ILC-TPC Micromegas: Ion Backflow Measurements

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Outline

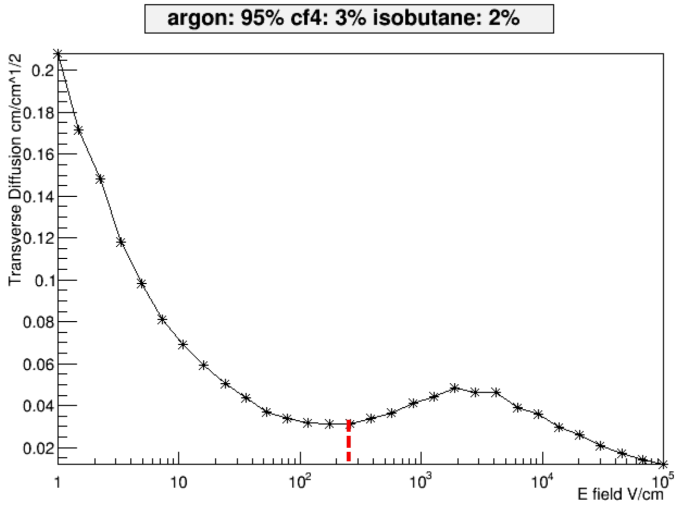
- Operational conditions in ILD-TPC for ILC
- Ion Backflow in Micromegas detectors
- Ion Backflow (IBF) Measurements
    - Principle
    - IBF vs. Micromegas Grid Geometry and Fields
    - IBF in bulk Micromegas
- Ion Backflow solution

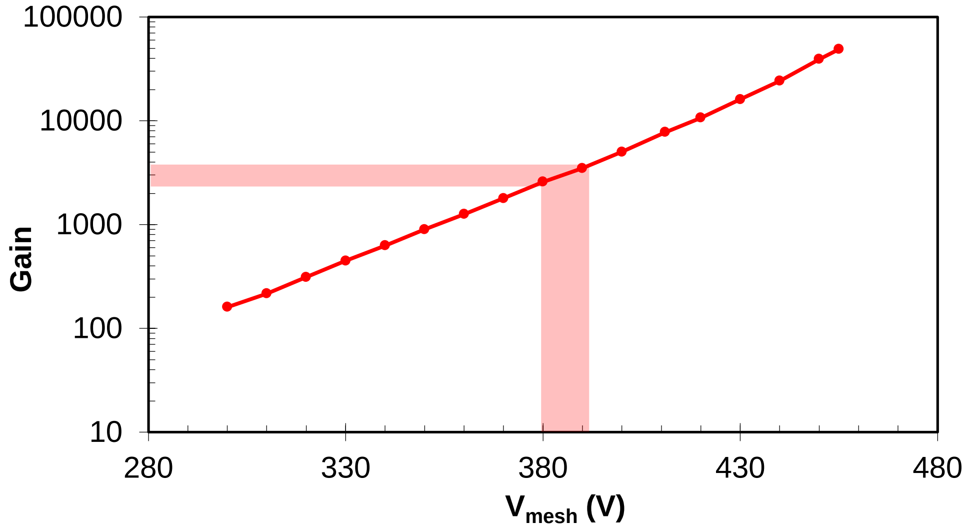
Operational Conditions in ILD-TPC for ILC

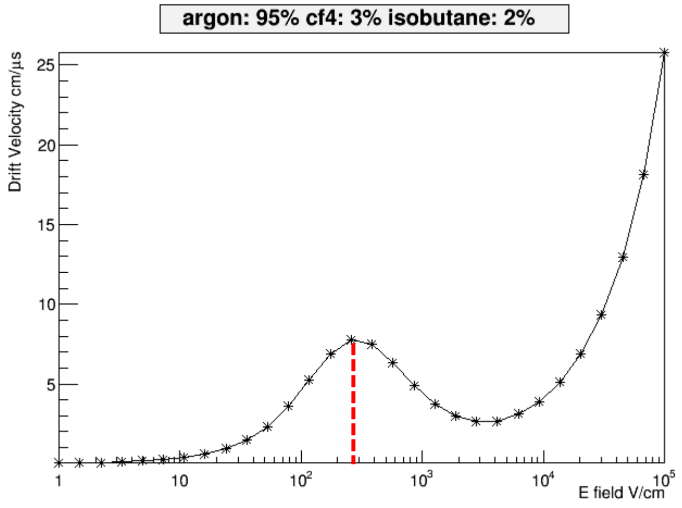
- T2K gas: $Ar/CF_4/iso\text{-}C_4H_{10}$ 95/3/2
- Drift field: $E_{drift} = 230$ V/cm ($V_{drift} = 7.5$ cm/µs)
- Bulk Micromegas:
  - amplification gap: 128 µm
  - hole pitch: 63 µm (400 lpi)
- Gas gain: 2000-4000 (380-400V)

→$E_{amplification}/E_{drift}=E_A/E_D=130\text{-}135$

- IBF requirement: < 1% (for margin <0.1%)



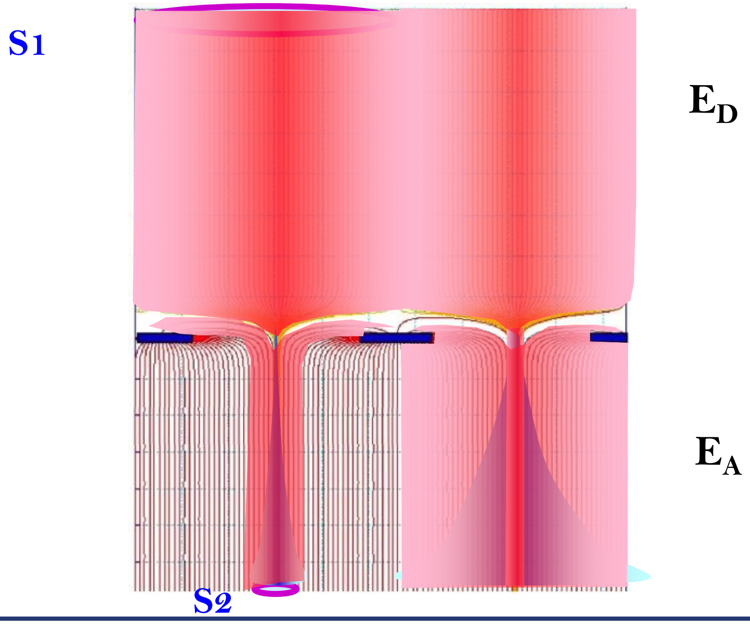




E_{drift}=230 V/cm

Micromegas: Intrinsic Suppresion of Ion Backflow

- Electrons are swallowed in the funnel, then make their avalanche, which is spread by diffusion
- The positive ions flow back with negligible diffusion (due to their high mass)
- If the pitch hole is comparable to the avalanche size, only the fraction $\sim S_2/S_1 = E_{DRIFT}/E_{AMPLIFICATION}$ drift back to the drift space.
  Others are neutralized on the mesh: optimally, the backflow fraction is as low as the field ratio
- This has been experimentally thoroughly verified

