S2 Simulation with Garfield++

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Workflow

Gmsh: 3D mesh generator and geometry defination

Elmer: Imports the mesh, allows to define the boundary conditions/potentials and solves the electric field map

Magboltz: calculates the transport properties for e for 60 different gases and their mixtures, includes excitation and ionization levels for all these gases

Garfield++: C++ framework with several classes to import the Elmer field maps and to do a microscopic MC transport of the e; allows to get back the position of any excitation or ionization

Geometry, Fields and Analysis Strategy

Strategy:

1. Place primary e- 0.49 cm below LEM, xy position randomized
2. Use Garfield++/Magboltz to drift and avalanche e-
3. Get back production point for ionization/excitation + end point of charged particles
4. Simulate at least 500 events per LEM voltage
5. Charge: calculate GTot/Geff/IBF from end point
6. Photons: propagate isotropic photons and check where they end wity pyRoot script
7. No charging up simulated

Geometry	
Extraction gap	5 mm
Induction gap	2 mm
LEM dielectric thickness	1 mm
LEM copper thickness	35 μm
LEM dielectric hole radius	250 μm
LEM copper hole rim	40 μm
LEM hole pitch	800 μm
LEM hole arrangement	hexagonal
Field/Voltage	
Extraction field	3 kV/cm
Induction field	5 kV/cm
LEM Voltage	2500 to 3500 V

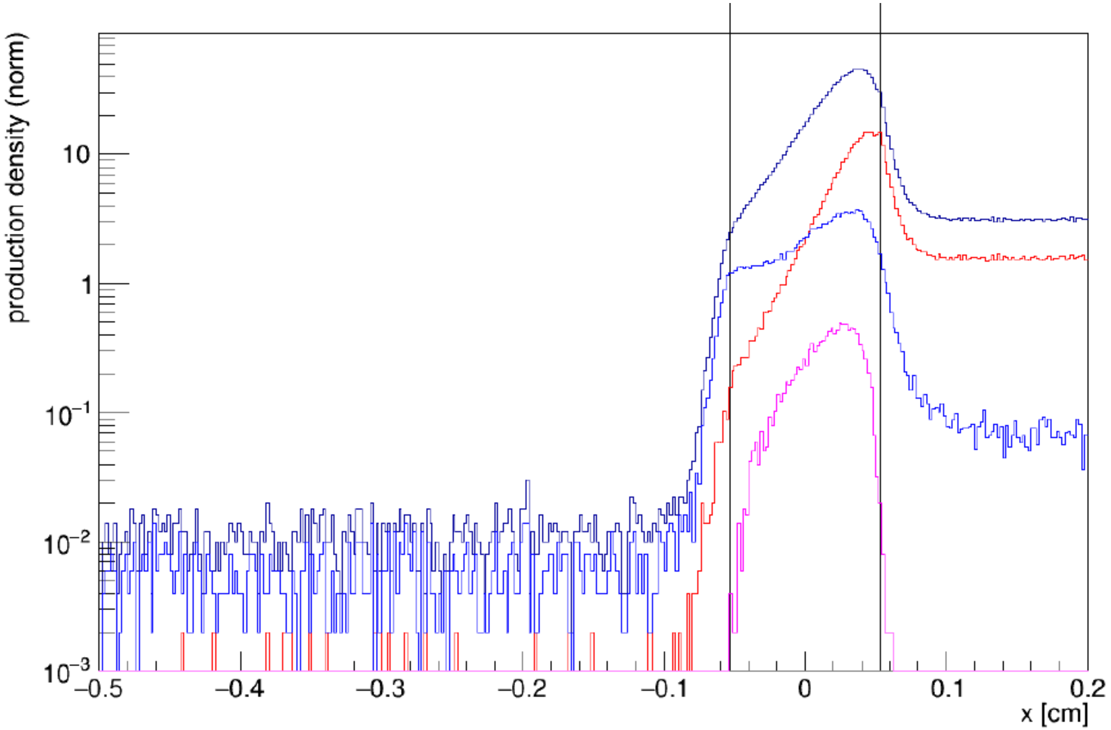
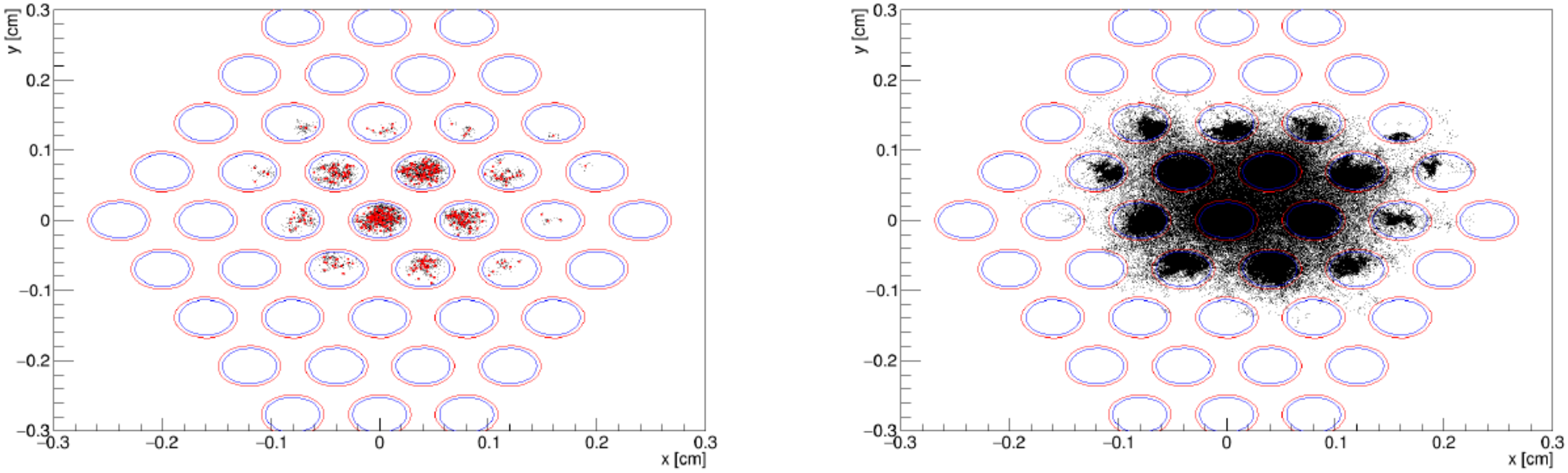


