

TDIS Update

Dipankar Dutta

Mississippi State University

SBS Meeting Mar 3, 2026

The Tagged Deep Inelastic Scattering (TDIS) Experiment

Goal:

A direct measurement of the mesonic content of the nucleon and a unique extraction of the pion's F_2 structure functions, by scattering from a **virtual pion target**, accessed via **spectator tagging**.

Spokespersons: D. Dutta, N. Liyanage, C. Keppel, P. King, R. Montgomery, H. Nguyen, B. Wojtsekhowski

Motivations:

C1 conditionally approved with A- rating for **27 PAC days**

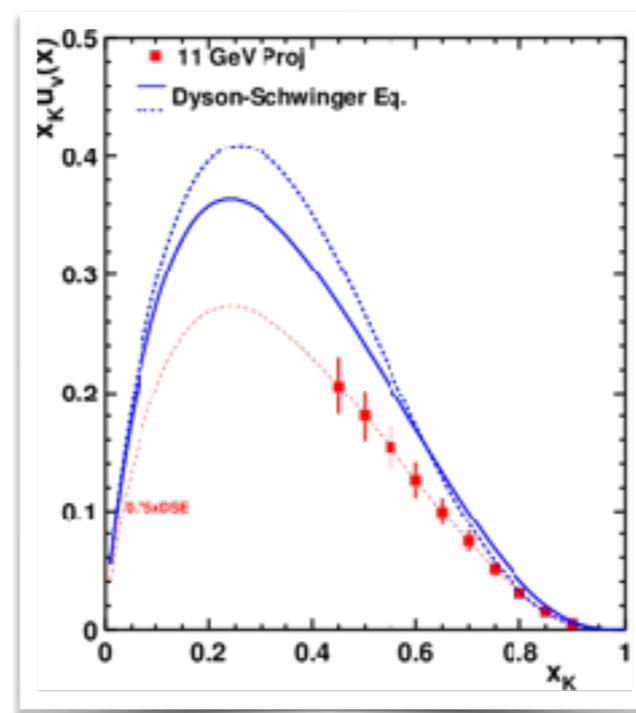
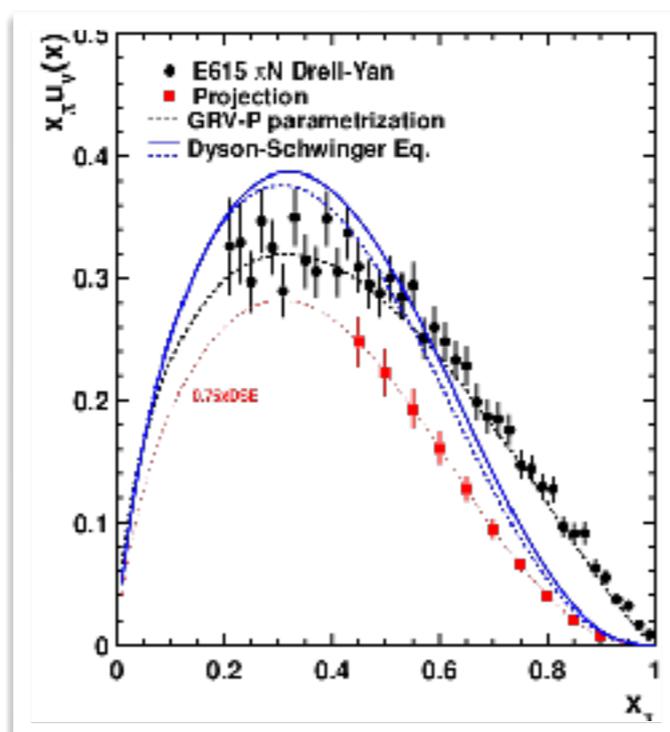
There is ample evidence that nucleons have pionic content in them, but no direct measurements.

Pions and kaons are the simplest bound states of QCD and its Nambu-Goldstone bosons- knowledge of meson structure is critical to a complete understanding of the emergence of hadron mass.

But, very little data due to the lack of “meson targets”.

TDIS will use spectator tagging - a well established technique- to tag the “meson cloud” of the nucleon.

TDIS is a pioneering experiment but the proposed technique to extract meson structure function is an essential proof-of-principle for future experiments at the EIC & 22 GeV JLab.

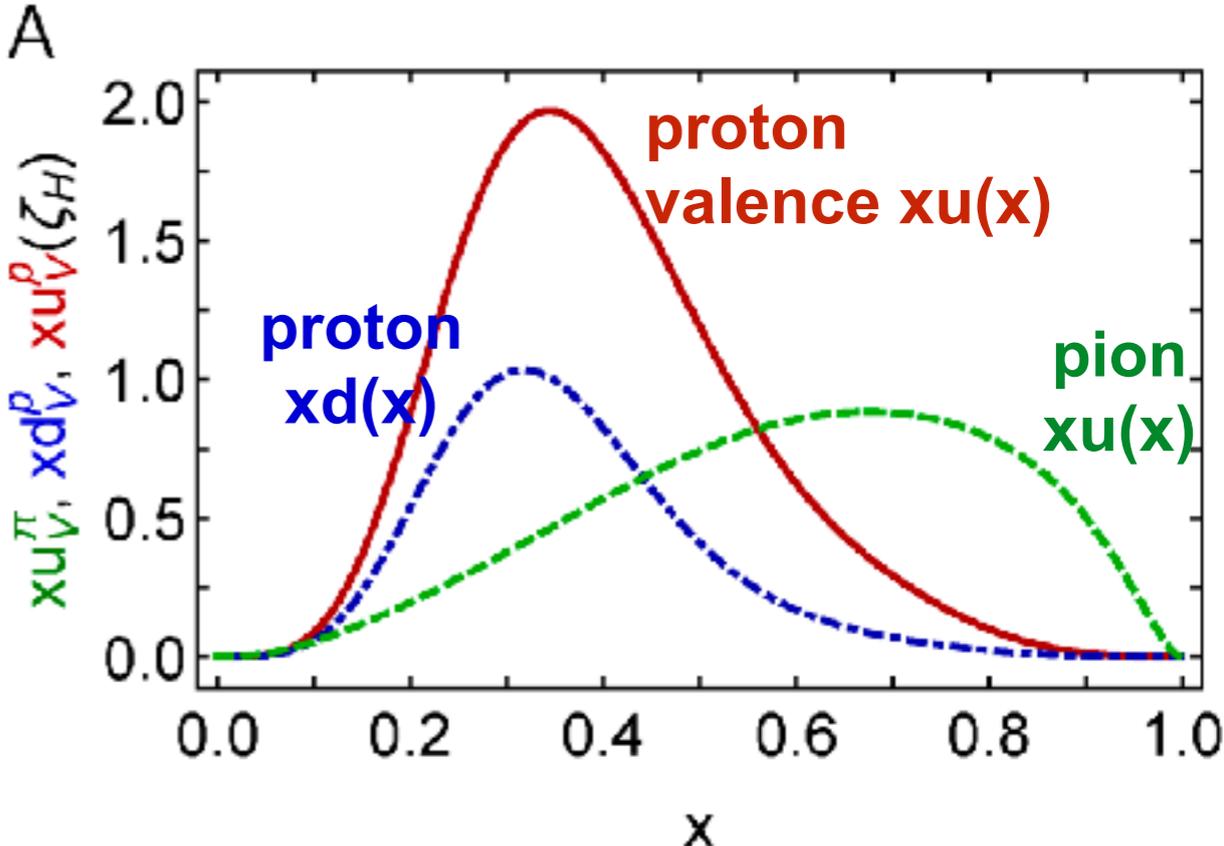
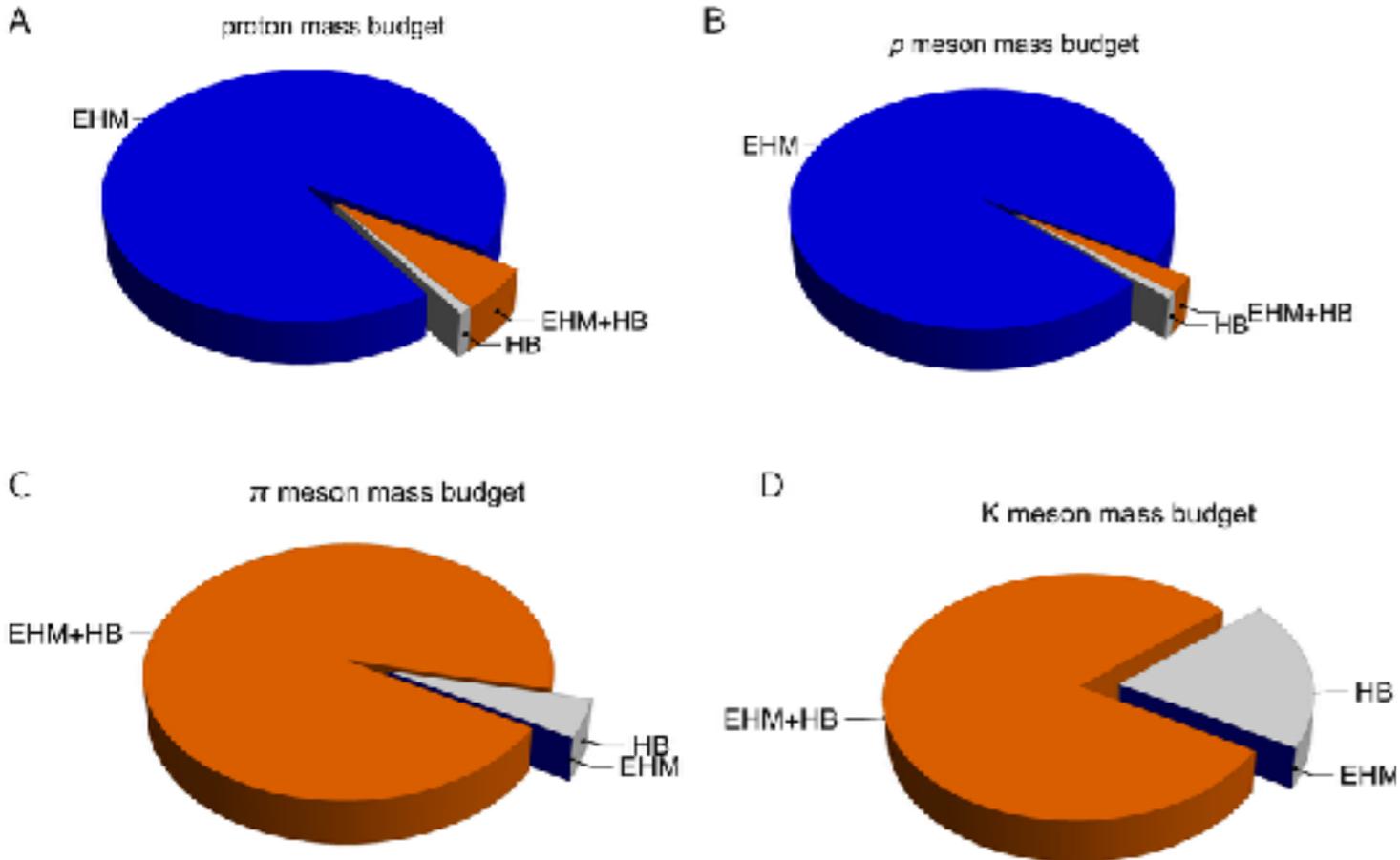


Since approval, there has been a surge of interest in both the technique and the science goal

Significant progress in understanding meson structure through emergent hadron mass - **over 50 publications with more than 1200 citations (including LRP white paper & EIC yellow report).**

Mass budget for mesons and nucleons are vastly different

- Emergent hadron mass
- Interference of emergent hadron mass & Higgs mechanism
- Higgs mechanism



pion/proton valence quark distributions are very different

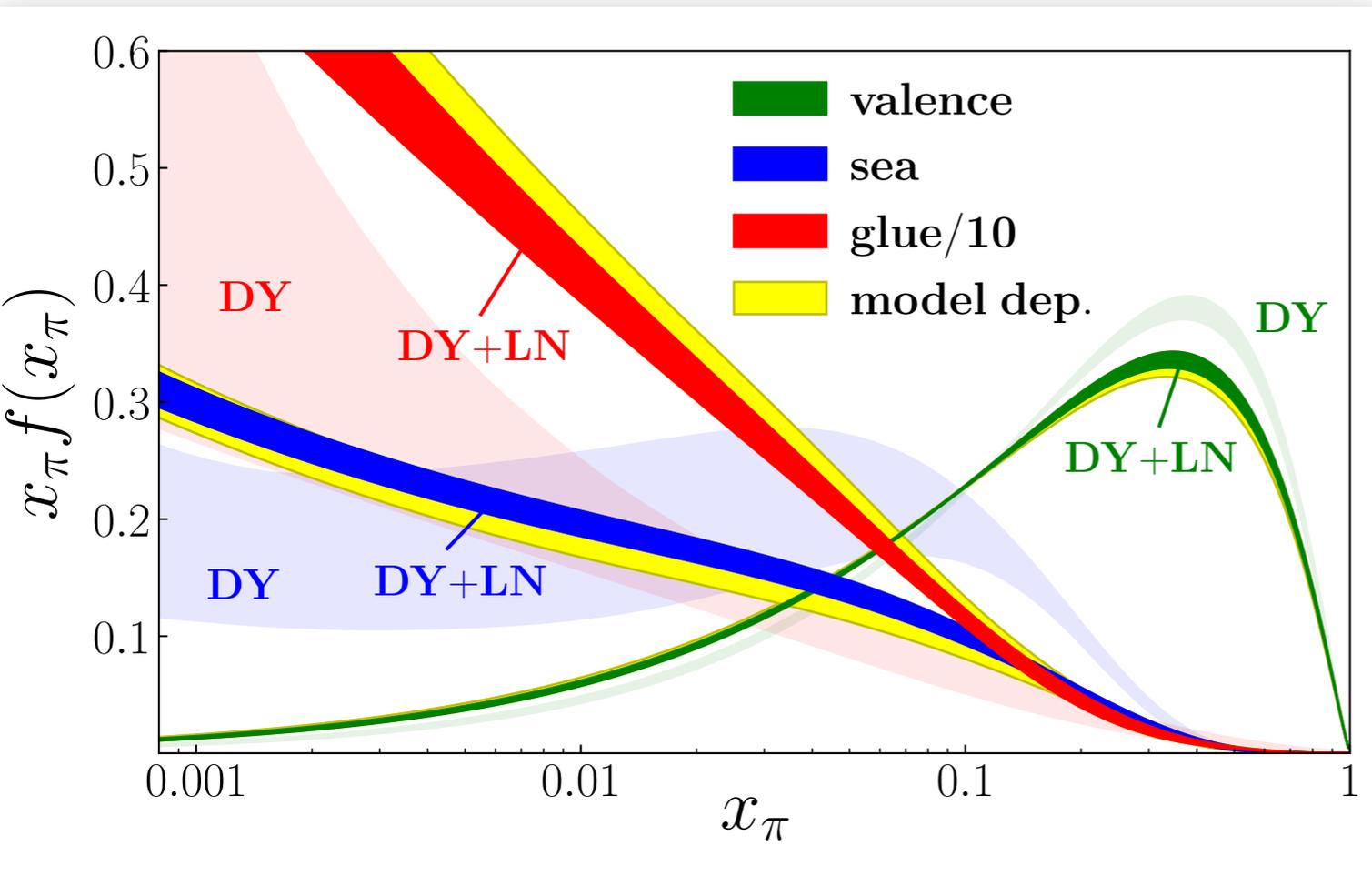
M. Ding, C.D. Roberts & S.M. Schmidt, *Particles* 6, 57 (2023)

