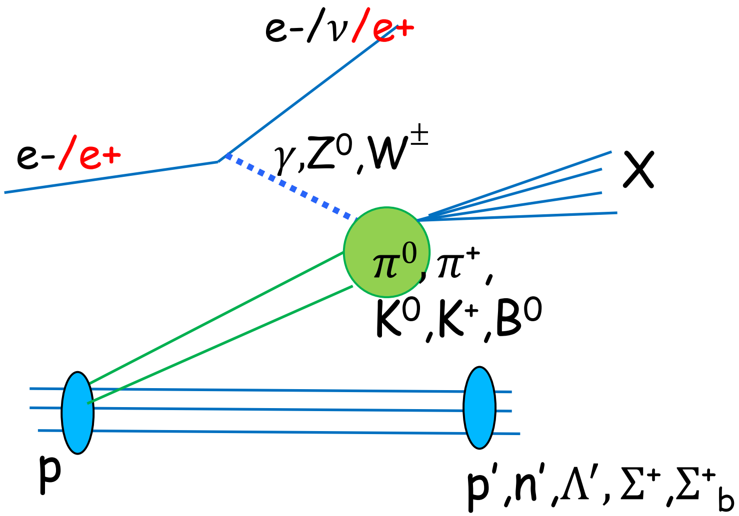
EIC Meson Structure Functions Working Group Update



14 May 2020

Workshop on Pion and Kaon Structure Functions at the EIC

Center for Frontiers in Nuclear Science
Workshop series

2-5 June 2020
Online
US/Eastern timezone

Remote Workshop in June

- Overview
- Call for Abstracts
- Timetable
- Contribution List
- Registration
- Participant List

Contact
cfns_contact@stonybroo...

The Lagrangian masses of the quarks deliver only ≈ 1% of the proton mass, *mp*; and it is the emergence of the bulk of *mp* and the (very probably) related mechanism of confinement that are the key unresolved issues in hadron physics. In addressing these issues, the potential of the EIC is enormous. It promises to enable a quantitative understanding of the structure of hadrons, such as the nucleon, pion and kaon, in terms of quarks and gluons, thereby achieving key goals of modern physics. Recent synergistic advances in computation, experiment and theory reveal the prospects for a precise description of the one-dimensional structure of hadrons, exemplified by parton distribution functions (PDFs) and electromagnetic form factors, and of constructing three-dimensional images of hadrons, as expressed in Generalized Parton Distributions (GPDs) and Transverse-Momentum-Dependent Distributions (TMDs). Hence, today, there is an unprecedented opportunity to chart the in-hadron distributions of, *inter alia*, mass, charge, magnetization and angular momentum.

This workshop will canvass recent progress toward a coherent program of pion and kaon structure studies at the Electron-Ion Collider (EIC) that will deliver these maps. Their drawing demands an interplay between experiment and theory. Here, recent experimental developments have been matched by new theoretical insights and rapid computational advances. The progress triad is completed by high-level phenomenology in the form of global structure function fitting frameworks. Machine learning and exascale computing are both expected to play a material role in this march of progress.

This workshop aims to capitalize on the success of two prior meetings (PIEIC2017, PIEIC2018), which led to a White Paper, published in Eur.Phys.J.A 55 (2019) 10, 190. Its near-term goals are to expand this documentation, driving toward a significant new element in the EIC User Group Physics and Detector Handbook, and develop contributions as part of the ongoing Yellow Report Initiative.

Large (remote) interest:

- All invited speakers accept
- 66 participants already

Starts Jun 2, 2020, 8:00 AM
Ends Jun 5, 2020, 7:00 PM
US/Eastern

Online

Craig Roberts
Tanja Horn

https://indico.bnl.gov/e/PIEIC2020

EIC Meson Structure Working Group

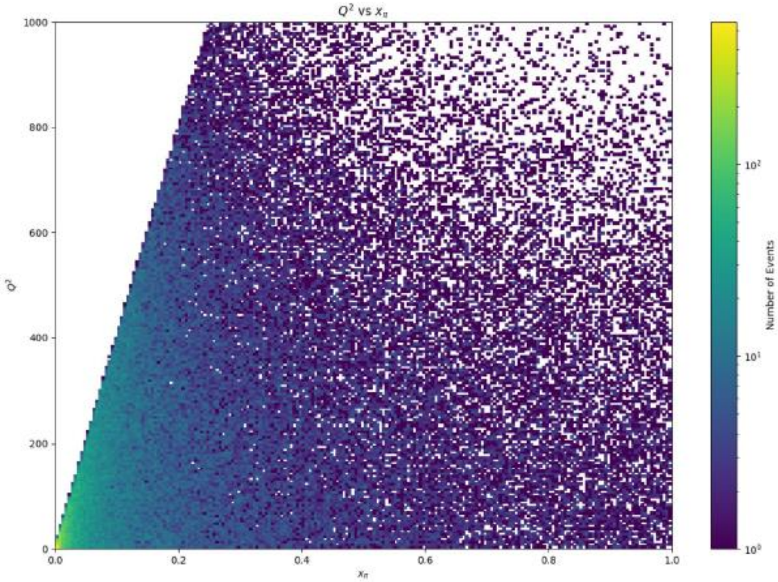
The charge from the Physics Working Group for the 20-22 May Pavia meeting:

