DONUT

Fermilab E872

University of Minnesota · High Energy Physics

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The DONUT collaboration

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

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  - J. Trammell

Outline

- Introduction
  - experimental goal
  - apparatus
- Analysis flow
- Emulsion analysis
- Neutrino interaction examples
- Preliminary physics results
- Outlook
- Conclusions

Tau neutrino

- From particle data group:

et al. (Particle Data Group), European Phys Jour **C3**, 1 (1998) and 1999 partial update for edition 200

ν_τ

$J = \frac{1}{2}$

Existence indirectly established from τ decay data combined with ν reaction data. See for example FELDMAN 81. ALBRECHT 92Q rules out $J = 3/2$ by establishing that the ρ^- is not in a pure $H_\rho = -1$ helicity state in $\tau^- \rightarrow \rho^- \nu_\tau$.

Not in general a mass eigenstate. See note on neutrinos in the ν_e section above.

- Experimental goal: establish ν_τ existence directly
  - also search for rare processes

Experimental Technique

- Neutrino production in D_s decay
  - High density beam-dump proton target
    - Short-lived particles decay
    - Long-lived particles interact before they can decay
  - High intensity proton beam (5 10^{13} P per spill)
- Identification of individual ν_τ CC interactions
  - Nuclear emulsion neutrino target
    - τ decay can be identified (decay length 2mm)
  - Shielding to protect the emulsion from muons
  - Conventional spectrometer
    - Determine which part of the emulsion to analyze
    - Identify interaction products

Apparatus

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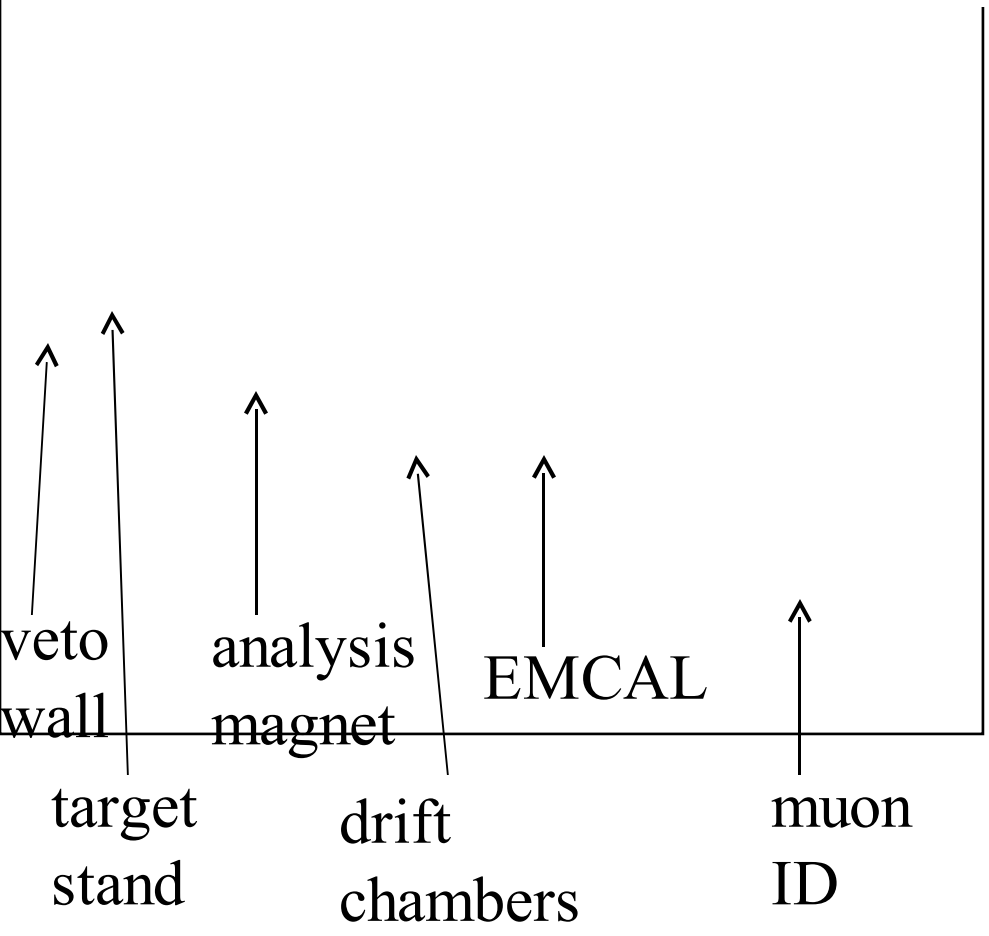
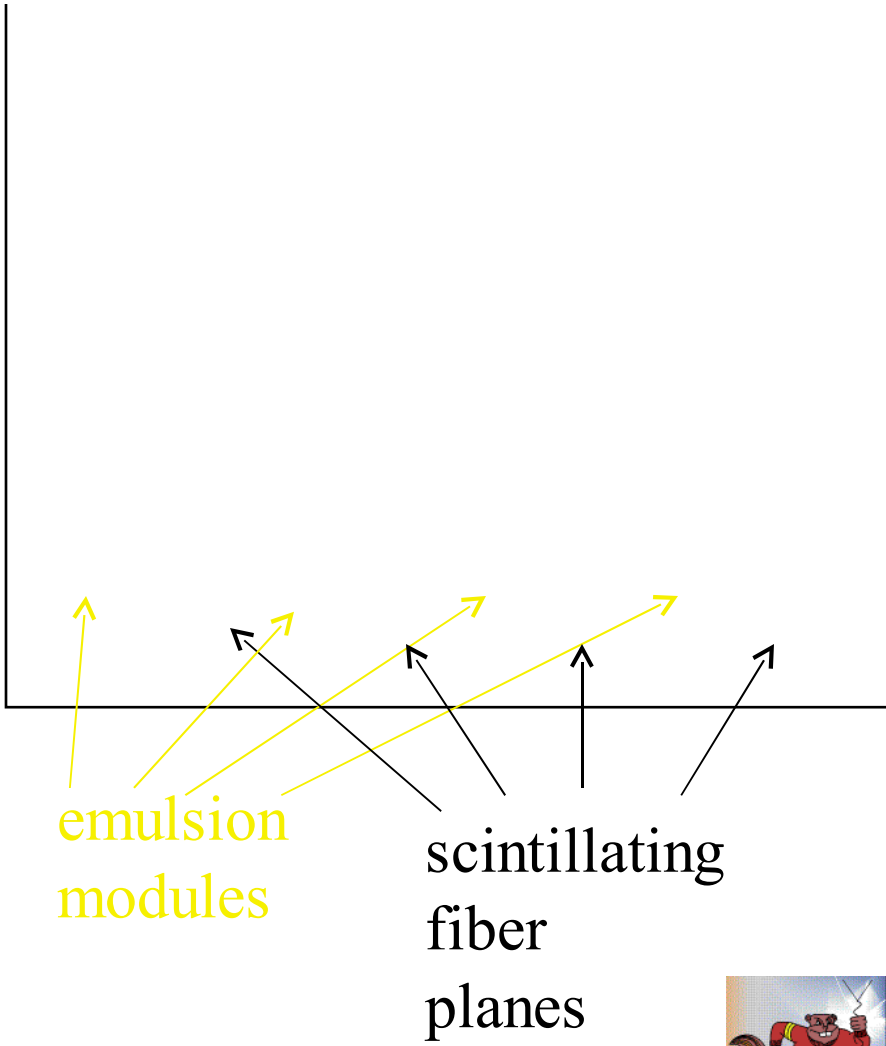
Spectrometer

