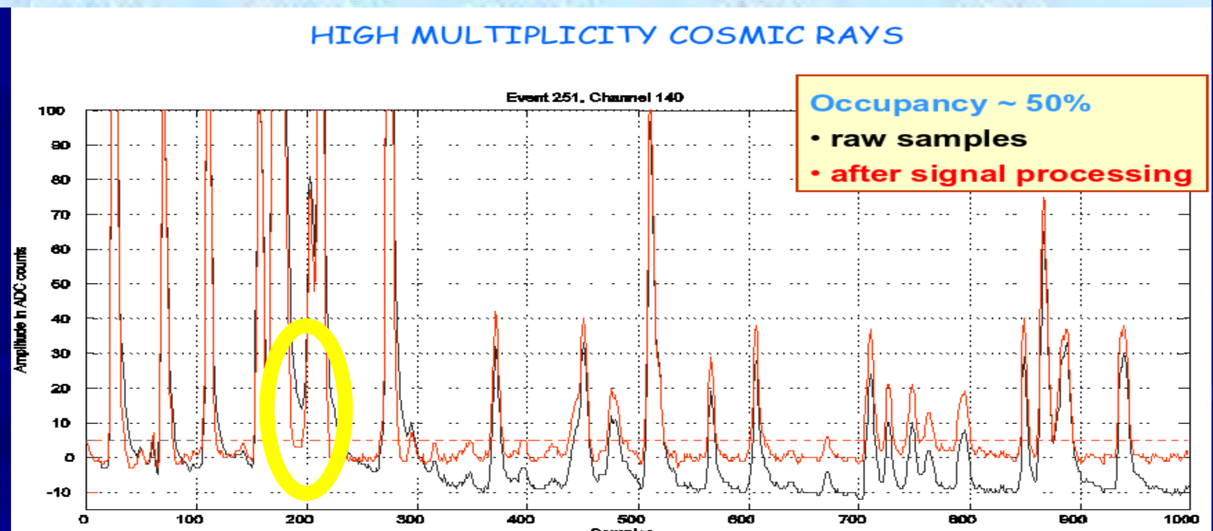


Electronics : ALTRO

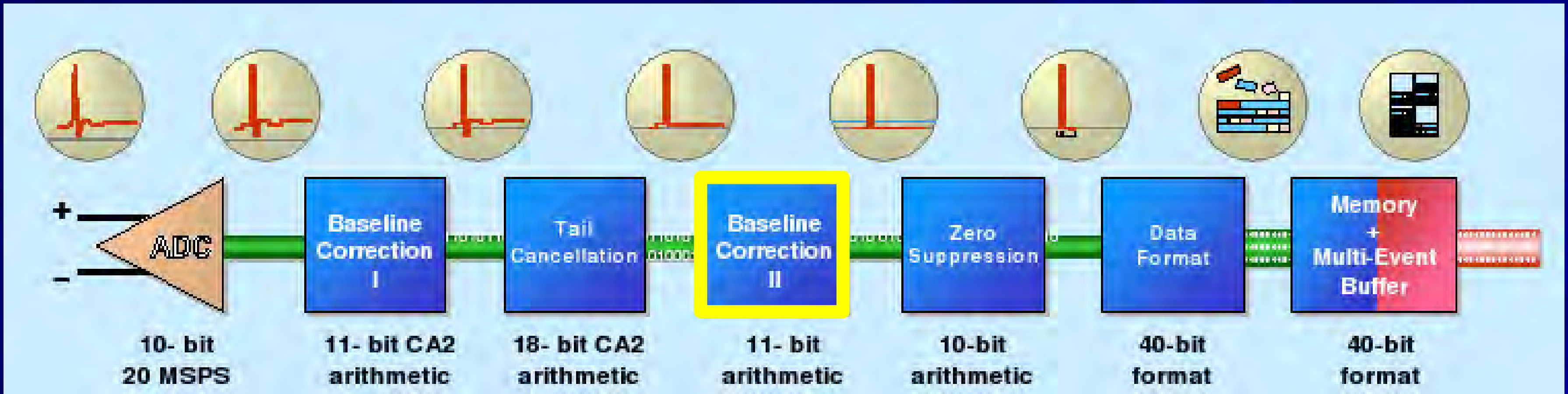


~digital oscilloscope

Total data in one event:
~ 1 GByte

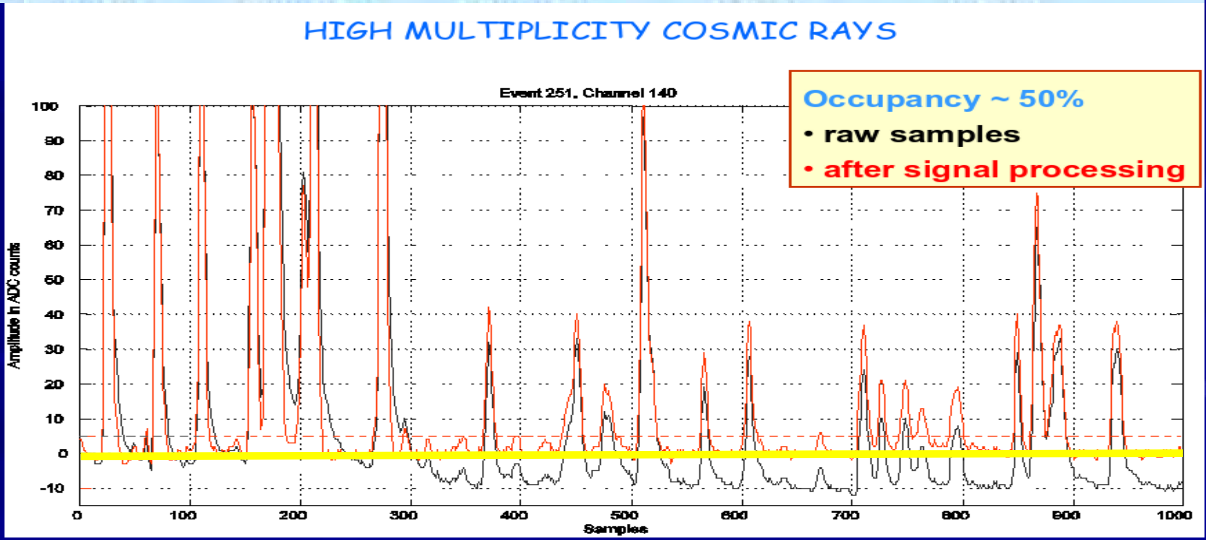


Electronics : ALTRO

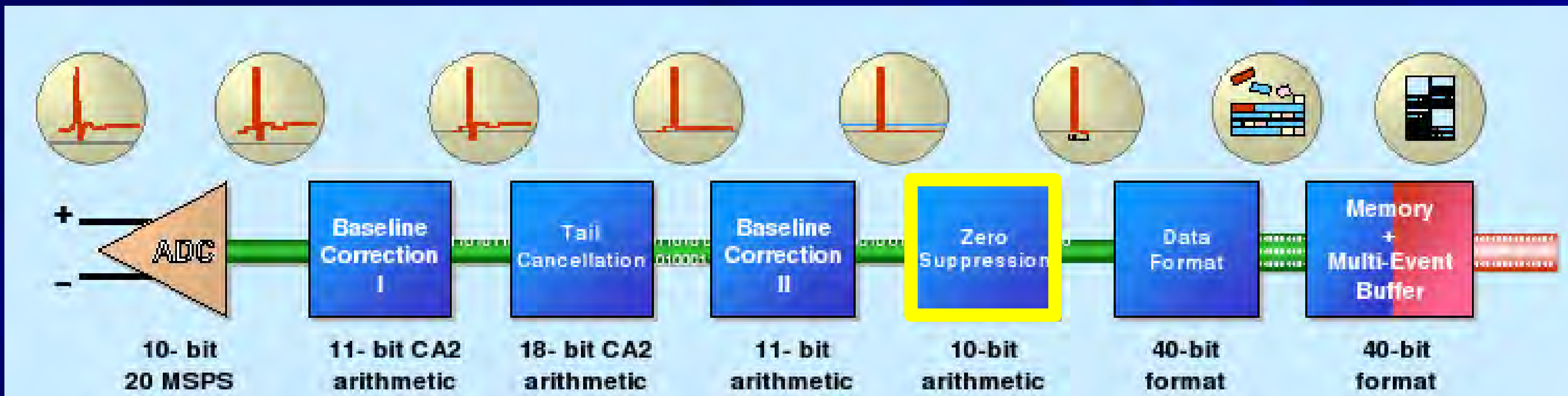


~digital oscilloscope

Total data in one event:
~ 1 GByte



Electronics : ALTRO

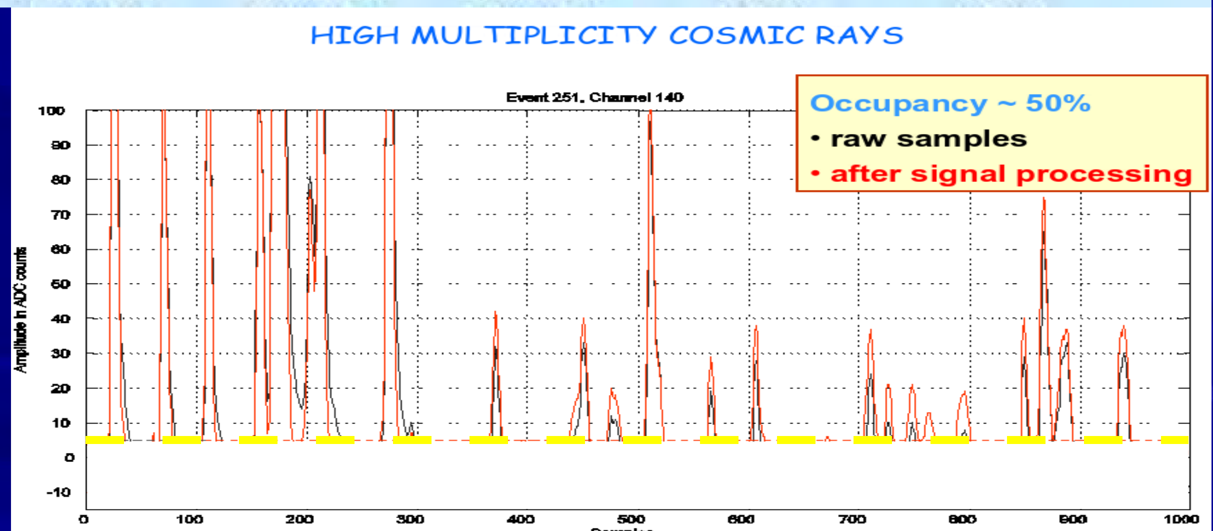


~digital oscilloscope

Total data in one event:

~ **60 MB**

(1 MB for p+p)

