NA65/DsTau: Study of Tau Neutrino Production in p-A Interactions

Emin Yüksel
Middle East Technical University
On Behalf of the DsTau Collaboration

eyuksel@cern.ch

Introduction

- The main source of ν_τ is a decay of D_s mesons produced in p-A interactions
- The DsTau experiment is proposed to measure the differential production cross-section of D_s in 400 GeV p-A interactions

Detailed understanding ν_τ production allows measuring precise cross section

- Test of Lepton Universality in neutrino scattering
- DsTau measurements can also provide inputs for ongoing and future ν_τ experiments. Such as FASER, SND@LHC and SHIP

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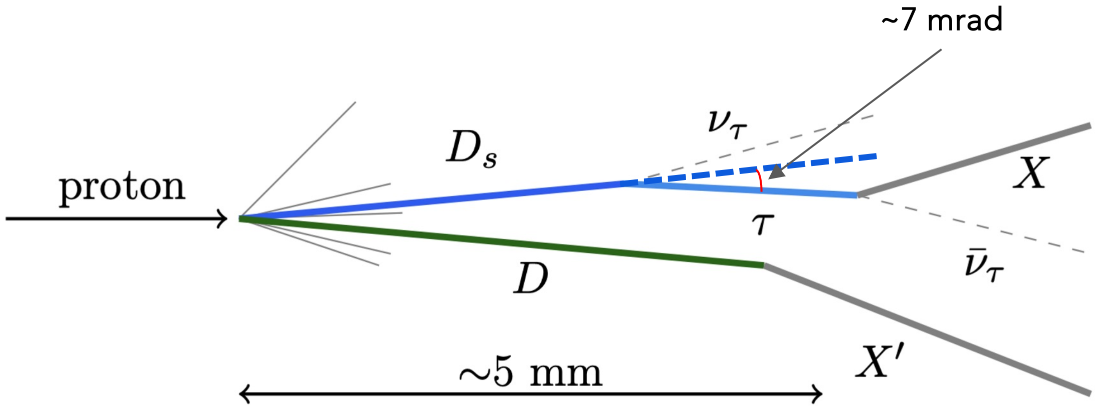
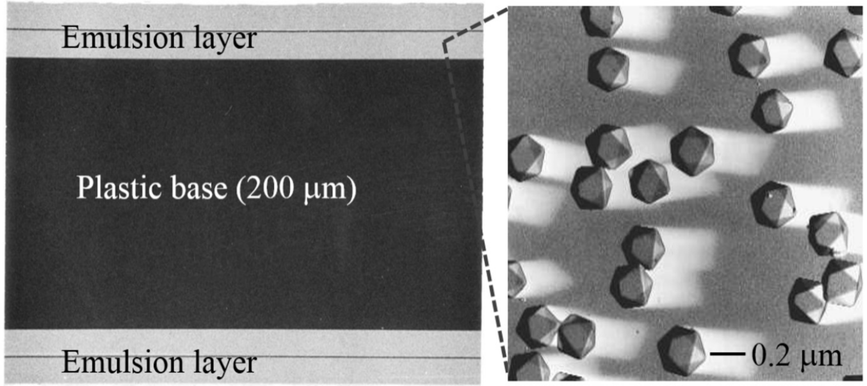
Introduction

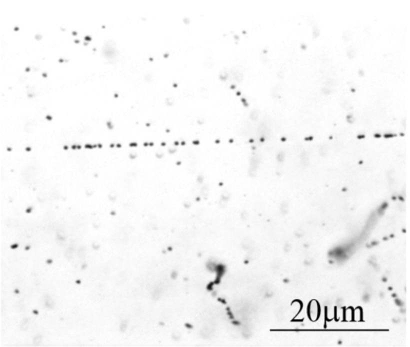
- The topology of $\mathrm{D_s} \to \tau \to X$ events appear as a double kink plus another decay topology (of pair charm particle) within some mm.
- The kink angle of $\mathrm{D_s} \to \tau$ decay is only $\sim 7\ \mathrm{mrad}$
- An emulsion detector with a nanometric spatial resolution is used to measure such decay topology in a short range

