Hydrogen-rich Gases for DUNE's High Pressure Time Projection Chambers Near Detector*

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on behalf of the DUNE collaboration

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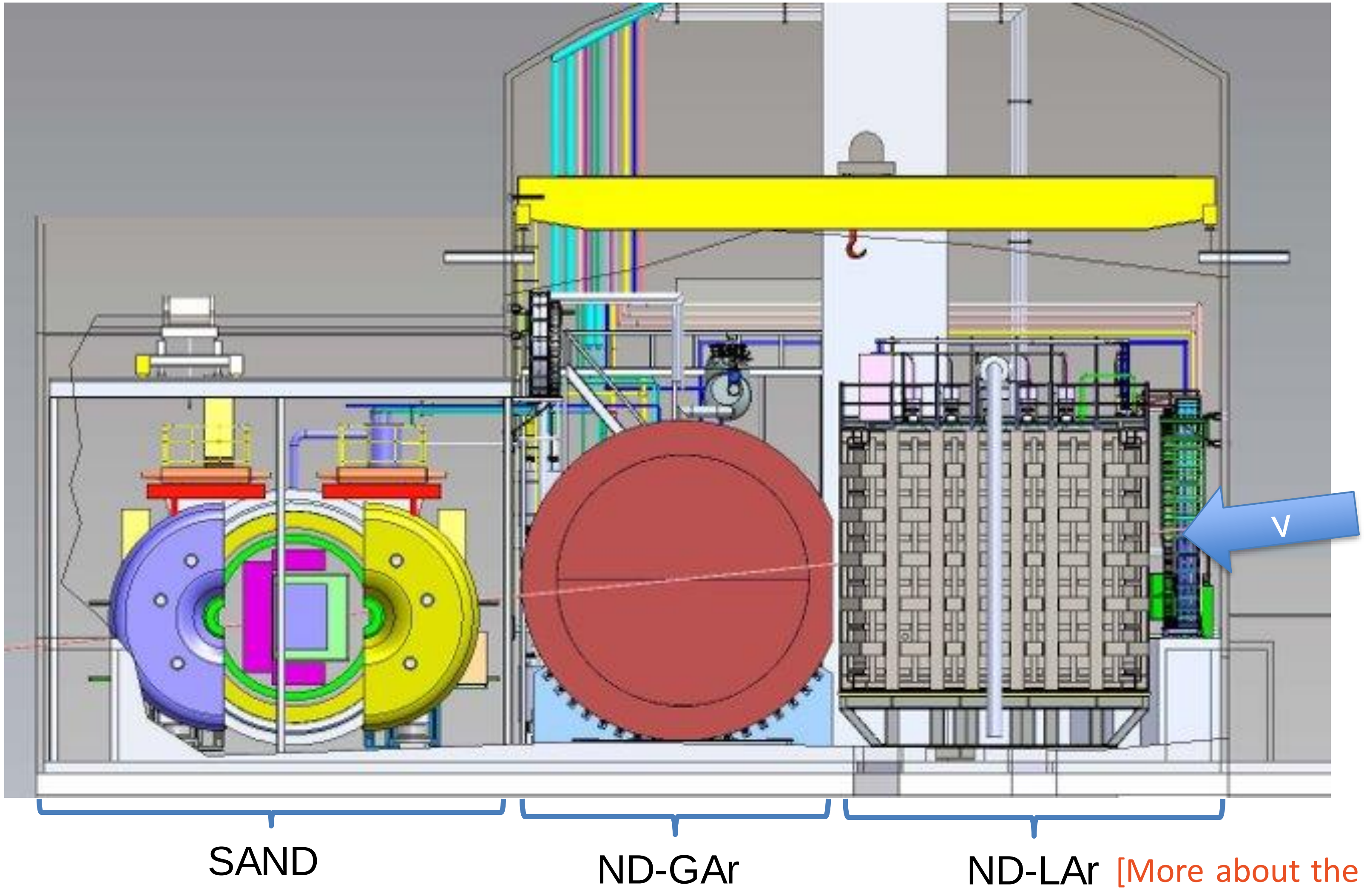
* based on *P. Hamacher-Baumann, X. Lu, J. Martín-Albo, Phys.Rev.D 102, 033005 (2020)*

(visitor from RWTH Aachen University)

The DUNE Near Detector



[More about the LAr technology in 12 minutes!]

ND-LAr

- Liquid Argon TPC
- Not magnetized

ND-GAr

- High pressure TPC
- Baseline mixture P10 (Ar + 10% CH_4)
- Magnetized + contains an ECAL
- Spectrometer for particles leaving ND-LAr
- Additional ν-Ar measurements
- *Very low tracking threshold*

