An integrated Ar detector for the DUNE near detector

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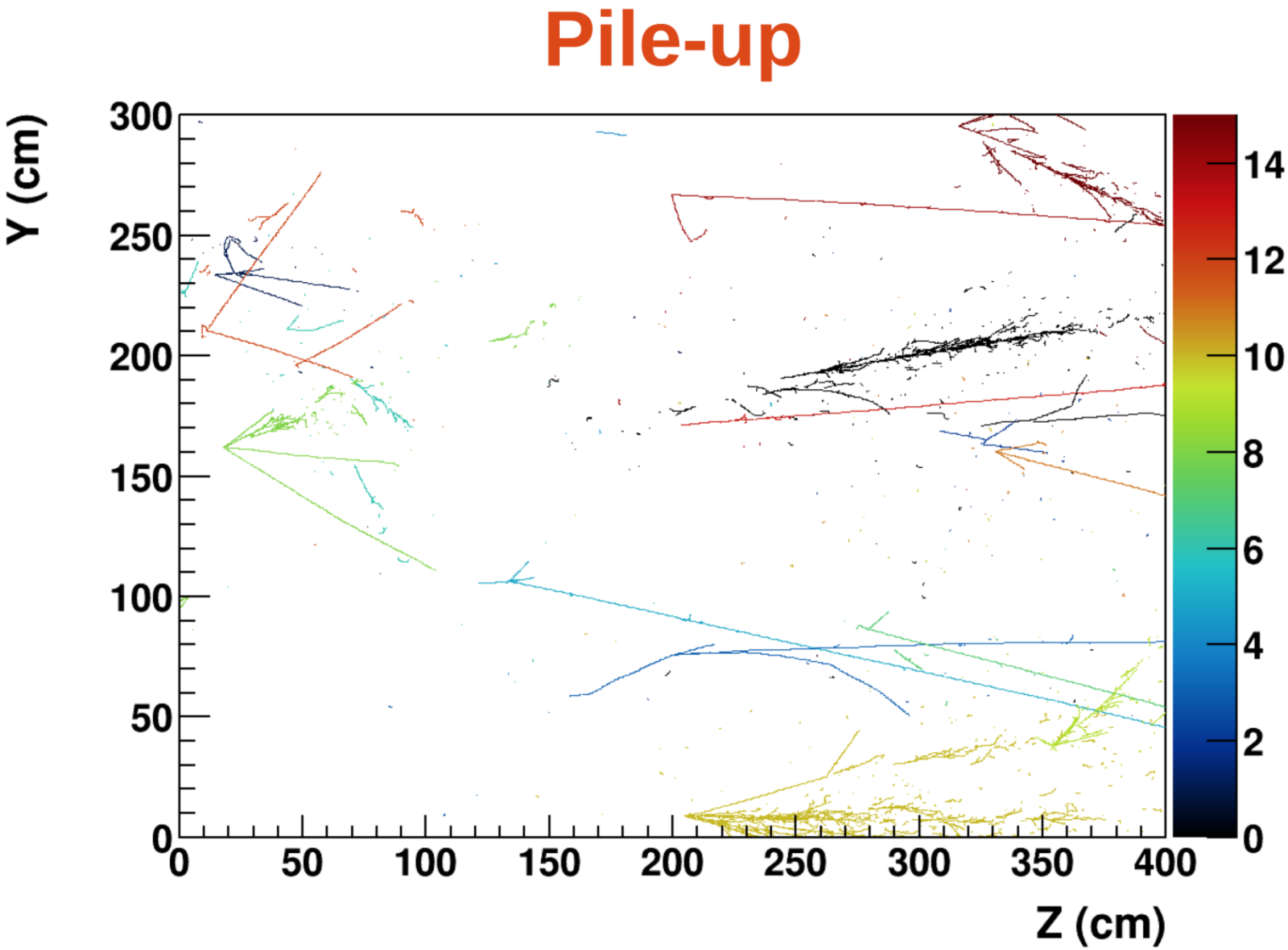
ArgonCube Collaboration Meeting

17-Oct-2017

Integrated Argon near detector for DUNE

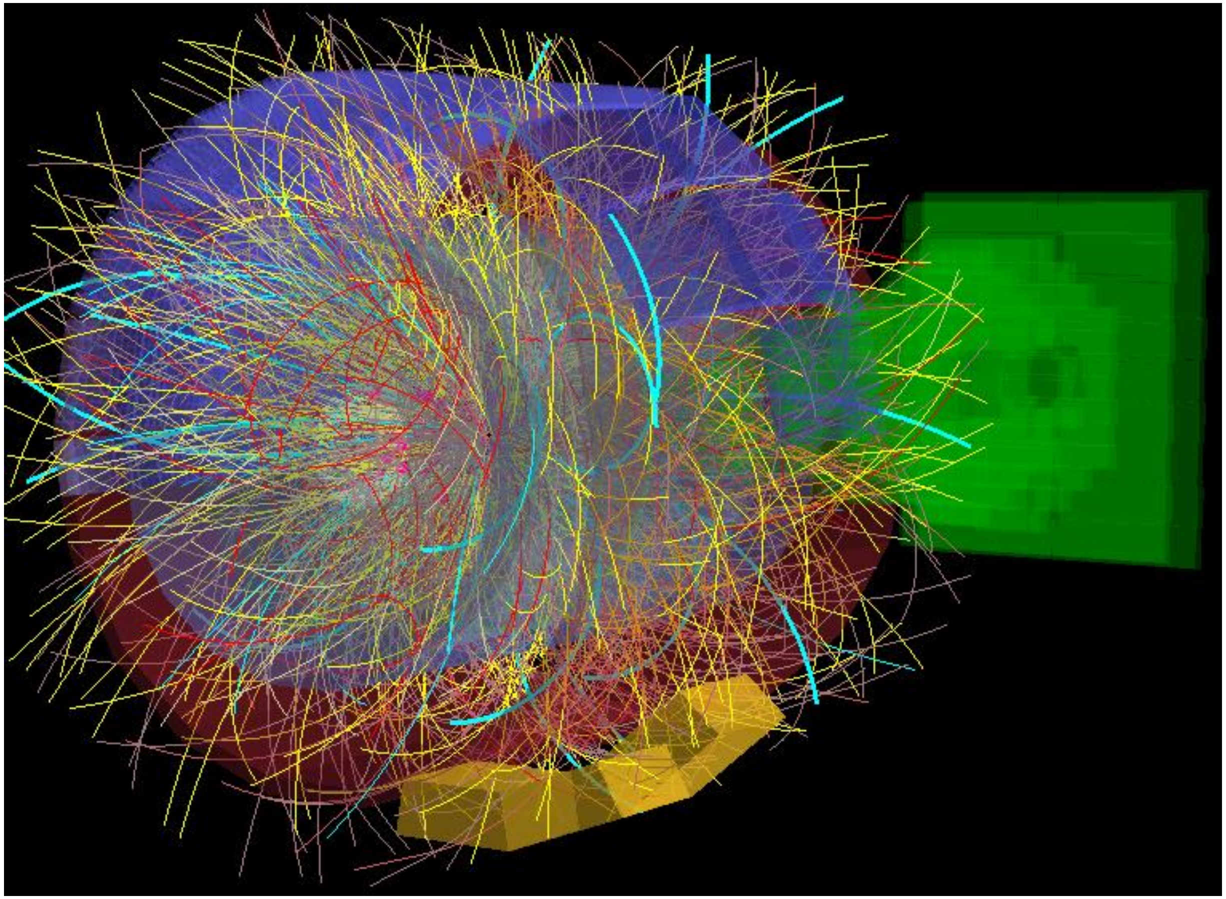
- We have reached a consensus that the ArgonCube concept is the preferred LAr implementation for the DUNE near detector suite
- A magnetized fine-grained tracker (FGT) is the second component of the detector suite
- We feel that a high-pressure (10ATM) gaseous Ar TPC provides the best solution for the FGT in that with ArgonCube, it forms an integrated Ar detector solution for the DUNE near detector
- A magnetized Gas TPC provides two functions:
  - Aids in event containment for the LAr
    - High-resolution μ spectrometer
    - Hadronic energy
      - dE/dx (in conjunction with μ tag) for particle ID
      - Momentum measurement ($\delta p/p$ in range of a 1-5% in momentum range of interest)
  - Stand-alone experiment
    - If high pressure (10 ATM), neutrino event yield is ~5-10M ν_μ CC events in 3 yr ν running
      - For the size detector we are considering
    - A HP Gas TPC offers unprecedented "3D vertex visualization" for an electronic detector
      - Only surpassed by emulsion detectors

From Chris' talk yesterday, we see that event pile-up at a LAr near detector is a potential concern



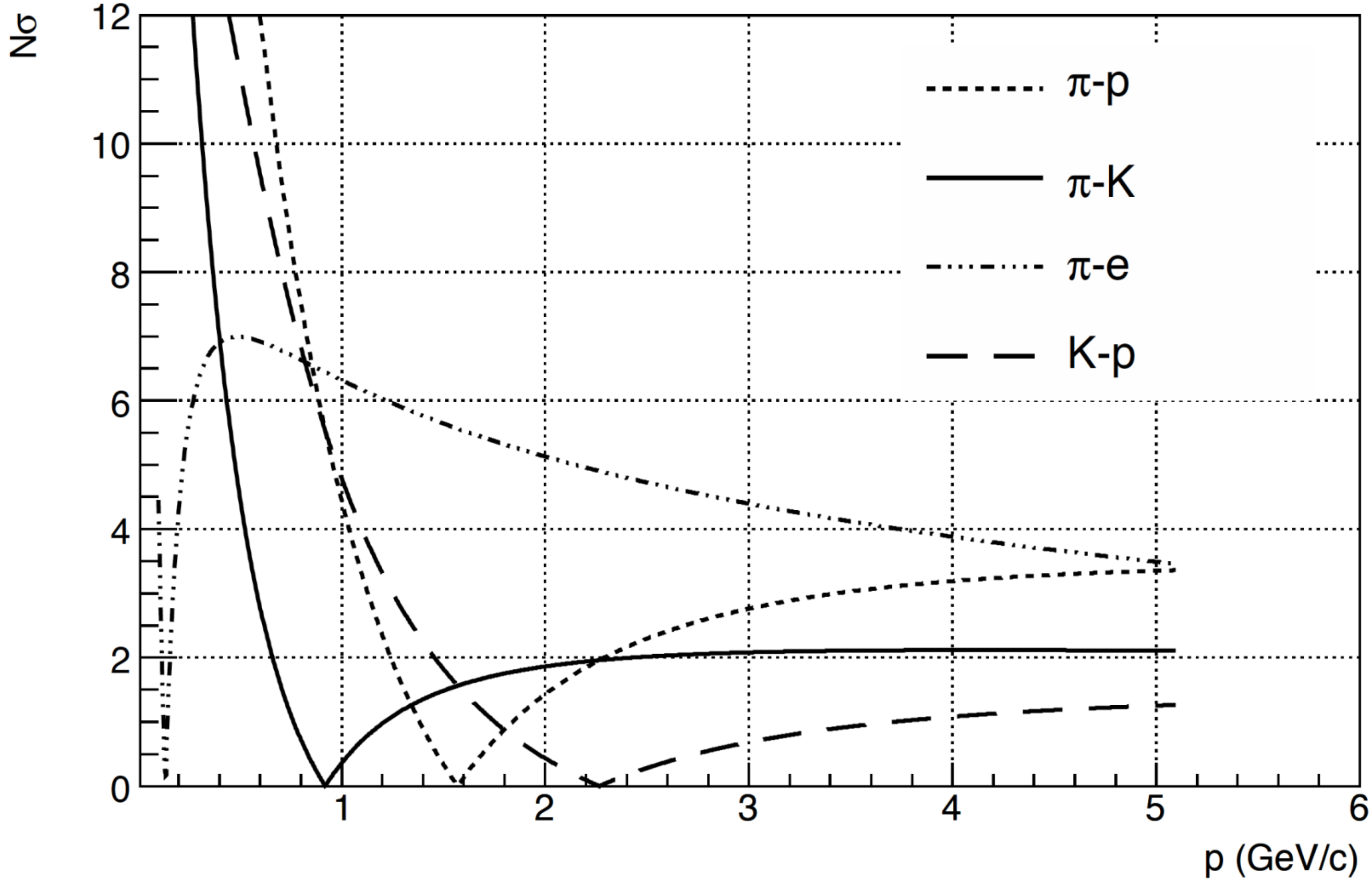
But, this is what real event pile-up looks like

