τ neutrino detection

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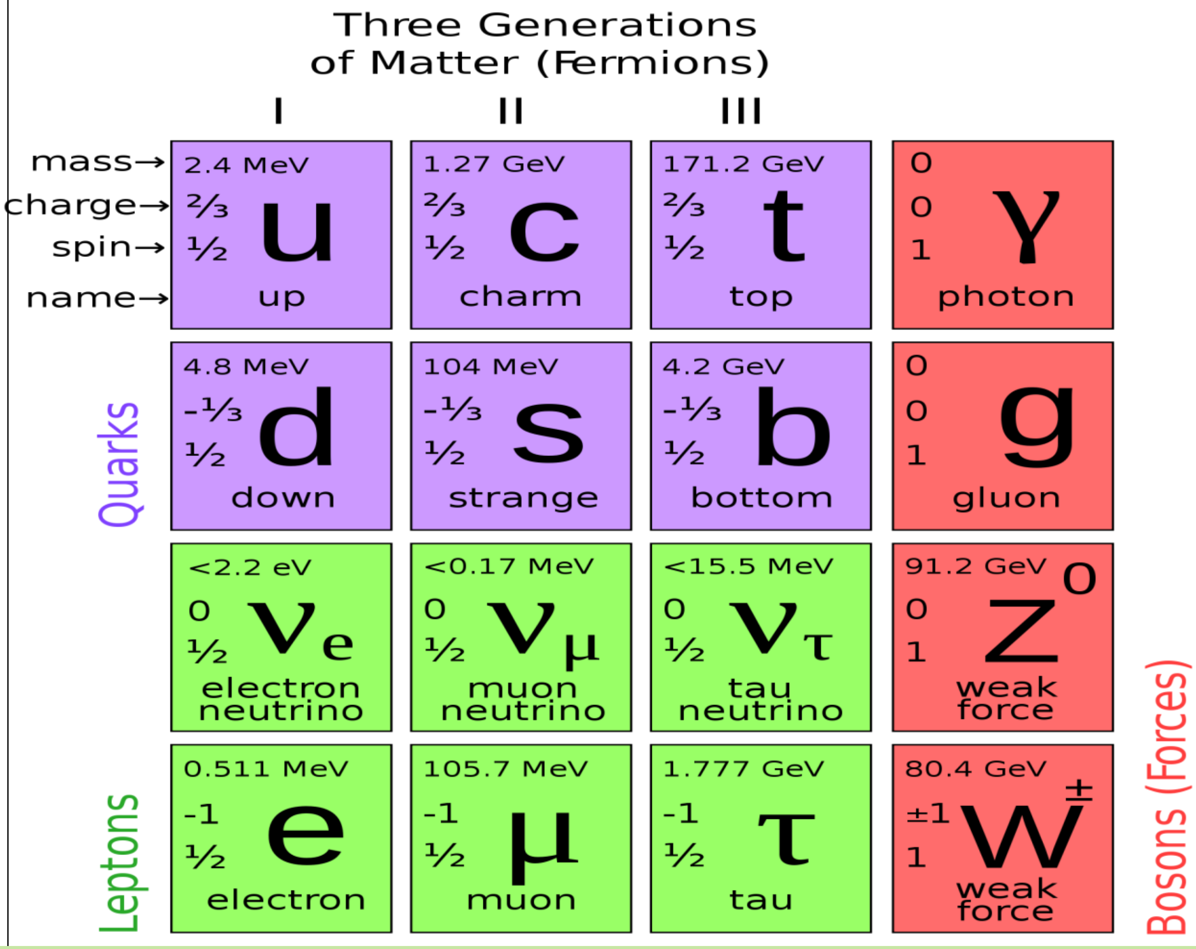
Outline

- Standard Model and History
- Detection of neutrinos (specifically ν_{τ})
- **D**irect **O**bservation of **NU T**au **(DONUT)**
- **O**scillation **P**roject with **E**mulsion-t**R**acking **A**pparatus **(OPERA)**

The Standard Model of Particle Physics



1898- electron
1937-muon
1956-electron neutrino
1962-muon neutrino
1974-charm quark
1975-tau lepton
1977-bottom quark
1995-top quark
2000-tau neutrino

Tau Neutrino was the last standard model fermion to be directly observed.