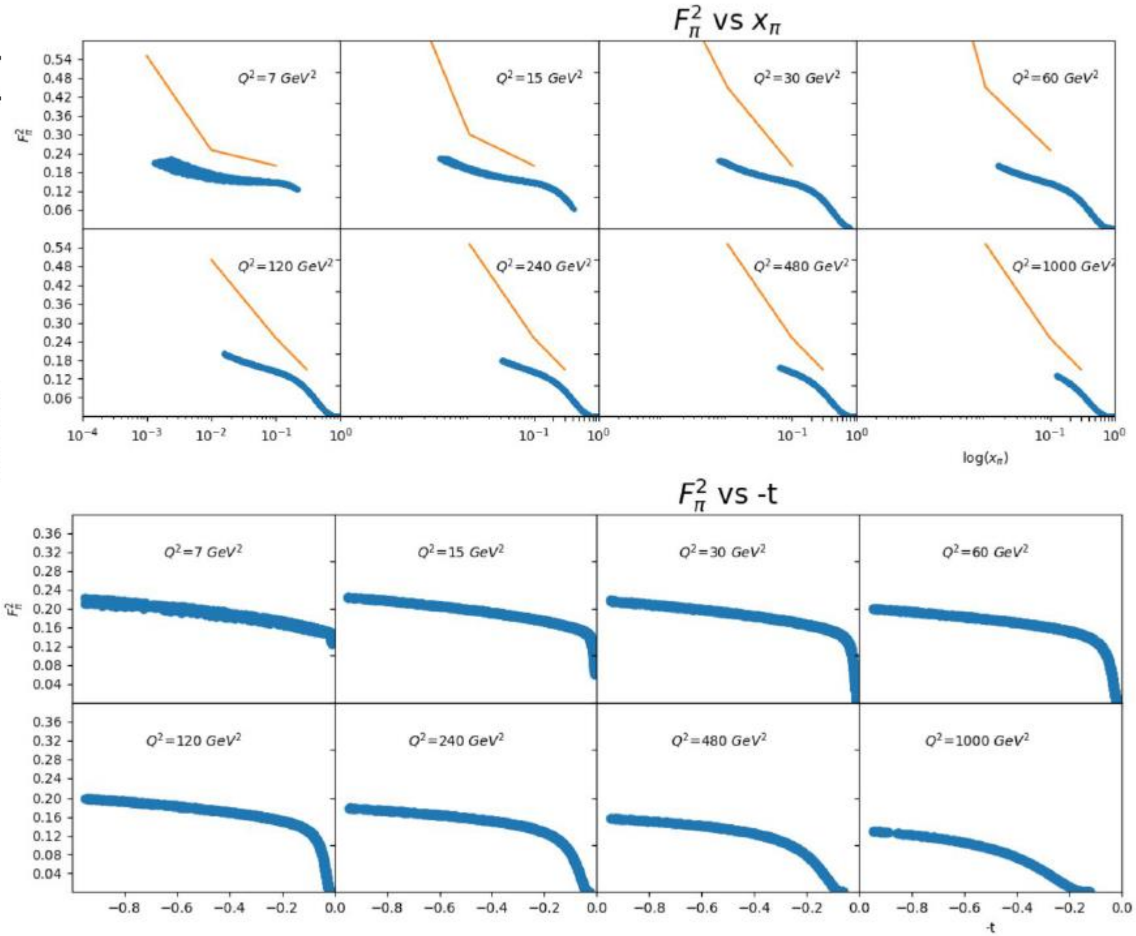
- Break-down physics deliverables into “physics objects” (PO) [electron, hadron (ID/noID), muon, jet]; map out kinematics for each PO.
  - Physics deliverables: pion/kaon structure function plots, pion form factor plot
  - Physics objects: scattered electron
    measure pion and tagged neutron → pion form factor
    measure “X” and tagged neutron → pion structure function
    measure “X” and tagged Lambda/Sigma → kaon SF
  - Produce kinematics plots/coverages for each, at 2-3 beam energies
    should pick energies where both e-p and e-d are doable
    (for FF, but also for SF) → 10x100, 10x135, 5x41

- Focus on fast simulations for the most demanding measurements first; determine the optimal/acceptable detector performance; confirm/check resulting impact on the rest of the measurements.
  - Fast simulations: ready with event generator
  - Optimal/acceptable detector performance: Meson Structure (most?) demanding for:
    - Detectors after FFQs and the ZDC
    - ZDC angular resolution (for pT/t resolution)
    - Hadronic calorimetry requirements (as for all physics at large-x)

Kinematic Coverage and F2 Projections

10 on 100 [(0.01 < y < 0.95)]
MC:[x(0.001-1.0),Q^2(1,1000)]