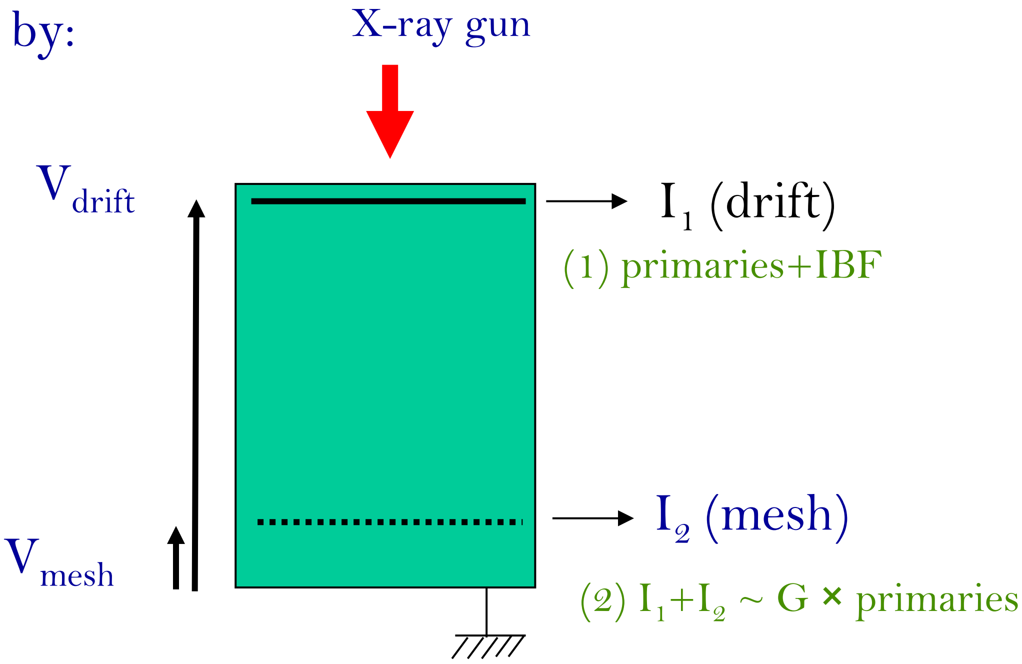


$$\boxed{FR = \frac{E_D}{E_A} = \frac{S_2}{S_1}}$$

Ion Backflow with Micromegas: Measurement Principle

- The ion backflow fraction is given by:

$$IBF = \frac{I_{drift}}{I_{mesh}} = \frac{I_1}{I_2}$$



X-ray gun

V_{drift}

V_{mesh}

I_1 (drift)

(1) primaries+IBF

I_2 (mesh)

(2) $I_1+I_2 \sim G \times$ primaries

- Determination of the primary ionisation from the drift current at low V_{mesh}
- Using equation (1) & (2) G is eliminated → IBF

Ion Backflow with Micromegas: Measurement Results

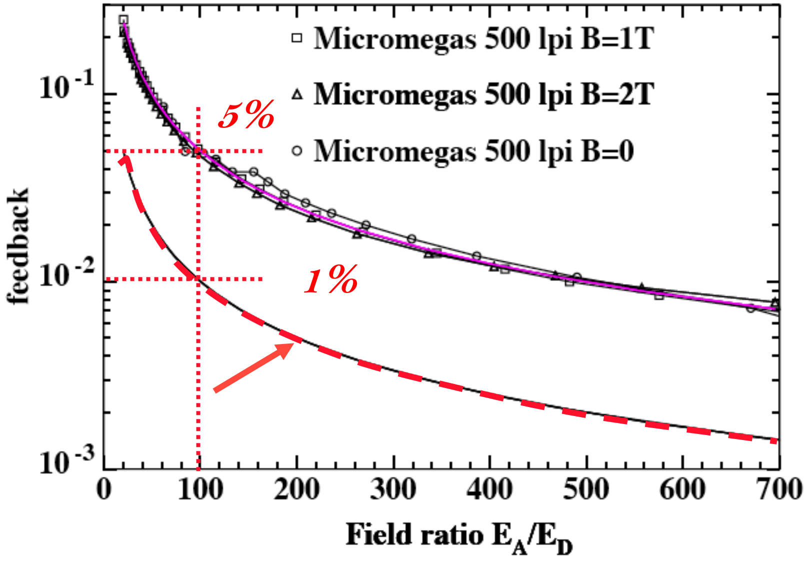
- MWPC-TPC: IBF~30%

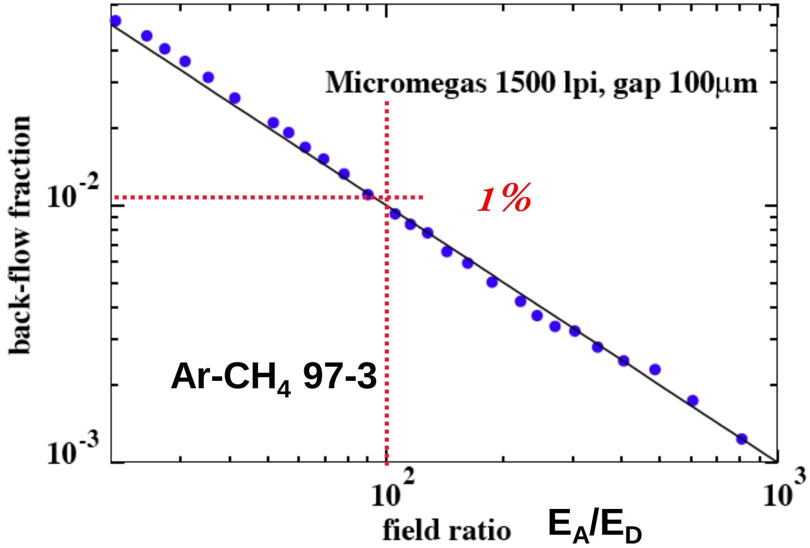
- The ions backflow depends on avalanche spread (transverse diffusion) but cannot be smaller than the field ratio

