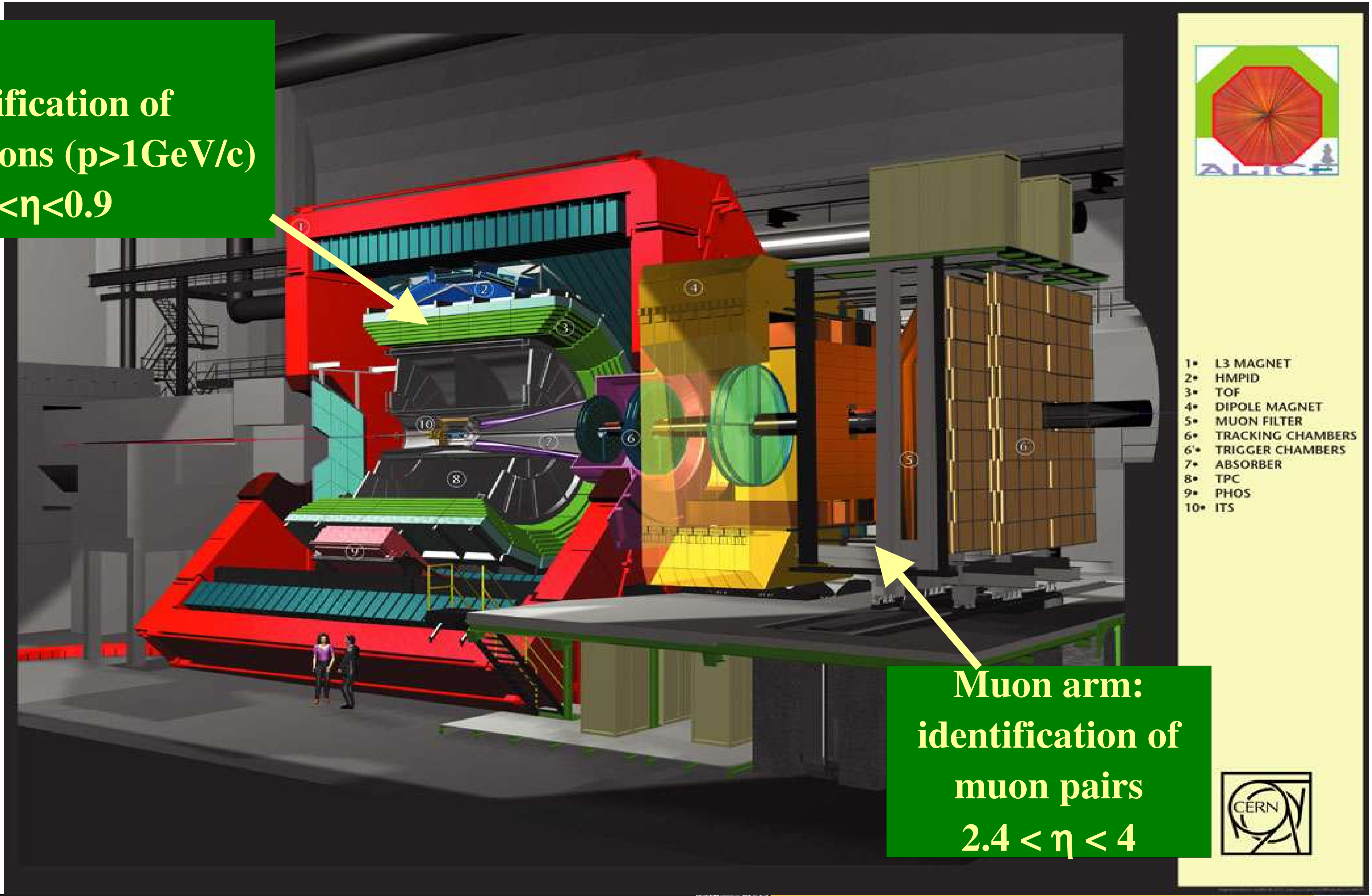
The ALICE TRD
detector and physics performance

- Physics requirements
- Detector concept
- Detector construction and performance
- Some physics issues

Lepton identification in ALICE

TRD:
Identification of electrons (p>1GeV/c)
$-0.9<\eta<0.9$



Muon arm:
identification of muon pairs
$2.4 < \eta < 4$

Required performance of the ALICE TRD

The TRD should:

- provide electron identification for momenta above 1 GeV/c
- provide trigger on high-p_t electrons

  both in high multiplicity environment of $dN_{ch}/dy \leq 8000$

- this requires:

  - pion rejection by factor 100
  - in bend plane: space point resolution < 400 µm
    angular resolution < 1°
  - perpendicular to bend plane: sufficient resolution for matching
  - fast momentum determination & electron identification

TRD will improve general tracking capabilities in central barrel

Trigger requirements

trigger mainly required to get Y in min. bias PbPb collisions due to DAQ Bandwidth of 1.2 Gbyte/s

also: high p_t J/ψ and jet trigger (several leading particles within cone)

in particular jet – photon coincidences

⇨ need to be able to trigger on

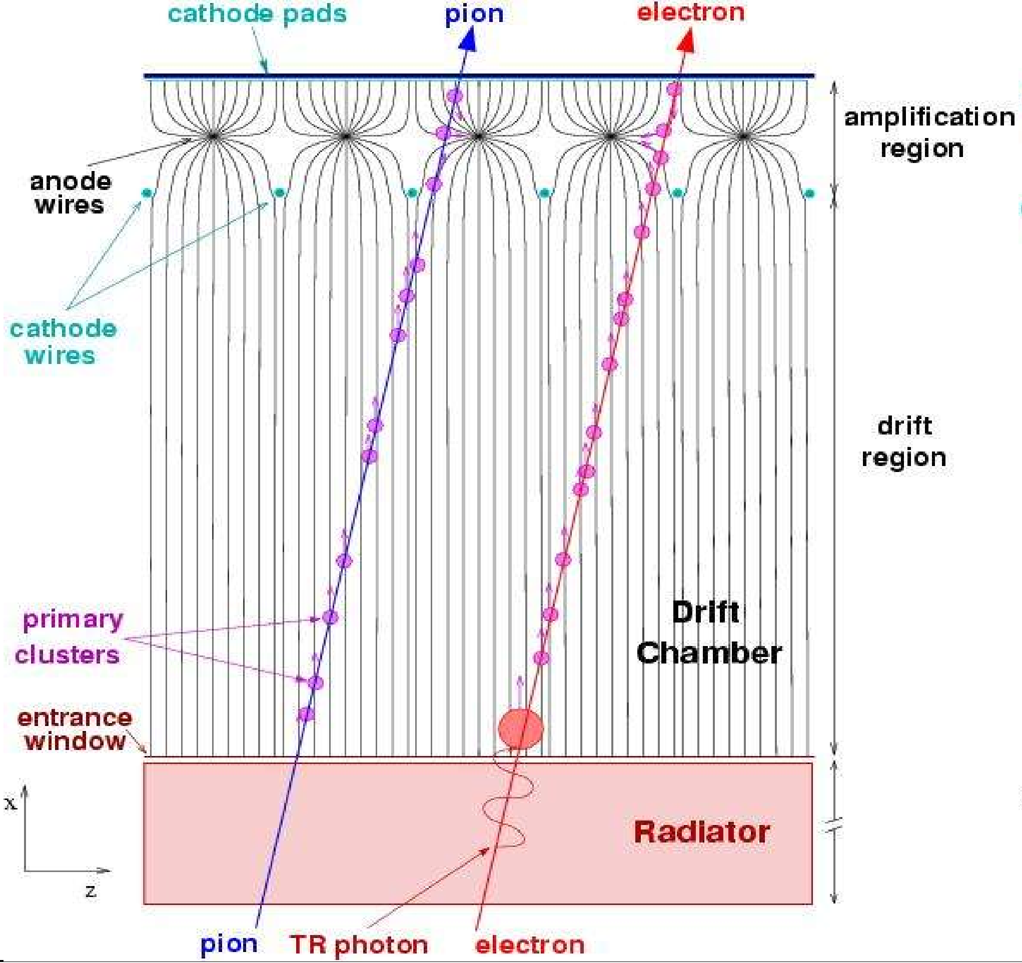
- electrons and
- opposite sign electron pairs
- with high p_t (typically above 2 GeV/c)

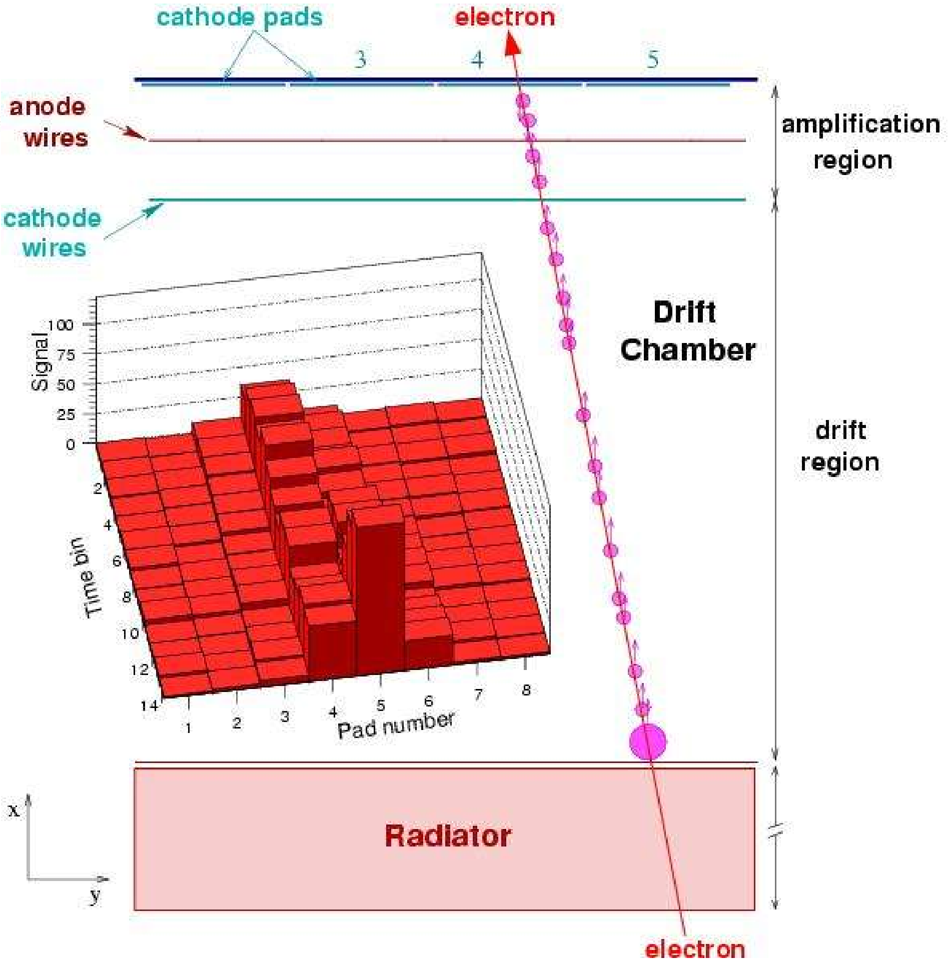
time scale: 6 μs

Working Principle of the TRD

Drift chambers with cathode pad readout at 10MHz combined with a fiber/foam sandwich radiator in front

Transition Radiation (TR) photons (< 30keV, only for electrons) are absorbed by high-Z gas mixture (Xe,CO_2)





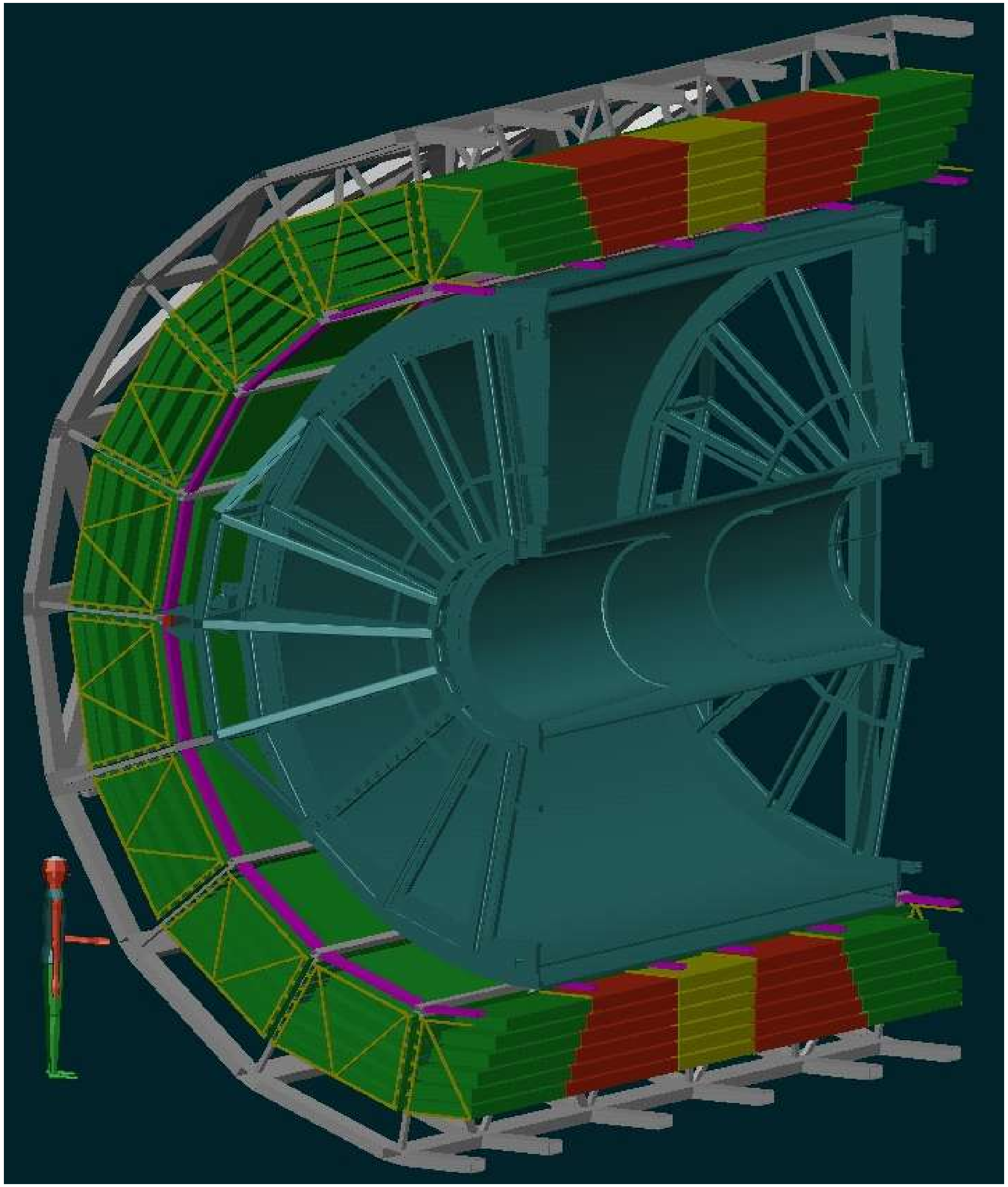
the TRD (Transition Radiation Detector)

- 540 detector modules
- 750 m^2 active area
- Length 7 m
- Filled with 28 m^3 of Xe/CO$_2$

⇒ Arranged in 18 supermodules

6 radial layers

5 longitudinal stacks



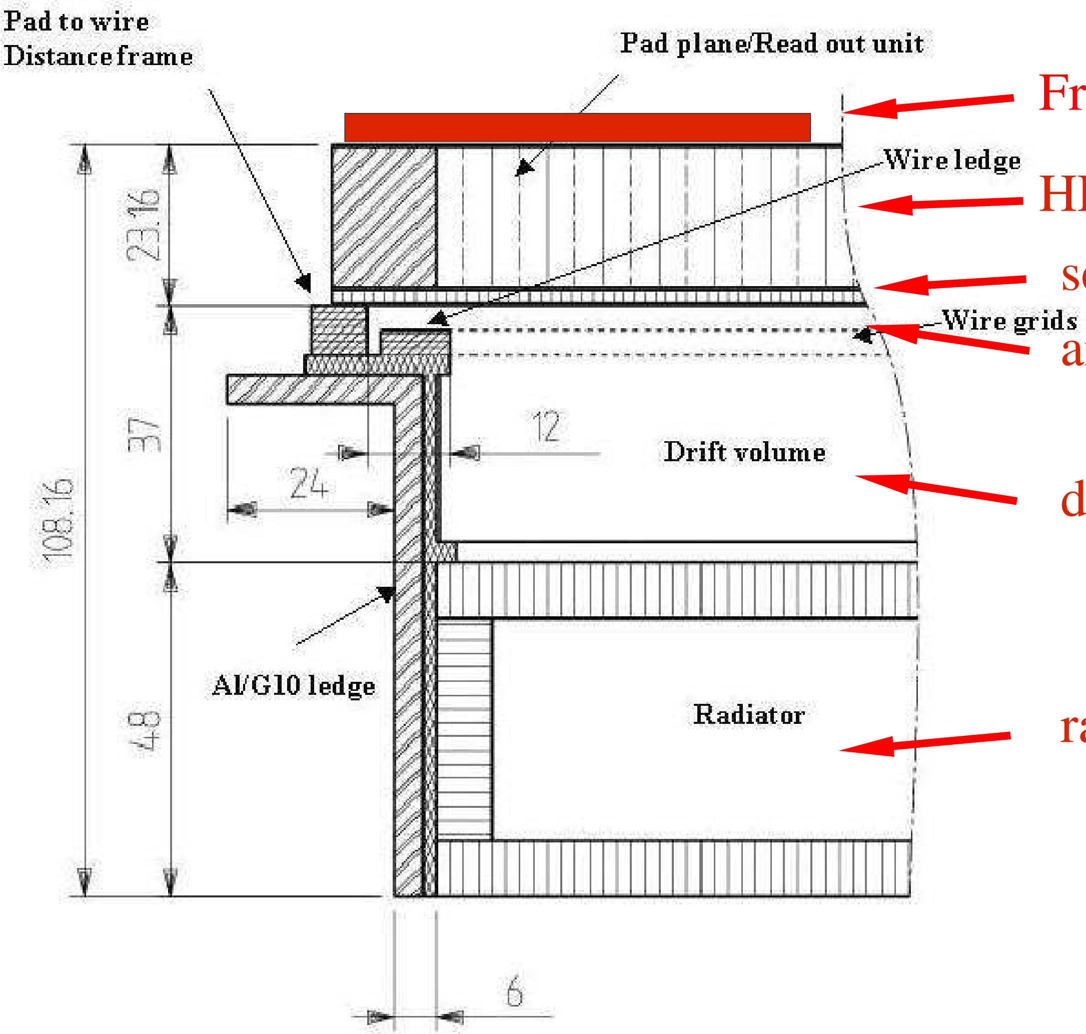
typical chamber size:

≈ 1.35 x 1.03 m^2

≈ 12 cm thick (incl. radiators and electronics)

in total 1.16 million read-out channels

the TRD chambers



Front-end Electronics

HEXCELL/CF backing (FACC)

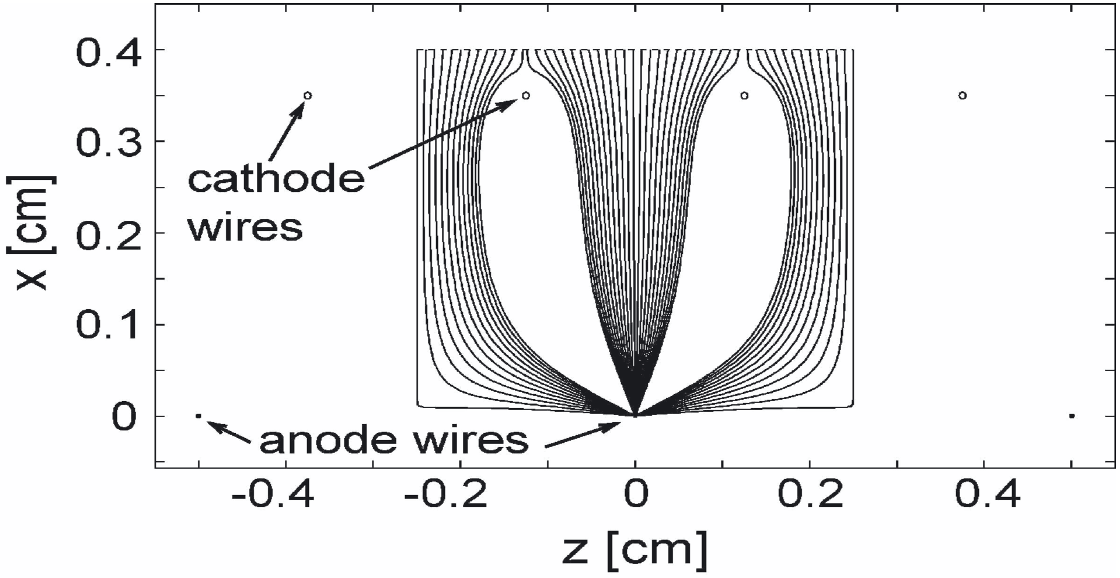
segmented cathode pad plane

amplification region (7 mm)

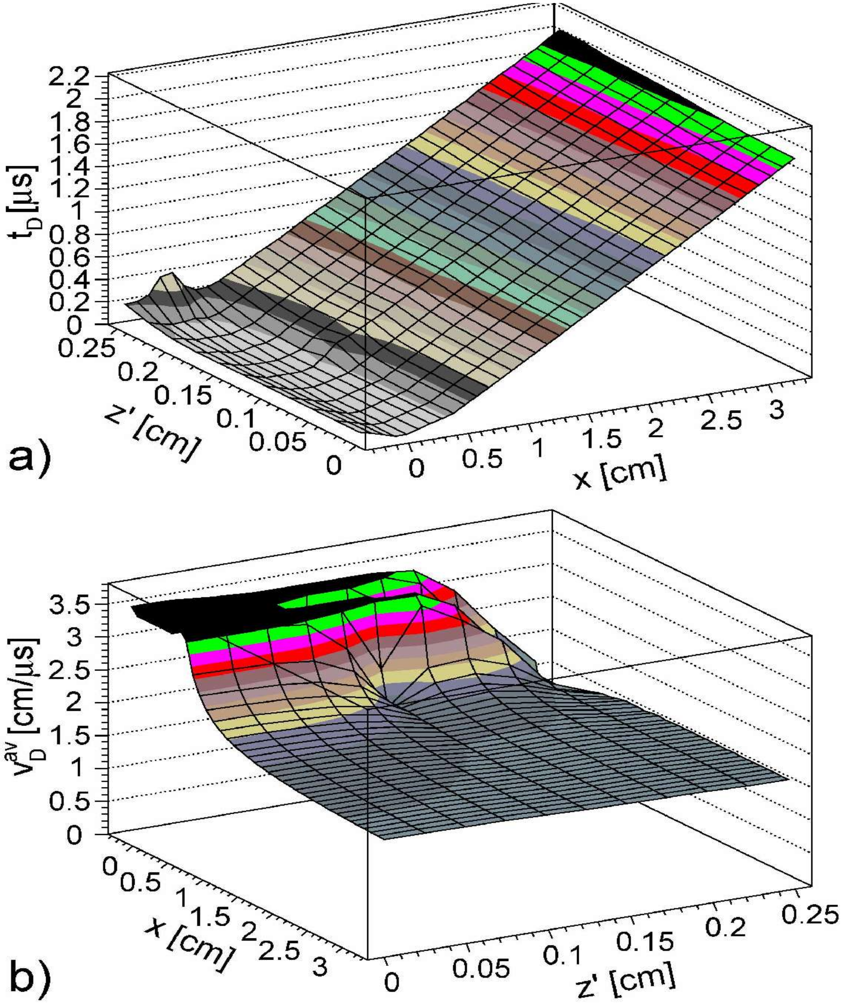
drift region (3 cm)

radiator (4.8 cm)

TRD Chambers



details of drift behavior
Garfield simulation
C.Adler et al., NIM A540(2005)150



gas: Xe/CO2 (15 %)