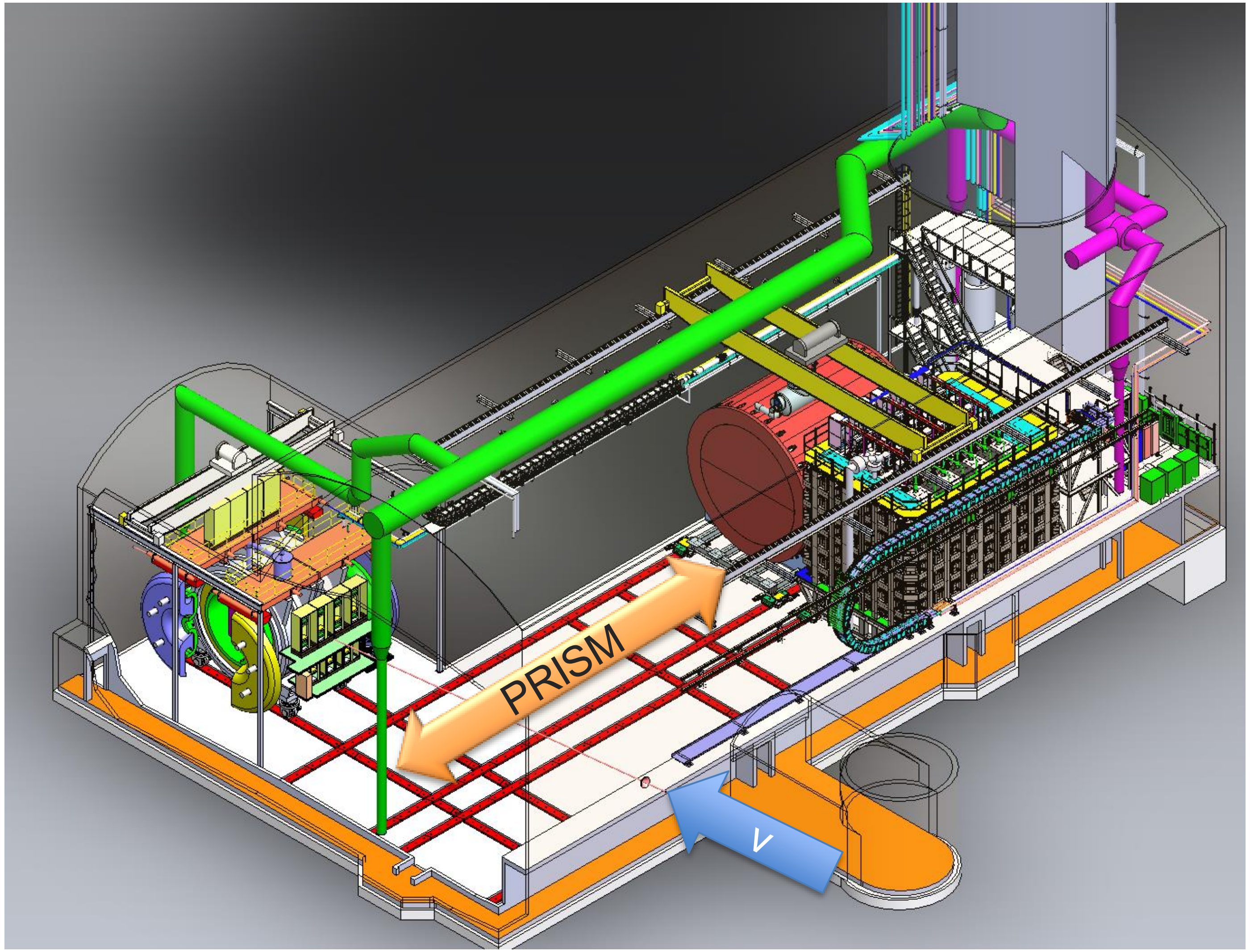
SAND

- Permanently on-axis beam monitor
- Magnetized

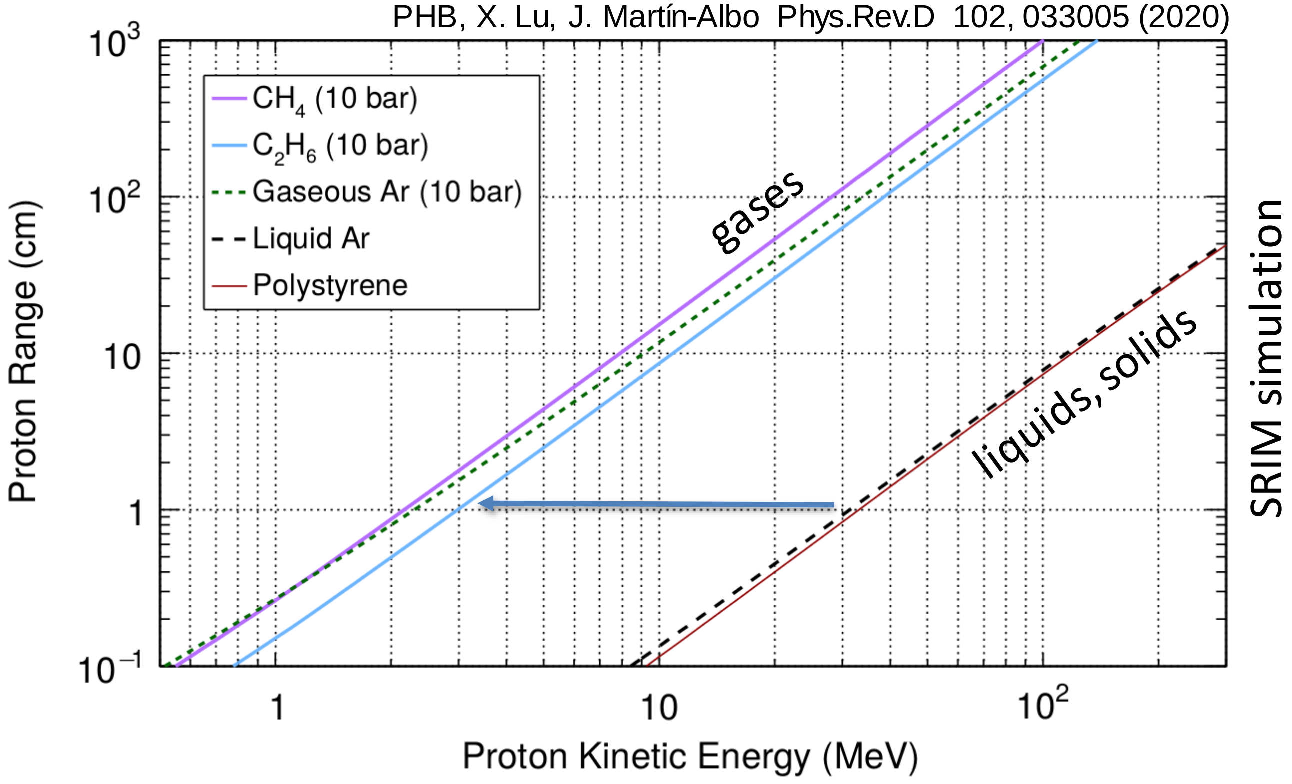
The DUNE-PRISM Concept

- ND-LAr and ND-GAr can be moved to off-axis positions.
