LArIAT
Introduction, Goals, Run Plan

Operational Readiness Review

October 13, 2015

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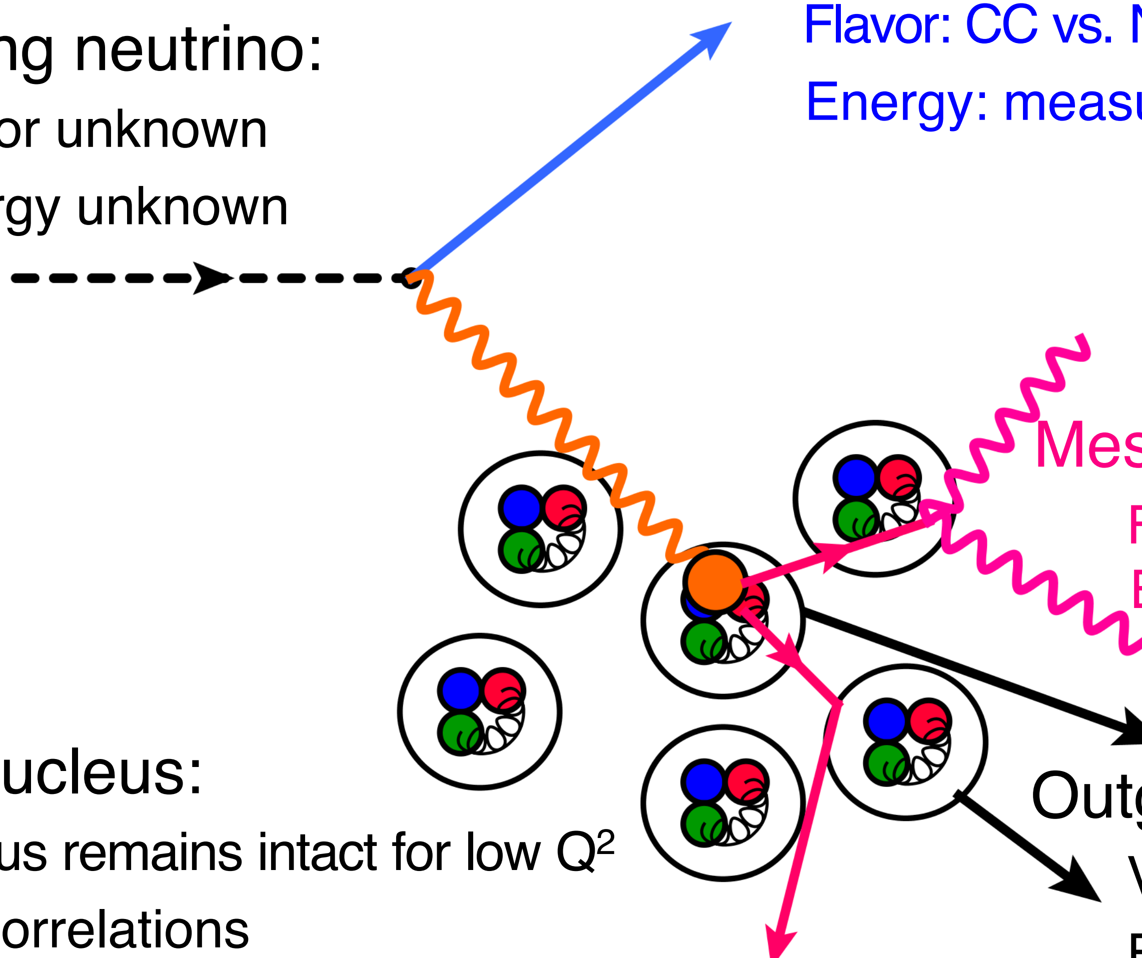
Motivation: Needs of Neutrino Experiments

Typical neutrino event

Incoming neutrino:
- Flavor unknown
- Energy unknown

Outgoing lepton:
- Flavor: CC vs. NC, μ^+ vs. μ^-, e vs. γ
- Energy: measure

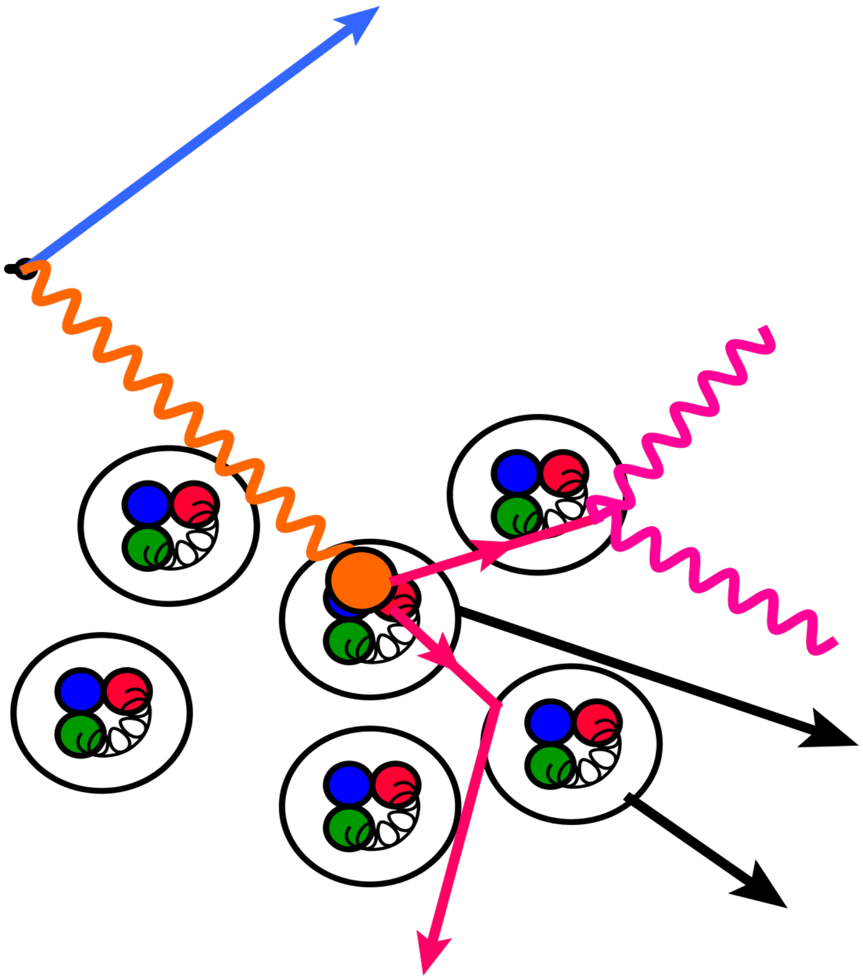


Mesons:
- Final State Interactions
- Energy? Identity?

Target nucleus:
- Nucleus remains intact for low Q^2
- N-N correlations

Outgoing nucleons:
- Visible?
- Energy?

