NA6/SHINE: Hadron Production for DUNE

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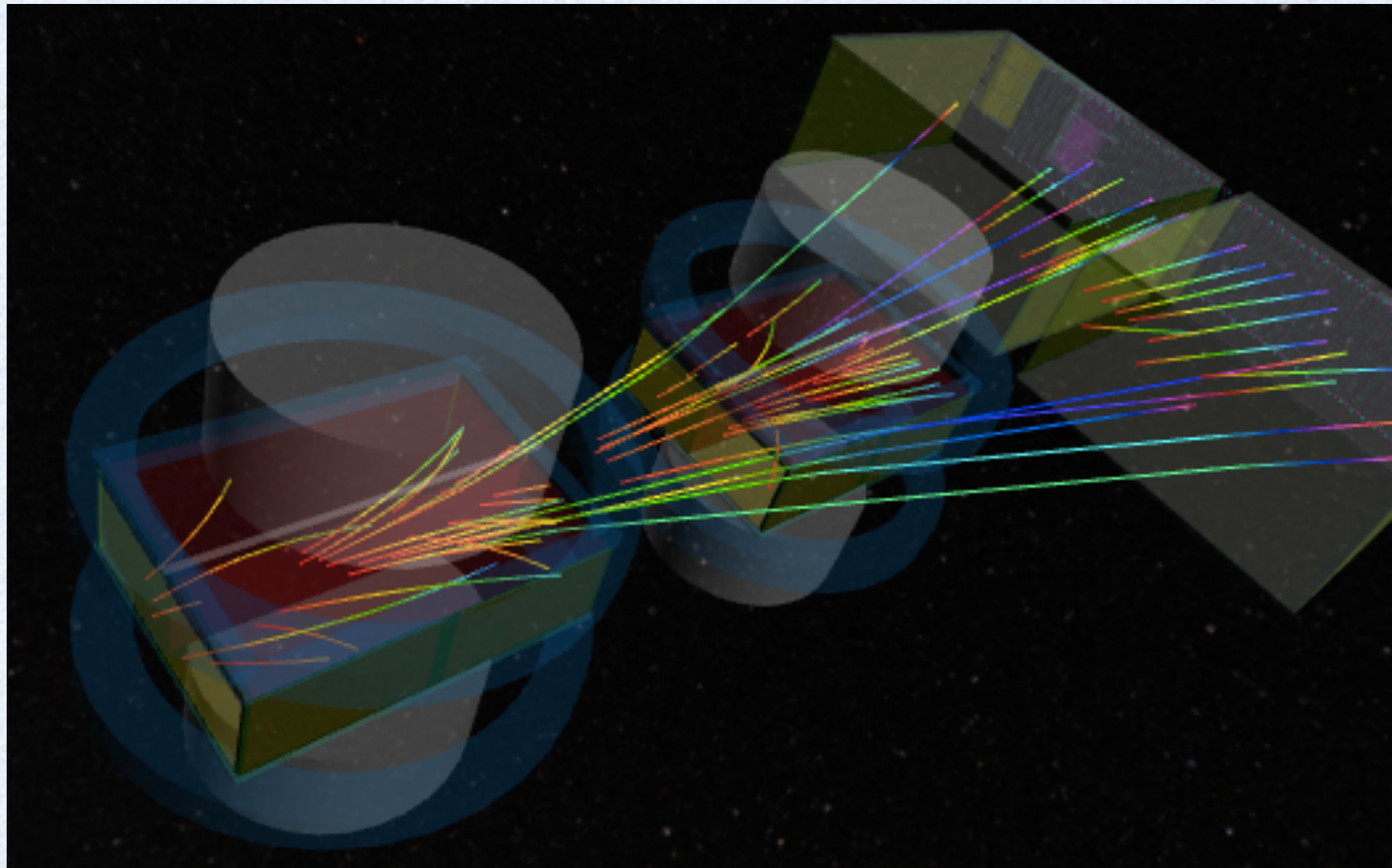
DUNE Collaboration Spectrometer Pre-Meeting, May15, 2017

NA61/SHINE @ CERN

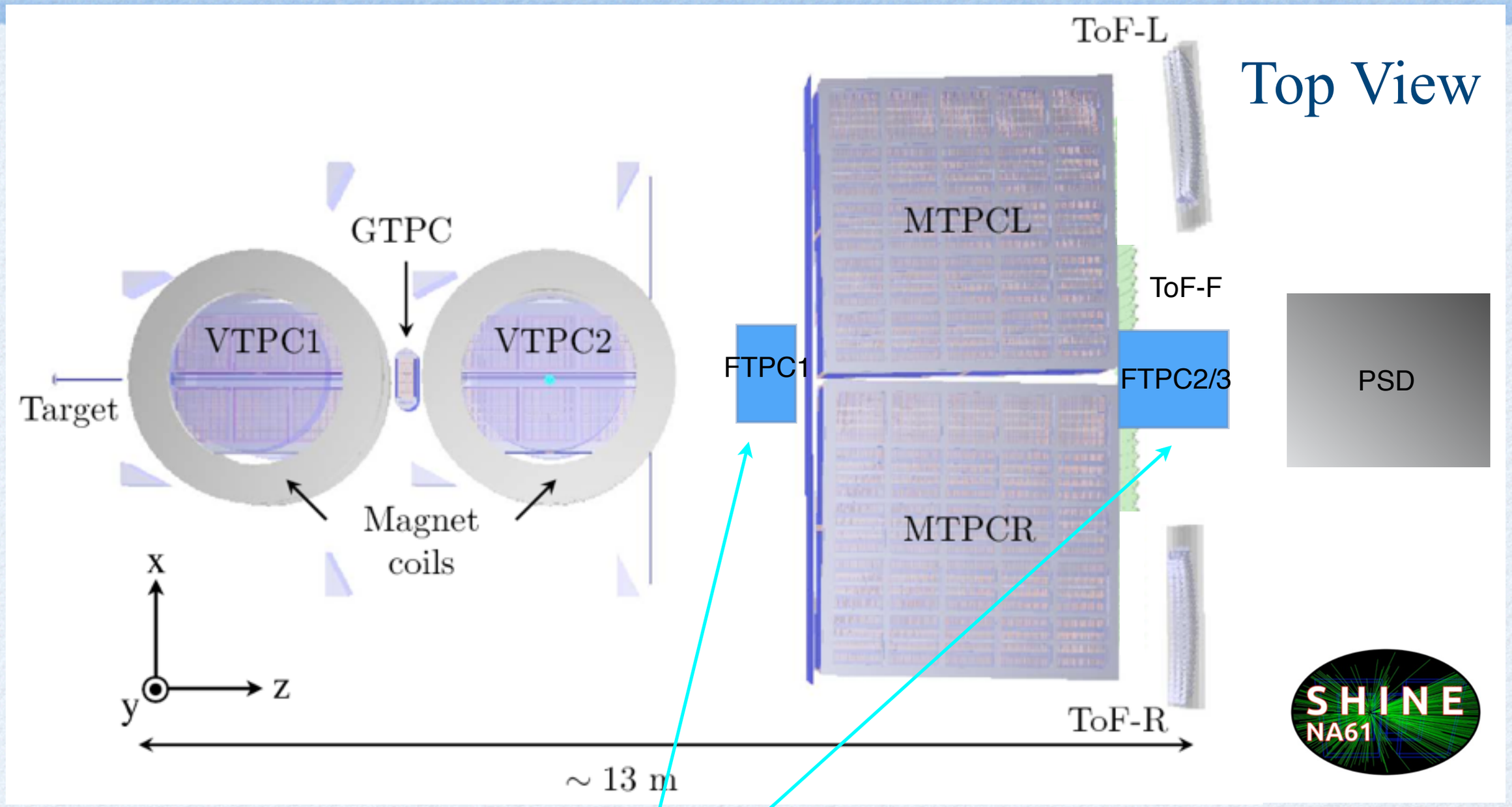
- **S**PS **H**eavy **I**on and **N**eutrino **E**xperiment located in the North Area at CERN
  - Fixed target experiment
  - Primary 400 GeV/c proton beam, Secondary beams from ~26A to 160A GeV/c

