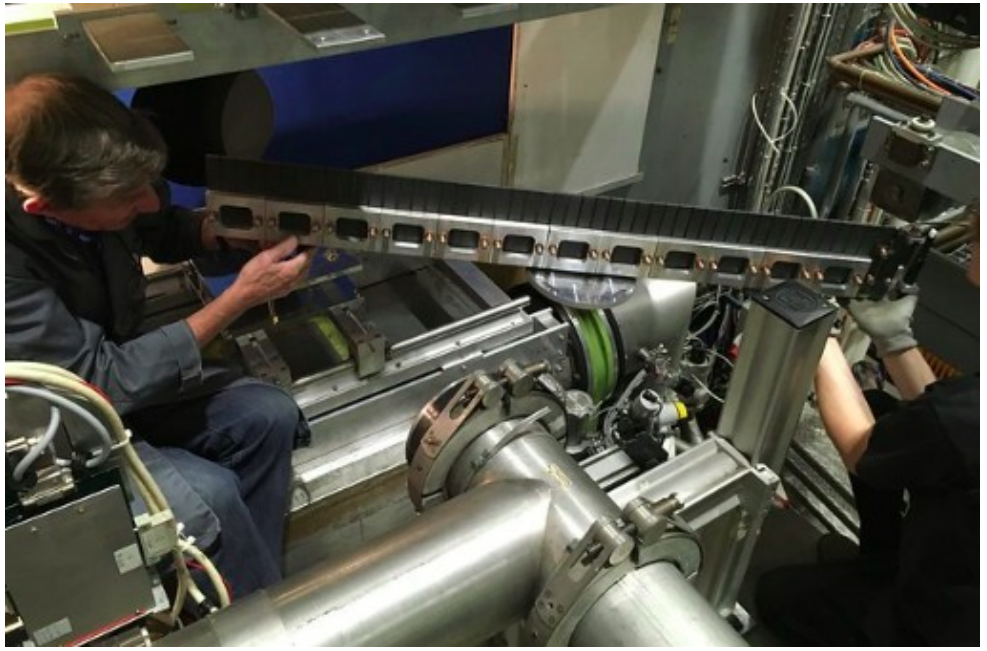
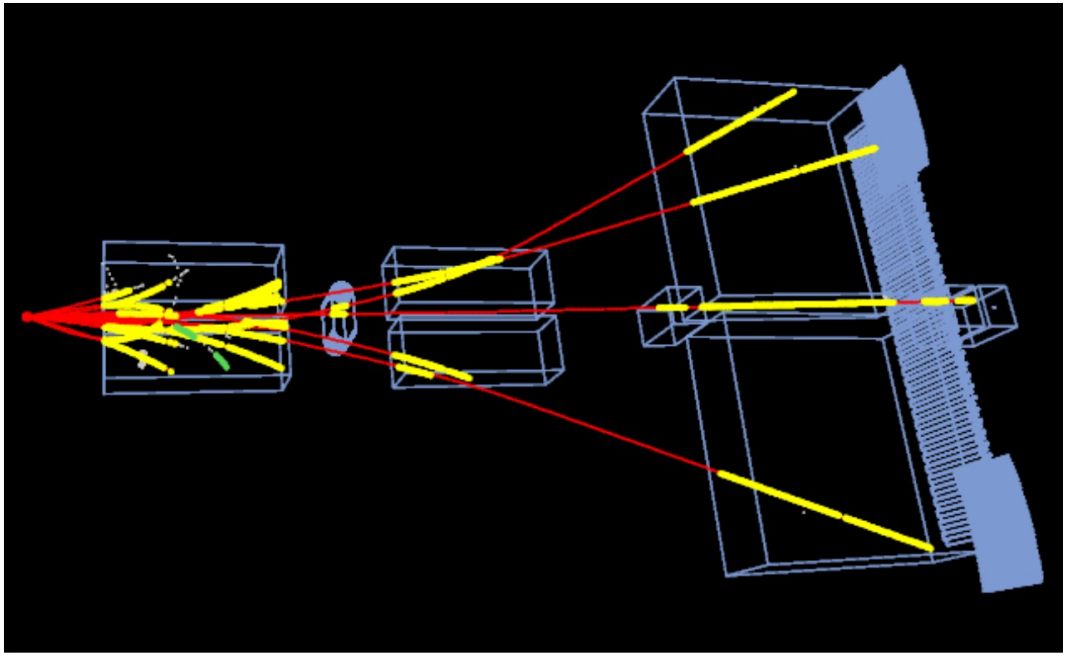
Hadron Spectra Analysis for Neutrino Experiments





Brant Rumberger
University of Colorado Boulder

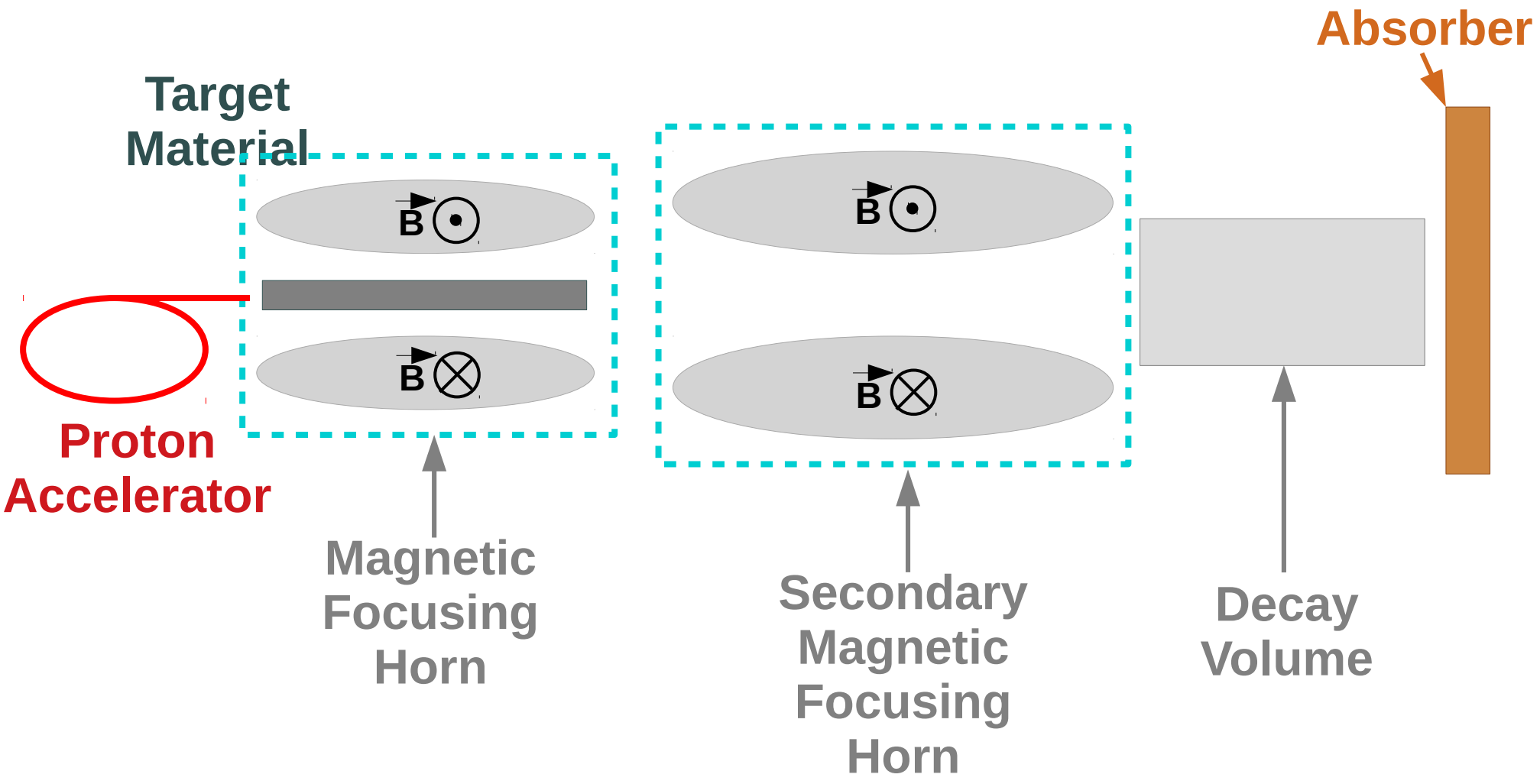
NA61 Autumn School
10/28/20

Overview

- Neutrino Beam Creation
- Reducing Neutrino Beam Flux Uncertainties
- Charged Hadron Yields & PID via dE/dx

Neutrino Beam Creation

(Two-horn configuration)



