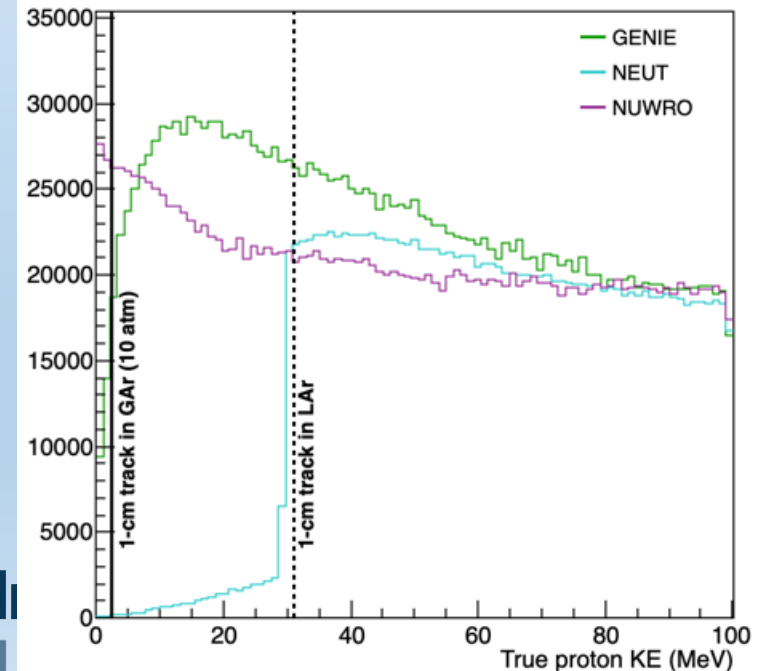
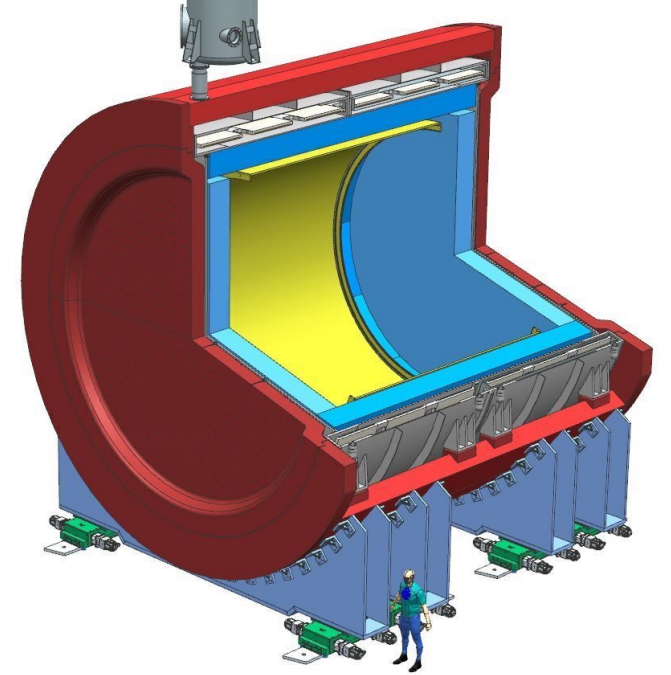


NDGAr as the more capable phase II near detector

Patrick Dunne for the High Pressure gas TPC group

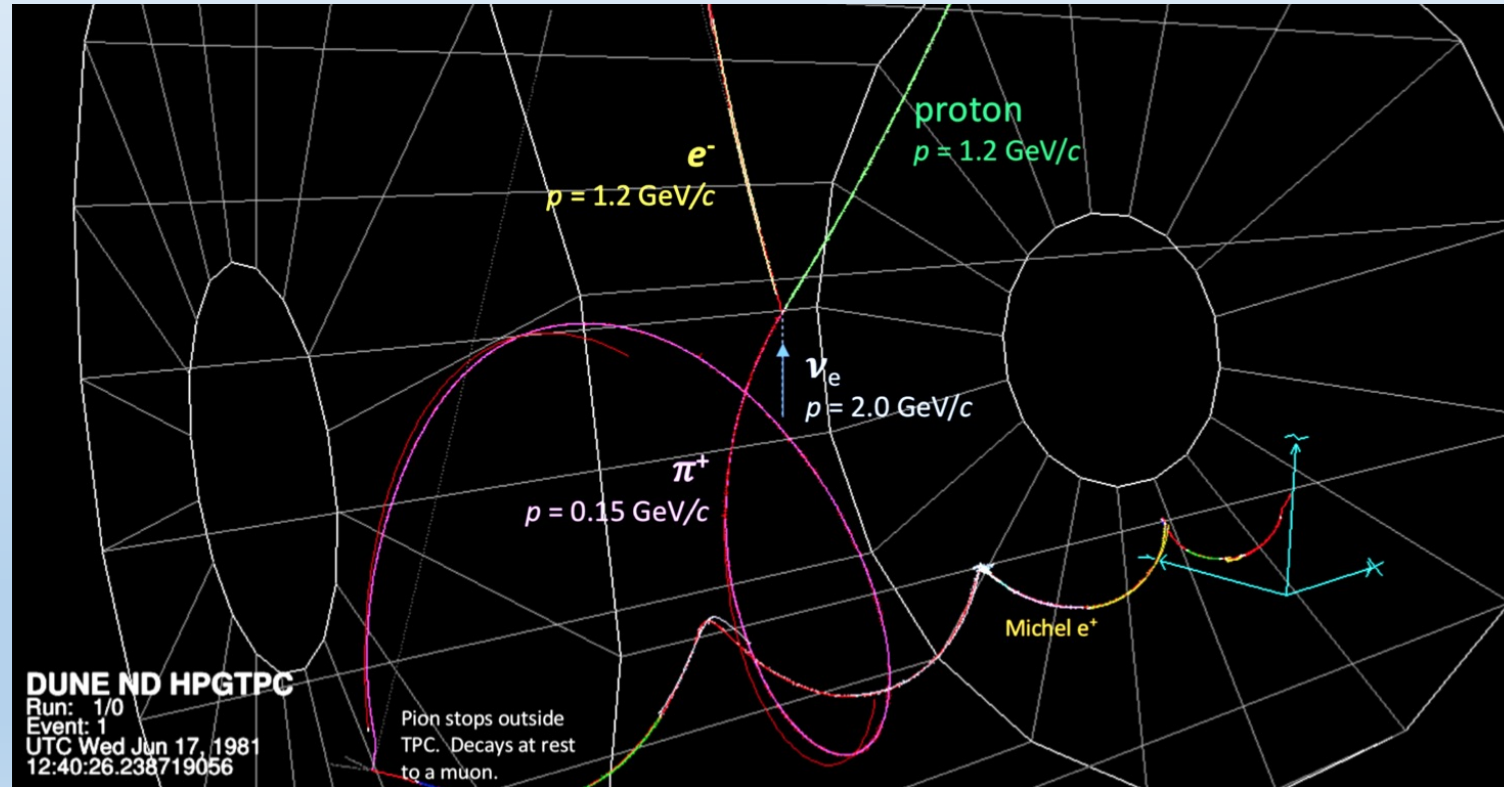
ND-GAr: Gaseous Argon

- 1-ton fiducial mass gas target TPC surrounded by ECAL and superconducting magnet
 - Magnets gives sign selection capability
- Gas target has much lower energy threshold than liquid
 - Also gives very good particle ID
- Detector has 4π solid angle coverage
- Key for hadronic final states which are hard to distinguish in ND-LAr and far detector that contribute to visible energy differently e.g. multi- π
- ND-GAr also fulfills the need for a spectrometer for ND-LAr escaping muons



