Preliminary results of the Pilot Run of NA65 (DsTau) experiment at CERN-SPS

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26 October 2022

Outline

1. Physics Motivation
2. The experimental technique
3. The analysis chain
4. Prospects

The ν_τ interaction cross-section is known with worse accuracy than for other neutrinos, due to low statistics and large systematic errors.

- DsTau will measure the ν_τ production in proton-nuclei interaction (decrease the systematic uncertainty in ν_τ produced flux to 10%)
- the statistical error of the cross section will be reduced to ~ 2% in future experiments with large statistics of registered ν_τ (SHiP)

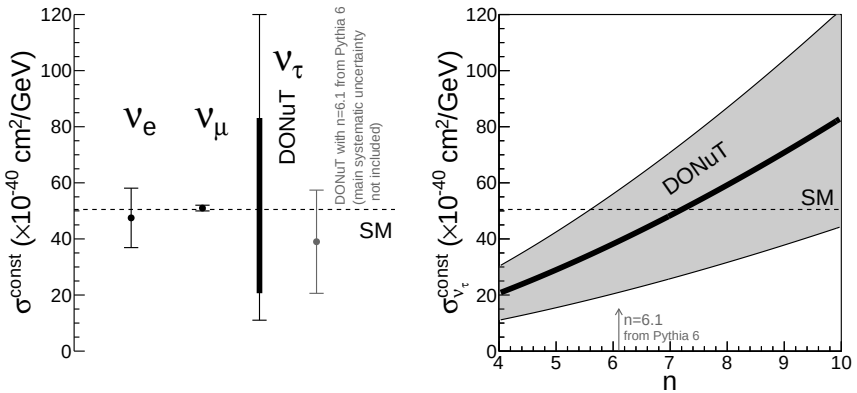


Figure: Left: $\nu, \bar{\nu}$ averaged energy independent cross section of all neutrino flavors. Right: ν_τ cross section in DONuT experiment, as a function of the parameter n [3]

Study of charm production in proton-nucleus interactions

- expected 10^5 events having pair charms

The DsTau experiment studies the ν_τ production from proton-nuclear interactions

$D_s \to \tau + \nu_\tau$ is the main source of ν_τ in the neutrinos beams

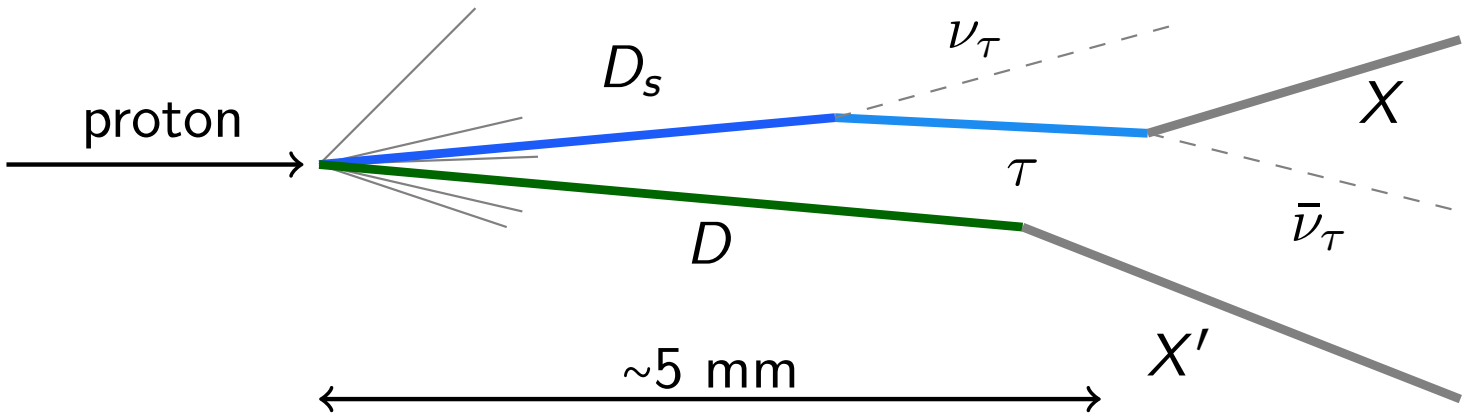


Figure: Double-kink topology of $D_s \to \tau \to X$ events [3]

Decay candidates are selected by the peculiar topology of the reaction
Average kink angle of $D_s - \tau$ is 6.2 mrad (Pythia), 10 mrad (G4) → **very challenging!**

