LArIAT

Liquid Argon TPC In A Testbeam

Jen Raaf, for the collaboration

LANL Liquid Argon Meeting

February 1-2, 2013

Motivation

One of the major questions that came out of the 2009 Fermilab-sponsored LAr R&D review:

How well known are the energy resolution and particle identification capabilities of LArTPCs?

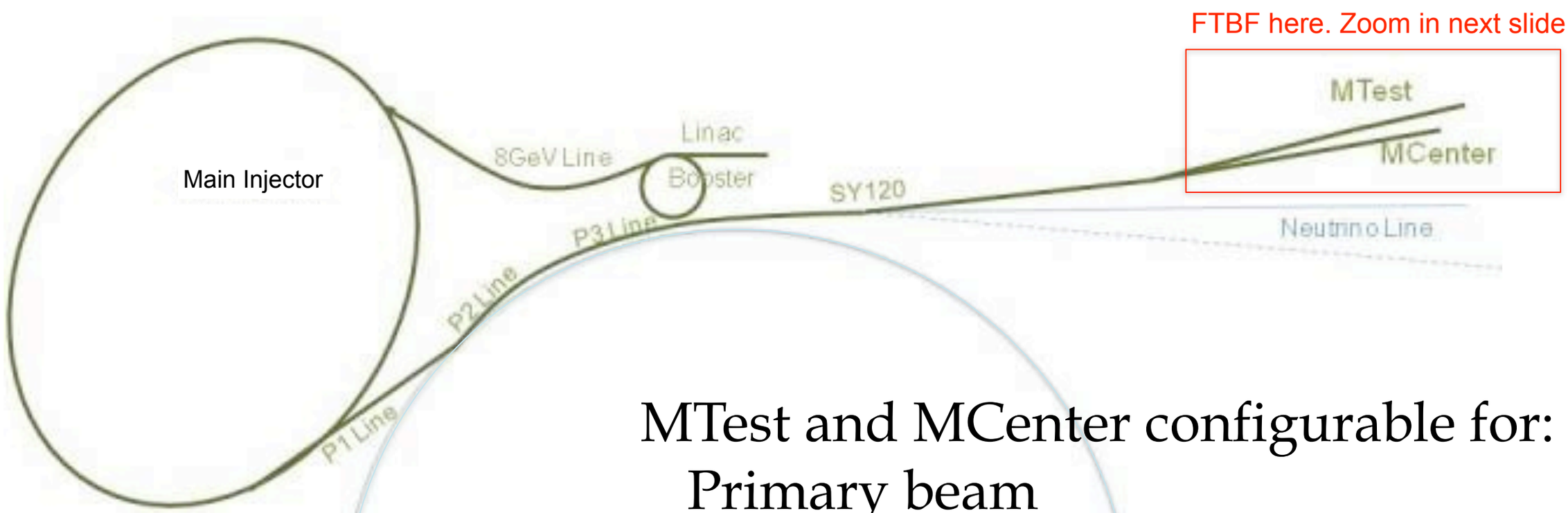
What has been done already?

WARP 50L test stand
ICARUS 3ton and T600 surface run with cosmic rays
T32 250L in JPARC charged particle beam

Fermilab Test Beam Facility is a good host for further characterization of LArTPC performance

Fermilab Test Beam Facility (FTBF)

http://www-ppd.fnal.gov/MTBF-w/



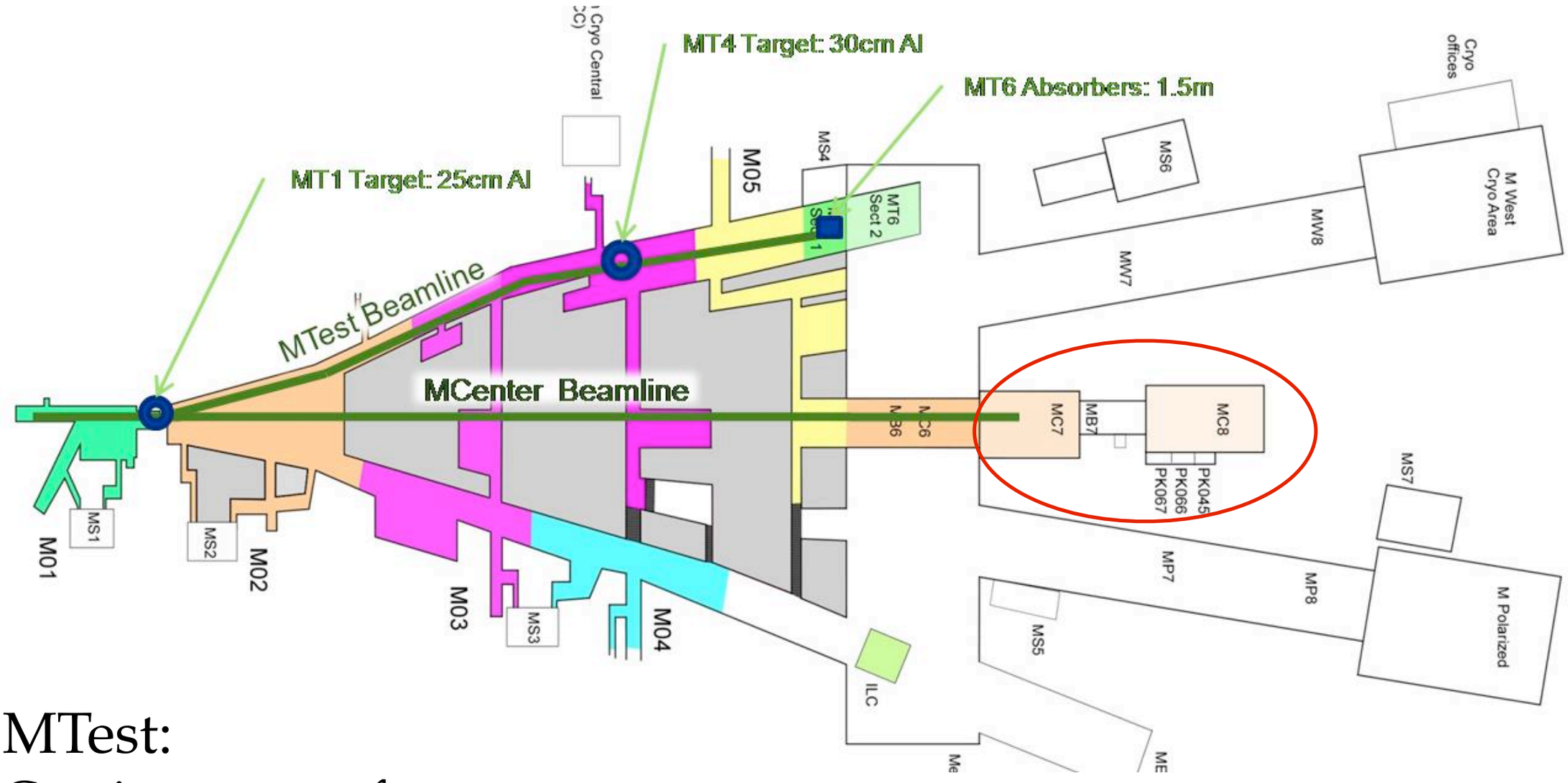
MISSION

The goal of the Fermilab Test Beam Program is to provide flexible, equal, and open access to test beams for all detector tests, with relatively low bureaucratic overhead and a guarantee of safety, coordination, and oversight.

MTest and MCenter configurable for:

- Primary beam
  - Proton Mode: ~66-120 GeV protons
- Secondary beam
  - Pion Mode: 8-66 GeV beam
  - Low Energy Pion Mode: 1-32 GeV beam
  - Muon Mode: Same energy range as above
- Tertiary beam
  - Low Energy Pion Mode: 200 MeV - 3 GeV

Closer Look at FTBF



MTest:

Continue to use for short-term experiments (few weeks to months)

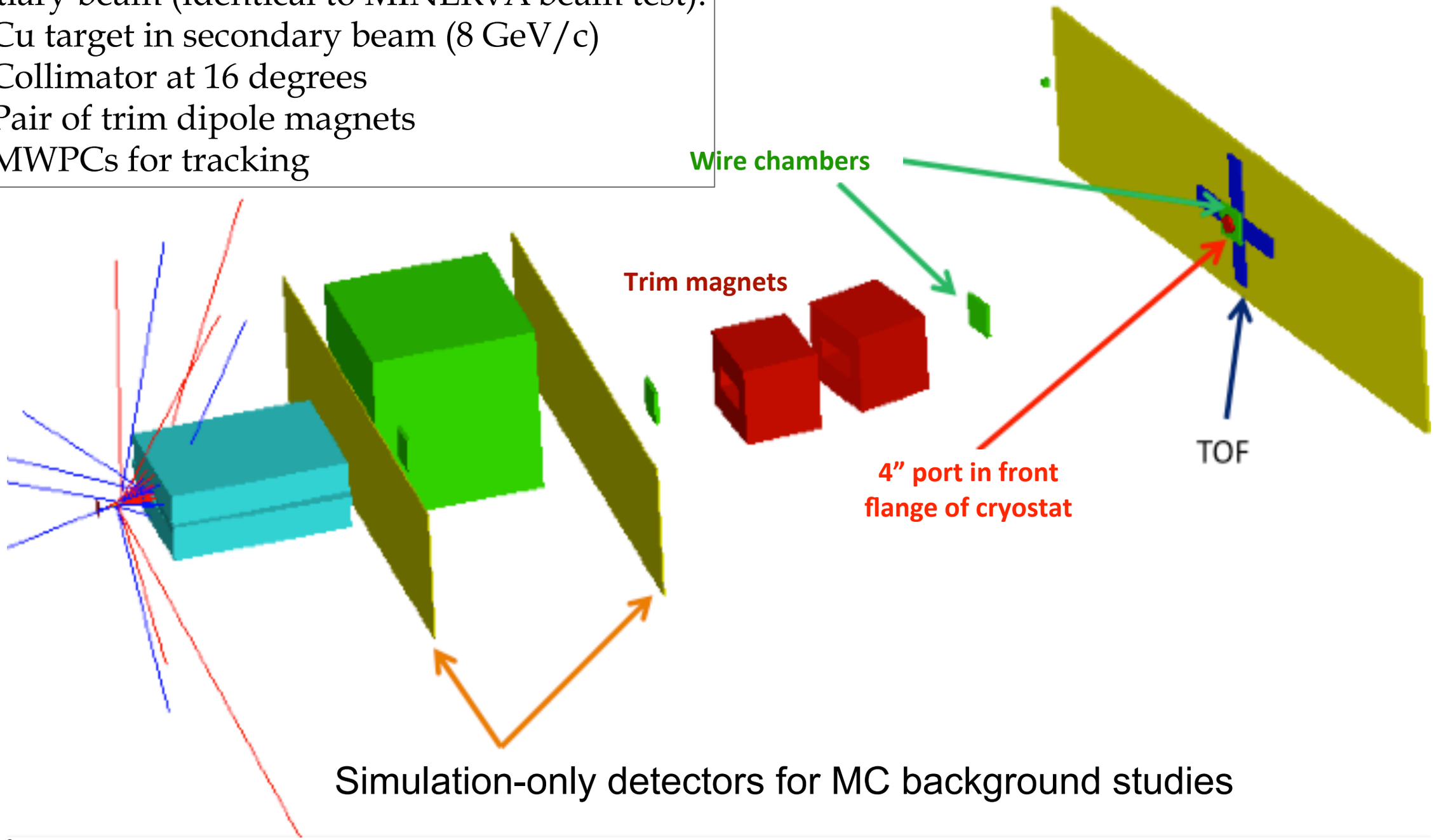
MCenter:

Create a facility for long-term LAr calibration and R&D with "generic" cryogenic plant in MC7/8 that will service upcoming experiments (LArIAT-I and -II) and any future LAr R&D in this beam.

