Study of tau-neutrino production with nano-precision particle detector

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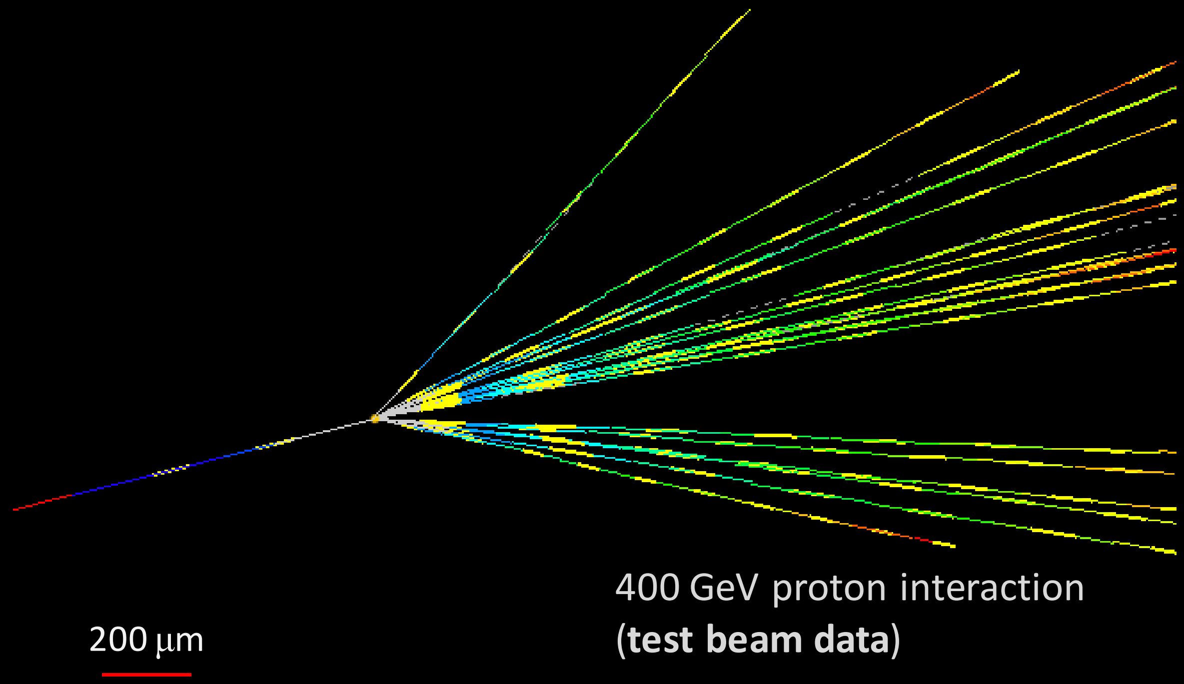
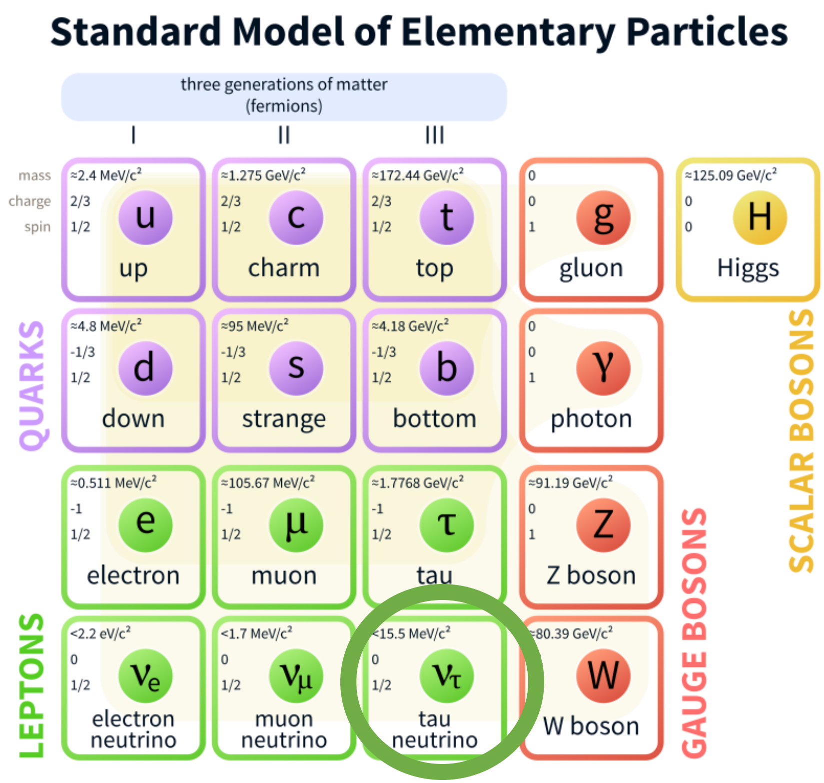


Tau neutrino



3rd generation of lepton

Predicted after discovery of tau in 1975

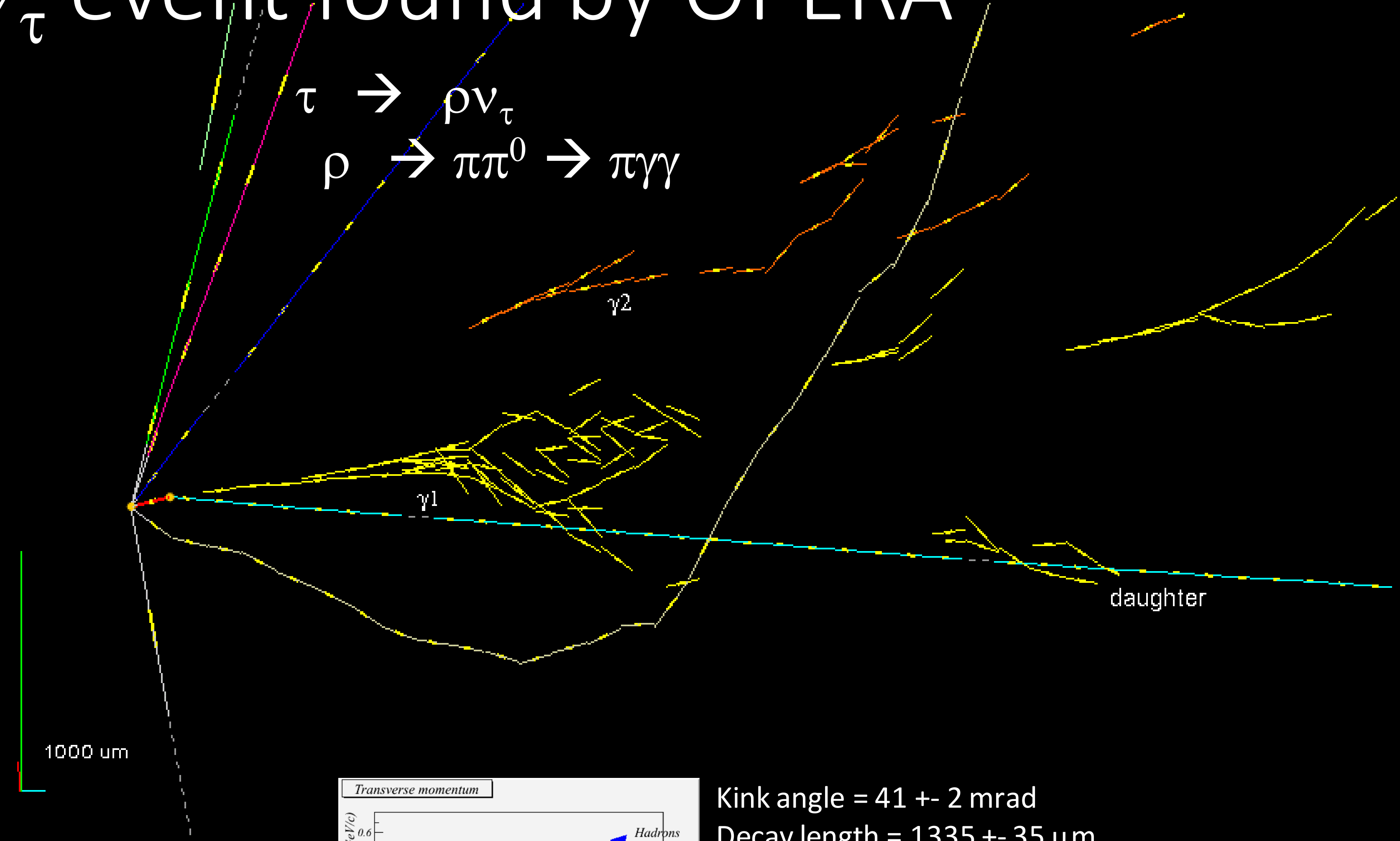
First direct observation in 2001
The last observed fermion

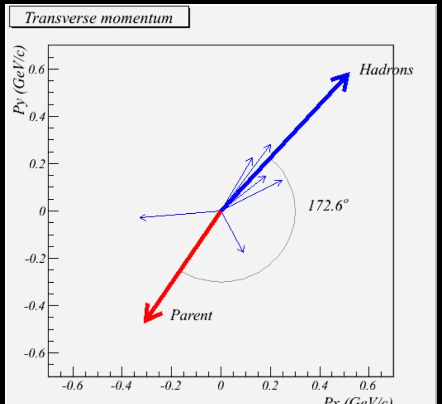
Neutrino oscillations
$\nu_\mu \to \nu_\tau$ appearance in 2015

ν_τ event found by OPERA

$\tau \rightarrow \rho\nu_\tau$

$\rho \rightarrow \pi\pi^0 \rightarrow \pi\gamma\gamma$





Kink angle = 41 +- 2 mrad

Decay length = 1335 +- 35 μm

P(daughter) = 12 $^{+6}_{-3}$ GeV

P_T(daughter) = 470 $^{+230}_{-120}$ MeV

Phi angle = 173 +-2 deg

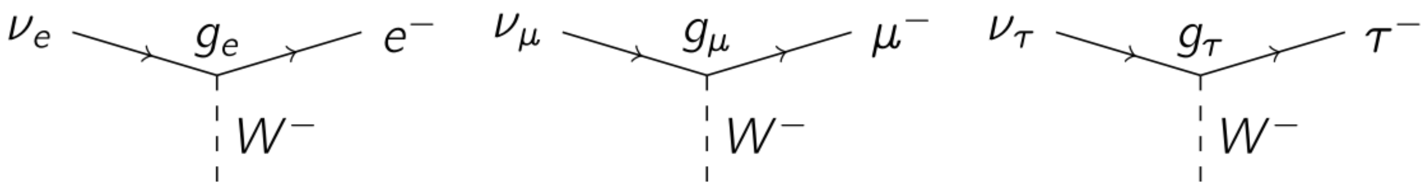
$M_{inv}(\gamma\gamma)$ = 120 +-20 +- 35 MeV

$M_{inv}(\pi\, \pi^0\, (\rho))$ = 640$^{+125}_{-80}$ $^{+100}_{-90}$ MeV

E_{total} = 44 +- 12 GeV

Lepton Universality

- Lepton Universality is a fundamental assumption of the Standard Model
- Three lepton families equally couple to weak boson



$$g_e = g_\mu = g_\tau$$

- Intensively tested, for example

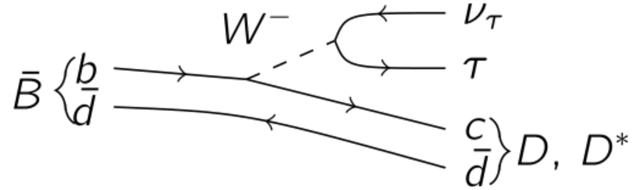
$$\left(\frac{g_\tau}{g_\mu}\right)^4 = 0.178 \left(\frac{m_\mu}{m_\tau}\right)^5 \left(\frac{\tau_\mu}{\tau_\tau}\right) \Rightarrow \frac{g_\tau}{g_\mu} = 0.999 \pm 0.003$$

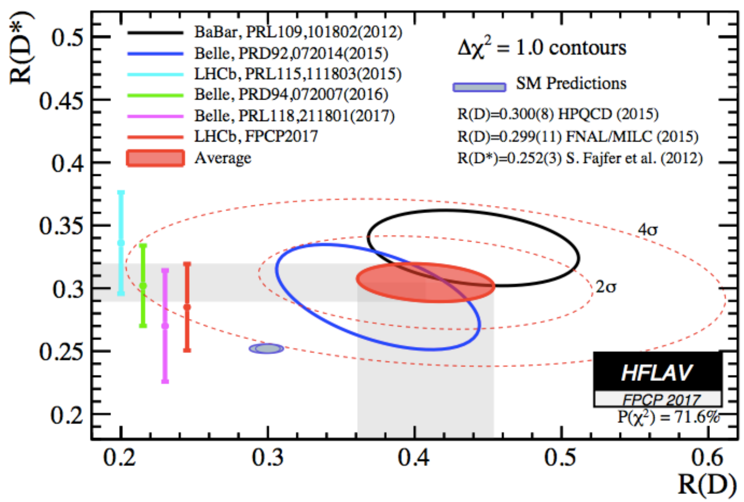
- It was consistent with all experimental results,,, until recently

Hints of lepton universality violation

- Semi-leptonic decays of B meson prefers to decay into τ and ν_τ

$$R(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\mu\bar{\nu}_\mu)}$$





BaBar:
- hadronic tag, leptonic τ

Belle:
- hadronic tag, leptonic τ
- semileptonic tag, leptonic τ
- hadronic tag, hadronic τ

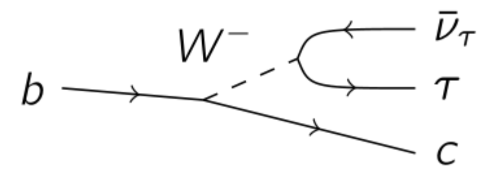
LHCb:
- leptonic τ (only muons)
- hadronic τ (3-prongs)

- Data is discrepant from the SM prediction by four standard deviations
- $B_c^+ \to J/\psi\tau^+\nu_\tau$ also has similar tendency (2 σ)
- → *Flavour anomalies*

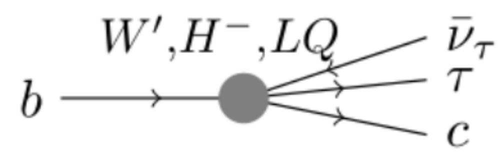
New physics effect?

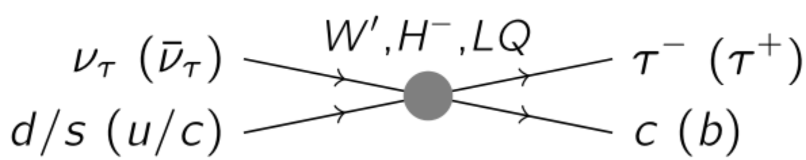
- There might be additional forces for between leptons and quarks, breaking Lepton Universality
- Several theoretical models.
  - Commonly discussed:
    W’, H^- and LQ
- Intensively discussed in collider environment
- How about neutrino scattering?
  - New particles might affect tau neutrino cross-sections

SM



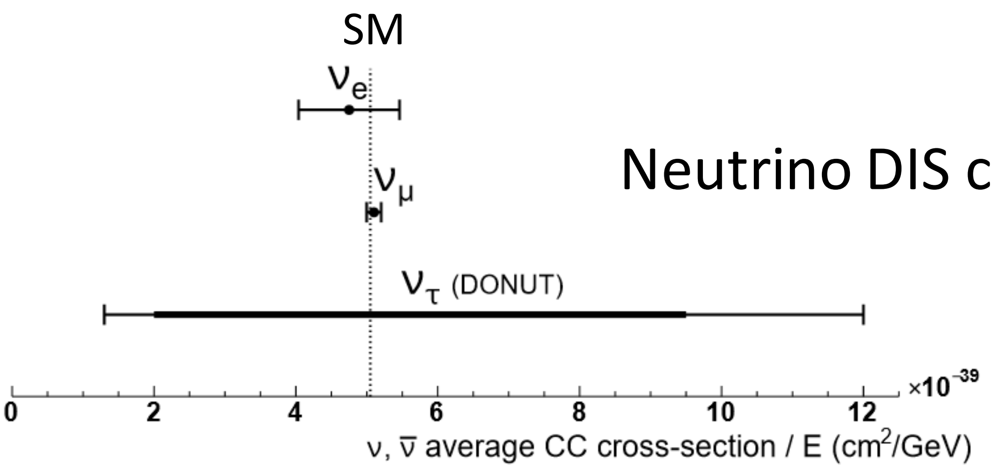
NP





Tau neutrino as a probe for new physics… The current status

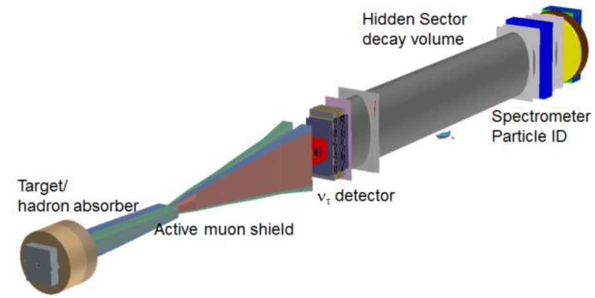
- Neutrino interactions provide a complementary approach for flavour anomalies.
- Status: the neutrino deep-inelastic scattering cross-sections other than ν_μ are poorly investigated



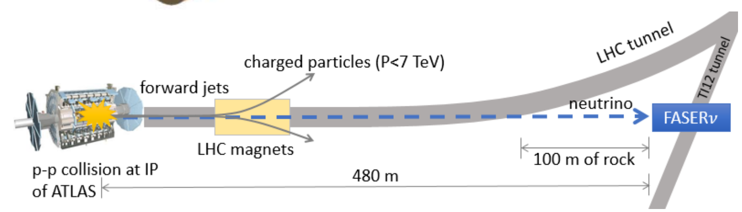
Neutrino DIS cross-sections

- Precise measurement (10%) of tau neutrino cross-section might be a key for new physics search
  - >50% of ν_τ production uncertainty → DsTau
  - 30% of observed ν_τ statistics (10 events) → Future experiments

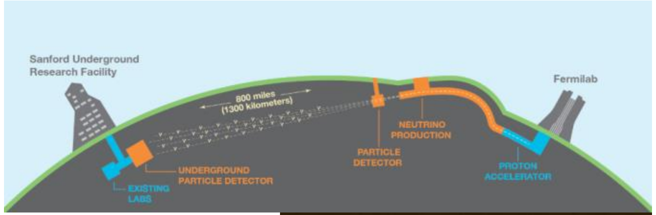
Future tau neutrino experiments

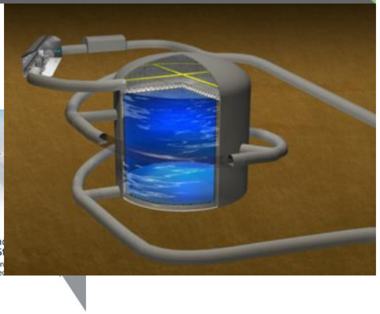


- SHiP: high statistics ν_τ measurement at the SPS beam dump facility at CERN
- FASERν: high energy ν_τ measurements at the LHC.