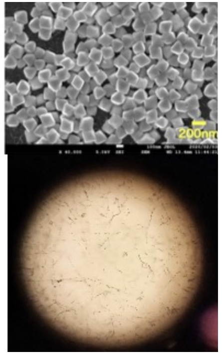


Nuclear Emulsion

- Nuclear emulsion consist of silver halide crystals and gelatin as the binder
- Charged particle tracks will be recorded and it will be appeared as a series of silver grains after chemical development
- Automatic optical microscopes are used for emulsion read out

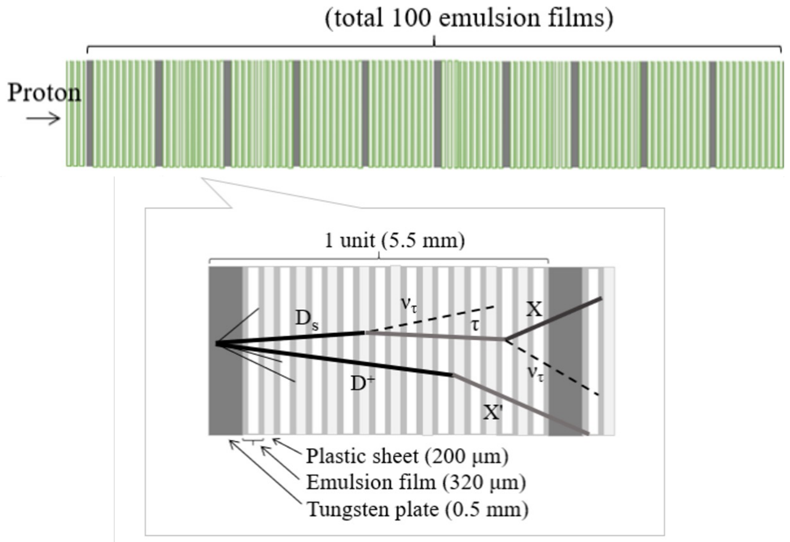






Data Taking

- The DsTau experiment takes place in CERN-SPS/North Area
- Expected to have $4.9 * 10^9$ 400 GeV protons on target with $2.3 * 10^8$ proton interactions on target.