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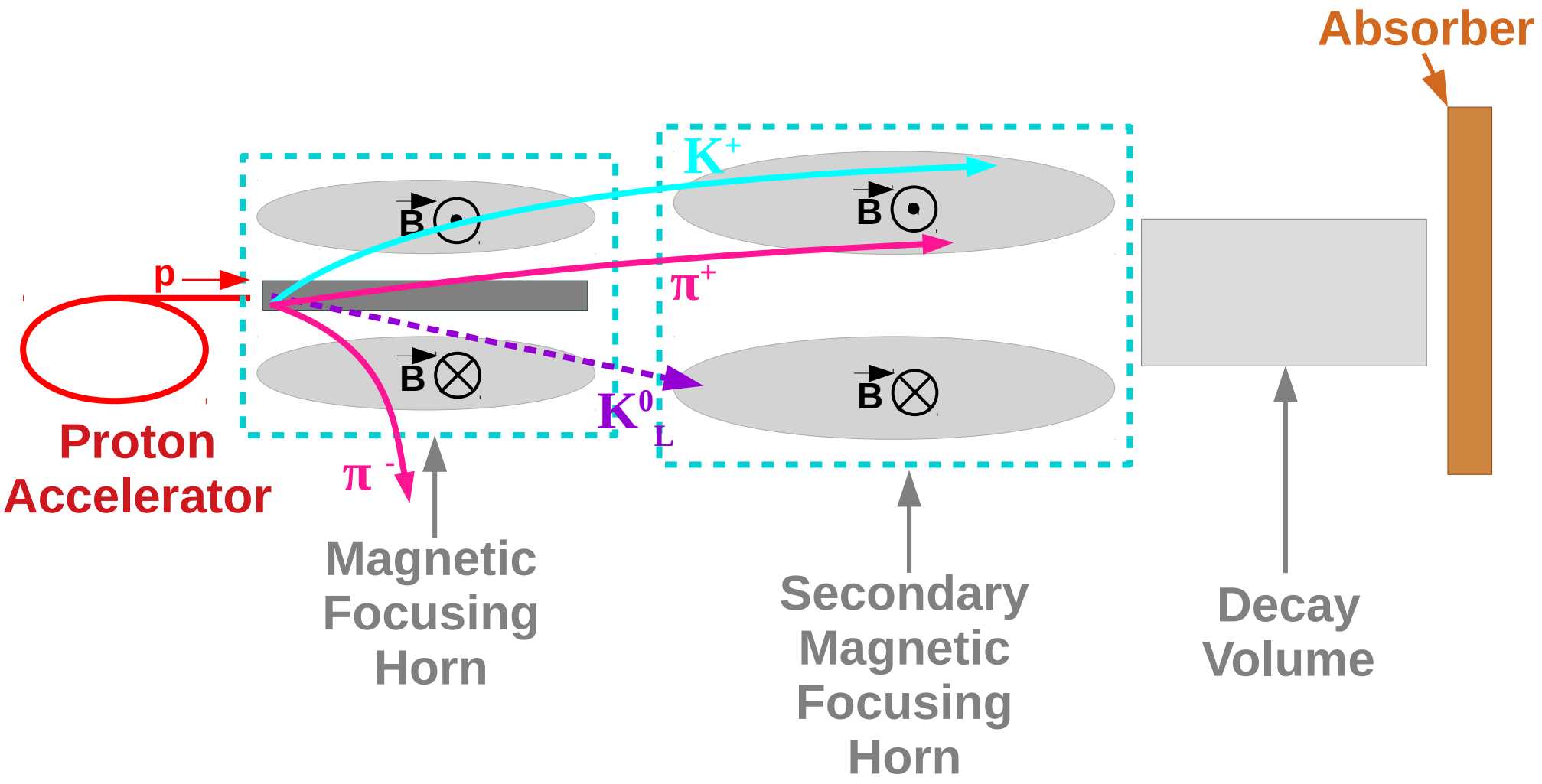

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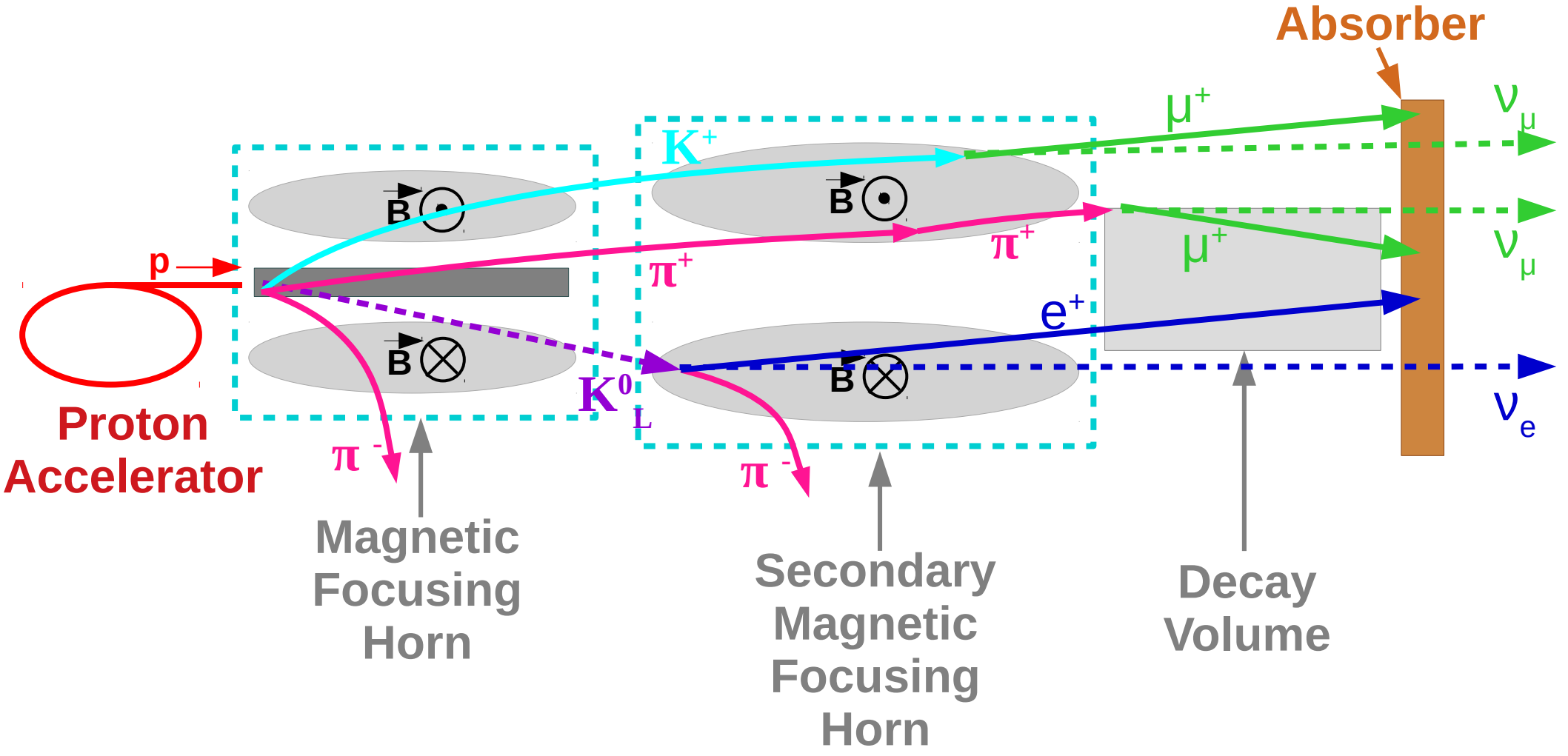

