Simulation for LArTPC Experiments

LUCAS MENDES SANTOS

ADVISOR: CARLOS ESCOBAR

FINAL PRESENTATION – SUMMER STUDENT PROGRAM

Contents

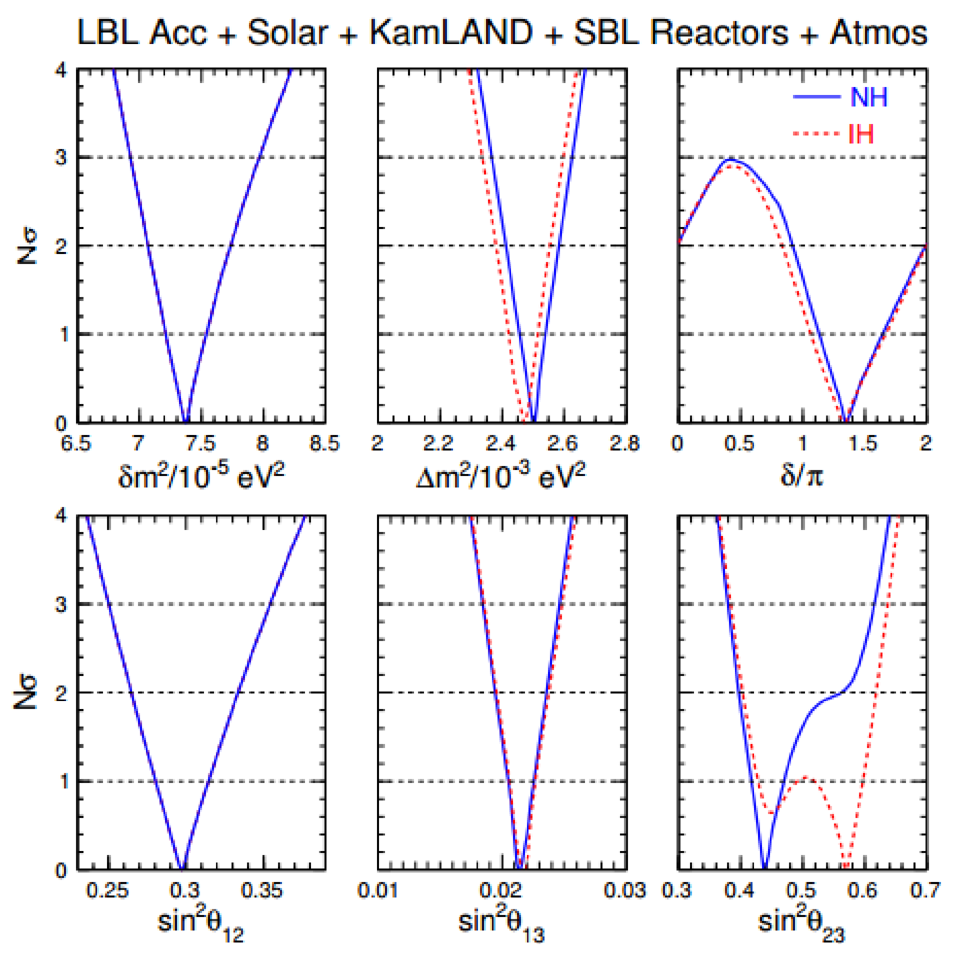
- Neutrinos + LArTPC
- Simulation progress for LArIAT
- The Sterile Neutrino and the SBN Program
- Simulation for SBND
- Conclusions

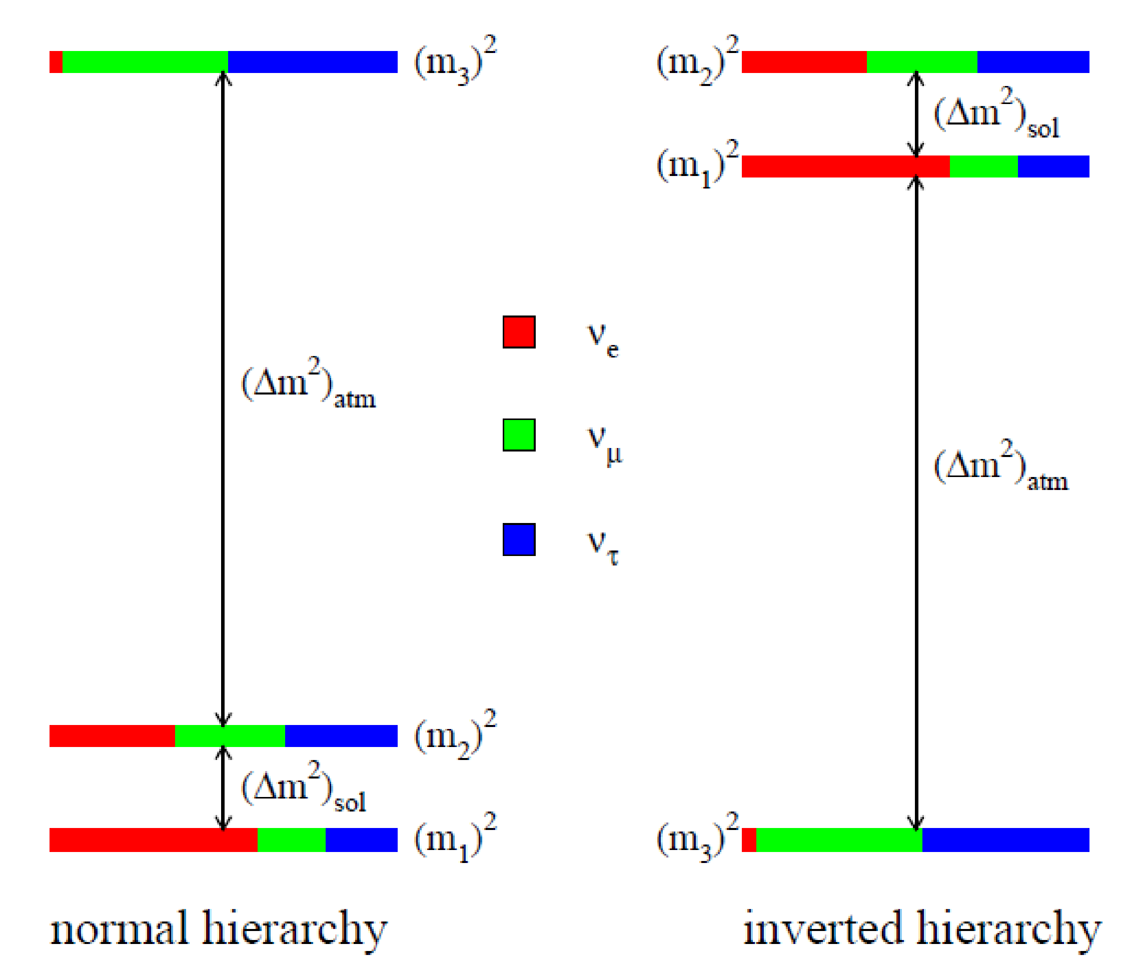
Neutrinos – What we know today

- Lepton with no electric charge, (~~no mass~~ → Standard Model) very little mass and spin-1/2
- Interacts through the weak and gravitational interactions
- Can be represented in its **flavor** eigenstates or **mass** eigenstates
- Due to been massive particles they **oscillate**!

$$P(\nu_\alpha \rightarrow \nu_\beta) = \left| \sum_j U^*_{\beta j}\, e^{-\frac{i m_j^2 L}{2E}}\, U_{\alpha j} \right|^2$$

