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BNB Flux Simulation Status

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Introduction

Plan for this talk:

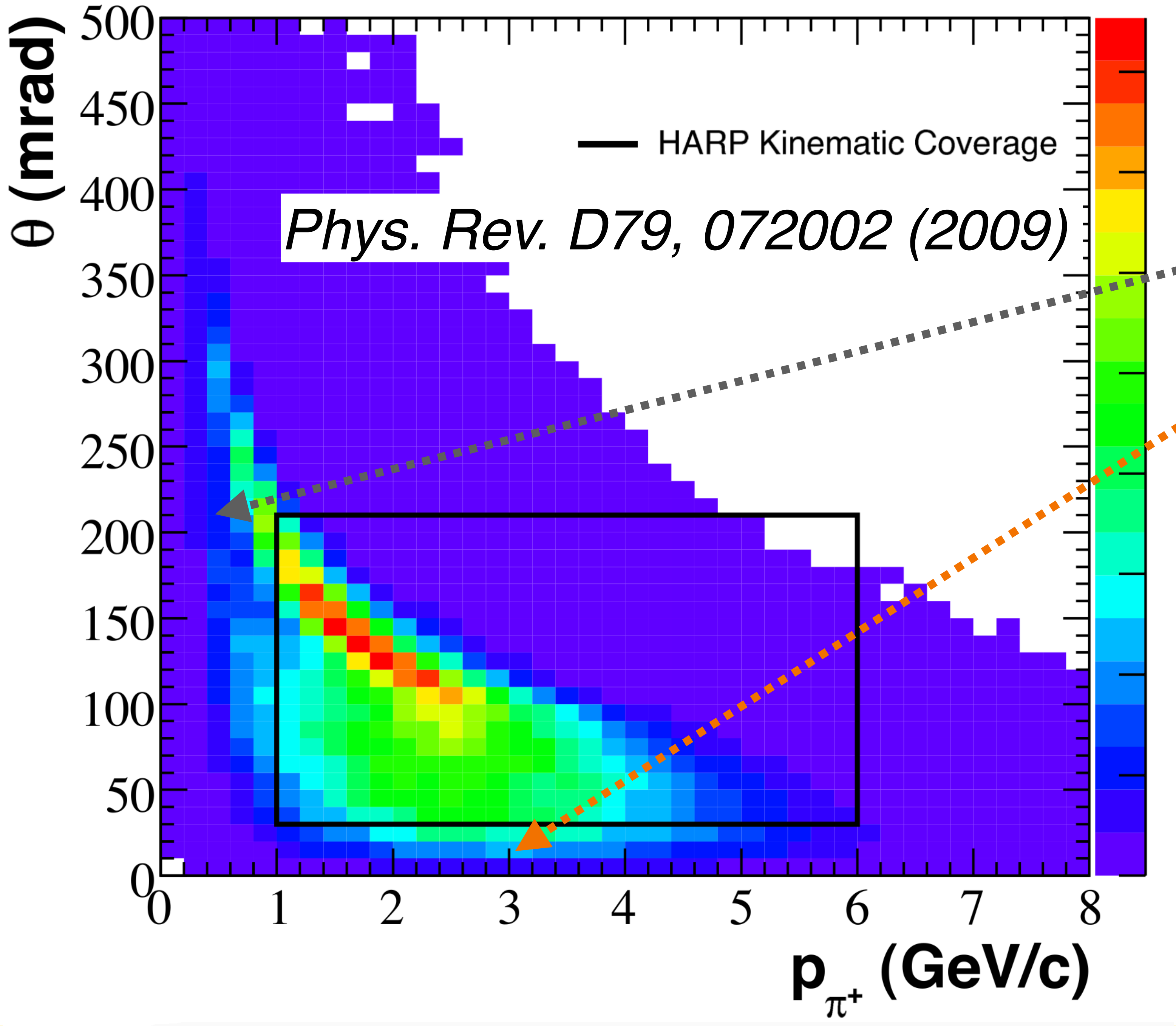
- Overview of current flux prediction and systematic uncertainty calculation

- Emphasis on areas for improvement in flux simulation and reassessment of systematics, in light of ongoing efforts of a new flux simulation and uncertainties

  ➡ *See Raquel's detailed update on the new flux simulation tomorrow*

BNB Flux Prediction Overview

- Sanford-Wang (SW) fits to HARP and E910 to get the pBe -> π^{+-}
- Feynman-x scaling based on fit world for pBe -> K^+ and additional constraint from SciBooNE.
- SW fits to E910 and KEK to get the pBe -> K0L
- Large data on (σ_{inel},σ_{prod}) is available. σ_{qe} data is sparse.



Large uncertainties come from data extrapolation

Small kaon uncertainty comes global fit and SciBooNE data: reduced from 14% to 7% (Phys. Rev. D 84, 114021)

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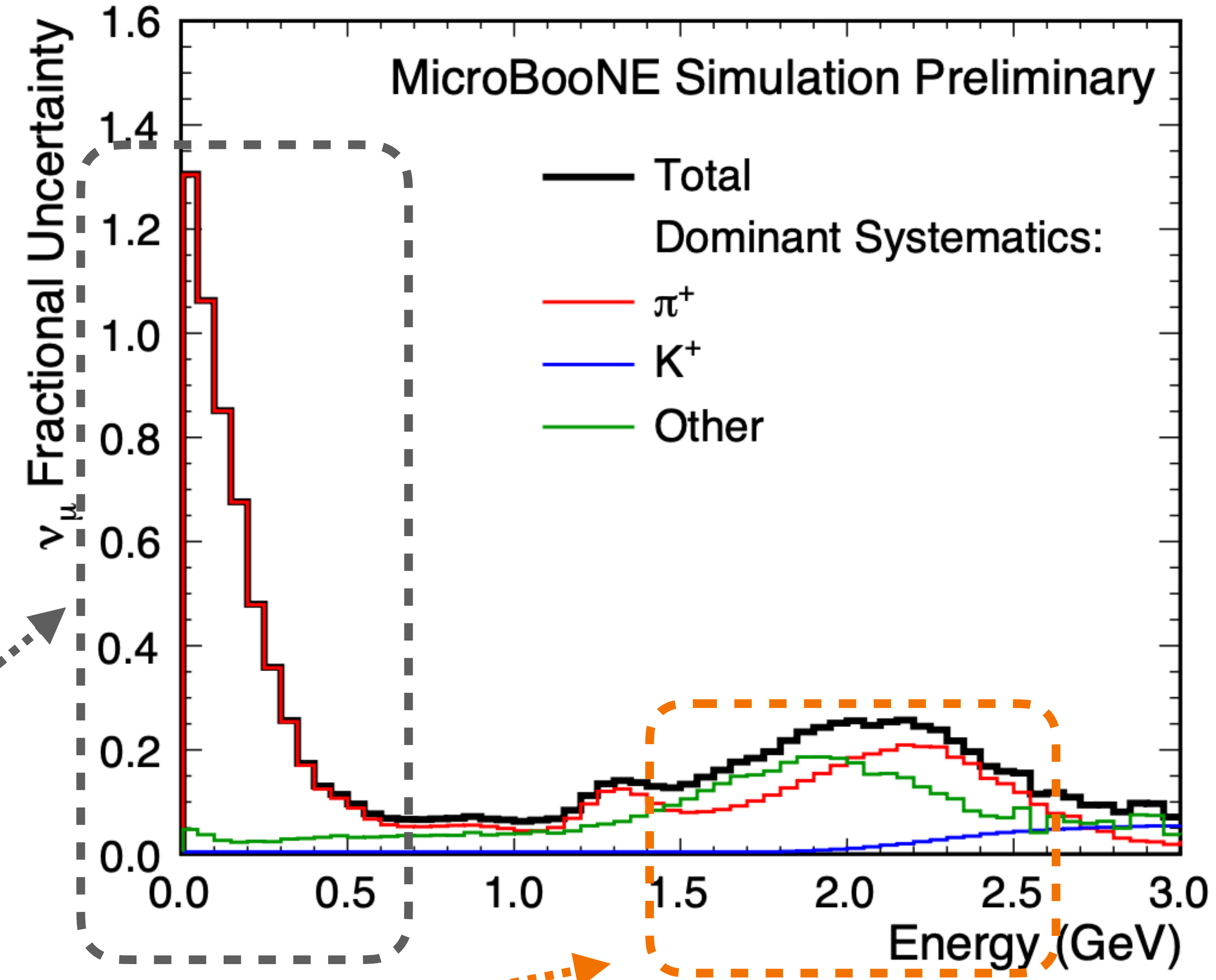

