Updates to Flux Prediction: MiniBooNE

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SBN Oscillation Physics Workshop
Jan 26th, 2016

Outline:

1. Motivation for long targets analysis

2. Overview:

=> HARP setup, track reconstruction and targets

3. pi+ production yield measurements :

=> 20 cm and 40 cm long targets data

4. Finding a new model to explain long target data:

=> Thin target pi+ production cross section from VERTEX4 reconstructions.

=> SW model parameters and comparisons

5. MC yield predictions for long targets:

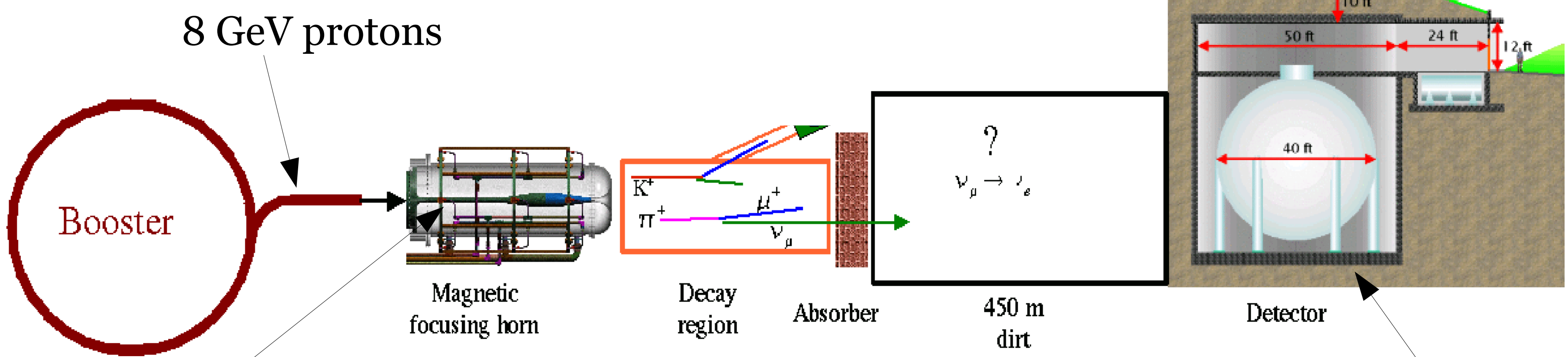
=> Overview of GEANT4 simulation

=> Long targets MC-data comparison

6. Muon Neutrino flux

1. Motivation for long targets analysis

The Mechanism of BNB Production



* 71 cm (10.2 cm*7 slugs) long beryllium target.

2cm Be

Data: Harp 2cm & E910 → *Fit SW model* → *Simulation* → 71 cm Be → *particle production* → *Neutrino flux*

BNB Monte Carlo

* Better to check HARP pion production data on 20.0 cm and 40.0 cm Be targets

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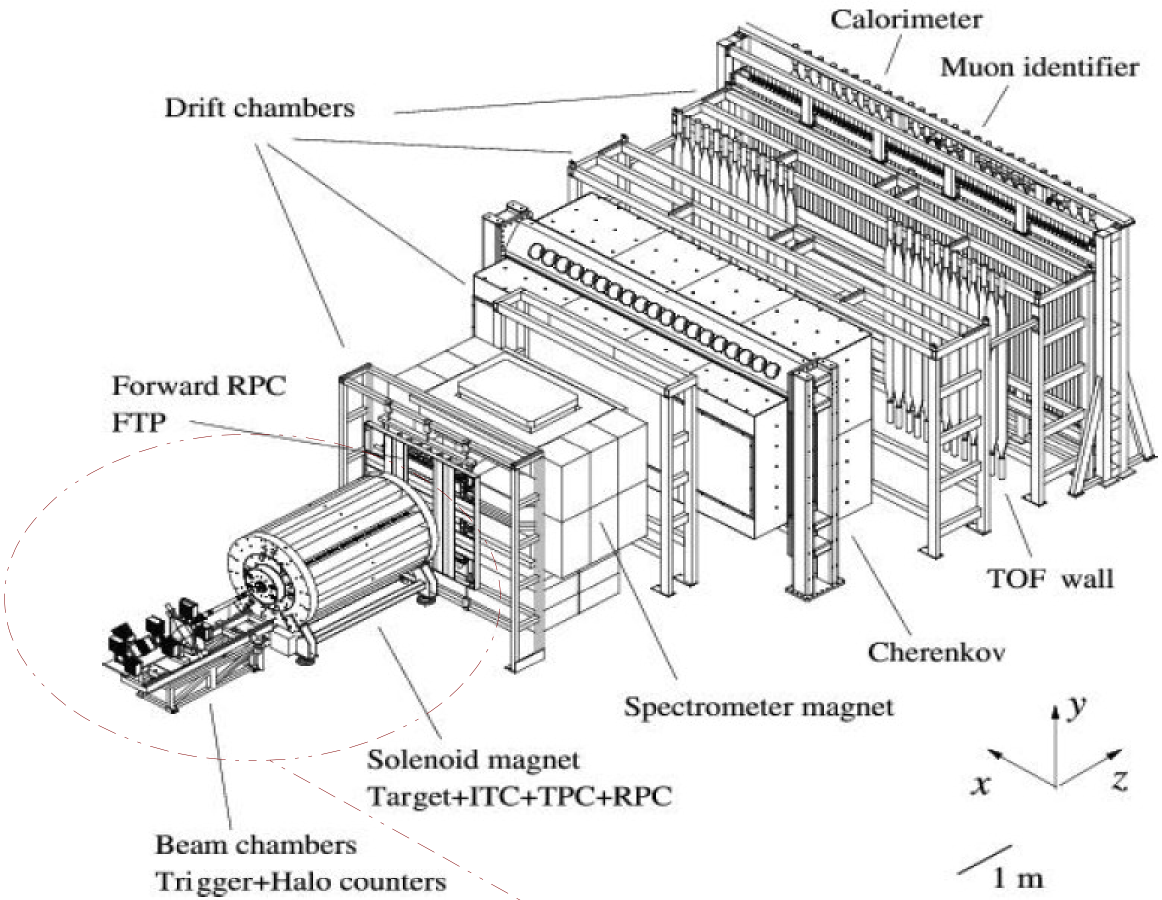
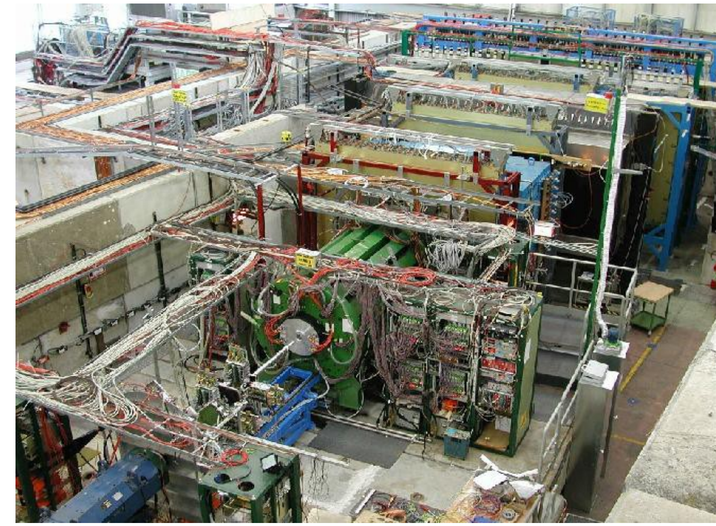
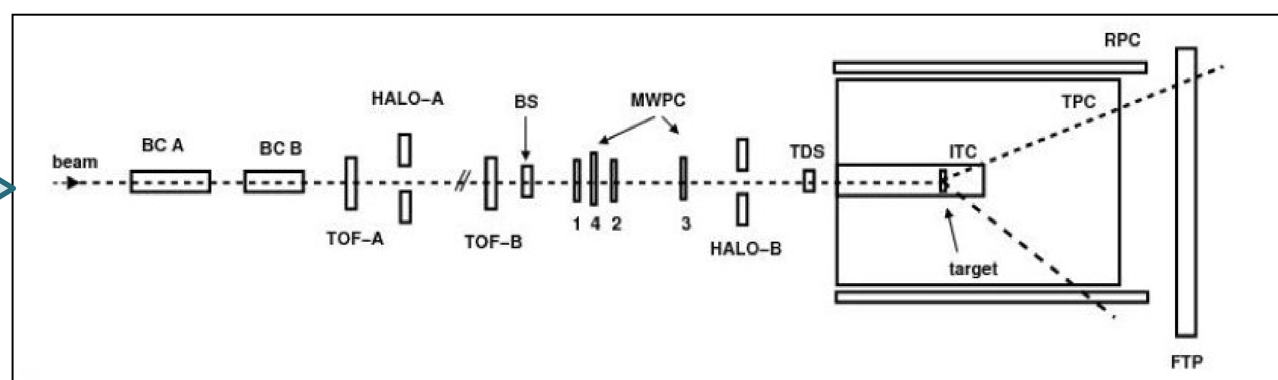
<u>*Overview of the HARP setup*</u>





Primary Beam line
(T9 beam)



