A WATER CHERENKOV TEST EXPERIMENT (WITH MULTI-PMTS)

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NEPTUNE Workshop
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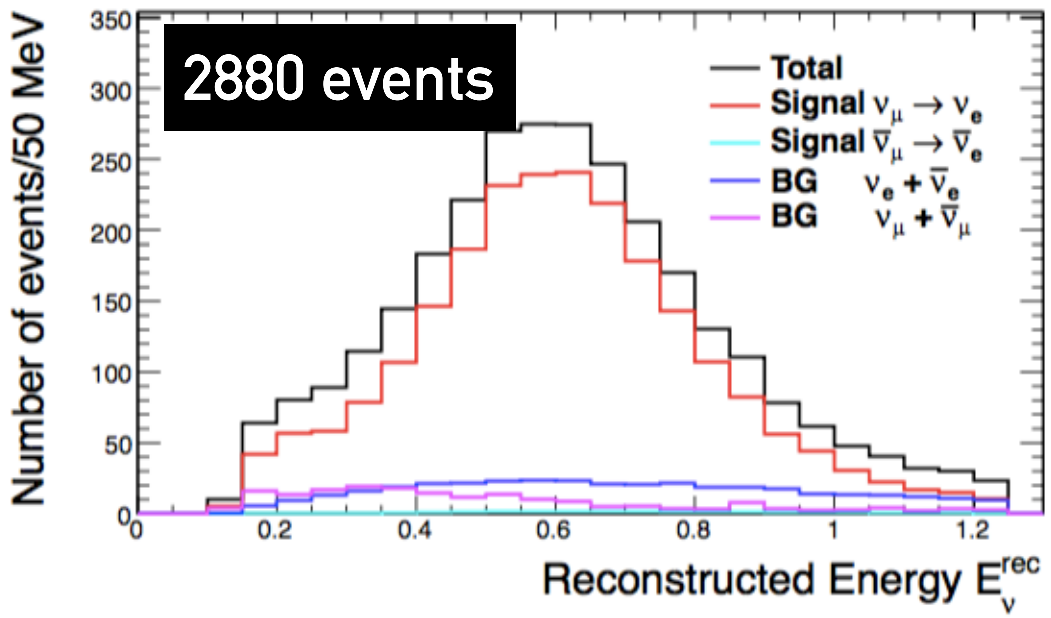
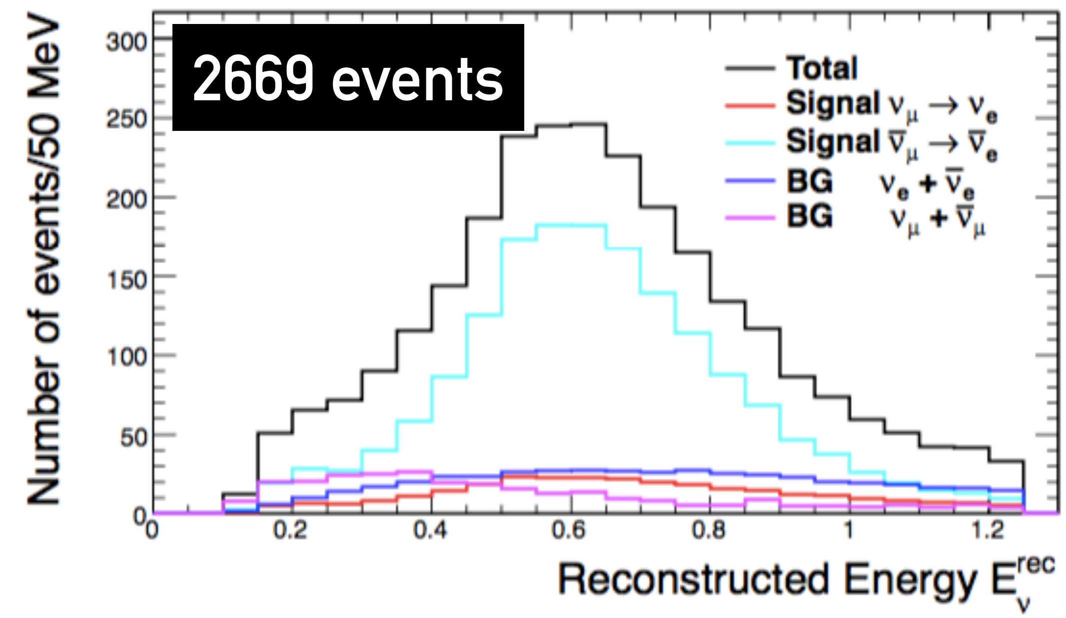
PRECISION OSCILLATION PHYSICS IN HYPER-K

Electron neutrino candidates



Electron antineutrino candidates

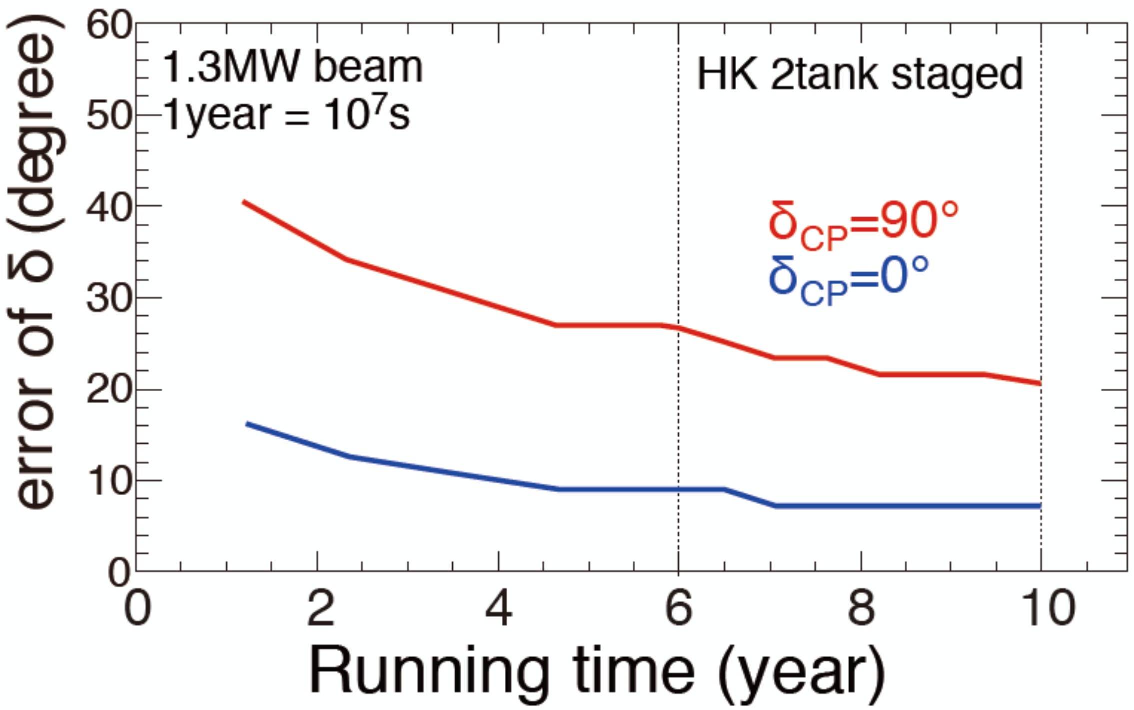


- Statistical errors in Hyper-K CP violation measurement are <3%
- In T2K, errors primarily from neutrino interaction modeling and far detector modeling
- E61 has been proposed to address critical systematic errors
- Need to reduce systematic errors to <3% to remain statistics limited

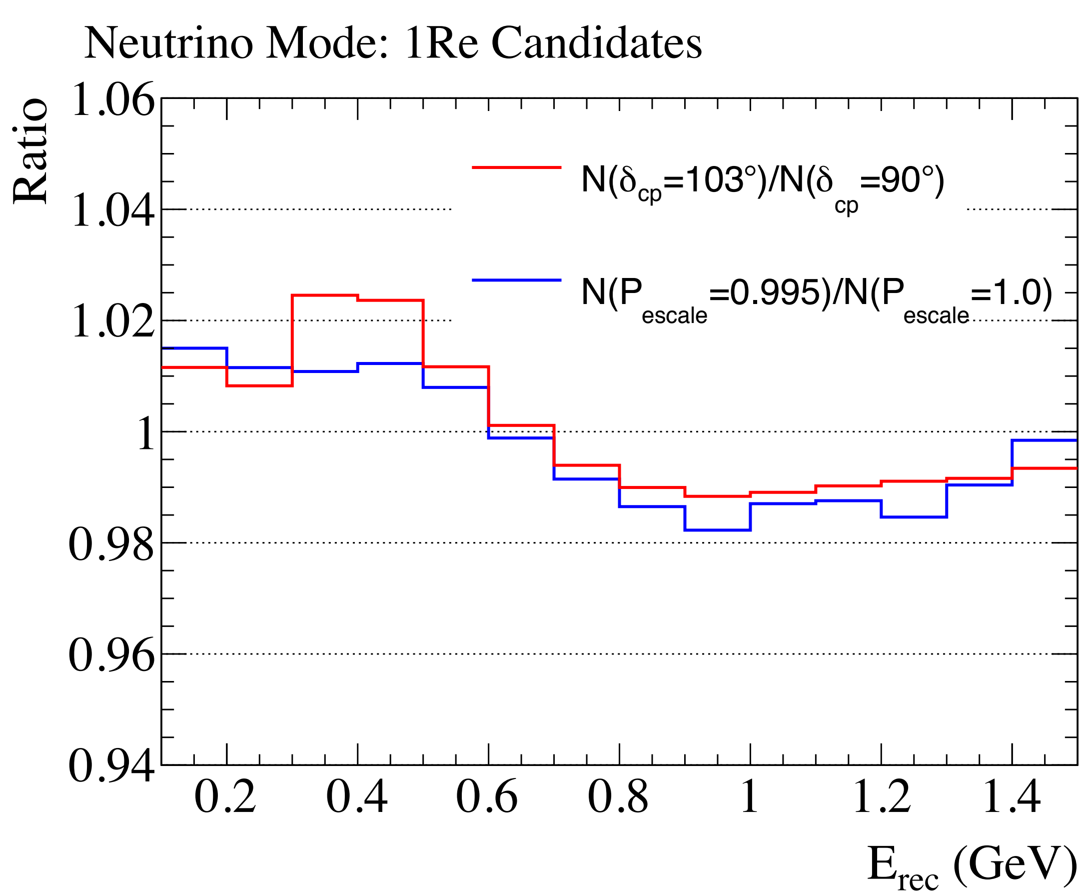
T2K Systematic Errors:

Error Source	% Error on neutrino/ antineutrino rate
Pion Interactions	1.58
Neutral Current Background	1.50
Electron (anti)neutrino cross section	3.03
Extrapolation from near detector	2.31
Removal Energy	3.74
Far Detector model	1.47
Total	5.87

