TPC Gate Discussion Introduction

Outine

Which gate?
Background?
Background removal?
Distortion calibration examples
Conclusions

TPC Gate Discussion

The TPC was (switched-, dynamically-, or) trigger-gated by Pep4, Delphi, Aleph, Alice and others, since this was allowed by the trigger frequency, and will be so at the ILC as the time structure for bunch-crossing is OK. For CEPC and FCCee the trigger would always be ``ON´´, so this won't work. What about a passive gate?

Email to Peter last year

Date: Wed, 14 Jun 2023 11:54:09 +0200 (CEST)
From: Ronald Dean Settles <settles@mpp.mpg.de>
To: Peter Kluit <s01@nikhef.nl>
Subject: gate

Hi Peter,

I've been thinking a bit about our gating issue, and it seems to me that the problem is solved with your sugestion of a doublegrid. The reference you give on page 32 of your lcws2023 talk, namely the slides you showed at the lctpc wp meeting #326, give the details of that work.

The reason that I believe this relates to the gating study that was done for the Aleph TPC. The bottom line is on page 152 (attached t this email) of the "Aleph Handbook". As you know, the Aleph TPC had wire g That plot shows that, with a gatinggrid voltage of 40 volts, the transparency electrons would be about 70% and for ions wold be zero percent. The reaso that electrons with an omegatau of 5 or 10 follow the Bfield lines, while ions with an omegatau of zero follow the Efield lines (as you know).

Of course all of this just said is idealized, and some fraction of the ions would pass through. But the discussion shows the principle. I called this way of running at LEP a "DC grid", while for Aleph we switched the grid c according to the beam structure (an "AC grid") and if there was a trigger. Th names are not official and just my way of thinking about things.

Anyway, the bottom line is on your slide 32: "With a hole size of 25microns an IBF of 3 10 -4 can be achieved and the value for IBF*Gain (200 would be 0.6" is rather good news for (DC) gating at CEPC and FCCee.

A problem I would like to understand better for a pixel TPC is the cooling. At Aleph we had to cool about 100 watts per square meter (witl the preamps on the endplate), while for the pixel TPC with essentially to whole readout on the endplate, one must cool one or tw orders of magnitue more...

Cheers,
Ron

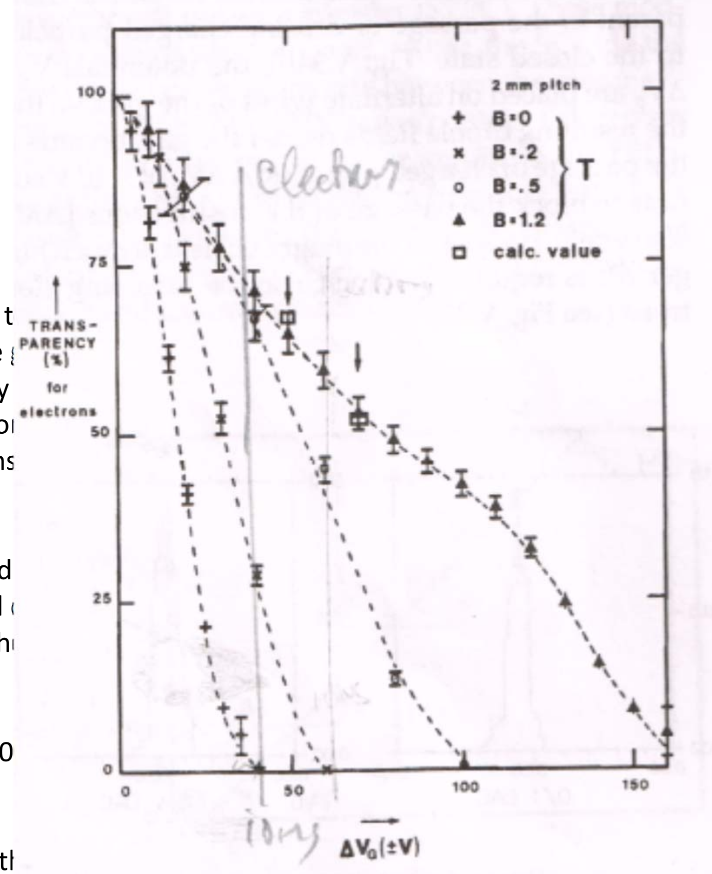


Fig. V.35 Transparency of the gating grid for electrons in the presence of a magnetic field, plotted as a function of ΔV_g. The transparency for ions is independent of the magnetic field and coincides with the one for electrons at B = 0.