Figure 2: z distribution of the production point of S2 photons (black) and ionizations (magenta) normalized to one event. The red curve shows the production point of the photons reaching the anode an in blue for the photons reaching the liquid surface. The vertical lines indicate the end of the position of the surfaces of the copper layers.



(a) Charge (b) Photons

Figure 3: The event distribution in the xy plane, perpendicular to the liquid surface, for the ionizations (a) and the photons (b). Block points in (a) indicate single ioniation events, while the red points indicate the centers of the avalanches. The plots show the accumulation of 500 events at 3300 V across the LEM. A correlation between the two processes is clearly visible although while the ionizations are limited to the holes, the photon production is much more spread. To guide the eye also the holes are drawn in the relevant region, blue the hole in the dielectric and in red the one in the copper.

Charge: Definitions

$$G^{Tot} = \frac{\#\text{ electrons produced}}{\#\text{ primary electrons}}$$

$$G^{Eff} = \frac{\#\text{ electrons reaching the anode}}{\#\text{ primary electrons}}$$

$$IBF = \frac{\#\text{ ions reaching the liquid}}{\#\text{ electrons reaching the anode}}$$

Charge results:

- GTot and Geff seem to behave well (forget fit)
- maximal Geff of about 13 at 3300 V before charging up
- IBF is very high as predicted (see next slide), starts at about 60% and stabilized finally at around 90%

