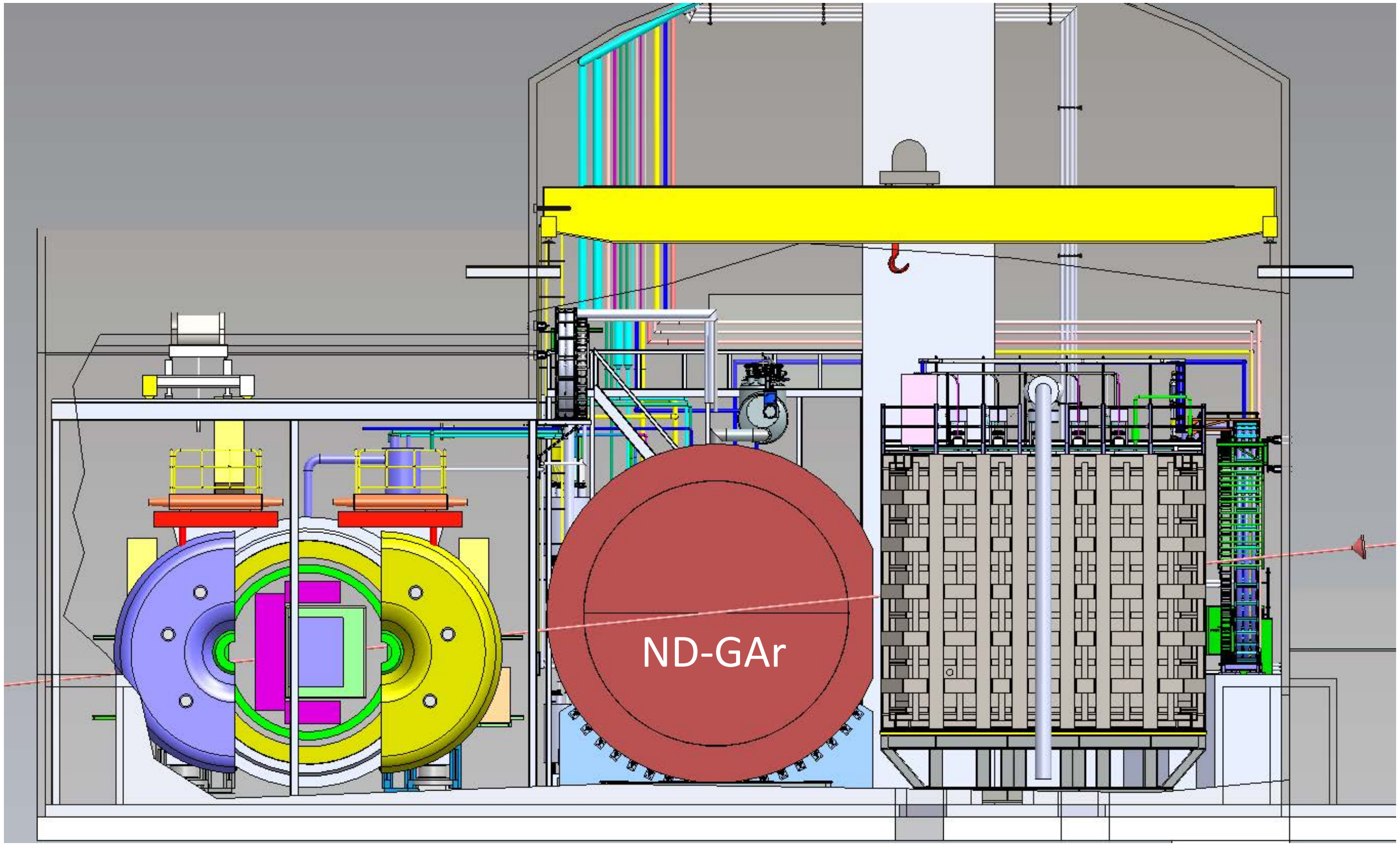
ND-GAr
Update



LBNC

March 4th, 2021

Near Detector Requirements

Motivation for ND-GAr

Overarching ND Requirements & ND-GAr

Unchanged from last presentation

Label	Description	Rationale
ND-O0	Predict the observed neutrino spectrum at FD	With available external information, the ND must predict observables at the FD in the presence of oscillation effects.
ND-O1	Transfer measurements to the FD	Measurements at the ND must be transferable to the FD in order to minimize systematic uncertainties
ND-O2	Constrain the cross-section model	Systematic errors from cross section modeling couple the FD response to the neutrino energy/flavor
ND-O3	Measure the Neutrino Flux	The ND must constrain the flux beyond what is achieved by *ab initio* modeling of the neutrino beam
ND-O4	Obtain measurements with different fluxes	The ND must verify that model predictions are robust with different neutrino fluxes.
ND-O5	Monitor time variation of the neutrino beam	The ND must detect potential variations in the neutrino flux.
ND-O6	Operate in high rate environment	All ND components must fulfill requirements in the presence of cosmic, beam-related backgrounds, and pileup.

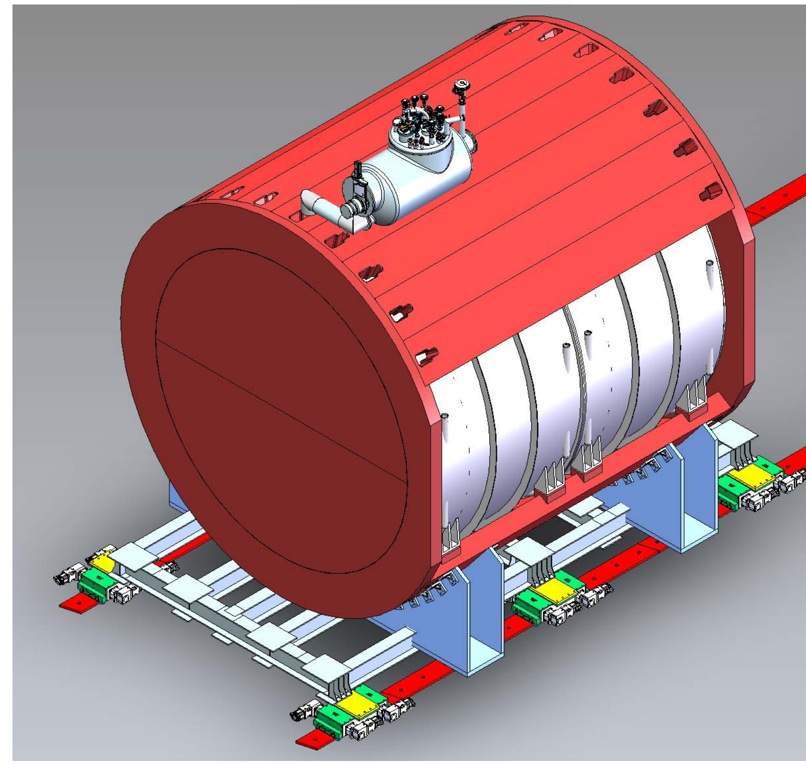
ND-GAr contributes (red box: ND-O1 to ND-O4)

ND-GAr meets requirement (blue box: ND-O6)

