WILLIAM & MARY
CHARTERED 1693

TDIS physics and software

Carlos Ayerbe Gayoso
William and Mary
On behalf of TDIS collaboration

Hall Winter Collaboration Meeting
27 January 2023

Motivation

Why pions?

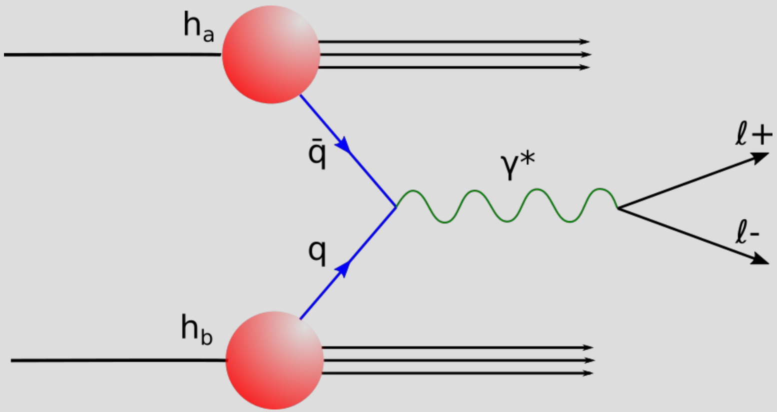
- (naïvely) Pions are the lightest QCD bound system $q\bar{q}$
- Even so, its partonic structure is not well understood as is for the proton
- In principle, the pion PDF is easier to compute in Lattice QCD and effective models, precisely due to its simple quark-antiquark composition.
- Experimental data is necessary to validate the calculations.

There are no ‘free’ pion targets…

HOW TO PROBE PION STRUCTURE?

Probe the pion

Drell-Yan

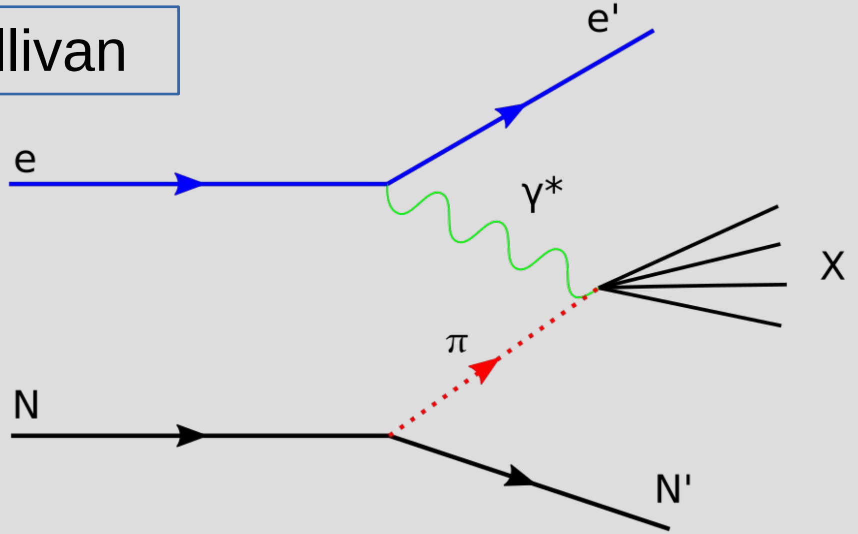


- high energy hadron–hadron scattering
  - quark – anti-quark
- Medium to large x_π range
- Example experiments (many more).
  - Fermilab E866/NuSea and E-906/SeaQuest
  - CERN NA39, Compass (pion beam)...

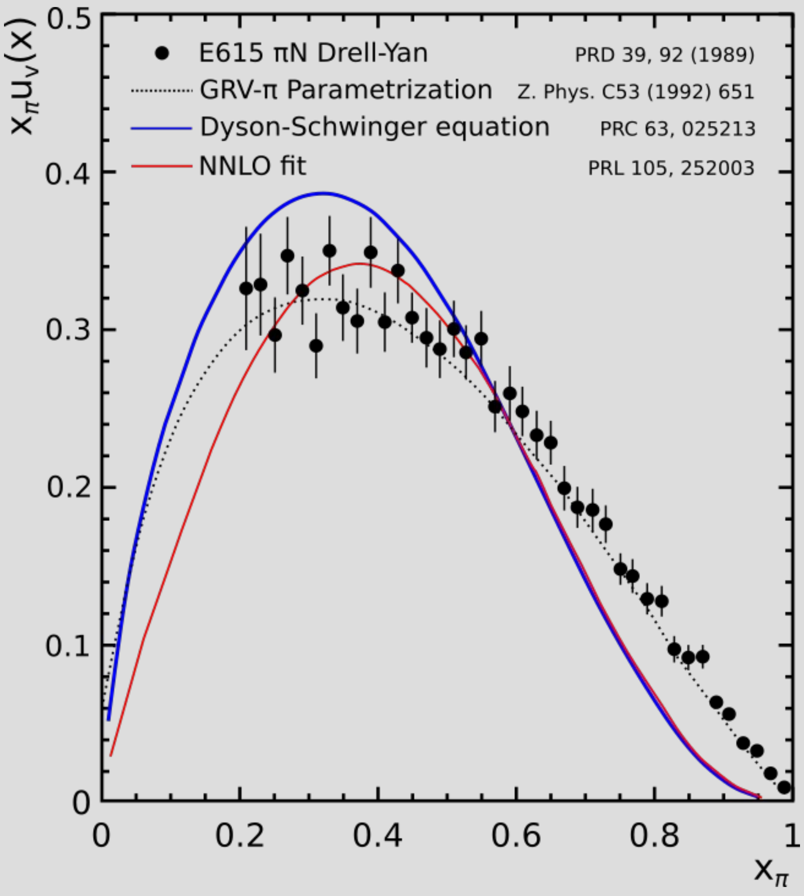
Probe the pion

- Lepton-nucleon deep-inelastic scattering
  - virtual photon scatters deep-inelastically off the meson cloud
- Small x_π range *(present data)*
- Example experiments:
  - DESY H1 and ZEUS
  - TDIS, EIC (future)

Sullivan



DY data

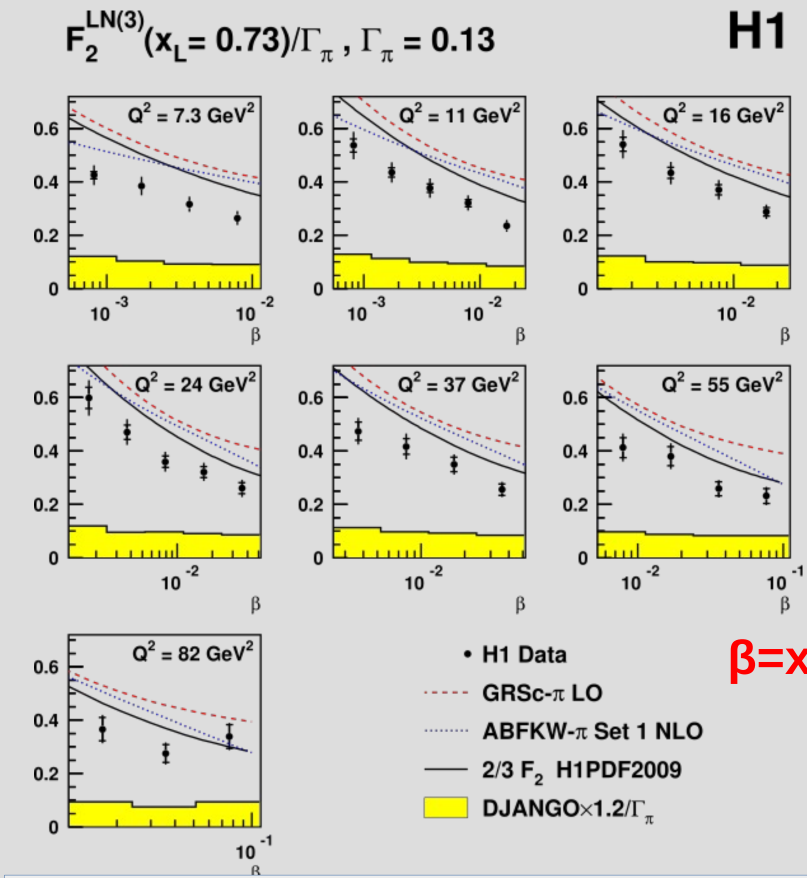


- Measurements at Fermilab and CERN
  - in particular E615@Fermilab
- It is constrained to medium-large x_π
- Models disagree with extracted data: pQCD, Dyson-Schwinger, Light Front,…
- Problem with data analysis?

