Gas Electron Multiplier (GEM) for Time Projection Chamber gating application

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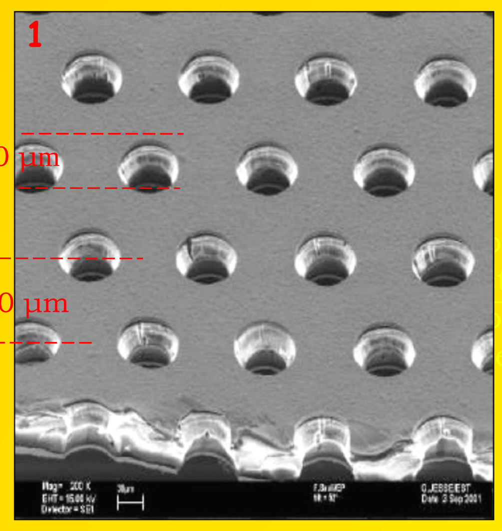
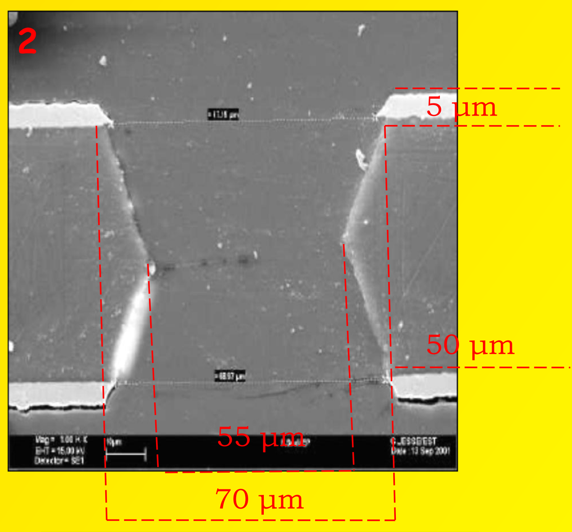
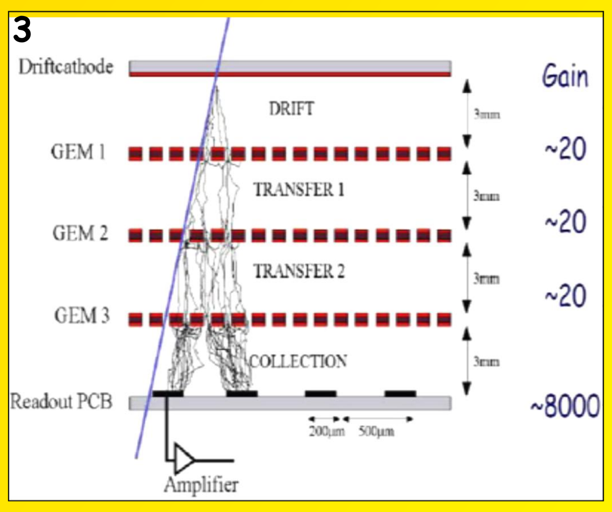
Gas Electron Multiplier (GEM)

The Gas Electron Multiplier (GEM), invented by F. Sauli in 1996 (NIM A 386 (1997) 531-534), consists of a thin Kapton insulating foil copper-clad on both sides and perforated by a high density, regular matrix of holes (50 to 100 per square millimetre). The distance between holes (pitch) is typically 140 μm and the diameter of about 70 μm. Upon an application of a potential difference between the GEM electrodes, a high dipole field develops in the holes, focusing the field lines between the drift electrode and the readout element. Electrons drift along the channel and the charge is amplified by a factor that depends on the field intensity and on the length of the channel. Localization is performed recording the charge reaching a suitably striped or padded readout board. Multi-GEM based detectors provide gain that are higher than 10^4 with a very low discharge probability since the multiplication process is shared between multiple electrodes. Software as Ansys and GARFIELD are employed to simulate GEM physics processes.







