Pi+ Production Cross Sections from HARP long targets

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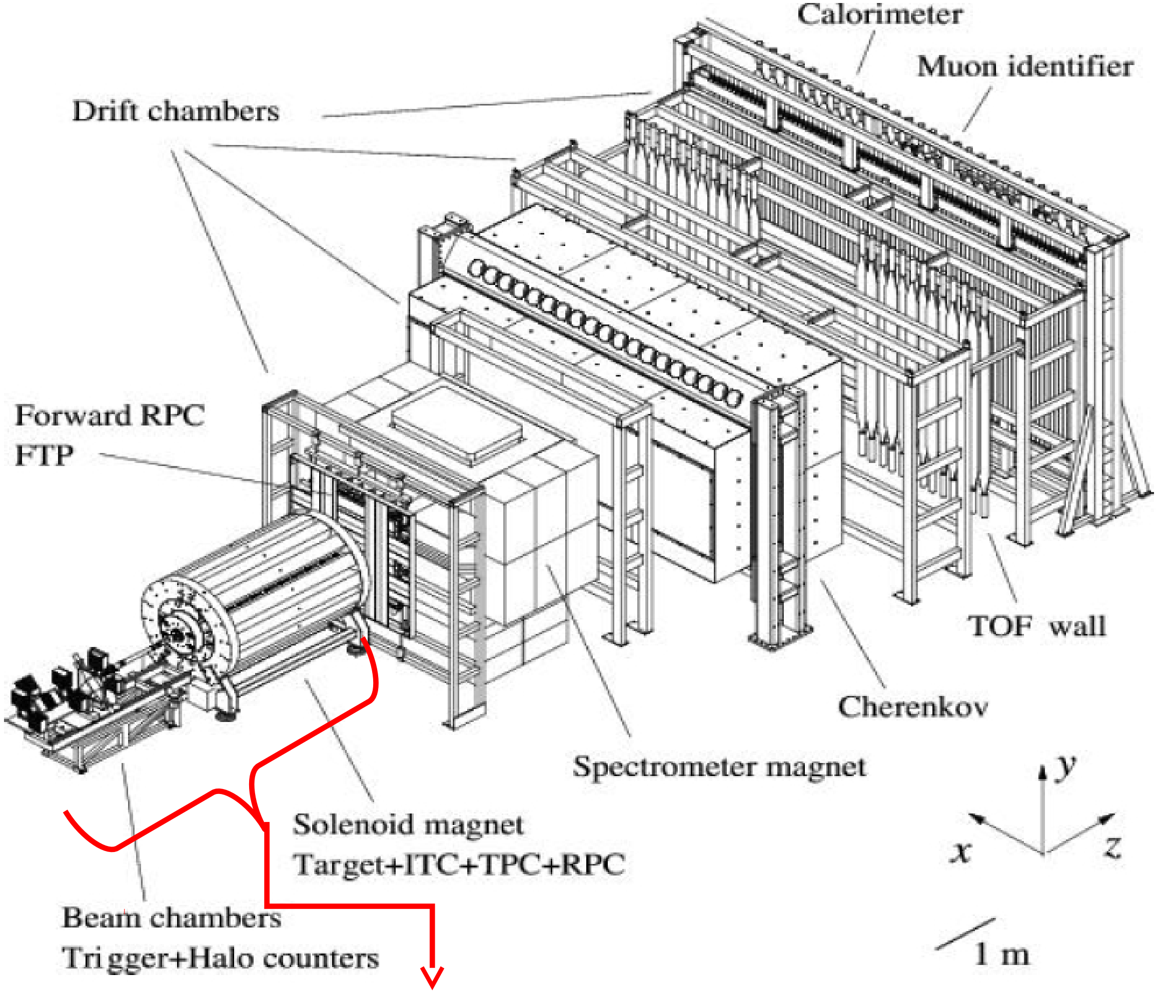
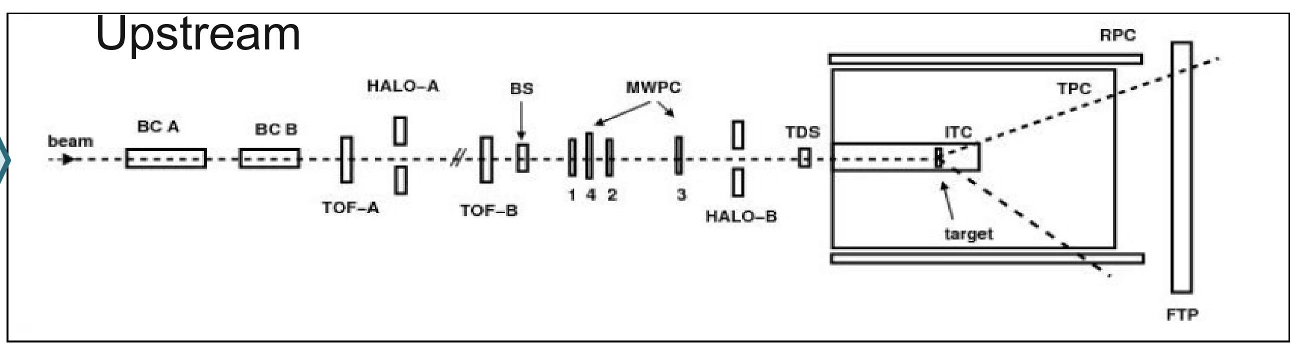
Introduction to the Harp setup



Primary Beam line (T9 beam)

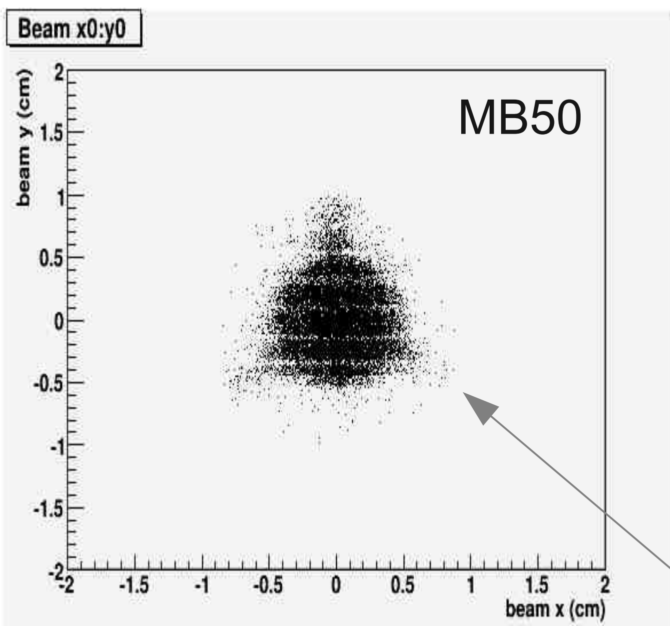


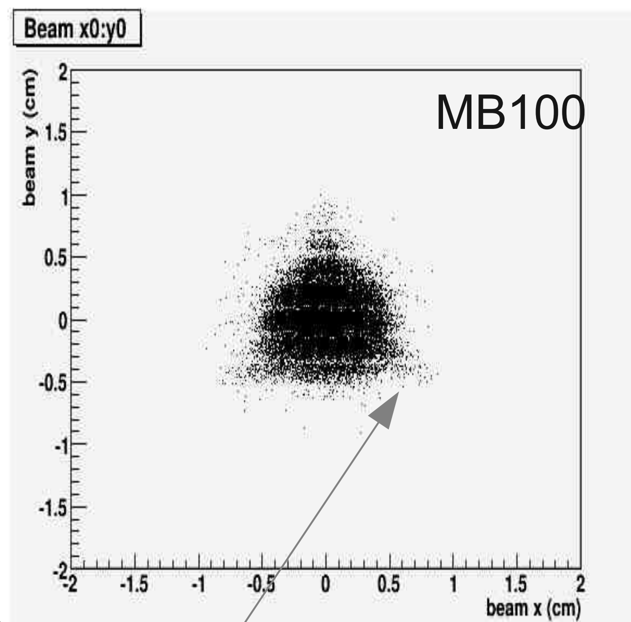
Targets for MiniBooNE

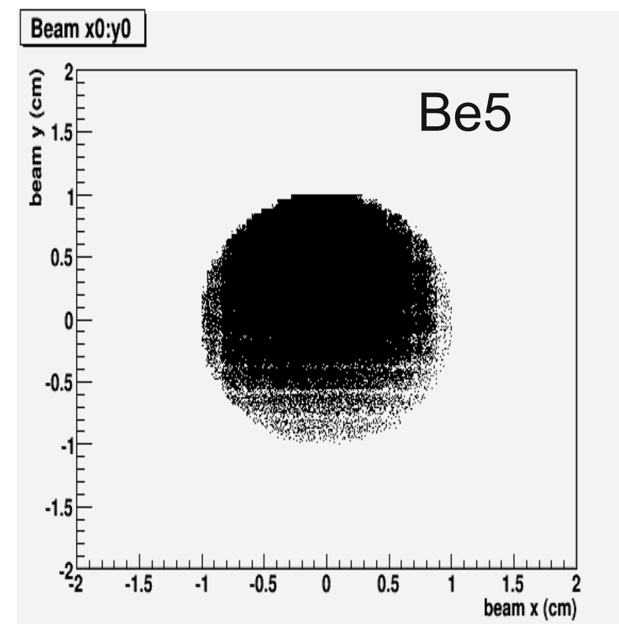
Thin targets : Be5 (5% λ) , Al5 (5% λ) - 2.0 cm
(David Schmitz has already analyzed these targets very well)

Thick targets : MB50 (50% λ) - 20.0 cm
: MB100 (100% λ) - 40.0 cm

Secondary pions from the targets







Fins

All have 1cm beam radius cut

Main Focuses =>

1. Improve the proton attenuation correction => Attenuation length

2. Tertiary particle correction. (Re-interaction of secondaries with Be)

3. Update the Sanford-Wang parameters with long target cross sections on MiniBooNE Beamline MC

=> Finally reduce the systematics on neutrino flux prediction.