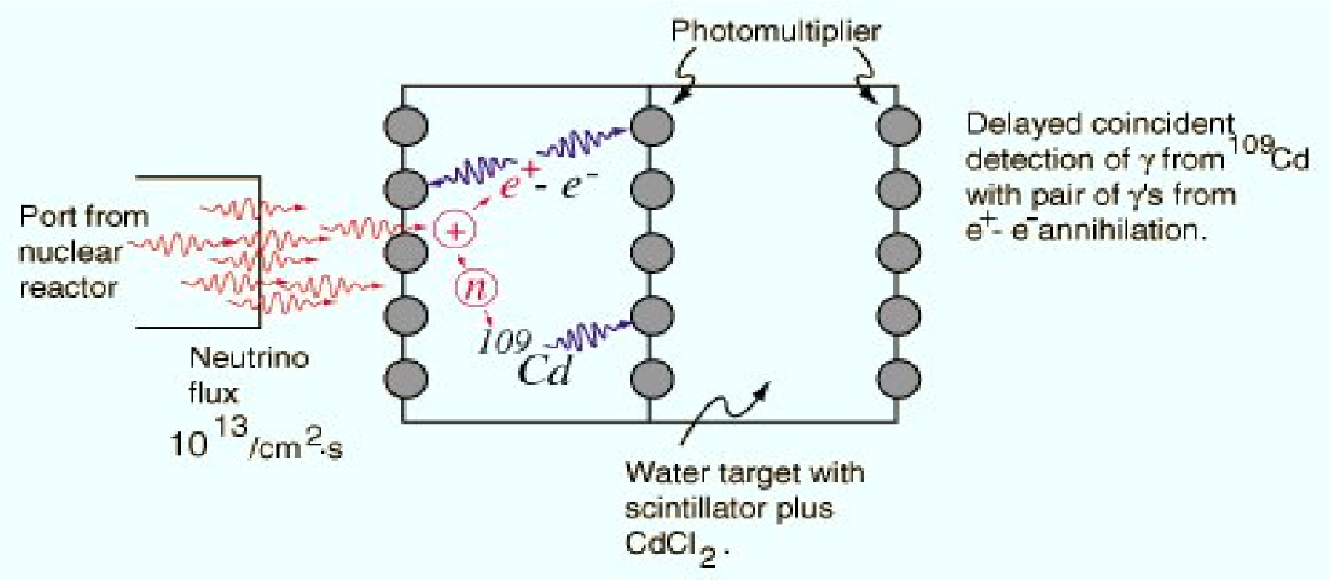
History

Discovery of electron neutrino: 1956

The million-dollar particle

- Reactor neutrinos: $\bar{\nu}_e + p \rightarrow n + e^+$
- $e^+ + e^- \rightarrow \gamma + \gamma$ (0.5 MeV each)
- $n +^{108}\mathrm{Cd} \rightarrow^{109}\mathrm{Cd}^* \rightarrow^{109}\mathrm{Cd} + \gamma$ (delayed)

Reines-Cowan: Nobel prize 1995

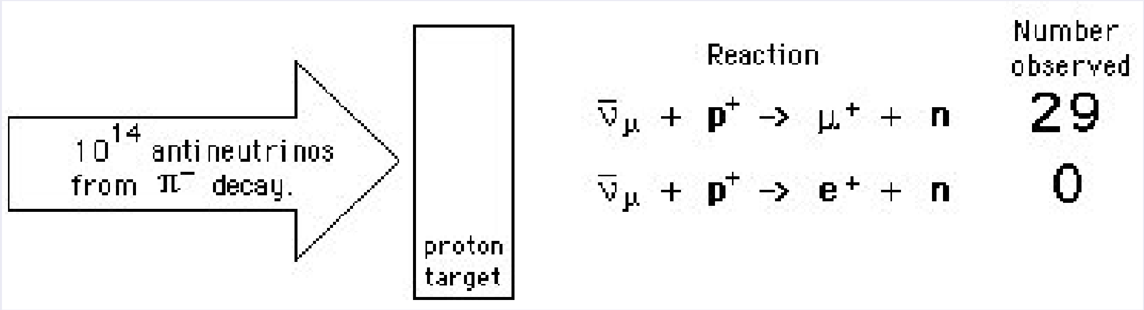


History

Discoveries of ν_μ and ν_τ

Muon neutrino: an unexpected discovery (1962)

- Neutrinos from pion decay: $\pi^- \to \mu^- + \bar{\nu}_{(\mu)}$
- $\bar{\nu}_{(\mu)} + N \to N' + \mu^+$
- Always a muon, never an electron/positron



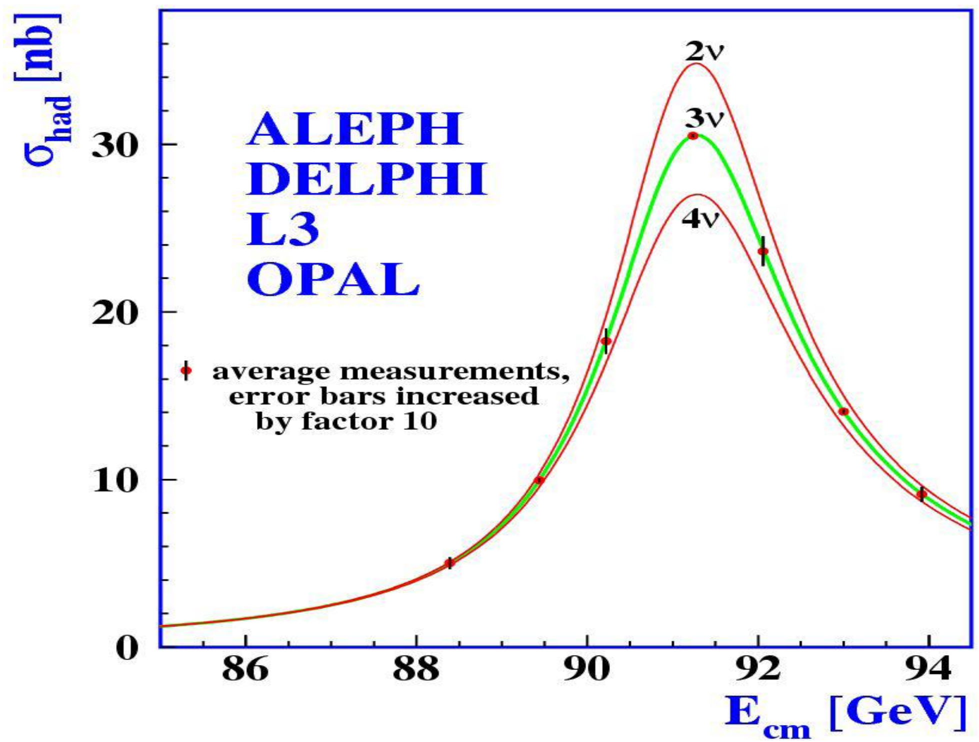
Steinberger-Schwartz-Lederman: Nobel prize 1988

Tau neutrino: expected, but hard to identify (2000)

DONUT experiment at Fermilab: $\nu_\tau + N \to \tau + N'$

Evidences before discovery

- The Discovery of τ in 1975 along with the proof in 1962 that ν_μ was distinguished from the ν_e, implied the existence of unique τ neutrino
- Constraint on total number of neutrinos (to be 3) by Big Bang nucleosynthesis
- Precise measurement of partial decay width of Z at LEP, predicts 3 light neutrinos



Neutrino interactions

- Neutrino interactions can be reduced to two categories :

  1. Neutral Current (Z) 2. Charged Current(+/-W)

- The purpose of the DONuT experiment is to study CC events

$$\nu_\tau + N \rightarrow \tau^- + X$$
$$\overline{\nu_\tau} + N \rightarrow \tau^+ + X$$

- However during data taking DONuT was recording interactions of all flavors of neutrinos.