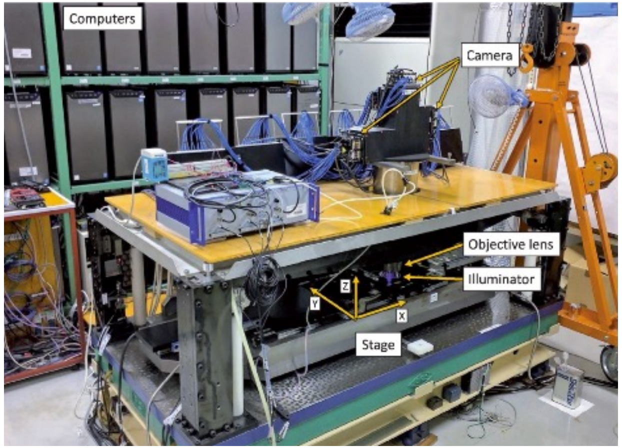


Target Mover

JINST 18 (2023), P10008

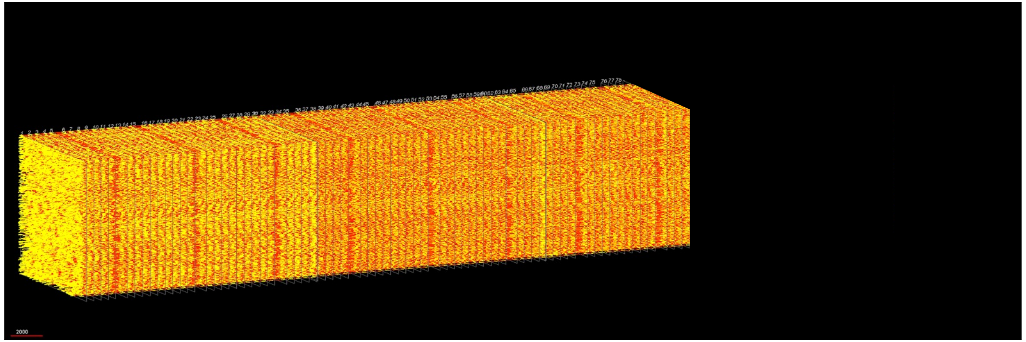
Emulsion Scanning

1. Full surface scanning is done to accumulate all charged tracks segments by Hyper Track Selector (HTS)
   - HTS scans emulsion tracks with the speed of $5000\ \mathrm{cm}^2/\mathrm{h}$
   - Emulsion film dimensions: $12.5\ \mathrm{cm} \times 10\ \mathrm{cm}$ ($25\ \mathrm{cm} \times 20\ \mathrm{cm}$)
2. Preselect events in the precision measurement to search for small-angle decay of $\mathrm{D_s} \rightarrow \tau$



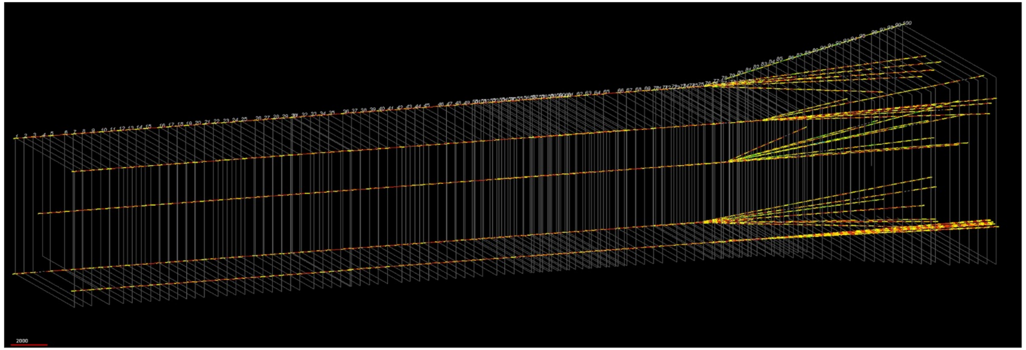
Hyper Track Selector

Data Reconstruction



- Proton tracks are constructed, and linked with a method called “Proton Linking”

In this image, only not interacted protons are selected

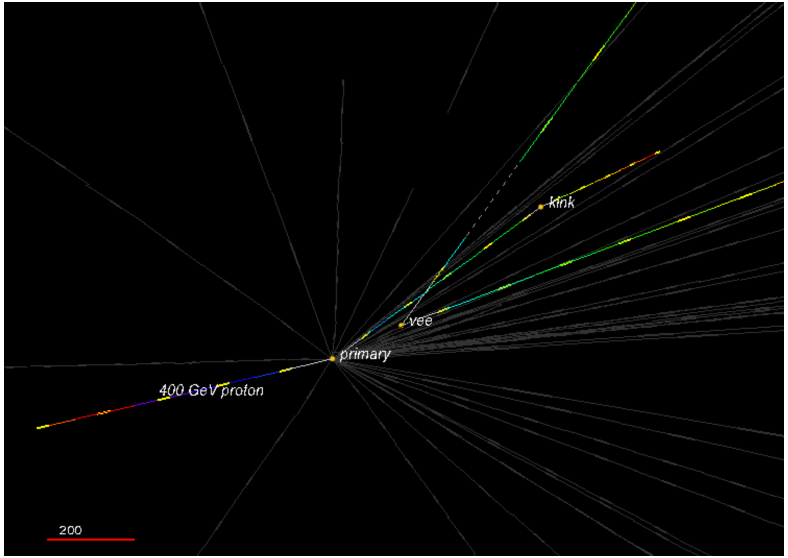


- Interaction vertex is constructed, and daughters are connected to incoming protons

In this image, only protons interacted in the last tungsten are selected

Yellow line segments show the trajectories of charged particles in the emulsion films

