

EMPHATIC

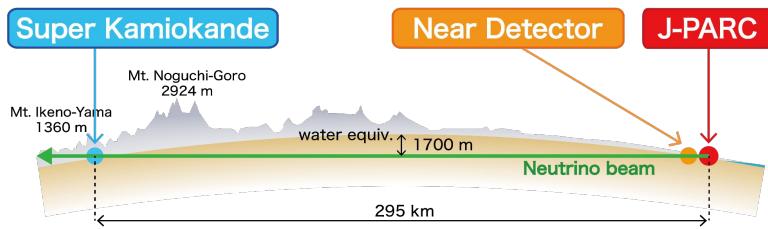


University
of Regina

MEASUREMENT OF KAON-CARBON FORWARD DIFFERENTIAL CROSS SECTION AT 30 GeV/c WITH EMPHATIC SPECTROMETER

Ph.D. Student: Bruno Ferrazzi, B.S., M.S.

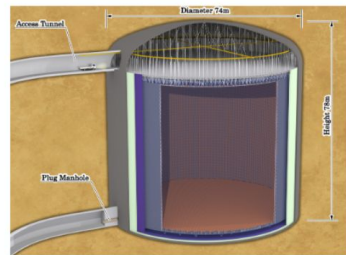
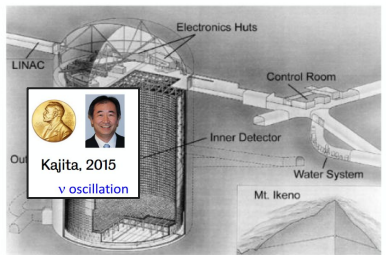
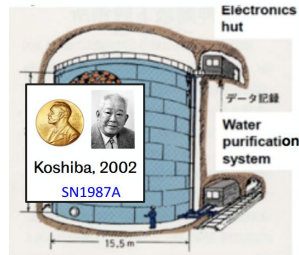
T2K AND HYPER-K



Kamiokande
1983–1996

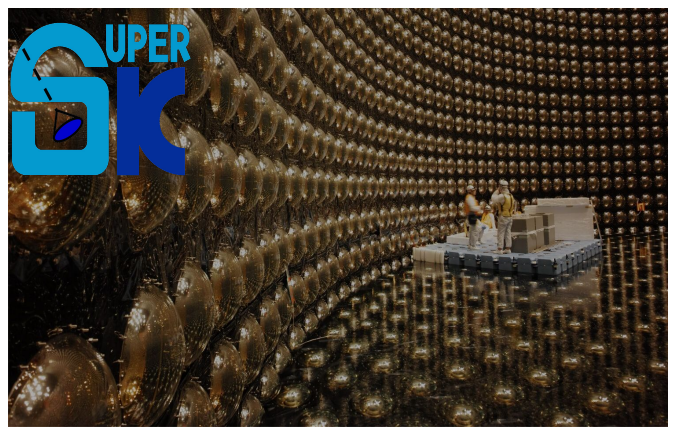
Super-Kamiokande
1996–today

Hyper-Kamiokande
~2026–

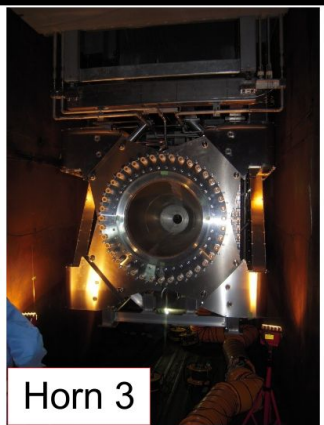
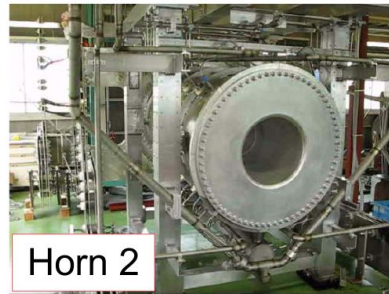
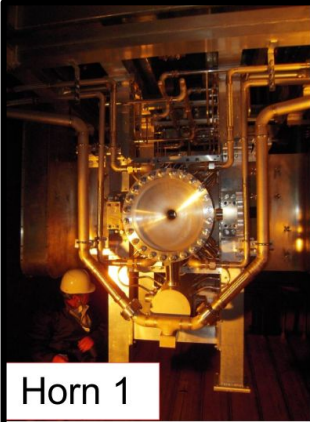
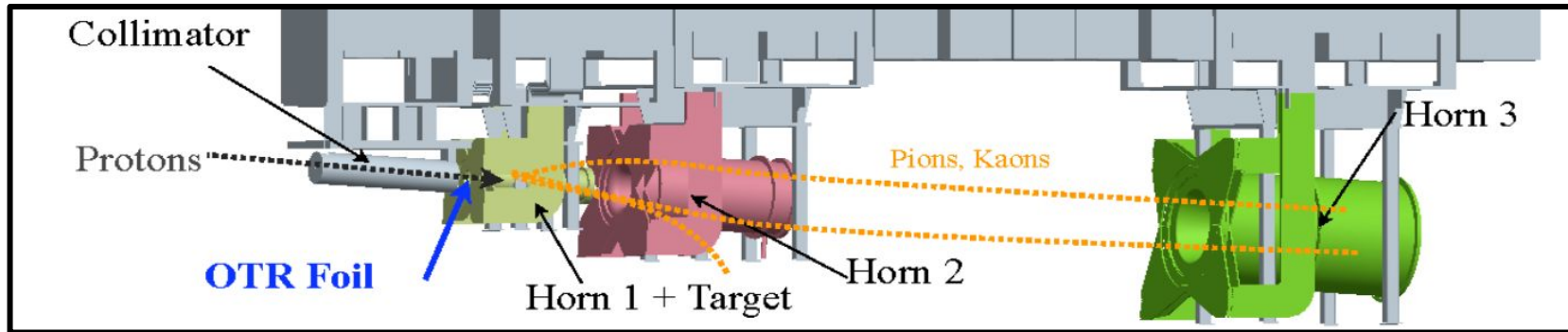


Broad physics research:

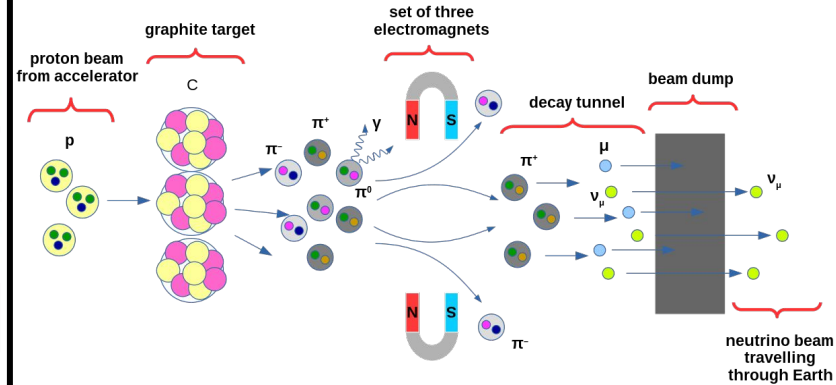
- Beam, earth's core, atmospheric, solar and supernova neutrinos studies;
- Proton decay, CP violation and BSM physics.



