Challenges of a Multi-Gas HP TPC: A personal view

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Physics Wish List

- Target for neutrinos between 500 MeV and 10 GeV => we need (some) mass

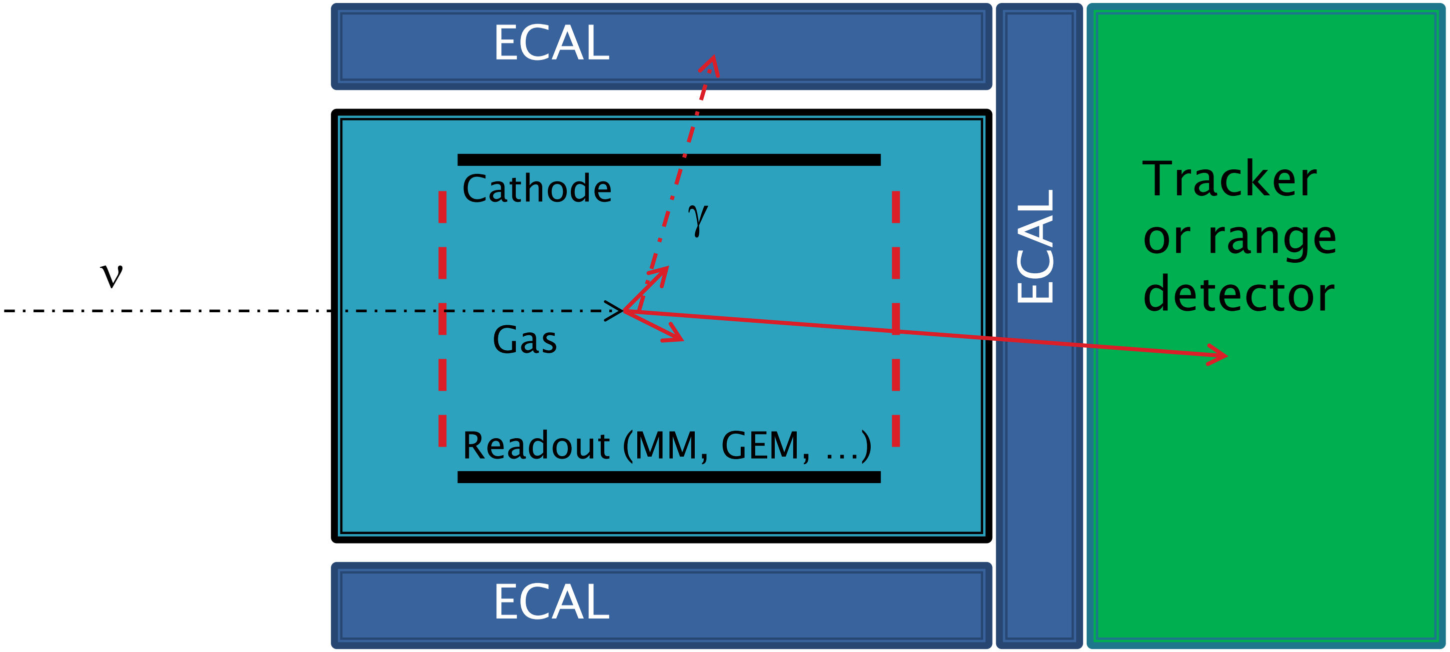
- Operation with different nuclei (Ar, He, Ne, …)

- Excellent pattern reconstruction => distinguish CCQE e.g. from CC1π / detect hadrons with low momentum (100 MeV/c)

- Good reconstruction of the neutrino energy

=> TPC might provide most of this but some challenges have to be overcome

Detector Concept



Implications => We need a thin wall high pressure TPC!

Gas Wish List

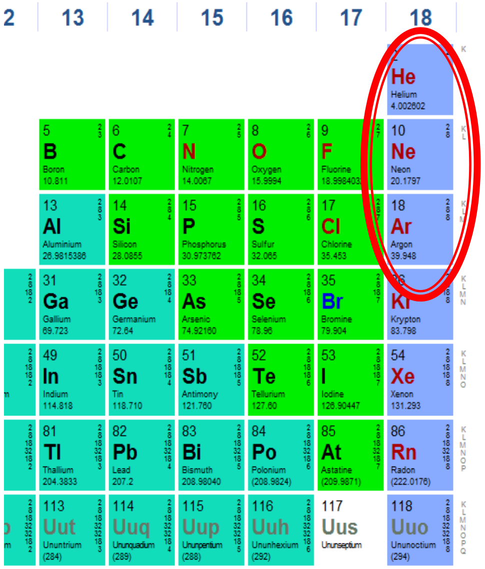
1. Gas should be as close as possible to oxygen or H2O
2. Provide as much mass as possible -> high pressure
3. “right” stopping power for FSI particles -> able to reconstruct track but particle should be stopped inside TPC
4. should allow some gain at high pressure (5-10 bar)
5. “fast” at low voltages -> electronics/ HV stability
6. Not too large diffusion to reconstruct well the tracks
7. non-flammable/non-toxic/non-corrossive
8. as cheap as possible

Compromises will be necessary!

3 Gas Scenarios

I consider three options for the TPC gas:

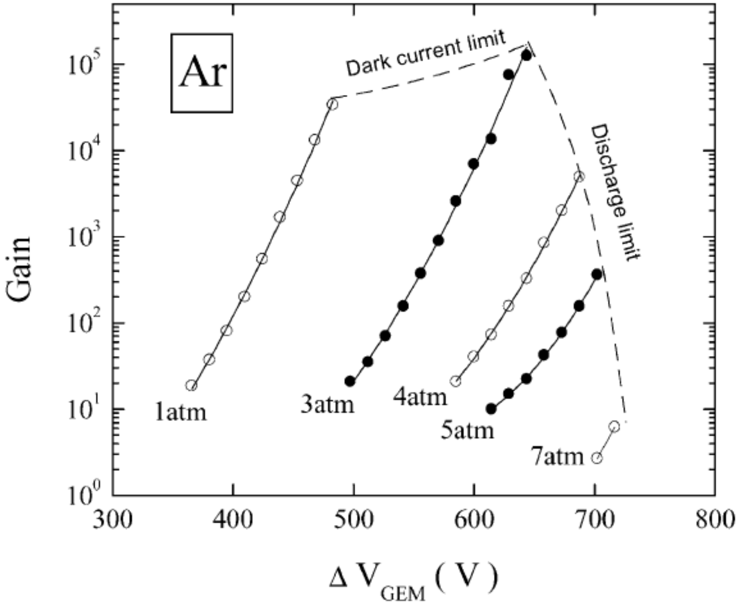
1. Pure noble gases
2. Noble gases + some quencher
3. More exotic gas (mixtures)