TR absorption length: 1 cm for 10 keV

drift field: 0.7 kV/cm

drift time: max 2 µs

anode wires: 20 µm ⌀Au pl. W, 5 mm pitch staggered

cathode wires: 75 µm ⌀ Cu/Be, 2.5 mm pitch

gas gain: 4000

wire sag electrostatic: 45 µm

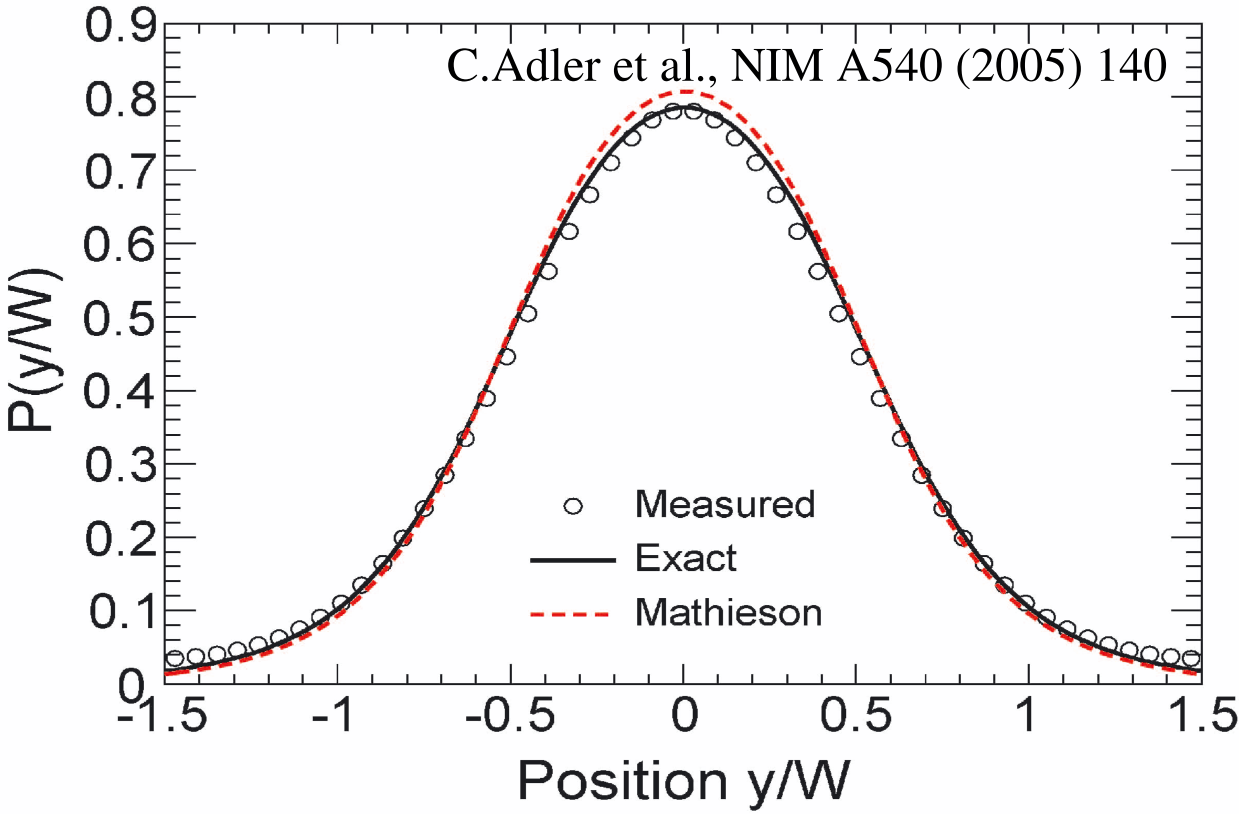
gravity: 0 – 20 µm

TRD Chambers - Image Charge

induced image charge on cathode pads of typically 0.75 × 8 cm^2

(pad - ground capacitance 20 – 25 pF)

pads tilted by 2^o to obtain z-resolution



typical signal size (3 GeV/c π):

dE/dx = 5.5 keV/cm

≙ 243 electrons/cm

sampled every 2 mm

× gas gain 4000

× 0.2 (image fraction × shaping fraction)

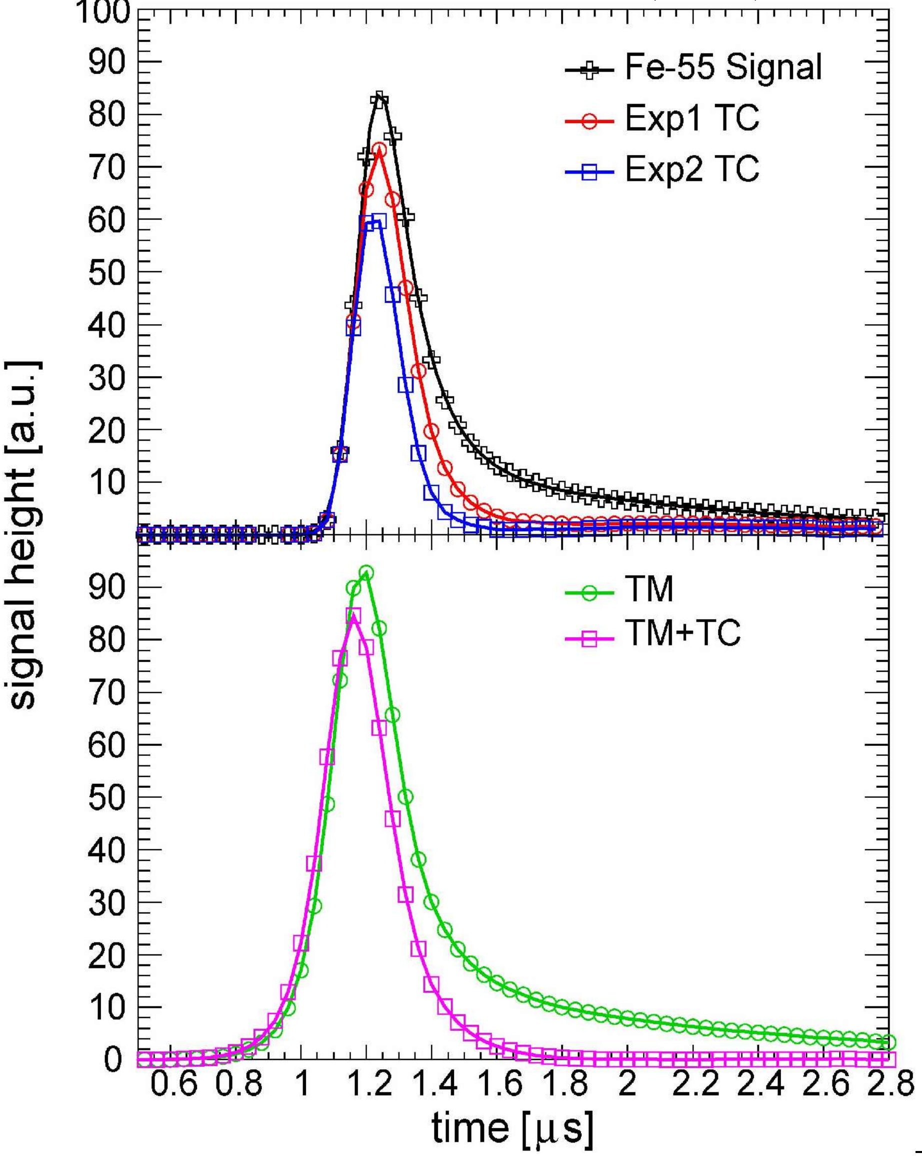
⇨ **40 000 electrons**

☛ aim for total electronics noise of 1000 electrons

typical width: σ ≅ 0.5 pad units ≙ 3.8 mm

TRD Chambers – time structure of signal

C.Adler et al., NIM A540 (2005) 140



Xe ion mobility: 0.57 10^{-6} cm^2/V μs
sampling frequency 10 Mhz
(one every 100 ns)

signals of consecutive time samples due to ion tail strongly correlated

diffusion negligible: D_l = 250 μm/√cm

tail cancellation schemes important
standard: single exponential
2 exp. costs too much S, less resolution

new: TM-TC method M. Ivanov

TRD Chambers
the great challenge: gain uniformity for very thin

require: gain uniformity over chamber of ±15 %
padplane should not deform more than 200 μm

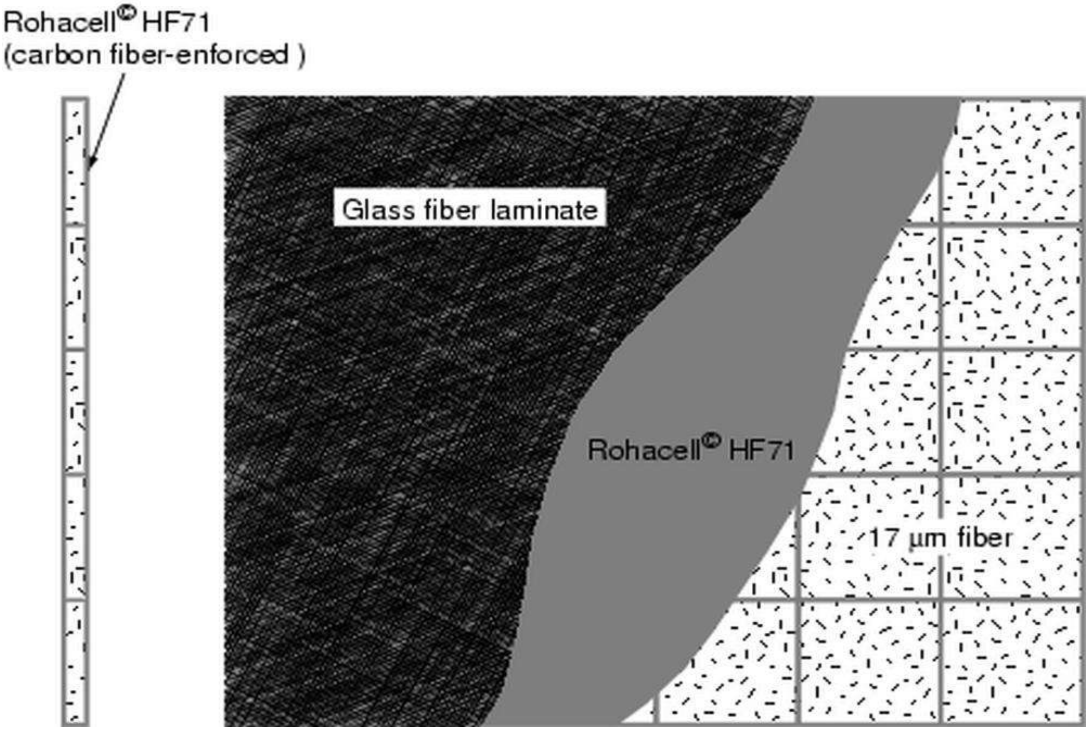
gas system operates at some overpressure (about 0.3 mbar)
for vertical chambers pressure difference due to Xe hydrostatic pressure between top and bottom 0.3 mbar

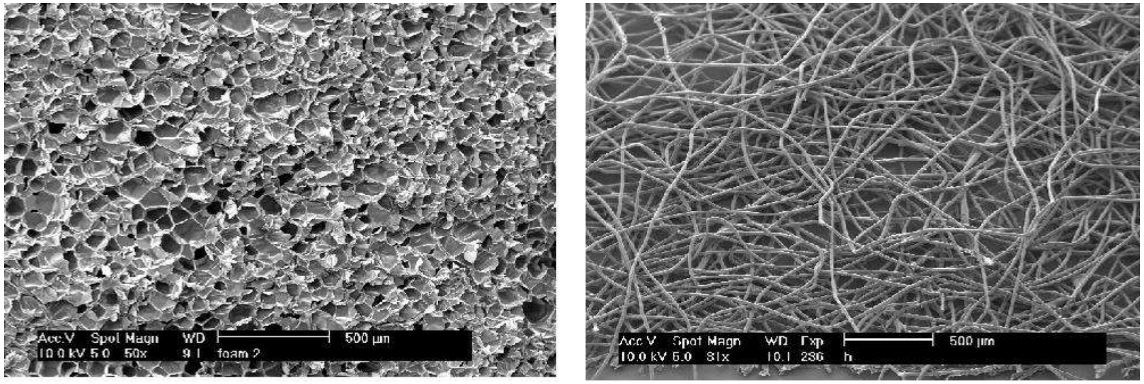
compromise with desired minimal radiation lenth of detector

the Radiator

- CF-laminated box-casing structure of:
- Rohacell HF71 covers (8 mm each)
  laminated with 100 µm CF sheet
- Rohacell grid structure
- filled with 7 layers of polypropylene fiber sheets (5 mm) from Freudenberg LRP375BK
- total thickness 4.8 cm
- drift cathode laminated on CF:
  25 µm aluminized mylar

deflection in center:
400 µm per mbar (typ. 17 kg equ.)
114 µm per kg wire tension
i.e. 400 µm for nominal tension

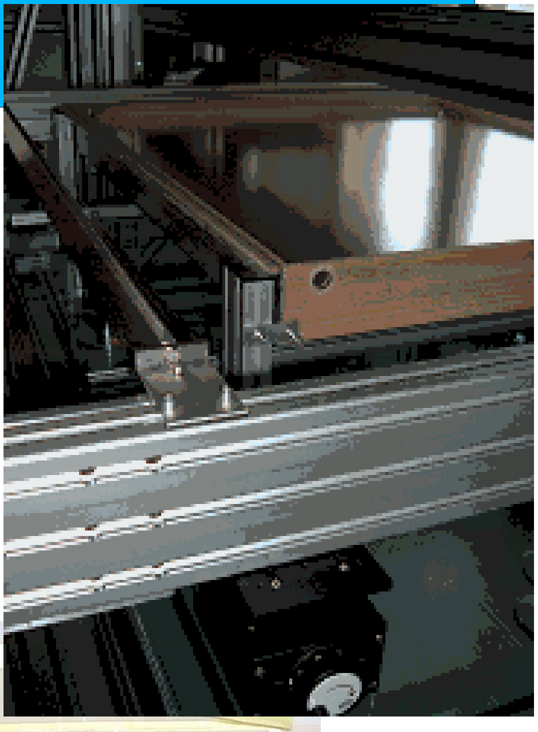




Soldering of cables to cathode padplanes and testing of connectivity U. Frankfurt

connectivity and shorts are tested via capacitance measurement (dominated by cathode pad)

Chamber construction

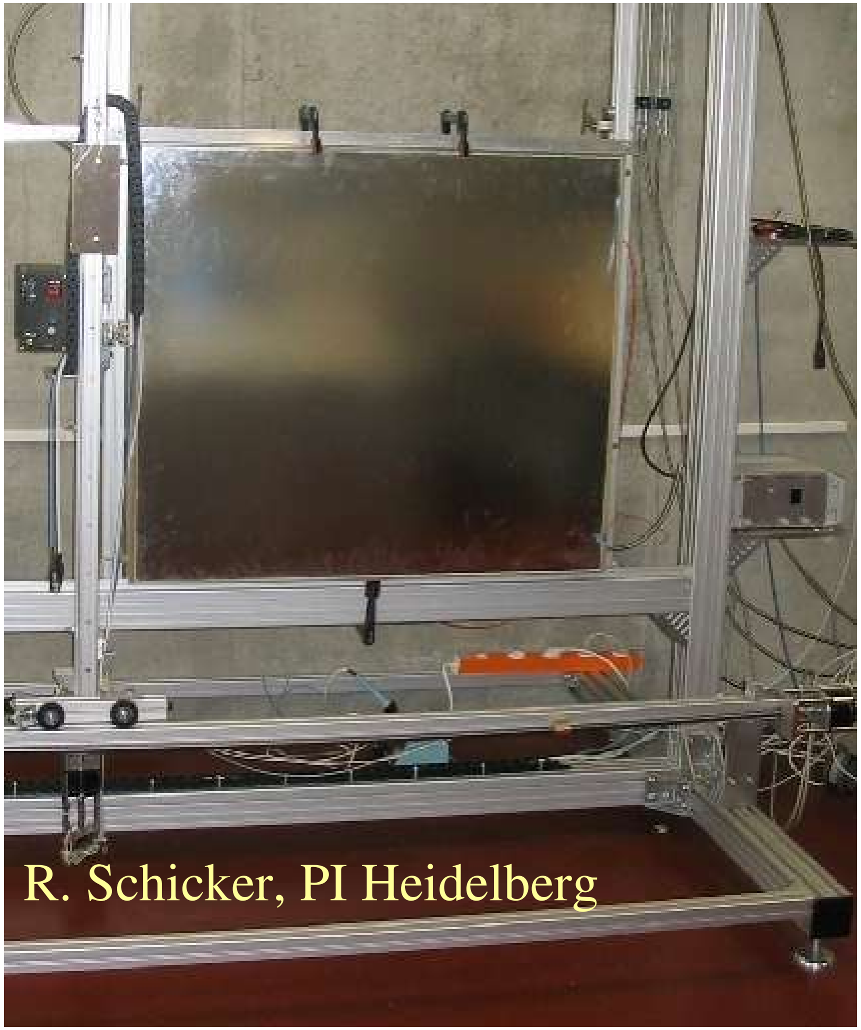


PI Heidelberg (development of procedure)
JINR Dubna
NIPNE Bucharest
GSI Darmstadt
IKF Frankfurt

typically 1 chamber each per week on average

25. 5. 2004

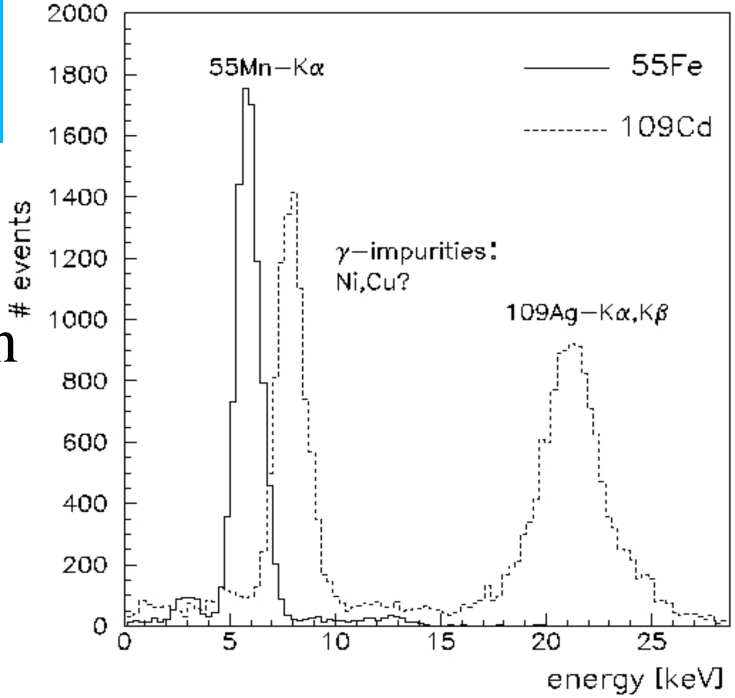
chamber tests in the lab: leak test and scan with source for gain uniformity

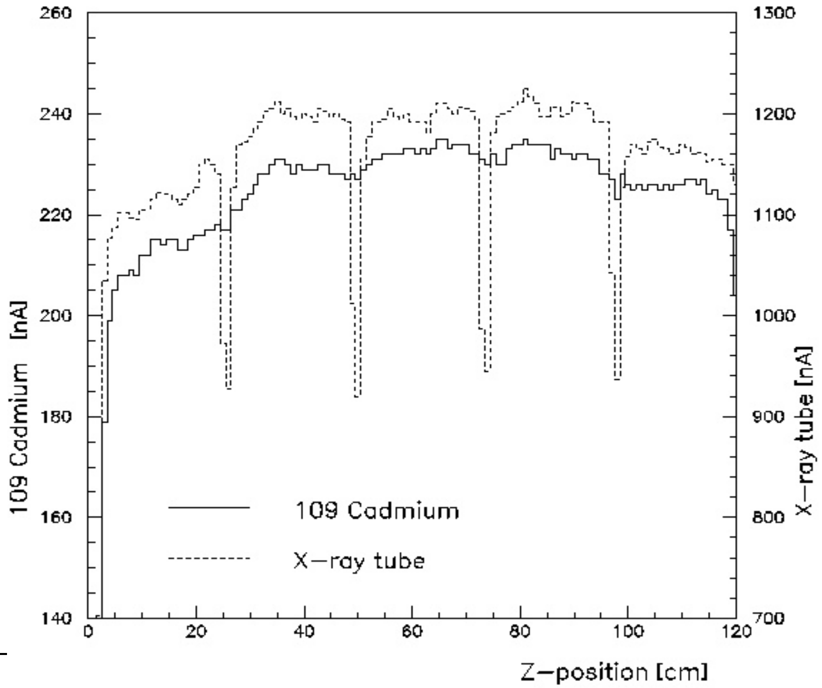


R. Schicker, PI Heidelberg

Fe source: too much absorption in radiator

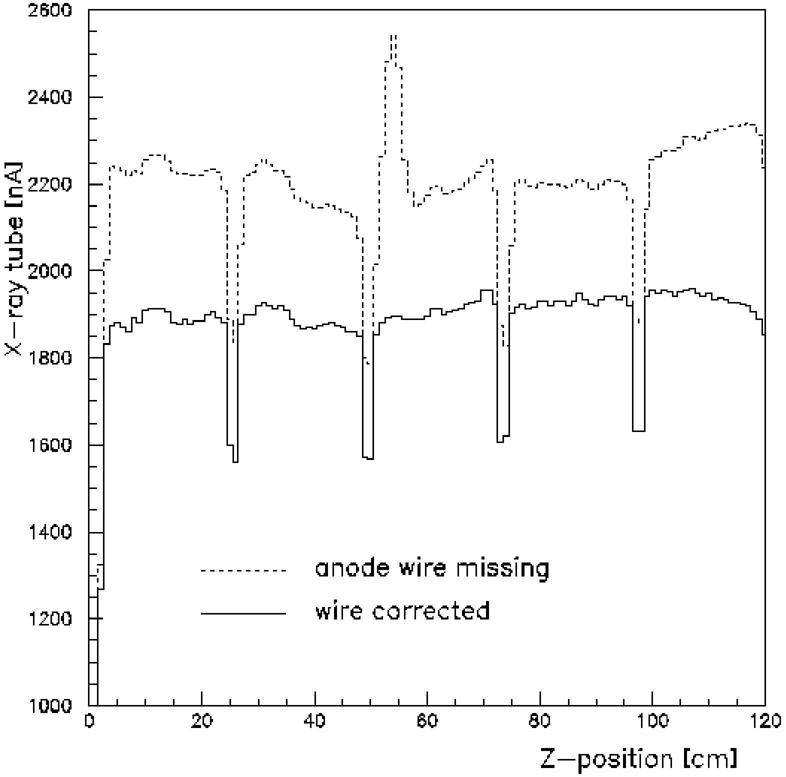
Cd source: optimal X-ray energy





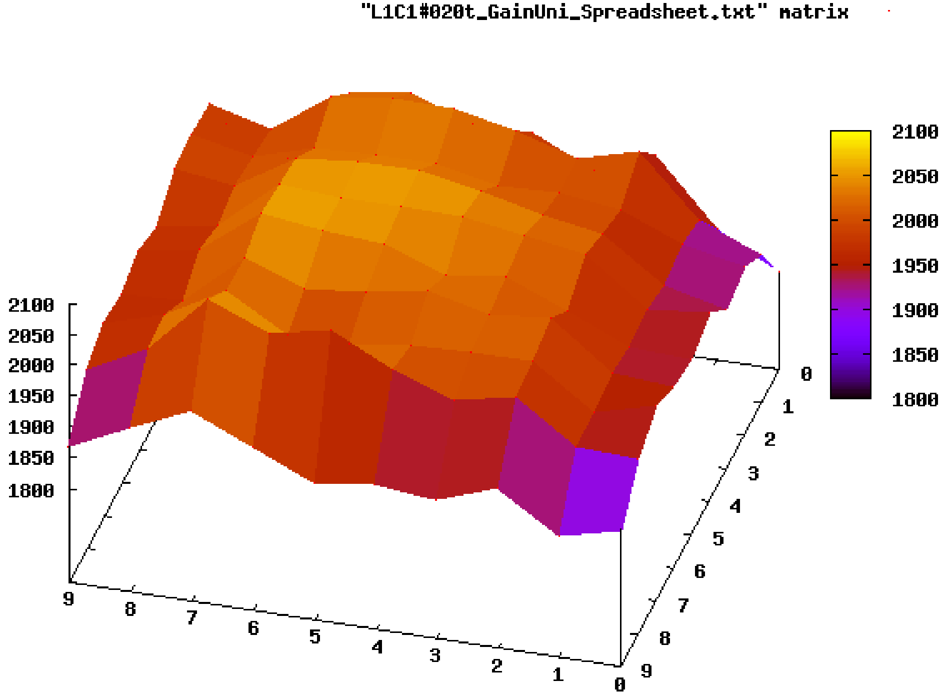
Chamber testing in laboratory: Quality assurance

leak rate < 0.2 mbar l /hour



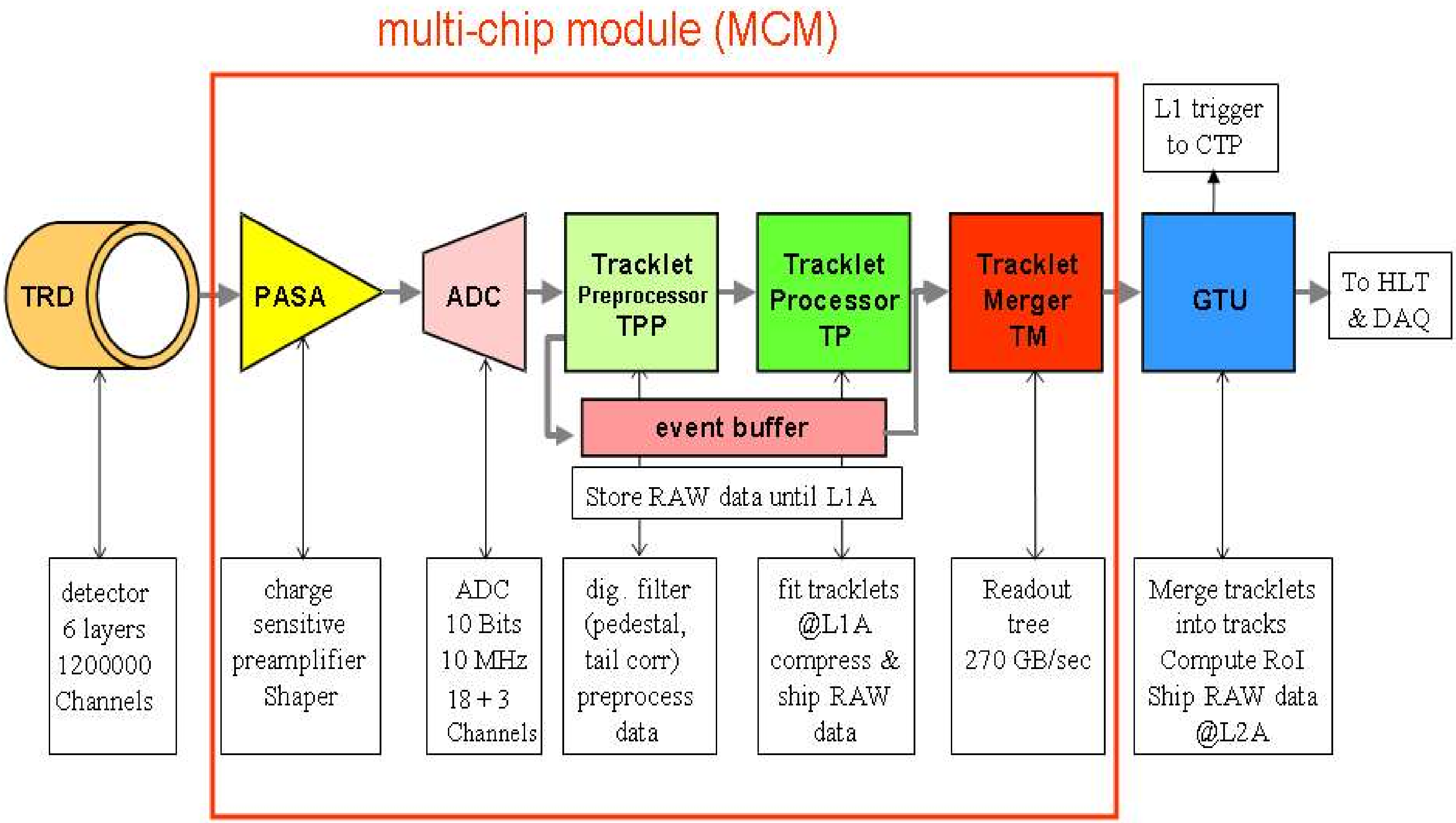
before glueing chambers: test reveals possible small problems such as not electrically connected anode wire

gain uniformity over chamber within desired limits of ±15 %



R. Schicker, S. Freuen, PI Heidelberg

The TRD front-end electronics



multi-chip module (MCM)

