NuSTORM flux

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Content

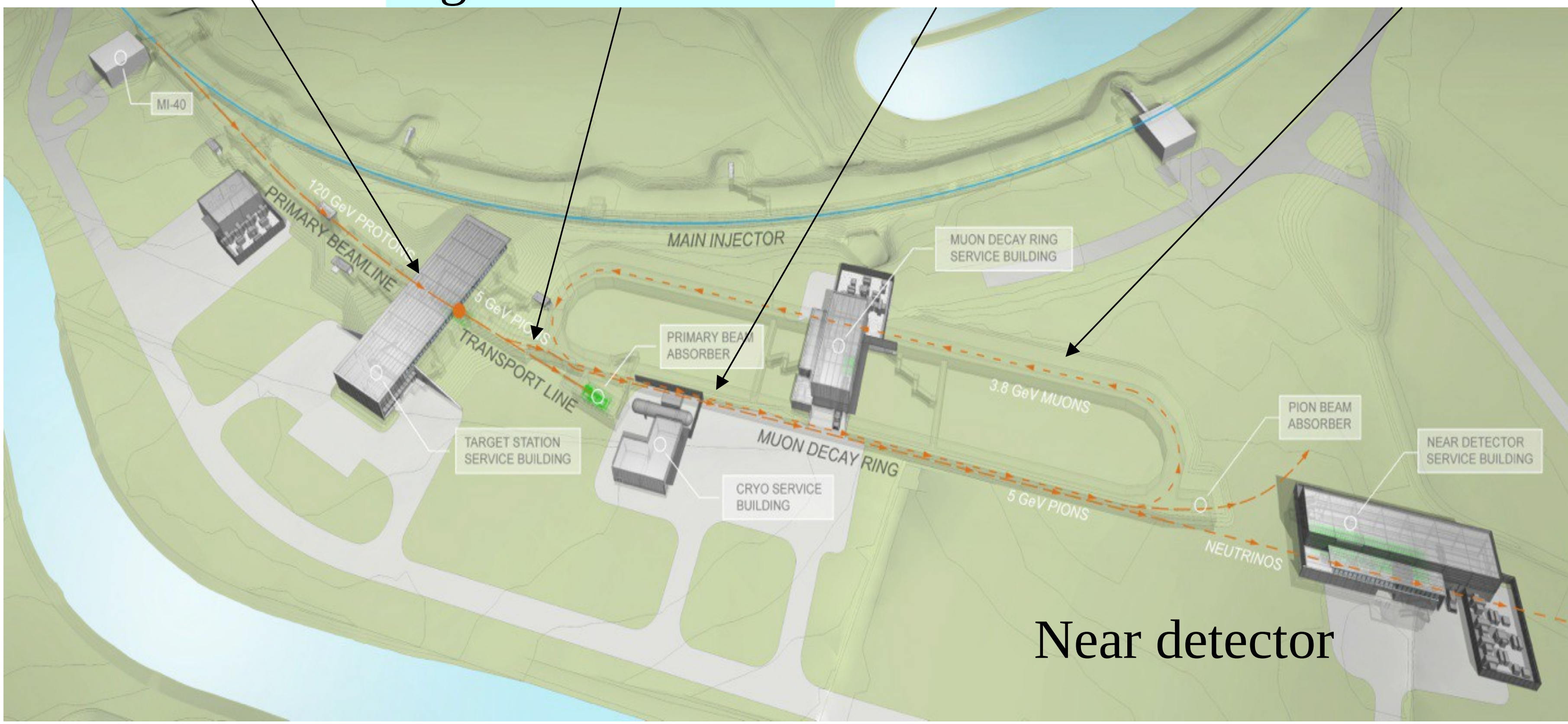
- Simulation and flux calculation methods
- Muon decay flux
- Pion decay flux
- Off-axis flux
- What is required for $<1\%$ error?

Protons on Target
Horn collection

Pion transport through dipoles – momentum and sign selection

Pions injecting into ring decay into muons

Stored muons decay with direction neutrino beam

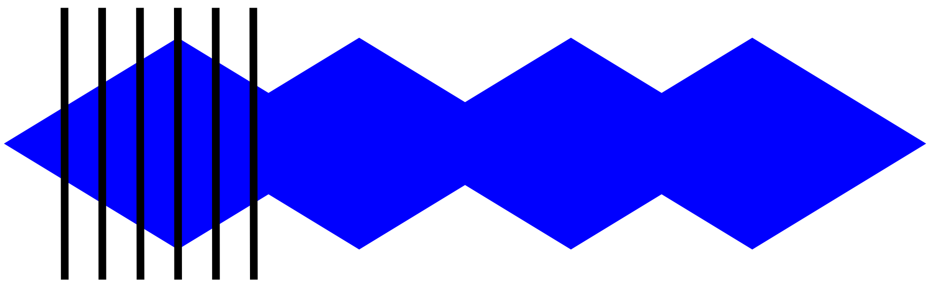


- Dipole chicane provides sign and momentum selection of pions
- Stored beam allows for instrumentation and characterization of beam
- Current, momentum, divergence, size, position

- Produces flavour-known beam with high statistics electron neutrinos, with a flux known to better than 1%

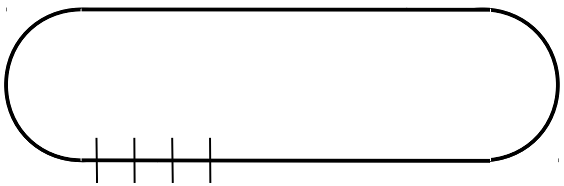
Muon beam tracking approximation

Sampling



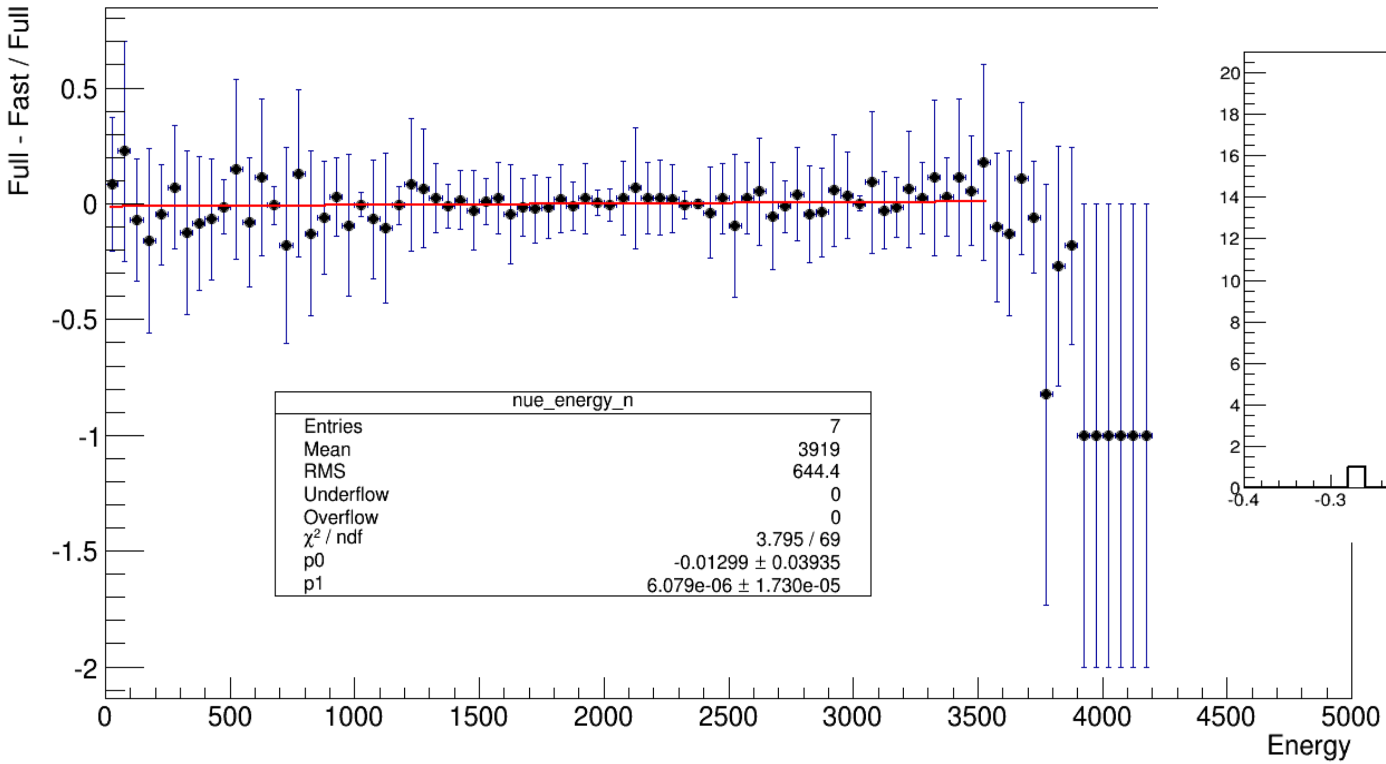
Full Geant tracking of muon beam through decay lattice is computationally intensive.