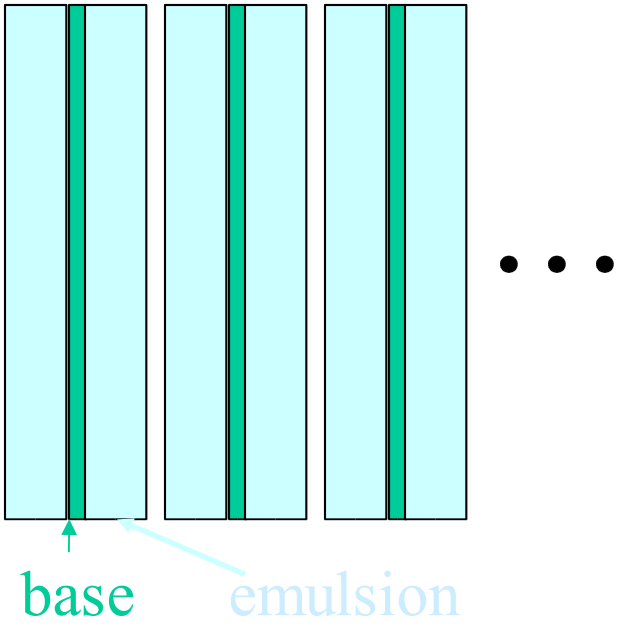


Target stand



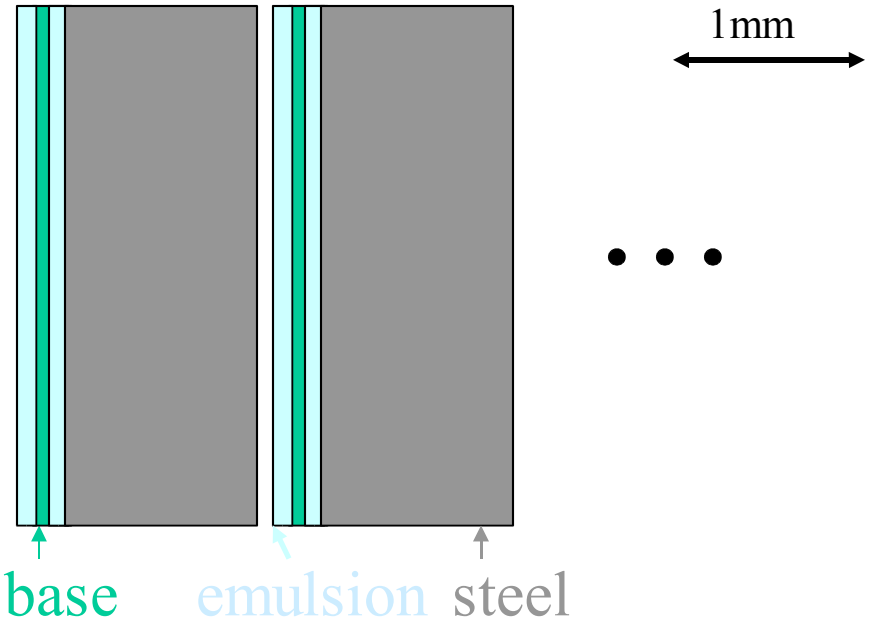
Emulsion module

Bulk module (84 plates)



