

The background of the slide is a grayscale image of a particle detector track. It shows a dense, horizontal band of activity, likely a muon track, with a central, darker line and a surrounding cloud of smaller, fainter tracks. The overall appearance is that of a complex, multi-layered detector structure.

# Full reconstruction of a neutrino event in ICARUS

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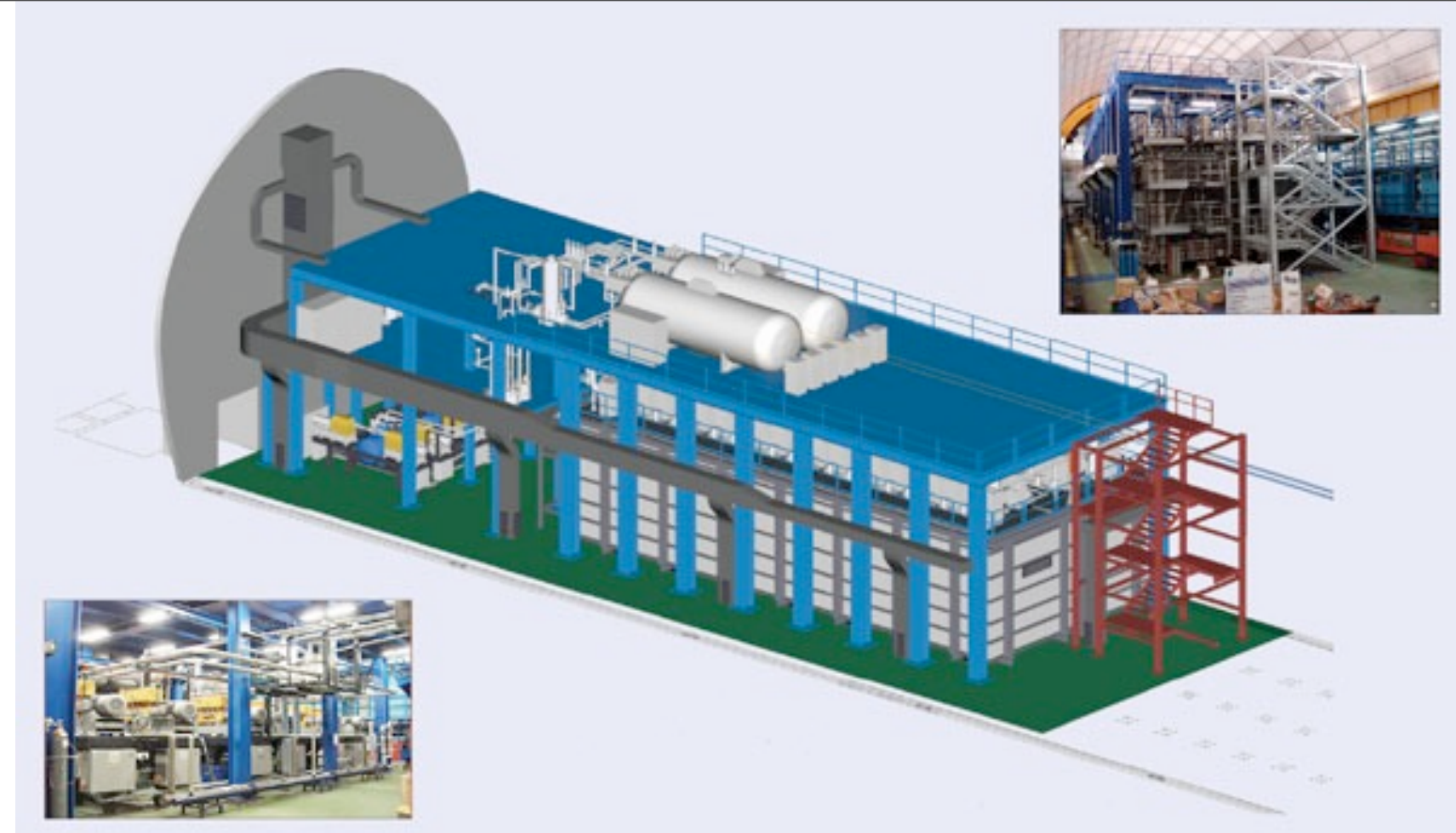
Oct 3<sup>rd</sup> 2014

Gran Sasso hands-on summer institute



# What is ICARUS?

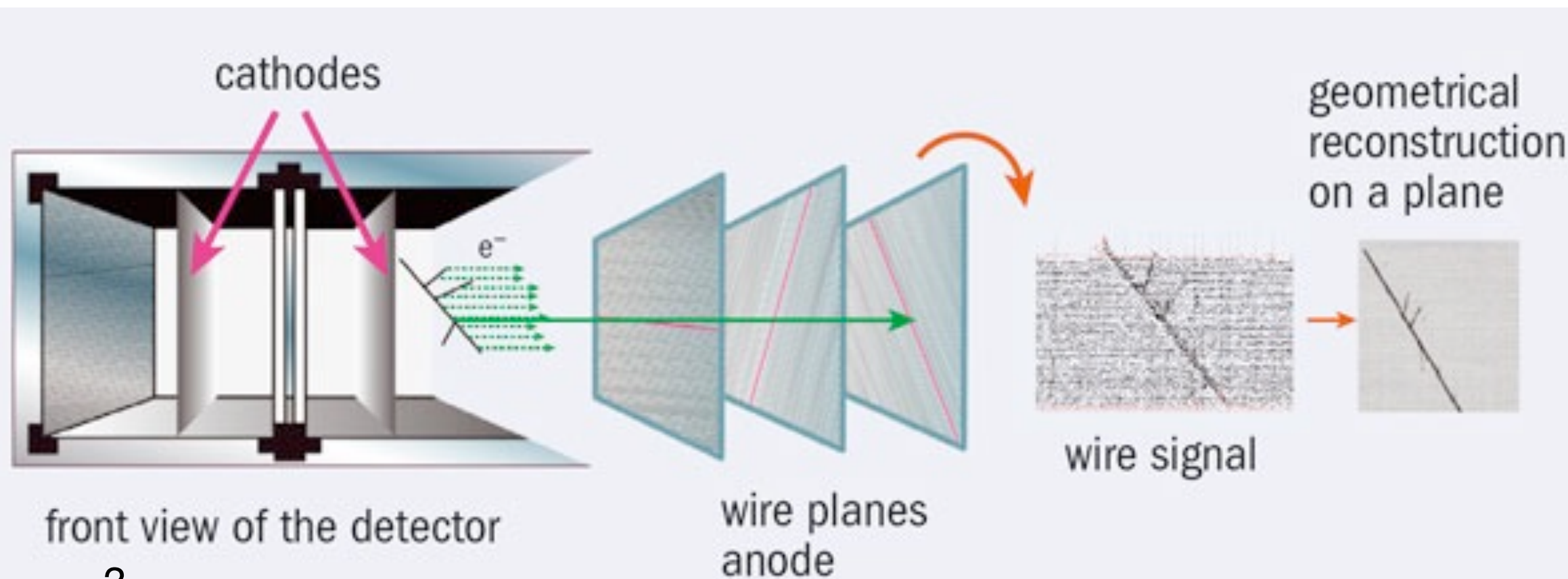
- Neutrino experiment
  - Neutrino oscillations from CNGS  $\nu_\mu$  beam
  - Sterile neutrinos (LSND anomaly)
  - Atmospheric neutrinos
  - Proton decay
  - Working from Oct. 1<sup>st</sup> 2010 to Dec. 3<sup>rd</sup> 2012
- LAr TPC with 476 ton of active mass
  - Good spatial resolution  $\sim 1 \text{ mm}^3$
  - Excellent calorimetry
  - Particle identification
  - Self-triggering
  - Ultra-high LAr purity



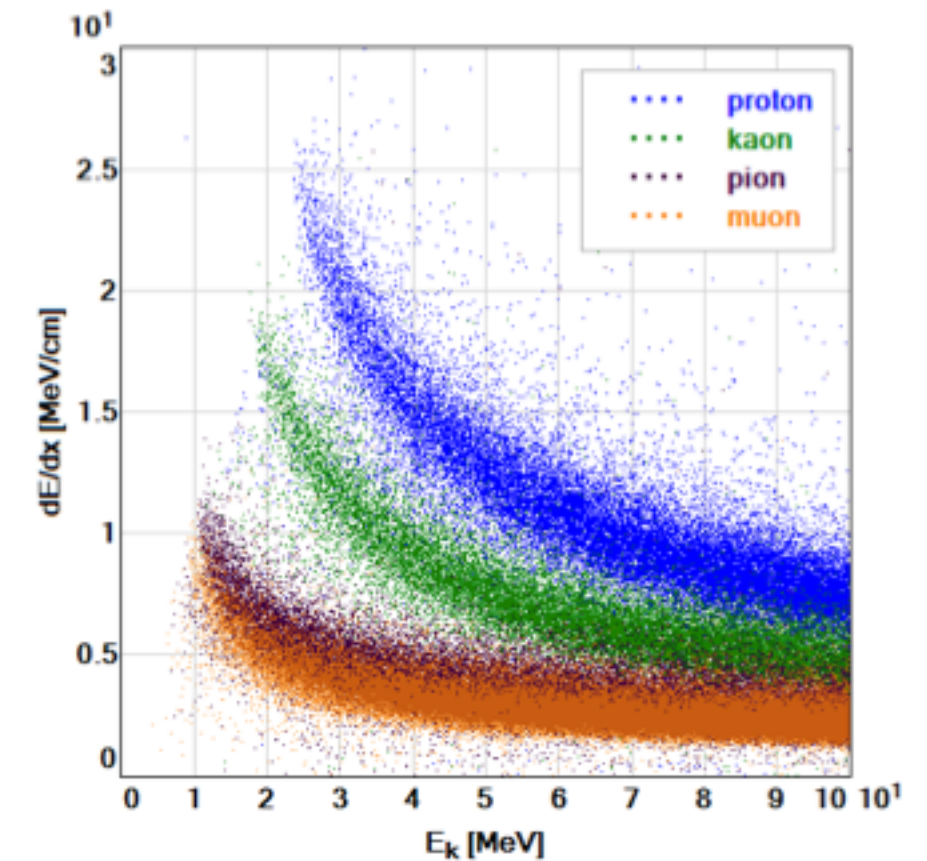


# How does ICARUS work?

- 2 identical modules
- 2 TPCs per module
- Charged particles ionize the LAr leaving a trail of electrons that drift to the anode
- 3 wire planes (  $0^\circ$ ,  $+60^\circ$ ,  $-60^\circ$  ) allow 3D reconstruction as well as calorimetry
- Particle identification through  $dE/dx$  vs residual particle range