NOT JUST "NORMALIZATION" UNCERTAINTIES

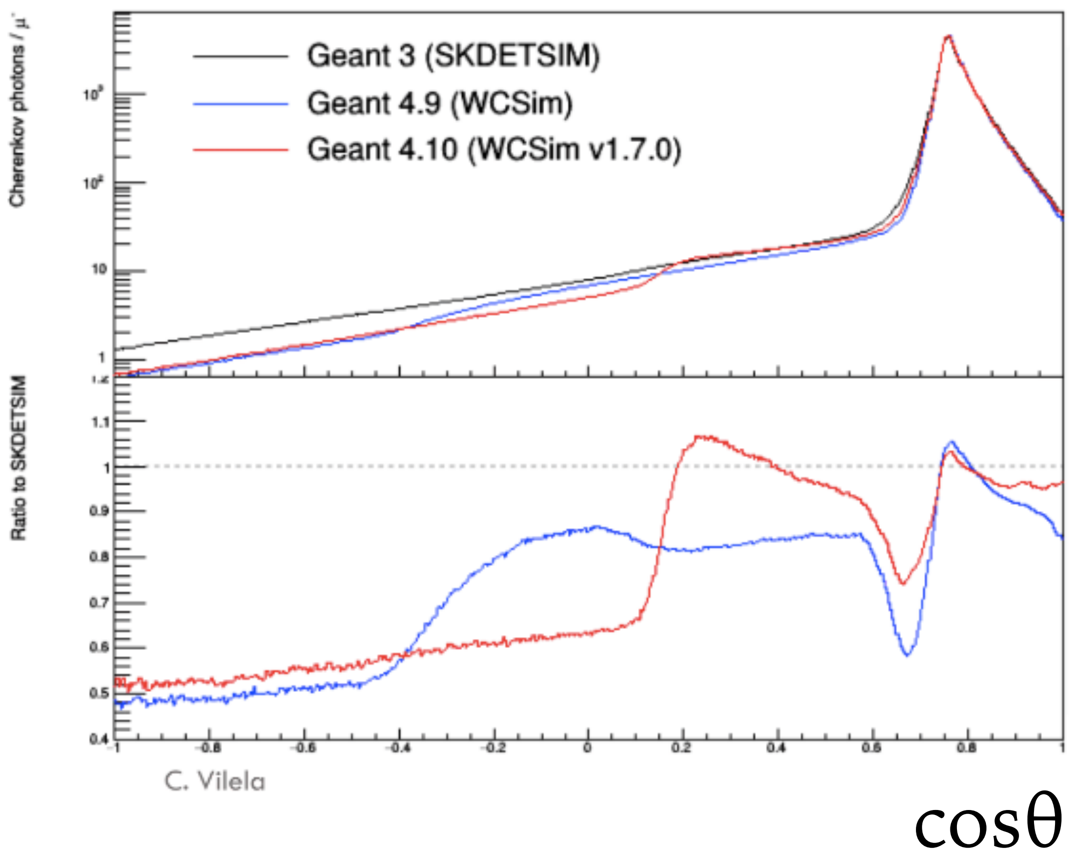


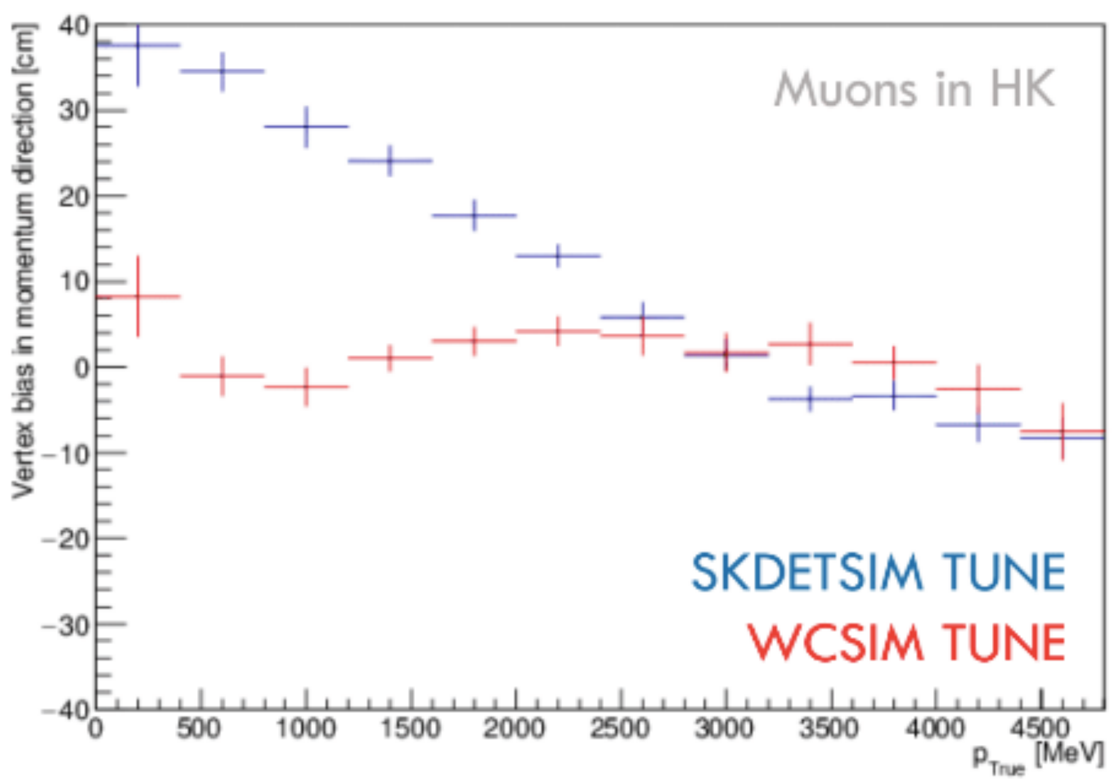
- If δ_{cp} is near 90° or 270° (T2K preference), precision measurement becomes challenging
- Rely on spectrum variations introduced by $\cos(\delta_{cp})$ term



- A shift of δ_{cp} by 13° is nearly indistinguishable from a change of energy scale by 0.5%
- We also need precise calibration of the energy response in an our "near" detectors and Hyper-K

GETTING THE PHYSICS RIGHT

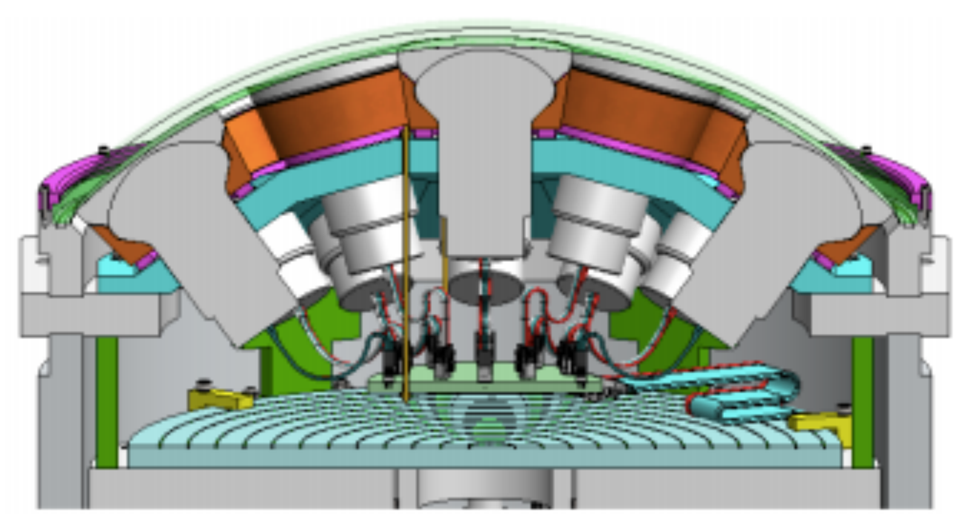


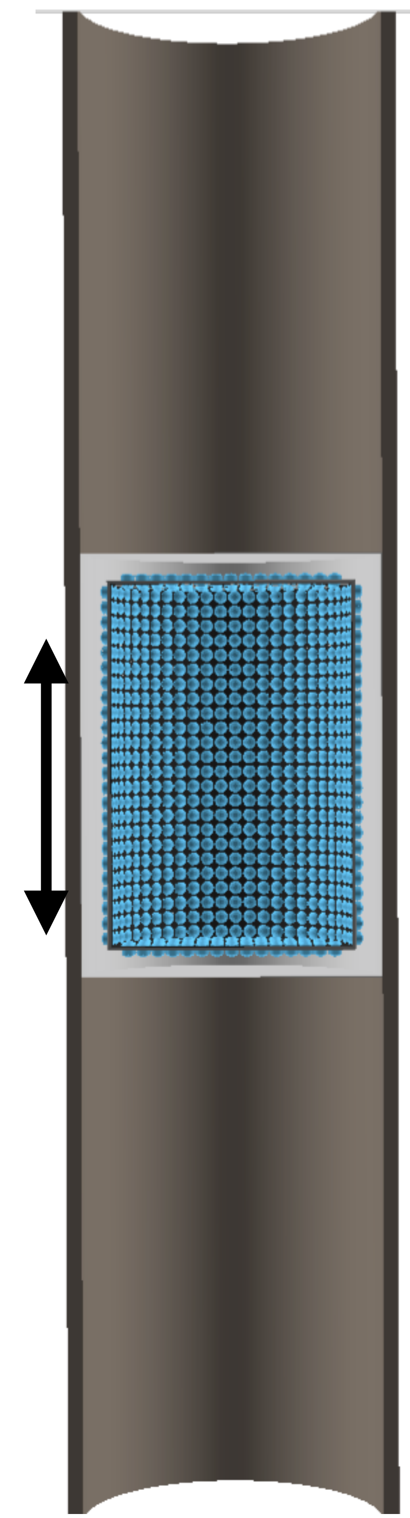


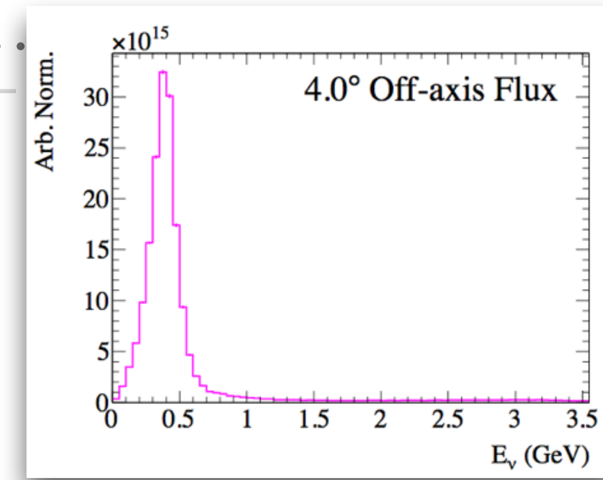
- Even something as simple as Cherenkov photons from muons shows differences in different simulation code
- Impact on reconstructed quantities (vertex) can be large
- Detailed investigation of models may help resolve these types of issues
- Can also benefit from direct measurements!

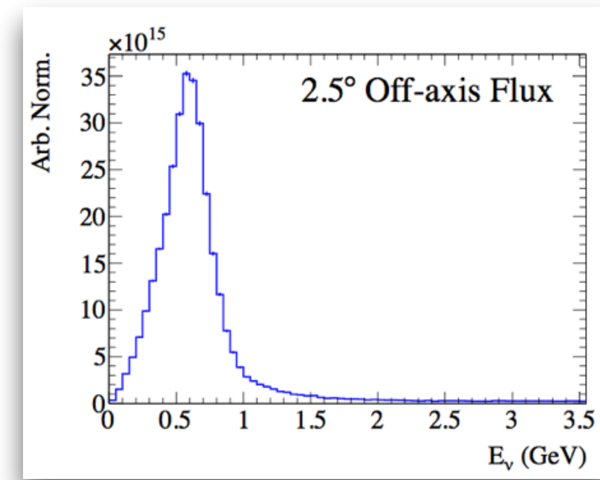
THE J-PARC E61 EXPERIMENT

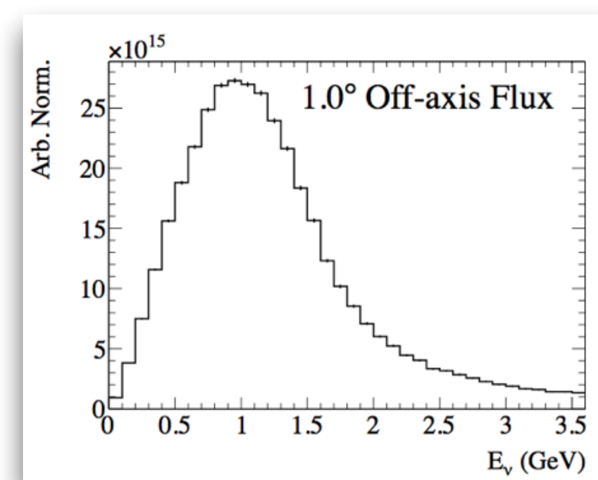
- Detector movings, changing off-axis angle to measure energy response in neutrino interactions
- Inner detector diameter is 8 m
- Inner detector height is 6-10 m depending on location
- Use multi-PMT photo-detectors:









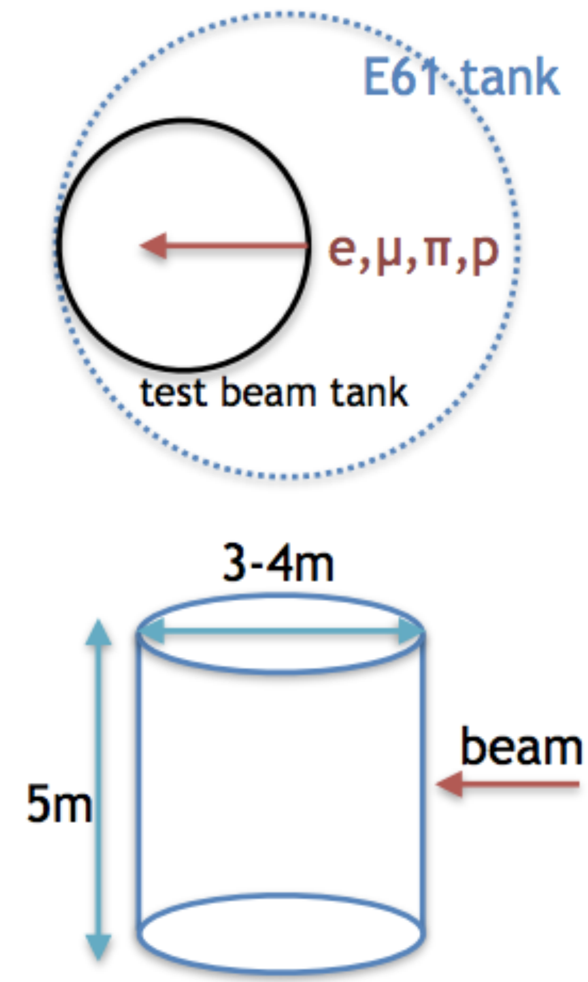


CALIBRATION IN E61 (AND HYPER-K)

- We plan to implement a "bottom-up" calibration approach
  - Define parameters describing systematic uncertainties in the detector model.
    - Light scattering/attenuation, reflective properties, PMT positions/response, etc.
  - Use ex-situ calibration, in-situ calibration and physics control samples to constrain systematic parameters
    - Ex-situ measurements of PMT response, in-situ light sources, Michel electrons, π^0, stopping/crossing muons, etc.
- **How do we demonstrate that the bottom-up calibration approach converges (to the right answer)?**
  - We typically don't have samples of independently known particle type and energy in the detector

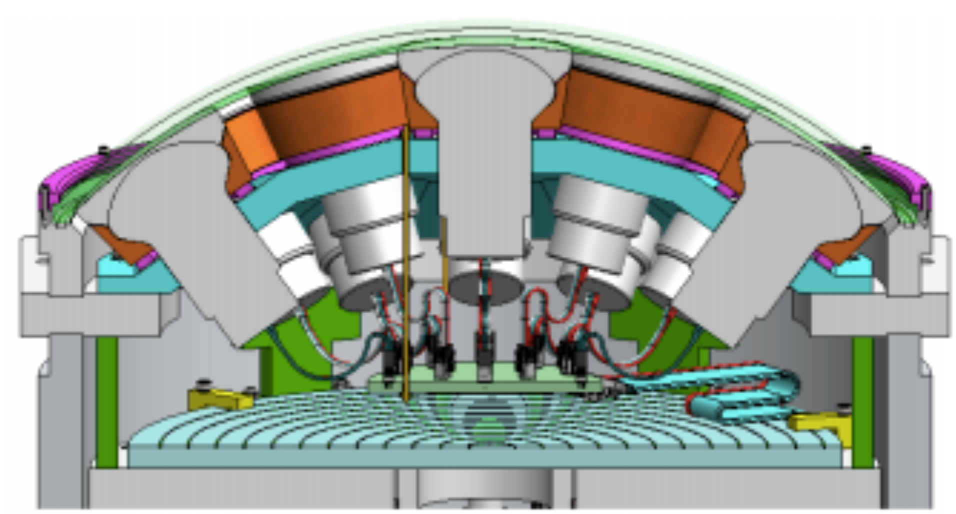
PUT THE DETECTOR IN A TEST BEAM!