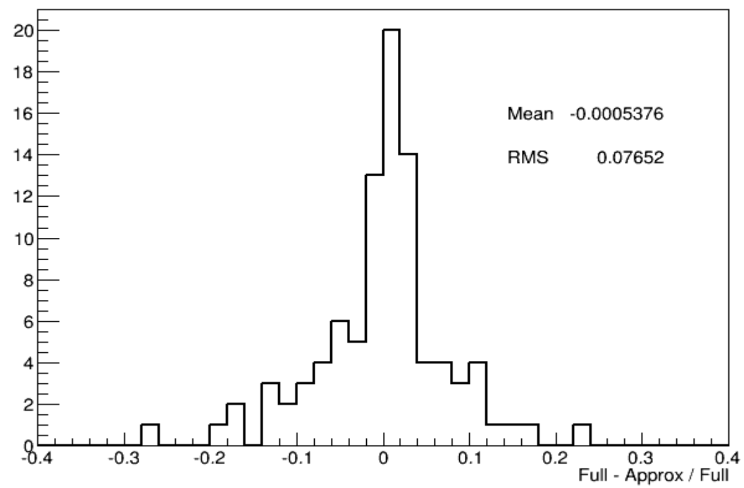
Beam was sampled a) with a single FODO cell b) over the entire straight and this sample used at decay points along the straight