- The absence of effect of the magnetic field on the ion backflow suppression has been tested up to 2T

- For a **E_A/E_D ~100, IBF~1-5%** depending on geometry (hole pitch)

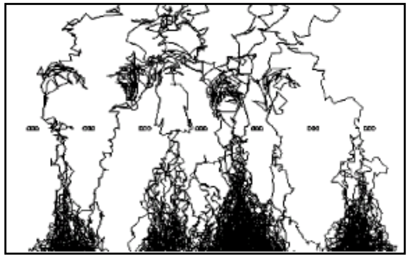
P. Colas *et al.*, NIMA535(2004)226

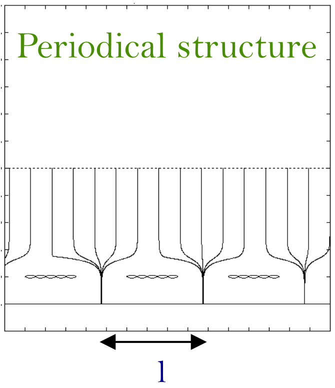


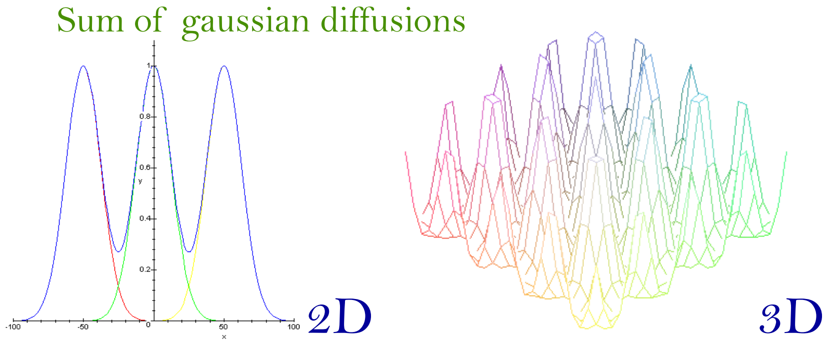


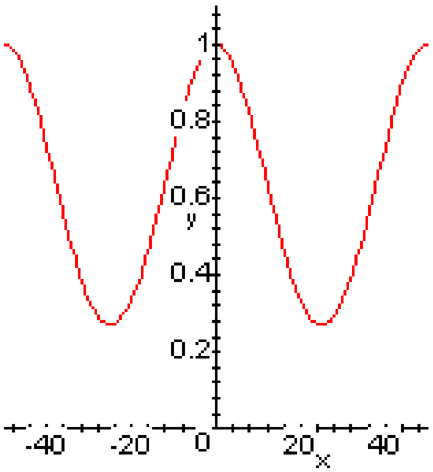
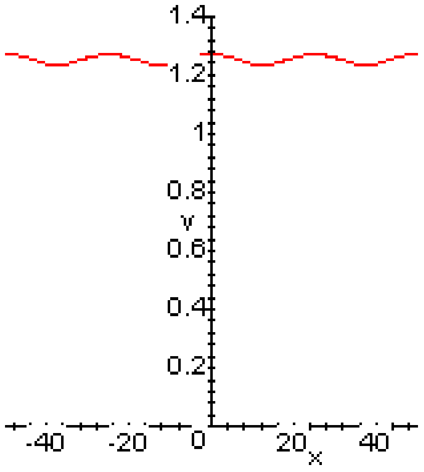
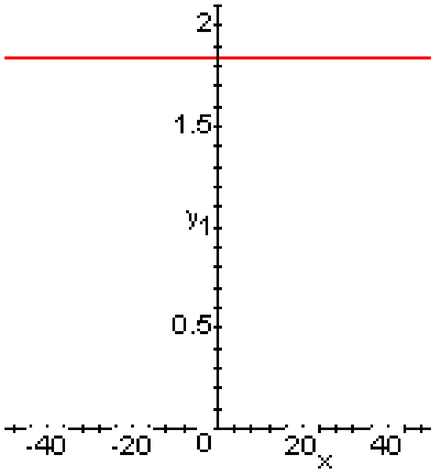
Ion Backflow with Micromegas: Simulation

- IBF calculation:

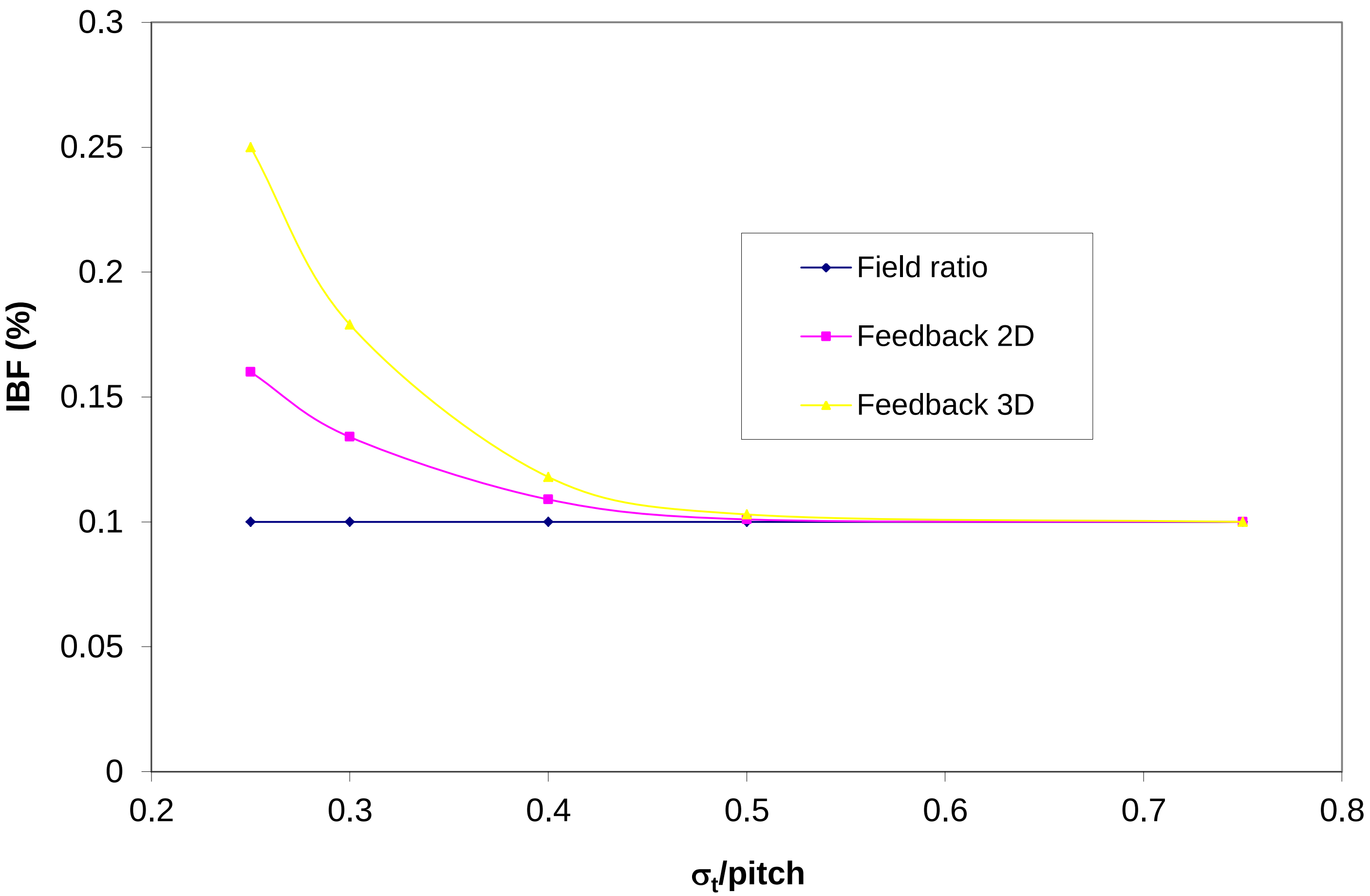






Mesh	500 LPI	1000 LPI	1500 LPI
σ_t/p	0.25	0.5	0.75
Theoritical model			
$\frac{IBF}{FR}$	2.5	1.03	1

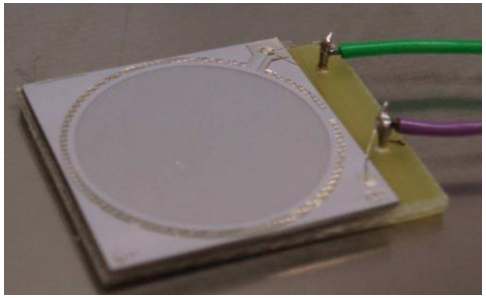
Ion Backflow with Micromegas: Simulation



Grid Geometry and Fields

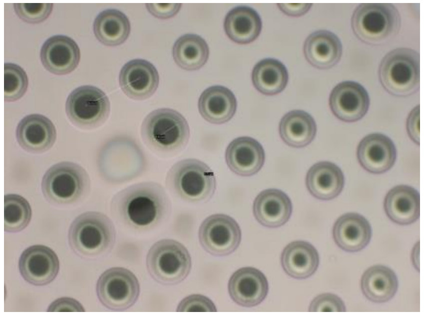
- $BF \propto \frac{1}{FR}\left(\frac{p}{\sigma_t}\right)^2$

- p = hole pitch
- σ_t = transverse diffusion = $D_t\sqrt{z}$ (D_t: transverse coefficient)
- FR = $\frac{E_{\text{drift}}}{E_{\text{ampplication}}}$