Date: Wed, 14 Jun 2023 11:54:09 +0200 (CEST)
From: Ronald Dean Settles <settles@mpp.mpg.de>
To: Peter Kluit <s01@nikhef.nl>
Subject: gate

We just heard about Peter's double grid. A measurement with the Aleph TPC which confirms this idea. The plot from the "Aleph Handbook" shows that, with a gating grid voltage of 40 volts, the transparency of electrons would be about 70% and for ions would be 0%... A closed gate would allow, in principle, the electons to pass (B field), but not the ions (E field). In practice some ions pass.

Hi Peter,

I've been thinking a lot about our gating issue, and it seems to me that the problem is solved with your sugestion of a doublegrid. The reference you give on page 32 of your lcws2023 talk, namely the slides you showed at the lctpc wp meeting #326, give the details of that work.

The reason that I believe this relates to the gating study that was done for the Alepn TPC. The bottom line is on page 152 (attached t this email) of the "Aleph Handbook". As you know, the Aleph TPC had wire g That plot shows that, with a gatinggrid voltage of 40 volts, the transparency electrons would be about 70% and for ions wold be zero percent. The reason that electrons with an omegatau of 5 or 10 follow the Bfield lines, while ions with an omegatau of zero follow the Efield lines (as you know).

Of course all of this just said is idealized, and some fraction of the ions would pass through. But the discussion shows the principle. I called this way of running at LEP a "DC grid", while for Aleph we switched the grid according to the beam structure (an "AC grid") and if there was a trigger. Th names are not official and just my way of thinking about things.

Anyway, the bottom line is on your slide 32: "With a hole size of 25micron an IBF of 3 10-4 can be achieved and the value for IBF*Gain (200 would be 0.6" is rather good news for (DC) gating at CEPC and FCCee.

A problem I would like to understand better for a pixel TPC is the cooling. At Aleph we had to cool about 100 watts per square meter (with the preamps on the endplate), while for the pixel TPC with essentially to whole readout on the endplate, one must cool one or tw orders of magnitue more...

Cheers,

Ron

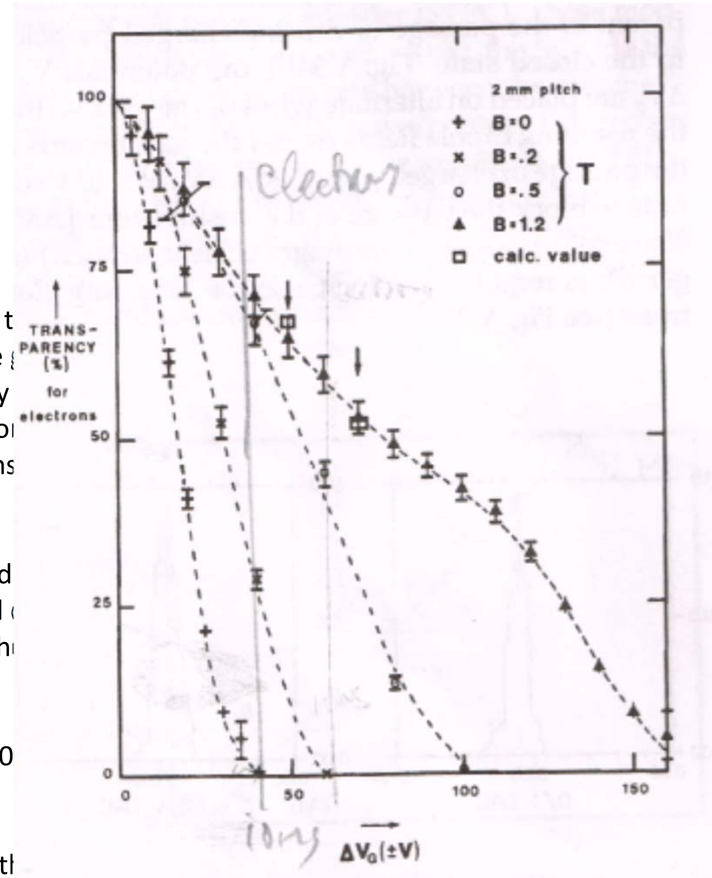


Fig. V.35 Transparency of the gating grid for electrons in the presence of a magnetic field, plotted as a function of ΔV_g. The transparency for ions is independent of the magnetic field and coincides with the one for electrons at B = 0.

Citation information: DOI 10.1109/TNS.2020.3042311, IEEE Transactions on Nuclear Science

Others have had a similar thought.