3



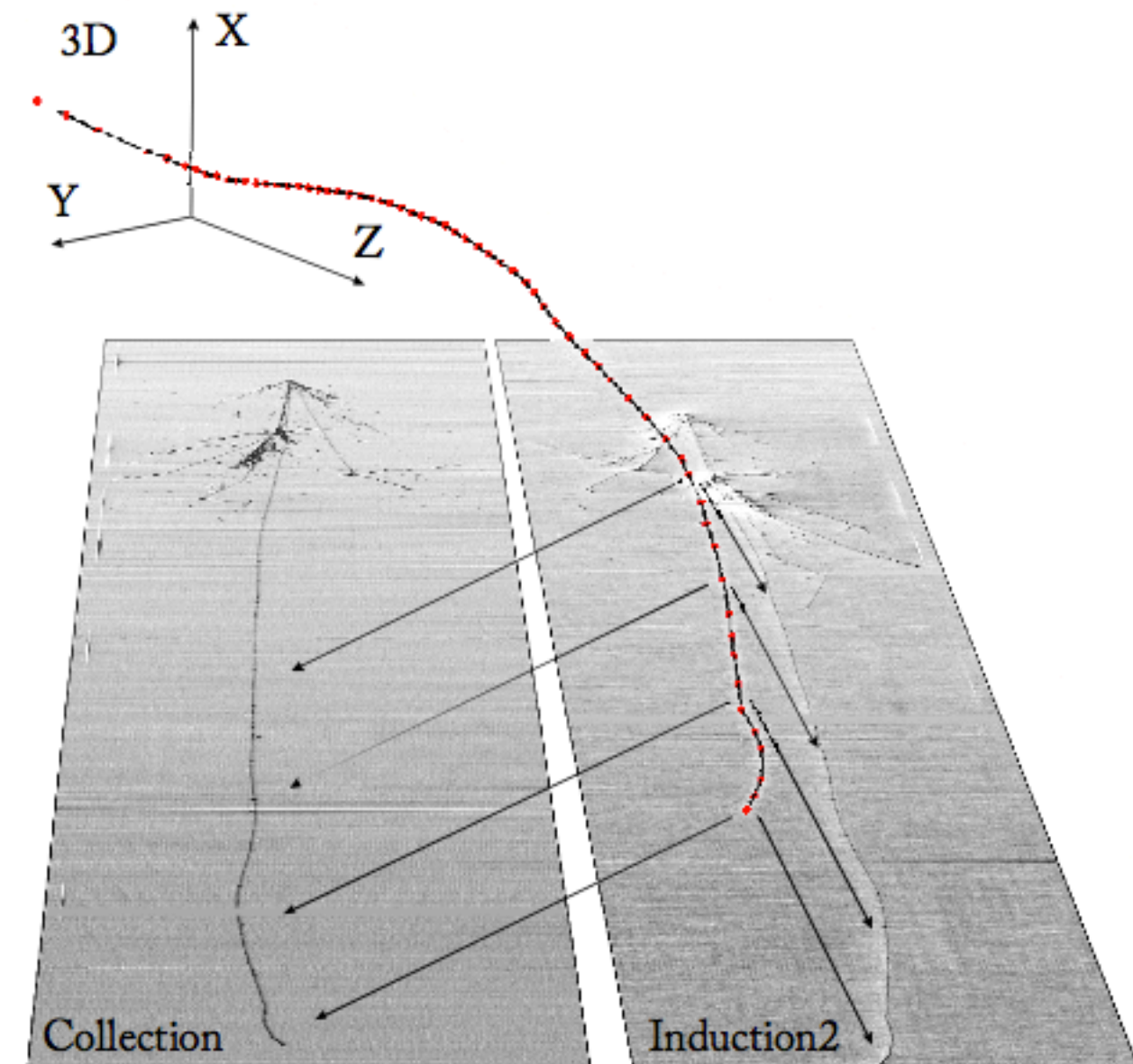
# The event reconstruction I

- Hit finding and fitting
- Energy calculation
  - Quenching correction  $\sim 0.64$
  - Electron lifetime correction (depends on the LAr purity)
- Composition of the 3D view
  - Hit matching (between Induction2 and Collection)

$$\frac{dQ}{dx} = \frac{Q_0 \frac{dE}{dx}}{1 + k_B \frac{dE}{dx}}$$

$$Q = Q_0 \cdot e^{-t/\tau}$$

$$\tau(\text{ms}) = \frac{0.3}{[O_2](\text{ppb})}$$



# The event reconstruction II

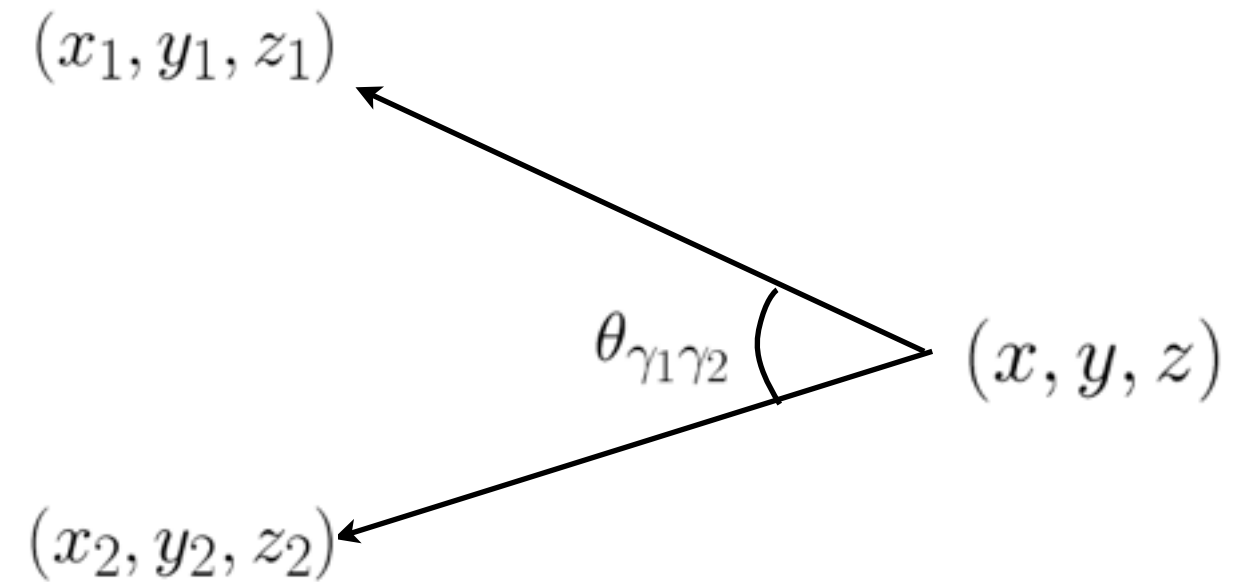
- Absolute particles momenta is obtained from the relativistic equation
- Momentum direction is extracted from the first segment of the track from the primary vertex
- Multiple scattering measurements of the muon allow us to compute its momentum
- The total momentum is computed as the sum  $|\sum_k \vec{p}_k|$
- Transverse momentum is also calculated
- The neutrino energy is obtained as

$$E_\nu = E_\mu + C^{\text{MC}} E_{\text{non-leptons}}$$

- Gamma-electron separation is performed based on dE/dx during the first ~2.5 cm of the cascade
- The  $\pi^0$  invariant mass is calculated from the photons' energy and the angle between them

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$$p = \sqrt{(E_k + m)^2 - m^2}$$



$$m_{\pi^0} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1 - \cos \theta_{\gamma_1\gamma_2})}$$