- Rich physics program includes
  - heavy ion physics
  - hadron production for neutrino beams
  - cosmic ray production

A π^+ + C event



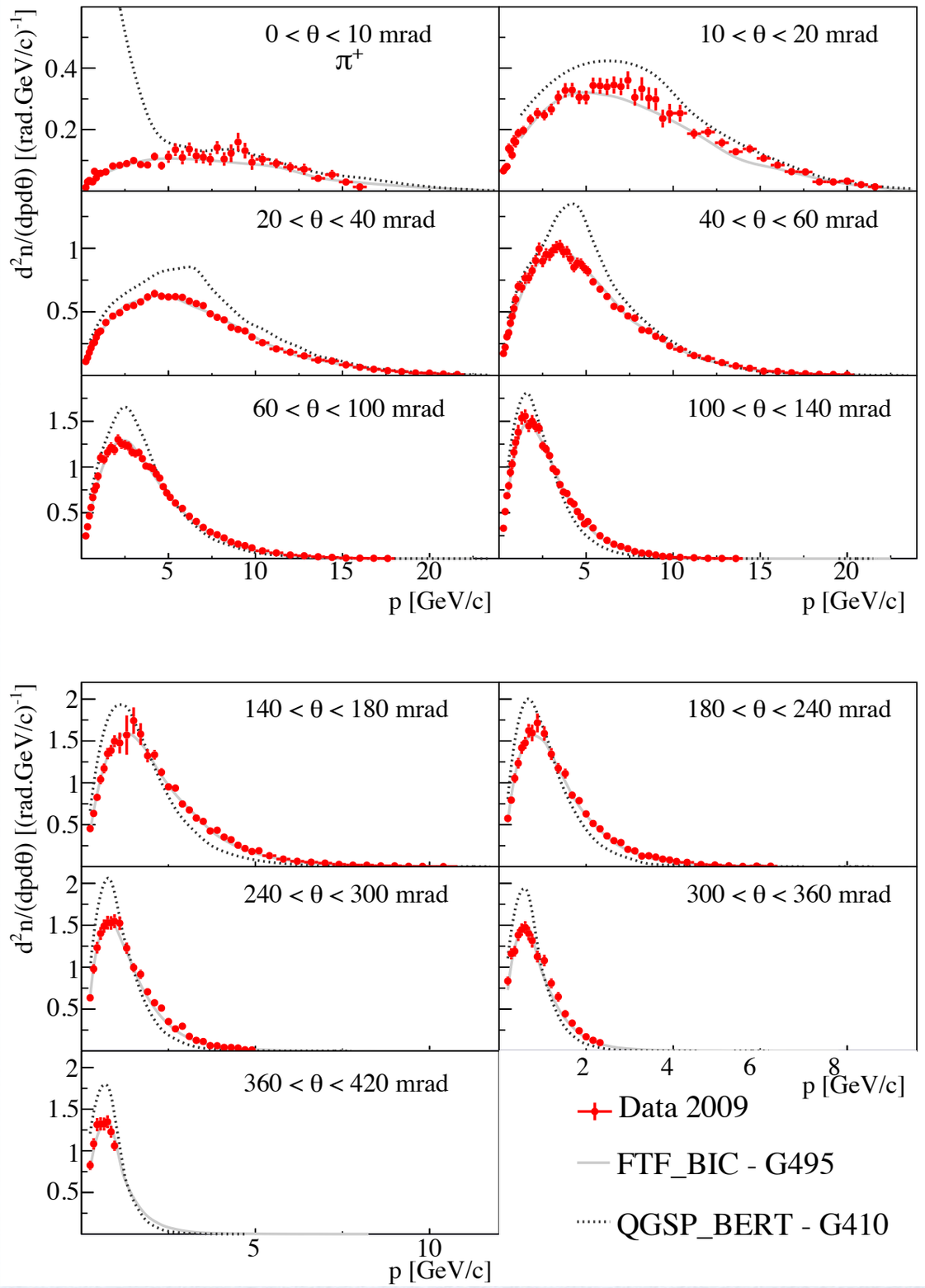
NA61/SHINE Detector



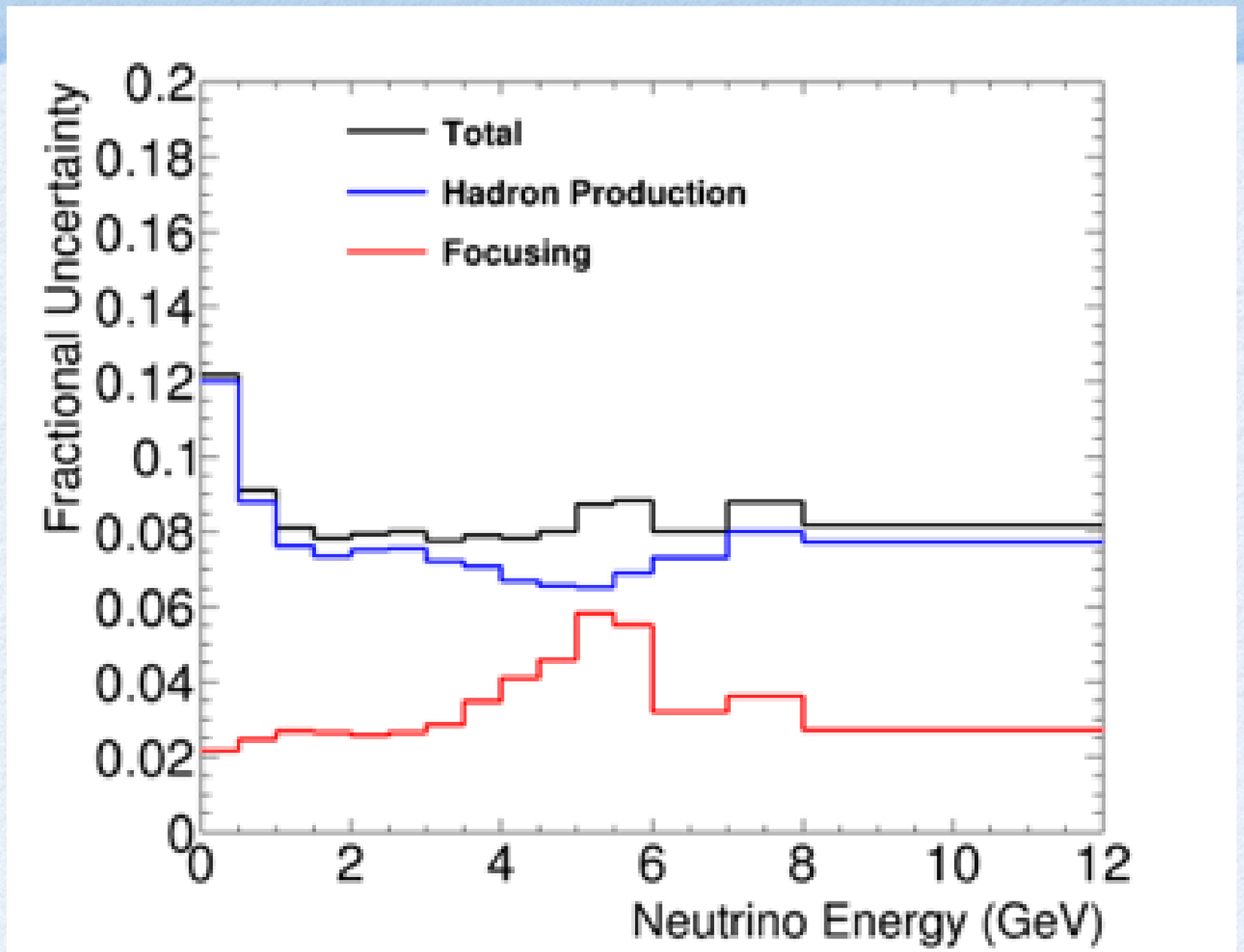
- Comprises several large acceptance TPCs, first two inside magnets
- In summer 2017 Adding two new TPCs in forward direction
  - Allows for better tracking and dE/dx separation for forward particles

NA61/SHINE and T2K

- NA61 Has made a number of measurements of **31 GeV/c protons** on **thin** and **full-scale replica** carbon targets that are highly relevant for T2K, including
  - Eur.Phys.J. C76 (2016) no.2, 84 (Thin C target measurements of π,κ,Λ,p production)
  - Eur.Phys.J. C76 (2016) no.11, 617 (π yields from T2K replica target)
