ILC TPC R&D studies at DESY/U. Hamburg

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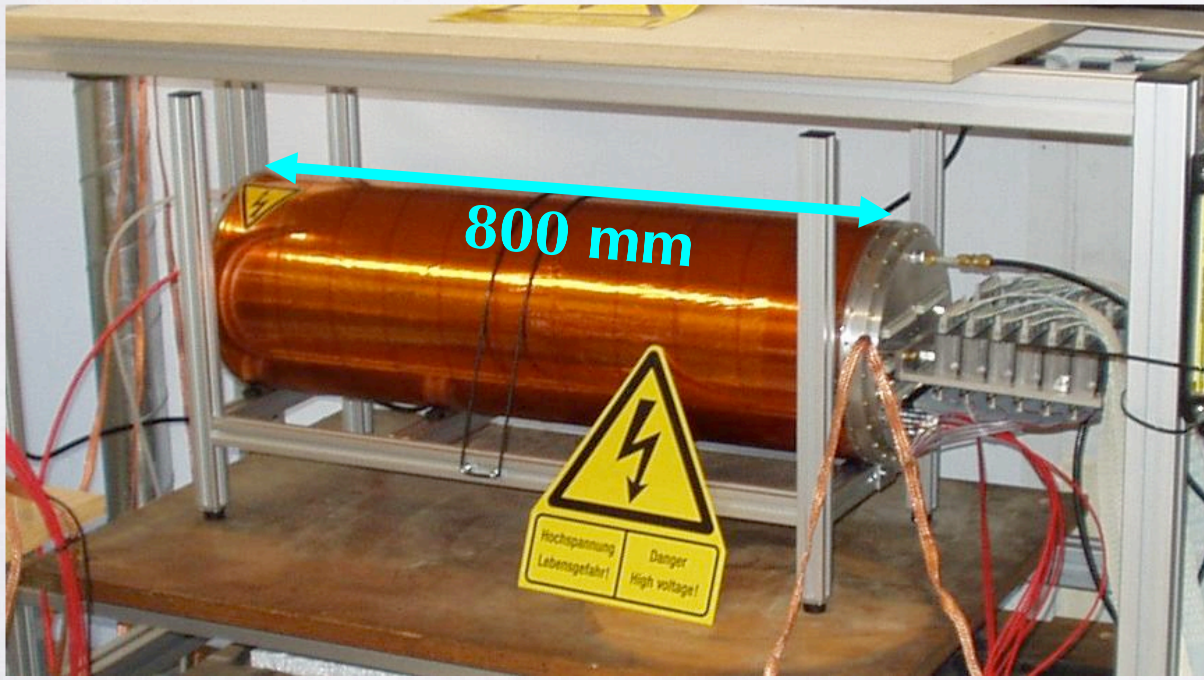
DESY TPC activities

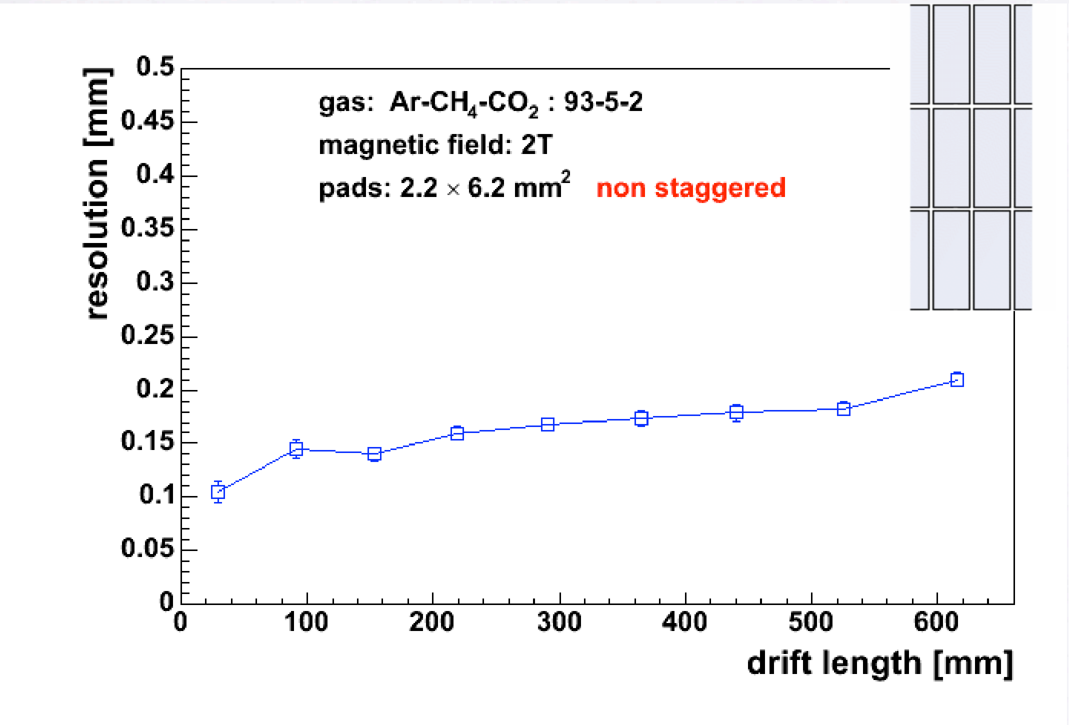
- Studying the behavior of (small)-prototypes with GEM amplification device (Demonstration phase)
  - Hardware, Analysis & Simulation studies ongoing
    - Recent highlight: Point resolution study using pad response function correction & MC efficiency study with different fitting algorithms
- Preparing a large prototype & test beam infrastructure in the framework of EUDET & LC-TPC collaboration (Consolidation phase)
  - Currently focus on development of a field cage & setting up a test beam infrastructure (Superconducting magnet)
    - Large prototype field cage based on DESY prototype TPC (Medi-TPC) field cage design
    - Magnet installation in DESY test beam area (collab. with KEK cryo. experts)
    - Goal: Enable efficient WW-R&D towards a ILC-TPC

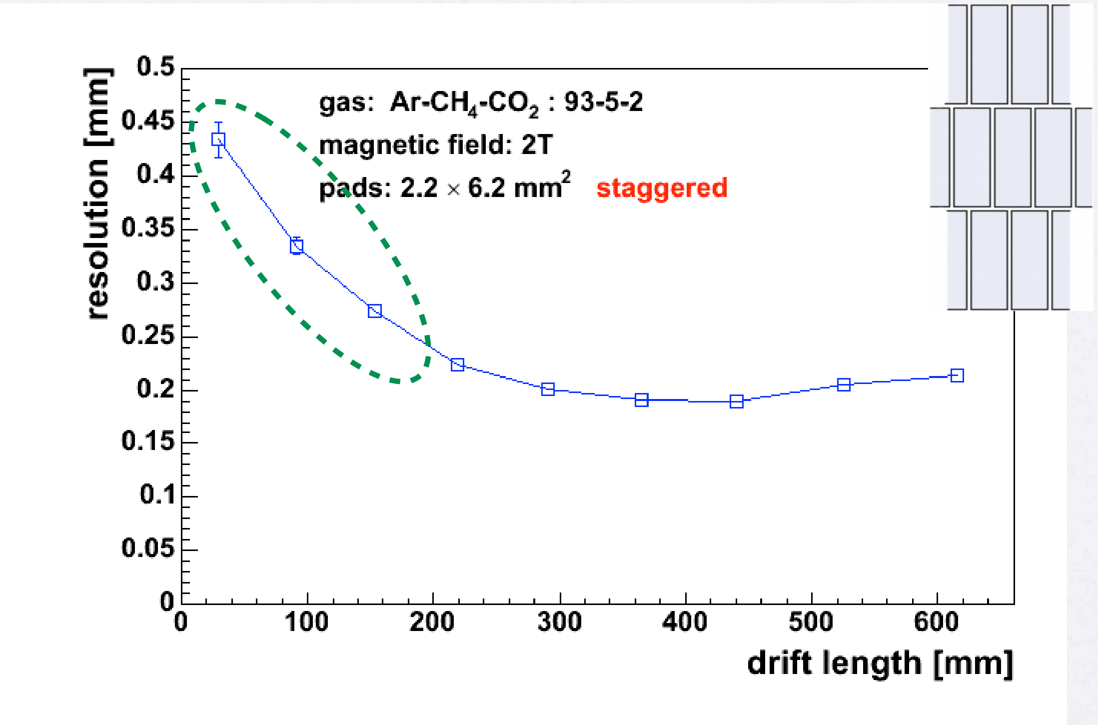
Prototype TPC & setup



- Prototype TPC (DESY Medi-TPC)
  - Length: 800 mm, Diameter: 270 mm
  - Sensitive volume: $666.0 \times 49.6 \times 52.8\ mm^3$
  - Triple-GEM amplification structure
  - Staggered and non-staggered layout pad planes (2.2 x 6.2 mm pitch)
  - Magnetic field up to 5.25 T