difference between meson PDFs: direct information on emergent hadron mass

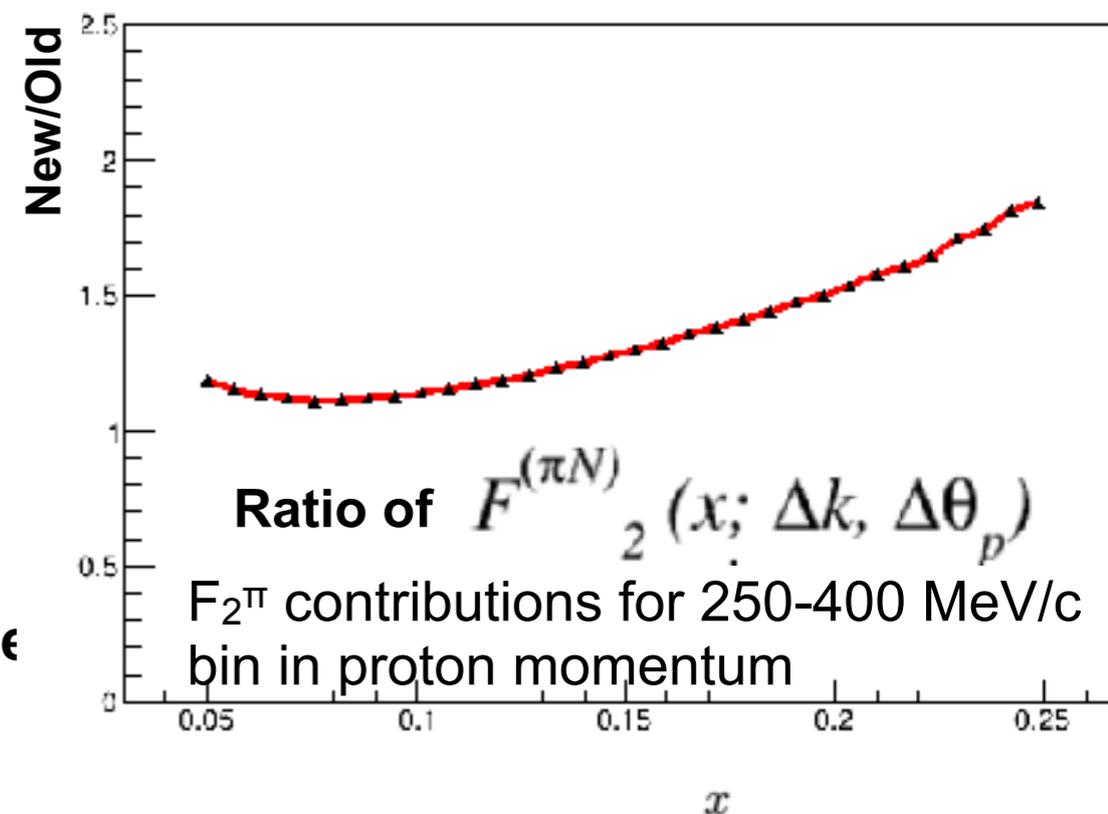
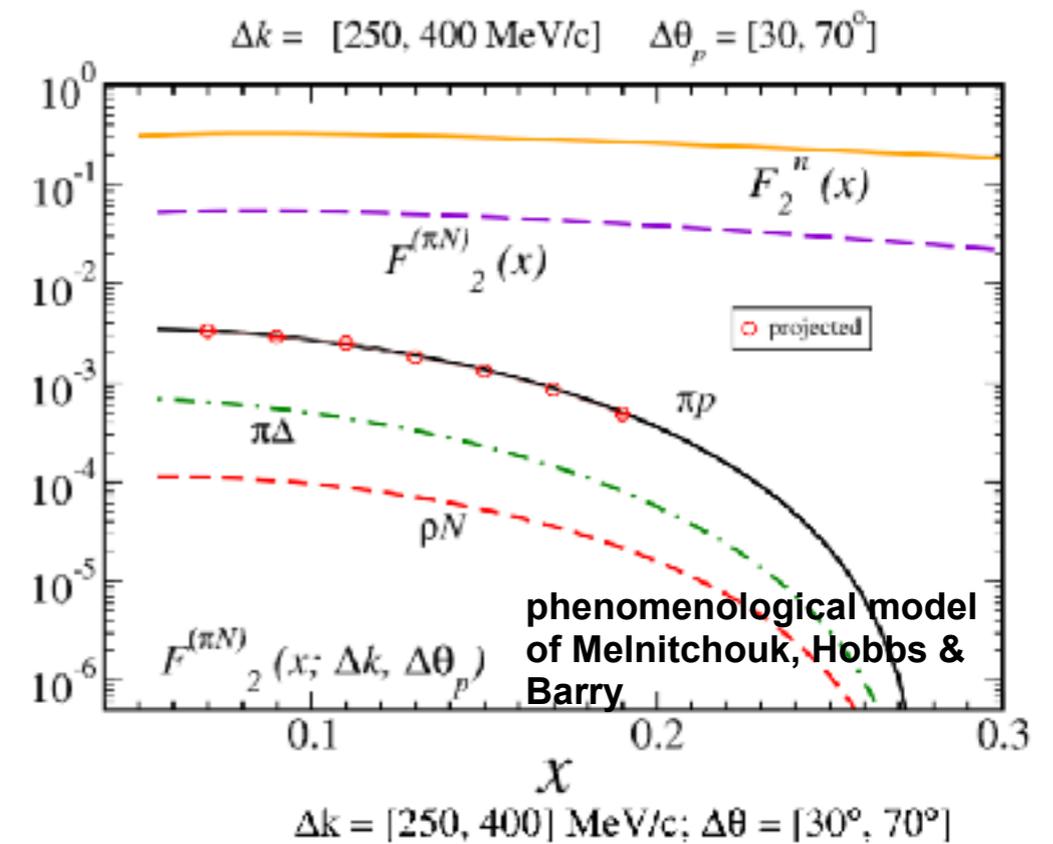
A global QCD analysis including the leading neutron HERA data has been completed

Peak of valence quarks momentum fraction shifted to smaller x , than that inferred from Drell-Yan data alone

P. C. Barry, N. Sato, W. Melnitchouk, and C-R. Ji,
Phys. Rev. Lett. 121, 152001 (2018)



Rate of TDIS signal events is expected to be larger and less sensitive to the pion flux factor; will help reduce the beam current to improve background and tracking.



plots credit: P. Barry & C. Ayerbe Gayoso

The TDIS experiment was reapproved by PAC 51

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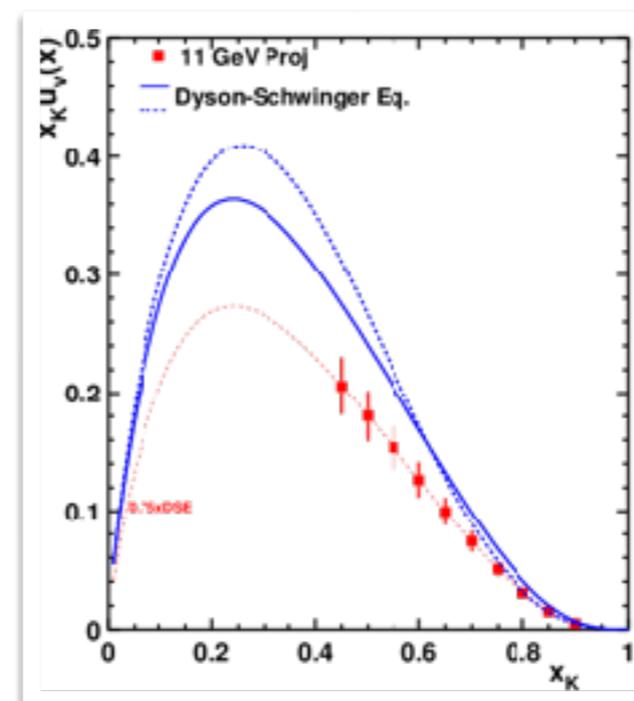
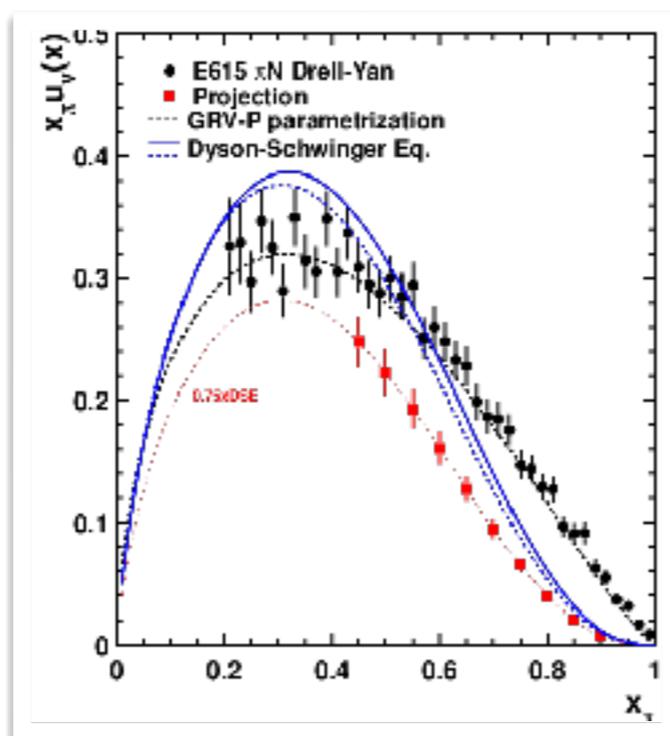
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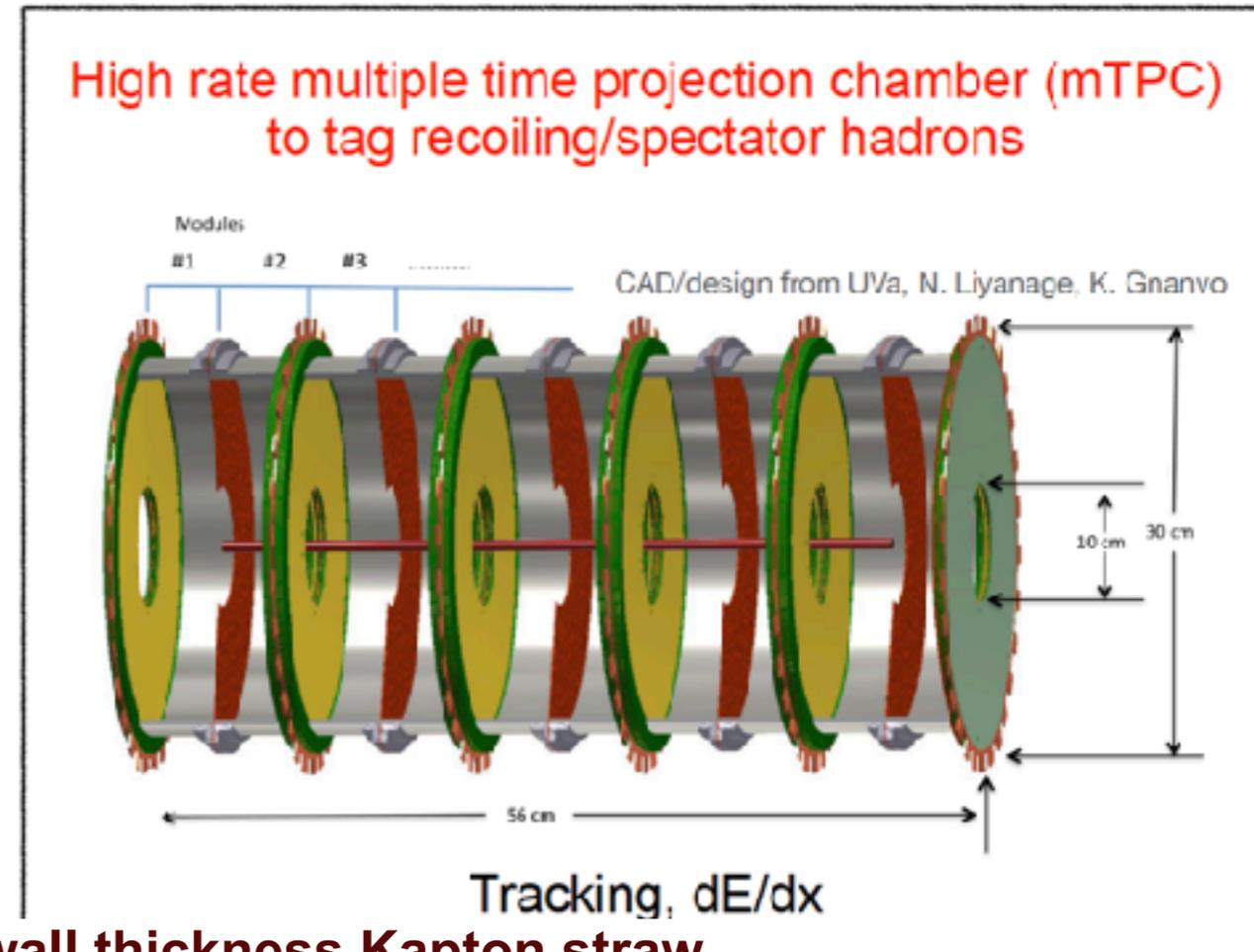
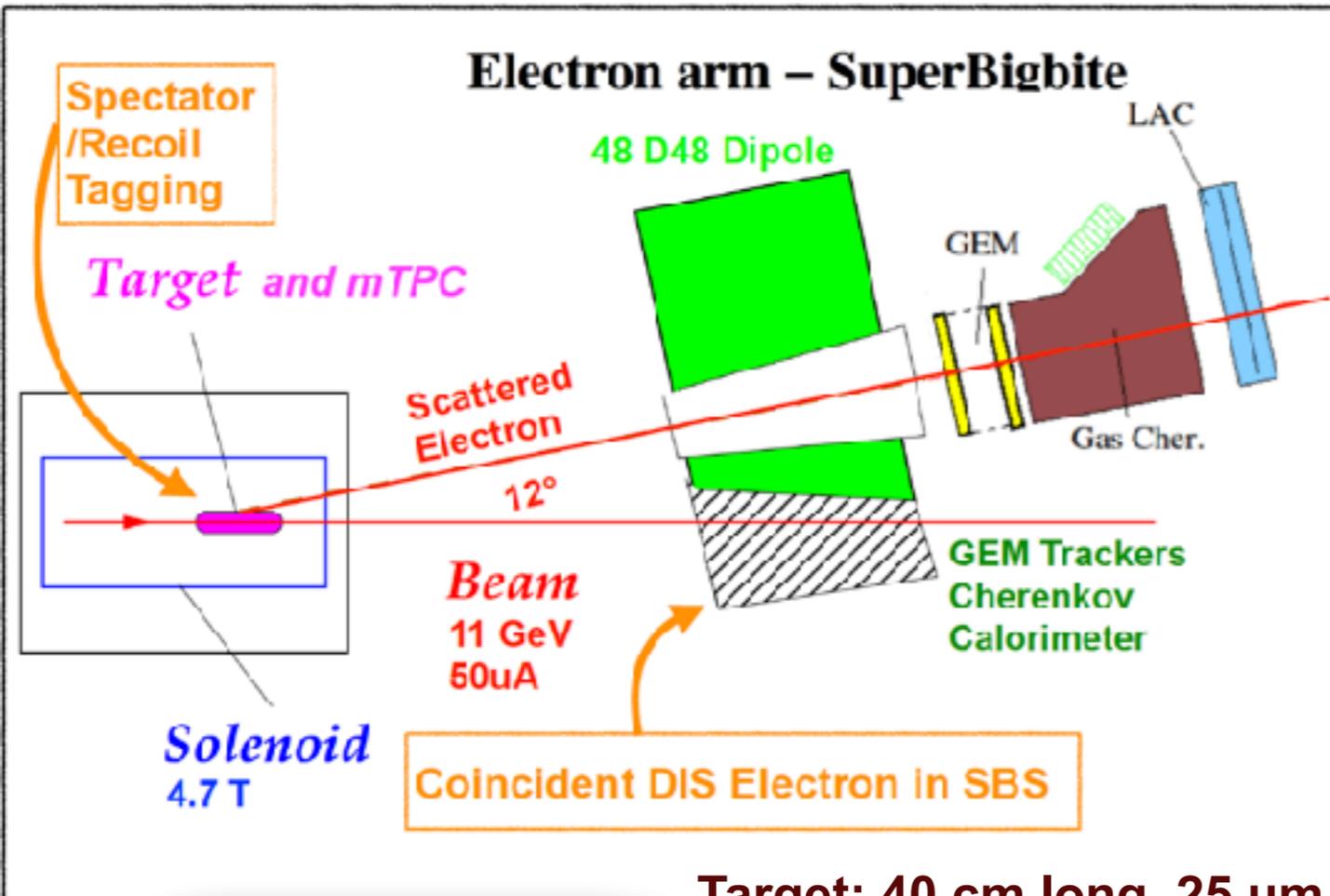
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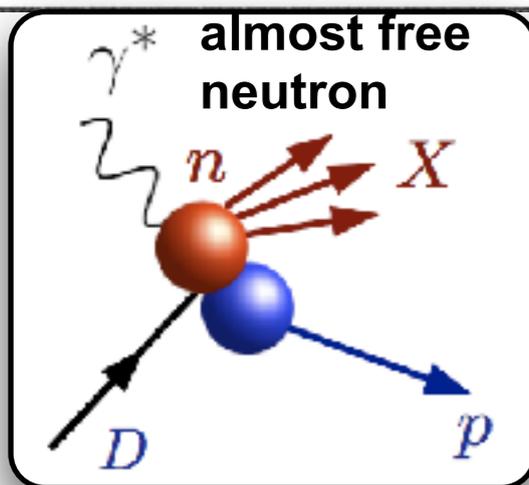


Spectator Tagging - a well established technique at JLab - can be used to tag the “meson cloud” target.

