GEM-TPC performance in a magnetic field

Paris LCWS 2004

April 21, 2004

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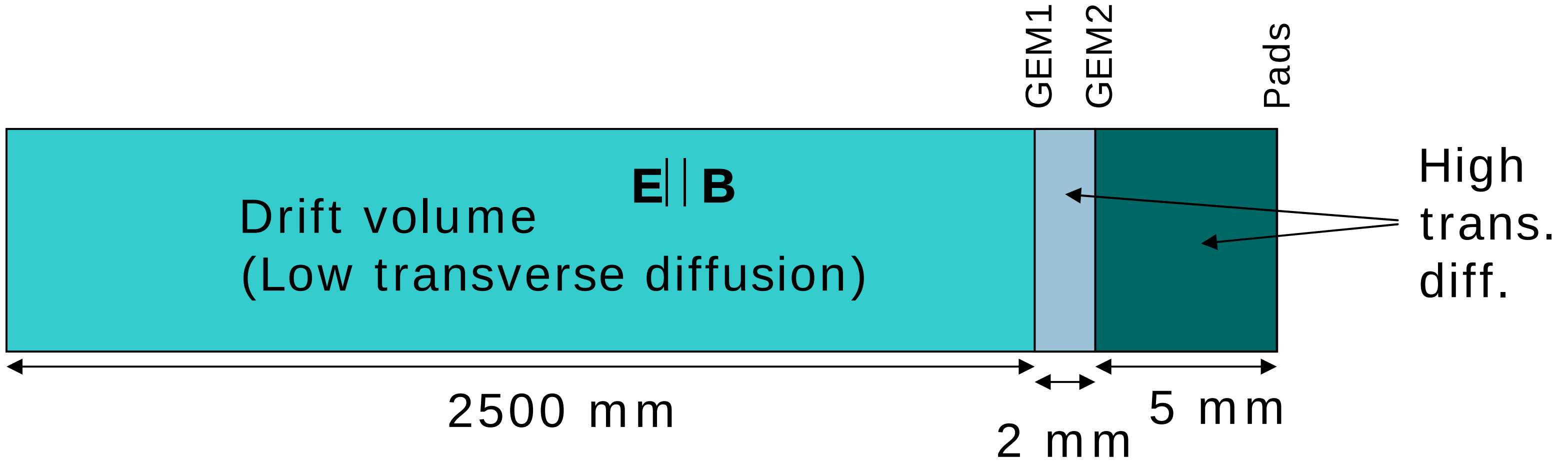
TPCs with MPGD readout

- MPGDs offer significant advantages for TPC readout
  - Reduced **E** × **B** ⇒ better r-ϕ resolution
  - Faster signals ⇒ better z separation, resolution
  - Narrower signals ⇒ better r-ϕ separation
  - Particularly well suited for a LC

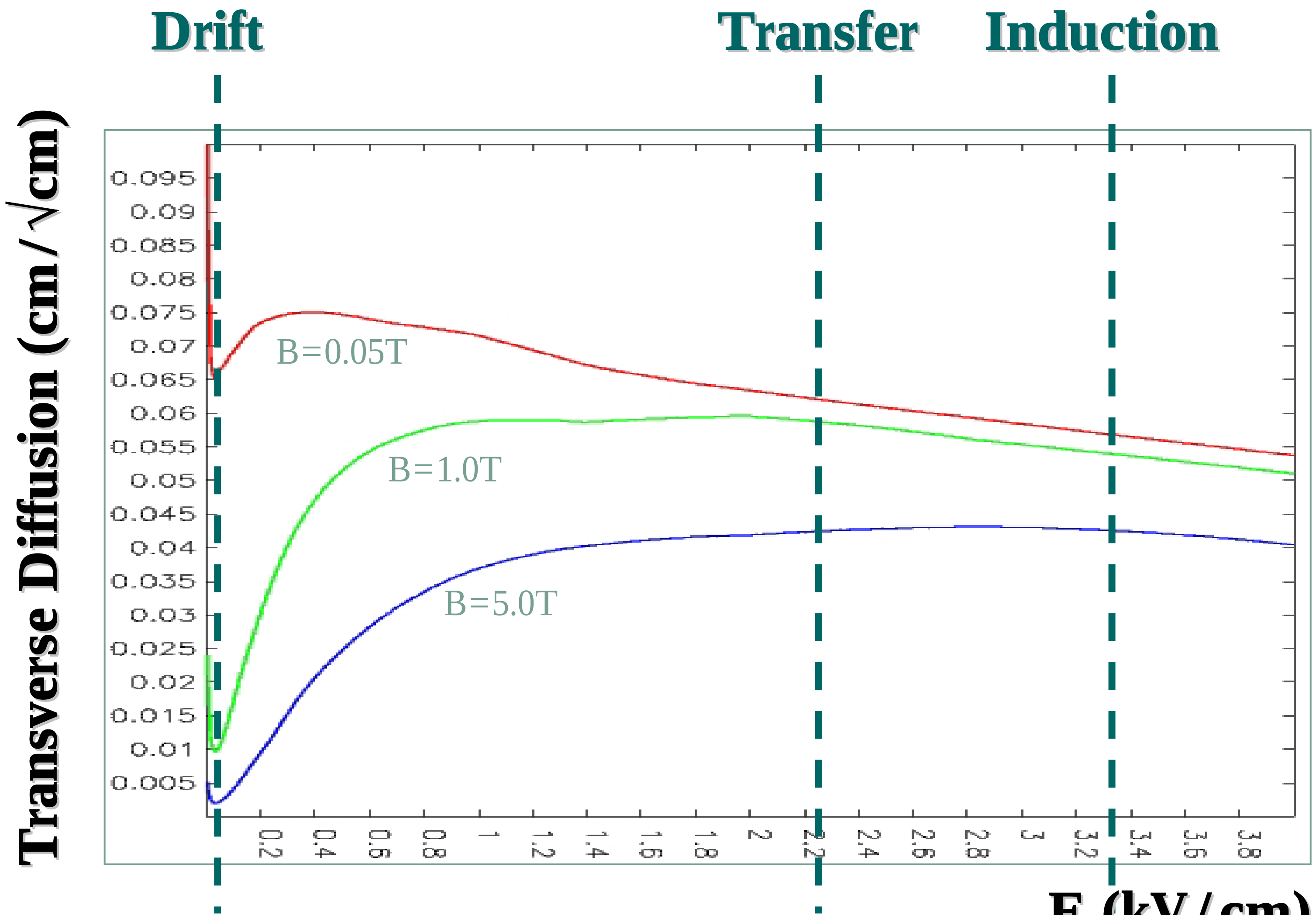
- Narrow signals present a new challenge for large scale TPCs:
  - How to accurately determine the centroid of the narrow charge distribution with a reasonable number of channels

TPCs with GEM readout

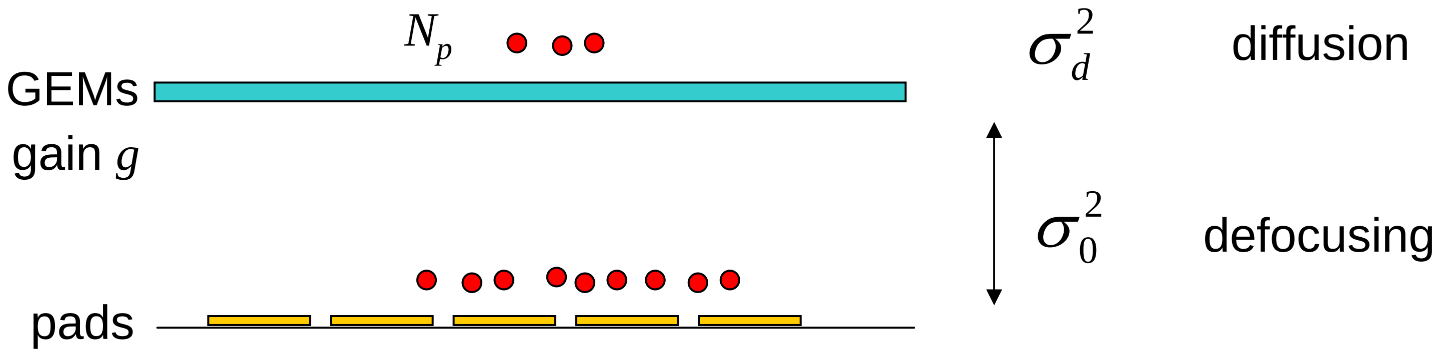
- GEMs offer a solution:
  - Use gas diffusion between the GEMs to spread the charge over a larger region
    - Since the defocusing occurs during and after the gain stage, the track resolution is not sacrificed
    - For the best two-particle separation, defocus as little as required



Example: P5


Drift
Transfer
Induction
Transverse Diffusion (cm/√cm)
0.095
0.09
0.085
0.08
0.075
0.07
0.065
0.06
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
B=0.05T
B=1.0T
B=5.0T
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
E (kV/cm)

Defocusing equations



If:

(a) the variance of the gain, $\sigma_g^2 = 0$

(b) the uncertainty of the x coordinate for each electron, $\sigma_x = 0$

Then:

the variance of $\bar{x}$ at the pads is: $\sigma_{\bar{x}}^2 = \frac{1}{N_p}\left(\sigma_d^2 + \frac{\sigma_0^2}{g}\right)$

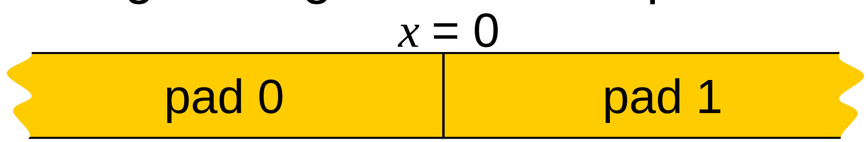
To achieve the "diffusion limit", the GEM term must be much smaller than the diffusion term. The GEM term increases for:

(a) $\sigma_g > 0$ - this deserves more attention

(b) $\sigma_x > 0$ - this increases by using large pads (next slide)

Sampling with large pads

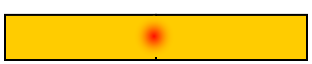
- Consider two neighboring semi-infinite pads with boundary at $x = 0$.



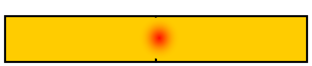
- If events are distributed according to the pdf $G(x)$, the expectation value for the fraction of events over pad 1 is $\langle F \rangle = \int_0^\infty G(x)dx$
- If $G(x)$ is Gaussian, with mean μ, standard dev. σ, the estimate, $\hat{\mu}$, determined from the observed fraction, F, has variance:

$$\sigma_{\hat{\mu}}^2 = 2\pi\sigma^2\, e^{(x-\mu)^2/\sigma^2} \sigma_F^2$$

- From binomial statistics, the variance of F is $\sigma_F^2 = p(1-p)/N$



if $\mu = 0 \Rightarrow \sigma_{\hat{\mu}}^2 = \frac{1}{2}\pi\sigma^2 / N \cong 1.6\,\sigma^2 / N$



if $\mu = 1\sigma \Rightarrow \sigma_{\hat{\mu}}^2 \cong 2.3\,\sigma^2 / N$

if $\mu = 2\sigma \Rightarrow \sigma_{\hat{\mu}}^2 \cong 9.\,\sigma^2 / N$

- the GEM term is to be small
- keep pad width < 4 σ
- noise/thresholds not incl.