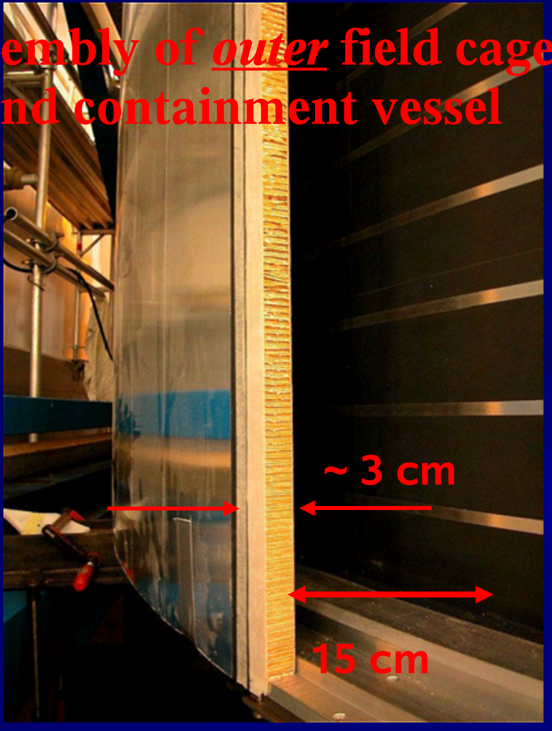


ALICE TPC design

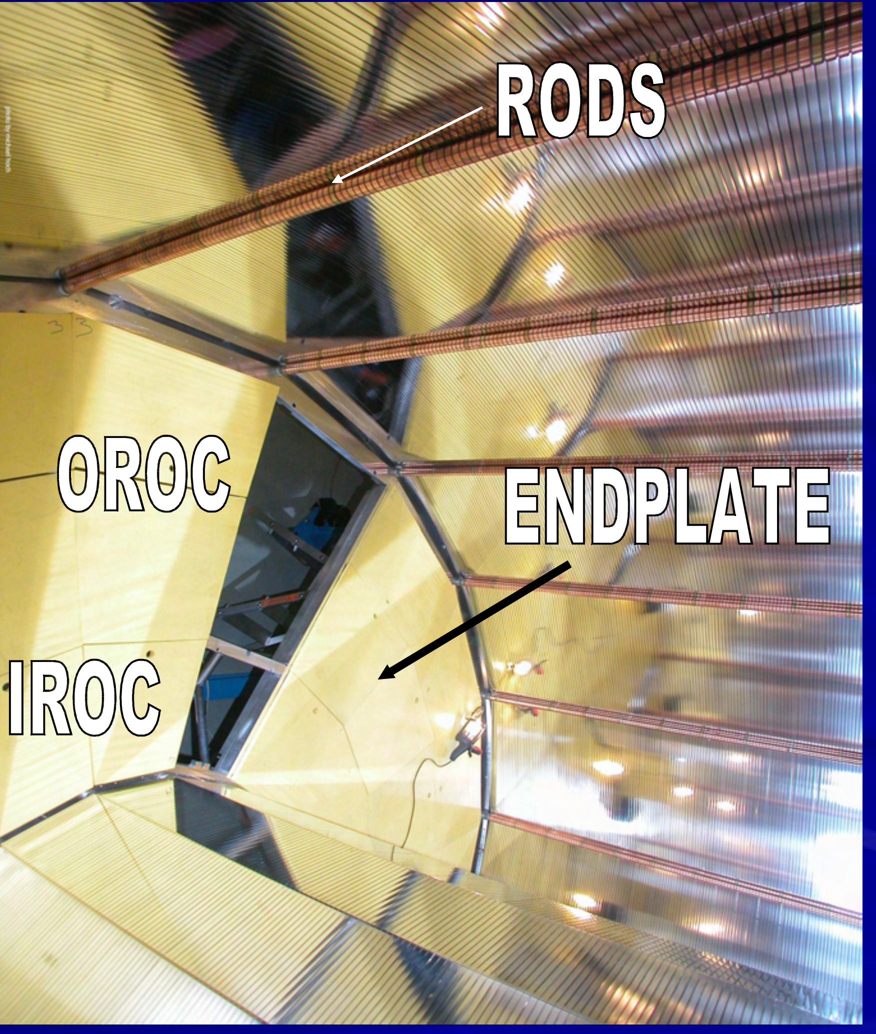
- Minimize multiple scattering
  - Composite materials for field cage
- High occupancy
  - High readout segmentation (3D)
    - Online reduction of data
  - Neon gas (fast ion drift velocity limits space charge effects)
  - CO_2 quencher (small diffusion and good aging properties)
- Small signal (Small pads, low density gas)
  - Low noise electronics (<1000e)
  - High gain ($\sim 10^4$)
    - Non-transparent gate ($<10^{-4}$)
- Good space point resolution
  - Small field distortions $\Delta E/E \approx 10^{-4}$ (field cage precision)
  - Temperature stability<0.1K gradient (Non-saturated gas)

TPC low mass field cage

Assembly of ***outer*** field cage and containment vessel

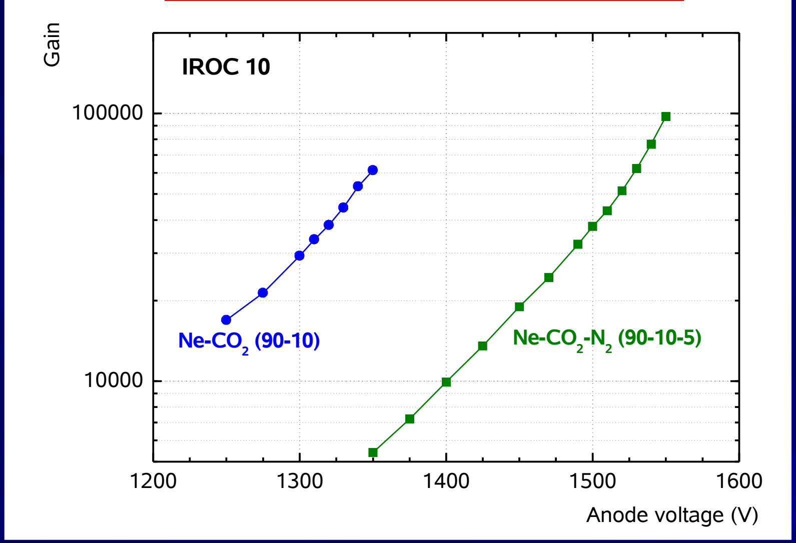


Total x/x_0 ~ 3% radiation length at $\eta = 0$



Gas mixture choice: Ne-CO_2(90-10) vs. Ne-CO_2-N_2(86-9-5)

Gain measurement



Drift velocity comparison

	90-10	*86-9-5*
Temperature	+0.37 % / K	+0.34 % / K
Pressure	-0.15 % / mbar	-0.15 % / mbar
CO_2 concentration	-7.6 % / %CO_2	-6.4 % / %CO_2
N_2 contamination	-1 % / %N_2	-1 % / %N_2

… and <u>same</u> diffusion coefficients.

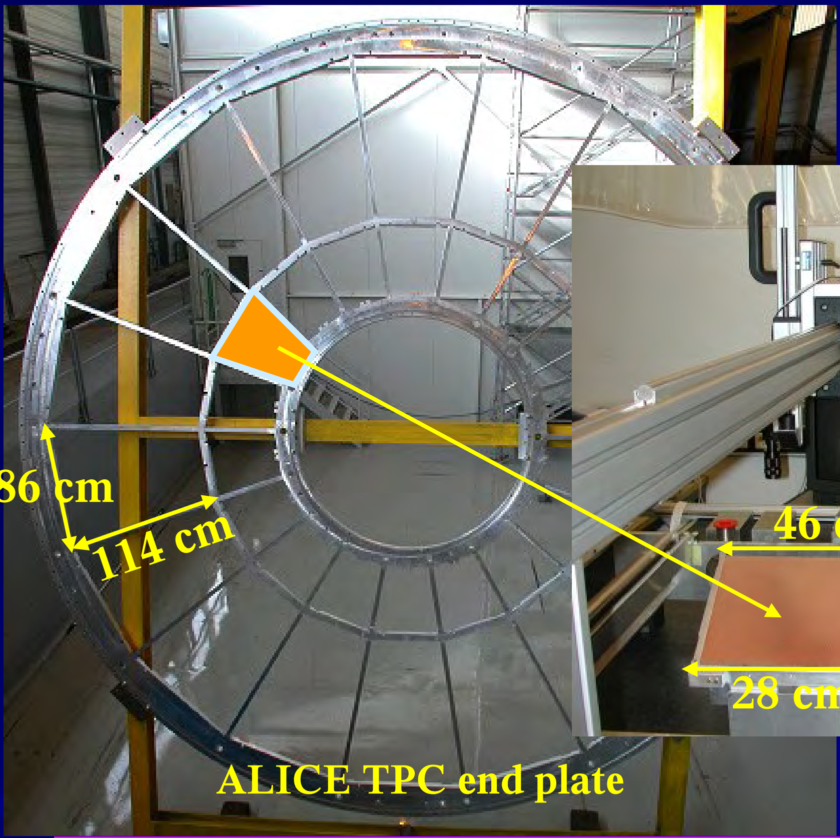
Gain comparison

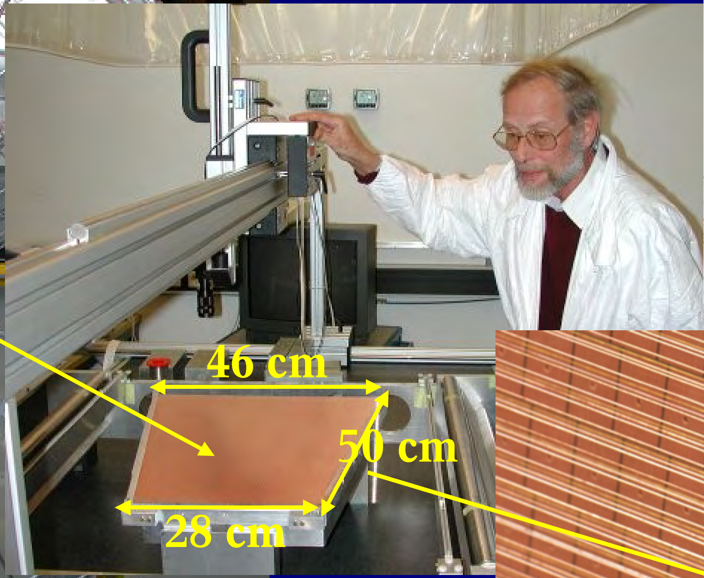
	90-10	*86-9-5*
CO_2 concentration	+67, -20 % / %CO_2	+17, -14 % / %CO_2
N_2 contamination	+34 % / %N_2	+6.3 % / %N_2