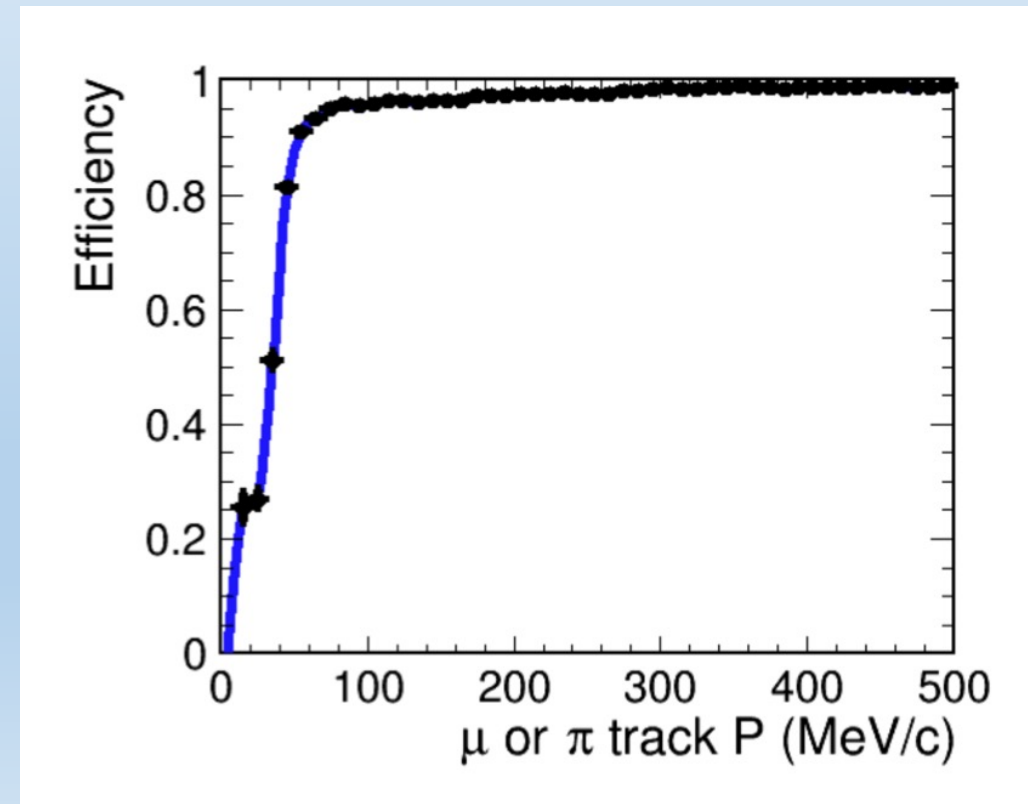
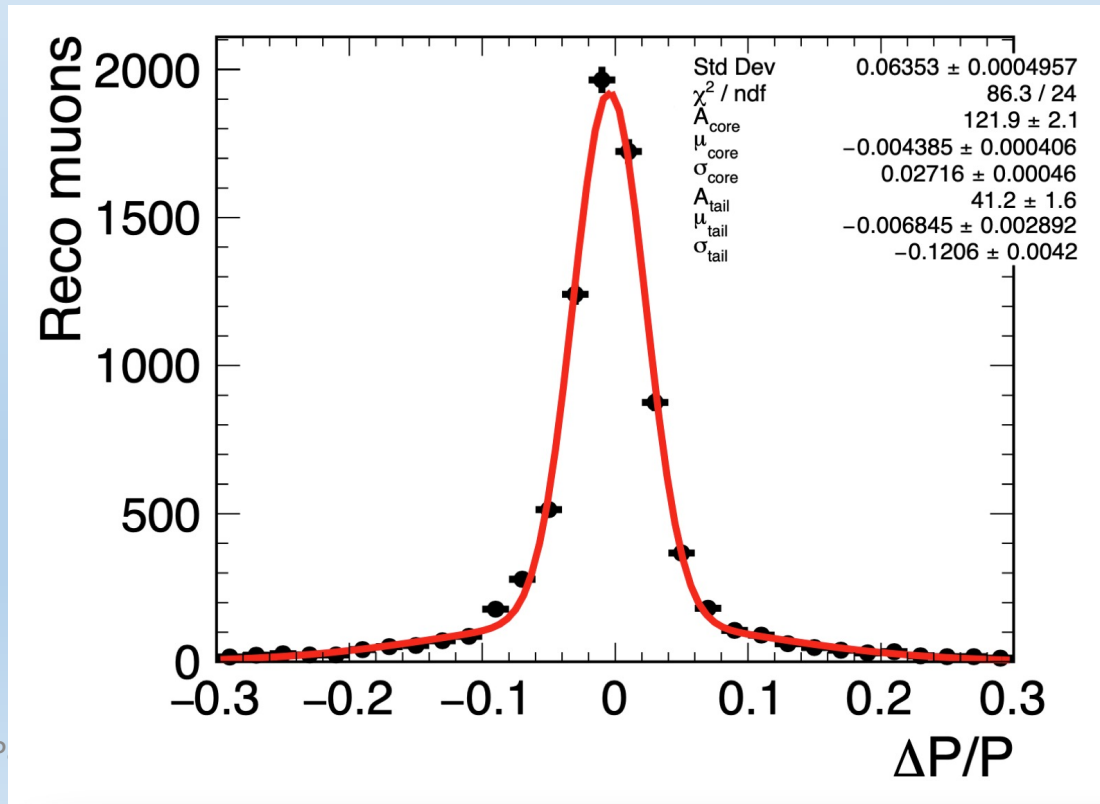
ND-GAr: Analysis status so far

- We have a full end to end simulation and reconstruction package 'GArSoft'



ND-GAr: Analysis status so far

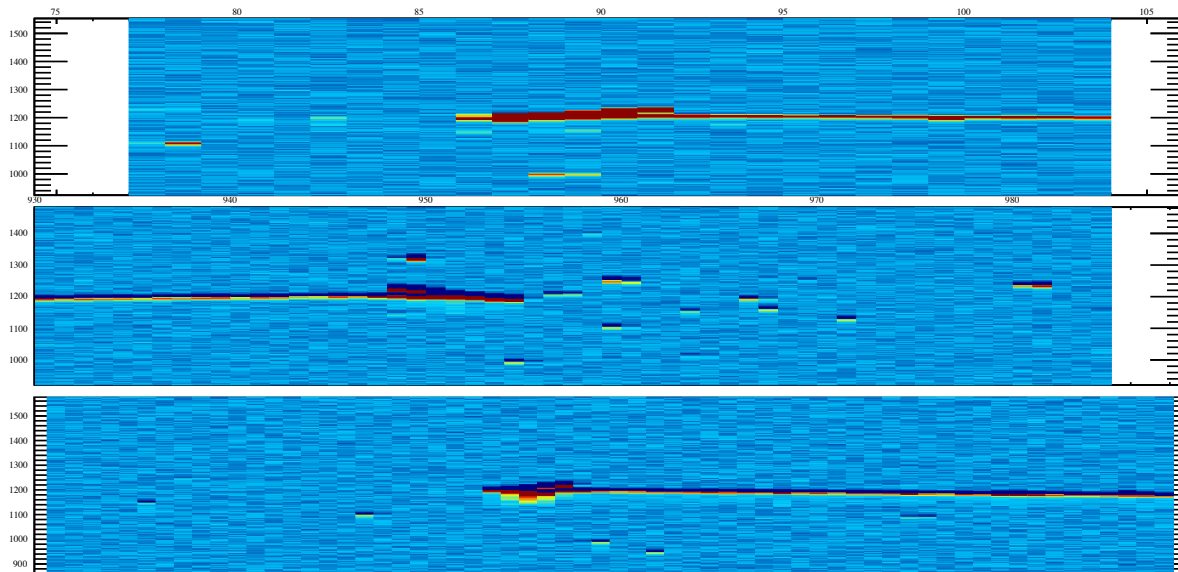
- We have a full end to end simulation and reconstruction package 'GArSoft'
- We have studies showing muon momentum resolution and mu/pi ID efficiencies with this reconstruction



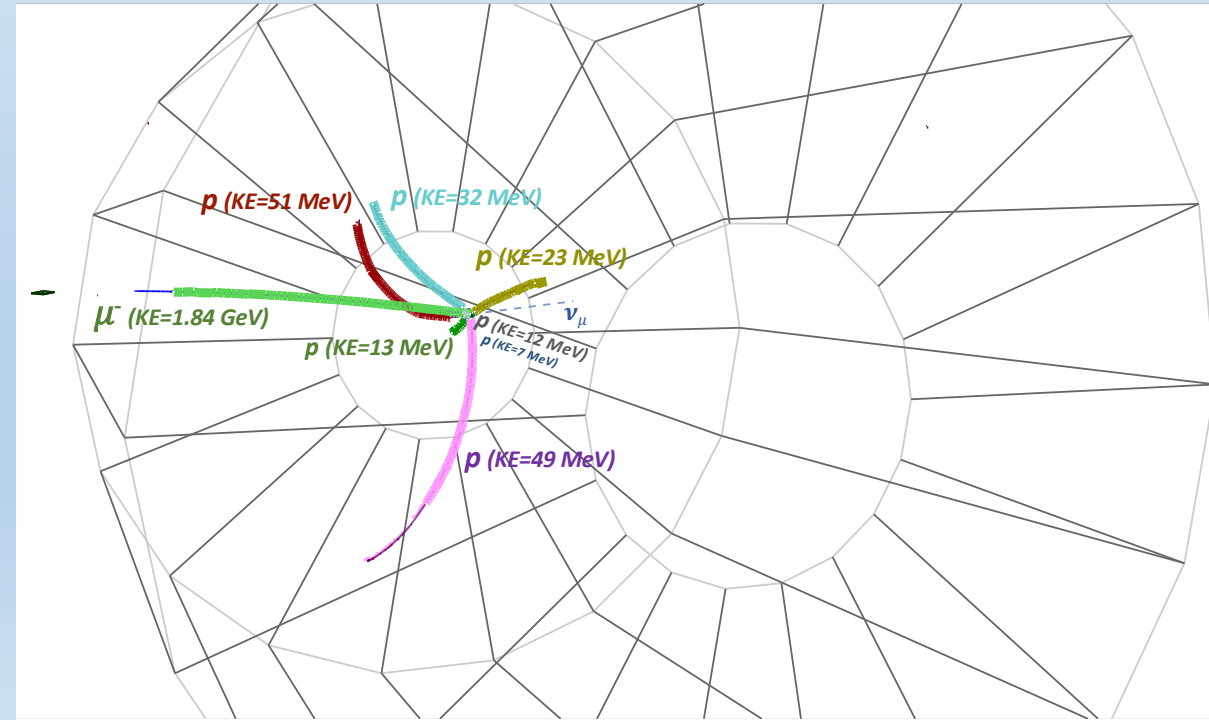
ND-GAr: Analysis status so far

- We have a full end to end simulation and reconstruction package 'GArSoft'
- This is what the same 7 proton hard scatter looks like when reconstructed in a LArTPC and ND-GAr (GArSoft finds all 7 including the $E_k=5$ MeV one)