Noble Gases:

	He	Ne	Ar
Density [kg/m3]	0.17	0.9	1.7
Volume [m3] (100 kg @ 10 bar)	56	12	6
Price	↙	↓	↑
HV insulation	↓	–	↑
Stopping power	Small	Medium	Large
High gain @ high pressure	↑	↑	–↙

Gain in Pure Noble Gases:



- Measurements performed with GEMs but should be the similar behavior for MM (to be confirmed by R&D studies).
- Maximal gain limited for Argon at high pressures
- Scintillation light in pure noble gases (He,Ne: ~15.5 eV, Ar: 9.7 eV) => Effect on detector material?

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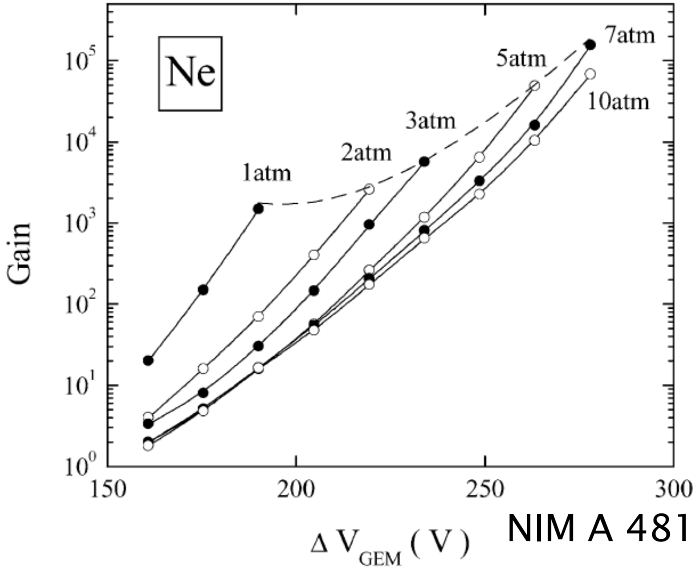

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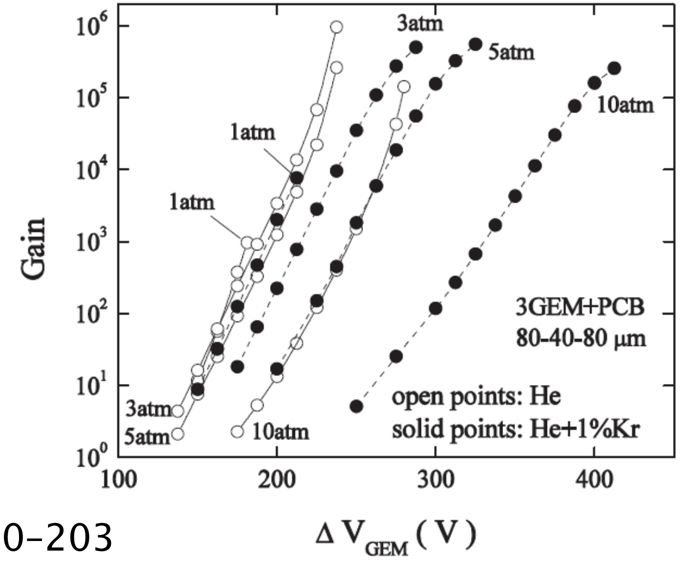
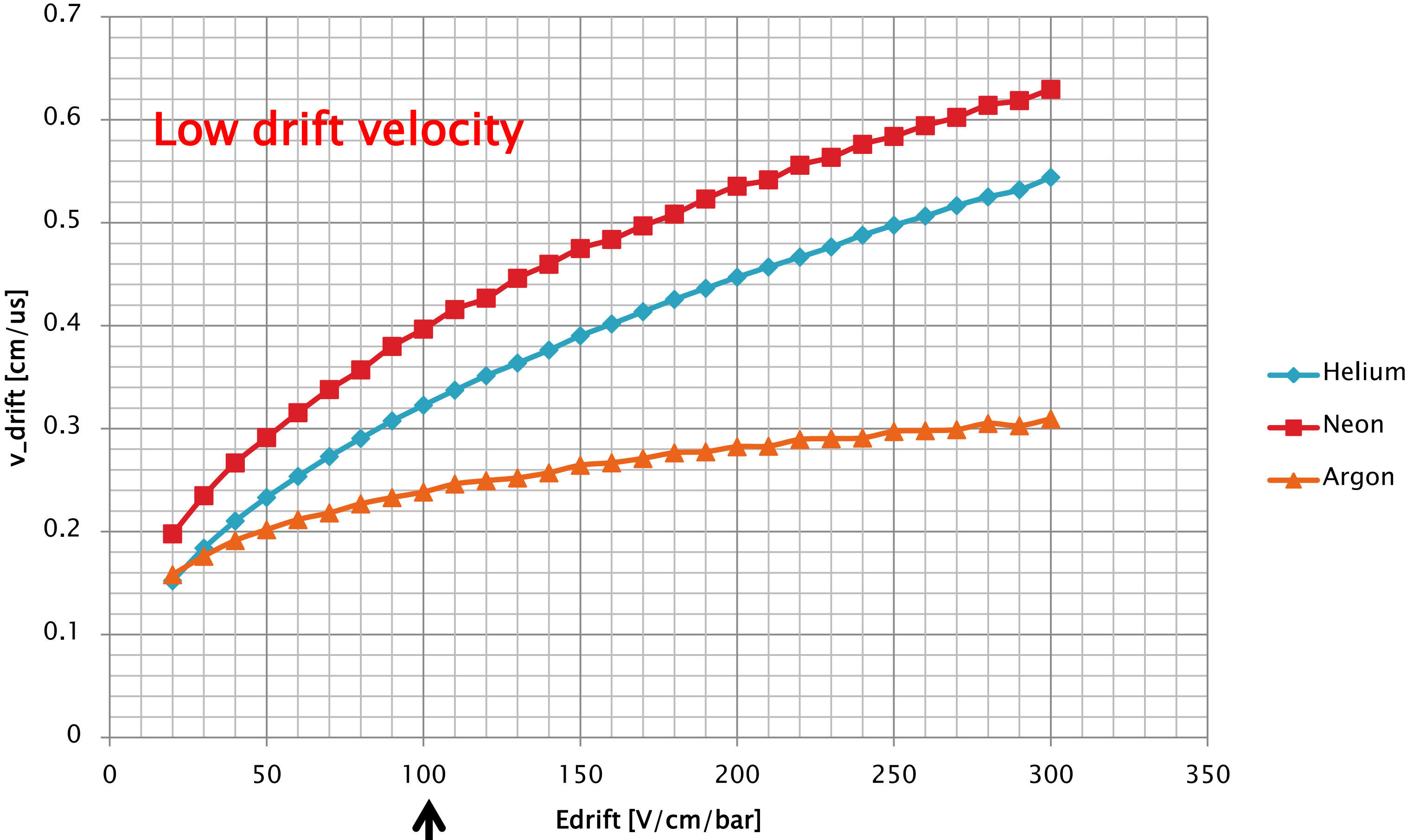


