FCC France workshop
January 21, 2021

Ion backflow in TPC

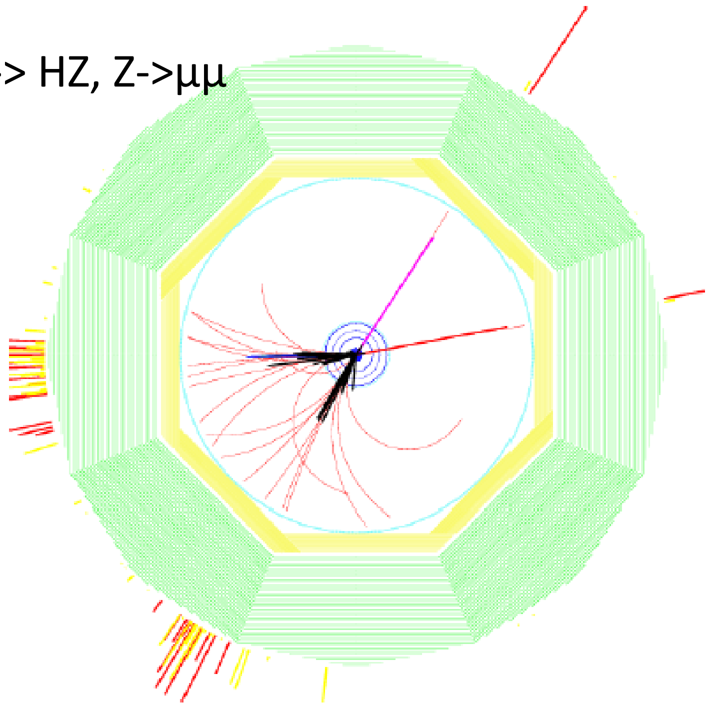
P. Colas

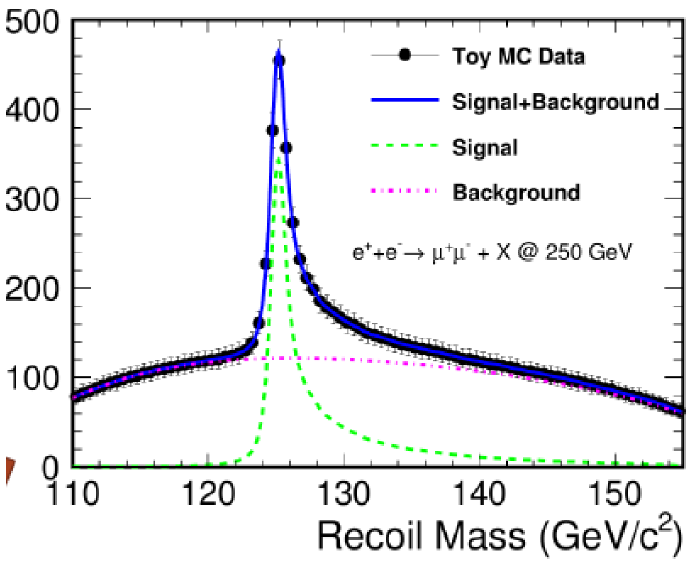
Motivation for the tracking at e+e- colliders as Higgs factories

- Need to reconstruct complex multi-track events (jets) in a noisy environment : calls for high segmentation
- Also need to reconstruct very accurately high energy tracks from Z recoil to Higgs. This translates into O(10 μm) control of the systematics on sagitta and $\Delta(1/P)=10^{-4}$ GeV $^{-1}$ for TPC only (2.10^{-5} GeV $^{-1}$ for the whole tracking system).

- Silicon detectors give point measurement accuracy, but also introduce multiple scattering, while a TPC provides a continuous 3D track reconstruction with minimal matter : useful for V0, kinks, connecting to vertex tracker, other silicon trackers, and to calorimeter.
- Also a TPC has dE/dx capability, for K/π separation, essential for Heavy Flavour physics at the Z pole.

e+e- -> HZ, Z->μμ





J. Yan, S. Watanuki, K. Fujii, A. Ishikawa, D. Jeans, J. S., J. Tian, H. Yamamoto

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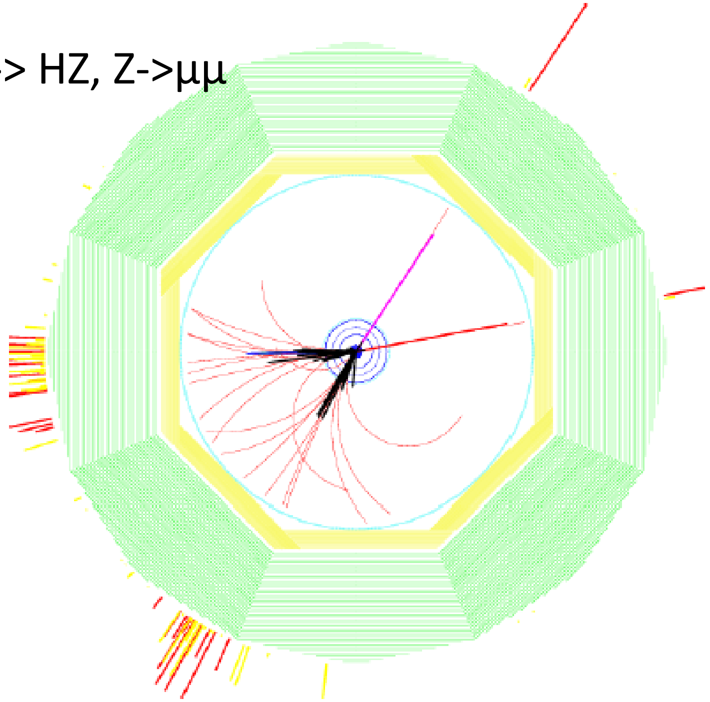

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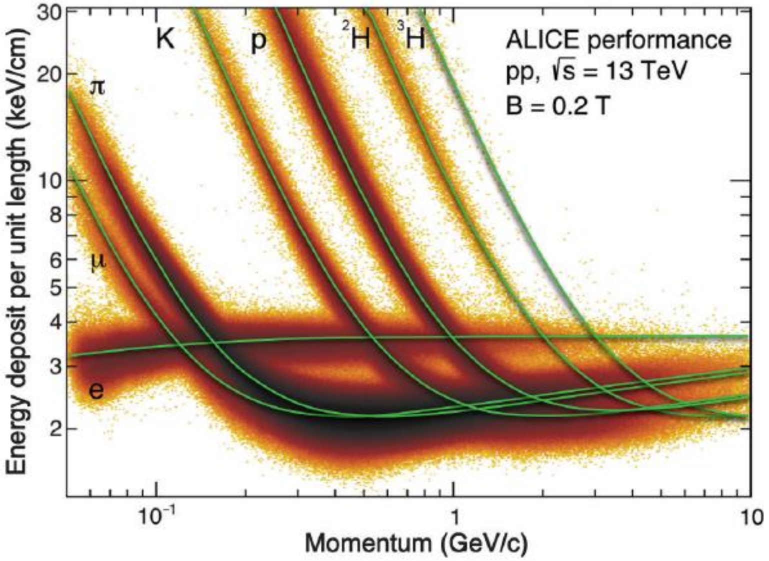
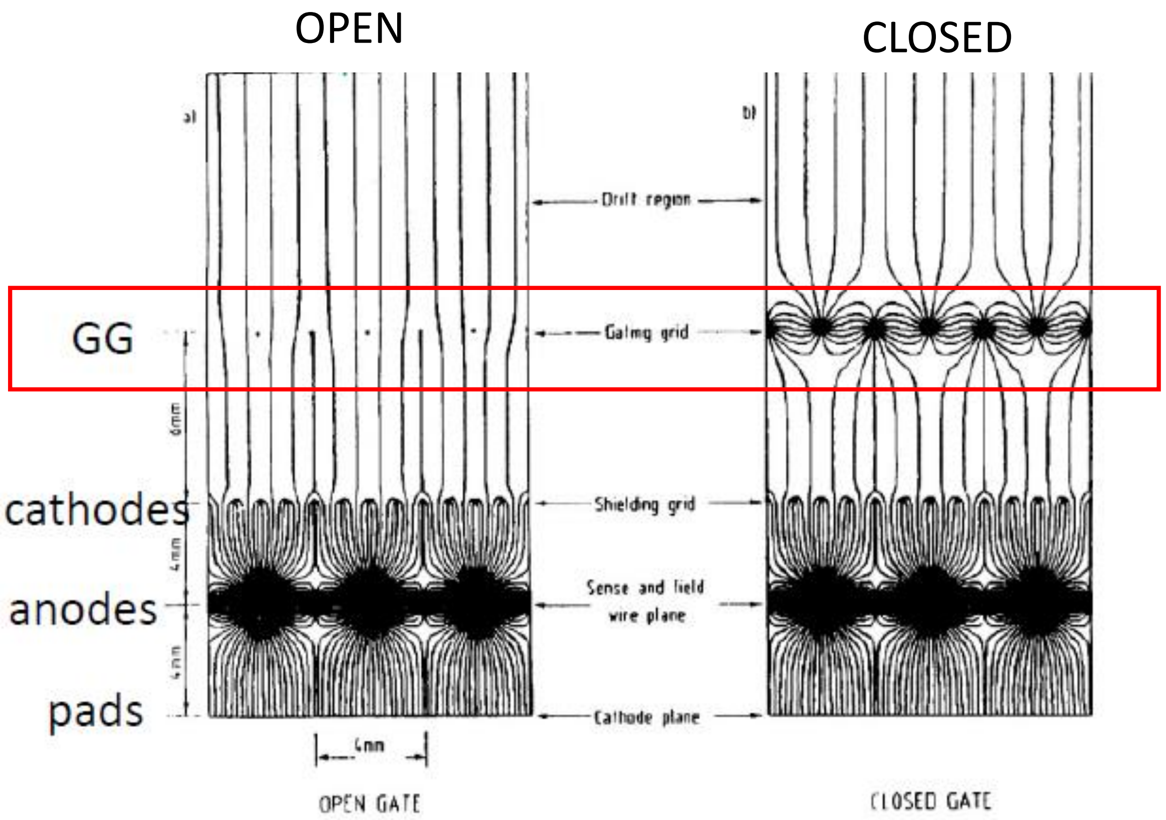


The Ion Problem

- Ions are copiously produced in the amplification device. A fraction of them will flow back in the drift space and add to the primary ions produced by the charged tracks and converted X-rays from the machine background.
- Ions drifting in the electric field of the TPC are very slow, of the order of a m/s
- As a consequence, this positive charge accumulates and gives rise to a space charge. The region where this space charge builds up being limited, and the density being non-uniform, this produces transverse E field components which produce distortions (enhanced by ExB effects)
- At the TeraZ, there is one Z produced in every drift time of the TPC. Even primary ionization produces enough space charge to distort the tracks.

