Institute for High Energy Physics

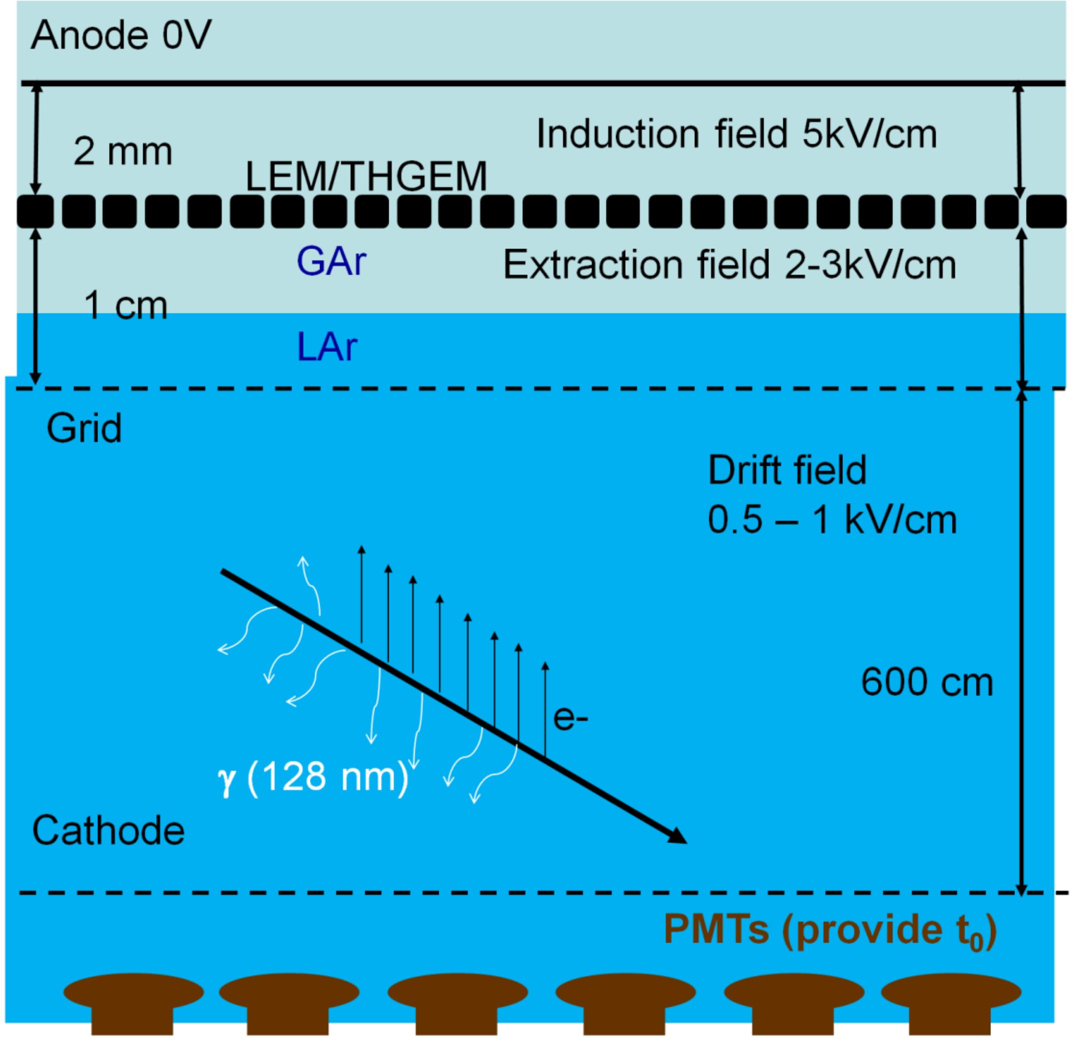
EXCELENCIA SEVERO OCHOA

Barcelona Institute of Science and Technology

Detector Physics of a large DP LAr TPC

Thorsten Lux

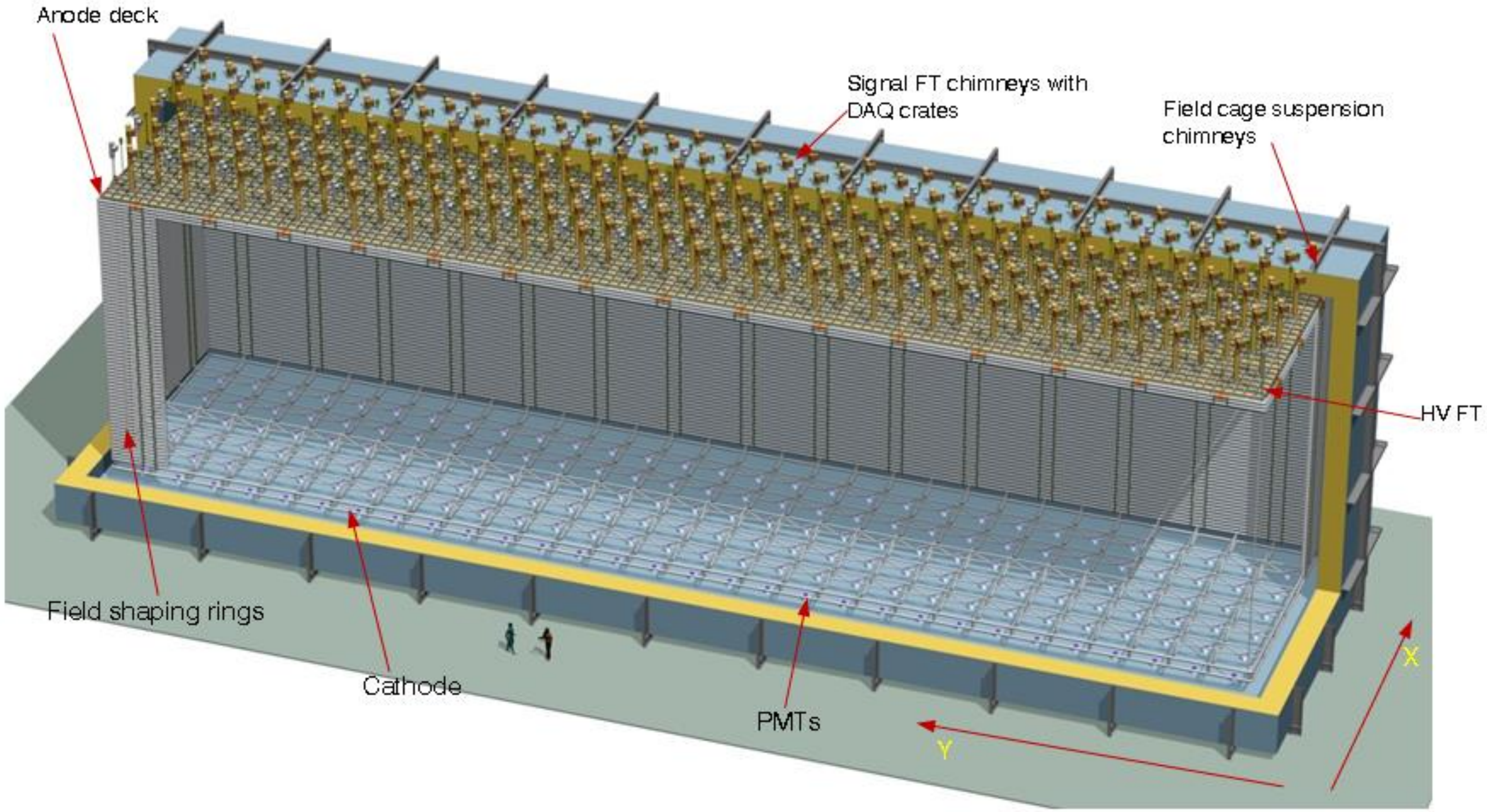
Dual Phase Liquid Argon TPC



- Tracking calorimeter
- LAr dense enough to serve as neutrino target => fully active
- Segmented anode: xy information, primary light: z coordinate => Full 3D reconstruction of the event
- Drift distances of few m proven in SP detectors
- Can we go to very large detectors with the DP approach?

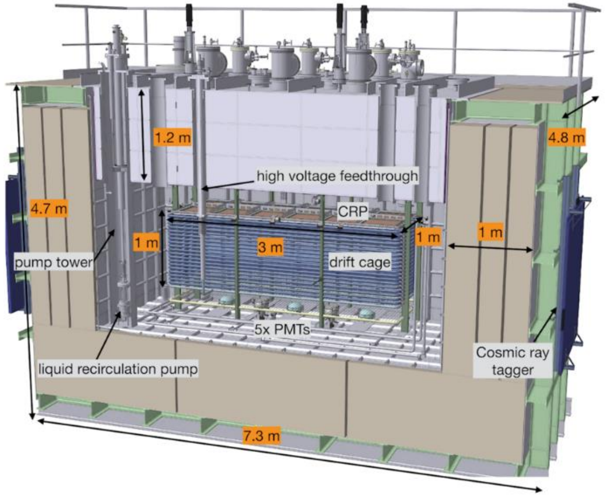
What means “very” large?

- Final DUNE Far Detector: 15x15x60 m
- IFAE building area but twice the height

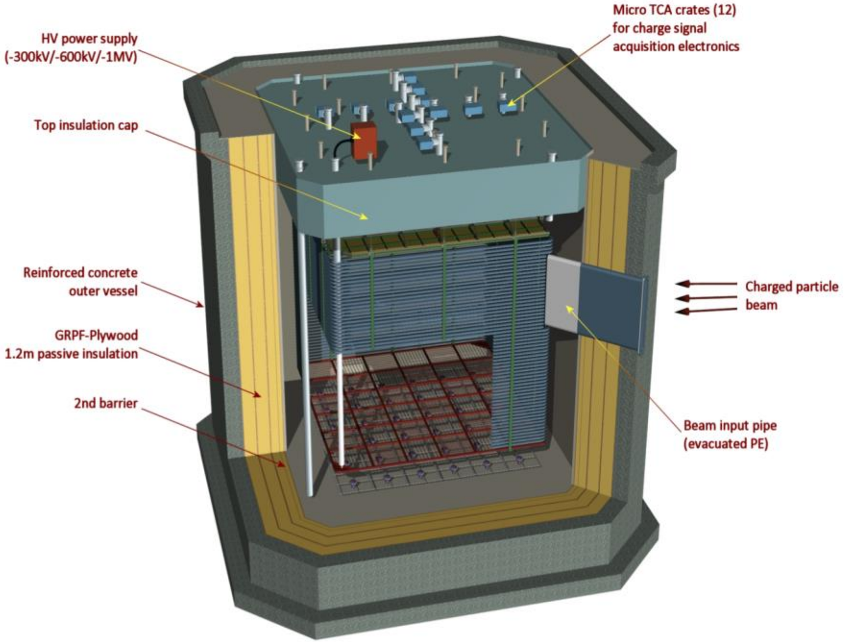


Prototypes

- 2 large prototypes
  - 311 detector (2017/2018)
  - protoDUNE-DP/WA105/666 (2019)
- Both at CERN
- IFAE/CIEMAT contribution: Photon detection system (PMTs and calibration system)
- Calibration system work basis of ATTRACT proposal