LArIAT: Study Final State Particles

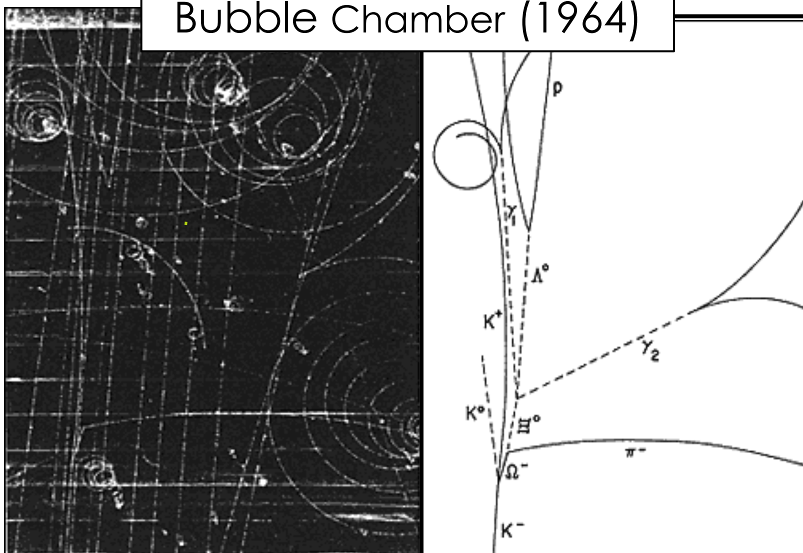


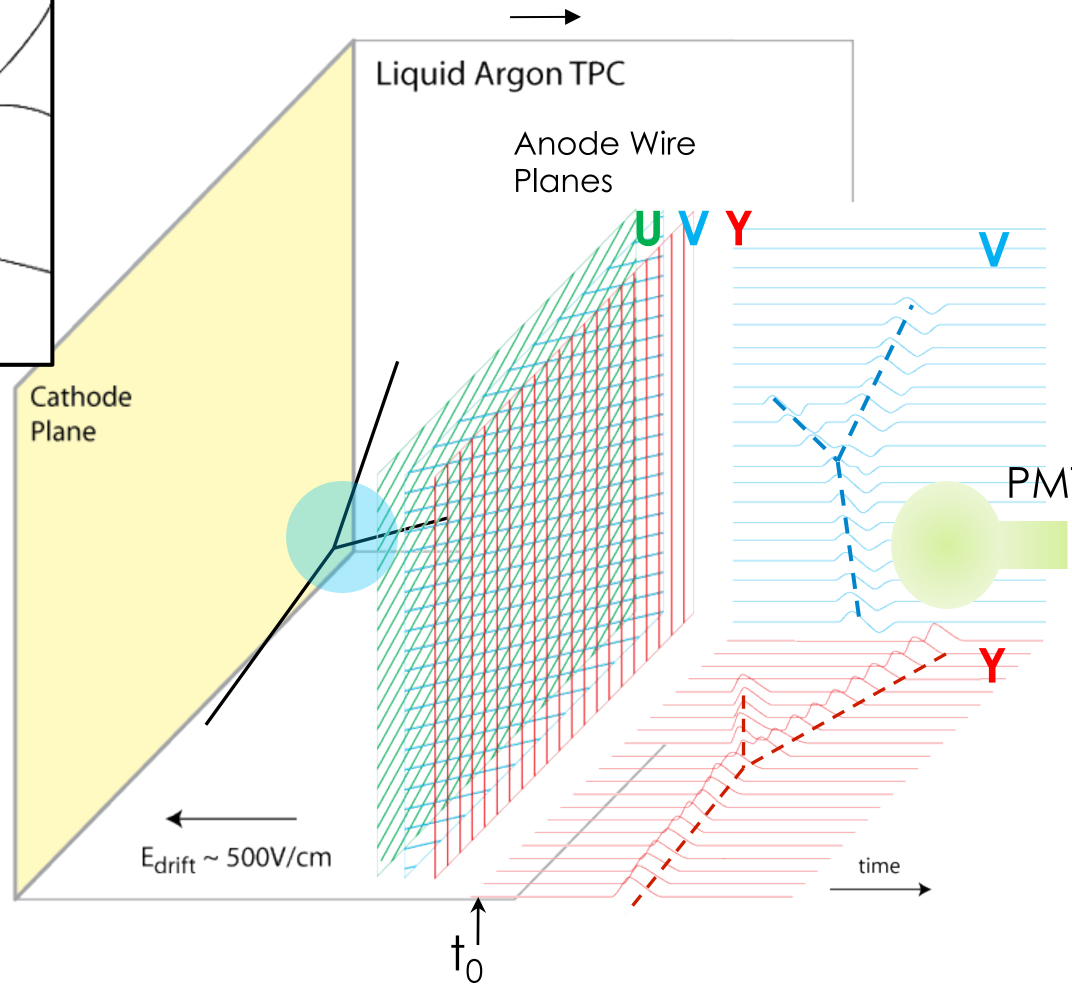
- Visible energy calibration
- Calorimetric response and resolution
- Particle identification
- Event reconstruction
- Hadron-argon scattering cross sections

LArTPCs enable us to study these topics in unprecedented detail.

Liquid Argon Time Projection Chambers

Bubble Chamber (1964)

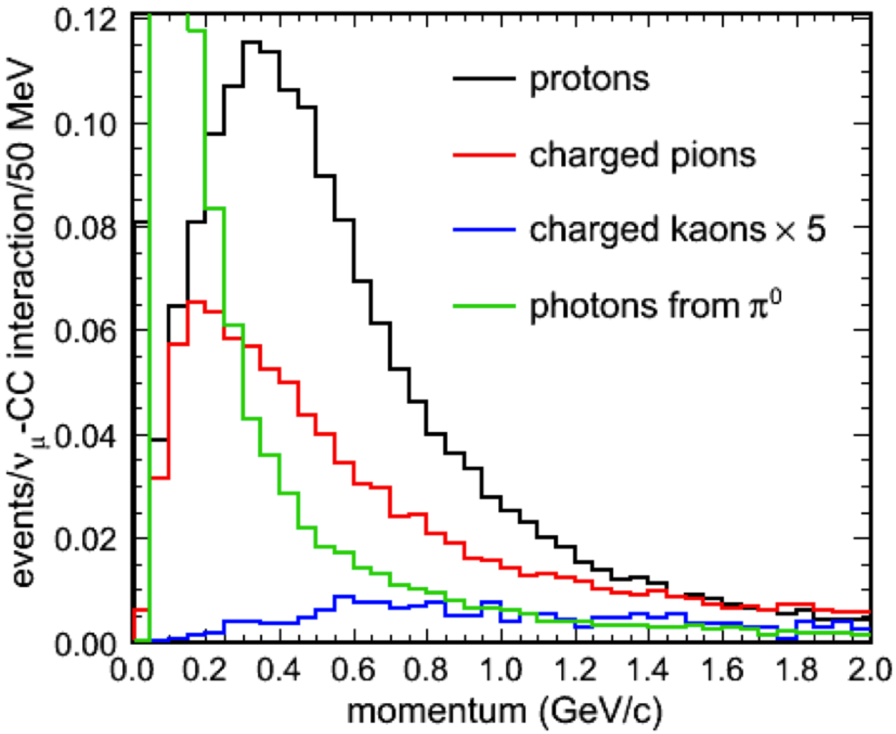




1. Energy loss by charged particles: Ionization and Excitation of Ar
2. Prompt light emission by Ar_2^+
3. Electrons drift to anode (Ar$^+$ ions drift to cathode)
4. Moving electrons induce currents on wires
5. Tracks are reconstructed from wire signals

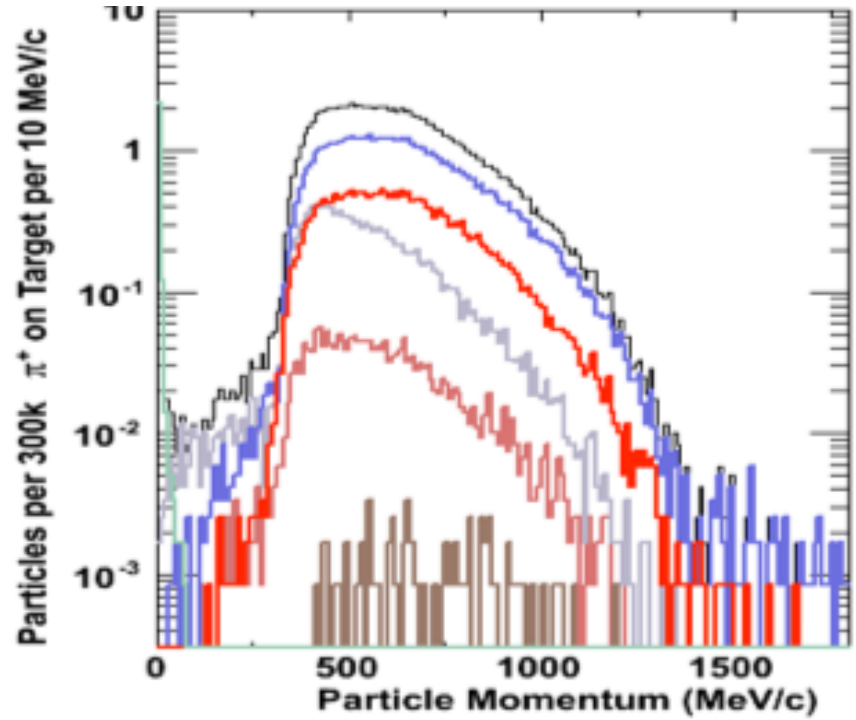
Motivation & Method

NuMI LE on-axis beam



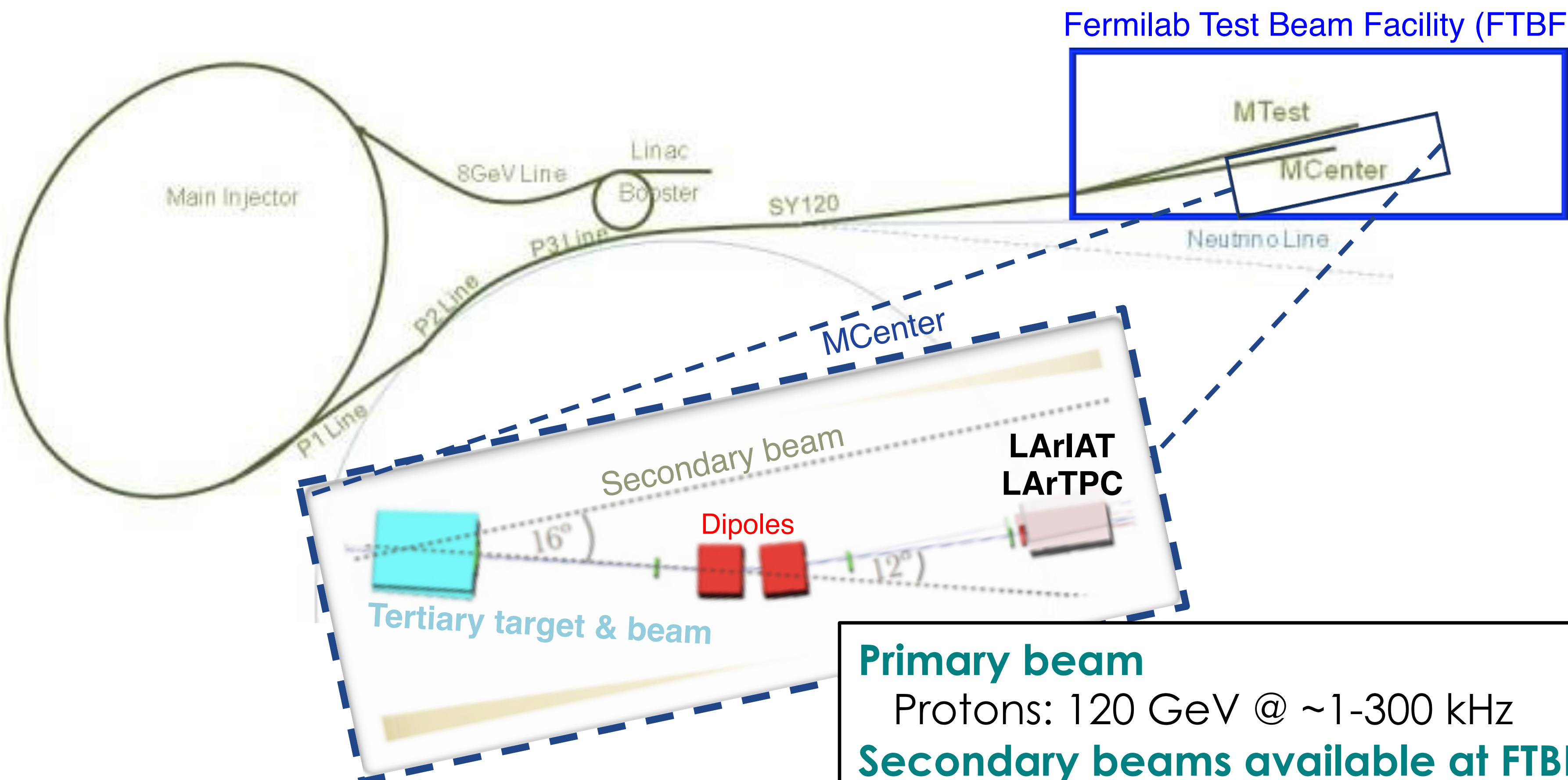
Study in LArTPC
Particles emerging from ν interactions in the energy range relevant for μB, SBND, and DUNE