TRD → PASA → ADC → Tracklet Preprocessor TPP → Tracklet Processor TP → Tracklet Merger TM → GTU → To HLT & DAQ

GTU → L1 trigger to CTP

event buffer

Store RAW data until L1A

- TRD: detector 6 layers 1200000 Channels
- PASA: charge sensitive preamplifier Shaper
- ADC: ADC 10 Bits 10 MHz 18 + 3 Channels
- Tracklet Preprocessor TPP: dig. filter (pedestal, tail corr) preprocess data
- Tracklet Processor TP: fit tracklets @L1A compress & ship RAW data
- Tracklet Merger TM: Readout tree 270 GB/sec
- GTU: Merge tracklets into tracks Compute RoI Ship RAW data @L2A

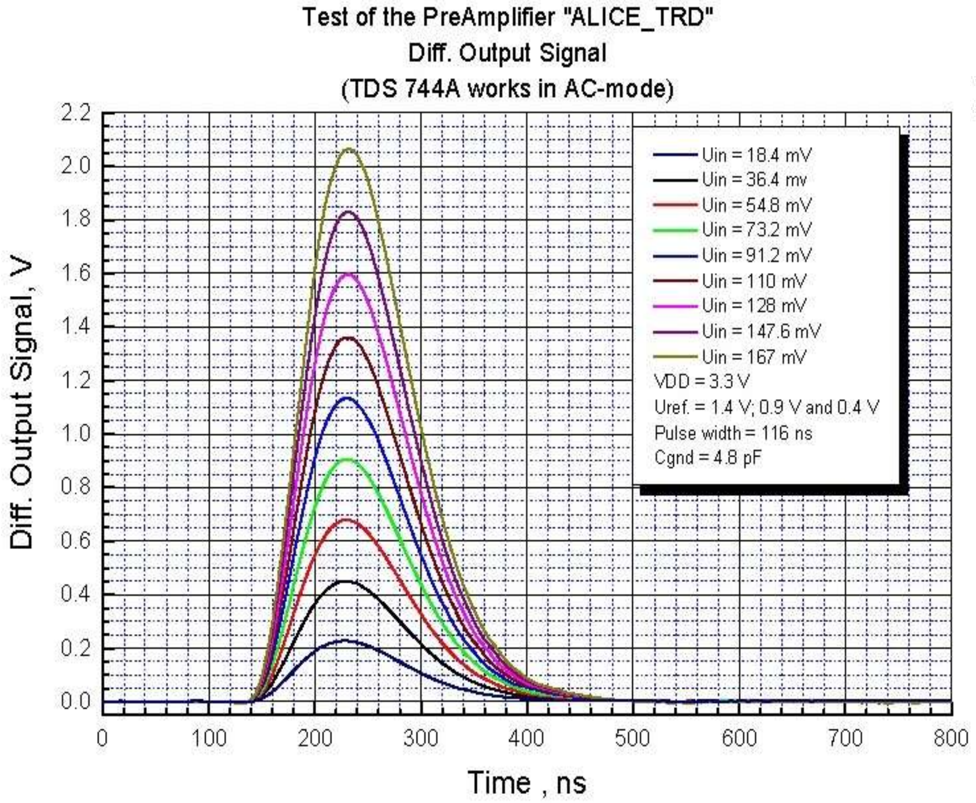
2 ASICs of 18 channels per MCM : PASA - AMS 0.35 µm
TRAP – 0.18 µm UMC containing ADC & digital processing
4 custom cpu's in 1 MCM for tracklet processing
16 + 1 MCM per read-out board

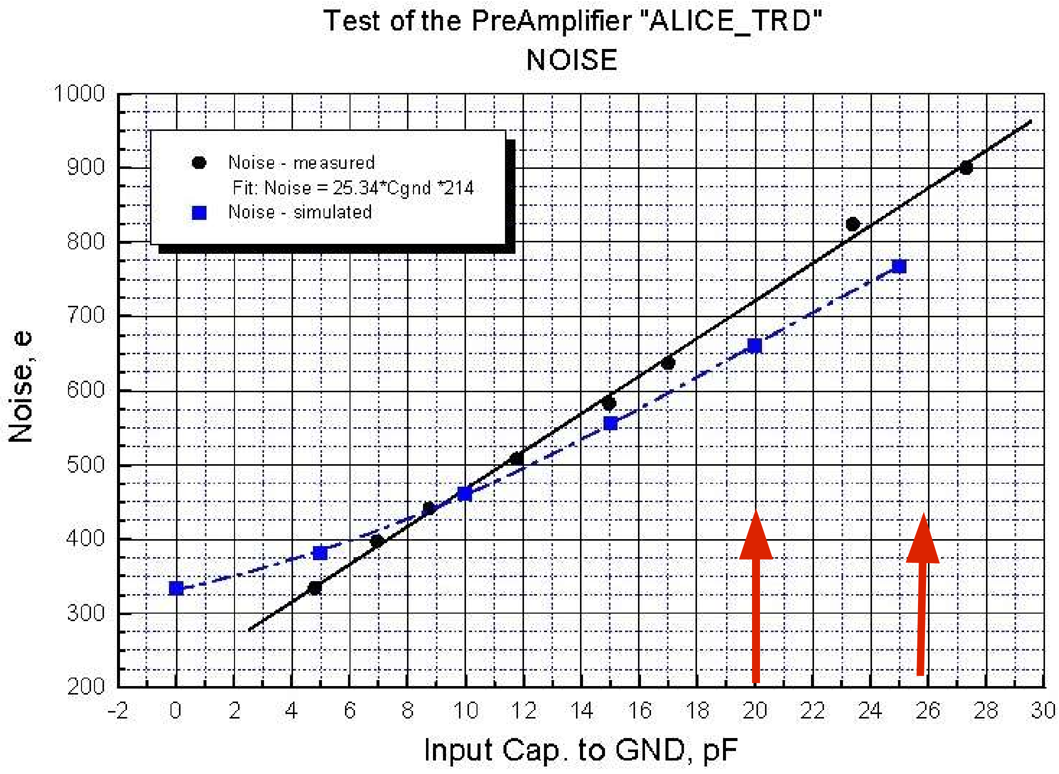
→ see talk by Venelin Angelov

Charge sensitive preamplifier/shaper

0.35 µm AMS CMOS process
18 channels per chip
6.1 mV/fC, 12 mW

typical pulse width 115 ns FWHM





operating range for TRD cathode pads

H.K. Soltveit, PI Heidelberg

ADC and Digital Chip

both functionalities in one chip:

0.18 µm UMC process

ADC:

10 bit, 10 Mhz, 12 mW/channel

18+3 channels per chip

tested performance: 9.5 ENOBs

ADC: D. Muthers, K. Tielert - TU Kaiserslautern

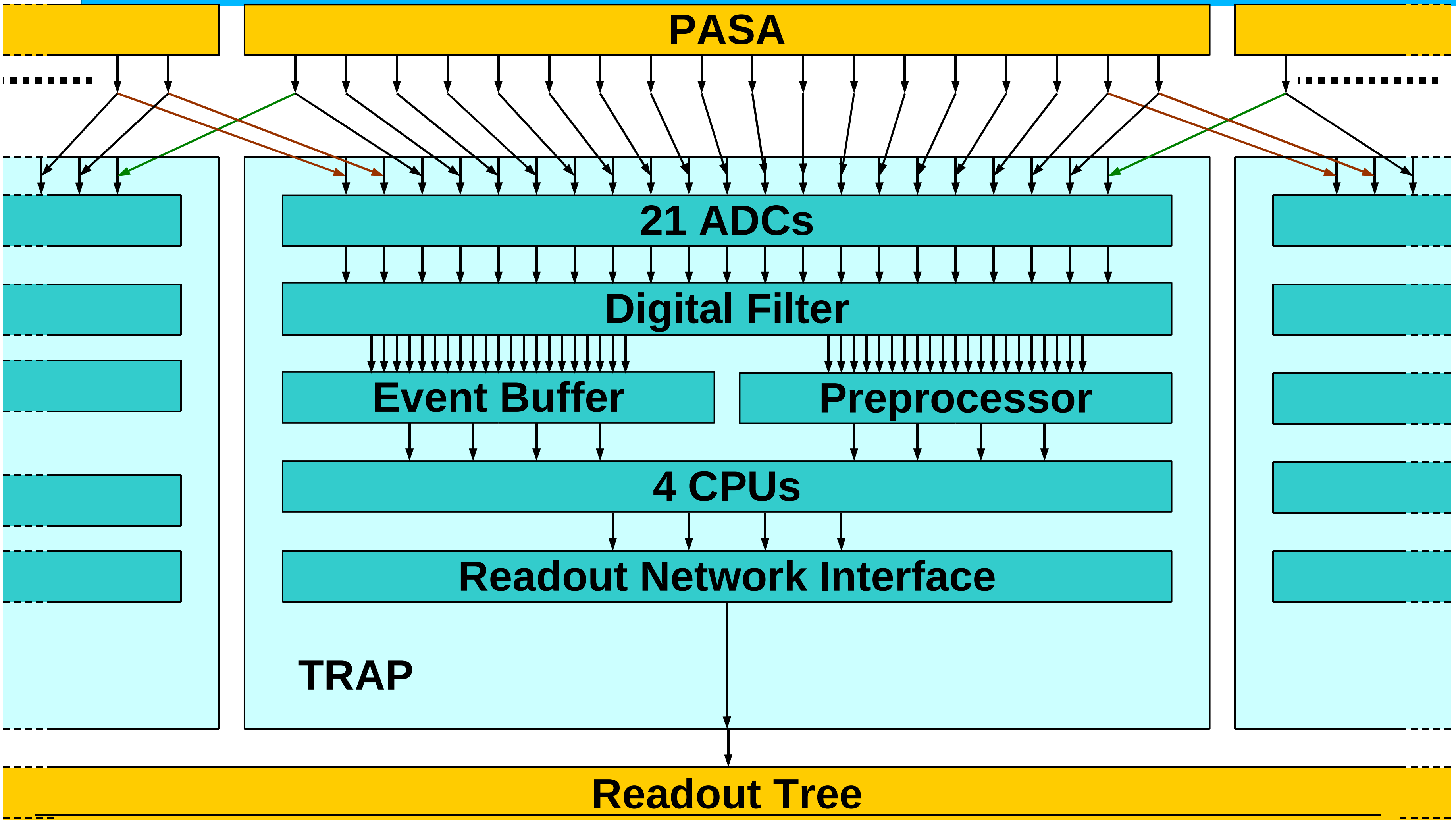
digital part of the chip (TRAP) – functionality:

tail cancellation, cross talk filter, zero suppression, gain equalization, storage of signal

reconstruction of up to 4 tracklets (fit of slope and intercept) (see below)

TRAP: , V. Angelov, F. Lesser, V. Lindenstruth, R. Schneider - KIP Heidelberg

Tracklet Processing Chip (TRAP)



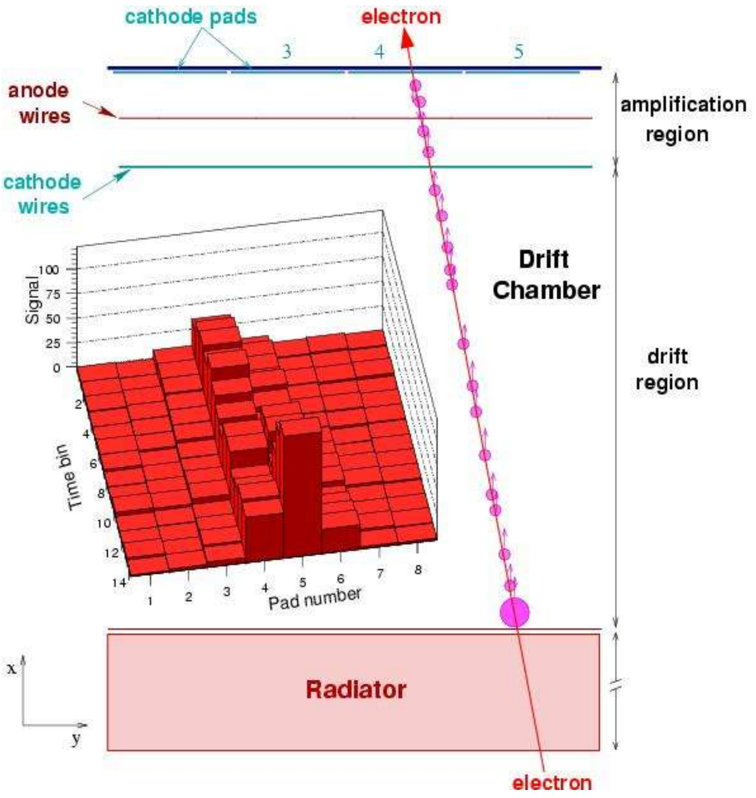
Track segment processing on chamber: in 4 cpu's in parallel, latency < 6 µs
max 4 tracklets per 18 channels

Fitting of Track Segments

each track segment (tracklet) 15-20 space points,
processors fit slope (momentum),
max. detectable slope < 2 pad rows

- During Drift Time (Preprocessor):
  - charge cluster detection
  - position determination via charge sharing for each time bin (15-20)
  - assembly of fit input

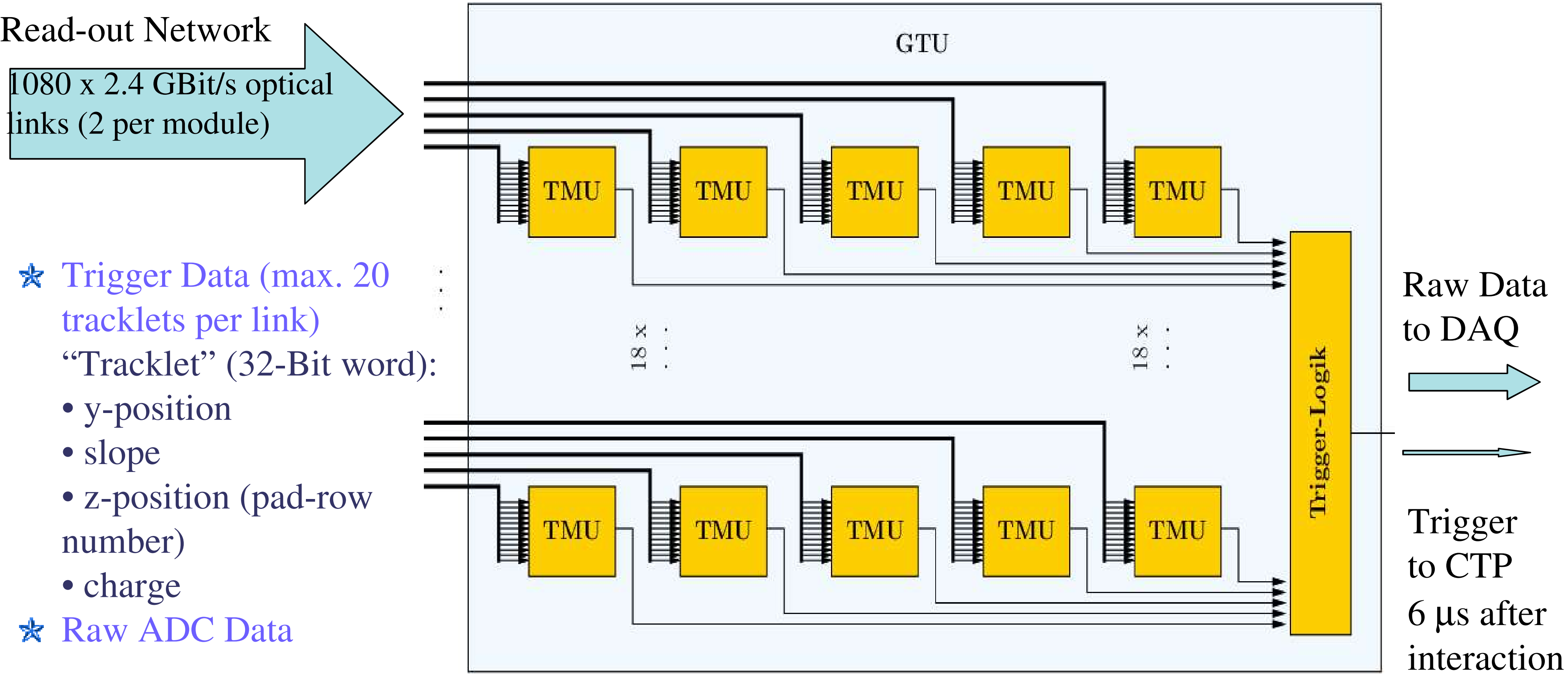
- After Drift Time (CPUs):
  - straight line fit of each tracklet candidate
  - merging of fit parameters of adjacent channels
  - fit parameter transmission



$$slope = \frac{N_i \cdot \sum_t X_i(t) \cdot Y_i(t) - \sum_t X_i(t) \cdot \sum_t Y_i(t)}{N_i \cdot \sum_t X_i^2(t) - \sum_t X_i(t) \text{¿} \sum_t X_i(t)}$$

$$offset = \frac{\sum_t Y_i(t) - slope \cdot \sum_t X_i(t)}{N_i}$$

Global Tracking Unit (GTU): Architecture



Read-out Network

1080 x 2.4 GBit/s optical links (2 per module)

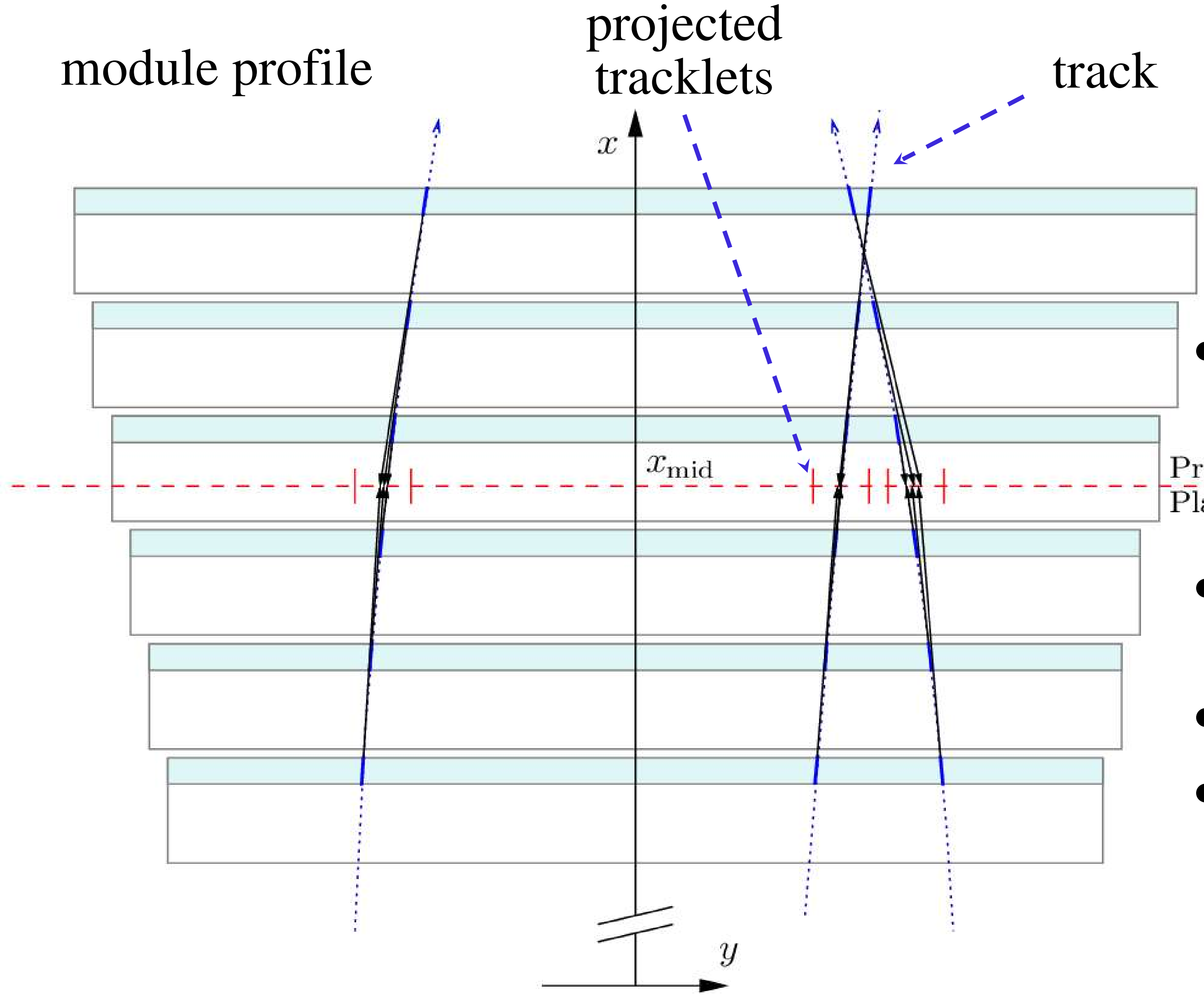
Raw Data to DAQ

Trigger to CTP
6 µs after interaction

- Trigger Data (max. 20 tracklets per link)
  “Tracklet” (32-Bit word):
  - y-position
  - slope
  - z-position (pad-row number)
  - charge
- Raw ADC Data

- each TMU receives data from 1 Stack (via 12 links)
- Parallel processing: 90 independent "Track Matching Units" (TMUs)
  - 1 (large) FPGA per TMU