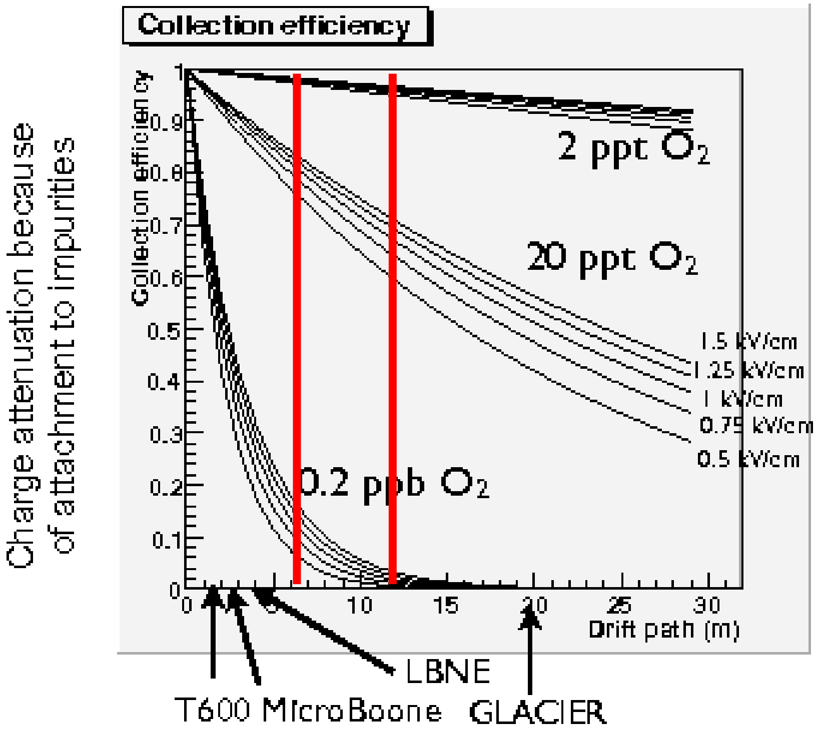
A 4 tonne demonstrator for large-scale dual-phase liquid argon time projection chambers
B. Aimard (Annecy, LAPP) *et al.*. Jun 8, 2018. 61 pp.
Published in **JINST 13 (2018) no.11, P11003**
FERMILAB-PUB-18-257-ND
DOI: 10.1088/1748-0221/13/11/P11003
e-Print: **arXiv:1806.03317 [physics.ins-det] | PDF**



A Light Calibration System for the ProtoDUNE-DP Detector
D. Belver (Madrid, CIEMAT) *et al.*. Feb 19, 2019. 16 pp.
Submitted and accepted by JINST
e-Print: **arXiv:1902.07127 [physics.ins-det] | PDF**

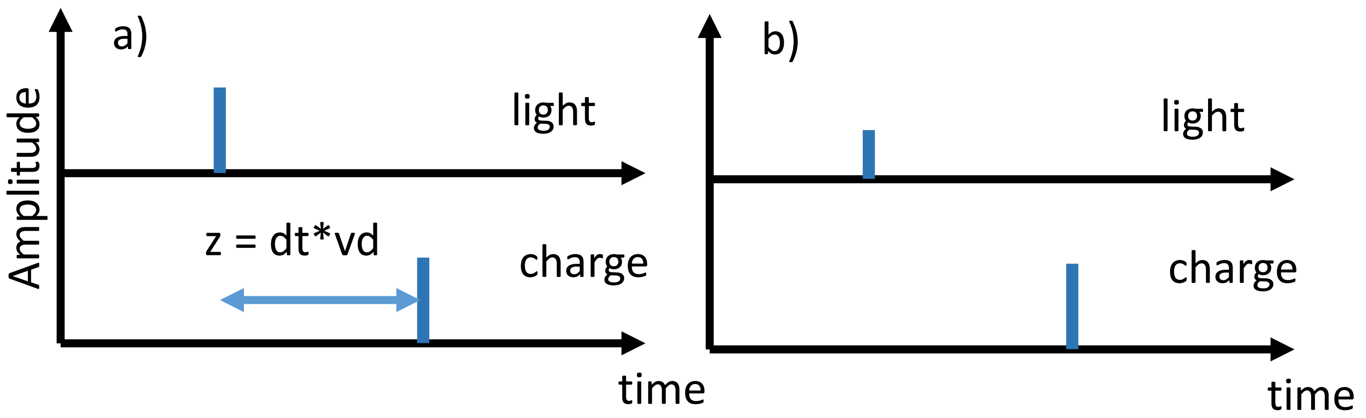
Why is the PDS important?

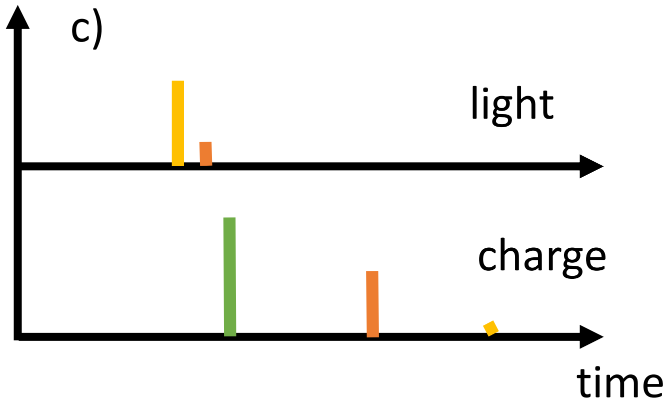
- Do we really need the absolute z position?
- Yes, because of attachment …
- 1 oxygen atom per 5.000.000.000 argon atoms leads to loss of 90% of electrons for 6 m drift
- Can correct for it if absolute z position is known
- Also important to trigger on non-beam physics: SN neutrinos (up to few 10s MeV) and proton decay

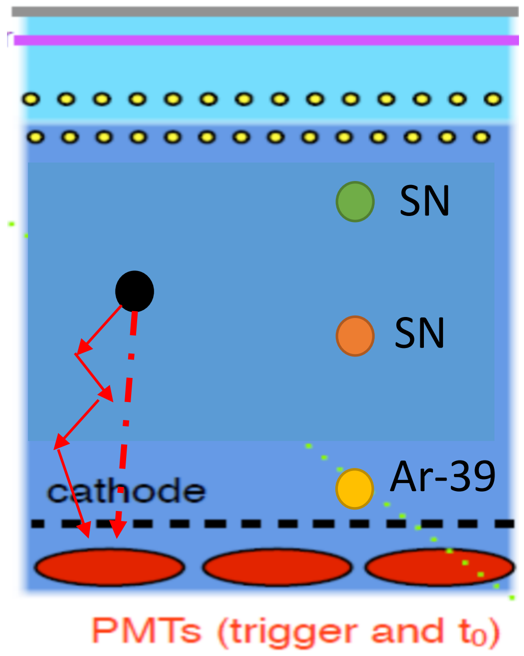


Is not it trival?

- Meassure arrival time of light and charge, calculate z and correct and we are done? (a)
- Of course, not …
- Light is attenuated, λ ≈ 30 m, and Rayleight scattering, λ ≈ 55 – 90 cm (b)
- Ar-39 present with 1 Hz/kg (300 kHz in 666) => close Ar-39 decay more photons than far SN neutrino (c)
- Light detection efficiency for events on top might be too low for reconstruction (c)