LArIAT beam



Study in LArTPC
Particles emerging from LArIAT's dedicated charged particle beam in Fermilab Test Beam Facility

Test Beam Facility



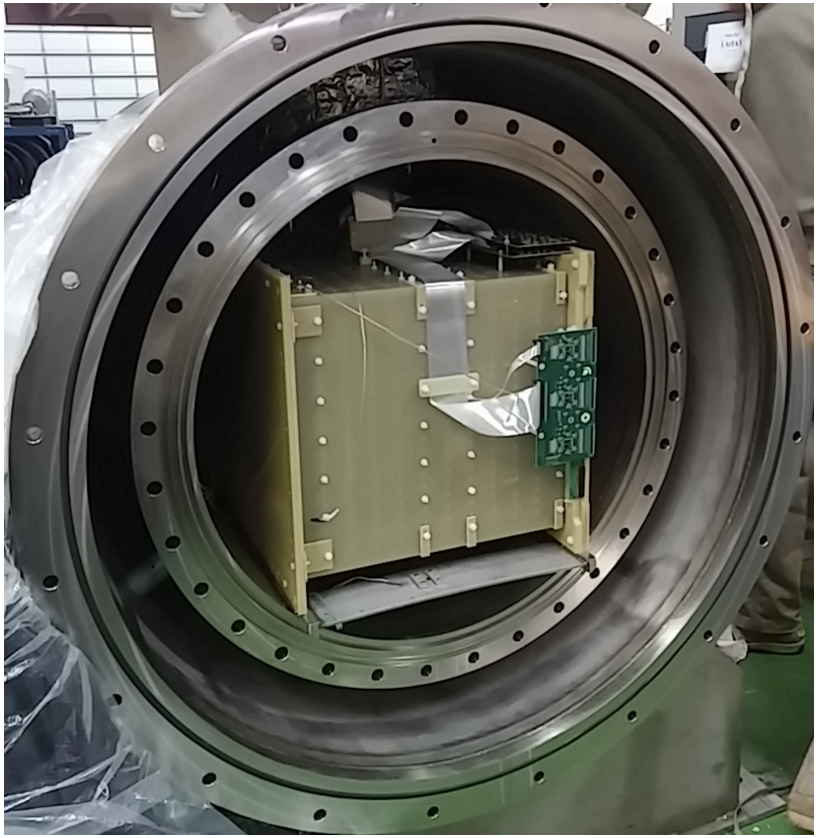
Primary beam
Protons: 120 GeV @ ~1-300 kHz
Secondary beams available at FTBF
Range ~1-80 GeV (predom. pions)
Tertiary beam (MCenter)
~200 MeV - 2 GeV

MTest
Short-term experiments (~few weeks)
MCenter
Longer-term experiments
Cryogenic infrastructure for LAr experiments

LArIAT Goals

Program for comprehensive characterization of LArTPC performance in the range of energies relevant to upcoming neutrino experiments.

- Physics goals
  - π-Ar interaction cross sections
  - Kaon interaction cross sections
  - Geant4 validation
  - Develop criteria for determining particle charge based on topology (decay vs. capture), without magnetic field
  - Electron/photon shower ID
- R&D goals
  - Ionization and light production properties
    - Establish relationship between energy deposited to charge and light collected, for stopping tracks of known energy
  - Optimization of particle ID methods
  - 2D & 3D event reconstruction



Pion-argon cross sections

D. Ashery et al.
Phys. Rev. C23, 2173 (1981)

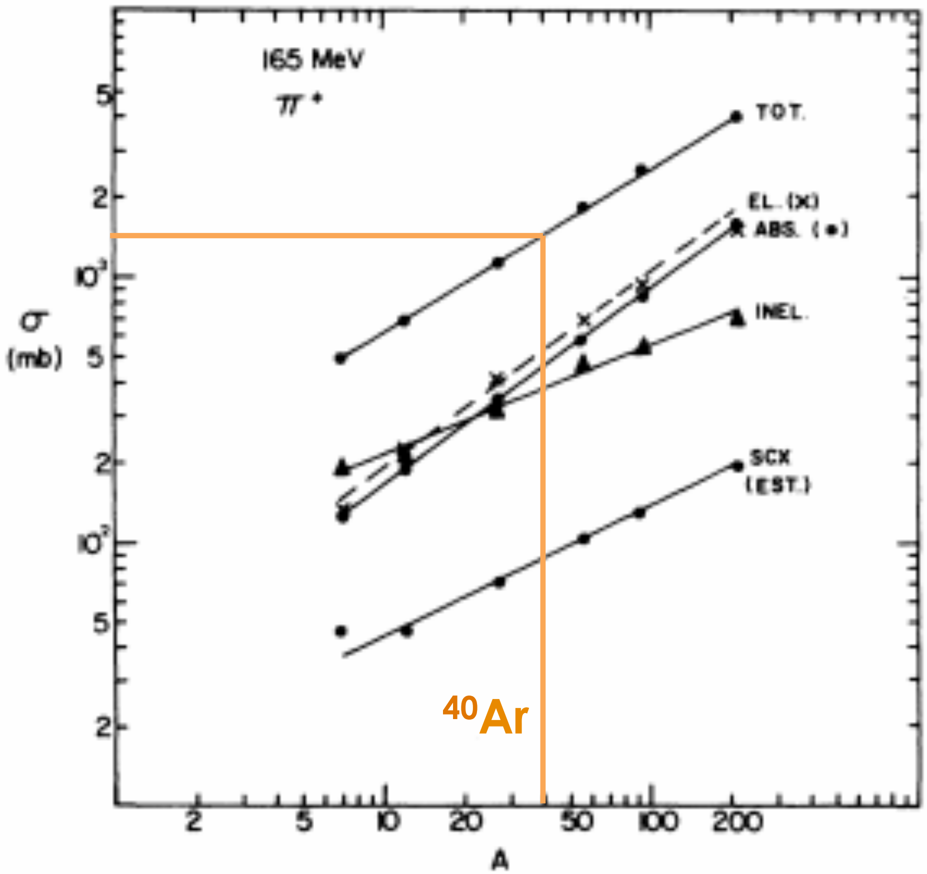


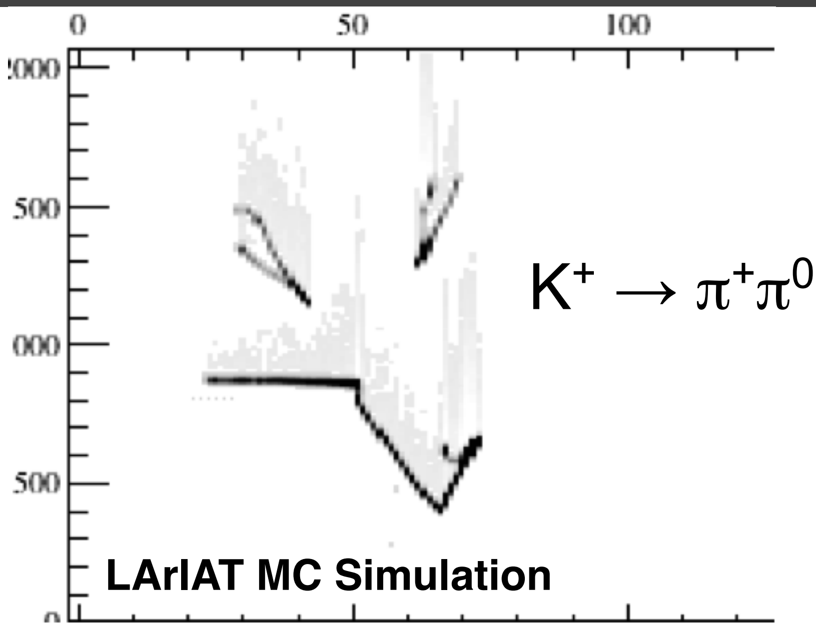
FIG. 9. Decomposition of the total π^+-nucleus cross section at 165 MeV. The lines are least squares fits to power laws.

