LArIAT: LArTPC In A Testbeam (T-1034)

Review

FNAL - Dec. 20th, 2012

Flavio Cavanna & Jennifer Raaf
for the LArIAT Collaboration

LArIAT (T-1034) Review charge

We would like the committee to focus on Phase 1 of LArIAT and address the following:

1. Are the goals well defined, attainable, and worthwhile?
2. Is the technical approach for beam and experiment sound?
3. Are the collaboration and laboratory resources needed to succeed with LArIAT well understood, and are the requested resources adequate?
4. Are the cost and schedule risks well identified, and what are they?

The Vision:
Create a "permanent" facility for physics of interactions in LAr, for detector response calibration and for detector R&D
Use a tertiary beam in MCenter

Timeline

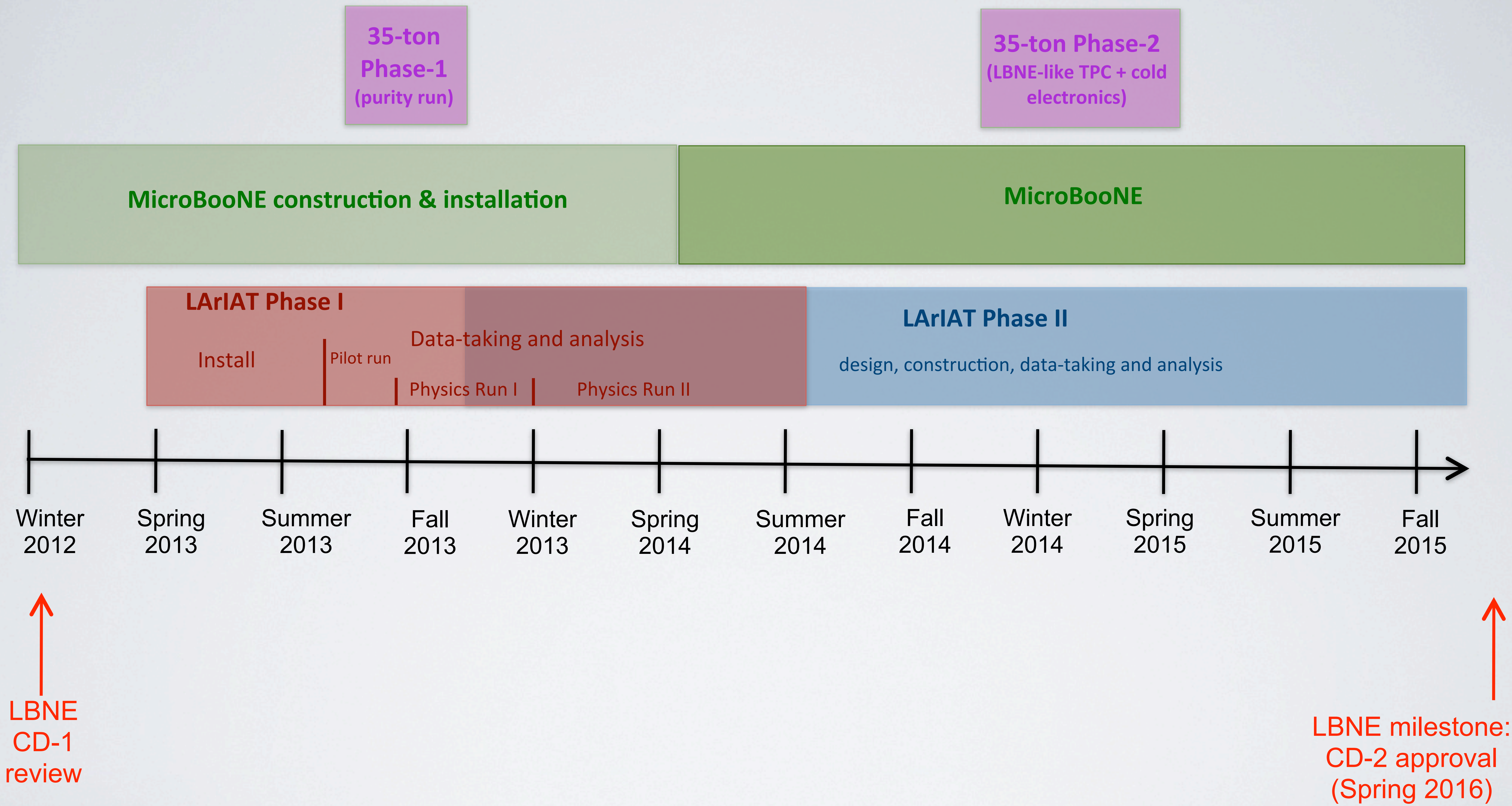
FNAL shutdown: April 28, 2012 – May 2013

- 1 year to plan and prepare facility for LAr TPC studies
  - MCenter: configure as broader use facility for LAr

Staged LArIAT program in MCenter

- Phase-I: ArgoNeuT in upstream end of beamline
  - Quick turnaround, can be ready before Aug 2013
- Phase-II: Larger LArTPC further downstream
  - Design facility for broader, longer-term use

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)

(1) Are the (physics) goals well-defined, attainable, and worthwhile?

➤ Science GOALS:

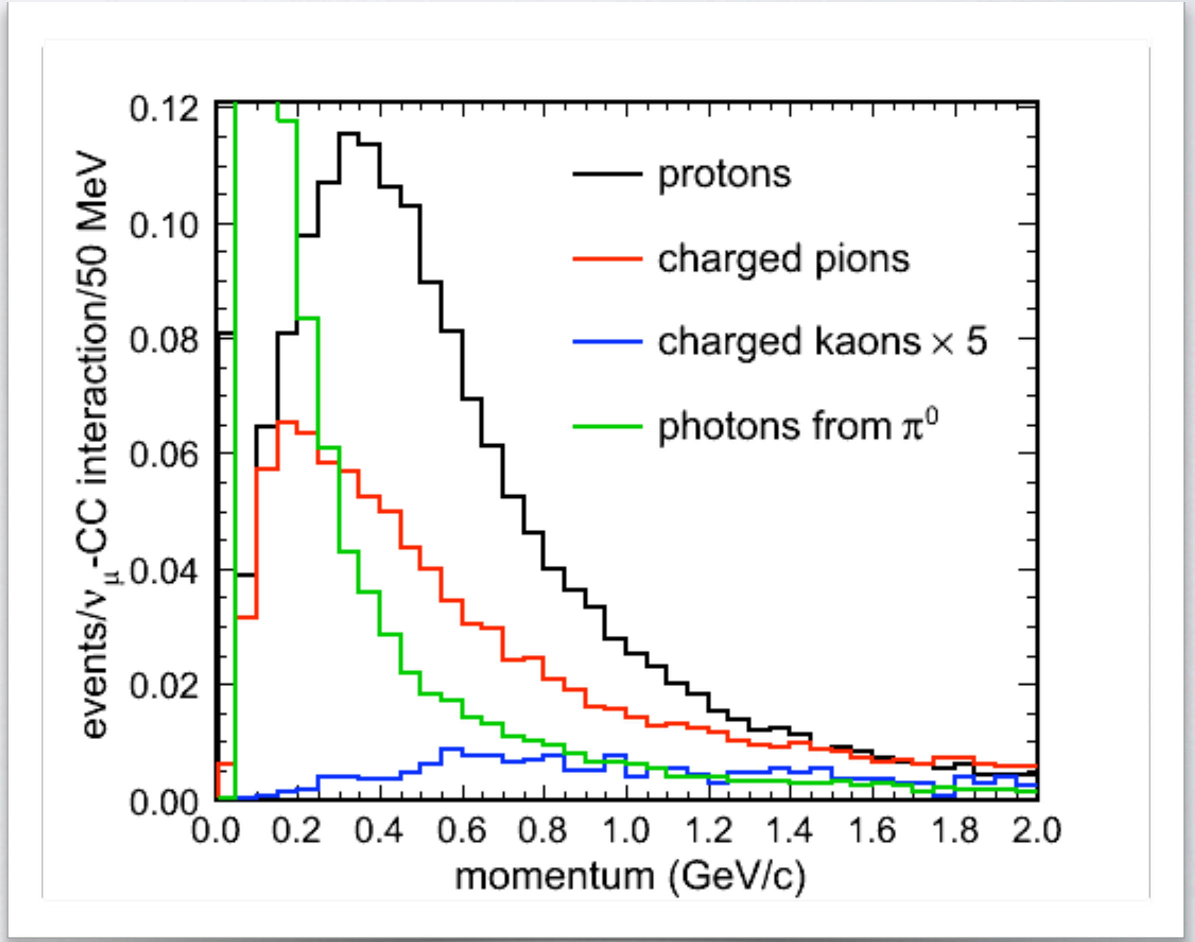
preliminary considerations

Calibration is a critical step to understanding the output response of any detector.

Every new detector (e.g., trackers, calorimeters) is always (or at least, usually) "calibrated" (before physics application).

A comprehensive characterization of LArTPCs performance is now considered of great interest.

It is desirable for the range of energies relevant to the forthcoming short baseline MicroBooNE experiment and to the future Long Baseline LBNE experiments for neutrino physics and for proton decay searches.



NB: The detector to be exposed to test beams must reproduce
as close as possible (though at reduced size)
all technical features of the final detector.

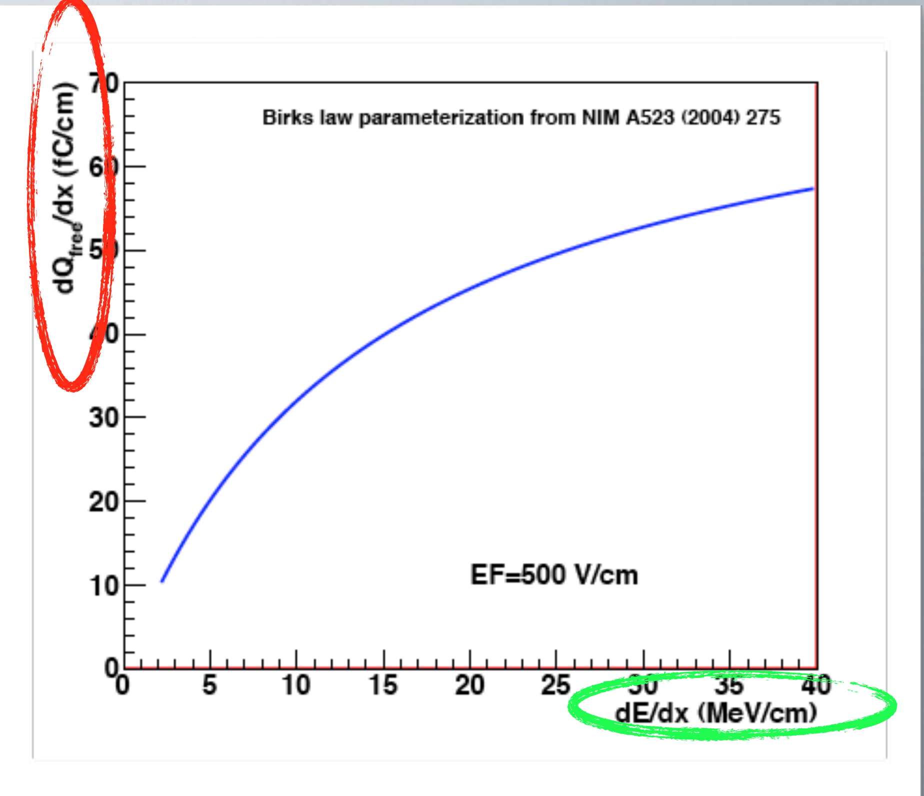
➪ **The "standard" (single-phase) LArTPC scheme, with multiple wire-planes read-out geometry for 3D imaging, fine wire spacing and very low-noise electronics, is the necessary choice for best informing the design and exploitation of all LAr detectors included in the present US neutrino program.**

LArIAT Phase-1 will repurpose the fine grained LArTPC from
ArgoNeuT [JINST 7 P10019 (2012)]
for an extended physics run with low momenta
charged particle beams at FTBF
starting as soon as the beam comes ON again (summer 2013 ?).

Summary of the Science goals for Phase-1 of the LArIAT program ➤➤➤

➤ Single Track calibration

most precisely/accurately establish the relationship between the collected ionization Charge at the TPC wires and the Energy deposited in LAr by incident particles of different types and stopping powers.



(1) over the most possible extended range of energy deposition rates ***(dE/dx)***
(2) for different electric field values (in the typical 0.3-1.0~kV/cm range for LArTPC operation)
(3) at different track-to-electric-field angles

This can be achieved with pure low momentum beams of muons, pions, kaons and protons that penetrate and slow down to stop in the TPC.
Modest volume LArTPC (like the existing ArgoNeuT detector) is sufficient for this task.

Available data above dE/dx~15-20 MeV/cm from the ICARUS measurements with cosmic rays are sparse and statistically limited.

Output: *enhance precision in calorimetric energy reconstruction*

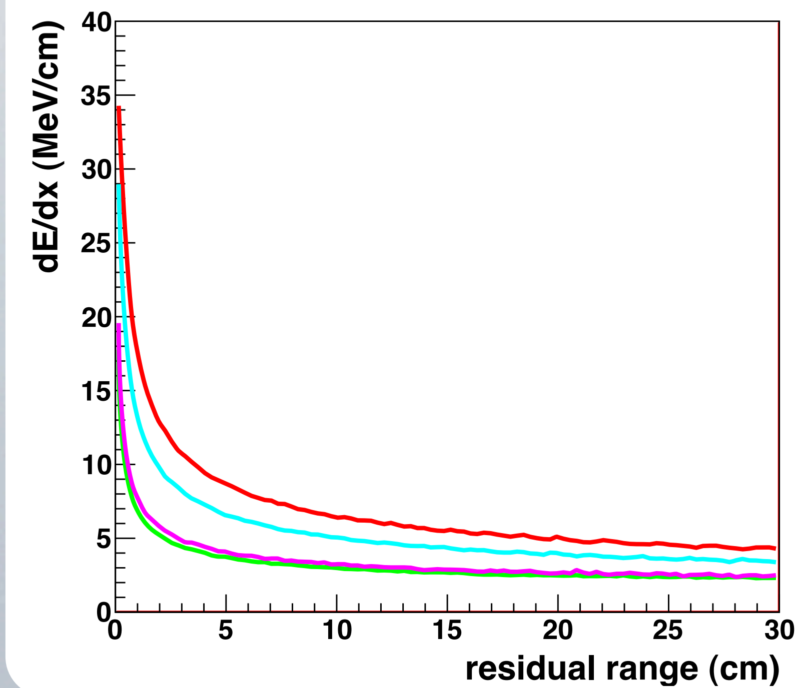
➤ Optimization of Particle Identification methods:

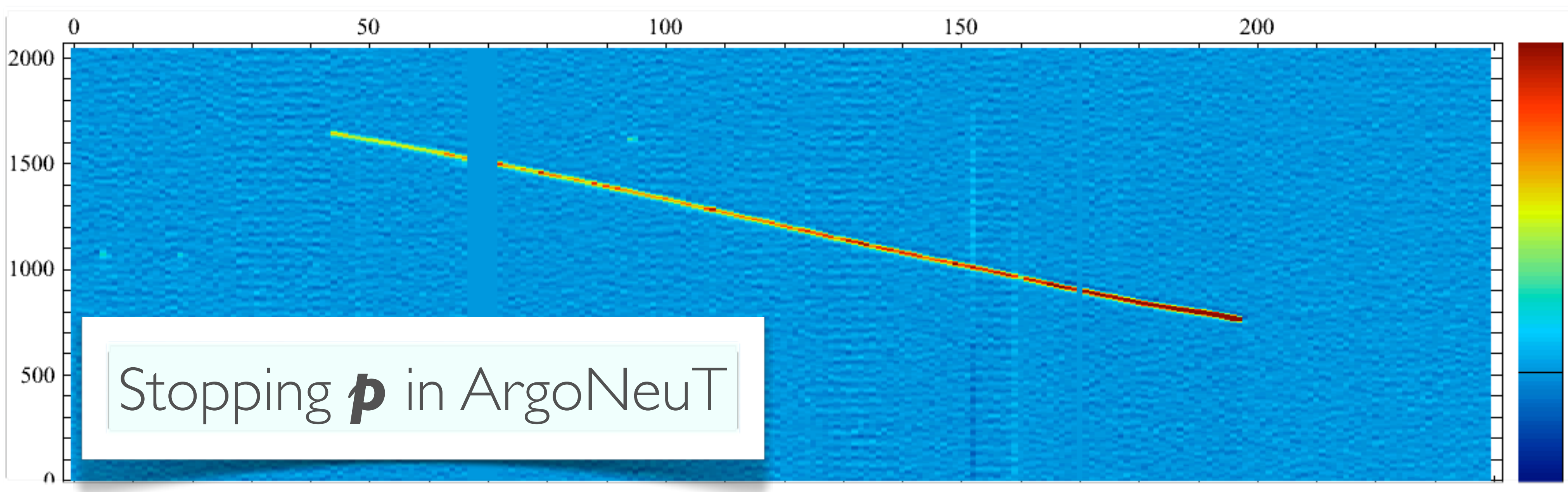
Single Track Calibration ⊕ 3D imaging ⇒ *(dE/dx) vs (residual Range)*

for tracks contained in the LArTPC volume.

⇨

Particle Identification: one of the key features of the LArTPC technology, relevant for neutrino oscillation experiments and proton decay searches.





High statistics test beam data will allow to experimentally determine:

- proton ID, p-to-K separation and purity/rejection factor

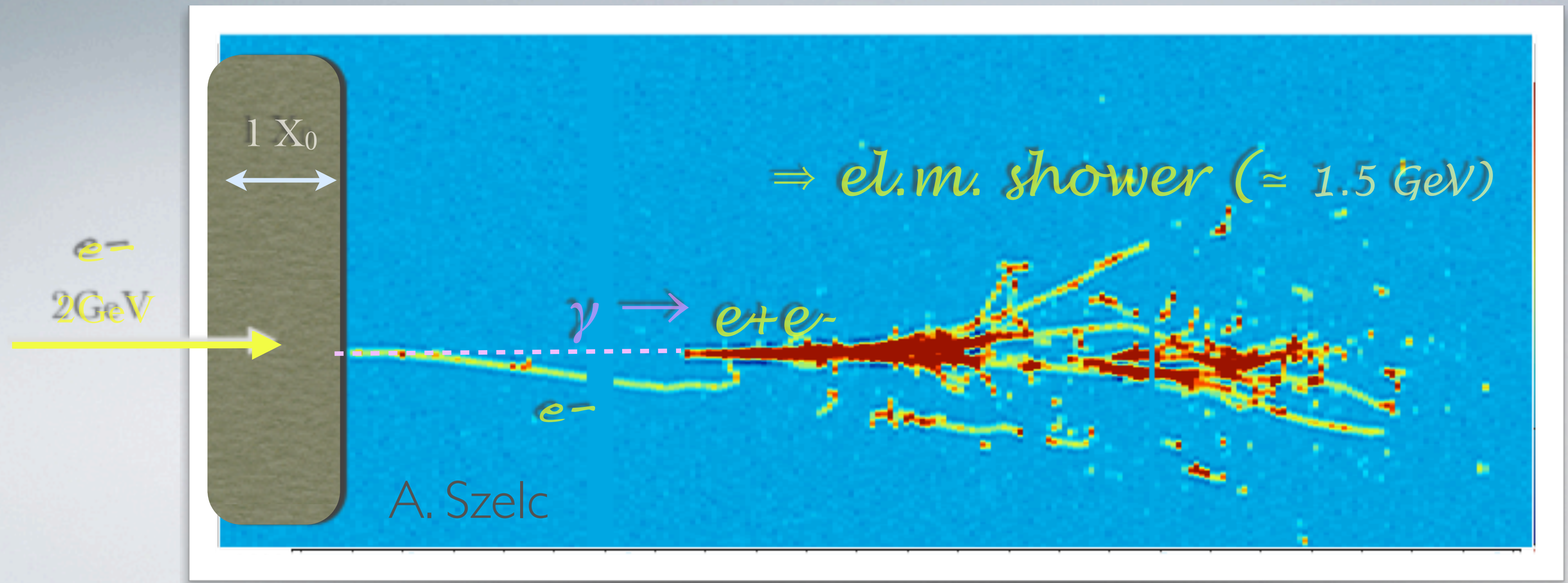
- kaon ID, K-to-π/μ separation and purity/rejection factor

➤ Experimental determination of the *e-to-γ* initiated shower separation

The e-to-γ (signal CC ν_e-to-NC π^o background) separation capability is the LArTPC key feature that led to the technology choice for both the short- and long-baseline neutrino detectors presently under construction or planned in the US.

Separation efficiency and sample purity for electron-induced vs. photon-induced showers have never been experimentally measured, and current indications rely on MC simulations.

Only the initial part of the shower is relevant for **e-to-γ** separation (because the **γ** converts to an e+,e- pair producing double ionization in the first portion of the track at the shower start) and <u>an experimental test can be performed using a small volume LArTPC</u> (as the ArgoNeuT TPC).



MC evt in LArIAT

➤ Development of criteria for charge sign determination:

Sign (without magnetic field) can be obtained for stopping particles in LArTPC by statistical analysis based on topological criteria.

