DONUT : EMCAL and Analysis Status

Direct **O**bservation of the **NUT**au

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-OUTLINE-

- **DONUT overview**
  - How the experiment is done
  - Prompt Neutrino Beam
  - Experimental Apparatus
- **EMCAL**
  - DONUT EMCAL
  - EMCAL Calibration
- **Neutrino Interaction Identification**
  - General Method & Current Status
- **Analysis Status of DONUT**

-Direct Observation of the ν_τ-

- Weak Isospin Lepton Doublets:

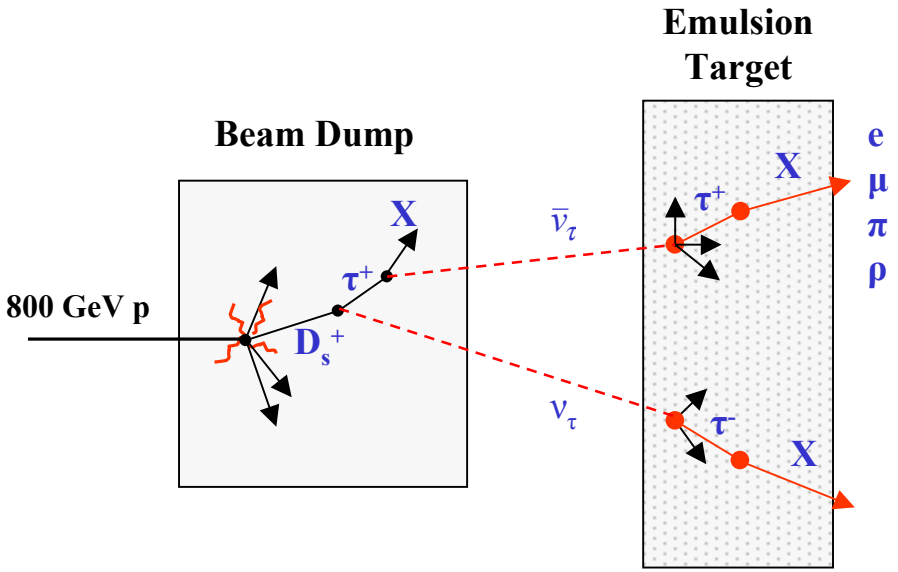
$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \qquad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \qquad \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}$$

- The ν_τ has not been directly observed yet, the way the other two neutrinos have, through its CC interactions although there is plenty of indirect evidence that the tau lepton has a neutral, spin 1/2 weak isospin partner.

- E872 Experiment : Direct Observation of the Tau Neutrino :

$$\nu_\tau + N \rightarrow \tau^- + X$$

-How the experiment is done-



- **Direct observation of the ν_τ :**

$$\nu_\tau + N \rightarrow \tau^- + X$$

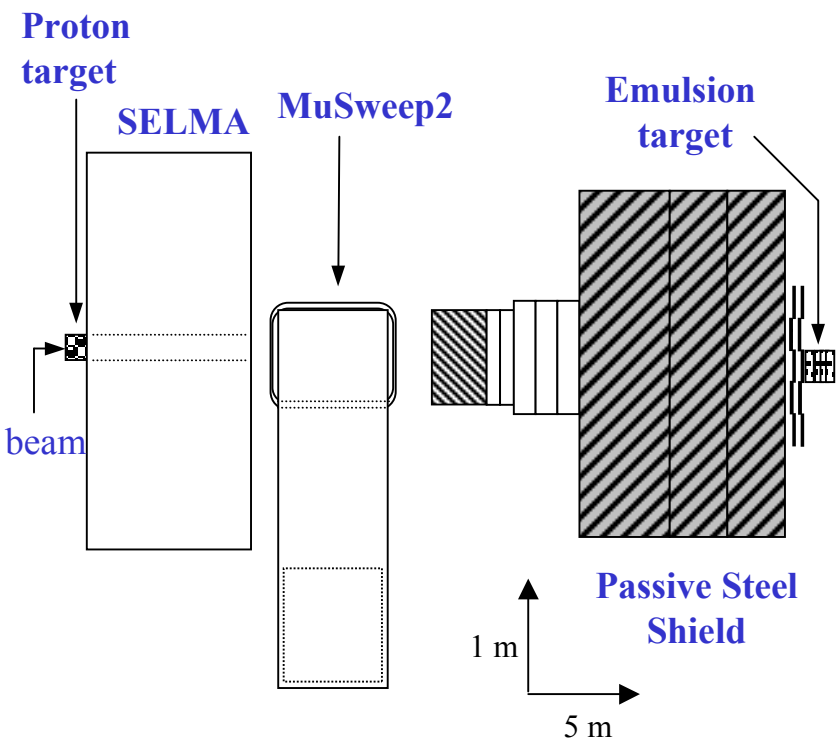
- **Detection of the ν_τ- Tau decay topology :**
  - $\gamma c\tau \approx 2mm$ decay angle ≈ 50mrad
  - 86 % of its decays produce only one charged particle.

- **Production of the neutrino beam :**

$$p + N \rightarrow D^+_S + X$$
$$\hookrightarrow \tau^+ + \nu_\tau$$
$$\hookrightarrow \bar{\nu}_\tau + \ldots$$

neutrino beam : 5 % ν_τ - 95 % ν_μ, ν_e

-Prompt Neutrino Beam-



- **Proton Target :**

  Tungsten alloy 10 % Copper -Nickel - Iron.
  Interaction length = 9.9 cm
  Total Length = 102 cm