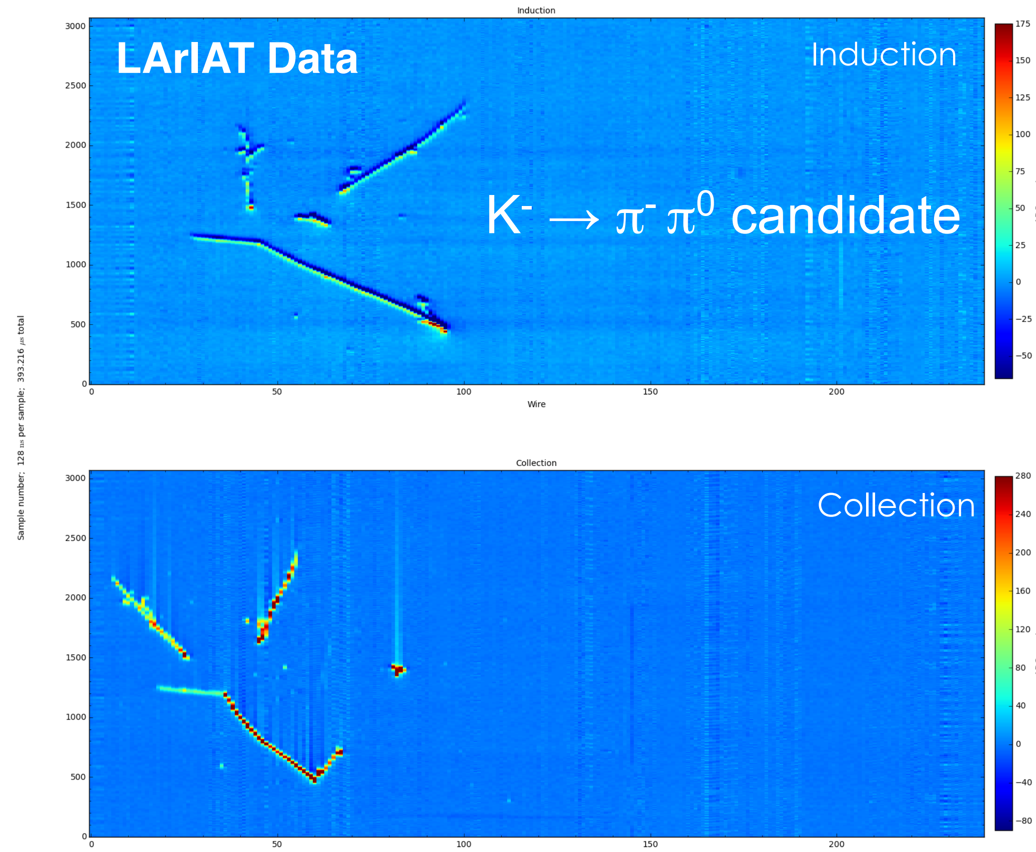
- No measurements for ^{40}Ar (yet!)
- Predictions come from interpolation between heavier/lighter nuclei

LArIAT measurement goals:
- Total interaction cross section
- Exclusive interaction channels
  - Absorption
  - Charge exchange
  - Inelastic & elastic scattering

Today we'll show preliminary results from the first stage of this analysis.

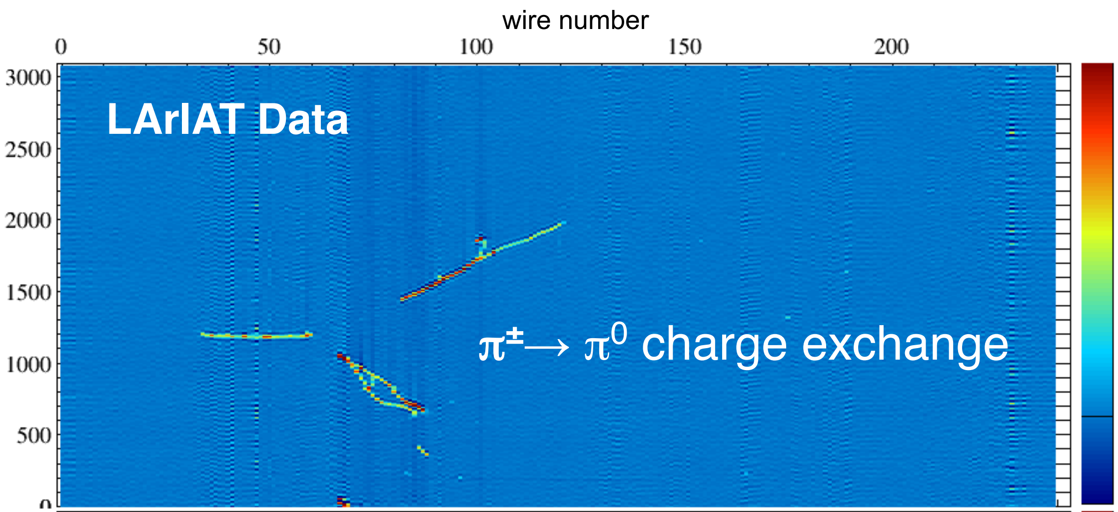
Kaon ID and reconstruction

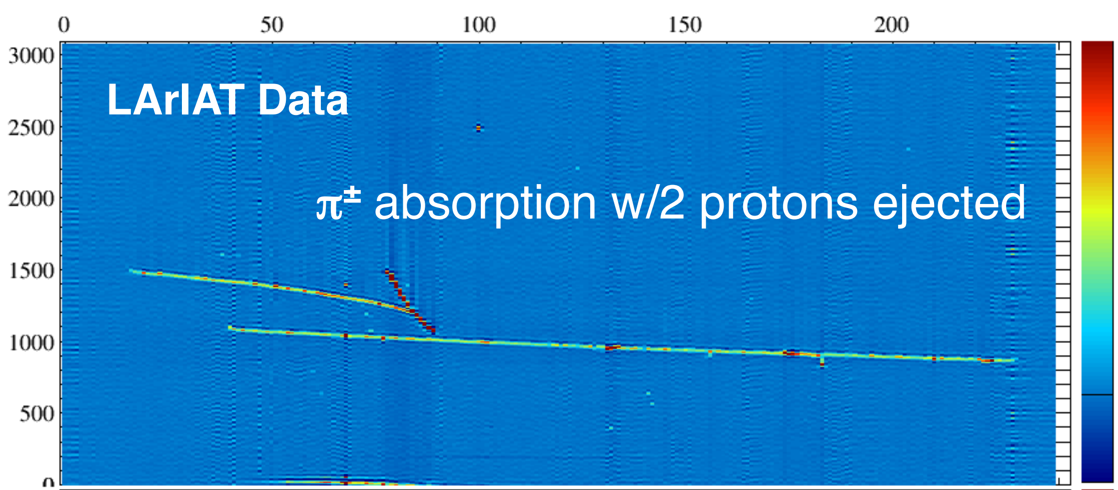




- $K^{\pm}$ reconstruction
- Study recombination
- Kaon-argon interaction cross section measurement
- Understand kaon/pion and kaon/proton discrimination
- ***Important for baryon-number-violation searches:*** relevant to proton decay searches in future experiments

Nuclear Effects & Final State Interactions



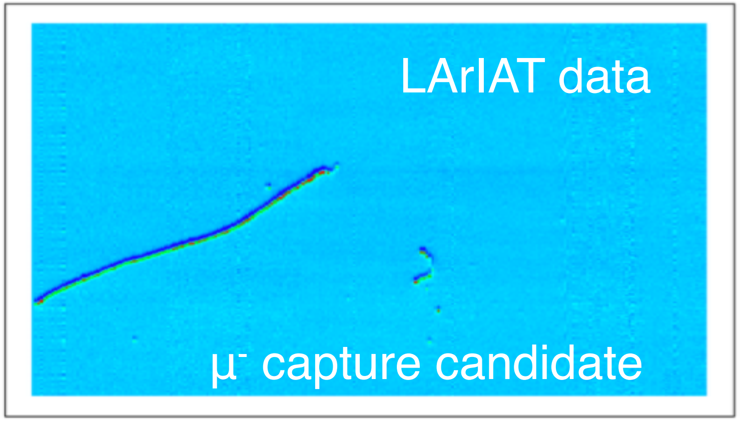


- Tune hadron-nucleus interaction models in Geant4 and neutrino generators
- Study reconstruction systematics & calorimetry
- ***Important for oscillation experiments:*** study/ constrain features of backgrounds to ν oscillation

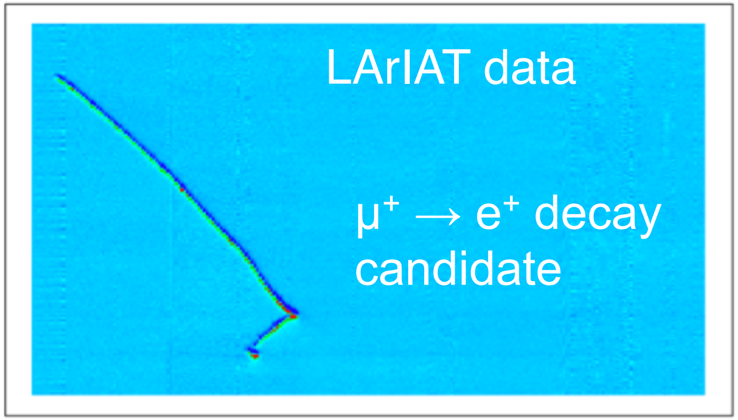
Charge Sign Determination (w/o magnetic field)

