Properties of the Tau-Neutrino

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Outline

Indirect Evidence

The DONUT Experiment

Spectrometer Data Analysis

Emulsion Data Analysis

Backgrounds

τ- signal

ν_T-N CC cross section

ν_T Magnetic Moment

ν_T Mass

Present S-M properties of the ν_T

Summary and Conclusions

Search for the Tau-Neutrino

Historical Development

1975- τ - lepton discovered ; 'ν_τ' postulated to exist

Late 70's: DELCO, MARK II, : τ - decay studies, Michel Parameter ρ, τ-lifetime, τ-μ Universality.

1980's - MARK II, TASSO, CLEO, ARGUS, LEP: τ - decay studies, 'ν_τ' helicity = -1, spin = ½.

1986 - E531 : Is 'ν_τ' may be ν_e, ν_μ? No, no direct couplings of the τ-lepton to ν_e,or ν_μ.

1991 - LEP demonstrates 3.00 ν 's

2000 – DONUT: Direct Observation: First 4 ν_τ CC events

The DONUT Experiment

- Designed to observe directly and study the charged-current interactions of the tau-neutrino.
- Uses a hybrid emulsion spectrometer to locate and identify ν_T – Nucleus CC interactions.
- First 4 events published in Phys. Lett. B 504, 218(2001)

DONUT = Direct Observation of NU Tau

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Observation of tau neutrino interactions

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Abstract

The DONUT experiment has analyzed 203 neutrino interactions recorded in nuclear emulsion targets. A decay search has found evidence of four tau neutrino interactions with an estimated background of 0.34 events. This number is consistent with the Standard Model expectation. © 2001 Published by Elsevier Science B.V.

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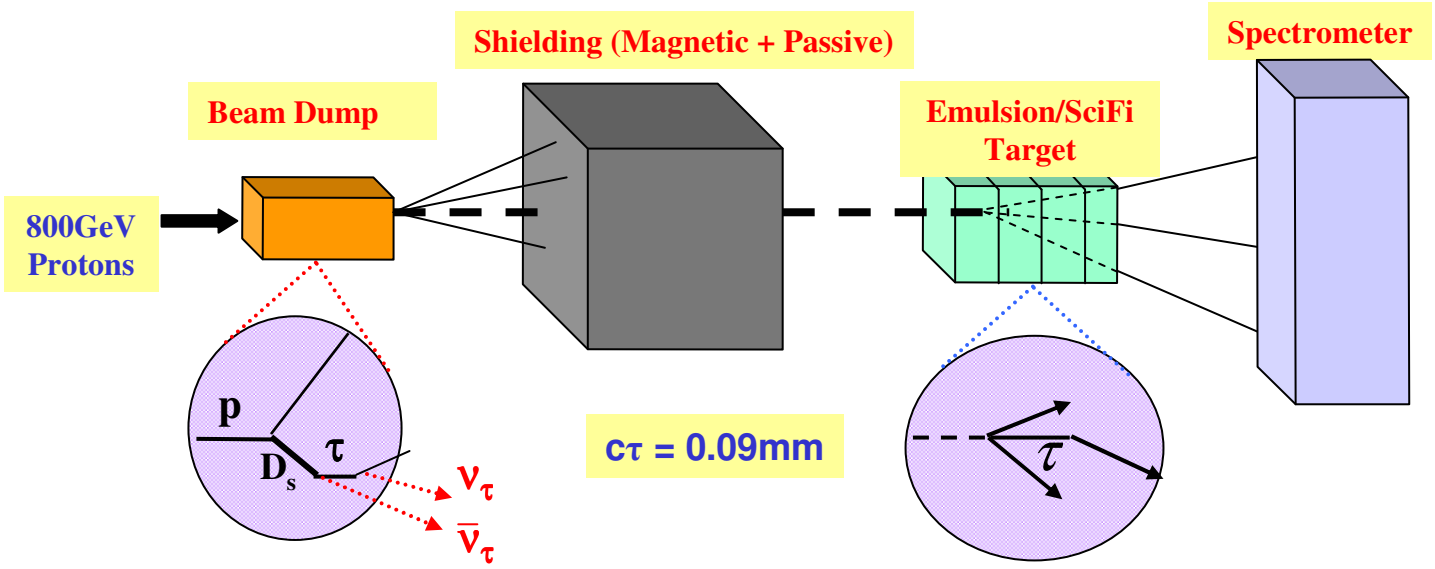
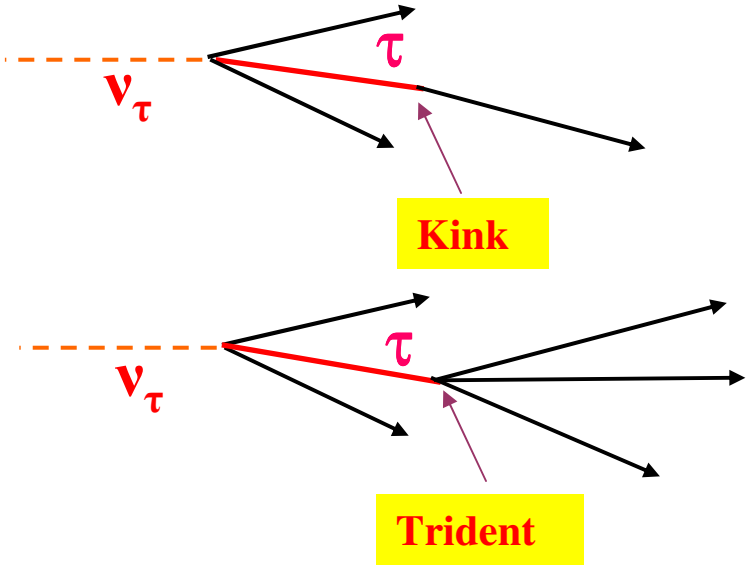
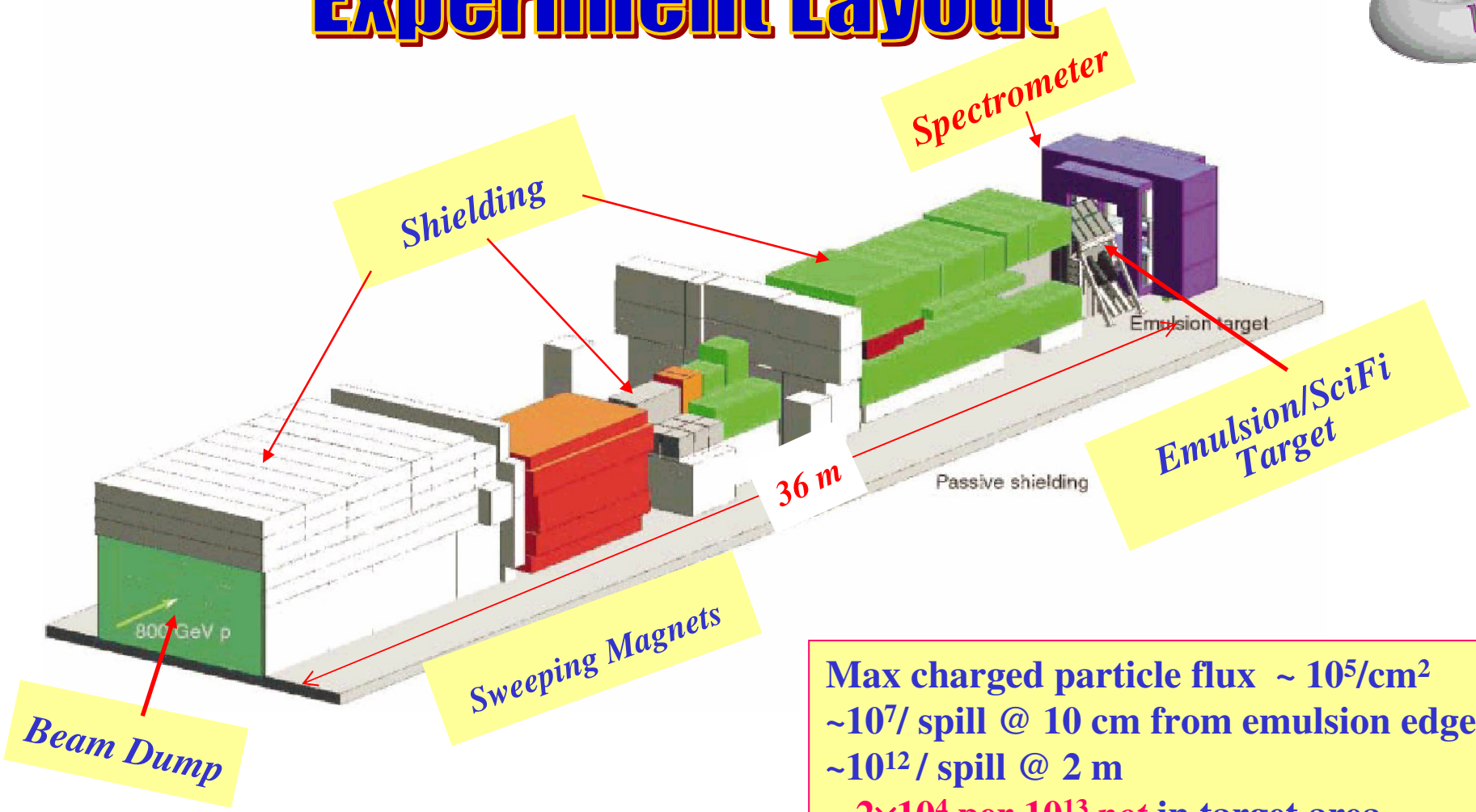
How is it Done?