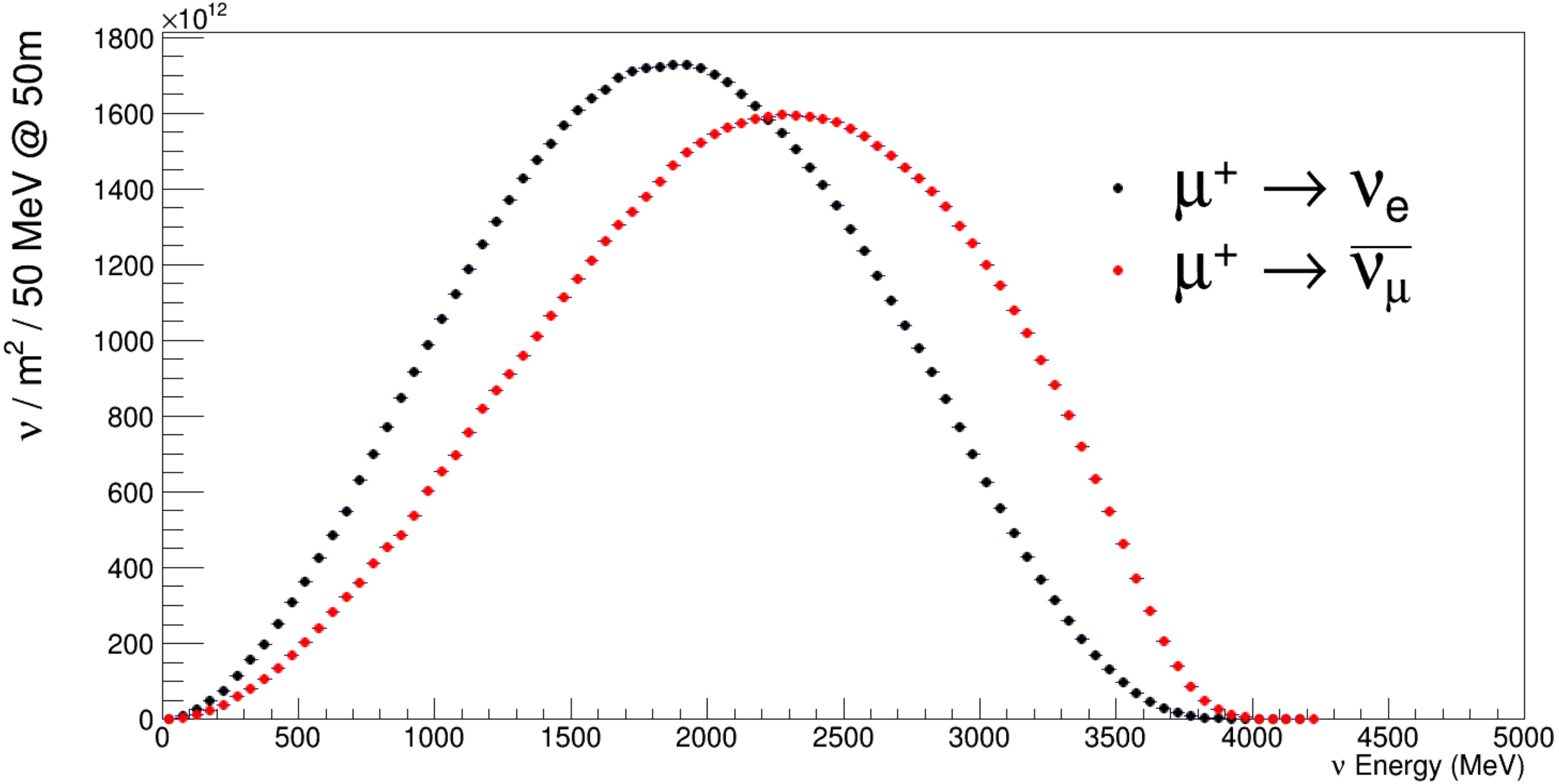
Decay points

Approximation accuracy





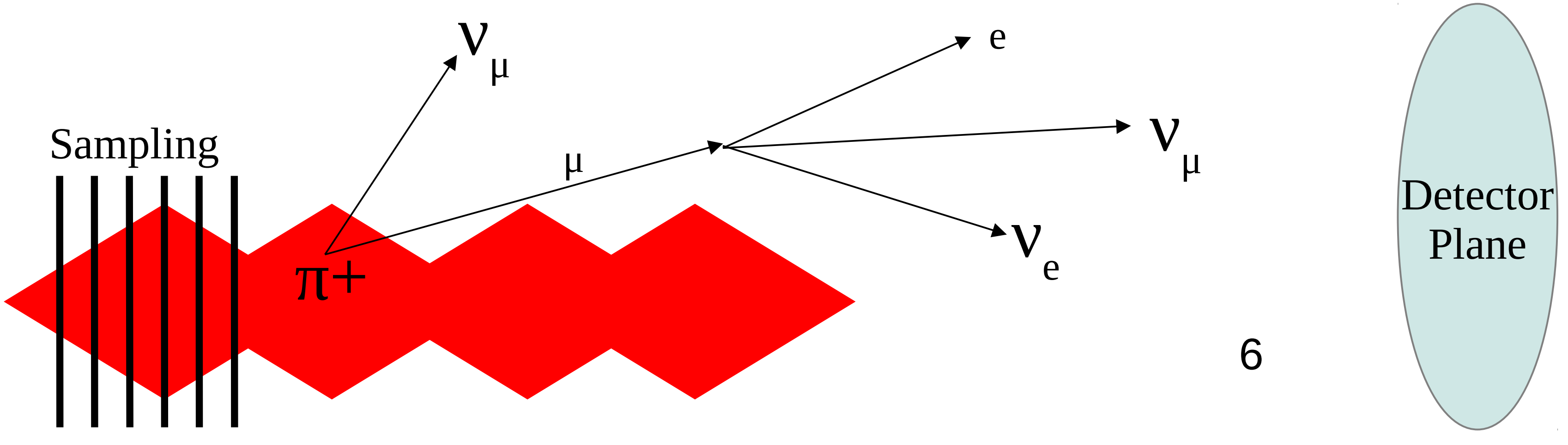
Flux from muon decay at 50m



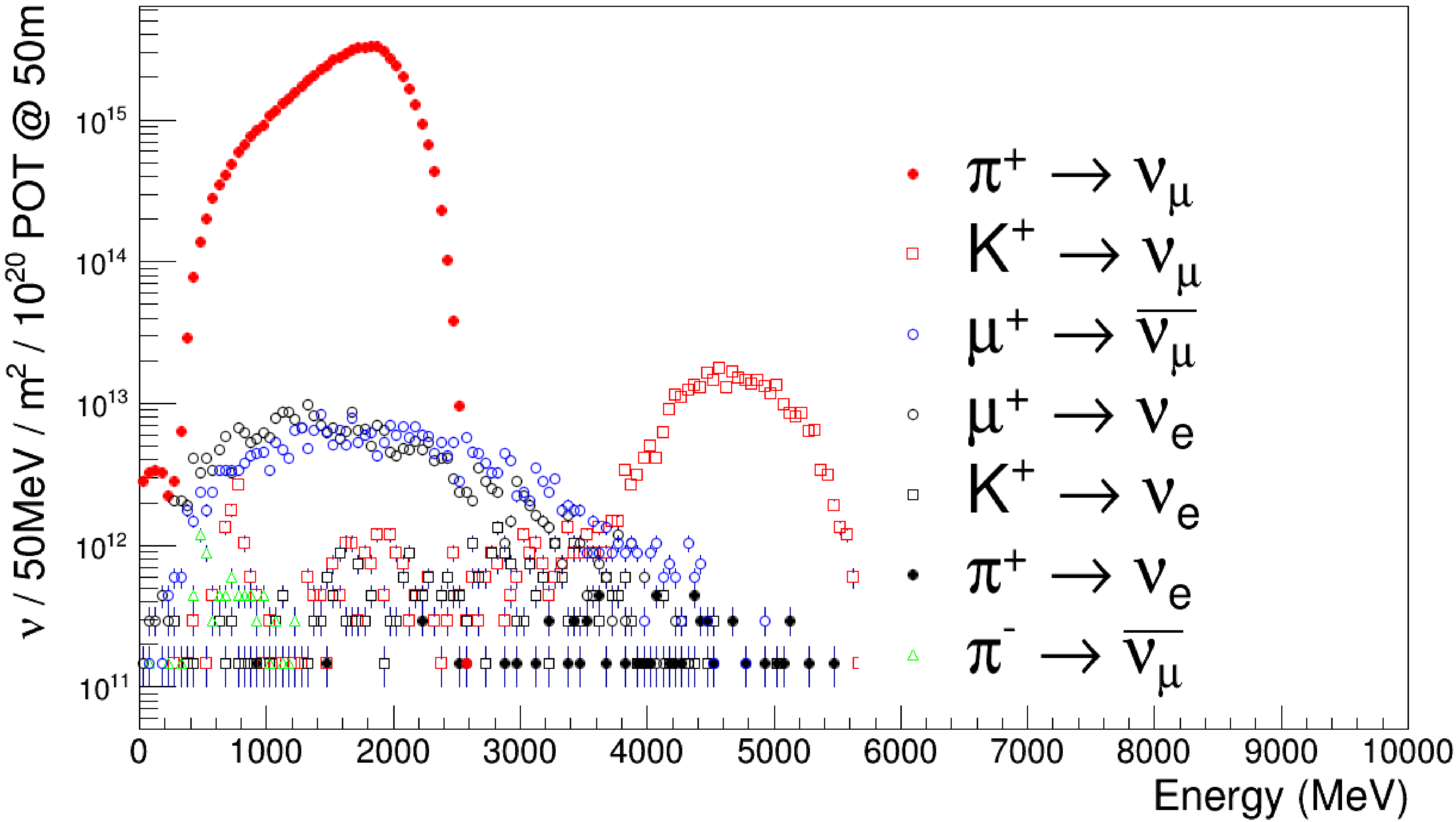
- Muon beam tracked through decay straight using G4Beamline
- Distribution used to generate decays and neutrinos sampled at 50m near detector site
- Likely amplification with horn optimisation

π decay simulation method

- MARS simulation of target and horn
- Particles produced and captured in horn tracked through transport line and into decay straight using G4Beamline
- Resulting neutrinos measured at sampling plane 50m from end of decay straight (near detector hall)
- For long baselines, position and divergence of each beam particle (pion, muon, kaon) to calculate flux of each channel at detector location
- Scaled to 10^{20} POT – full exposure 10^{21} POT