Pure Noble Gases: Drift Velocity

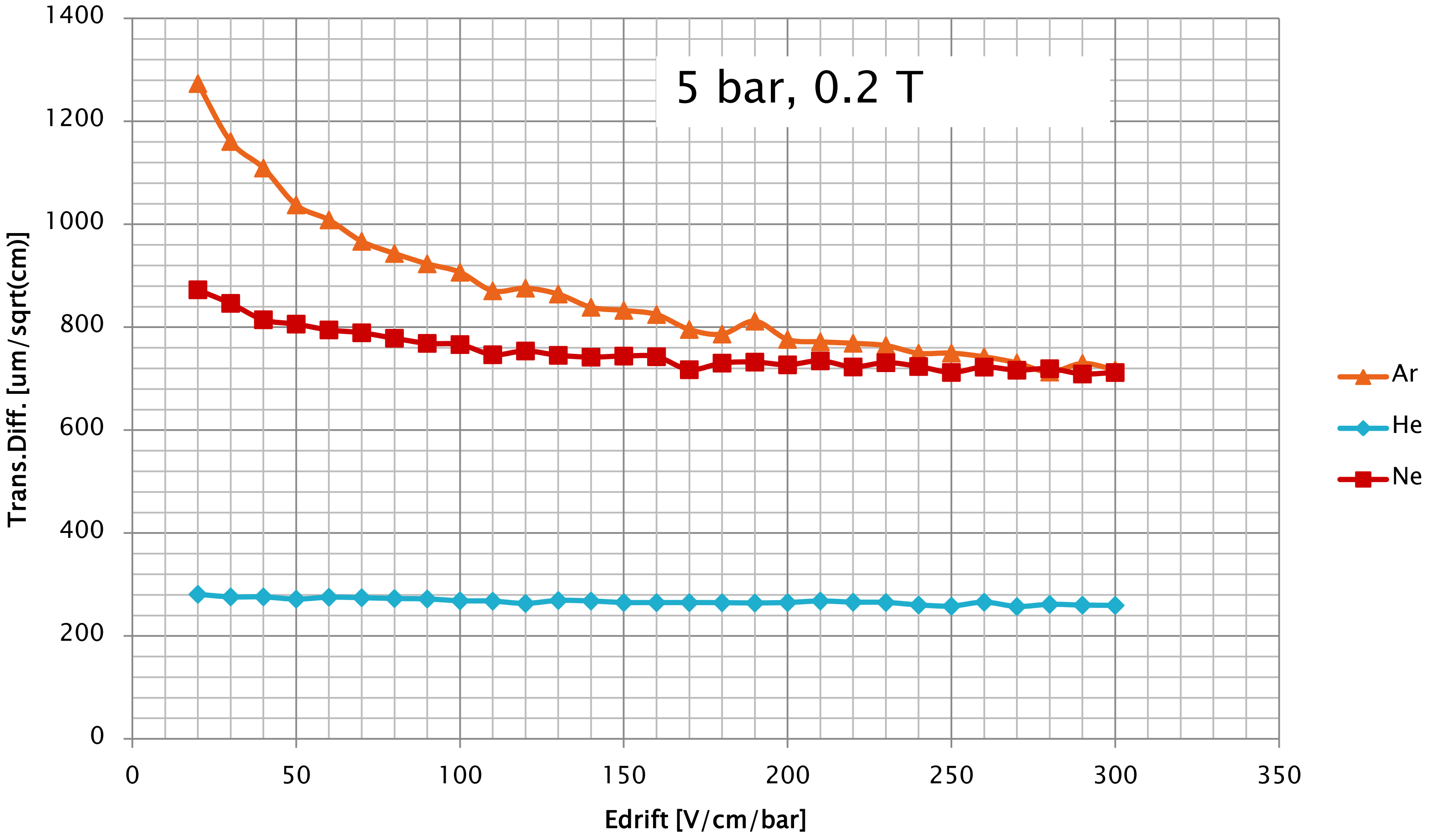
The same for all pressures