- 800 GeV protons → Beam Dump → ($D_s \rightarrow \nu_T$ + ..)
- Magnetic/Passive shield to protect the emulsion
- Emulsion target at 36 m
- Spectrometer: vertex, track ID, P
- Emulsion scanning: Locate vertex, Decay search
- Find ν_T by topology: Kinks and tridents



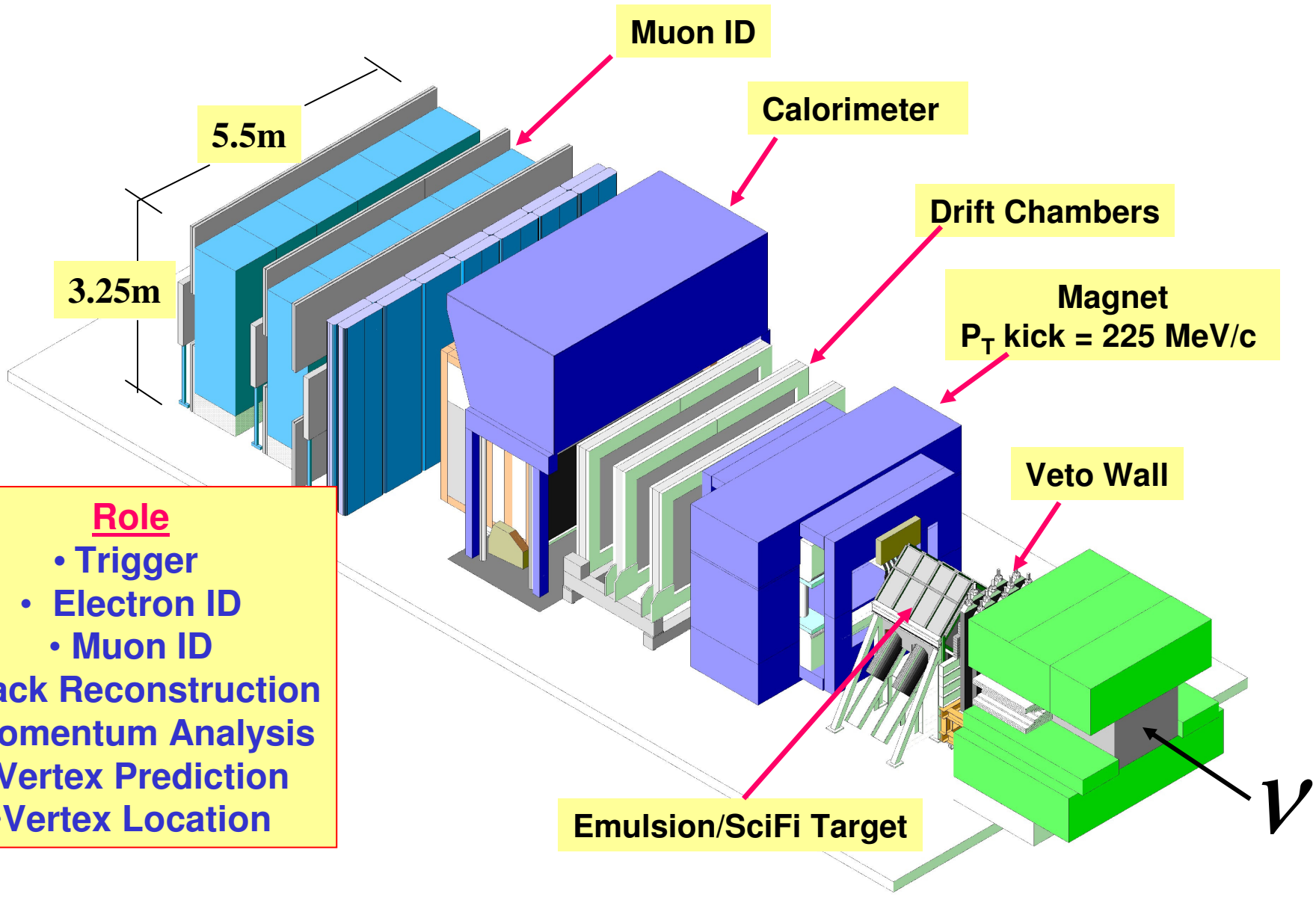
Experiment Layout



Max charged particle flux ~ 10^5/cm^2
~10^7/ spill @ 10 cm from emulsion edge
~10^{12} / spill @ 2 m
~ 2×10^4 per 10^{13} *pot* in target area

- ~ 8 x 10^{12} protons/spill, Spill = 20 sec/min
- Emulsion Target at 36 m from beam dump