- The ion backflow problem impacts TPCs at colliders (LEP, RHIC, LHC/Alice). It is usually escaped by stopping and neutralizing the ions with a gating grid of wires between collisions.

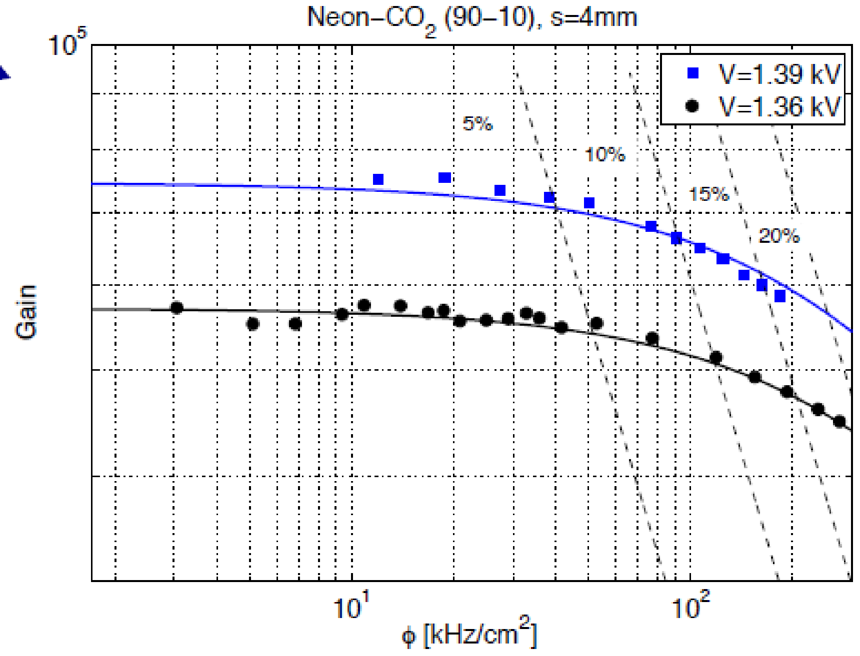


Parallel wires are set at alternating potentials to close the gate by producing a transverse field. The gate is open only during electron drift (50 µs at LEP)

C. Garabatos in workshop
«New Horizons for TPCs»,
October 7, 2020

MWPC won’t work for ALICE in Run 3

- In 2022 the LHC will deliver 50 kHz Pb-Pb collision rate
- At ~100 kHz/cm^2 the space charge near the anode wires would affect dE/dx resolution
- With a gating grid, only 3 kHz can be achieved
  - GG must stay closed while ions from the avalanche reach the wires, otherwise 10% of them escape and would produce ~1 m distortions in the drift volume

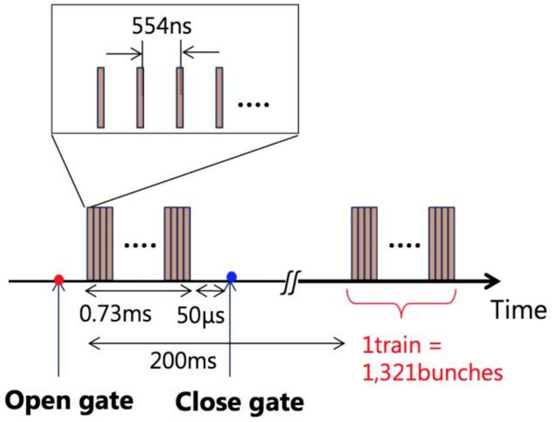


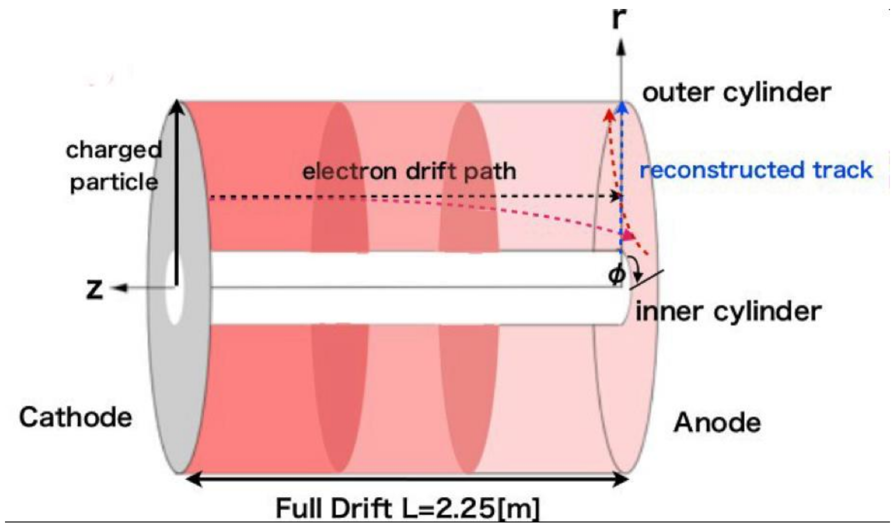
Diego et al. *JINST* 4 (2009) P10014

Need for gating

In TPCs, ions are produced and migrate very slowly (1 m/s) . They produce a charge density which can be one or two orders of magnitude above the primary ionization (IBF*Gain). Present-day electronics allows running at a gas gain of 2000 or a bit less. 500 could be in reach. Thus backflow fractions of 0.5% to 2% would not add to the primary ionization.
The resulting electric field can be the origin of distortions.

At the ILC, the bunch trains last about 1ms every 200 ms, giving rise to ion disks slowly drifting to the cathode





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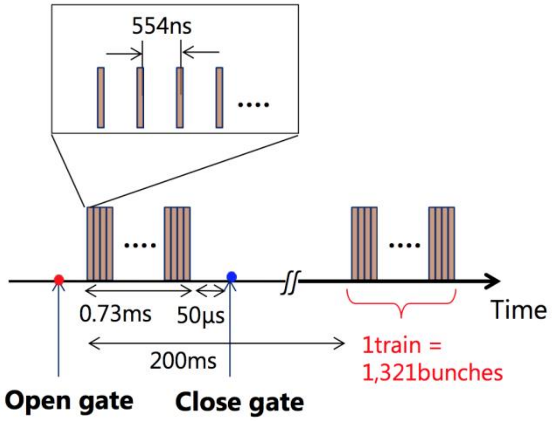
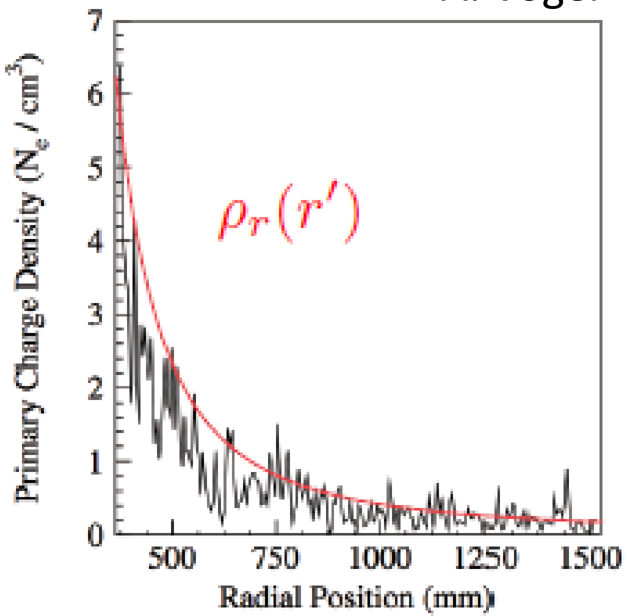