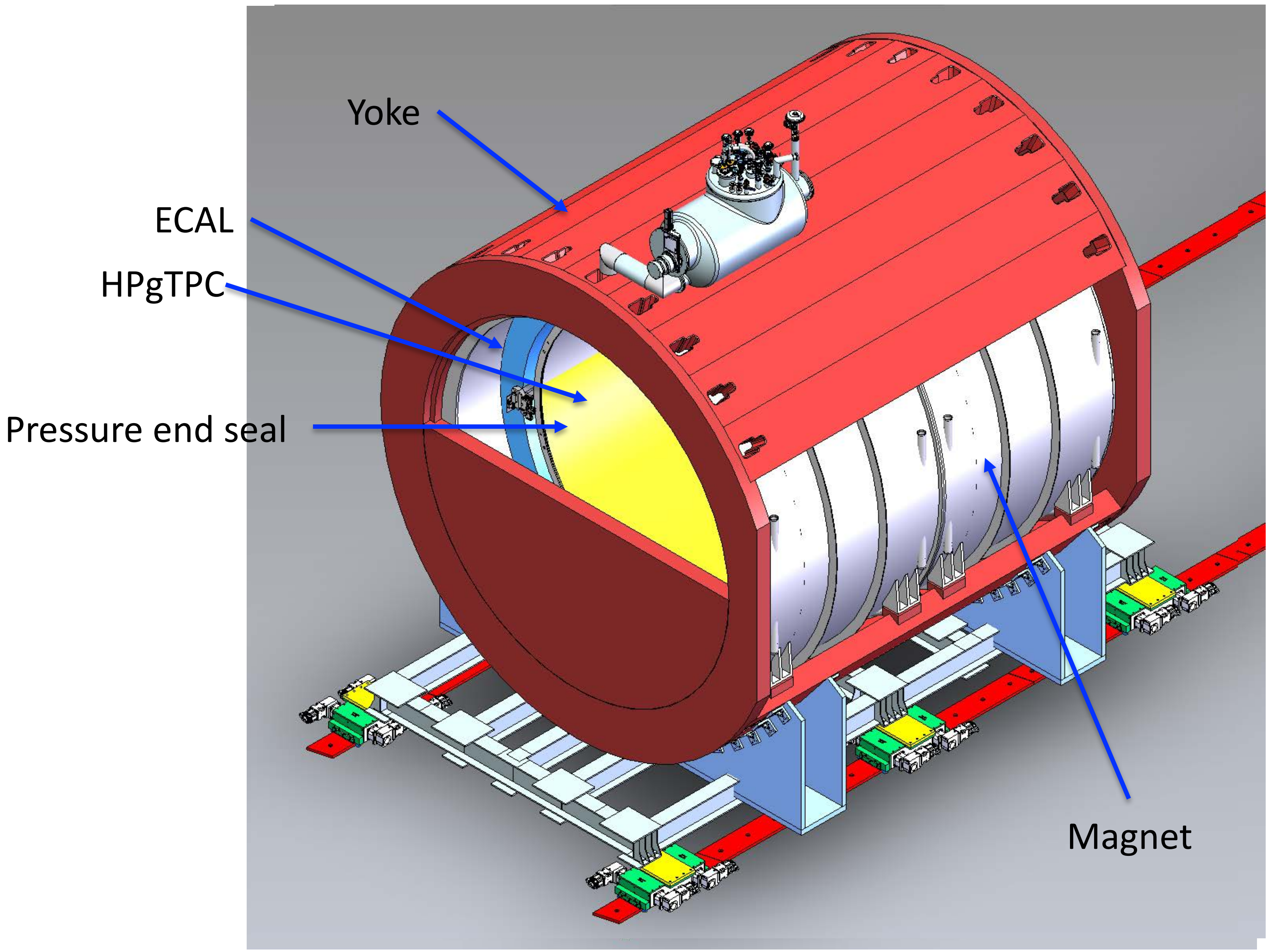
ND-GAr design status

ND-GAr design update

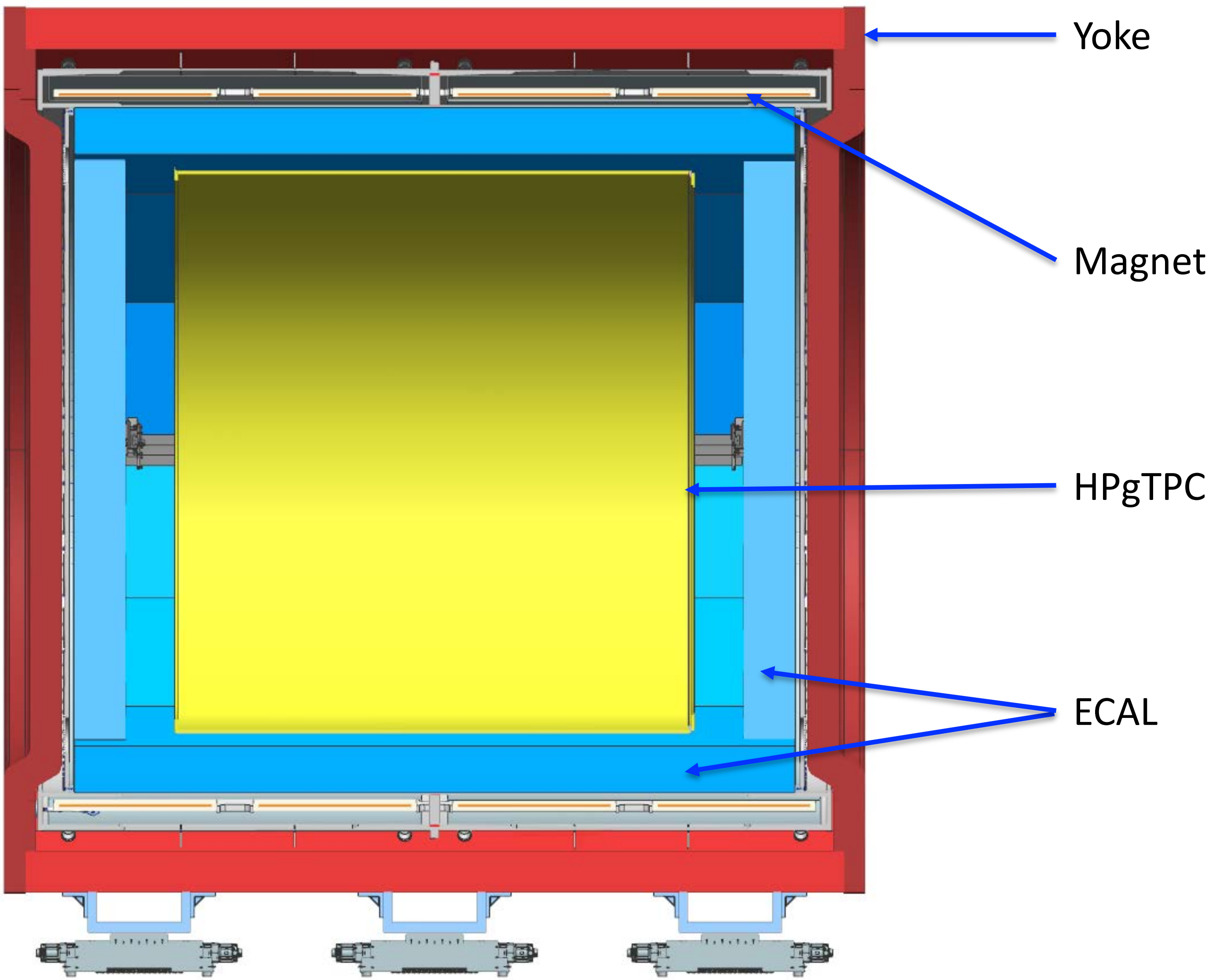
- Magnetized volume including high-pressure (10 atm) gaseous argon TPC + ECAL. Plus external muon tagger
  - Copy of ALICE TPC (5m in diameter X 5m long active)
  - 1t fiducial target mass
- Magnet: Solenoid with Partial Return Yoke (SPY)
  - 0.5T field
  - Acts as pressure vessel for HPgTPC
- HPgTPC surrounded by high-performance ECAL
  - Optimization study underway
- Muon tagger
  - Outside return Fe
    - Scintillator, RPCs or MicroMegas (tbd)



ND-GAr

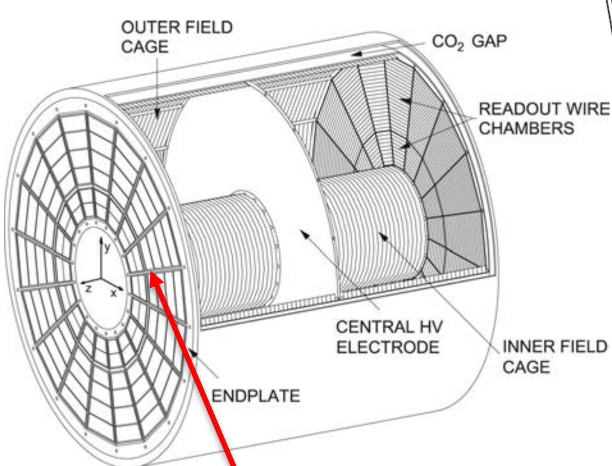


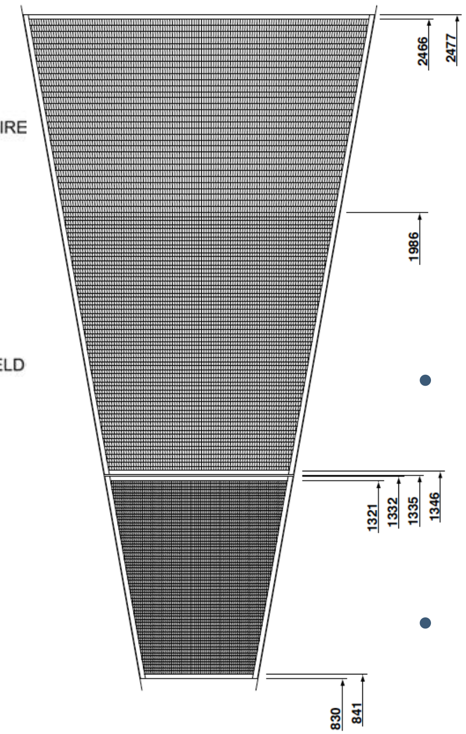
ND-GAr cut-away

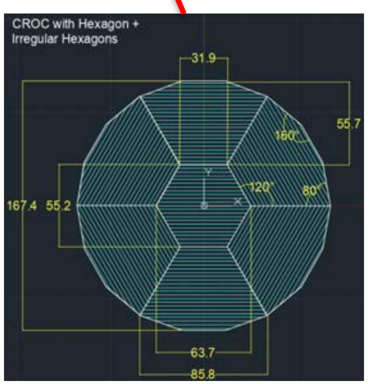


HPgTPC details

ALICE (18-fold symmetry)







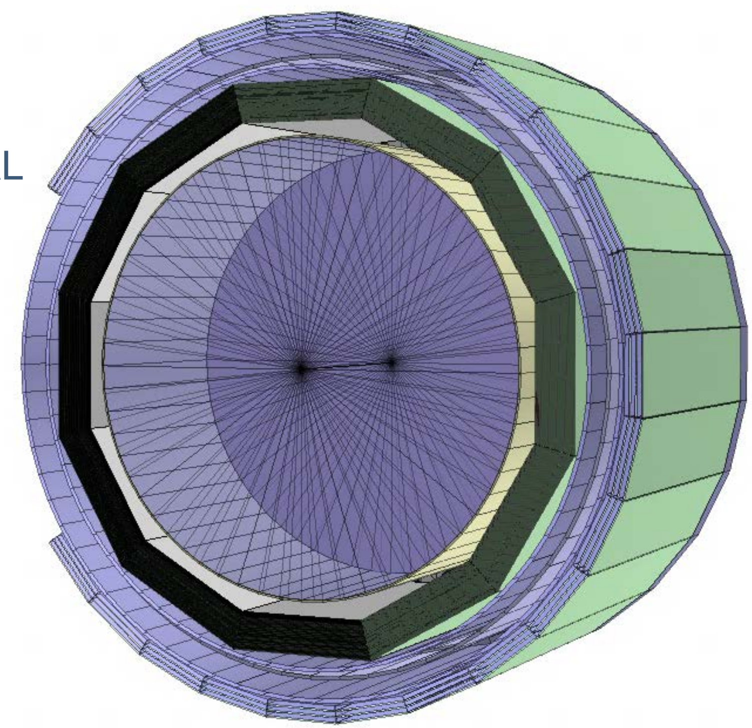
Central readout chambers (2, new design)

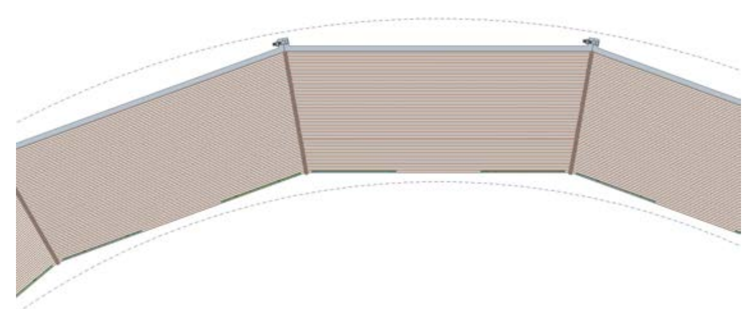
- Pad readout ONLY. True 3D. No Wires
- Readout Pads (ALICE)
  - Inner chambers (36)
    - 4X7.5 mm^2 (5504/chamber)
  - Outer (36)
    - Inner rows: 6X10 mm^2 (5952/chamber)
    - Outer rows: 6X15 mm^2 (4032/chamber)
  - Total pads: ~554k
- Readout Pads (Central)
  - Still under study
  - Starting with 6X6 mm^2 pads as reference
  - ~125k
- Total channels: ~680k
  - Typical voxel occupancy/spill ~ 0.03%
- Readout Electronics
  - Front-end: Modification of LArPix (GArFastPix)
  - Back-end: same

ECAL Baseline Design

Eldwan Brianne
Marco Oriunno

- 12-sided geometry
  - Considering 16-sided also
- Key design features
  - High granular layers based on CALICE R&D (AHCAL SiPM-on-tile design)
    - 0.7 mm Lead / 5 mm plastic scintillator tiles of 2.5x2.5 cm^2
  - Cross-striped layers in the back based on Mu2e
    - 1.4 mm Lead / 10 mm scintillator
    - 4 cm width spanning the full module width/length (~few m)
  - SiPM readout
  - Estimated number of channels: ~1- 3M
- Based on simulation studies
  - Energy resolution ~ 6%/Sqrt(E) + 4%
  - Angular resolution ~ 8^o/Sqrt(E) + 4^o
  - Neutron detection eff. ~ 40%