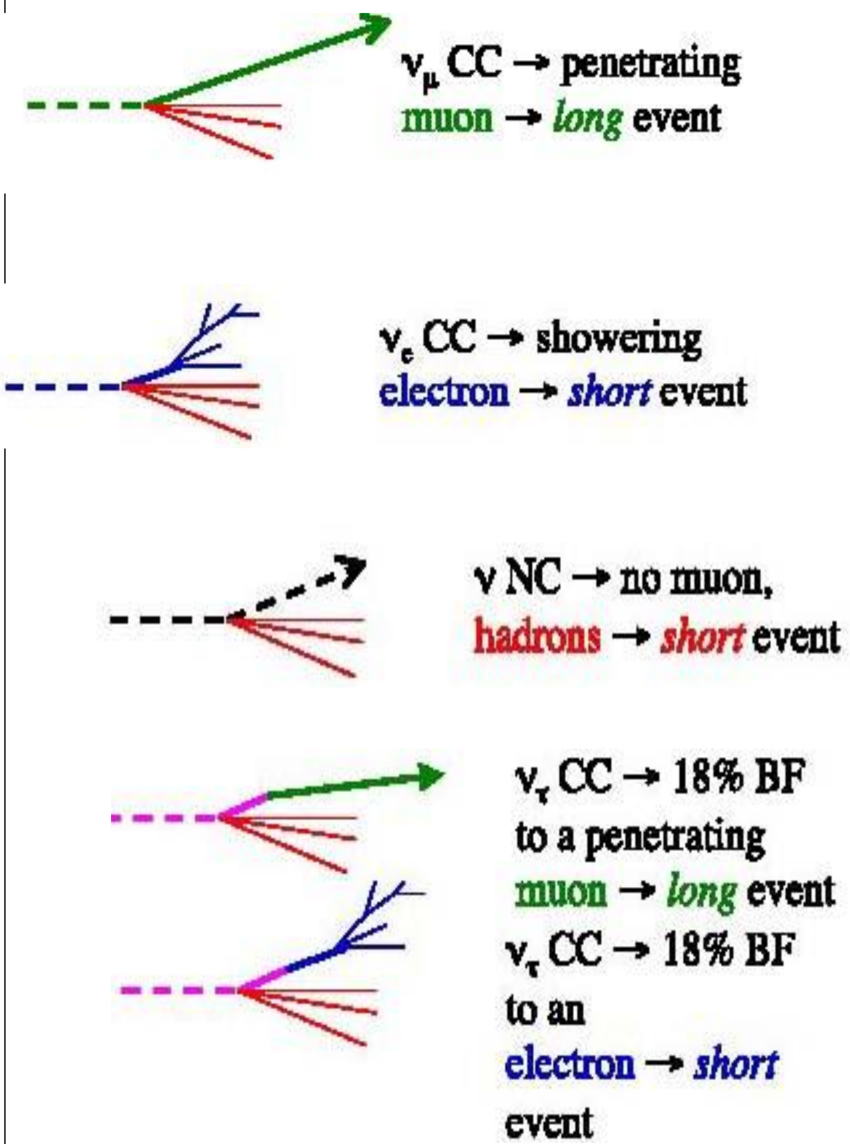
  1. CC event $\nu_l + N \rightarrow l^- + X$