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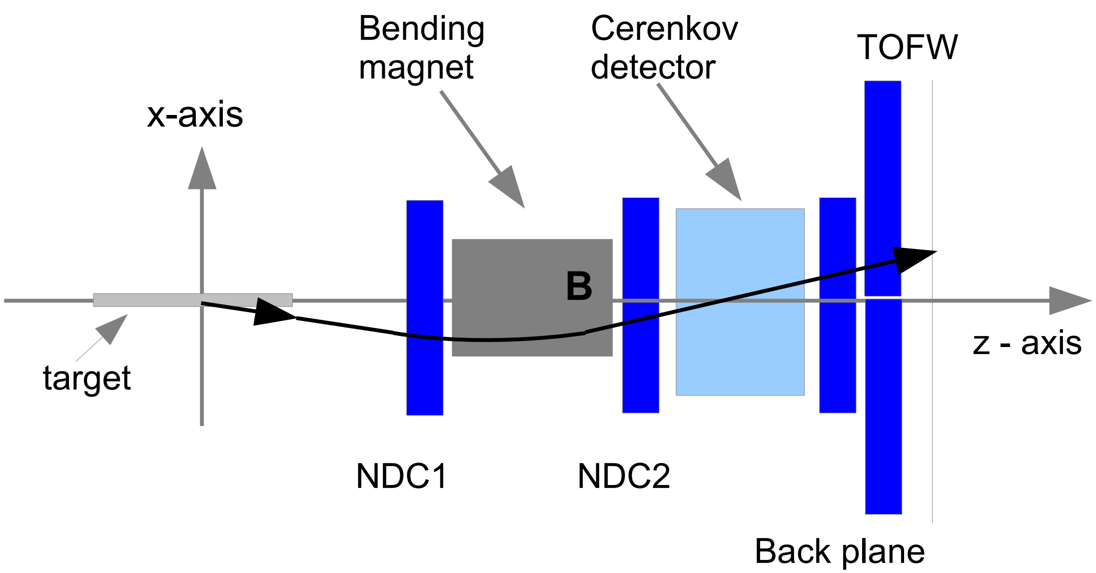
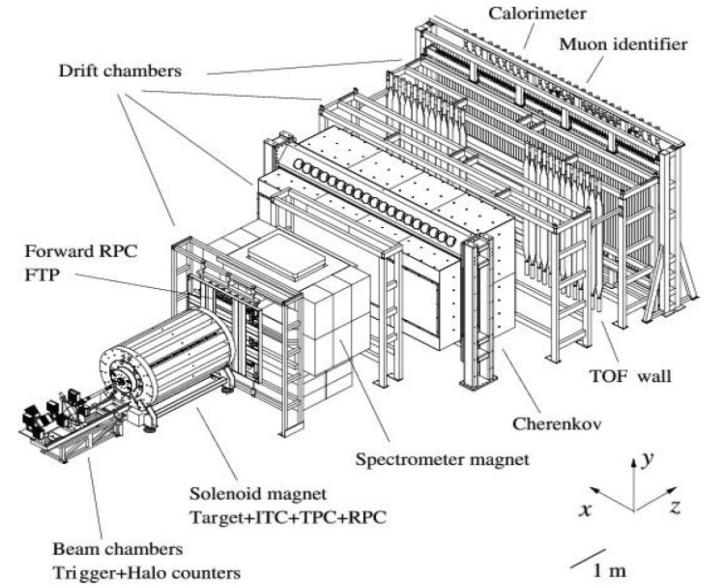
p2 and p4 momentum reconstructions

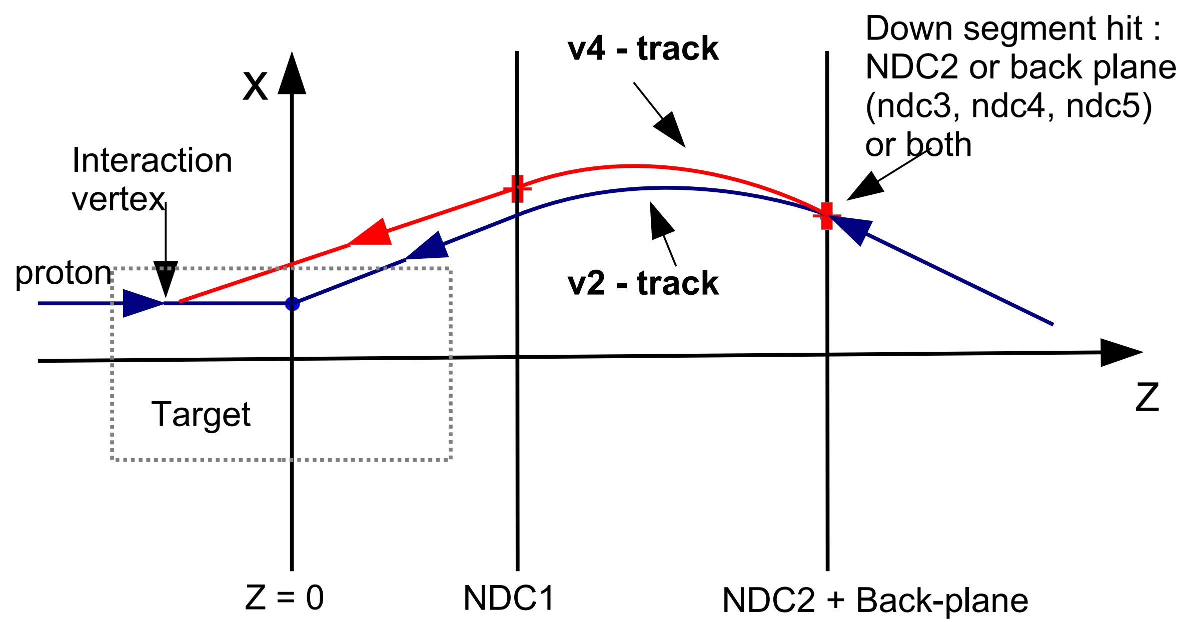




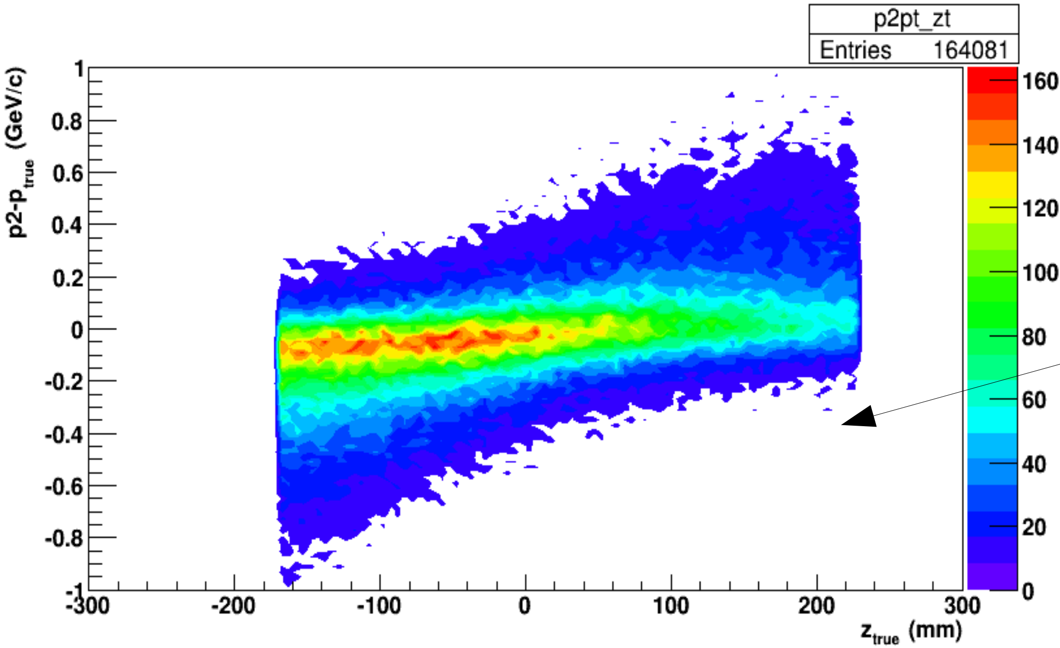
VERTEX 2 tracks (p2 momentum):
connect down segment hit to the plane z = 0 at the center of the target. This is called "vertex2 -algorithm".

Vertex2 tracks are correlated with the center plane of the target.

VERTEX 4 tracks (p4 momentum):
connect down segment hit to a 3D segment of NDC1 chamber. This is called "vertex4-algorithm".