ALICE: Pb-Pb collisions



- ALICE can reconstruct
  - Up to 8000 tracks/unit rapidity
  - With >99% efficiency
- In pp collisions reconstructs and tracks in 17 overlapping interactions per crossing
  - Vertex constraint used last
- Showers make it more difficult, but showering from e/γ in the TPC is limited due to low mass.
  - Requires detailed analysis of backgrounds from events originating external to the TPC

Tracking + dE/dx +E/p is very powerful



Tracking efficiency

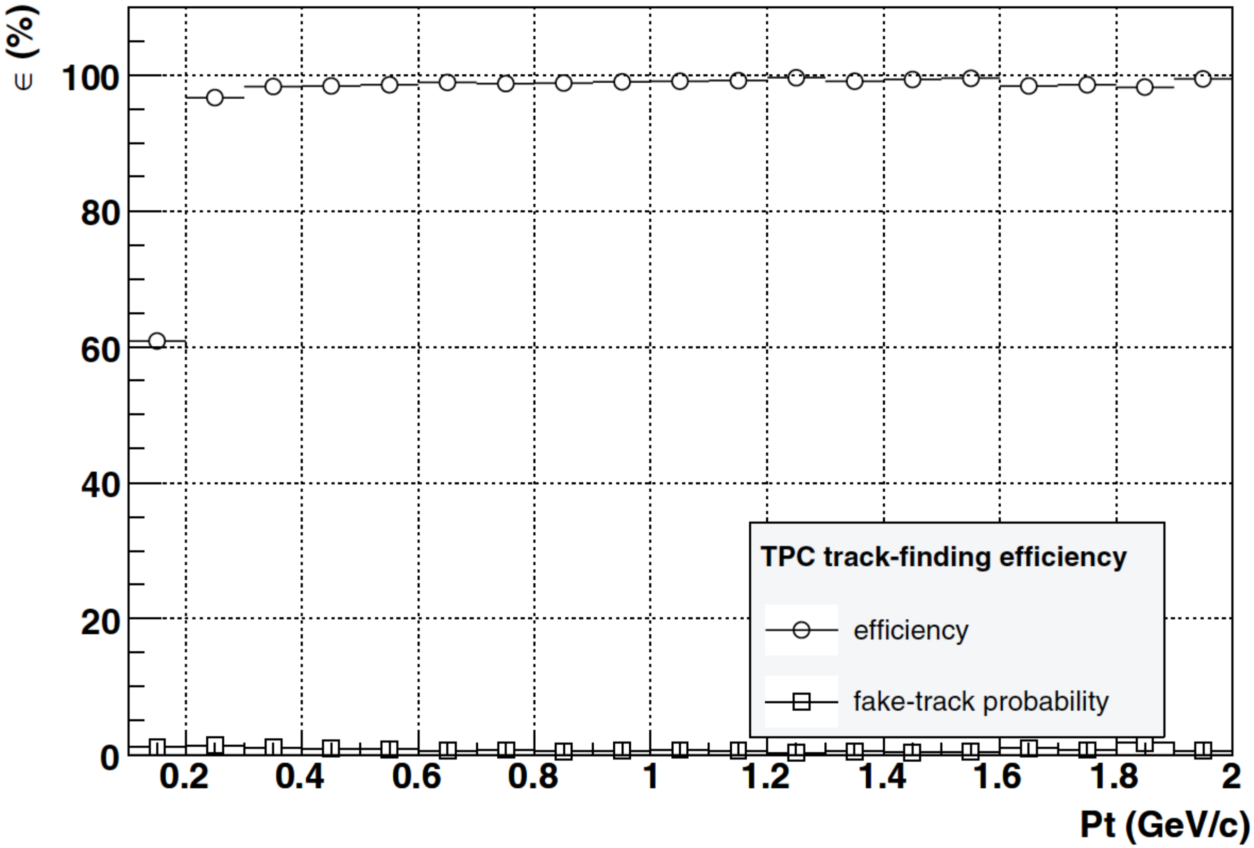
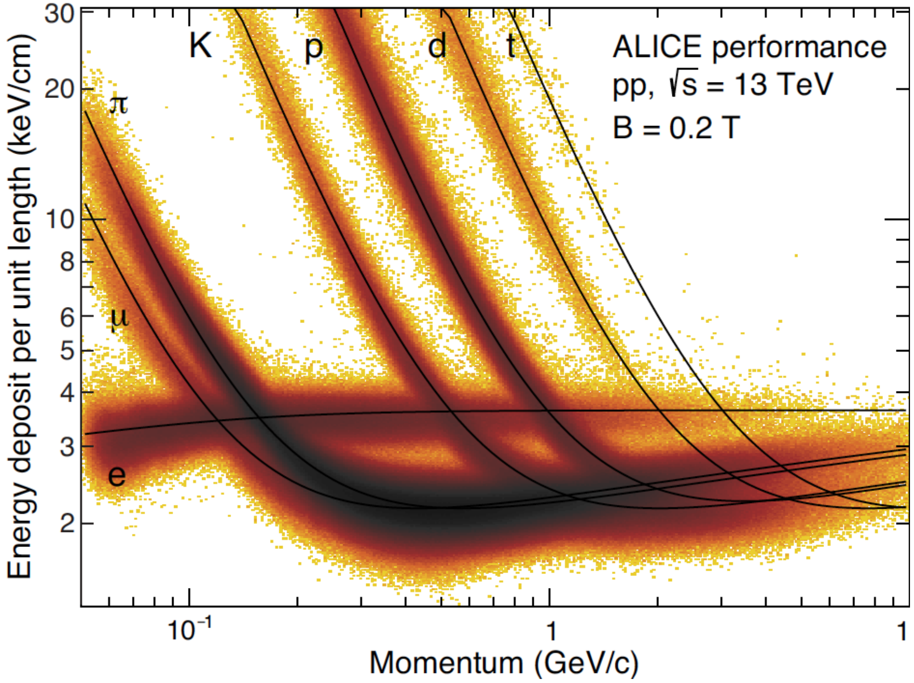
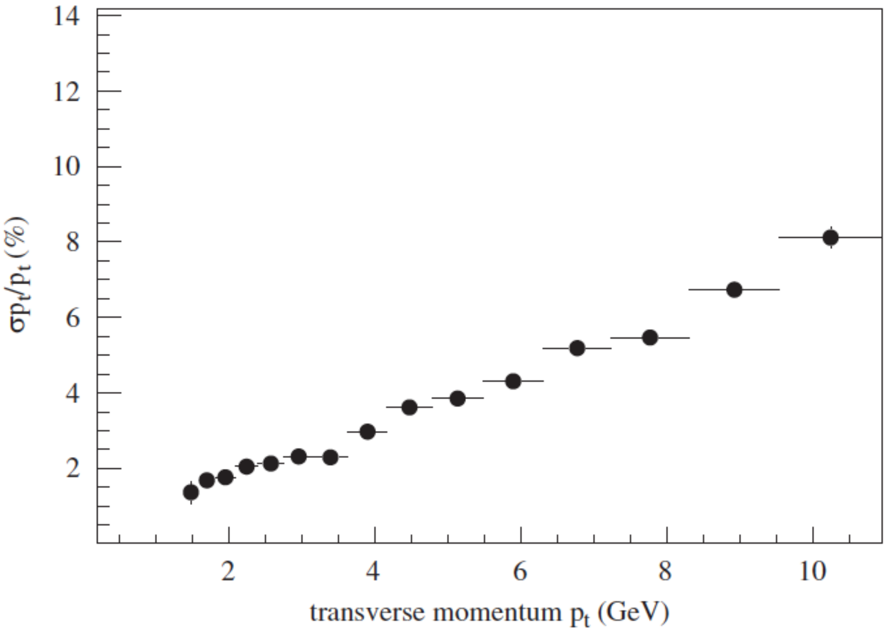


Figure 5.12. Efficiency of the TPC track-finding software as a function of particle transverse momentum for central Pb–Pb collisions ($dN_{ch}/d\eta = 6000$).

With excellent momentum and dE/dx resolution





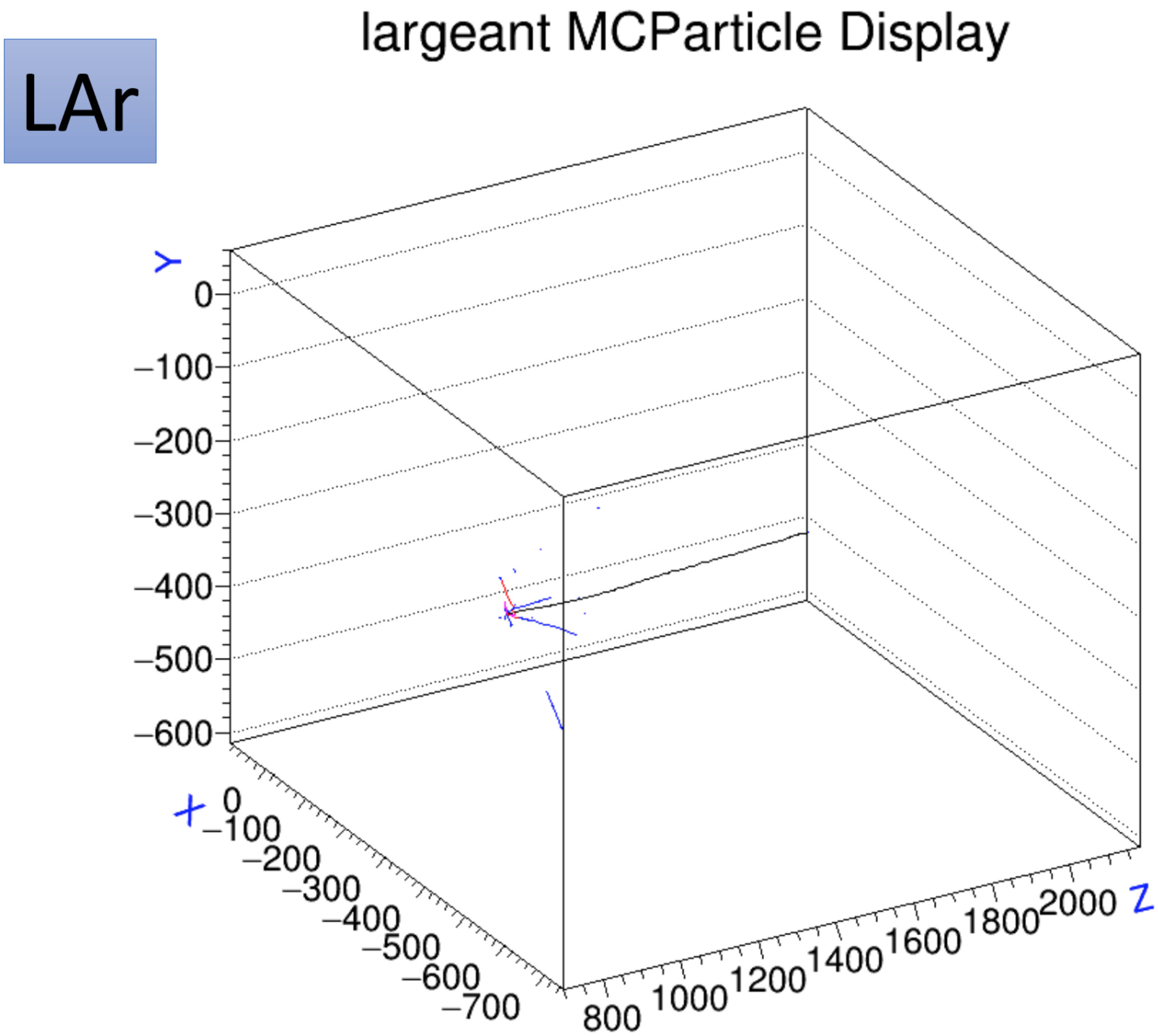
Our concept for HP Gas TPC

- Re-purpose ALICE readout chambers
  - Existing chambers will be replaced in 2019 for High-lumi LHC
    - In discussion with ALICE management
    - Represents significant $$ contribution
  - They have only operated at 1 ATM, but calculations indicated that operation at 10ATM looks possible without introducing electrostatic instability
    - Test stand now being setup at Fermilab using one of ALICE's inner readout chambers (IROC)
- Tremendous synergy with ArgonCube
  - Target nucleus
    - Not 100% Ar, but 90% Ar + 10% CH_4 is certainly a possibility
      - Also looking into CO_2, Xenon, N_2 and H_2 doping (more later)
  - Raw 3-D data
  - Similar readout electronics architecture
  - Common data structure
  - Common pattern recognition, track finding, event recon. Algorithms
  - Light detection – Tricky