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TNS.2020.3042311, IEEE Transactions on Nuclear Science

Measurement of the ion blocking by the passive bi-polar grid

E. Shulga, V. Zakharov, P. Garg, T. Hemmick, and A. Milov

Abstract—**The ion backflow is the main limiting factor for operating time projection chambers at high event rates. A significant effort is invested by many experimental groups to solve this problem. This paper explores a solution based on operating a passive bi-polar wire grid. In the presence of the magnetic field, the grid more effectively attenuates the ion current than the electron current going through it. Transparencies of the grid to electrons and ions are measured for different gas mixtures and magnitudes of the magnetic field. The results suggest that in a sufficiently strong magnetic field, the bi-polar wire grid can be used as an effective and independent device to suppress the ion backflow in time projection chambers.**

***Index Terms*—Time Projection Chamber, Ion backflow suppression, GEM, gaseous detector**

I. Introduction

Charges in the TPC volume are carried by slow-moving ions produced in the readout elements of the TPC. This is known as the positive ion backflow (IBF) problem.

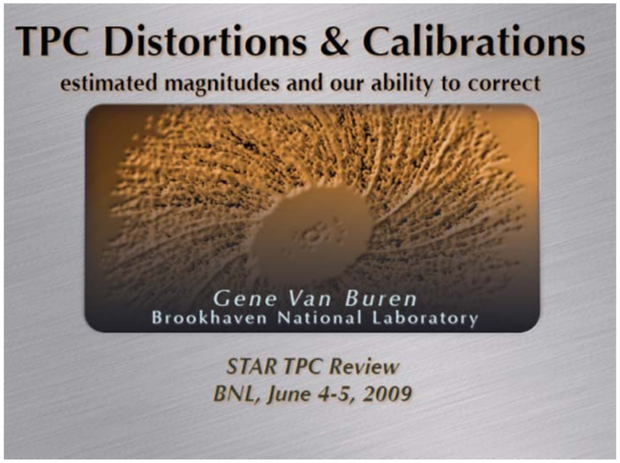
To address the IBF problem the first TPC built in 1984 [2] used a plane of wires called the bipolar gating grid (BPG) separating TPC readout elements from the drift volume. Applying positive and negative bias voltages to odd an even wires of the grid stops the ion and electron flow through the BPG. TPCs developed in recent years [9]–[11] adopt the concept of amplification element being also the IBF-stopper. Multiple-layer micropattern detectors used as amplification elements are capable of trapping ions between their layers [12]–[20]. Nevertheless, most of the large TPCs built by the present time

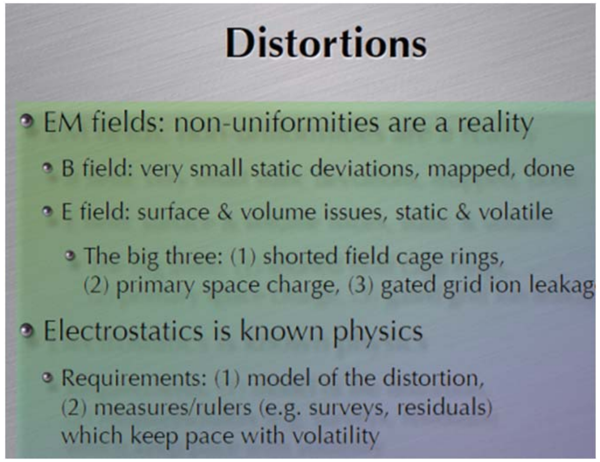
Examples of TPC backgrounds and distortion calibration