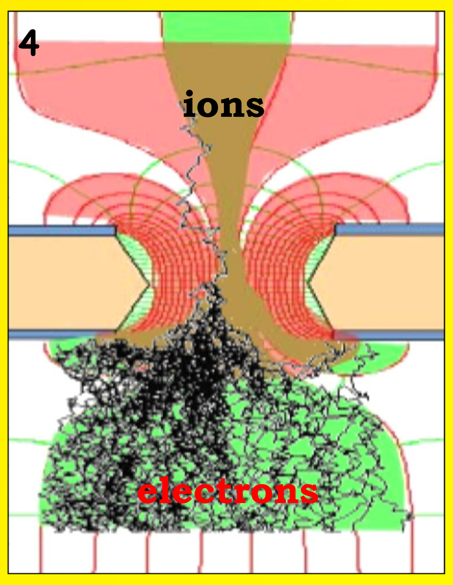


Fig 1: Microscopic view of a GEM foil. Fig 2: Cross-section picture of a standard GEM hole. Fig 3: Schematic view of a Triple-GEM detector and its operation principle. Fig 4: Garfield-Ansys simulation of a GEM electronic avalanche and of GEM ion feedback

GEM based TPC

Among the shortcomings that make MWPC based TPCs not suitable for next generation detectors (ILC, CLIC,…) we include:

- *E*x*B* distortion that take place in the last millimeters of the drift regions where the radial electric field of the anode is not parallel to the B field and provokes a worsening of the spatial resolution.
- High ions feedback that changes the electrons drift properties of the tracks that will not be reconstructed in the correct way
- Low rate capability and low track density reconstruction

The adoption of a GEM endcap would solve all these problems and allow the possibility to have larger gains and more geometrical freedom. From the construction point of view, GEM TPC will imply easier mechanics and increased detector robustness.

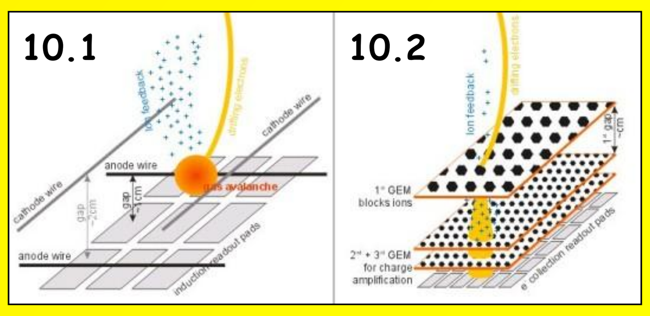


Fig 10: Examples of MWPC (Fig 10.1) and GEM (Fig 10.2) TPC readout

Time Projection Chamber (TPC)

The Time Projection Chamber (TPC) concept, invented by David Nygren in the late 1970's, is the basis for charged particle tracking in a large number of particle and nuclear physics experiments. A uniform electric field drifts tracks of electrons/ions produced by charged particles traversing a gas volume towards a surface segmented into 2D readout pads. The signal amplitudes and arrival times are recorded to provide full 3D measurements of the particle trajectories.