Cross Section Measurements

$$\frac{d^2\sigma^{\alpha}_{long}}{dpd\Omega}(p,\theta)=\frac{\sigma_{p-Be}}{N_0\left(1-e^{-nl\sigma_{p-Be}}\right)}\frac{d^2N^{\alpha}(p,\theta)}{dpd\Omega}$$

$$=\frac{\sigma_{p-Be}}{N_0\left(1-e^{-nl\sigma_{p-Be}}\right)}M^{-1}_{p\theta\alpha.p'\theta'\alpha'}\frac{N^{\alpha'}(p',\theta')}{\Delta p\Delta\Omega}$$

$$n=\frac{N_A\cdot\rho}{A_{target}}$$

Secondary Hadron Yield

Double differential Production Cross Section of α type particle

Thick target correction term

Correction matrix to unfold the true variables (p,θ,α) from reconstructed (p',θ',α')

Bin sizes of momentum and solid angle

Short Target Approximation

$$\textit{if the target length}: l \ll l_0(\textit{interaction lenght}) \Rightarrow \left(1-e^{-n.l.\sigma_{p-Be}}\right)\approx n.l.\sigma_{p-Be}$$

$$\frac{d^2\sigma^{\alpha}_{short}}{dpd\Omega}(p,\theta)\approx\frac{A_{target}}{N_A.\rho.l}\frac{1}{\Delta p.\Delta\Omega}\frac{1}{N_0}M^{-1}_{p\theta\alpha.p'\theta'\alpha'}N^{\alpha'}(p',\theta')$$

n : *number density of Be nuclei*

l : *Thickness of the target along the beam axis*

ρ : *Target density*

A_{target} : *Molar mass of the target*

N_A : *Avogadro number*

N_0 : *Protons on the target*

$$\frac{A_{target}}{\rho N_A l}=(\textit{number of target nuclei per Area})^{-1}$$

Complete Analysis :

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

Track reconstruction efficiency

$$M^{-1}_{p\theta\cdot p'\theta'} = \frac{1}{\varepsilon^{\text{e-veto}}(p,\alpha)} \cdot \frac{1}{1-\eta^{\text{absorb}}(p,\theta_x,\theta_y,\alpha)}$$

$$\cdot\, M^{-1}_{p\cdot p'}(\theta') \cdot (1-\eta^{\text{tert}}(p',\theta'_x,\theta'_y,\alpha)) \cdot \frac{1}{\varepsilon^{\text{acc}}(\theta')} \cdot \frac{1}{\varepsilon^{\text{recon}}(p',\theta'_x,\theta'_y)}$$

electrons veto cut

Momentum migration
Need a mock MC

Correction for Tertiary particles

Geometric acceptance correction

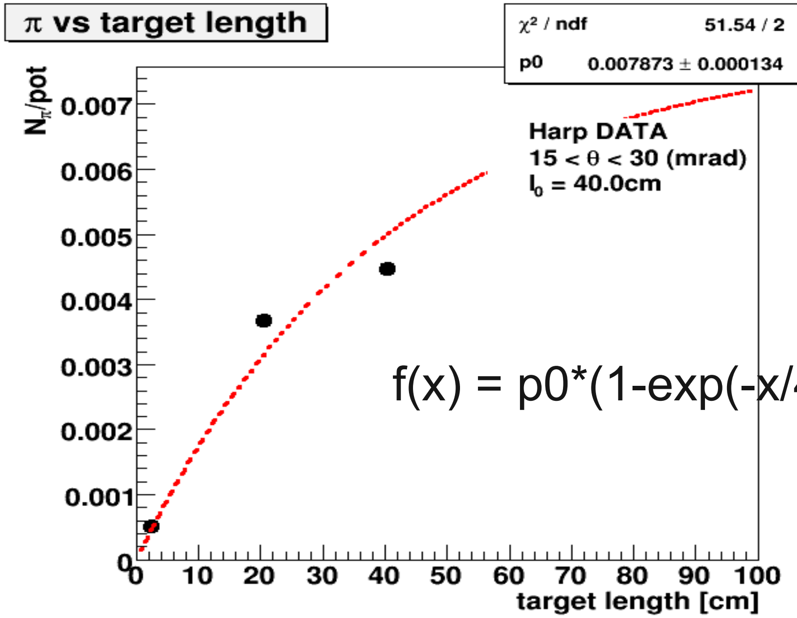
$$\frac{d^2\sigma^{\alpha}_{long}}{dp\,d\Omega}(p,\theta) = \frac{\sigma_{p-Be5}}{(1-e^{-n l \sigma_{p-Be5}})} \frac{1}{\Delta p\,\Delta\Omega} M^{-1}_{\alpha.\alpha'} \left(M^{-1}_{p\theta.p'\theta'} \left[\frac{N^{\alpha'}_{target}(p',\theta')}{N_0} - \frac{N^{\alpha'}_{empty}(p',\theta')}{N_{empty}} \right] \right)$$

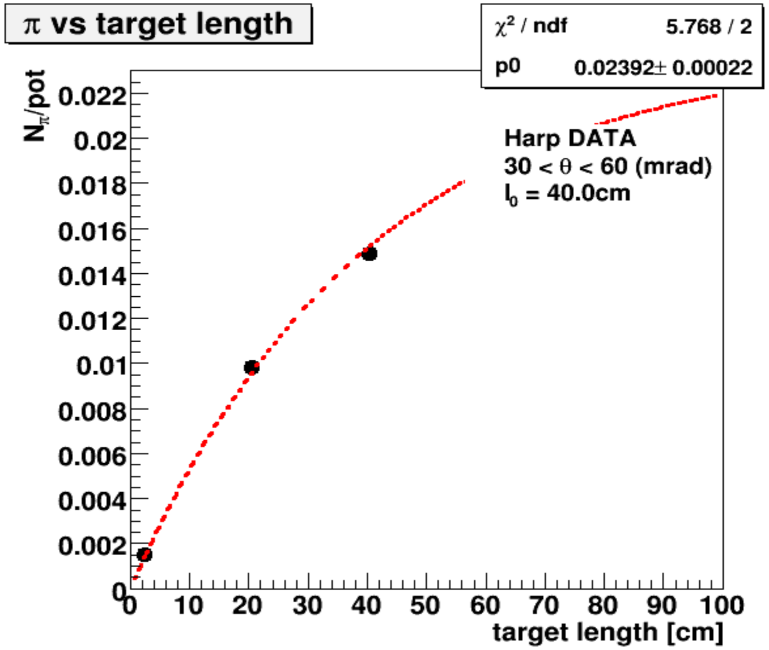
Particle ID efficiency and migration matrix