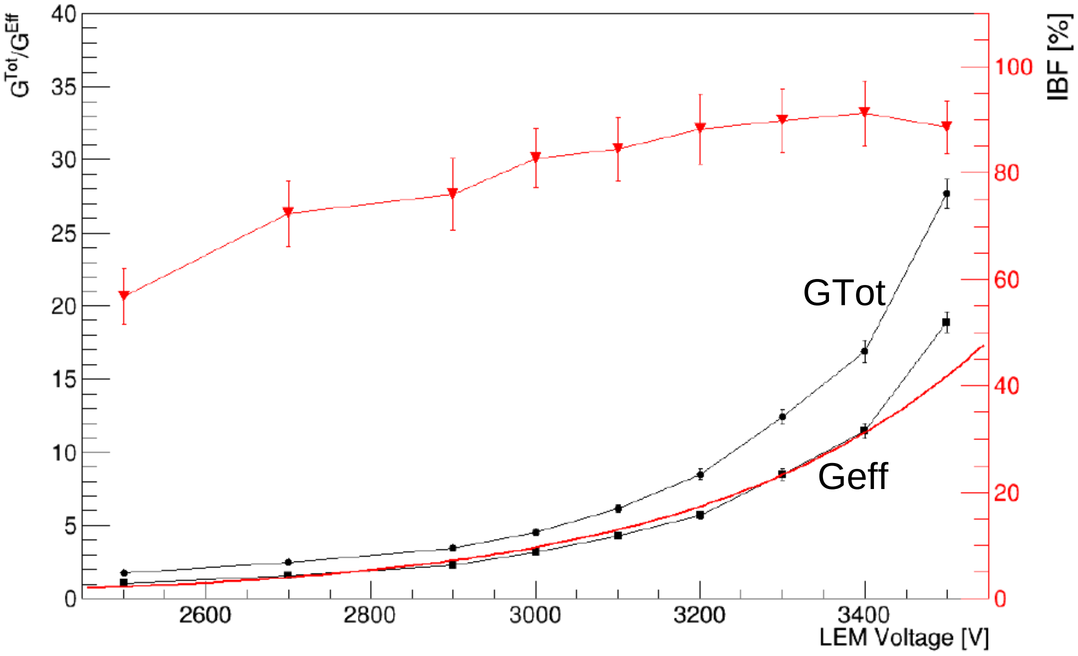


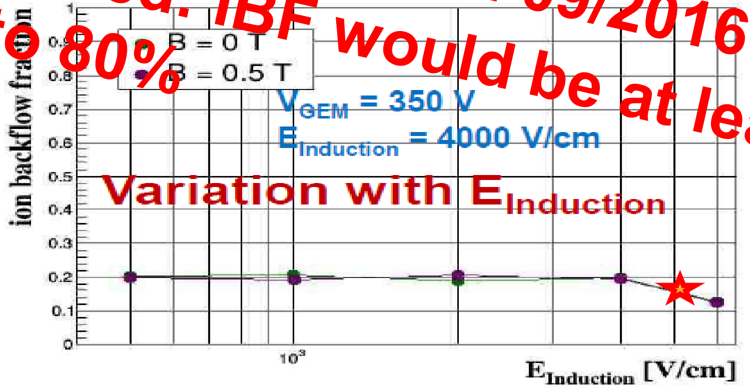
Figure 4: Total (black dots) and effective gain (black squares) in function of the applied LEM voltage. An exponential fit is added to G^{Eff} to show that the data follows the expected curve. In red also the IBF in respect to G^{Eff} is added. A high IBF of about 90% is observed for all LEM voltages.

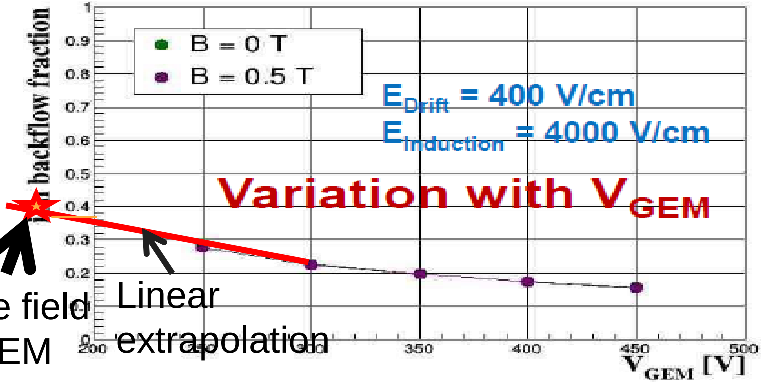
Simulations for GEMs

WA105 presentation 09/2016 Guessed: IBF would be at least 70 to 80%

Did not find measurements for single THGEM and my simple simulations still not finished but there was an interesting talk by Purba Bhattacharya about simulation with single GEM (50 um thick).

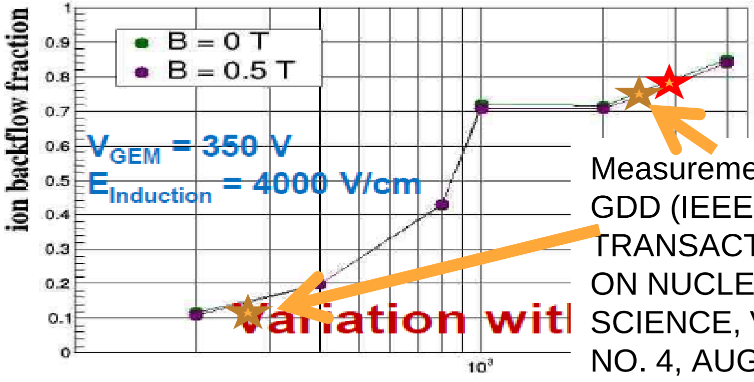
=> Simulations should consider worst case scenario of IBF of 0.5 to 1!