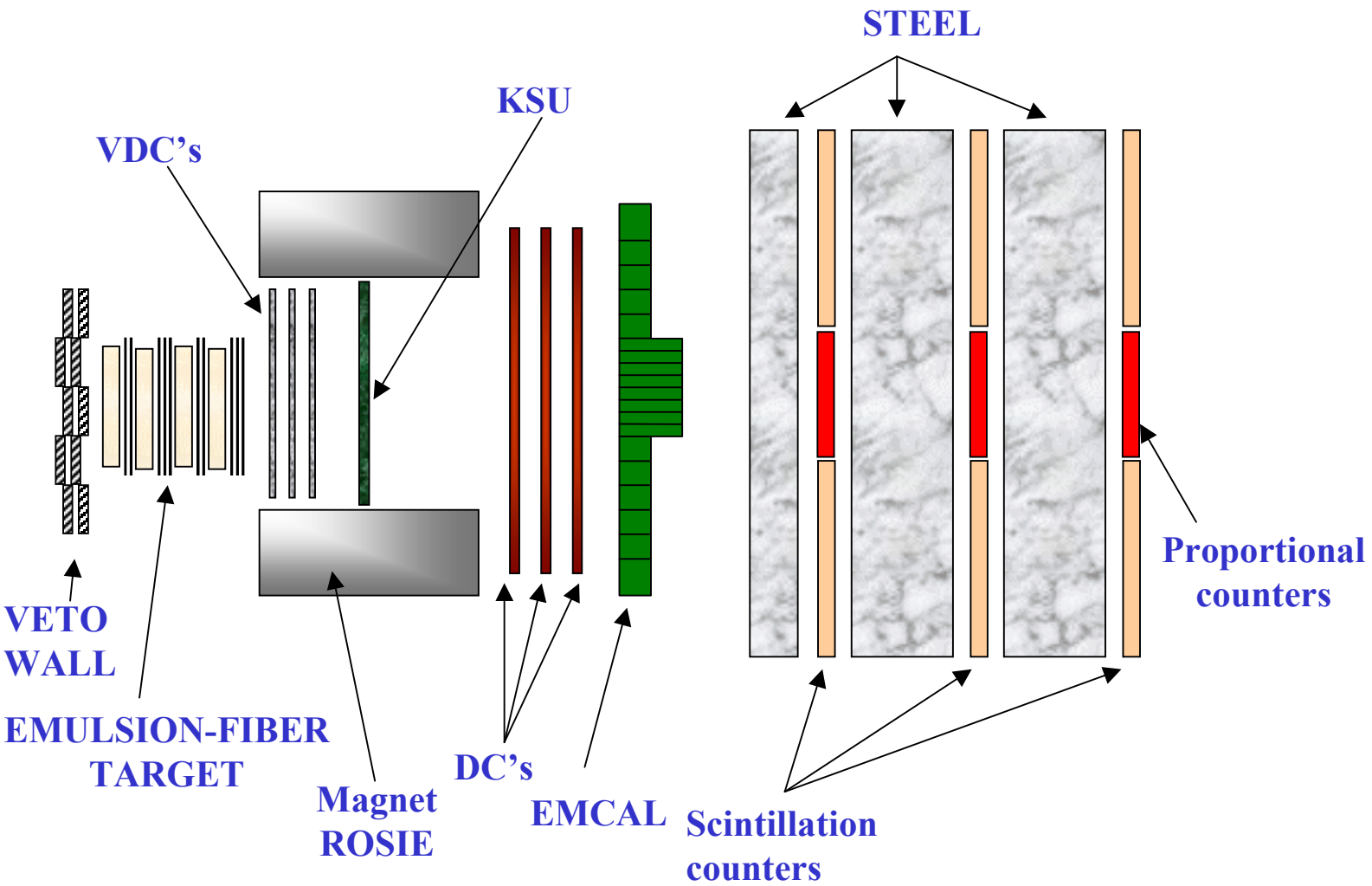
- **Muon Shielding Strategy :**

  - Magnet SELMA (Magnetic sweeping of high momentum muons)
  - Magnet MuSsweep2 (Defocusing of lower momentum return muons)
  - Passive shielding (Absorption of low energy (< 20 GeV) muons)