- 95% of the mass is emulsion
- fully sensitive

ECC module (54 plates)



- 5% of the mass is emulsion
- sampling detector
- less emulsion volume
  cheaper than bulk
- new technology

Emulsion technique

- Charged particles passing through emulsion
  - ionization
  - black silver grains after development
    - size 1μm
  - plates must be aligned to 1μm
    - hardware: x-ray sources
    - software: penetrating muons
  - Scanning stage (microscope) must have resolution < 1μm

Emulsion scanning station

- Scanning table
  - Microscope
  - CCD camera with frame grabber
  - X-Y precision moving table
  - digitize one field of view ((200μm)^2) at 16 depths
- track recognition hardware
  - *track selector*
  - combine 16 dots to track segments
- Computer
  - control stage
  - record track segments
- Current scanning speed: 8h/event ((5mm)^2 20mm)

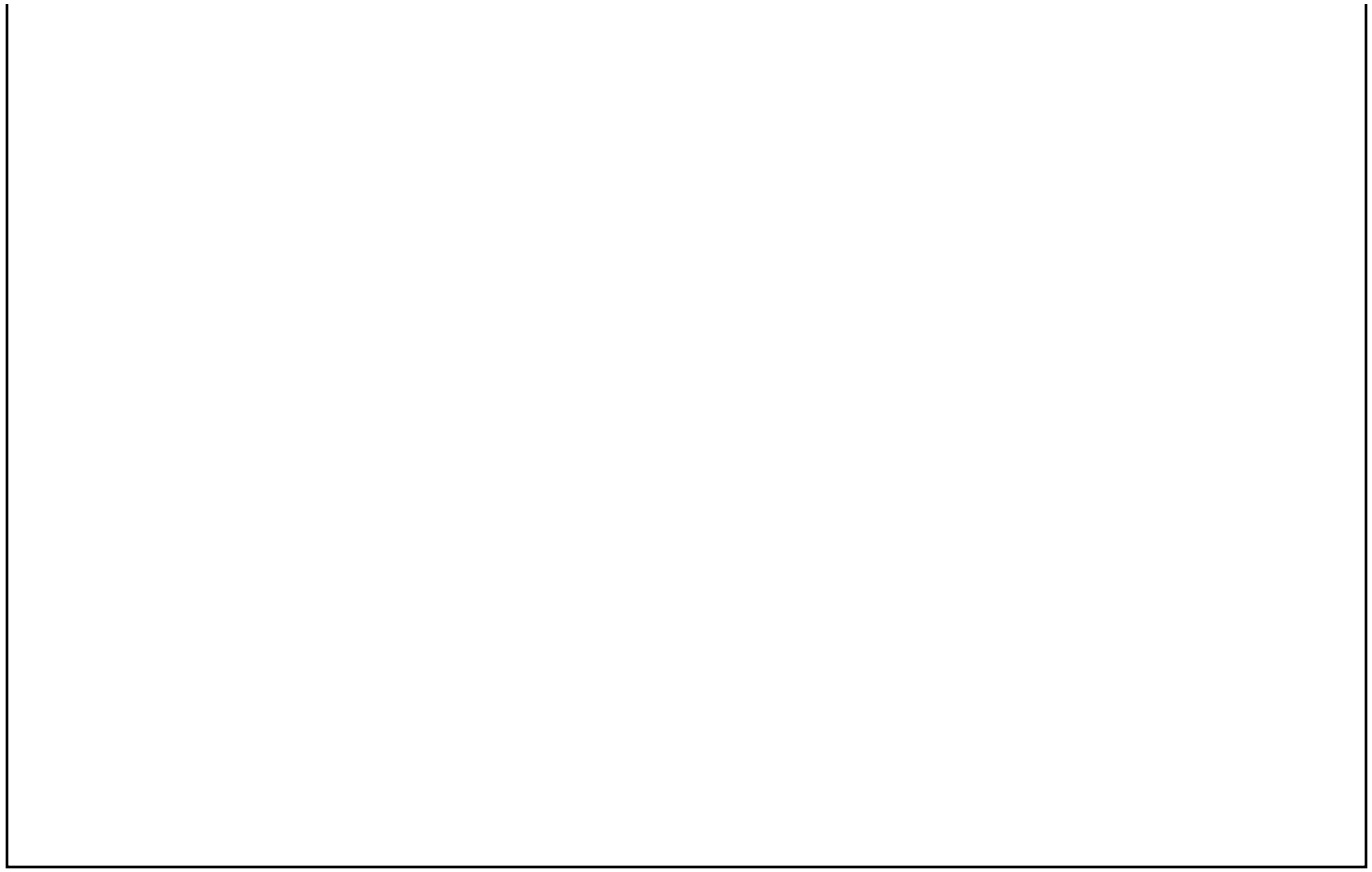
Data analysis flow

	# of events	step completed?
Events on tape	6,600,000	
Strip events • vertex in U view or • high p track or • calorimeter energy >30GeV	330,000	☑
Filter • neutrino interaction vertex	70,000	☑
Human scan • remove background • predict vertex location	1,000	☑ event selection ☐ vertex prediction
Emulsion scanning • in Japan • locate event		☐
Event analysis • decay kink search		☐