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

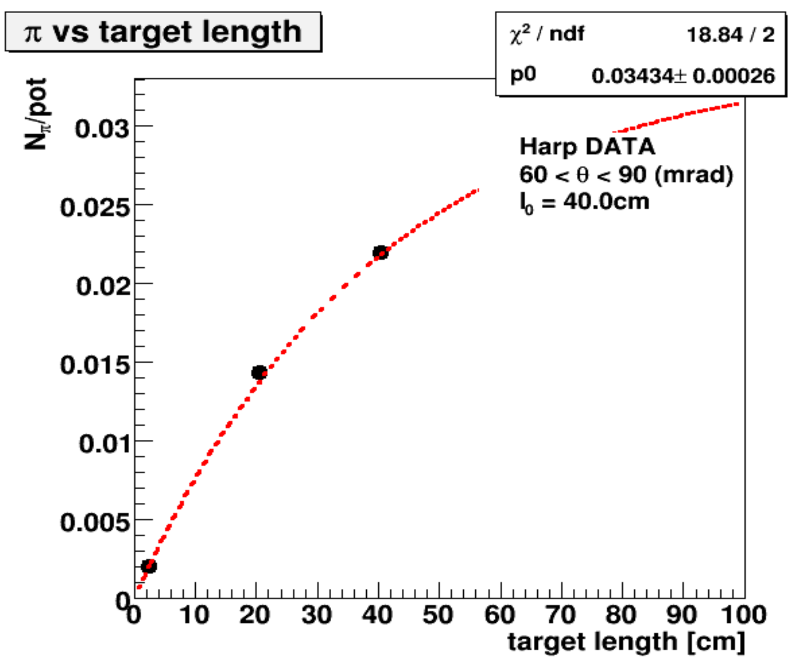
Example: Pion to proton migration

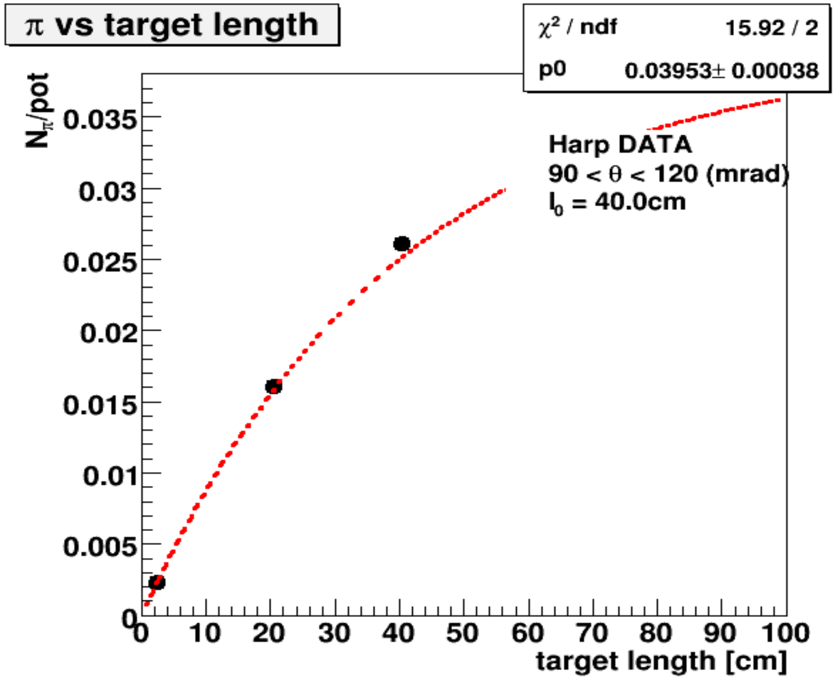
Pi+ distribution vs target length

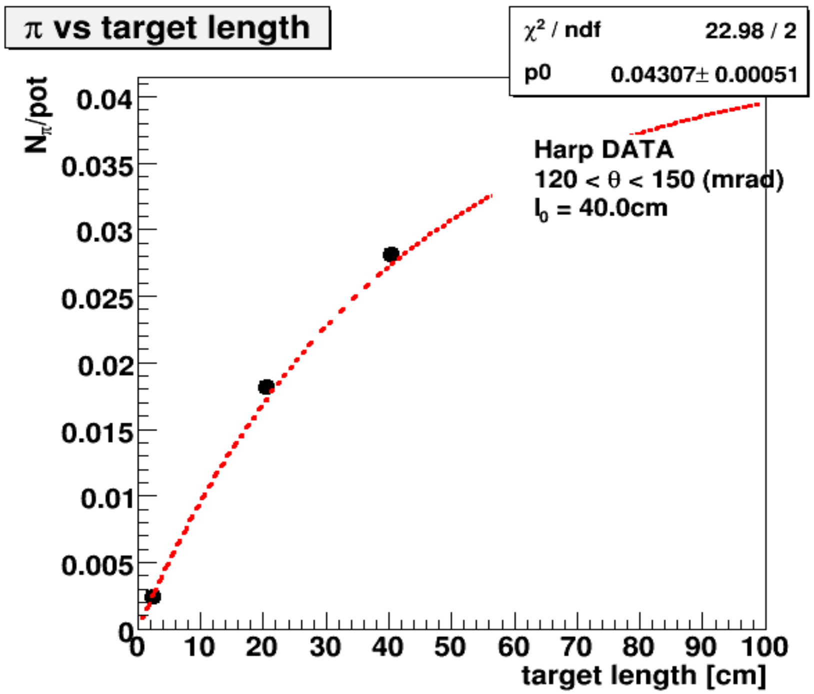


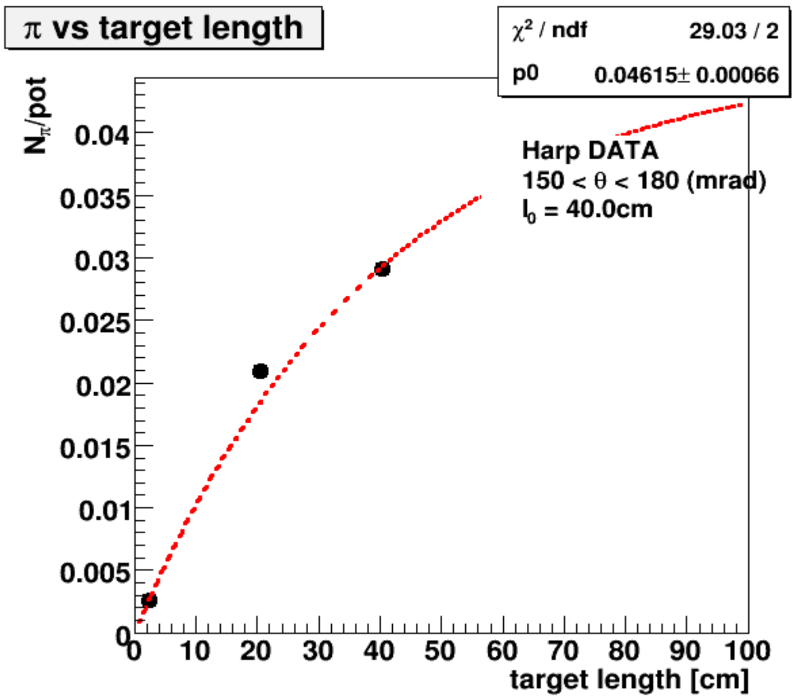


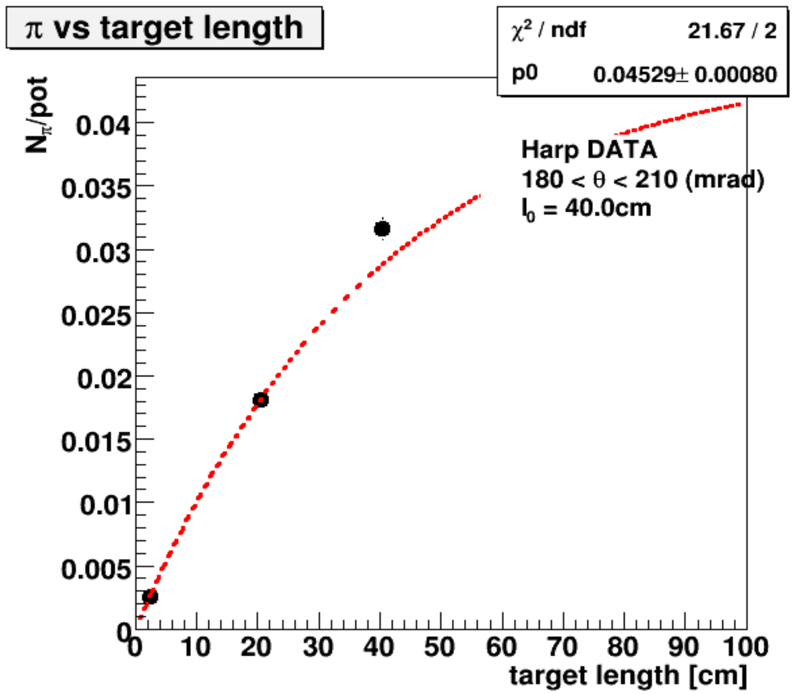
f(x) = p0*(1-exp(-x/40.0))

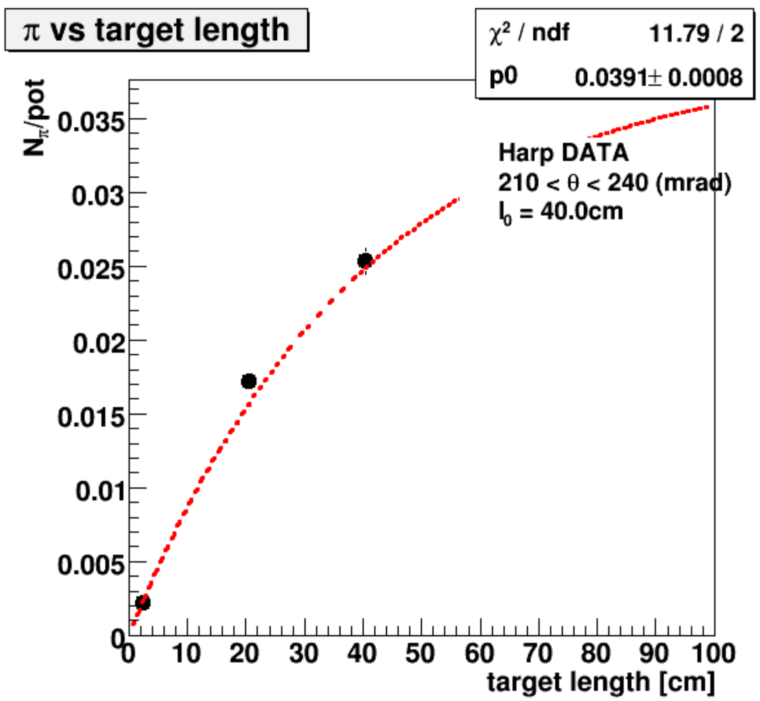




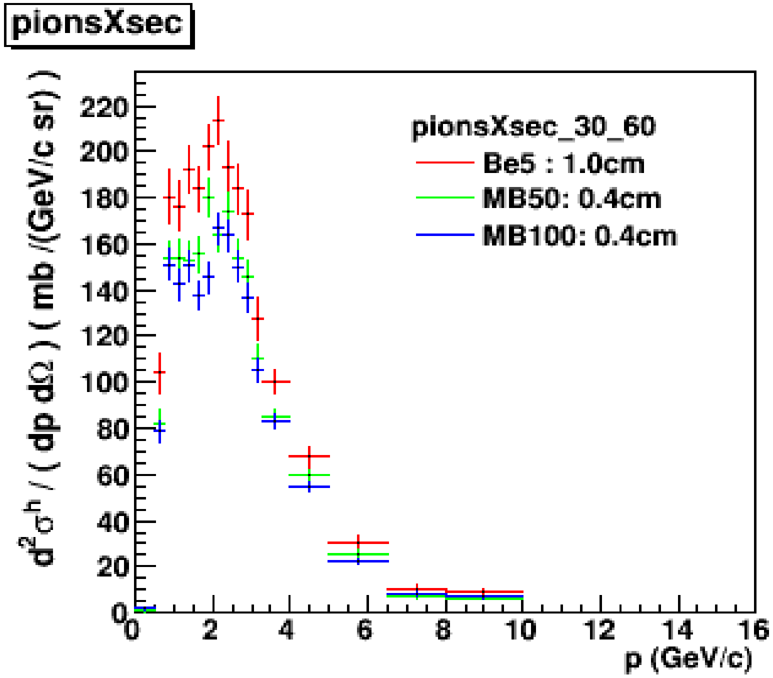

π vs target length
χ² / ndf 22.98 / 2
p0 0.04307± 0.00051
Harp DATA
120 < θ < 150 (mrad)
l0 = 40.0cm
Nπ/pot
target length [cm]