D_s is produced by 400 GeV protons from CERN-SPS on W/Mo targets

Predictions for Ds and τ detection

Ds mean lifetime: $5 \times 10^{-13} s$ and τ mean lifetime: $3 \times 10^{-13} s$ [7]

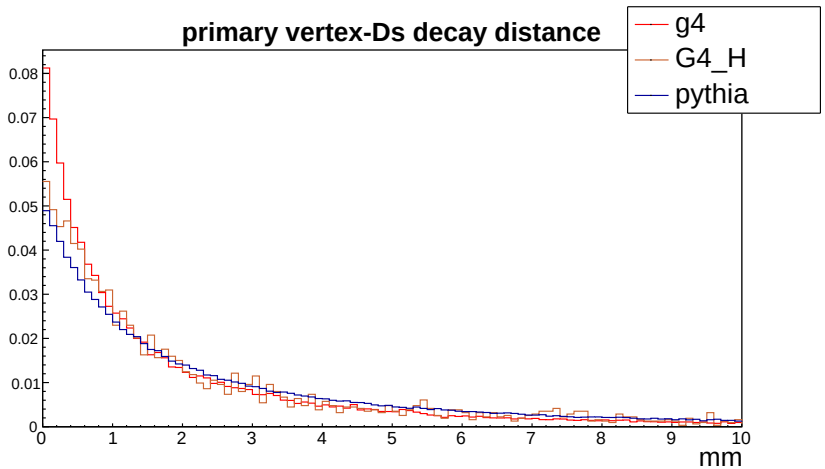


Figure: Ds decay length

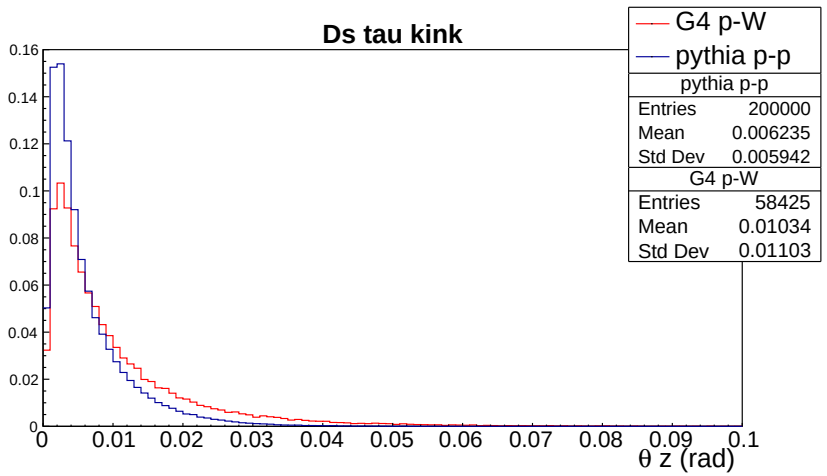


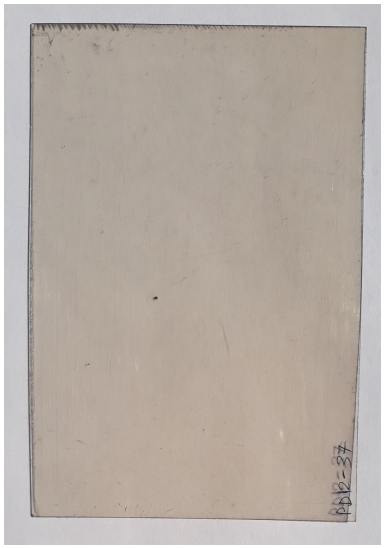
Figure: Ds - τ kink

generator	mean (mm)	median	entries
pythia p-p	3.58 ± 0.01	1.72186	219649
G4 p-W	2.38 ± 0.02	1.08666	58425
G4 p-H	3.15 ± 0.09	1.40686	3133
fluka p-W	2.7 ± 0.57	1.95	23

target	mean (rad)	median	entries
pythia p-p	$0.0062 \pm 1.3e-05$	0.0042	200000
G4 p-W	$0.0103 \pm 4.5e-05$	0.0066	58425

Solution for detecting Ds decaying $\tau \rightarrow$ high resolution tracking emulsion detectors