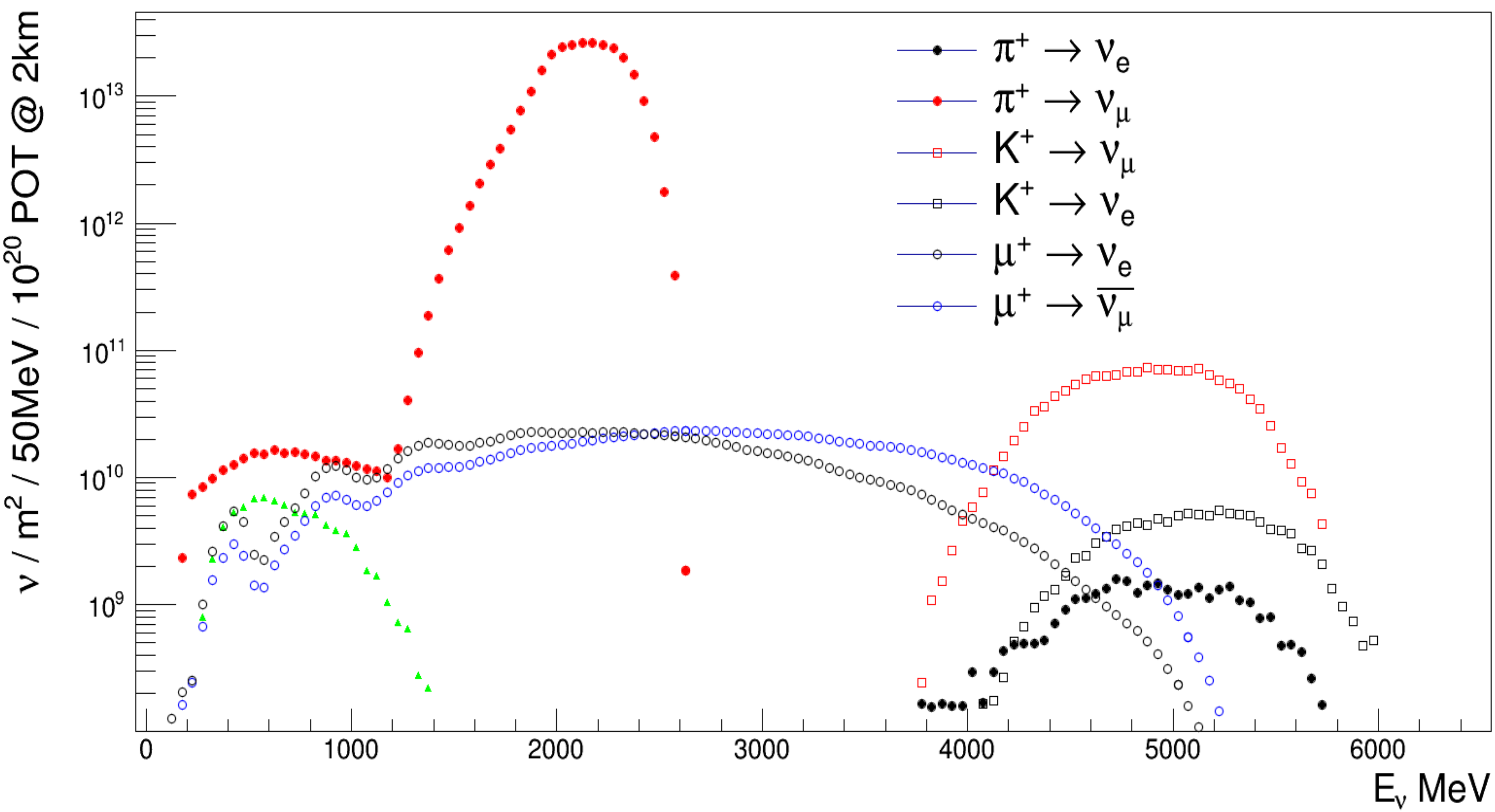
Near (50 m) detector flux from pion decay



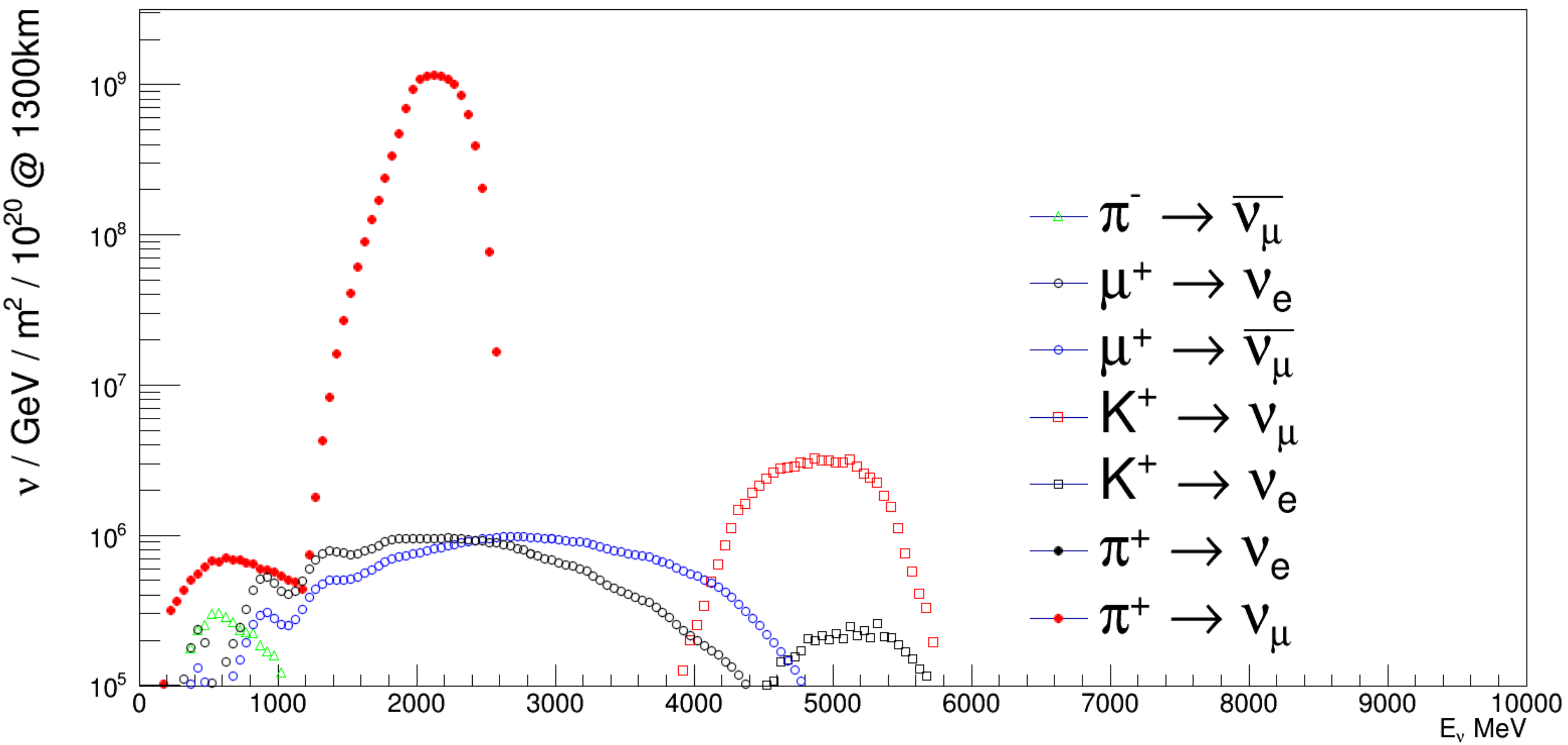
μ+ Stored		μ- Stored	
Channel	Events	Channel	Events
$\bar{\nu}_\mu$ NC	1,174,710	$\bar{\nu}_e$ NC	1,002,240
ν_e NC	1,817,810	ν_μ NC	2,074,930
$\bar{\nu}_\mu$ CC	3,030,510	$\bar{\nu}_e$ CC	2,519,840
ν_e CC	5,188,050	ν_μ CC	6,060,580
π+		π+	
ν_μ NC	14,384,192	$\bar{\nu}_\mu$ NC	6,986,343
ν_μ CC	41,053,300	$\bar{\nu}_\mu$ CC	19,939,704

- Event ratesat 50m per 100T for full exposure of 10^{21} POT

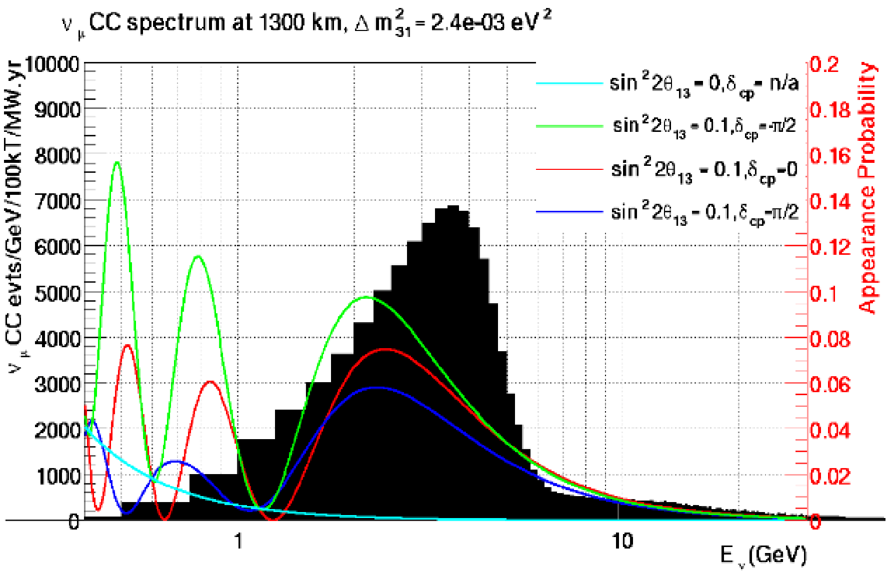
Far (2 km) detector flux from pion decay



