Phase II ND Workshop and Plans Going Forward

Patrick Dunne for the Phase II gaseous ND group

Imperial College London

Introduction

- Phase II of DUNE consists of ND, FD and beam items
- For ND, phase II requires a more capable ND (MCND) to control systematics appropriately for the high statistics full physics program of DUNE
- Workshop was held 20th-22nd June at Imperial to collect DUNE and community input on MCND
  - Spokesperson, IB chair, LBL convener and both phase II coordinators present
- Key goal was to set scope for future work towards funding proposals

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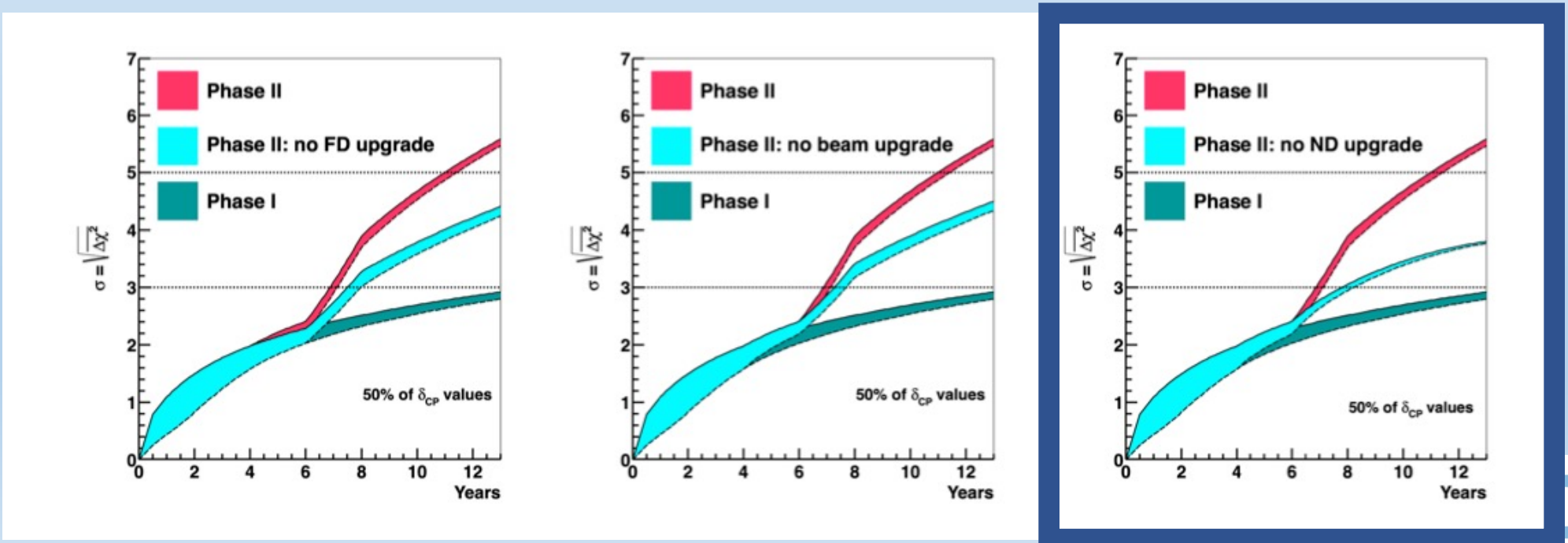
Reminder: High-level physics case

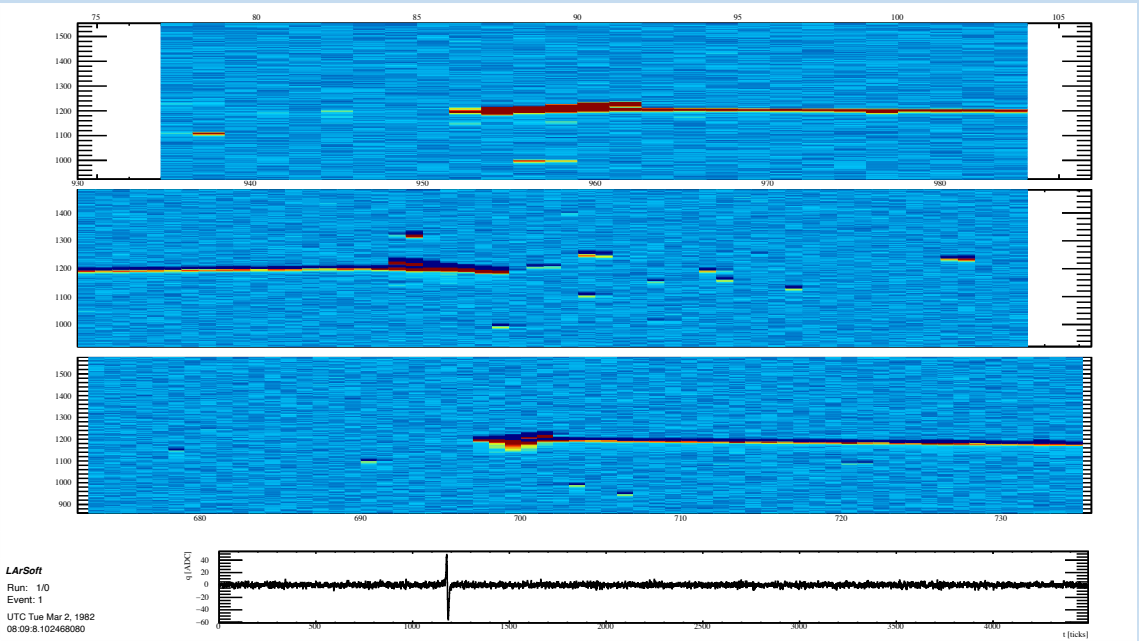
- P5 Phase II case so far has focussed on LBL
- ND is the only upgrade targeting systematics
  - Running the beam longer can't make up for not doing it
- Case made so far uses fake data with different hadronic energy deposition to show bias would occur without MCND with low energy thresholds



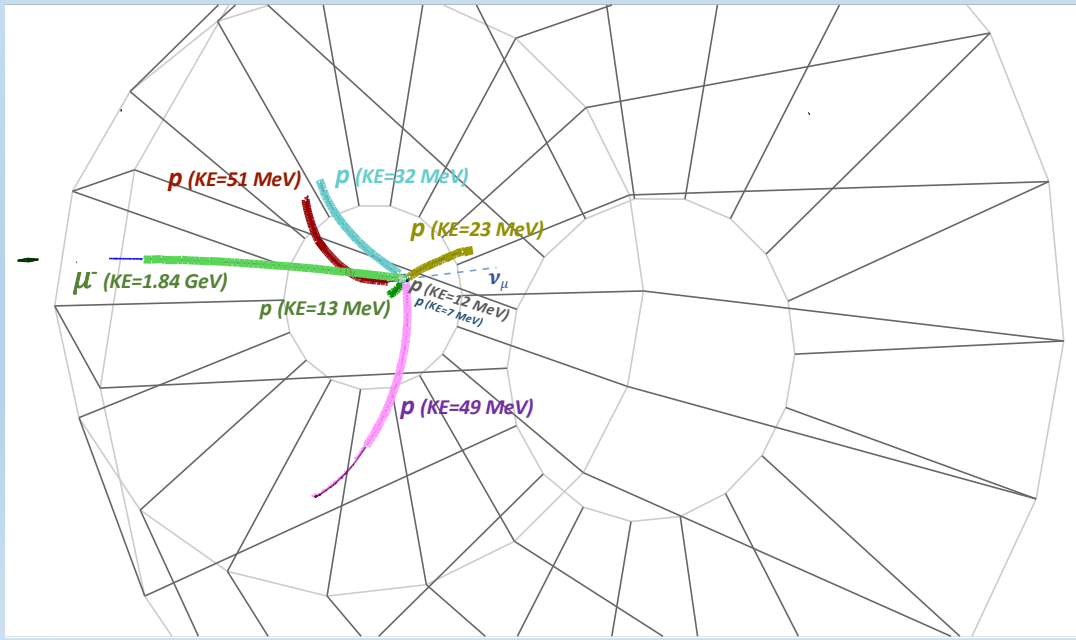
Why a gas detector to do this? - Elevator pitch