Measured point resolution

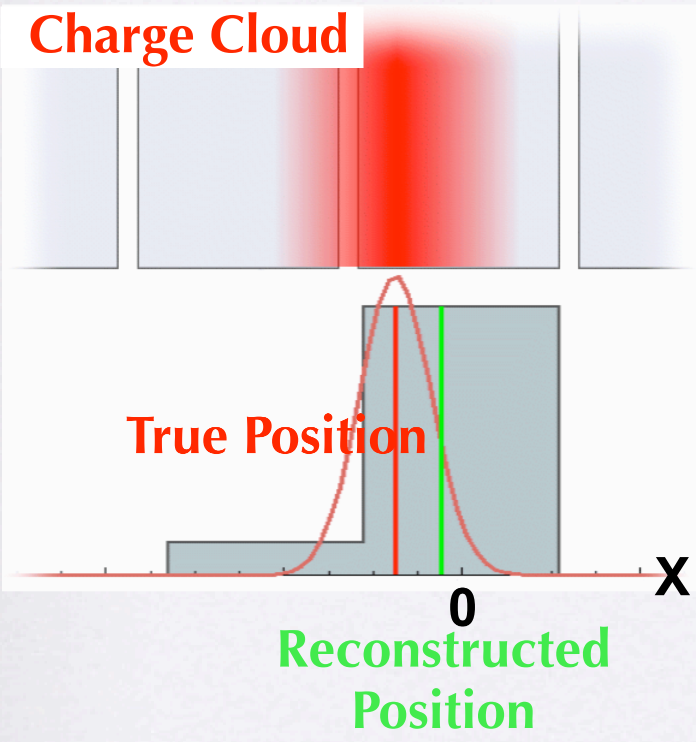




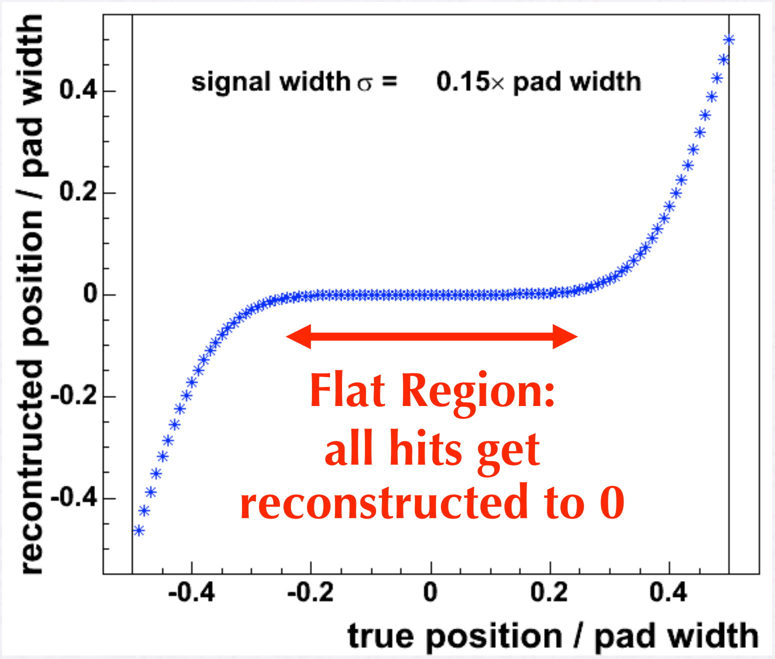
- Transverse point resolution for non-staggered pad layout:
  - Reasonable dependence of drift distance
- Transverse point resolution for staggered pad layout:
  - Increasing values at short drift distance
  - Explanation: not enough charge sharing on pads for correct reconstruction hit position and residuals
  - Need a correction of hit coordinate in xy-plane useing the pad response function (PRF)

Effects of small charge sharing

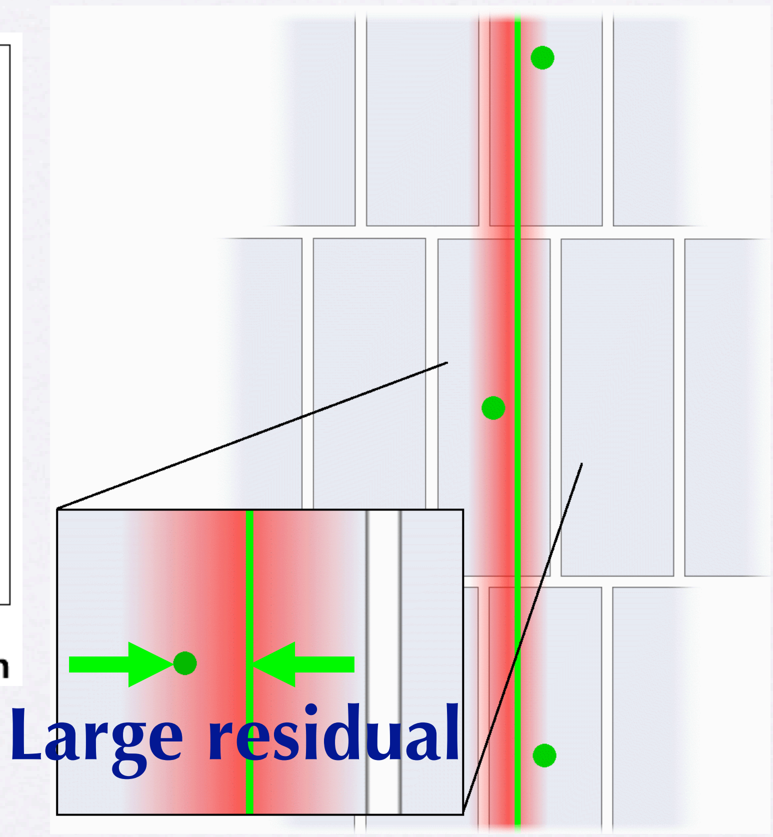
Small charge sharing



Pad response function



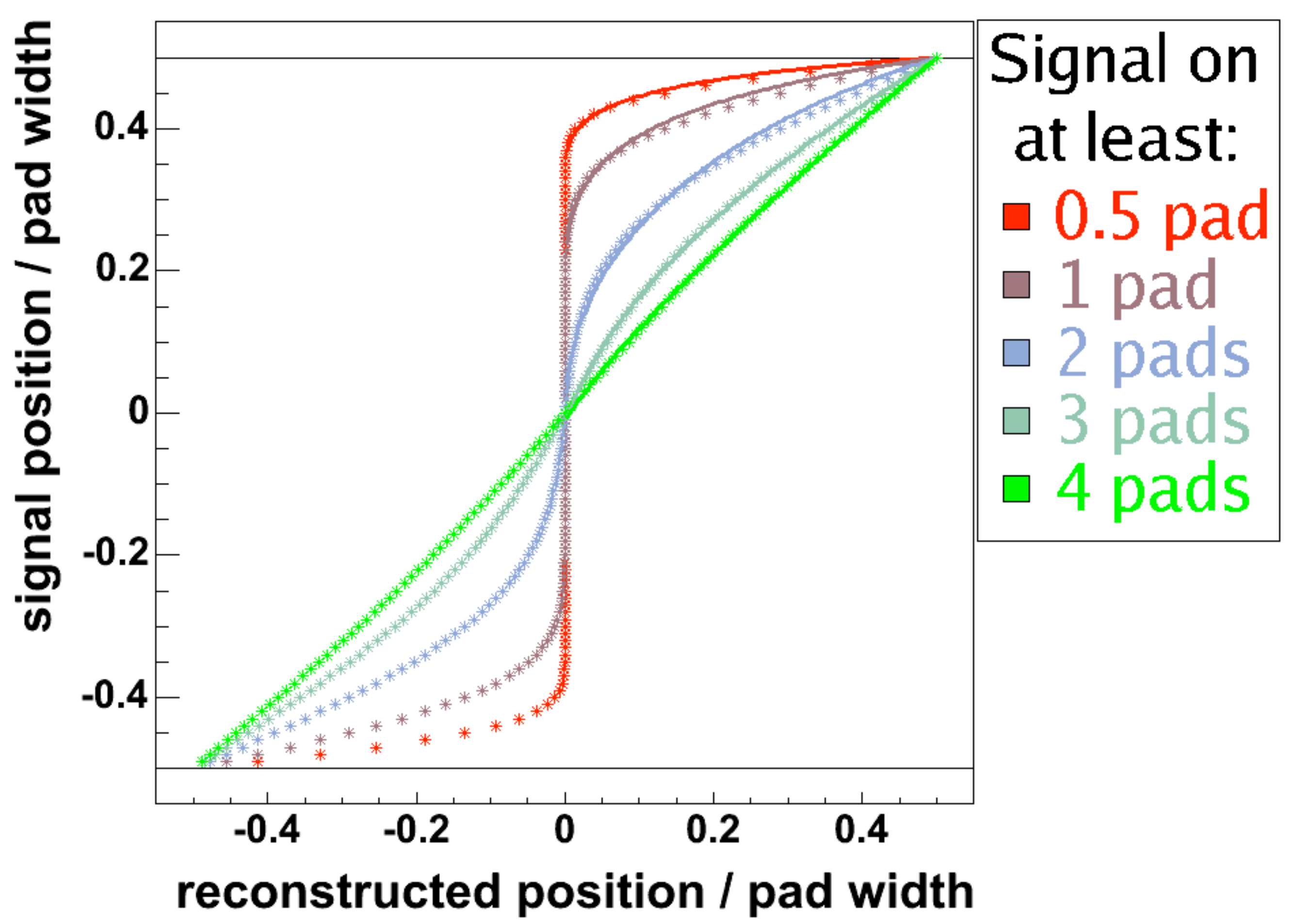
Effect on staggered pads



- Too small charge sharing on pads
  -> Hits get reconstructed towards the center of the pad with highest signal instead of at the true position
- Staggered pad row: Track-associated hit shifts far from reference track -> Calculated residuals become large

