Analysis of Trident Events

Emily Maher

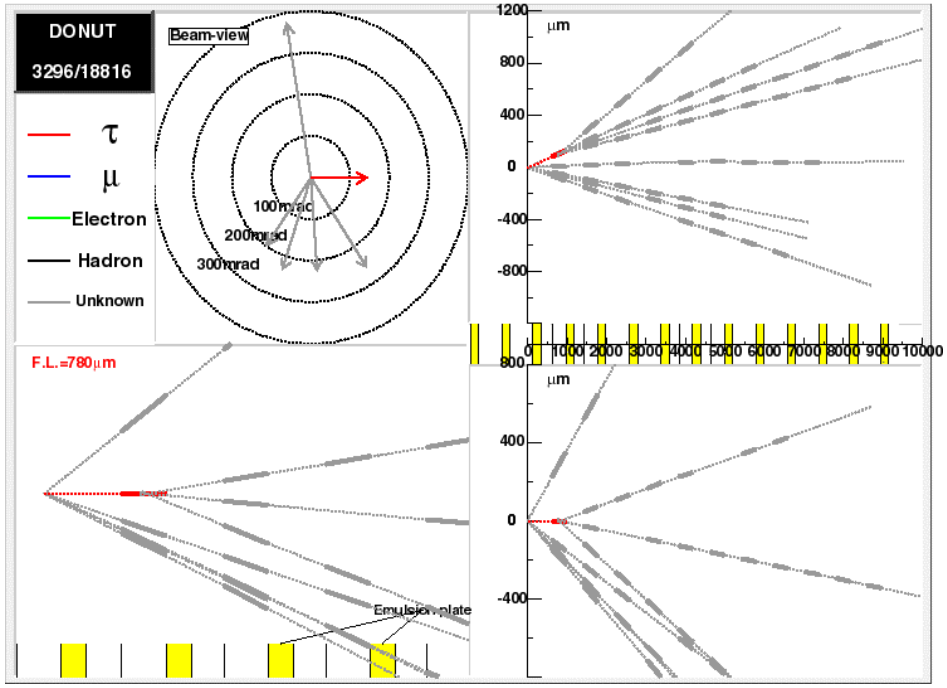
DONUT Collaboration Meeting

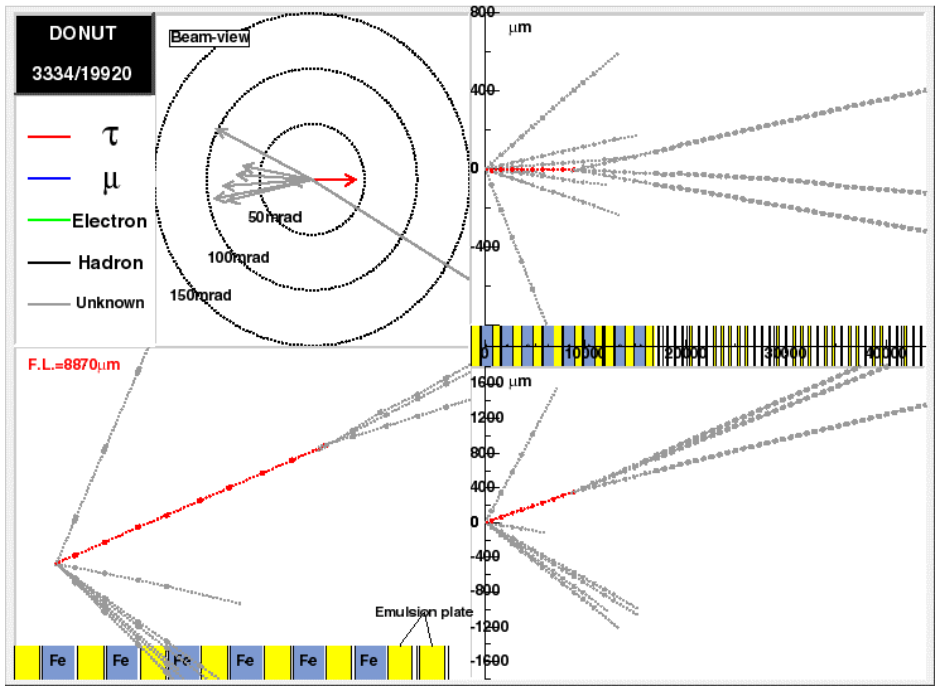
November , 2002

Outline

- Bayesian Probability Formula
  - Prior Probability
  - Probability Density Function
- Parameters
  - Only using parameters relating to primary vtx
- Results for Trident Events
- Results for Single Prong Events
- Conclusions
- Future Extensions

New n_t Trident Candidates





Primary vertices occurred in iron for both events

Secondary vertex occurred in emulsion for 3296_18816 and plastic for 3334_19920

Bayesian Probability Formula

Individual event probabilities

$$P(hypothesis_\alpha \mid \vec{e}) = \frac{A_\alpha \cdot PDF(\vec{e} \mid hypothesis_\alpha)}{\sum A_i \cdot PDF(\vec{e} \mid hypothesis_i)}$$

P = The probability of an event *e* being a result of hypothesis α.

α = *tau*, *interaction* *or* *charm* event

Two inputs for each hypothesis:

1. A_i prior probability: "normalization"

   Previous knowledge of the likelihood of each hypothesis

2. PDF (hypothesis$_\alpha$| *x*) probability density at *x* under hypothesis α

   Fraction of simulated events which reside in a region of parameter space centered around the parameters of the event , *x*

1 parameter example with two hypotheses: ν_τ vs interaction

Assume the only possibilities are ν_τ or hadron interaction.

Use only one parameter Φ to evaluate event.