  2. NC event $\nu_l + N \rightarrow \nu_l + X$

- Background: Charm production in NC event of ν_μ and ν_e

$$\nu_l + N \rightarrow l^- + C^\pm + X$$

Neutrino Interactions



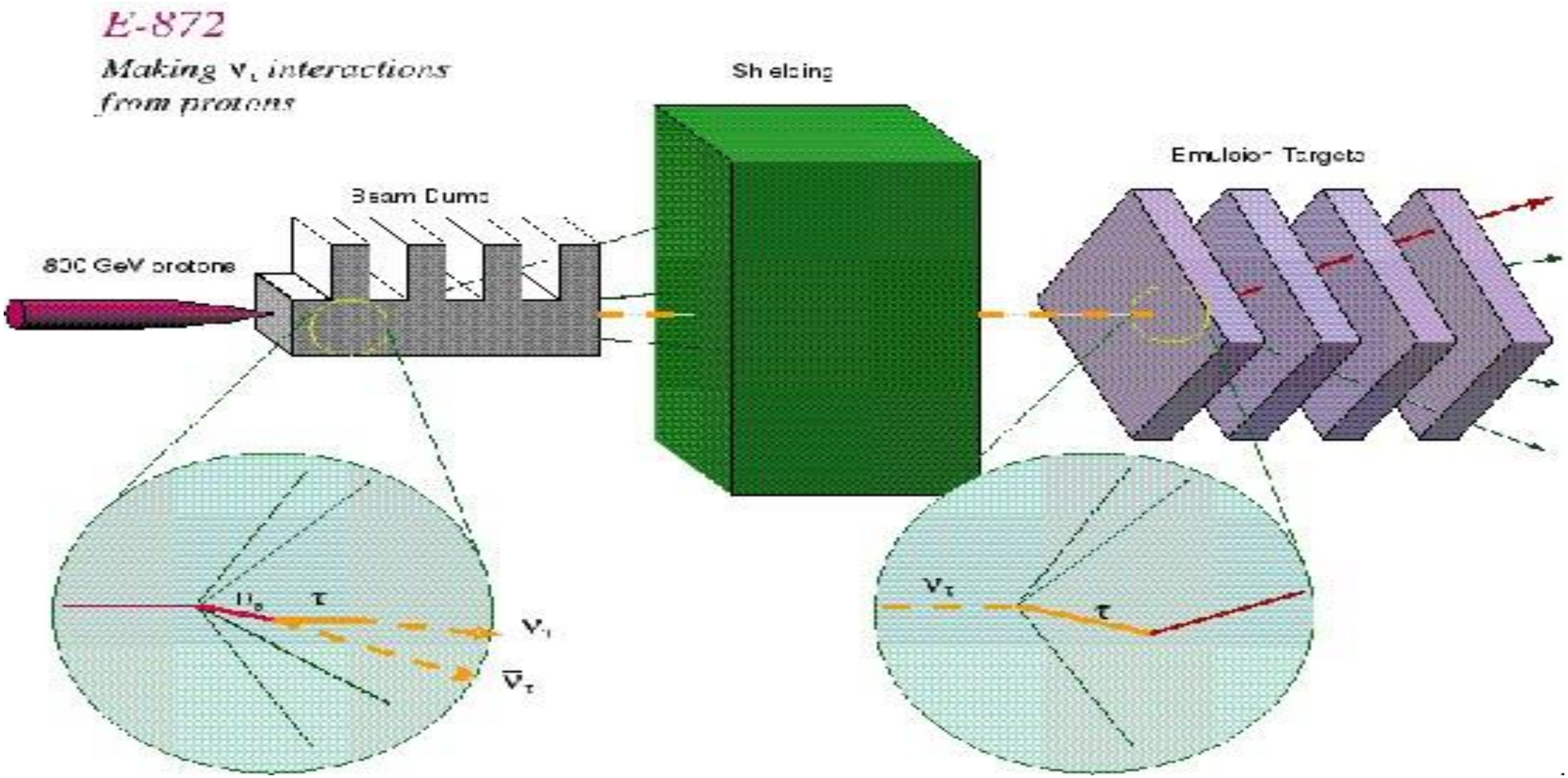
CC ν_μ interaction to a muon, giving long track of muon.

CC ν_e interaction to an electron, producing showering event.

NC event any neutrino can undergo, only multiple hadron products

CC ν_τ bit more difficult due to $\boldsymbol{\tau}$ lifetime

DONuT Design



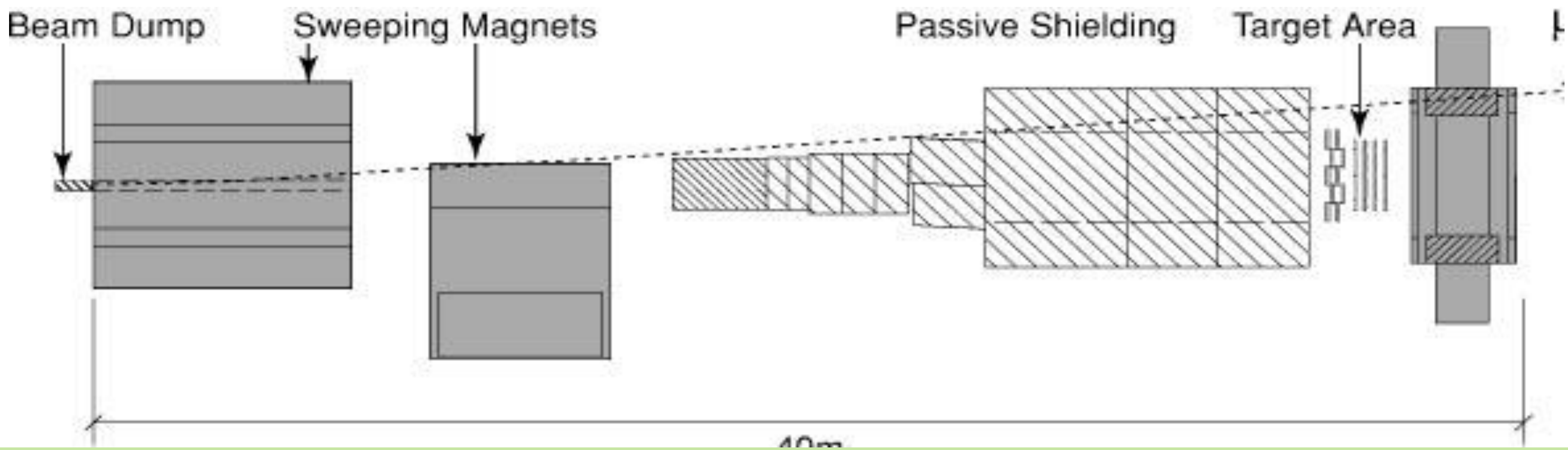
1. 800 GeV proton beam (Tevatron) stopped in beam dump (block of tungsten).
2. Produces D_s (meson) decays to ν_τ and $\boldsymbol{\tau}$
3. $\boldsymbol{\tau}$ then decays to tau neutrino
4. Which is detected in emulsion target

Beam Dump

- 800 GeV proton beam from TeVatron collide with block of tugsten.