Modern nuclear emulsion technique



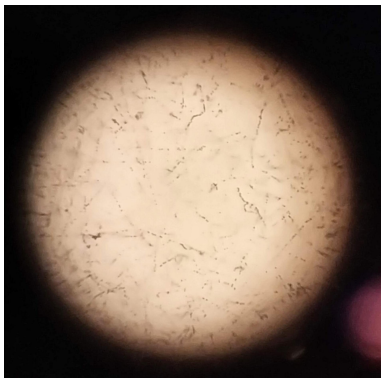


Figure: left: DsTau emulsion plate with 2 emulsion layers on a plastic base; right: traces under the microscope

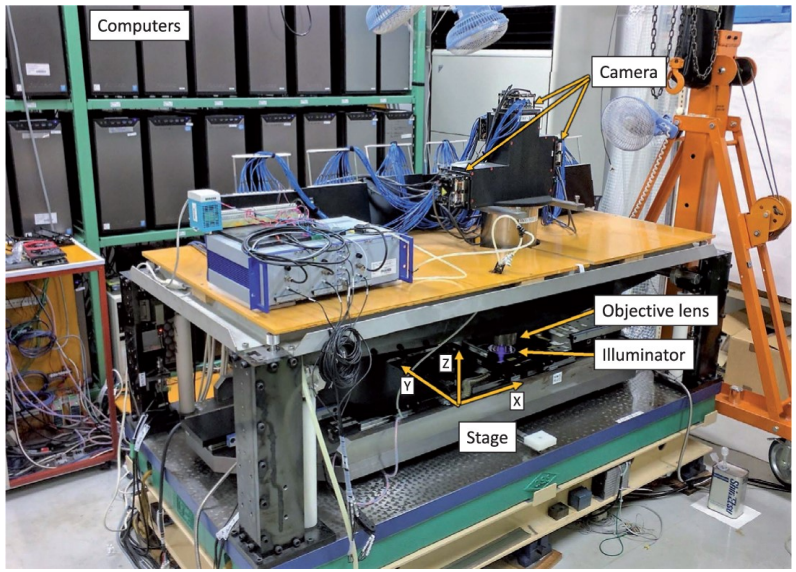
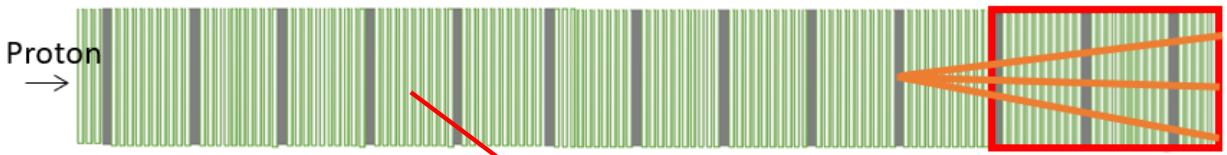


Figure: Hyper Track Selector-HTS [8]

- intrinsic angular resolution 0.35 mrad, spatial resolution 0.4 μm
- **high density of tracks** $10^5 tracks/cm^2$
- fully automatic
- scanning speed $0.5 m^2/hour/layer$
- angular resolution $2 mrad$

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

Experimental set-up



Physics Run detector module (not in scale) [2]

600 m^2 high accuracy emulsion films on plastic bases

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

2021 and 2022 data taking at CERN SPS

On sites, experimental set-up, instruments and part of the exposure team

Current status of the experiment

Pilot run 2018

- 30 modules of 12.5cm × 10 cm were exposed
- performed to validate and justify the technique
- the emulsions have been scanned and are processed now
- **development of the data processing algorithms**