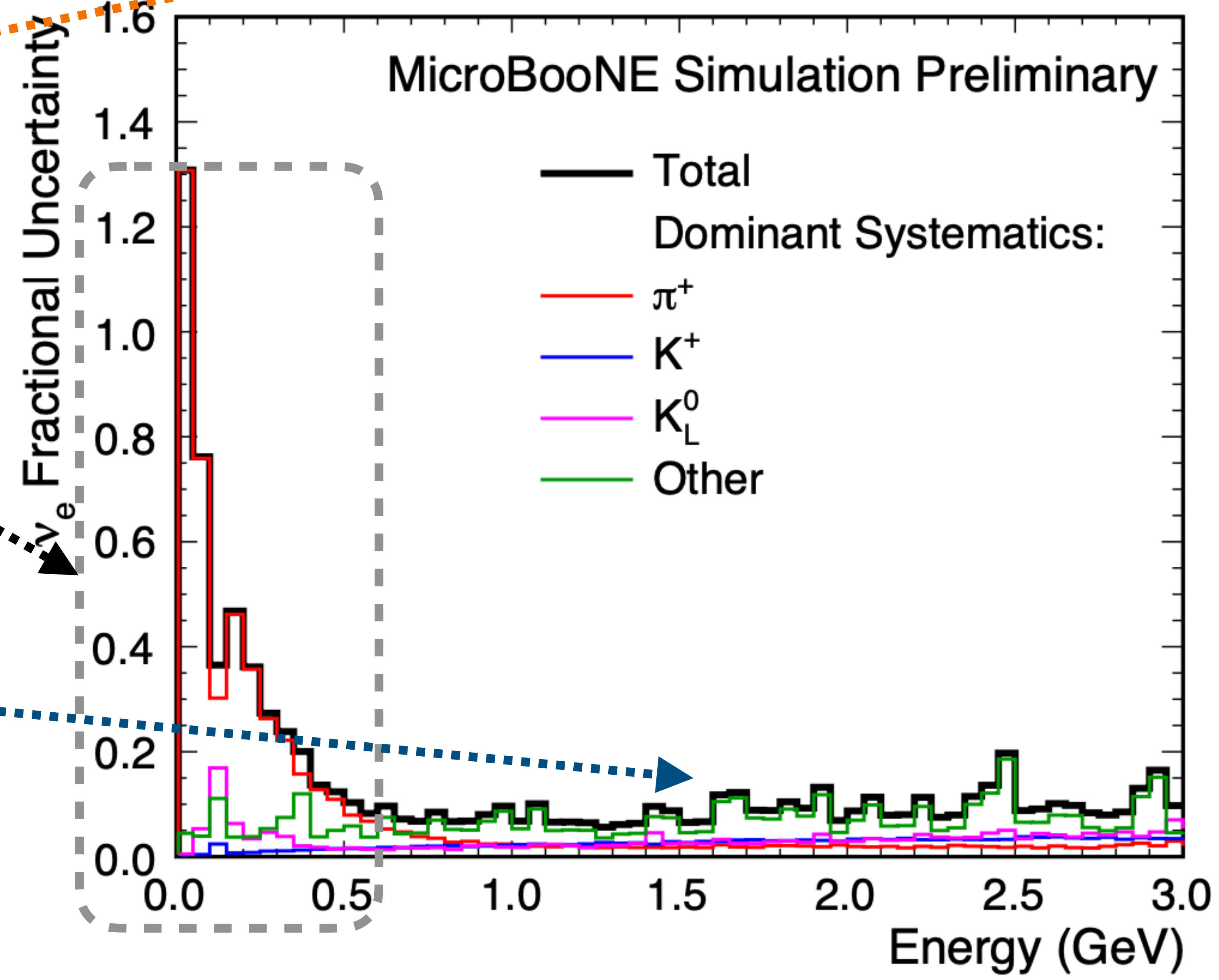

SBN Simulation Infrastructure

Current flux simulation comes from MiniBooNE

- Baseline MC is Geant 4-08-01-patch-02
- Incorporates parametrized hadronic cross-sections (BooNE cross section model based on data)
- MiniBooNE ntuples files are used to fill GSimple ntuples.

GSimple has limited information, mostly neutrino parent kinematics

- Serves as input for the GENIE simulation
- Information is copied in MCFlux and stored in our standard ART files

Uncertainty calculators live in sbncode/SBNEventWeight (SBNSoftware)

- Calculators generates weights to account for systematic shifts
- Uses MCFlux as input to get the neutrino type and parent kinematic
- Calculators use input from pre-calculated cross sections, ratios, covariance matrix from MiniBooNE

BNB Flux Uncertainty Calculators

There are 3 types of uncertainties implemented in SBNEventWeight:

1. Focusing uncertainties

Unisims: pre-calculated 2 or 3 universes to generate weights: overall systematic assuming they are a Gaussian distributed

2. Beam attenuation

Unisims based on integrated cross sections: pre-calculated +- 1σ variations

$$\sigma_{total} = \sigma_{elastic} + \underbrace{\sigma_{inelastic} + \sigma_{quasi-elastic}}_{\sigma_{absorption}}$$

Calculators:

- Horn current magnitude (pre-calculated +- 1σ variations)
- "Skin effect" on the horn conductor (spread between models)
- π total and π quasi-elastic
- Nucleon total, inelastic and quasi-elastic

BNB Flux Uncertainty Calculators

3. Hadron production

Based on hadron production data (differential cross sections)

Uses Multi-Gausian smearing

Calculators:

- Charged pions
- Charged kaons (neutral kaons are disable)

Caveats:

Due to the limited information stored in GSimple files, some assumption were made:

- If the pion was generated by a secondary hadron, it is re-written as coming from the original proton with momentum (0,0,8 GeV).
- Only a single hadronic production is assumed

Charged-Pion Uncertainty Calculator

Uses the calculator ***PrimaryHadronSWCentralSplineVariation.***

- HARP double differential cross sections interpolated using splines on each universes generated as multivariate normal deviates
- Splines also used to extrapolate outside the HARP region
- The "weight" per universe for uncertainties as the ratio of the interpolated value from the spline (Sp) and the SW :