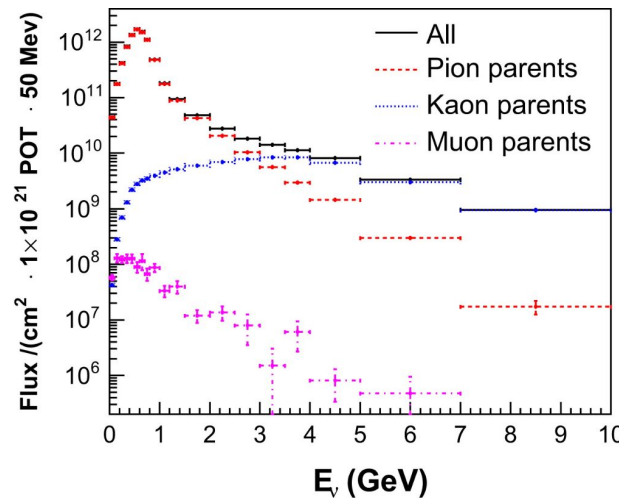
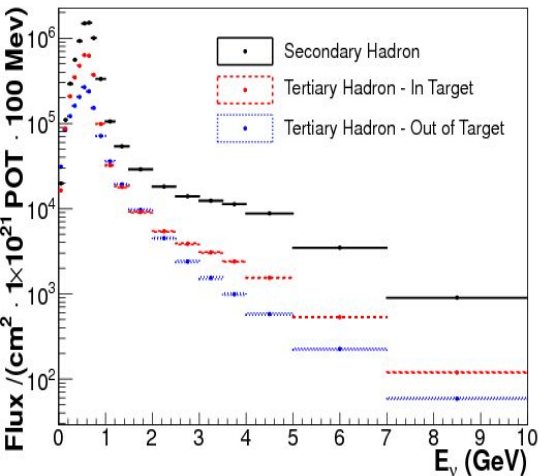
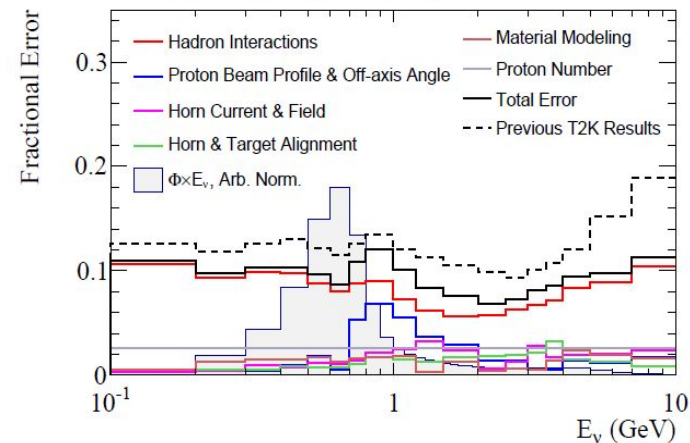
T2K Beamline



Images: Shibata, M.



Hadron Production

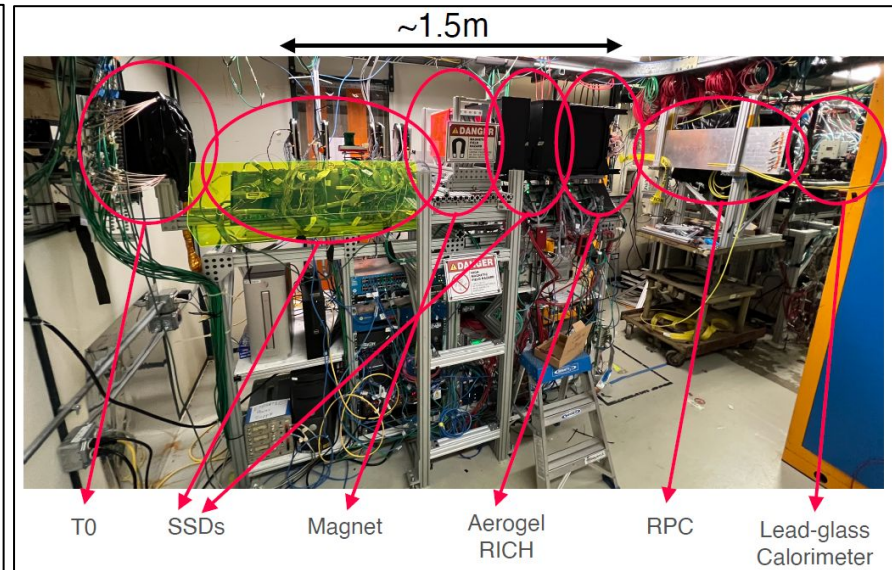
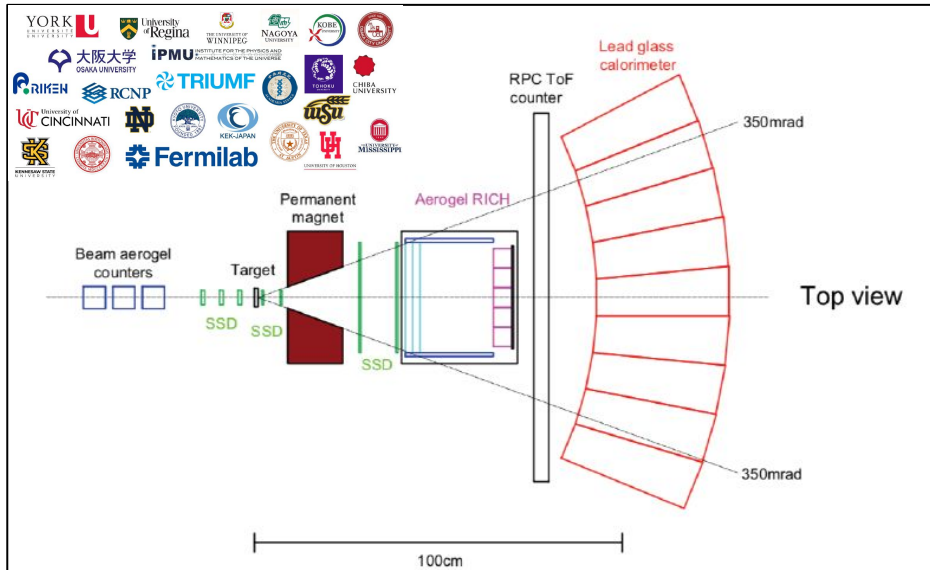
SK: Positive Focussing Mode, ν_μ 

Secondary and tertiary components of the ν_μ flux prediction at the T2K far detector. Abgrall, N. et al.

ν_μ flux prediction based on FLUKA2008.3b and re-weighted by the NA61 thin target data at the near T2K detector. Abgrall, N. et al.

ν_μ total flux uncertainties at Super-K. T2K Col.