A. Vogel



Charge density for 100 bunches

Need for gating

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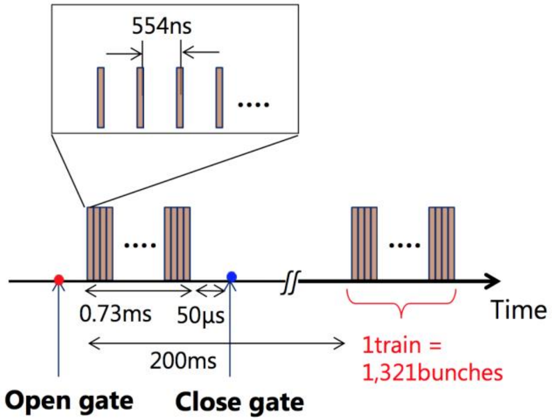
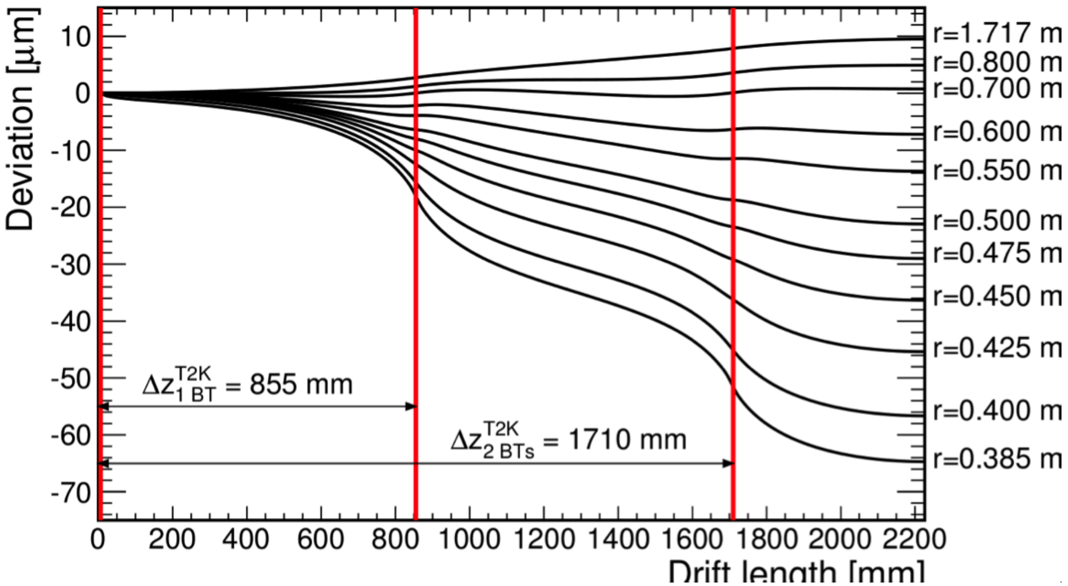
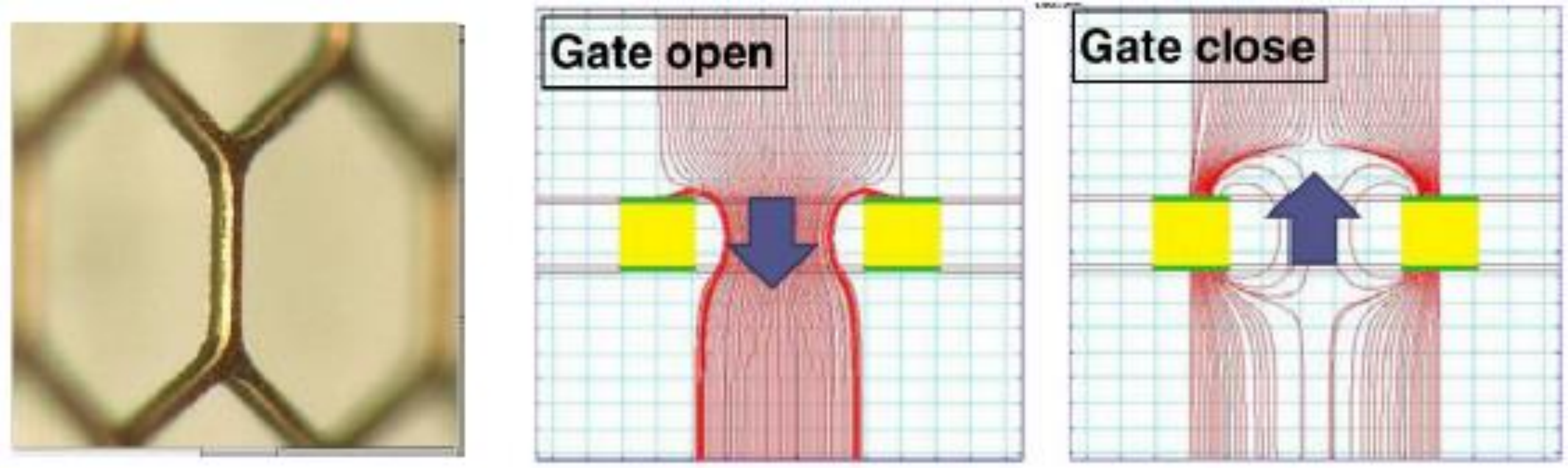


Calculation by Daisuke Arai



One gating solution: the gating GEM



A. Sugiyama et al.

86 % transparency for electrons demonstrated for Delta V = 4 V over 50 µm
Preservation of the resolution demonstrated in a beam test
Ion blocking expected for DeltaV =-40V

Other solution : equipotential wire grids (was not possible at LEP as there was no time to switch it on and off)

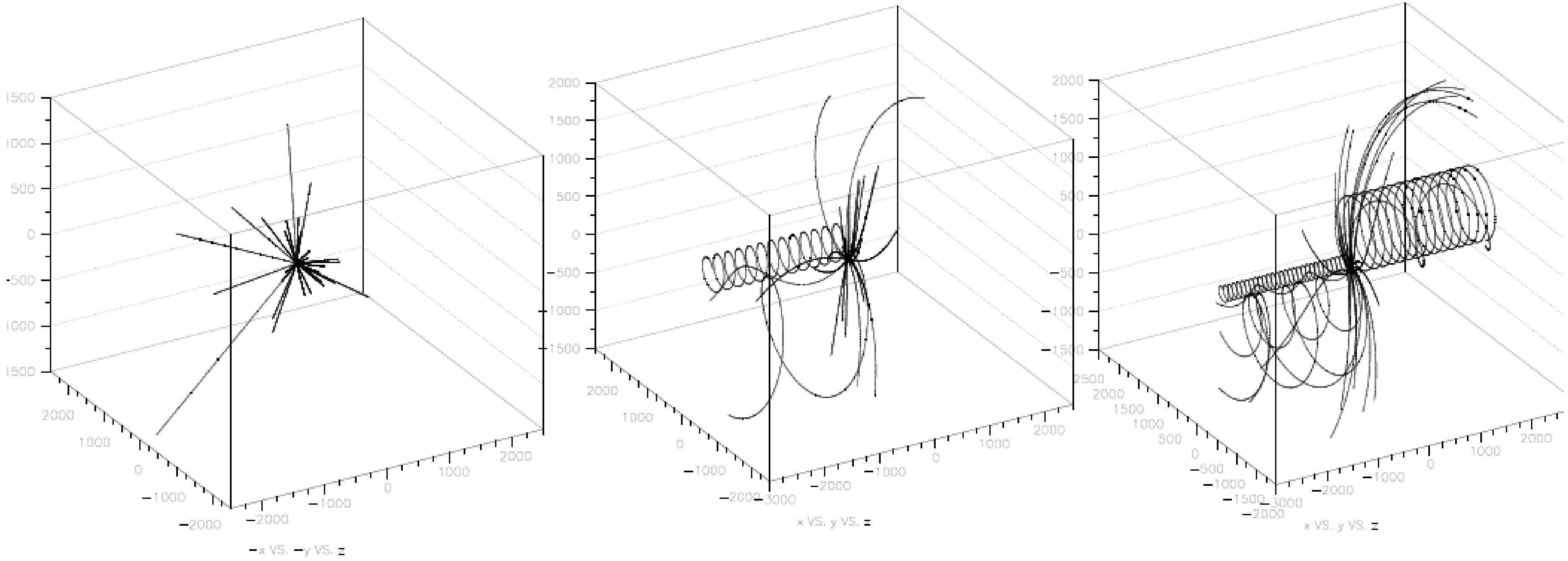
Summary on gating

- Gating is a solution for ILC @ nominal luminosity, for instance with a gating grid, thanks to the beam time structure at 5 or 10 Hz.
- However mechanically very difficult.
- In many other applications (sPhenix@EIC, ALICE@LHC, FCCee, CEPC), gating is not possible because of continuous beam.

