



v 2000  
17 June 00

# DONUT

## *Direct Observation of Nu Tau*

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The primary goal is to directly observe the charged-current interactions of the tau-neutrino.

The experiment can find and identify tau-lepton decays using an emulsion target and spectrometer.

Byron Lundberg FERMILAB  
*for the DONUT collaboration*



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# DONUT Collaboration

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- Nagoya, Kobe, Aichi
- FNAL, Minnesota, Pittsburgh, Kansas State, Tufts, South Carolina
- Athens
- Gyeonsang, Kon-kuk

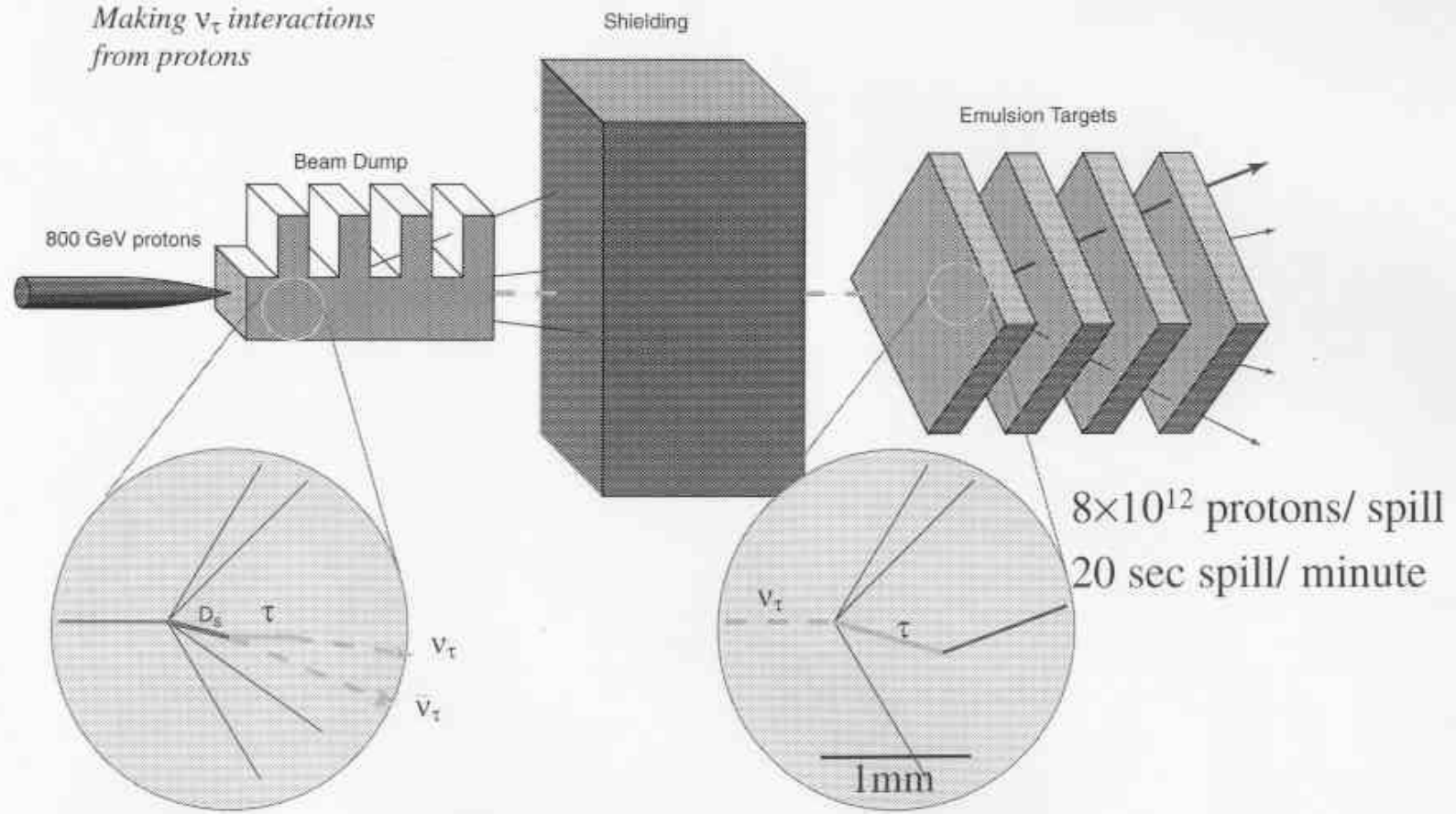


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# Prompt Neutrino Beam

*E-872*

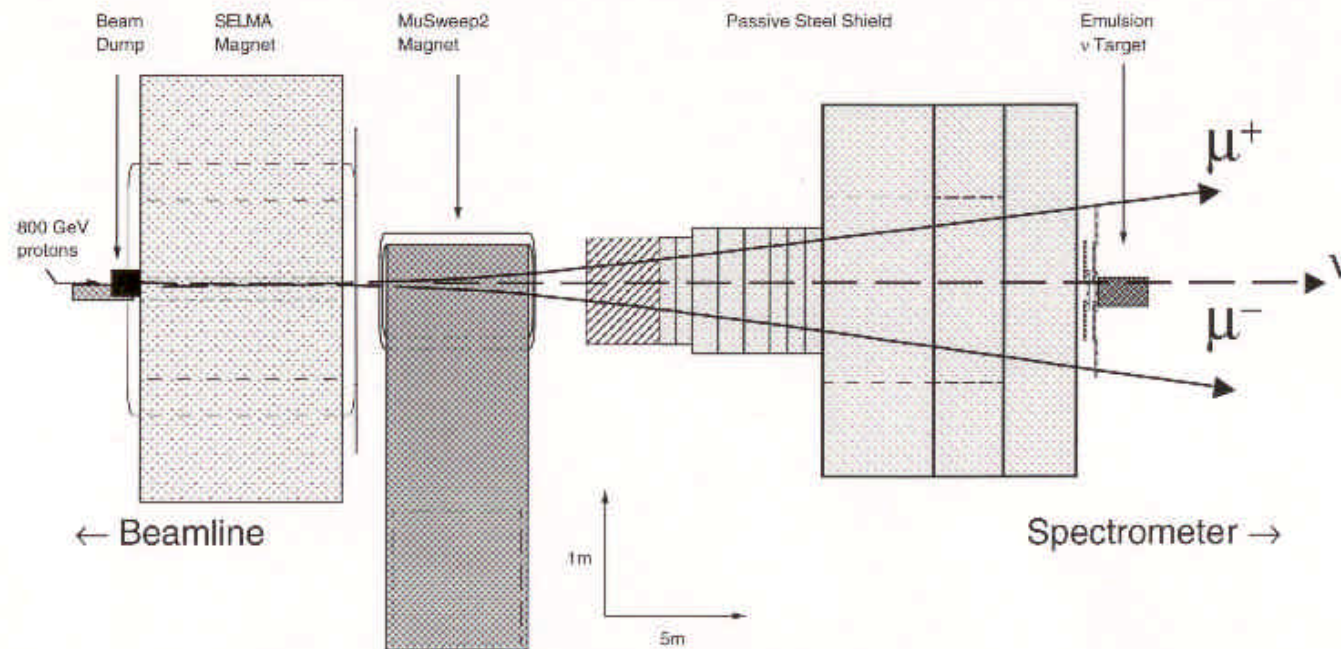
*Making  $\nu_\tau$  interactions  
from protons*





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# Prompt $\nu$ Beam /Shield

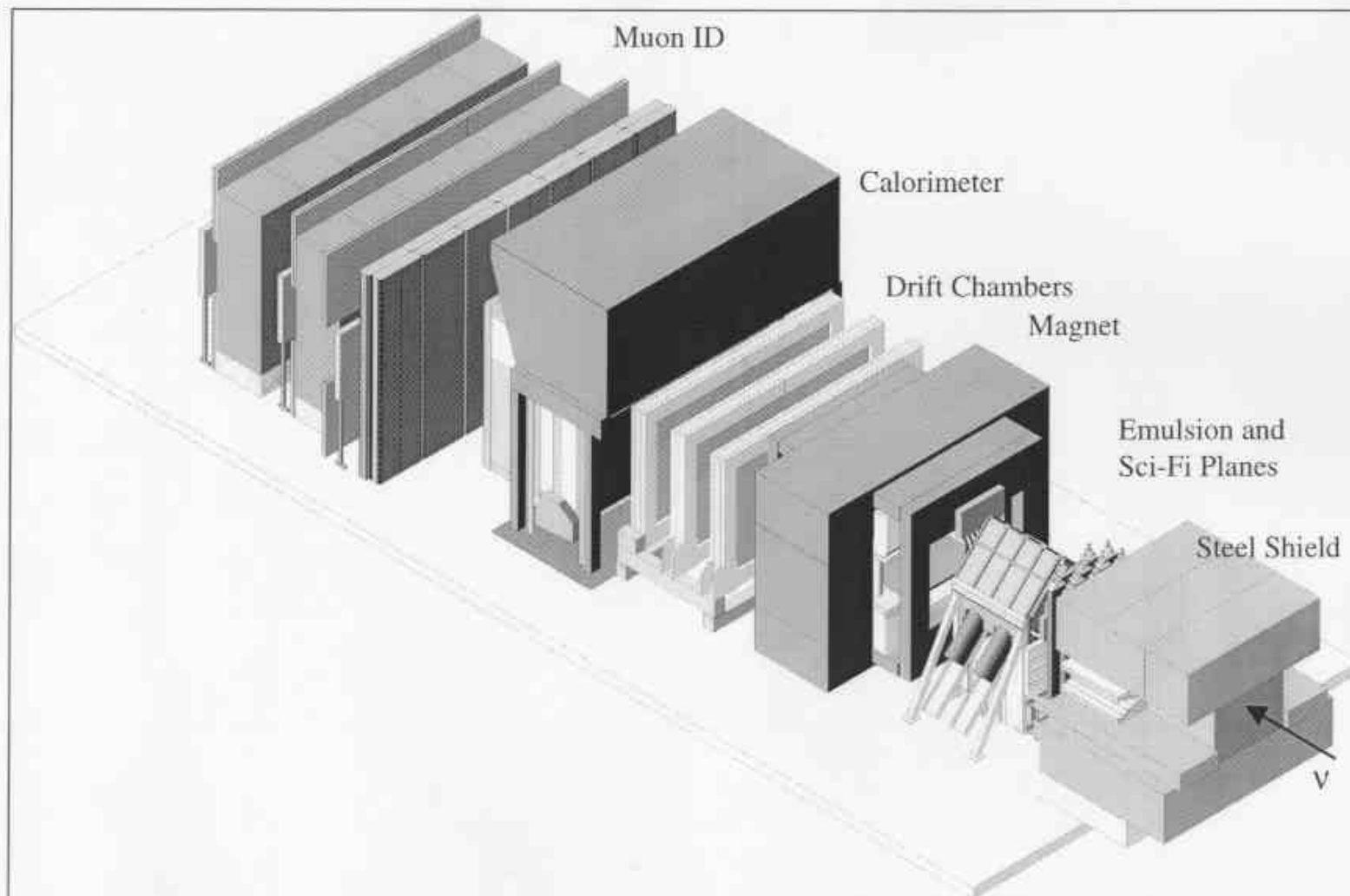


- Emulsion Target 36m from beam dump
- Muon rate  $\sim 2 \times 10^4$  per  $10^{13}$  pot in target area