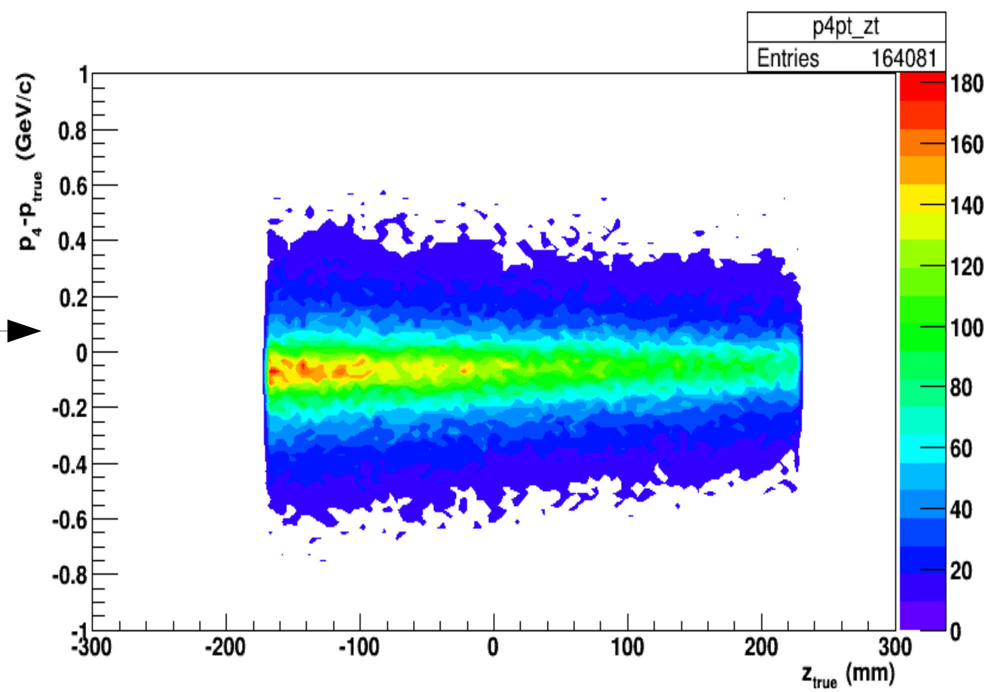


Correlation of p2 and p4 momentum with the target length

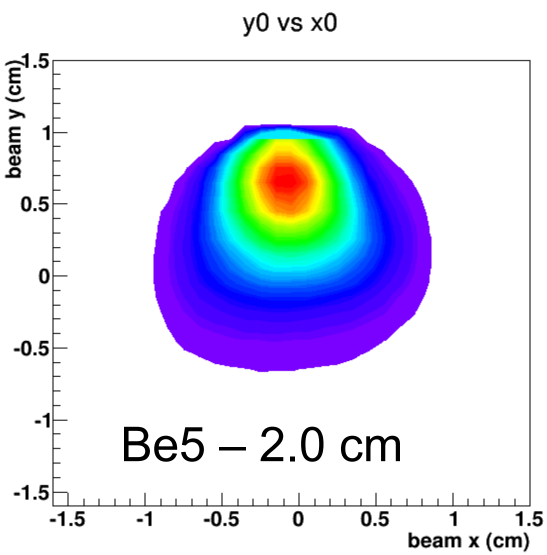


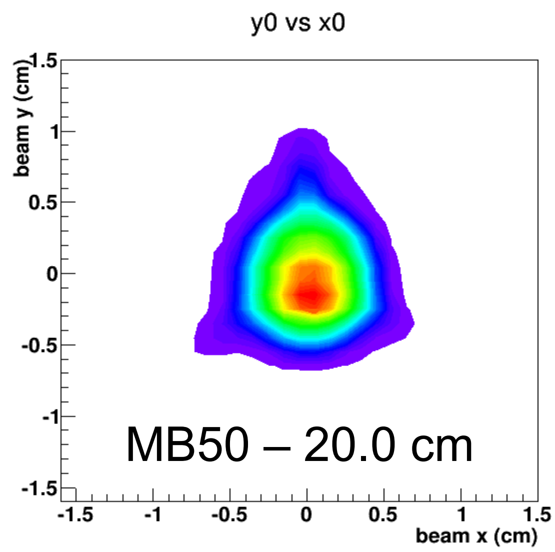
Since p2 is highly correlated with center plane,
p2 tracks have an asymmetry at the edges

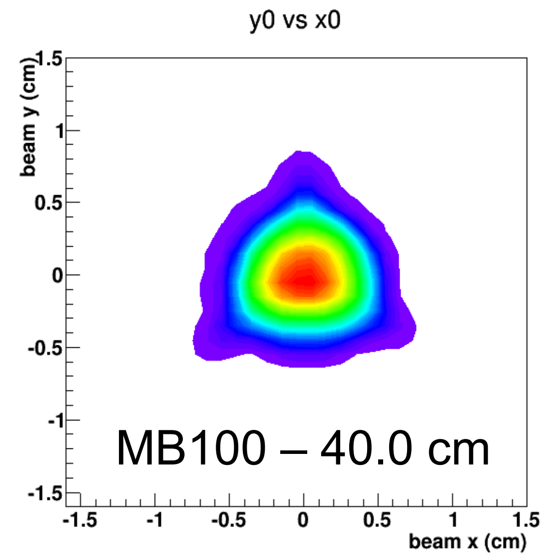
Since p4 does not correlate with center plane, this is good for long targets.



HARP measurements from three Be targets







DATA	Beam radius cut (reduce the edge effect)	P.O.T
MB100	0.4 cm	622791
MB50	0.4 cm	814749
Empty	0.4 cm	475776
Be5	1.0 cm	13070000
Empty	1.0 cm	1990000

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Yield measurement overview

$$\frac{d^2 N^{\alpha}}{dp d\Omega}(p,\theta)=\frac{1}{\Delta p \Delta\Omega}\cdot M^{-1}_{\alpha.\alpha'}\left(M^{-1}_{p\theta.p'\theta'}\left[\frac{N^{\alpha'}_{target}(p',\theta')}{N_0}-\frac{N^{\alpha'}_{empty}(p',\theta')}{N_{empty}}\right]\right)$$

Particle ID efficiency and migration matrix

$$M_{\alpha'\cdot\alpha}=\begin{pmatrix} M_{\pi\pi} & M_{\pi p} \\ M_{p\pi} & M_{pp} \end{pmatrix}$$

Absorption / decay of secondaries :– before they hit the TOF

Momentum migration

MC Correction for Tertiary particles created downstream the target

$$M^{-1}_{p\theta.p'\theta'}=\frac{1}{\varepsilon^{e-veto}(p',\theta')}\cdot\frac{1}{1-\eta^{absorb}(p',\theta'_x,\theta'_y)}\cdot M^{-1}_{p.p'}(\theta').(1-\eta^{tert}(p',\theta'_x,\theta'_y))$$

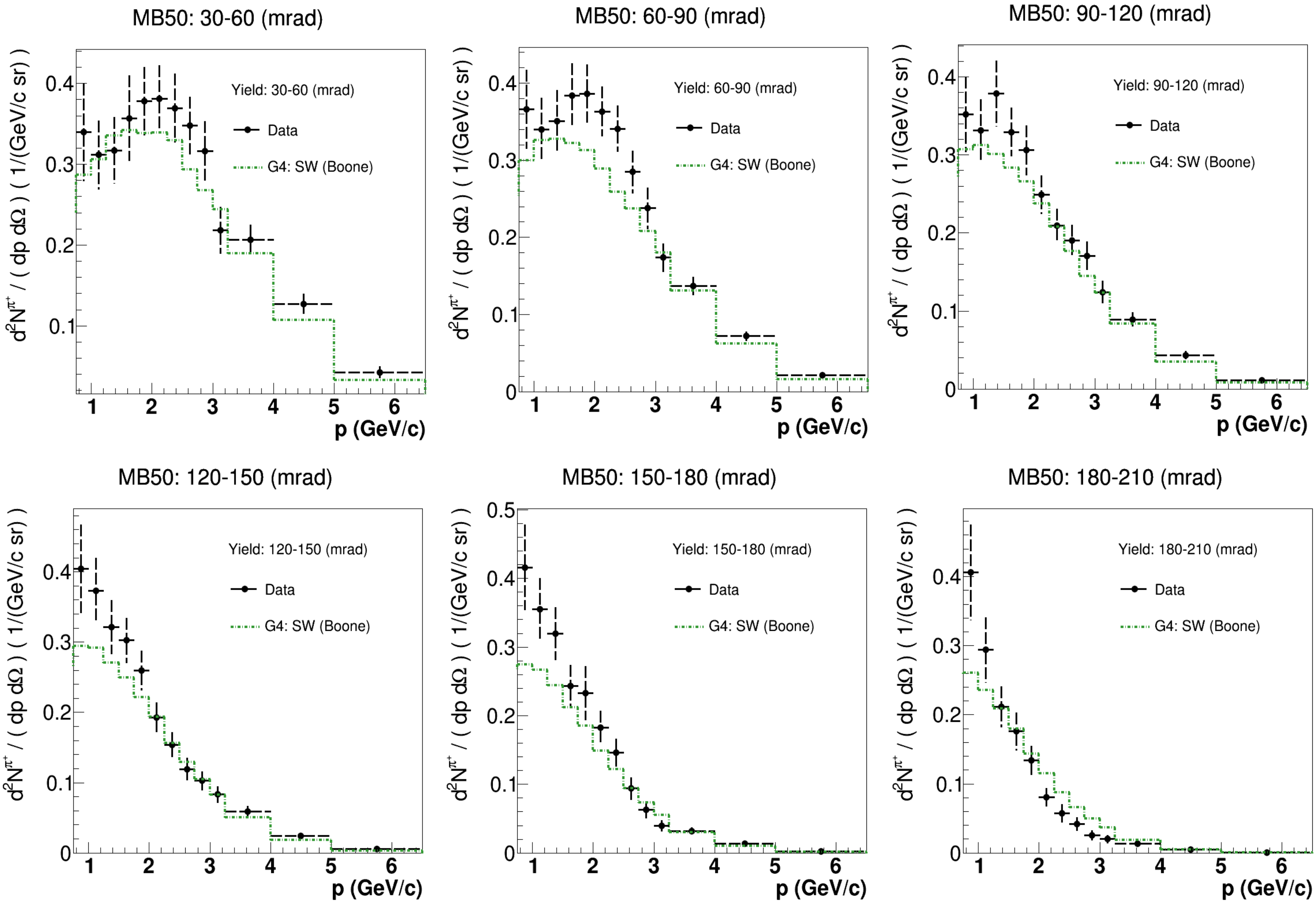
$$\cdot\frac{1}{\varepsilon^{acc}(\theta')}\cdot\frac{1}{\varepsilon^{rec}(p',\theta'_x,\theta'_y)}$$