- DUNE must measure low energy particles to reduce interaction systematics
  - Every pion rest mass we miss is ~100 MeV we get Erec wrong by
- Far detectors need to be dense to get enough events, but ND doesn't
- Low energy particles go further in gas (Figures are same 7 proton interaction)

Liquid detector



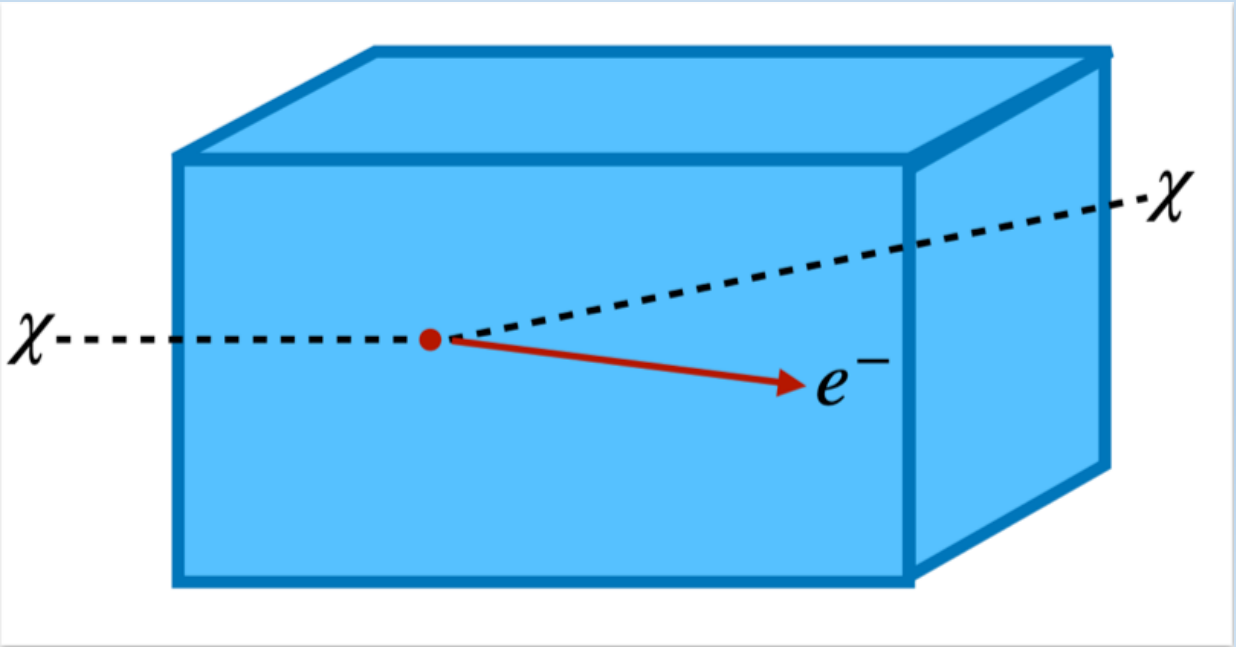
Gas detector



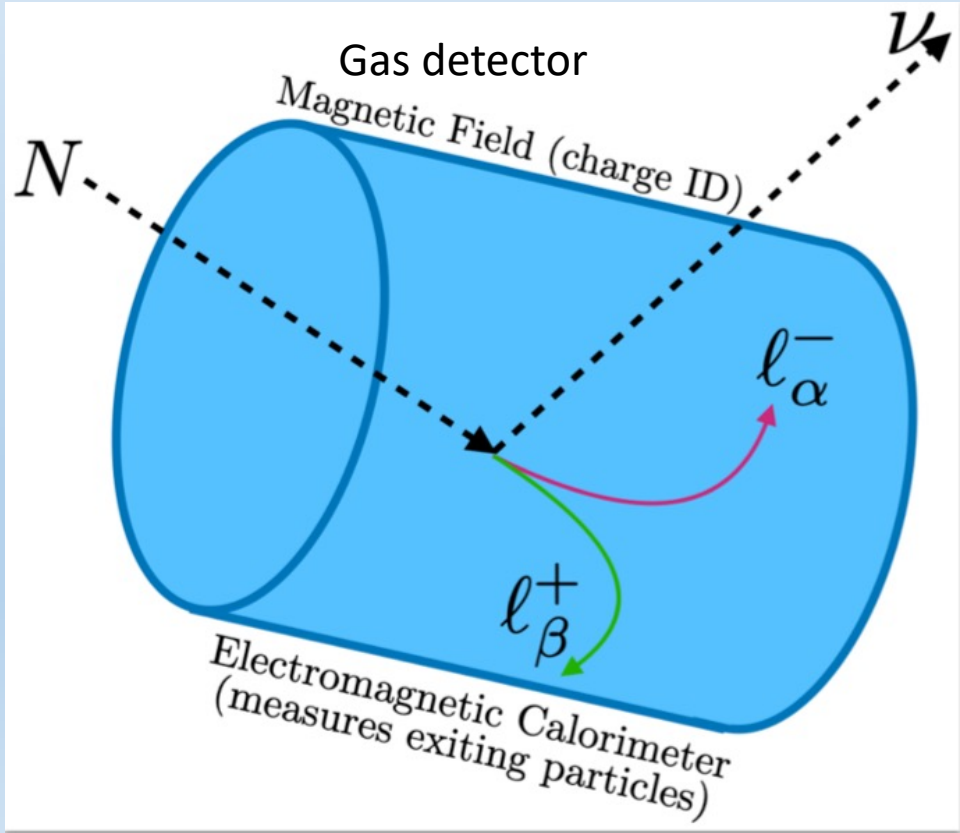
Why a gas detector to do this? - Elevator pitch

- DUNE will impinge the world's most intense proton beam on a beam dump
- Proposed BSM physics is either rarely interacting or long-lived then decaying
- For long-lived: signal ∝ volume, background ∝ mass
- Large low-density gas detector is perfect

Liquid detector



Gas detector



What did we see at the workshop

- 3 streams of talks plus long discussion sessions

Physics overview and goals	• LBL – Future needs and current experience • BSM • Xsec
Detector systems and facilities	• Gaseous argon detector progress • ND-LAr and SAND upgrades • ND facility constraints
R&D and community ideas	• Longer-term R&D that we need/may impact us • Community ideas from submitted abstracts

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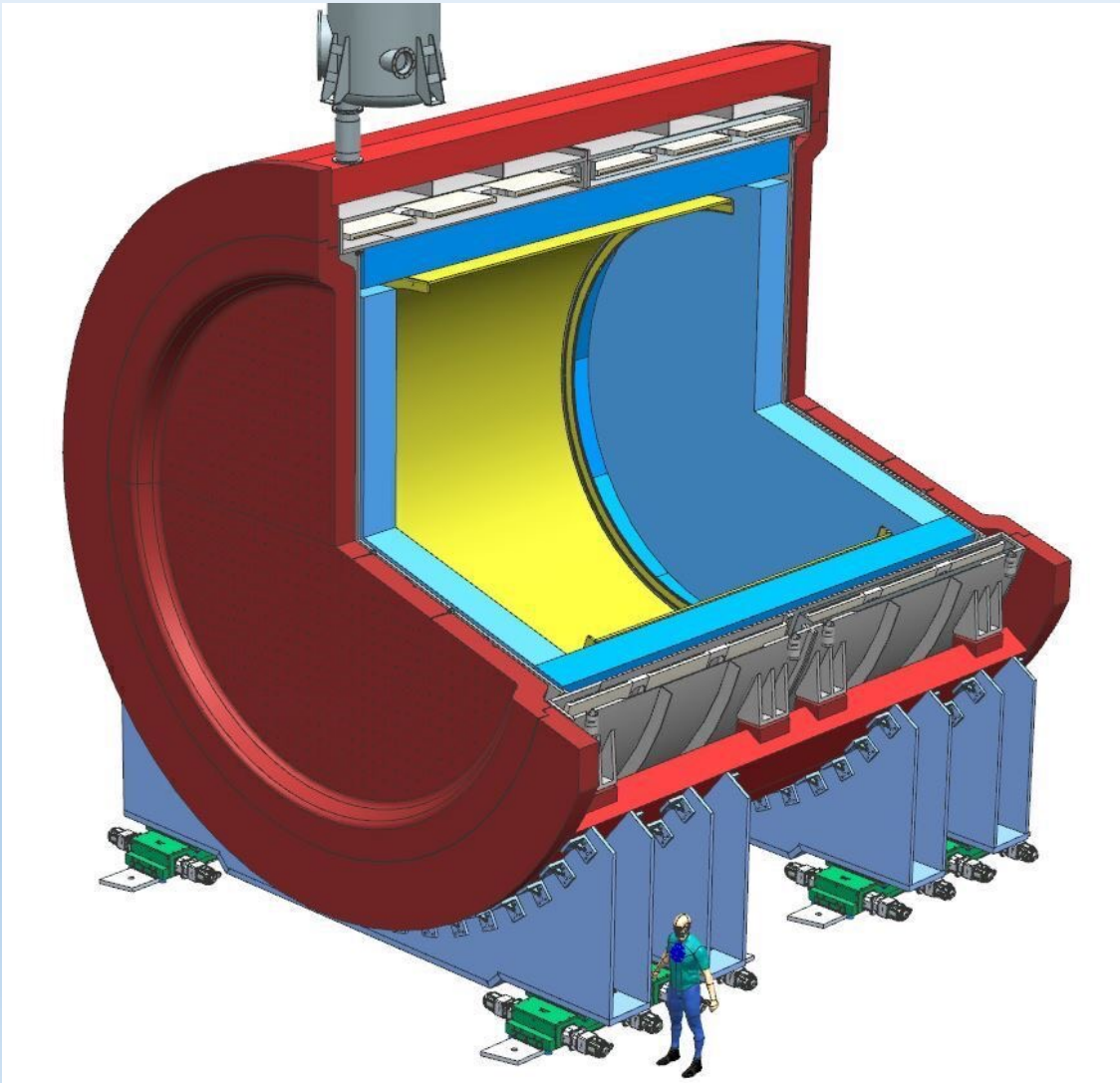
DUNE

