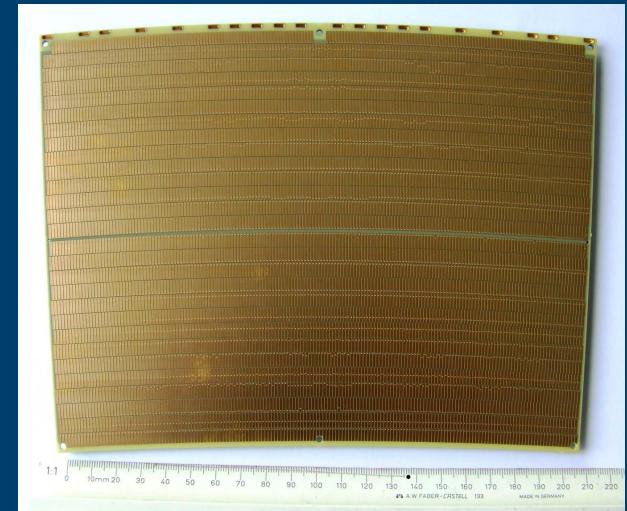
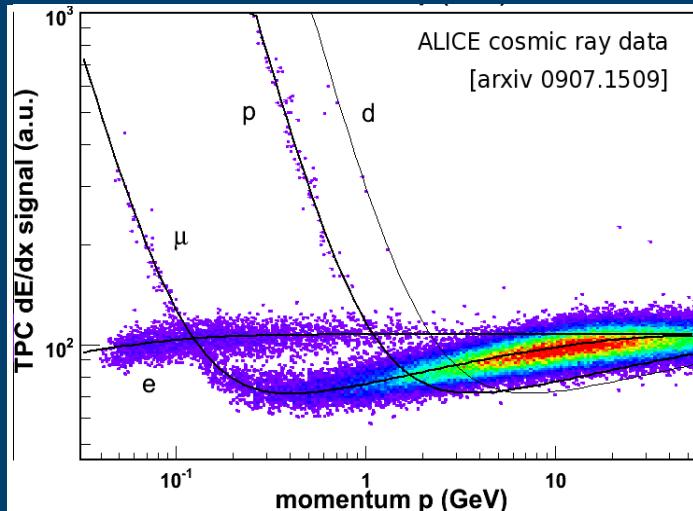
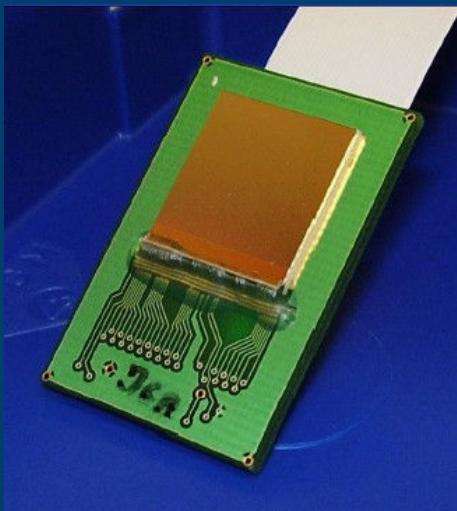


Pad side studies.

Annika Vauth

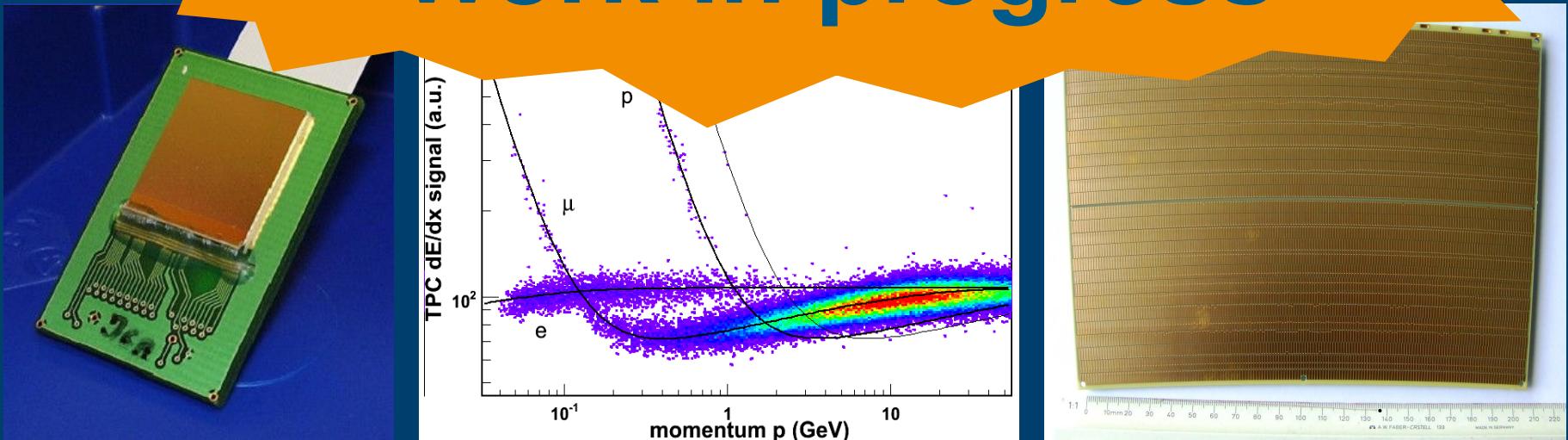


FLC group meeting
Hamburg, 01.06.15

Pad side studies.

Annika Vauth

Work in progress



FLC group meeting
Hamburg, 01.06.15

Introduction

Simulation

dE/dx

Hardware

Outlook

Introduction

Simulation

dE/dx

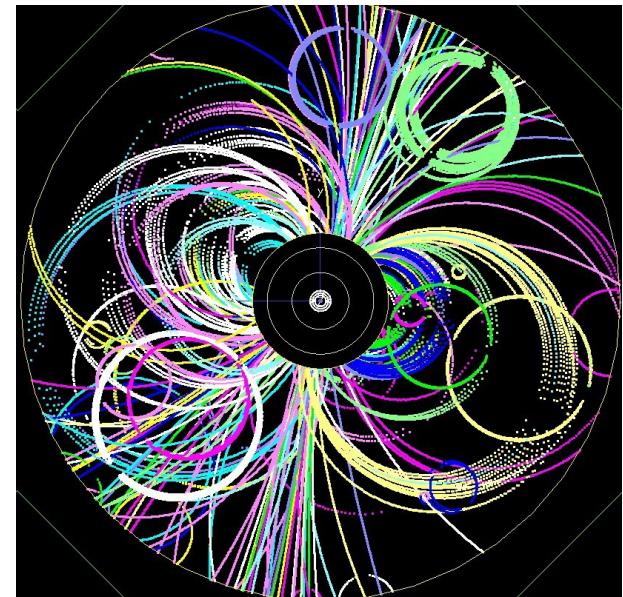
Hardware

Outlook

ILD TPC.

ILC TDR Requirements:

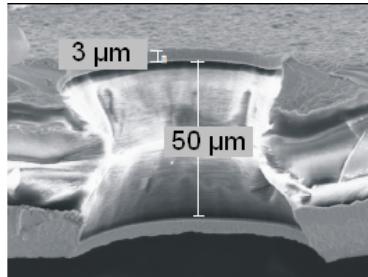
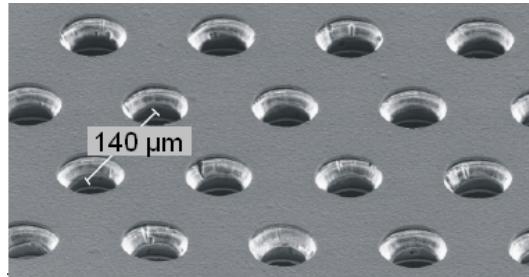
- ▶ **Tracking efficiency**
close to 100% down to
low momenta for Particle Flow
 ≈ 200 position measurements along
each track in TPC
- ▶ **Minimum material**
in front of calorimeter
TPC: less than $0.05X_0$ (barrel)
 $/ 0.35X_0$ (endcaps)
- ▶ **Momentum resolution**
 $\sigma(1/p_t) = 2 \times 10^{-5} / \text{GeV}$
(TPC alone $10^{-4} / \text{GeV}$)
single point resolution $\sigma_{r\phi} < 100 \mu\text{m}$



Detector options.

Different types of Micro-Pattern Gas detectors considered

- ▶ Micro-Mesh Gaseous Detectors (MicroMeGas)
- ▶ Gas Electron Multipliers (GEM)



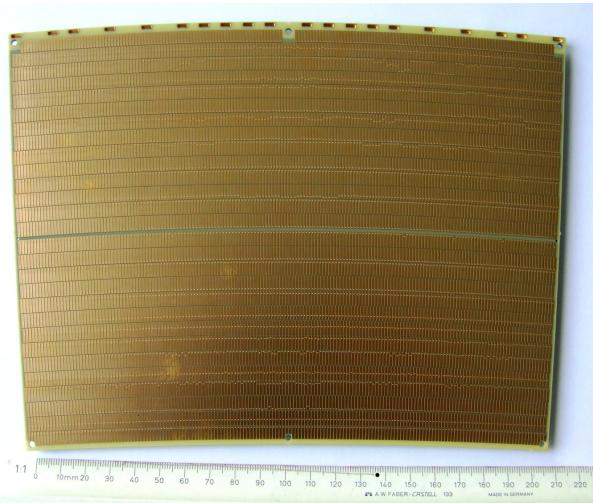
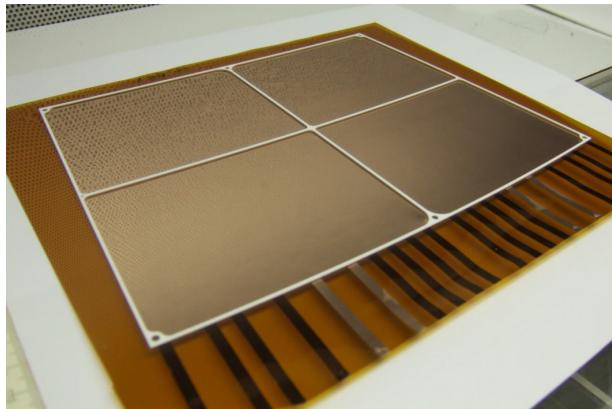
F. Sauli, NIM A386 1997

Different readout options

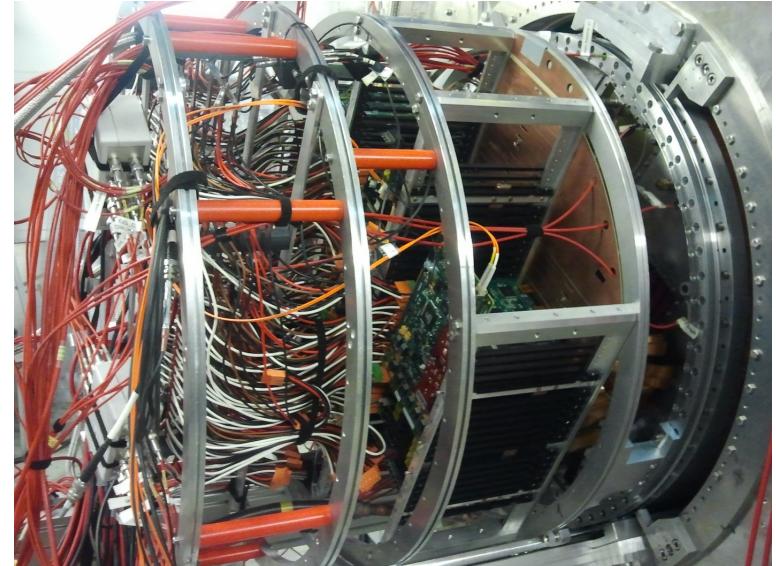
- ▶ anode plane with **pads**
- ▶ pixel readout

GEMs with Pads.

DESY GEM module:
Triple GEM stack



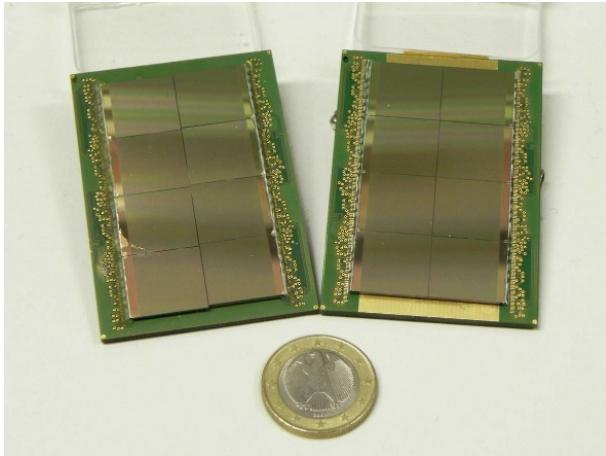
ALTRON readout electronics
 \approx 10000 channels



(planned: replace with SALTRO)

Pixel Readout.

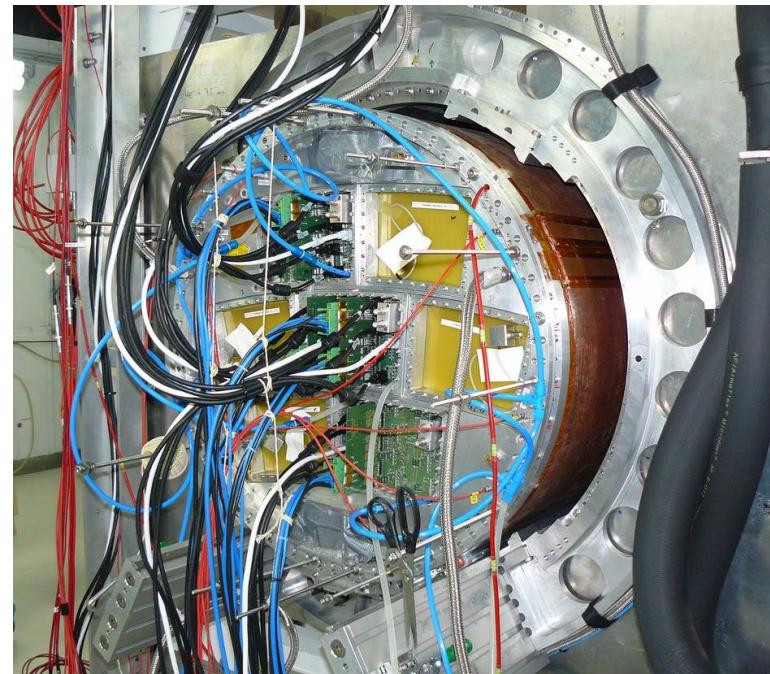
Bump bond pads for Si-pixel detectors as charge collection pads
Octoboards with Timepix chips
readout (+ water cooling)



M. Lupberger, RD51 12/2014



M. Lupberger, LCTPC 04/2015



M. Lupberger, LCTPC 04/2015

ILD TPC.

How do current readout concepts scale to ILD TPC?