Hole field of LEM

Linear extrapolation



Measurement by GDD (IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 50, NO. 4, AUGUST 2003)

Possible Implications

WA105 presentation 09/2016

- Measurements in gas will provide IBF of LEM under close to real conditions
- Measurements with LAr will provide "ion gas to liquid transition probability" (IGLTP)

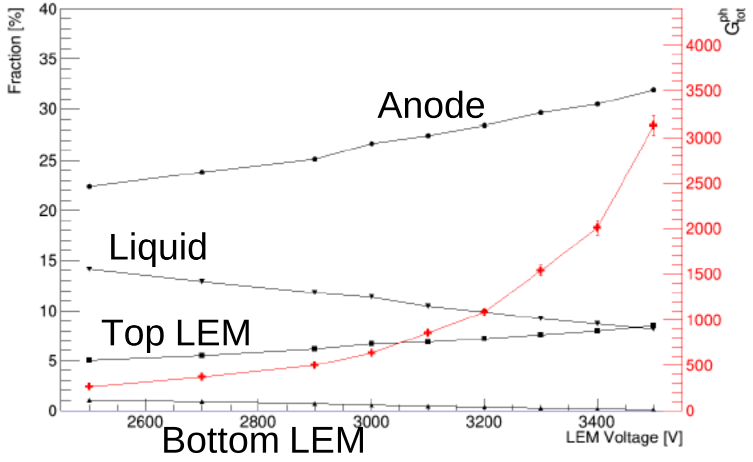
This is no "Fun R&D" (like testing other MPGDs to get a gain of 22 instead of 20) but could have serious impact on the design of WA105!

Case:

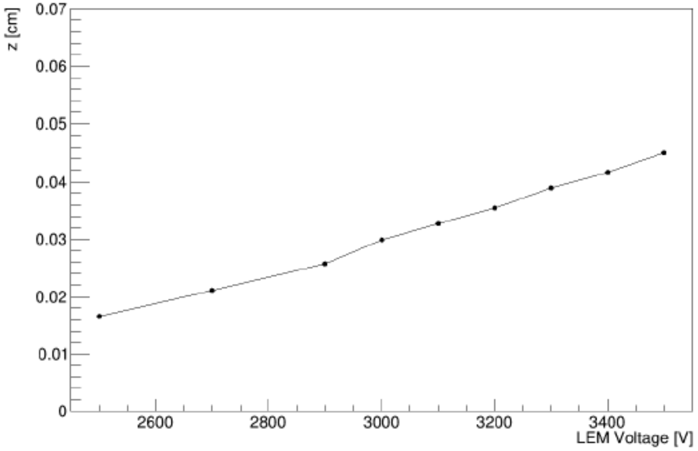
1. IBF < 10-20%: Safe and one continue as until now
2. IBF >> 10% && IGLTP low: ions are transported by convection but charging up in the gas extraction region might be huge, especially for 6x6 m2 => Do we will need electrodes for the ions around each LEM?
3. IBF >> 10%&&IGLTP high: ions go into the liquid and the field distortions will be enormous => Do we need a gate? How could it be realized?

Photon results:

#Photons reaching liquid
@ 3300 V about 160

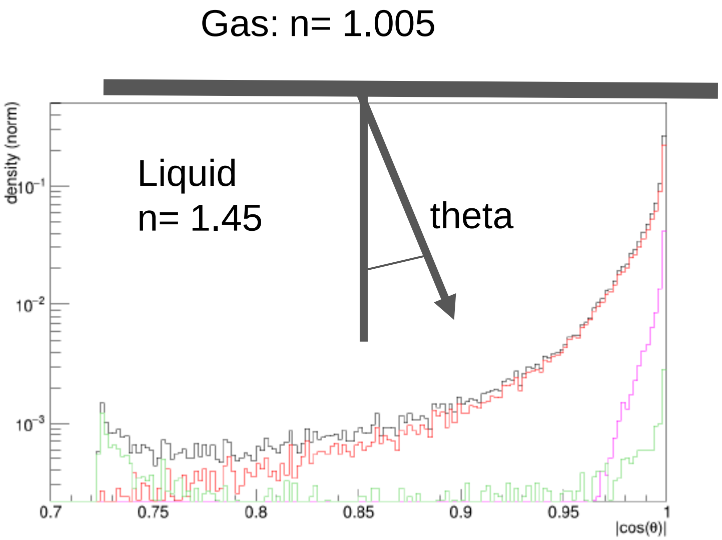


(a) G^{Tot}_{Ph} and photon end point distribution.

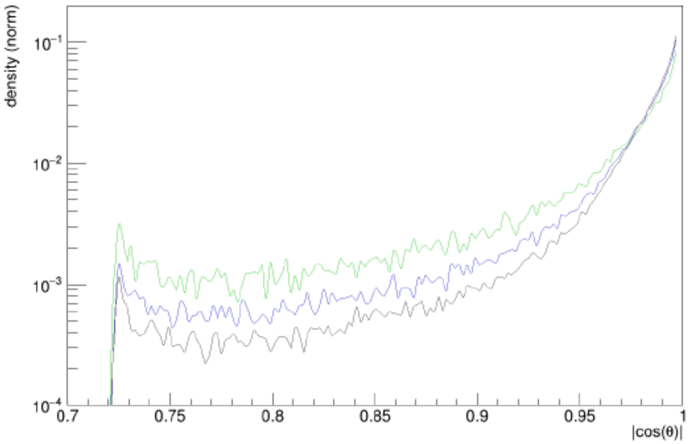


(b) z mean production position versus LEM voltage

Figure 5: (a) The total photon gain in function of the LEM voltage (red). Also the fractions of the total photons ending on one of the 3 electrodes, anode (dots) and top (square) and bottom side (up triangle) of the LEM or reaching the liquid argon surface (down triangle) in function of the LEM voltage. (b) Shifting of the mean z position of the photon production in function of the applied LEM voltage.



