Tpc/x Response Simulator

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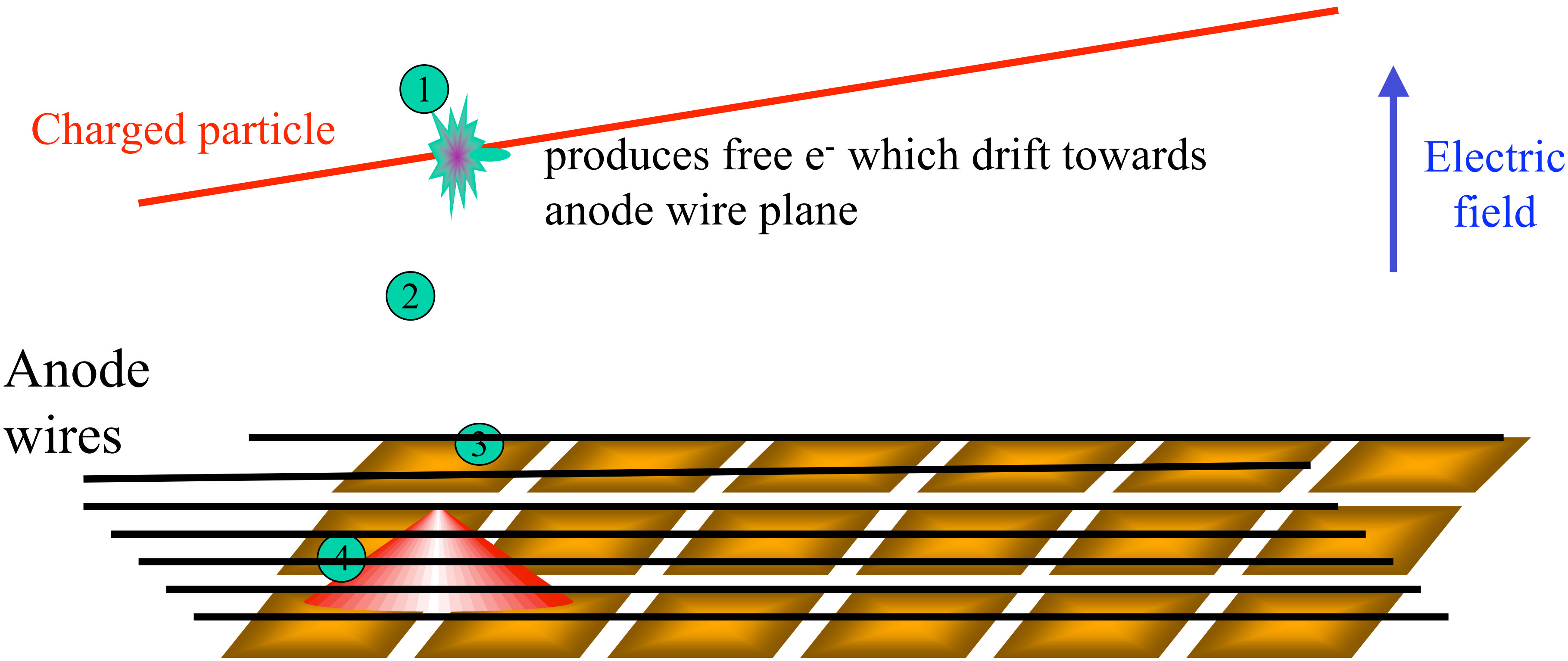
Outline

- Why new Tpc RS ?
  - GEANT3 dE/dx model
  - Tail cancellation
- TpcRS
  - Goals
  - Bichsel's dE/dx Model (NIM A 562 (2006) 154)
  - e^- transport in main drift volume and around wire planes
  - Gas amplification
  - Time development of anode charge and inducing charge on pad.

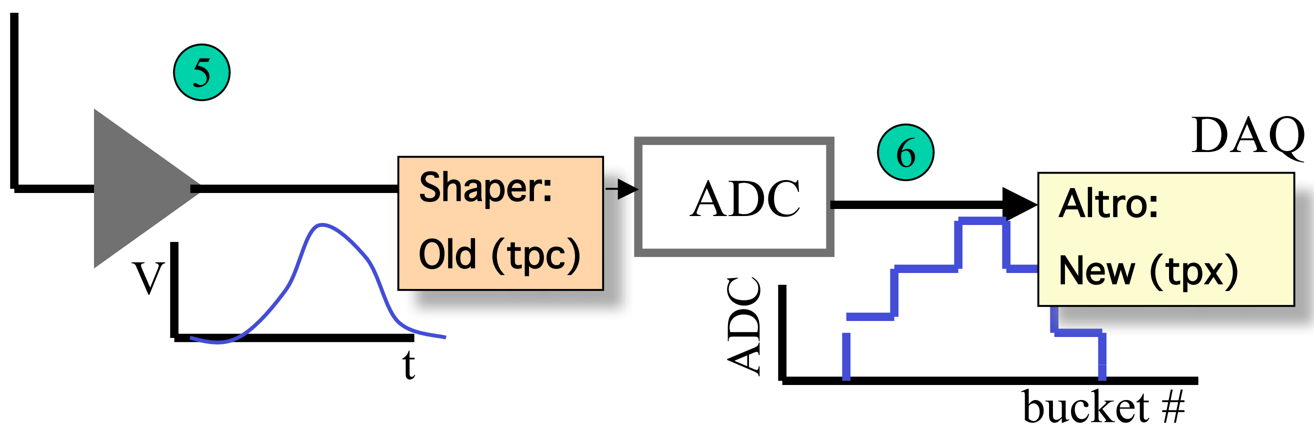
(The basic formulae and parameters are taken from Mathieson's Book "Induced charge distribution in proportional detectors": http://www.inst.bnl.gov/programs/gasnobledet/publications/Mathieson's_Book.pdf)

  - Signal digitization
- Turning and Comparison with real data
- Adc correction
- Pads
- Conclusions

Operation of a Time Projection Chamber



1. Free electrons production
2. Transport in E ‖ B fields
3. Transport near anode wires, **E⊥B**
4. Gas amplification and induced charge on pads
5. Time development of the signal
6. Digitization



Why new Tpc Response Simulator ?

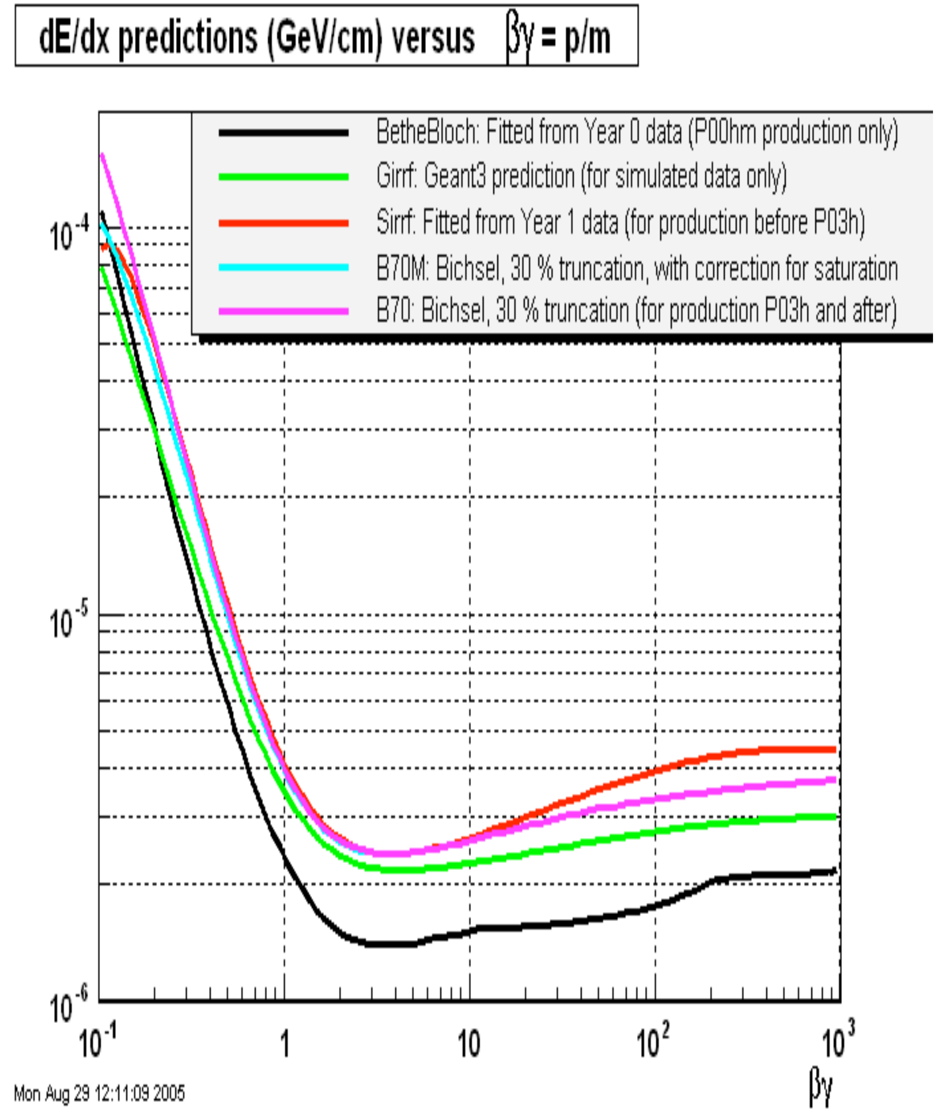
- We have a long history of response simulator for STAR TPC:
  - tss - a FORTRAN module based on ALEPH slow simulator. tss used for induced on pad charge with
    - Gaussian distribution in pad direction,
    - Gamma distribution in time (z) direction (~ $(t/\tau)^2 \exp(-t/\tau)$) which supposed account for shaper response and perfect two pole tail cancellation, and

    modified by gas gain fluctuations and diffusion.
  - StTrsMaker was created later and represents the same model converted from FORTRAN to c++ in very complicated way.
- All these simulators have the following problems due to that they
  - try to use GEANT3 dE/dx model, which does not describe the data,
  - assume perfect tail cancellation which is not true for our case, and
  - new electronics (ALTRO TPX) does tail cancellation on digital level i.e. it requires digitization of the analog signal before applying tail cancellation algorithm.

GEANT3 dE/dx model

GEANT3 has two ways to simulate ionization energy loss:

1. Landau/Vavilov distribution, which does not account atom shell structure (scattering on free electrons only), and
2. GEANT3 partial implementation of Photo Absorption Ionization (PAI) Model ("*Ionization energy loss in very thin absorbers.", V.M. Grishin, V.K. Ermilova, S.K. Kotelnikov* NIM A309:476-484,1991), where only atom shell structure is accounted (no off shell electron contribution).
3. The essential moment is that GEANT3 (Girrf) does not reproduce the data which is well reproduced by Bichsel's (full PAI) model (B70M). This problem is permanent pain for all embedding studies.