ILD TPC:

size of endcaps: $\sim 10 \text{ m}^2$

module size $\sim 17 \times 23 \text{ cm}^2$

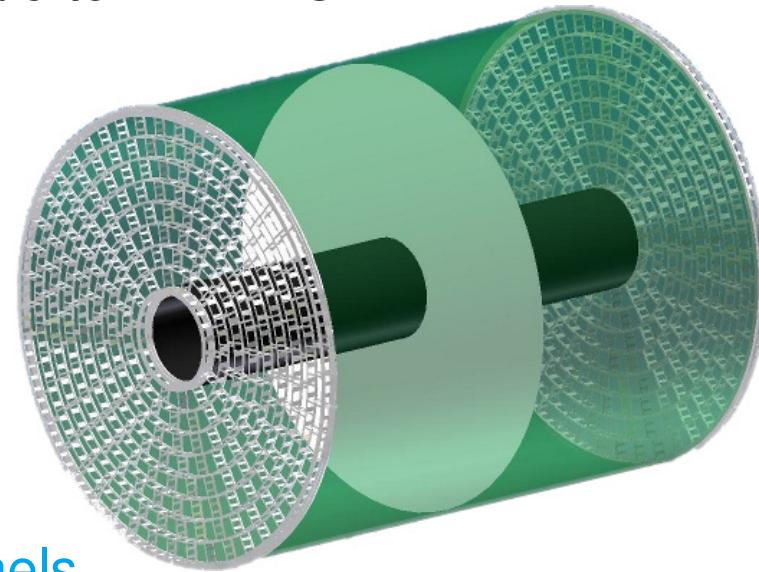
\rightarrow 240 modules per endcap

with $1 \times 6 \text{ mm}^2$ pads: $\sim 4 \cdot 10^6$ channels

with ~ 100 chips per module \rightarrow 50,000 chips

$\sim 3 \cdot 10^9$ channels!

for comparison: STAR TPC $\sim 135,000$, ALICE TPC $\sim 570,000$



Cornell University (2010)

Pad size.

How granular should the readout be?

Extrapolation from prototype data with pad size $1.25 \times 5.85 \text{ mm}^2$:
single point resolution $\sigma_{r\phi} < 100 \mu\text{m}$ possible.

If we could have any pad size we wanted: what would be optimal?

- spatial resolution
- double track resolution
- low occupancy → better track finding, δ & kink identification?
- dE/dx (possible improvement with cluster counting?)

Introduction

Simulation

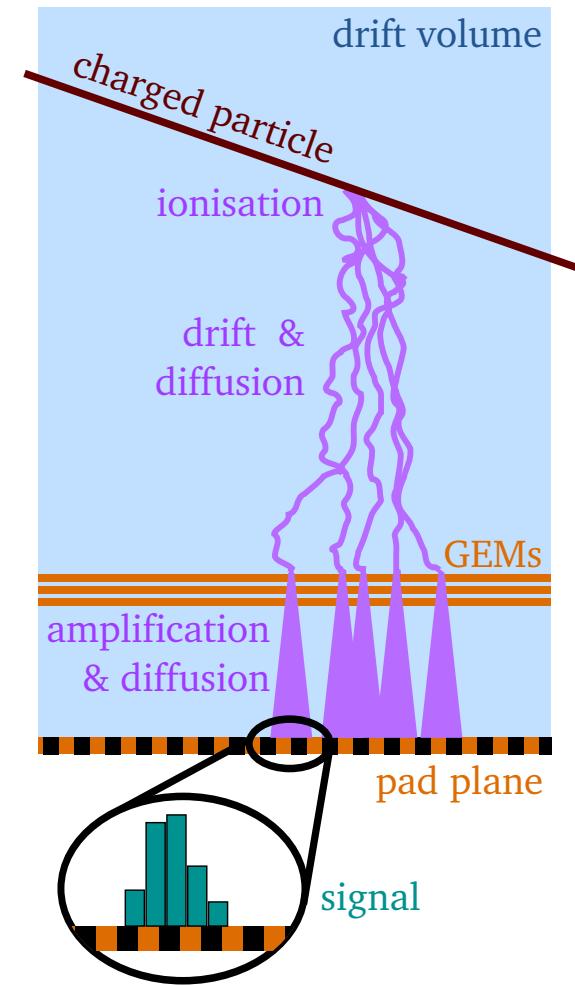
dE/dx

Hardware

Outlook

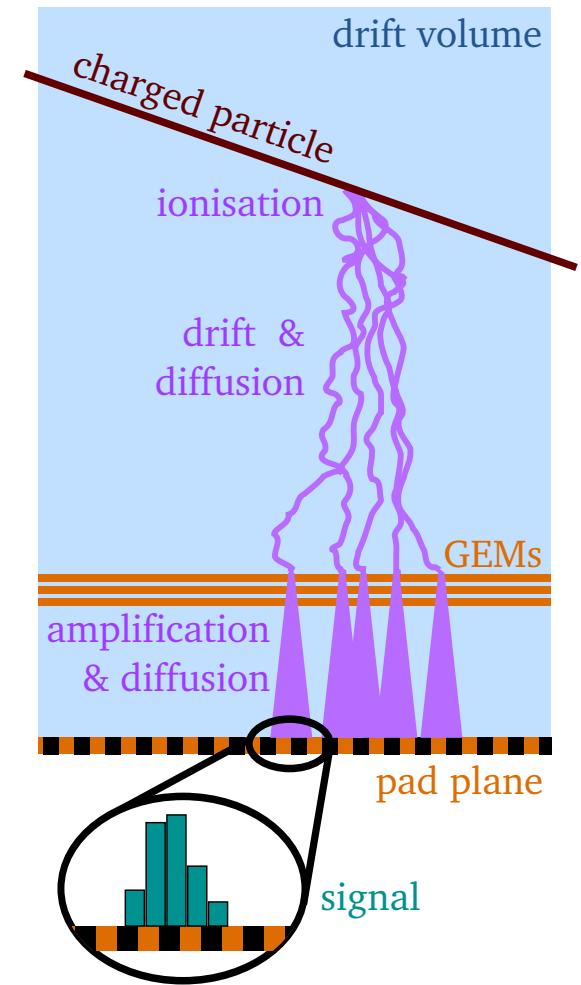
Simulation with MarlinTPC.

0. electrons (pion/kaon/...) track
1. primary ionisation
2. drift
3. amplification with GEMs
4. pad plane
5. electronics
6. reconstruction & analysis



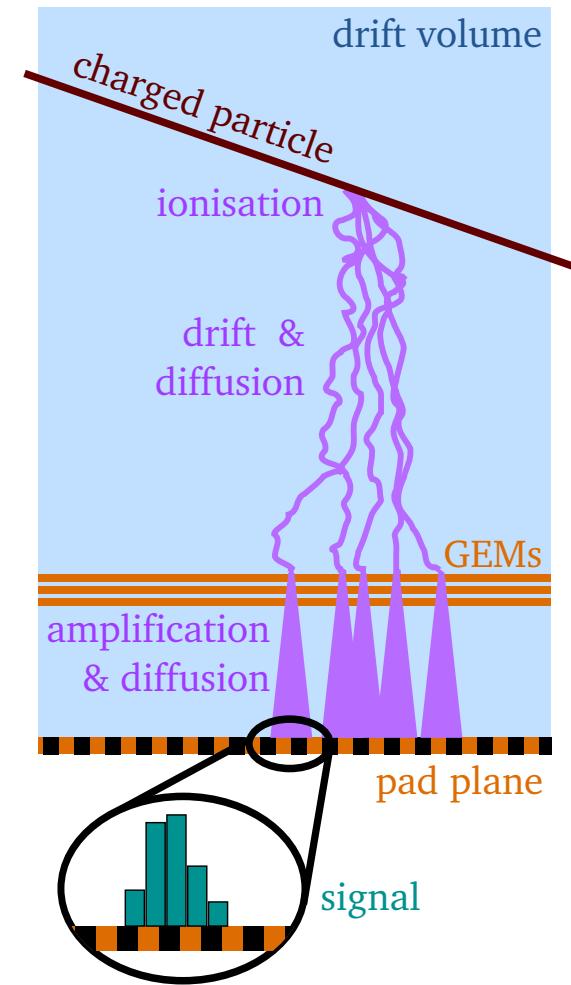
Simulation with MarlinTPC.

0. electrons (pion/kaon/...) track
1. primary ionisation: generate electrons along track according to parametrizations obtained with HEED
2. drift
3. amplification with GEMs
4. pad plane
5. electronics
6. reconstruction & analysis



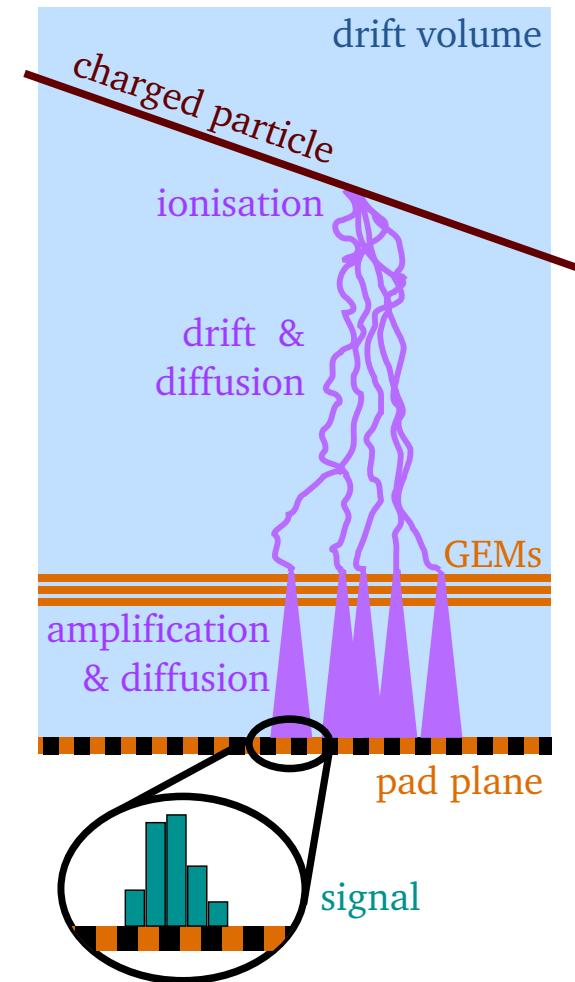
Simulation with MarlinTPC.

0. electrons (pion/kaon/...) track
1. primary ionisation
2. drift these electrons through gas based on gas properties obtained from a parametrization of MAGBOLTZ simulations
3. amplification with GEMs
4. pad plane
5. electronics
6. reconstruction & analysis



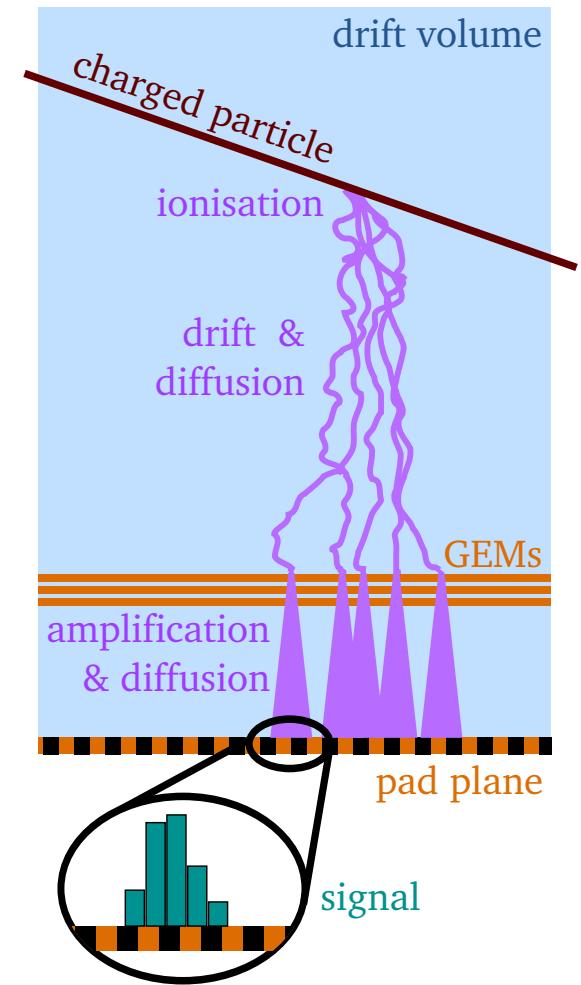
Simulation with MarlinTPC.

0. electrons (pion/kaon/...) track
1. primary ionisation
2. drift
3. amplification with GEMs: charge transfer in the GEM stack, different options to model gain, ...
4. pad plane
5. electronics
6. reconstruction & analysis



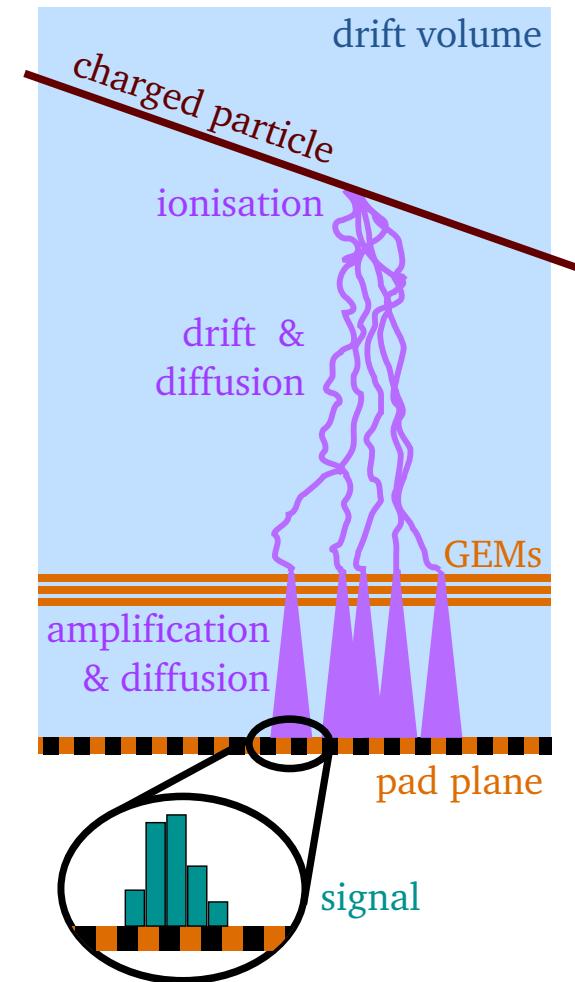
Simulation with MarlinTPC.