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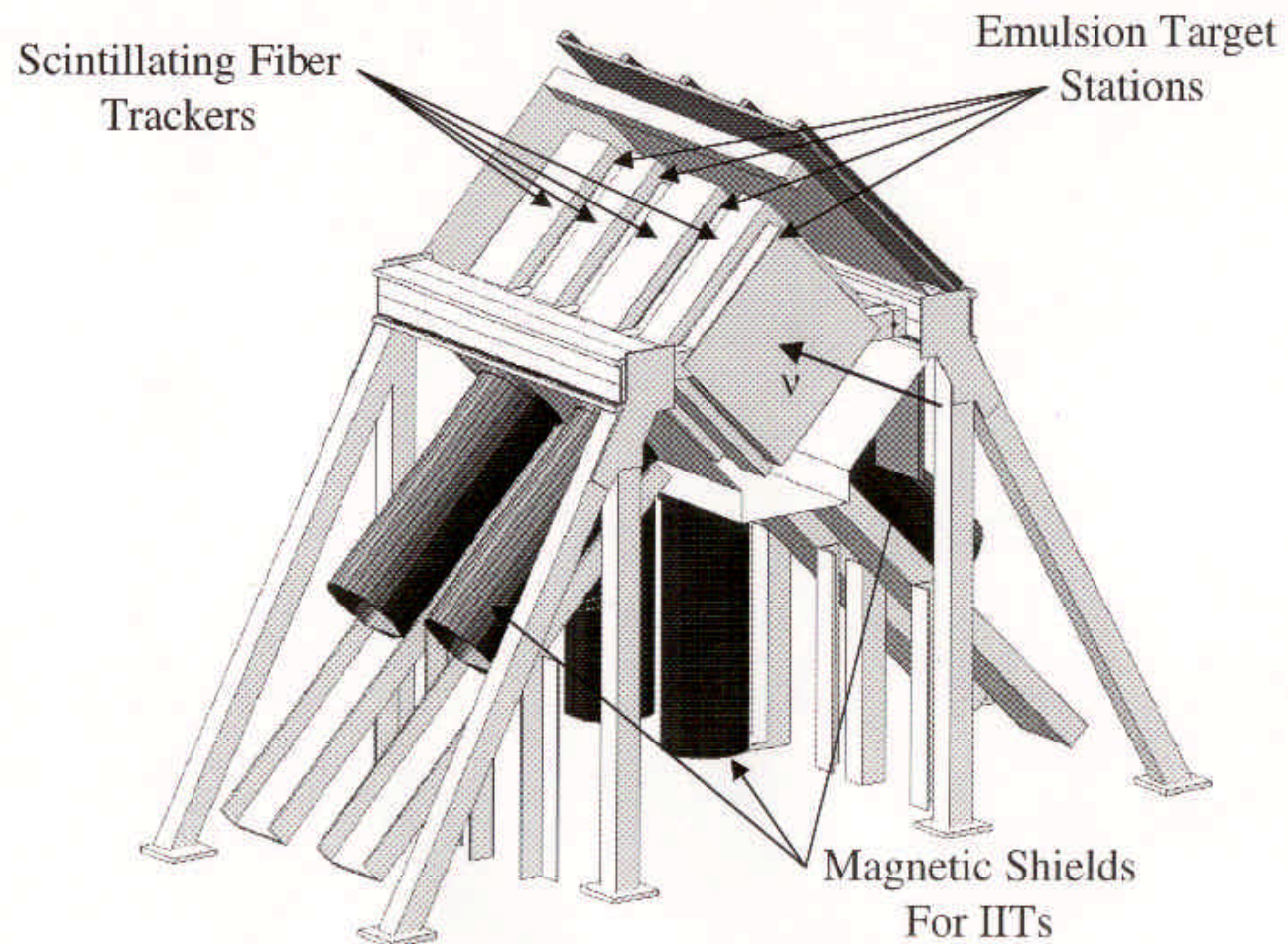
# Spectrometer





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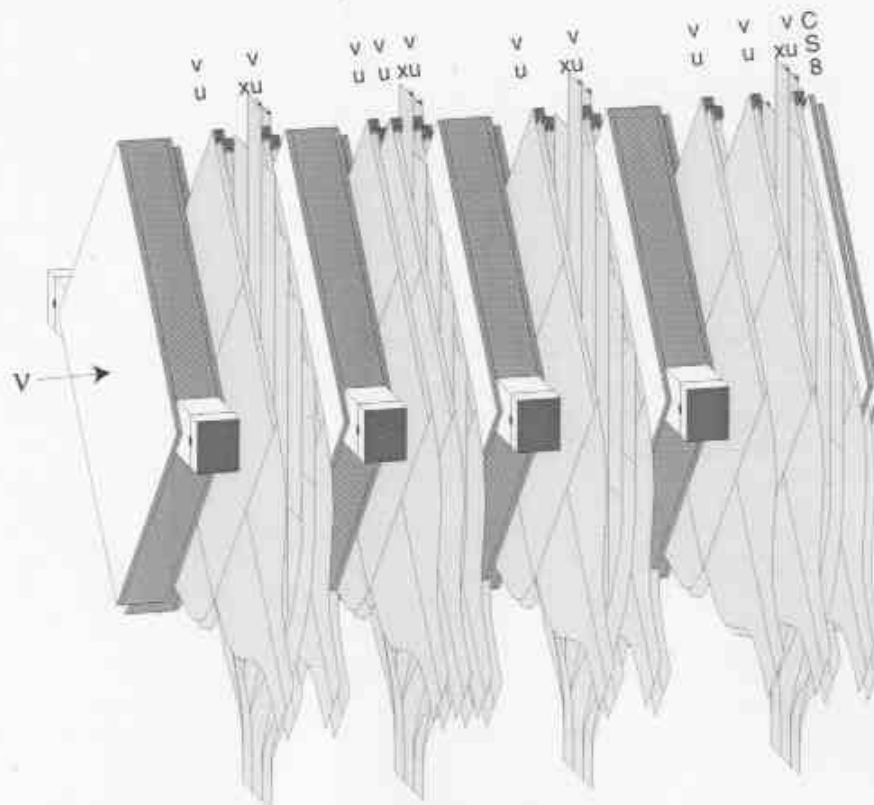
# Emulsion Target





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# Emulsion Target / Vertex Detector



- Four target stations
- 260 kg total fiducial
- Interleaved with sci-fi
- Total 7 modules exposed
- Modules  $\sim 2-3 X_0$  each



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# $\nu$ Flux / Interactions

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Prompt  $\nu$  beam  $\Rightarrow$  number  $\nu_e \sim$  number  $\nu_\mu$

Primary  $\nu_\tau$  source  $D_S \rightarrow \nu_\tau \tau \rightarrow \bar{\nu}_\tau X$

$\nu_e + \nu_\mu$	$2.5 \times 10^{-4} /(\text{pot } m^2)$	52 GeV
$\nu_\tau$	$2.1 \times 10^{-5} /(\text{pot } m^2)$	54 GeV

Total *protons on target* =  $3.6 \times 10^{17}$

Expected number of interactions = 1100 (all types)

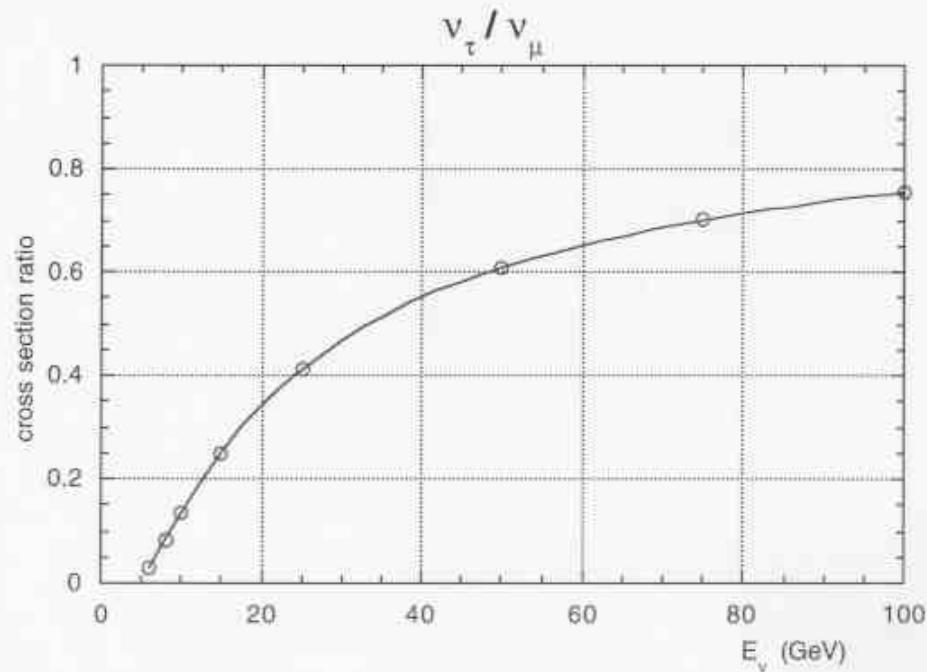
Data taken from April to September 1997





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# How many $\nu_\tau$ ?