The TDIS experiment will use spectator tagging in a cylindrical recoil detector



Target: 40 cm long, 25 um wall thickness Kapton straw at room temperature and 3 atm. pressure.



Deuteron Spectator proton (backward going slow proton)

TDIS will be a pioneering experiment that will be the first direct measure of the mesonic content of nucleons.

The techniques used to extract meson structure function will be a necessary first step for future experiments

Questions from the TDIS Technical Review

mTPC:

Is the structural design of the mTPC sound?

Is the inner tube strong enough to support the lateral loads of the individual cells keeping them aligned?

Is the diffusion of the Helium gas into the target cell understood and within the tolerances of the experiment?

What is the double peak timing resolution in a readout cell? How far do two pulses have to be apart to be detected as individual hits in the same pad?

Solenoid/SBS Magnet:

What is the interaction between the solenoid field and the SBS Dipole iron?

What are the forces between these magnets?

Are additional support structures required to mitigate the forces on the magnets?

Tracking:

How can tracks be identified and reconstructed given the expected high occupancy, in particular in the first few layers/rings of a single detector module?

What is the yield of “false”/“fake” tracks given the high hit multiplicity?

Can either algorithm be run from the outer ring in, reducing the effect of the inner ring occupancy?

Target:

It is strongly recommended that a JLAB Design Authority be assigned to this system.

What are the safety margins regarding target operation (pressures/temperatures)?

What safety mitigations are planned if the pressure margin requirements cannot be met?

What is the impact of the downstream flange material on the scattered electron trajectory?

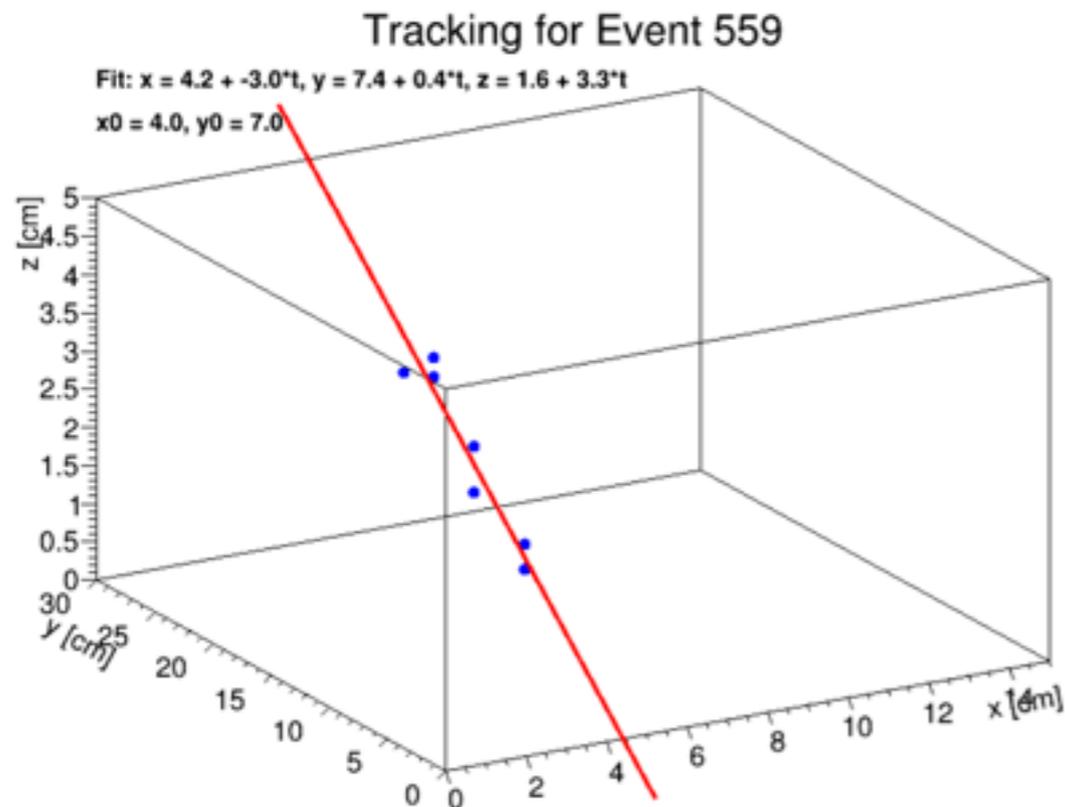
What is the impact of beam-heating on the aluminum entrance and exit windows?

Is active cooling required?

What is the impact of the heat and radiation environment on the target flange seal o-rings? Are special/dedicated materials needed?

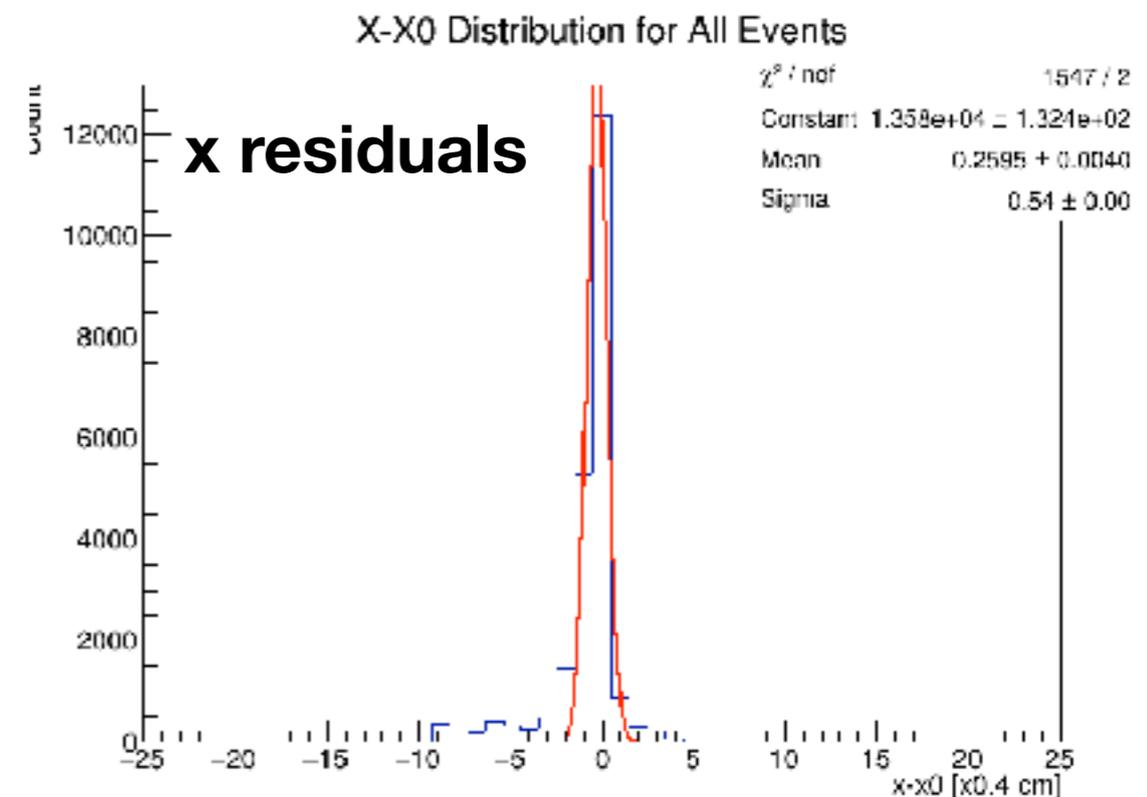
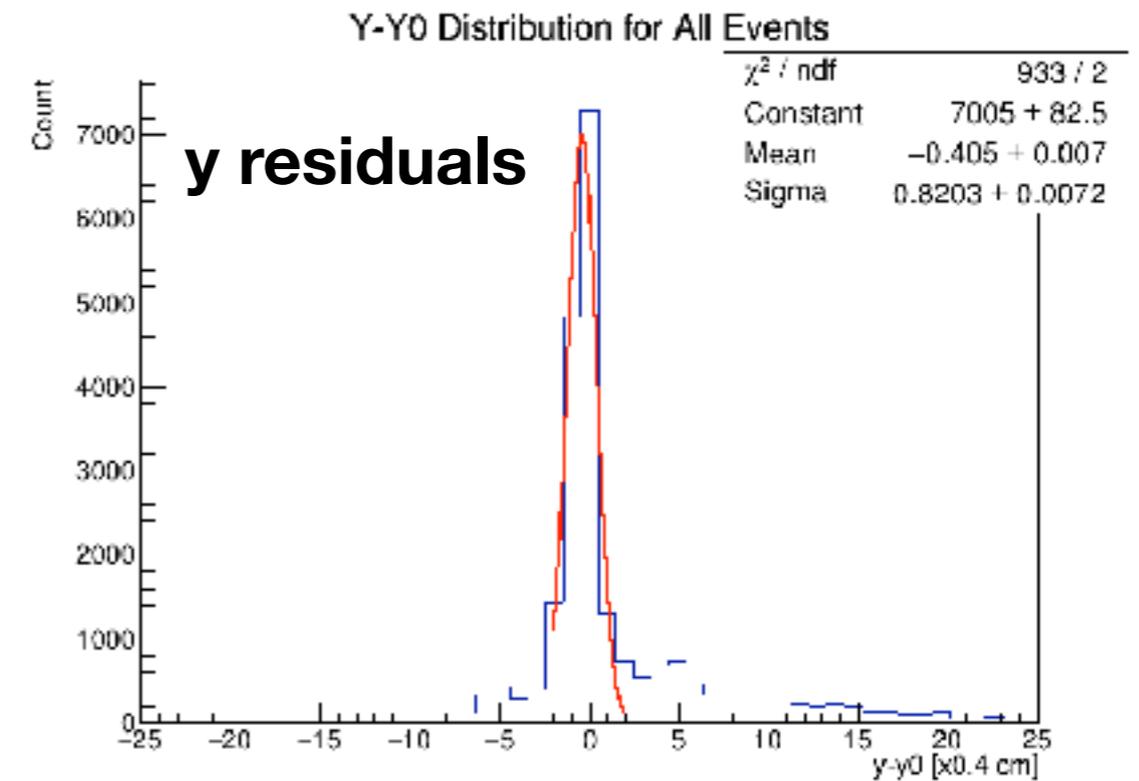
Prototype successfully tested with cosmics

Analysis and images by Aruni Nadeeshani

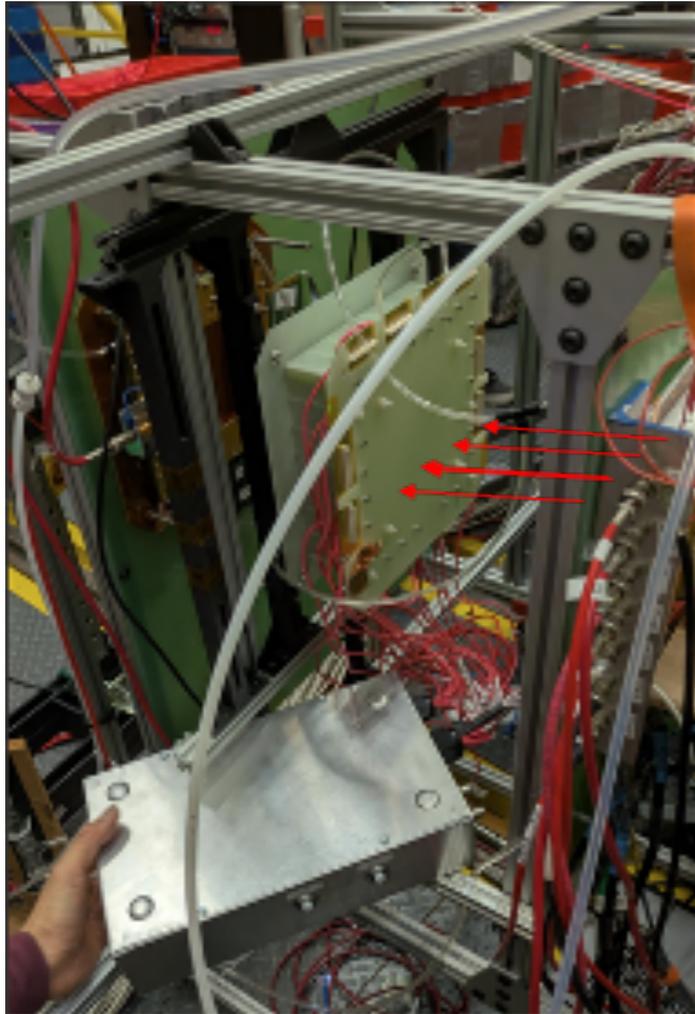


limited cosmic data, analysis software is ready and validated.