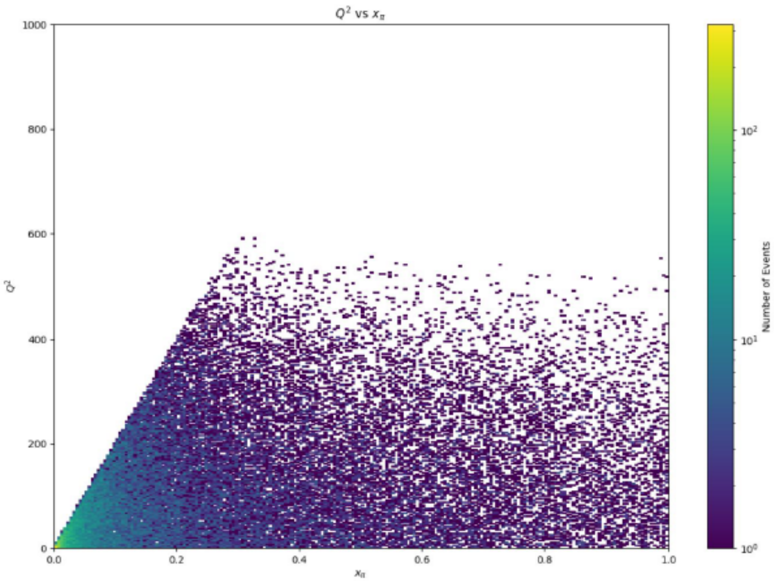


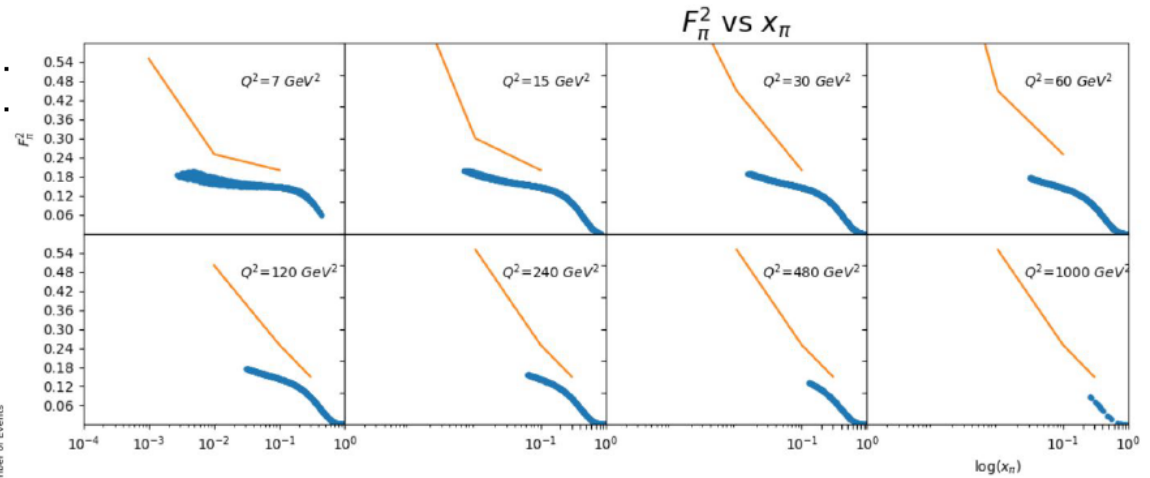


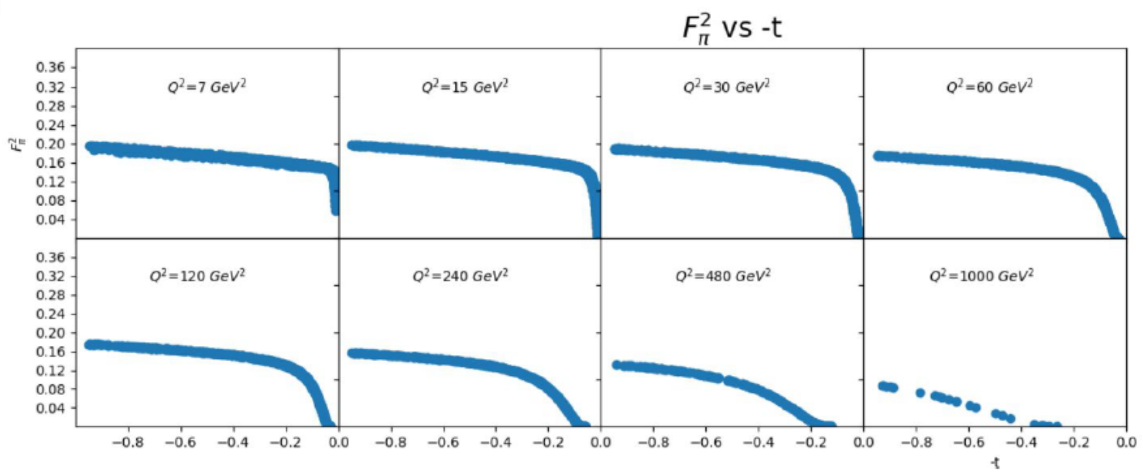
To reach the large x region at a certain intermediate Q^2, the lowest possible energy is normally best. For high beam energies this area requires y to be low

Kinematic Coverage and F2 Projections

5 on 100 [(0.01 < y < 0.95)]
MC:[x(0.001-1.0),Q^2(1,1000)]



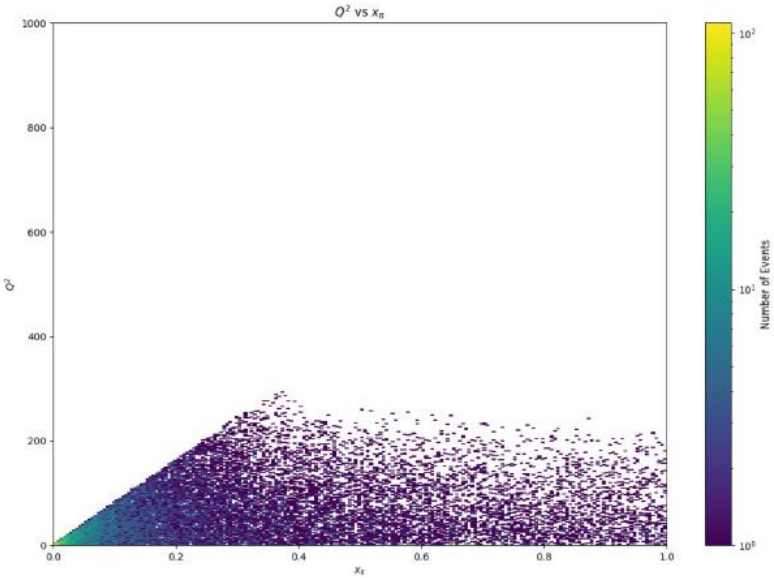


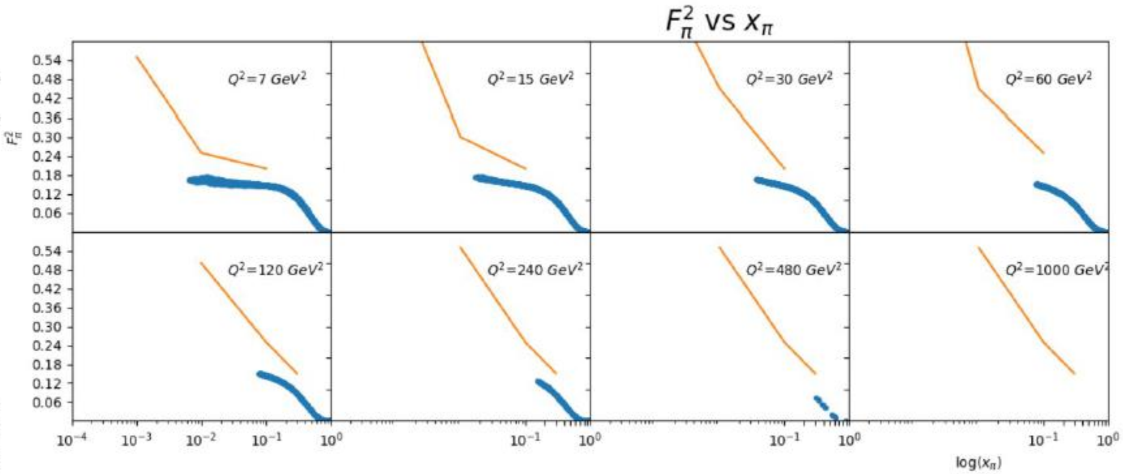


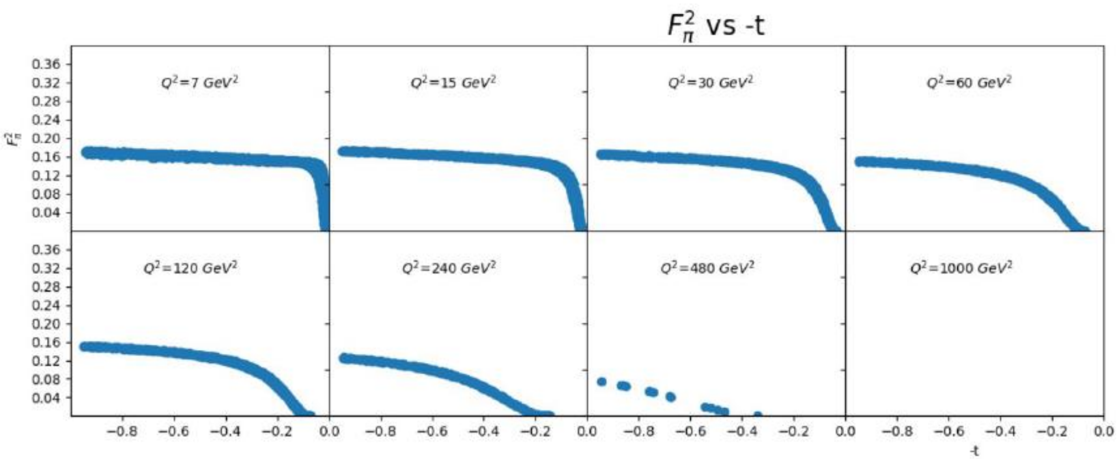
For 5 on 100 can access more acceptance at high-x, but lose acceptance to the low-x region, ….