“Event Samples”

- Tom Junk and Minerba Betancourt used the LarSoft implementation of Far detector to see what some events look like, if you replace the LAr with 10ATM of Ar gas
- No pattern recon, reconstruction, since this framework assumes wire planes.
- MC Truth

ν_μ CC with 2 pions

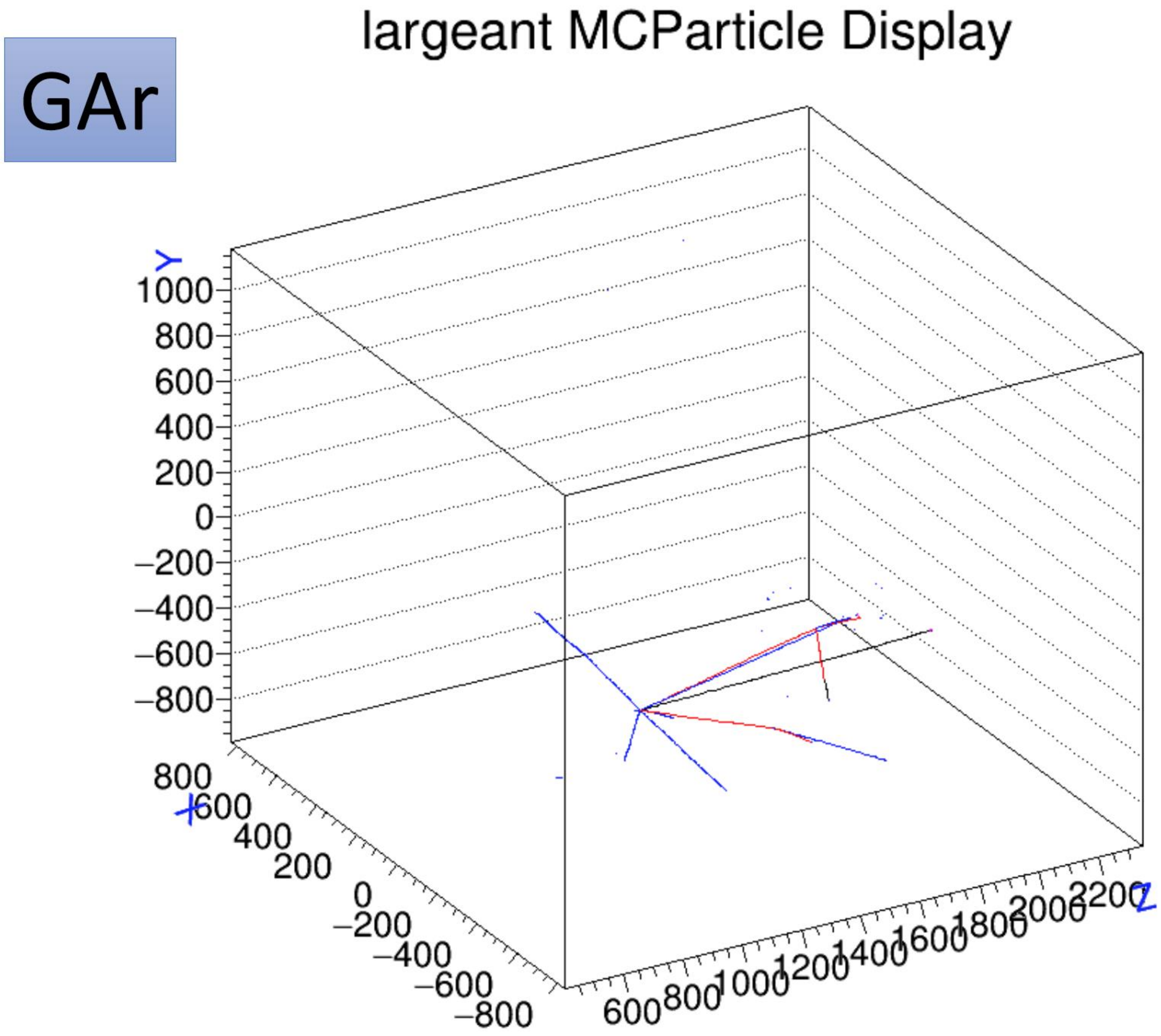


Another CC Event, with two pions

Red: Charged π

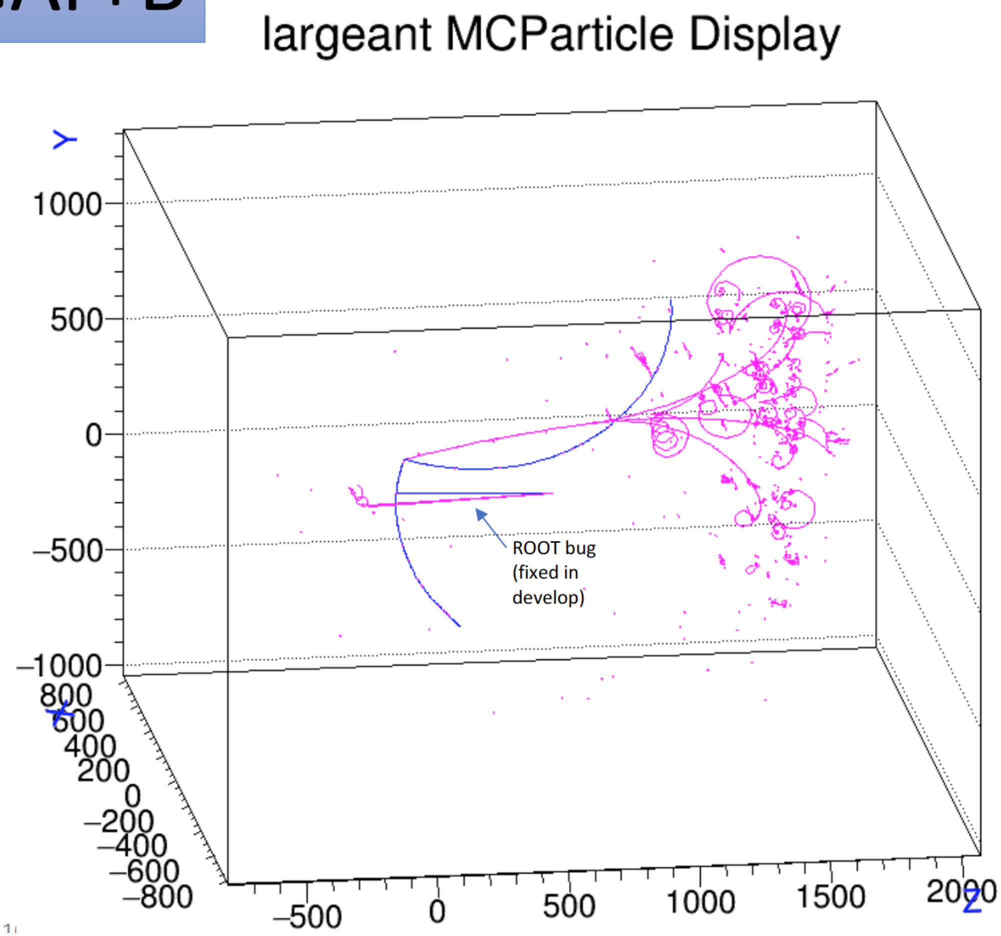
Fermilab

Same event


GAr
largeant MCParticle Display
Y
1000
800
600
400
200
0
−200
−400
−600
−800
X
800
600
400
200
0
−200
−400
−600
−800
Z
600
800
1000
1200
1400
1600
1800
2000
2200

ν_e CC, but with B (0.5T) on

GAr+B



- Notes:
  - This is a giant (~ 20 X 20 X 25 m^3) volume
  - Most electrons will not shower in TPC

3 GeV e$^-$

muon
proton
charged pion
electron

TJ's observations (with my edits in blue)

- Track lengths are great for low-energy particles in Gar as compared with LAr
- Separation of $\mu^{\pm}$ from $\pi^{\pm}$ over the momentum range of interest will require muon chambers outside of the GAr
- Electrons that shower in GAr are wonderful, but given the size of the gas TPC, an ECAL will be needed.
  - But momentum analysis and dE/dx are powerful tools
- Very low-energy particles may turn around and go back in the B field before hitting the ECAL
  - dE/dx for energy determination or possibly momentum analysis
- Low-energy particles spiral around magnetic field lines

- That said: 4π visualization is unmatched

Integrated Ar detector, well almost. TPC gas considerations

TPC Gas

- Although many of the conventional TPC gases will work fine to track secondaries from ν interactions, we strive to match the target nucleus to that of the far detector. Noble gas + additives are necessary
  - Ar-CH_4 (90-10, P10); Ar-CO_2;……

Gas	Ratio	Density*10^{-3} (g/cm^3)	Radiation Length (m)	N_p (cm^{-1})	N_t (cm^{-1})
He		o.178	5299	4.8	8
Ar		1.782	110	24.3	94
Ne		0.9	345	12	43
Xe		5.86	15	44	307
CF_4		3.93	92.4	51	100
DME		2.2	222	60	160
CO_2		1.98	183	35.5	91
CH_4		0.71	646	26.5	53
C_2H_6		1.34	340	41	111
i-C_4H_{10}		2.59	169	84	195
Ar-CH_4	90-10	1.67	120	24.5	90
	80-20	1.57	132	24.7	85.8
	70-30	1.46	147	25	82
Ar-C_2H_6	90-10	1.74	118	26	95.7
	80-20	1.69	127	27.6	97.4
	70-30	1.65	138	29	99.1
Ar-iC_4H_{10}	90-10	1.86	114	30.27	104.1
	80-20	1.94	118	36.24	114.2
	70-30	2	122.8	42.21	124.3
Ar-CO_2	90-10	1.8	114.5	25.42	93.7
	80-20	1.82	119.5	26.54	93.4
	70-30	1.84	124.9	27.66	93.1

Can we run with pure Ar?