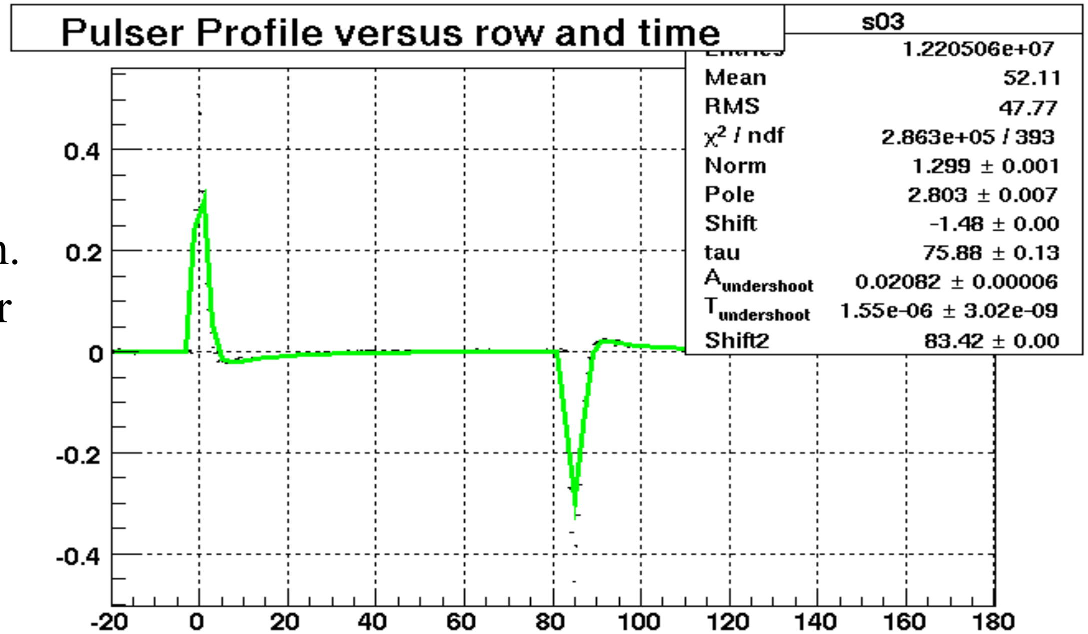


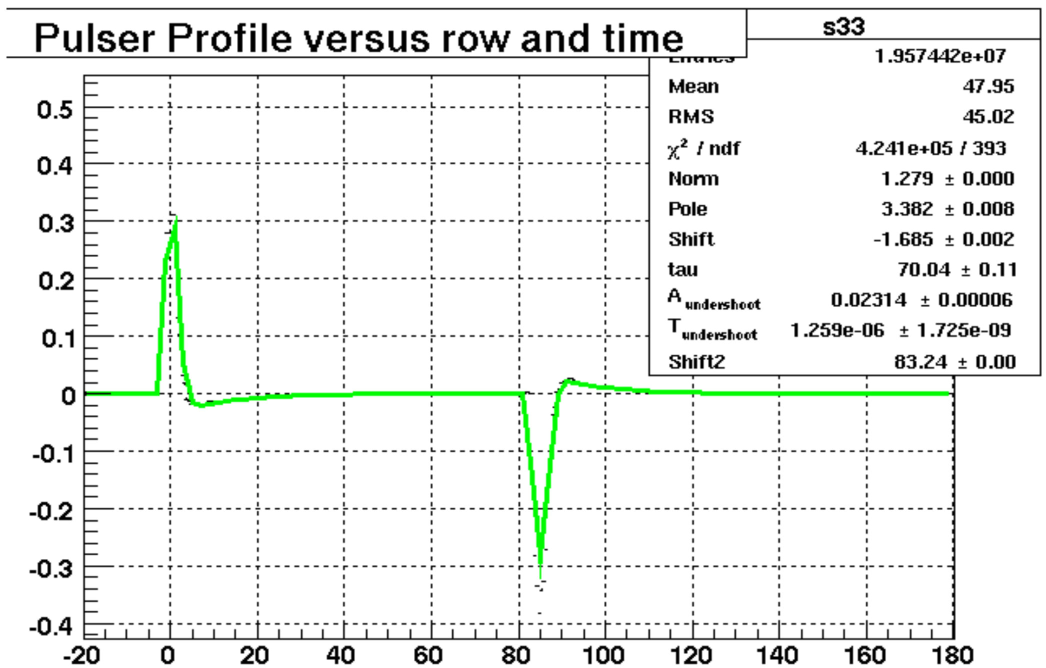
Undershoot

An other problem is undershoot.

Undershoot is negative signal which is appeared as side effect of tail cancellation. It can be seen for pulser signal shown (for row 3 and row 33) before zero suppression. The reason for undershoot will be discussed later.

In event with high hit occupancies undershoot effectively reduces dE/dx for track, this reduction is depended on a prehistory of the current hit, and this is main reason for observed in STAR dependence of dE/dx versus global track multiplicity.





Goals for new Tpc Response Simulator

- The main goals for new StTpcRSMaker are to provide:
  - Accuracies for embedding which have to (at least) match with our statistical errors,
  - A handle to optimize tail cancellation parameters for particular detector running conditions (hit occupancies, …)
  - A possibility to estimate systematical biases in both :
    - dE/dx measurements, and
    - Spatial cluster reconstruction.
  - understanding influence of alignment, distortions, … on the detector performance.
- To achieve these goals we need to have:
  - adequate description of ionization in TPC gas,
  - Transport to anode wires,
  - Accounting distortions (to be done):
    - I have to remind that we have started distortion correction when distortions were on level of ~mm,
    - Now we have distortions on level of ~ cm,
    - There are concerns that the distortion corrections have 2-nd order effects which can be significant.
  - Gas amplification,
  - Analog signal simulation,
  - Tail cancellation, digital signal simulation,
  - Calibration corrections
  - …
- These goals first of all should be achieved for new Tpc electronics (tpx) but it would be useful to support old electronics too.

1

Bichsel PAI model

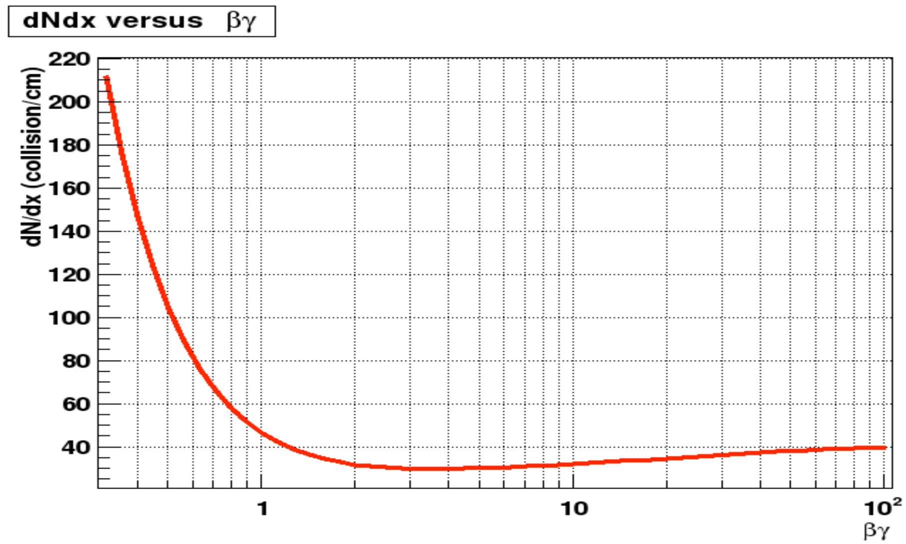
- No. of primary clusters:

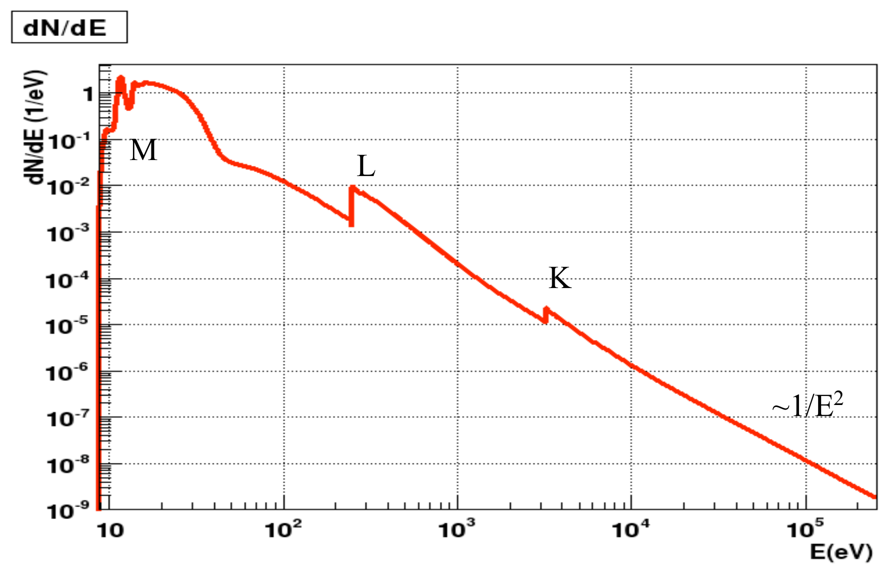
  $1/\lambda = dN/dx(\beta\gamma)$ (≈28 e^-/cm for Ar at $\beta\gamma=4$)

  $ds = -\lambda \log(rndm())$
- Kinetic energy (E) for each primary electron is defined from dN/dE(E) distribution.
- Range of slow electrons

  $R = 55\ \mu m\ (E/3000\ eV)^{1.78}$.
- Average no. of secondary electrons per one primary one is defined as

  $n_0 = (E - I_0)/W/(1 - F)$, where
  - $I_0 = 13.1$ eV, average minimum energy of ionization for gas mixture,
  - W = 28.5 eV, average ionization potential of the gas,
  - F = 0.3, Fano factor,
- Total no. of electrons per one primary e^- is
  - $N = 1 + \text{Binomial}(n_0, prob=1-F)$





Transport to anode wire

2

In the almost parallel electric and magnetic fields electrons are drifting towards anode wire plane affected by diffusion (electron attachment should be accounted altogether all other calibration parameters).