$$w^i = \frac{Sp^i\,(p,\theta)}{SW\,(p,\theta)}, \; i = \text{universe}$$

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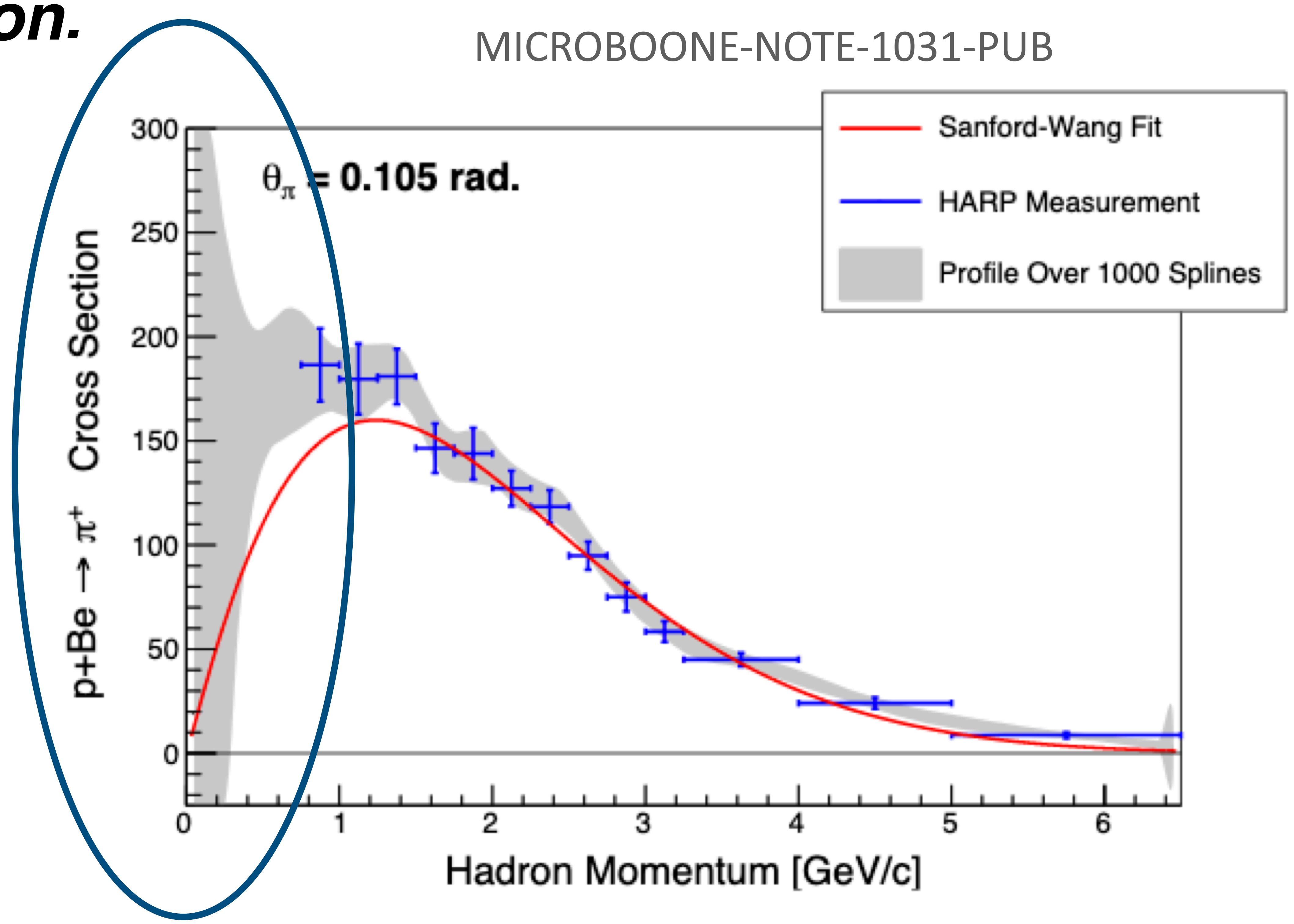
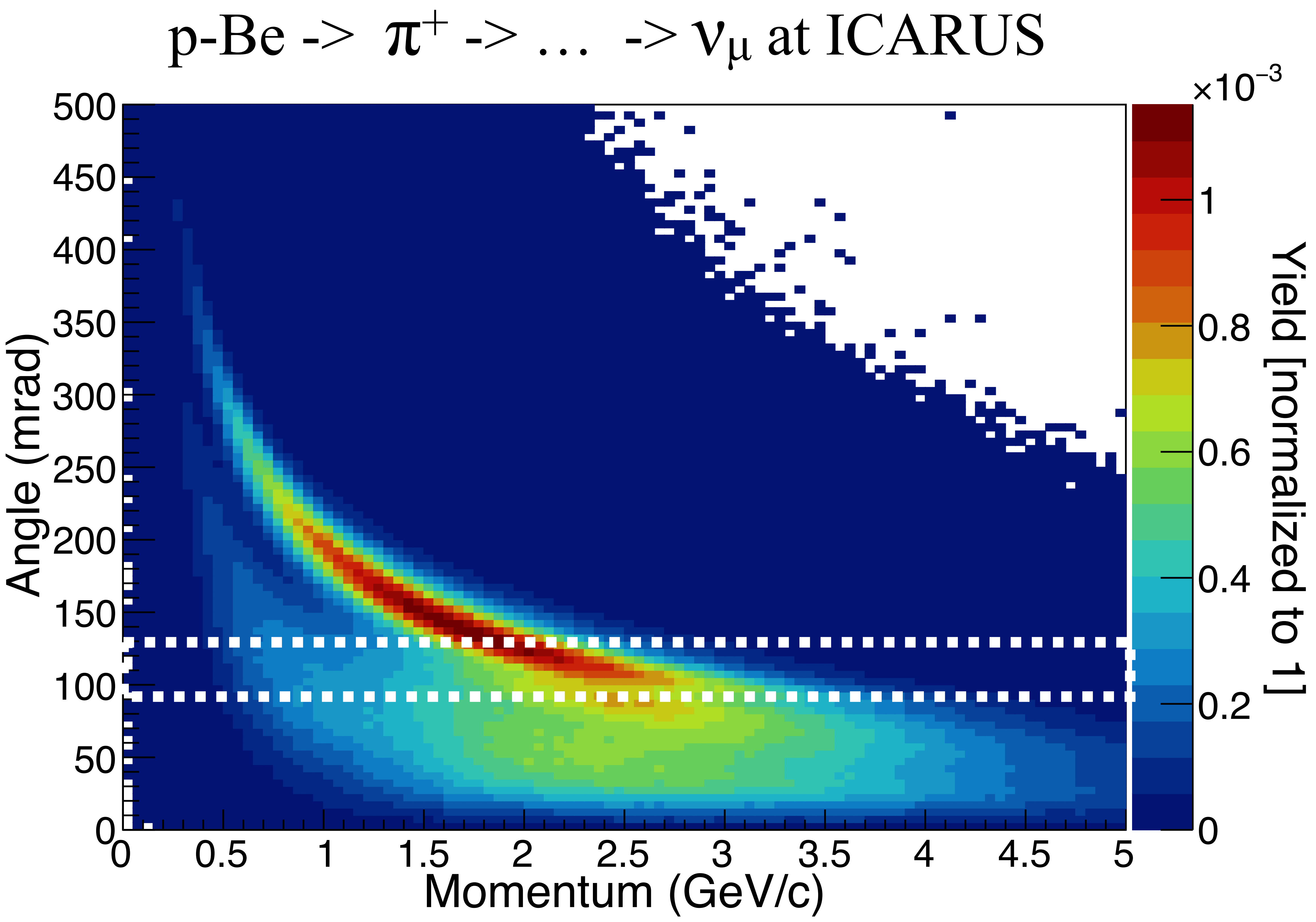
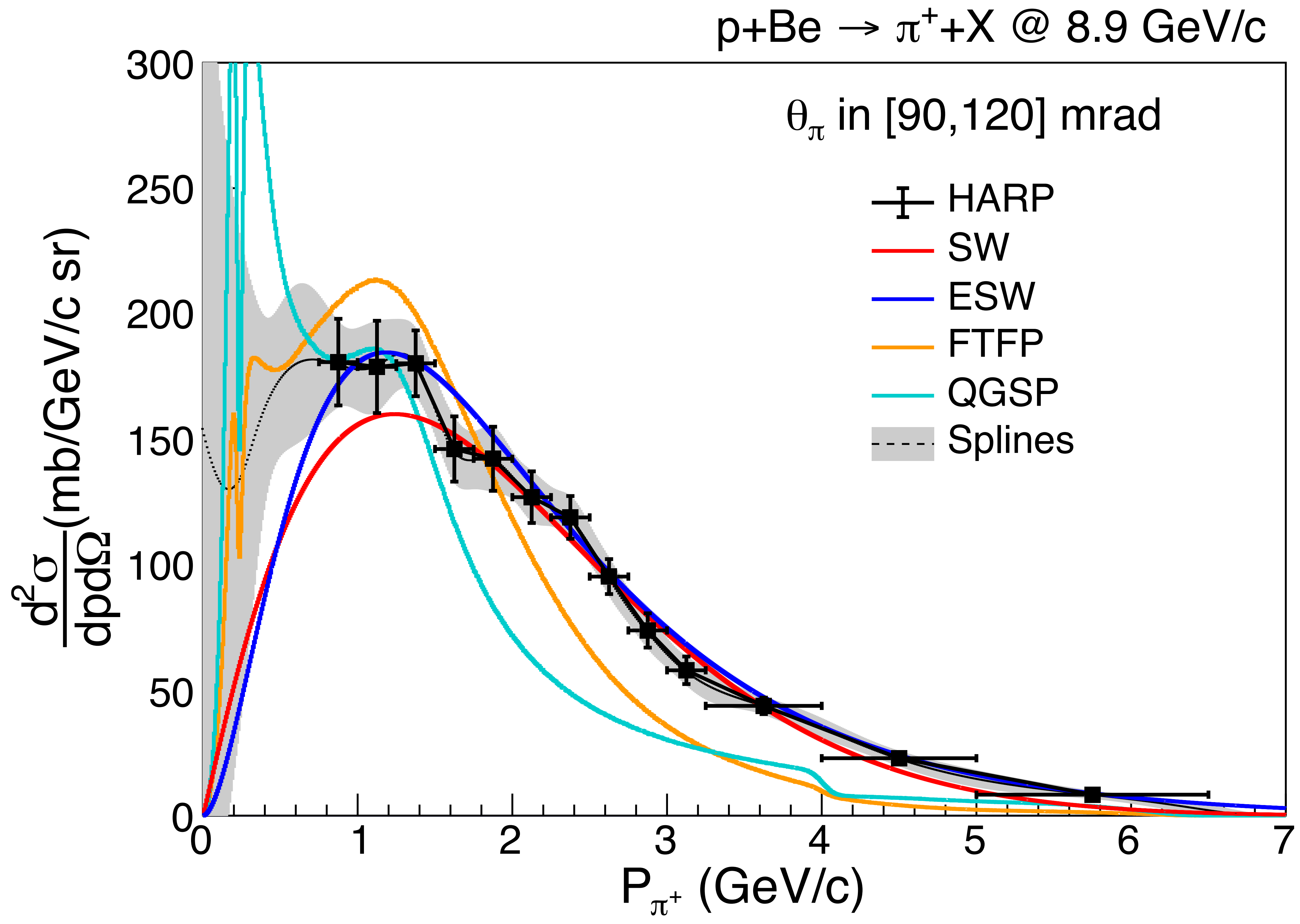