- **Emulsion track density**

  - **$< 10^5$ /cm^2**

-Hybrid Emulsion Spectrometer-

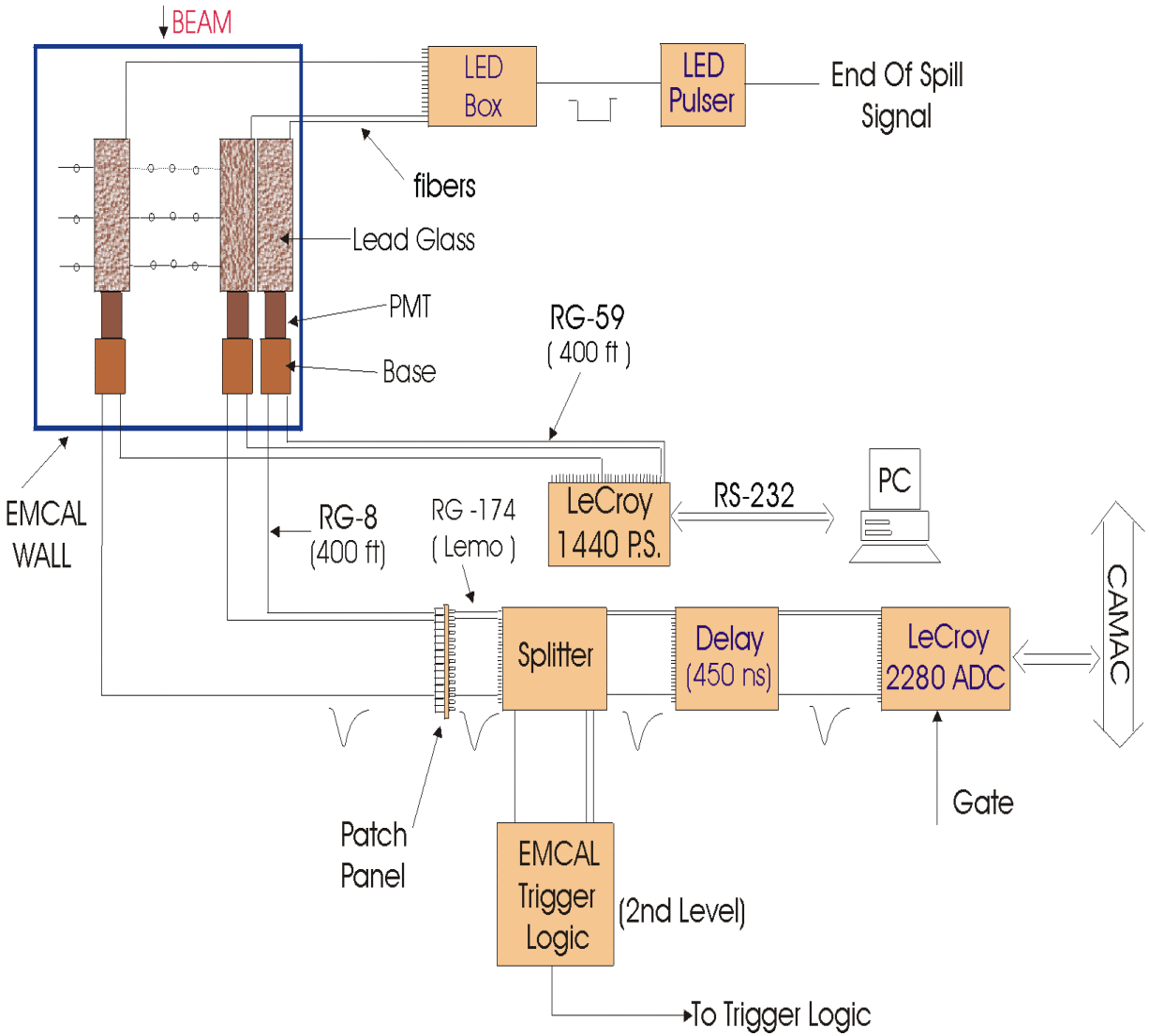


-The DONUT Collaboration -

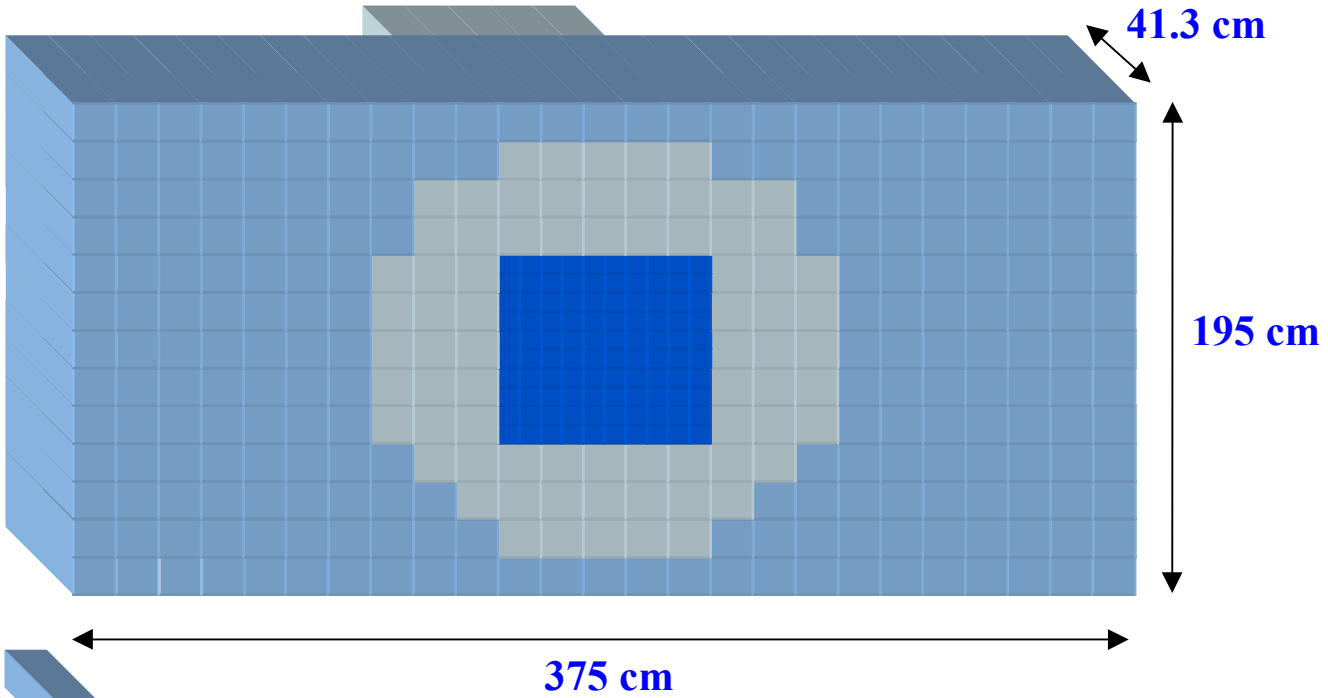
Aichi University of Education - **Athens** University - **California at Davis** University - **Changwon** National - University- **Chonnam** National University - **Fermilab** - **Gyeongsang** National University- **Kansas State** University - **Kobe** University - **Kon Kuk** University - **Korean** National University of Education - **Minnesota** University - **Nagoya** University - **Osaka** Prefecture Science Education Institute - **Pittsburgh** University - **Pusan** National University - **South Carolina** University -**Toho** University- **Tufts** University - **Utsunomiya** University - **Wonkwang** University

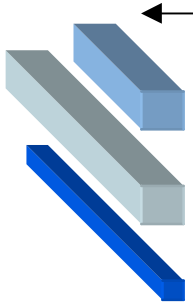
- **University of Athens group :**
  - C.Andreopoulos, N.Giokaris, N.Saoulidou, P.Stamoulis, G.Tzanakos
- **Projects :**
  - Electromagnetic Calorimeter
  - Analysis of experimental data

-Schematic of the Calorimeter-



-EMCAL-





15x15x41.3 cm^3 PbG

15x15x89 cm^3 SCG1-C

7.5x7.5x89 cm^3 SCG1-C

Lead - Glass blocks ~ 16.8 Radiation Lengths

Scintillating - Glass blocks ~ 20.9 Radiation Lengths

-EMCAL Calibration-

- The energy deposited (in GeV) in the calorimeter by any passing particle is given by the relation :

$$E_e = \sum_i E_{e_i} = \frac{e_i}{(<\mu>/<led>)_i * led_i} * \frac{1}{k_i}$$

Three Calibration Constants

Where **i** = block number that belongs to the EMCAL cluster of the electromagnetic shower (if there is one) of that particular particle.