Kinematic Coverage and F2 Projections

5 on 41 [(0.01 < y < 0.95)]
MC:[x(0.001-1.0),Q^2(1,1000)]





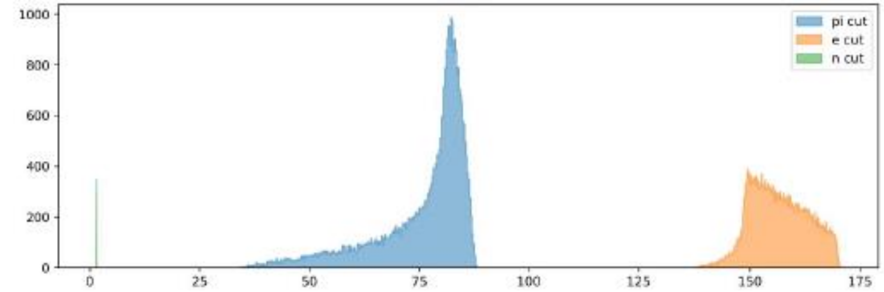


…for 5 on 41 even more.

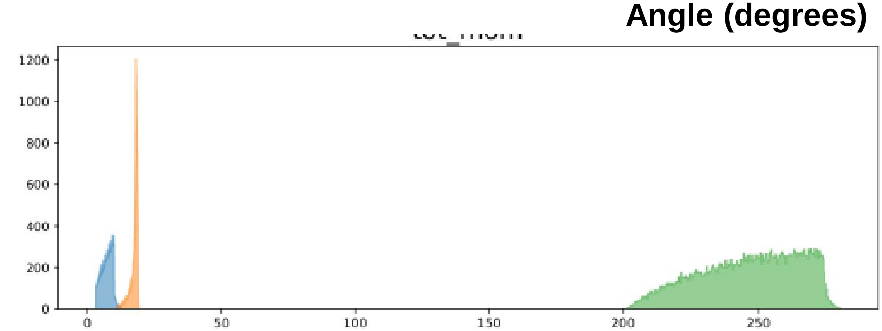
there are also some advantages for lower proton energy for K-Lambda detection

Where do scattered particles go

- Scattered electrons can be detected in the central detector
- Baryon (neutron, lambda) at very small forward angles and nearly the beam momentum

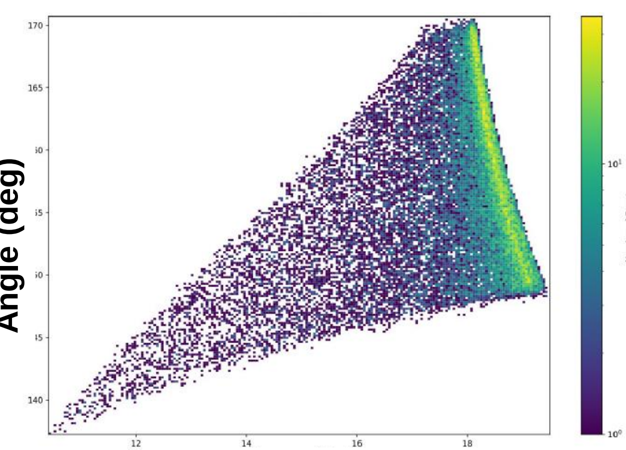


Angle (degrees)



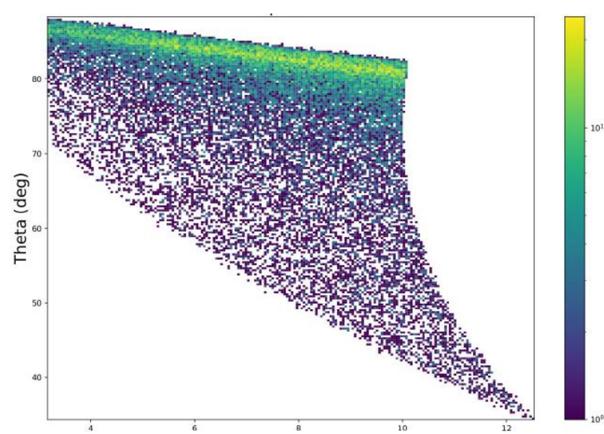
Momentum (GeV)

Electron



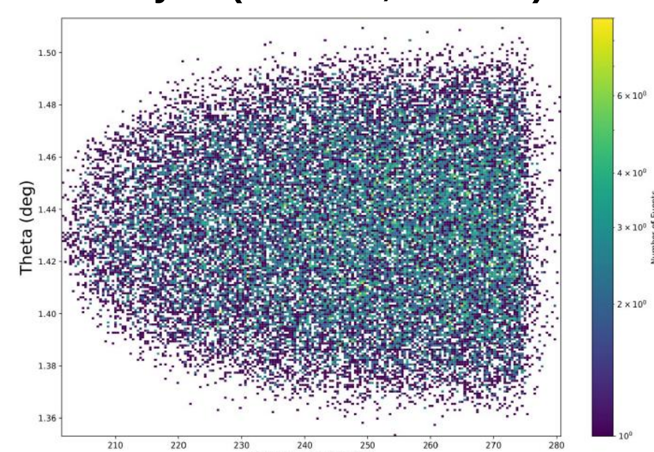
Momentum (GeV)

Meson (pion, kaon)



