The ALICE Transition Radiation Detector and Time Projection Chamber

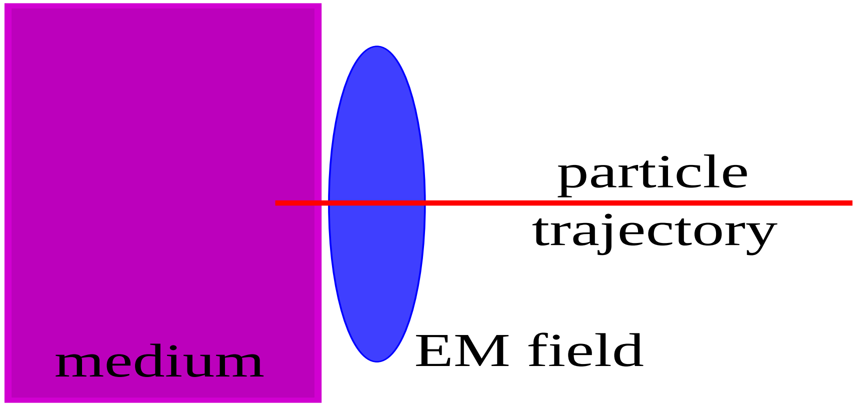
A. Andronic – GSI Darmstadt

- TRD characteristics
- Detector physics of TRD (prototype measurements)
  - signal generation, propagation, amplification
  - ...and the associated problems
  - performance
- The TRD status
- TPC characteristics and challenges
- TPC achievements and status

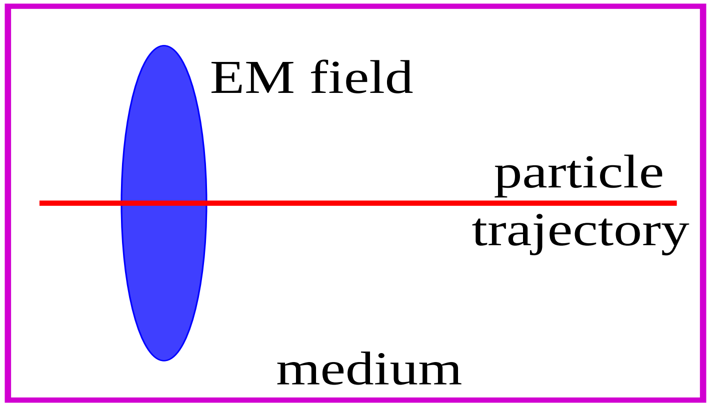
What is transition radiation?

"Transition radiation is *omitted* whenever a charged particle crosses an interface between two media with different dielectric functions." — L. Durand, Phys. Rev. D 11, 89 (1975)

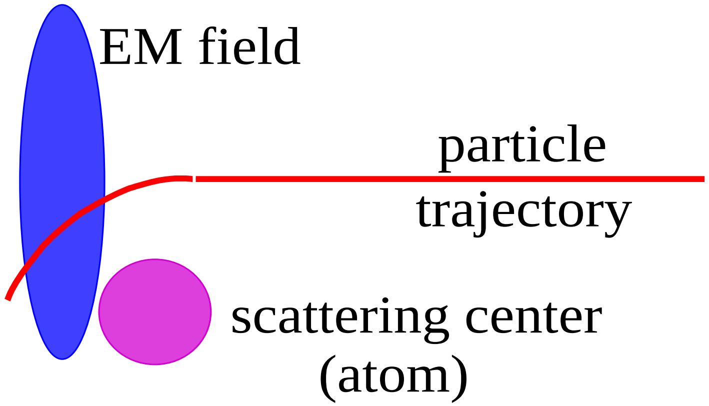
- Predicted: Ginzburg & Frank, 1946
- Observed: Goldsmith & Jelley, 1959 (optical)
- It's sizeable (X-rays) for relativistic particles



Cherenkov

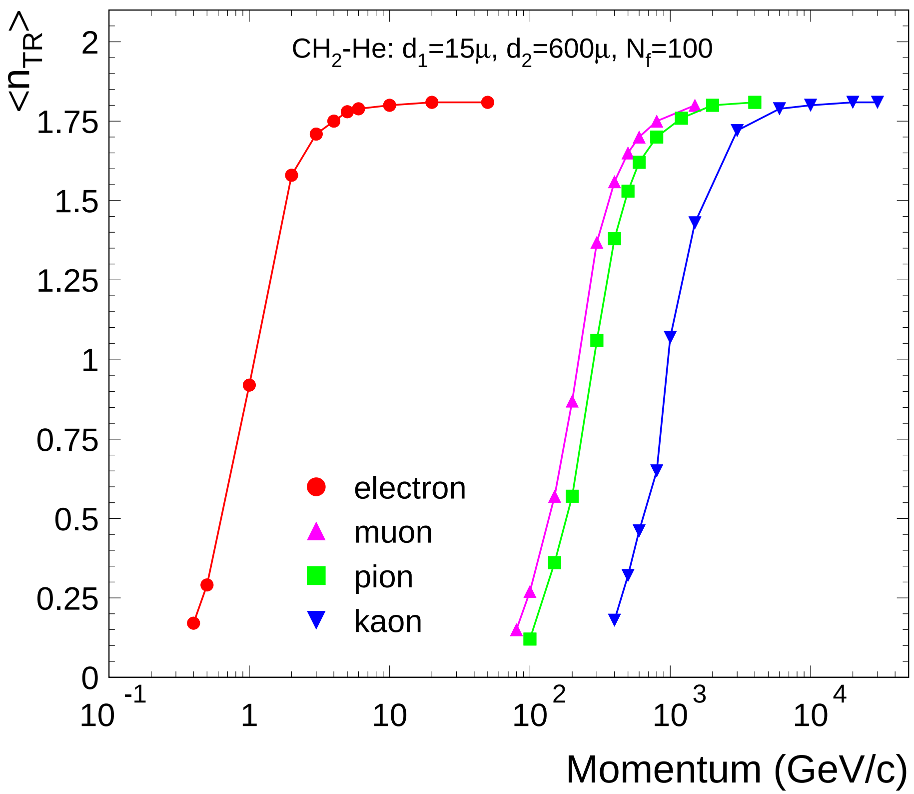


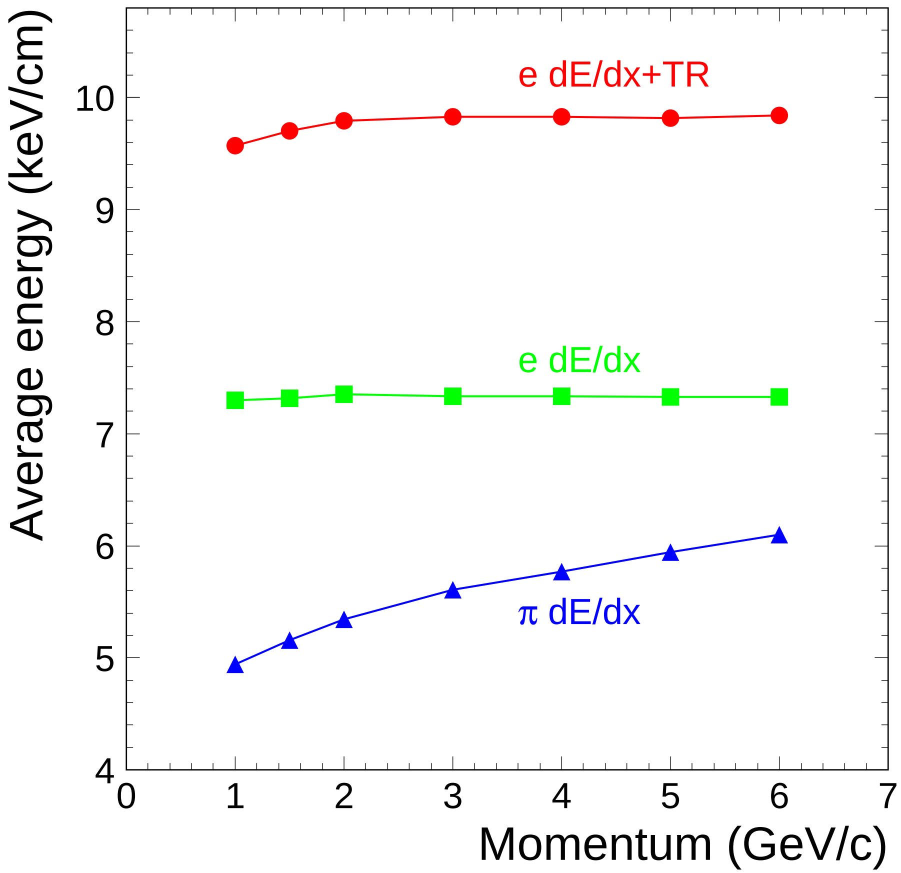
Brehmsstrahlung



How does it work: from TR to TRD

Radiator ... + Detector (Xe) $\longrightarrow$



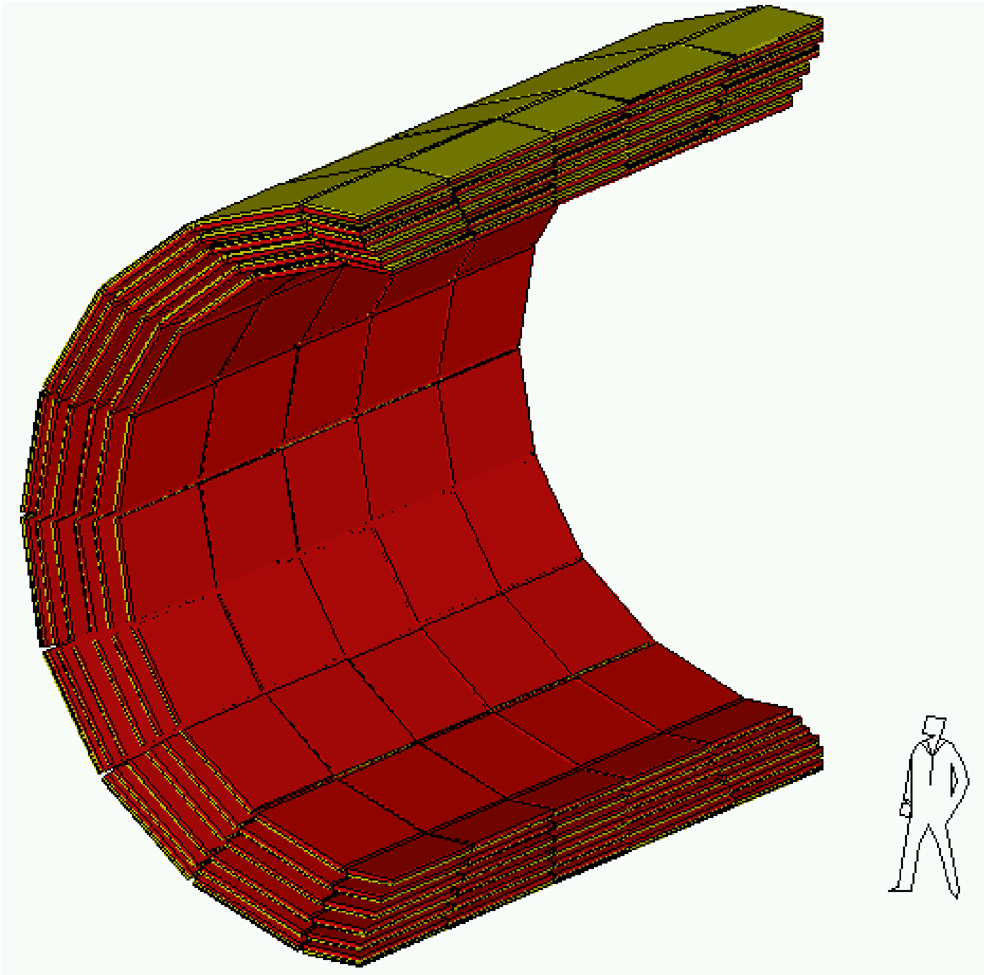


▷ TRDs are not "hadron-blind", they see all charged particles dE/dx

▷ TR gives a much needed boost to dE/dx of electrons

ALICE TRD at a glance

Goal: pion rejection factor of 100, fast trigger for high-p_t electrons and jets



Parameters:

- 540 modules (18×5×6)
- Total area: 767 m^2
- Gas volume: 27 m^3 , Xe,CO_2(15%)
- 1.2 mil. readout chan. (≃20 M pixels)
- 15 TB/s on-detector bandwidth
- Rad. thickness X/X_0: ∼ 22%
- Total weight: 21 tons
- Total power consumption: 70 kW
- 60 persons, 10 institutions

Conditions in ALICE

Pb+Pb $\sqrt{s_{NN}} = 5.5$ TeV

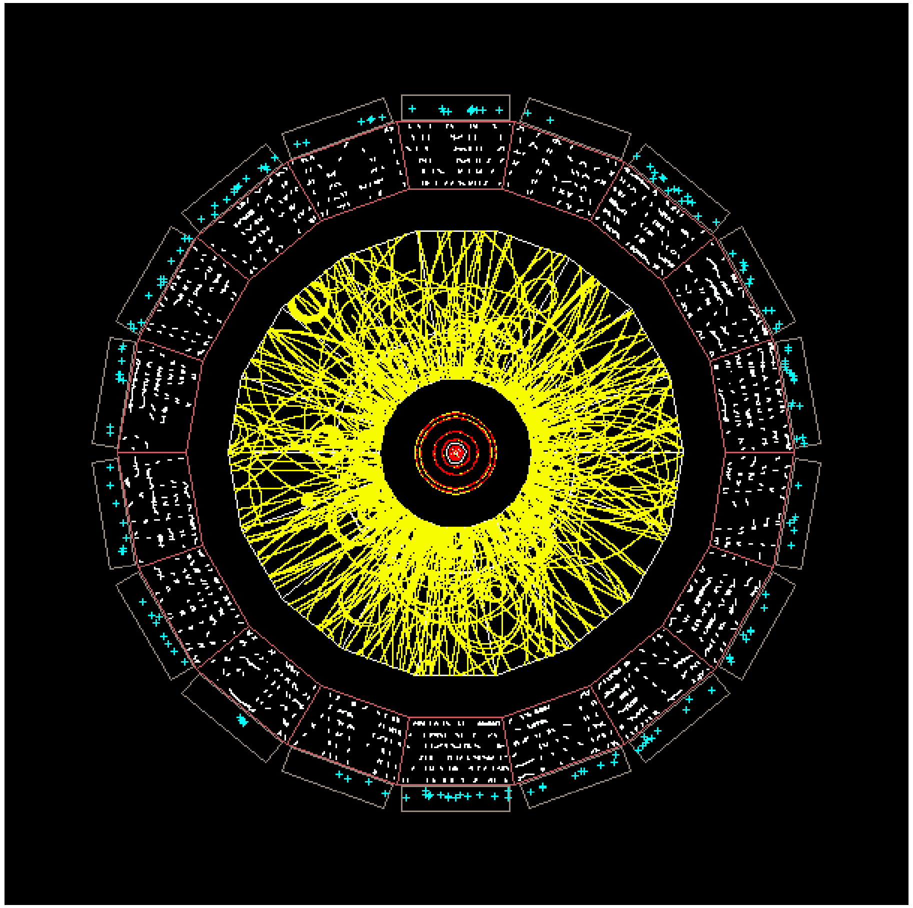
- 8 kHz interaction rate (10^{27} $s^{-1}cm^{-2}$)
- dN$_{ch}$/dy=8000 (central collisions)
  1% of a central Pb+Pb event at LHC

  $\longrightarrow$

  (recent extrapolations: dN$_{ch}$/dy$\simeq$2000)

  <u>need high granularity</u>

- the TRD will work in conjunction with all central detectors
  (TRD+ITS in high-rate pp, C+C)