Physics Run 2021 and 2022

- 34 modules of 20 cm × 25 cm were exposed

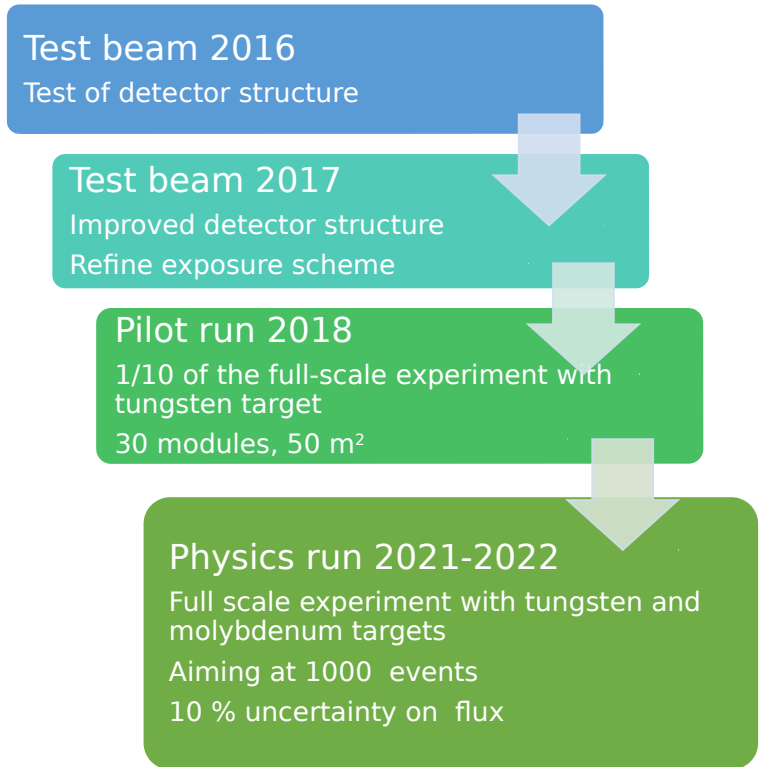


Figure: Plan presented in [1]

Data analysis is ongoing

The analysis chain

Emulsion read-out:

1. Films development
   - make the particles tracks visible for microscope
2. Automatic scanning with HTS
   - 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)

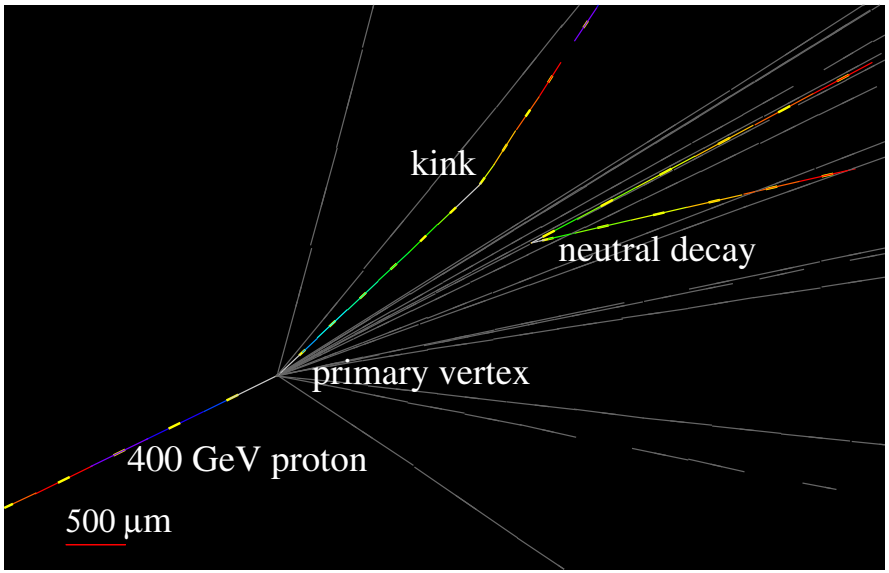
Dedicated software for the extraction of events of interest:

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

Films development

→ several chemical processes similar with photographic plate development

Reconstructed vertices



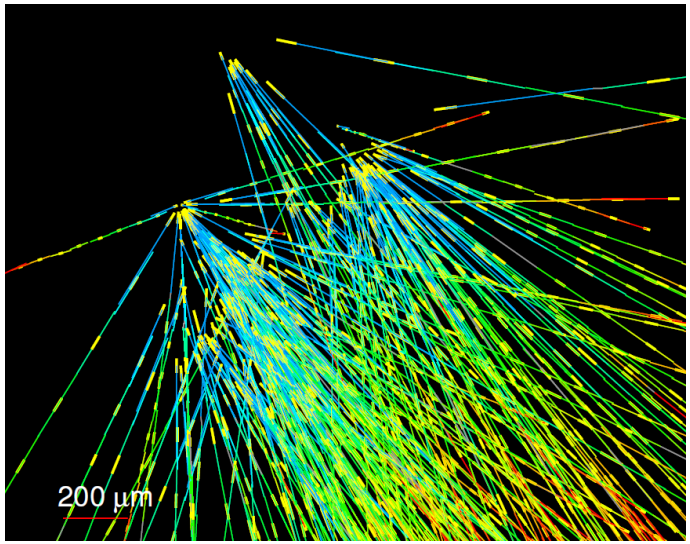
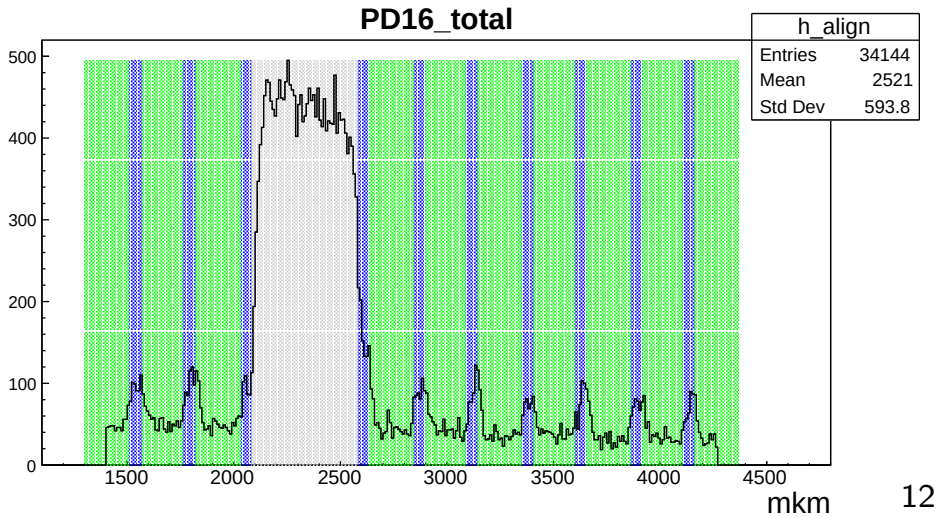