- Transverse diffusion: $\sigma_T = \sigma_{T0}(B)\sqrt{L_D}$, where
  - $B = 5$kG for P10, $\omega\tau \approx 2$, and
  - L_D - drift length
  - σ_{T0} (5kG) = 260 μm•cm$^{-1/2}$, this value has been measured using data,

    Roy Bossingham calculations using Magboltz 2, V3.1 (Biagi, 2000) gives

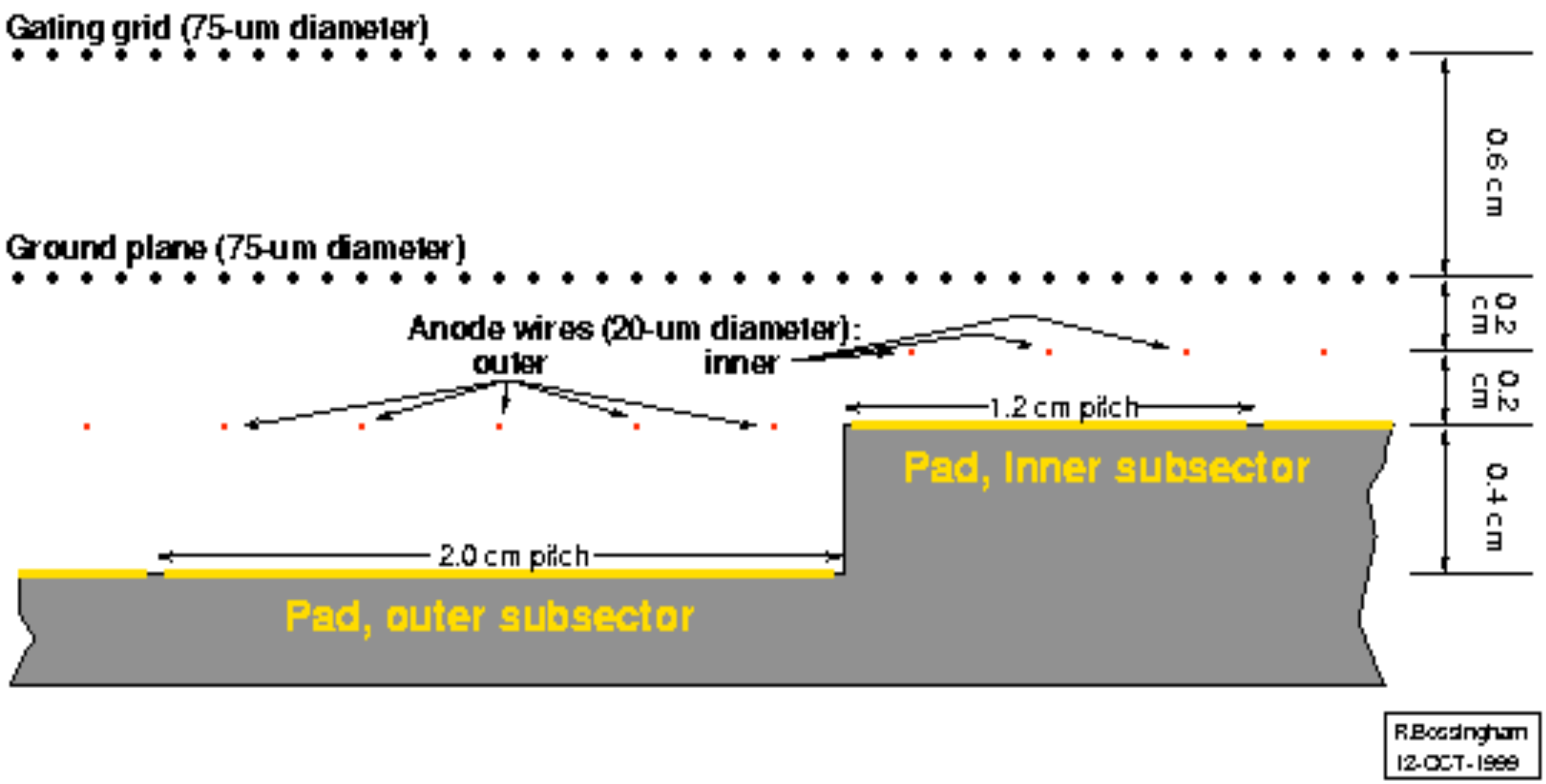
    σ_{T0} (5kG)= 240 μm•cm$^{-1/2}$
- Longitudinal diffusion : $\sigma_L = \sigma_{L0}\sqrt{D}$, where
  - σ_{L0} = 360 μm•cm$^{-1/2}$, Roy Bossingham calculations (still has to be checked with data).

Transport near wire planes region

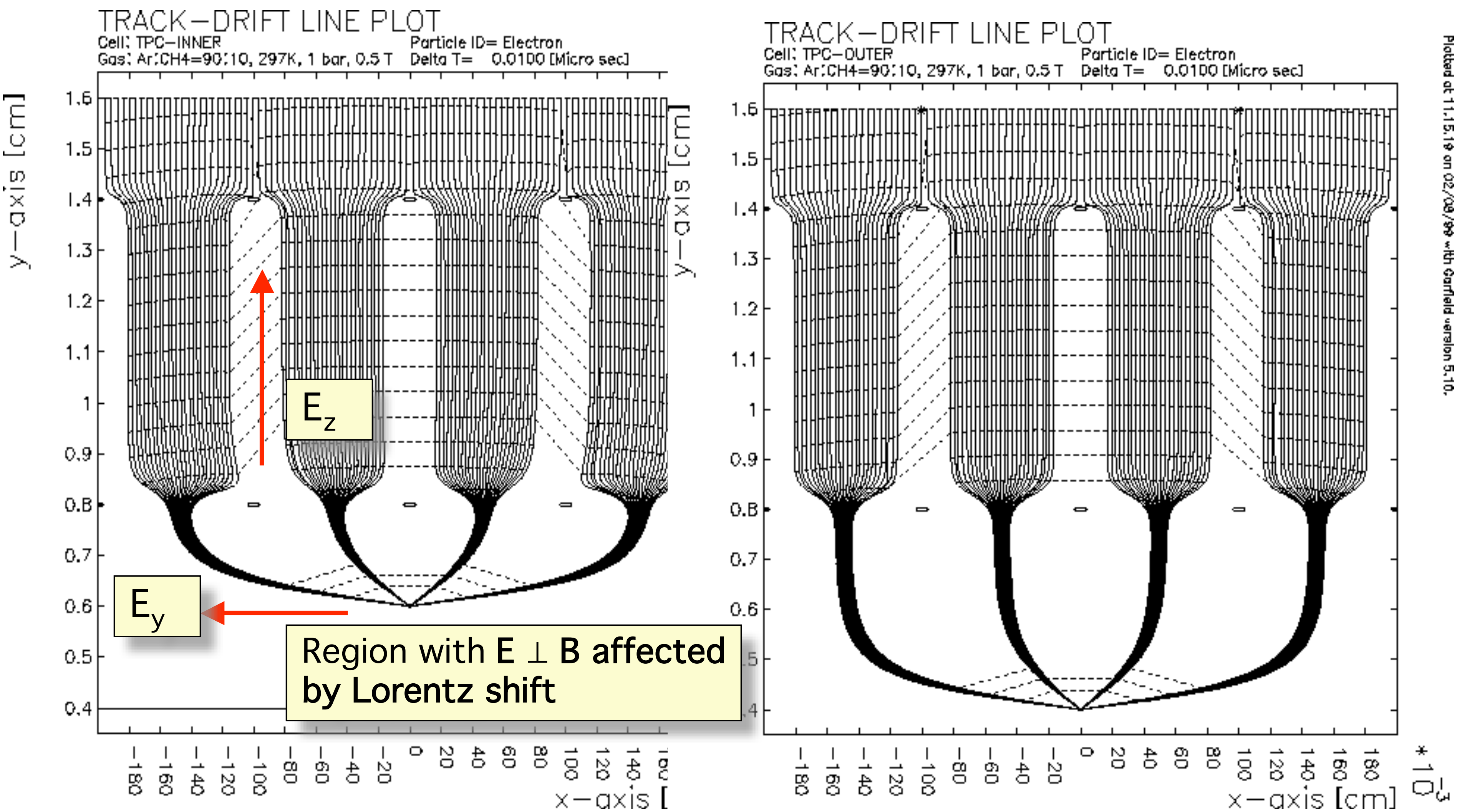
3

Wire planes region contains:

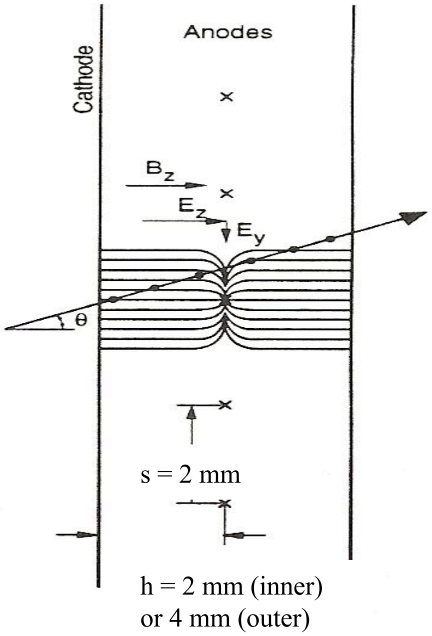
Gating Grid (1 mm step), Ground (Cathode) plane (1 mm), and Anode wire plane (4 mm step)