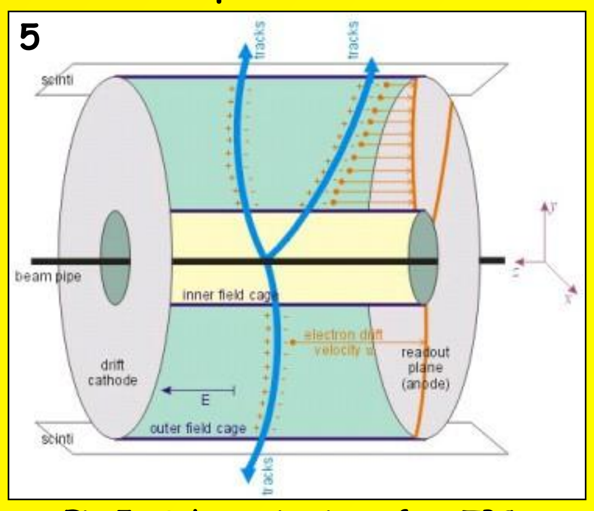


Fig 5: Schematic view of a TPC

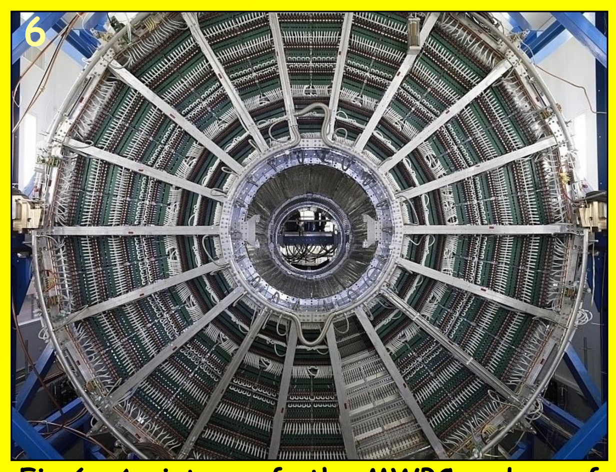


Fig 6: A picture of the MWPC endcap of the Alice TPC

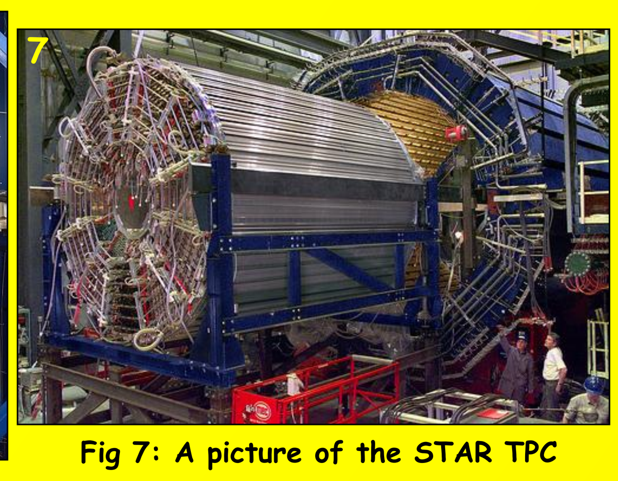


Fig 7: A picture of the STAR TPC

Gaseous TPCs are often designed to operate within a strong magnetic field (typically parallel to the drift field) so that particle momenta can be estimated from the track curvature. Since the amount of ionization along the length of the track depends on the velocity of the particle, ionization and momentum measurements can be combined to identify the types of particles observed in the TPC. Until recently, the gas amplification system used in TPCs have exclusively been planes of anode wires operated in proportional mode (Multi Wire Proportional Chambers, MWPC) placed close to the readout pads.

Conventional TPC Ions Gating technique

The greatest challenges for a large TPC arise from the long drift distance, typically 100 times further than in a comparable wire chamber design. In particular, the long drift distance can make the device sensitive to small distortions in the electric field. In a gaseous TPC, the motion of positive ions is much slower than the electrons, and so the positive ions produced by many events may exist in the active volume.

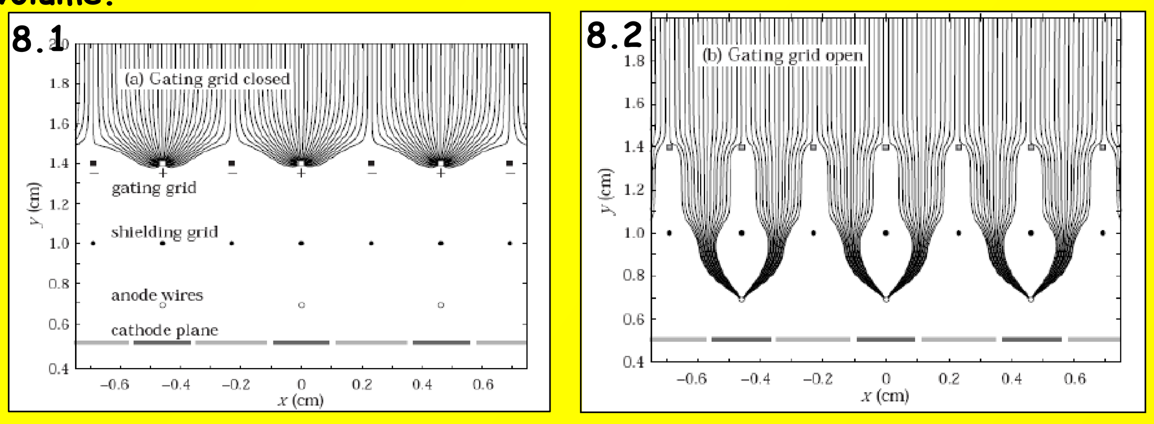
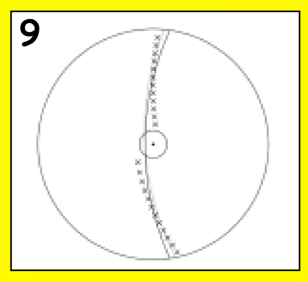


Fig 8: Conventional TPC wire gating



Boyko,I et al. "TPC track distortions III: fiat lux", HARP Memo 05-101

Fig 9: Schematic transverse view of a cosmic muon track. Solid lines represents the true trajectory and the crossed ones the distorted trajectory