- Thin target π uncertainties ~5%, K uncertainties 10%; current full target π uncertainties ~4% in most bins



Estimated DUNE Flux Uncertainty

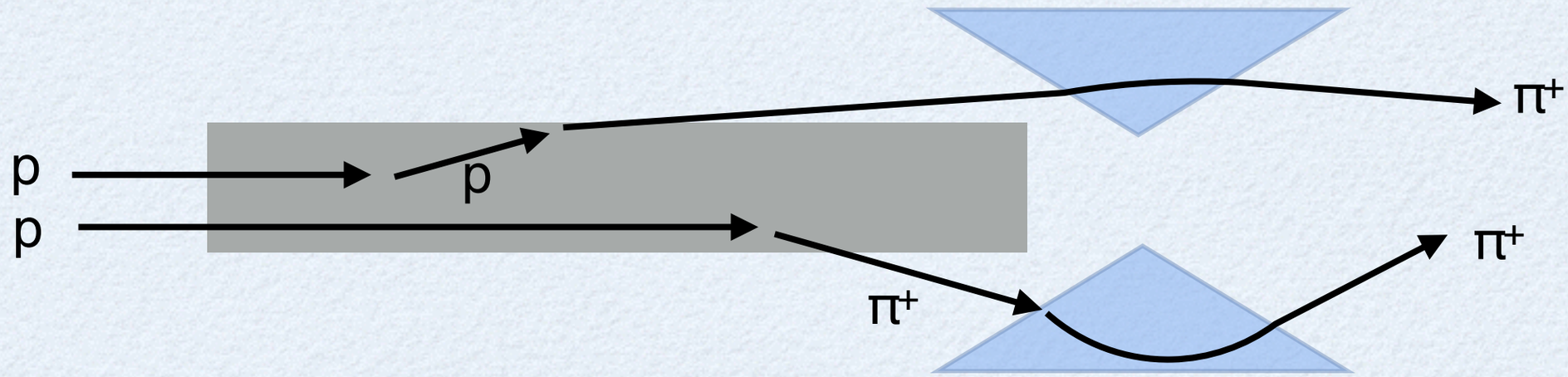


L. Fields, DUNE Collab Meeting, Sept 2016

- Dominated at low energies by π/K reinteractions and p interactions not covered by existing data, and at medium energy by uncertainties on existing pion production data

NA61/SHINE and DUNE

- Effort in the US to make a suite of measurements of hadron production at energies and on targets relevant for DUNE and other Fermilab experiments
  - Measure primary 60-120 GeV/c proton interactions on potential target materials (graphite and Be) from
  - Measure interactions of secondary pions and kaons from 30-60 GeV/c on target and horn materials (graphite, Be, and Al)