Tertiary Beam at MCenter

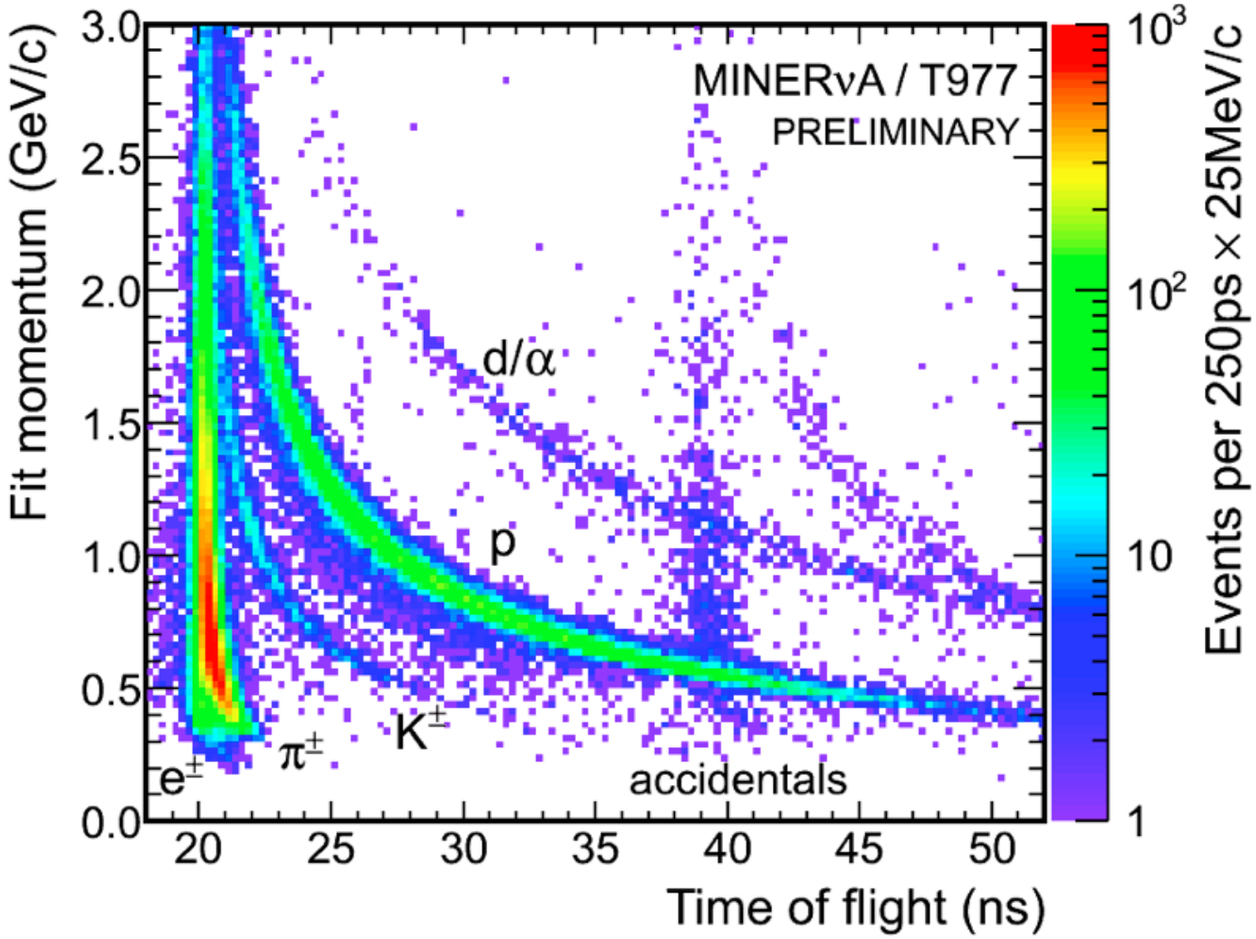
Secondary beam: Max ~300k particles/spill
One 4-second-long spill per minute

Tertiary beam (identical to MINERvA beam test):
- Cu target in secondary beam (8 GeV/c)
- Collimator at 16 degrees
- Pair of trim dipole magnets
- MWPCs for tracking



Simulation-only detectors for MC background studies

MINERvA Tertiary Beam Composition



Tertiary beam composition as measured in MINERvA calibration run at MTest

Tertiary beam components have been moved from MTest to MCenter and will be set up in exactly the same configuration.

LArIAT

16 institutions
40+ physicists

New members welcome!

Scientific Goals

Phased program for comprehensive characterization of LArTPC performance for the range of energies relevant to upcoming experiments like MicroBooNE and LBNE

Phase-I: Modified ArgoNeuT detector

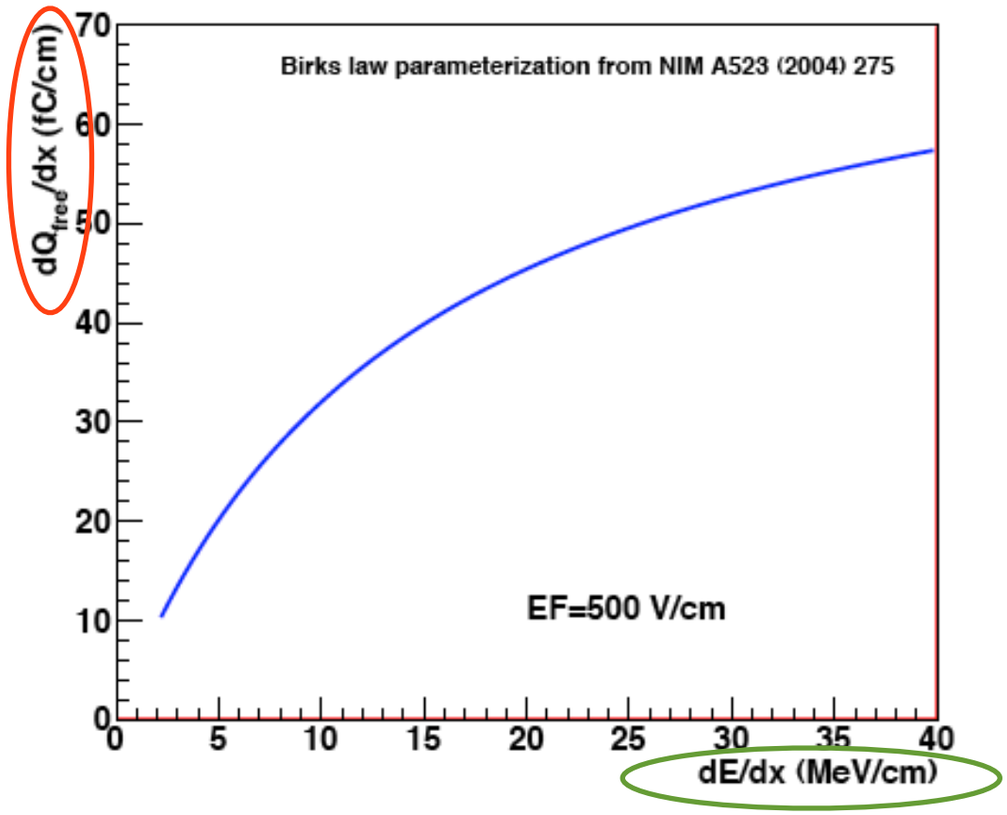
Single-track calibration (recombination/charge-to-energy calibration)
Experimental measurement of e/gamma separation
Optimization of particle ID methods
Development of criteria for charge-sign determination

Phase-II: Larger volume TPC (TBD)

Reconstruction of collective topologies (detected-to-incident energy calibration)
Characterization of EM and hadronic showers
Testing ground for LAr detector subsystems under development for future use (cold electronics, new wire plane designs, study longer drift distances, cryostat insulation schemes, etc.)

Single Track Calibration

Precisely establish relationship between ionization charge collected at TPC wires and energy deposited in LAr by incident particles of different types and stopping powers.



Below 15 MeV/cm, Birks parameterization well-validated; above ~15-20 MeV/cm data from ICARUS cosmic ray measurements, but sparse and statistically limited.

With low-momentum beam of particles that penetrate and stop in TPC, can determine calibration for:

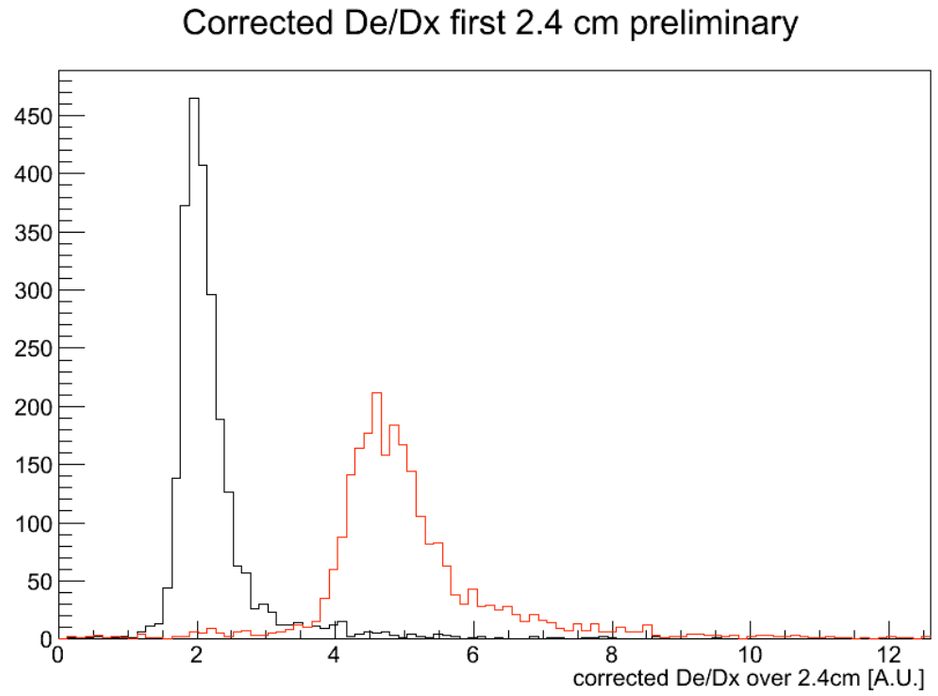
- Extended range of energy deposition (dE/dx)
- Different E field values (~0.3-1.0 kV/cm range, typ. LArTPC operation)
- Different track-to-electric field angles

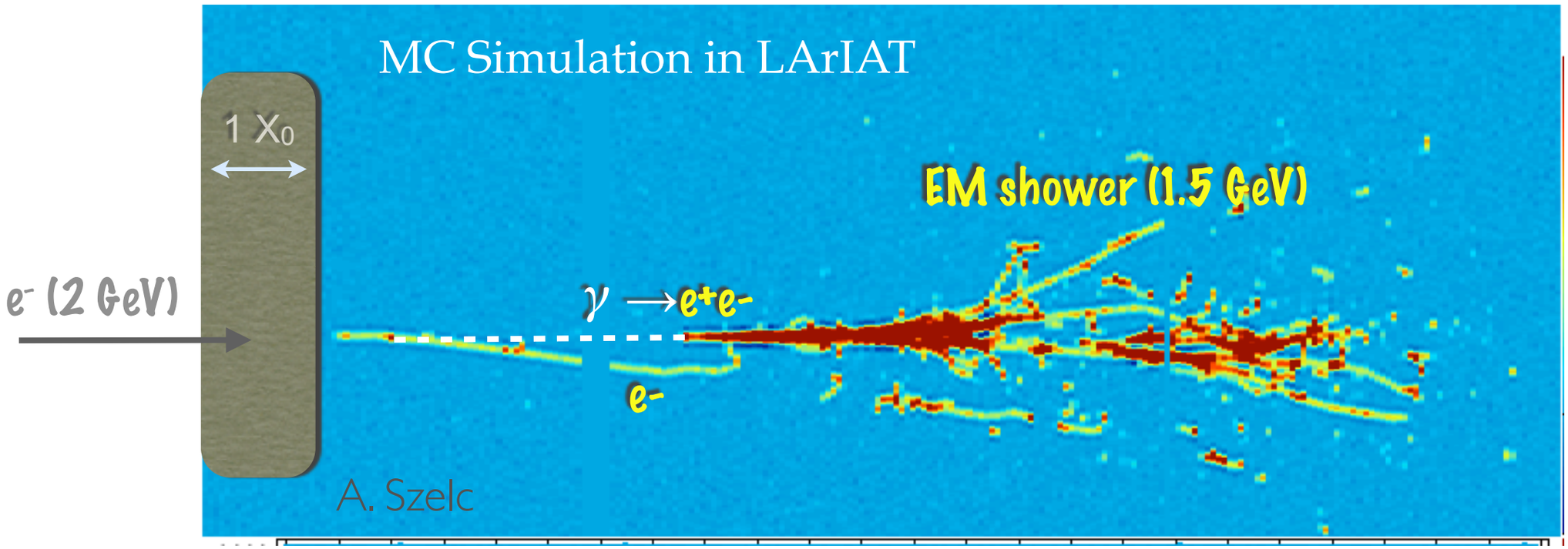
Goal: Provide to MicroBooNE (LArSoft) verification of parameterization or tables of ionization charge vs. energy deposited for each measured setting.