LArTPC with 5mm wire spacing

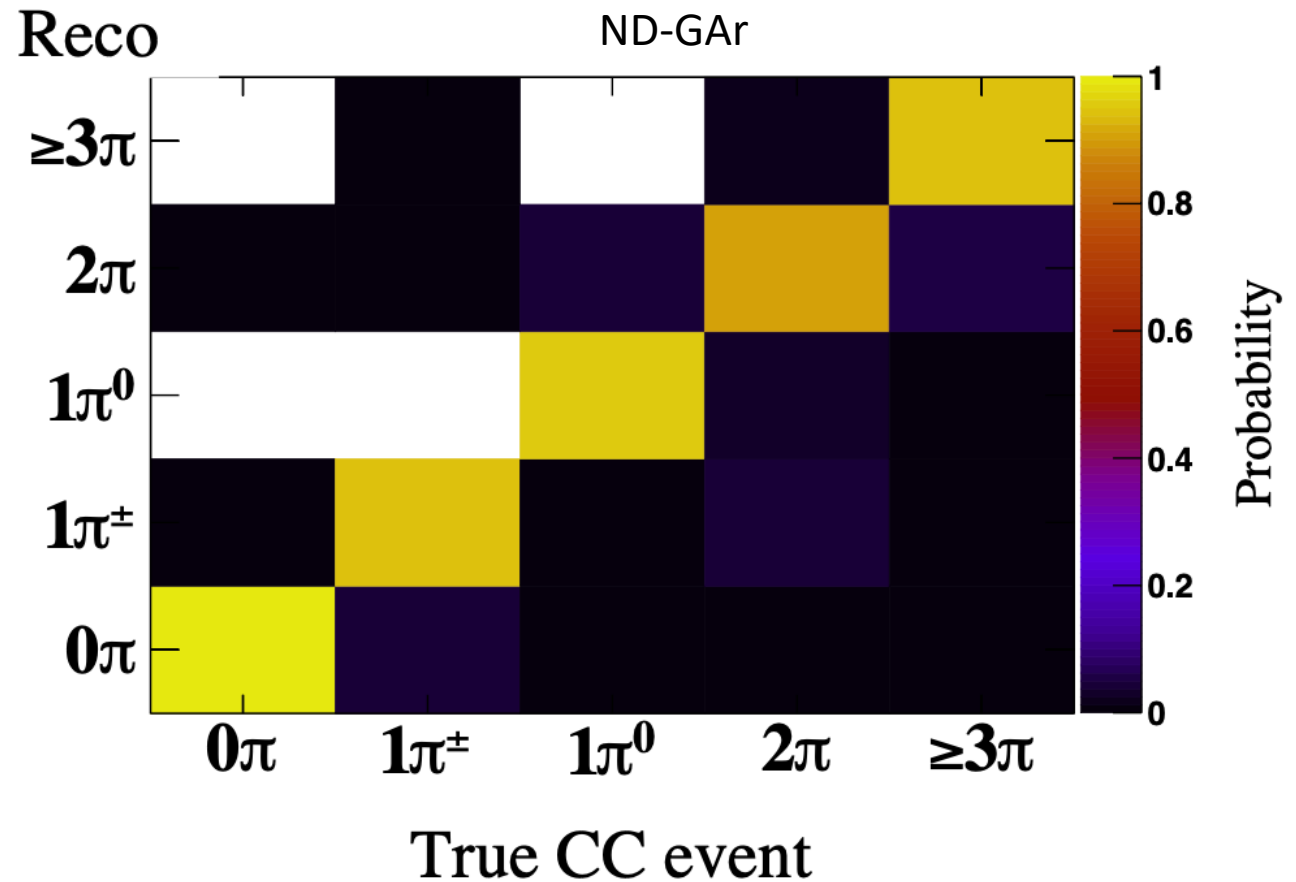
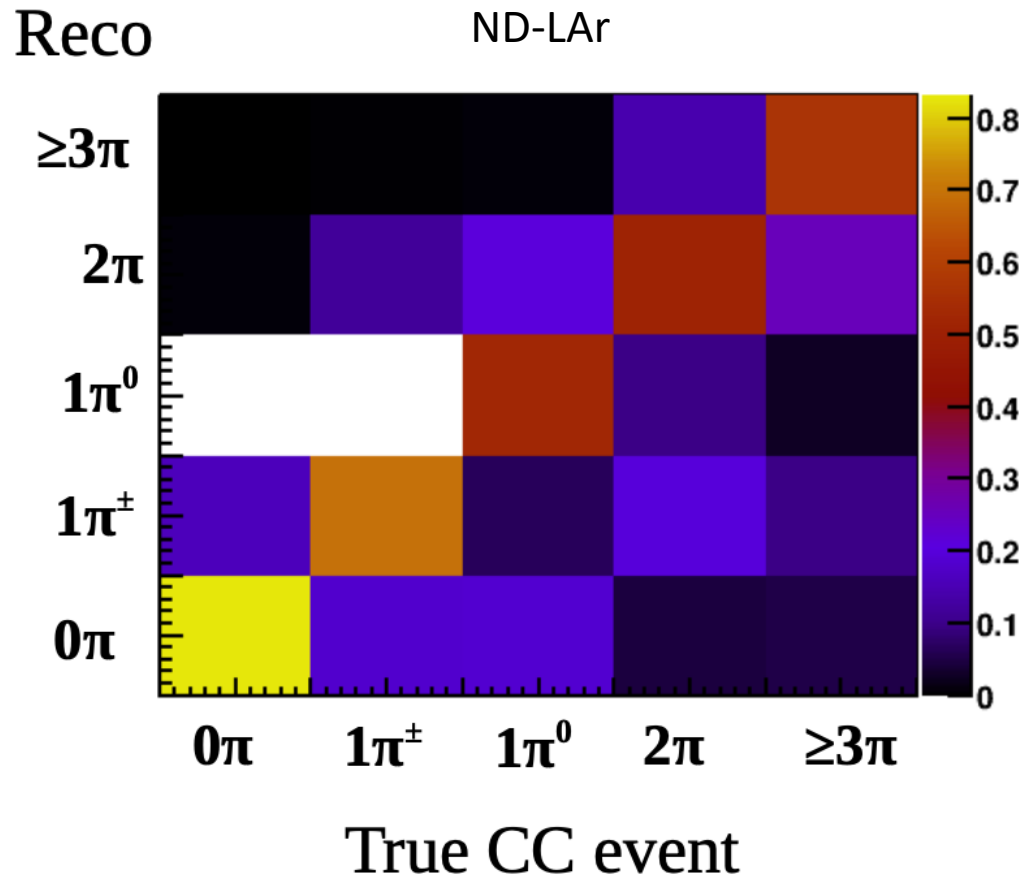


ND-GAr



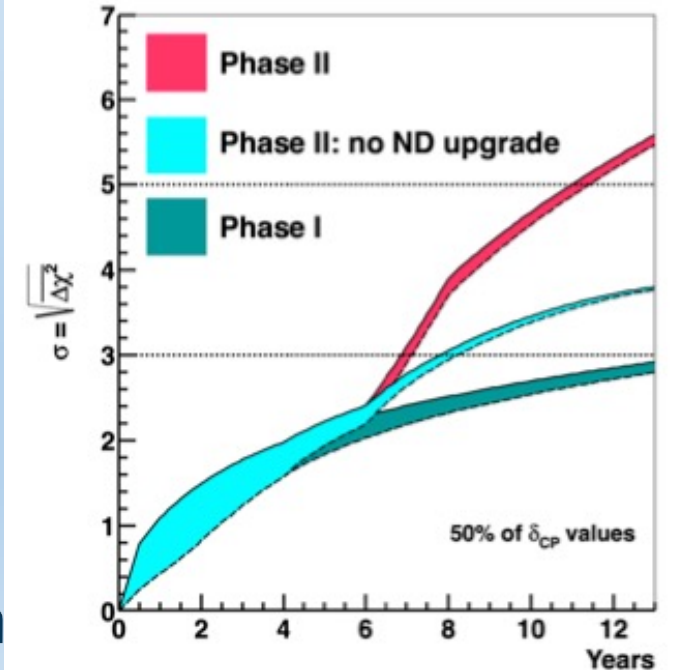
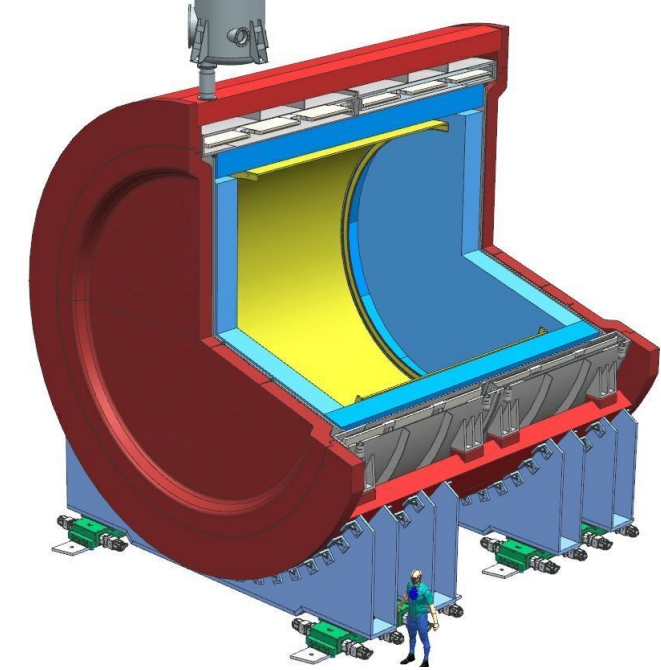
ND-GAr analysis status so far