0. electrons (pion/kaon/...) track
1. primary ionisation
2. drift
3. amplification with GEMs
4. pad plane: distribute charge cloud
(two dimensional Gaussian with a width given by diffusion in the GEM stack)
5. electronics
6. reconstruction & analysis



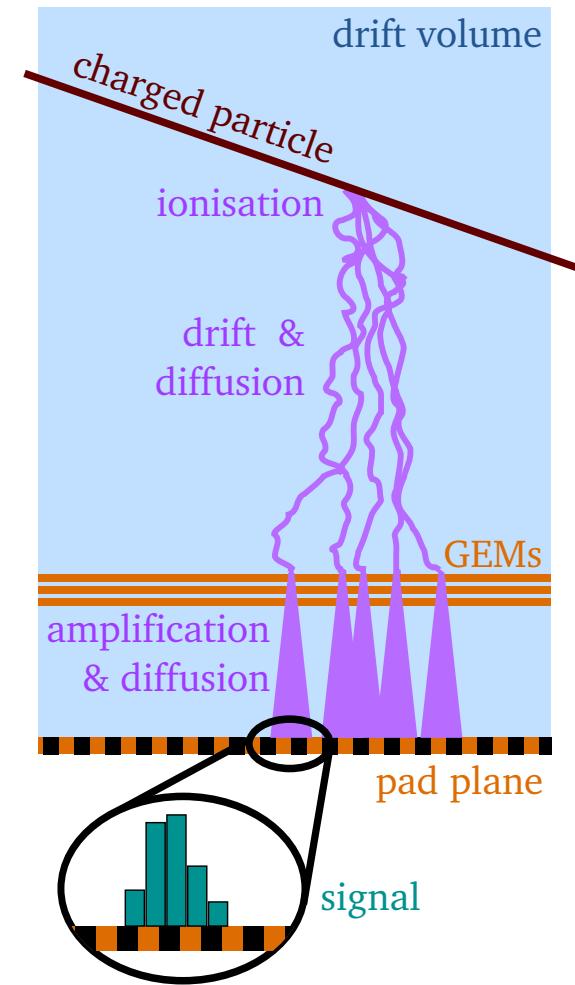
Simulation with MarlinTPC.

0. electrons (pion/kaon/...) track
1. primary ionisation
2. drift
3. amplification with GEMs
4. pad plane
5. electronics: simulation of the shaper and ADC
6. reconstruction & analysis



Simulation with MarlinTPC.

0. electrons (pion/kaon/...) track
1. primary ionisation
2. drift
3. amplification with GEMs
4. pad plane
5. electronics
6. reconstruction & analysis: same chain as for raw data

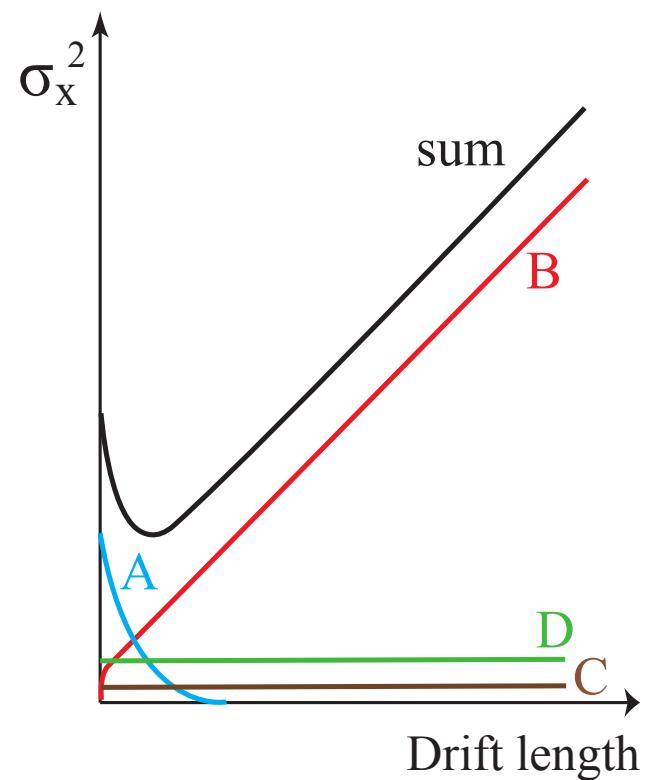


Alternative simulation.

Alternative to study the spatial resolution:

Code by Ryo Yonamine,
using analytic formula to predict resolution

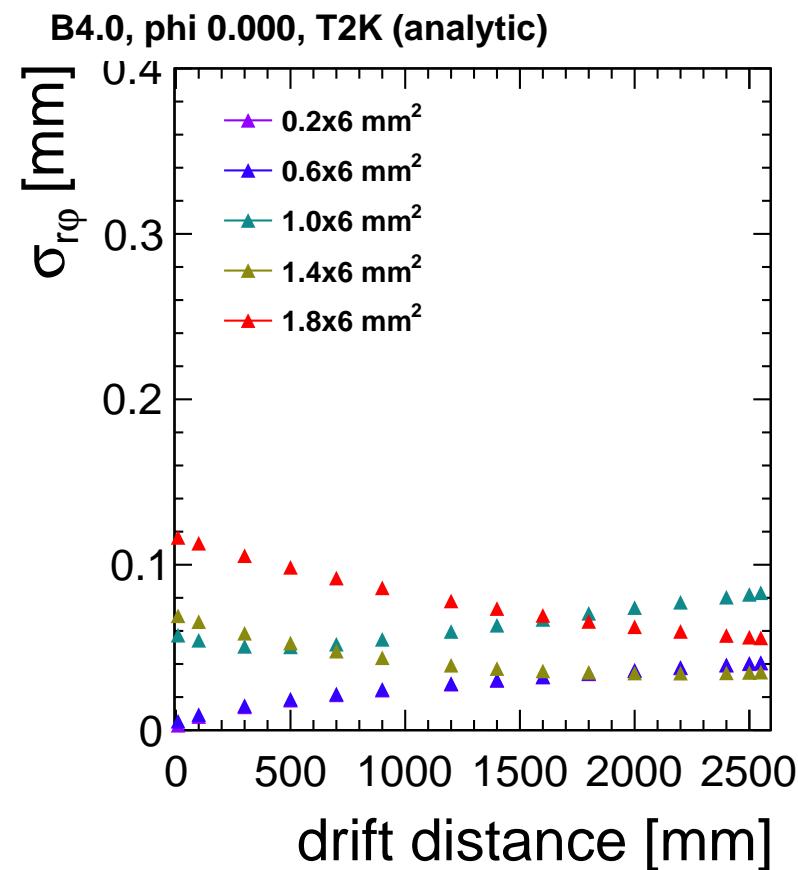
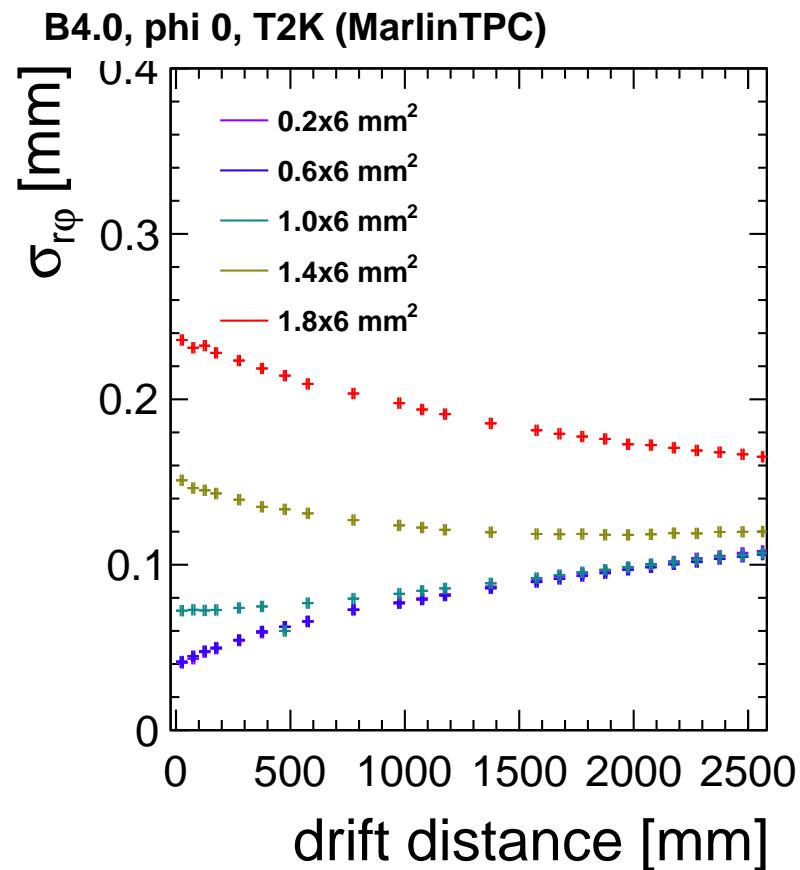
- (A) systematics due to finite pad size
- (B) diffusion effects
- (C) noise term
- (D) primary cluster fluctuation
(depending on ϕ)



Also: option to add crosstalk & pulse threshold
→ “Monte Carlo version“ of the code

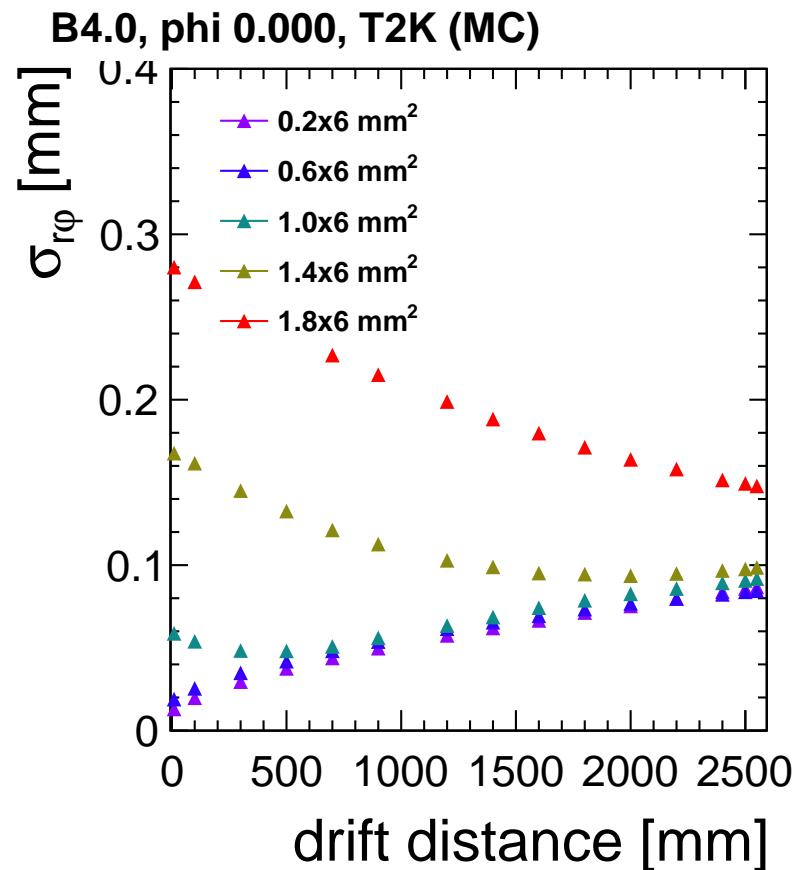
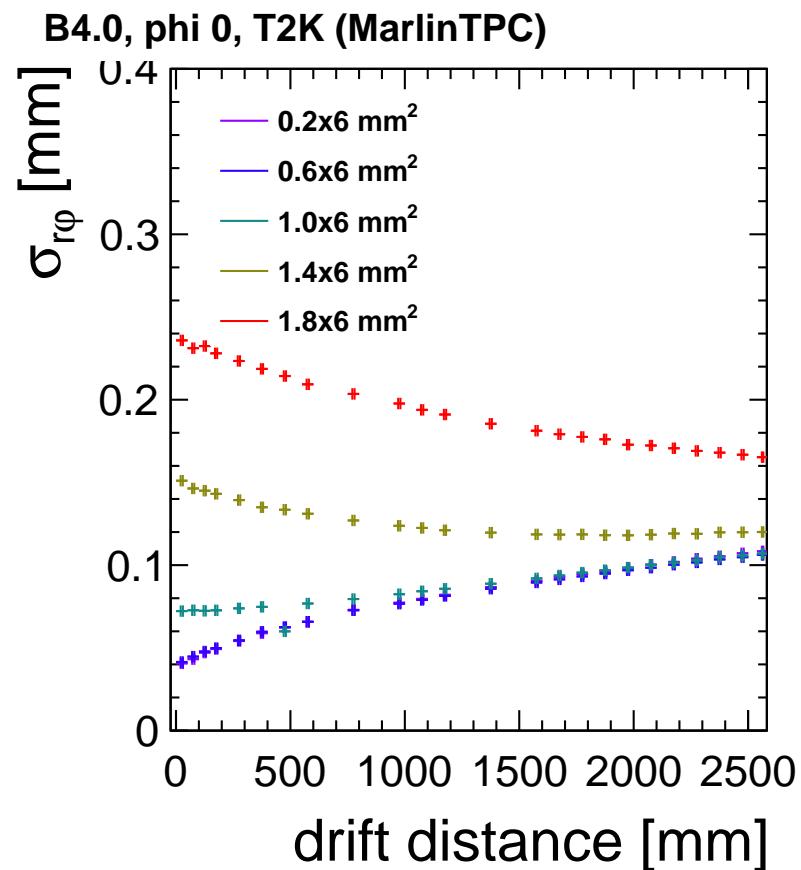
Simulation comparison (T2K 4T).

Comparison MarlinTPC / Ryo's code for analytic calculation



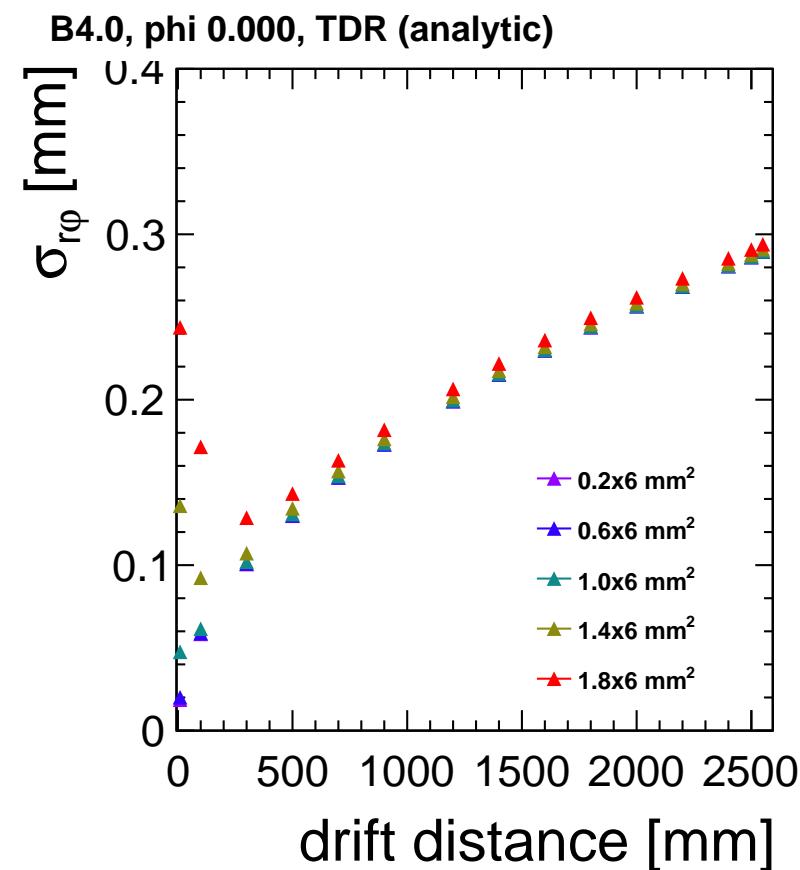
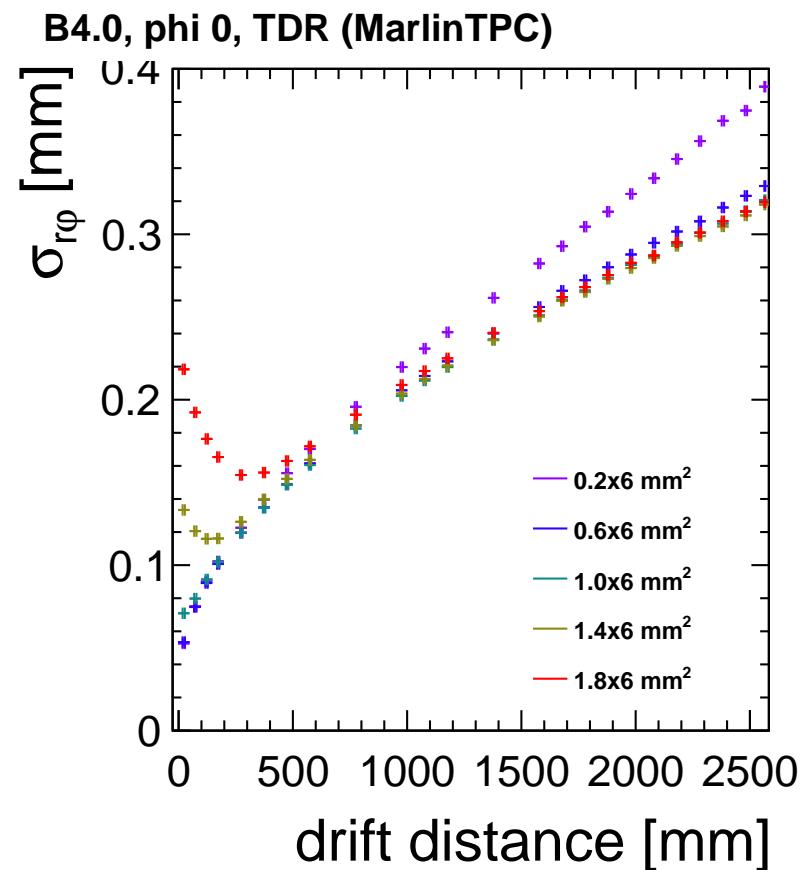
Simulation comparison (T2K 4T).