- Changes ν flux and spectrum

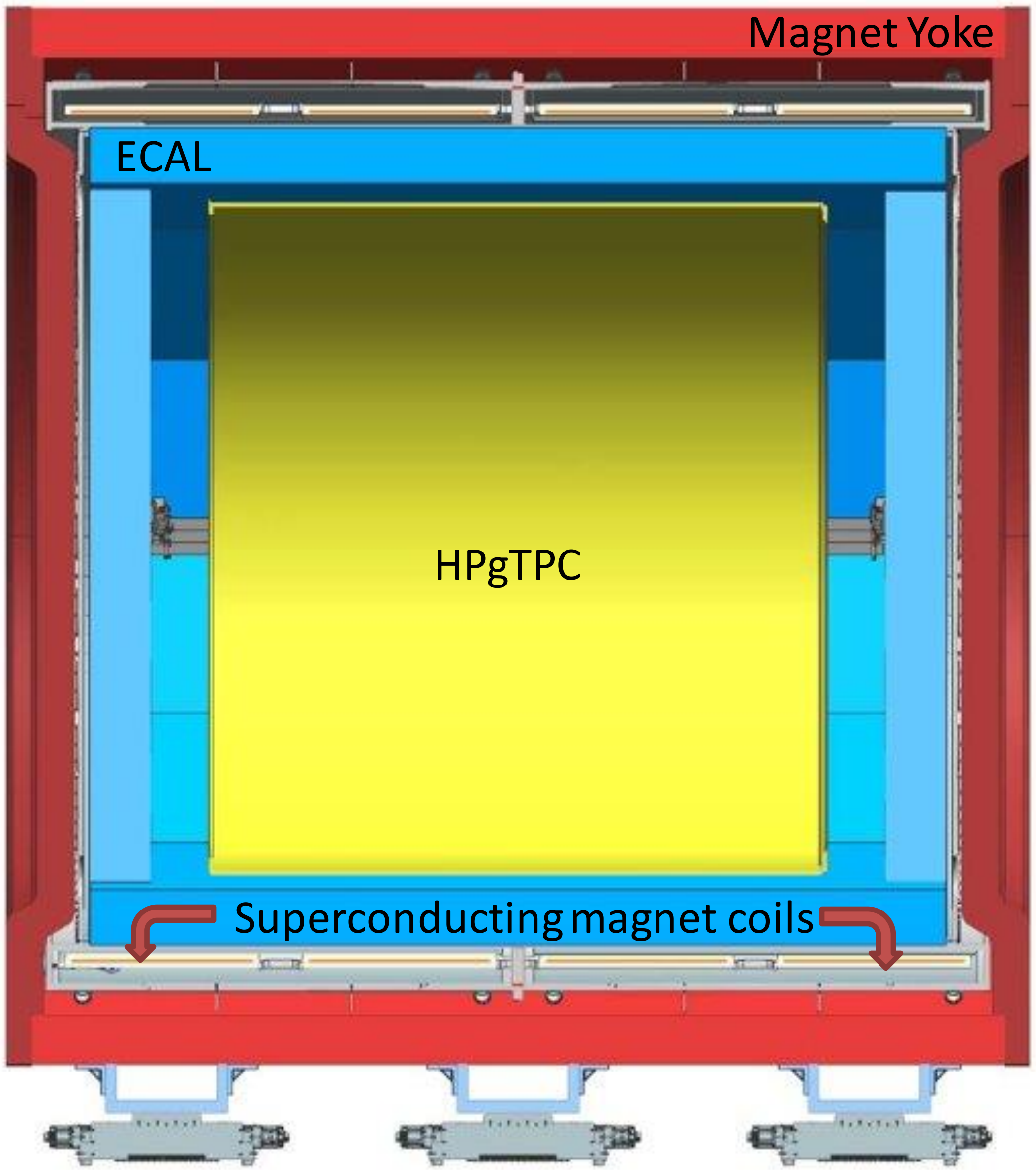
DUNE Near Detector CDR:
arXiv:2103.13910



ND-GAr



10 bar pressurized gas has ~10x lower tracking threshold, compared to liquids and solids.