**Run 9722**

**Event number 284**

**Date: Sep 20th of 2010 at 20:08:32**

**Electron life time = 3.062 ms**

**2<sup>nd</sup> module, left TPC**

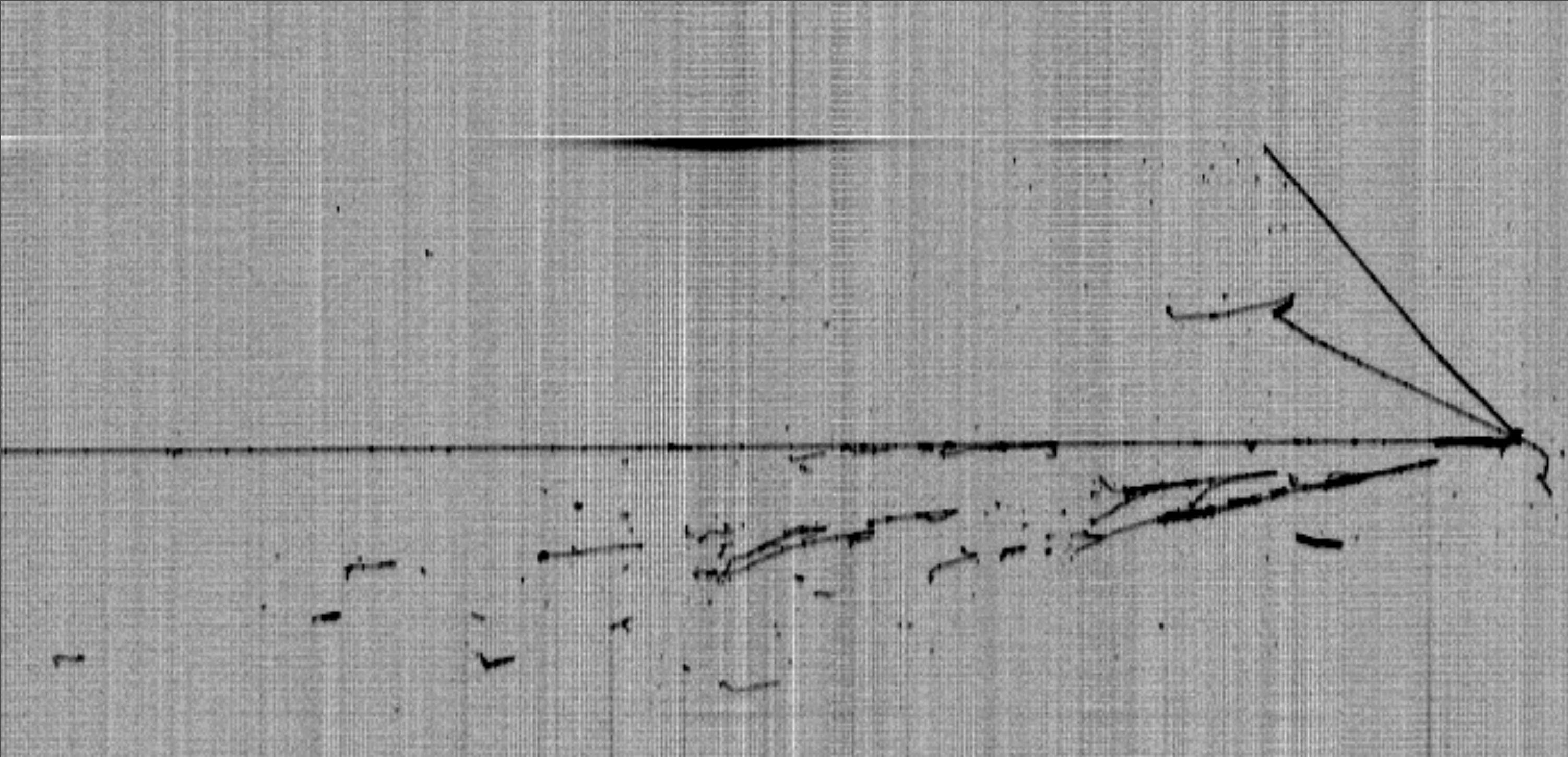
**Induction 2**

**CC**

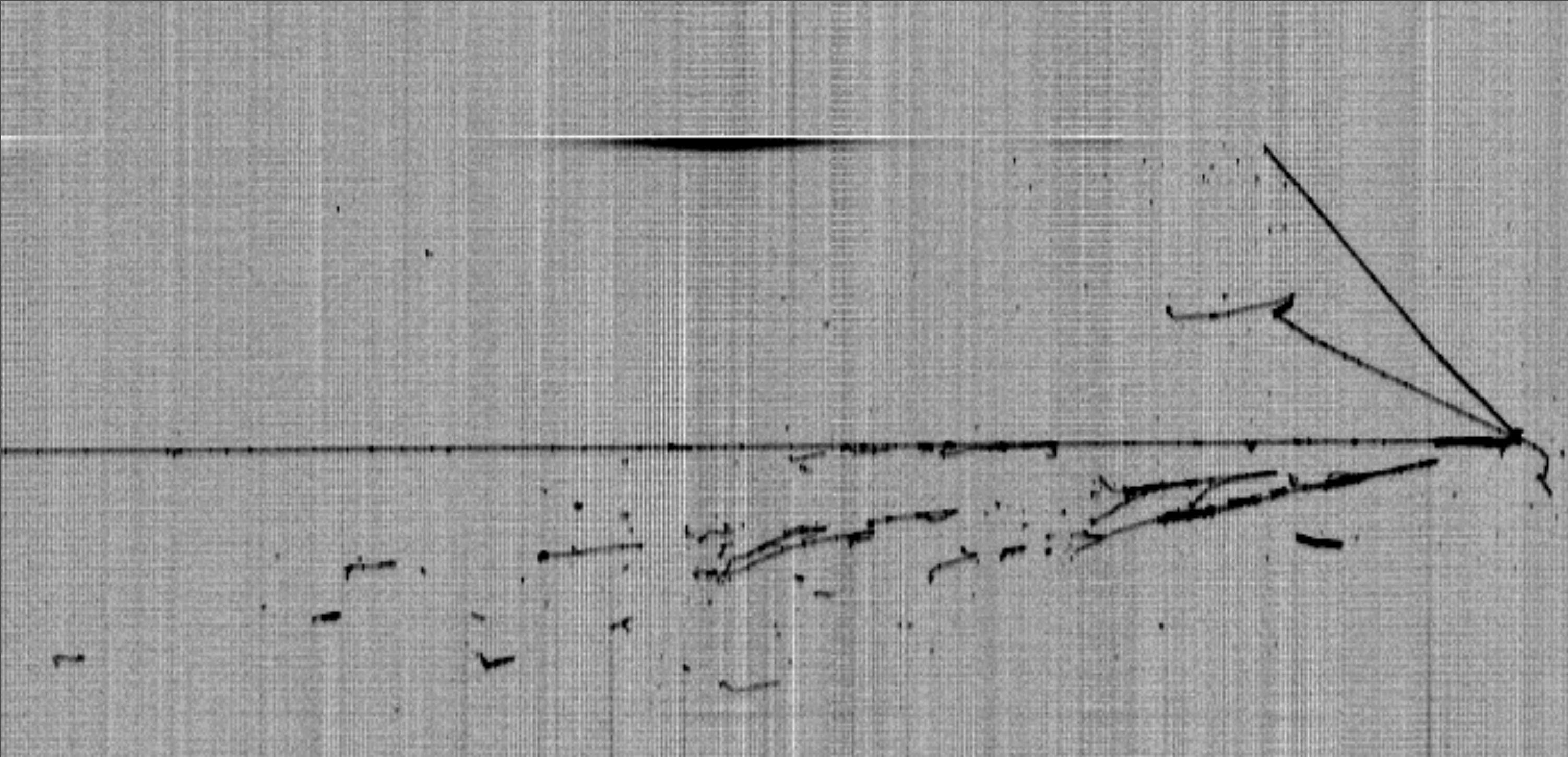