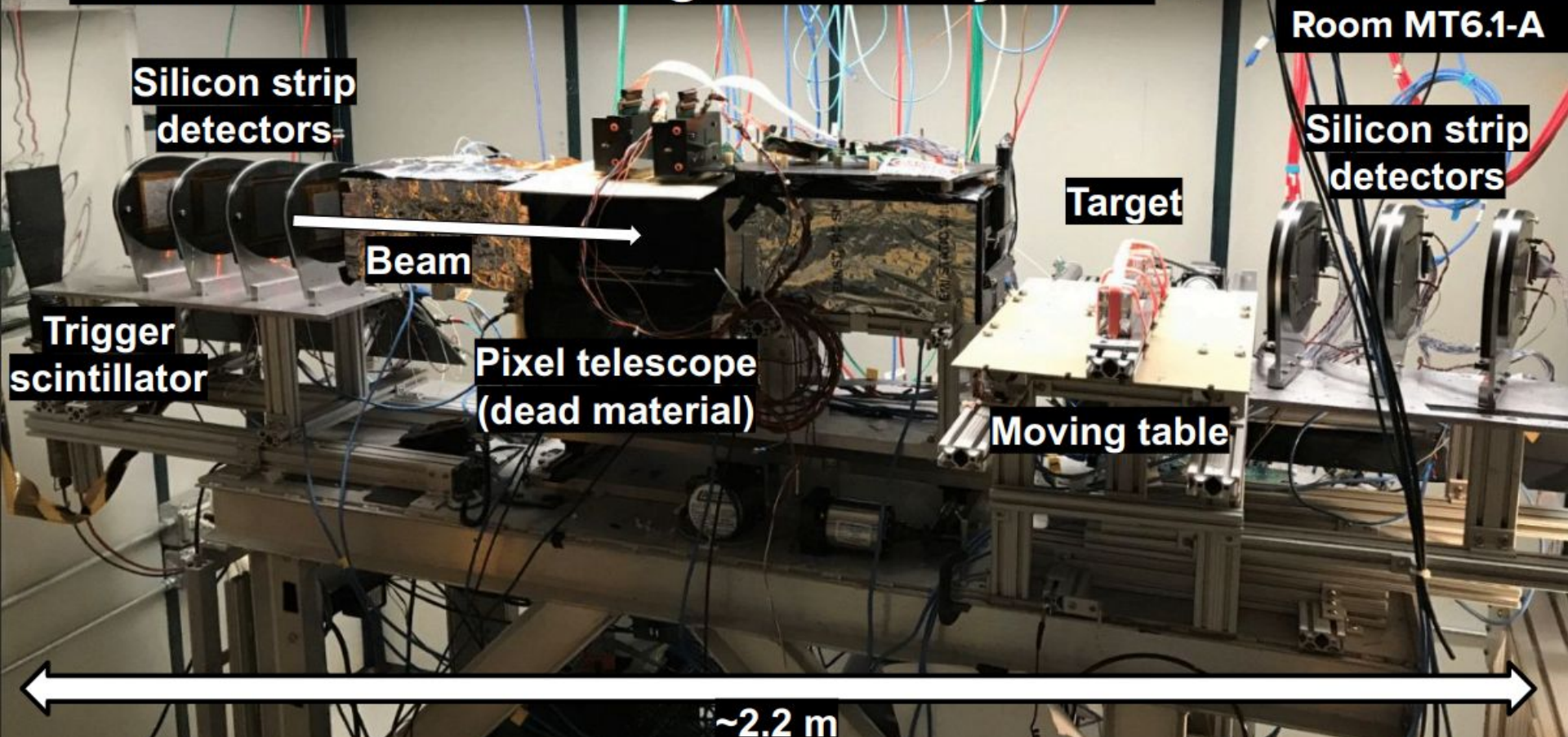
EXPERIMENT TO MEASURE THE PRODUCTION OF HADRONS AT A TEST BEAM IN CHICAGOLAND



The EMPHATIC collaboration has been operating a compact experiment at FERMILAB. Measurements of hadron production cross sections that are particularly relevant to neutrino flux predictions and not possible in other experiments.

EMPHATIC

EMPHATIC data-taking in January 2018



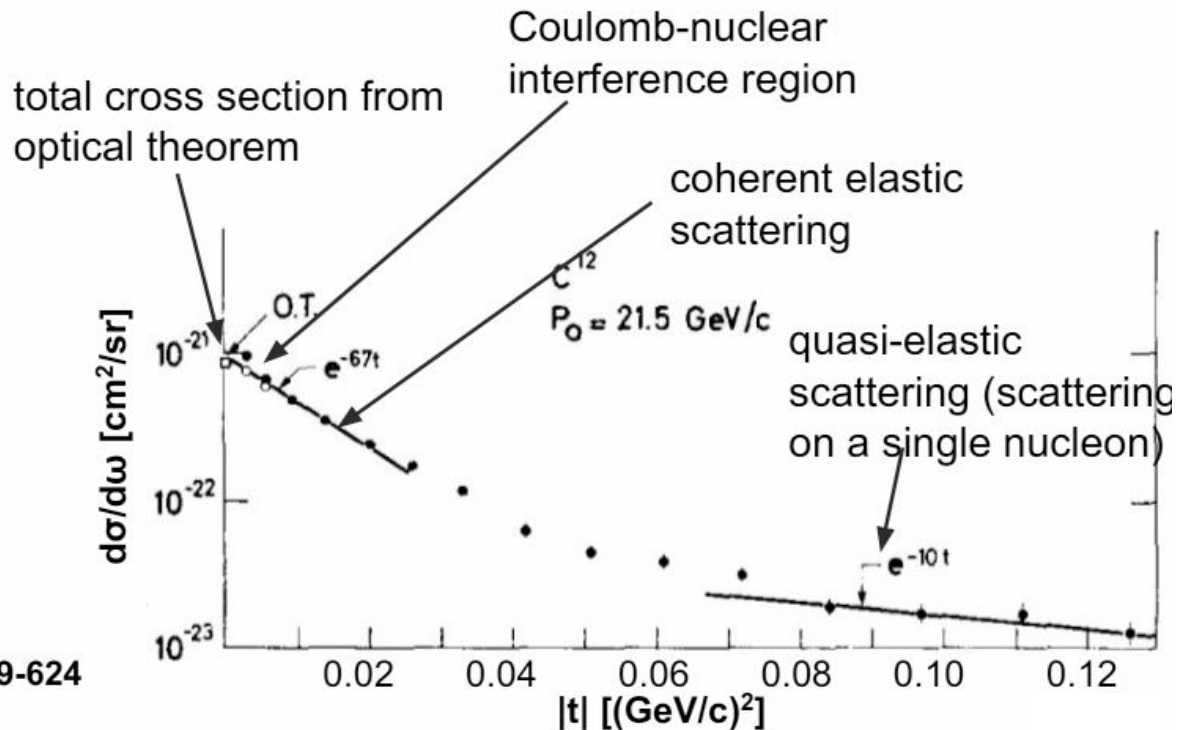
Optical Theorem

$$|t| \approx p^2 \theta^2$$

Beam momentum

Scattering angle

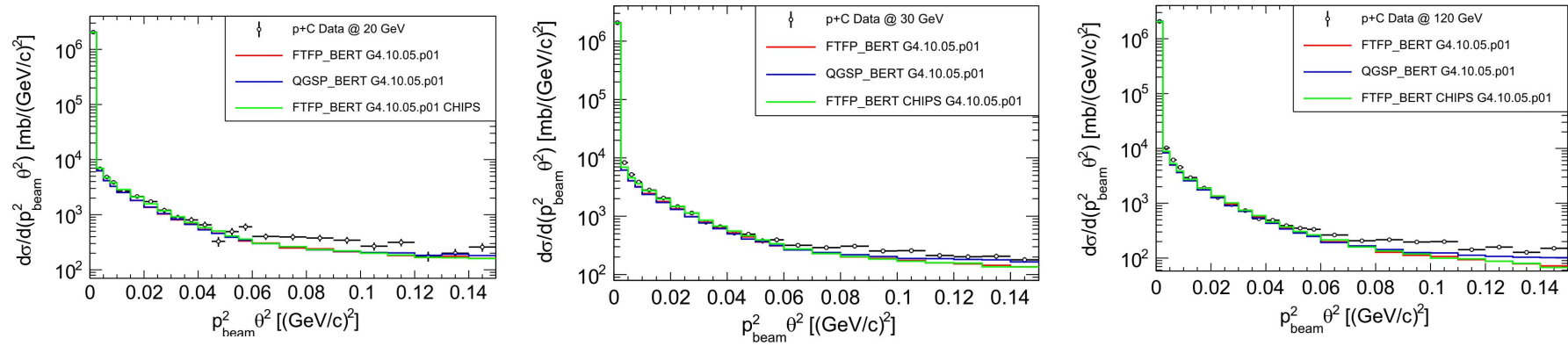
Bellettini et al., Nucl.Phys. 79 (1966) 609-624



Measurement of proton-carbon forward scattering in a proof-of-principle test of the EMPHATIC spectrometer

PhysRevD.106.112008, 2022

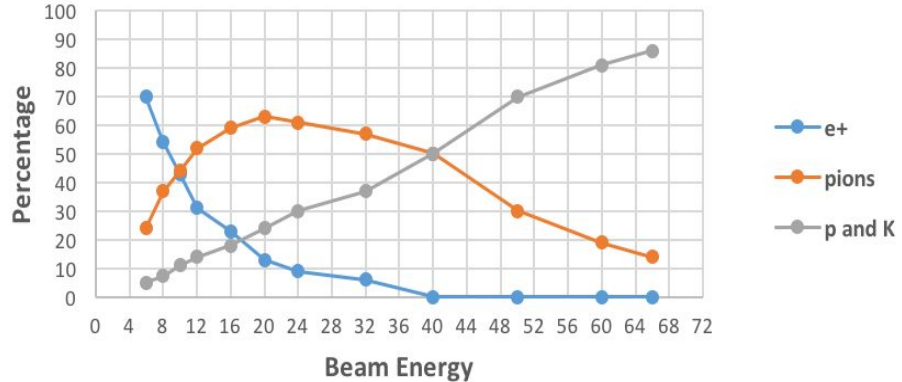
<https://journals.aps.org/prd/abstract/10.1103/PhysRevD.106.112008>