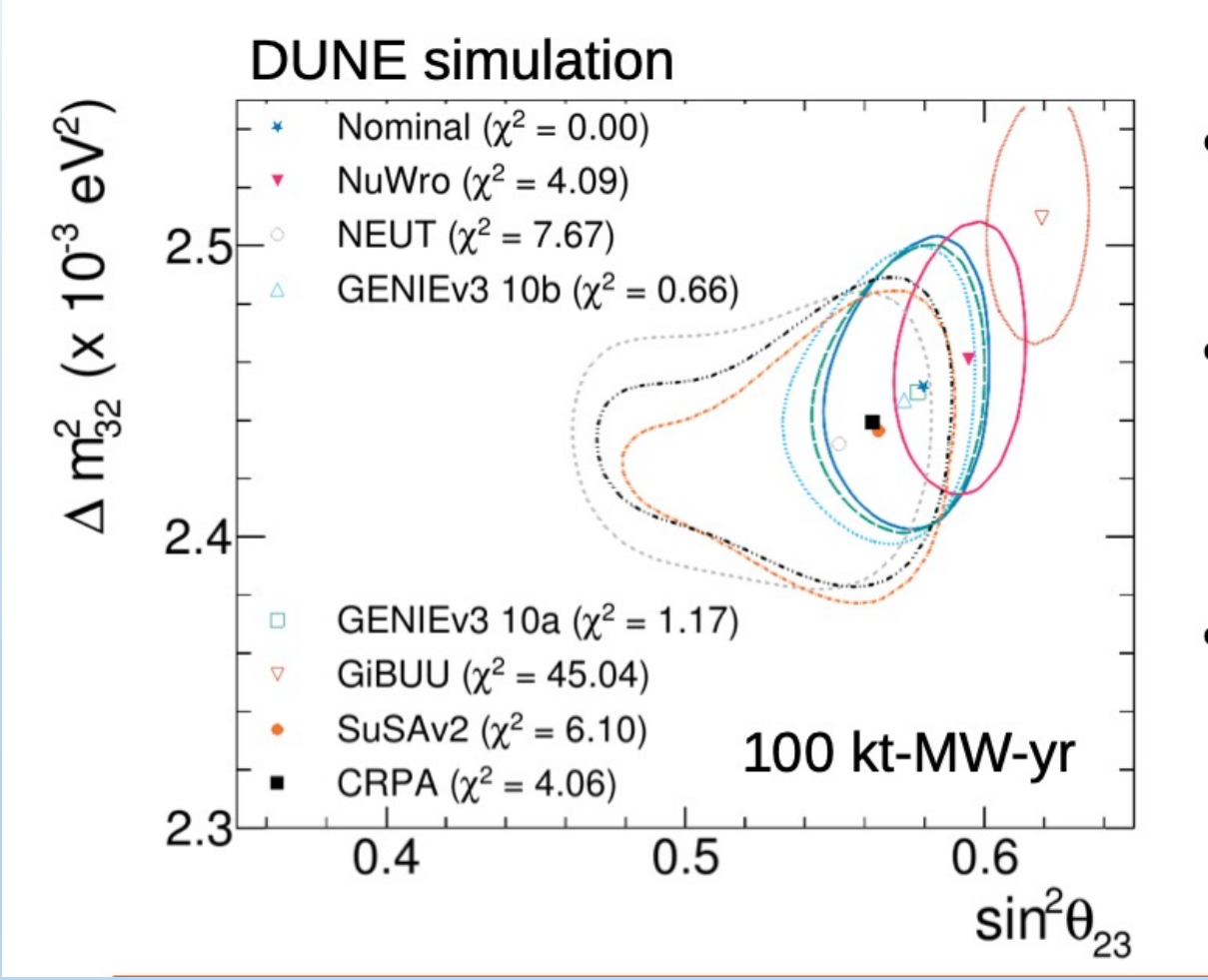
What did we see at the workshop?

- Broad agreement from all streams that large high-pressure gas argon detector should meet currently identified needs and has exciting BSM opportunities
- Several options for most potential sub-systems
- Producing a full set of clear requirements to provide path to CDR/PDR/TDR is the priority



What did we see - LBL

- Talks from Mary Bishai, Callum Wilkinson, Mark Scott
- Studies exist showing where below threshold/neutral hadronic energy goes is important for LBL
- These need advancing to the point where full gaseous argon ND samples and reco are included in the analysis



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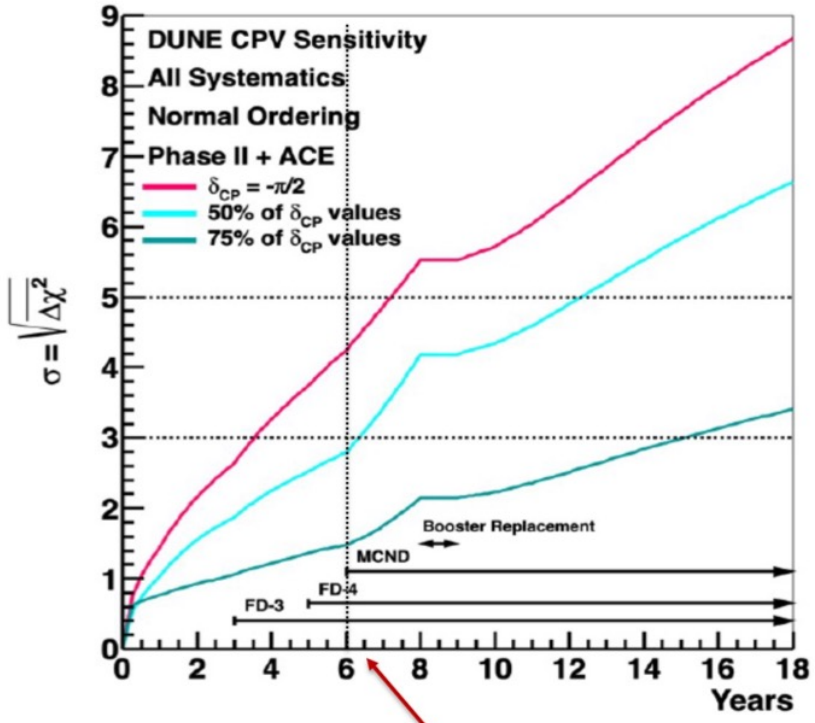
Mary Bishai, Chris Marshall

DUNE Phase II = ultimate CPV reach



- If $\delta_{CP} = \pm 90°$, DUNE reaches 3σ CPV in 3.5 years, 5σ in 7 years
  - Hyper-K will likely get there first, if/when the mass ordering is known
- If $\delta_{CP} = \pm 23°$, it is extremely challenging to establish CP violation at $3\sigma \rightarrow$ DUNE and Hyper-K are competitive and complementary

Improved systematics constraints from "More Capable" ND necessary to reach osc. physics goals

15 6/20/2023 Mary Bishai, Phase II ND Workshop, ISE June 26-28, 2023

What did we see - LBL

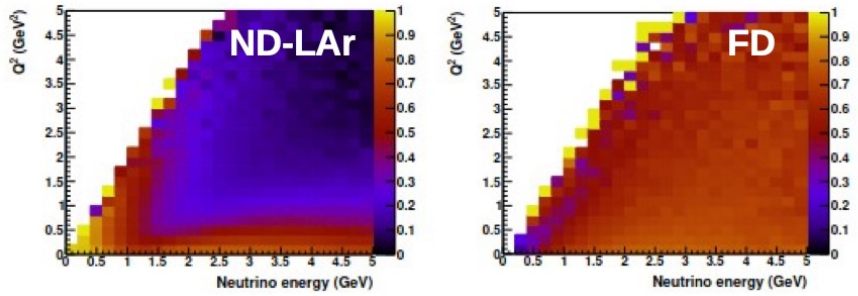
Doesn't DUNE-PRISM solve everything?