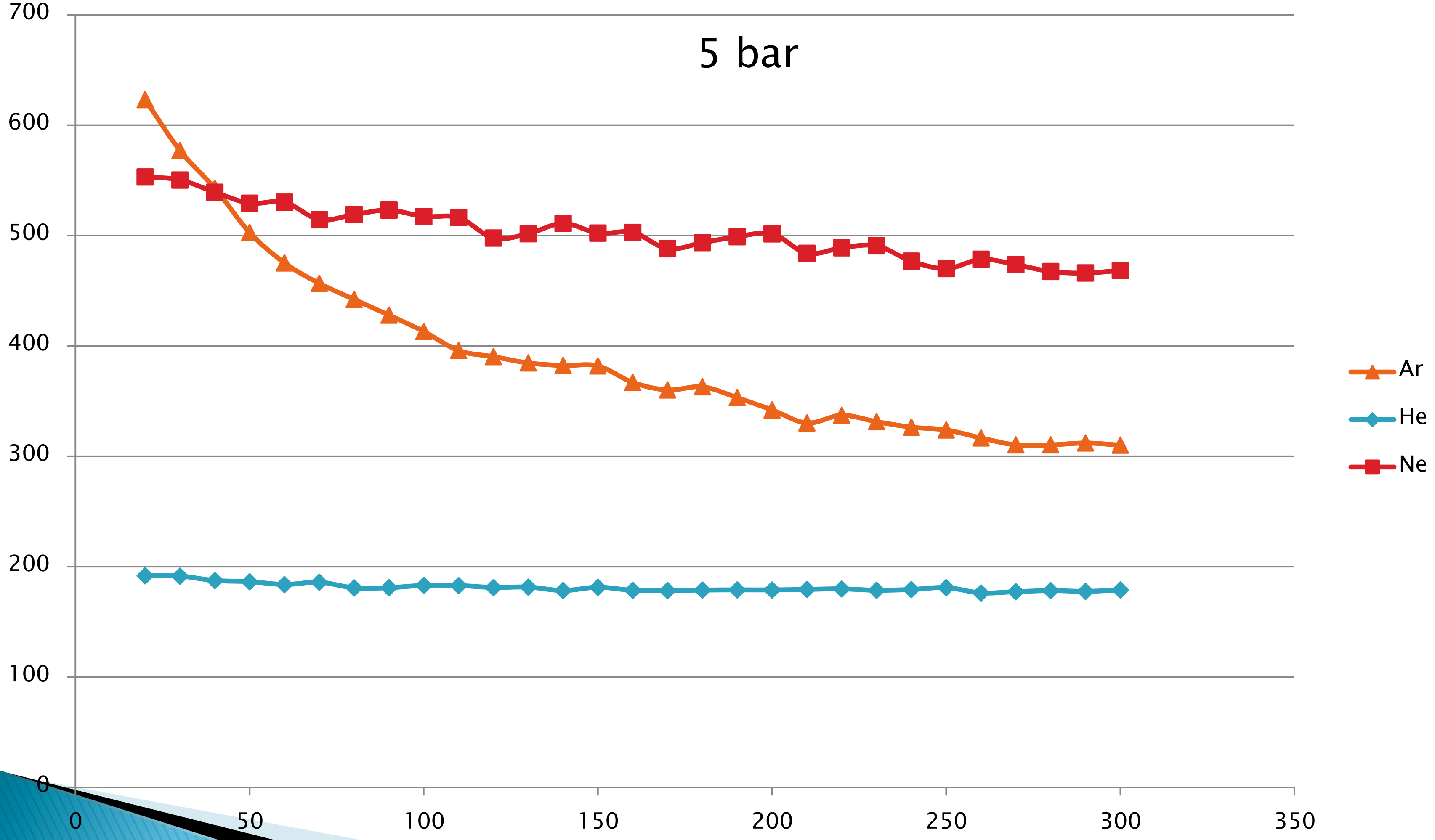
Low drift velocity

Corresponds at 10 bar and 1 m drift to 100 kV at cathode!