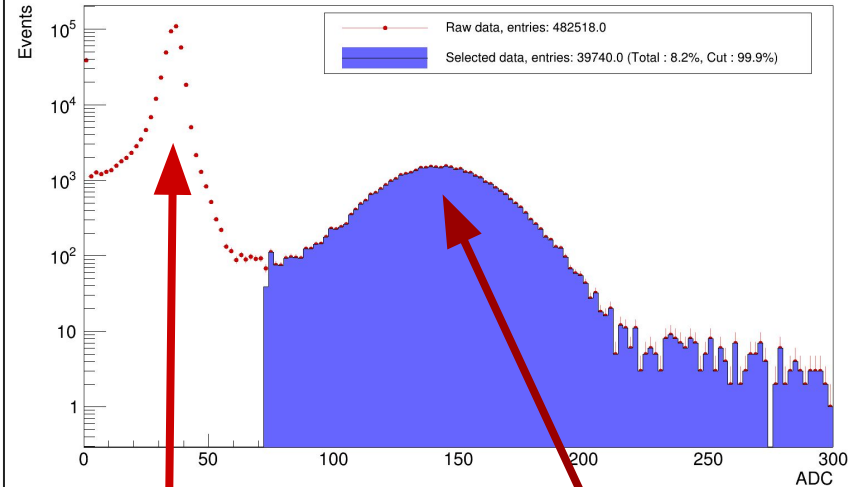
The p+C differential cross section at 20 GeV/c, 30 GeV/c, and 120 GeV/c

BEAM CONTENT

Beam Composition

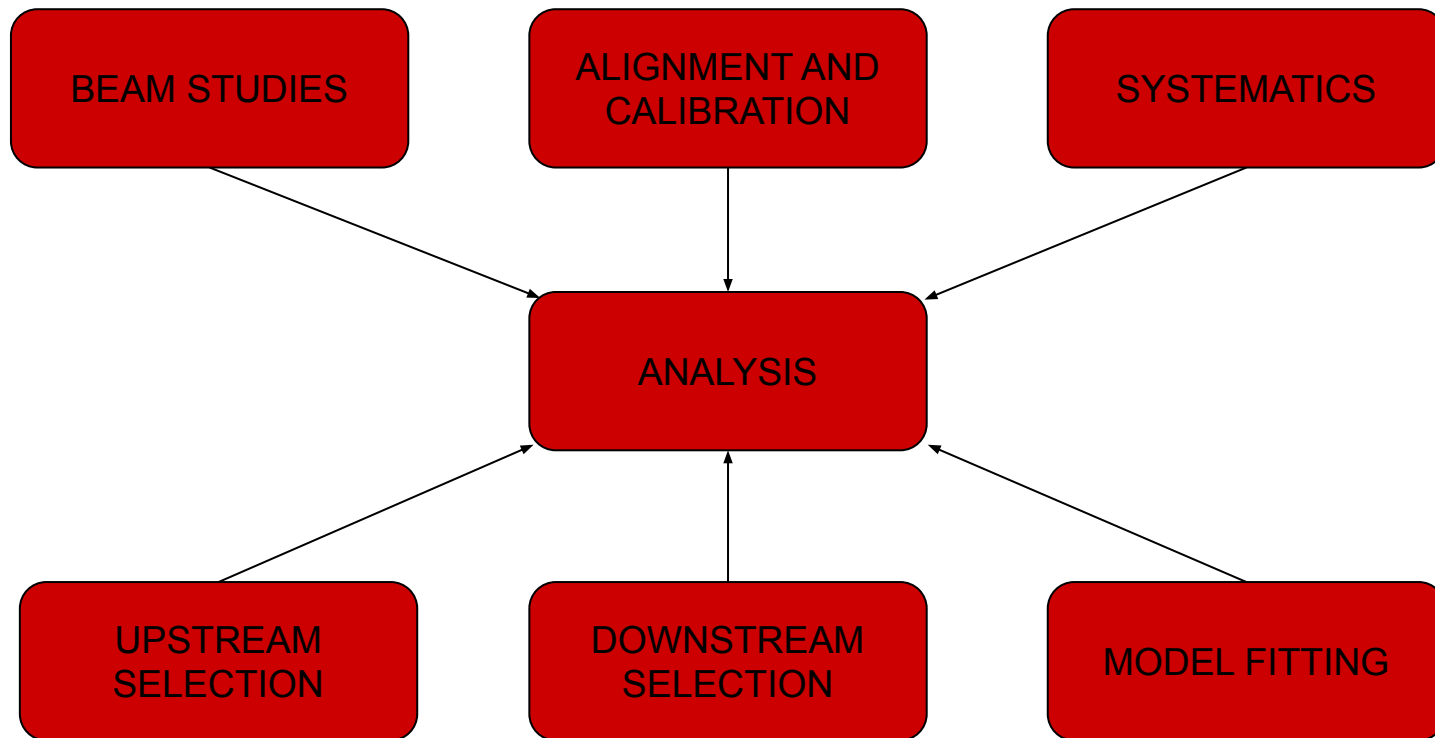


Cherenkov "Out" ADCs for k^+ on C 30 GeV

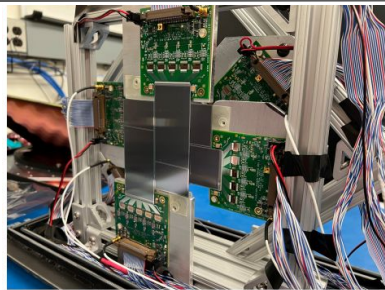
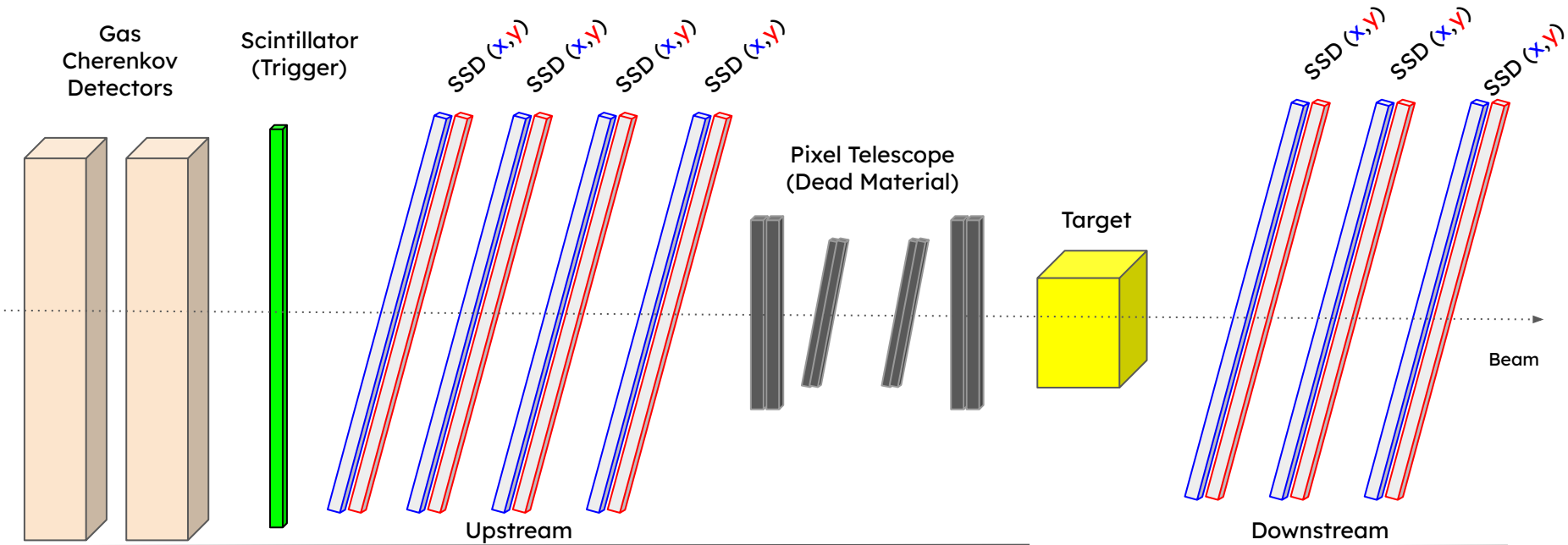