Figure: Example of DsTau 3D reconstructed events

Amount of vertices reconstructed in a small volume of Pilot Run detector, along Z-axis. Grey - Tungsten plate, blue - emulsion, green - plastic



Reconstructed vertices

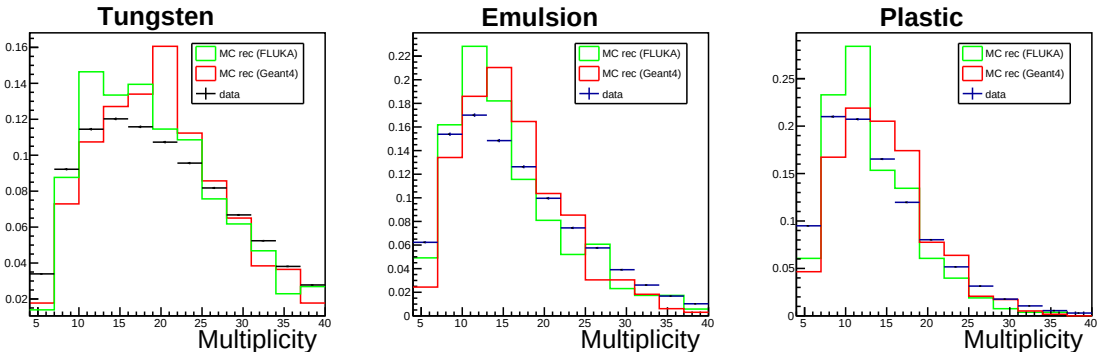


Figure: Multiplicity data compared to Fluka and G4

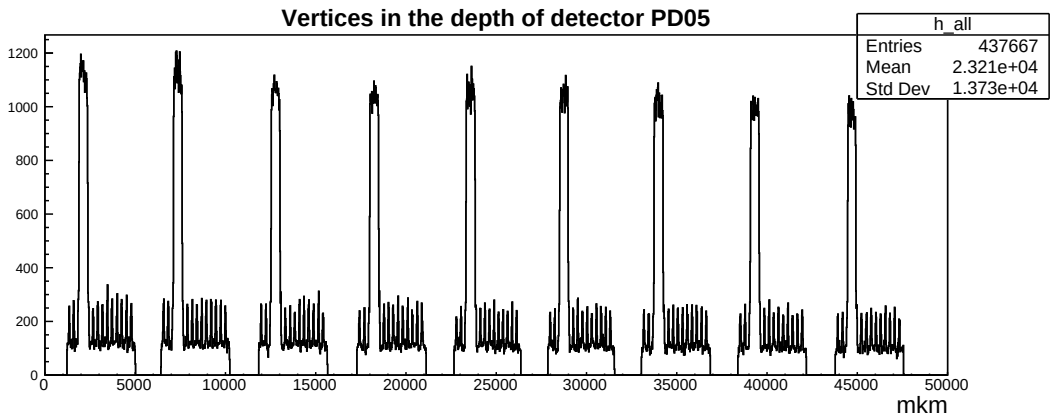


Figure: Reconstruction of the interactions in first 9 W plates together with part of the emulsion and plastic plates, for one brick