Drift lines plots



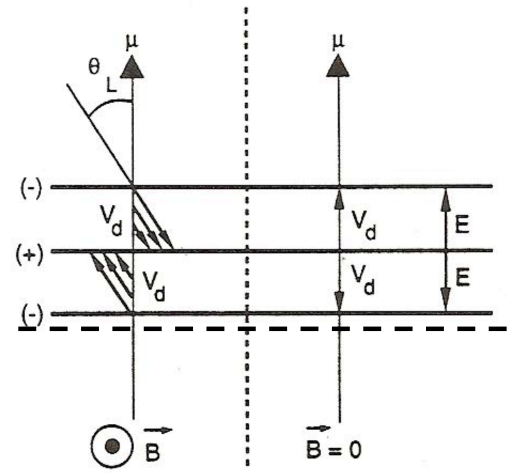
Lorentz effect near anode wires



Cathode plane

Anode plane

Pad plane



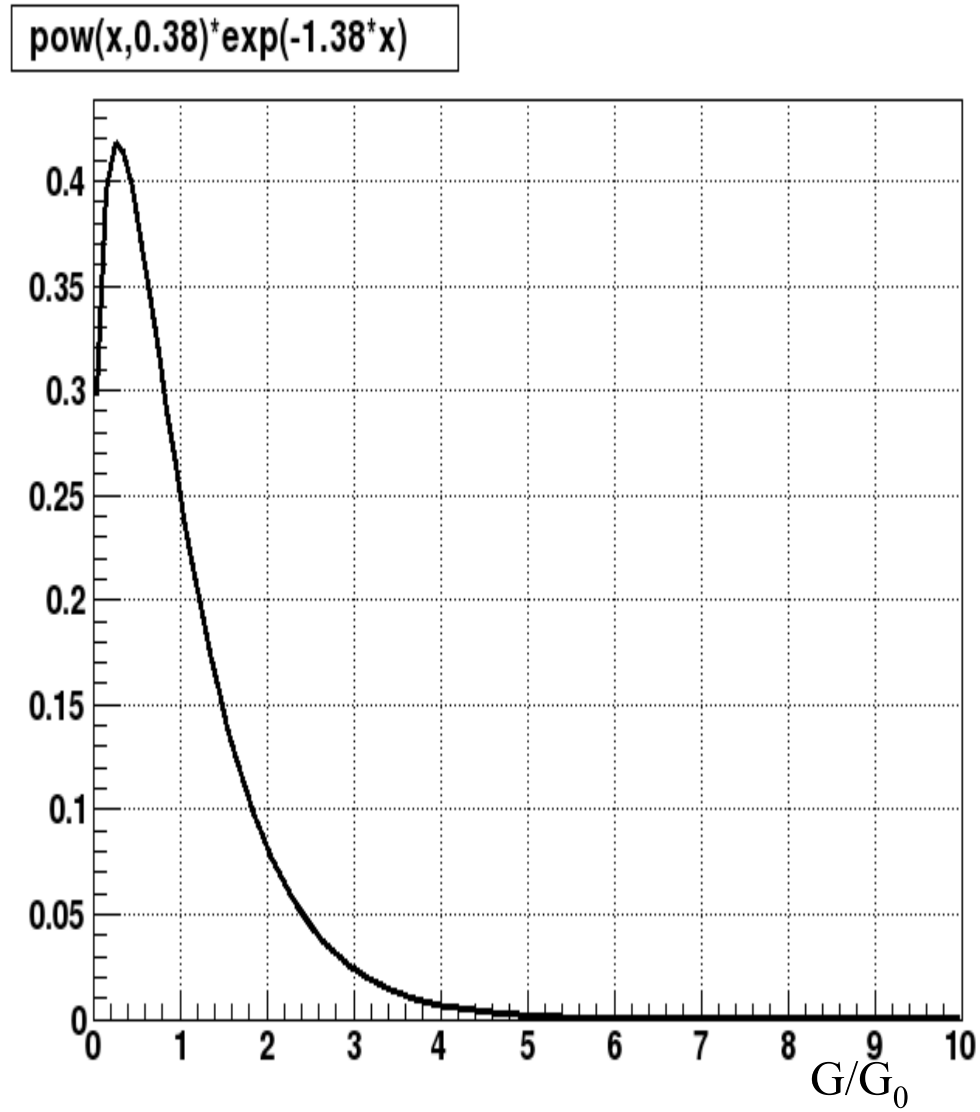
Near wire planes E is not ∥ B anymore i.e. there is $E_\perp$ component to B which creates a Lorentz shift along a wire: ~1 mm • $\tan(\Theta_L)$, where $\tan(\Theta_L) = \omega\tau$ in wire region is estimated to be ~2/3 $\omega\tau$ = 4/3 of $\omega\tau$ (= 2) main drift volume.

Gas gain fluctuations

Gas gain fluctuations are described by Polya distribution. See

http://www4.rcf.bnl.gov/~lebedev/tec/polya.html

(R.Bellazzini and M.A.Spezziga, INFN PI/AE-94/02).



Time development of anode charge

Current of positive ions created in avalanche near anode wire for coaxial geometry has the following time dependence:

$i(t) \sim 1/(1 + t/t_0)$, t_0 is a characteristic counter time, which depends on electric field near anode wire (V_a), anode wire radius (r_a), and ion mobility (μ): $t_0 = r^2_a/(4\mu CV_a)$ (~1 ns).

A charge-sensitive amplifier is following by an amplifier with differentiating time constant T_1 and integrating time constant T_2 with impulse response

$H(t) \sim (\exp(-t/T_1) - \exp(-t/T_2))$.

For T_1 and T_2 constant we have only guess (15 ns and 30 ns for inner, and 20 ns and 50 ns for outer sectors, respectively).

The output voltage is given by convolution i(t) with H(t):

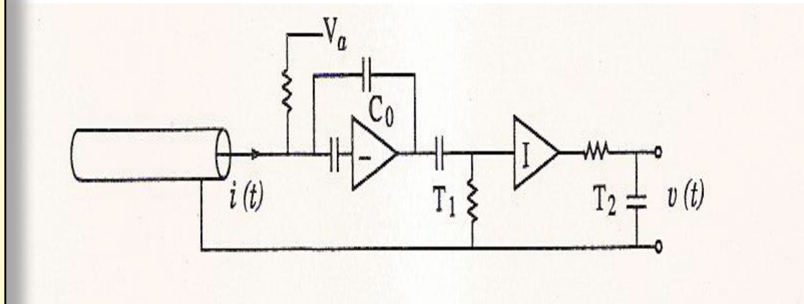
$v(t) \sim f(t,t_0,T_1) - f(t,t_0,T_2)$, where

$f(t,t_0,T) = \exp(-(t+t_0)/T) \int e^z/z \, dz$, in $z = [t_0/T,(t+t_0)/T]$.

Two pole tail cancellation (old TPC electronics) procedure:

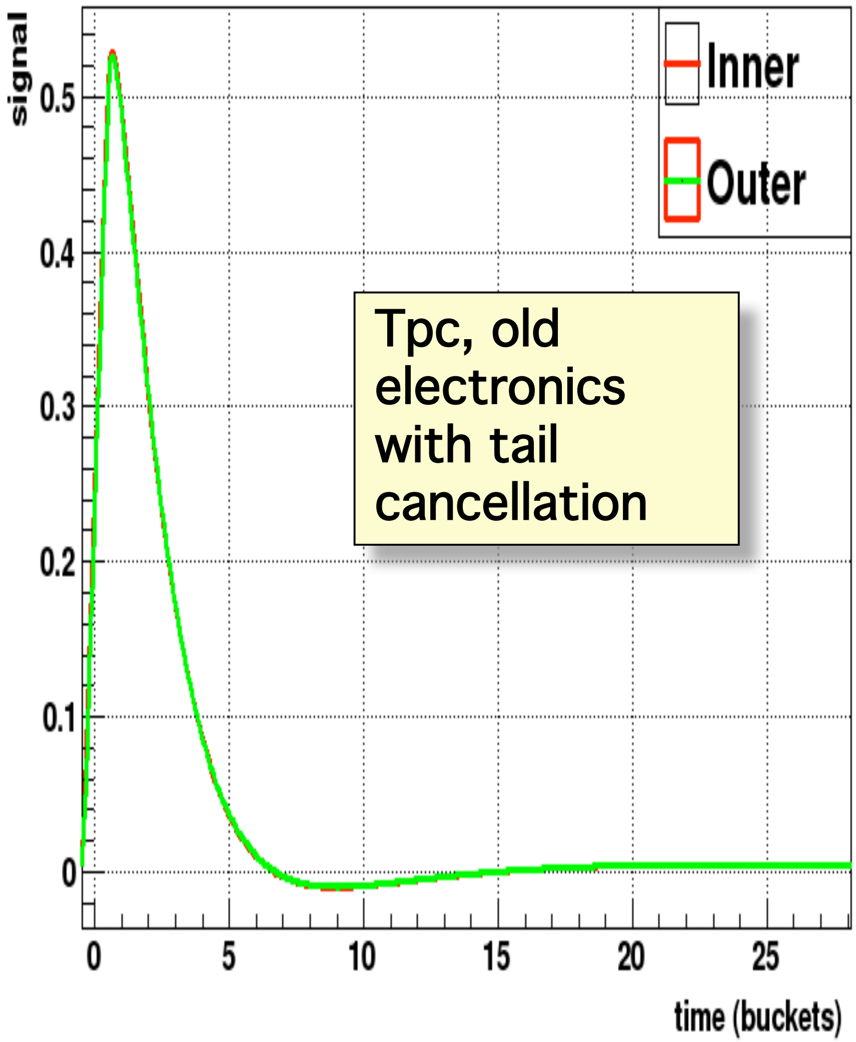
- $v(t)$ is approximated by $\Sigma^3_{i=1} A_i \cdot \exp(-t/\tau_i)$, and "shaper" removes 2-nd exponent:
- First of all after shaper still exists the 3-rd long exponent (~2% in amplitude).

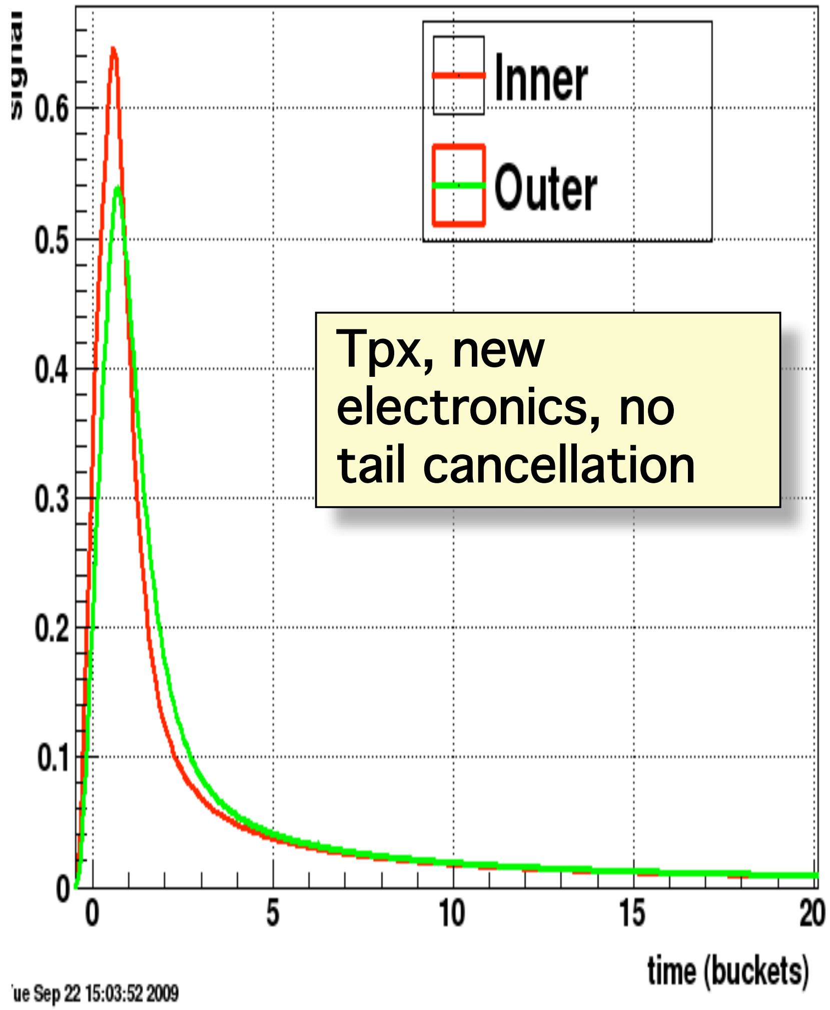
The comment: these 2-nd exponents are different for inner and outer sectors (due to ~10% difference in t_0).