Of greatest concern is the ions produced in the gas amplification stage. Large gaseous TPC's built until now with wire planes have included a gating grid that prevent the positive ions from escaping into the drift volume in the interval between event triggers. Figure 8 explains the operation of a gating grid showing the field lines when the ions are blocked (Fig 8.1) and allowed to pass (Fig 8.2)

GEM TPC Gating technique

When a GEM foil is powered at very low potential difference (from 10V up to 40V) it does not act as an electron amplifier device. Its electron transparency (the ratio between the number of electrons that are able to pass into the GEM holes and the number of approaching ones) is reduced to few tens of percent depending on the applied potential difference, on the external fields, on the GEM geometry and on the chosen filling gas. A voltage-controlled Gas Electron Multiplier (GEM) powered at low potential difference can be used to block the re-injection of positive ions in large volume Time Projection Chambers.

A GATED PULSE that inverts the GEM potential difference STOPS ALL THE IONS produced in the amplification stages below the gating GEM.

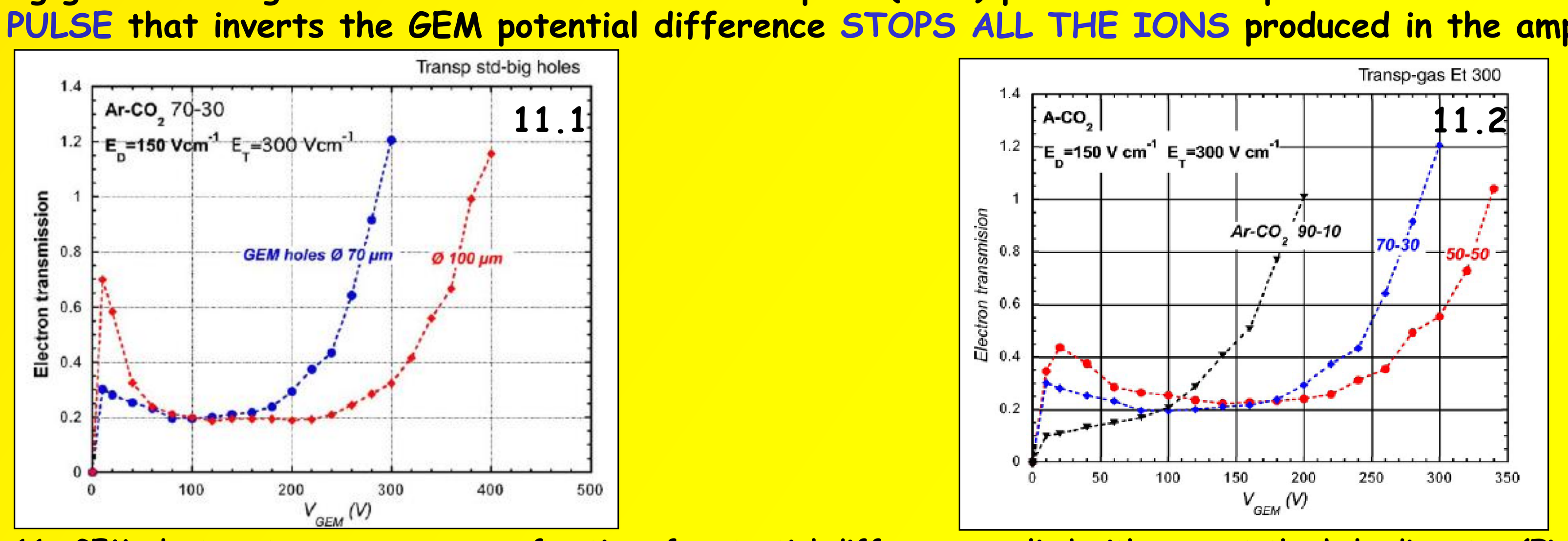


Fig 11: GEM electron transparency as a function of potential difference applied with respect the hole diameter (Fig 11.1) and the chosen filling gas (Fig 11.2) (F. Sauli et al, "*Ion feedback suppression in time projection chambers*", NIM A, Vol. 560, Pages 269-277)