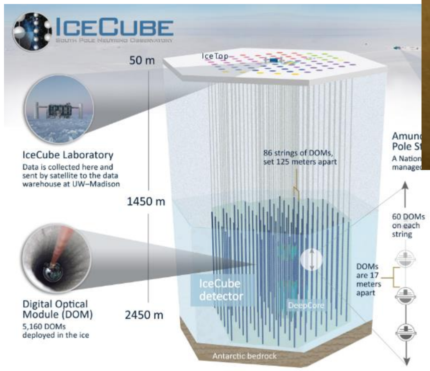


- Long baseline neutrino oscillation experiments
  - DUNE, Hyper-K, SK
  - Tau neutrinos dominate the neutrino flux at the long baseline neutrino oscillation experiment
  - 90 % of neutrino flux is at oscillation maximum
  - ν_τ is background to ν_e, due to $\tau \to e$

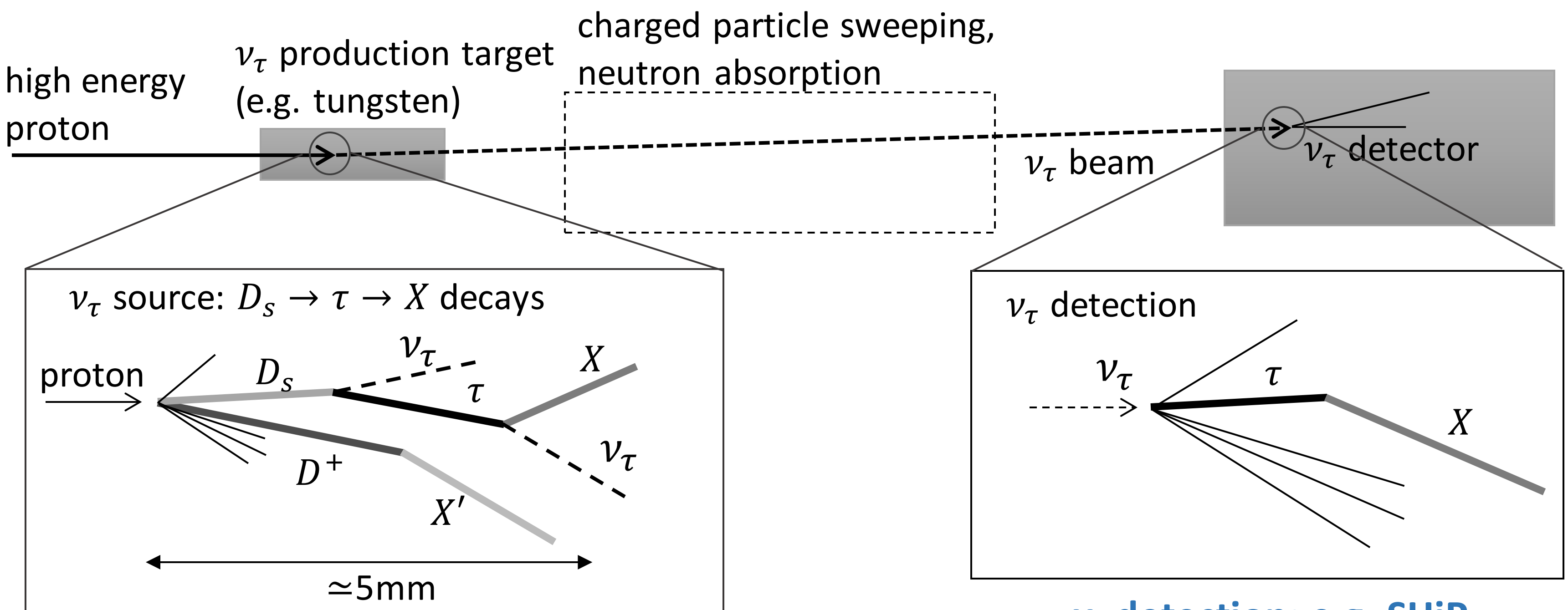




- IceCube
  - Astrophysical ν_τ neutrino measurement



Concept of ν_τ cross section measurement (accelerator based)



ν_τ production study: DsTau

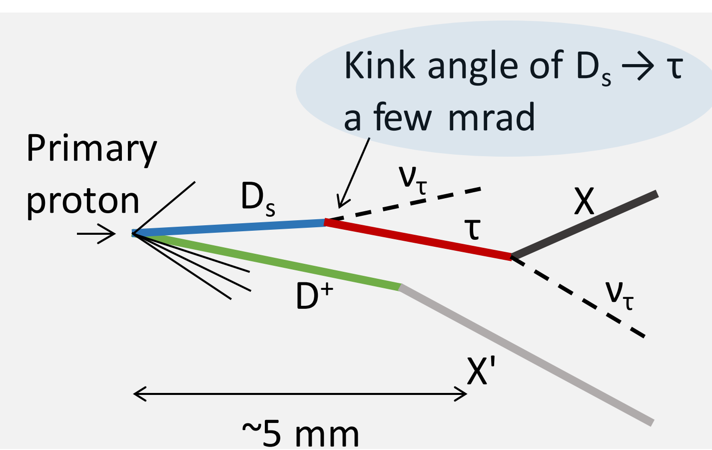
- No experimental data on the Ds differential cross section
- Large systematic uncertainty (~50%) in the ν_τ flux prediction

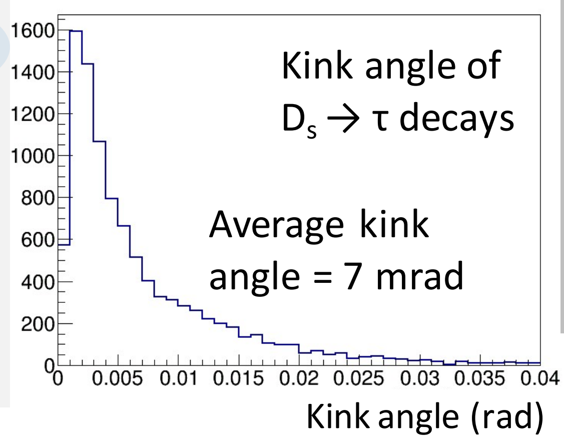
ν_τ detection: e.g. SHiP

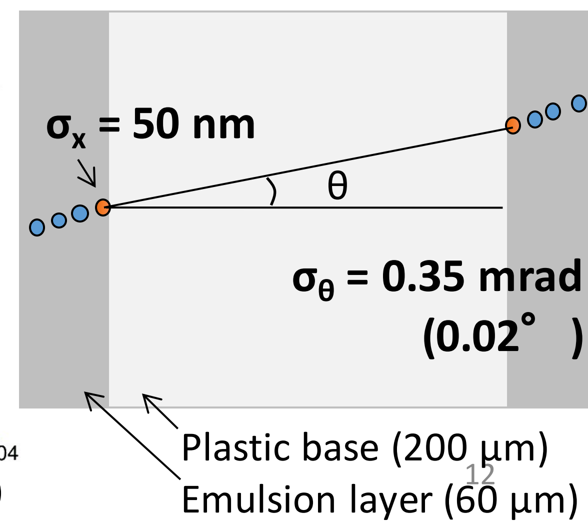
- Statistical uncertainty 33% in DONUT
- Will be reduced to the 2% level in future experiments

The DsTau project at the CERN SPS (SPSC-P-354)

- **Goals**
  - Measurement of ν_τ production.
  - Reduction of systematic uncertainty in the cross section measurement 50% → 10%.
    - Fundamental input for future ν_τ experiment: ν_τ program in SHiP.
  - Byproduct: charm physics, e.g. intrinsic charm component in proton.
- **Principle of the experiment**
  - Detection of double-kink + another decay topology within a few mm.
  - 2.3×10^8 proton interactions, 10^5 charm pairs, $1000\ D_s \rightarrow \tau \rightarrow X$ decays.







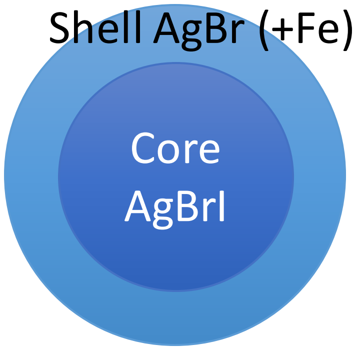
Emulsion detector

A minimal detector:

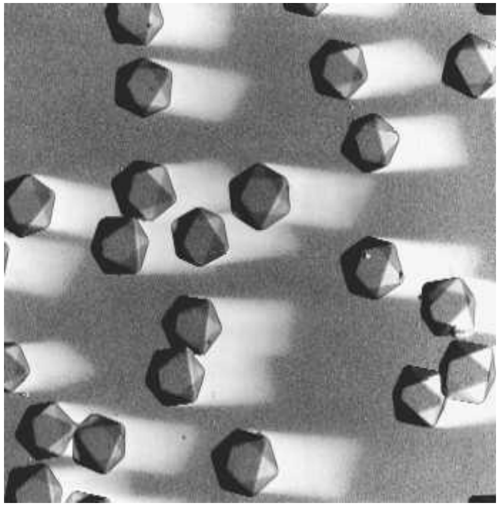
Silverbromide (AgBr) Cristal

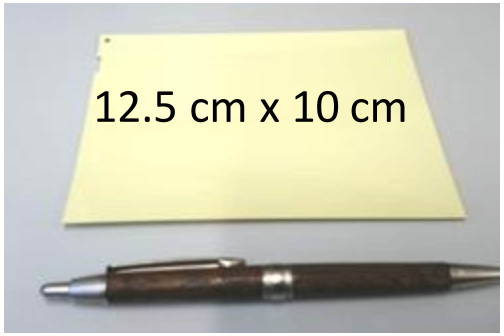
- diameter = 200 nm
- core-shell structure
- detection eff. = 0.16/crystal
- noise rate = 0.5×10^{-4}/crystal
- volume occupancy = 30%

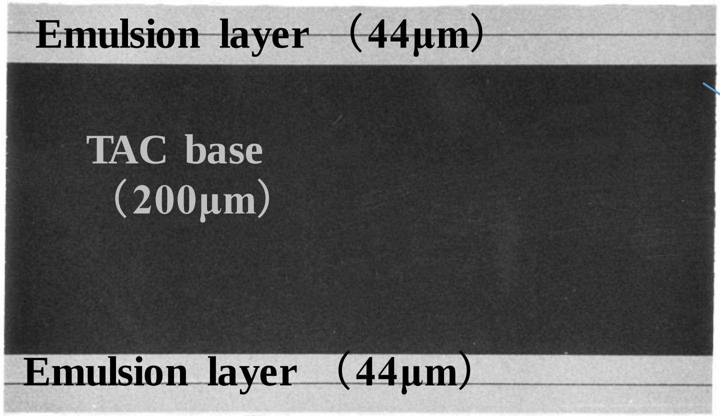
10^{14} crystals in a film



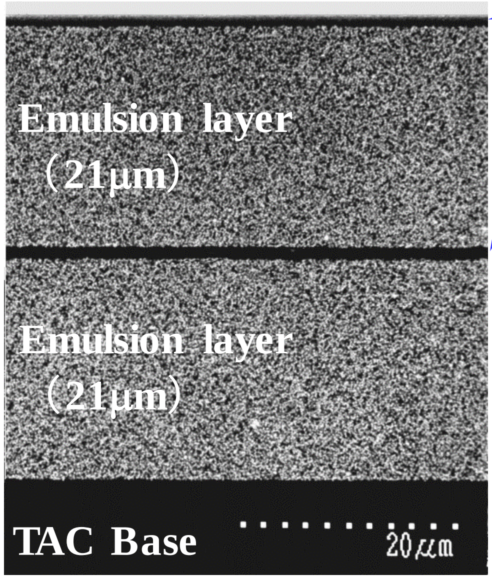
Core-shell structure





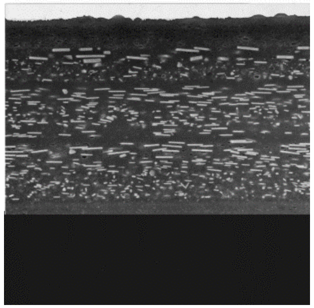


Zoom



Protection Coat
(1μm)

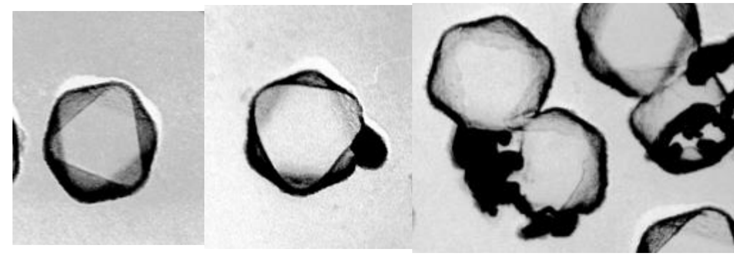
Color negative film

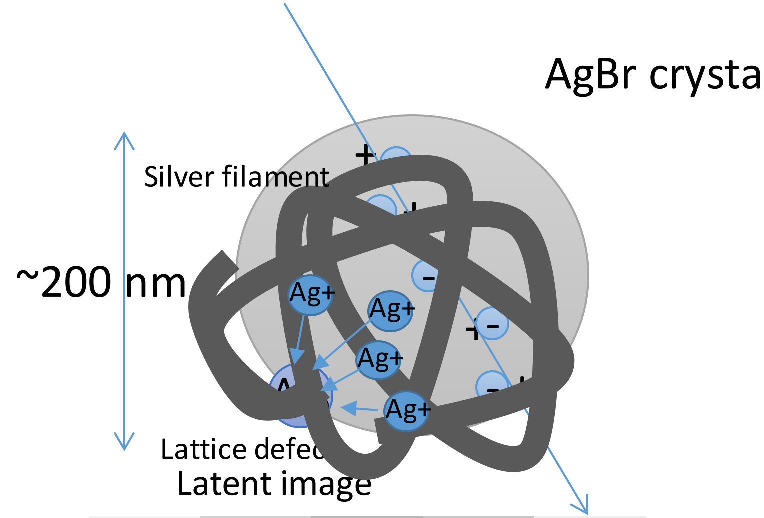


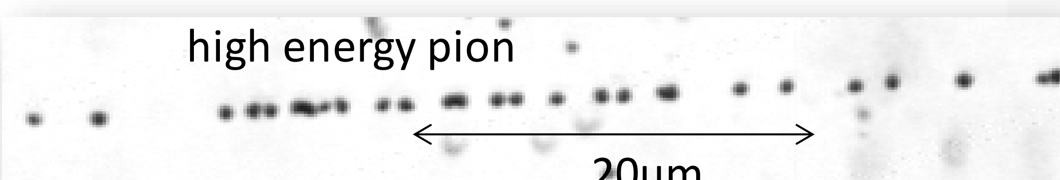
Nucl. Instrum. Methods A 556 80 (2006)

Detection principle of emulsions

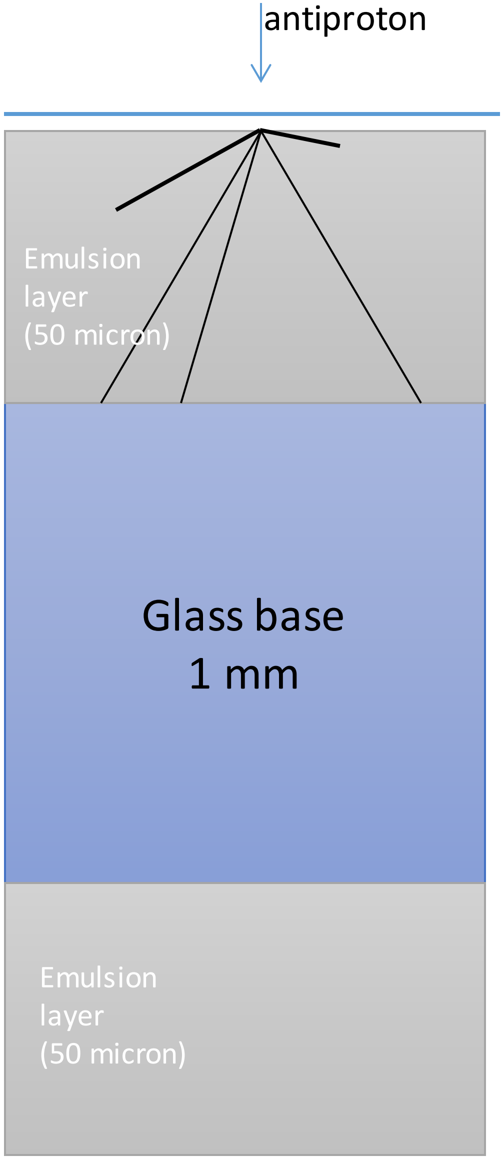
1. Ionization by a particle
   - band gap of 2.5 eV
2. Electrons trapped in a lattice defect on the surface of crystal
   - Attract interstitial silver ions
   - Making a “latent image” = Ag_n
   - n>=4, developable
3. Amplification of signal chemically
   - Development → silver filaments
   - Gain 10^7 - 10^8
4. Resolve crystal
5. Ready to observe under optical microscopes







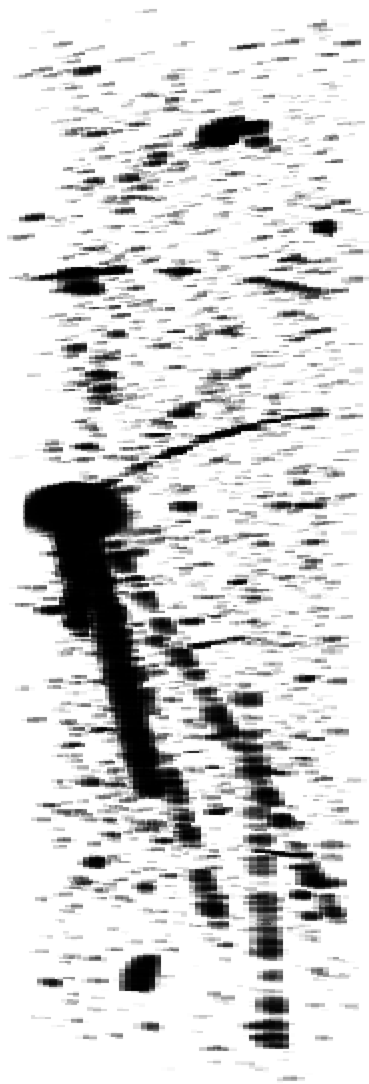
Antiproton annihilation in emulsion



Antiproton annihilation taken in AEgIS 2012

200 microns

3D view of emulsion detector



- 3D high resolution hits
- Work as tracker
- dE/dx proportional to darkness (Number of grains)

Emulsion = a detector with high detection channel density

150 μm x 120 μm x 50 μm

1.2x10⁸ channels (crystals) in this volume.

10^{14} channels in a film (12.5 cm x 10 cm).

ATLAS-IBL pixel sensor FE-14

1 pixel = 250 μm x 50 μm x 200 μm

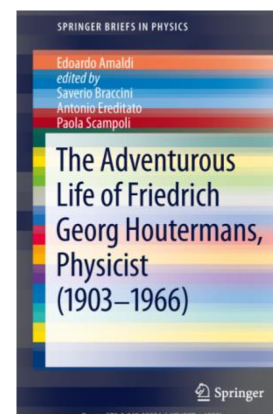
Sum of all channels in ATLAS = **~10^8**

High density of detection channels, O(10^{14}) channels/cc, makes emulsion attractive for many purposes.

Scanning in Bern some time ago

F.G. Houtermans im Kreise seiner Scannerinnen im Physikalischen Institut Bern 1955/56

Emulsion detector readout was used to be analogue and labor-intensive

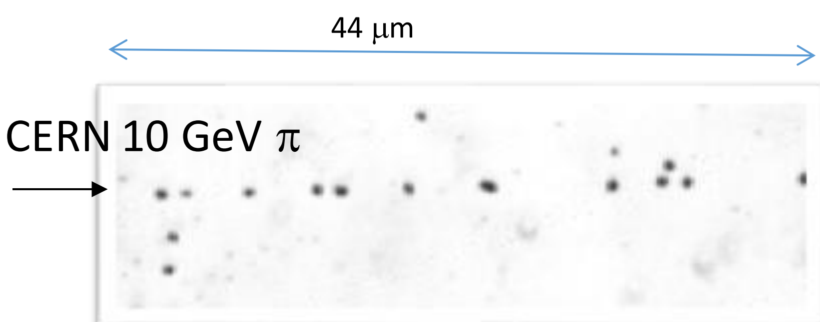


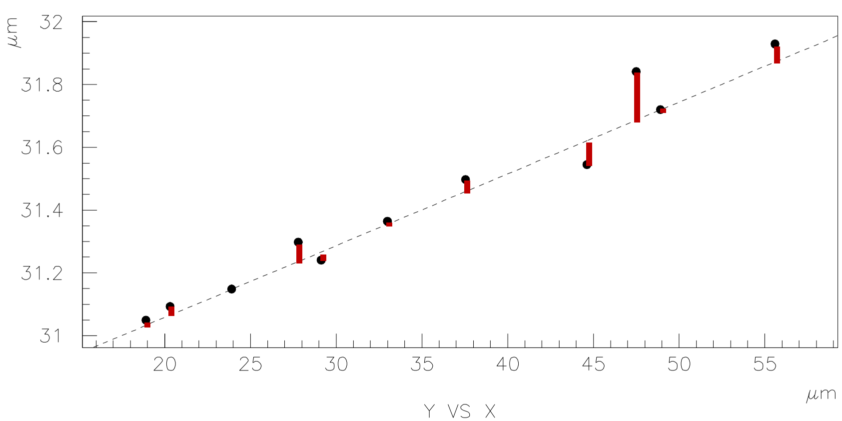
Bern scanning station (2008-)

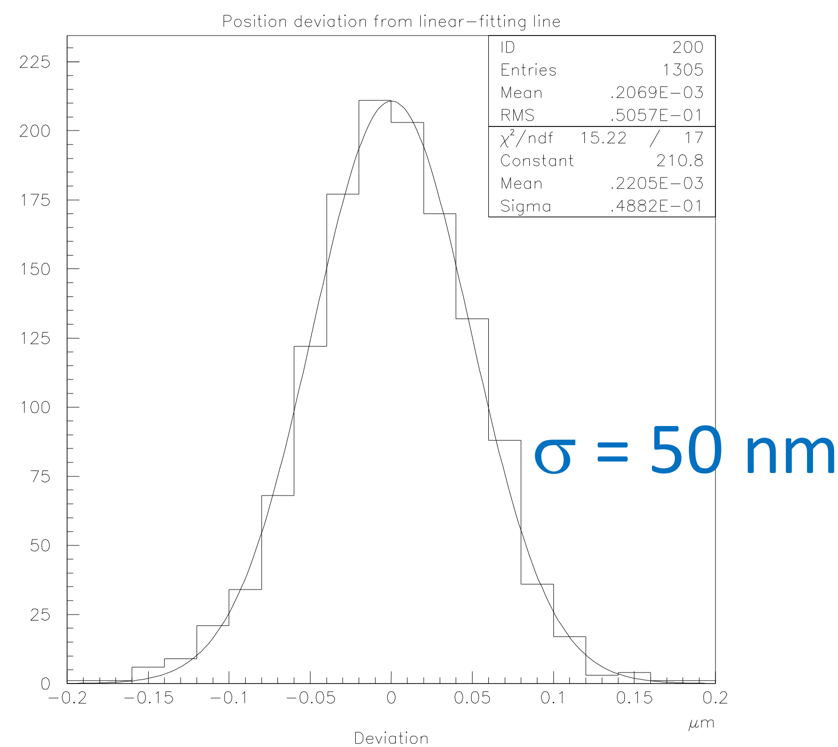
Emulsion detectors are no more an analog detector, but a digital detector.