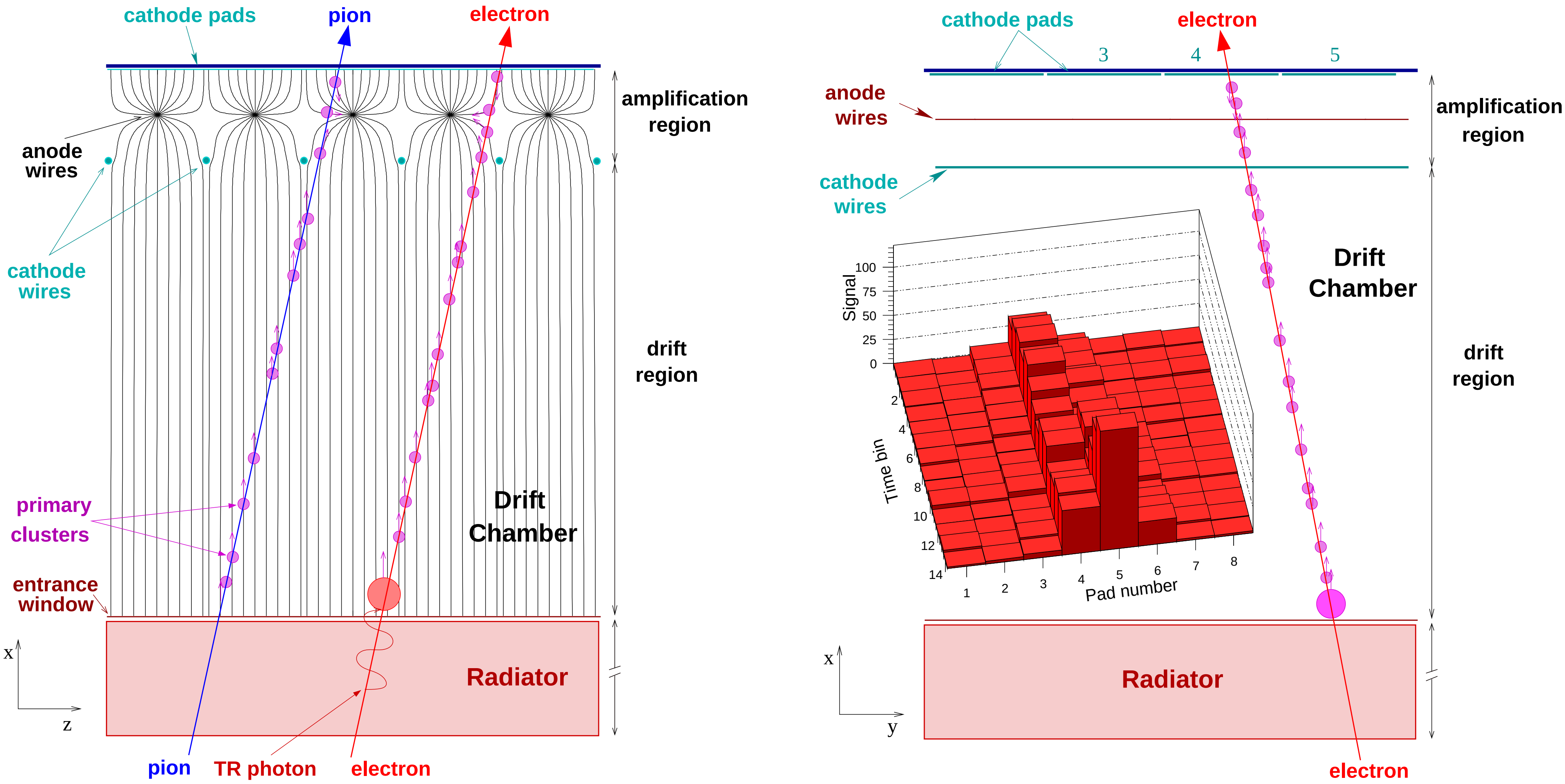


A comparison of TRDs

Experiment	Radiator (x,cm)	Detector (x,cm)	Area (m^2)	N	L (cm)	N. chan.	Method	π_{rej}
HELIOS	foils (7)	Xe-C_4H_{10} (1.8)	0.5	8	70	1744	N	2000
H1	foils (9.6)	Xe-He-C_2H_6 (6)	1.8	3	60	1728	FADC	10
NA31	foils (21.7)	Xe-He-CH_4 (5)	4.5	4	96	384	Q	70
ZEUS	fibres (7)	Xe-He-CH_4 (2.2)	3	4	40	2112	FADC	100
D0	foils (6.5)	Xe-CH_4 (2.3)	3.7	3	33	1536	FADC	50
NOMAD	foils (8.3)	Xe-CO_2 (1.6)	8.1	9	150	1584	Q	1000
HERMES	fibres (6.4)	Xe-CH_4 (2.54)	4.7	6	60	3072	Q	1400
kTeV	fibres (12)	Xe-CO_2 (2.9)	4.9	8	144	∼10 k	Q	250
PAMELA	fibres (1.5)	Xe-CO_2 (0.4)	0.08	9	28	964	Q,N	50
AMS	fibres (2)	Xe-CO_2 (0.6)	1.5	20	55	5248	Q	1000
PHENIX	fibres (5)	Xe-CH_4 (1.8)	50	6	4	43 k	FADC	∼300
ATLAS	fo/fi (0.8)	Xe-CO_2-O_2 (0.4)	31	36	51-108	425 k	N,ToT	100
ALICE	fi/foam (4.8)	Xe-CO_2(3.7)	126	6	52	1.2 mil.	FADC	200

all radiator material CH_2

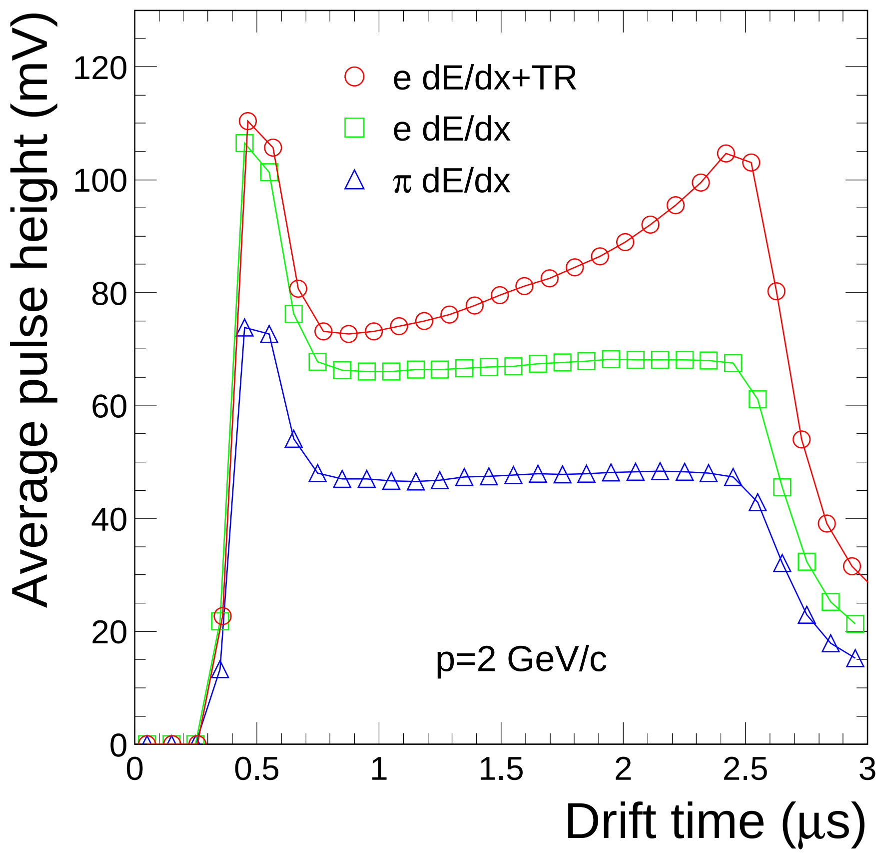
ALICE TRD – The principle



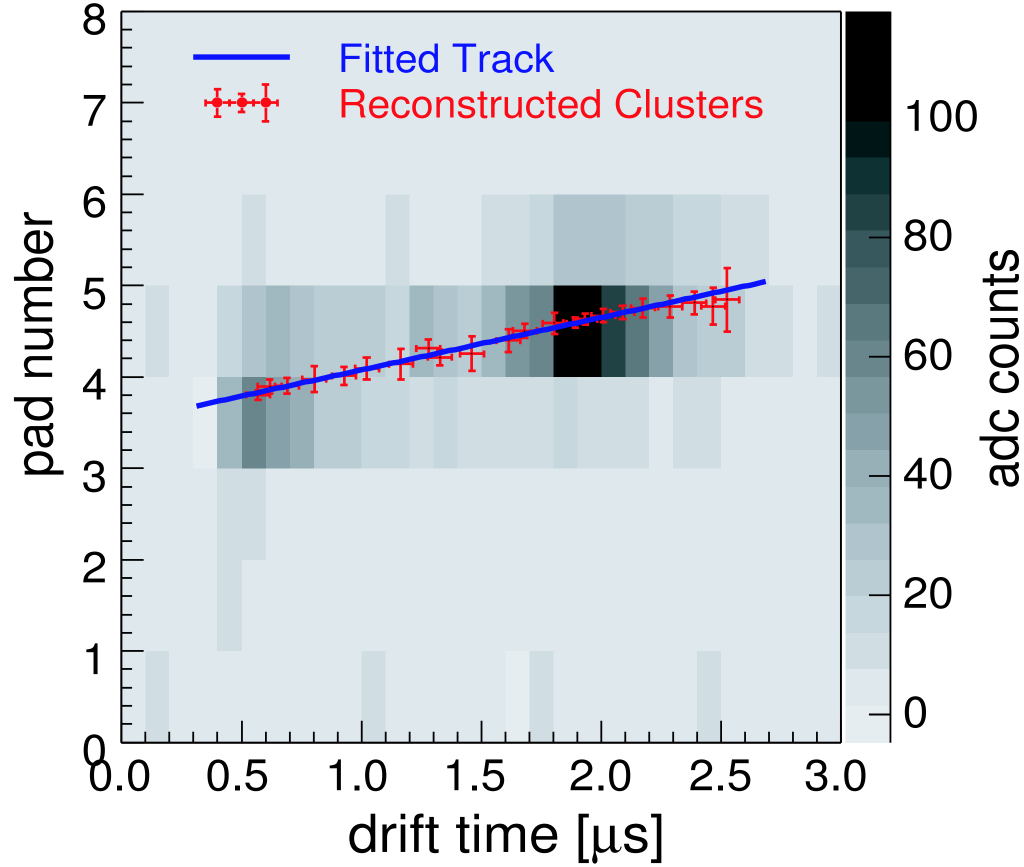
wires: Au-W 20μm, Cu-Be 75μm; pads: $\simeq 7 \times 80$ mm^2