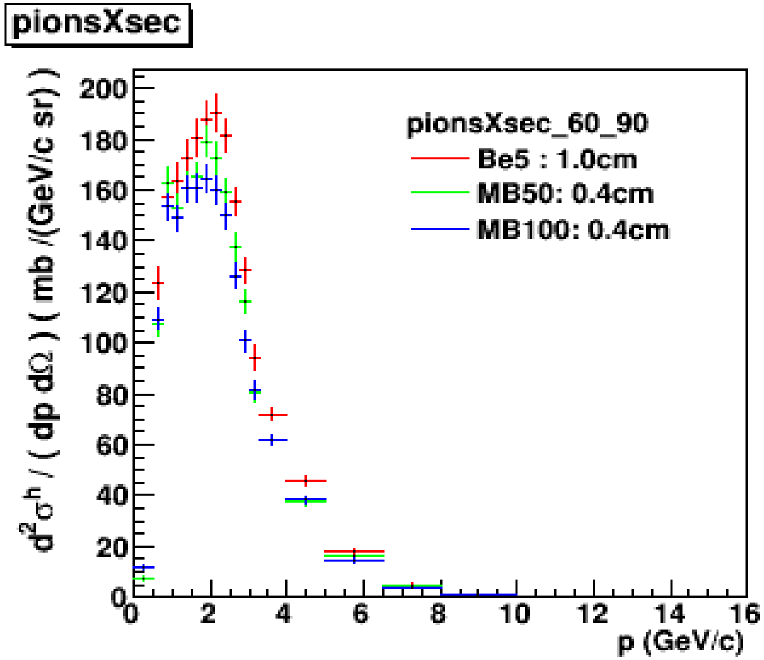

π vs target length
χ² / ndf 29.03 / 2
p0 0.04615± 0.00066
Harp DATA
150 < θ < 180 (mrad)
l0 = 40.0cm
Nπ/pot
target length [cm]

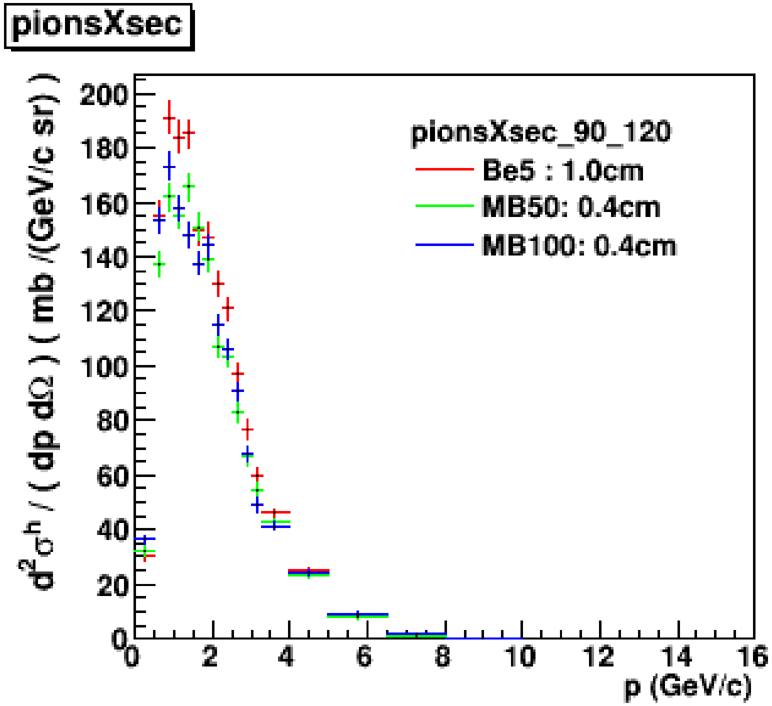

π vs target length
χ² / ndf 21.67 / 2
p0 0.04529± 0.00080
Harp DATA
180 < θ < 210 (mrad)
l0 = 40.0cm
Nπ/pot
target length [cm]

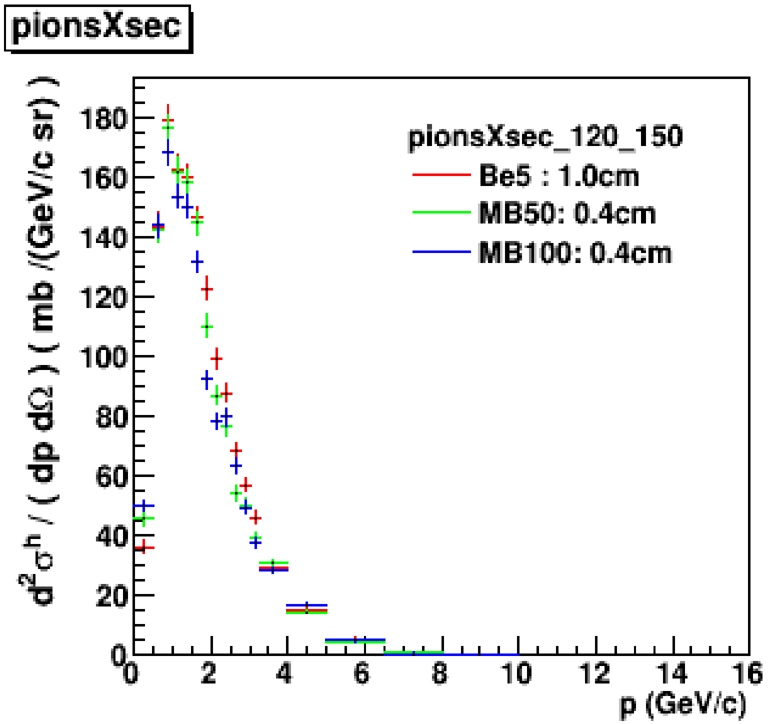

π vs target length
χ² / ndf 11.79 / 2
p0 0.0391± 0.0008
Harp DATA
210 < θ < 240 (mrad)
l0 = 40.0cm
Nπ/pot
target length [cm]