**Induction 1**

**Collection**






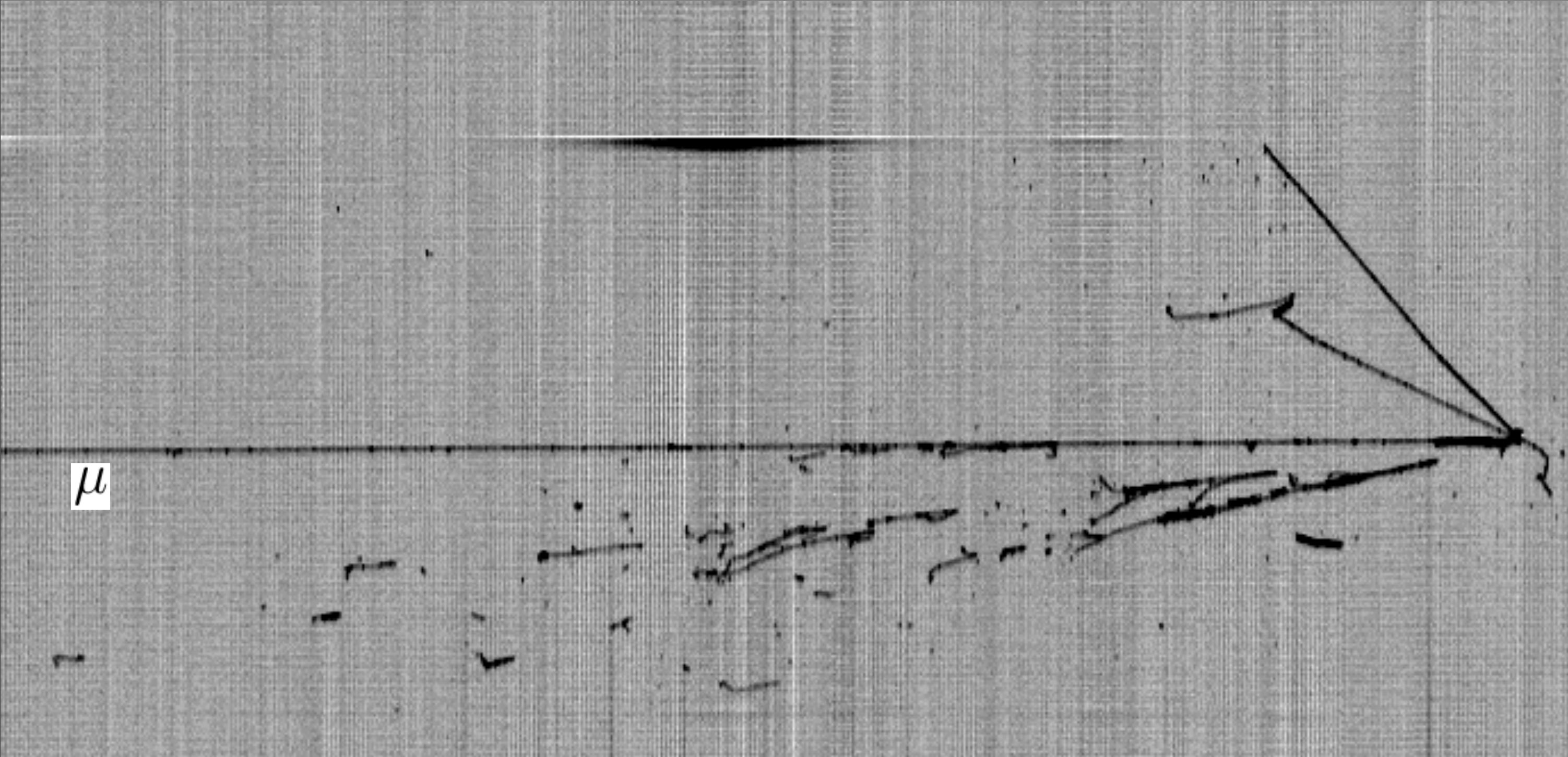




$\nu_{\mu}$





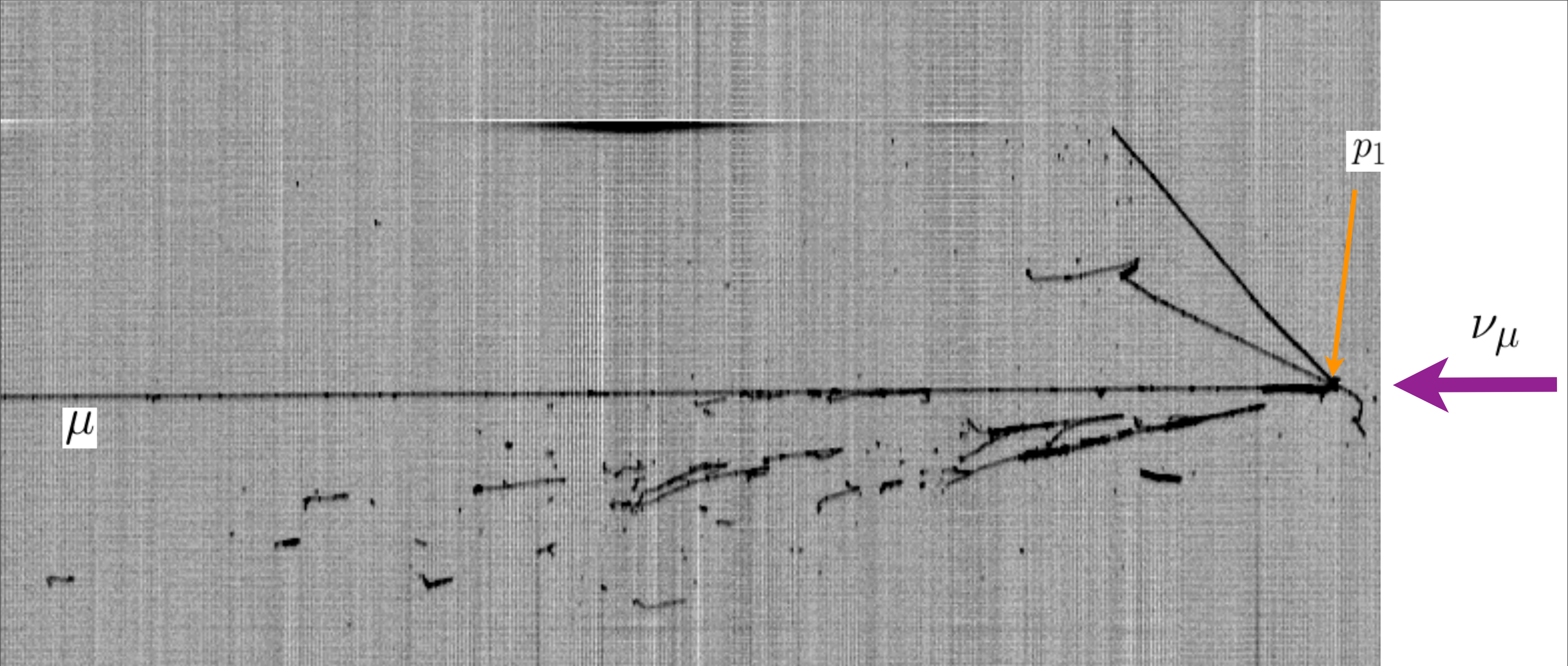


$\mu$

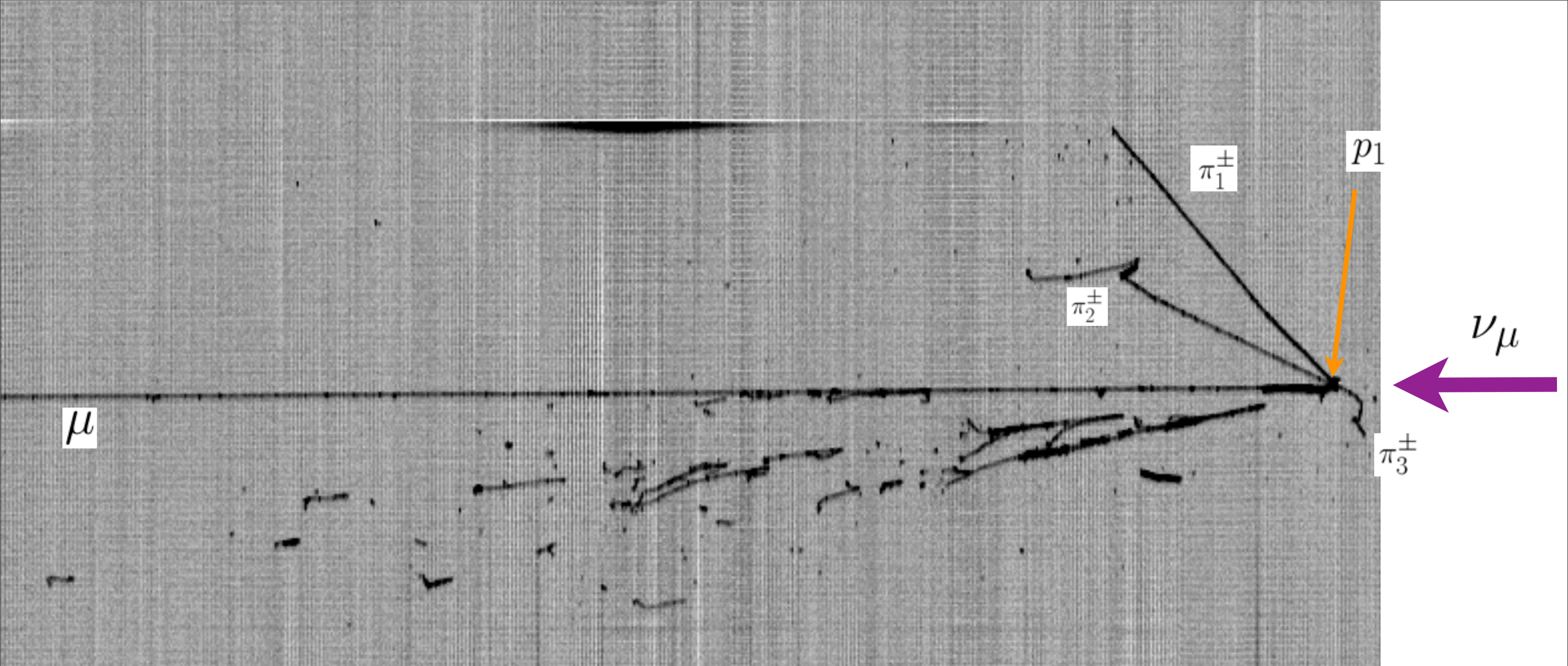
$\nu_\mu$



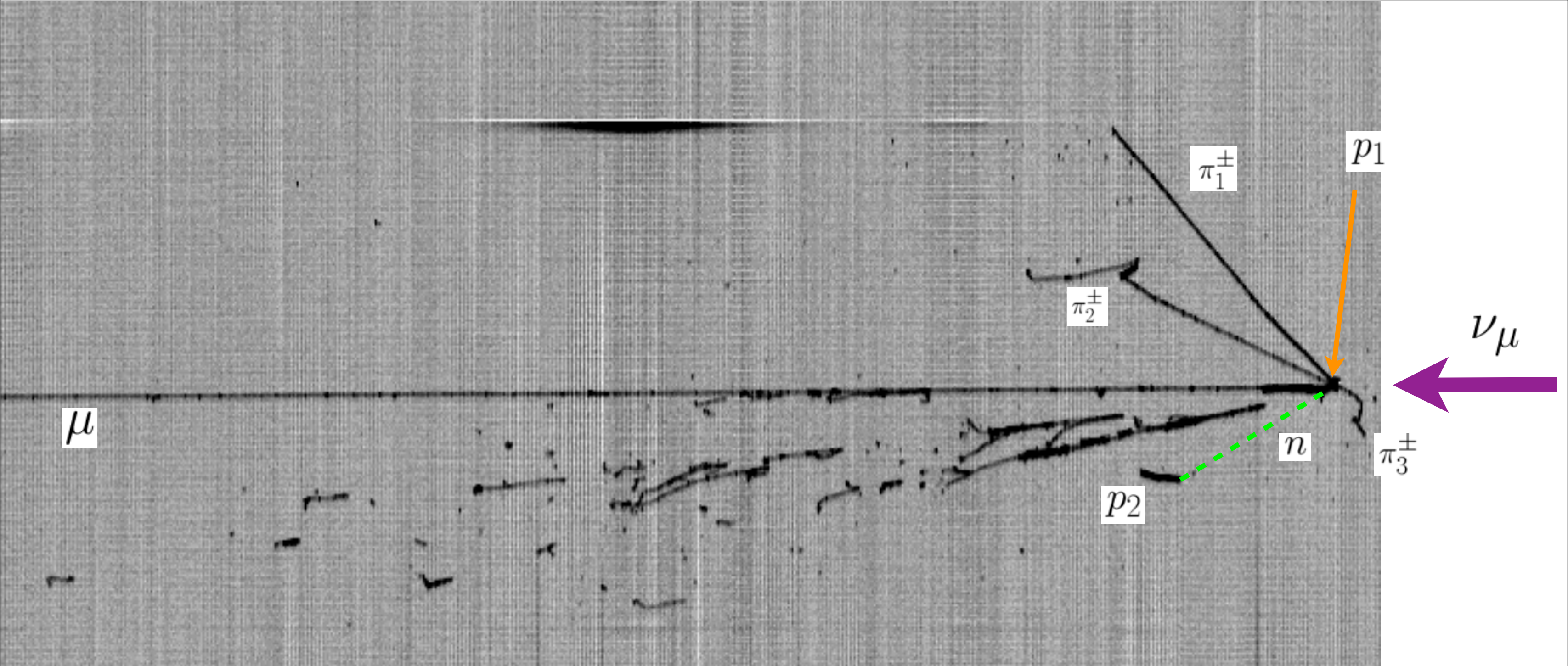




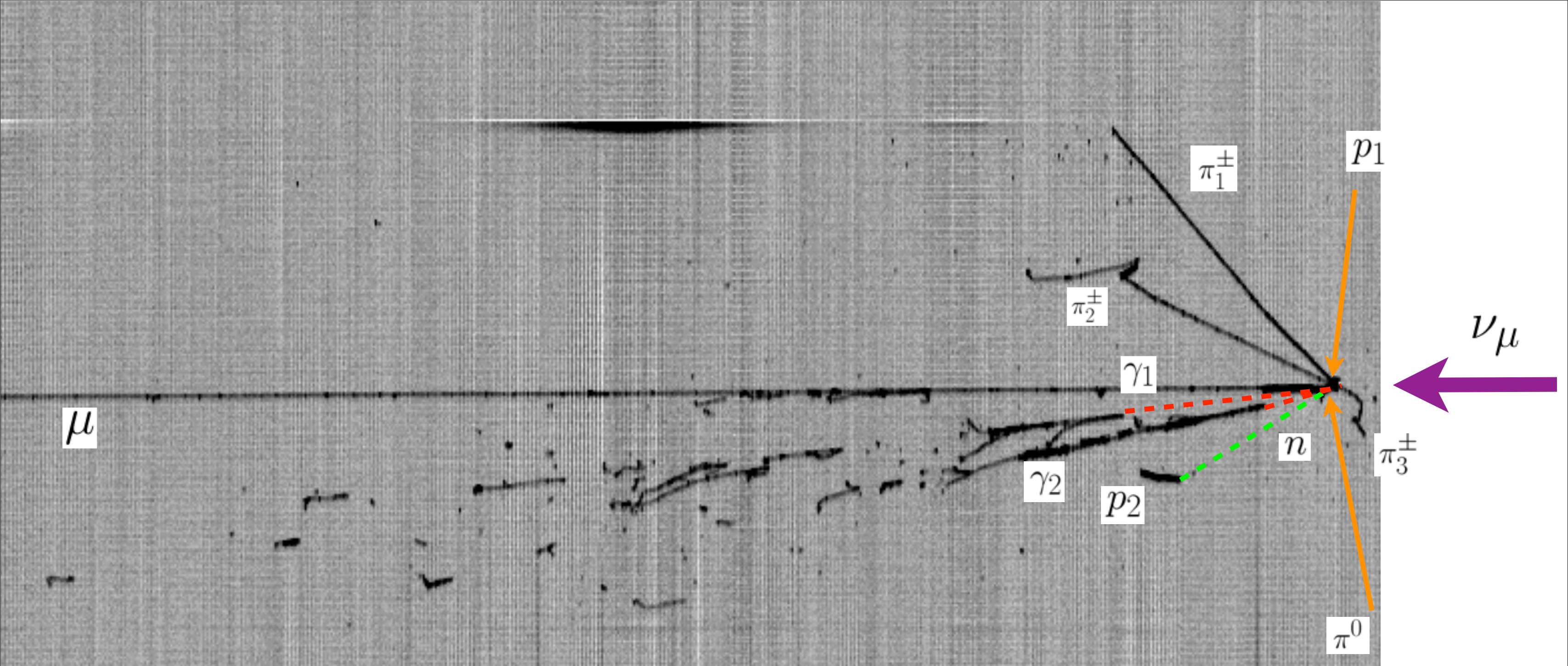