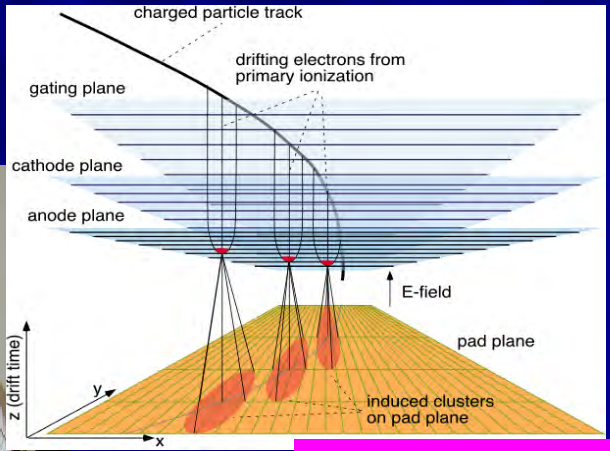
Choice: *Ne-CO_2-N_2(86-9-5)*

- 5% lower drift velocity
- better gain stability

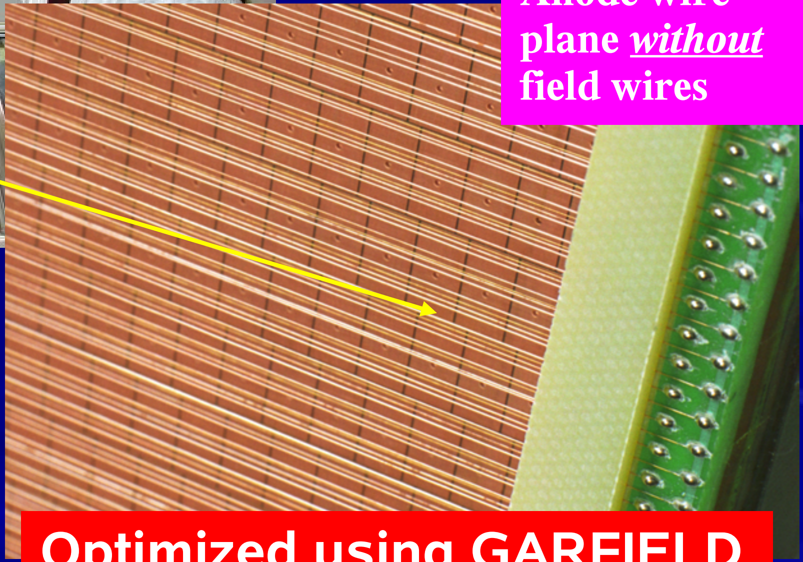
TPC Readout Chambers







Anode wire plane *<u>without</u>* field wires

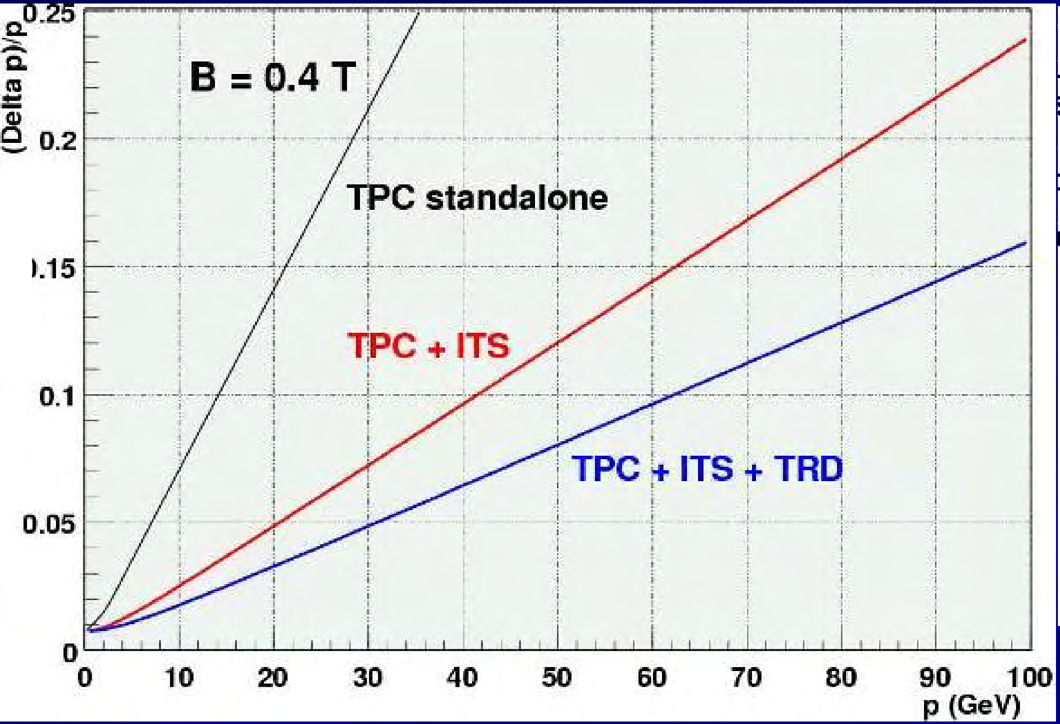


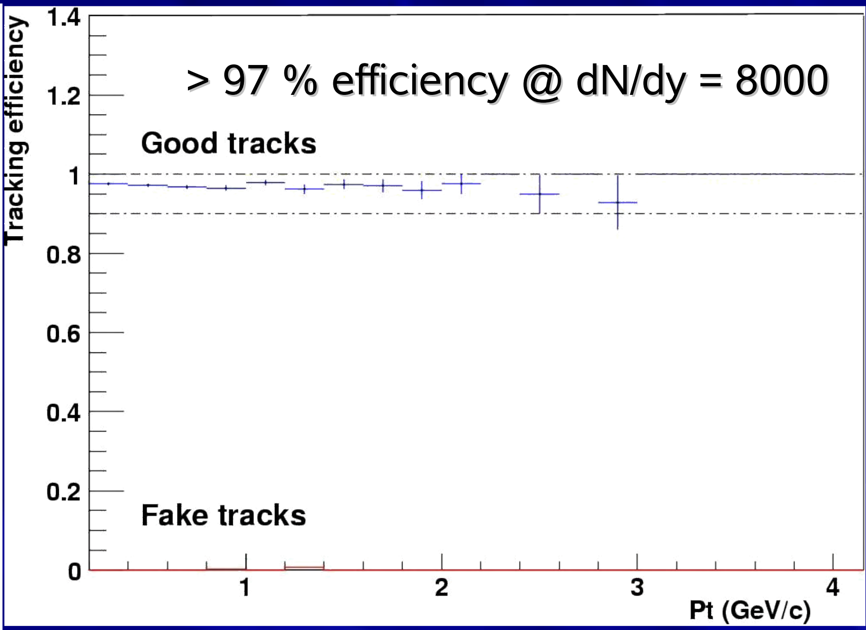
In total 570,132 pads
63 rows with 4 x 7.5 mm^2 (inner radius)
64 rows with 6 x 10 mm^2
32 rows with 6 x 15 mm^2 (outer radius)

Optimized using GARFIELD

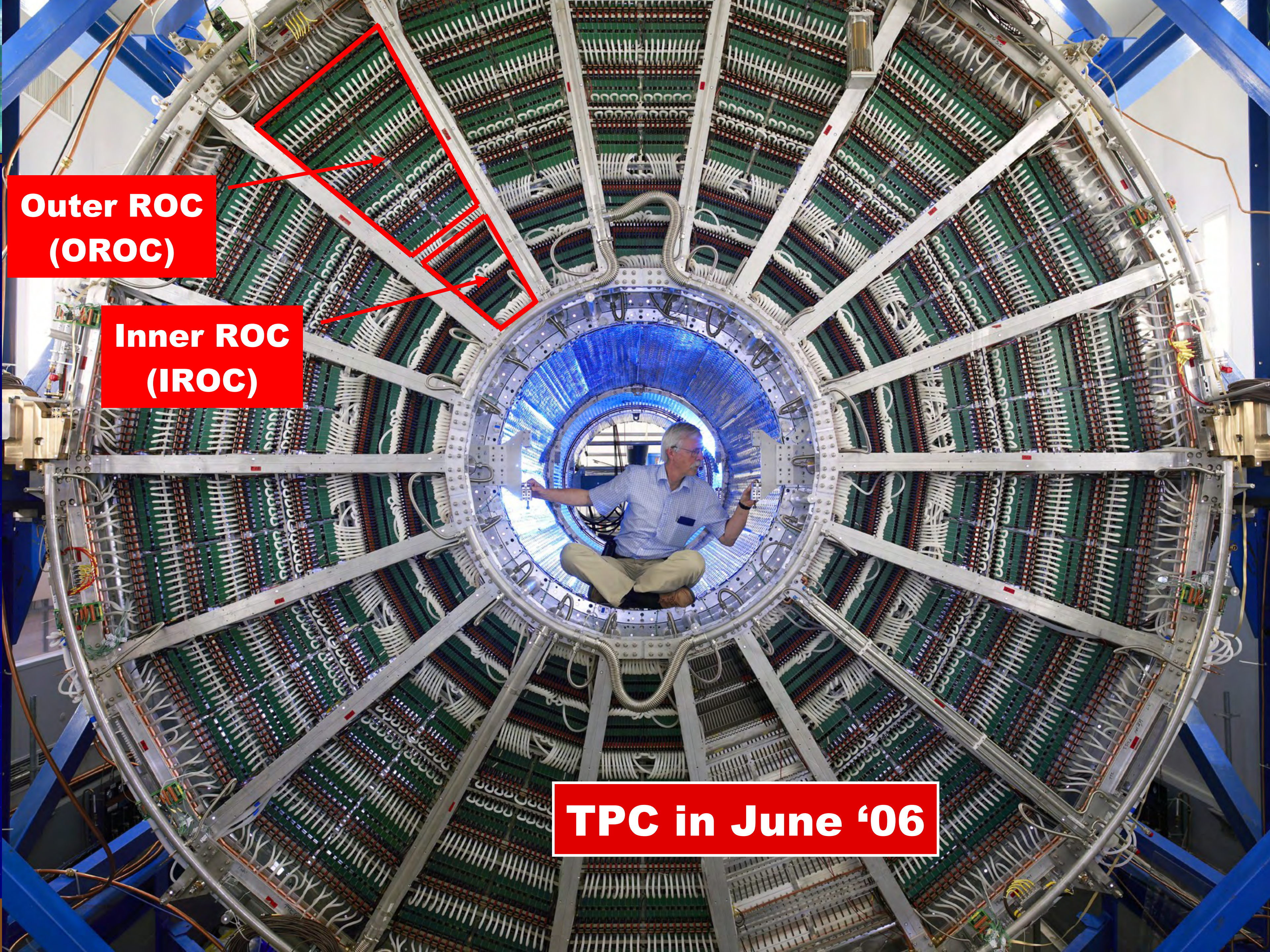
Simulated TPC tracking performance

dp/p

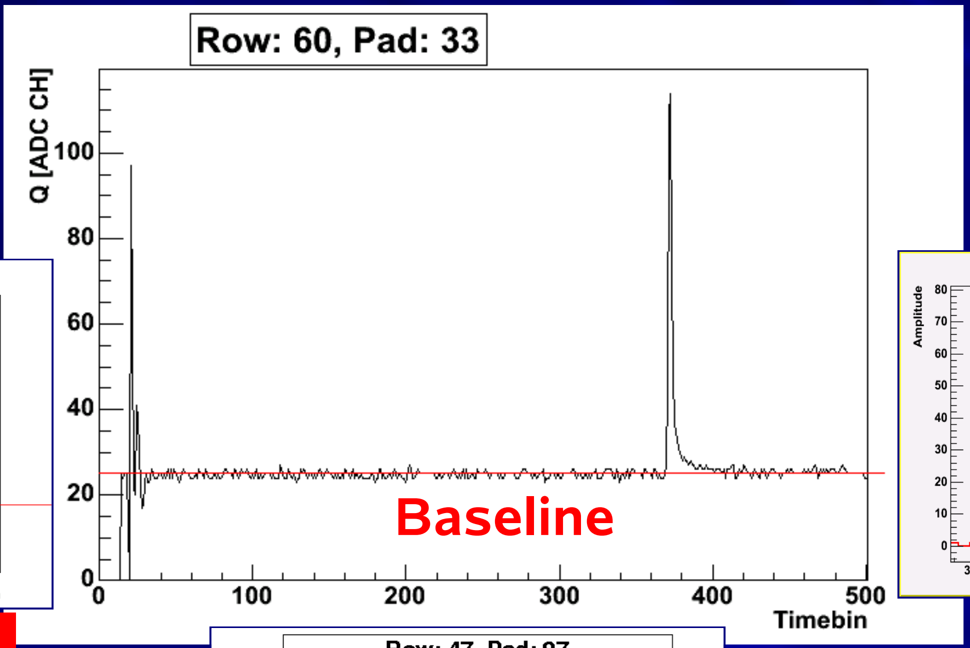




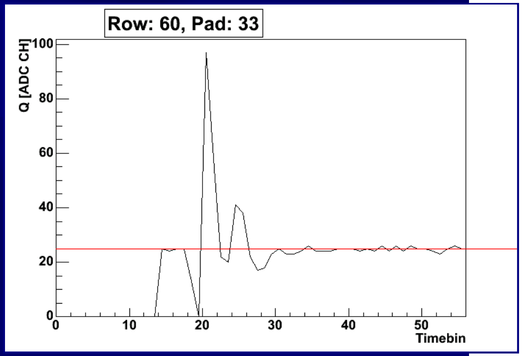
- TPC is ALICE main tracking detector in central barrel
- Note: standard field **0.5 T**
- dp/p vs dN/dy: 16% $\rightarrow$ **9% @ 100 GeV**, dN/dy = 2000