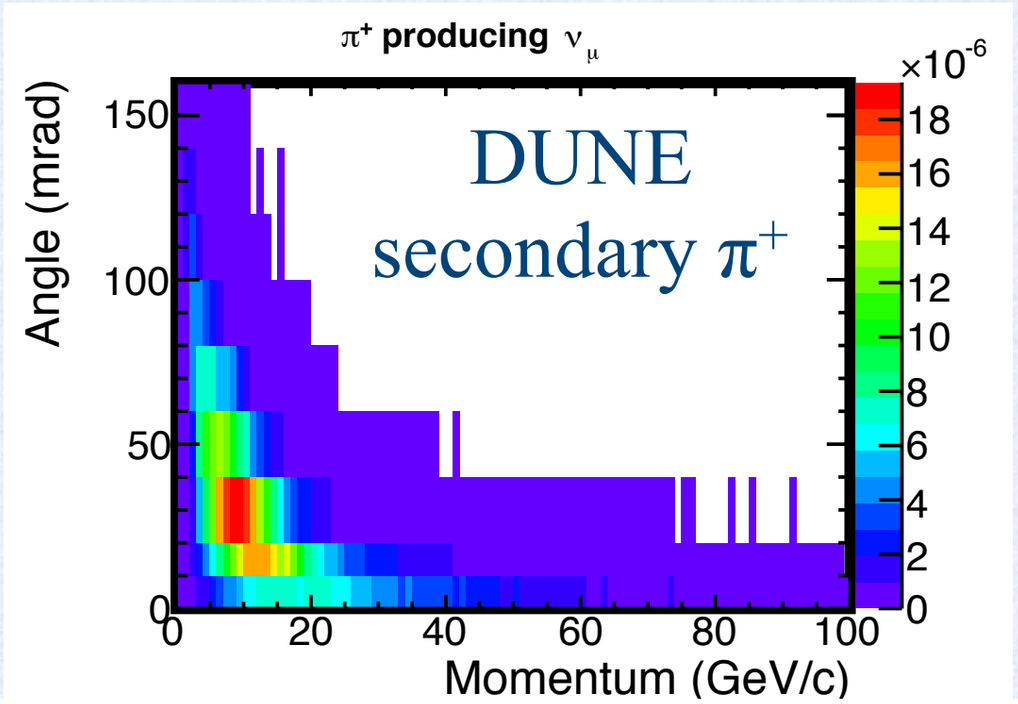
US NA61

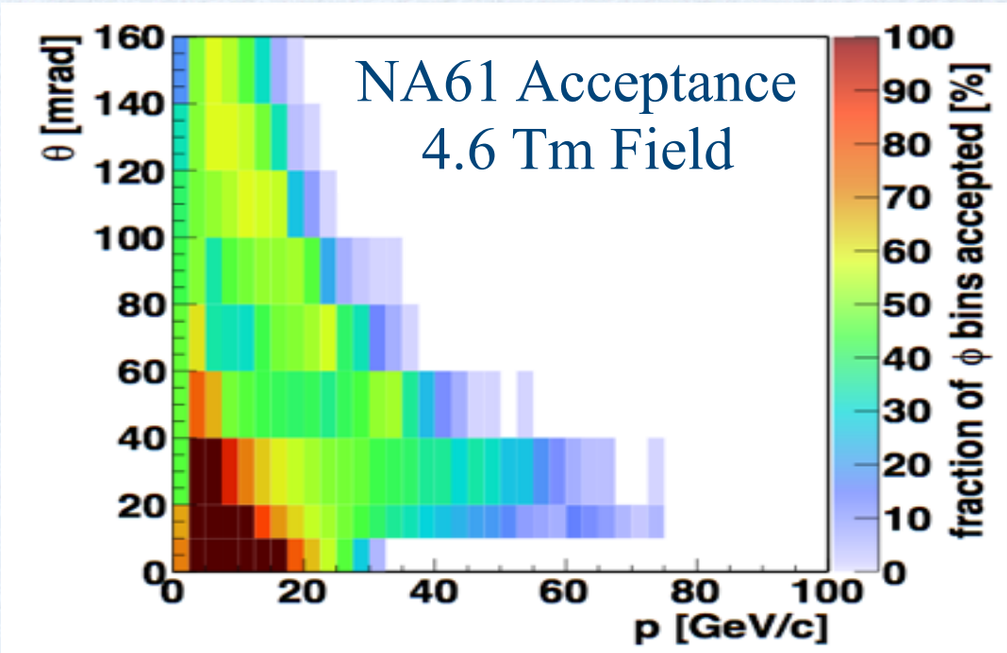
- University of Colorado: Scott Johnson, Alysia Marino, Yoshikazu Nagai, Brant Rumberger, Eric Zimmerman
- Fermilab: Alberto Marchionni
- Los Alamos National Laboratory: Geoff Mills
- University of Pittsburgh: Christian Farina, Ben Messerly, Vittorio Paolone, Athula Wickermansinghe