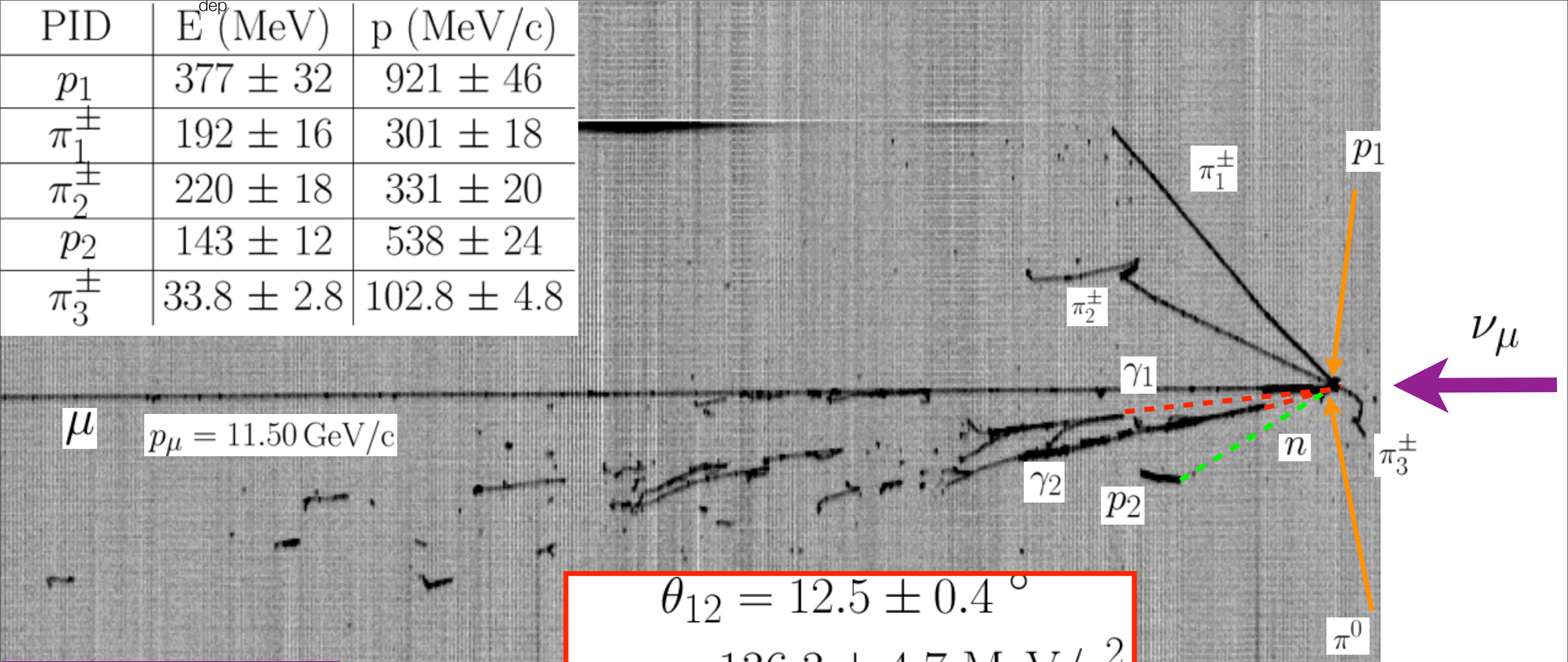








PID	$E$ (MeV)	$p$ (MeV/c)
$p_1$	$377 \pm 32$	$921 \pm 46$
$\pi_1^\pm$	$192 \pm 16$	$301 \pm 18$
$\pi_2^\pm$	$220 \pm 18$	$331 \pm 20$
$p_2$	$143 \pm 12$	$538 \pm 24$
$\pi_3^\pm$	$33.8 \pm 2.8$	$102.8 \pm 4.8$