PDF ~ $(1 - x_\pi)$ as $x_\pi \to 1$

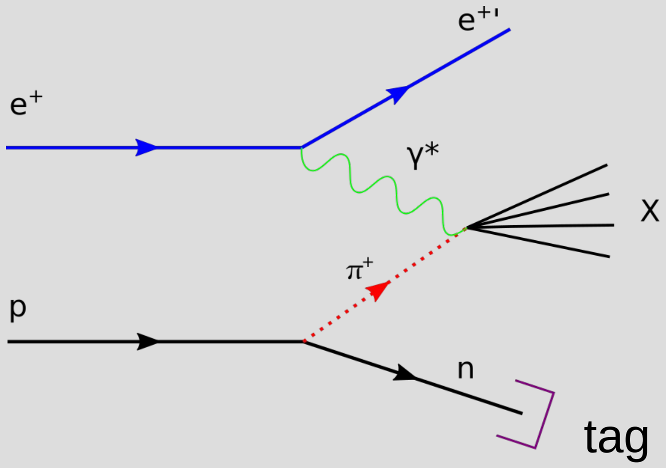
- Agrees with structureless model
- Differs from pQCD prediction of $(1 - x_\pi)^2$

LN Data



$\beta = x_\pi$

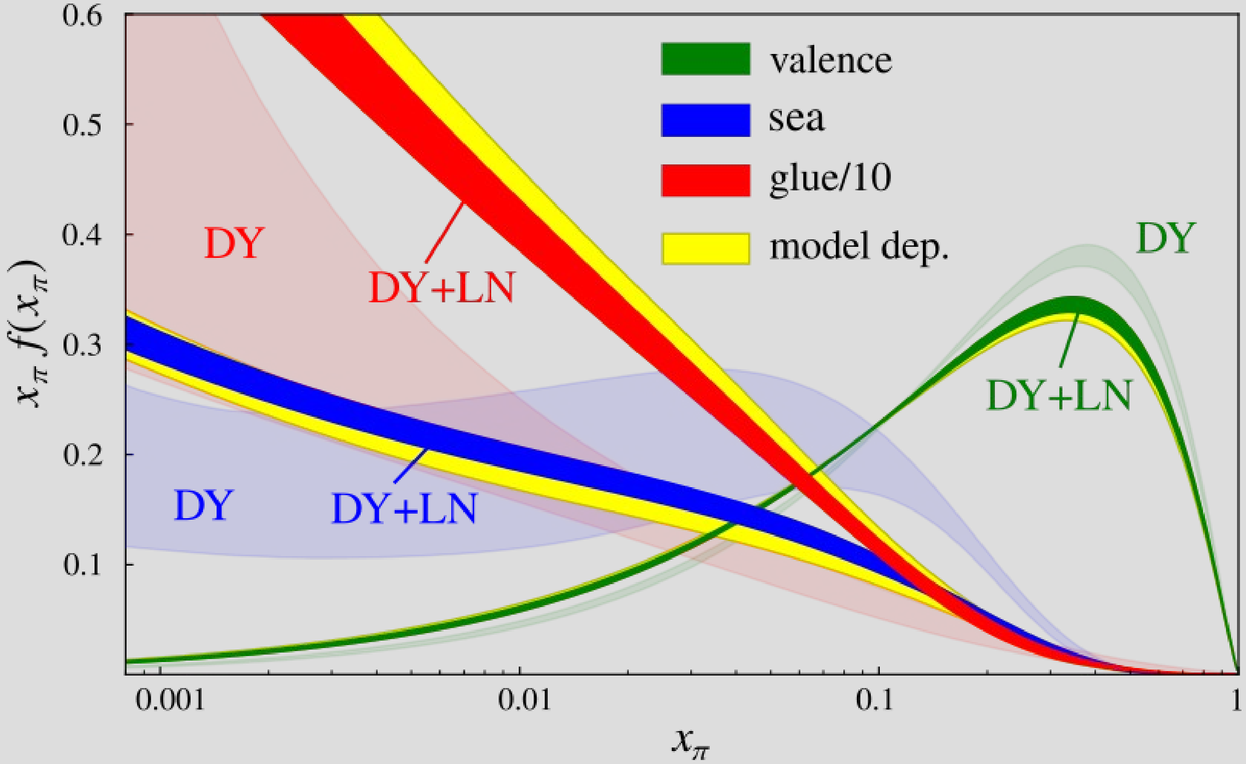
Data shows
$F_2^\pi < 2/3\ F_2^p$

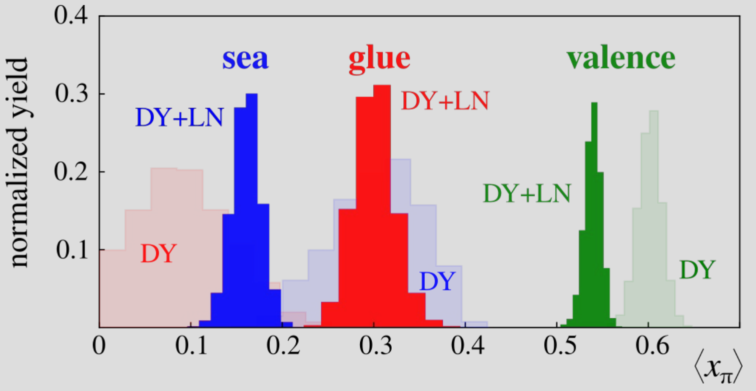


- Events from very collinear neutrons
  - Pion is practically on-shell
- Reaction dominated by single pion exchange
- Limited to charged pions.
- Data at low x_π

The H1 Collaboration, Aaron, F.D., Alexa, C. et al. Eur. Phys. J. C (2010) 68: 381.

JAM Global Fits





Adding the LN data to the global fit analysis, changes drastically the role of the sea and glue contribution to the pion momentum

Resulting tensions between DY and LN require constrains at medium x_π

Featured in Physics Open Access

First Monte Carlo Global QCD Analysis of Pion Parton Distributions

P. C. Barry, N. Sato, W. Melnitchouk, and Chueng-Ryong Ji (Jefferson Lab Angular Momentum (JAM) Collaboration)

Phys. Rev. Lett. **121**, 152001 – Published 10 October 2018

Physics See Synopsis: More Gluons in the Pion

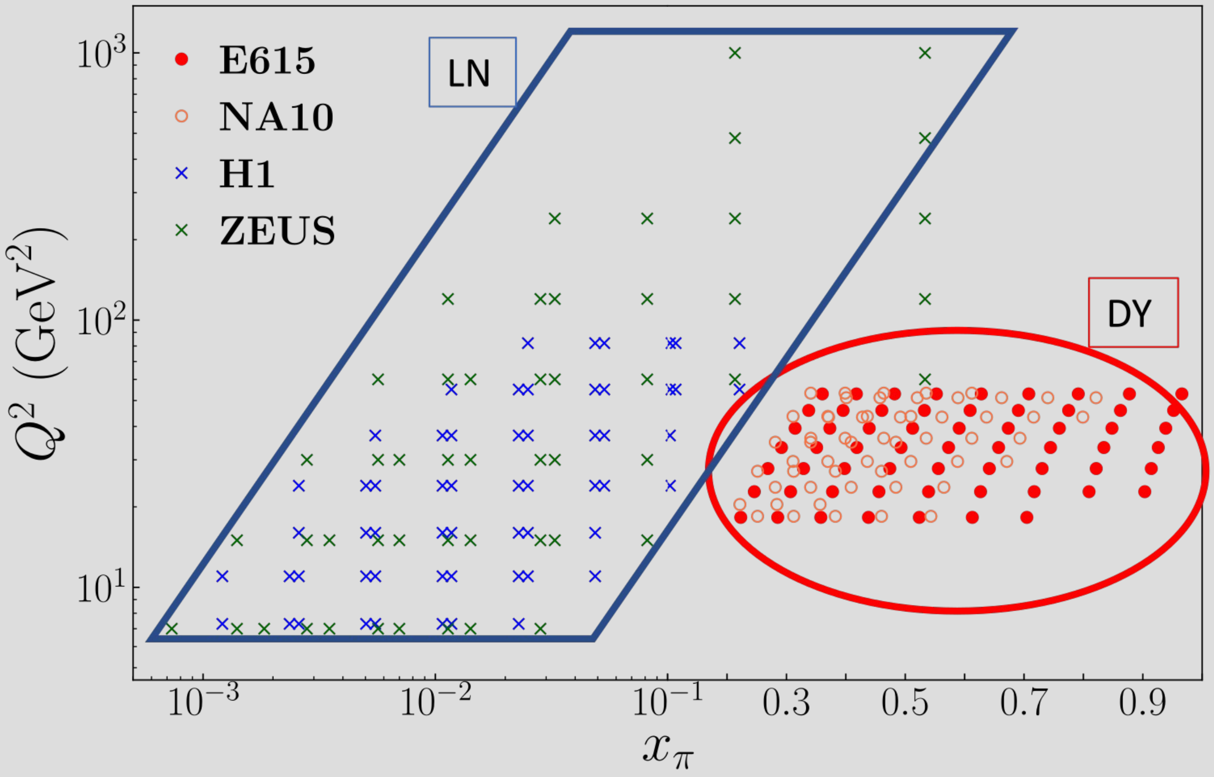
Dataset

- Large x_π – Drell-Yan (DY)
- Small x_π – Leading Neutron (LN)
- Not much data overlap
- In DY:

$$x_\pi = \frac{1}{2}\left(x_F + \sqrt{x_F^2 + 4\,\tau}\right)$$

- In LN:

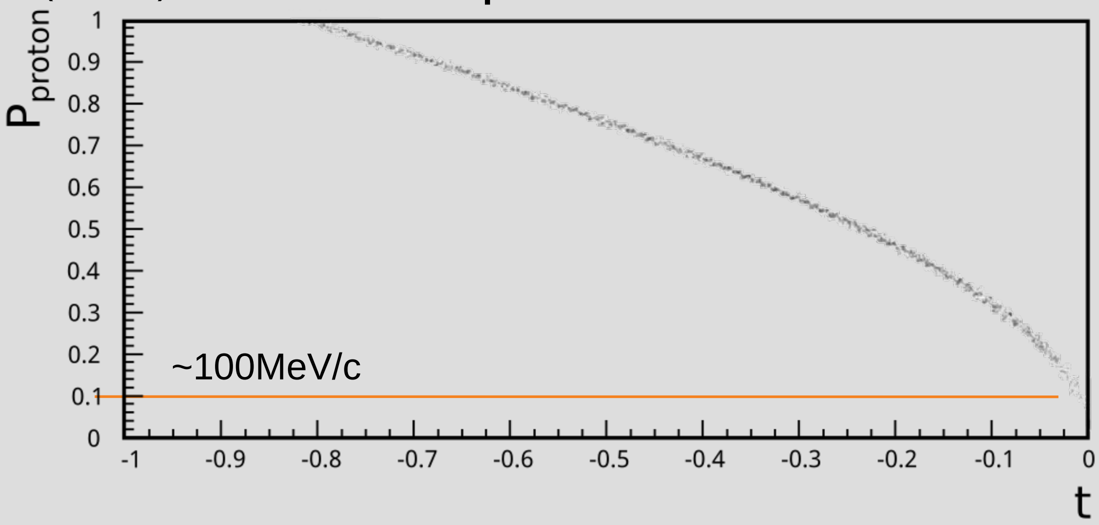
$$x_\pi = x_{Bj} / \bar{x}_L$$



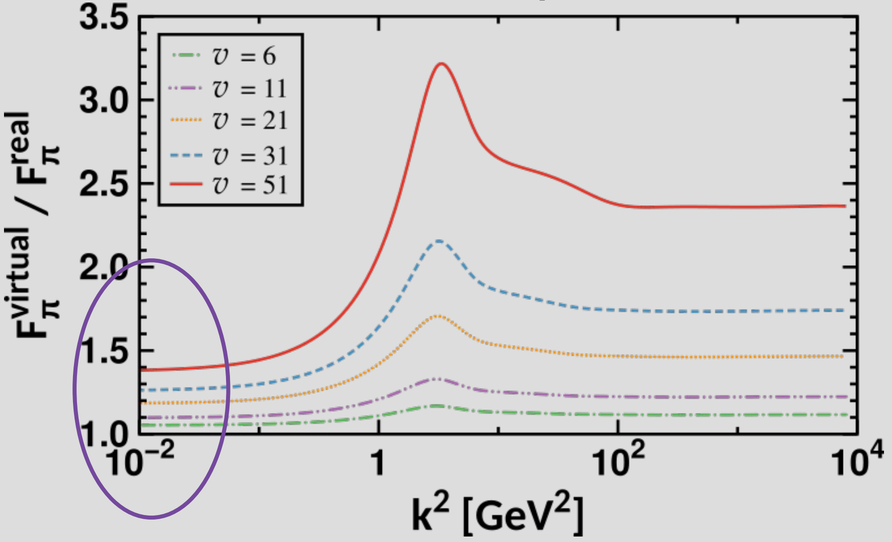
Slide from Patrick Barry
Light Cone 2021

Conditions to probe the pion

Sullivan process kinematics



Ratio of off-shell to on-shell pion EM form factors



Proton momentum

"…in order to **maximize** the true-pion content in any measurement, kinematic configurations are chosen in order to **minimize** $|-t|$"

Si-Xue Qin, Chen Chen, Cédric Mezrag, and Craig D. Roberts
Phys. Rev. C 97, 015203 (2018)

$$P^2 = (v-1)\, m_\pi^2$$

$v \geq 0$: pion virtuality

P: pion momentum (k-k')

virtuality-independent form factor implies virtuality-independent pion structure function

Detection of very low momentum recoil protons

Reaching the pion SF

What we measure

DIS

$$R^T \sim \frac{d\sigma(ep \to e'p'X)}{d\sigma(ep \to e'X)} \sim \frac{F_2^T}{F_2^p} \Rightarrow$$

implicit dependence in Q^2

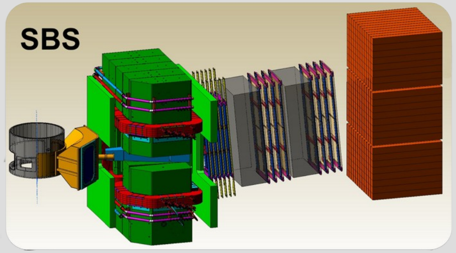
$$\Rightarrow F_2^T \sim R^T F_2^p$$

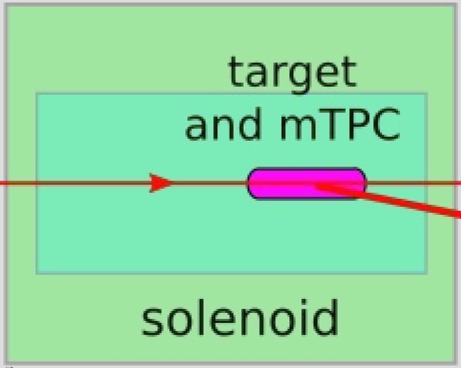
Pion ‘flux’ – Model dependent

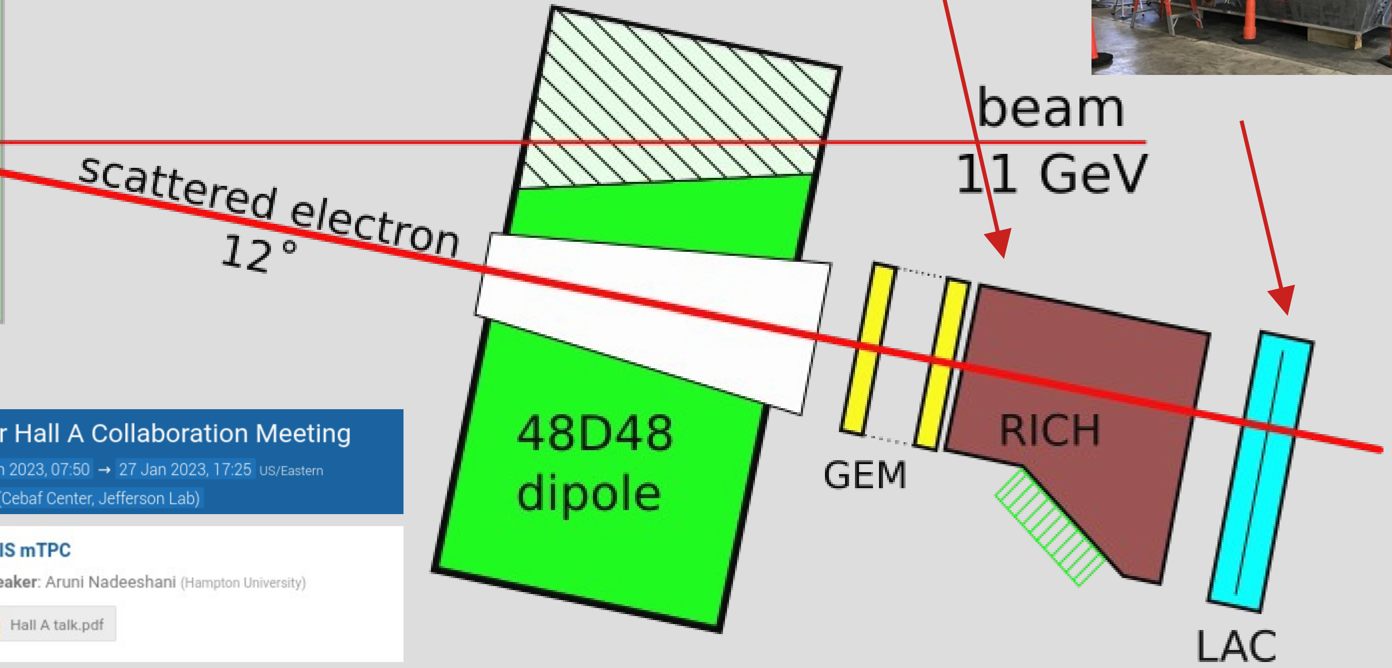
Pion structure function

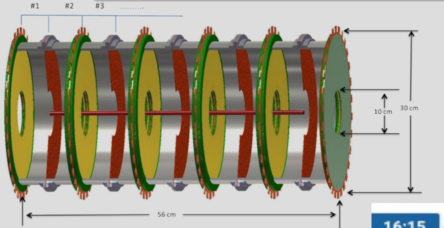
$$F_2^{\pi N}(x, z, k_\perp) = f_{\pi N}(z, k_\perp) F_2^{\pi}(\frac{x}{z})$$