Explore a LArTPC feature never before (systematically) studied

- decay vs. capture in LAr
- μ^+ only decay, μ^- capture (76%) or decay (24%)



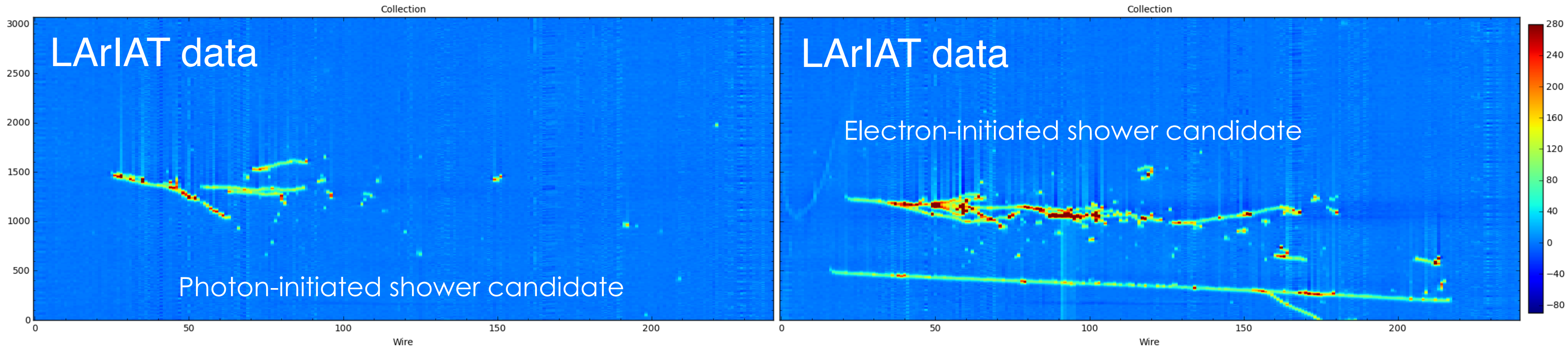
Timing & pattern recognition



Important for oscillation experiments:

Constrain capability to charge-ID primary lepton in ν_μ CC interactions of particular interest for CP violation w/DUNE

Electron/Gamma Discrimination



- First few cm of shower used to separate electron-initiated showers from photon-initiated showers (single vs. double ionization)
- Direct experimental measurement of the (MC-estimated) separation efficiencies
- Enable development of reliable separation criteria/algorithms in the LArSoft offline reconstruction code
- **Important for oscillation experiments**: support measurement of the low-energy e-like excess from MiniBooNE (primary goal of MicroBooNE), and for DUNE separation of ν_e CC signal from NC π^0 BG

6. **Does the proposed scope and run plan serve the purpose of the neutrino community? Does the committee recommend further actions to ensure full exploitation of the LArIAT program?**

The LArIAT program aims to be flexible and responsive to the needs of the neutrino community.

Our physics program will provide useful input to the community

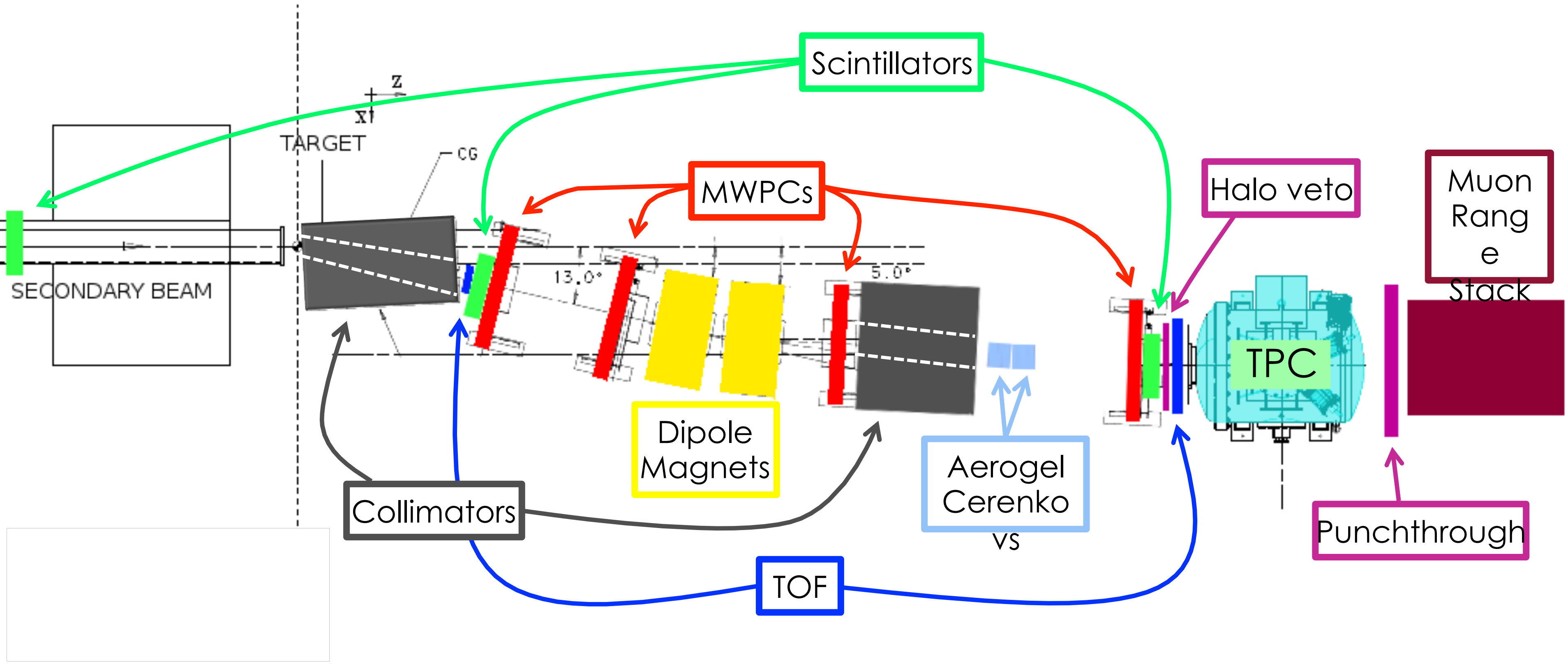
- Never-before-measured π-Ar cross sections
- Direct measure of PID efficiencies for products of neutrino interactions
- Direct measure of ability to distinguish e- from γ-induced showers

Our R&D program has some already identified paths, but is designed to be nimble

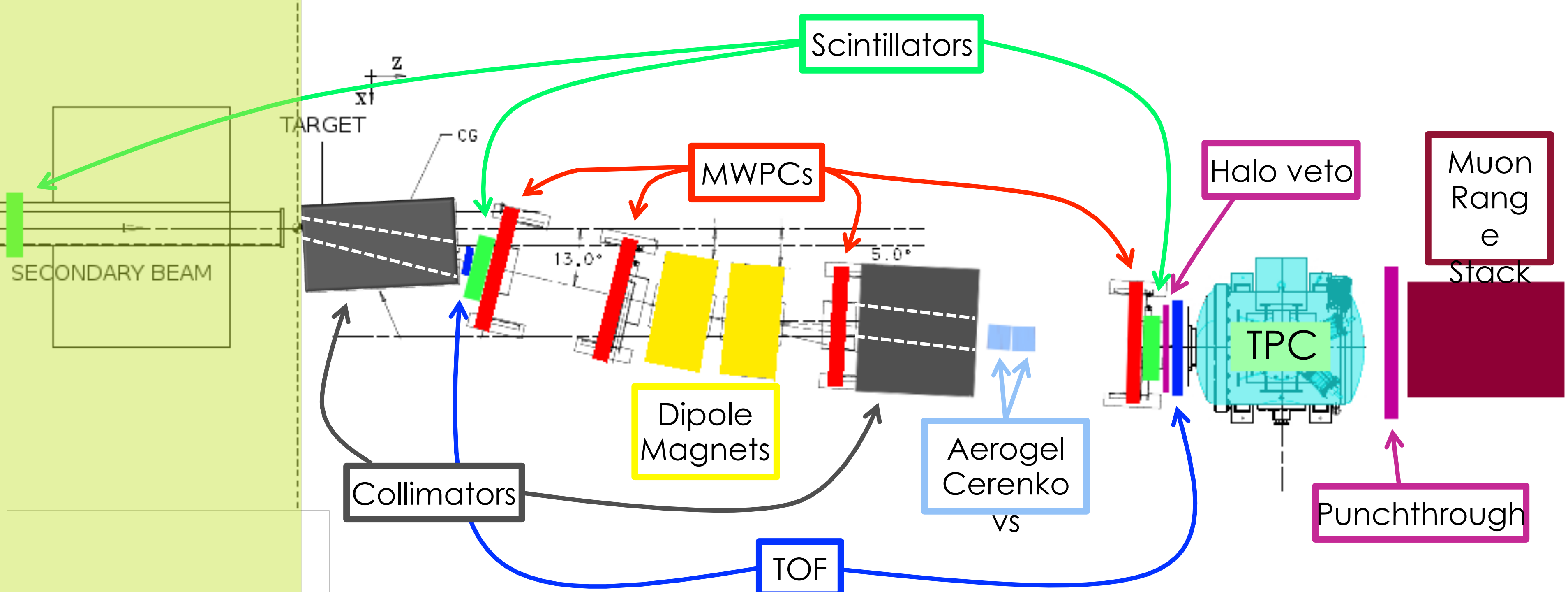
- Tests of new light collection ideas
- Direct measurement of 3mm vs. 5mm wire spacing
- … other ideas not yet proposed!