e/γ Shower Separation

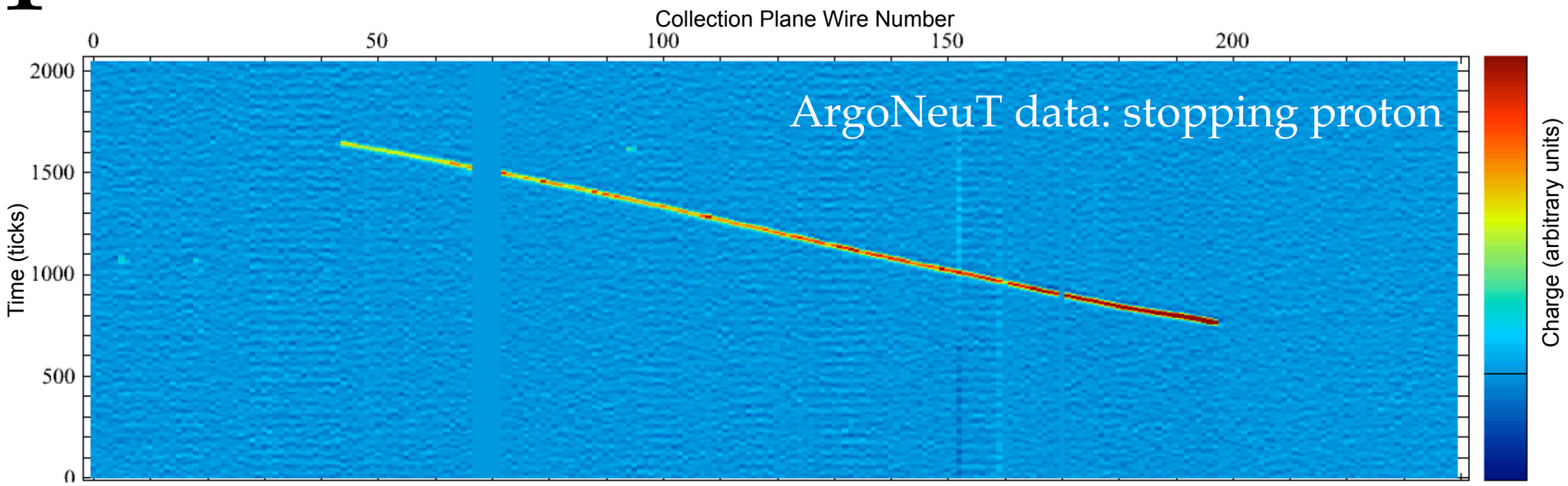
Separation efficiency and sample purity of electron-induced *vs.* photon-induced showers never experimentally measured.

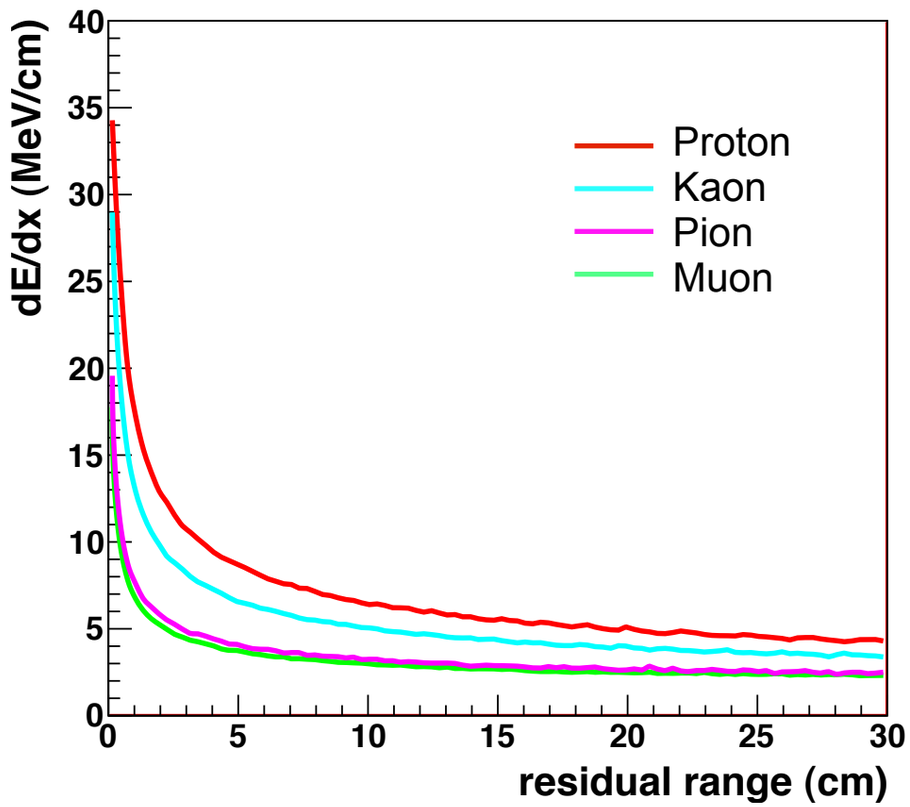
Only initial part of shower relevant for separation (γ converts to e^+e^- pair w/double ionization at shower start).





Optimization of PID Methods





Single track calibration + 3D imaging
⇒ dE/dx vs. residual range

High-statistics test beam data will allow experimental determination of:

Proton ID, p/K separation and purity/rejection factor
Kaon ID, K/π/μ separation and purity/rejection factor

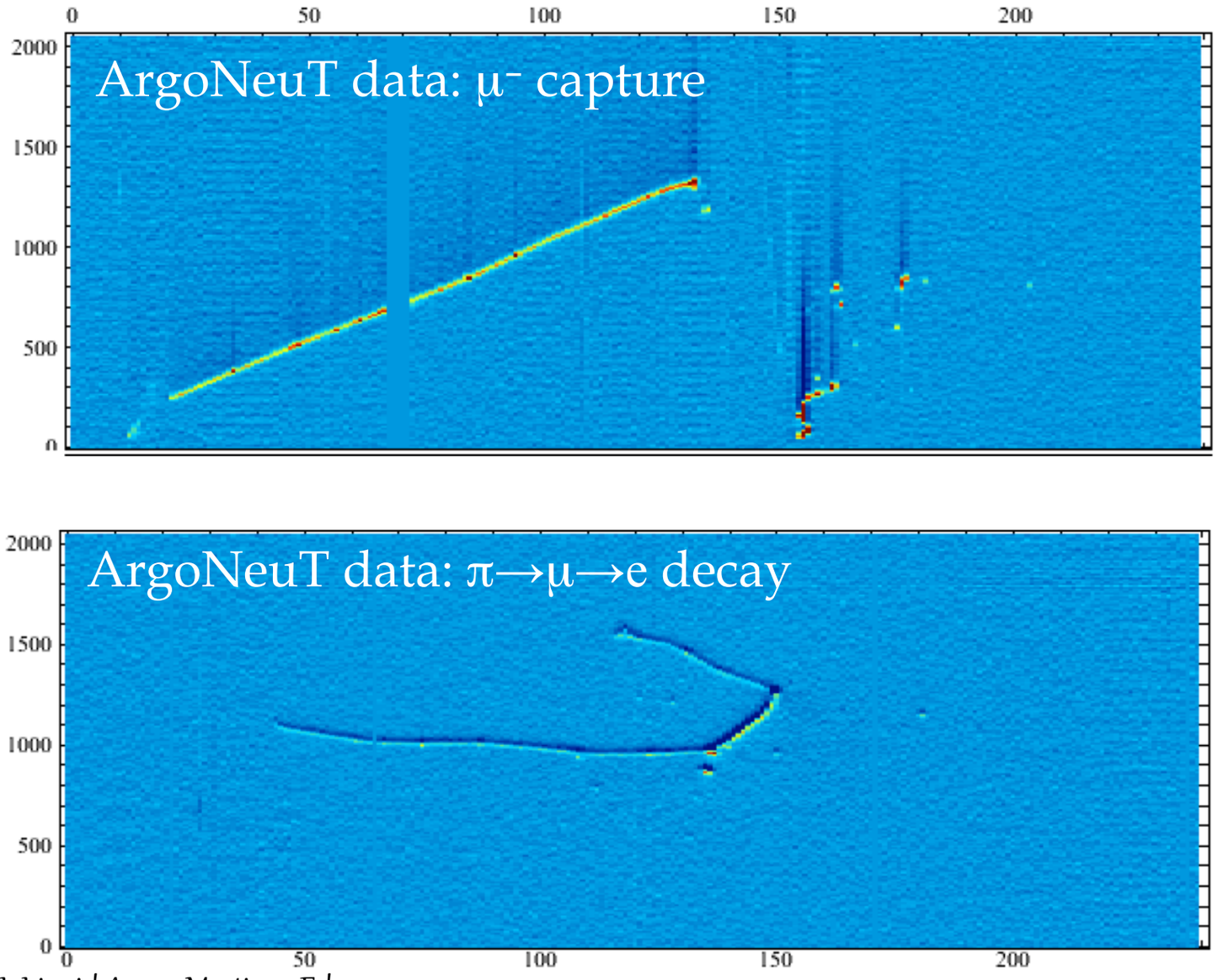
Charge-Sign Determination

Sign selection without magnetic field can be done by statistical analysis based on topological criteria.

μ^+ only undergo decay

μ^- capture on nuclei (75%, followed by γ or n emission) or decay (25%)

Systematic study of capture in Ar and LArTPC sign-selection capabilities have not been explored before.



EM & Hadronic Showers

EM energy deposition mechanism is very well understood (MC simulations are very reliable)

However, in LAr, a substantial fraction of the incident energy (~30%, depending on incident energy) goes into soft electrons (< 2 MeV)

How well can the incident energy be reconstructed?

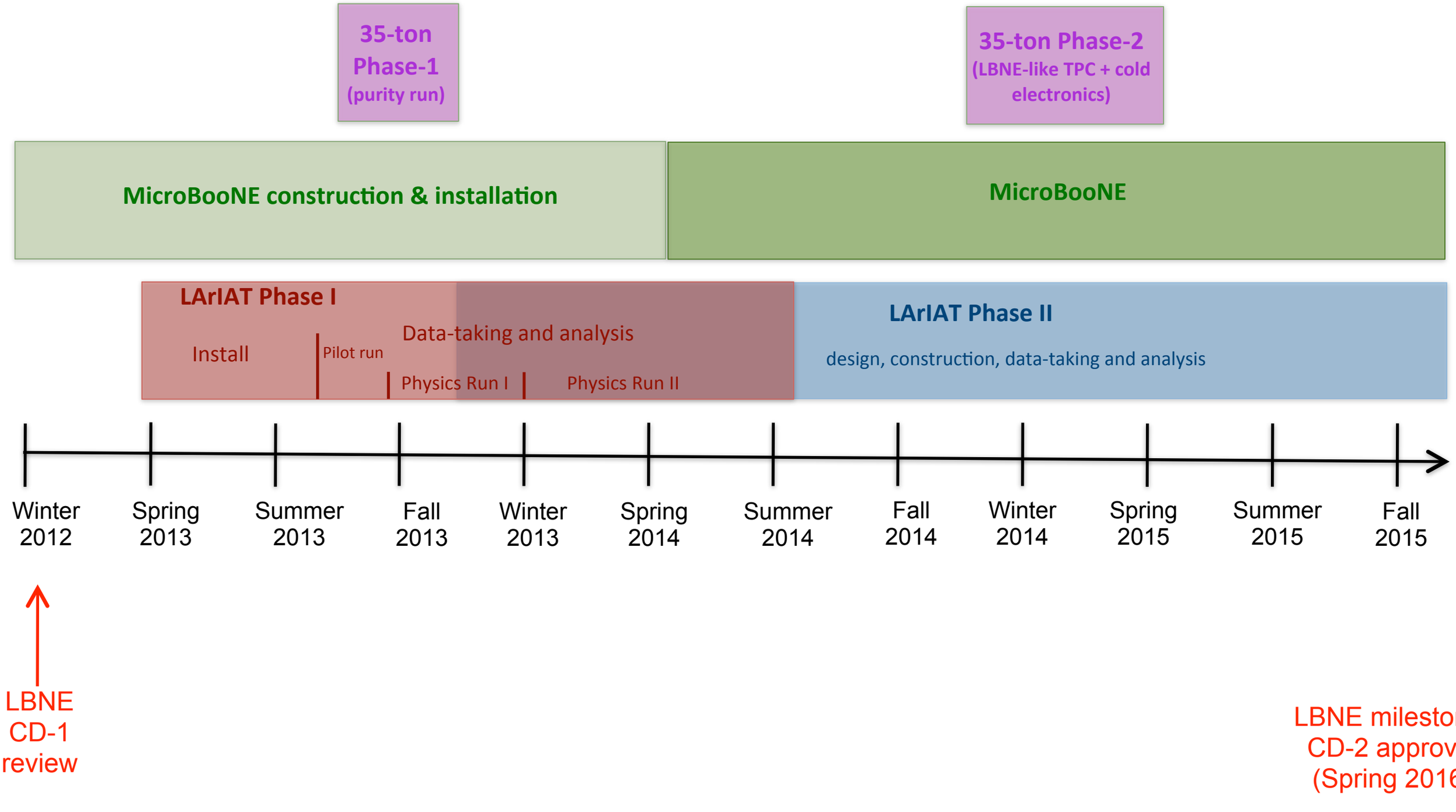
Hadronic showers are more complicated (develop on λ_{int} scale rather than X_0 scale, $\lambda_{int} \sim 5X_0$). Containment more difficult.