Outer ROC
(OROC)
Inner ROC
(IROC)
TPC in June ‘06

The signal in a single pad

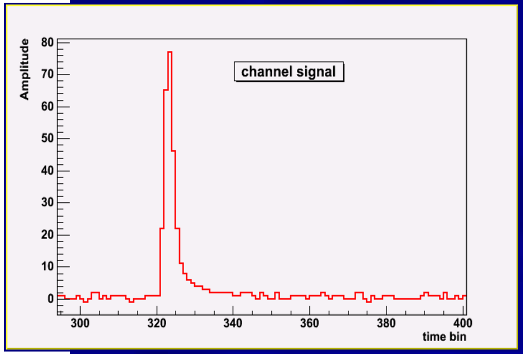


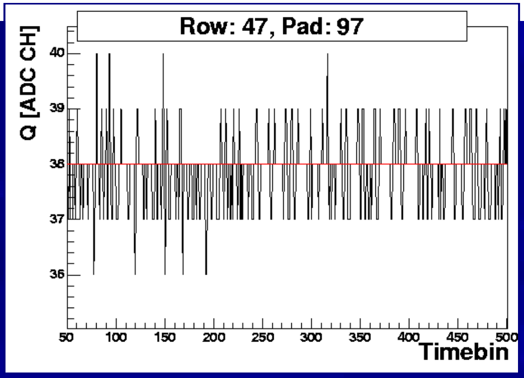
Gating signal



Gate voltages:
-130V±100V
Height: 50-70 ADC
Width:15-20 ch~2µs

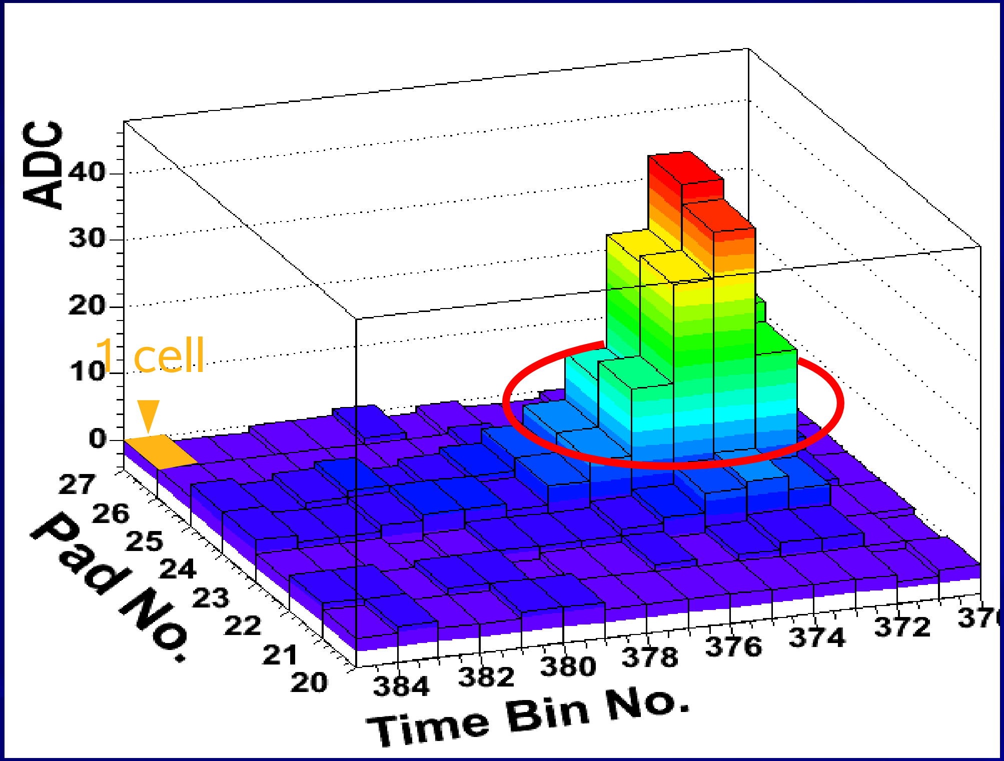
Signal





Noise

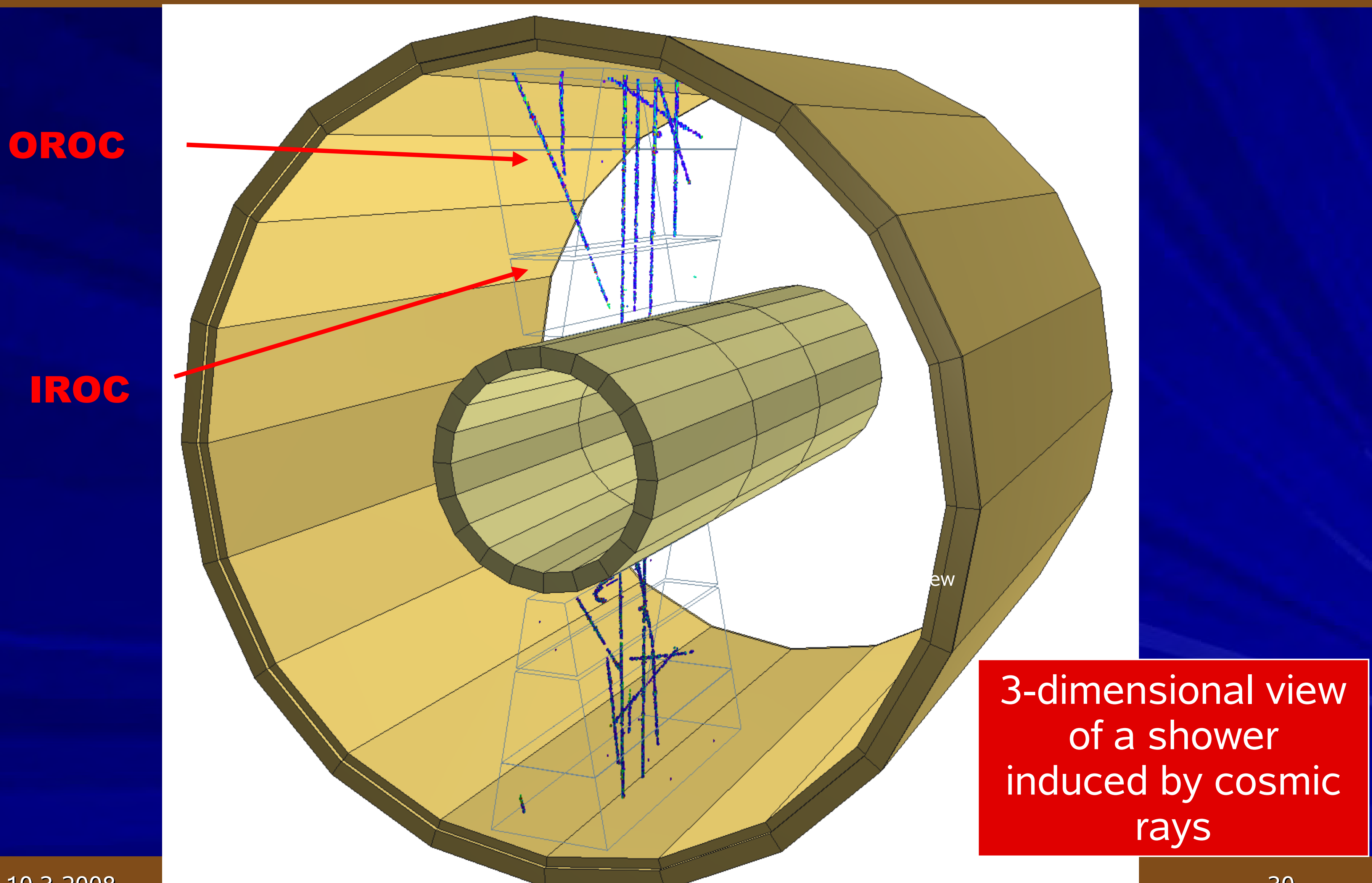
Clusters



- Position
- Width
- Max Charge
- Total Charge

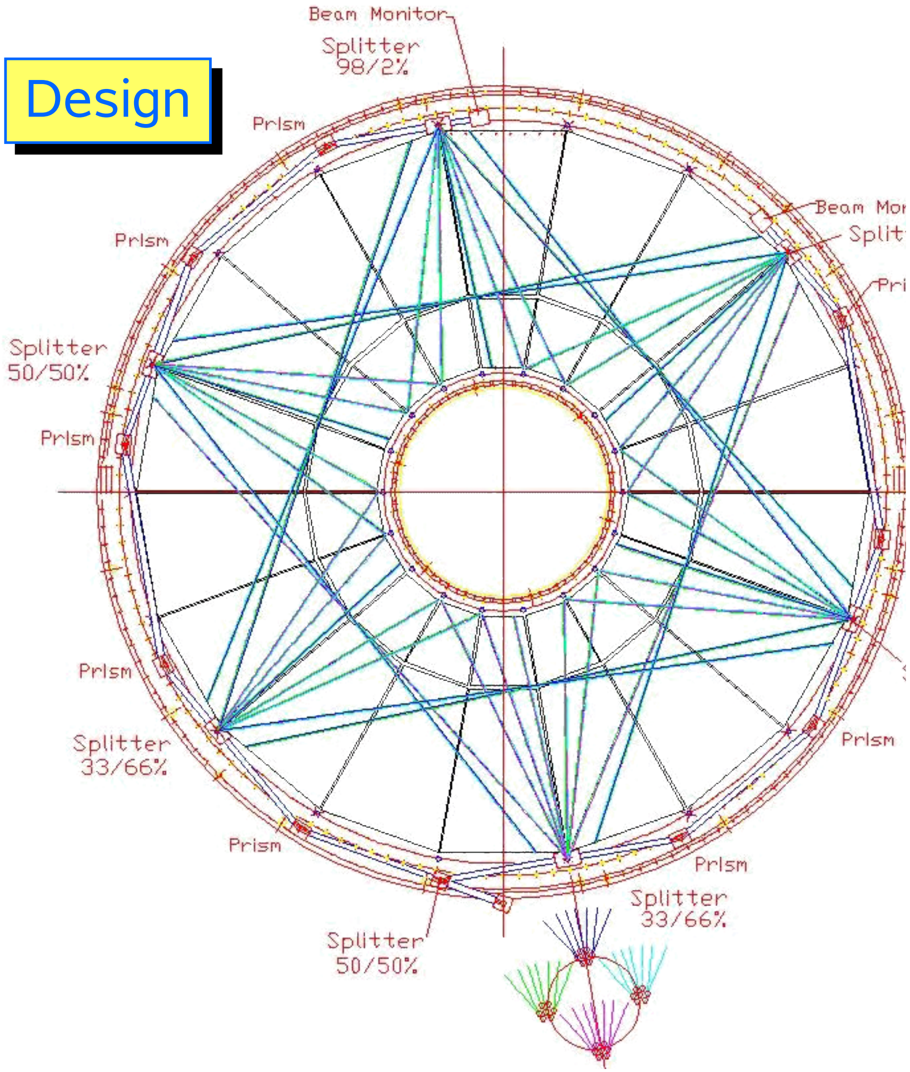
maximum dimension 5x5

First Cosmic Ray Data

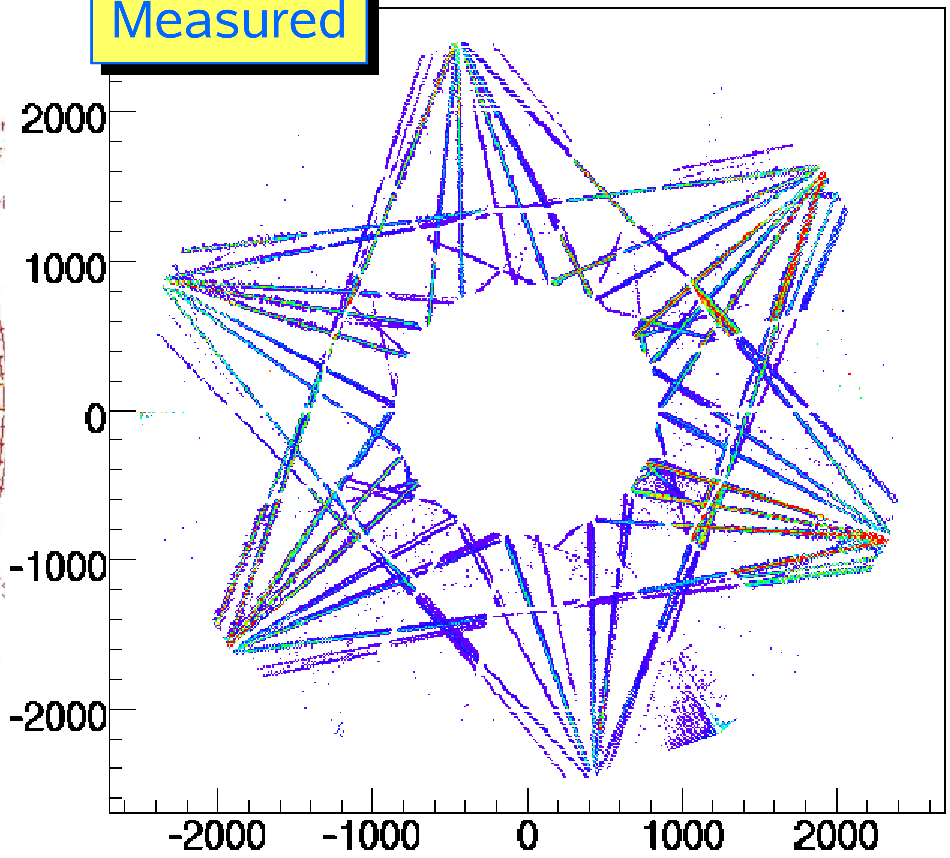


Laser tracks in the TPC

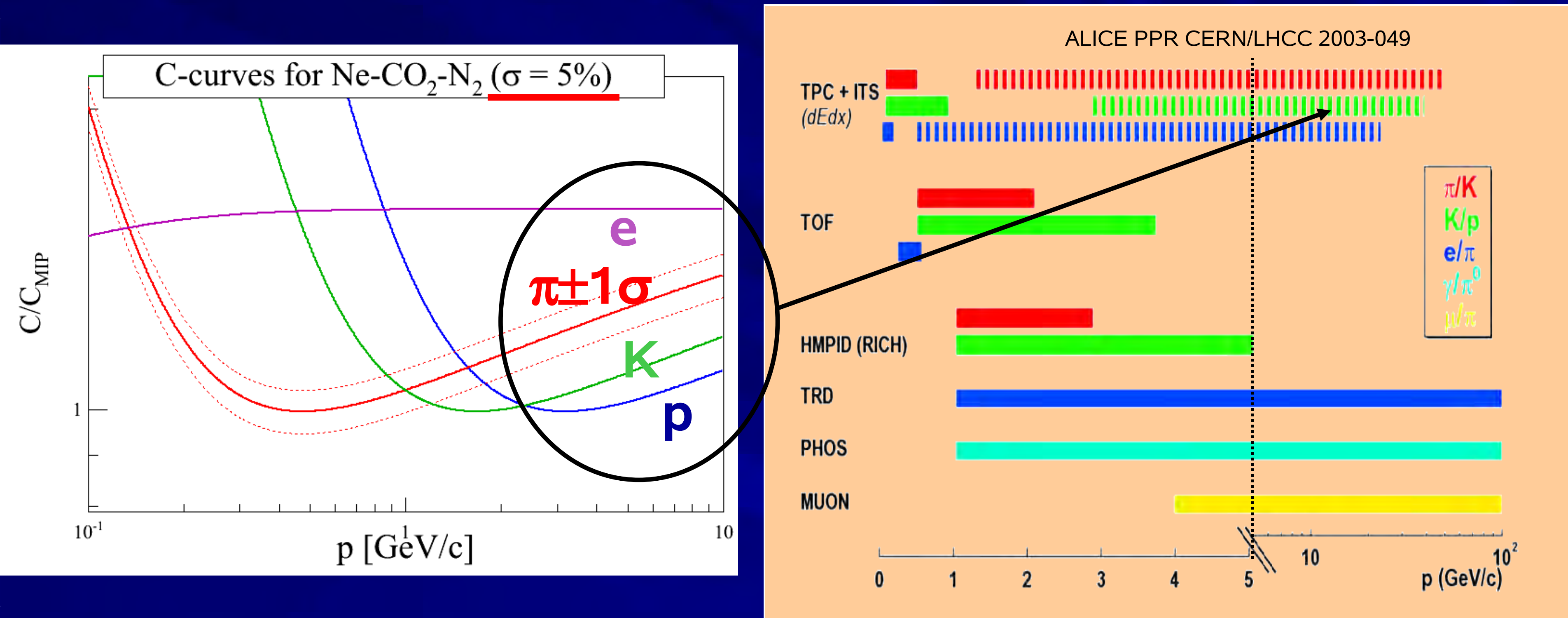
Design



Measured