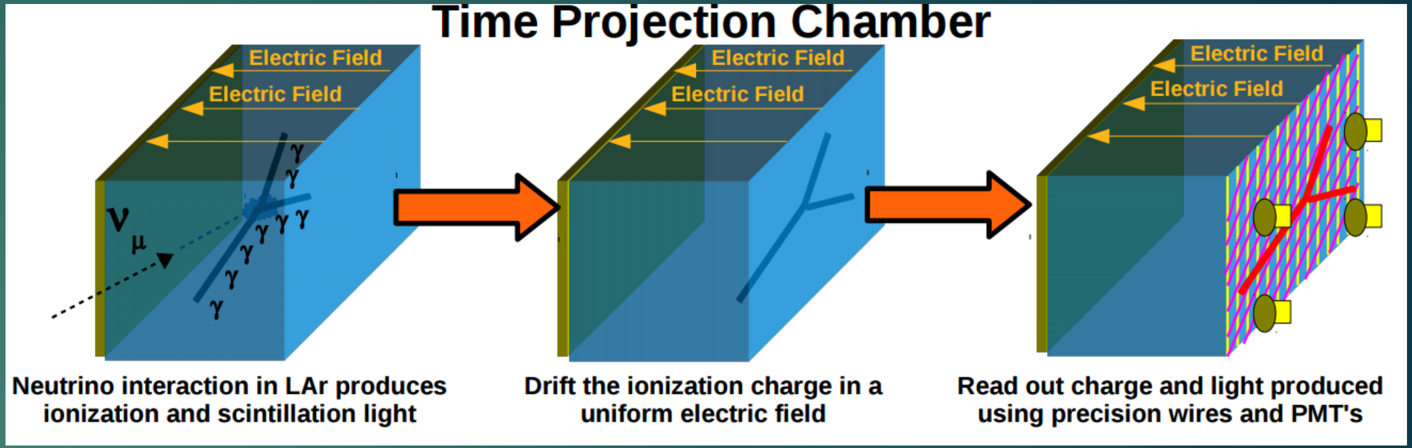
Neutrino Physics Today

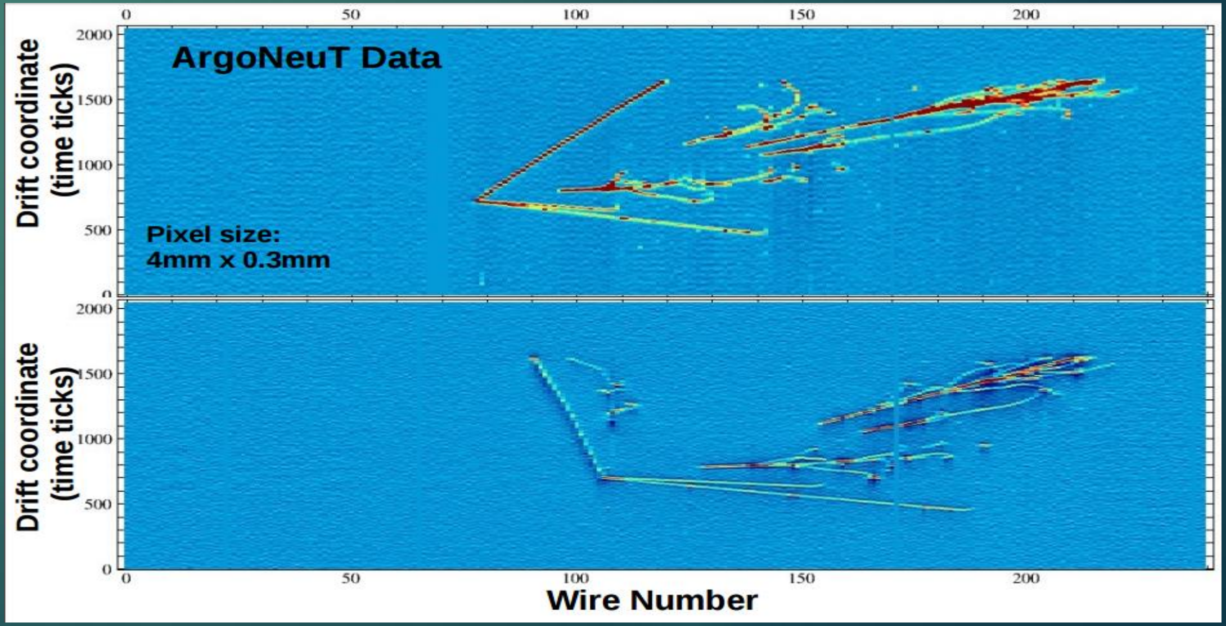




LArTPC – Why is the best choice?

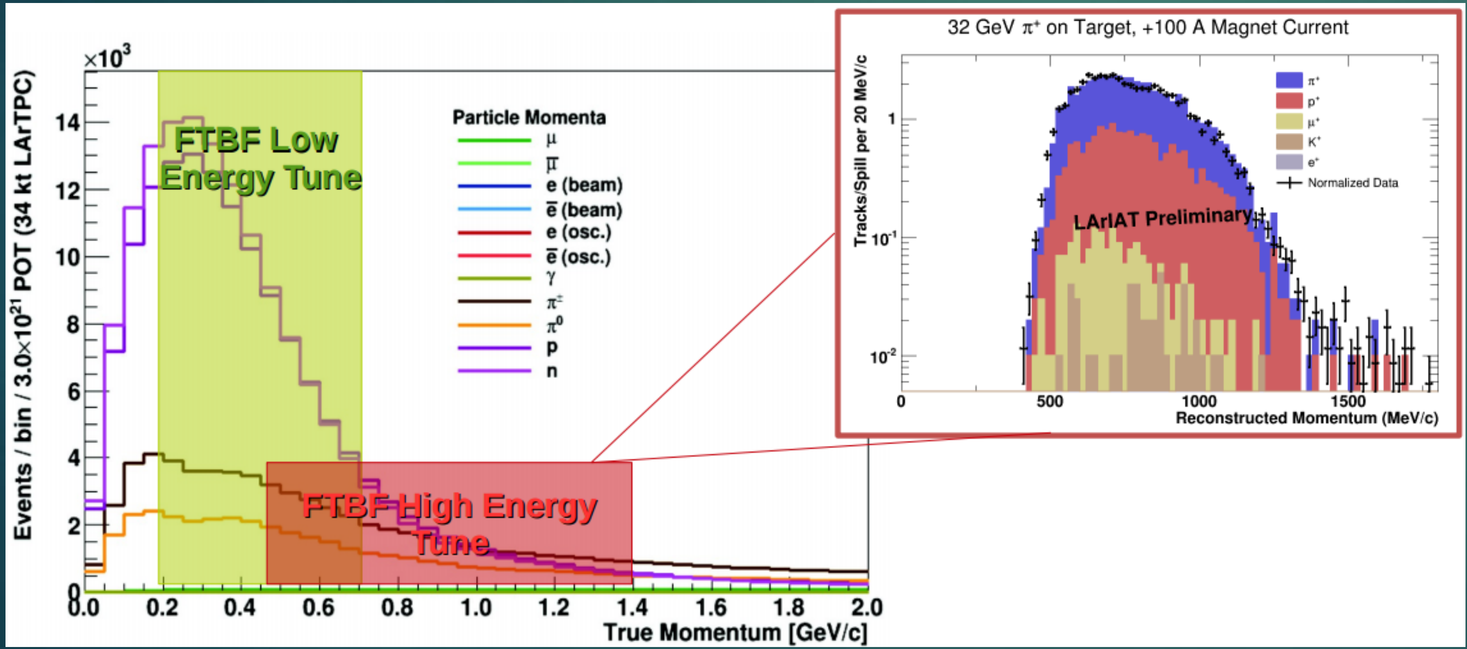
- Liquid argon is the best choice for neutrino detection
  - Dense → 40% more dense than water
  - Abundant → 1% of the atmosphere
  - Ionizes easily → 55,000 electrons / cm
  - High electron lifetime
  - Produces copious scintillation light → 40000 photons/MeV
  - Transparent to light produces



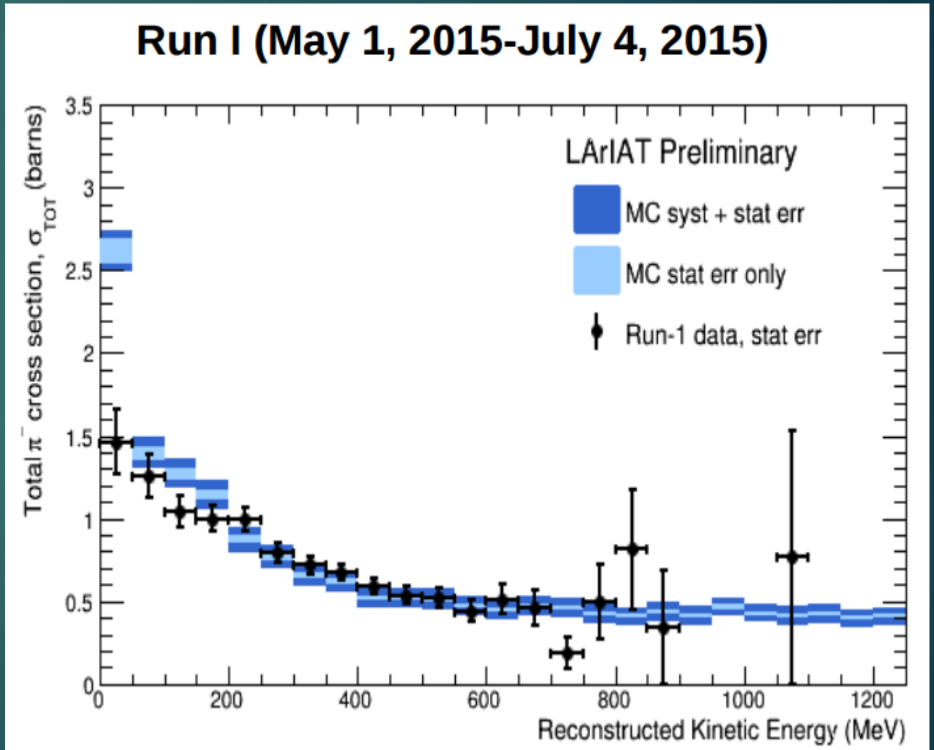


LArIAT – Liquid Argon In a Testbeam

"A LArTPC in the Fermilab Test Beam Facility is well suited to study charged particles in the energy range relevant to both the short-baseline and long-baseline neutrino experiments."