Intrinsic resolution of emulsion detector

- Precision measurement of hits (5nm)
- Deviation of grains from a fit line
- Resolution was found to be 50 nm
  - 0.35 mrad angular resolution

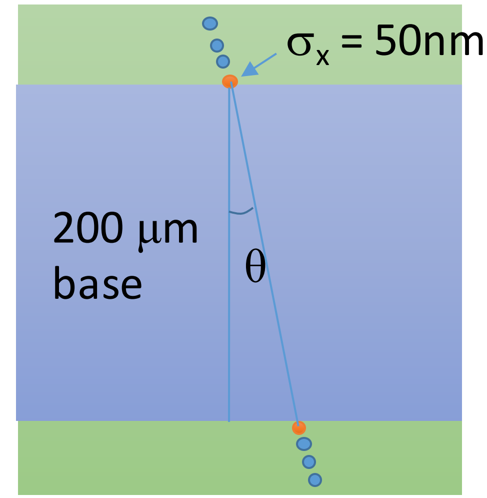


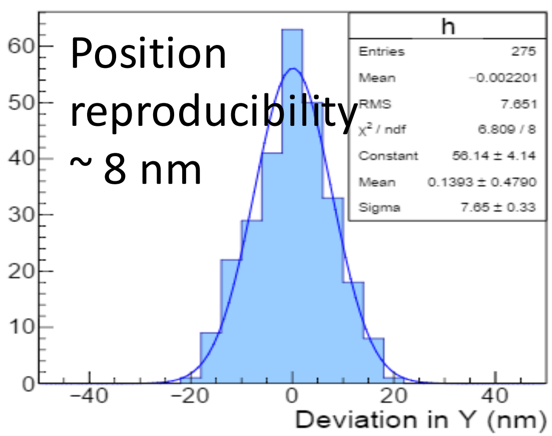


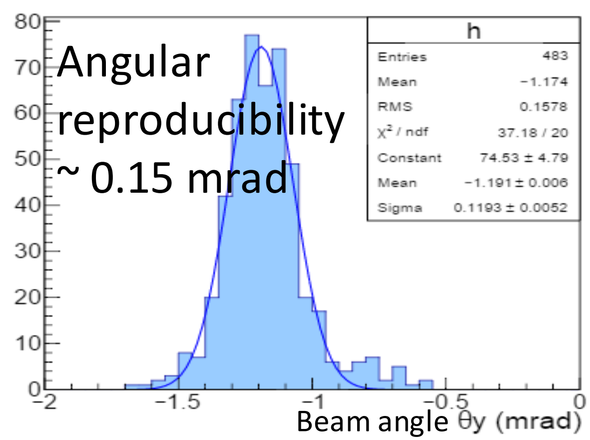


High precision measurement of track angles

- Intrinsic resolution of each grain = 50 nm
  - Two grains on top and bottom of 200 μm base → 0.35 mrad
  - Discrimination of 2 mrad at 4σ level
- A high precision system with a Piezo-based Z axis developmented

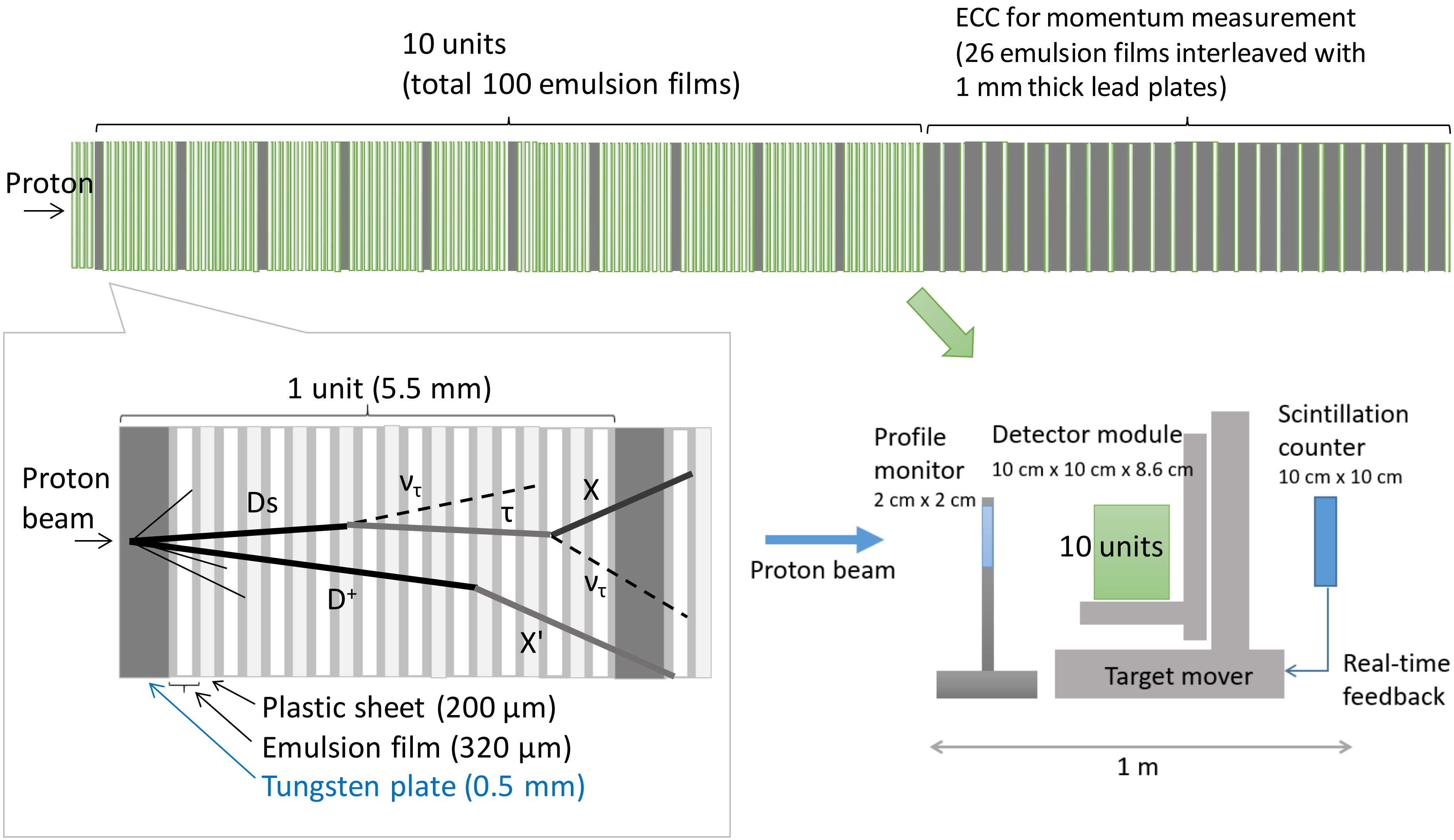




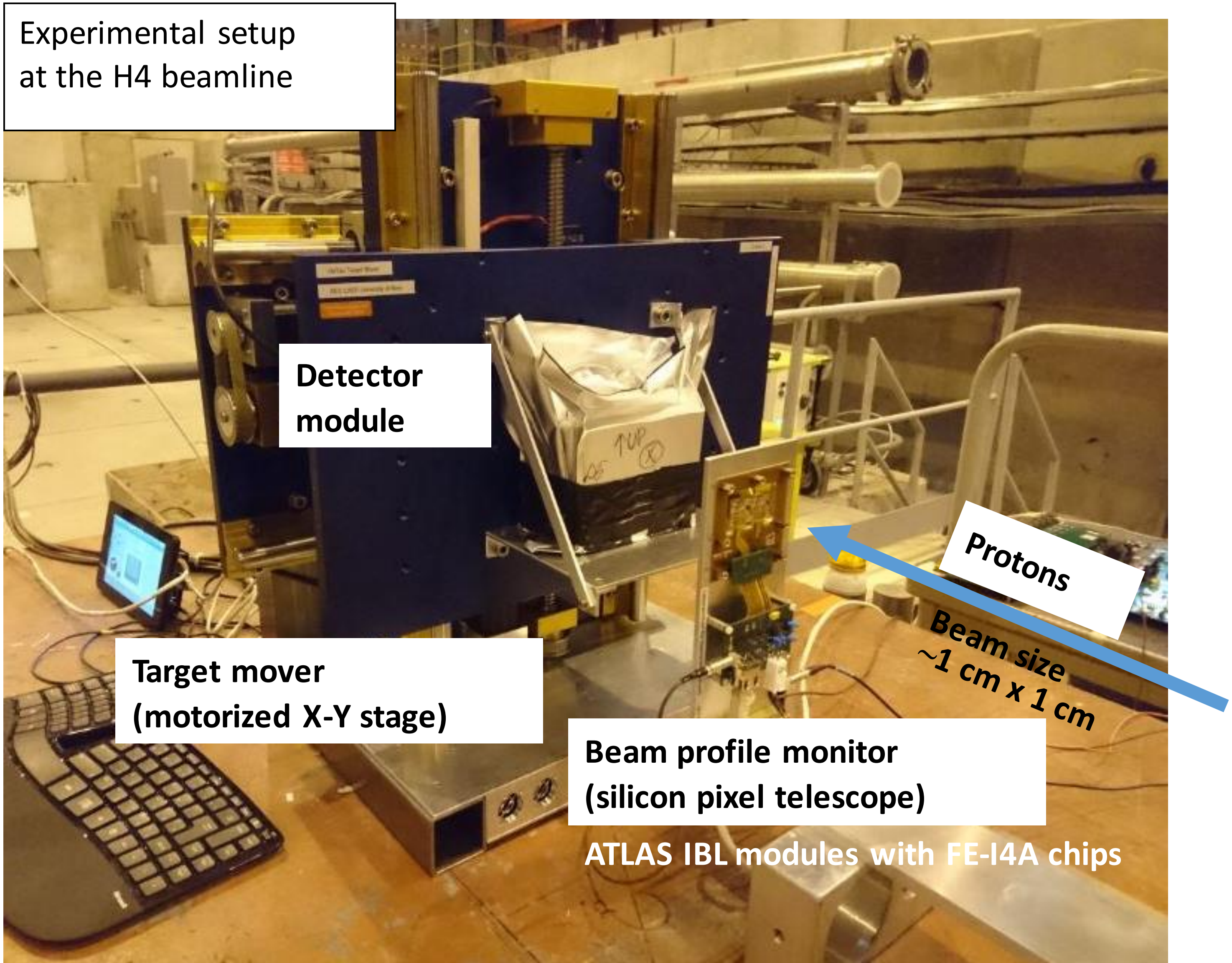


Piezo objective scanner

Module structure for $D_s \to \tau \to X$ measurement

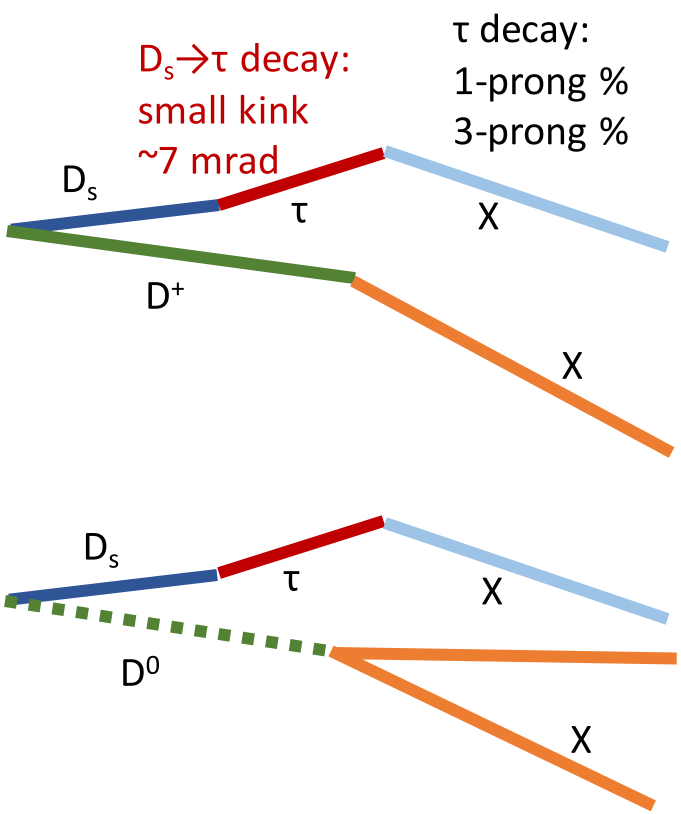


Detector setup



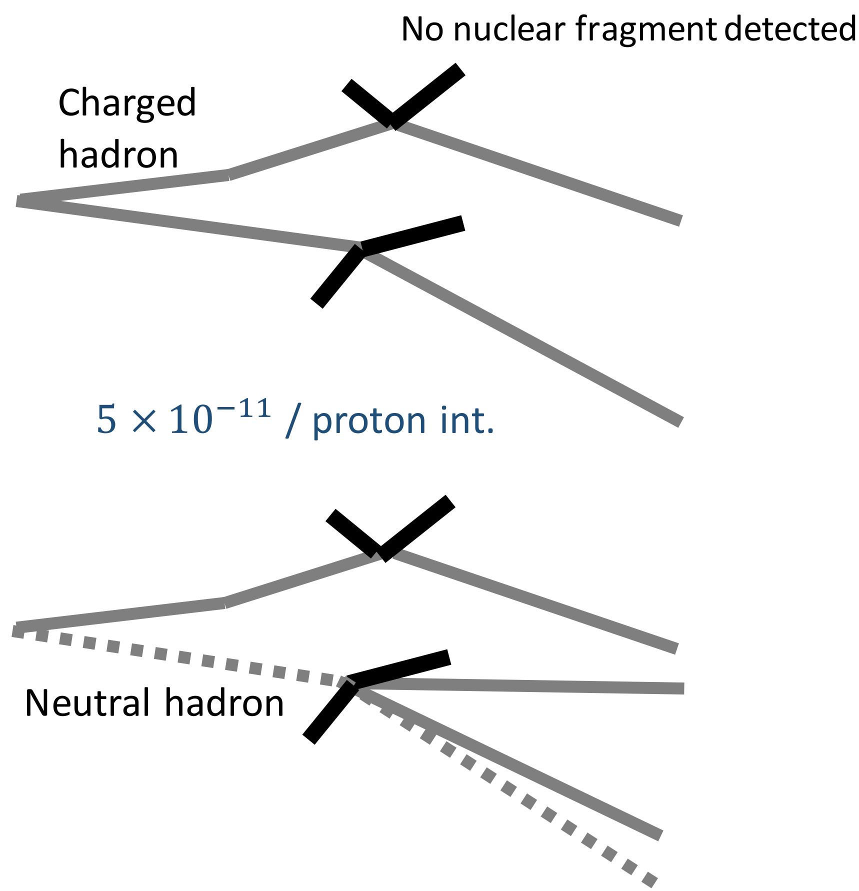
Signal and background

- Signal



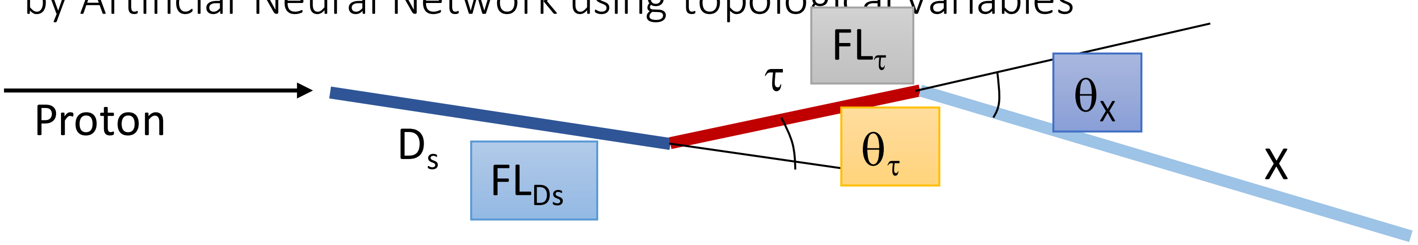
Detection efficiency = 20%
signal probability 5×10^{-6} /proton int.

- Main background



New method for Ds momentum reconstruction

by Artificial Neural Network using topological variables

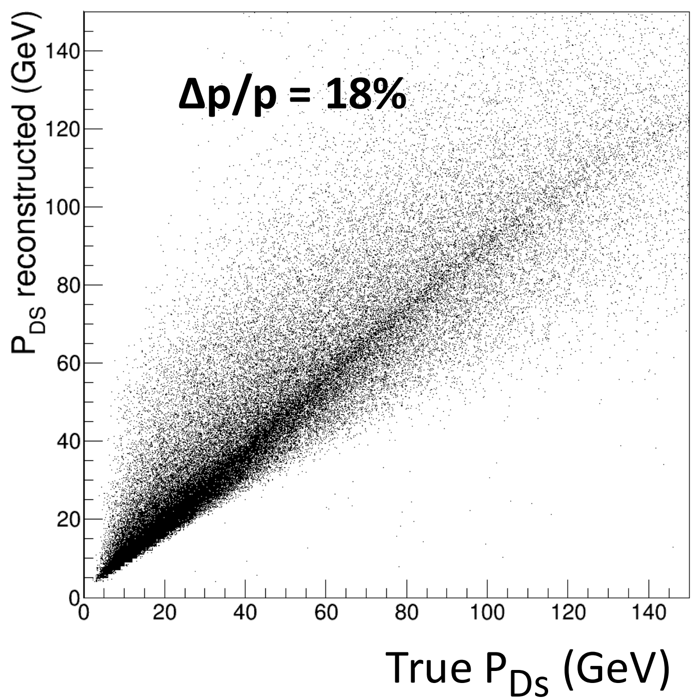


FL: flight length

- Difficult to measure Ds momentum directly due to short lifetime

→ Ds momentum reconstruction by topological variables

- A Neural Network with 4 variables was trained with MC events
- Momentum resolution for $\tau \rightarrow 1$ prong decays $\Delta p/p = 18\%$



Status of the DsTau project

- Letter of Intent, Feb. 2016
  - Beam tests in Nov. 2016, May 2017
- **Proposal (SPSC-P-354), Aug. 2017**

- Presentation at the 128th Meeting of the SPSC (open session):
- Reviewed during the SPSC meeting, Jan. 2018

→ **Positive feedback**

- **"The 2018 run has been approved and the Committee recommends that the beam time requested for 2021 will be granted.“**

CERN-SPSC-2017-029 / SPSC-P-354
29/08/2017

Experiment Proposal

Study of tau-neutrino production at the CERN SPS

S. Aoki[1], A. Ariga[2], T. Ariga[2,3,*], E. Firu[4], T. Fukuda[5], Y. Gornushkin[6], A. M. Guler[7], M. Haiduc[4], K. Kodama[8], M. A. Korkmaz[7], U. Kose[9], M. Nakamura[5], T. Nakano[5], A. T. Neagu[4], H. Rokujo[5], O. Sato[5], S. Vasina[6], M. Vladymyrov[2], M. Yoshimoto[10]

Collaboration

Japan:
- Aichi University of Education
- Kobe University
- Kyushu University
- Nagoya University

Romania:
- Institute of Space Science

Russia:
- JINR-Joint Institute for Nuclear Research

Switzerland:
- University of Bern

Turkey:
- METU-Middle East Technical University

DsTau load map

Test beam 2016
- Test of detector structure

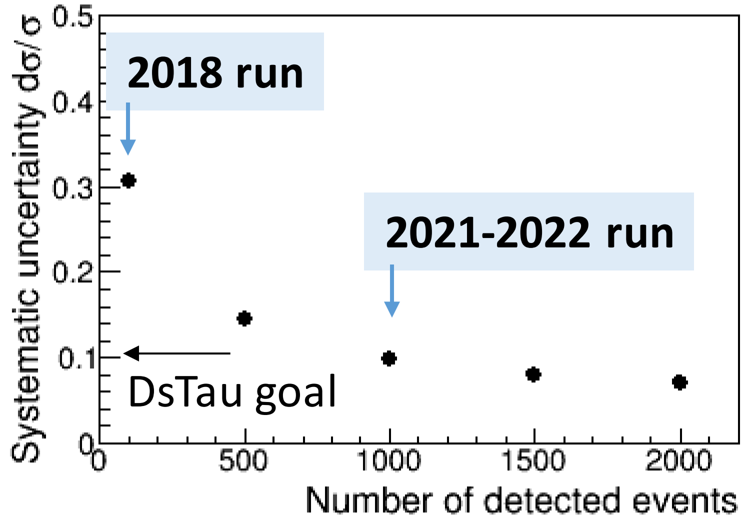
Test beam 2017
- Improved detector structure
- Refine exposure scheme

We are here

Pilot run 2018
- 1/10 of the full scale experiment
- 30 % uncertainty
- Charm physics

Physics run 2021-2022
- Full scale experiment
- Aiming at collecting 1000 $D_s \to \tau \to X$ events
- 10 % uncertainty

Expected performance



Pilot run Emulsion film production

- Needed: 50 m^2 (4000 films) for pilot run
- Shifts: 2 persons x ~10h/day x 11 weeks (June 4 – August 17)
- Production speed: ~5 m^2/week
- ~4500 films produced