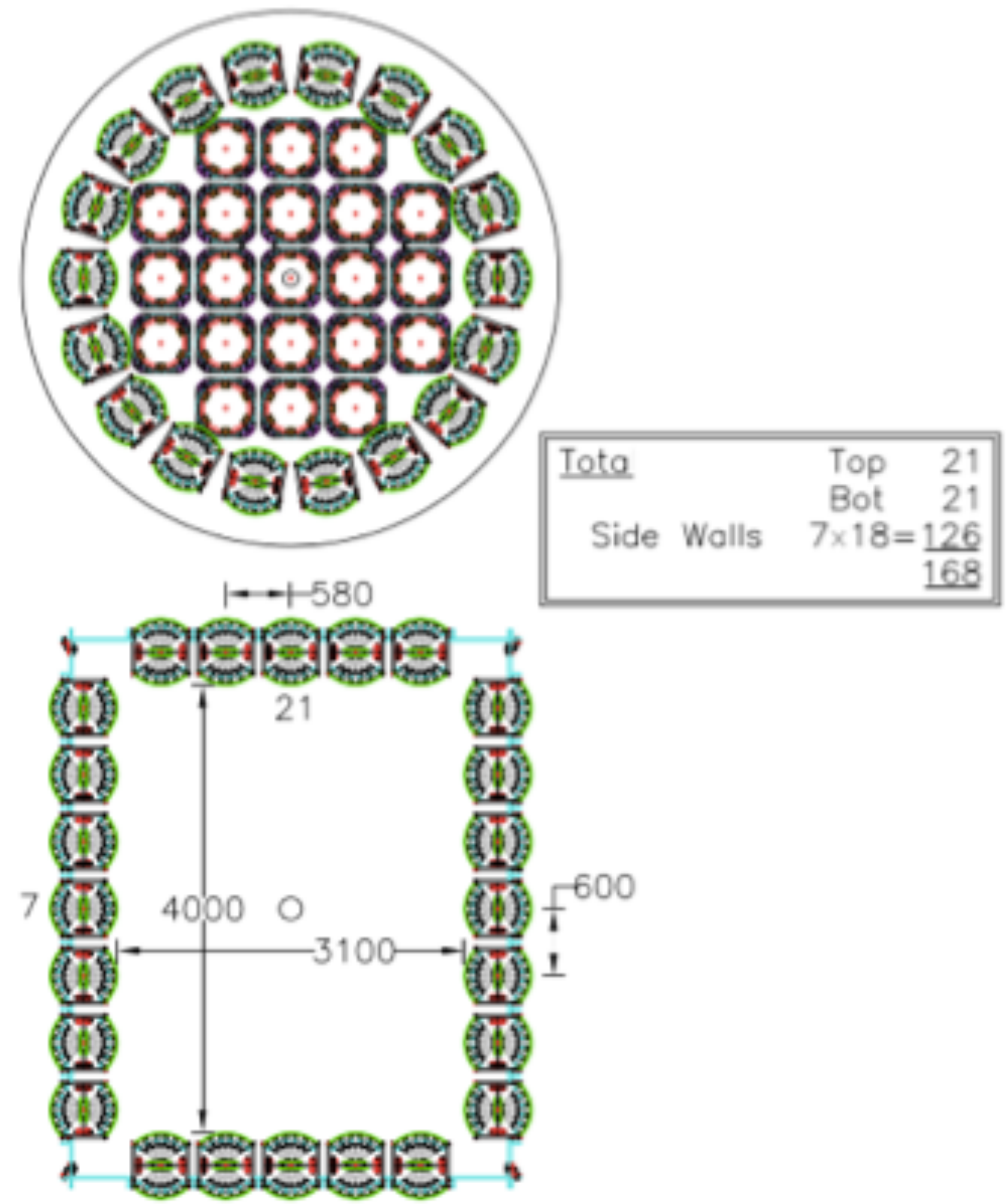
- Best solution is to put the detector in a **charged particle test beam where particle type and energy are known**
- For E61, full detector is not practical (at this time)
  - Scaled version of 3-4 m diameter will have particle path lengths similar to interactions at the center of full detector
- Goals:
  - Test critical components for full E61
  - Prove bottom-up calibration of WC detector
  - Measure physics processes, such as Cherenkov light profile and pion scattering



EXAMPLE ARRANGEMENT FOR THE TEST BEAM

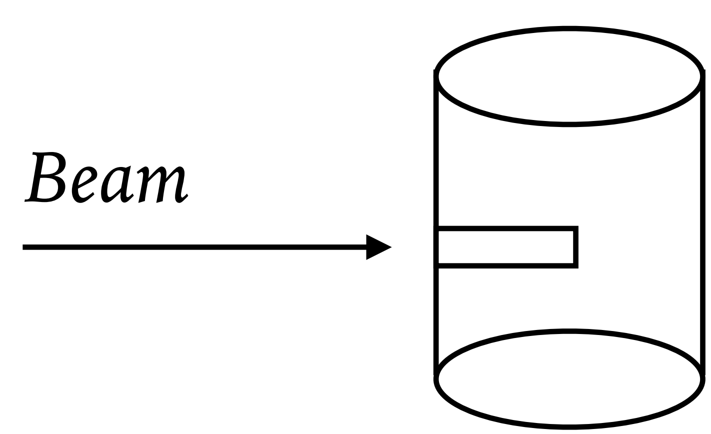
- For a test experiment of this size, we need ~150 multi-PMT modules
- We don't plan to test the outer-detector performance
    - Design will be updated to account for new proposal for half mPMT modules





WHAT ARE THE REQUIREMENTS FOR THE TEST BEAM

- We want a test beams with particle momenta from ~140 MeV/c (muon Cherenkov threshold) up to ~1200 MeV/c
- Particle types should include e, p, $\pi^{\pm}$, $K^{\pm}$, $\mu^{\pm}$
    - Doing $\pi^{\pm}$ and $\mu^{\pm}$ in same beam configuration is challenging - likely need a dedicated beam configuration for muons
- Mis-ID rates for particles in the beam should be <1%
- Bias in momentum measurement of particles in the beam should be <0.5%
    - Aim for momentum resolution at the 1-3% level
- Injection of particles into center of detector may be desired - need an "air"tube

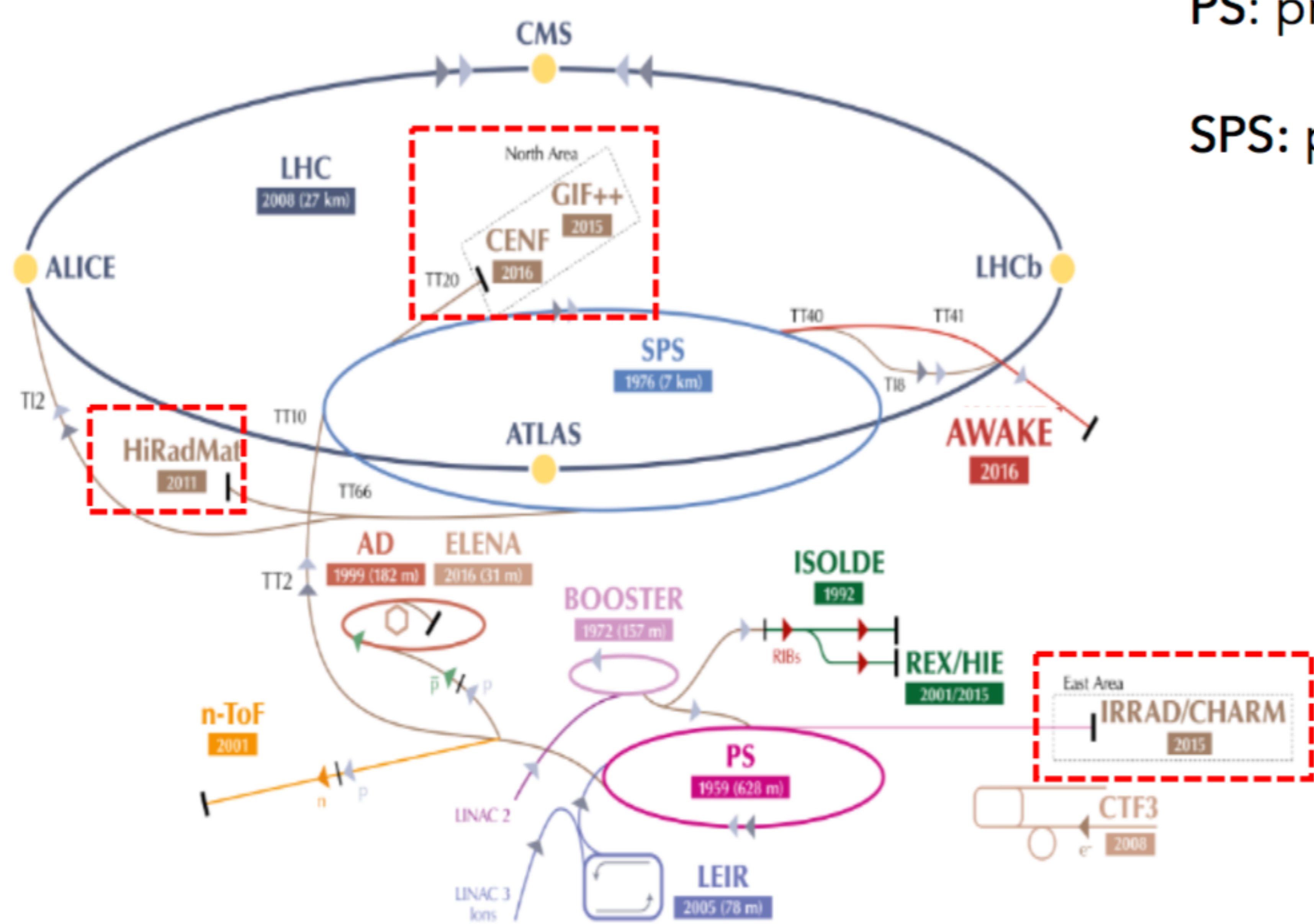


WHERE DO WE DO THE TEST EXPERIMENT?

- This test experiment requires tertiary beams with with momenta ranging from ~140 MeV/c to ~1200 MeV/c
- Primary candidate locations are CERN and Fermilab
- New tertiary beams may be necessary to go as low in momentum as we prefer
- Have had discussions with responsible people at Fermilab (M. Rominsky) and CERN (S. Bordoni)
  - Tertiary beam area at Fermilab is currently not taken for the time period of interest (2021-2022)
    - We can proceed with proposal submission at Fermilab
  - Discussion for CERN was more preliminary (see following slides)