Added channels of electron neutrino appearance and NC disappearance



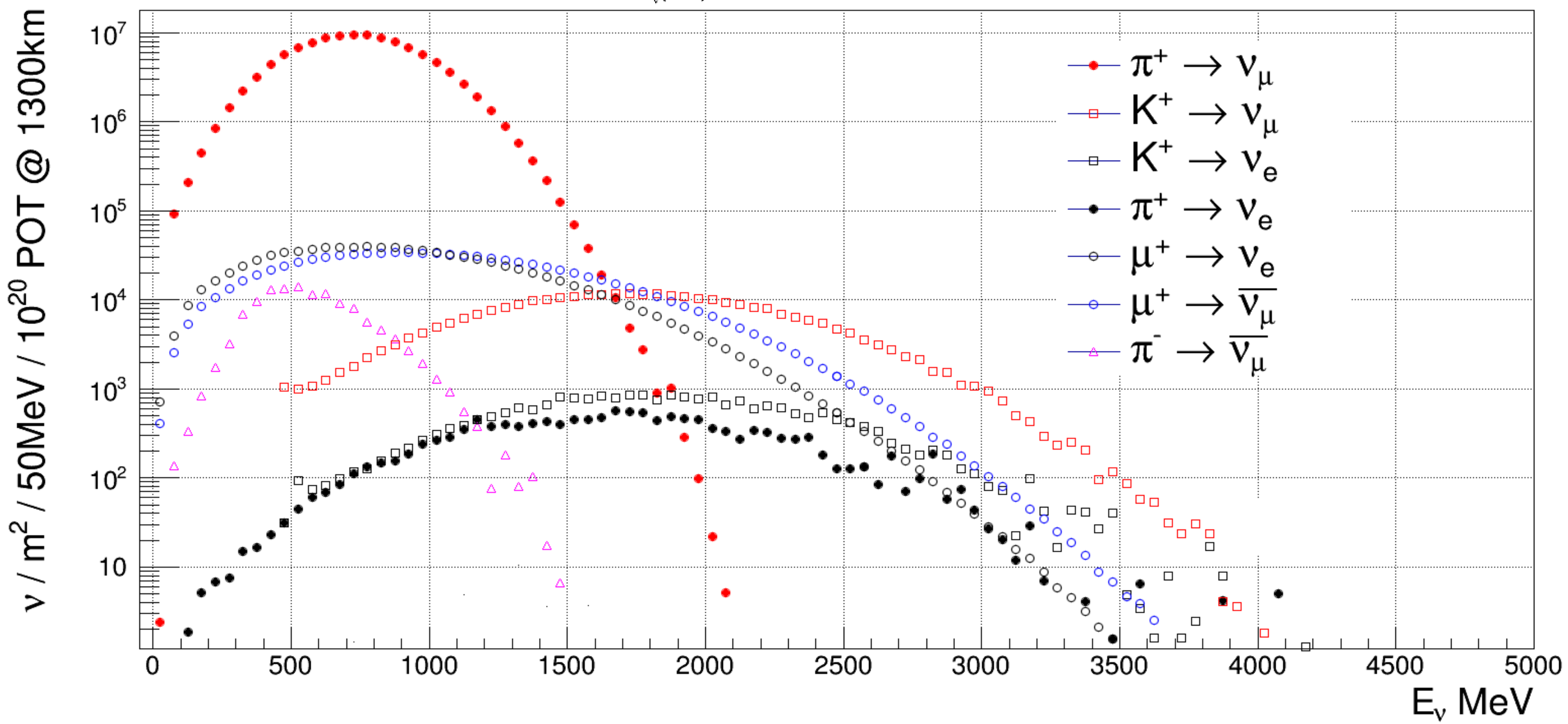
Very Far (1300 km) detector flux from pion decay

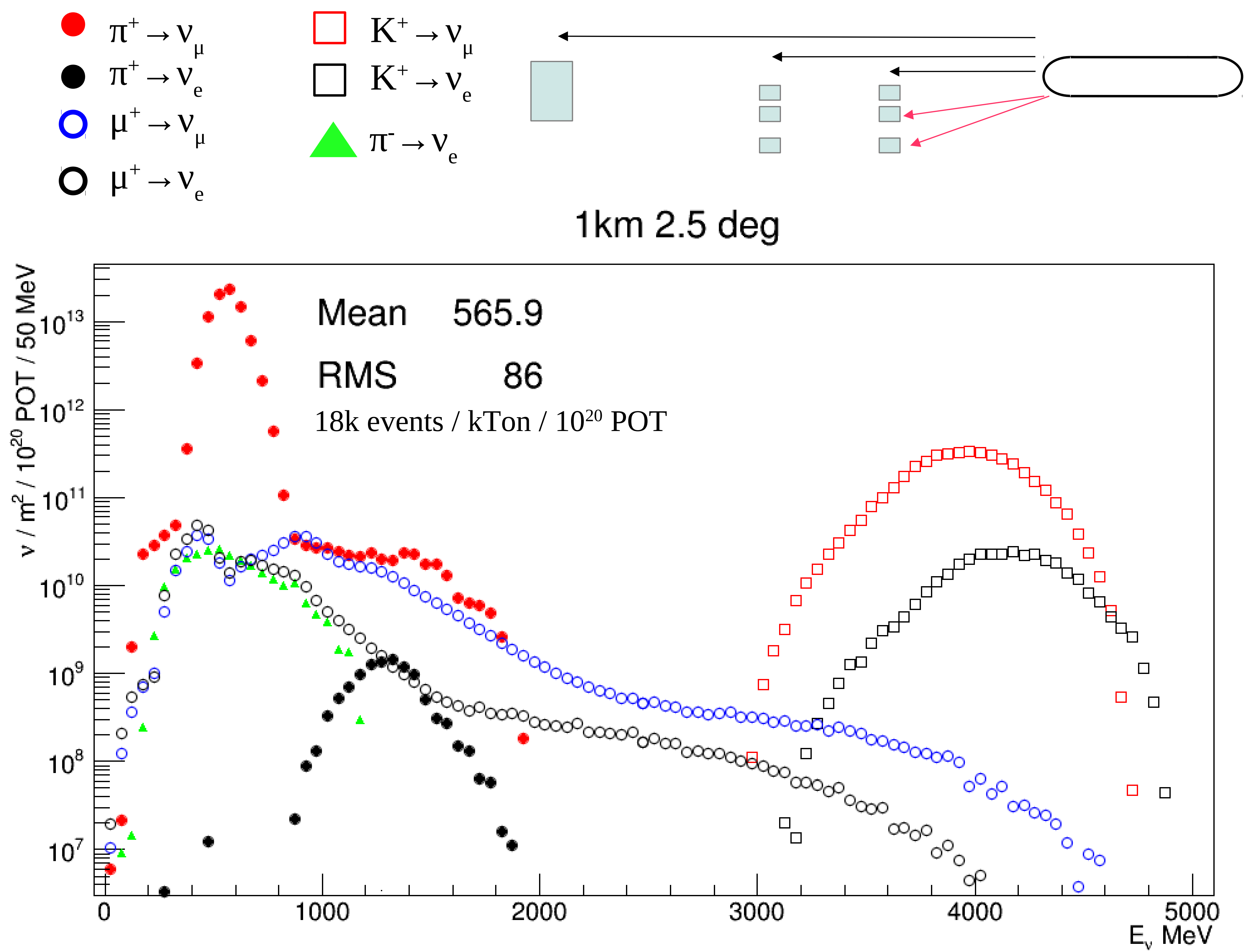


Very Far (1300 km) detector flux from pion decay – 2nd oscillation maximum

Still not an optimised pion beam, increased rate with momentum acceptance and move to pion only beam