electrons veto cut

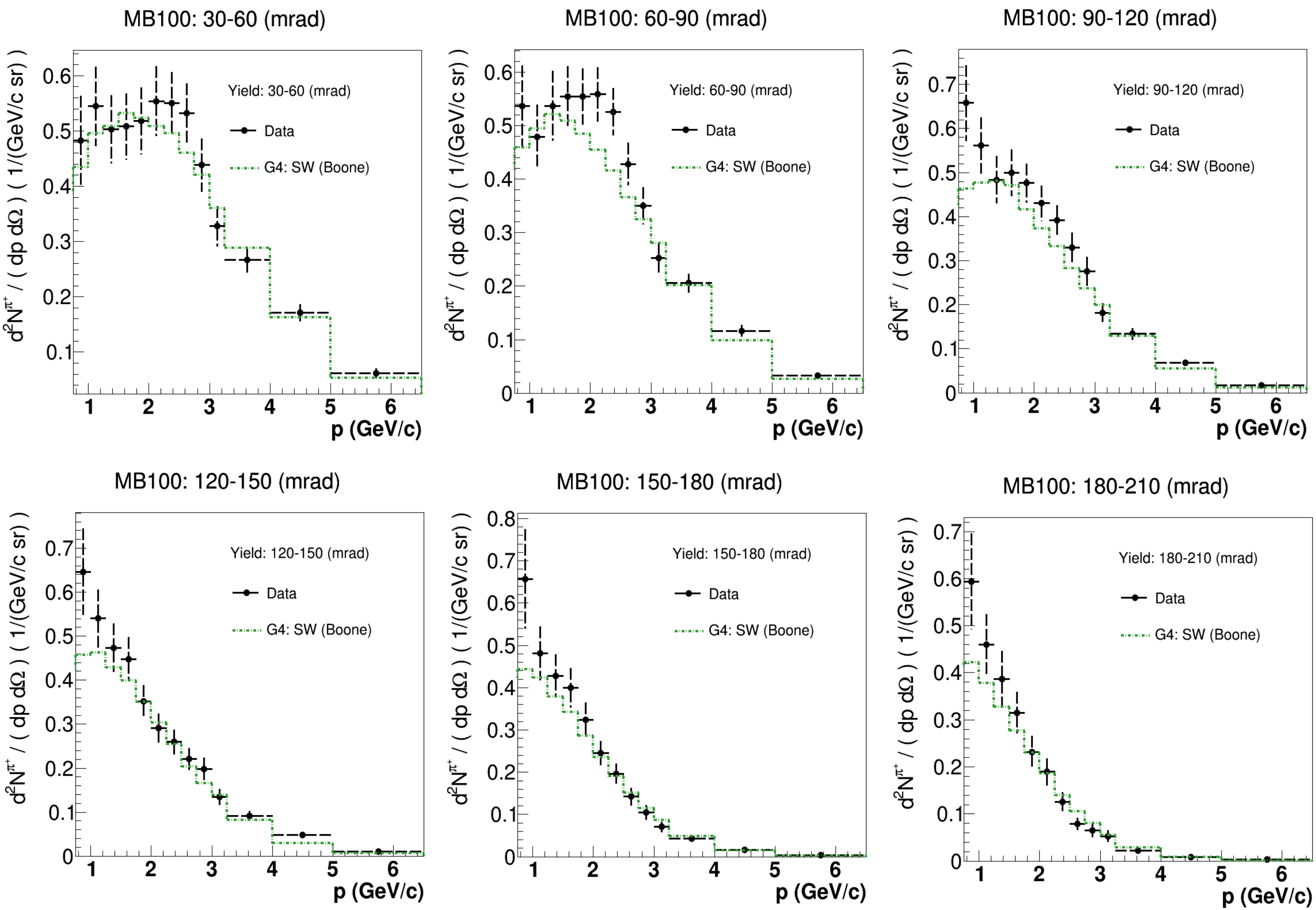
Geometric acceptance correction

Track reconstruction efficiency

MB50 data


MB50: 30-60 (mrad)
Yield: 30-60 (mrad)
Data
G4: SW (Boone)
MB50: 60-90 (mrad)
Yield: 60-90 (mrad)
Data
G4: SW (Boone)
MB50: 90-120 (mrad)
Yield: 90-120 (mrad)
Data
G4: SW (Boone)
MB50: 120-150 (mrad)
Yield: 120-150 (mrad)
Data
G4: SW (Boone)
MB50: 150-180 (mrad)
Yield: 150-180 (mrad)
Data
G4: SW (Boone)
MB50: 180-210 (mrad)
Yield: 180-210 (mrad)
Data
G4: SW (Boone)
$d^2N^{\pi^+}$ / (dp dΩ) (1/(GeV/c sr))
p (GeV/c)
0
0.1
0.2
0.3
0.4
0.5
1
2
3
4
5
6

MB100 data


MB100: 30-60 (mrad)
Yield: 30-60 (mrad)
Data
G4: SW (Boone)
MB100: 60-90 (mrad)
Yield: 60-90 (mrad)
Data
G4: SW (Boone)
MB100: 90-120 (mrad)
Yield: 90-120 (mrad)
Data
G4: SW (Boone)
MB100: 120-150 (mrad)
Yield: 120-150 (mrad)
Data
G4: SW (Boone)
MB100: 150-180 (mrad)
Yield: 150-180 (mrad)
Data
G4: SW (Boone)
MB100: 180-210 (mrad)
Yield: 180-210 (mrad)
Data
G4: SW (Boone)
$d^2N^{\pi^+}$ / (dp dΩ) (1/(GeV/c sr))
p (GeV/c)

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Thin target cross section measurement overview

$$\frac{d^2\sigma^{\alpha}(p,\theta)}{dpd\Omega} = \frac{A}{N_A.\rho.t}.\frac{1}{\Delta p.\Delta\Omega}.M^{-1}_{\alpha.\alpha'}.\left(M^{-1}_{p\theta.p'\theta'}.\left[\frac{N^{\alpha'}(p',\theta')}{N_{pot}} - \frac{N^{\alpha'}_{empty}(p',\theta')}{N^{empty}_{pot}}\right]\right)$$

t : *Thickness of the target*
ρ : *Target density*
A : *Molar mass of the target*

Changes from the yield measurements :

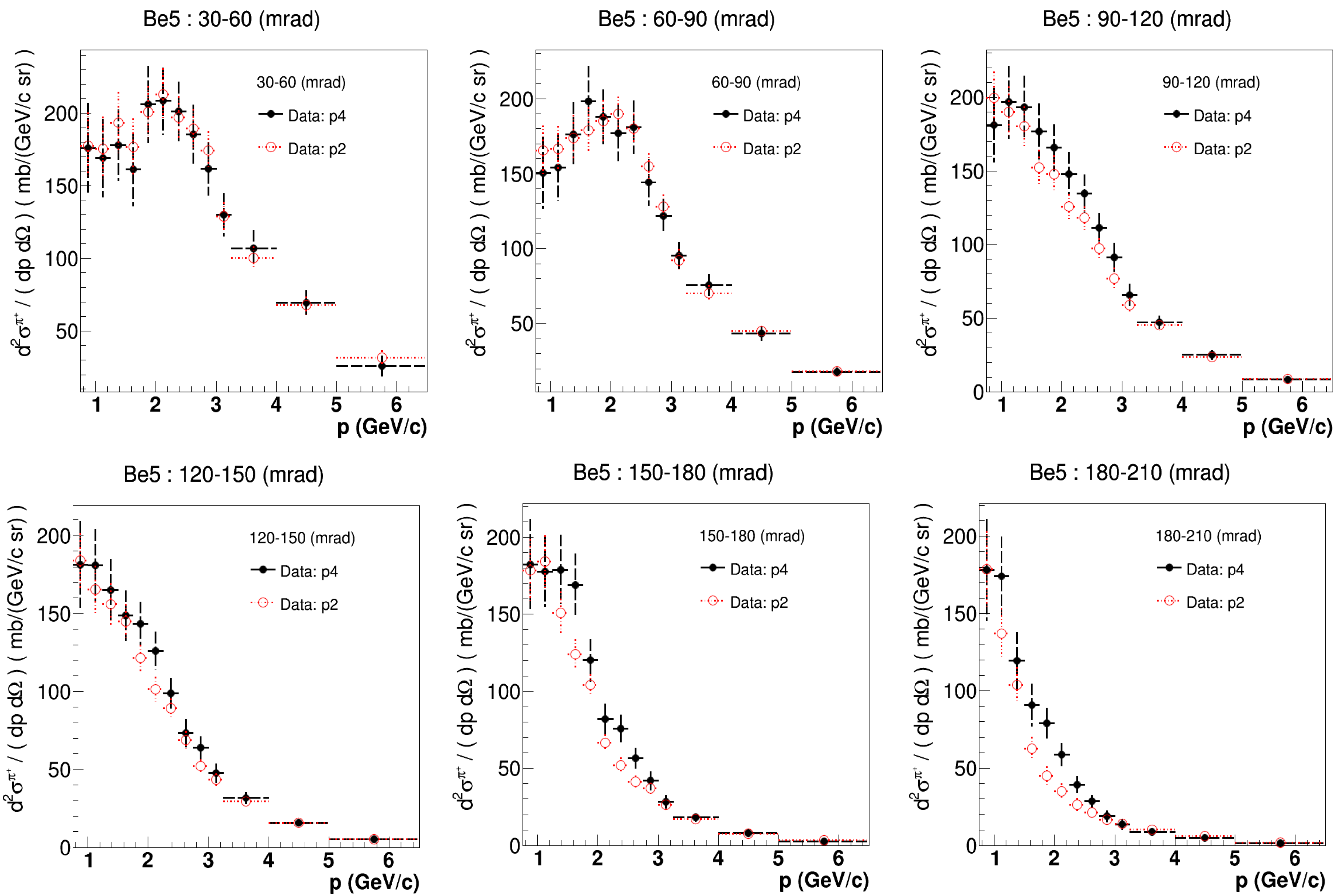
** Add cross section factor.*

** Tertiary particle correction: used every tertiary particle that created within the target or outside the target.*

Real challenge:

** Understanding the incoming beam effects on the first drift chamber.*

Be5 cross section comparison :



Fitting HARP data with two Sanford Wang models

1. Sanford-Wang model (SW:thesis):

$$\frac{d^2\sigma}{dpd\Omega}(p,\theta) \;=\; c_1 \cdot p^{c_2}\left(1-\frac{p}{p_{\rm B}-c_9}\right)e^{-g(p,\theta)}$$

Where

$$g(p,\theta) \;=\; c_3 \cdot \frac{p^{c_4}}{p_{\rm B}^{c_5}} + c_6\theta\,(p - c_7 \cdot p_{\rm B} \cdot \cos^{c_8}\theta)$$

Beam momentum = p_beam = 8.89 GeV/c

Data : Fitting Be5 p2 and E910 (SW thesis)

c1 = 220.7; c2 = 1.080; c3 = 1.0; c4 = 1.978; c5 = 1.320; c6 = 5.572; c7 = 0.08678; c8 = 9.686; c9 = 1.0;

Ref : A. A. Aguilar-Arevalo, et al., The Neutrino Flux prediction at MiniBooNE, Phys.Rev. D79 (2009) 072002

2. Extended SW model (ESW):

$$\frac{d^2\sigma}{dpd\Omega}(p,\theta) = \exp[A]p^{c_2}(1-\frac{p}{p_{\rm beam}}) \times (1+\frac{p}{p_{\rm beam}})^{c_9\theta(p-c_7 p_{\rm beam}\cos^{c_8}\theta)}$$

Where

$$A = c_1 - c_3\frac{p^{c_4}}{p_{\rm beam}^{c_5}} - c_6\theta(p - c_7 p_{\rm beam}\cos^{c_8}\theta)$$