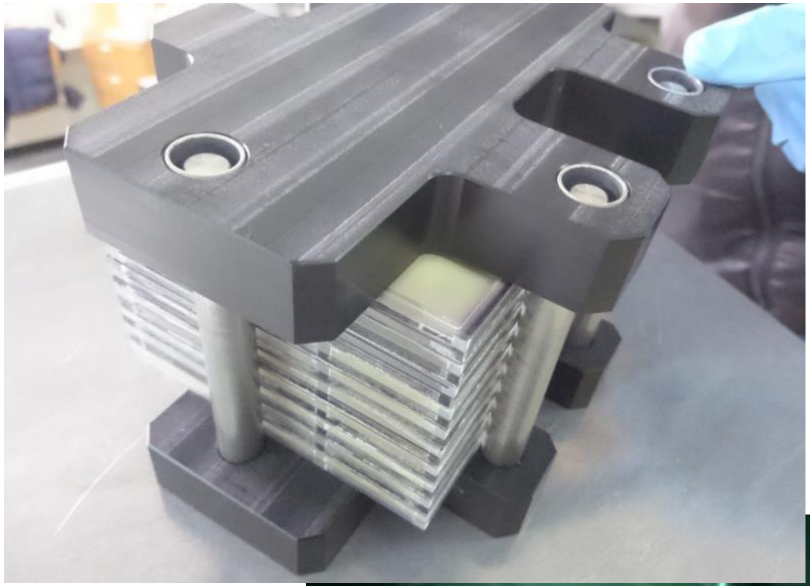
Emulsion

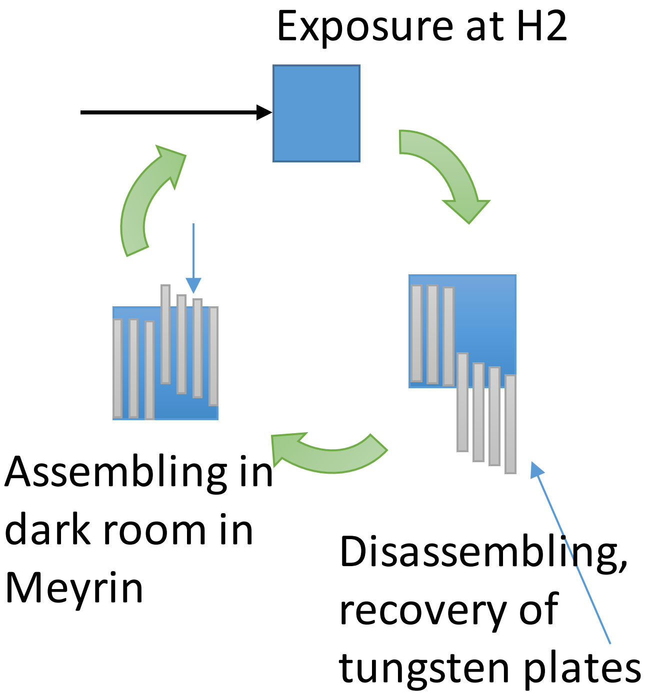
Base

Emulsion

Detector modules

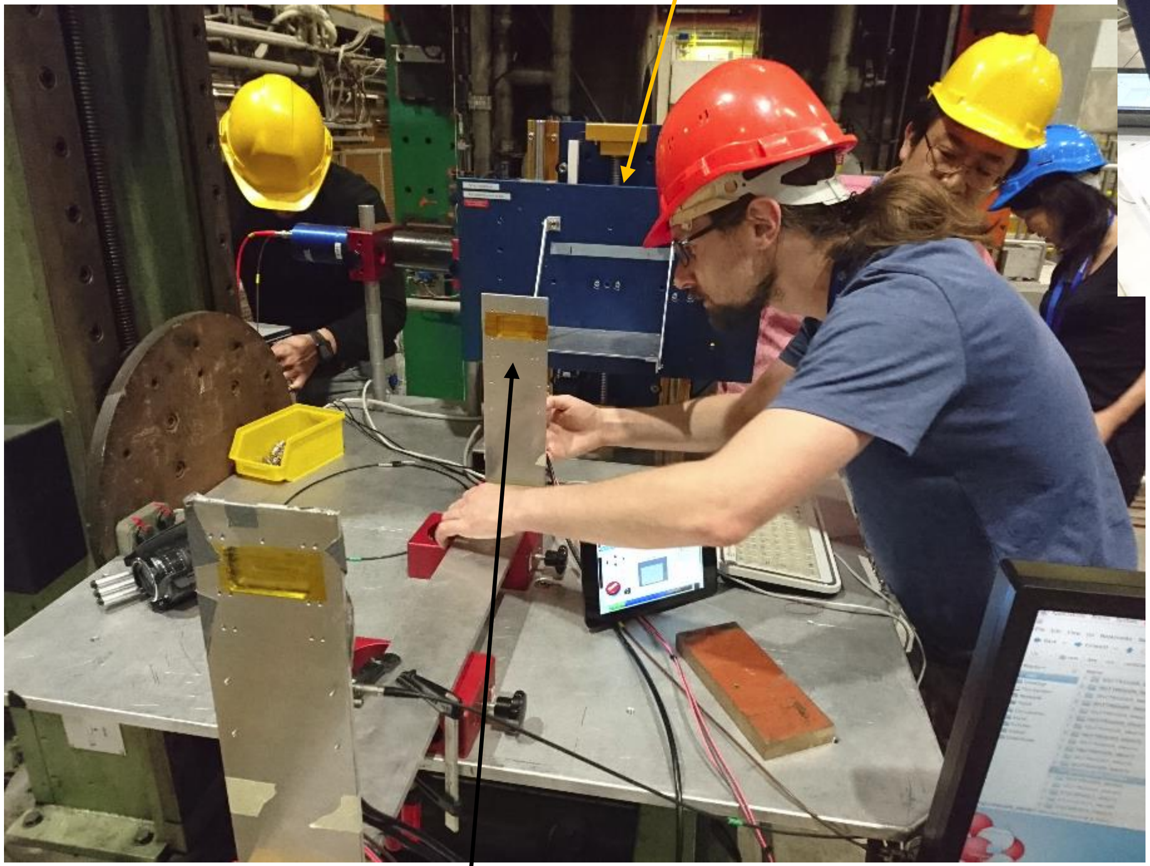
- 30 modules (131 films/module) prepared in total



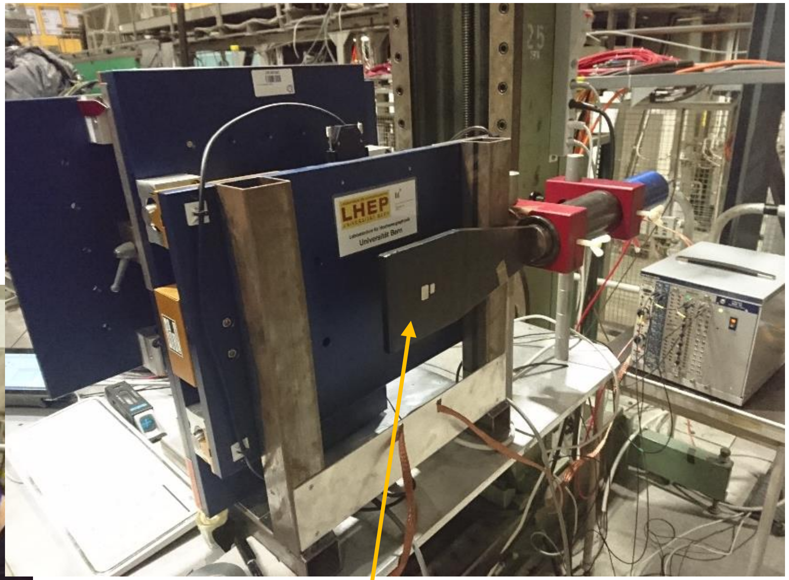


Installation

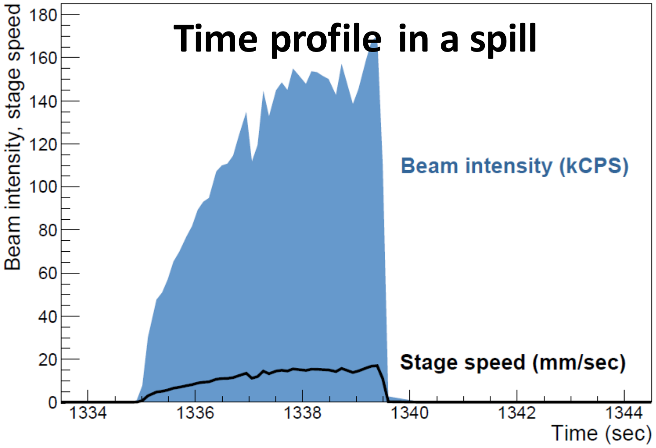
Target mover



Silicon pixel profile monitor

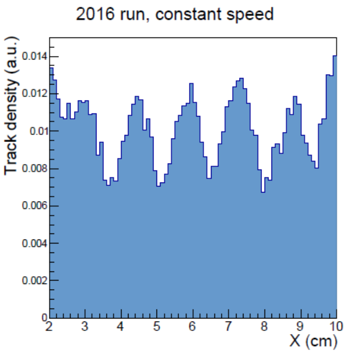


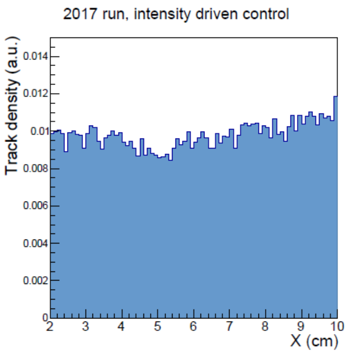
Scintillator for intensity driven control



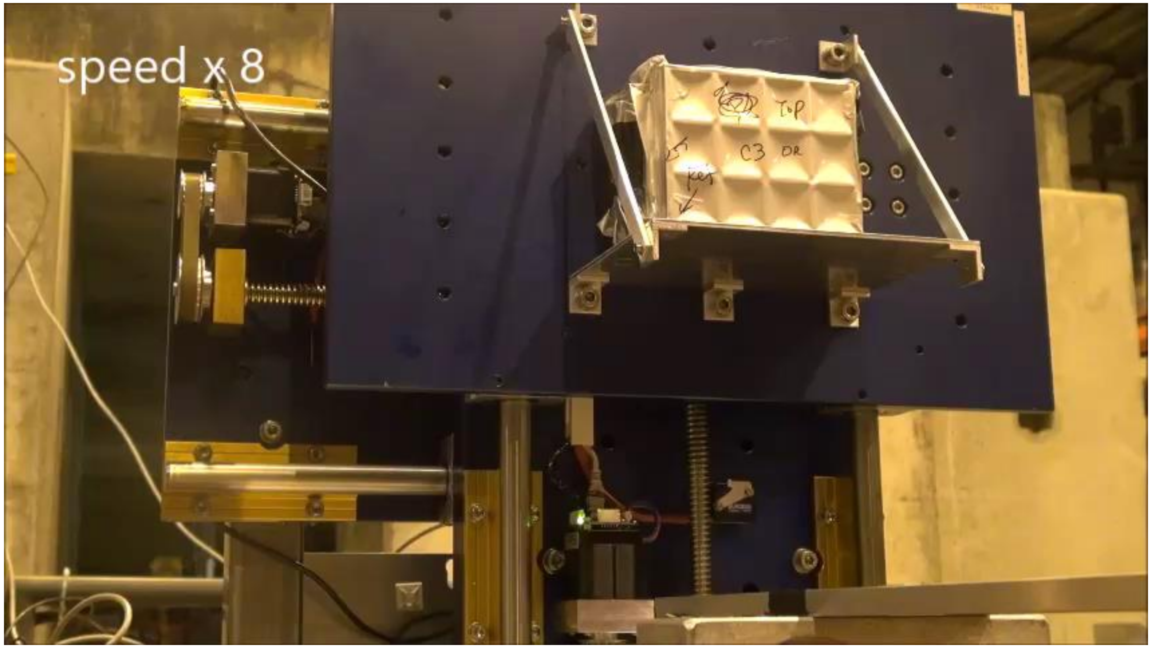
Exposure scheme

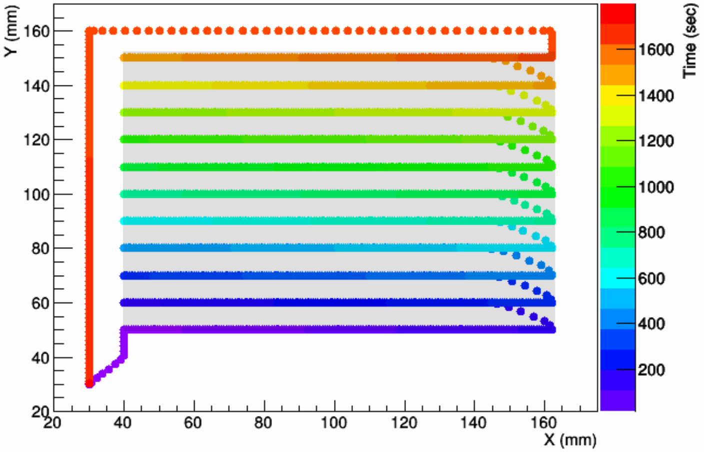
- Target mover (scanning on X)
    - 2016: moved at a constant speed during the spill
    - 2017, 2018: intensity driven control by scintillator counter (feedback each 0.2 sec)
- 0.5 - 1 hour per module





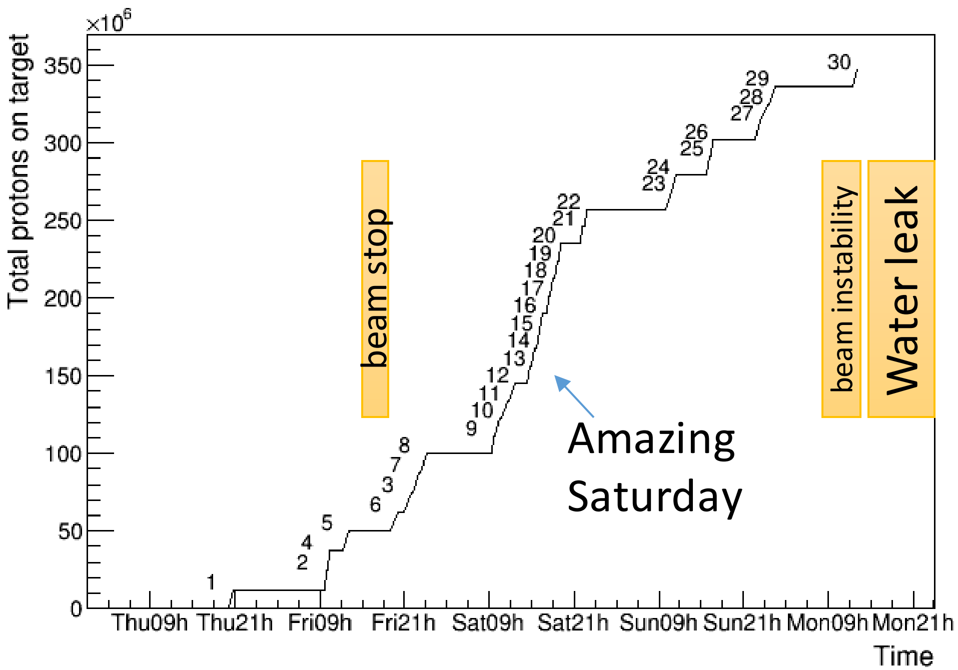
Scanning sequence of the target mover

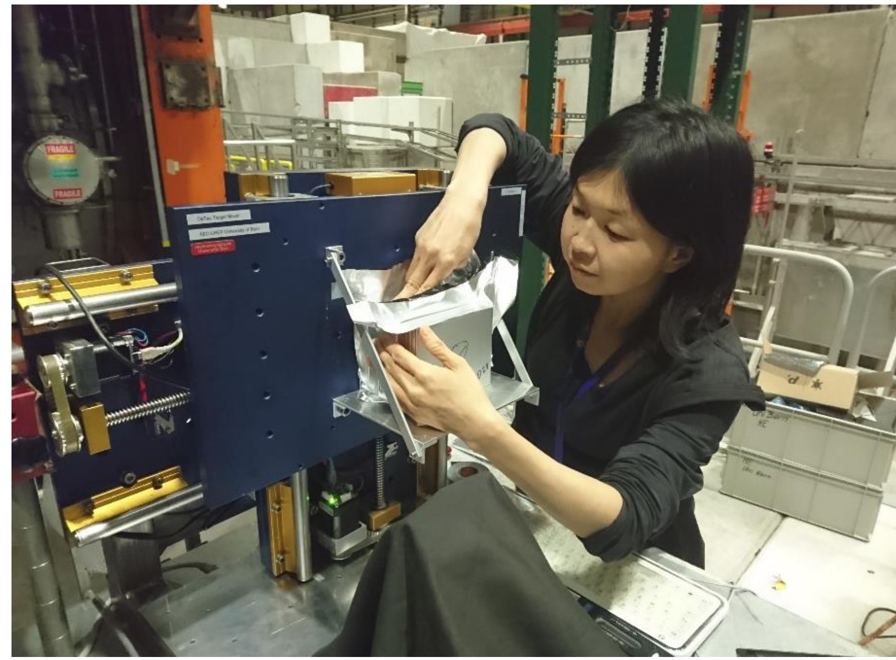




Emulsion module exposure

- $10^5\ protons/cm^2 \rightarrow 1.25 \times 10^7$/module
- 30 modules in total
- c.a. 18 million proton interactions in tungsten

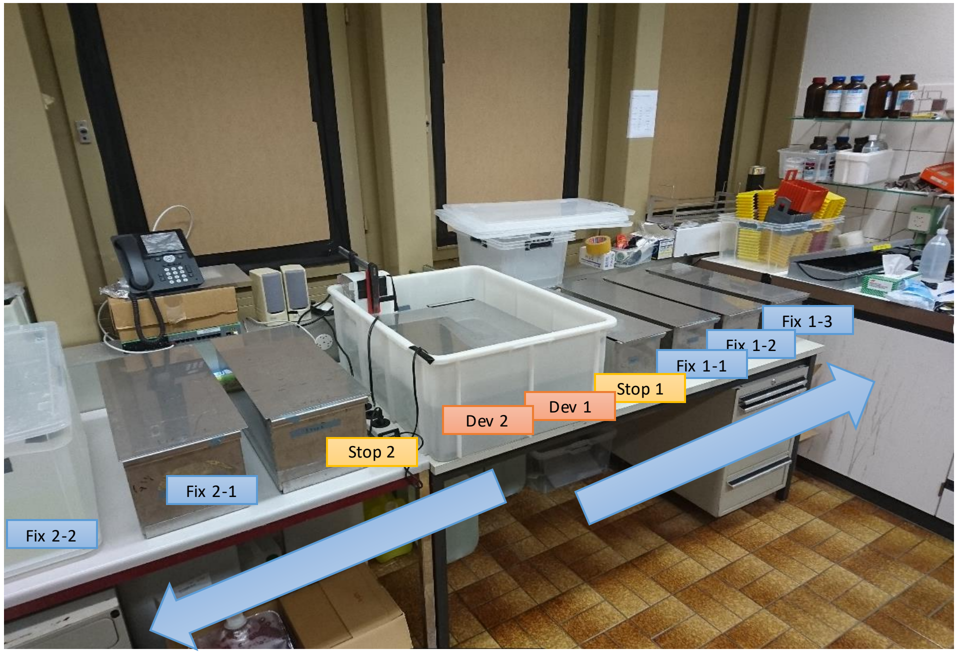


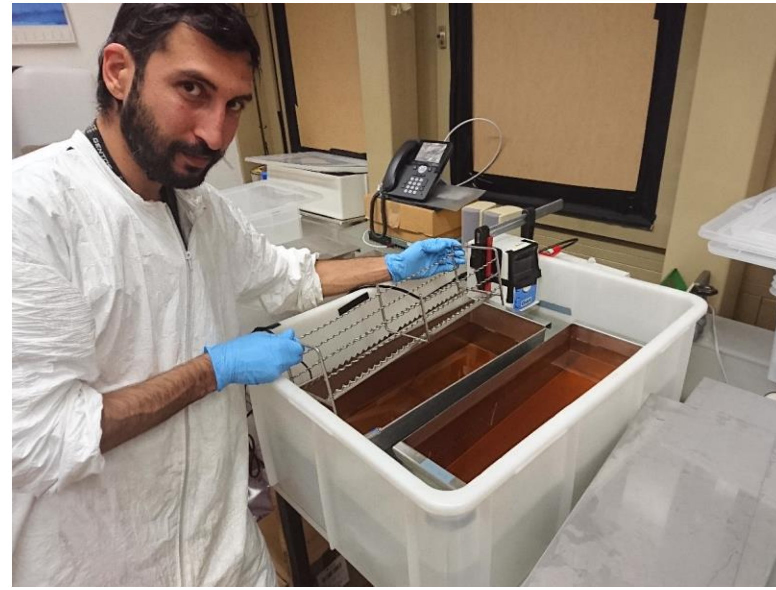


We progressed quicker than planned, thanks to two Flat-Top in a Super Cycle.

The DsTau team participated in the campaign

Development in Bern, 8/28-10/4





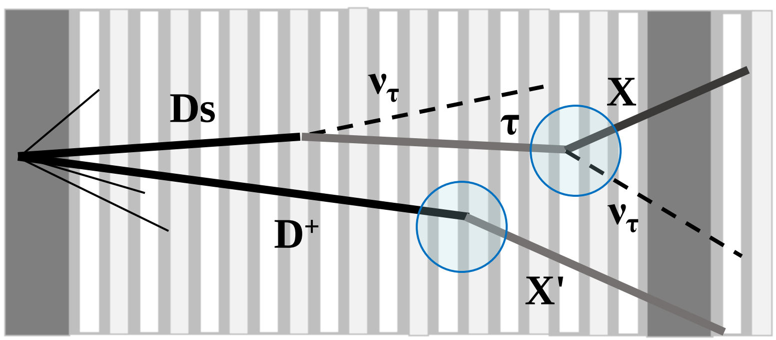
- Total 4000 films
- max speed: 360 films/1.5 days.
- Tons of chemical was used.