Set-up









Winter Hall A Collaboration Meeting

26 Jan 2023, 07:50 → 27 Jan 2023, 17:25 US/Eastern

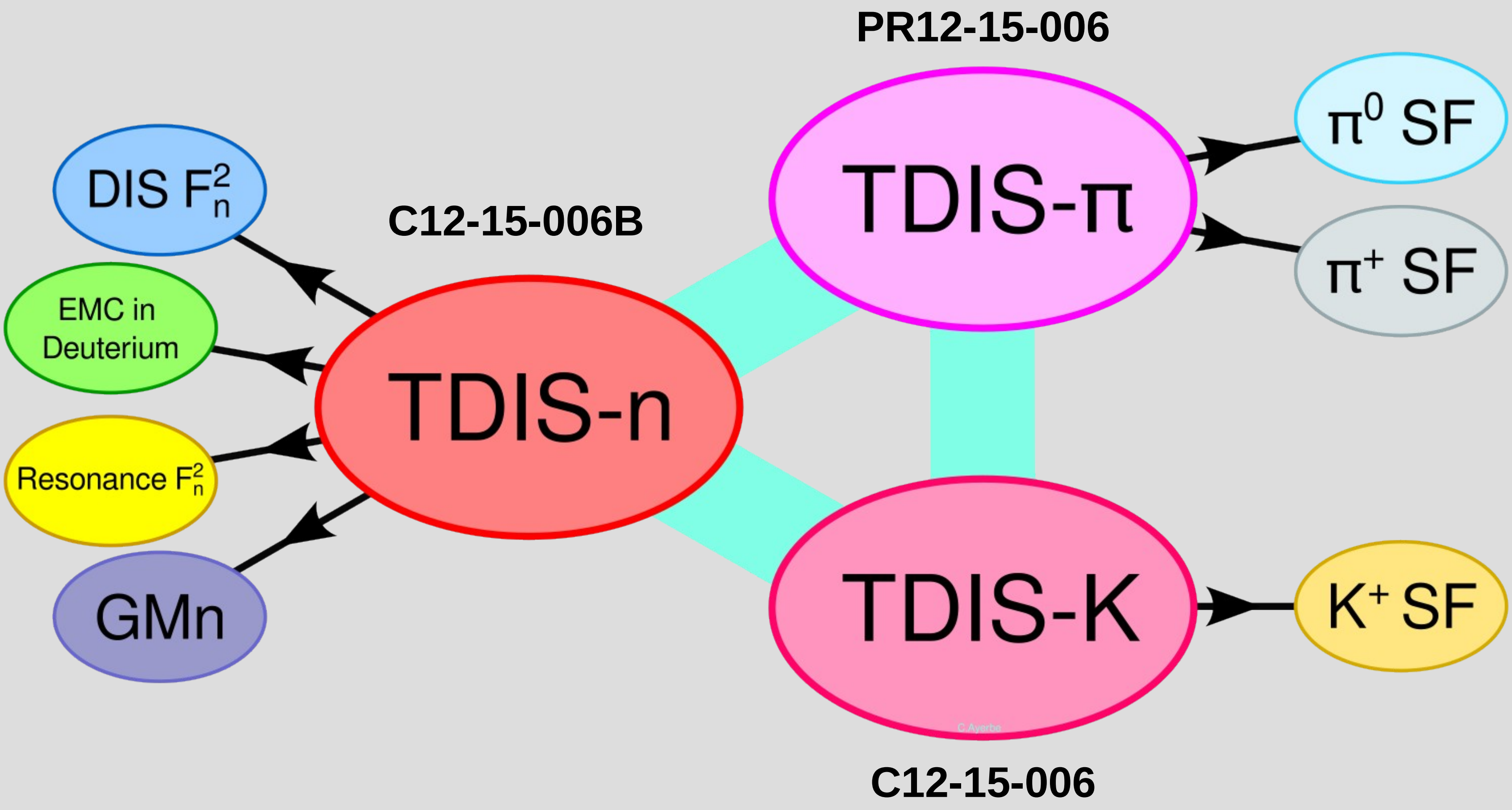
F113 (Cebaf Center, Jefferson Lab)

16:15 → 16:40 **TDIS mTPC**

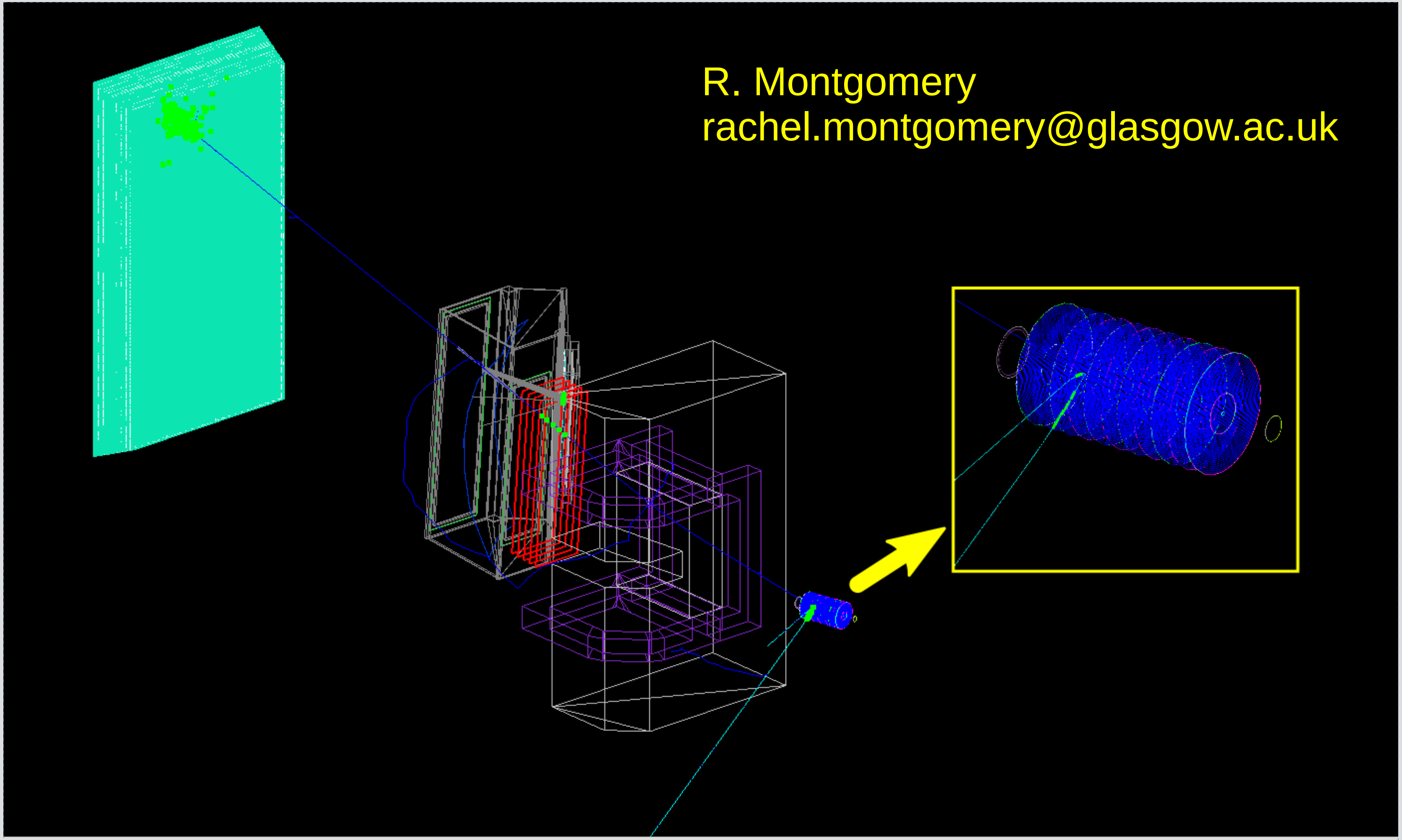
Speaker: Aruni Nadeeshani (Hampton University)