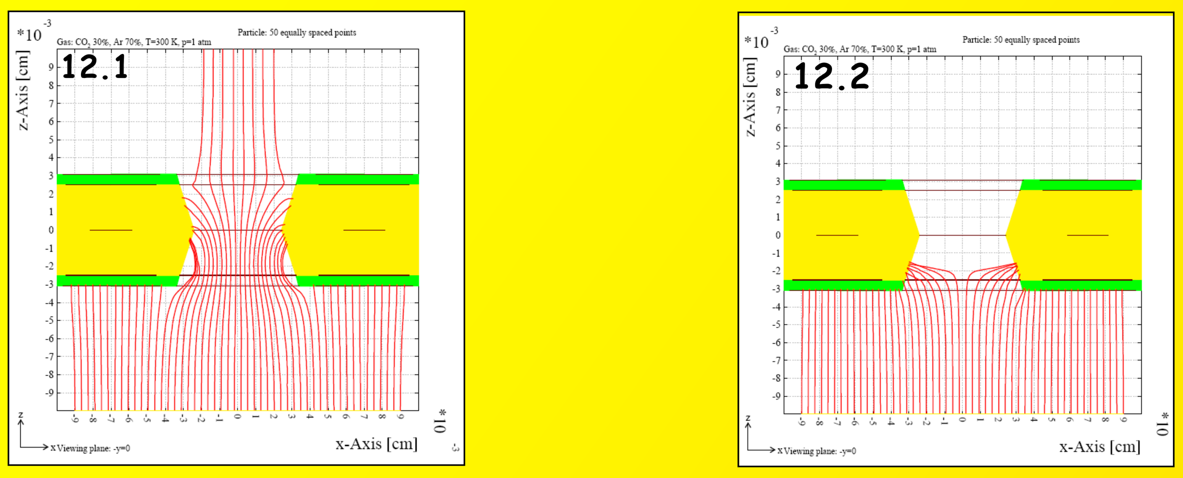


Fig 12: Garfield simulation of ion drift lines in case of open GEM gate (Fig 12.1) and closed GEM gate (Fig 12.2) with gas filling Ar/CO_2 70%/30%. The GEM Kapton walls are charged up with negative charges

Gating GEM TPC Prototype: an improved solution

The introduction of a gating GEM implies a degradation of Energy Resolution (ER) because of the loss of primary electrons. Fig 13 shows the prototype that was built in order to study gating GEM properties. A PREAMPLIFIER GEM was added IN FRONT OF THE GATING GEM to improve the energy resolution because the primary electrons are amplified before being stopped by the Gating GEM. The gas mixture used through all the measurement is Ar/CO_2 70%/30% and the source is 8.9 KeV Copper X-Rays (number of primaries n_p ~ 320).

C = Bottom GEMs peak
B = Gating GEM peak
A = PreAmp GEM peak

$C = n_p * G_{Amplification}$
$B = n_p * \varepsilon_{GateGEM} * G_{Ampl}$
$A = n_p * G_{PreGEM} * \varepsilon_{GateGEM} * G_{Ampl}$
$\varepsilon_{GateGEM} = B/C$
$G_{PreGEM} * \varepsilon_{GateGEM} = A/C$