Hugely important part of the DUNE strategy, but no:

1) Linear combination analysis unlikely to reach the same sensitivity as model-dependent fit

(trade ND stat. and flux for XSEC uncertainties)

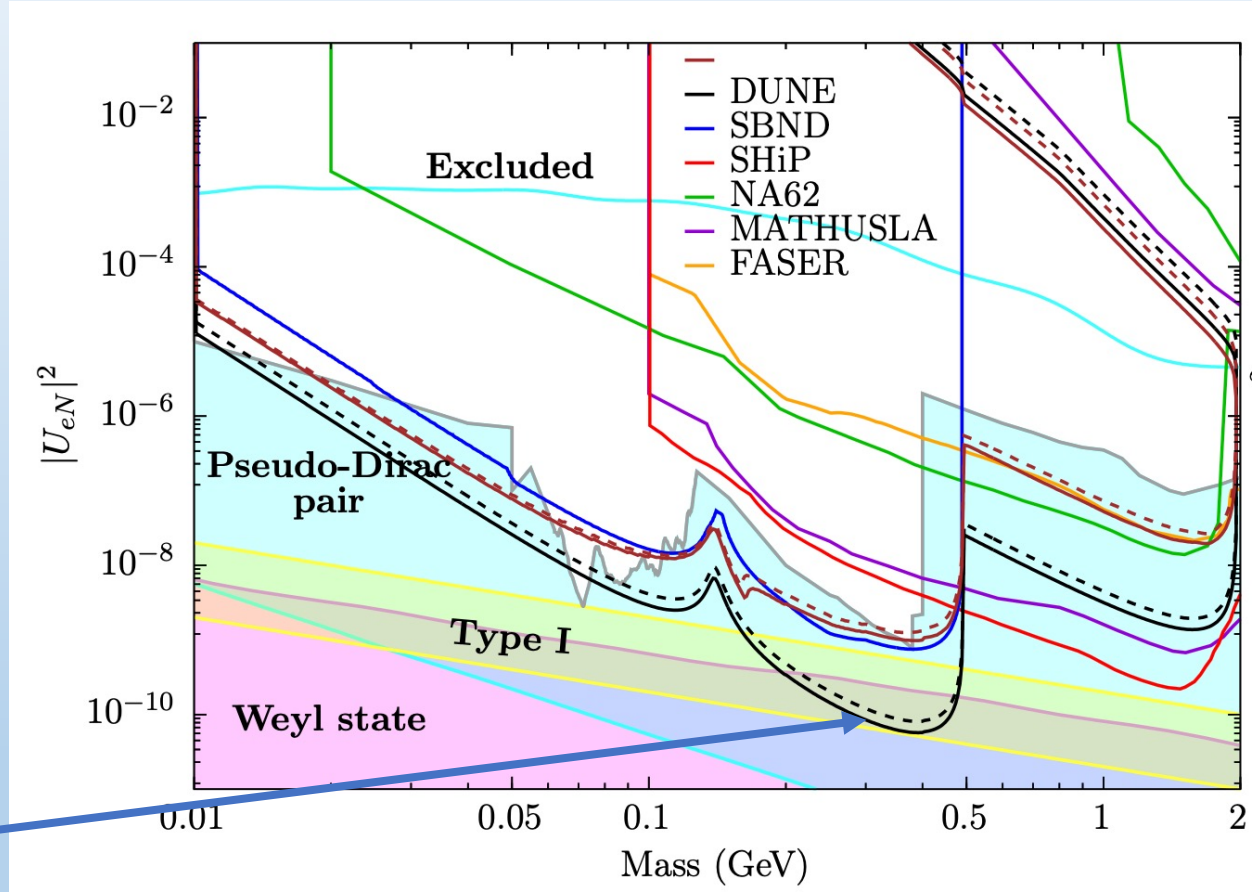
2) ND and FD acceptances and performance will be different, model-dependent corrections required



But, DUNE-PRISM breaks important degeneracies, shown with FDS → a good way to frame other ND improvements

What did we see - BSM

- Main priority will always be meeting DUNE's LBL needs
- With detector that does that, there are BSM searches theory community is interested in
  - Talks from Silvia Pascoli, Kevin Kelly, Frank Deppisch, Jaehyeok Yoo
- E.g. Silvia showed HNL search limits
  - We meet see-saw model limit in mass ranges not accessible to other experiments e.g. SHiP



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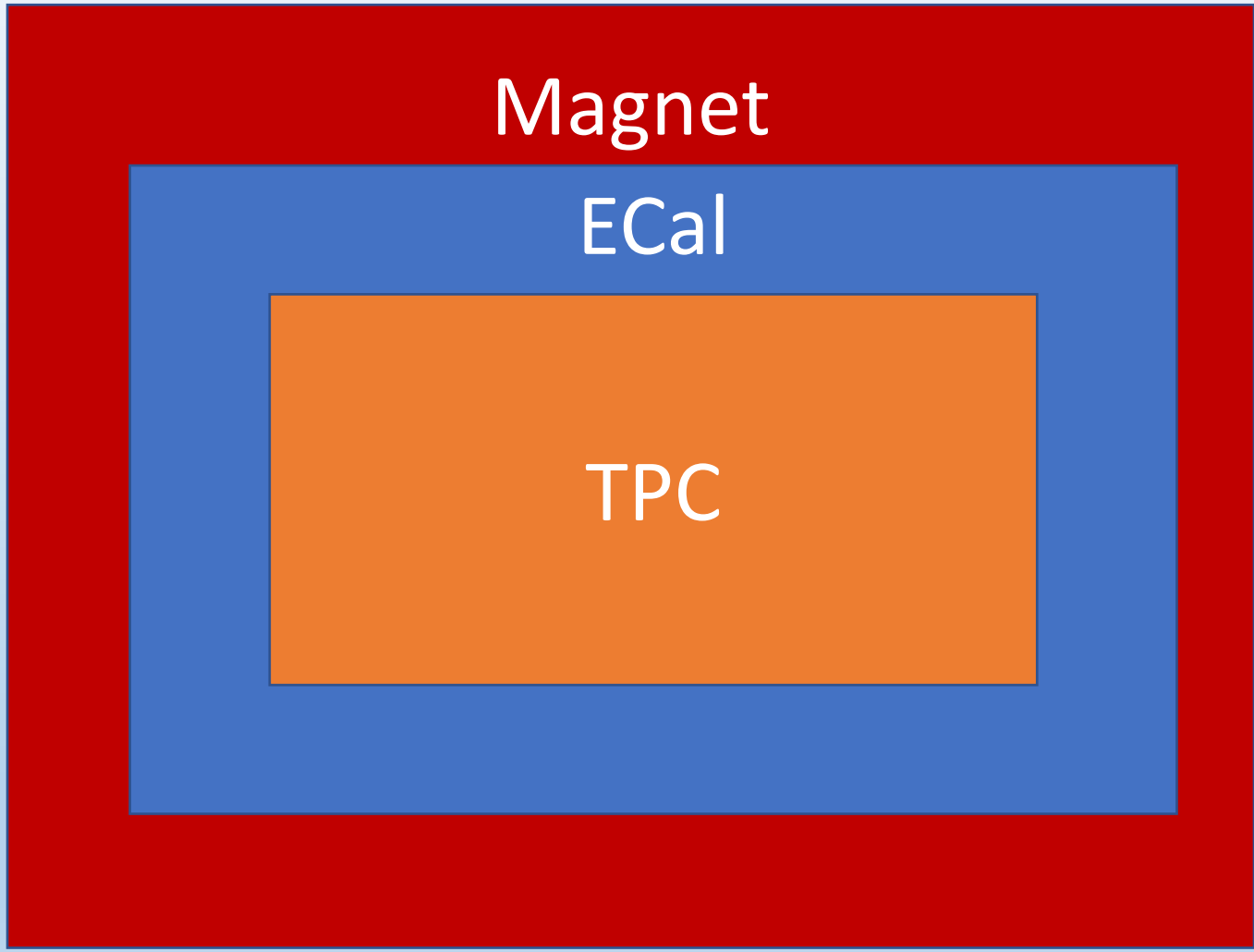
Conceptual design