- No
  - Gain instability due to photon feedback
  - Large transverse diffusion (even with B field)
- That's why CO_2, CH_4, etc. are added
- Take another approach
  - One gas to quench photons
  - Another to reduce transverse diffusion
- Possibility:
  - 100-1000 ppm Xe +
  - ~1% H_2 +
  - Maybe a little N_2
- Advantages
  - Possibly run with up to 98% Ar
  - Still maintain some scintillation light in the detector
    - Fast timing

Xe doping

Neumeier et. al

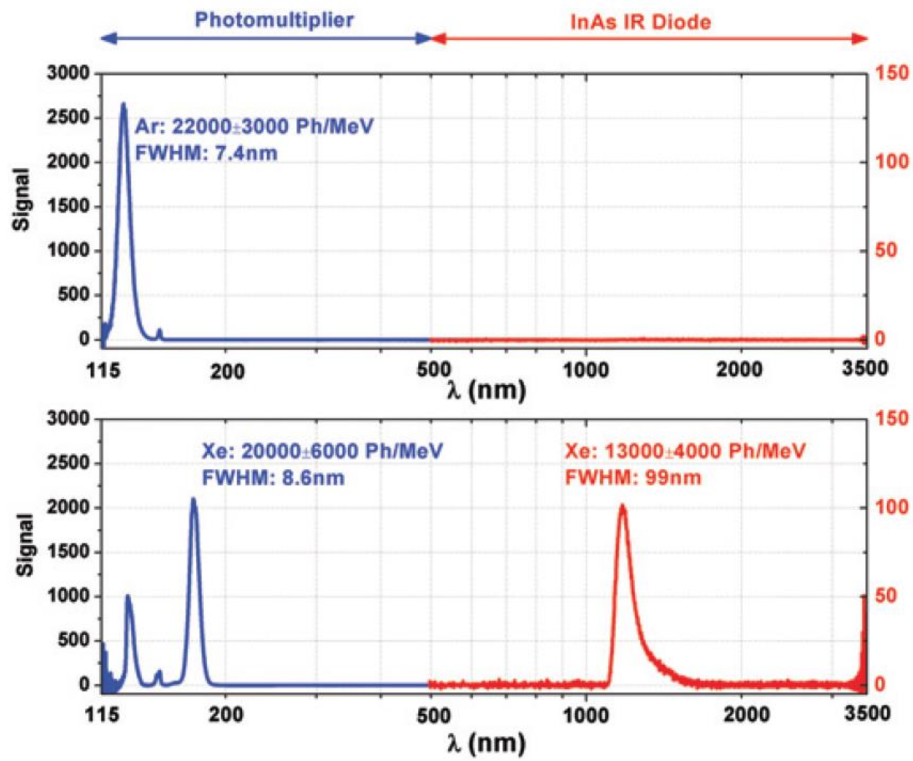


Fig. 1: (Colour on-line) Electron-beam–induced VUV and IR emission spectra of pure liquid argon (upper panel) and liquid argon doped with 10 ppm xenon (lower panel). In the VUV, the Xe doping leads to a shift of the signal from the 127 nm Ar emission to the 174 nm xenon emission. In addition to the VUV, an IR emission is formed at $\sim 1.18\,\mu$m peak wavelength

Xe + N_2 in Ar

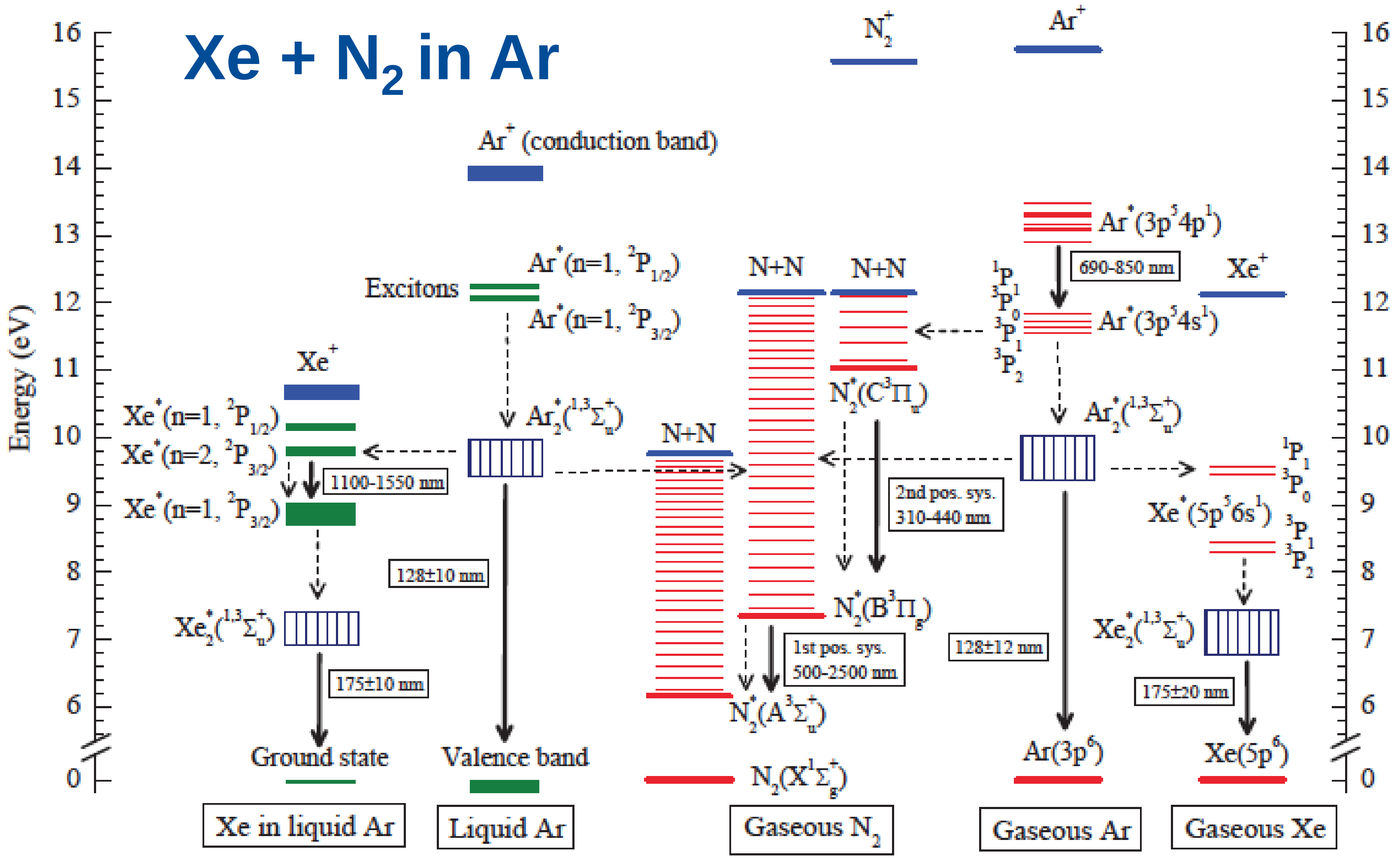


Fig. 1: Energy levels of the lower excited and ionized states relevant to the ternary mixture of Ar doped with Xe and N_2 in

Various opportunities for light in near-UV, visible and near-IR

Adding H_2

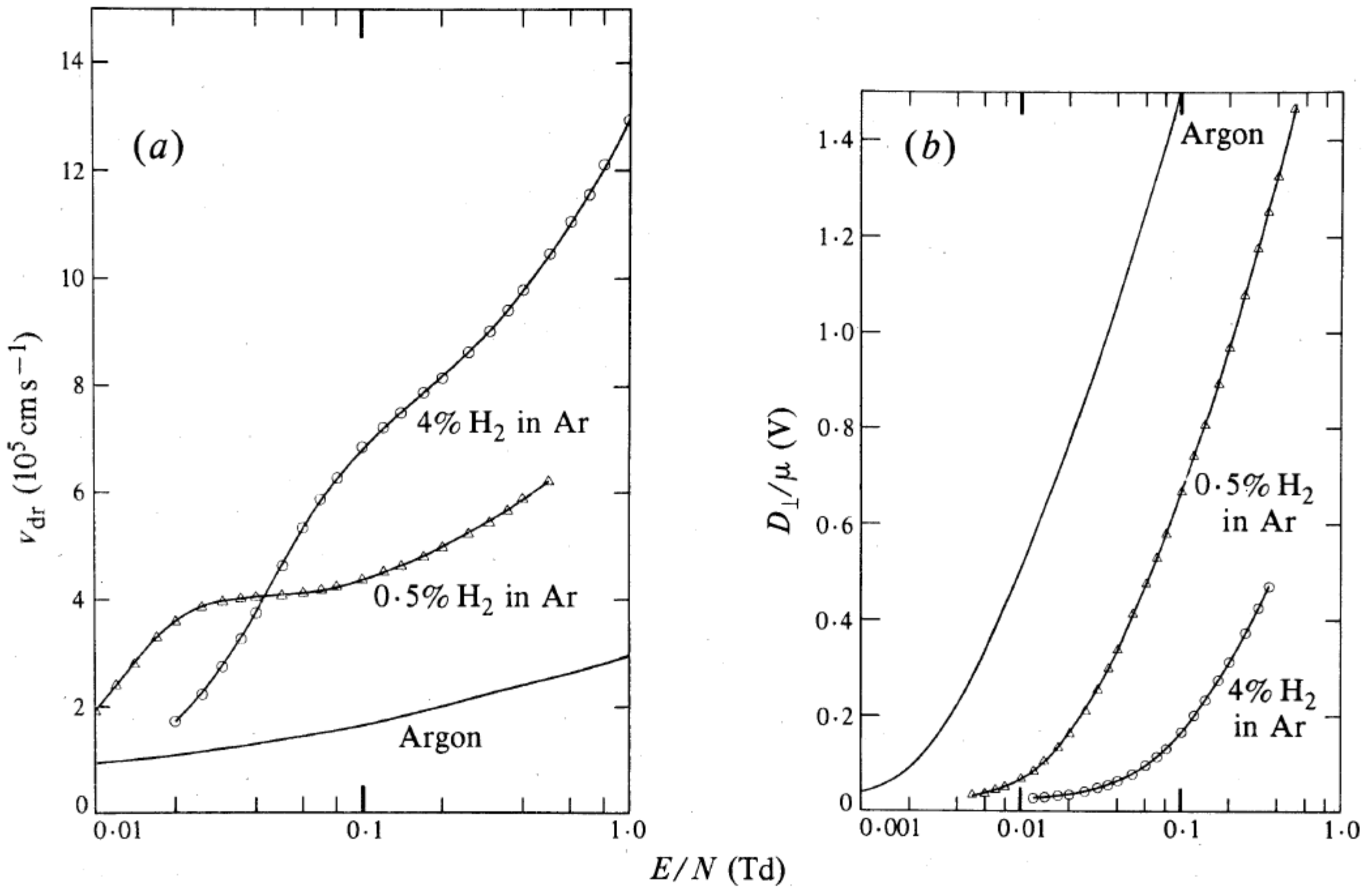


Fig. 3. Measurements of (*a*) drift velocity v_{dr} and (*b*) $D_\perp/\mu$ as functions of E/N for mixtures comprising 0·5% and 4% H_2 in Ar. The data for pure argon from the work of (*a*) Robertson (1977) and (*b*) Milloy and Crompton (1977) are shown for comparison.

There’s always a downside – electron attachment

stage.