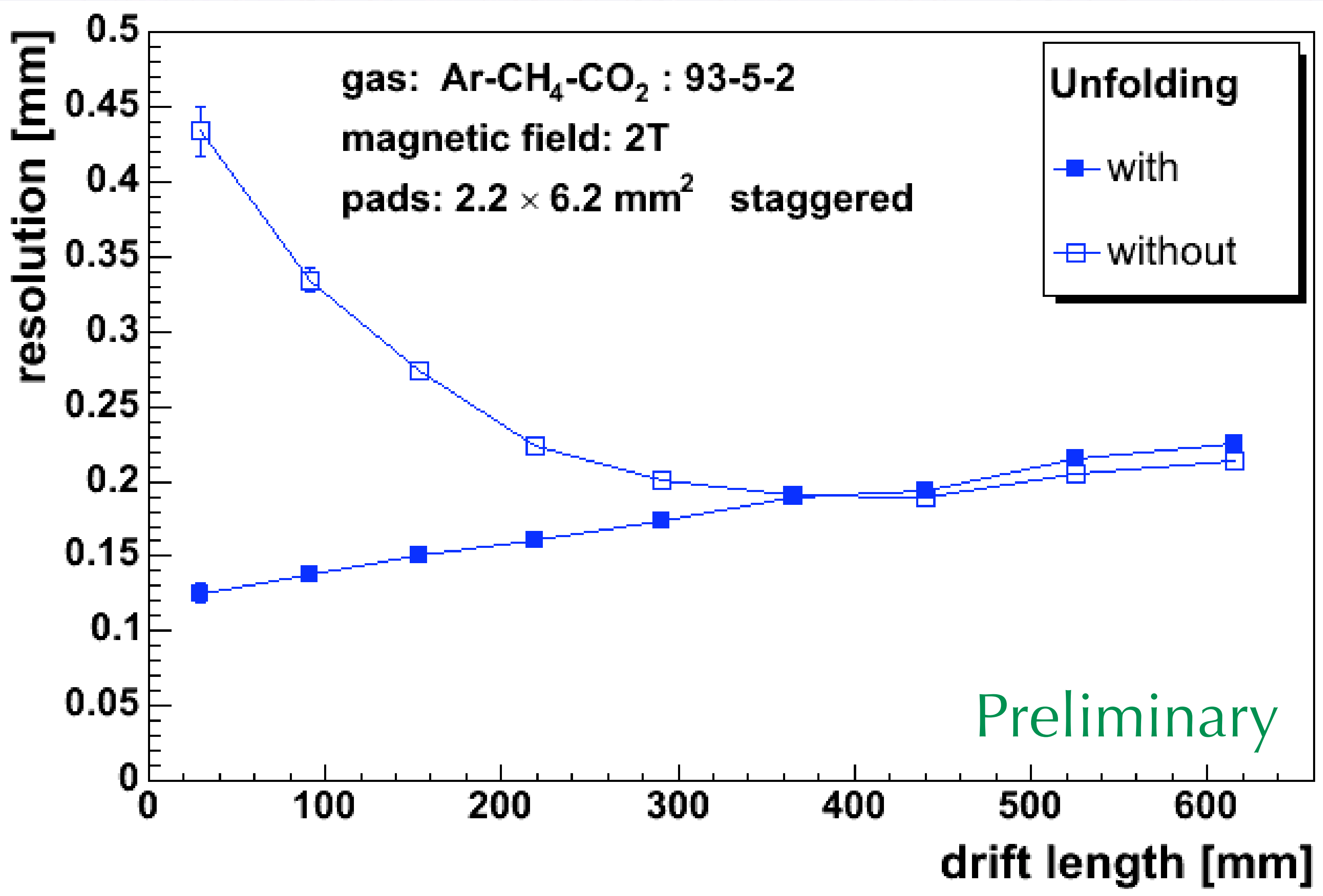
PRF implementation

- Parametrized pad response function (PRF)
  - Calculate the signal width out of diffusion constant & defocusing constant (diffusion in amplification region) from MAGBOLTZ simulation



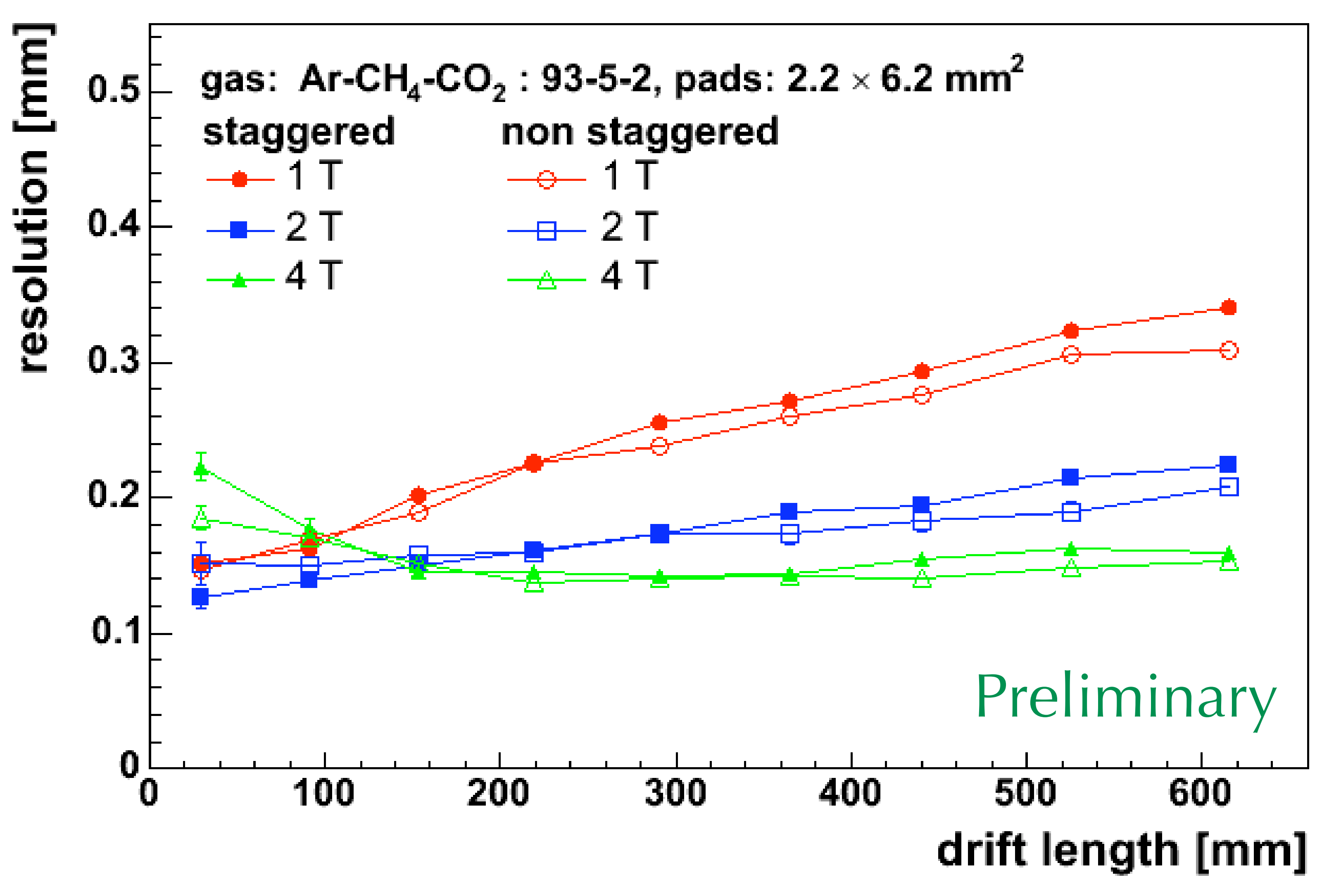
- No flat region if signal on at least 2 pads
- Straight Line (no unfolding needed) for signal on more than 4 pads

Point resolution w/ PRF



- Use of PRF in the point reconstruction brings significant improvement of the transverse point resolution calculation for staggered pad layout

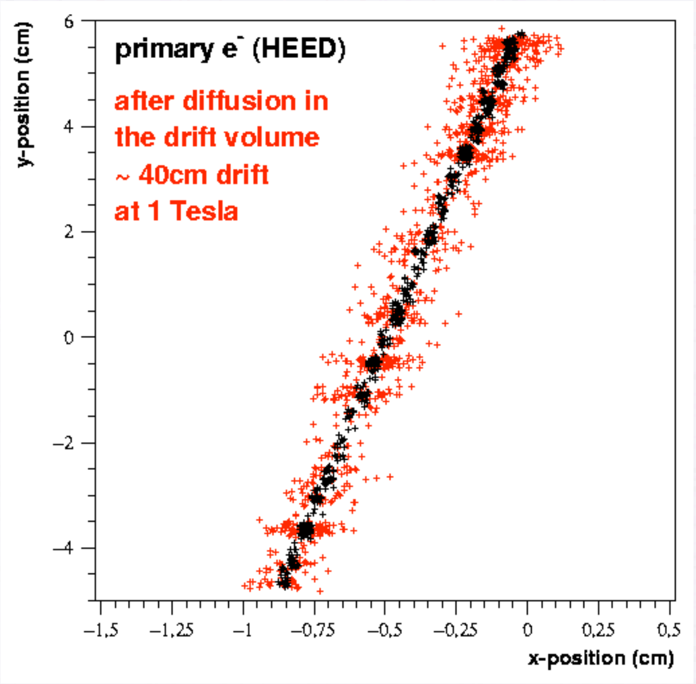
Point resolution w/ PRF (cont'd)



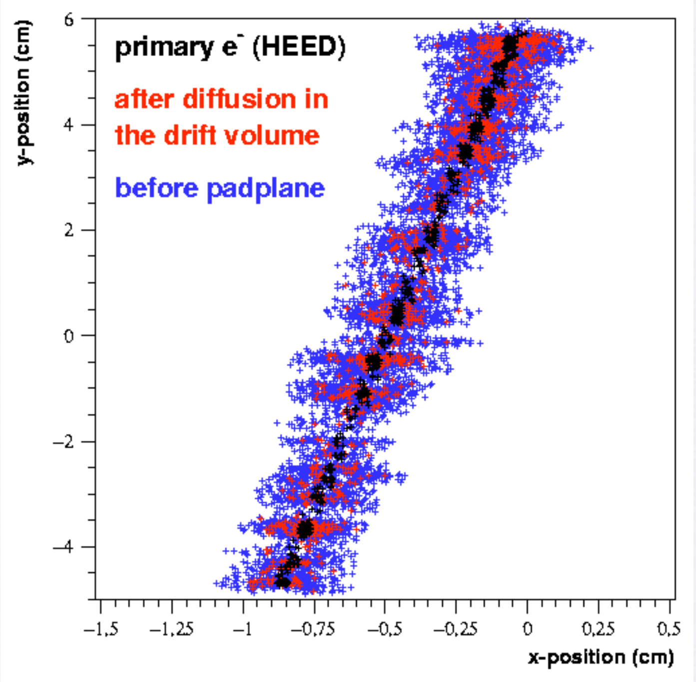
- Staggered and non-staggered measurements get comparable
- Bigger values for short drift distance in 4T (2T) data still indicate not enough charge sharing
  - Preparing smaller (1.27 mm pitch) pads for coming CR tests

Working principle of MC TPC sim.