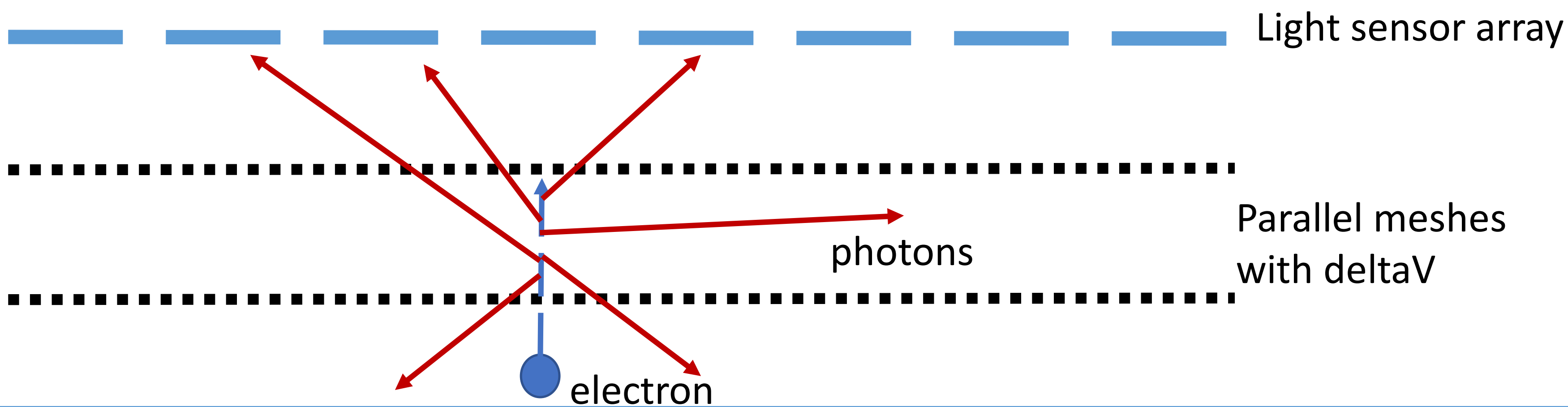




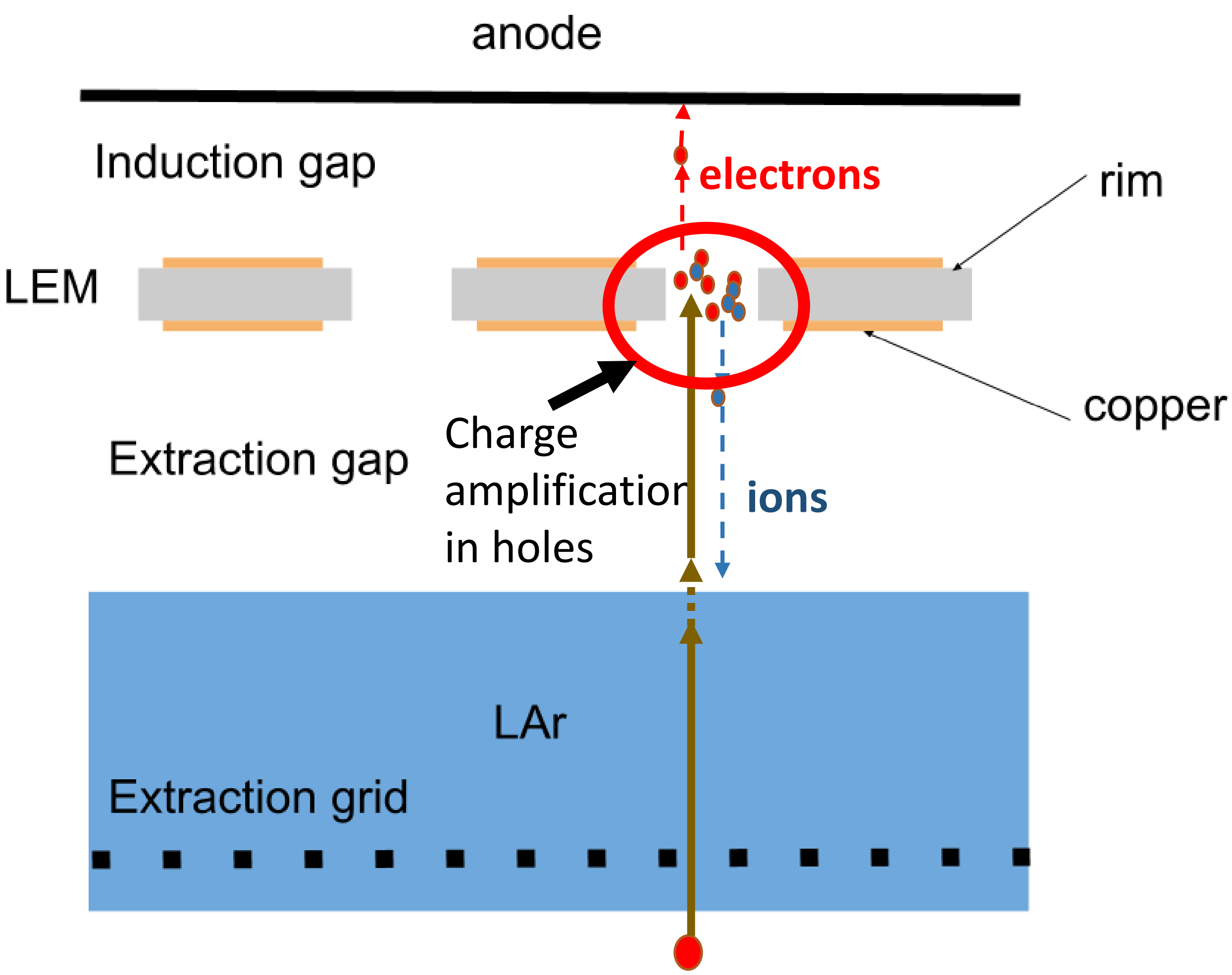
The real problem …

- But the real problems just begin …
- Remember DM talks from last year?
- Secondary scintillation light: electrons in high electric field excite gas and in de-excitation photons are emitted
- Same wavelength as primary scintillation light
- Ar-39 and cosmics also contribute and not only physics events …

DM case:

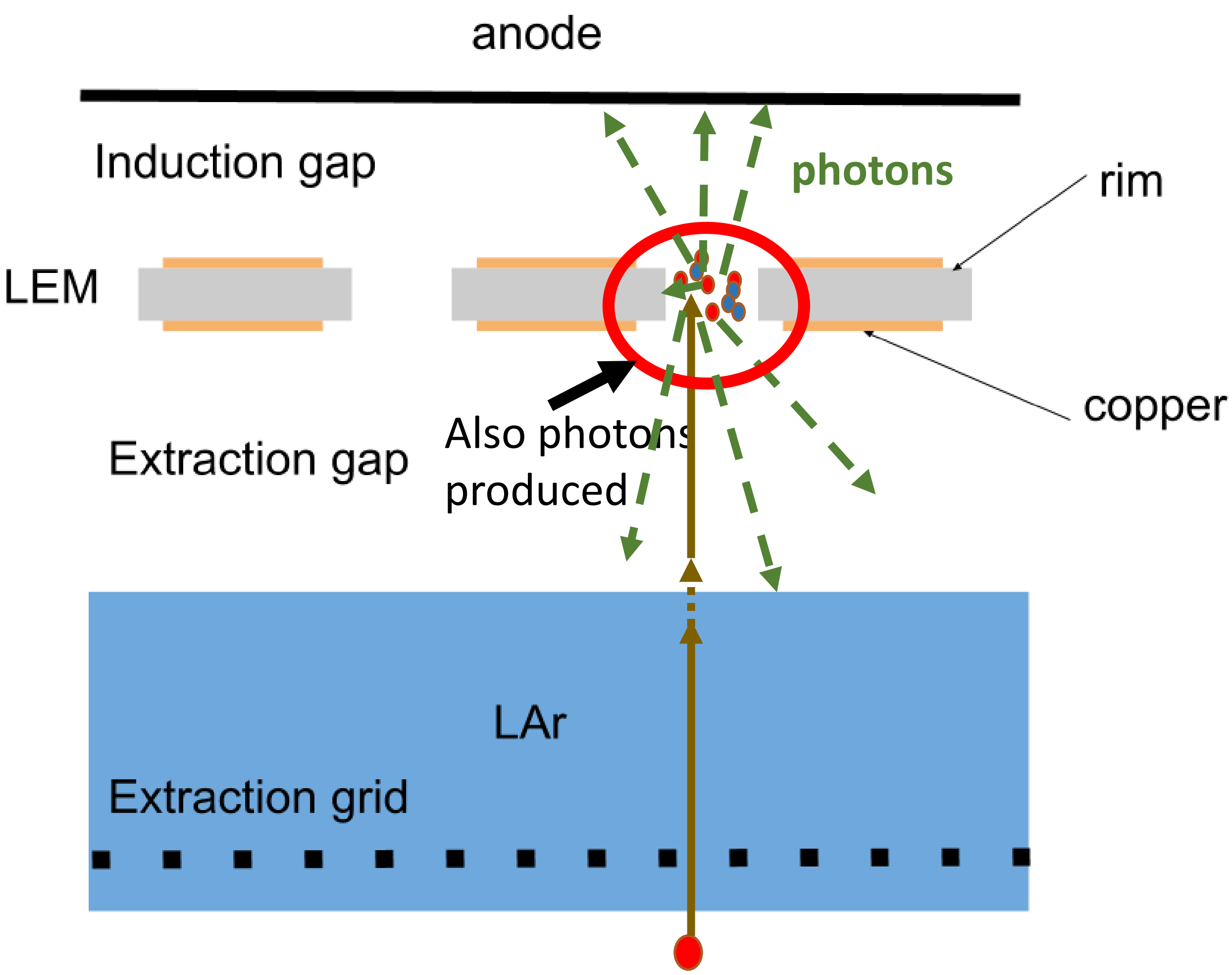


The Charge Amplification region in a DP LAr TPC



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

The Charge Amplification region in a DP LAr TPC



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Simulation Study

- First complete study of electron, ion and photon production in amplification region
- Other studies/measurements focussed purely on electron signal
- Important input for performance studies about the PDS, especially for non-beam physics
- Outcome recently published:

[Charge and Light Production in the Charge Readout System of a Dual Phase LAr TPC]
T. Lux (Barcelona, IFAE). Dec 20, 2018.
Published in **JINST 14 (2019) no.03, P03006**
DOI: 10.1088/1748-0221/14/03/P03006
e-Print: **arXiv:1812.08700 [physics.ins-det] | PDF**

Charge and Light Production in the Charge Readout System of a Dual Phase LAr TPC

T. Lux,[a]

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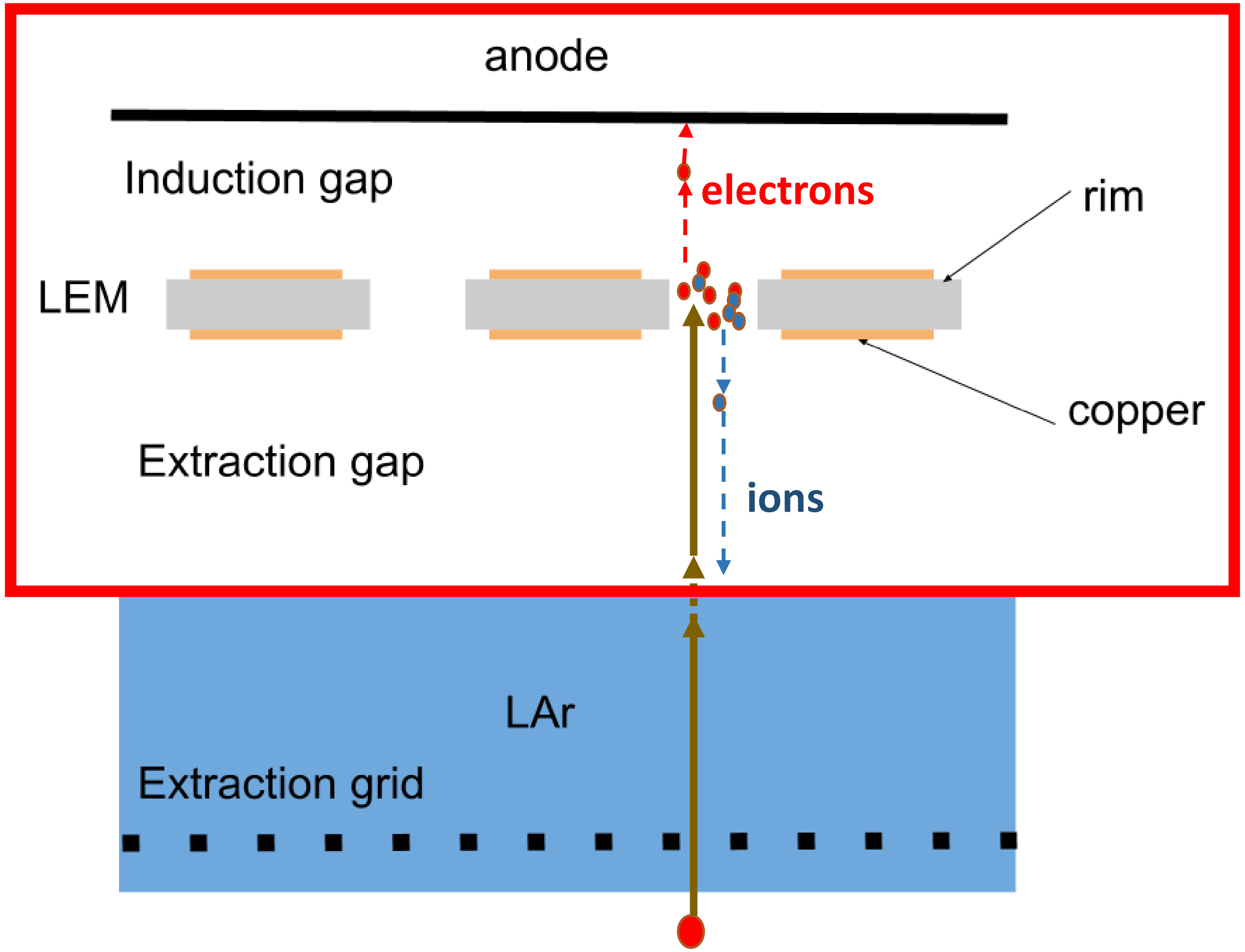
E-mail: Thorsten.Lux@ifae.es

Abstract: For the future neutrino oscillation experiment DUNE, liquid argon time projection chambers with a fiducial mass of 10 kton each are foreseen. The dual phase concept is one of the two implementations considered, wherein electrons produced by ionization in the liquid are extracted to a gaseous region above the liquid where they are amplified. For the amplification, large electron multipliers will be used. The technology was tested in various prototypes, most recently with a 3 x 1 x 1 m^3 large setup. An even larger prototype of 6 x 6 x 6 m^3 is currently being constructed and will start operation in 2019. An intensive R&D program was carried out with the focus on achieving an effective gain of at least 20. In the simulation study here presented for the first time not only the electron signal is considered but also the ion backflow and the expected production of secondary scintillation light is studied, because the latter might limit the capability of the detector to trigger on low energetic no-beam physics. It is found that the ion backflow and the light yield can be expected to be very large. The results for the effective gain show a discrepancy with experimental data, both in size and shape of the gain curve. Based on literature studies, it is argued that photon feedback contributes to the gain in detectors filled with pure noble gases, especially in the case of pure argon.