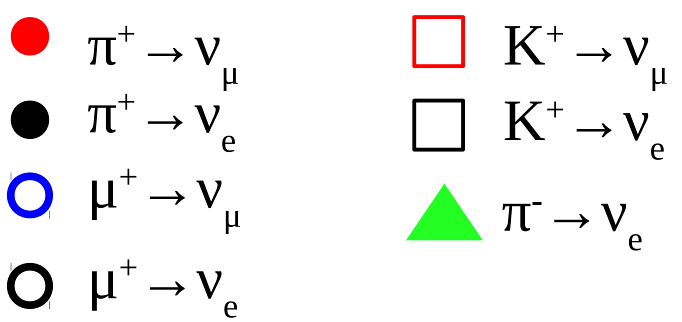
P_π = 1.3 GeV

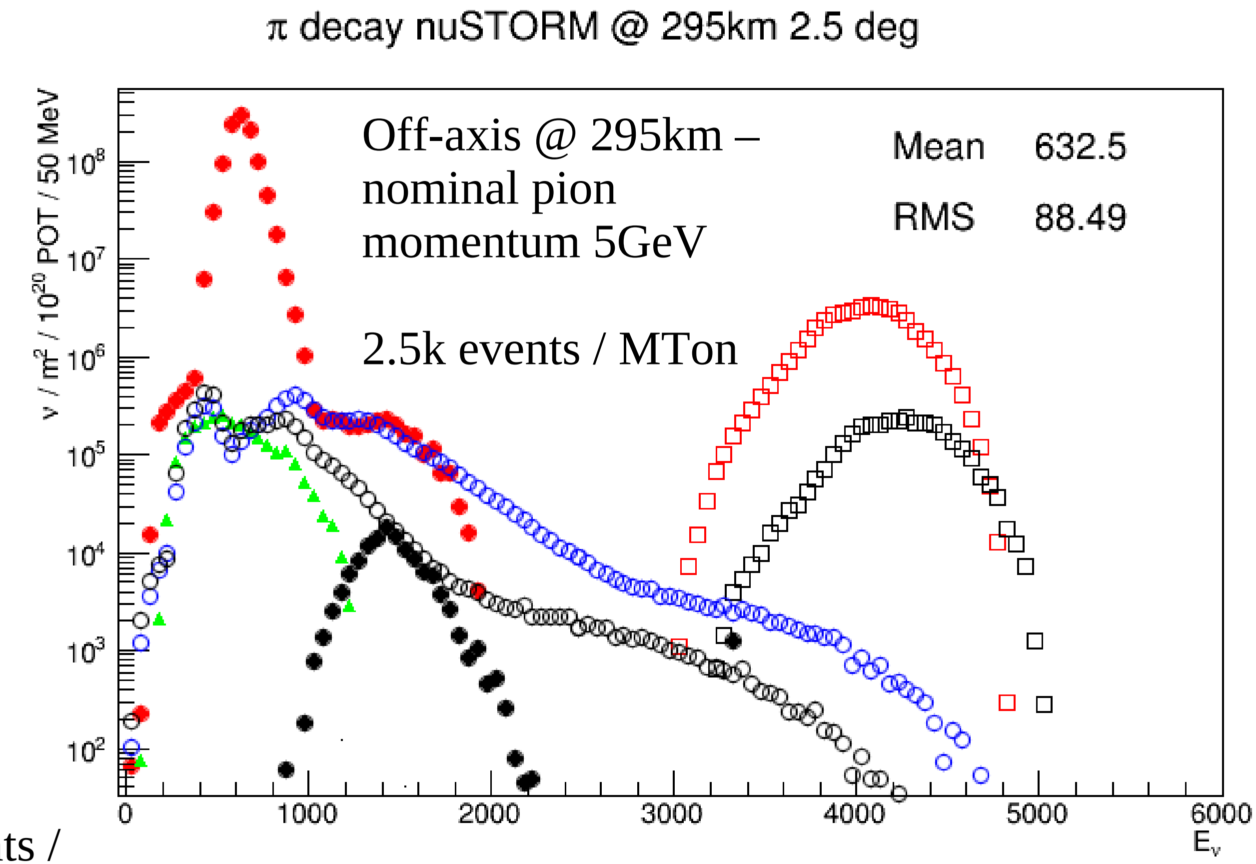


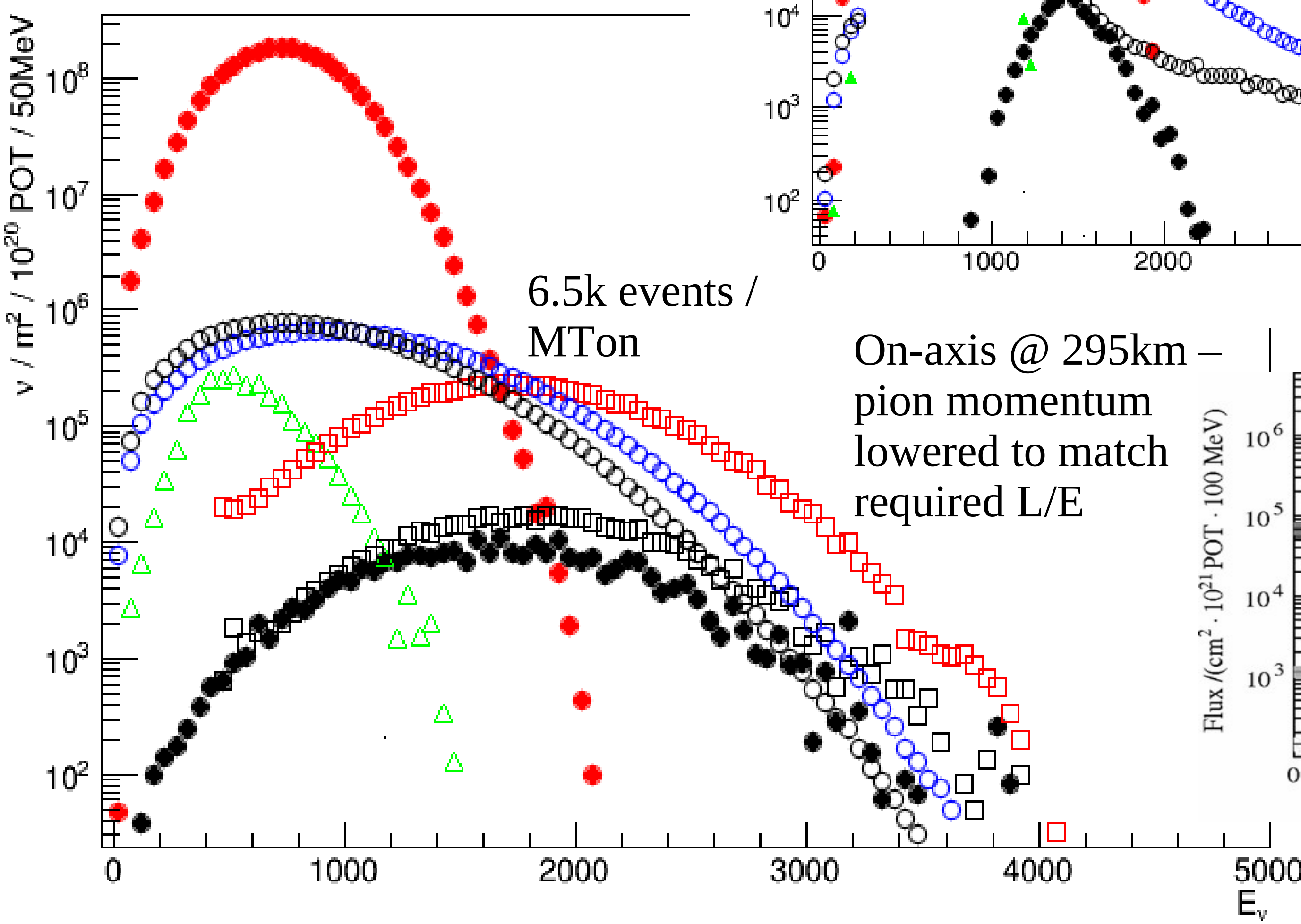


$\pi^+ \to \nu_\mu$
$\pi^+ \to \nu_e$
$\mu^+ \to \nu_\mu$
$\mu^+ \to \nu_e$
$K^+ \to \nu_\mu$
$K^+ \to \nu_e$
$\pi^- \to \nu_e$
1km 2.5 deg
Mean 565.9
RMS 86
18k events / kTon / 10^{20} POT
ν / m^2 / 10^{20} POT / 50 MeV
E_ν MeV