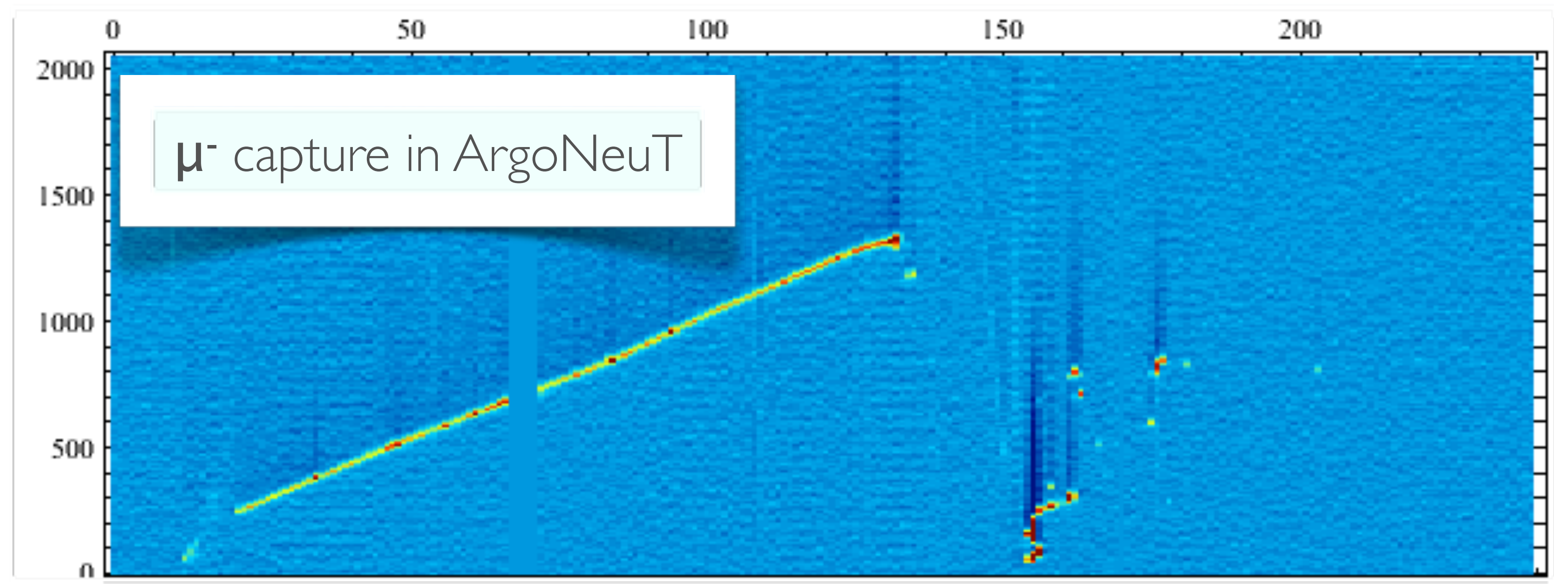
e.g. **μ+** undergo ***decay*** only, with **e+** emission of known energy spectrum.

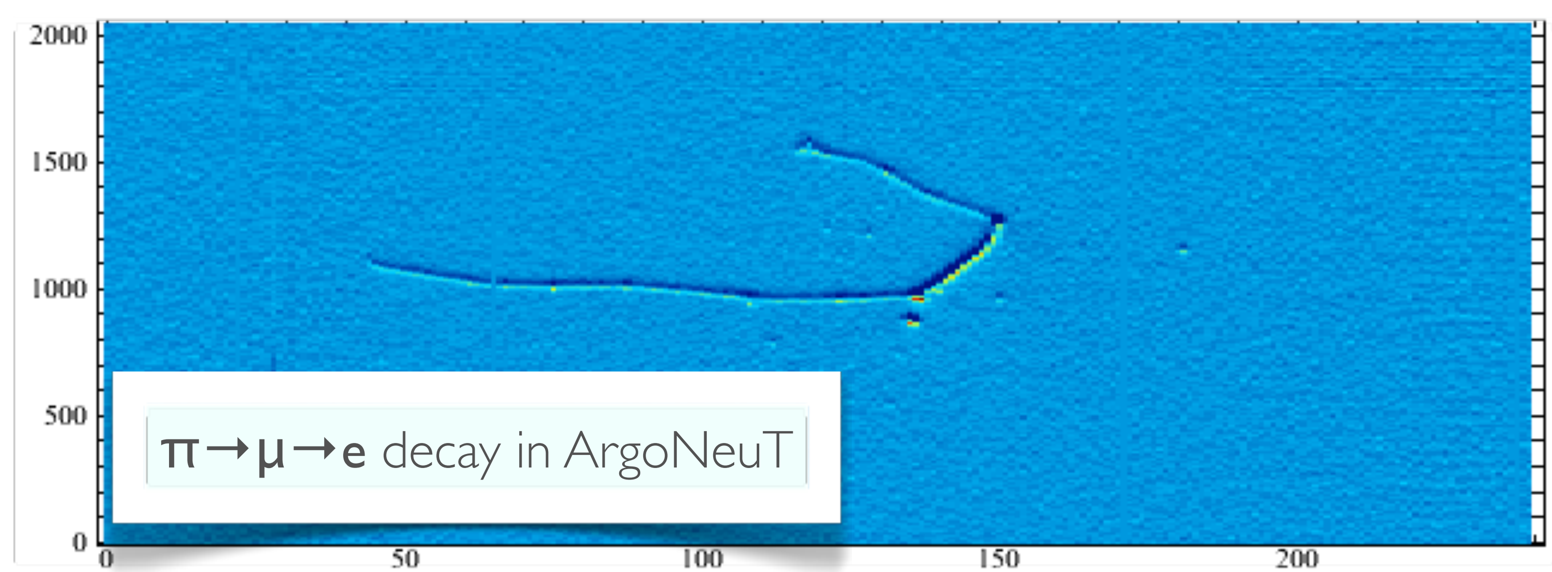
μ^- undergo ***capture*** by nuclei (75%, followed by γ or n emission) or ***decay*** (25%).

μ^- capture can thus be topologically separated against μ+ decay

Systematic study of μ-capture in Ar never performed and LArTPC sign determination capability never explored.

Beams with selectable polarity will provide data for direct measurement of the sign separation efficiency (and purity) for muons as well as for pions (and potentially also for kaons).



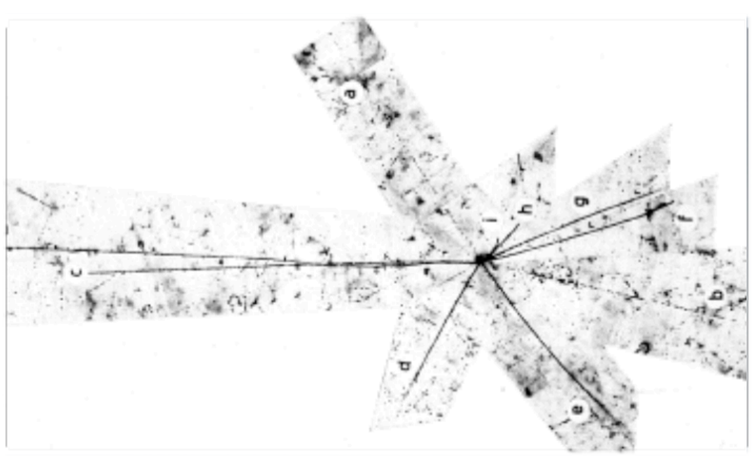


... if available in the test beams... even at very low rate....

low momentum anti_p may allow the first study of hadron star topology from anti_p-p annihilation at rest in Argon (anti-p-Ar reaction).

➤ Characterization of Antiproton Stars in Ar

$\pi^{\pm}$, π^{0}, $K^{\pm}$,... multiplicity in hadron stars can be accurately determined with LAr imaging detector. This information is considered very relevant for ***nnbar-oscillation search*** with future large LArTPC detectors.



Antiproton Star Observed in Emulsion*

O. Chamberlain, W. W. Chupp, G. Goldhaber, E. Segrè, and C. Wiegand, *Radiation Laboratory, Department of Physics, University of California, Berkeley, California*

and

E. Amaldi, G. Baroni, C. Castagnoli, C. Franzinetti, and A. Manfredini, *Istituto di Fisica della Università, Roma Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Italy*

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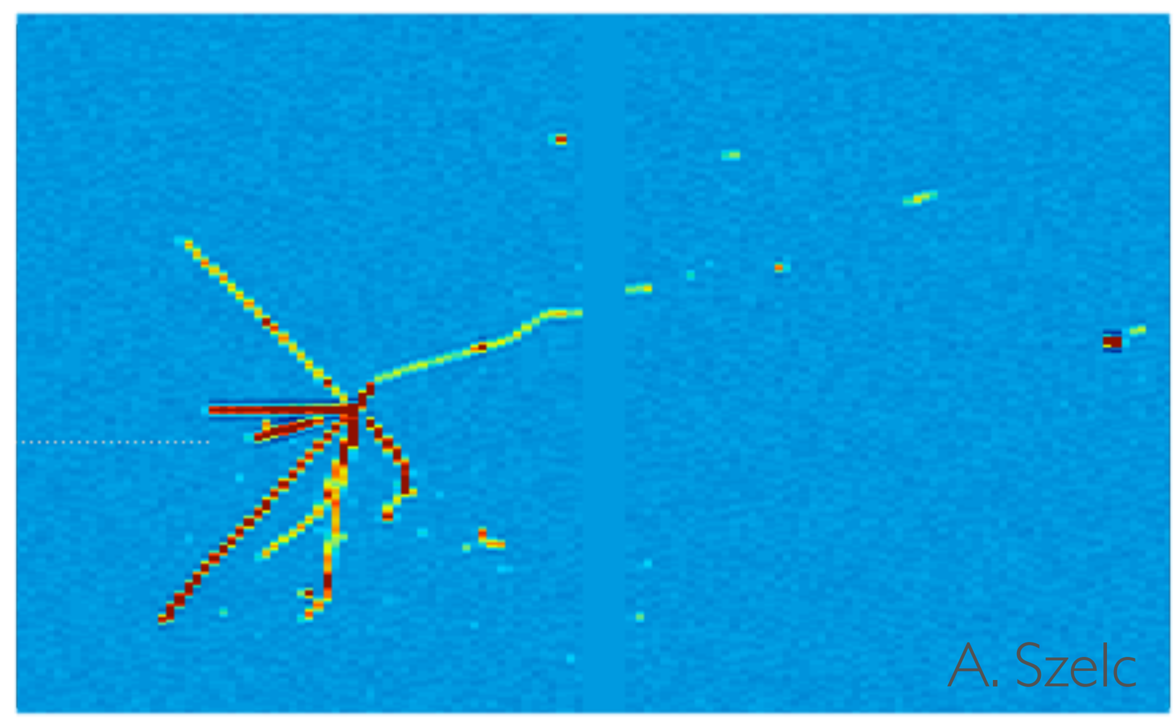


Simulation of Antiproton Star in LAr

Goals for the First Physics Run with LArIAT @ FTBF (tertiary beam)

PARTICLE TYPES	MOMENTUM RANGE (FOR PARTICLES STOPPING INSIDE TPC VOLUME)	ELECTRIC FIELD SETTINGS	NUM TRIGGERS (PER SETTING)	PHYSICS STUDIES
μ+, π+, K+, p	~300-900 MeV/c	0.3, 0.5, 0.8 kV	μ: 5k π: 10k K: 2k p: 20k	All particles: dE/dx [recombination, PID] μ: decay at rest [sign ID] π: decay at rest [sign ID] K: decay topology reconstruction p: hadron interaction topology
μ-, π-, K-, pbar	~300-900 MeV/c	0.3, 0.5, 0.8 kV	μ: 5k π: 10k K: 2k pbar: 0.5k (or as many as possible)	All particles: dE/dx [recombination, PID] μ: capture at rest [sign ID] π: capture at rest [sign ID] pbar: annihilation at rest
e+ (e-)	TBD MeV/c	0.5 kV	10 k	dE/dx [e-to-γ shower separation]
γ	from e-brems	0.5 kV	5 k	dE/dx [e-to-γ shower separation]

* Absorbers may need to be added to degrade beam for lower momentum studies

Cost permitting, we would also like to have the capability of studying particles at various incident angles (by use of a "glacier pad" or similar to allow detector & system to be easily moved/rotated).

This will provide crucial data for the study of reconstruction capabilities in LAr detectors; angular dependence of reconstruction has never before been studied in LArTPCs.

are the goals WELL DEFINED?

➤➤ Variety of precision studies on ***fundamental mechanisms of energy release in a LAr target***, immediately translating into ***calorimetric energy resolution improvement*** and ***enhancement of particle identification*** capability of LArTPC's.

are these ATTAINABLE ?

➤➤ a small LArTPC volume is sufficient. A detector of this type exists (ArgoNeut) and is available for use in a test beam with a limited effort.

is this effort WORTHWHILE ?

➤➤ LArSoft: code upgraded through optimization and development of ***now data-based*** algorithms and methods for both off-line analysis and detector response simulation, providing a truly ***state-of-the-art software package for all LArTPC's in US.***

➤➤ MicroBooNE: for exclusive channel cross-section measurements based on reliable PID, for sterile ν searches with best signal CC ν_e-to-NC π^0 background separation capability,

➤➤ LBNE: gain confidence in the estimate of signal to background separation from MC simulations, and later on from data analysis.

➤➤ Training of (young) physicists during extended beam operation and real data analysis is also an invaluable add-on in view of future Short & Long Baseline and Underground LArTPC experiments.

(2) Is the technical approach for ***beam*** *and experiment sound?*

Technical Approach: Beam

Tertiary Beam Design and Possible Upgrades

- **Starting option**: exact tertiary beam used successfully by MINERvA in MTest
  - simply move components from MTest to MCenter
  - MINERvA data and simulations provide useful input here (R. Gran, M. Kordosky)

- **Possible upgrades**: Additional simulations with G4Beamline underway since July 2012 (D. Jensen, J. Huang, J. St. John, A. Marchionni)
  - Add shielding to reduce punch-through

    Existing collimator too short to contain shower from beam dumping
  - Add collimator upstream of detector
  - Change tertiary beam bend angle from 16 to 8 degrees
  - Add pair of quadrupole magnets for focusing

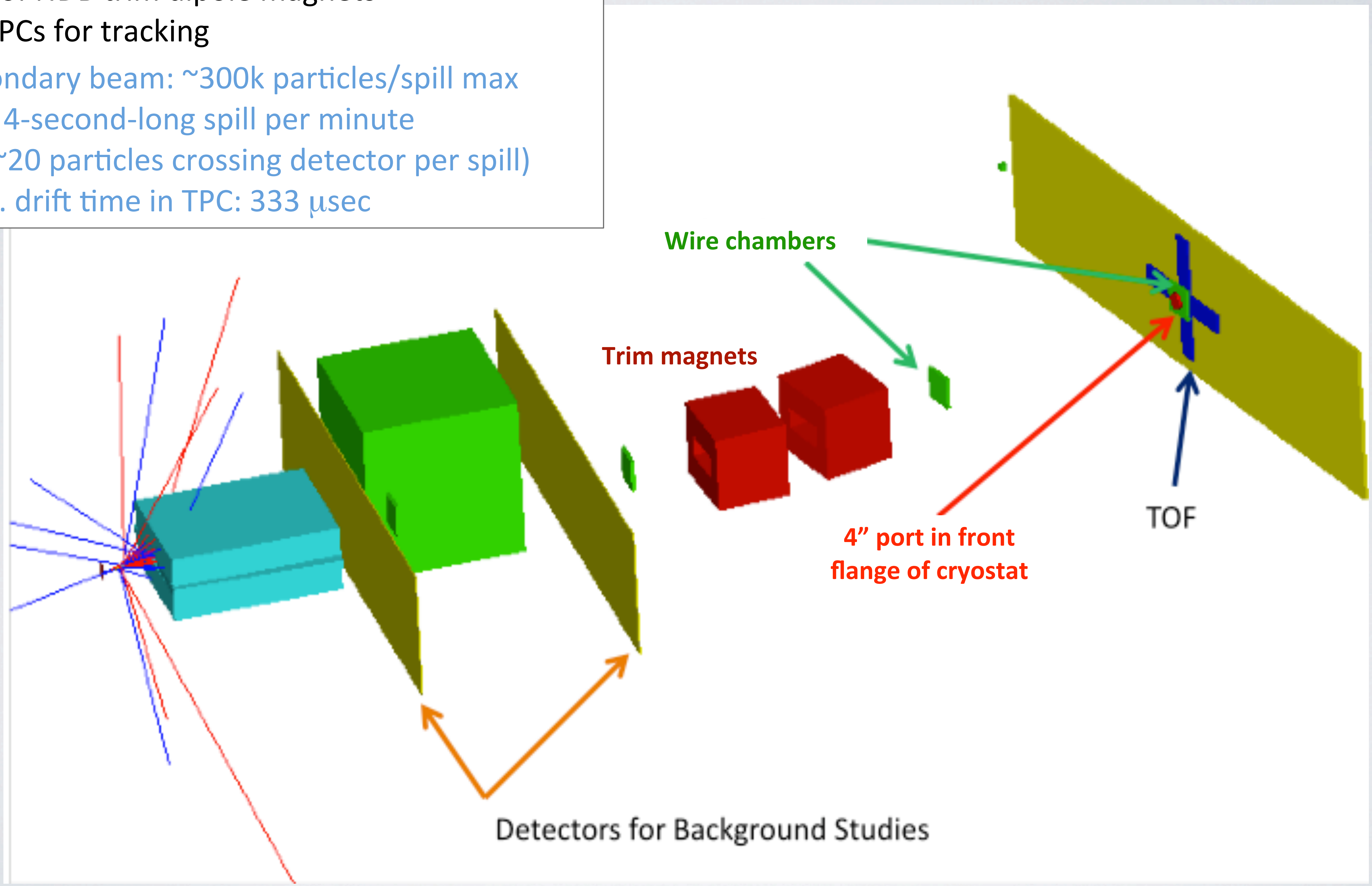
    Improve beam placement in target volume, improve momentum bite

Nominal Tertiary Beam (Starting Option)

Cu target in secondary beam (8 GeV/c or higher)
Collimator at 16 degrees
Pair of NDB trim dipole magnets
MWPCs for tracking

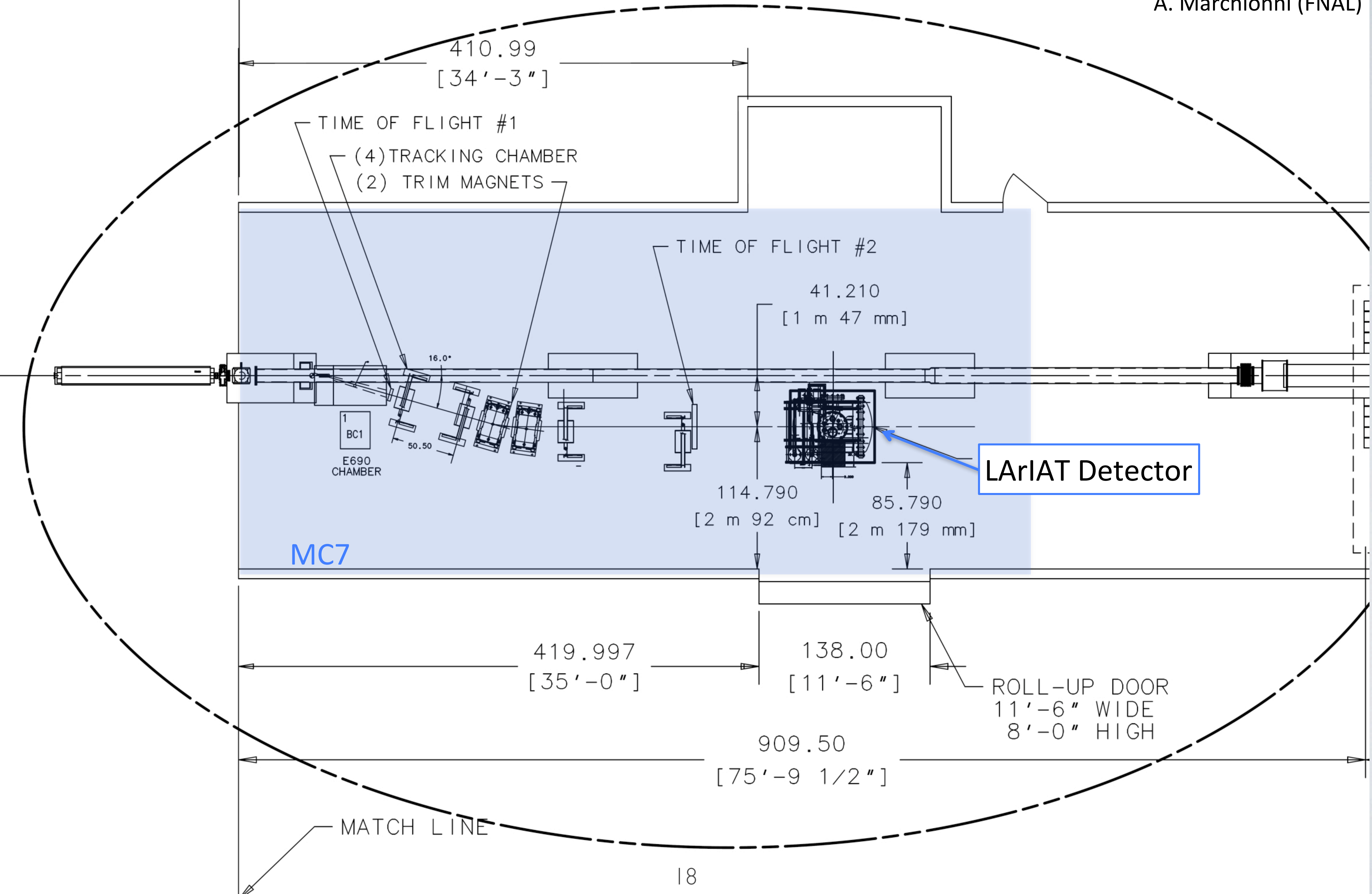
Secondary beam: ~300k particles/spill max
One 4-second-long spill per minute
(~20 particles crossing detector per spill)
Max. drift time in TPC: 333 μsec