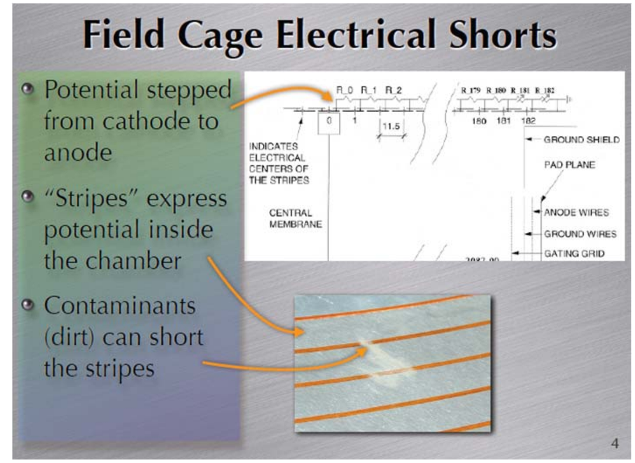
STAR TPC Review 2009

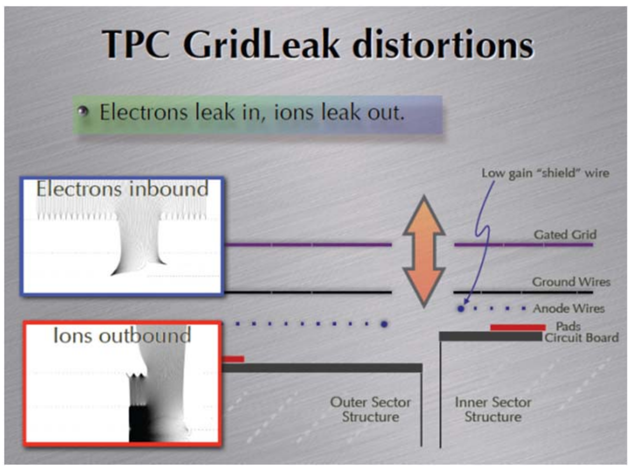
talk by Gene Van Buren

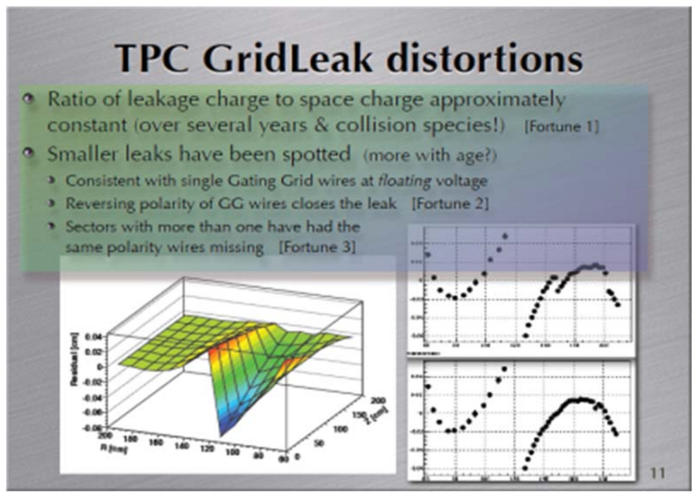
(the question was whether the TPC could continue for the next physics run)

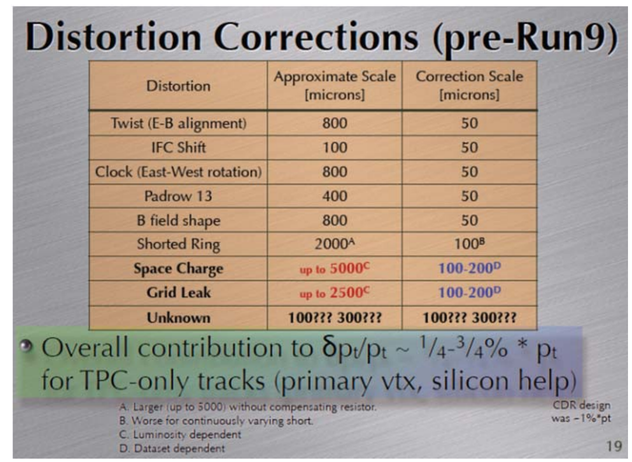












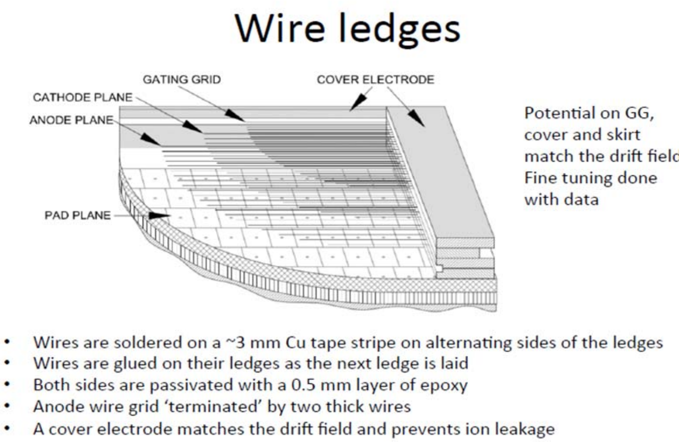
Distortion	Approximate Scale [microns]	Correction Scale [microns]
Twist (E-B alignment)	800	50
IFC Shift	100	50
Clock (East-West rotation)	800	50
Padrow 13	400	50
B field shape	800	50
Shorted Ring	2000[A]	100[B]
Space Charge	up to 5000[C]	100-200[D]
Grid Leak	up to 2500[C]	100-200[D]
Unknown	**100??? 300???**	**100??? 300???**

Fieldcage shorts,`Gridleak´ (due to misaligned gate grid)., etc.

Conclusion: learned how to correct the distortions,.