ONE MUST FIND WAYS OF MITIGATING THE BACK-FLOW WHILE KEEPING GOOD ELECTRON EFFICIENCY

Note that at the TeraZ, even primary ionization rules out the use of TPC

Hadronic Z decays



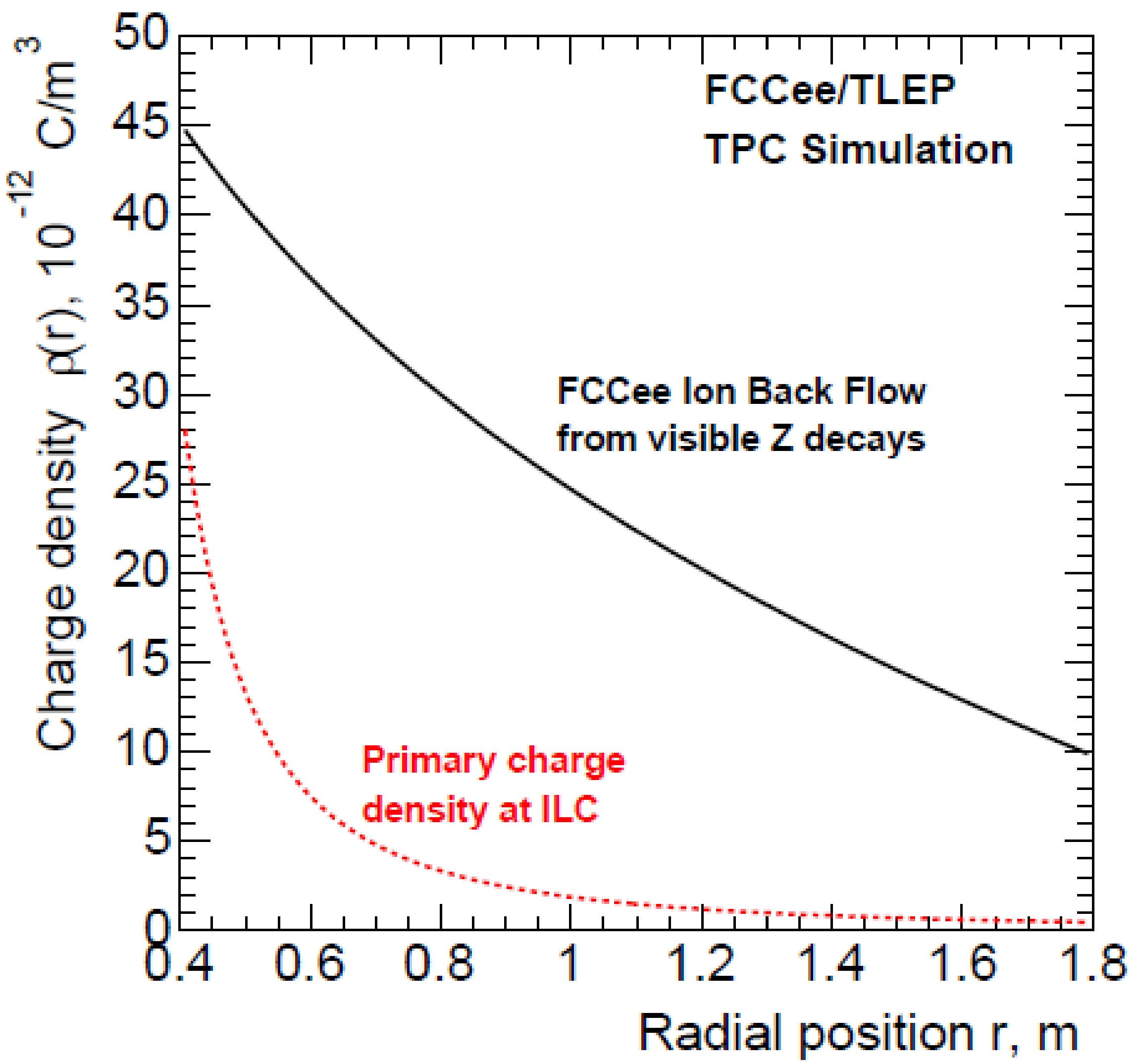
B=0

B=1.5 T

B=3.5 T

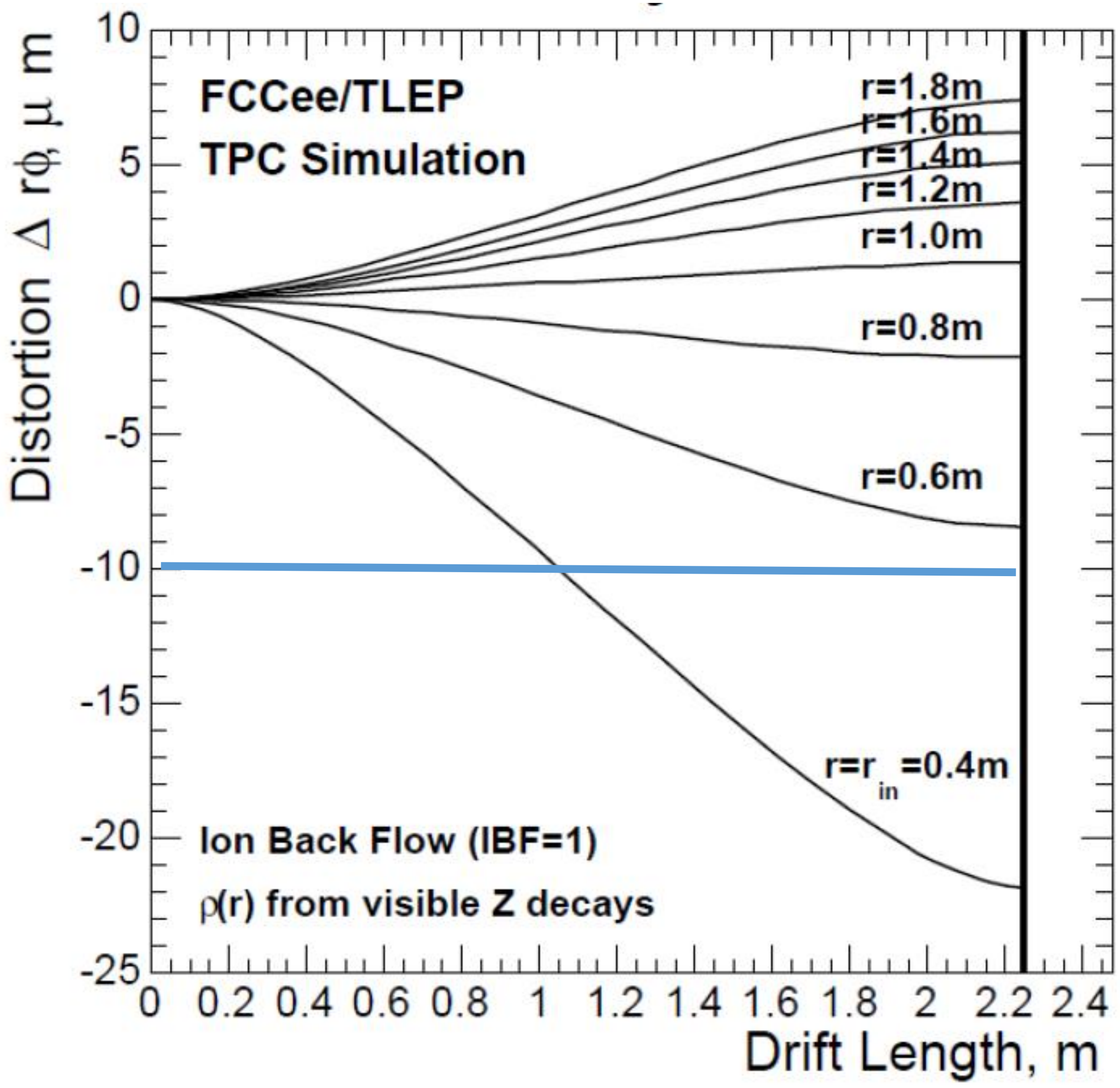
Philippe Schwemling

The higher the magnetic field, the more curlers, increasing ionization


FCCee/TLEP
TPC Simulation
FCCee Ion Back Flow
from visible Z decays
Primary charge
density at ILC
Charge density ρ(r), 10^-12 C/m^3
Radial position r, m
0
5
10
15
20
25
30
35
40
45
50
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

S. Ganjour

Philippe Schwemling



This estimate is probably a lower limit, if not an underestimate.
No background is included.
Assumes 20 kHz Z rate (should be up to 40 kHz) and 40 ions per cm (should be 100)
Assumes IBF*gain=1

Possible handles : lower magnetic field, inner radius increased to 50cm?

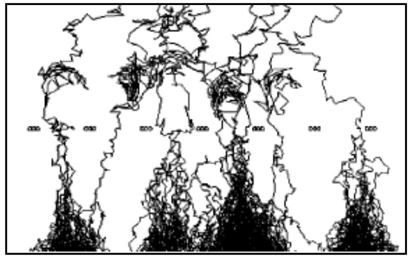
Still OK for CEPC parameters (1 to 2 orders of magnitude less in luminosity)
(Huirong Qi assuming Gain*IBF=5 with a Micromegas + GEM)

Ion backflow mitigation/suppression

- Several ideas have been proposed to suppress ion backflow
- 4-GEMS, 2 or 3 GEMs + Micromegas, double or triple meshes, staggered, crossed…
- The situation is rather confused : impressive results like 10^{-4} or even 10^{-5} ion backflows are suspected to be due to screening by space charge . The measurement is extremely difficult.
- The suppression is often obtained at the cost of resolution

(in energy/dE/dx and position)

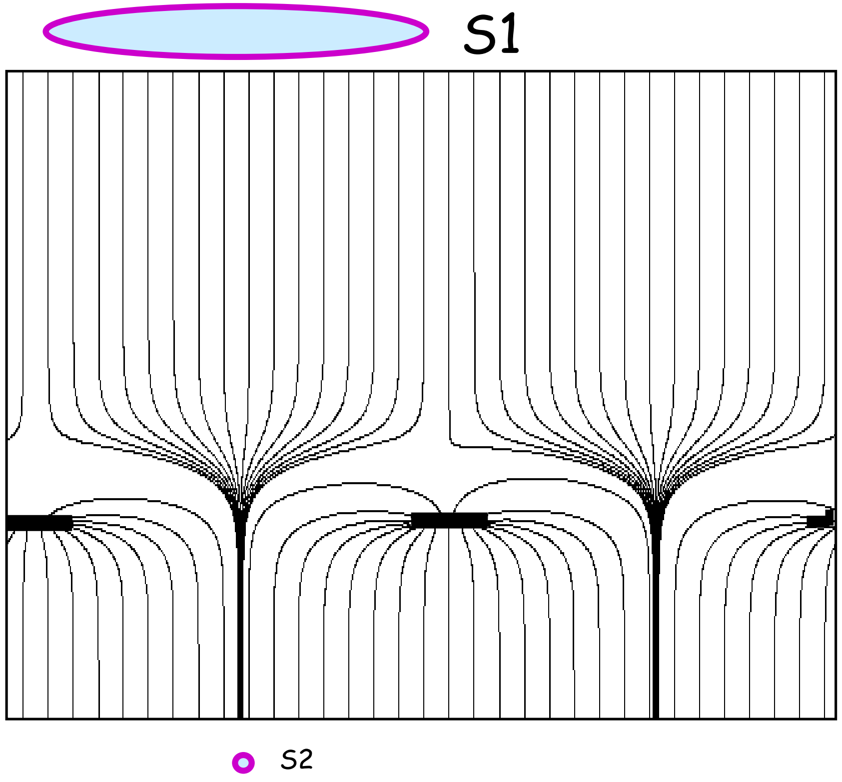
Ion backflow natural suppression in Micromegas



σ

Electrons from the avalanche undergo transverse diffusion. The ions created follow field lines with negligible diffusion. Thus most of them (outside the funnel) go back to the mesh where they are neutralized.