D. Jensen (FNAL)



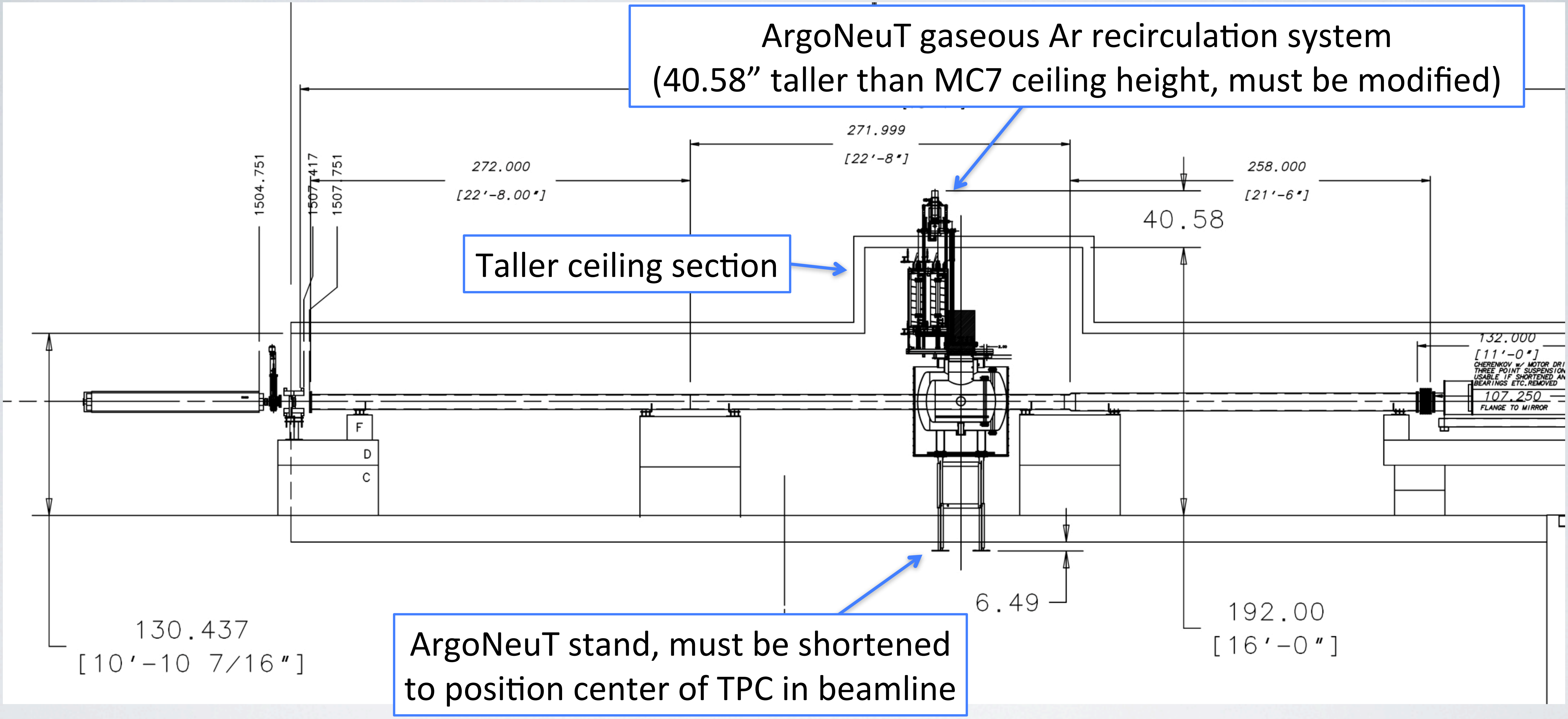
Nominal Tertiary Beam (Top View, at MC7)

A. Marchionni (FNAL)



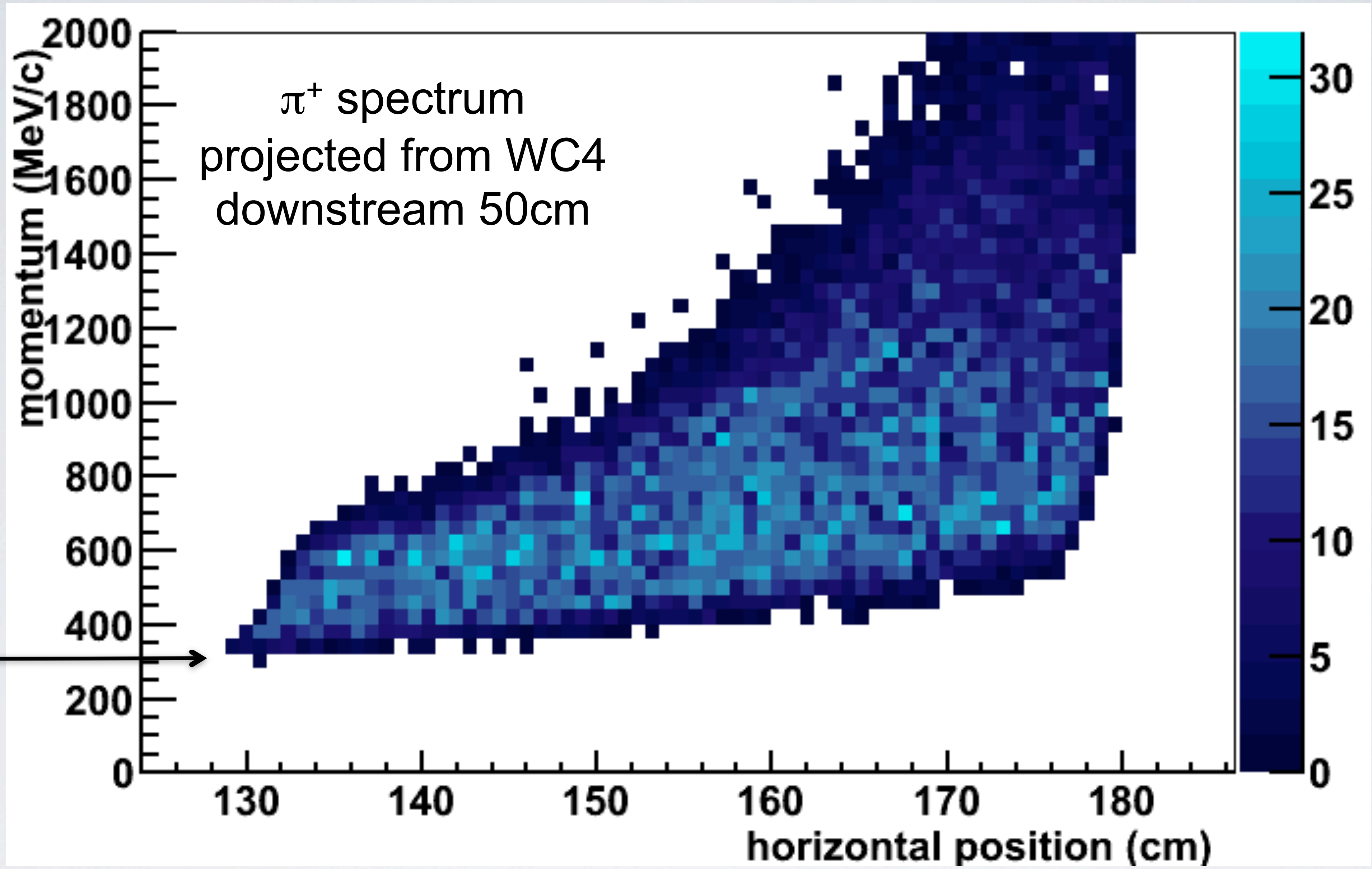
LArIAT in MCenter (Side View)

A. Marchionni (FNAL)



Horizontal Beam Profile (50 cm downstream of WC4) as measured by MINERvA Test Beam Detector

R. Gran (U. Minn Duluth)



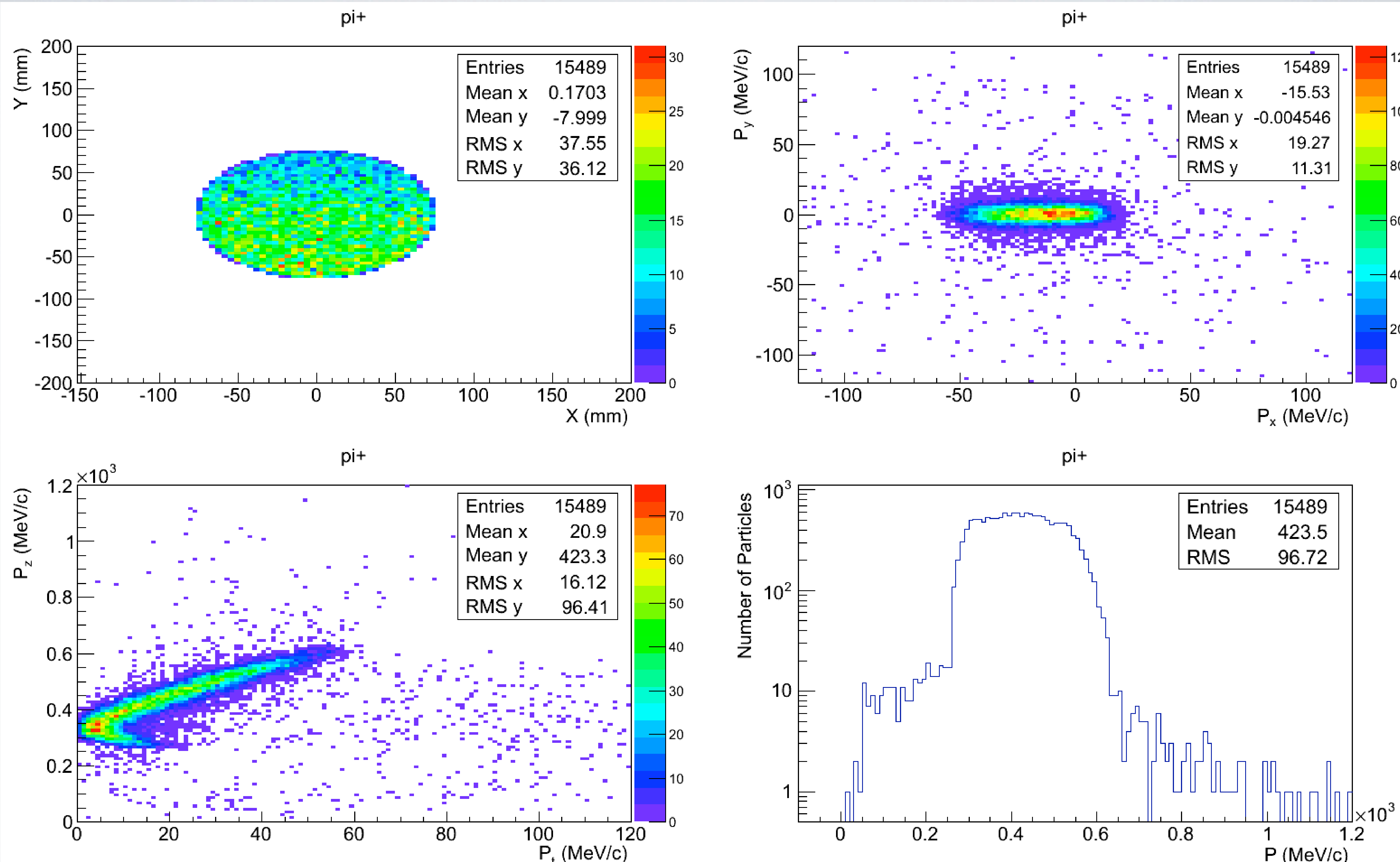
Artificial momentum threshold (likely due to geom constraints of magnet & wire chambers)

6” (15 cm) diam beam window in LArIAT front flange

Change observed momentum spectrum by moving detector (or by adjusting magnet field). Optimize experimental layout.

Nominal Tertiary Beam (G4Beamline Simulation in MCenter)

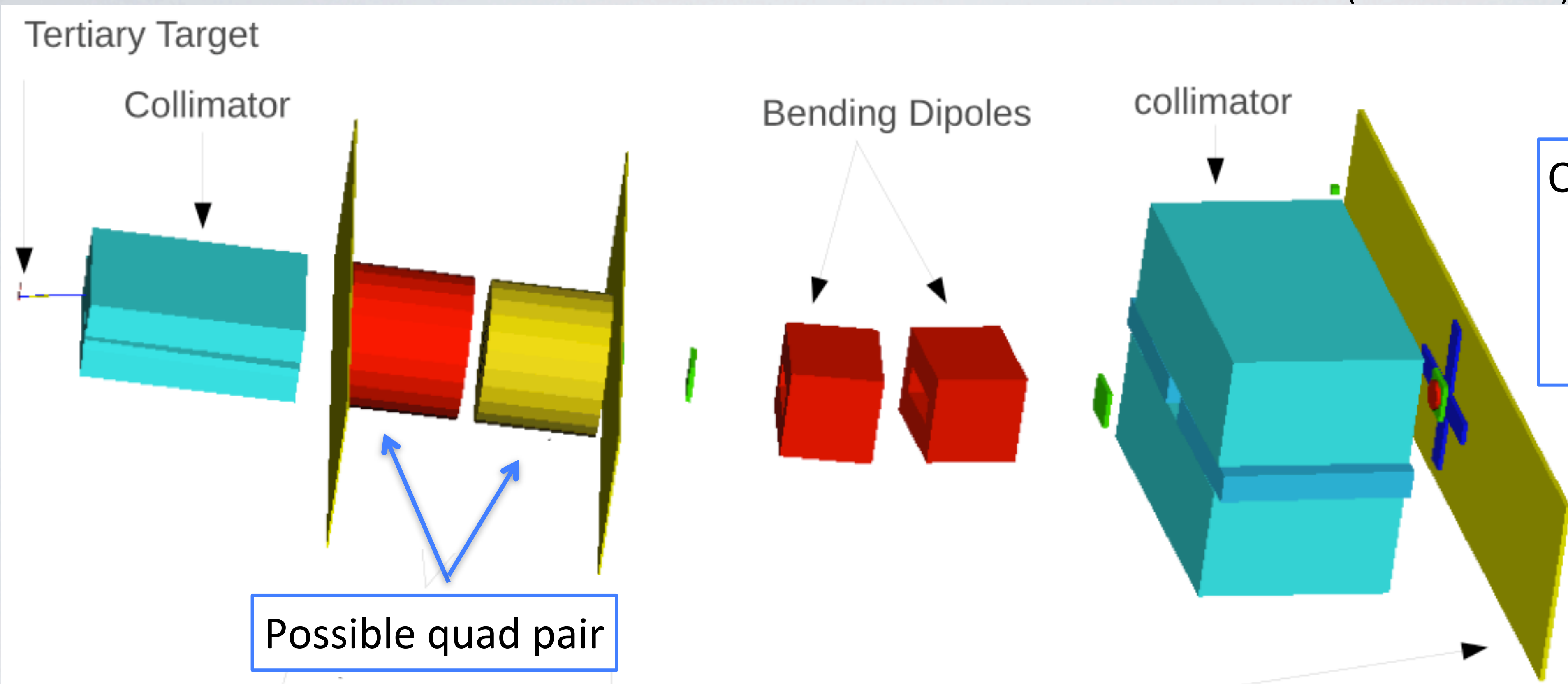
J. Huang (UT Austin)



High statistics tertiary beam spill simulations on FermiGrid used to estimate rates for different particle species.

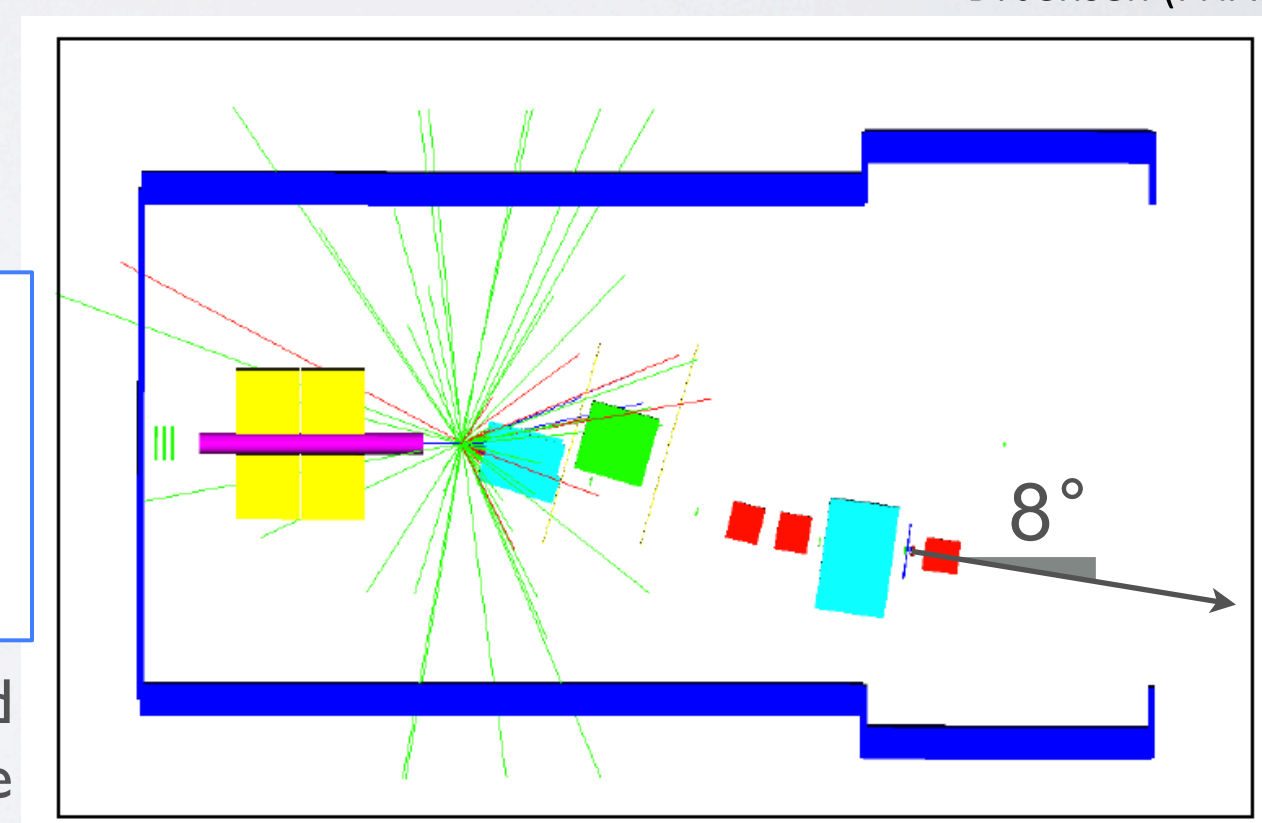
Tertiary Beam (Other Options, Ongoing Studies)

J. St. John (U. Cincinnati)



Optional quads:
- Improve beam placement
- Improve momentum bite
- No results from study yet

D. Jensen (FNAL)

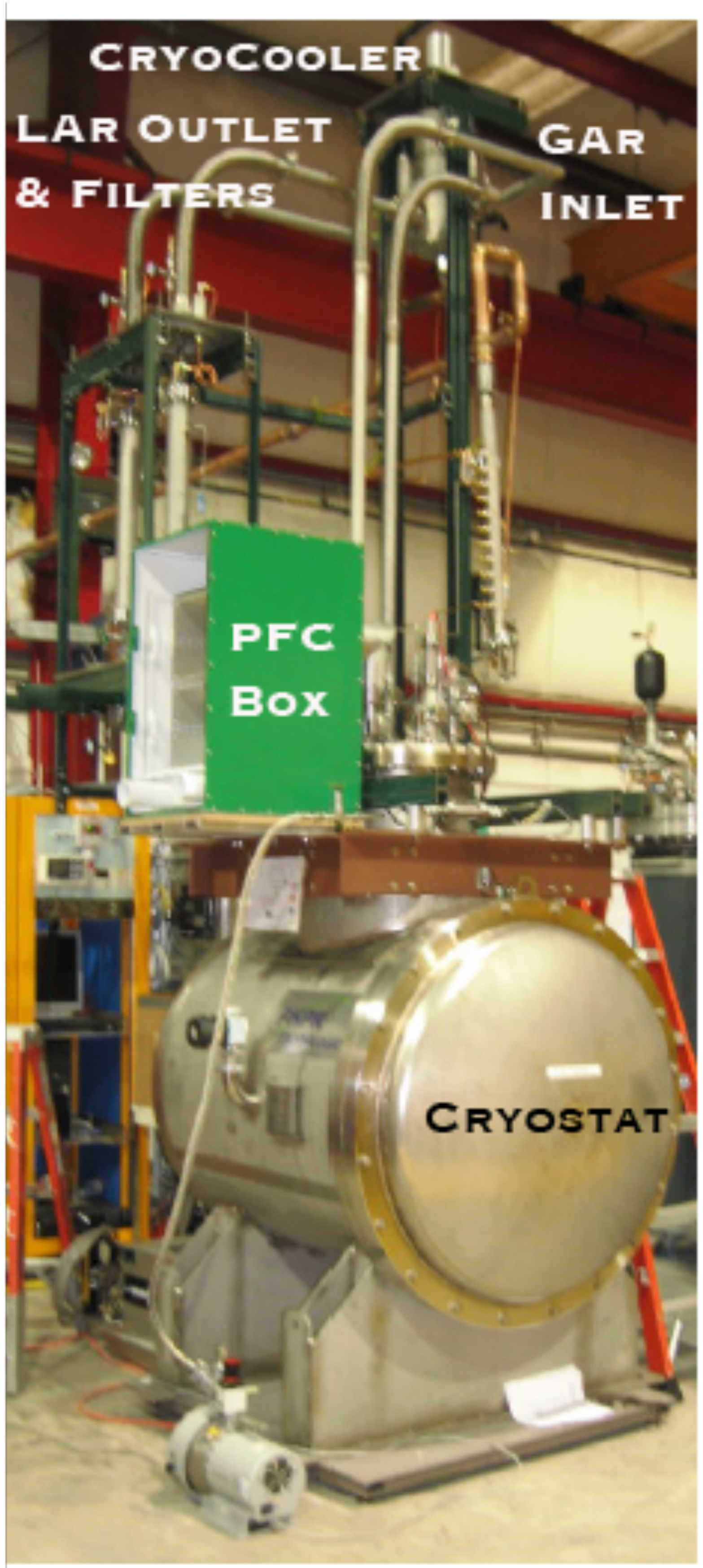


Optional 8 degree bend with 16 GeV/c incident secondary pion beam momentum:
- Higher rates
- More kaons
- Higher mean momentum

NB: LAr detector & cryogenics system would need to be configured to rotate and translate

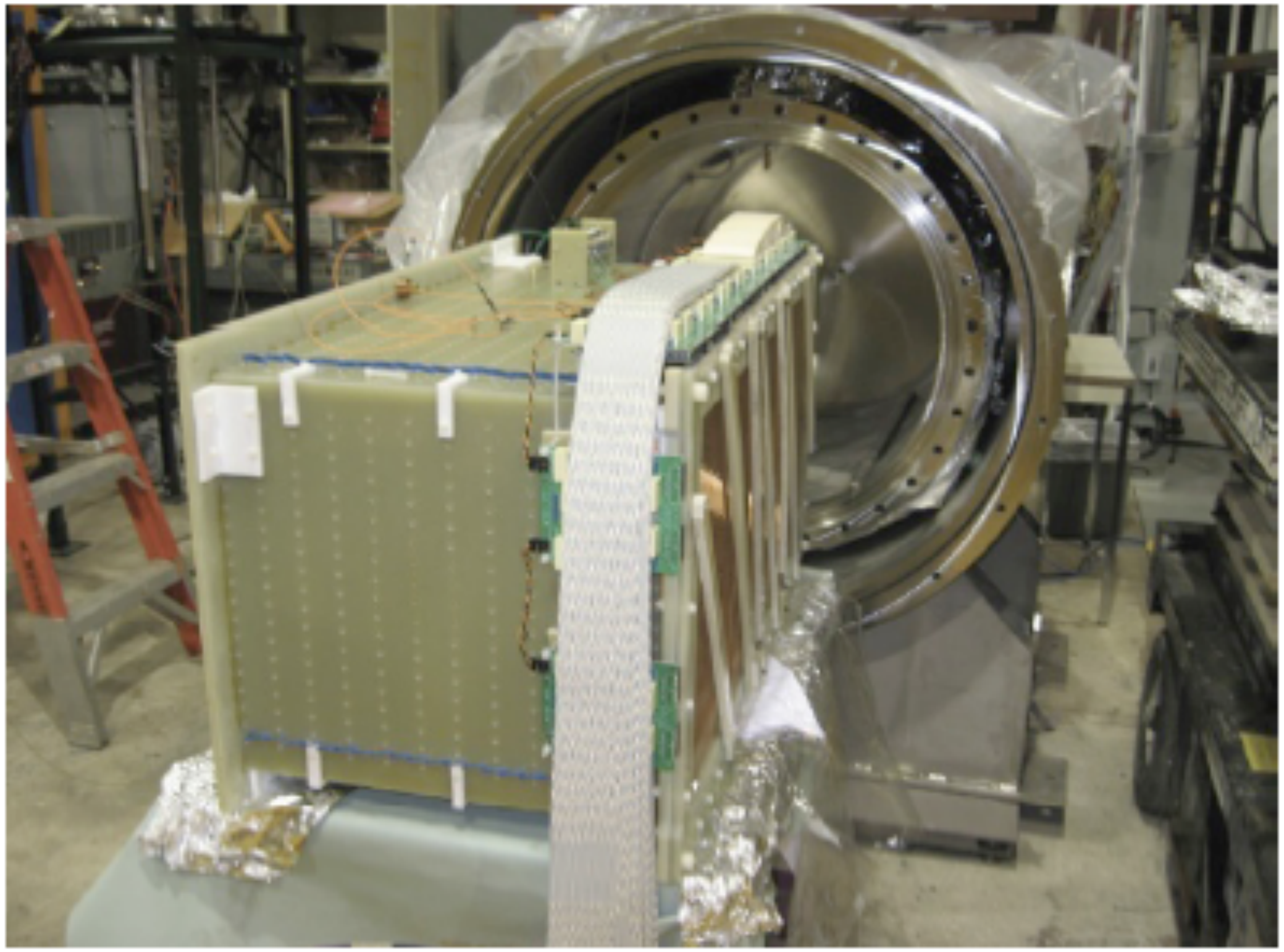
(2) Is the technical approach for beam and ***experiment*** *sound?*

Experimental Setup



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

P.O. for necessary cryostat modifications to make vessel suitable for a charged particle beam has been submitted to original vendor (PHPK Technologies, Inc.) through Yale/DOE funding.