$\mu$   $p_\mu = 11.50 \text{ GeV}/c$

$$\theta_{12} = 12.5 \pm 0.4^\circ$$

$$m_{\pi^0} = 136.3 \pm 4.7 \text{ MeV}/c^2$$

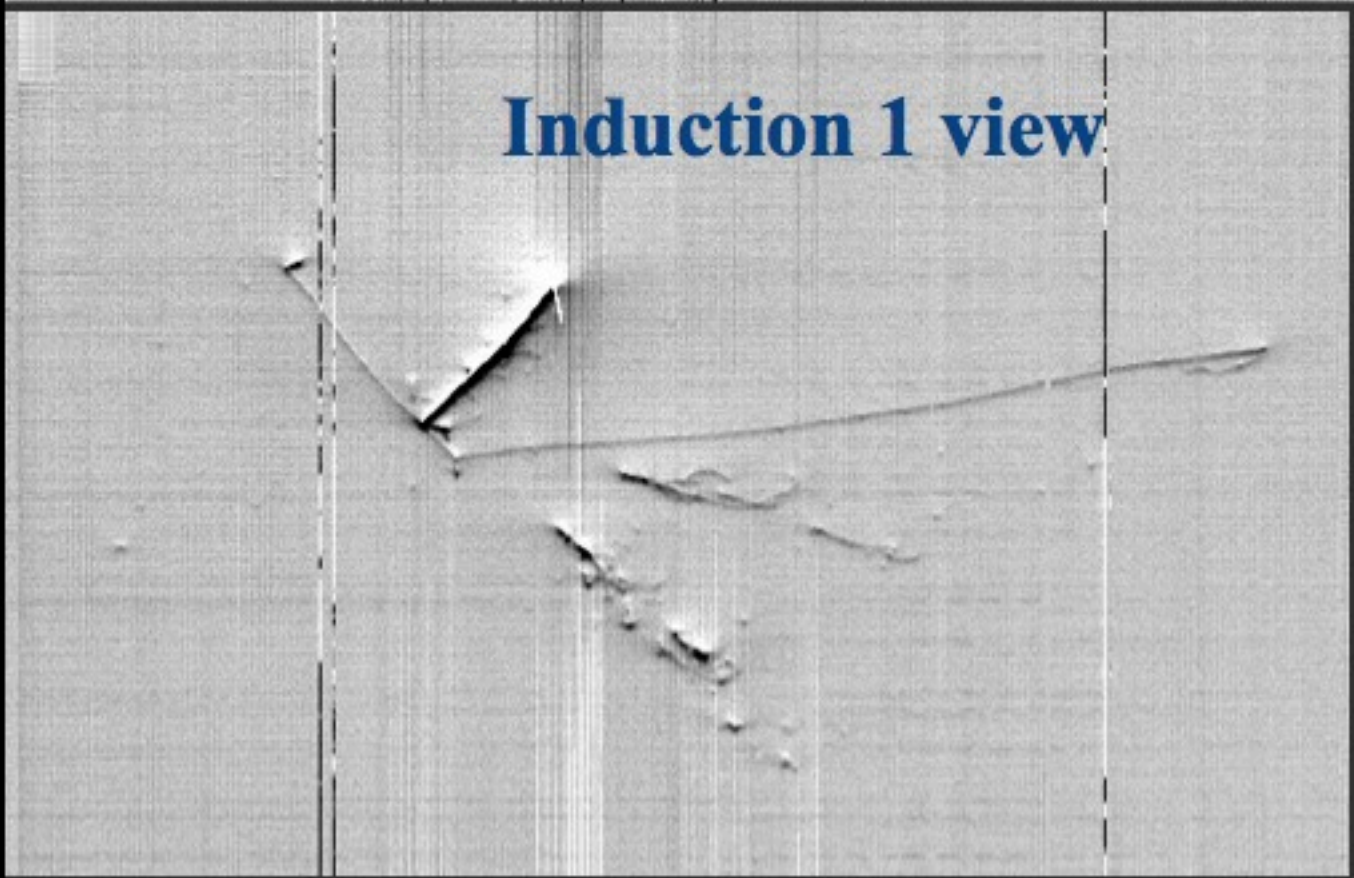
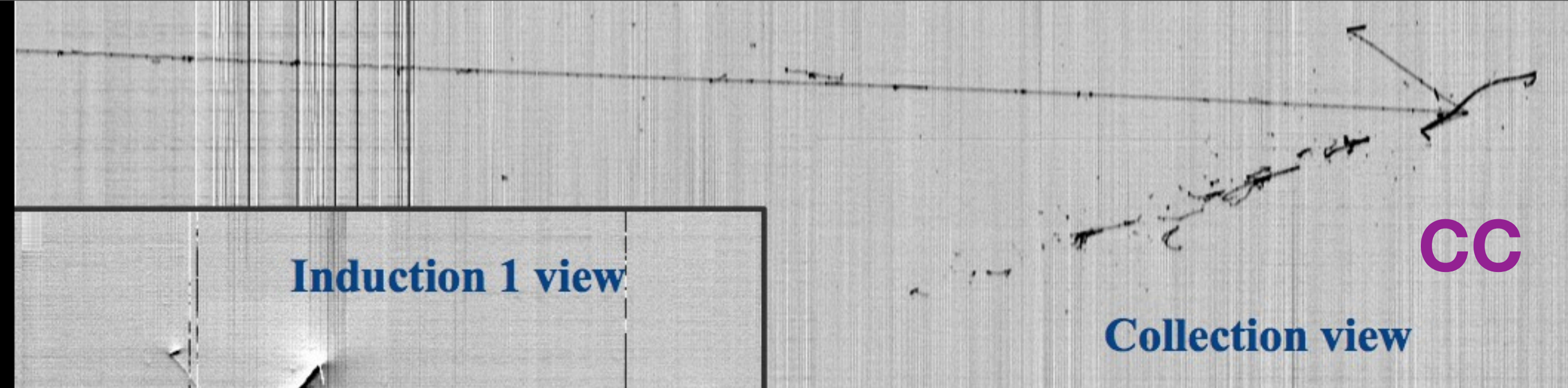
$$p_T = 497.6 \text{ MeV}/c$$

$$p = 13.69 \text{ GeV}/c$$

$$E_\nu \approx 15.09 \text{ GeV}$$

$E_{\gamma_1} = 698 \pm 59 \text{ MeV}$	$d_{\gamma_1} = 339 \text{ mm}$	$\frac{dE}{dx}_{\gamma_1} = 4.32 \text{ MeV}/\text{cm}$
$E_{\gamma_2} = 565 \pm 48 \text{ MeV}$	$d_{\gamma_2} = 117 \text{ mm}$	$\frac{dE}{dx}_{\gamma_2} = 6.19 \text{ MeV}/\text{cm}$



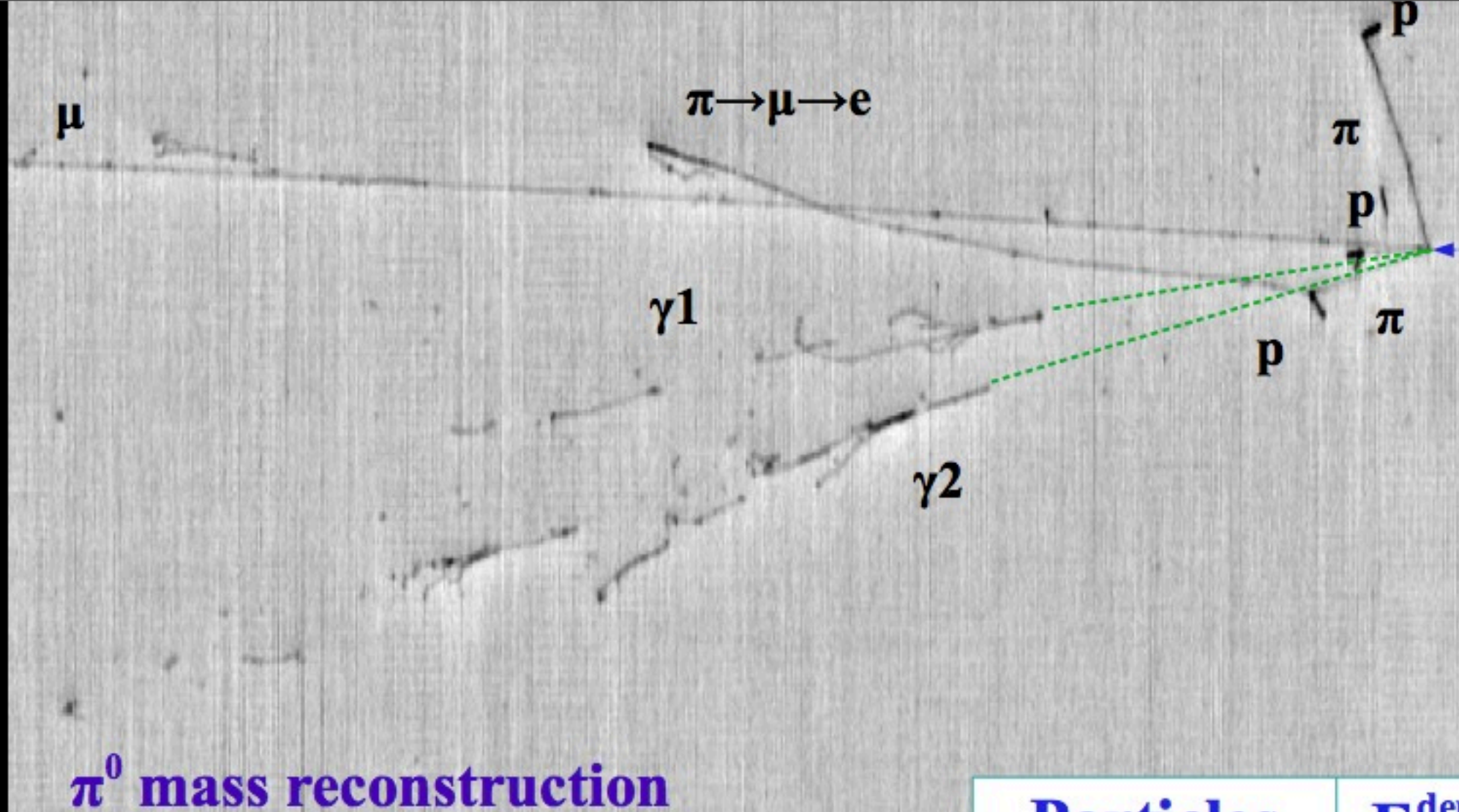


**Run 9831 – Event 1387**

- › **23-Oct-2010**
- › **Primary vertex (cm) :**  
**(429.43, 108.41, -5268.36)**
- › **Second module (East)**
- › **Electron lifetime = 2.644 ms**