- Particle ID and tracking performance translates into significantly improved correct identification of particle topology



ND-GAr current status in DUNE

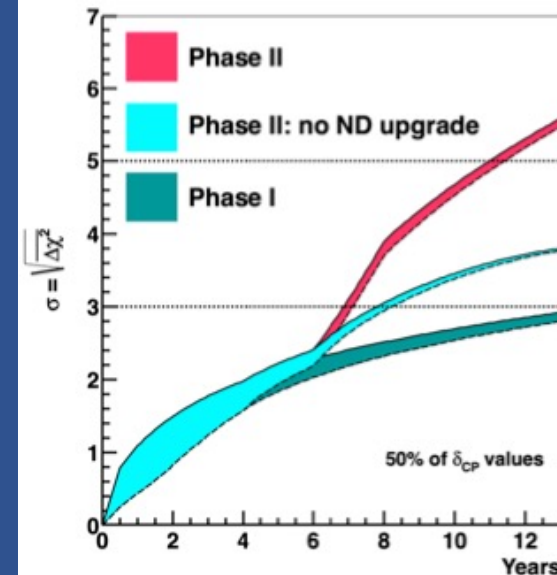
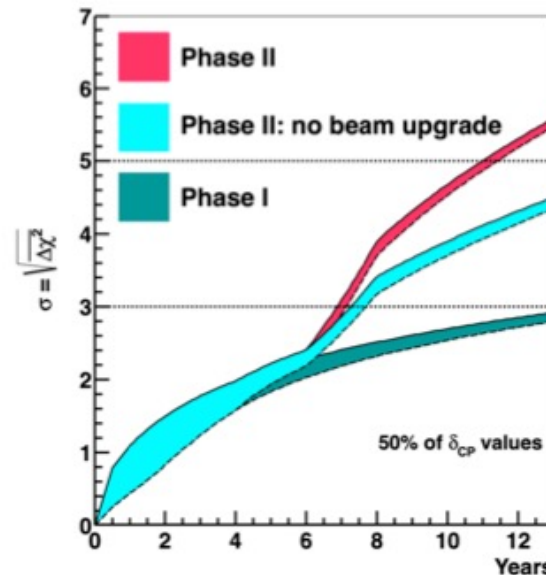
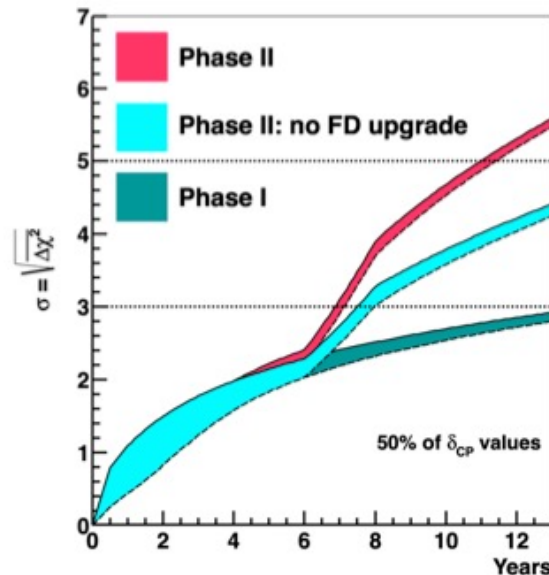
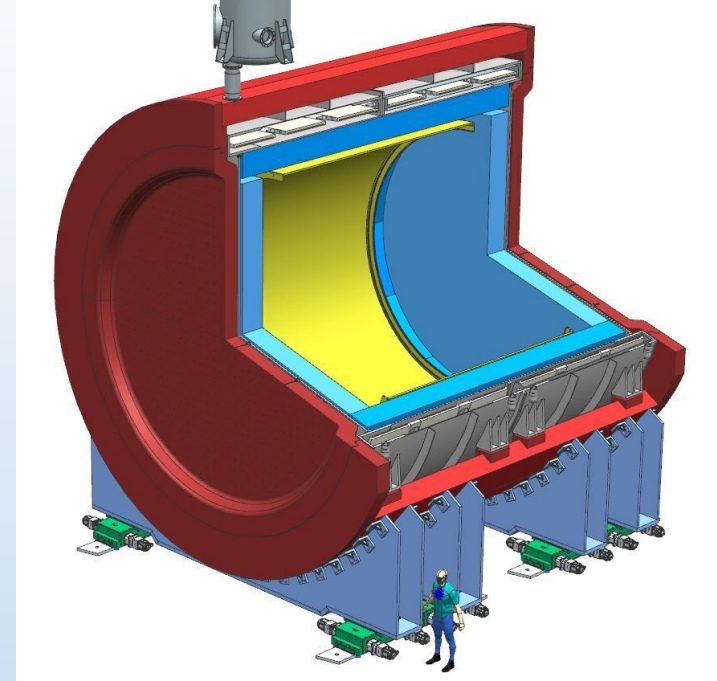
- ND-GAr was part of near detector CDR
- Phased approach pushed ND upgrade into phase II and DoE ND cost envelope makes it unlikely will be built with US money
- Nevertheless, community was told at Snowmass that DUNE won't achieve P5 goals (5σ CPV) without upgraded ND



What now?

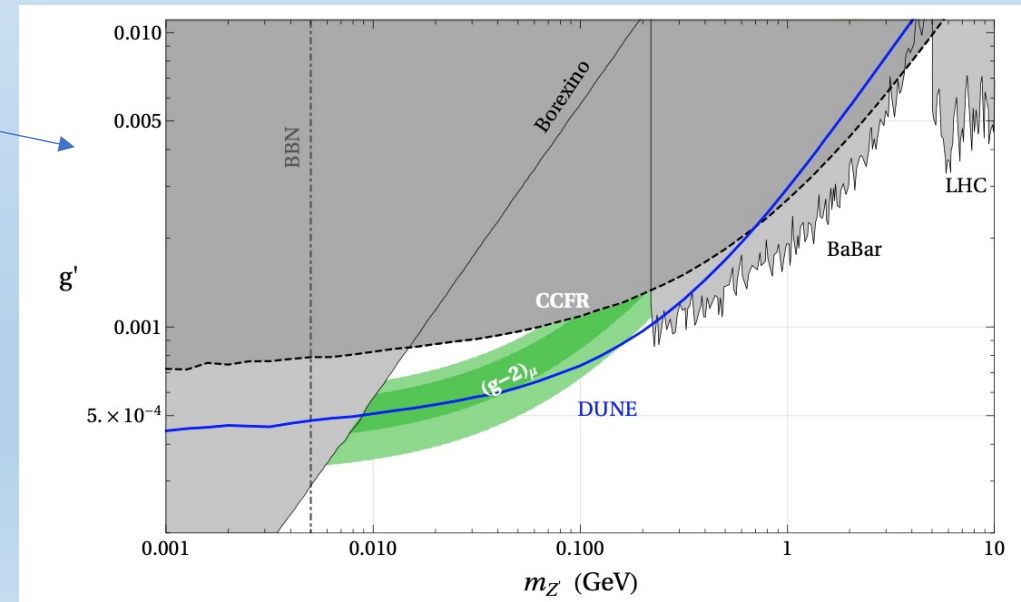
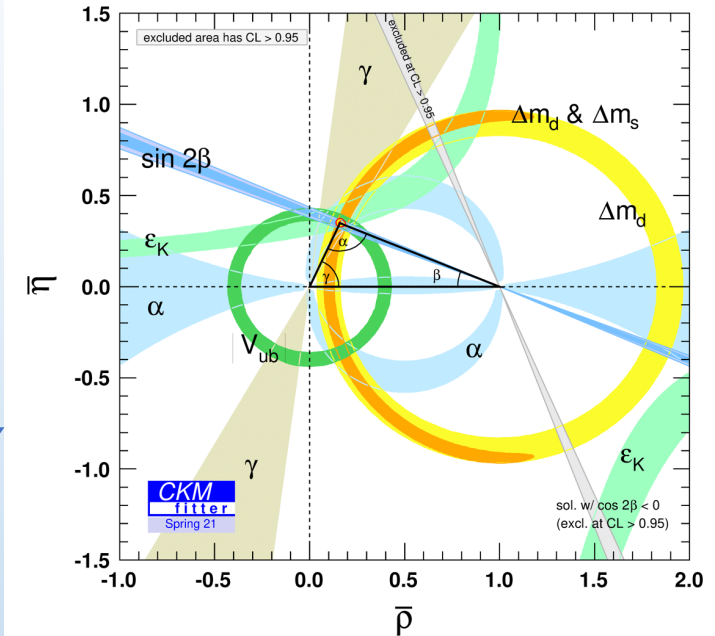
ND-GAr in DUNE