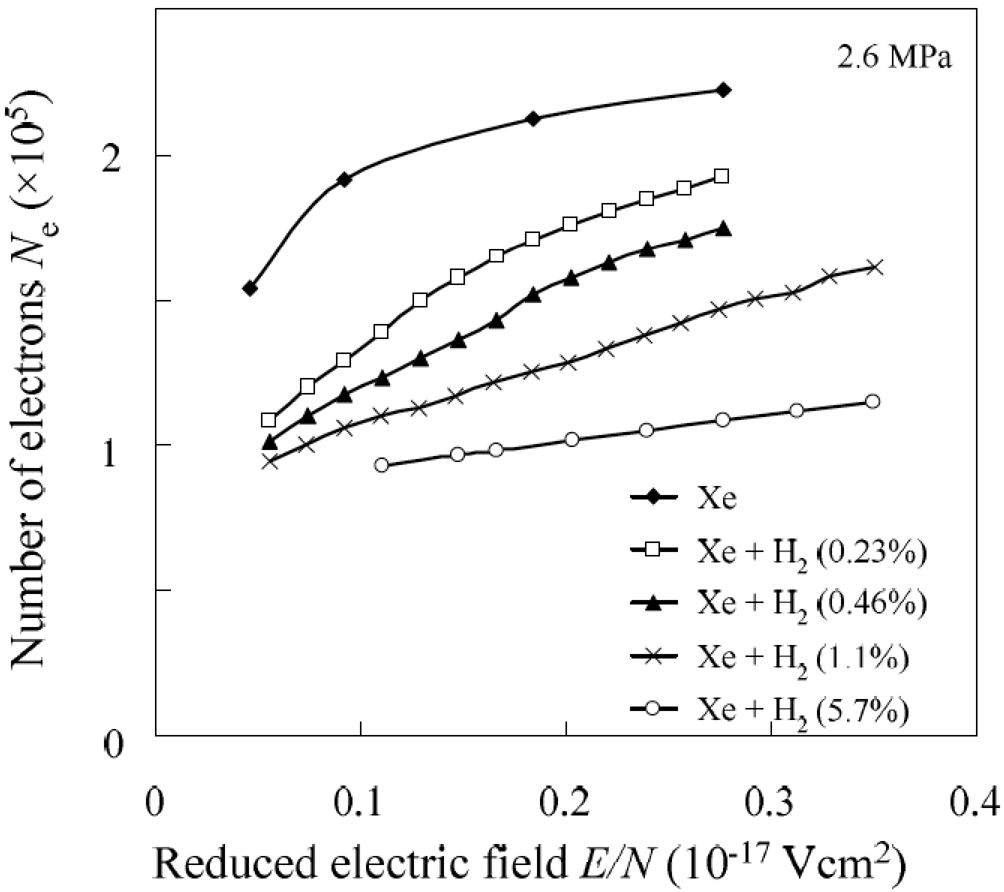


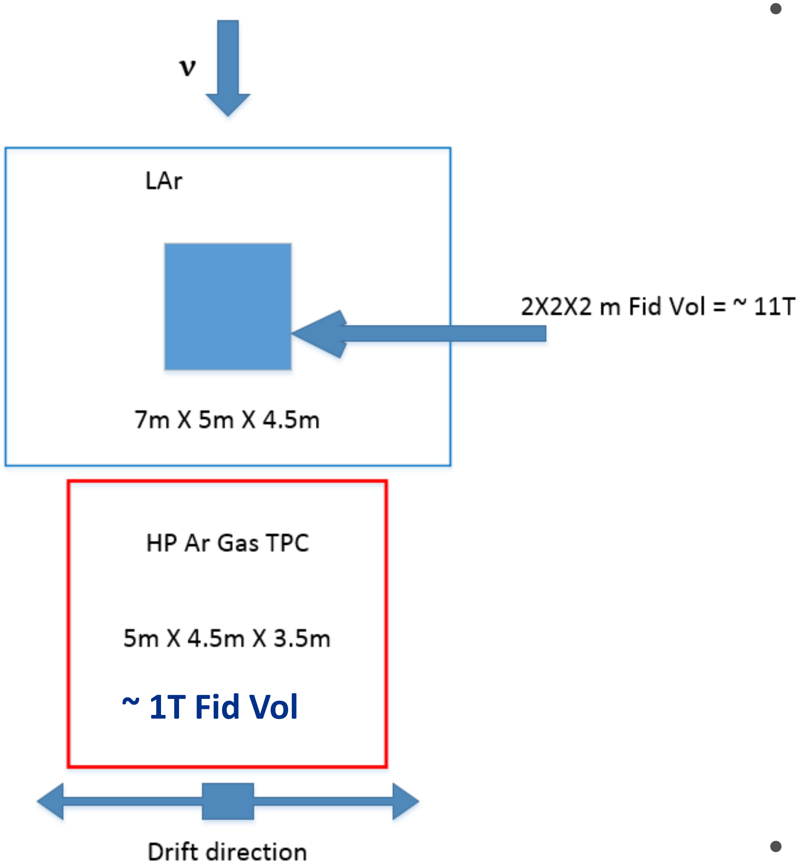
Fig. 4. Dependence of the number of collected electrons N_e in pure Xe gas and Xe doped with 0.23, 0.46, 1.1 and 5.7 % H_2 at 2.6 MPa on reduced electric field.

TPC Gas mixture: Outlook

- More to be done. Exact mixture will require a delicate balance
- Stefan Roth at Aachen has test setup that can measure V_d, diffusion constants, gain, etc. at 1ATM now. Maybe higher pressure with some mods.
- $Ar+Xe+N_2$
  - Reach a balance that shifts UV fluorescence of Ar (responsible for photon feedback in gain region) to long enough wavelength to maintain chamber stability, but also present photons detectable by "typical" LAr light system?
- Another interesting possibility
  - Ar + Xe in the gas phase has been shown to emit lots of light in the near (800 nm) IR. Synergy with studies in LAr?
    - Being studied at Fermilab (Carlos Escobar) for FAR detector application in LAr
    - And Xe doped LAr for particle astrophysics (Lippincott)
  - The Xe might not only quench photon feedback, but might a yield light signal that could be used for fast timing using silicon photo-detectors
    - The Low-Gain Avalanche Detector (LGAD) is an interesting candidate.
      - Currently being investigated by both CMS and Atlas

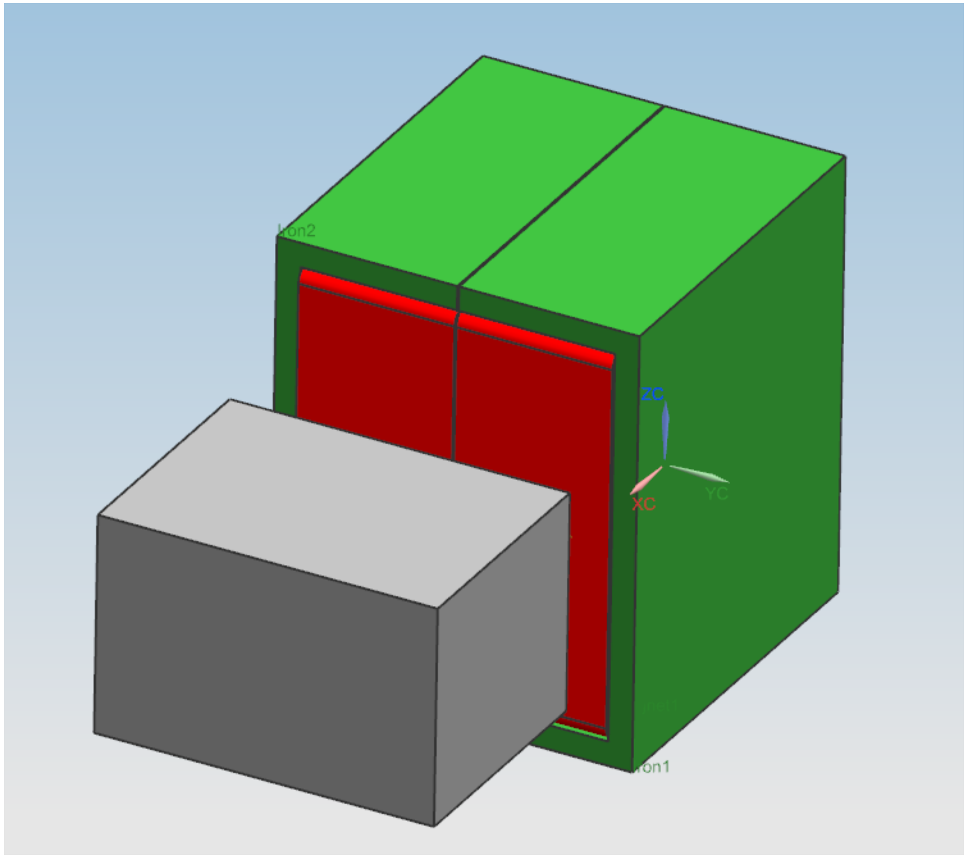
Configuration

Proposed iArDet Configuration



- 11T of 30 T produces ~ 50-100M ν_μ CC evts in 3 yr ν run
- From Chris Marshall's presentation at the DUNE-ND meeting of 9/13:
  - Hadrons, 90% contained all E_ν bins:
    - Within ~ 1.2m transverse
    - ~1.75m longitudinal
  - Hadrons, 99%
    - 2.05 m transverse
    - 3.45 m longitudinal
  - Leptons, 90%
    - 2.7 m transverse (close with this config.)
    - >5 longitudinal (need GTPC)
  - Conclusions
    - Need ~3.25m to contain 99% of events in 3-5 GeV E_ν
    - Transverse dimension could be ~2.5m
      - Need side μ tagger
- TPC can be extended in drift direction to help
  - Cost increase solely due to increase in magnetic volume

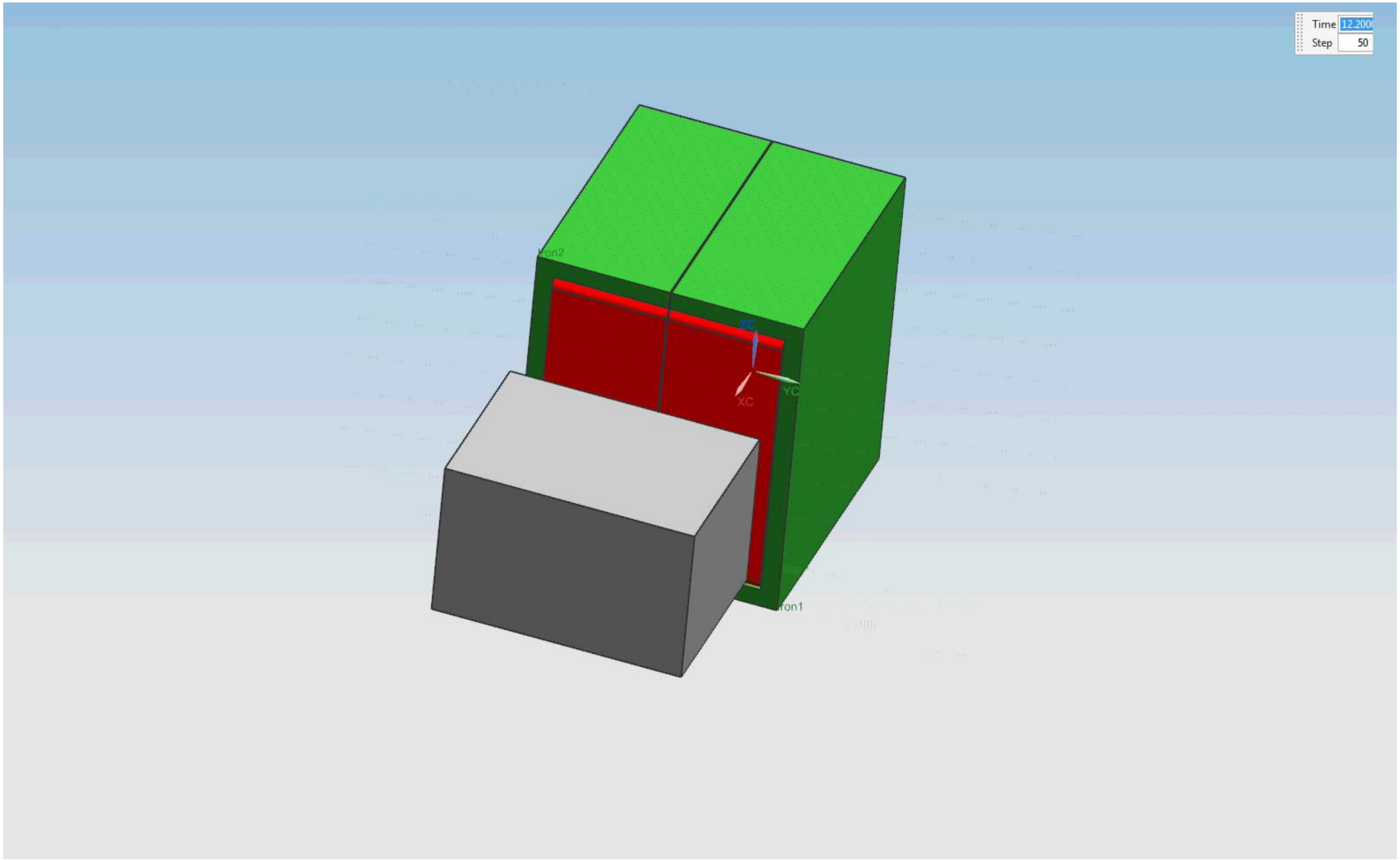
Mechanical concept (Iron-dominated magnet)