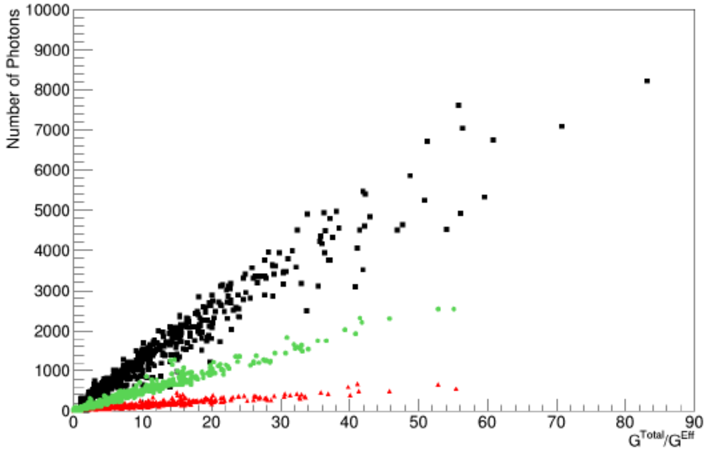
(a) Opening angle contributions



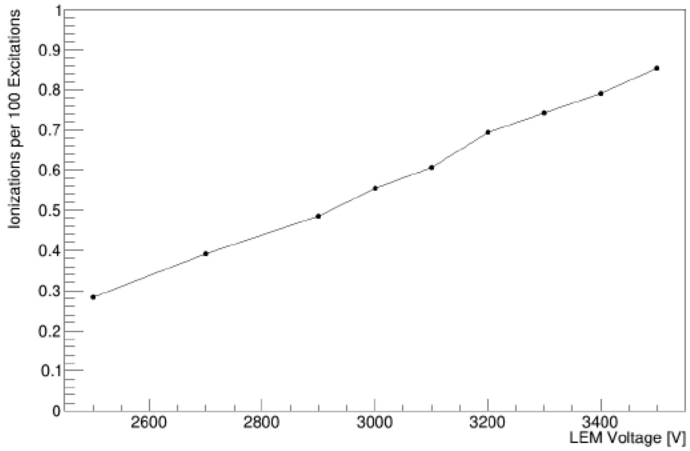
(b) Opening angle relation to LEM voltage

Figure 6: (a) Absolute value of the cosine of the opening angle of the photon cone inside the liquid argon assuming a wavelength of 128 nm, n^{gas}= 1.0005 and n^{liq}= 1.45. Also the distributions of the different photon productions regions is shown: photons from the extraction region (green), from inside the holes (red) and from the induction region (blue). (b) The same distribution for different LEM voltages: 2900 V (red), 3300 V (blue) and 3500 V (black).

Correlations between charge and light



(a) Charge versus photon gain



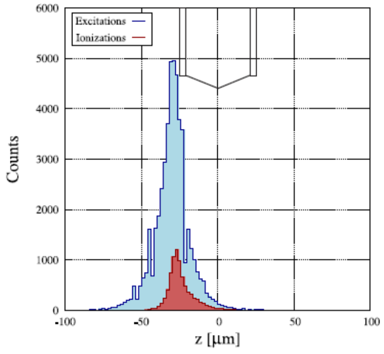
(b) Number of ionizations per 100 excitations.

Figure 7: (a) Charge versus photon gain: G^{Tot} versus G_{Ph}^{Tot} (black), G^{Eff} versus photons reaching the anode (green) and G^{Eff} versus photons reaching the liquid (red).

Discrepancy between data and simulation:

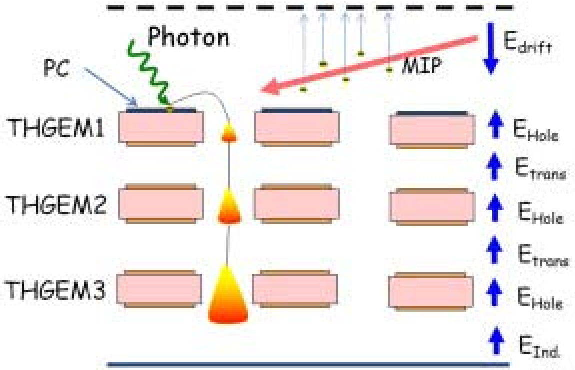
- simulated gain at 3300 V is around 7-8, while the reported one is about 65 (both before charging up)
- Checked Magboltz gas file and it confirms that I simulated 1 bar argon at 90 K.
- Voltages reported when Garfield++ simulation starts are also agreeing with expectations
- Beside of gain simulations give consistent results and fulfil expectations based on other studies
- if boosting gain, amount of S2 is also boosted accordingly => would be big problem

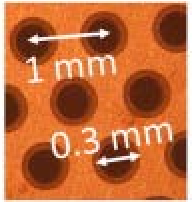
- Could it be Photon-Feedback?