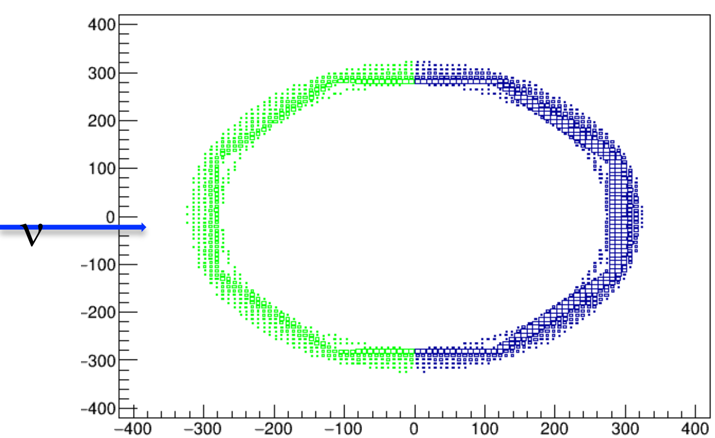


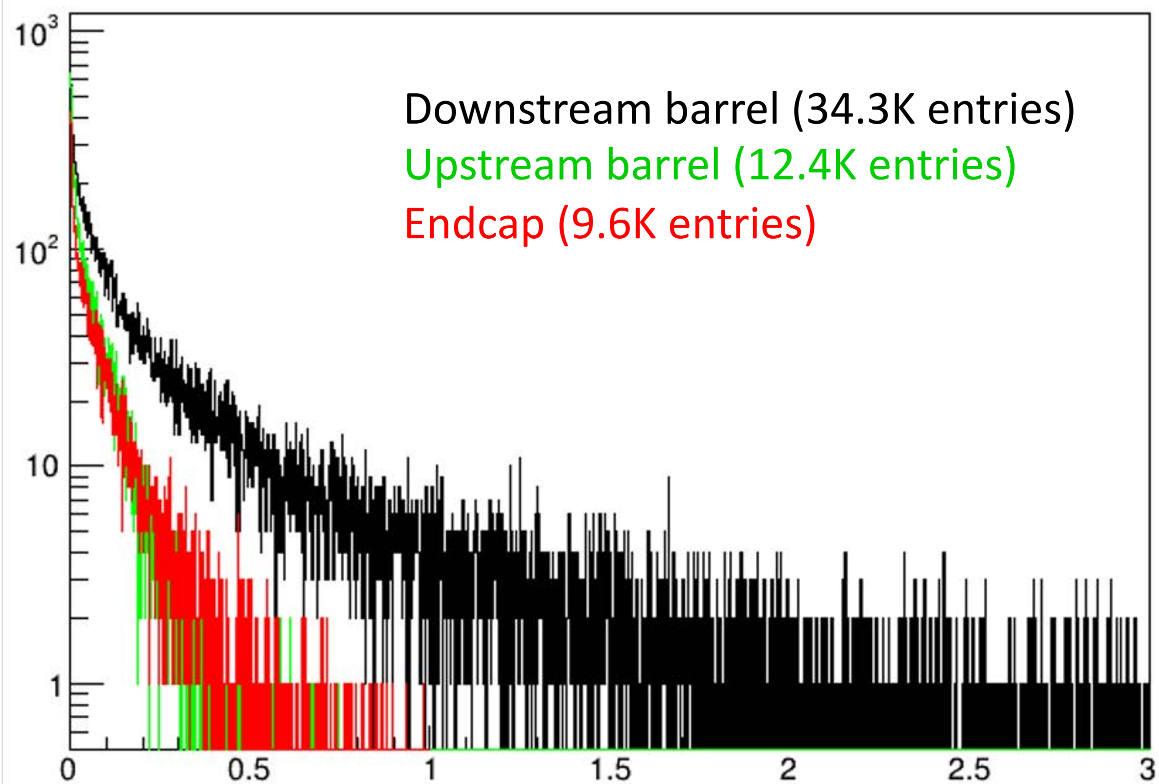


ECAL Optimization

Vivek Jain

- Baseline is uniform in θ, ϕ
  - Is this needed?
- Truth energy flow analysis in regions (US barrel, DS barrel, end caps for ν_μ evts.
  - Just neutrals here, n and γ. KE plotted

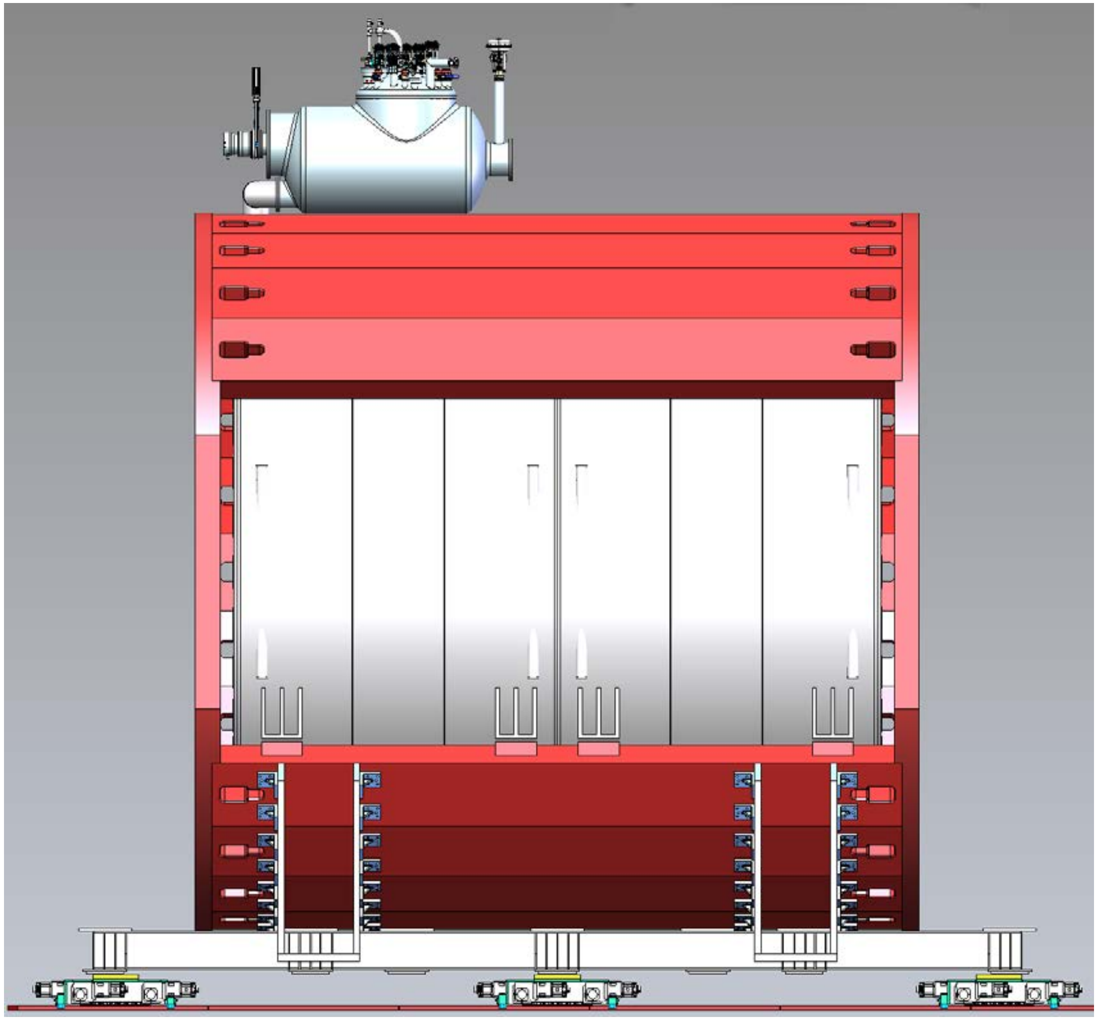




Solenoid with Partial return Yoke (SPY)

Andrea Bersani, Don Mitchell, Colin Narug

- Team at INFN, Genoa has been taking design forward
  - Interacting with ASG Superconductor
- Strengths over Helmholtz coil design
  - ~ 1/3 stored energy (Cost ↓)
    - C($) ∝ $E_s^{0.7}$
  - Better central field uniformity
    - Now ~ ± 2%
  - Less stray field
  - More natural incorporation of steel for muon tagging system
  - Existing TDR
    - 75% scale model exists



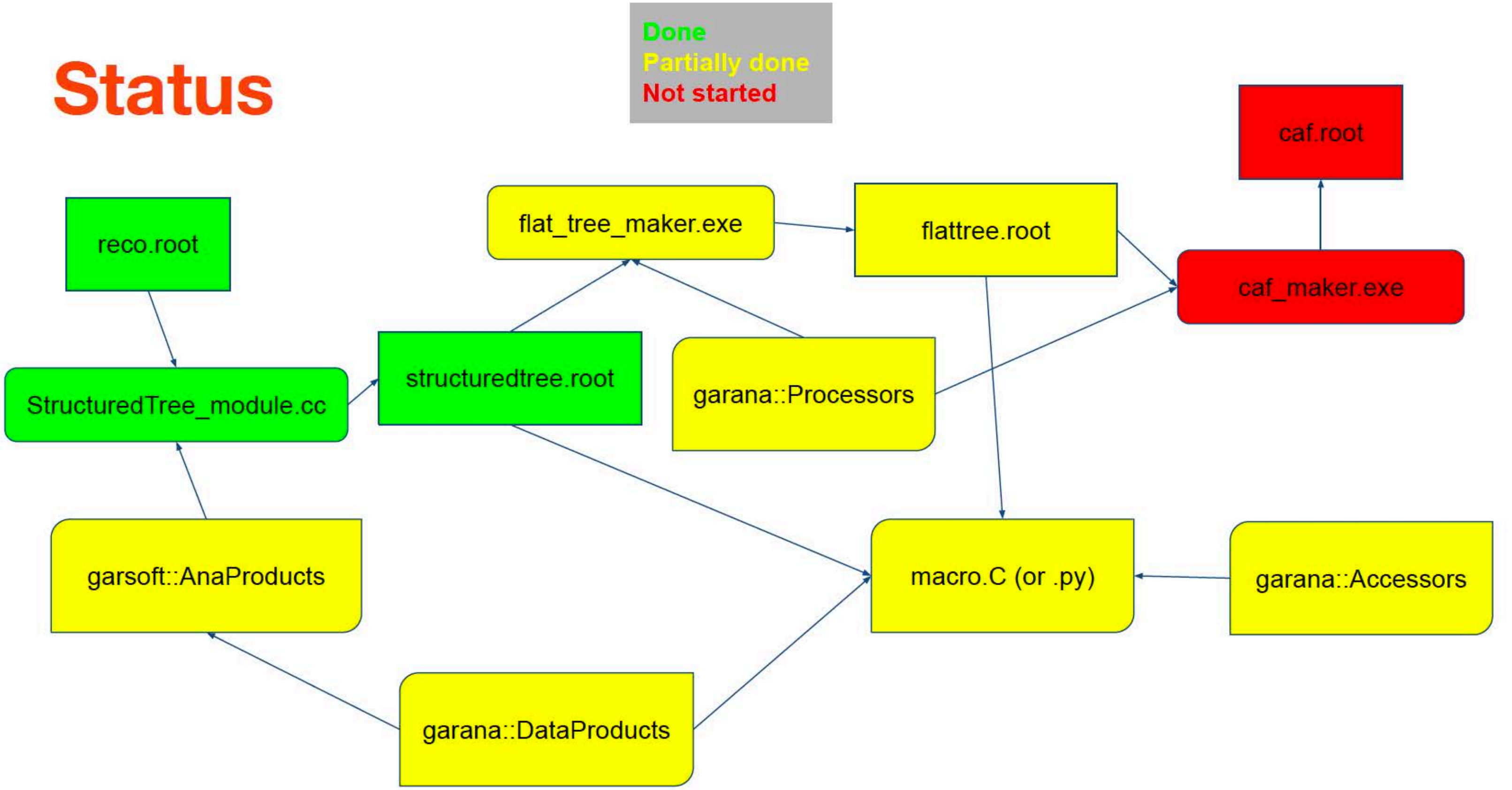
Software development: Analysis Framework proposal

Chris Hilgenberg

- New repository, Garana
  - Condensed versions of GarSoft products
  - Tools for reading class-based or flat trees
  - Tools for class-based → flat tree conversion, consistency checking
  - Standalone, lightweight event display
  - Backtracking
  - Support for C++ or Python analysis with ROOT
- Make GarSoft depend on Garana
  - Extensions for garana products to facilitate construction from nusimdata objects
  - Class-based trees produced by new analyzer module, StructuredTree_module.cc
  - Garana takes care of the rest

Framework status

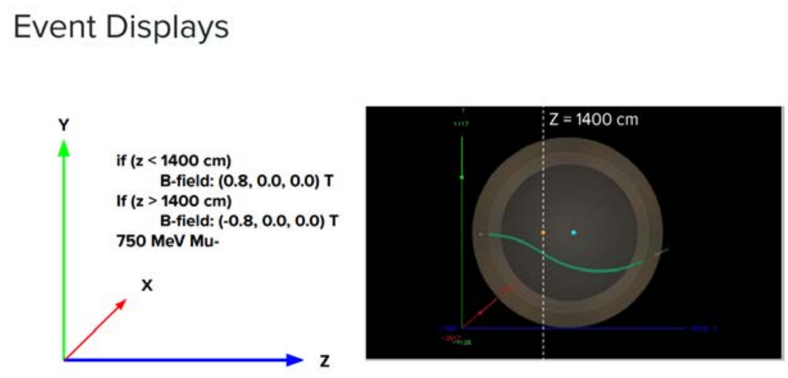
Status

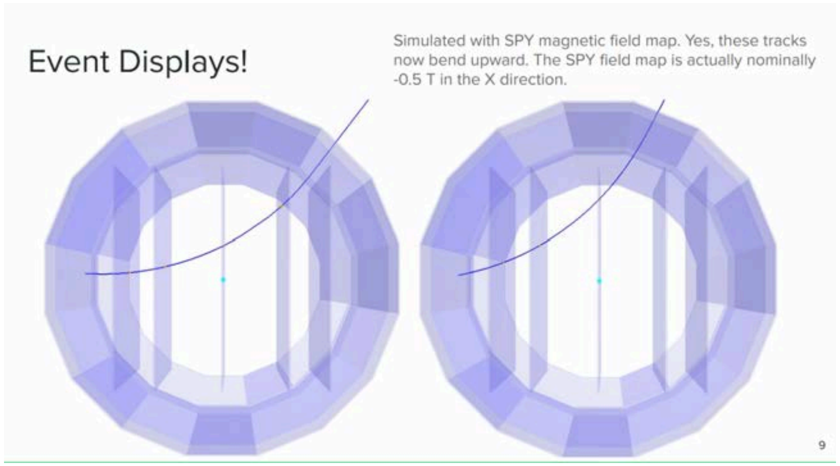


GarSoft: Custom Magnetic Field

Eldwan Brianne
Andrew Cudd

- Due to the ND-GAr magnet, we need to use a custom magnetic field to simulate non-uniformities and see the impact on tracking performance (also may be good to understand the impact of the fringe field on the ND-LAr)
- Andrew Cudd nicely implemented this in
  - edep-sim (see PR: https://github.com/ClarkMcGrew/edep-sim/pull/10)
  - GArSoft as a standalone art service (MPDMagneticField_service.cc)
  - He demonstrated that it works perfectly with edep-sim
- GArSoft is currently in code-review (branch bfield)