You'll hear more about some of these in Flavio's talk later today

Experiment Overview

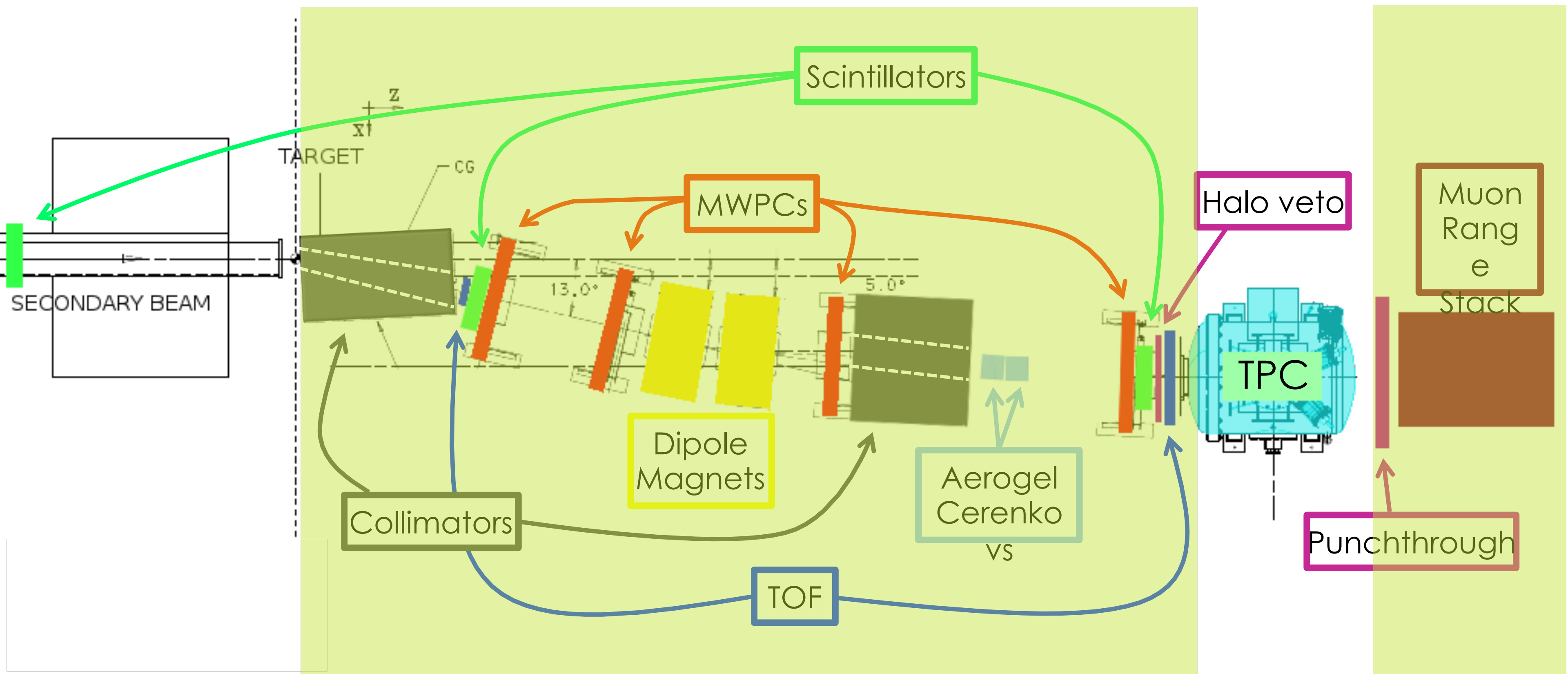


Talks in this review



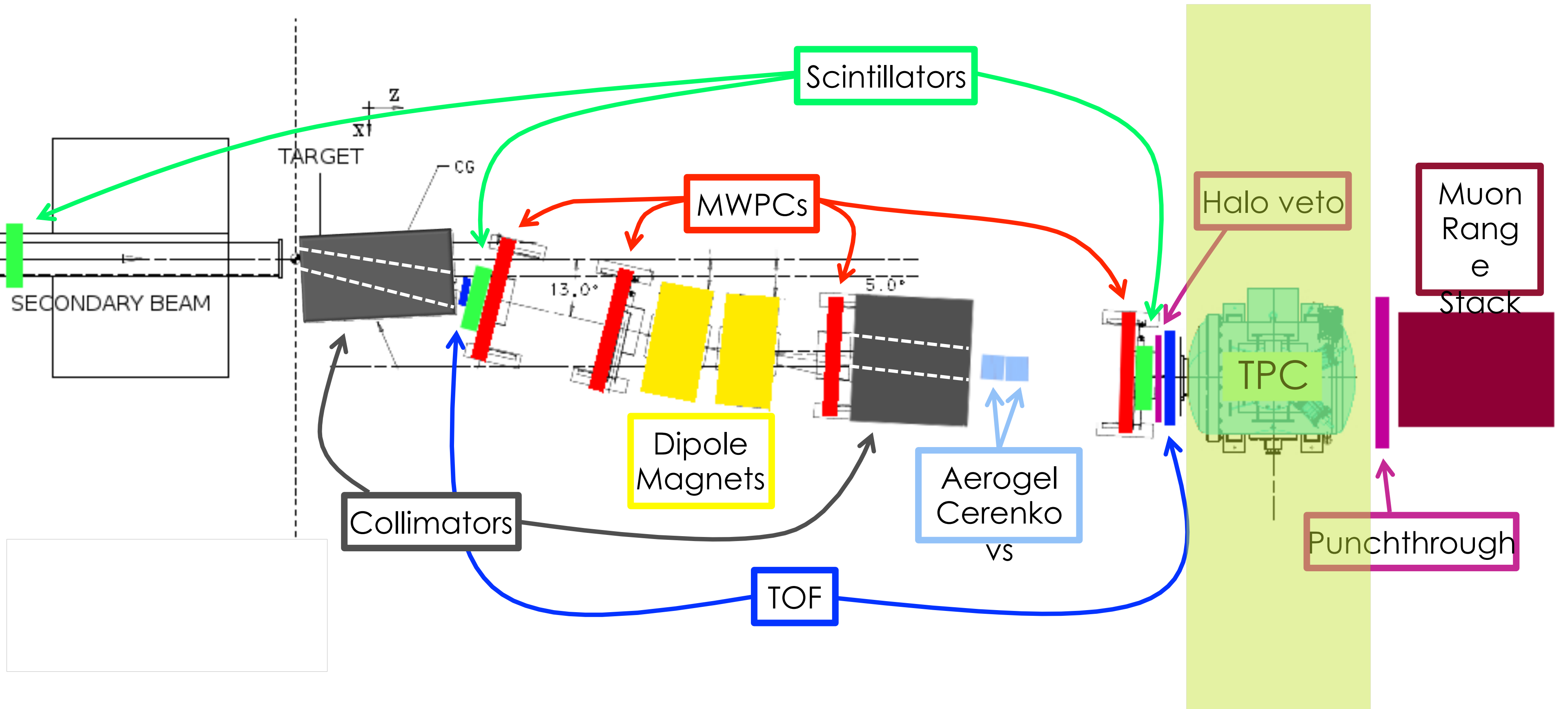
Michael Backfish, AD Beam Liaison
(Beam Delivery & Tuning)