Expected number of  $\nu_\tau$  interactions:

~ **5%** of total

Uncertainties:

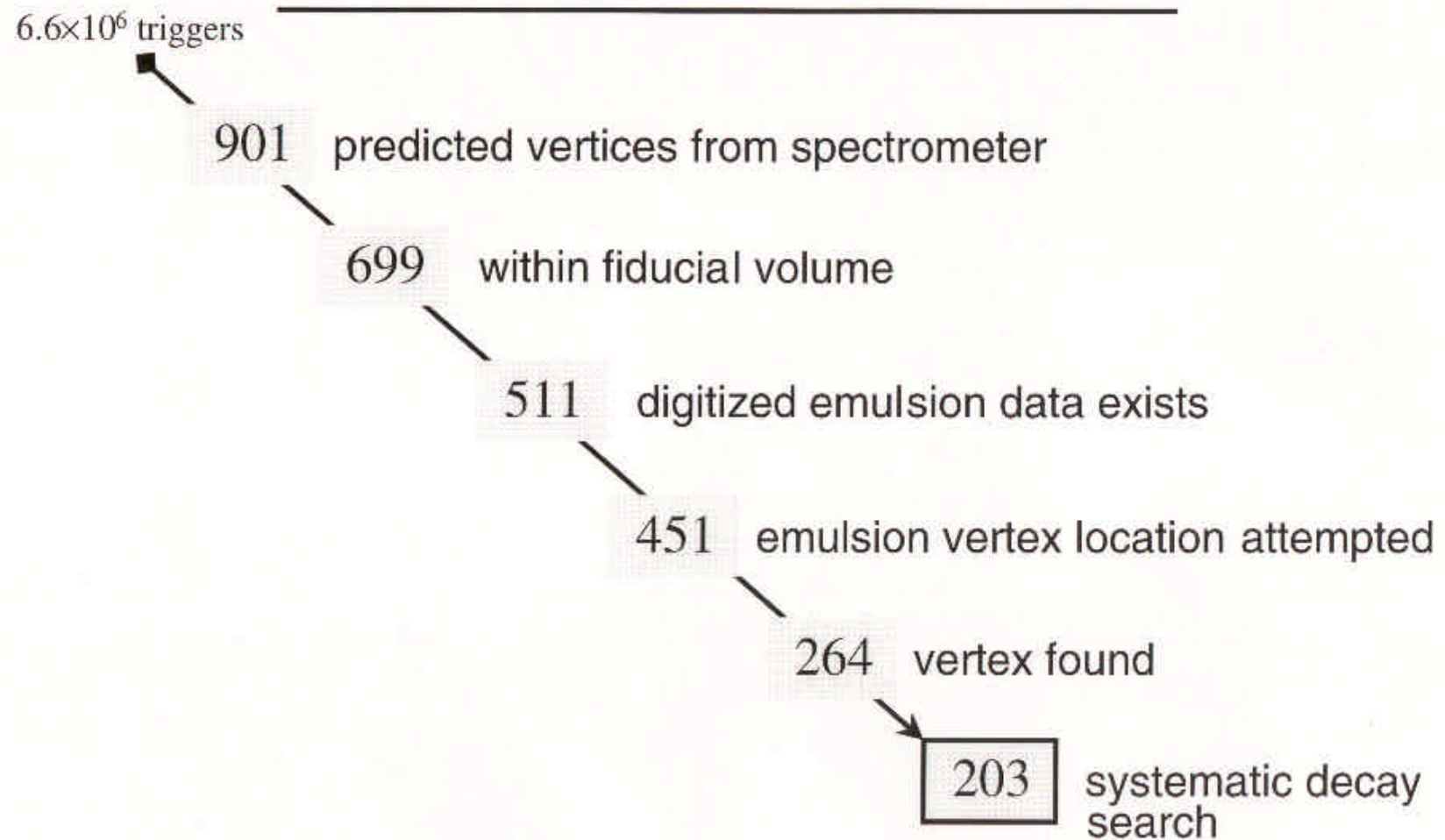
$D_S$  production  $\pm 20\%$

$f_{D_S} \Rightarrow \text{BR}$   $\pm 15\%$



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# Data Set





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# Data Sample : 203 events

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203 events:

- Primary located in emulsion
- Emulsion data well calibrated
- Decay search performed
- Systematic studies *nearly* complete



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# 203 set : $\nu_{\mu}$ CC Events

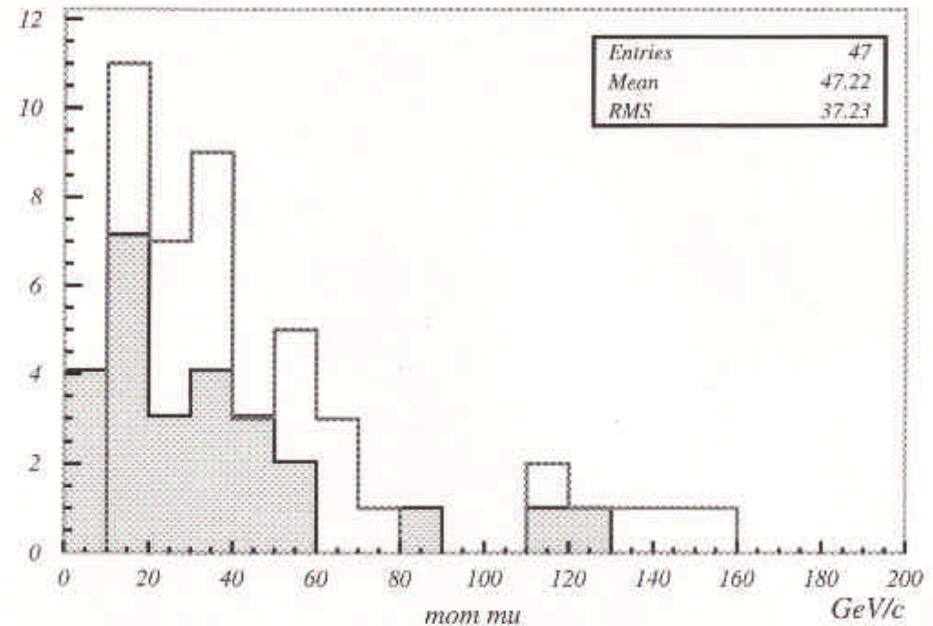
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75  $\nu_{\mu}$  CC interactions

- 47  $\mu^{-}$
- 28  $\mu^{+}$

$$\frac{N(-)}{N(+)} = 1.7$$

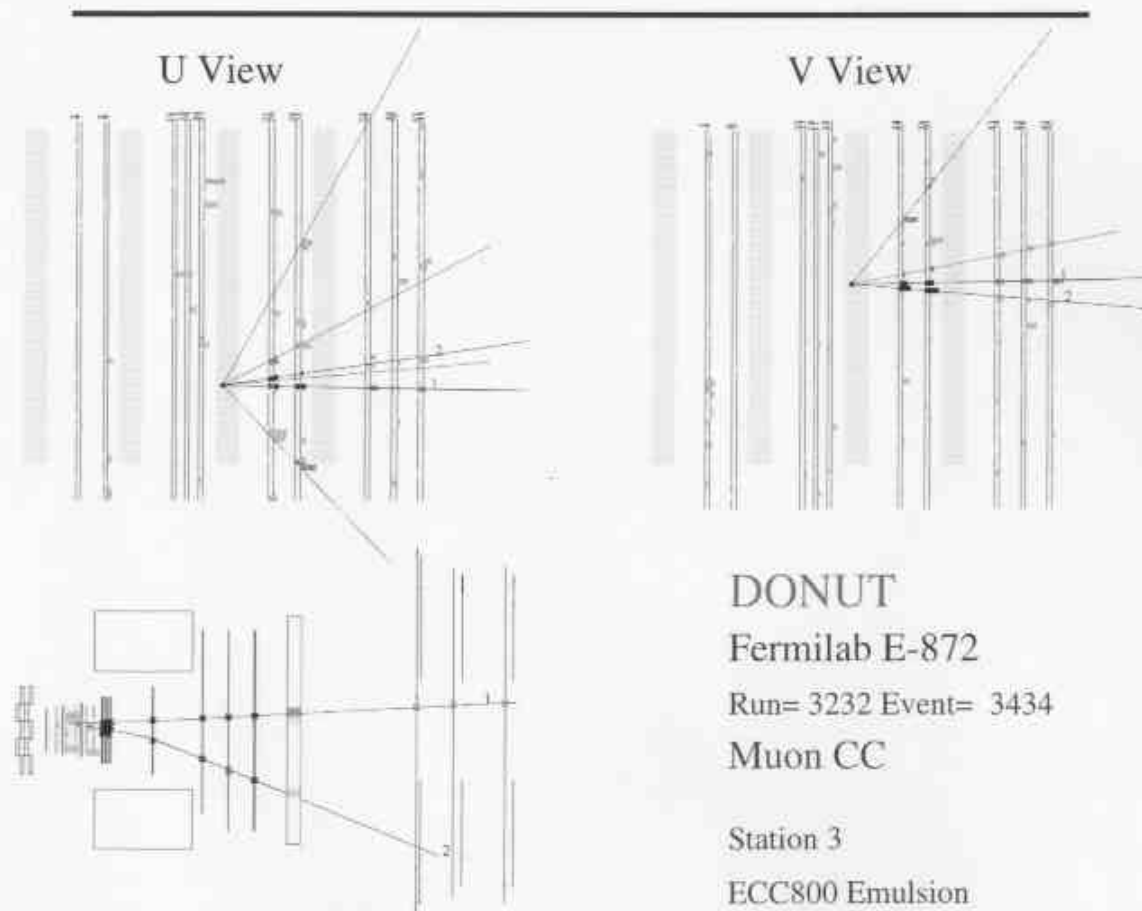
*expect* 1.8





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# $\nu_\mu$ CC interaction



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Fermilab E-872

Run= 3232 Event= 3434

Muon CC

Station 3

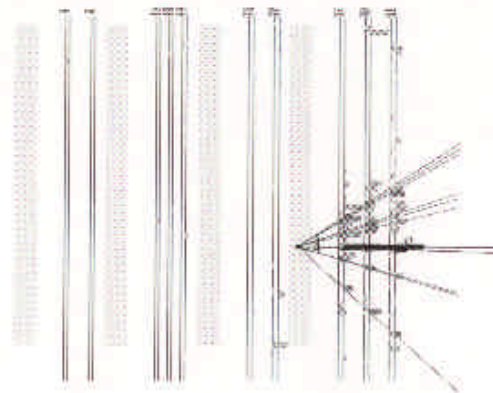
ECC800 Emulsion



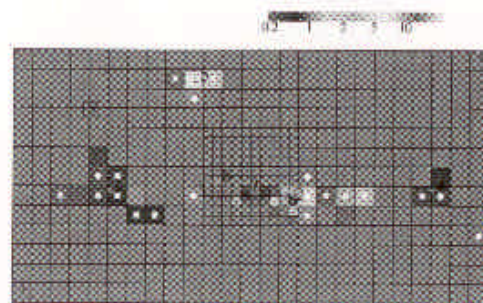
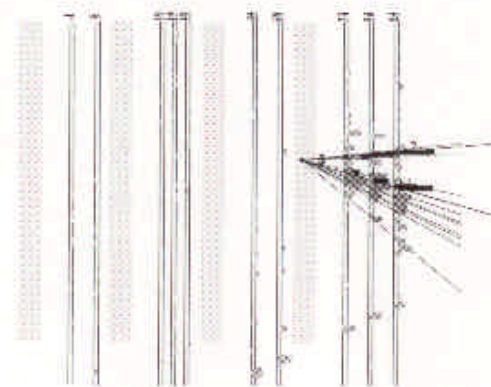
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# $\nu_e$ CC interaction