Beam test in Hall D completed in September

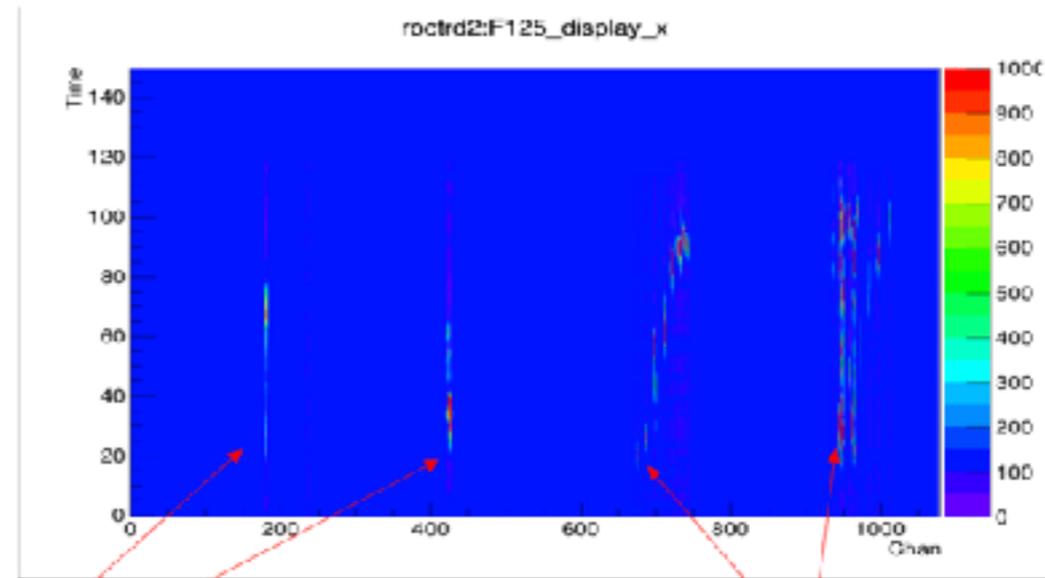


Square prototype was recently tested in the Hall D beamline



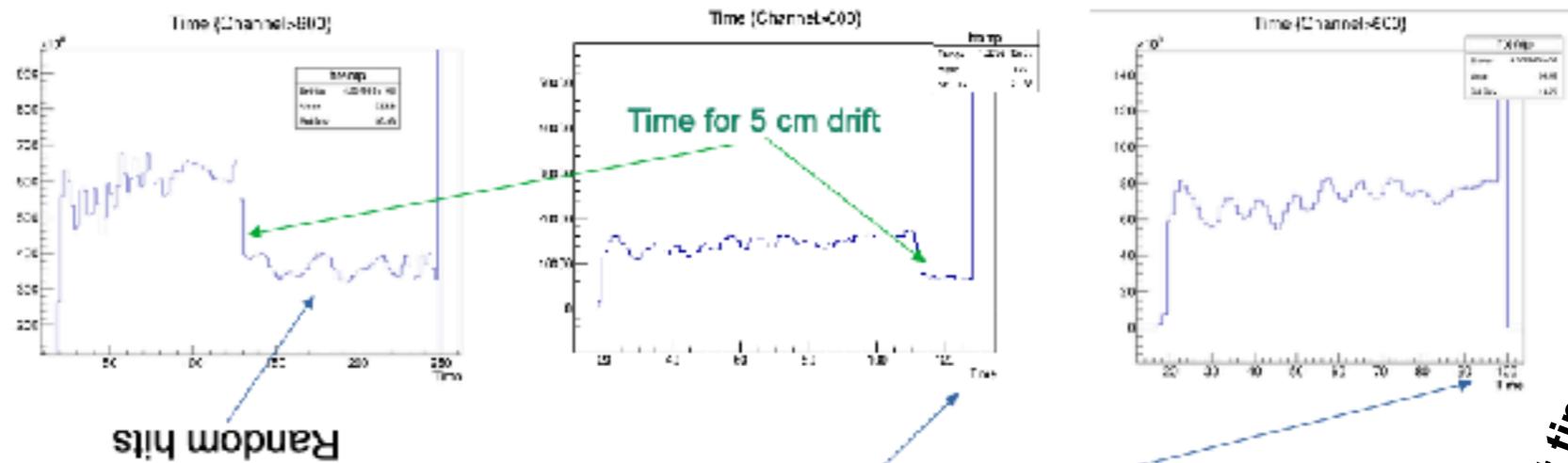
Beam

Example event in online display



Tracks from two other detectors

TDIS Tracks



Drift time distributions

images courtesy of Sudipta Saha and Eric Christy

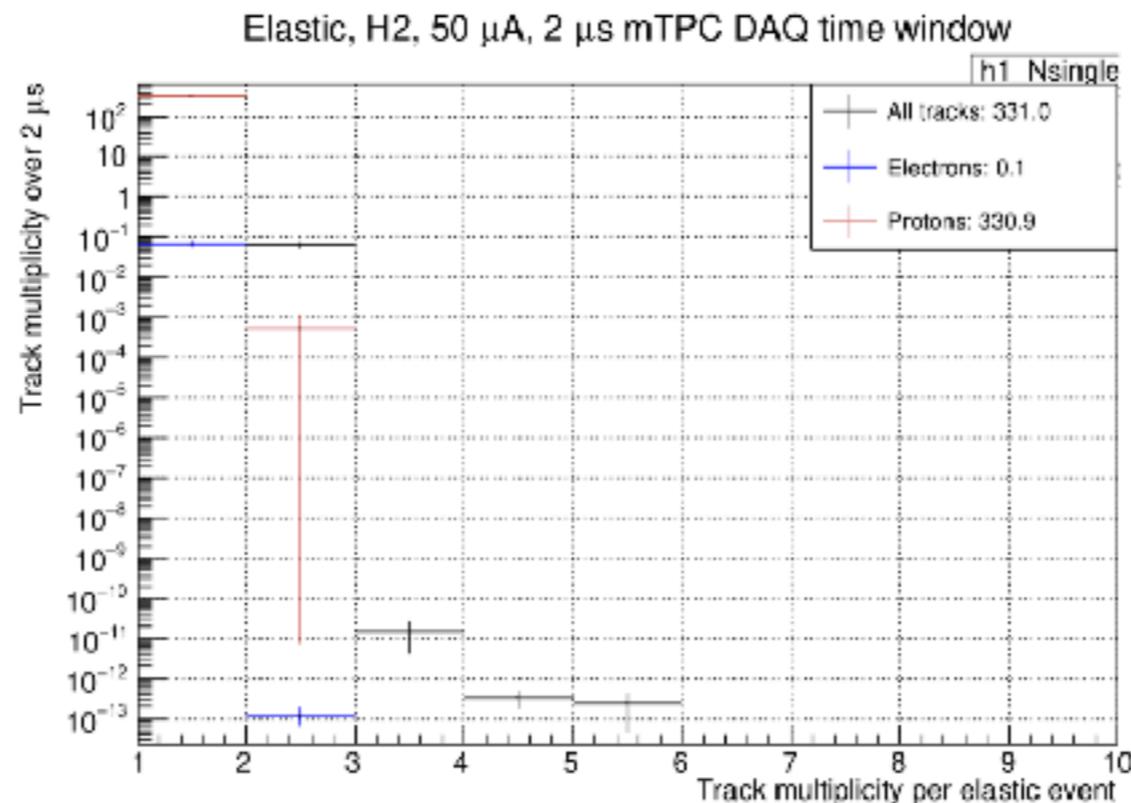
→ Time window was reduced to lower data rate in raw mode
 => This turned out to be too aggressive and removed hits with the longest drift

Detailed analysis underway to determine optimal pad size and characterize the drift volume

Comprehensive Geant4 simulation by Eric Fuchey and digitization by Rachel Montgomery

mTPC Rate Calculations

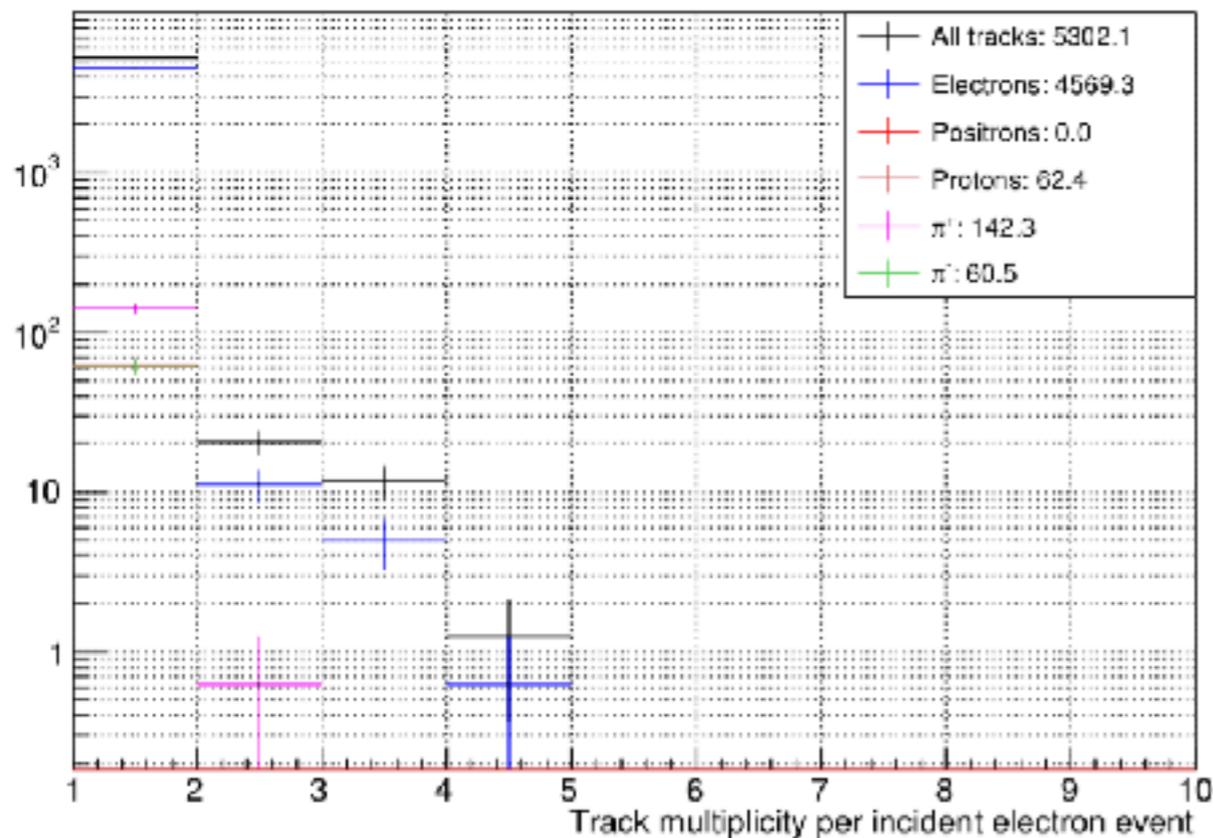
- Elastic: assuming 2 μ s mTPC data acquisition window:
 - H₂, 50 μ A: **330 proton tracks** (33 tracks per module) => 165 MHz;
 - consistent with Carlos' estimations from 2020;
- Comparison with BoNuS12: 250 nA on 50 cm D₂ (factor 100 less luminosity)
 - 20 tracks including *p*, *d*,... over **7.2 μ s**
 - Scaling to TDIS luminosity and mTPC DAQ time window: **550 *p*, *d* tracks**
 - Our comparison does not account for track reconstruction efficiency



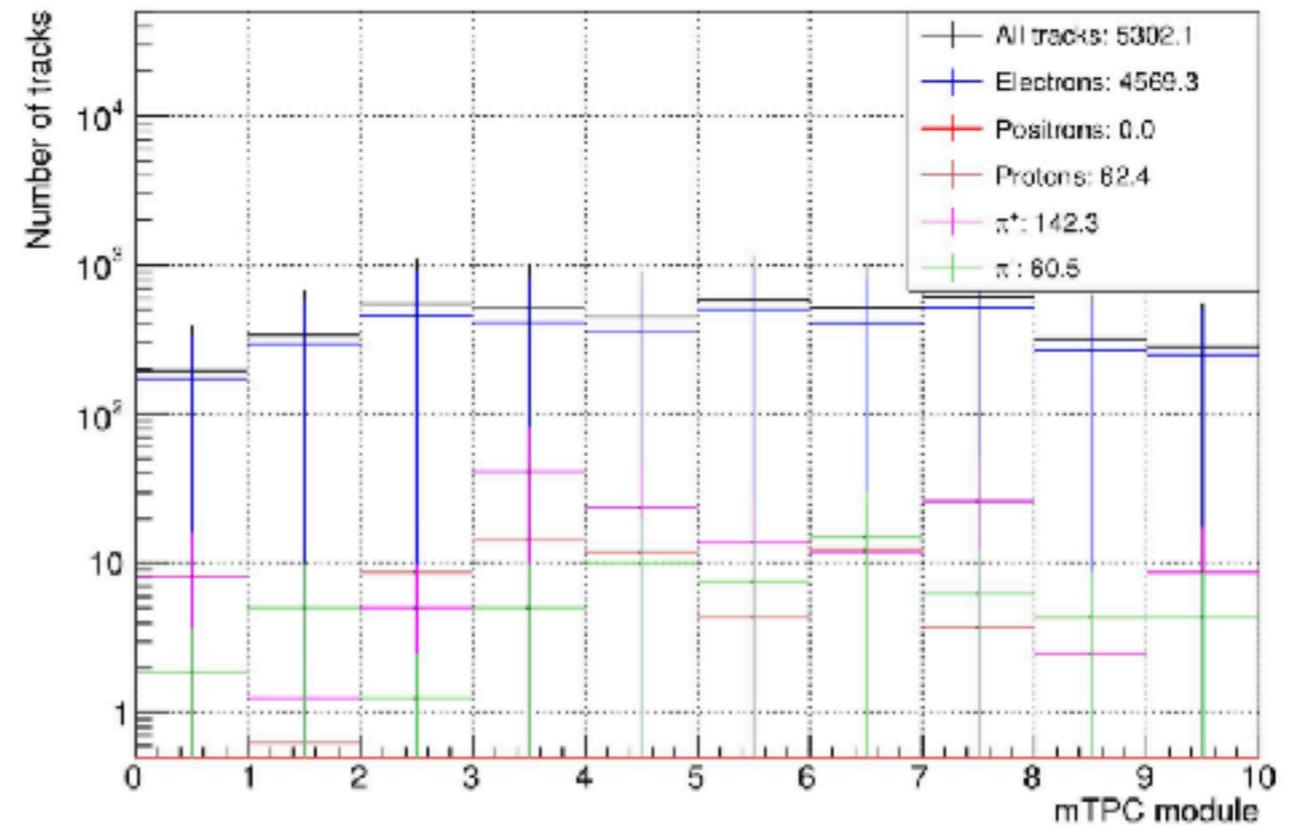
Comprehensive Geant4 simulation by Eric Fuchey and digitization by Rachel Montgomery

- Beam-on-target, assuming $2\mu\text{s}$ mTPC data acquisition window:
 - Particles that deposit some energy in mTPC gas are counted (true for all tracks);
 - H_2 , $50\mu\text{A}$: no e^+ , 4.6k e^- , $140\pi^+$, $60\pi^-$, $60p$;
 - roughly distributed evenly over the 10 modules;

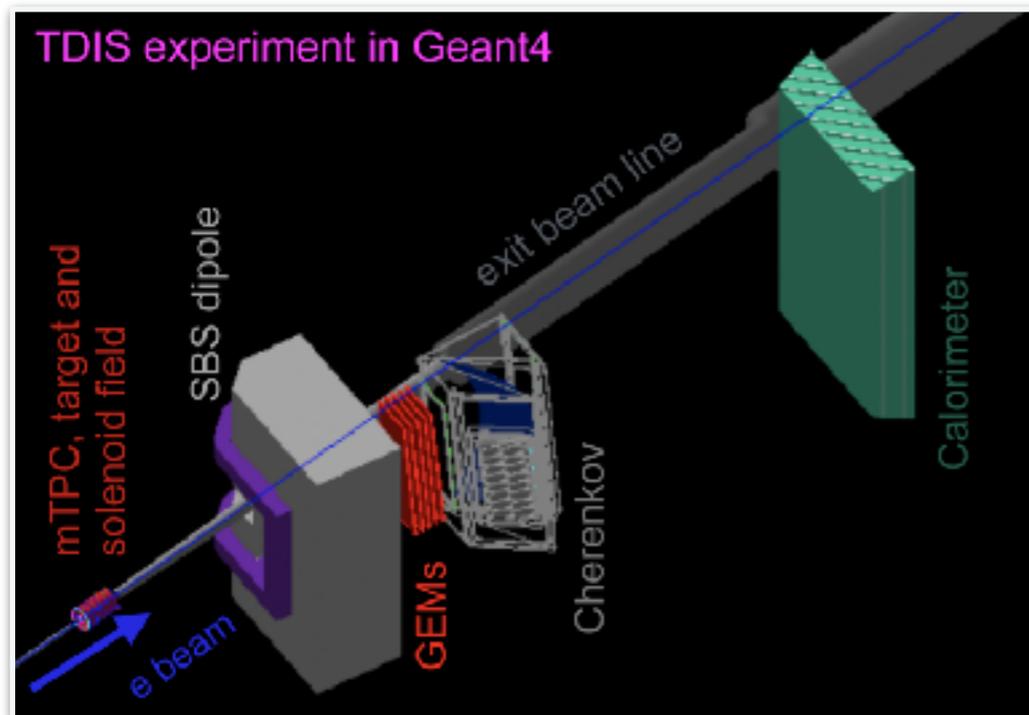
Beam background, H_2 , $50\mu\text{A}$, $2\mu\text{s}$ mTPC DAQ time window