- Broad agreement on concept:
- Gas TPC
  - Large target volume
  - Low density for low thresholds
- Ecal
  - Neutral hadrons
  - Pion/muon separation
  - T0
- Magnet
  - Allow momentum measurement
  - Minimise mass that ND-LAr exiting muons pass through



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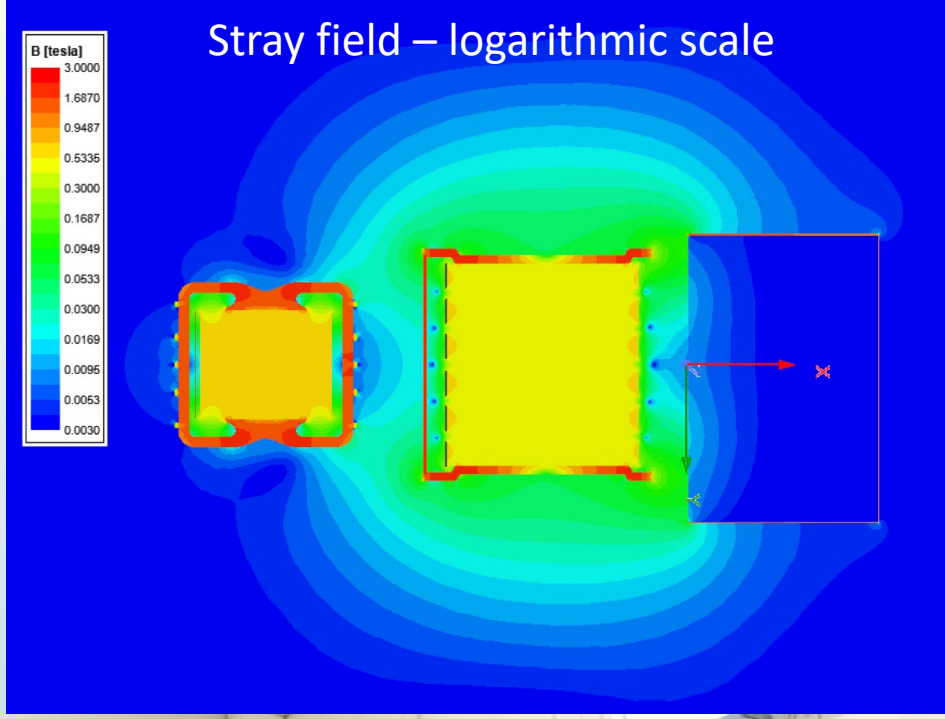
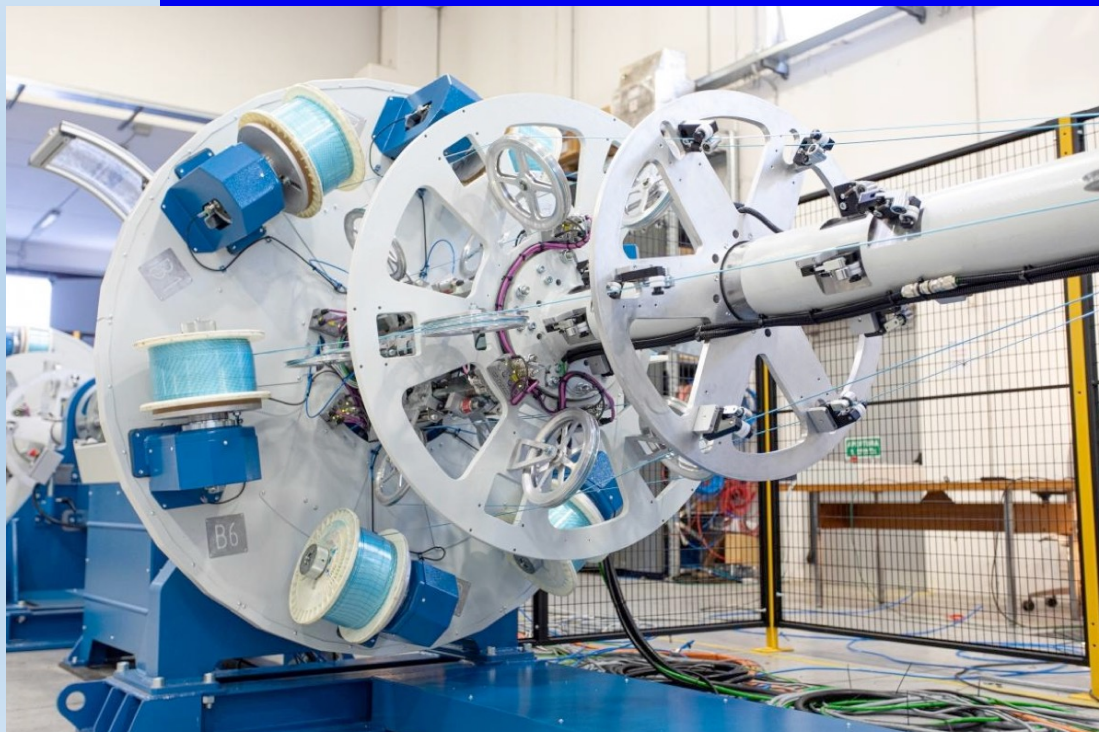
Magnets

- Quite advanced design from INFN Genova and others
- Particularly exciting work moving from NbTi (4.2K) to MgB2 (10K)
  - Significantly reduced cost $15-20M in Italian accounting (pre-Ukraine)
  - R&D work being done by INFN anyway for other projects
- Needs to be kept under review as we develop requirements/other systems particularly which international partners will fund and build





TPC - Amplification

- Original CDR-lite ND-GAr was going to use ALICE chambers
  - Will be very old by the time of phase II
- Wires well tested and groups with wire stretchers were at the meeting: eg Budapest
- GEMs are also now fairly well tested and there's UK strength in the area
  - Kostas Mavrokoridis
- Building framework for decision to be made is an important short-term goal