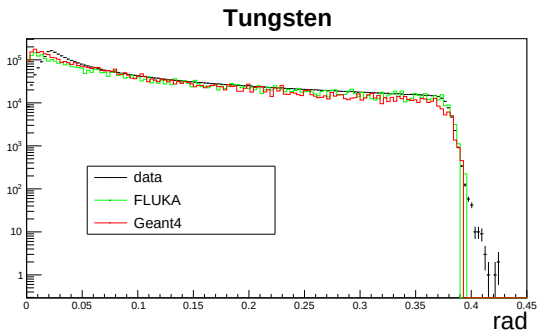


Figure: Angular distribution of primary daughters, normalization to the number of vertices in data

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.

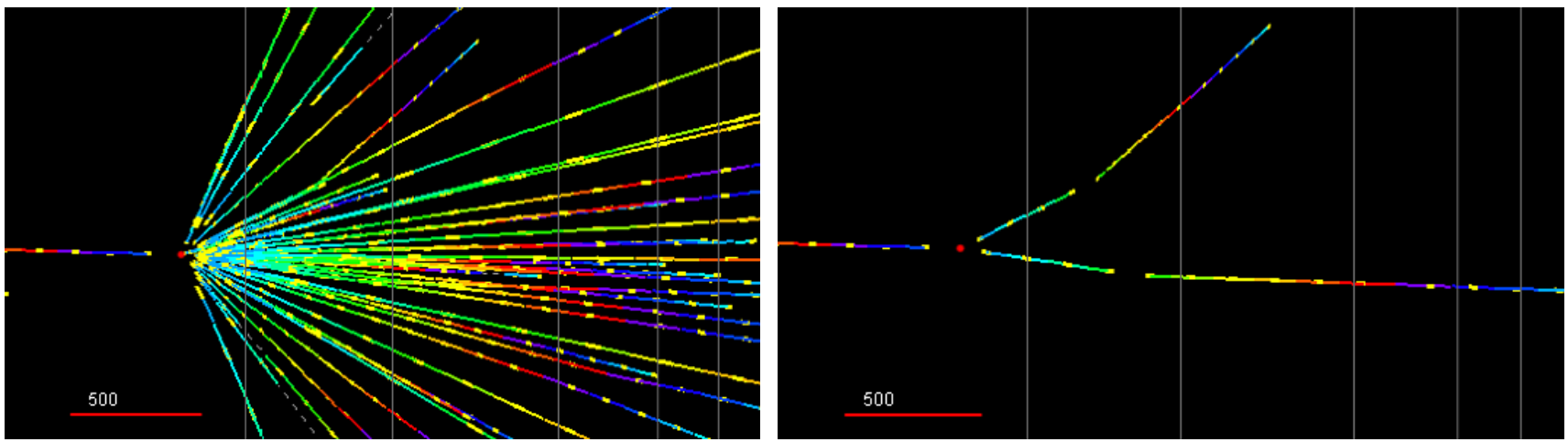


Figure: Event with double (charged) charm candidates [4]

Prospects

- 4.6×10^9 protons, 2.3×10^8 proton interactions, 10^5 charm pairs, 1000 $D_s - \tau$ decays, according to previous estimations
- data analysis tools under development