Fraction of energy goes to:

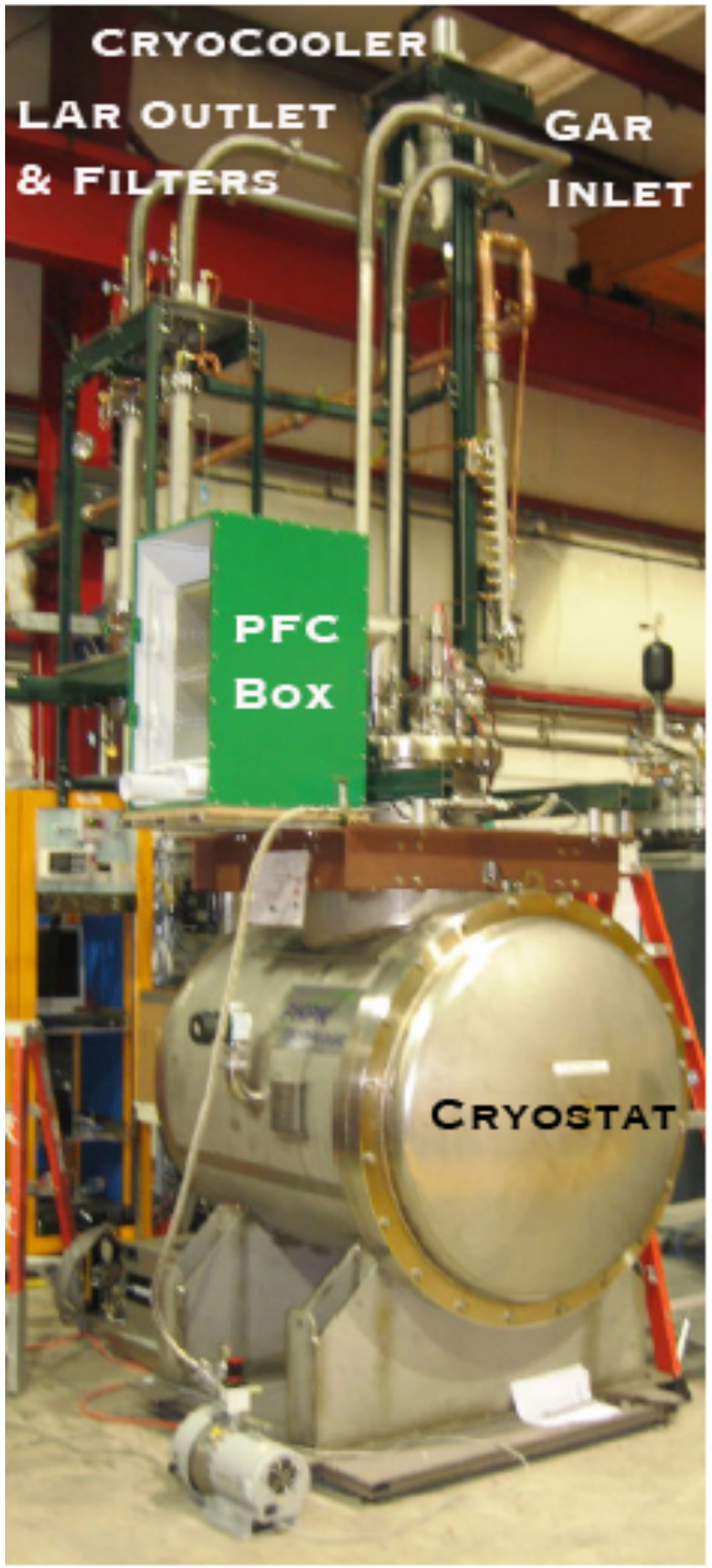
EM: fluctuates and is E-dependent (never measured in LAr)
Soft neutrons: few tens of neutrons per GeV (~10%)
Undetectable: fraction not well known (~10%?)

Need to measure energy-dependent calibration constants for pions

Timeline

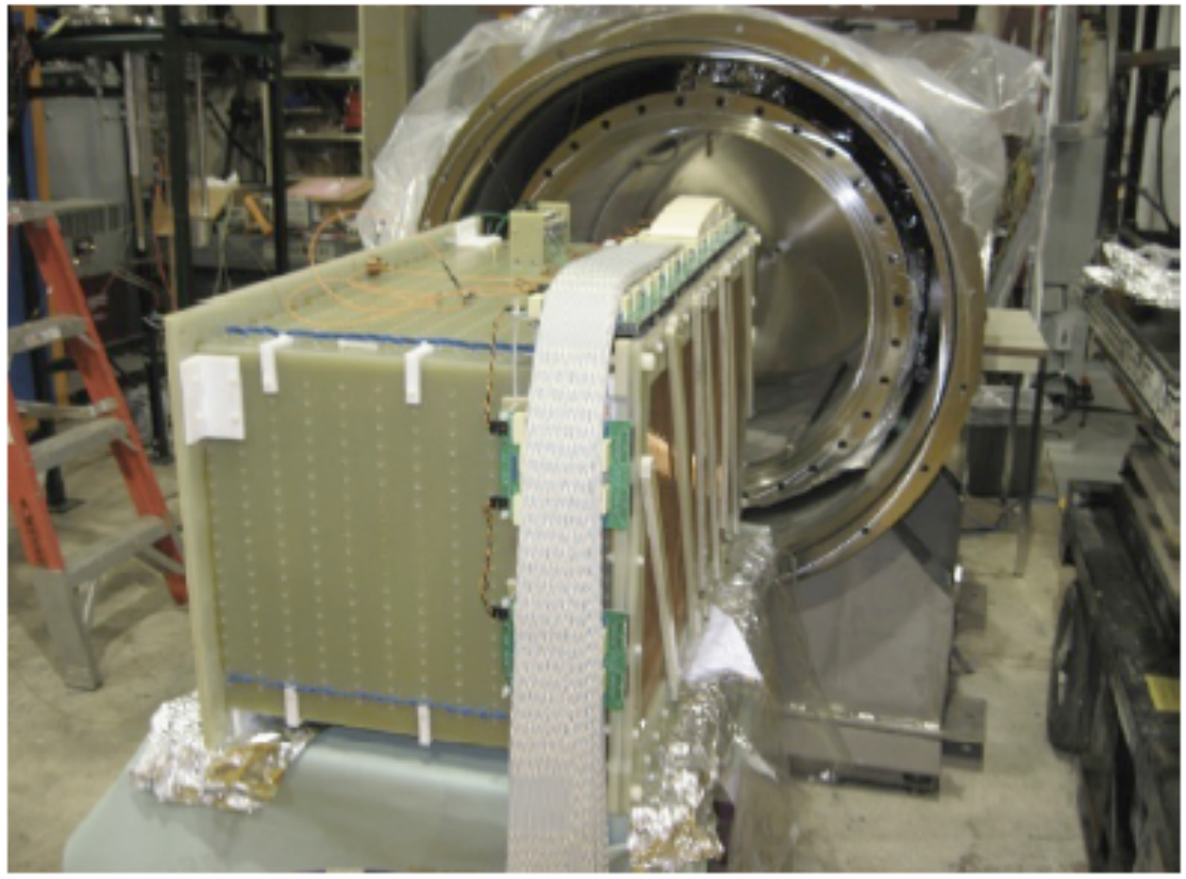

35-ton Phase-1 (purity run)
35-ton Phase-2 (LBNE-like TPC + cold electronics)
MicroBooNE construction & installation
MicroBooNE
LArIAT Phase I
Install
Pilot run
Data-taking and analysis
Physics Run I
Physics Run II
LArIAT Phase II
design, construction, data-taking and analysis
Winter 2012
Spring 2013
Summer 2013
Fall 2013
Winter 2013
Spring 2014
Summer 2014
Fall 2014
Winter 2014
Spring 2015
Summer 2015
Fall 2015
LBNE CD-1 review
LBNE milestone: CD-2 approval (Spring 2016)

Phase-I Experimental Setup



The LArIAT experimental test beam program capitalizes on the availability of the existing hardware from the ArgoNeuT experiment.

Cryostat volume: 550 liters
TPC size: 40x47x90 cm^3 (~175 liters)
Induction/Collection planes: ±60°
4mm plane separation and wire spacing

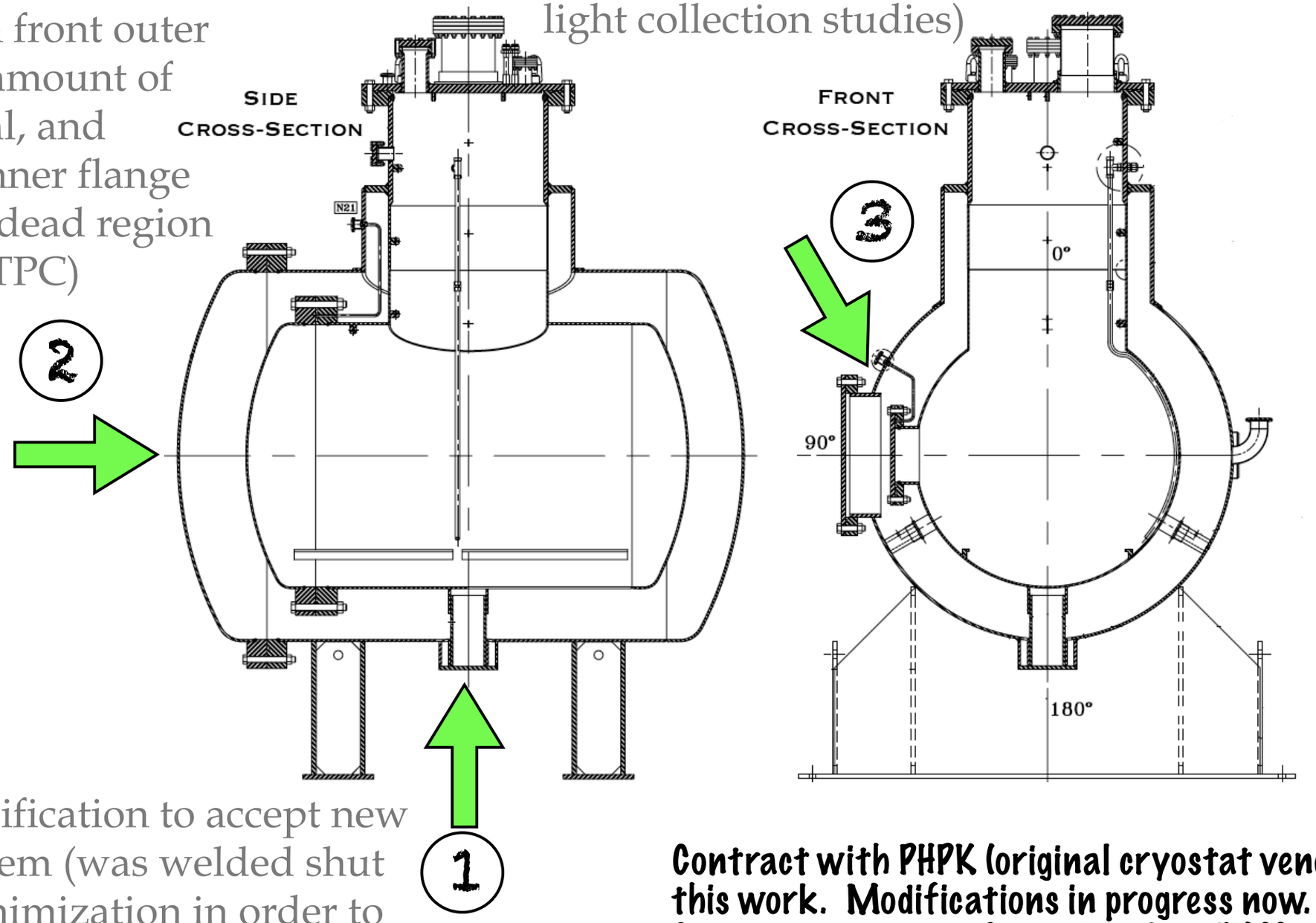


Making ArgoNeuT into LArIAT

For charged particle beam running, ArgoNeuT detector requires some modifications:

Lateral port modification to accept PMTs (not required, but desired for scintillation light collection studies)

Beam window in front outer flange to reduce amount of upstream material, and modification of inner flange to minimize LAr dead region (before reaching TPC)