E_e = the deposited energy (in GeV) of the particle

E_{ei} = the deposited energy (in GeV) of the particle in block i

e_i = the particle response (in ADC counts) in block i

$(<\mu>/<led>)_i$ = the mu/led ratio for block i

led_i = the led response (in ADC counts) in block i

k_i = the e/μ constant for that particular kind of block

NOTE : $(<\mu>/<led>)_i * led_i$ = muon peak μ_i for block i

-Estimation of calibration constants-

- **BNL test** : Calculation of the constant $k_i = \langle e \rangle / \langle \mu \rangle * 1/E_e$ for all i = 4 different kinds of blocks of our calorimeter (E_e : in GeV, $\langle e \rangle$, $\langle \mu \rangle$: in ADC counts)

- **Muon Calibration** : Calculation of the mu/led ratio $(\langle \mu \rangle / \langle led \rangle)_i$ for every block i of the calorimeter. (by proccesing all PW5 tapes)

- **Led Calibration** : Calculation for every run, every block and every event the led value led_i for block i (by proccesing all DATA tapes)

-Strategy of the Analysis for the BNL test-

- **DATA :** We took data for **muons (~4 GeV)** ,**electrons (4, 2, 1, 0.5 GeV)** and **pions(~4, 2, 1 GeV)** passing through the **13 calorimeter blocks** that were transferred to Brookhaven as well as for **Pedestals**.

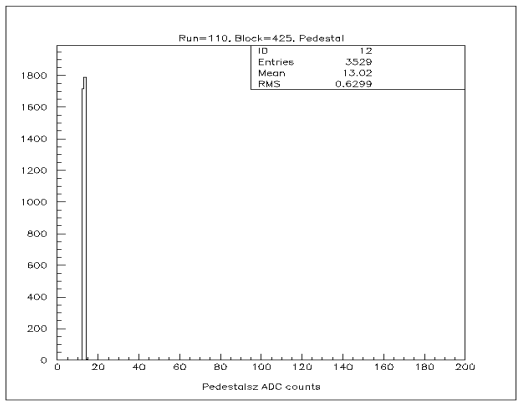
- **GOAL :** The estimation of the calibration constant $k = \frac{< e >}{< \mu >} \cdot \frac{1}{E_e}$

- **STRATEGY :**

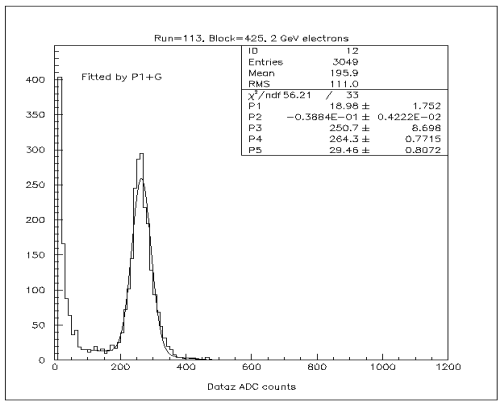
  - Calculation of the **Pedestals** for every ADC channel that we used in the test
  - Calculation of the **mean electron response <e>** (in ADC counts) for every block after Pedestal subtraction
  - Calculation of the **mean muon response <μ>** (in ADC counts) for every block after Pedestal subtraction
  - Repetition of the above procedure (for muons) for pions also.

-Analysis of the BNL test-

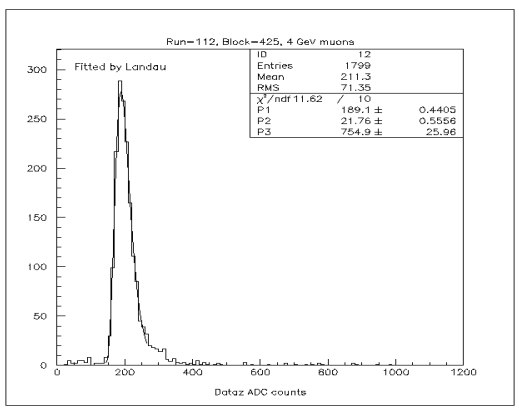
PEDESTAL distribution for block 425



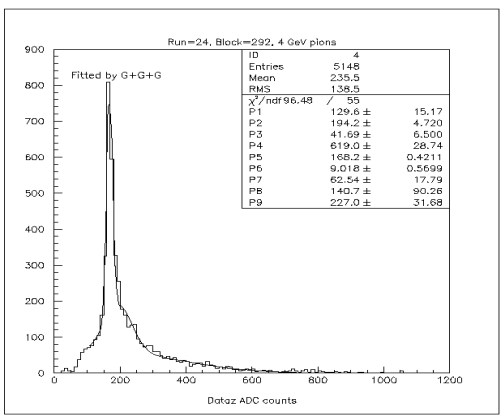
Energy Distribution of 2 GeV e^- block 425



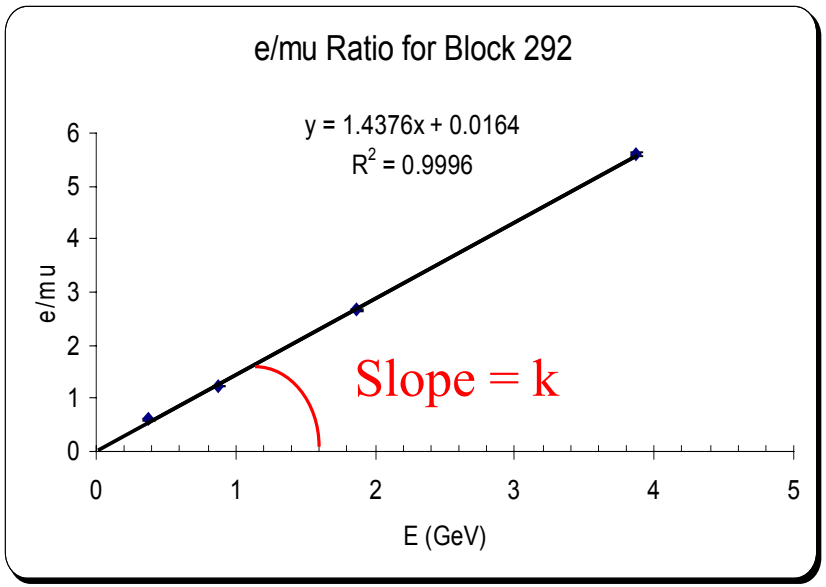
Energy Distribution of ~ 4 GeV μ^- block 425