U View



V View



Cluster  $\Sigma E$  104 GeV

4.7  
13.1  
13.8  
1.0  
0.3

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Fermilab E-872

Run= 3250 Event= 470

Electron CC

Station 4

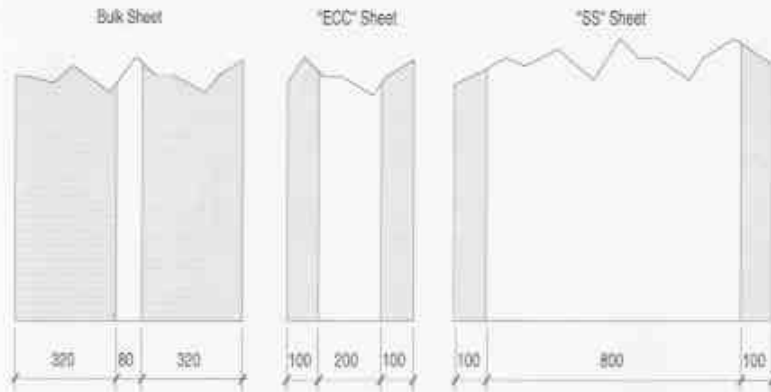
Bulk Emulsion



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# Emulsion Plates

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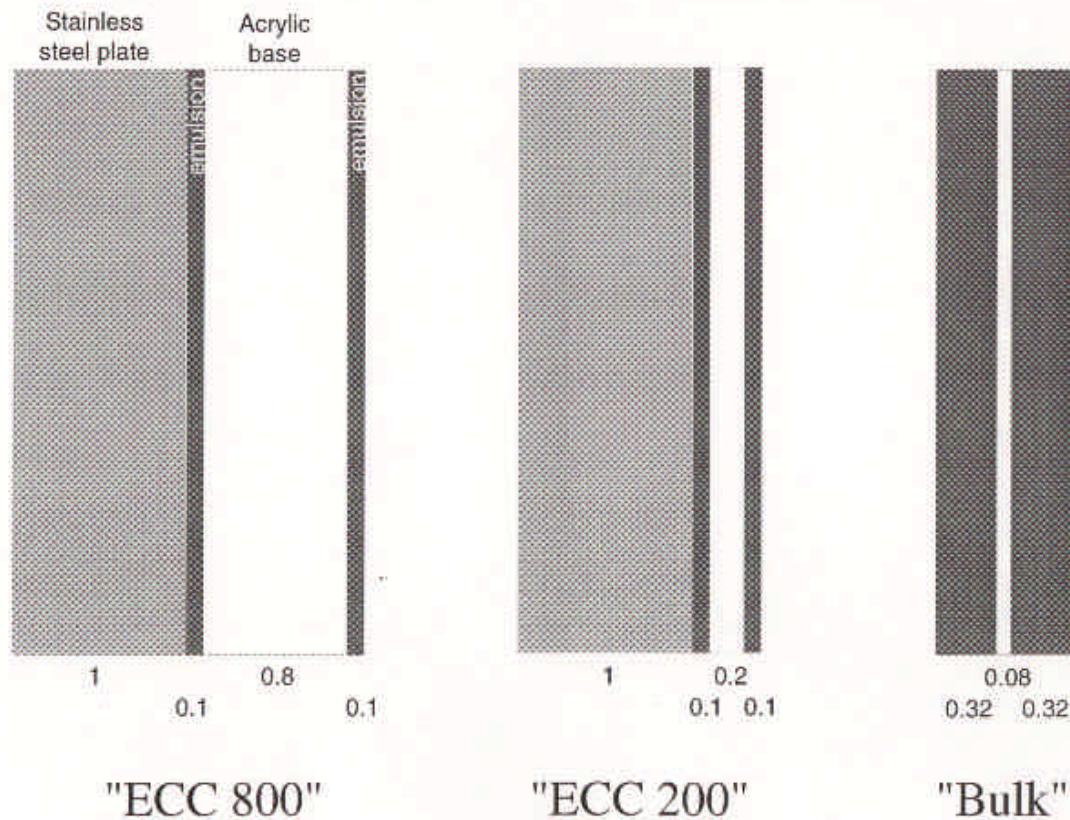
- Fuji ET7C
- Grain size  $0.7 \pm 0.2 \mu\text{m}$
- $29 \pm 2$  grains per  $100 \mu\text{m}$  for m.i. track
- *Information capacity* (i.e.  $50 \times 50 \times 6 \text{ cm}^3$ ) :  
 $1 \times 10^5 \text{ tracks/cm}^2 @ 3000 \text{ grains/cm} \Rightarrow$   
 $10^{12} \text{ grains} \Rightarrow \sim \text{Terabytes of data}$

**AgBr** suspended  
in a gel is coated  
on plastic sheets.



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# Target Designs



- 3 target types
- Bulk 95% emulsion
- ECC 5% emulsion
- ECC for OPERA

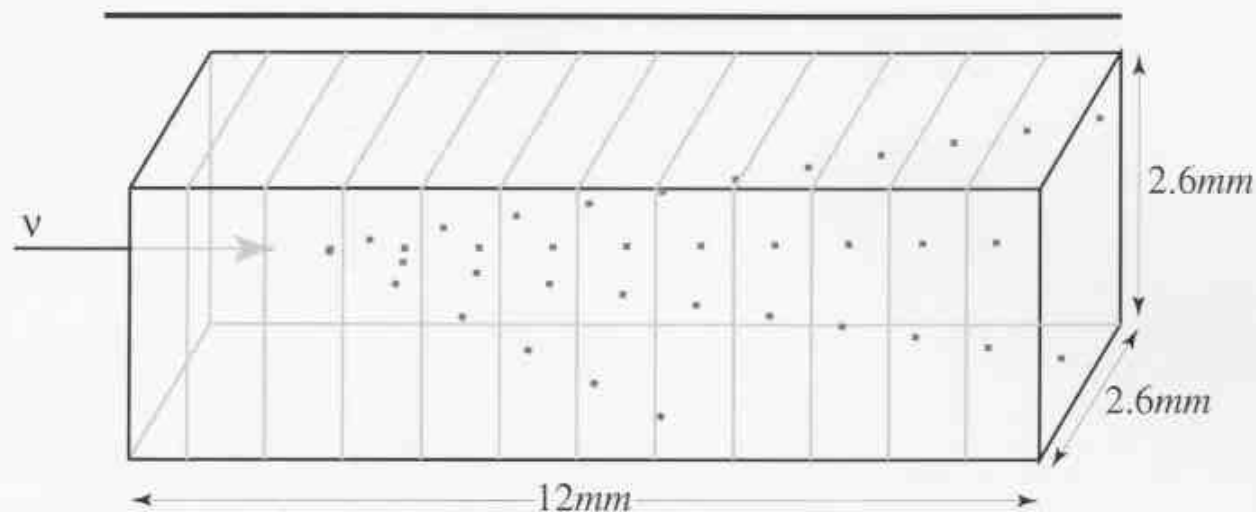




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# Emulsion Scan Volume

## Decay Search

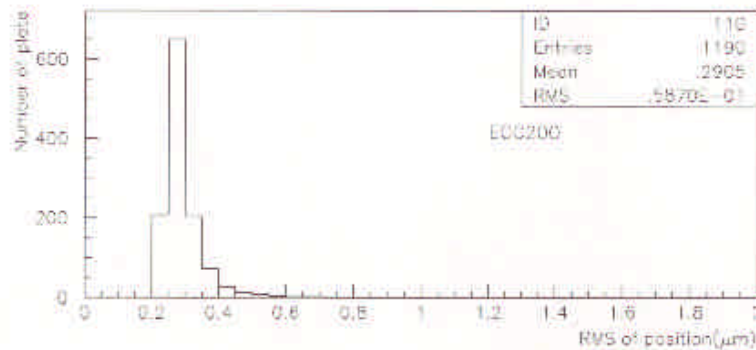
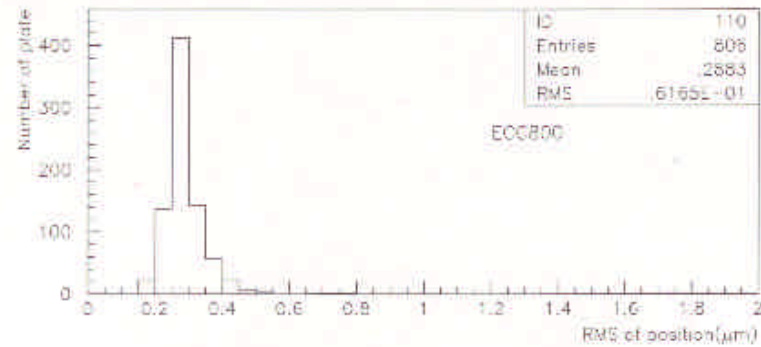
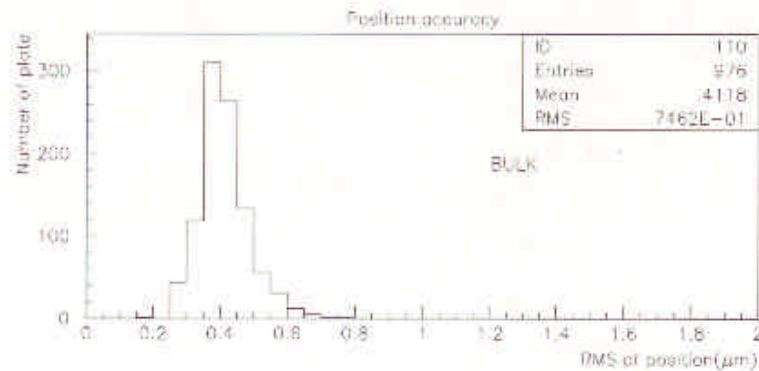