Protons

Kaons
(8%, ~40k events)



For Kaons we face new challenges as: low statistics and different systematics

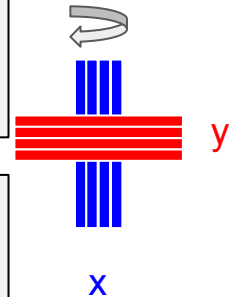
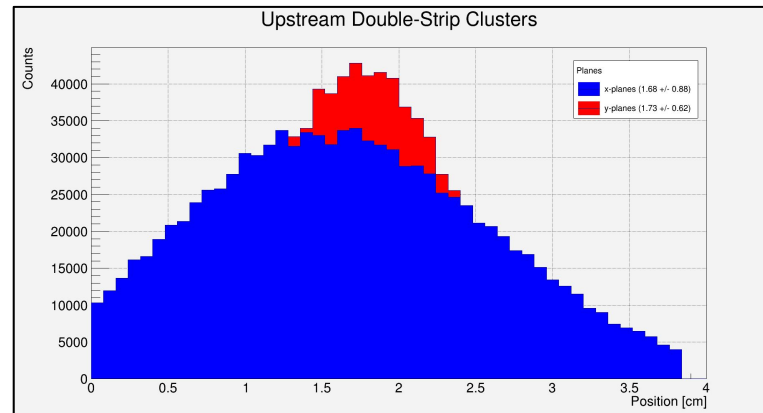
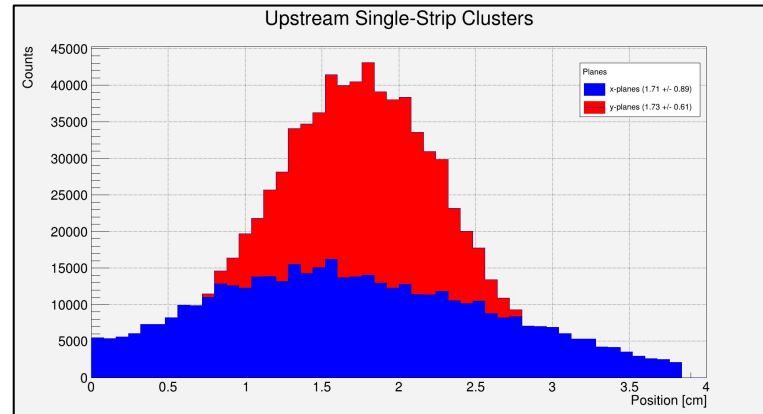


SSD: Silicon Strip Detector
 60 μm of pitch with 10 μm of resolution

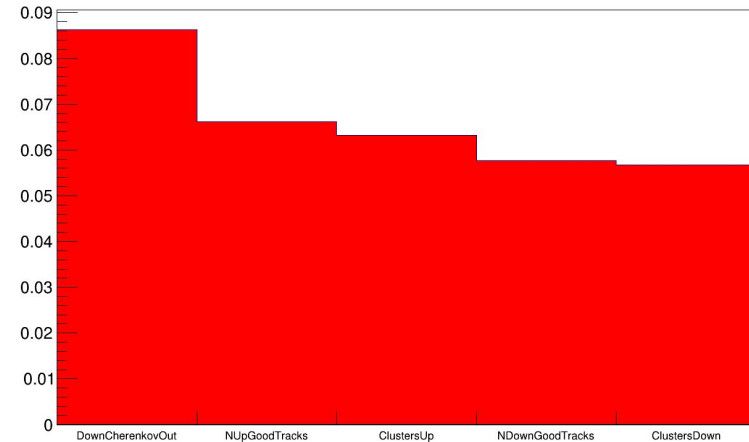
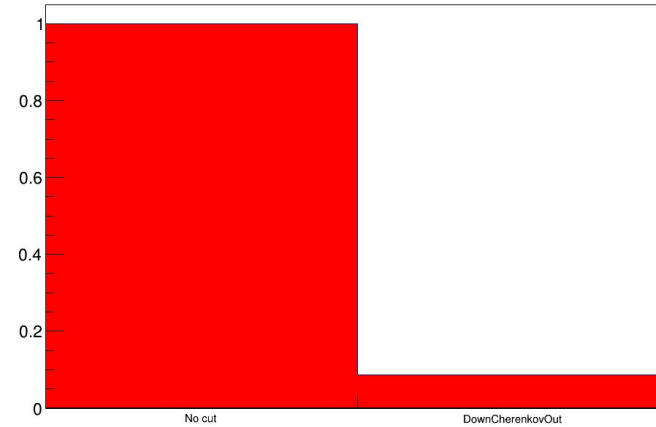
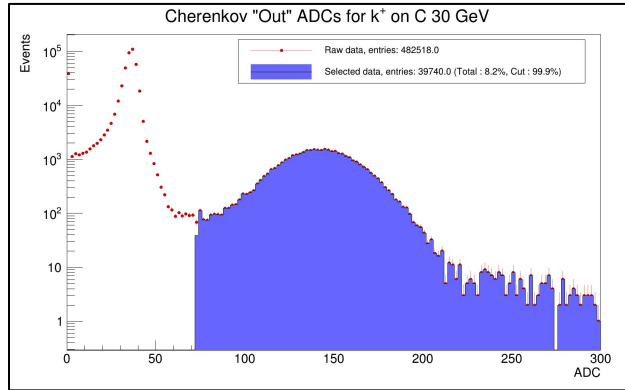
Finding Clusters

$$P = (\text{StripID} + 0.5) \times 0.006$$

Single-strip clusters represents **45%** of the Data
 Double-strip clusters represents **52%** of the Data
 Multi-strip clusters represents **3%**



Data Cuts

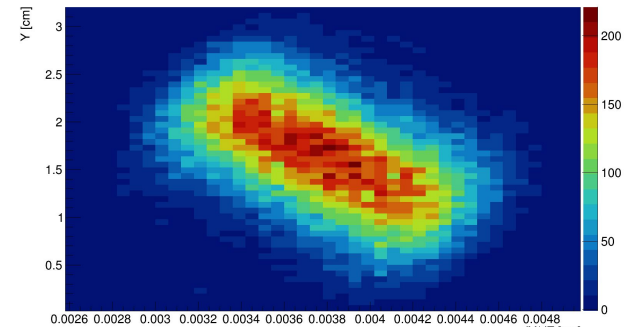
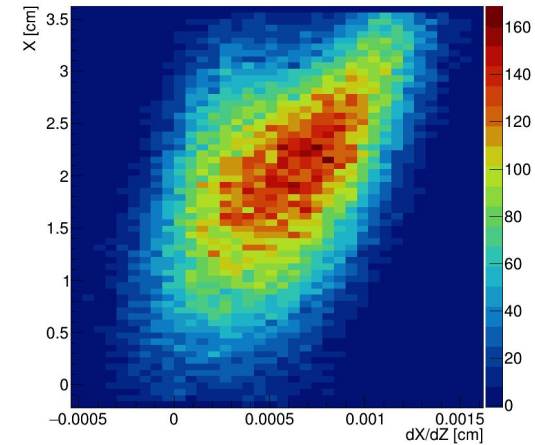
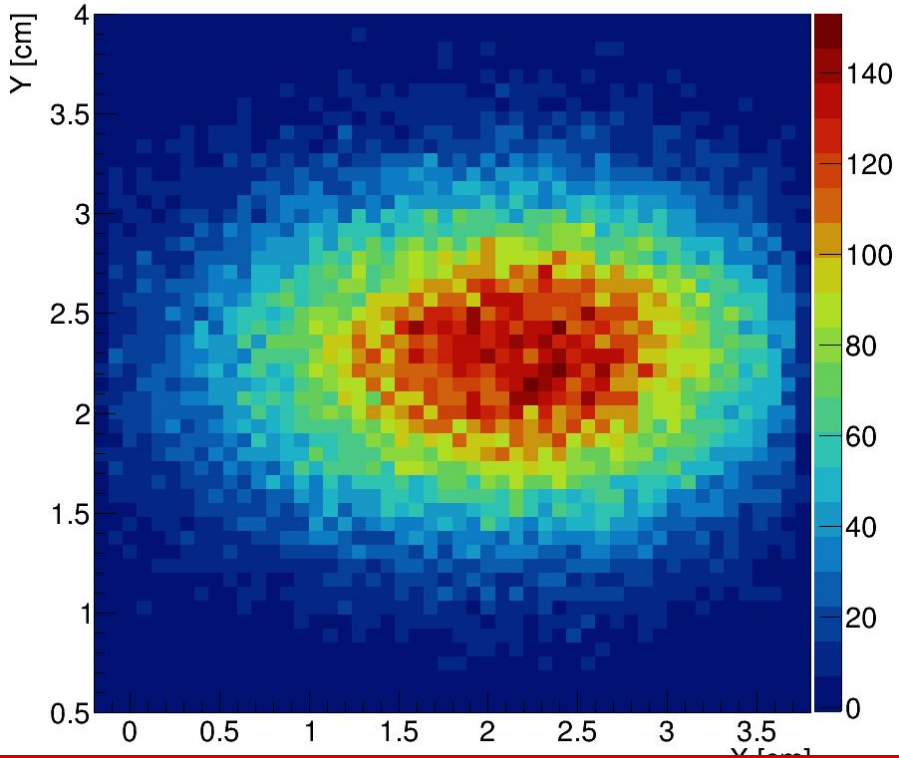


```
"DownCherenkovOut" : [73, 300],
"NUpTracks" : [1],
"ClustersUp" : [8],
"NDownTracks" : [1],
"ClustersDown" : [6],
```