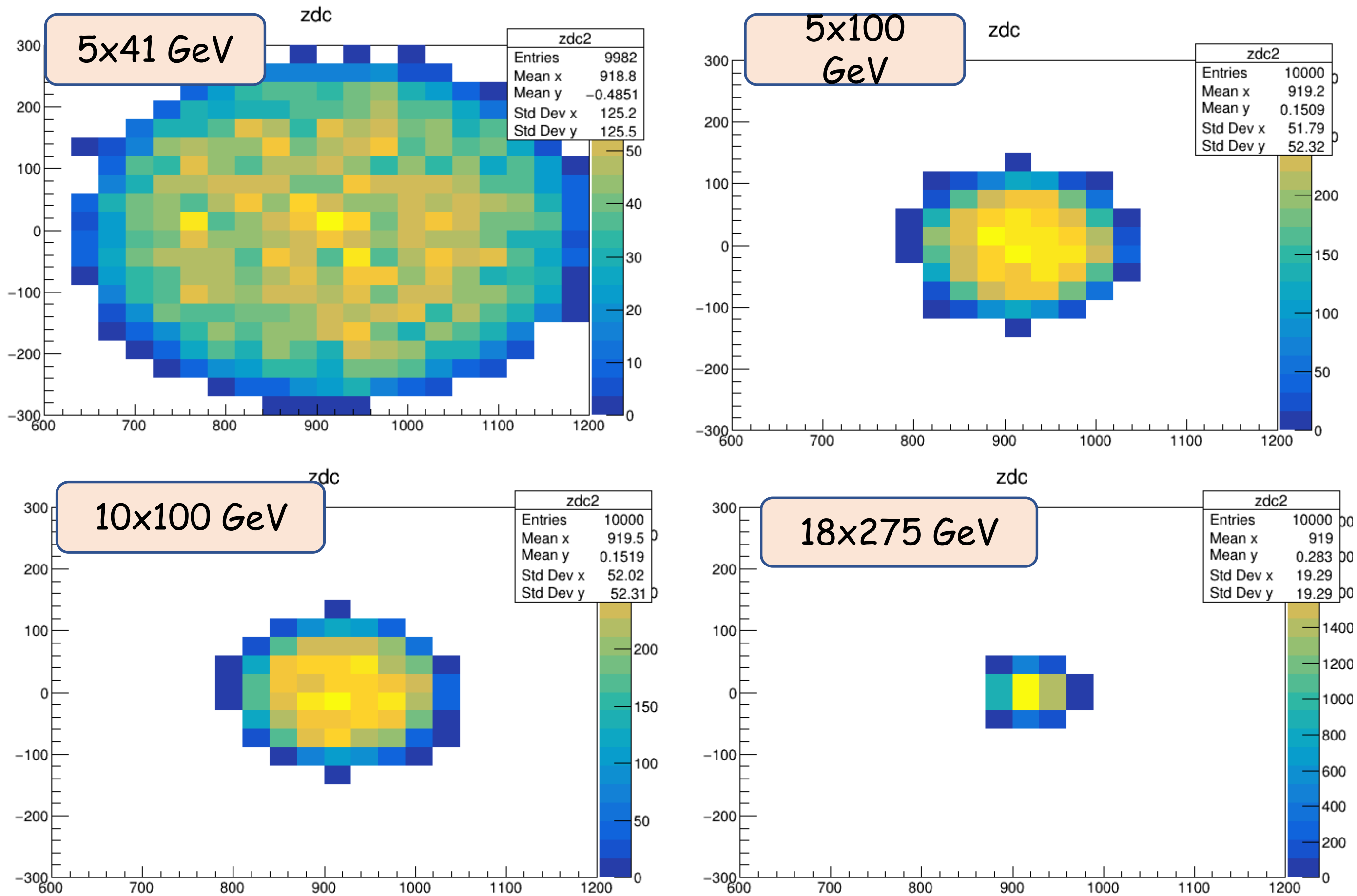
Momentum (GeV)

Baryon (neutron, lambda)



Momentum (GeV)