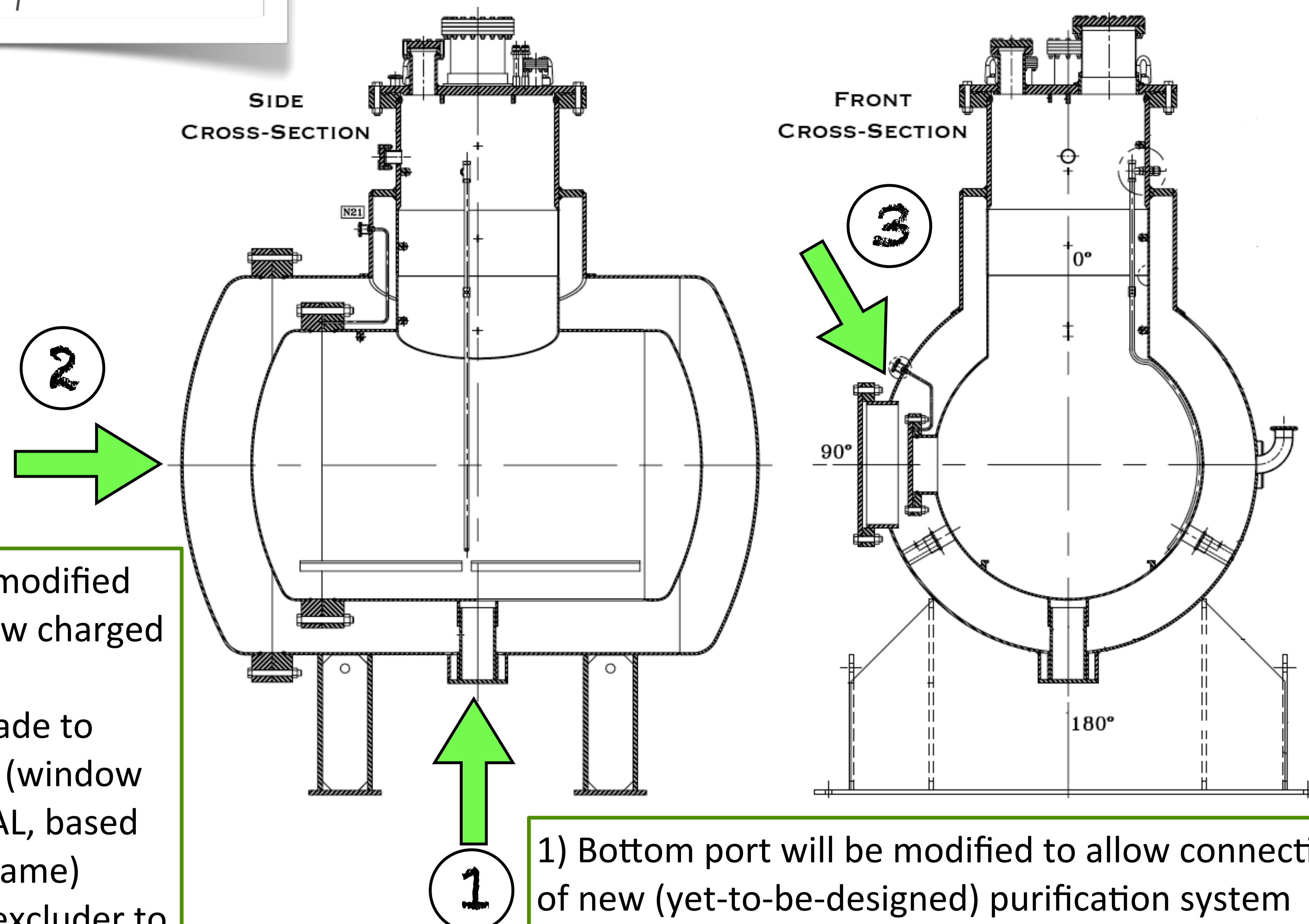
The experimental layout for LARIAT PHASE-1 requires a number of hardware upgrades to the existing ArgoNeuT layout, including the realization of some new components and the modification of some existing components.

Modification of existing components		***New components***
CRYOSTAT	**TPC DETECTOR**	(A) Scintillation light detection and read-out system
① Bottom Side - connection to Cooling/Purification System	④ Wire frame sustaining supports	(B) Beam trigger system
② Front Side - ``Beam Window"	⑤ DAQ Readout	(C) Argon cooling and purification system
③ Lateral Side - housing and connection to scintillation light readout system		(D) Cold Electronics

Modification of Existing Components: Cryostat

DOE + Yale funding covers cryostat modifications

3) Side port will be modified to accept scintillation light readout system



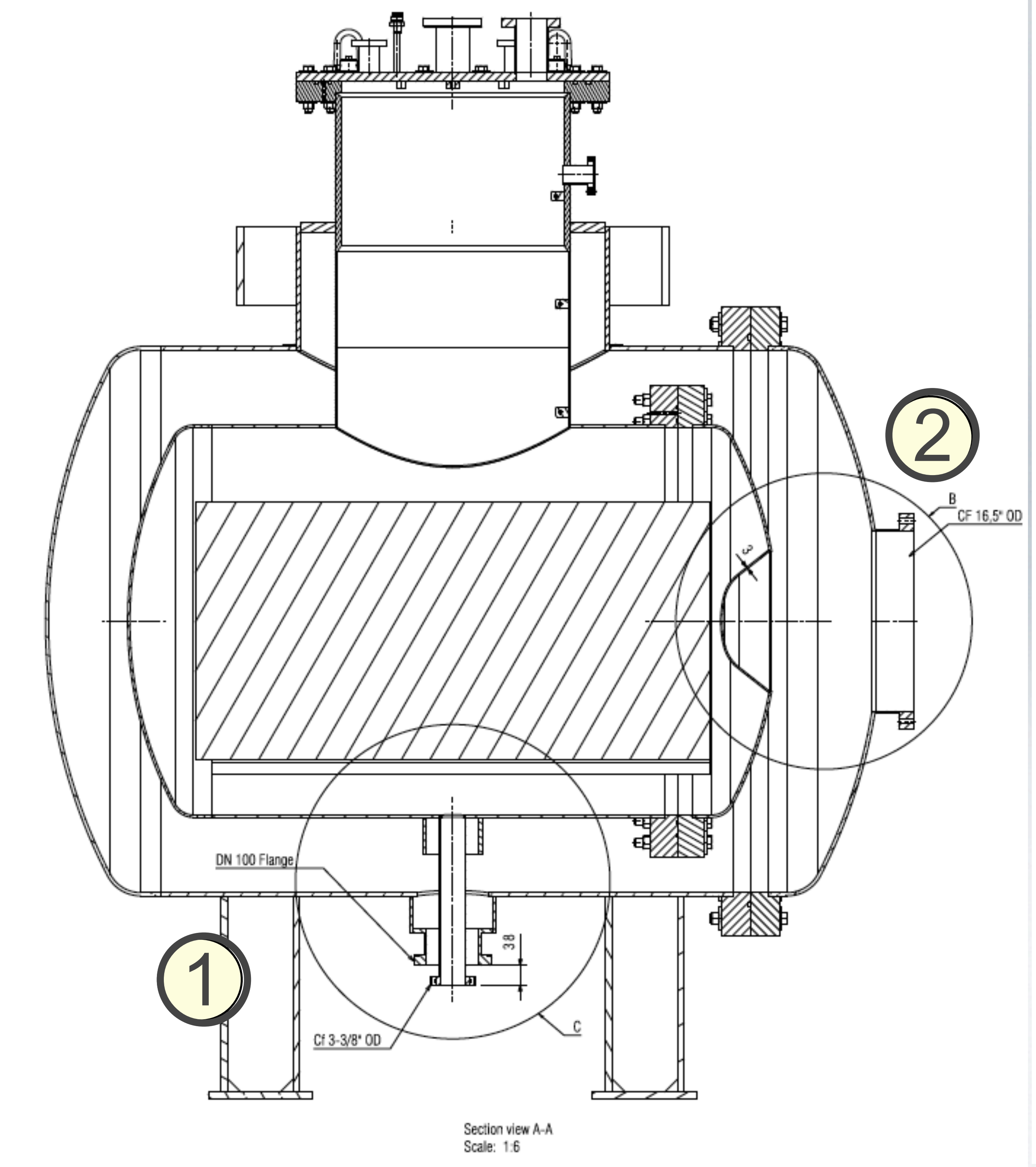
2) Front flanges will be modified (inner and outer) to allow charged particle beam:
- Outer flange will be made to accept Ti beam window (window itself to be made by FNAL, based on previous designs of same)
- Inner flange will have excluder to decrease amount of “dead” LAr beam travels through before reaching TPC

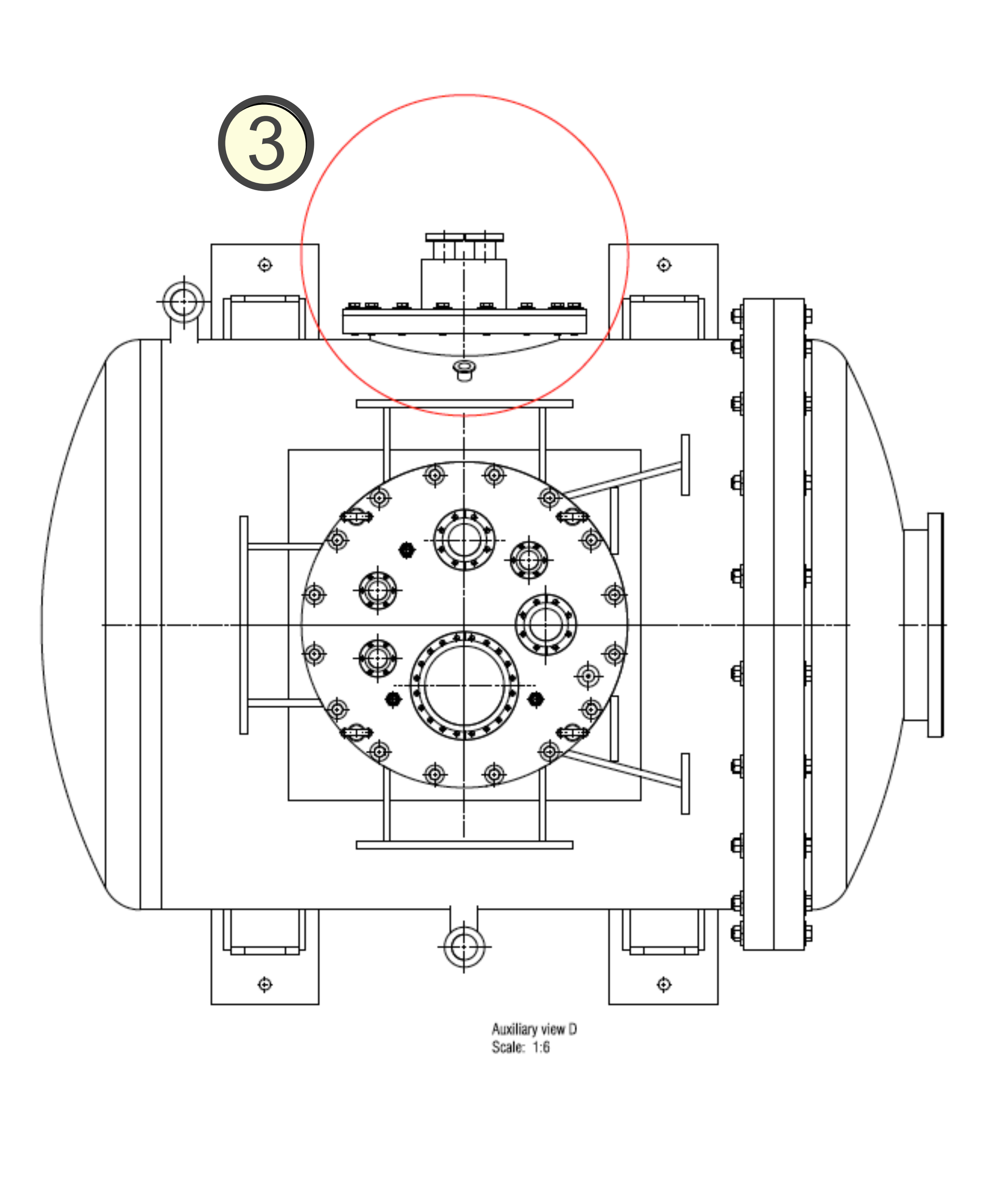
1) Bottom port will be modified to allow connection of new (yet-to-be-designed) purification system

Modification details in backup slides

Modification of Existing Components: Cryostat

Drawings made at Gran Sasso - E.Tatananni - Head of Mech WS





Modification of Existing Components: TPC & DAQ

④ Simple change: Existing TPC wire frame supports currently block viewing region for new PMT scintillation light system that will be housed in cryostat lateral port. (Syracuse)

⑤ Non-trivial change: Improve DAQ rate by factor of >5

- Existing ArgoNeuT readout system DAQ rate: ~1 Hz
- **Expected good trigger rate at FTBF: ~ 5Hz**
  (~20 particles/spill in 4 second spill once per minute)

M. Stancari (FNAL) & C. Bromberg (MSU)

- Bottlenecks of existing system are the ADF-2 card VME readout speed and "bit-3" VME-PC interface
- Two proposed improvements
  - Firmware upgrade of ADF-2 digitizer (block transfers, improved timing) - cost of MSU engineer, 3 months
  - Replace "bit-3" PC-VME interface with Motorola 5500 CPUs from CDF or D0. Readout 15 ADF-2 cards in parallel with one CPU each – cost of PPD DAQ support or university programmer, 2-3 months

Modification of Existing Components: DAQ

Simplified version; more details in backup M. Stancari (FNAL)

	Speed factor gained over existing ArgoNeuT rate (1 Hz readout)	*MSU engineer time? (required external funds)*	*Need programmer for DAQ software?*	*New hardware*	*Total Cost*
ADF-2 FIRMWARE UPGRADE	~4x	2-3 months (~$45k)	No (minor changes)	None	~$45k
New VME-PC INTERFACE (Motorola PROCESSORS)	~8x	none	2-3 months ($50k) NB: Could be done by university group for $0	15 VME 2-slot backplanes (~$500/ea); Crate processors from PREP	~$10-60k

* *Rate upgrade paths are independent (multiply rate increase if both upgrades are done).*

- *Can reach adequate readout speed with existing electronics; very little risk, but some cost.*
- *Option to decrease sampling frequency with either/both of these options gives additional factor of 2 increase in DAQ rate (but lower data quality, therefore less desirable).*
- *More modern DAQ solutions (i.e., not merely applying bandaid to current system) have also been costed at ~$100-150k. Risker option, and slightly more expensive, but higher throughput.*
- *Fallback option: Do nothing. Readout rate remains low... must collect data for longer period.*

New Components: Scintillation Light System

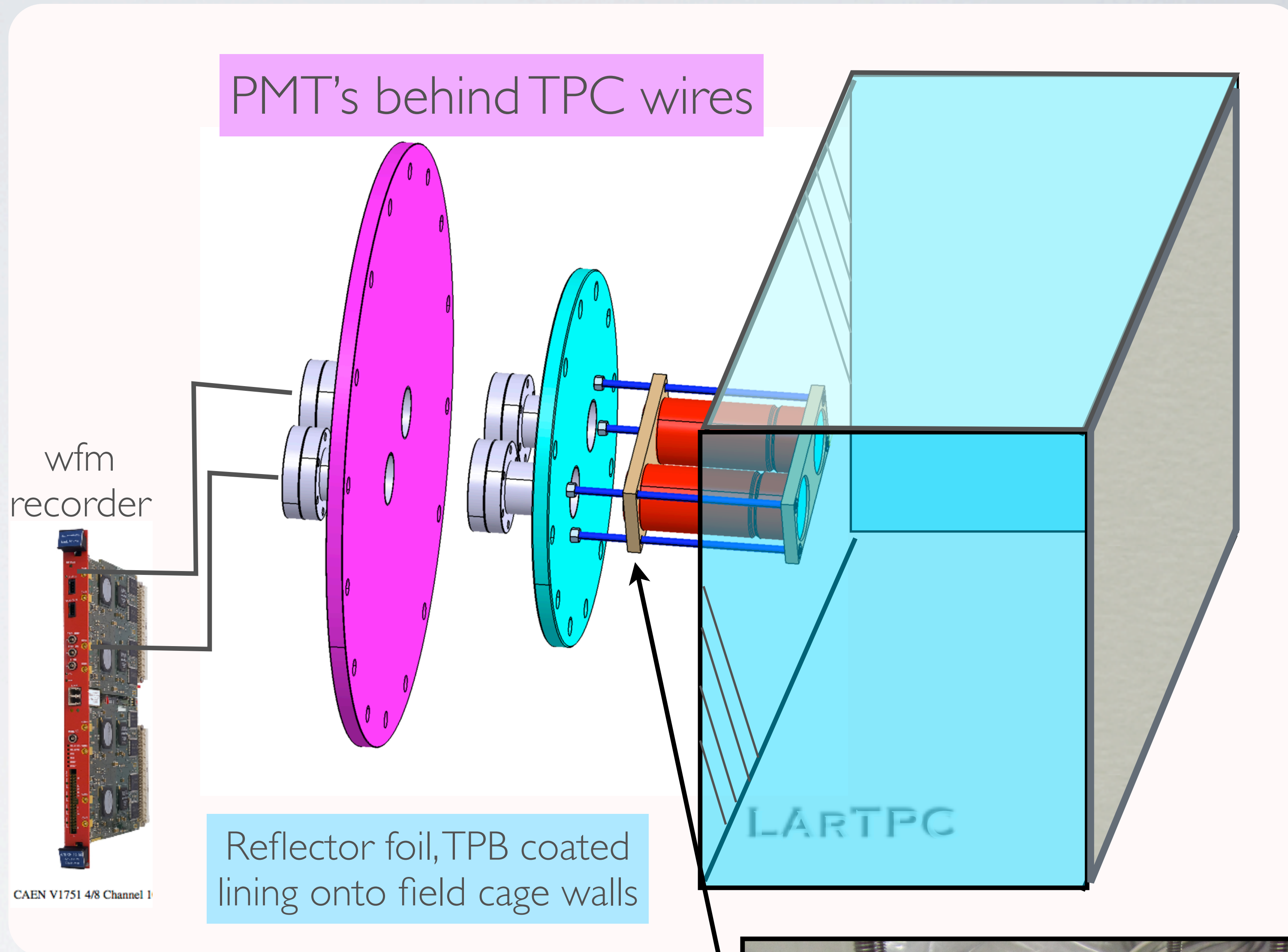
F. Cavanna (L'Aquila/Yale) & A. Szelc (Yale)

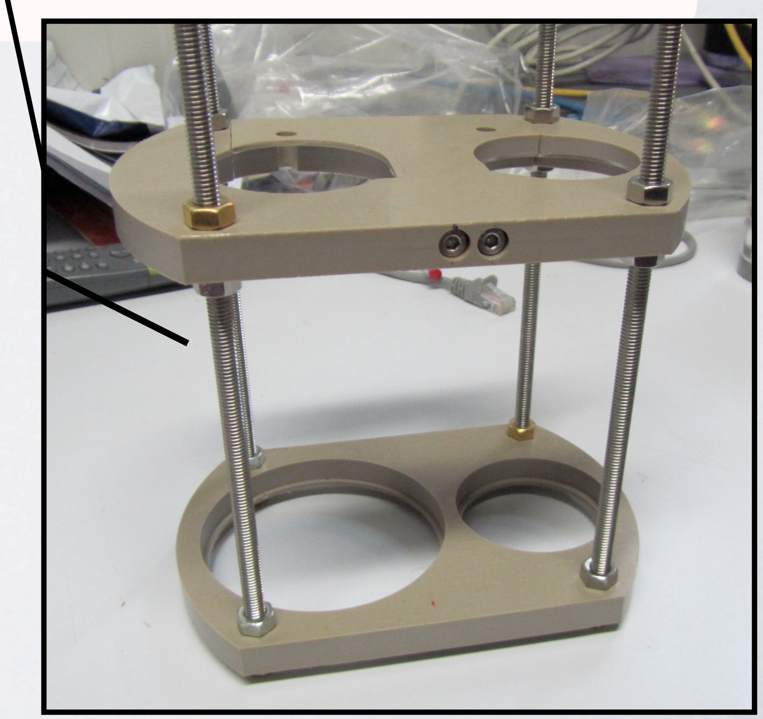
Contribution from
U. of L'Aquila
(Shipped to FNAL this week)