- All aspects of full phase II are needed to reach P5 goals in 12 years
- However, ND upgrade is the only part of phase II targeting getting our systematics to the required level for the P5 physics program



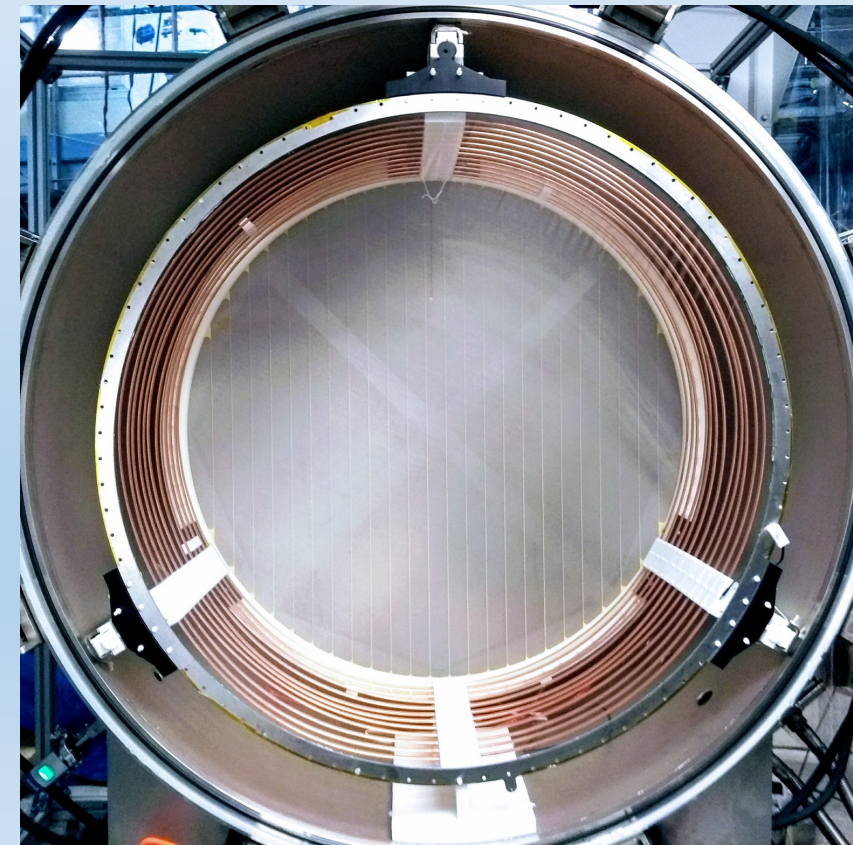
ND-GAr current status in DUNE

- Major strength of DUNE vs HK is our wideband beam and good systematics control, i.e. we can do more than 5σ CP violation discovery
- ND upgrade is even more crucial to realise these precision measurements and stress-test the PMNS paradigm (cf hadron flavour CKM fitting efforts)
- ND-GAr also brings its own BSM physics program e.g. neutrino tridents (green region is area that explains $g-2$ anomaly with a Z')
- Showing that phase II isn't just phase I with more stats is likely to be crucial to getting all elements of it approved
- Building ND-GAr in the UK gives us leadership of this physics program and early access to data



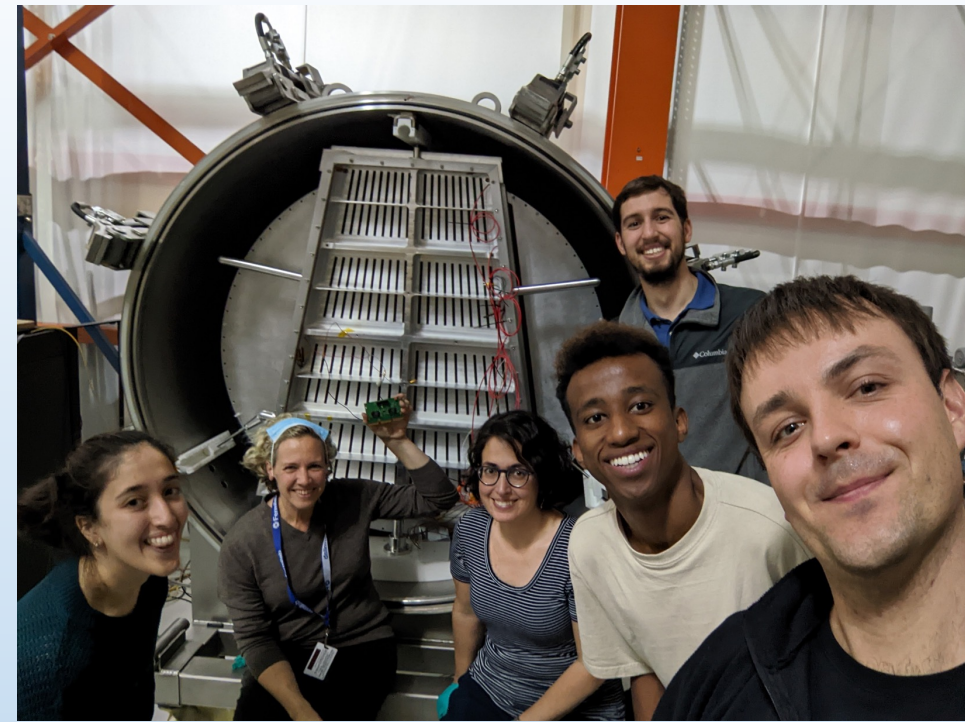
ND-GAr in UK: Background

- ~a decade of HPgTPC work in the UK including STFC PRD funded CERN beam test
 - Papers [here](#) and [here](#)



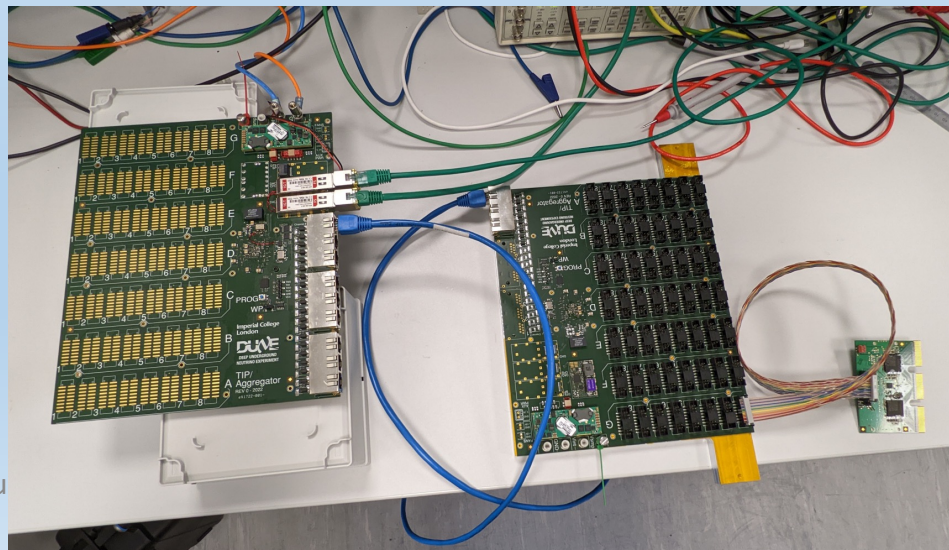
ND-GAr in UK: Today

- UK groups are currently leading ND-GAr prototyping including TOAD beam test
- This will be the first full slice test of DUNE HPgTPC
- Program is funded mostly in the UK: 3 FLFs, Royal Society & STFC capital funding
- Developed at Imperial, Lancaster, RHUL, QMUL, Oxford, UCL, Warwick
- Not only technology demonstration but will also give low threshold proton-argon interaction data



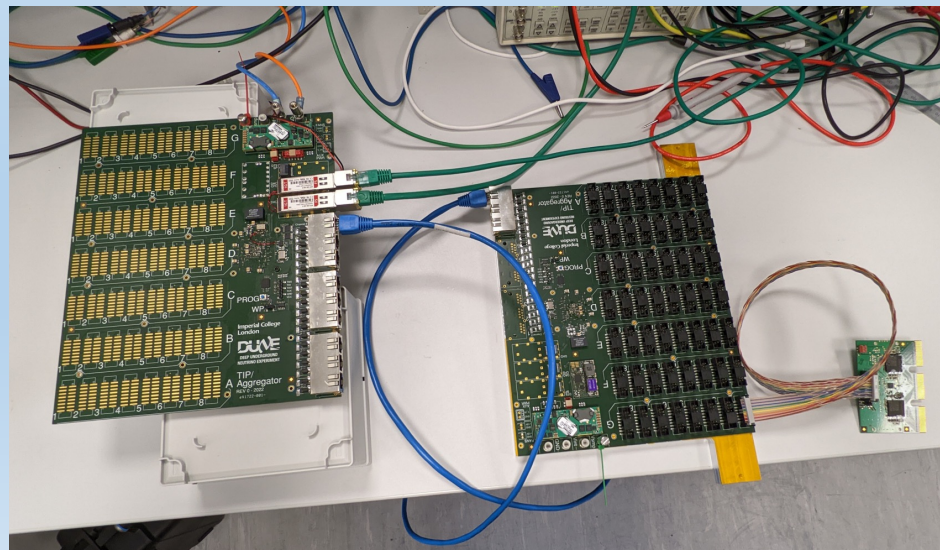
ND-GAr in UK: Today

- Wider community with interest in ND-GAr opportunities
- Imperial electronics development has shown electronics cost \sim £2M not £155M
- Liverpool work on GEM readout places us well to instrument the TPC
- RAL TD magnet expertise has identified a company that should be able to build the large 0.5T magnet required