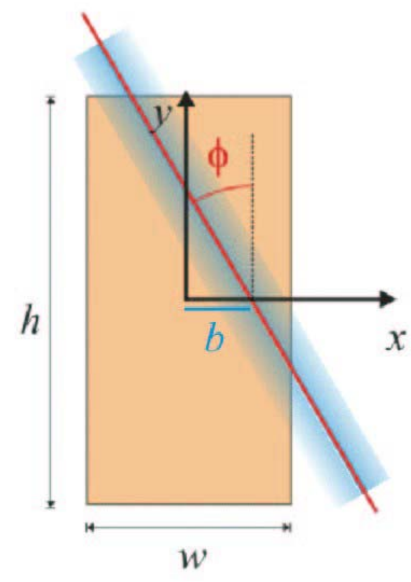
Limited defocusing

- It depends on the gain, and other factors, but as rough figure, the defocusing should be at least

$$\sigma_0 \approx \tfrac{1}{4}\,\text{pad width}$$

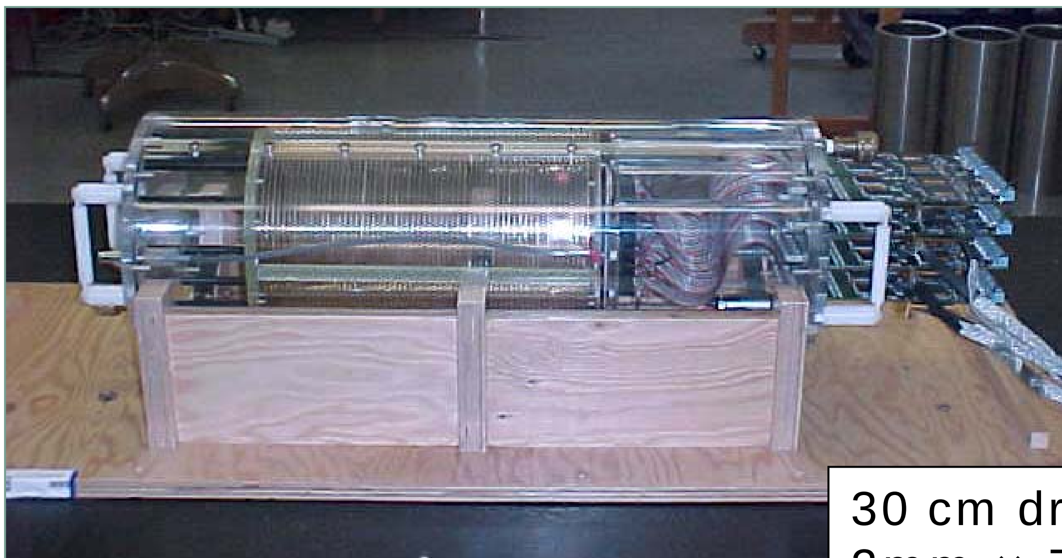
- Charge sharing typically over 2 pads:
  - Important to account for non-linear sharing
  - Track fitting is performed by maximum likelihood:

$$x_0, \phi_0, \sigma, r^{-1}$$



Test of concept in a magnetic field

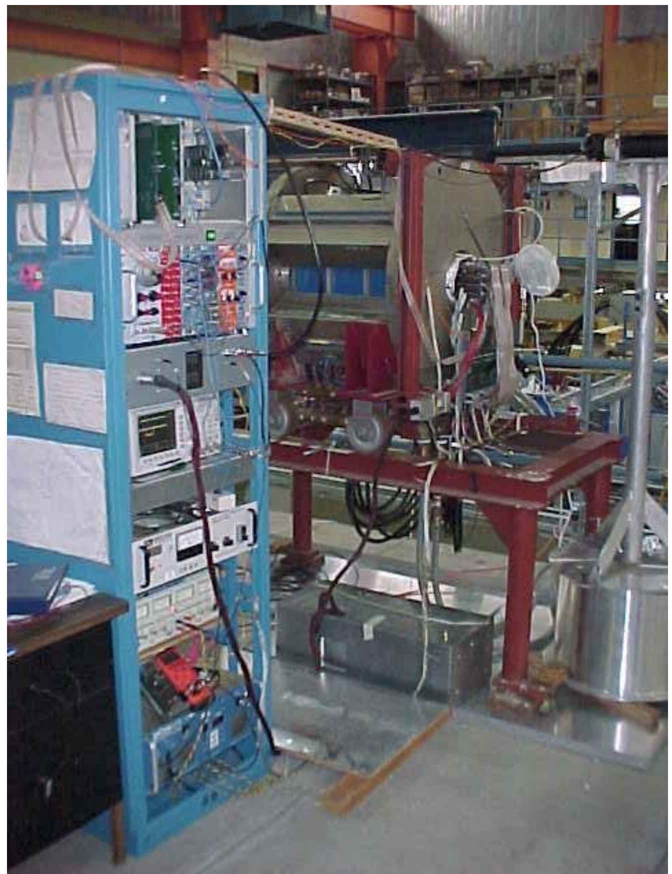
- Small TPC prototype with GEM readout designed for cosmic ray tests in TRIUMF and DESY magnets:

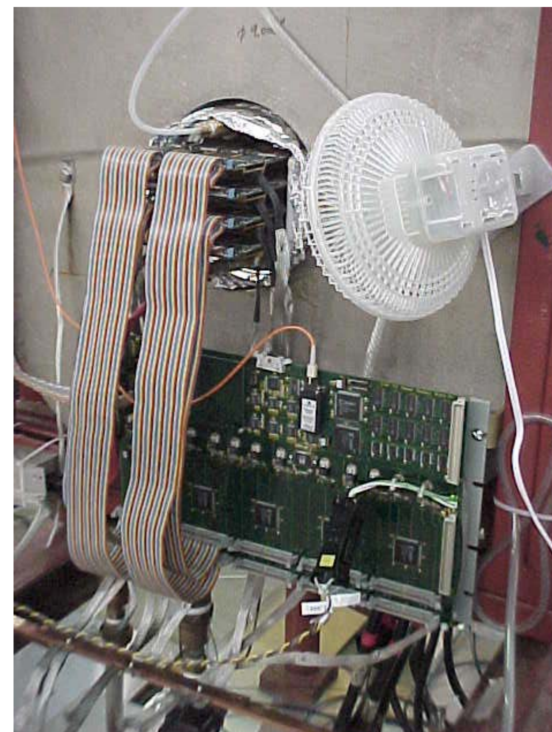


30 cm drift
2mm × 7 mm pads

First GEM-TPC tracking in B fields

- TRIUMF tests (0 – 0.9 T): June 2003



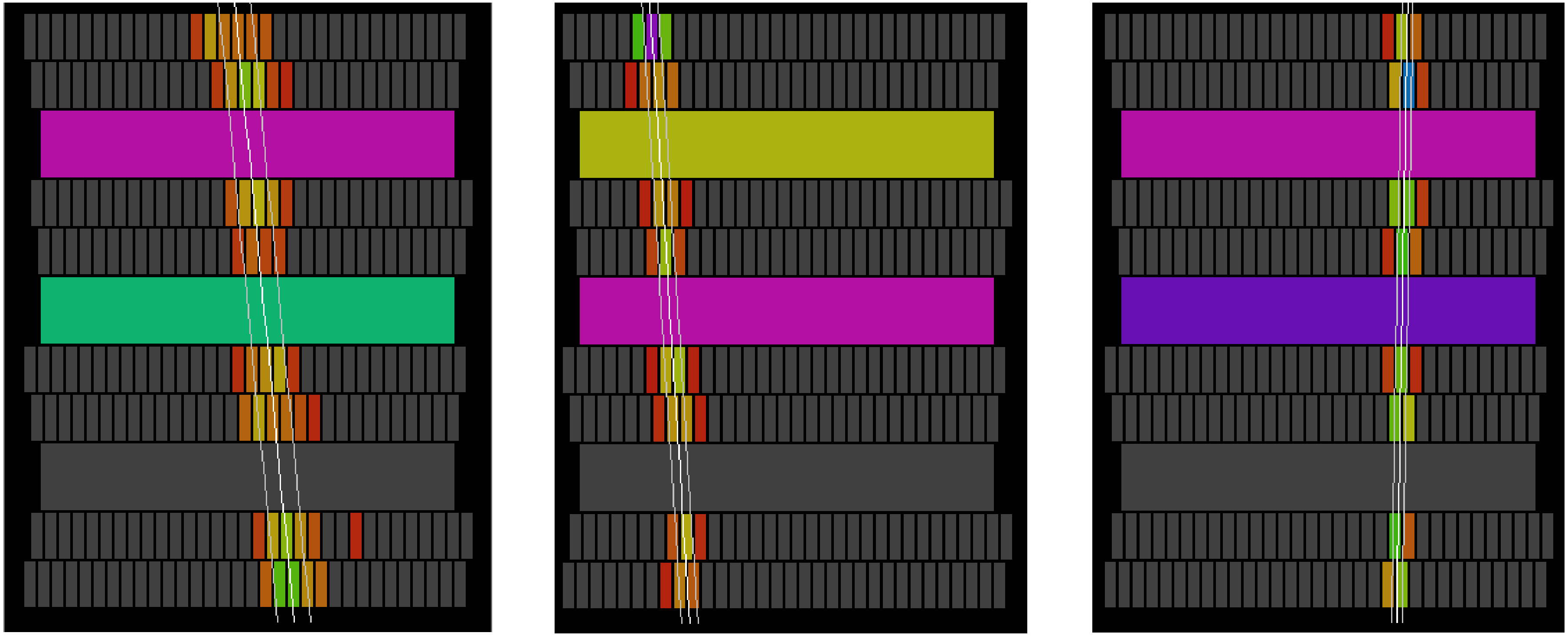


Example events at ~ 25 cm drift

- Gas: P10

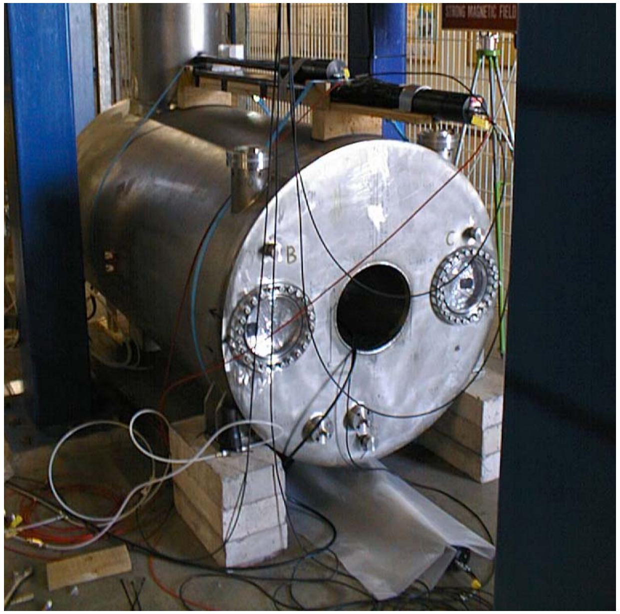
pads: 2 mm x 7 mm

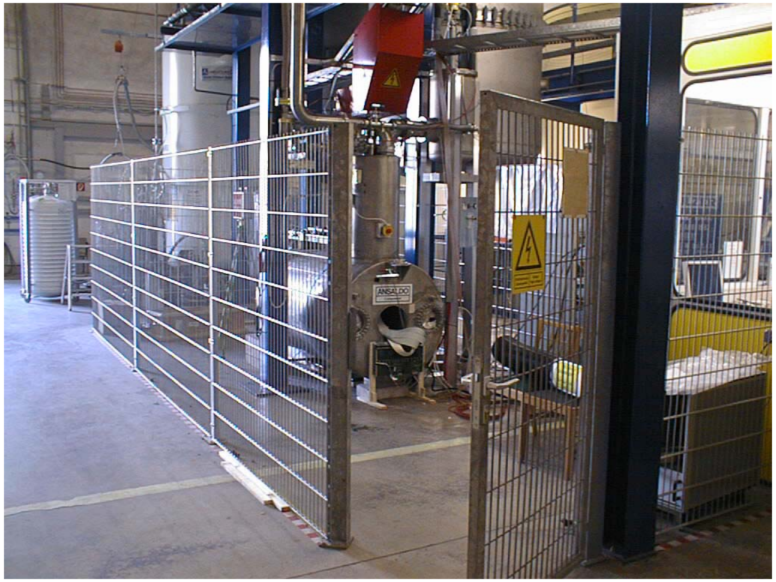
0 Tesla	0.45 Tesla	0.9 Tesla

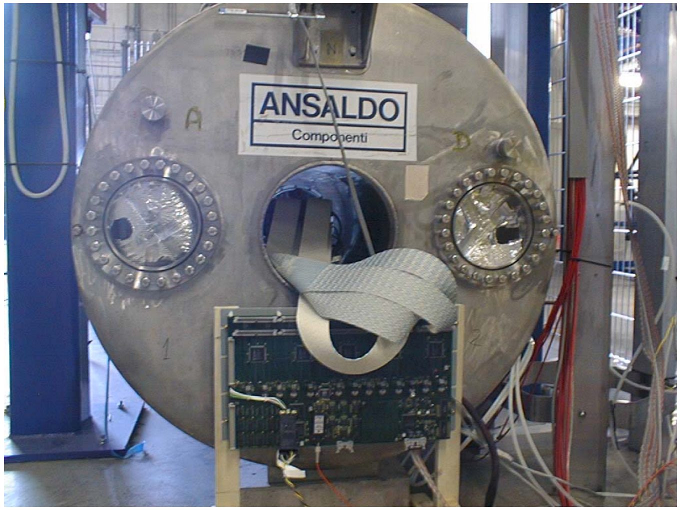


σ = 2.3 mm	σ = 1.2 mm	σ = 0.8 mm

DESY tests (0 – 5.3 T): July/August 2003

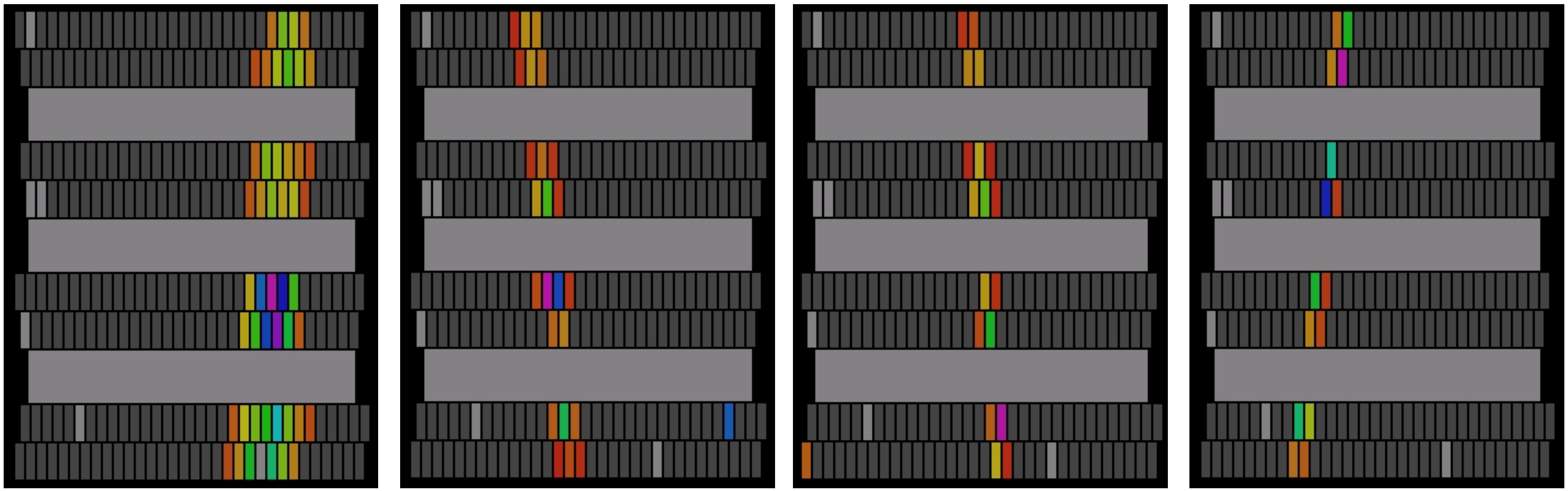






Example events at ~ 25 cm drift

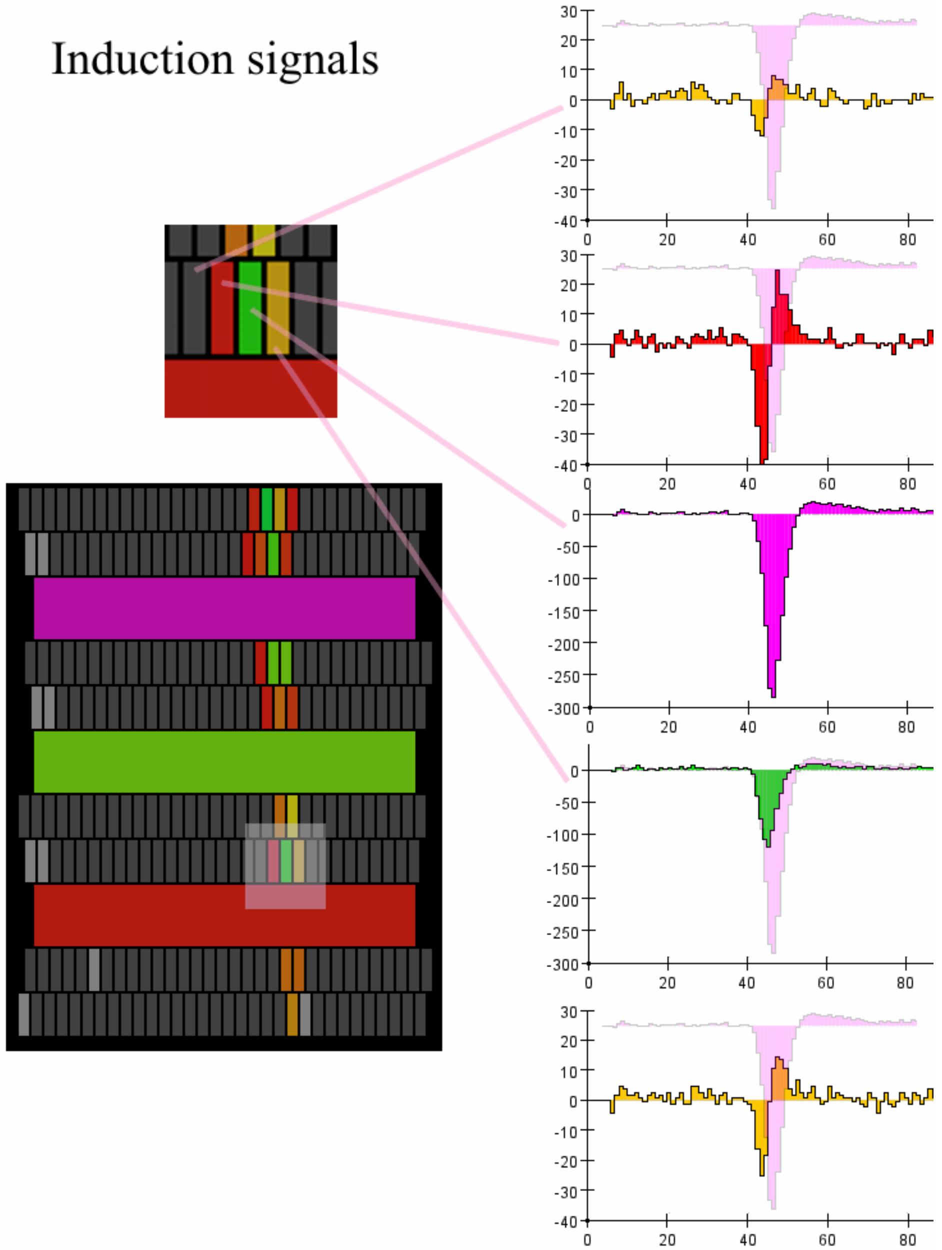
- Gas: P5



B=0T	B=0.9T	B=2.5T	B=4.5T

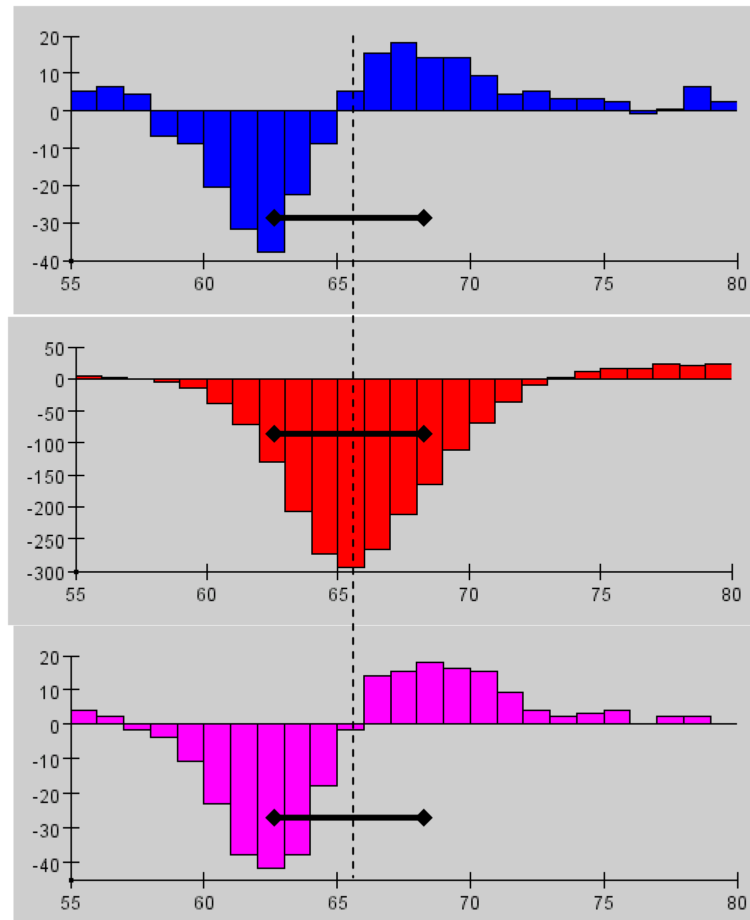
Pulse analysis

- Both induced and real pulses are seen.
  - electronics shaping responsible for the unipolar (real) and bipolar (induced) shapes for these pulses