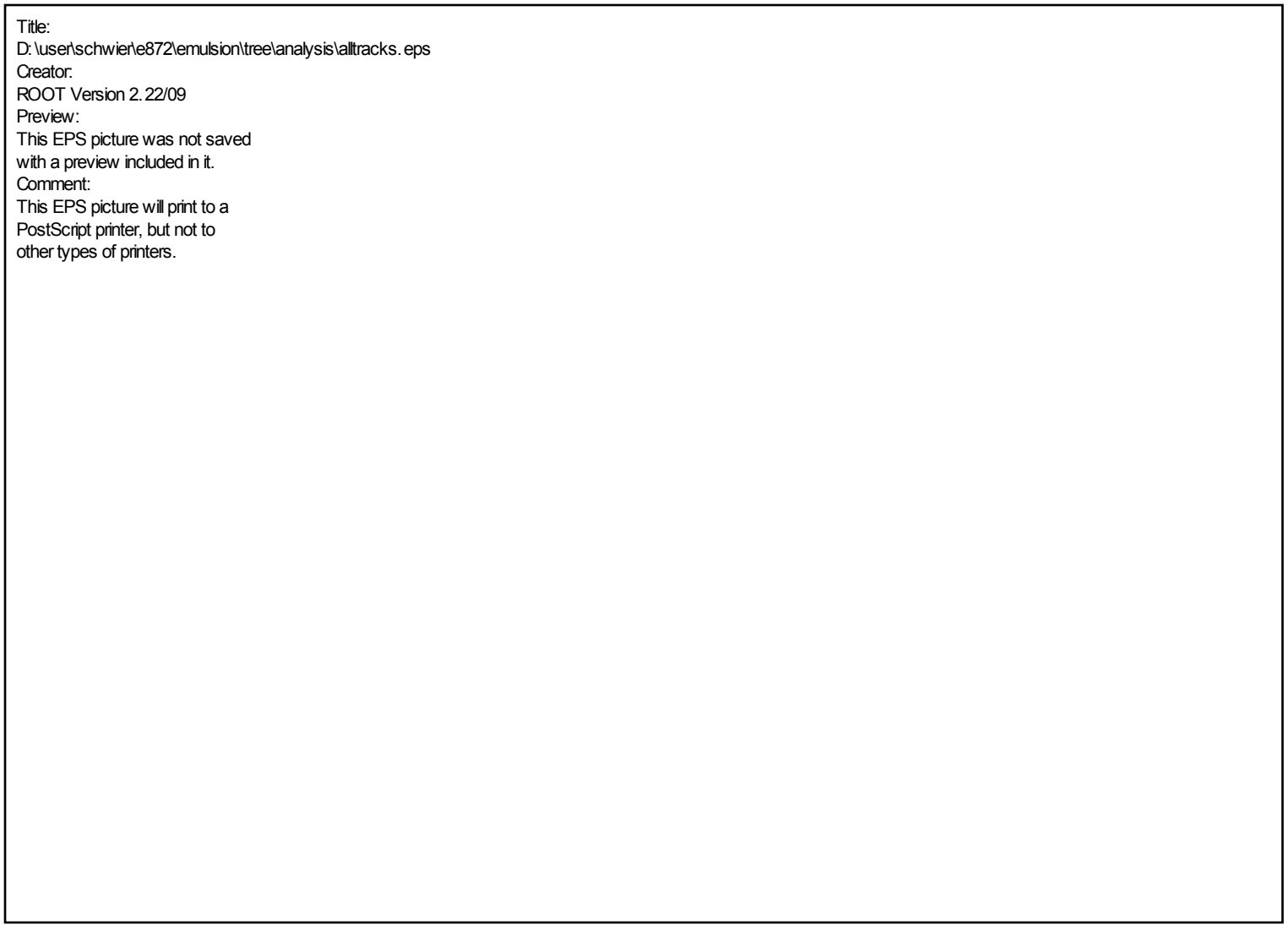
Emulsion data analysis

- Scan Back
  - project a single track from spectrometer into emulsion
  - follow the track upstream until it stops
  - locate other tracks coming from this vertex
  - difficult in events with many tracks
- Net Scan
  - predict a vertex position with the spectrometer
  - scan the volume around this position
  - software vertex search
  - takes more time than scan back

