The reconstruction of the primary proton vertices in the DsTau(NA65) experiment

Mădălina Mihaela Miloi

miloi@jinr.ru

Joint Institute for Nuclear Research - Dzhelepov Laboratory of Nuclear Problems
University of Bucharest - Faculty of Physics

30 October 2023

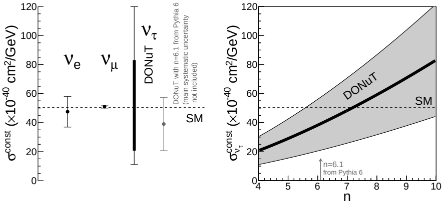
Outline

1. Physics Motivation
2. DsTau experimental technique
3. Reconstruction of the primary vertices

Physics Motivation of DsTau experiment

1. Evaluation of ν_τ flux produced in p-nucleus interactions

- The ν_τ interaction cross-section is known with worse accuracy than for other neutrinos, due to low statistics of registered tau neutrinos and large systematic errors in tau neutrino flux estimation for the beams
- $D_s \to \tau + \nu_\tau$ is the main source of ν_τ in the accelerator neutrino beams
- DsTau will measure the Ds double-differential production cross-section (inclusively decaying to τ and ν_τ) in proton-nuclei interaction



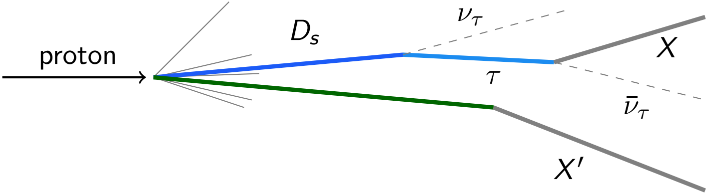
Left: $\nu, \bar{\nu}$ averaged energy independent cross section of all neutrino flavors. Right: ν_τ cross section in DONuT experiment, as a function of the parameter n.

2. Study of charm production in proton-nucleus interactions

- expected 10^5 events having paired charms

DsTau experimental technique

400 GeV protons interacting on W/Mo targets → D_s



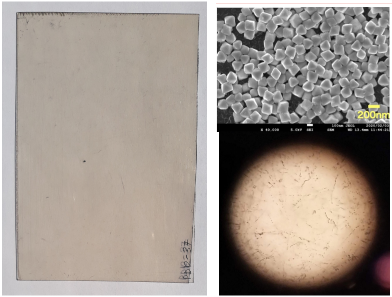
Double-kink topology of $D_s \to \tau \to X$ events

Decay candidates are selected by the peculiar double kink topology of the reaction

- Average kink angle of $D_s - \tau \sim 10$ mrad (G4)
- Average kink angle of τ decay ~ 96 mrad
- Ds decay length (mean lifetime: $5 \times 10^{-13} s$) ~ 2.4 mm (G4, Fluka)
- τ decay length (mean lifetime: $3 \times 10^{-13} s$) ~ 1.4 mm (G4)

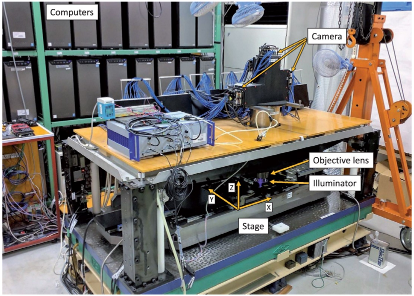
→ **very challenging!** → high resolution tracking emulsion detectors

Nuclear emulsion detector in DsTau



left: DsTau emulsion plate with 2 emulsion layers on a plastic base; right: electron microscope view of the AgBr crystals (diameter of 200 nm) and traces under the microscope

- intrinsic angular resolution 0.35 mrad, spatial resolution 0.4 μm
- **high density of tracks** $10^5 - 10^6 tracks/cm^2$



Hyper Track Selector (HTS)

- automatic procedure
- scanning speed $0.5 m^2/hour/layer$
- angular resolution $2 mrad$

After scanning, the information about the tracks is in digital format

Films development

→ several chemical processes similar with photographic plate development

Experimental set-up - at SPS (CERN)