ALICE TRD – What do we measure

pulse height

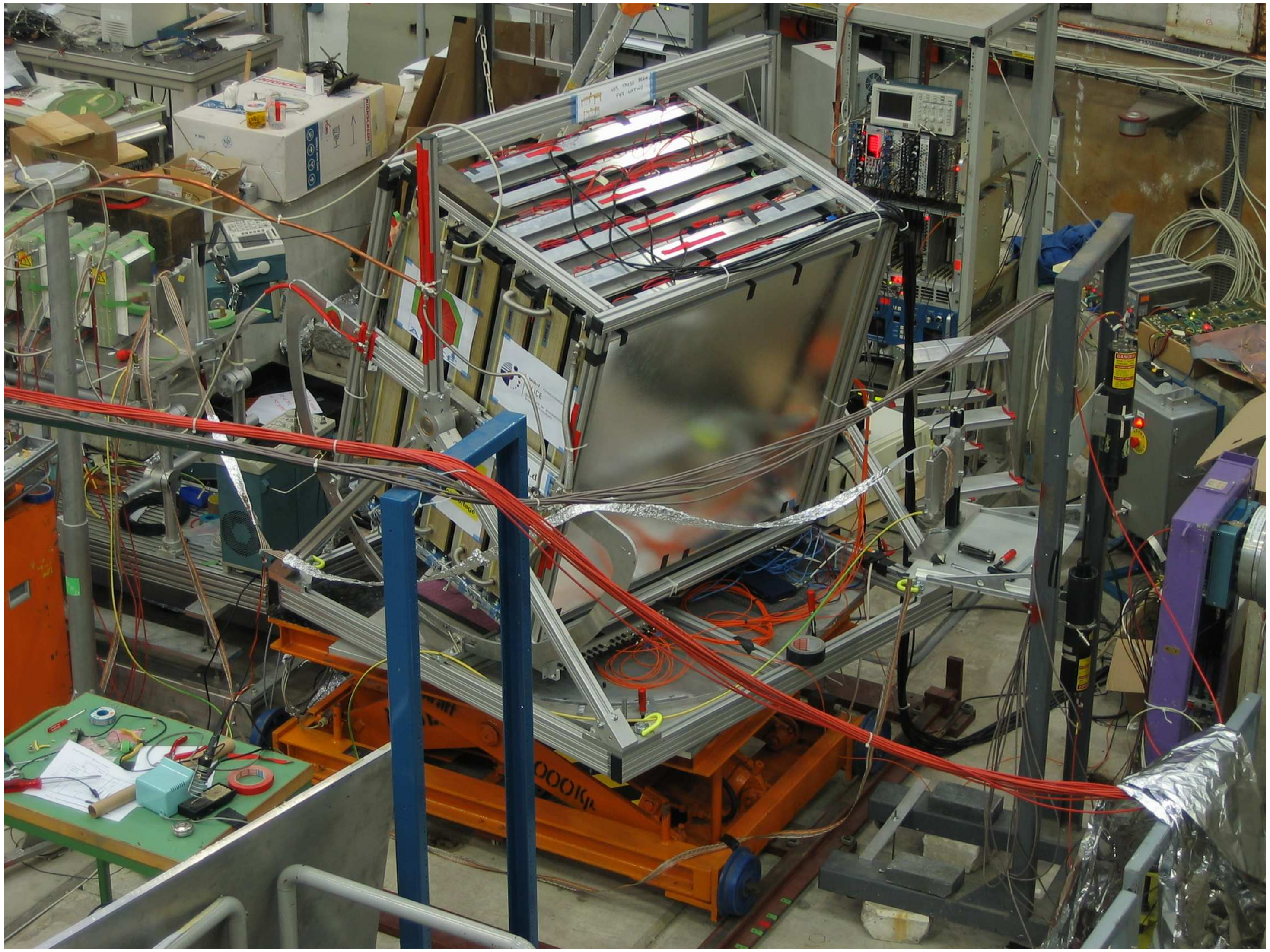


charge sharing



ADC: 10 bit, 10 MHz sampling, 2 V dynamic range; Noise: ≃1.3 LSB

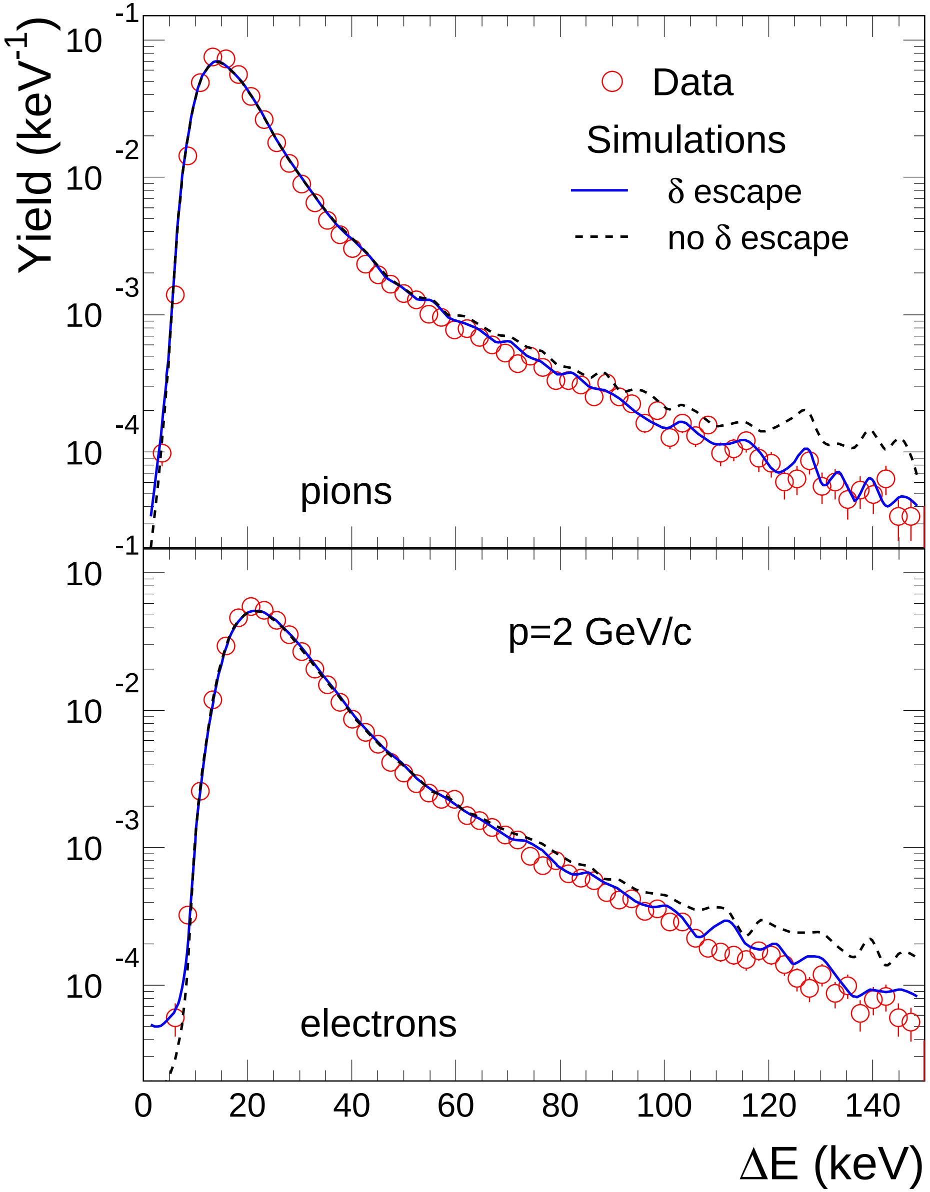
Prototype tests



- beams: e,π
  1-10 GeV/c
- GSI, CERN
  1998-2004

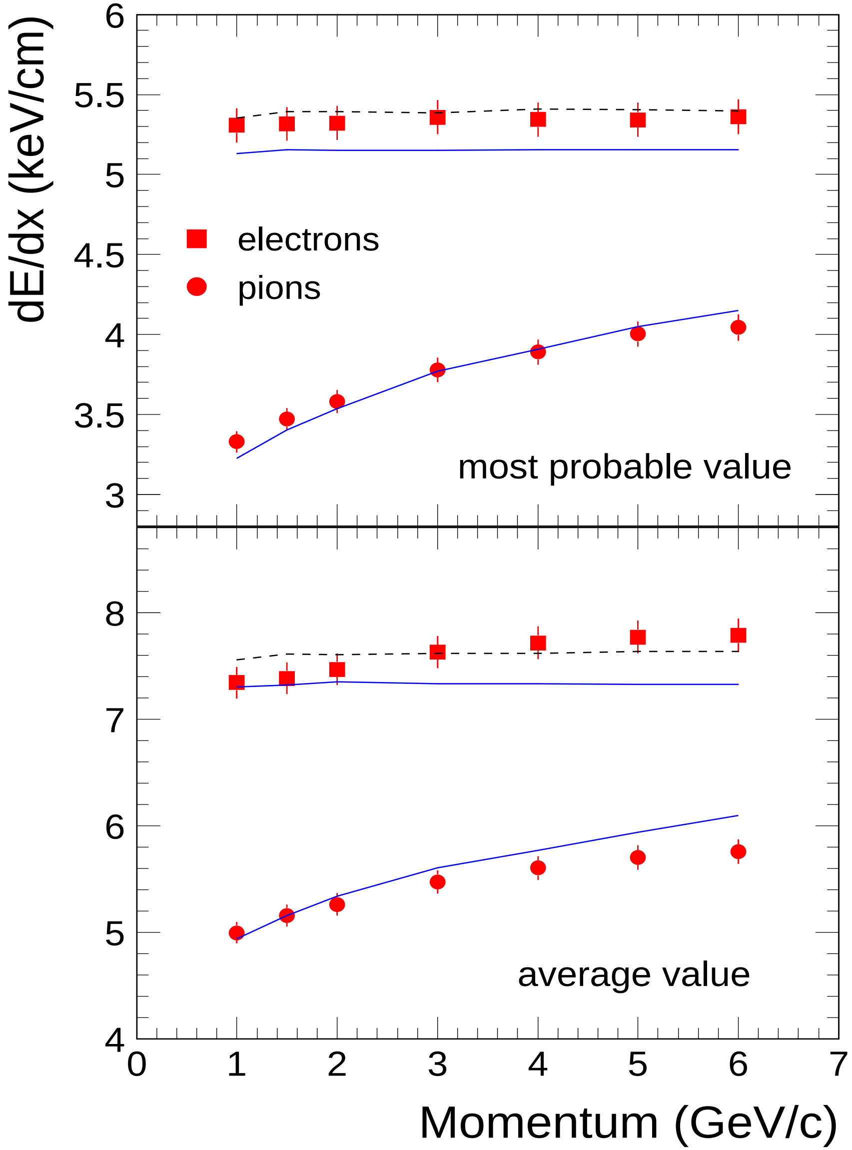
dE/dx: spectra

NIM A519(2004)508 [physics/0310122]

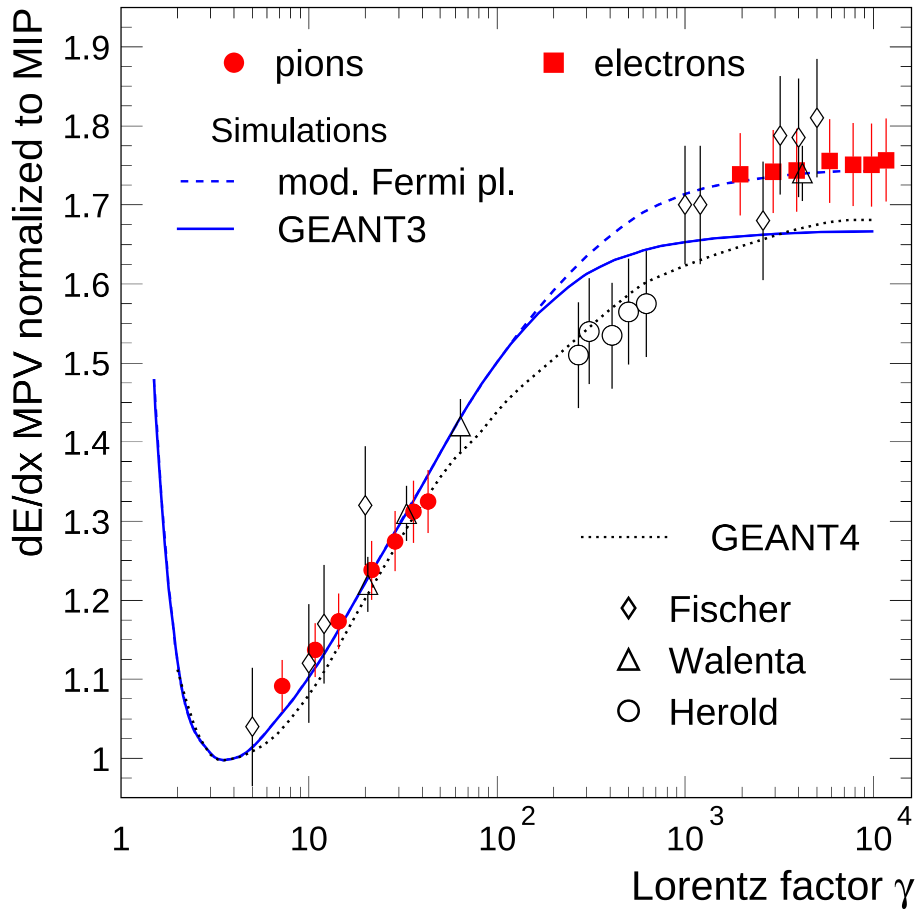


- Landau distribution
- Basic quantity for particle id.
- ...and for tracking (S/N)
- Needs to be well understood (simulations; GEANT3)
- Details (δ-rays) matter

dE/dx: momentum dependence



NIM A519(2004)508 [physics/0310122]



dE/dx: do we understand all?

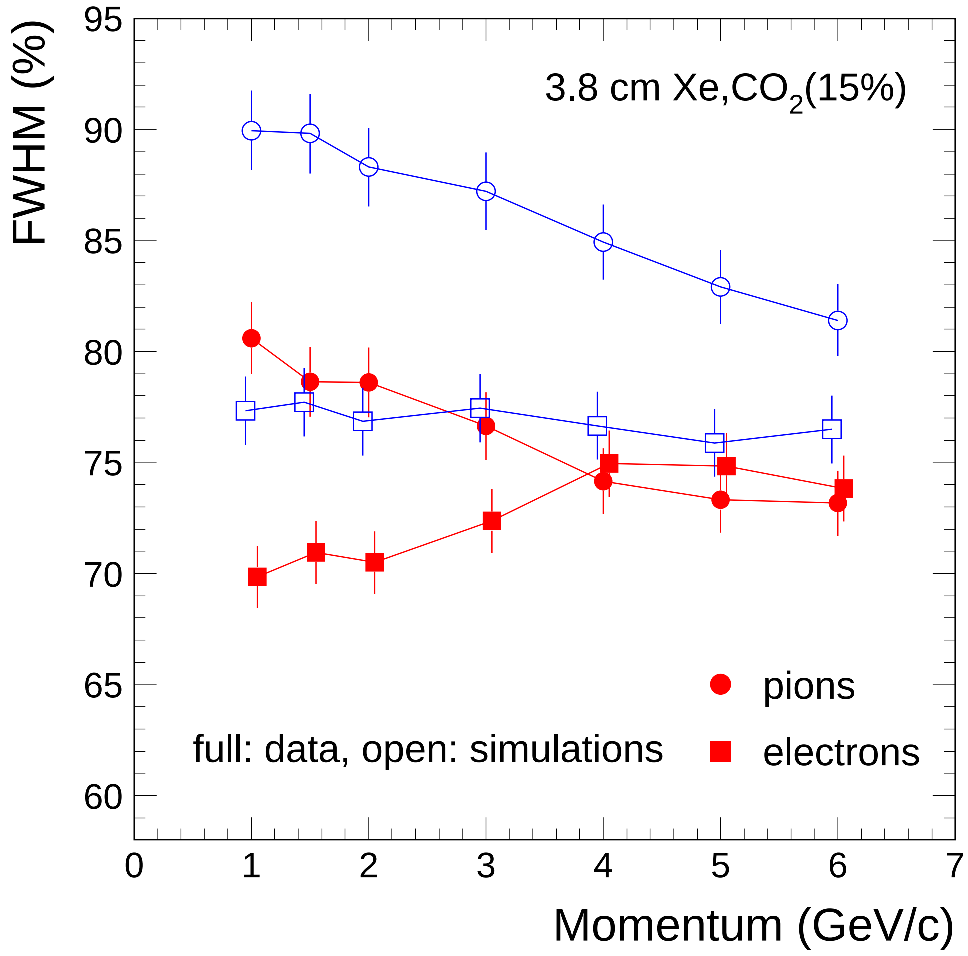
NIM A519(2004)508 [physics/0310122]

Almost, but not all...

Example: width of dE/dx spectrum

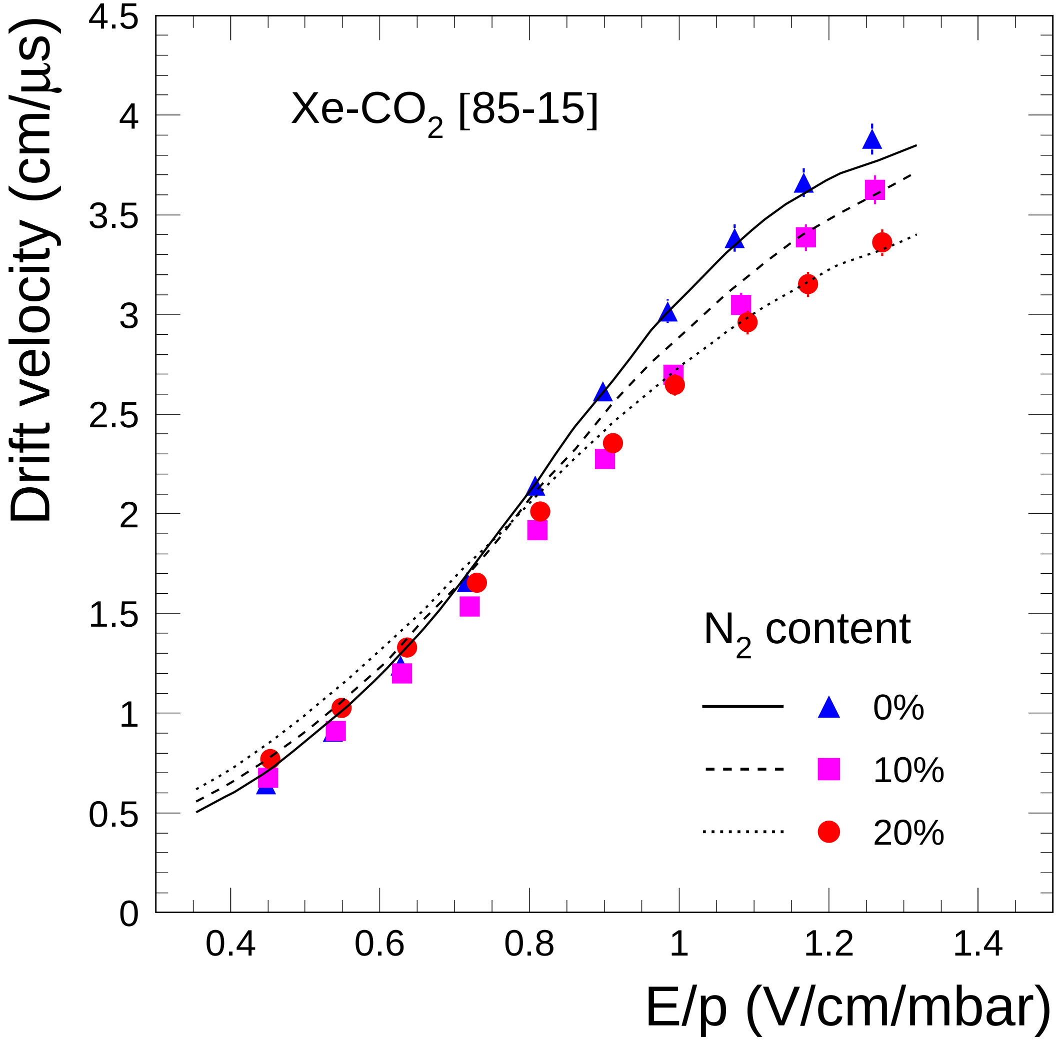
- determines PID quality
- is determined by $\langle N_{prim} \rangle$

  ...too small in GEANT3

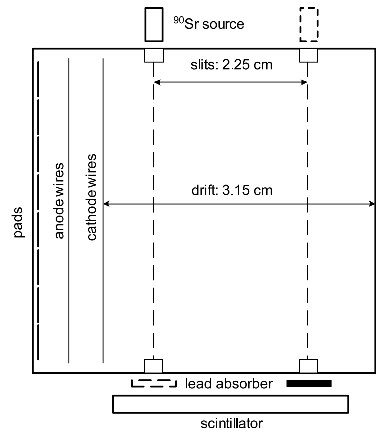


Drift velocities

NIM A523 (2004) 302 [physics/0402044]

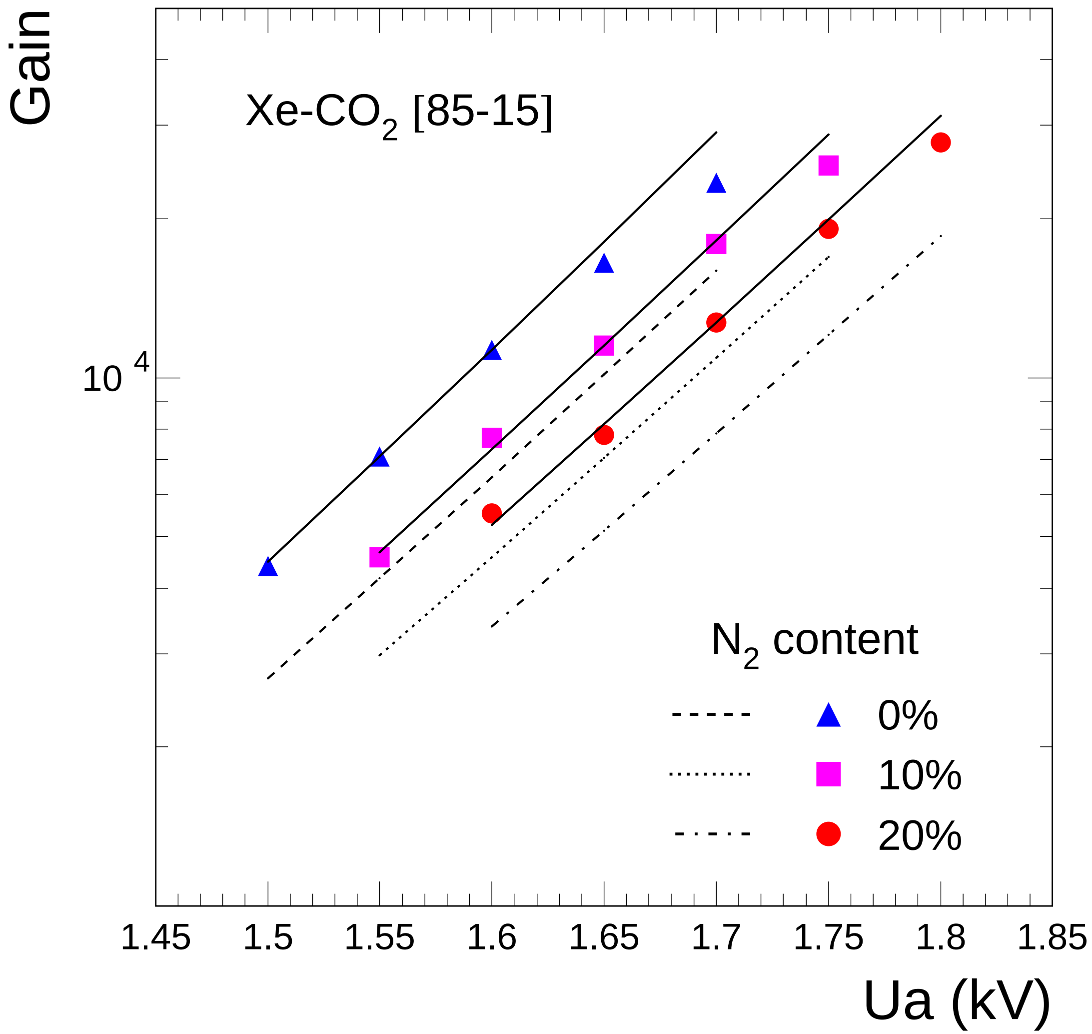


- measured using a drift MWPC



- measurements (symbols) and calculations (MAGBOLTZ, lines) agree well
- N_2 due to buildup (via leaks) from atmosphere (O_2 and water are filtered out)