Alice TPC Review

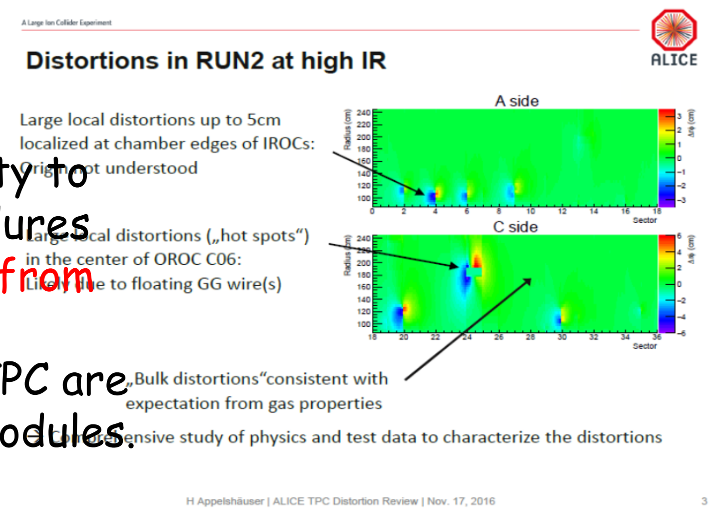
Short Summary



The ALICE Review of TPC Distortions

17-November-2016

Attending: Gigi Rolandi, Leszek Ropelewski, Fabio Sauli, Ron Settles, Jim Thoma, Rob Veenhof, Howard Wieman, with Jamie Dunlop attending on behalf of LHCC; Harald Appelshauser, Chilo Garabatos, Jens Wiechula, Robert Munzer, Peter Braun-Munzinger, Ruben Shahoyan, Werner Riegler, Marian Ivanov, Luciano Musa, KaiSchweda from ALICE



Conclusions:

It is not possible at this time to locate, precisely, the source of distortions. However, this does not affect the collaborations ability to properly calibrate and analyze Run 2 data. The calibrations procedures are very good and very well done. The distortions can be removed from the data with high precision.

The local sources of spacecharge which distort the tracks in the TPC are most likely due to the construction of the wire chamber readout modules. A similar problem is not expected for the upgraded GEM modules because the GEM foil readout chambers will utilize entirely different construction techniques. The GEM ROCs will almost certainly have their own problems, which will require attention from the experts, but not these problems.

In brief, the problems reported here are being expertly addressed by the collaboration and they will not affect Run 3.

Distortion Corrections for the ALEPH TPC

Werner Wiedenmann

Werner.Wiedenmann@cern.ch

Tour through some problems and their correctic

- Static problems (always there)
  - TPC tilt
  - Endplate bowing
  - Nonlinear potential on fieldcage
- Single incidents
  - Disconnected gating grids (space charge)
  - Shorts on field cage

- Compute distortions from Langevin equation

$$\vec{v}=\frac{\mu}{1+(\omega\tau)^2}\left(\vec{E}+(\omega\tau)\frac{\vec{E}\times\vec{B}}{|\vec{B}|}+(\omega\tau)^2\frac{\vec{B}(\vec{E}\cdot\vec{B})}{\vec{B}^2}\right)$$

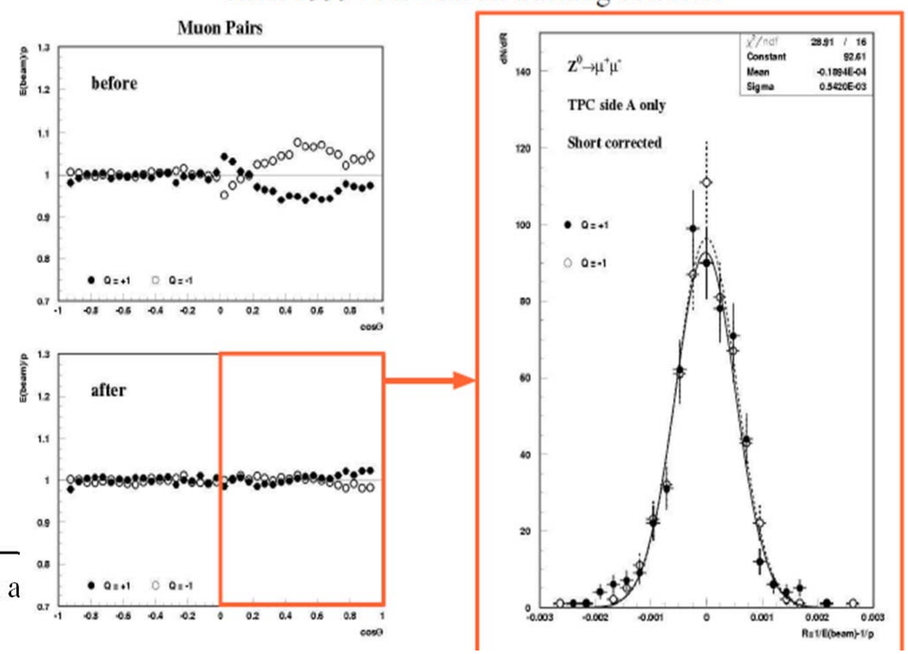
$$\Delta\widehat{r\varphi}_E=\frac{1}{1+(\omega\tau)^2}\int_z^{z_M}\left(\frac{E_\varphi}{E_z}-(\omega\tau)\,sign(B_z)\frac{E_r}{E_z}\right)dz\;;\quad \Delta\hat{r}_E=\frac{1}{1+(\omega\tau)^2}\int_z^{z_M}\left(\frac{E_r}{E_z}-(\omega\tau)\,sign(B_z)\frac{E_\varphi}{E_z}\right)dz\;;$$