  8×10^{12} protons per 20 second spill

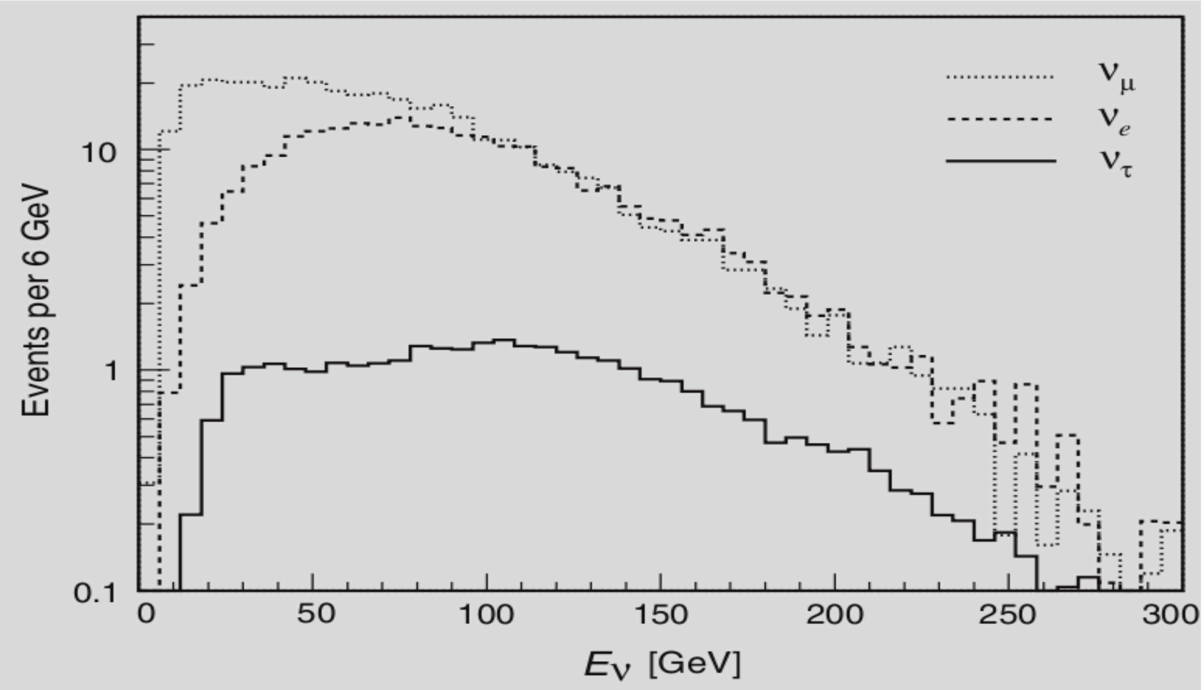
- In the Dump D_s (along with other charm particles) is produced .



- Neutrinos from decay of charmed particle are called prompt neutrinos.
- Neutrinos from decay of $\pi\pm$ and K $\pm$ are called Non prompt neutrinos.
- 95% of neutrino flux are ν_e(37%)and ν_μ(58%)and rest is ν_τ
- 93% of ν_e are prompt, substantial ν_μ are both prompt and non prompt and almost ν_τ all are prompt

Neutrino Beam Energy

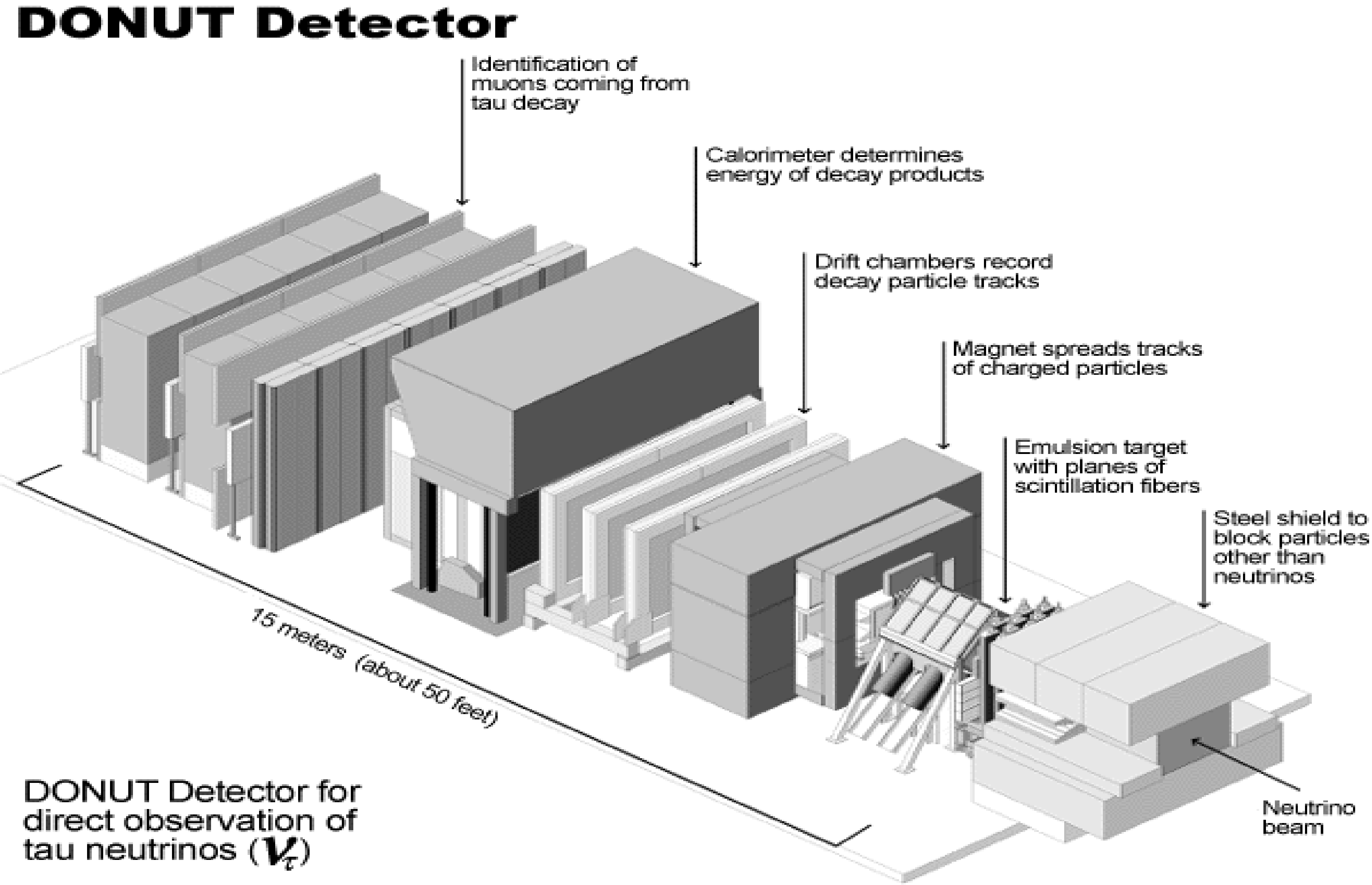
- The calculated (PYTHIA output) neutrino energy spectra of all neutrinos that interacted in DONuT