CERN ACCELERATORS

- Test beams from the PS or SPS are possible



PS: protons/ions @ 24 GeV/c/Z

SPS: protons/ions @ 400 GeV/c/Z

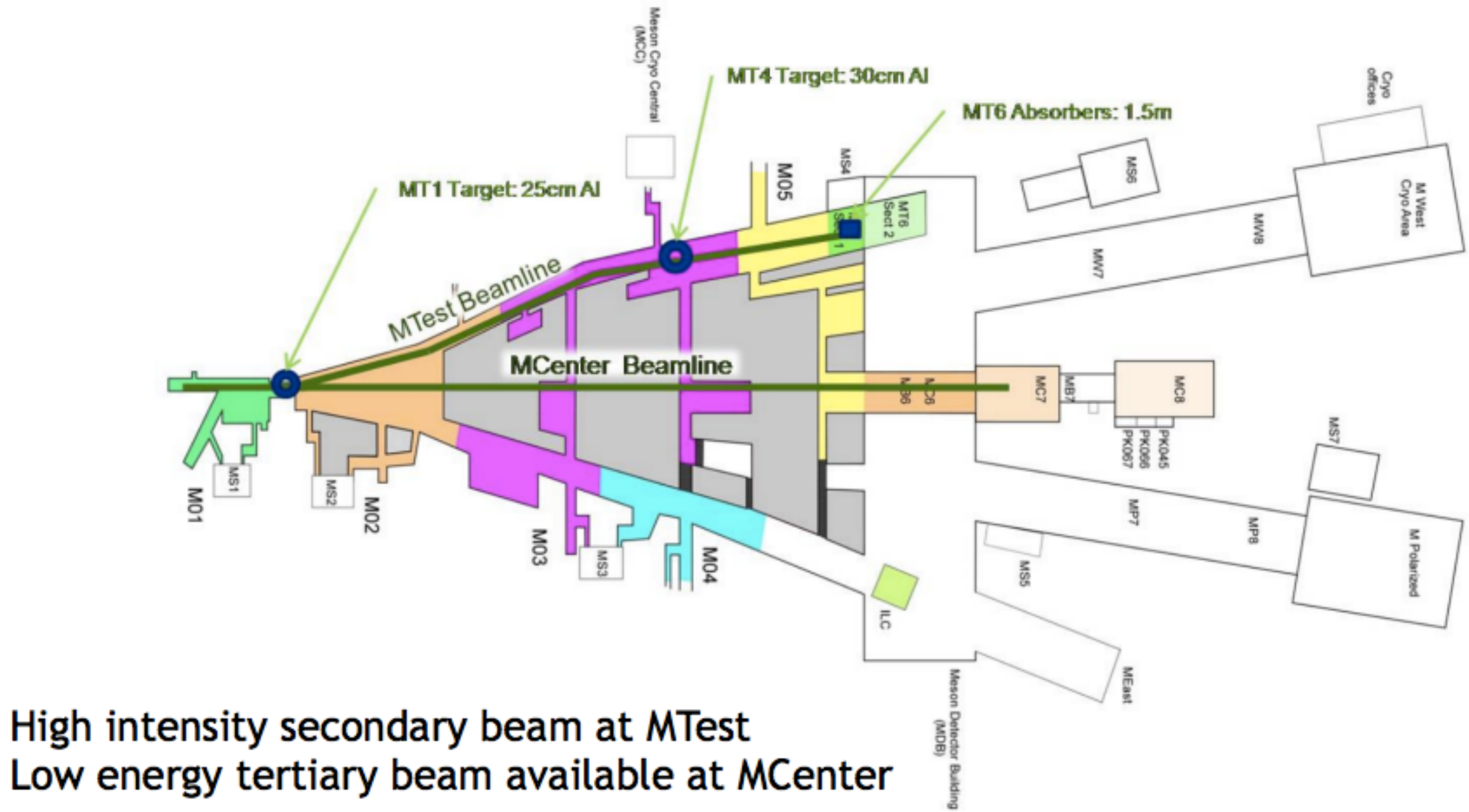
SUMMARY OF CERN BEAMLIENS

S. Bordoni

Area	East Area		EHN1-ext (NP)		EHN1 – North Area			
Beam line	T9	T10	H2VLE	H4VLE	H2	H4	H6	H8
p_{min} (GeV/c)	0.5	10	0.4	0.4	10	10	10	10
p_{max} (GeV/c)	0.5	6	12	7	400	400	205	400
Particles	Mixed. h or e-enr. Tgt Some μ		Mixed. h or e-enr. Tgt		e,π ,μ Quite pure beams			

- Currently no beam line has a minimum momentum down to our requirement
- According to S. Bordoni, other neutrino related users have asked for lower momentum beams
- May be possible to work with CERN to set up a low momentum test beam

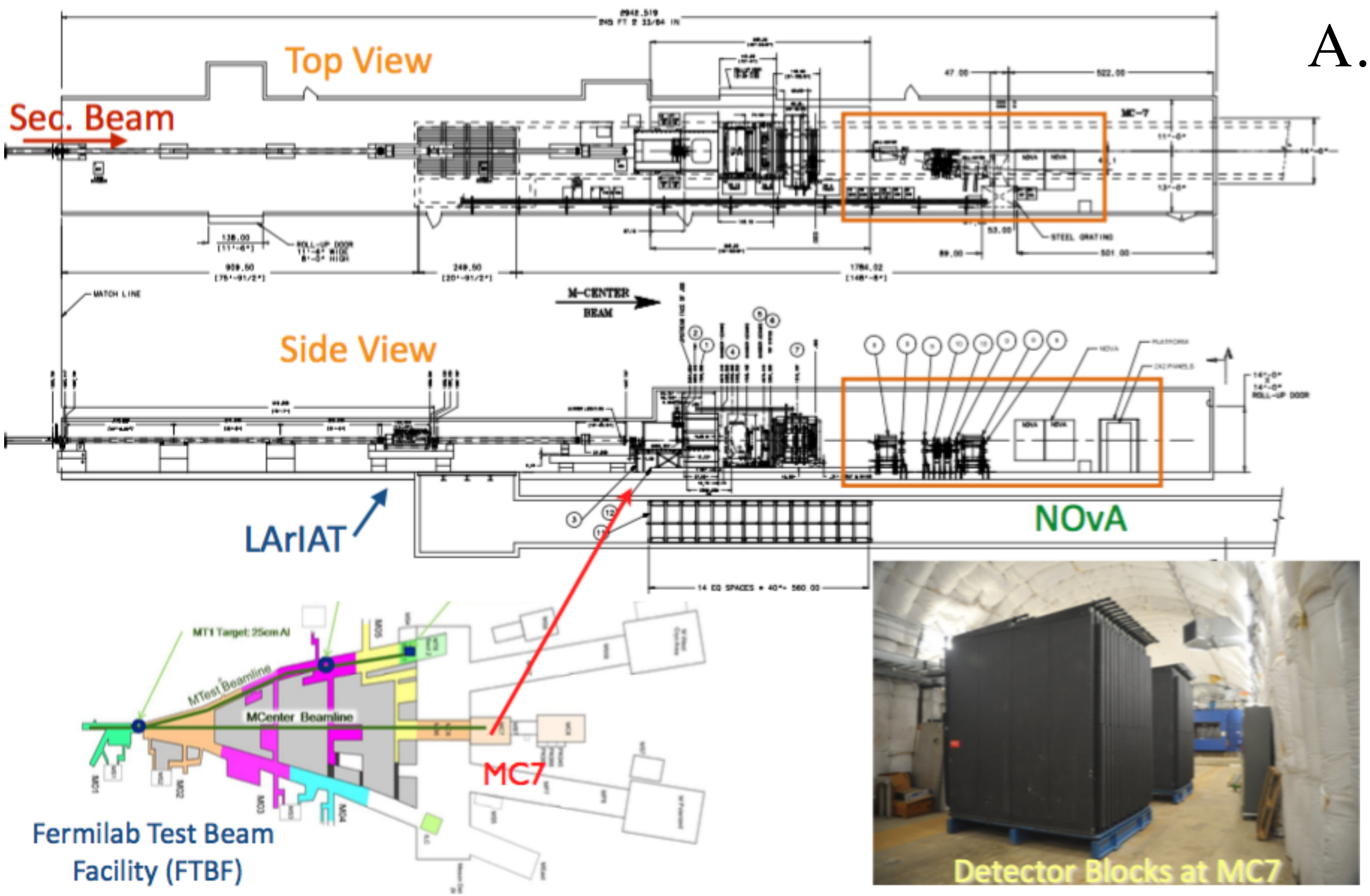
FERMILAB TEST BEAMS



- MCenter is the default for tertiary beams
  - Some limitations for experimental area size and access
- MTest has taller experimental hall and access through removable roof
  - Would require new tertiary beam

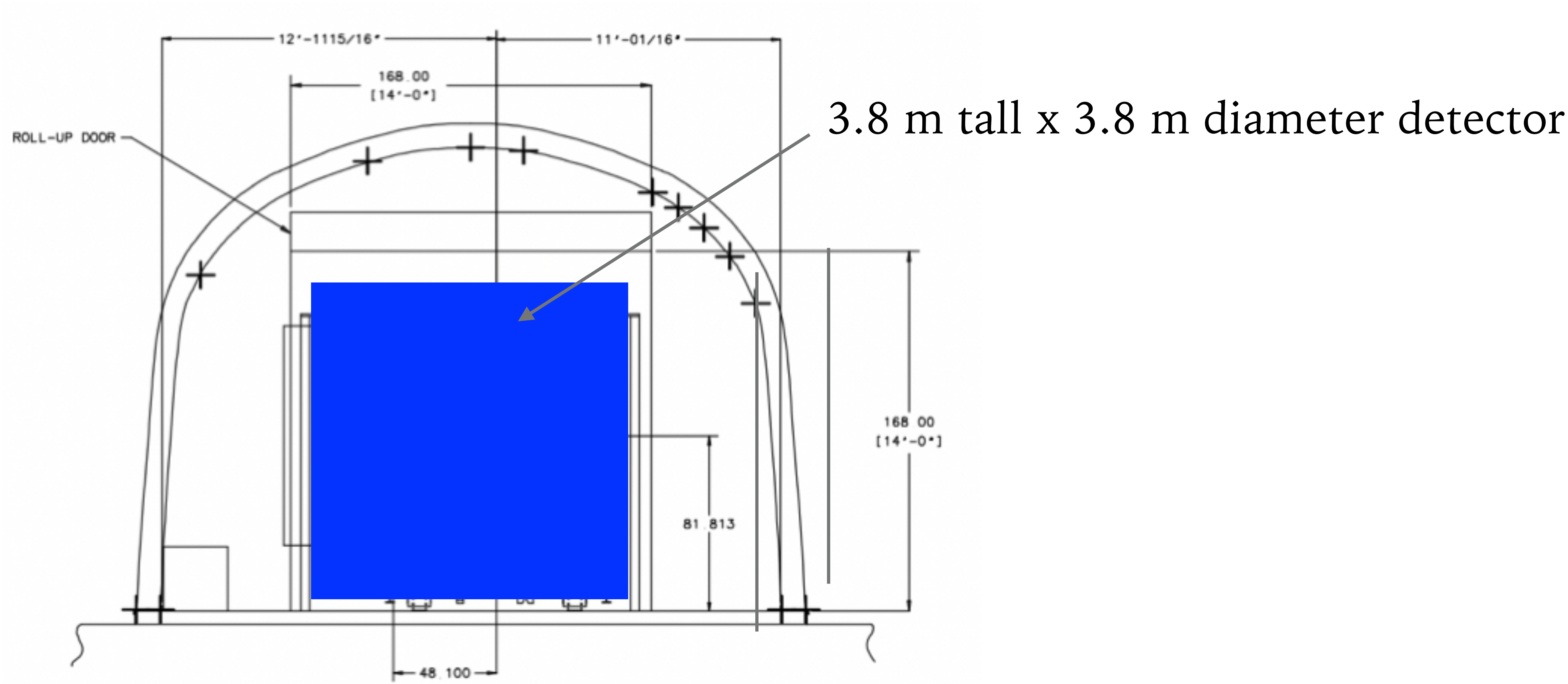
FERMILAB TEST BEAM (MCENTER)

A. Sousa



- ➤ From now through 2019, the MC7 area at MCenter is used by NOvA for a test experiment
- ➤ Area is currently not taken after 2019

DETECTOR SIZE & MASS



- A ~4 m sized detector is a tight fit for this area.
- Space for access at the top of the detector is limited
- Motivation for pursuing the MTest option

MCENTER BEAM PROPERTIES

- Multiple test experiments have run in MCenter, including MINERvA and LArIAT
- MINERvA: https://doi.org/10.1016/j.nima.2015.04.003
- LArIAT: https://arxiv.org/pdf/1406.5560.pdf