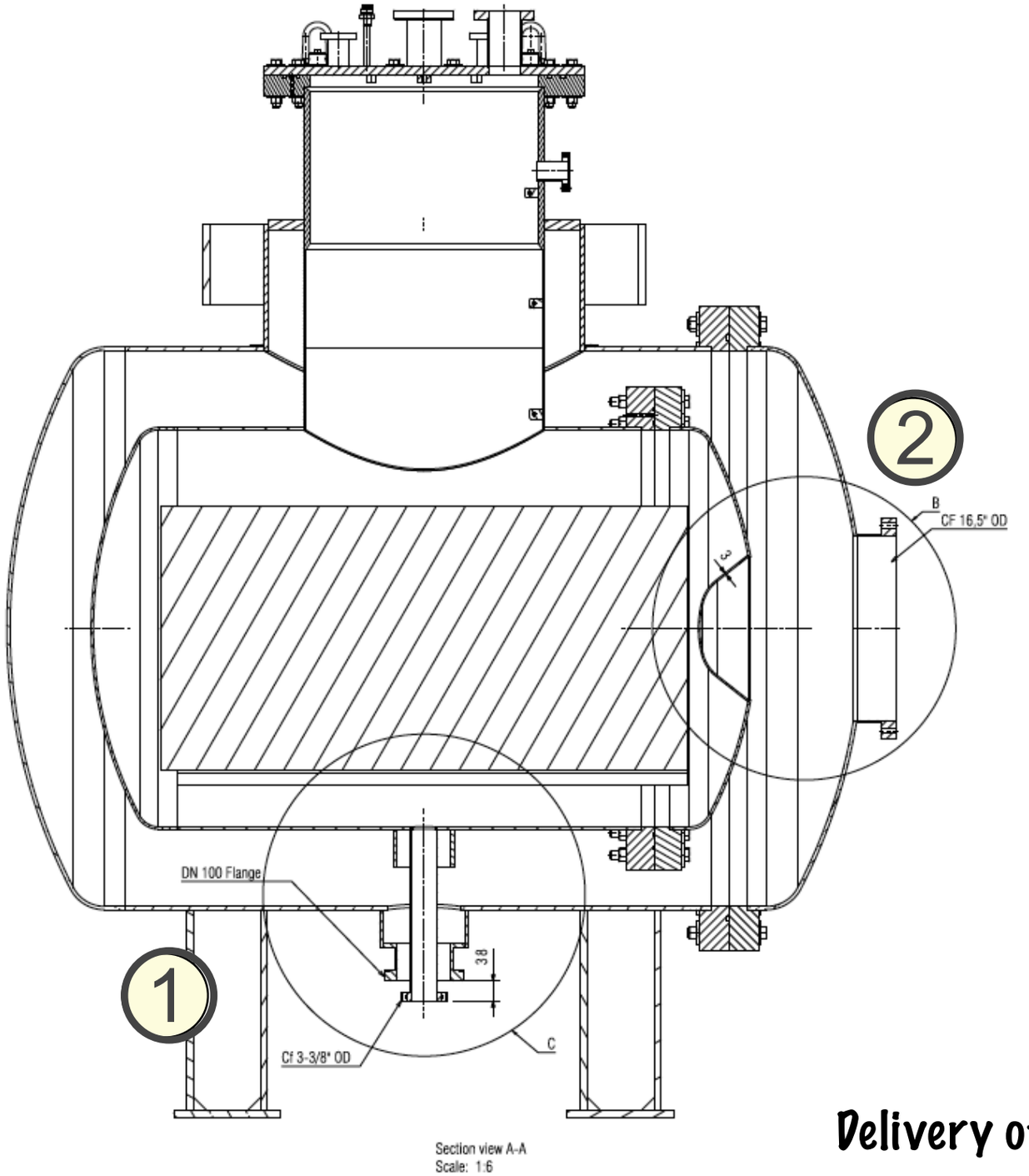


Bottom port modification to accept new recirculation system (was welded shut for ODH risk minimization in order to run underground in NuMI beam)

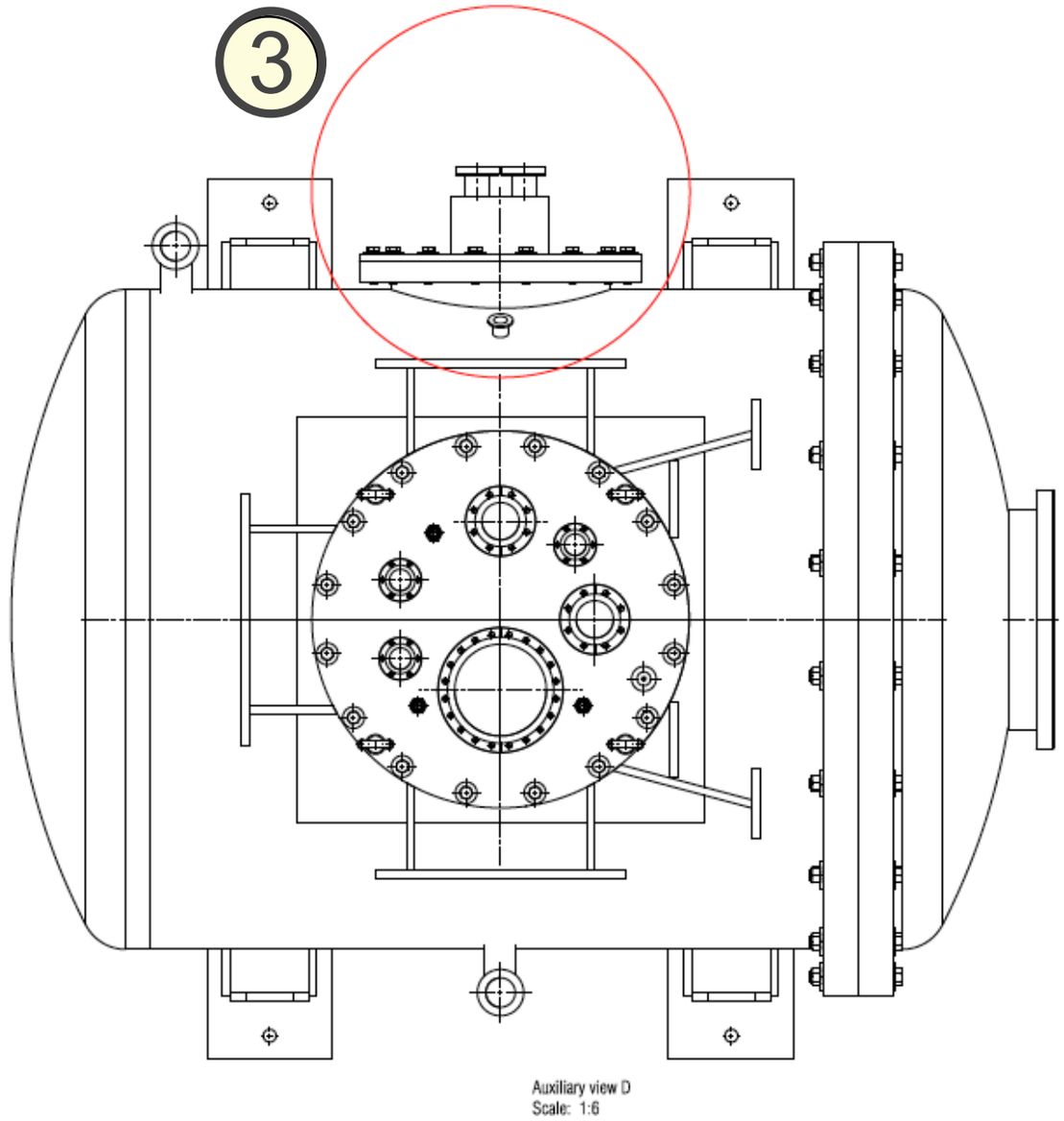
Contract with PHPK (original cryostat vendor) for this work. Modifications in progress now. Cryostat due to be delivered back to FNAL in March.

Cryostat with modifications

PMTs mounted in this port and readout provided by L'Aquila University



Section view A-A
Scale: 1:6

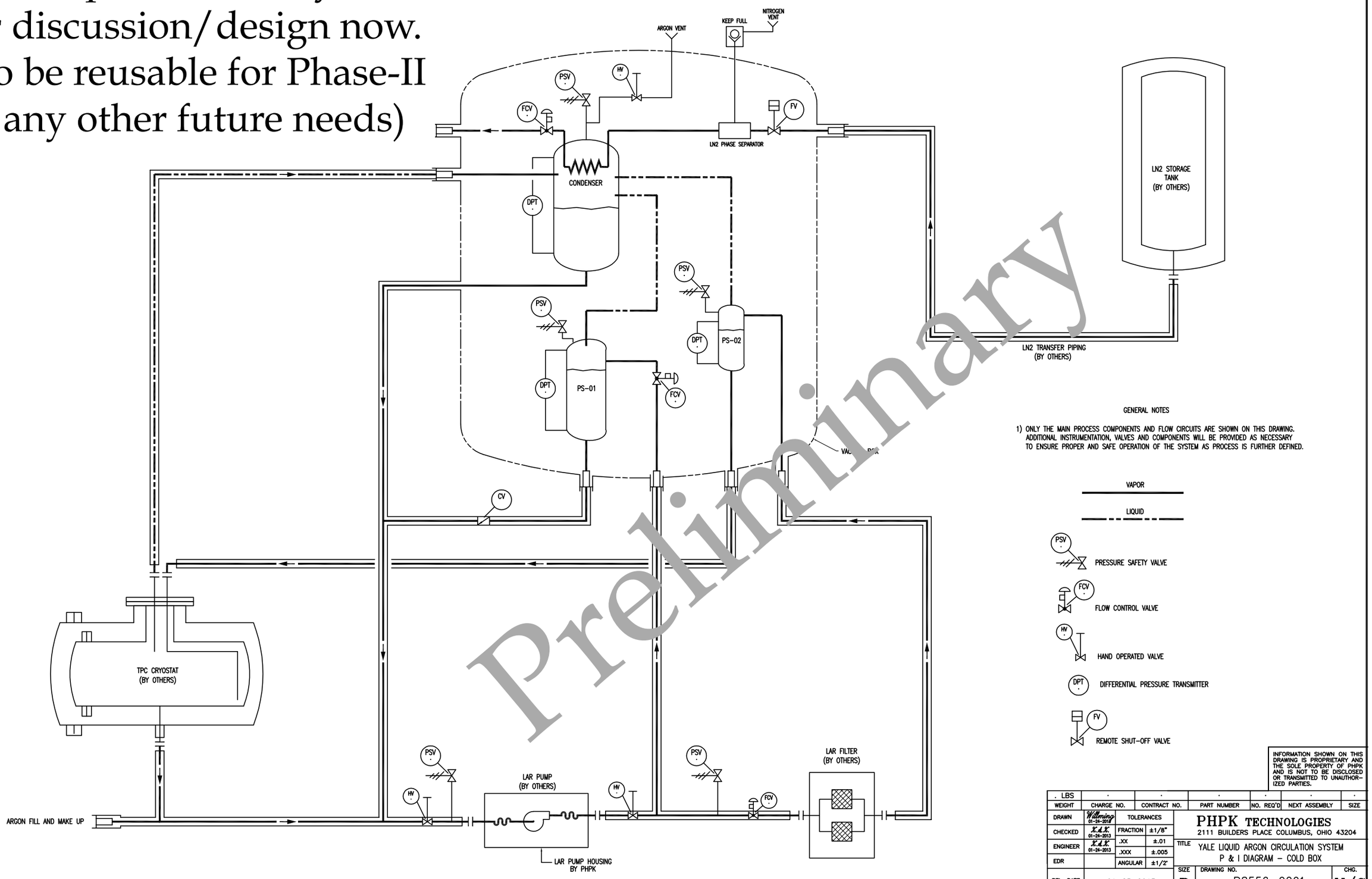


Auxiliary view D
Scale: 1:6

Delivery of modified cryostat expected in March 2013

Argon Cooling/Purification System

"Generic" purification system under discussion/design now. Plan to be reusable for Phase-II (and any other future needs)



GENERAL NOTES

1) ONLY THE MAIN PROCESS COMPONENTS AND FLOW CIRCUITS ARE SHOWN ON THIS DRAWING. ADDITIONAL INSTRUMENTATION, VALVES AND COMPONENTS WILL BE PROVIDED AS NECESSARY TO ENSURE PROPER AND SAFE OPERATION OF THE SYSTEM AS PROCESS IS FURTHER DEFINED.