Hybrid Emulsion Spectrometer



Role

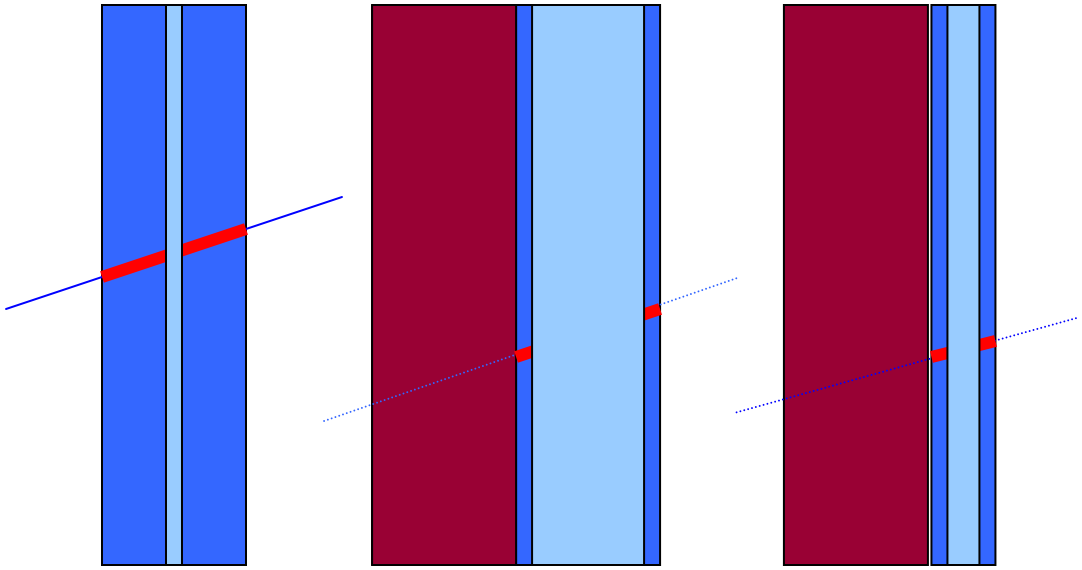
- Trigger
- Electron ID
- Muon ID
- Track Reconstruction
- Momentum Analysis
- Vertex Prediction
- Vertex Location

Emulsion Target Technology

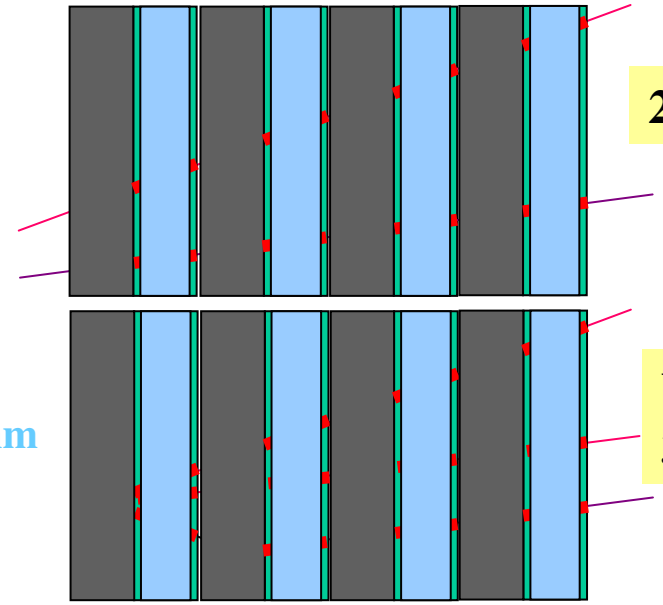
3-D Tracker

Basic Block: Steel / Emulsion / Acrylic / Emulsion

EAE	SEAE	SEAE
BULK	ECC800	ECC200
	1.0 mm	1.0 mm
0.32 mm	0.10 mm	0.10 mm
0.08 mm	0.80 mm	0.20 mm



95% emulsion 5% emulsion

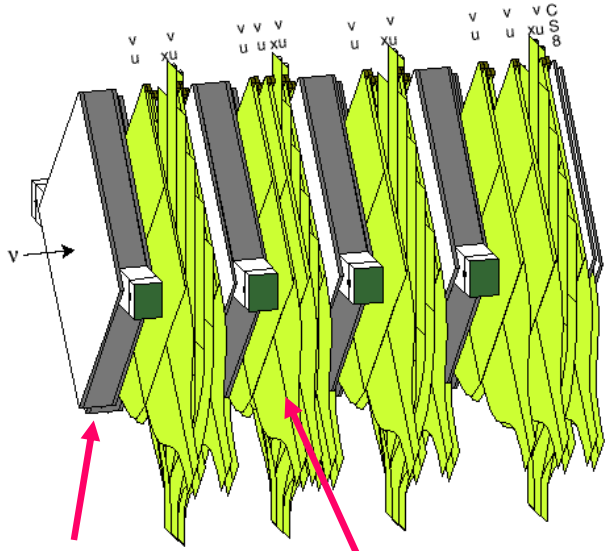


2 tracks

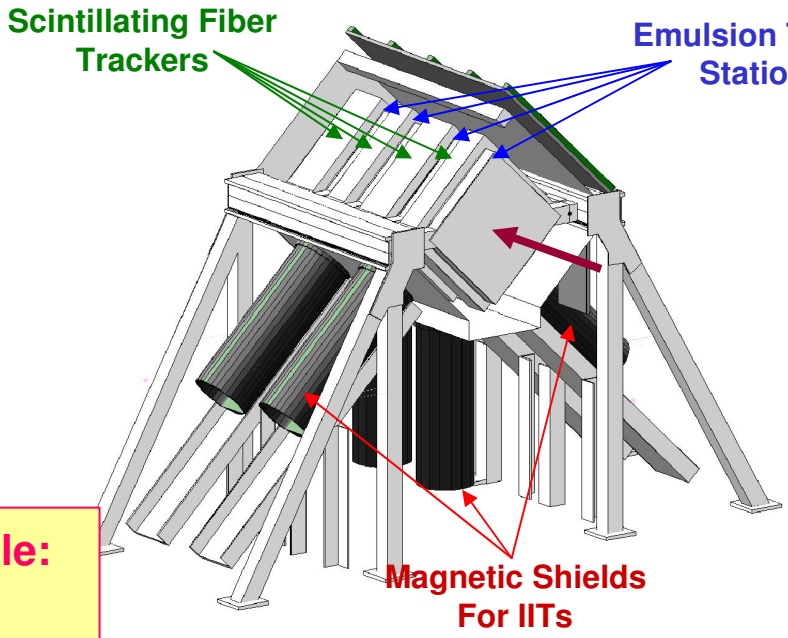
Vertex + 3 tracks

- AgBr suspended in a gel (Fuji ET7C) coated on plastic sheets.
- 29±2 grains per 100 μm for minimum ionizing track
- Spatial Resolution: 0.3 μm
- Vertex Resolution: 0.8 μm
- OPERA: Same idea