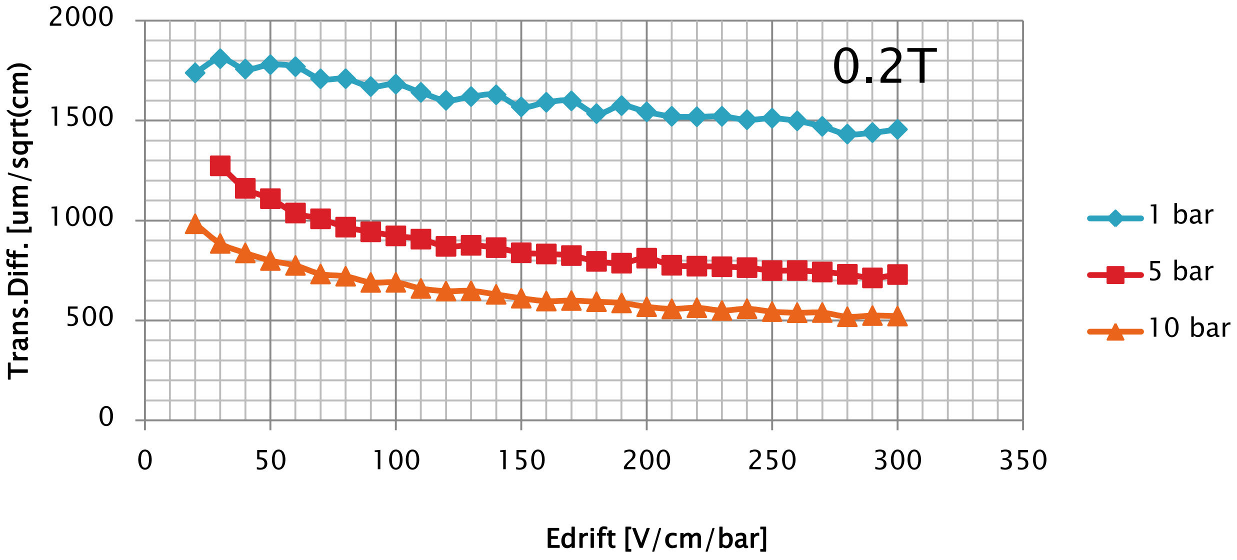
Pure Noble Gases: Transverse Diffusion



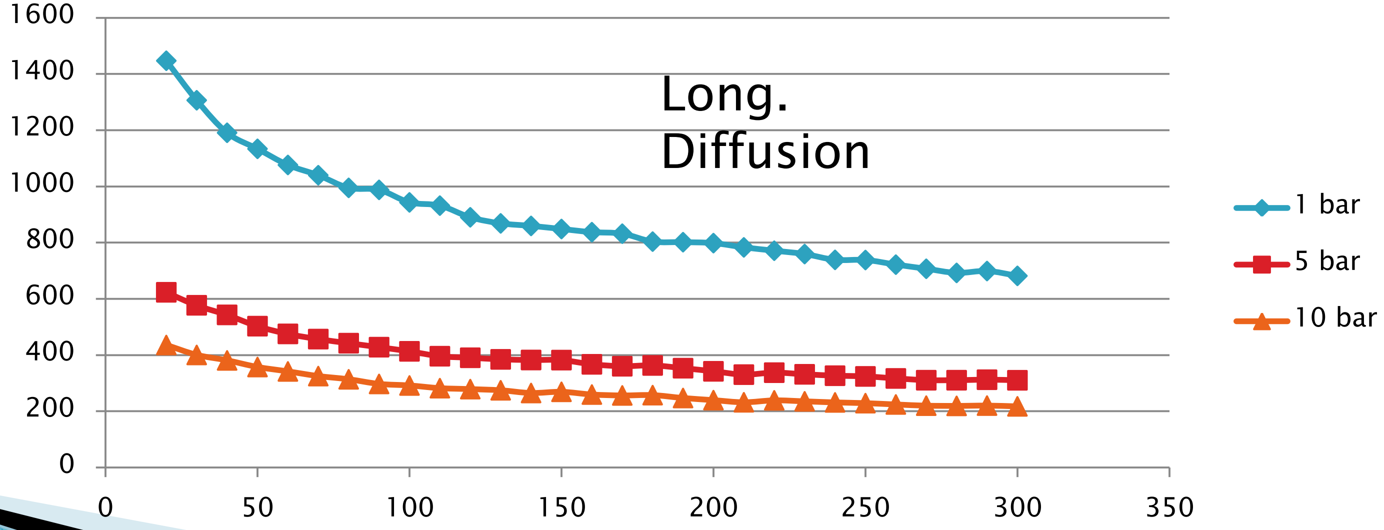
Pure Noble Gases: Longitudinal Diffusion



Pure Noble Gases: Pressure Dependency



Pure argon



Pure Noble Gases: Stopping Power + dE/dx

Let us assume MIP-like and protons with 100 MeV/c (~ 5 MeV kinetic energy) at 10 bar:

	MIP	**proton (100 MeV/c)**	
	e- per cm	**CSDA range [cm]**	**dE/dx [MeV/cm]**
He	80	~19.5	~0.25
Ne	430	~5.3	~0.95
Ar	940	~3.5	~1.4

NIST DB

Large differences between the gases but one could play also with the pressure …

Pure Noble Gases: Summary

- A He HP TPC would have to be huge to achieve enough mass

- pure noble gases are quite slow at low E fields

- diffusion relatively large for Ar and Ne (pressure and possibly higher B field would help)

- Ne, He promise good gains at high pressures, Ar not (needs confirmation from R&D study)

- in the case of Ne and He probably for cost reasons a closed gas system is needed

Noble Gas + Some Quencher:

Adding a small amount of quencher might help:
- to improve gain stability/ increase maximal achievable gain
- to make the gas faster
- to reduce the diffusion
- might avoid vacuum operation for a closed gas system (ALICE approach)

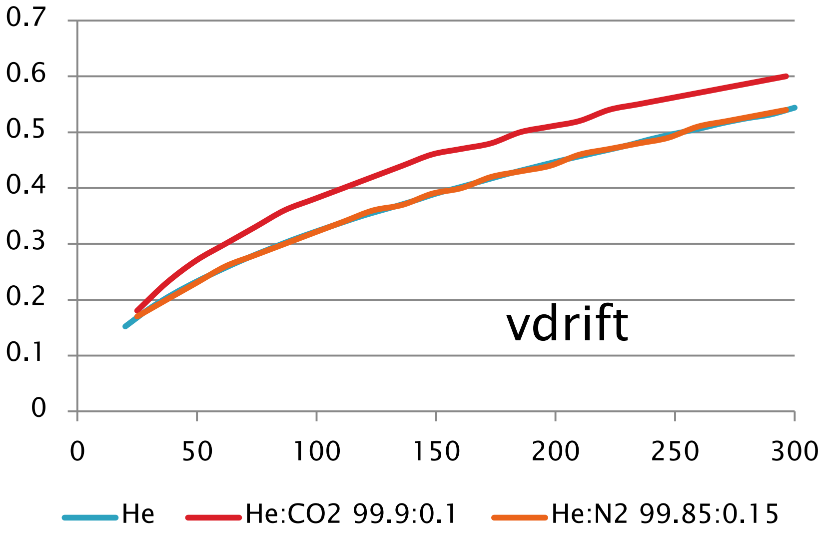
On the other hand:
- affects cross section measurements -> which amount of quencher is acceptable? 1% in mass?
- increases sensitivity to electron attachment