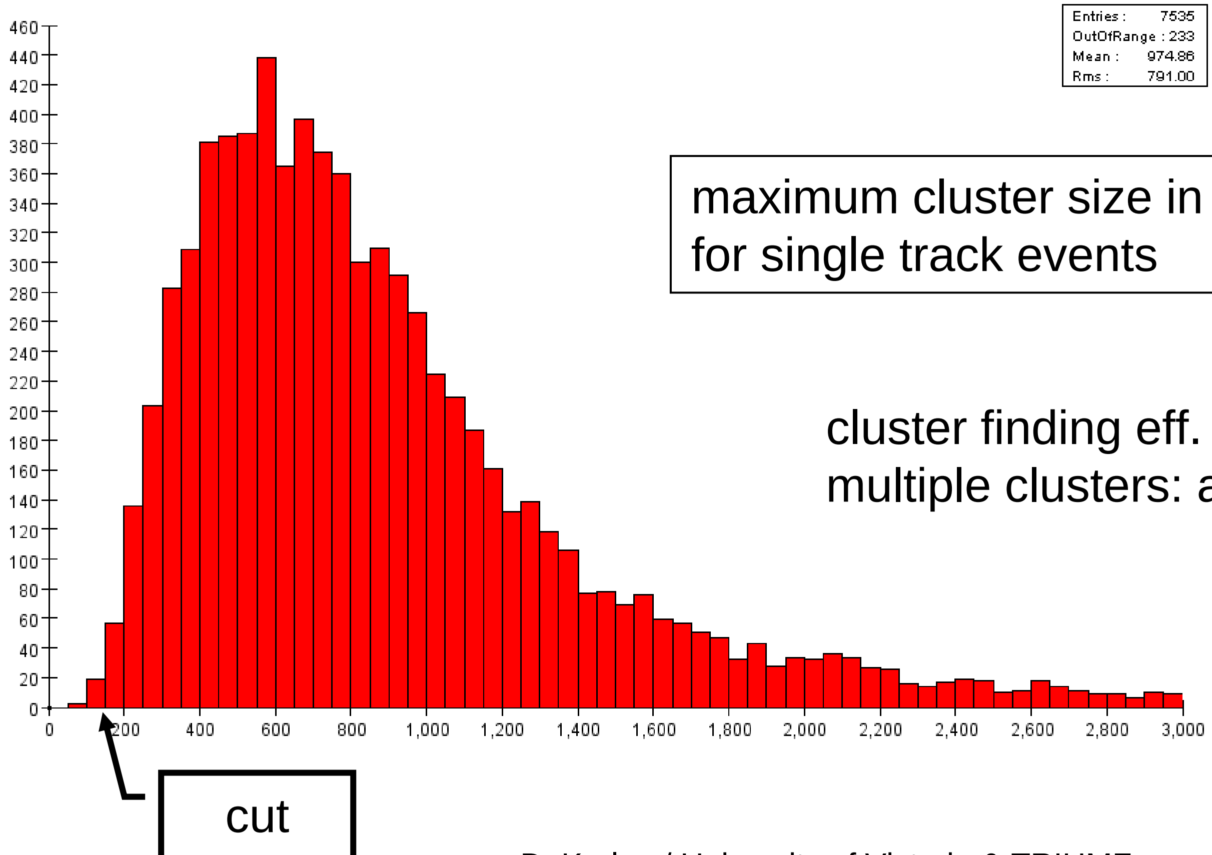
Real/Induced signal separation

- To measure the distribution of electrons directly, we need to remove the induced component:
  - Look at events from high field (low diffusion) where track goes through centre of pad:
  - Sum amplitude over the 7 bins shown (peak +/- 3 bins) – induced component is nullified
    - weighting of pre/post peaking adjusted – found that weight=1is optimal



Cluster finding

- Data is scanned in each row for a cluster of signals in bins of space-time.

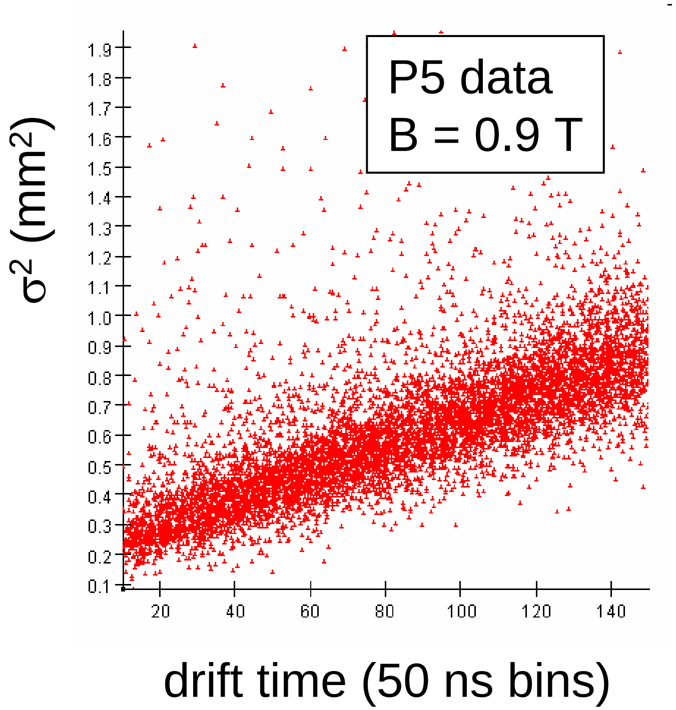


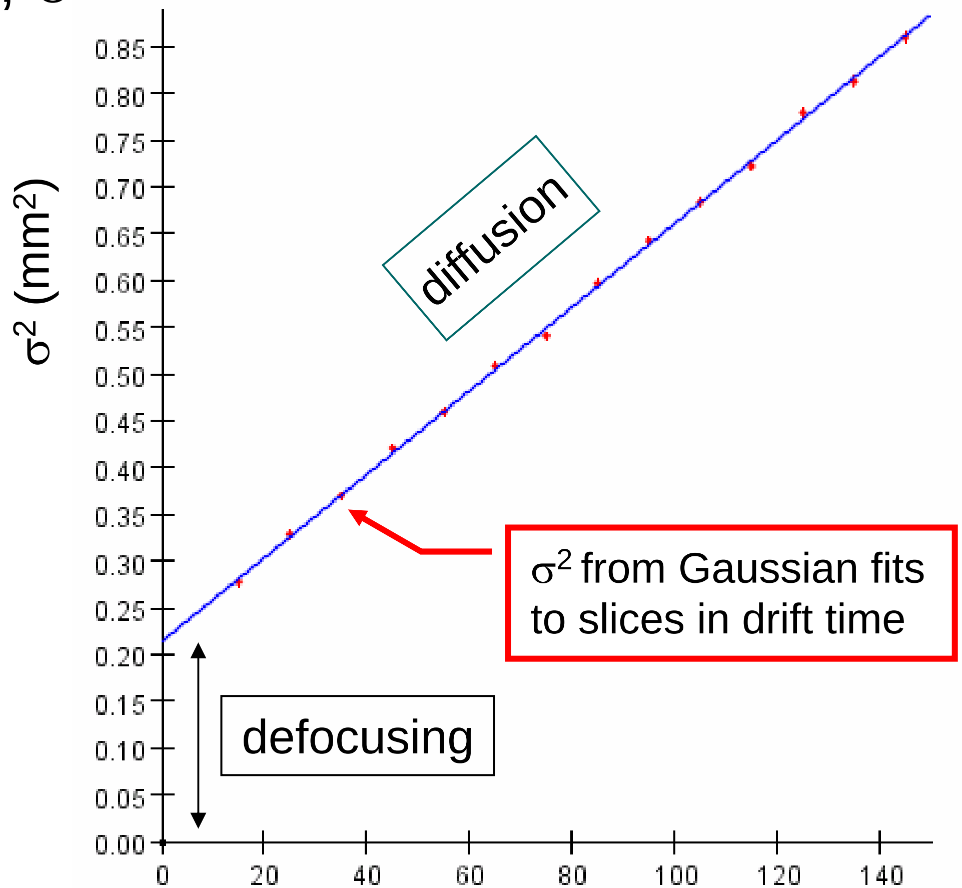
maximum cluster size in a row for single track events

cluster finding eff. 99.5 – 99.9 %
multiple clusters: about 1%

Electron transport measurements

- The maximum likelihood track fit includes, as a parameter, the standard deviation of the charge clouds as they arrive on the pads, σ