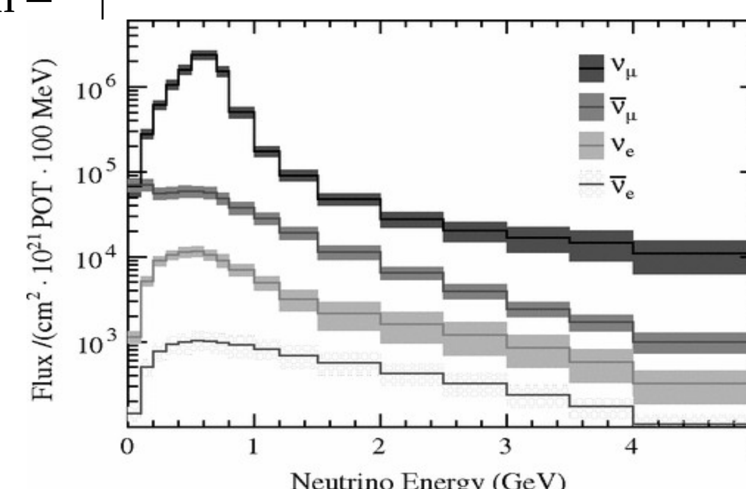
295km







On-axis @ 295km – pion momentum lowered to match required L/E

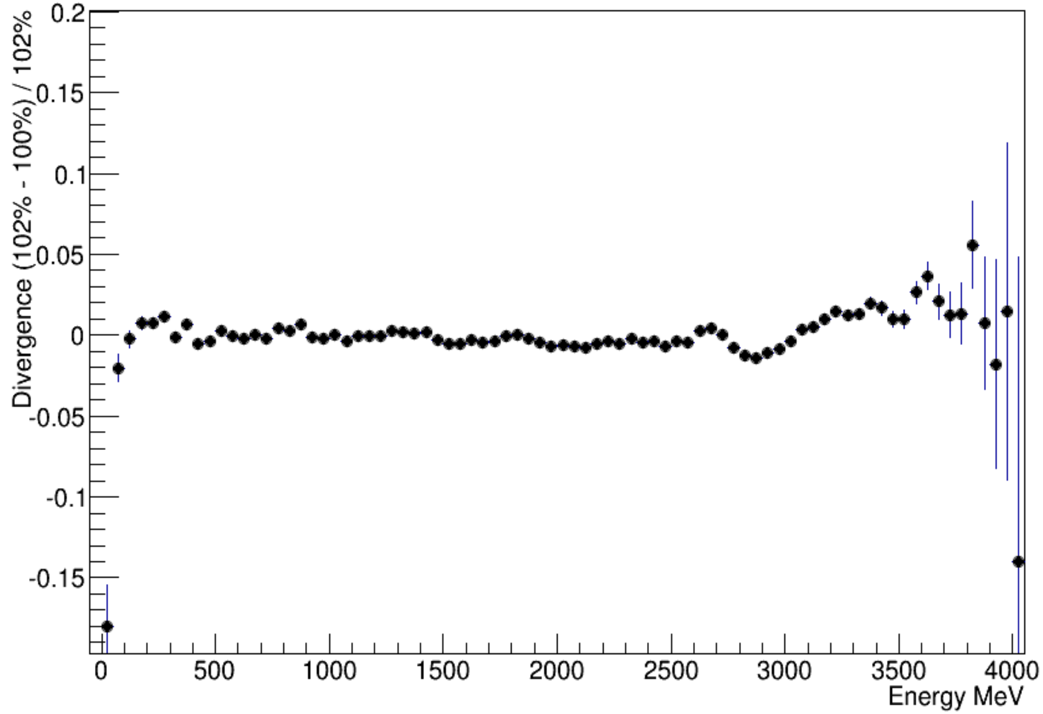


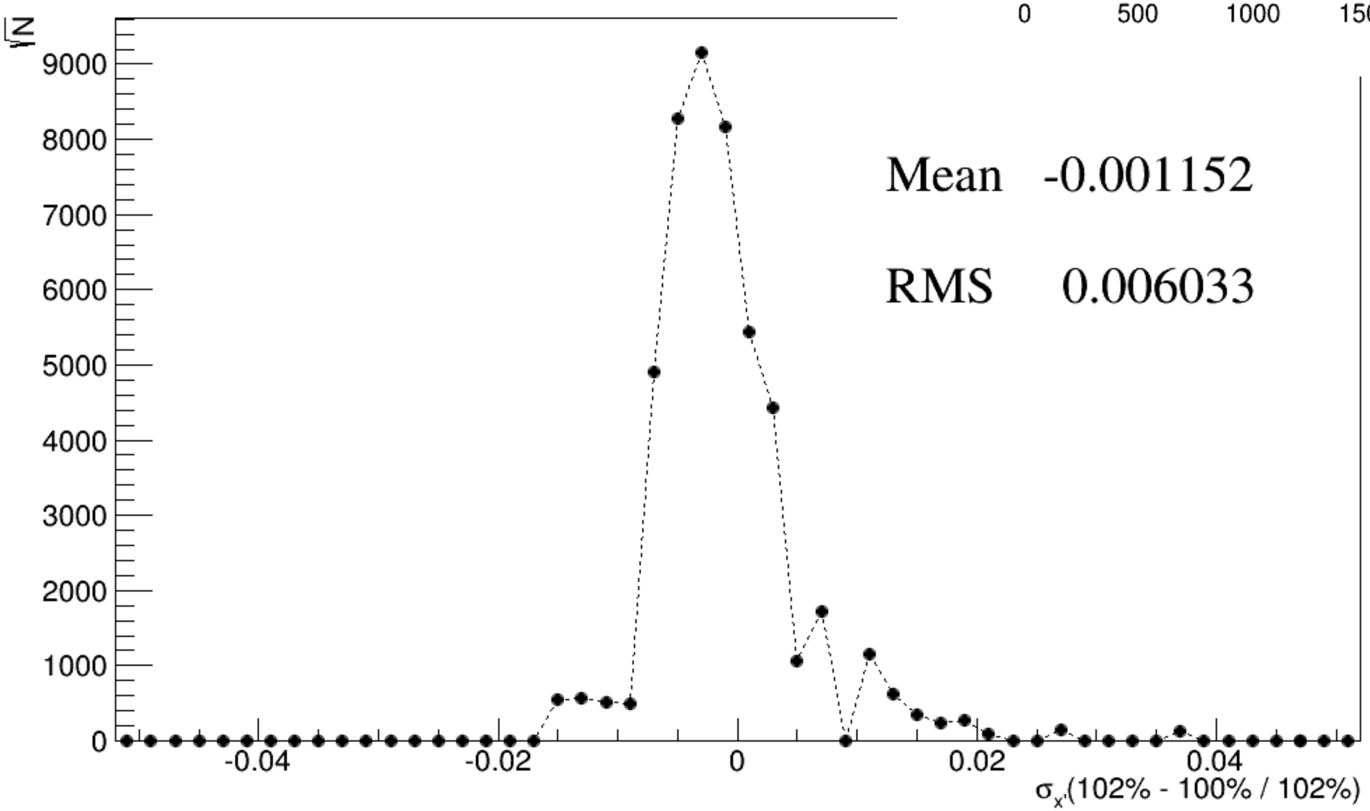
How to get to < 1% flux error

Systematic	**nuSTORM issue?**
Hadron production	*Not really* – beam current will be measured although proton contamination will need to be known
Proton beam targeting	*No* – current and position of pion/muon beam will be measured
Target movement within horn	*No*
Target degradation	*No*
Horn pulse consistency	*No*
Horn degradation	*No*
Power supply issues	*No* – lattice PS will be monitored
Pion divergence	*No* – will be measured

Contribution from muon divergence

- Muon beam re-simulated with a divergence inflated by 2%
- Resulting neutrino flux compared to nominal beam
- Less than 1% difference bin-to-bin

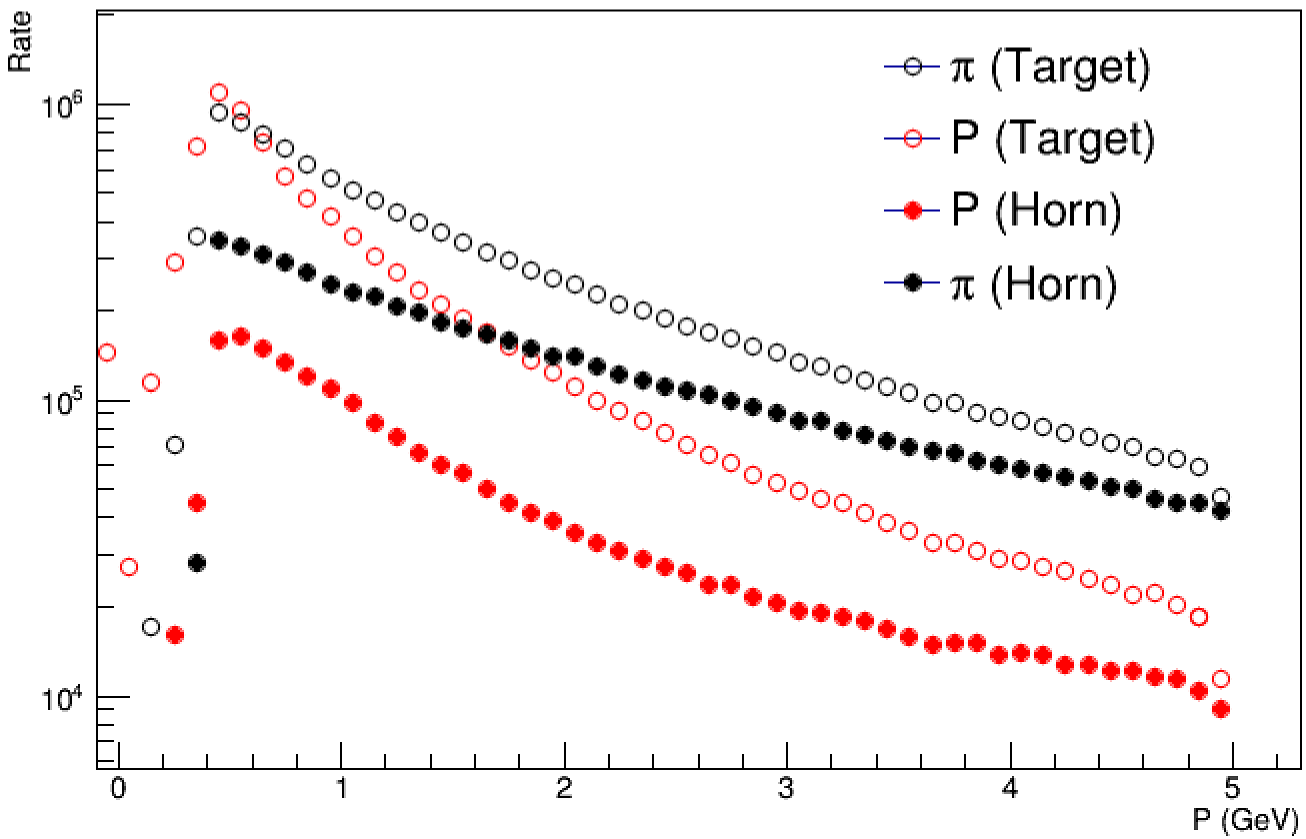