$$\Delta\widehat{r\varphi}_B=\frac{(\omega\tau)}{1+(\omega\tau)^2}\int_z^{z_M}\left((\omega\tau)\frac{B_\varphi}{B_z}-\frac{B_r}{|B_z|}\right)dz\;;\quad \Delta\hat{r}_B=\frac{(\omega\tau)}{1+(\omega\tau)^2}\int_z^{z_M}\left((\omega\tau)\frac{B_r}{B_z}-\frac{B_\varphi}{|B_z|}\right)\;;$$

- Use real data : Muon pairs from Z–decays
- Prerequisite: preliminary calibration of inner tracking detectors exists already
  - Global alignment e.g. from survey measurements or from previous data alignments
  - Internal calibration for VDET and ITC (Can be done without TPC)
- Fit the 2 tracks of each muon pair with a common single helix
  - Momentum is constrained to beam energy
  - Helix parameters are determined with 4 hits from VDET and up to 16 hits from ITC. TPC is not in the track fit.

Model parameters for track trajectory from fit (see above)

Short 1999 : Fit with all tracking detectors



dscussion a

Distortion corrections for STAR and ALICE didn't require the precision needed for e+e- data, while for Aleph they did (to ca. 50 microns or less).

Graham Wilson has also presented ideas for calibration using measured phyics quantatives, not only Z-> mumu, for detector calibration and also for measuring the center-of-mass energy, if I understood correctly.

Background removal

(this picture from the ILD LoI)

arxiv:1006.3396v1
study by Steve Aplin

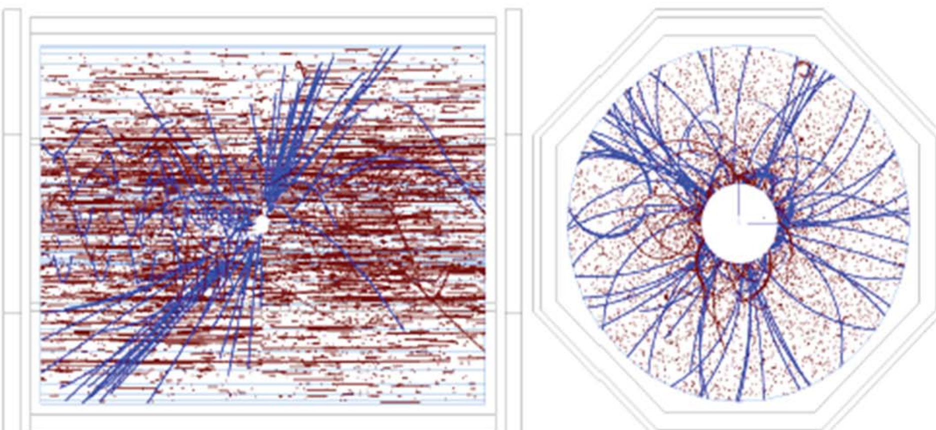
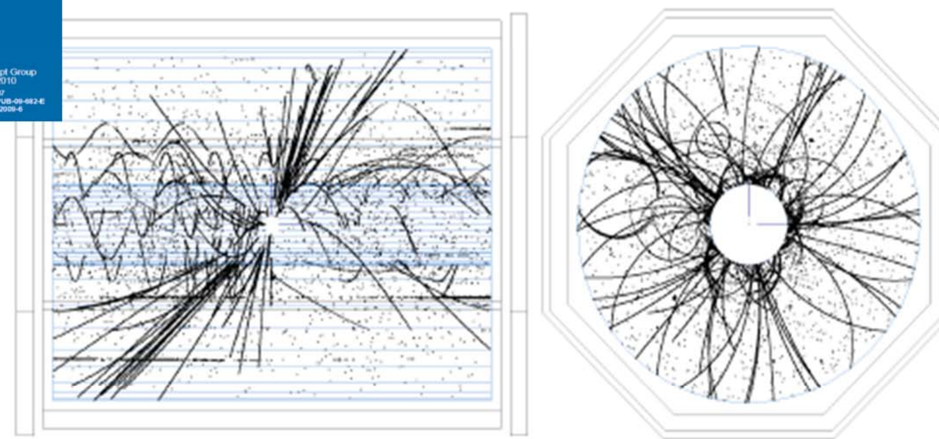


FIGURE 3.2-5. The rz and $r\phi$ views of the TPC hits from a 500 GeV $t\bar{t}$ event (blue) with 150 BXs of beam background (red) overlayed.