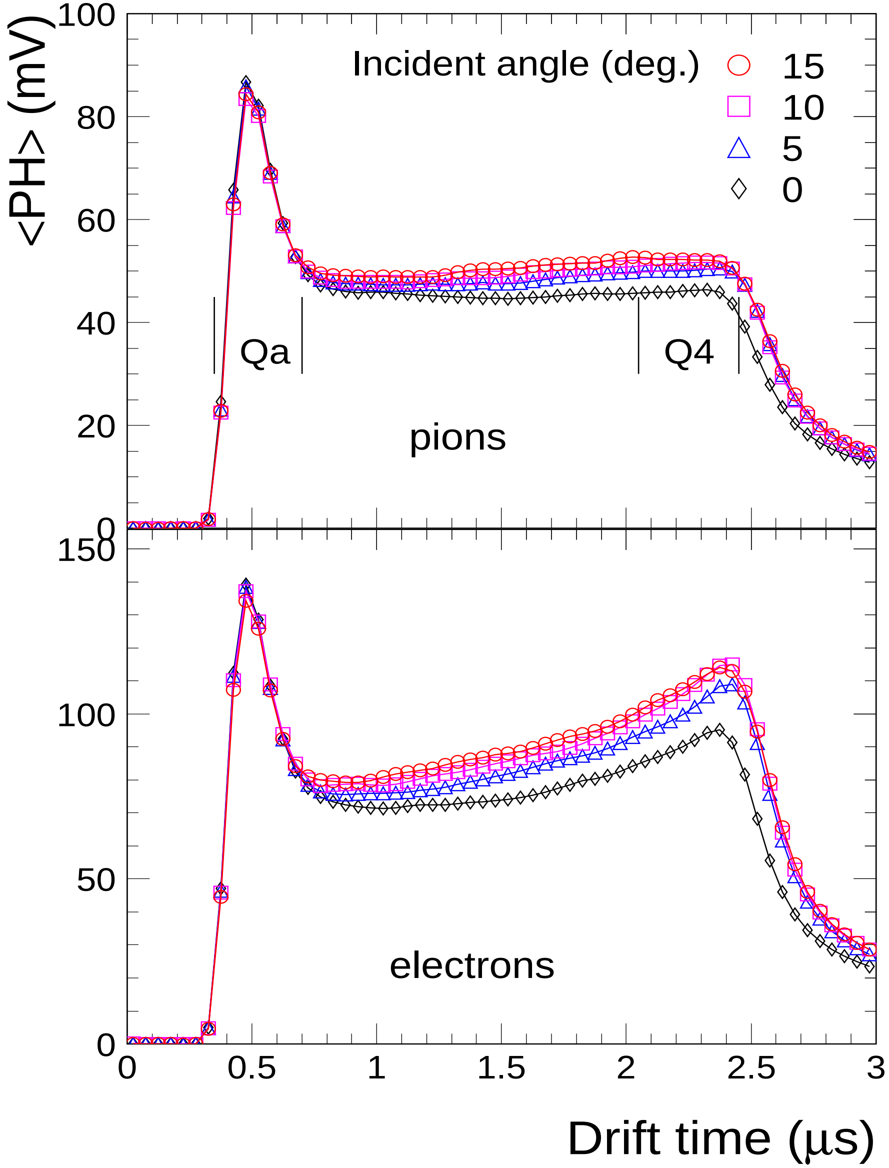
Gas gain (amplification)



NIM A523 (2004) 302 [physics/0402044]

- measured using ^{55}Fe:
  5.96 keV / $W \simeq 260$ electrons
  measure rate (Bq) and current on the anode (nA)
- measurements (symbols) and calculations (Imonte, lines) agree well
- ...only if Penning effect taken into account
  $CO_2^* + Xe \longrightarrow CO_2 + Xe^+ + e^-$

Space charge

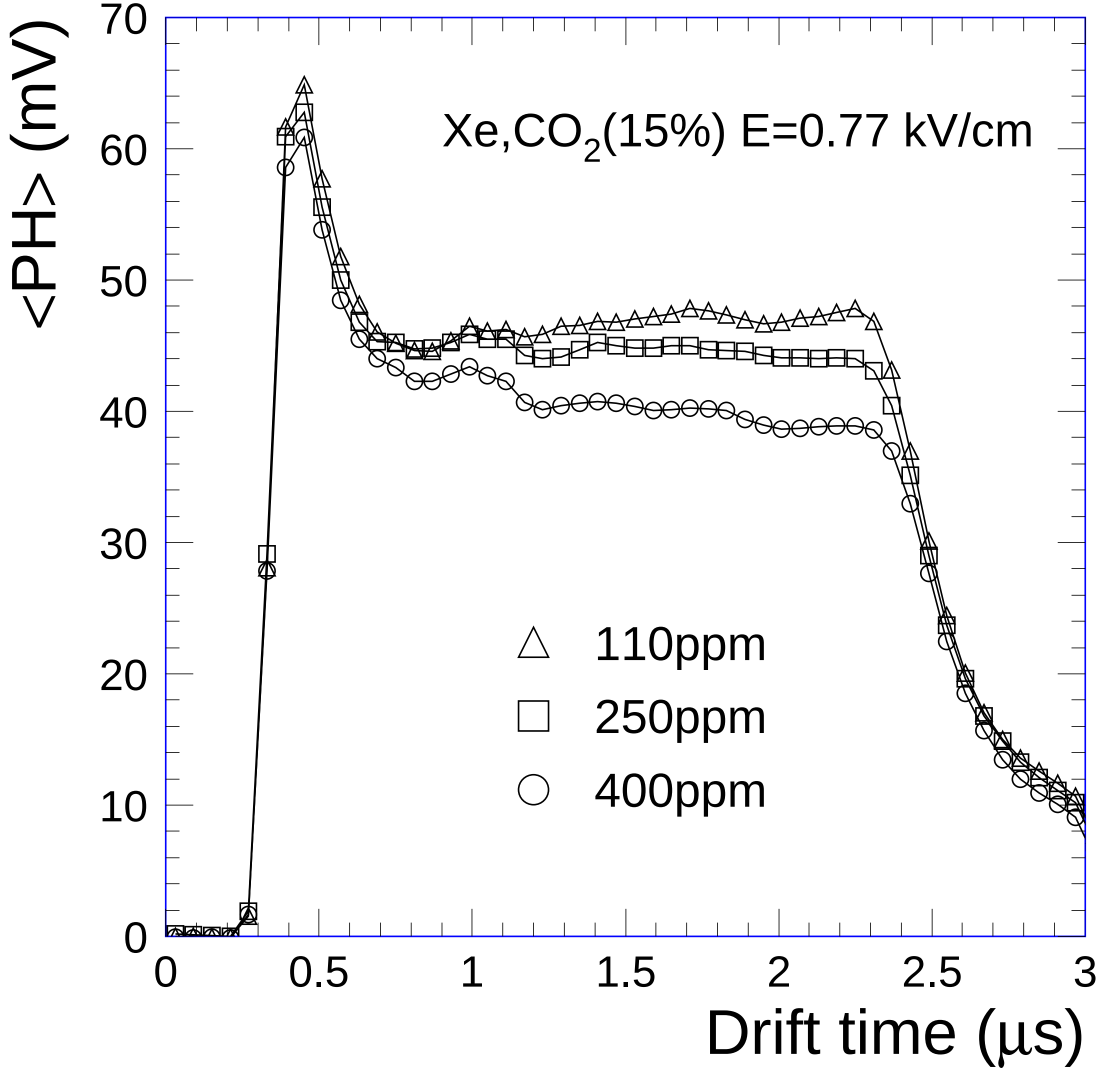


... around the anode wires

- reduction of late signal due to reduced effective gas gain (screening from earlier avalanches, slow moving ions) - *quantitatively understood*
- pronounced at normal incidence (0 deg.), a local effect ($\sim 100\mu$m)
- larger for higher gains
- leads to a slight degradation of e/π identification perf.

NIM A525 (2004) 447 [physics/0402043]

Electron attachment: on oxygen



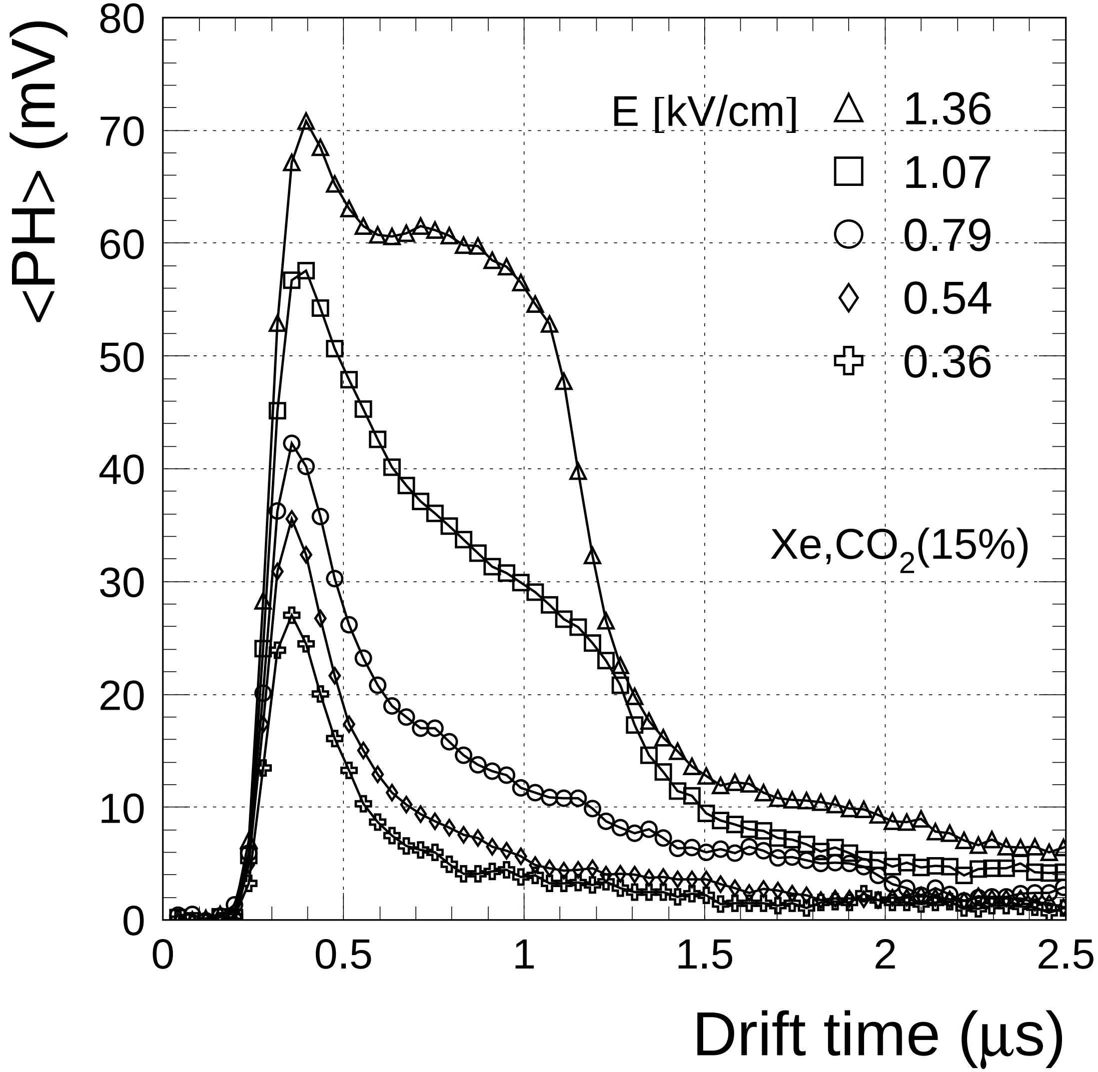
NIM A498 (2003) 143 [physics/0303059]

- three-body resonant capture:
  $I + e^- \longrightarrow I^{-*}$
  $I^{-*} + S \longrightarrow I^- + S^*$
  I=O_2, H_2O; S=quencher

- attachment on O_2 is moderate, can be serious for long drifts (TPCs)

- conditions in drift chambers: O_2 ~10 ppm, H_2O~100 ppm

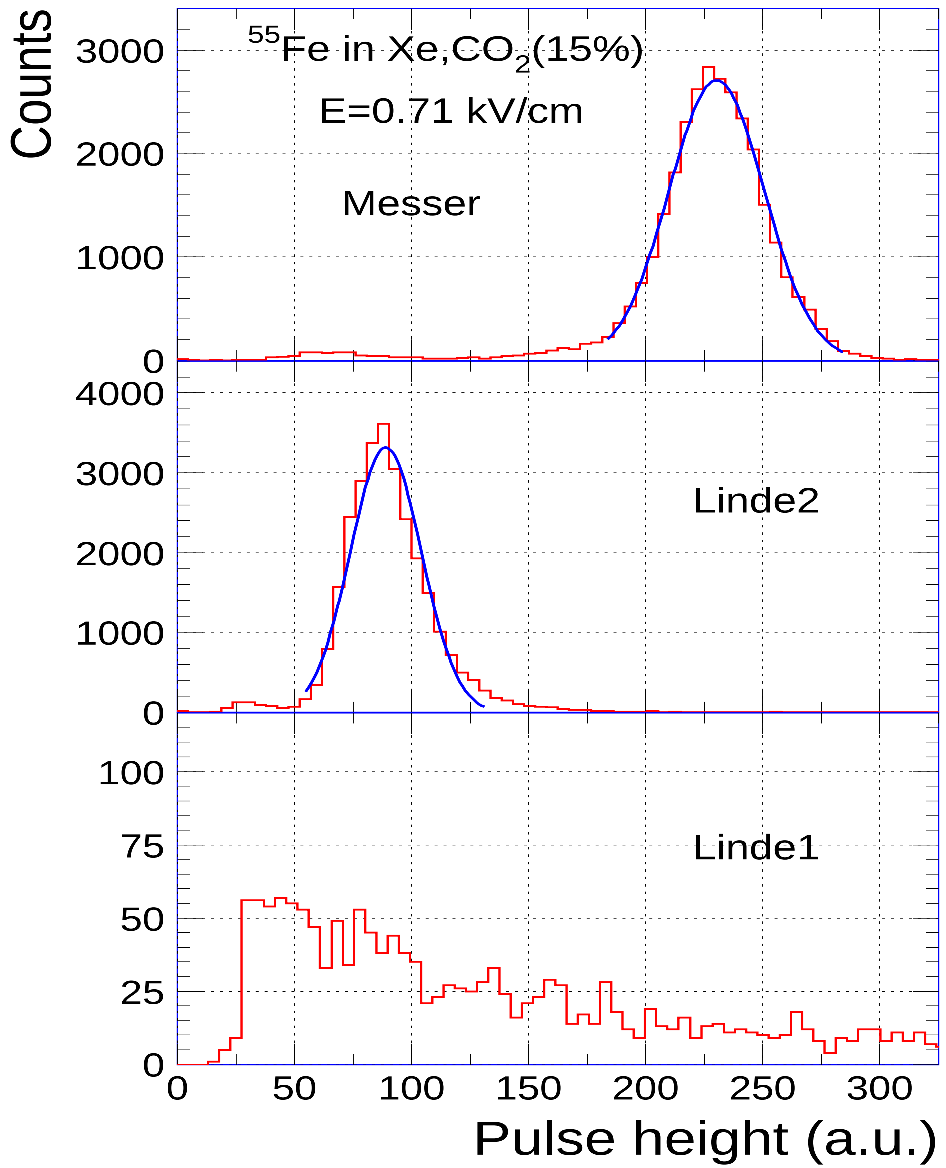
Electron attachment: on SF_6



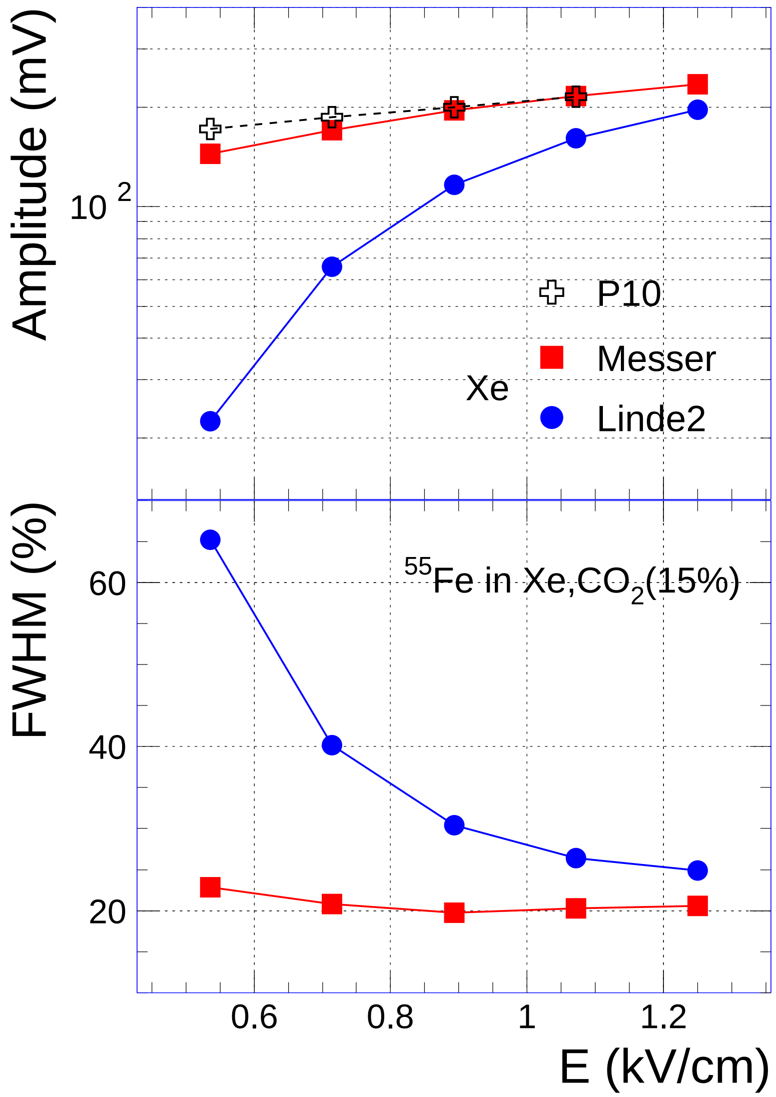
NIM A498 (2003) 143 [physics/0303059]

- huge! ...but can be quantitatively understood
- strong dependence on E (electron characteristic energy)
- enhanced by CO_2 presence present, but reduced, with CH_4
- why SF_6? present (0.9 ppm) in the Xe bottle (we found it by chance - during beam tests...)