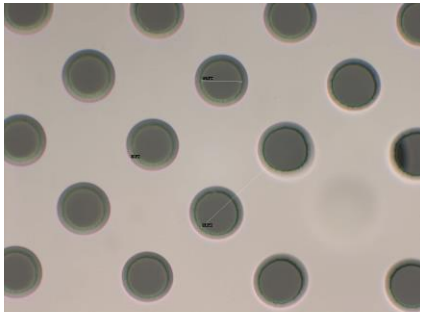


Ingrid sample

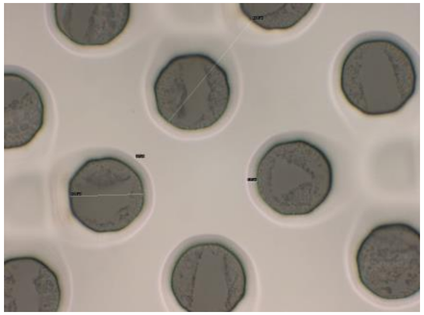
20 µm hole pitch



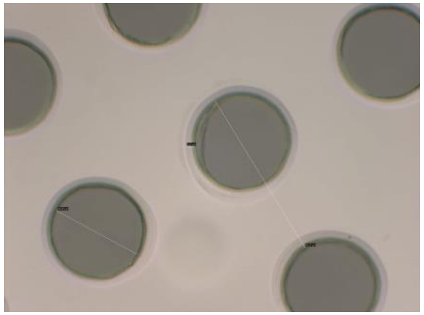
32 µm hole pitch



45 µm hole pitch

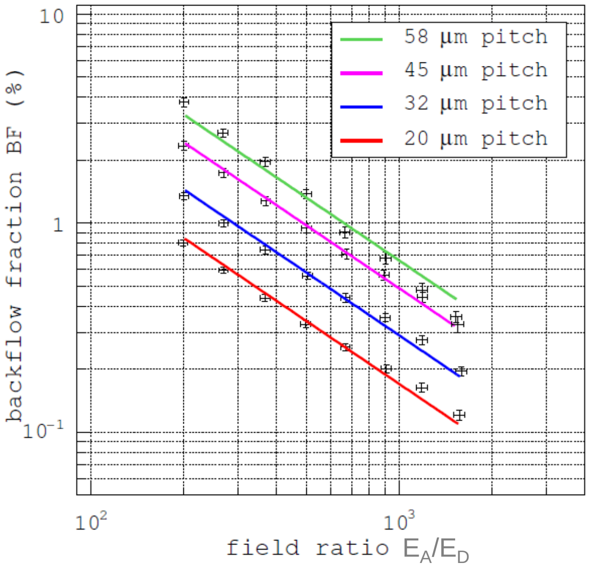


58 µm hole pitch

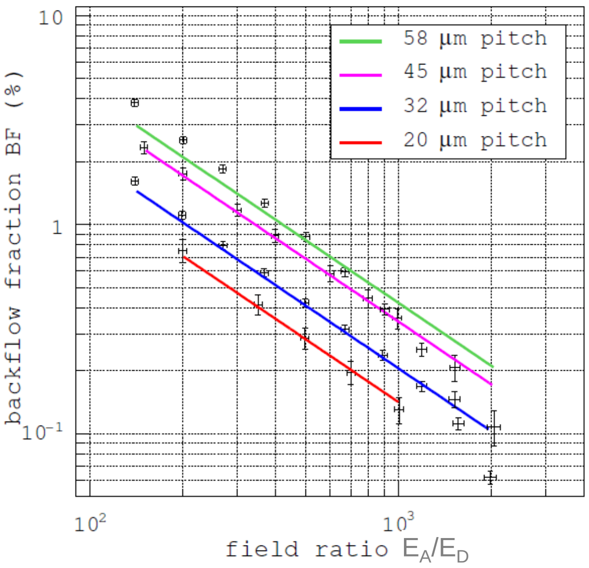


Grid Geometry and Fields

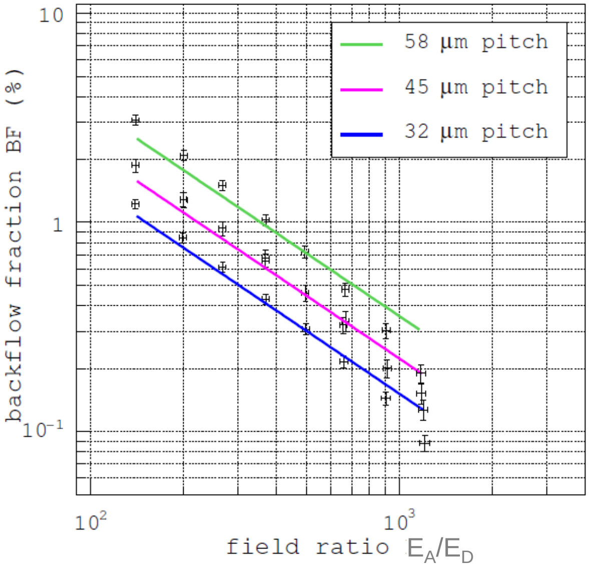
45 µm gap



58 µm gap



70 µm gap



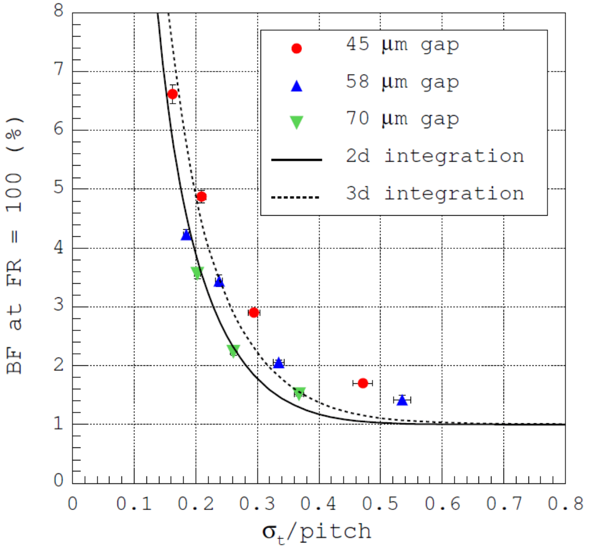
Fit using:

$$BF(x,y) = \frac{x}{FR^{-y}}$$

with $y \sim 1$

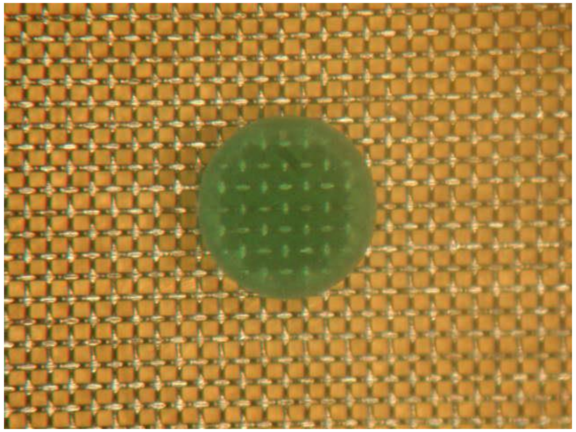
M. Chefdeville, PhD Thesis (2009)

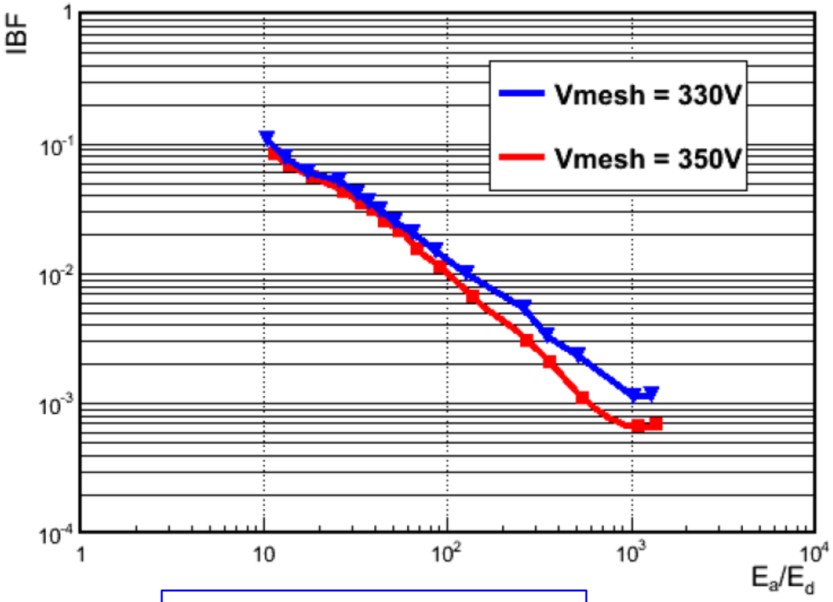
Gap (µm)	Hole pitch p (µm)	Hole ∅ d (µm)	σ_t/p
45	20	12	0.47
	32	23	0.30
	45	32	0.21
	58	21	0.16
58	20	9	0.58
	32	15	0.36
	45	34	0.26
	58	22	0.20
70	32	18	0.43
	45	32	0.30
	58	22	0.24



