NA65/DsTau experiment, status and plans

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DsTau paper: 10.1007/JHEP01(2020)033
DsTau web site: https://na65.web.cern.ch/
Motivation to tau neutrinos

- Tau neutrino is one of the least studied particles
  - Only a few measurements  
    Direct $\nu_\tau$ beam: DONUT (DIS)
    Oscillated $\nu_\tau$: OPERA (DIS), Super-K (QE), IceCube (DIS).
  - DONUT’s $\nu_\tau$ cross section error >50% (DIS) due to systematic uncertainty in $\nu_\tau$ production

- Lepton Universality test in neutrino scattering
  - Hints of LU violation from B decays, $\bar{B} \rightarrow \tau \nu_\tau D^*(\ast)$. New physics in tau sector?
  - A precise measurement of $\nu_\tau$ cross-section would provide a complementary information
Forward charm production

• Large theoretical uncertainty for forward charm production.
  • ex) “intrinsic charm” content of proton can affect $\nu_\tau$ flux drastically, by enhancing charm meson production in forward direction

• $\nu_\tau$ flux may change by a factor of 10

• Neutrino experiments needs data on forward charm production!

Due to large uncertainties of forward charm production among different hadron generators (Pythia, Sibyll, DPMJet)

arXiv:2105.08270
The NA65/DsTau experiment at the CERN SPS

- Study of $\nu_\tau$ production for future tau neutrino experiments.
  - $D_s$ double differential production cross section measurements
  - Reduce $\nu_\tau$ flux uncertainty from >50% to 10% → Fundamental input for future $\nu_\tau$ experiment: SHiP, and indirectly FASER

- Forward charm physics, charm/gluon PDF

- Principle of the experiment
  - Detection of "double-kink + charm decay" topology within 10 mm.
  - $4.6 \times 10^9$ protons, $2.3 \times 10^8$ proton interactions in target, $10^5$ charm pairs, 1000 $D_S \rightarrow \tau \rightarrow X$ detected events.
Change of structure for momentum measurement

Momentum measurement is relevant to reject low energy events (MCS mimicking $D_s \rightarrow \tau \rightarrow X$ events)

- Original structure had more material $\rightarrow$ too high track density
  - Dedicated scanning is required
- Reduce material, but sufficient performance
- Making data taking procedure simple

<table>
<thead>
<tr>
<th>Structure</th>
<th>Original: lead emulsion ECC</th>
<th>New: additional tungsten units</th>
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</thead>
<tbody>
<tr>
<td>25 1mm lead, 26 emulsion plates</td>
<td>3 0.5mm tungsten, 25 emulsion plates</td>
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<tr>
<td>Momentum resolution</td>
<td>20 - 40% (upstream ev.)</td>
<td>15 - 40% (upstream ev.)</td>
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<tr>
<td></td>
<td>20 - 40% (downstream ev.)</td>
<td>35 - 45% (downstream ev.)</td>
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<tr>
<td>Weight</td>
<td>15.0 kg</td>
<td>2.4 kg</td>
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- 2018

10 units (total 100 emulsion films)

ECC for momentum measurement
(26 emulsion films interleaved with 1 mm thick lead plates)

New 2021-

10 units (total 100 emulsion films)

Momentum analyzer for events at downmost tungsten plates:
3 tungsten plates and 25 emulsion plates

Proton

Proton

W - 10 units +ECC
W - 12.5 units
Mo - 12.5 units

Original

New
DsTau milestones

LOI in 2016
- Test beam 2016
  - Test of detector structure

TP in 2017
- Test beam 2017
  - Improved detector structure
  - Refine exposure scheme

Approved as NA65 in June 2019
- Pilot run 2018
  - 1/10 of the full-scale experiment with tungsten target
  - 30 modules, 50 m²

Physics run 2021-2022 (2023)
- Full scale experiment with tungsten and molybdenum targets
- Aiming at 1000 $D_s \rightarrow \tau \rightarrow X$ events
- 10% uncertainty on $\nu_\tau$ flux
DsTau 2021 run

• Originally, we planned to use a total area of emulsion films of \(>200\) m\(^2\) → reduced to \(110\) m\(^2\) due to COVID19

• Several new:
  • Film size
  • Target mover
  • Development facility
2021 run: Module assembling

- New assembling table
  - Films size from 12.5 cm x 10 cm → 25 cm x 20 cm
  - A total of 259 components/module

Vacuum packed to keep sub-micron alignment

A total of 17 modules were produced
Setup in H2

- New target mover
- XDWC for beam profile monitor
- Scintillator(s) to feedback beam intensity in real-time
Exposure process

1. Set a module on the target mover: 20 min
2. Exposure: 1 hour ~ 4 hours
   - Nighttime: 2 spills/SC
   - Daytime: 1 spills/SC
3. Remove the exposed module: 20 min
Film labeling

- Emulsion films are labeled by an optical label printer
- Raspberry pi -> LED dot matrix -> lens -> emulsion
- A trouble during operation (a fraction of films doesn’t have a readable pattern), but recoverable.