3024_30175 has $\Phi = 1.04$

$$P(n_t \mid \Phi) \equiv \frac{A_n \cdot PDF(\Phi \mid n_t)}{A_n \cdot PDF(\Phi \mid n_t) + A_{\text{int}} \cdot PDF(\Phi \mid n_t)}$$

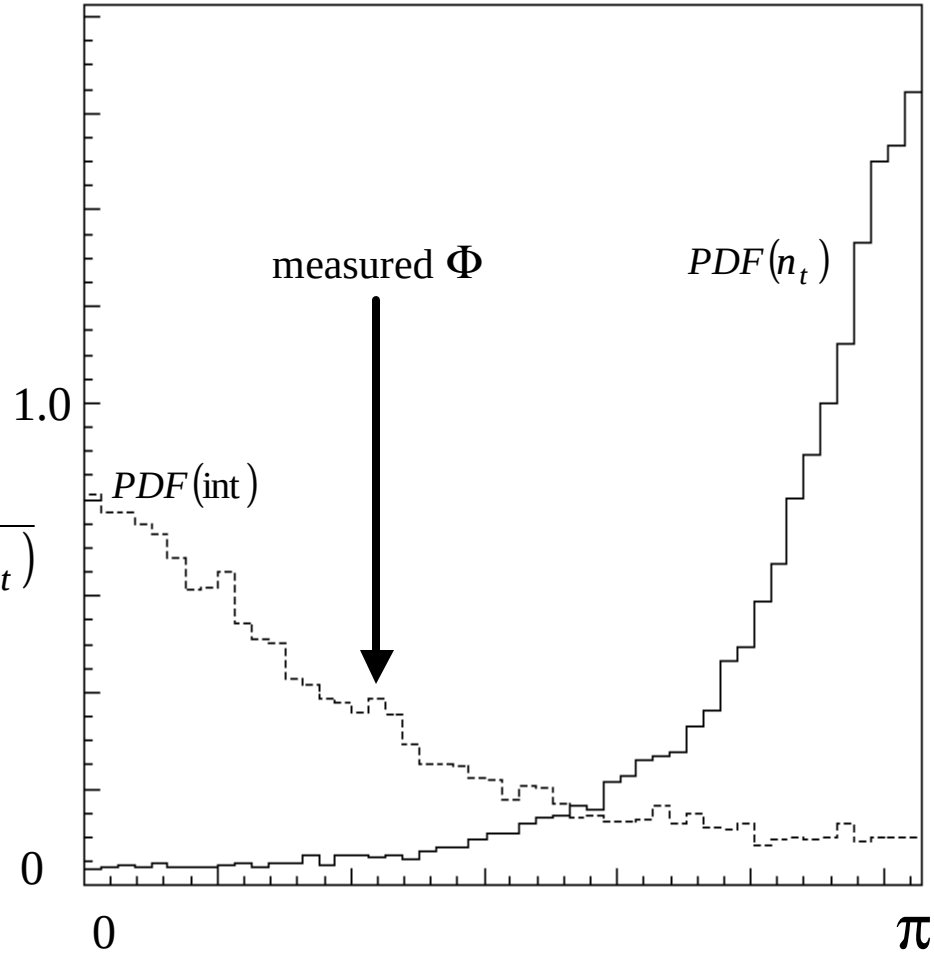
Expect .11 interaction evts. A_{int} .11

Expect 4.2 ν_τ events $A_{\nu\tau}$ 4.2

PDF(int. | $\Phi = 1.04$) = .38

PDF(ν_τ | $\Phi = 1.04$) = .06

$$P(n_t \mid \Phi = 1.04) = \frac{(4.2)\cdot(.06)}{(4.2)\cdot(.06) + (.11)\cdot(.38)} = .86$$

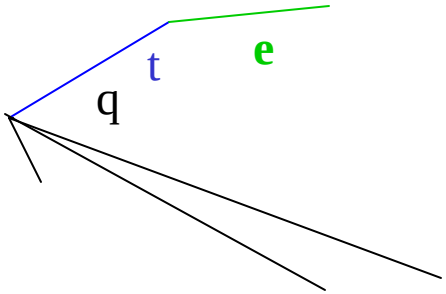


$$P(\text{int} \mid \Phi = 1.04) = .14$$

Production Angle q

Angle between the original neutrino direction and the candidate t track

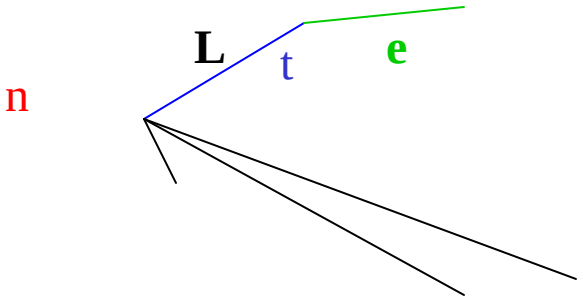
Event	q
3334_19920	39.8 mrad
3296_18816	141 mrad



Decay Length L

Decay length of the candidate t track

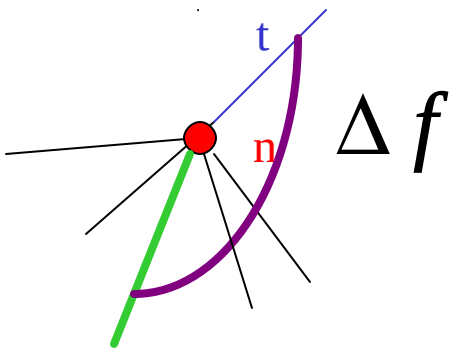
Event	L
3334_19920	8.87 mm
3296_18816	0.78 mm



f Asymmetry Δf

- To Calculate f Asymmetry
  - Project all tracks into plane perpendicular to beam direction
  - Measure f for all tracks from an arbitrary $f = 0$ point
  - Average the f angles for all non-tau tracks by treating each track as a unit vector, adding the tracks vectorially to get a resultant track (green track), and calculating the angle of the resultant track
  - Subtract f angle of t track from f angle of resultant track to get Δf (purple angle)

Event	Δf
3334_19920	3.11 rad
3296_18816	1.74 rad



Prior Probability of n_t Trident Events

$$A_{n_t \to 3} = \frac{N_{n_t} P(t \to 3prong)}{N_{events}}$$

N_{n_t} is the number of n_t events expected in the data (17.32 events)

$P(t \to 3prong)$ is the probability that a tau will decay to 3 charged particles (0.1457 from PDG)

N_{events} is the total number of events (429 events)

$$A_{n_t \to 3} = 5.9 \times 10^{-3}$$

Number of Expected n_t Events

N_{n_t} is measure from N_{n_m} and N_{n_e} events using:

$$\frac{N_{n_t}}{N_{n_l}} = \frac{Rate_{n_t}}{Rate_{n_l}} \cdot \frac{E_{n_t}}{E_{n_l}}$$

where E is the total efficiency, and the ratio of the interaction rates are defined by:

$$\frac{R_{n_t}}{R_{n_a}} = \frac{\left\langle \frac{s(D_s)}{s(D^0)} \right\rangle \cdot Br(D_s \to nt) \cdot \int h(E)\, s(E) \frac{dN}{dE}}{\sum_i \left\langle \frac{s(C_i)}{s(D^0)} \right\rangle \cdot Br(C_i \to na) \cdot \int h(E)\, s(E) \frac{dN}{dE} dE_a}$$

where C is $D^0, D^{\pm}, D_s$, $h(E)$ is the target acceptance, $s(E)$ is the neutrino-nucleon cross section, and the integral is over the energy spectrum of the produced neutrinos

$$\frac{R_{n_t}}{R_{n_{n_m}}} = 0.163 \qquad \frac{R_{n_t}}{R_{n_{n_e}}} = 0.139$$