DONUT Emulsion/SciFi Target



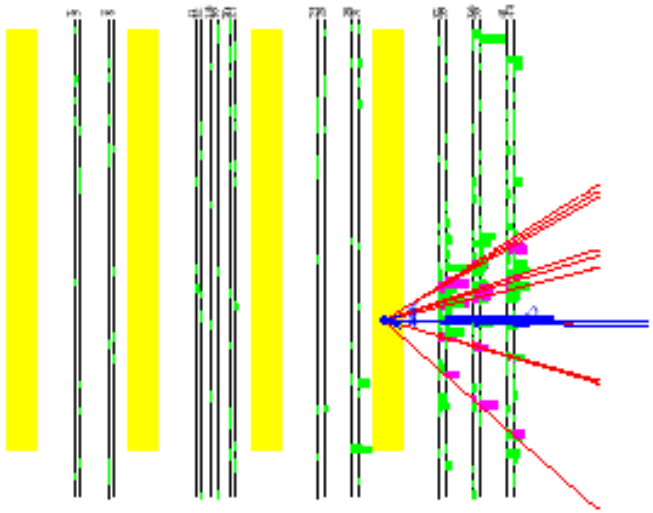
One Module:
2-3 X_0
0.2 - 0.3 λ_{int}



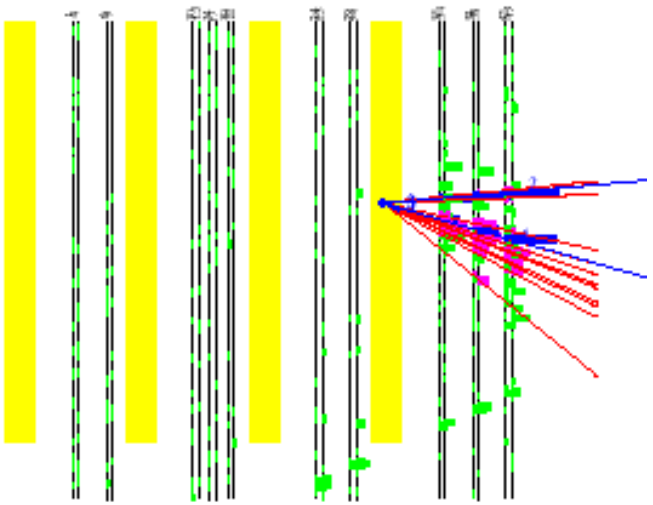
- 4 Emulsion target stations
- Interleaved with sci-fi
- Fibers → predict vertex
- Total 7 modules exposed
- 260 kg total mass

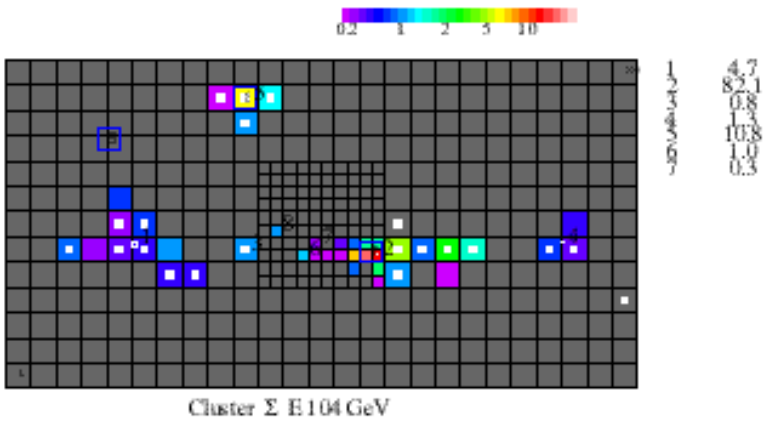
Example: ν_e CC interaction

U View



V View





EMCAL: Beam View. Tracks disperse in the bend plane

DONUT

Fermilab E-872

Run= 3250 Event= 470

Electron CC

Station 4

Bulk Emulsion

Data Reduction

6.6×10^6 triggers : 3.54×10^{17} POT

DONUT Preliminary

1026 predicted vertices from spectrometer

812 within fiducial volume

633 digitized emulsion data exists

633 emulsion vertex location attempted

581 vertex found

563 systematic decay search

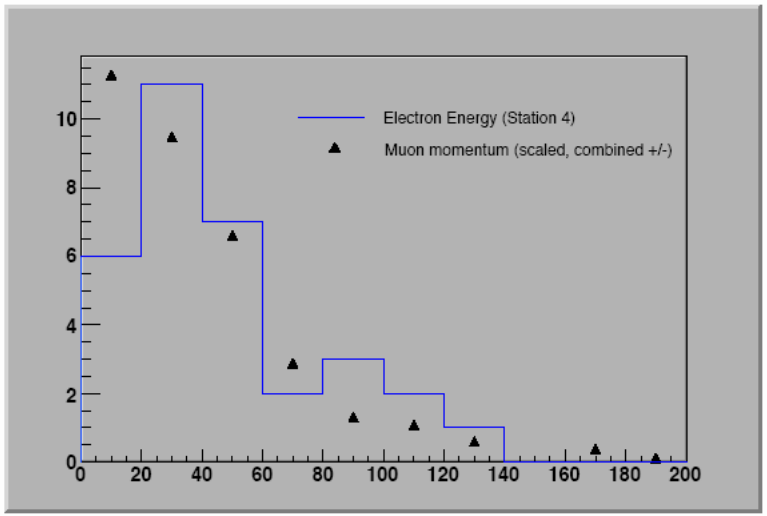
Location efficiency: 72%

9 ν_τ candidates

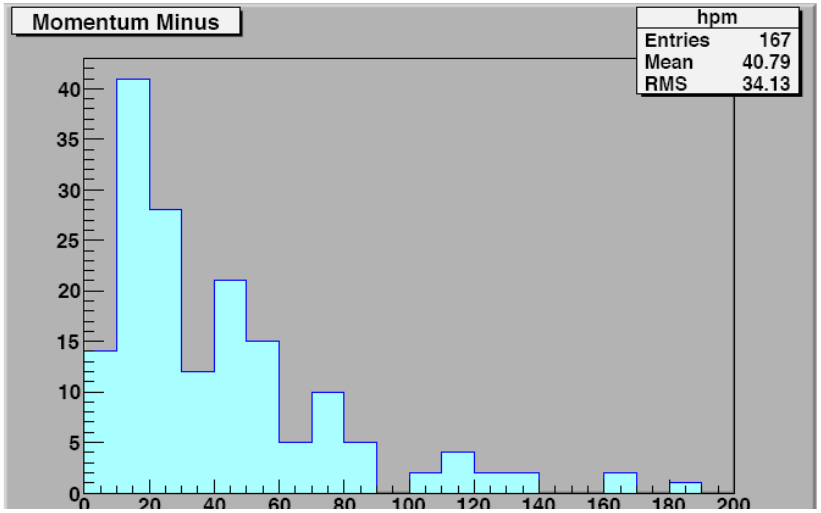
7 charged charm candidates

Flavor Selection

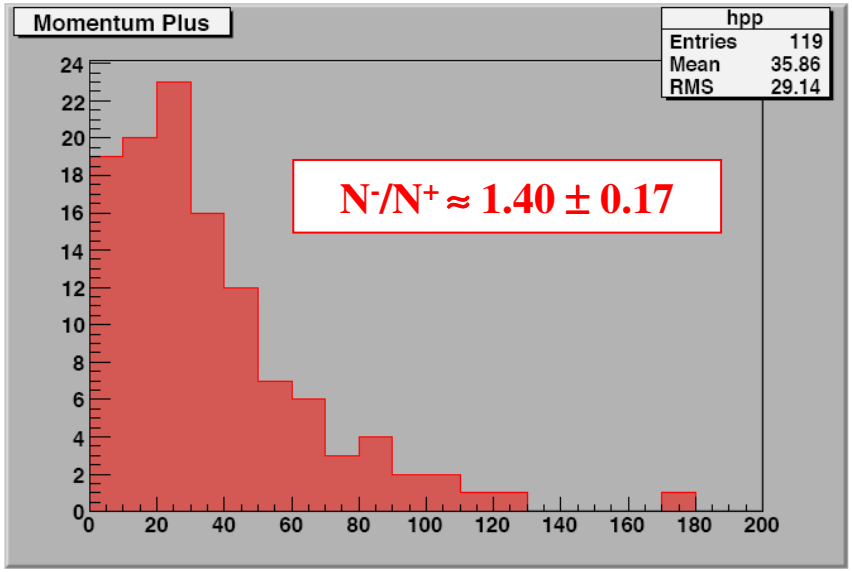
- ν_μ CC interactions by μ - ID (Prompt vs non-prompt)
- ν_e CC Interactions by e -ID
- ν_τ CC Interactions by τ-ID (emulsion scanning)
- CC/NC separation by ANN technique