The maximum backflow is thus proportional to the field ratio (0.3% in the ILC TPC case).

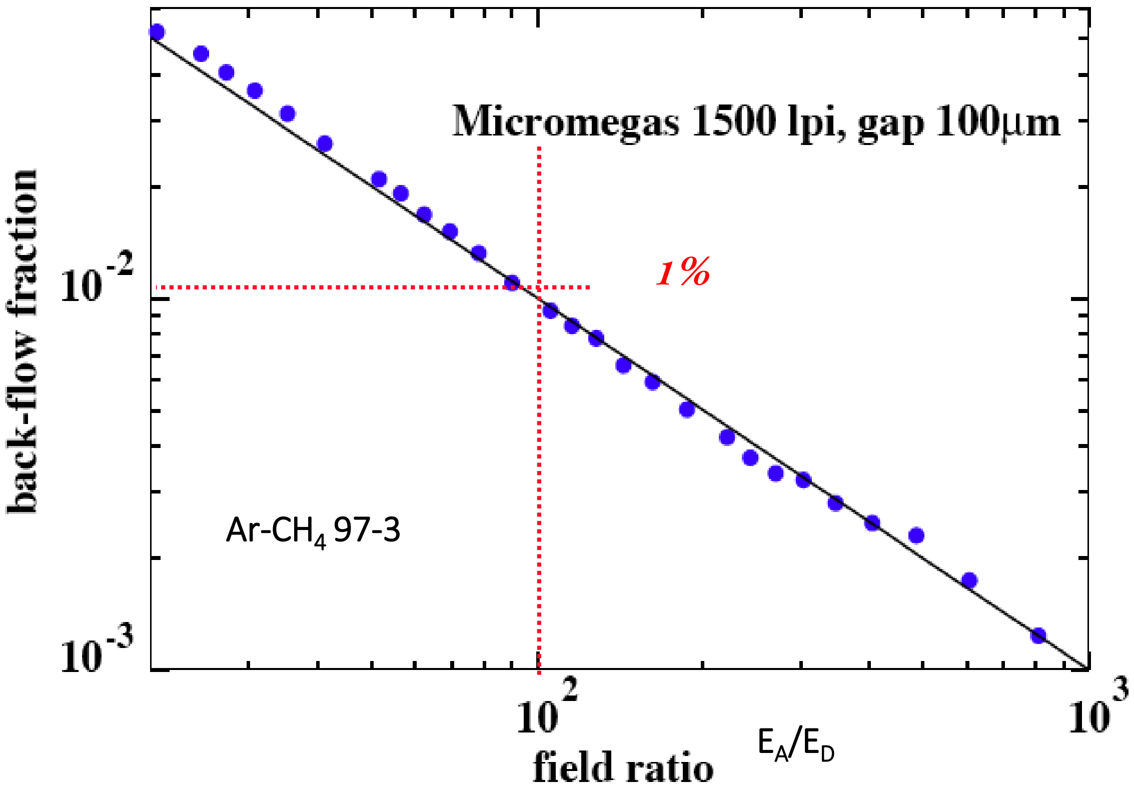


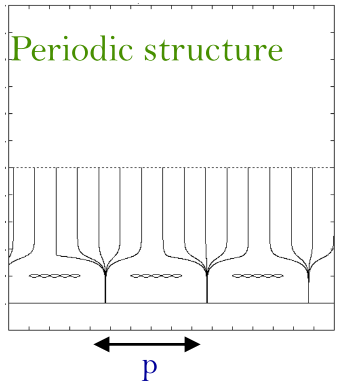
$S2/S1 = E_{drift}/E_{amplif} \sim 200/60000 = 1/300$

The inverse field ratio law is well verified experimentally

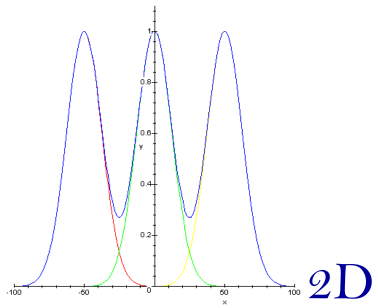
P. Colas *et al.*, NIMA535(2004)226

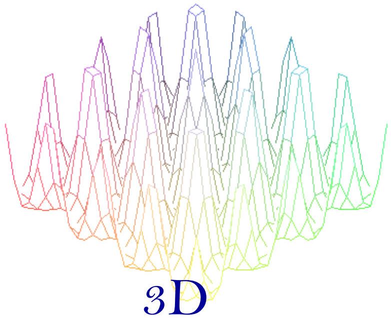
More detailed measurements have been carried out with Ingrid detectors.
(M. Chefdeville's thesis)

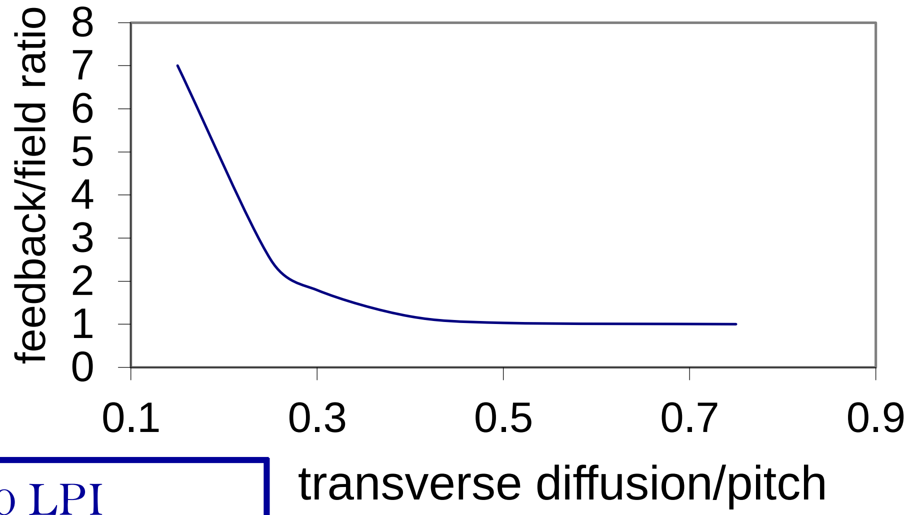


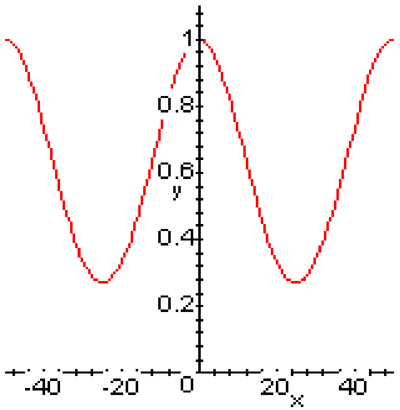
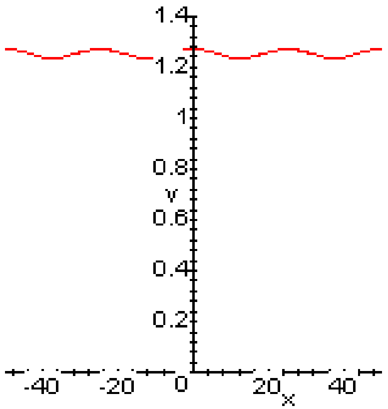
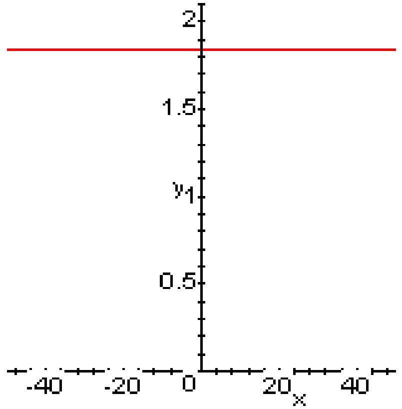