K. Kodama (DONuT Collaboration), Physical Review D 78, 052002 (2008)

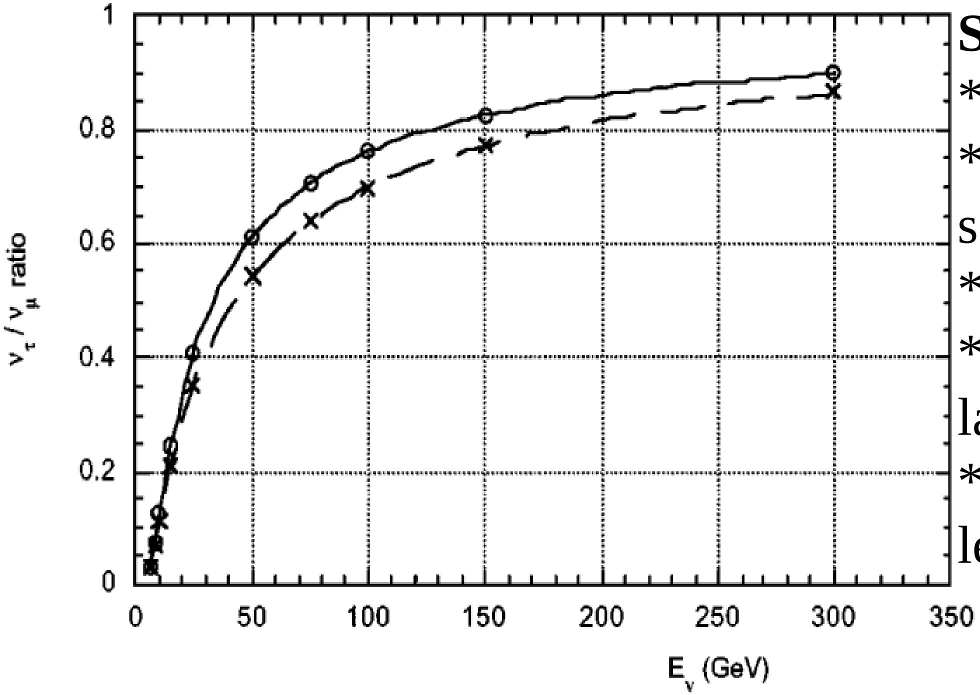
- The average neutrino energy was 53 GeV

DONuT Detector



DONuT Target

- DONuT scientists had to overcome two difficulties:
  1. High resolution: τ has short lifetime ~$239*10^{-15}$s (PDG)
  2. tau-neutrino is extremely non-interacting



Solution: EMULSION

*Spatial Resoltion~1μm

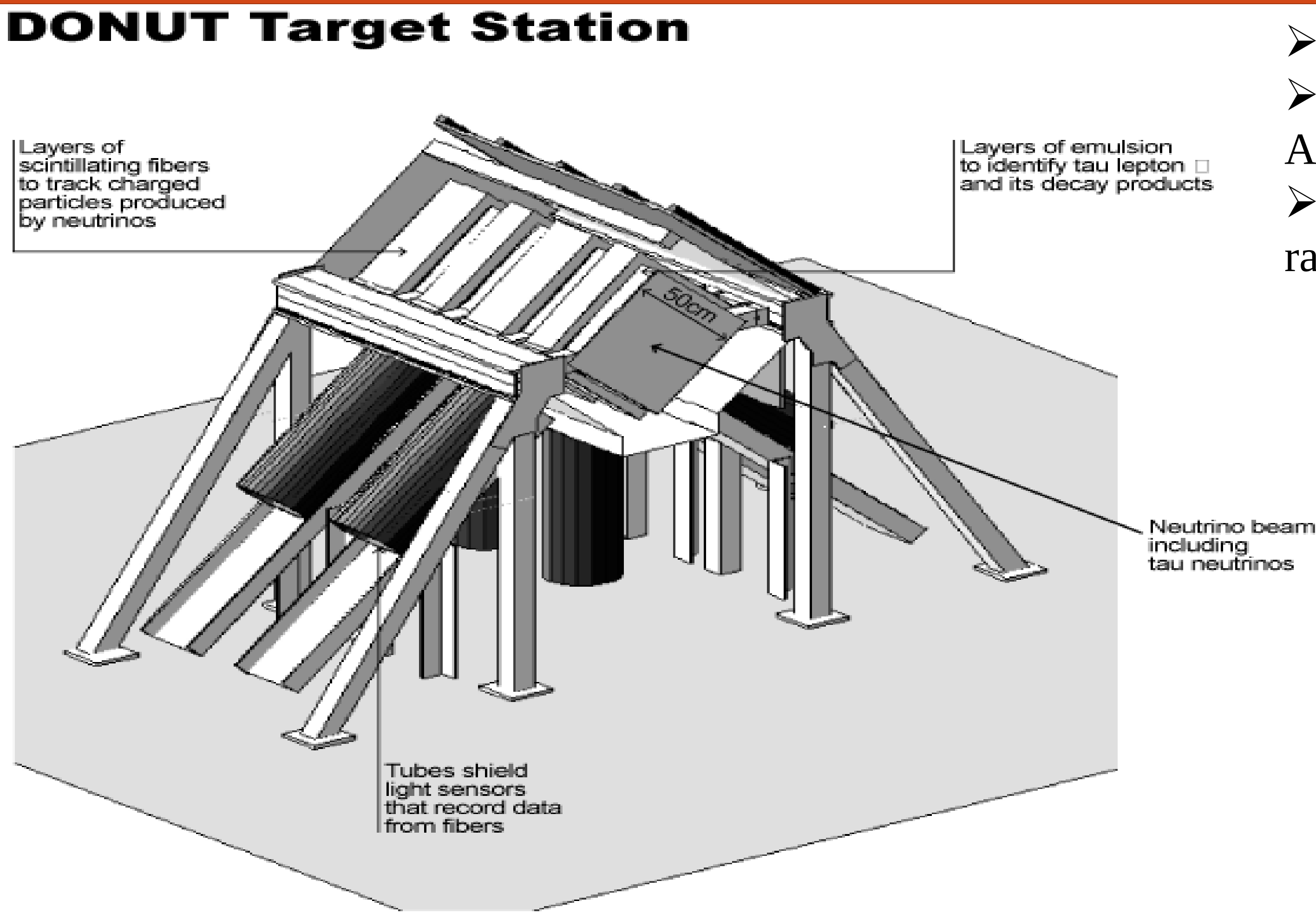
*Extremely sensitive and also continuously sensitive