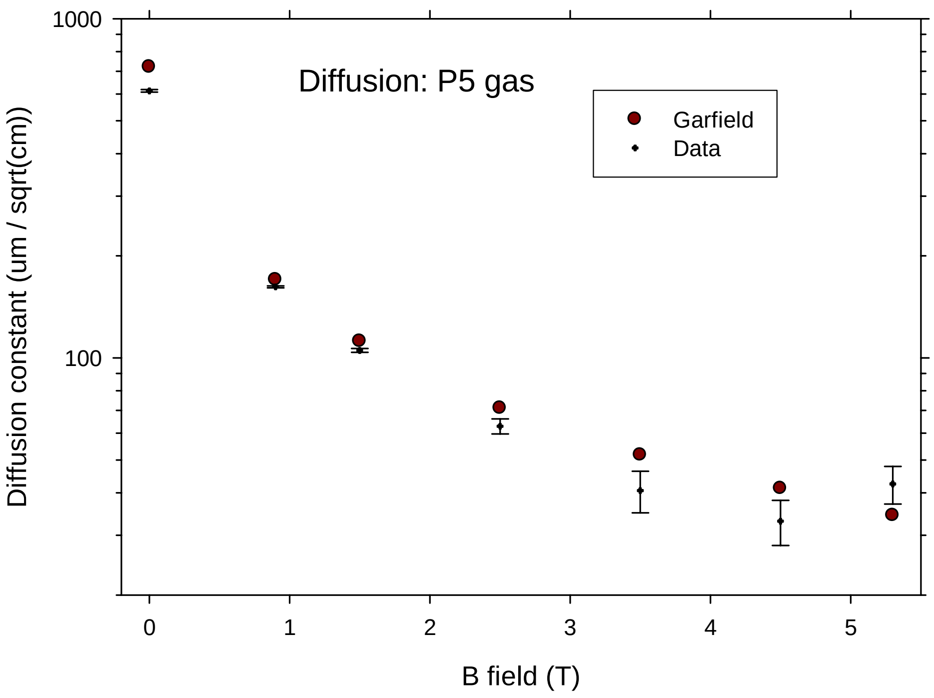
Diffusion constants: check with MC

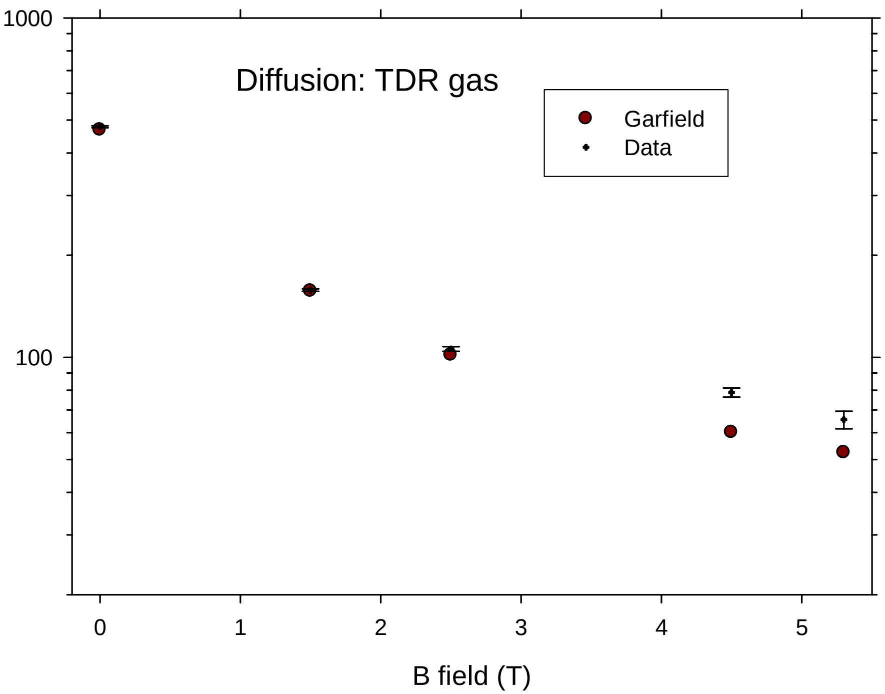
- Monte Carlo samples produced with diffusion constants from Garfield
  - analysis of samples yield diffusion constants somewhat smaller than input constants:
    - Table shown for P5 MC
  - To correct for analysis: add ~8 (except for B=0)

B (T)	Input (μm/√cm)	Output (μm/√cm)
0	721	671 ± 4
0.9	170	162 ± 1
1.5	112	105 ± 1
2.5	71.1	63.2 ± 0.8
3.5	51.7	42.7 ± 1.1
4.5	41.2	31.8 ± 1.5
5.3	34.3	24.8 ± 2.1

Diffusion constants: P5 and TDR gases

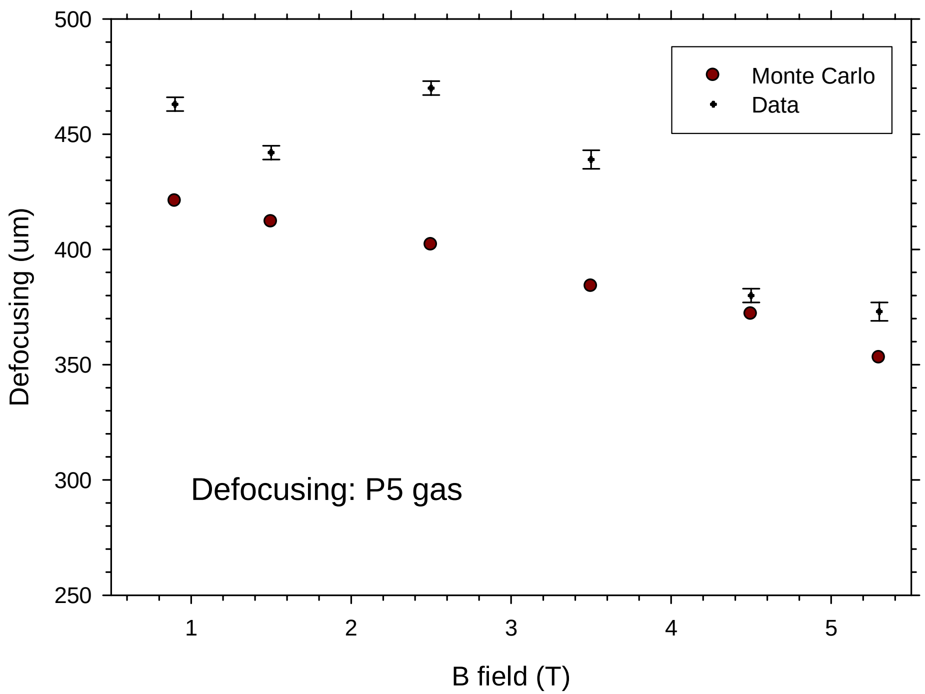
- In reasonable agreement with Garfield

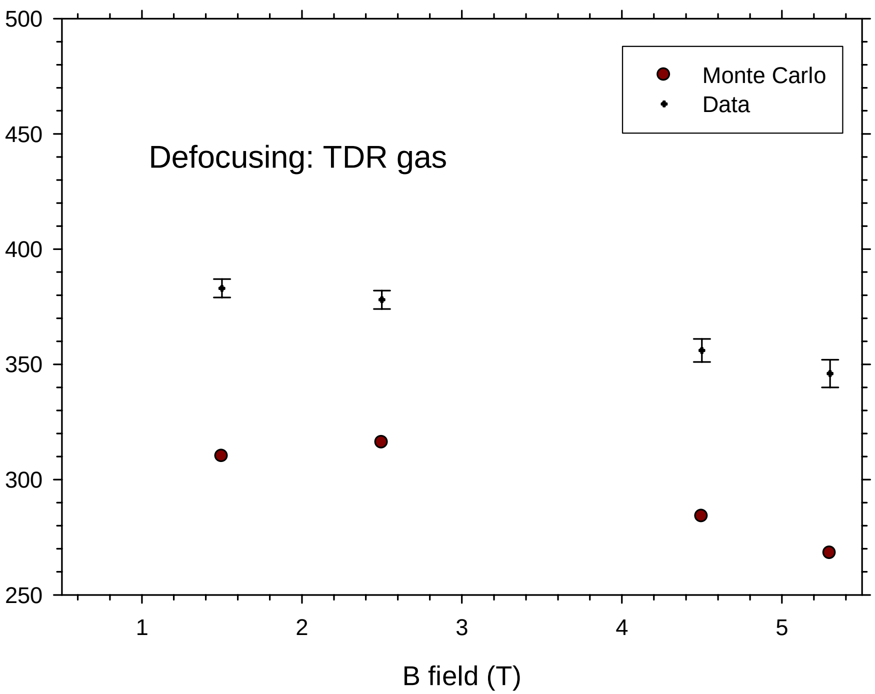




Defocussing: P5 and TDR gases

- Somewhat more defocusing seen in data
- Need more defocusing for best resolution with 2mm pads





Diffusion and defocusing

- Some systematics were studied:
  - noise (added to MC)
  - gain non-uniformity (included in MC samples)

      - The diffusion and defocusing estimates are found to be relatively insensitive to these

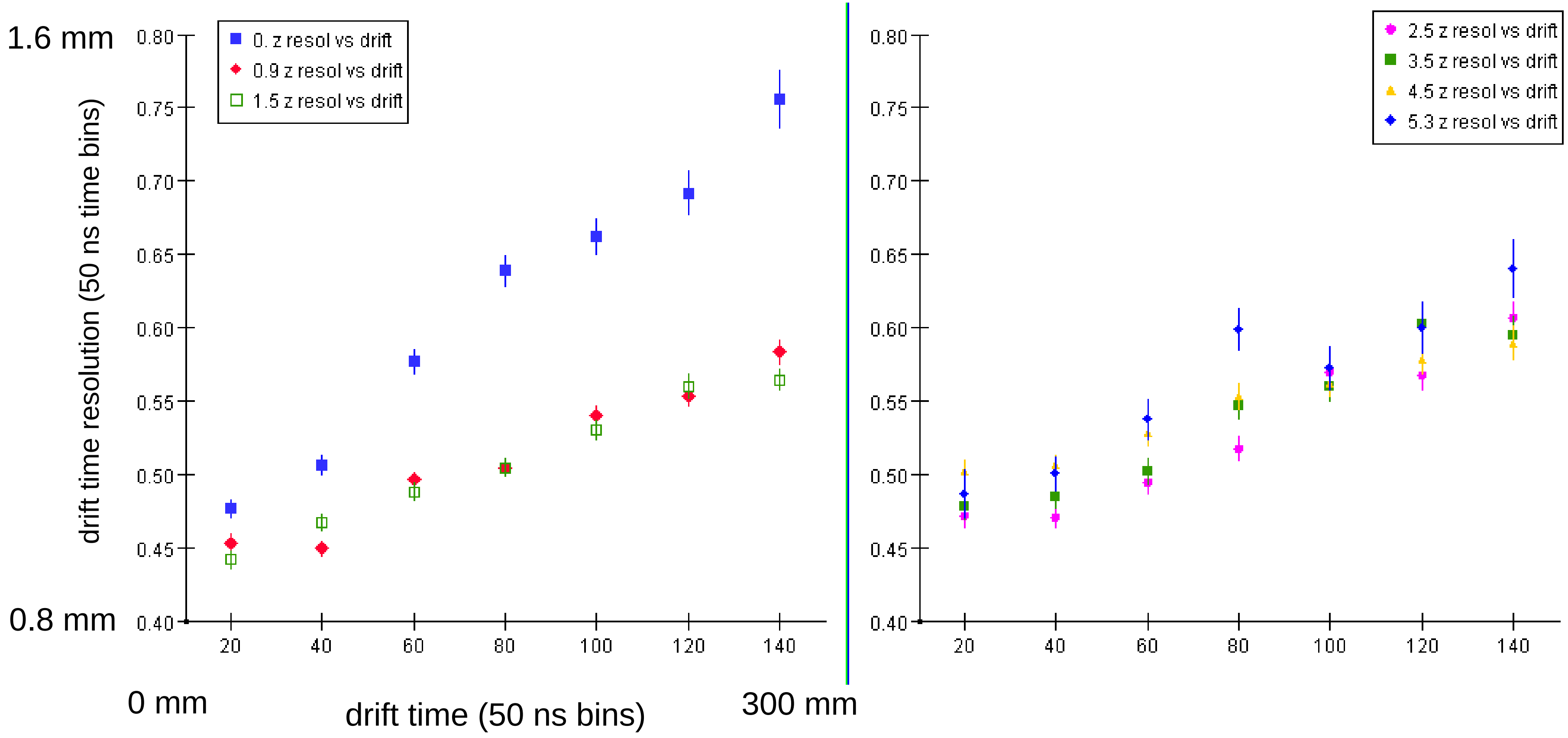
- defocusing estimates are sensitive to the weightings of pre/post peak (induced signal removal)

Resolution studies

- Quoting the resolution from a single pad row is useful to compare different technologies and to estimate the performance of a large scale device
- To define resolution for a row: take the geometric means of the standard deviations of the residual distributions with and without including the row in the reference track fit
- From MC studies, this was found to correctly estimate the intrinsic resolution of a single row