Cross-section ratio

Experiment		D_s/D^0	D^+/D^0
CLEO	e+e-	.32±.14	.38±.10
NA32	Pion	.24±.10	.51±.15
WA92	Pion	.16±.05	.42±.05
E653	Pion	-	.4±.1
E653	Proton	-	.8±.4
E691	Gamma	.14±.04	.51±.11
E769	Pion+	.28±.07	.44±.06
E769	Proton	.27±.18	.42±.05
E769	Pion-	-	.27±.06
E791	Proton	-	.57±.22
Mean		.18±.03	.41±.02

Charm production parameters

Experiment	b	n
E653	.84±.09	6.9 ±1.9
E743	.80±.2	8.6±2.0
Mean	.83 ±.11	7.7 ±.1.4

$$\langle h \rangle = 7.4\%$$

D_s branching fraction

$D_s \quad \nu_\tau$	BR %
CLEO	6.6 ± 1.1
WA 75	5.6 ± 1.7
BES	9.7 ± 3.8
E653	6.6 ± 1.0
L3	7.1 ± 1.9
DELPHI	7.6 ± 1.1
Mean	6.6 ± 0.6

Charm branching fractions (PDG)

Decay	BR %
$D^+ \quad \nu_e$	17.2 ± 1.9
$D^0 \quad \nu_e$	6.75 ± .29
$D_s \quad \nu_e$	8 ± 5
$D^+ \quad \nu_\mu$	16 ± 3
$D^0 \quad \nu_\mu$	6.6 ± 0.8
$D_s \quad \nu_\mu$	8 ± 5

Prior Probability of Charm

$$A_{charm\to 3} = \sum_i \frac{N_{charm_i} P(charm_i \to 3\,prong) x}{N_{events}}$$

N_{charm_i} is the number of charm particles expected of type i which is either $D^{\pm}$, D_s, or Λ_c

$P(charm_i \to 3\,prong)$ is the probability that the charm particle will decay to 3 charged particles

x is the probability that the primary lepton is not identified

$$A_{charm\to 3} = 2.1\times 10^{-3}$$

Expected Number of Charm

$$N_{\text{charm}_i} = N_{cc} F a_i$$

where N_{cc} is the number of charged current events, F is the average charm particle production factor, and a_i is the fraction of the time a charm quark will produce a particle of type i, where i is a $D^{\pm}$, D_s, or Λ_c

N_{cc} is 326 events (239 events identified so far), F is 0.066 (from E531 data), and a_i is summarized:

Particle	a_i
$D^{\pm}$	0.24
D_s	0.09
Λ_c	0.10

Prior Probabilities for Charm

Particle	N_{charm}	$P(\text{c} \rightarrow \text{tri})$	χ	A_{charm}
$D^{\pm}$	5.16	0.3656	0.3	0.57
D_s	1.94	0.0323	0.3	0.19
Λ_c	2.15	0.1988	0.3	0.13
Total				0.88

0.88 charm background events are expected out of 429 events; the prior probability for charm is 0.88/429 = 2.05×10^{-3}.

Prior Probability of Interaction

$$A_{scatter} = \frac{\sum_i L_i P(\text{int})_i x}{N_{events}}$$

L_i is the total length of all the hadron tracks through material i, where i is iron, emulsion, or plastic

these lengths were found by scaling up lengths from 203 data set

$P(\text{int})_i$ is the probability per unit length that the hadrons will interact to produce 3 charged i particles in material

$$A_{scatter} = 5.5 \times 10^{-3}$$

Lengths in 429 Data Set

Material	Length (mm)
Iron	3629.0
Acrylic	1874.7
Emulsion	2821.2

Results of Prior Probability

Type of Event	Prior Probability
Tau Neutrino	5.9×10^{-3}
Charm Decay	2.1×10^{-3}
Hadronic Interaction (in iron)	5.5×10^{-3}
Hadronic Interaction (in emulsion and plastic)	$<10^{-5}$

Multi-dimensional Probability Density calculation

Calculating multi-dimensional probability density for a candidate event

1. Each event has measured values of parameters $\rightarrow$ ($q, \Delta f,$ and L)
2. Define a (small) interval in parameter space around measured values: Δv
3. Simulate hypothesis event type:
   count number of events which pass all tau selection cuts (N_{total})
   count number of events which are within the interval Δv ($N_{\Delta v}$)

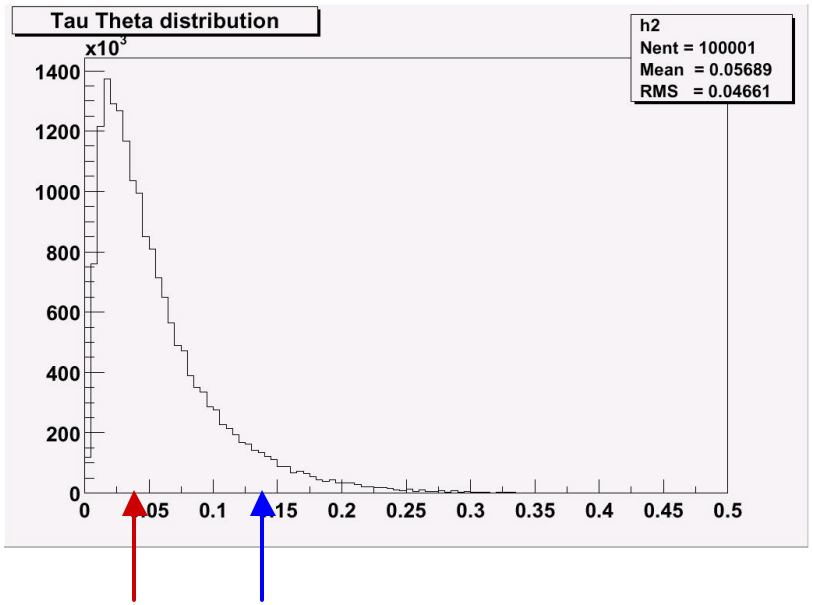
$$\left.\begin{array}{l} q \pm \Delta q \\ \Delta f \pm \Delta(\Delta f) \\ L \pm \Delta L \end{array}\right\}$$