- Emulsion data digitized, stored on disk
- Vertex, decay search similar to electronic detectors
- Background muon tracks  $\sim 5 \times 10^4 \text{ cm}^{-2}$



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# Emulsion Performance: Spatial Resolution



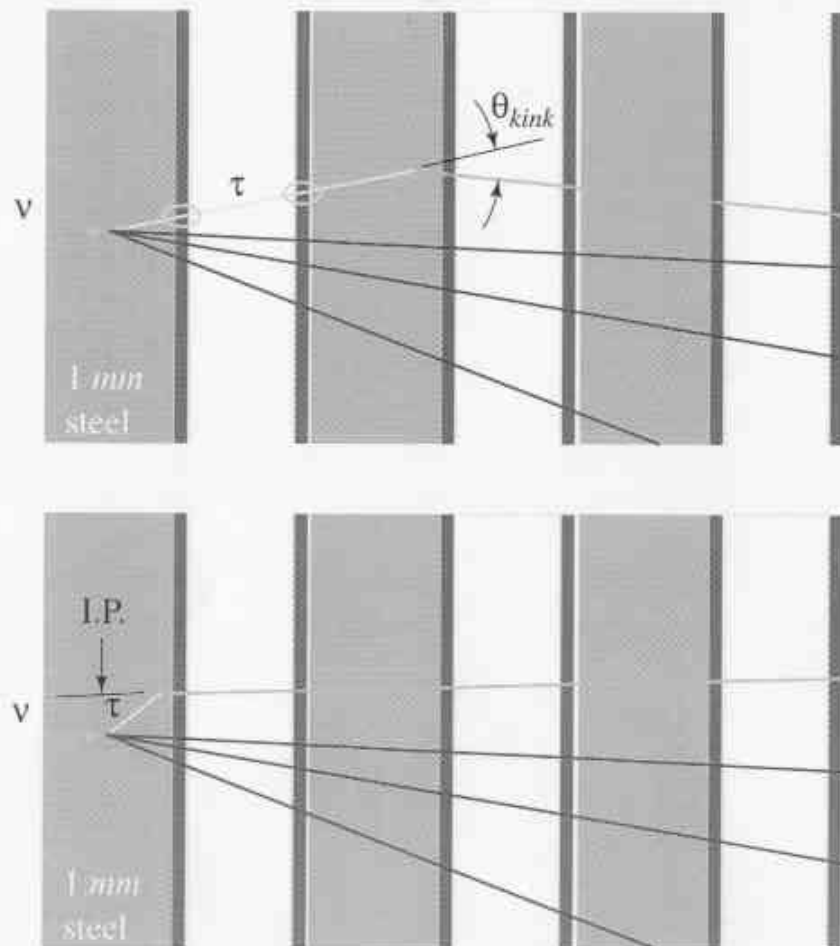
Emulsion data calibrated to  $0.3 \mu\text{m}$  in transverse coordinates ( $0.4 \mu\text{m}$  for bulk emulsion)

Typical vertex precision (C5)  $0.5 \mu\text{m}$  transverse, and  $15 \mu\text{m}$  along beam



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# C1 Decay Search



## 1. *Long Decays*

- parent measured
- kink resolved
- $\tau \Rightarrow$  no 1<sup>st</sup> lepton
- $\sim 75\%$

## 2. *Short Decays*

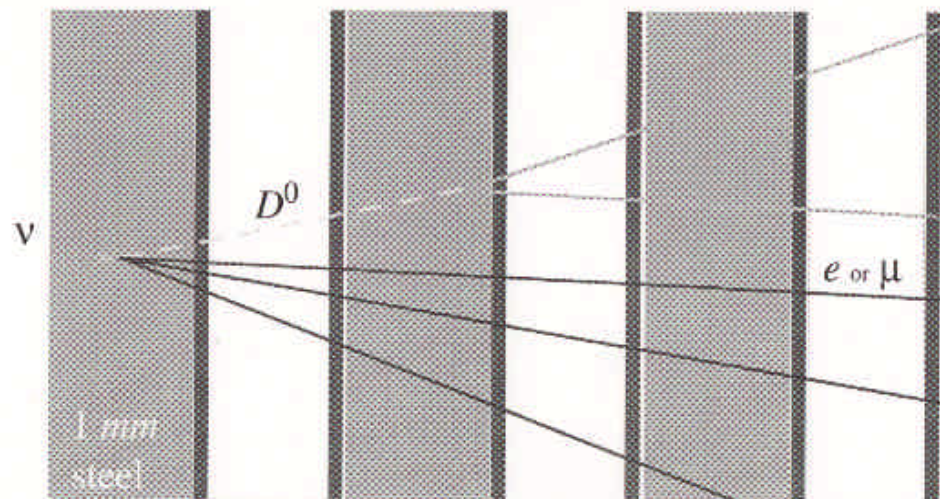
- IP wrt 1<sup>st</sup> vertex
- only daughter meas.
- daughter seen in spect.
- $\sim 25\%$



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# Neutral Decay Search

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### 3. Neutral search

- *charm* only
- daughters in spect.



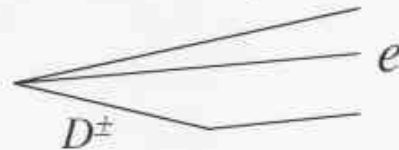
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## $\tau$ Background : *charm*

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$\nu_{e,\mu} \rightarrow \text{charm} (D^{0,\pm})$  provides good systematic check of data...

*but* is also a background to  $\nu_\tau \rightarrow \tau$  if lepton from  $l^\gamma$  not seen



$$\begin{aligned} N_{charm}^{kink} &= CC/tot \cdot \text{charm fraction} \cdot D^\pm \text{ fraction} \cdot \text{kink decay} \cdot 203 \text{ ev.} \\ &= 0.75 \cdot 0.07 \cdot 0.4 \cdot 0.4 \cdot 203 \\ &= 1.7 \text{ events} \end{aligned}$$

$$\begin{aligned} N_{charm}(\text{background}) &= 1.7 \cdot (1 - \epsilon_{lep}) \cdot \epsilon_{decay} \\ &< 0.3 \text{ events} \end{aligned}$$

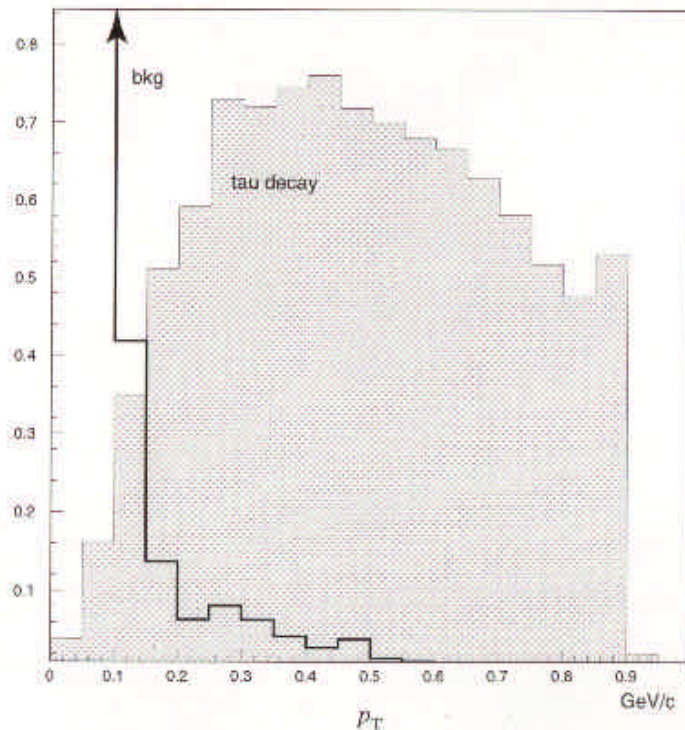


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# $\tau$ Background : *Interactions*

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“NC interactions” + hadron scatter =  $\tau$  background



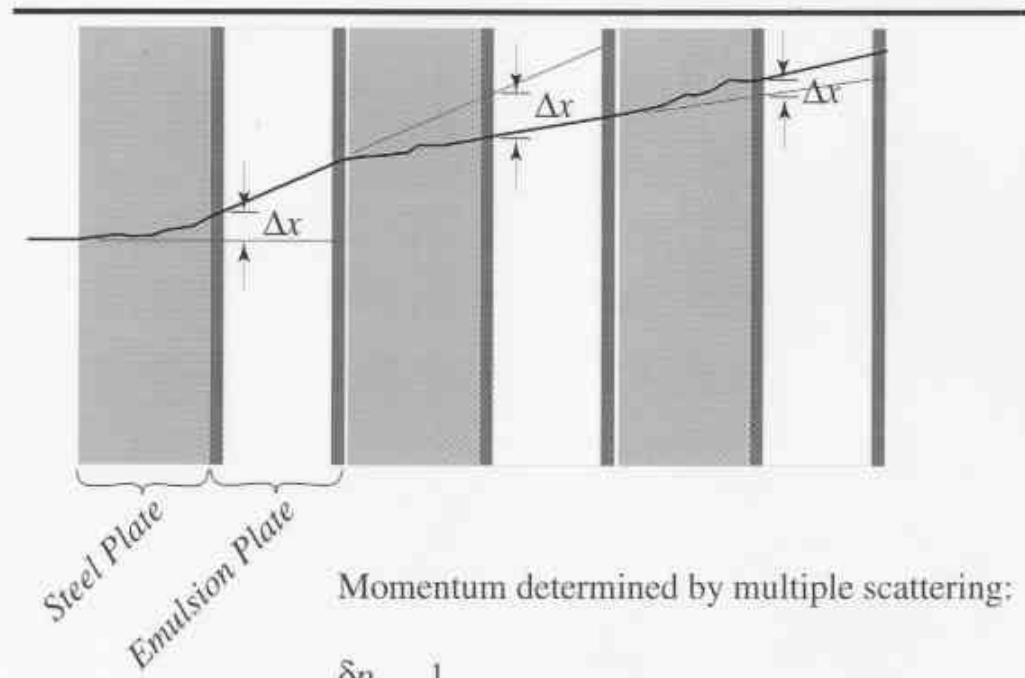
- Rapidly decreasing with  $p_T$
- Depends on total path length
- *Short / Long* separate analysis