Beam Configuration for MINERvA Test Experiment

16 GeV pion secondary beam

16 degree production angle

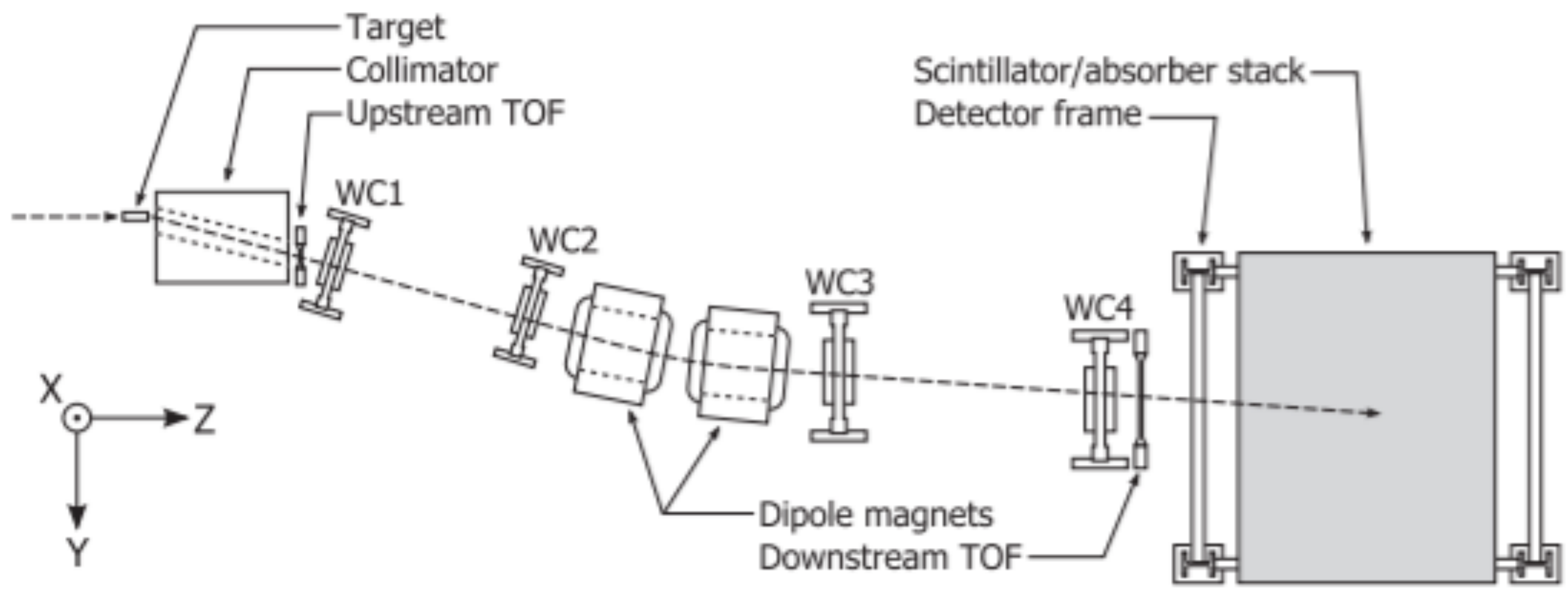
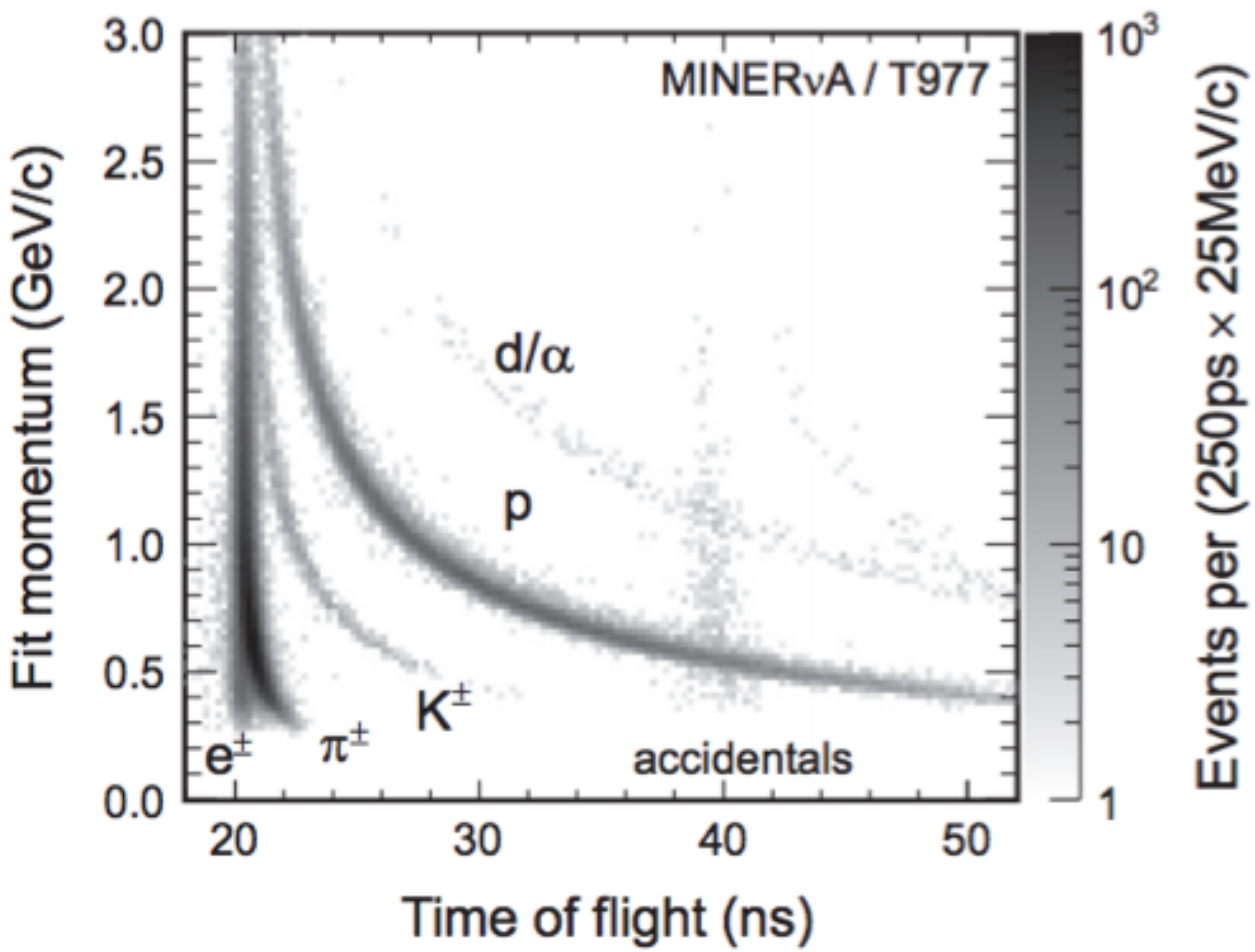


Fig. 1. Diagram of the beamline built for this experiment, viewed from above with the beam going from left to right.

MINERVA TEST EXPERIMENT BEAM

- Momentum range used in MINERvA experiment is 0.35-2.0 GeV/c
- TOF system has a path length of 6 m and timing resolution of 200 ps

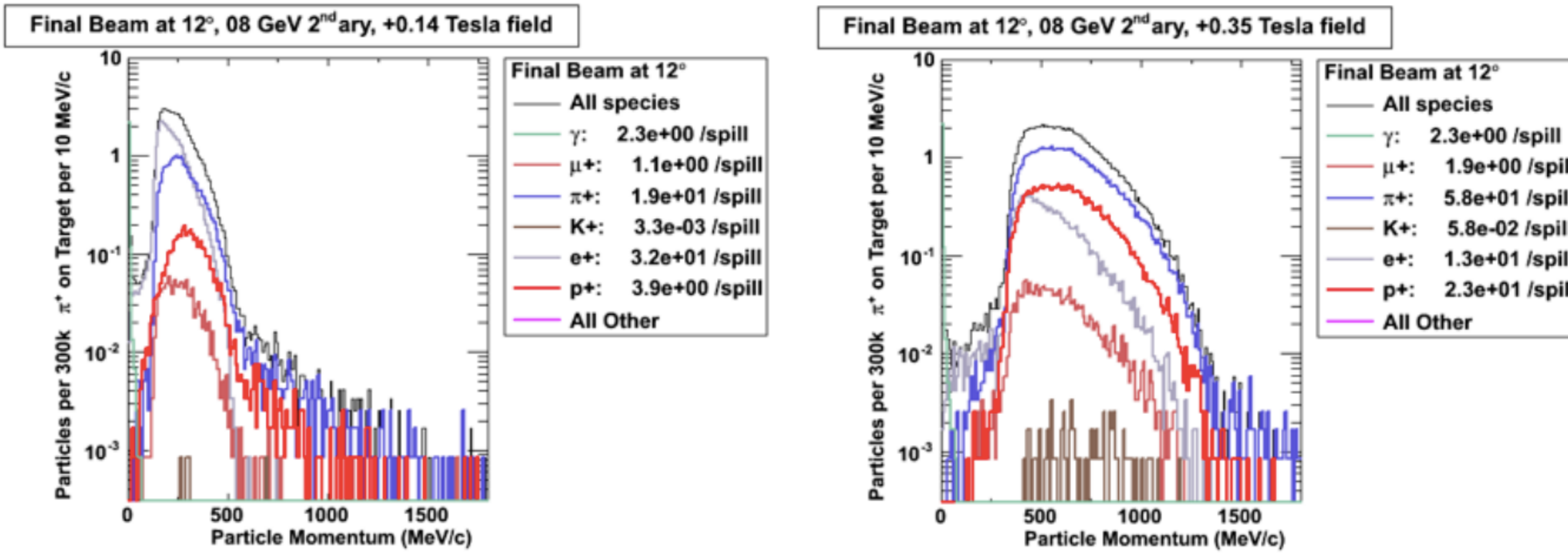


- Good proton/kaon/pion separation below 1.0 GeV/c
- Need alternative approach for electron ID
  - Cherenkov threshold detector with low index of refraction aerogel

NIMA,Vol. 798, pp. 28-42 (2015)

LARIAT BEAMS

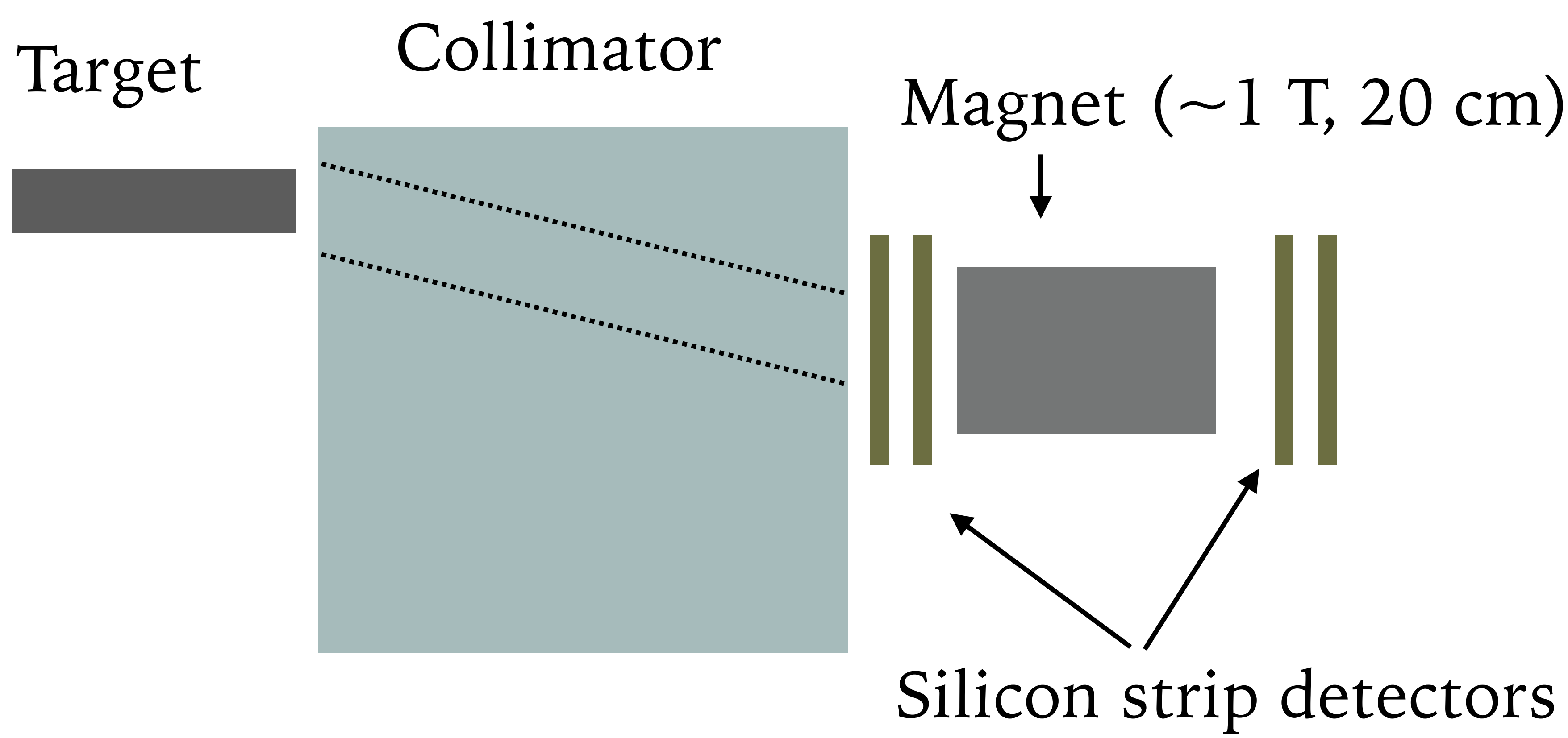
https://arxiv.org/pdf/1406.5560.pdf



- Beam momenta down to at least 200 MeV/c have been used by LArIAT
  - At low momentum pion fraction of ~30% is achieved
- Higher energy beam configuration is primarily pions and protons
- For muons configuration with far upstream tertiary target is needed

A COMPACT SPECTROMETER

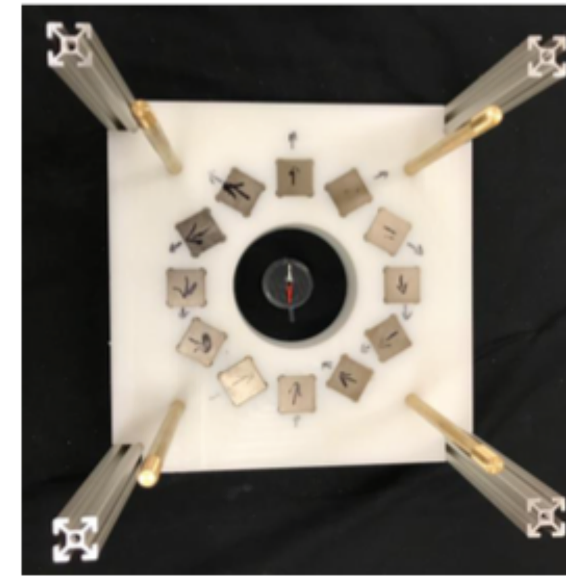
- We want to measure the particle momentum event-by-event with resolution in the 1-3% range
- One proposal is compact spectrometer using Halbach cylinder permanent magnet and silicon tracking detectors
  - Proposed with emulsion tracker previously (NIMA, Vol. 592, pp 56-62 (2008))



HALBACH ARRAY MAGNET

- Arrange permanent magnets to achieve a strong magnetic field in the desired region

Halbach array built by M. Lang at U. Winnipeg



NIMA, Vol. 592, pp 56-62 (2008)