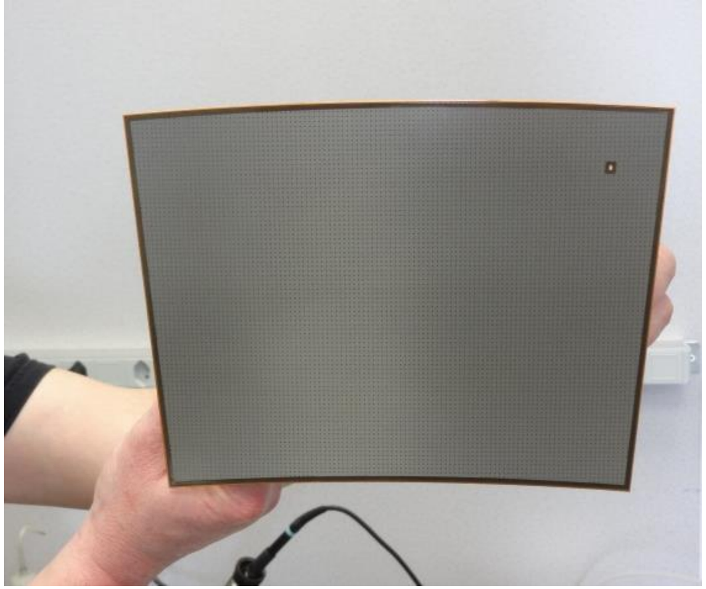
Ion Backflow in Bulk Micromegas

- Micromegas for LC-TPC:
  - (resistive) bulk technology
  - 128 µm gap
  - woven mesh with pillars
  - 45 µm hole / 18 µm wire ∅
  - 400 LPI

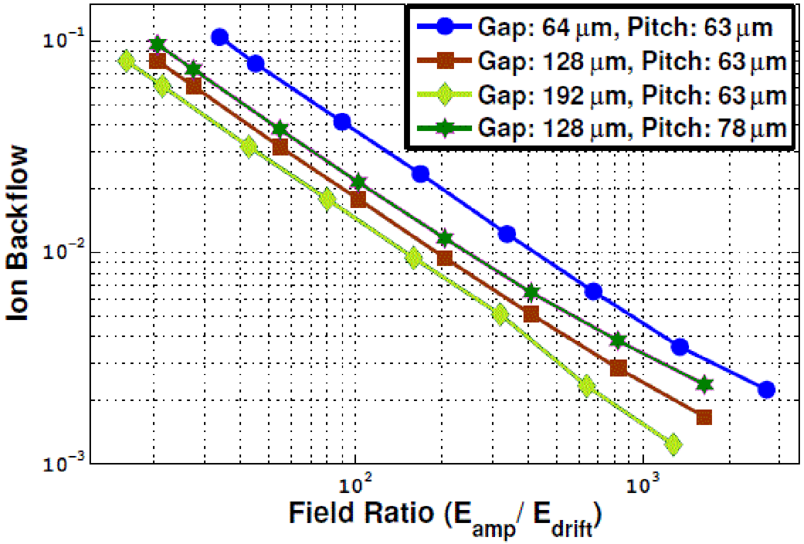


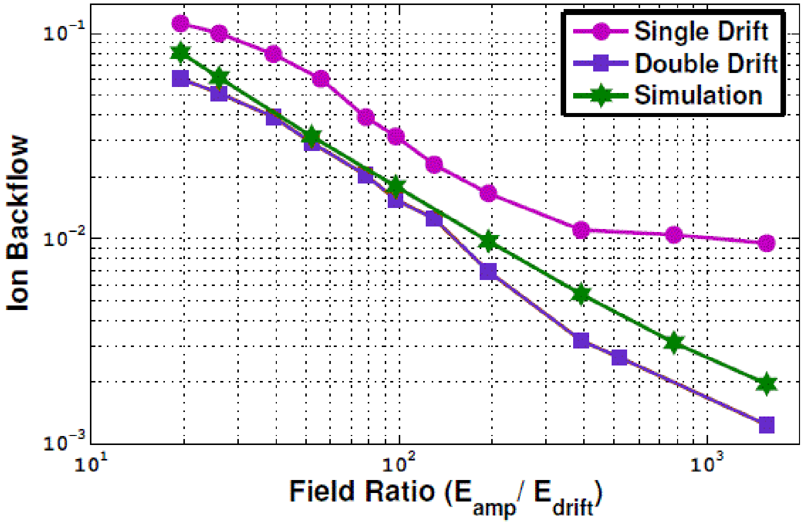


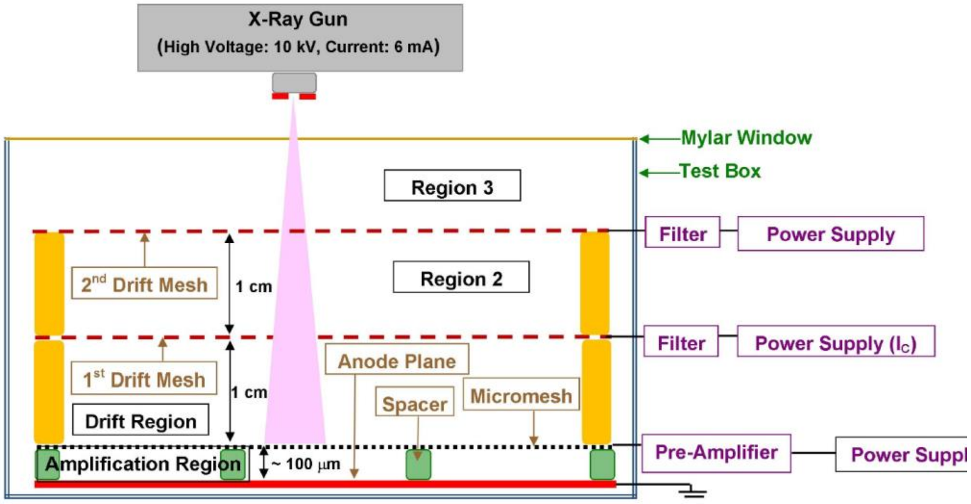
W. Wang, PhD Thesis (2013)