	Inner sector	Outer sector
s, Anode wire spacing (cm)	0.4	0.4
h, Cathode Anode gap (cm)	0.2	0.4
Potential on anode wire (V)	1170	1390
r_C(cm) (Cylinder approx.)	0.306	1.473
E(V/cm)	1605.3	1496.5
t_0(ns)	1.08	1.16

Time development of anode charge





Induced charge distribution

Induced charge distribution is defined by geometry of cathode-anode gap via Gatti formula:

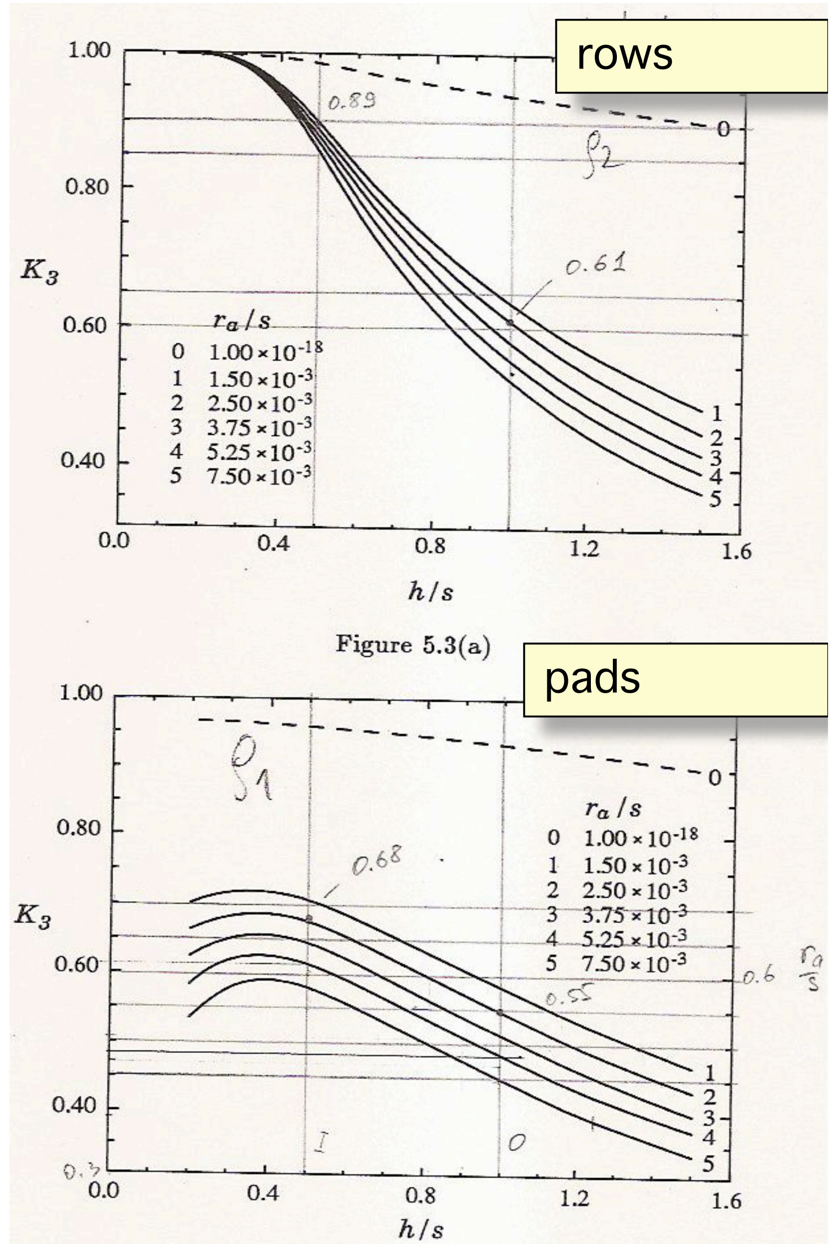
$\Gamma(\lambda) = K_1\,(1 - \tanh^2(K_2\,\lambda))/(1 + K_3 \tanh^2(K_2\,\lambda))$,

where

- $\lambda = x/h$, and h is anode cathode spacing,
- $K_1 = K_2 \sqrt{K_3}/(4 \tan^{-1}(\sqrt{K_3}))$,
- $K_2 = \pi/2(1 - (\sqrt{K_3})/2)$.

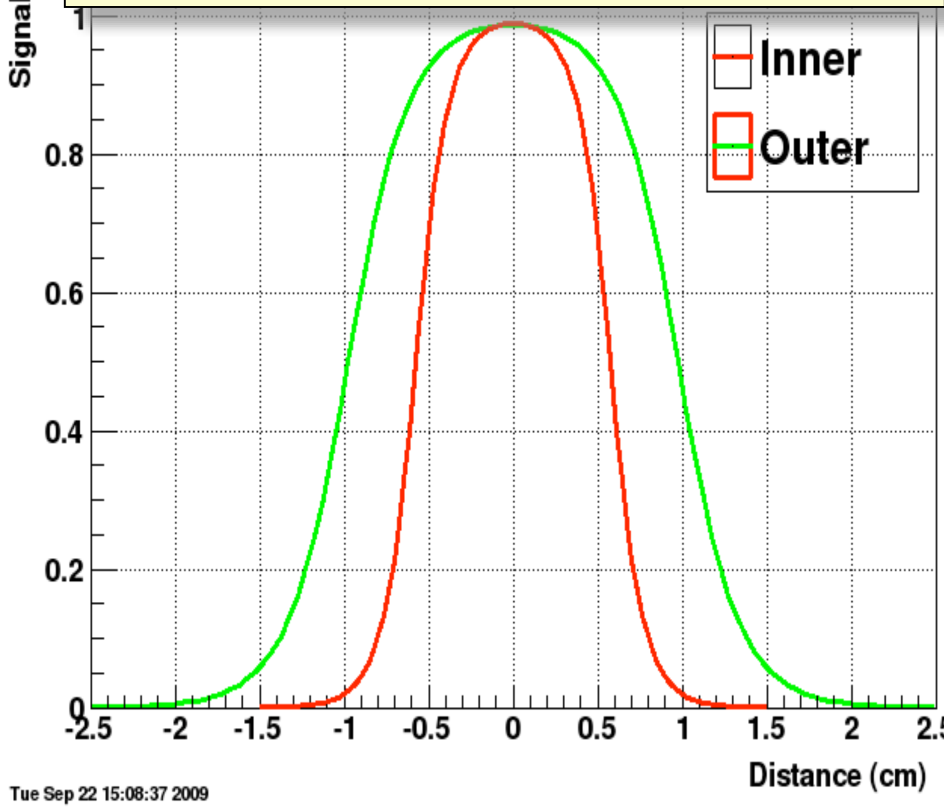
• K_3 does depend on h/s (h = Cathode Anode gap, s = Anode wire spacing) and r_a/s (r_a = anode wire radius = 10 μm)

	inner	outer
h/s	0.5	1
r_a/s	2.5×10^{-3}	2.5×10^{-3}
K_3, pads	0.68	0.55
K_3, rows	0.89	0.61

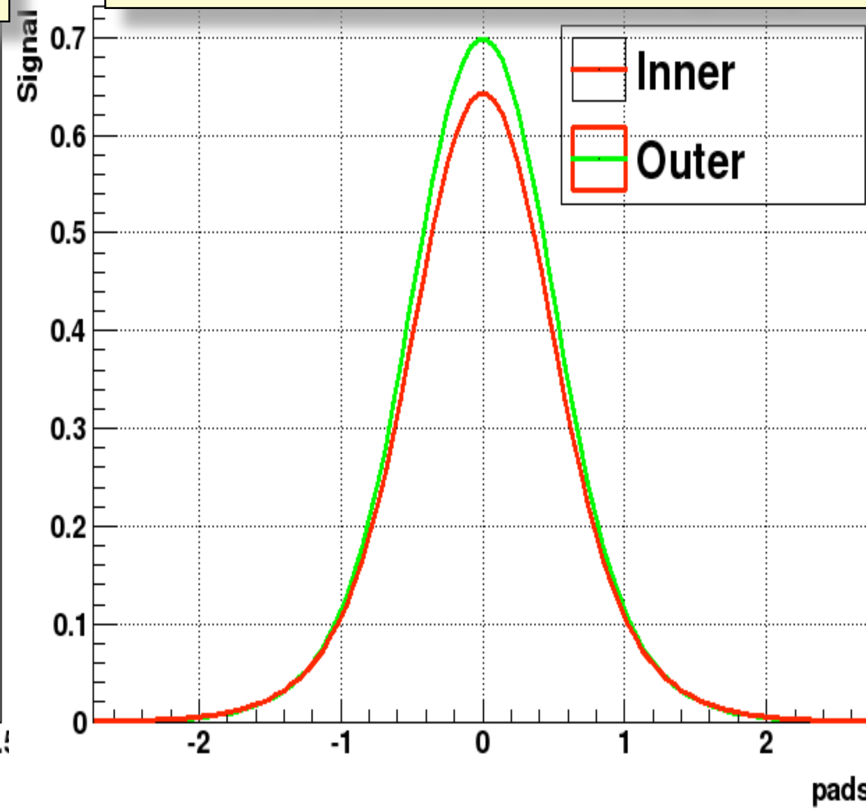


Induced charge (cont.)