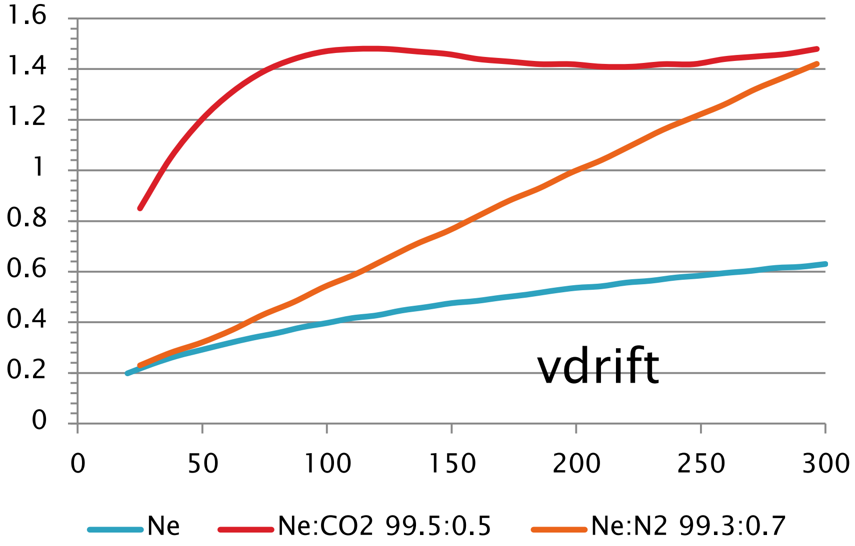
Possible quencher gases:
N2[*], CO2, CH4, CF4, i-C4H10, …

[*] almost not avoidable in a closed gas system due to outgassing, adding it makes the gas properties more stable (following the idea of Rob Veenhof for the ALICE TPC gas mixture)

Some Magboltz Simulations:

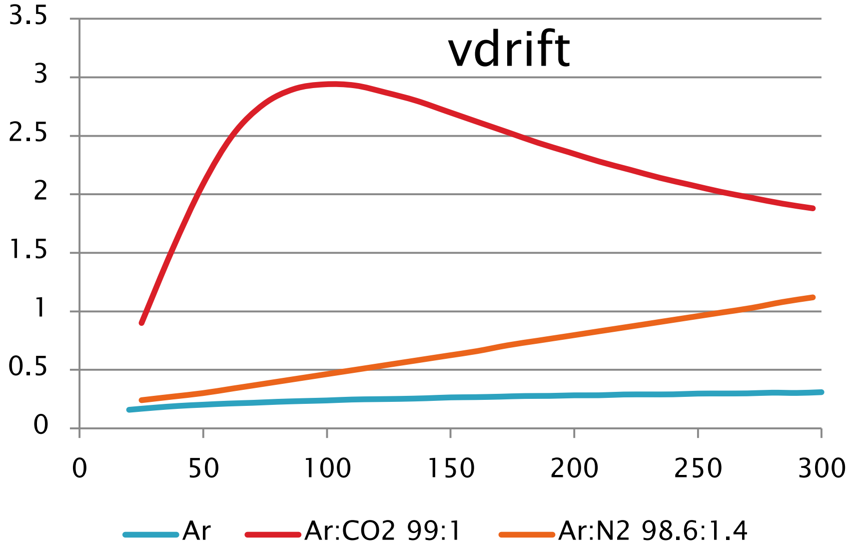
- Quencher: N2 and CO2 (more in the future)
- 1% in mass:
  - He: CO2=0.1%, N2=0.15%
  - Ne: CO2=0.5%, N2=0.7%
  - Ar: CO2=1%, N2=1.4%
- B=0.2 T
- P=5 bar

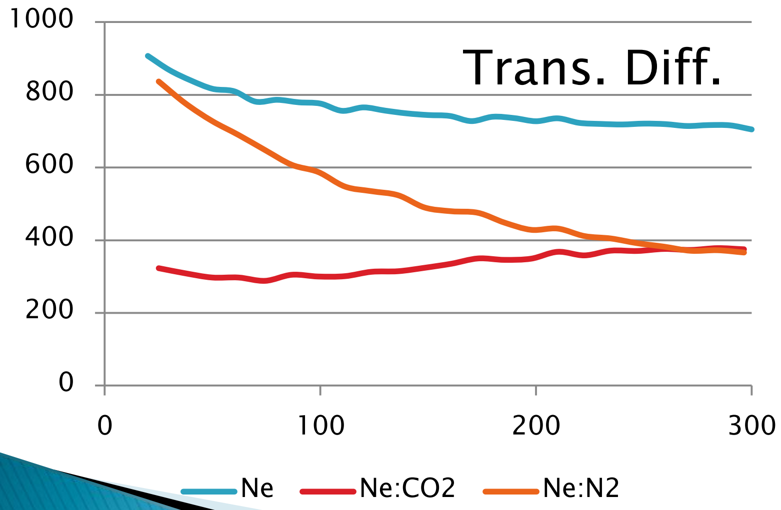


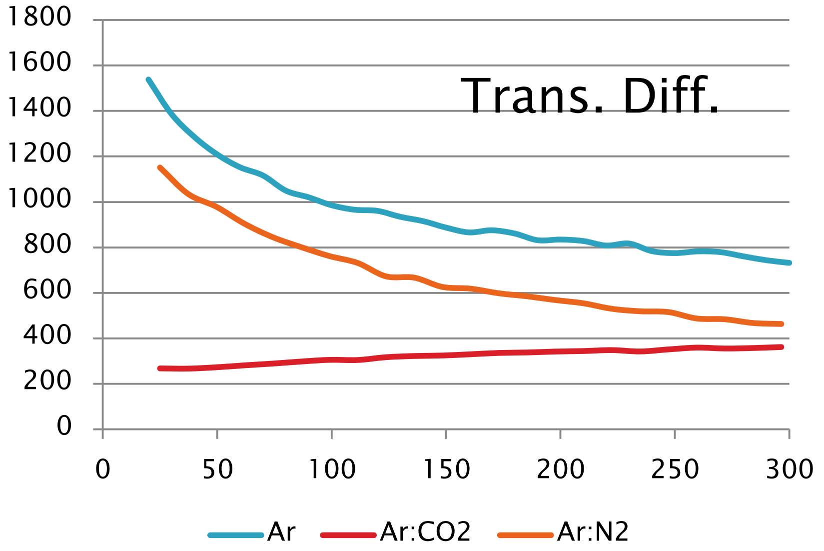


Some Magboltz Simulations:

- 1% in mass:
  - ➢ He: CO_2=0.1%, N_2=0.15%
  - ➢ Ne: CO_2=0.5%, N_2=0.7%
  - ➢ Ar: CO_2=1%, N_2=1.4%







3-Body Attachment:

Loss of electrons during the drift due to attachment to oxygen:

1) $e^- + O_2 \rightarrow O_2^{*-}$
2) $O_2^{*-} + X \rightarrow O_2^- + X$

X is a molecule which carries away the excitation energy of the oxygen. Efficiency depends on molecule.