Structure of detector modules (not in scale)

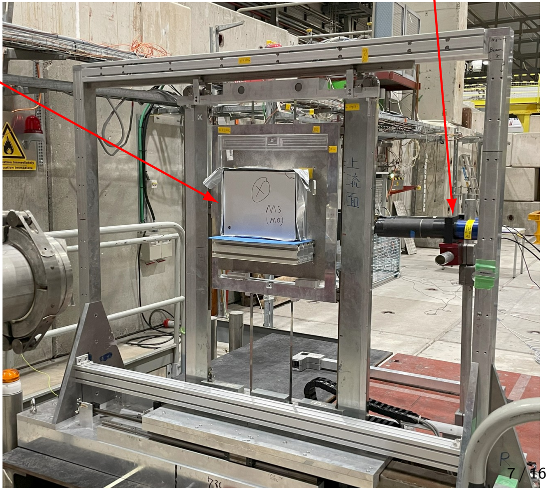
PMTs (uniform exposure)

$530\ m^2$ high accuracy emulsion films on plastic bases

beam monitor + target mover → uniform exposure
$\mathbf{3 \times 10^5}$ **protons/cm^2**

fluctuations 1.9±0.3%

Data taking - **completed**



The analysis chain

Emulsion read-out:

1. Films development → will finish this week
   - make the particle tracks visible for microscope
2. Automatic scanning with HTS → in progress
   - digital microtracks (the part of the track left in each emulsion layer)
   - microtracks are combined → basetracks

Offline dedicated software for the reconstruction of events:

3. Basetracks are combined in tracks (tracks reconstruction)
4. Alignment
5. Vertex reconstruction
   - 2 dedicated software (standard, fast → under development, in JINR)

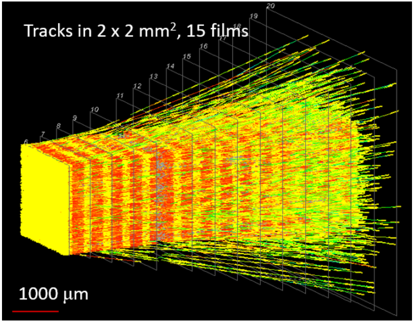
Dedicated software for the extraction of events of interest:

6. Searching events with secondary vertices corresponding to short lived particles
7. Searching for Ds decaying τ

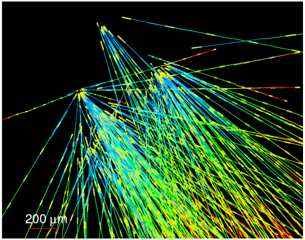
Under analysis

4.6×10^9 protons, 2.3×10^8 proton interactions, 10^5 charm pairs, 1000 $D_s - \tau$

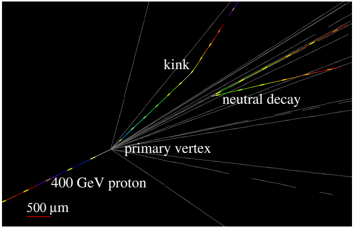
Tracks and vertices reconstruction



Proof of the technique capabilities: reconstruction and recognition of events is a high track density environment

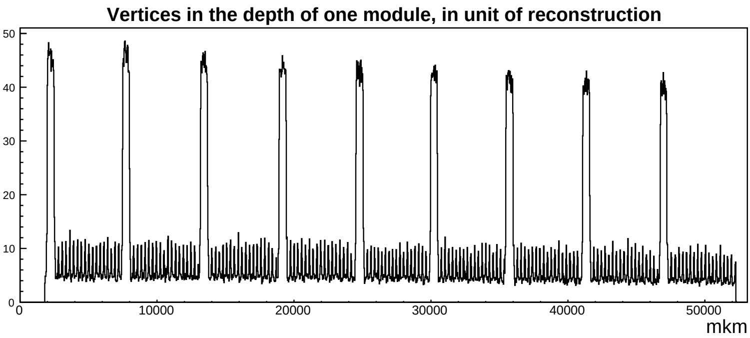


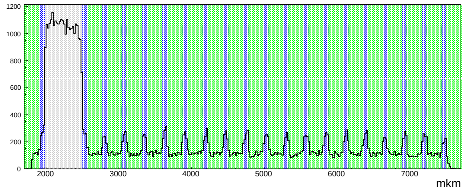
Examples of DsTau 3D reconstructed events