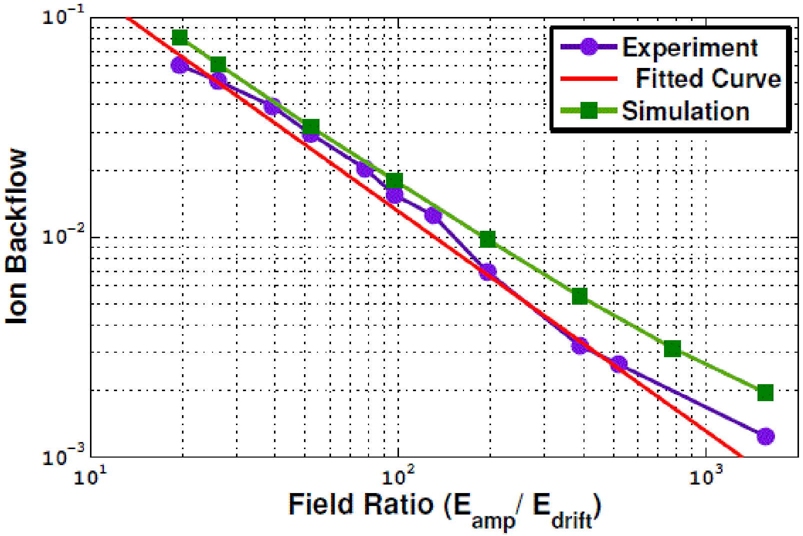


Ion Backflow in Bulk Micromegas





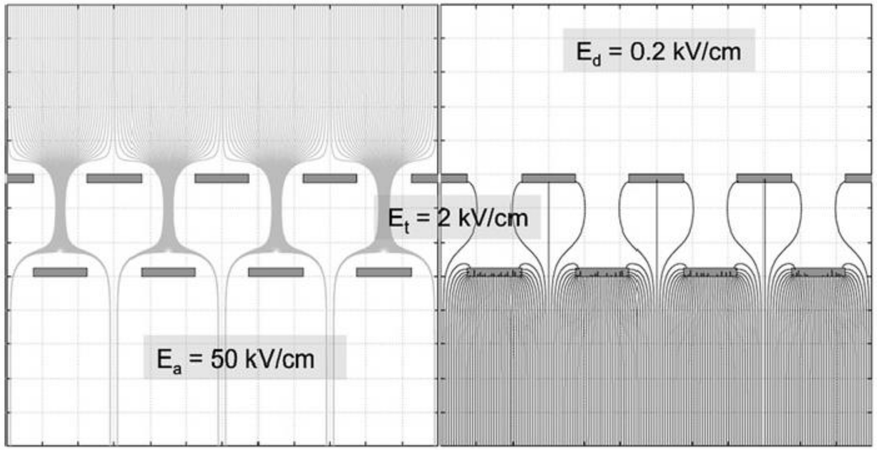


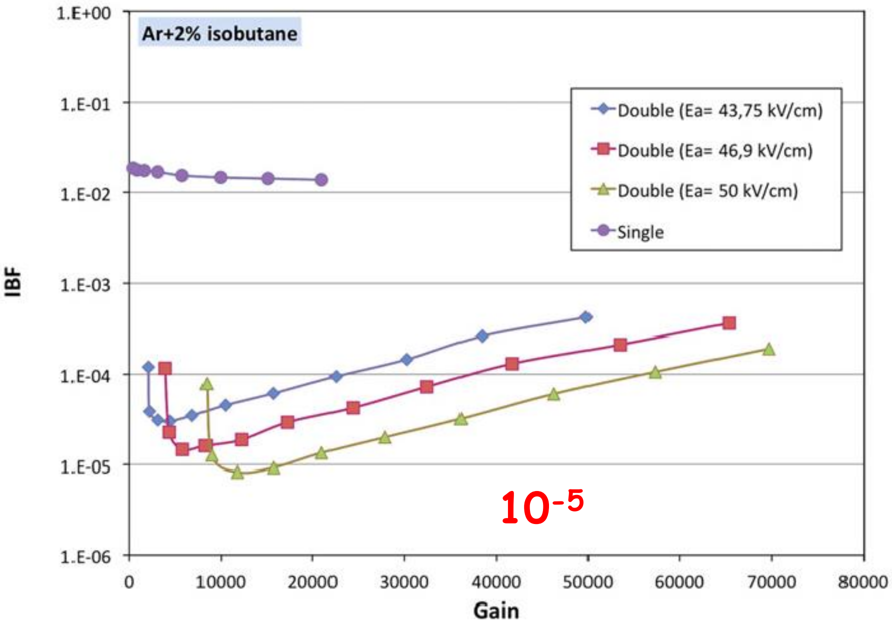


Bhattacharya et al. JINST 9 C04037 (2014)

Possible Solution without Gating Grid

- Micromegas with offset metal meshes:





10^{-5}

- Open questions:
  - never used in TPC
  - effect of magnetic field?
  - large area?