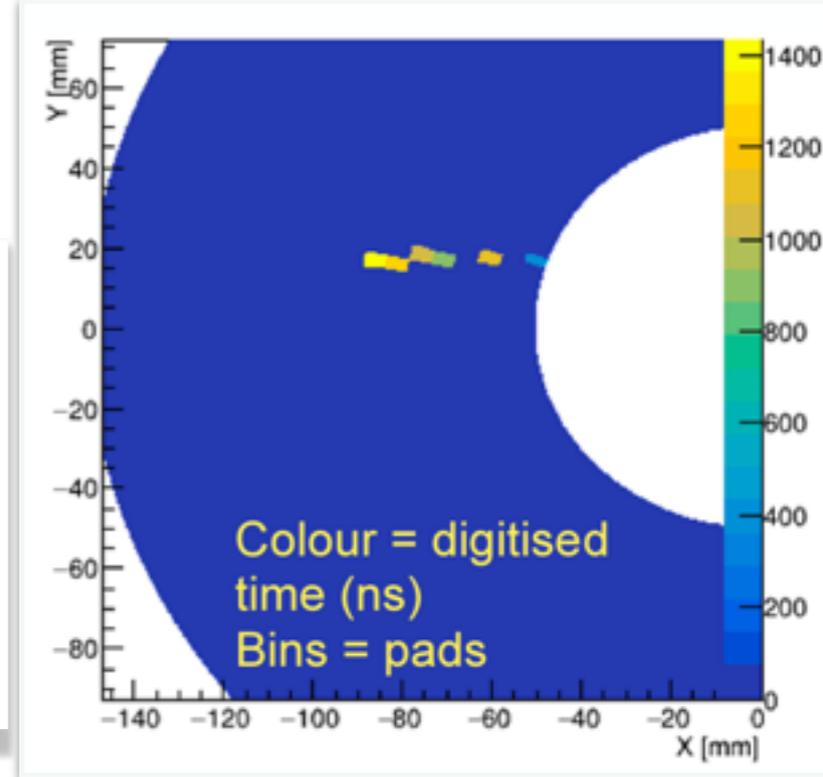
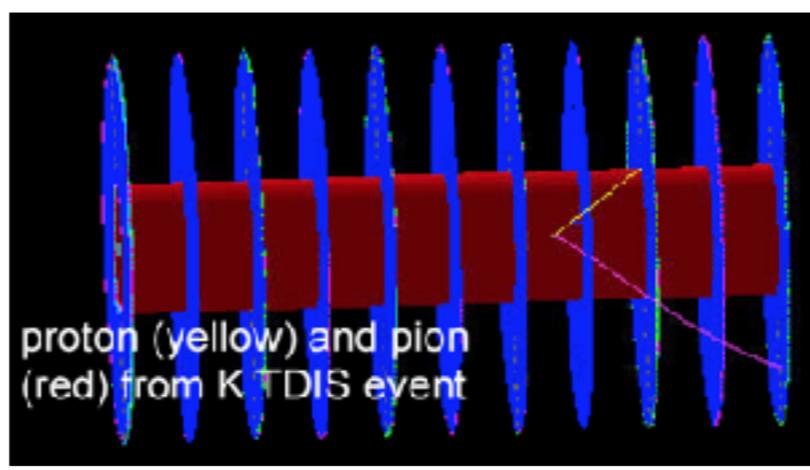
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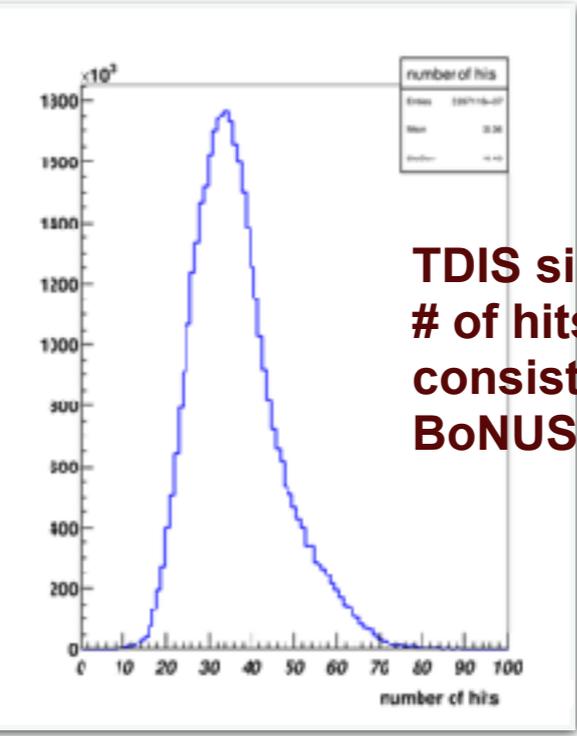
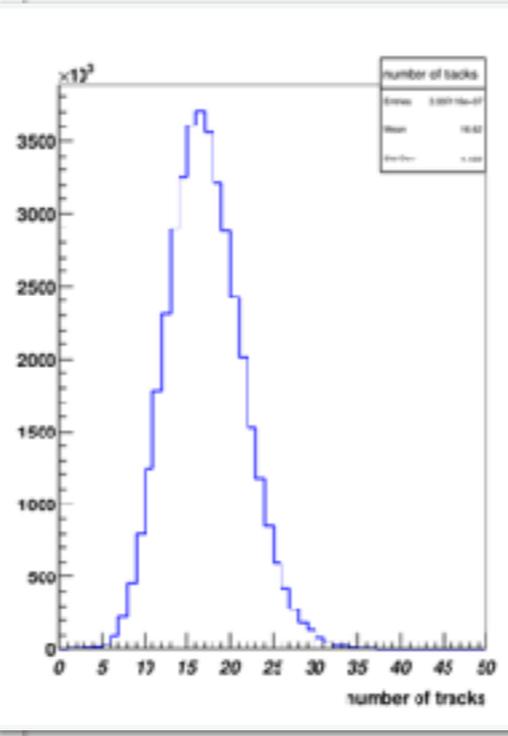
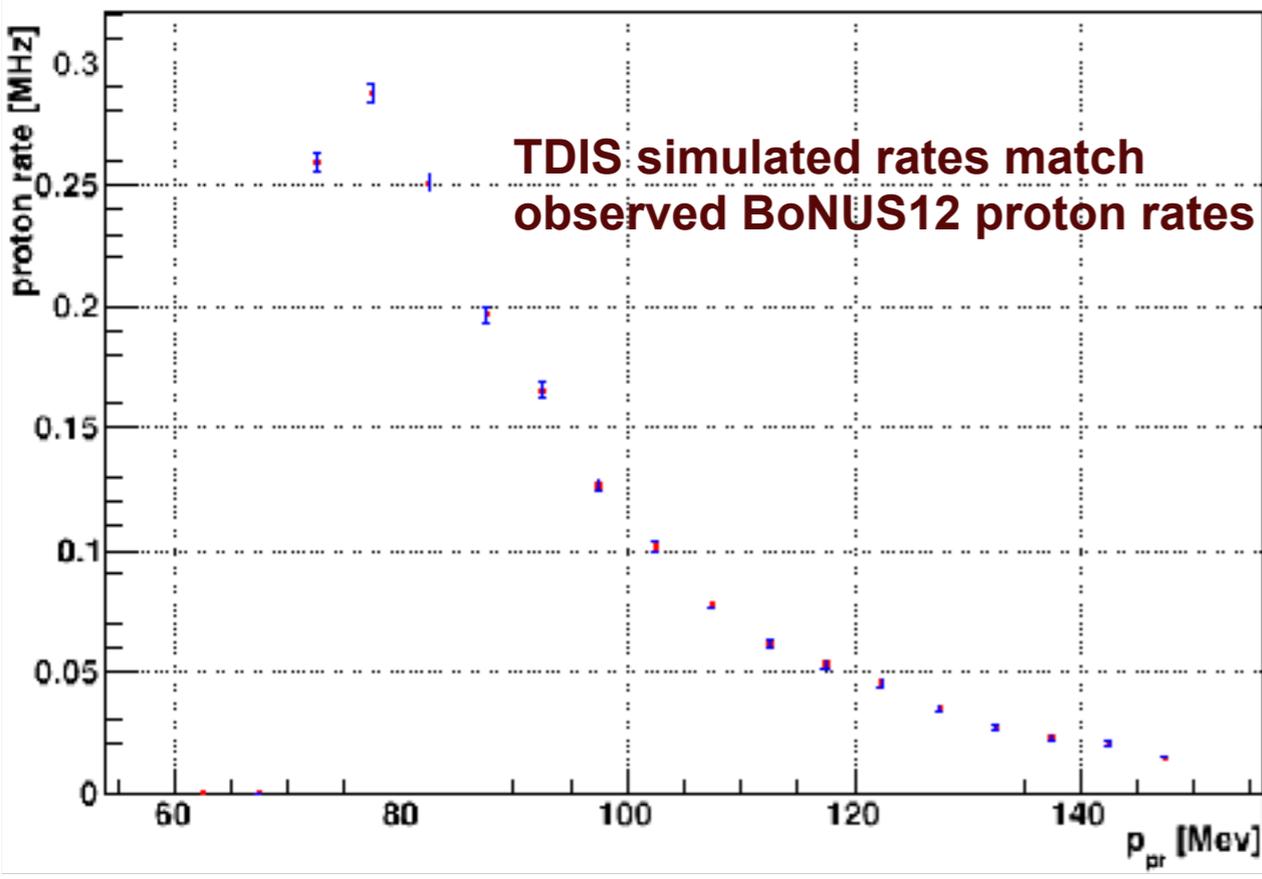
A comprehensive Geant4 based simulation with digitization validated with BoNUS12 data.



mTPC simulated with Magboltz/Garfield



images credit: R. Montgomery

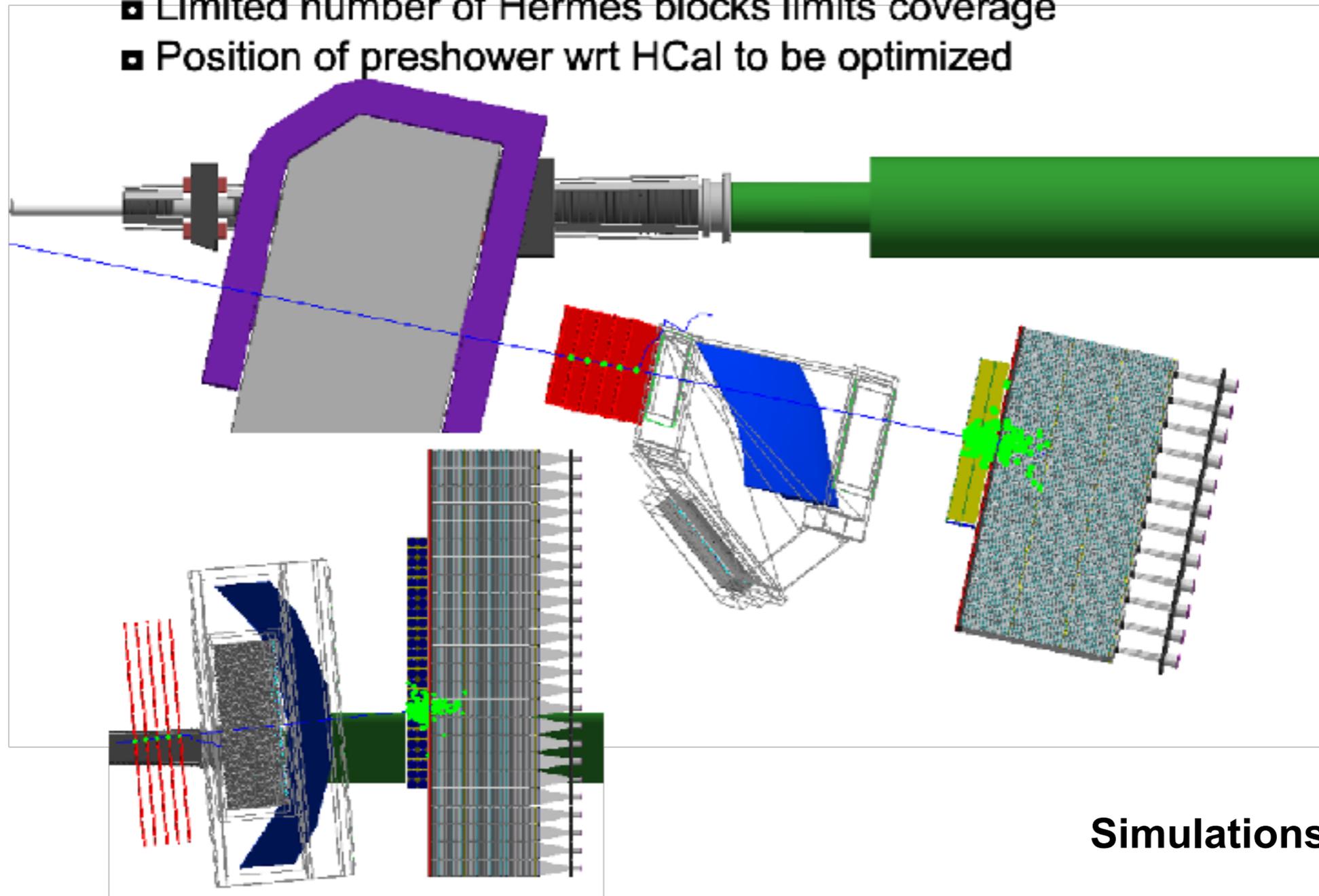


TDIS simulated # of hits & tracks consistent with BoNUS12

plots credit: A. Nadeeshani

For electron detection, the LAC can be replaced with HCal + HEMES blocks as preshower

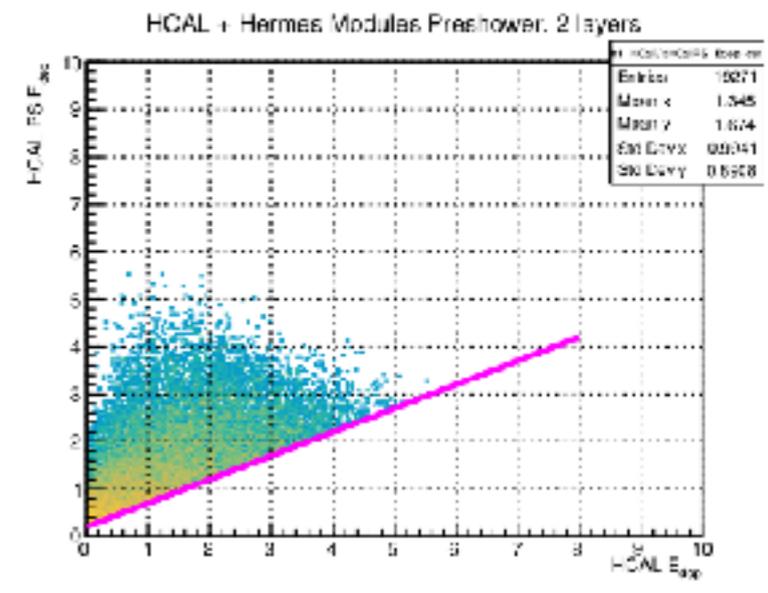
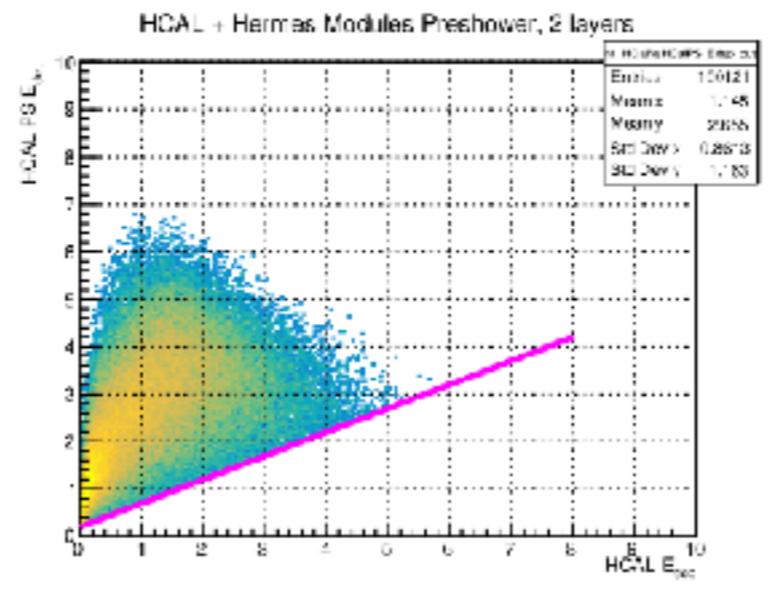
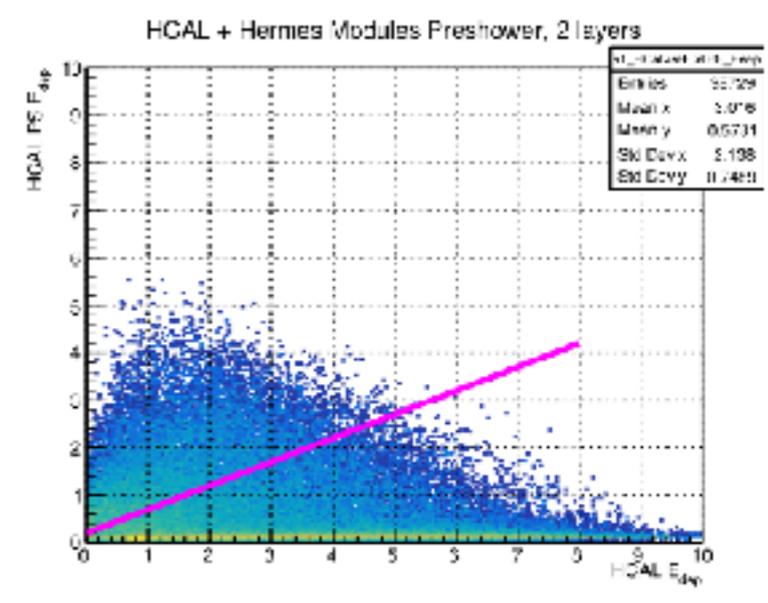
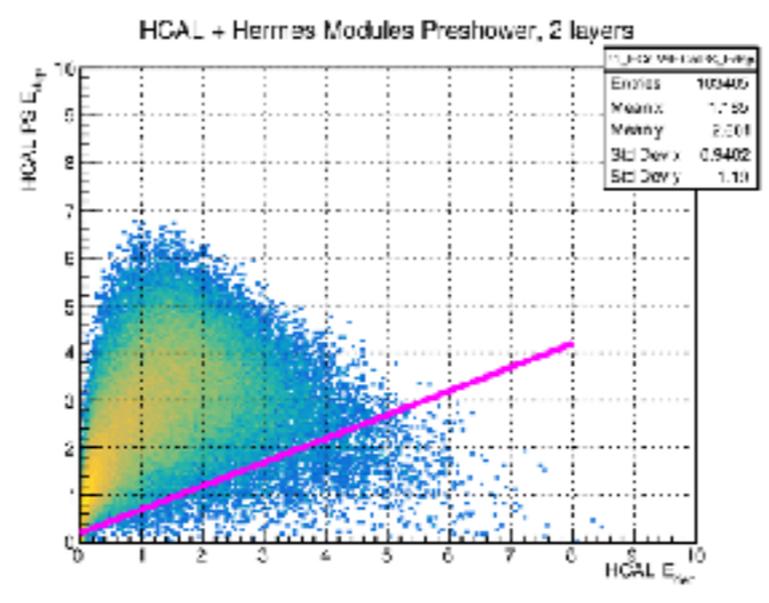
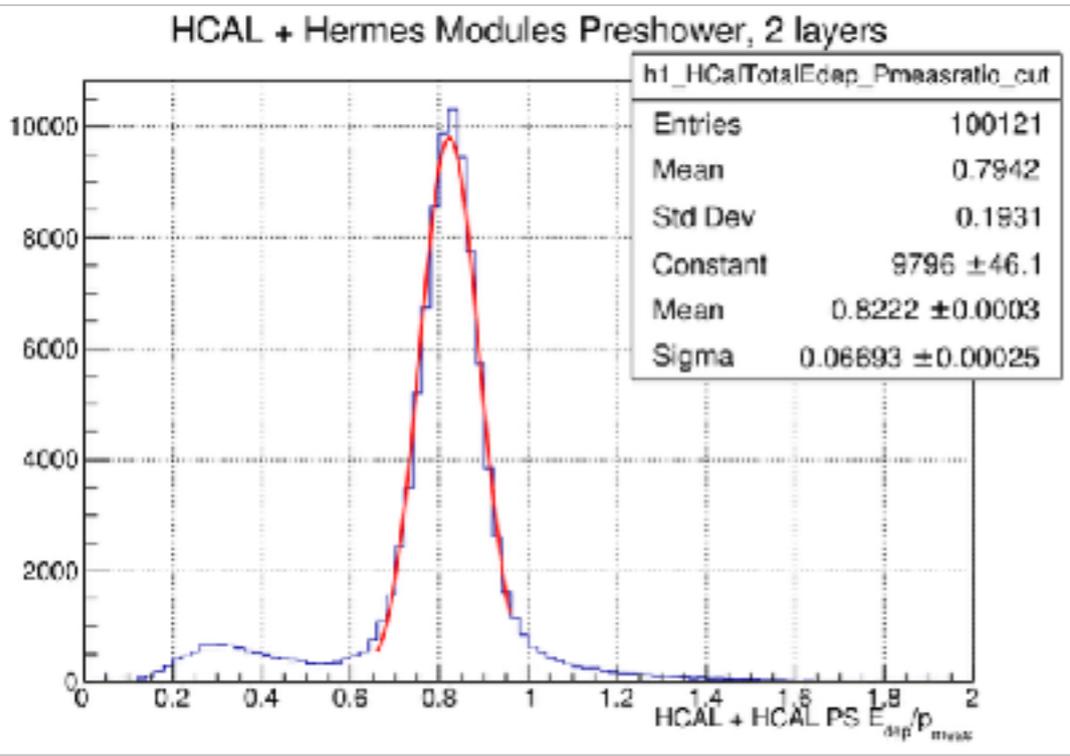
- TDIS electron detection: LAC replaced by HCal, combined with a preshower;
- HCal preshower Hermes blocks (2 layers):
 - ▣ Limited number of Hermes blocks limits coverage
 - ▣ Position of preshower wrt HCal to be optimized