Data Reconstruction



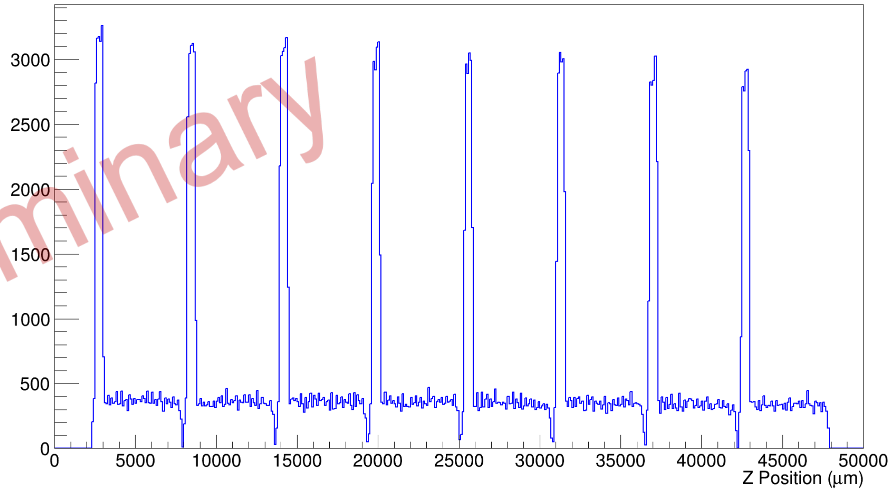
- As a final step "Decay Search" algorithm applied to charm decay candidates
- Higher order interactions are constructed and attached to parent tracks
- Decay Search process is going on

Reconstructed visual of a D_s decay candidate

Data

A sub sample of 2018 pilot run data is used to proton interaction features and measurement of interaction length in tungsten will be reported here

Tungsten	N	N_0	N/N_0 (%)
1	12,638	3,227,127	0.39
2	11,913	3,224,119	0.37
3	10,824	3,190,880	0.34
4	10,964	3,150,340	0.35
5	10,949	3,094,766	0.35
6	10,137	3,021,212	0.34
7	9,591	2,938,091	0.33
8	8,511	2,837,072	0.30



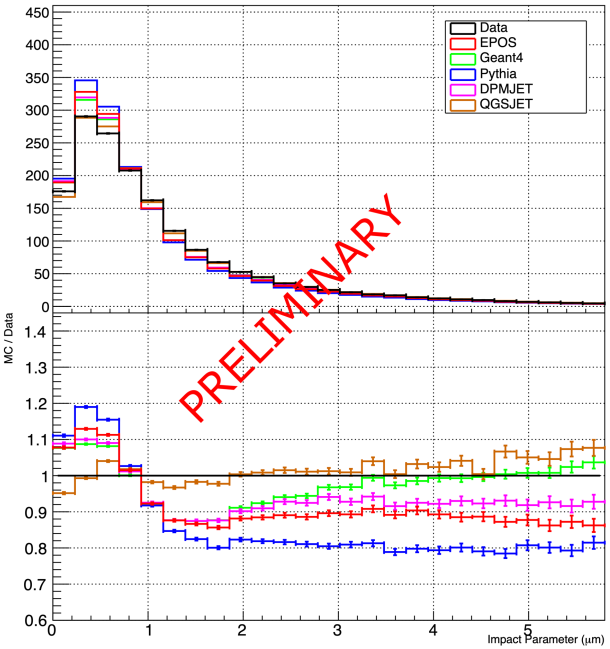
MC/Data Comparisons

- Proton interactions are generated using following event generators.
    1. Geant4
    2. Pythia
    3. EPOS
    4. QGSJET
    5. DPMJET