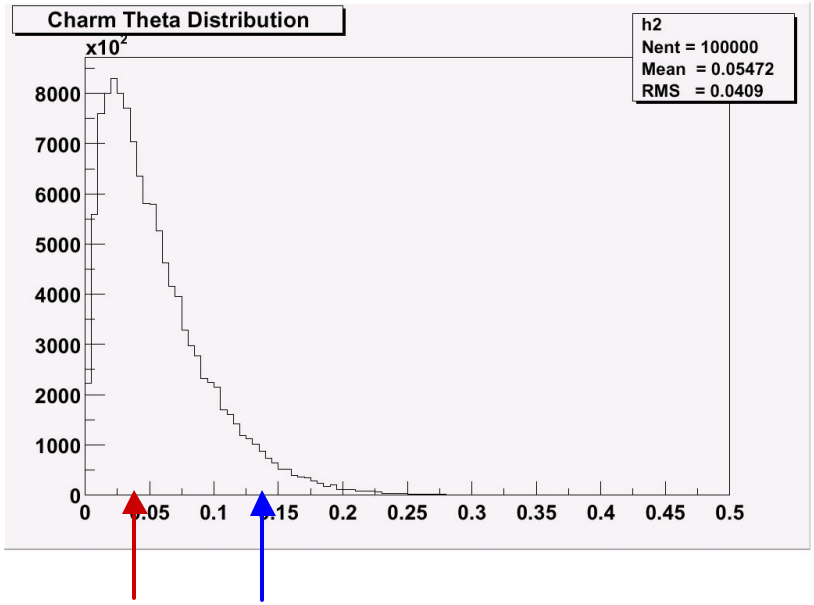
Δv

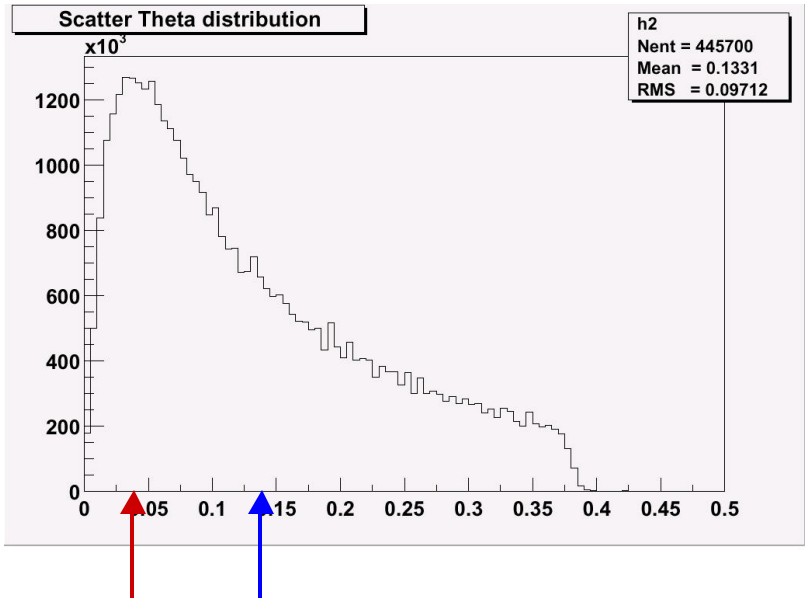
probability density for event $\equiv$ $\dfrac{N_{\Delta v}}{N_{total} \cdot \Delta v}$

Used Jason's simulated data for typical tau events, charm events, and hadrons events in our data