Talks in this review



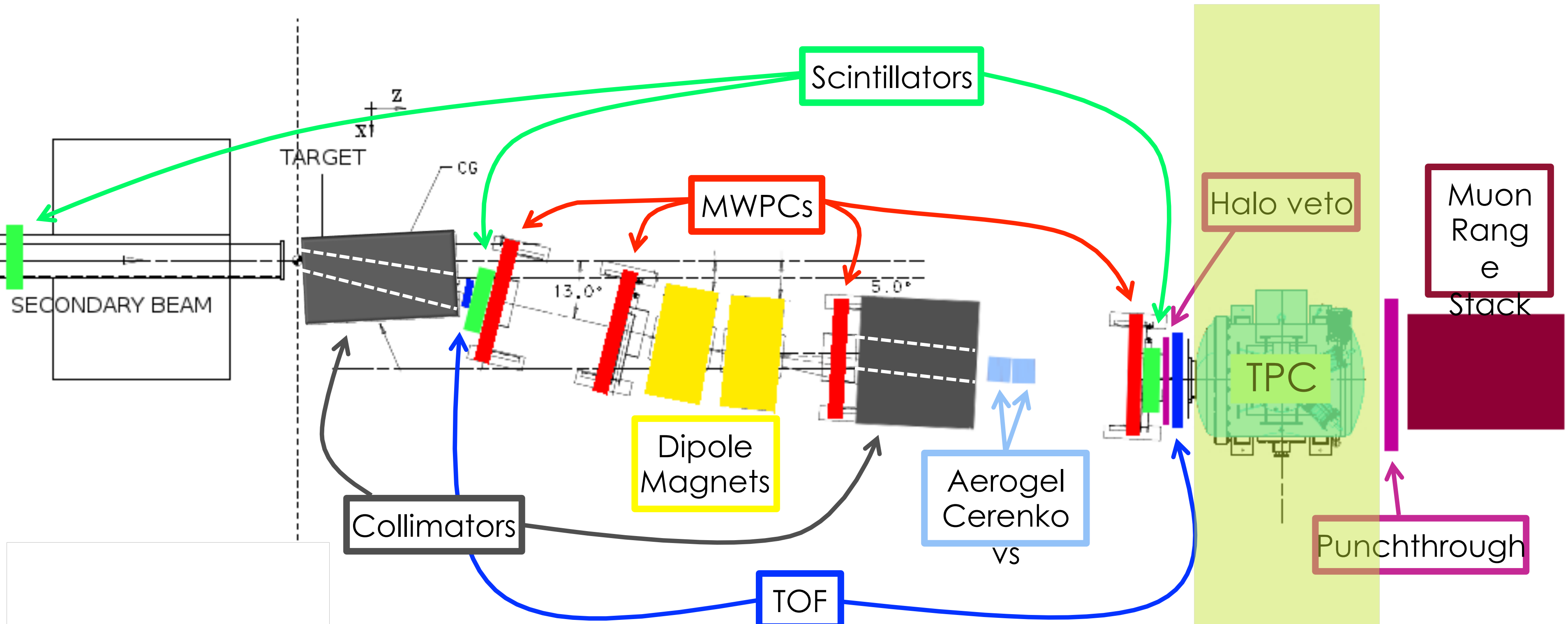
Jason St. John, Run Coordinator
(Tertiary Beam & Beamline Detectors)

Talks in this review



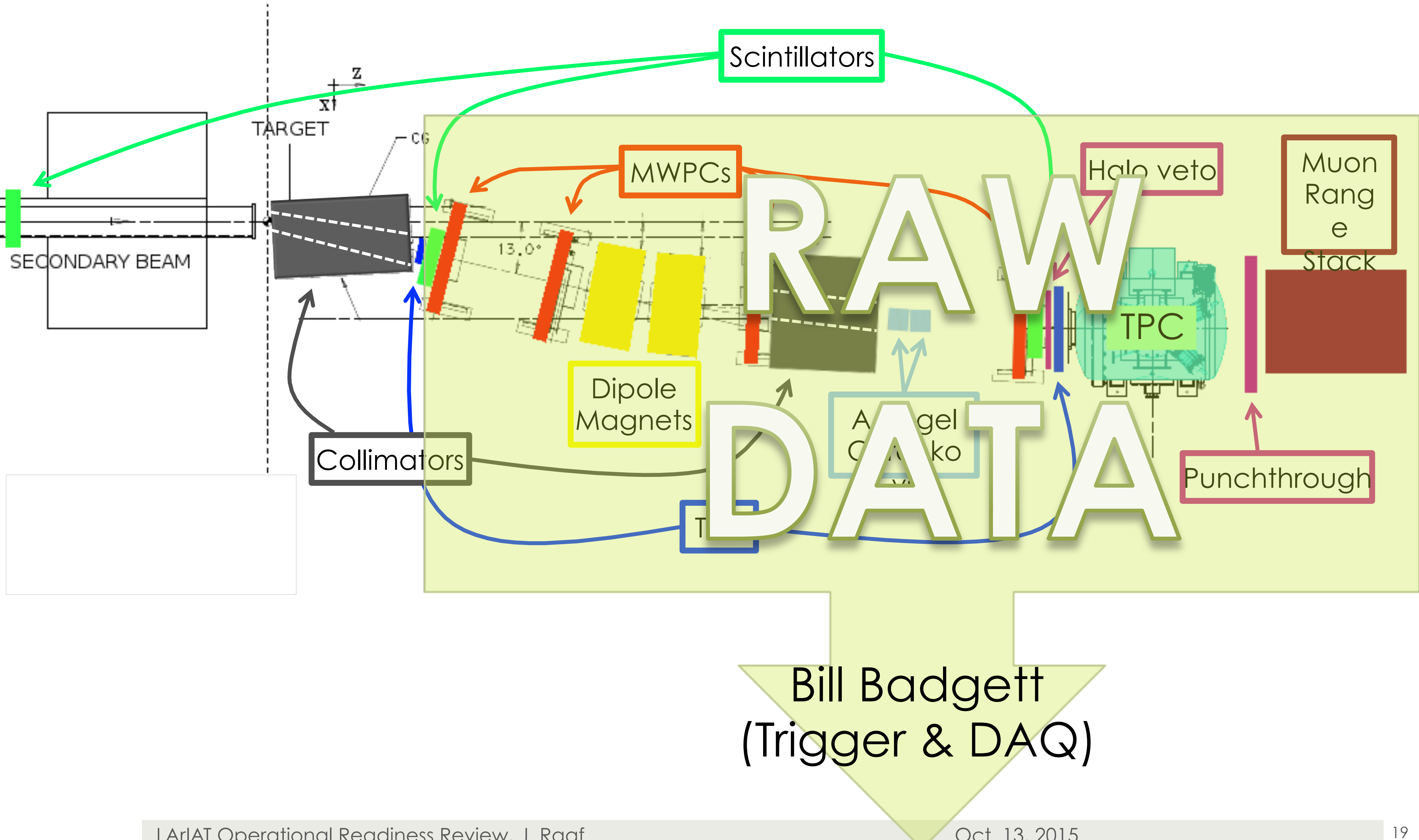
Roberto Acciarri
(LArTPC + Light Collection System)

Talks in this review

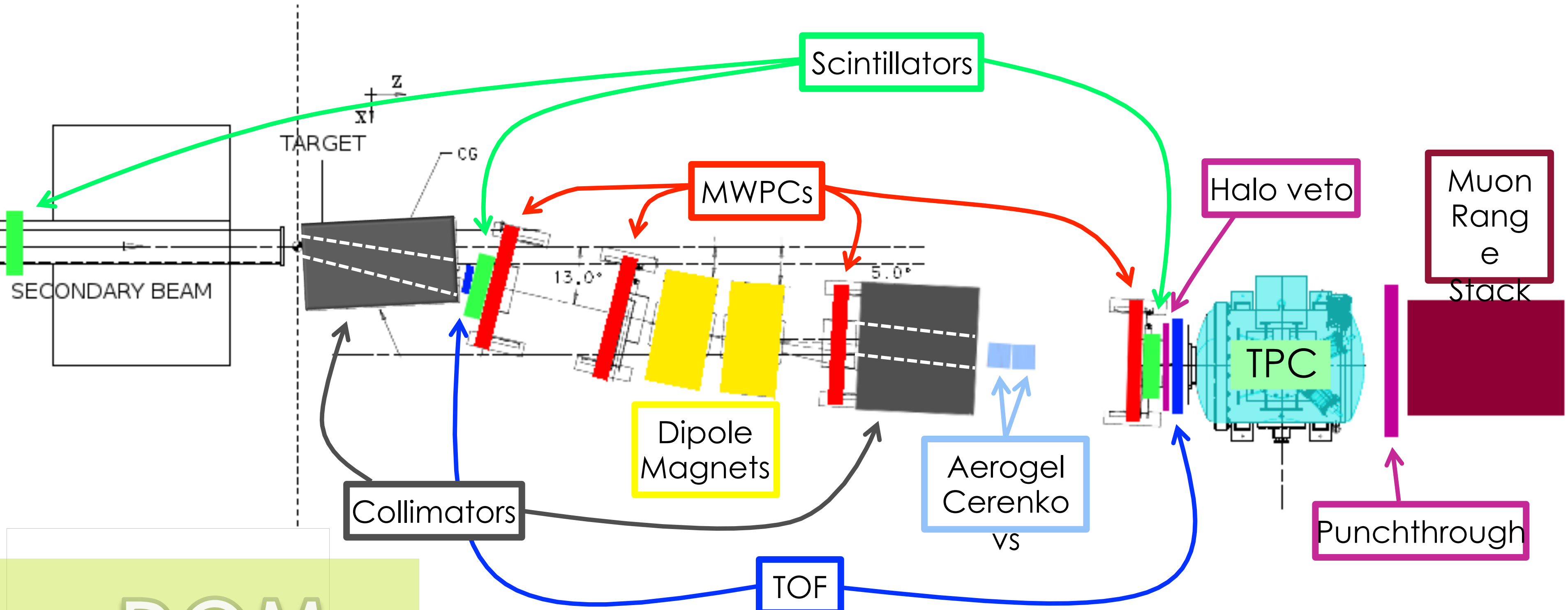


Carl Bromberg
(TPC Electronics)