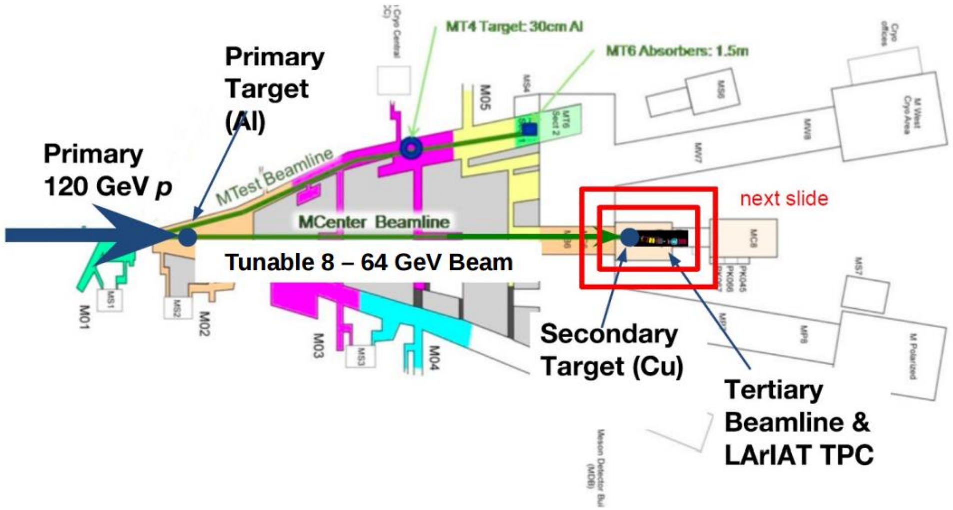


R&D Work

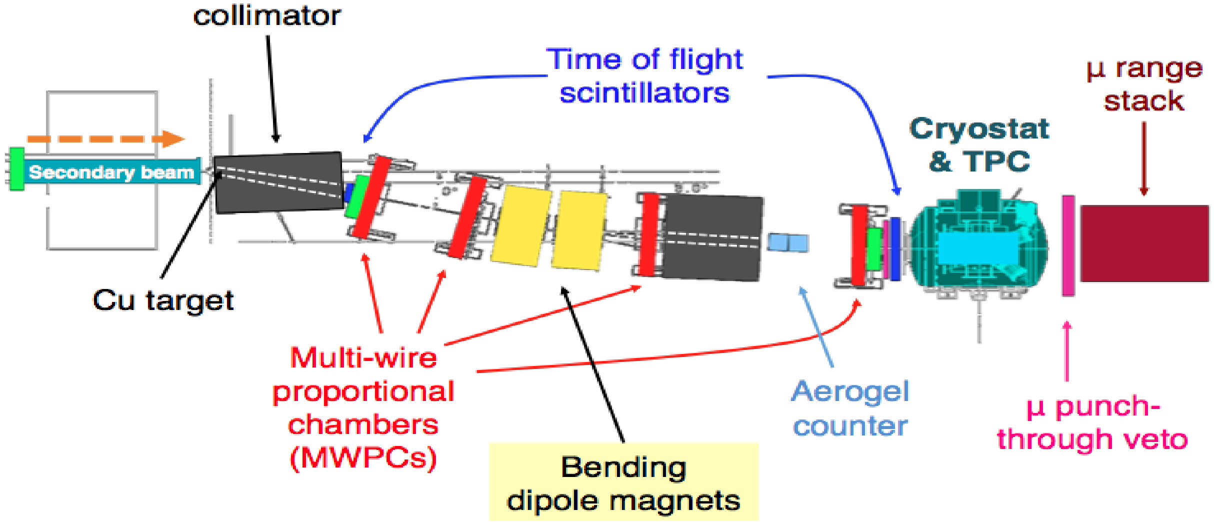


Extract Physics from the detector!

Acquiring know-how – Liquid Argon In A Testbeam (LArIAT)



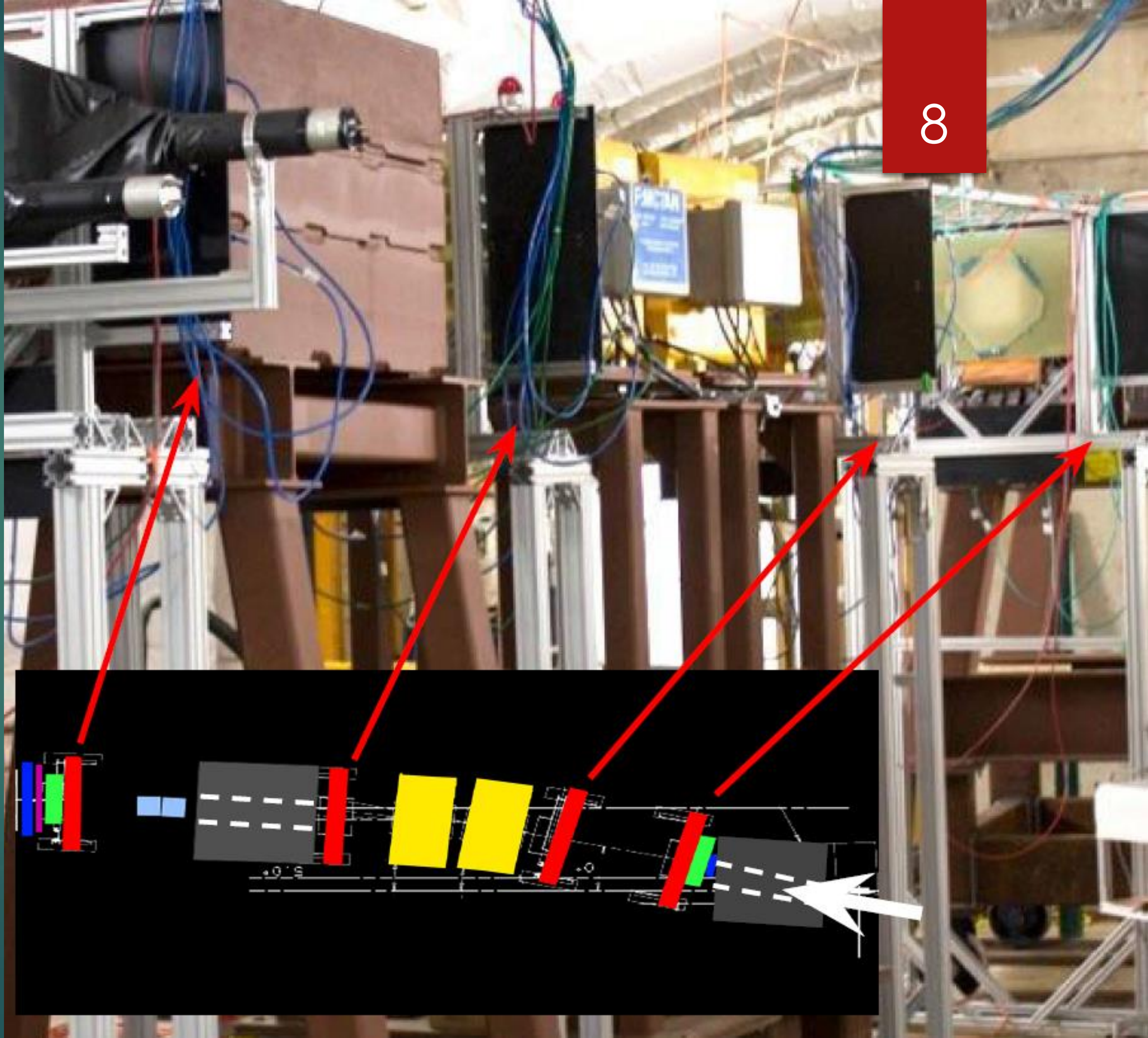
The Secondary Beam



LArIAT

LArIAT – The Beamline Detectors

- As a charged particle passes through each wire chamber (WC), it induces a signal on a nearby wire in each chamber.
- The combination of the subsequent wire chambers before and after the magnets gives us the trajectories of the particle before and after the bending. Combining them with the magnetic field gives us the momentum.
- Changing the polarities (charge) of the magnets gives the possibility to choose what kind of particle we want to study.



Wire Chamber Momentum Reconstruction

The 1 Magnet Scenario

- The momentum reconstruction as we do today consider one uniform magnet over an effective length

$$p = \frac{\int BdL}{\sin(\theta_e) - \sin(\theta_l)}$$

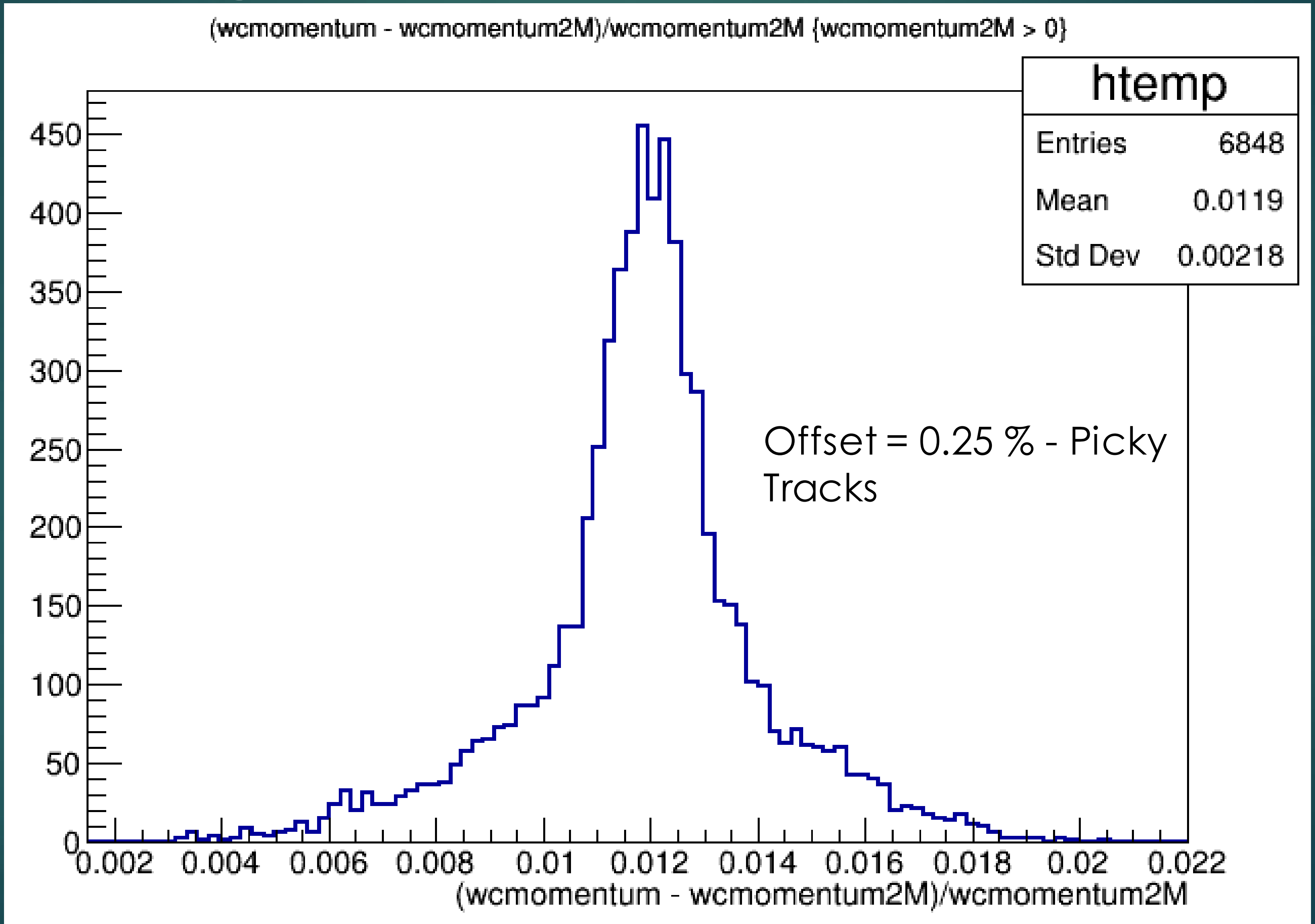
The 2 Magnets Scenario

- The method can be described as follows:
  - We consider a mid plane between the 2 magnets where the angle w.r.t. the beam axis is the biased by the 2 magnets fields