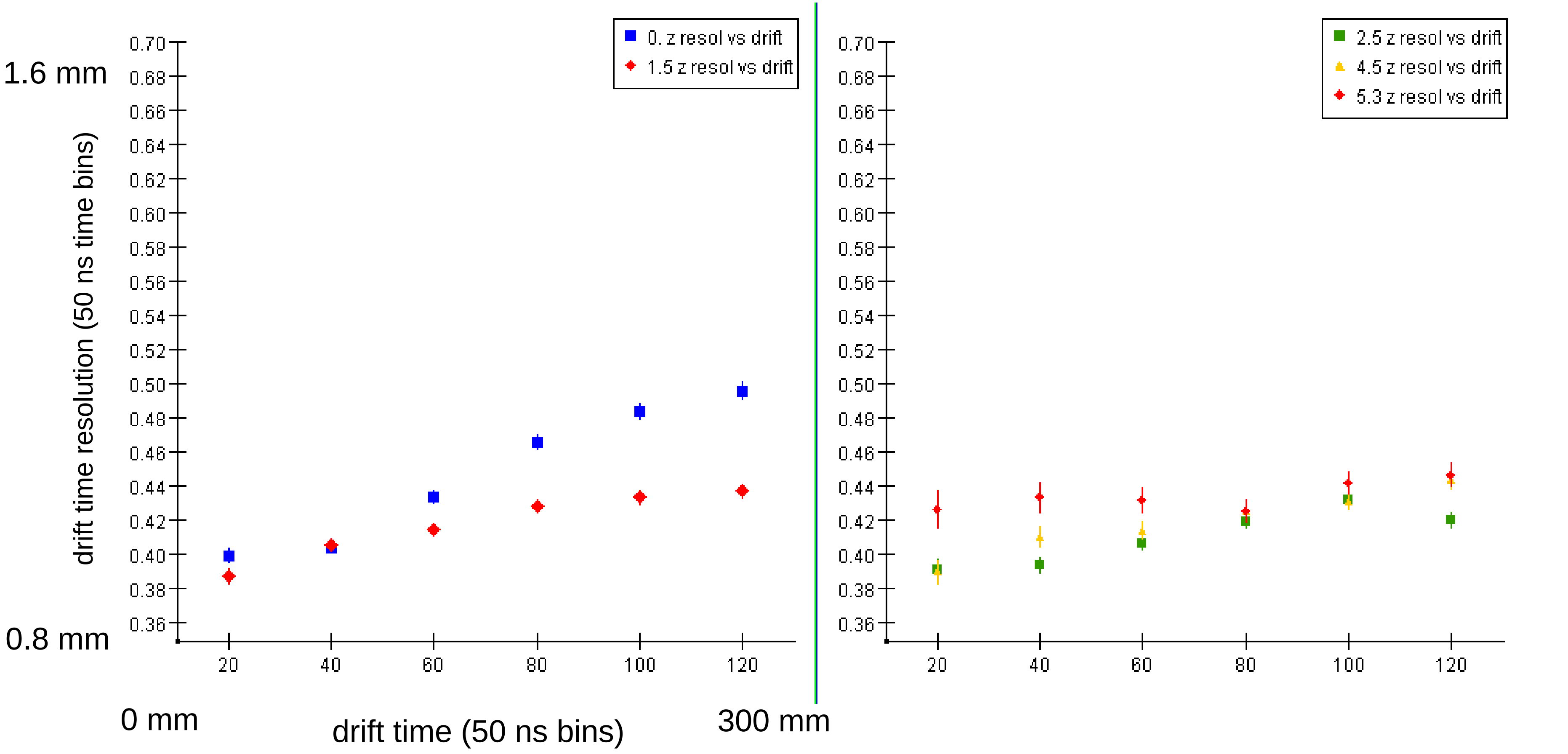
Resolution in drift direction (P5 gas)

- A simple time of arrival is used for each row: peak bin of the pad with the largest signal



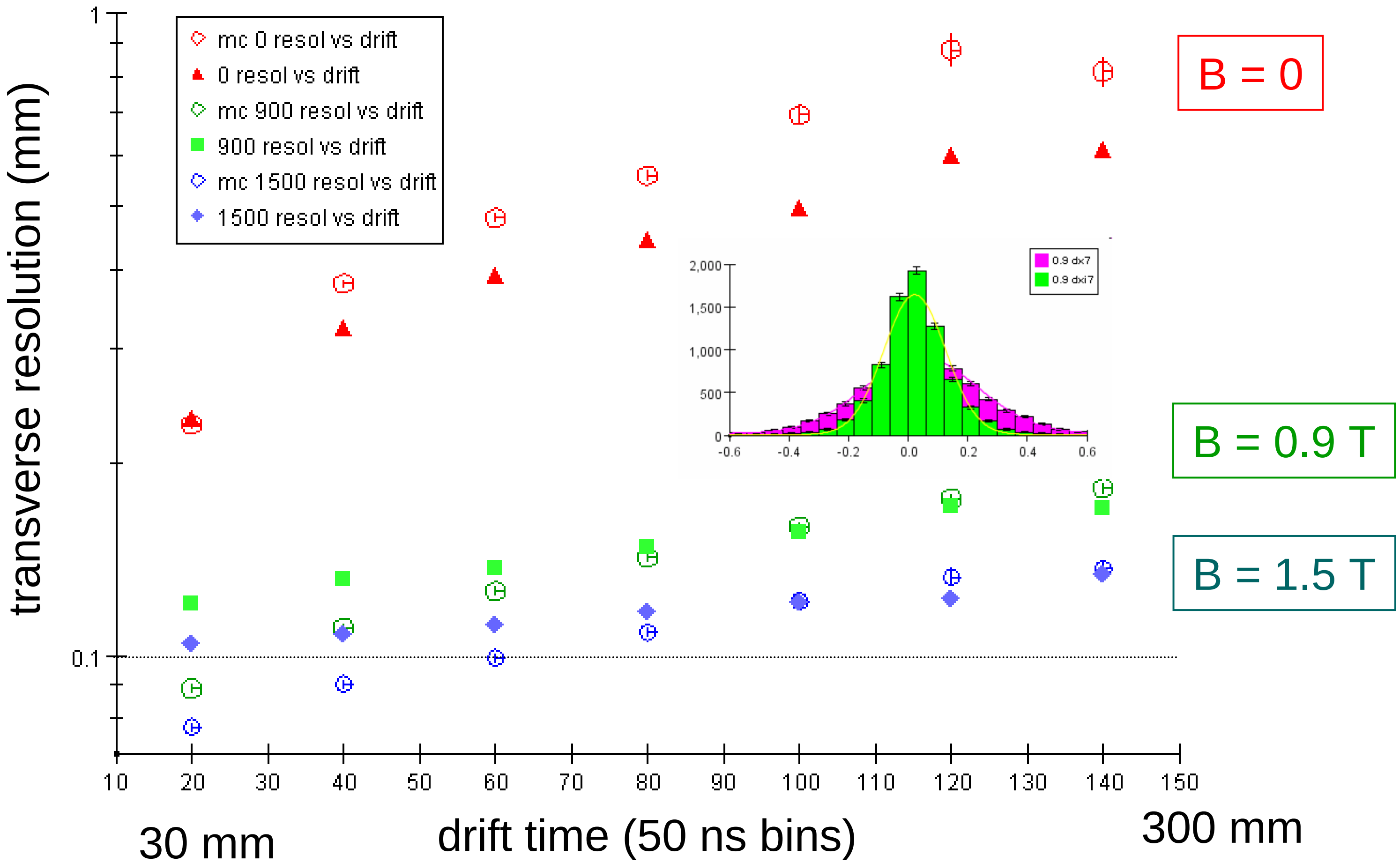
Resolution in drift direction (TDR gas)

- Somewhat better resolution in TDR gas



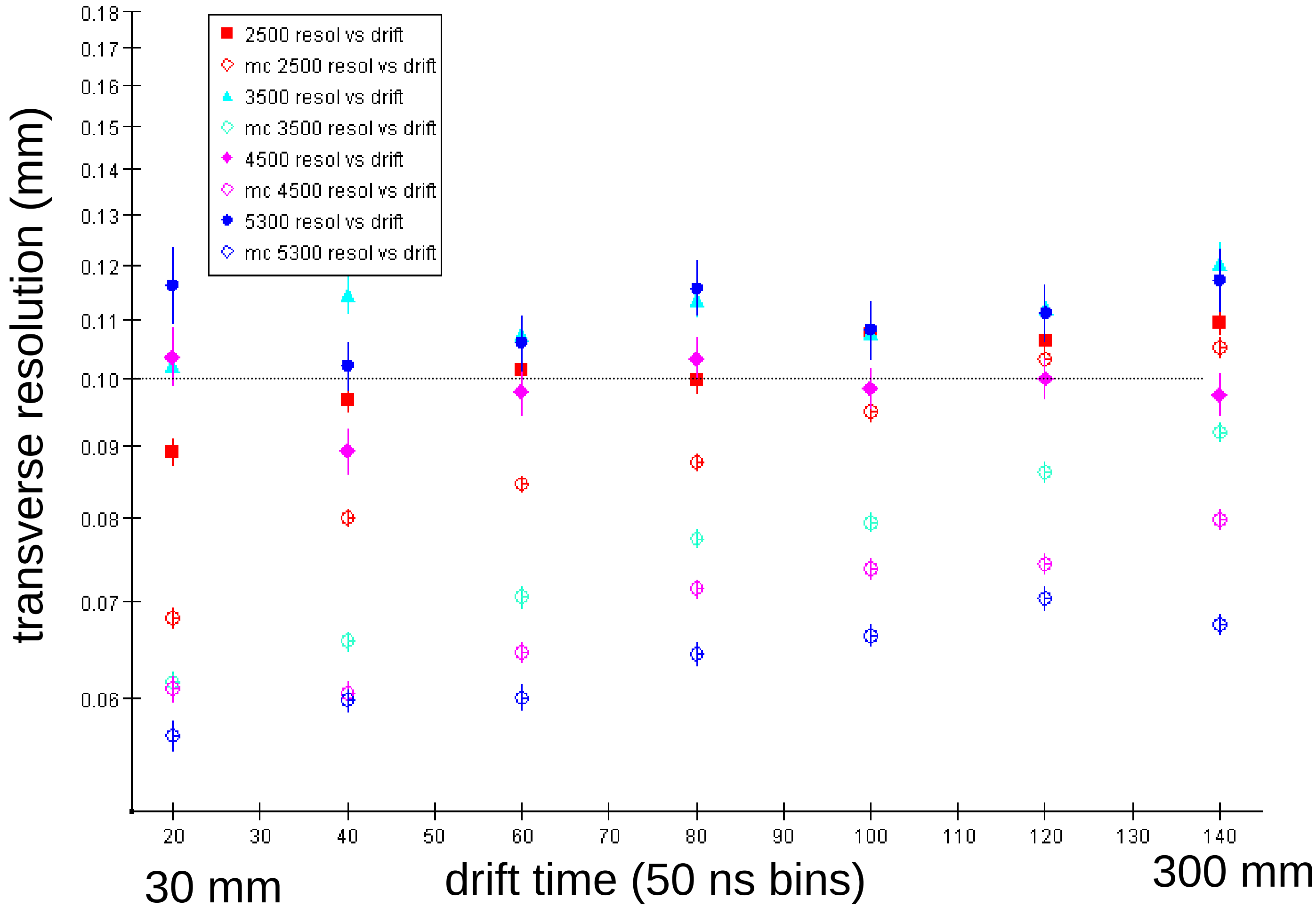
Resolution in transverse direction (P5 gas)