DONUT Preliminary

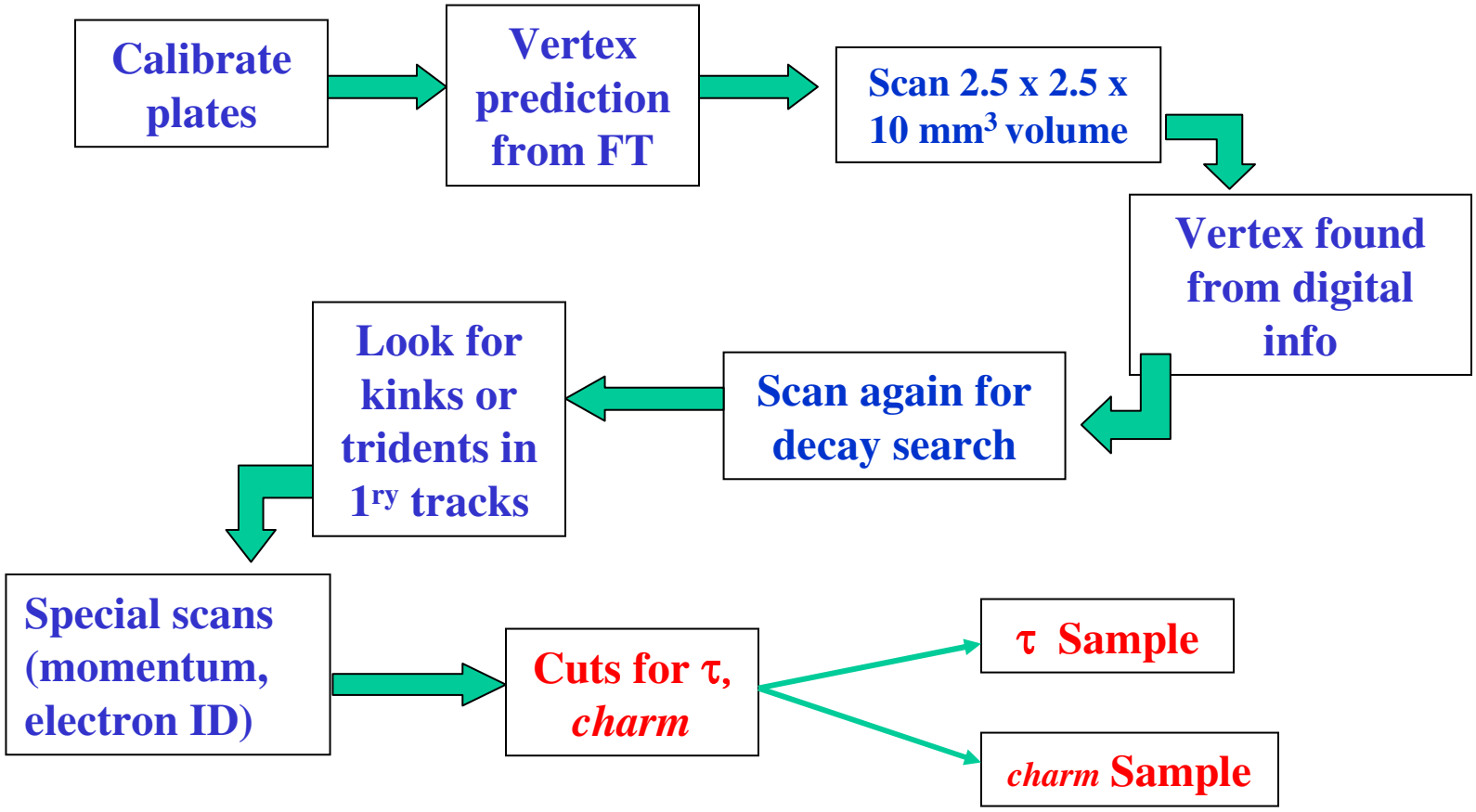


P (GeV/c)

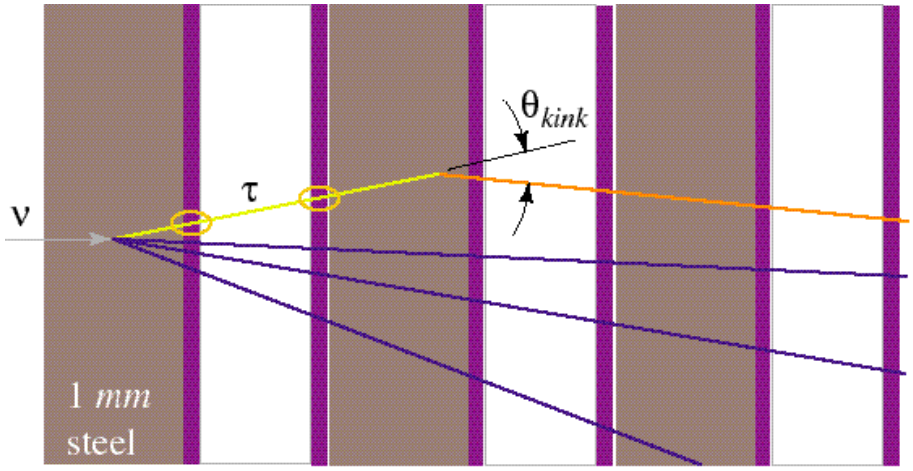


P (GeV/c)