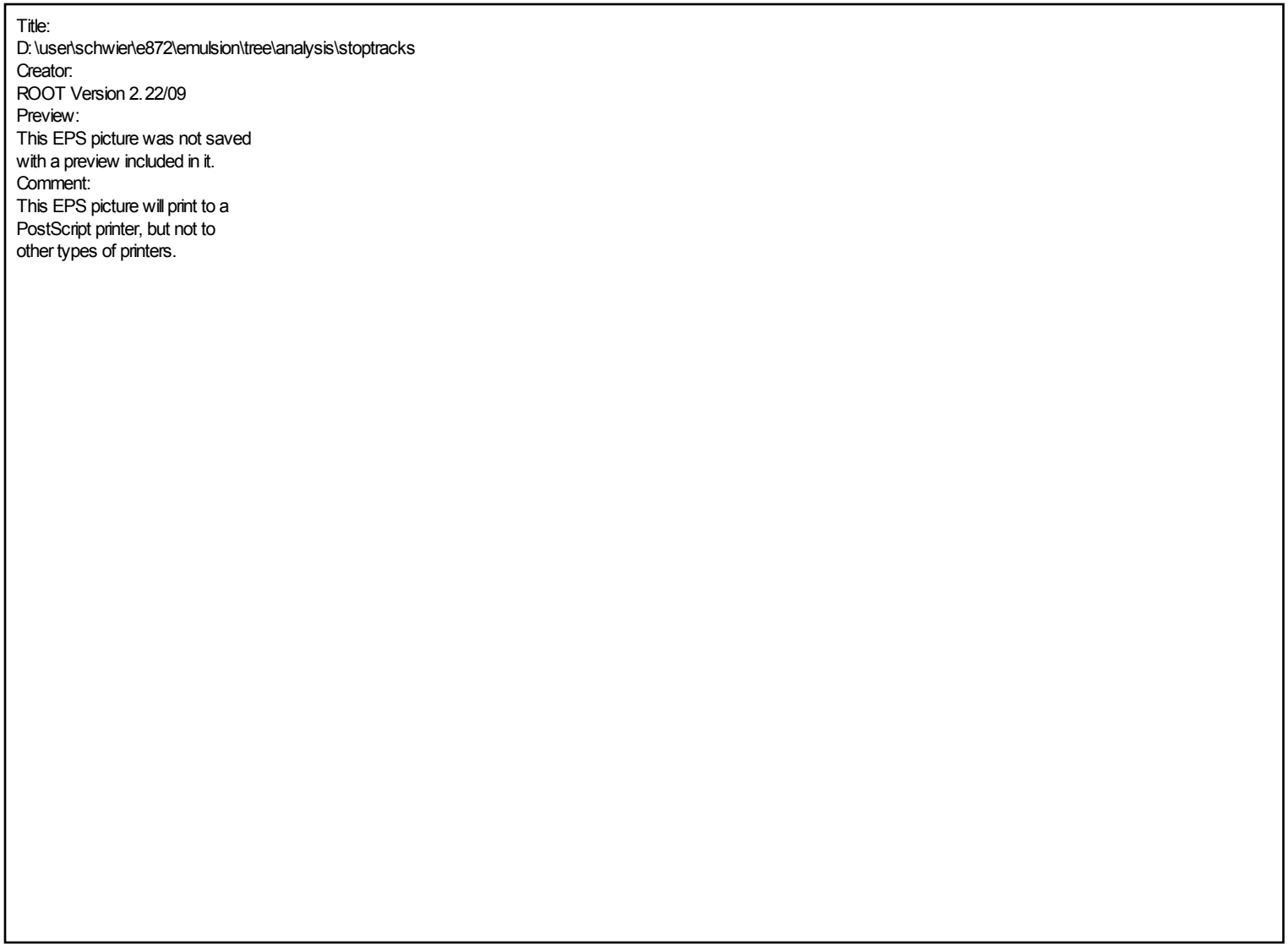
Emulsion net scan step 0: prepare vertex prediction