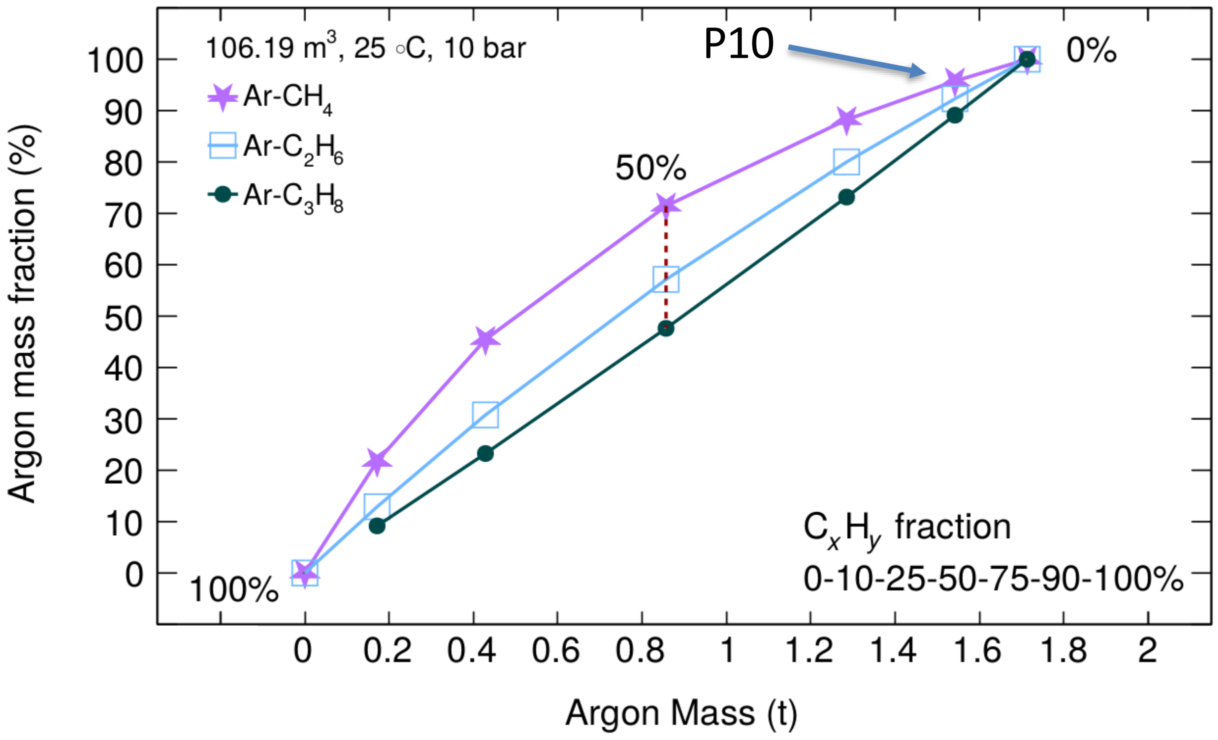
A Drift Gas for Neutrino Physics in ND-GAr

- Alkanes added to Ar as quenchers
- Contain a lot of hydrogen:
  - More H per mol in C_xH_y than in H_2
  - ν-H interactions can be selected by Transverse Kinematic Imbalance (TKI)

=> Clean interactions on single nucleons

Assess usability of Ar+C_xH_y mixtures in high pressure TPCs.

PHB, X. Lu, J. Martín-Albo Phys.Rev.D 102, 033005 (2020)



- 97% of ν interactions on Ar for P10
- Option for special run with high alkane-%

More details on ν-H interactions

- See Federico's talk (L14.3) today for more on TKI and its physics reach
- X. Lu, et al., Phys. Rev. D92, 051302 (2015)
- PHB, X. Lu, J. Martín-Albo Phys.Rev.D 102, 033005 (2020)

Pressurized Drift Gases

Electron drift strongly depends on gas density

- TPCs historically operated at close to atmospheric pressure
- Understanding at atmospheric conditions can be scaled to high pressure region

Scale drift field

$$\boldsymbol{E \rightarrow \frac{E}{N} \propto E\frac{T}{p}}$$

magnitude	scaling ($n = N/N_0$)
electron, ion drift velocity v_d	$v_d(E/n)$
electron, ion diffusion coefficients $D^*_{L,T}$	$\frac{1}{\sqrt{n}} D^*_{L,T}(E/n)$
attachment coefficient η	$n \cdot \eta(E/n)$ ^{*a}
Light transparency $\mathcal{T}$	$\exp(-n\Pi_a L^*)$
scintillation probability P_{scin}	$\frac{1}{1+n\tau k}$
particle range R	R/n
Fano factor F_e, W_I, W_{ex}	$\sim$ constant
charge multiplication coefficient α	$n \cdot \alpha(E/n)$ ^{*b}
secondary scintillation coefficient Y	$n \cdot Y(E/n)$ ^{*b}