Hall A talk.pdf

Pion is not the only one

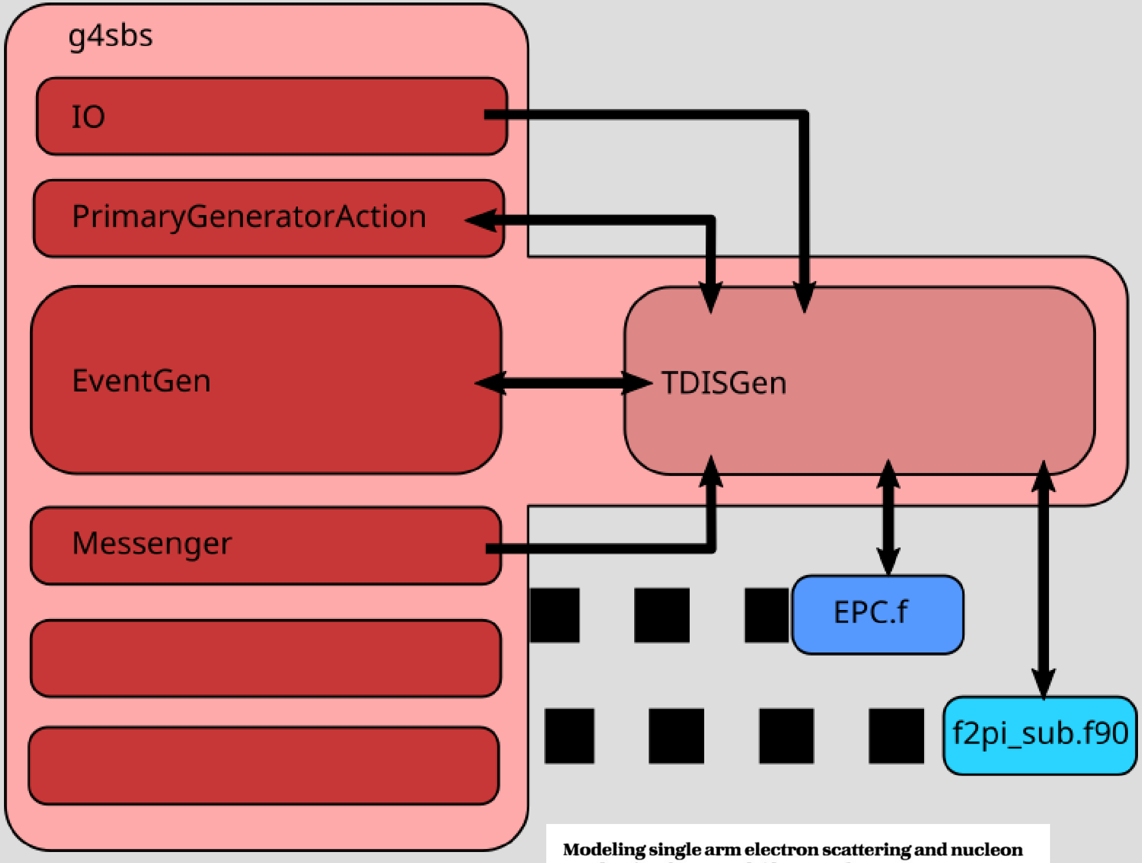


Geant4 simulation (g4sbs)



R. Montgomery
rachel.montgomery@glasgow.ac.uk

Generators



TDISGen is forked from the EventGen class of g4sbs.

- It is intended to develop all the generators required in TDIS in this class with minimal disturbance to the g4sbs framework and according to its programming philosophy
- Elastic and quasielastic
- TDIS generator
  - T. Hobbs phenomenological model
  - D. Adhikary and K. Park parametrization
- DIS events from PYTHIA pre-generated ep/en files from A. Puckett

TO ADD:

- Kaon TDIS
- Neutron SF generator

Modeling single arm electron scattering and nucleon production from nuclei by GeV electrons

J.W. Lightbody, Jr.[a]
National Science Foundation, Washington, DC 20006
J.S. O'Connell
National Bureau of Standards, Gaithersburg, Maryland 20899

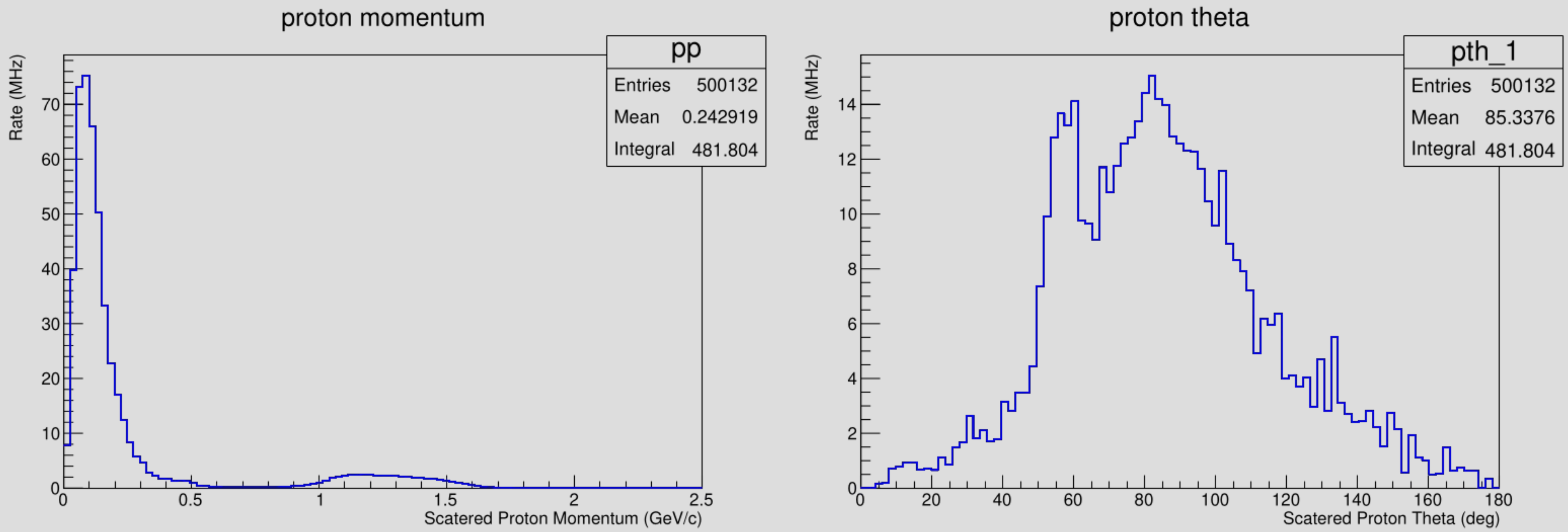
(Received 7 December 1987; accepted 25 January 1988)

T. J. Hobbs

Phenomenological Implications of the Nucleon's Meson Cloud

Received: 10 November 2014 / Accepted: 10 February 2015 / Published online: 24 February 2015

Output example



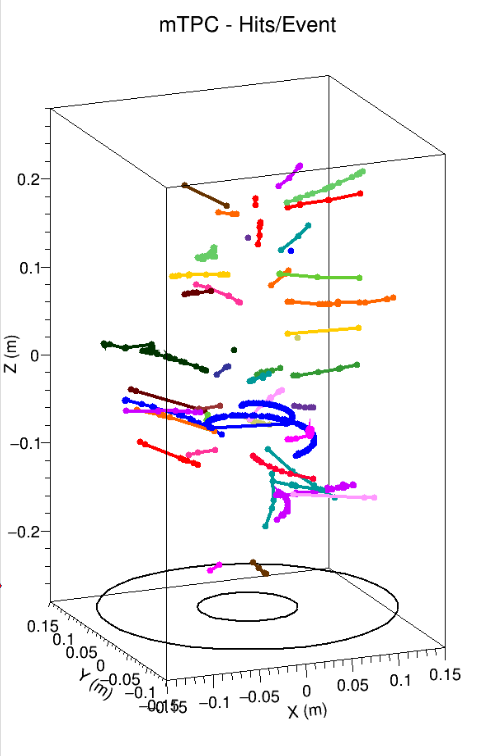
Event Display

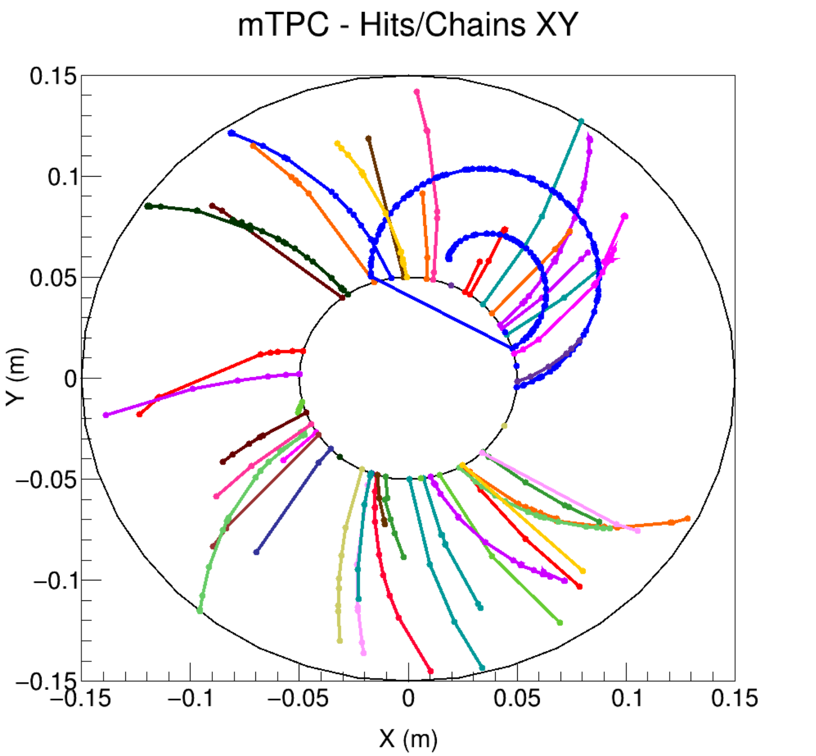
Quite simple program making use of ROOT classes to represent the output from g4sbs.