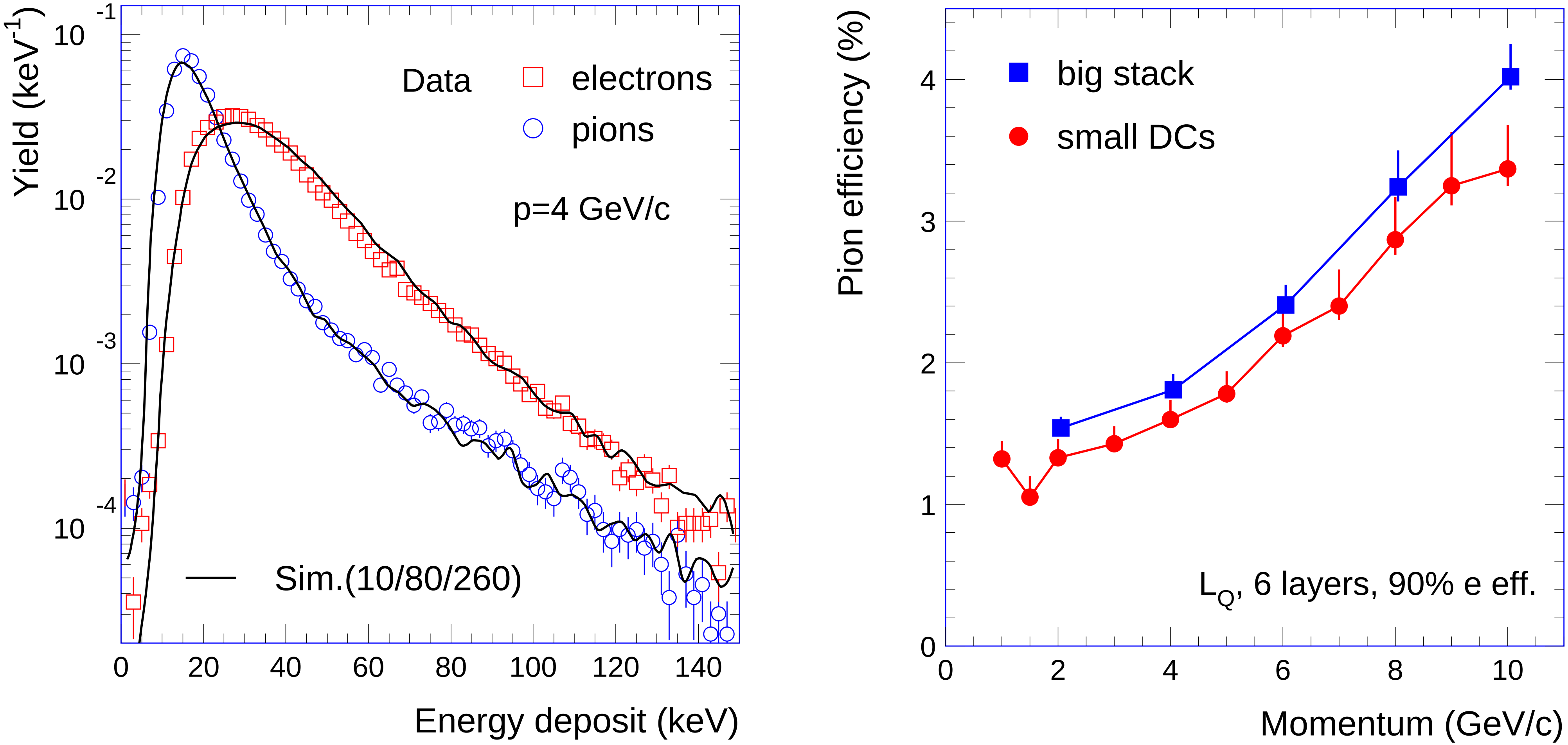
Electron attachment: early diagnosis



...using a prototype DC



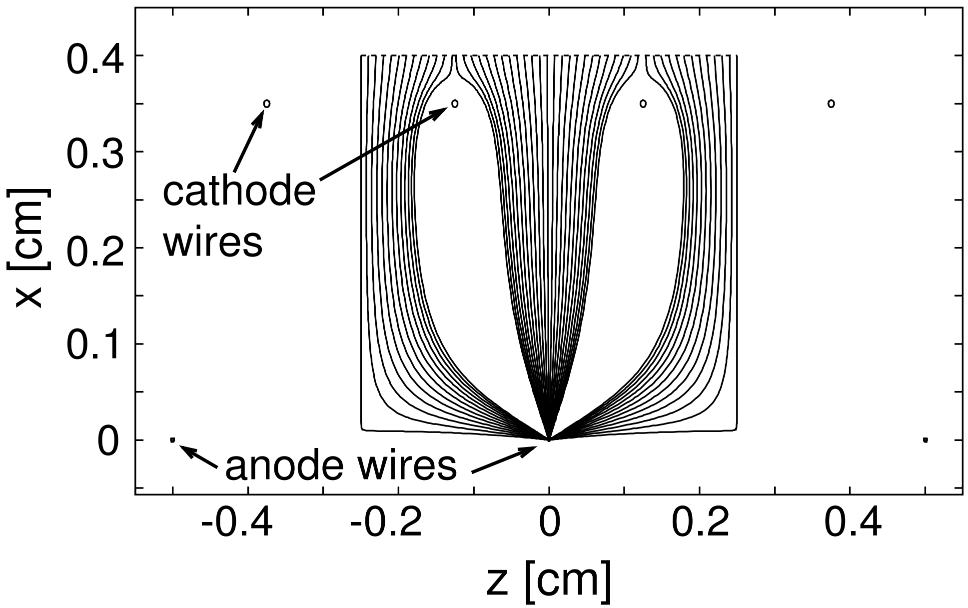
Electron/pion identification

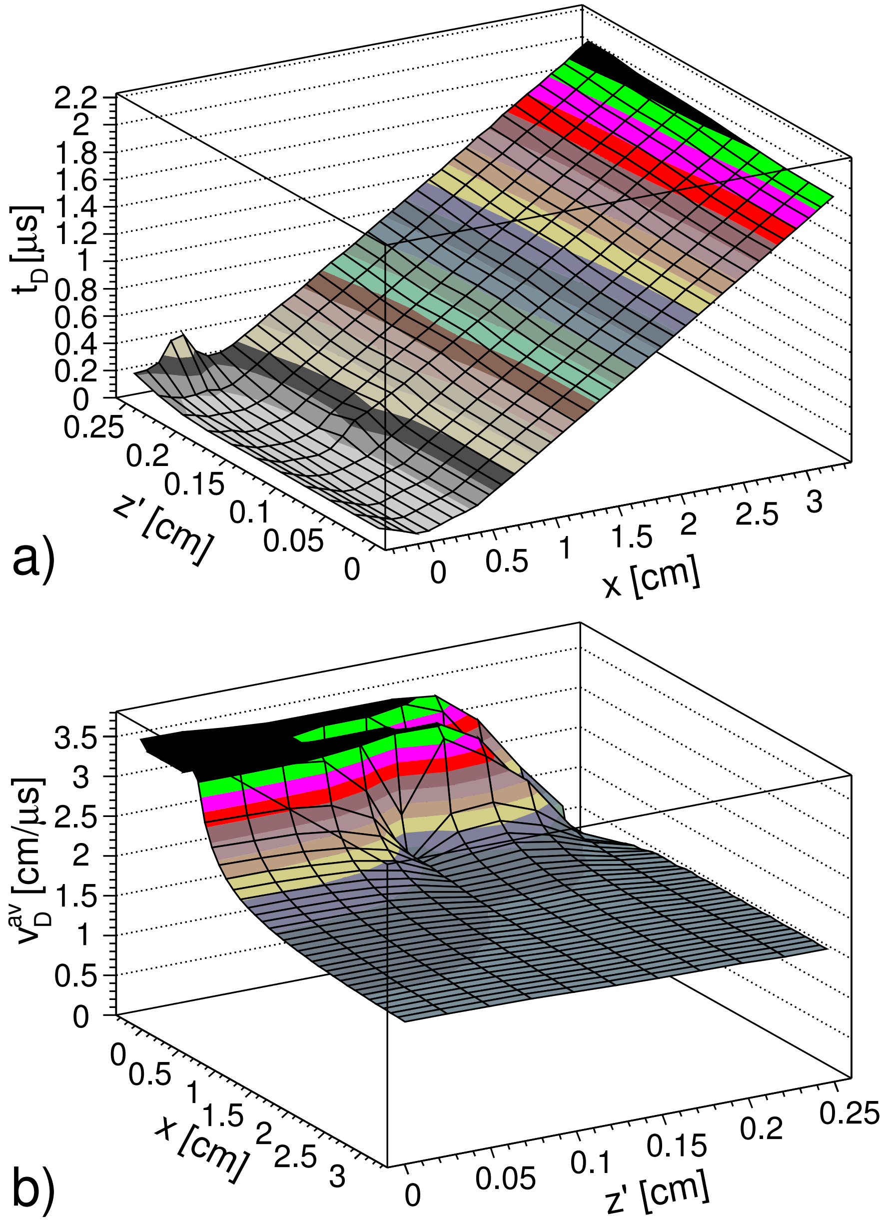


- Likelihood on total charge, including TR (well described by simulations)
- Pion rejection of 100 achieved, further improvements possible

Position resolution: detector geometry

drift cell

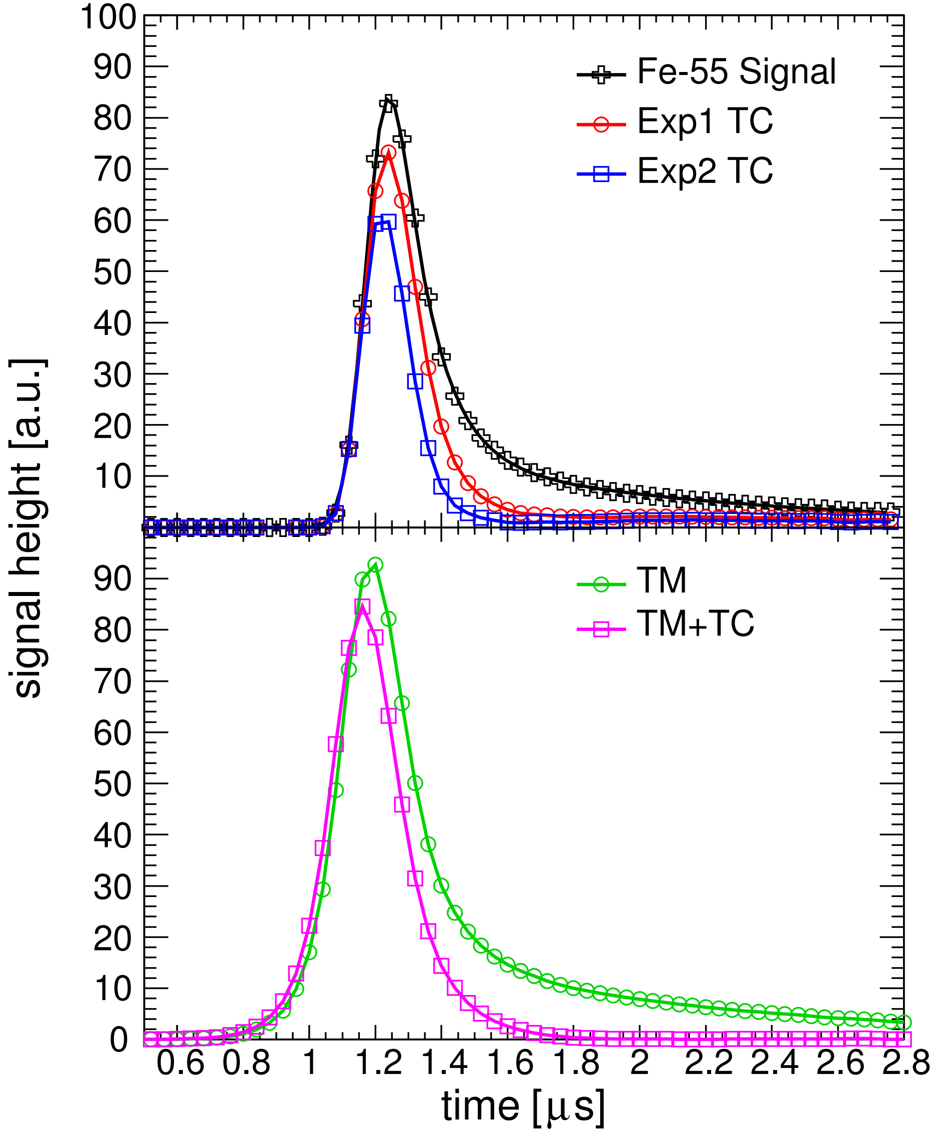




→ non-isochrony

NIM A535 (2004) 457

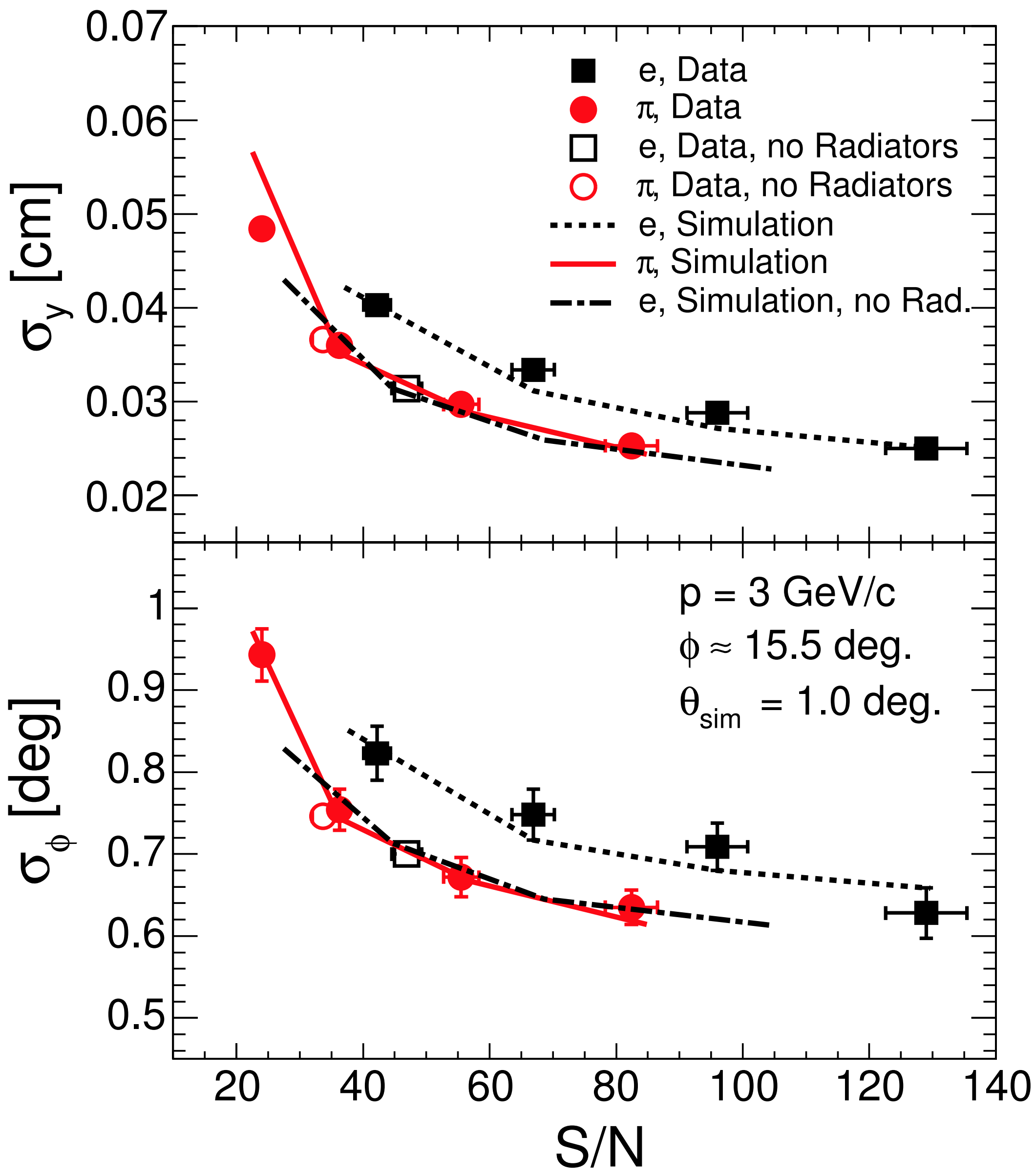
Position resolution: detector signal



- asymmetric due to slow ions (ion tail) leads to angle distorsions
- we do "tail cancellation" (on-line)