Using the Monte Carlo version (=with threshold effects and noise):



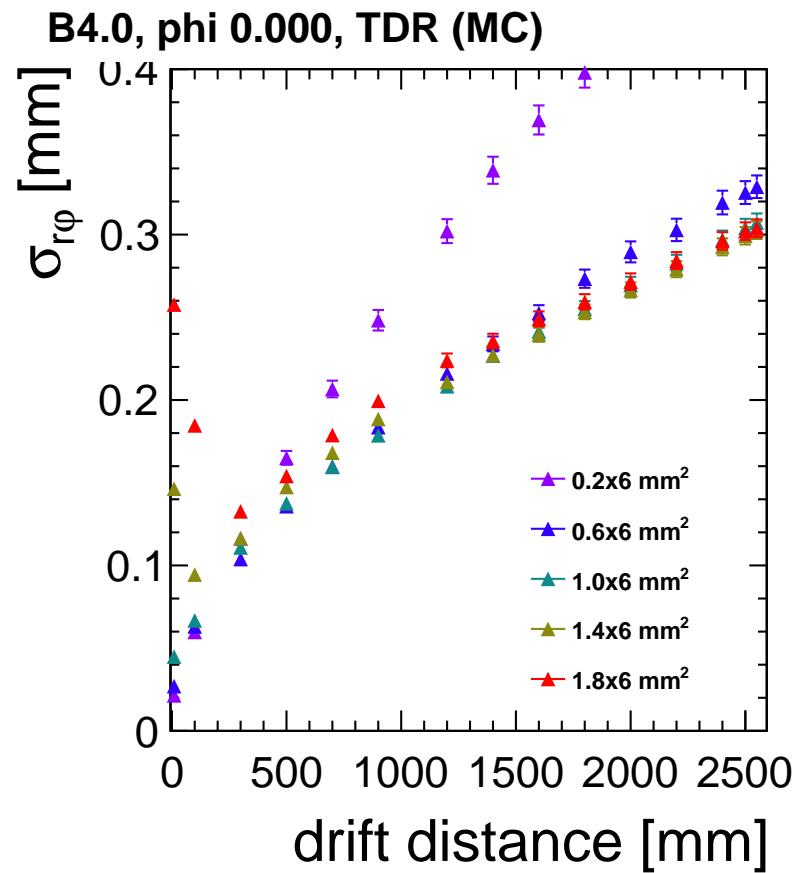
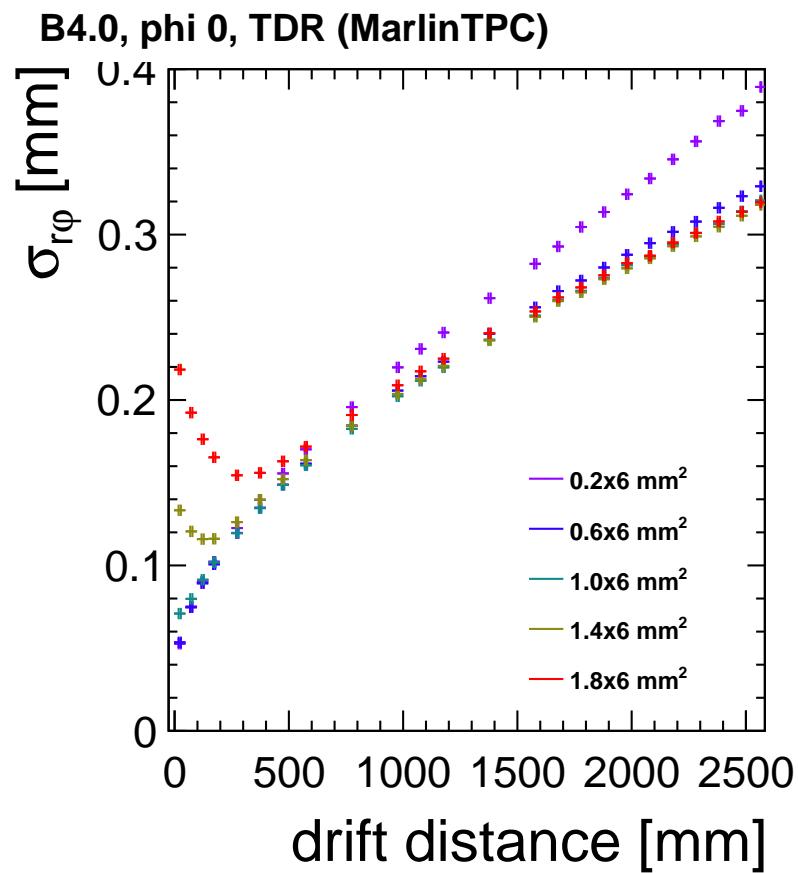
Simulation comparison (TDR 4T).

The same for TDR gas



Simulation comparison (TDR 4T).

Monte Carlo version:



Simulation comparison.

- ▶ Still some differences - lots of parameters to be tuned...

Felix working on this to describe Testbeam data: find correct values for gain factor, include systematics, ...

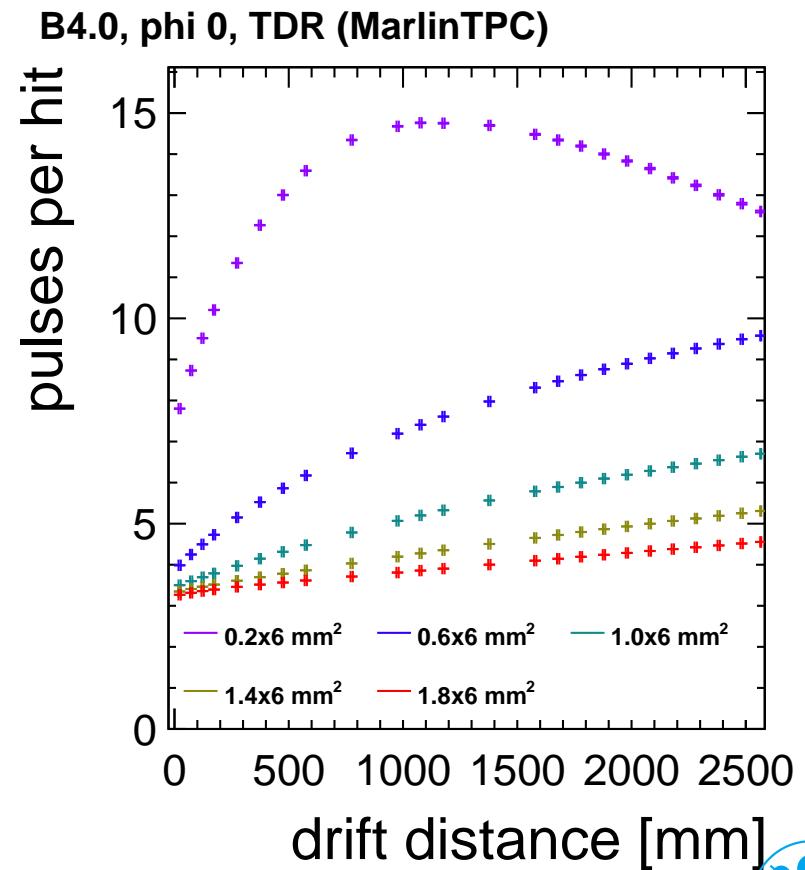
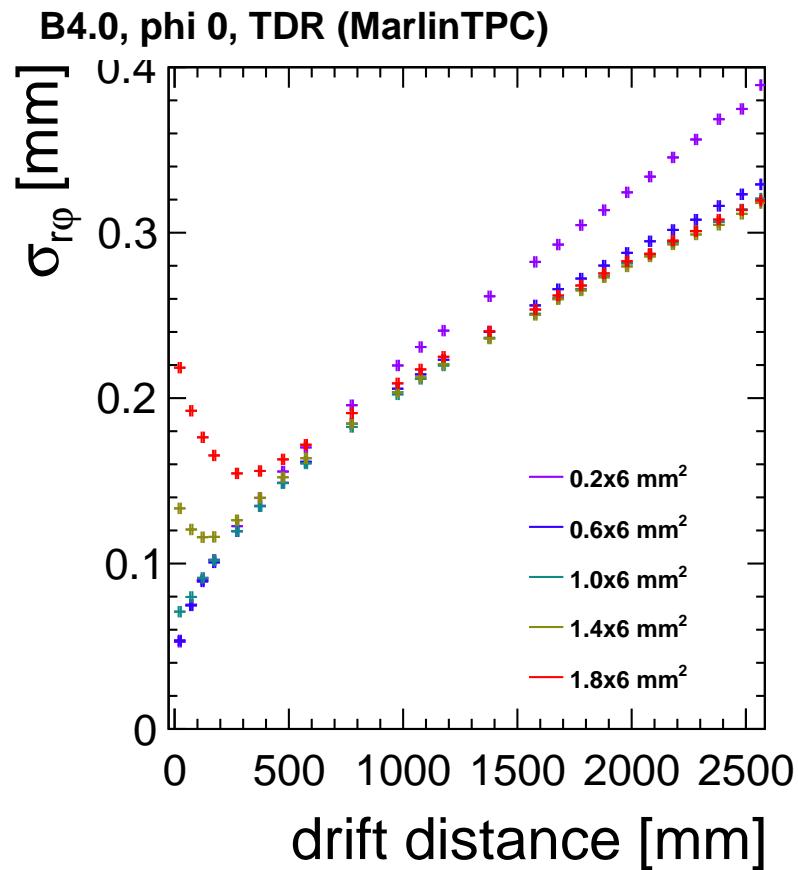
- ▶ Stick with MarlinTPC - also to look at dE/dx, ...
- ▶ “Strange“ effect for small pad sizes in TDR gas:
worse resolution at long drift distances in TDR

Maybe charge per pad get's too small so that pulses are below threshold?

Pulses per hit.

For smaller pad sizes: expect charge to spread over more pads

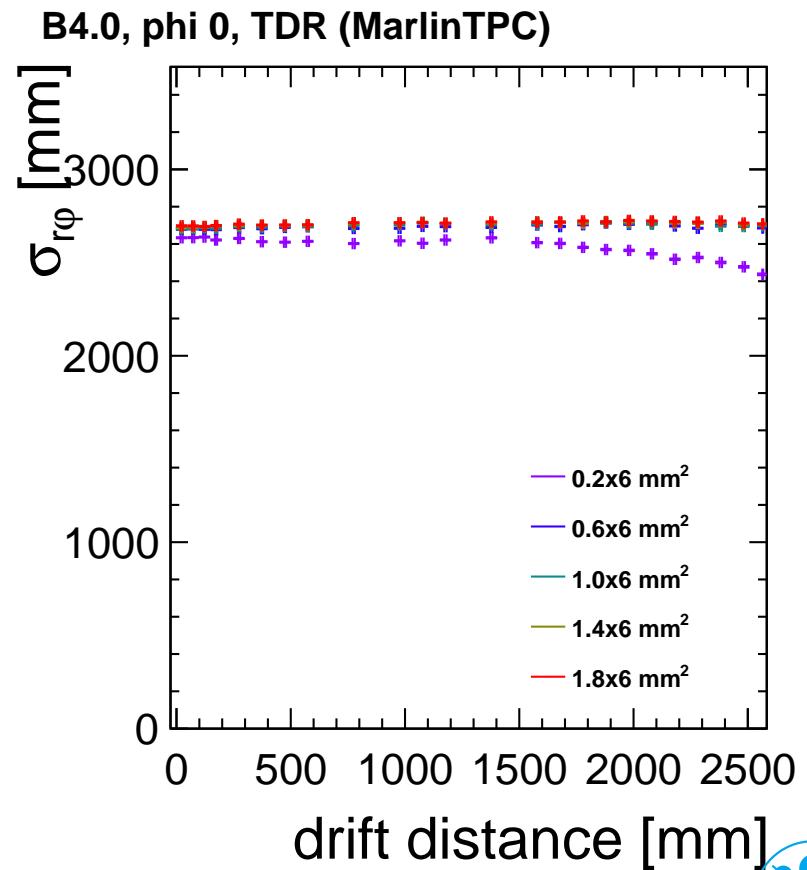
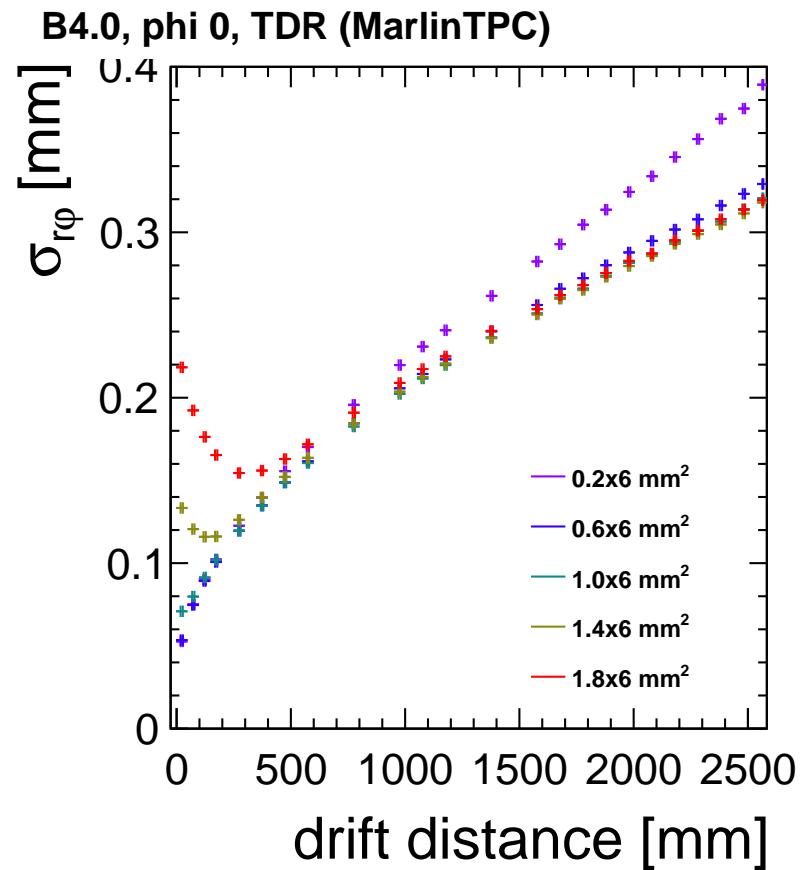
Currently applying same threshold in the reconstruction



TDR 4T.