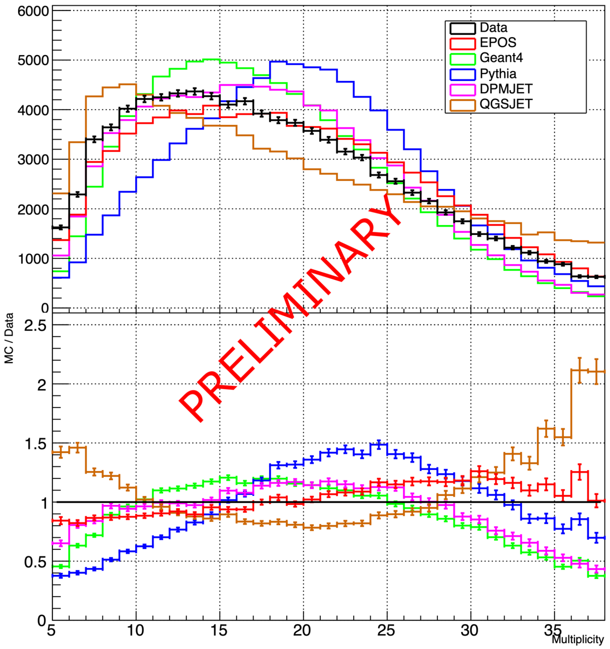
- Generated output transported through the module with Geant4
- Data driven smearing has been applied to reproduce the effect of measurement
- The DsTau reconstruction algorithm is processed to MC samples to reconstruct tracks and vertices