F. Jeanneau *et al.*, NIMA623(2010)94

Summary & Outlook

- Micromegas: natural ion backflow suppression
  - **E_A/E_D~100 → IBF~ 1-2%**
  - E_A/E_D~1000 → IBF~ 0.1-0.2%

- For margin, grid geometry has to be optimized and/or a gating grid will be used

- Inside RD51, R&D on thin grid is in progress

Backup Slides

Ions Mobility in Gases

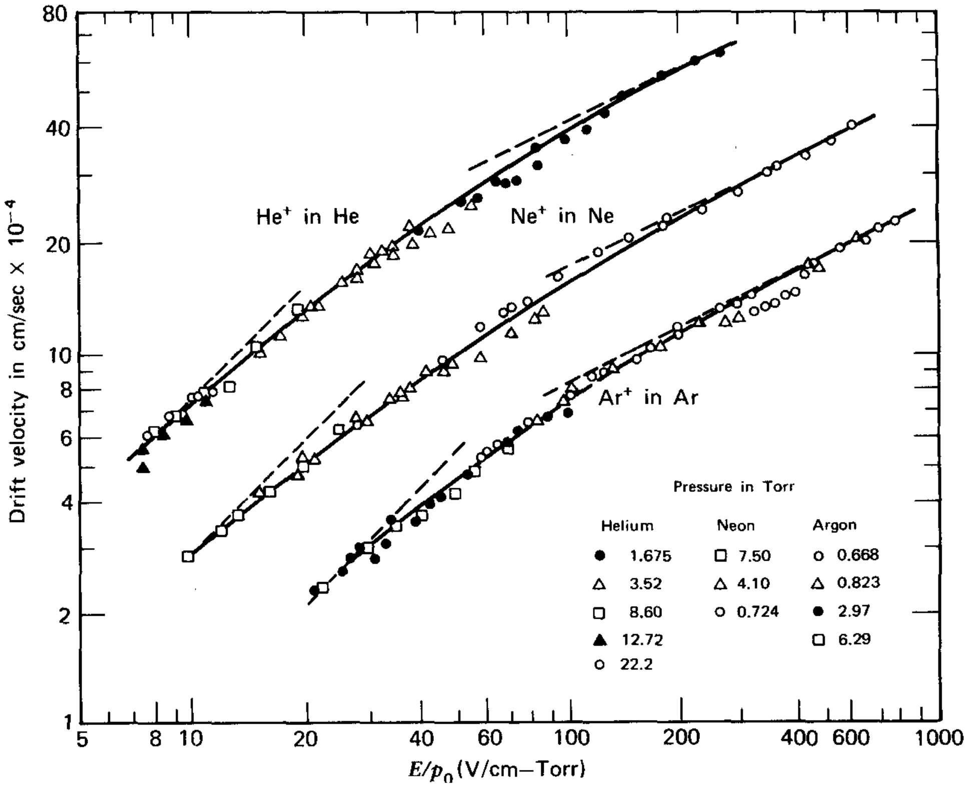
- Mobility: ratio of velocity and field $\mu^{+} = \frac{v_{+}}{E}$

(NTP: 300K, 760 mmHg)

Gas	Ion	μ^{+} (cm^{2}s^{-1}V^{-1})
He	He^{+}	10.2
Ar	Ar^{+}	1.7
CH_4	CH_4^{+}	2.26
$Ar\text{-}CH_4$	CH_4^{+}	1.87
CO_2	CO_2^{+}	1.09

- $Ar\text{-}CH_4$, E=1kV/cm

→ v_{+}=1.8 μm/s



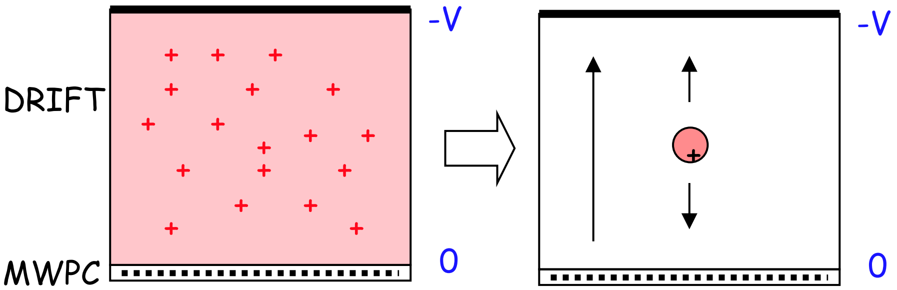
S. C. Brown Basic Data in Plasma Physics (Wiley, New York 1959)

Positive Ion Feedback

A fraction of the positive ions produced in the avalanches slowly drift in the sensitive volume and modify the electric field:

$Ar\text{-}CH_4$ 80-20 E=200 V/cm $w^+ \sim 320$ cm/s

For 1 m drift $T^+ = 300$ ms



For uniform irradiation releasing R electrons per second per cubic meter, the positive ion charge density is given by:

$$\rho^+ = \frac{eRLM\varepsilon}{w^+}$$

L: drift length

M: gain

ε: fractional ion feedback

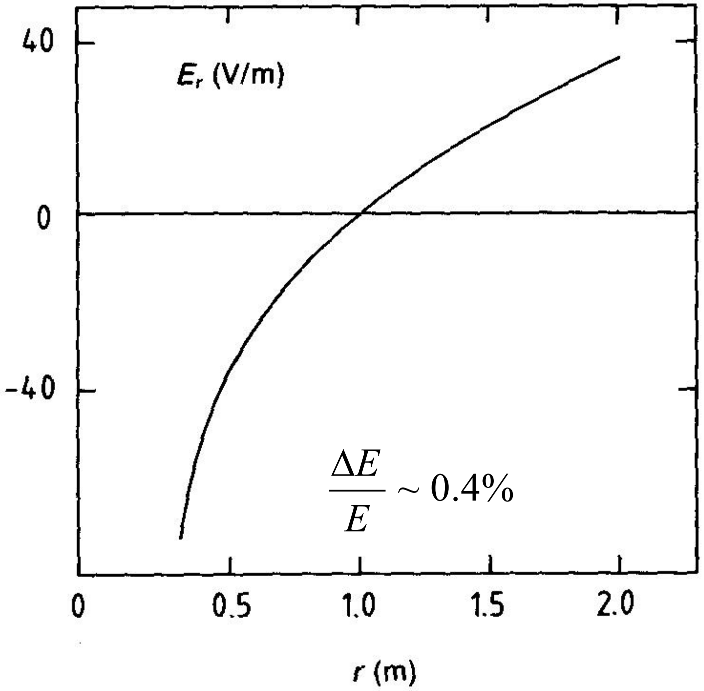
EXAMPLE: ALEPH TPC

$R=2.10^6\ s^{-1}\ m^{-3}$ $w^+=1.5\ m\ s^{-1}$

$M=10^4$ $\varepsilon=10^{-1}$

$M\varepsilon=10^3$: ion feedback per primary electron

$E=10^4\ V\ m^{-1}$



$$\frac{\Delta E}{E} \sim 0.4\%$$

W. Blum, W.Riegler and L. Rolandi
Particle Detection with Drift Chambers (Springer 2008)