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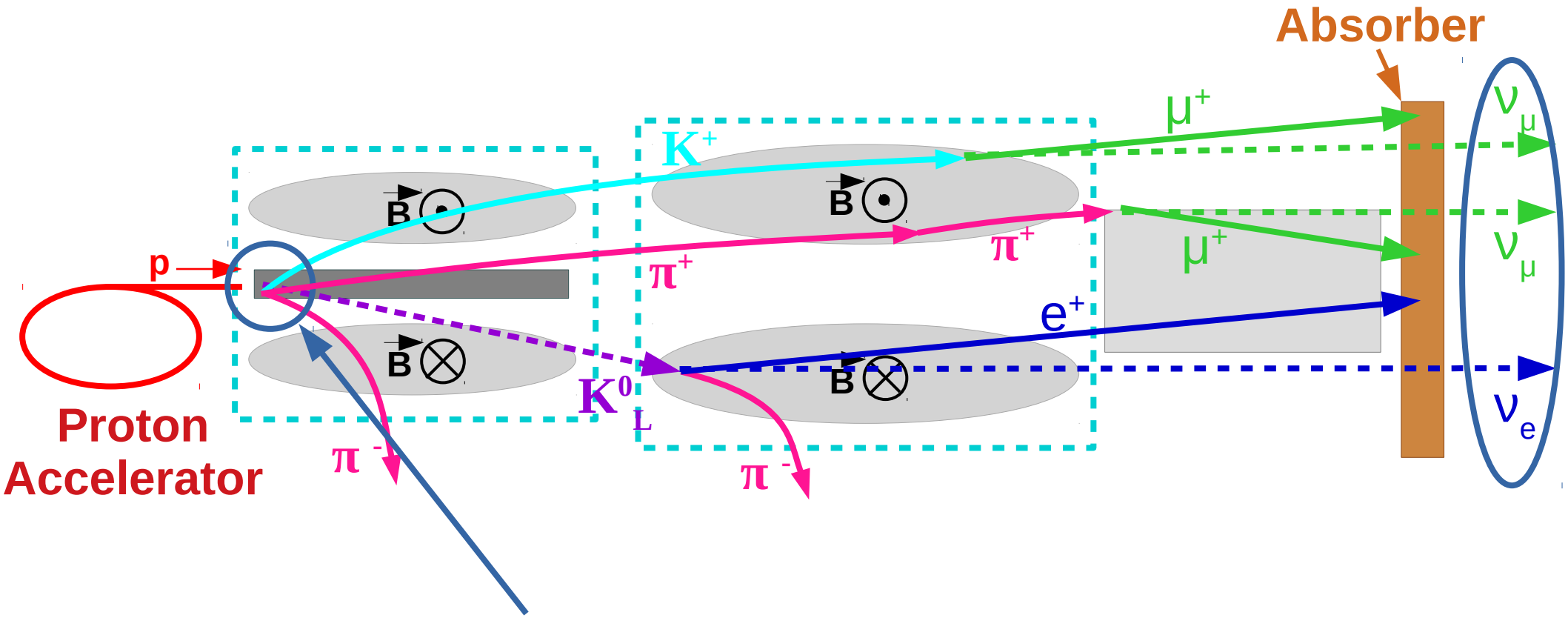
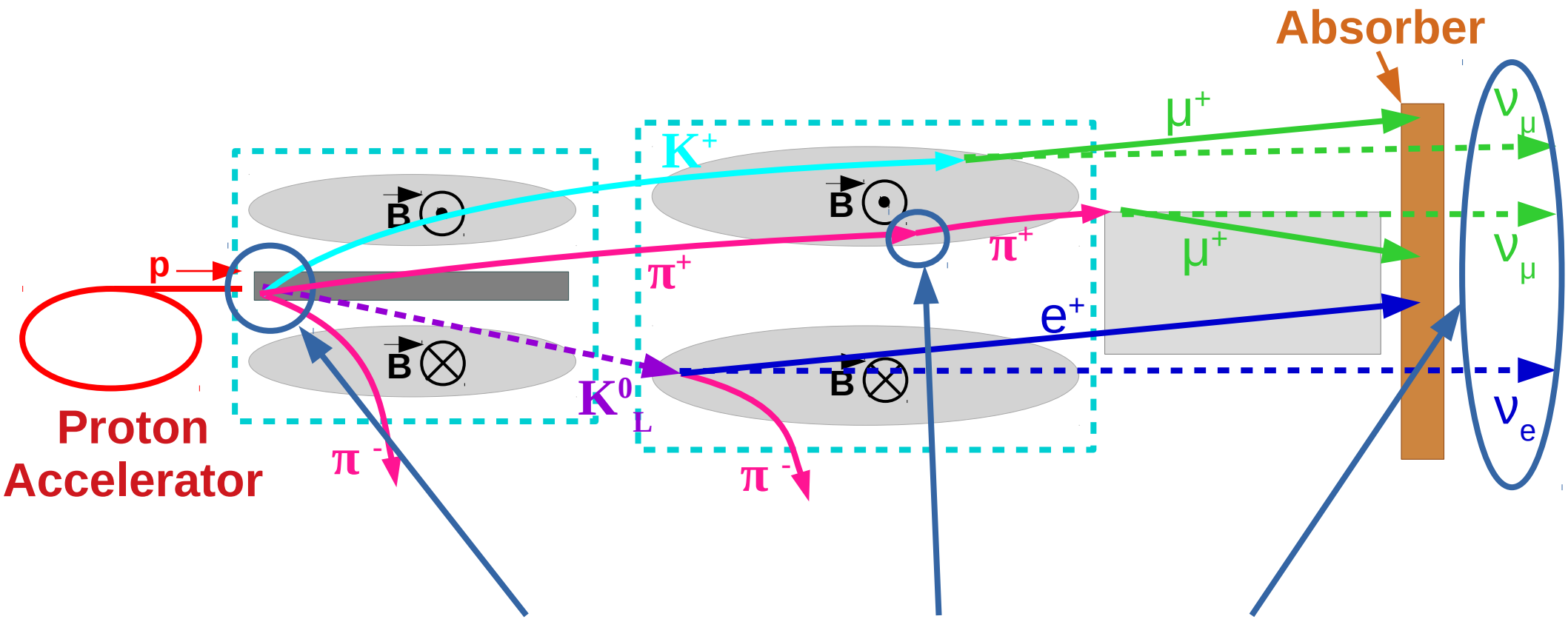


Neutrino beam content depends on initial hadron production in target

Neutrino Beam Flux Uncertainties

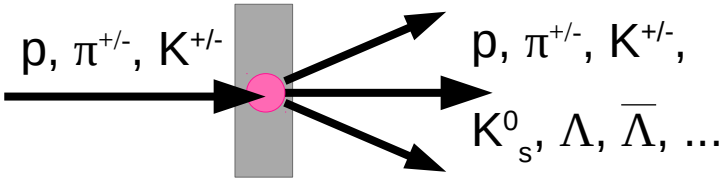


Neutrino beam content depends on primary & secondary hadron production in target & horns

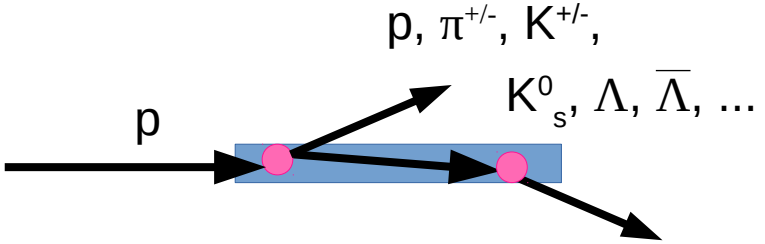
No constraint data:
Large uncertainty!

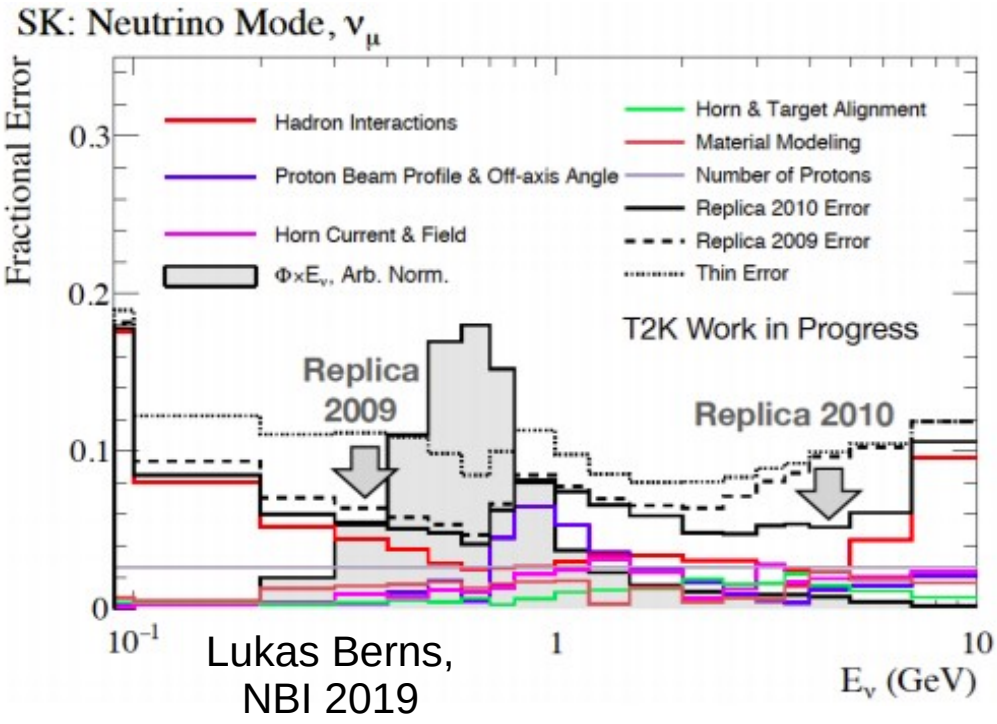
Reducing Flux Uncertainty: Hadron Production Measurements