Energy Distribution of 4 GeV π^- block 425



-Results of the BNL test-



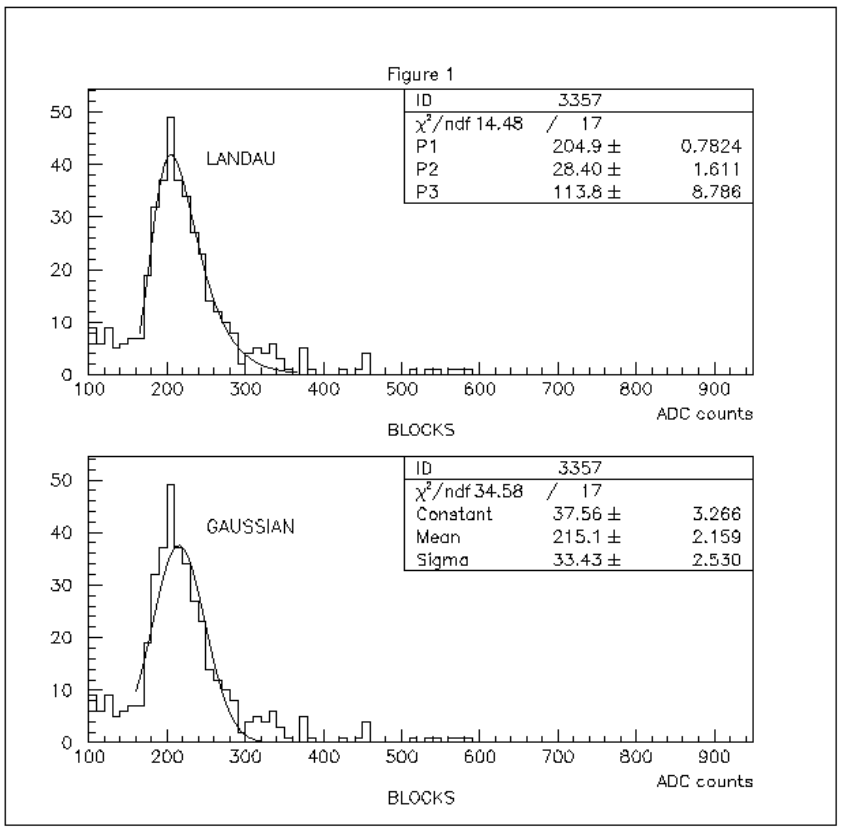
Block Type	Blk	$\frac{<e>}{<\mu>}$	b(%)	α(%)
SF5 – Lead glass 15x15x41.3 cm^3	294	1.54±0.03	6.58±0.30	0.42±0.20
SF5 – Lead glass 15x15x41.3 cm^3	293	1.54±0.02	3.27±0.30	2.42±0.20
SF5 – Lead glass 15x15x41.3 cm^3	292	1.44±0.02	4.43±0.30	1.58±0.40
SCG1- Scintillating glass 7.5x7.5x89cm^3	425	1.24±0.01	7.89±0.90	4.58±0.70
SCG1- Scintillating glass 7.5x7.5x89cm^3	414	1.14±0.01	5.88±1.00	5.76±0.70
SCG1- Scintillating glass 7.5x7.5x89cm^3	900	1.76±0.05	8.82±1.00	3.06±0.60
SCG1-Scintillating glass 15x15x89 cm^3	265	1.45±0.02	6.60±0.40	0.62±0.10
SCG1-Scintillating glass 15x15x89 cm^3	240	0.93±0.04	6.06±1.00	1.58±1.10
SF5 – Lead glass 15x15x35 cm^3	317	2.17±0.03	5.25±0.20	1.44±0.20
SF5 – Lead glass 15x15x35 cm^3	318	2.73±0.08	4.88±0.40	2.84±0.20
SF5 – Lead glass 15x15x35 cm^3	319	2.37±0.04	6.01±0.20	1.21±0.10

$$\frac{\sigma(E)}{E} = \left[\frac{b^2}{E} + a^2\right]^{1/2} = a \oplus \frac{b}{\sqrt{E}}$$

-Muon Calibration-

- **Apparatus / Beam / Data taking**
  - Experimental Apparatus : E872 Hybrid Spectrometer
  - Beam : Muons
  - Data : Muons and LED light passing through the calorimeter blocks (34 Muon Runs)

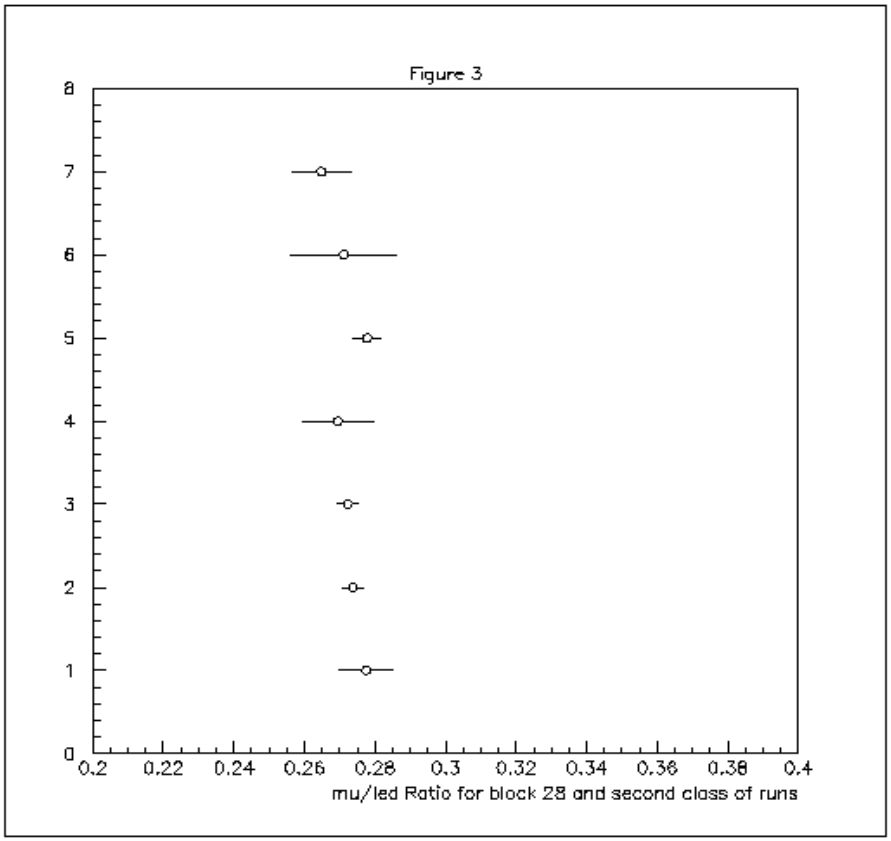
-Analysis of Muon Calibration-



- **Analysis**
  - **Goal :** Estimation of the **position of the muon peak** for every block of the calorimeter so as to be able to calculate the energy deposition in it in GeV
  - **Strategy of the analysis :** Calculation (by fitting the muon and LED distributions (in ADC counts) in the calorimeter blocks) and study of the **ratio l = <μ>/<led>** for every block so as to use it in the following relation :