- Track generation for cosmic-ray setup
  - Straight tracks with realistic energy & angular spectra
    - μ-generator: angular spectrum of incident cosmics (a la BaBar)
    - Read in of energy list for cosmic μ (produced by CORSICA)
  - Prototype TPC geometry & trigger acceptance
  - Primary ionization simulated with HEED (after initialization with gas-mixture, p, T), called for each track
- Signal development in the TPC
  1. Drift of the e- to the endplate: Gaussian smearing (accord. to diffusion const. from Magboltz) for (x, y, z) coordinates separately
  2. Electrons reaching GEM1 are forced into closest GEM-hole
  3. Amplification accord. to average effective gain * RND
  4. New electrons are smeared (flat) inside GEM-hole
  5. Repetition of steps 1 to 4 for the transfer-gaps GEM1->GEM2, GEM2->GEM3, and induction-gap GEM3->pad plane
  6. Collection of the electrons on the pad plane



Position evolution (smearing) done for each primary electron separately



Track fitting methods

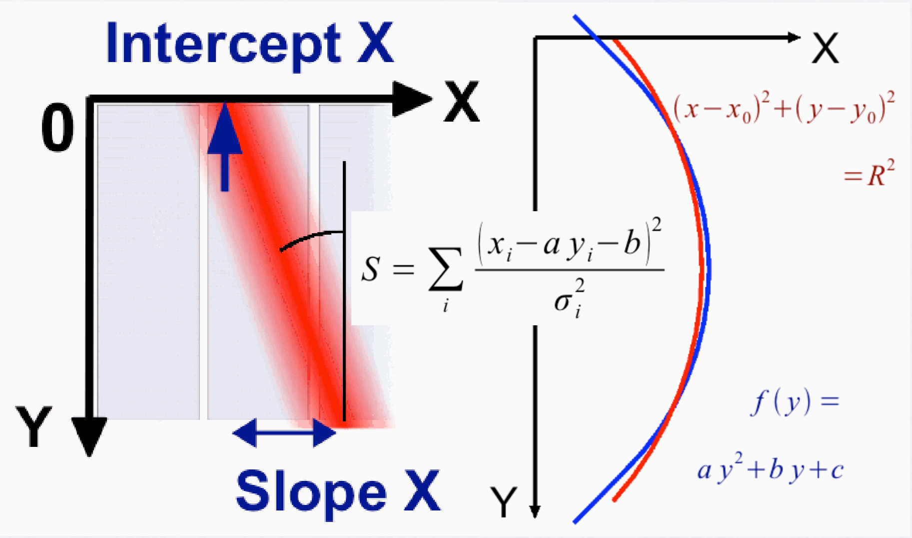
- **Chi squared method** (least squares method)
  - Straight line -> a: Slope X, b: Intercept X

$$x = f(y) = a\,y + b$$

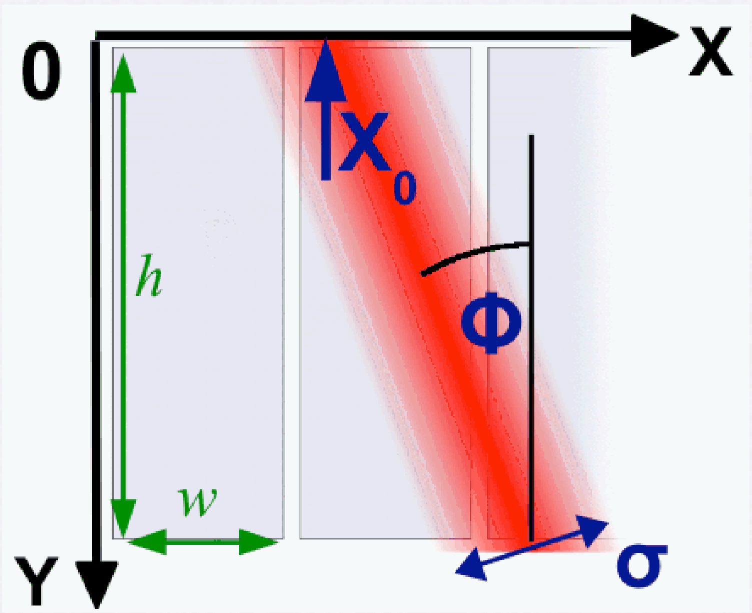
  - Circular arc -> C: Curvature, (x_0, y_0): Center

$$x = f(y) = x_0 \pm \sqrt{\frac{1}{C^2} - (y - y_0)^2}$$

  - Initialize with results from polynomial method



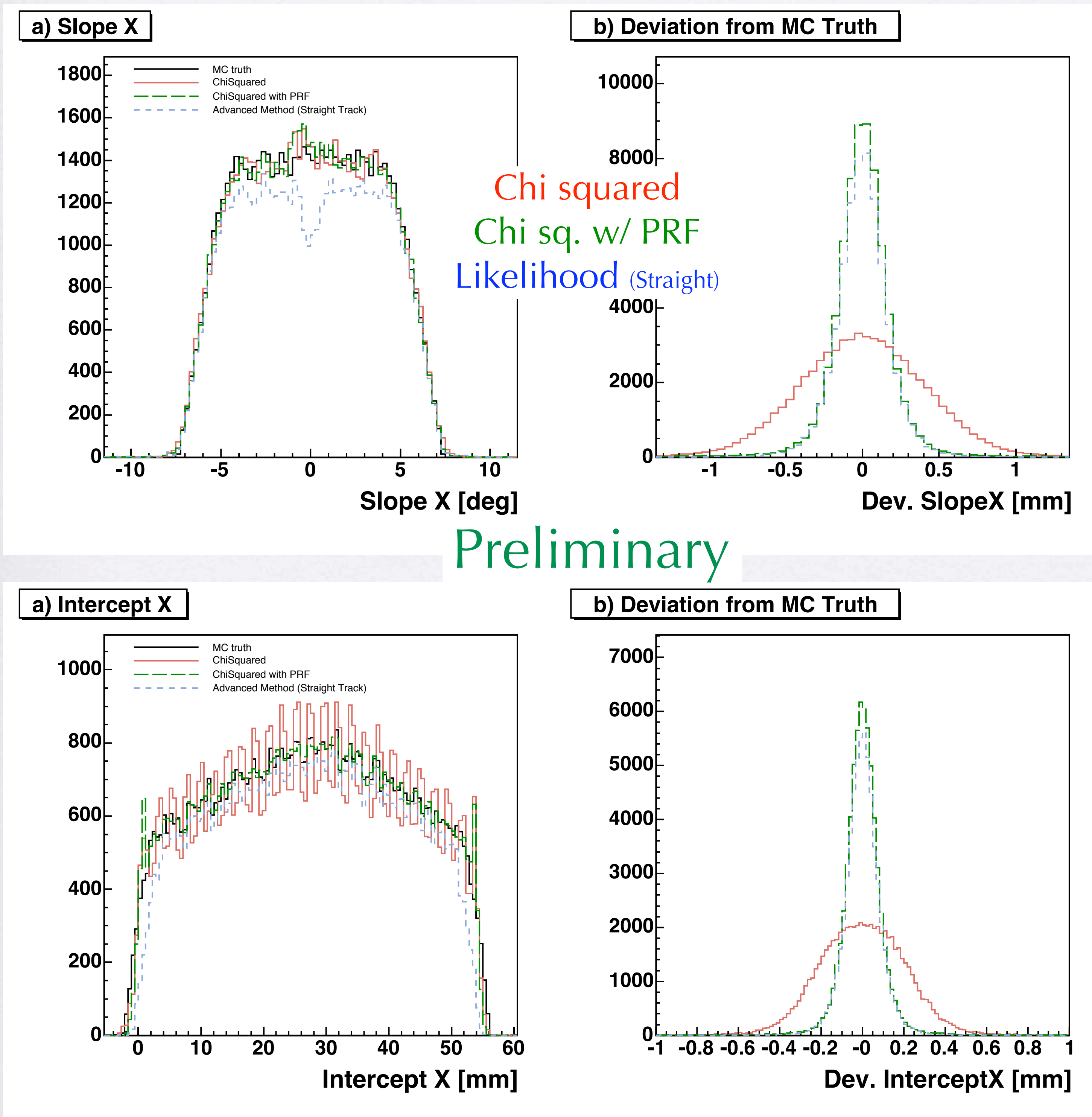
- **Advanced fit method** (likelihood track fit)
  - XY track fit uses Gaussian model for charge cloud
  - Track can be described by a straight line for each row
  - Three/Four parameter fit
    - -> Intercept X_0 (x at y=0), φ (azimuthal angle)
      - depend on curvature C and center (X_c, Y_c)
    - -> σ (transverse size of the cloud)
  - Maximizes binned likelihood function of observed charge on each pad



$$\ln L = \sum_{Pad} Q_{measured} \ln\left[\frac{Q_{expected}}{\sum_{Row} Q_{expected}}\right]$$