Thin-Target Measurements



Replica-Target Measurements





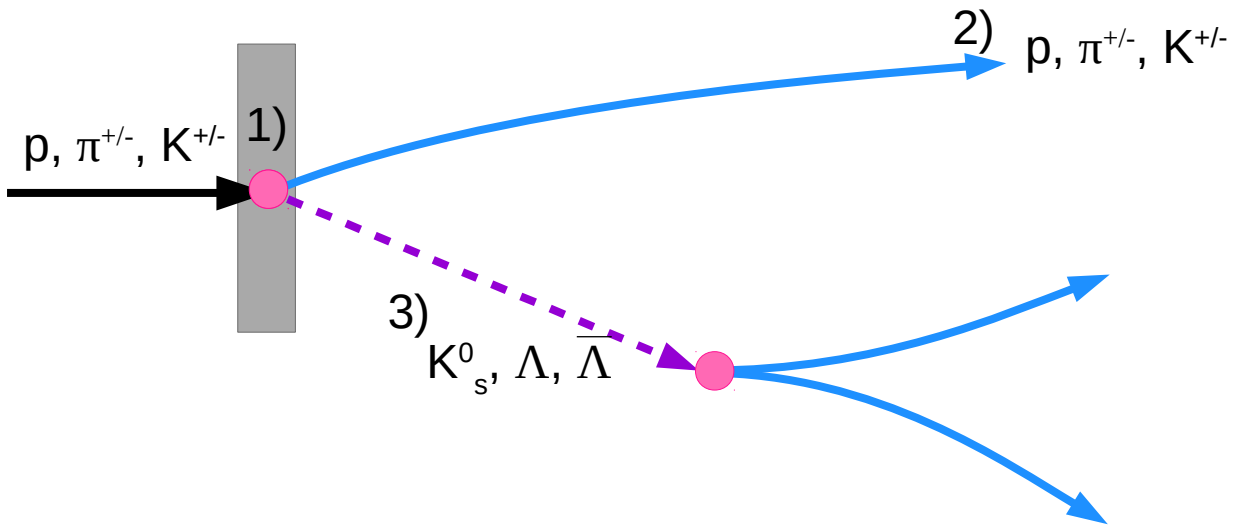
Lukas Berns, NBI 2019

Beam reactions:

- T2K: 30 GeV/c protons on carbon
- NuMI: 120 GeV/c protons on carbon

Thin Target Analyses

1) Total / inelastic / production cross-sections
2) Charged hadron yields
3) Neutral hadron yields



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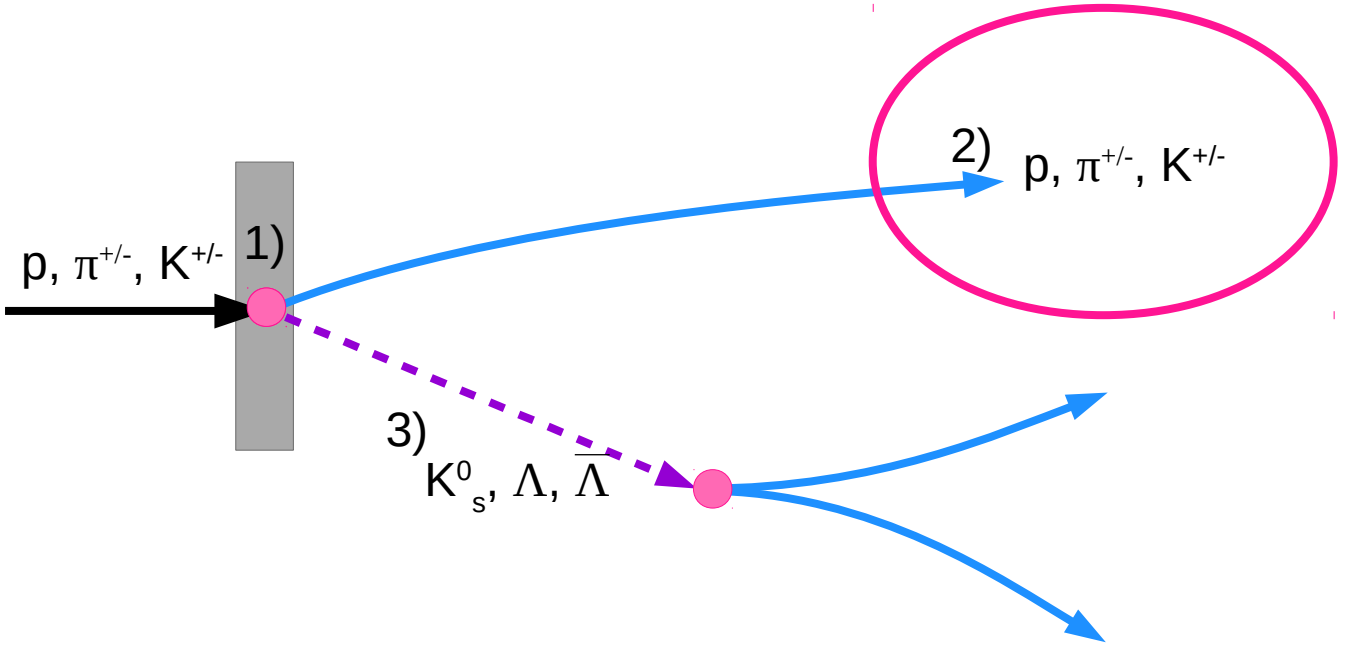
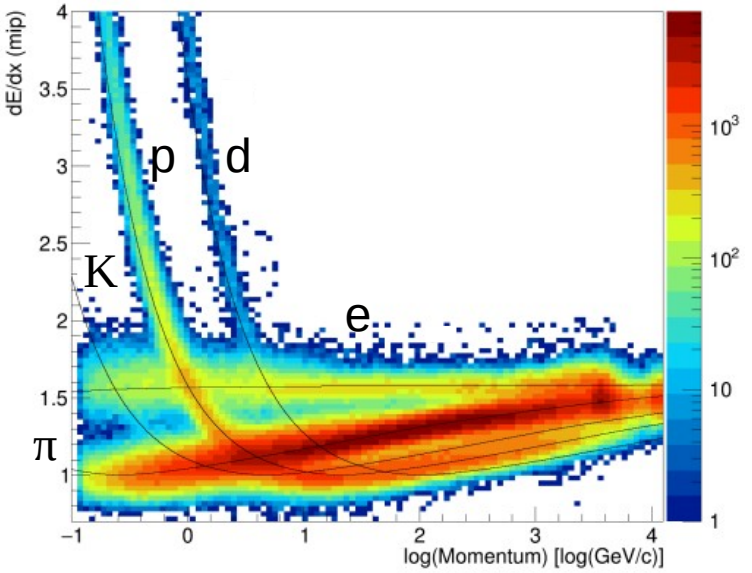
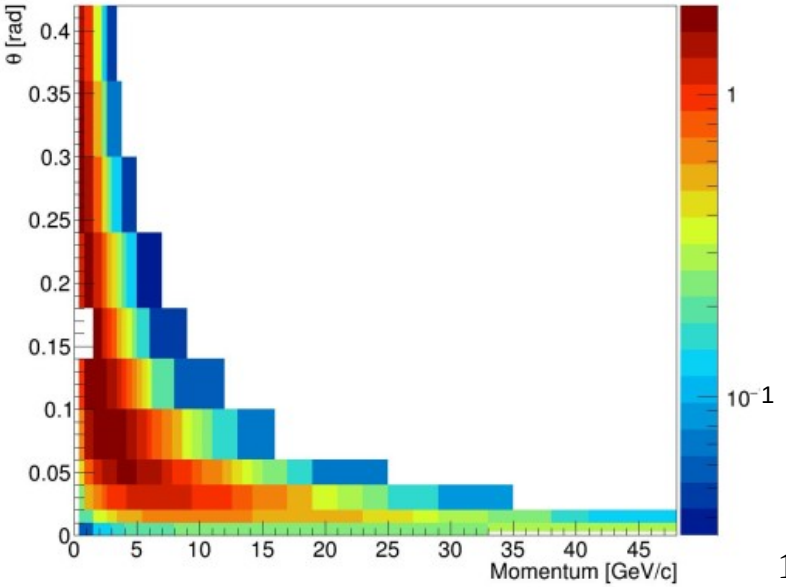


Charged Hadron Yield

- Doubly-differential particle species yield as a function of phase space
- ID of produced particles obtained using track momentum & dE/dx
- Charged tracks binned for analysis
- dE/dx fit performed in each bin
- Resulting multiplicities obtained for [p,θ] bins
- Used to improve hadron production models