Example of DsTau reconstructed double charm event (neutral and 1 prong decaying particles visible)

Reconstruction of primary proton vertices





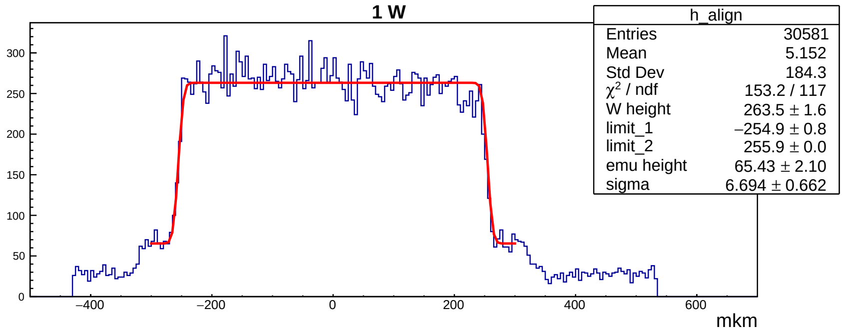
⟶

Subsample with interactions in the first tungsten target and soft materials

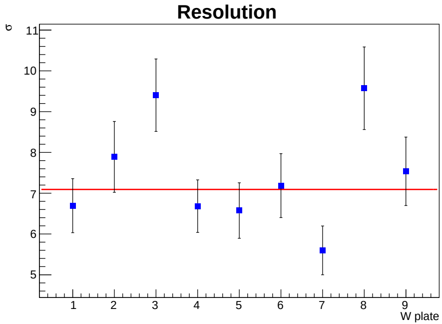
Fine structure of the detector is visible:
emulsion - 60um, plastic - 200 um, W - 500 um

Extraction of the resolution and targets thicknesses

The resolution of reconstruction along the beam axis is the same in the entire detector, despite the increase of the track density in the depth ($10^5 \rightarrow 10^6 tracks/cm^2$).

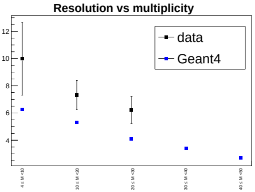


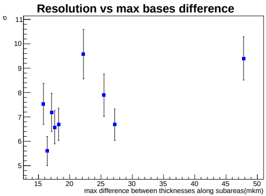
Fit with a convolution of a box function (with wings) with Gauss: limits defining the box function, the heights of it and sigma are free parameters → resolution along the beam axis and the thickness of the target

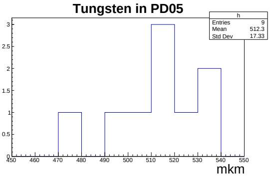


The average extracted resolution (along Z) is ~**7 um** and depends on:

- quality of emulsion films
- flatness of the target
- multiplicity
- position inside target