Ref: M. G. Catanesi et al. [HARP Collaboration], arXiv:hep-ex/0702024

Data :Be5 p2-data (ESW:p2)

c1 = 5.13; c2 = 1.87; c3 = 6.67; c4 = c5 = 1.56; c6 = 11.9; c7 = 0.173; c8 = 19.8; c9 = 16.0;

Ref: M. G. Catanesi et al. [HARP Collaboration], arXiv:hep-ex/0702024

Data :Be5 p4-data (ESW:p4)

C1 = 5.39; C2 = 2.30; C3 = 7.19 C4 = C5 = 1.17 C6 = 11.2; C7 = 0.191; C8 = 18.4; C9 = 13.2

ESW:p4 fitting algorithm

$$\chi^2 = \sum_i \frac{(Data - ESW)_i^2}{\delta_{ii}^2} + \sum_{i,j} (Data - ESW)_i M(C)_{ij}^{-1} (Data - ESW)_j$$

Diagonal elements only

- *Absorption correction (sys)*
- *Tertiary particle correction (sys)*
- *Overall normalization*

covariance matrices

- *Absorption correction (stat)*
- *Tertiary particle correction (stat)*
- *Reconstruction efficiency (stat)*
- *Particle ID (sys)*
- *e-veto (stat)*
- *Momentum migration (sys + stat)*

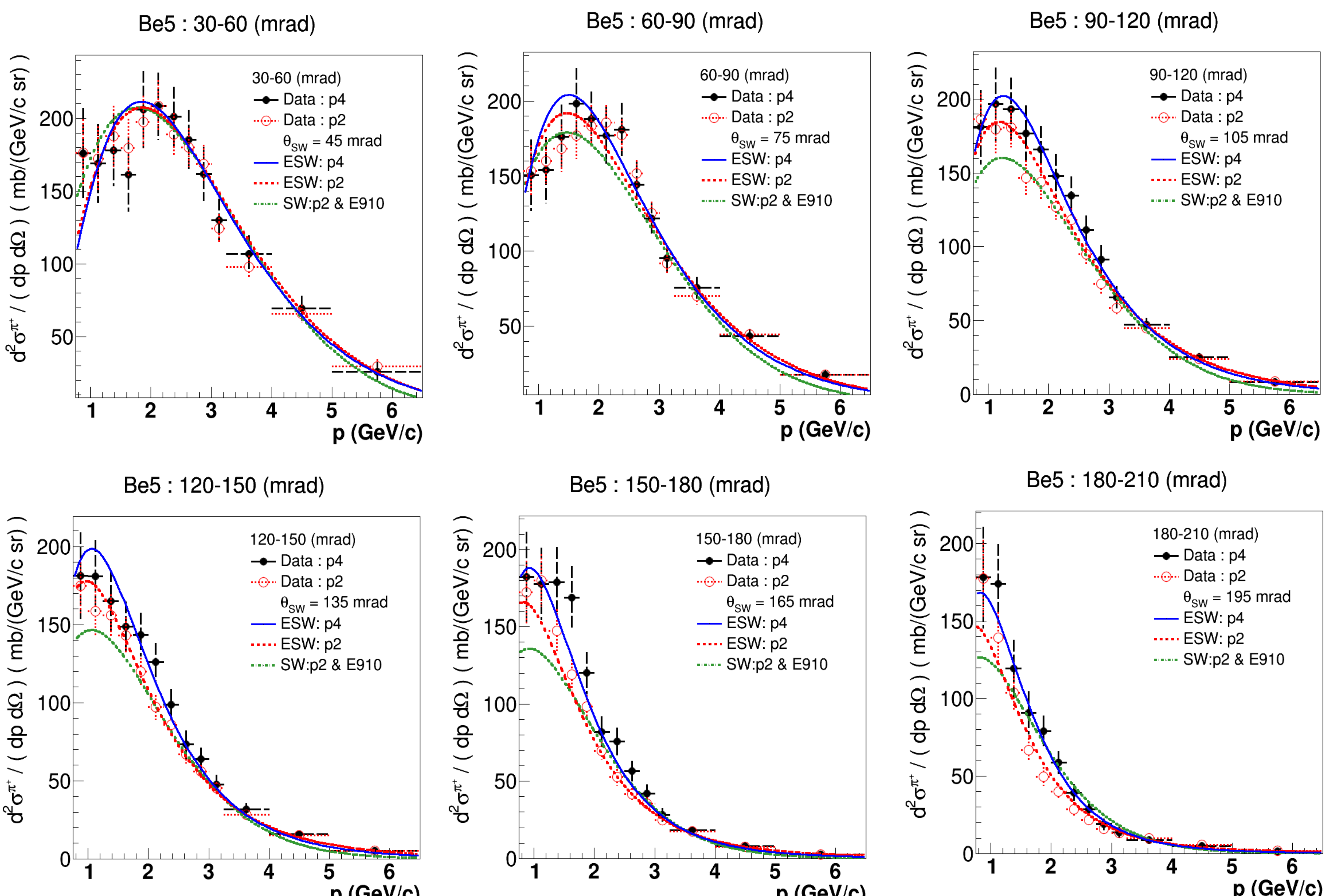
Chi2/dof = 125.4 / 70

Parameter	Best fit value
c_1	5.39 ± 0.32
c_2	2.30 ± 0.29
c_3	7.19 ± 0.68
$c_4 = c_5$	1.17 ± 0.22
c_6	11.2 ± 0.6
c_7	0.191 ± 0.008
c_8	18.4 ± 1.8
c_9	13.2 ± 1.4

Correlation coefficients of ESW parameters

parameters	c_1	c_2	c_3	$c_4 = c_5$	c_6	c_7	c_7	c_9
c_1	1							
c_2	0.848	1						
c_3	0.711	0.926	1					
$c_4 = c_5$	-0.975	-0.884	-0.697	1				
c_6	-0.507	-0.056	0.157	0.485	1			
c_7	-0.161	0.090	-0.029	-0.032	0.085	1		
c_8	0.089	0.028	-0.084	-0.184	-0.418	0.723	1	
c_9	-0.534	-0.112	0.157	0.539	0.977	0.0316	-0.390	1

Best fitted Be5 cross section comparison :