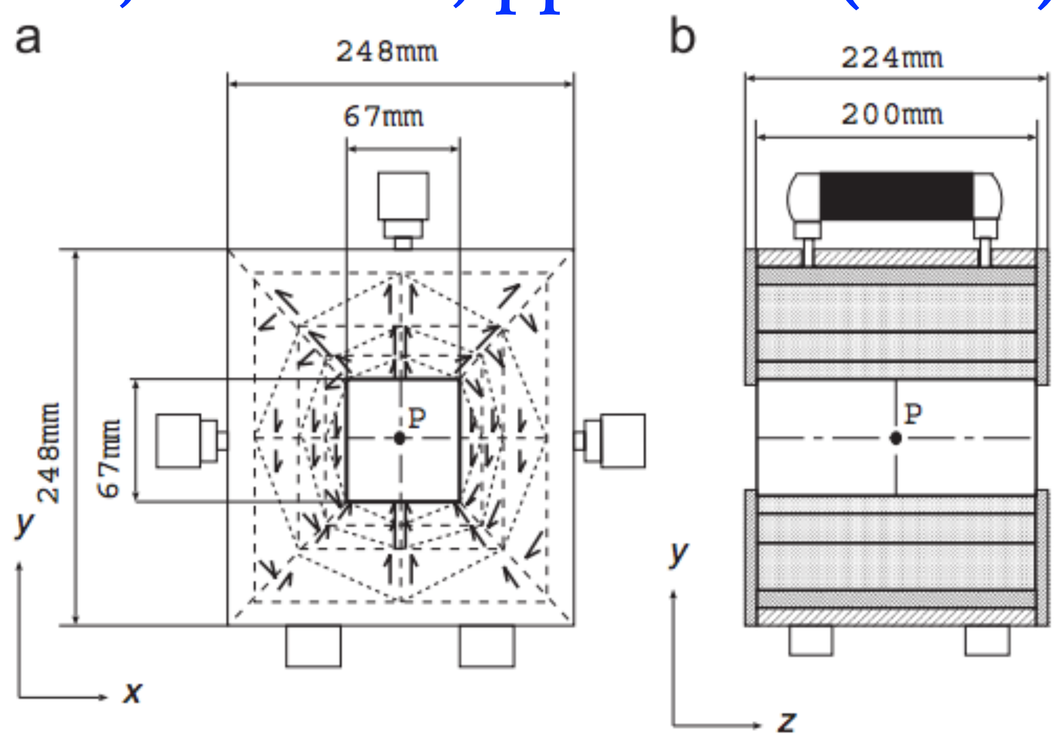


Fig. 1. The configuration of the compact permanent magnet viewed from downstream (a) and from the side (b).

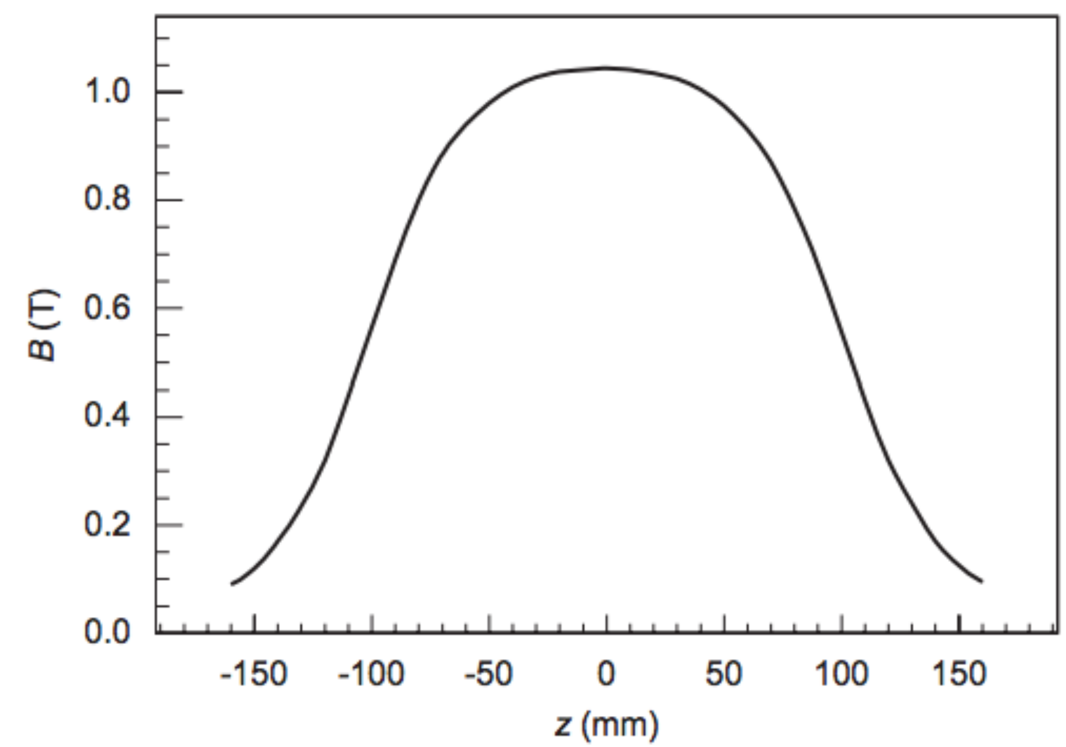
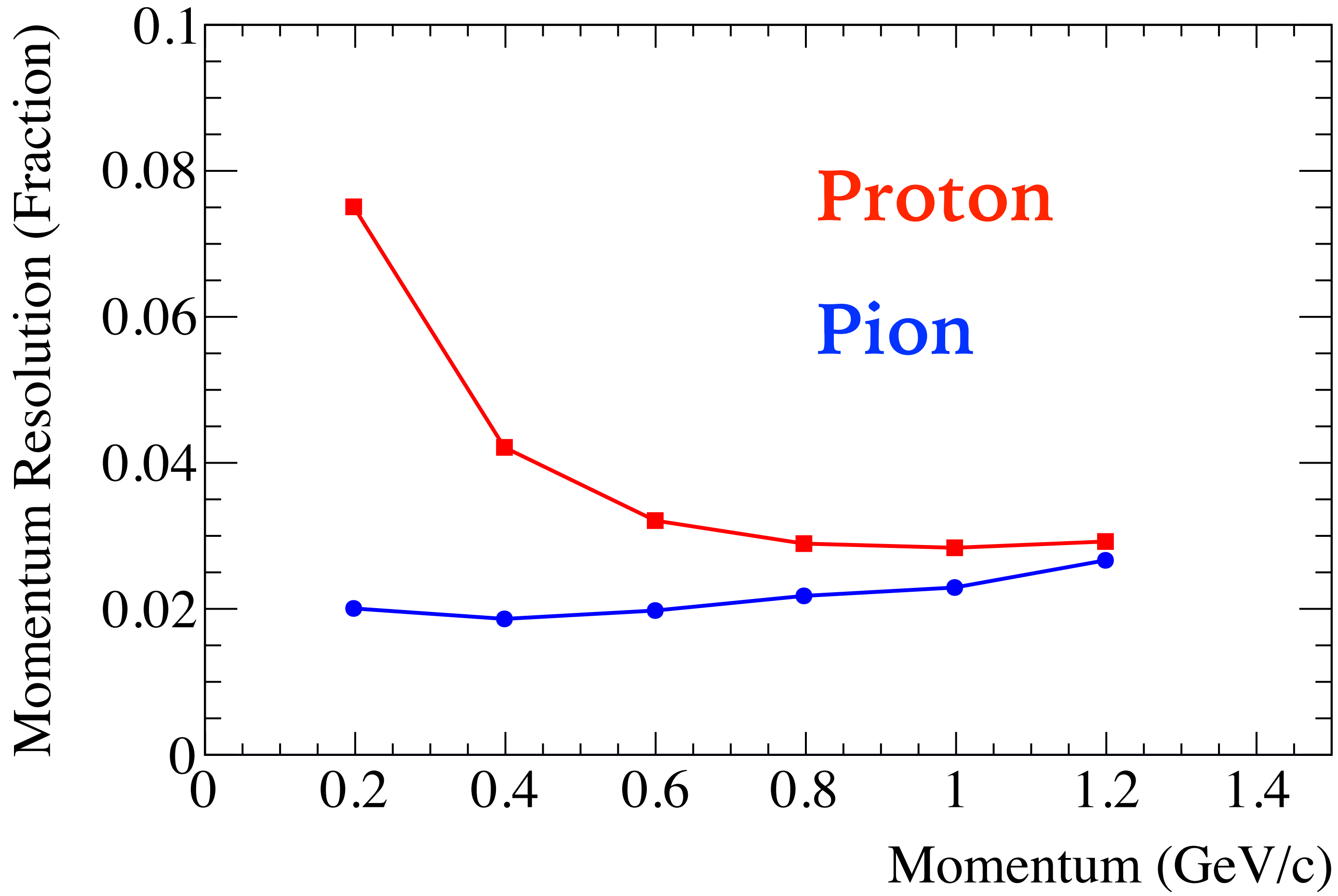


Fig. 2. Magnetic field B along the central line ($x = y = 0$). The size of magnet material is from -100 to 100 mm.

- ~1 T field over 15 cm length is possible

SPECTROMETER PERFORMANCE STUDY

- Consider silicon strip detectors with 1-2 mrad angular resolution (limited by multiple scattering) and 20 micron spatial resolution
- Assume 1 T field over 20 cm

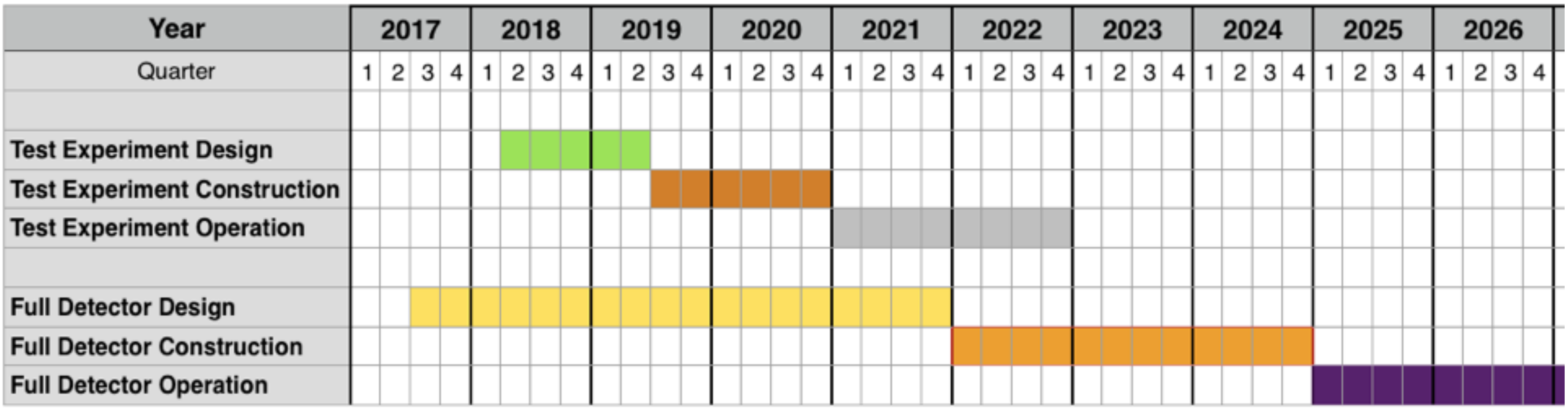


- Can achieve 2% resolution for pions
- Proton resolution becomes worse at low momentum due to multiple scattering - supplement with precision TOF

STATUS OF THE TEST EXPERIMENT

- Studies of the performance of the test experiment are ongoing
  - Stick around for the E61 meeting tomorrow for R. Fukuda's report if interested
- Current plan is to prepare a proposal for the test experiment at Fermilab this year
- We want collaborate with other groups working on WC detectors and photosensors
- This test experiment has the potential to be a general purpose testbed for this community
- We are also open to the possibility of the test experiment at CERN
  - If there is interest, please let us know and we can have further discussion with S. Bordoni

SECHEDULE



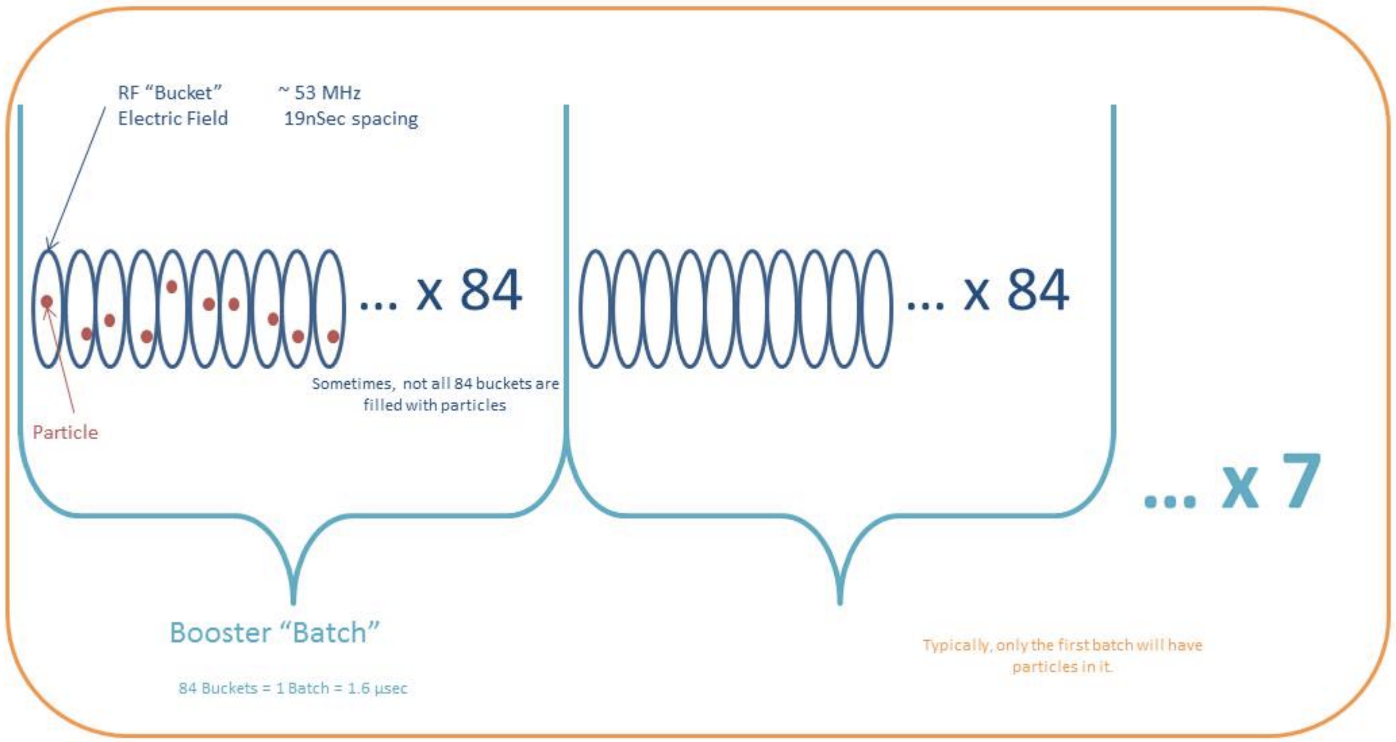
- ➤ Schedule will be driven by completion of mPMT design and acquisition of funding to build mPMT modules
- ➤ Aiming for data taking on 2021-2022 period