For some reason, running as a macro gives some issues, which I think are coming from the use of stl:: vector.
Compiling the code gave no issues.

The 3D output allows to rotate the graph in any direction.

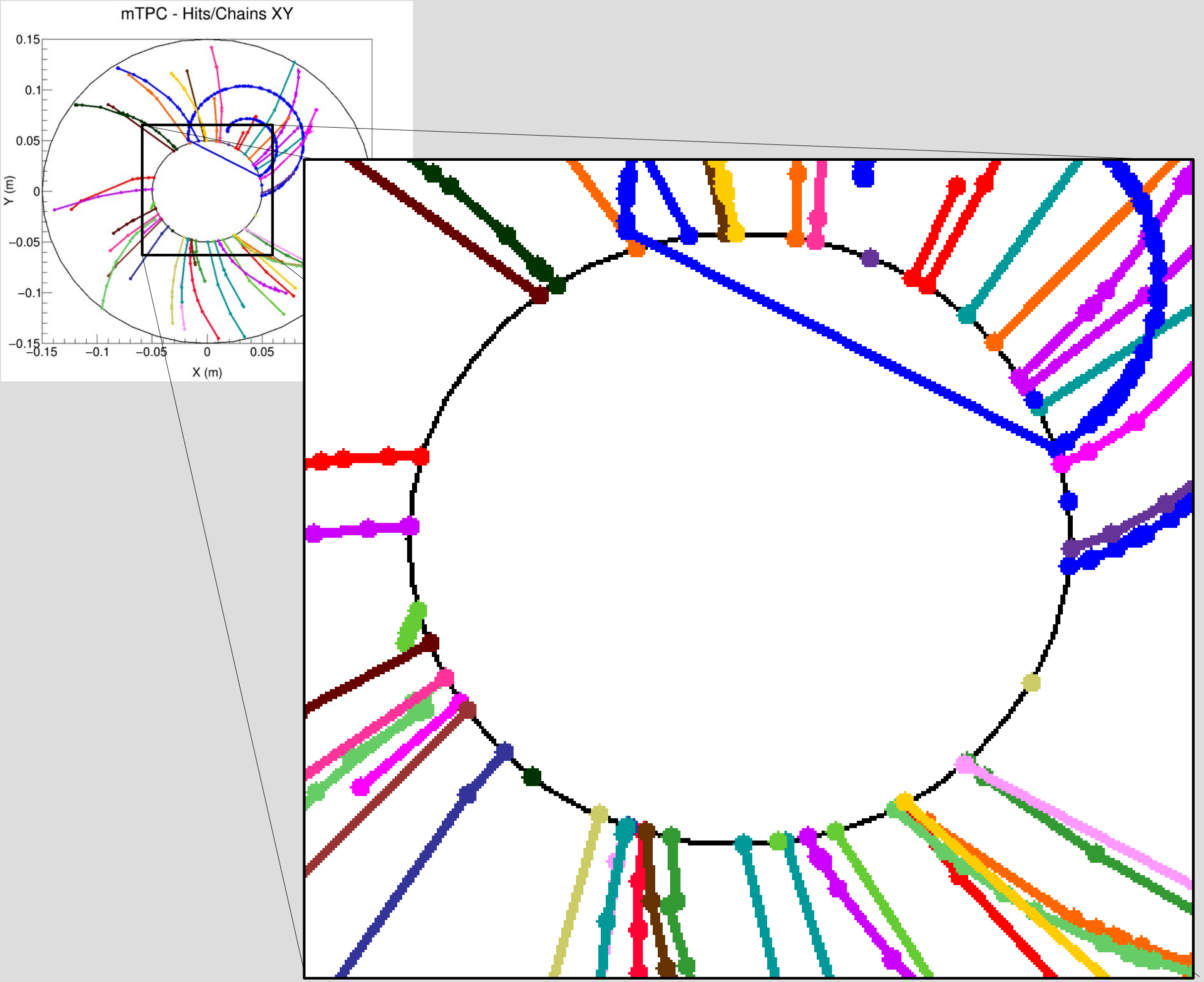
50 QE g4sbs protons with p<400MeV/c





A projection in the X-Y plane helps to visualize better the tracks

It helps to find issues



The first hit on each event starts at the inner kapton distance. For the track finder, that is not an issue, but maybe it is for further analysis.

```
Entry: 0

Hit: 0 x: 0.0247969 y: -0.0434318 z: 0.203962
Radius (cyl): 0.0500121

Hit: 1 x: 0.03342 y: -0.055369 z: 0.208807
Radius (cyl): 0.0646732
(...)

Entry: 1

Hit: 0 x: 0.0423682 y: 0.0265735 z: -0.174295
Radius (cyl): 0.0500121

Hit: 1 x: 0.0523834 y: 0.0370613 z: -0.174454
Radius (cyl): 0.0641682
(...)

Entry: 2

Hit: 0 x: -0.0104591 y: -0.0489062 z: 0.0197546
Radius (cyl): 0.0500121

Hit: 1 x: -0.00973801 y: -0.0591202 z: 0.0243124
Radius (cyl): 0.0599168
(...)
```

Digitization

R. Montgomery
rachel.montgomery@glasgow.ac.uk

g4SBS

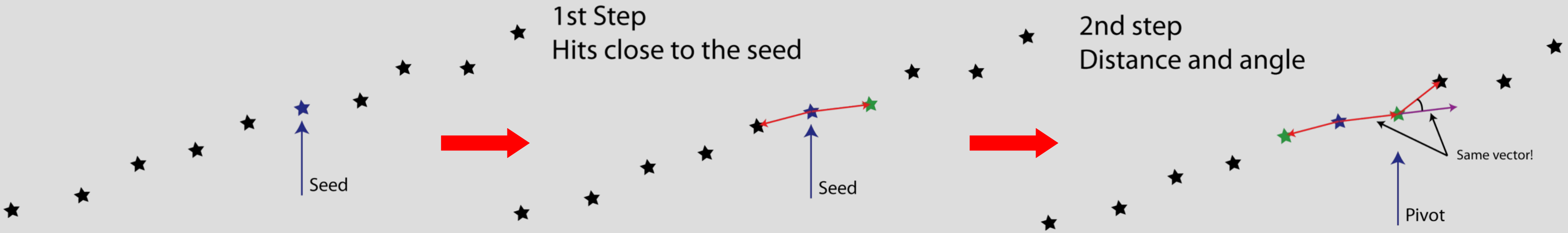
Rachel's digitization

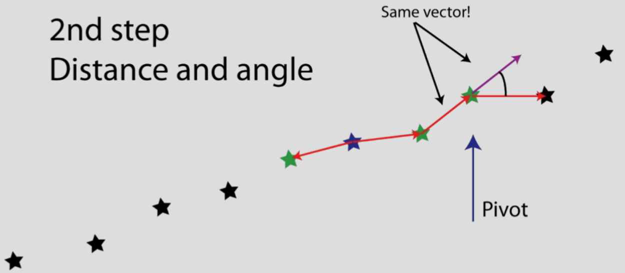
Incorporate into g4sbs?

ASCII to ROOT

- Event (int)
- Momentum (double)
- theta (double)
- phi (double)
- zvertex (double)
- NoHits (int)
- TimeofArrival (vector double)
- ADC (vector double)
- ring (vector int)
- pad (vector int)
- plane (vector int)
- ZtoGEM (vector double)
- XHitPos (vector double)
- YHitPos (vector double)
- ZHitPos (vector double)

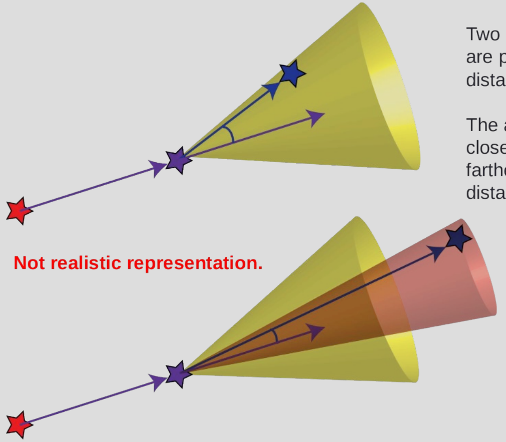
Graphic explanation of the chain finder





The process is repeated until there are not more hits in the pool which fulfill the requirements