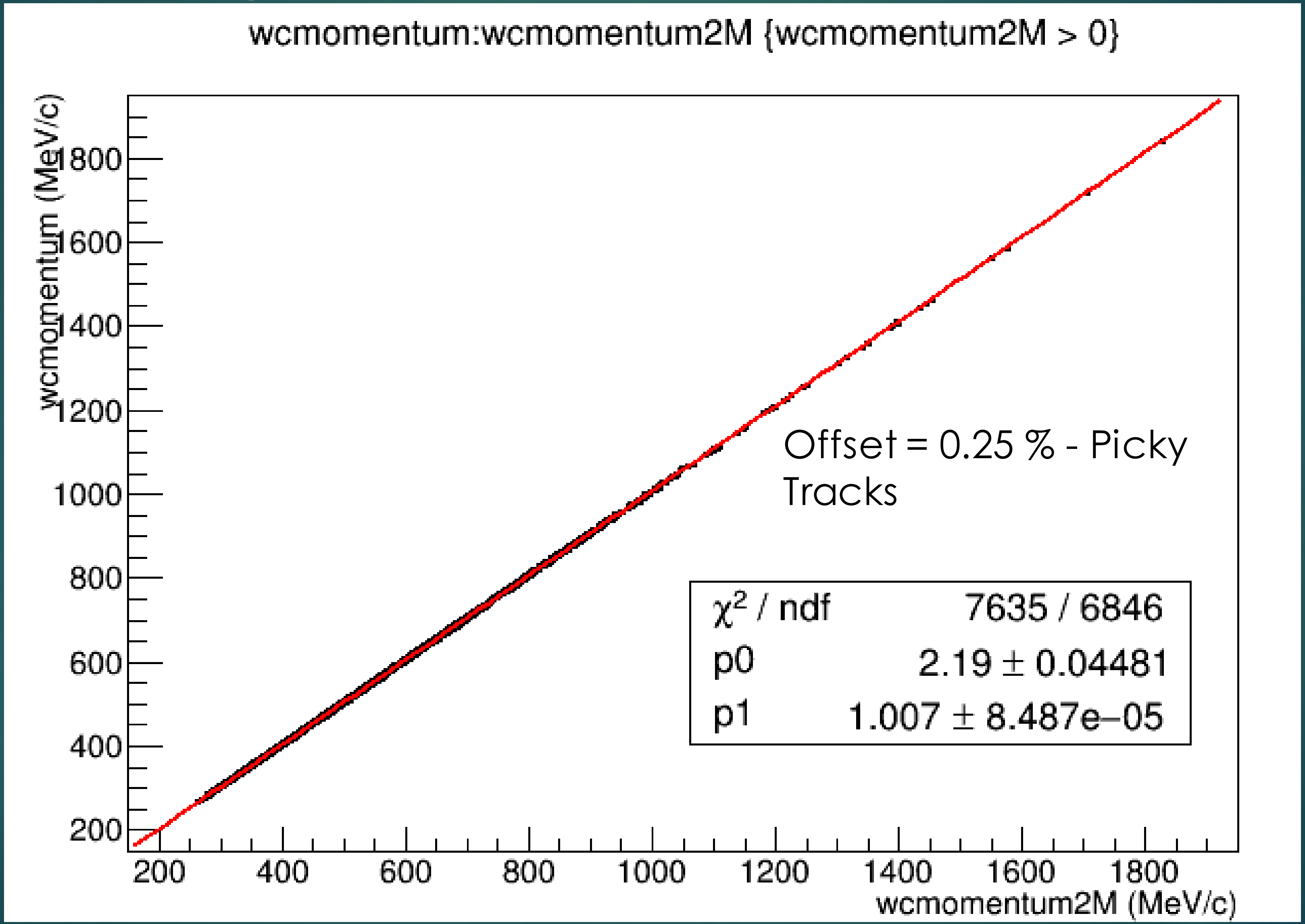
$$\theta_C = B\frac{(1 + offset)\theta_e + (1 - offset)\theta_l}{2}$$

  - Calculate the momentum before and after the midplane
  - Final Momentum is the average between the two momenta