Simulation Tools, Geometry and Fields



- Open source programs used: Gmsh (geometry), Elmer (electric field map), Magboltz (gas properties), Garfield++ (charge transport and photon production)
- Only gas phase was simulated
- Production and end point of each particle recorded

Geometry	
Extraction gap	5 mm
Induction gap	2 mm
LEM dielectric thickness	1 mm
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LEM dielectric hole radius	250 μm
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LEM hole arrangement	hexagonal
Field/Voltage	
Extraction field	3 kV/cm
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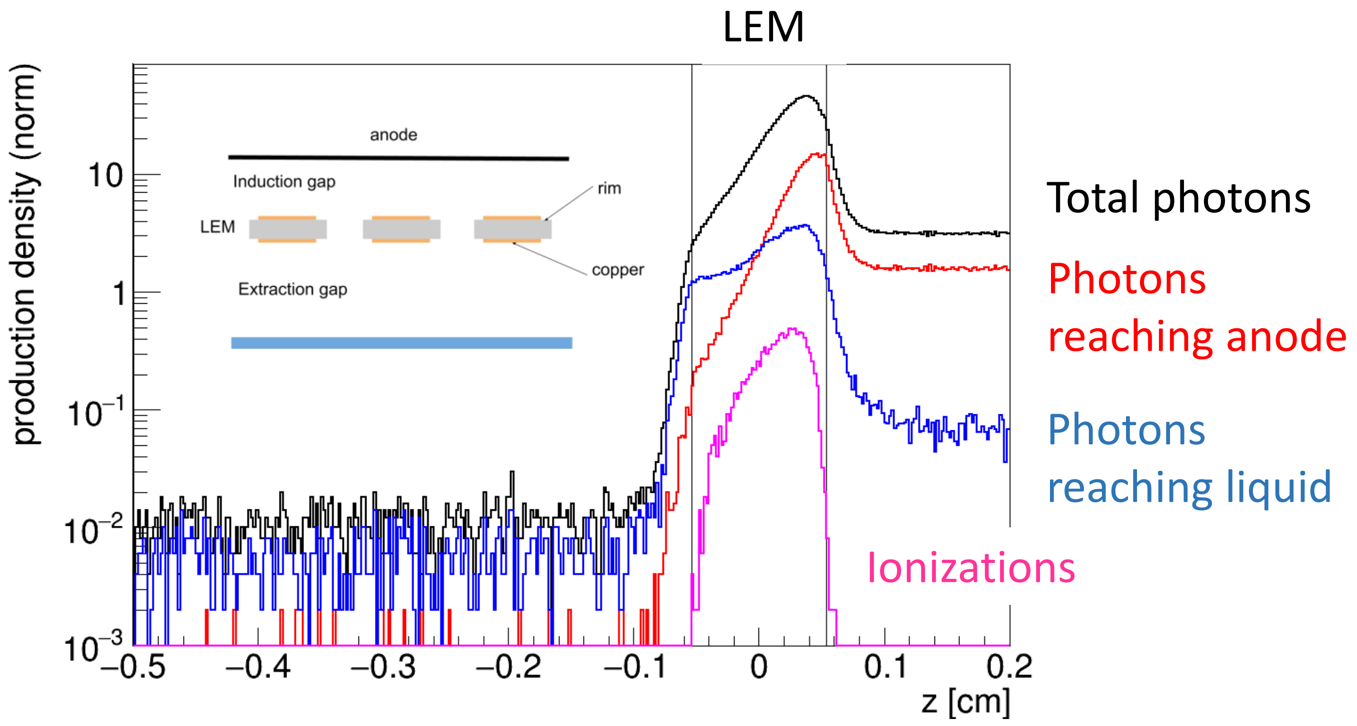
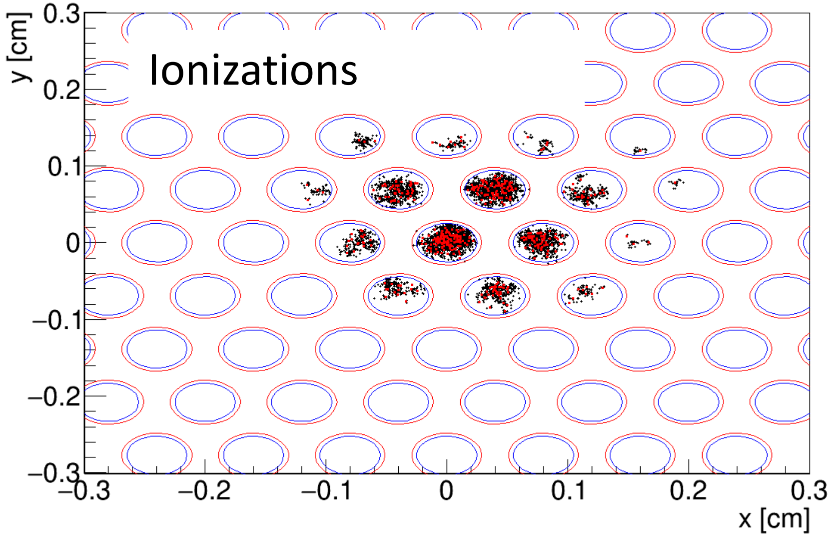
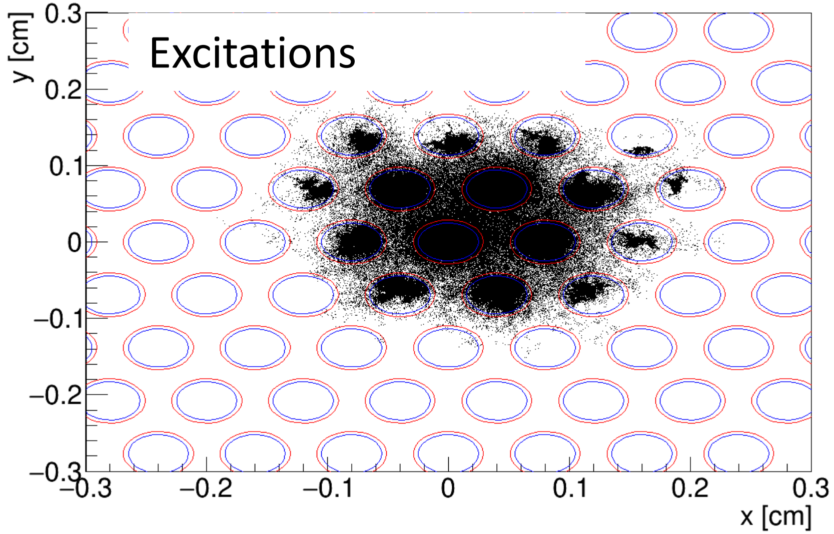
Production Locations of Particles

- Ionizations contained in holes
- Photons produced mainly in holes but also to small extend in extraction region and to larger extend in induction region







Relevant Parameters

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

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

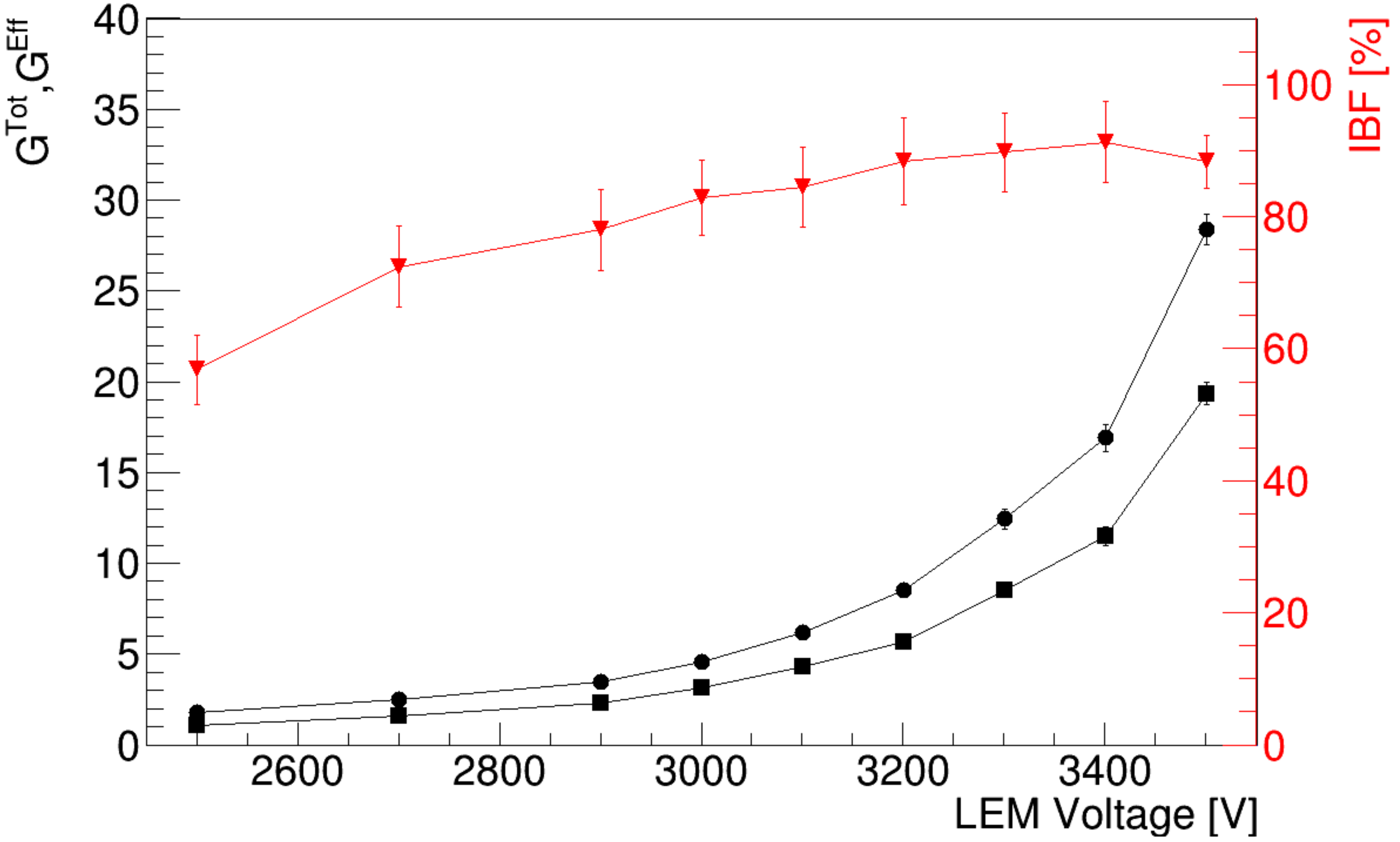
$$IBF = \frac{\text{\# ions reaching the liquid}}{\text{\# electrons reaching the anode}}$$