- Large discrepancies between spline prediction and SW outside the data coverage results in large uncertainties at low momentum

Caveat: HARP-Be in pi+ is every material (Be and non-Beryllium)

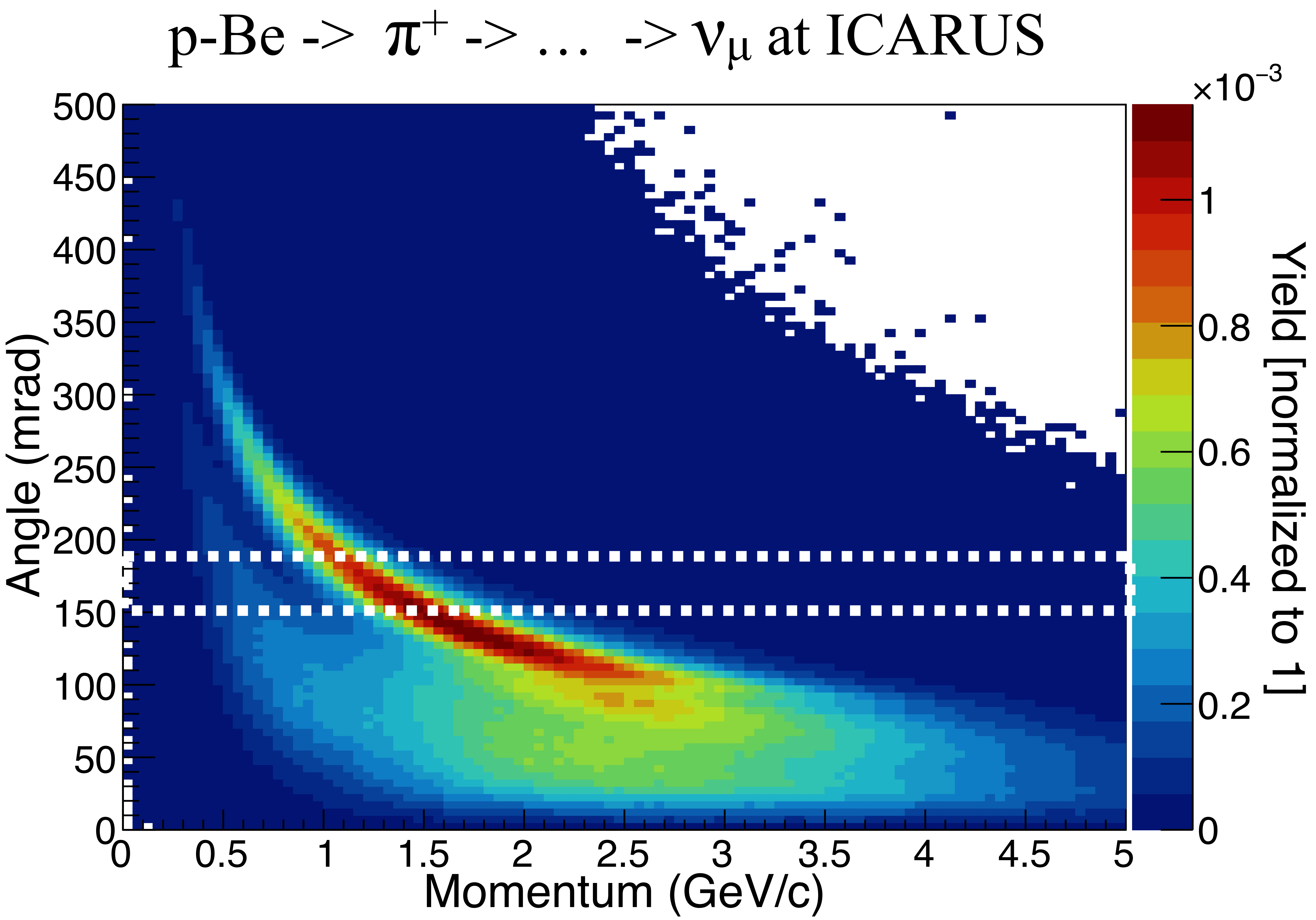
Impact of HARP Extrapolation

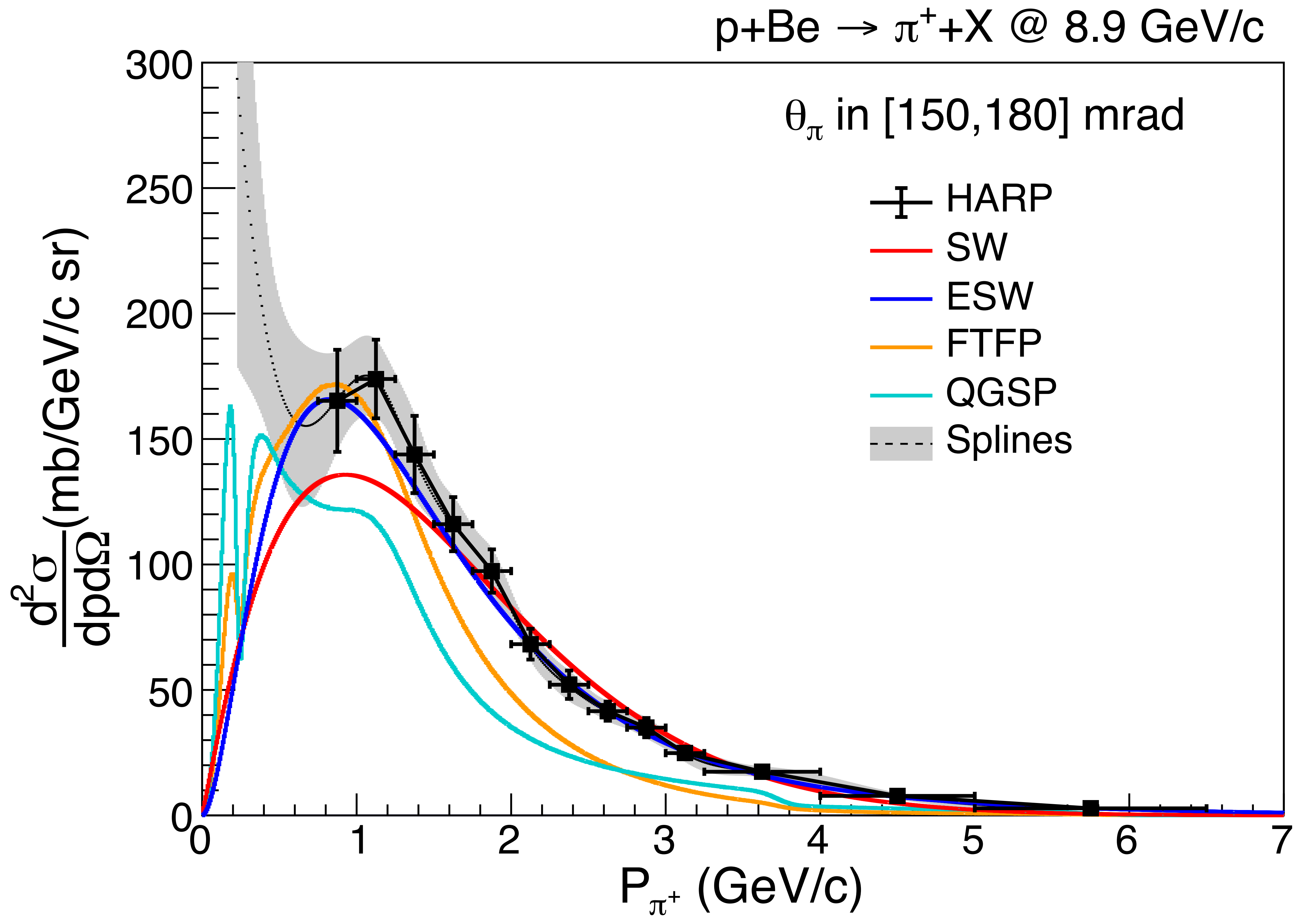




Large asymmetry outside the data coverage results in large uncertainties at low momentum