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

+ WLS reflector foil lining TPC

CAEN digitizer readout





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

New Components: Beam Trigger System

To be fully developed/built by College of William & Mary

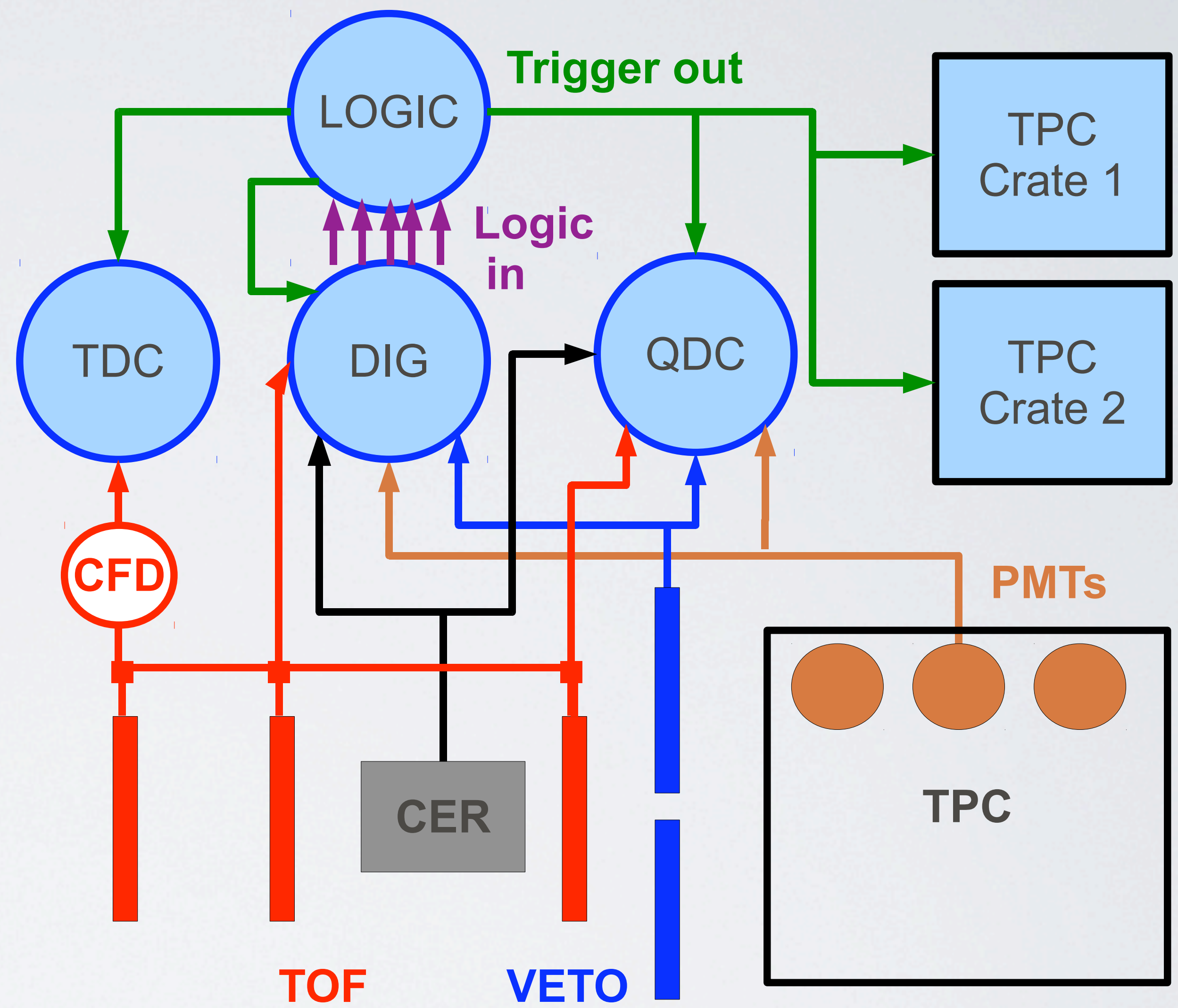
as contractor in Yale/DOE funding

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

Use this feature to collect good beam events & reject events with pileup

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



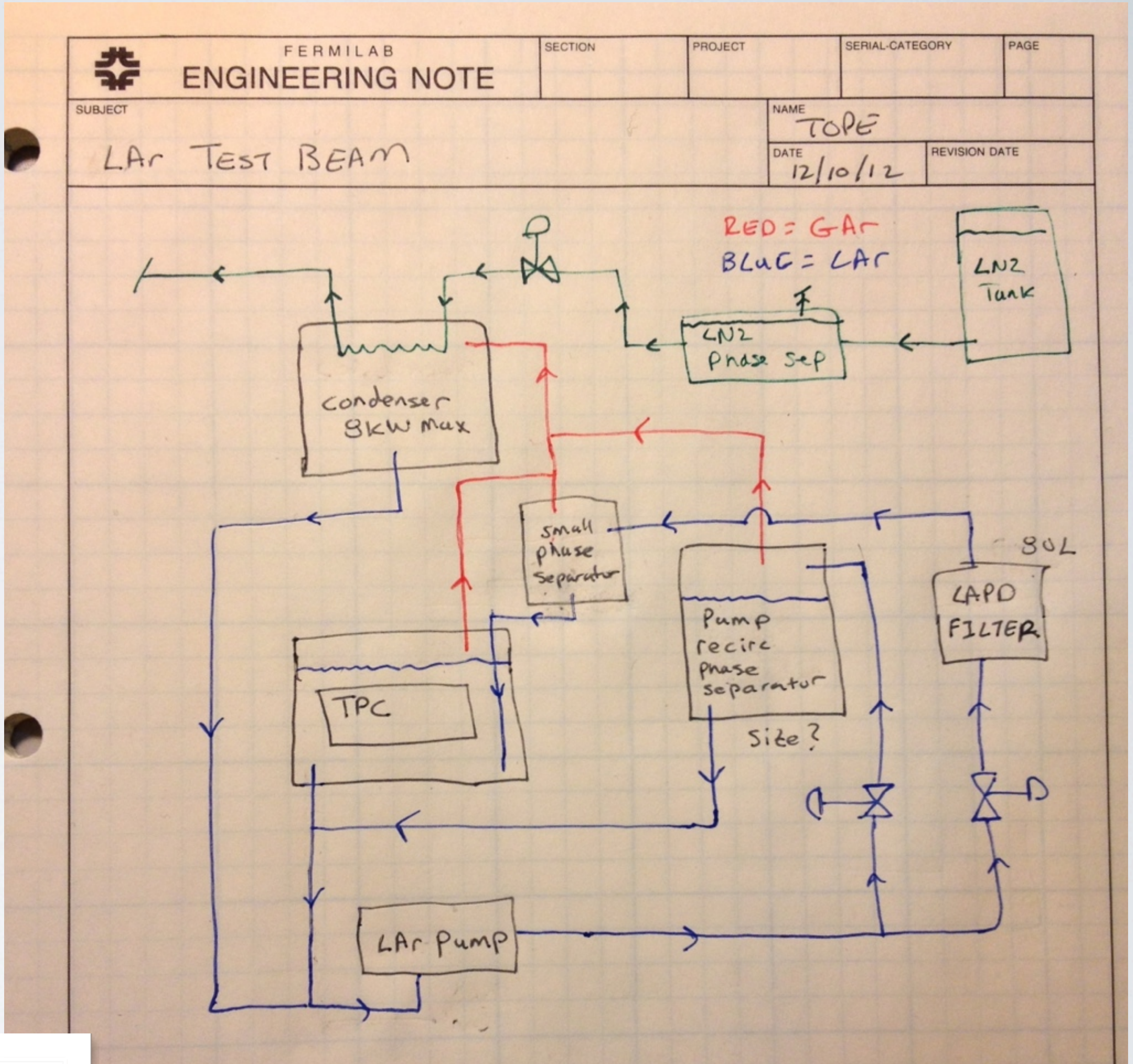
New Components: Argon Cooling & Purification

Aim to design facility for broader, longer-term use (Phase-II) at FTBF

Original ArgoNeuT design relied on gaseous Ar purification only.

Very low flow rate:
Full volume exchange (~500 liters): ~7-8 days

For faster, more stable and reliable operation (and a system which could be adapted for use in Phase 2 as well): ***a new system for purification in liquid phase was outlined with the help of the FNAL cryo-engineering team in Summer 2012.***



Planned as FNAL contribution to LArIAT, but PPD cryogenic engineers have almost no availability.

Current status: lack of available labor *severely* limits progress

New Components: Argon Cooling & Purification

Available/existing individual purification system components:

Recirculation pump (identical to MicroBooNE pumps) — *Purchased by FNAL PPD, Sept. 2012*

Filter — *Available from LAPD; requires upgrade for filter material containment*

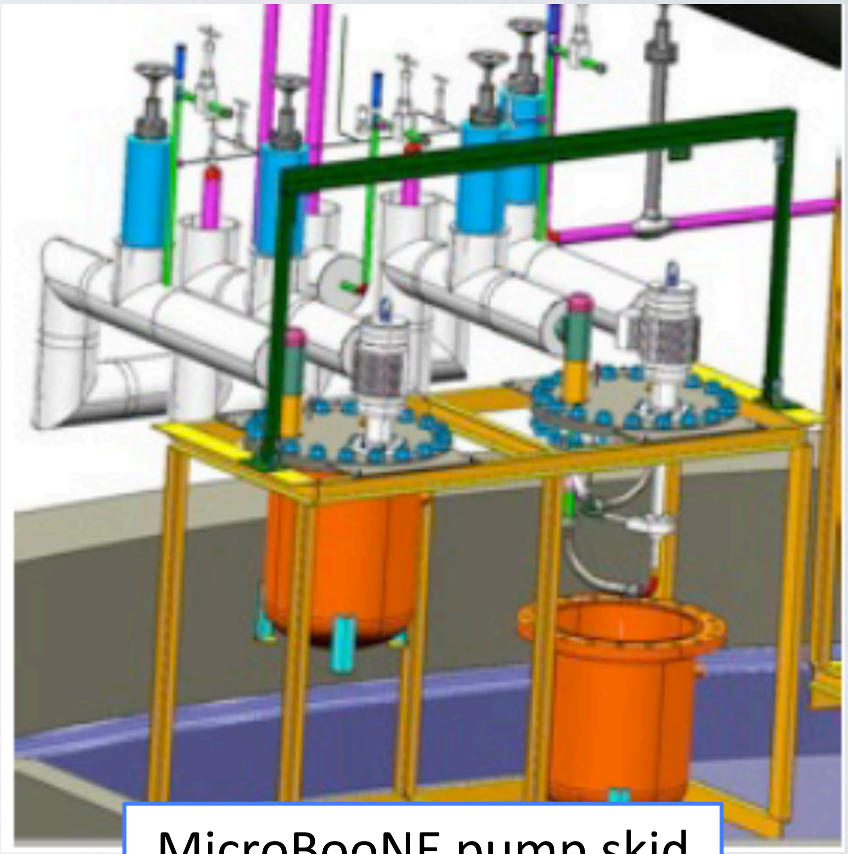
Other cryo system options, if FNAL engineering resources are not available to design new system:

Outsource

- Specialized companies (e.g., PHPK) can design and build system to fit in available space at MC7
- Still requires some FNAL engineer time to define requirements

Fallback

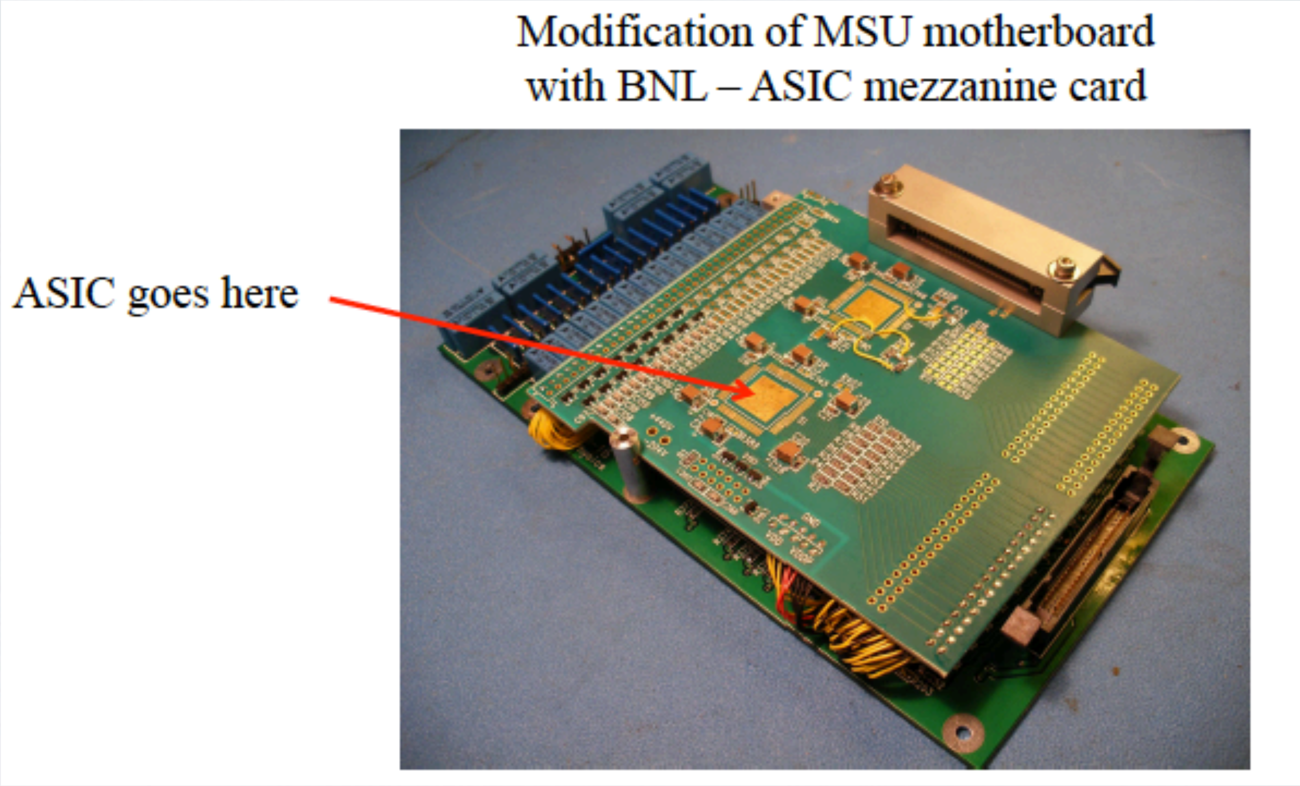
- Refurbish ArgoNeuT GAr system
- *Still requires some modification to system or MC7 ceiling ... existing system too tall for building (cut hole in roof?)*



MicroBooNE pump skid

Lack of progress here is our major concern

New Components: Cold Electronics



Strongly desired upgrade option

Improved signal-to-noise

C. Bromberg (MSU)

Can do and install in <6 months for ~$110k
- Replace warm preamps with cold version from Bo, or possibly extra BNL ASICs
- Improves S/N < 20 (warm) to S/N > 30 (cold)

LArIAT Phase-I
- M&S for 480 channels + spares (15%) & assoc. cabling: ~$110/ch ($62k)
- Tech/engineering labor: ~$45k
- Includes: purchasing, component testing, production, board testing, installation, & commissioning
- Commissioned in < 6 months

Existing Equipment: Ready for Re-use

Equipment	*Type/Model*	owned by
LAr cryostat	PHPK Tech.	*Yale*
TPC Detector (2 active planes, 240 wires each)	(custom)	*Syracuse*
Cryocooler	CRYOMEC AL300	*Yale*
Chiller	NESLAB HX300	FNAL
Slow-Control	Beckoff Autom.	FNAL
Turbo+Primary Vacuum Pump system	Pfeiffer	*Yale*
Two Primary Vacuum Pump	Varian TriScroll 300	*Yale*
HV pwr supply (125 kV)	GLASSMAN	FNAL
LV pwr supply	LeCroy 1440	FNAL
R/O electronics: Bias Voltage Distribution Card Preamplifier and Filter Card Digitizer Module	(custom) 20 units (x 24 chs. each) 30 units (x 16 chs. each) 15 units (x 32 chs. each	*Michigan State U.*
DAQ computer (for TPC)	-	*Yale*
Trigger System Instr. (TDC, QDC,..)	-	*W&M*
UV lamp for purity monitor	Hamamatsu	*Yale*
Beam Trigger/Beam Monitor detectors set of ToF scint. counters set of Wire Chambers	(custom) 2 units 2 units	FNAL-FTBF

Table 1: Available Equipment for LArIAT Phase-1 experiment at FTBF. VME crates, cables and feed-through's are also available as part of the TPC read-out system.

(3) Are the ***collaboration*** *and* ***laboratory resources*** *needed to succeed with LArIAT well-understood? And are requested resources adequate?*

Collaboration

LArIAT: a Liquid Argon TPC in the Fermilab Test Beam Facility

LArIAT Collaboration

Fermilab: ⓈJ. Raaf, B. Rebel, R. Acciarri, P. Adamson, B. Baller, A. Hahn, D. Jensen, M. Kirby, H. Lippincott, A. Marchionni, K. Nishikawa, M. Stancari, G. Zeller
Yale U.: B.T. Fleming, ⓈF. Cavanna, E. Church, O. Palamara, A. Szelc
Syracuse U.: M. Soderberg, J. Asaadi
William and Mary Coll.: M. Kordosky, P. Vahle
Michigan State U.: C. Bromberg, D. Edmunds
U. Texas Austin: K. Lang, J. Huang
U. Texas Arlington: J. Yu, A. Farbin, S. Park
U. Chicago: D. Schmitz
U. Cincinnati: R. Johnson, J. St.John
U. Minnesota Duluth: A. Habig, R. Gran
U. College London(UK): R. Nichol, J. Thomas
Imperial College London(UK): M. Wascko,
Manchester U. (UK): J. Evans, P. Guzowski
U. of L'Aquila and INFN-Gran Sasso Lab(It): F. Cavanna*, O. Palamara* (*presently at *Yale*)

Ⓢ Elected Spokespersons for LArIAT Phase-1

Collaboration Structure & Sharing of Responsibilities

Institution	PI/Exec. Board	Main Responsibility
Yale U.	B.T. Fleming	Cryostat
Syracuse U.	M. Soderberg	TPC detector
William and Mary	M. Kordosky	Beam Trigger
Fermilab	Ⓢ J. Raaf	Cryogenics and Argon purification
Michigan State U..	C. Bromberg	TPC R/O Electronics
U. Texas Austin	K. Lang	Beam Counters
U. Texas Arlington	J. Yu	Off-line sw
U. Cincinnati	R. Johnson	Tertiary Beam Installation and Beam Counters
U. Chicago	D. Schmitz	Det's syncrhonization and Scint. Light system Test
U. Minnesota Duluth	A. Habig	Tertiary Beam SetUp and Operation
U.College London(UK)	R. Nichol	Beam Trigger
Imperial College London(UK)	M. Wascko	On-line, Off-line sw
U. Manchester(UK)	J. Evans	MC simulations
U. of L'Aquila(It)	Ⓢ F. Cavanna	Scintillation Light read-out System

Table 2: LArIAT Collaboration: Institutions and PIs Members of the Executive Board - Ⓢ elected spokepersons for Phase-1. Preliminary Sharing of Responsibilities [(Phase-1) experimental program at FTBF].

Required Resources (including indirect)

		Category	Cost Estimate	Comments
M&S	*Modifications of existing components*	Cryostat modifications	$59.3k	By PHPK via Yale/DOE funds
		TPC wire frame support structure	$10k	By Syracuse via Yale/DOE funds
		DAQ rate increase	$10-105k	Cost range depends on choice of upgrade
	New components	Scint. light detectors	$23.2k	In-kind contribution, U. of L'Aquila
		Scint. light readout	$15.4k	By Yale via Yale/DOE funds
		Beam trigger & readout	$14.6k	By W&M via Yale/DOE funds
		Cold electronics	$107k	By MSU via MSU + FNAL funds
		Cryo/purification system	$180k	Based on experience from LAPD & MicroBooNE
	Operations	Cryogens & gases	$65k	Based on experience from LAPD & MicroBooNE
		Computing (storage, VM, etc)	$12k	
		ES&H (ODH fan, etc)	$10k	
		M&S Total	**$507-602k**	Range due to DAQ rate options
SWF	Design of cryo system (0.5 FTE engineer-yr)		$150k	Estimates here based on experience with LAPD and MicroBooNE cryogenic systems. These are fully burdened costs including indirect. *This assumes we are designing a system that will be used for both phases of LArIAT.*
	Installation of cryo syst (1 FTE technican-yr)		$175k	
	3D model/drafting (0.25 FTE designer-yr)		$50k	
	Controls system (0.5 FTE controls group)		$125k	
	SWF Total		**$500k**	

Estimates of design time and system cost for cryogenic/purification system have significant uncertainties. It is difficult to understand requirements without more detailed FNAL engineering input.

Laboratory Resources

Fermilab KA-15 budget (LAr Test Beam portion) should cover:

- LAr recirculation/purification system for Phase-I and Phase-II
  - Design & construction (SWF)
  - System components (M&S)
- Partial cost of Phase-1 electronics upgrade (DAQ + cold electronics)
- Operation costs

Anticipated $300k M&S from FNAL PPD dedicated to LAr Test Beam activities.
Delivered M&S is $200k ($245.8k incl. indirect) due to emergency redirection of funds.
Delivered SWF is $260k ($448k incl. indirect costs).