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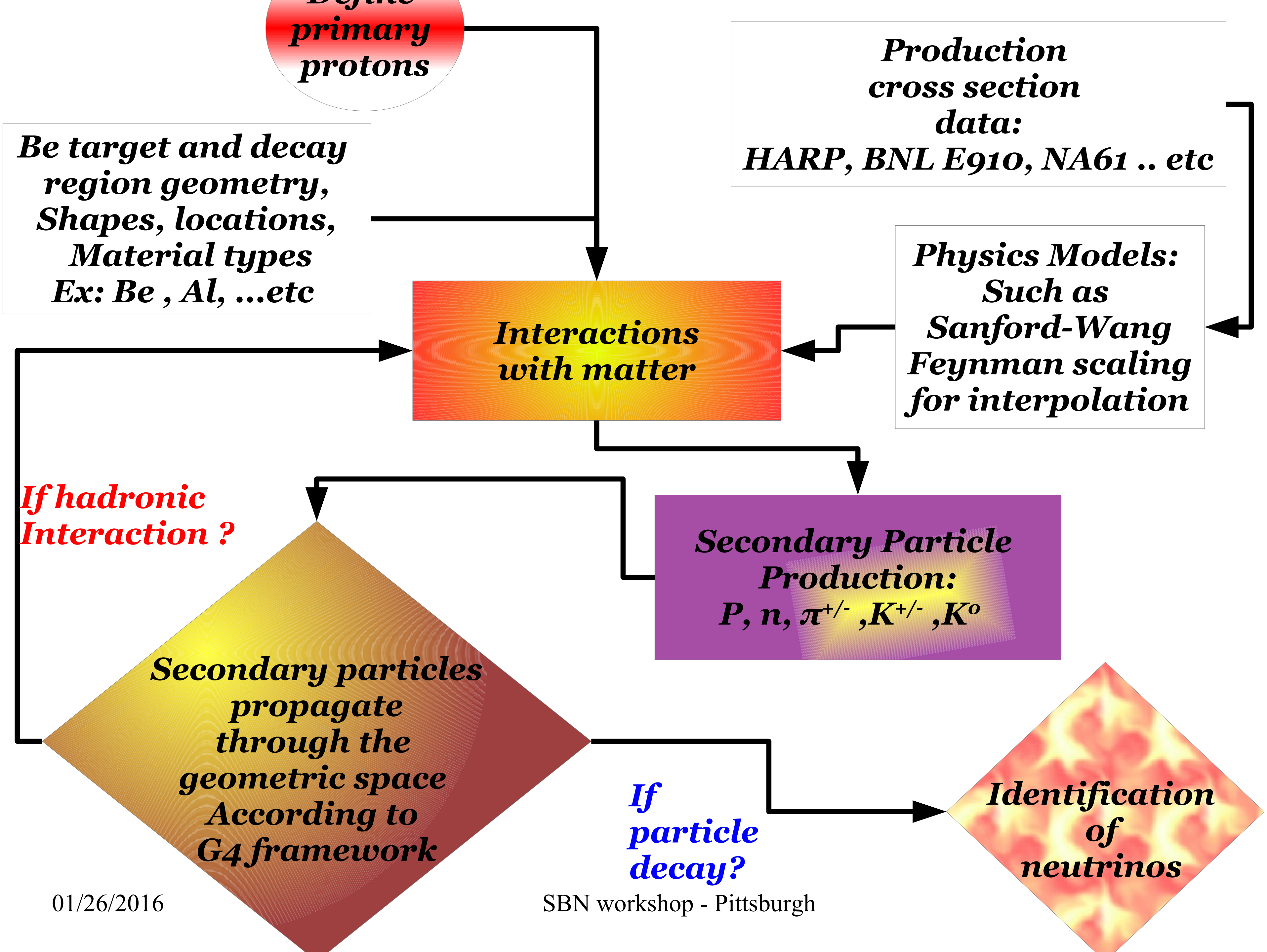
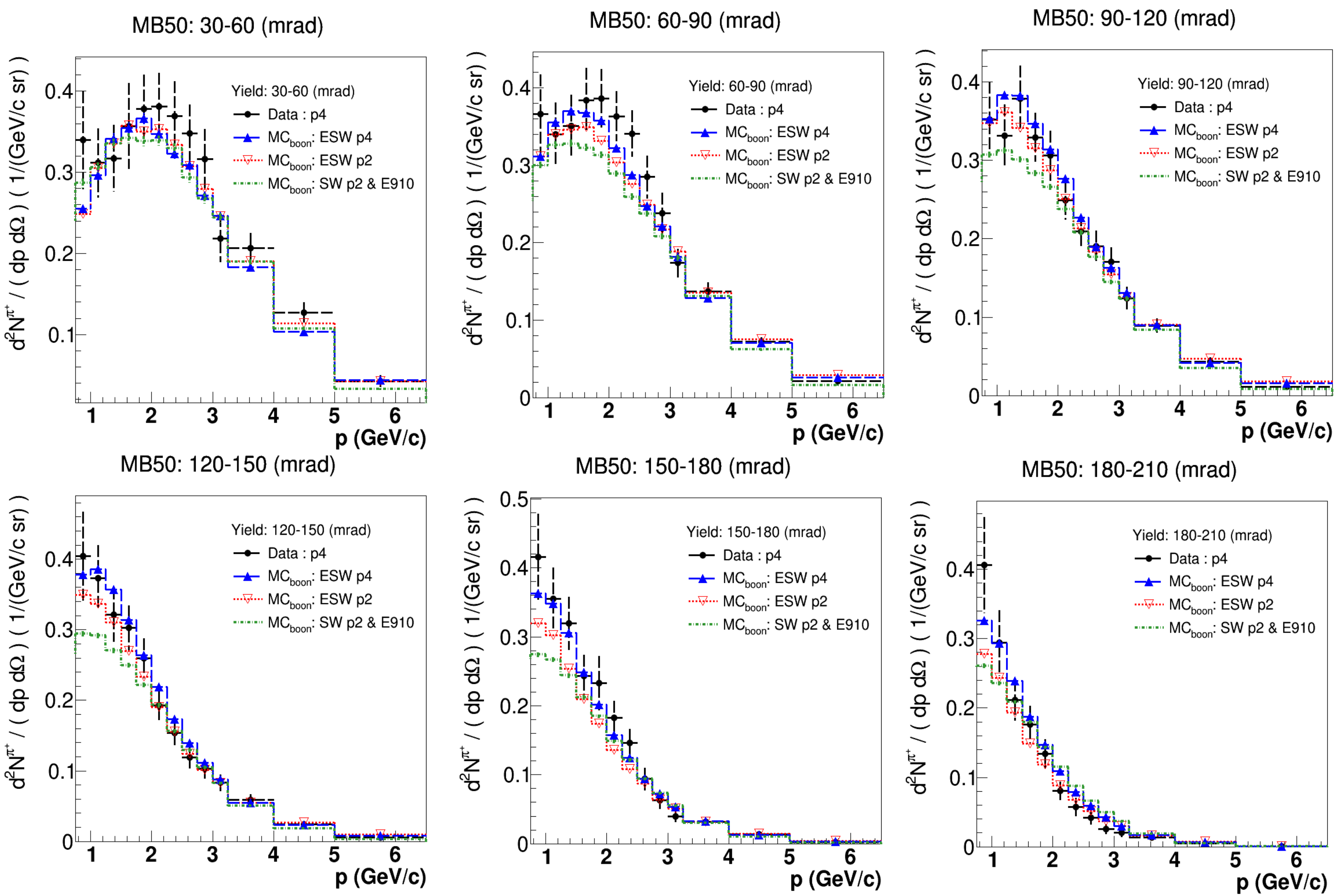
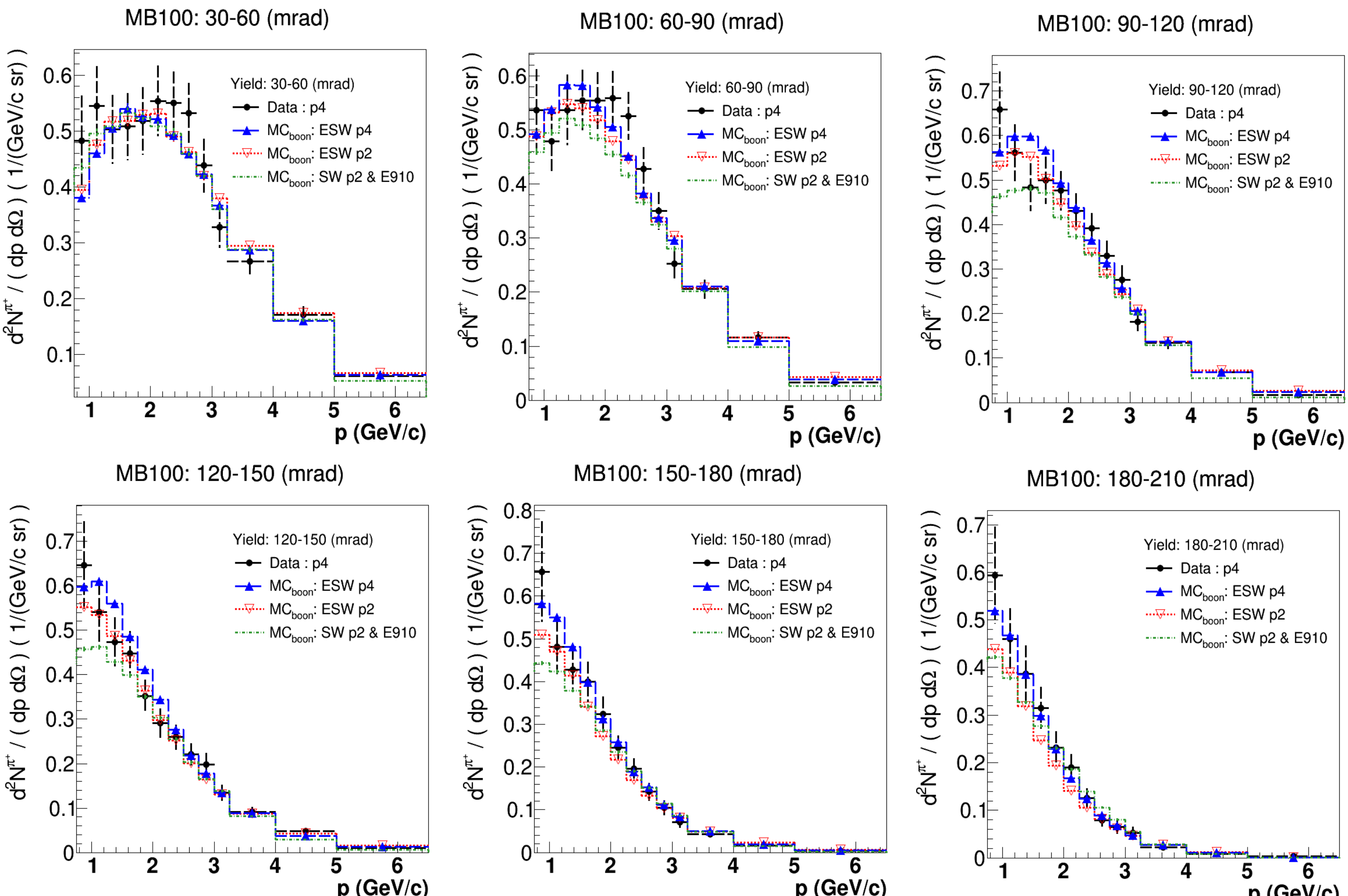
Overview of Geant4 simulator



Data - BooNE MC comparison : MB50 (20 cm) pi+ yield



Data - BooNE MC comparison : MB100 (40 cm) pi+ yield



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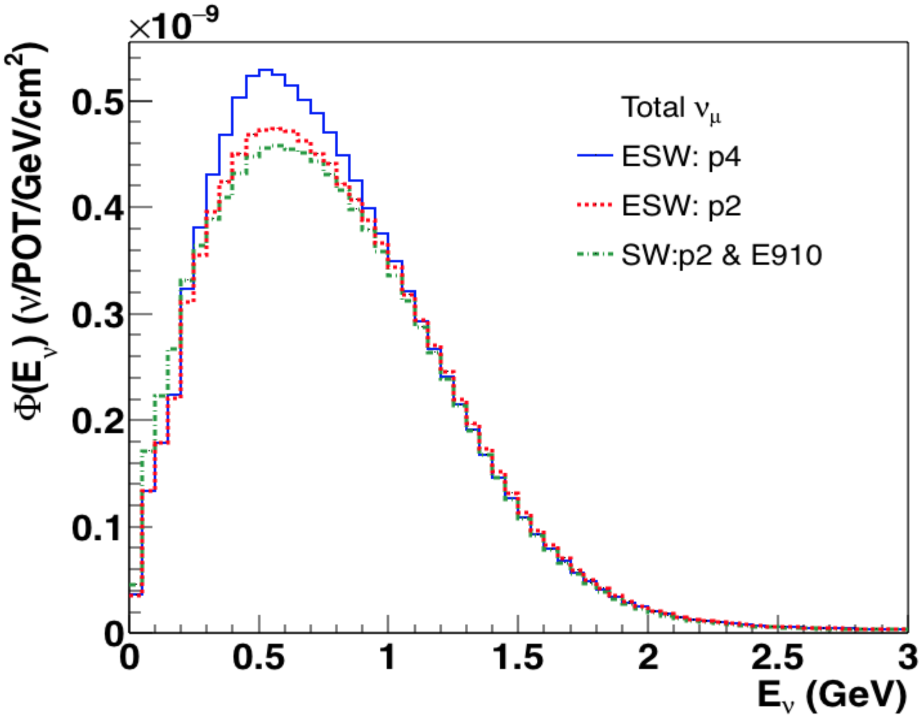
Muon neutrino flux comparison:



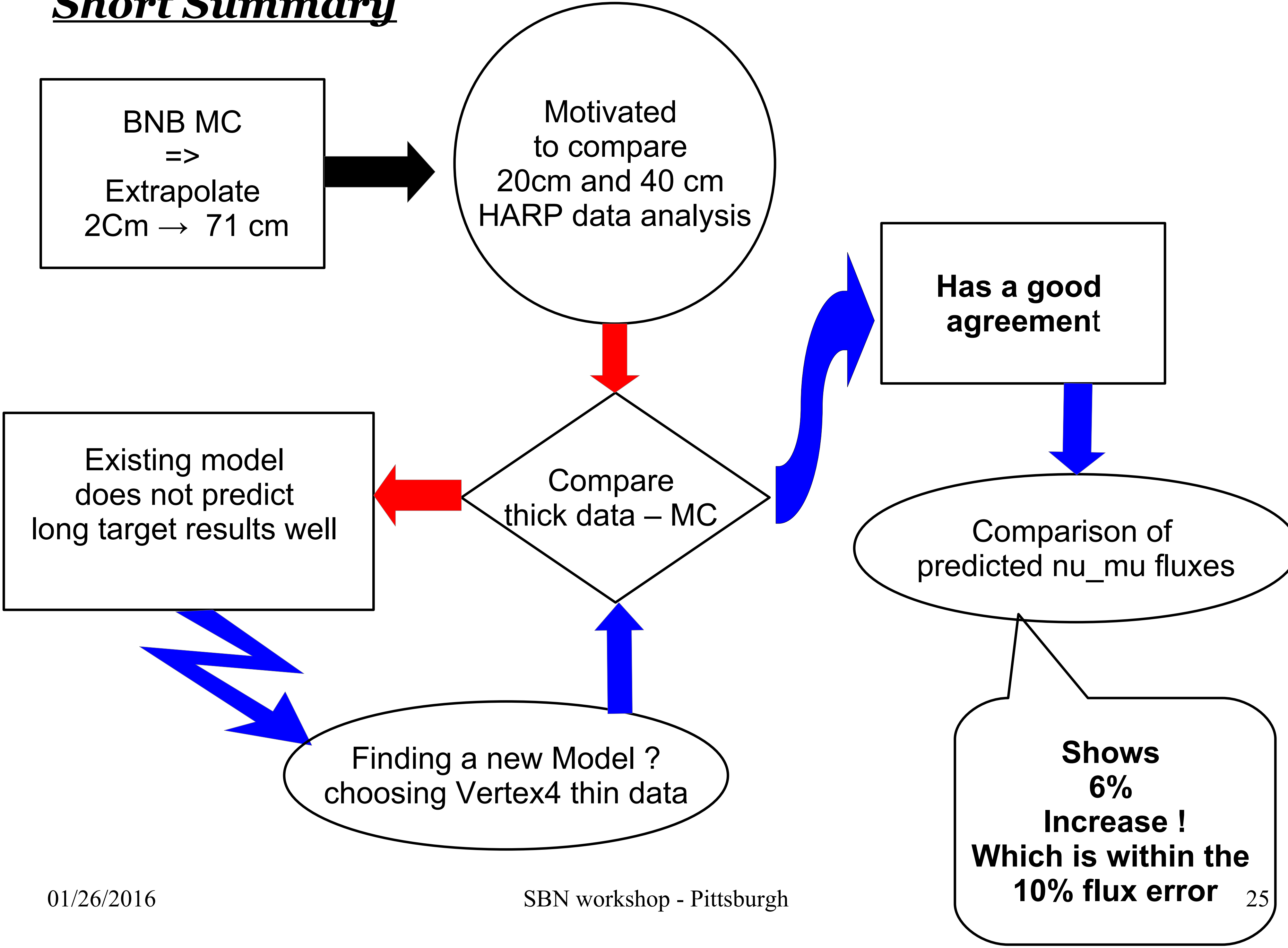
SW:p2 & E910 = 2007 April generated flux

MC statistics for p2 and p4:
P.O.T =5,000,000,000

Total flux (0-3 GeV) = 5.47 E-10 (υ_μ /POT/cm^2)
Integrated ratio = (ESW:p4)/(SW:thesis) = 1.061
(6% higher than 2007 April flux)

* *This will help to reduce systematics on CCQE cross section measurements.*
* *2007 flux has a 10% error on it but this study will help to reduce the error.*

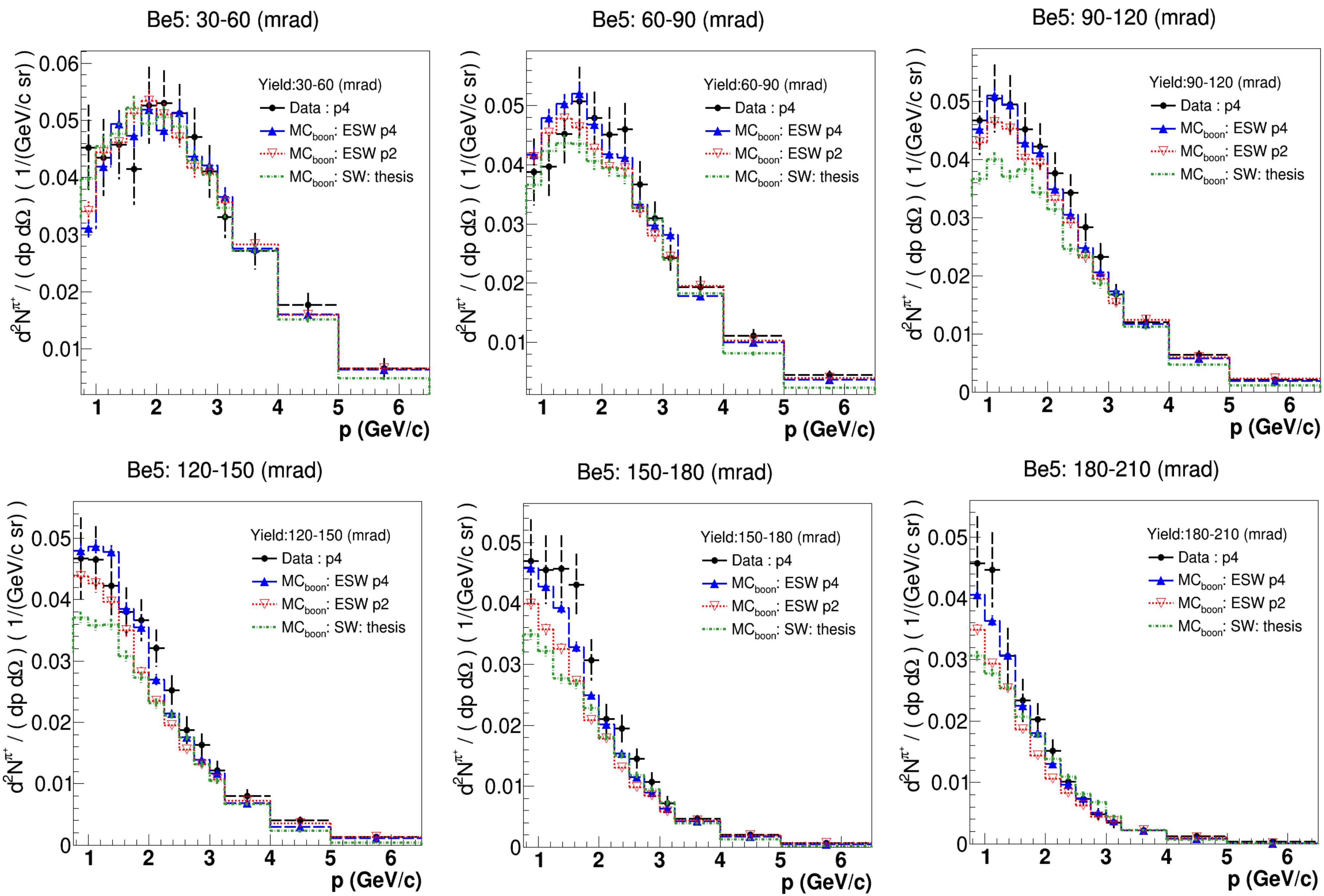
Short Summary



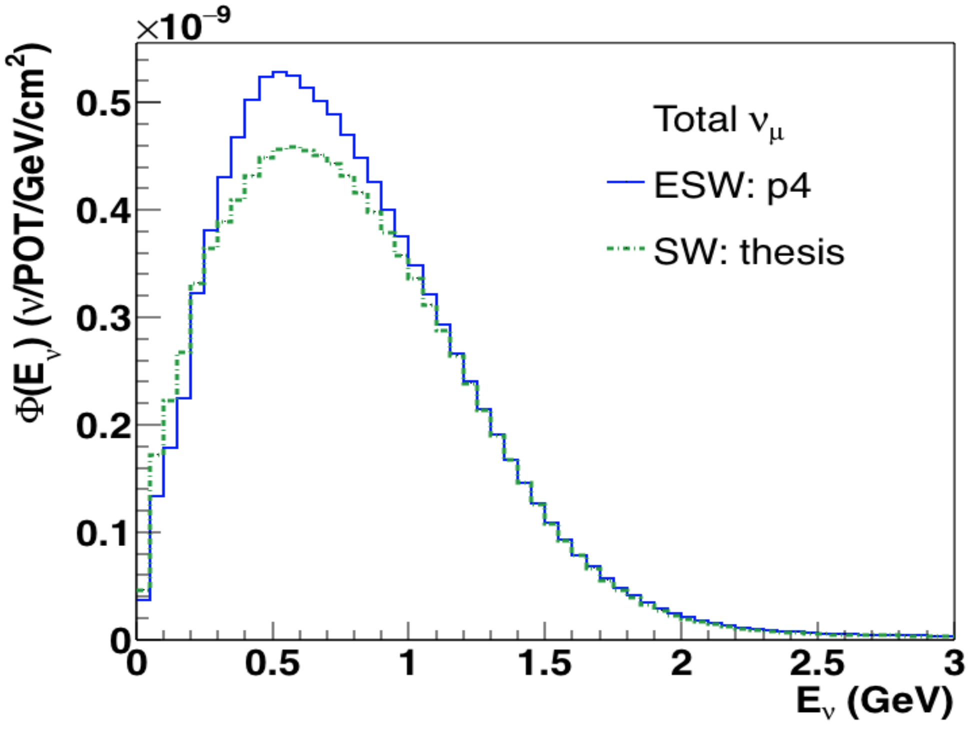
Thank you !