Comparing the Reco

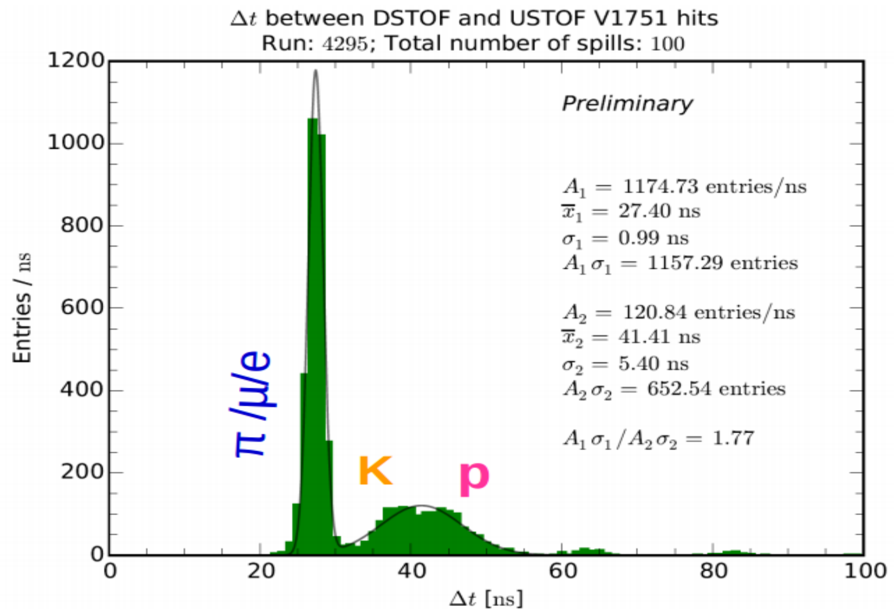


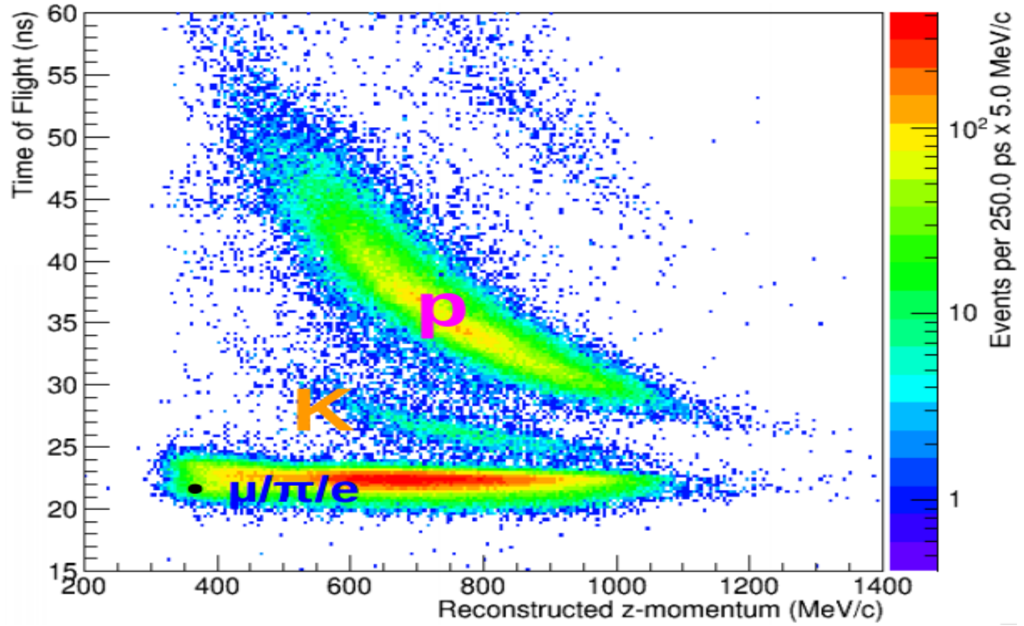
Comparing the Reco



LArIAT – The Beamline Detectors

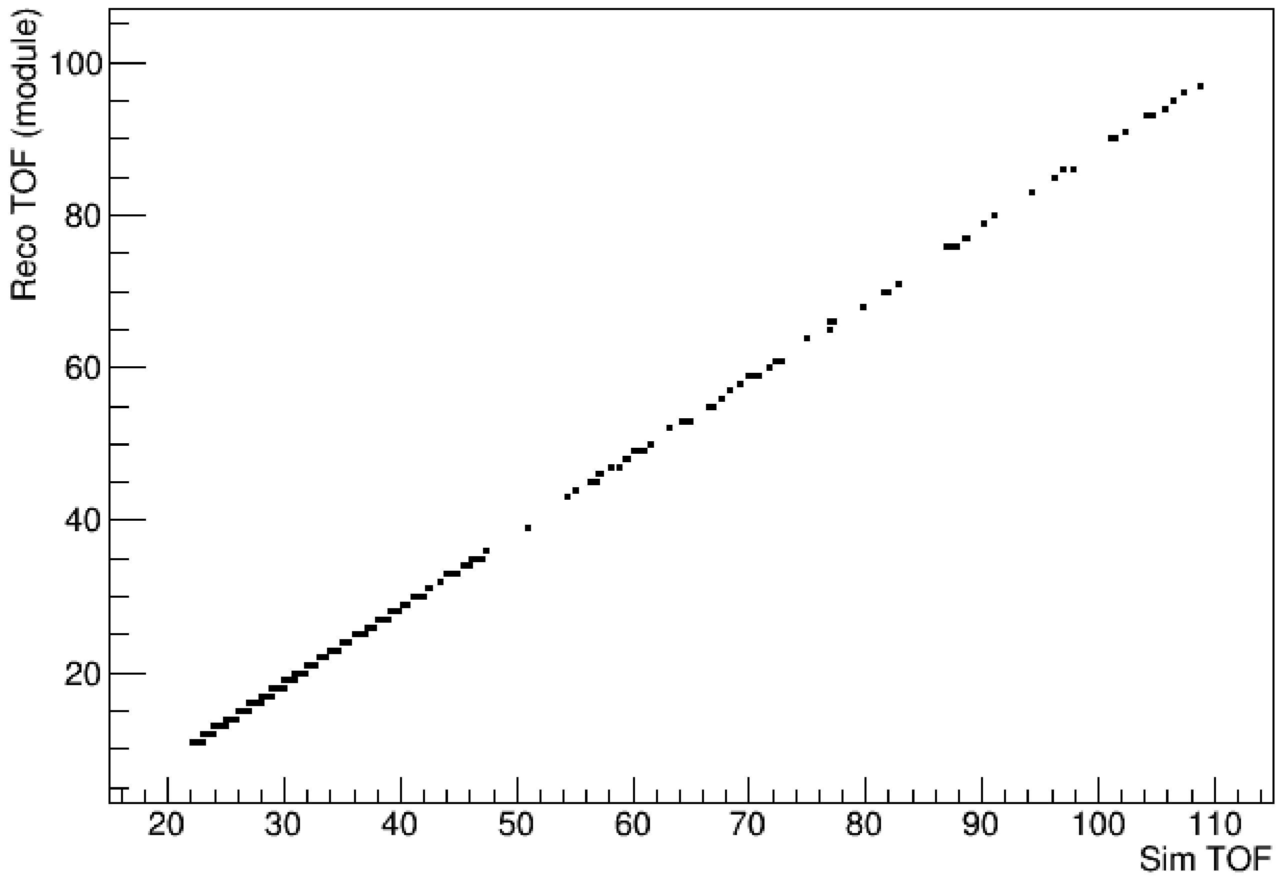
- Time of Flight (TOF) provides a clock information for how long a particle takes to travel through the beamline.
- Given the timing of the readout of the TOF + MWPC's momenta you can do particle ID($\mu/\pi/e$, p and K) before the particle enters your LArTPC



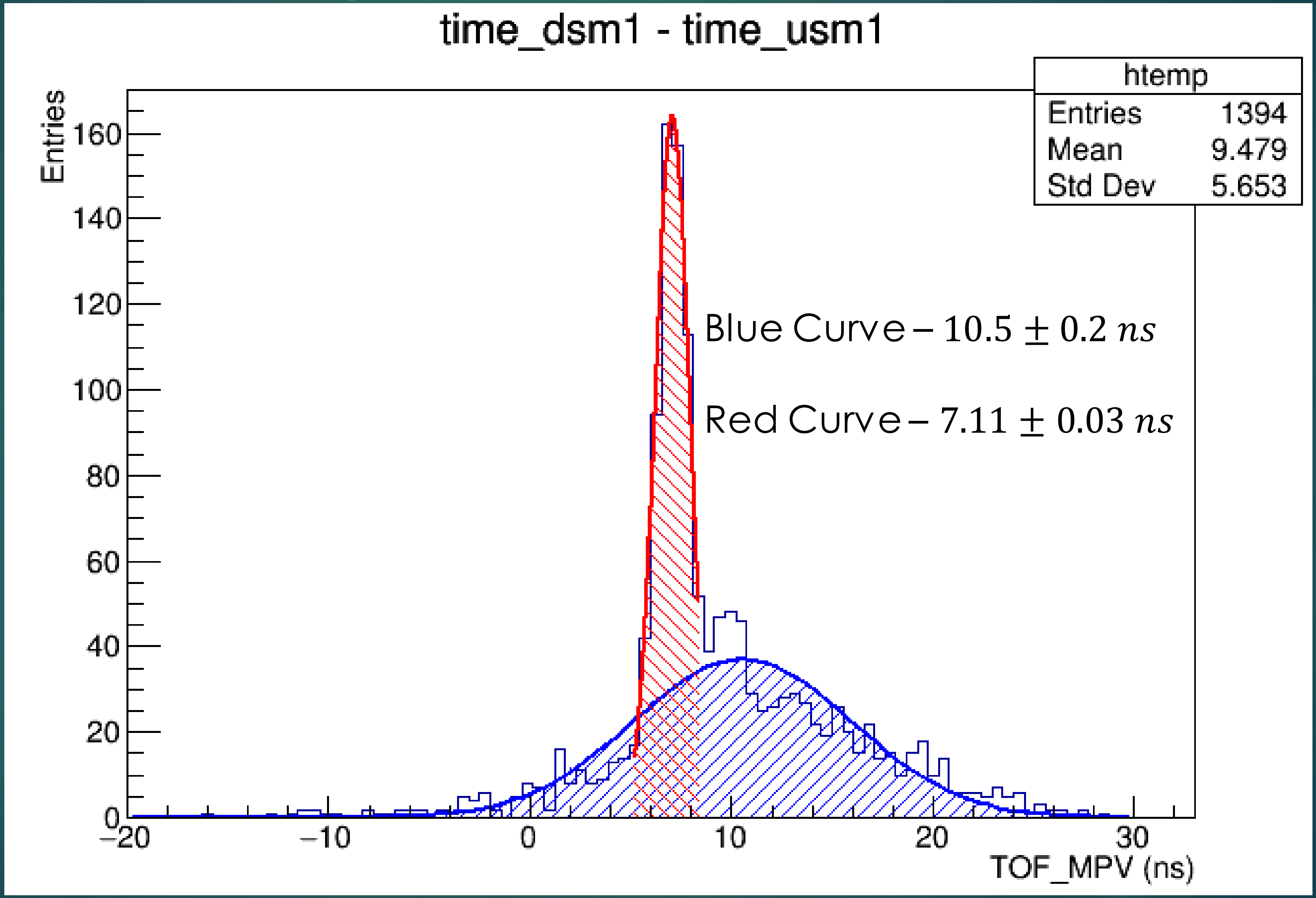


The Time of Flight Offset

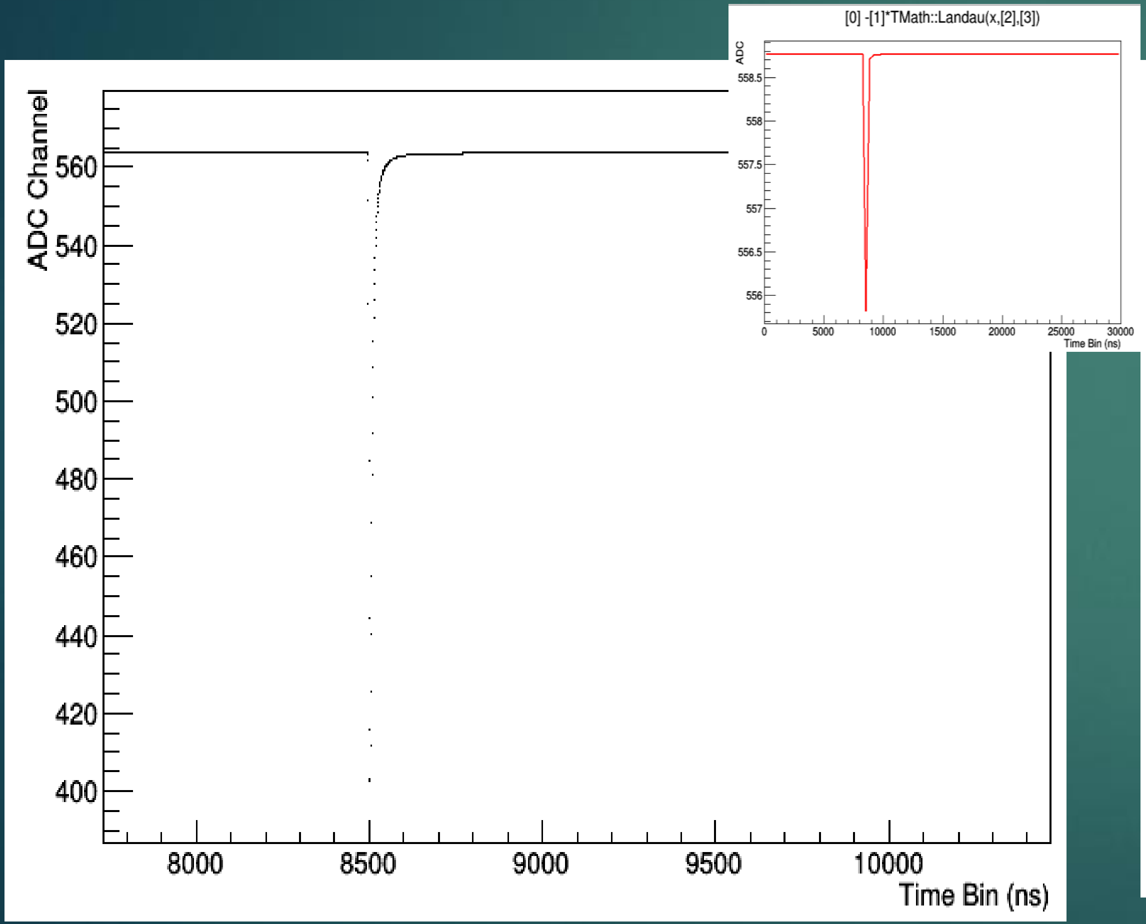
- As discussed on my last presentation there is an offset of 10'sh nanoseconds between the USTOF and DSTOF → This is already know and take into account in our reconstruction.
- However is it really a sharp 10 ns? → Need Investigation!
- How we did that?
  - Fitted the waveforms
  - Took the peak time parameter as our time