MC/Data Comparison of p-W interactions

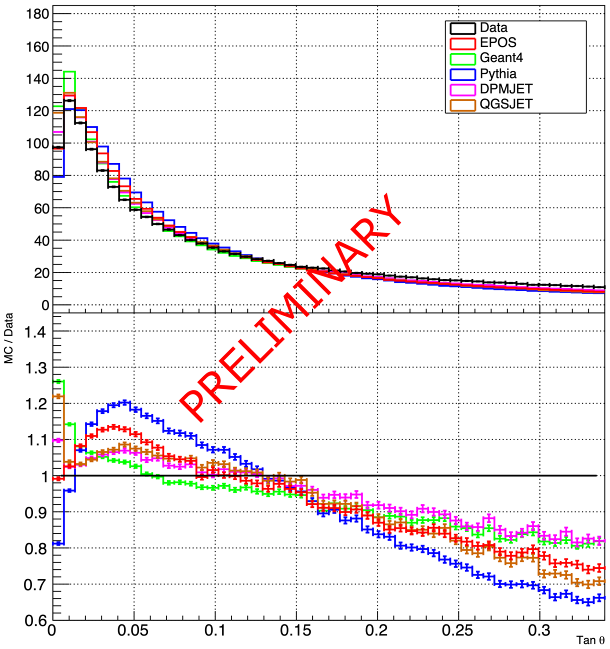
Impact Parameter



Charged Track Multiplicity



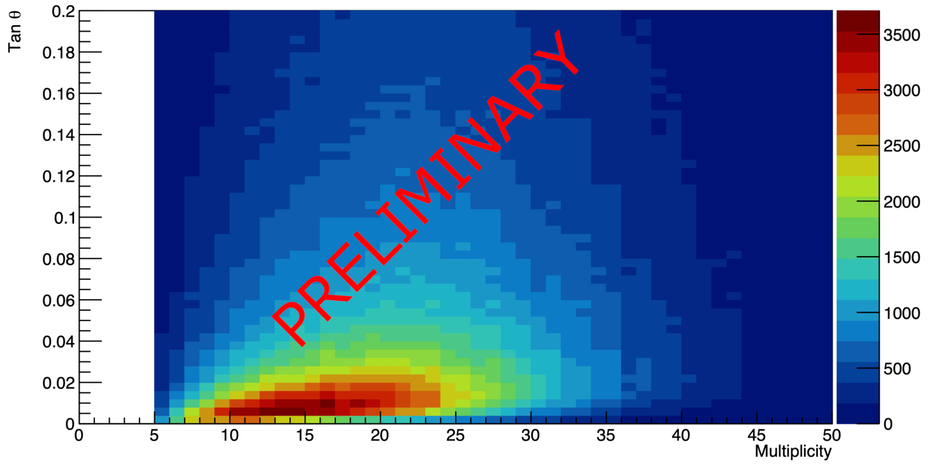
Track Angle



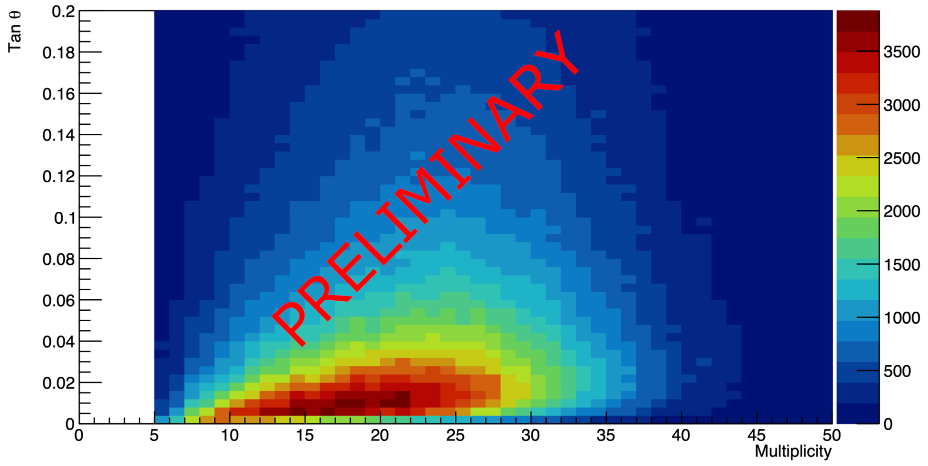
Track Slopes vs Event Multiplicity

- To understand the discrepancy in track slope in MC/Data comparison track slope vs multiplicity distribution has been studied
- Average track angle of EPOS increases more with multiplicity