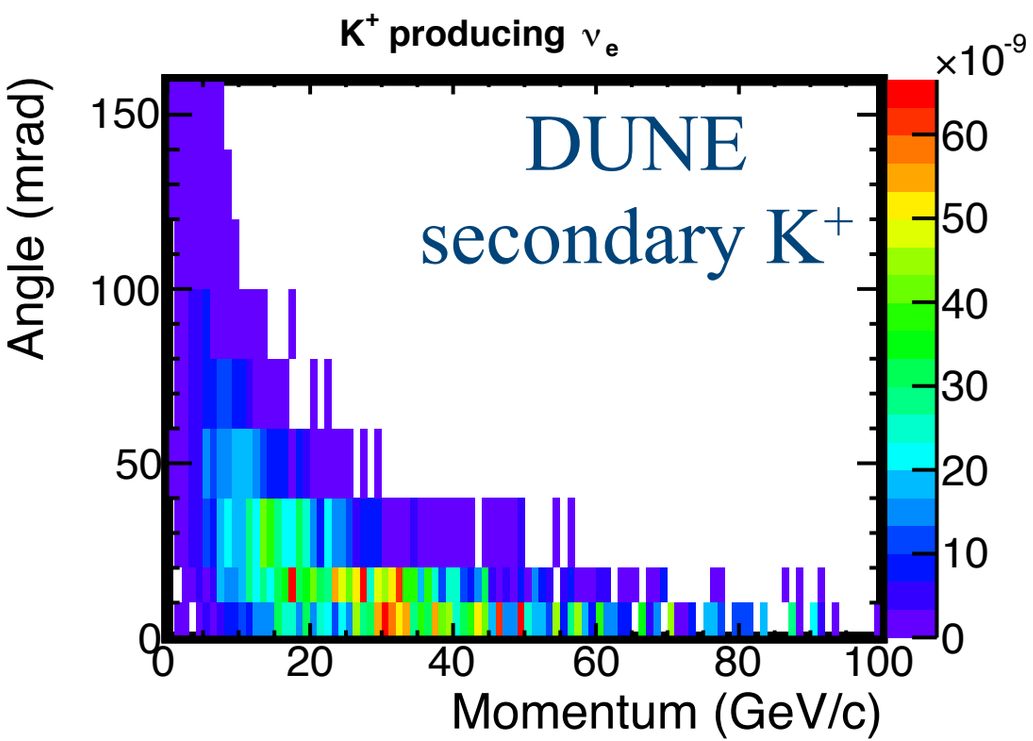
Secondaries in DUNE

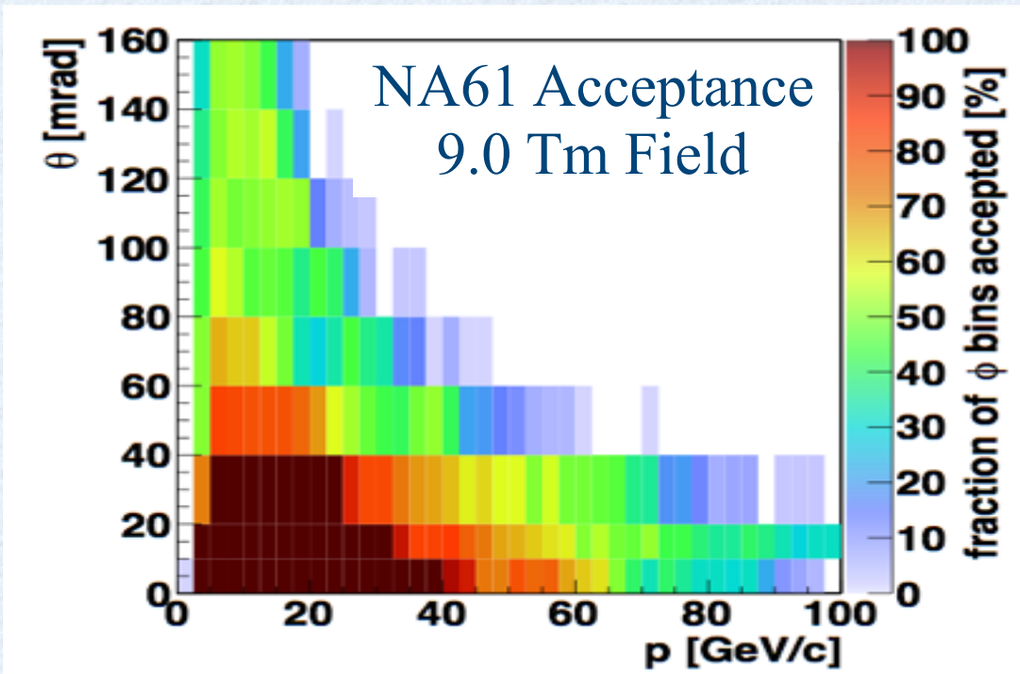
- DUNE secondaries are well-matched to NA61 acceptance

120 GeV Reference Beam









Data Sets Taken for Fermilab ν Experiments 2012-2016

Data Type	Year	triggers	Detector
p + C @ 120 GeV/c	2012	1M, 2.8M	No magnets, No VTX1 magnet
π^+ + C @ 31GeV/c	2015	745k	No magnets
π^+ + Al @ 31GeV/c	2015	565k	No magnets
p + C @ 31GeV/c	2015	388k	No magnets
π^+ + C @ 60GeV/c	2015	577k	No magnets
π^+ + Al @ 60GeV/c	2015	535k	No magnets
K^+ + C @ 60GeV/c	2015	506k	No magnets
K^+ + Al @ 60GeV/c	2015	339k	No magnets

- Can't measure spectra, but will measure overall production cross section from these datasets. Analysis in progress for most of these.

Running in 2016

- Magnet repaired in May 2016.

Data Type	triggers	Comment
p + C @ 120 GeV/c	4.3 M	Fall 2016, with magnets
p + Be @ 120 GeV/c	2.2 M	Fall 2016, with magnets
p + C @ 60 GeV/c	2.9 M	Summer 2016, with magnets
p + Al @ 60 GeV/c	3.2 M	Fall 2016, with magnets
p + Be @ 60 GeV/c	2.1M	Fall 2016, with magnets
π^+ + C @ 60GeV/c	4.2 M	Fall 2016, with magnets
π^+ + Be @ 60 GeV/c	2.6	Fall 2016, with magnets

Running in 2017-18

5.5 Weeks of running approved this fall. Will make a similar request for 2018. Additional thin target running under consideration:

- Run 120 GeV p+C and p+Be with new FTPCs
- 90 GeV p+C
- 60 GeV π^+ + Al
- 30 GeV π^+ + C , (TOFs)
- 60 GeV π^- + C
- 60 GeV K^+ + C

In 2018, possibly NOvA replica target

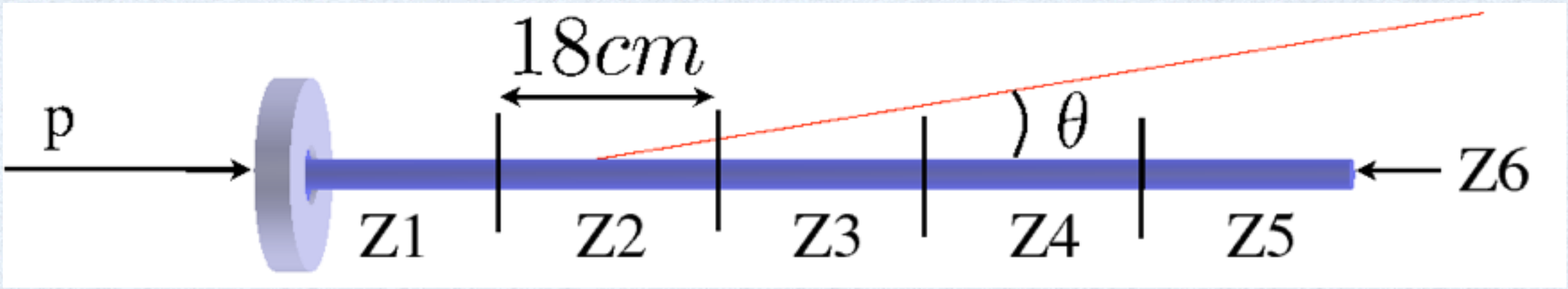
Beyond 2018

- No beam for SPS in 2019 or 2020 (LHC Long Shutdown #2)
- NA61/SHINE is formulating a plan for running after 2020
- If available in 2021 or 2022, prototype targets for the LBNF beam might make sense