Estimated background using  
GEANT calculation :

0.2 - 0.3 event



# Momentum Measured using Multiple Scattering in Emulsion Targets



Momentum determined by multiple scattering:

$$\frac{\delta p}{p} \propto \frac{1}{\sqrt{n}}$$

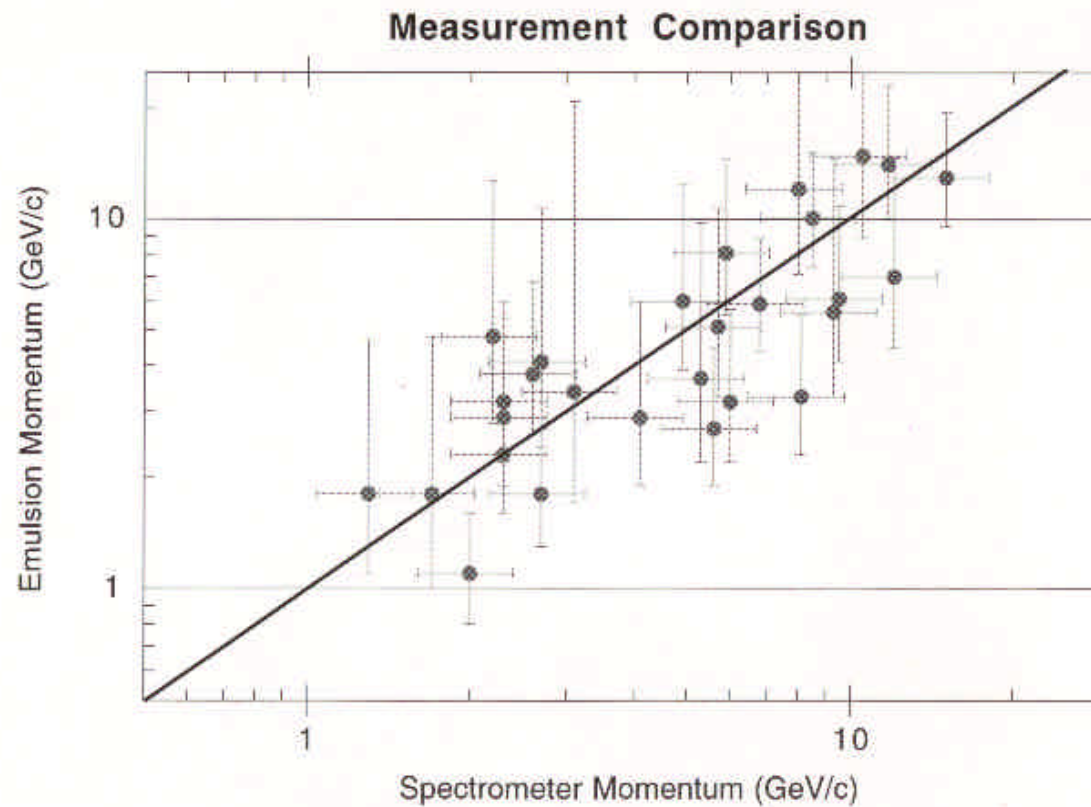
if ( $p = 10 \text{ GeV}/c$ ;  $1\text{mm}$  steel) then

$$\frac{\delta \theta_{rms}}{\theta_{rms}} = 0.3 \mu m$$



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# Momentum Measured using Multiple Scattering in Emulsion Targets







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# Summary: *charm* in 203 set

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*charm* production provides an important  
systematic check of  $\tau$  analysis

$$\text{expect } \underbrace{(0.75)}_{\text{CC/tot}} \underbrace{(0.07)}_{\text{charm}} \underbrace{(0.4)}_{\text{chgd}} \underbrace{(203)}_{\text{N}} (\epsilon_{\text{decay}}) = 4.3 \pm 0.8 \times \epsilon_{\text{decay}} D^{\pm}$$

and  $6.5 \pm 1.3 \times \epsilon_{\text{decay}} D^0$

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- 1 event from *Long* decay search ( kink decay)
- 1 event *di-lepton* tag ( $\mu^+ \mu^-$ )
- 2 events from *Neutral* decay search



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# Summary: $\tau$ candidates

from 203 set

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- 4 events from *Long* decay search;

$$\text{expect } \underbrace{(0.048)}_{\tau \text{ frac}} \underbrace{(0.86)}_{\text{CI decay}} \underbrace{(0.75)}_{\text{Long}} \underbrace{(203)}_N (\epsilon_{\text{decay}}) = 6.4 \pm 1.7 \times \epsilon_{\text{decay}}$$

- 1 event from *Short* decay search

$$\text{expect } 2.1 \pm 0.5 \times \epsilon_{\text{decay}}$$

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## Background Analysis:

*Hadronic interactions* : 0.2 to 0.3 events\*

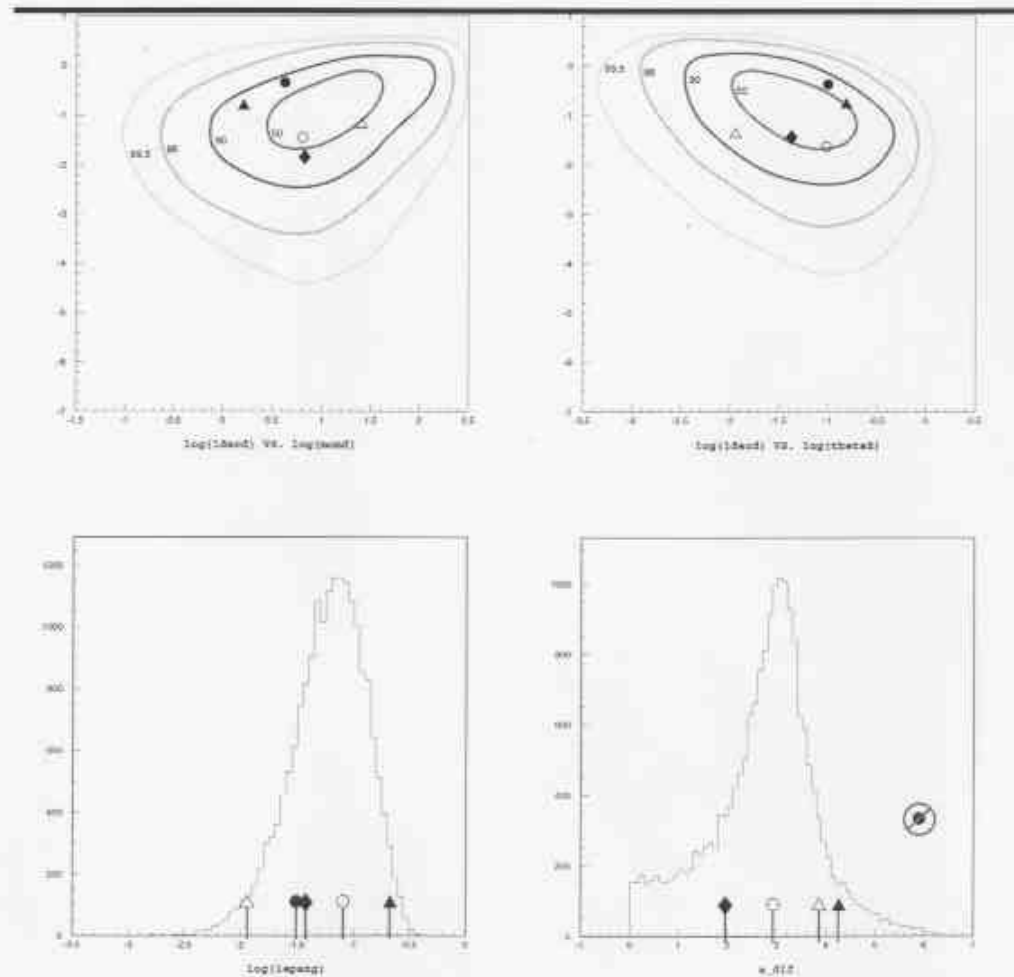
*Charm* : <0.3 events\*

\* studies in progress



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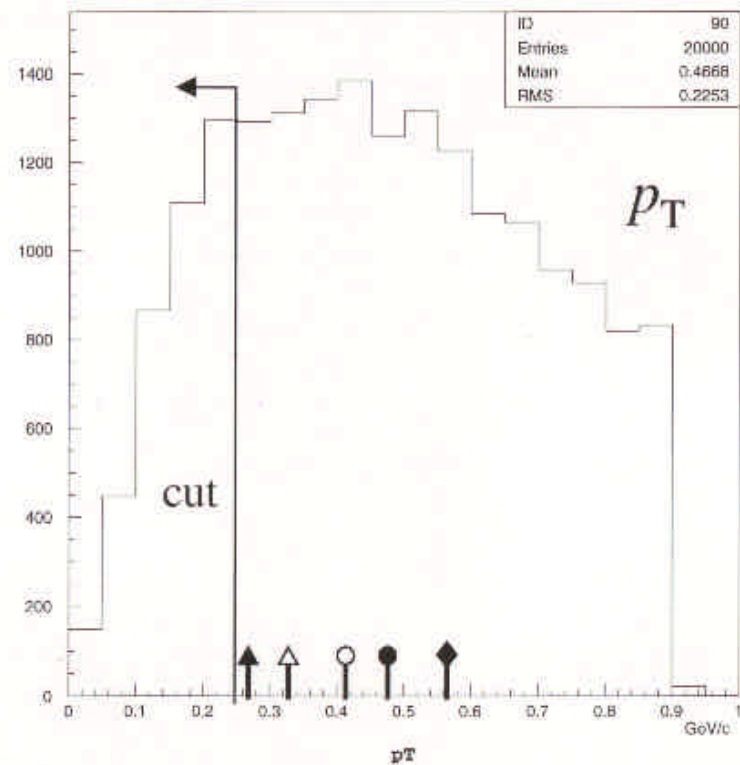
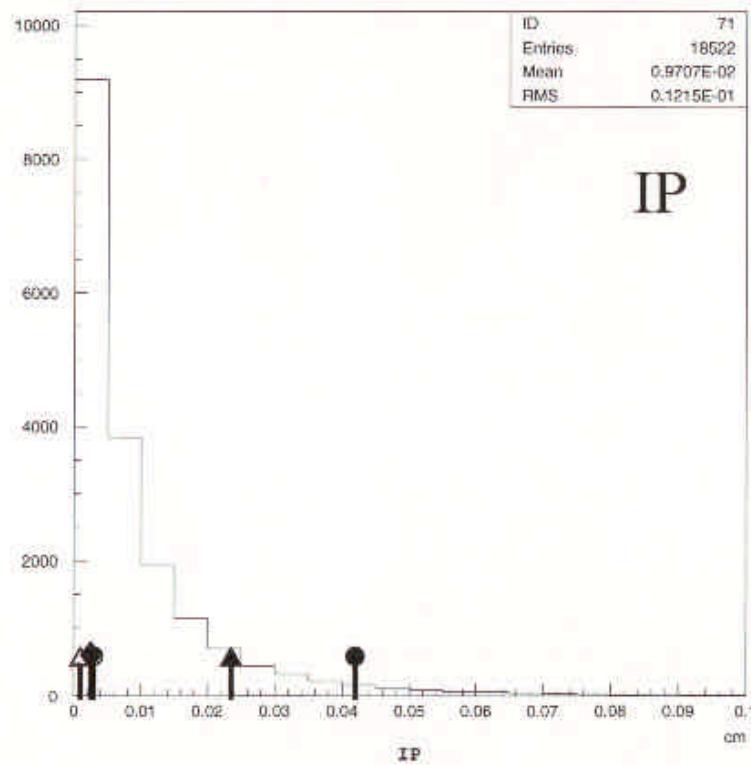
# $\tau$ candidates: Expected Distributions





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# $\tau$ candidates: Expected Distributions



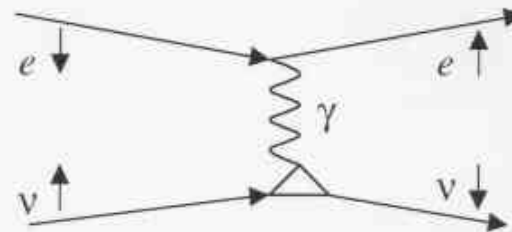


# $\nu_\tau$ magnetic moment

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- Interaction of  $\nu$  with  $e^-$  via a dipole moment has a distinct signature

- single, forward  $e^-$
- dominates e-w process for  $T/E < 0.2$



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

2 events observed satisfying cuts; 4.4 events expected

$$\mu_\nu < 4.2 \times 10^{-7} \mu_B$$

90% CL



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## In Conclusion

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- We have 5 tau candidates in a sample of 203 interactions
  - Agrees with expected number and expected distribution
  - ...but at this time, background checks in progress
  - Hope to have complete results in a few weeks
  - Increase sample to 300 interactions
- Charm signal at expected level
- Efficiency study of decay search also in progress

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Fermilab E-872

Run= 3024 Event= 30175

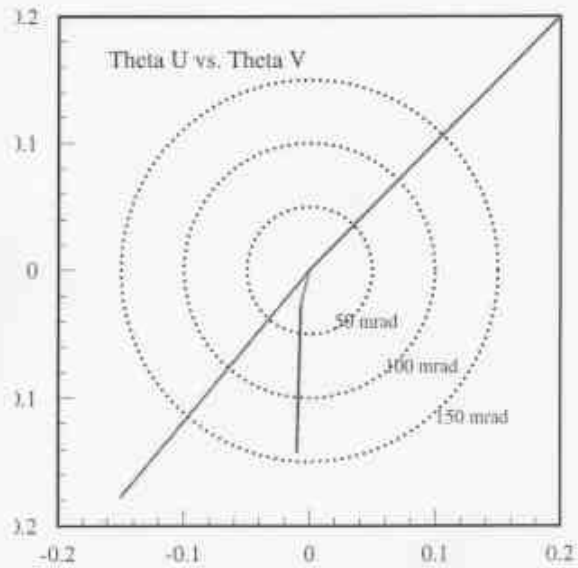
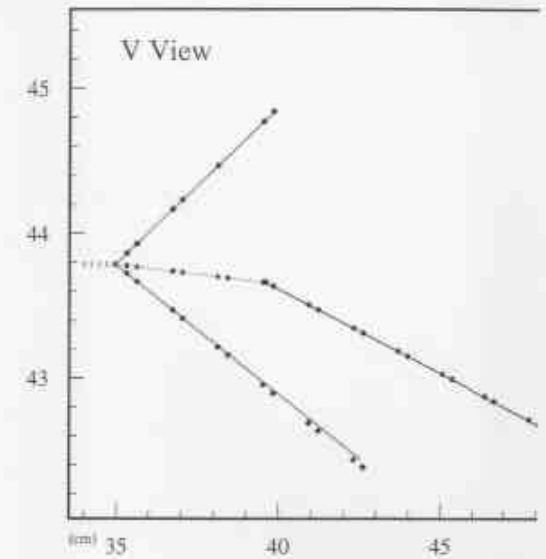
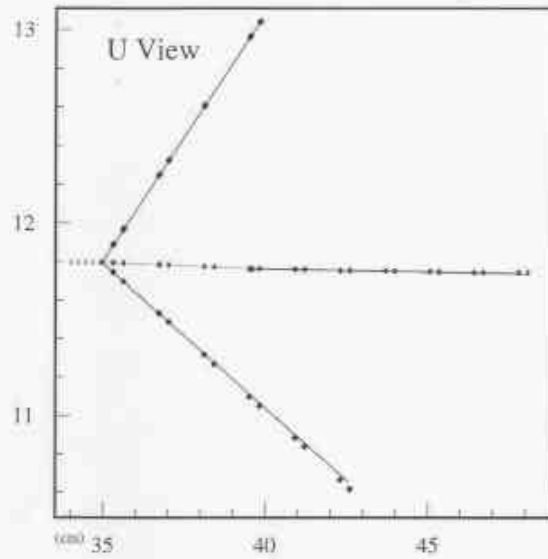
Tau Candidate

LL Decay

tau - electron

Flight Length : 4.5 mm

Kink Angle : 93 mrad



# DONUT

Fermilab E-872

Run= 3039 Event= 1910

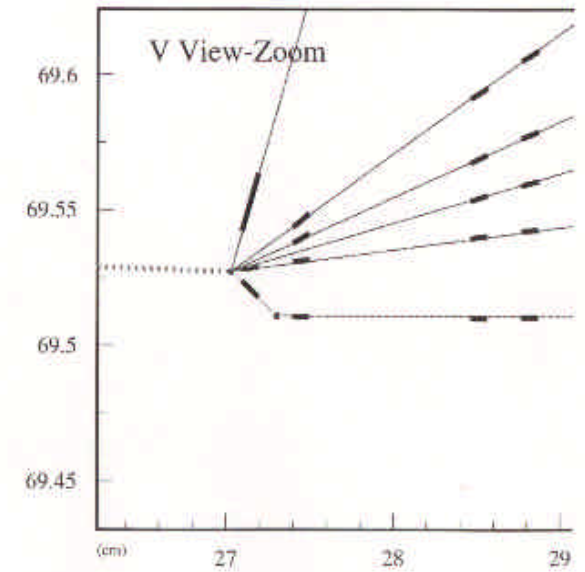
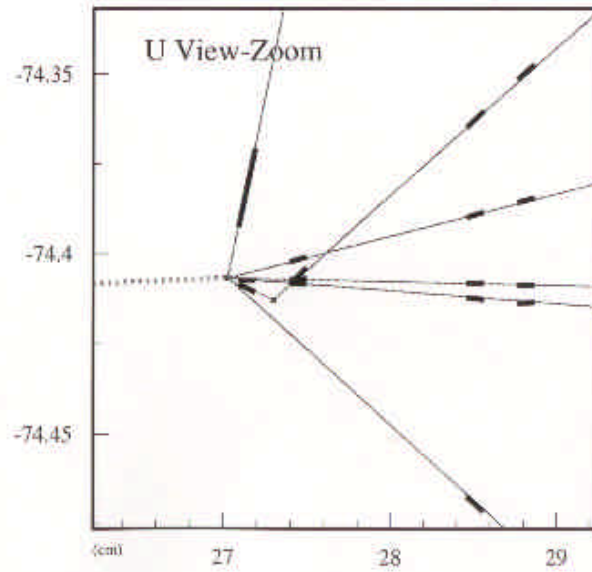
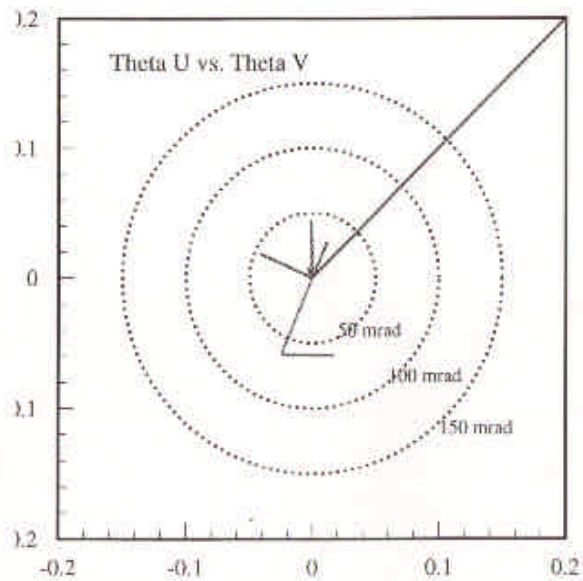
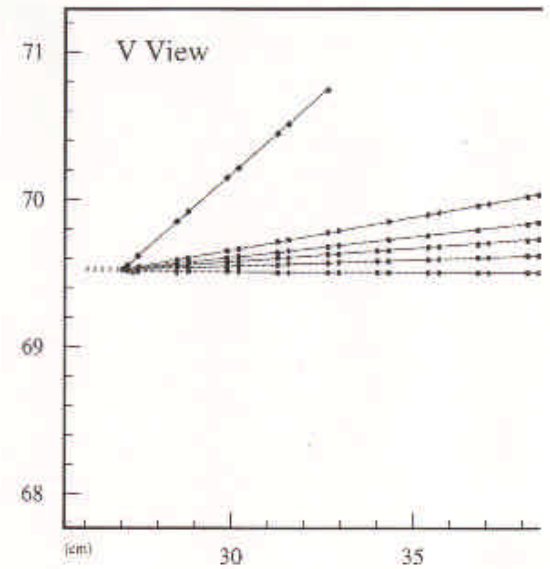
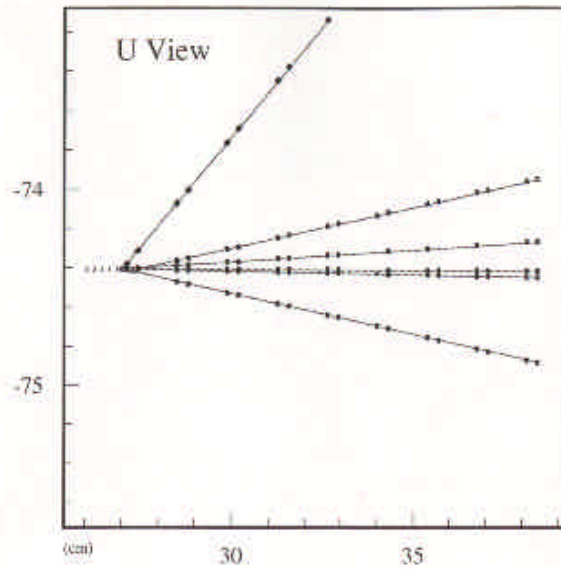
Tau Candidate