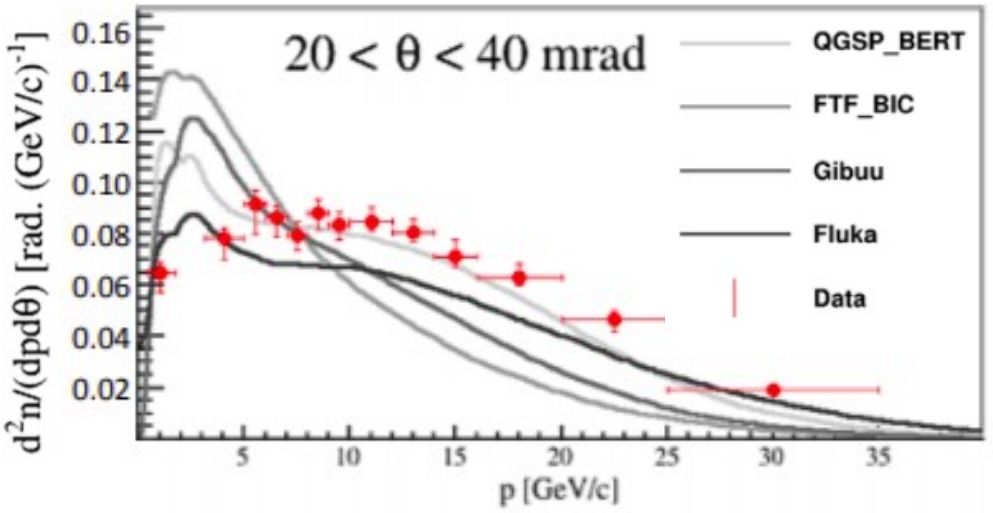


π^+ Yield: π^+ C, 60 GeV/c



S. Johnson, Ph.D Thesis, 2019

Produced Protons



Phys. Rev. D100, 112004 (2019)

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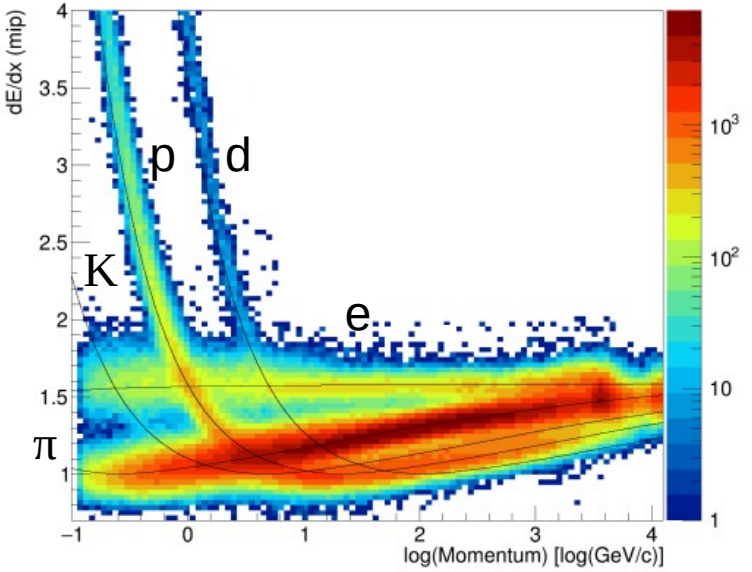

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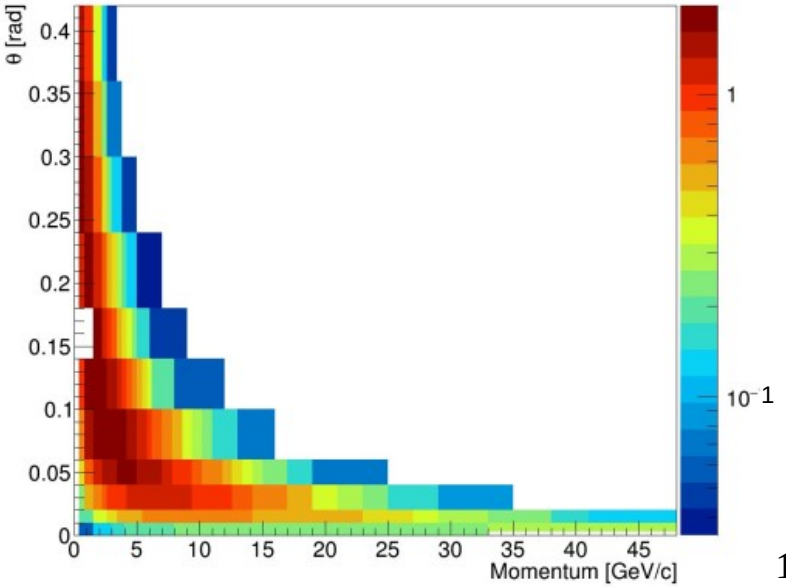

S. Johnson, Ph.D Thesis, 2019

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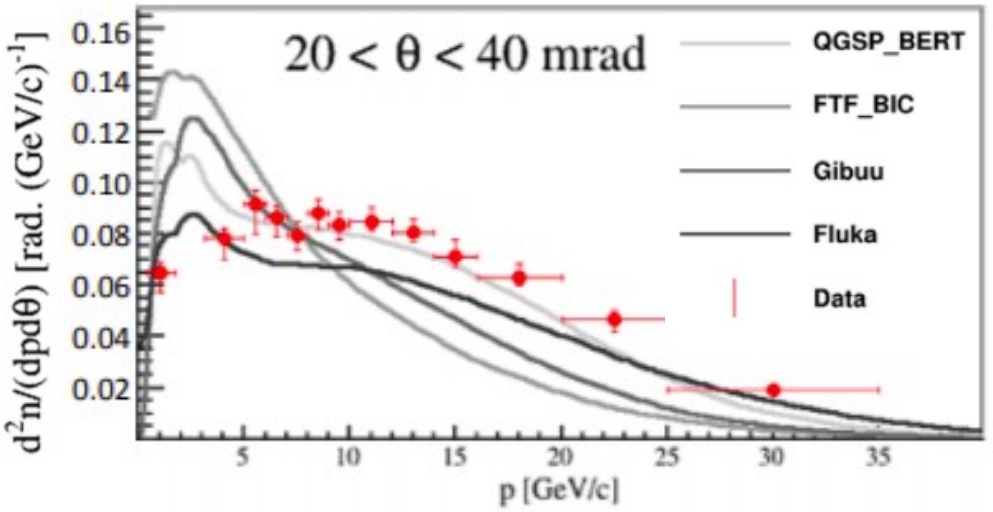


Phys. Rev. D100, 112004 (2019)