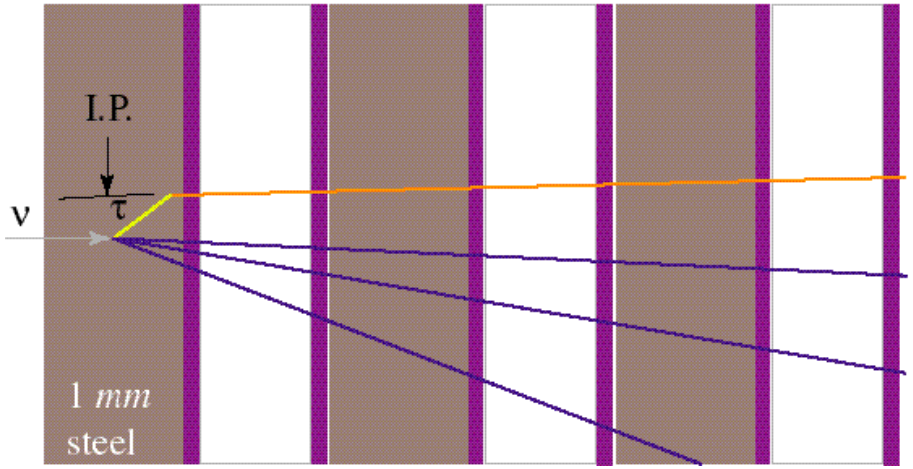
Emulsion Scanning/Analysis



Decay Search

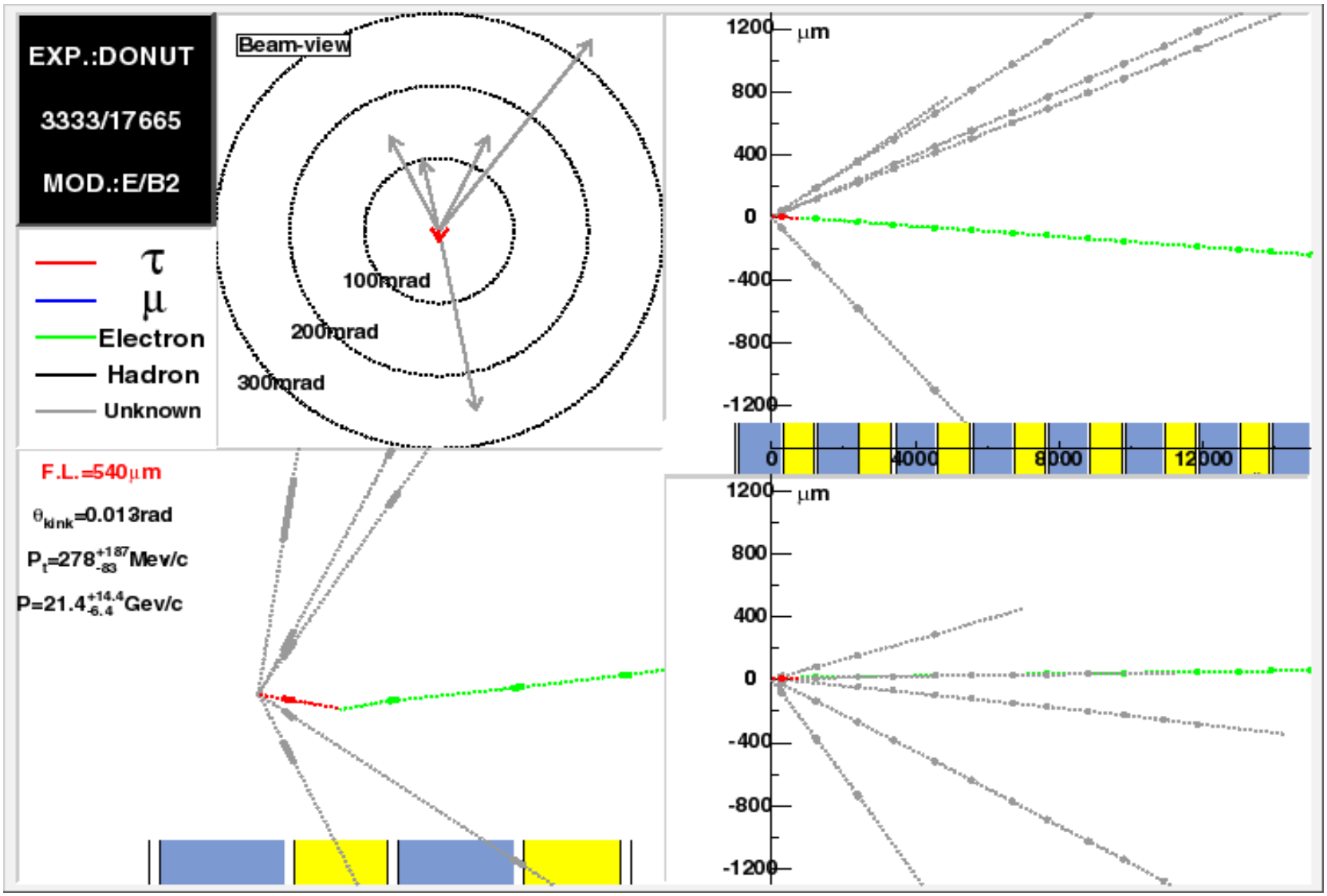


1. ***Long Decays***
   - parent measured
   - 1-prong (kink)
   - 3-prong (trident)
   - τ ⇒ no 1ry *lepton*
   - ~75% of kinks

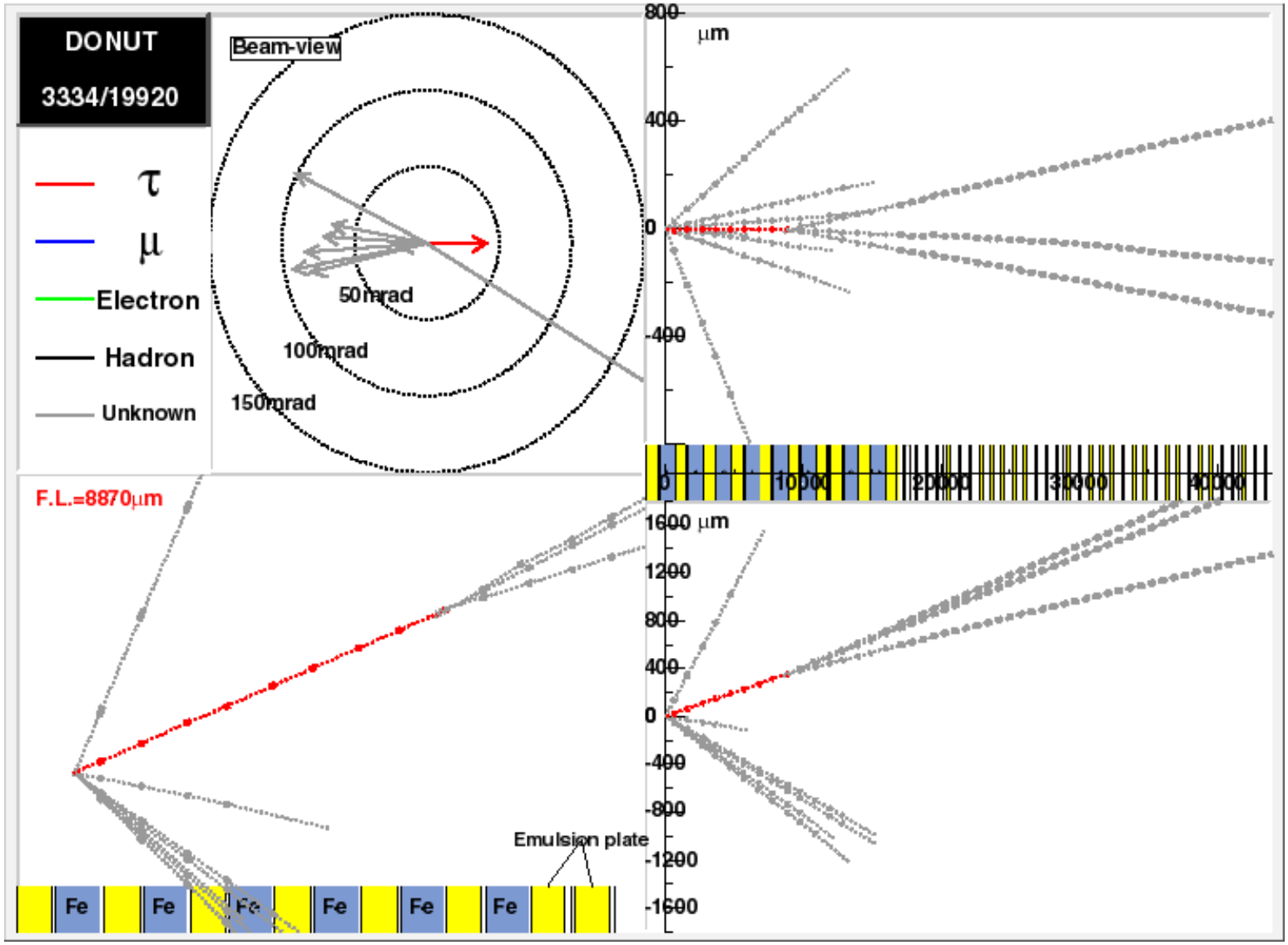


2. ***Short Decays***
   - IP wrt 1ry vertex
   - only daughter meas.
   - daughter seen in spect.
   - ~25% of kinks