Detection Efficiency – forward Neutron

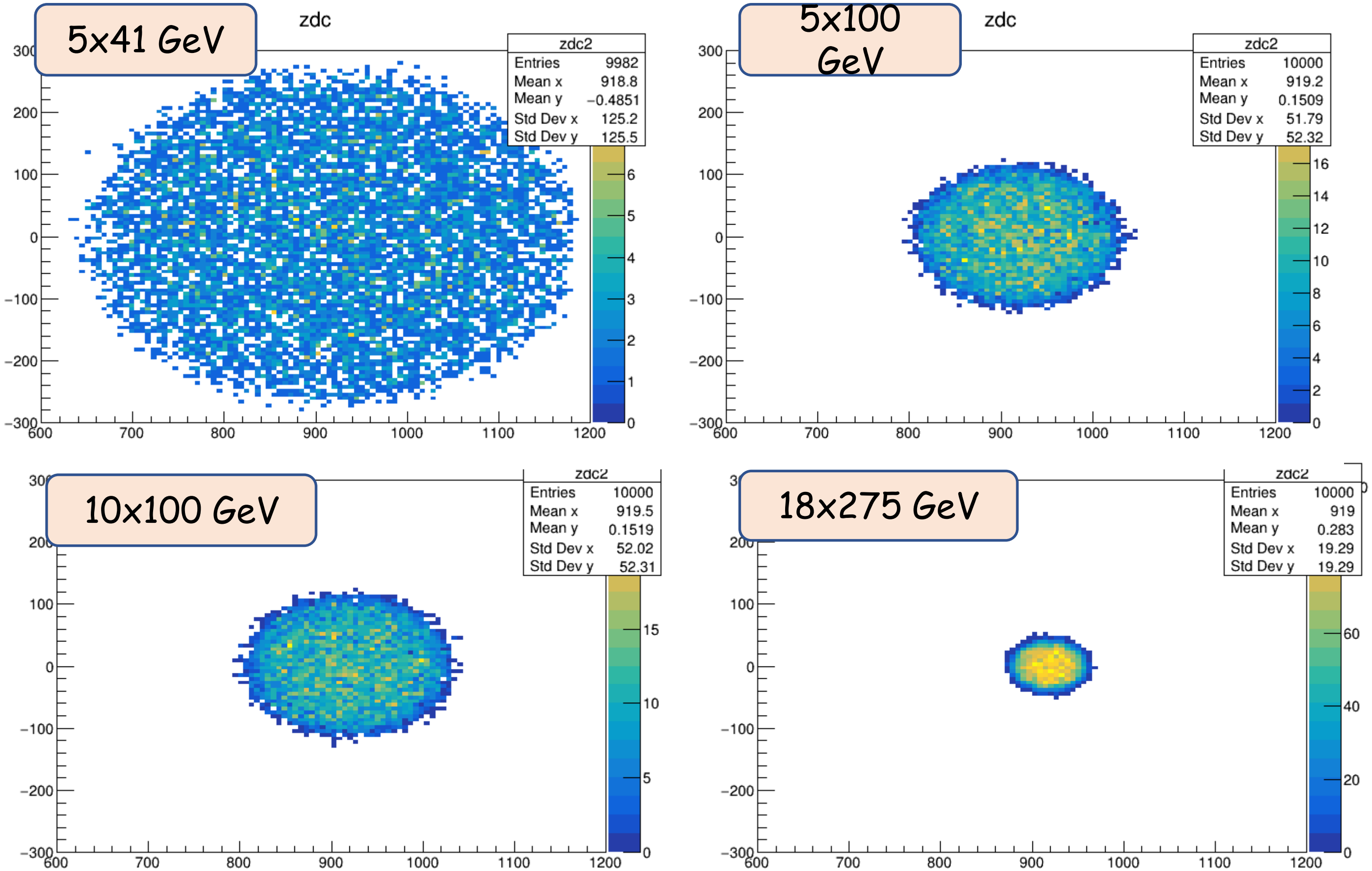


ZDC
60x60 cm
20bins => 3cm
towers

Neutrons measured in the ZDC – 100% detection efficiency ✔

But need good ZDC angular resolution for the required t resolution

Detection Efficiency – forward Neutron

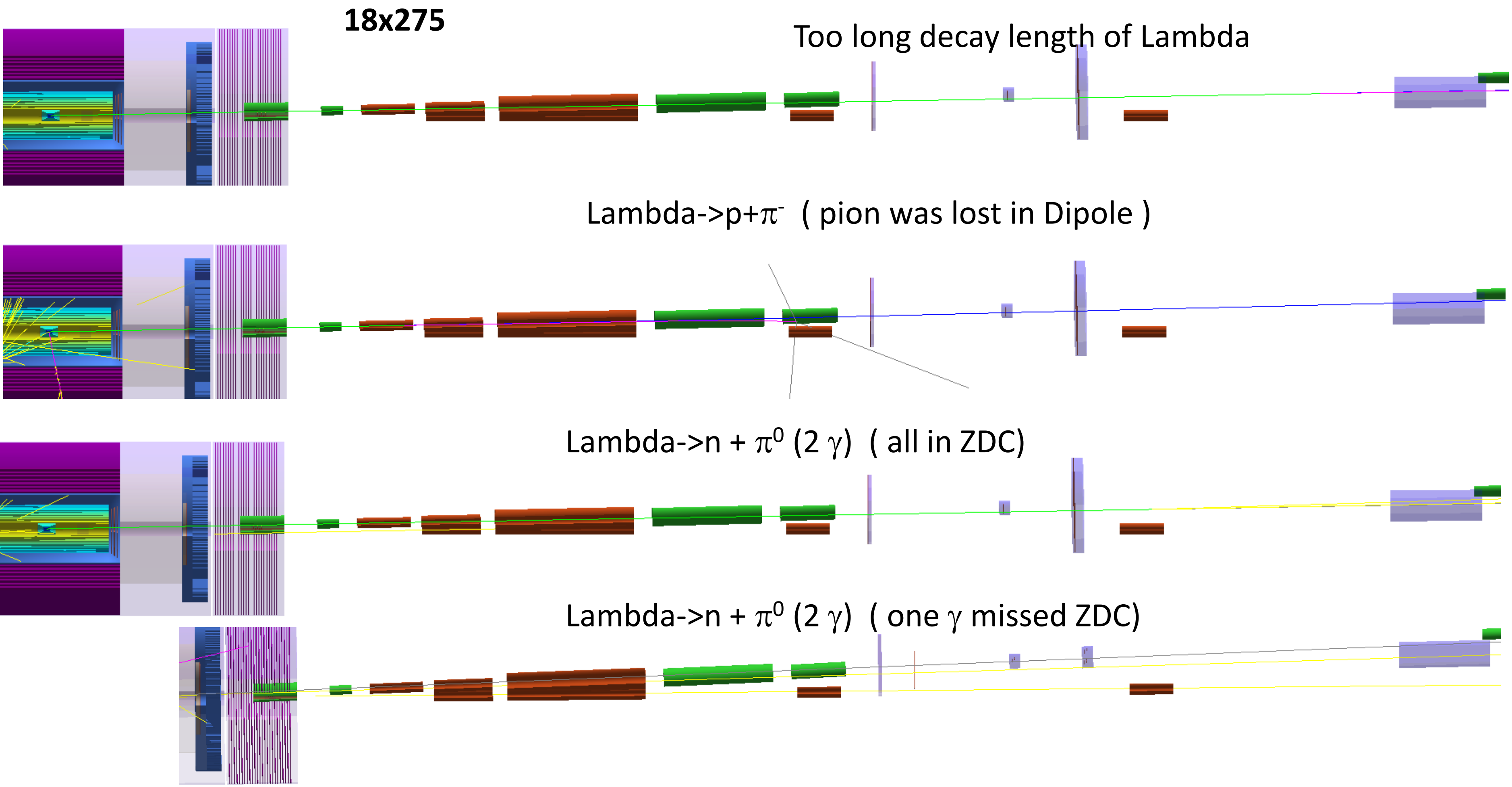


ZDC
60x60 cm
100bins =>
0.6cm
towers

Neutrons measured in the ZDC – 100% detection efficiency ✓

But need good ZDC angular resolution for the required t resolution

Detection Efficiency – forward Lambda



$\Lambda \rightarrow p + \pi^-$: very challenging!

- ➢ need additional particle tracking between dipoles and ZDC

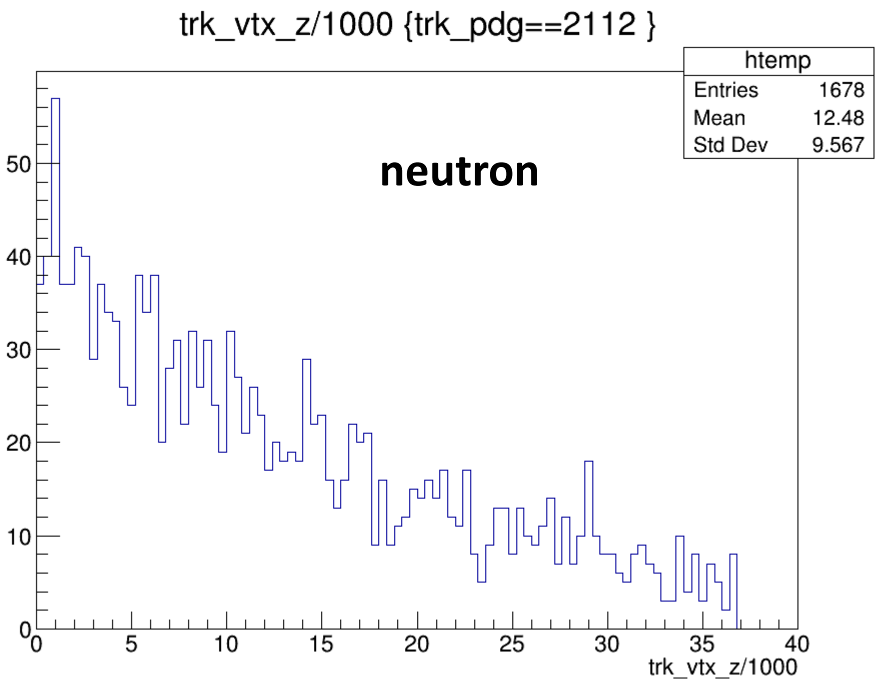
$\Lambda \rightarrow n + \pi^0$: looks promising