VAPOR

LIQUID

PSV — PRESSURE SAFETY VALVE

FCV — FLOW CONTROL VALVE

HV — HAND OPERATED VALVE

DPT — DIFFERENTIAL PRESSURE TRANSMITTER

FV — REMOTE SHUT-OFF VALVE

. LBS	.	.	.	.	.	.
WEIGHT	CHARGE NO.	CONTRACT NO.	PART NUMBER	NO. REQ'D	NEXT ASSEMBLY	SIZE

DRAWN	Willming 01-24-2013	TOLERANCES	
CHECKED	X.d.X. 01-24-2013	FRACTION	±1/8"
ENGINEER	X.d.X. 01-24-2013	.XX	±.01
EDR		.XXX	±.005
REL. DATE	01-25-2013	ANGULAR	±1/2°

DIMENSIONS ARE PROVIDED PRIOR TO SURFACE TREATMENTS UNLESS NOTED.

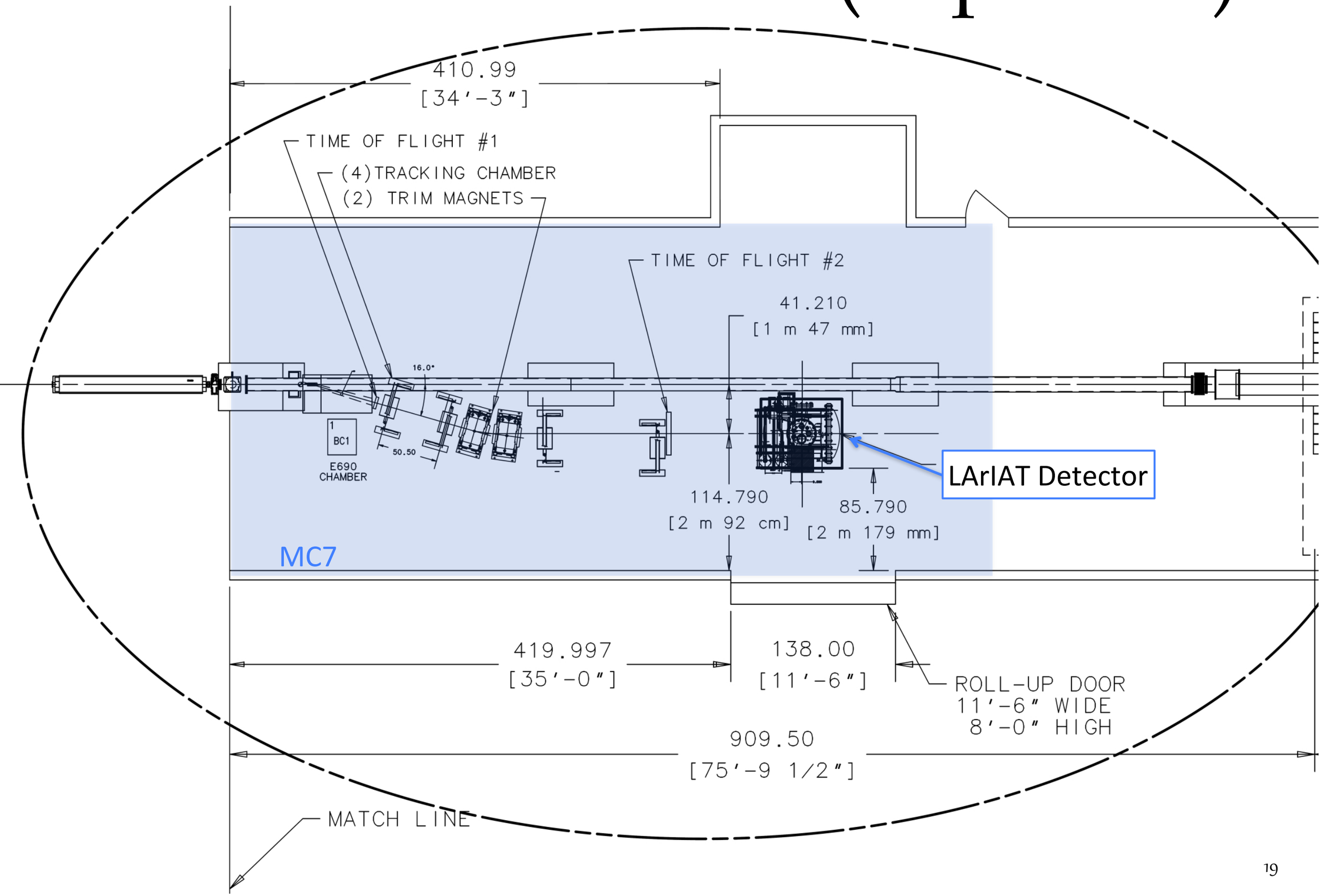
PHPK TECHNOLOGIES
2111 BUILDERS PLACE COLUMBUS, OHIO 43204

TITLE: YALE LIQUID ARGON CIRCULATION SYSTEM
P & I DIAGRAM – COLD BOX

SIZE	DRAWING NO.	CHG.
B	P8556-0201	N/C

SCALE NONE — SHEET 1 OF 1

LArIAT in MCenter (Top View)

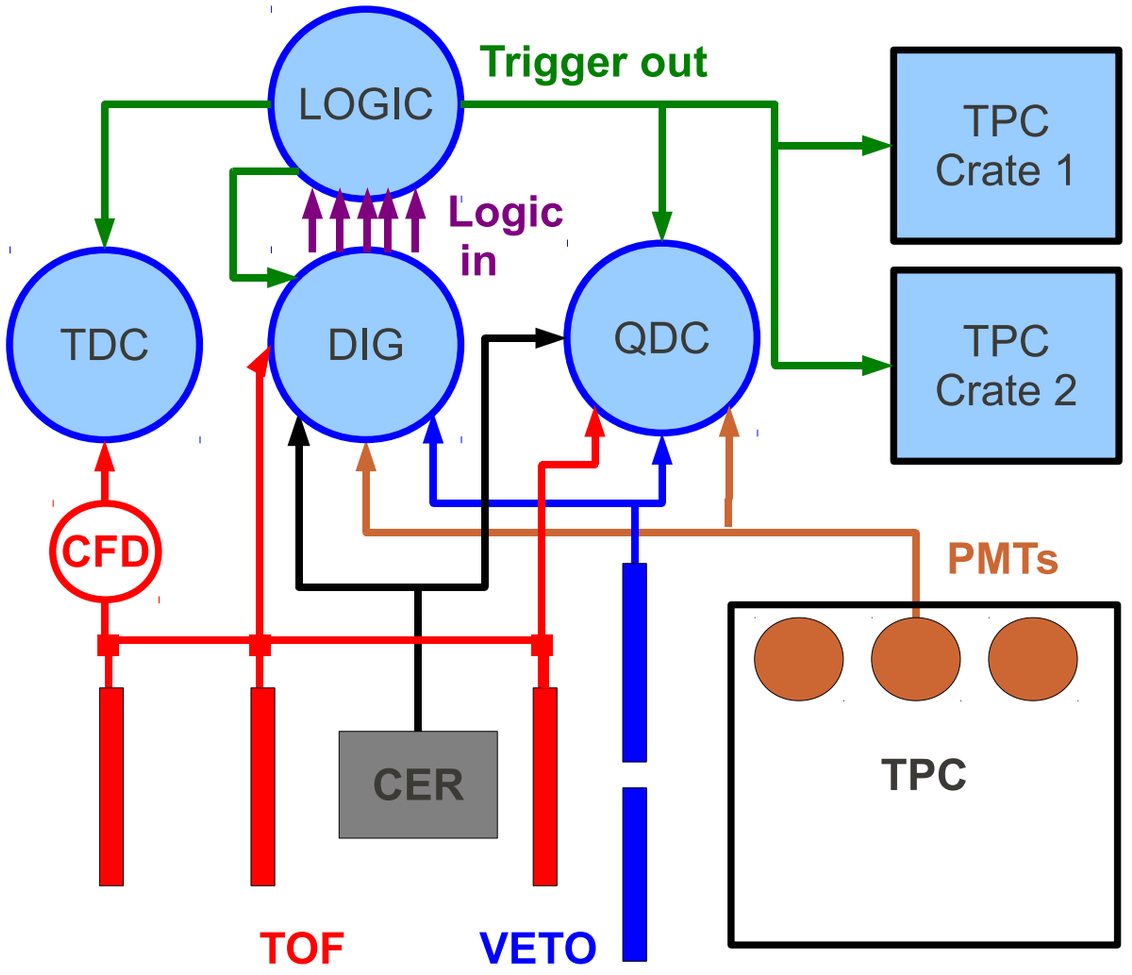


Beam Trigger Development

Existing DAQ crate controllers already accommodate an input signal to trigger on the neutrino beam spill and/or internal PMT signals

Feed information from beam ToF counters, Cherenkov counters, PMTs in vessel, & veto counters into 12-bit digitizer.

Digitizer will discriminate signals by pulse shape, then send fast logic pulses to FPGA-equipped logic module to test for one or more trigger conditions & enable FEM readout



Under development using joint DOE/Yale funding

Electronics & DAQ

DAQ rate must be increased by factor ≥5

Existing ArgoNeuT DAQ rate: ~1 Hz

Expected good trigger rate at FTBF: ~5 Hz

(~20 particles/spill in 4 second spill once per minute)

Two planned improvements to reach up to 32x rate increase:

- ADF2 digitizer firmware upgrade for improved VME readout speed
- Replace "bit-3" PC-VME interface with Motorola SBCs (which we can get from CDF or D0)

ArgoNeuT warm electronics can be used again, but we strongly prefer to instead upgrade to cold electronics (improved signal-to-noise)

Maybe not feasible with available FNAL funding…

Looking for external funds for this

Schedule

MILESTONES			
Tertiary Beam Config. Study & Simulations	LArIAT Coll.	Jul.'12 - Jan.'13	in progress
New Cryogenics/Filter **Design**	FNAL + LArIAT Coll.	Sep.'12 - Feb.'13	in progress
Cryostat Modifications **Design**	LArIAT Coll.	Oct.'12 - Dec.'12	***completed***
New Cryogenics/Filter **Fabrication**	FNAL + LArIAT Coll.	Nov.'12 - Jun.'13	in progress
Cryostat Modifications	LArIAT Coll. (Yale)	Jan.'13 - Mar.'13	in progress
Tertiary Beam Installation (MC7)	FNAL	Feb.'13 - Apr.'13	
TPC Modification	LArIAT Coll. (Syrac.)	Mar.'13-May'13	
Cryogenics/Cryostat/Detector **Assembly**	LArIAT Coll. + FNAL	Apr.'13 - Jul.'13	
Electronics & DAQ Installation	LArIAT Coll. + FNAL	May'13-Jul.'13	
Beam Monitor Detectors Installation	FNAL + LArIAT Coll.	Feb.'13 - Jun.'13	
Beam Trigger	LArIAT Coll. (W&M)	Mar.'13 - Jun.'13	
Detector Synchronization, Online Monitoring, DAQ test/debugging	LArIAT Coll.	Jun.'13-Jul.'13	
Commissioning (LAr Filling/Purification)	LArIAT Coll.	Aug.'13	
BEAM ON at FTBF	FNAL	Aug.'13	
Debugging/Pilot Run	LArIAT Coll.	Aug.'13 - Sept.'13	
Extended Physics Run #I * 0°, 0.5 kV - μ, π, K, P both polarities	LArIAT Coll.	Oct.'13 - Dec.'13	
Extended Physics Run #II *0°, 0.5 kV - e, γ, Anti-proton run, angular scan, EF scan	LArIAT Coll.	Jan.'14- Aug.'14	
DELIVERABLES			
Results from Recombination Studies (Run#I) [Calorimetry and PID]	LArIAT Coll.	Mar.'14 (+ 6 months for paper)	
Results from e, γ separation Studies (Run#2)	LArIAT Coll.	Jul.'14 (+ 6 months for paper)	

Summary

LArIAT scientific goals:

- Direct/experimental proof of e/γ separation in LArTPCs
- Detailed measurements of recombination factors
  p, K, π, μ PID and accurate calorimetry
- Direct measurement of energy resolutions for EM and hadronic showers
- Fine-tuning software for offline analysis

Phase-I effort is well underway

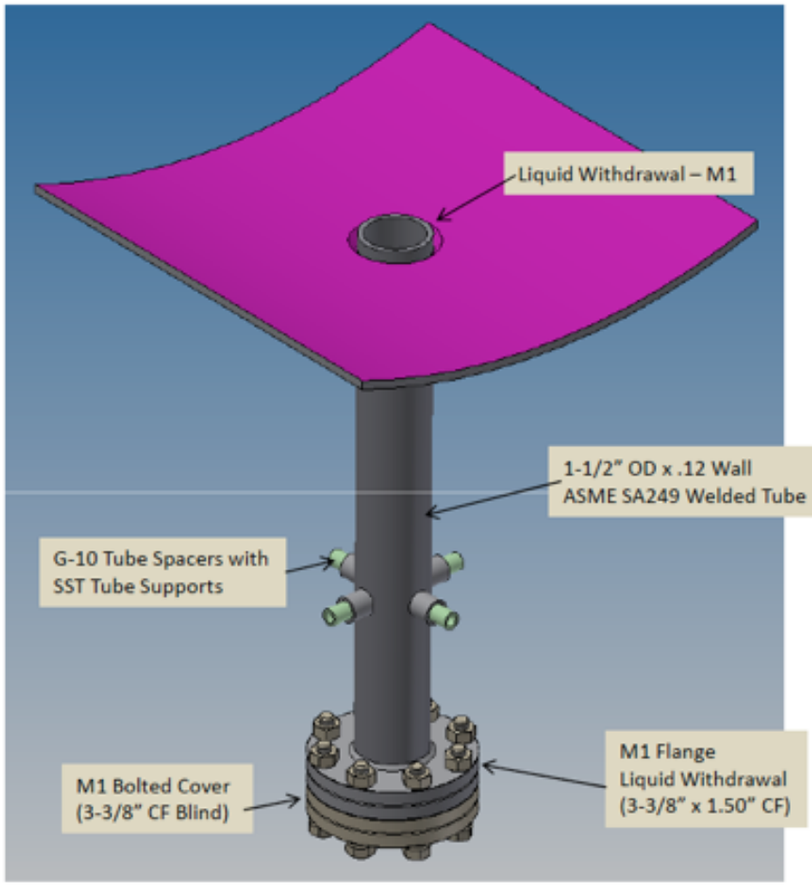
Working hard to be ready for beam startup (Summer 2013)

Phase-II simulation & planning has begun

Plenty of opportunities for new members to contribute!