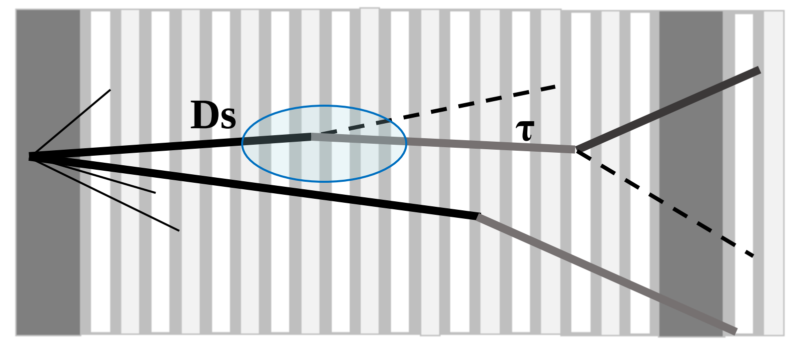
Analysis scheme for double-kink search

- Full area scanning by the fast scanning system
- Select decays with Δθ > 20 mrad

- Precision measurement to detect Ds -> τ decay (a few mrad)

Proton beam

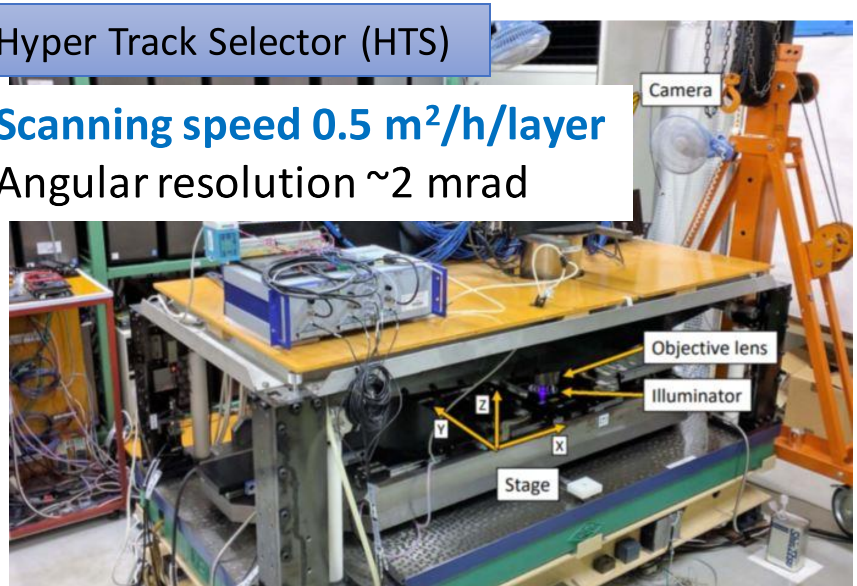




Hyper Track Selector (HTS)

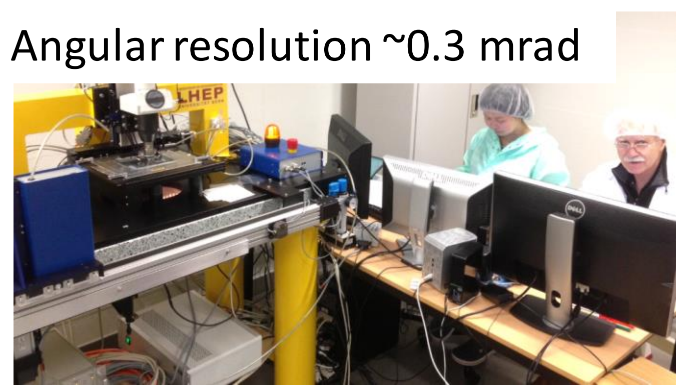
Scanning speed 0.5 m^2/h/layer

Angular resolution ~2 mrad



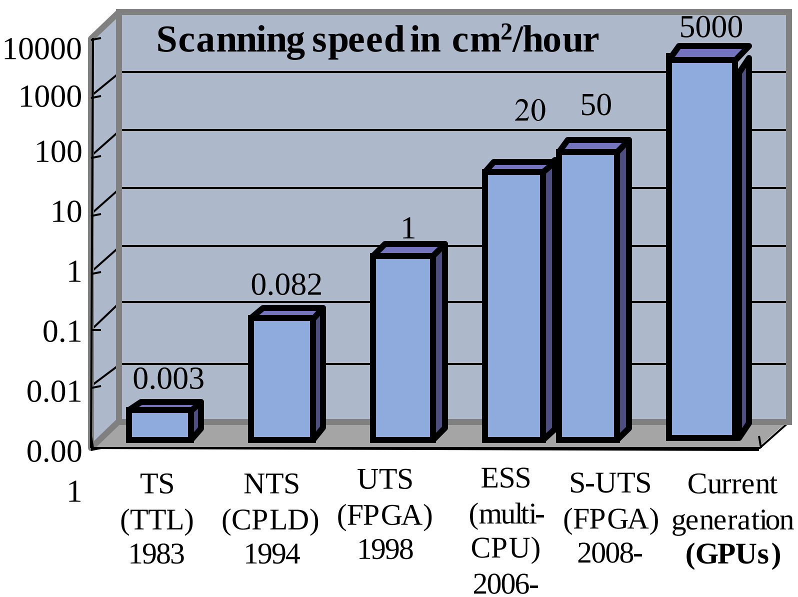
Dedicated high-precision systems

Angular resolution ~0.3 mrad



Evolution of automated scanning system

Development of scanning system started in 1970s.

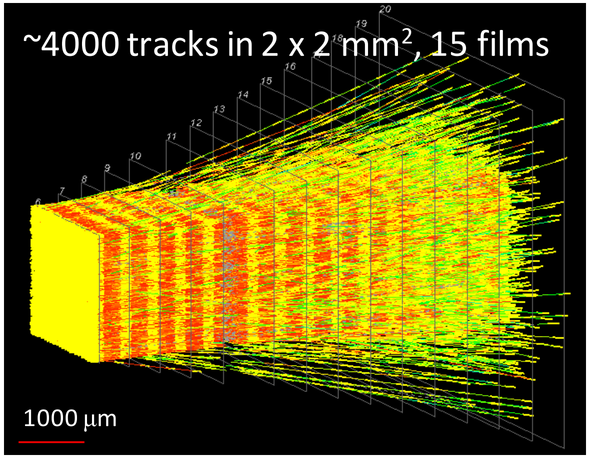


100 times faster than OPERA

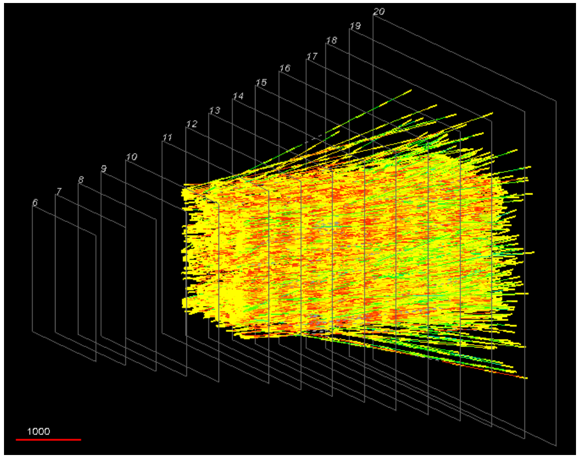
Reconstruction of proton interactions

- Microscope data taking
  - Pixel size = 0.3 μm x 0.3 μm x 2 μm
- Data size
  - ~10 TB image data / film (125 cm^2)
  - ~50 PB will be processed in the 2018 pilot run (50 m^2)
  - 10 GB / film after compression to be stored
- Track density
  - OPERA: 100 tracks/cm2 in wide angular space (θ<500 rad)
  - DsTau: 100,000 tracks/cm2 in small angular space (θ<10 mrad)

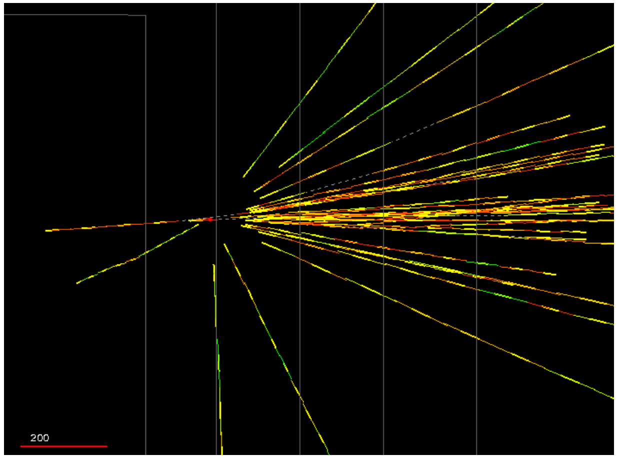
Reconstructed tracks



Tracks starting after tungsten

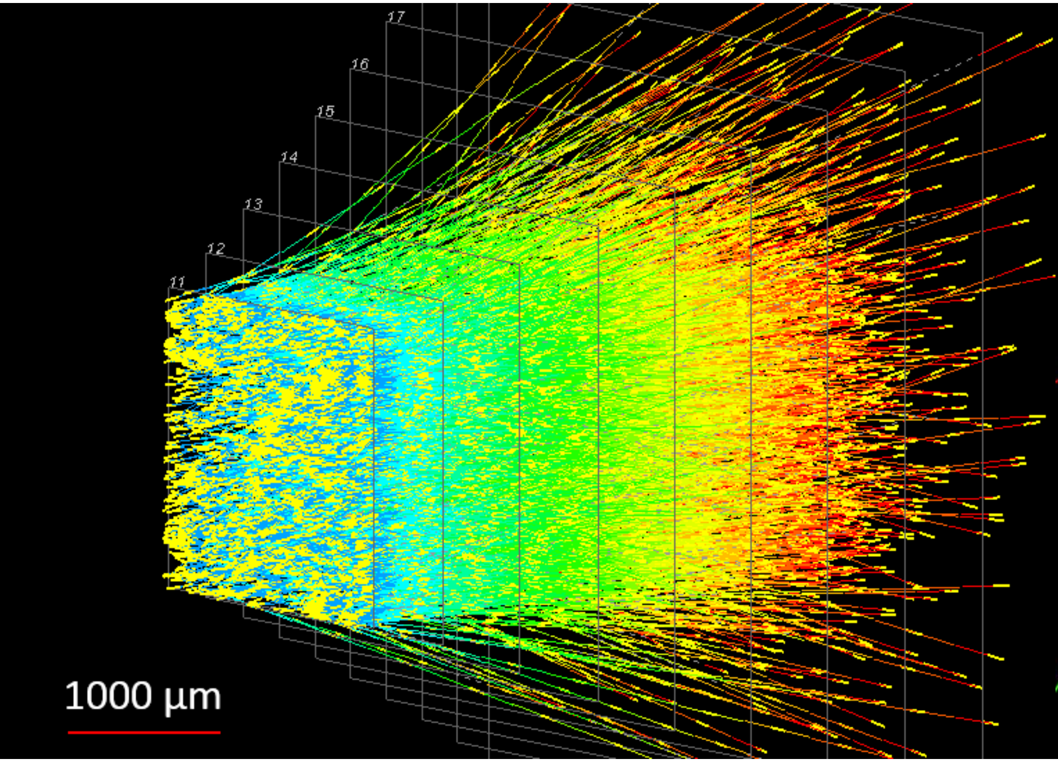


Vertex reconstruction

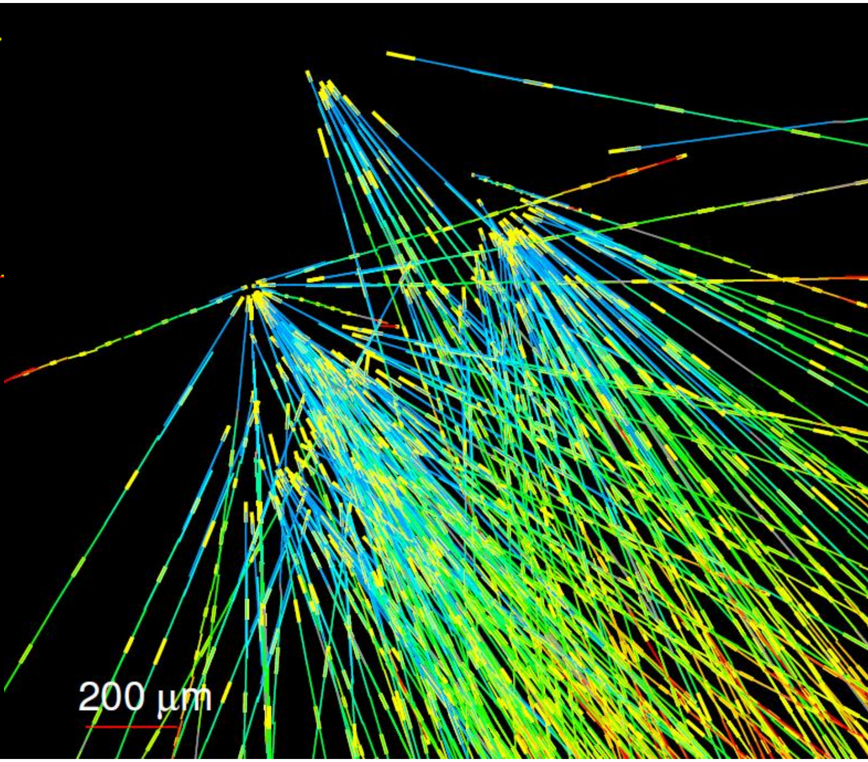


A piece of data

Tracks 1 mm x 1 mm

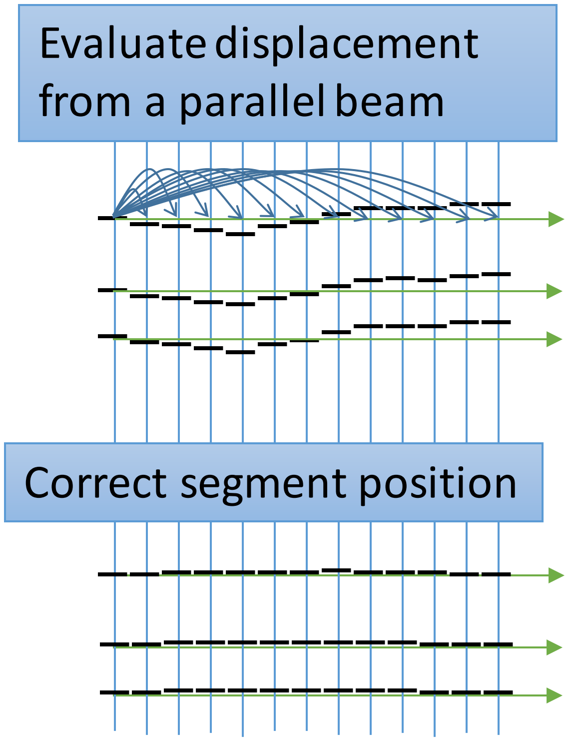


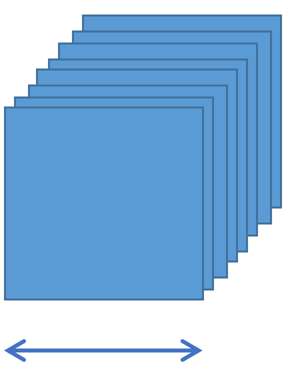
Tracks emerging from tungsten target



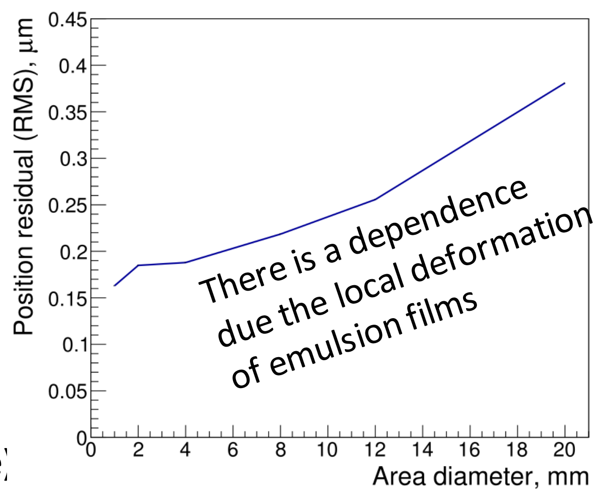
Alignment of between emulsion films

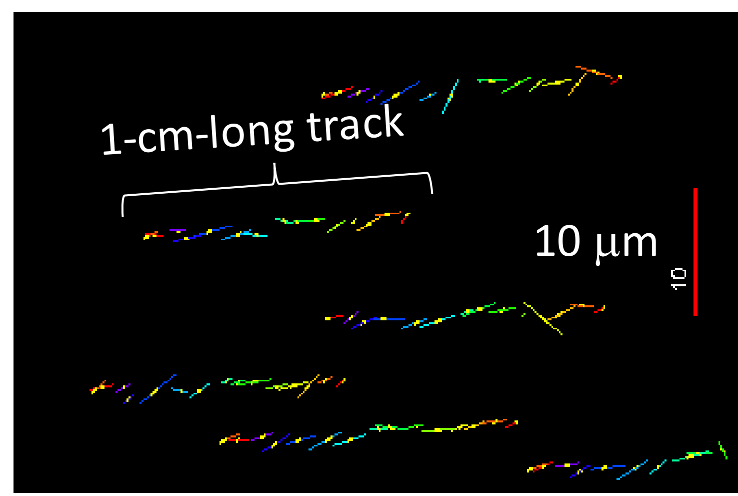
- “**Proton tracks run straight!**”
  - scattering of 400 GeV proton is negligible
- Align films to minimize the displacement from the beam proton
- Position residual of track segments to a linear fit is < 0.4 μm, depending on processing area size





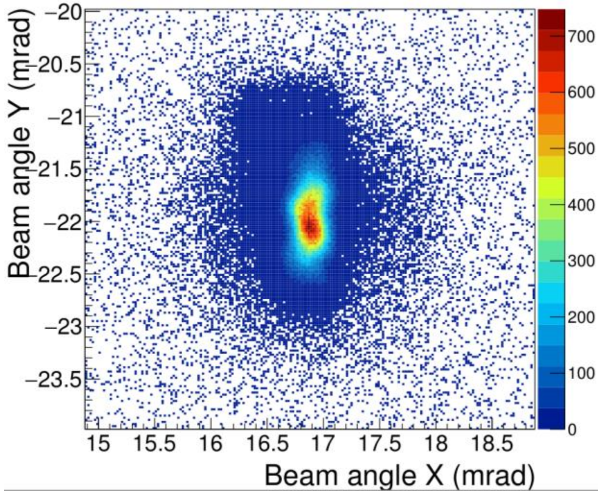
Area diameter
(Processing unit size)

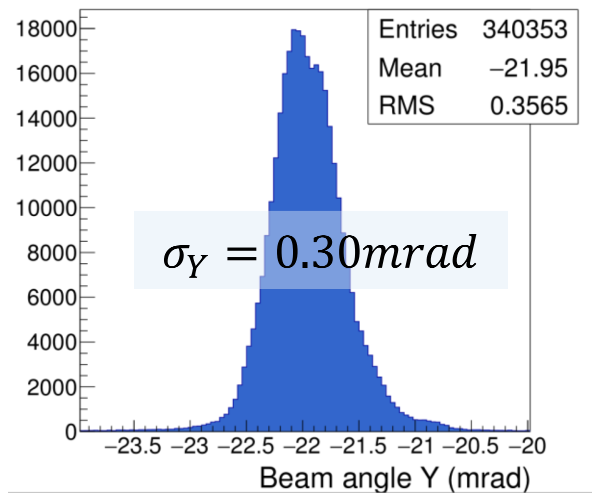


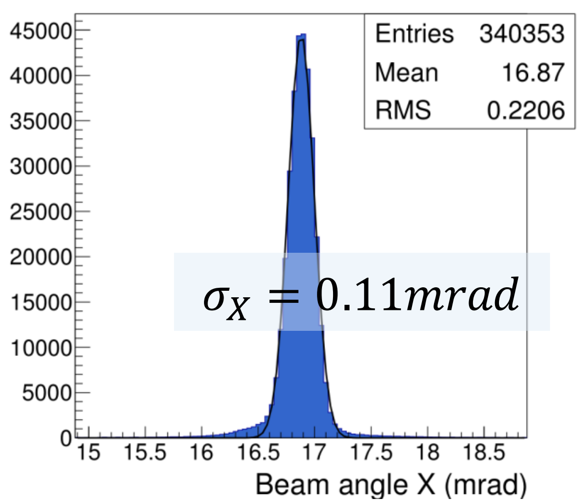


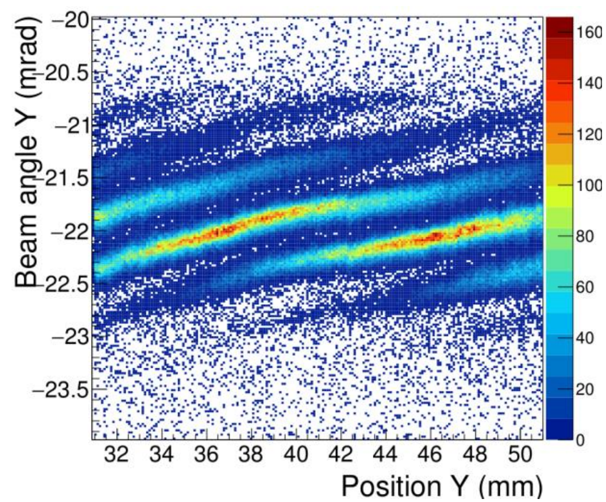
Proton beam angle structure

- Tracks reconstructed in 20 emulsion films, thickness of 1.1 cm
  - Expected angular resolution is $0.4\mu m \cdot \sqrt{2}/11000 = 51\ \mu rad$
- An asymmetric structure in X and Y was observed.