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

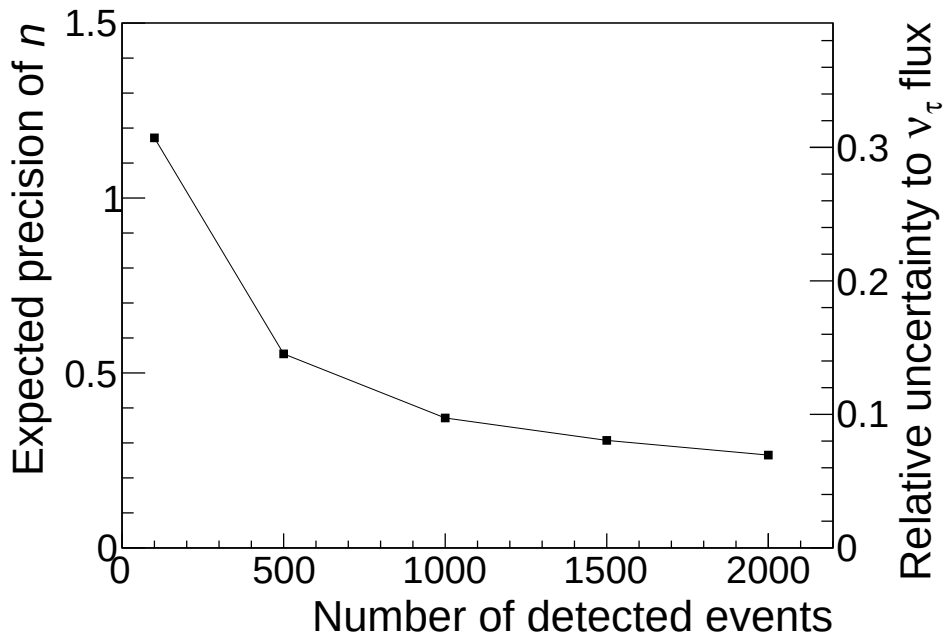


FIGURE: Expected precision for the measurement of parameter n as a function of the number of detected Ds $\rightarrow$ $\tau \rightarrow$ X events. The estimated relative uncertainty of the flux is also given as the y-axis on the right. [3]

References I

[1] S. Aoki at al. "Experiment Proposal Study of tau-neutrino production at the CERN SPS". In: (2017). DOI: arXiv:1708.08700v1[hep-ex]. URL: https://arxiv.org/pdf/1708.08700.pdf.

[2] DsTau collaboration. "DsTau status report 2021". In: (2021). URL: https://cds.cern.ch/record/2771162/files/SPSC-SR-295.pdf.

[3] The DsTau collaboration. "DsTau: study of tau neutrino production with 400 GeV protons from the CERN-SPS". In: *Journal of High Energy Physics* 2020.33 (2020). DOI: https://doi.org/10.1007/JHEP01(2020)033.

[4] The DsTau collaboration. *NA65/DsTau experiment, status and plans 2020*. URL: https://indico.cern.ch/event/927344/.

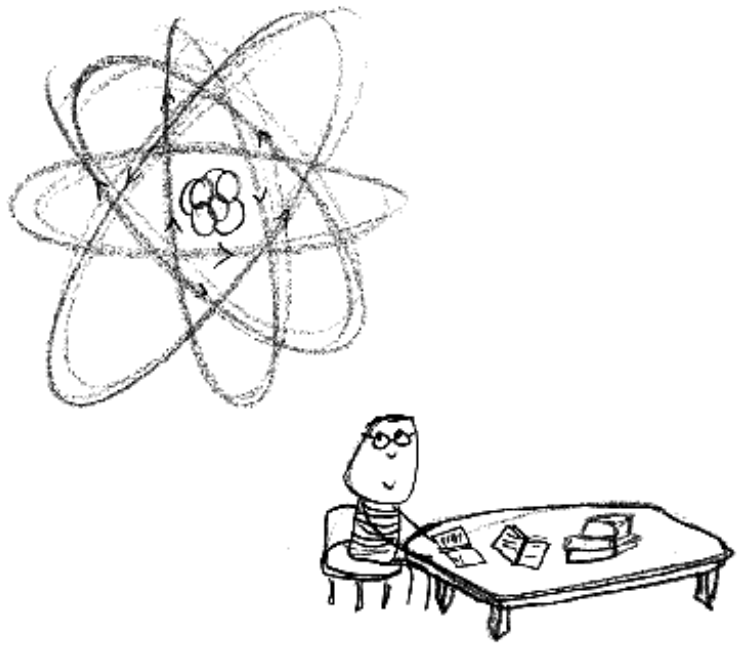
[5] The DsTau collaboration. *NA65/DsTau experiment, status and plans 2021*. URL: https://indico.cern.ch/event/1037851/.

[6] The DsTau collaboration. *NA65/DsTau experiment, status report 2021*. URL: http://cds.cern.ch/record/2811105/files/SPSC-SR-315.pdf.

[7] Particle Data Group et al. "Review of Particle Physics". In: *Progress of Theoretical and Experimental Physics* 2020.8 (Aug. 2020). 083C01. ISSN: 2050-3911. DOI: 10.1093/ptep/ptaa104. eprint: https://academic.oup.com/ptep/article-pdf/2020/8/083C01/34673722/ptaa104.pdf. URL: https://doi.org/10.1093/ptep/ptaa104.