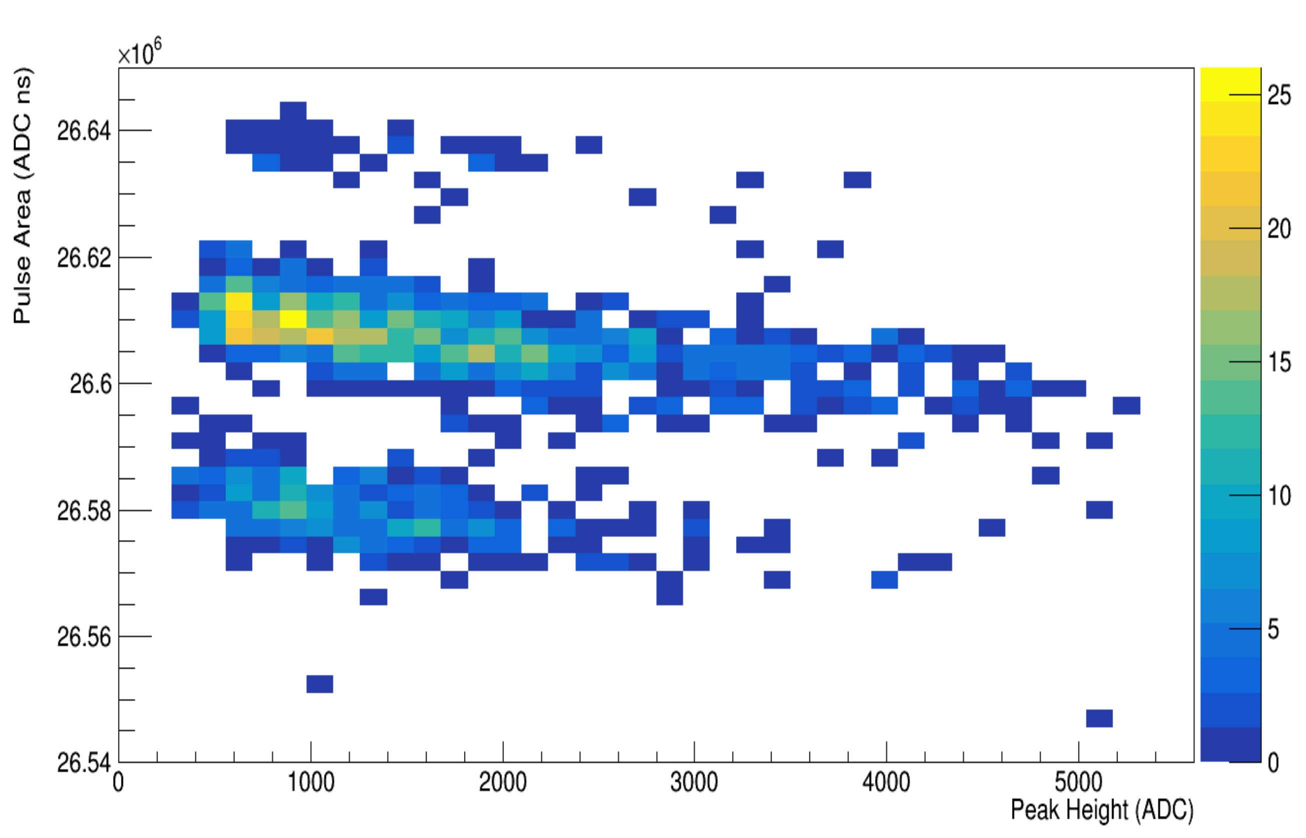


The Time of Flight Offset

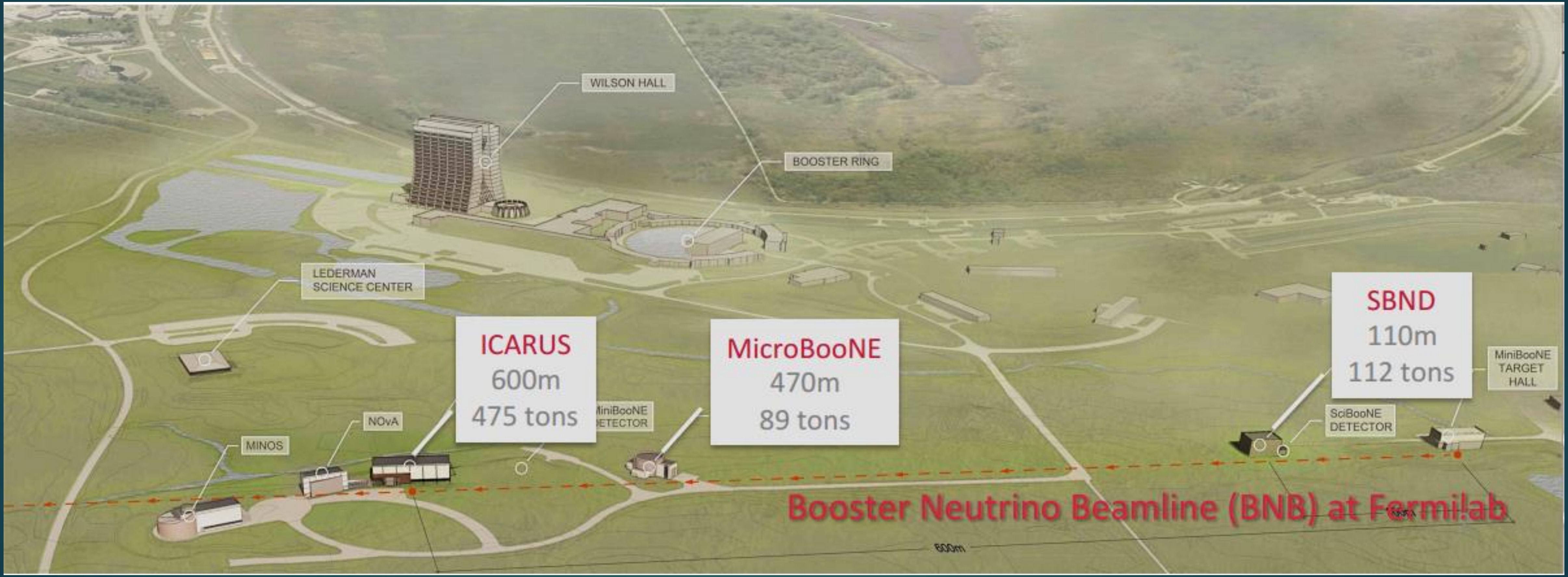


LArIAT – The Baseline Detectors Simulation



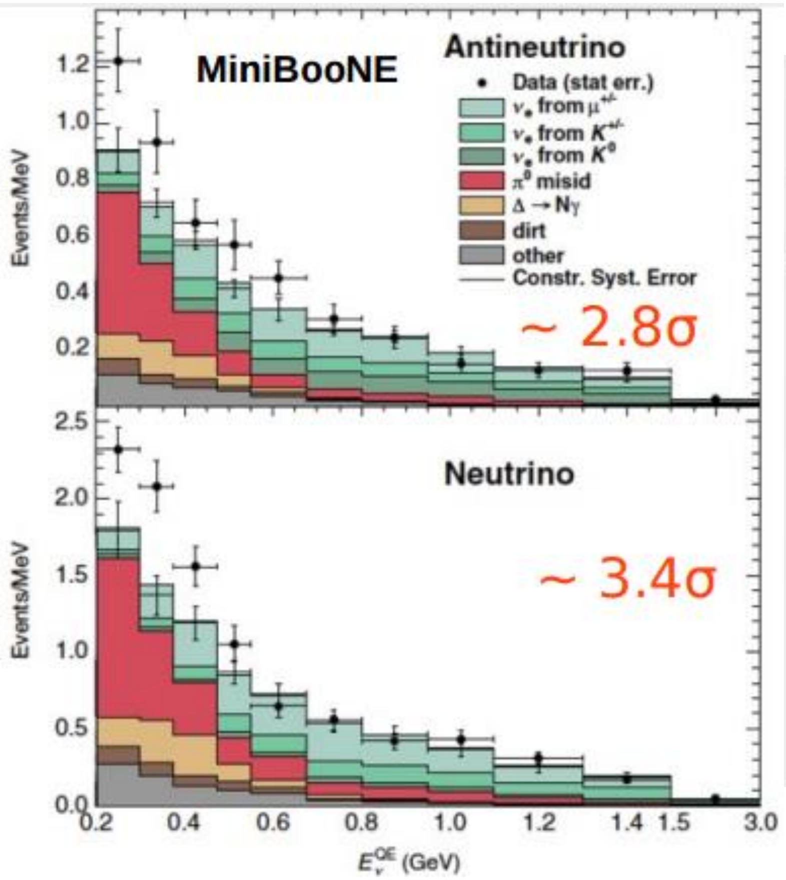


The Sterile Neutrino Problem and the SBN Program

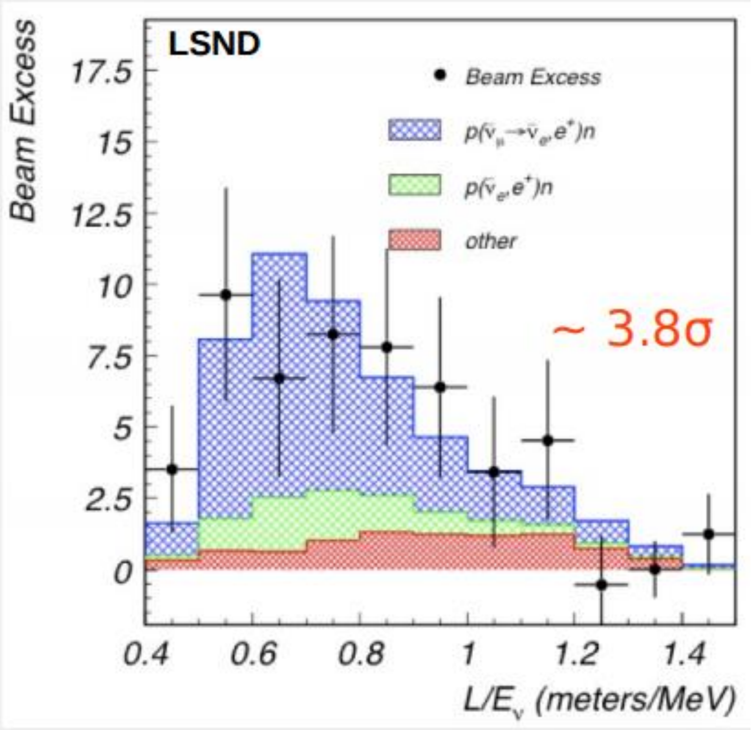


The Sterile Neutrino Problem and the SBN Program

- Anomalies in a variety of experiments provide hints to the possible existence of sterile neutrino
  - Evidence for an electron-like excess from neutrinos from particle accelerators