Sum of gaussian diffusions







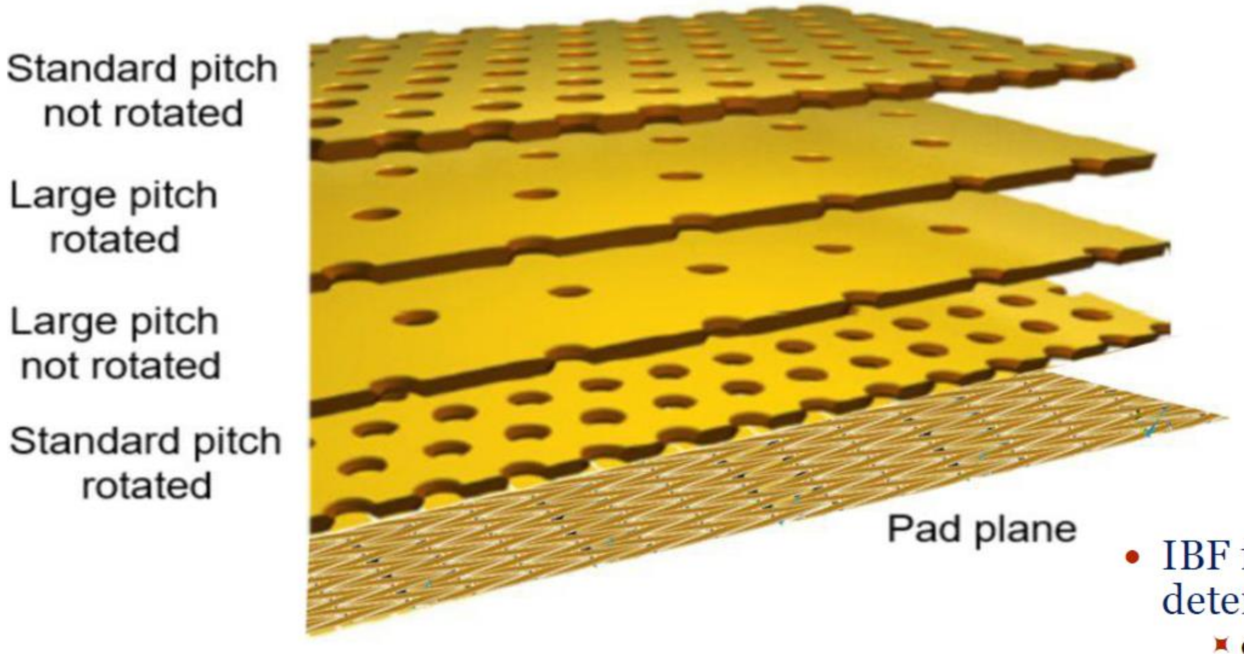
Mesh	500 LPI	1000 LPI	1500 LPI
σ_t/p	0.25	0.5	0.75
Theoretical model			
$\frac{IBF}{FR}$	2.5	1.03	1

J. Martin (2003)

When the avalanche extends to neighbouring holes, the minimum backflow is attained

4 GEMs

ALICE with 4 GEMs
Also adopted by SPhenix



V	sPHENIX			
Setting	1	2	3	4
G1 Top	4208	4658	5124	5118
G1 Bot	3951	4401	4851	4861
G2 Top	3051	3351	3651	3661
G2 Bot	2721	3021	3321	3342
G3 Top	1821	1971	2121	2142
G3 Bot	1409	1559	1709	1709
G4 Top	1379	1529	1679	1679
G4 Bot	900	1050	1200	1200

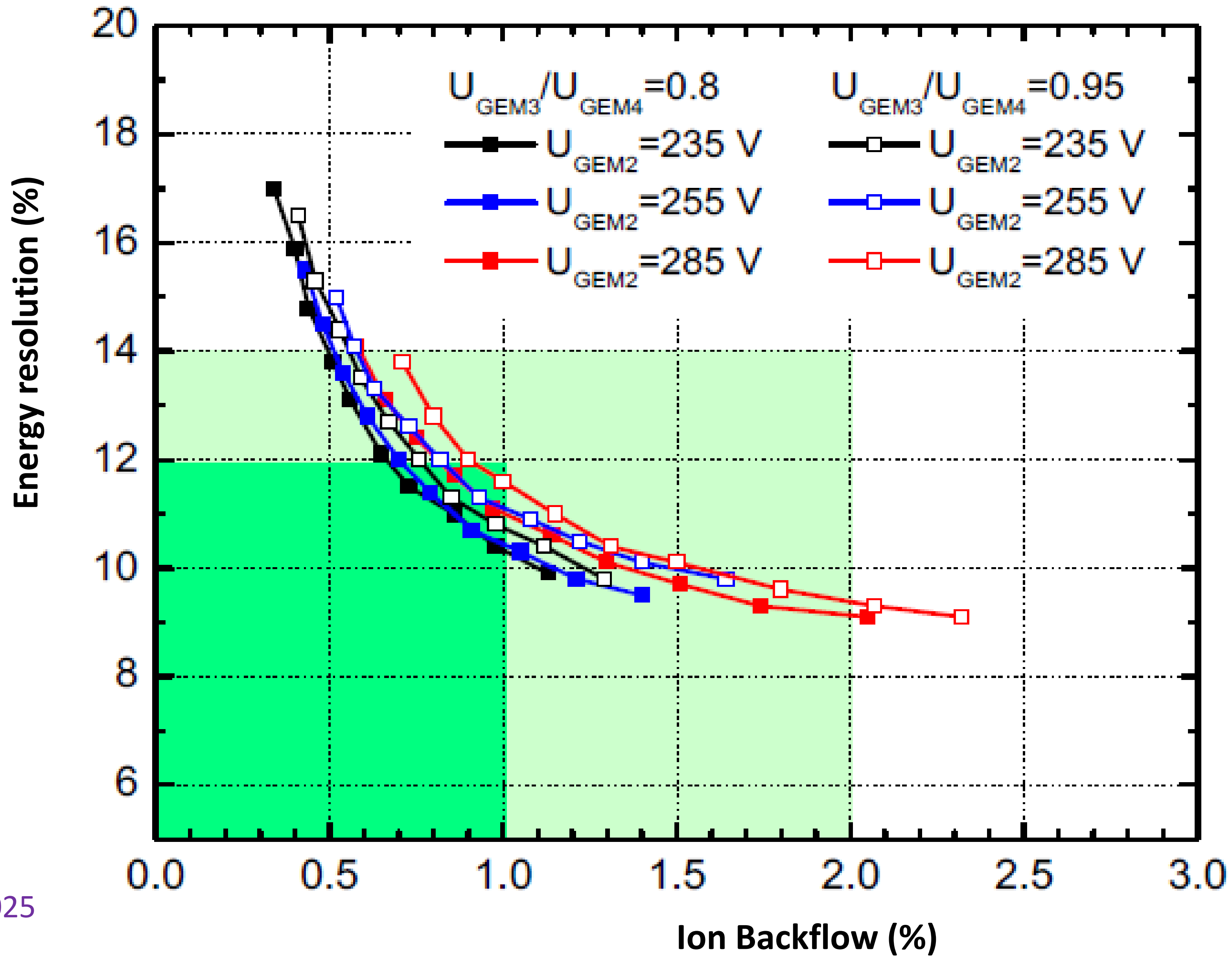
- IBF for these configurations determined with X-ray
  - 0.44%, 0.39%, 0.33%, 0.31%
- All configurations tested in test-beam

Piotr Gasik
Klaus Dehmelt

4 GEMs

ALICE with 4 GEMs

Distortions up to 20 cm

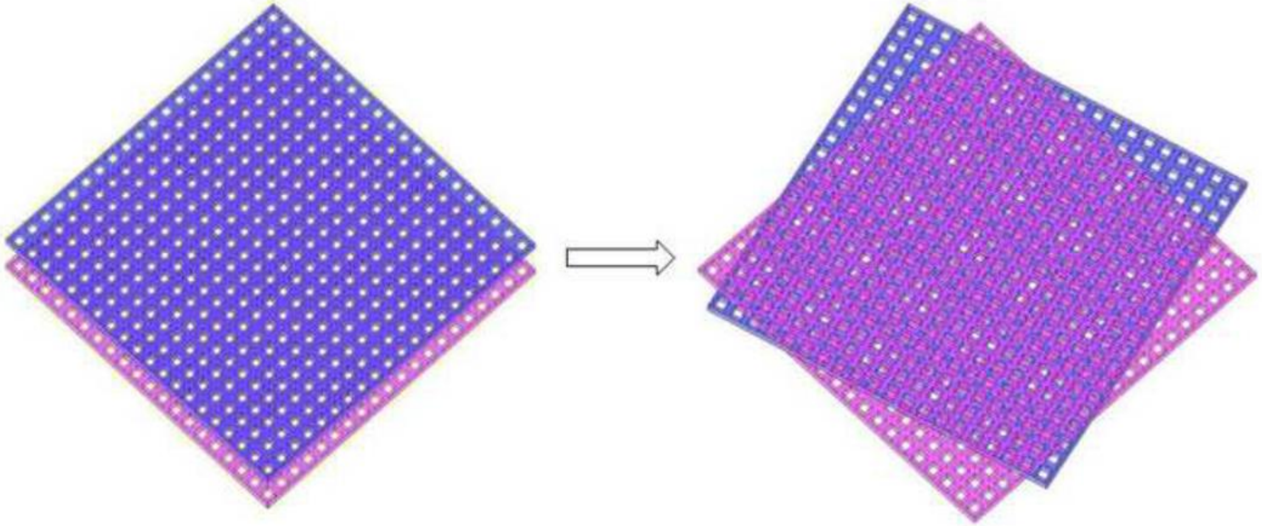


See also : M Ball *et al* 2014 *JINST* **9** C04025

Double Micromegas

DMM (Jianbei Liu et al., USTC)
Claim that misaligning the meshes reduces the backflow.

But resolution also degrades.