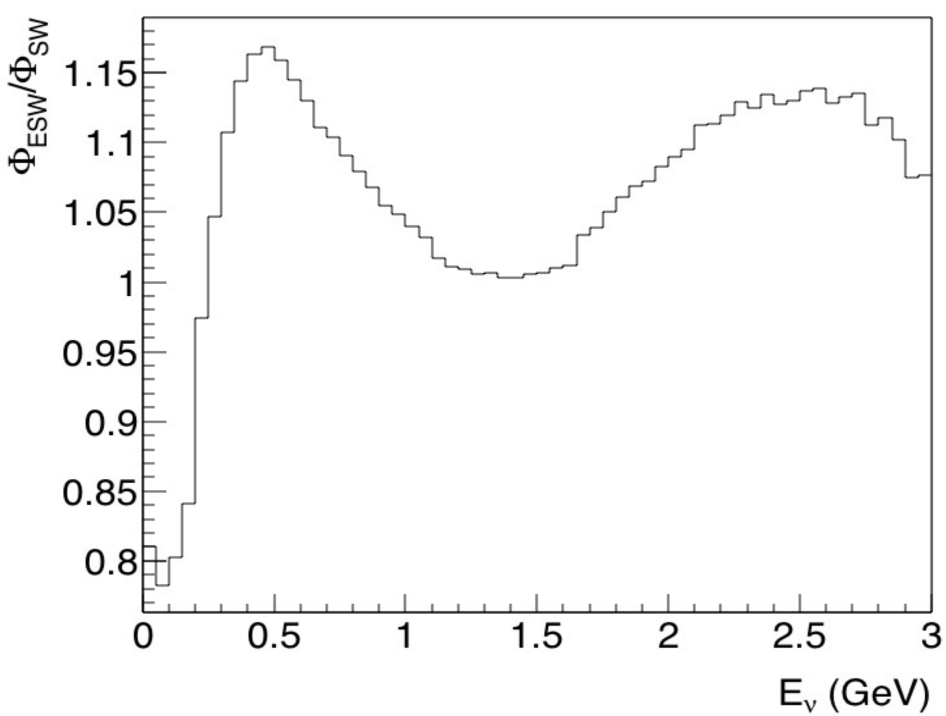
Backup slides

Data - BooNE MC comparison : Be5 yield

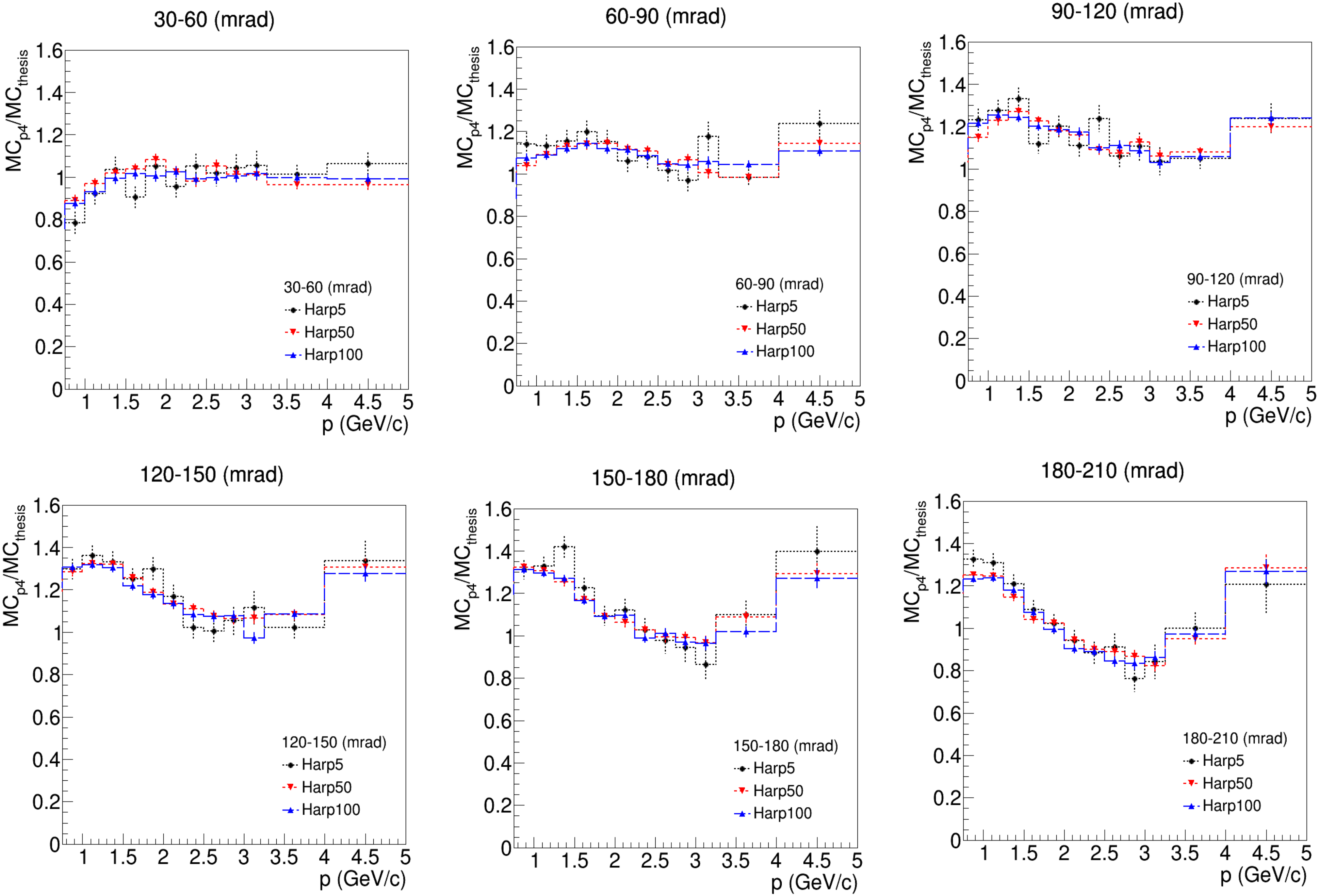


ν_μ flux ratios





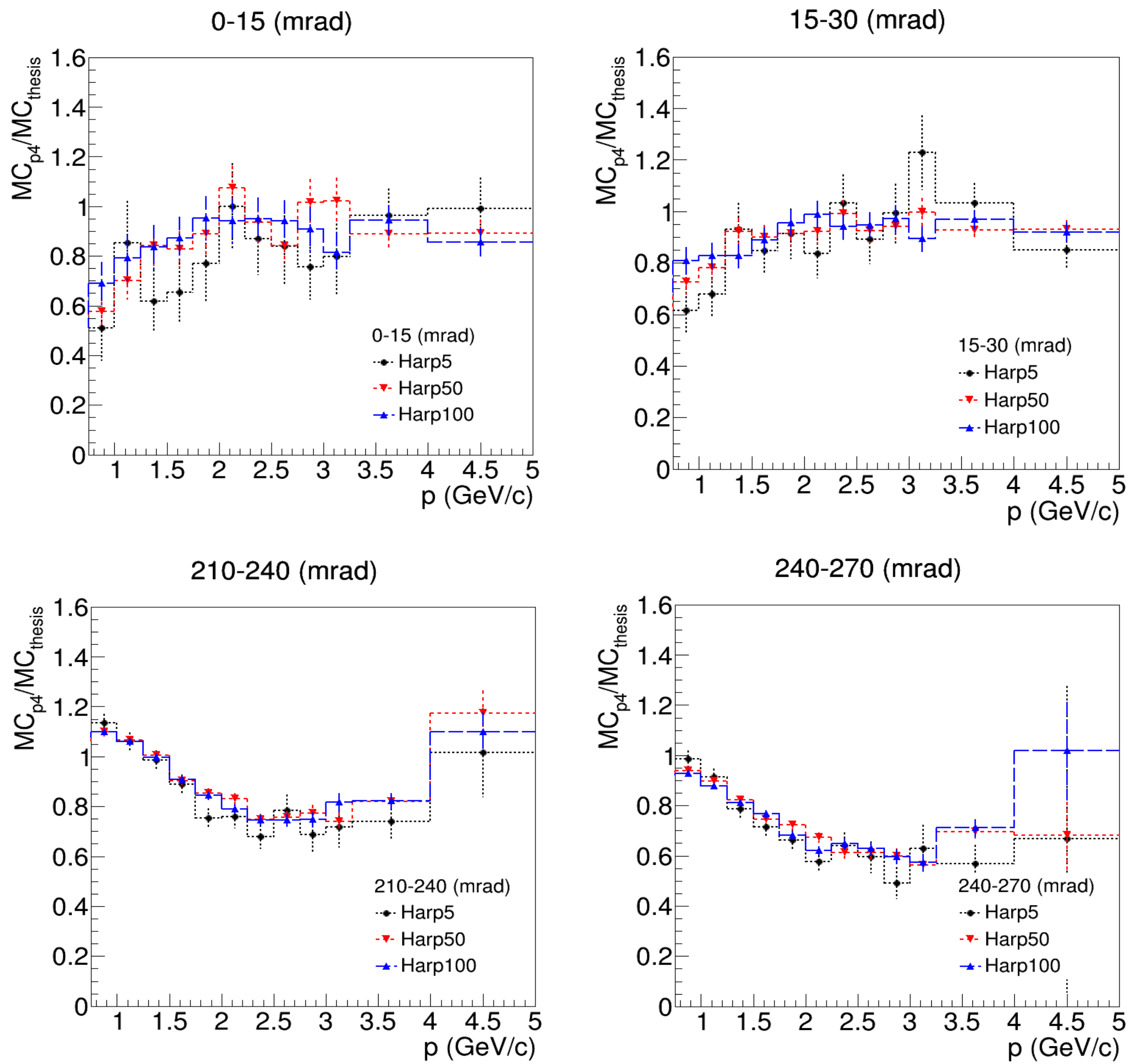
<u>*MC Yield ratio plots for all three targets:*</u> *30 <= θ <=210 mrad*



MC Yield ratio plots for all three targets:

θ < 30 mrad

θ > 210 mrad



Vertex2 momentum reconstruction : long target