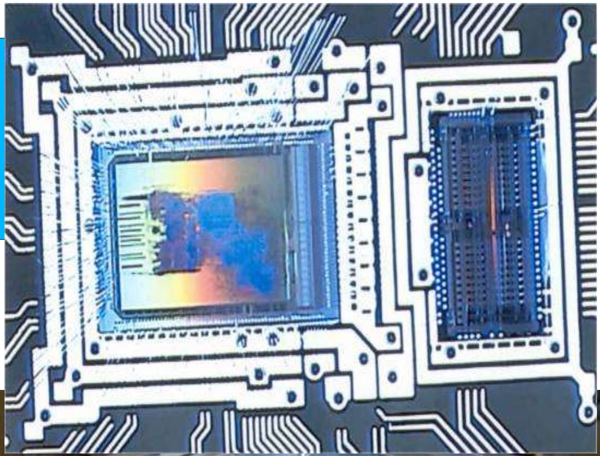
Track Assembly in Global Tracking Unit

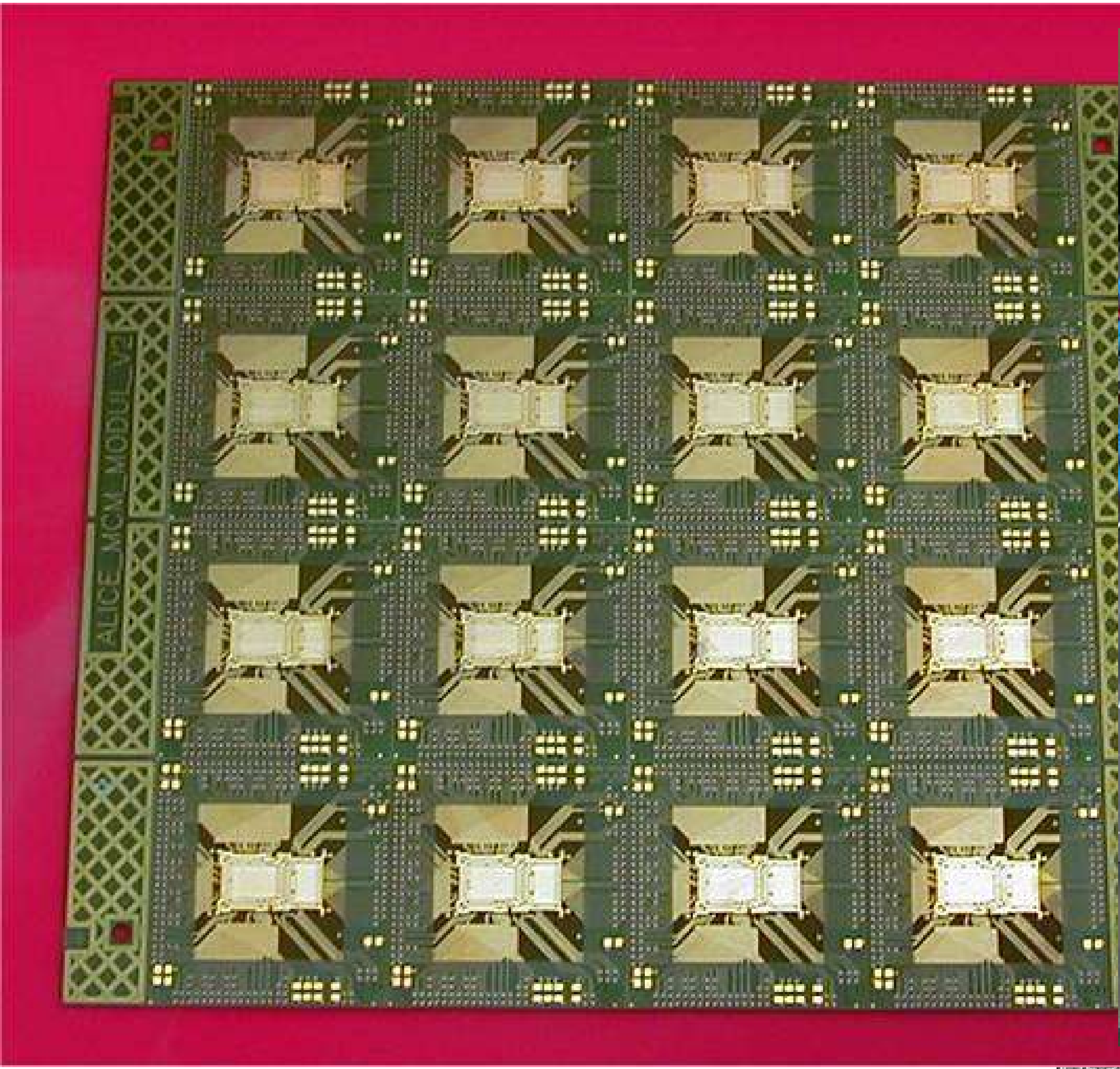


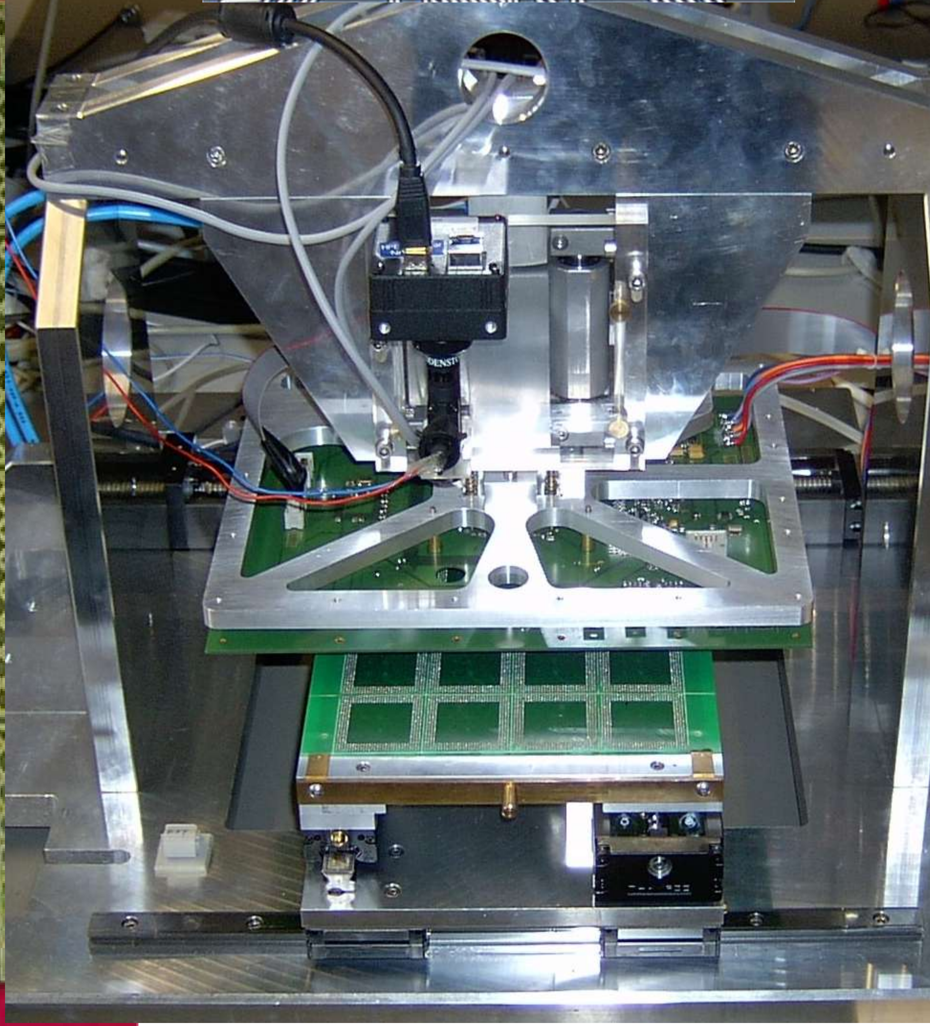
- Search for tracklets belonging together (3-dimensional matching task)
- Projection of tracklets to virtual central plane
- Sliding window algorithm
- A track is found, if ≥ 4 tracklets from different layers inside same window

the multi-chip modules

MCM bonding at FZ Karlsruhe



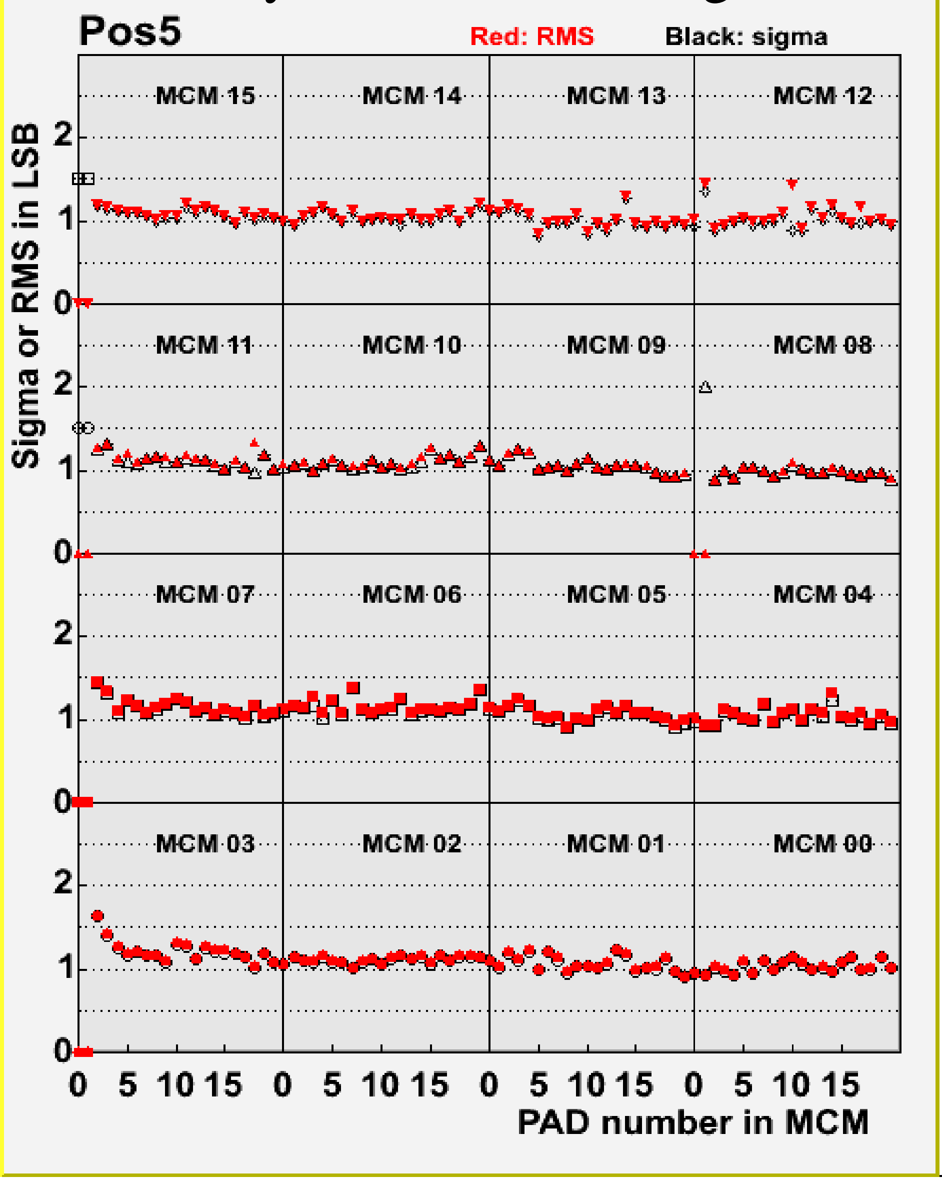




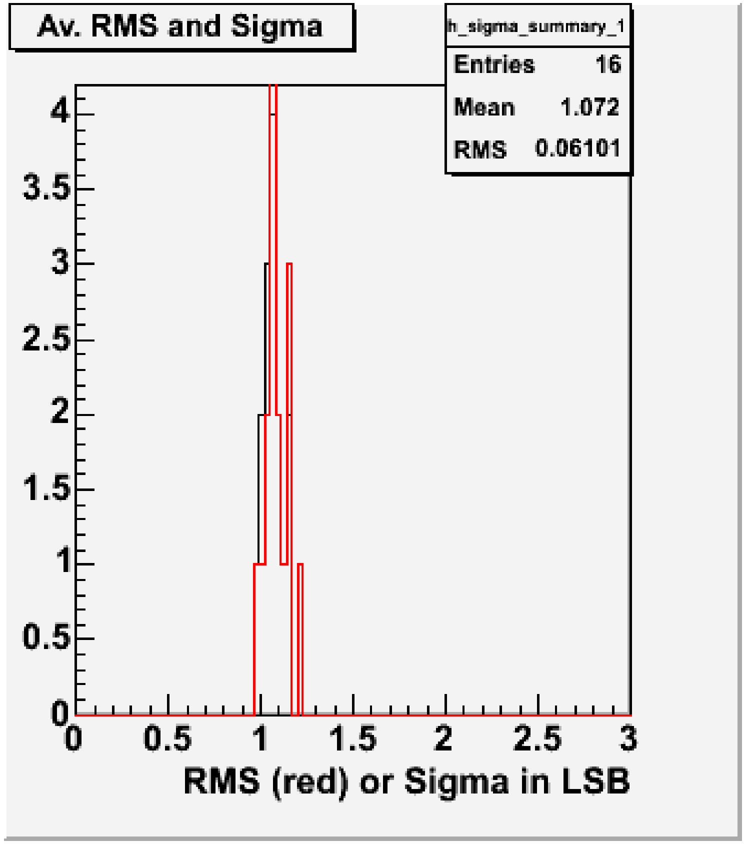
View of the on-chamber electronics

Noise Performance of Read-out Boards integrated on Chamber

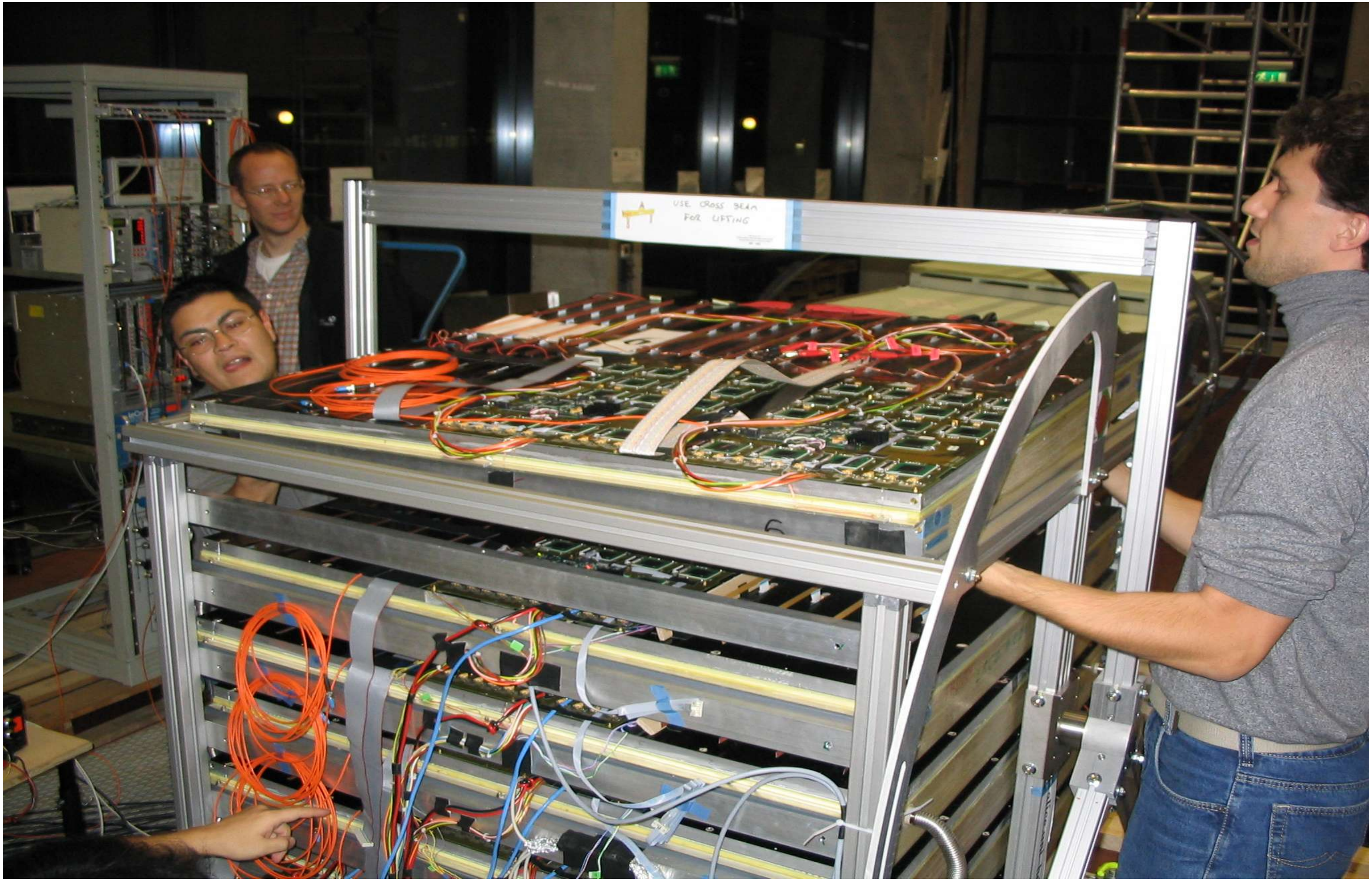
K. Oyama PI Heidelberg



8/2005 - first fully equipped chamber: average noise for 18 MCMs 1.1 channels = 1400 electrons



The first stack of 6 detector modules

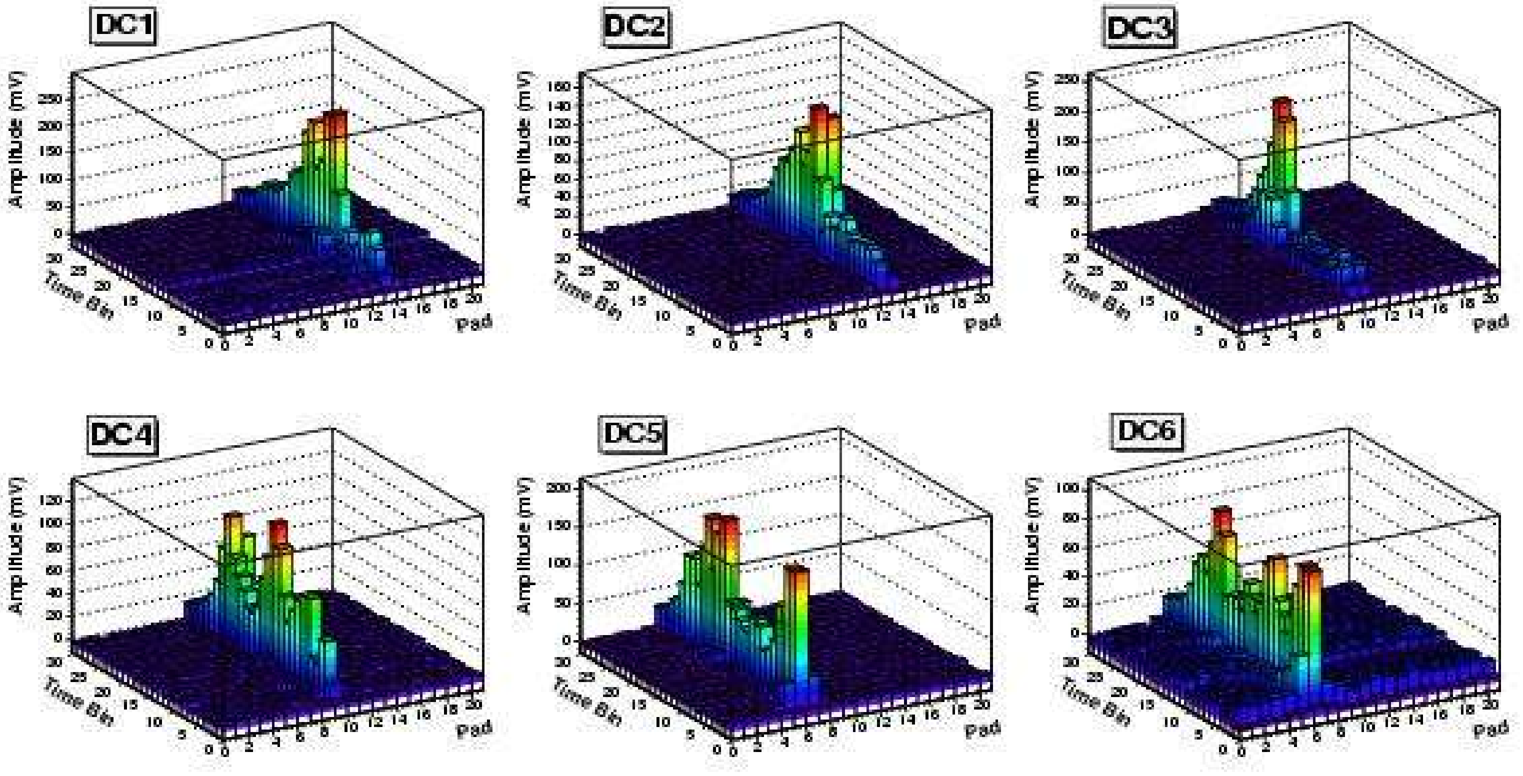


Test beam measurements

- since 1997 at GSI SIS: pions/electrons 0.7 – 1.4 GeV/c
2001, 2002, 2004 CERN PS: pions/electrons 1 – 10 GeV/c

- measurements with small prototype chambers (20 x 35 cm^2)
and full size chambers (2002) and stack of 6 of these (2004)
increasing amount of final electronics, software, DCS, DAQ

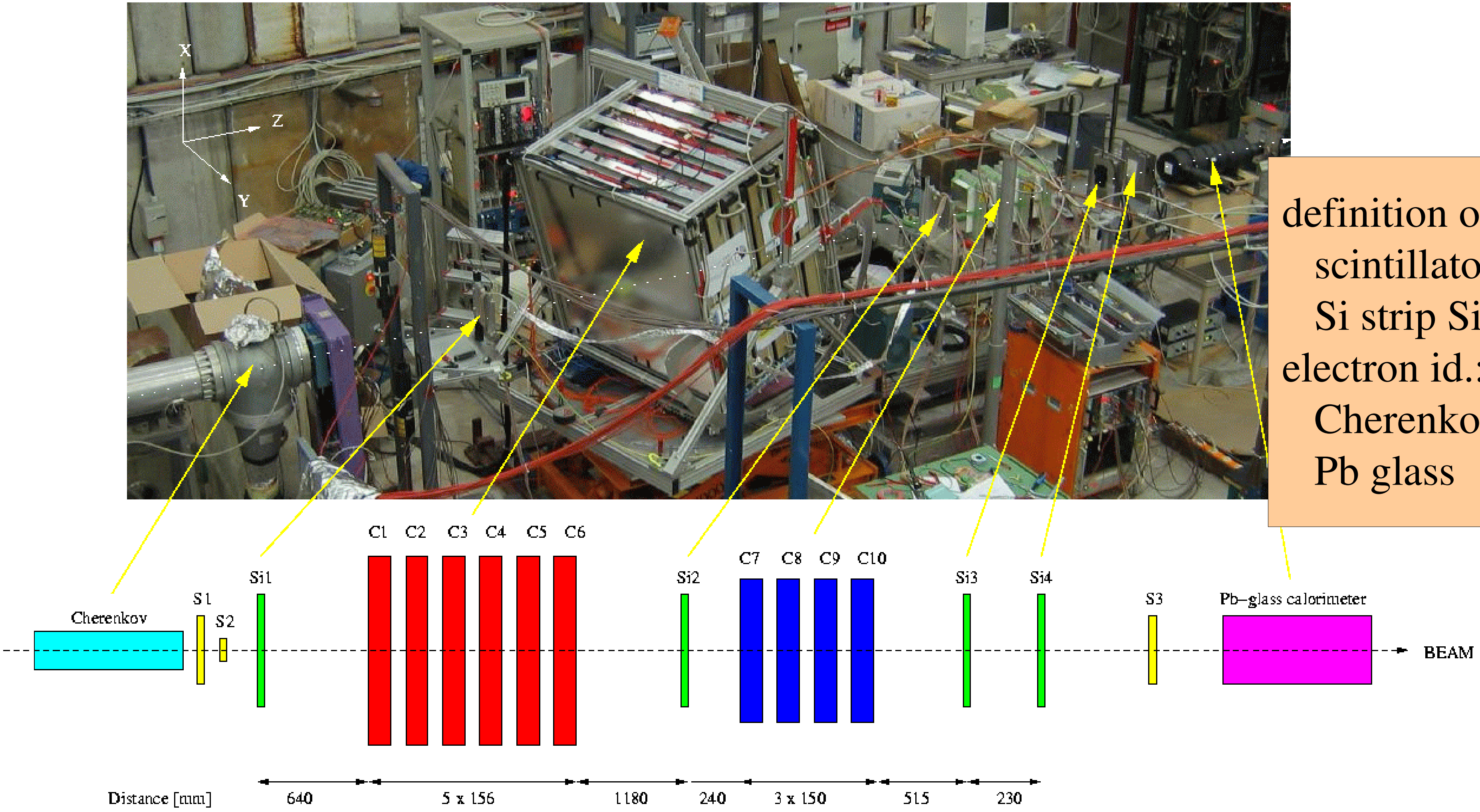
example:
one track traversing
all 6 layers