Charge Results

- Effective gain at 3300 V (nominal voltage) simulated: ~ 8
- IBF: ~ 90% above 3000 V
- Reported gain at 3300 V: ~ 65

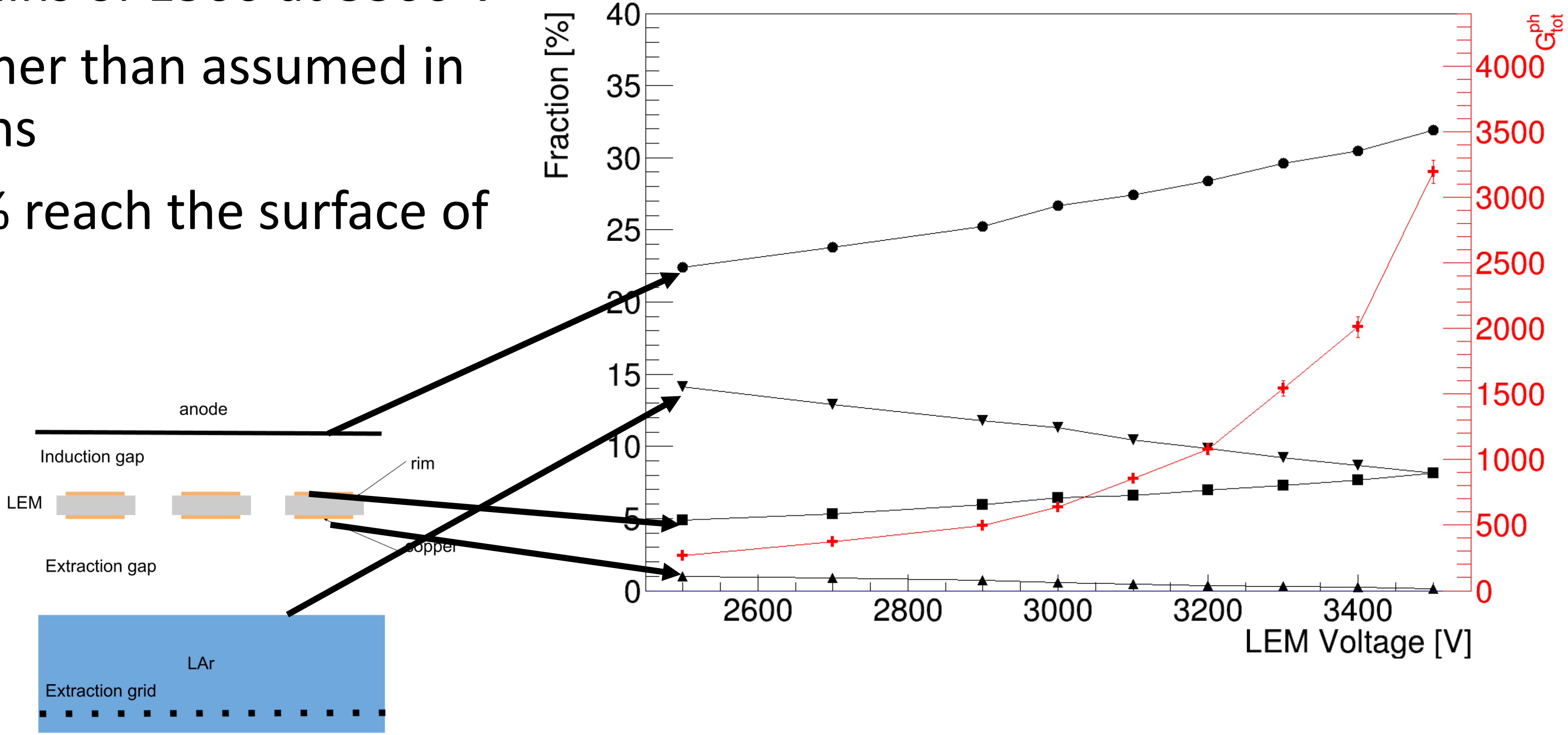
????

Will come back to this …



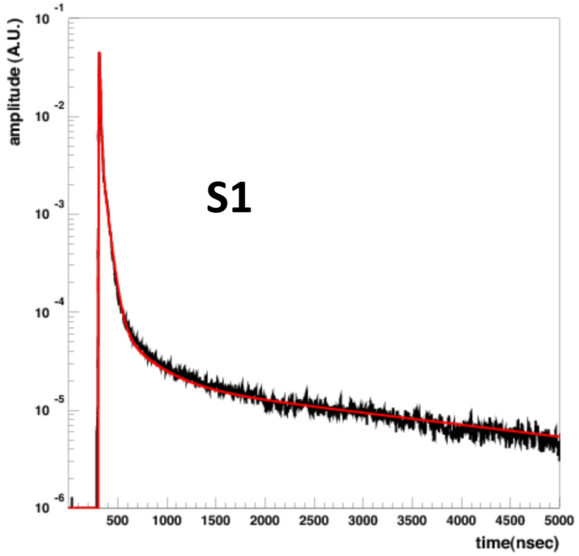
Photon Results

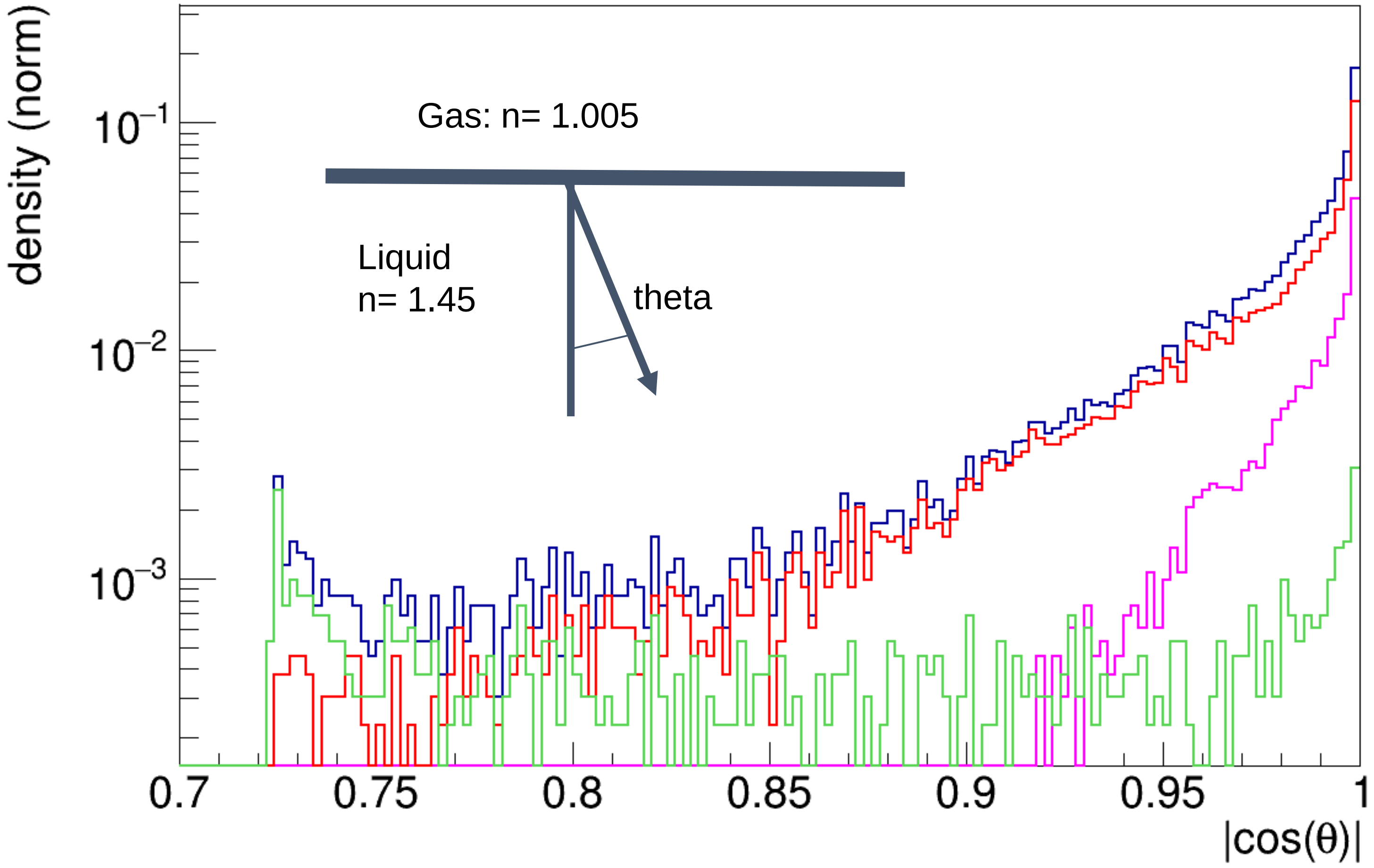
- Photon gains of 1500 at 3300 V
- Much higher than assumed in simulations
- About 8% reach the surface of the liquid



Angular Distribution

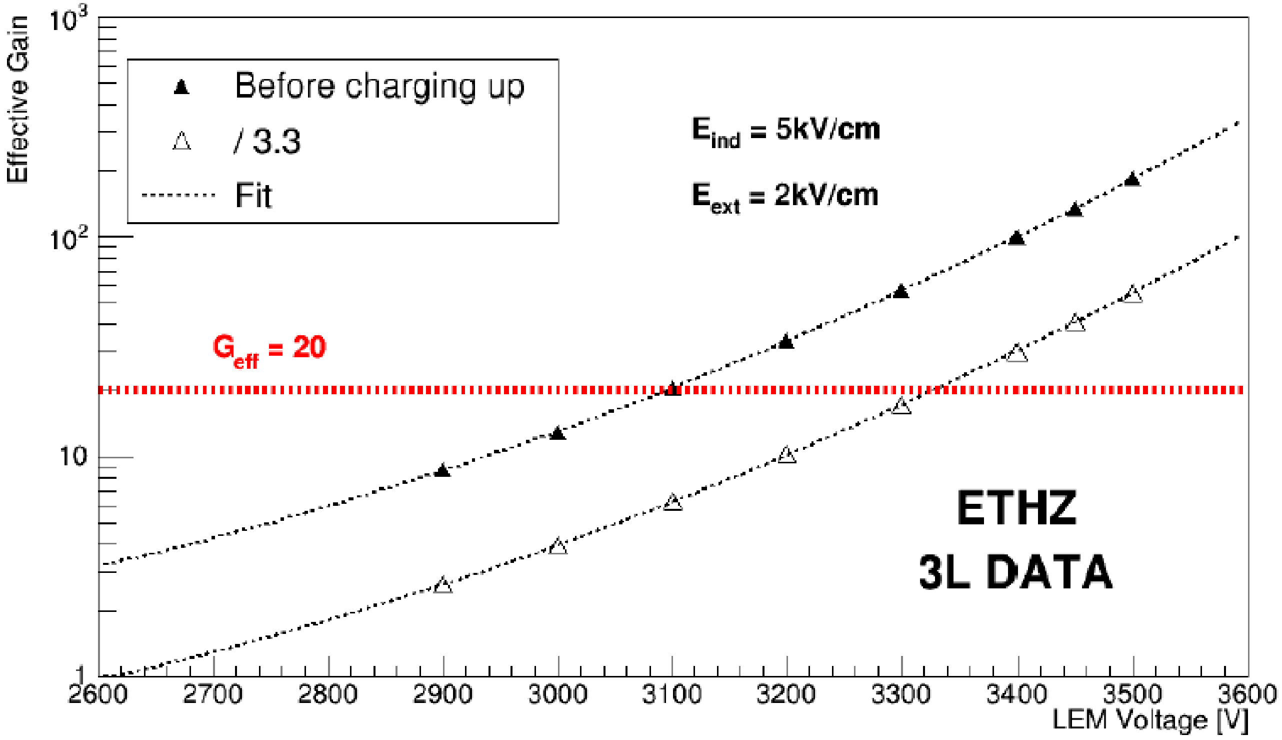
- Angular distribution of photons peaked towards cos Θ ≈ 1
- “Shining” directly on PMTs
- To have an idea:
  - S1: 1 electron - 1 γ
  - S2: 1 electron - 120+ γ
- But S2 further away and different time shape





Coming back to Charge Gain

- What I am doing wrong that the charge gain does not agree with measurements?
- Probably nothing …
- Avalanche gain follows exponential
- But reported gain raises faster than exponential
- Could there be other processes contribute to the charge gain?