$v_{\mu}$

$P_T = 463 \text{ MeV}/c$   
 $P_{tot} = 9.8 \text{ GeV}/c$   
 $E_v^{rec} = 10.7 \text{ GeV}$

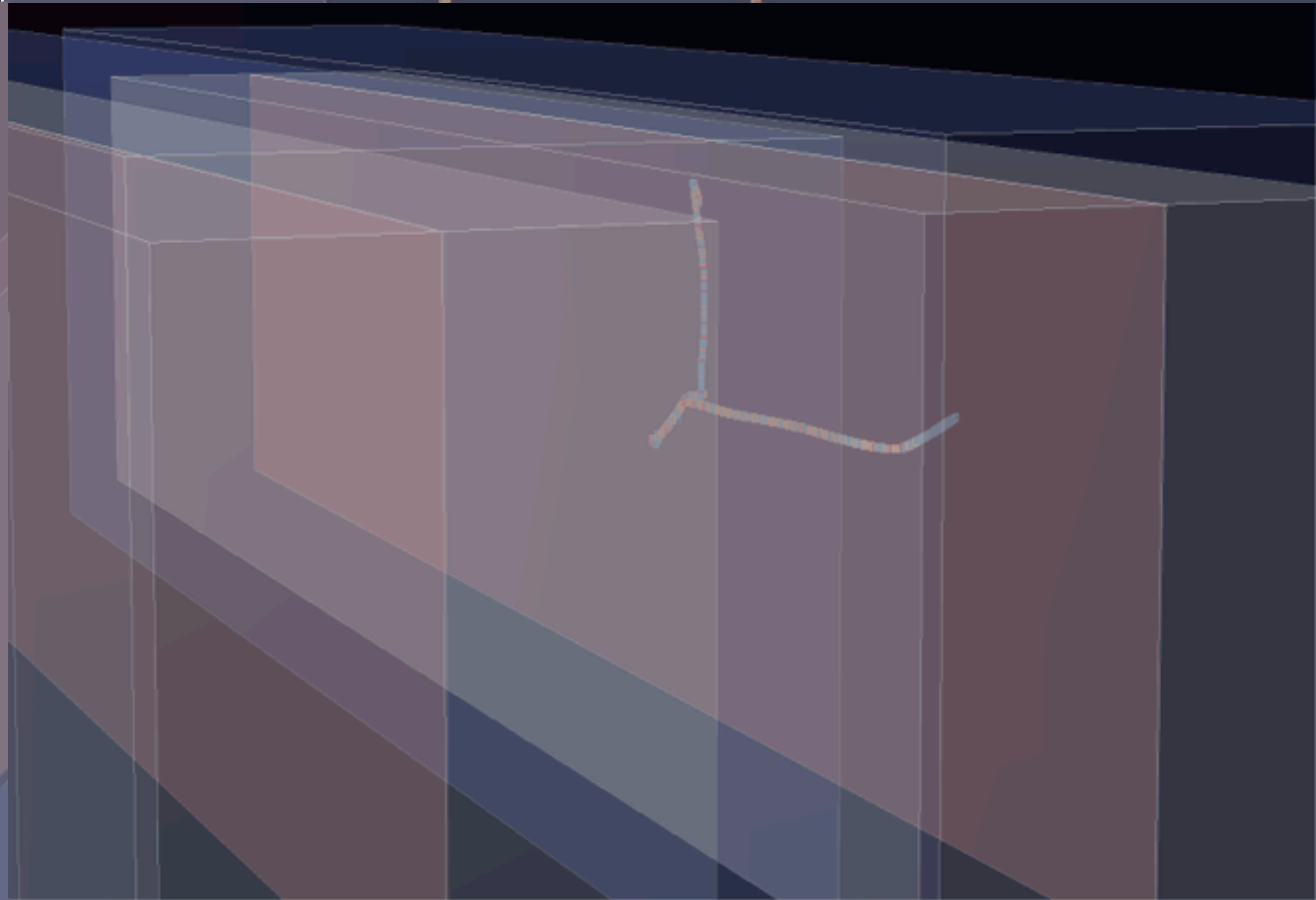
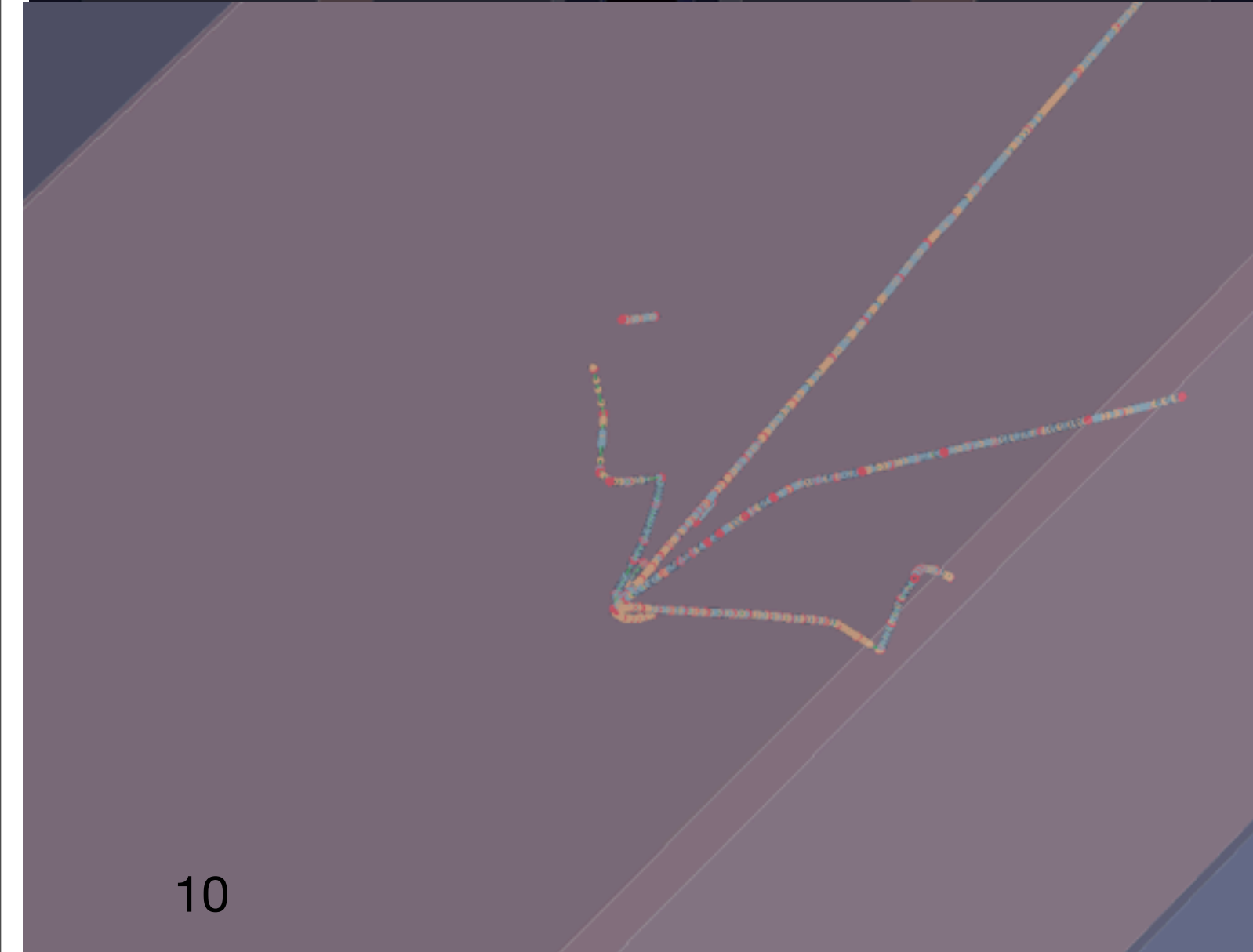
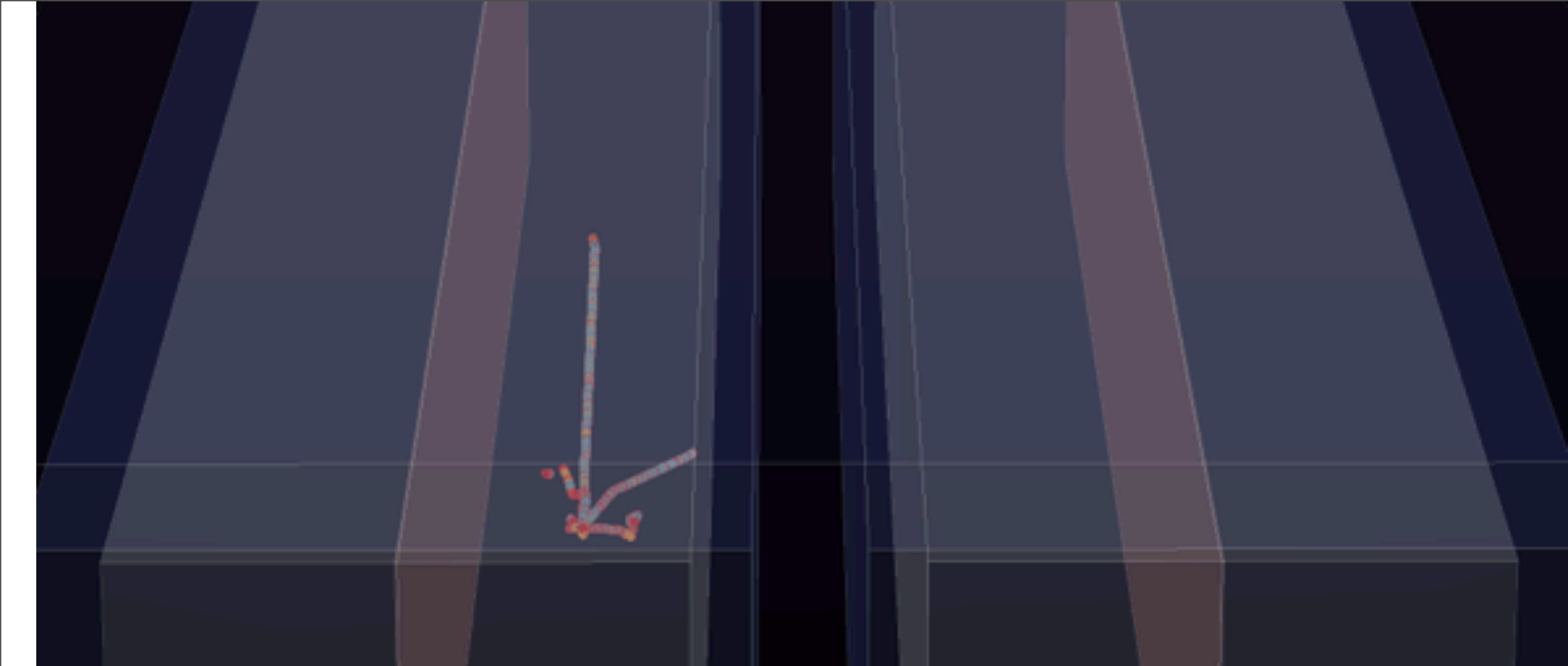
### $\pi^0$ mass reconstruction