Test beam set-up 2004: first full-size stack plus small test chambers plus electron identification

definition of beam:
- scintillators S1 - 3
- Si strip Si1 - 4

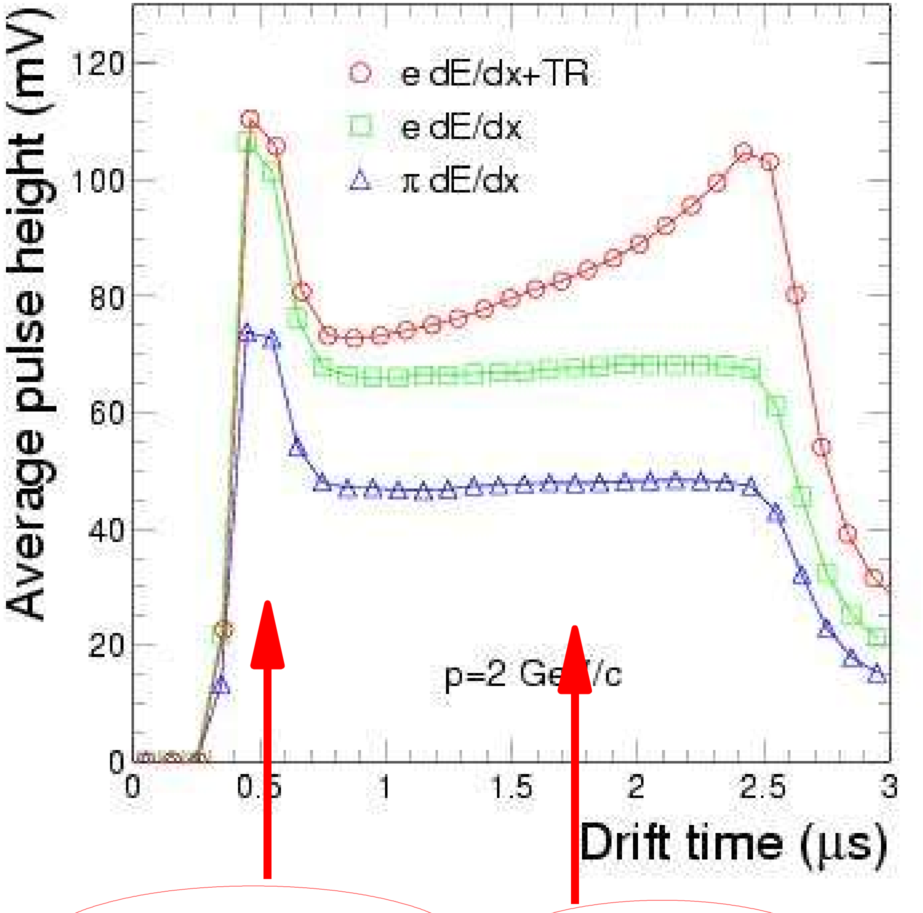
electron id.:
- Cherenkov and Pb glass



Test beam results:
pulse height vs. time characteristics for electrons and pions

- 2 GeV/c incident momentum
  - pions
  - electrons, only dE/dx
  - electrons, dE/dx+TR

A. Andronic et al., NIM A522 (2004) 40

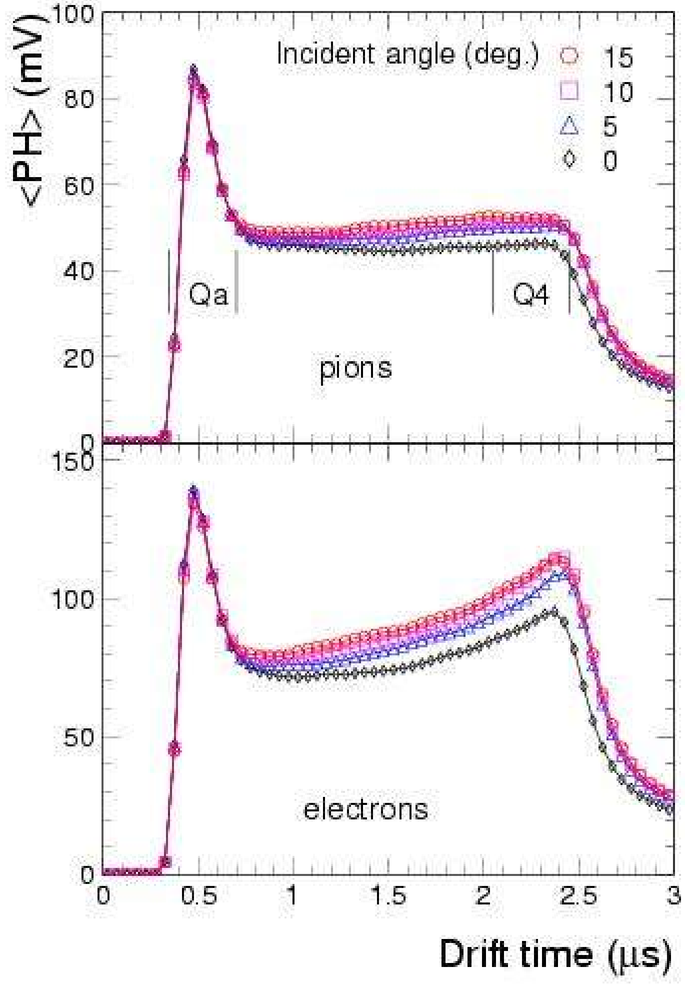


ampl. region

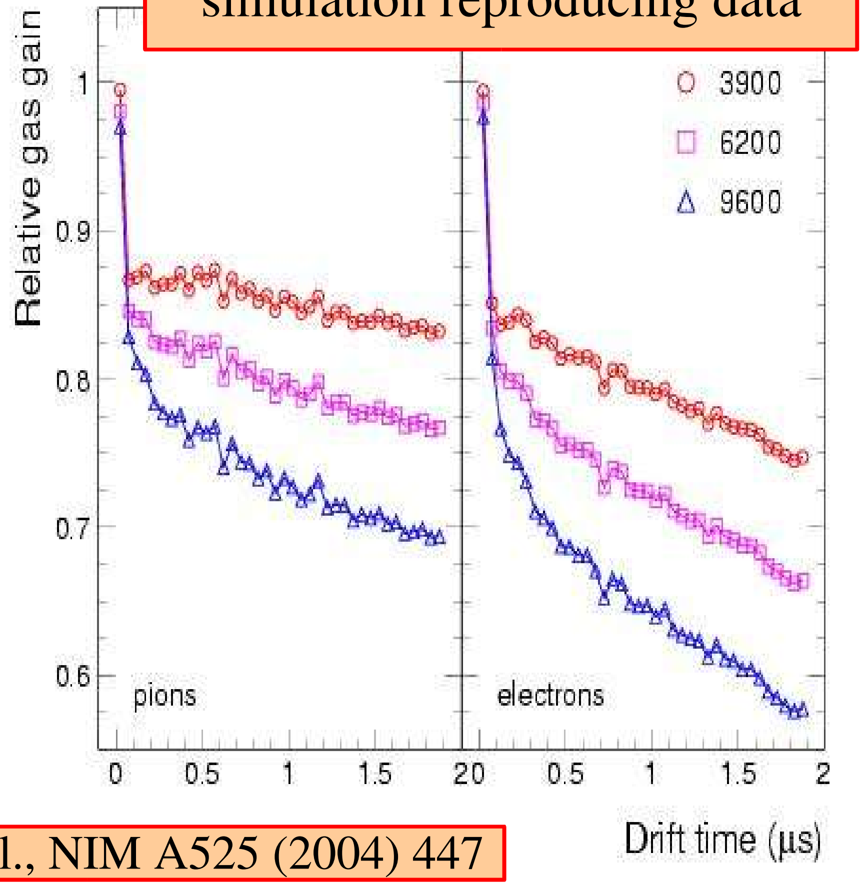
drift region

Test beam results: space charge effects on pulse height vs time characteristics for electrons and pions

at incidence perpendicular to wire: local space charge large enough to lead to screening of electric field and thereby gain reduction for electron arriving at later times - quantitatively understood by simulations 20 % effect for largest drift times and nominal gain of 4000 reduces pion rejection capability for such angles



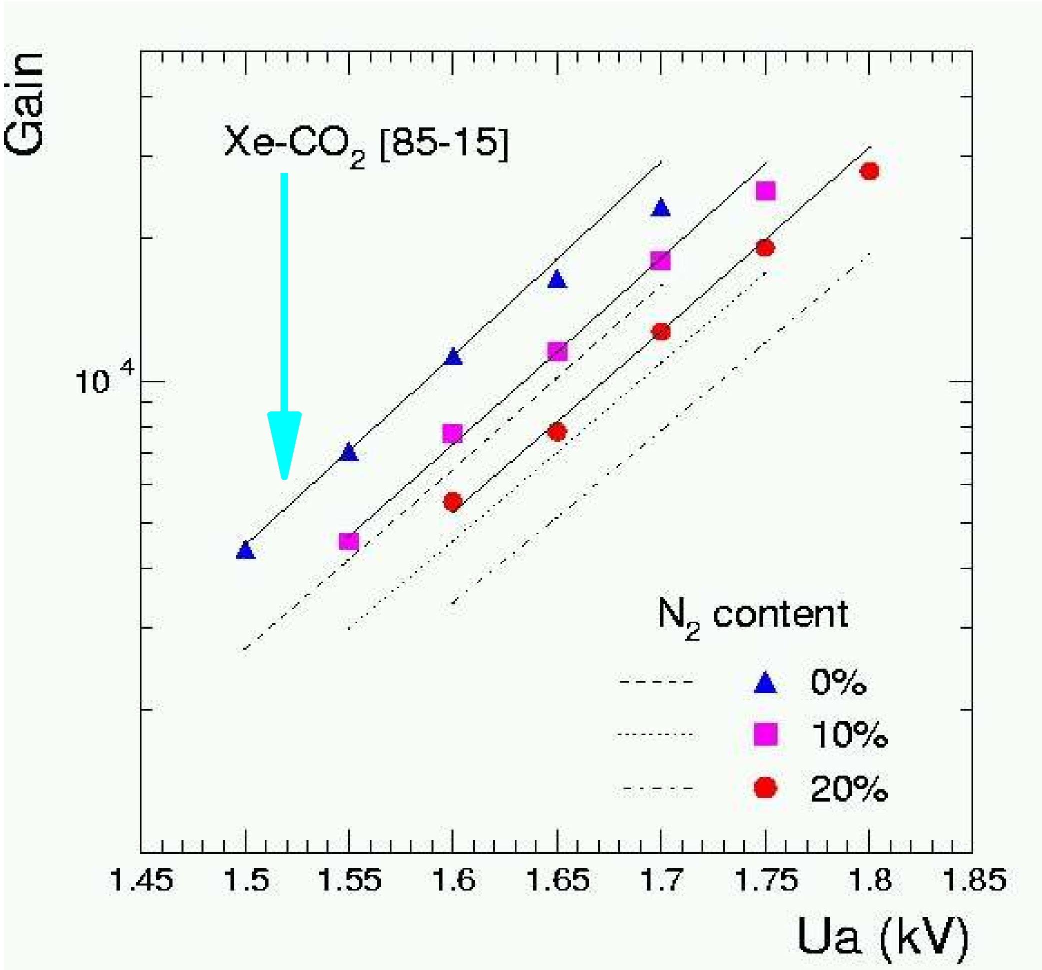
simulation reproducing data

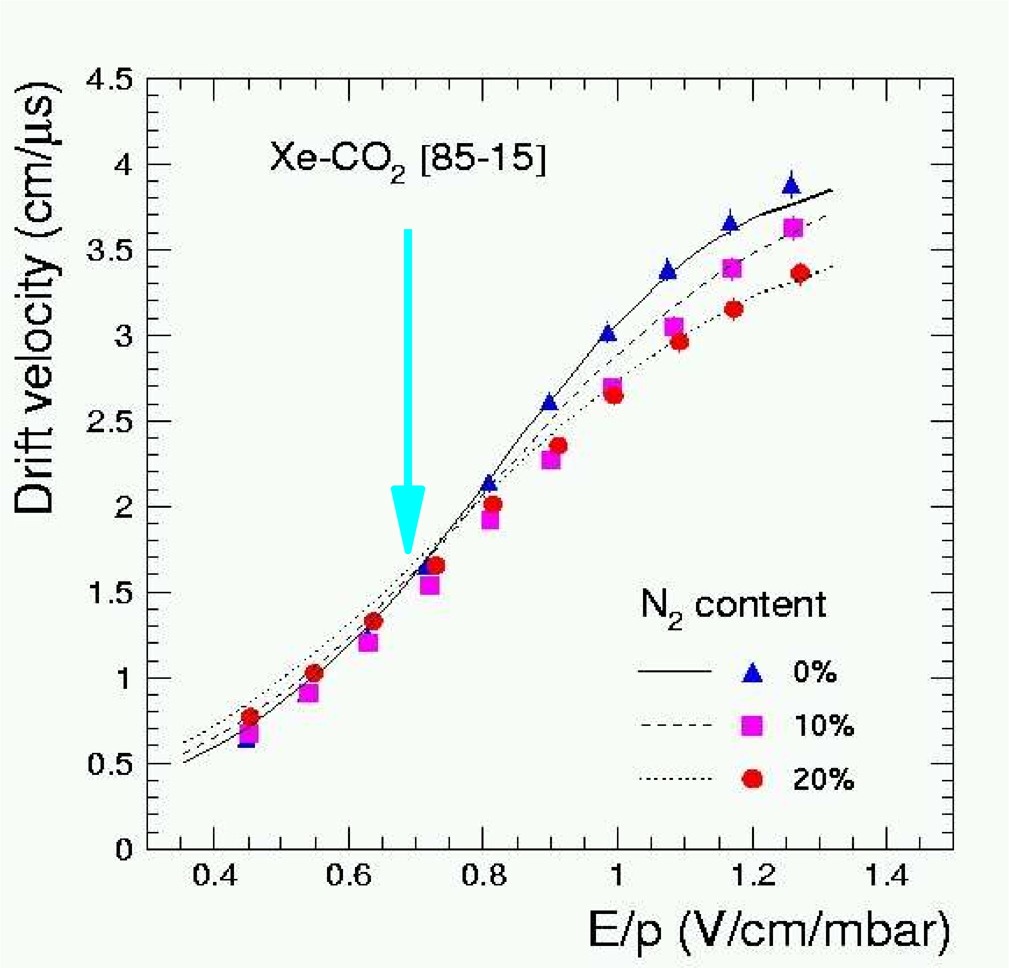


A Andronic at al., NIM A525 (2004) 447

measured gas properties

A. Andronic et al., NIM A 523 (2004) 302



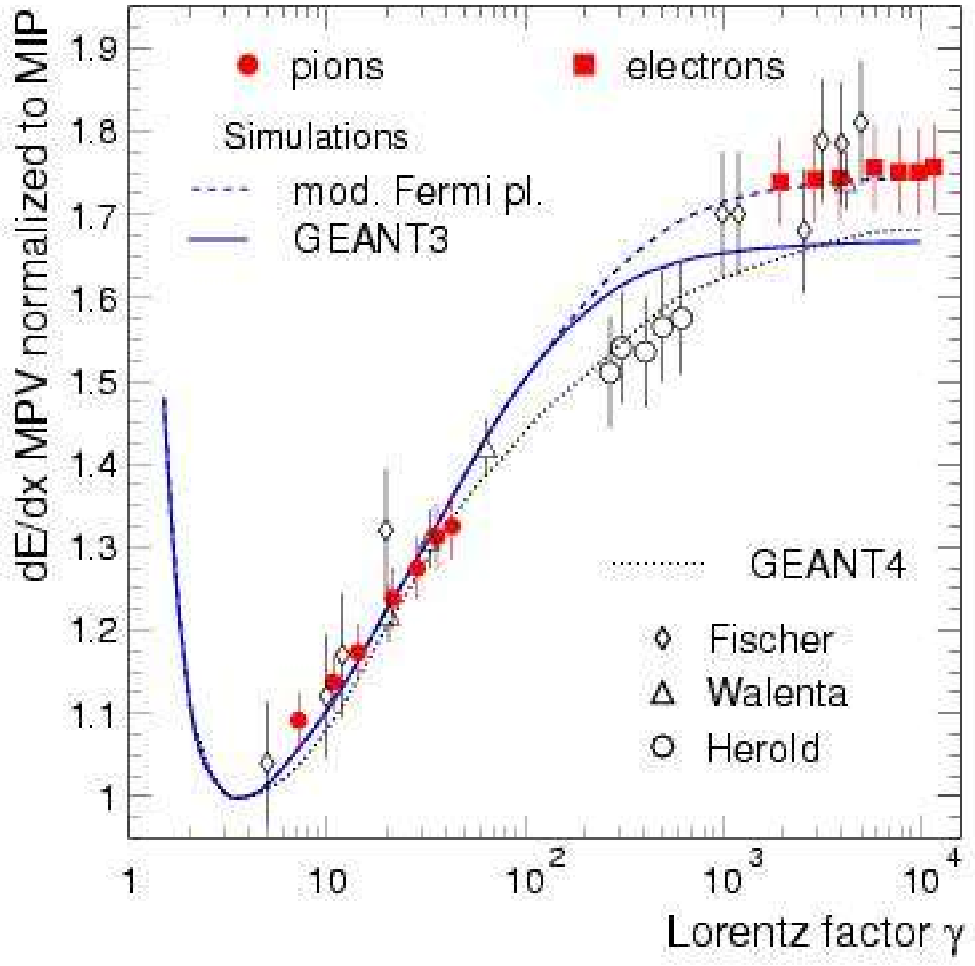


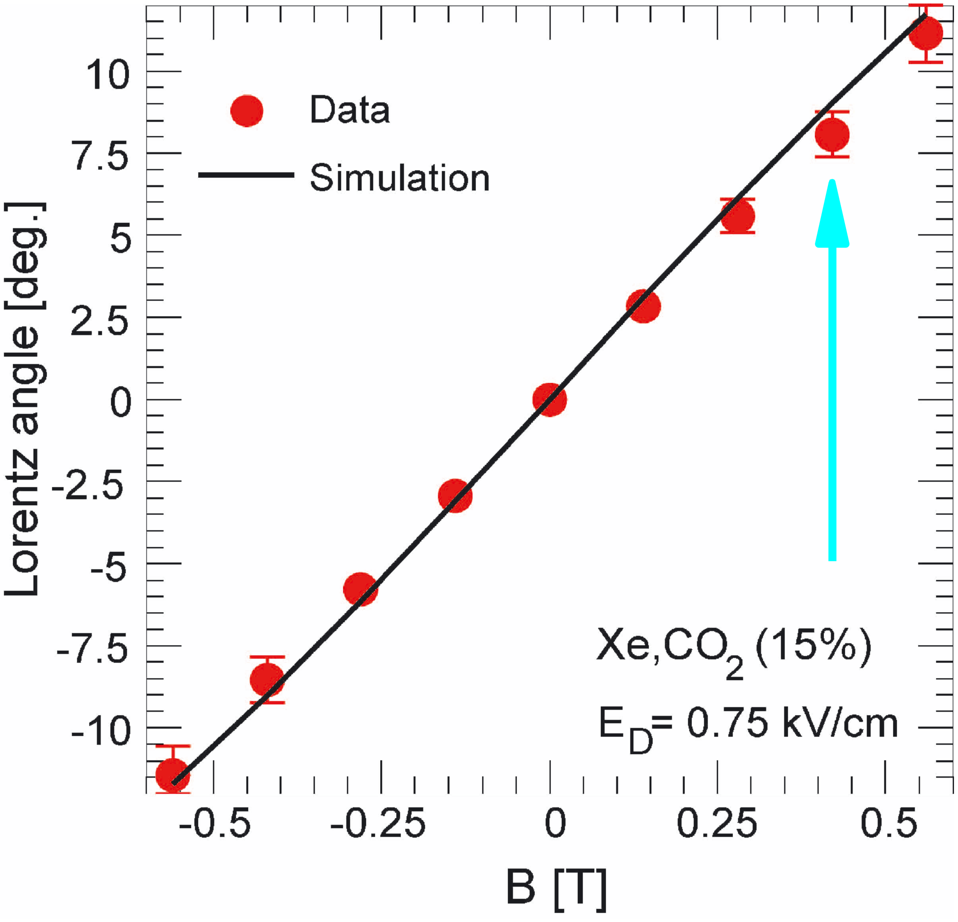
some nitrogen accumulating over the run not really harmful

Energy loss and Lorentz angle in Xe/CO2 (15 %)