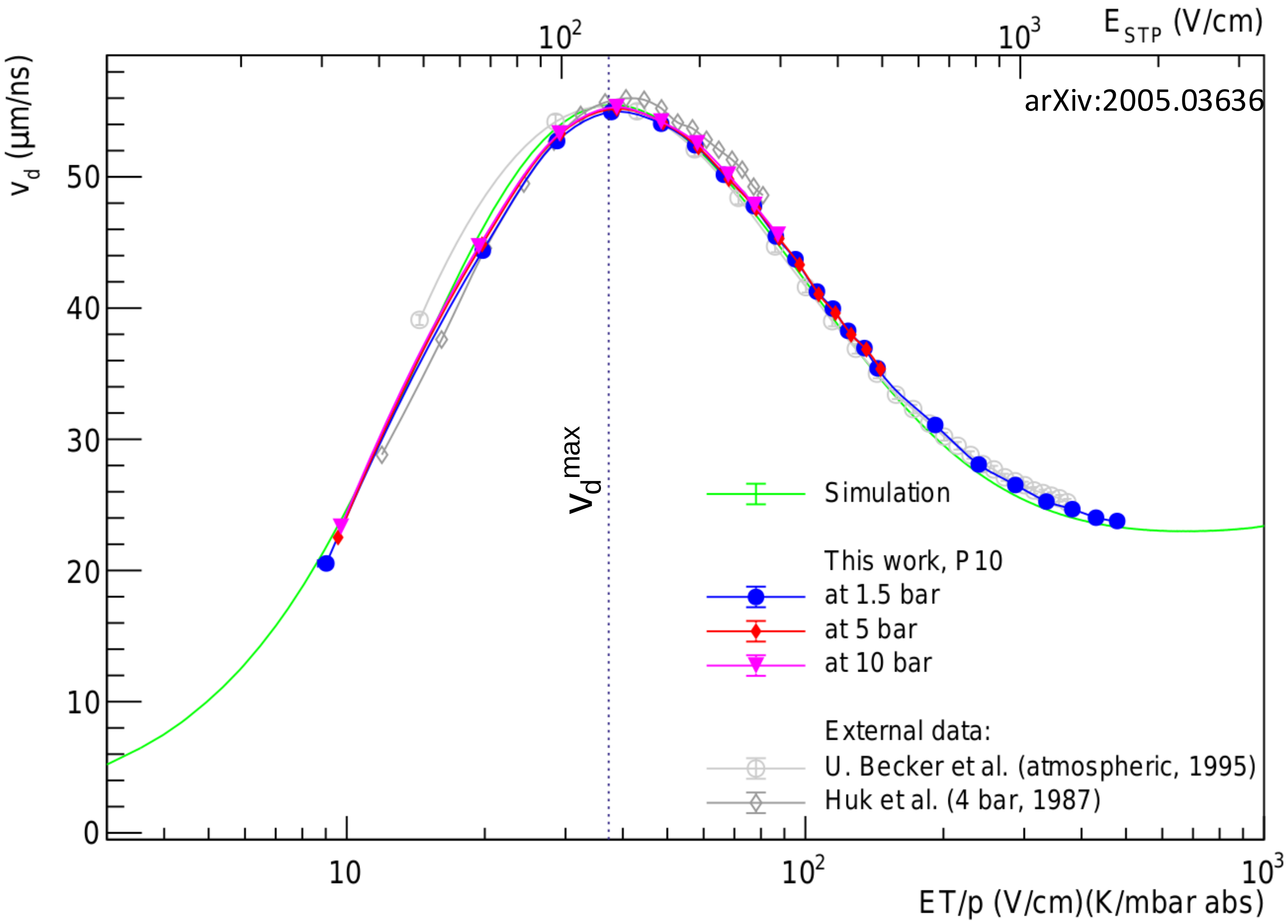
[D. Gonzalez-Diaz, F. Monrabal, S. Murphy *Nucl.Instrum.Meth.A* 878 (2018) 200-255]

Drift Velocity – Measurement in P10

Measurement done with High Pressure Gas Monitoring Chamber [PHB, arXiv:2005.03636]

- 10 bar pressure range covered
- Data corrected for pressure is self-consistent
- Matches with other data
- Simulations provided by MagBoltz

Pressure scaling in T/p verified for 10 bar range!