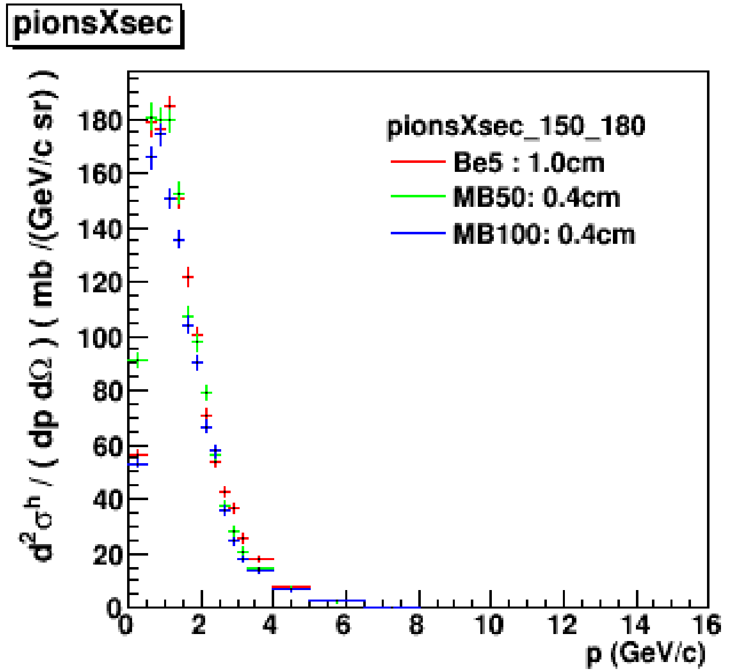
Cross section Results and Comparison

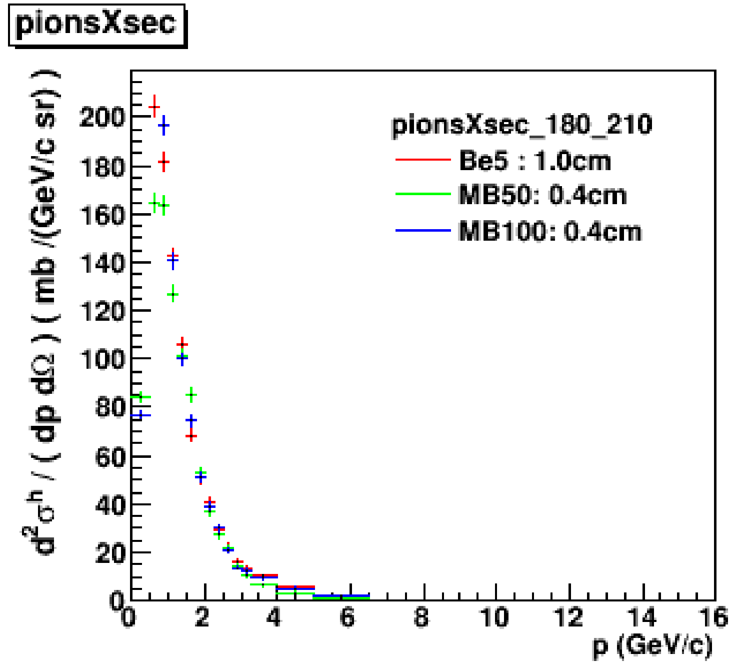


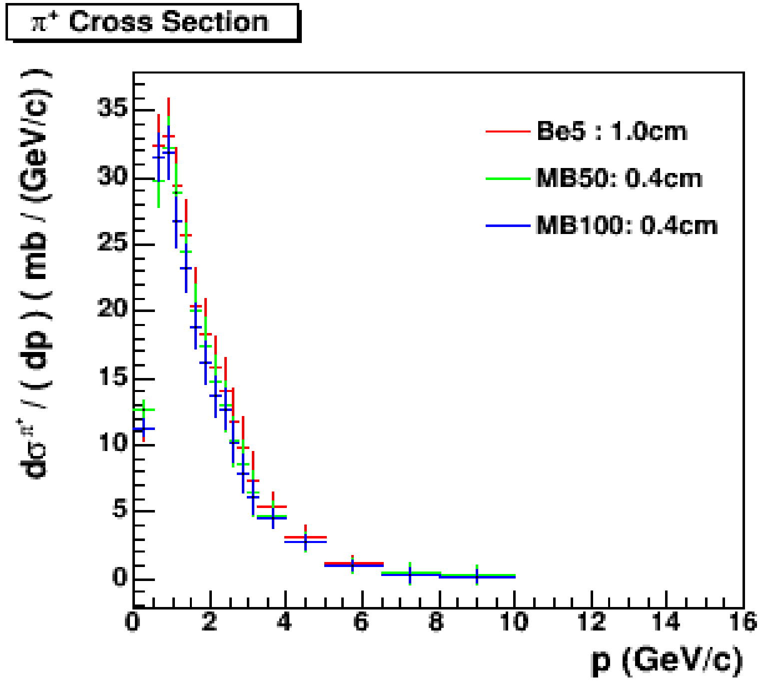


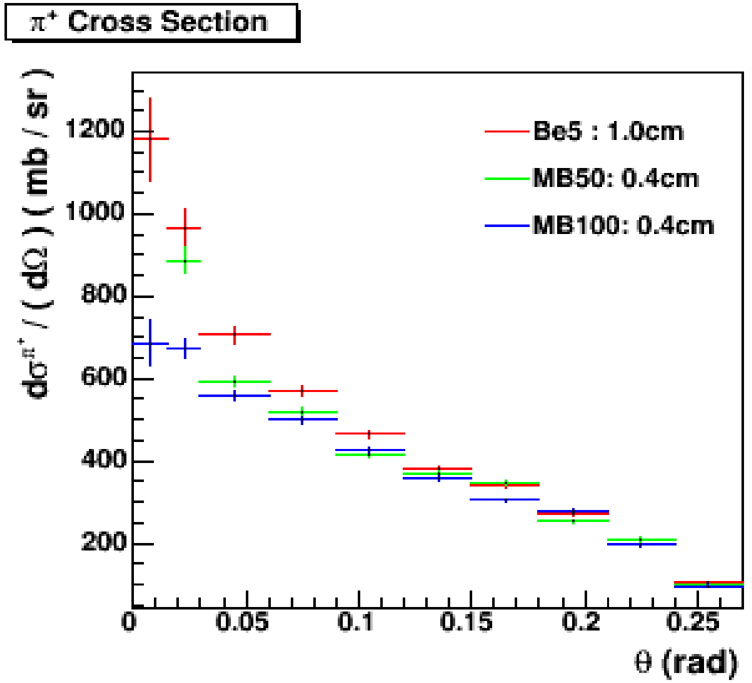





pionsXsec
pionsXsec_150_180
Be5 : 1.0cm
MB50: 0.4cm
MB100: 0.4cm
d²σʰ / (dp dΩ) (mb /(GeV/c sr))
p (GeV/c)


pionsXsec
pionsXsec_180_210
Be5 : 1.0cm
MB50: 0.4cm
MB100: 0.4cm
d²σʰ / (dp dΩ) (mb /(GeV/c sr))
p (GeV/c)


π⁺ Cross Section
Be5 : 1.0cm
MB50: 0.4cm
MB100: 0.4cm
dσ^π⁺ / (dp) (mb / (GeV/c))
p (GeV/c)


π⁺ Cross Section
Be5 : 1.0cm
MB50: 0.4cm
MB100: 0.4cm
dσ^π⁺ / (dΩ) (mb / sr)
θ (rad)

MiniBooNE Beamline MC

Simulated Beam profile :

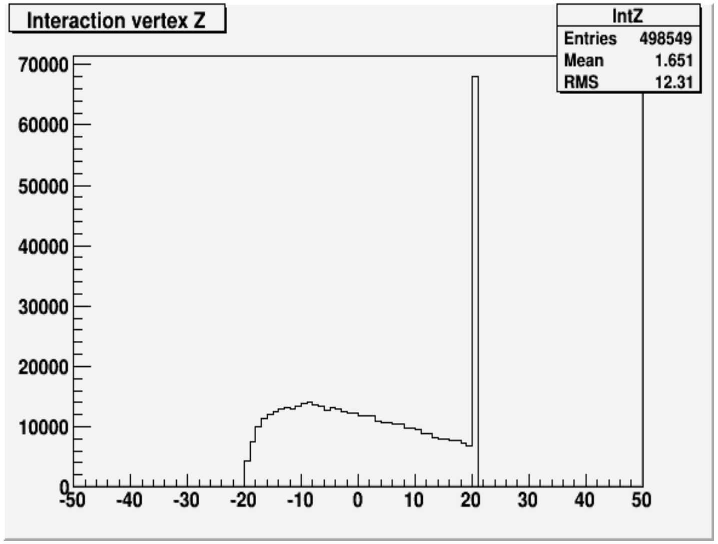
/boone/primary/mean_x 0. mm
/boone/primary/mean_y 0. mm
/boone/primary/sigma_x 0.2 mm
/boone/primary/sigma_y 0.2 mm
/boone/primary/mean_thetax 0. mrad
/boone/primary/mean_thetay 0. mrad
/boone/primary/sigma_thetax 0.66 mrad
/boone/primary/sigma_thetay 0.40 mrad
/boone/primary/zPosition -1. cm

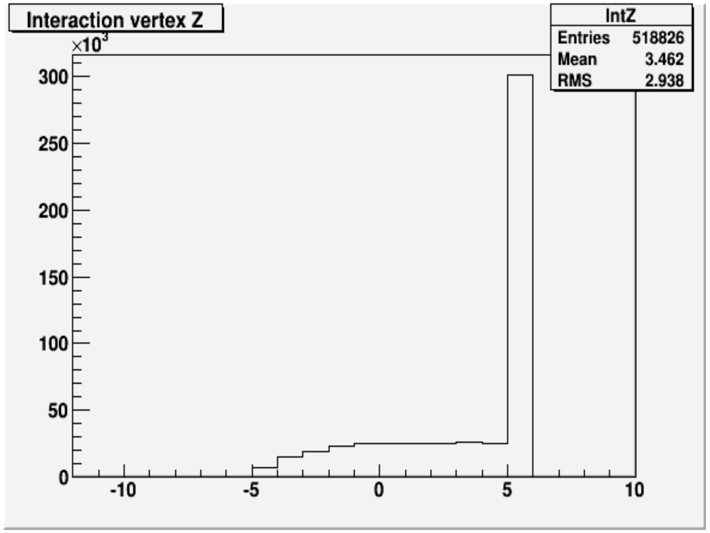
Use a pencil dot beam

Has to change
For
Target coordinates

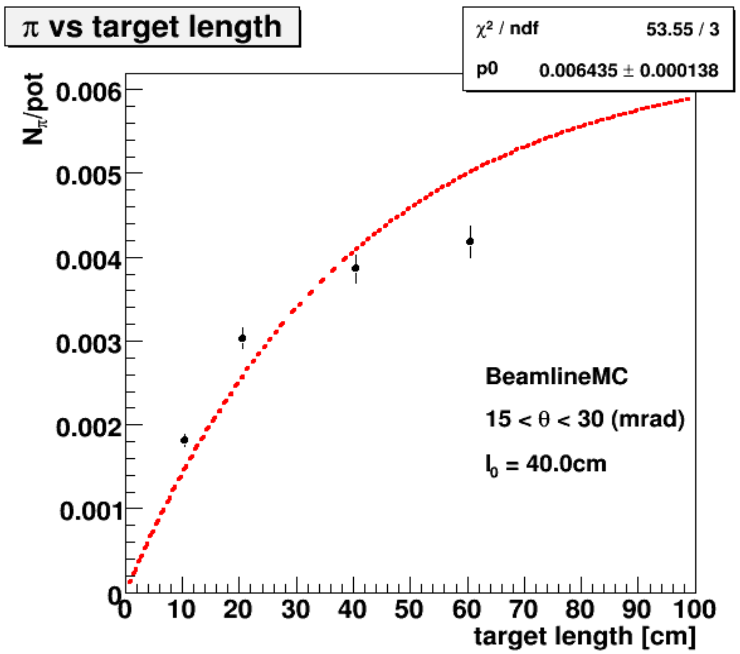
Geometries of Targets:

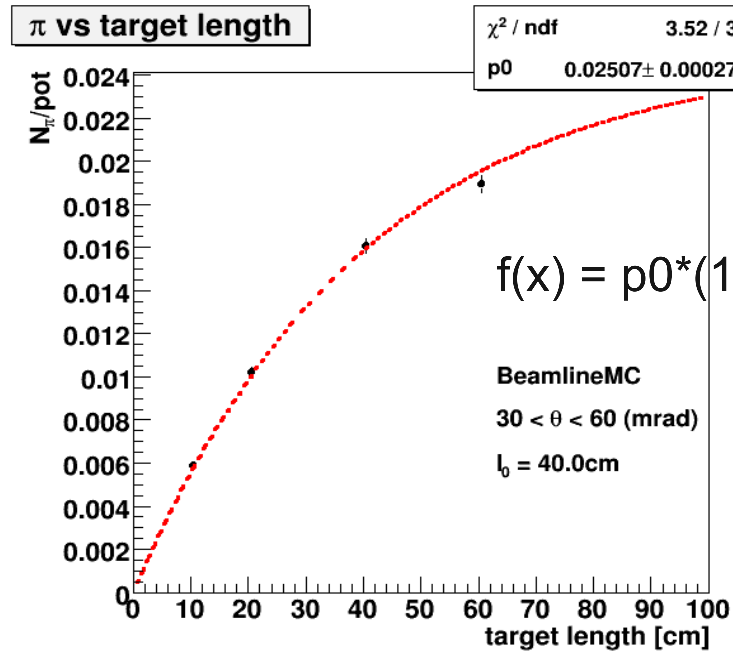
HARP25 = 10.0cm
HARP50 = 20.0cm
HARP100 = 40.0cm
HARP150= 60.0cm