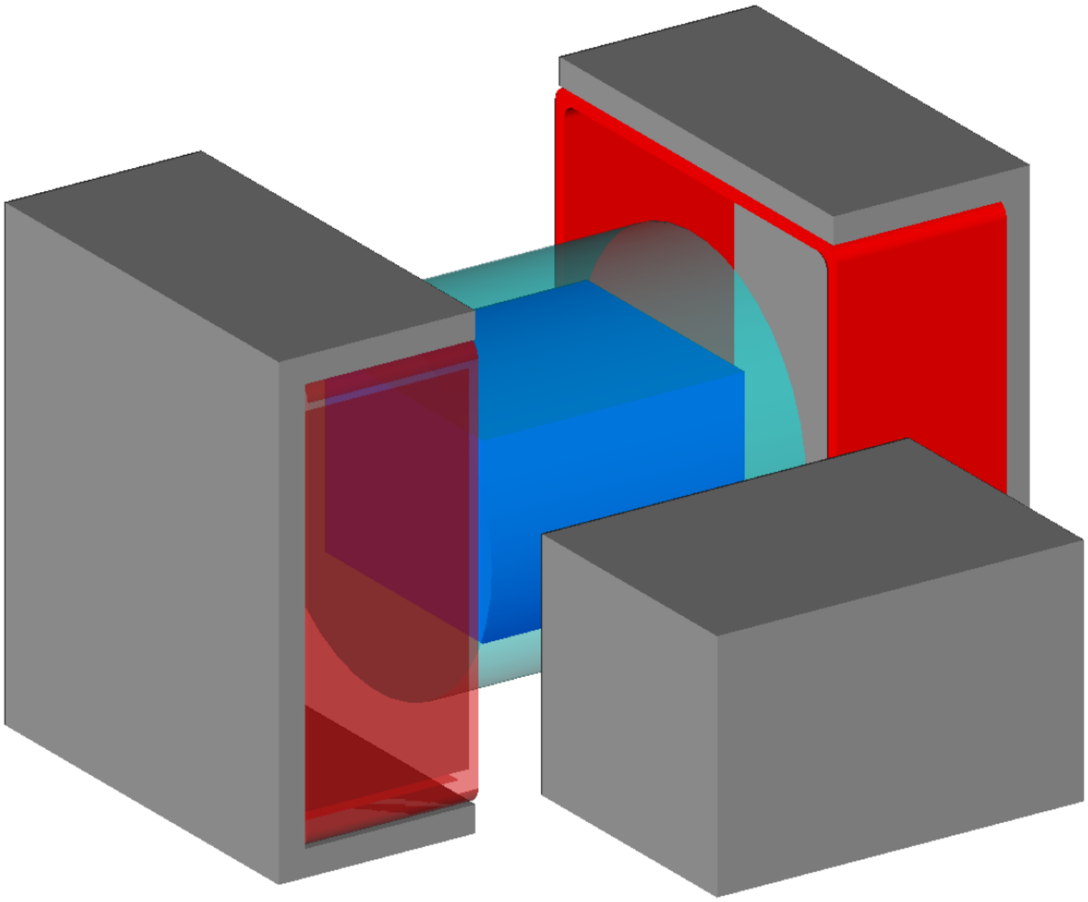
Working with ND mechanical engineering department to optimize geometry, pressure vessel, etc.

Katherine Cipriano & Barry Norris

System Visualization



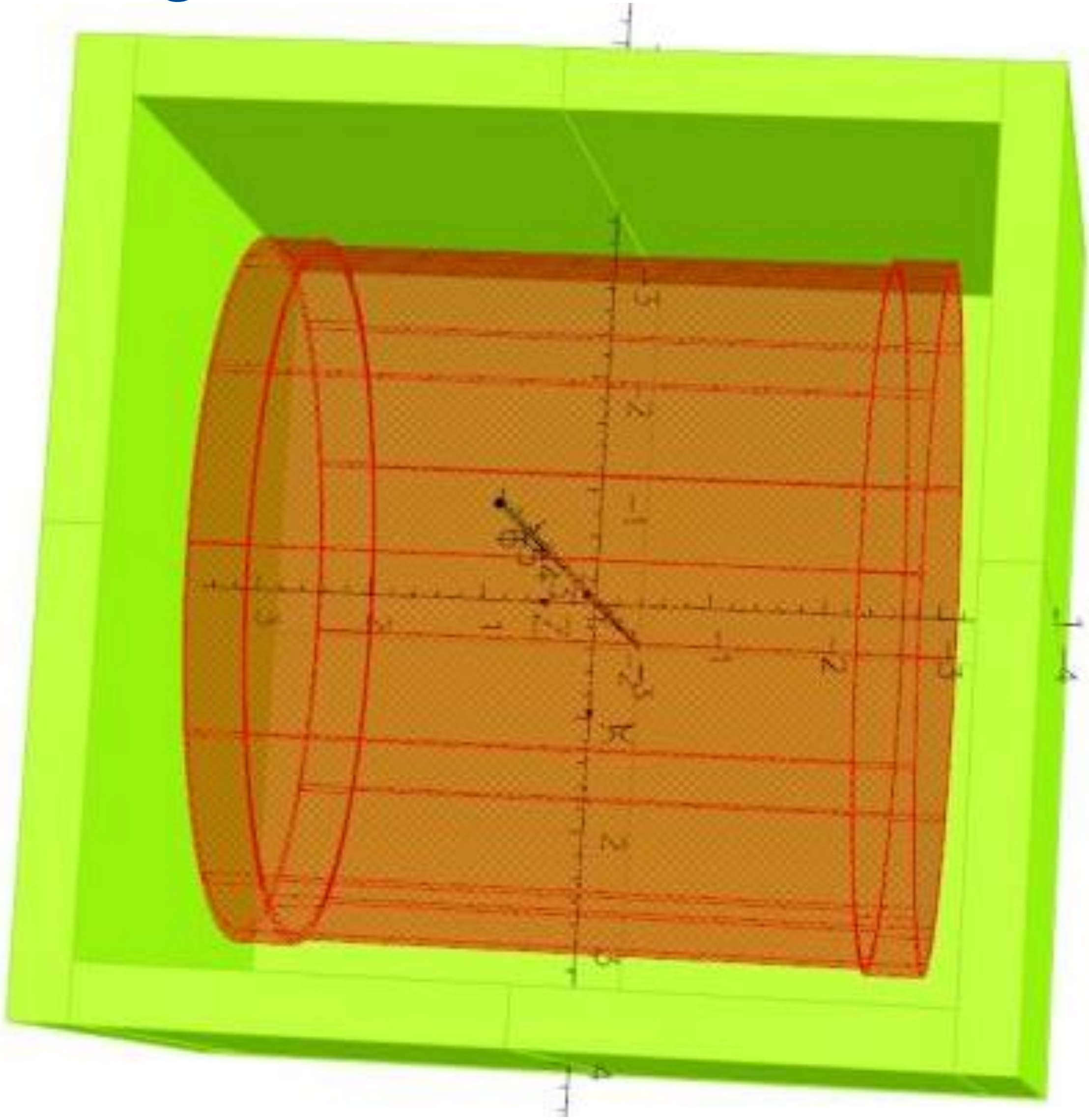
Isometric view



- LAr cryostat:
  - 7m wide x 5m deep x 4.5m tall
- Gas TPC:
  - 5m wide x 4.5m deep x 3.5m tall
    - 5m: Drift direction, 2.5m drift from center electrode
    - E parallel to B
- Pressure vessel:
  - 6m long, 6.5m diameter
    - This diameter gives 0.8m of space on the diameter between TPC and vessel wall. Allows for possibility of EM Cal inside
    - Then would be smaller

Solenoid magnet design

Vladimir Kashikhin



Solenoid R&D (Thomas Strauss, Sasha Zlobin, AB)

- Submitted pre-proposal to Fermilab LDRD program
  - *"Non-conventional, very-large volume magnet for DUNE near detector"*
- We did not receive approval to submit full proposal
- Comments:
  - Novel idea. Long term potential for DUNE.
  - Nicely written proposal. This seems to be an essential cost savings for DUNE.
  - This sounds pretty novel and relevant for the future of the lab/field.
  - Not sure why this is not part of Dune work.
  - Good proposal related to FNAL mission, but should be funded by project, not LDRD
  - Novel magnet concept is good. Seems like the project would naturally explore this option rather than commit to $10+M magnet.

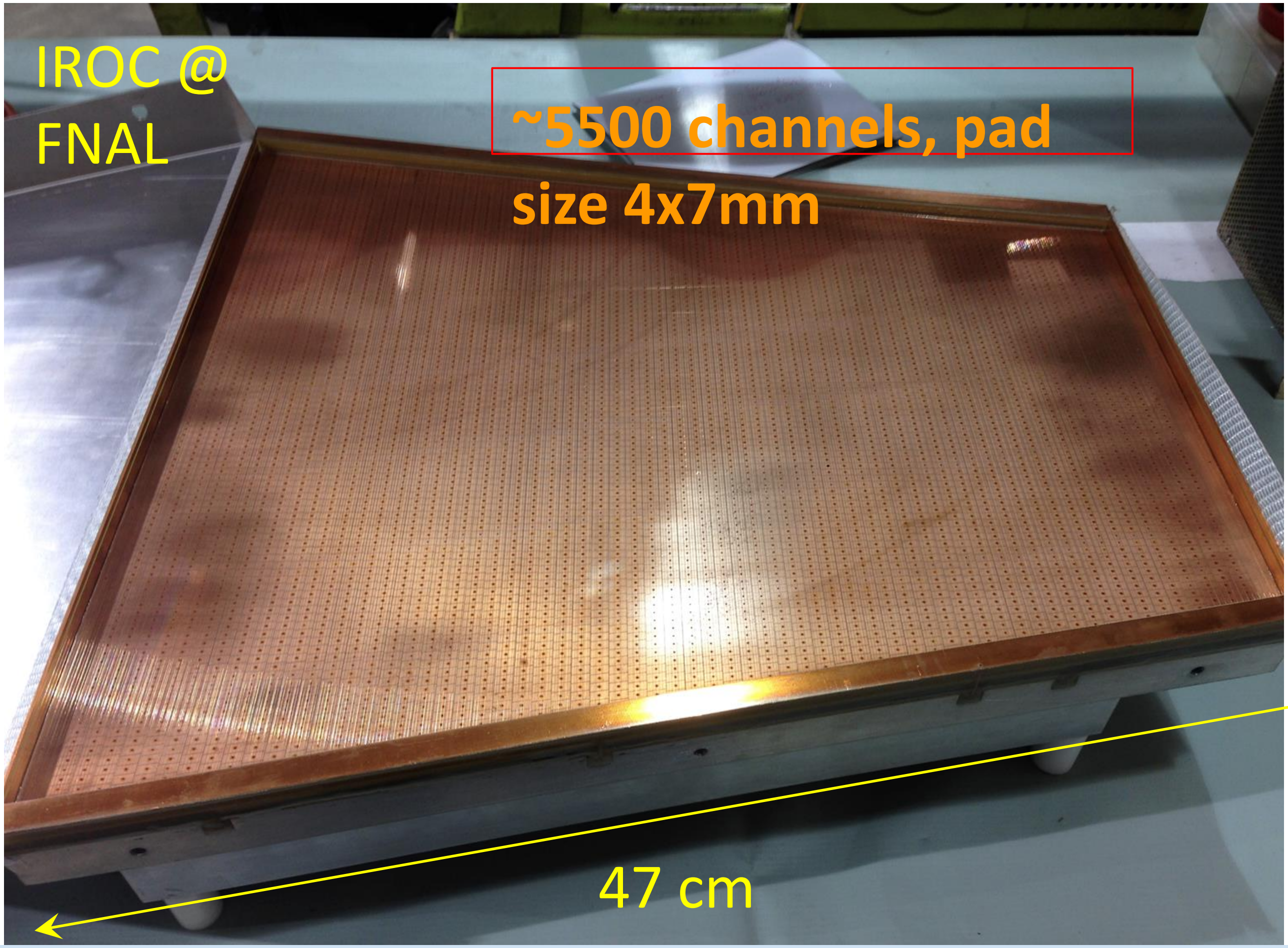
- Hmmmm – Sounds like approval to me? But Youse-Guys pay