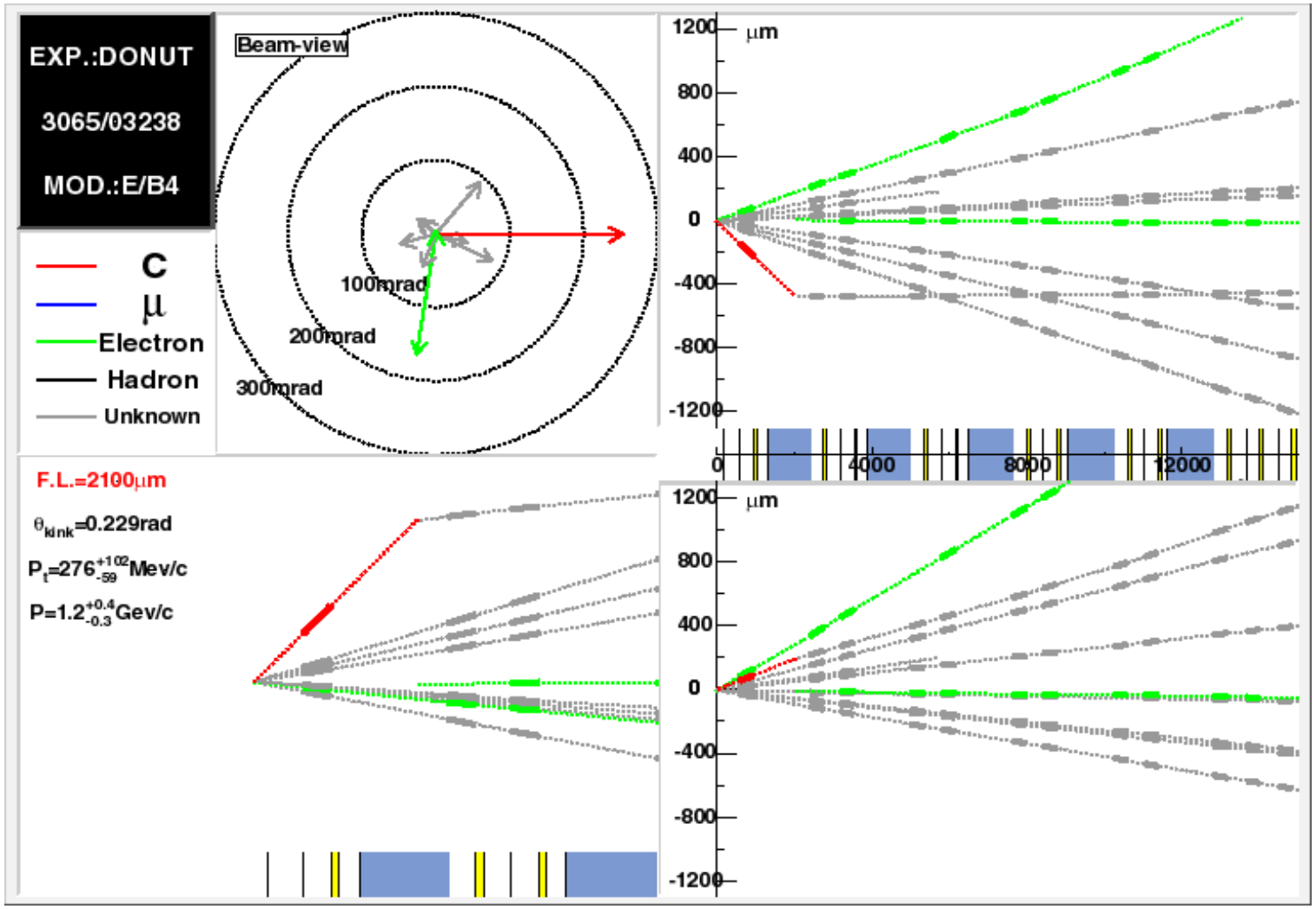
Example: Kink: ν_τ CC interaction



Example: Trident: ν_τ CC interaction

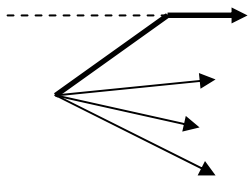


Example: Charm event: e + c

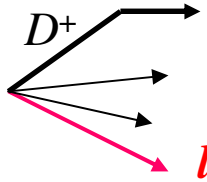


Kink Classification

- Randomly associated tracks
  - e.g. Primary track + stale muon track

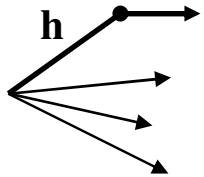


- *Charm* background

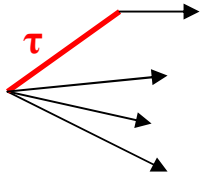


lepton : not recognized

- Interactions (scattering)



- Tau signal



Tau/Charm Selection

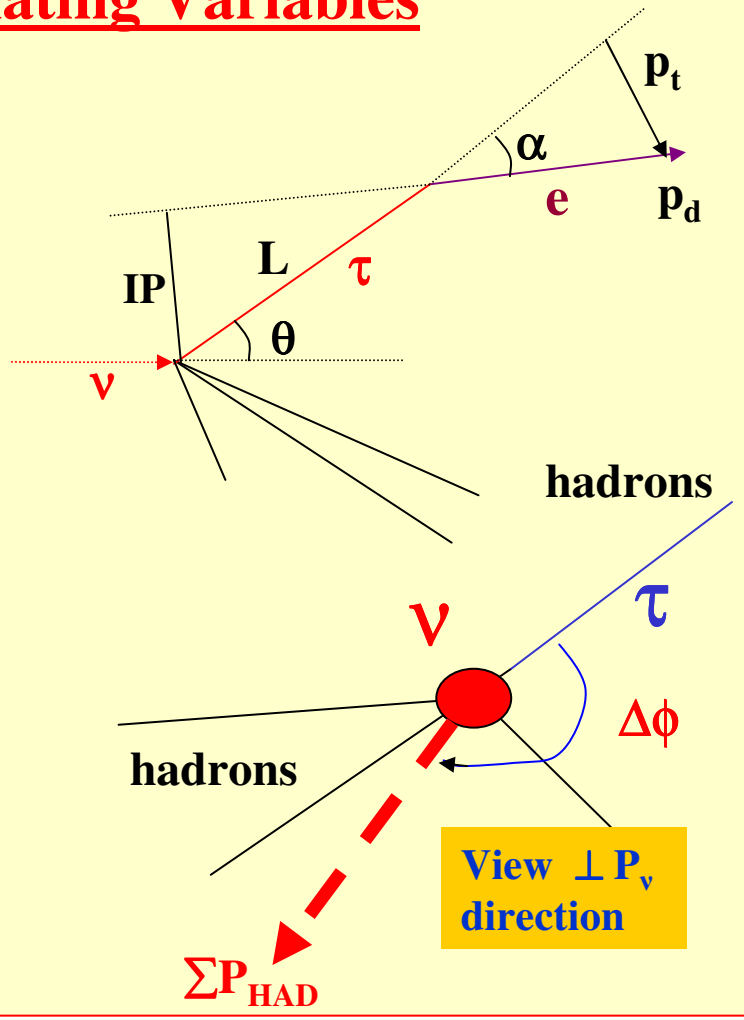
Discriminating Variables

A. Kinks: 5 Parameters

- Production angle, θ
- Azimuthal asymmetry: Δφ
- Decay length: L
- Kink angle: α
- Daughter momentum: P_d