Also studied in F. Jeanneau et al. NIMA623(2010)94, but very difficult measurement

Caveats : Moiré modulation of the gain, effect of magnetic field

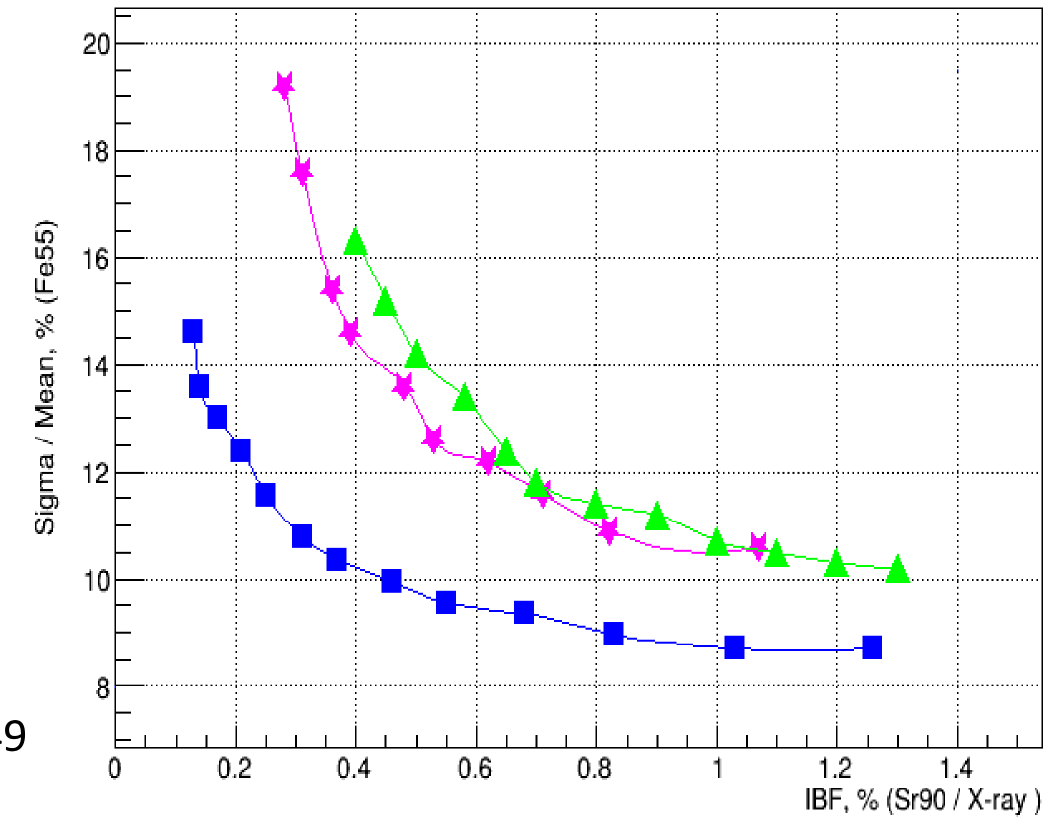
It is also possible to make use of a magnetic field in a high $\omega\tau$ gas (E. Shulga, Weizmann)

Micromegas + nGEMs

Also measurements have been done with Micromegas + 1, 2 or 3 GEMs
At the end marginally better than Micromegas alone

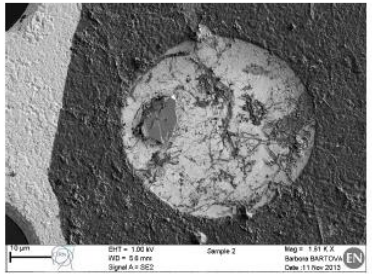
Hugo Peireira
Nikolai Smirnov

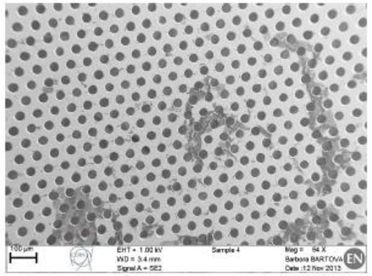
F. Bossu
S. Aune
et al.

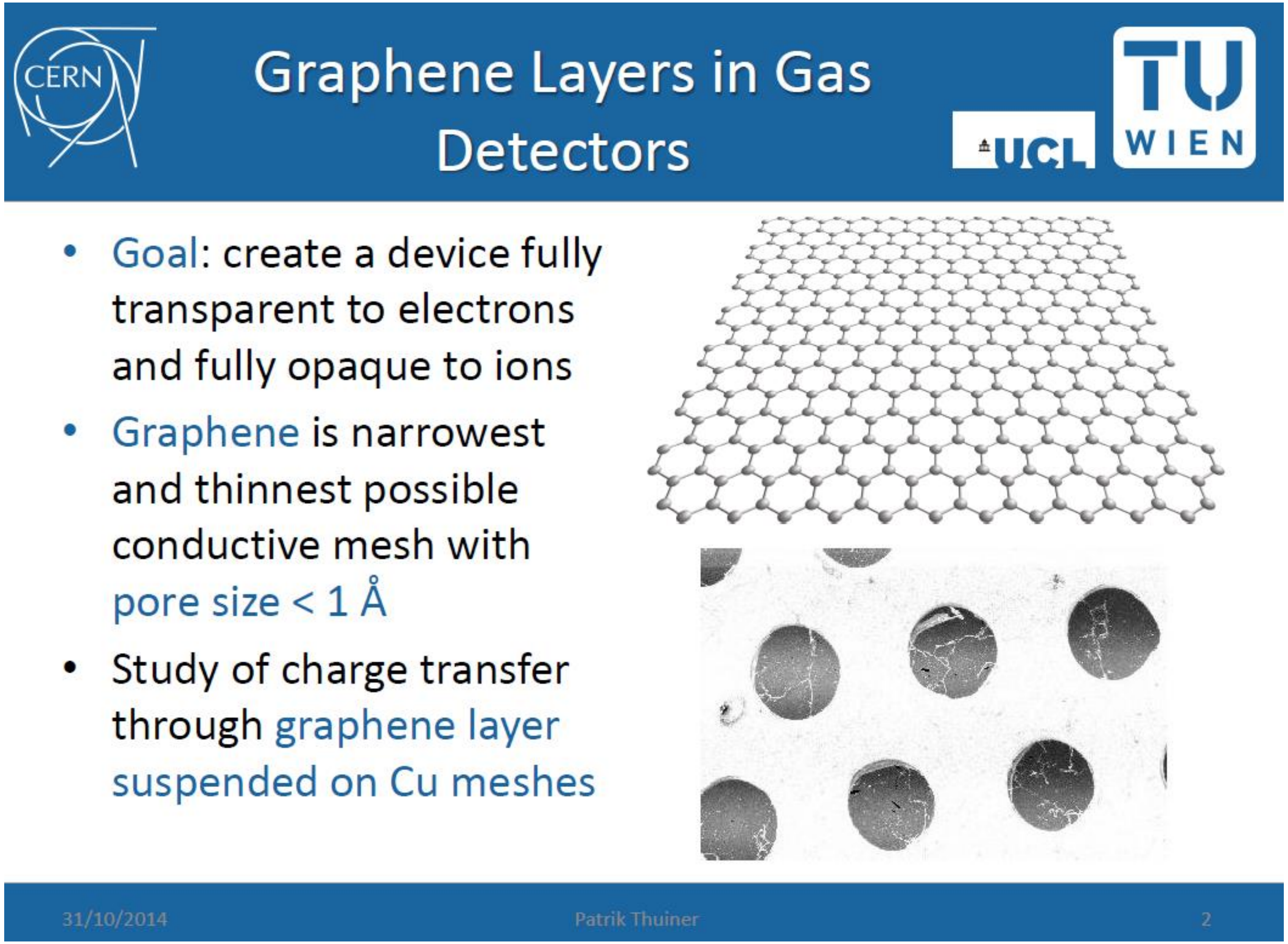


More results can be found. NIM A 834 (2016) 149

One direction of research is to use Graphene, but this looks very difficult



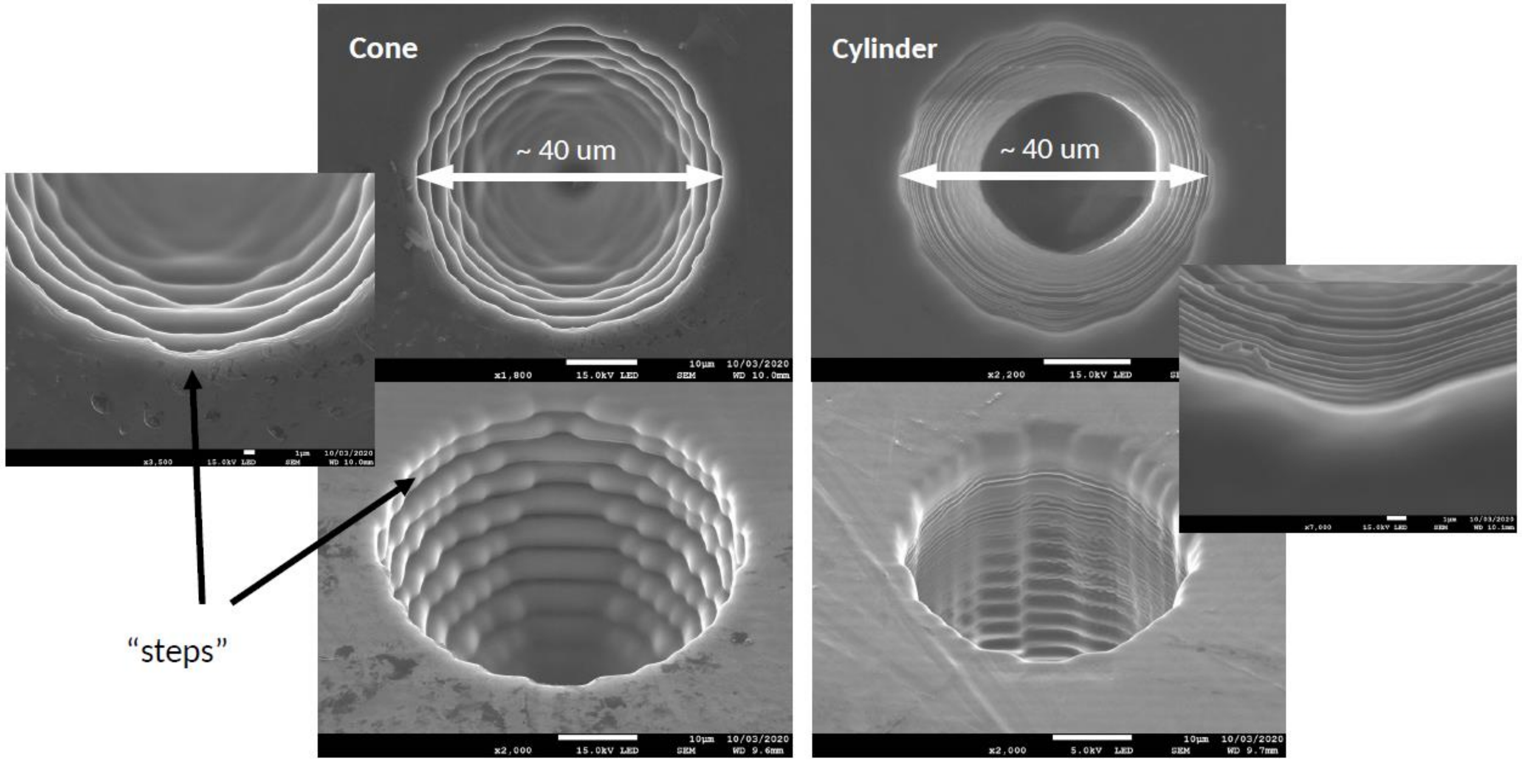




Patrick Thuiner

Possible solution : shape the field so that they converge to a small region, from which electrons escape by diffusion. Necessitates to shape the anode at the hole scale level.