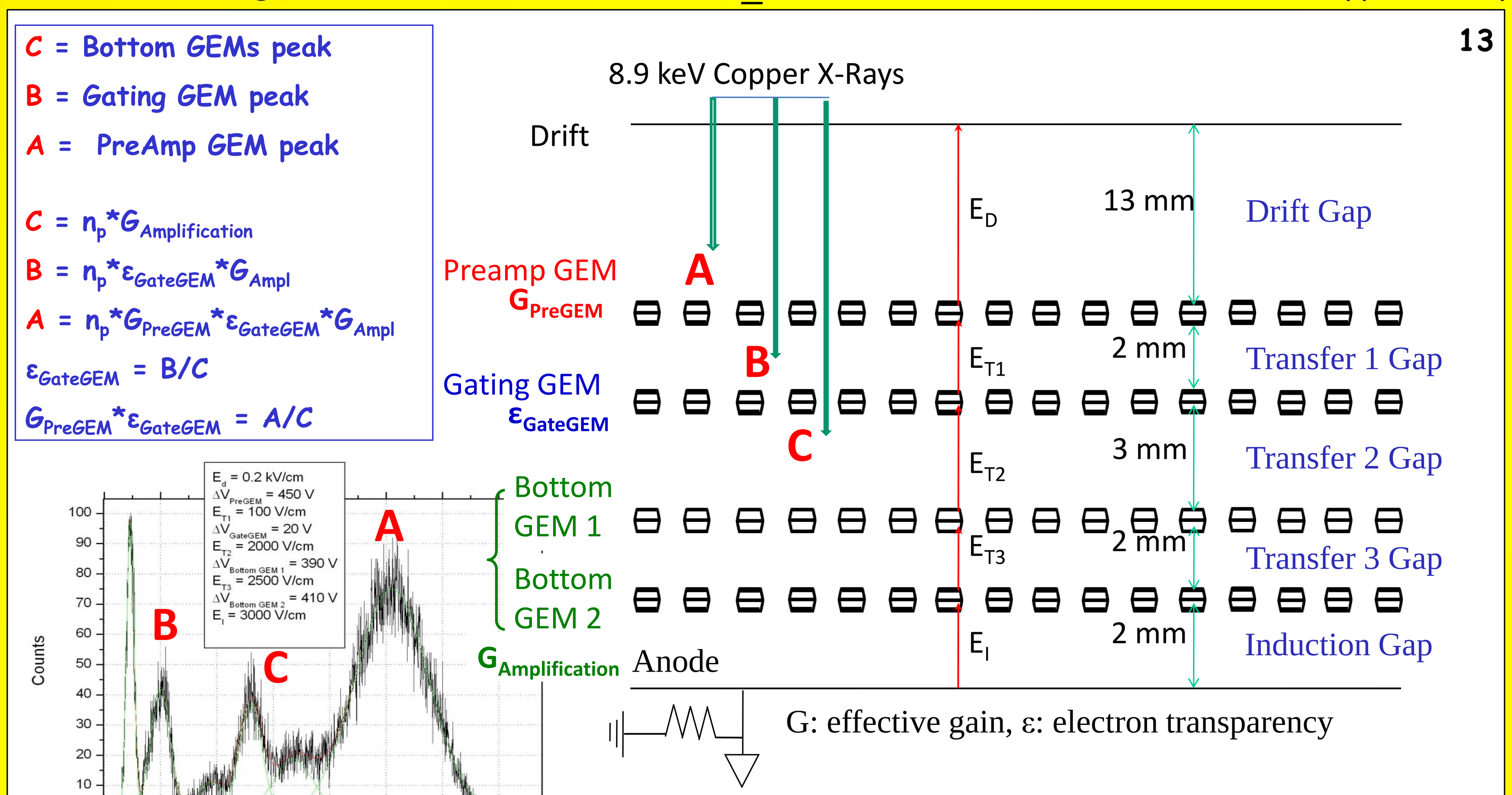
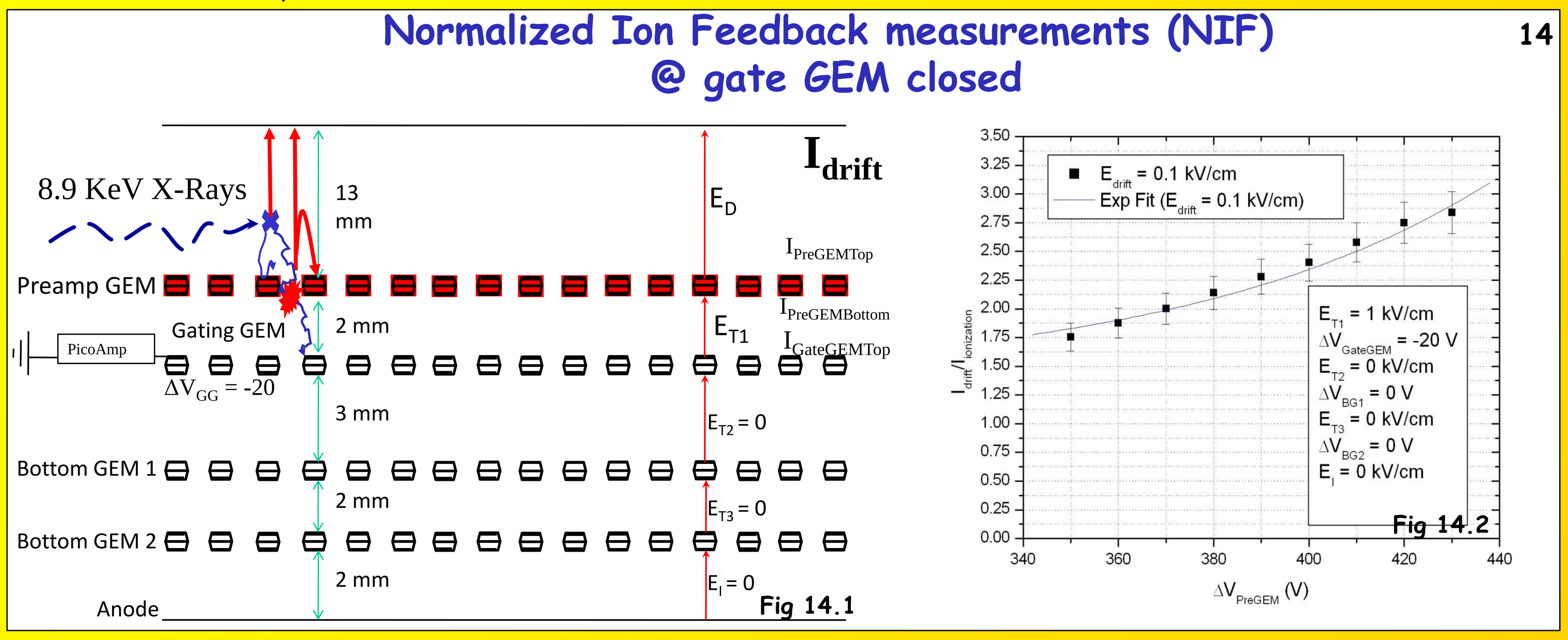