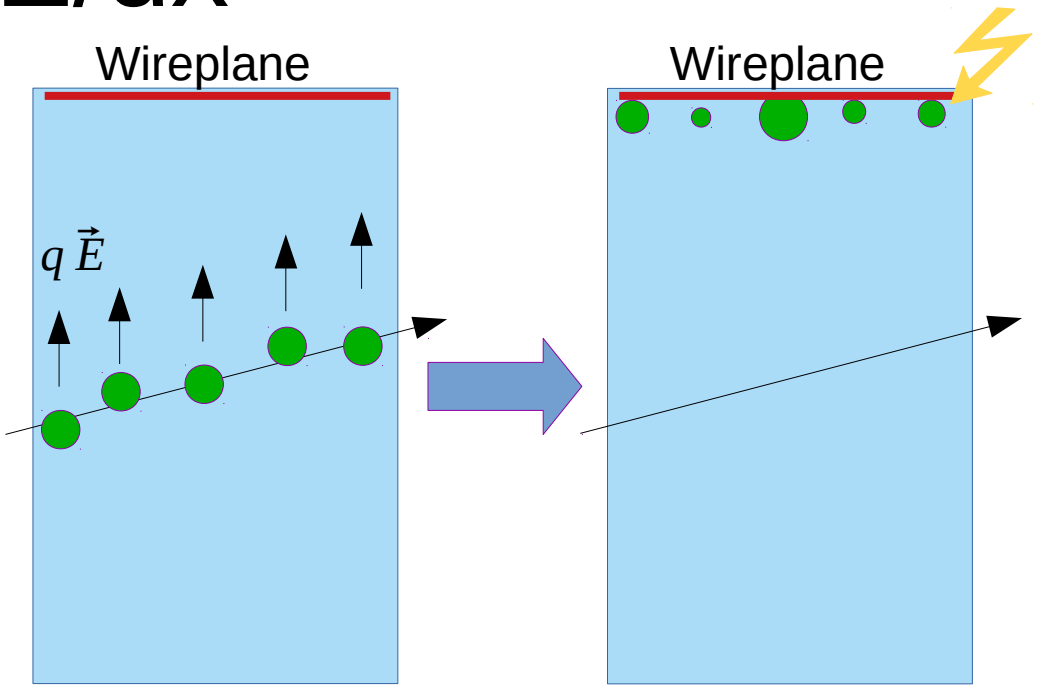
Particle Identification via dE/dx

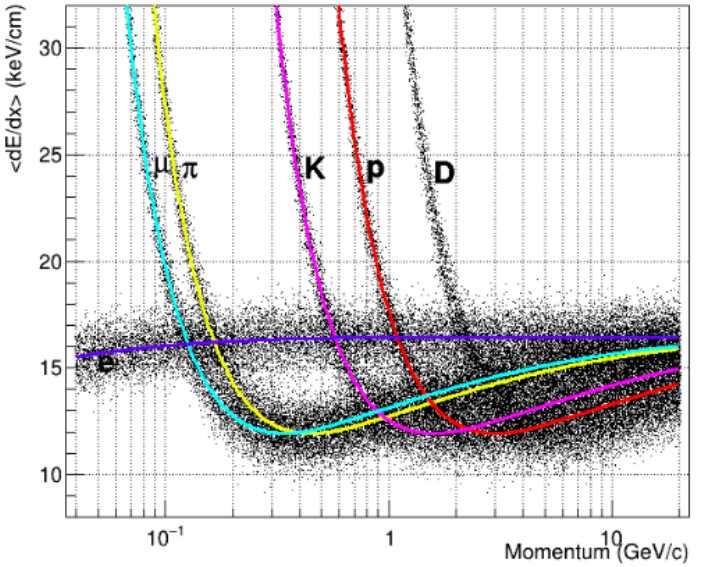
Particle Identification via dE/dx

- TPC provides track **position** and **ionization** measurements
  - Position used for tracking
  - Ionization used for dE/dx estimate
- Particles deposit energy along trajectory according to Bethe-Bloch formula:

$$\frac{dE}{dx} \propto \frac{Z^2}{\beta^2} \ln\left(a\beta^2\gamma^2\right)$$

- Dependence on velocity β allows **separation of particle species** by mass

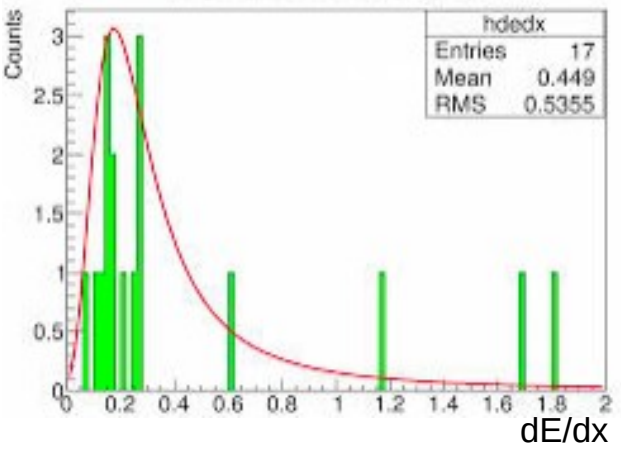




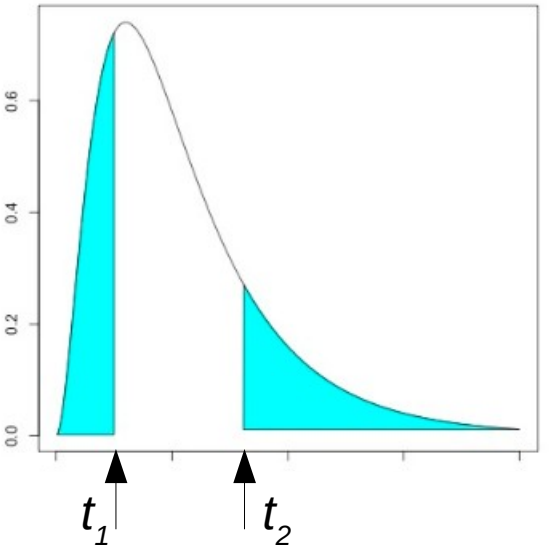
Particle Identification via dE/dx

- Issue: Energy deposit is stochastic along particle's trajectory
- Bethe-Bloch only gives mean dE/dx
- Distribution: "Straggling function"
  - Long tail toward higher energy depositions (large upward fluctuations)
  - Particular shape will depend on sampling width
- Trick: use Truncated Mean $[t_1,t_2]$
  - Truncated means of tracks with same PID can be approximated with **asymmetric Gaussian**
  - Easier to fit

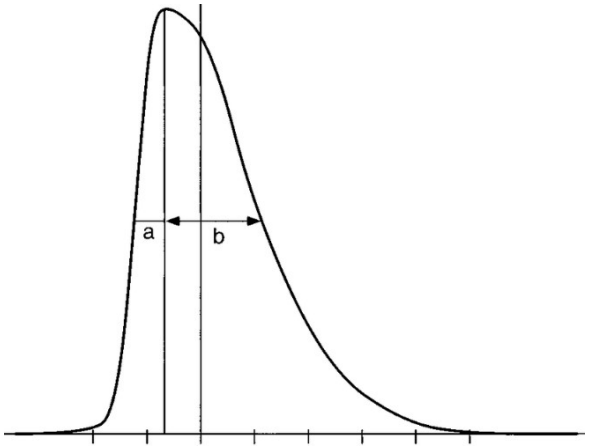
dE/dx Samples



Truncated Mean Calculation

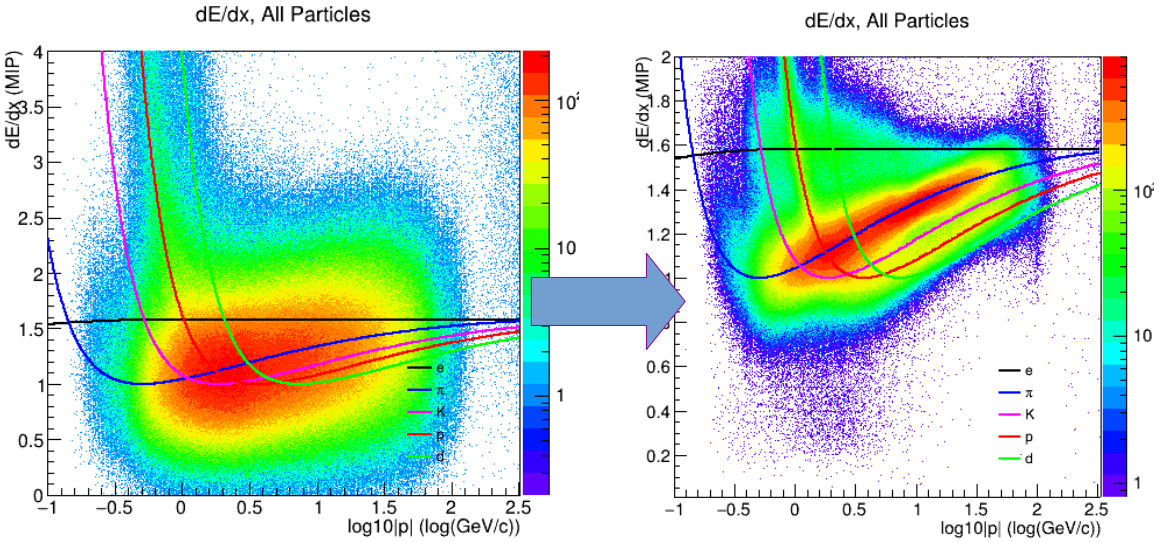


Resulting Track dE/dx Distribution

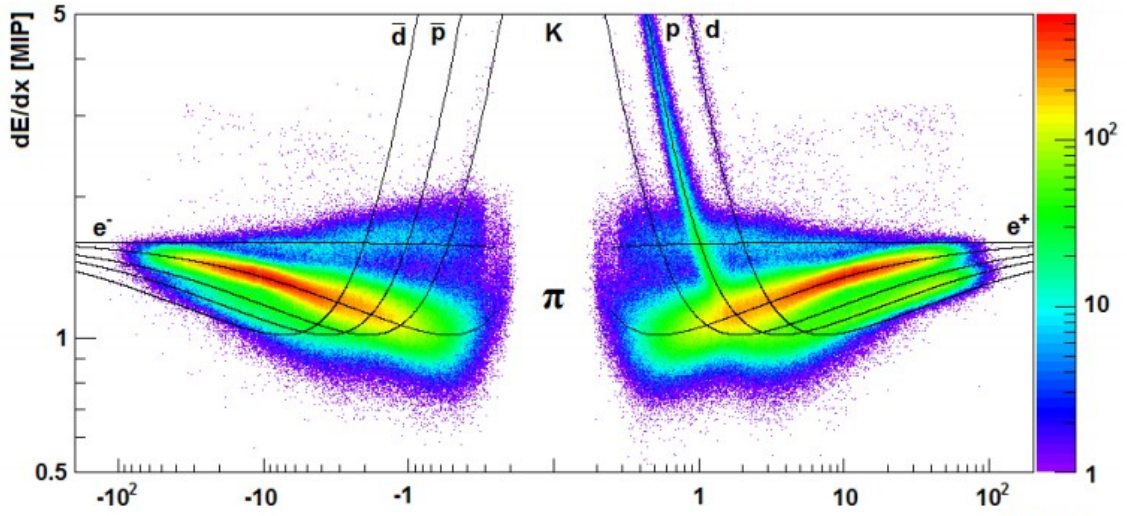


Particle Identification via dE/dx

- Critical step: dE/dx calibration
- Various detector effects distort measured dE/dx
  - HV sector amplification variation
  - Pad / timebin charge sampling
  - Track angles
  - Charge loss during drift
  - Etc…
- These effects create large distortions (order of several percent!)
  - For reasonable PID, dE/dx resolution must be *O*(%)