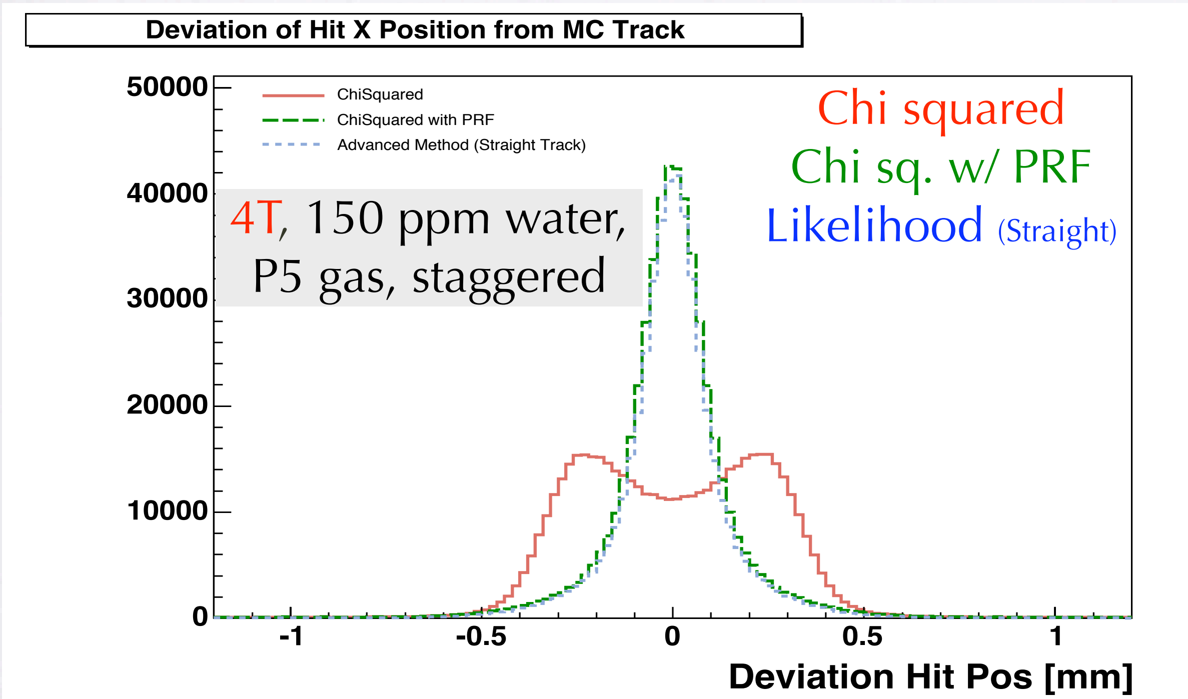
$$Q_{exp} = \int_{-\frac{h}{2}}^{\frac{h}{2}} dy \int_{-\frac{w}{2}}^{\frac{w}{2}} dx \, \frac{1}{2\pi\sigma} e^{\frac{[(x - X_0)\cos(\phi) + y\sin(\phi)]^2}{2\sigma^2}}$$

MC efficiency studies

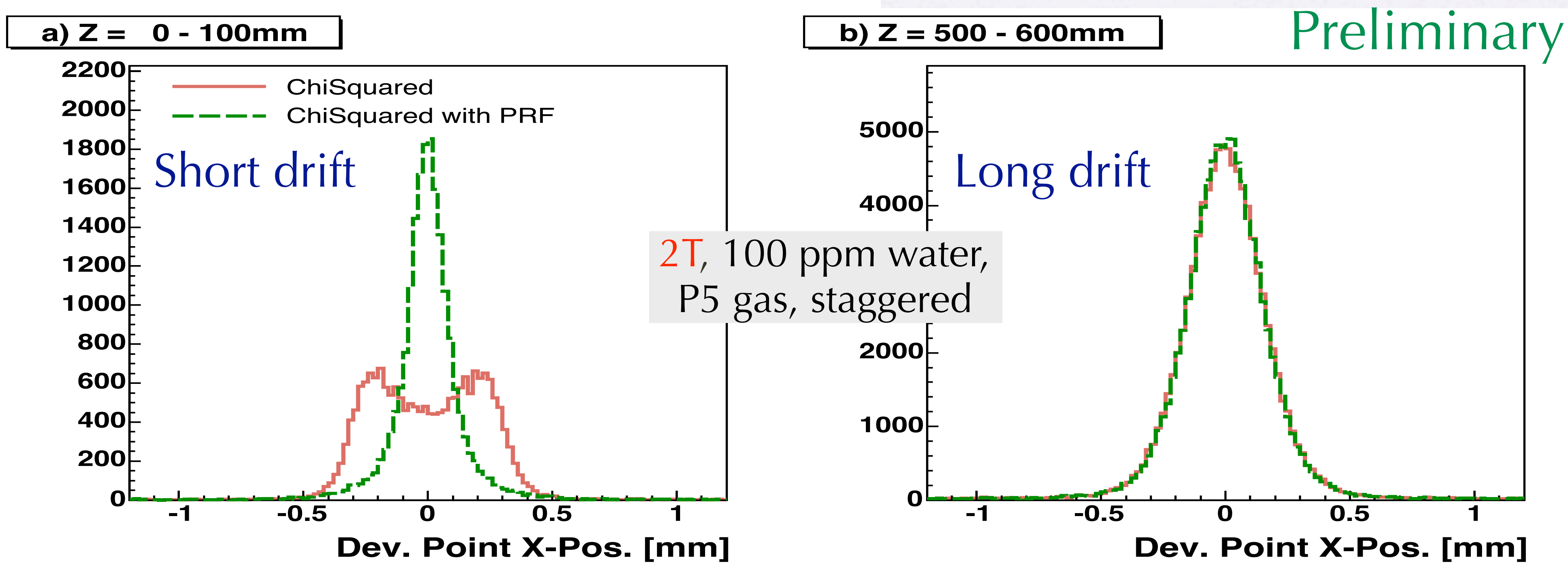


- Track data from MC TPC sim. (4T, P5 gas, 150 ppm water, staggered pad layout)
- Distribution & deviation from MC truth for Slope X & Intercept X using 3 different fitting methods
- Track fitting efficiency
  - Chi squared: 99.57 %
  - Chi sq. w/ PRF: 99.56 %
  - Likelihood (straight): 89.36 %
- Significant improvement for Likelihood track fitting

MC efficiency studies (cont'd)

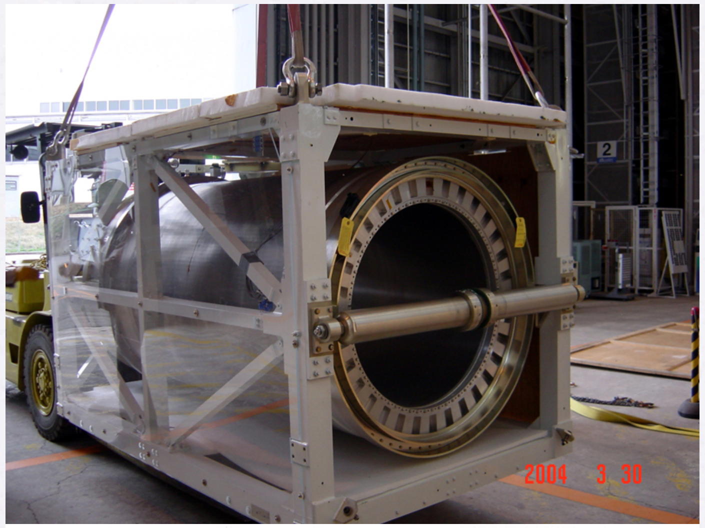


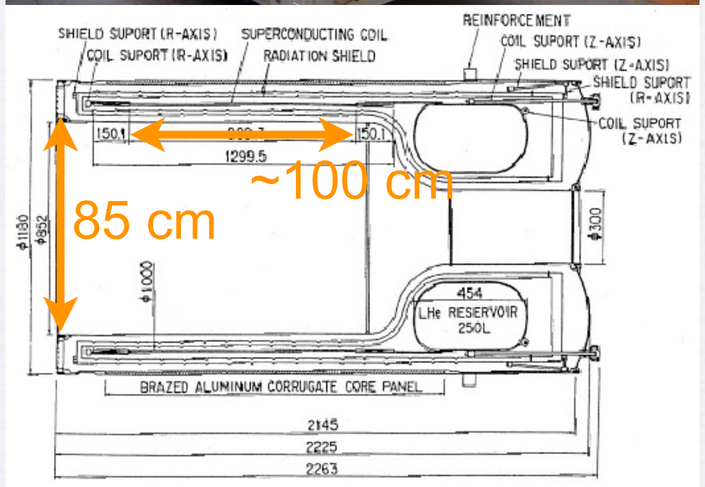
- Deviation of x-position of hit from MC track
- Positive effect of PRF implementation visible
- For 2T MC data, enough charge sharing in the drift range of 50 - 60 cm drift distance

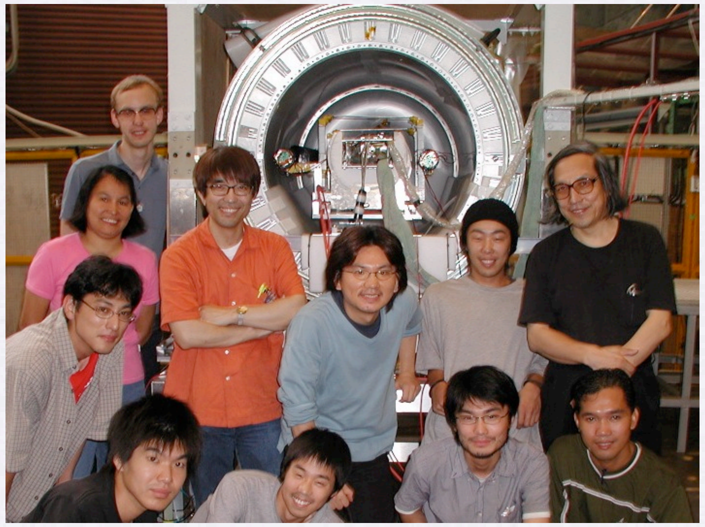


Superconducting magnet (PCMAG)