ILD - Letter of Intent



IGURE 3.2-6. The same event as the previous figure, with the micro-curler removal algorithm applied. 'his is the input to the TPC track finding algorithm.

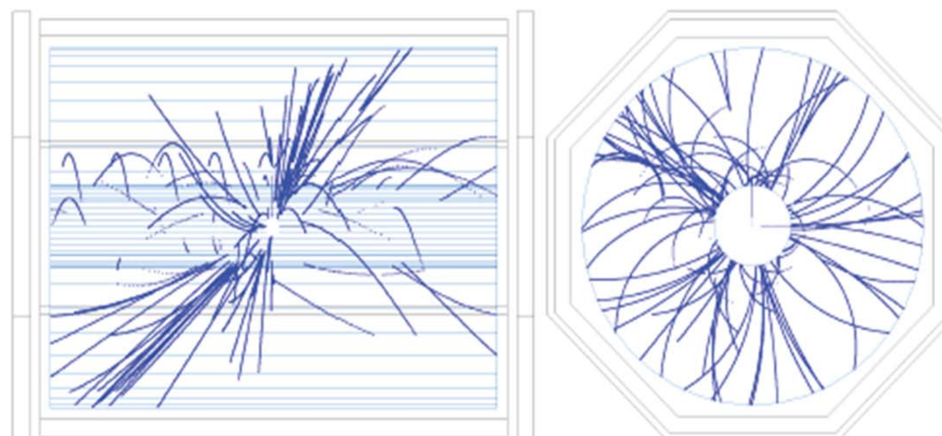
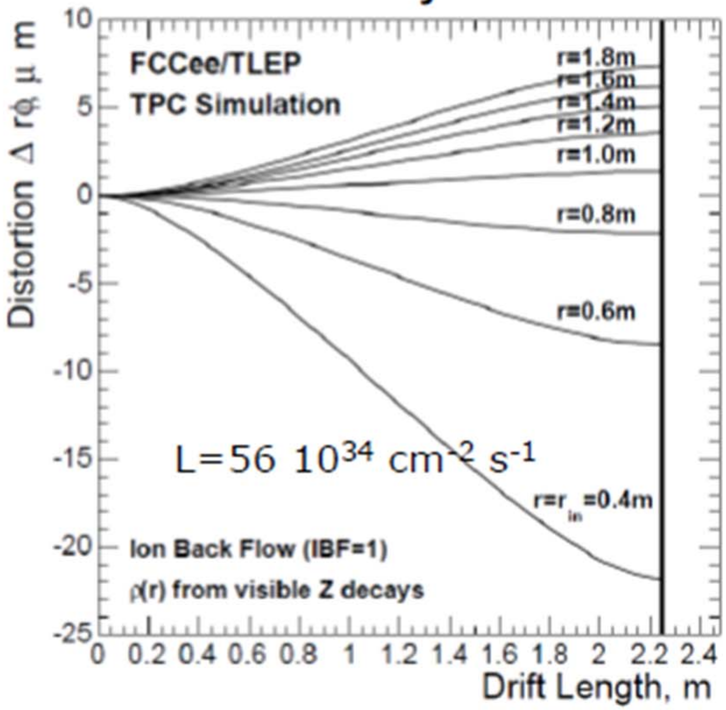


FIGURE 3.2-7. The same event as the previous plot, now showing the reconstructed TPC tracks.

A Pixel TPC at the FCC-ee or CEPC

Electron trajectories



Philippe Schwemling

- What is the size of the track distortions?
- The distortions for IBF=1 according to the TLEP studies range up to < 22 μm (L=56 10^{34} cm^{-2} s^{-1}).
- In WP#370 the extrapolation to 200 10^{34} cm^{-2} s^{-1} is performed (correcting the factor 4 lumi 2; factor 2.5 ions/cm; factor 1.67 in ion drifttime (1.67). In total a factor 16.7
- For FCC-ee or CEPC this means: distortions < 750 μm
- The ion back flow of current the quad is measured to be 1.3% at a gain of ~2000. So IBF*Gain is ~25.
  - This means that this would lead to distortions < 2 cm.
- Note that distortions can be corrected for on average. But it will lead to a broadening of the track parameters.