SUMMARY

- Calibration of detectors to the 1% level will be critical for the Hyper-K experimental program
  - Includes the Hyper-K detector and E61
- A water Cherenkov experiment in a charged particle test beam provides a test bed to study detector calibration and prove 1% level calibration with known particle fluxes
- The E61 collaboration plans to perform a 50 ton scale test experiment at Fermilab or CERN
- **We are interested in collaborating with others who can benefit from a water Cherenkov detector in a test beam!**

THANK YOU

BEAM TIMING STRUCTURE



7 Batches = 1 MI Cycle = 11.2 microSec

- 19 nanoseconds = 1 RF bucket (53 MHz)
- 1.6 microseconds = size of booster (84 RF buckets), called a "batch"
- 11.2 microseconds = size of Main Injector (7 Batches)
- 4.2 seconds = length of spill
- 60 seconds = approximate rep rate of spill

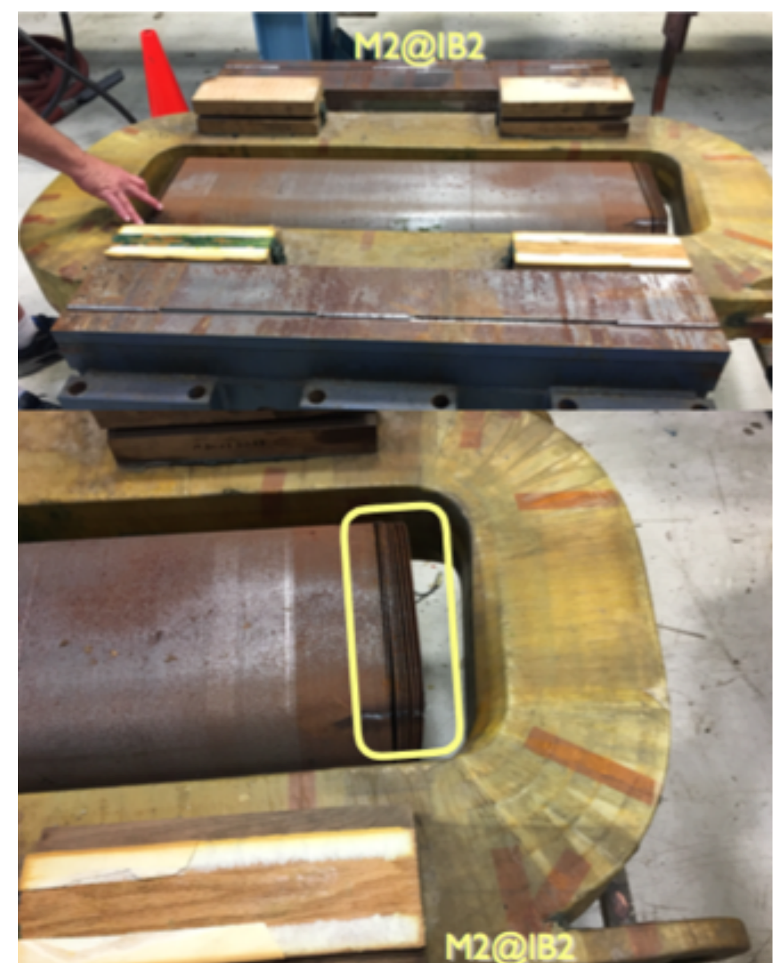
NOVA TEST EXPERIMENT

- NOvA plans a test experiment in MCenter
- Will operate into 2019
- Located downstream of LArIAT and will use a new tertiary beam setup
- Replace the 2 20 inch dipole magnets with one 42 inch dipole magnet

There are 2 42 inch dipole magnets available

At least one will be refurbished

Second may be refurbished as a spare

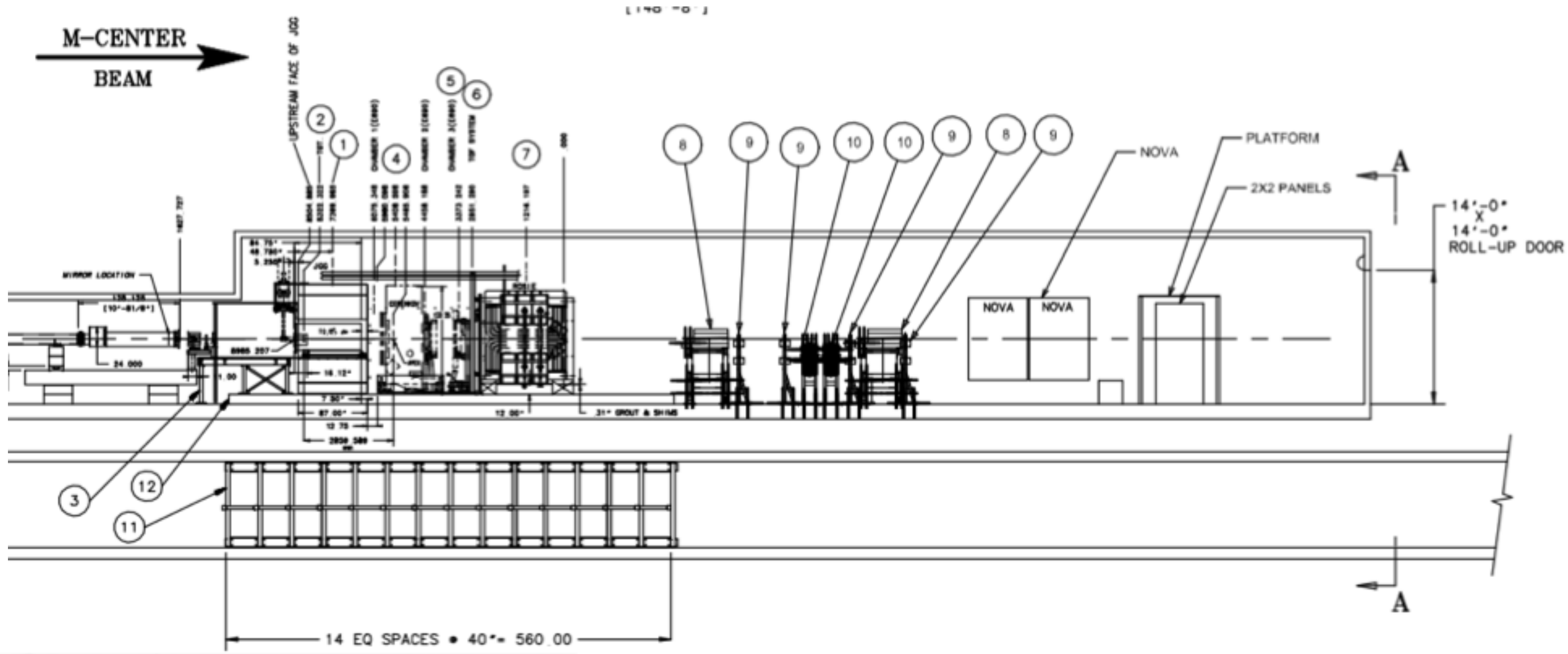


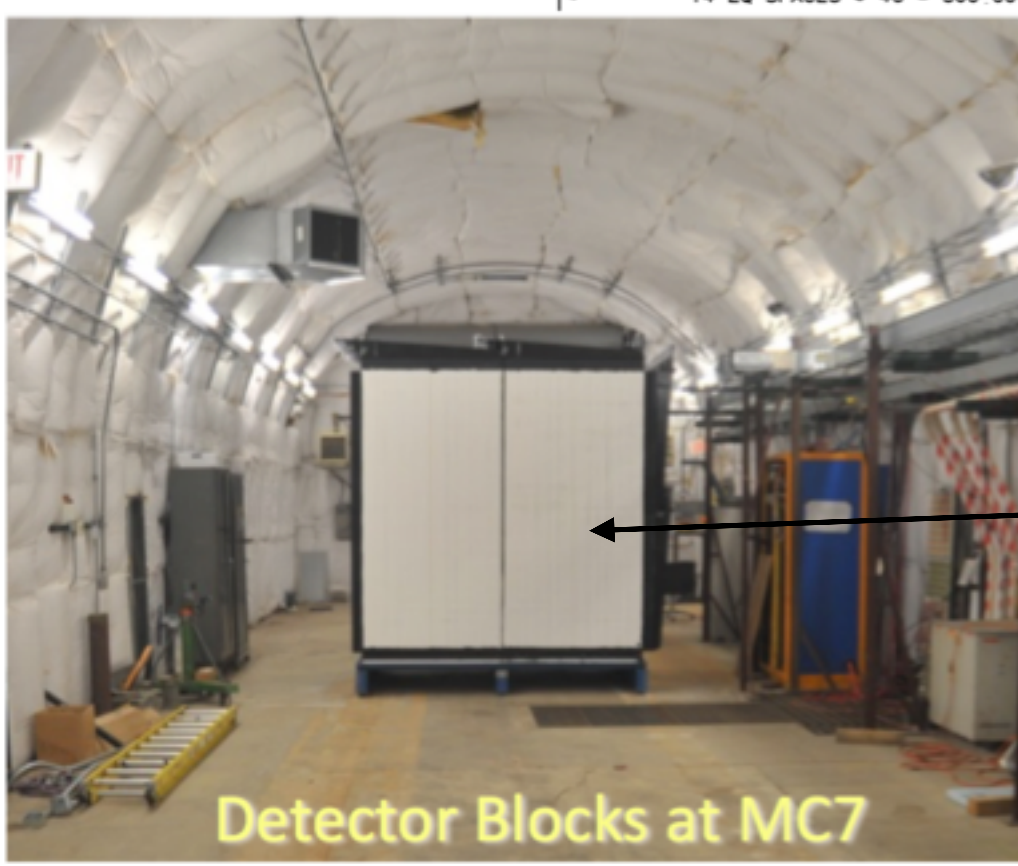
CURRENT NOVA SCHEDULE

A. Sousa

- FY '17 - Complete procurement and production of components for tertiary test beam line
- Dec. '17 - Feb. '18 - Installation of tertiary test beamline
- Jan. '18 - Beam line and detector DAQ integration testing
- Feb. '18 - March '18 - Commission tertiary beamline components and DAQ, if MCenter beam available
- March '18 - April '18 - Install detector at MC7, survey
- May '18 - Oct. '18 - Detector outfitting and commissioning
- Dec. '18 - Jan '19 - Commission and tune beam line + detector
- Jan. '19 - June '19 - Operations and data taking