Fig 13: Prototype experimental setup, explanation of parameters and typical acquired PH spectrum



Using the setup in Fig 14.1 we measured the Normalized Ion Feedback, that is defined as the ion current in the drift region normalized to the primary ionization current (NIF = $I_{drift}/I_{ionization}$) vs $\Delta V_{PreAmpGEM}$ (Fig 14.2) With a Drift Field of 0.1 kV/cm (the same that is usually present in a TPC gas volume), the NIF @ $\Delta V_{PreAmpGEM}$ = 390 V is 2-3.

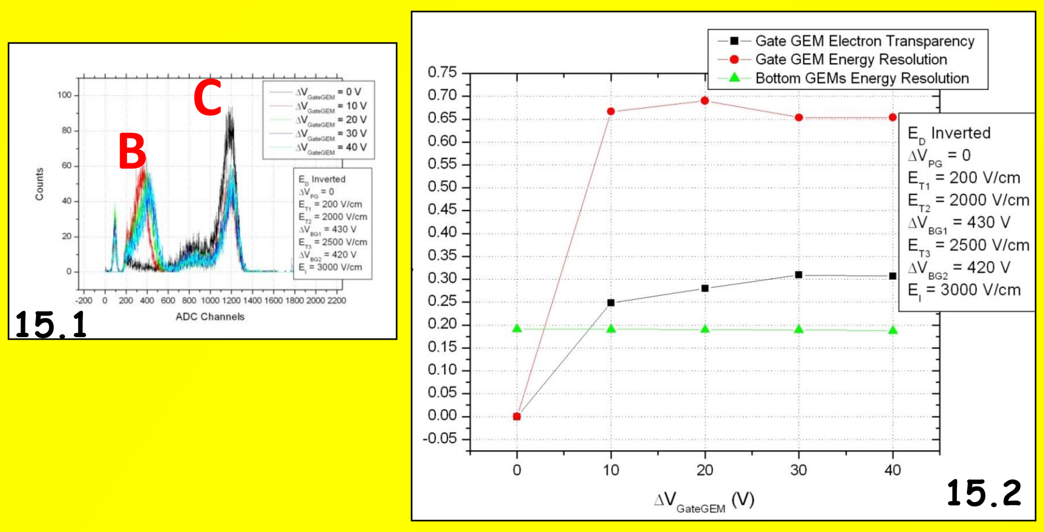
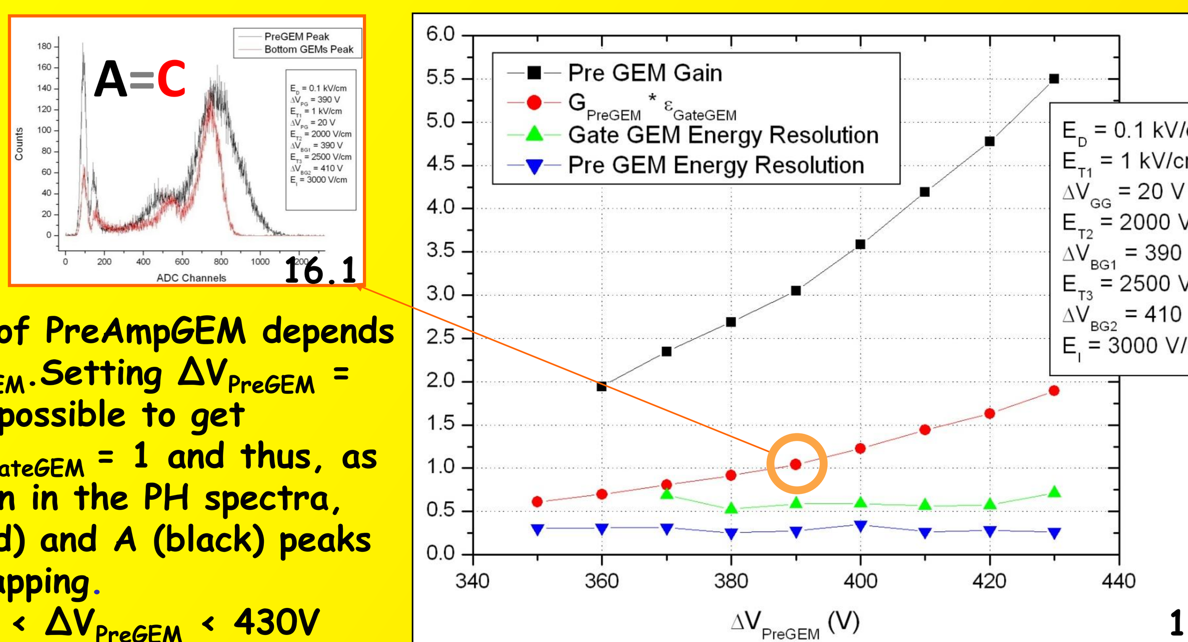