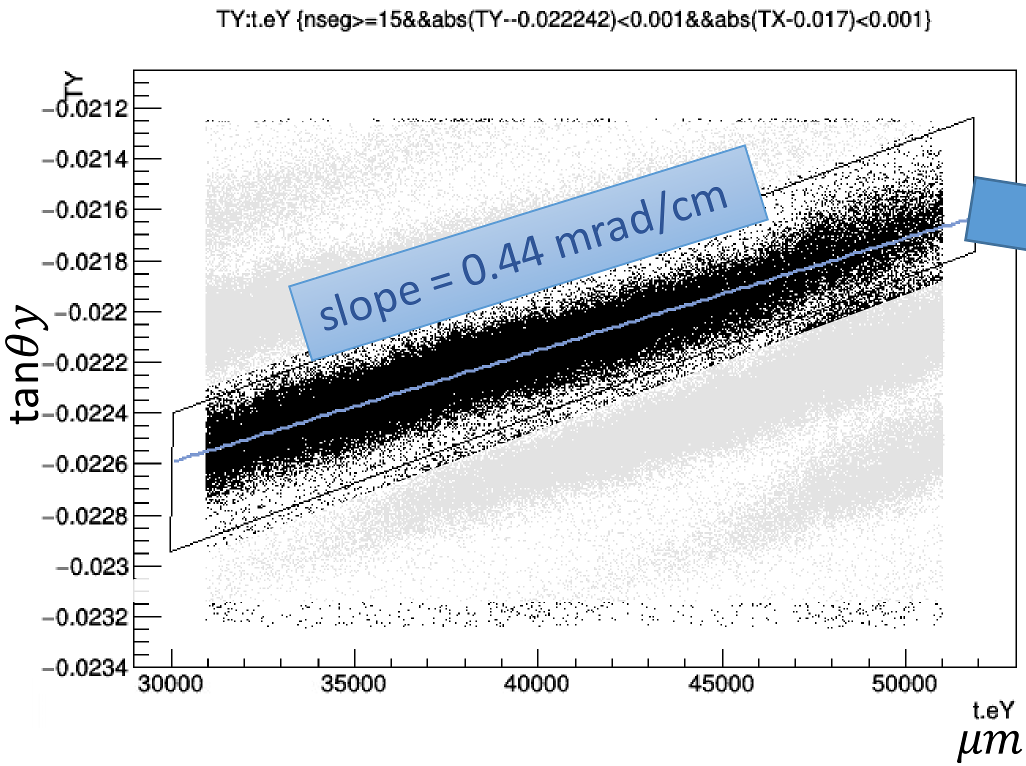




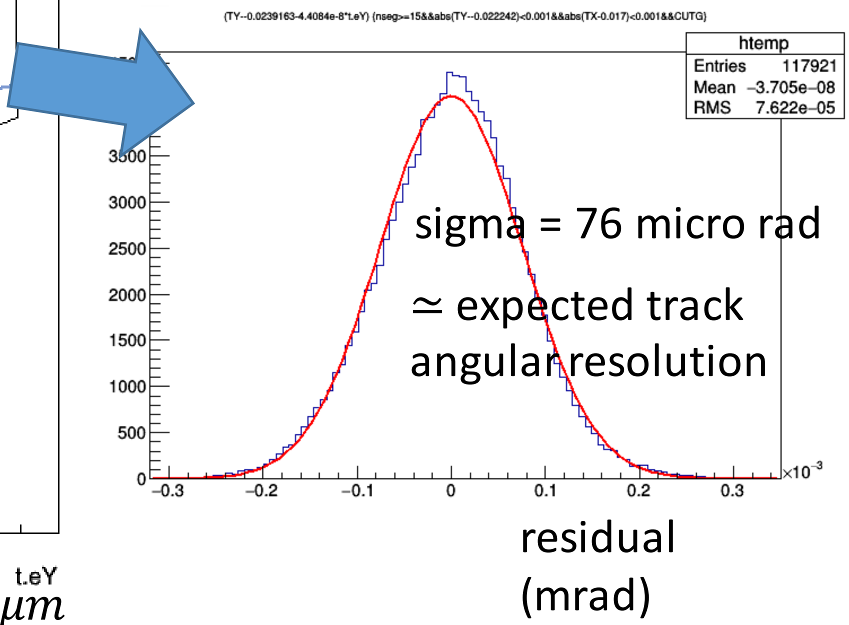




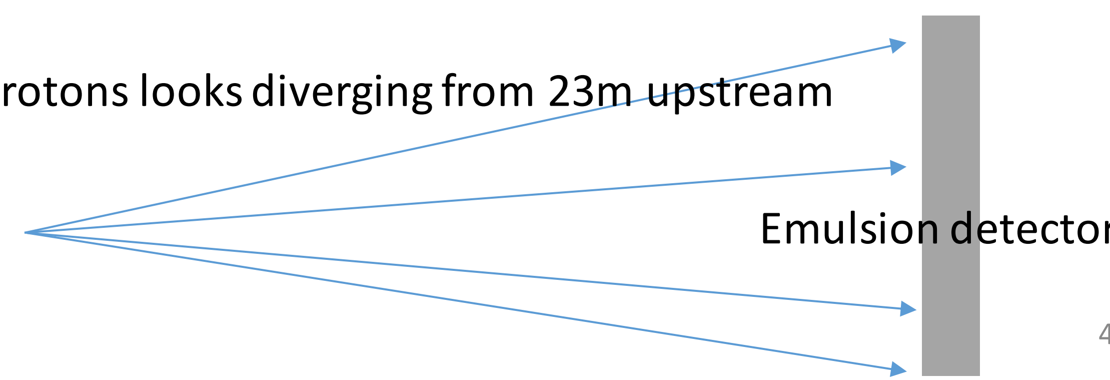
Close look in the TY



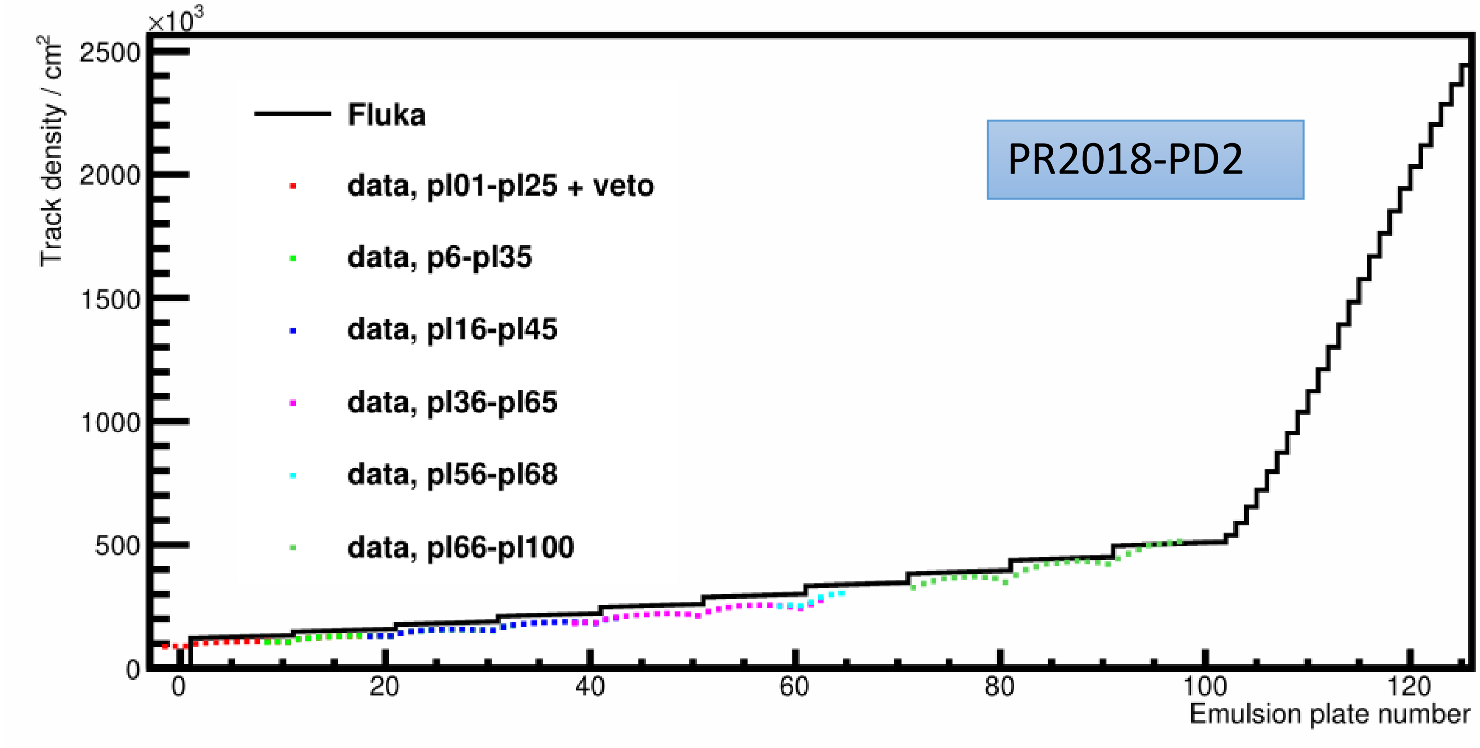
- Residual from the fit.



The "right-shoulder up" feature is consistent with a "diverging beam".
1/(0.44mrad/cm) = 23m.

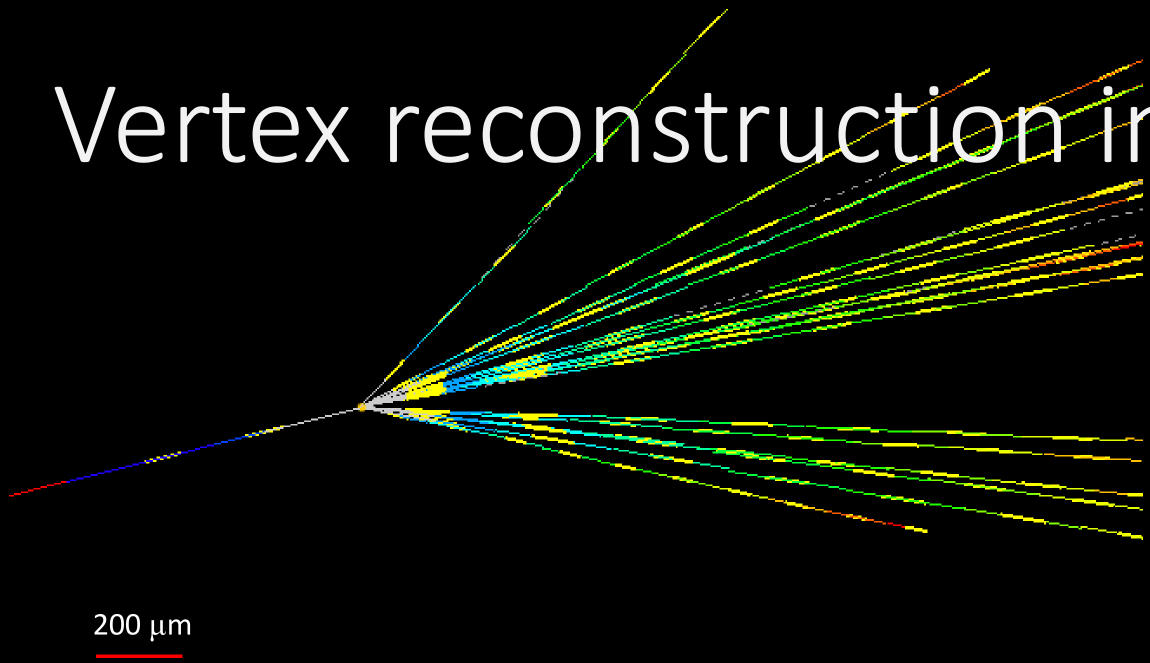


Data/MC, Track density evolution



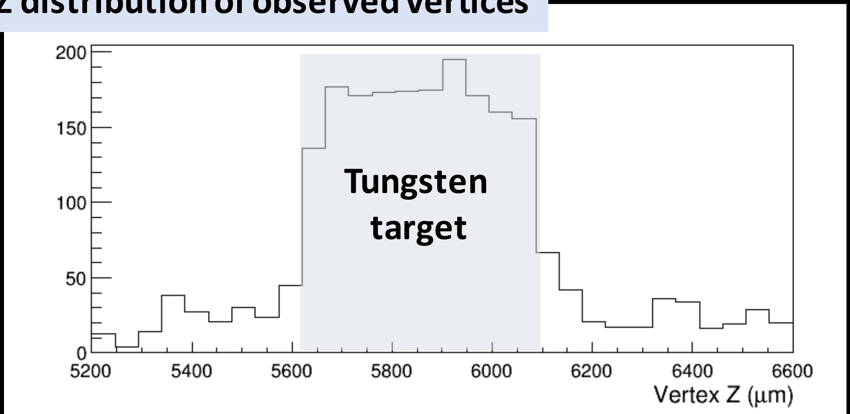
- Data (2018) and FLUKA
- Track density evolution as a function of depth in the detector.
- In good agreement.

Vertex reconstruction in 3D



Measured proton beam density in the analyzed region: 4.36×10^5 beam tracks/3.61 cm^2

Z distribution of observed vertices



Interactions in a tungsten plate

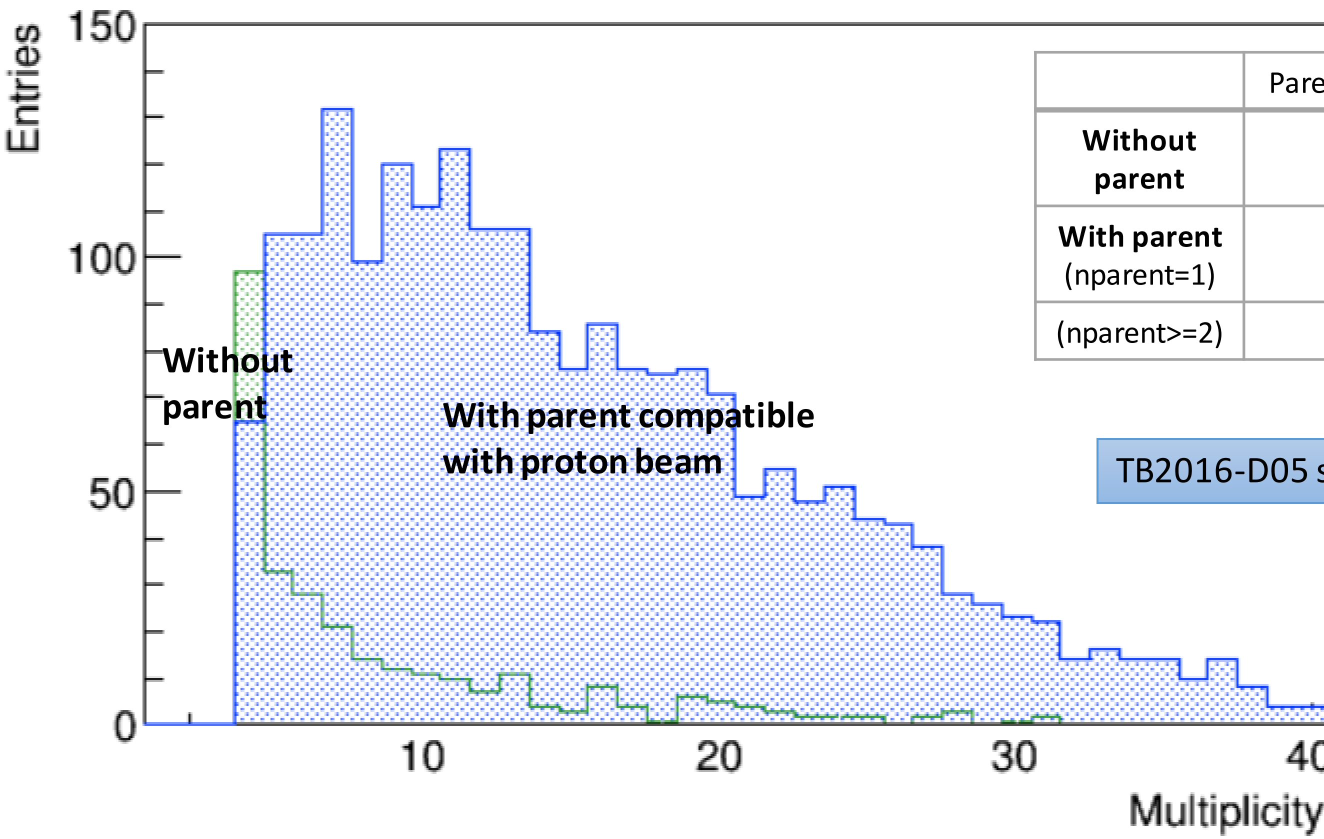
	N vertices
Expected	1860
Observed	With parent 1832
	Without parent 130

Consistent with the expectation

Vertex multiplicity of proton interactions in tungsten plate

Refined vertexing/decay search are applied to sub sample of 2016 data

For example in a volume of 1.9 cm x 1.9 cm x 20 films:
Possible beam track selection: <10 mrad from the peak → 436674 tracks/(1.9 cmx1.9 cm)
→ 2205 int. expected if all are protons



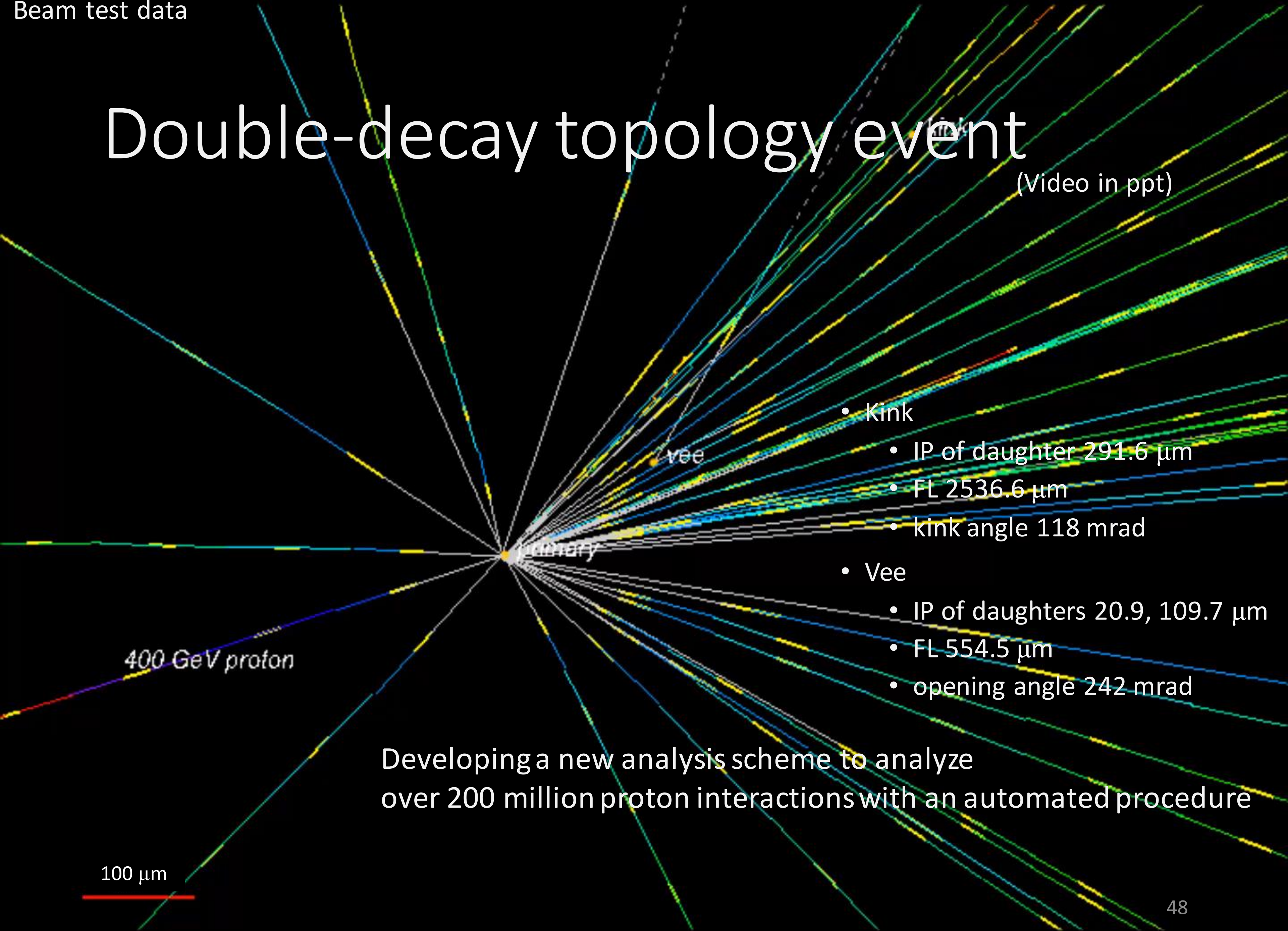
	Parent: IP<5 μm
Without parent	294
With parent (nparent=1)	2022
(nparent>=2)	69

TB2016-D05 subsample

Beam test data

Double-decay topology event

(Video in ppt)

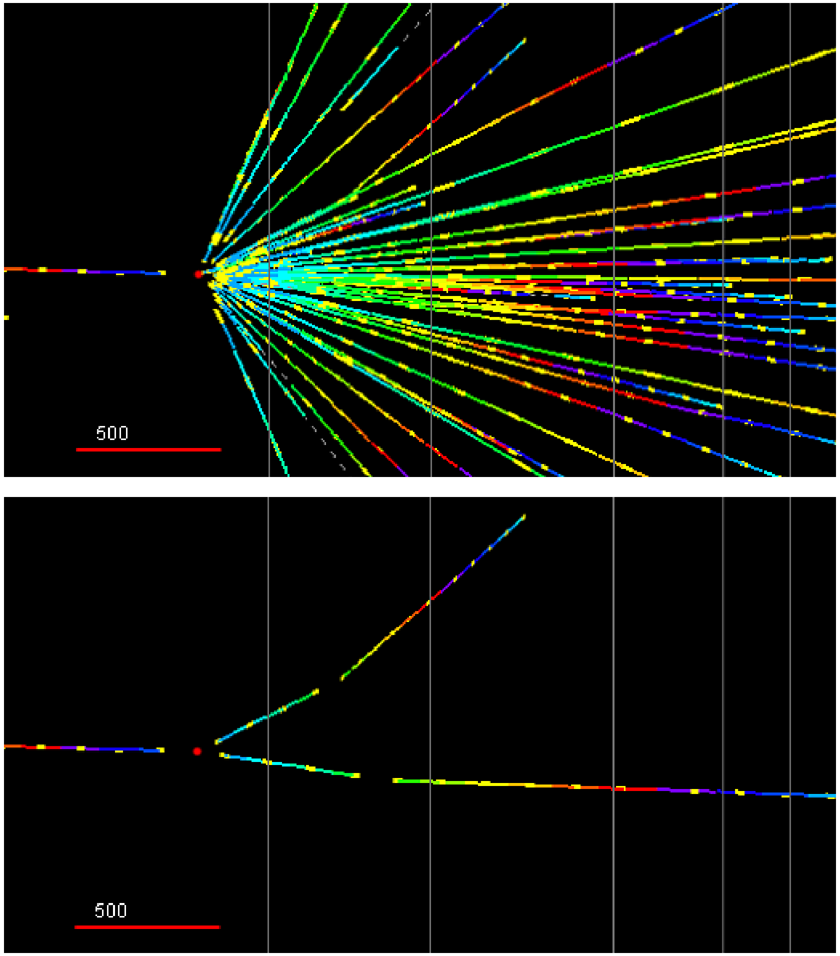


- Kink
  - IP of daughter 291.6 µm
  - FL 2536.6 µm
  - kink angle 118 mrad
- Vee
  - IP of daughters 20.9, 109.7 µm
  - FL 554.5 µm
  - opening angle 242 mrad

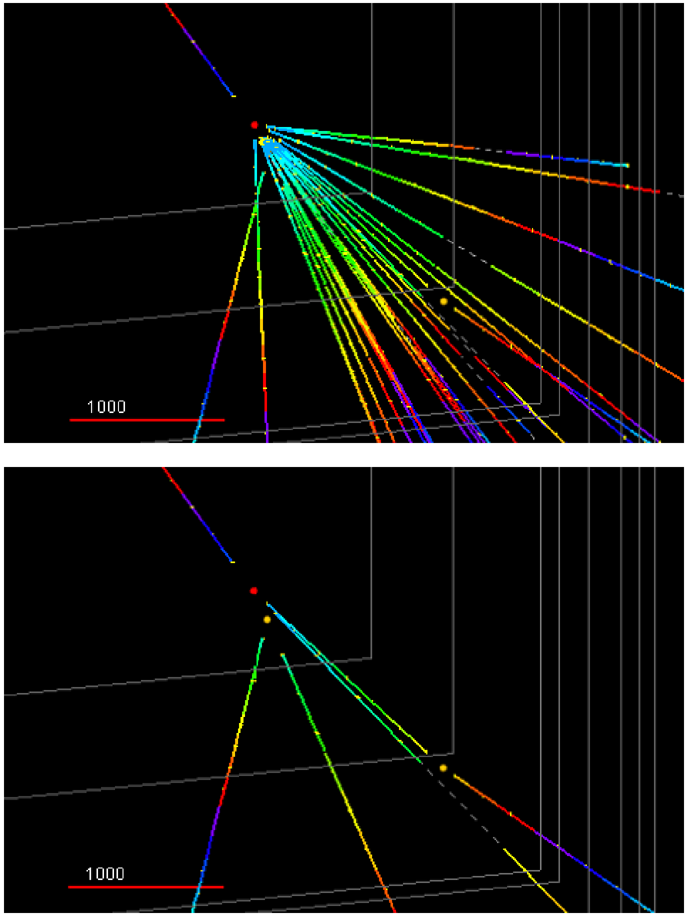
Developing a new analysis scheme to analyze
over 200 million proton interactions with an automated procedure