Distributions for q



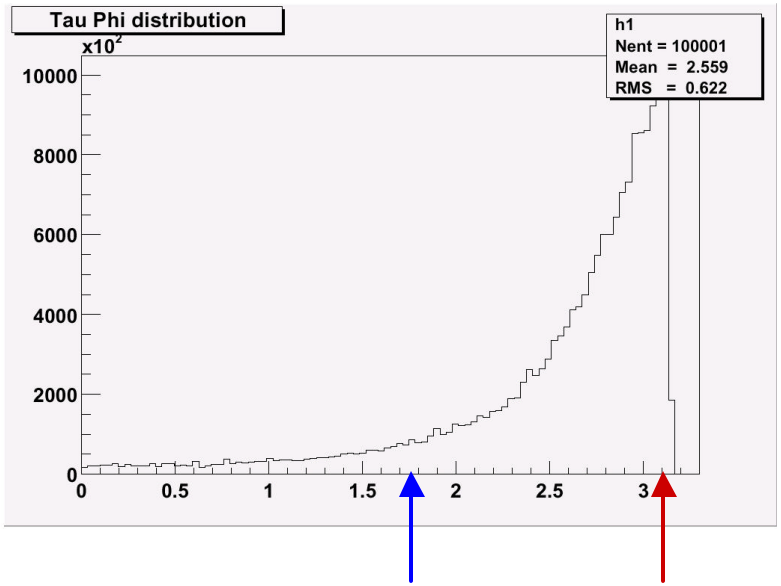


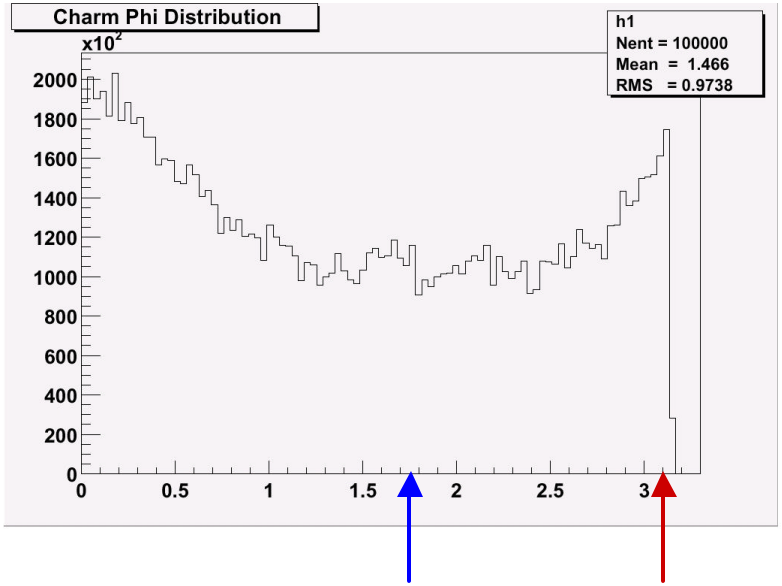


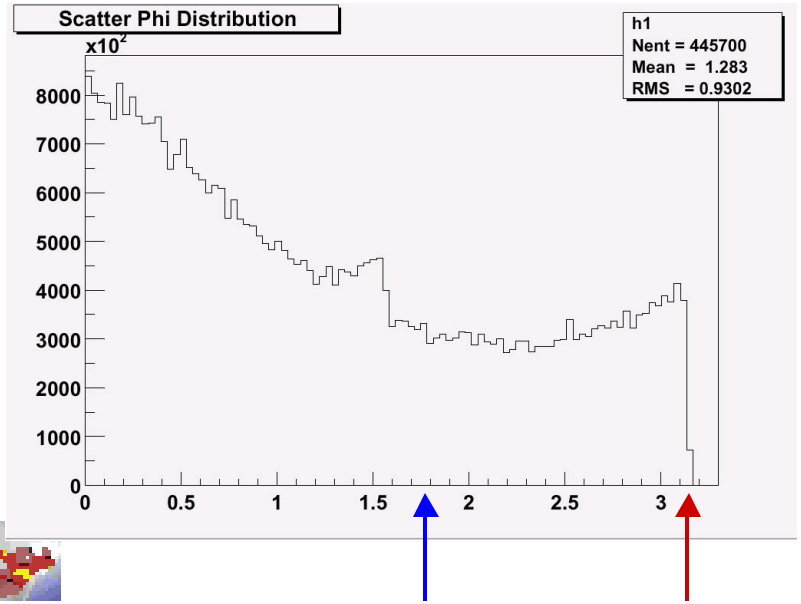
3334_19920

3296_18816

Distributions for Δf



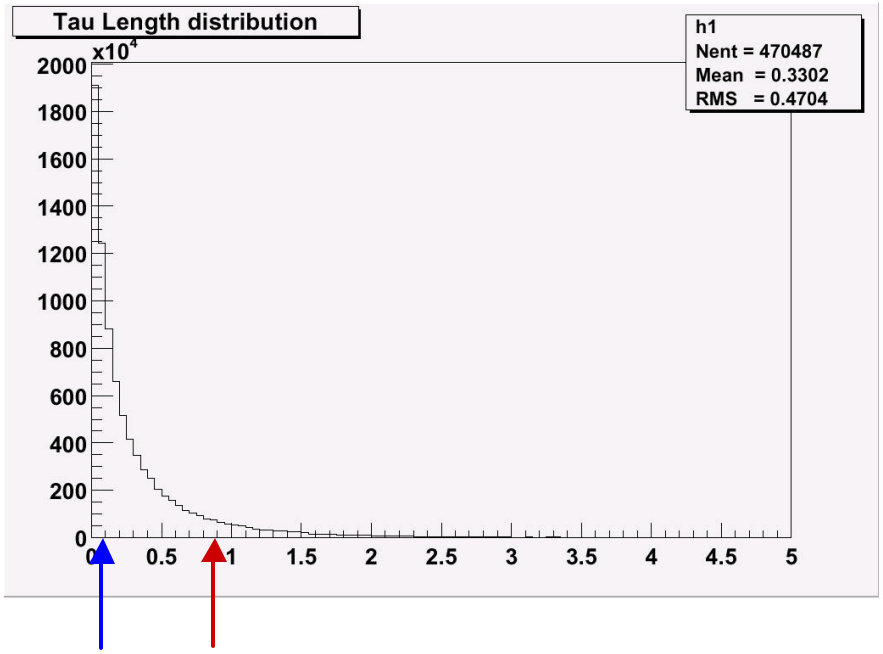


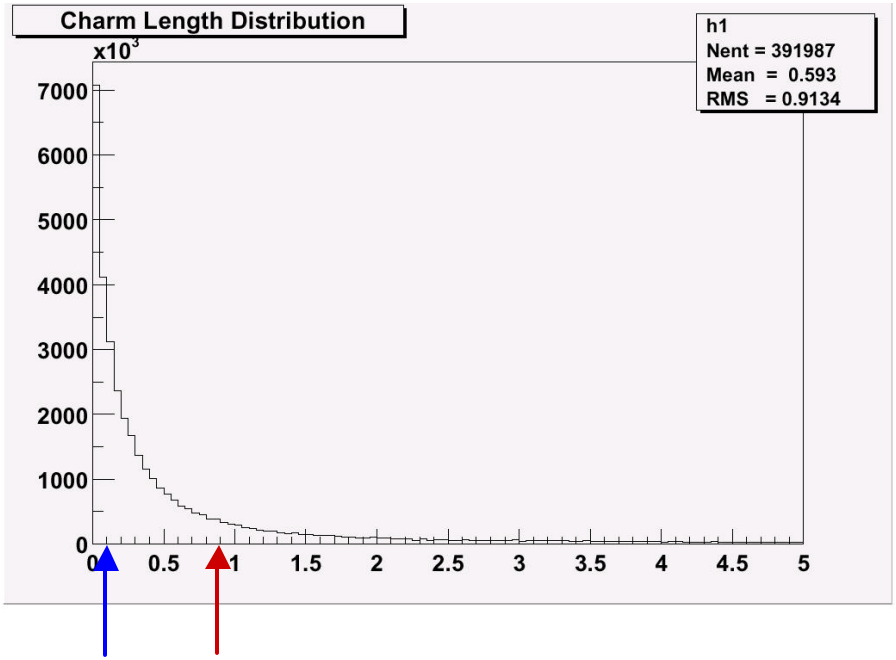


3334_19920

3296_18816

Distributions for *L*





3334_19920

3296_18816

Results for Probability Density (in $1/\mathrm{rad}^2\mathrm{mm}$)

Type of Event	3334_19920	3296_18816
Tau Neutrino	1 .653	0.545
Charm Event	0.565	0.020
Interaction Event	0 .042	0.052

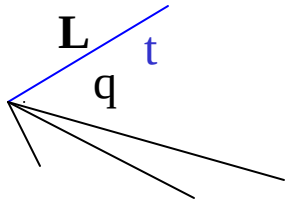
Results for Tridents

Type of Event	3334_19920	3296_18816
Tau neutrino	0.89	0.98
Charm Event	0.11	0.02
Interaction	0.00	0.00

Results for Tridents

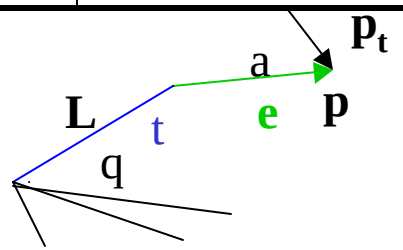
Type of Event	3334_19920	3296_18816
Tau neutrino	0.88	0.91
Charm Event	0.10	0.01
Interaction	0.02	0.08

Single Prong Events



3 Parameter Analysis: $P(\text{bkg} = 4) = 2.9 \times 10^{-6}$

Event	3024_19920	3039_01910	3263_25102	3333_17665
Tau	0.870	0.996	0.060	0.994
Charm	0.130	0.002	0.030	0.002
Interaction	0.000	0.002	0.910	0.004