HPgTPC Workshop

- Workshop held January 11th - 13th
  - ~ 80 registered for the meeting
  - Focus was on the HPgTPC, but included ECAL
  - Three working groups, but included cross-cutting discussion sessions

- Physics/simulation
  - GArSoft
  - ND-GAr lite
  - Single drift
  - dE/dx resolution
  - μ catcher
  - Calibration & concept of Fluorescence tagging

- Mechanical
  - Plans for scintillation light studies
  - Temps and gas properties
  - ECAL calibration
  - TPC calibration thoughts
    - perhaps for a ND-GAr calibration task force soon?
  - Muon system

- Electrical
  - Requirements
  - Interfaces
  - System design
  - Digitiser ASIC options
  - Aggregator
  - Timing

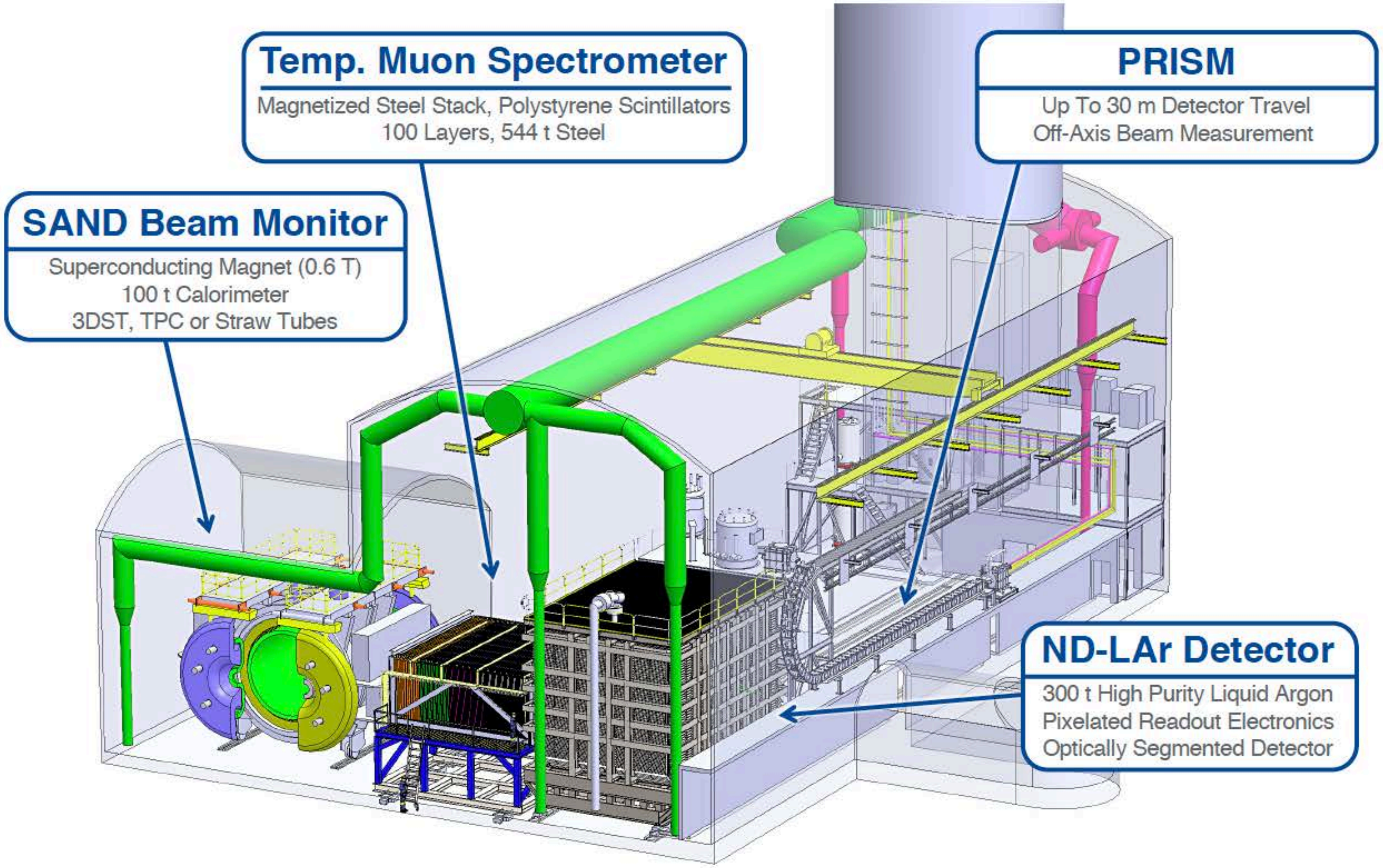
R&D Plan

- HPgTPC (DOE Research Consortium Proposal)
  - Gas Mixture studies
  - Electronics and DAQ
  - Central Readout chamber design
  - Mechanical engineering
  - Field cage and HV
  - Gas & Cooling system
  - Calibration and slow controls
  - Light collection
  - Test stands
- ECAL
  - Starting with CALICE engineering
    - Detailed design and optimization will come with TDR
    - Initial engineering resources are now coming from SLAC
- Magnet (coils & yoke)
  - Preliminary design being developed in Genoa with engineering support from FNAL
    - In consultation with ASG
- Muon detector
  - TBD ➛ Technology choice and then mostly development.