Beam Profile

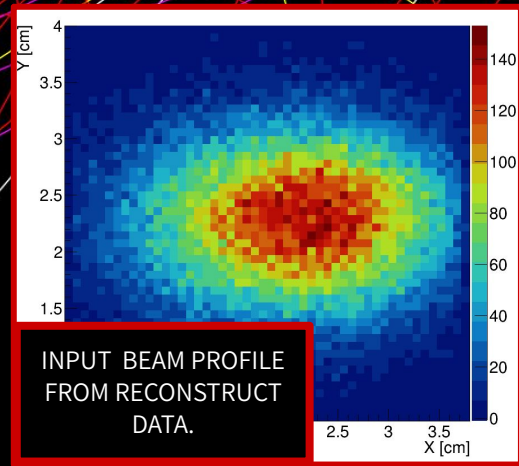
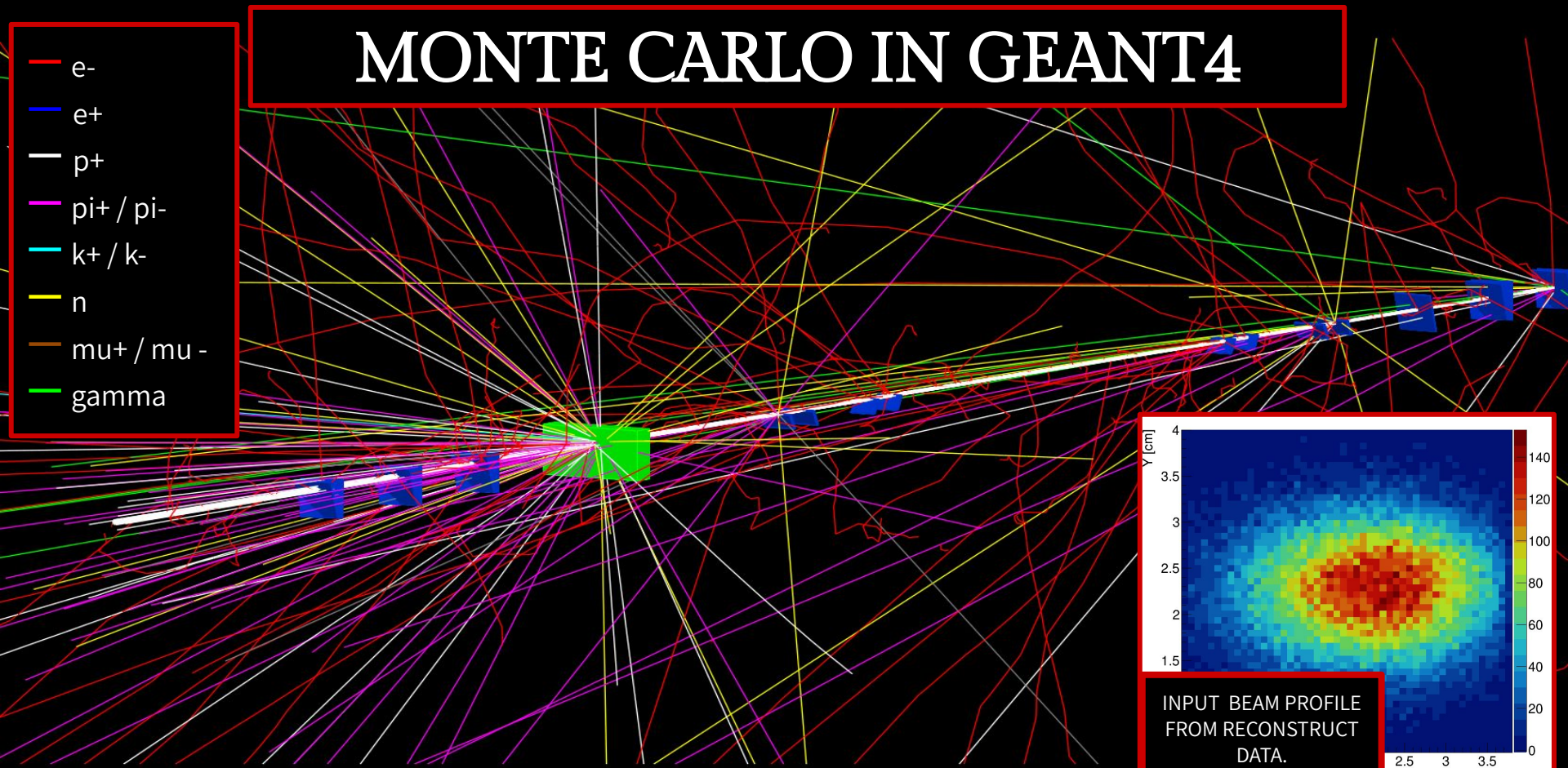
Beam XY-slopes profiles from the first upstream SSD