Simulations by E. Fuchey

For electron detection, the LAC can be replaced with HCal + HEMES blocks as preshower

- HCAL preshower Hermes blocks (2 layers):
 - pion rejection ~80% in “central” region;
 - electron efficiency ~97% in “central” region;
 - Reconstruction performance:
 - ◆ ~17% energy leaks;
 - ◆ resolution



Simulations by E. Fuchey

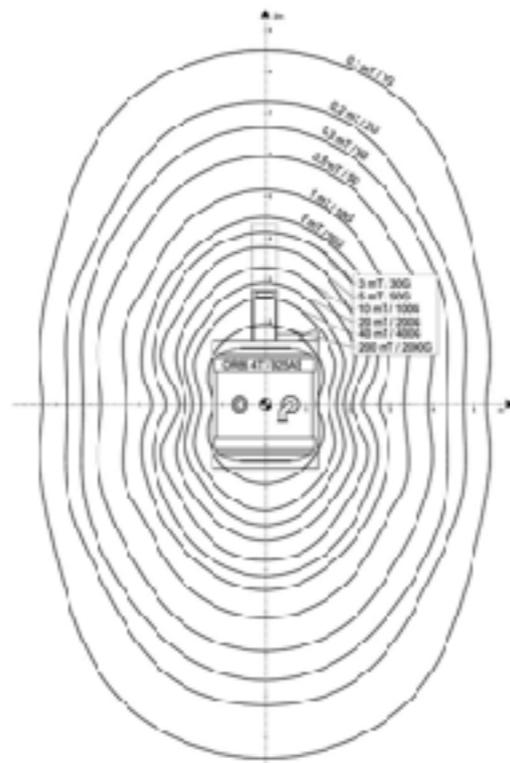
A New Large Bore MR Magnet has been located at ANL



4.4. Fringe field distribution, OR66 magnet

Oxford OR66 **Not available after 2027**

60 cm diameter bore
4 T field, 100 ppm uniformity



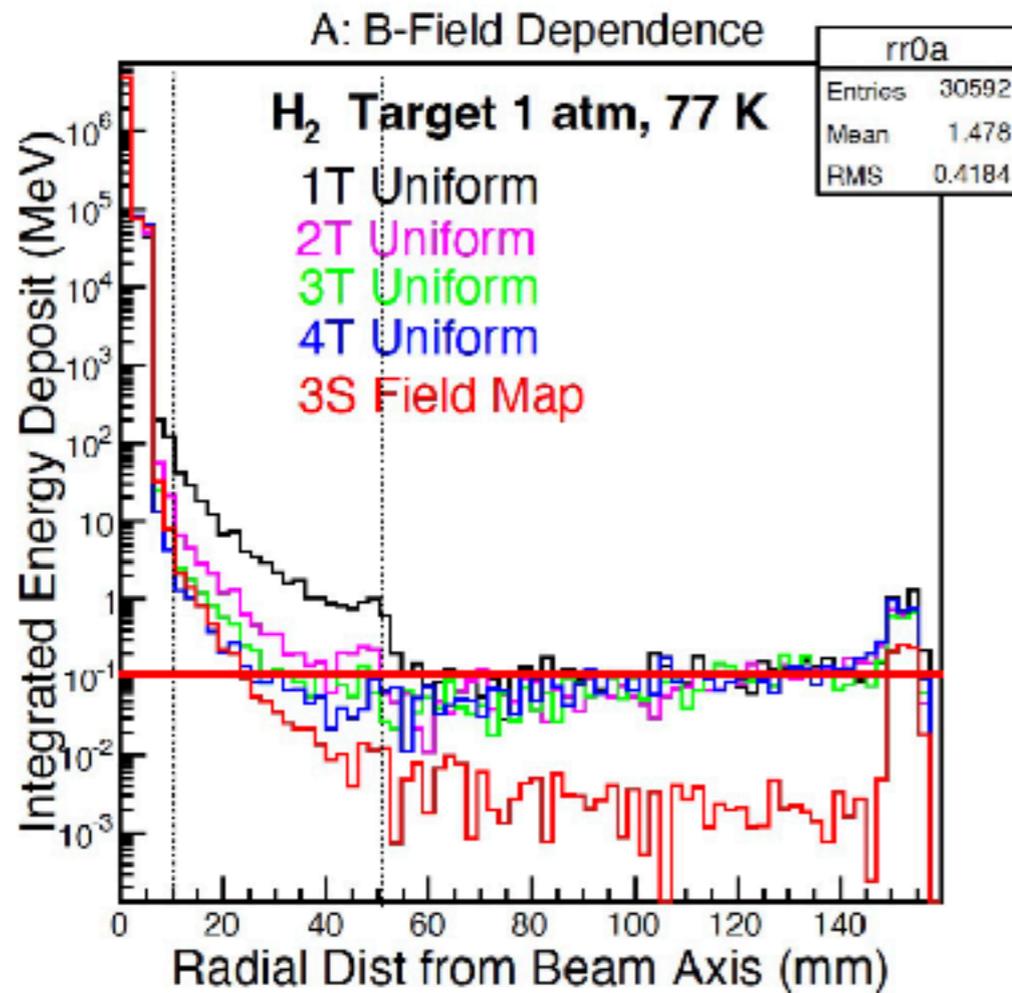
Oxford OR62

60 cm diameter bore
2.8 T field, 100 ppm uniformity

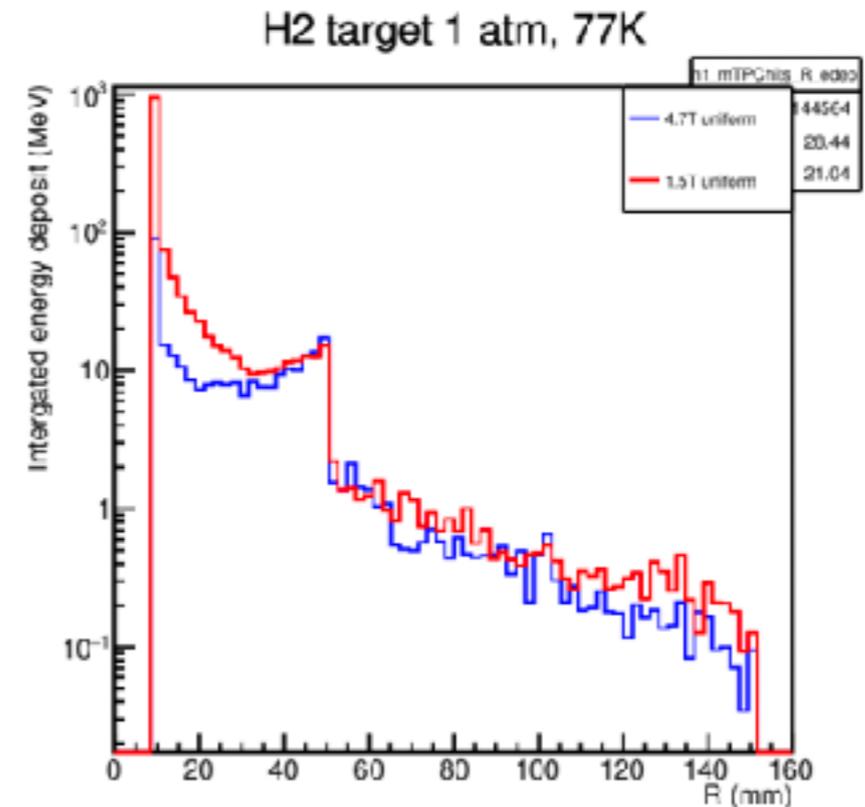
Currently in use in the ATLAS spectrometer.
Will be swapped with OR66 in 2027

Geant4 simulation was used to study possible operation at 1.5T field instead of 4.7T

Do we need a 4.7T solenoid field?



0.15 atm 4He
 $d_{H_2} = 0.084e-3 * 293./77. \text{ g/cm}^3$
 8×10^8 electrons



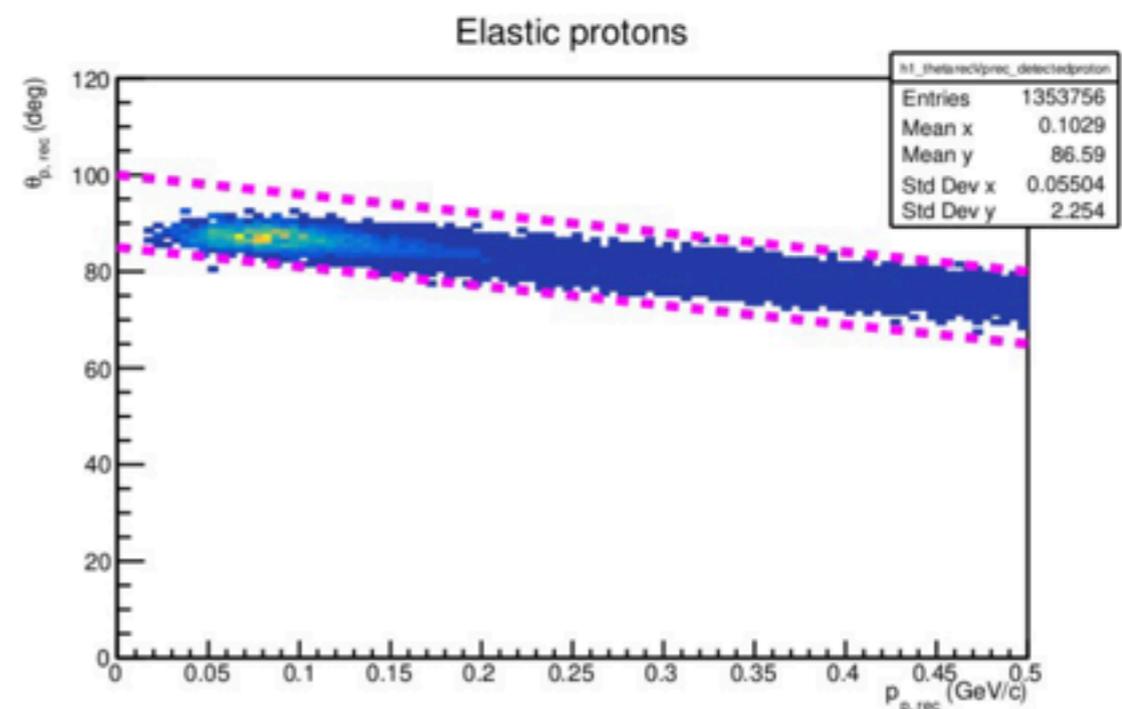
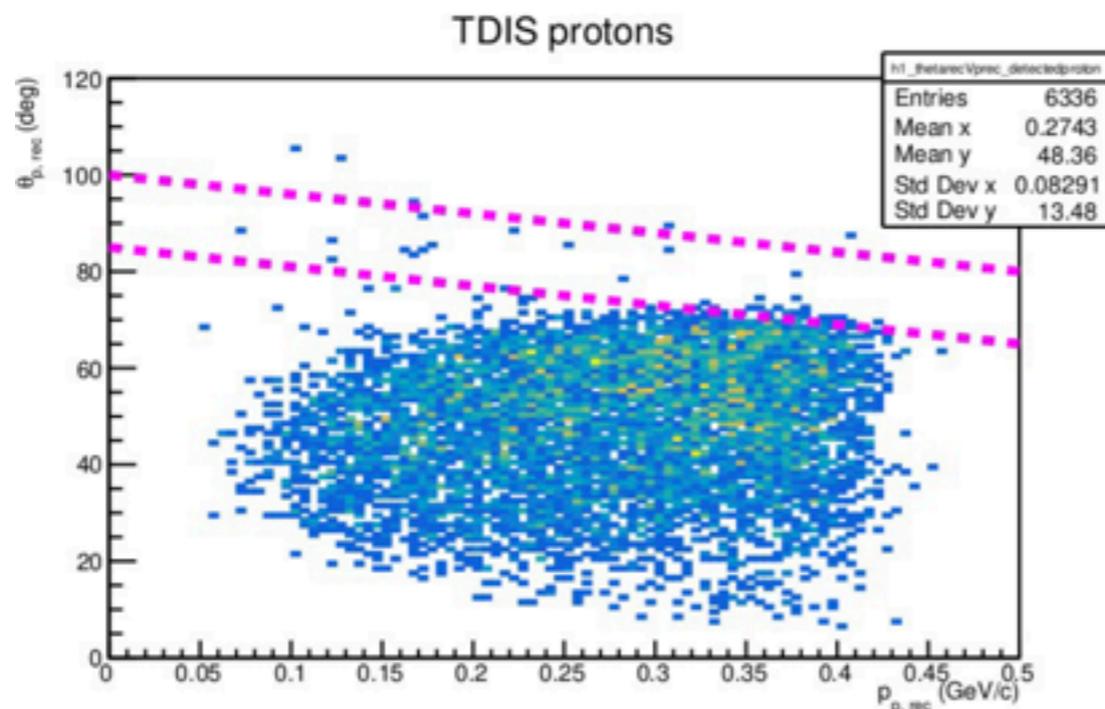
0.15atm 4He, 77K
 $d_{H_2} = 0.084e-3 * 293./77. \text{ g/cm}^3$
 Normalized to 8×10^8 electrons
 Electrons generated 35cm
 upstream of center of target