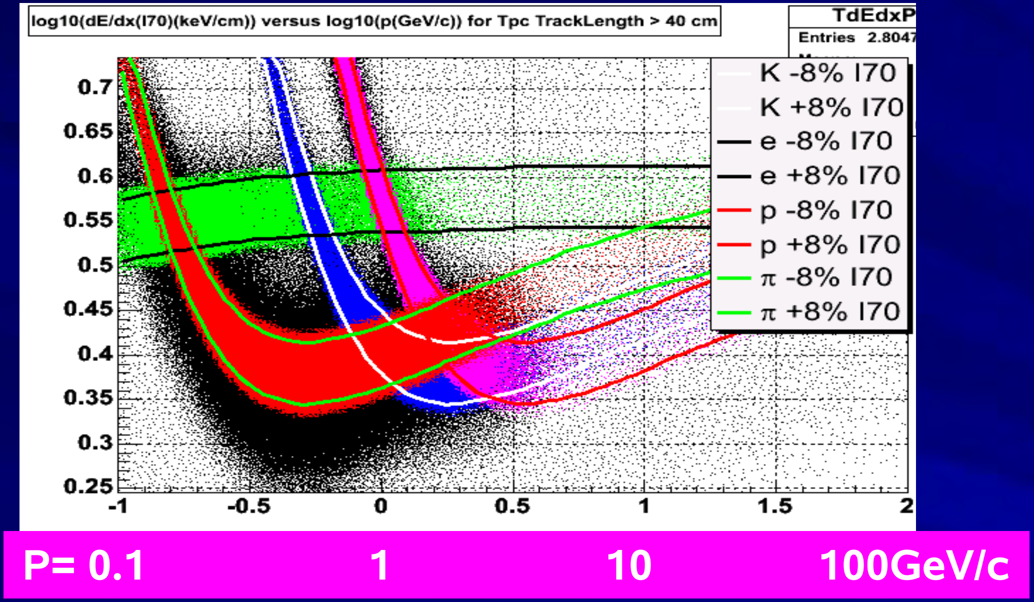
PID in ALICE

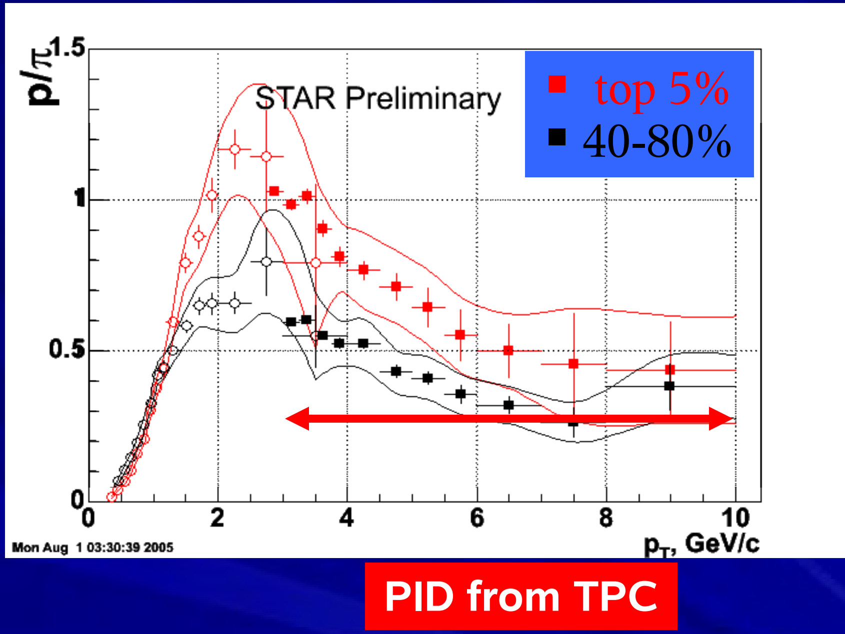


- The TPC provides PID track by track at low momentum (p<1)
- The TPC **can** PID on a statistical basis at intermediate (3 < p < 50) if **the resolution and/or calibration is sufficient**.

STAR TPC PID

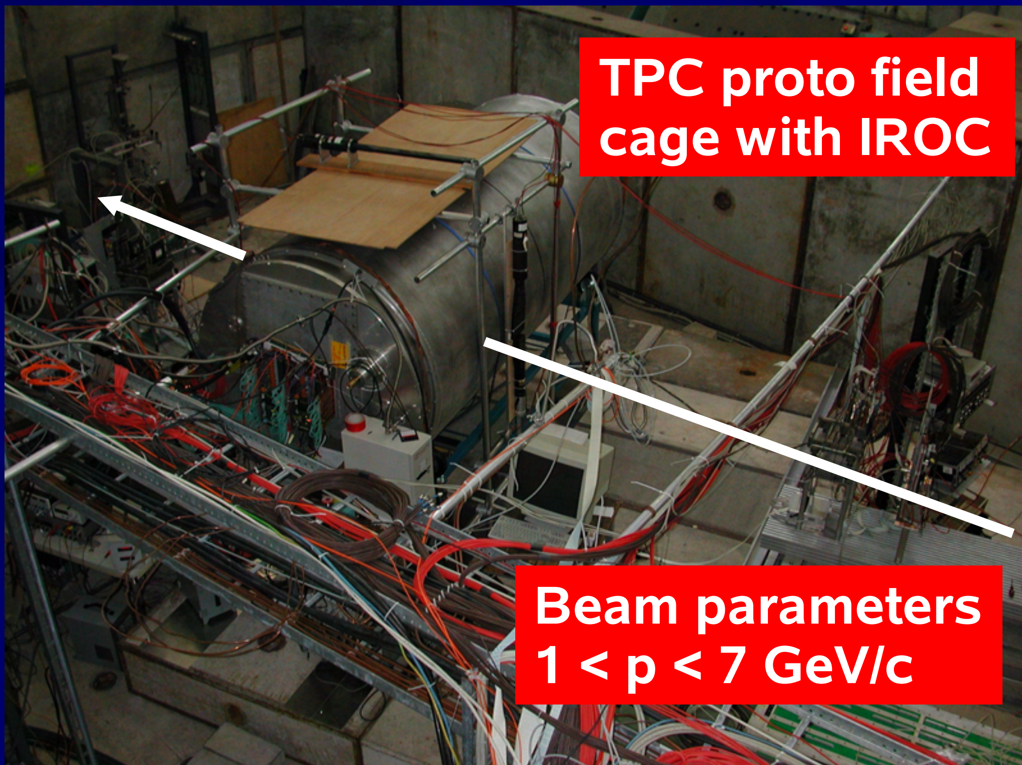
STAR PID using dE/dx (high momentum!)

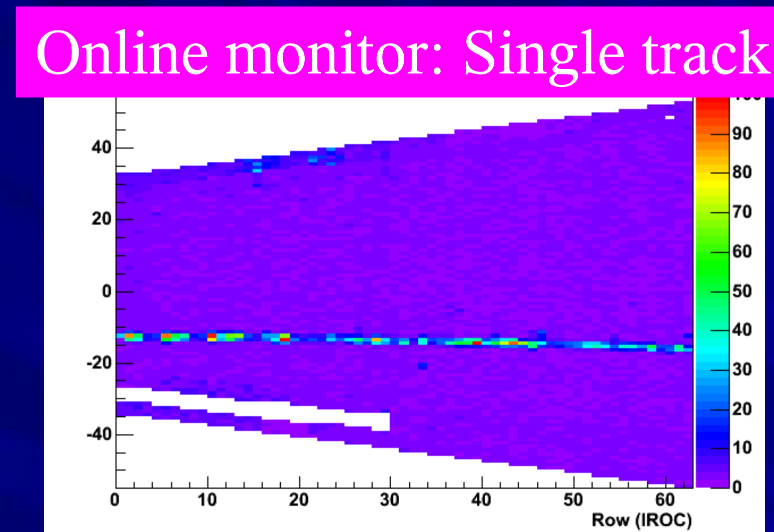


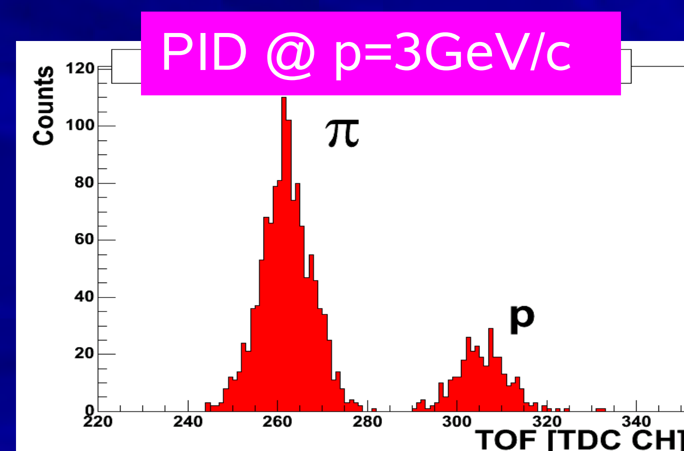


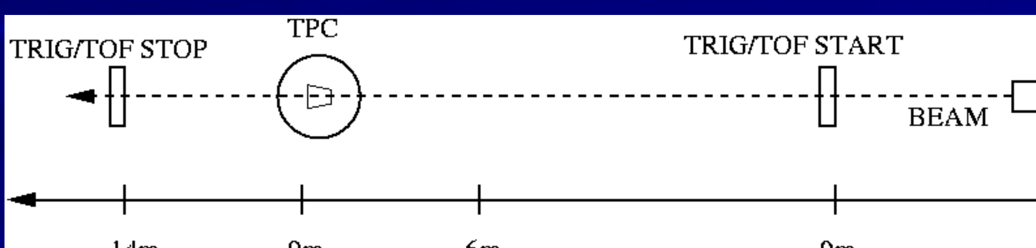
- The PID on the relativistic rise is an added benefit, i.e., it was not originally thought of as feasible!