$$E_i = \frac{e_i}{l_i \cdot led_i} \cdot \frac{1}{k_i}$$

-Results of Muon Calibration-



- **Result of the muon calibration :**
  - The ratio **l = <μ>/<led>** remains the **same** for every block ,although the ADC channel that the **muon peak** appears for this block **changes**

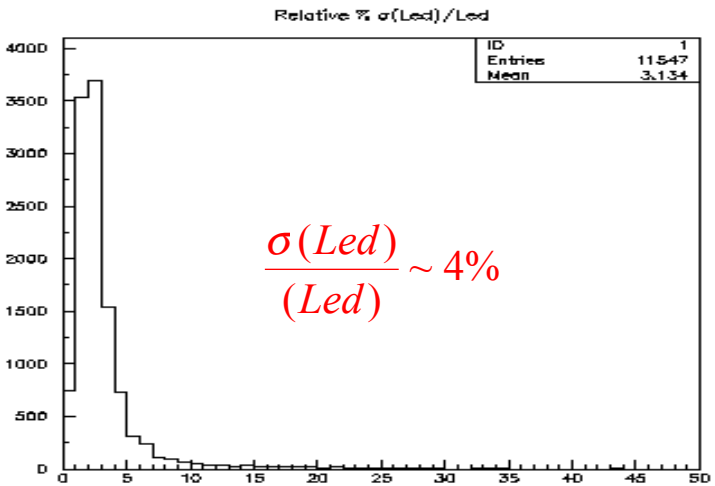
-Study of the LED values-

- Having the ratio **l=<μ>/<led>** for every block we are able to calculate the position of the muon peak **<μ>** (in ADC counts) for that particular block and thus the energy deposition in (GeV) , namely:

$$< \mu >= l * Led \qquad E_e = \sum_i E_{e_i} = \sum_i (e_i / \mu_i) * 1 / k_i$$

where Led = the Led response in ADC counts

- The **precise knowledge** of the **LED response <led>** for every block is **essential** for the calculation of the **energy deposition (in GeV)** of each particle in the **EMCAL**



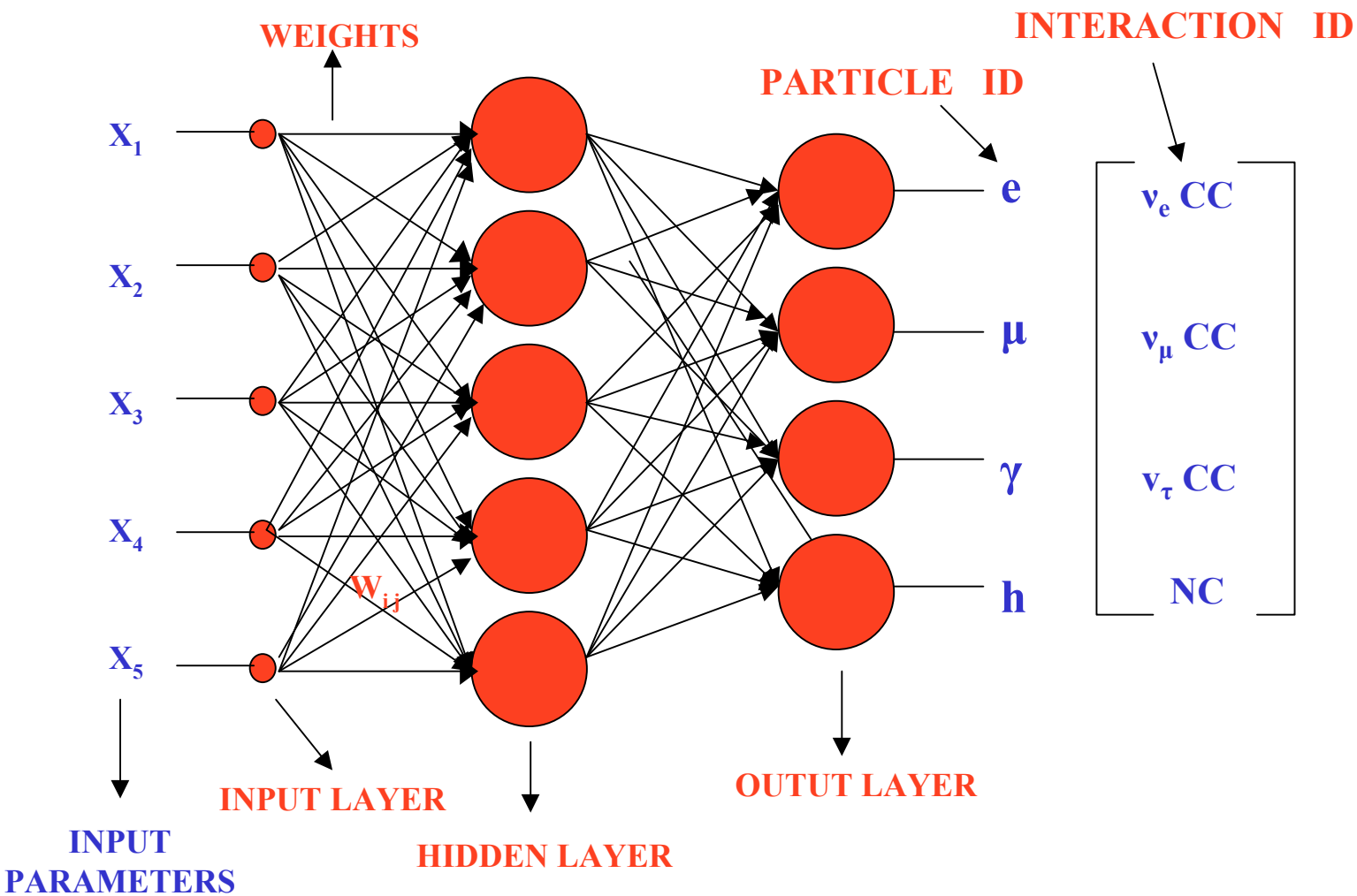
- Processed 320 tapes (all runs) and produced **files (one for each run)** that for **every block** contain :
  - **Mean led value.**
  - **Starting event number.**
  - **Ending event number**.