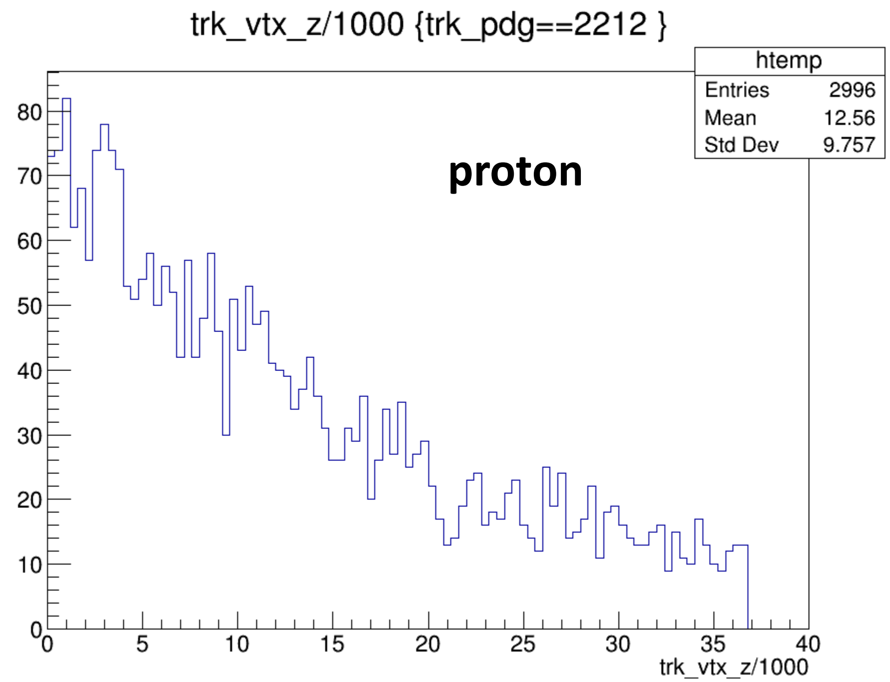
- ➢ need additional high-res/granularity EMCal+tracking before ZDC

Decay Length (p/n vertex)

18x275 GeV

mode[0] = new G4PhaseSpaceDecayChannel("lambda",0.639,2,"proton","pi-");
G4PhaseSpaceDecayChannel("lambda",0.358,2,"neutron","pi0");