A. Andronic et al., NIM A519 (2004) 508

C.Adler et al., NIM A540 (2005) 140

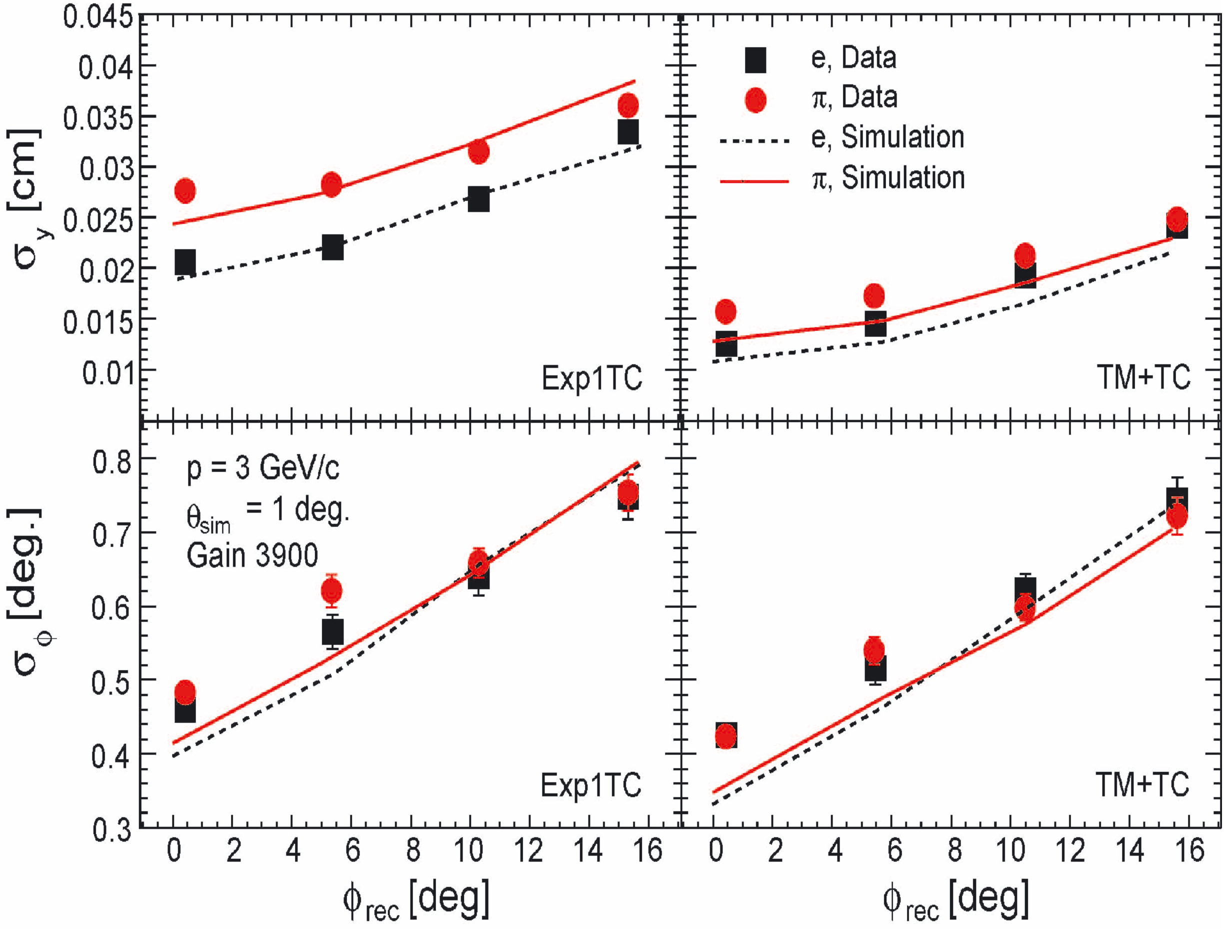


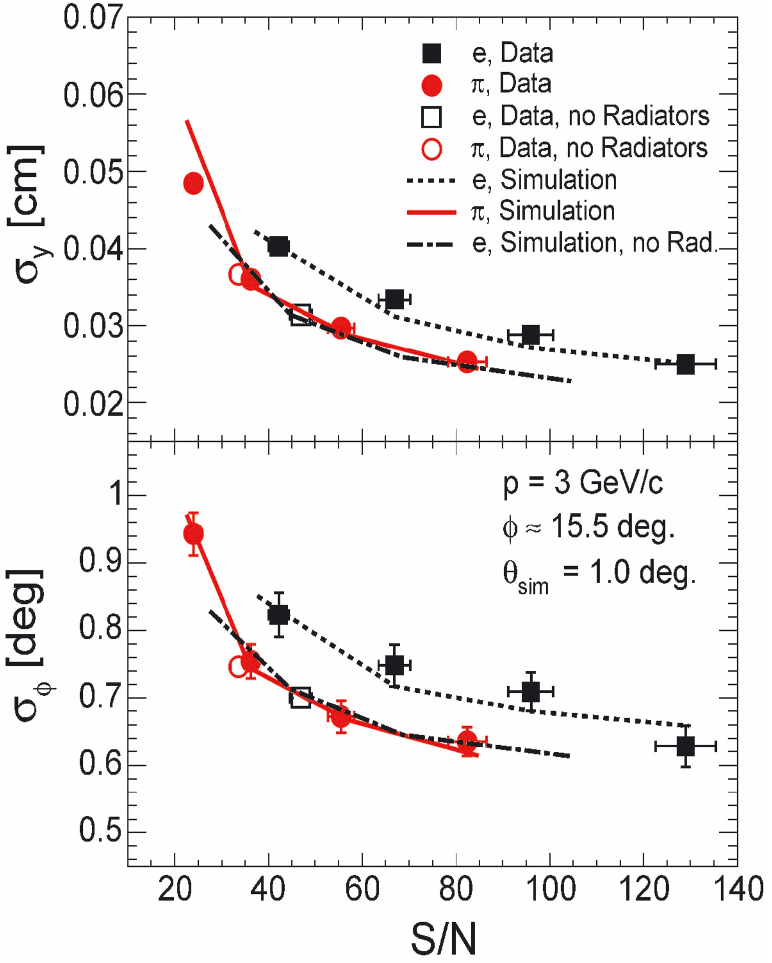


space point and angular resolution

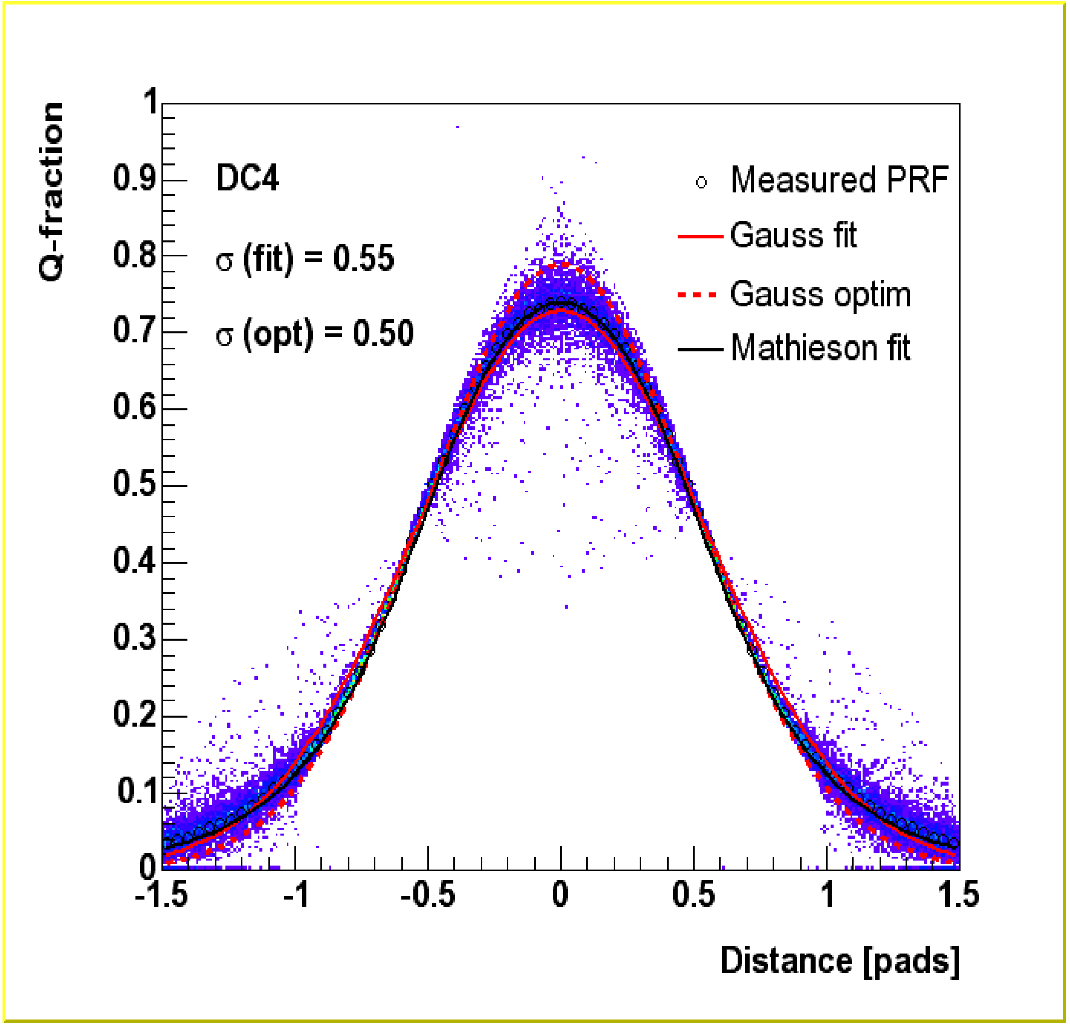
C. Adler et al., NIM A540 (2005) 140

crucial to implement in simulation fine geometry of charge deposition for X-ray: photoel. eff., fluor. photons, Auger elec.

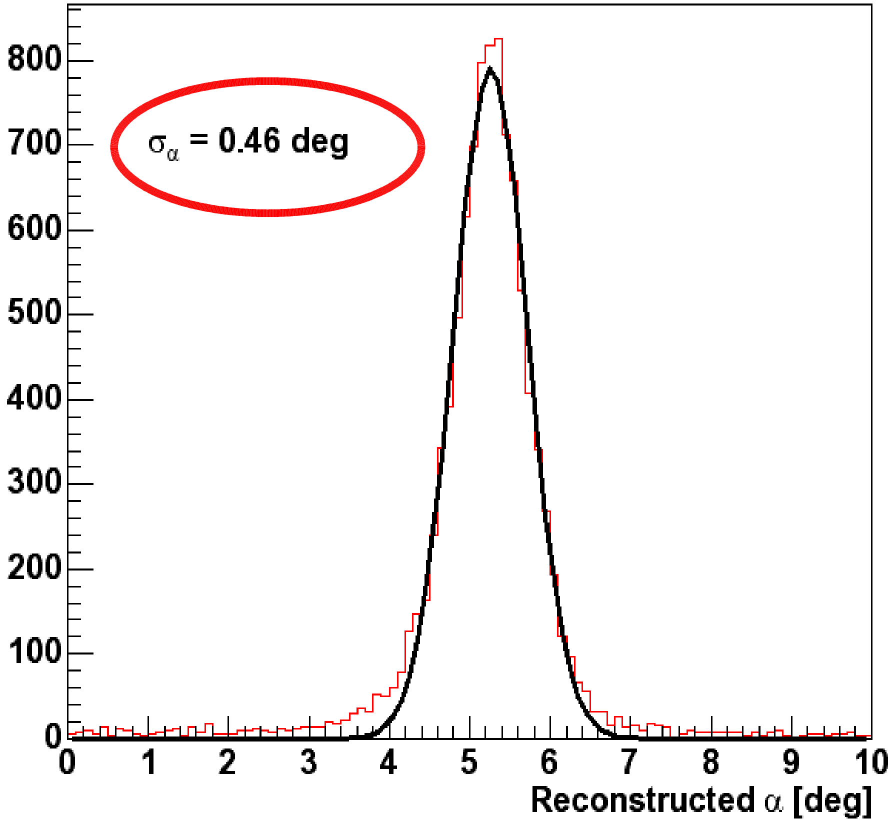




optimized angular resolution – important for trigger



4 GeV/c pions, φ = 5°, θ = 15°
full-size stack of chambers

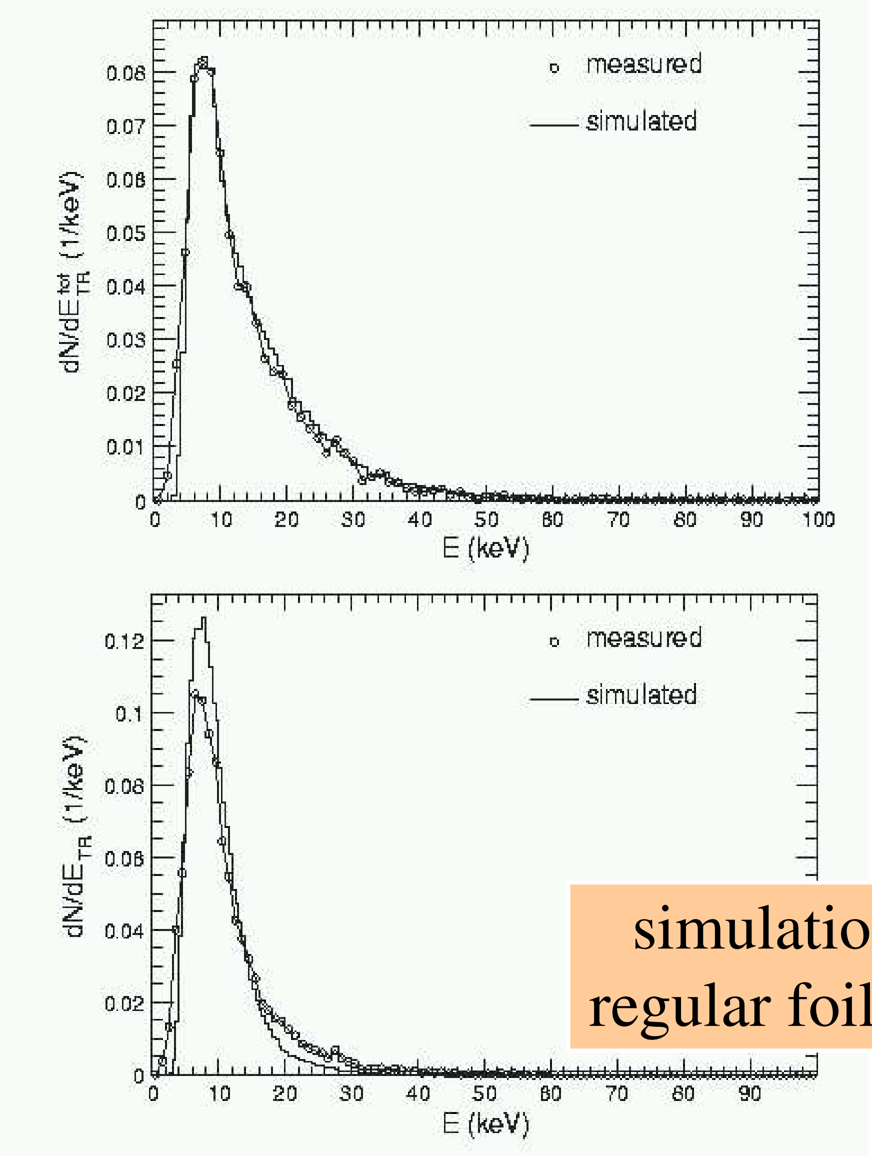


B. Vulpescu, PI Heidelberg

best angular resolution obtained for slightly reduced pad response function

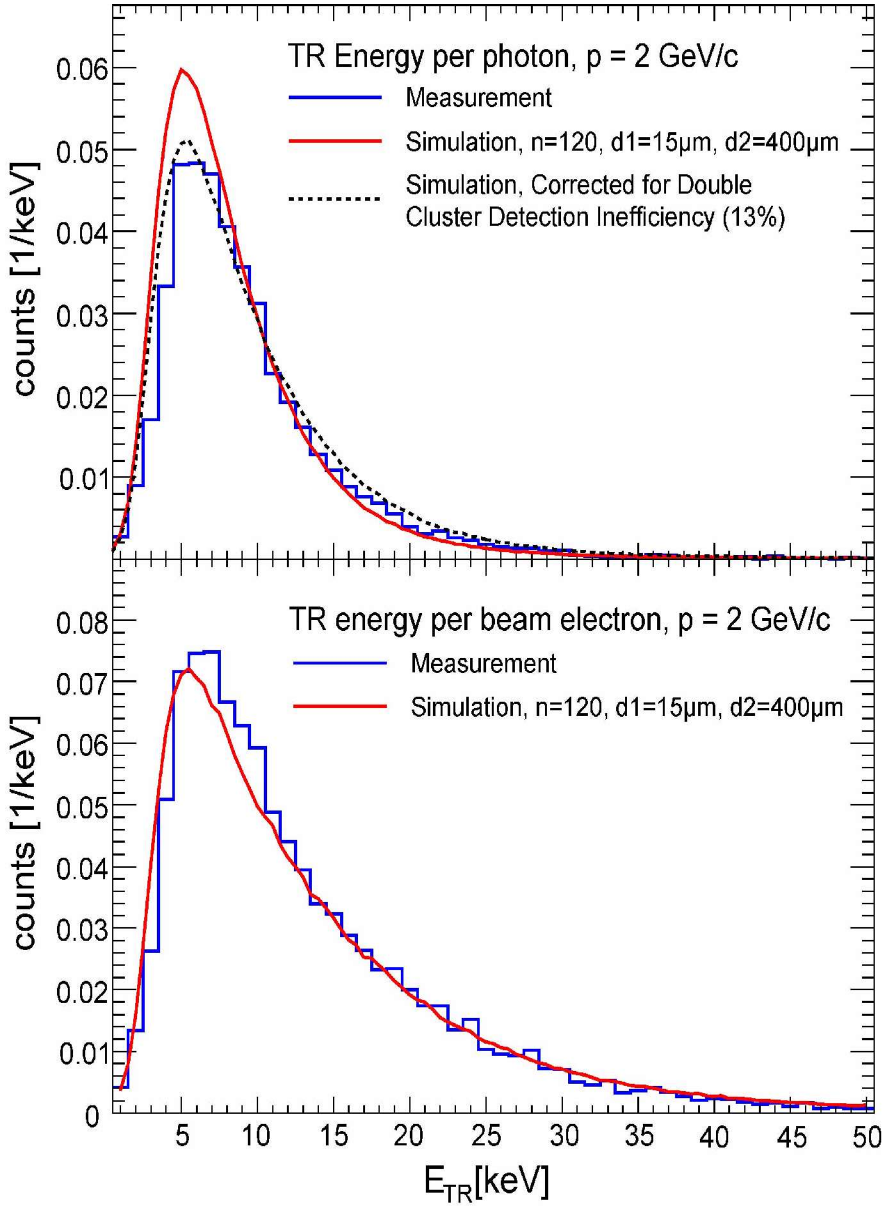
Measurement of energy per TR photon and TR energy per electron

O. Busch, NIM A522 (2004) 45



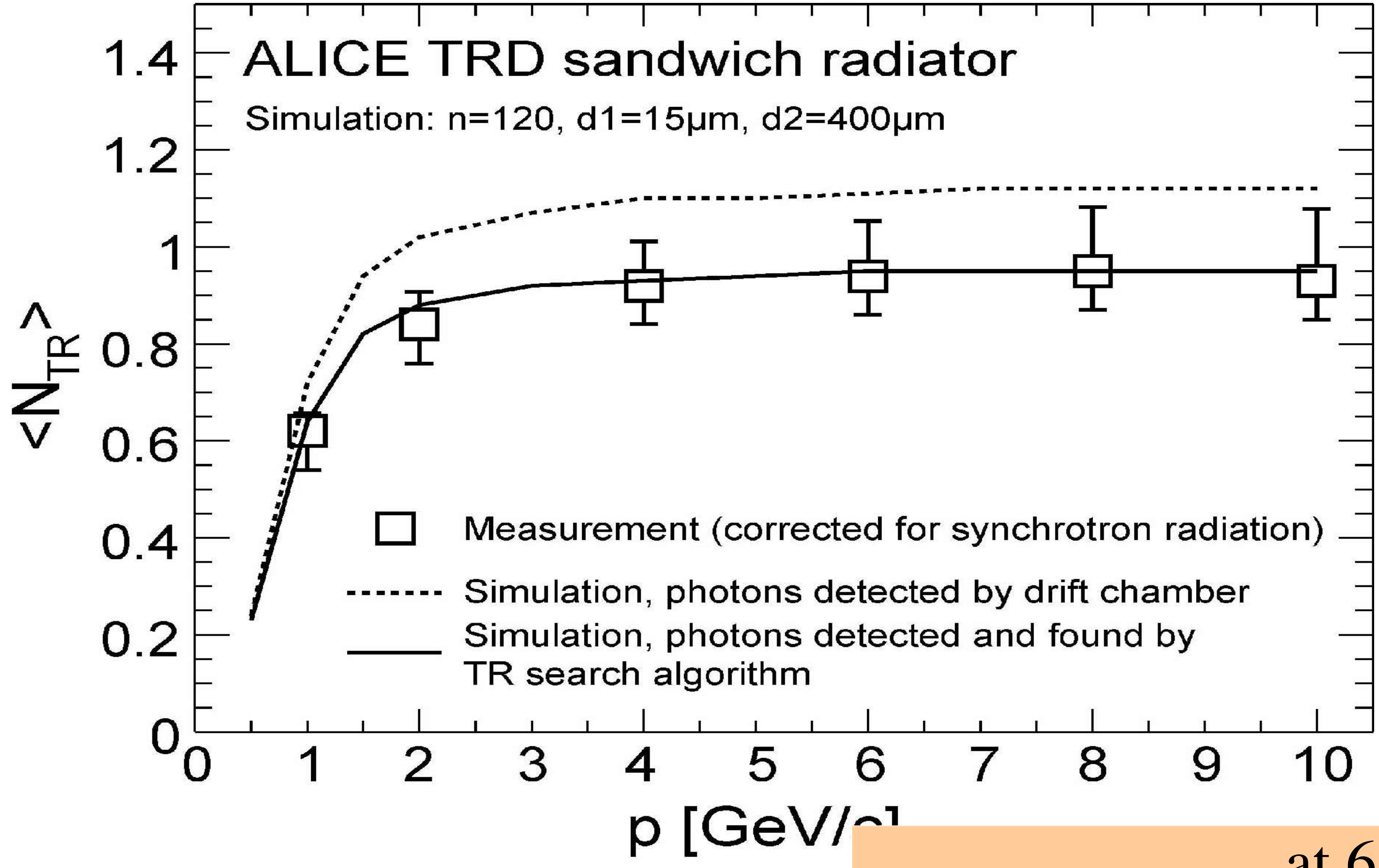
simulation with regular foil radiator

C. Lippmann, R. Bailhache 2004 data



Number of TR photons per electron vs momentum

after correction for synchroton radiation



→ see talk by Rafaelle Bailhache

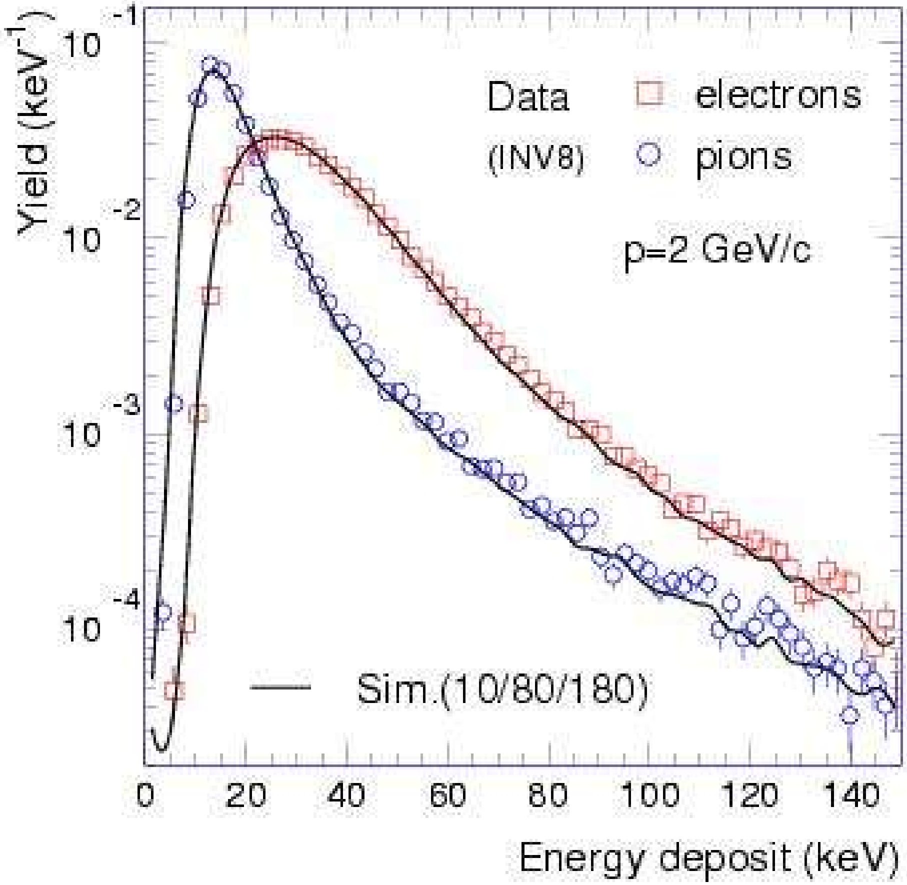
at 6 GeV/c:
absorption of 0.4 TR photons before detection
-> 1.5 TR photons per electron from radiator

C. Lippmann, R. Bailhache 2004 data

Average Electron and Pion Energy deposit

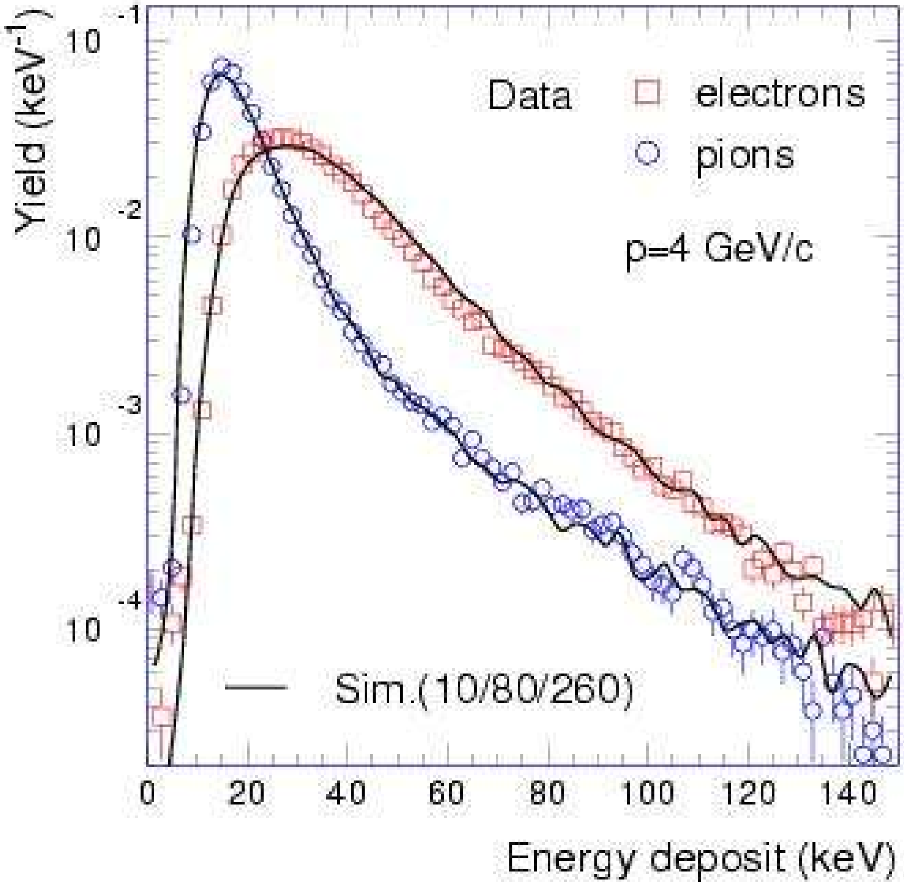
small prototype chambers

A. Andronic et al., NIM A522 (2004) 40



full size chambers

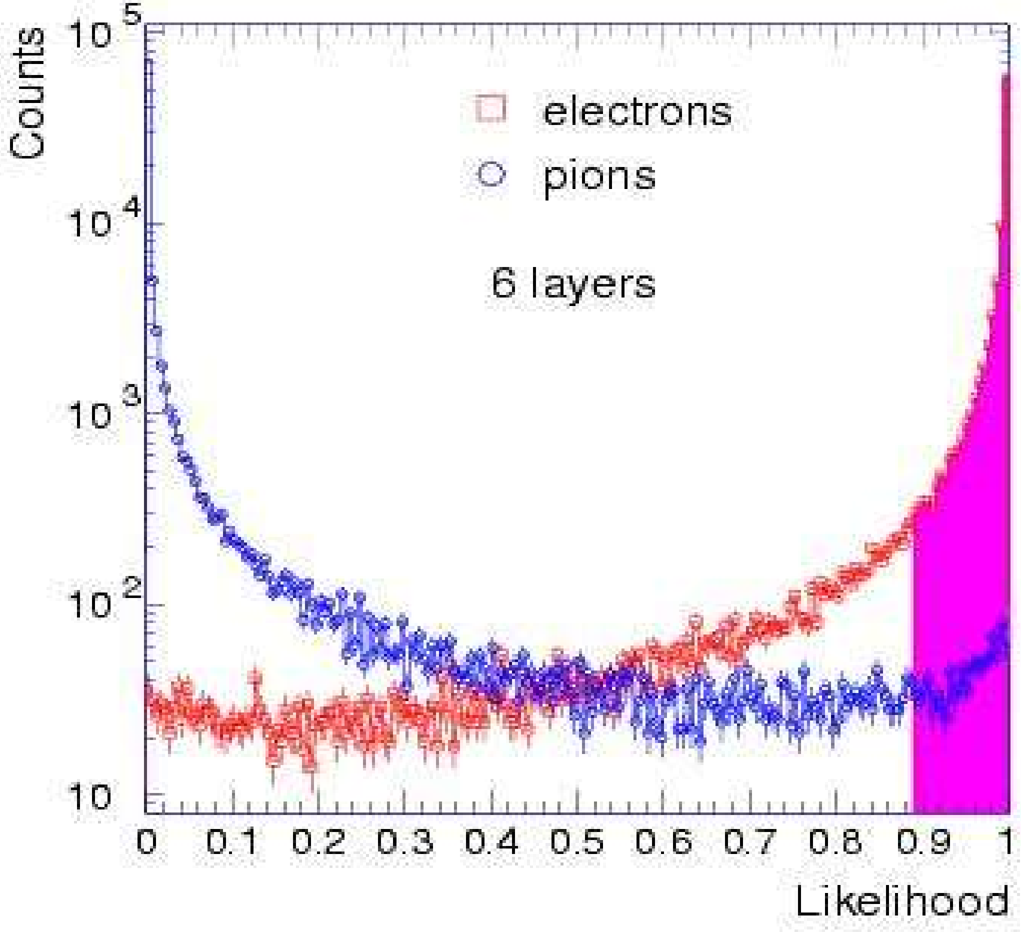
R. Bailhache, C. Lippmann



data well reproduced by simulation
(based on regular foil radiator)