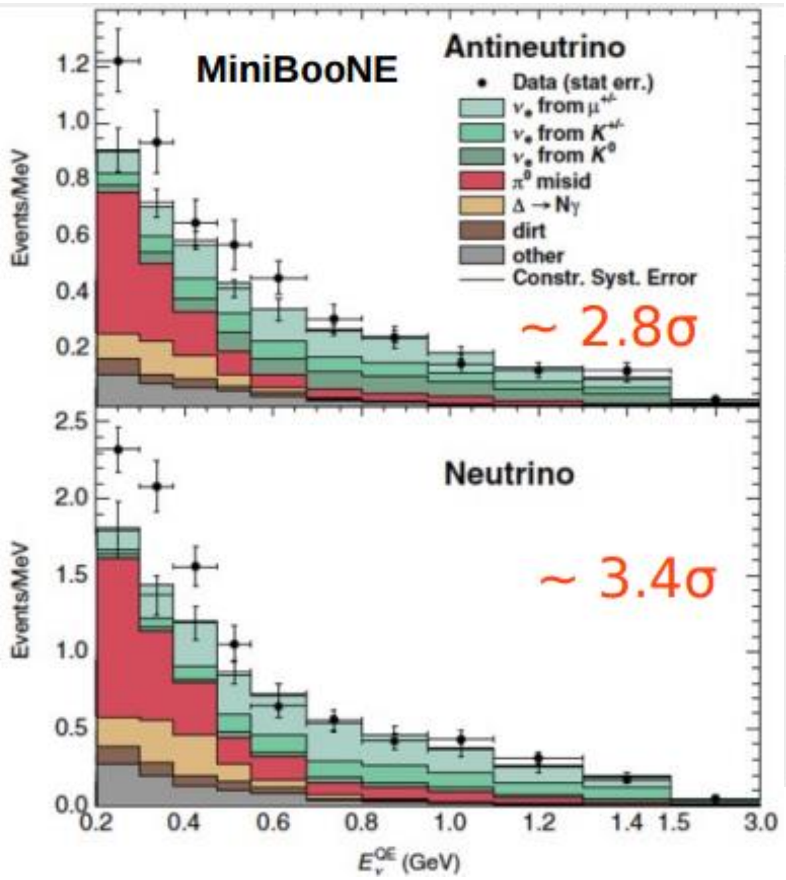
Phys. Rev. D 64, 112007



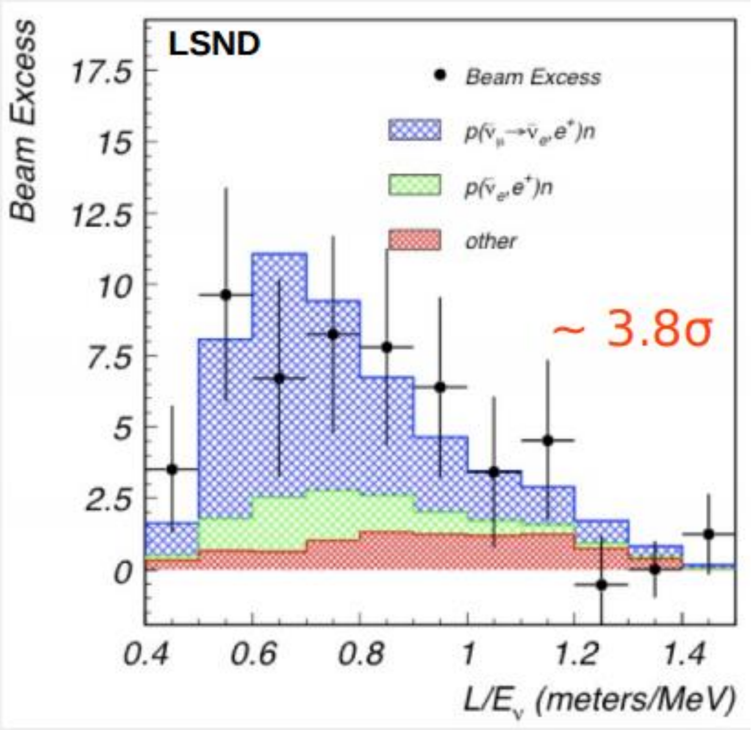
Phys. Rev. Lett. 110, 161801

The Sterile Neutrino Problem and the SBN Program

- Short-baseline anomalies can not be explained with three flavor neutrino oscillations
  - Interpreted as oscillations involving sterile neutrinos with $\Delta m^2 \sim 1\ eV^2$ and an $\frac{L}{E} \sim \frac{1km}{GeV}$
  - New experimental efforts are needed to eventually solve the puzzle



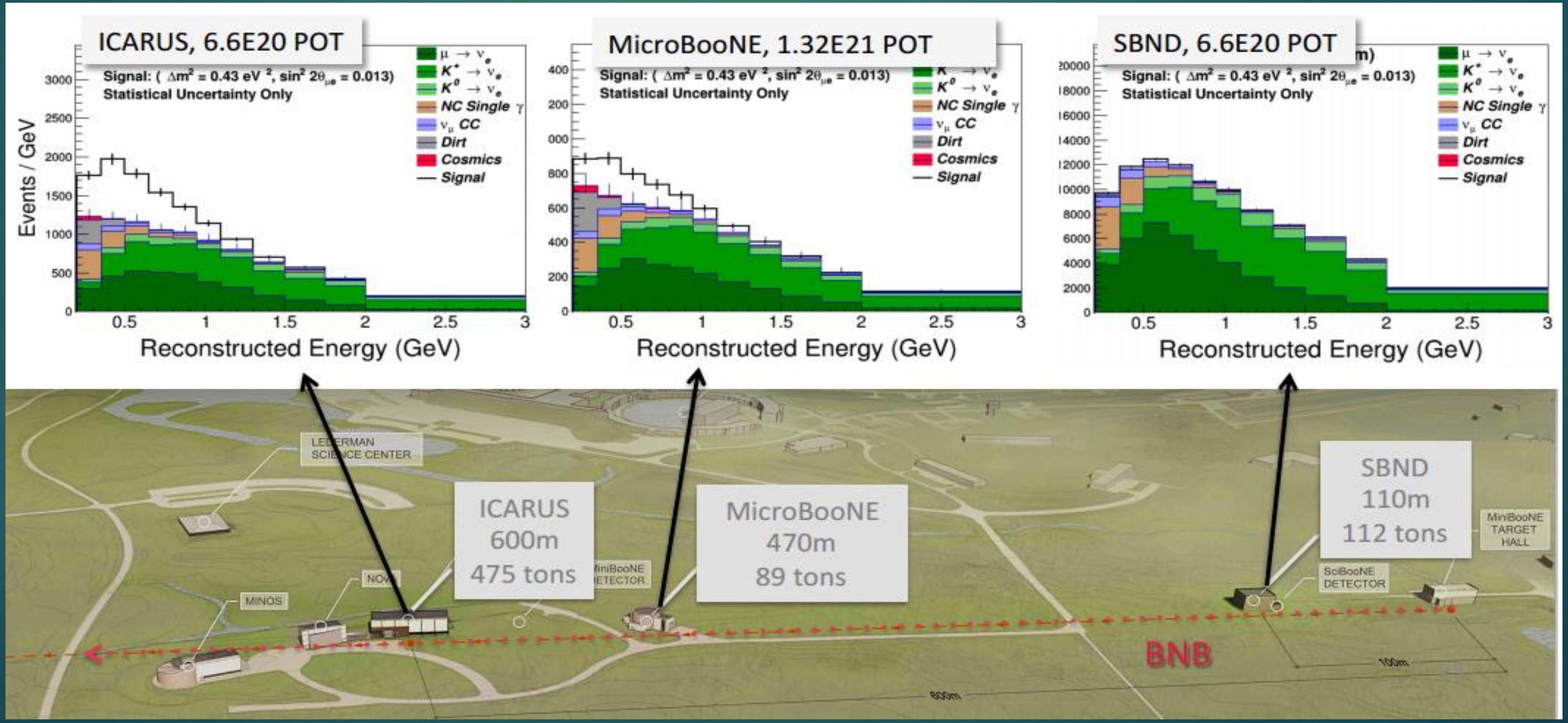
Phys. Rev. D 64, 112007



Phys. Rev. Lett. 110, 161801

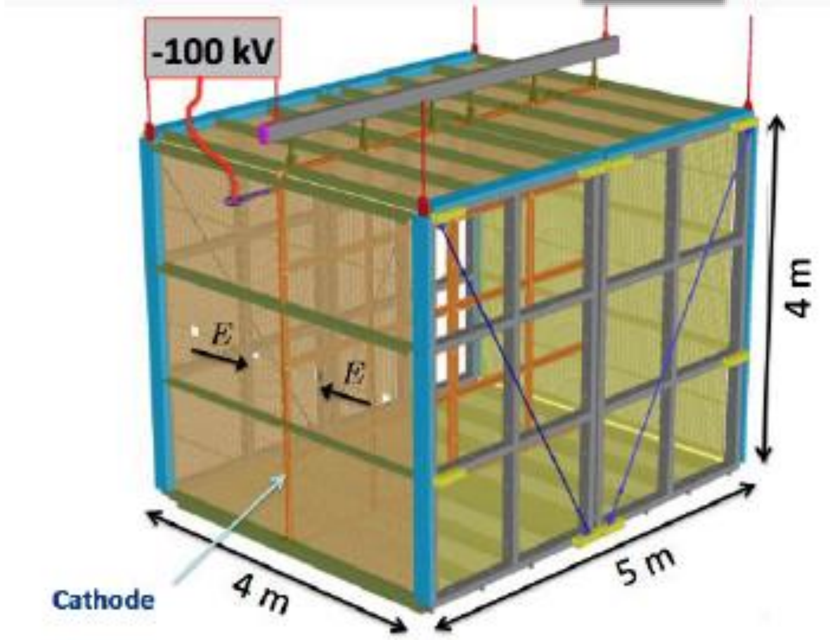
The Sterile Neutrino Problem and the SBN Program