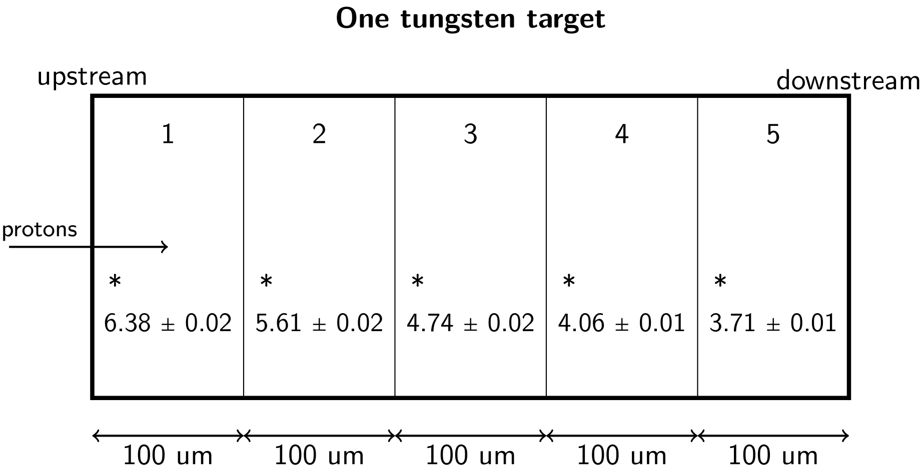






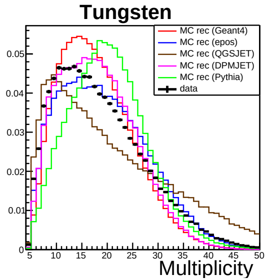
Detailed study of the resolution

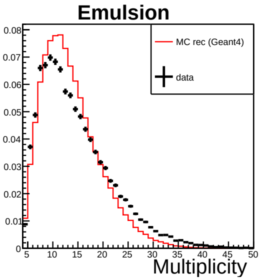
Resolution dependence on the position inside the target

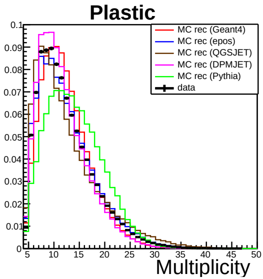


*mean resolution along beam axis in the first 8 plates of the module, generated with G4; **In MC, the resolution is ~ 5 um** (variation of thicknesses and non-flatness is not included)

MC is transformed in the same format as the real data (basetracks) and, then, tracks and vertices are reconstructed with the same tools as for the real data







	tungsten	emulsion	plastic
G4	17.38 ± 0.01	13.2 ± 0.01	11.83 ± 0.007
epos	18.96 ± 0.03		12.09 ± 0.02
QGSJET	20.02 ± 0.03		12.2 ± 0.02
DPMJET	17.63 ± 0.02		11.27 ± 0.02
pythia	19.74 ± 0.02		13.58 ± 0.02
data	18.18 ± 0.02	14.2 ± 0.03	11.92 ± 0.01

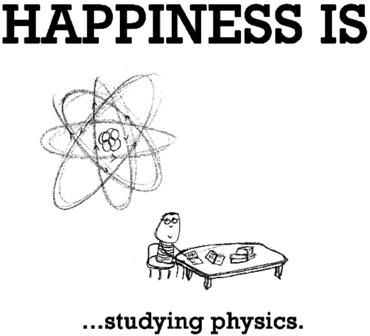
MC models work with 5-10% accuracy

Indicated errors are statistical

Observed multiplicity for data is consistent with expectations

Summary

- data taken completed, scanning and analysis ongoing, faster algorithms under development in JINR group
- the existing algorithms are capable to reconstruct events in a track density of 10^5-10^6 tracks/cm^2
- the primary events in the scanned data are reconstructed with a resolution of $\sim 7\ \mu$m



2021 and 2022 data taking at CERN-SPS

Thank you for your attention!

Back-up slides

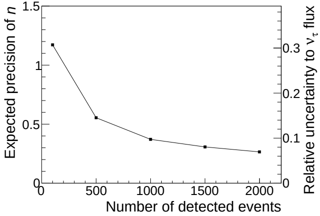
Status of the experiment

- 2018: 30 modules (with a surface of $12.5 \times 10\ cm^2$) were exposed, all plates scanned, all reconstructed
- 2021: 17 modules (with a surface of $25 \times 20\ cm^2$) exposed, scanning started
- 2022: 17 modules exposed
- 2023: 40 modules exposed

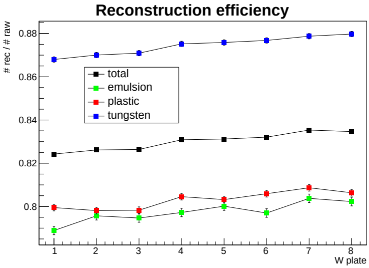
DsTau web site:
`https://na65.web.cern.ch/`