DETECTOR HALL





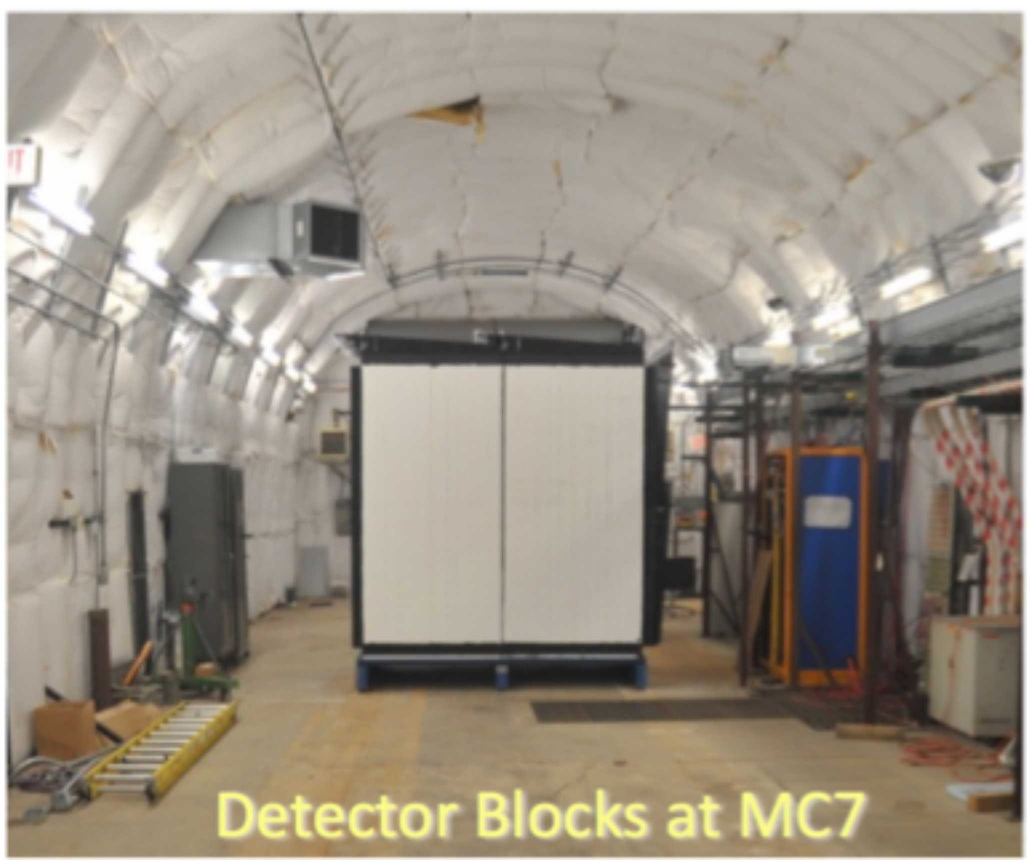
- Would use the area being used by NOvA

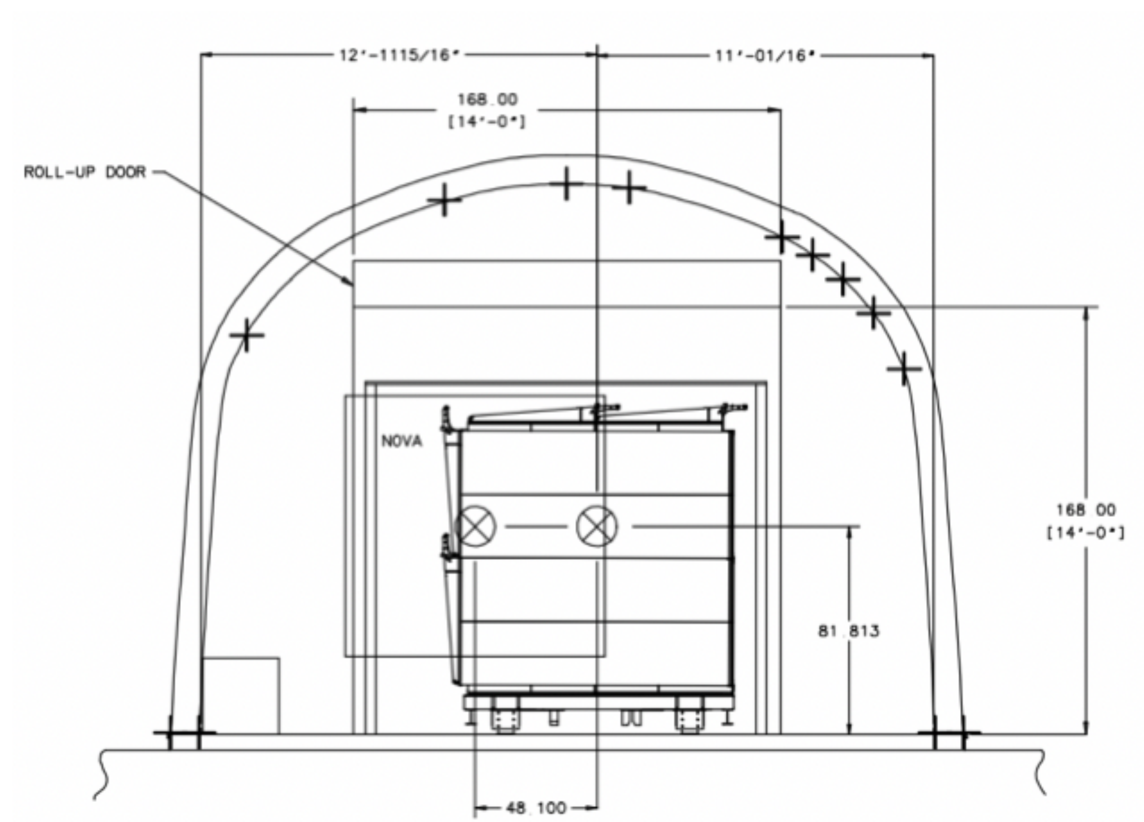
2.6 m x 2.6 m

TEST EXPERIMENT AT MC7 AREA

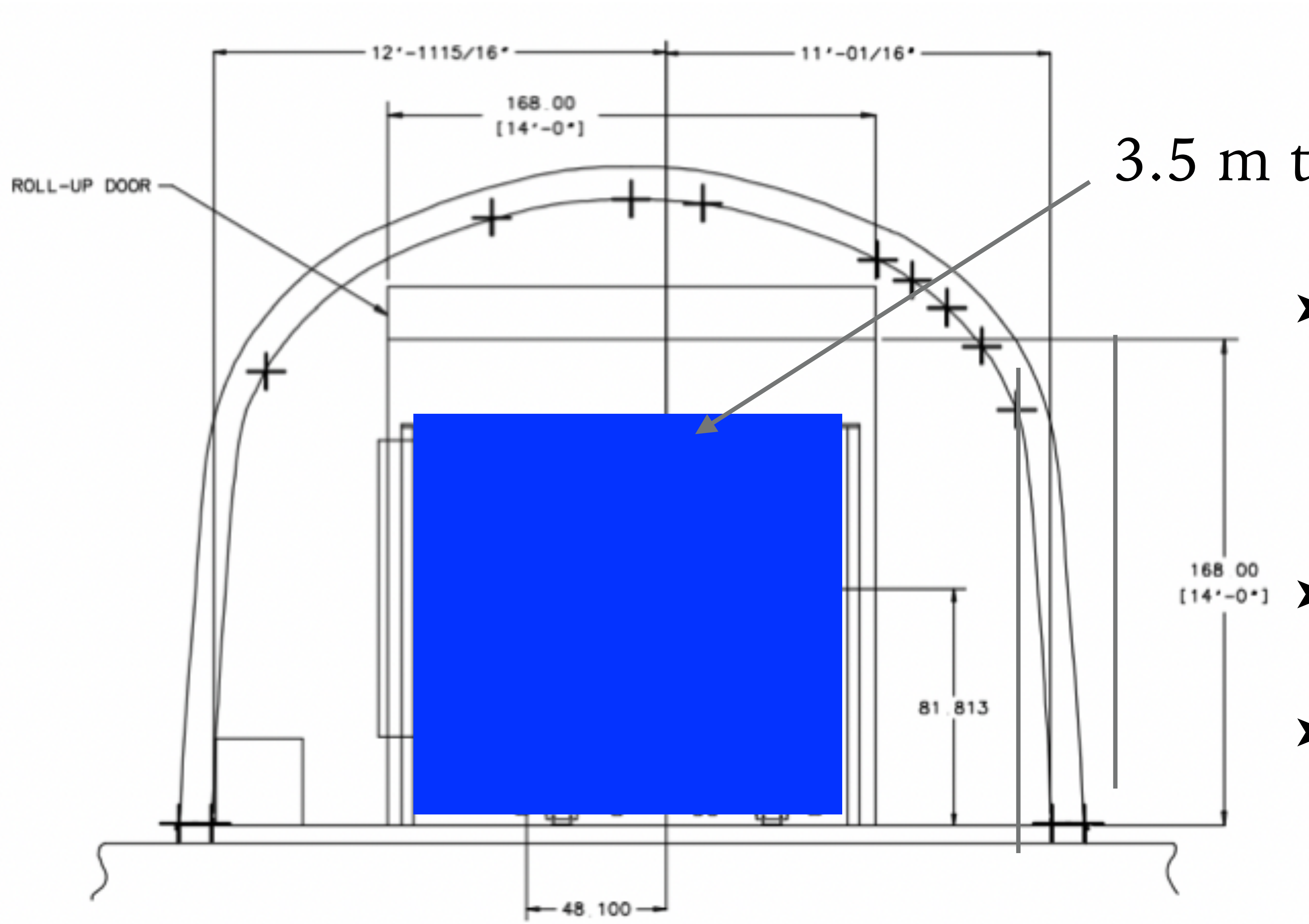
- Area can house a detector of size ~4 m x 4 m x 4 m (3 m height may be best to allow overhead access

- Test beam facility managers have given positive feed-back to possibility of water Cherenkov test experiment in MC7





DETECTOR SIZE & MASS

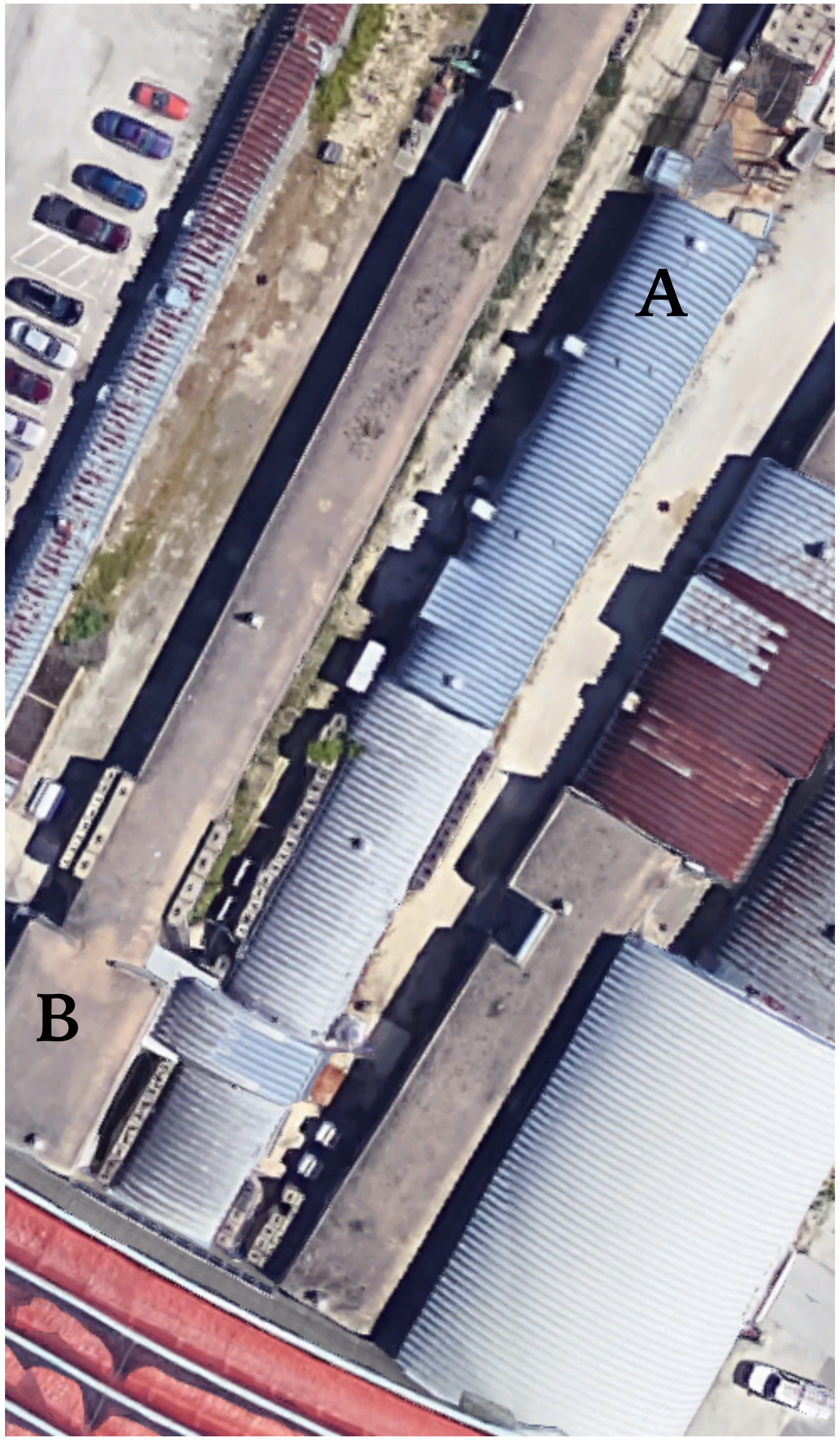


3.5 m tall x 3.8 m diameter detector

- Fits in the detector hall with overhead space for installation
- Fits through the rolling door
- Is this ok for measurements?

- Assuming mass of detector is equivalent to water mass: 40,000 kg

DAQ AND LOW VOLTAGE RACKS



- The DAQ and low voltage can either reside in the experimental hall (A) or a counting room (B)
- In the counting room, the cable run will be ~60 m
- Need to know the amount of rack space and total power consumption for DAQ and low voltage
  - ~3 W power consumption per PMT
    -> 300-500 W total
    -> Low voltage power requirements and racks space requirements are small
- Need to know if we should use A or B location

POTENTIAL TEST EXPERIMENT LOCATION

- We want a test beam with particle momenta from ~140 MeV/c (muon Cherenkov threshold) up to ~1200 MeV/c
- Test beams from proton synchrotrons are needed to cover the full range
  - Not available at J-PARC
  - CERN:

Area	East Area		EHN1-ext (NP)		EHN1 – North Area			
Beam line	T9	T10	H2VLE	H4VLE	H2	H4	H6	H8
p_{min} (GeV/c)	0.5	10	0.4	0.4	10	10	10	10
p_{max} (GeV/c)	0.5	6	12	7	400	400	205	400
Particles	Mixed. h or e-enr. Tgt Some μ		Mixed. h or e-enr. Tgt		e,π ,μ Quite pure beams			

No test beams at CERN currently reach the low momentum range we are interested in