Likelihood for electron and pion

A. Andronic
(data of NIM A522 (2004) 40)

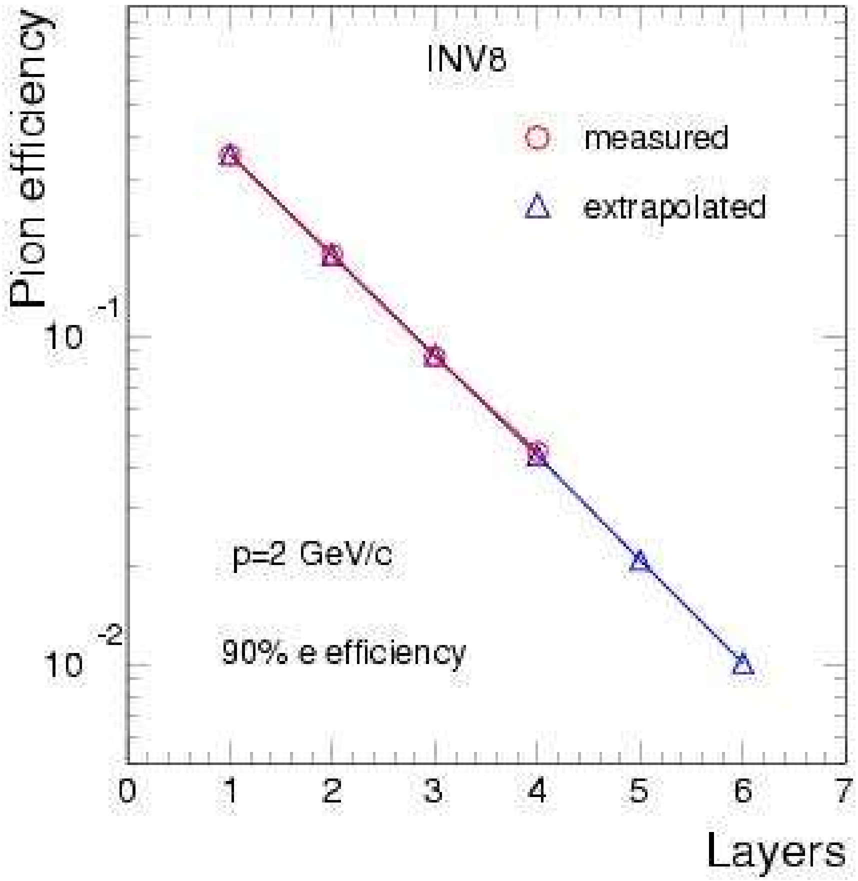


Likelihood can be based on

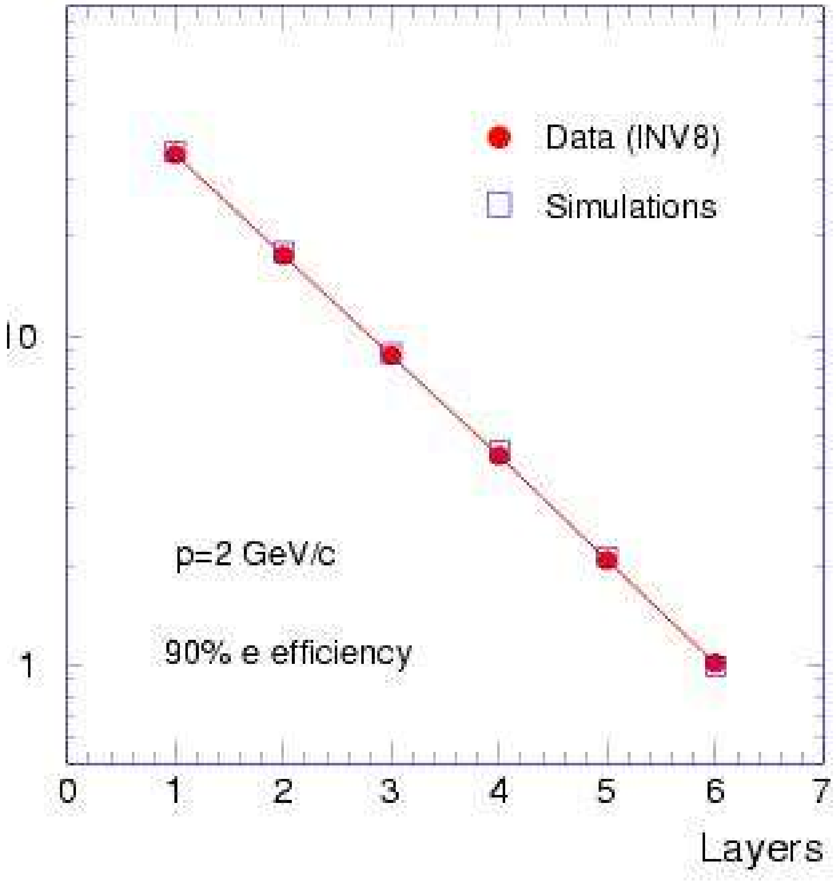
- ✯ total deposited charge (LQ)
- ✯ deposited charge/position (LQX)
- ✯ typically pick 90 % el. eff.

Pion rejection – LQ method

A. Andronic et al., NIM A522 (2004) 40
small prototype chambers

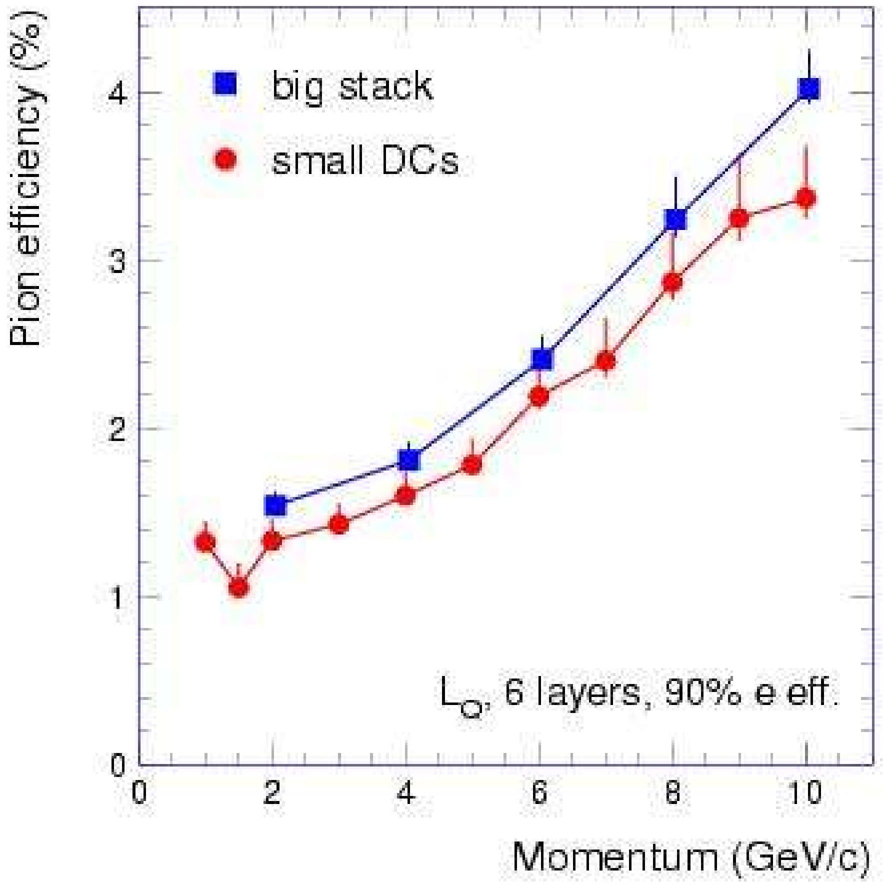


same data and simulation



factor 2.1 suppression per layer – well reproduced by simulation

Pion rejection vs momentum



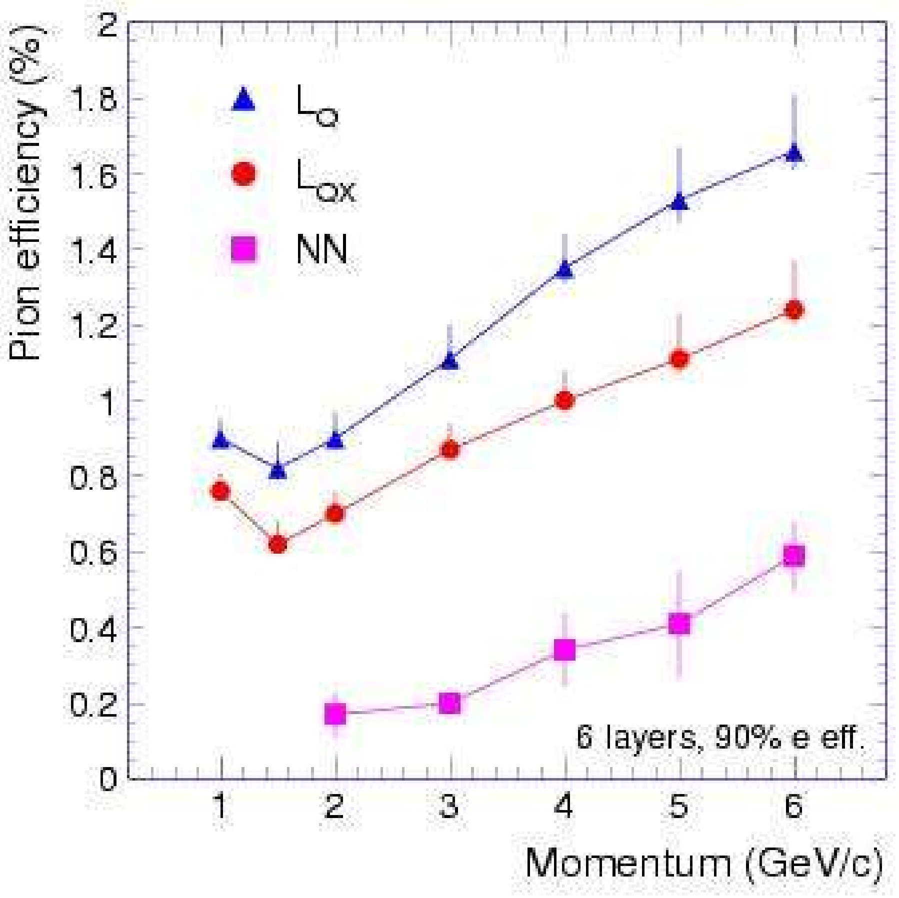
final chambers compare
well to small prototypes

performance even
with only LQ method
close to desired 1%
at 1-3 GeV/c

factor 2.5 deterioration
for momenta of 10 GeV/c
due to relativistic rise

R. Bailhache, C. Lippmann, 2004 data

Different pion rejection techniques



2-dimensional likelihood (simplified) improves rejection power by 30 %

recently a neural network approach was employed based on the Stuttgart Neural Network Simulator
→ talk by A. Wilk
finds factor 3 improvement
Nucl. Instr. Meth. (2005)

Functional Tests of Tracklet Preprocessor

Beamtime (CERN PS 2004)

(Preprocessor Operation)

- Track Segment Identification
- Number of Hit Points
- Angle Reconstruction

Good agreement to a level of less than 1/1000 Track Segments

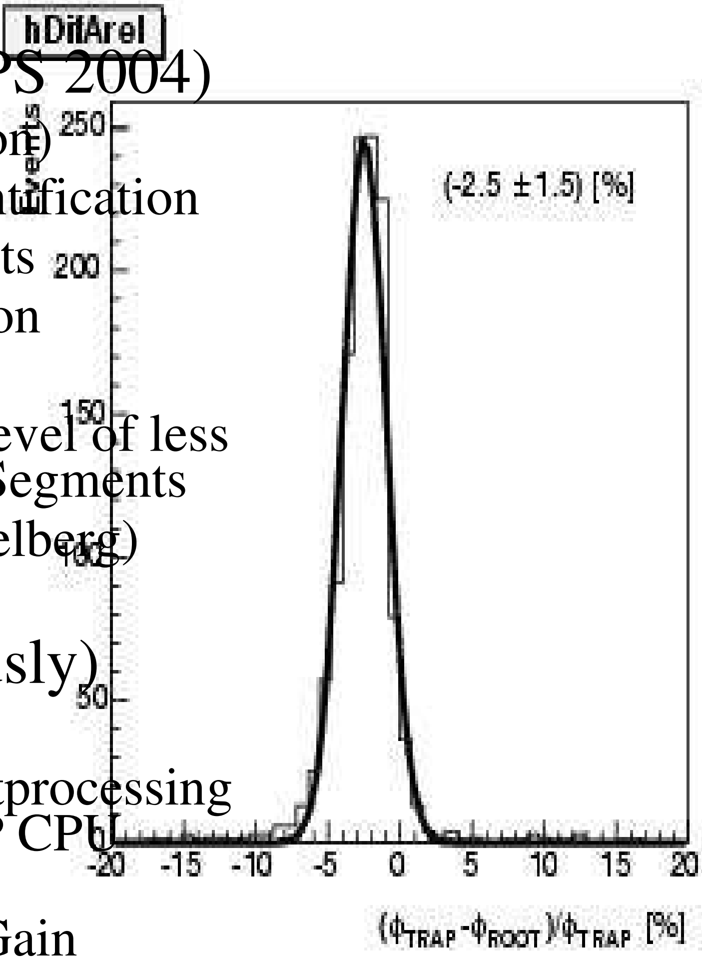
(B. Vulpescu, PI Heidelberg)

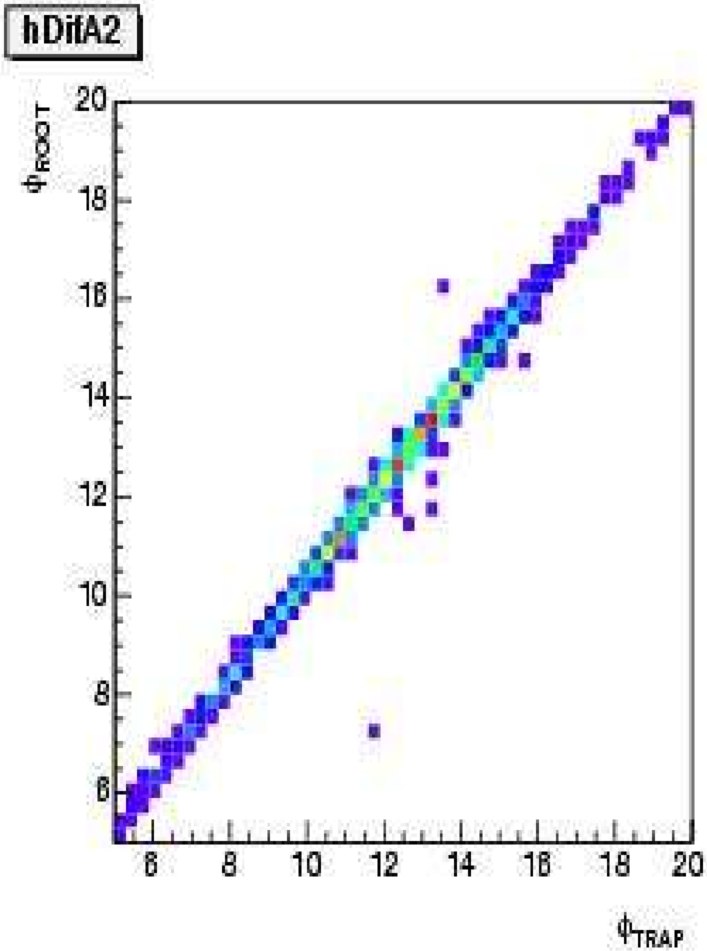
Cosmics (continuously)

(Full Operation)

- Track Segment Postprocessing included into TRAP CPU program
- Filter Calibration (Gain Correction, Tail Cancellation)

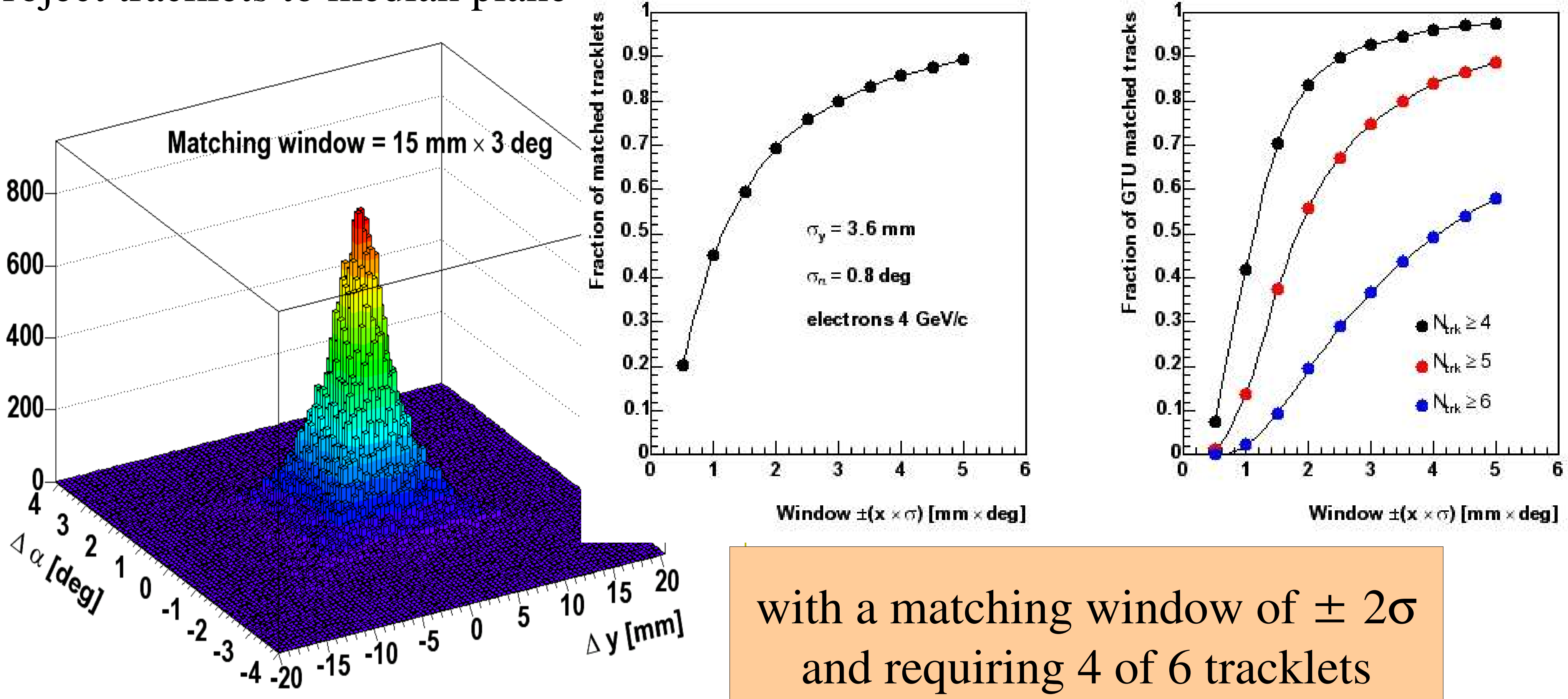
(M. Gutfleisch, KIP Heidelberg)





Matching (offline) of real tracklets like in GTU
Test of Electron Trigger

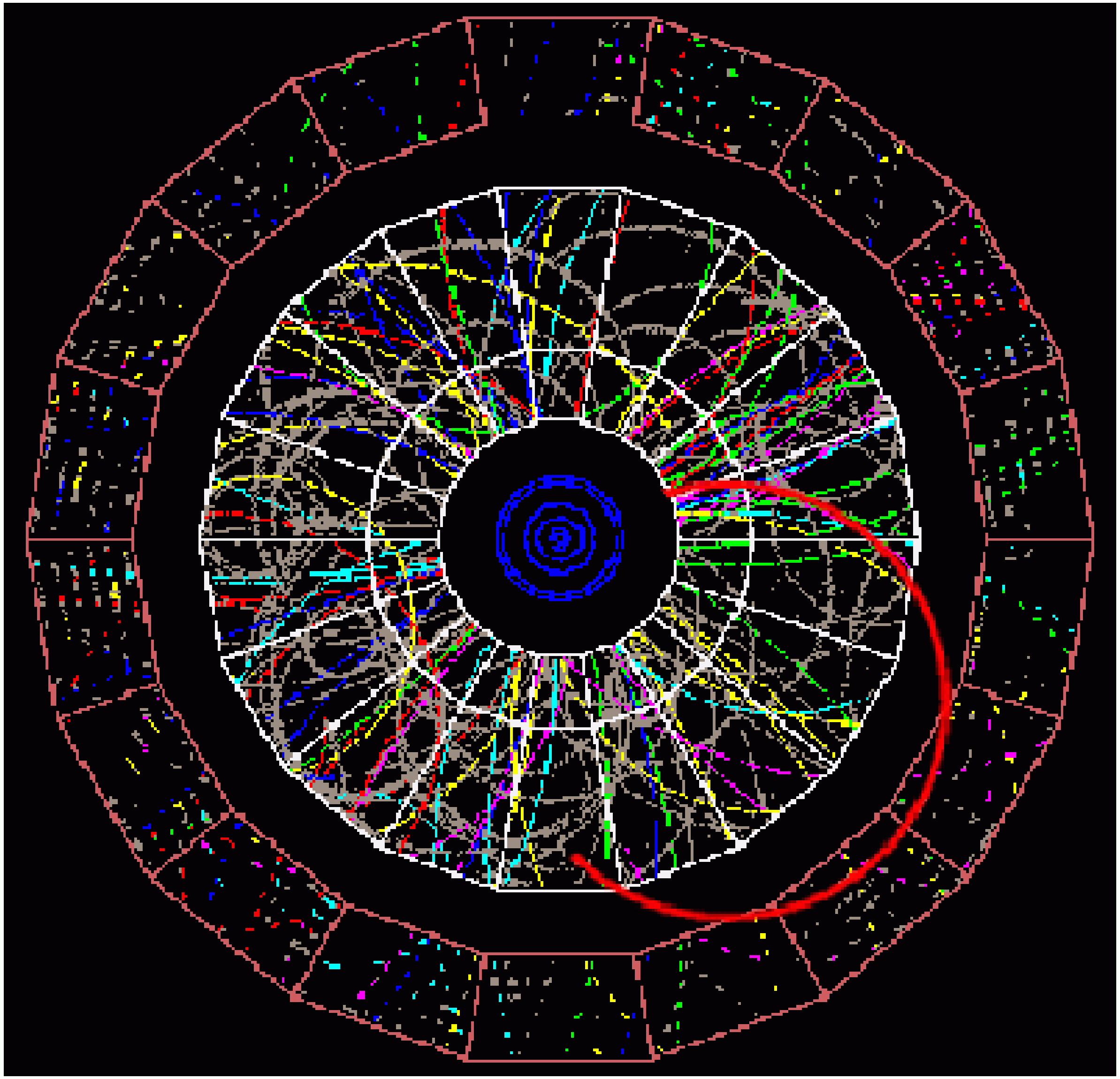
project tracklets to median plane



with a matching window of ± 2σ
and requiring 4 of 6 tracklets
85 % of 4 GeV/c electrons survive
matches simulation well