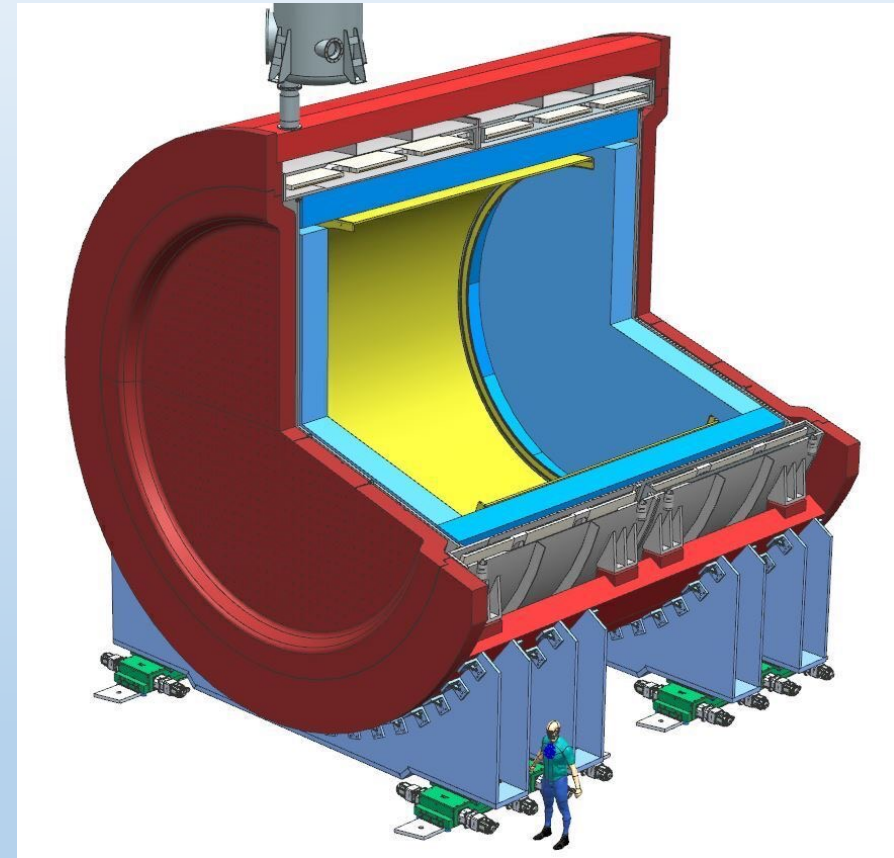
Electronics point of interest

- ~£150M to £2M sounds like an unrealistic reduction
- This is driven by £150M cost being estimated from a scale up by endcap area of a heavy ion collider gas TPC
- We are not a 40 MHz bunch crossing, high occupancy detector
- Work at Imperial has shown we can use one FPGA per 3,584 channels rather than per 32 channels which has driven this cost reduction



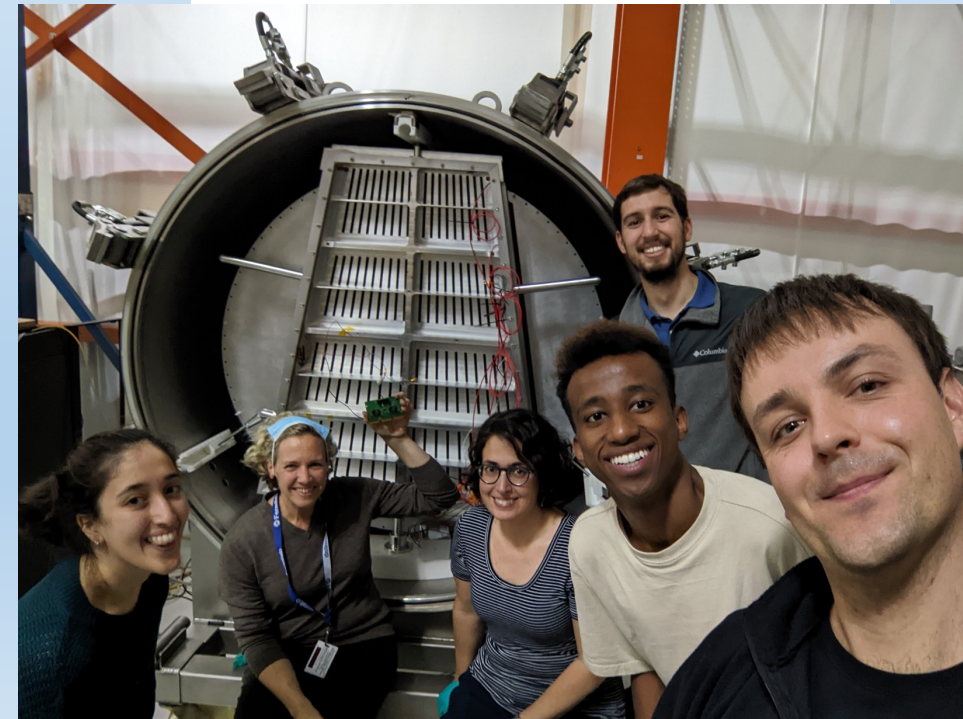
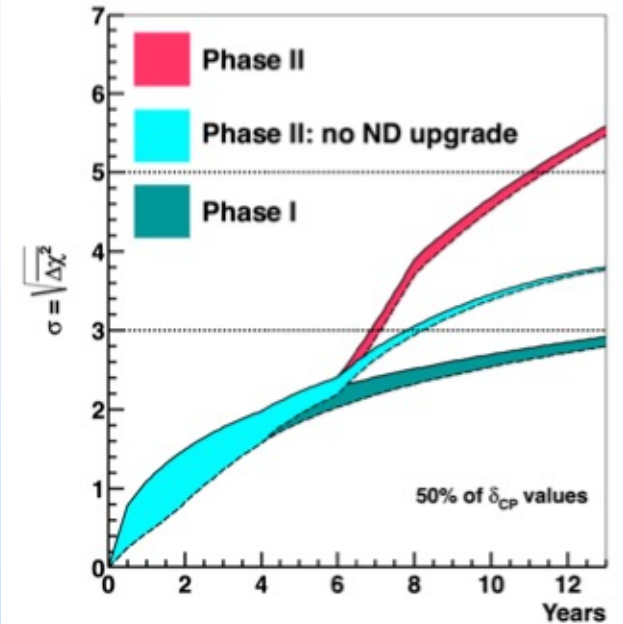
What we need to build to get liftoff

- Magnet, pressure vessel, TPC and readout electronics
 - Cost estimated at ~£70M plus capitalised PDRA, technical and project management time
- This is a self-contained system that would deliver most of the physics benefits of ND-GAr regardless of other international contributions
- RAL TD have identified a company that could build the magnet with UKRI funding to increase capacity
- We also have UK companies capable of building the TPC readout electronics
- Leaves open possibility of other countries contributing ECal (e.g. Germany) or light collection systems (e.g. Spain)



Summary

- An upgraded near detector is key to the success of DUNE phase II
- The UK is already leading work on high-pressure gas TPCs within DUNE
- Cross-section analyses and improved systematics constraints lead to many of the PhD projects on current generation experiments
- As we look to phase II strategy this should be a key part of it