Test beam setup with Inner ROC at CERN PS T10



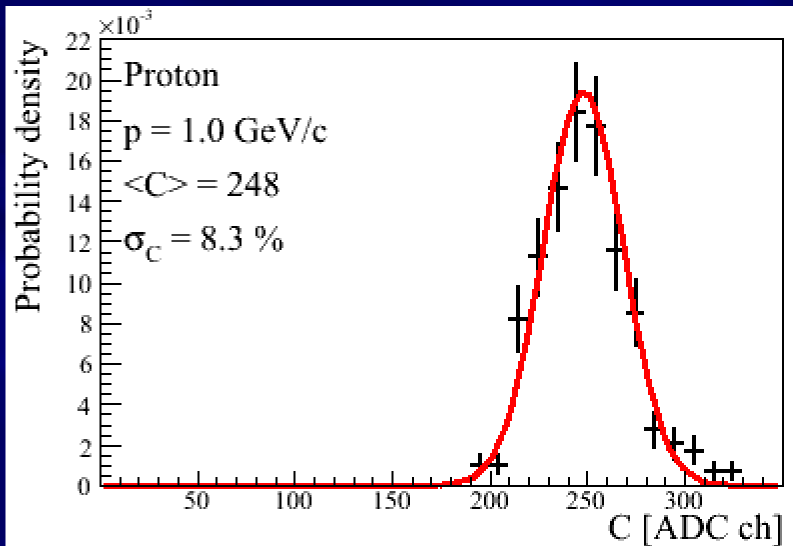


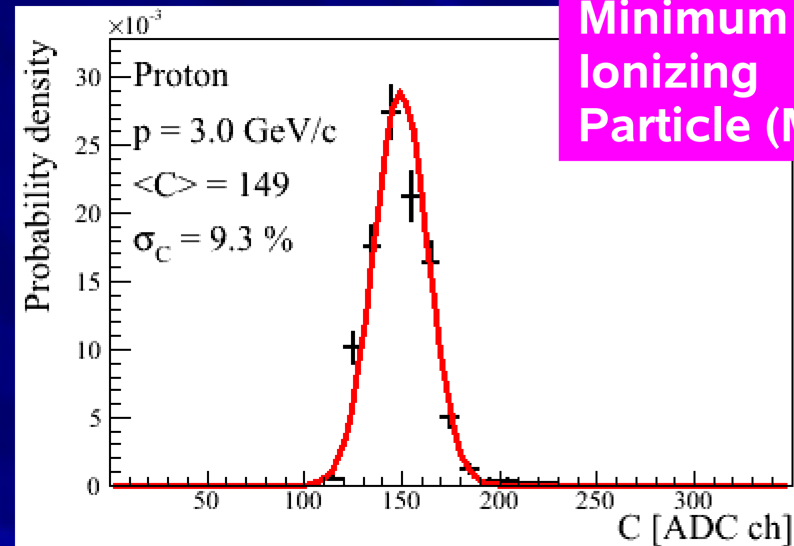




Energy loss resolution of identified particles

Minimum Ionizing Particle (MIP)

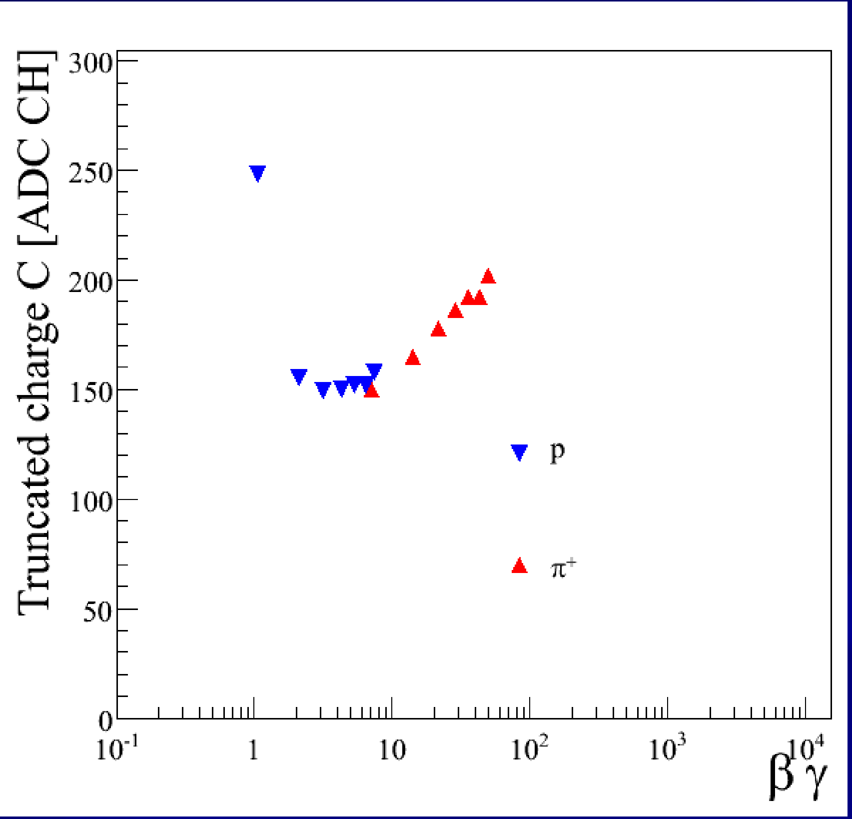


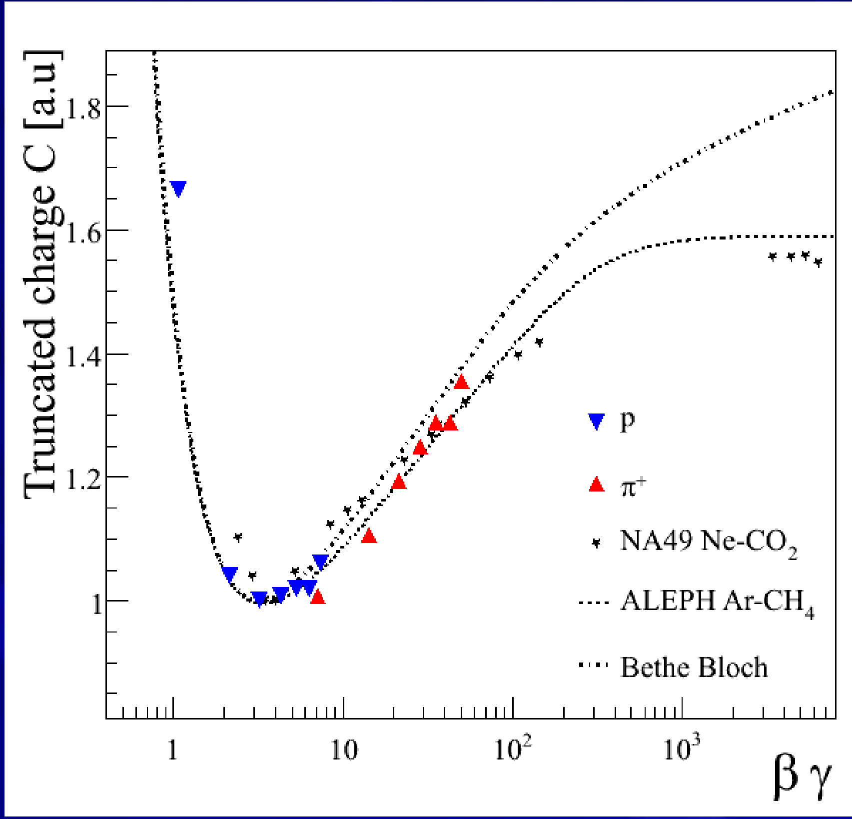


Energy loss resolution for the truncated charge C is ~9%
(IROC~47cm out of IROC+OROC~160cm)
⇒ Estimated final energy loss resolution (160 cm track):

$9.0\%/\sqrt{3.3} \sim 5.2\%$
(low multiplicity e.g. p+p)

Truncated charge C vs beta-gamma βγ

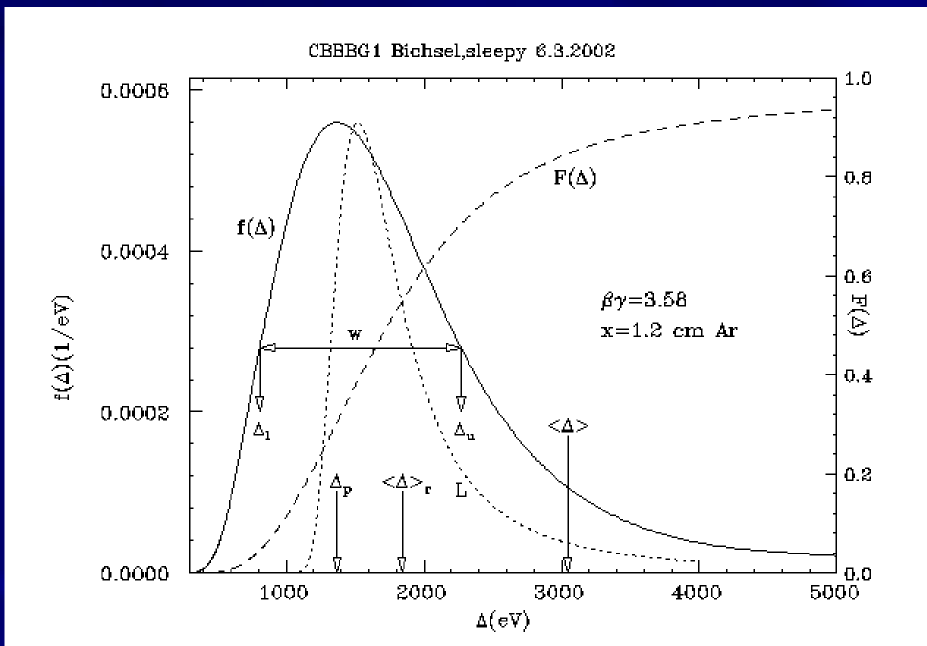




- The truncated mean dependence on βγ is similar to what was observed by Aleph (used in sim/TDR) and NA49.
- This confirms that there is the expected separation!

Model calculations of energy loss straggling functions

Monte Carlo simulation data from Hans Bichsel showing the Bichsel straggling function, and the Landau straggling function.