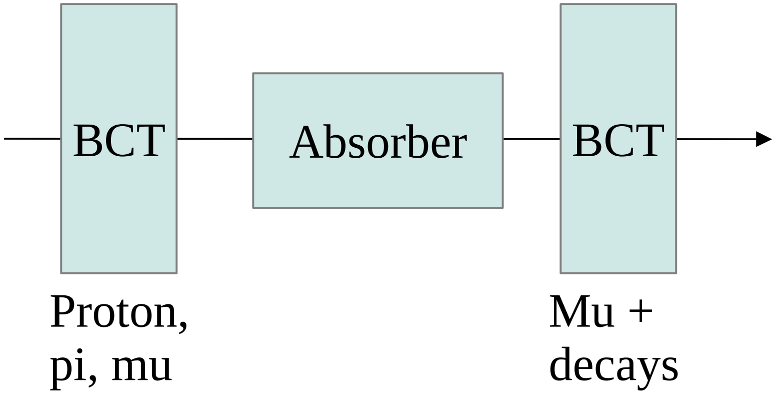
Source	**Error**
Intensity	0.1%
Divergence	0.6% with 2% measurement
Energy spread	0.1%

Primary proton contamination

- BCTs quoted as measuring intensity to 0.1%
- What about proton contamination?
- What about large beam size?
- What about halo hitting BCT?
- What about pion beam v. Muon beam



- According to vendor, size not an issue
- Beam collisions would need experiment
- Pion contamination could be measured during destructive commissioning phase



Summary

- Neutrino flux produced from muon and pion decay
- Options for baselines
- Options for energy tuning
- Options for off-axis detectors
- The 1% systematic error claim needs precision diagnostics in novel situations
- Thanks to A Liu and S Striganov for data

Backups

CP violation sensitivity

Results for 34kt, 6 yrs of data taking, 1%-5% sys