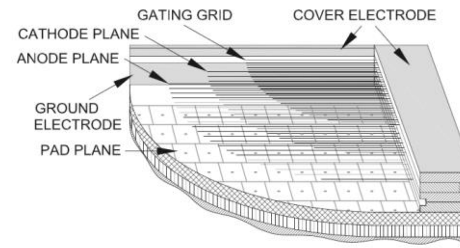
TPC R&D Program

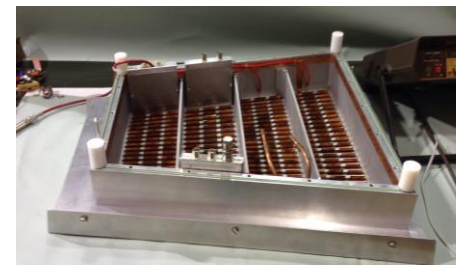
Guillermo Fernandez Moroni
Jen Raaf

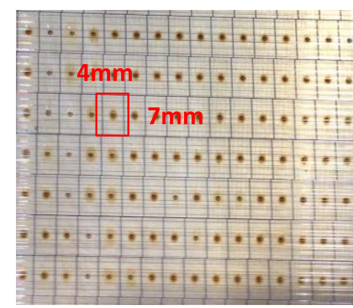
Fermilab

Inner Readout Chamber (IROC) @ FNAL

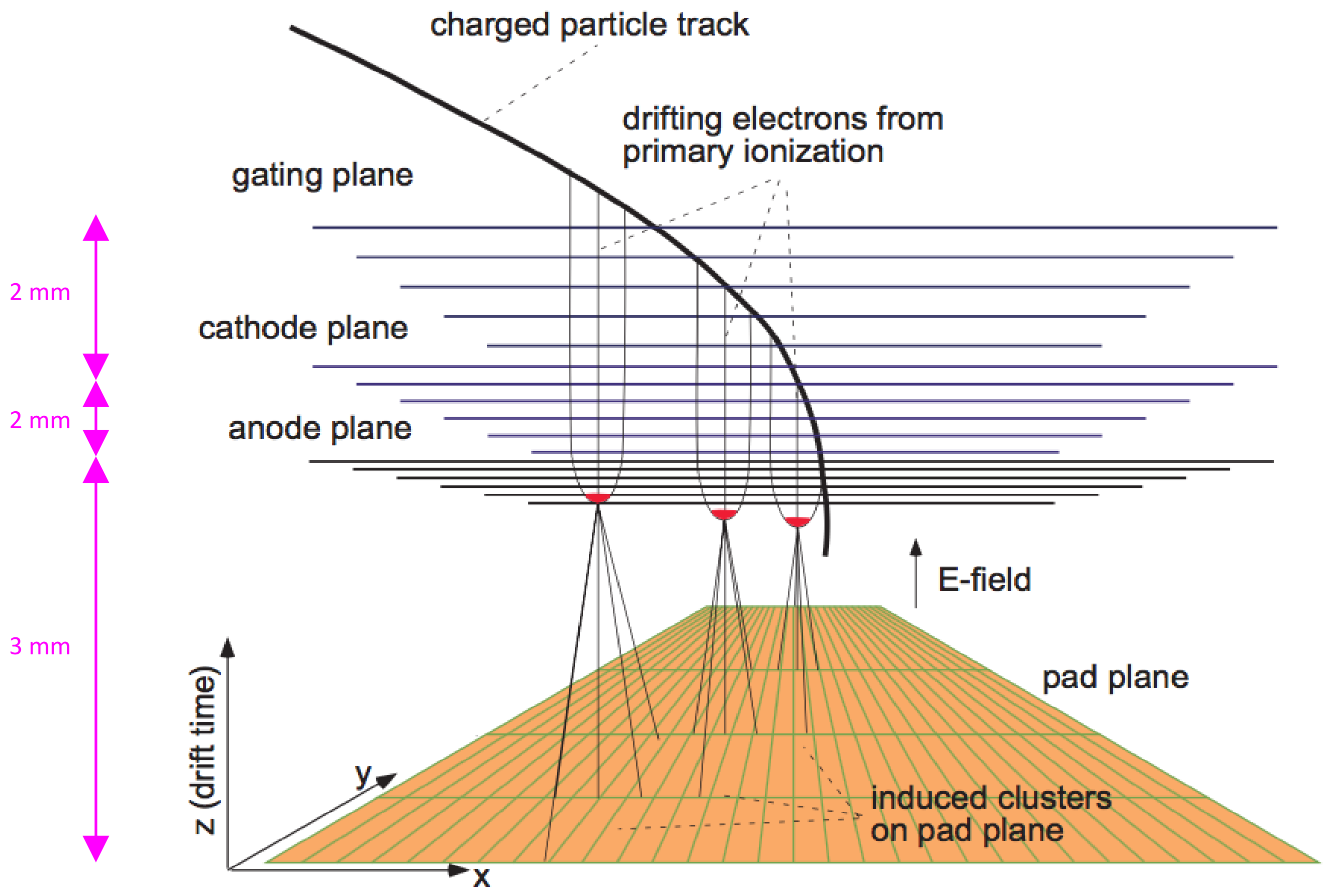


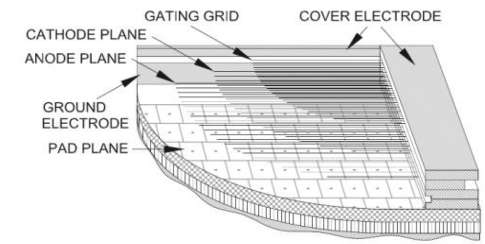






IROC





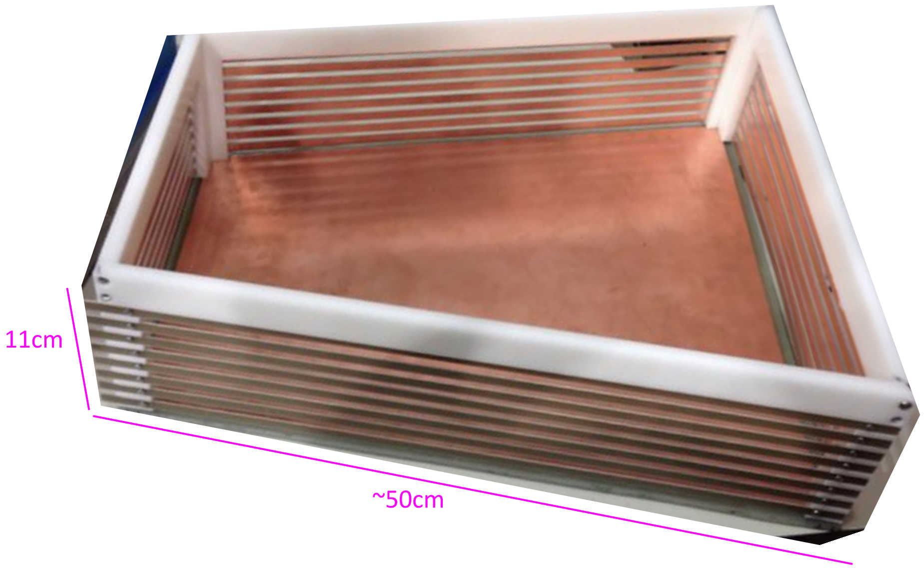
gain = 2-4x10^4

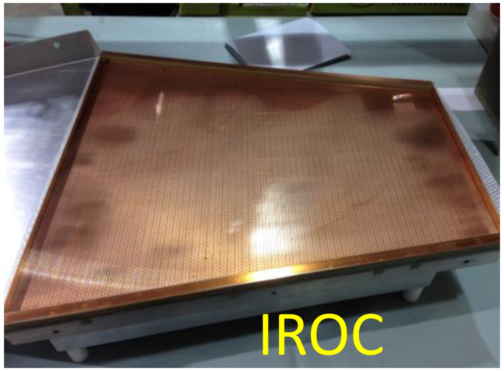
Readout plane

Characterization of a fully equipped ALICE TPC Readout Chamber, M.L. Knichel

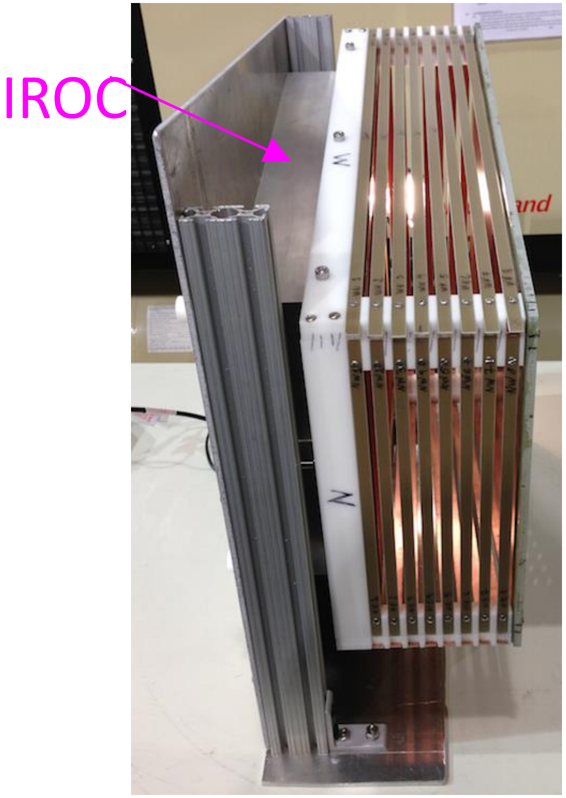
Field cage ready

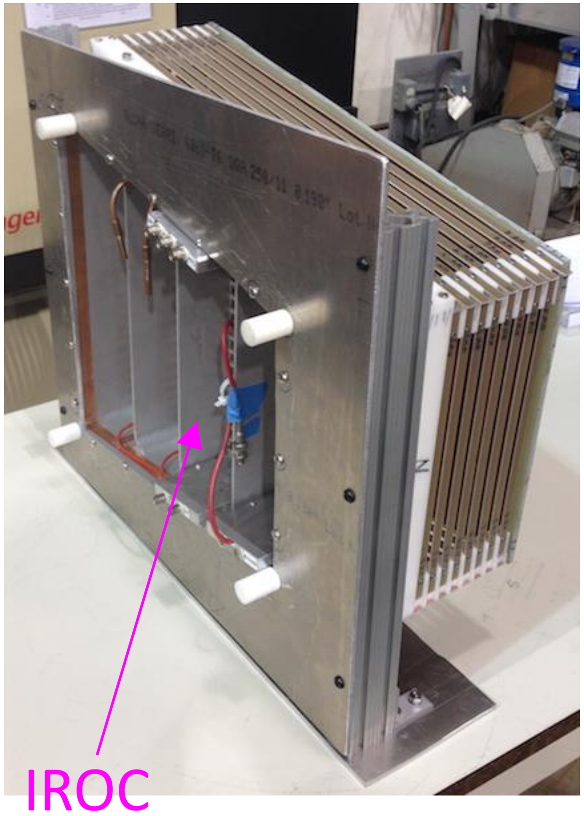
- **Field cage under construction**
  - Following ALICE test bench design
  - Active volume ~0.025m^3 = 25L.
  - Ok for test at 1 and 10 atm.
  - It is attached to IROC chamber
  - The whole detector can be moved to different vessel
  - Open field cage for light detectors