Eric Fuchey has confirmed the Moller background is independent of the field

Geant4 simulation was used to study possible operation at 1.5T field instead of 4.7T

TDIS vs Elastic proton, LH2, 1.5T

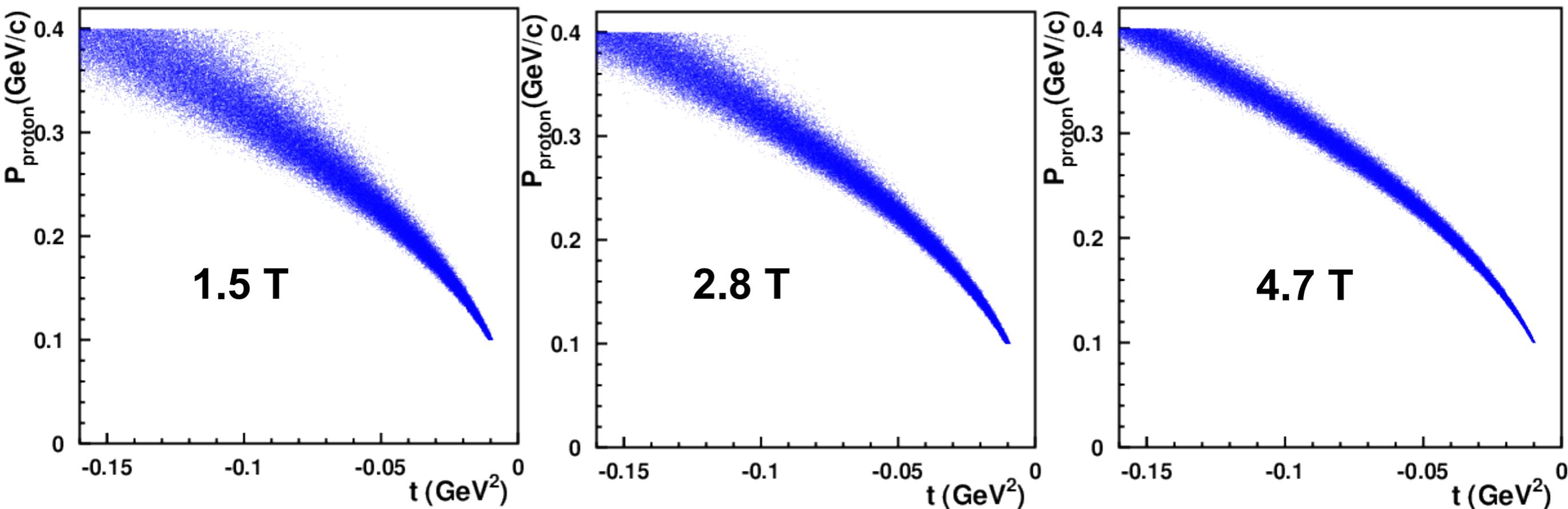
- *Generated* p vs θ ;
- Tracks with total path length ≥ 0.025 m, number of hits ≥ 3 ;
- “reconstructed” p vs θ ;
 - p_{gen} smeared by 0.02 GeV/c,
 - θ_{gen} smeared by 1.5 deg
- Cut : $85-p*40$ (deg) $< \theta < 100-p*40$ (deg)



Ongoing work by Eric Fuchey to determine how well the protons of interest can be separated from other background protons.

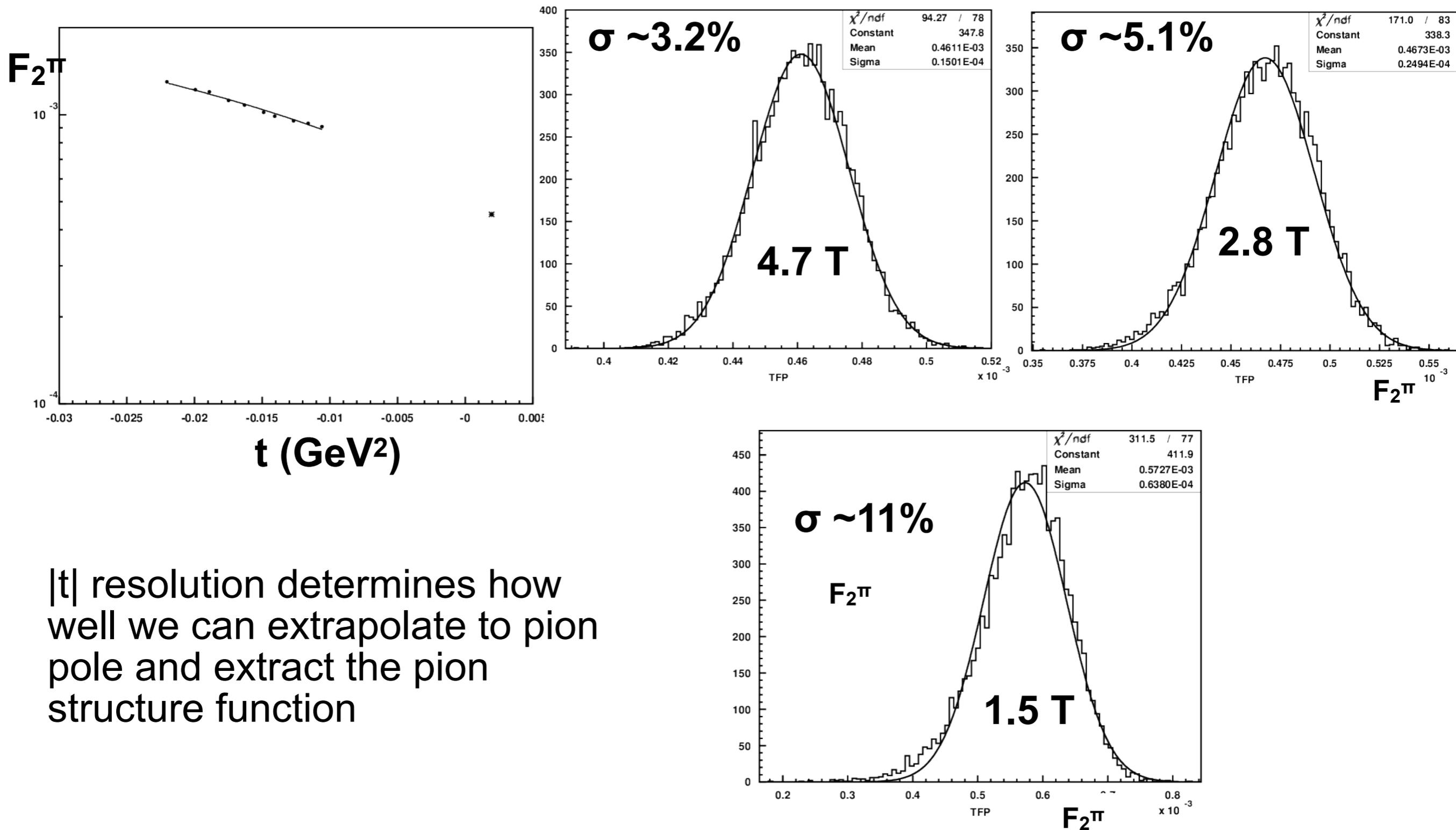
The momentum resolution has large impact on the exacted pion structure function

Proton momentum resolution is directly related to the $|t|$ resolution



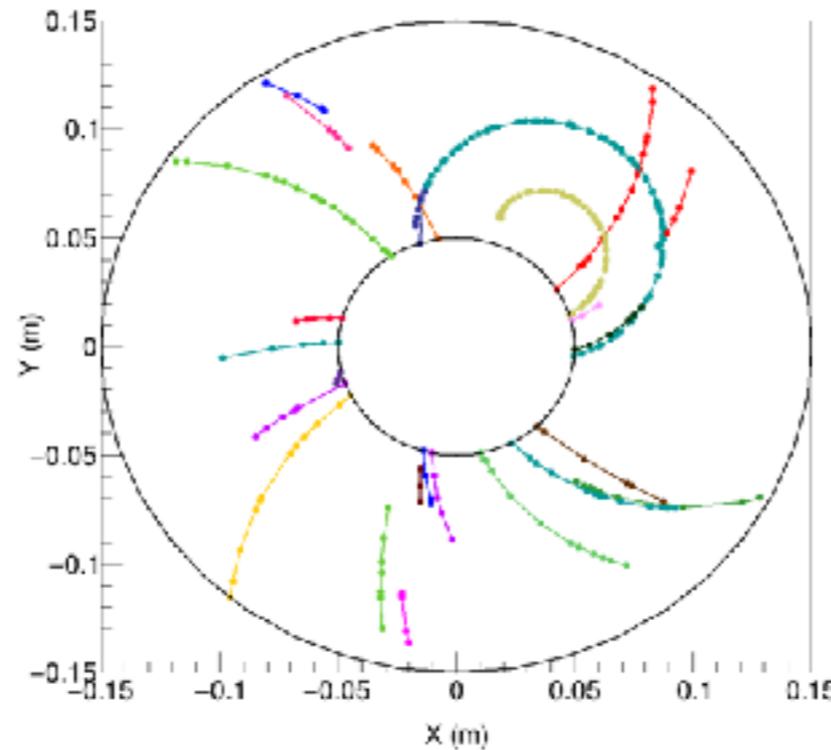
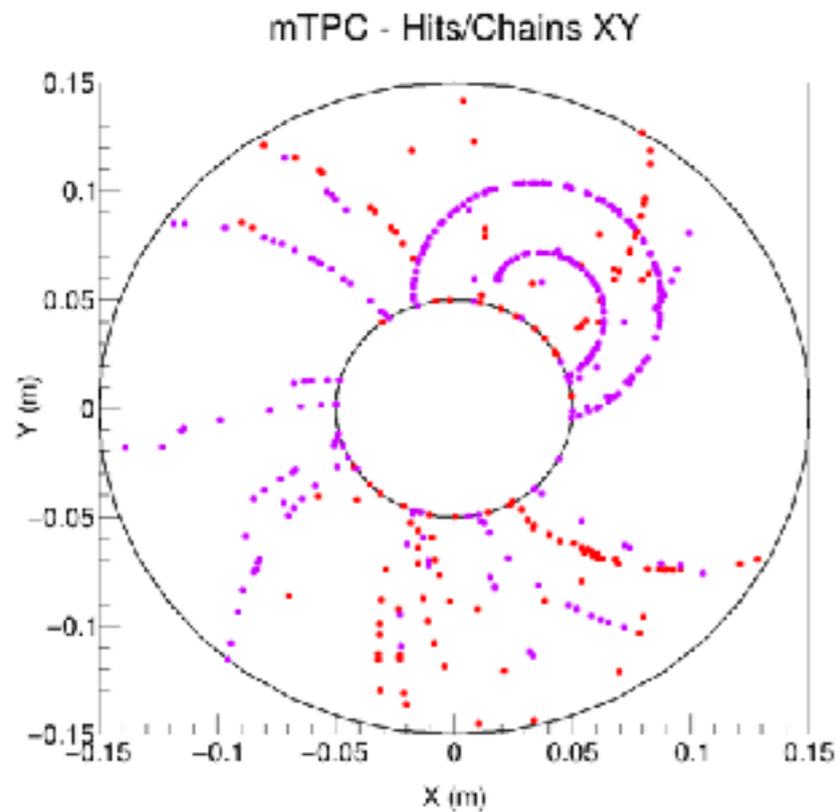
$|t|$ resolution determines how well we can extrapolate to pion pole and extract the pion structure function

The momentum resolution has large impact on the extracted pion structure function



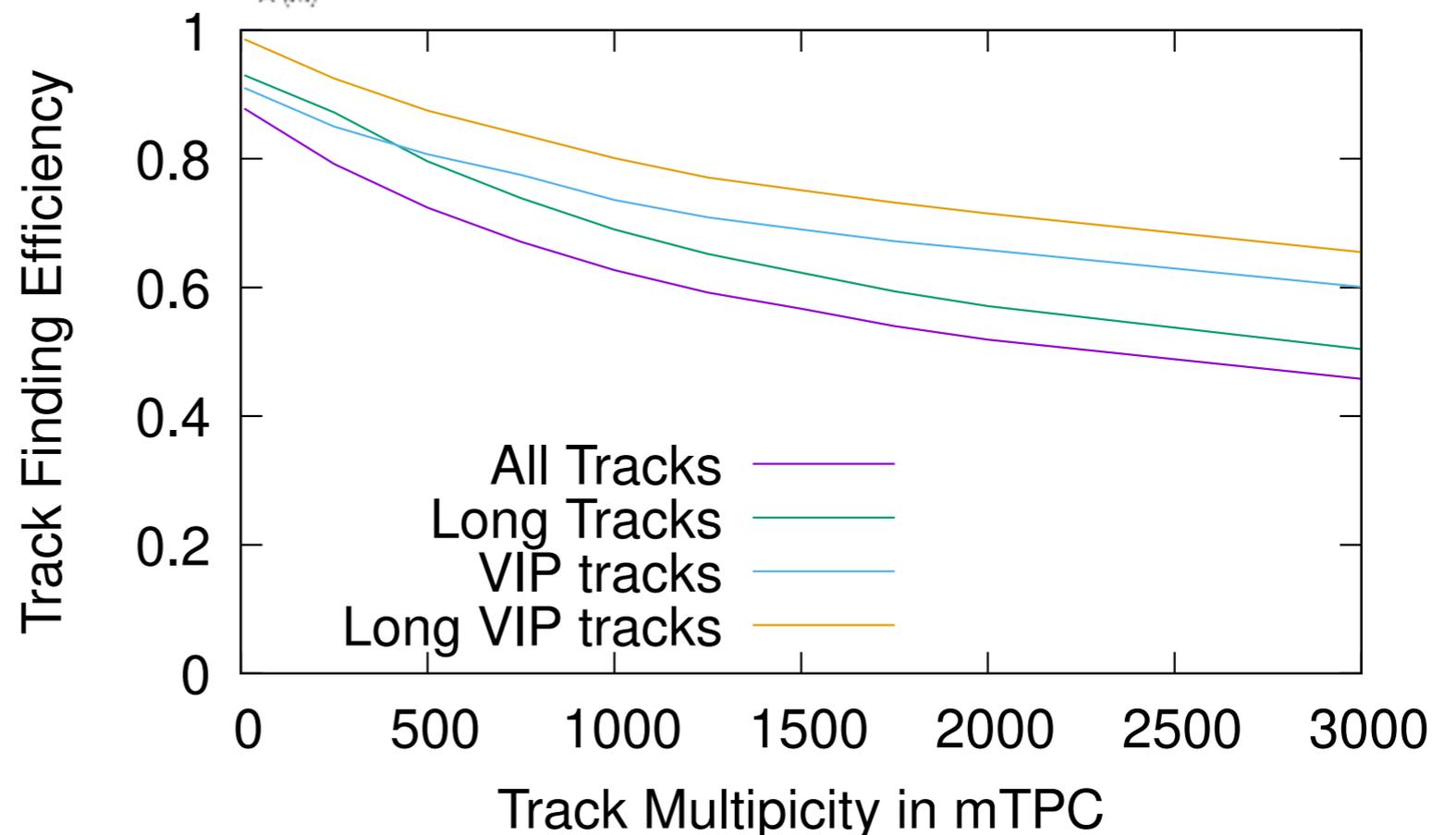
$|t|$ resolution determines how well we can extrapolate to pion pole and extract the pion structure function

High rate and high occupancy tracking algorithms have been developed and are being optimized



Two tracking algorithms have been developed, a new hybrid version is being developed using the best features of each.