NIM A535 (2004) 457

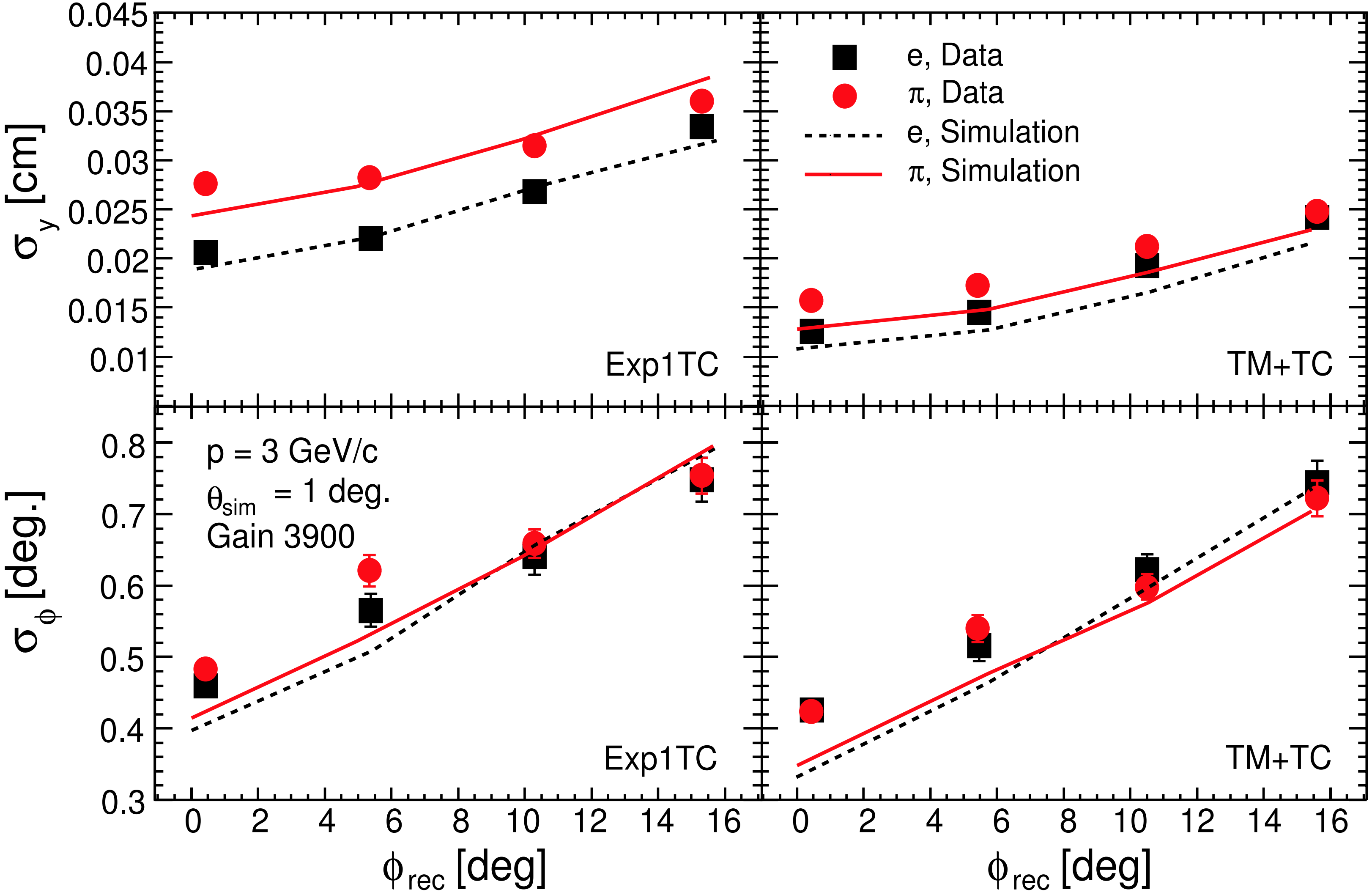
Position resolution: S/N dependence



- Expected improving of resolution with signal-to-noise ratio
- Electrons: worse than pions (due to TR, angular dep. of absorption)
- Good agreement with simulations
- Same resolutions with or without B-field

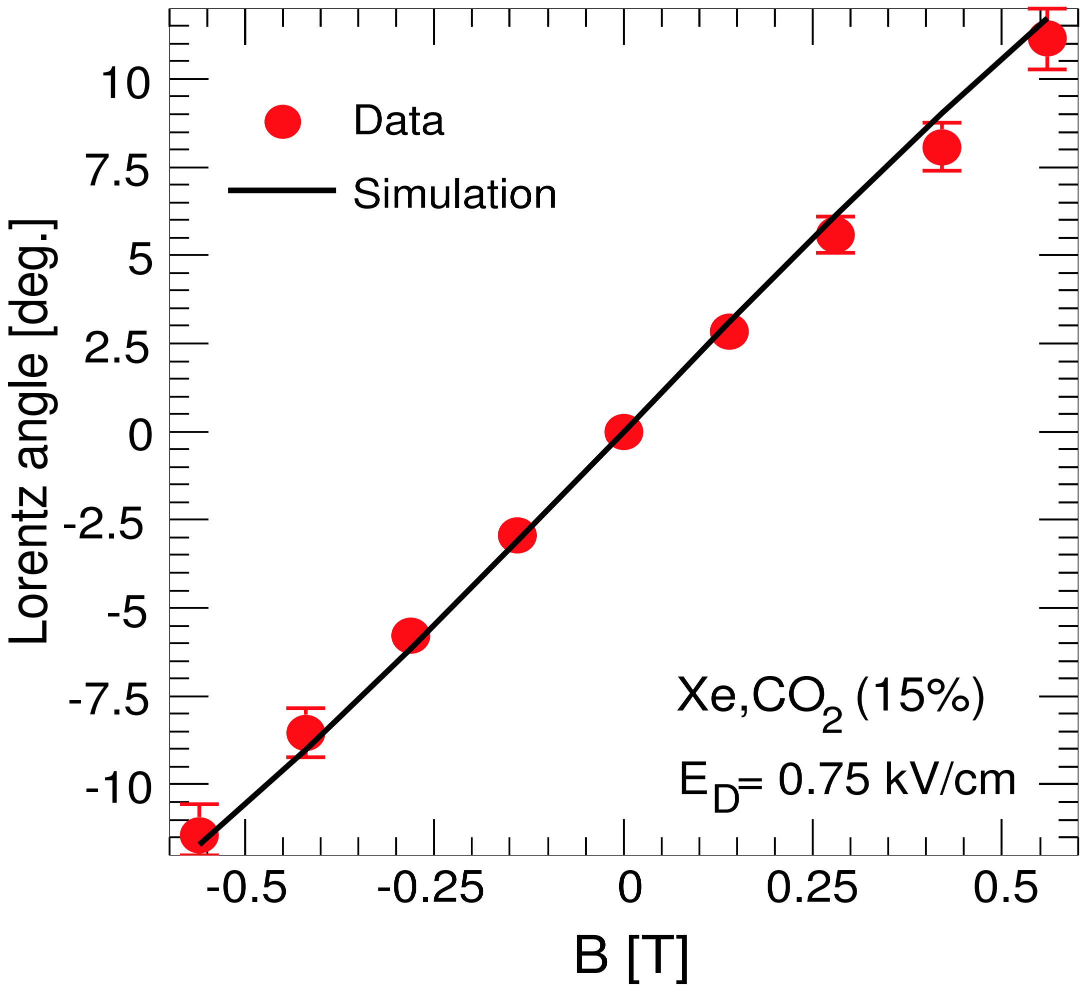
NIM A535 (2004) 457

Position resolution: angle dependence



due to remanent signal asymmetry; point resolution: 130 μm

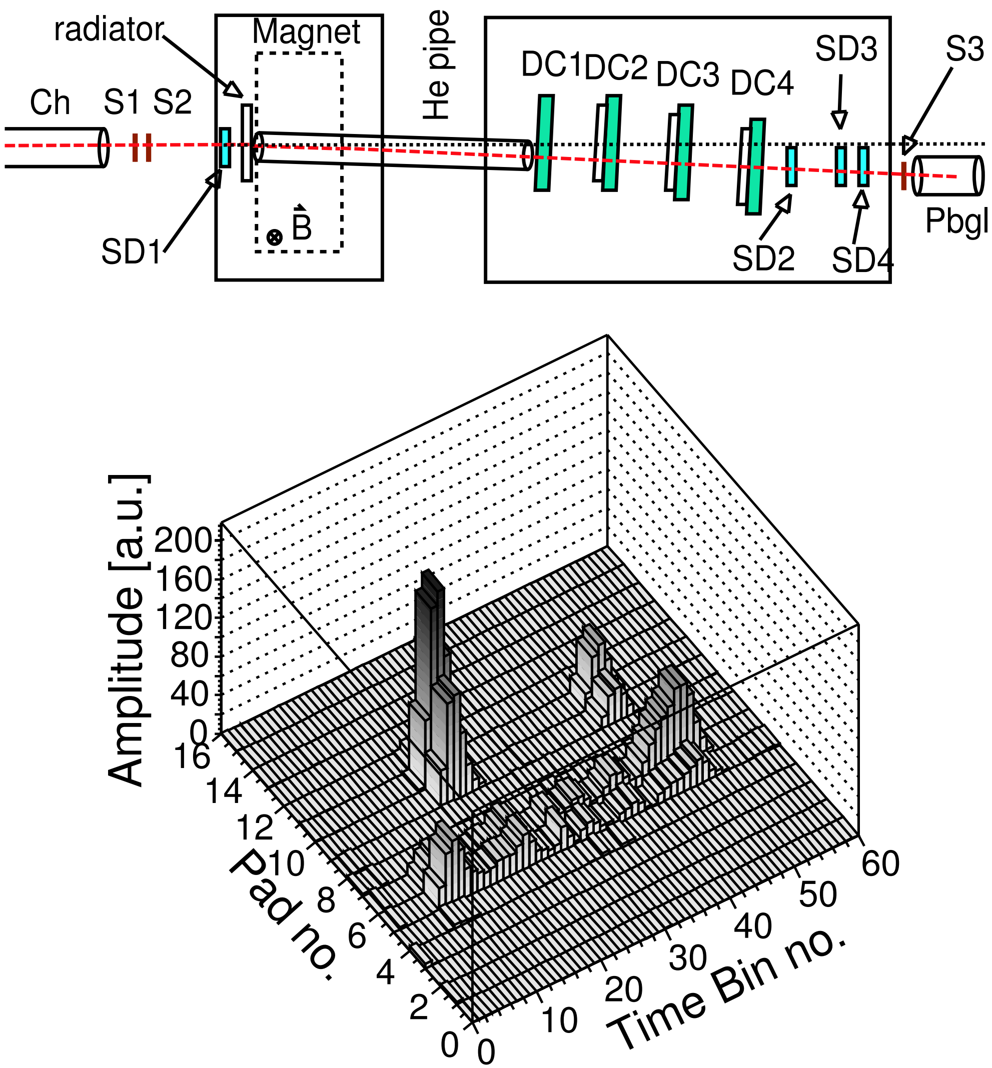
Lorentz angles

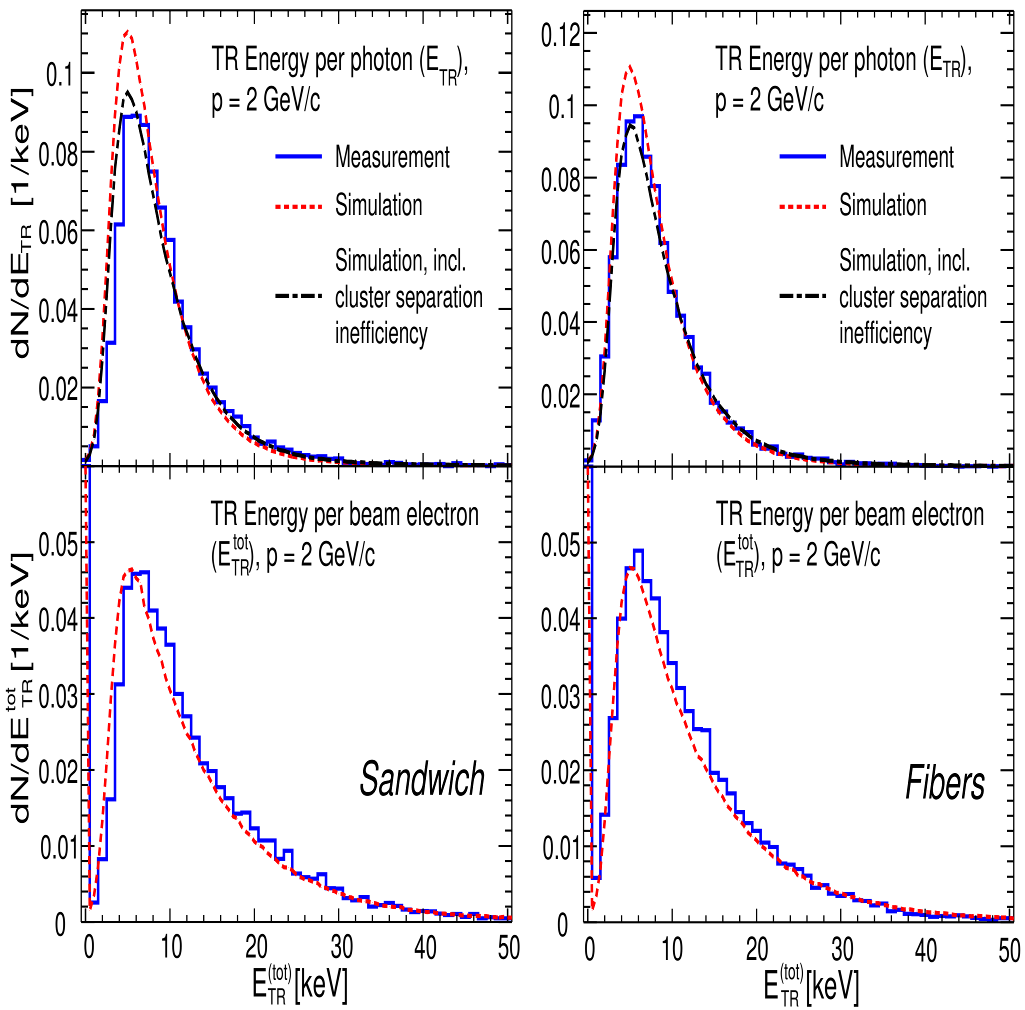


- angle measurement in magnetic field with our prototype chambers
- need good alignment of detectors
- good agreement with simulations (Magboltz)