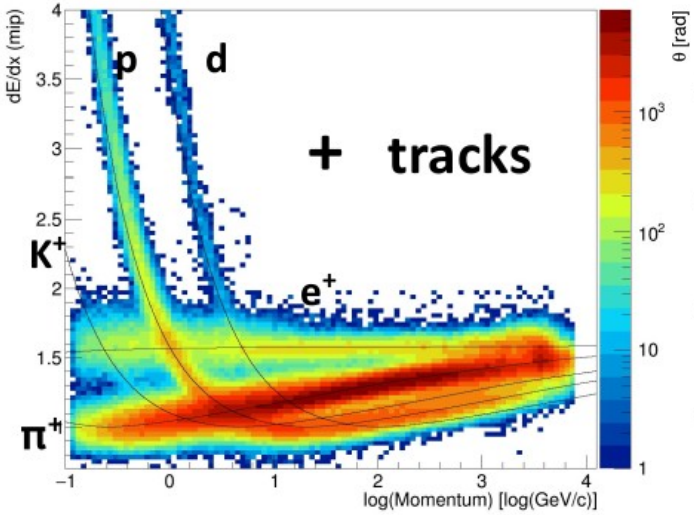
Un-Calibrated dE/dx Calibrated dE/dx

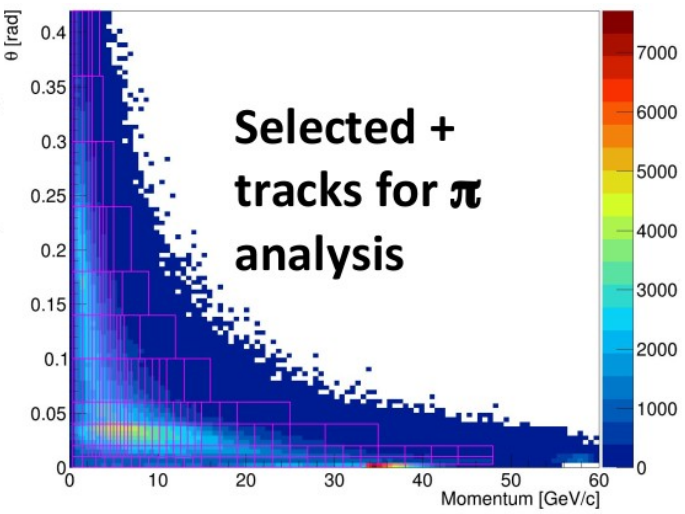


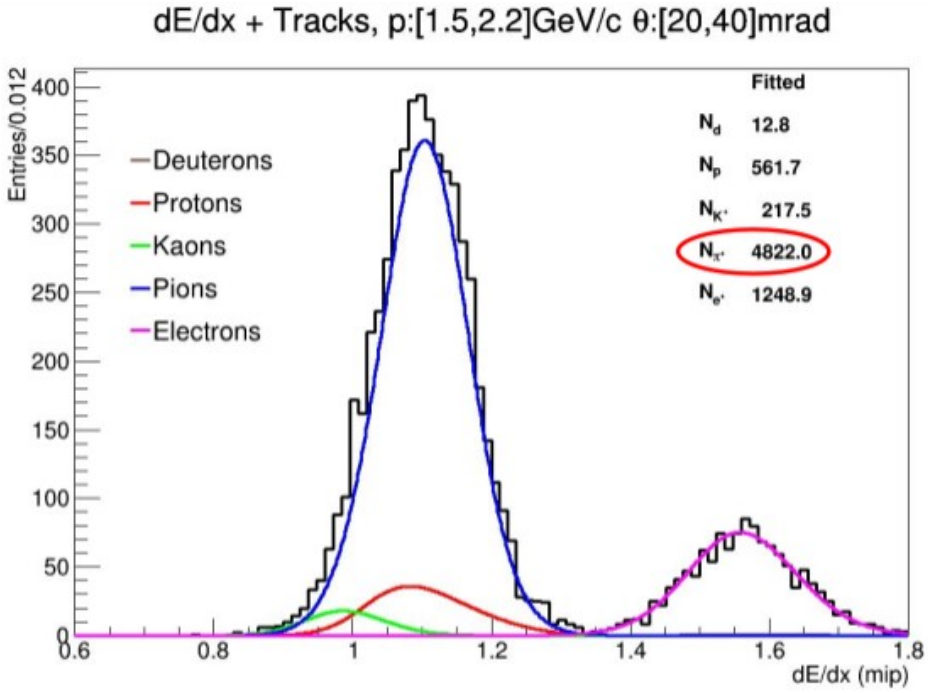
Measured dE/dx vs log(p), with parameterized Bethe-Bloch curves overlayed