- B_{max} = 1.2 T, Ø = 85 cm, L_{eff} ~ 100 cm
- Provided from KEK for EUDET
- Originally developed for a balloon experiment in antarctica
  - Standalone operation (Persistent current mode, 250L LHe reservoir = refilling once a week)
  - Small material @half wall (0.13/0.19 X_0 for Coil/Coil+Cryostat) -> low multiple scattering
  - Light weight, No return yoke (~ 500 kg)
    - Movable -> Hadron beam @CERN or FNAL
    - Large stray field
- 2 year operation experience for small prototype TPC beam test @KEK 12GeV PS
  - Among Japan-Philippines-German-France-Canada TPC R&D groups
- Field homogeneity
  - Planning to 2D calculation & 3D field mapping

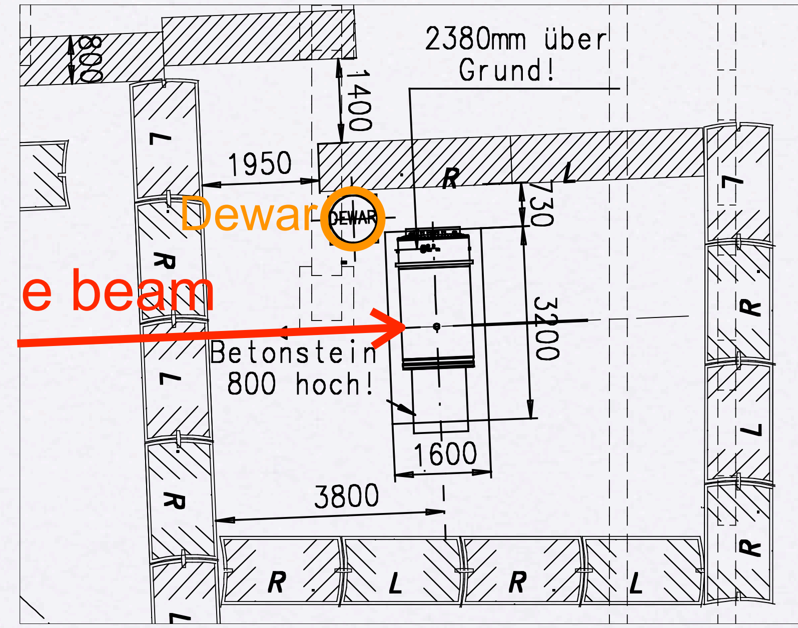


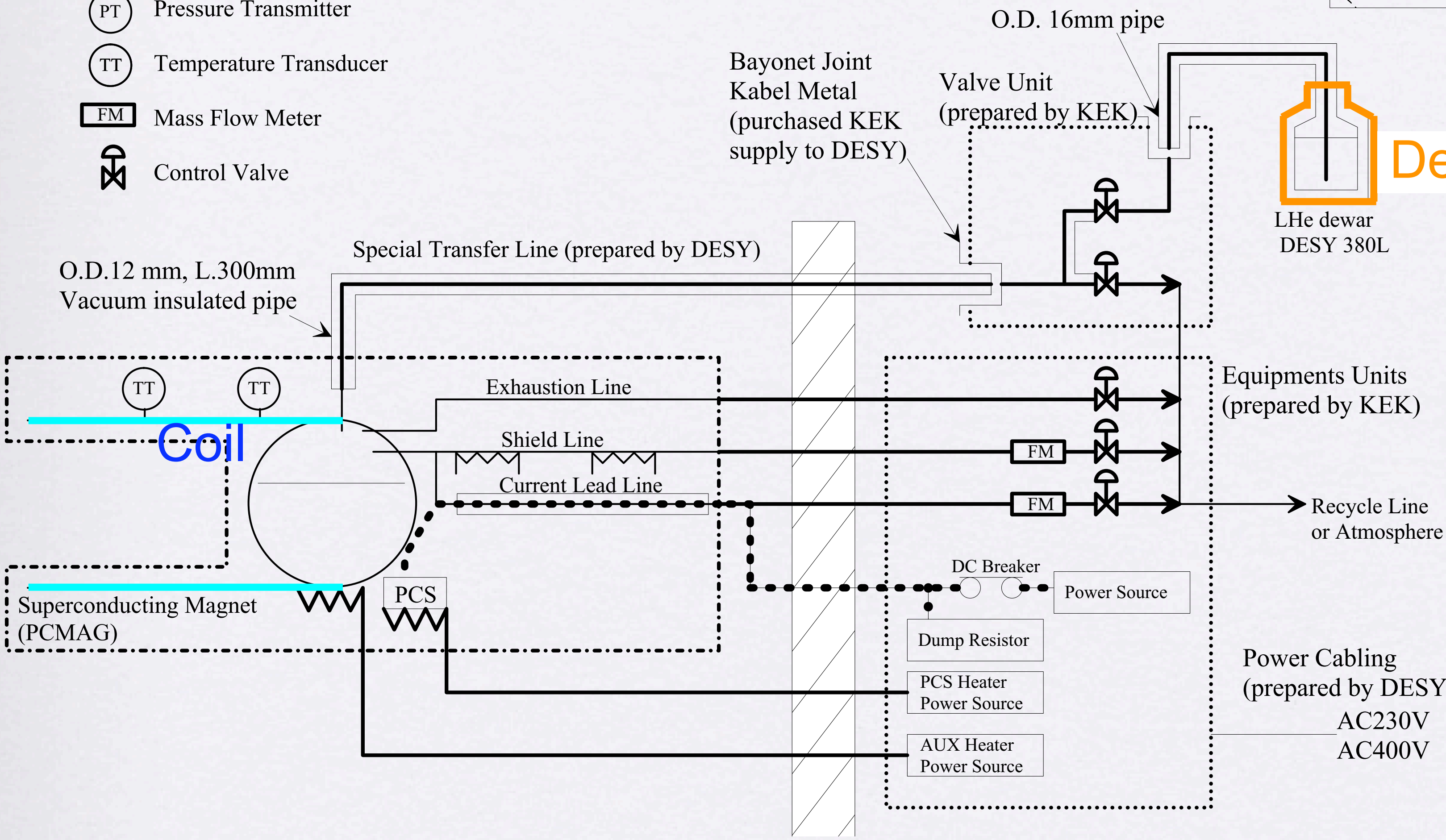




PCMAG at DESY test beam area

- Place PCMAG at "Strahl 24/1"
- Automatic LHe refilling system proposed by KEK cryo. expert will be implemented & tested at KEK before shipping to DESY
- Allows LHe refilling during magnet excited