NIM A535 (2004) 457

Transition radiation spectrum



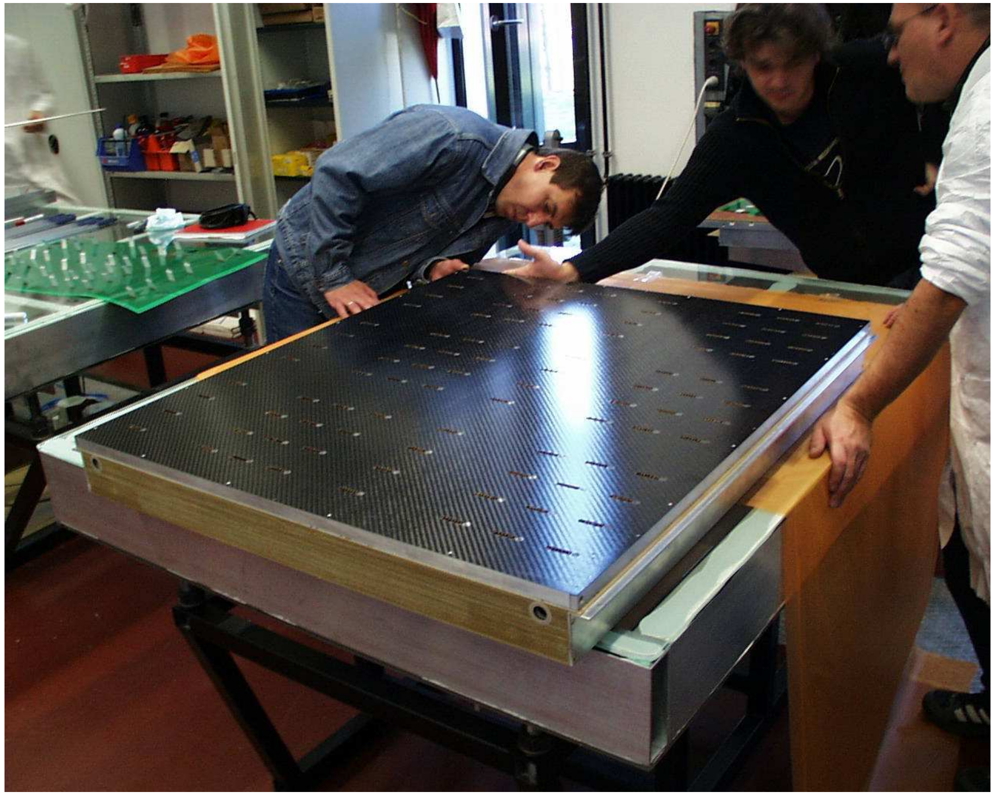


nicely reproduced by simulations (important for physics perf. simulations)

Chamber construction

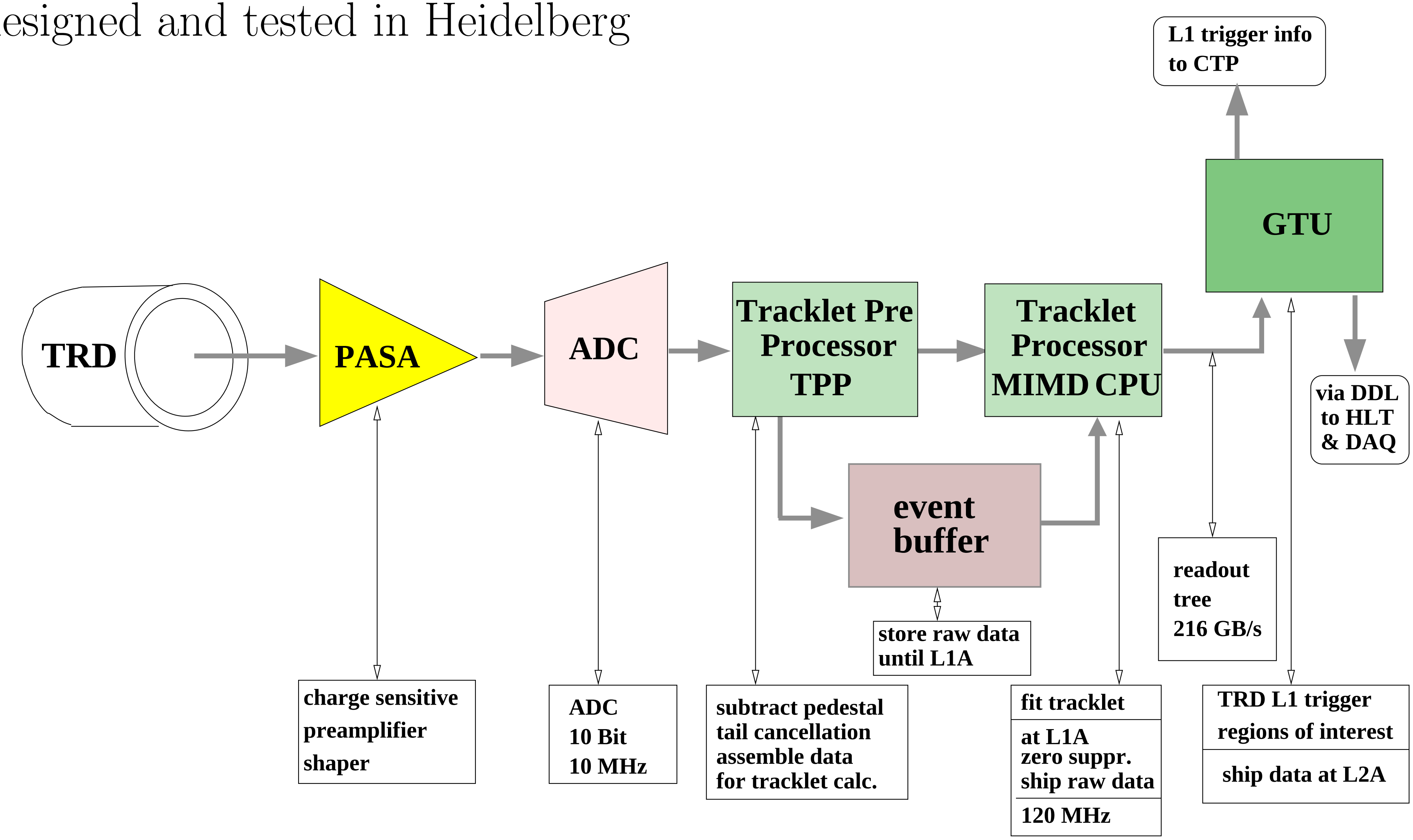
Ongoing, 60% accomplished

Bucharest, Darmstadt, Dubna, Frankfurt, Heidelberg, Münster



Front-end electronics

designed and tested in Heidelberg



DCS and services

Detector control system

- network of complex custom computers (Linux) and interfaces
- clock distribution to MCMs, possibility of (slow) detector data readout
- setting and monitoring voltages, monitoring currents, temperature

Gas system

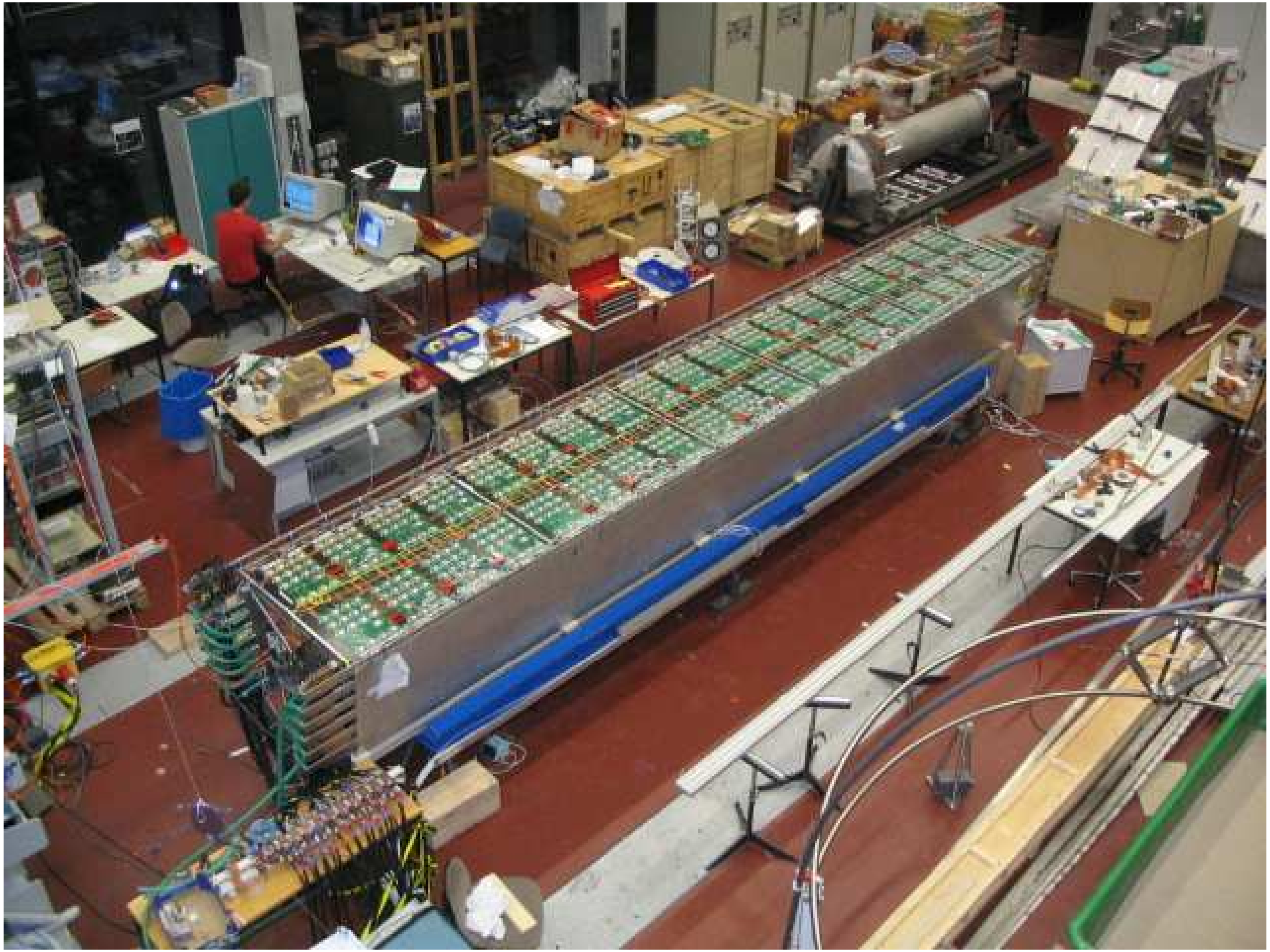
- cooking the right mixture, circulate it, filter O_2 and H_2O
- monitoring gas quality and environment (pressure) via drift velocity meas.

Cooling system

- water-based, transporting away the power (70 kW) dissipated on-detector

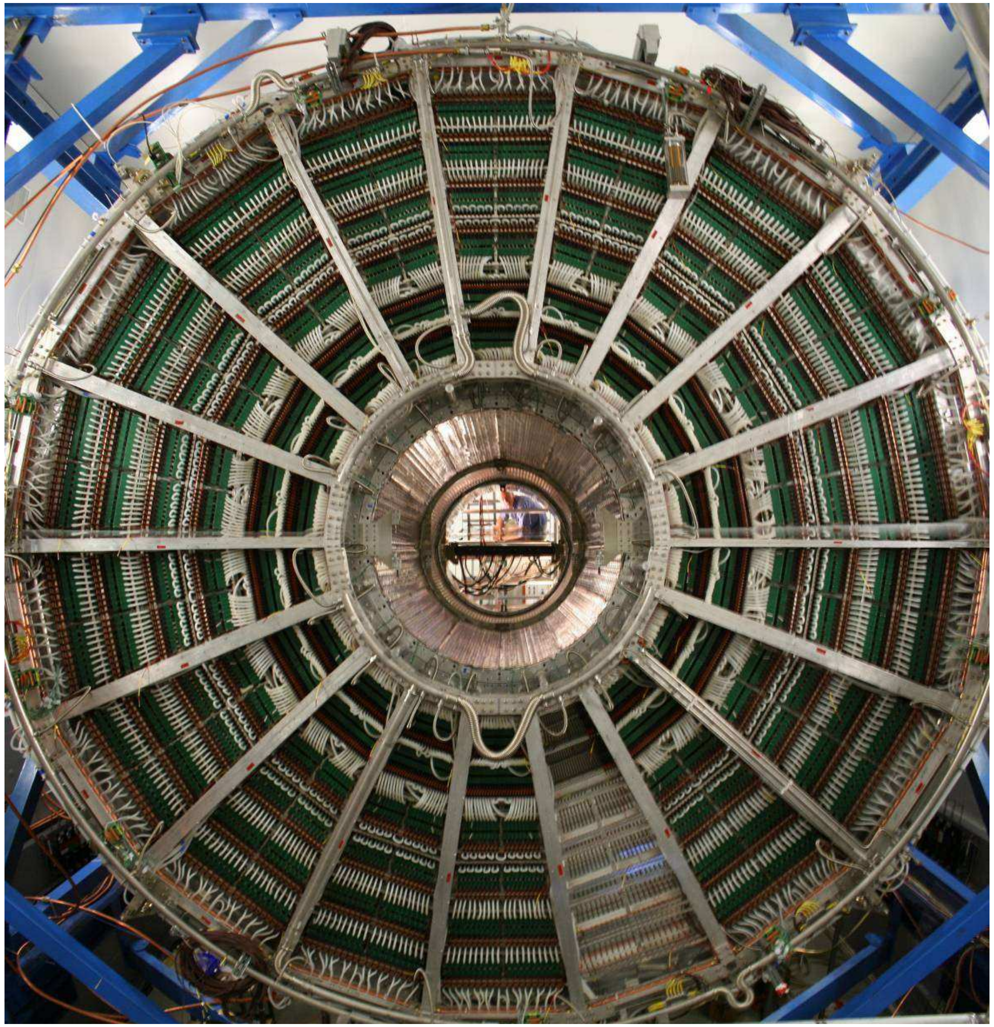
The real ALICE TRD (1/18, or ≃0.5 mil. euros)

built in Heidelberg, now at CERN (about to be mounted in ALICE)



ALICE TPC at a glance

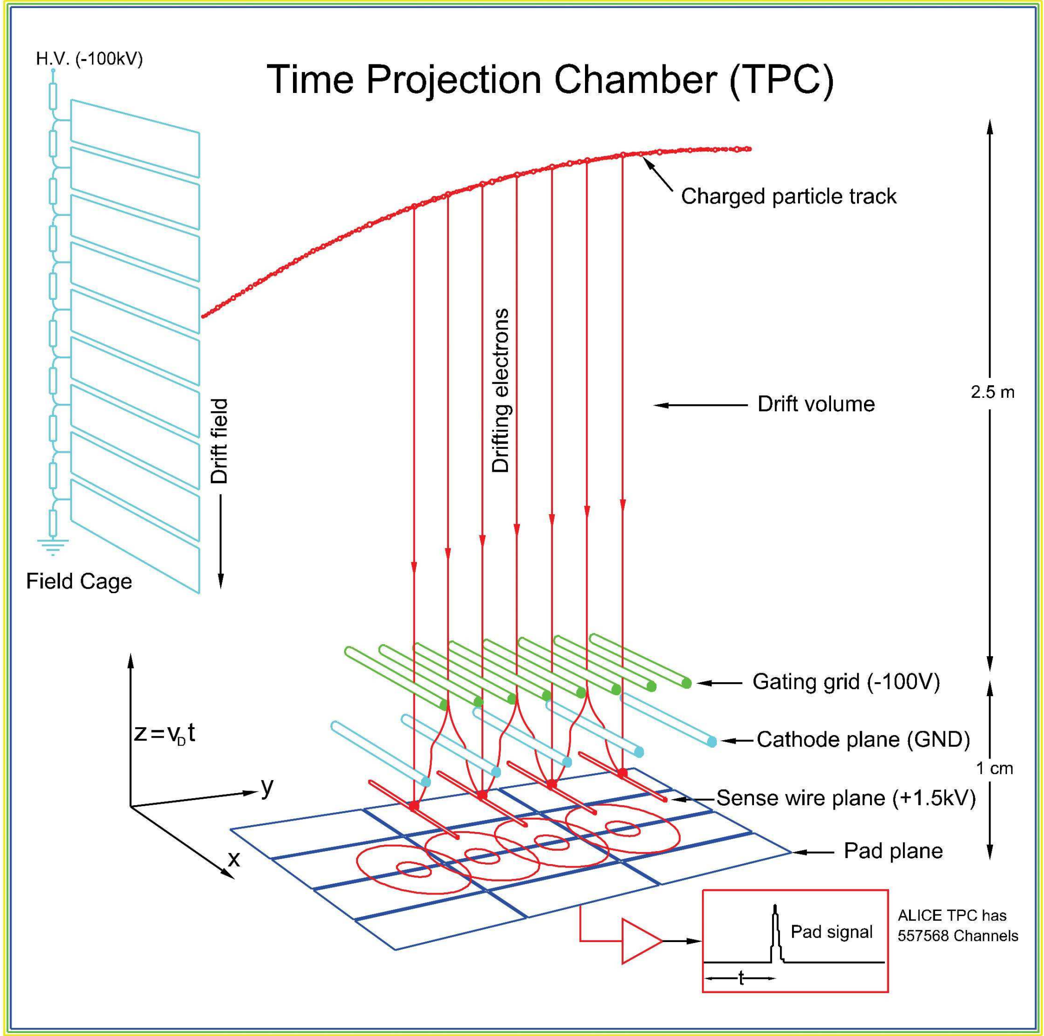
Goal: particle tracking and identification, level-3 trigger for some event classes



Parameters:

- Dimensions: r_{min}=0.85 m, r_{max}=2.5 m, L=5 m
- Readout chambers: $2\times2\times18 = 72$
- Gas: $Ne/CO_2/N_2$, Volume= 95 m^3
- Drift time: 88 μs (1000 time bins)
- Electronics channels: 560 k (occ.$<$25%)
- Max. trigger rate: 200 Hz
- Event size: 60 MB
- Momentum resolution: $<$2.5% @ p=4 GeV/c and B=0.4 T

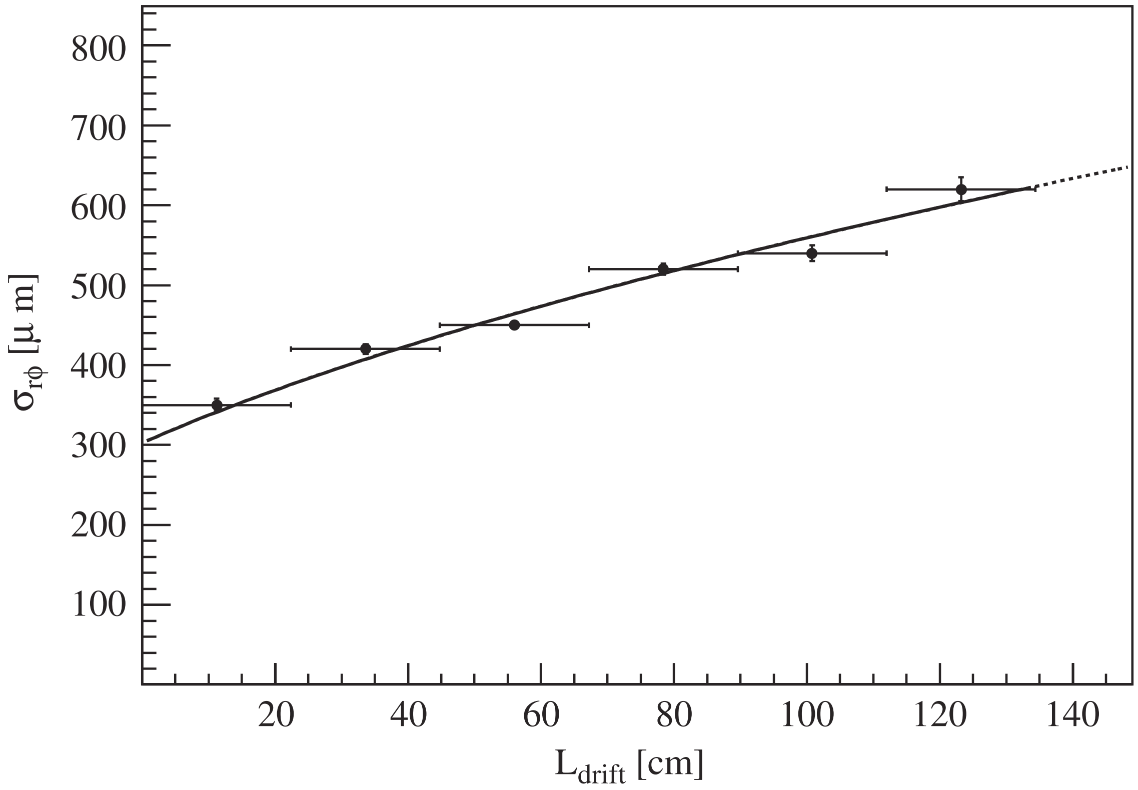
TPC principle



Challenges in ALICE:

- long drift path (attachment, diffusion, baseline)
- large volume (precision)
- large voltages (discharges)
- extreme load in Pb+Pb coll. space charge in the drift volume leads to distorsions of $\vec{E}$ gating grid opened (fast, $\sim 1\mu$s) for triggered events only, otherwise opaque ($\pm\Delta V$)

ALICE TPC: point resolution

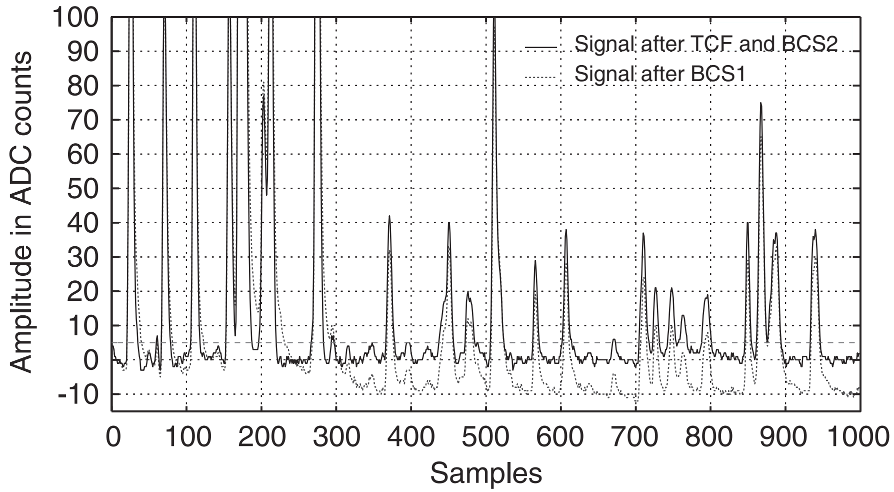


$$\sigma_{r\phi} = \sqrt{\sigma_0^2 + L_{drift} \cdot \sigma_1^2}$$

σ_0 - intrinsic resolution (dep. on S/N and pad size)

σ_1 - transverse diffusion

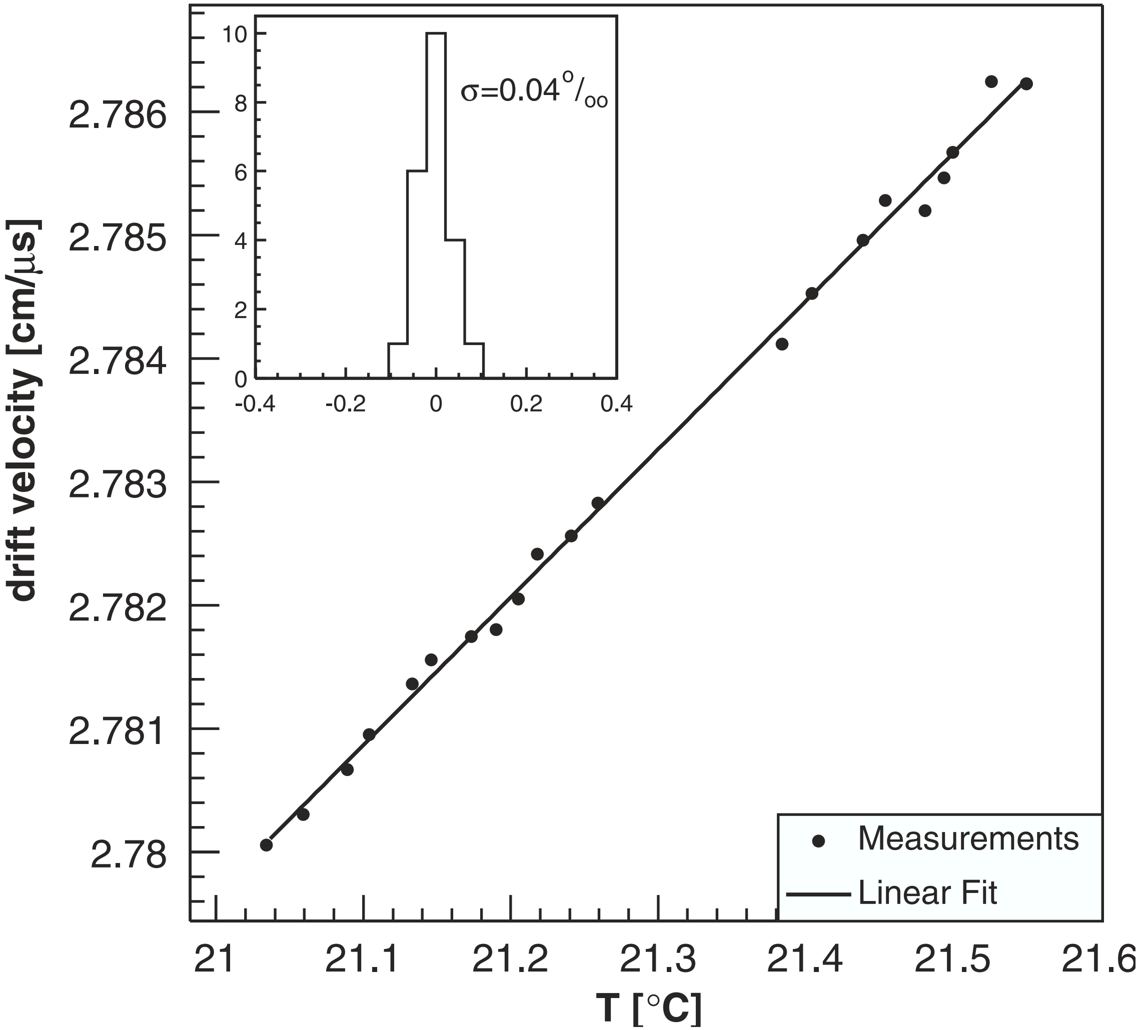
...and baseline



measurements in beam (CERN)

D.Antonczyk et al., NIM A565 (2006) 551

ALICE TPC: drift velocity



converts time into z coordinate

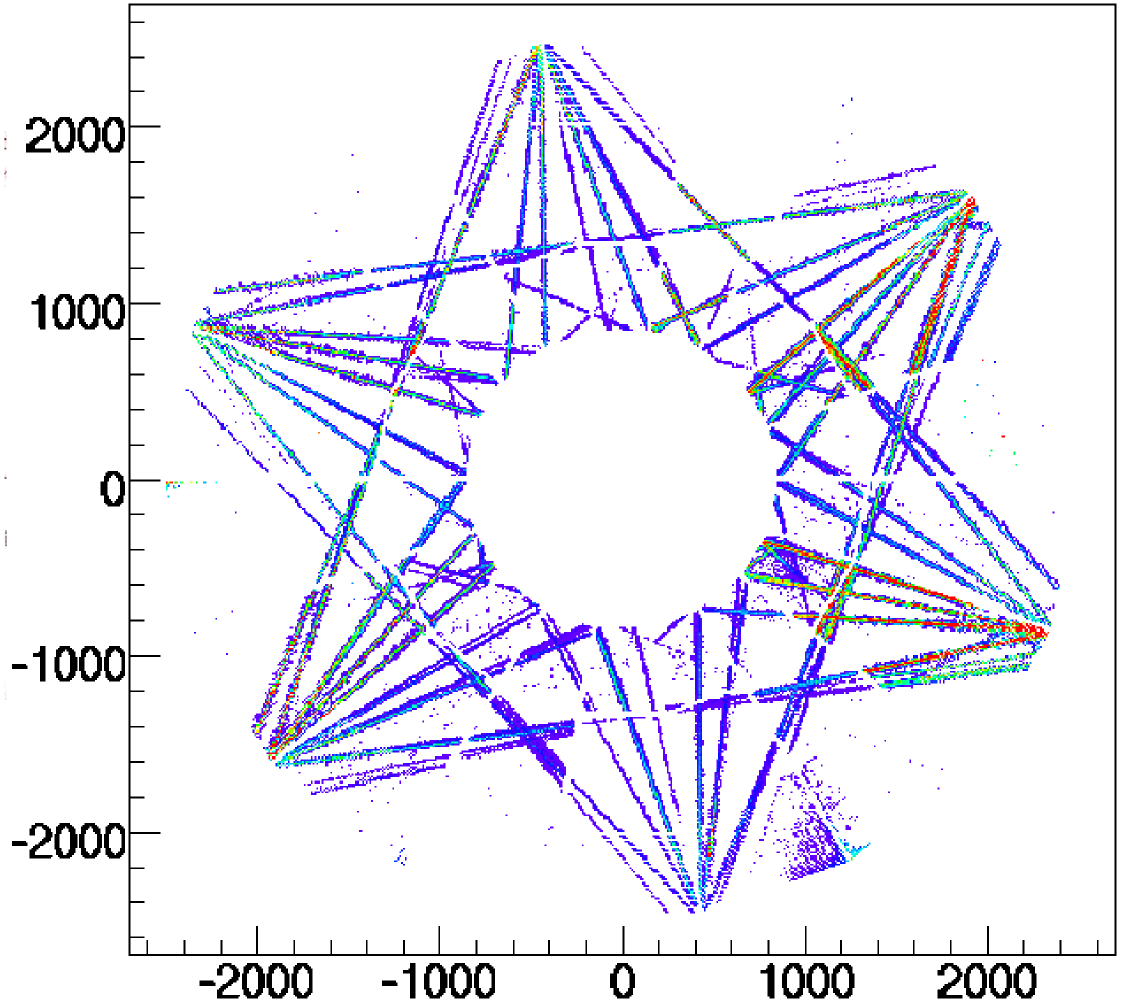
extreme precision needed...

measured with a small TPC
(using a laser for gas ionization)

J.Wiechula et al., NIM A 548 (2005) 582

ALICE TPC field cage

ALICE TPC: the laser system

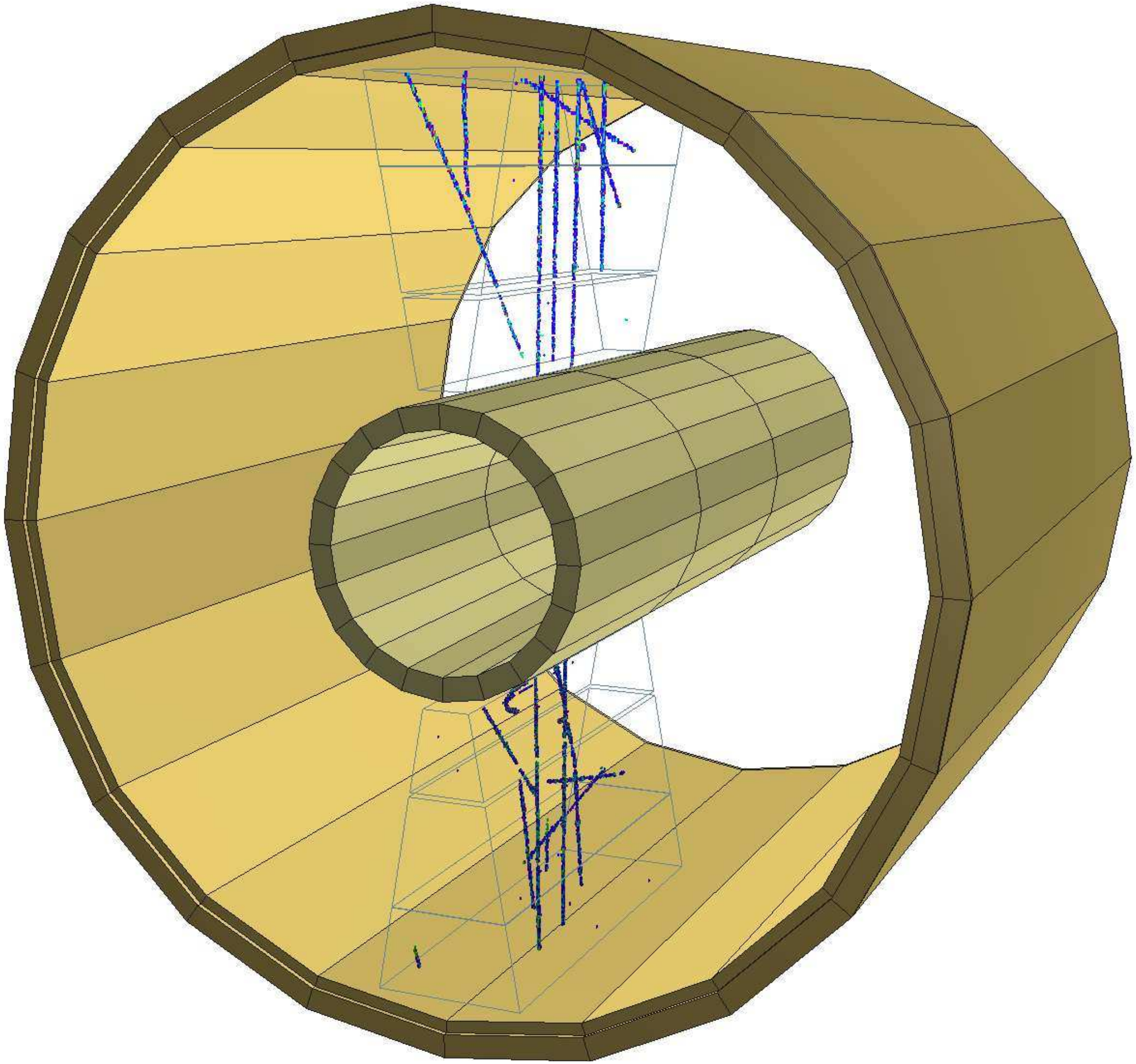


already working...

essential for:

- alignment of readout chambers
- calibration of time
  (delays due to cables)
- map non-uniformities in $\vec{E}$,$\vec{B}$

ALICE TPC up and running (CERN)



cosmics shower

- gas system (<10 ppm O_2)
- full FEE (2 sectors)
- cooling