Other Available Resources

- Approved DOE/Yale funding of $100k will cover:
  - Front/side/bottom port modifications on the ArgoNeut cryostat
  - Modification of existing TPC or construction of new one (by Syracuse, acting as contractor in Yale/DOE grant)
  - Scintillation light readout system
  - Development of trigger system (by W&M, acting as contractor in Yale/DOE grant)
- Scintillation light system provided as in-kind contribution from L'Aquila University ($23.2k)
  - Optical System (HQE cryogenic PMTs, reflector, and wavelength-shifter) and engineering design & fabrication of support structure for lateral port of cryostat
- Cold electronics design/commissioning work by MSU ($26k)
  - 2-3 months engineer time; engineer has vast experience with this system
- Early Career Award, Sam Zeller ($30k)
  - Toward equipment or tech/engineer labor
- Smaller university contributions to collaboration Common Funds anticipated (Total of order $100k)

Total collaboration resources available: ~$280k

FNAL LAr Test Beam M&S: (orig $300k) $200k ($245.8k w/indirect costs)

FNAL LAr Test Beam SWF: $260k ($448k w/indirect costs)

*(4) Are the **cost** and **schedule risks** well-identified? And what are they?*

Costs (M&S)

<table>
<tr><th colspan="2">Modification of existing components</th><th>New components</th><th>Operation Costs</th></tr>
<tr><td rowspan="2">CRYOSTAT</td><td rowspan="2">TPC DETECTOR</td><td rowspan="2">(A) Scintillation Light Detector
$ 23.2 k
and read-out electronics
$ 15.4 k</td><td>CRYOGENS</td></tr>
<tr><td>LAr Filling $ 5 k
LN2 Cooling $ 60 k</td></tr>
<tr><td rowspan="4">① Bottom Side - connection to cooling/ purification system

② Front Side - beam window and LAr excluder

③ Lateral Side - housing and connection to scintillation light readout system

$ 59.3 k</td><td>④ Wire frame sustaining supports
$ 10 k</td><td>(B) Beam Trigger System
$ 14.6 k</td><td>COMPUTING</td></tr>
<tr><td rowspan="3">⑤ DAQ (ADF-2 Card) Upgrade

$ 10 -105 k

(depending on max rate attainable)</td><td>(C) Argon cooling and purification system
$ 180 k</td><td>BlueArc (30TB) + Tape storage (20TB) + Virtual Machine
$ 12 k</td></tr>
<tr><td rowspan="2">(D) Cold Electronics
$ 107 k</td><td>ES&H</td></tr>
<tr><td>ODH sensors, fan, exhaust piping
$ 10 k</td></tr>
</table>

Time 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	about starting
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)	

Risks

LArIAT schedule slips to point where Run-I overlaps with MicroBooNE physics run (assumed to start a few months after initial startup)

The main purpose of LArIAT is to provide useful data to best tune/optimize/develop analysis tools (e.g., in LArSoft) in time for MicroBooNE data analysis, therefore the goal of starting data-taking in Summer 2013 is our main priority for Phase-1.

- *If delay is due to late beam startup, could tolerate up to ~6 months delay by changing from assumed 2 shifts/day to 3 shifts/day and accelerating preliminary data analysis as much as possible.*

  Data accumulation and analysis can still be performed in parallel with MicroBooNE initial operations, without affecting MicroBooNE.

- *If delay is due to detector issues (e.g., delay with new cryogenic & purification system design/ fabrication/mounting), LArIAT experimental program should be entirely revised*

Design time and system cost for cryogenic system may be under-estimated by a large factor

We would like to design a system with future needs in mind, but:

- *If time required to design/build system is too long (or cost is too high), fallback option of refurbishing existing GAr system from ArgoNeuT may be necessary.*

  This fallback option still requires some labor/materials resources in order to make the existing system fit into the MC7 space.

Risk of no LAr testbeam program

Soon-upcoming and future LAr TPCs will be forced to continue using simulation as input until useful calibration data are collected and analyzed.

Conclusions

- Phase-I LArIAT program will undertake precision studies of the fundamental mechanisms of energy release in LAr, which will feed directly into future LArTPC experiments by improving calorimetric energy resolution and particle ID.

- Both the (tertiary) beam and the experiment capitalize on the use of existing equipment as much as possible
  - The aim for the recirculation/purification system is to design a forward-looking system that will serve as the cryogenic infrastructure for this and future experiments in MCenter
    - ✦ Lack of engineering availability on the timescale that we need severely limits progress toward this goal
    - ✦ If an outside company designs/builds the system, this may solve the problem on the right time scale, but money would need to come from a different source than the allocated SWF in the LAr Test Beam budget
  - Modifications to the ArgoNeuT cryostat are in progress, due to be completed by Mar. 2013
  - DAQ upgrade, cold electronics, and triggering system will be completed by June 2013

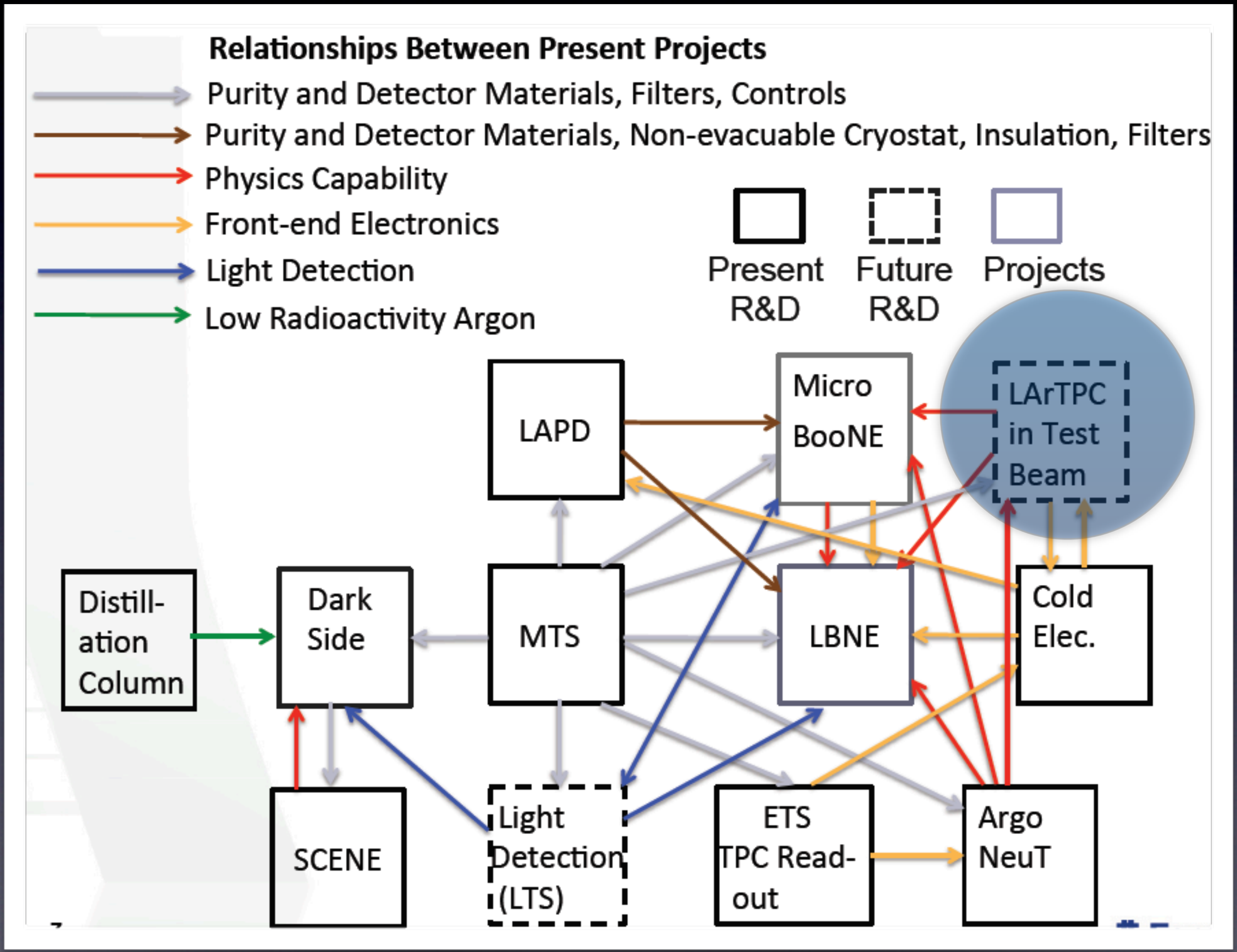
- Necessary resources have been estimated to the best of our ability, but may be off by a large factor. It is difficult to understand system requirements without engineering input.

- The most serious risk is the possibility of large delay due to lack of available labor for the cryogenic system design, fabrication, or mounting. In this case, the experimental program should be entirely revised.

Liquid Argon R&D at Fermilab

taken from

DOE Review Laboratory Detector R&D
July 24, 2012



We believe LArIAT can play a significant role in this great picture.

The collaboration exists, the detector is largely available, and the (tertiary) beam was already successfully operated.

We only need dedicated support from FNAL in order not to lose the momentum gained in the last 8 months of intense activity.

List of Events

LArTPC

LArIAT meeting	11 Dec 2012
LArIAT meeting	04 Dec 2012
LArIAT meeting	27 Nov 2012
LArIAT Meeting	13 Nov 2012
LArIAT Meeting	06 Nov 2012
LArIAT Meeting	30 Oct 2012
LArIAT Meeting	22 Oct 2012
LArIAT Meeting	16 Oct 2012
LArIAT Meeting	04 Oct 2012
LArIAT Meeting	27 Sep 2012
LArIAT Meeting	20 Sep 2012
LArIAT Meeting	13 Sep 2012
LArIAT Meeting	06 Sep 2012
LArIAT Meeting	30 Aug 2012
LARIAT Meeting	23 Aug 2012
LArDBT Meeting	16 Aug 2012
Basics of Purity	13 Oct 2010

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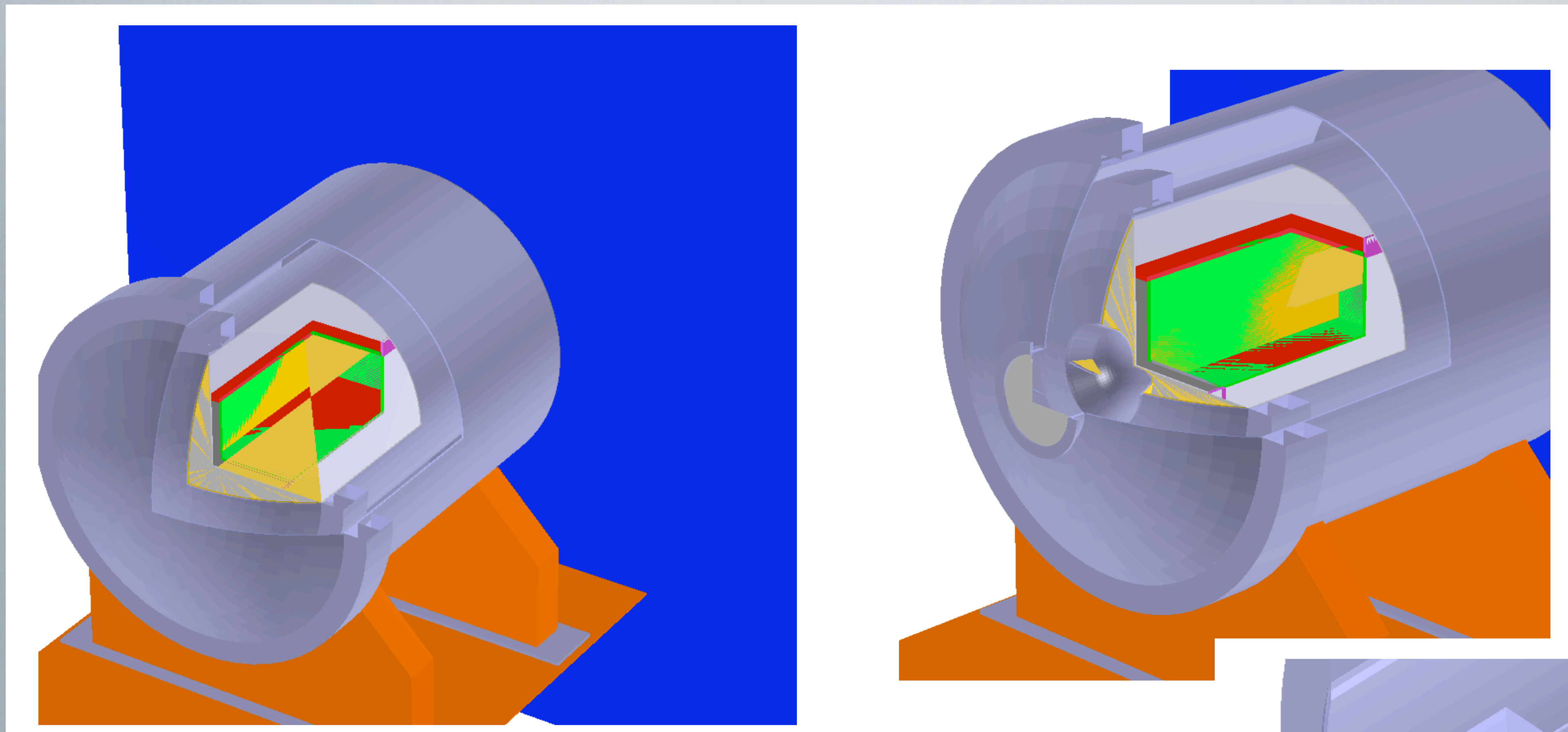
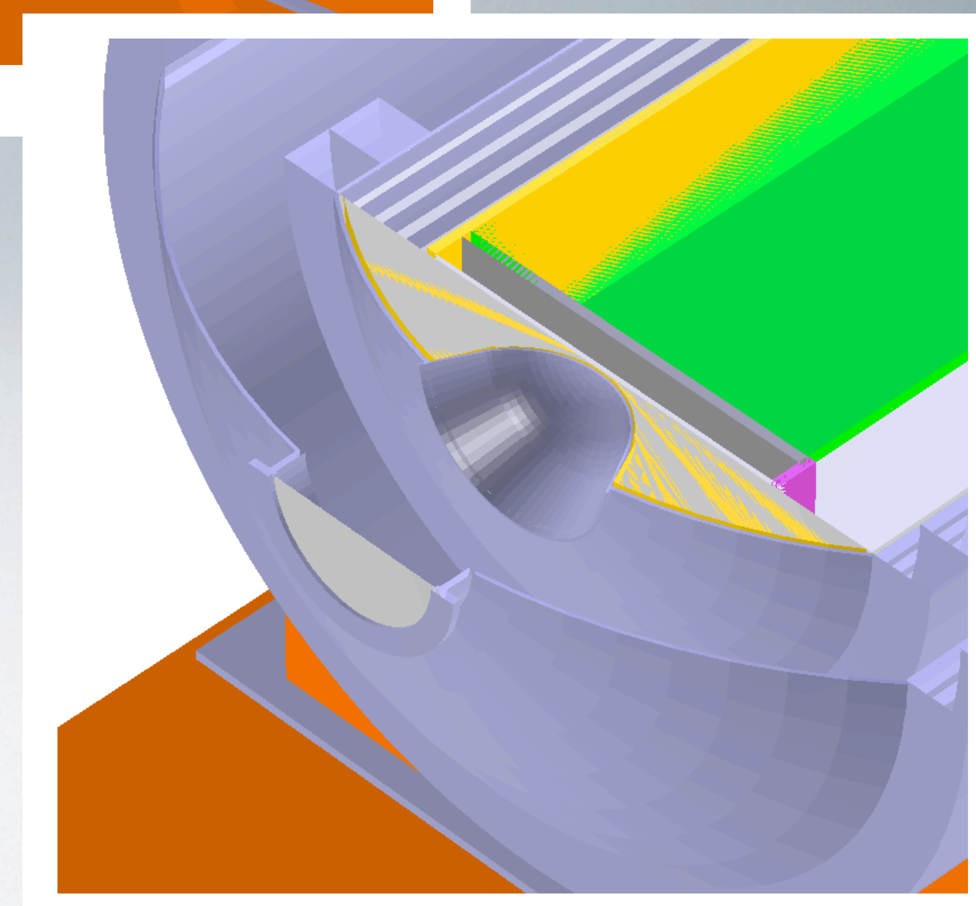
Extra Slides

New Cryostat Geometry Implemented in Geant



A. Szelc (Yale)



Initial studies w/new geometry underway:

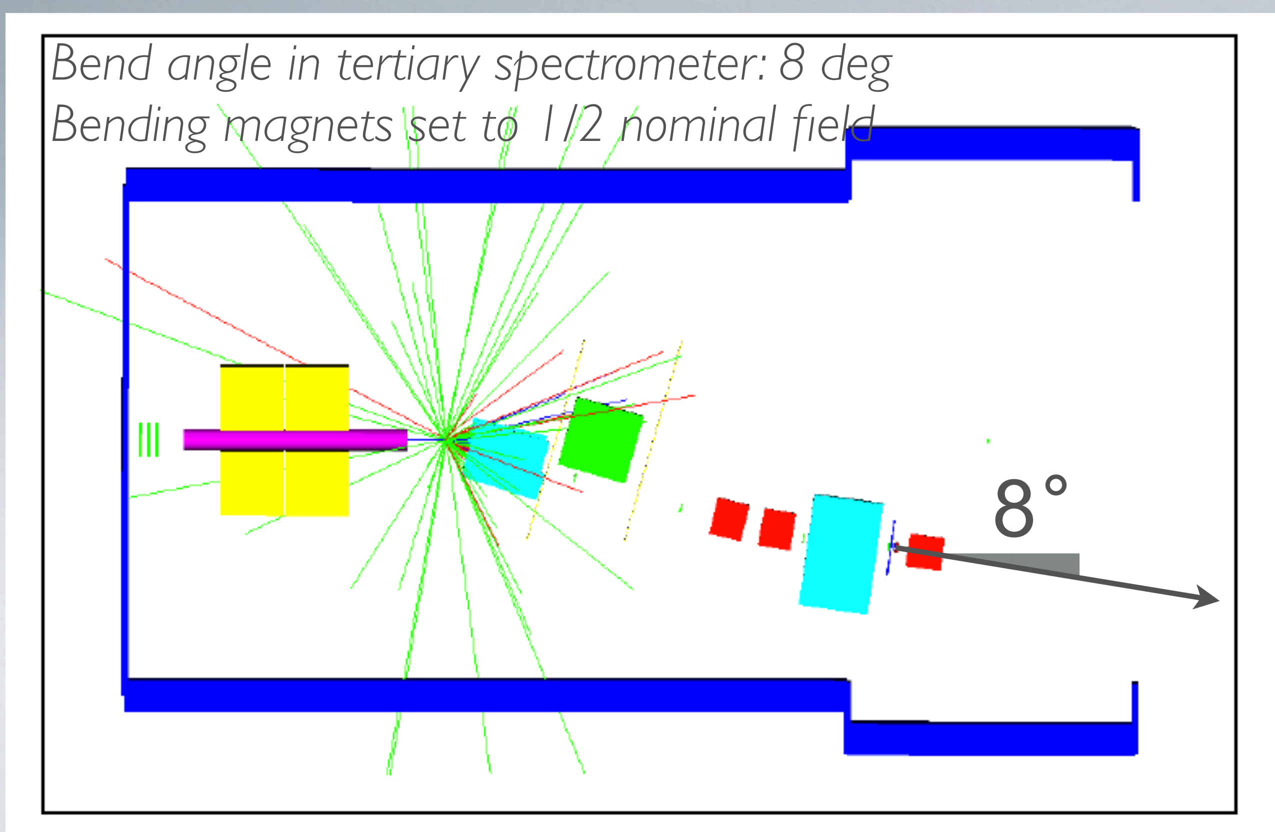
- Ran μ,π^+, protons, electrons and $\bar{p}$
- 300 events at momenta 0.25, 0.5 ... 2.5 GeV/c
- looked at endpoint, effective energy and deposited energy

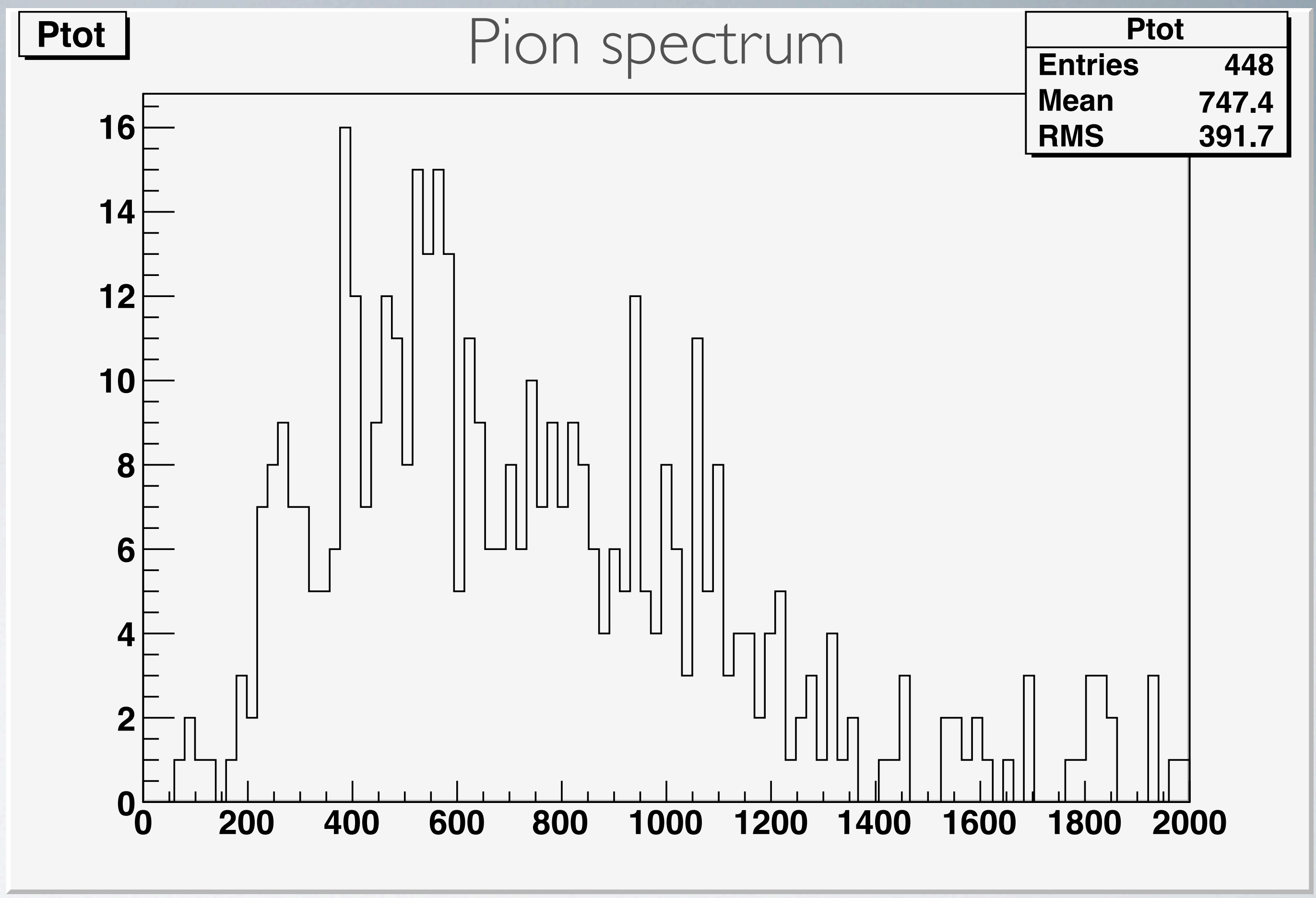
Optional Tertiary Beam Adjustment: 8 Deg Bend

D. Jensen (FNAL)

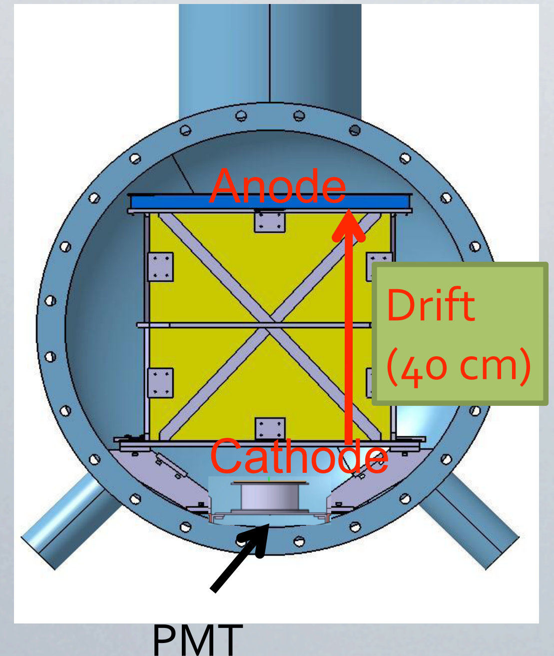
- A 16 GeV/c incident beam, 8 deg. Spectrometer bend yields
  higher rates ~70 π^+ / spill
  K^+ / π^+ ~ 1/200
  (~100 total p, pi, K, mu, e, crossing detector per 4-sec spill)
- Background Issues still need checking
- Detector height in building needs checking

- To probe this option as well as 16 deg 8 GeV/c beam, the LAr detector + Cryo MUST be configured to translate and rotate easily.