5 Parameter Analysis: $P(\text{bkg} = 4) = 7.1 \times 10^{-5}$

Event	3024_19920	3039_01910	3263_25102	3333_17665
Tau	0.698	0.982	0.130	0.985
Charm	0.302	0.018	0.140	0.015
Interaction	0.000	0.00024	0.730	0.000

Conclusions

- This analysis produced similar results to Jason's analysis
- 3334_19920 and 3296_18816 are both most likely to be tau neutrino trident events according to this analysis

Future Extensions

- Calculating efficiencies for locating trident events
- Use current data set to calculate more accurate values for number of expected n_t interactions, number of expected charm background decays, and total lengths of hadron tracks in different materials
- Add parameters to this analysis which relate to decay products

Event 3024_30175

Probability density evaluation

Φ = 1.04 ± 0.1 rad

Θ_p = .027 ± .007 rad

L_d = 4.5 ± 0.5 mm

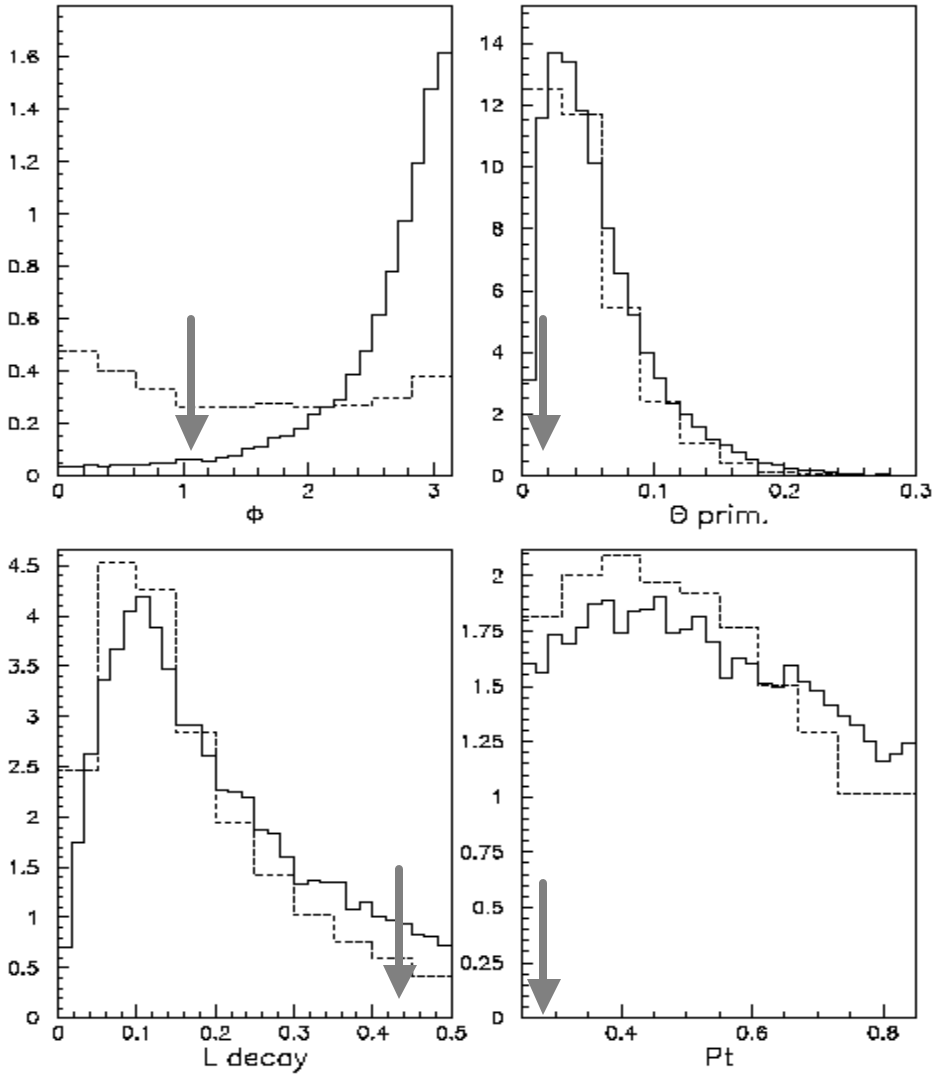
Θ_k = .093 ± .010 rad

P = 2.9 ± 30 %* GeV/c

Δv

ν_τ	.70
charm	6.7
interaction	-

PDF: ν_τ and charm



Event 3039_01910

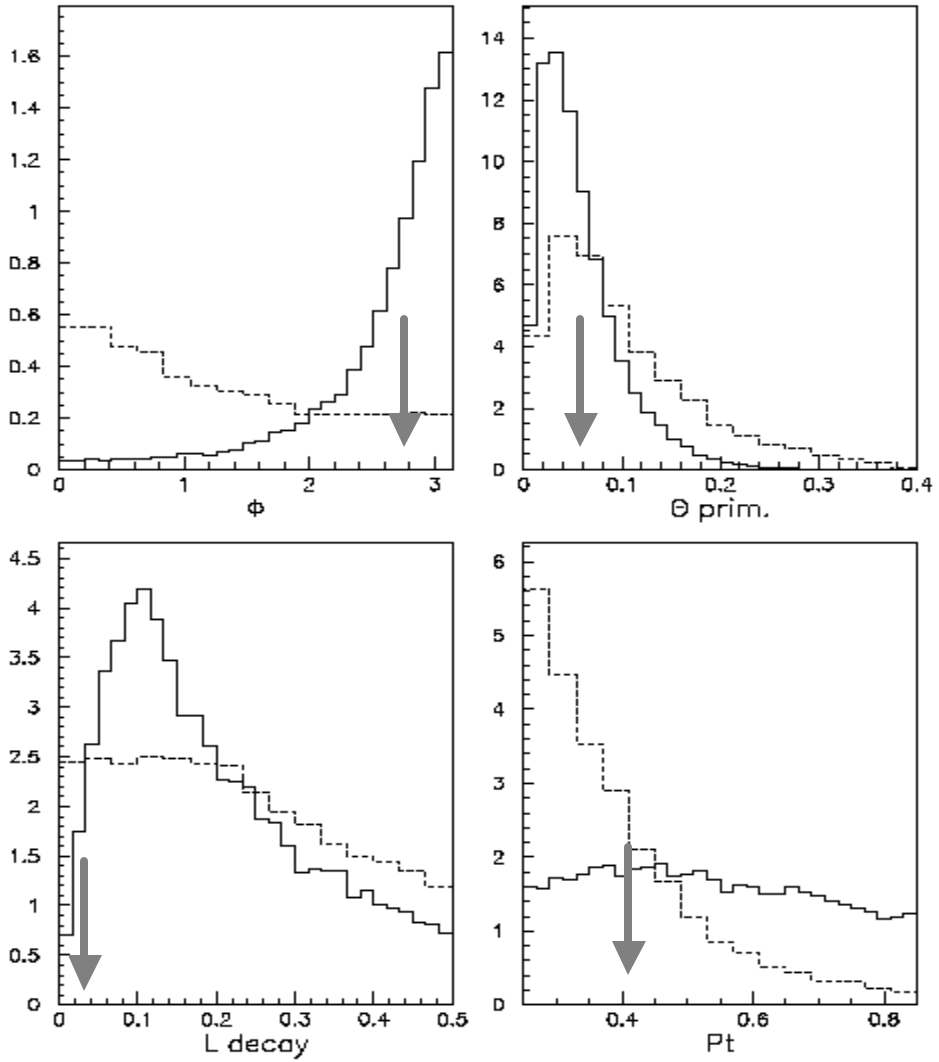
Probability density evaluation

Φ	=	2.71 ± 0.1		rad
Θ_p	=	.063 ± .010		rad
L_d	=	.280 ± 0.04		mm
Θ_k	=	.090 ± .010		rad
P	=	4.6 ± 30 %*		GeV/c