Light pattern on emulsion film

Labels after development
This was the first large scale development after CHORUS in 90s!
~2200 films were developed in 3 weeks
Comparing beam size with 2018 and 2021

2018                                           2021

Single spot irradiation

12.5 cm

Irradiation with scanning by target mover

Bad example from the 2018 run

2021 run
Evaluation of track density uniformity

Distribution of density, fitted by Gauss function

\[
\text{mean} \approx 2.4 \times 10^5 /\text{cm}^2 \\
\sigma \approx 7.97 \times 10^3 /\text{cm}^2 \\
\frac{\sigma}{\text{mean}} \approx 0.038
\]

\[
3.8\% < 10\% \text{(target)} \\
\rightarrow \text{enough uniformity is achieved by Target Mover}
\]
Summary the DsTau 2021 run

• 17 modules were exposed
  • 12 tungsten and 5 molybdenum targets
  • → about 30% of total (incl. 2018 run)
• All films were developed within 3 weeks
• Currently
  • Silver removal is being done
  • Swelling and scanning is ongoing
Emulsion facility at Meyrin (B169)

• DsTau, FASER$\nu$, SND@LHC + SHiP-charm need to share the same emulsion facility, **but it was very old**

• These experiments jointly requested a renovation $\rightarrow$ Accepted

• Renovation work is ongoing since 2021

• 4 bodies made an “Emulsion facility task force” to organize activities and schedule
Plan for 2022, 2023 runs

- Still, no foreign shifters can contribute to emulsion film production in Japan due to Covid.
  - Limited amount of emulsion, ~100 m²
  - Shortened beam time (1 week) was requested
- Need an additional data taking in 2023
- 2022 run is scheduled 28 Sep – 5 Oct, for now
  - Crash with other LHC experiments (FASER, SND@LHC) in the use of emulsion facility. Hoping to delay the beam time ~2 weeks later.
Data processing

- Film to film alignment and track reconstruction procedures require powerful processing servers with CPU/GPU and high memory (~128-256~GB of RAM) and disk space (~10~TB for each data module) resources.
- Distributed data processing is being done gradually. Up to now, 25 out of 30 modules in 2018 run have been fully processed (track reconstruction).

**Japan (Nagoya/Kyushu):**
- 2 processing servers
- CPU, GPU, 256 GB of RAM
- Storage capacity: ~150 TB
  (+2 in Chiba in near future)

**Russia (JINR):**
- 2 processing servers
- CPU, GPU, 256 GB of RAM
- Storage capacity: ~150 TB

**Turkey (METU):**
- TRUBA computing center resources
- CPU, GPU, 128 GB of RAM
- Storage capacity: 100+ TB

**Romania (ISS):**
- 1 processing server
- CPU, GPU, 128 GB of RAM
- Storage capacity: ~40 TB

Batch system of the CERN computing center is also going to be used to process the 2021 physics run data.
Study of Proton interaction with tungsten

• Proton interaction vertices location by fine alinement on the material boundaries.
• Secondary tracks multiplicity distribution by each detector components.
• The results will be summarized into a paper soon.
Momentum reconstruction

• Charm decay? or Coulomb scattering?
  • Kinematical information (= momentum, decay Pt) is important to discriminate charm decays from BG

• Algorithm has been implemented and tested

• Systematic application still needs a reorganization of data access over different data sets and alignment between them → Work in progress

Signal $D_s \rightarrow \tau \rightarrow X$

BG

MCS of low P particle

Alignment and tracking are closed in a data set of 30 films
MC studies with different generators

• Now FLUKA/G4 frameworks are available
• Different hadron interaction generators (G4, Pythia, EPOS) can be tested.
• Pythia8 as an external decayer for charm.
• Comprehensive study is still to be done.
Study for detecting $D_s \rightarrow \tau \rightarrow X$ decays

Efficiencies are floating due to

1. Difference in generator: Since G4’s charm flight length distributions are shorter than Pythia, efficiencies will be higher for events from the other simulations. (Can be fitted with DsTau data).
2. Analysis strategy: Efficiency will be increased by applying the high-precision readout.
3. Reconstruction effects: Position resolutions implemented in the simulations seem larger than that of the data. MC reconstruction might be revised.
Summary

• DsTau 2021 data taking campaign was successfully finished
  • 30% of planned exposure was done
• We are progressing in data readout, reconstruction and analysis
• MC studies are under revisited
• 2022 run will be again rescaled due to COVID19
  • Consequently we need 2023 run
  • Hoping to optimize the beam time
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- TS2 Coldex RP
- Calice Sdhalc 14
- NA65
- CMS HGCal 14
- LHCb ECAL 14
- ALICE Focal 7
- GIF RD51 14
- CMS ECAL 12
- LHCb EP-PIXEL MALTA 14
- NA62 14
- ATLASS AFP 14
- MONOLITH EP-PIXEL MALTA 14
- PICSEL 7
- ALICE Focal 7
- GS 7
- EP FT5 7
- PRE SHOWER 7
Tracking improvement

• Miss reconstruction study
  Since the track density is bit high than other emulsion experiment application, sometimes tracks are connected to different track at track-reconstruction process.
  The track miss-reconstruction spoil decay hunting efficiency and MCS momentum measurement accuracy

• MC study
  A set of MC data were used to estimate wrongly connecting miss-reconstruction rate ~4%.
Estimated exposure time

- Usually (intensity: 5.0e05, daytime of weekday) it takes about 3 ~ 4 hours to finish exposing 1 module.
- On weekends or night (maybe after 7:00 p.m.) it takes shorter (about 1 ~ 2 hours).

↑ CERN Visters SPS Page1, weekday night (left) and daytime (right).
QCD with accelerators