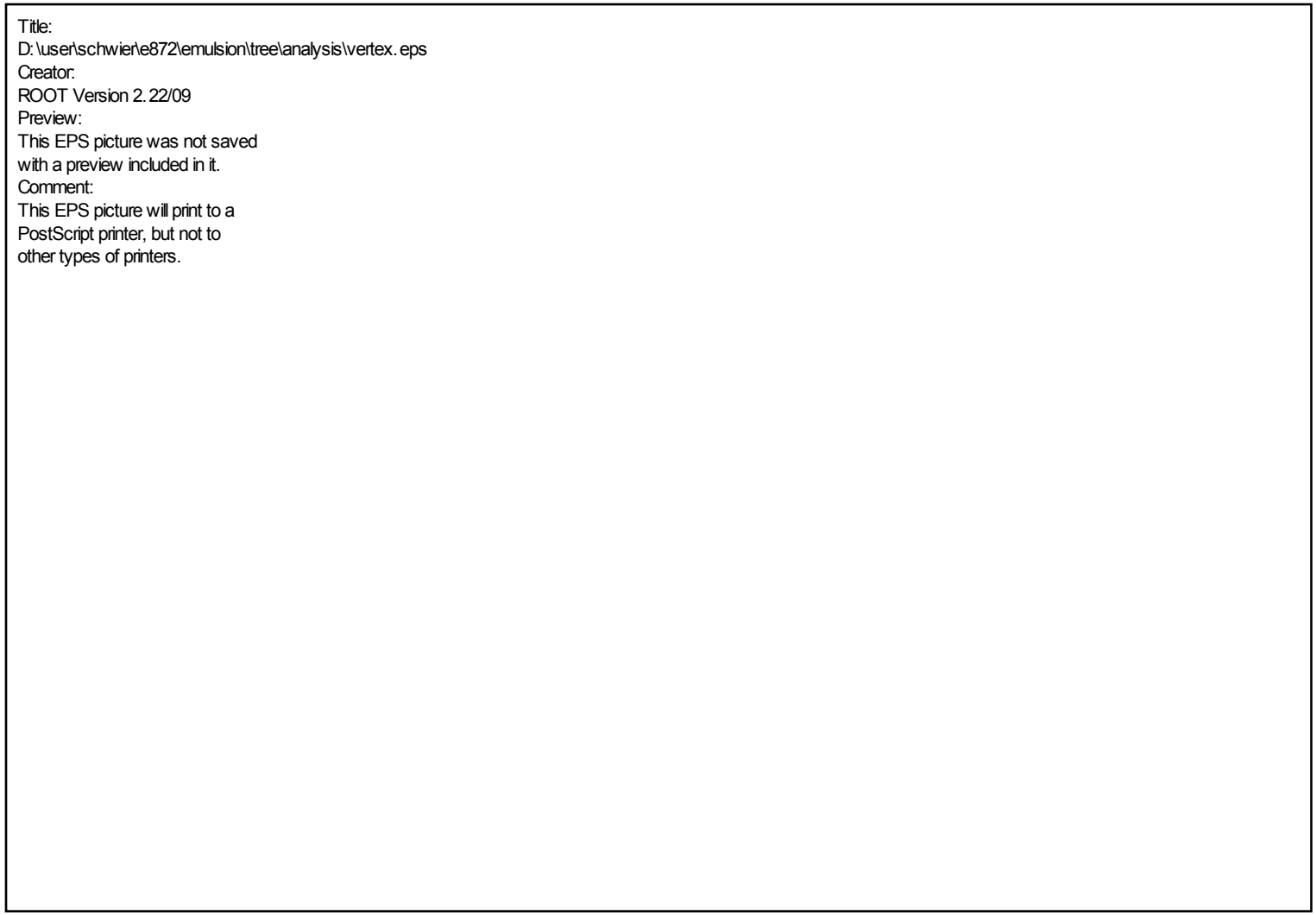
Emulsion net scan step 1: all tracks



Emulsion net scan step 2: tracks that start inside the volume



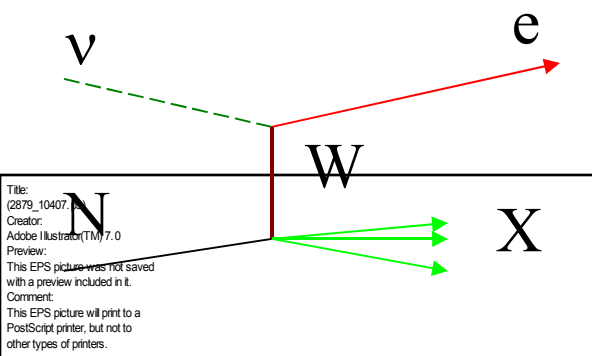
Emulsion net scan step 3: 3-track vertex



Example events

- ν_e CC interaction
- ν_μ CC interaction
- ν_τ CC interaction candidate
- charm production candidate