- We **implemented** that new information in the **E872 code** by developing several algorithms.

-Study of Neutrino Interaction ID-

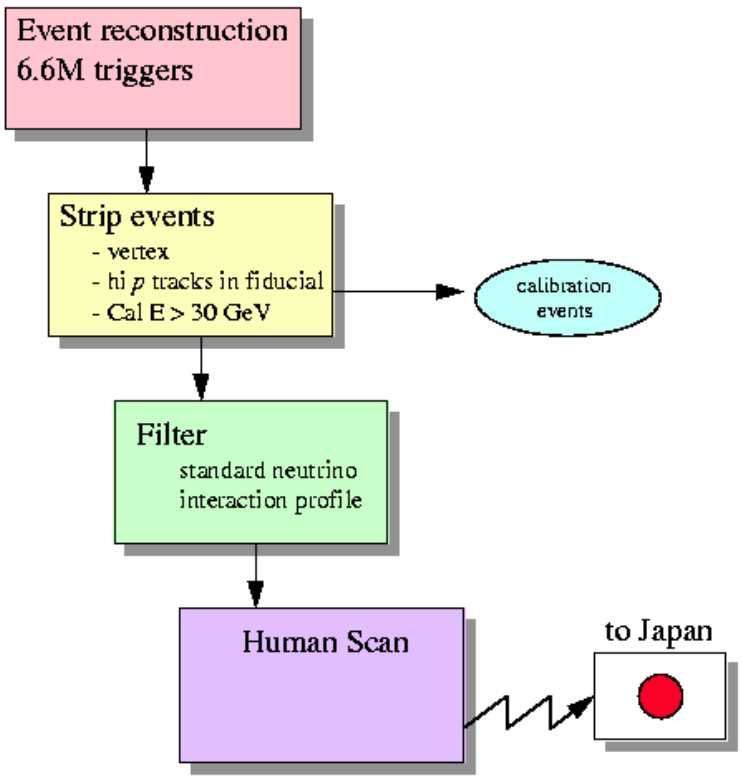
- **Goal :** Separate ν_μ , ν_e , ν_τ interactions CC and NC
- **Procedure :** Use ANN to do classification. That is :
  a) particle identification
  b) neutrino interaction identification
- **Inputs :**a) For **particle identification** the input vector ($x_1,x_2,\ldots,x_n$) could be **track properties** like momentum,energy,hits in the MID,hits in the DC's. e.t.c
  b) For **interaction identification** the input vector ($x_1,x_2,\ldots,x_n$) could be **event properties** like total number of hits in the SF's,DC's,VDC's, total energy e.t.c
- **Output of ANN analysis :** Probabilities.
- **Technique :** Backpropagation algorithm.
- **Current status :** Working on the MC in order to make MC data " look like " real data but with the additional information of what particle generated them.
  The purpose of this is that we want to finally **train our ANN with simulated (MC) data that are similar to the real ones.**

- ANN Structure-



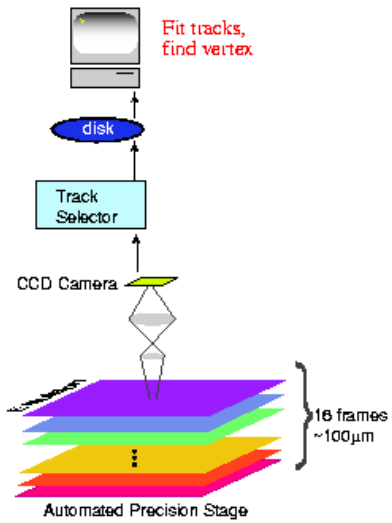
-Analysis Flow for the experiment's data-

Event Reduction



Automatic Scanning

- Emulsion digitized
- Tracks found with special processor
- Stored
- Analyzed in a conventional manner
- Can be re-fit, etc.



-Decay Search & Further Analysis-

- **Emulsion Data Analysis :**

  ➔ Connect track segments and reconstruct tracks.

  ➔ If three or more charged particles (tracks) are found coming from the neutrino interaction then the **vertex can be located.**

  ➔ If the vertex is found then a **decay search** is performed using emulsion data for all tracks coming from that (primary vertex)

  ➔ If that search yields to a track with a significant **"kink"** then the event is categorized as a **tau neutrino candidate.**

- **Offline Analysis :**

  ➔ Connect tracks form the emulsion with tracks form the spectrometer to identify the **type of neutrino interaction** by studying the overall characteristics of the event.