Data

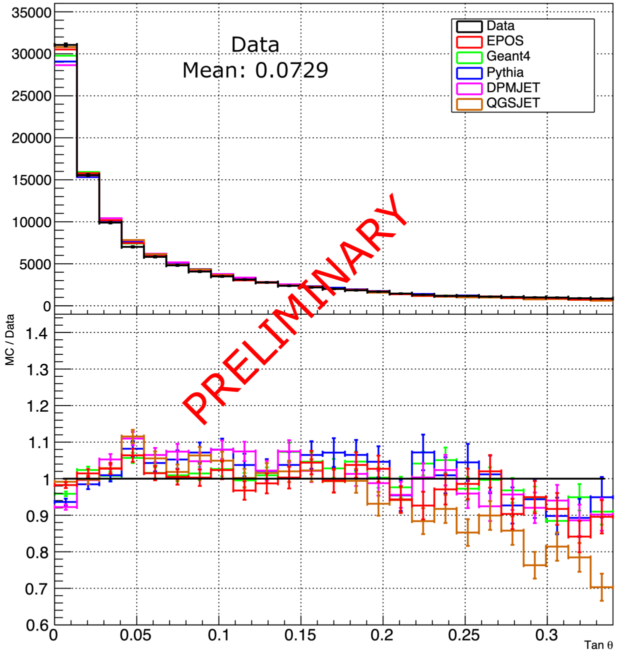


EPOS

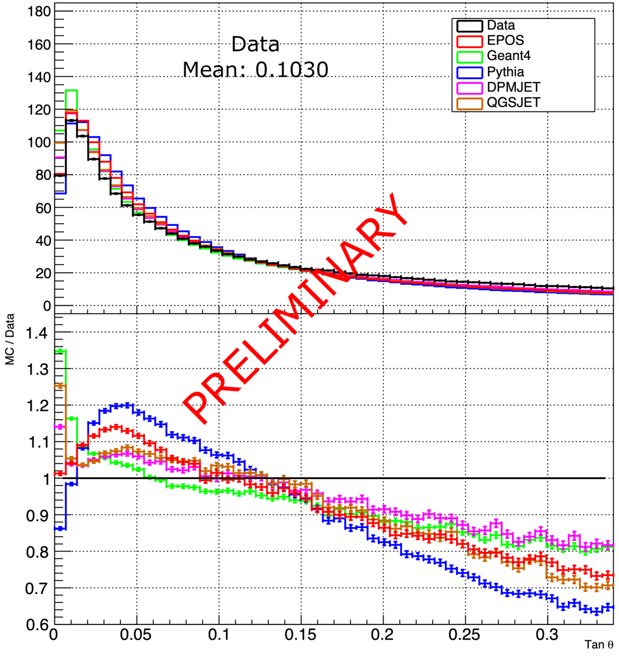


Angle Dependence on Multiplicity

Multiplicity < 10



Multiplicity >= 10

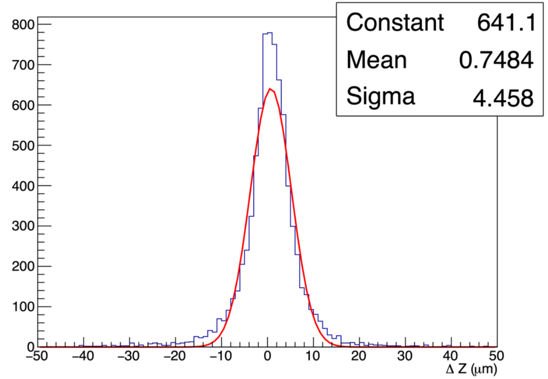


- To further analyze this discrepancy MC/Data comparison was examined in two different multiplicity regions.
- With multiplicity < 10 both MC and Data are in good agreement.

This can be explained by constant P_T distribution of hadron interactions.

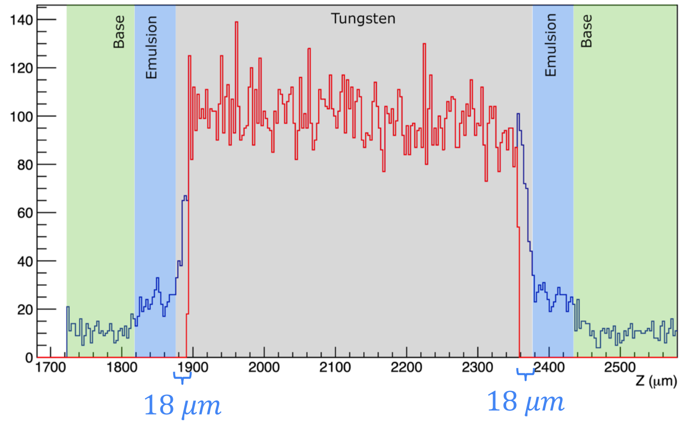
Efficiency Estimation

- Vertexing and Proton Linking efficiencies are calculated using Geant4-based MC
- To estimate the vertex reconstruction efficiency, the true vertex position is compared with the reconstructed Monte Carlo



$$4\sigma_{\Delta z} \approx 18\ \mu m$$
$$4\sigma_{\Delta T2} \approx 1.8\ \mu m$$

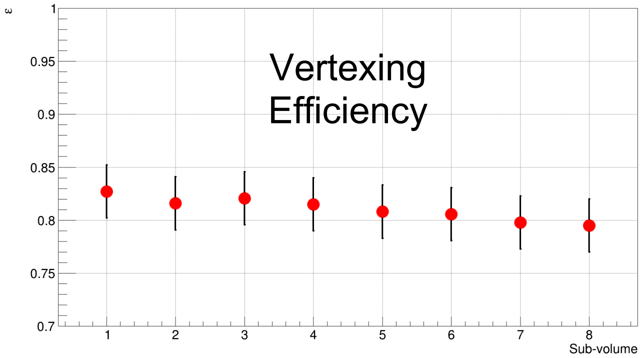
Vertex Migration

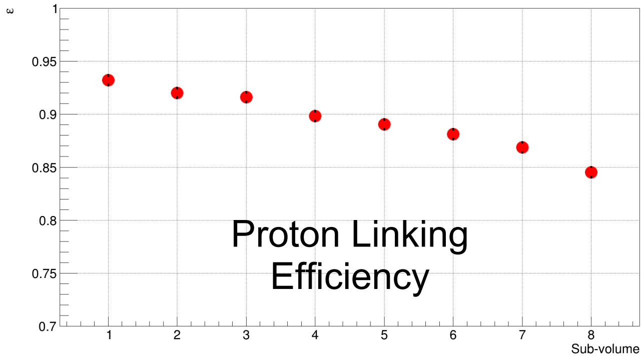


Vertex is correctly reconstructed if the vertex is found within the 4σ in z and transverse axis