ND Configuration at beginning of ops

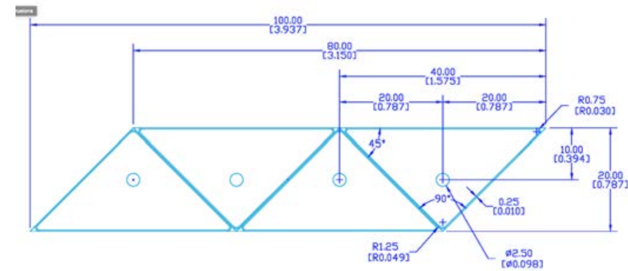
ND-GAr-Lite as TMS

Day 1 Configuration currently imposed by resource constraints

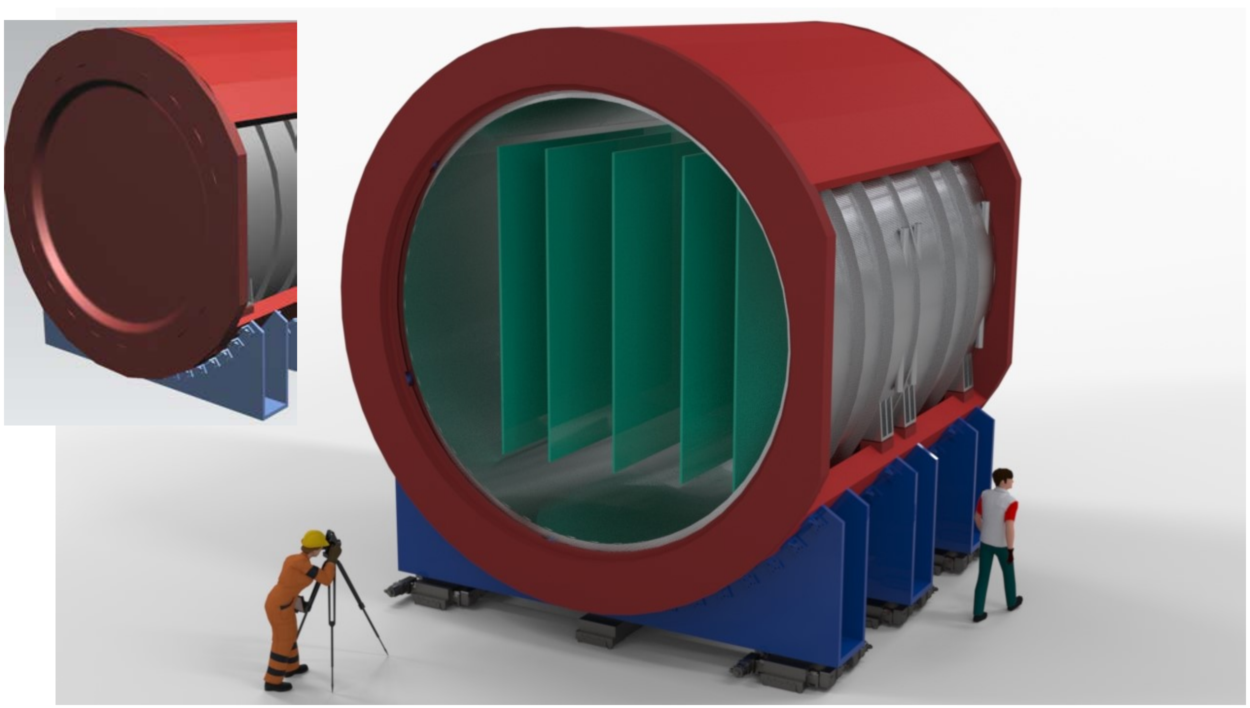


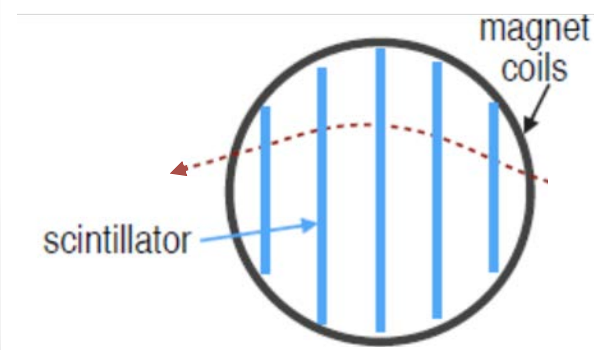
TMS: ND-GAr-Lite

Alternative TMS: ND-GAr-Lite

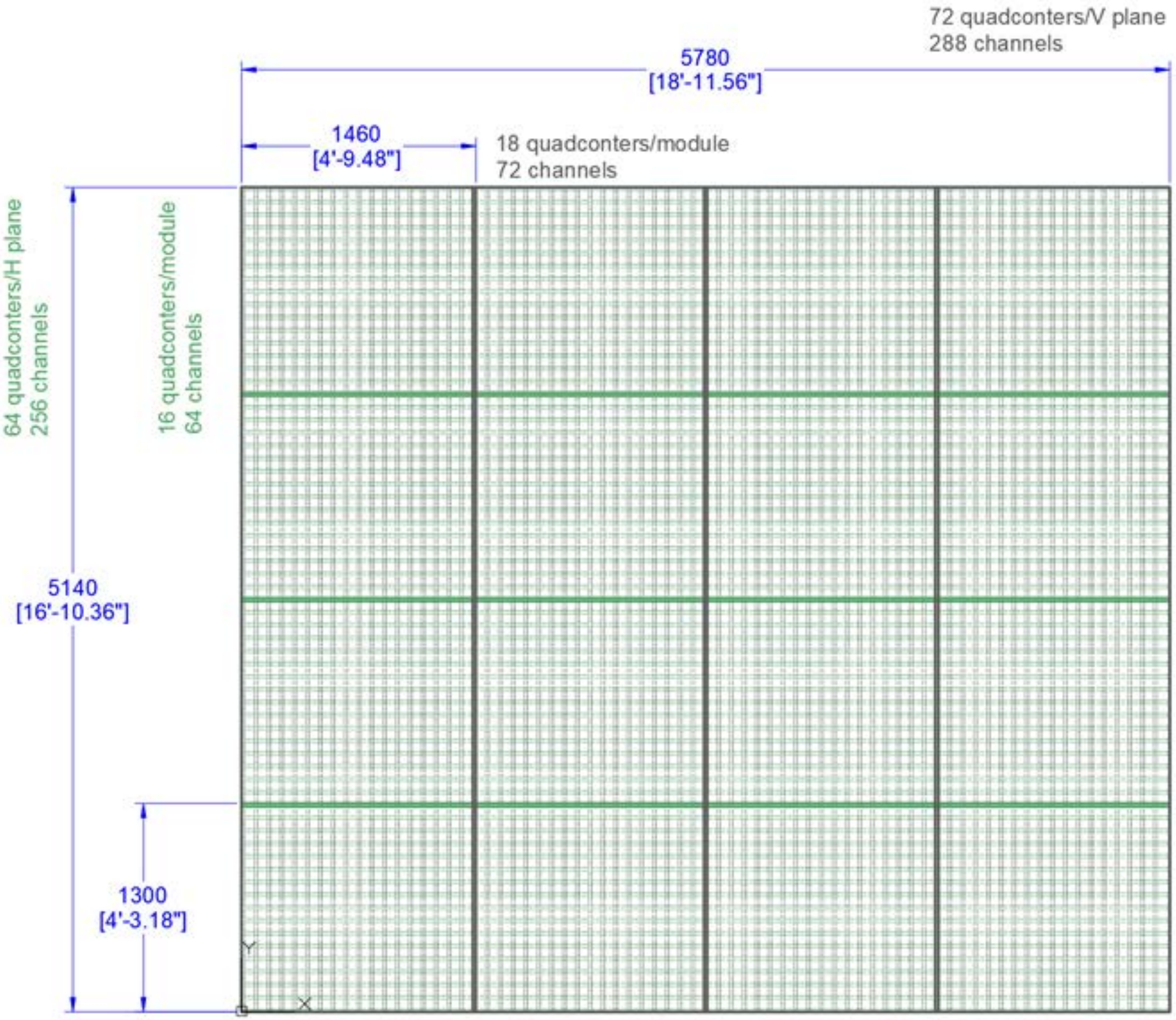


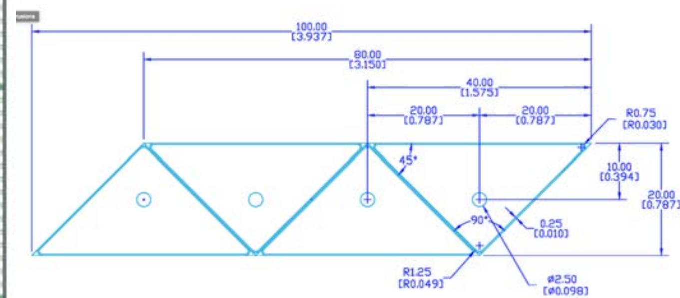
- ND-GAr-Lite
  - SC Magnet including partial return-yoke
  - Scintillator tracking planes
    - Update of MINERvA
    - Similar electronics as SSRI
  - ECAL modules could be added (but may degrade performance)





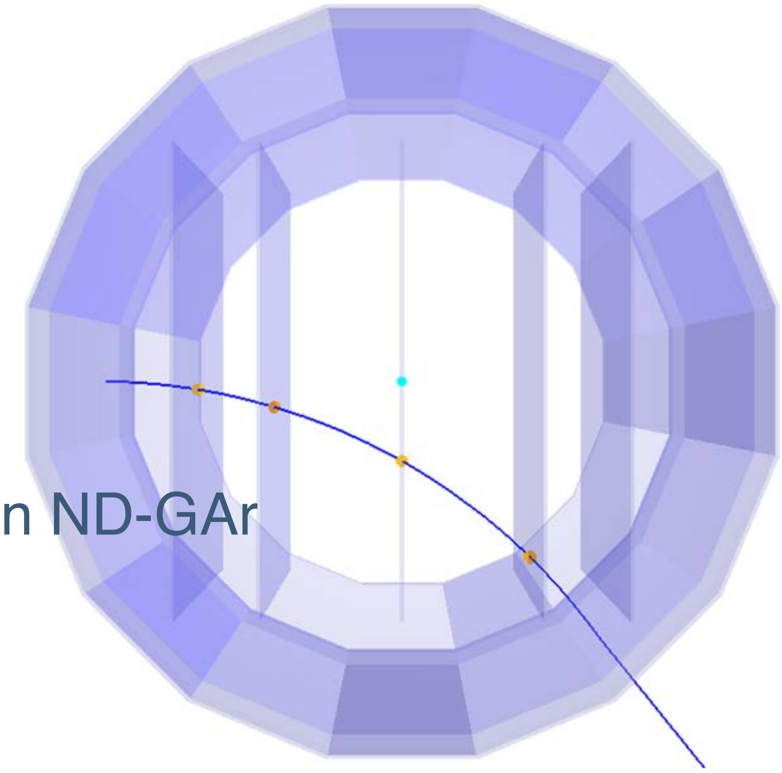
Tracker plane concept





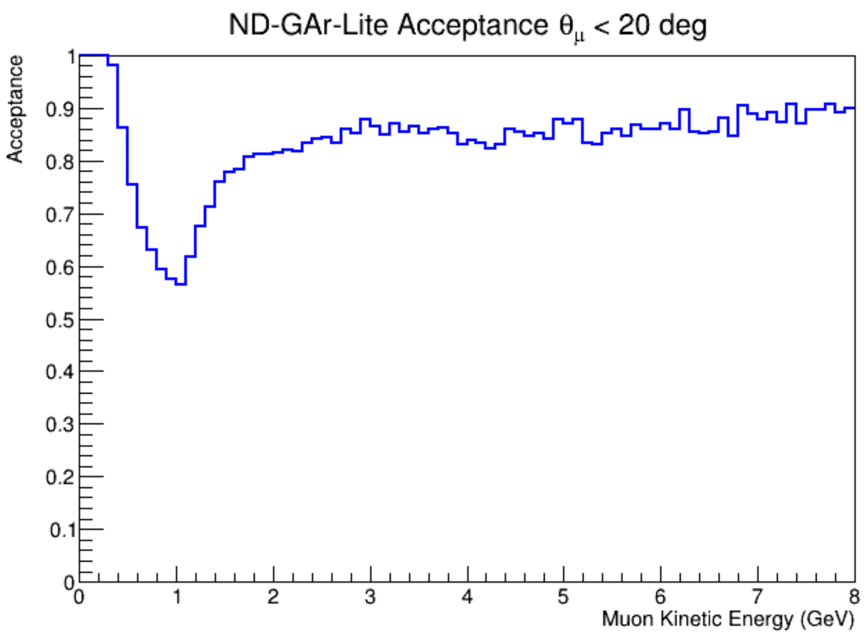
TMS: ND-GAr-Lite Nominal Design

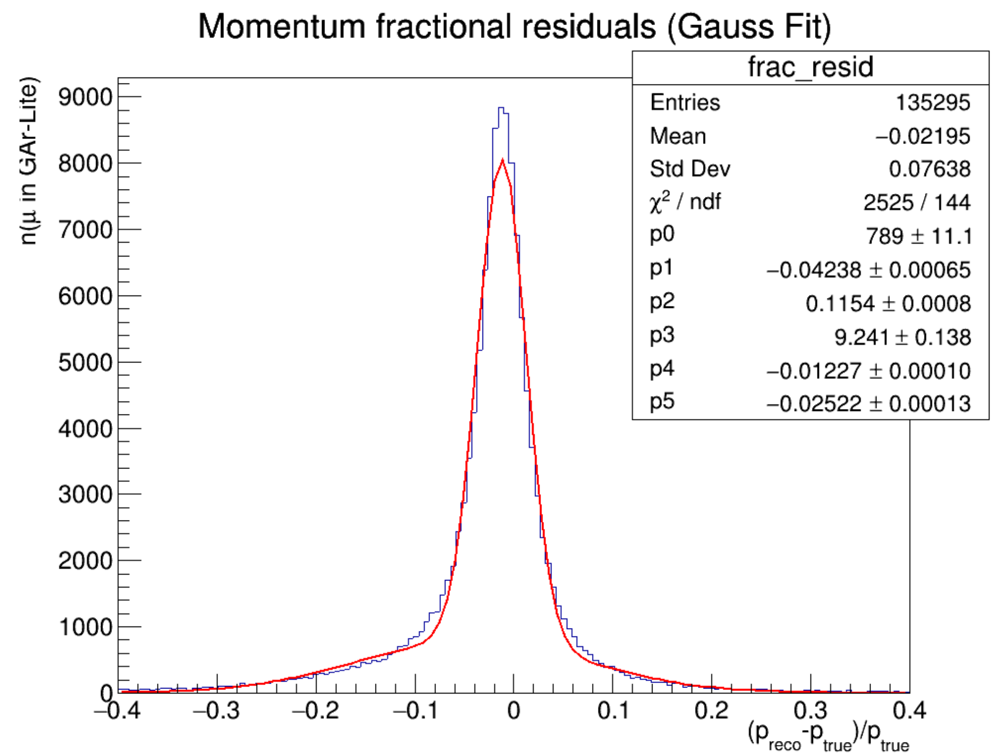
- Simple reconstruction
  - Require 3 hit scintillator planes
  - planes at
    z = {-240, -150, 0, 150, 240} cm
- Not optimised for low-p muons
  - will bend to not hit third plane
- Larger cross section for muons than ND-GAr
- Optimisation needed
  - Geometry
  - Tracking reconstruction



Federico Battisti

Performance: Acceptance and Momentum Resolution



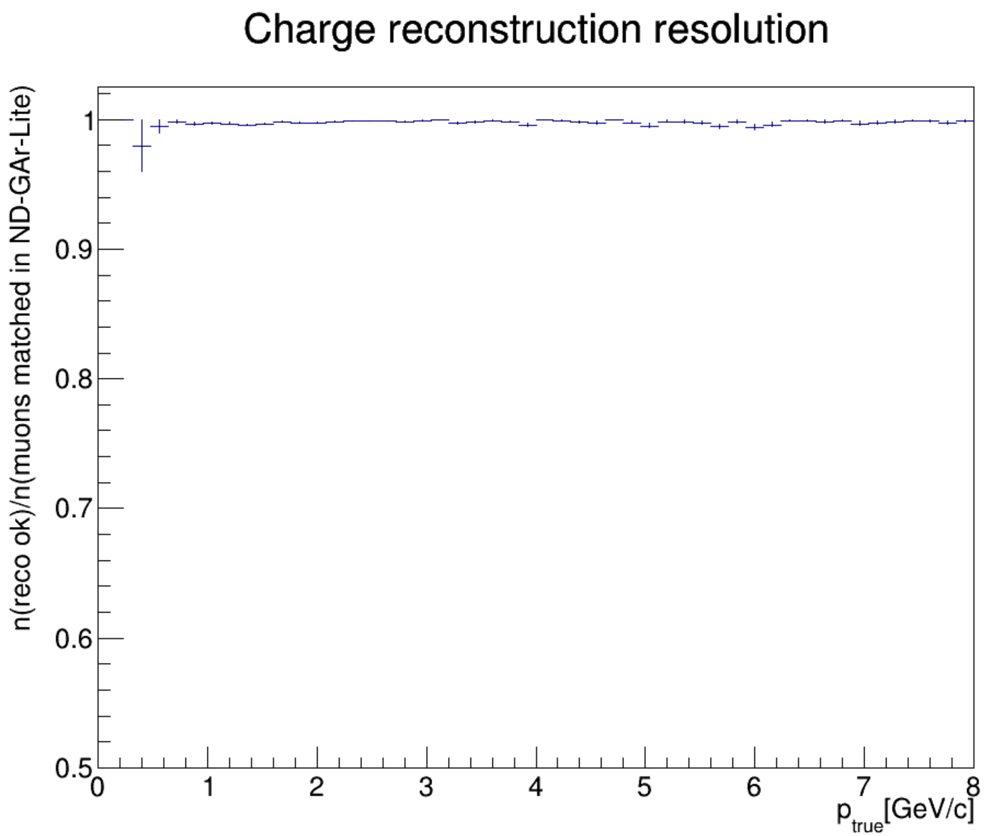


Muons from neutrino interactions in ND-LAr

- Includes ND-LAr-contained muons
- ND-GAr-Lite muons crossing first plane

Performance: Charge-sign Determination

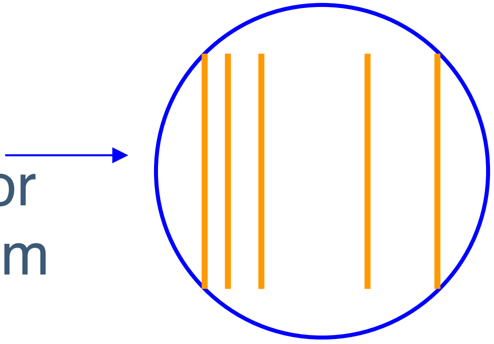
- excellent capability to determine charge sign