B. Tridents: 4 Parameters

- Production angle, θ
- Azimuthal asymmetry: Δφ
- Decay length: L
- Sum of IPs: Σ(IP)



ν - τau Event List

Kinks

DONUT Preliminary

Run	Event	FL (mm)	θ_{kink} (rad)	IP (μm)	Daug t	P (GeV/c)	P_T (GeV/c)	P_T	P_c	P_l
3024	30175	4.47	0.093	416.0	e	5.2.± 0.8	0.48	0.64	0.36	0.0
3039	01910	0.28	0.089	23.5	h	$4.6^{+1.6}_{-1.0}$	0.41	0.96	0.04	0.0
3140	22143	4.83	0.012	60.2	μ+	$16.8^{+18.4}_{-6.0}$	0.20	0.97	0.03	0.0
3333	17665	0.66	0.011	7.7	e	53 .± 12	0.69	0.99	0.01	0.0
3024	18706	1.7	0.014	22.6	e	50 .± 10	0.70	1.0	0.0	0.0
3139	22722	0.53	0.022	11.8	h	$15.8^{+12.7}_{-5.1}$	0.35			

ν - ταυ Event List

Tridents

DONUT Preliminary

Run	Event	FL (mm)	θ_d (rad)	IP (μm)	P (GeV/c)	P_T (GeV/c)	P_τ	P_c	P_l
3296	18816	0.78	0.054	38.2	5.0	0.27	0.71	0.29	0.0
			0.190	148.1	$1.3^{+0.6}_{-0.3}$	0.25			
		0.80	0.130	112.0	1.9	0.25			
3334	19920	8.88	0.017	147.4	$11.6^{+5.9}_{-3.0}$	0.20	1.0	0.0	0.0
			0.011	98.0	$15.7^{+17.2}_{-5.6}$	0.17			
			0.011	94.1	$3.2^{+1.1}_{-0.7}$	0.04			
3250	01713	0.83	0.133	109.9	$1.3^{+.03}_{-0.2}$	0.17	0.71	0.03	0.26
			0.192	160.7	$2.4^{+0.8}_{-0.5}$	0.46			
			0.442	354.7	$0.5^{+0.2}_{-0.1}$	0.21			

Cross Section Estimation

	N^{obs}	ε
ν_τ	9	0.49
ν_e	143	0.57
ν_μ	210	0.56

DONUT Preliminary

Prompt ν_μ fraction = 0.60 ± 0.11

ν_τ/ν_e σ_{DIS} ratio = 1.04 ± 0.41 ± 0.18

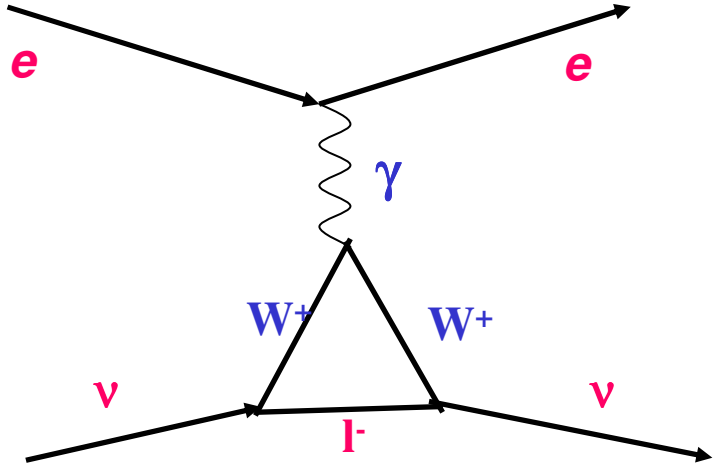
Statistical

Charm BR′ s
Production σ′ s

ν_τ/ν_μ σ_{DIS} ratio = 1.00 ± 0.40 ± 0.14

ν - tau Magnetic Moment

Interaction of ν with e^- via a dipole moment has a distinct signature
- single, forward e^-
- dominates e-w process
for $T_e/E_\nu < 0.2$



$$\frac{d\sigma^{\mu}}{dy} \propto \left(\frac{\mu_\nu}{\mu_B}\right)^2 \left(\frac{E_\nu}{T} - 1\right)$$

1 event observed after cuts
2.3 Bgnd events expected

$\mu_\nu < 3.9 \times 10^{-7}\ \mu_B$ **90% CL**

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ν - tau Mass

Effective mass squared: $m^2_{\nu\tau} = \sum_i |U_{\tau i}|^2 m^2_{\nu i}$

$m^2_{\nu\tau} \leq \mathrm{Max}_i \{m^2_{\nu i}\}$

Most stringent limit: ALEPH, 1998

From $\tau^- \rightarrow 2\pi^- \pi^+ \nu_\tau$ @ $\tau^- \rightarrow 3\pi^- 2\pi^+ (\pi^0) \nu_\tau$

(From the fit the distribution of E_h vs m_h)

$m_{\nu\tau} < 18.2$ MeV/c^2 at 95% CL

Present S-M Properties

V-A coupling: τ- decay

• τ – ν_τ coupling: V-A : τ-lepton decay parameters: LEP (ALEPH, DELPHI, L3, OPAL), ARGUS, SLD, MAC, CLEO. Most precise ALEPH.

Michel Parameters

Parameter	SM	ALEPH	PDG Fit	PDG Average
ρ (e or μ)	3/4	0.742±0.014 ± 0.006	0.745±0.008	0.749±0.008
ξ (e or μ)	1	0.986±0.068 ± 0.031	0.985±0.030	0.981±0.031
η (e or μ)	0	0.012±0.026± 0.004	0.013±0.020	0.015±0.021
(δξ) (e or μ)	3/4	0.776±0.045± 0.024	0.746±0.021	0.744±0.022

Present S-M Properties

Universality

Strength of coupling from τ-lepton lifetime. If $G_\tau = G_\mu$ (Universality)

$$\rightarrow \quad \tau_\tau \approx (m_\mu/m_\tau)^5 \tau_\mu BR(\tau \rightarrow e) = 2.91 \times 10^{-13}\ s$$

Most precise data from DELPHI, ALEPH, L3, OPAL, CLEO

$$\tau_\tau = (2.909 \pm 0.014 \pm 0.010) \times 10^{-13}\ s \quad \text{(DELPHI)}$$

$$\tau_\tau = (2.906 \pm 0.010) \times 10^{-13}\ s \quad \text{(PDG Average))}$$

Number of Neutrinos from tle LEP Experiments

$$N_\nu = 2.9840 \pm 0.0082$$

Summary and Conclusions

- DONUT has directly observed the tau-neutrino as a particle via its CC interactions with nuclei.
- 9 (CC) tau events have been identified in DONUT. Number consistent with expectations from the S-M. (Also consistent with charm production from prompt ν_μ, ν_e).
- First measurement of ν_τN DIS consistent with S-M.
- We have precise τ – decay studies from collider experiments (Michel parameters, life time) and $N_\nu = 3$ from LEP which are in excellent agreement with the S-M.
- **Conclusion:** Above properties justify assigning this neutral particle of J=1/2, H = -1, as the weak isospin ½ partner of the τ-lepton .