At multiplicity of 500 tracks per event (i.e. rate of 250 MHz in the mTPC) shows an efficiency of ~80% for clean tracks

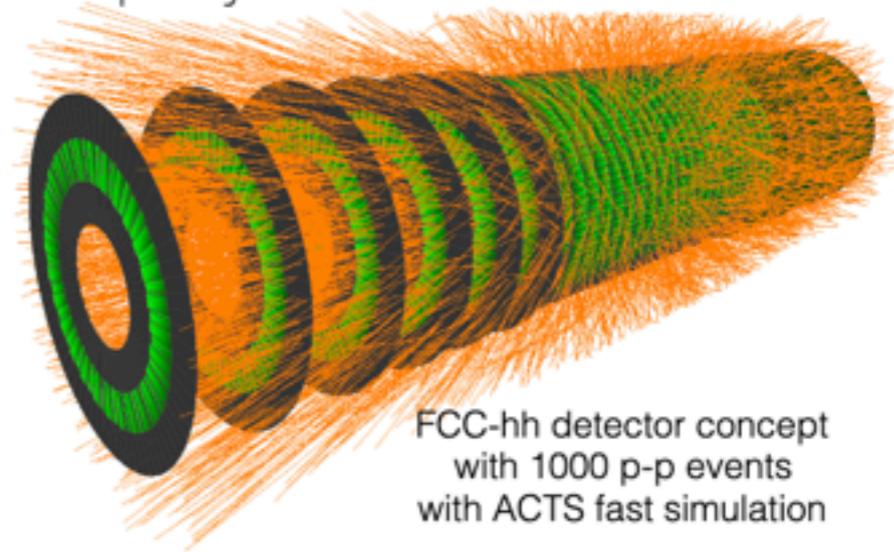


plots credit: C. Ayerbe Gayoso, S. Wood

Tracking remains the main challenge (several new efforts)

ACTS A Common Tracking Software project

Project to preserve and enhance LHC track reconstruction software for future **detectors** and **computing infrastructure**



A flexible, **open source R&D testbed**:

- facilitate collaboration across experiments and external contributors, e.g. machine learning experts
- allow for novel algorithms and detector components (e.g. timing, track lets)

A **high-performant toolbox** for track reconstruction based on LHC experience

- modern code and software concepts to allow for concurrent computing
- support high luminosity and high precision tracking algorithms

Currently developers from ATLAS, LHCb, FCC-hh

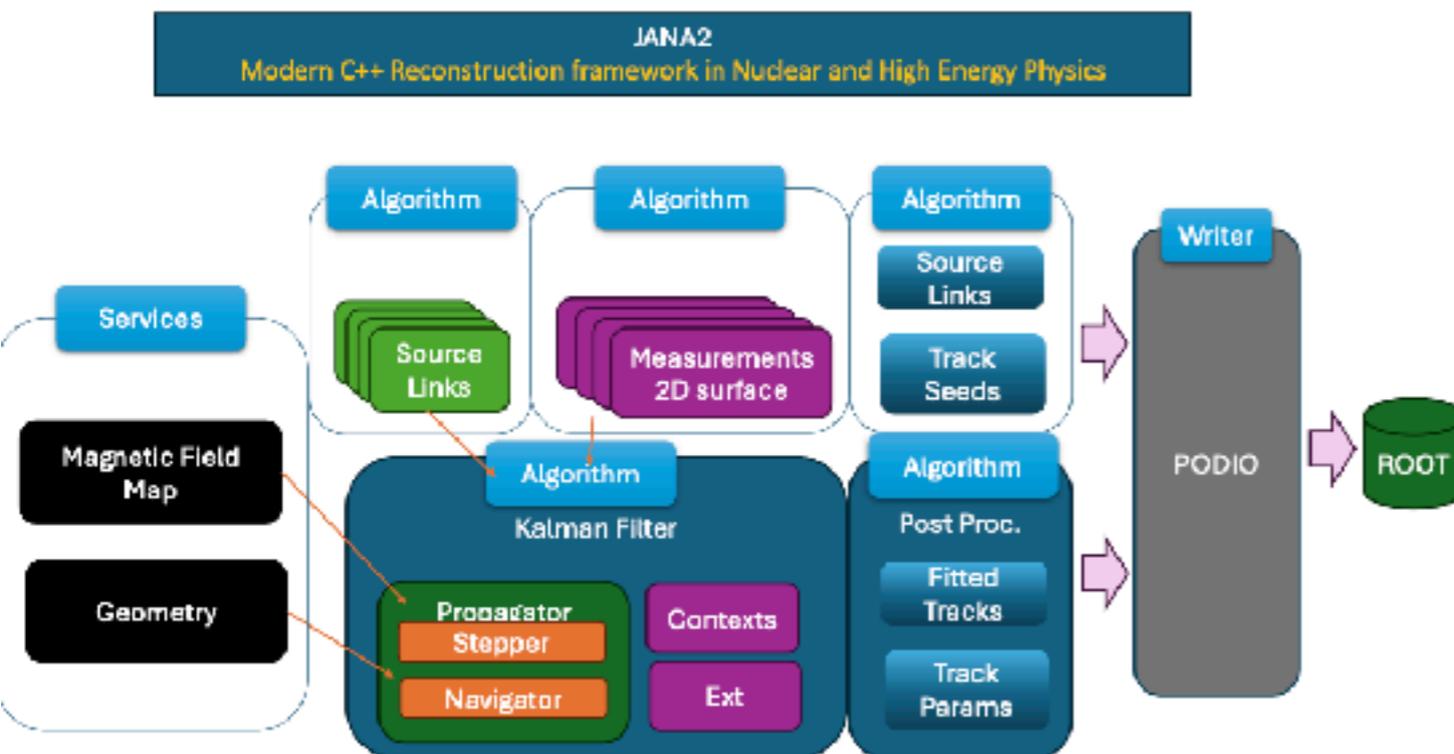
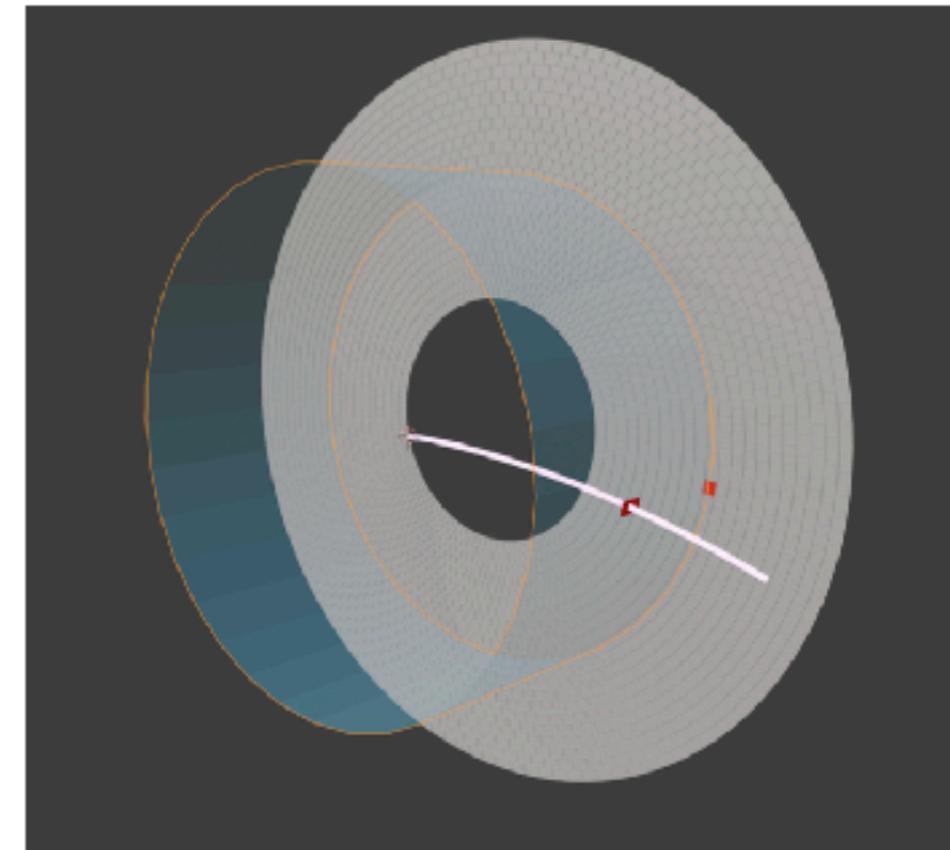
- supporting: FCC-hh, Tracking machine learning challenge

<http://acts.web.cern.ch/ACTS/>

ACTS expert Dmitry Romanov has been giving us 10% of this time

Using A Common Tracking Software

1. The Translate the tracking detector geometry in to analogous ACTS geometry: ACTS takes many formats of geometry input eg: GEANT4, Fun4All, DD4hep.
2. For TDIS experiment we used the existing geometry in the GEANT4 and make gdml files.
3. ACTS has available ROOT Geometry plugin that can take relevant active TGeo objects and covert them into Acts: Surfaces. TGeo plugging developments are ongoing...
4. The ACTS virtual cylinder planes definition and a hit-on-a-plane corresponding to a pad for Kalman filter algorithm with covariants out of special x,y,z information.

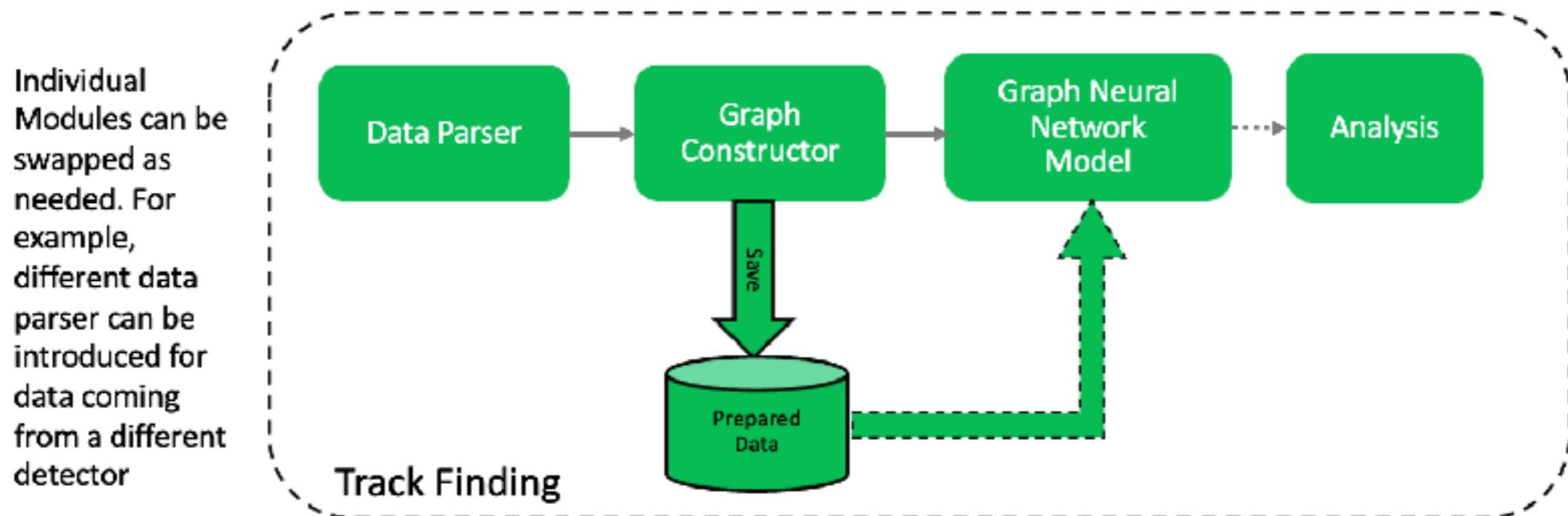


Contributors: Dmitry Romanov, Eric Fuchey and Aruni Nadeeshani

Tracking remains the main challenge (several new efforts)

A Composable Framework for Tracking

- Modular and Composable framework for track finding with GNN
- Maximum code re-use across different data sources

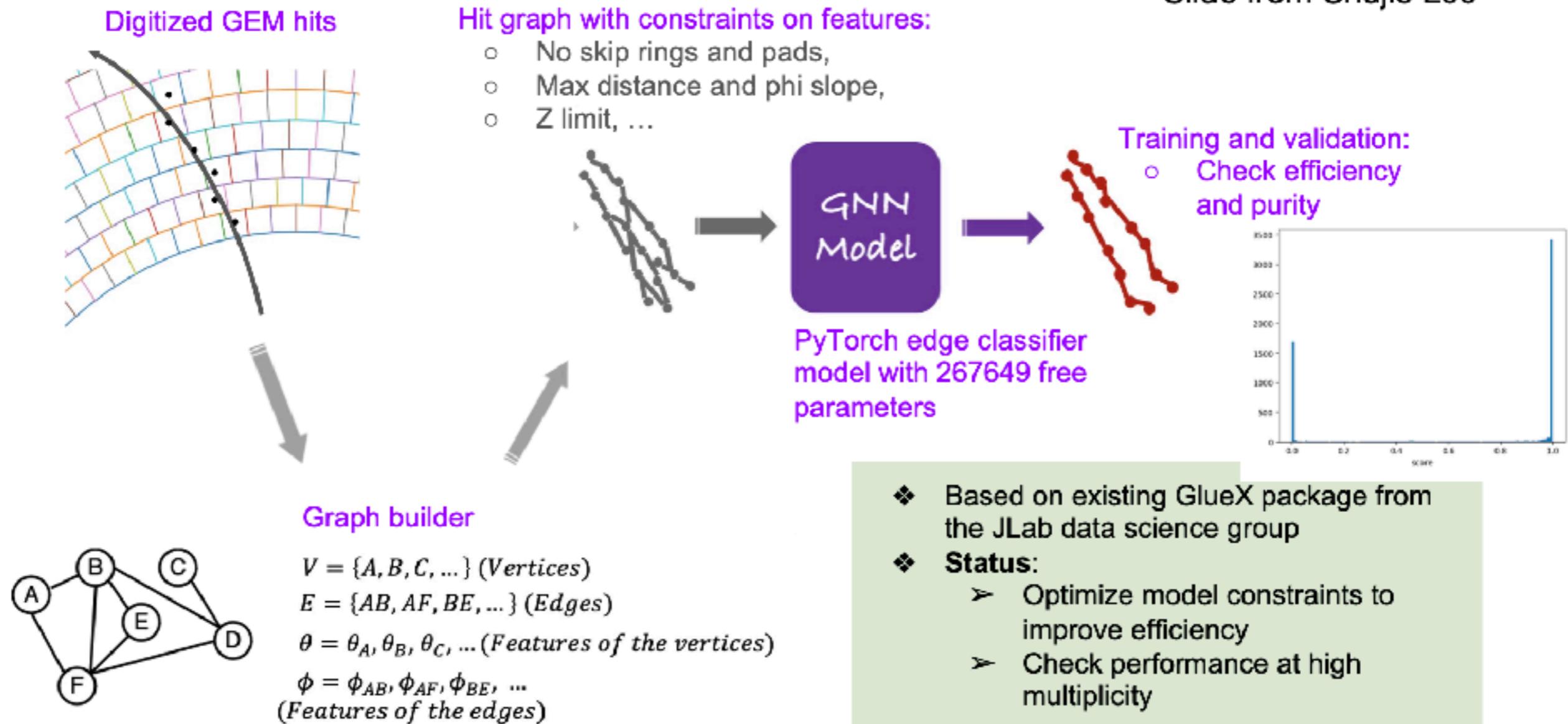


- The workflow is being tested at CLAS as well; simply replaced data parser and graph constructor
- The plan is to introduce track fitting using Recurrent Neural Networks in the above workflow

Run-group co-spokesperson Shujie Li is working on GNN

Using Graphic Neural Network (GNN)

Slide from Shujie Lee



Reached >90% edge-level efficiency and purity, can achieve 95%

Goals for 2026

1. Focus on answering the bulk of the review committee's questions

- a) Get basic device parameters from the square prototype and move forward with a cylindrical prototype.
- b) Make progress with including the toy algorithm within an already developed framework such as ACTS + adopt ML/AI.
- c) Establish if new magnet should be included in technical review.

Aim for passing technical review by Dec 2026.