Literature

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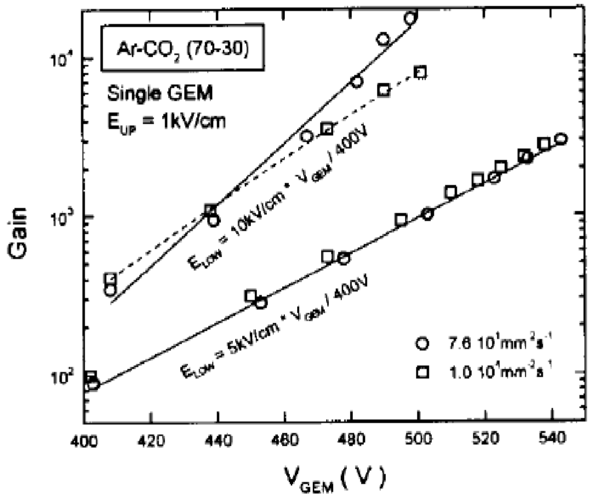
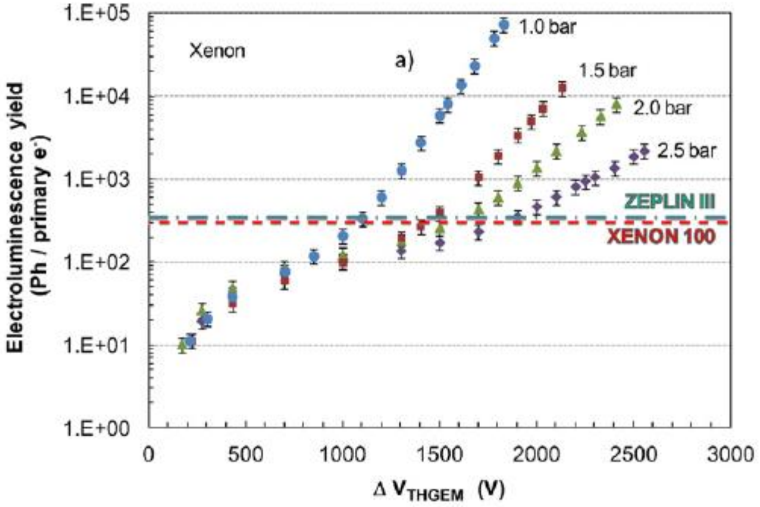
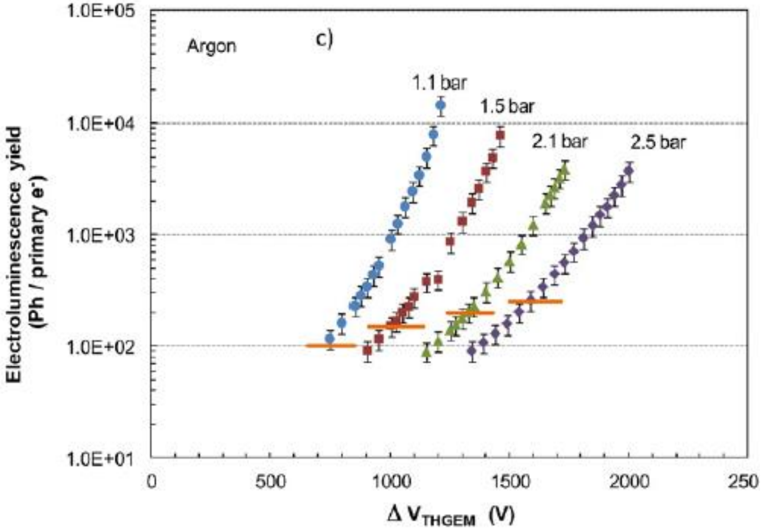
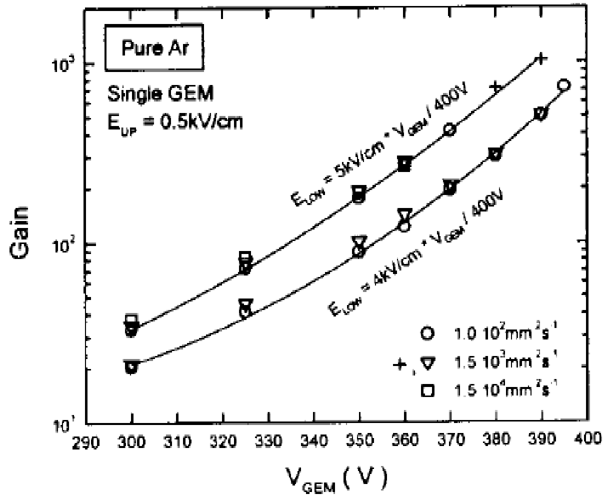
- Over-exponential behaviour reported previously
- Charge gain with GEM:
  - Over-exponential in pure argon
  - Exponential in Ar:CO2
- S2 yield measured with THGEM shows the same









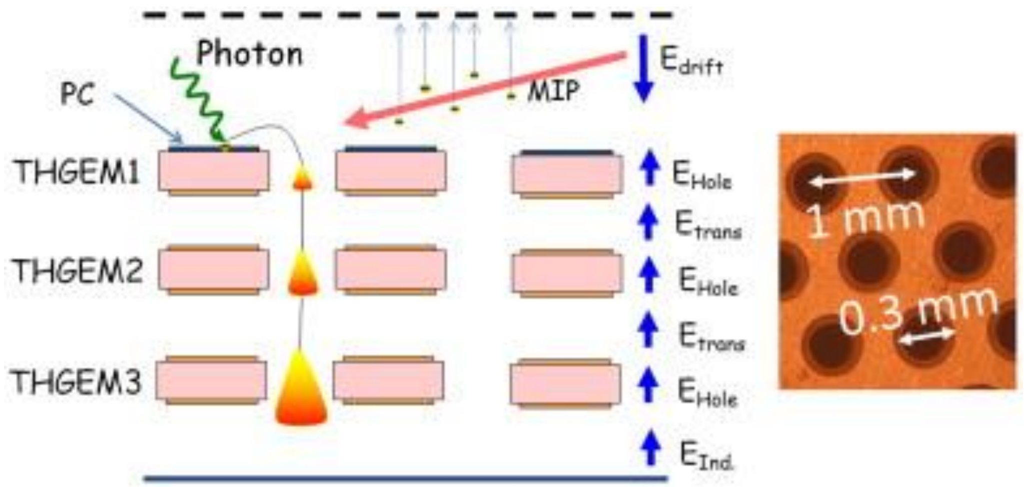
Photon-Feedback?

- Paper from beginning of 90s might provide explanaition
- High energetic photons (128 nm = ~10 eV) can imping on surface and kick out electron
- Work function in vacuum: 4.5 eV (copper)
- With gas higher but very high electric fields on the LEM surfaces
- Used to construct gaseous PMTs based on LEMs although with photosensitive layer
- Simulated same geometry and settings as for S2 with THGEM study

Feedback and Breakdown in Parallel-plate Chambers

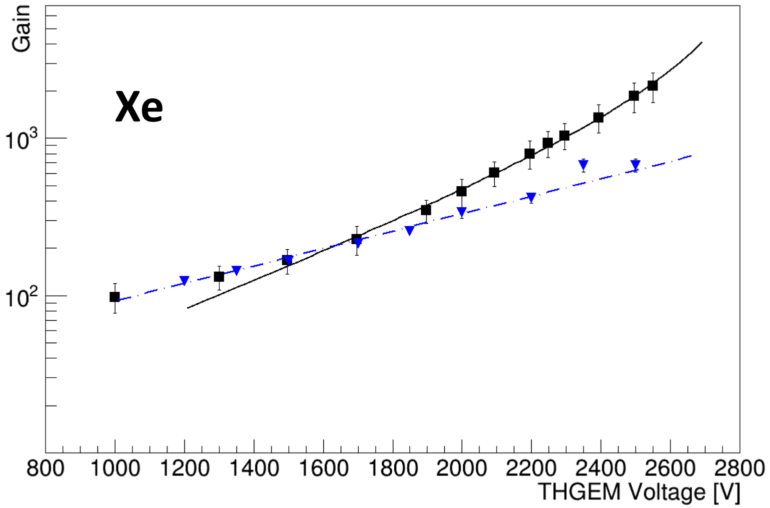
P.Fonte[1,2], V.Peskov[2,3], and F.Sauli[2]

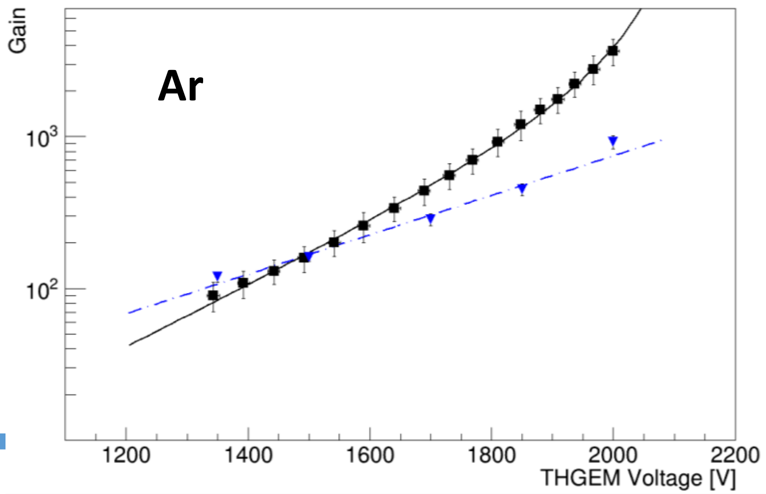
If there is a large amount of feedback the total gain will increase over-exponentially, because (eq.(3)) $G_t(E) = G(E)/(1 - \eta G(E))$. The deviation of $G_t(E)$ from an exponential behavior allows an estimation of the feedback level η. This method depends only on the total charge in the avalanche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