Long Target Running

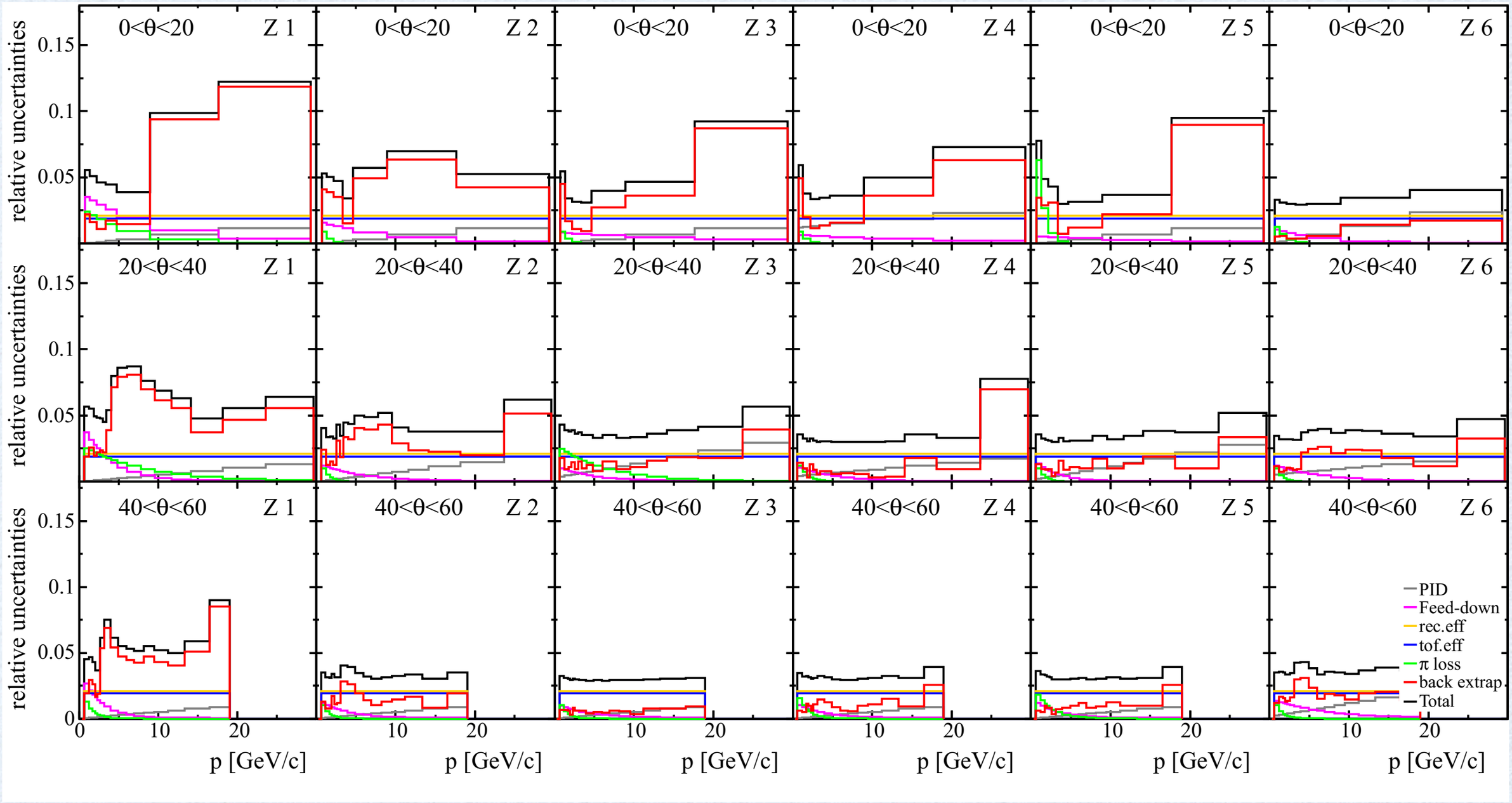
- T2K Long target data on π^{+-} published in Eur.Phys.J. C76 (2016) no.11, 617
- Update with more statistics and more species coming later this summer

T2K Replica Target Binning



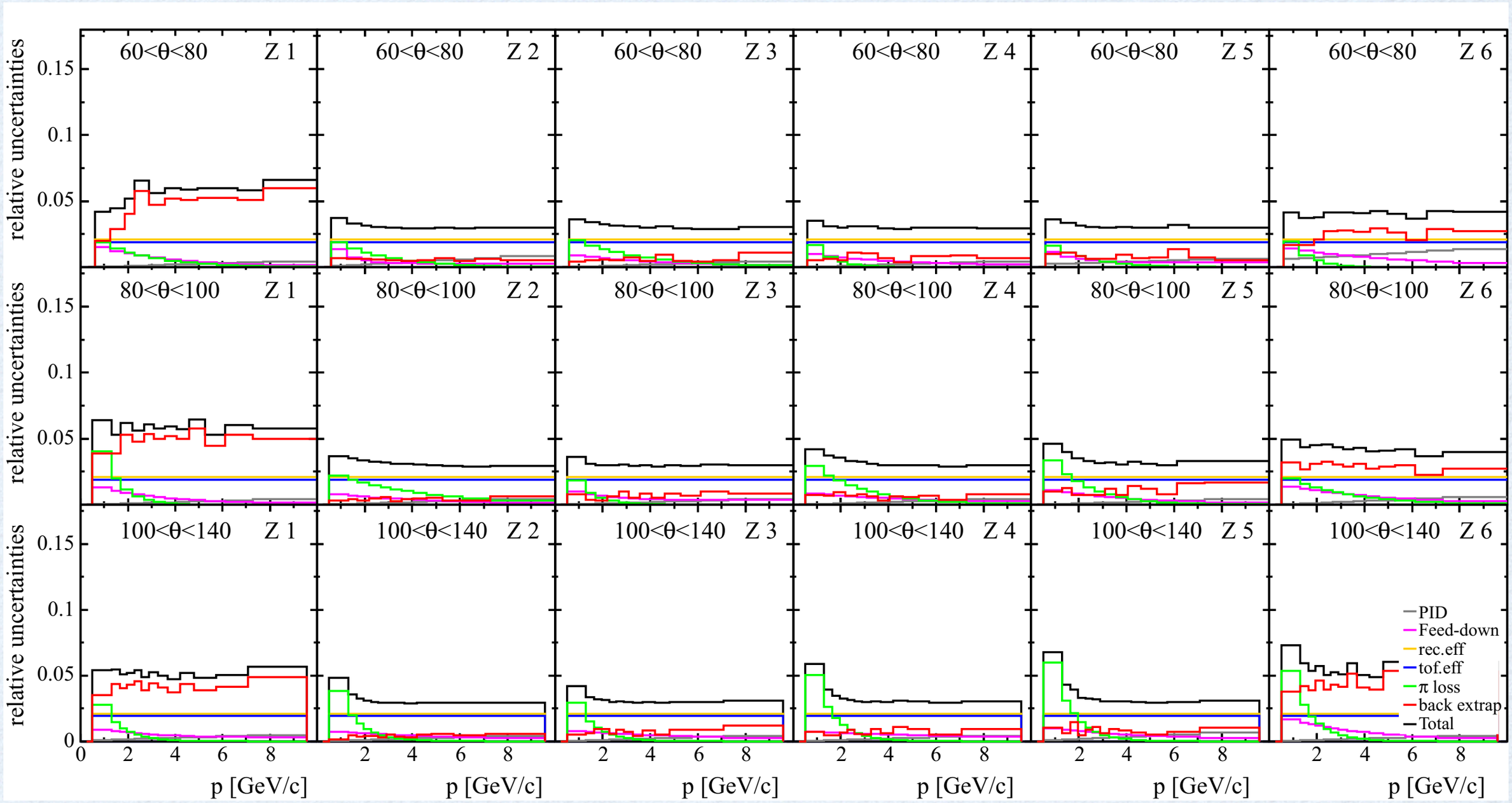
- T2K target is 90 cm long (1.9 nucl. int. lengths)
- 6 bins: 1-5 are 18 cm slices of target, last bin is the downstream face
- Track extrapolated backward to determine where it exited target. Point of closest approach used if no intersection and within 1σ of target surface