Δv

ν_τ	56.8
charm	20.6
interaction	2.6

PDF: ν_τ and interaction



Event 3333_17665

Probability density evaluation

Φ = 2.85 ± 0.035 rad

Θ_p = .016 ± .003 rad

L_d = .540 ± 0.04 mm

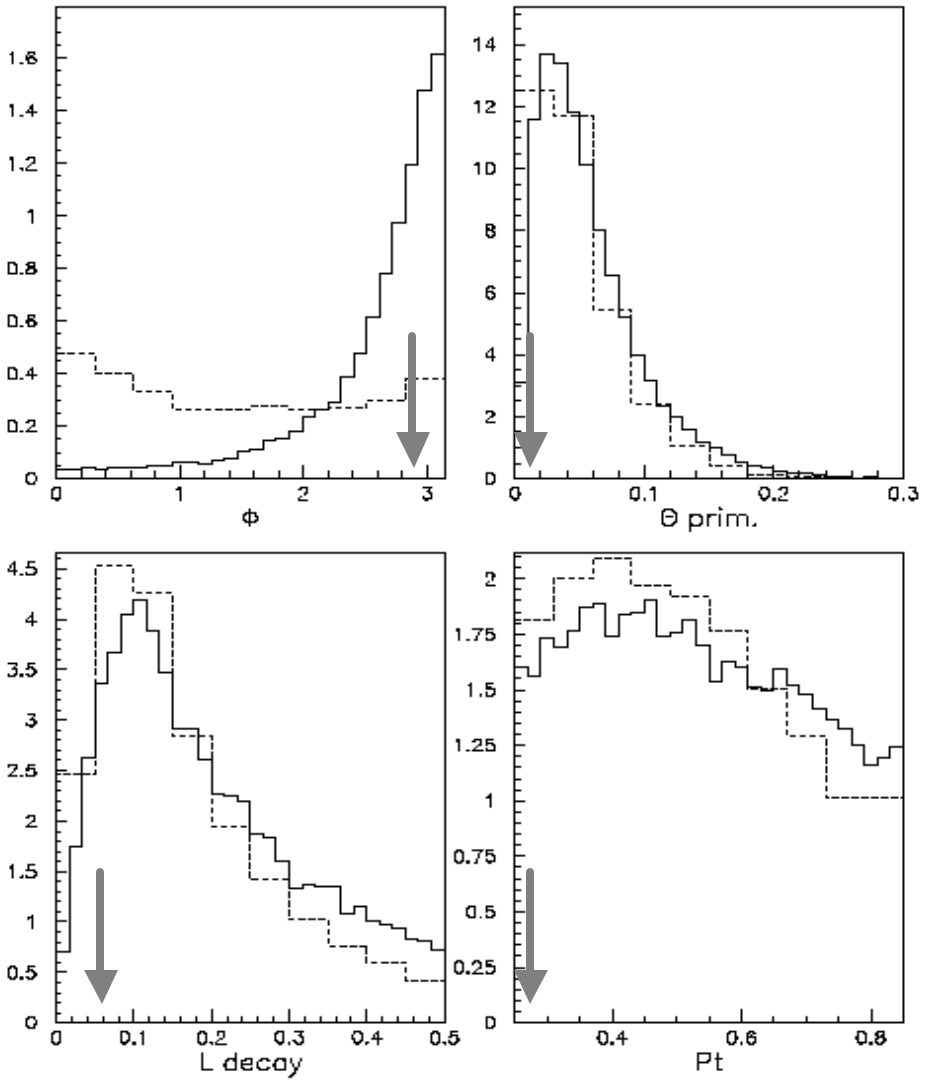
Θ_k = .013 ± .002 rad

P = 21 ± 30 %* GeV/c

Δv

ν_τ	37.5
charm	25.7
interaction	-

PDF: ν_τ and charm



Event 3263_25102

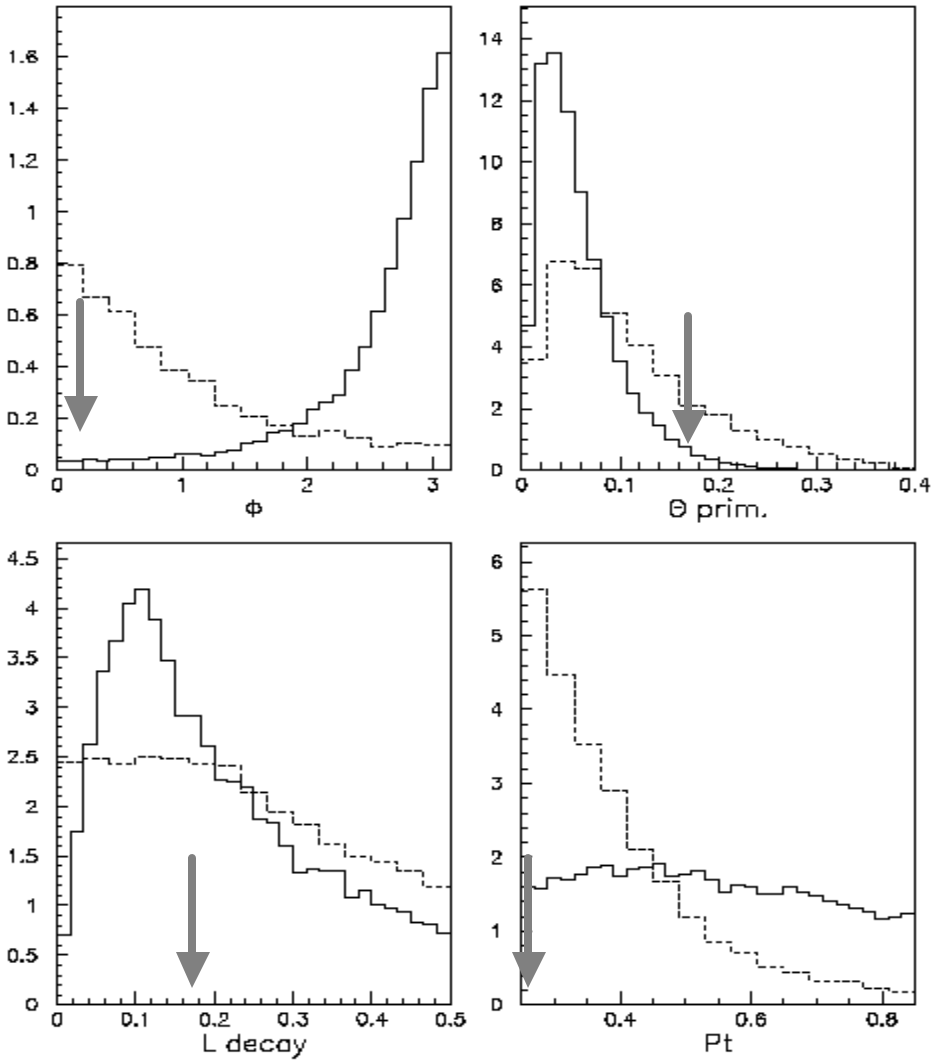