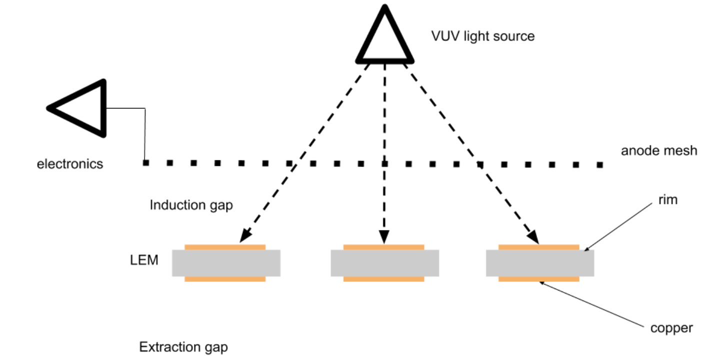


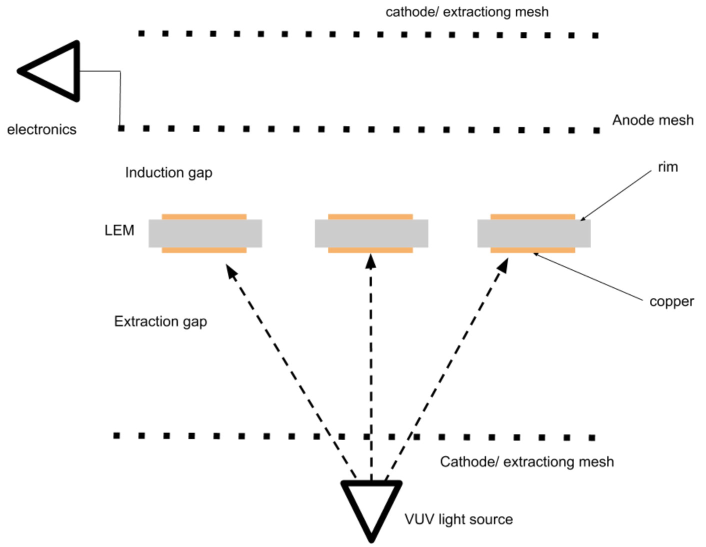
Photon-Feedback?

- Simulation (blue) follows exponential
- Data (black) for Xe and Ar well described by PF equation
- I do not claim it proof but a good hint
- Direct, well controlled measurement necessary for confirmation
- PF in induction and extraction region should be studied separetly



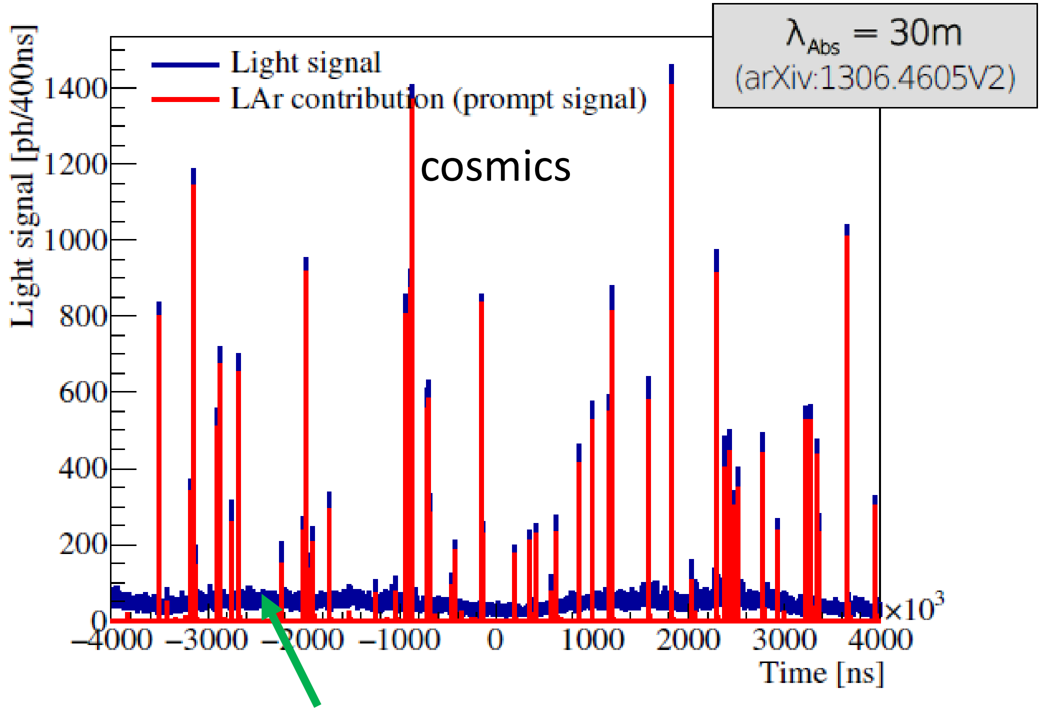






Possible Implications for protoDUNE-DP and beyond

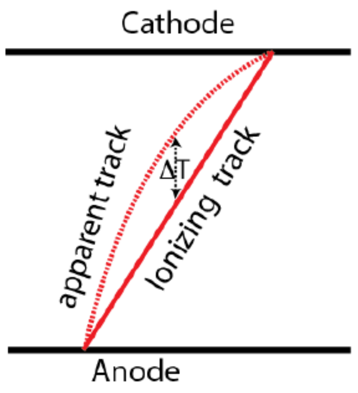
- S2 signal much larger than assumed until now
- No problem for cosmics at surface but might an issue for SN trigger even underground due to Ar-39
- Well, we will see how the PMTs will like “constant” background
- But charge gain will be much lower than 20, possibly 4-5

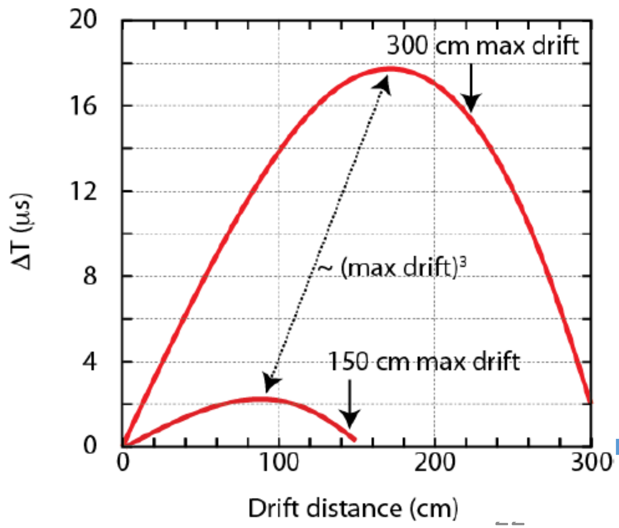


S2 background should be scaled by factor 5 at least if gain of 20 could be achieved

Possible Implications for protoDUNE-DP and beyond

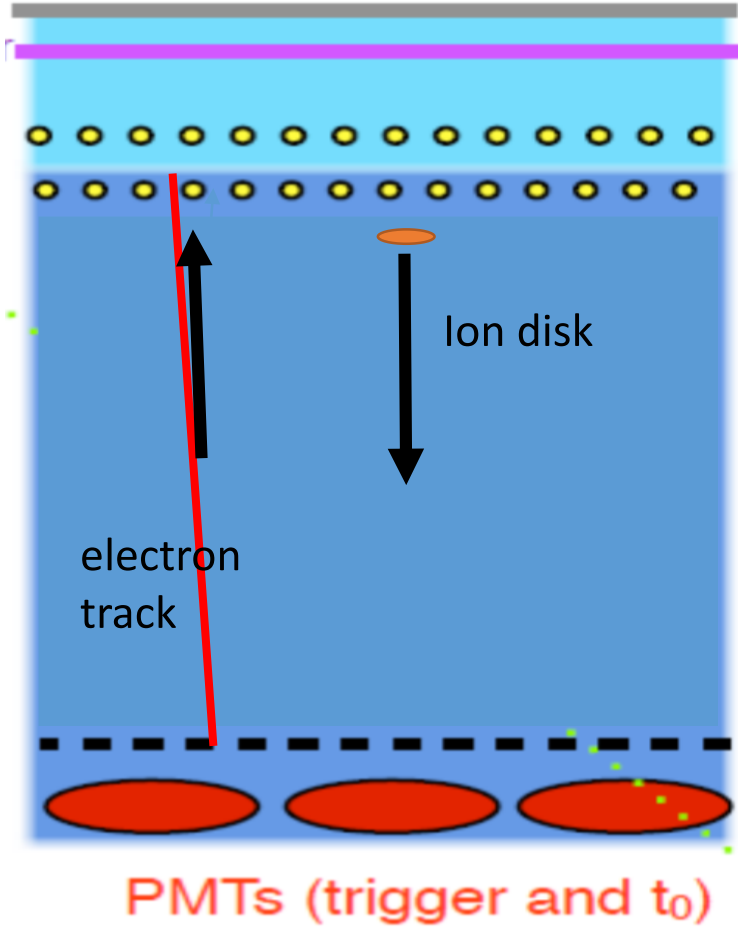
- Much bigger problem: space charge effects
- Space charge affects electric field and electron-ion recombination possible
- SP observes huge and twice as large track deformations as expected from primary ionization
- SP has a drift of 3.5 m, DP of 6 m and effect goes with power to 3
- Remember: Production of ions in gas phase in addition
- And no option to change drift field
- **We might observe nothing!**





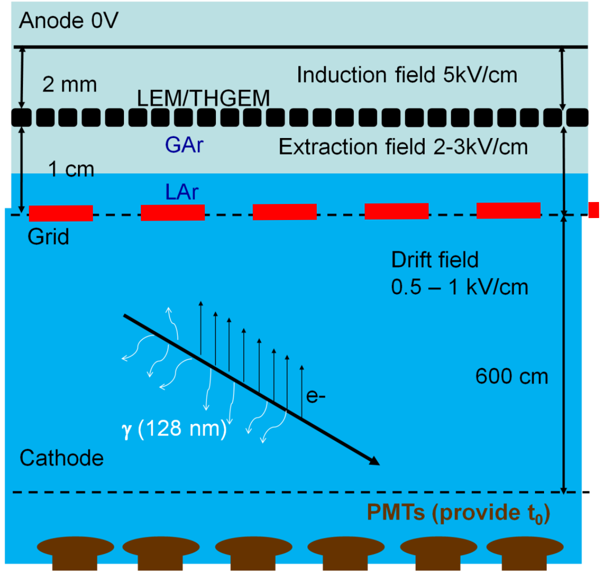
"Funny Effects"