*Target and detector are not separate.

*To improve target densities emulsions are layered on sheets of metal.

*number of grains developed per unit track length gives rate of energy loss

DONuT Target



- Emulsion-Target
- 50x50x6cm^3

Aluminium support frame

- Masses of these module range from 56kg -100kg

OPERA

- An appearance experiment to search for $\nu_\mu \leftrightarrow \nu_\tau$ oscillations in CNGS beam
- OPERA is a long baseline experiment located at the Gran Sasso laboratory.
- The Detector design is based on massive lead/nuclear emulsion target
- The Concept of emulsion detector in OPERA is same as DONuT, one difference in the nature of passive material. In OPERA there are lead plates but in DONuT there are iron plates
- The most stringent constraint comes from SuperK which yeilds the following 90% C.L.

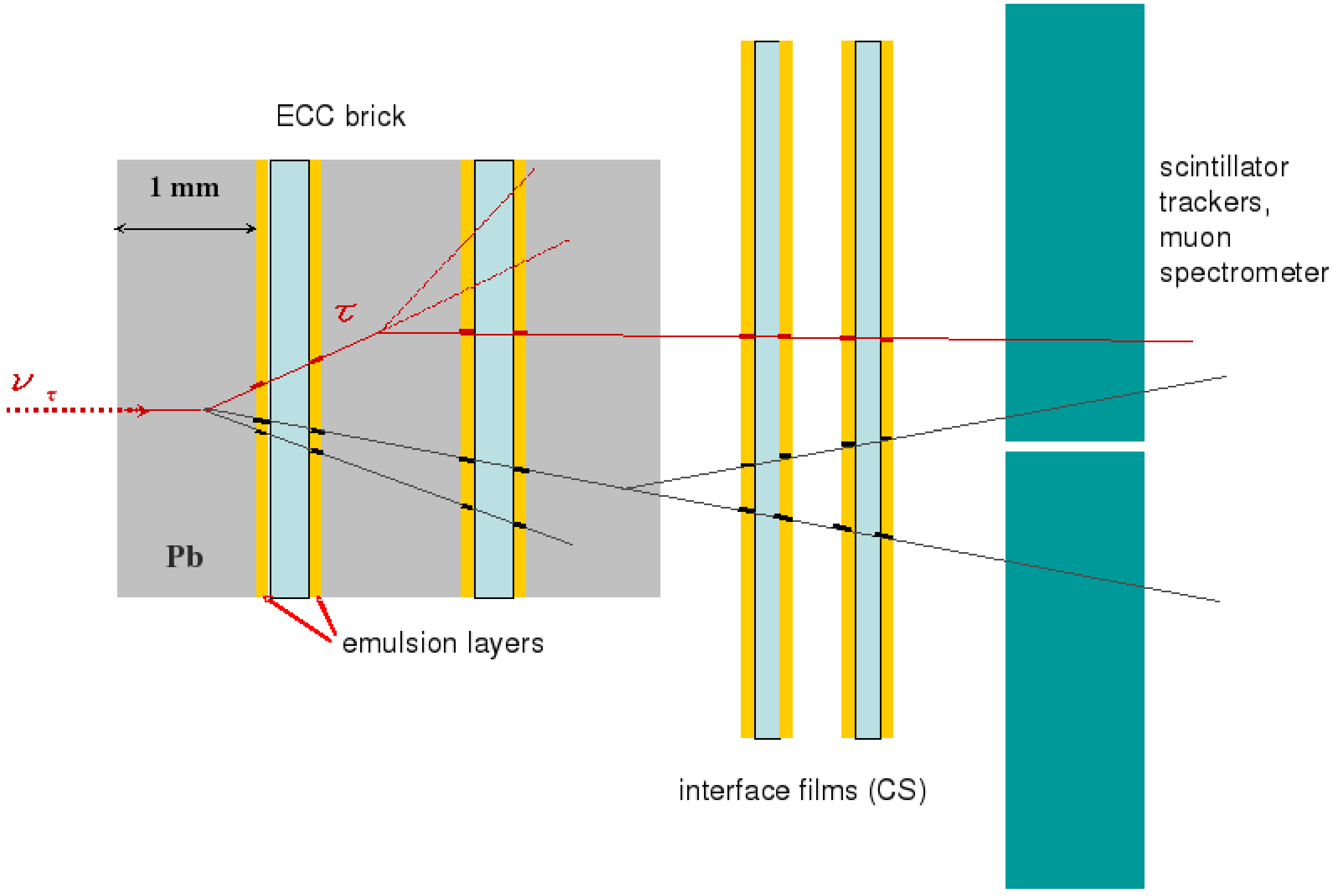
  $\Delta m^2 \sim (2\text{-}6) \times 10^{-3}\ eV^2$