Impact of HARP Extrapolation at Low momentum

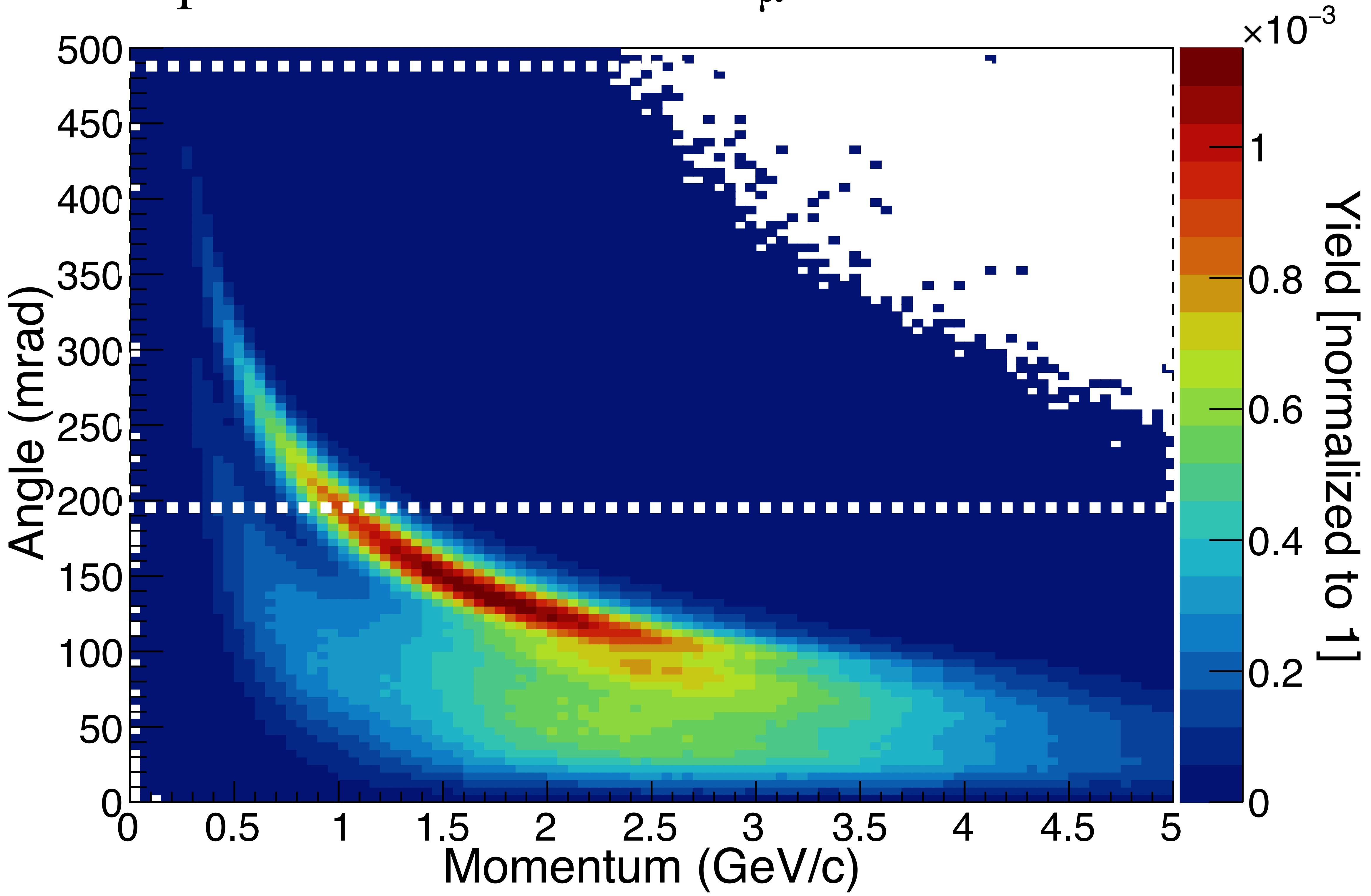




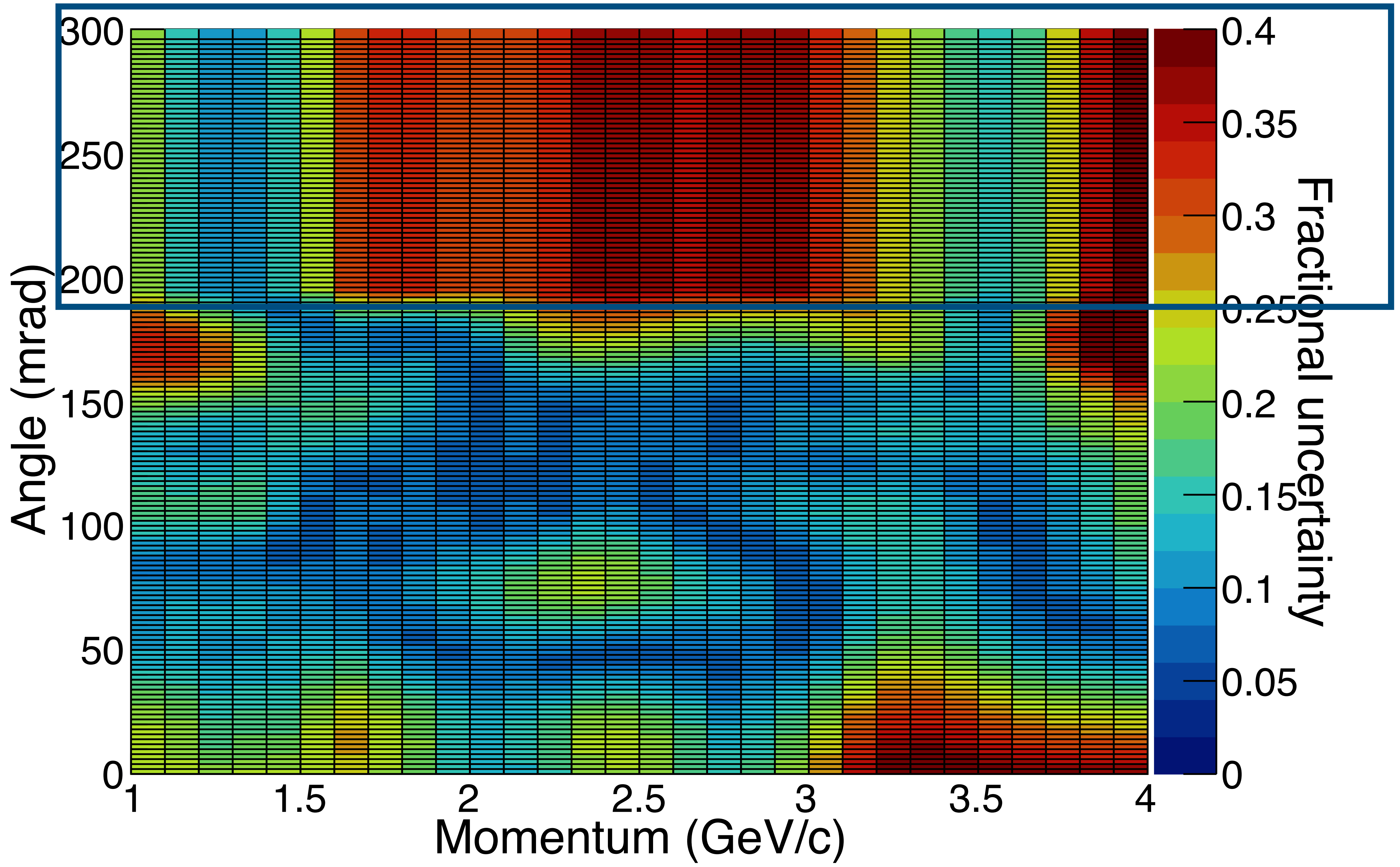
Large asymmetry outside the data coverage results in large uncertainties at low momentum