Backup

UKRI infrastructure fund

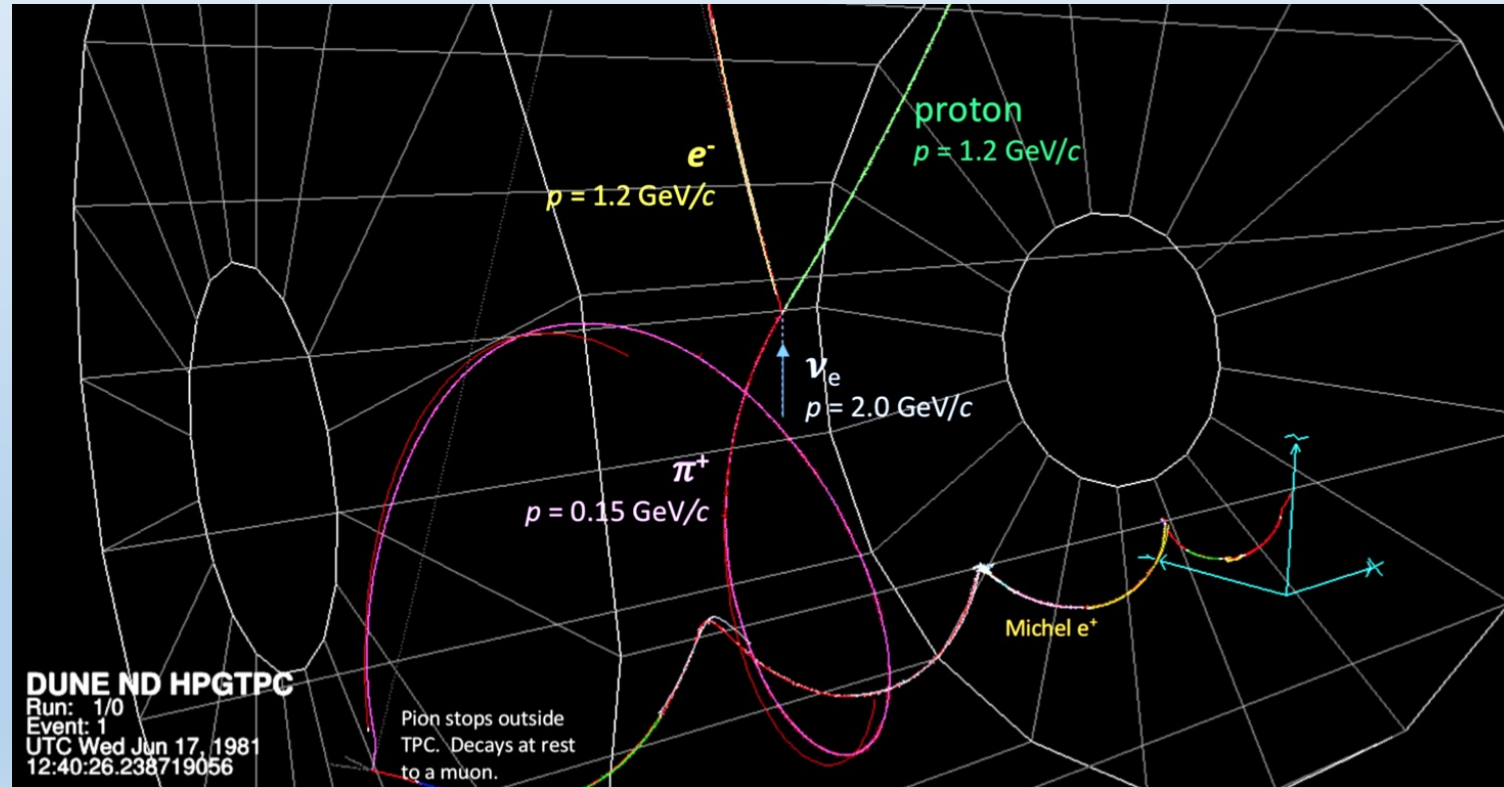
- UKRI infrastructure fund asked for expressions of interest (Eols) last Summer
- This infrastructure call is funded out of non-STFC money
- Two types of Eol requested
 - Full projects at business case stage with cost between £50M to £150M
 - Preliminary projects at earlier stage but targeting a specific full infrastructure project
- Several PIs (17) working on High-pressure gas TPCs put a preliminary project Eol in to PPAP
 - ‘full project’ targeted was everything on the last slide: ND-GAr magnet, TPC, readout
- PPAP judges these projects before sending to UKRI, feedback was that this was an important project but that we should get more signatories to demonstrate enough interest from a large UK community to justify the full project cost and try again
- Also asked to clarify situation with international partners
 - i.e. we need a statement of support from DUNE collaboration

ND-GAr in UK: This year's expression of interest

- Hoping to answer first feedback item today
- Talking to LHCb and nustorm who have had successful infrastructure proposals, expectation is that the whole supportive community signs
 - PIs, RAs and students signed the other proposals
- Successful bids are expected to have a large user community who will benefit from the facility even if they don't help build it so we need that type of signature
 - Signing doesn't have to be a commitment to build something
 - For example, we have existing signatories from HK and dark matter communities
- Timeline for this year's preliminary project call is expected to be Summer (different to the February full project call)
 - The proposal is still being developed so let us know if you have ideas
- For collaboration support initial discussions with collaboration leadership (spokespeople, phase 2 leadership) are positive and we hope to secure statement of support

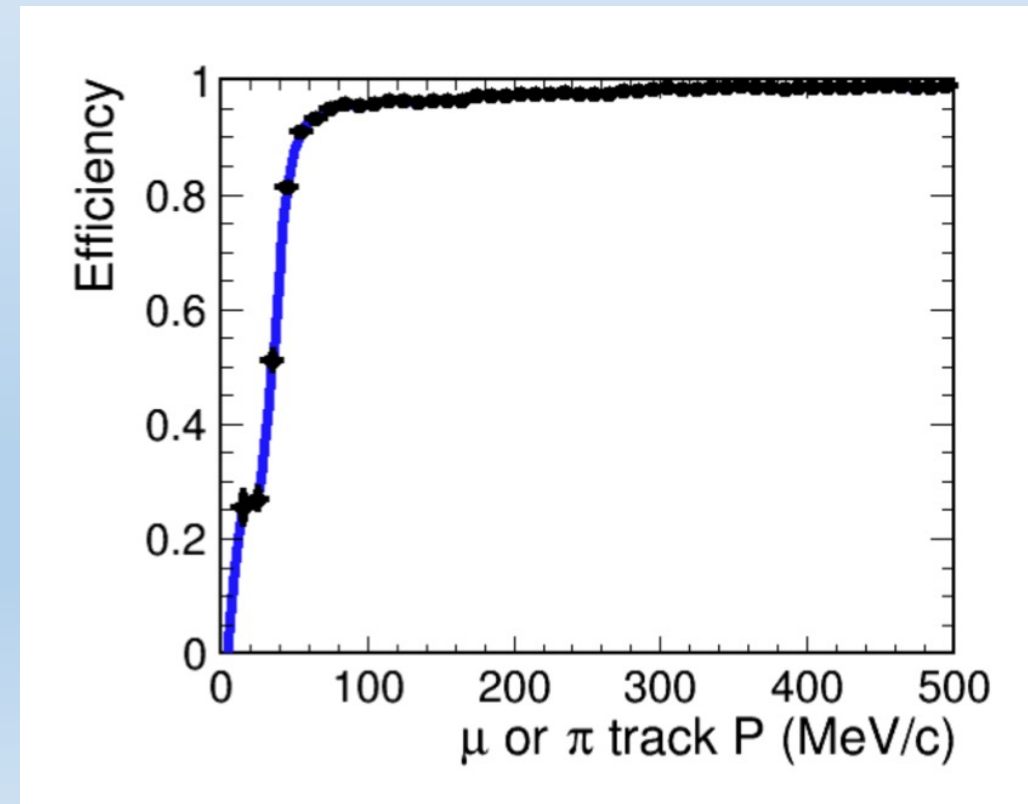
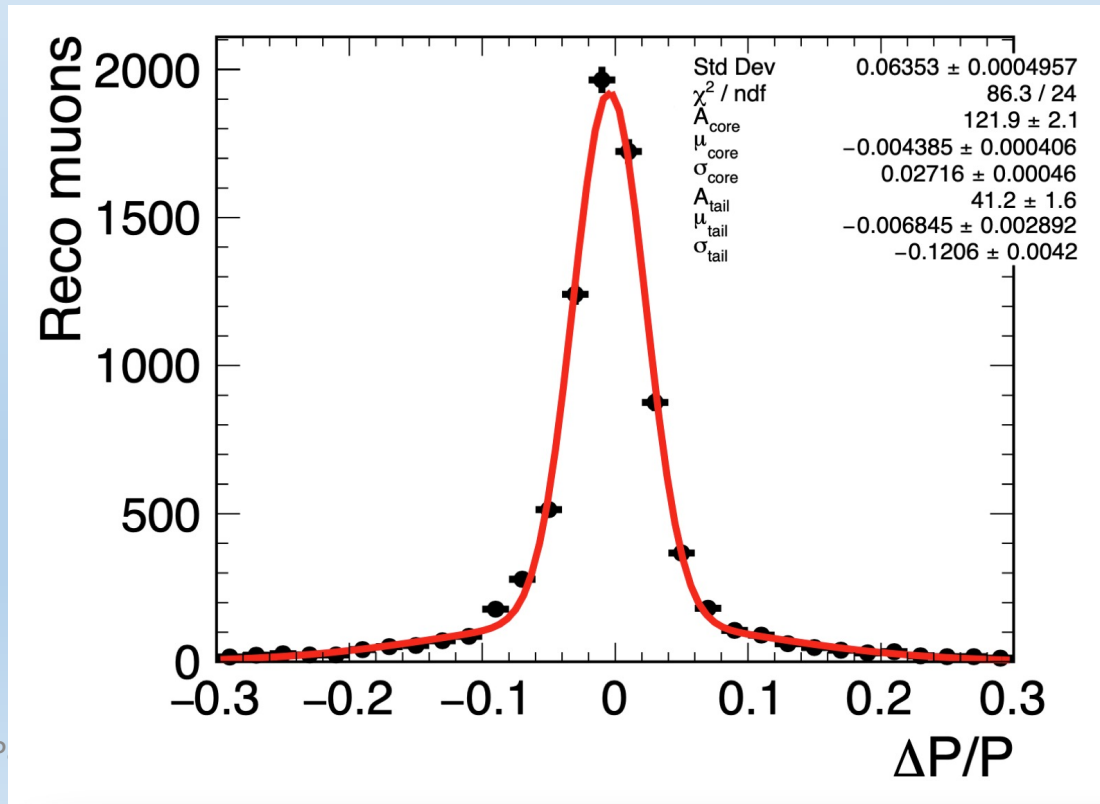
ND-GAr: Analysis status so far