ν_e charged current interaction



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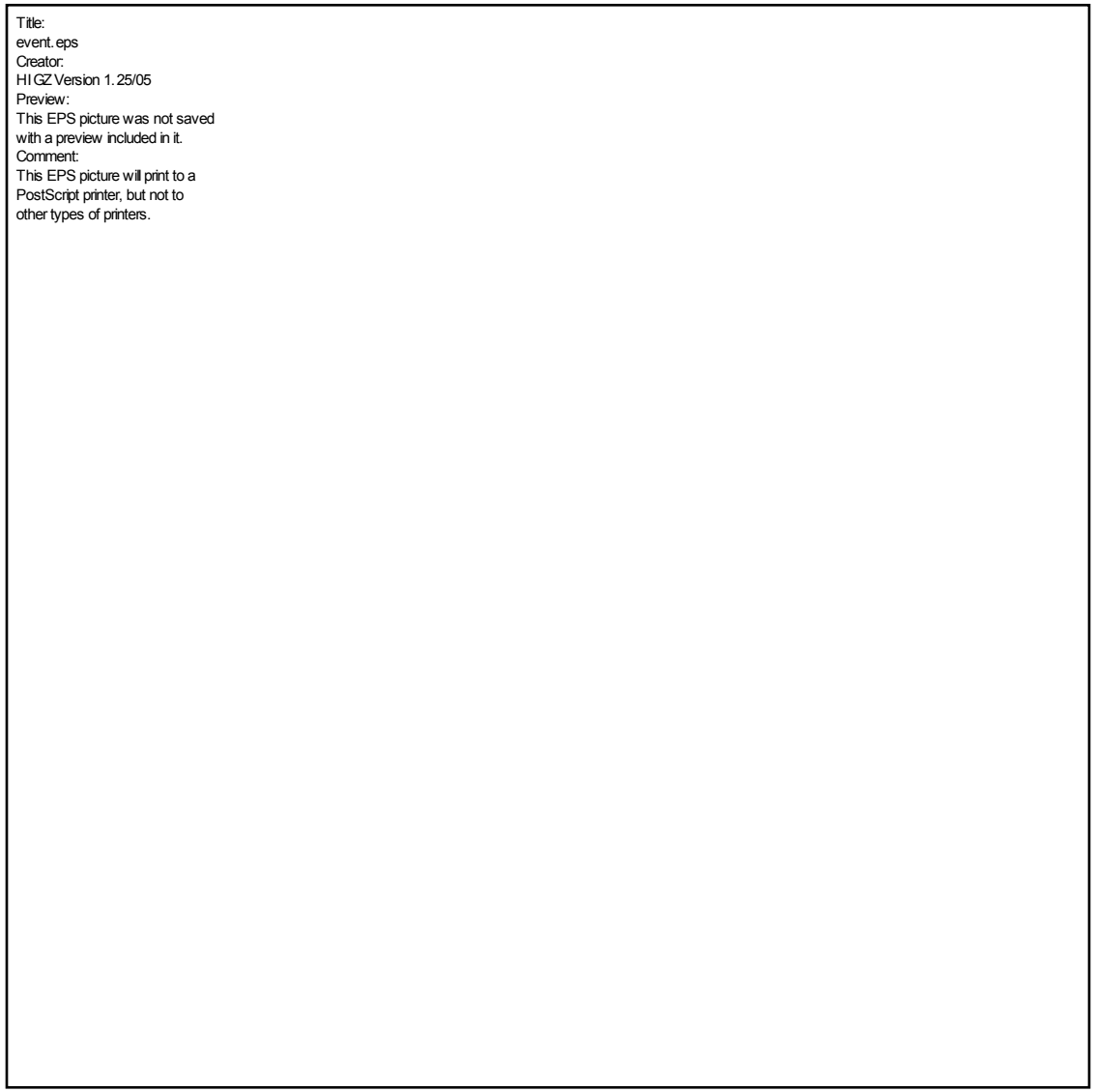
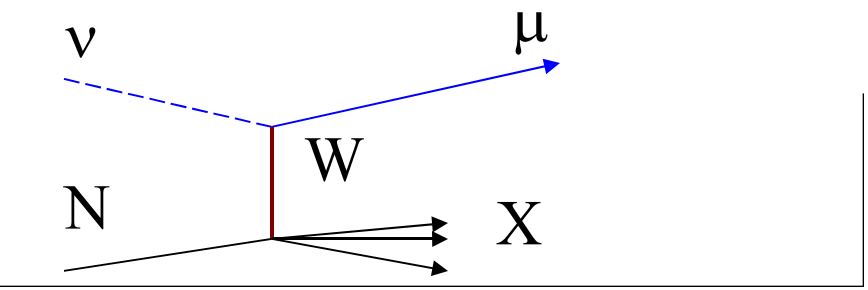
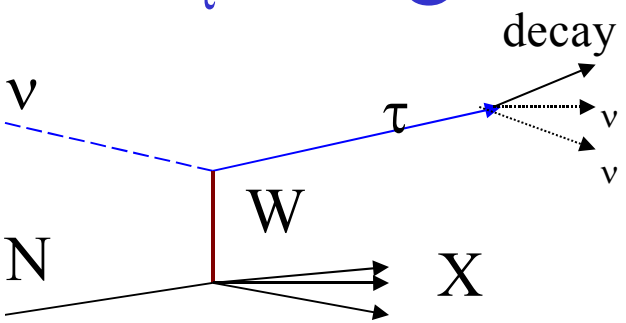
ν_e charged current interaction