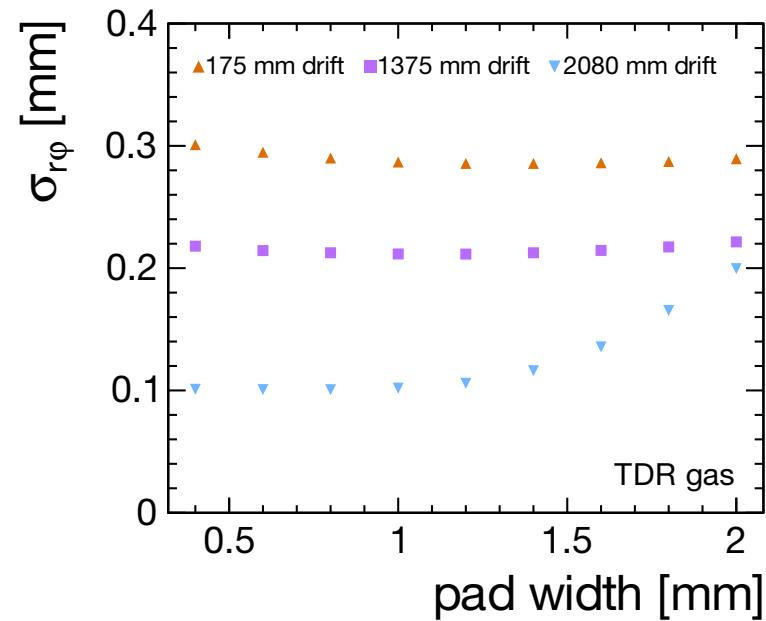
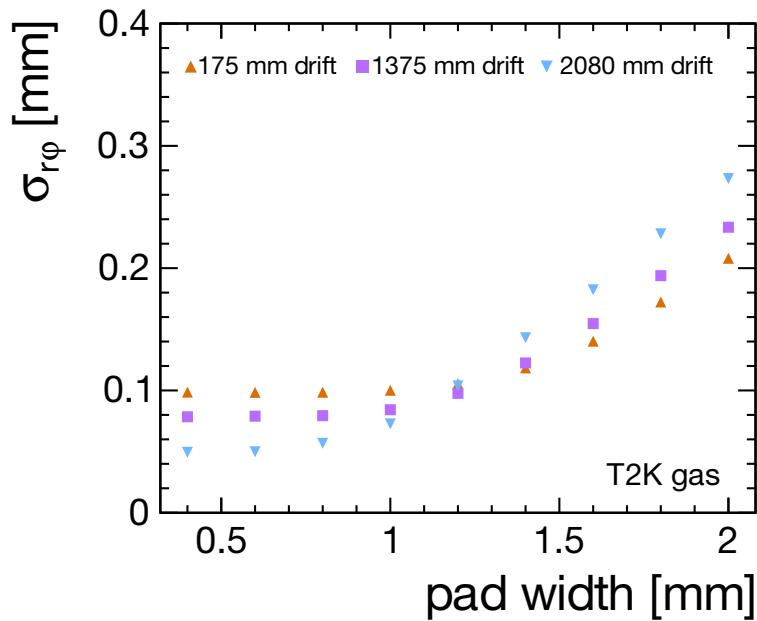
Also visible in the hit charge

→ Next step: vary thresholds, find way to set equivalently



Sneak preview.

Single point resolution vs. pad width



Introduction

Simulation

dE/dx

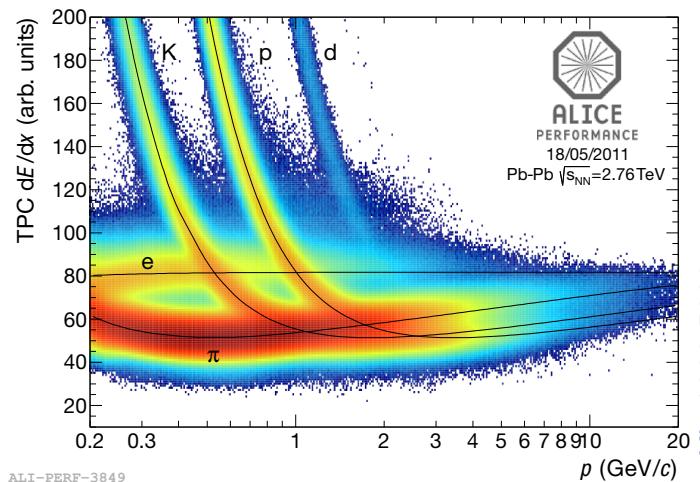
Hardware

Outlook

Particle identification via dE/dx.

One method for particle identification:

Specific energy loss



$$-\langle \frac{dE}{dx} \rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \left(\frac{2m_e c^2 \beta^2 \gamma^2}{I^2} \right) - \beta^2 - \frac{\delta(\beta \gamma)}{2} \right]$$

- ▶ powerful especially at low momenta
- ▶ so far dE/dx not implemented in simulation
- ▶ (nearly) not used in physics studies
(first study by Masakazu Kurata, see e.g. talk ALCW)

Particle identification via dE/dx.

In gas at 1 bar typically:

~30 primary interactions/cm

secondary ionisation: ~90 e⁻/cm

“conventional” method:

truncated mean of charge distribution

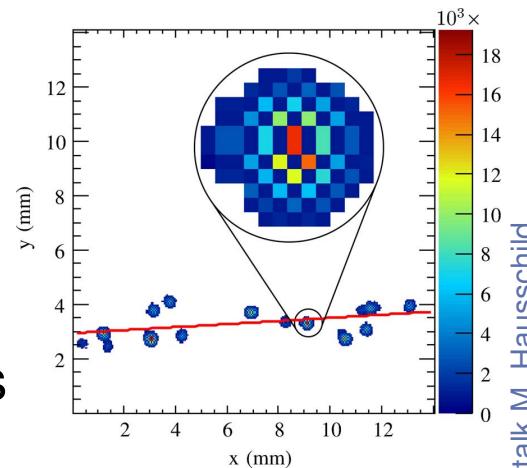
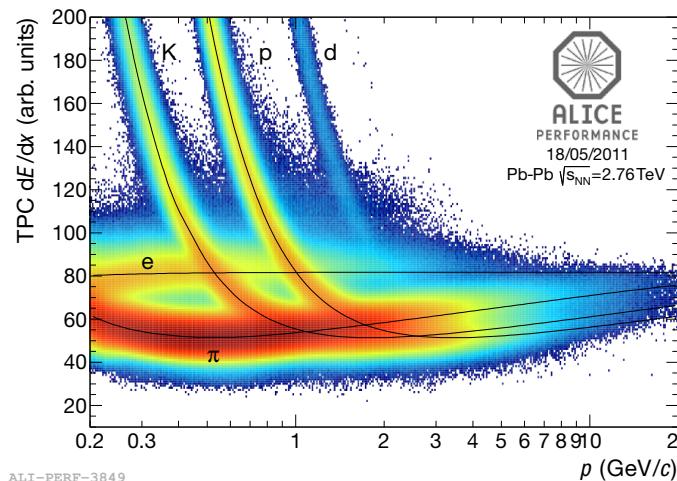
With highly granular readout:

dE/dx by cluster counting might be an option

(typical cluster-to-cluster distance $\mathcal{O}(300 \mu\text{m})$ in Ar-based gas)

use ionisation clusters instead of charge

→ avoid problems caused by gas gain variations



Cluster counting study (M. Hausschild).

dE/dx resolution for ILD:

charge measurement: 4.3%

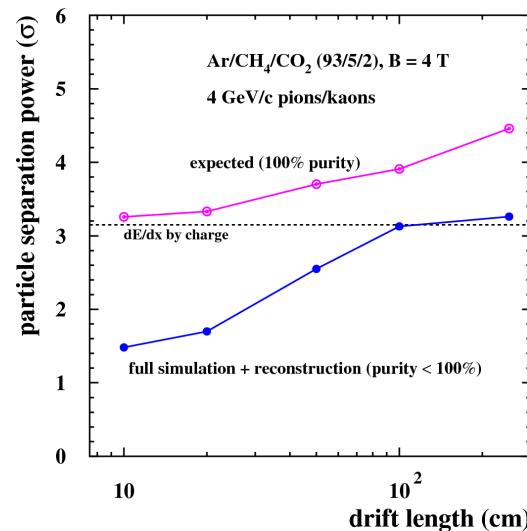
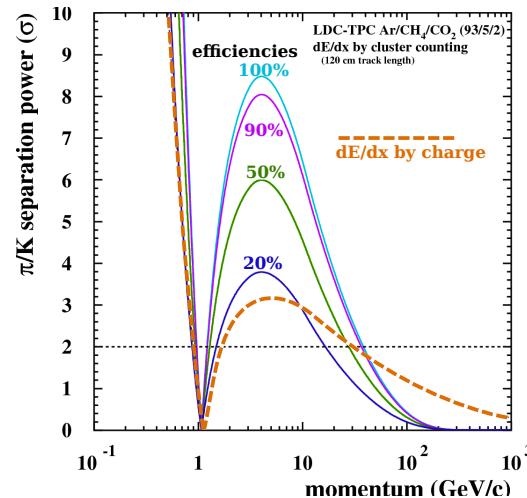
<2% with cluster counting

(for 100% cluster finding efficiency / purity)

Separation power at 20% efficiency
close to classic approach

Full simulation & reconstruction:
worse results!
(unresolved primary clusters)

Here: simple cluster finding algorithm
(search for connected areas, centre-of-gravity as position)
→ improvement possible with
more sophisticated cluster finder?



talk M. Hausschild

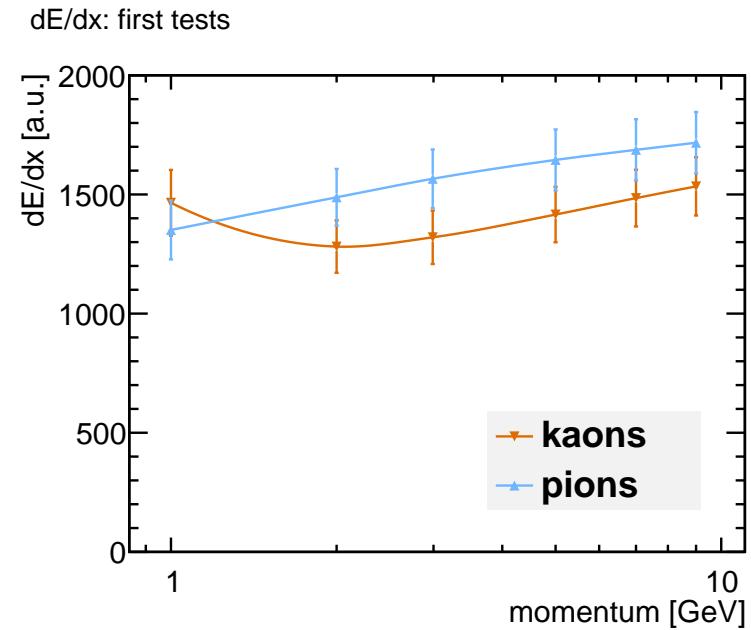
dE/dx first steps.

First step: simulate kaons / pions instead of electrons in MarlinTPC

Using SimpleHelixGeneralBrokenLineInterfaceProcessor:

$\frac{1}{\sqrt{Q}}$ as simple dE/dx estimator (roughly Gaussian)

For now: just started,
using different momenta to check
that those give different dEdx...



Introduction

Simulation

dE/dx

Hardware

Outlook

Pads & Pixels.

If we find an optimised pad size, could we actually build it?

Idea: join both concepts

i.e. pixel readout chip + pad plane (with pads larger than pixel pitch)

→ highly granular readout, still fewer channels than a pixel-TPC

Would allow flexible pad size, e.g. pad sizes of few 100 µm.

Challenges:

- connect small chip pads to readout plane:
bump bonding of the chip to PCB (printed circuit board)
routing on PCB (between bump bond pads and charge collection pads)
- Timepix optimised for low input capacitance (10-100 fF)
connection to pad plane: much higher (1-20 pF)
→ sufficient signal-to-noise ratio possible? (10 or better)



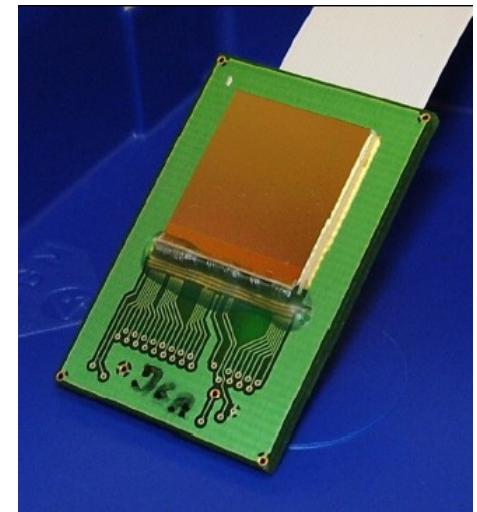
Timepix.