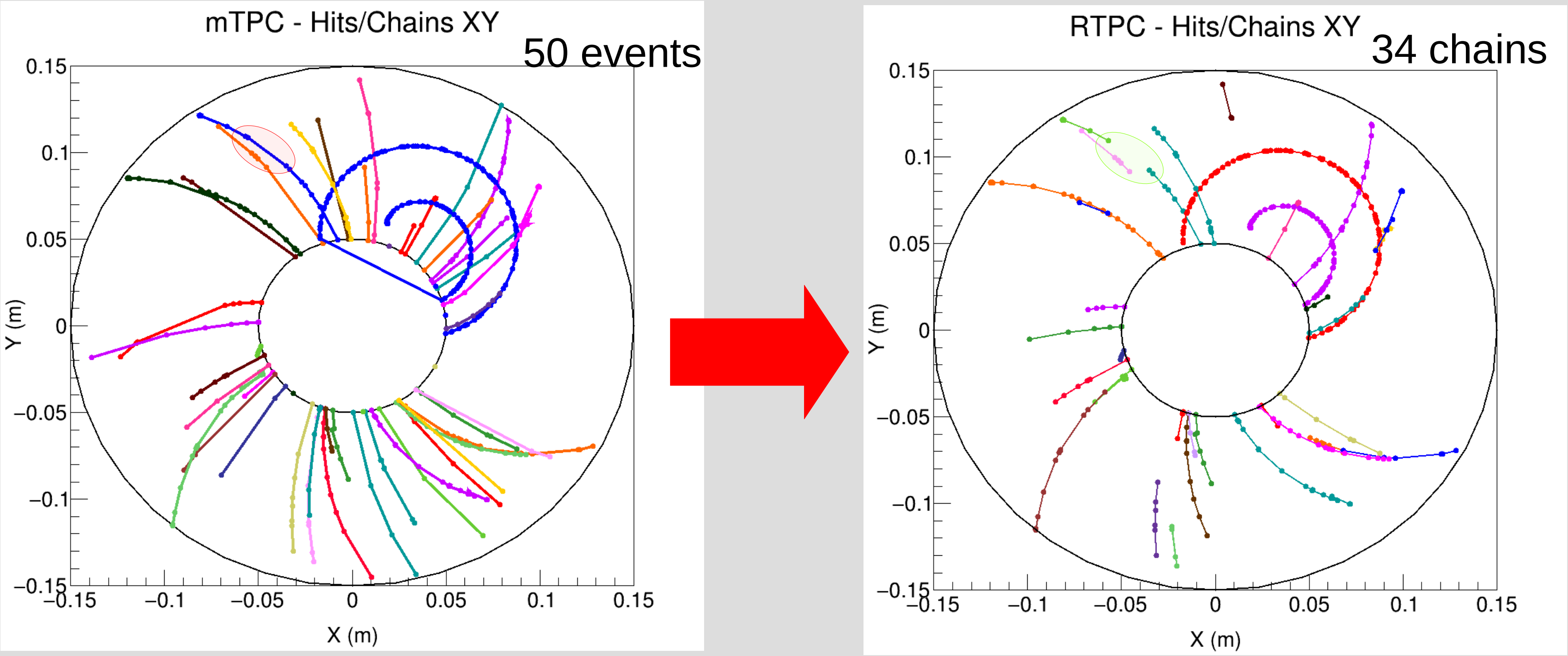
Angle constrain



Two possible acceptances are possible depending of the distance to the candidate hit.

The acceptance is larger for close hits and shorter for farthest hits but within the distance condition.

Example of chain finder



Parameters:

Max distance between hits: 25mm

Short distance angle: 20deg

Long distance angle: 15.3deg

Max distance between hits:15mm

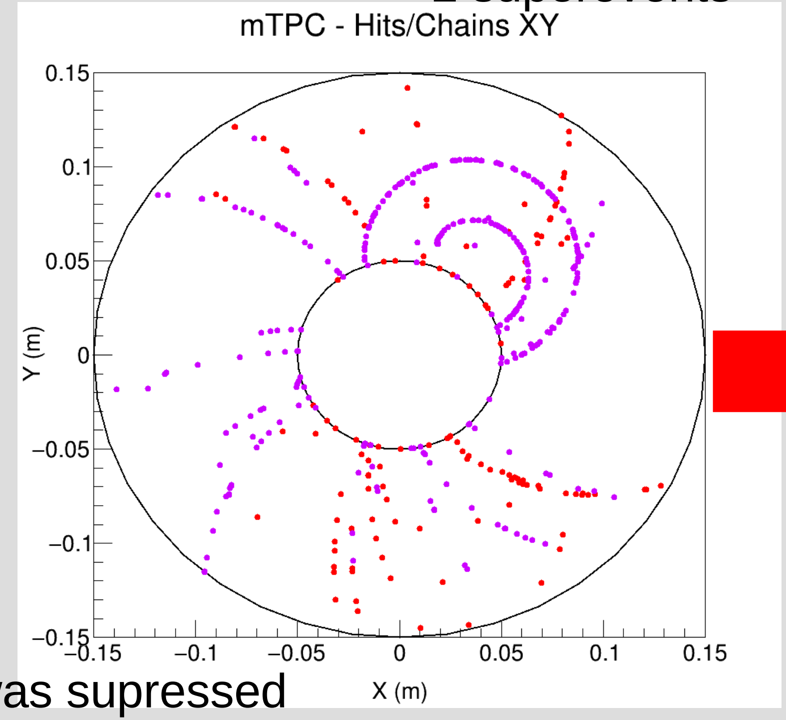
Min # of hits: 4

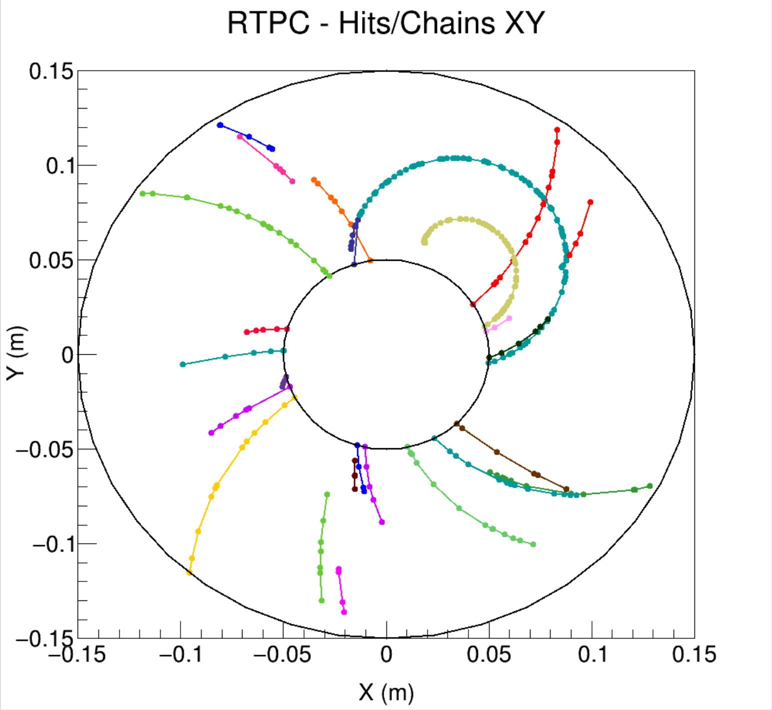
The same but combining events

2 superevents

24 chains

50 g4sbs events were comprised in 2 ‘superevents’





Line was supressed

Parameters:

Max distance between hits: 25mm

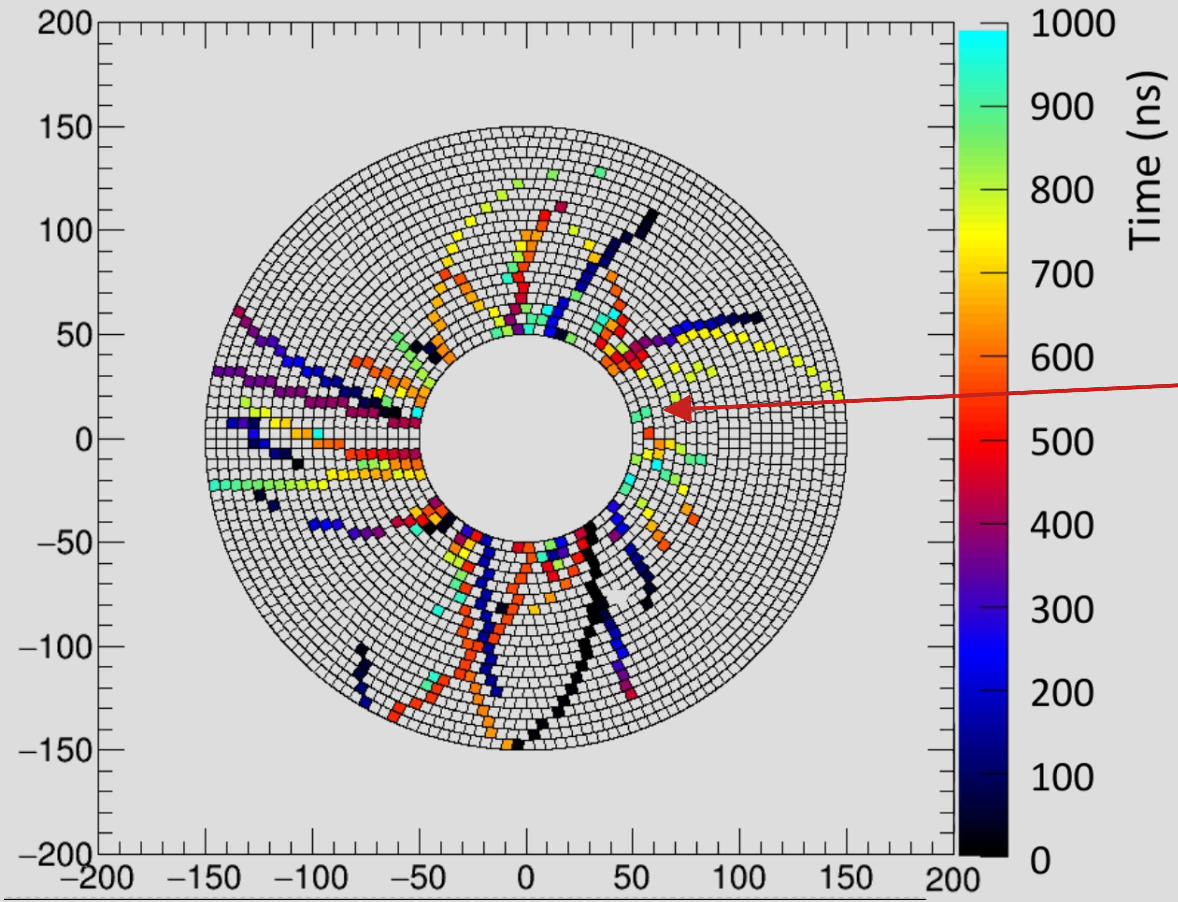
Short distance angle: 20deg

Long distance angle: 15.3deg

Max distance between hits: 15mm

Min # of hits: 4

Not an easy task



Inner rings highly populated

Occupancy based in ~480 MHz QE protons background: ~10%

AI/ML pattern recognition techniques could help here

Why stop at 11 GeV

We are working the present, preparing the future of this project

TDIS meson production – a theory perspective

Patrick Barry, Jefferson Lab

Science at Mid x, July 23rd, 2022

In collaboration with Chueng-Ryong Ji, Wally Melnitchouk, and Nobuo Sato

Meson structure at JLab 22 GeV

Patrick Barry, JLab

Science at the Luminosity Frontier: Jefferson Lab at 22 GeV Workshop

January 23th, 2023

Winter Hall C Collaboration Meeting

12 Jan 2023, 08:00 → 13 Jan 2023, 17:00 US/Eastern

Auditorium (Cebaf Center Jefferson Lab)

Arun Tadepalli (Jefferson Lab), Stephen Kay (University of Regina), Tanja Horn (Catholic University of America), William Henry (Jefferson Lab)

Tagged DIS 30m

Speakers: Carlos Ayerbe Gayoso (Mississippi State University), Dipangkar Dutta (Mississippi State University), Rachel Montgomery, Tanja Horn (Catholic University of America)

20230113-HallC_Co...

Science at the Luminosity Frontier: Jefferson Lab at 22 GeV Workshop

23 Jan 2023, 03:20 → 25 Jan 2023, 22:50 US/Eastern

CEBAF Auditorium (Jefferson Lab)

Probing light meson structure via spectator tagging (15+10)

Speaker: Rachel Montgomery

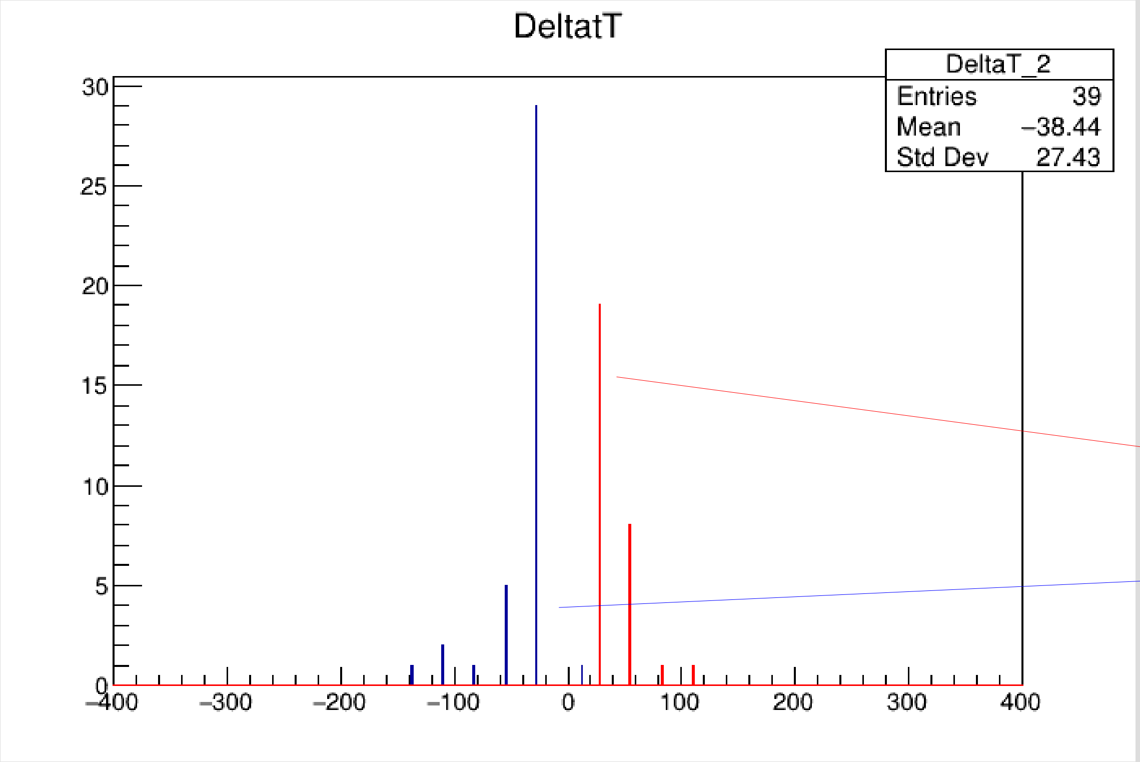
Montgomery_SIDIS...

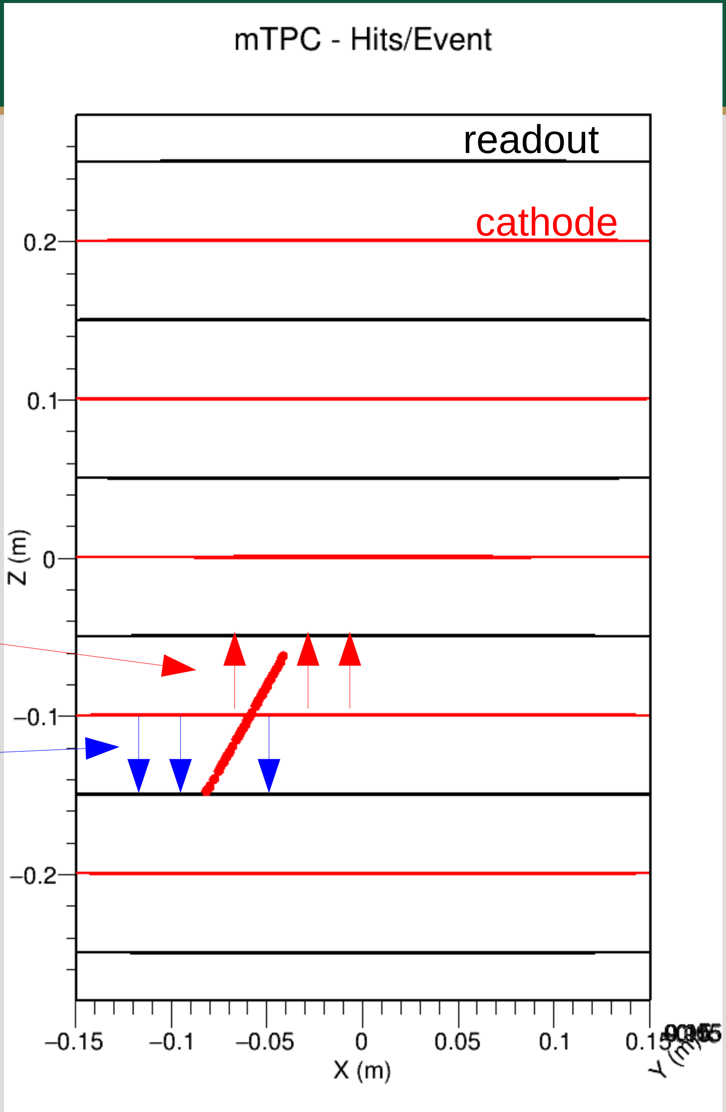

That's all Folks!

That's all Folks?

BACKUP SLIDES

Event analysis





G4 data enter in the data pool as first produced, first event → inner to outer

https://userweb.jlab.org/~gayoso/file.gif

Sorting (making use of Tvector and Quick Sort algorithm
http://www.algolist.net/Algorithms/Sorting/Quicksort
→ outer to inner

https://userweb.jlab.org/~gayoso/file_01.gif

Gif animations of these two events showing the data pool sorted (before and after)