Talks in this review



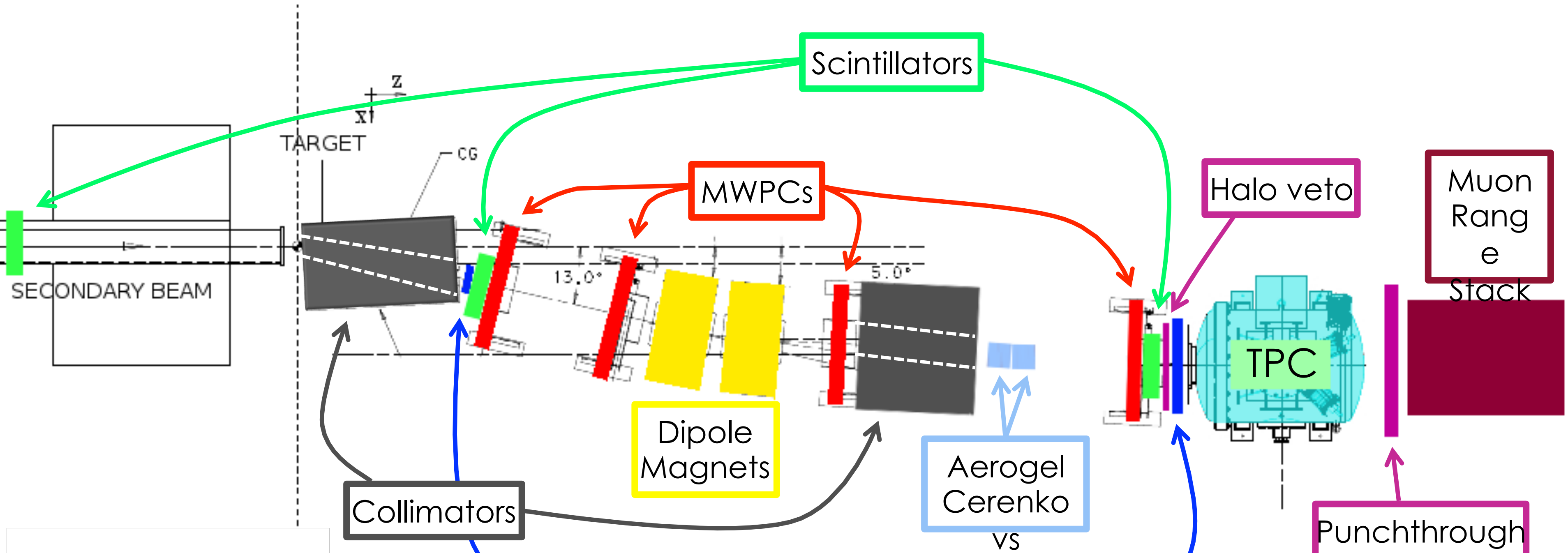
Talks in this review



DQM
+
Offline

Johnny Ho (Monitoring)
+
Jonathan Asaadi
(Offline Infrastructure & Data Processing)

Talks in this review



Analyses

Will Foreman (Michel electrons)
Pawel Kryczynski (PID with light & charge)
Animesh Chatterjee (π^- inclusive xsec)

Run Plans

- Engineering Run (August 2014, ~2 weeks)
  - Commissioned beamline detectors (no TPC), started characterizing beam
- Run-I (Completed: April 30, 2015 – July 7, 2015)
  - All detectors installed and operational
  - Filled cryostat with LAr April 29, 2015
  - First TPC track April 30, 2015
  - Beam data collected May 1 – July 3, 2015
- Run-II (Expected start: February 2016)
  - Focus is currently on Run-I analysis to inform data-taking for Run-II (more on this in a few slides)
  - During shutdown (now), implementing cryogenic system phase separator improvement: expect ~15-20% savings in LAr cost
  - Also during shutdown, making a few small changes inside cryostat (PMT fix, bias voltage card modification)

Run-I Summary

- Total: 9 weeks beam data + 1 week special runs
  - Data from first 3 weeks not entirely good physics quality, mostly beam tuning
  - Final 6 weeks: ~44k beam spills with good 2ndary beam recorded to tape
  - ~20 events/spill, of which ~25% are "good" events (without pileup)

  → average ~5 good events/spill with a mix of particle types

Secondary beam energy	Tertiary beam magnet setting	Number of spills recorded
16 GeV	+100A	7950
16 GeV	-100A	10843
16 GeV	-60A	6573
32 GeV	-60A	91
32 GeV	-100A	2252
32 GeV	+100A	3287
64 GeV	+100A	1315
64 GeV	-100A	5205
64 GeV	-40A	3149
64 GeV	-20A	497
64 GeV	+40A	2189

What We Know So Far (from Run-I data)

- So far, only a fraction of the Run-I data analyzed
  - Excellent overall data quality throughout run
  - Very good beam performance after the initial ~3 weeks of tuning
- Clear from Run-I data what improvements can be made to LAr detector, beam, and beamline instrumentation for even better Run-II data
  - Repair base of one PMT in light collection system (in progress)
  - Minor change to TPC bias voltage distribution cards to eliminate "shadow" seen in induction plane (completed)
  - Additional shielding may reduce beam halo (under study by AD)

Run-II Plans

- Run-I analyses inform Run-II plans
  - Goal: better than 10% statistical uncertainty on **inclusive** pion cross section
    - So far, we have analyzed ~1/10th of the data for which we had good secondary beam and no pileup in TPC
    - In that 1/10th of data: ~1200 pions (after selection cuts)
    - Scaling to total dataset: expect we have ~18k good pions

    → *Existing Run-I statistics will allow measurement of inclusive cross section to better than 10% statistical uncertainty*
  - For **exclusive** channels (absorption, charge exchange, scattering), would need at least 3x more data to achieve same level of statistical uncertainty (although charge exchange channel needs even more to reach same stats level)
  - Kaons: analysis just beginning, handful collected in Run-I
    - In Run-II, we'll tune the beam to make more kaons, with aim of measuring kaon-Ar interaction cross sections as well (estimates of achievable statistical uncertainty can only be made after we move forward with this analysis)

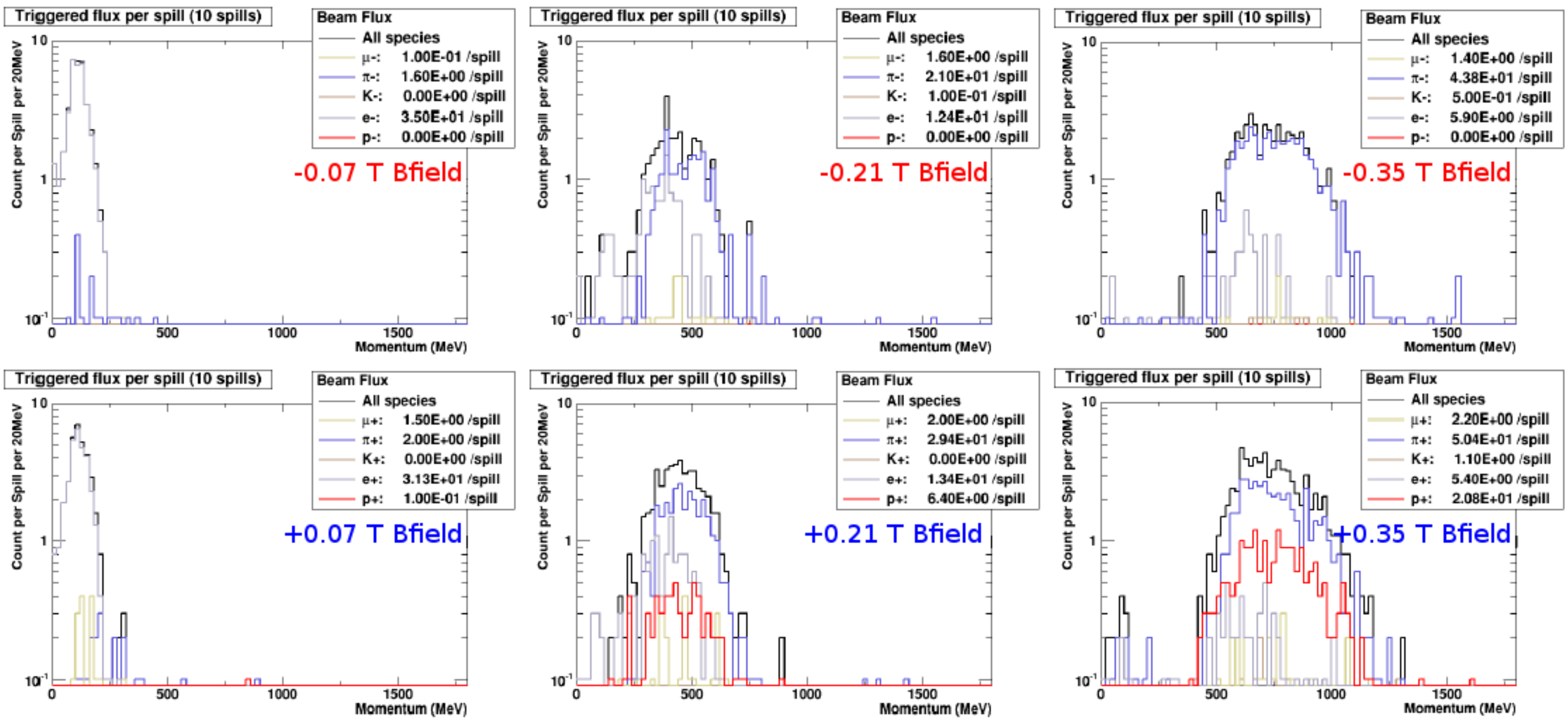
Thank you

Extras

Beam Composition: Simulations

- Secondary and tertiary beam polarities can be switched
- Mostly pions, but possible to tune composition of beam depending on energy of secondary beam and tertiary magnetic field

+80 GeV π^+ secondary beam on target



Timescale: Cryostat Opening

- Clearing space in front of cryostat:
  - ~3-4 full days of work with ~4 LArIAT collaborators
- Opening outer & inner flanges:
  - 0.5 days (but would have been only a few hours if the fork truck hadn't broken)