Efficiency Estimation

- Efficiencies of vertex reconstruction and proton linking are estimated using EPOS
  - Vertexing Efficiency = 81.0 ± 0.9%
  - Proton Linking Efficiency = 89.4 ± 0.1%
- Proton purity for proton selection measured as 96.0 ± 0.2%





Proton Interaction Length in Tungsten

$$\lambda = -\frac{L}{\ln(1 - \frac{N}{N_0})}$$

λ = Proton interaction length in tungsten
L = Tungsten plate length
N = Number of proton interactions in tungsten plate
N_0 = Number of protons entering the tungsten plate

- Polystyrene interaction rate is calculated using the ratio of number of proton interaction in tungsten and polystyrene per unit length

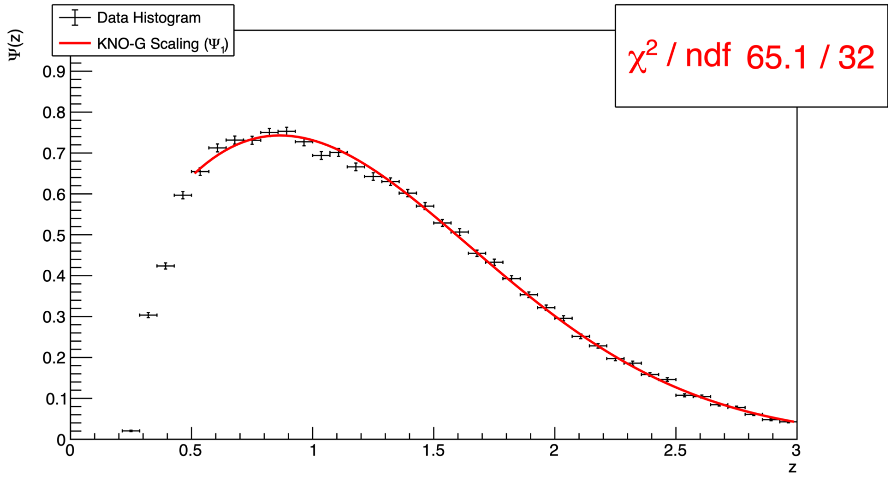
Proton Interaction Length in Tungsten (Data-Left/EPOS-Right)

Sub-volume	Tungsten (mm)	Polystyrene (mm)
1	95.9±2.7	762.1±28.5
2	99.6±2.7	818.2±30.5
3	109.8±3.1	880.4±33.7
4	105.7±3.1	886.1±33.7
5	103.4±3.0	858.6±33.3
6	109.2±3.2	869.5±33.8
7	110.7±3.3	937.5±37.3
8	120.3±3.7	1048.8±43.7
Mean	105.6±1.1	882.6±12.2

Sub-volume	Tungsten (mm)	Polystyrene (mm)
1	95.1±2.7	755.5±28.4
2	96.7±2.7	794.1±29.7
3	98.6±2.8	790.3±30.0
4	98.7±2.9	827.6±31.4
5	99.7±2.9	827.4±32.1
6	100.1±3.0	797.2±30.7
7	102.4±3.1	867.1±34.2
8	104.5±3.2	911.2±37.1
Mean	99.2±1.0	821.3±11.2

KNO-G Scaling

- Data is analyzed to look for their scaling behavior
- KNO-G scaling is tested with function $\psi(z)$



KNO-G fits on the scaled multiplicity

KNO – G Function: $\psi(z) = a_1 z^{a_3} e^{(-a_2 z^2)}$

Parameters	Our Fit	[1] *
a_1	1.15	1.19
a_2	0.45	0.62
a_3	0.67	0.66

[1] * A. I. Golokhvastov, Physics of Atomic Nuclei, Vol. 64, No. 1, 2001, pp. 84–97. Translated from Yadernaya Fizika, Vol. 64, No. 1, 2001, pp. 88–100.

Summary

- The DsTau experiment aims to decrease ν_τ production uncertainty
- A sub-sample of pilot run data is analysed to study proton interactions in tungsten
- Proton interaction length in tungsten is measured for the first time. The results will be submitted for a publication
- The analysis of physics runs data is going on