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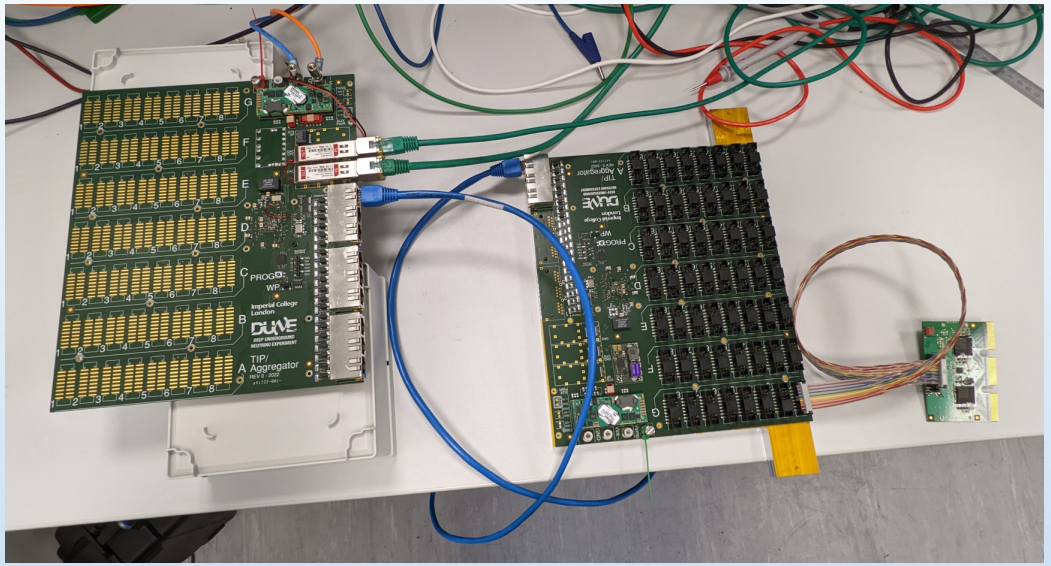
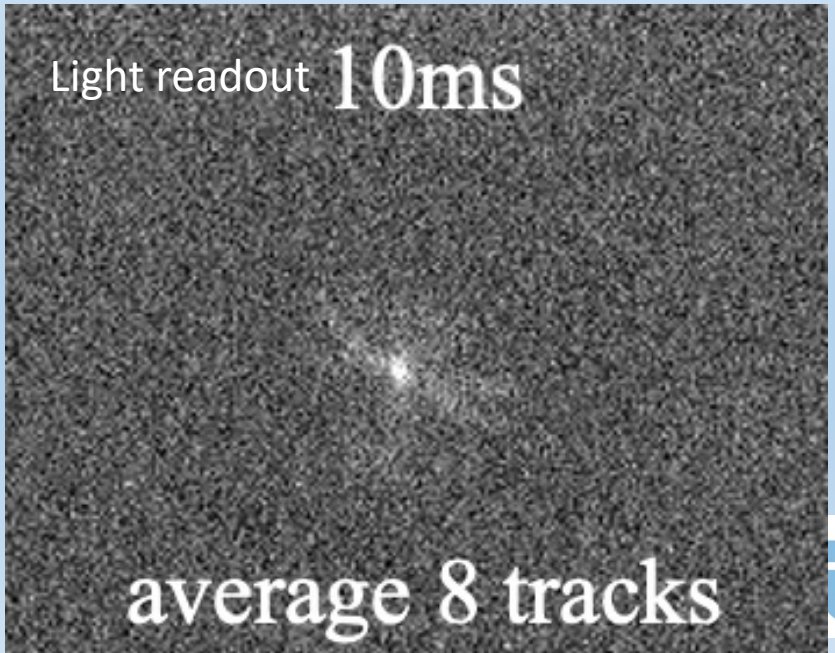
TPC - Readout

- Key discussion was charge vs optical
- Charge readout of an HPgTPC is a proven technology e.g. PEP4 at 8.5 bar
  - Prototype DUNE hardware in hand
  - Current physics case built on thresholds with this technology: excellent counting/ID of few MeV hadrons in event with 0.1-few GeV Etotal
- Optical readout provides exciting opportunities for even lower thresholds
  - Much more R&D (never successfully operated at scale with high pressure gas, needs CF4)
  - Doing that R&D would need clear physics case for even lower thresholds: something targeting events with few MeV Etotal





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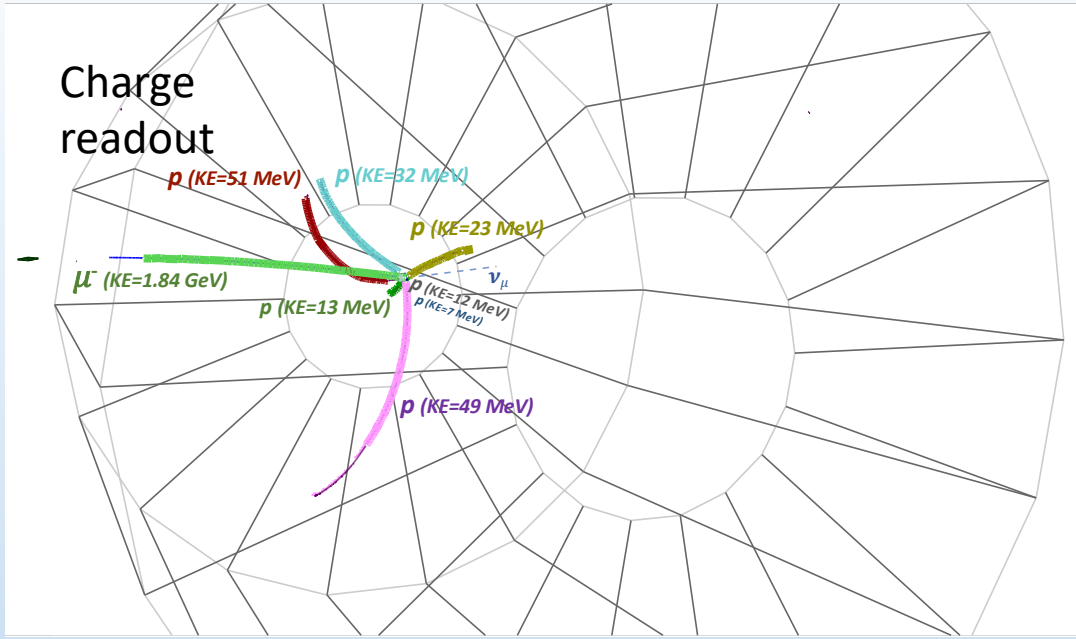
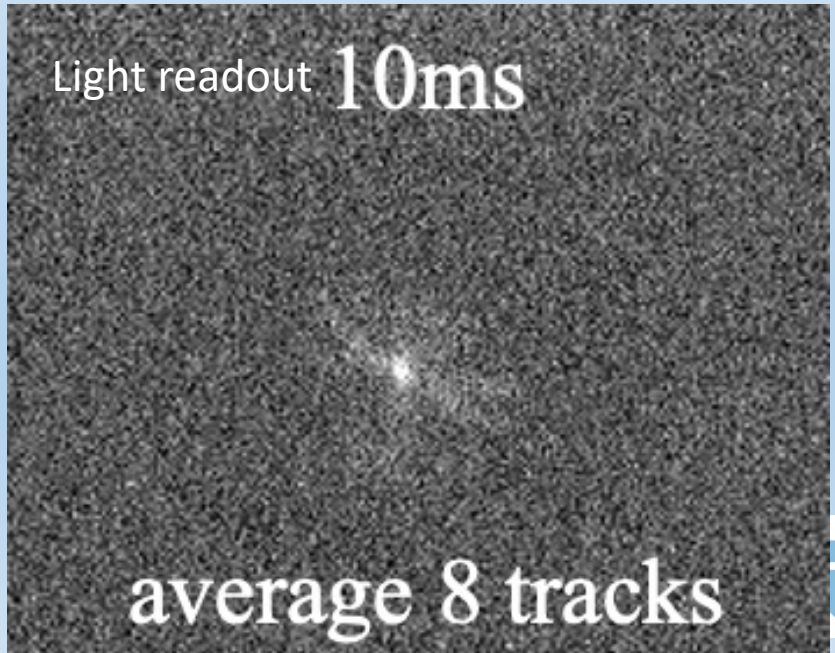
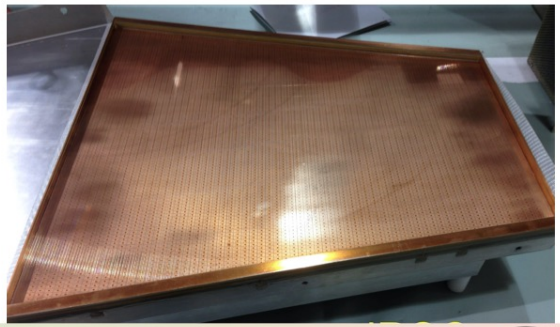




TPC - Test stands

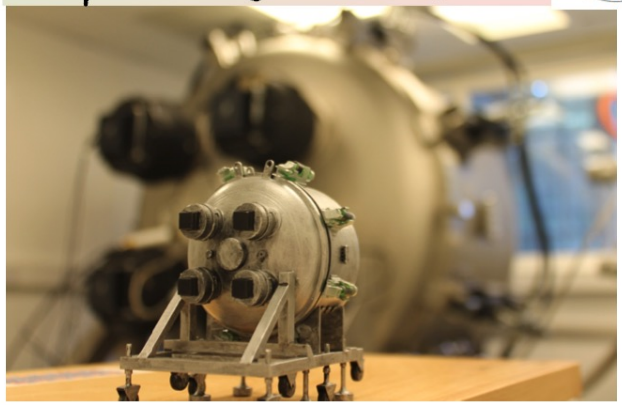
Test Stands for Developing the Charge Readout System