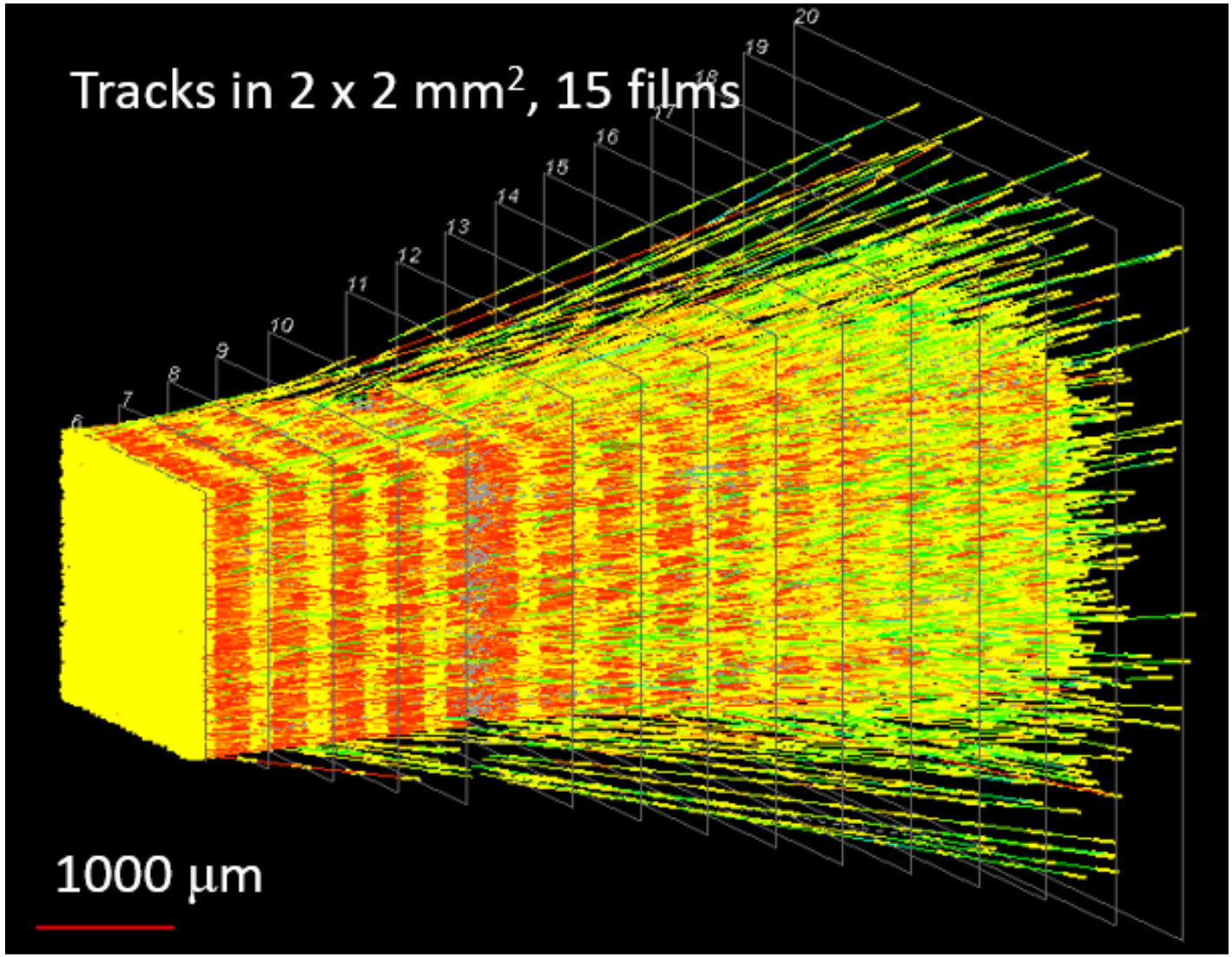
[8] Masahiro Yoshimoto et al. "Hyper-track selector nuclear emulsion readout system aimed at scanning an area of one thousand square meters". In: *Progress of Theoretical and Experimental Physics* 2017.10 (Oct. 2017). 103H01. ISSN: 2050-3911. DOI: 10.1093/ptep/ptx131. eprint: https://academic.oup.com/ptep/article-pdf/2017/10/103H01/21300870/ptx131.pdf.

HAPPINESS IS



...studying physics.

Back-up slides


Tracks in 2 x 2 mm^2, 15 films
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1000 µm

The DsTau experiment will highlight the ν_τ from D_s leptonic decay

$\rightarrow$ In DONuT experiment, 95% of ν_τ sources were from $D_s \rightarrow \tau + \nu_\tau$

Measurement of D_s differential production cross section:

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

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.