Probability density evaluation

Φ	=	.11	± 0.035	rad
Θ_p	=	.18	± .003	rad
L_d	=	1.8	± 0.04	mm
Θ_k	=	130	± .002	rad
P	=	1.9	± 30 %*	GeV/c

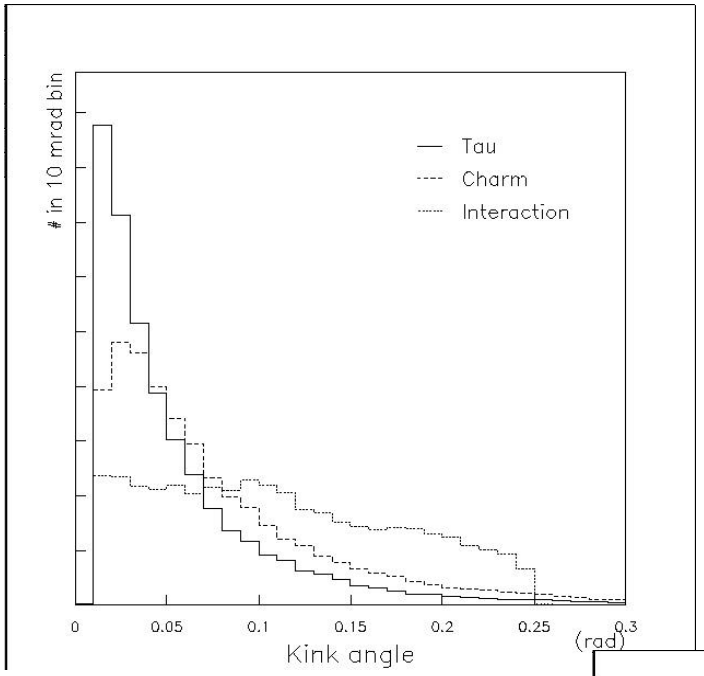
Δv

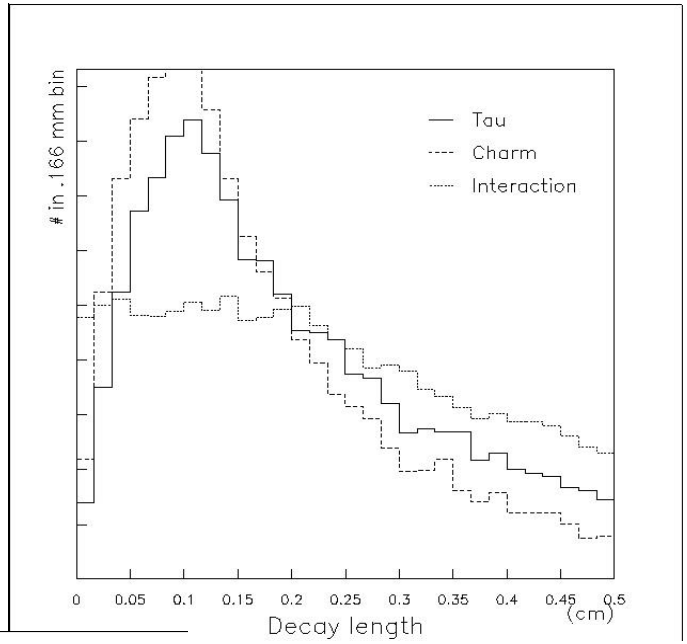
ν_τ	.04
charm	.67
interaction	4.8

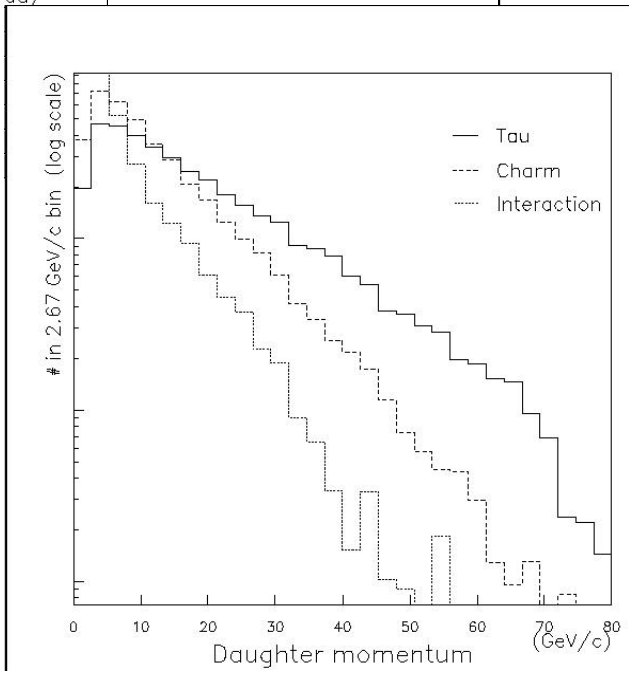
PDF: ν_τ and interaction



Distributions







More Distributions