Timepix chip (used e.g. by Uni Bonn, Saclay)

256×256 pixels

$55 \times 55 \mu\text{m}^2$ pixel pitch

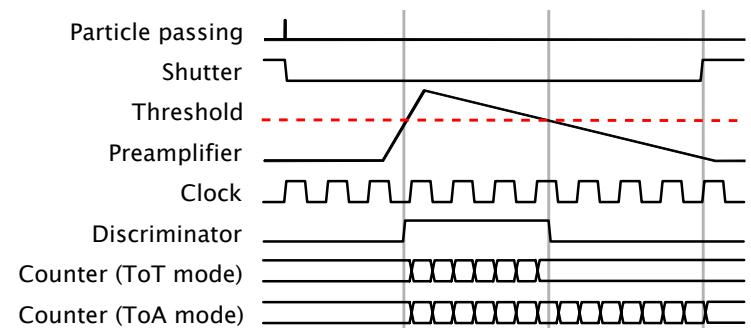
$14 \times 14 \text{ mm}^2$ chip size



talk J. Kaminski, Bonn 3/2013

Different operation modes

- single hit
- “Medipix” (events over threshold)
- time of arrival
- time over threshold

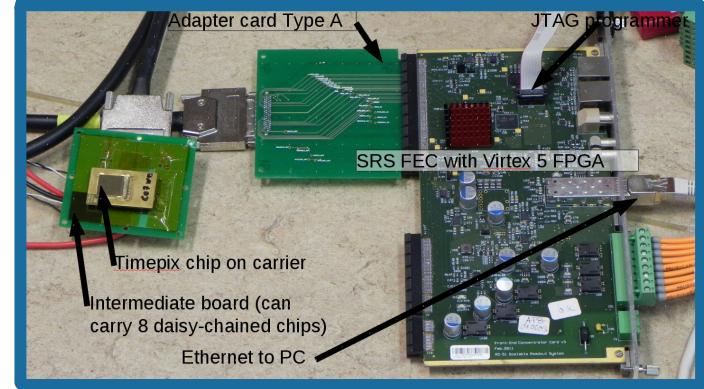
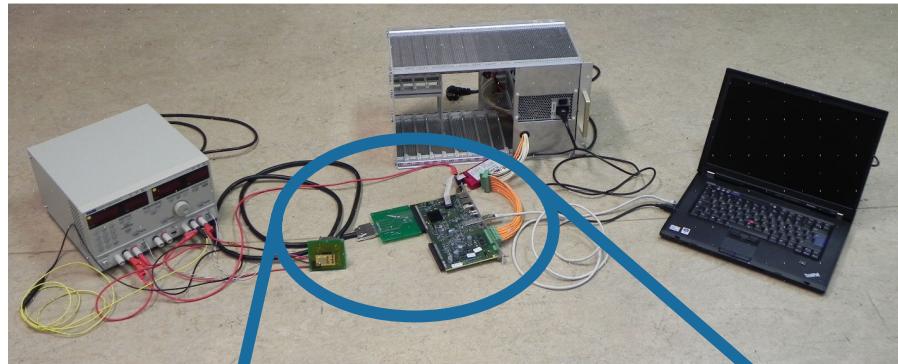


SRS.

Readout system for Timepix:
Scalable readout system
(RD51 collaboration)

Basic version consists of

- chip
- adaptor card
- FEC (+crate) (front-end concentrator card)
- computer



Parts are ordered...

(project in collaboration with Uni Bonn)

Introduction

Simulation

dE/dx

Hardware

Outlook

Outlook.

Started studying readout pad size of the ILD TPC

Planned next steps:

- ▶ Continue simulation studies: chose consistent handling of threshold and gain for different pad sizes, look beyond σ_{point}
- ▶ dE/dx performance: cluster counting algorithm? Apply to simulation and old (testbeam) data
- ▶ For optimal pad size: capacity of those pads?
→ test setup with Timepix
- ▶ Assemble and start operating SRS setup for Timepix

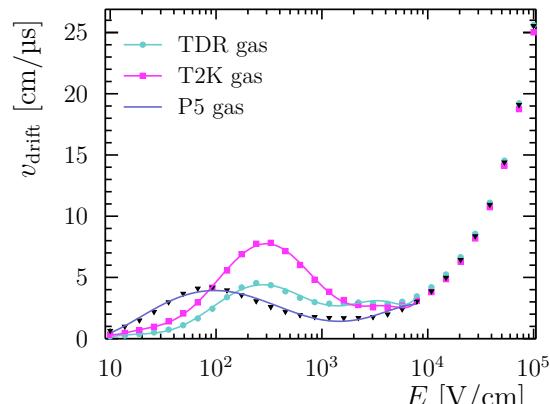
Backup Slides.

Gas mixtures.

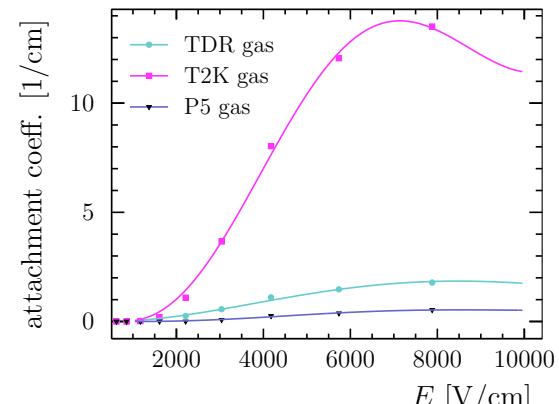
P5 95%Ar, 5% CH_4

T2K 95%Ar, 3% CF_4 , 2% iC_4H_{10}

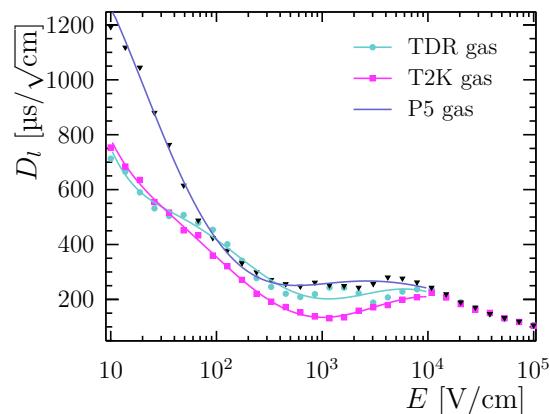
TDR 93%Ar, 5% CH_4 , 2% CO_2



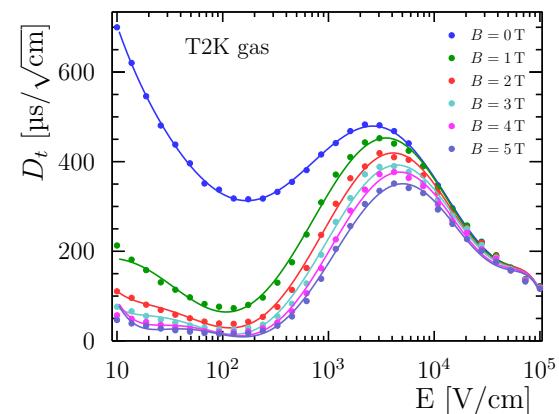
(a) Drift velocity.



(b) Attachment coefficient.



(c) Longitudinal diffusion.



(d) Transverse diffusion for different magnetic field strengths.

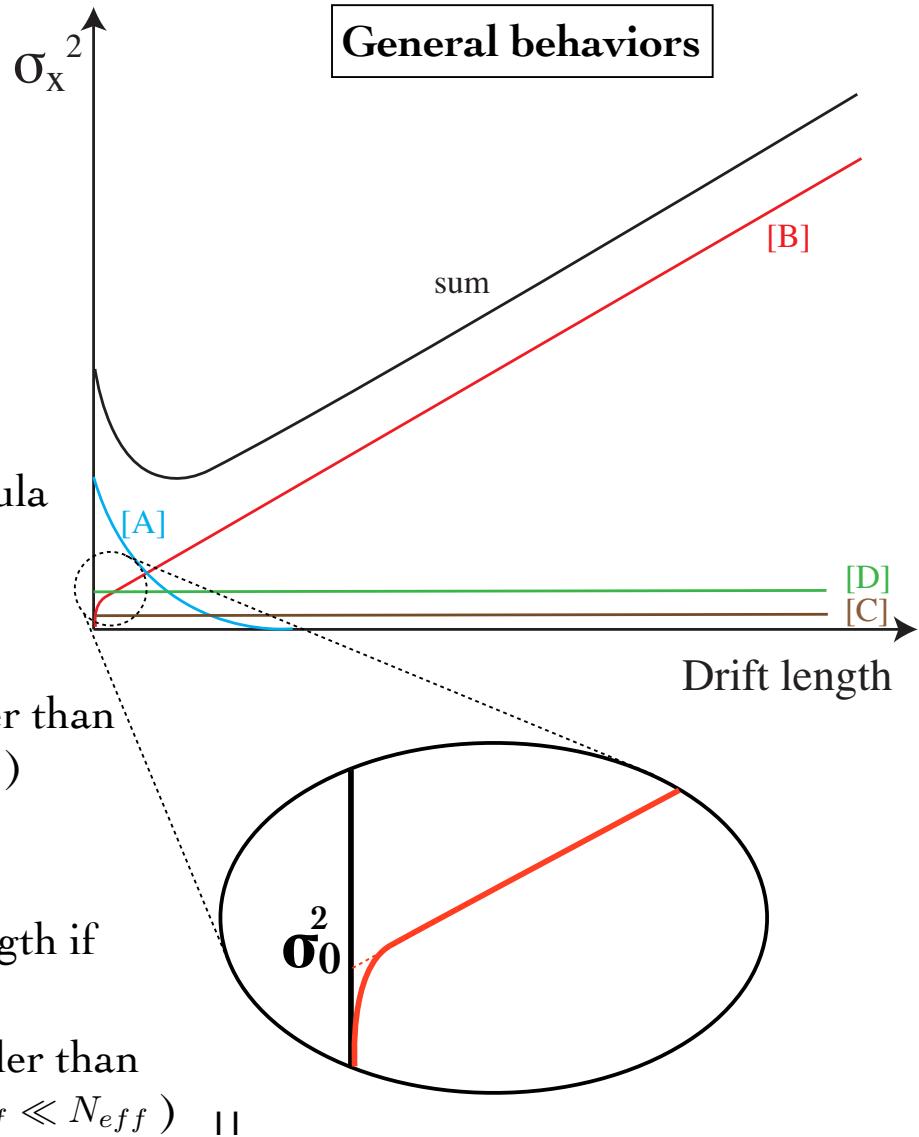
Figure 7.36: Gas parameters for different gases. Circle markers show the result of a MAGBOLTZ simulation using 10 collisions. Lines show the parameterisation used in MARLINTPC.

Obtained Knowledge

- ❖ Spatial resolution consists of 4 components.
- ❖ [A] : systematics due to finite pad readout.
disappears if $\sigma_{PR}/w \gtrsim 0.4$
(long drift length or inclined tracks)
- ❖ [B] : diffusion effect
 - Gas property
 - We found that σ_0^2 in the asymptotic formula
$$\sigma_x^2 = \sigma_0^2 + \frac{C_d^2}{N_{eff}} z$$

can be written as $\sigma_0^2 = [A]_{z=0}/N_{eff}$.

 - We understood why N_{eff} is much smaller than average of seed electrons. ($N_{eff} \ll \langle N \rangle_N$)
- ❖ [C] : noise effect
- ❖ [D] : primary cluster fluctuation
almost constant as a function of drift length if ϕ is fixed. It vanished for $\phi=0$.
 - We understood why \hat{N}_{eff} is much smaller than effective number of seed electrons. ($\hat{N}_{eff} \ll N_{eff}$)



Generalization to Inclined Tracks

$$\sigma_x^2(z; w, L \tan \phi, C_d, N_{eff}, \hat{N}_{eff}, [f]) = [A] + \frac{1}{N_{eff}} [B] + [C] + \frac{1}{\hat{N}_{eff}} [D]$$

Notation:
 $\langle g(y) \rangle_y := \int_{-\Delta Y/2}^{+\Delta Y/2} \frac{dy}{\Delta Y} \bar{P}_{SI}(k, y) g(y)$

$$[A] := \int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \left(\sum_a (aw) \langle \langle F_a(\tilde{x} + y \tan \phi + \Delta x) \rangle_{\Delta x} \rangle_y - \tilde{x} \right)^2$$

diffusion-averaged & cluster
position average charge centroid
systematics

Generalization of [A] for perpendicular tracks Effective secondary ionization probability

$$[B] := \int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \left\langle \left(\sum_a (aw) F_a(\tilde{x} + \Delta x) - \sum_a (aw) \langle F_a(\tilde{x} + \Delta x) \rangle_{\Delta x} \right)^2 \right\rangle_{\Delta x}$$

displacement due to diffusion for a single electron

Exactly same as with the [B] for perpendicular tracks.

$$[C] := \left(\frac{\sigma_G}{G} \right)^2 \left\langle \frac{1}{N^2} \right\rangle_N \sum_a (aw)^2$$

Exactly same as with the [C] for perpendicular tracks.

$$[D] := \frac{L^2 \tan^2 \phi}{12}$$

variance projected to x-axis for a primary cluster

Visible only when $\phi \neq 0$.

$$N_{eff} := \left[\left\langle \sum_{i=1}^N \sum_{j=1}^{k_i} \left\langle \left(\frac{G_{ij}}{\sum_{i=1}^N \sum_{j=1}^{k_i} G_{ij}} \right)^2 \right\rangle_G \right\rangle_{N,k} \right]^{-1}$$

Normalized gain for a seed electron

Generalized effective number of electrons.

$$\hat{N}_{eff} := \left[\int_{-1/2}^{+1/2} d\left(\frac{\tilde{x}}{w}\right) \left\langle \sum_{i=1}^N \left\langle \left(\sum_a (aw) \langle F_a \rangle_{\Delta x} - \sum_a (aw) \langle \langle F_a \rangle_{\Delta x} \rangle_y \right)^2 \right\rangle_y \right\rangle_{N,k} \right]^{-1} \times \tan^2 \phi \frac{L^2}{12}$$

$$\approx \left[\left\langle \sum_{i=1}^N \left\langle \left(\frac{\sum_{j=1}^{k_i} G_{ij}}{\sum_{i=1}^N \sum_{j=1}^{k_i} G_{ij}} \right)^2 \right\rangle_G \right\rangle_{N,k} \right]^{-1}$$

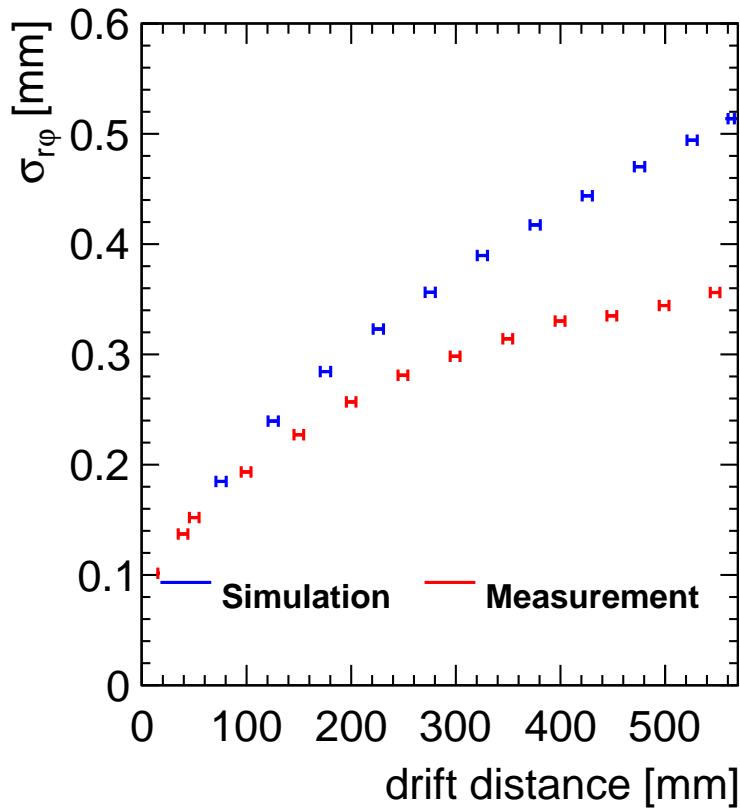
Normalized gain for a single primary cluster

Effective number of primary clusters.