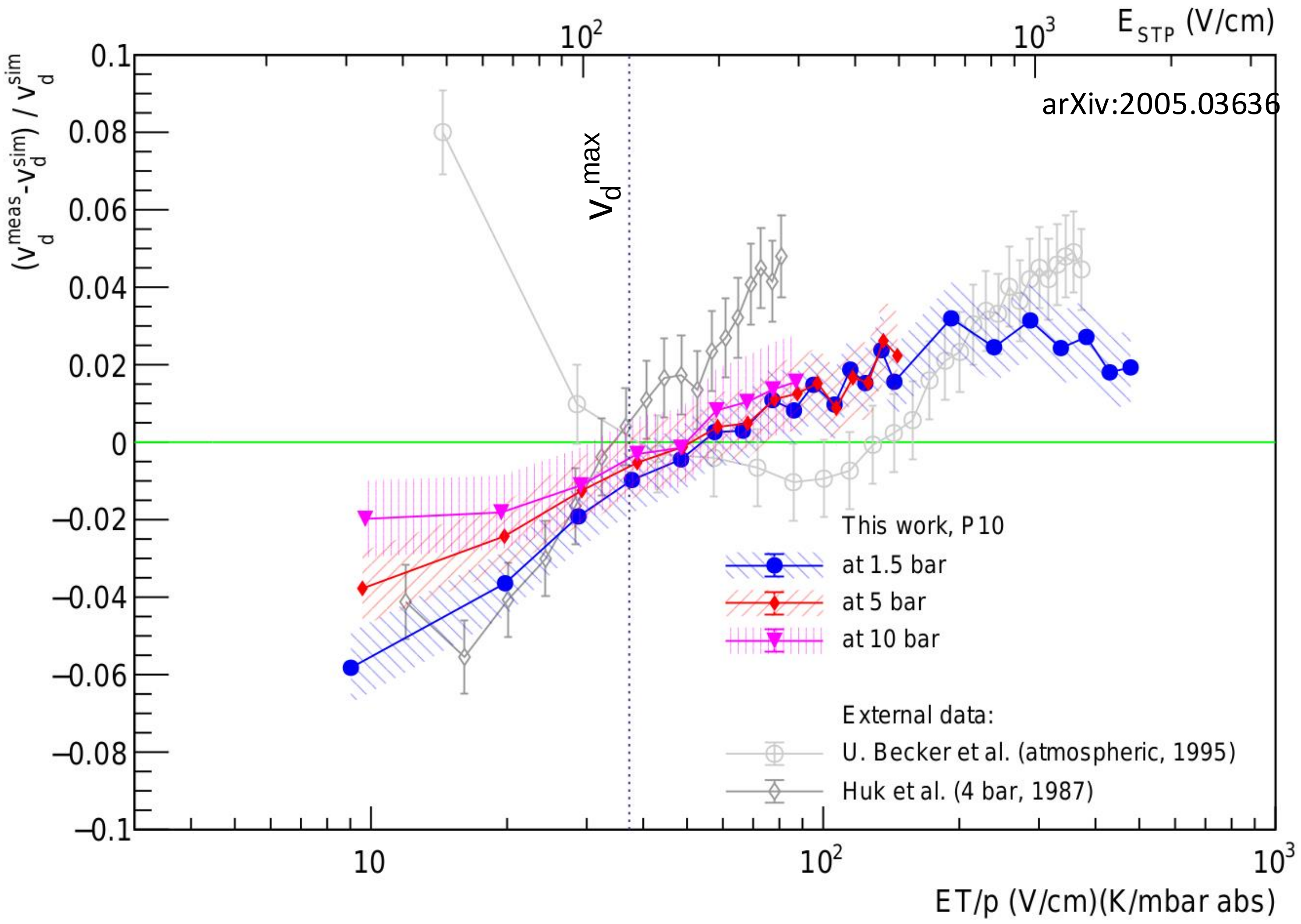
Measurement to Simulation Comparison

Simulation and measurement of v_d do not line up perfectly:

- Underestimated at low fields
- Overestimated at higher fields
- *Maximum not at same field for data and simulation!*

Simulation precision can be improved upon by calibration.

Simulation accurate to ~4% level.