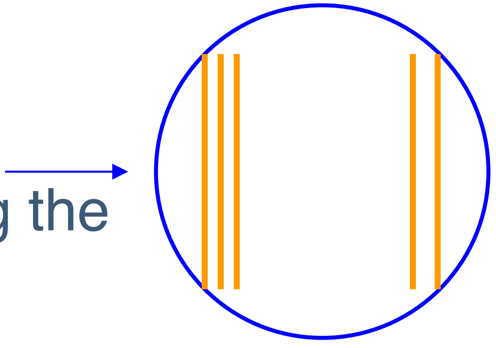
Andrew Cudd

Optimisation

Increase efficiency/acceptance for low momentum muons by adjusting the scintillator plane spacing -- closer planes at the upstream end.



Adjusting the plane spacing will affect the momentum resolution, primarily by changing the lever arm available for measuring a track.



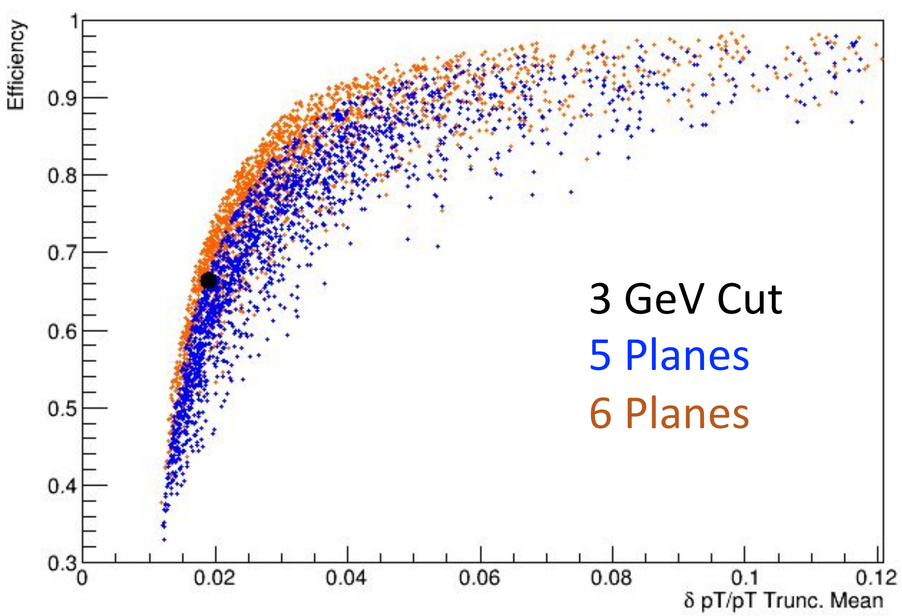
Some spacing configurations can make the efficiency or resolution better/worse for particular momentum ranges.

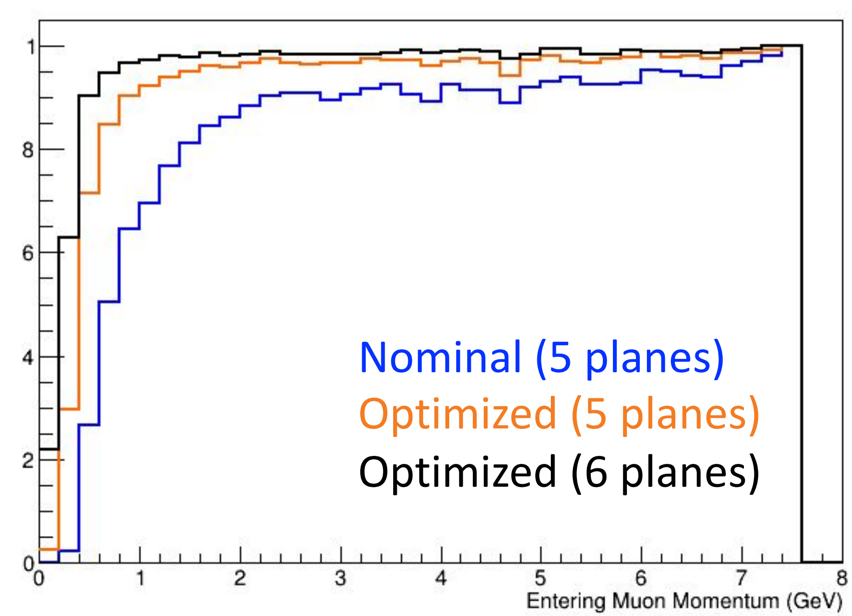
Optimisation method

- Using the true trajectory information for a sample of muons that reach ND-GAr from ND-LAr.
  - For each MC trial, estimate the efficiency and momentum resolution for a proposed plane spacing using the muon sample.
  - The proposed plane spacing fixes the first plane and places the other four planes randomly within ND-GAr-Lite.
  - Efficiency is estimated by how many tracks "hit" three or more scintillator planes.
  - Momentum resolution is estimated using the Gluckstern formula.
- Repeat many times and build an efficiency vs. resolution graph.

Optimisation

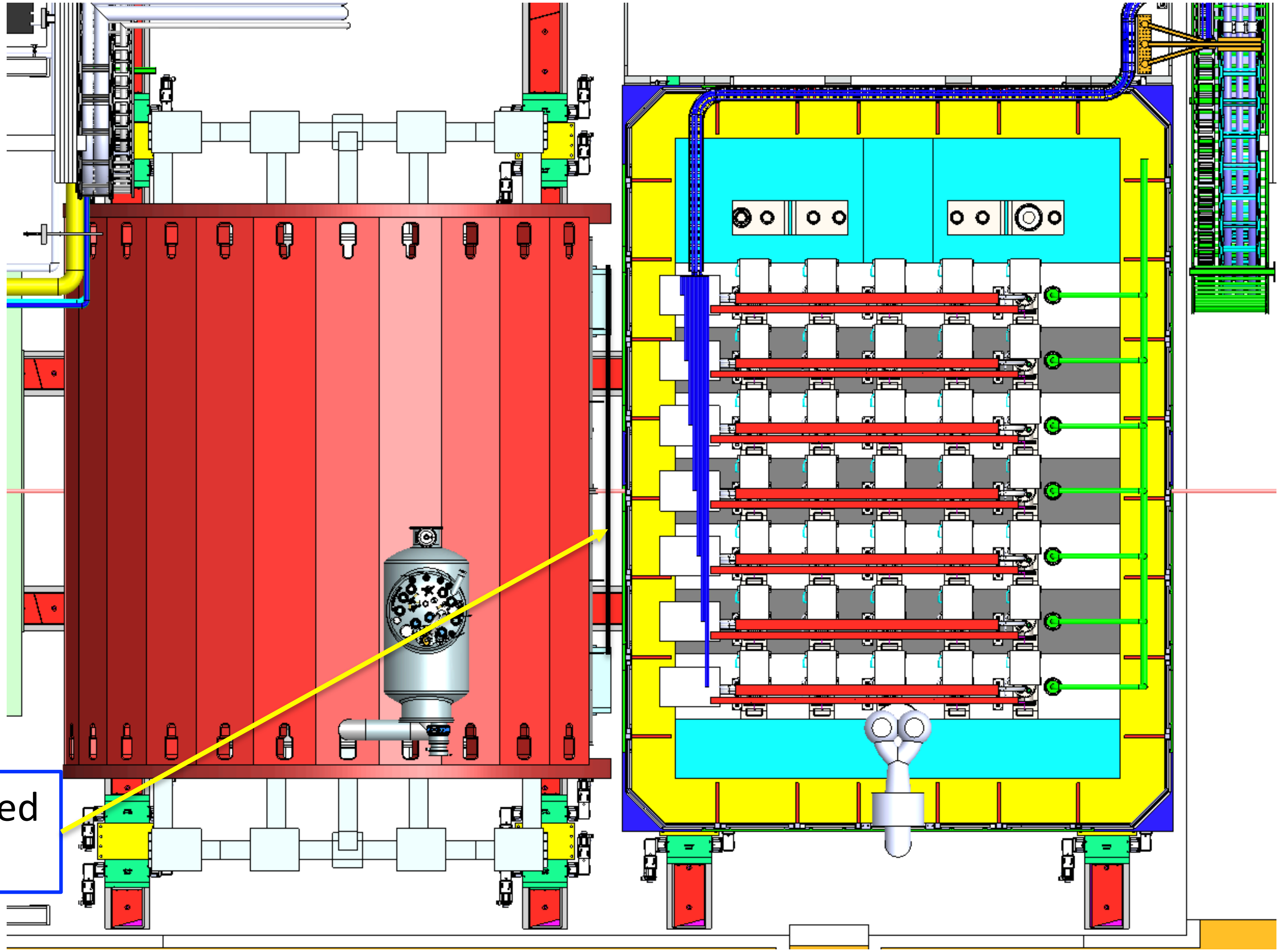
- **Work in progress!**
- Aim for improved efficiency with minimal degradation in momentum resolution





On average adding a sixth plane improves total efficiency 5 to 6% for a given resolution.

ND-GAr lite & ND-LAr



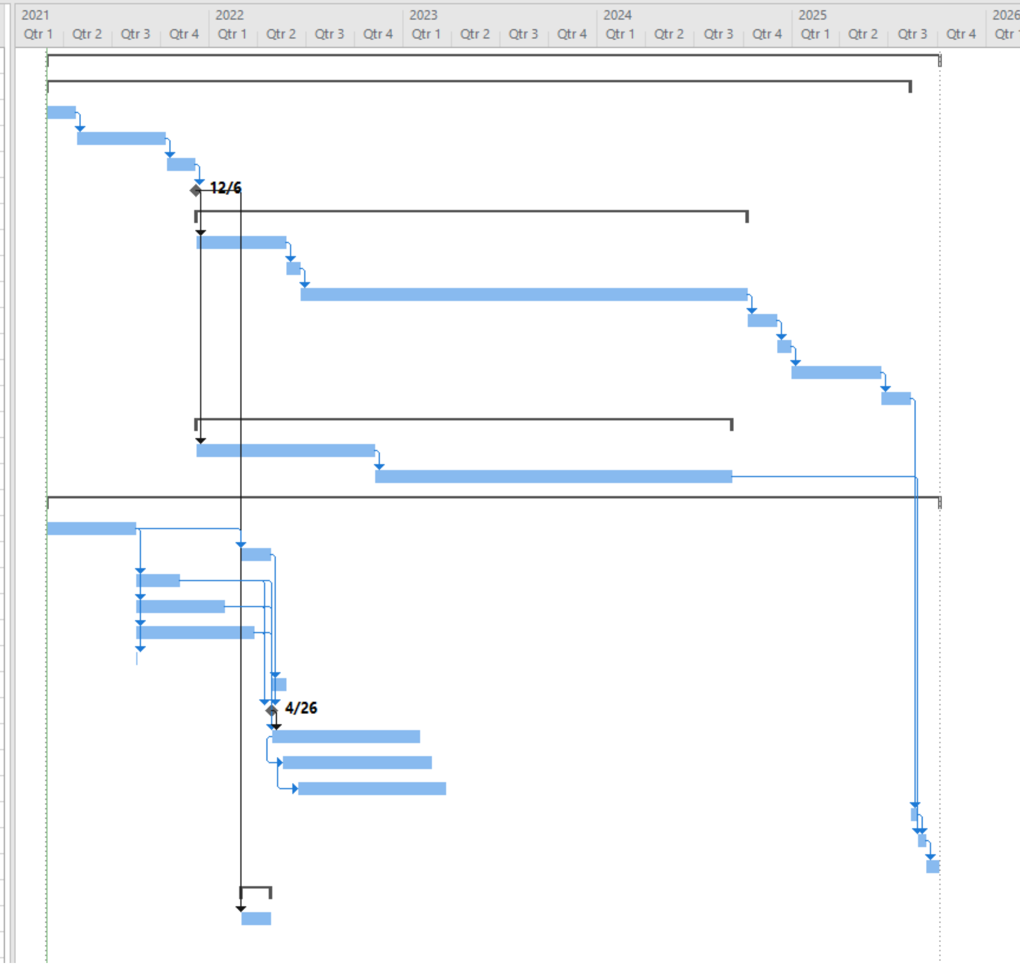
Additional instrumented plane?