(d) $V_{GEM} = 500$ V

• Photo Feedback well known process since decades
• high energetic photons from S2, about 10 eV, “perfect” for PF
• possible electrodes: Top and bottom of LEM
• Bottom LEM: few photons in extraction gap per primary e but high electric fields to extract them and these could undergo full amplification process and therefore would have quite an impact on Geff => would double ions and photons roughly
• TOP LEM: much more photons but lower E fields and only 2 mm direct way to anode => no additional ions, but possible additional feedback from released e, few photons would reach liquid (shielded by LEM)





• same principle is used in RICH detectors
• longer wavelength and therefore photosensitive coating but the principle is the same
• for 128 nm this can happen without coating

- Implications on gain curve: a) more gain than expected from exponential at lower voltages since even without amplification due to primary e which could produce PF in induction region b) positive feedback and change of mean photon production point towards induction gap should lead to over exponential for high LEM voltages => these features seem to be in ETH data
- Implications II: gain should depend strongly on induction field => if extraction == induction field no PF => strong effect for GEM in pure argon reported as also over exponential gain curve

High gain operation of GEM in pure argon

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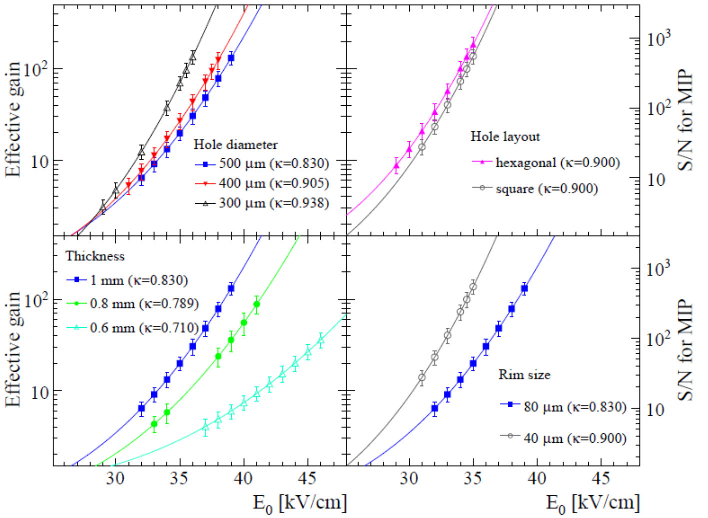
Abstract

We study the operation of the Gas Electron Multiplier (GEM) in pure Ar, in comparison to that in Ar-CO$_2$ mixture. In pure Ar, high GEM gains, of above 700 and 3000 for single and double GEM structures correspondingly, have been obtained. It is observed that the GEM effective gain and its charging-up are strongly affected by electric field values above and below the GEM. Applications to the development of non-ageing gas photomultiplier are discussed.

Performance study of the effective gain of the double phase liquid Argon LEM Time Projection Chamber



- Over exponential also observed in EL study with THGEM
- Simulated their geometry with argon and xenon
- 1500 V agrees with argon data and 1500 + 1700 V with xenon
- Divergence for higher voltages
- Larger for argon
- Expected for PF since less Xe S2 and less energetic

Secondary scintillation yield from GEM and THGEM gaseous electron multipliers for direct dark matter search