Systematics 0 - 60mrad



- Backward extrapolation (red) dominates in most upstream bin, up to 10% at small angles

Systematics - 60-140 mrad



- Smaller effect at larger angles, but backward extrap still dominates upstream bins

DUNE long target

- For a 2-m long DUNE target, backward extrapolation likely to be a serious issue.
- Will likely need to run with target at least partially inserted into vertex TPC1
- Will soon begin MC studies to understand acceptances in this configuration

NA61 BEYOND 2020

Future Physics Opportunities with the NA61/SHINE Spectrometer

July 26-28, 2017

UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES
Section de physique

https://indico.cern.ch/event/629968/

SHINE
NA61

Summary

- NA61/SHINE experiment at CERN is taking thin target data of hadron production that is highly relevant for the LBNF beamline
- Currently focussed on thin target measurements, to be as flexible as possible for future target options
- Beyond 2020, the biggest impact could be from DUNE replica targets.

Backup

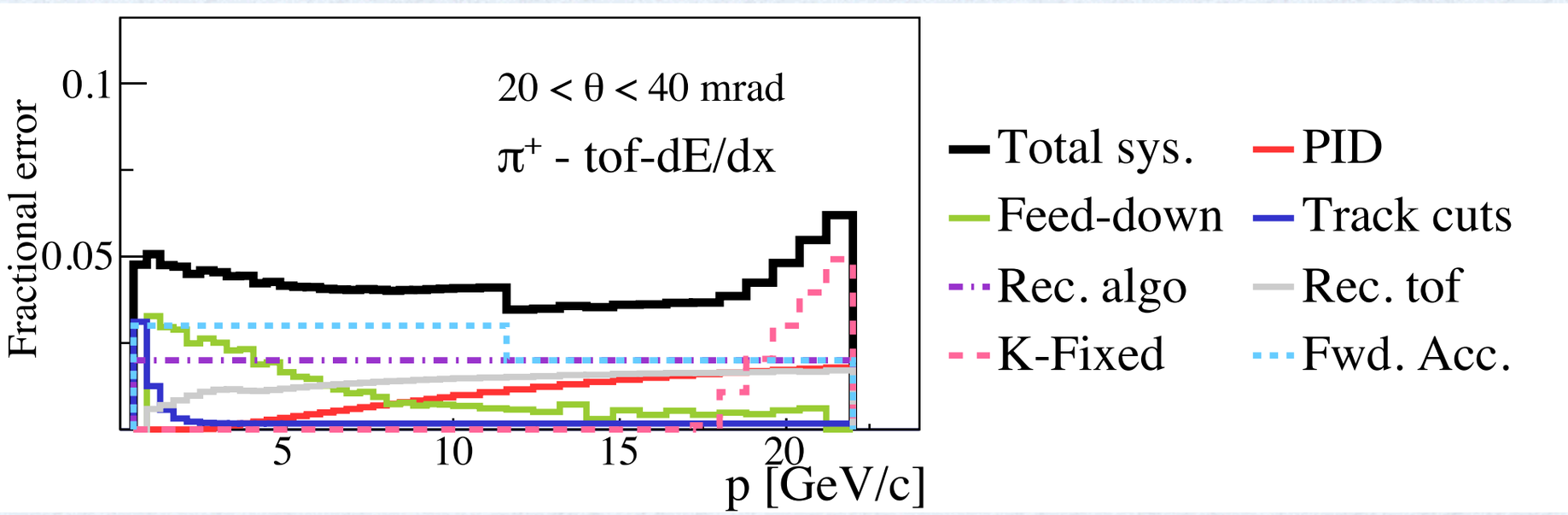


Fig. 16: (Colour online) Breakdown of systematic uncertainties of π^+ spectra from the *tof*-dE/dx analysis, presented as a function of momentum for the [20,40] mrad angular interval.

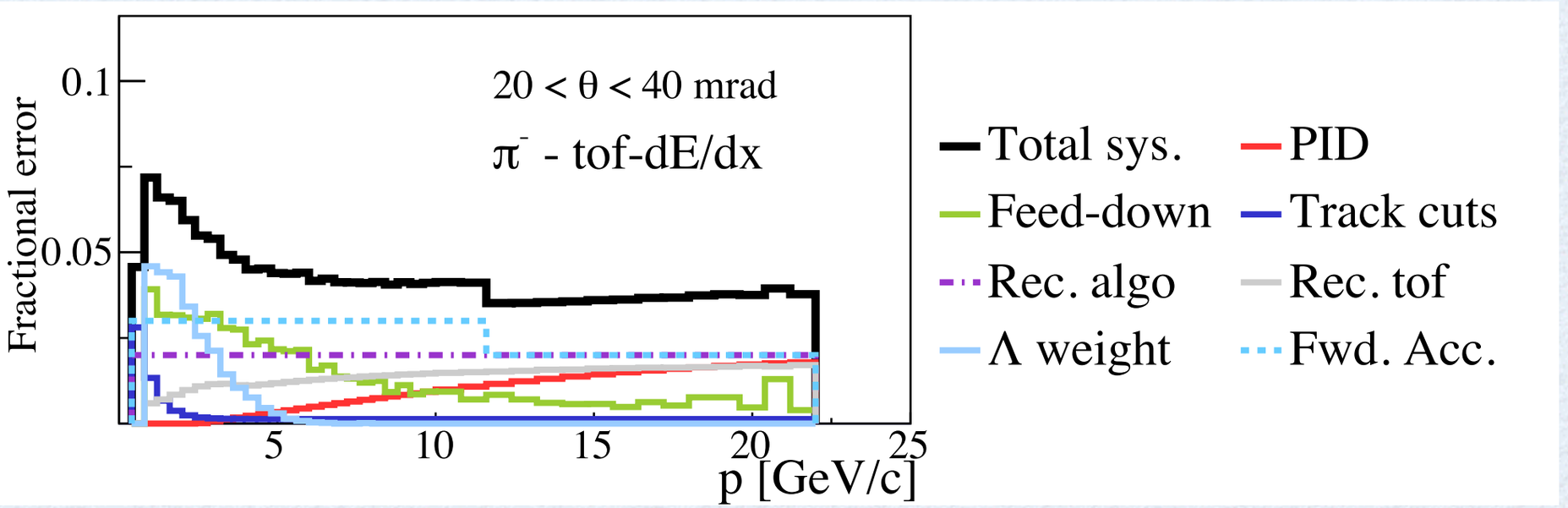


Fig. 17: (Colour online) Breakdown of systematic uncertainties of π^- spectra from the *tof*-dE/dx analysis, presented as a function of momentum for the [20,40] mrad angular interval.