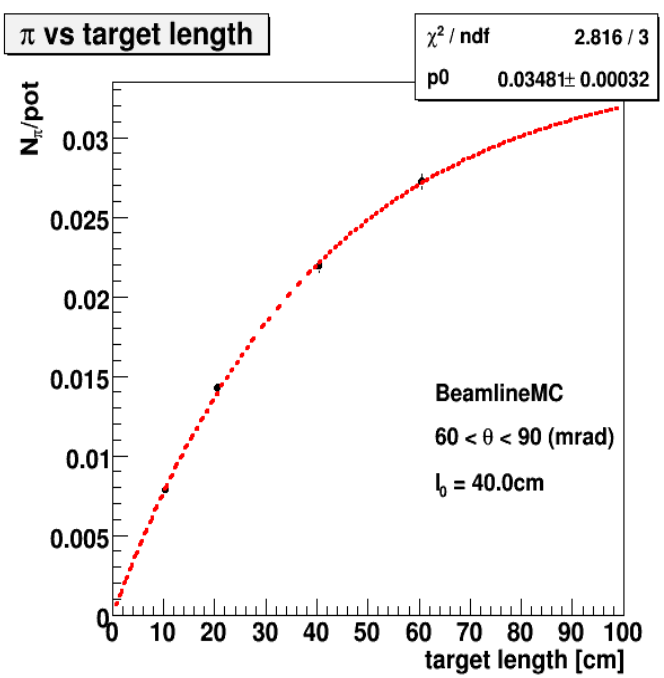


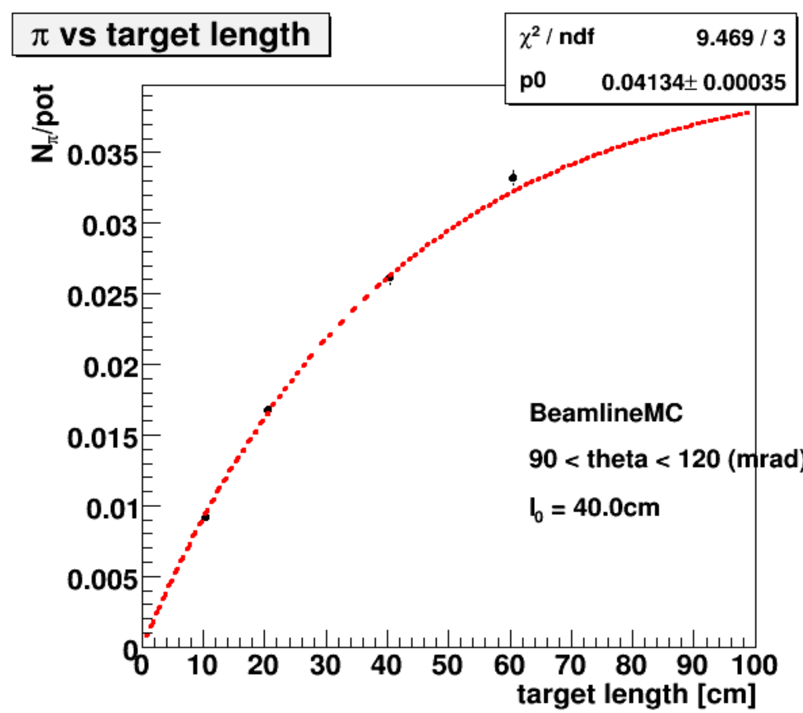
Pion distribution : Beamline MC

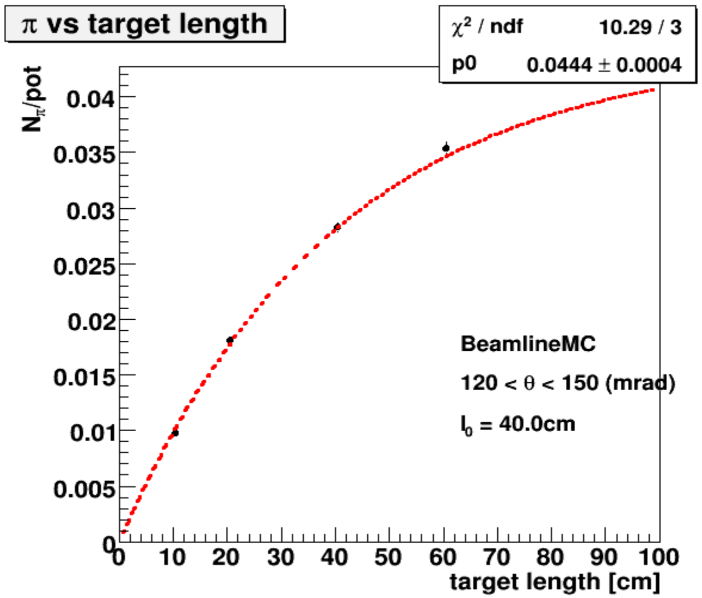


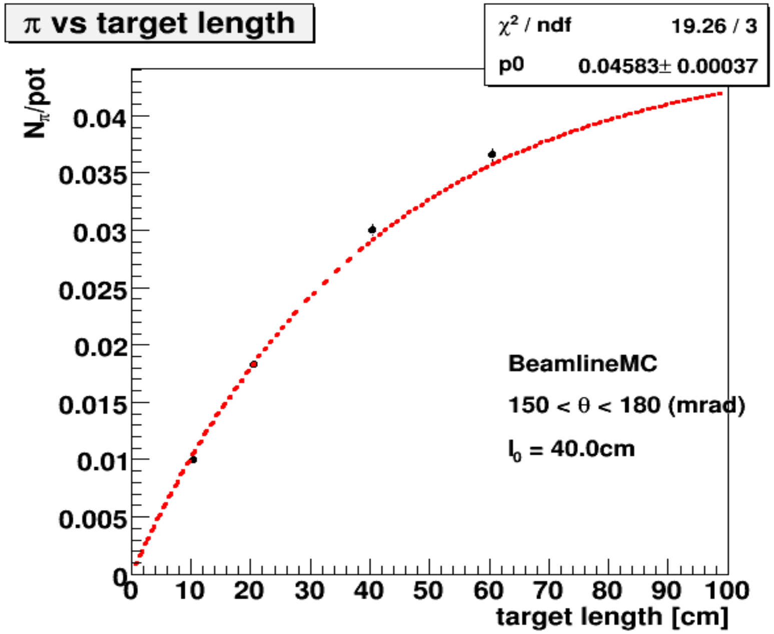


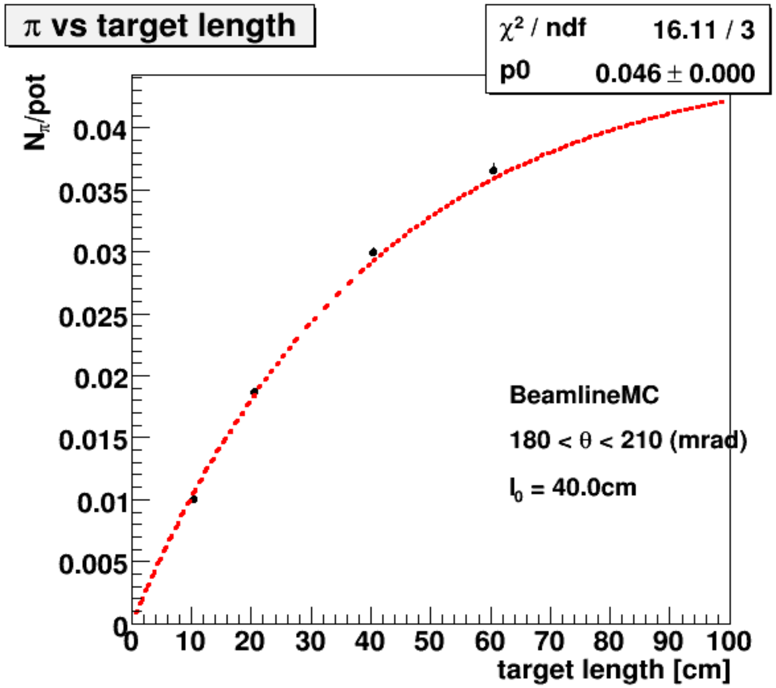
$f(x) = p0*(1-\exp(-x/40.0))$

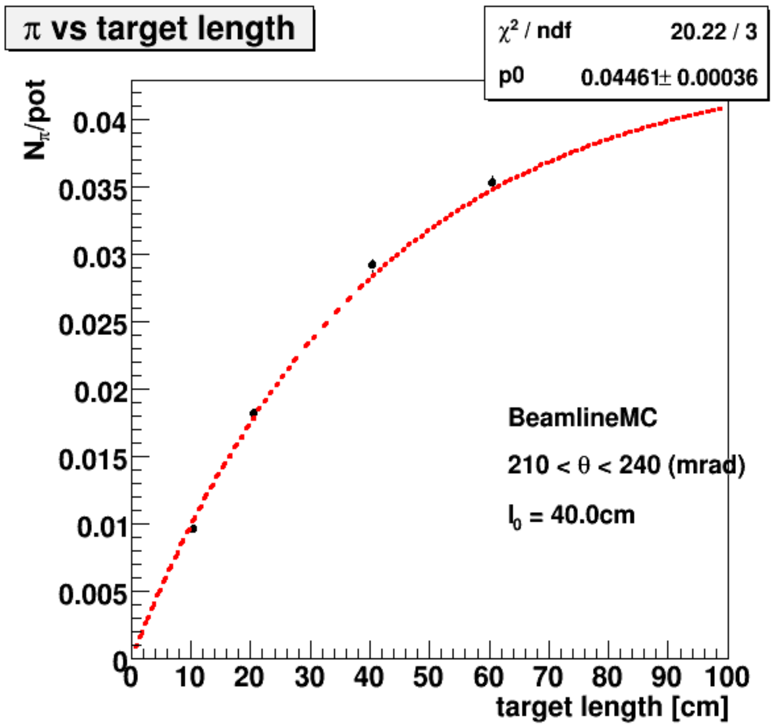




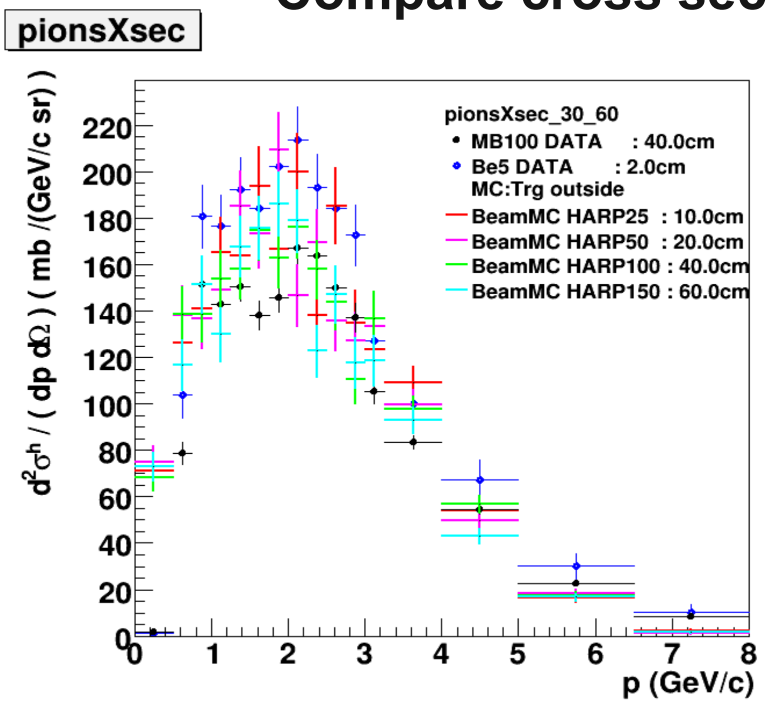

π vs target length
χ² / ndf 10.29 / 3
p0 0.0444 ± 0.0004
N_π/pot
target length [cm]
BeamlineMC
120 < θ < 150 (mrad)
l₀ = 40.0cm

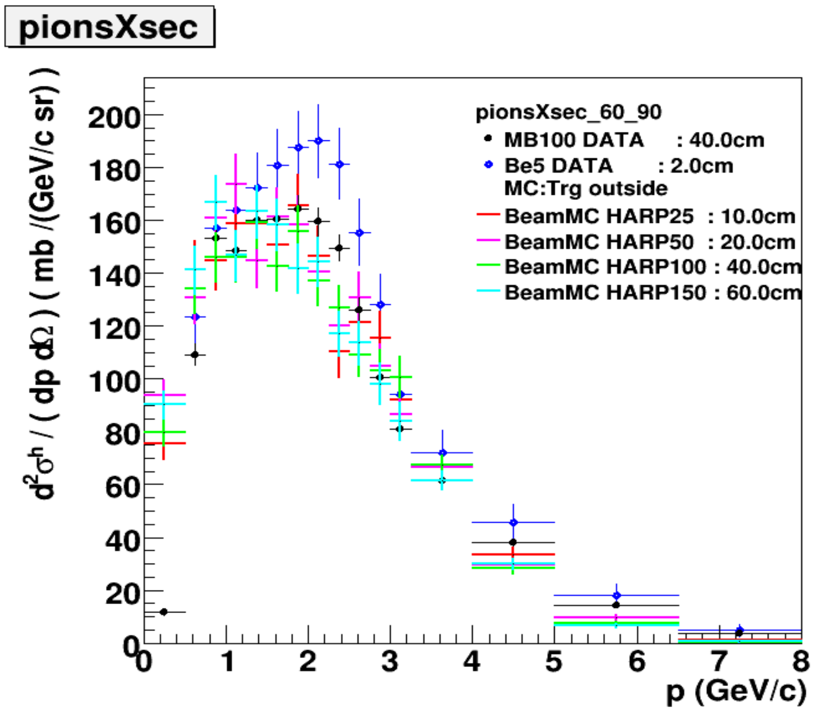

π vs target length
χ² / ndf 19.26 / 3
p0 0.04583± 0.00037
N_π/pot
target length [cm]
BeamlineMC
150 < θ < 180 (mrad)
l₀ = 40.0cm

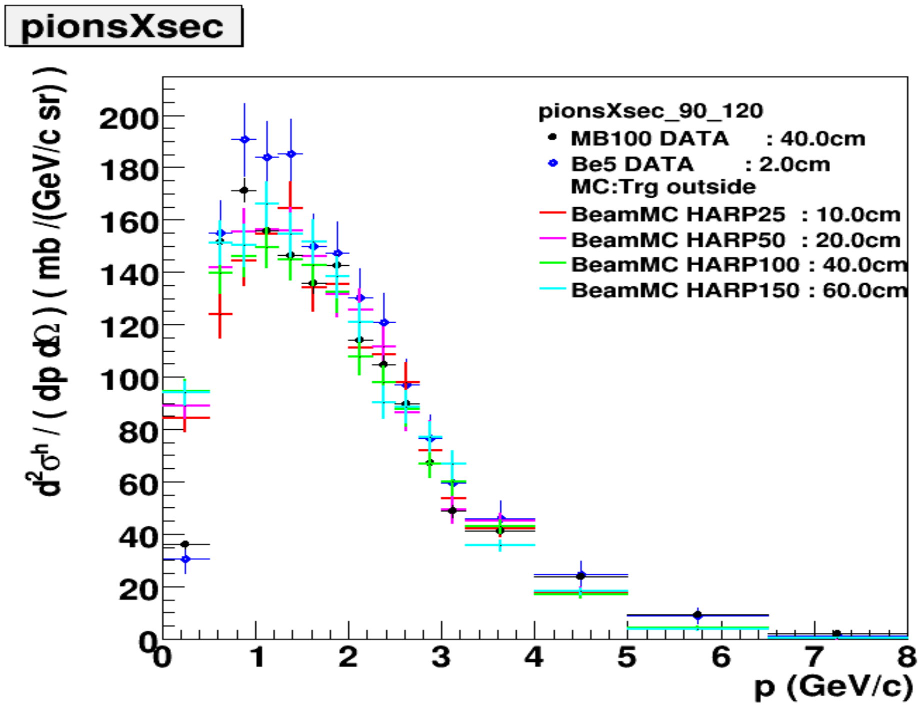

π vs target length
χ² / ndf 16.11 / 3
p0 0.046 ± 0.000
N_π/pot
target length [cm]
BeamlineMC
180 < θ < 210 (mrad)
l₀ = 40.0cm