Charge induced on row versus distance to pad row center from avalanche (cm)



Charge induce on pad versus distance to center of pad from avalanche (pads)



Induced charge on a given pad row includes charge coming before and after the pad row (equipped pad readout is ~1 cm for inner and ~2 cm for outer sectors, respectively). This brings up two issues:

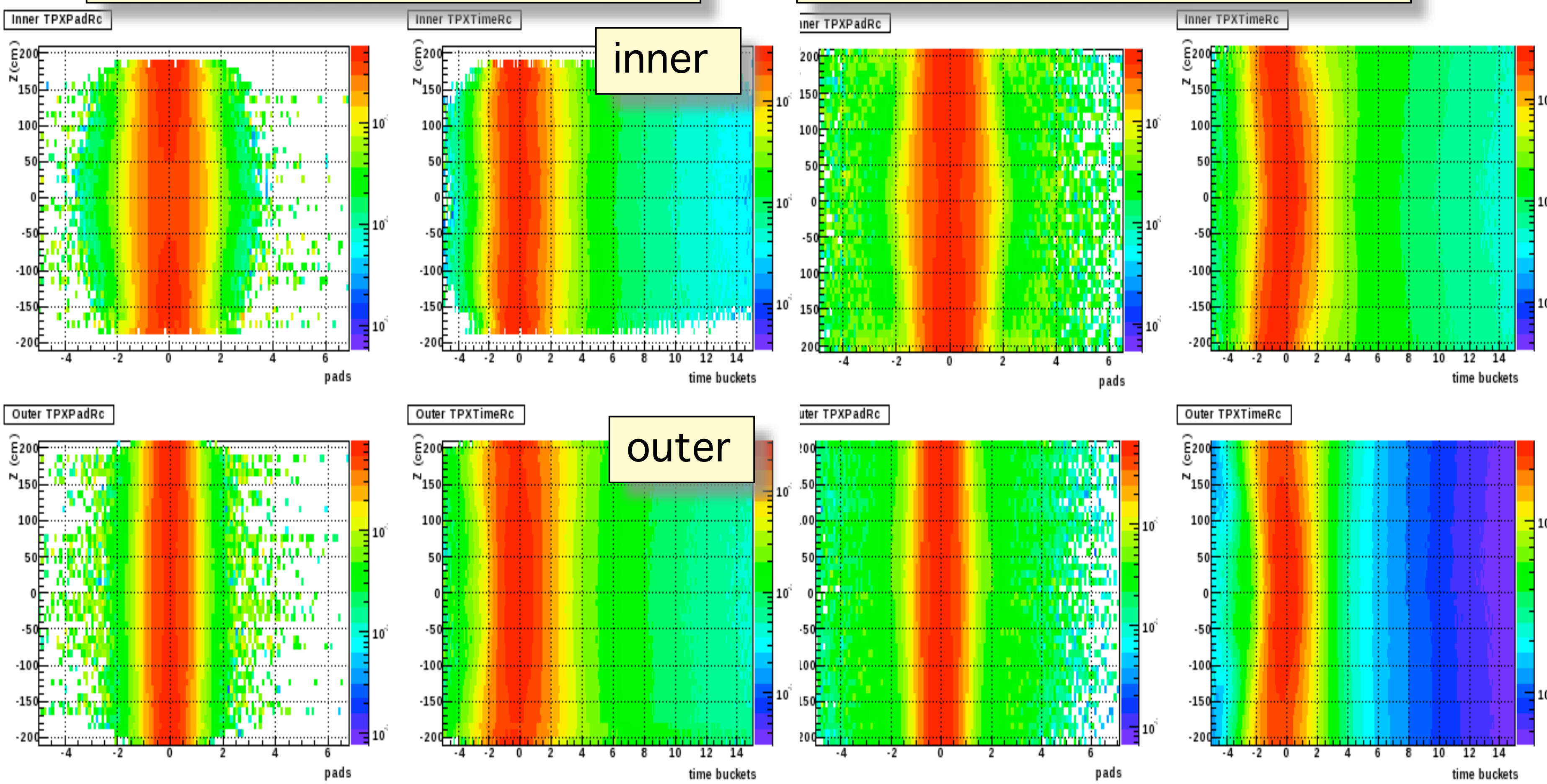
- For outer sectors (where pad rows are very close to each other) there is ~25% correlation in charge collected in neighbor pad rows.
- For inner sector there is essential contribution from wires which are not equipped by pad readout (pseudo pad rows). Thus it is necessary to account charge coming from pseudo pad rows.

Comparison with real data

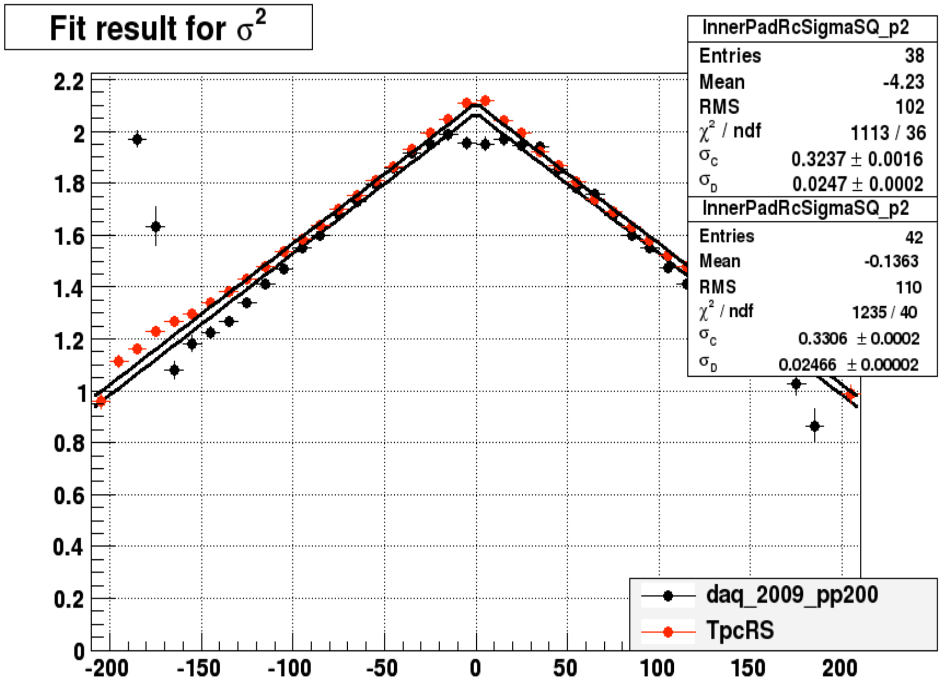
Profile histogram with weight $A_i/\Sigma A_i$ (where A_i is ADC count for a given pixel) versus distance of pixel (pad or time bucket) from cluster position and Z of cluster. The clusters were selected by:

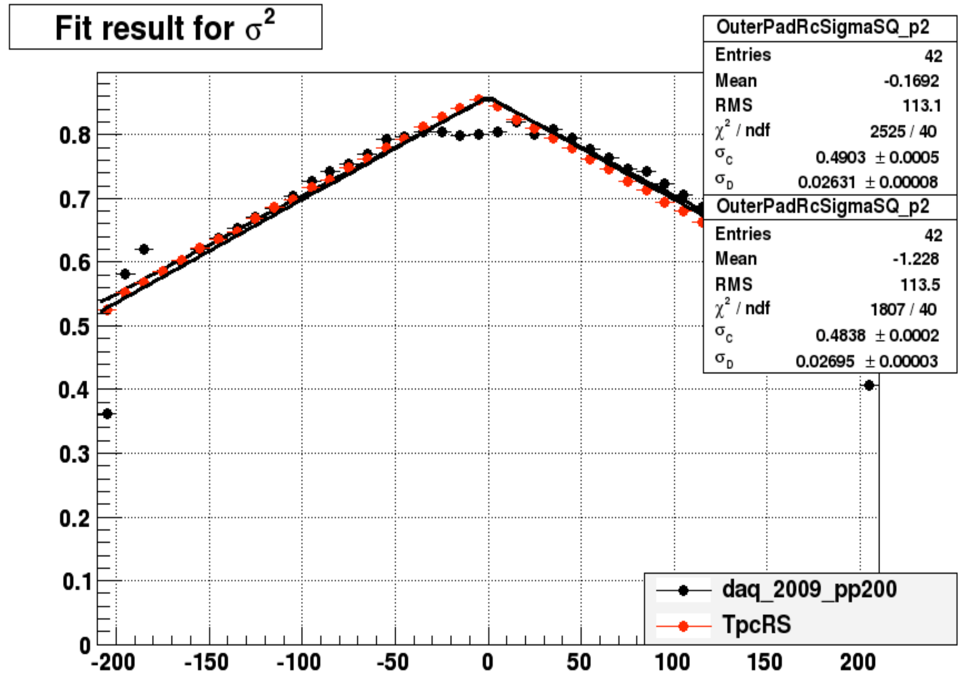
- used in primary track fit,
- track reconstructed p⊥ in range [0.4,0.6] GeV/c (~ MIP for π),
- Primary vertex |Z| < 20 cm.
- Full set of plots can be found at http://www4.rcf.bnl.gov/~fisyak/star/Tpc/TpcRS/Y2009H/Shape/