Beam XY profile from the first upstream SSD

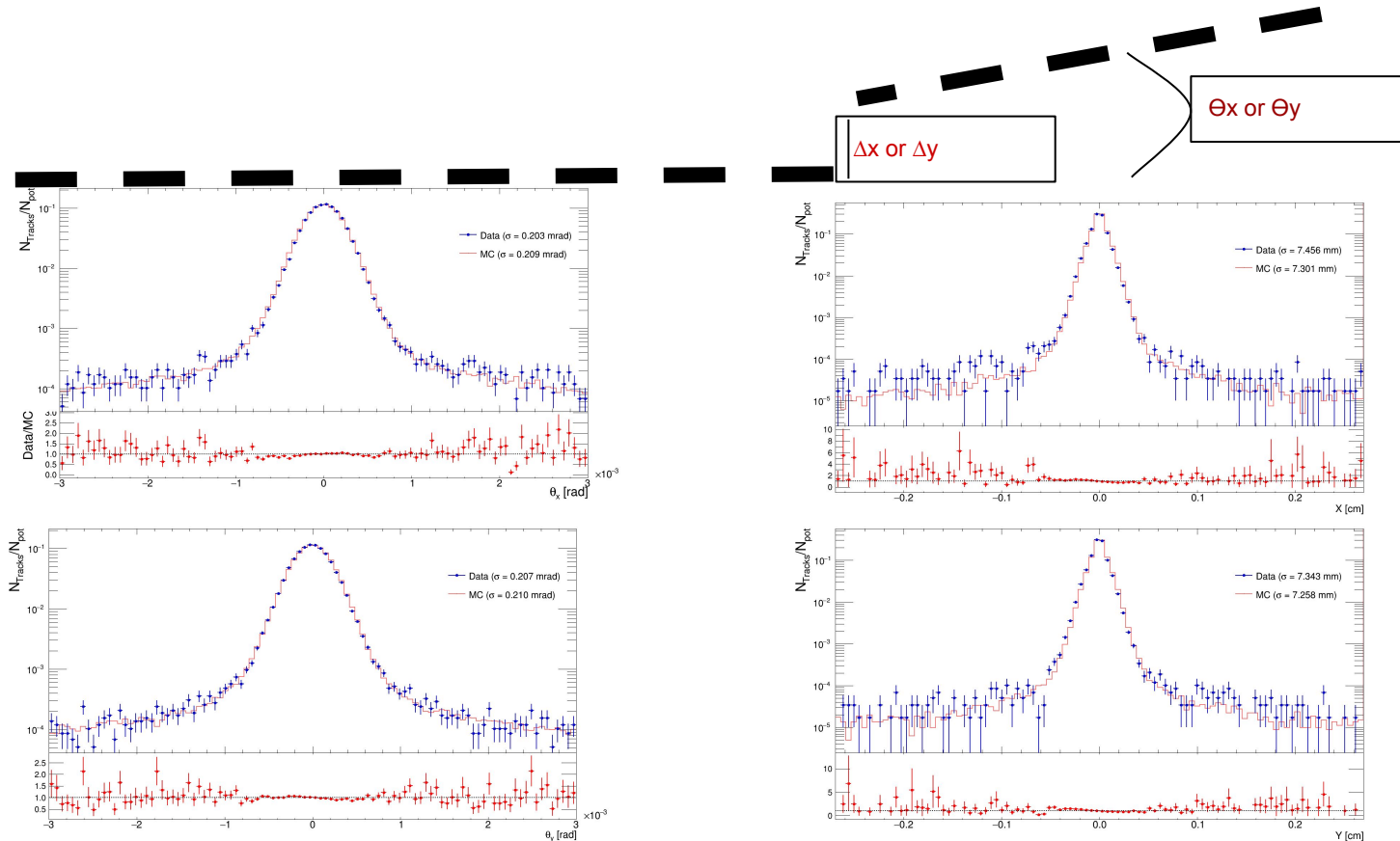


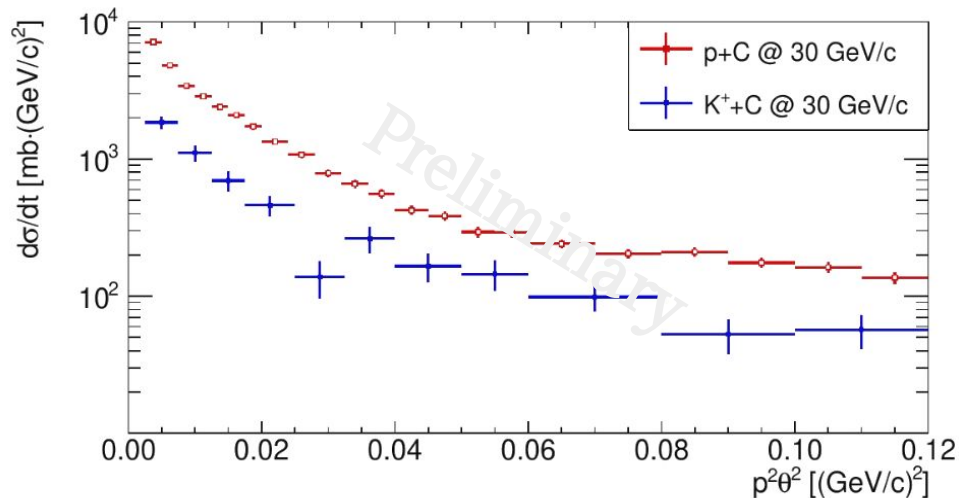
MONTE CARLO IN GEANT4

- e-
- e+
- p+
- pi+ / pi-
- k+ / k-
- n
- mu+ / mu-
- gamma



Track Reconstruction and Selection





Differential cross-section

$$\left(\frac{d\sigma}{dt}\right)_i = \frac{1}{nd} \frac{1}{\Delta t} \frac{N_i}{N_{pot}} \cdot C$$

- i - bin number
- n - number density
- d - target thickness
- N_i - number of tracks in a bin i
- N_{pot} - number of protons on target
- Δt - momentum transfer bin size
- C - total correction factor

Systematics

- Beam PID (TBD, very small)
- Target density and thickness (2%)
- Interactions in the pixel detector (< 15%)
- Production of secondaries in the target (< 5%)
- Production of secondaries in the trigger scintillator (negligible)
- Alignment (TBD)
- SSD efficiency (2%)
- Selection efficiency (TBD)

Conclusions

Neutrino flux uncertainty is a limiting factor for neutrino beam experiments;

Additional data below 15 GeV/c is needed to further constrain neutrino flux and NA61/SHINE beam cannot go below 13 GeV/c;

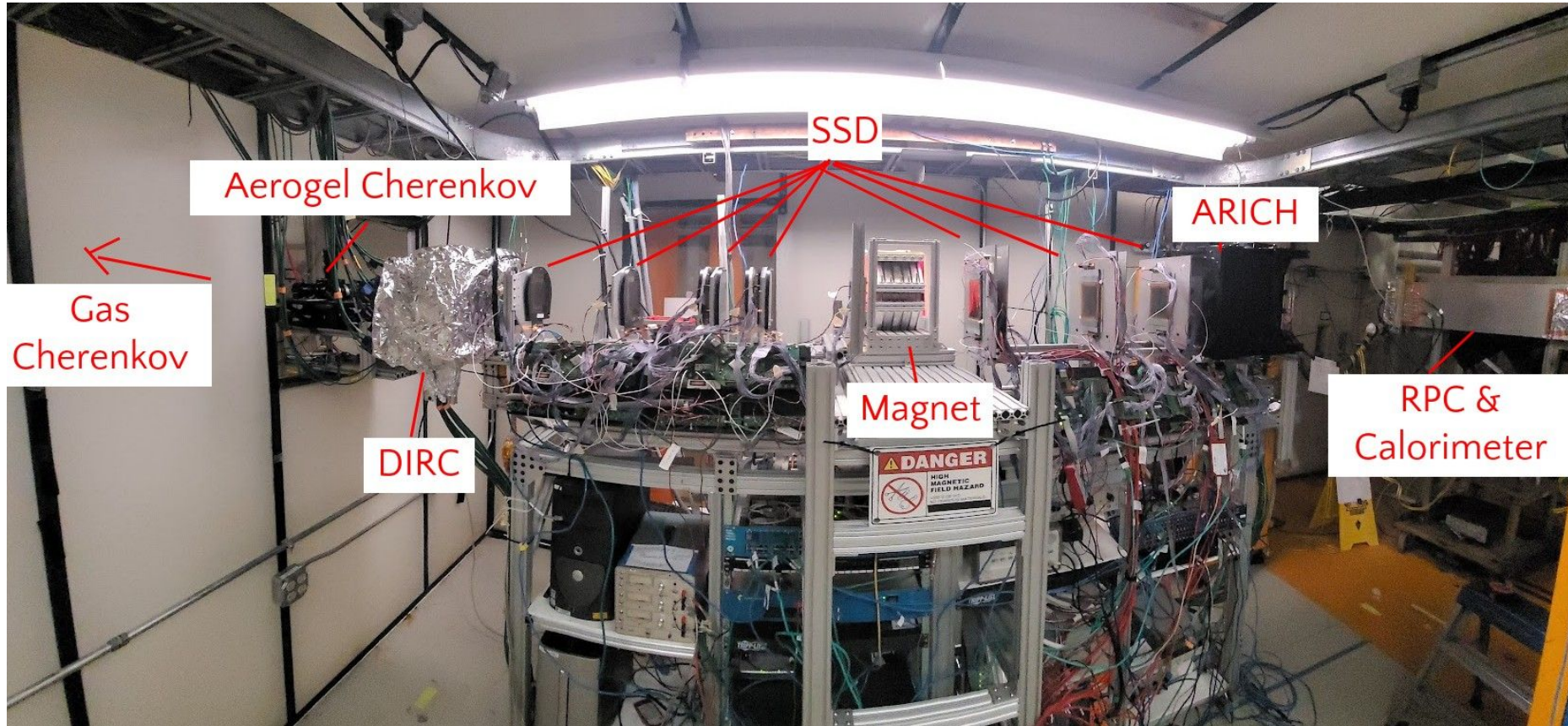
EMPHATIC is a table top experiment designed to take additional hadron production data at Fermilab Test Beam Facility (FTBF);