Preliminary schedule

- Technically limited estimate but does include detailed schedule input from external projects that have similar components
  - Magnet system
    - Genoa group (Bersani, Fabbricatore) met with ASG management:
      - Sergio Frattini – Managing Director
      - Antonio Pellecchia - Commercial Manager Magnets & Systems unit
      - Giovanni Grasso - Business Development Manager, MgB_2 wire unit
      - Daniele Magrassi - Engineering and R&D Manager, Columbus MgB2 unit
    - Input based on completed magnet for MPD experiment at NICA heavy-ion accelerator at JINR
  - Tracking system
    - Obtained “as-built” estimates from Craig Dukes (Mu2e Cosmic-ray Veto L2 manager)

ND-GAr lite schedule

Task Mode	Task Name	Duration	Start	Finish	Predecessors
	◢ **ND-GAr lite**	**1201 days**	**Mon 3/1/21**	**Mon 10/6/25**	
	◢ **Magnet System**	**1161 days**	**Mon 3/1/21**	**Mon 8/11/25**	
	Conceptual Design Report	2 mons	Mon 3/1/21	Fri 4/23/21	
	Preliminary Design Report	6 mons	Mon 4/26/21	Fri 10/8/21	3
	Tender preparation	2 mons	Mon 10/11/21	Fri 12/3/21	4
	PO tendered	1 day	Mon 12/6/21	Mon 12/6/21	5
	◢ **Magnet production & test at vendor**	**740 days**	**Tue 12/7/21**	**Mon 10/7/24**	
	Technical deisign report	6 mons	Tue 12/7/21	Mon 5/23/22	6
	Pre-production design review	1 mon	Tue 5/24/22	Mon 6/20/22	8
	Production and test at vendor	30 mons	Tue 6/21/22	Mon 10/7/24	9
	Preparation for shipping	2 mons	Tue 10/8/24	Mon 12/2/24	10
	Shipping	1 mon	Tue 12/3/24	Mon 12/30/24	11
	Re-assembly and test	6 mons	Tue 12/31/24	Mon 6/16/25	12
	Commissioning	2 mons	Tue 6/17/25	Mon 8/11/25	13
	◢ **Cryo Infrastructure**	**720 days**	**Tue 12/7/21**	**Mon 9/9/24**	
	Valve box design	12 mons	Tue 12/7/21	Mon 11/7/22	6
	Procurment and installation	24 mons	Tue 11/8/22	Mon 9/9/24	16
	◢ **Tracker System**	**1201 days**	**Mon 3/1/21**	**Mon 10/6/25**	
	System design optimization	6 mons	Mon 3/1/21	Fri 8/13/21	
	Support system engineering	2 mons	Tue 3/1/22	Mon 4/25/22	19,6FS+3 mons
	Scintillator procurement	3 mons	Mon 8/16/21	Fri 11/5/21	19
	WLS fiber procurement	6 mons	Mon 8/16/21	Fri 1/28/22	19
	SiPM procurement	8 mons	Mon 8/16/21	Fri 3/25/22	19
	Strong back procurement	1 day	Mon 8/16/21	Mon 8/16/21	19
	Factory setup	1 mon	Tue 4/26/22	Mon 5/23/22	20
	Ready for assembly	1 day	Tue 4/26/22	Tue 4/26/22	20,21,22,23
	Quad counter assembly	10 mons	Wed 4/27/22	Tue 1/31/23	26,21,22,23
	Modual assembly	10 mons	Wed 5/18/22	Tue 2/21/23	27SS+3 wks
	Modual testing	10 mons	Wed 6/15/22	Tue 3/21/23	28SS+1 mon
	Installation into magnet	2 wks	Tue 8/12/25	Mon 8/25/25	14
	Final testing	2 wks	Tue 8/26/25	Mon 9/8/25	30,17
	Commissioning	1 mon	Tue 9/9/25	Mon 10/6/25	31
	◢ **ECAL support integration**	**40 days**	**Tue 3/1/22**	**Mon 4/25/22**	
	ECAL module suport design	2 mons	Tue 3/1/22	Mon 4/25/22	6FS+3 mons



Preliminary, technically limited

Participating Institutions

- Georgia
  - The Georgian Technical University
- Germany
  - DESY
  - University of Mainz
  - MPI, Munich
  - RWTH-Aachen
- India
  - Bhabha Atomic Research Center
  - Tata Institute for Fundament Research
  - University team forming
- Italy
  - INFN, University of Genoa
- Poland
  - University of Warsaw
- Spain
  - Santiago
  - Valencia
- UK
  - STFC
  - Imperial College
  - Queen Mary
  - Royal Holloway
  - University College London
  - University of Oxford
  - University of Edinburgh
- US (next page)

US Institutions

- Abilene Christian Univ.
- ANL
- Univ. of CA, Santa Barbara
- Univ. of Colorado
- Fermilab
- Indiana Univ.
- Univ. of Iowa
- LBNL
- Univ. of Minnesota
- Univ. of Mississippi
- Univ. of Pittsburgh
- Univ. of Rochester
- Rutgers Univ.
- SLAC
- Univ. of Texas, Arlington
- Univ. of Wisconsin, Madison
- Wichita State
- William and Mary

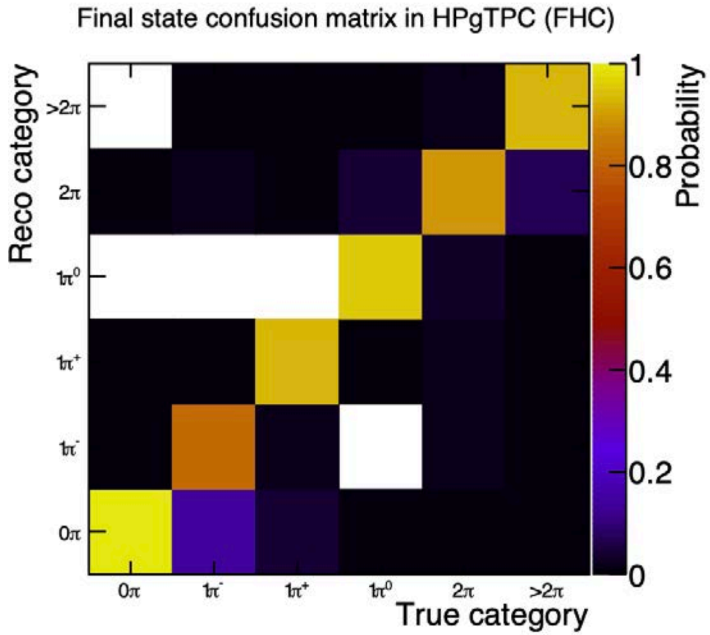
Conclusions

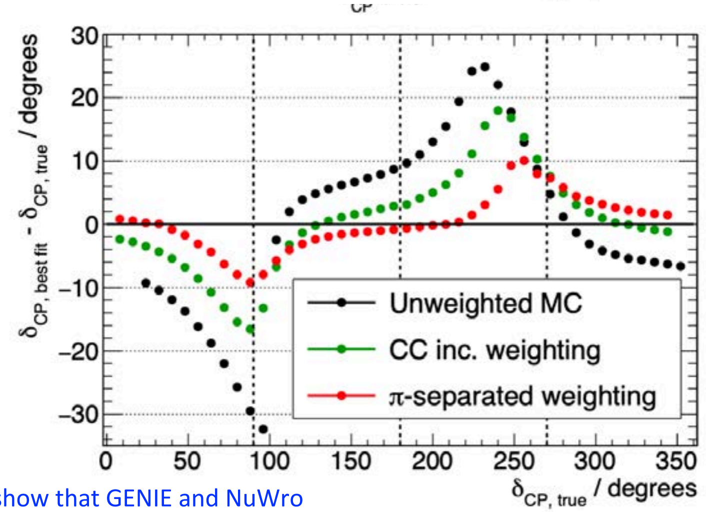
QUESTIONS?

ND-GAr's strengths: An example

Seb Jones

- Case study: Genie, NuWRO differ greatly in pion production channels
  - Genie model fit to NuWRO "fake" data leads to enormous biases in extracting δ_{CP}. Case study of unknown, unknowns.
- ND-LAr will to some extent be able to measure/correct such a discrepancy inclusively in accordance with capabilities at FD. Issues:
  - Secondary interaction effects and thresholds
  - Non-trivial acceptance corrections
- ND-GAr can perform detailed channel decomposition and correction with cleanly separate the channels
  - *The precision tracking capability of the HPgTPC allows ND-GAr to accurately identify and separate final states in neutrino interactions. Measuring various kinematic distributions for these exclusive final states allows deficiencies with the interaction model to be identified and fixed.*

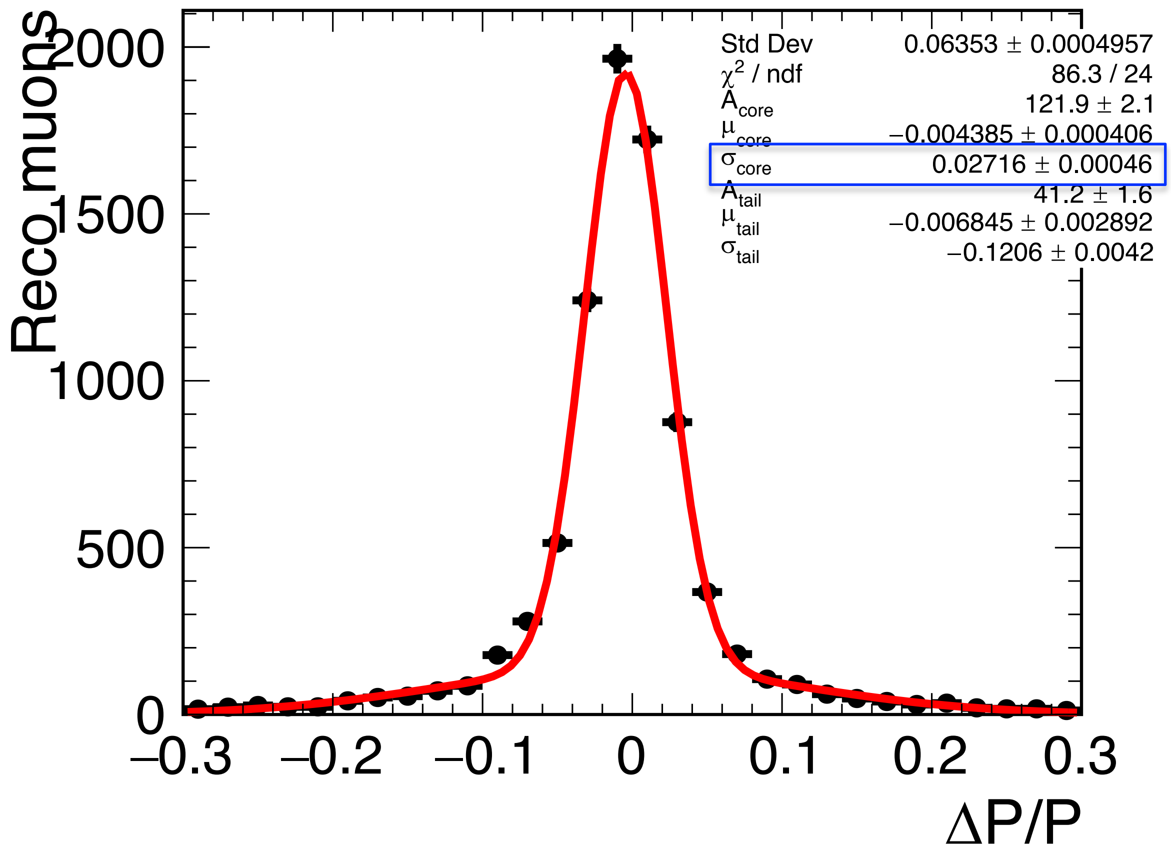




102. I am puzzled by this whole procedure. What is this intended to show? If you just wanted to show that GENIE and NuWro give different results, you wouldn't need to reweight one to look like the other, would you?