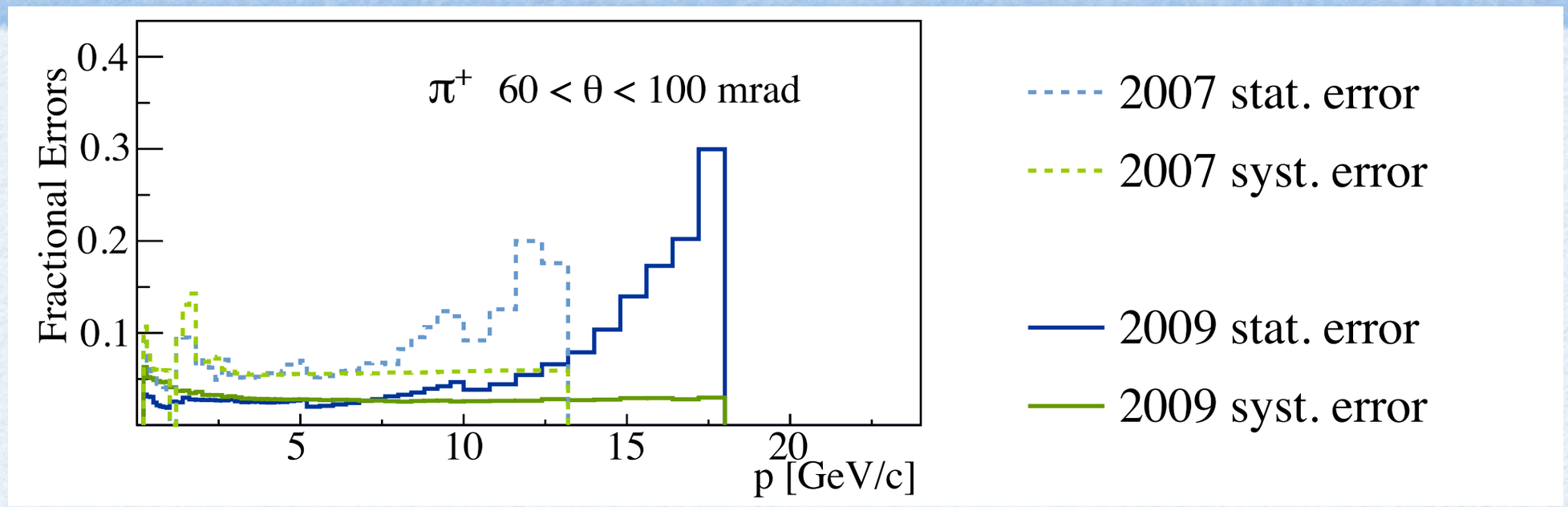


Fig. 24: (Colour online) Comparison between NA61/SHINE statistical and systematic uncertainties obtained using the 2007 [5 the 2009 datasets in a selected angular interval [60,100] mrad for π^+.

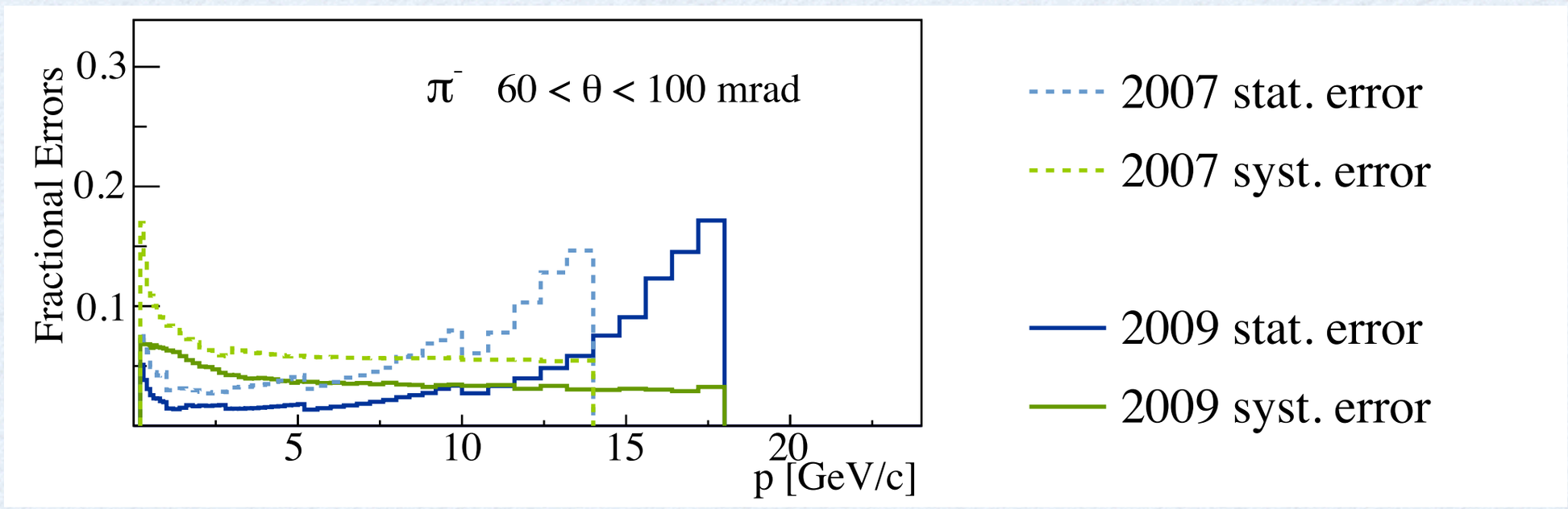


Fig. 25: (Colour online) Comparison between NA61/SHINE statistical and systematic uncertainties obtained using the 2007 [5 the 2009 datasets in a selected angular interval [60,100] mrad for π^-.