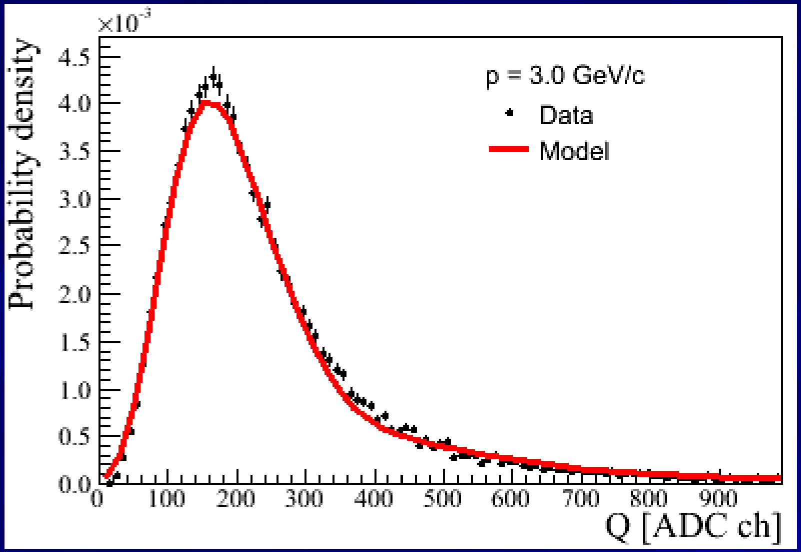


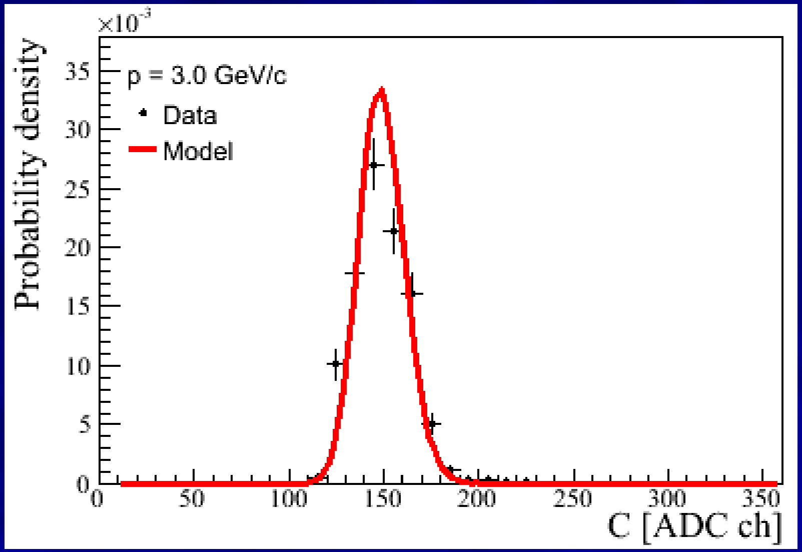
- PAI (Allison and Cobb model).
- Cross sections from Berkowitz.

- Hans Bichsel operates with different straggling functions:
  - **Energy loss Δ (Theoretical)**
  - Energy deposit & ionization
  - Electron drift and amplification
  - **Final ADC value (Experimental)**

NIM A 562 p.154 (big review)
NIM A 566 p.1 (ALICE sim comment)

First Comparison

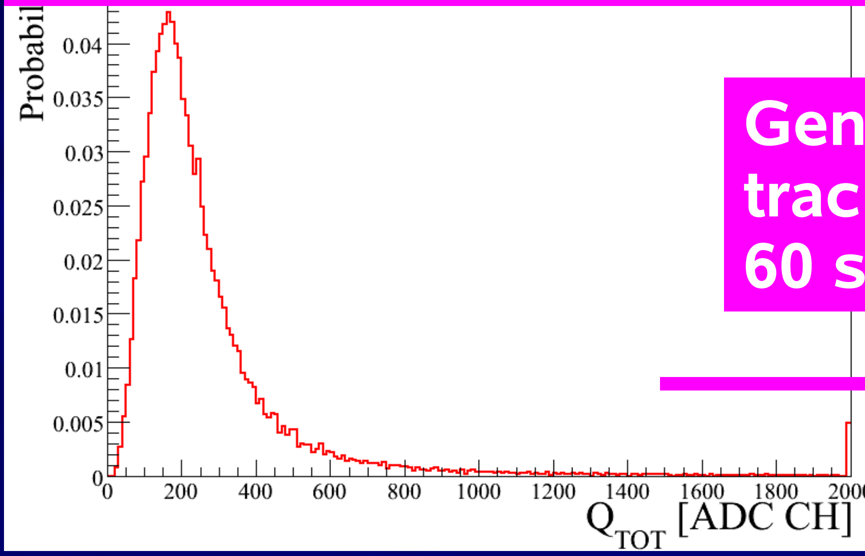




- Qualitative agreement between data and calculation (100% Neon at correct gas density)
  - <u>1 parameter</u>: 1 ADC ~ 3 eV
- Calculations predicts an energy resolution σ_C~8.1% while for the data we find 9.3%! (Discrepancy of 15%)

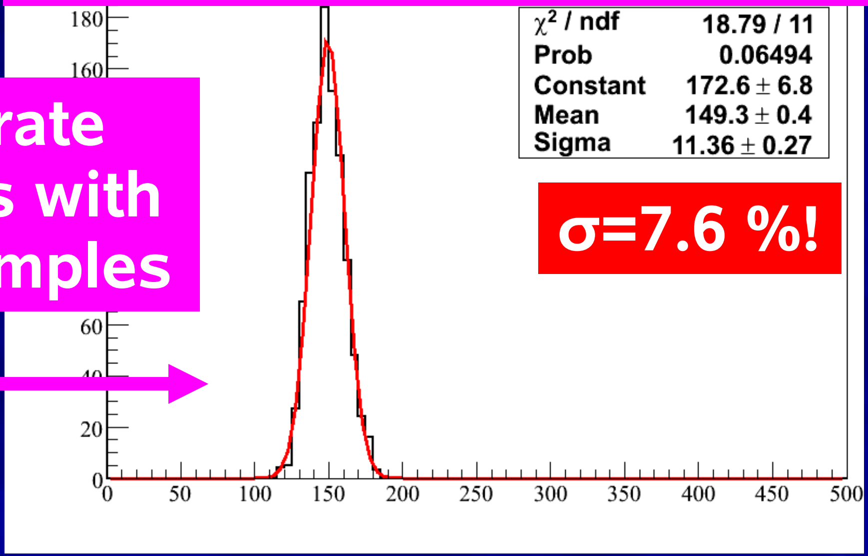
Energy resolution derived from straggling function

Exp. straggling data



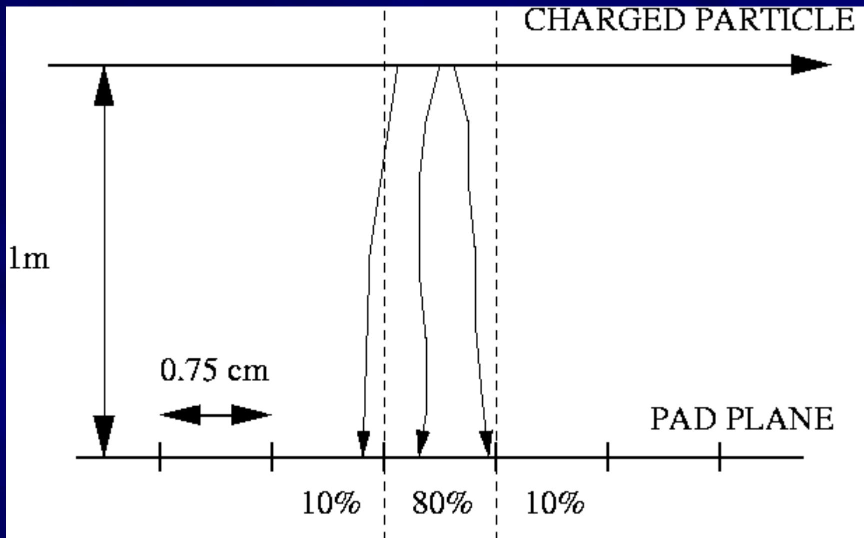
Generate tracks with 60 samples

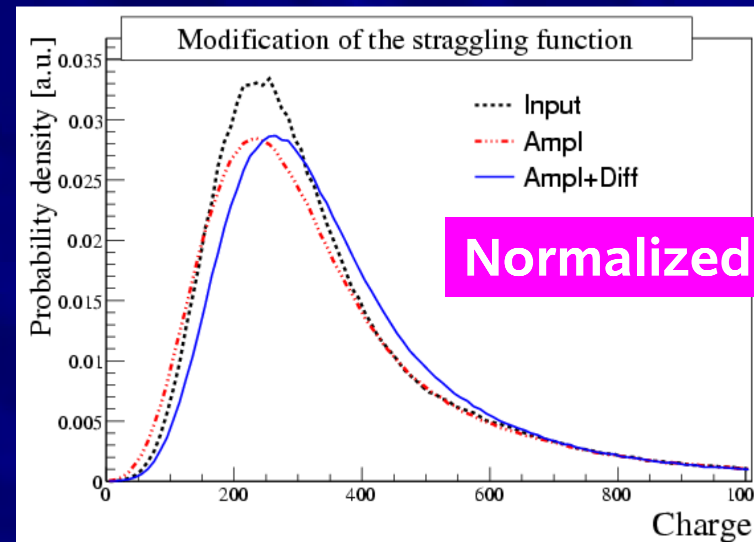
Derived truncated mean



- The resolution derived from the experimental straggling function is 7.6% and NOT the measured 9.3%!
- Signals in neighboring rows show a correlation of +33%.
  - $\Rightarrow$ Information loss due to charge sharing that reduces the resolution
- **The straggling function does not contain all information!**