Fig 15: Different parameters measured (Fig 15.2) as a function of ΔV_{GG} made with setup in Fig 13 using the PreAmpGEM as cathode. PH spectra acquired for this measurement (Fig 15.1)

ε_{GG} ~ 30% for 10V < $\Delta V_{GateGEM}$ < 40V

The GateGEM (B) peak ER is ~ 65% FWHM



The gain of PreAmpGEM depends on ΔV_{PreGEM}. Setting ΔV_{PreGEM} = 390 it is possible to get $G_{PreGEM} * \varepsilon_{GateGEM}$ = 1 and thus, as it is shown in the PH spectra, the C (red) and A (black) peaks are overlapping.

For 350V < ΔV_{PreGEM} < 430V

PreGEM ER is about 30%

Fig 16. Different parameters measured as a function of ΔV_{PreGEM} considering the setup in Fig 13 and PH spectra for circled point

A small pulse of 40V completely closes the gate

With open gate (ΔVGateGEM = 20) the NIF is about 15 and the overall Gain is around 3000.

With closed gate (ΔVGateGEM = -20) the NIF is about 3 and the overall Gain is zero.

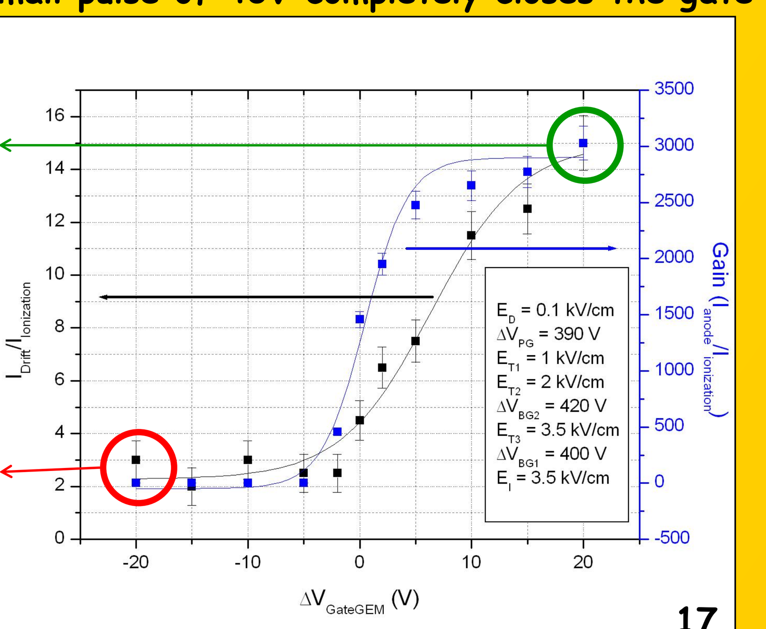


Fig 17: NIF (black) and overall gain ($I_{anode}/I_{ionization}$, blue) as a function of $\Delta V_{GateGEM}$ considering the full setup, measuring in current mode and shooting X-rays from the side (negative $\Delta V_{GateGEM}$ values mean closed gate)

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