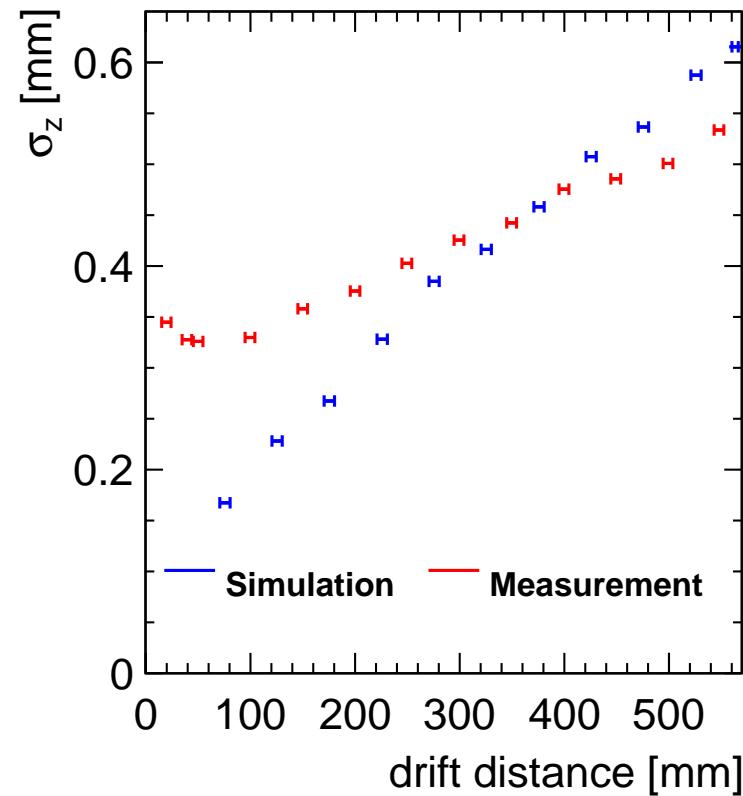
Sim vs Data comparison (0T).

Testbeam 2013 data, B=0T

mean all rows



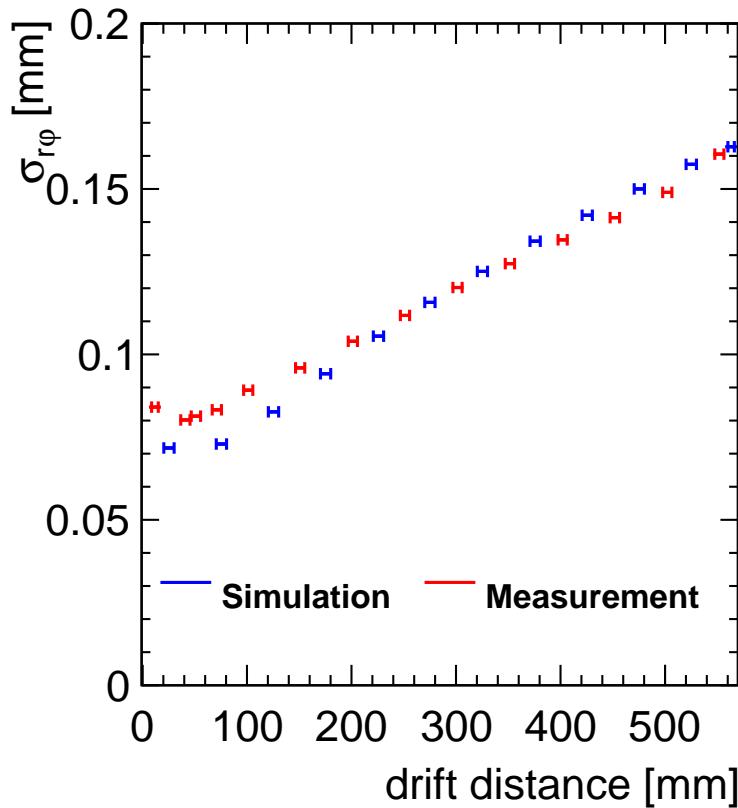
mean all rows



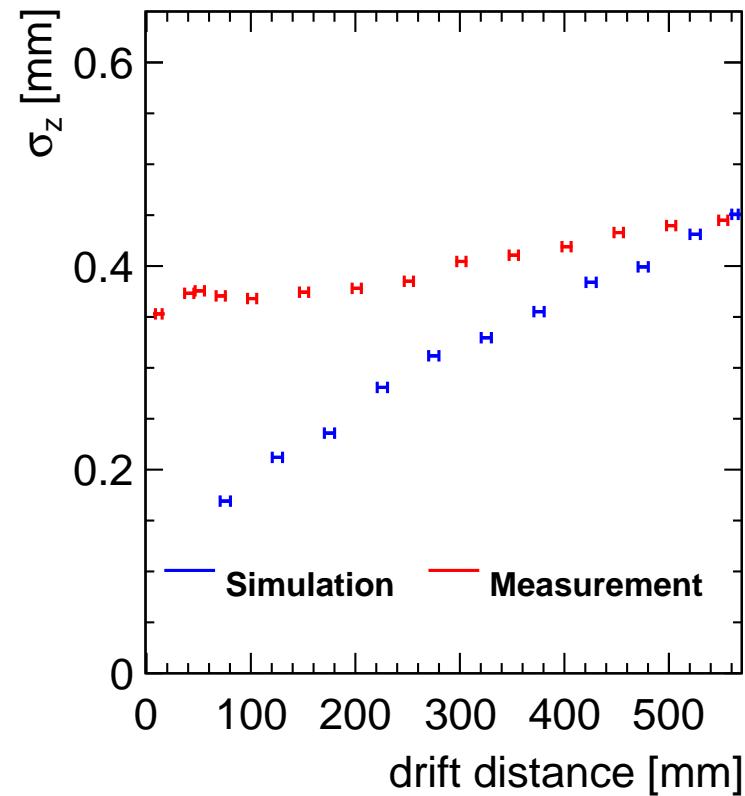
Sim vs Data comparison (1T).

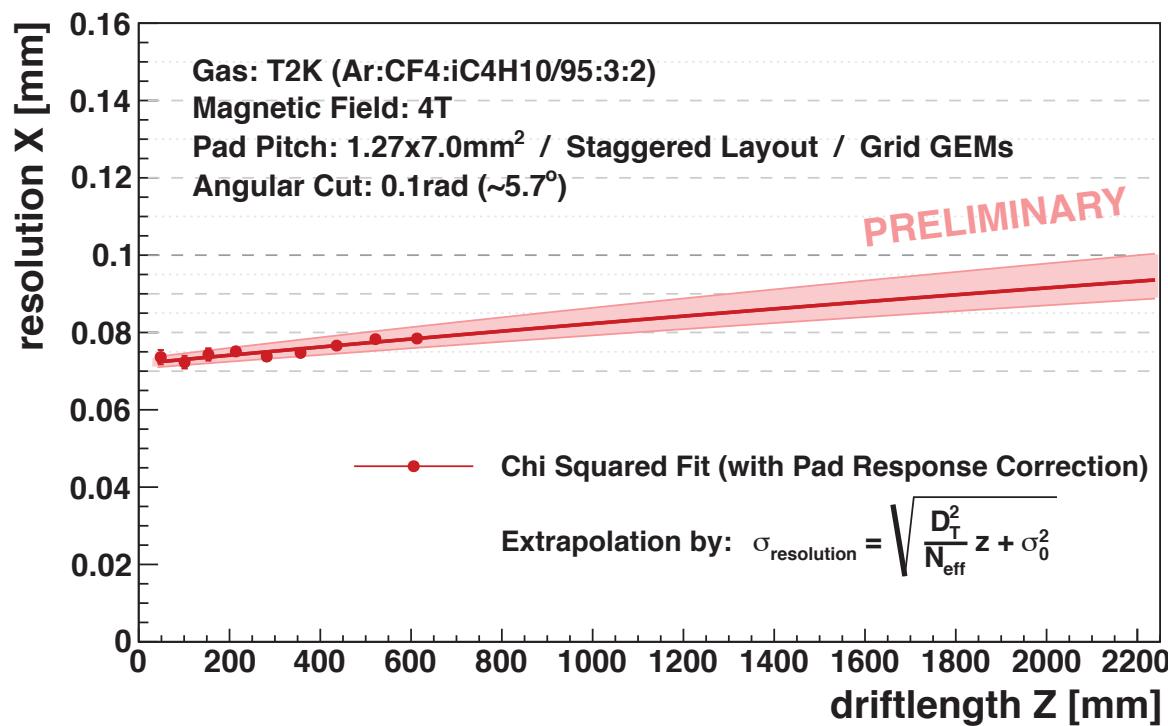
Testbeam 2013 data, B=1T

mean all rows



mean all rows

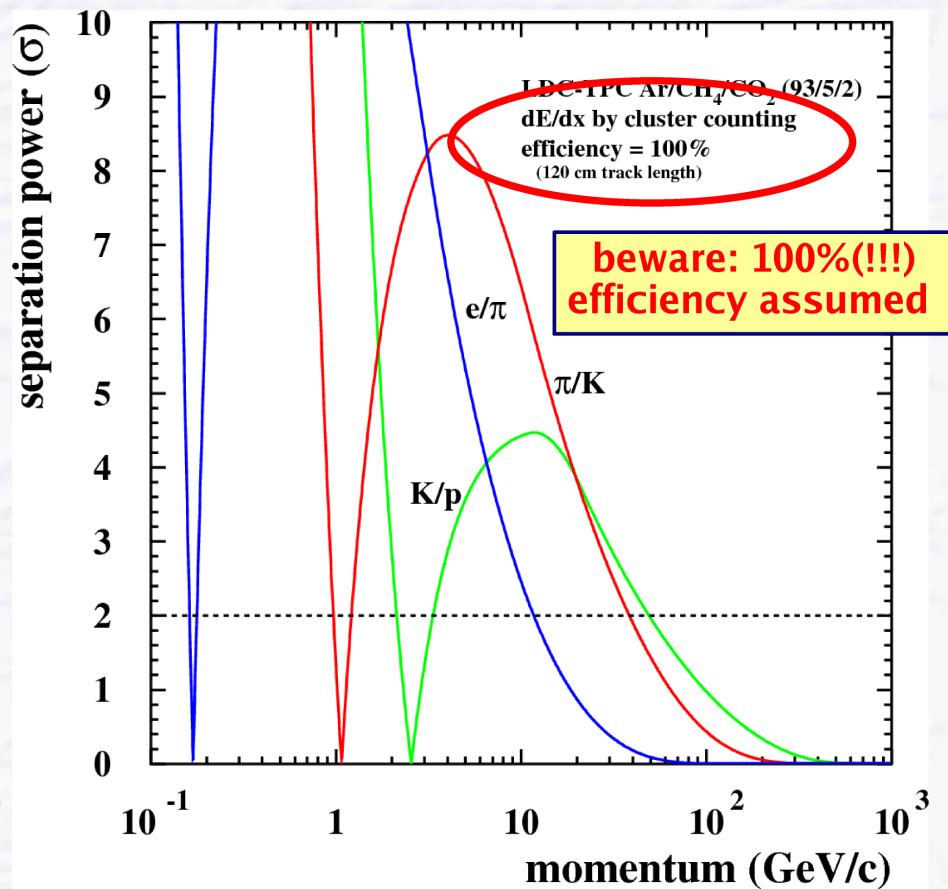
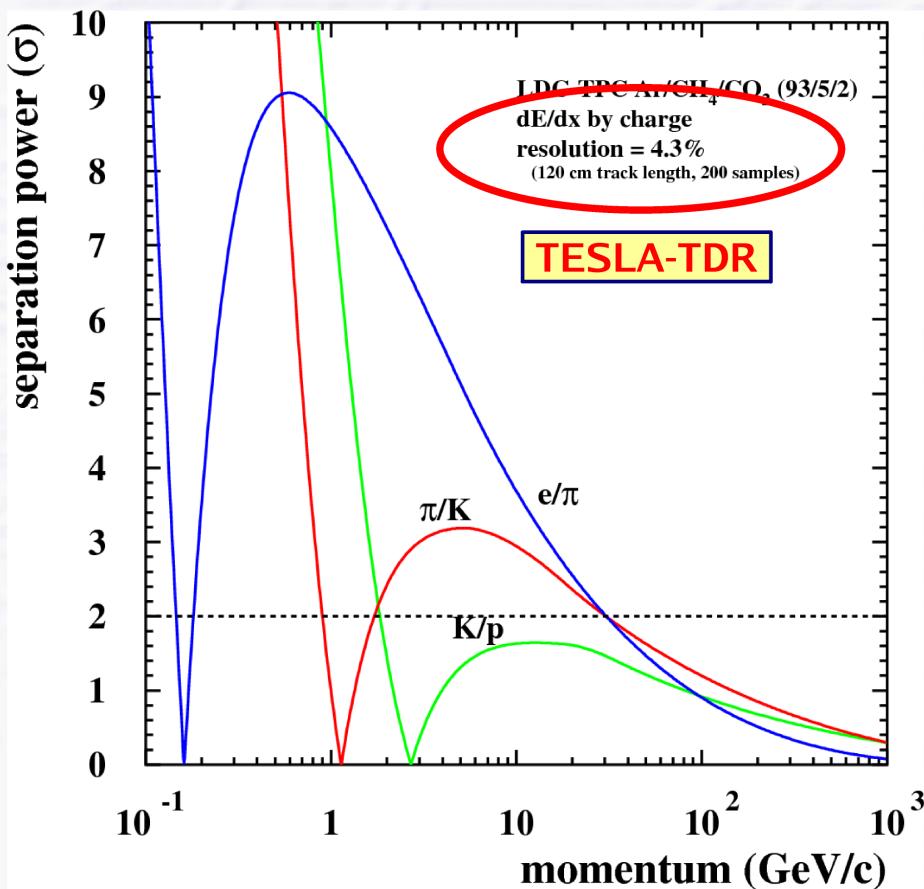




Measured point resolution using data taken with a triple GEM stack at a magnetic field of 4 T, recorded in a small TPC prototype with T2K gas.