Gas	Attachment coefficient [1/(μs*bar²)]
CH4	~170
i-C4H10	~2300
CO2	~2300
N2	~50 (?)
CF4	?
Ar/Ne/He	0

$\propto p^2$ => minimize quencher at high pressures!
=> Should be fine with mass limit!

More Exotic Gas (Mixtures)

Alain's idea: Let us construct H20!

Measure with CO_2, CH_4 and iC_4H_{10}:

$\frac{1}{2} CO_2 + 13/6\ CH_4 - 2/3\ iC_4H_{10} = H_2O$

Some problems:

1) Performance quite unknown especially at HP
2) CO_2 and iC_4H_{10} highly attaching
3) iC_4H_{10}, CH_4 as also H_2 highly flammable => would require extreme safety regulations if possible at all

Not saying that impossible but very challenging and requires even more R&D!

Readout Technology

The never ending story: MM, GEMs or something else?
What gain is necessary? Pad size? Pads or strips?

MMs: Well established T2K technology but we cannot use T2K gas

GEMs: Multi-stage amplification perhaps allows more stable operation?

THGEM: Do we need the fine pitch of MM/GEMs? Certainly robust

RPWELLS, …?

No judgment, we need to define requirements and possible gas mixtures and do R&D studies …

Electronics

Measuring with different gases, requires very flexible electronics.

T2K electronics good starting point but (assuming up to 1 m drift) …

- pure Ar and Ne and also some mixtures would need peaking times above 2000 ns => ballistic effects

- slow drift and small diffusion in some gases (He, CO2, …)might lead to only one or 2 time bin information => no pulse shape

- large dE/dx differences between muons and protons and differences between noble gases + large differences in diffusion => dynamic range issue?

Conclusion: One electronic for different gases challenging!

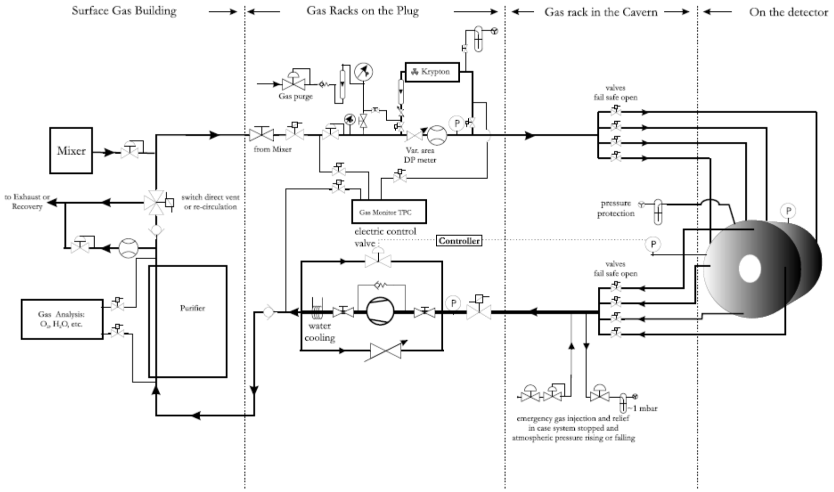
Gas System

Challenges:

- Stability of low quencher quantities over time?
- Oxygen: ppt to very few ppm; H2O: < few ppm
- Filling of the chamber for Ne/He mixtures
- Recovery system for expensive gases

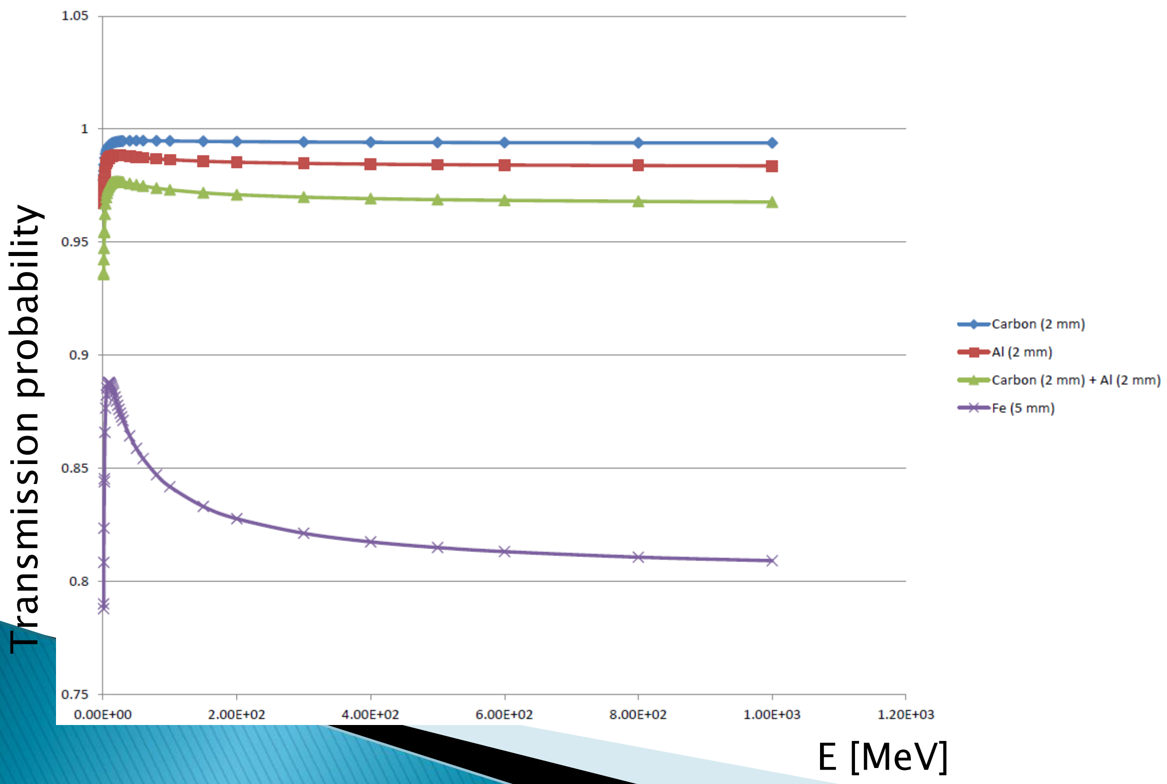
3 options:

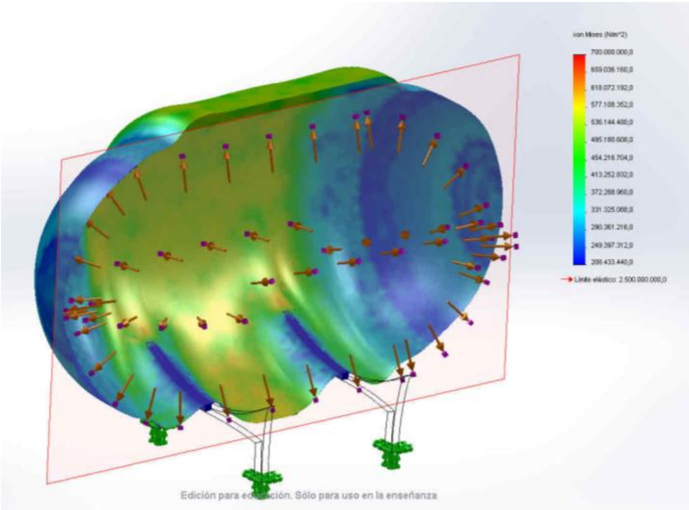
- Open loop (T2K): simple, cheap but only possible with Ar (gas costs)
- Closed loop (ALICE): more complex and more expensive but necessary with Ne(/He) and gases as CH4/iC4H10
- Closed loop with vacuum (NEXT): adds more complexity and costs, for pure noble gases and for some mixtures



Vessel

Challenges for the vessel:
- suitable for high pressure of 10 bar + margin
- thin to not stop e.g. photons before ECAL
- possibly also suitable for vacuum
- **Feedthroughs for ??? thousands of readout channels**





Field Cage

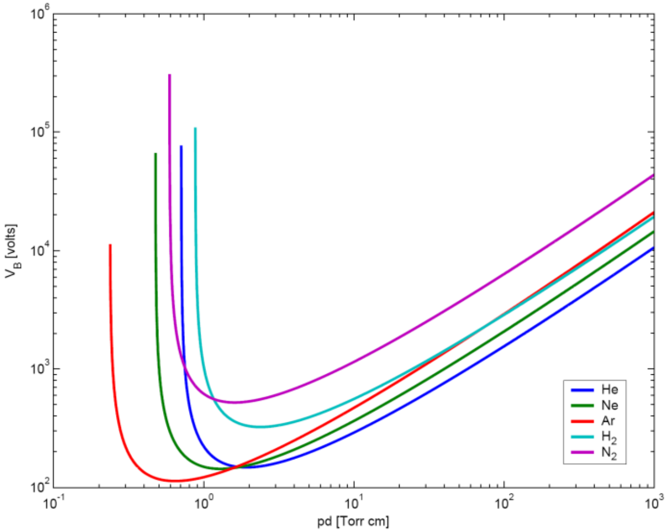
Obviously the field cage should be also light but this should not be the problem …

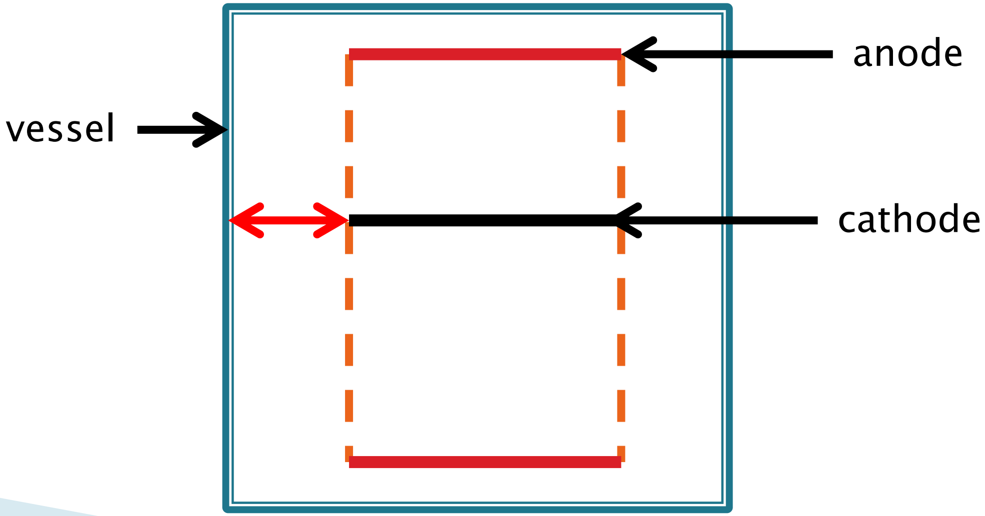
The problem is the HV insulation of the cathode!

HV @ cathode easily could reach 100 kV + margin = 150 kV!

Solid insulator contradicts thin walls + is delicate … spark might damage it permanently …

Insulation through HP gas is another option but factor 2 differences between gases (He ~ 10–15 cm, Ar ~5–7 cm @ 10 bar)





Personal Conclusions

- from the detector point of view a fascinating project

- using the same TPC with different gases challenging

- only one target nucleus or at least only Ne + Ar would simplify things a lot

- “exotic” fill gases not excluded but huge R&D necessary

- for sure not cheap

- large and well defined R&D program with input from physics necessary