ν_μ charged current interaction



ν_τ charged current interaction candidate



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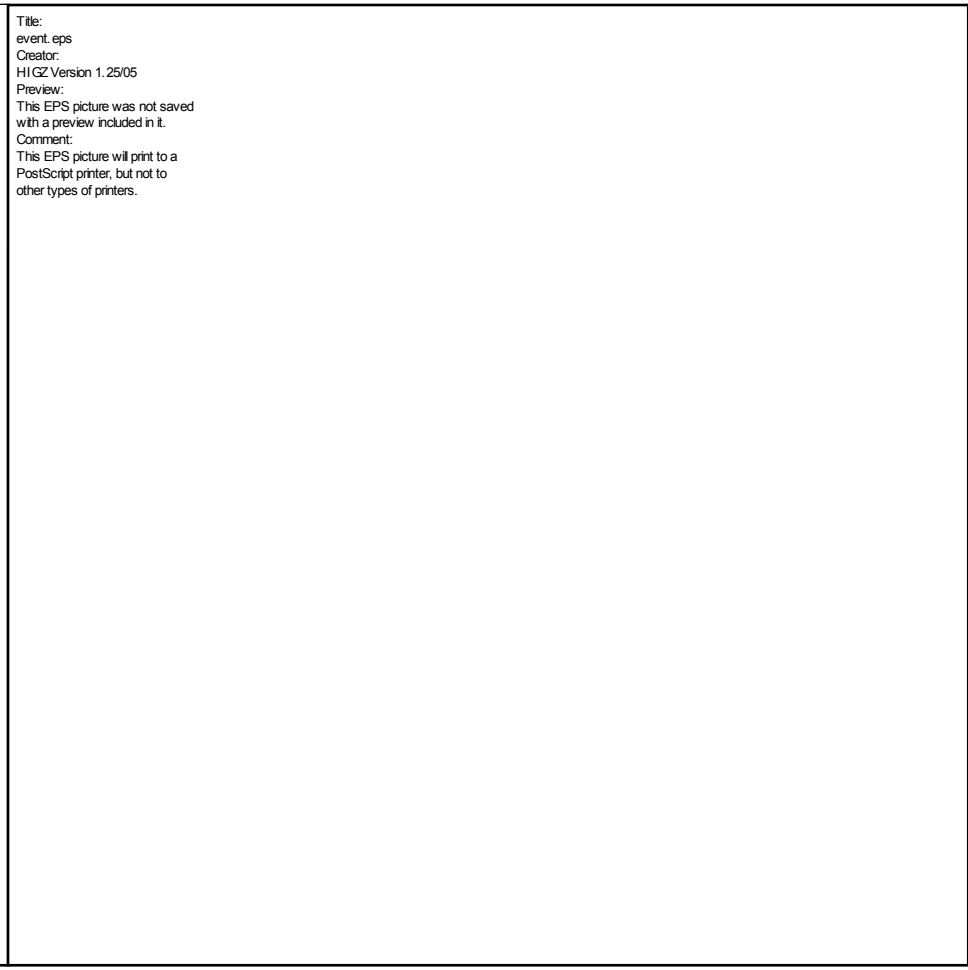
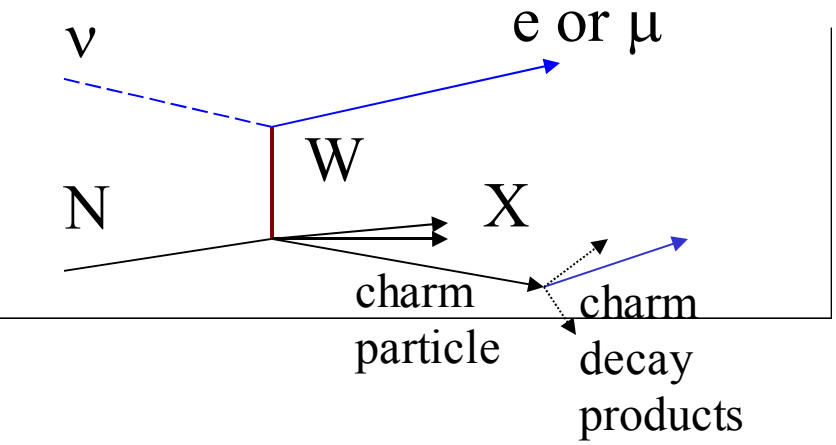
ν_τ charged current interaction candidate



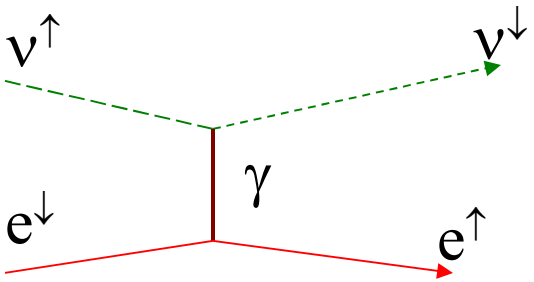
Charm production candidate



Searching for rare events: $\mu_{\nu\tau}$

- Tau neutrino magnetic moment
- current limit $\mu_{\nu\tau} < 5.4 \times 10^{-7} \mu_B$
- interaction: $\nu^{\uparrow} + e \quad \nu + e^{\uparrow}$
- expect 40 magnetic moment interactions
  - if $\mu_{\nu\tau} = 5.4 \times 10^{-7} \mu_B$
  - for a low-energy electron cutoff at 1GeV

Neutrino magnetic moment interaction (MC)



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Analysis status

- 860 neutrino interactions have been found with the spectrometer
- 450 events have been scanned
- 144 interactions have been located so far

Preliminary physics result

Number of events

	Calculated†	Data		
Total # of interactions	980	860		
ν_μ CC interactions	330	316		
kink candidates	70	24*	Bulk	ECC
			8	16
charm candidates	75	12*	3	9

†: Prompt neutrinos; does not include efficiencies, background, etc

*: out of 144 found events; from an enriched sample

Outlook

- Spectrometer analysis:
  - predict vertex location for all events
  - MC studies
    - efficiencies, neutrino spectrum, ...
- Emulsion analysis:
  - more events have to be scanned
    - Nagoya
  - vertex search
    - Nagoya, starting in the US
  - decay kink search
    - Nagoya, starting in the US

Challenges

- Alignment
  - spectrometer
  - spectrometer to emulsion
  - emulsion :
    - sheet to sheet
    - distortions in a sheet
- Information exchange Nagoya US
  - presence of US collaborators in Nagoya improves information flow
- Spectrometer analysis
  - good vertex prediction
- Emulsion analysis
  - vertex location

Conclusions

- DONUT will achieve its goal
  - Preliminary result:
    - we have seen ν_τ interaction candidates
    - we will see >10 ν_τ interactions
      - we will do parameter studies
- Some work still remains
  - Emulsion scanning takes time
  - vertex location takes precision