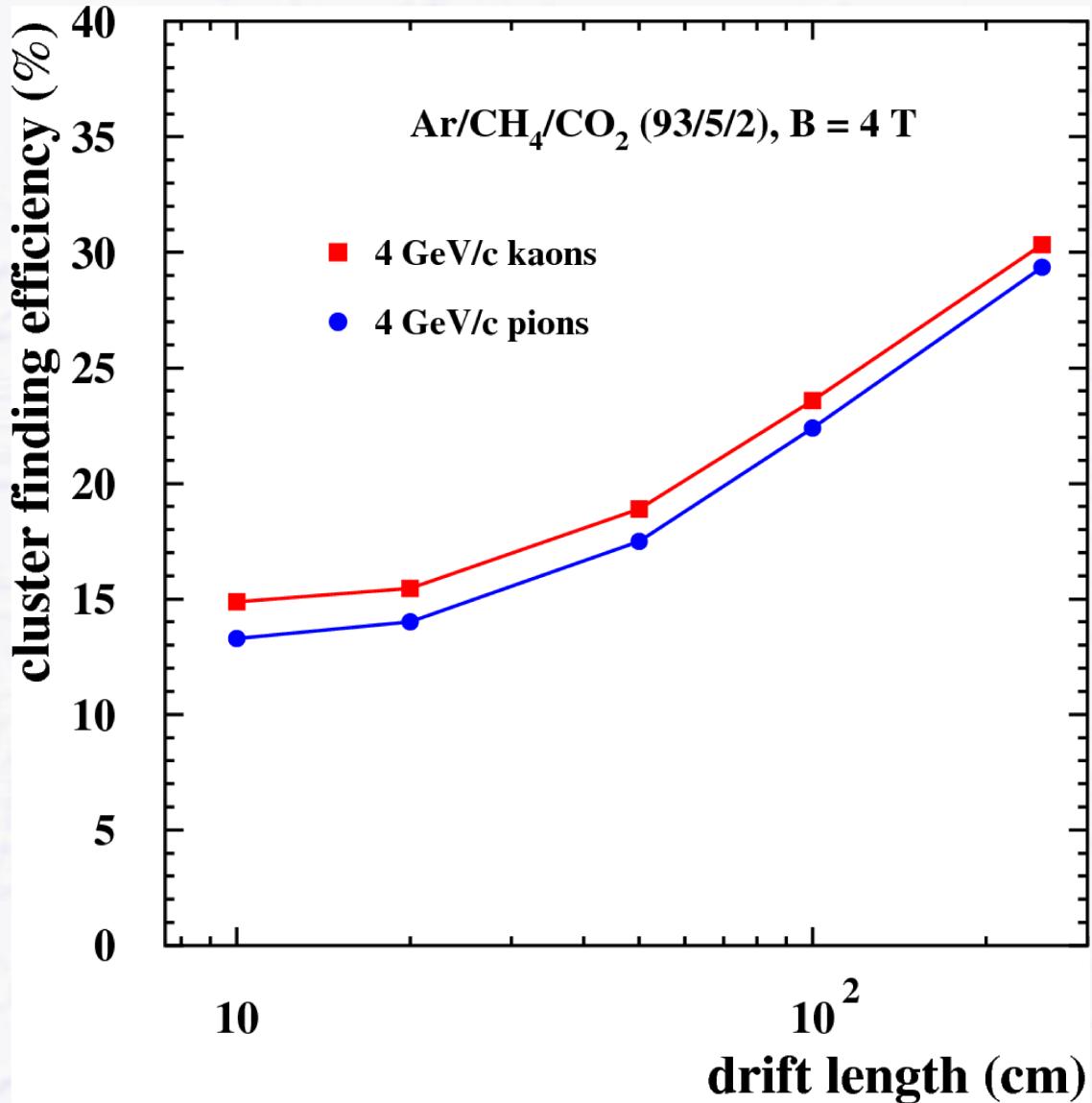
Particle Separation Power *(charge measurement + cluster counting)*

- Shape of particle separation power differs
 - maximum separation at somewhat higher momenta for cluster counting
 - more separation below, less separation above certain momentum for cluster counting



Efficiency vs. Drift Length

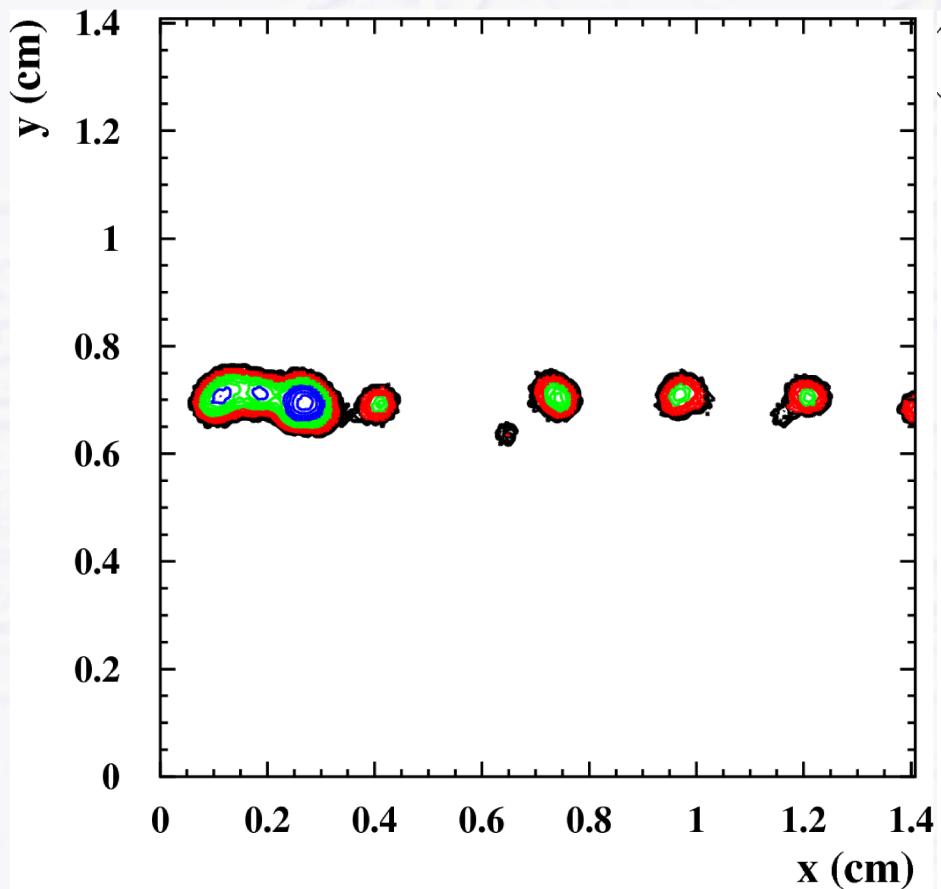
- 4 GeV/c pions and kaons
- Strong dependence on drift length
 - about 2 better efficiency at 250 cm drift length compared to short drift
 - (lateral) diffusion spread much larger at larger drift length
 - easier to find clusters
- Slight differences between pions and kaons
 - lower primary cluster density for kaons



Diffusion Spread

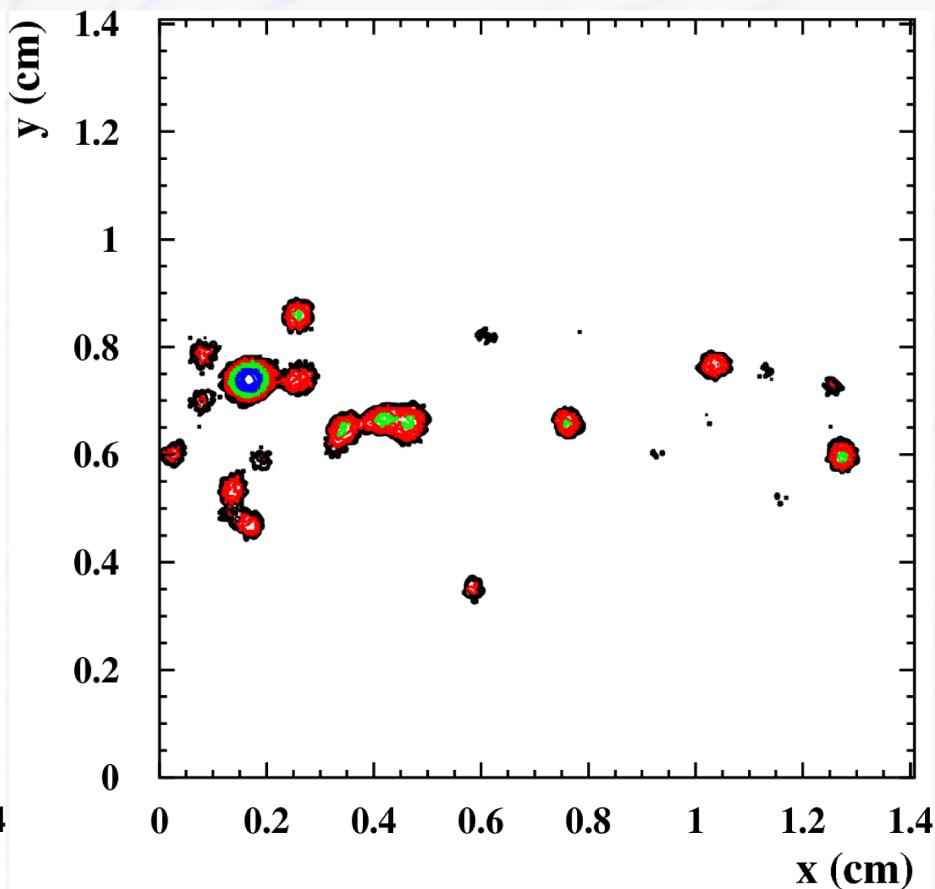
10 cm drift length

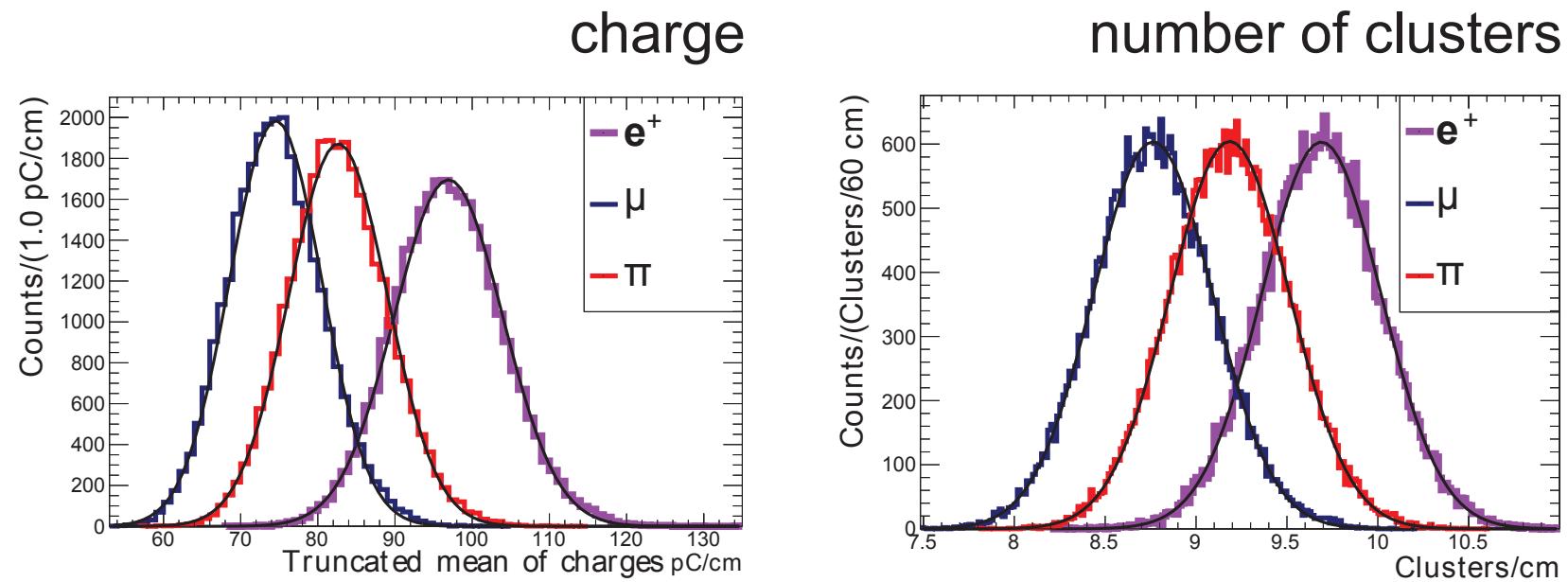
efficiency = 13.5%



250 cm drift length

efficiency = 29.5%





Capacity.

Calculate C from length / width of lines
to get an idea how large differences are

$$C_0 = \frac{0.67(\epsilon_r + 1.41)}{\ln\left(\frac{5.98H}{0.8W+T}\right)} \text{ [pF/inch]}$$

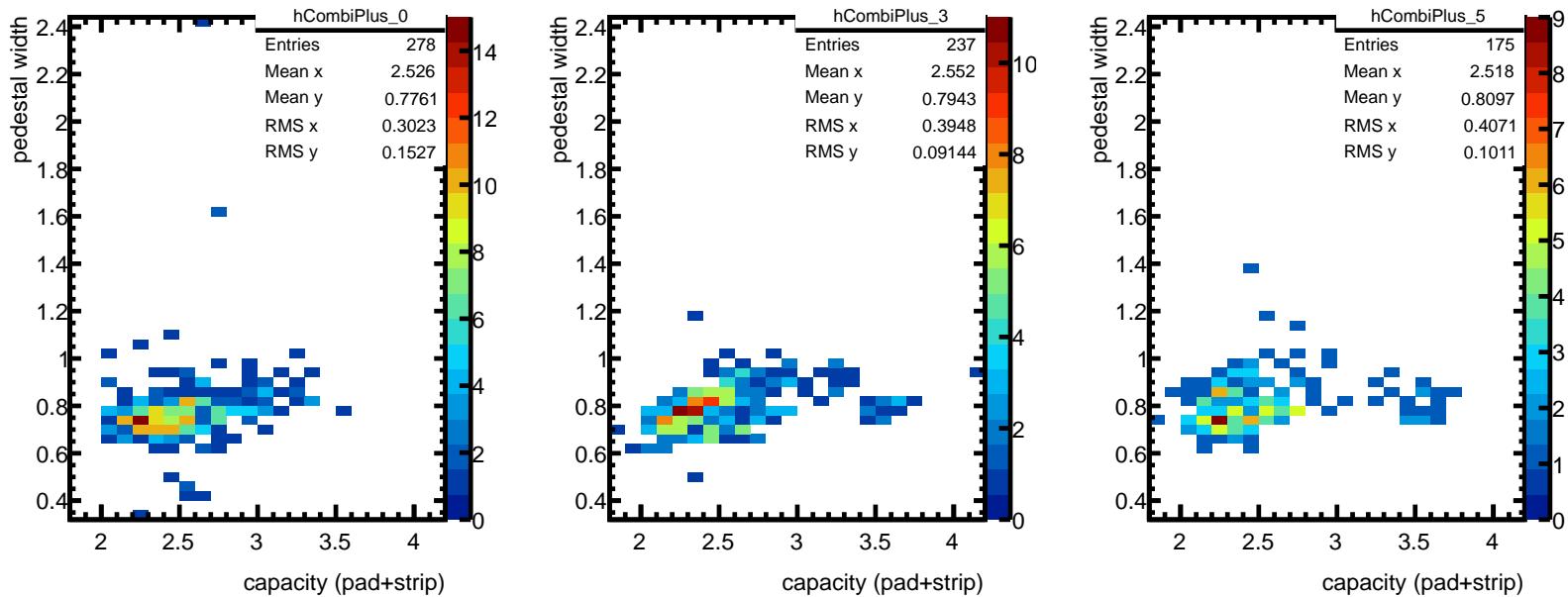
formula from the Design Guide for Electronic Packaging Utilizing High-Speed Techniques (4th Working Draft, IPC-2251, February 2001)

pad size: $5.85 \times 1.26 \text{ mm}^2 \Rightarrow 1.37 \text{ pF}$

$$C_0 = 8.8542\epsilon_r \frac{(w - h)(l - h)}{h} + 26.4(\epsilon_r + 1.41) \frac{(w + l)}{\ln\left(\frac{5.98H}{0.8W+T}\right)} \text{ [nF, using mm]}$$

(Manataro engineering)

Compare to pedestal width.



Correlation coefficient:

module 0
0.23

module 3
0.38

module 5
0.15