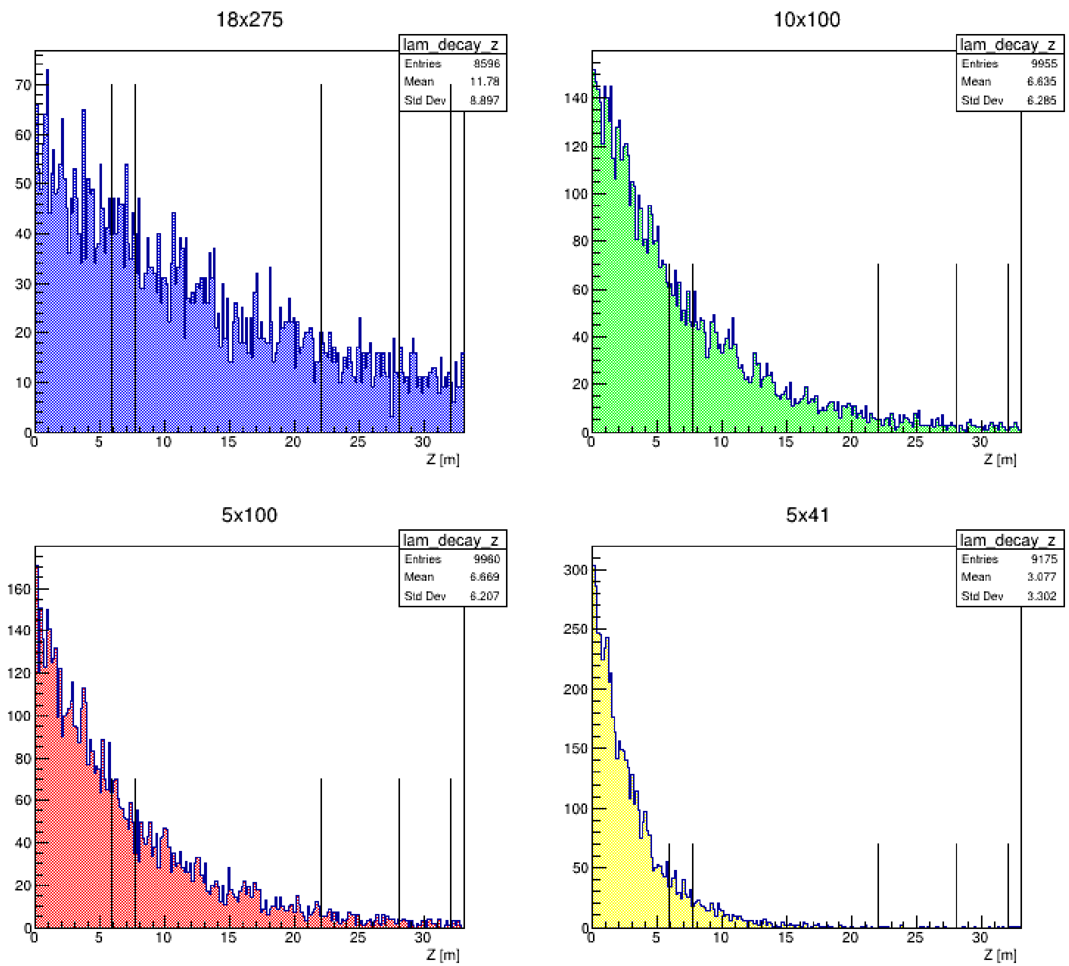


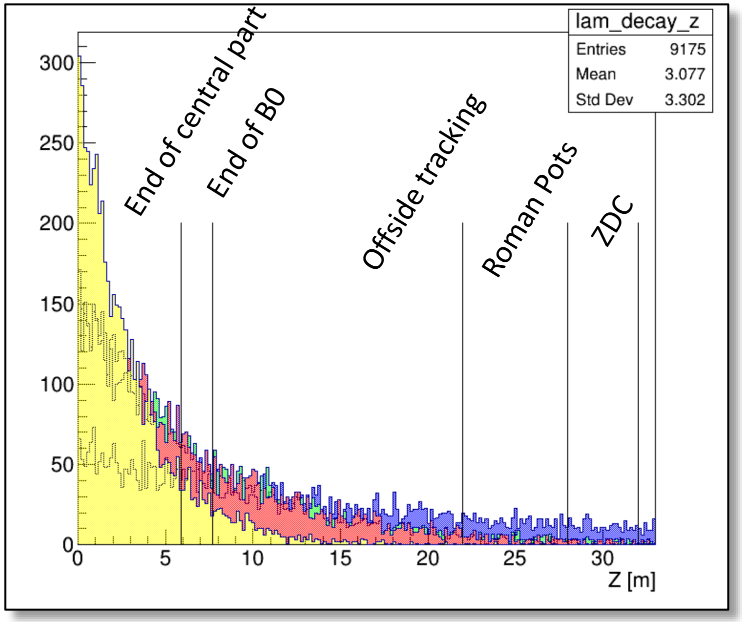
10k events total => 3580 neutrons => ~ 47%
Need to add pi0 efficiency

10k events total => 6390 protons => ~ 47%
Need to add pi- efficiency

For 275 GeV proton energies the boost of the Lambda gets to be large → difficult to distinguish Lambda from neutron

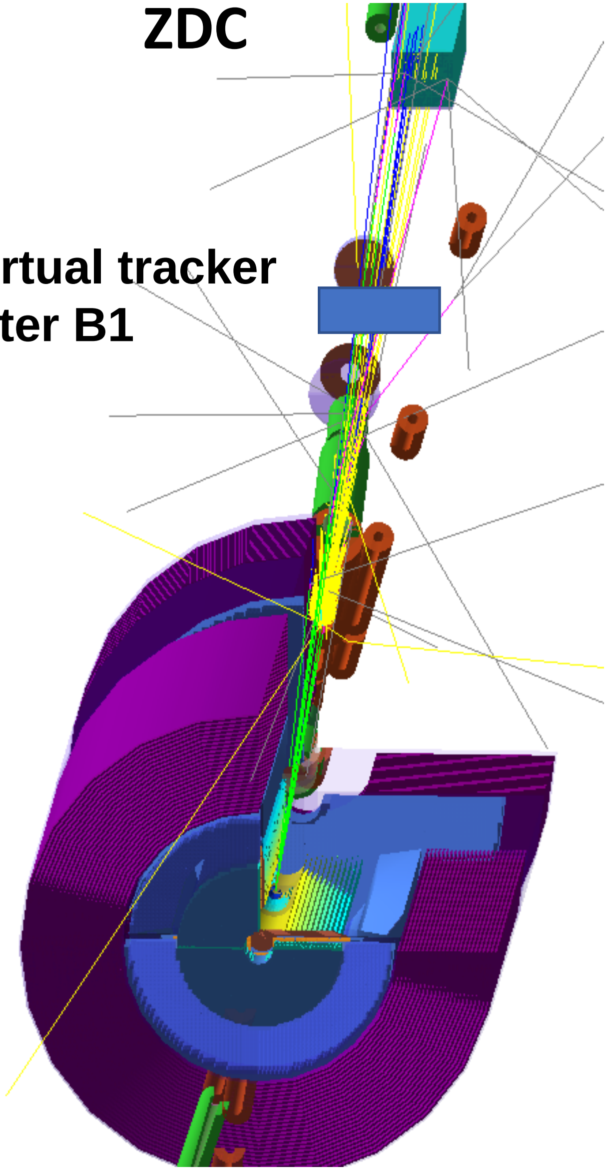
Decay Length (p/n vertex)





There are some advantages for lower proton energy for K-Lambda detection

Summary of Detector Requirements



- For π-n the neutron detection efficiency is ~100% with planned ZDC, but need that 60 cm by 60 cm ZDC size
- For both π-n and K-Λ need good ZDC resolution for the required t resolution
- For K-Lambda also need
  - $\Lambda \to n + \pi^0$: additional high-res/granularity EMCal+tracking before ZDC – seems doable
  - $\Lambda \to p + \pi^-$: additional trackers in opposite direction (charge) on the path to ZDC – more challenging
- Electron detection in the central region
- Good hadronic calorimetry to obtain good x resolution at large x

Summary EIC Meson Structure Working Group

- Produced initial physics deliverables, physics objects, and kinematics plots/coverage
  - Physics deliverables: pion/kaon structure function plots, pion form factor plot
  - Physics objects: scattered electron
    measure pion and tagged neutron → pion form factor
    measure "X" and tagged neutron → pion structure function
    measure "X" and tagged Lambda/Sigma → kaon SF

- Evaluated with simulations detector performance/requirements
  - Scattered electron detection in the central detector
  - For the tagged neutron: 100% detection efficiency, need a tracking device, high granularity/resolution EMCal for π^0 (2γ), and good angular resolution ZDC
  - For measuring the tagged Lambda
    - For $\Lambda \to n + \pi^0$: need a tracking device, high granularity/resolution EMCal for π^0 (2γ), and good angular resolution ZDC
    - For $\Lambda \to p + \pi^-$: protons can be detected efficiently, but need additional trackers in opposite direction (charge) on the path to ZDC
  - Hadronic calorimetry requirements as for all physics at large x

EIC Meson Structure Working Group

Action item list

- Fix bug to prevent particles to acquire energies >> proton/ion energies
- Then "ready" to do pion and kaon structure function projections a la HERA F2 plots, and redo pion form factor projections
- Produce tables/plots of neutron detection efficiency with ZDC for various beam-energy combinations.
- For ZDC apply smearing correction for energy and angular resolutions (~50%/√E and 0.3 mr/√E, respectively) to link with required missing mass and t-resolution (for EM can use smearing corrections for 2x2cm^2 crystals).
- Produce plots illustrating neutron missing mass and missing momentum resolution.
- Produce plots illustrating Lambda and Sigma missing mass reconstruction.
- Produce tables/plots of Lambda and Sigma detection efficiency with single-layer detector sensor, and determine required size for our physics.
- Determine angular and energy resolution needs of single-detector sensor behind FFQs for identifying exclusive final state using missing mass (Lambda, Sigma).
- Granularity requirement of such detector plane for angular or t resolution.
- Find ways to parameterize hadronic calorimetry resolution and make plot that illustrates impact on x-resolution (relevant for large-x)

Progress