Double charm candidates

cand_20190117_p11_61598.3_47632.7
C1+C1 candidate

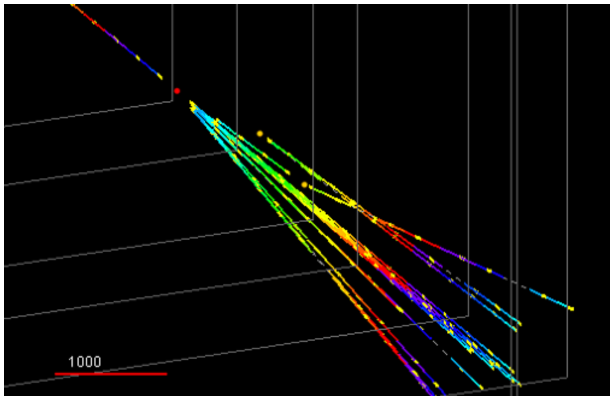


cand_20190117_p11_61427.6_56633.2
C1+N2 candidate

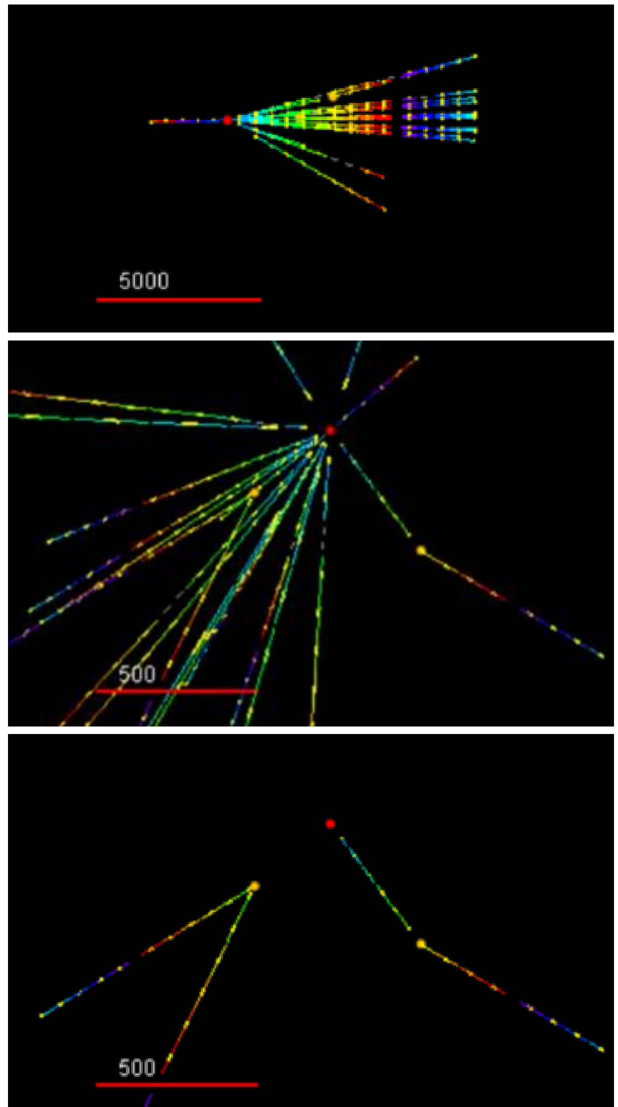


Double charm candidates

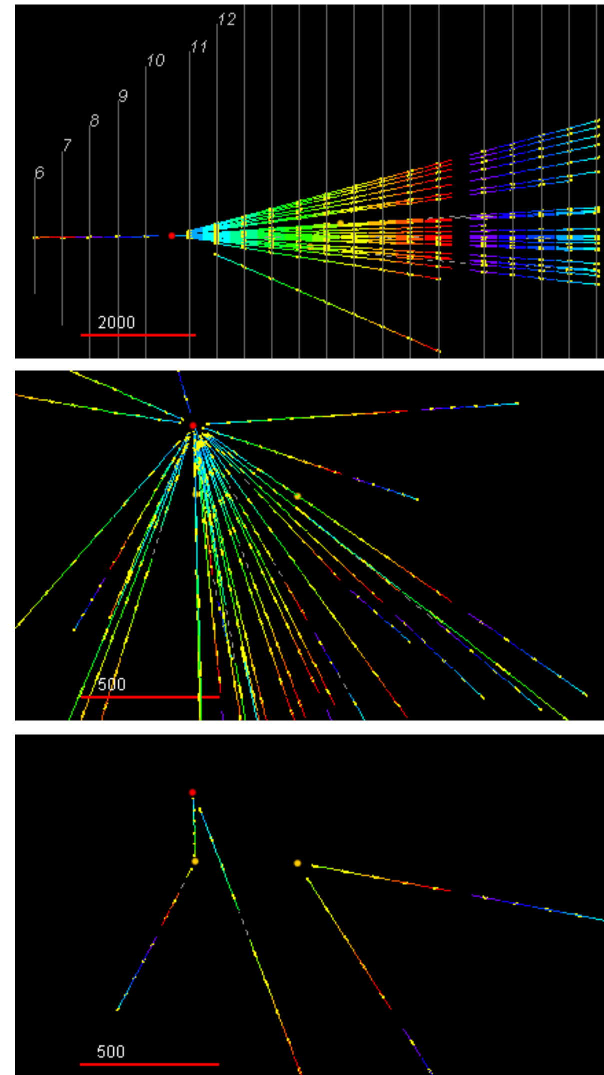
cand_20190117_p11_71651.2_33380.6
C1+N2 candidate



cand_20181205_p11_47291.8_32047.5
C1+N2 candidate



cand_20181205_p11_72182.0_63924.7
C1+N2 candidate



More events are coming.
10^4 double charm events are expected from the pilot run.
We will analyze
- flight length (γ factors)
- angle between charm pairs
- psuedrapidity distribution

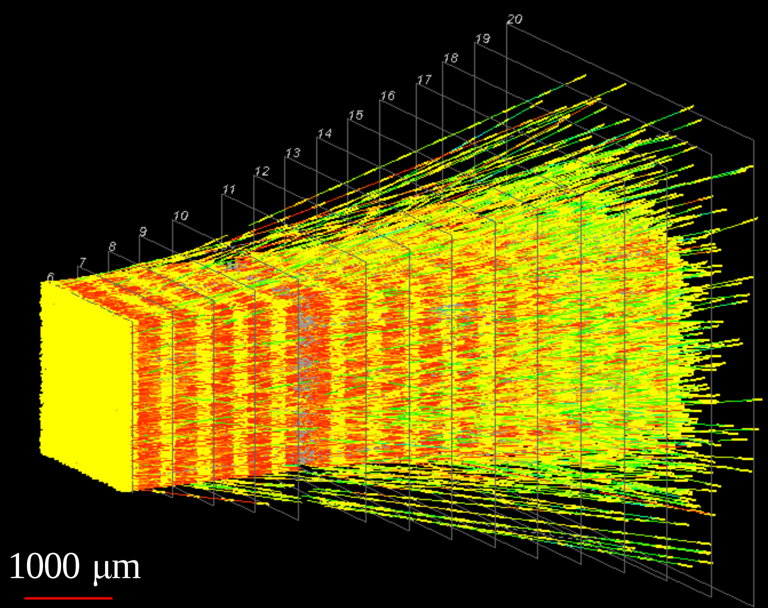
(to study intrinsic charm content in proton)

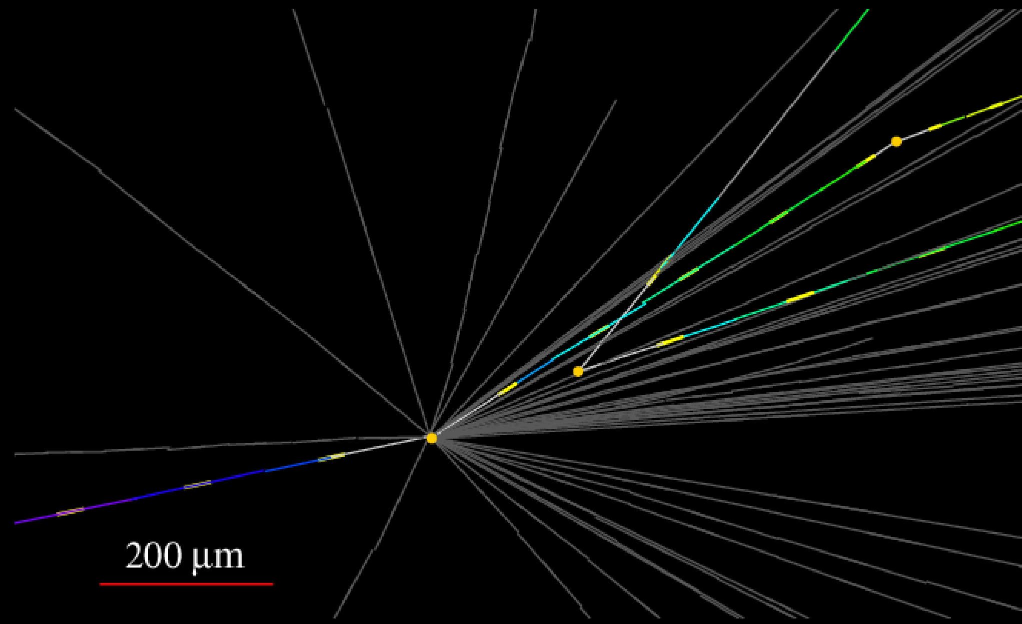
Summary

- A new precise measurement of the ν_τ cross section is important
  - to test new physics effects in ν_τ –nucleon CC interactions
  - for neutrino oscillation experiments and astrophysical ν_τ observations

- The DsTau project has been proposed at the CERN SPS to study ν_τ production (SPSC-P-354)
  - detect 1000 Ds → τ decays in 2.3×10^8 proton interactions employing emulsion detectors with a spatial resolution of 50 nm
  - reduce the systematic uncertainty in the ν_τ cross section measurement from >50% to 10%
- Pilot run in 2018 successfully performed, analysis is under way.
  - Data/MC comparison, ok
  - Systematic double charm event search, ok.
  - Physics publication(s) soon.
- Physics run in 2021-

Thank you for your attention





Future experiments with emulsion

OPERA technology

New technology

Physics experiments

- Neutrino oscillation
- Neutrino Cross-section
- Lepton Universality (ν_e-ν_μ-ν_τ)
- Hadron physics
- Charm physics
- Antimatter
- Double hyper nuclei

Accelerator

- beam monitoring
- Muon beam study in neutrino beamline

Medical application

- neutron source imaging
- proton radiography

Geosciences

- muon radiography
- Volcanoes
- Glaciers

Astronomy

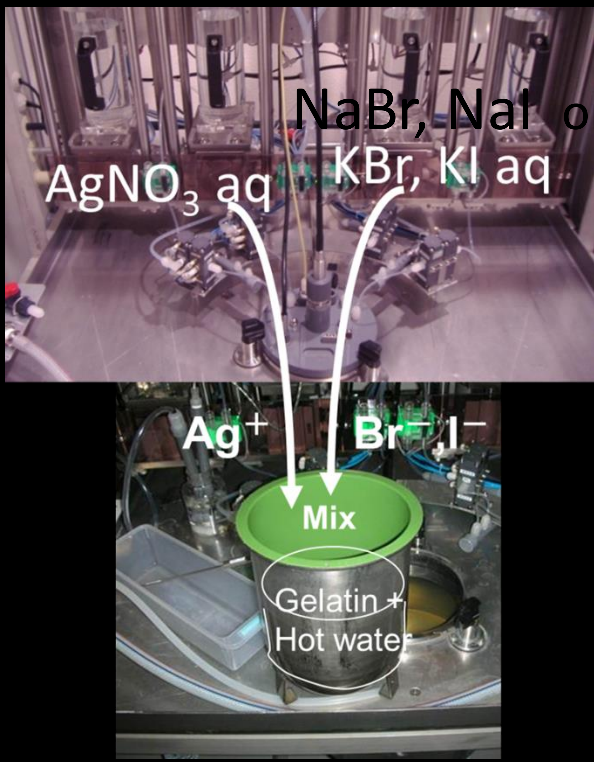
- Gamma-ray telescope

Dark matter

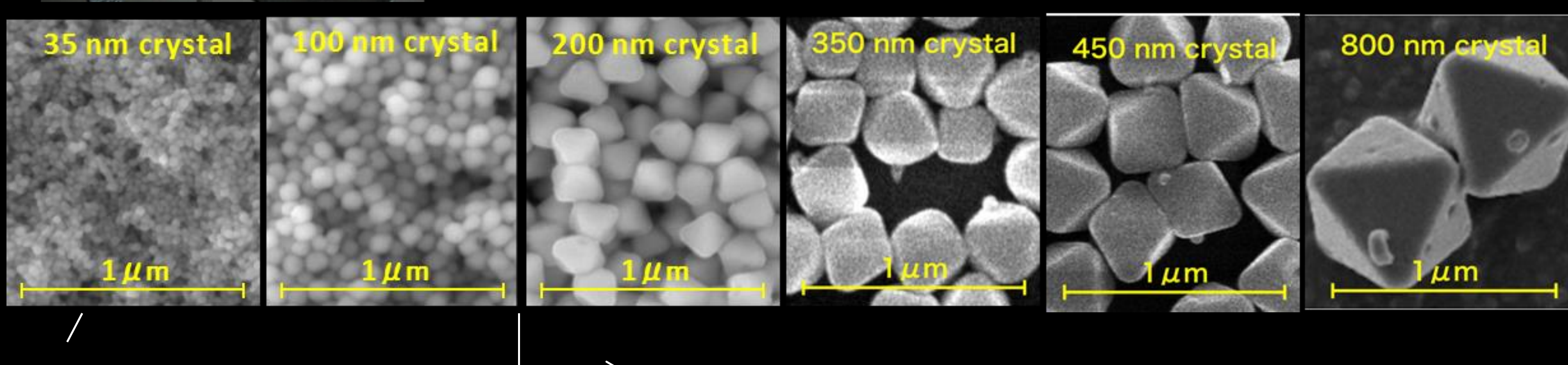
- Directional sensitivity

Nuclear emulsion gel produced at Nagoya University

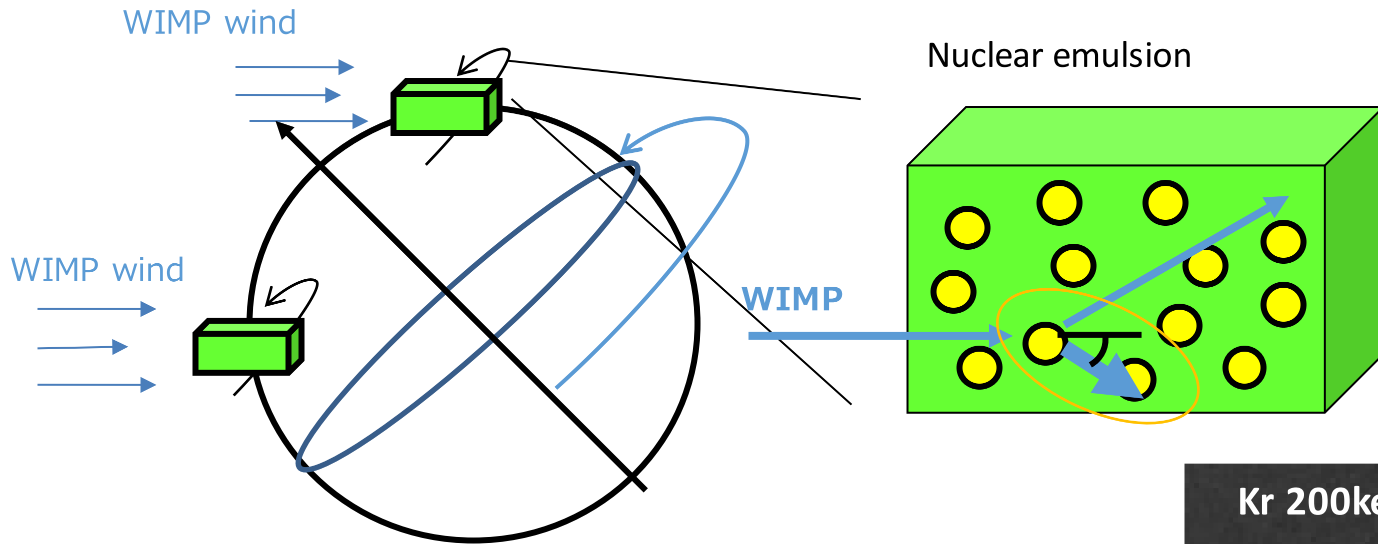
(development and production since 2010)



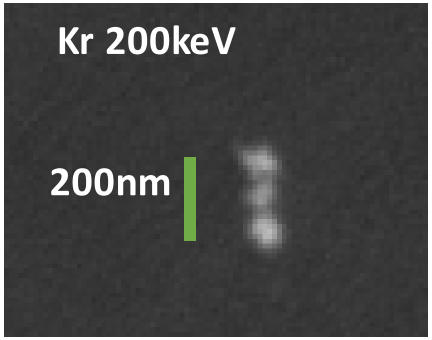
- Emulsion gel tuned for each experiment (Sensitivity, crystal size, and silver halide density)
- Crystal growth of AgBr·I in gelatin solution by double jet method (addition speed, temperature, and mixing speed are controlled)
- Sensitization is done after crystal growth and desalination.
- Emulsion gel for ~3 m^2 emulsion film can be produced in a day.



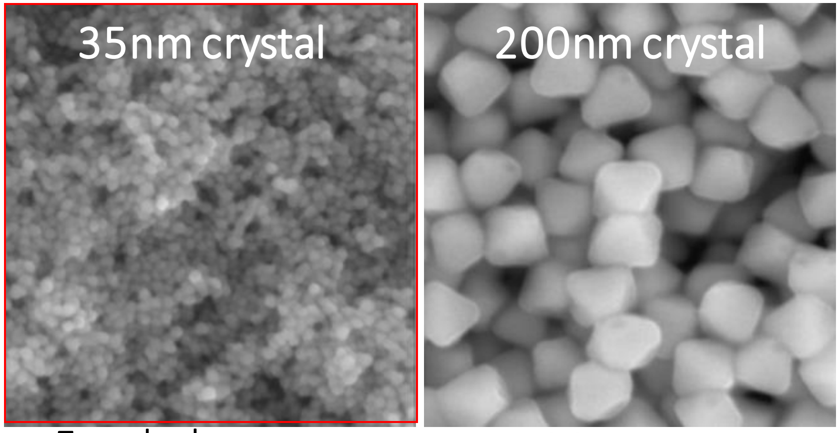
Ultra Fine Grain Emulsion
For Directional Dark Matter Search



Range < 1μm

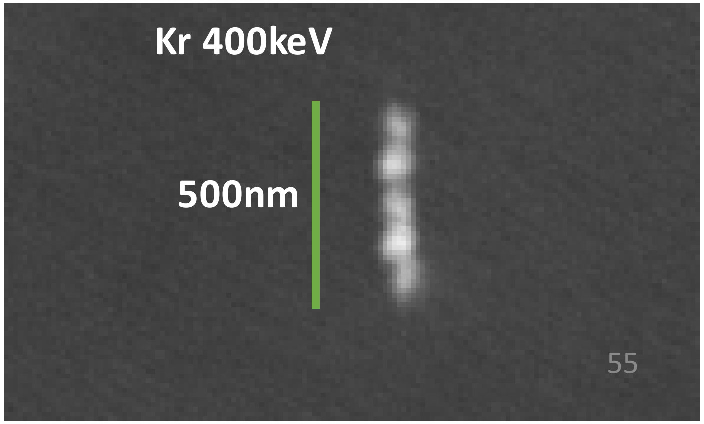


Fine grain crystals produced in Nagoya University



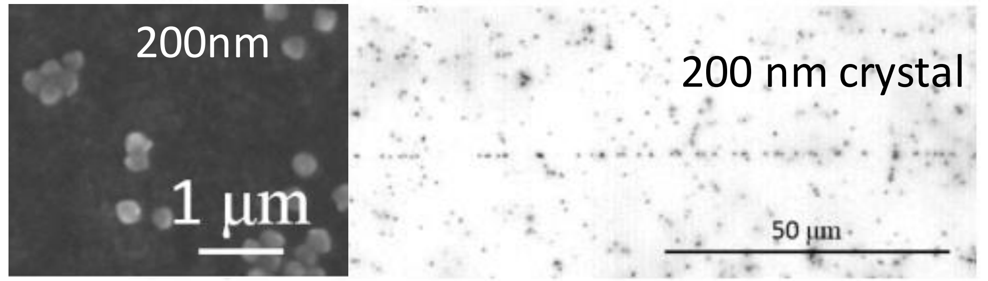
For dark matter

500nm



Development of extra-large crystals for Fast Readout

- To speed up readout speed
- Succeeded to produce 1,200nm crystal! (standard size = 200nm)
  - →Magnification of objective lens can be lower by a factor of 6.
  - →Naively **36 times faster** to read out.
- Enough sensitive to MIP
- The long term stability is not yet satisfactory