Impact of HARP Extrapolation at Large Angles

p-Be -> π^+ -> … -> ν_μ at ICARUS



π^+ uncertainty from calculator

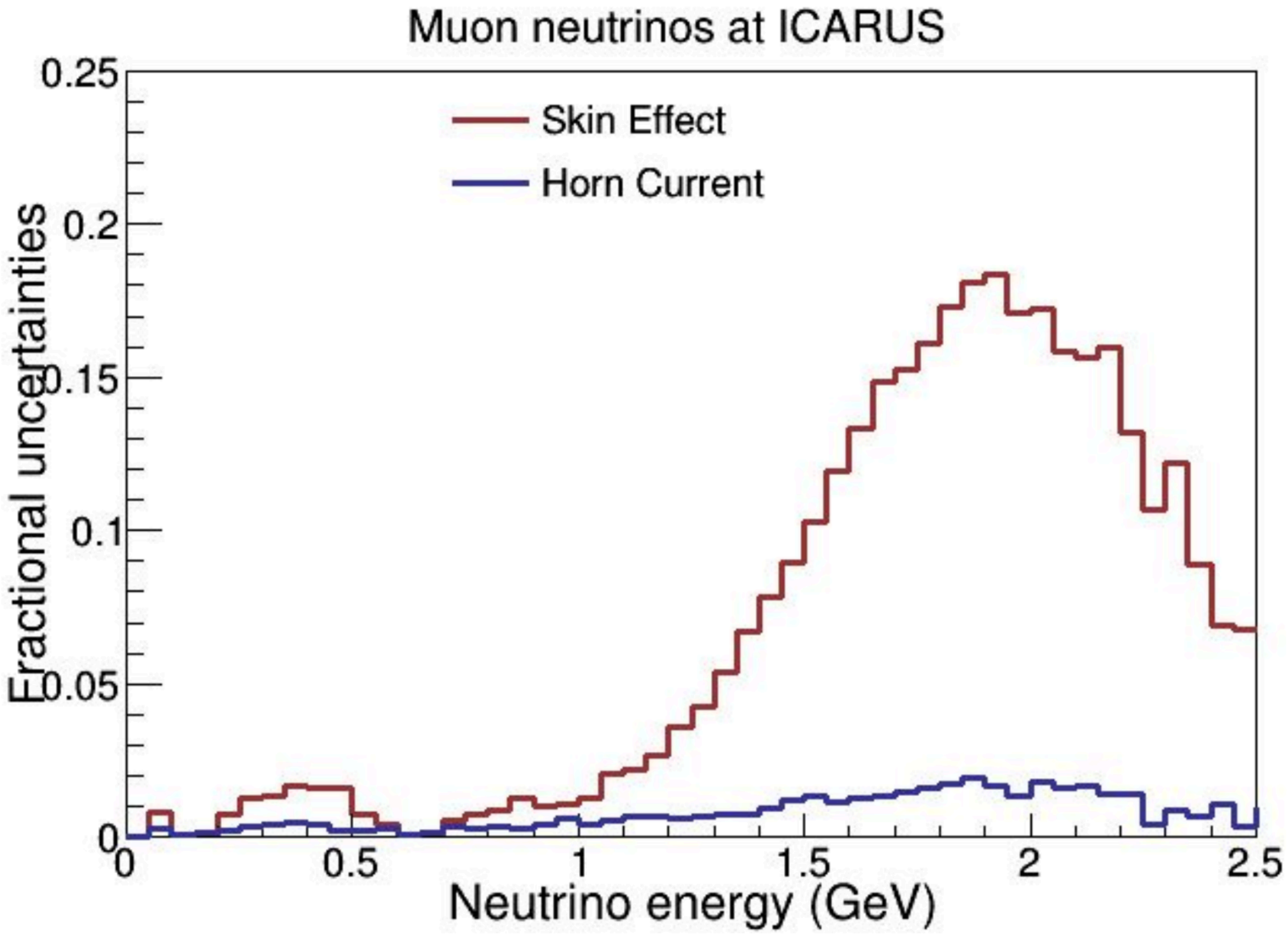


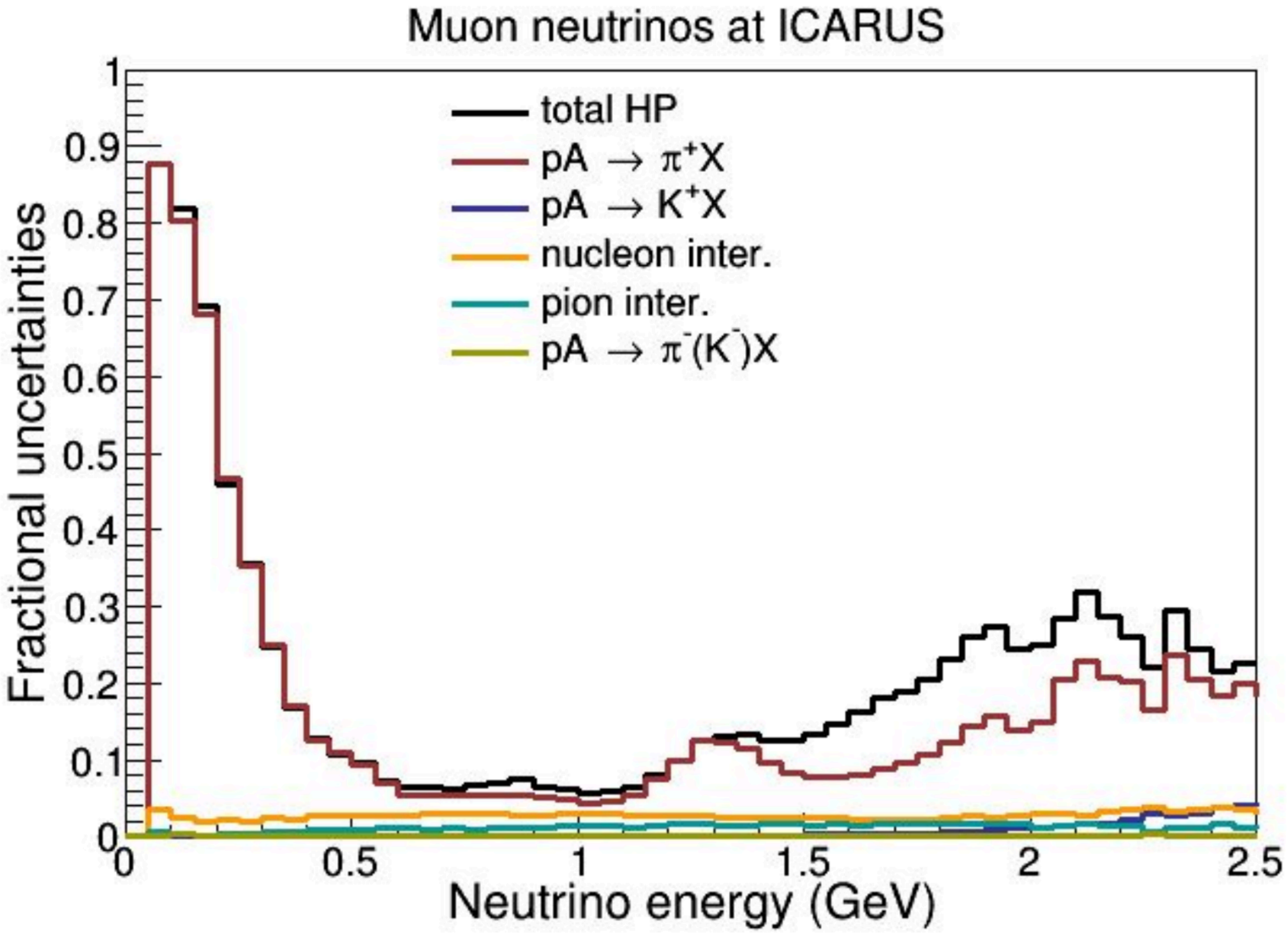
Caveat: the calculator assigns 195 mrad angle for pi+ (out of HARP coverage). The reason is to control the spline variations.