Simulation: Detector effects

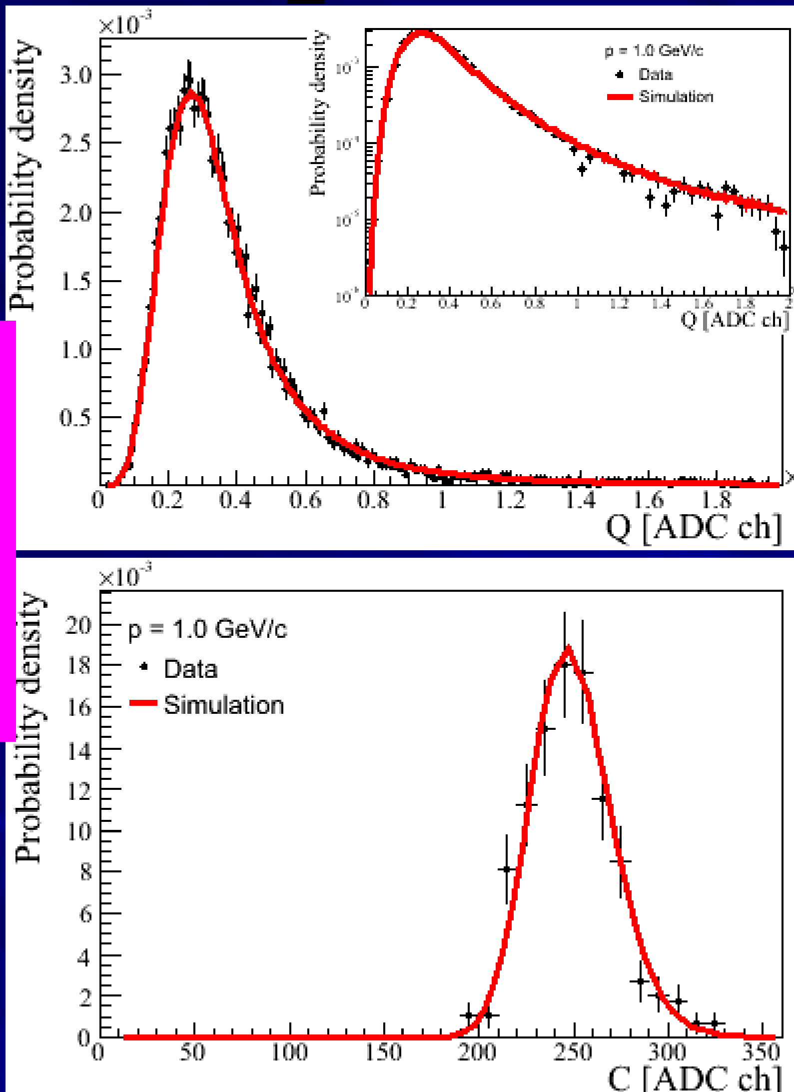




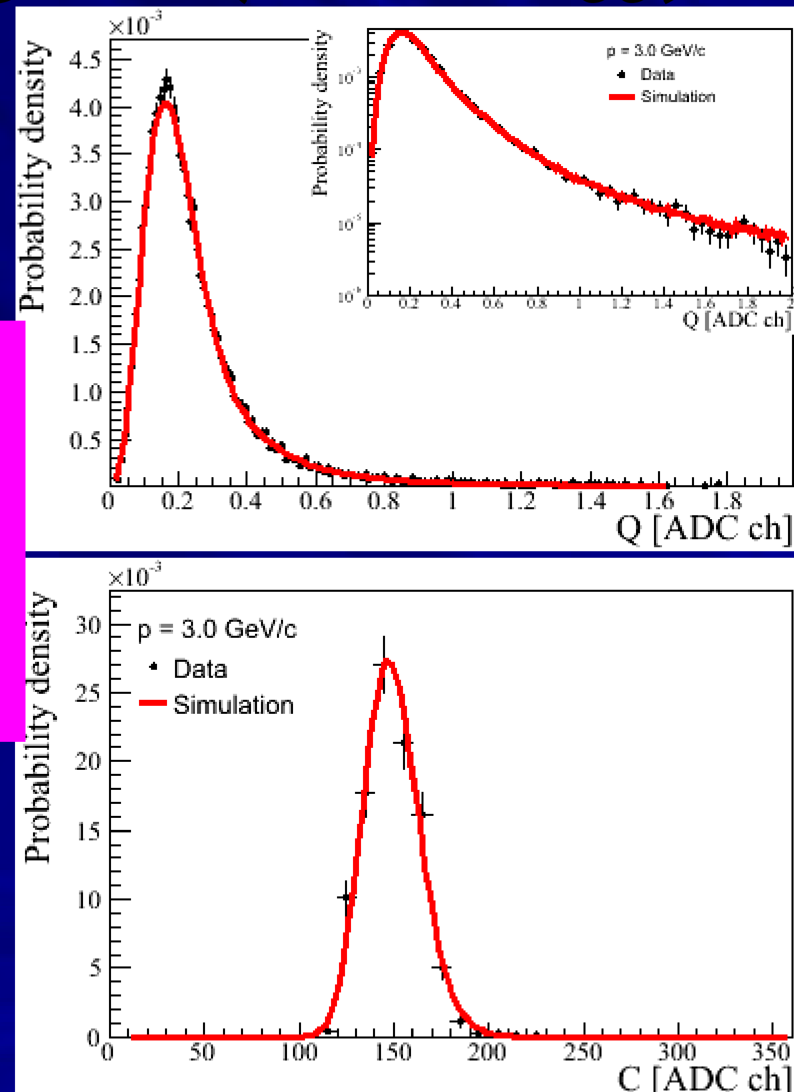
- Simulation (include charge sharing detector effect) :
  - Input E (from Bichsel's energy loss straggling function)
  - Convert to total electrons N = E/W (W=30eV)
  - Diffuse (220μm/√cm) and Amplify (exp.) each electron
- Other detector effects not included:
  - Capacitive coupling between neighboring rows (signal sharing)
  - Delta-electrons (small effect)

*Final comparison 3 params: 2*gain (<3% diff)& W*

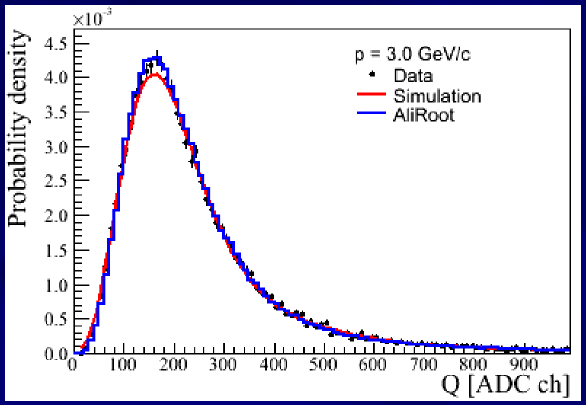
Proton 1GeV/c

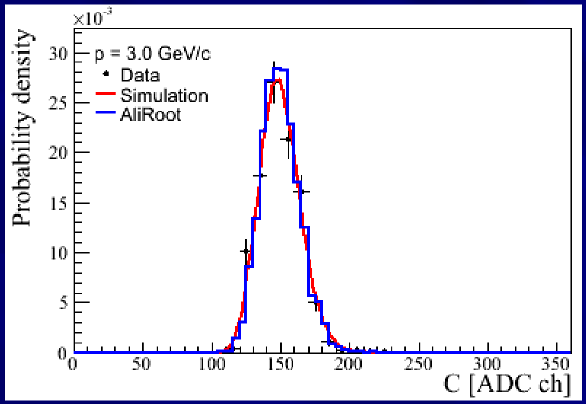


Proton 3GeV/c



Tuning the ALICE simulation (3 GeV/c)

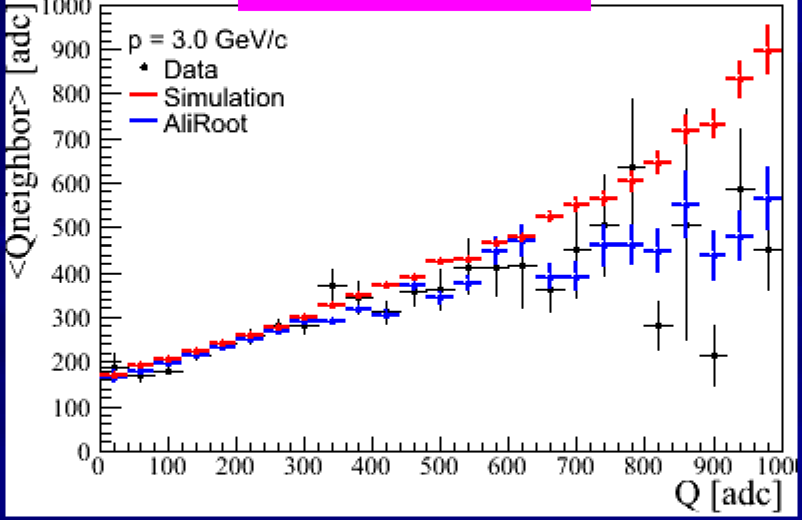




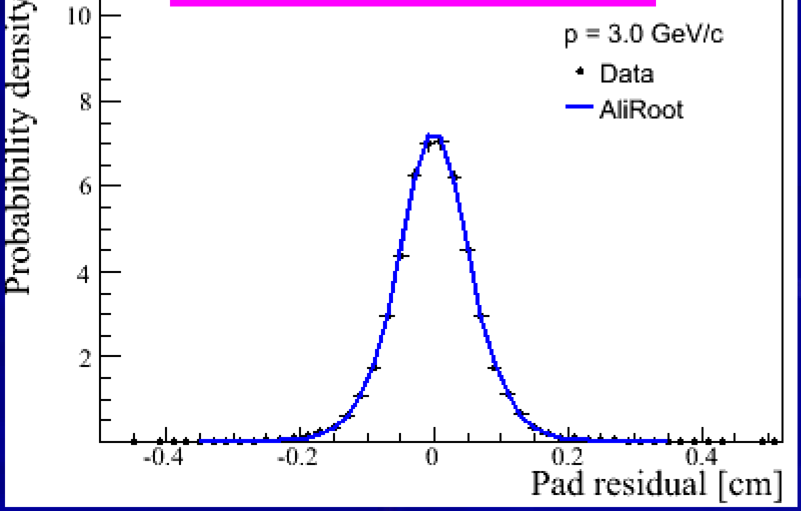
Energy loss can be well described in the simplified ALICE simulation model.

But also the correlations and spatial resolution is well described!

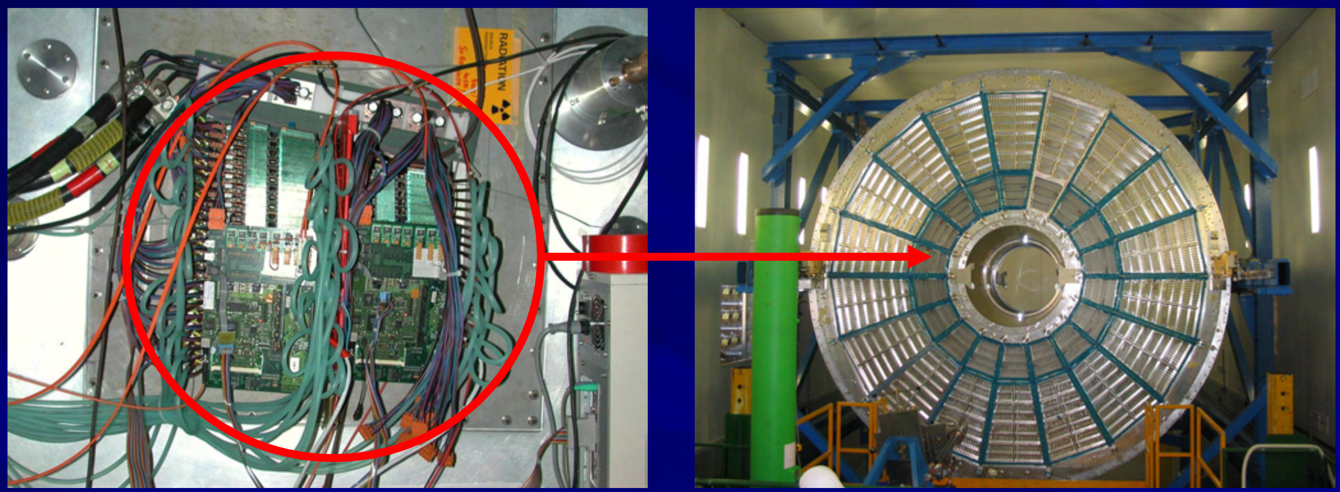
Correlations



Spatial resolution



Conclusions

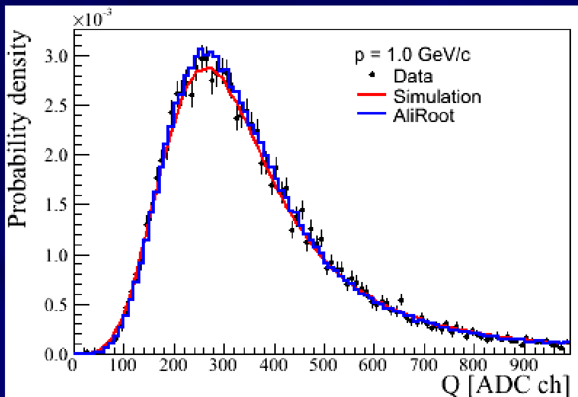


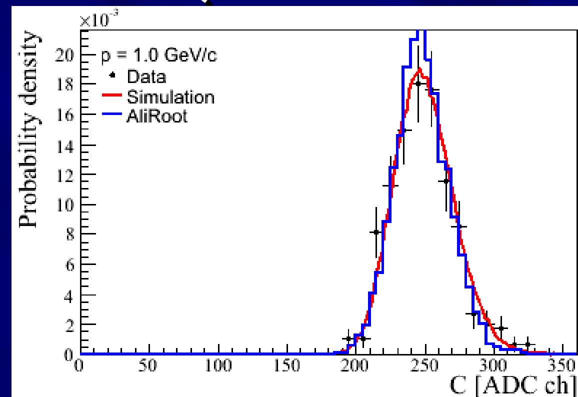
- From the test beam results we concluded
  - σC/<C> ~ 5% (p+p) -> 7% (PbPb central)
  - C(beta-gamma) according to expectations
  - Consistent with model calculations
- The results (and model calculations) is now being used to calibrate the ALICE TPC simulation and improve the PID description

Test beam:
NIM A 565 p. 551
PID:
physics/0703097

Backup slides

Tuning the ALICE simulation (1 GeV/c)





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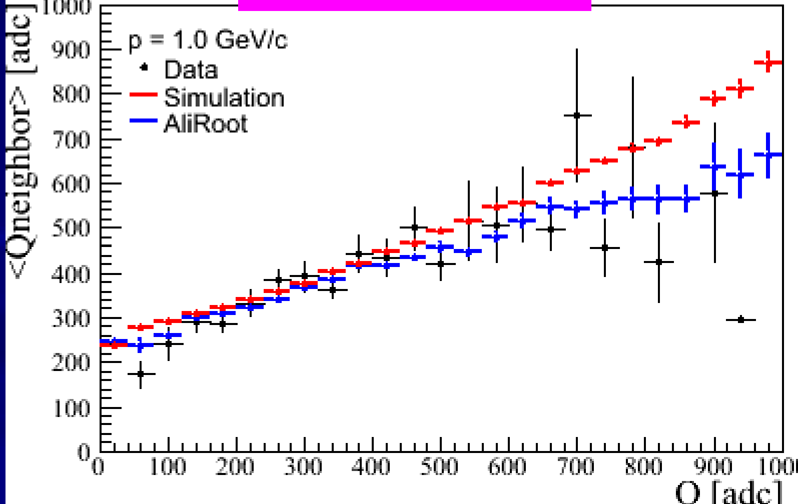
Correlations



Spatial resolution