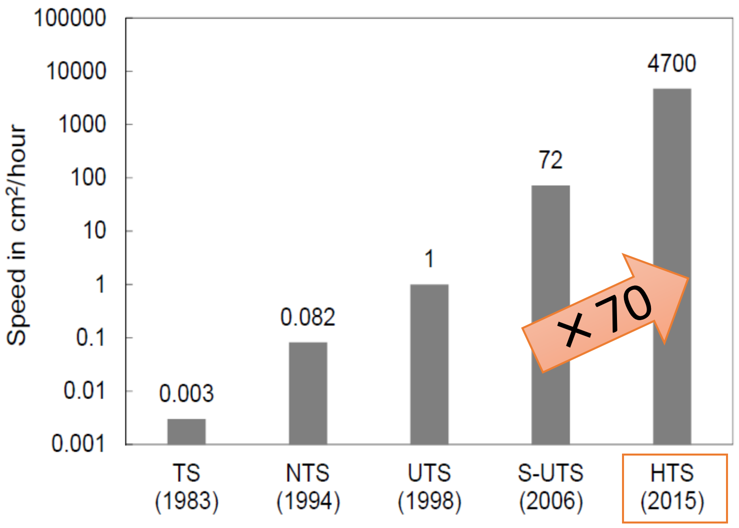
(a) OPERA film

(b) Sample-2

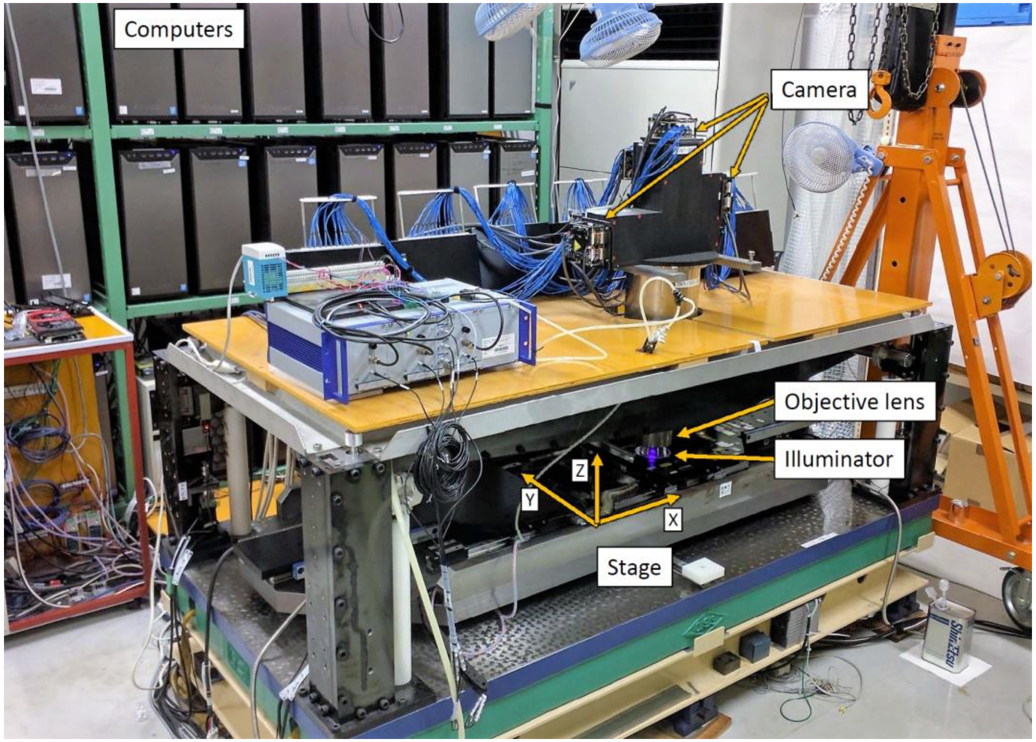
(c) Sample-3

HTS : the fastest emulsion readout system

- HTS has a capability to read-out 1000 m^2
  - with wide field lens, multi-sensors, and GPUs.
  - 20 Giga-Bytes/sec or 2 Peta-Bytes/day



arxiv:1704.06814



GRAINE project

Gamma-**Ra**y **A**stro-**I**mager with **N**uclear **E**mulsion

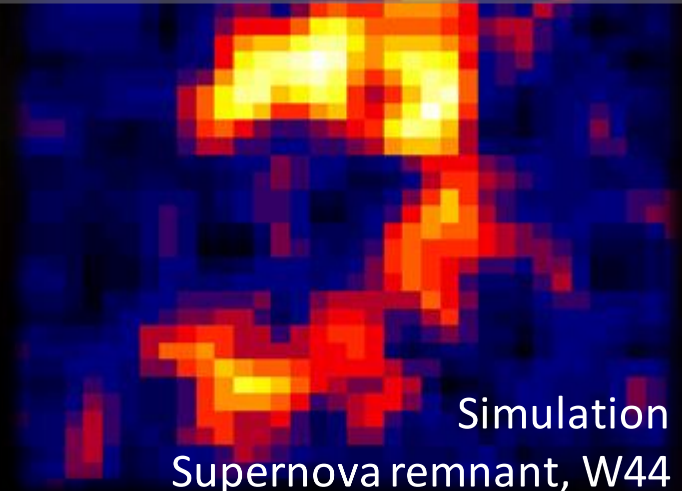
Precise observation of high-energy gamma-rays

Exploring extreme universe by balloon-borne emulsion telescope

PI: S. Aoki (Kobe Univ). Aichi Univ of Education, ISAS/JAXA, Kobe Univ, Nagoya Univ, Okayama Univ of Science

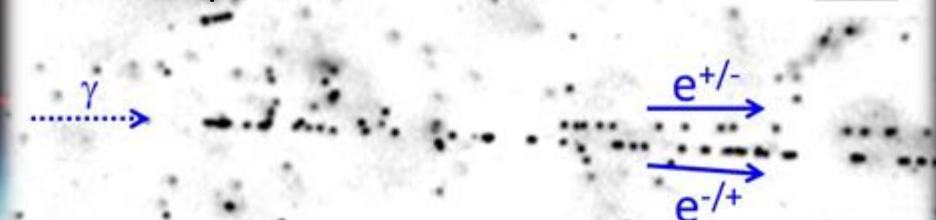
2018 balloon-borne experiment

- Overall demonstration of emulsion telescope
  - Detecting and imaging a γ-ray source, Vela pulsar



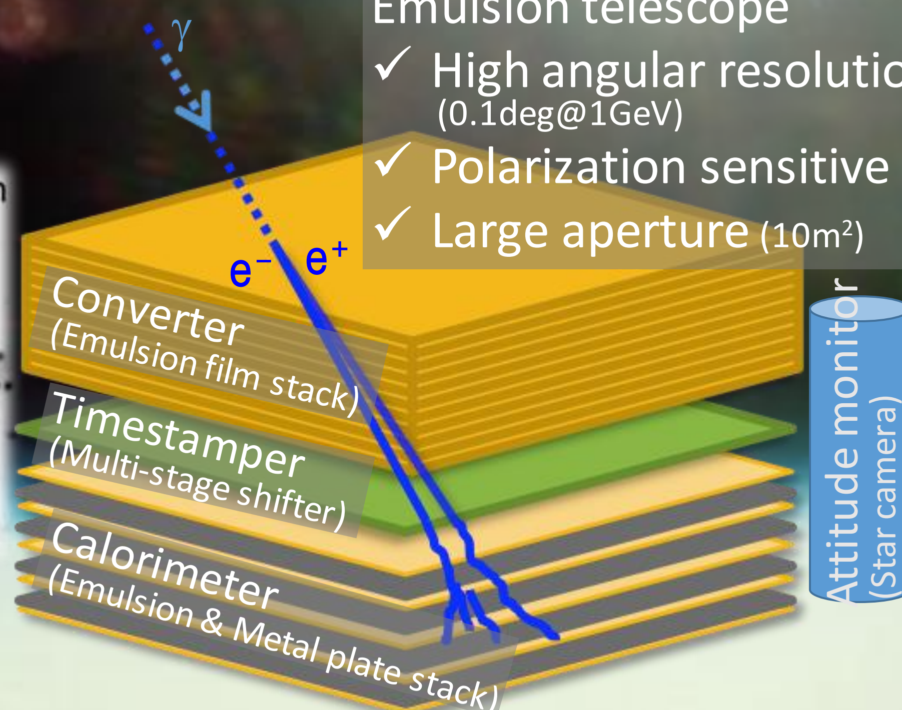
Simulation
Supernova remnant, W44

Microscopic view of an emulsion film



Precisely tracking e-pairs w/i 1μm
suppressed multiple Coulomb scattering
→ High angular resolution
→ Polarization sensitive
+Automatic large-area-analysis technique
+Timestamping technique

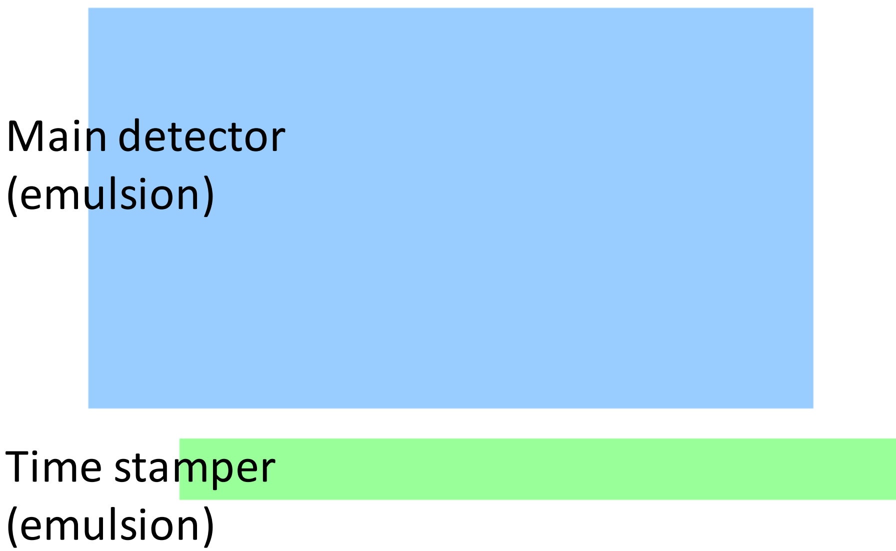
Emulsion telescope
- ✓ High angular resolution (0.1deg@1GeV)
- ✓ Polarization sensitive
- ✓ Large aperture ($10m^2$)

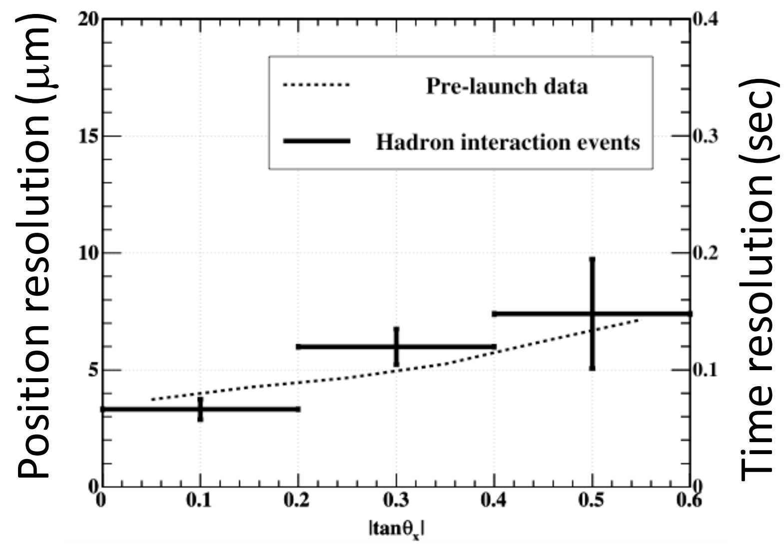


BG photo: GRAINE 2011, JAXA scientific ballooning (taken by NHK)

Time stamping by emulsion

- Get time stamp only with emulsion detectors
- Time resolution of 0.1 sec achieved by GRAINE gamma ray telescope





Track slope

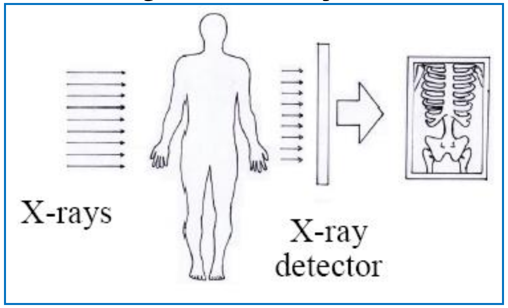
Position difference between two module gives time stamp as

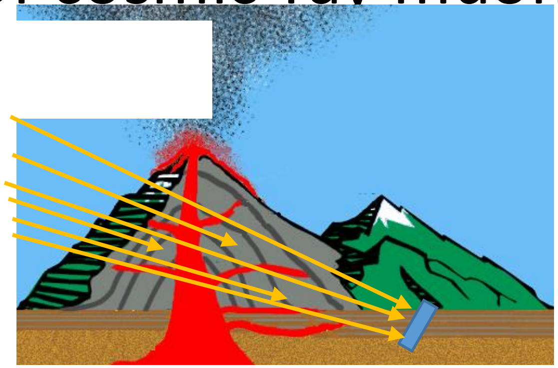
$$t = \frac{\delta x}{v}$$

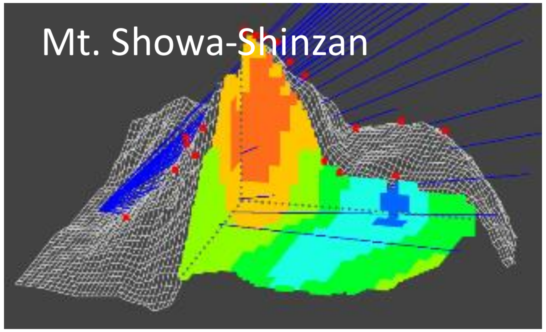
Time resolution of 0.1 sec achieved (v = 50 μm/s)

Muon radiography with emulsion

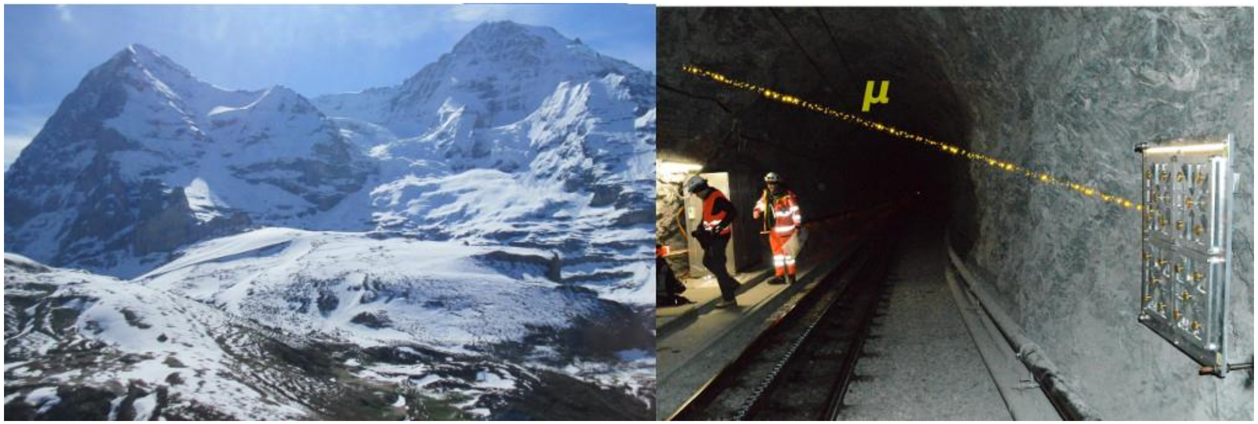
- Measurement of inner structure of large object by means of cosmic-ray muons.

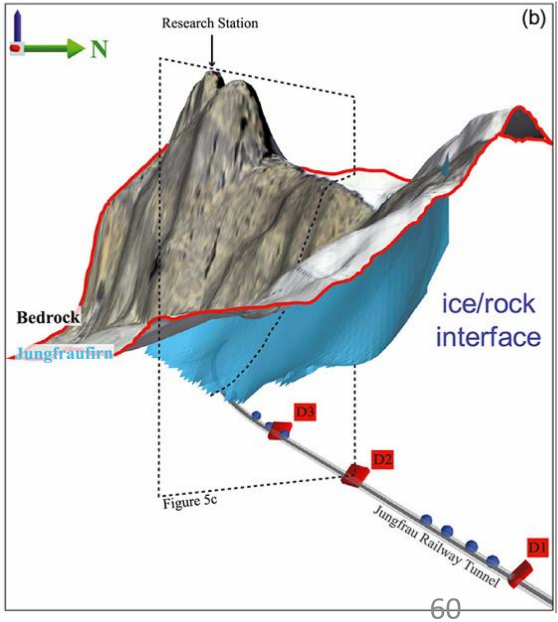






Tomography of glaciers in Swiss Alps





Summary 2

- Emulsion detectors are no more an analogue device, but a digital high precision detector.
- Wide range of applications, where a high resolution and/or large detector surface are required.
- An large flexibility and capability to develop new.

Charm production cross section results

$$\frac{d^2\sigma}{dx_F dp_T^2} \propto (1-|x_F|)^n \exp(-bp_T^2)$$

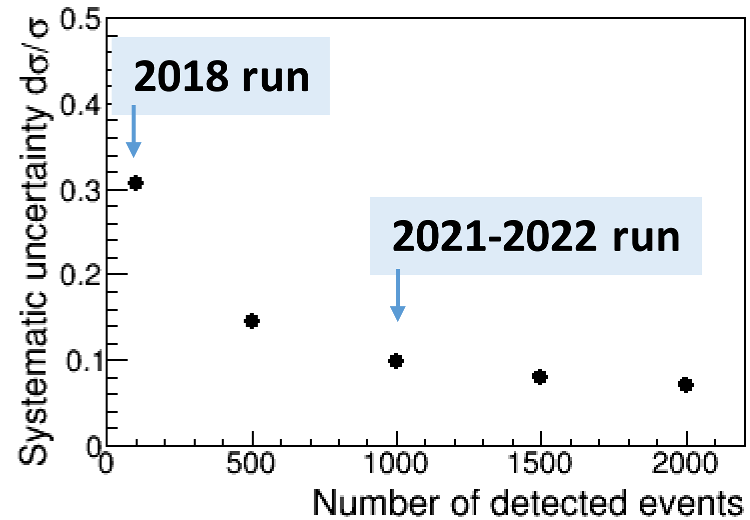
Experiment	Beam type / energy (GeV)	$\sigma(D_s)$ (μb/nucl)	$\sigma(D^\pm)$ (μb/nucl)	$\sigma(D^0)$ (μb/nucl)	$\sigma(\Lambda_c)$ (μb/nucl)	x_F and p_T dependence: *n* and *b* $(GeV/c)^{-2}$
HERA-B	p / 920	18.5 ± 7.6 (~11 events)	20.2 ± 3.7	48.7 ± 8.1	-	$n(D^0, D^+) = 7.5 \pm 3.2$
E653	p / 800	-	38 ± 17	38 ± 13		$n(D^0, D^+) = 6.9^{+1.9}_{-1.8}$ $b(D^0, D^+) = 0.84^{+0.10}_{-0.08}$
E743 (LEBC-MPS)	p / 800	-	26 ± 8	22 ± 11		n(D) = 8.6 ± 2.0 b(D) = 0.8 ± 0.2
E781 (SELEX)	Σ^- (sdd) / 600					~350 D_s^- events, ~130 D_s^+ events ($x_F > 0.15$) $n(D_s^-) = 4.1 \pm 0.3$ (leading effect) $n(D_s^+) = 7.4 \pm 1.0$
NA27	p / 400		12 ± 2	18 ± 3		
NA16	p / 360		5 ± 2	10 ± 6		
WA92	π / 350	1.3 ± 0.4		8 ± 1		
E769	p / 250	1.6 ± 0.8	3 ± 1	6 ± 2		320 ± 26 events ($D^\pm, D^0, D_s^\pm$) $n(D^\pm, D^0, D_s^\pm) = 6.1 \pm 0.7$ $b(D^\pm, D^0, D_s^\pm) = 1.08 \pm 0.09$
E769	$\pi^\pm$ / 250	2.1 ± 0.4		9 ± 1		1665 ± 54 events ($D^\pm, D^0, D_s^\pm$) $n(D^\pm, D^0, D_s^\pm) = 4.03 \pm 0.18$ $b(D^\pm, D^0, D_s^\pm) = 1.08 \pm 0.05$
NA32	π / 230	1.5 ± 0.5		7 ± 1		

(Results from LHCb at $\sqrt{s}$ = 7, 8 or 13 TeV are not included since the energies differ too much)

No experimental result effectively constraining the D_s differential cross section at the desired level or consequently the ν_τ production

Expected performance

Run	Beam time	Emulsion surface	Systematic uncertainty for the cross section measurement
2018 pilot run	1 week	48 m^2 (30 modules)	30% → Re-evaluation of the DONUT result
2021 physics run	2 weeks	545 m^2 (338 modules)	10% → Input for future measurement
2022 physics run	2 weeks		



Uncertainties in the cross section measurement

	DONuT	Systematic uncertainty after DsTau outcome	Future ν_τ measurement with DsTau outcome
ν_τ statistics	0.33		0.02
D_s differential cross section (x_F dependence)	>0.50	0.10	0.10
Charm production cross section	0.17	0.05	0.05
Decay branching ratio ($D_s \rightarrow \tau$)	0.23 (0.04 at present)		
Target atomic mass effects	0.14		

Aiming at ~10% precision to look for new physics effects in ν_τ -nucleon CC interactions

Efficiency of $D_s \rightarrow \tau \rightarrow X$ detection

Selection	Total efficiency (%)
(1) Flight length of $D_s \geq 2$ emulsion layers	77
(2) Flight length of $\tau \geq 2$ layers & $\Delta\theta(D_s \rightarrow \tau) \geq 2$ mrad	43
(3) Flight length of $D_s < 5$ mm & flight length of $\tau < 5$ mm	31
(4) $\Delta\theta(\tau) \geq 15$mrad	28
(5) Pair charm: 0.1 mm < flight length < 5 mm (charged decays with $\Delta\theta > 15$ mrad or neutral decays)	20