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ND-GAr: Analysis status so far

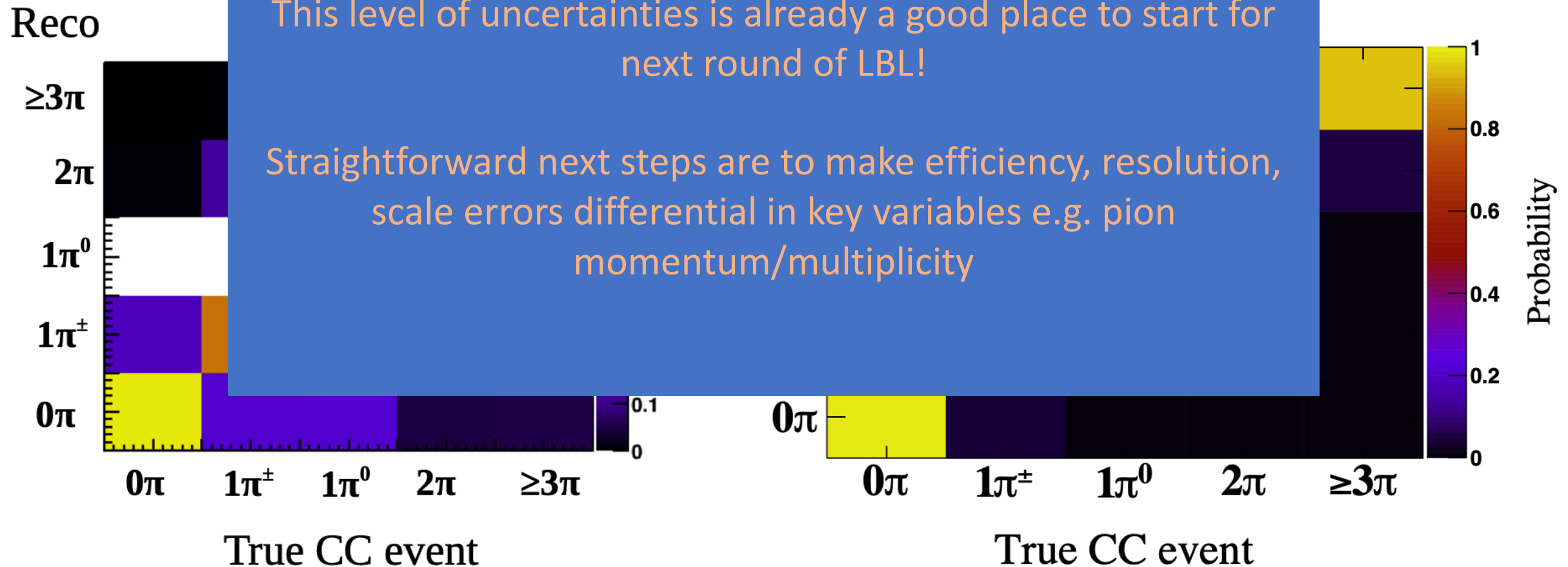
- We have a full end to end simulation and reconstruction package 'GArSoft'
- We have studies showing muon momentum resolution and mu/pi ID efficiencies with this reconstruction



ND-GAr analysis status so far

- CDR:

- Confusion matrix



Proposal:

Goals for this workshop

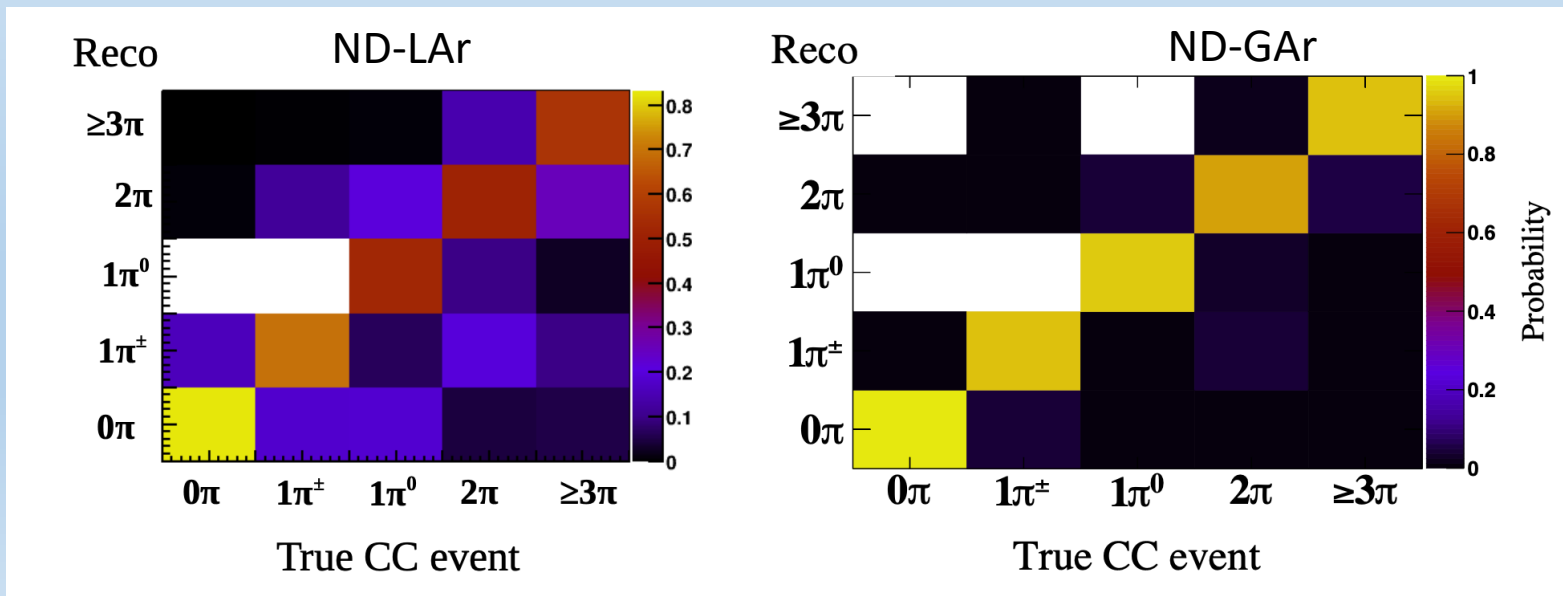
- We'd like to move from existing FDS based studies to having a sample in the fit
- We would like to have samples binned in pion multiplicity with 4π solid angle coverage and demonstrate that ND-GAr can better constrain Etrue-Erec mapping by giving information on below LAr threshold particles
- To show benefit we would need interaction and detector models with sufficient freedom to change the fraction of energy going into the different multiplicities
 - Looking forward to working with DIRT experts at this workshop
- We already have some resolution/efficiency numbers that can be used for first tries at detector uncertainties

DIRT II model elements we will target

- A large impact we're expecting is below LAr threshold hadron multiplicity measurements to constrain pion mass loss in E_{rec}
- Key xsec systematics we will target are:
 - Pion absorption and production in final state interactions
 - Hadronization effects in SIS/DIS
- These are still not well constrained and would cause the effect we're looking to constrain
- There will also be work to make sure we have dials sufficiently affecting pion momentum

Sample we will use to do this

- For terminology reasons the planned sample is called CC Inclusive
- However aim is to constrain individual hadron topologies
- To do this we will split sample by π^\pm multiplicity
- Not yet determined what variables we will further bin in but likely there will be something π^\pm momentum related



Production of ND-GAr MC

- For next round of LBL we need to get our MC produced by central sim-reco production
- Alex Booth is working on integrating our toolchain with the sim-reco tools
- Summary: For “mainline” ND production you use a python script to generate a job submission script. For a given geometry, this script runs genie via `gevgen_fnal` rather than via `art` as we do in `garsoft` (`prodgenie.fcl` or similar name). `Edepsim` is then run on this output from `genie`.
- Alex has run this script using a `NDLAr+NDGAr+SAND` geometry. There is then an `art` module which takes the the `genie` and `edepsim` output and makes an `art` file then be used in `garsoft` (for `reco` etc) which Alex is working on getting working
- Next step is to extend the ND Production standard to include this step (and run `reco`).
- Workshop also had good discussion on analysis level file formats for inclusion in fitters like `MaCh3`

Summary and personpower

- We have a first implementation of an end to end reconstruction package and initial ideas for detector uncertainties motivated by this reconstruction (this is similar place to other NDs)
- Planning to move from FDS-based studies to samples in the fit starting with CC inclusive sample split by pion multiplicity
- There are people who are funded specifically to work on ND-GAr (including non-US money) with interest in these physics studies