  $Sin^2 2\theta \sim 0.8 - 1$

OPERA Requirements

- The energy of ν_μ must be over the $\boldsymbol{\tau}$ production threshold.
- The distance from the ν_μ production point to the detector (baseline) must be long enough to allow a reasonable fraction of neutrinos to oscillate to a different flavour.
- The beam intensity must be high enough to provide a reasonable number of events.
- The detector must have enough mass to provide a reasonable number of events.
- The detector must have a capability to detect short-lived leptons, that is high spatial resolution.

Detecting nu tau @ OPERA

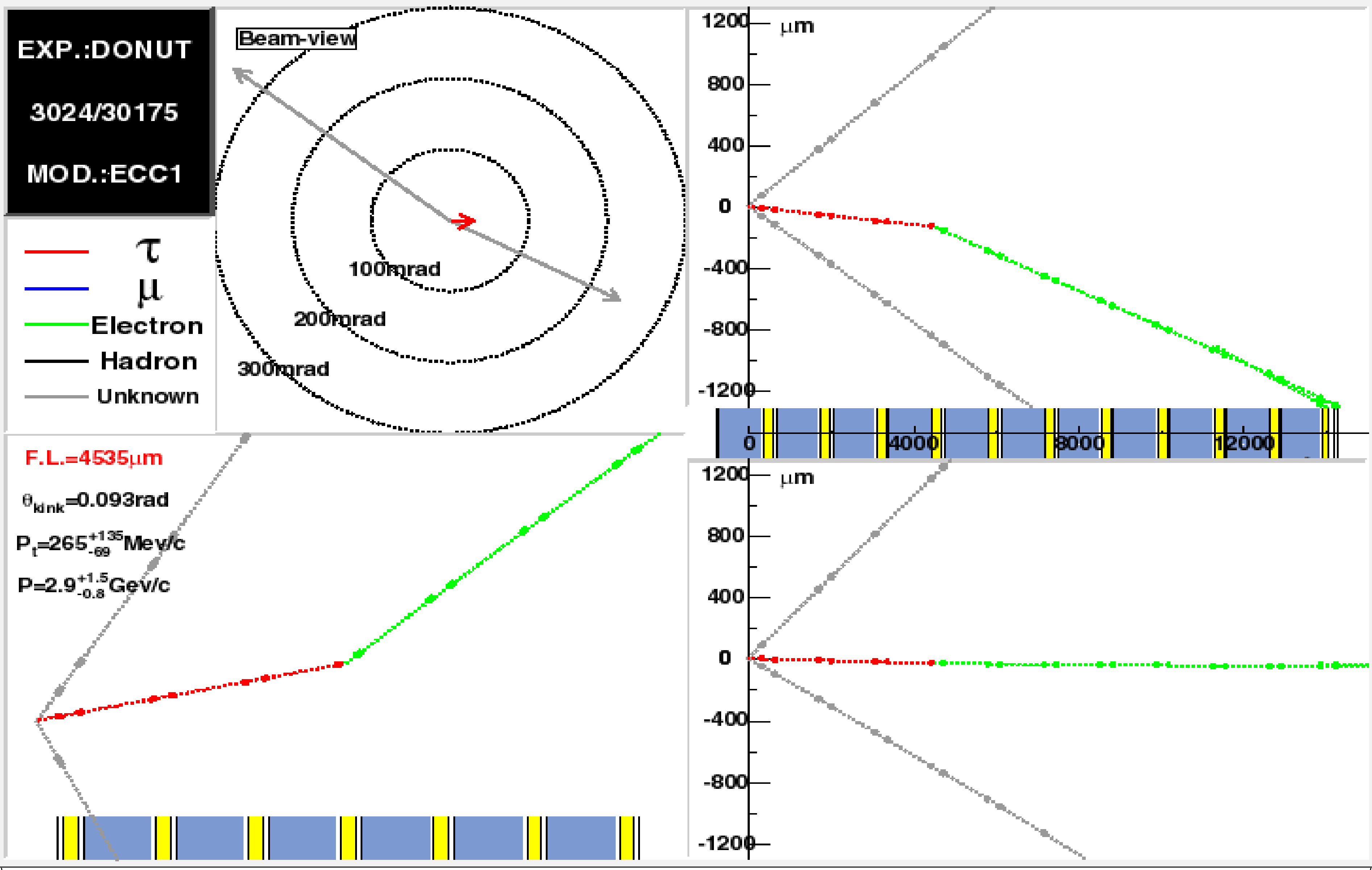


Conclusion

- The results from DONuT in July 2000, confirmed the existence of most suspected nu tau.
- Finding τ decay in DONuT was made possible by state-of-the-art digital technology with precise nuclear emulsion.
- The OPERA detector received CNGS nu beam for a brief period in 2006 and obtained first event in 2007.

THANK YOU !!!

Back-up


EXP.:DONUT
3024/30175
MOD.:ECC1
τ
μ
Electron
Hadron
Unknown
Beam-view
100mrad
200mrad
300mrad
F.L.=4535μm
θ_{kink}=0.093rad
$P_t=265^{+135}_{-69}$Mev/c
$P=2.9^{+1.5}_{-0.8}$Gev/c
1200
800
400
0
-400
-800
-1200
μm
0
4000
8000
12000