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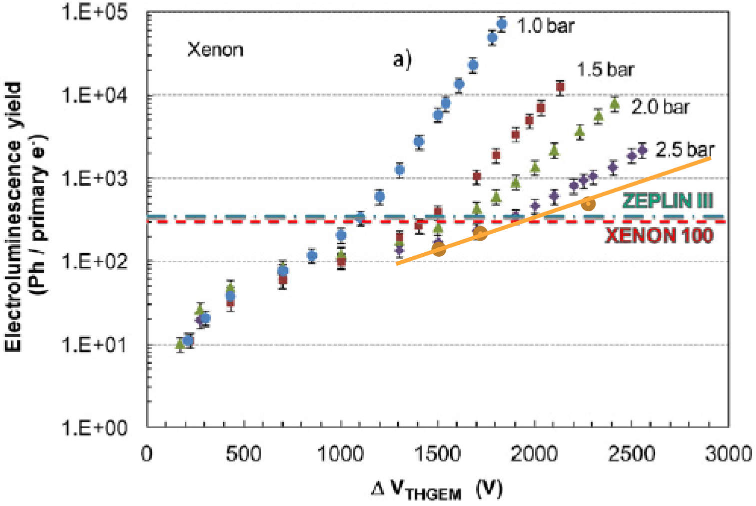
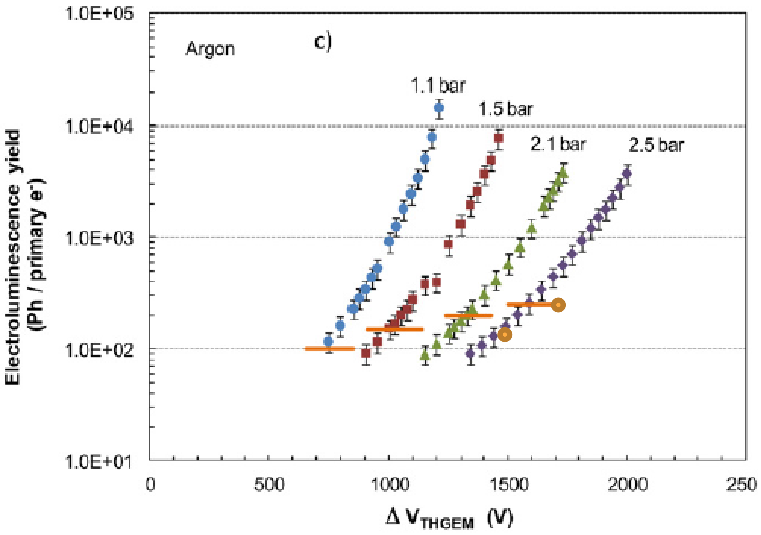
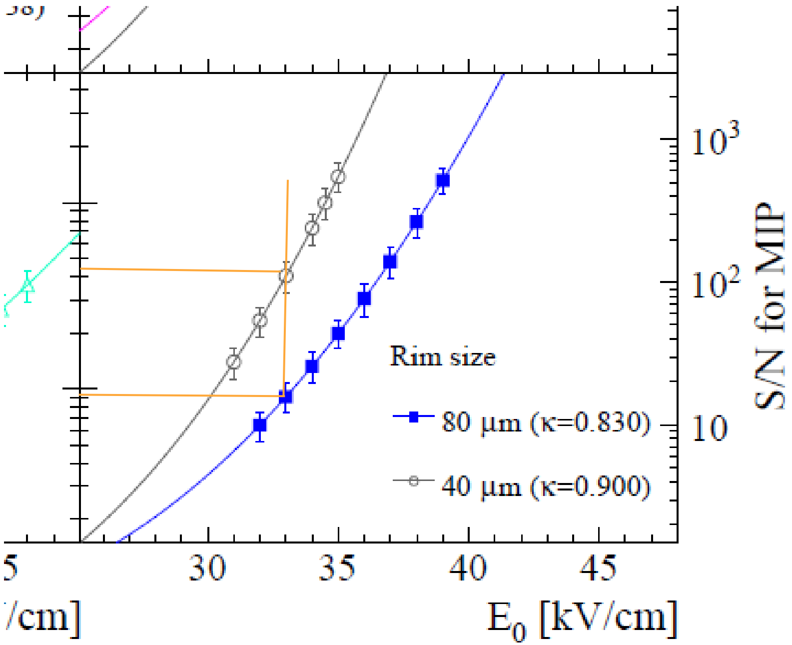




• big effect on gain by doubling rim size
• simulated this geometry and compared with 40 um result
• charge gain dropped by 40% but should have dropped by 80%
• light gain also dropped by 40%
• in addition probability for PF reduced due to larger rim
• also shape of curve changed by rim
• might be another hint for relevant PF in the system



High gain operation of GEM in pure argon

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- in 1990 reported gains of 500 with single gain in pure argon
- intereresting since measured pure argon and Ar:CO2
- Ar:CO2 exponential behaviour, while pure argon not
- CO2 highly absorbing for VUV photons

=> Measurement of avalanche gain + PF (pure argon) and only avalanche gain (Ar:CO2)

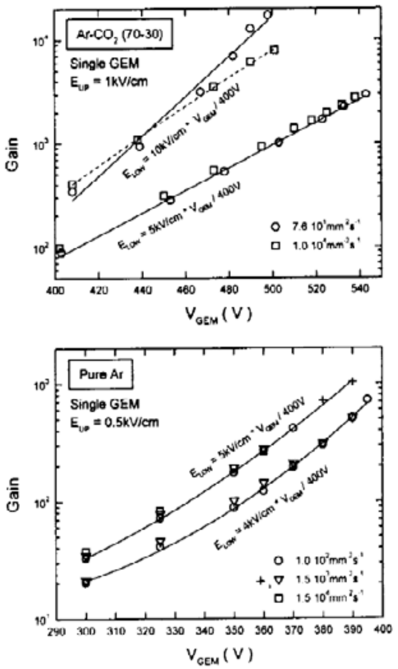

Figure 2 Effective gain of a single GEM as a function of GEM voltage measured in Ar-CO_2 and in pure Ar at different rates and different E_{LOW} . The exposed area of the detector was 40 cm^2 , except of the last two data points in Ar plot (cross symbols) where it was reduced to 2 mm^2 .