Fractional Uncertainties

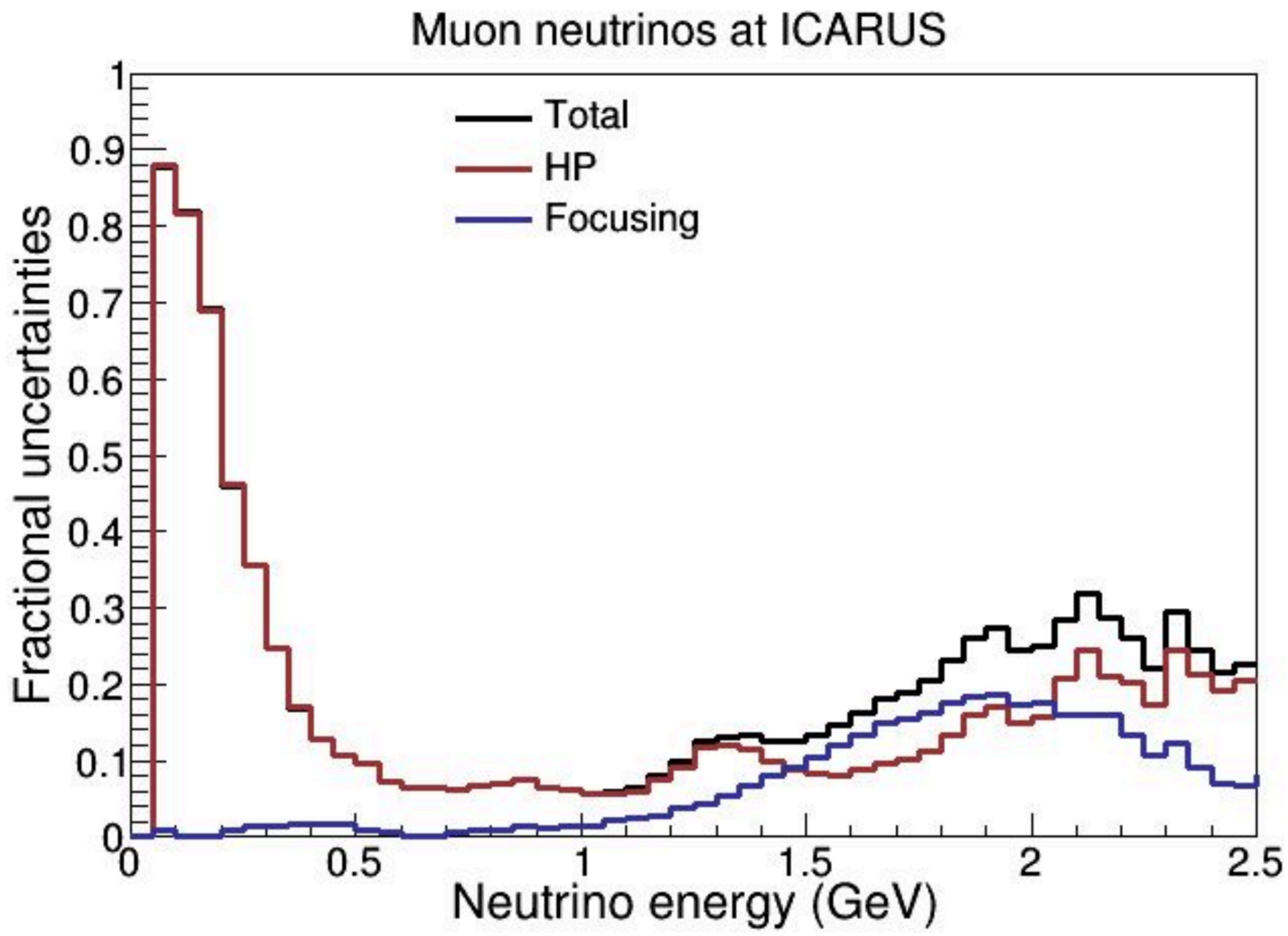
Uncertainties are calculated using the flux systematic universes directly from the true information and no selection is applied

Method: Standard deviation of with a biased reference (flux central value)