Data (y2009) pads time **Simulation (TpcRS)** pads time



Induced charge on pads, transverse diffusion

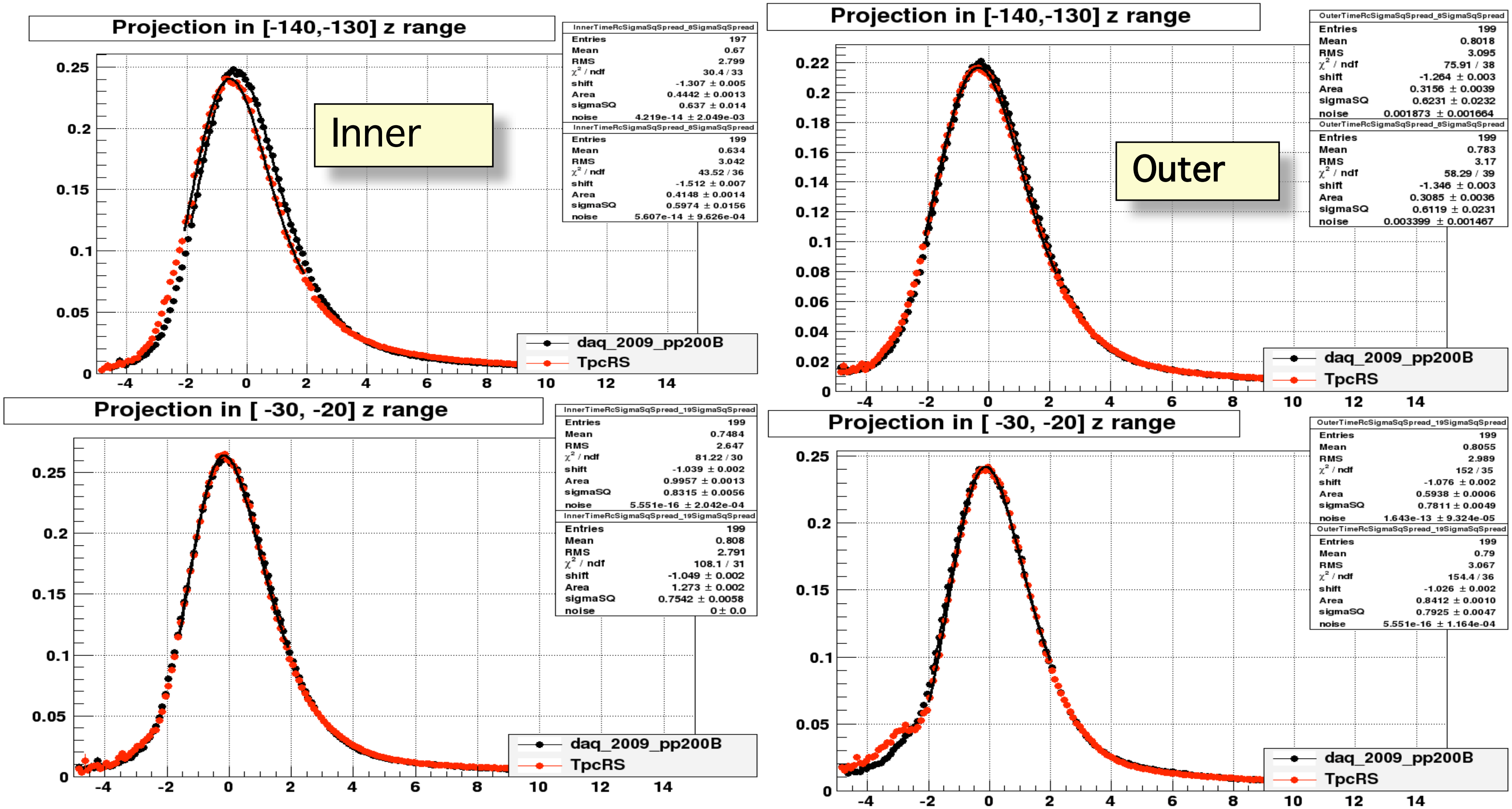




- The above plots represents σ^2 of fit slices of the above pad distribution by Gatti function convoluted with Gaussian (with σ) in Z. Lines are result of fit : $\sigma^2 = \sigma^2_c + \sigma^2_d \times (209.3 - |Z|)$
  - diffusion constant $\sigma_d^{Data} = 255 \pm 5$ µm•cm$^{-1/2}$ pretty well matched with $\sigma_d^{MC} = 258 \pm 6$ µm•cm$^{-1/2}$,
  - differences in constant terms for
    - inner $\sigma_c^{Data} = 0.325$ cm and $\sigma_c^{MC} = 0.330$ cm and
    - outer $\sigma_c^{Data} = 0.490$ cm and $\sigma_c^{MC} = 0.484$ cm

  are explained by difference in cathode - anode gap where applied Lorentz forces.
- Pad distributions are adequately described by simulation.

Time development



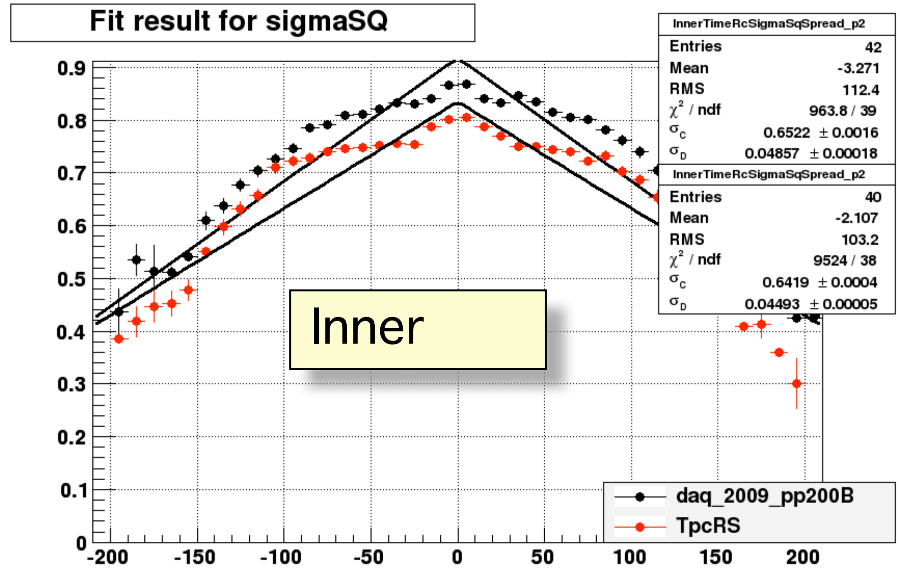
The match between data and MC near TPC membrane is pretty good.

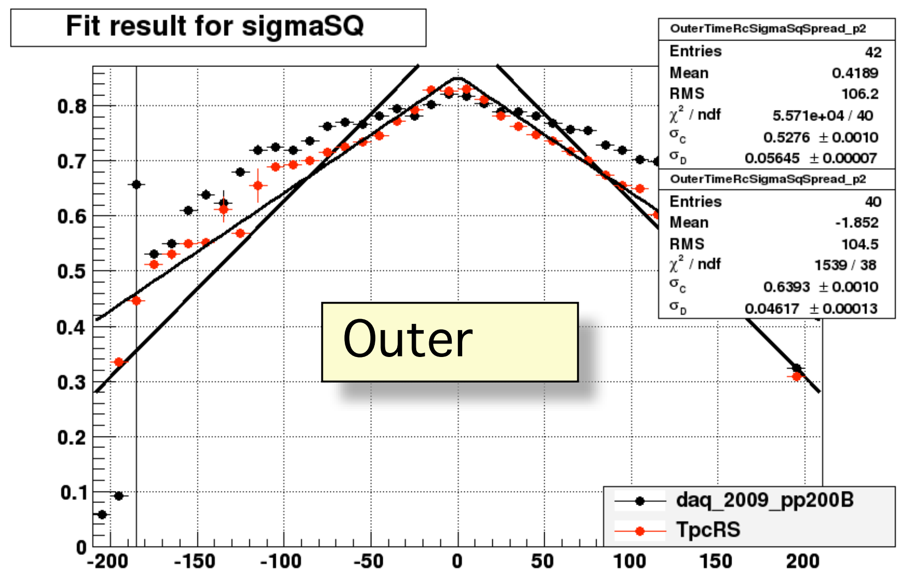
Near endcap there is a problem, MC has longer tail. This issue has to be revisited after applying calibration to MC.

Time Development (cont.)

As some guidance we can compare σ obtained by assuming Gamma distribution for diffusion convoluted with spread in z (projection of track on pad row) and TPC signal shape in time (~ $1/(1 + t/t_0)$). For fit only central 75% of signal has been used.

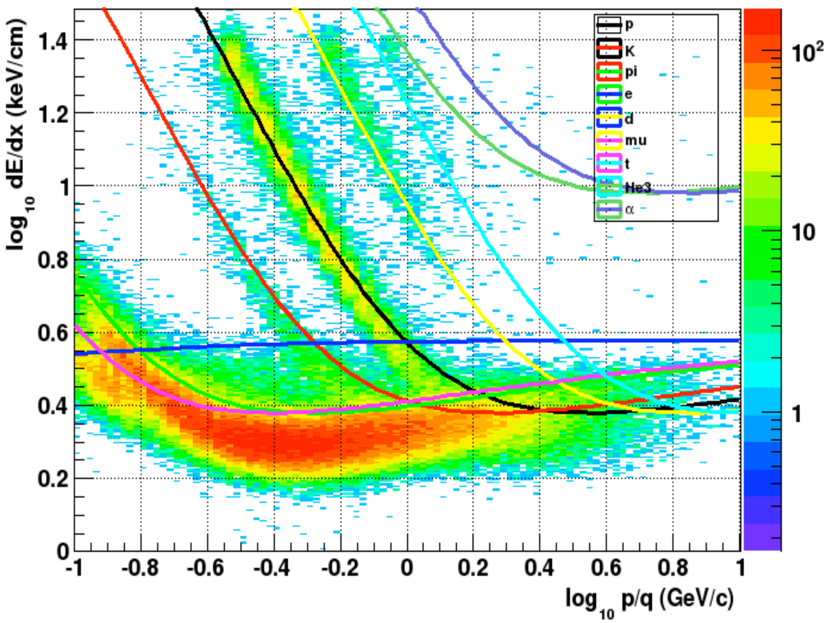
Data and simulation are compatible but it requires more tuning after applying calibration to simulation.



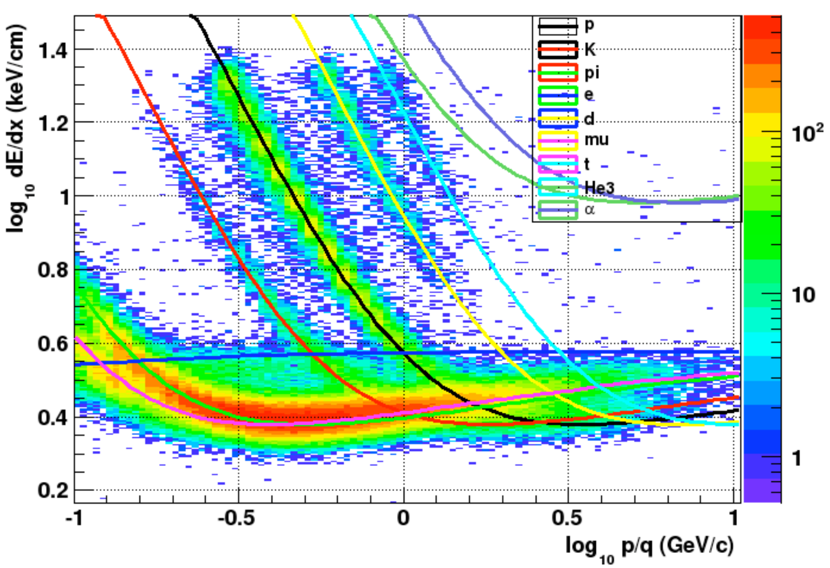


Adc nonlinearity

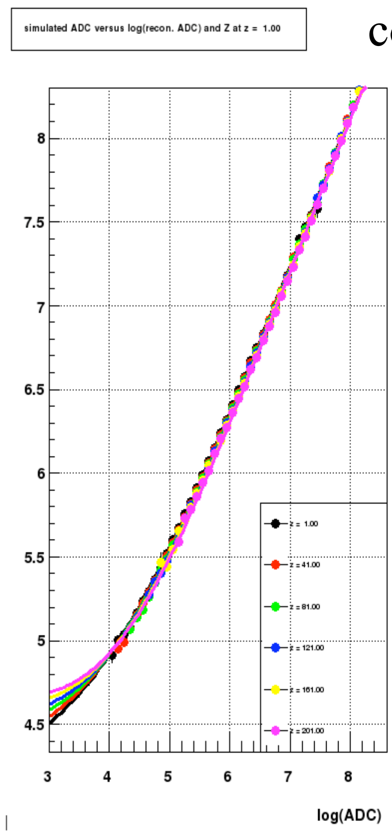
Before correction

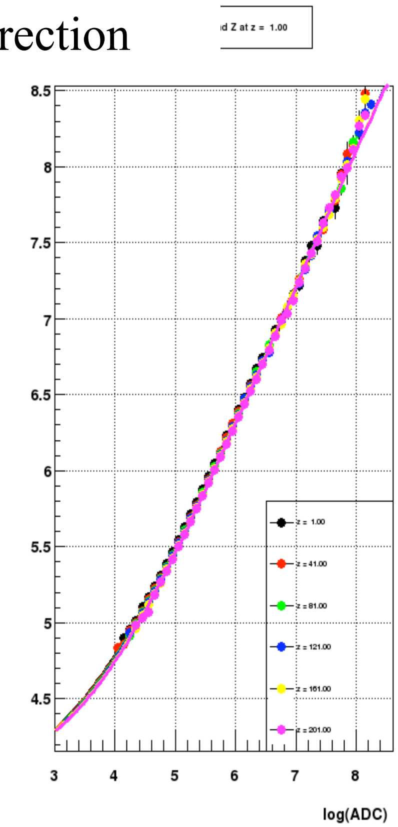


After correction



correction





- Effects of thresholds in cluster finder on reconstructed cluster charge can be seen from comparison distribution of dE/dx versus p/q with Bichsel's model prediction. We can see a pretty good match for kaons, protons and deuterons but there is an obvious offset for pions.
- Correction is done by using difference between cluster charge (q) simulated and reconstructed q versus reconstructed q and Z position of cluster.