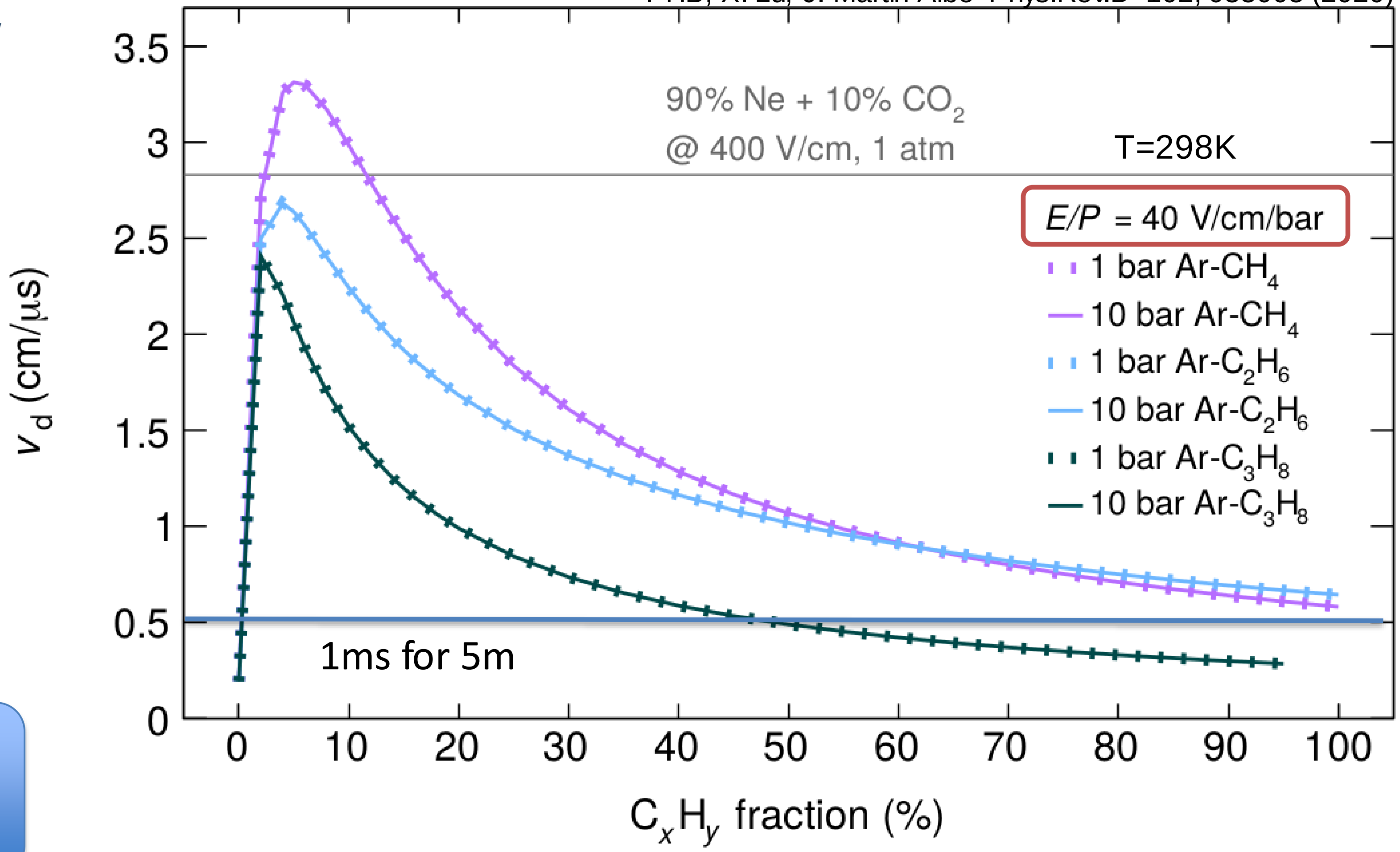


Drift Velocity in Hydrogen-Rich Mixtures

- *H*-rich mixtures relatively slow at constant E/P
  - v beam arrives at O(1Hz)
  - kHz extraction times possible
- Fields for different C_xH_y can still be optimized

_H_-rich gases are slow, but usable.

PHB, X. Lu, J. Martín-Albo Phys.Rev.D 102, 033005 (2020)



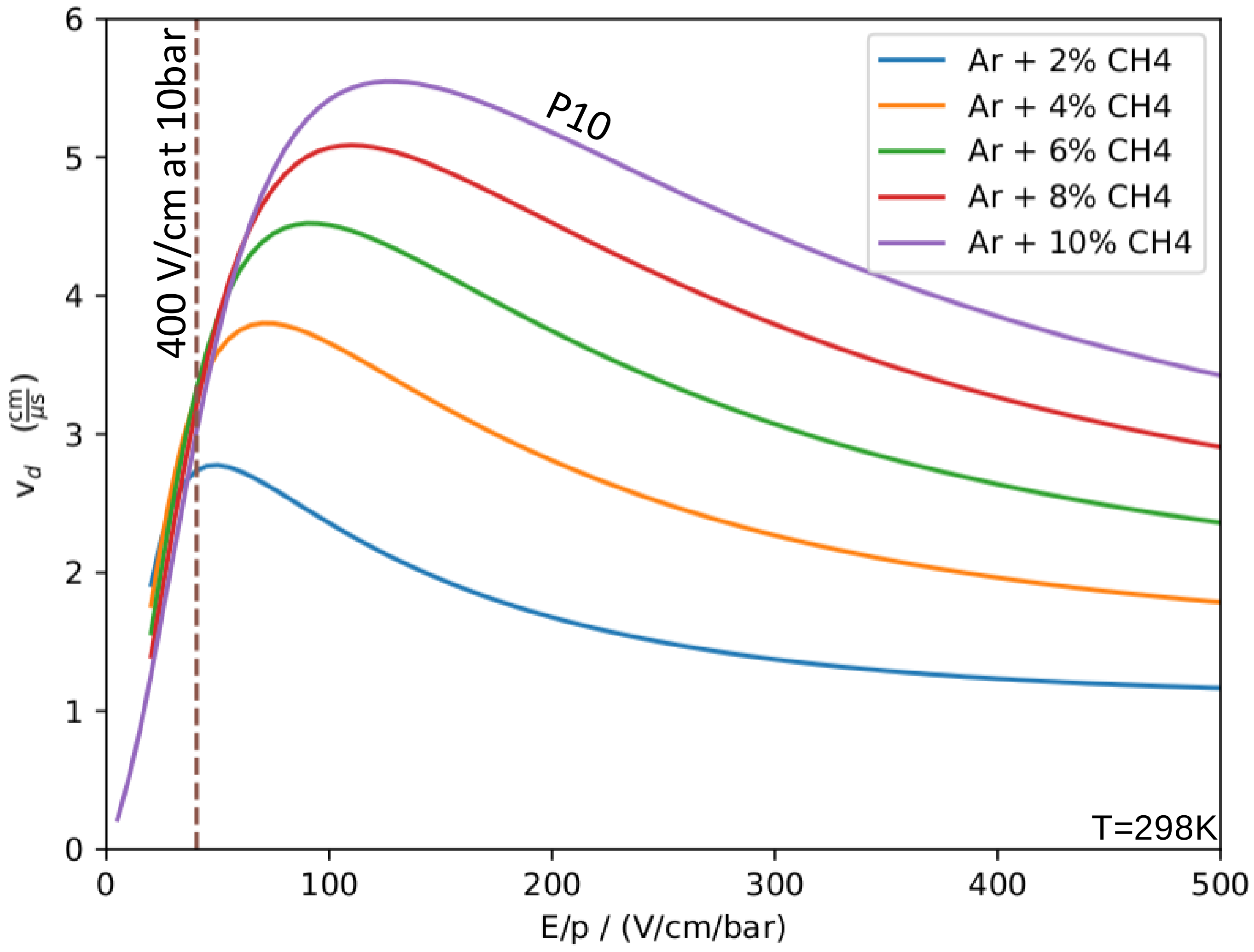
Alternative Baseline Gas Mixture

- Fields limited by cathode HV
- Operation point lies on rising flank of v_d

Q: What would be a good operation point for a given gas mixture and cathode HV?