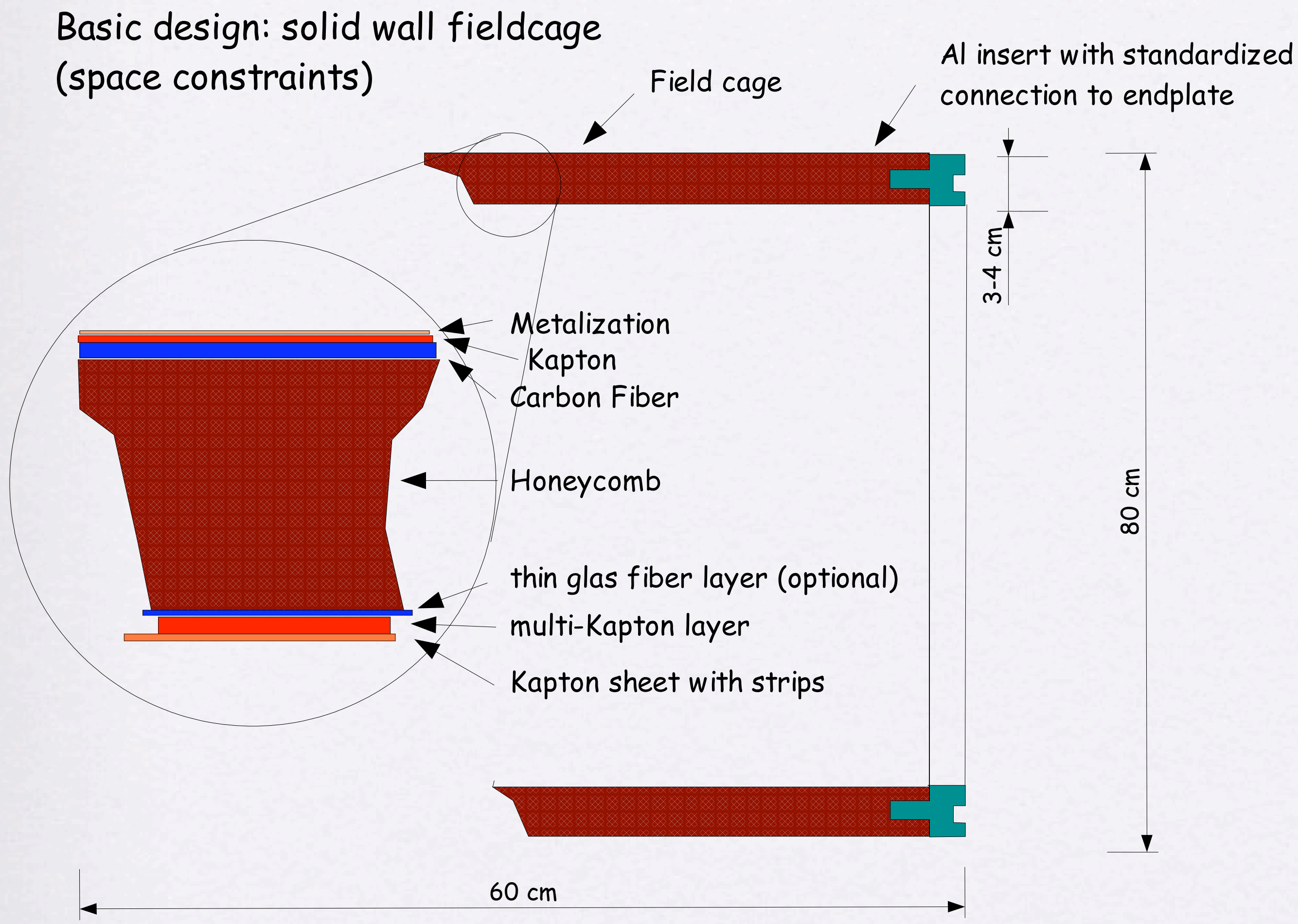


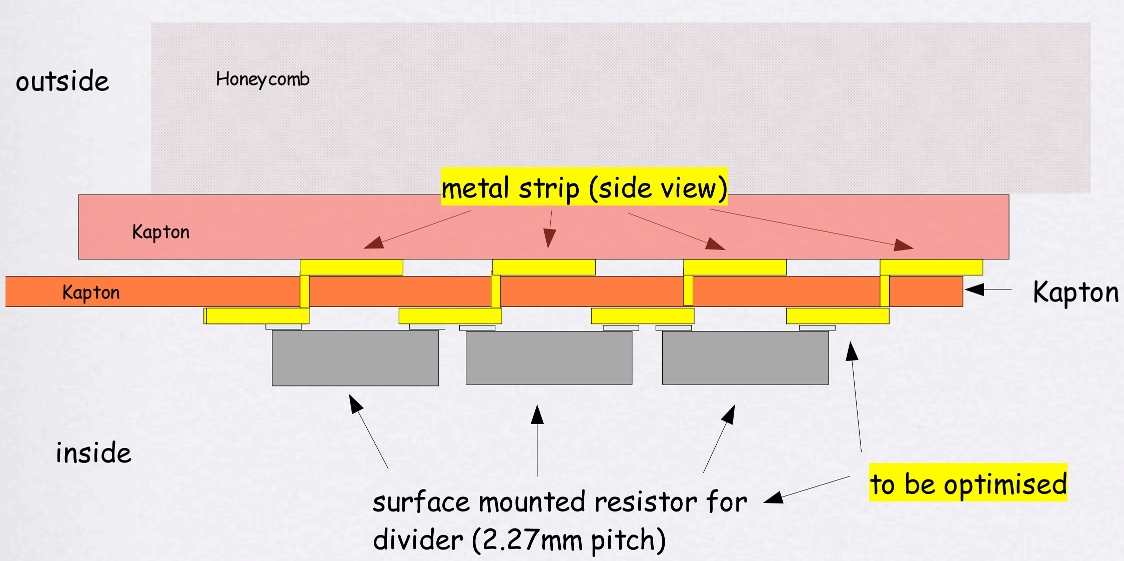


EUDET activities for large prototype

- Development & building of a low mass field cage
  - should fit into the PCMAG
    - length: 60 - 70 cm, to be defined by field homogeneity of the magnet
    - diameter: ~ 80 cm (allow for silicon devices on both sides within 2 cm between field cage and magnet)
  - "generic" field cage to be used for different end-det. technologies
  - realistic field cage to test mechanical structure and HV behavior
  - end-plate as realistic as possible to test MPGD behavior
    - not realistic due to easy exchange for different end-plates
  - cathode not realistic in first iteration (massive construction: G10 plate, Cu clad on the inside, ground plane on the outside), but possibility to make a realistic version should exist
  - connection between field cage and end cap designed for robustness
  - Based on the DESY small prototype TPC (Medi-TPC) field cage design

Field cage design





- layered construction, light weight, composite structure with honeycomb core, carbon fibre layer on the outside, possibly thin glas fibre on the inside
- Kapton foils for insulation on the inside
- field strips with pitch 2.7 mm (Cu strips)
- second row of field strips shifted by 1/2 period for shielding purposes
- resistive divider mounted on the inside of the field cage, inside the gas volume, from surface mount resistors
- 4 divider chains for redundancy and reduced heat load
- approx thickness of field cage wall: 3-4 cm
- thin Al layer on the outside as ground shield

Milestones

- First half 2006:
  - Field cage: iteration with EUDET & LC-TPC on the design & the parameters
    - calculation to estimate the mechanical strength
    - tests on the field cage structure (HV stability, mechanical stability)
  - Magnet: development, test & construction of a cryo. system at KEK, Ship to DESY
- Second half 2006:
  - Field cage: develop "production" facility at DESY to wind the field cage
  - Magnet: Commissioning at DESY test beam area
- First half 2007:
  - Field cage: build the field cage, Commissioning at lab.
  - Magnet: 3D field mapping
- Summer 2007:
  - Field cage, magnet & (part of) prototype elec.: ready to be used

Summary

- Implementation of pad response function results in more reliable on the hit reconstruction for Chi squared track fitting & the point resolution calculation
- Developed Monte Carlo TPC Simulator
- MC efficiency studies with 3 different fitting methods
  - Comparison of deviation from MC truth for track parameters (Slope X, Intercept X) and x-position of hits
  - Positive effect of PRF implementation clearly seen
  - Efficiency and deviation from MC truth for Likelihood track fitting show improvement of our implementation
- DESY TPC R&D group is developing the field cage and the magnet for test beam as an infrastructure of large prototype studies in the framework of EUDET

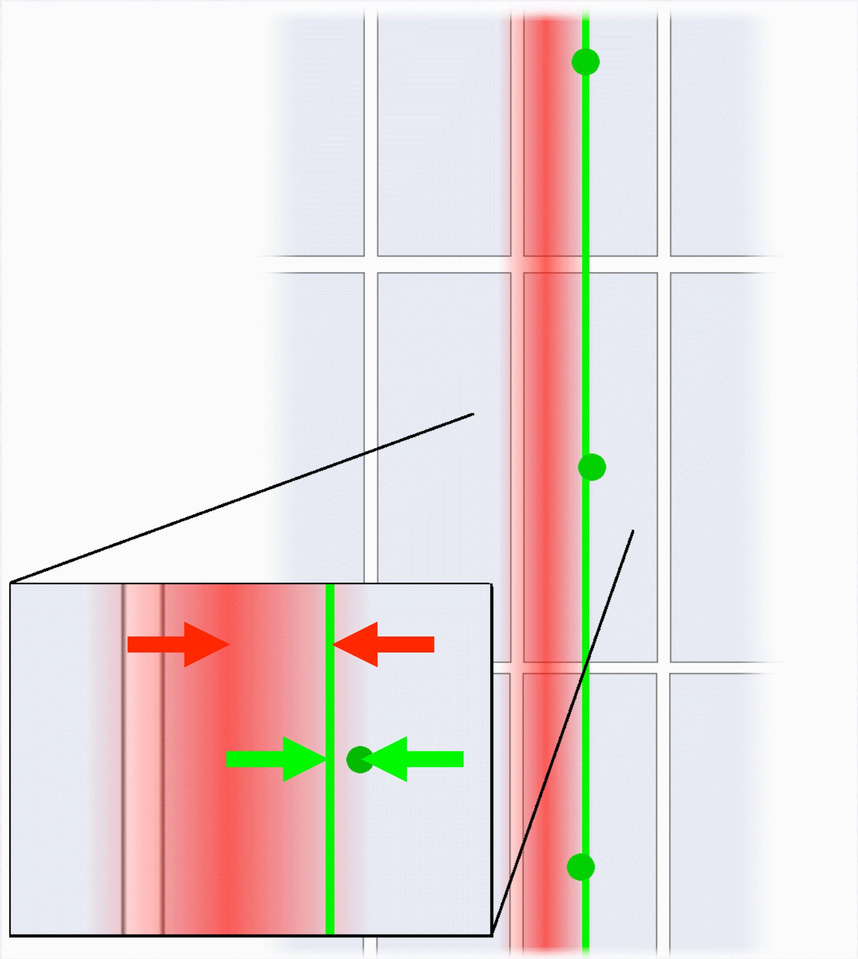
Backup slides

Staggered & non-staggered pad

Non-staggered pads:

Reconstructed track "gets drawn" towards the reconstructed hits

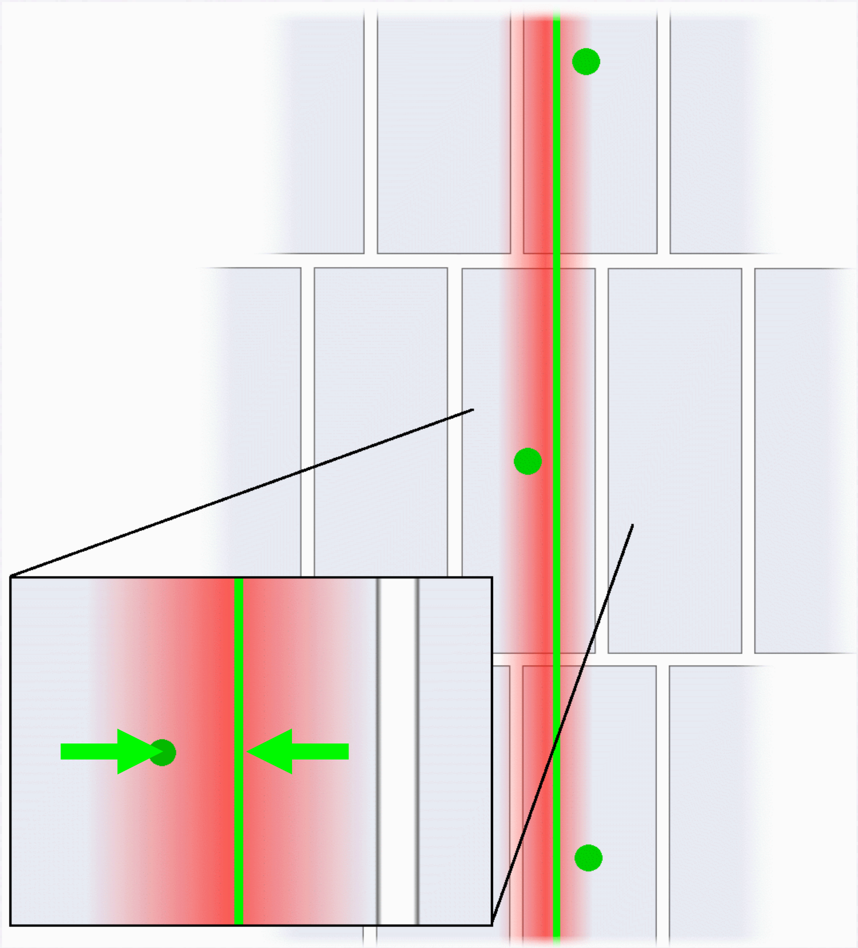
calculated residuals -> small



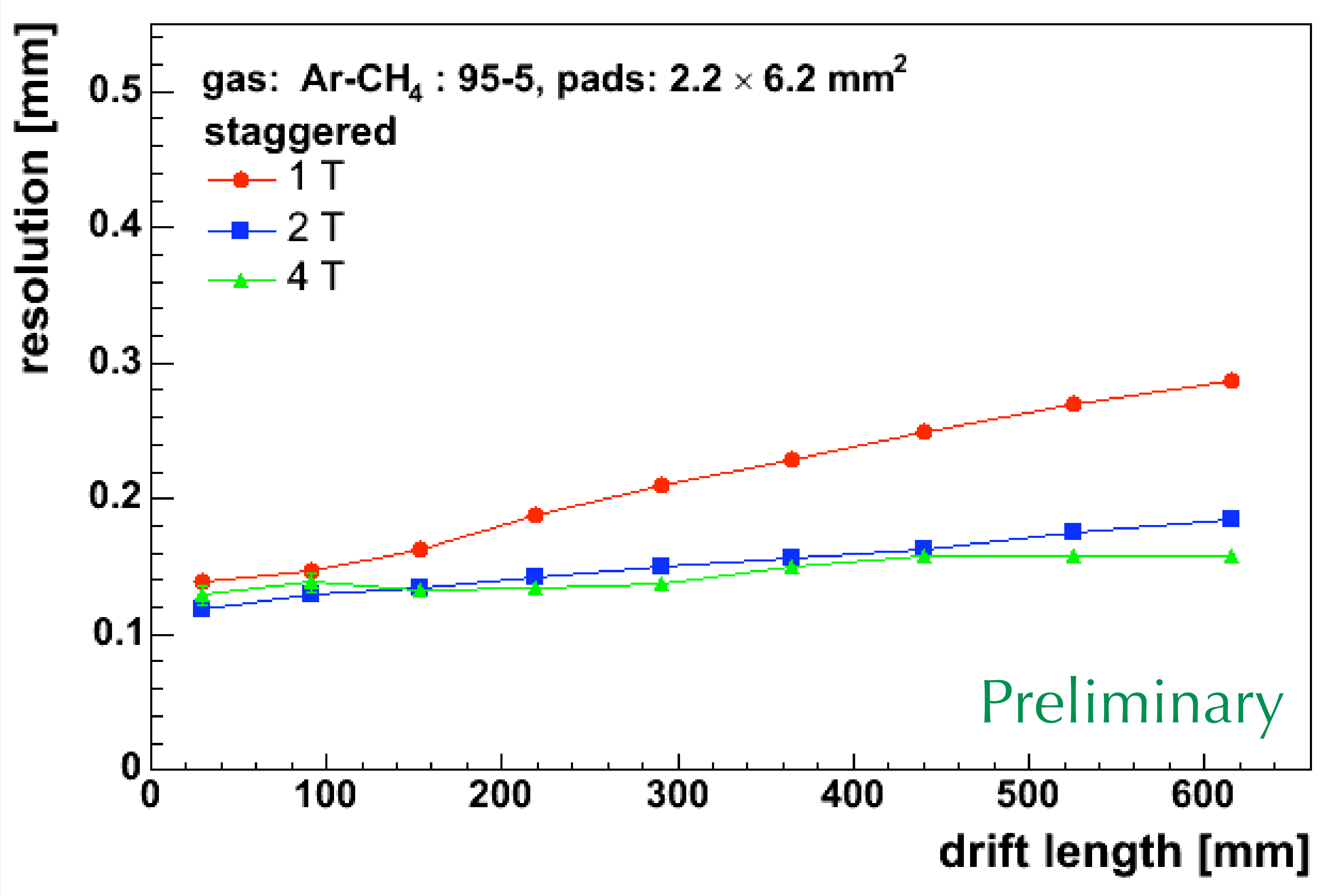
Staggered pads w/ small charge sharing:

Hits get reconstructed far from reference track

calculated residuals -> big



Point resolution w/ P5 gas



- For P5 gas no increasing values at short drift distance are seen
  - Indicates enough charge sharing due to large diffusion in the transfer gap

Tasks of MC TPC simulation

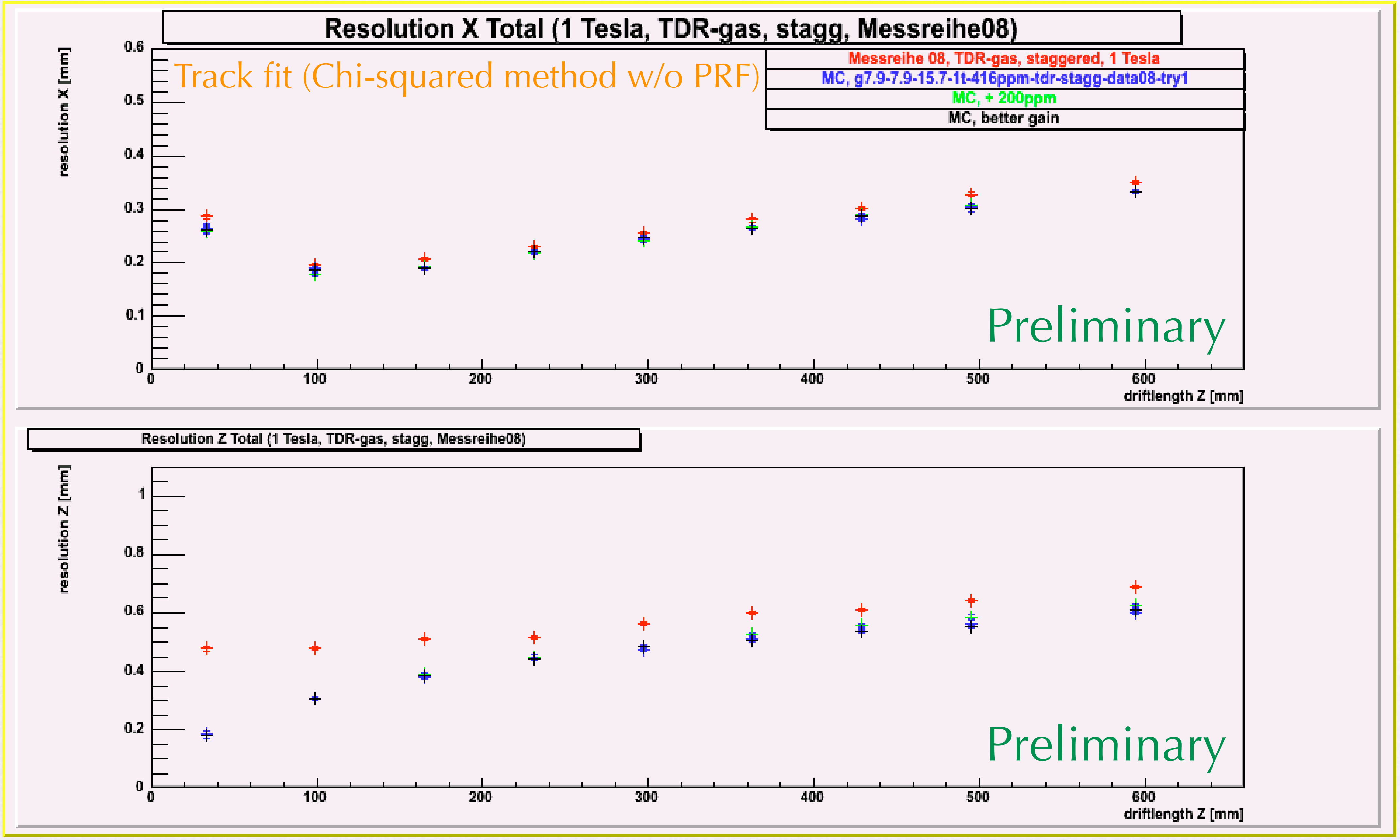
- Flexible simulation tool to understand data from test setups
  - Identification of effects with significant impact on the data
  - Disentangling of the not separately measurable effects
- For the current R&D setups -> Medi-TPC & big-TPC
  - Cosmic muons & test beam
  - Adjustable geometries for different setups (e.g. chamber-size, amplification, pad shapes & layouts, triggers, ...)
    - 3 GEM structure with separately adjustable effective gains
  - Applied fields (B-field, E_{drift}, $E_{transfer\_i}$, $E_{induction}$)
  - Gas-mixture (water content, O_2), temperature, pressure, ...
- Once sufficiently well understood also:
  extrapolations beyond the currently available setups like
  - Optimization of pad size and shape (appropriate resolution with reasonable pad shapes and a low number of channels)
  - Larger readout plane e.g. for efficiency studies
  - Longer drift distances, ...

Limitations & capabilities for our MC TPC simulator

- No generalized formulas e.g. for gains available yet. For direct comparisons with data sets tuning/iterations necessary
- Restricted to uneven number of rows and pads/row
- Although B-field taken into account for diffusion, only straight tracks are handled, no curvature possible! (Would need major re-design, will not be changed)
-
- Parameters used are all motivated and meaningful, no arbitrary fetch factors
- Still relatively fast -> large scale productions possible
- Have gained at least some trust in the outputs...

Point resolution (1T, TDR): comparison btw meas. & MC

- Staggered pad layout (2.2 x 6.2 mm^2 pitch)



Point resolution (2T, TDR): comparison btw meas. & MC

- Staggered pad layout (2.2 x 6.2 mm^2 pitch)