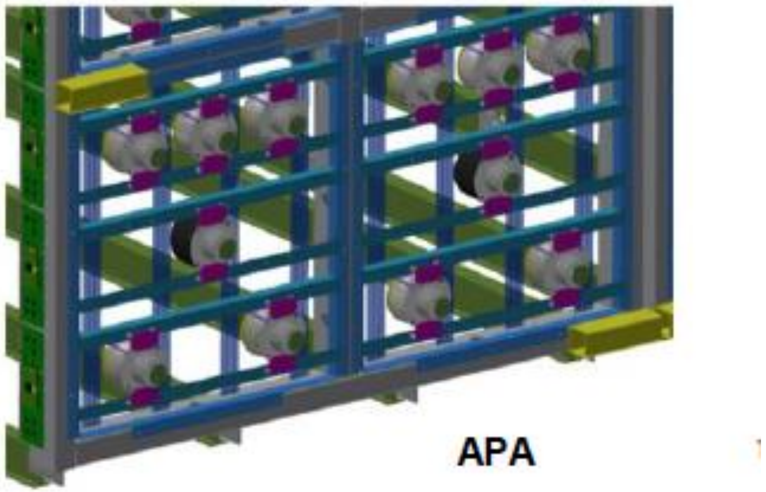
- (3+1) ν_e appearance: SBND's high statistics constrain the expected ν_e background event rates. ICARUS' large mass provides necessary statistical power for an electron neutrino appearance search.



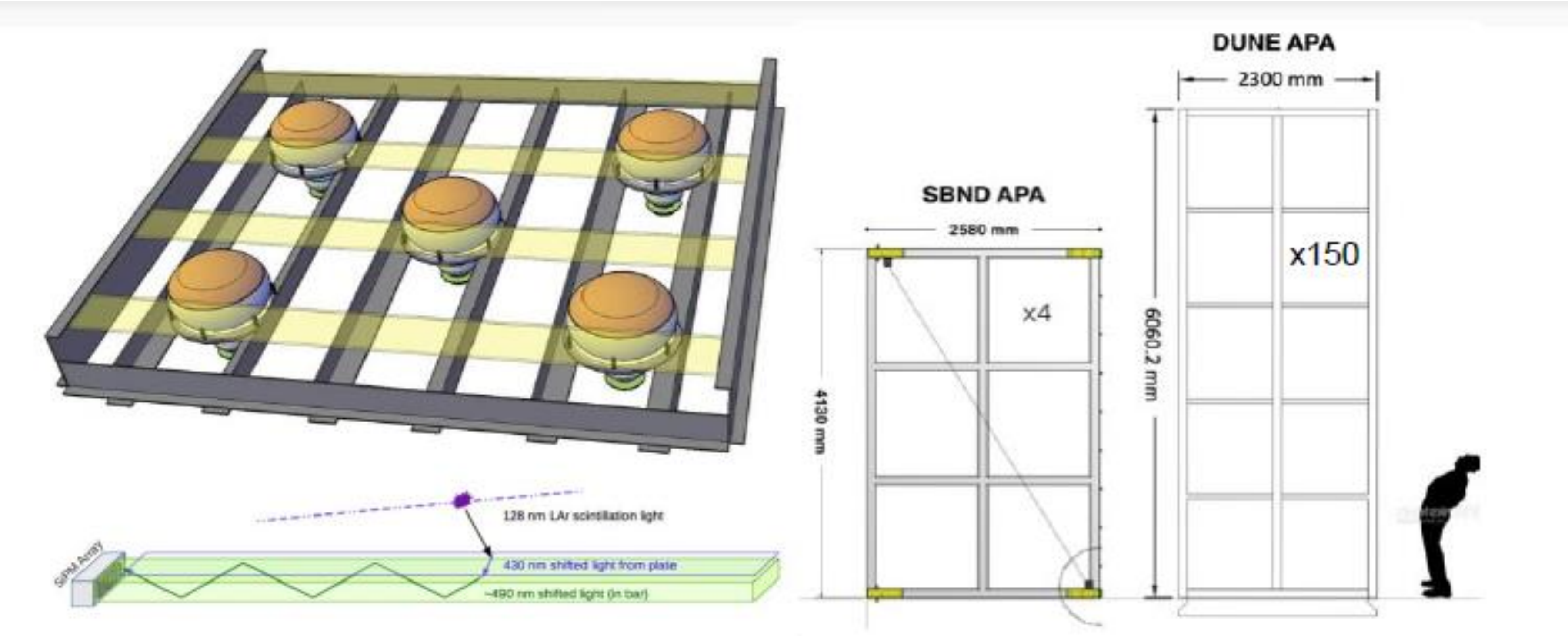
The SBND

- 260 t LAr (112 t active)
- Membrane cryostat
- Two **TPCs**
  - 2 m drift distance
  - 3 wire planes (vert, ±60°)
  - 3 mm pitch
- 120 8" **PMTs** coated with TPB
  - Acrylic light guides; SiPM readout
- Reflective foils under study
- **Laser** calibration system
- External **cosmic ray tracker** (nearly full coverage)





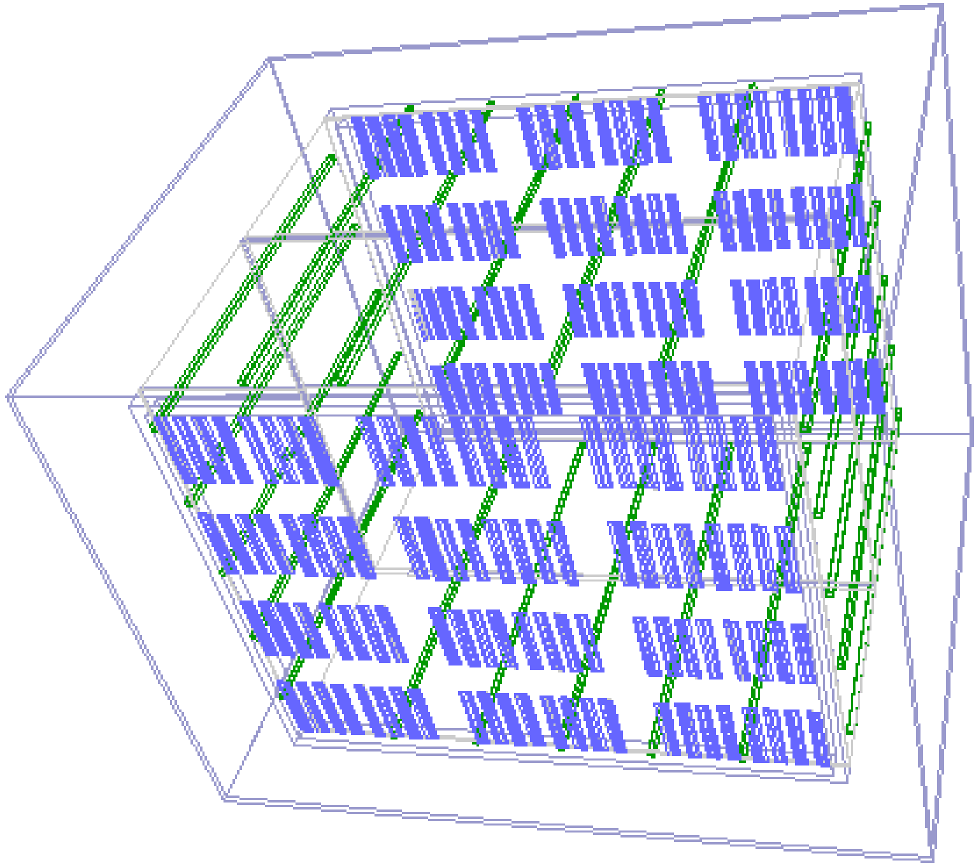
The SBND - R&D



DUNE APA
2300 mm
6060.2 mm
x150
SBND APA
2580 mm
4130 mm
x4
128 nm LAr scintillation light
430 nm shifted light from plate
~490 nm shifted light (in bar)
SiPM Array

The SBND – Simulating the Scintillation Bars

- The SBND right now is under construction, but the simulation is being developed;
- My work on this subject:
  - Implement the geometry of the scintillation bars the most realistic way as possible
  - Implement the physics of the bars;
- Next steps:
  - Generate the Optical Library for the Scintillation bars → Good for fast optical simulation



Conclusions

- Work point of view:
  - All the work done until now for both experiments are still ongoing
  - When they are fully functional, they will be of crucial importance for the whole collaboration → Everybody can benefit from these studies
- Personal point of view:
  - The Summer Program provided a chance to work intensively with my group
  - It opened up a variety of opportunities for my PhD thesis as well for future prospects

Thanks!