The Z physics program at FCC-ee or CEPC with an ILD-like detector with the TPC sliced between two silicon trackers (SIT and SET) can be pursued. One expects that only the combined track momentum resolution will be worsened due to electric field distortions. This statement needs more quantitative studies.

ILD strategy meeting Hamburg

Peter Kluit (Nikhef)

23

- Is it possible to reduce the IBF for a pixel TPC?
  - IDEA: by making chip with a double grid structure (see next slide)
  - This idea was already realized for an INGRID: TWINGRID NIMA 610 (2009) 644-648
  - For GEMs for the ALICE TPC this was also the way – several GEMs on top of each other to reduce IBF
  - For the Pixel the IBF can be easily modelled and with a hole size of 25 μm an IBF of 3 10^{-4} can be achieved and the value for IBF*Gain (2000) would be 0.6.
  - YES: the IBF can be reduced to 0.6 but this needs R&D
  - In the new detector lab in Bonn it is possible to make and study this device
- What would be the size of the distortions?
  - For FCC-ee or CPC-ee this means: distortions up to < 750 μm
  - ILD like detector the distortions can be mappped out using the SIT/SET

Preceeding talk by Peter:

Conclusions: Pixel TPC at a circular collider

- YES: a pixel TPC can reconstruct the Z events in one readout cycle
- YES: the current readout of the Timepix3 chip can deal with the rate
- The current power consumption is 1W/cm^2. By running the TPX chips in low power mode this can be reduced by a factor of 10. Still good cooling is important no show stopper; but needs extensive R&D.
- Track distortions in the TPC drift volume are a concern at high lumi Z running:
  - Track distortions from Z decays in TPC are O(100) μm
  - It is possible to reduce the IBF for a pixel TPC by making a device with a double grid
  - A double grid needs dedicated R&D that can be performed in the new lab in Bonn
- The Z physics program at FCC-ee or CEPC with an ILD-like detector with a Pixel TPC (with double grid structures) sliced between two silicon trackers (VTX-SIT and SET) can be fully exploited. The reduction of beamstrahlung needs more study.
- A pixel TPC can perfectly run at WW, ZH or tt energies where track distortions are several orders of magnitude smaller

Talk by Daniel at SW Analysis meeting

TPC integrates over many collisions; maximum ion drift time ~ 0.44 s

roughly estimate number of primary ions in the TPC volume (42 m^3) at any time, taking account of different collision rates

number of ions ~ primary ions/BX * BX freq * 50% [ions already reached cathode]

Collider	FCCee-91	FCCee-240	ILC-250
Detector model	ILD_l5_v11γ	ILD_l5_v11γ	ILD_l5_v05
BX frequency (average)	30 MHz	800 kHz	6.6 kHz
primary ions / BX	270 k	800 k	450 k
primary ions in TPC at any time	4.1×10^{12}	3.2×10^{11}	1.5×10^{9}
average primary ion charge density nC/m^3	15	1.2	0.006

primary ion density in TPC: 2500 times higher at FCCee-91 than ILC-250
200 times higher at FCCee-240 than ILC-250

13

must also consider **secondary ions**, produced in the gas amplification device

O(1000) ions produced in the device for each incoming ionisation electron

without any mitigation, significant fraction flow back into the main TPC volume
"Ion Back Flow" IBF

ILC bunch structure → gating device can stop most of these
open gate only during bunch train
a few per-mille of secondary ions may leak : 1~5~10 per initial electron ?

distortions increased by factor 2x ~ 10x ?

with quasi continuous collisions @ FCCee, cannot apply the same gating trick
multi-layer GEM , micromegas+GEM , ….
nano-material through which ions cannot pass ?

15

Summary

TPC background from beamstrahlung:
same order **per BX** at ILC250 and FCCee

average BX frequency: **4.5k times higher at FCCee**

TPC ions from **beamstrahlung** dominate those from ee → qq @ FCCee-91

guestimate: maximum distortions up to 15mm in R-phi from **primary ions** only
secondary ions add a multiplicative factor of 2~10 (?): gating/blocking of ions

FCCee-91 looks similar to ALICE-TPC environment

dominated by **MDI**: can it be redesigned to reduce back-scatter?

can a TPC work (with the required precision) at FCCee ?

17

CONCLUSION

I believe it can: A passive gate should work. Needs simulation to understand space-charge distortions, which can be corrected for, and needs R&D to find and solve problems for a Pixel TPC.