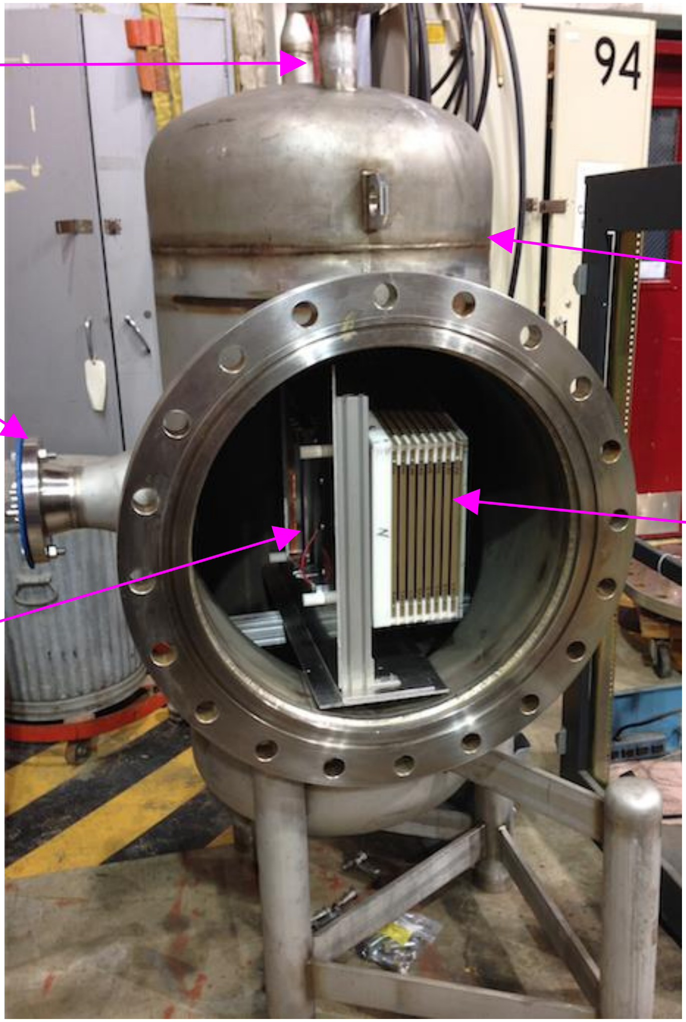


TPC





TPC final setup



Gas flange

Vessel: rated for 150 psi operation

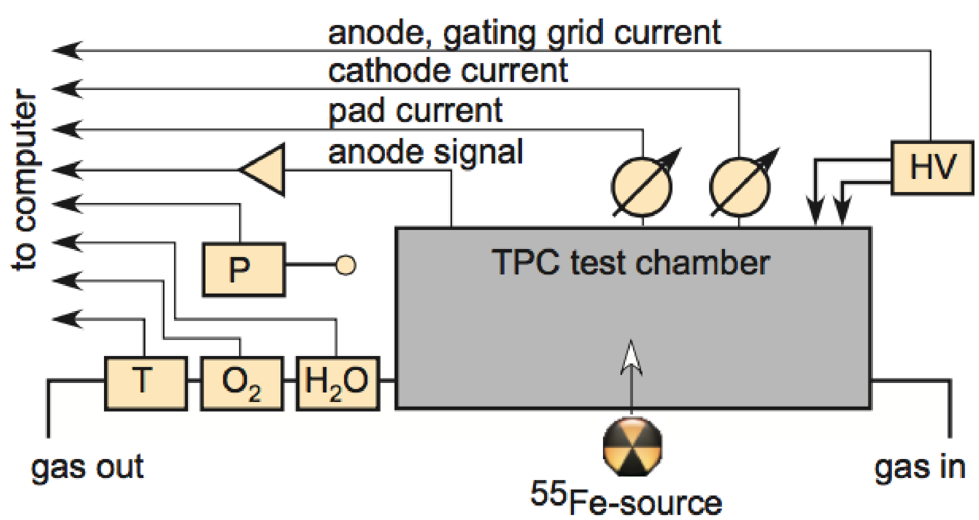
Connectors flange

Field cage

IROC

First Test

- Reproduce Alice test results
- Gain vs anode Voltage
- Dark current
- Measure oxygen outgassing
- Gain stability
- Gain uniformity
- Different gas mixtures
- Being setup now that it can run at 10 ATM even though initial tests will be at 1 ATM



Comparing ArgonCube and GAr TPC readout

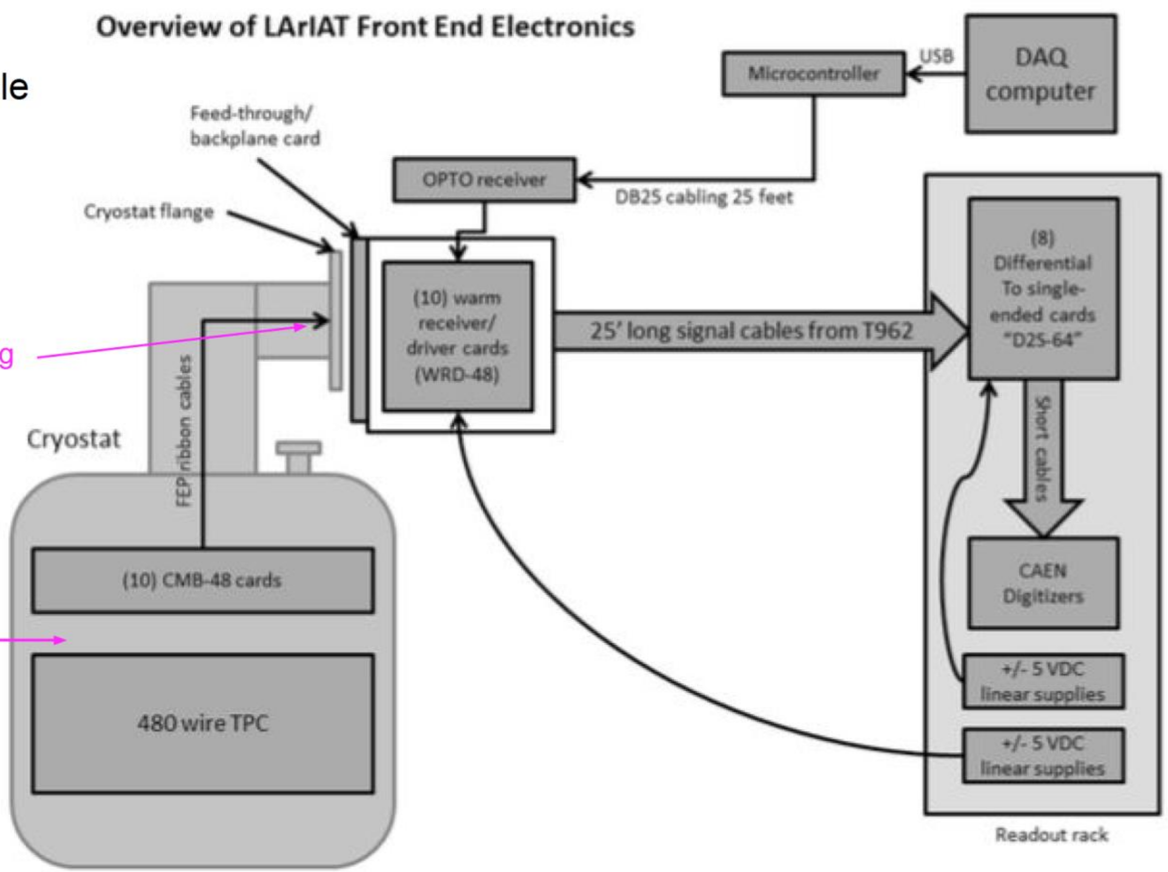
- LAr:
  - 50k e-/cm for MIP
  - Unipolar signal (direct charge collection)
  - 1.5mm/μs drift velocity @500V/cm
  - 1 MHZ sampling rate
- Gar TPC (ALICE):
  - up to ~500k e- for MIP (gas gain, gas mixture)
  - Induction signal only
  - 5cm/μs @ 500V/cm can be slowed down (gas mixture, E field)
    - Will want to work at closer to 200-300V/cm
  - 4-10 MHZ sampling rate
    - Might be able to go a bit lower
  - pad capacitance similar to ArgonCube

Single pad readout test: using lariat electronics

- ~500 channels available
- Few modifications

New tube adapting existing flange for signals feedthrough

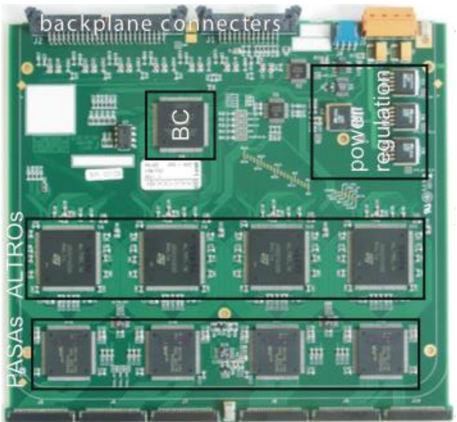
New cables connecting FEC to TPC channels



Note: Same setup to be used for PixLAr tests

Single pad readout test: new cable already desing

Alice Front End Card



Lariat Front End Card

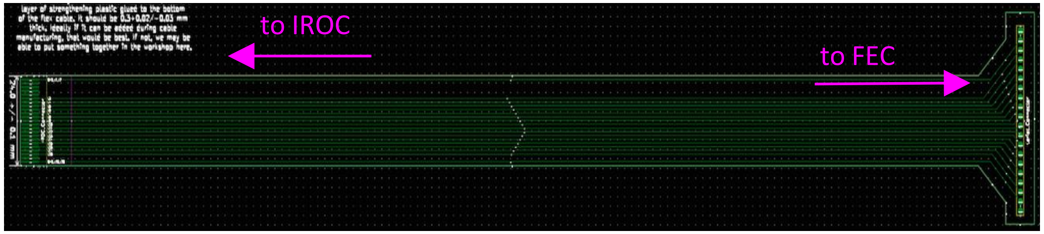
TPC channels connectors

HP gas TPC cable (Kirsty Duffy)

Alice cable

to IROC

to FEC



R&D program - summary

- Readout chamber is ready and we are now in the final assembly.
- The gas system is under construction. A new configuration has been arrived at that will allow us to move from 1 to 10 atmosphere with no modifications to the system.
- For pad readout test, we are adapting existing LAr electronics. Cable design almost ready for fabrication.

Conclusions

- ArgonCube + HP Ar gas TPC provides a powerful detector suite
- R&D on the TPC is limited (not pushing state-of-the-art)
  - Gas mixture
  - Front-end electronics
- The TPCs largest effort is likely to be in mechanical engineering
- This said: We still need to make the physics case
  - How well does ArgonCube do alone?
    - What are the limitations?
  - How well does the TPC add to the physics capabilities of ArgonCube?
  - How well does the TPC do alone?
    - What new physics capabilities does it add?

THANK YOU