Total Fractional Uncertainties

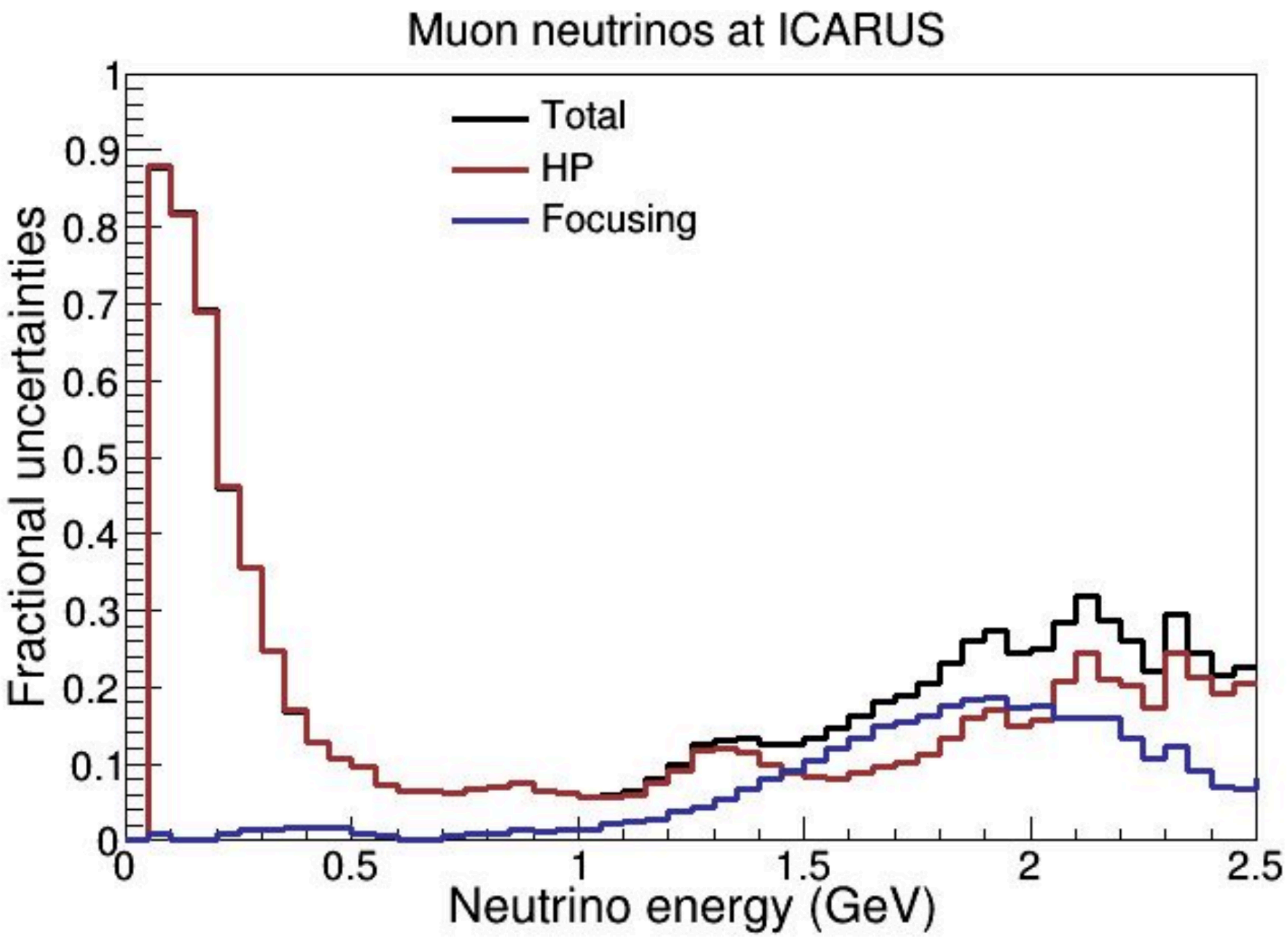


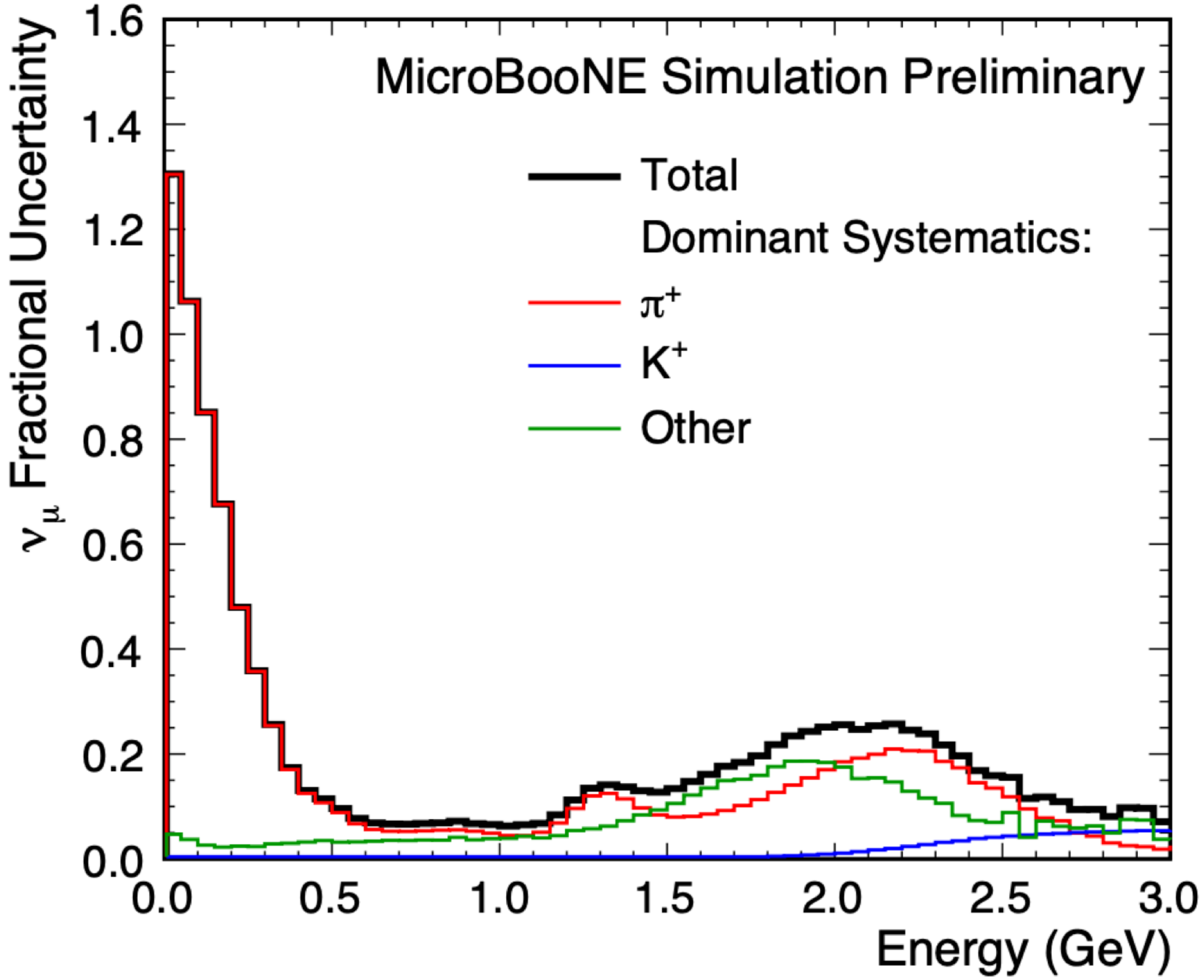
Total uncertainties are calculated using the flux systematic universes directly from the true information and no selection is applied

Method: Standard deviation of with a biased reference (flux central value)

Comparison with MicroBooNE

ICARUS at around 0.8 GeV (peak): ~6%.
MicroBooNE at around 0.8 GeV: ~7.5%





Summary

- I presented an overview of the current flux prediction methods and systematic uncertainty calculations, with a particular focus on beamline pion production

- Areas for improvement in both flux simulation precision and uncertainty assessments have been identified. Addressing these gaps is crucial for enhancing the overall accuracy of our predictions.

- The ongoing efforts to finalize a new flux prediction, including the validation process and reassessment of uncertainties, will have a large positive impact

    - There is a current work on validation and reassess uncertainties

    - With new hadron production data from EMPHATIC at Fermilab and NA61/SHINE at CERN, we expect to improve phase space coverage and further reduce uncertainties

➡ *See Raquel's detailed update on the new flux simulation tomorrow*

Backup

Impact of HARP Extrapolation at Low momentum