B. Vulpescu, PI Heidelberg

Event display – ALICE central barrel



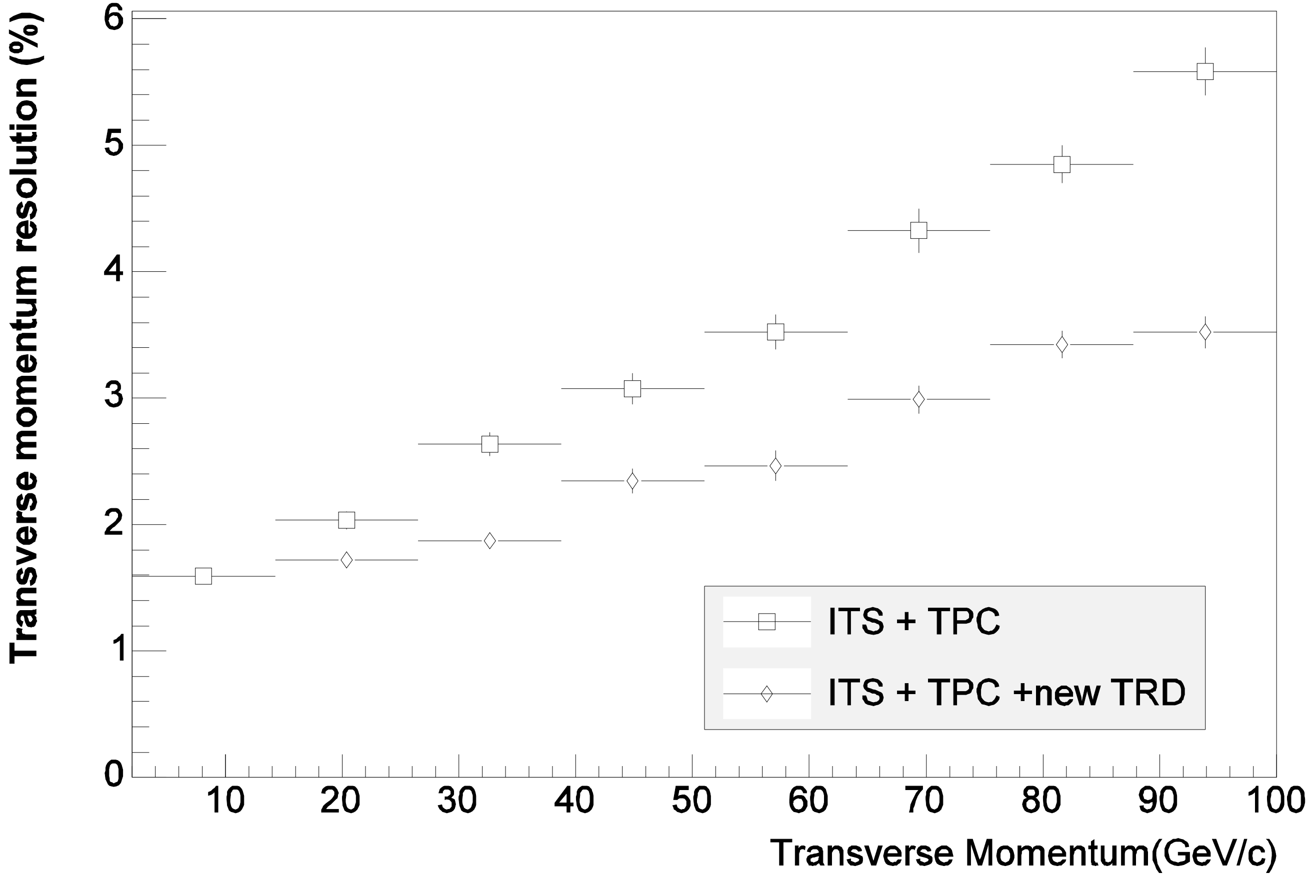
1/500 of acceptance in pseudorapidity

6 layers of Si
90 m^3 TPC
6 layers of TRD

Combined Momentum Resolution in Central Barrel

$dN_{ch}/dy \sim 5000$

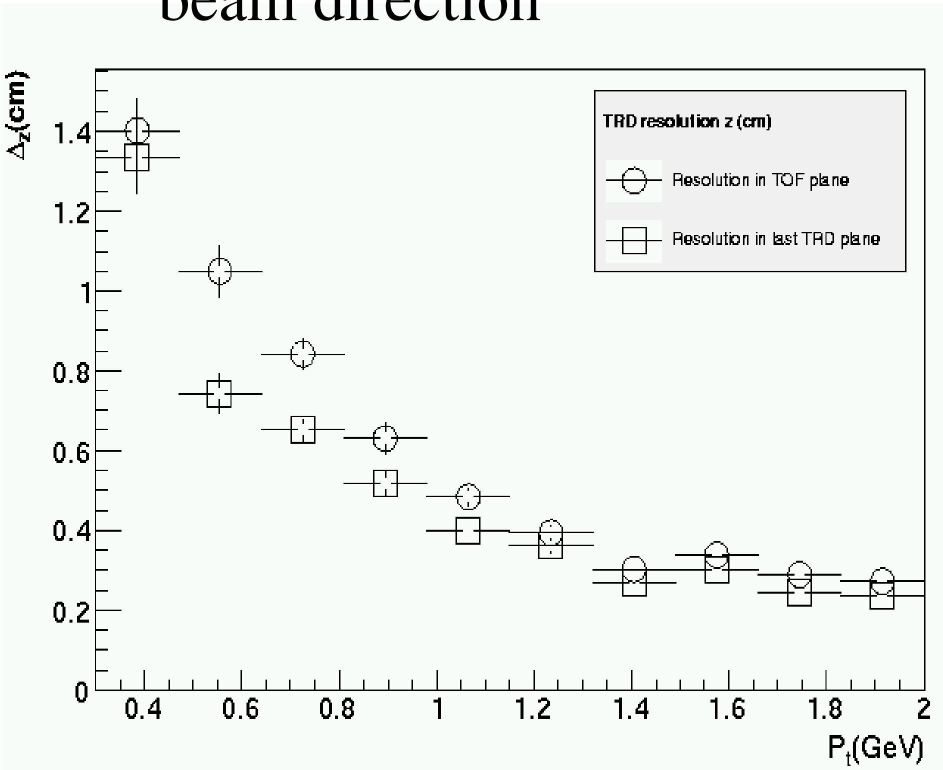
M.Ivanov, CERN & PI
Heidelberg, March 05



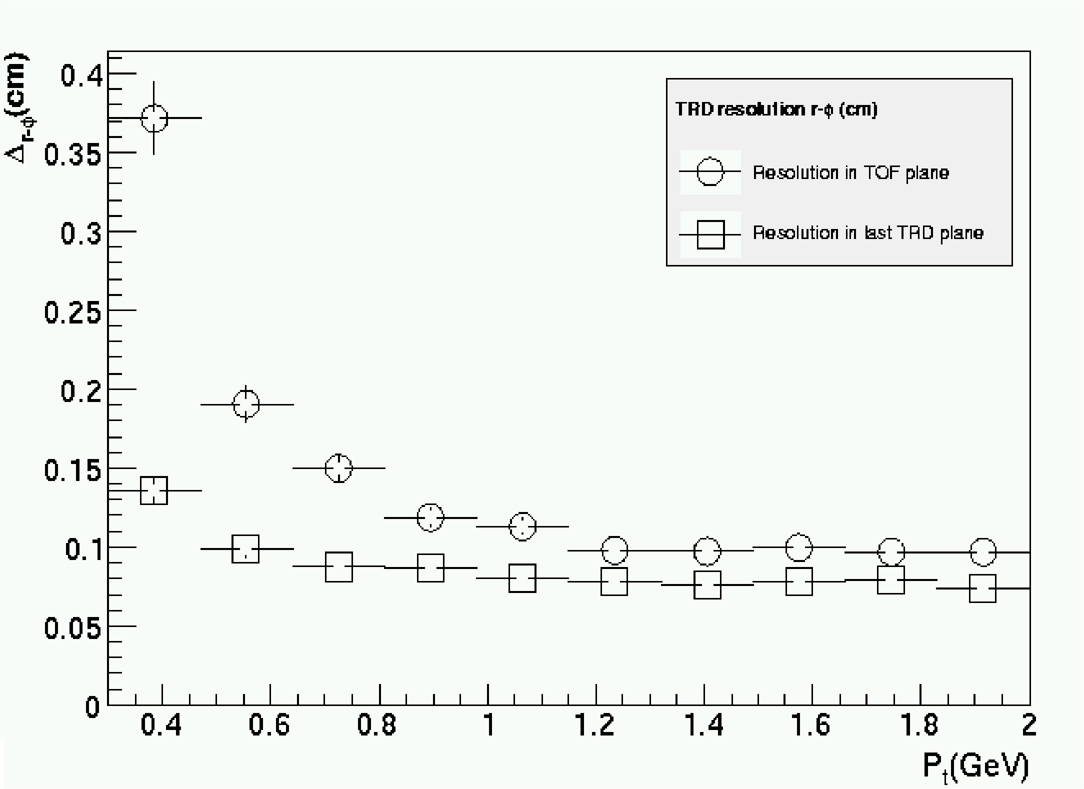
resolution ~ 3% at 100 GeV/c
excellent performance in hard region!

Space point resolution of a track at end of TRD

beam direction



bend direction



Marian Ivanov, CERN and PI Heidelberg

Physics observables accessible with the TRD

specifically for heavy ion physics and quark-gluon plasma observables:

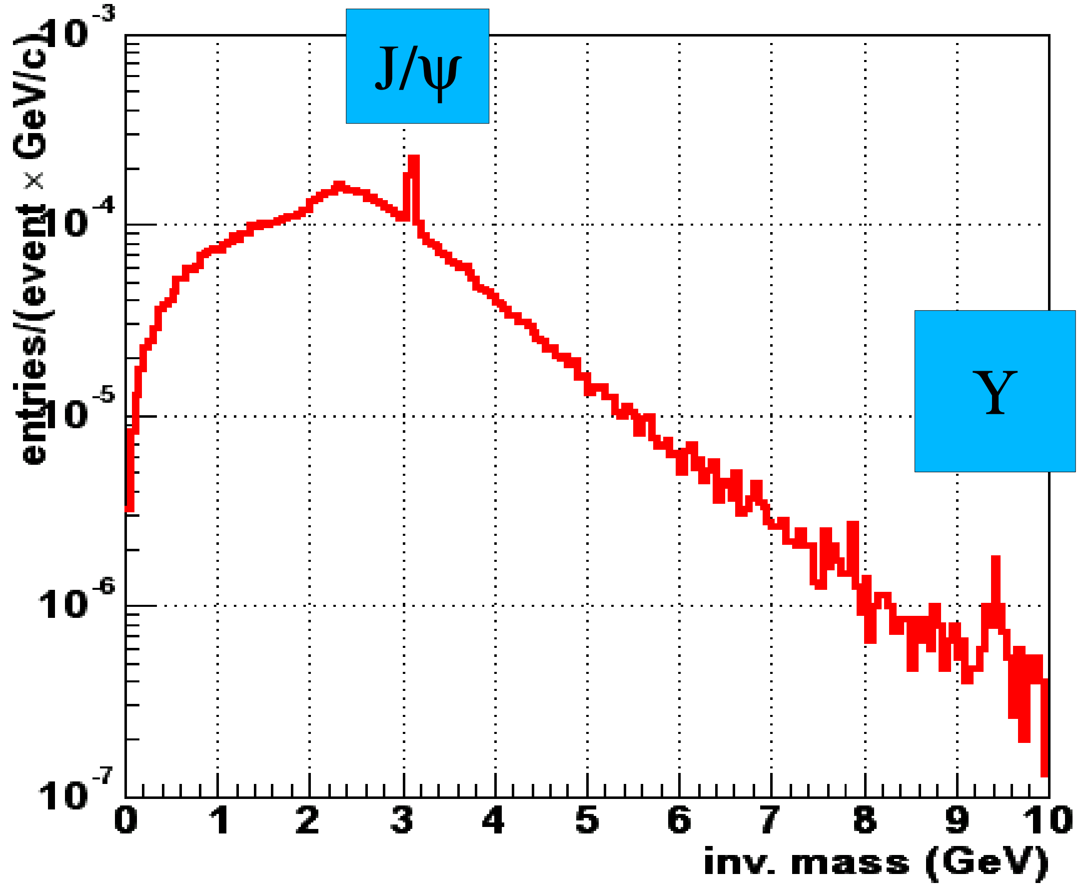
- the new physics at LHC beyond RHIC is in the hard sector
- focus on heavy flavor and jet physics

quarkonia	screening in QCP and (enhanced) reformation at hadronization
open charm from semi-leptonic decays	normalization charmonia, thermalization of charm quark, elliptic flow
open beauty from semi-leptonic decays	normalization for Y, thermalization of beauty, elliptic flow
$B \rightarrow J/\psi$	indendent measurement of bbar
jets, γ-jet coincidences	trigger (on a few leading particles)
virtual photons $\rightarrow$ ee , Drell-Yan	thermal radiation in mass window between J/ψ & Y, very challenging

Expect prominent signals for J/ψ and
in central Pb+Pb at ALICE

J/ψ→ ee:
mass resolution
better than 40 MeV,
about 40000/month

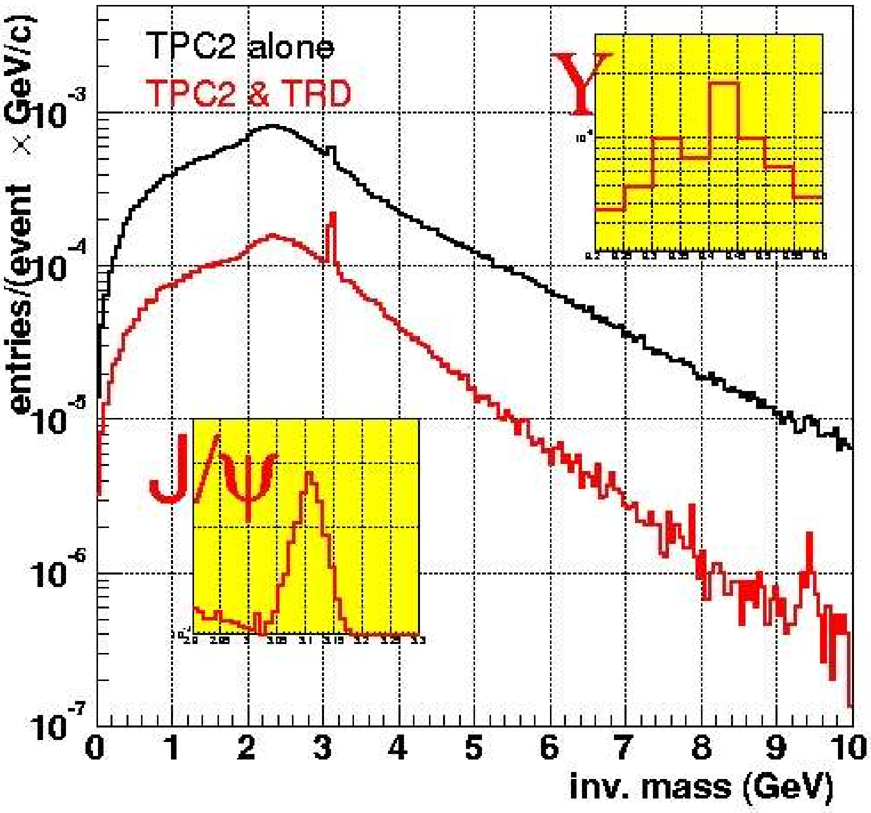
Υ → ee:
mass resolution
better than 90 MeV,
about 1000/month

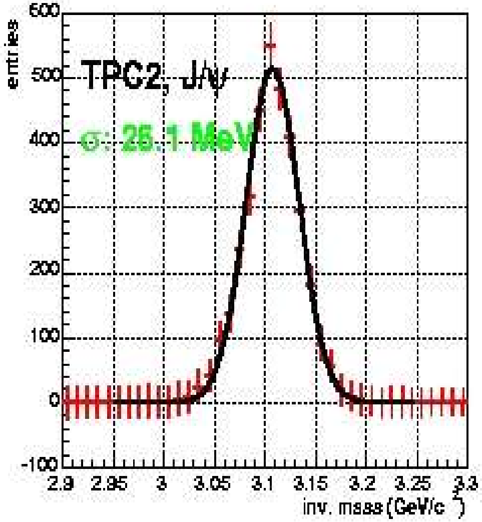


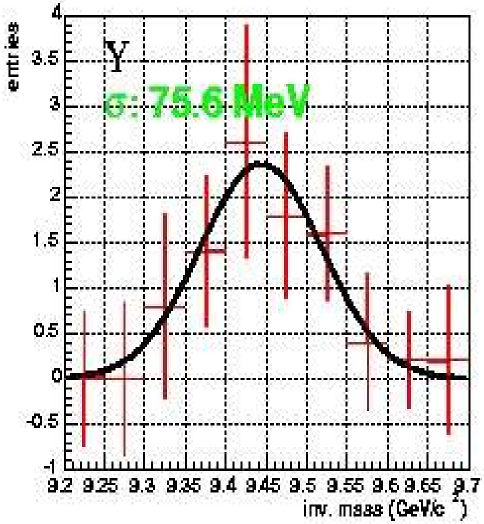
doctoral thesis T. Mahmoud, PI Heidelberg

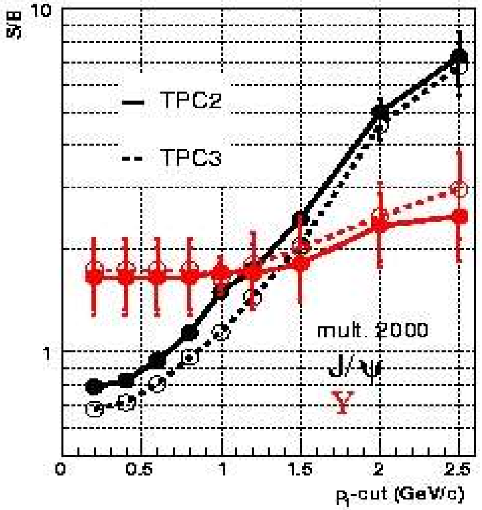
Charmonia in ALICE at mid-rapidity

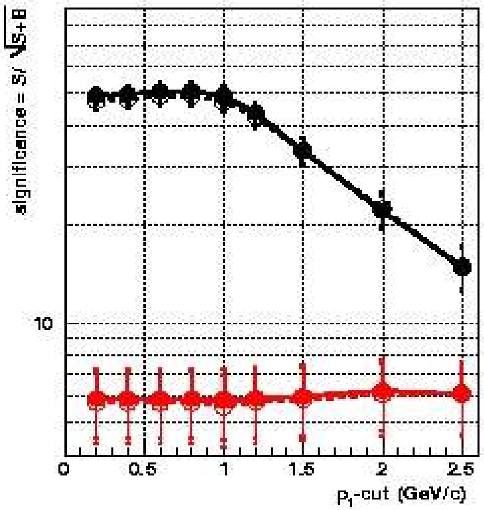
Electron identification with TPC and TRD









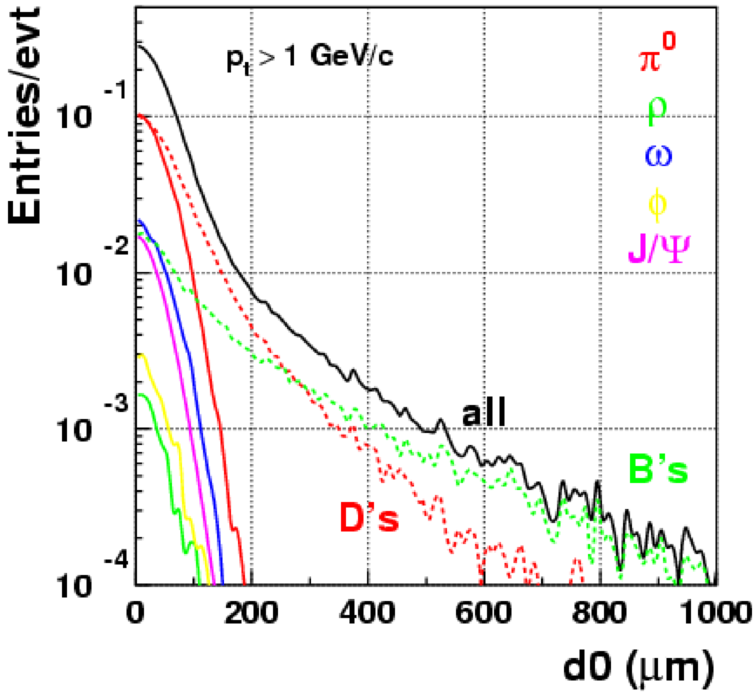


Good mass resolution and signal to background

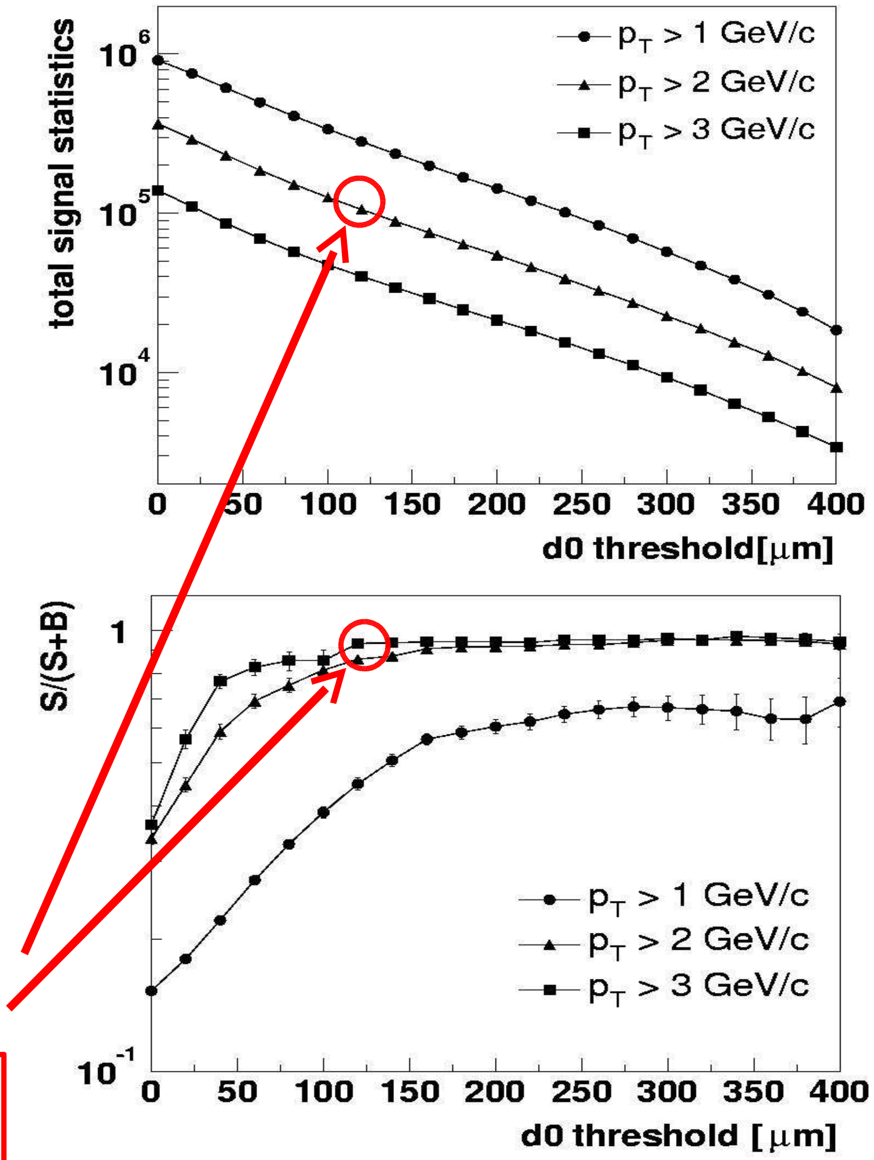
Open heavy flavor measurements in (semi-)leptonic channels in ALICE

- single lepton p_t distributions, c & b
- single leptons with displaced vertices, c & b

	$D^{\pm}$	D^0	$D_s^{\pm}$	$B^{\pm}$	B^0	B_s^0
$c\tau$ (μm)	315	124	140	495	468	462



B → e in ALICE ITS/TPC/TRD
$p_t > 2$ GeV/c & $d_0 > 180$ μm:
100000 electrons with S/(S+B) = 90%



A. Dainese, Padova

ALICE TRD Collaboration

Main Contributions:

- Germany:
  - Frankfurt University (IKF)
  - GSI Darmstadt
  - Heidelberg University (PI, KIP)
  - Münster University (IKP)
- Russia:
  - JINR Dubna (LHE)
- Romania:
  - NIPNE Bukarest

Additional Subsystems:

Japan: Tokyo University, Nagasaki University
Greece: Athens University
Germany: FH Köln, Univ. Kaiserslautern, FH Worms, TU Darmstadt