- Compared to MC results



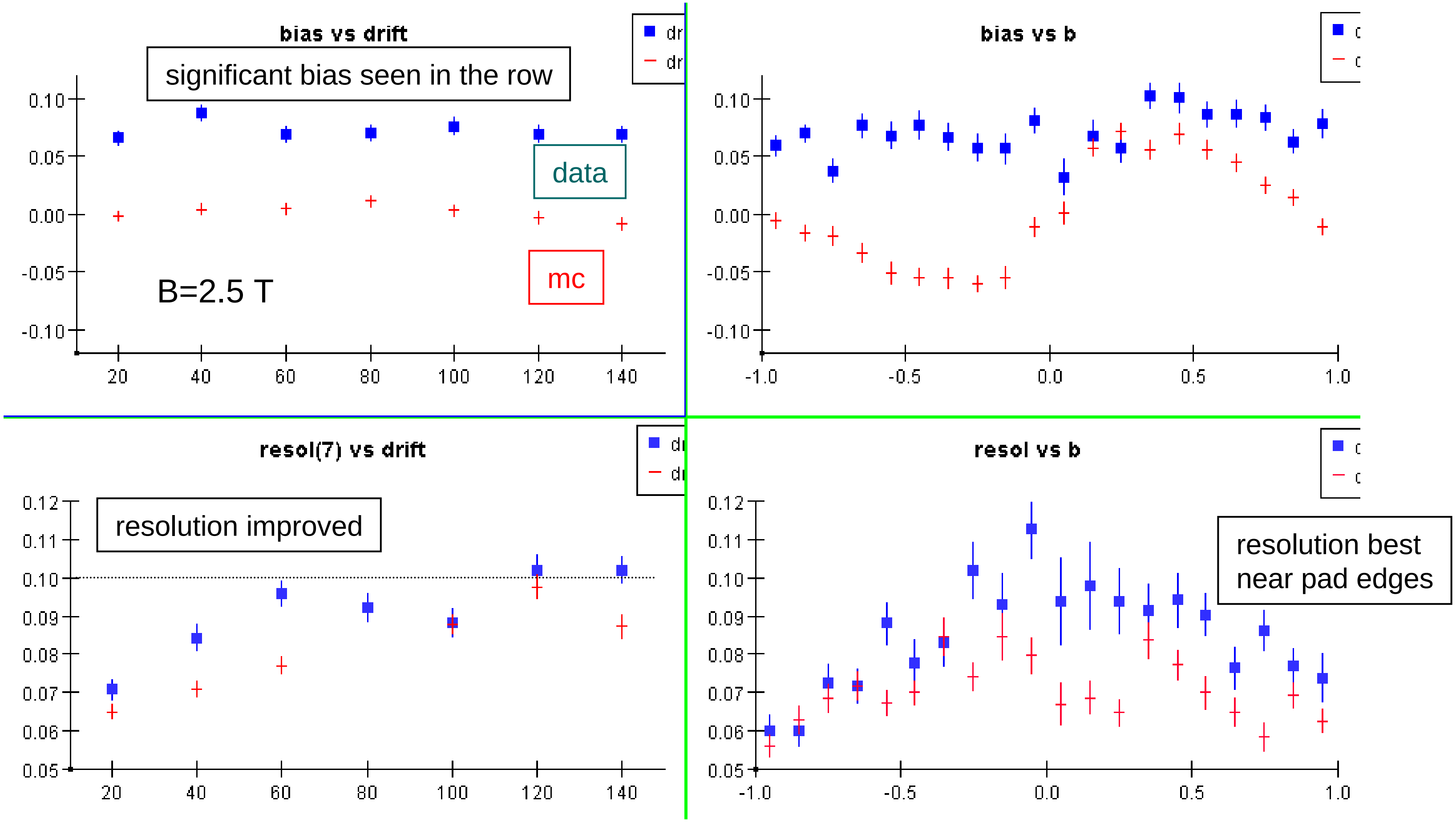
Resolution in transverse direction (P5 gas)

- At high fields, the data resolution is worse than MC expectations



Single row systematics

- Looking at only one row, resolution improves – bias is evident

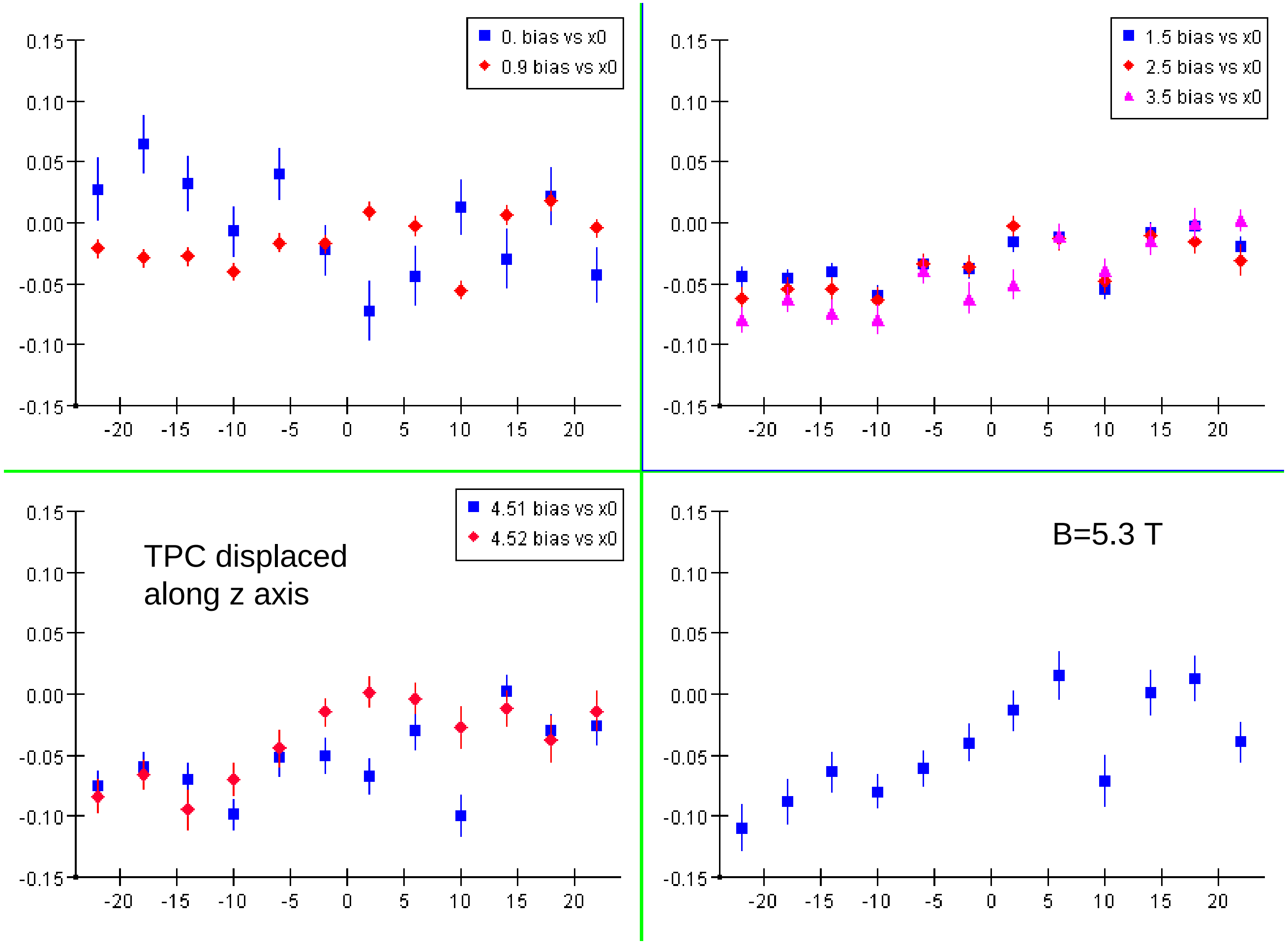


drift time (50 ns bins)

local pad coordinate (mm)