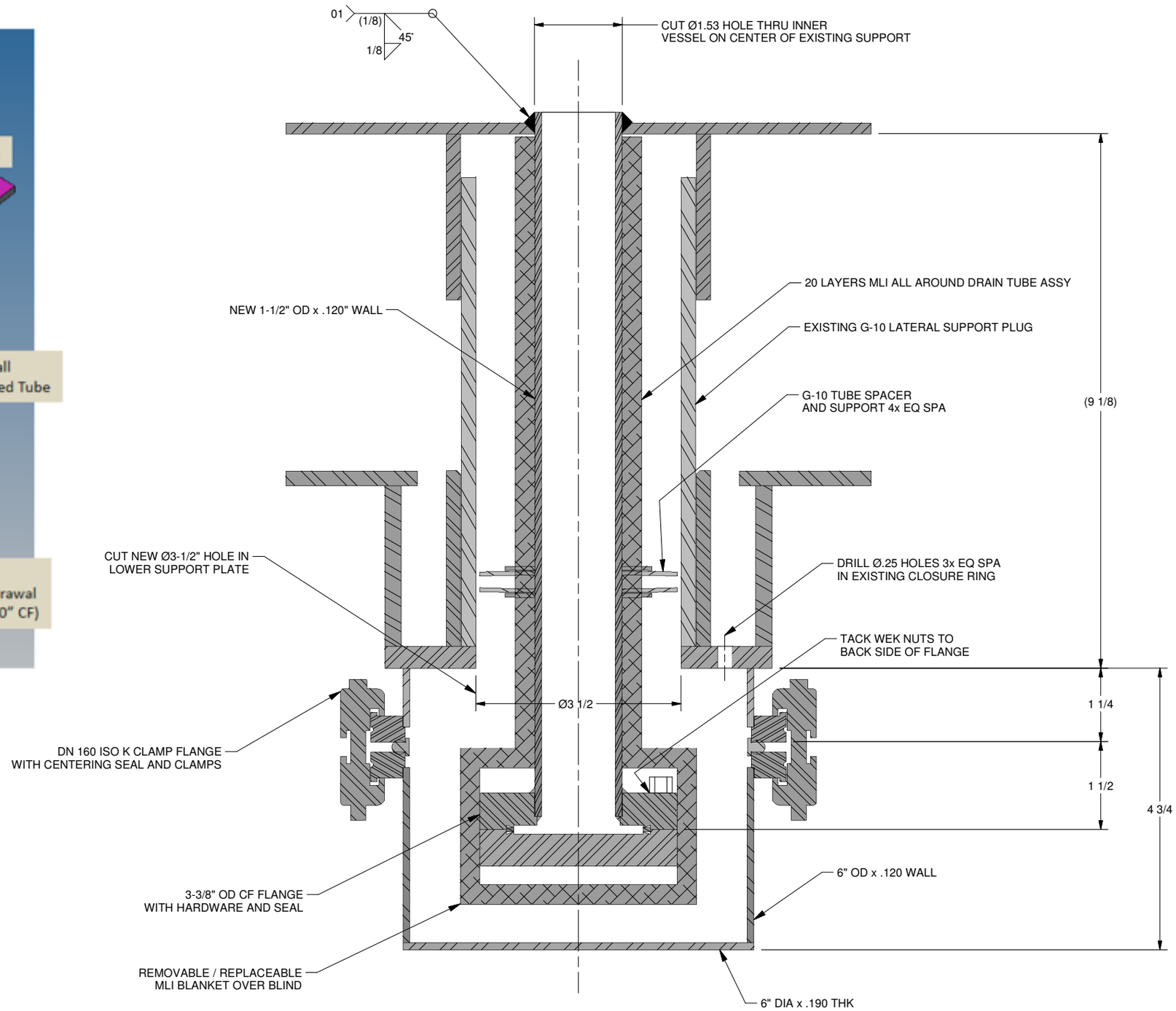
extras

Bottom Port Modification



MODIFICATION 01

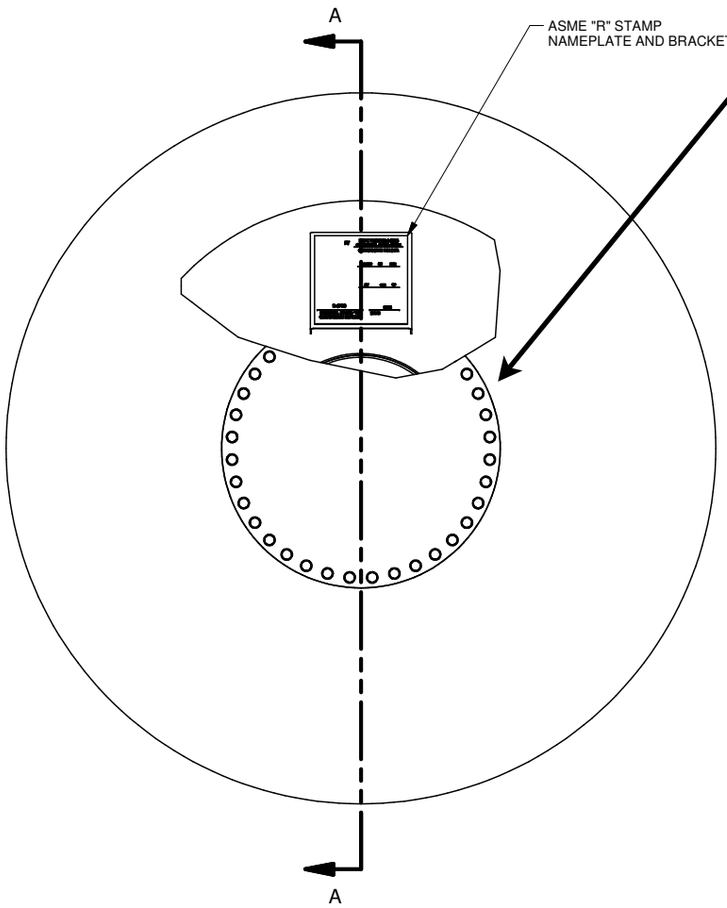
Add new 1-1/2" OD Nozzle for Liquid Withdrawal