Muons from ν_μCC events in gas (LBNF beam)

Tom Junk



- Correct hits assigned to track
  - Pattern reco in development
- No noise
- Full pad response
  - Drift/Diffusion simulated
- Point resolution needs optimization
- Kalman fit
  - Needs optimization
- Track stitching across cathode

Funding sources/opportunities

- INFN is committed to support the MPD magnet coil design using current funding.
- US groups have submitted a R&D Consortium Proposal to the DOE that will focus on the development of the HPgTPC and will produce a technical design report.
  - 3 years and $1.7M.
  - Currently under review.

Not needed at Day 1 for μ spectrometer

- UK groups are preparing a ND DAQ proposal
- UK fellowship (P. Dunne) will fund the design and prototyping of large parts of the electronics for HPgTPC
- German groups are preparing a targeted R&D proposal for the ECAL.
  - To be submitted soon.

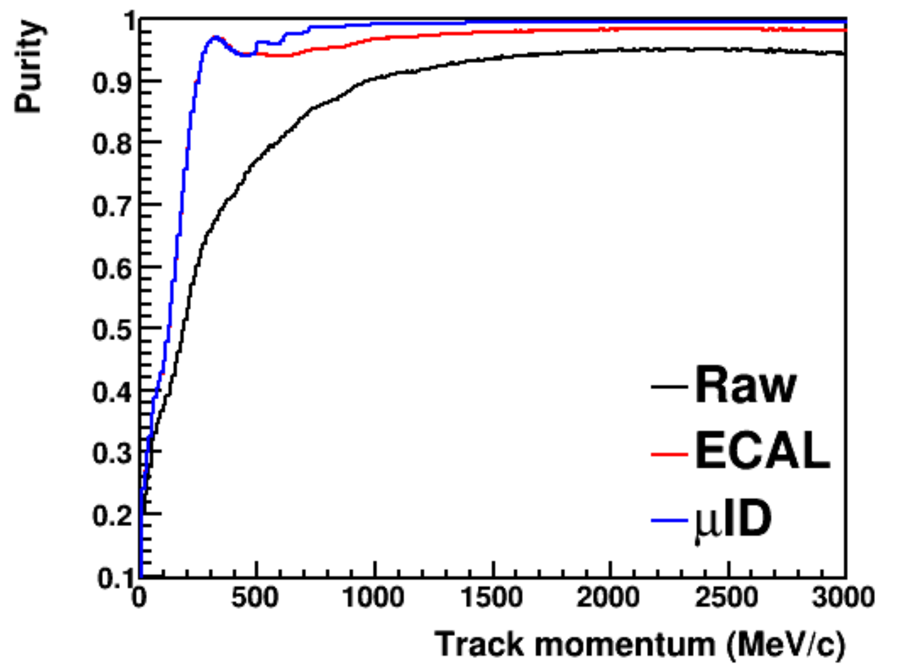
- Indian groups are looking for funding for the partial-return yoke and muon tagging detectors

Muon catcher -- Requirements

Chris Marshall

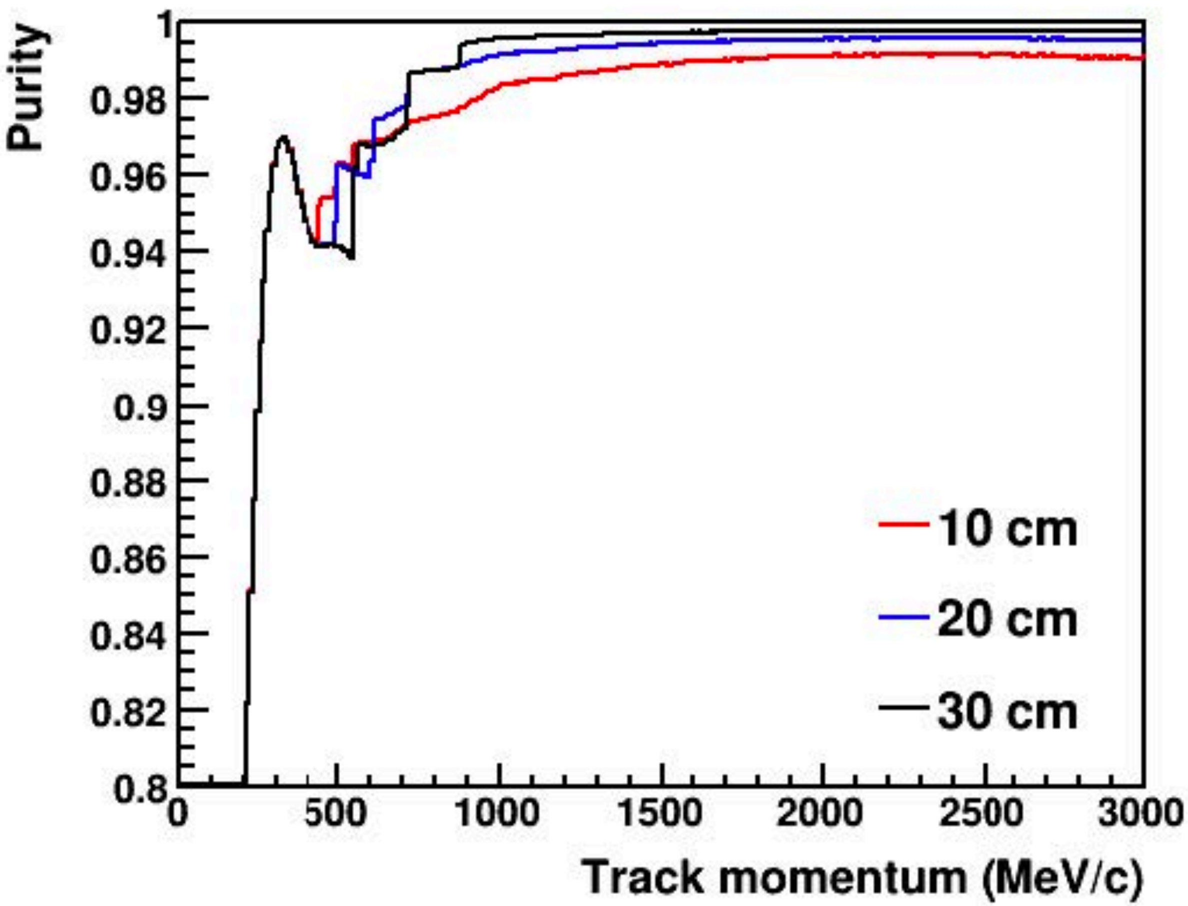
- Design is obviously coupled to that of ECAL and magnet
- Preliminary study with 20 cm Fe. Some conclusions
  - Muons and pions stopping in ECAL can be separated by range with nearly 100% efficiency
  - µID is required to get right-sign CC purity above 95%
  - 20cm iron µID gets ~100% purity for high-momentum tracks
  - Backward µID is not needed if there is a backward ECAL
  - Increasing the number of ECAL layers would improve the purity in the 400-500 MeV/c momentum range
- Detailed design is in progress.

FHC ν_μCC purity (μ^-/π^-)



Note: Raw ≡ Select highest P track from µs and πs

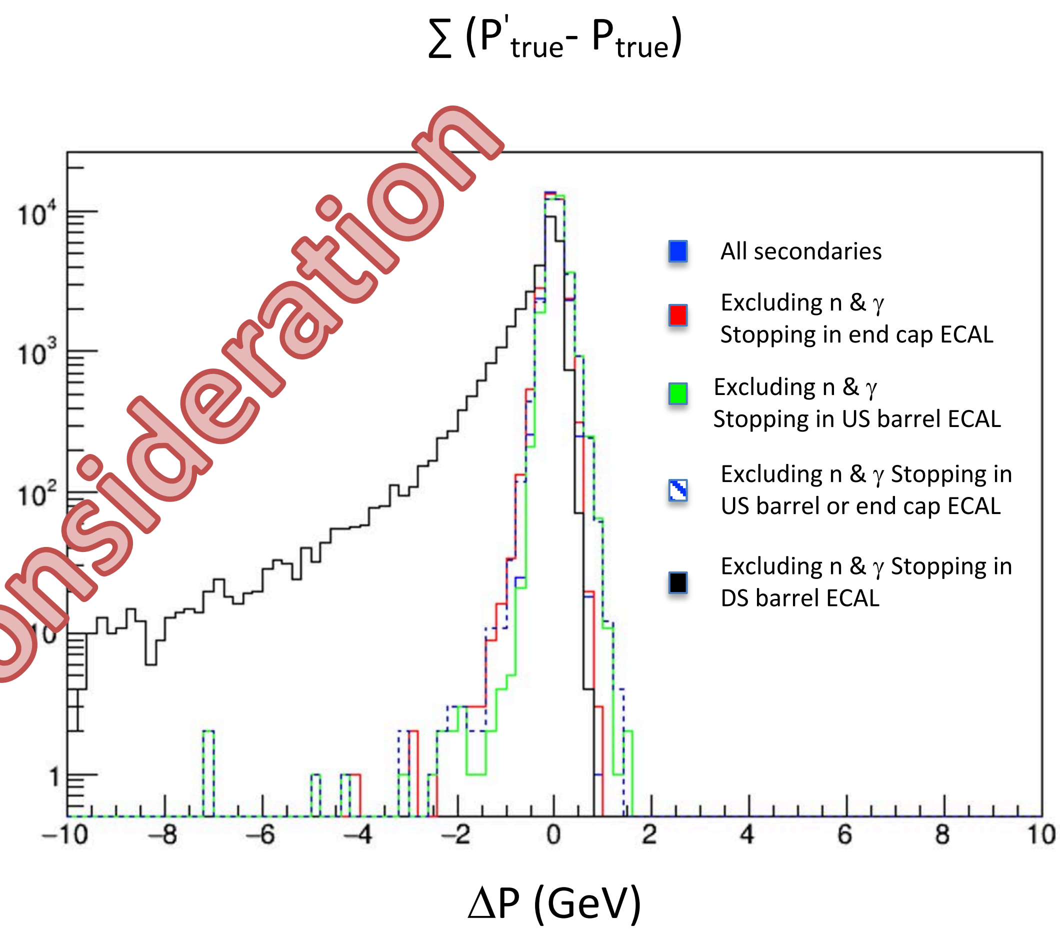
μ purity vs. Fe thickness



For each case, the steel was segmented into 3 sections: 3.3, 6.6, 10 cm

ECAL Optimization

- Baseline is uniform in θ, ϕ
  - Is this needed?
- Truth energy flow analysis in regions for ν_μCC evts.
  - Barrel upstream (US), Barrel downstream (DS) and end caps



Assumption: all charged secondaries measured in HPgTPC

Under consideration