Pads (RC versus MC)

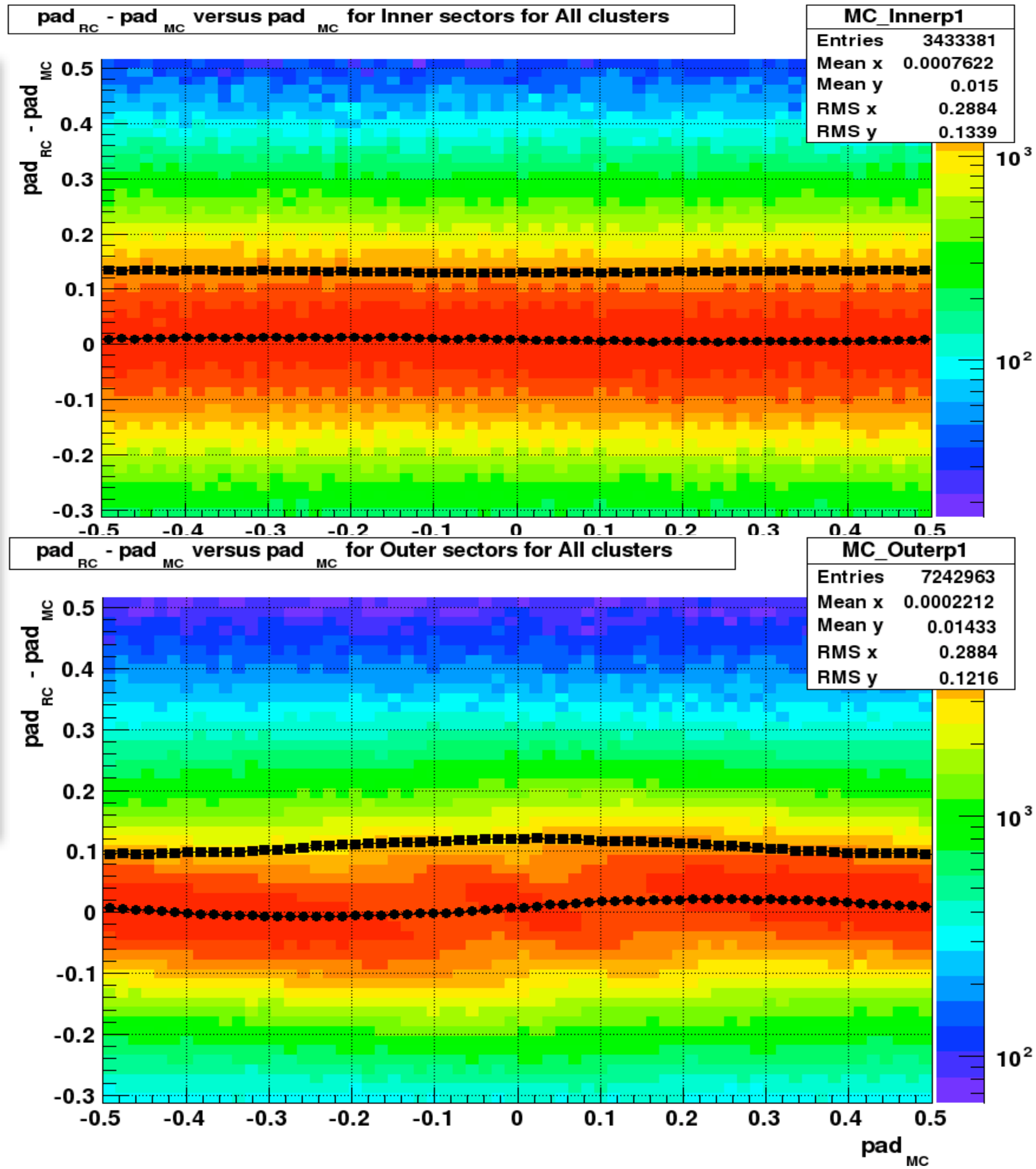
pad_{RC} reconstructed cluster position,

pad_{MC} cluster position of GEANT hit

Markers represent results of slice fit by Gaussian for

μ and σ.

Full set of plots can be found at
http://www4.rcf.bnl.gov/~fisyak/star/Tpc/TpcRS/Y2009H/Pads/MC.html



Pads (MC versus RC)

- Full set of plots at http://www4.rcf.bnl.gov/~fisyak/star/Tpc/TpcRS/Y2009H/Pads/RC.html

Tpc resolution (see http://www4.rcf.bnl.gov/~fisyak/star/CHEP2007/SVT_Alignment_JPCSL.pdf)

$\sigma_{\rho\varphi}$=0.6 mm for Inner and

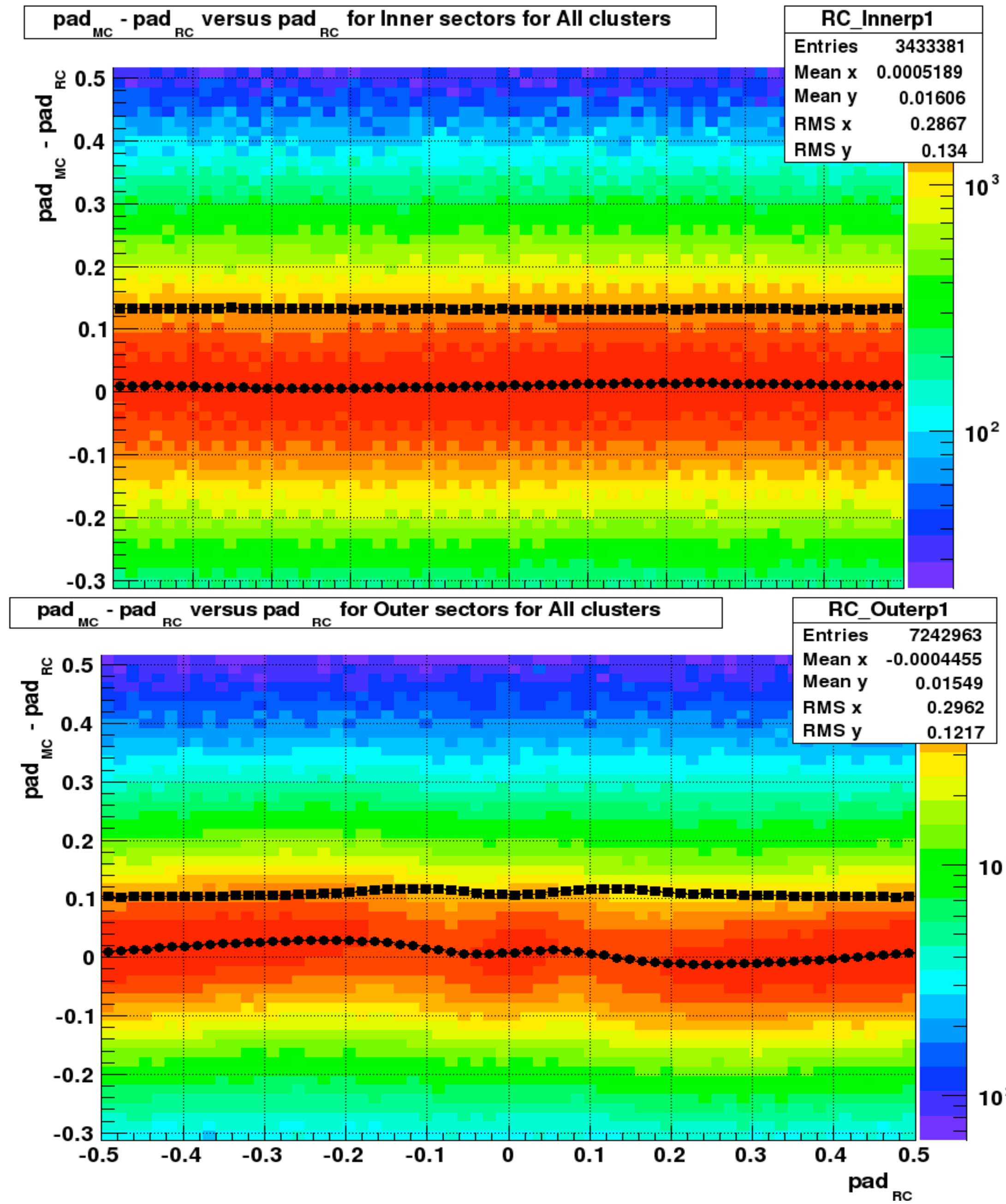
1.2 mm for Outer sectors

Ultimate resolutions from these plots are

$\sigma_{\rho\varphi}$=0.14 pad = 0.14 • 3.35 mm = 0.5 mm for Inner

$\sigma_{\rho\varphi}$=0.1 pad = 0.1 • 6.75 mm = 0.7 mm for Inner

Thus we have some room for increasing our precision especially for Outer sector.



Conclusions

- A reasonable description of new TPC electronics in TpcRS simulator has been achieved
- It has obtained cluster charge correction (Adc non linearity correction) which we can be used for run IX data dE/dx calibration.
- One more pass with fine tuning of TpcRS is required after applying dE/dx calibration to simulation.
- There is a possibility to extract spatial correction for clusters due to systematics in pad coordinate measurements.
- The package is ready to be released and used for simulation and embedding.