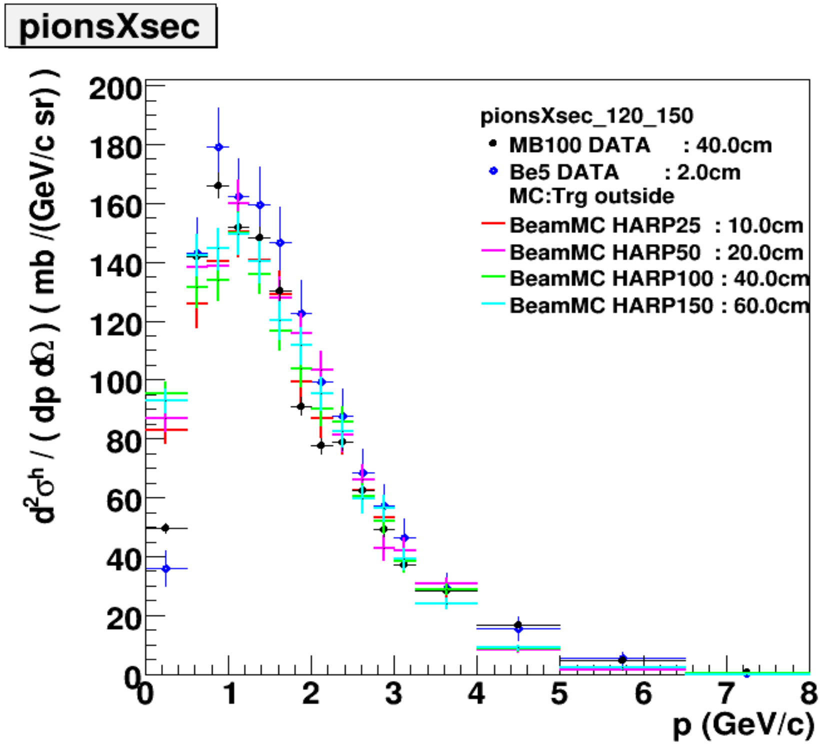

π vs target length
χ² / ndf 20.22 / 3
p0 0.04461± 0.00036
N_π/pot
target length [cm]
BeamlineMC
210 < θ < 240 (mrad)
l₀ = 40.0cm

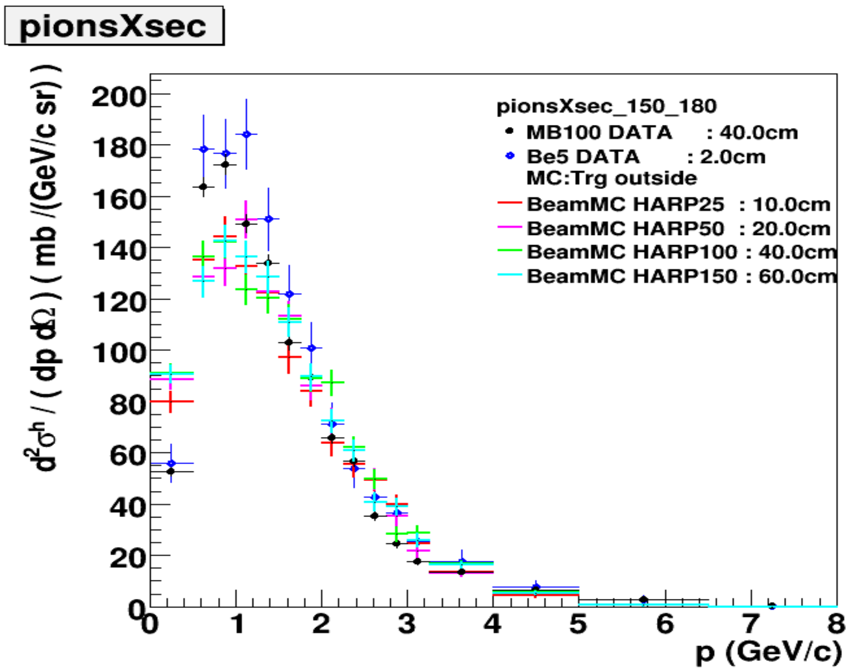
Compare cross sections

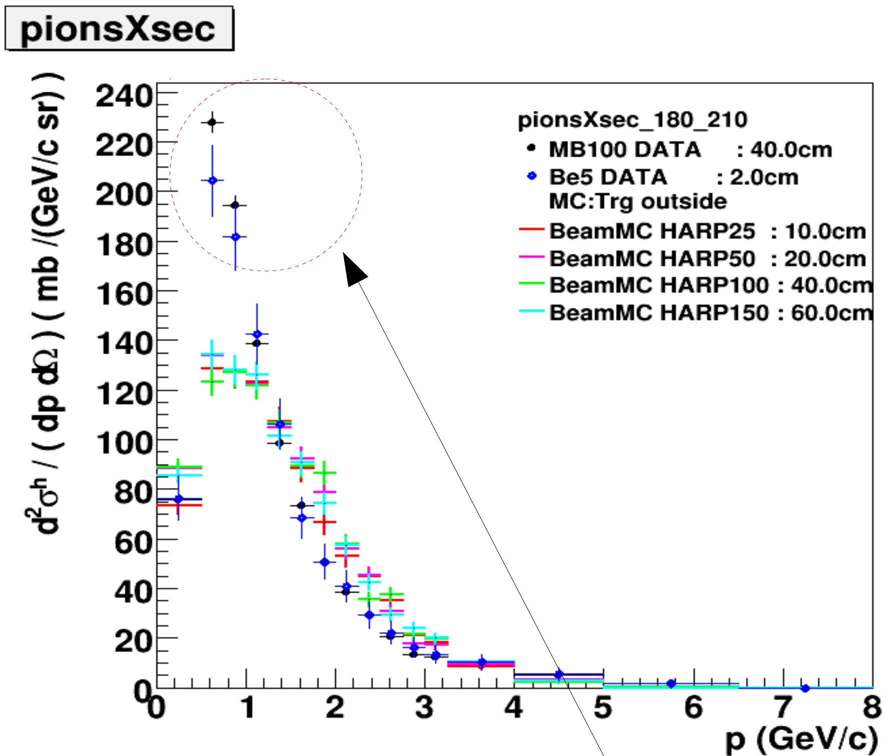


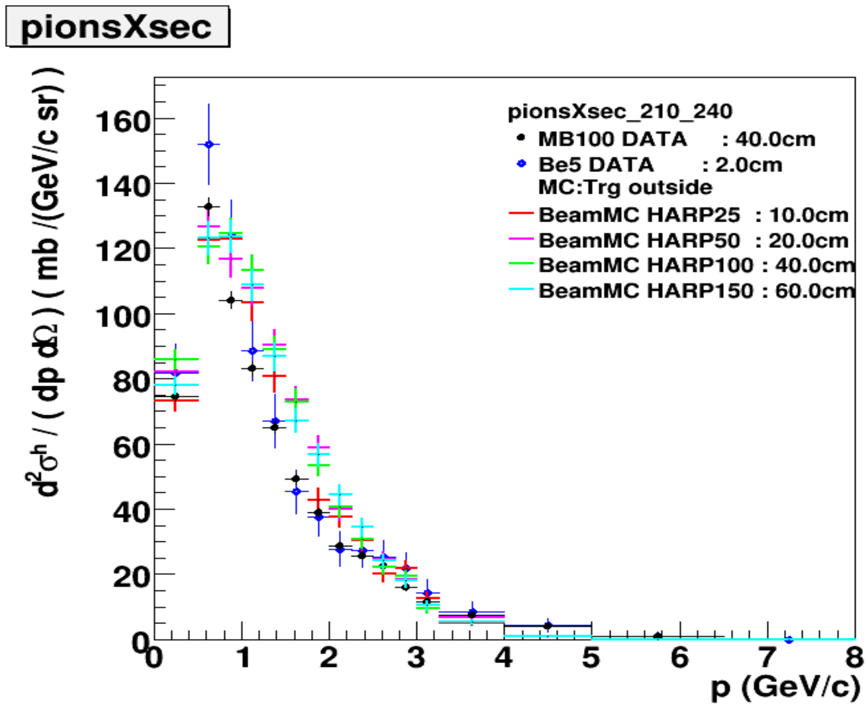












Data has some higher cross section ?

Backup slides

Calculation of thick target correction term

$$\xi_l = \frac{\sigma_{p-Be}}{\left(1 - e^{-nl\sigma_{p-Be}}\right)}$$

For Beryllium

$\rho \quad = 1.85\, g\, cm-3$

$A_{targ} = 9.012\, g$

$N_A = 6.022 \times 10^{23}$

$$n = \frac{N_A . \rho}{A_{target}}$$

$$n = 1.236 \times 10^{23}\, cm^{-3}$$

$$N_{intr} = N_0 . e^{-n.l.\sigma_{p-Be}} \Rightarrow n.l_0 . \sigma_{p-Be} = 1 \; \textit{for one interaction length}$$

$$\Rightarrow \sigma_{p-Be} = \frac{1}{n.l_0} \approx 202\, mb$$

Assuming one interaction length = 40 cm

Correction terms

$$\xi_{Be5} \approx 4147.15 \approx \frac{1}{n.l} = 4045.31\text{mb} \quad \textit{effective correction} = 1.025 \;\; \textit{thin target result}$$

$$\xi_{MB50} \approx 513.90\, mb\, , \quad \frac{1}{nl} = 404.53\, mb \quad \textit{effective correction} = 1.27 \;\; \textit{thin target results}$$

$$\xi_{MB100} \approx 319.80\, mb\, , \quad \frac{1}{nl} = 202\, mb \quad \textit{effective correction} = 1.58 \;\; \textit{thin target results}$$