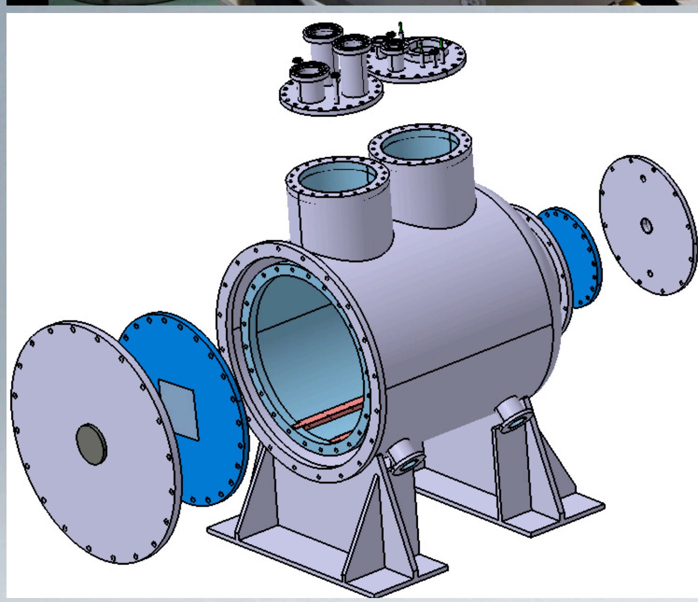


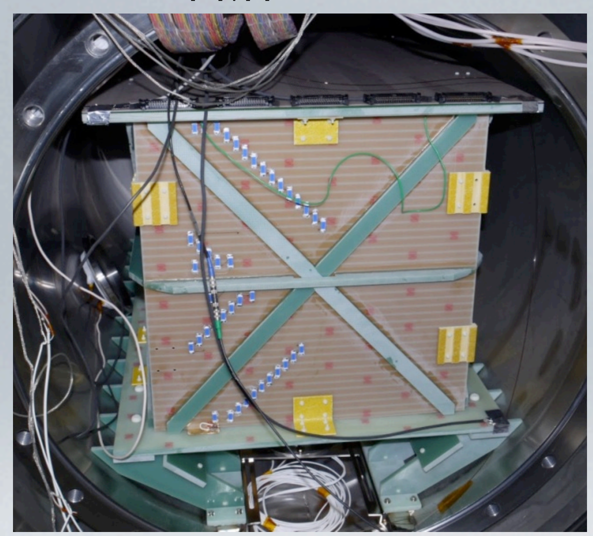


Test Beam Efforts: T-32 250-liter test at J-PARC

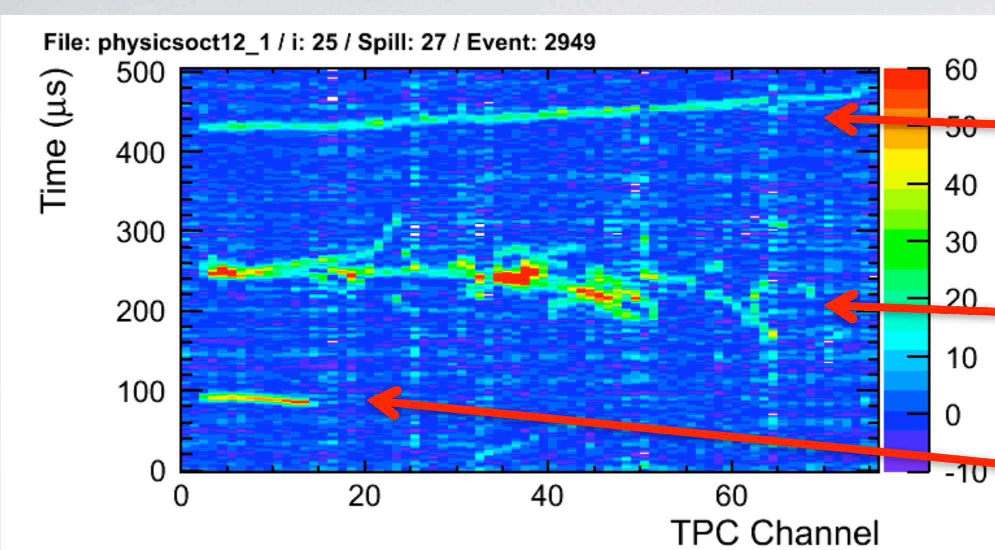


Event Category		No. of events
K^+	800 MeV/c with degrader → 540 MeV/c	7,000
K^+	800 MeV/c with degrader → 630 MeV/c	40,000
K^+	800 MeV/c with degrader → 680 MeV/c	35,000
π^+	200 MeV/c	70,000
e^+	800 MeV/c	2,500
P	800 MeV/c	1,500
e^+	200 MeV/c	10,000
π^+ dominant 800 MeV/c		~ 3,000
total		~170,000





- Similar configuration as ArgoNeut
- 250L Vessel: 70cmϕ x 1m dewar vessel
  - Previously used prototype of MEG Xe calorimeter
- 40 x 40 x 80 cm^3 TPC
- LAr Purity goal: 1 ppb
  - ~ 30 cm drift electron attenuation length



800 MeV/c pion passing thorough TPC as ~MIP
Good sample for detector calibration and simulation tuning

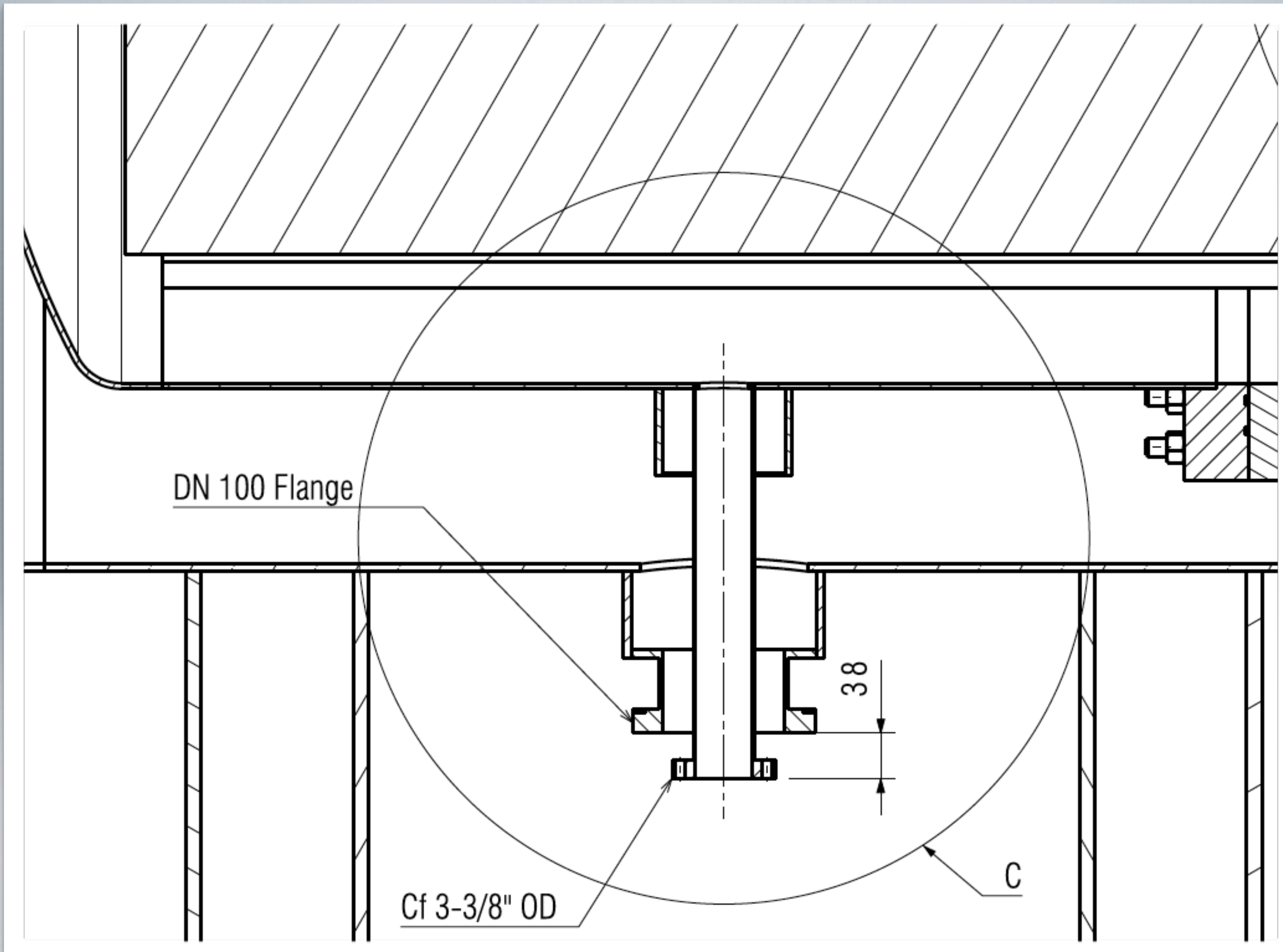
800 MeV/c positron triggered event overlapping with proton and pion

800 MeV/c proton, range ~20 cm
Test of detector performance for large dE/dx

Only LArTPC in a test beam so far, but only coarse readout (1-cm wide strips). No 3D reconstruction (single plane only). Not enough to benchmark full performance of LArTPC.

1

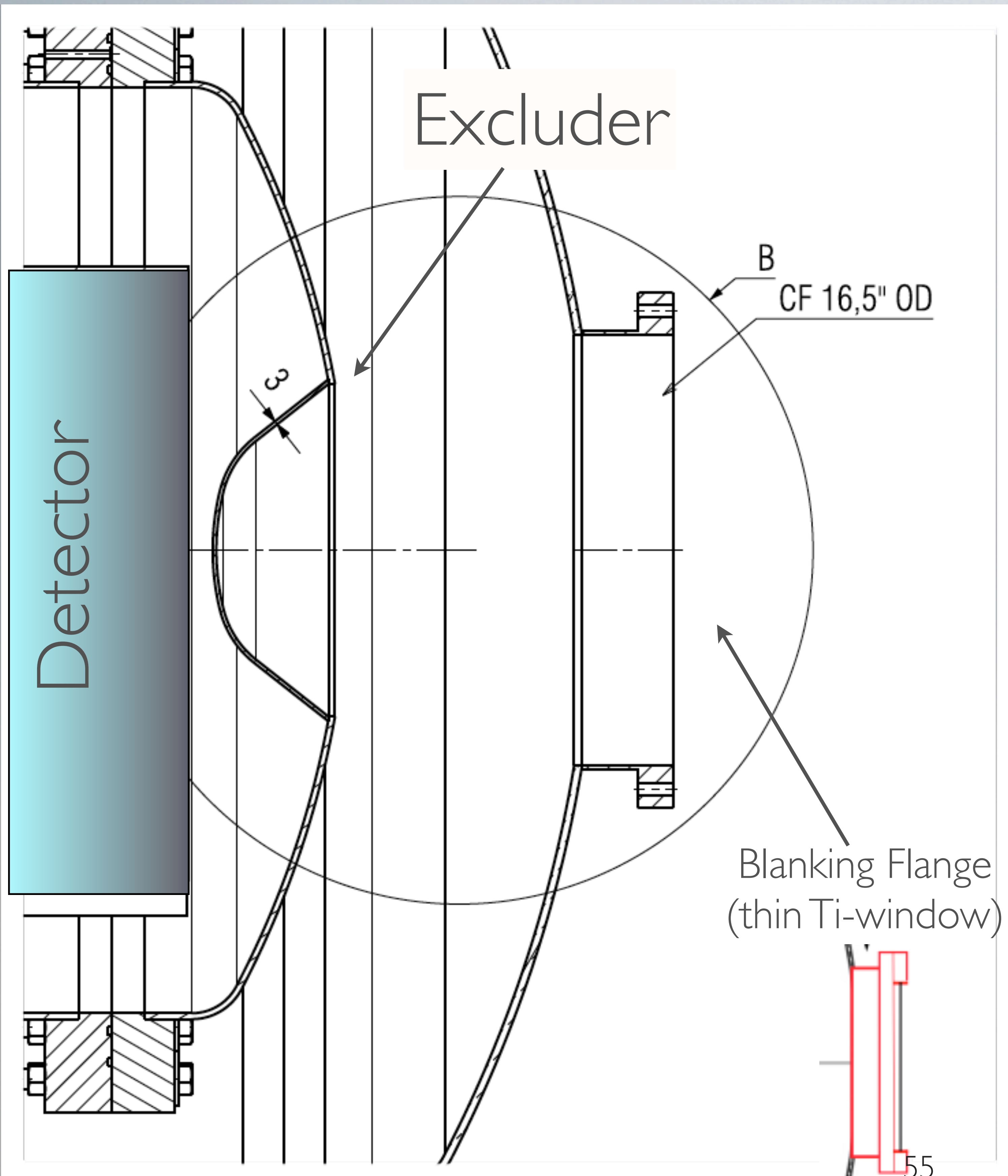
Bottom Side -
LAr outlet for connection to the liquid phase Cooling/Purification System



1-1/2” SCH 10 pipe connection to the inner vessel (instead of 1”), ended with CF 3-3/8” flange.

[drawings made at GS -
E. Tatananni - Head of Mech WS]

2 *Front Side - "Beam Window"*



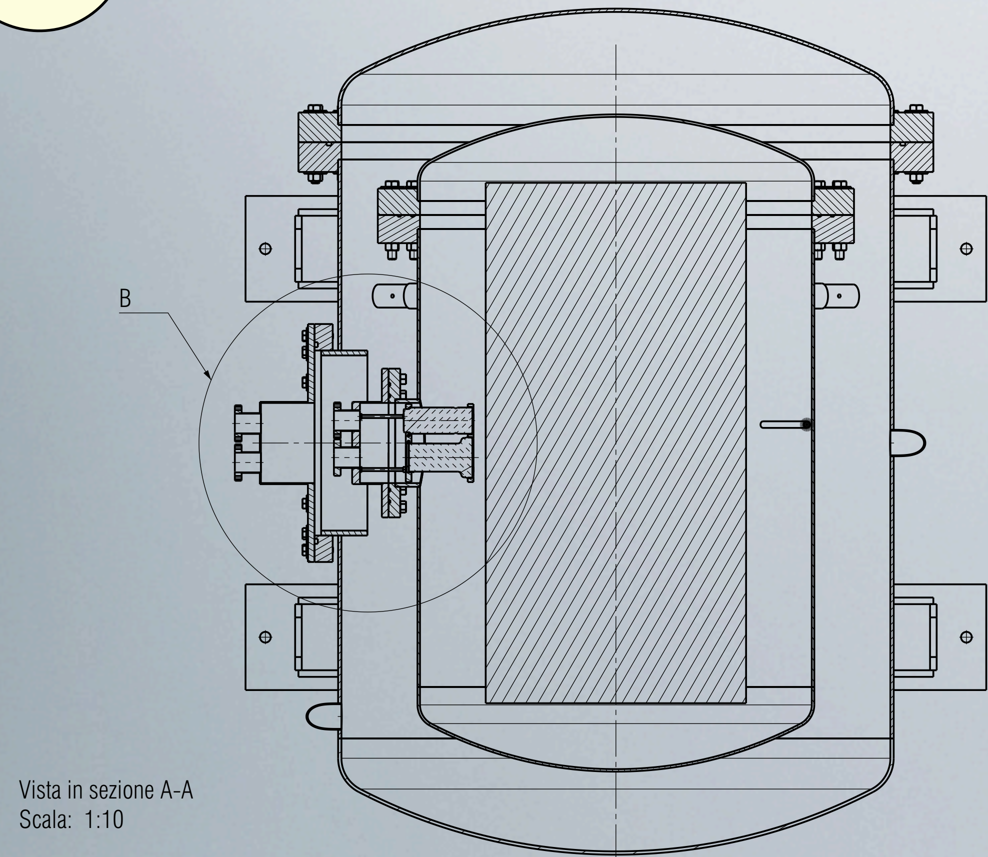
1)outer vessel: CF 16-1/2" OD which attaches to a 14" OD tube

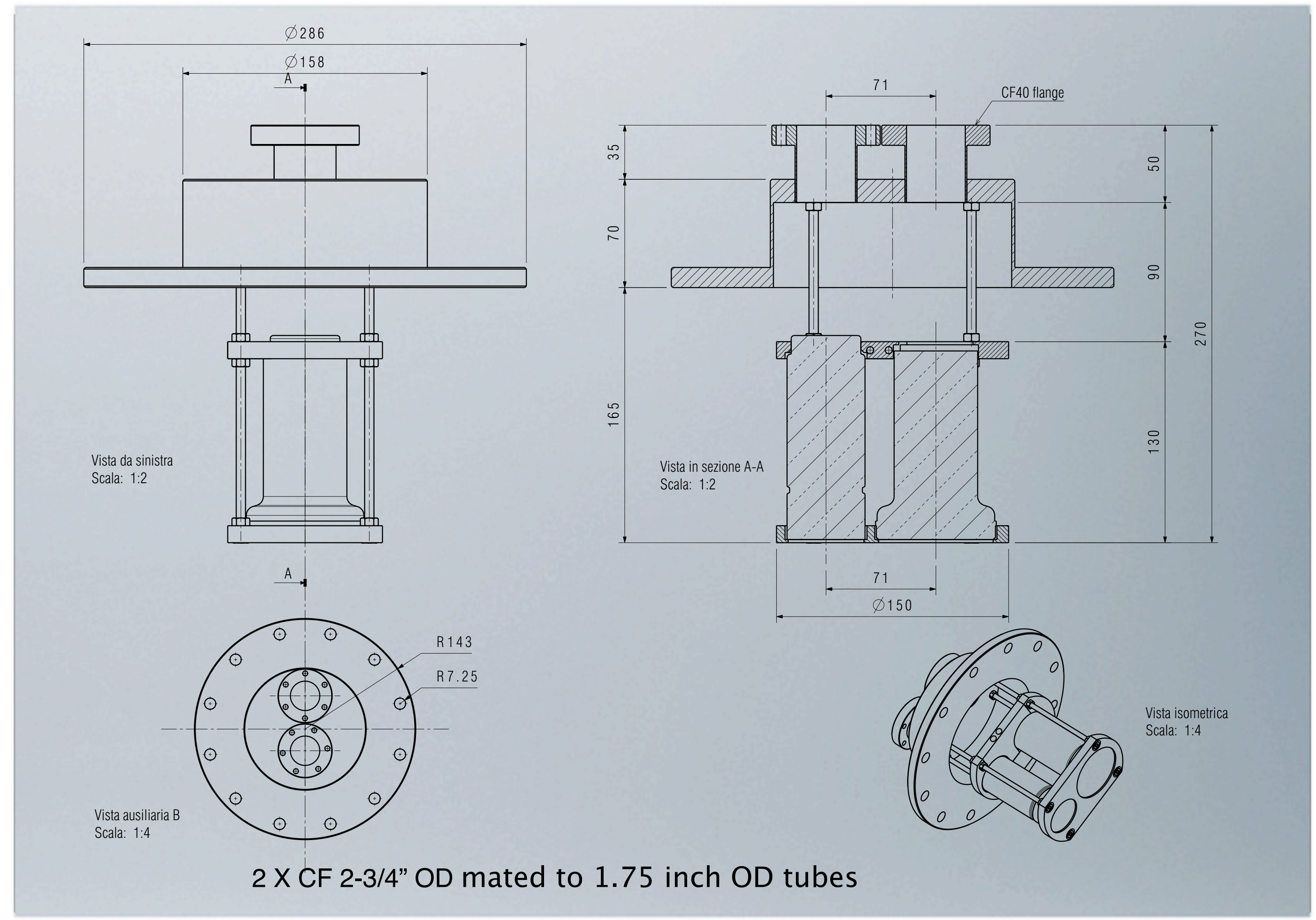
2)inner vessel: (liquid Ar) **excluder** – i.e. an inward protruding tube and cap (the thinnest cap the ASME code allows – tentatively indicated in 3 mm)