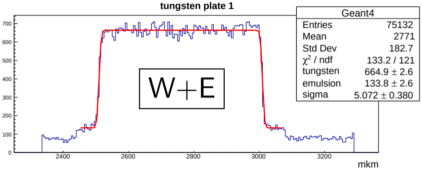
`https://link.springer.com/article/10.1007/JHEP01(2020)033`

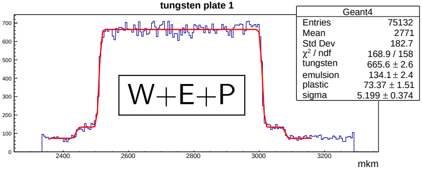
Experiment proposal:
`https://arxiv.org/pdf/1708.08700.pdf`

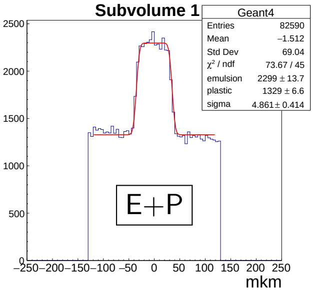


Reconstruction resolution and efficiency - G4 data



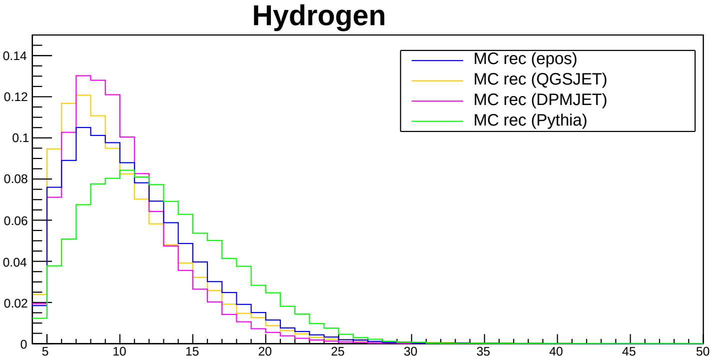






Resolution (μm)	
W+E	5.37 ± 0.14
W+E+P	5.57 ± 0.13
E+P	4.64 ± 0.15

Model discrepancy - the simplest case



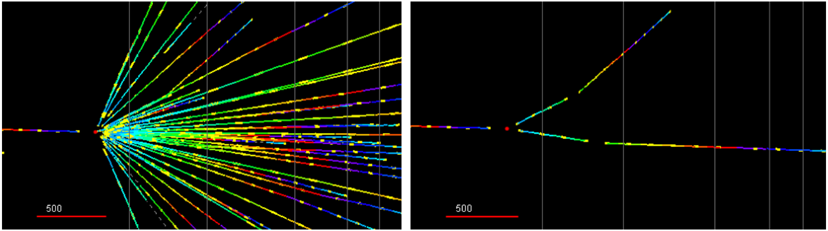
generator	mean
epos	10.28 ± 0.03
QGSJET	9.65 ± 0.02
DPMJET	9.41 ± 0.02
pythia	12.16 ± 0.03

A clear discrepancy between generators, in p-p interactions (simplest case) - showing the different MC approaches;

The final goal of the experiment is to measure the **Ds decaying via tau cross section**. For this, not only the number of the events have to be known, but also the efficiencies for recognising these events has to be calculated.

Codes for estimation of detection efficiency are under development: efficiency of Ds reconstructed track recognition (38.09 ± 0.13) % and for τ track 25.3 ± 0.1 % according to Geant4 data

Codes capable to recognise Ds decaying tau are under development.



Event with double (charged) charm candidates [**?**]

The DsTau experiment will highlight the ν_τ from D_s leptonic decay
→ In DONuT experiment, 95% of ν_τ sources were from $D_s \to \tau + \nu_\tau$

Measurement of D_s differential production cross section:

$$\frac{d^2\sigma}{dx_F \cdot dp_T^2} \propto (1- \mid x_F \mid)^n \cdot e^{-b \cdot p_T^2}, \quad (1)$$

where x_F is the longitudinal momentum $p_L/p_L max$ and p_T is the transverse momentum. n and b are the parameters controlling the longitudinal and transverse dependence of the differential production cross section, respectively.