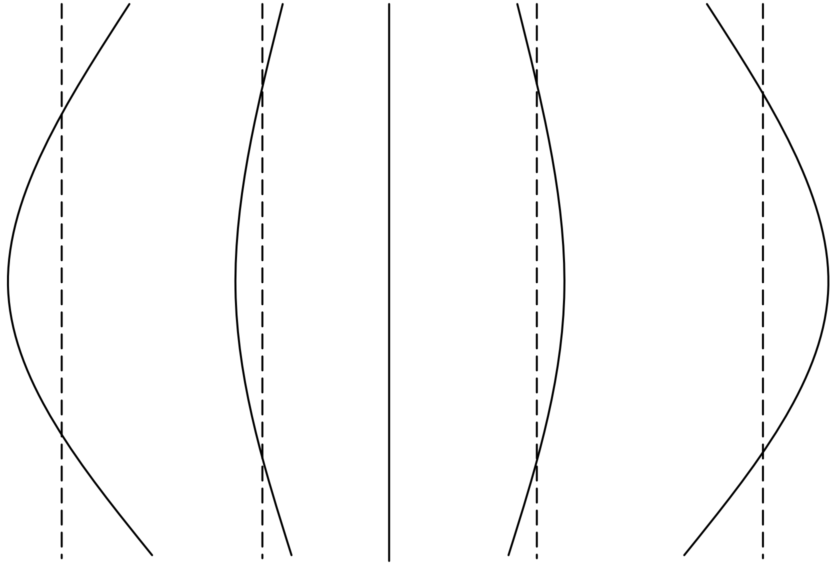
Bias depends on magnetic field

- Look at bias, from straight track fits, vs x_0



Track distortions

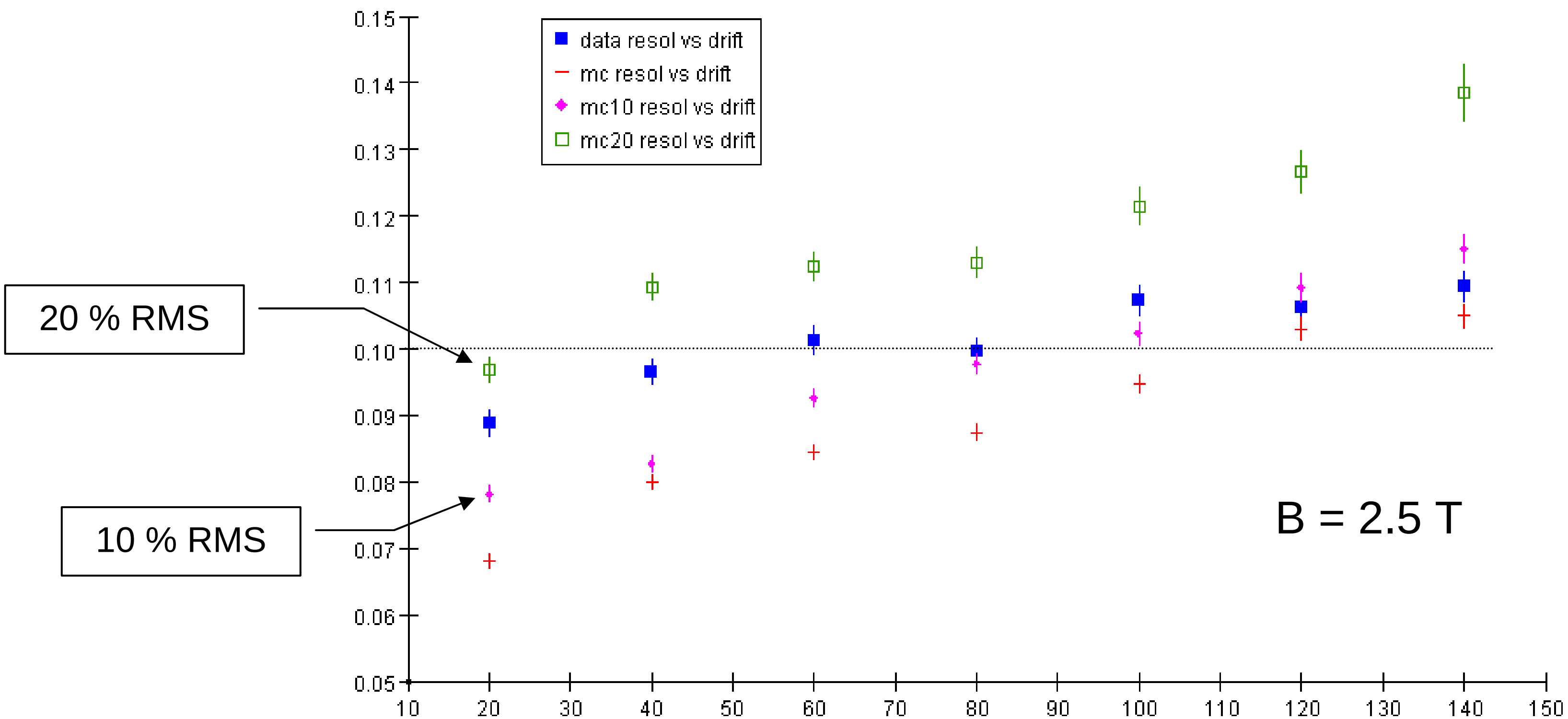
- By comparing the mean residual vs x_0 for different rows, it appears that the track distortion is in the form of outward bowing:



  - need to account for non-uniform magnetic field?

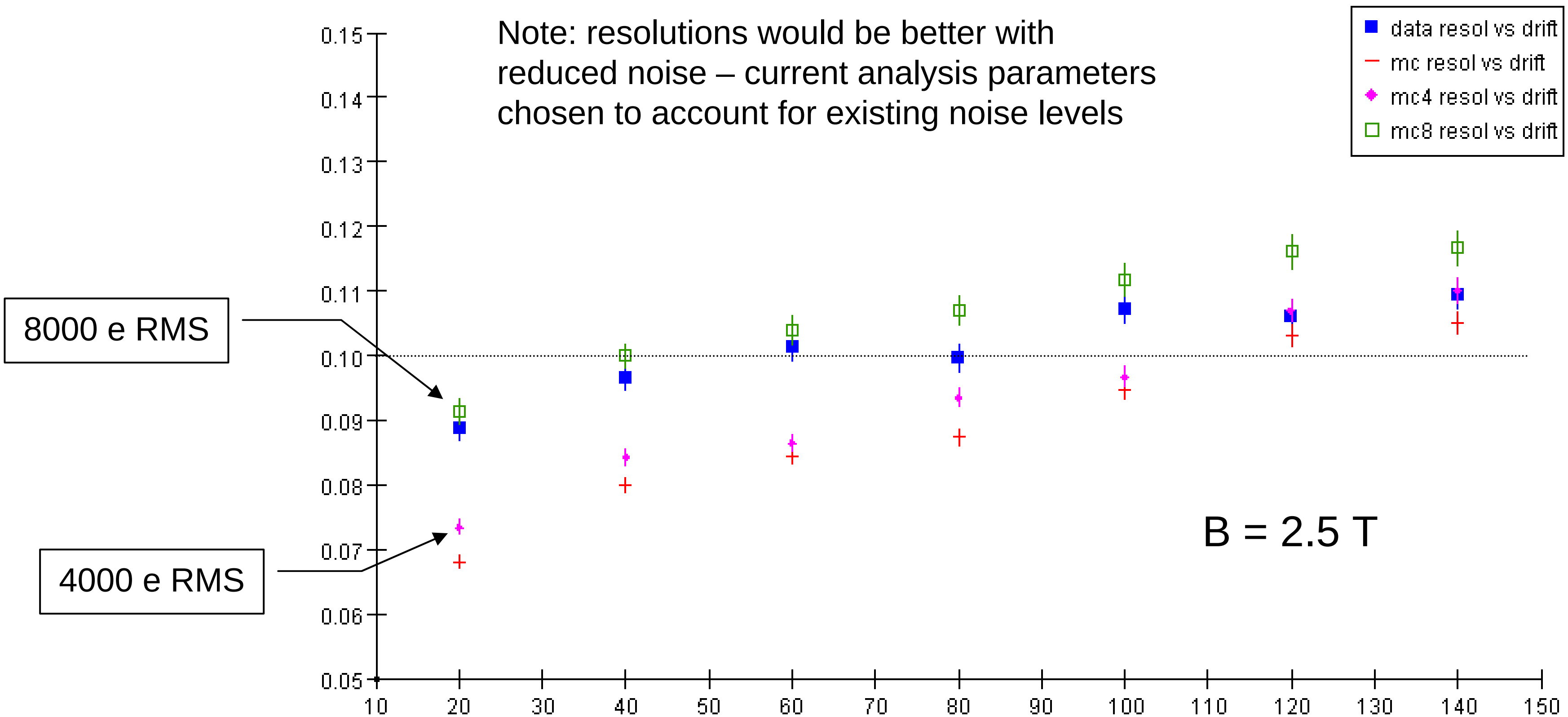
Systematics – non-uniform gain

- Channel to channel gain calibrations are not performed. A study with cosmic tracks indicates the RMS of gains is less than 5%
- MC samples with non-uniform gain suggests that the effect of a 5% gain variation on resolution is small



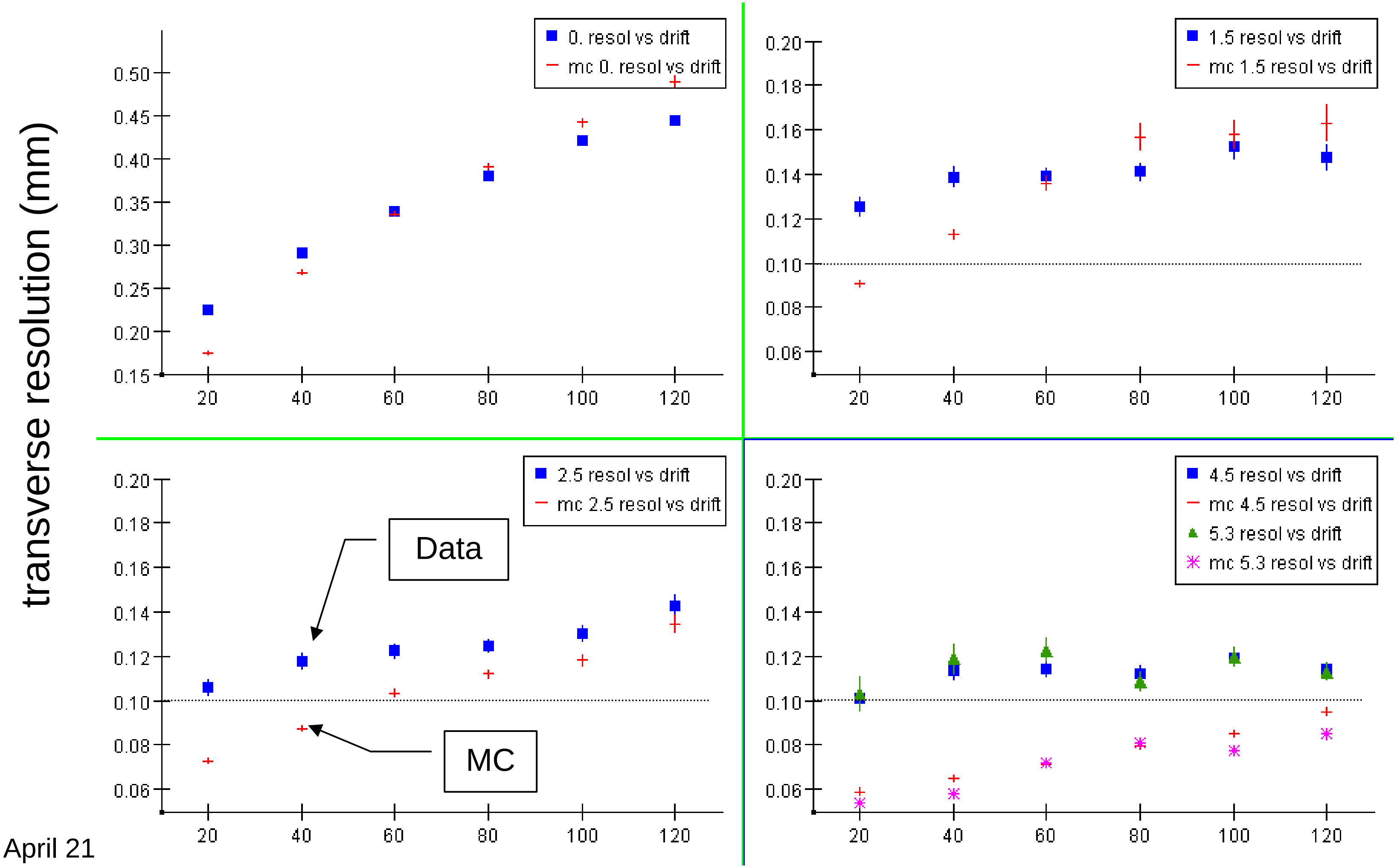
Other systematics – noise

- The data has noise with RMS of about 3000 e
- A MC analysis with noise added indicates that the effect of 3000 e RMS noise on the resolution is small:



Resolution in transverse direction (TDR gas)

- Similar conclusions as with P5 gas (poorer overall)



Plans for future work

- Finalize analysis of DESY/TRIUMF data
- Prepare TPC for laser studies at DESY:
  - track distortions
  - 2 track resolution
  - ion feedback

- Interested in trying out micromegas in our TPC
  - second readout endplate under construction

Conclusions

- Defocusing by GEMs is sufficient to allow good resolution with relatively large rectangular pads
  - reached 100 μm with 2 x 7 mm^2 pads
    - to improve on this: need more defocusing, treatment of non-uniform field?

- Acknowledgements
  - Support staff at Carleton University and University of Victoria – TPC construction
  - LBNL – STAR electronics
  - TRIUMF laboratory – 1 T magnet setup
  - DESY group – 5 T magnet setup and operational support (P. Wienemann, F. Sefkow, T. Lux, …)