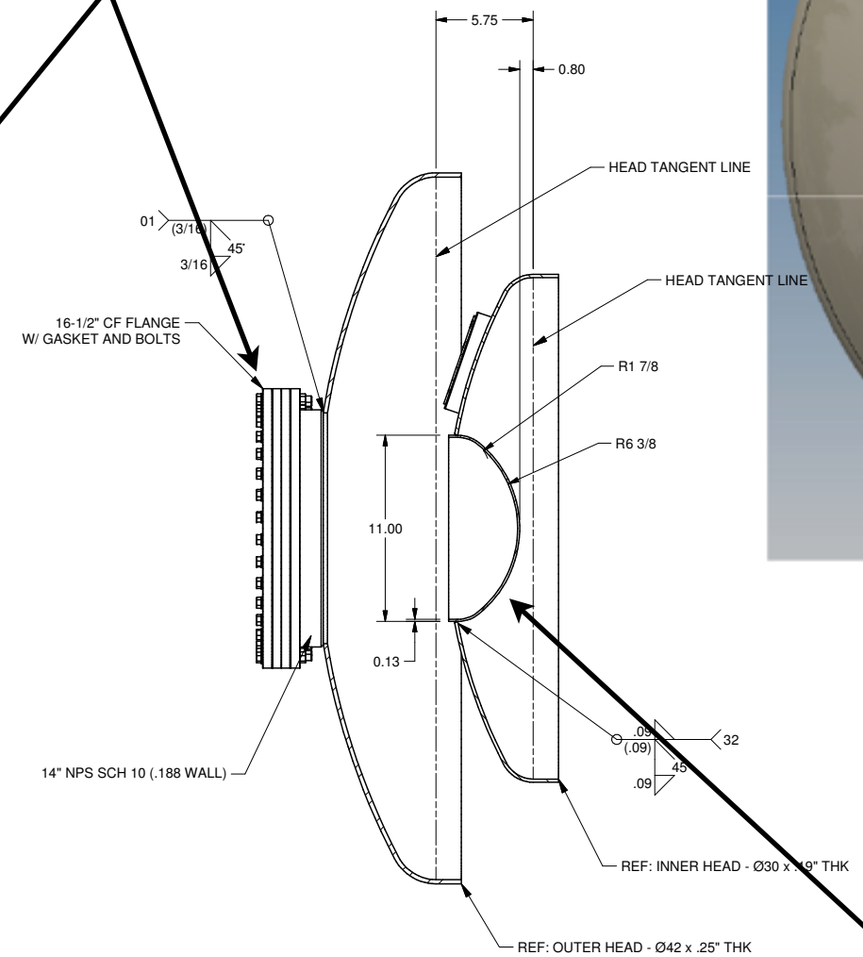


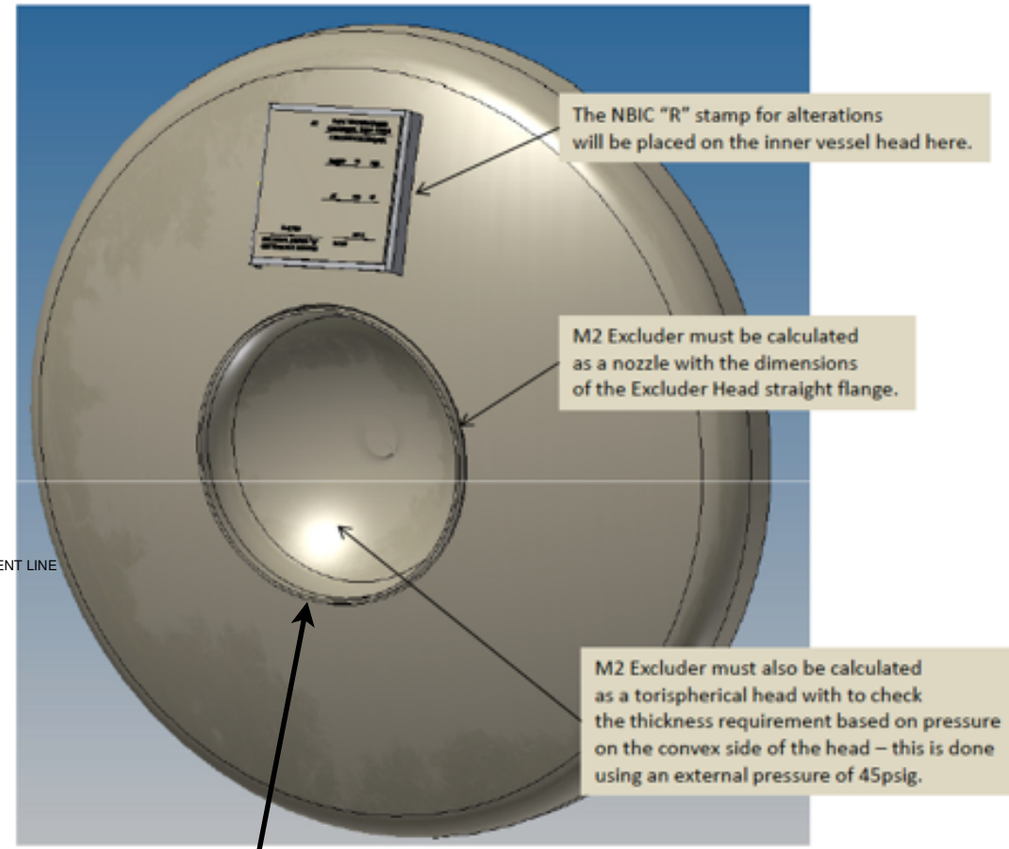
SECTION A-A

Front Flanges Modification

Outer flange with new addition of CF flange to accept Ti beam window





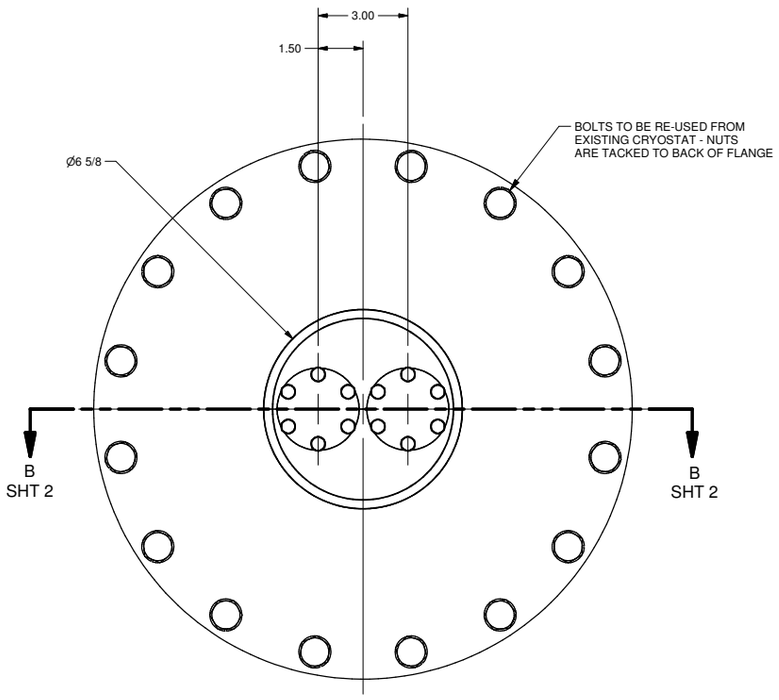


MODIFICATION 02

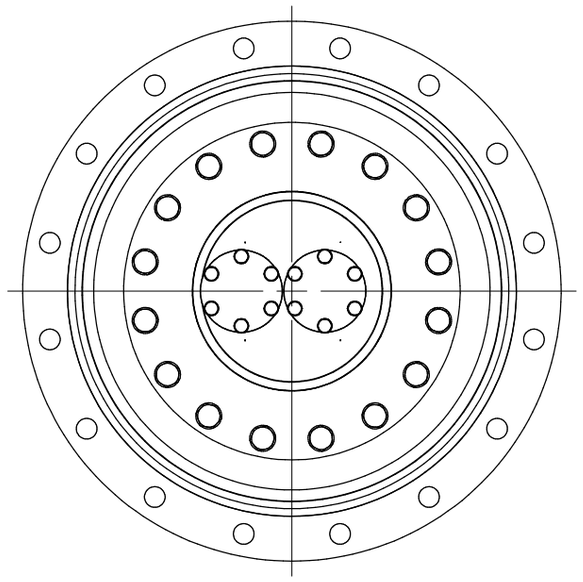
Add custom head to existing flanged head

Inner flange with "LAr excluder" to minimize region of dead LAr before particles enter TPC

Mod for Scintillation Light Collection

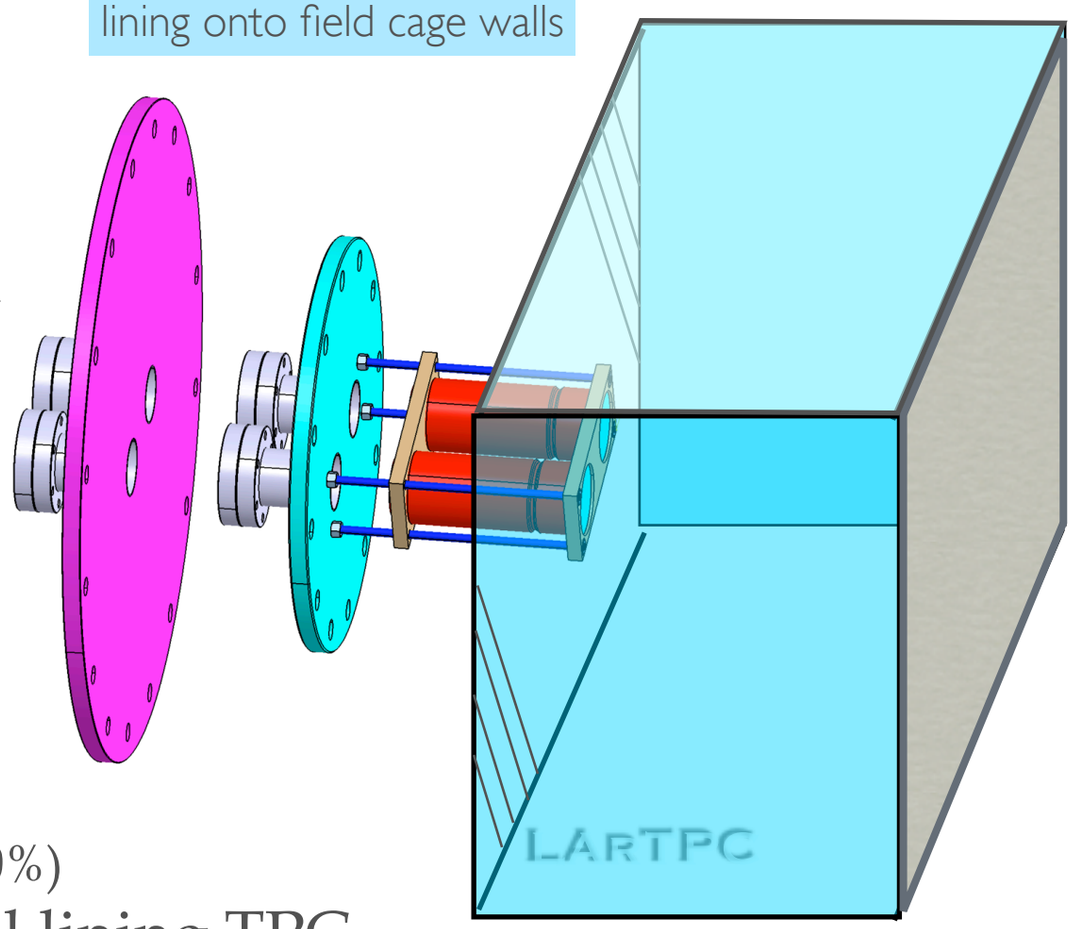


SCINTILLATION CONNECTION PORT - OUTER FLANGE VIEW



SCINTILLATION CONNECTION PORT - INNER FLANGE VIEW

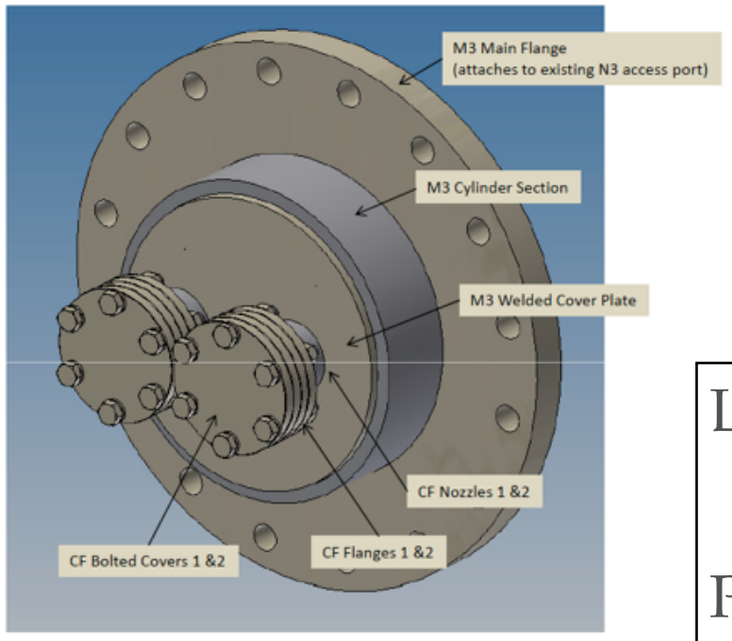
Reflector foil, TPB coated lining onto field cage walls



2 cryogenic PMTS
- one 3″ high QE (30%)
- one 2″ standard QE (20%)

+ WLS reflector foil lining TPC

CAEN digitizer readout



MODIFICATION 03
Add removable instrument port

Large light signal due to reflector foil
Precise calorimetry (although poor position resolution)

Pulse shape discrim of minimum- vs. highly-ionizing particles
This feature has never been explored with LAr ν detectors

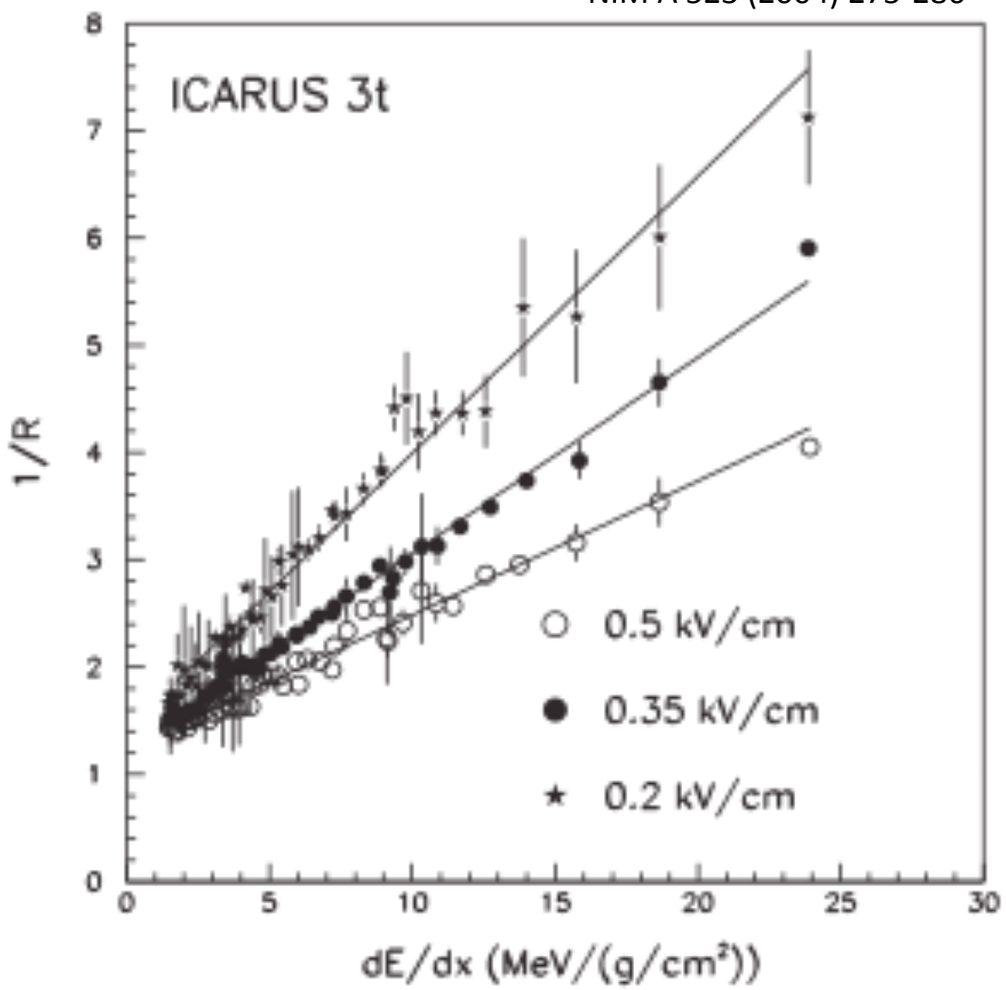
ICARUS Recombination Studies

Collected charge is (usually) converted into deposited energy (dQ/dx → dE/dx) by a Birks'-like formula depending on 2 parameters (or 3 in a more sophisticated model).

This turns into a recombination factor, R, for LAr (at different electric fields).

Precise knowledge of this is necessary for PID and calorimetric energy reconstruction.

NIM A 523 (2004) 275-286



LArIAT in MCenter (Side View)