- PF must exist in this readout scheme
- Widely described in early works
- In “Feedback and Breakdown ..:” also over-exponentioal behaviour is described
- In “Electron ionization ..:” the PF is attributed a higher gain at low voltages than expected
- Open question is it the dominant gain production process? Or at least relevant?

If there is a large amount of feedback the total gain will increase over-exponentially, because (eq.(3)) $G_t(E) = G(E)/(1 - \eta G(E))$. The deviation of $G_t(E)$ from an exponential behavior allows an estimation of the feedback level η. This method depends only on the total charge in the avalanche and thereby it can be used also for gases containing He.

Feedback and Breakdown in Parallel-plate Chambers

P.Fonte[1,2], V.Peskov[2,3], and F.Sauli[2]

Electron ionization and excitation coefficients for argon, krypton, and xenon in the low *E/N* region

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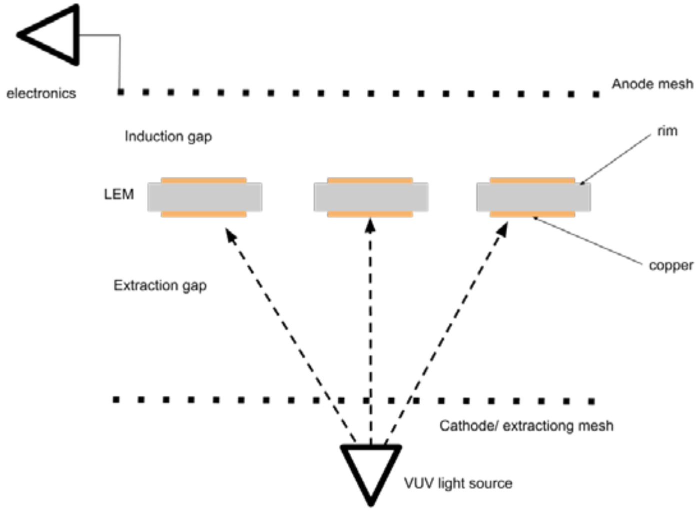
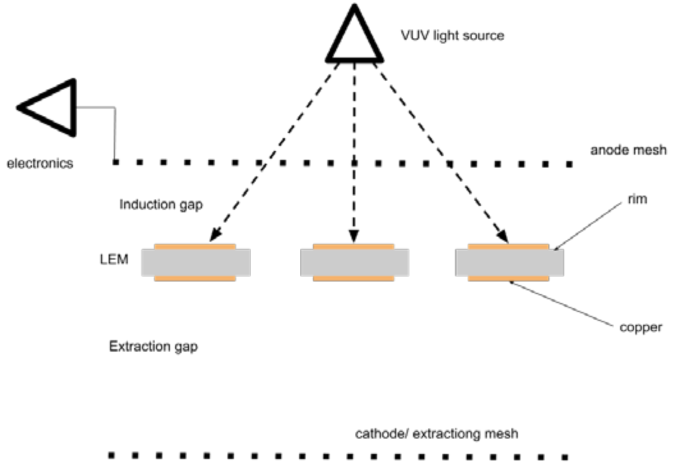
The electron ionization coefficients for Ar, Kr, and Xe have been measured in the low E/N region [$(0.5\text{–}4)\times 10^{-16}$ V cm^2] using a drift-tube apparatus. At low field values, the ionization coefficient was found to be anomalously large, a fact attributed to surface photoelectron emission from radiating metastables. This contribution also explains the discrepancy between earlier measurements and recent calculations based on the transport equation. The measurements were analyzed on the basis of two contributions to the ionization rate and calculations of the transport equation, yielding a revised set of inelastic cross sections which differ from earlier ones primarily in the inclusion of shape resonances.

PF could and should be studied

- could be simple setup
- VUV light source, Xe lamp or EL detector, + detector with transparent meshes
- anode mesh would have to read out





Summary

- Simulation results consistent and fulfill expectations
- IBF very high as expected from GEM simulations by other groups
- Problem: simulated gain much lower than observed one
- Photon-feedback could explain the difference? Shape of gain curves certainly … hints towards this in results from 3 studies
- If PF is dominanted factor for gain production, there is a big problem => highly sensitive to settings and gas quality => stable operation on large scale might be difficult with current design
- **But also might be an opportunity: there might be an optimized scheme with high gain with limited IBF and not pushing the voltages for avalanche gain to the limit**