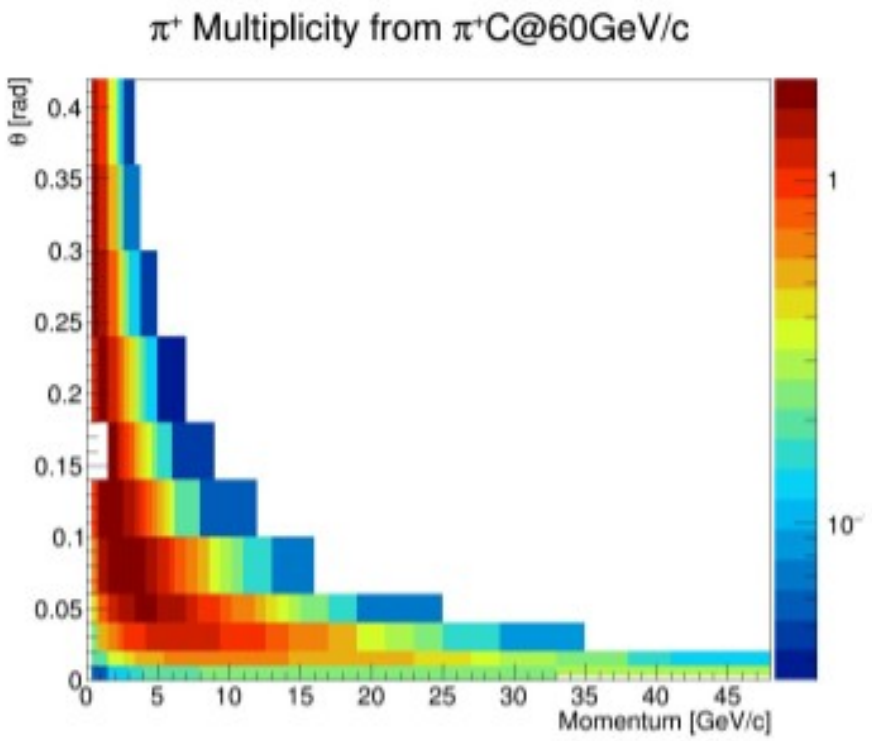
Particle Identification via dE/dx

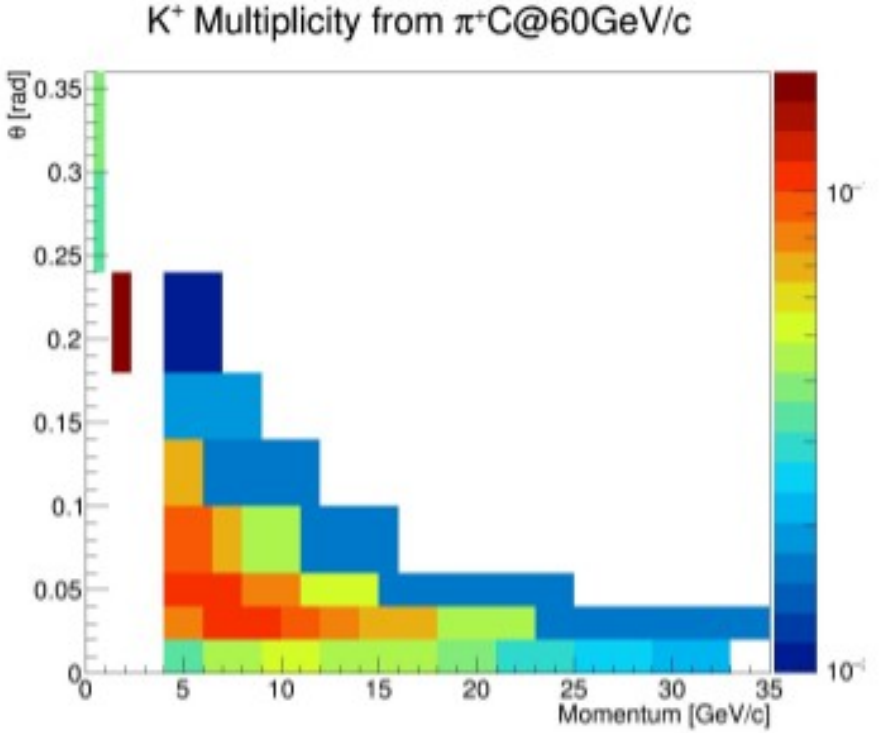
- Calibrated data binned in phase space
- Simultaneous 5-species fit performed to positive & negative tracks
  - 5 asymmetric Gaussians with variable positions & shape parameters (11 parameter fit)
- Result: Species yield in each phase space bin








π⁺ Multiplicity from π⁺C@60GeV/c
θ [rad]
Momentum [GeV/c]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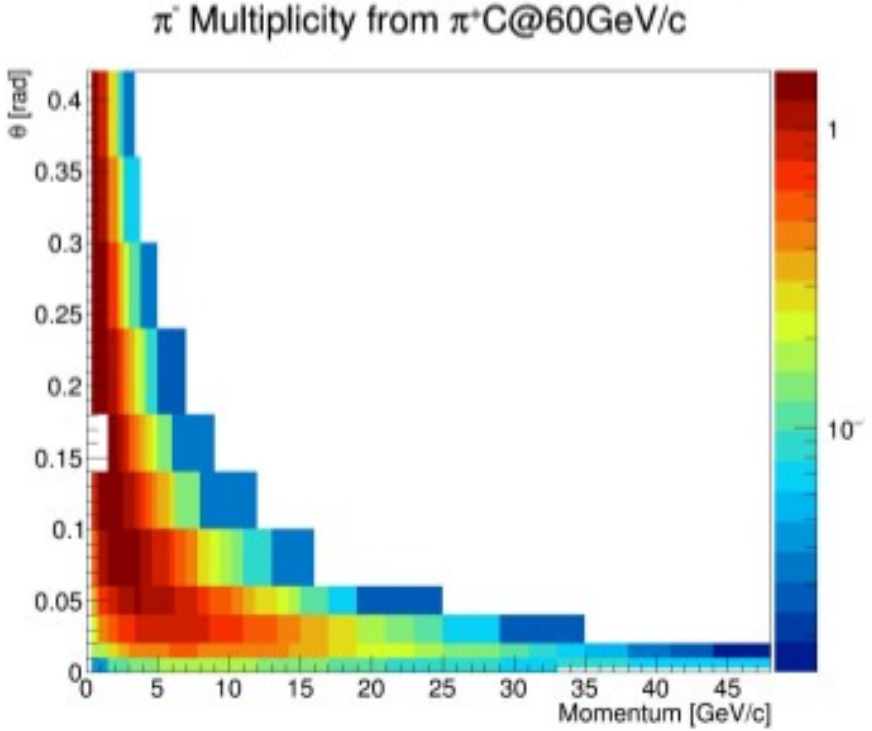
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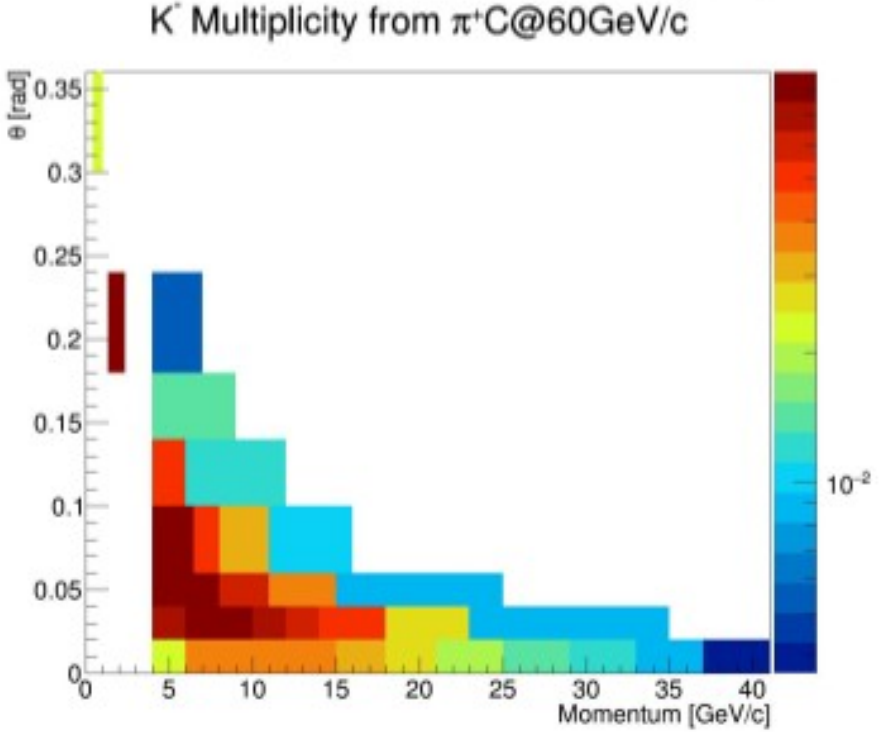
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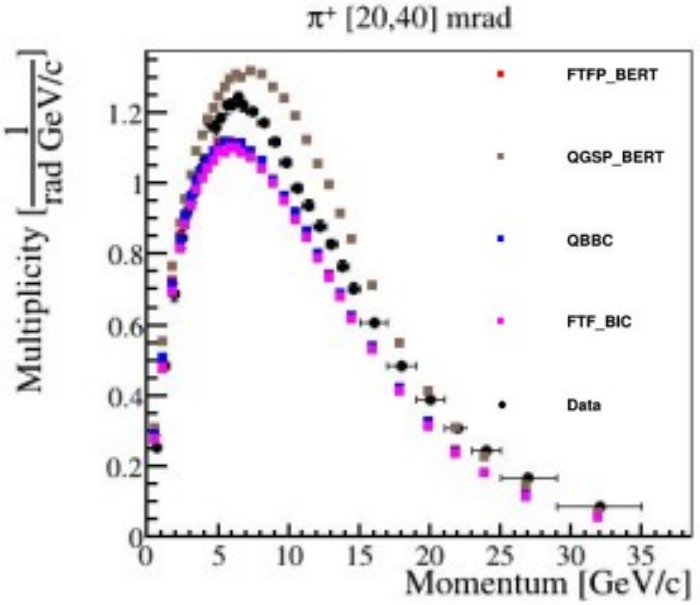
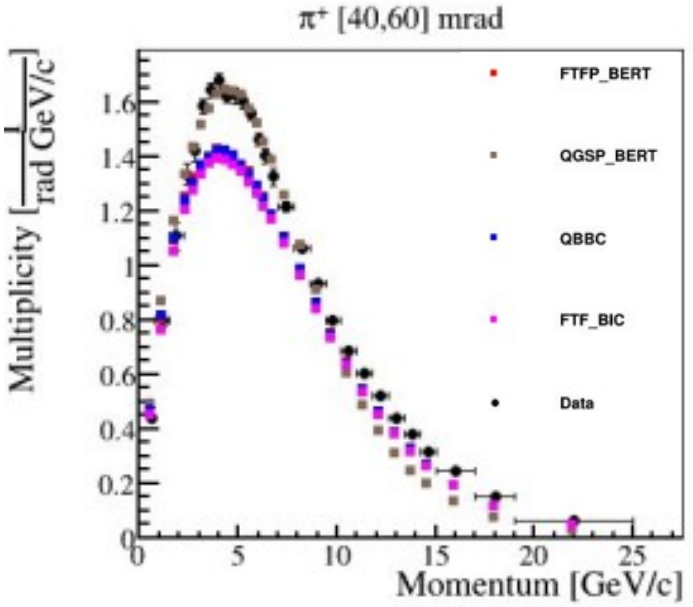
θ [rad]
Momentum [GeV/c]

Results & Model Comparisons

- Differential particle yield results used for:
  - Improving long-baseline neutrino flux estimates
  - Improving generator models across phase space
    - Significant discrepancies in many generators!





Thanks!

Thanks to the entire NA61 collaboration!