-Event Location Analysis-

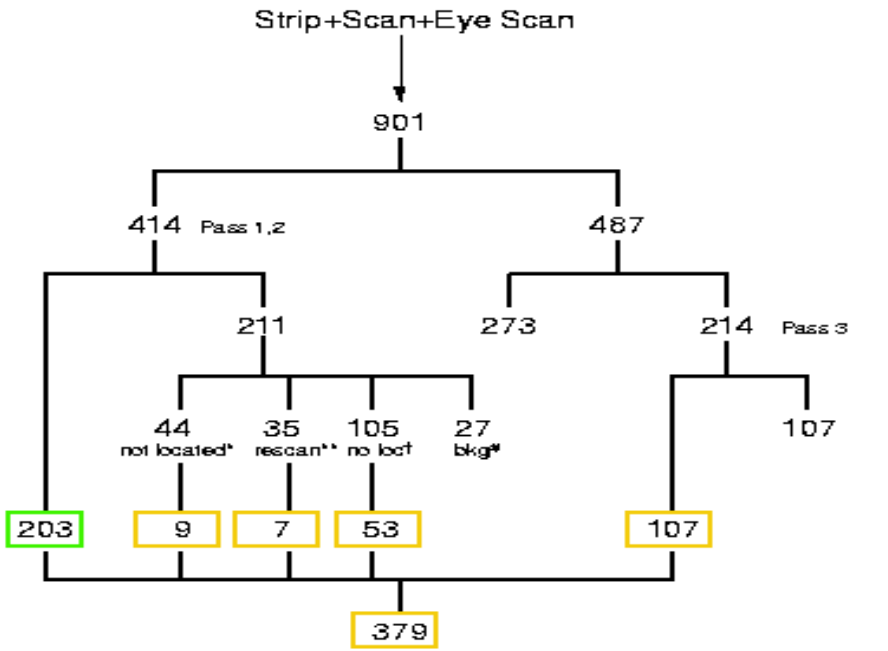


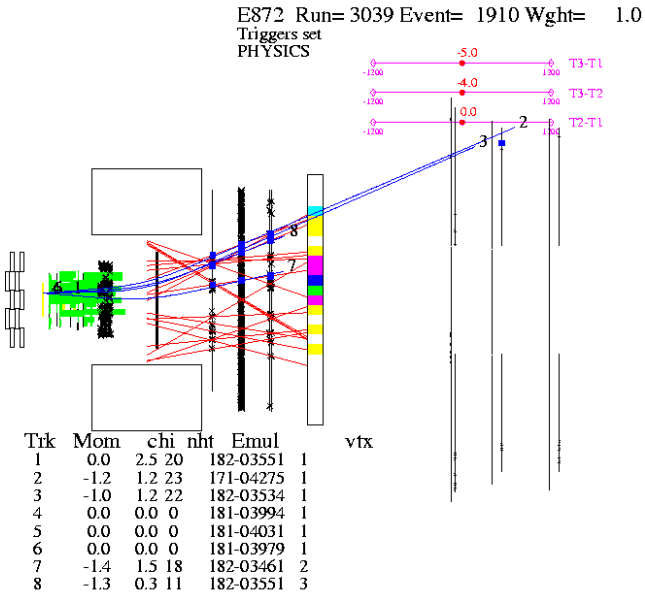
Figure 1. Event location status as of 16 Nov 1999. The numbers in yellow boxes are estimates.

-τ yield from E872-

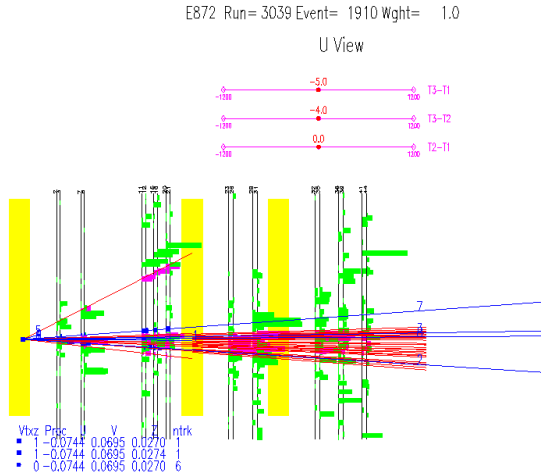
- Experimental efficiencies
  - fiducial and vertex location: 60%
  - trigger : 95%
  - total live-time : 89% (5 Hz)
- Physics uncertainties
  - $\sigma_{D_s} = 13 \pm 3 \mu b$
  - $BR(D_s \rightarrow \tau\nu) = 5.1 \pm 1.0\ \%$
  - $\sigma(\nu_\tau CC) = (0.42 \pm 0.09) \times 10^{-37} cm^2$

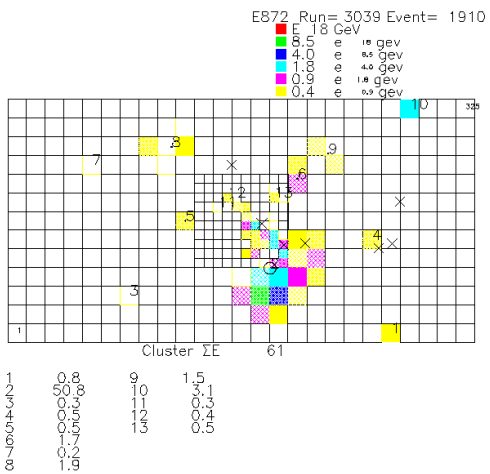
$\Rightarrow$ 42±15 τ's should be *observed* for 5×10^{17} protons on target

-ν_τ candidate-

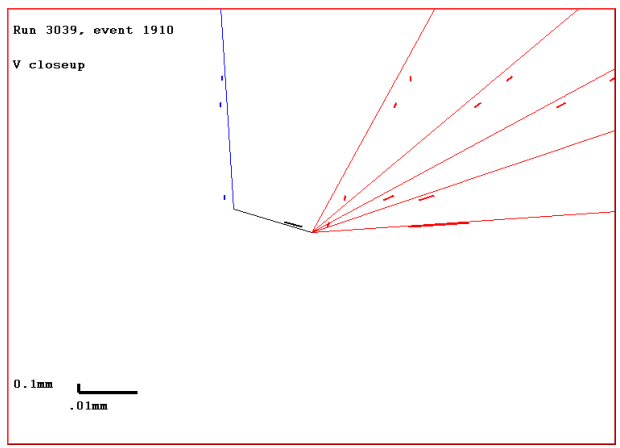


Trk	Mom	chi	nht	Emul	vtx
1	0.0	2.5	20	182-03551	1
2	-1.2	1.2	23	171-04275	1
3	-1.0	1.2	22	182-03534	1
4	0.0	0.0	0	181-03994	1
5	0.0	0.0	0	181-04031	1
6	0.0	0.0	0	181-03979	1
7	-1.4	1.5	18	182-03461	2
8	-1.3	0.3	11	182-03551	3





1	0.8	9	1.5
2	50.8	10	3.1
3	0.3	11	0.3
4	0.6	12	0.4
5	1.7	13	0.5
6	0.2		
7	0.2		
8	1.9		



-Conclusions-

- **The Calibration of the Calorimeter of the DONUT experiment is completed and the results are implemented and used in the analysis**

- **The Neutrino Interaction ID study is underway**

- **We are analyzing our data and expect to have results in the next 1-2 years.**