- ›  $E_{\gamma 1} = 329 \pm 21 \text{ MeV}$
- ›  $E_{\gamma 2} = 705 \pm 32 \text{ MeV}$
- › Conversion distances : 49 cm , 58 cm
- ›  $dE/dx : 5.8 \text{ MeV}/\text{cm} , 5.4 \text{ MeV}/\text{cm}$
- ›  $\theta_{12} = 15.8^\circ \pm 0.5^\circ$

$m_{\pi^0} = 132 \pm 6 \text{ MeV}/c^2$

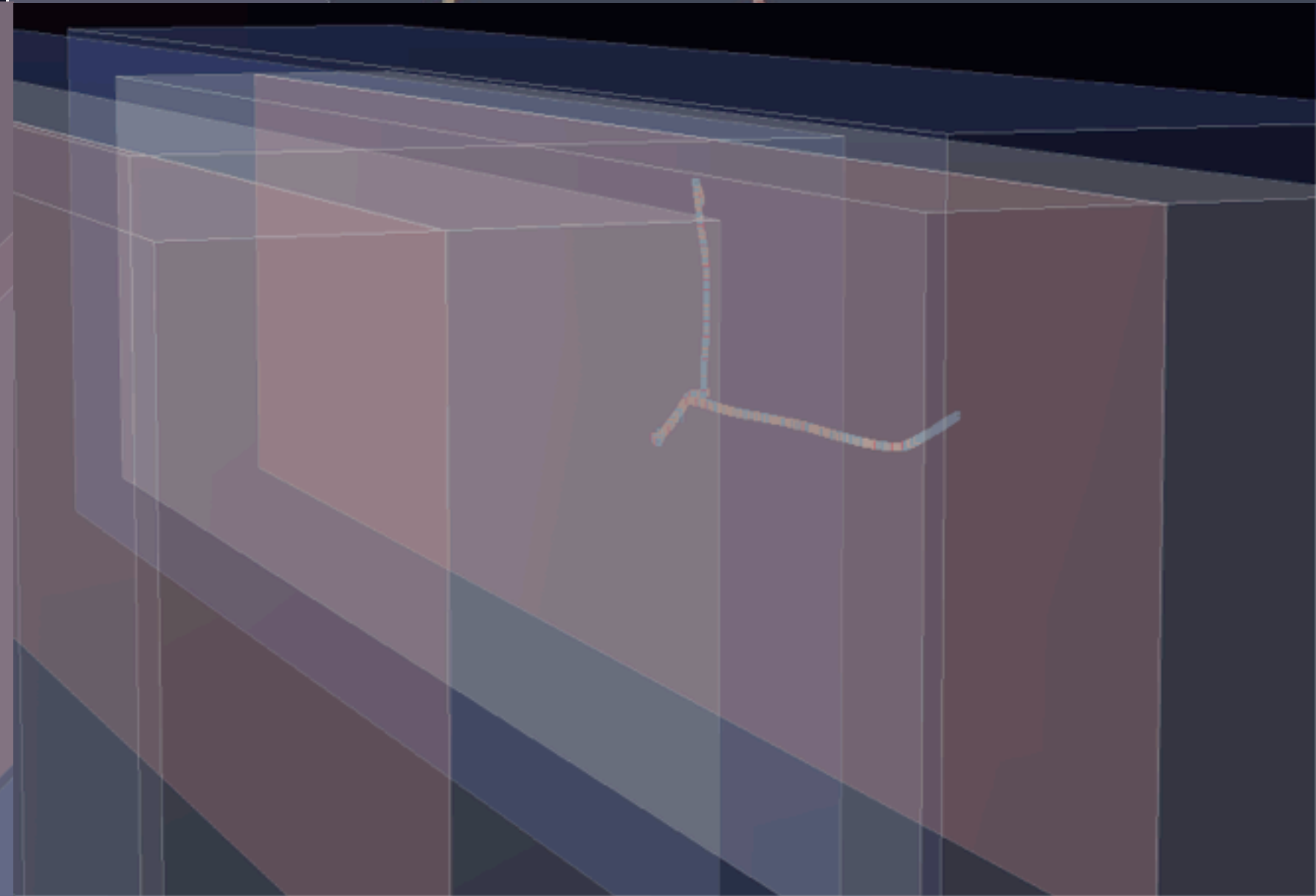
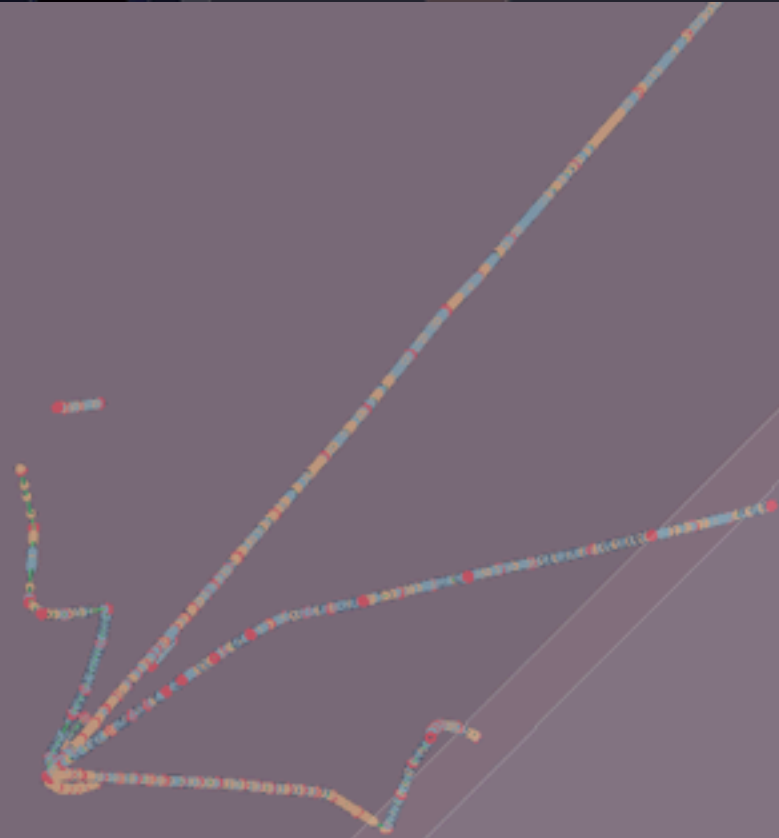
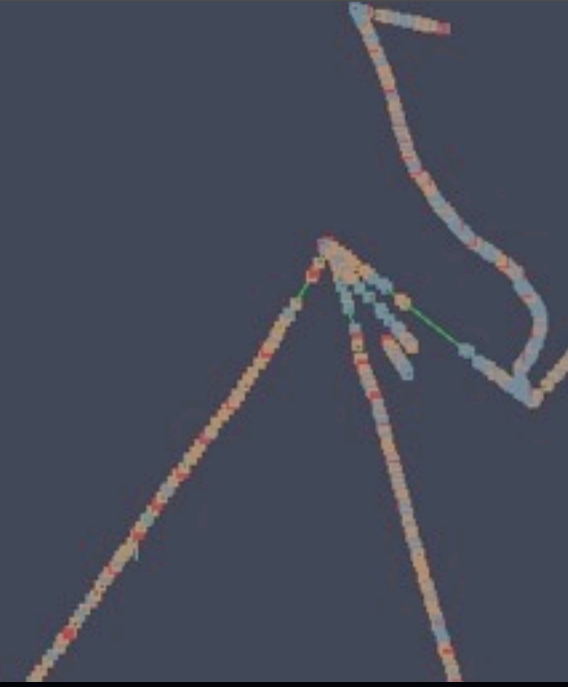
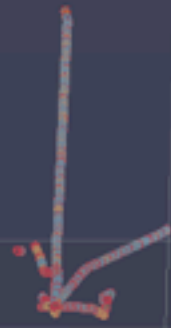
Particles	$E^{dep}$ (MeV)	p (MeV/c)
$\pi, p$	$172 \pm 15$	$279 \pm 16$
$\mu$		8100
$\pi, 2p$	$71 \pm 6$	$157 \pm 8$
$\pi, p, (\pi \rightarrow \mu \rightarrow e), n$	$457 \pm 39$	$580 \pm 40$







# Grazie!





# Backup slides