S Decay

Tau - hadron

Flight Length : 270 microns

Kink Angle : 88 mrad





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Fermilab E-872

Run= 3263 Event= 25102

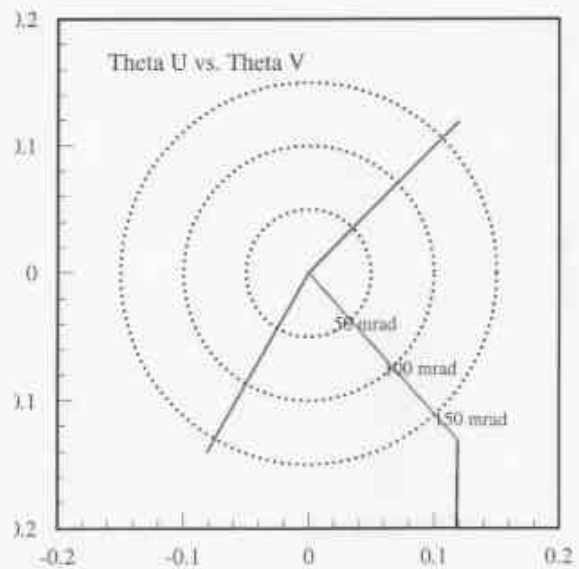
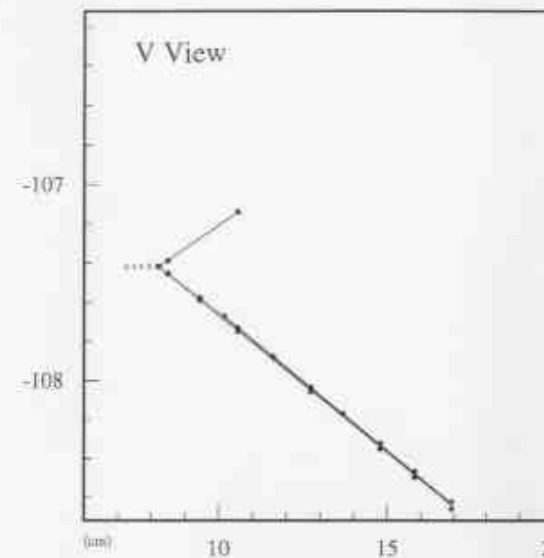
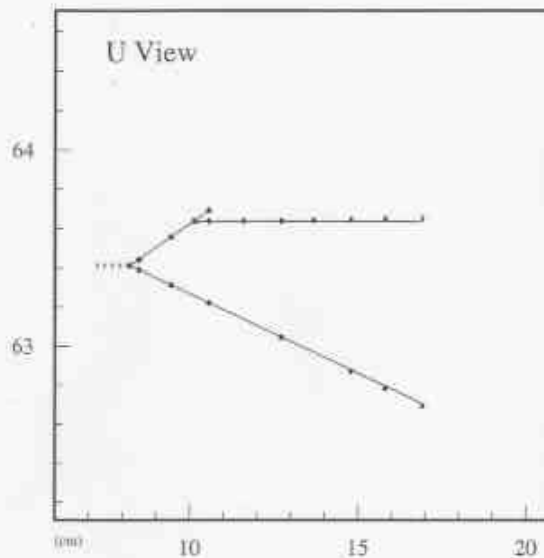
Tau Candidate

LL Decay

Tau - hadron

Flight Length : 1.95 mm

Kink Angle : 119 mrad



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Fermilab E-872

Run= 3356 Event= 17099

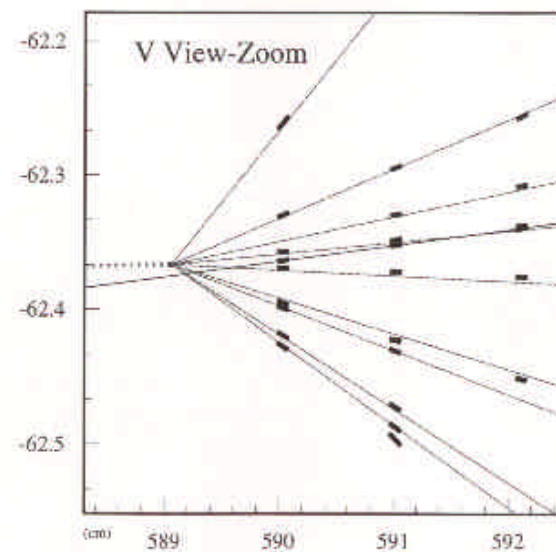
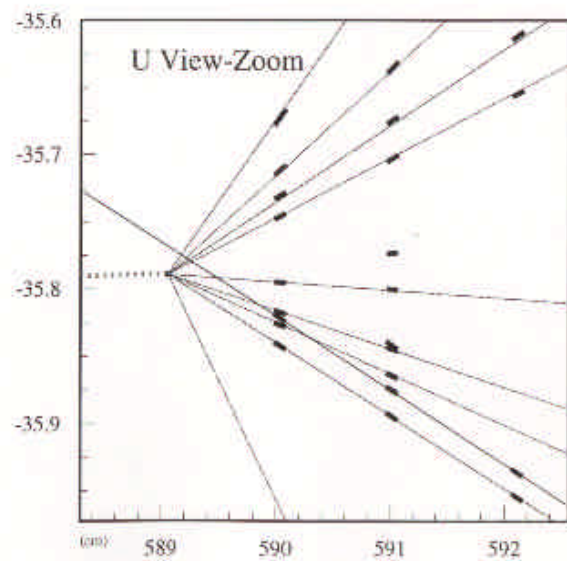
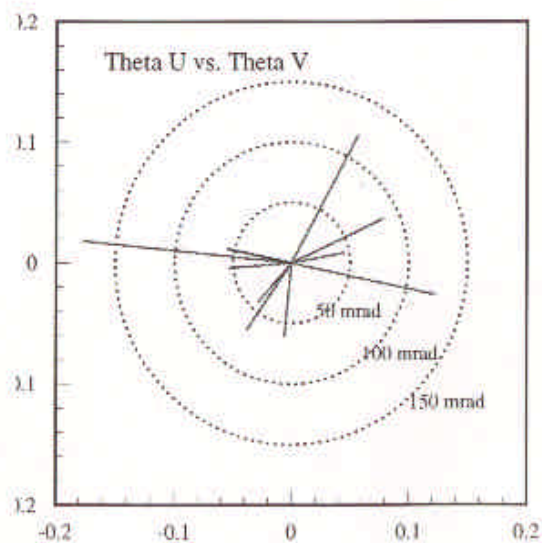
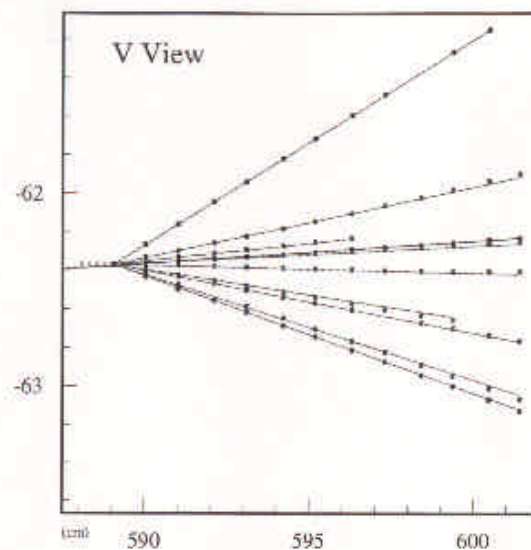
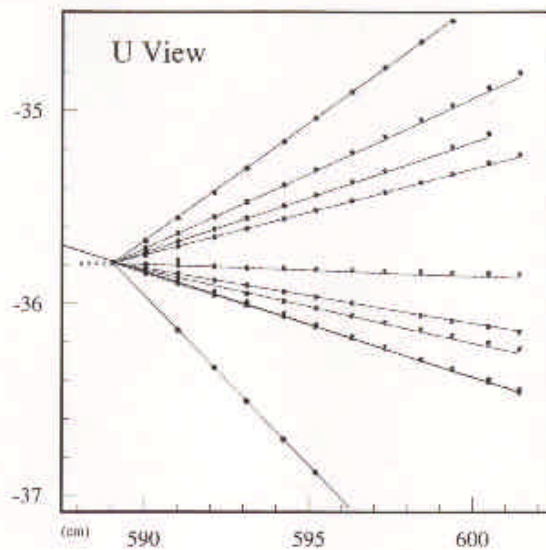
Tau Candidate

S decay (IP = 23 microns)

Tau - hadron

Flight Length(max) : 0.9 mm

Kink Angle(min) : 110 mrad



# DONUT

Fermilab E-872

Run= 3333 Event= 17665

Tau Candidate

LS Decay

tau - electron

Flight Length : 0.58 mm

Kink Angle : 13 mrad