This can be done using micro-additive fabrication at the sub-micronic level (example from Tiago Silva, Sao Paulo)



Non-exhaustive list of potential issues with indicative expectations:

Potential issues →	Ions in drift chamber		Readout Occupancy
Future colliders ↓	Primary ions	Backflow ions	
ILC 1 TeV	Acceptable	GEM ion gate	Low (< 1% voxel)
CLIC 3 TeV	Requires investigation	Gating is possible	100% pads (30% voxel) 40% pixel (lower voxel)
FCC-ee 91 GeV $(L = 230 \cdot 10^{34}\ cm^{-2}\ s^{-1})$	Too high (distortions > 100 µm)	Too high (gating is not possible)	Most likely low
CEPC 91 GeV $(L = 34 \cdot 10^{34}\ cm^{-2}\ s^{-1})$	Acceptable	~25% event loss if gated Other solutions	Low (<< 1% voxel)

Peter Kluit, Nikhef, CEPC workshop, Shanghai, Oct. 2020

Conclusions

- Ion backflow has to be suppressed if one is to select Higgs recoils.
- If gating is not possible (case of FCC and CEPC) one needs to find a new structure to suppress the ion backflow without degrading the space resolution or dE/dx resolution.
- So far many trials with multiple GEMs or Micromegas or combinations have been done, but still IBF limited to 1 permil or a few.
- Micro-additive fabrication of the anode might provide a technical solution.

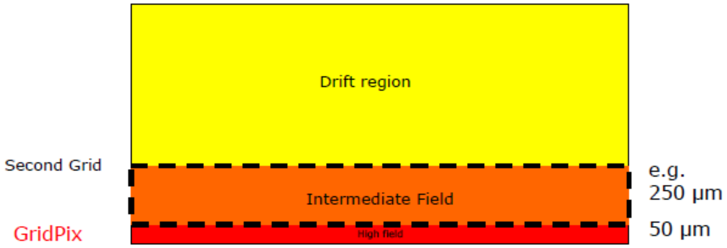
Peter Kluit : ‘there is no need for a gating device (a double grid suffices)

Reducing the Ion back flow in a Pixel TPC

The Ion back flow can be reduced by adding a second grid to the device.

It is important that the holes of the grids are aligned. The Ion back flow is a function of the geometry and electric fields. Detailed simulations – validated by data - have been presented in LCTPC WP #326.

With a hole size of 25 μm an IBF of 3 10^{-4} can be achieved and the value for IBF*Gain would be 0.6. Well below the specifications.



We plan to test this idea at Nikhef

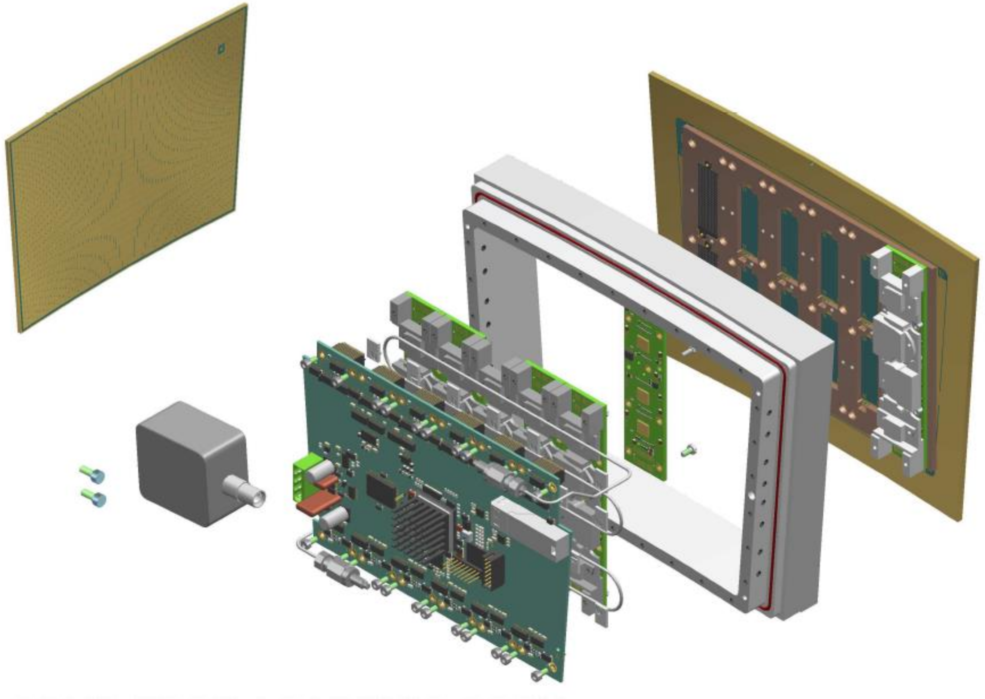
Ion backflow	Hole 30 μm	Hole 25 μm	Hole 20 μm
Top grid	2.2%	1.2%	0.7%
GridPix	5.5%	2.8%	1.7%
Total	12 10^{-4}	3 10^{-4}	1 10^{-4}
transparancy	100%	99.4%	91.7%

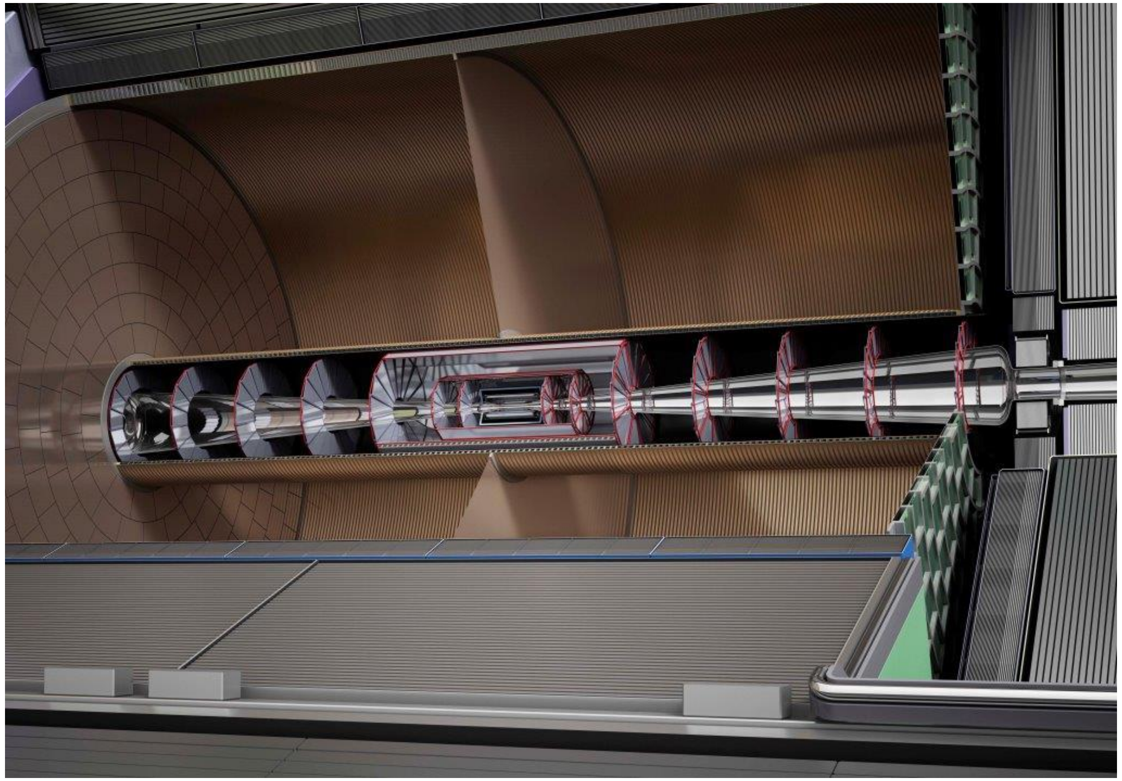
26/10/2020 Pixel TPC R&D (Peter Kluit) 19 / 19

A TPC for ILC

Options : GEM and Micromegas with pads or pixels

R&D lead to a design of a Micromegas module with fully integrated readout and 2-phase CO2 cooling. The ERAM concept (Encapsultated Resistive Anode Micromegas) proved to ‘do the job’ : 200 points with 60 µm resolution





This ERAM concept is adopted by T2K/ND280 for its upgrade. If successful, it might be used at DUNE/SAND