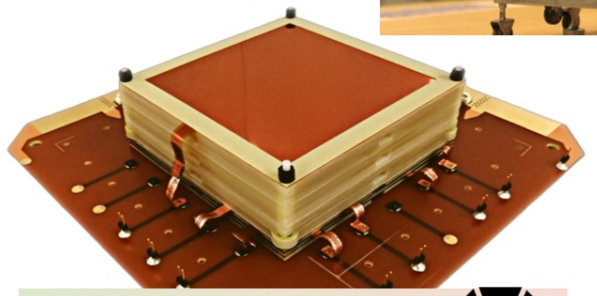
- Tests of **ALICE inner & outer multiwire chambers** (GOAT & TOAD) & a **Gas Electron Multiplier, GEM** (GORG)



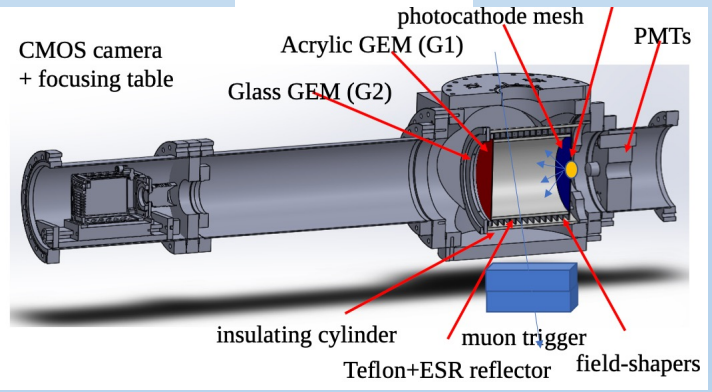
ALICE chamber Testing - Gas-Ar Operation of ALICE TPC, GOAT

ALICE chamber Testing - Test of Overpressure Argon Detector, TOAD





GEM Testing - GEM Over-pressurized with Reference Gases, GORG



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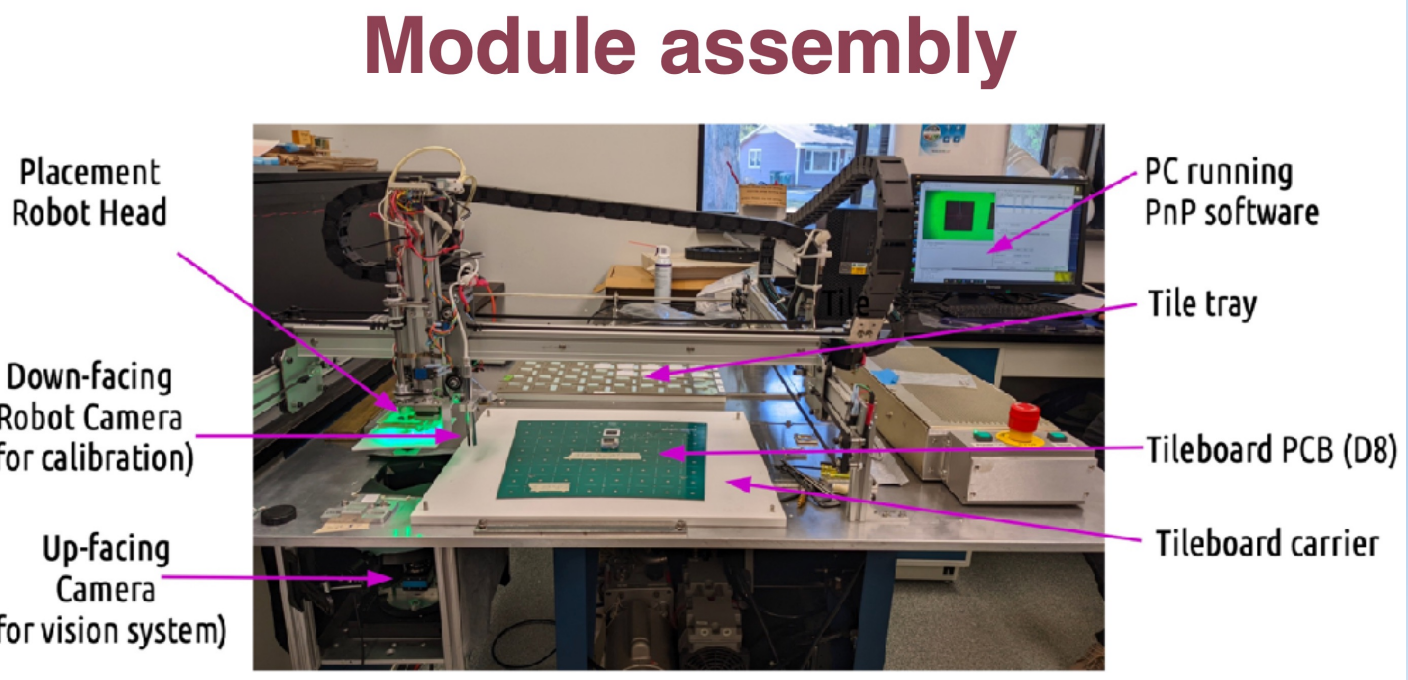
ECal

- Similar to TPC, fairly advanced design for CDR-lite targeted at day 1
- New technology & partnership opportunities come with move to phase II
- Particularly exciting talk from Ted Kolberg on injection moulded and robot assembled tile ECal
  - Currently delivering CMS HGCal, FSU has joined DUNE interested in doing this work

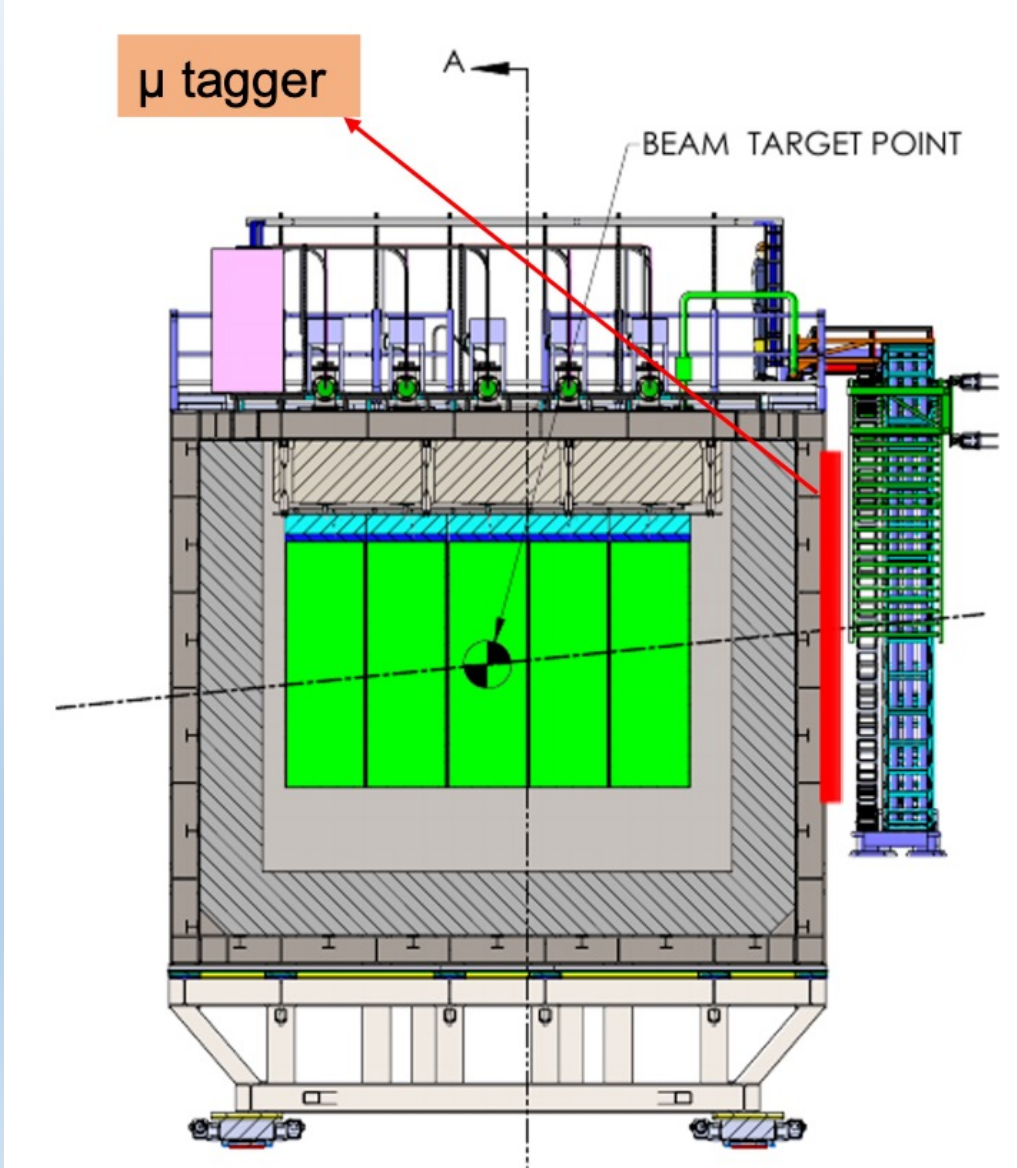


SAND and ND-LAr upgrades

- Most ideas presented either:

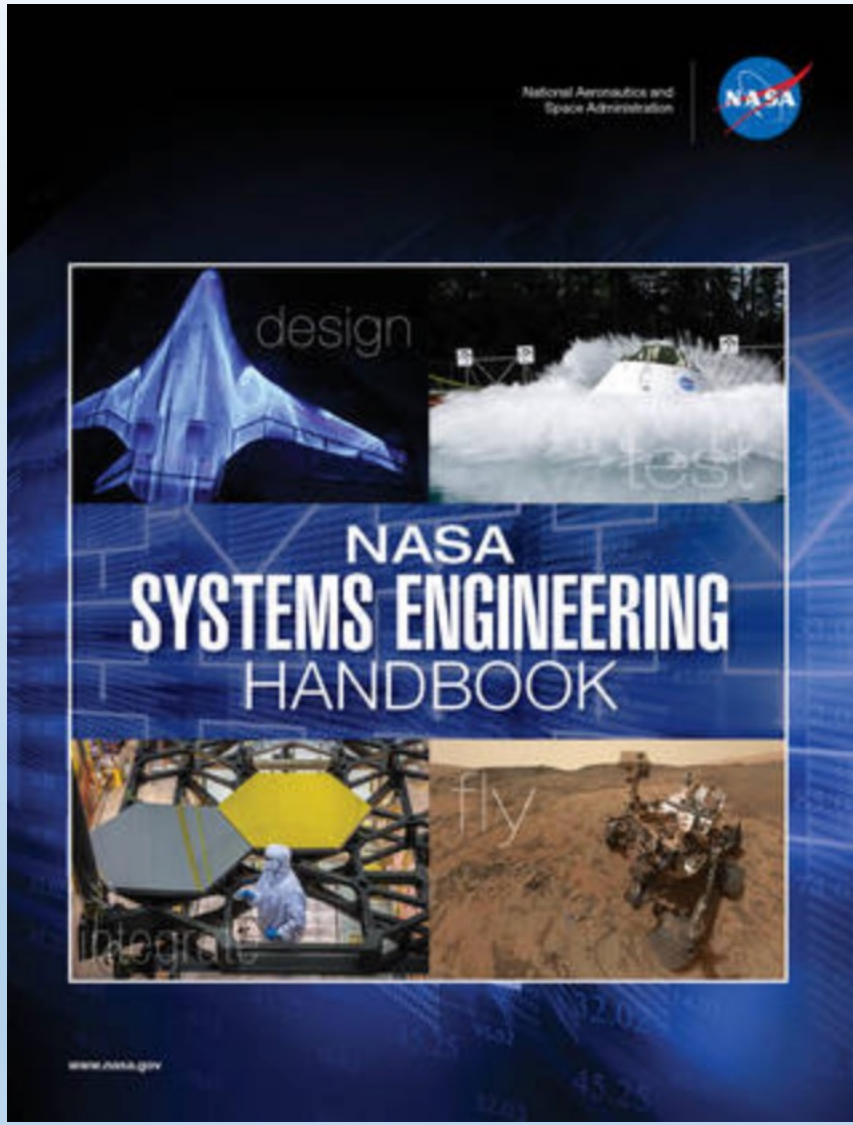
1. Very ambitious
   - E.g. Magnetise the whole ND-LAr
2. Could be done incrementally
   - Most promising proposal was upstream rock muon veto for ND-LAr

- Phase II co-ordinators didn't see anything at critical mass level now requiring a separate Phase II working group
- Will keep under review and provides important context for gas TPC



Plans

- Key conclusion from workshop is that gas argon near detector is supported by collaboration and community as leading option for more capable ND
- Day one ND-GAr group/protoconsortium will become the Phase II gas argon ND working group (led by Alysia Marino (Colorado) and me)
- First goal is to put together physics-driven requirements and set up technology choice framework
  - Has been key for phase I ND passing review



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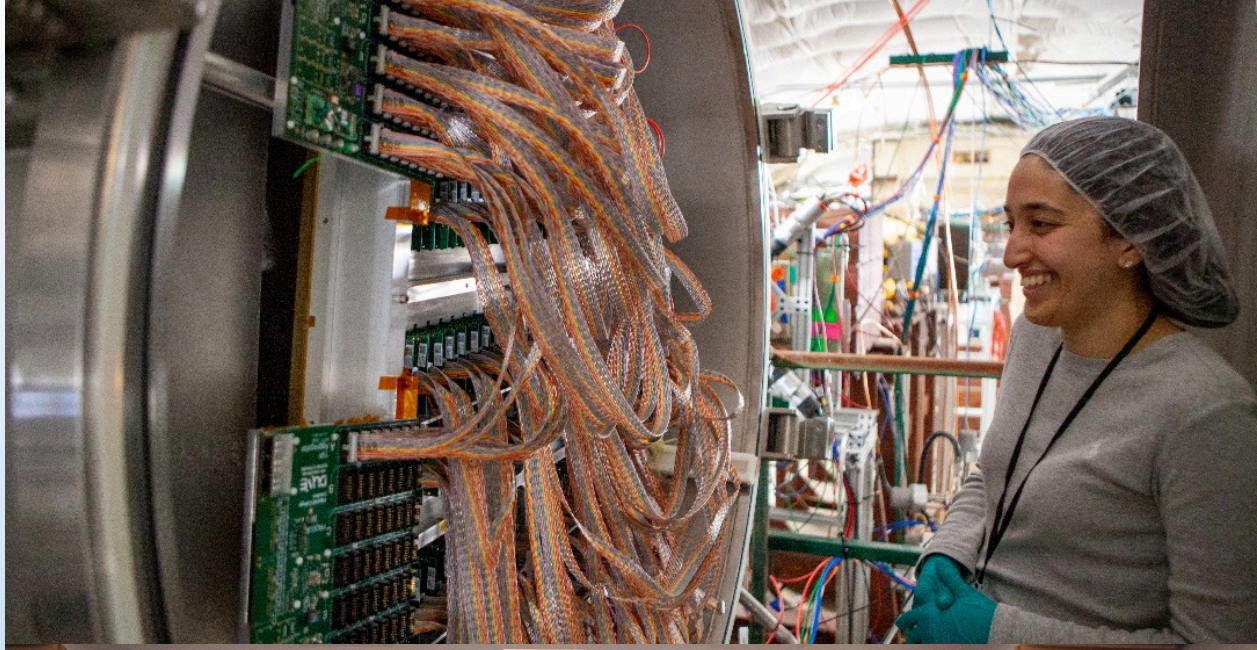
Summary

- 3 days of discussion of Phase II ND with ~80 members of collaboration and community
- Clear agreement we want a gas argon ND and that there are several exciting technology opportunities
- Much of the charge readout, GEM amplification, prototyping and sensitivity work being done in the UK
- Most DUNE UK institutes have been supportive of this direction for period after phase I project
- Time to turn this into a reality



Backup

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DUNE

Why we are not sPHENIX

- sPHENIX bunch crossing rate is 200 kHz → We have O(1 Hz)
- We see O(10s) of tracks per spill not nearly saturated heavy ion events
- Both mean many more digitisers per FPGA and less sophisticated backend
- Initial cost estimates for system described today of ~£2M for 700k channels