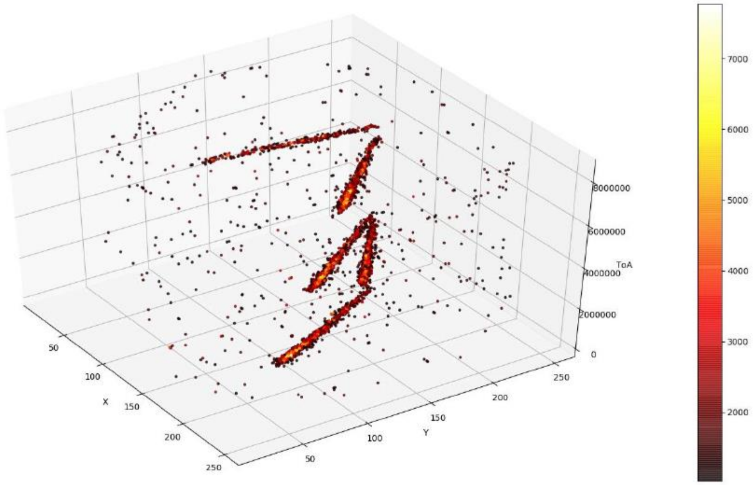
- And if it works more or less?
- There could be "funny" effects:
  - Electrons drift much faster as ions => 6 m long "electron" track compressed to sub-mm "ion" disk
  - Ion disk needs 10 to 60 min to reach cathode
  - Electrons of later track might recombine with these ions => loss of charge signal and sudden burst of photons
  - Simple estimation indicates "plasma" in liquid of extraction region
  - Neutral LAr good insulator but with this "plasma" could there be sparks between mesh and LEMs?
  - Low ohm 3x3 m^2 mesh => could be epic sparks
  - CERN expert could not exclude this
  - SP is considering this to explain slight HV instabilities of their cathodes



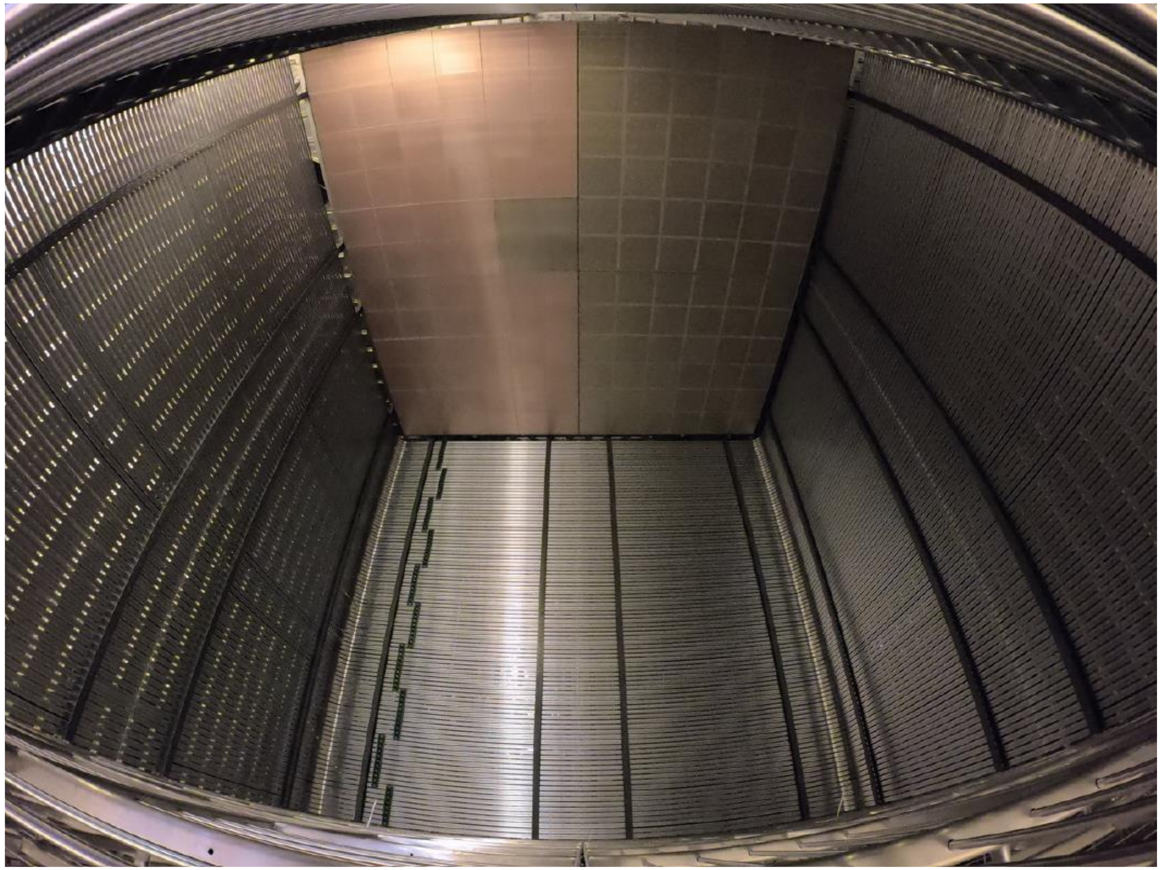
Is this the end?

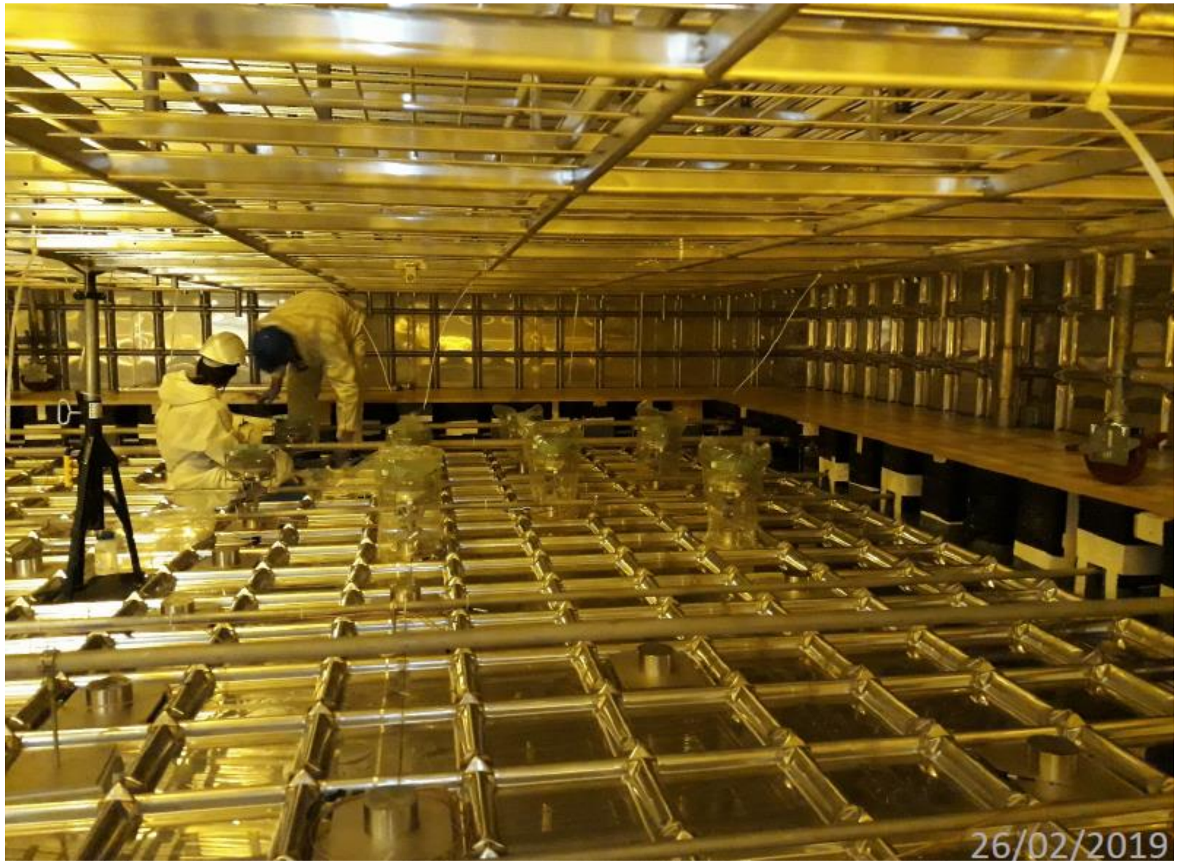
- Proposals to overcome the possible problems are on the table:
  - Extraction LEM (proposed by IFAE):
    - Replace grid by LEM-like structure
    - Could be used as gate to block ions going back
    - Would reduce back going S2 light
    - Reduces capacitance problem
  - Light readout:
    - Use transparent anode
    - Exploit S2 light
    - Make video of event using Timepix3 camera
    - No ions?
    - Currently doing simulation study how an optimized LEM for this purpose should look like





Photos from 666





Summary

- first complete simulation study of the charge and light production in the amplification region of a DP LAr TPC presented
- Relevant input for performance studies
- Discovered that the charge amplification process is not well understood in a LAr DP TPC
- No problem for DUNE since SP works well
- Excited to go to CERN and get 666 running, nice R&D, but no way to volunteer to produce 200 TPB coated PMTs for final detector
- Classical case of how to bring an interesting technology approach to failure: follow blindly one person, ignore warnings, prioritize schedule over common sense, …

Some Extra Motivation …

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BIST Barcelona Institute of Science and Technology

- Had warned for secondary scintillation and back going ions long time ago with little success …
- Even published proceedings with Ds group from CIEMAT and working on more complete paper
- Recently realized we see too much light in 311 compared to simulation for poor gain achieved
- Discovered:

G = Number of photons produced in GAr / drifted electron

For the time being, G is estimated ~300ph/e → Has to be determined more precisely

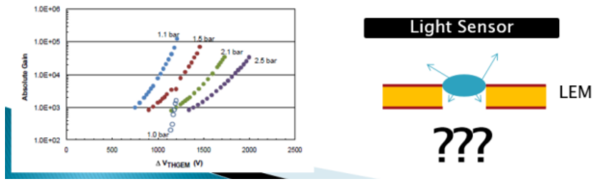
- Could be factor 10 too low

Impact of the positive ion current on large size neutrino detectors and delayed photon emission
R. Santorelli (Madrid, CIEMAT), S. Di Luise (Barcelona, IFAE), E. Sanchez Garcia, P. Garcia Abia (Madrid, CIEMAT), T. Lux (Barcelona, IFAE), V. Pesudo, L. Romero (Madrid, CIEMAT). Dec 21, 2017. 7 pp.
Published in **JINST 13 (2018) no.04, C04015**
DOI: 10.1088/1748-0221/13/04/C04015
Conference: C17-09-22 Proceedings
e-Print: **arXiv:1712.07971** **[physics.ins-det]** | PDF

LEM EL **WA105 CM Feb. 2015**

- during amplification within LEM holes also γs are produced
- amount could be significantly higher than parallel EL
- Ar measurements by Portugues group (but with different LEM geometry)
- light gains up to 2–3*10⁴ @ 2.5 bar!
- Light sensor on anode side
- simulations indicate light is produced mainly close to anode exit of the hole but depends on geometry + voltages

Any measurement for WA105 LEM on cathode side?



WA105 CM Sep. 2016
Simulations for GEMs

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!