"R" stamp as per ASME BPVC, for inner vessel modification

[drawings made at GS - E. Tatananni - Head of Mech WS]

3 Lateral Side - housing and connection to the Scintillation Light r/o System

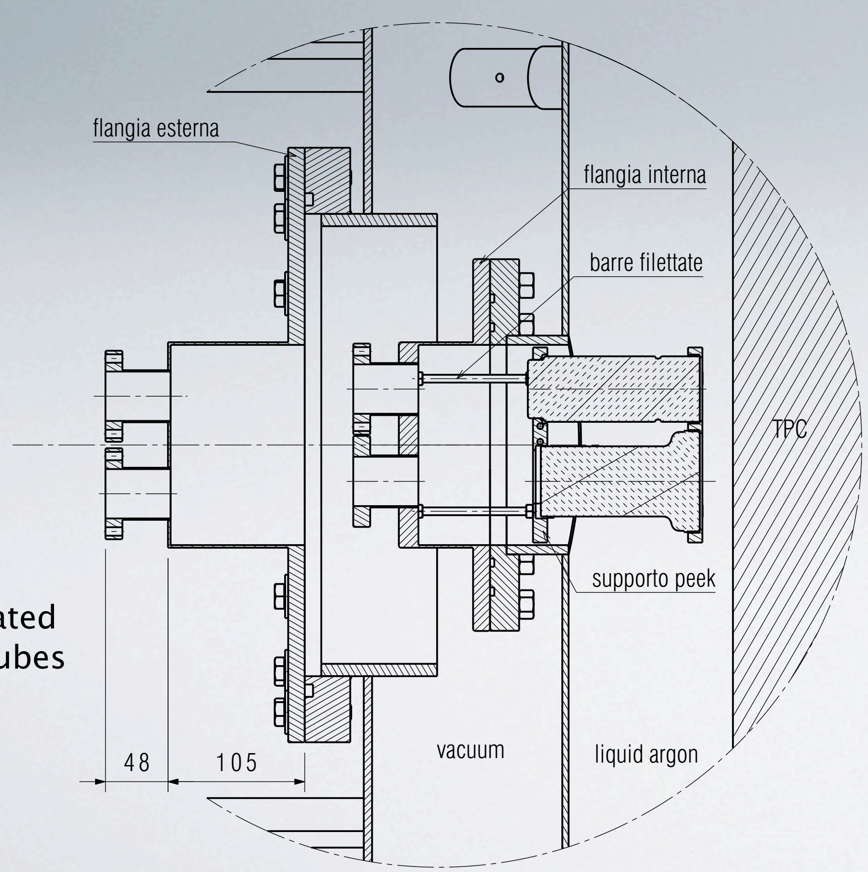




2 X CF 2-3/4" OD mated to 1.75 inch OD tubes

Outer Lateral Port

2 X CF 2-3/4" OD mated to 1.75 inch OD tubes



Dettaglio B
Scala: 1:4

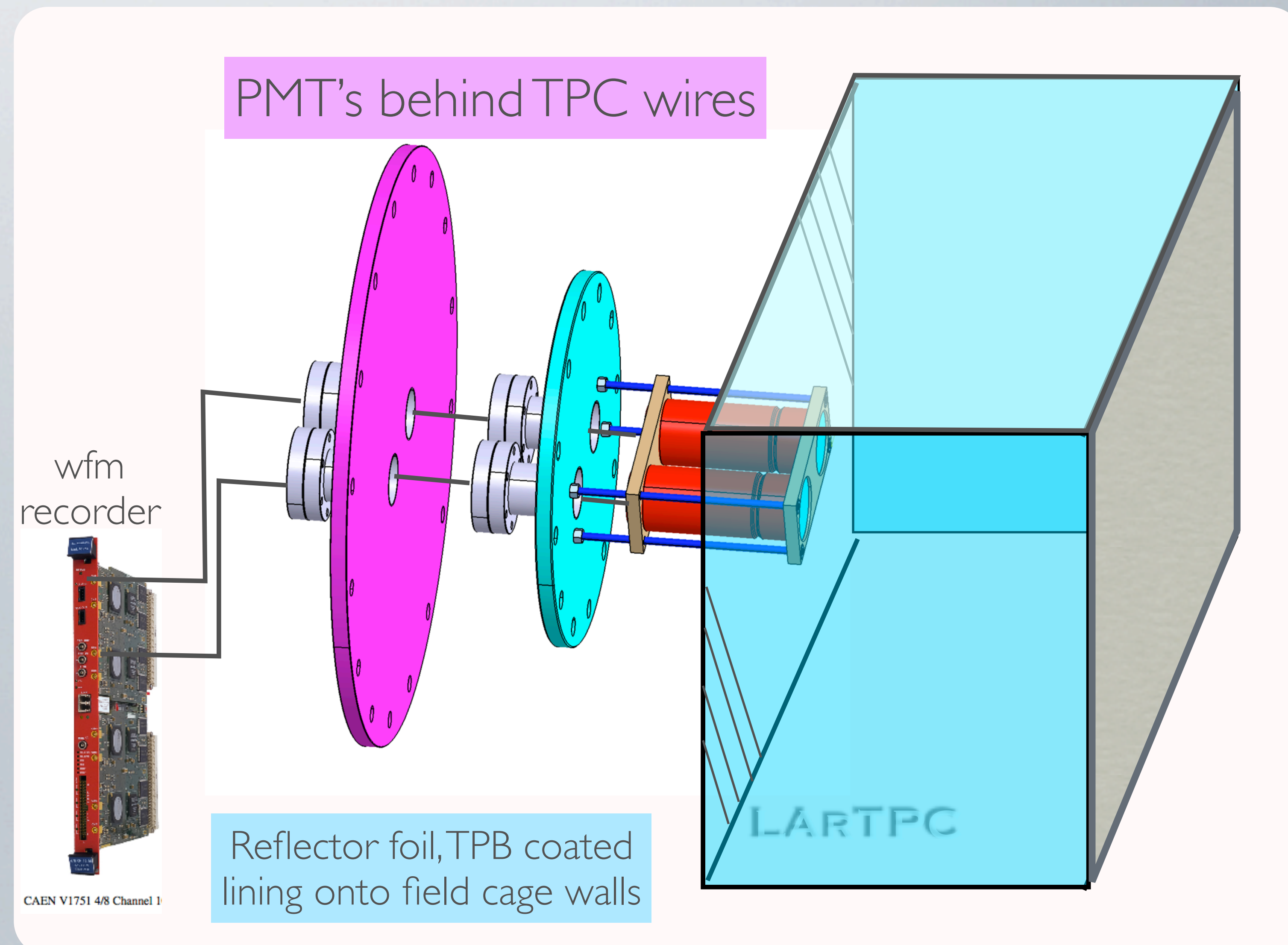
Detail of the Inner Lateral Port

[drawings made at GS - E. Tatananni - Head of Mech WS]

➤ New Components

(A) Scintillation Light Detection and R/O system

HQE PMT array in LAr
⊕
wls film on Reflector surface



The optical system consists of:

1) an array of 2 PMTs, developed for operating at cryogenic temperature, viewing the LArTPC volume from behind the wire-planes.

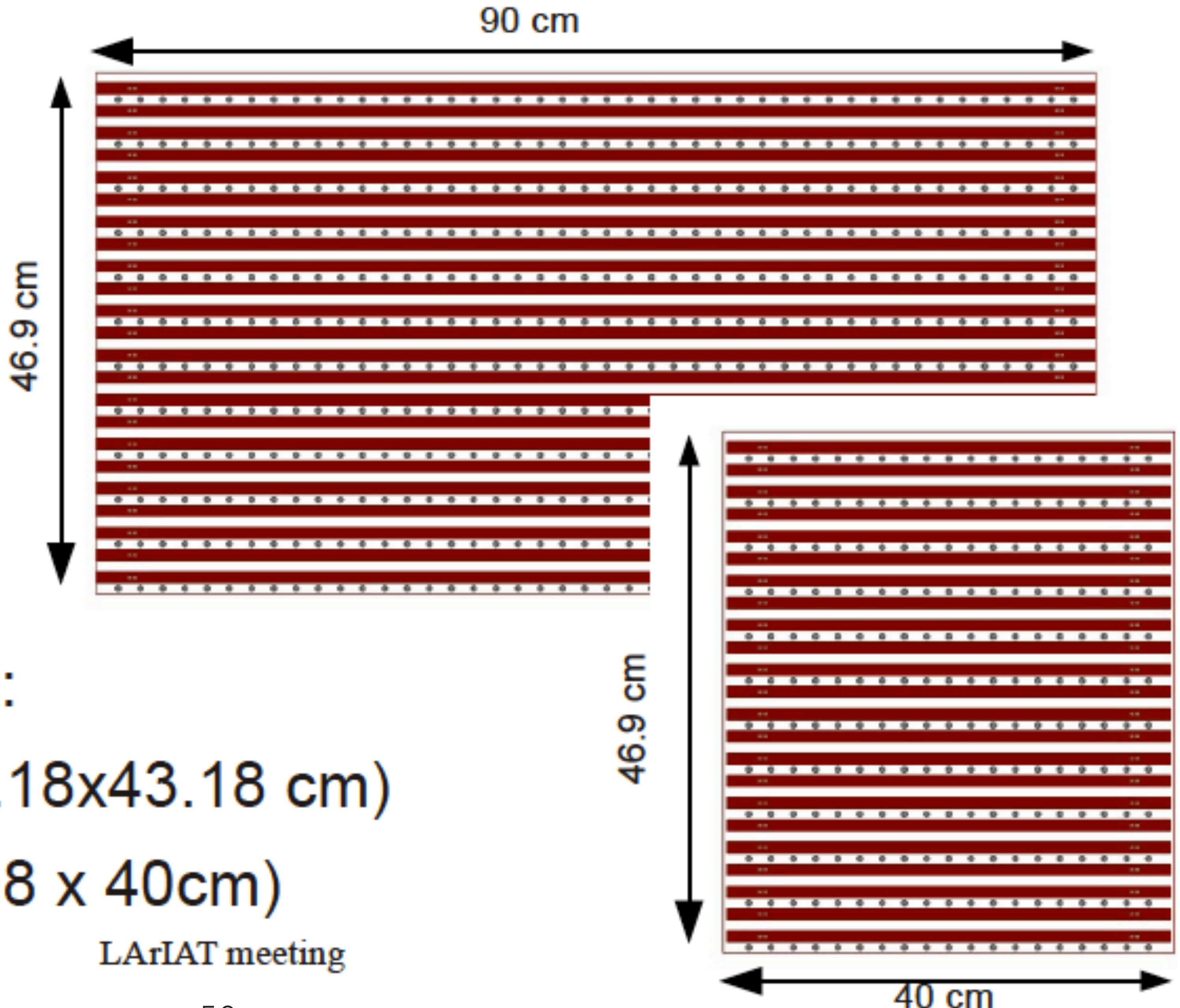
2) highly reflecting foils coated by a thin wls film lining onto the inner surfaces of the field cage

The reflector layer is a polymeric multi-layer plastic mirror, totally dielectric and with highest specular reflectivity (about 99%), and the wls film is TPB (WLS efficiency ~100%), obtained by deposition with vacuum evaporation technique (about 300 $\mu g/cm^2$).

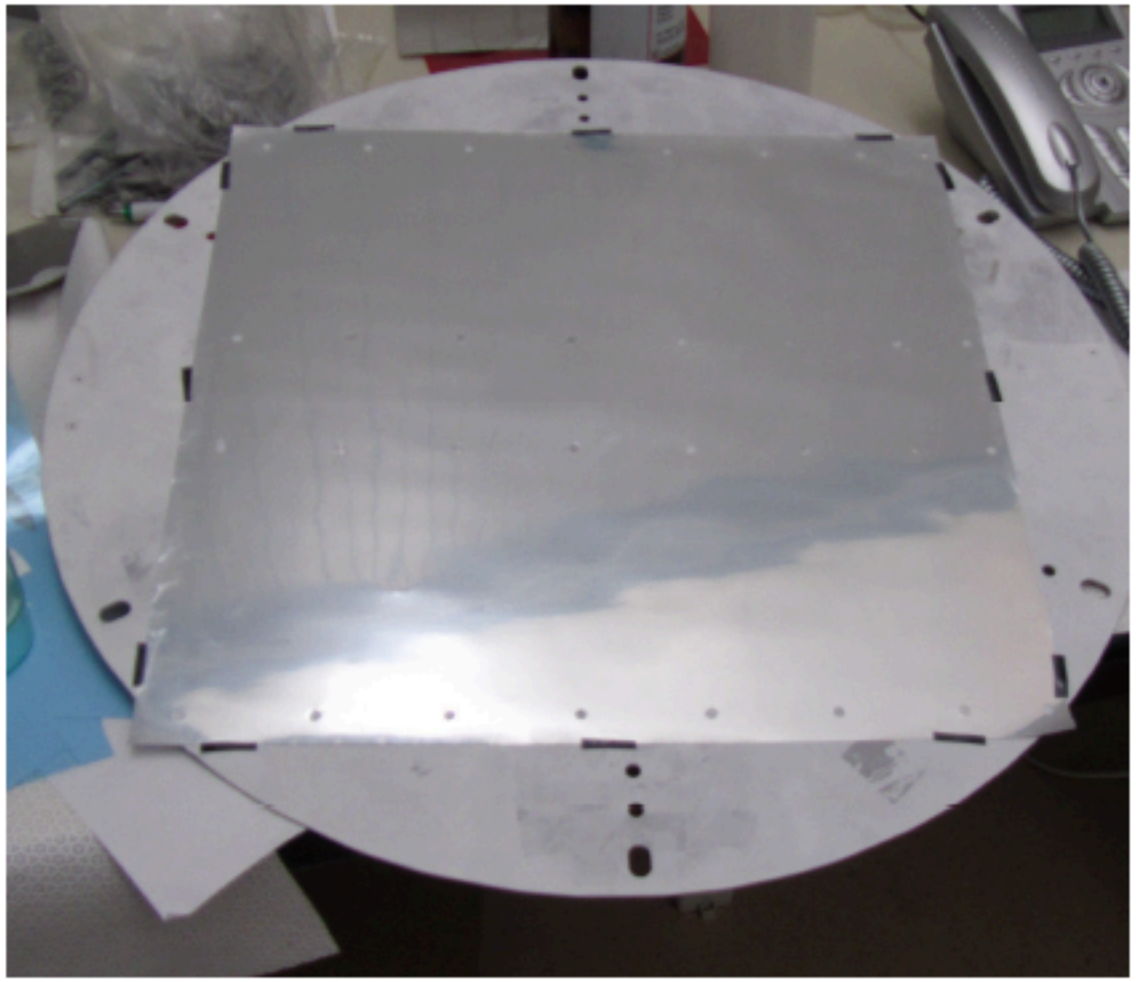
This choice has been defined to optimize both the down-conversion efficiency for the impinging VUV photons and the reflection efficiency of the blue-shifted photons. In this way, scintillation VUV photons from energy deposition in the LAr volume propagate inside the LAr volume, then are wl-shifted into visible photons when hitting the TPB film on the surface boundaries and finally the visible photons are reflected (several times) from the mirror surfaces beneath, up to collection from the active (photo-cathodic) area of the PMT coverage. The TPB film is, in first approximation, transparent to the visible photons.

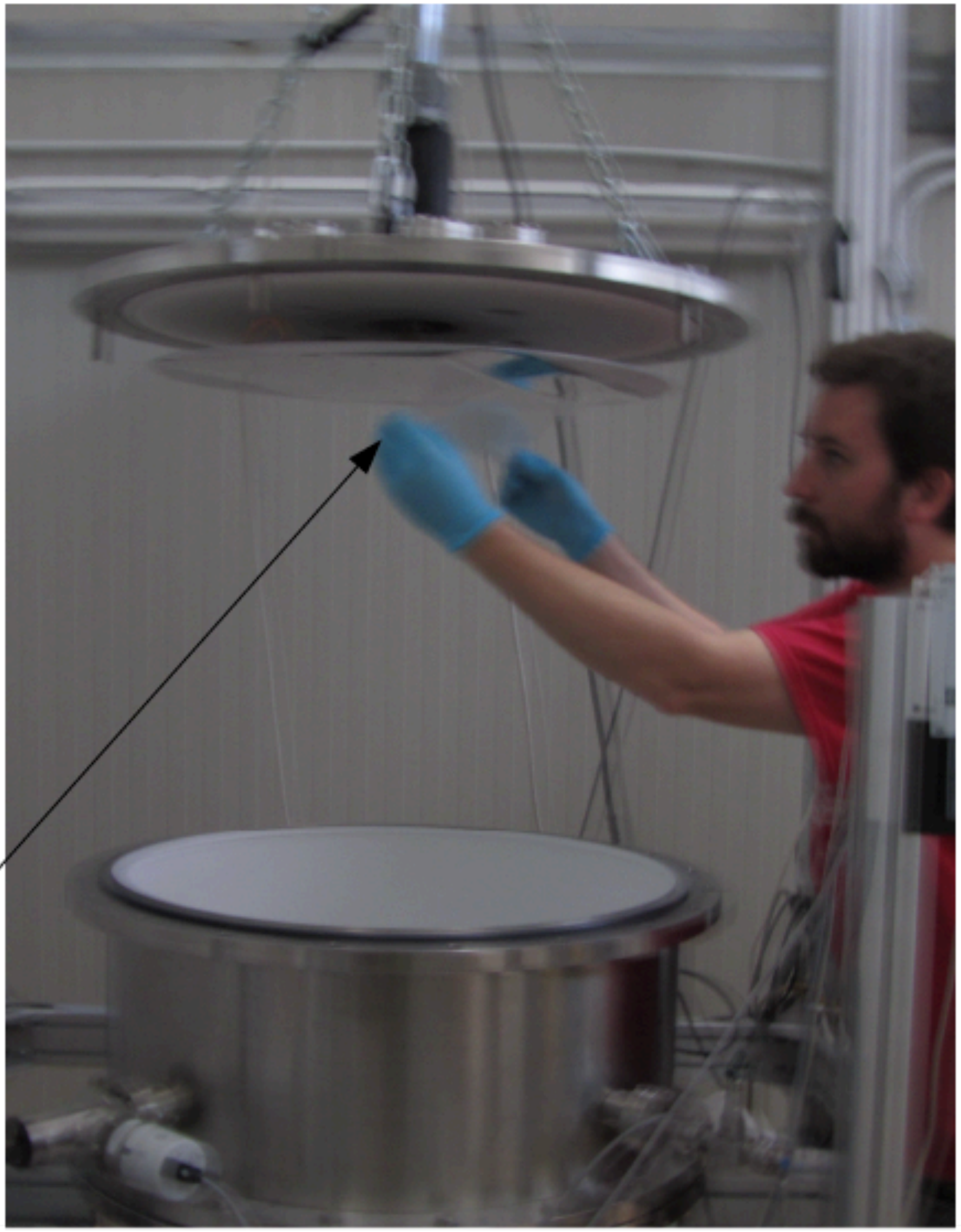
- 3M provides 17"x17" sheets:

- Slightly smaller than internal dimensions of the fieldcage:



- Need a total of 6 foils:
- top+bottom: 2x2 (43.18x43.18 cm)
- front+back: 2x1 (43.18 x 40cm)





Trickiest part:
Removing the protective layer at the last moment.

Evaporating at ~200 ug/cm^2.

Modification of Existing Components: Readout

	Sample duration	Sampling frequency	Samples per channel per event	Total window	Event size	Readout time per event	Rewrite DAQ software?	Readout speed	Max acq. Rate assuming immediate readout (events/second)	Acquire while reading out?	Circular buffer depth (events)	Maximum acquired events per 4 second spill (buffered+realtime readout)
ArgoNeut	198 ns	5 MS/s	2048	0.41 ms	2 MB	1000 ms	no	2 MB/s	1 Hz	no	0	4
	396 ns	2.5 MS/s	1024	0.41 ms	1 MB	500 ms	no	2 MB/s	2 Hz	no	0	8
ADF-2 firmware upgrade	396 ns	2.5 MS/s	1024	0.41 ms	1 MB	125 ms	slight	8 MB/s+I14	8 Hz	no	0	32
New VME-PC interface (Motorola processors)	396 ns	2.5 MS/s	1024	0.41 ms	1 MB	62 ms	yes	2 MB/s per digitizer	16 Hz	no	0	64
Both above	396 ns	2.5 MS/s	1024	0.41 ms	1 MB	15 ms	yes	8 MB/s per digitizer	64 Hz	no	0	256
	198 ns	5.0 MS/s	2048	0.41 ms	2 MB	30 ms	yes	8 MB/s per digitizer	32 Hz	no	0	128

➤➤The high accuracy and statistical precision of the test beam data will be fundamental to achieve an in depth ***understanding of the recombination mechanisms in LAr*** and an optimal way to ***best model their effects within the LArSoft*** off-line reconstruction and detector simulation package for future LArTPC experiment in the US

➤➤ ***PId information***, based on direct measurement with beam particles of known type, will greatly enhance confidence in the estimate of signal to background separation for future nucleon decay searches and current/forthcoming neutrino cross-section studies with LArTPC detectors (ArgoNeuT/MicroBooNE).

➤➤Models for simulation of anti-proton annihilation at rest are subject of continuous development within GEANT4 (e.g.: CHIPS, FRITIOF, LEP aka. GEISHA).
Validation from experimental data is of interest as models predictions vary widely in the multiplicity and energy spectra for the secondary produced.

➤➤Data from the testbeam will readily enable more reliable separation criteria/algorithms in the LArSoft offline reconstruction code, thus benefitting multiple LArTPC experiments.

➤➤ GEANT4: modules for capture at rest of **π**, K and annihilation of anti-p comparisons with experimental data.

➤➤ In addition capture topology and identification of the decay/capture products will further constrain the capability to charge-ID the primary lepton in muon neutrino CC interactions of particular interest for CP violation, and for validating the reaction models implemented for Argon nuclei in the GEANT4 simulation package.

Optional Configuration:

Searching for anti_protons

- 2×10^6 32 GeV/c π^- on the target
- Look for anti-protons coming out of the collimator
- Beware p acceptance

- 2x rate for p_π = 64 GeV/c
- .2x rate for p_π = 16 GeV/c