Measurements of Kaon forward scattering is possible and Kaon+Carbon at 30 GeV/c differential cross-section analysis is going on;

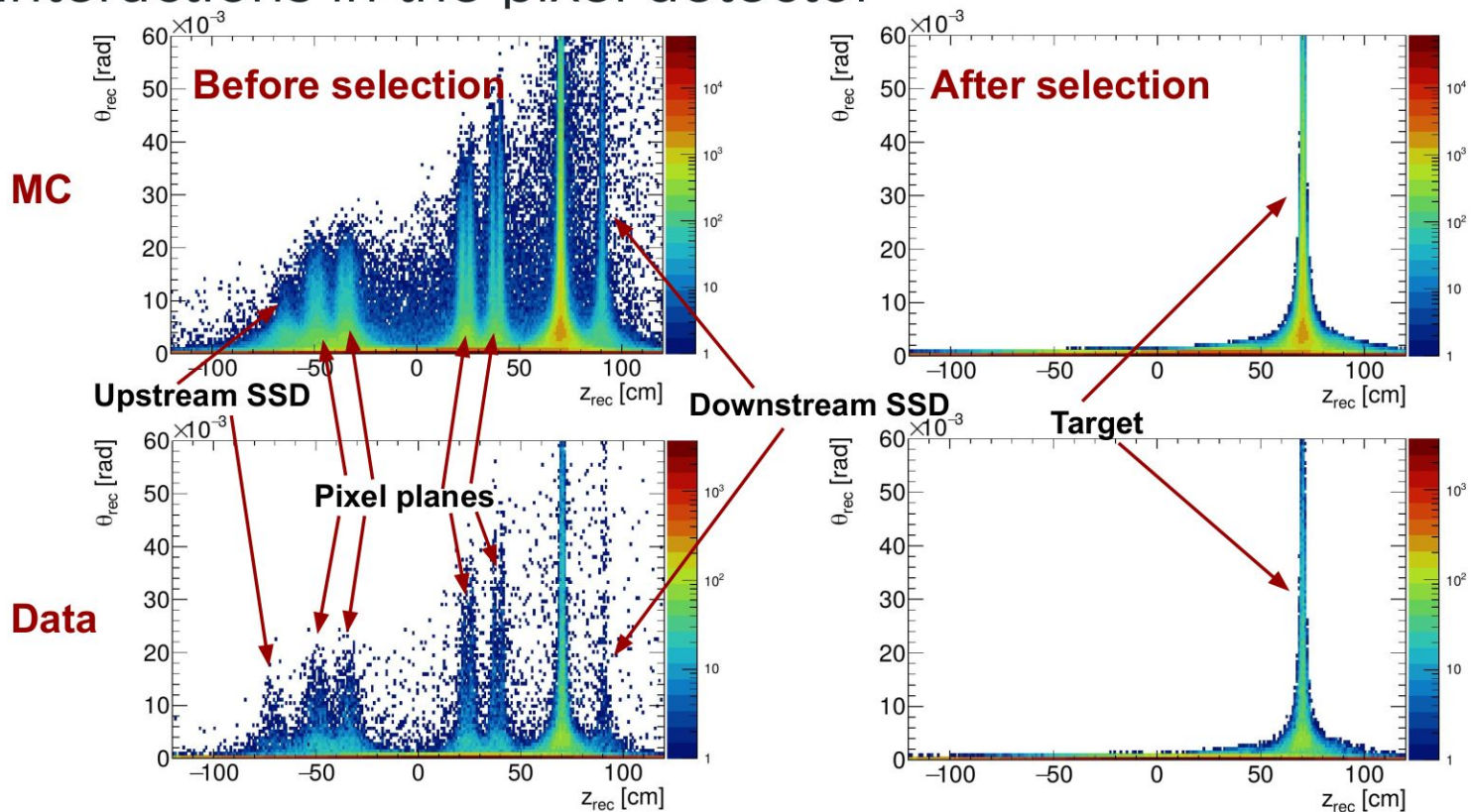
New measurements of particle production were done and is currently under analysis.

Backup

EMPHATIC 2023



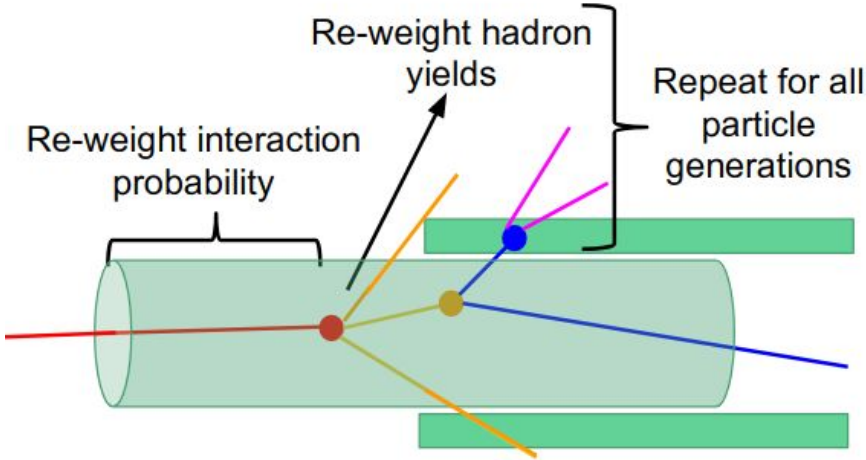
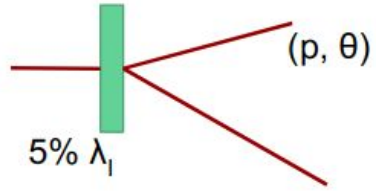
Interactions in the pixel detector



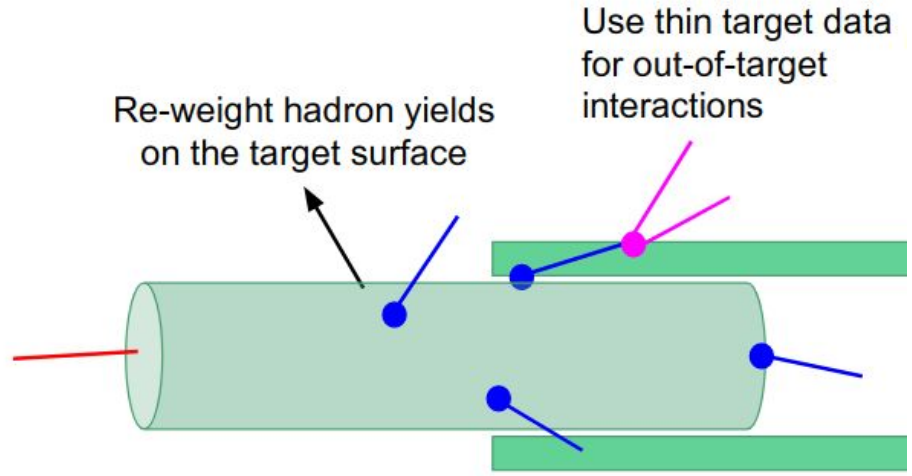
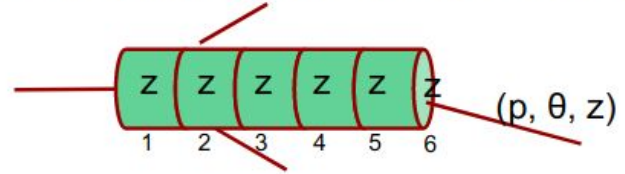
M. Pavin

Hadron production measurements

① Thin target measurements



② Replica target measurements



Both approaches are necessary to completely constrain neutrino flux!

M. Pavin