A: Choose CH_4 content such that v_d maximum at ALICE's field for close-to T, p independence.

For the ALICE field at 10 bar, using Ar + 2% CH4 compensates for small T, p fluctuations.



Diffusion

Diffusion suppressed by √p

- 10 bar suppression ~3.2
- Comparable for σ_T to a 3 T magnetic field

At 10 bar, a 0.5 T field only reduces σ_T by ~1%.

Pressure reduces longitudinal and transverse diffusion close to the thermal limit!

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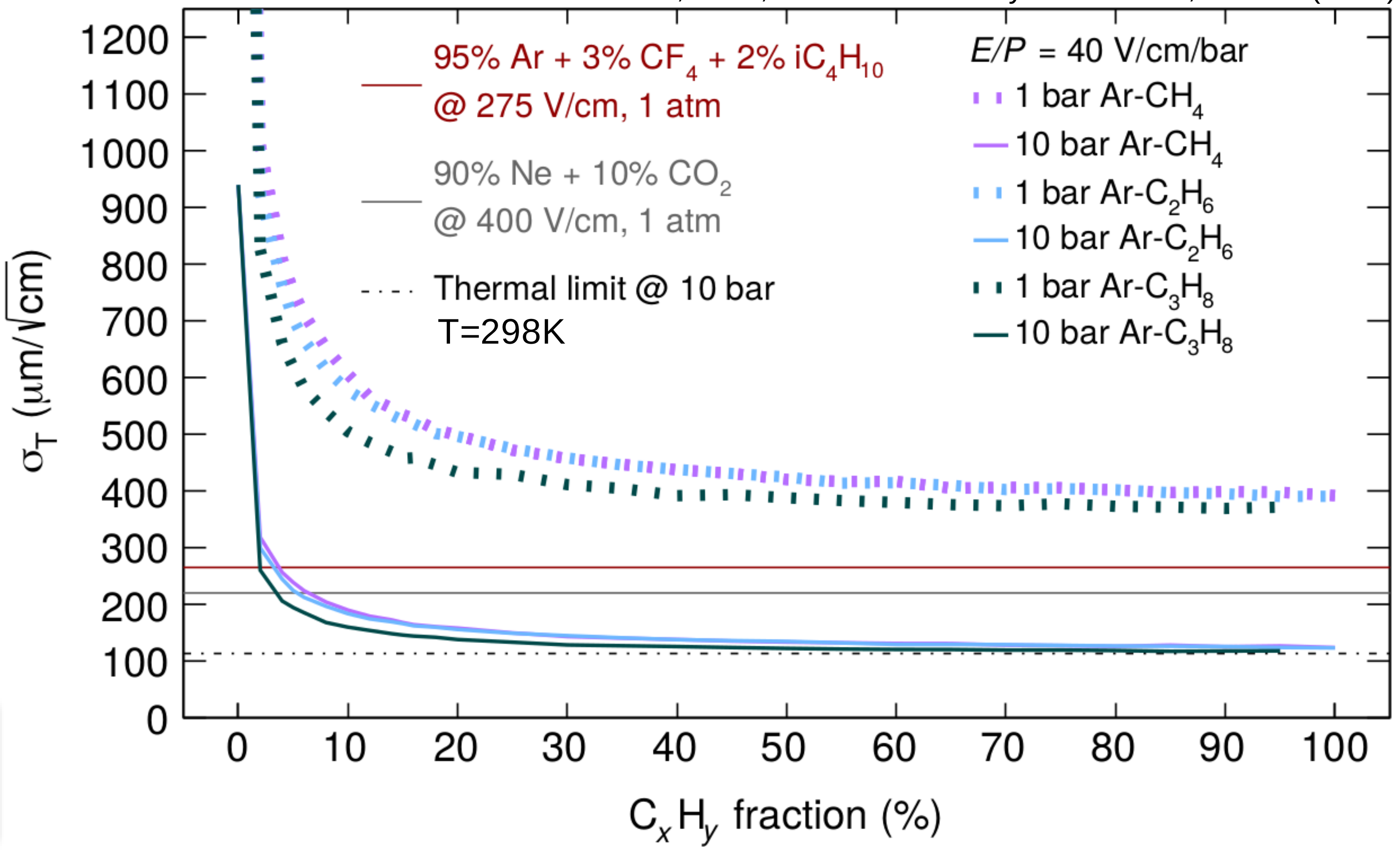

Conclusion

The baseline gas P10 can be simulated down to few %-level precision

- Pressure scaling confirmed up to 10 bar pressure
- Multiple data sources confirm precision
- Mitigation by continuous calibration is possible

H-rich (high-% alkane or even pure) mixtures can be used to operate a large high pressure TPC

- **T**ransverse **K**inematic **I**mbalance analysis extracts ν–hydrogen interactions from mixed target material, without relying on pure hydrogen gas. (Reminder: *L14.3* later today)
- Optional run with high alkane fraction in HPgTPC gas a possibility

Also performed the swarm parameter study with He + C_xH_y

- Helium has significantly fewer bound protons (compared to Ar)
- Mixtures generally slower in electron drift velocity, but still usable

For more see *P. Hamacher-Baumann, X. Lu, J. Martín-Albo, Phys.Rev.D 102, 033005 (2020)*

Thank You!