Recent Results from E815 (NuTeV)

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Recent Results from NuTeV

1) Beam and Detector

2) Physics Menu (topics I'm ignoring)

3) Electroweak mixing angle

4) Decay searches

- Neutral Heavy Leptons
- KARMEN Timing Anomaly
- High mass decays → Anomalous events

E815 (NuTeV)

- High energy neutrino deep inelastic scattering at Fermilab
- Refurbished Lab E (CCFR) detector
- New sign-selected neutrino, antineutrino beams
- New decay detector allows searches for exotic particle decays.

E815 (NuTeV) Collaboration

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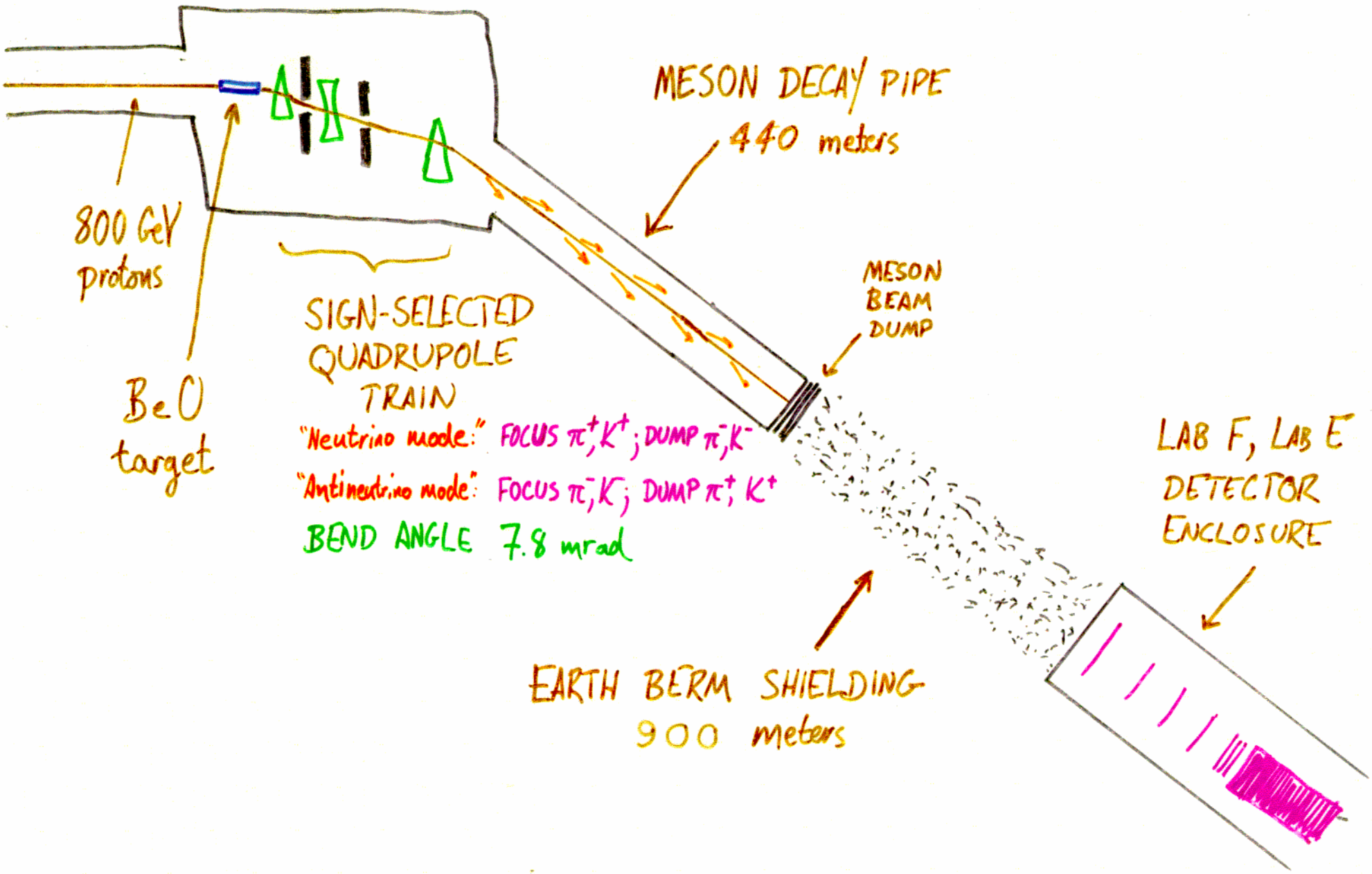
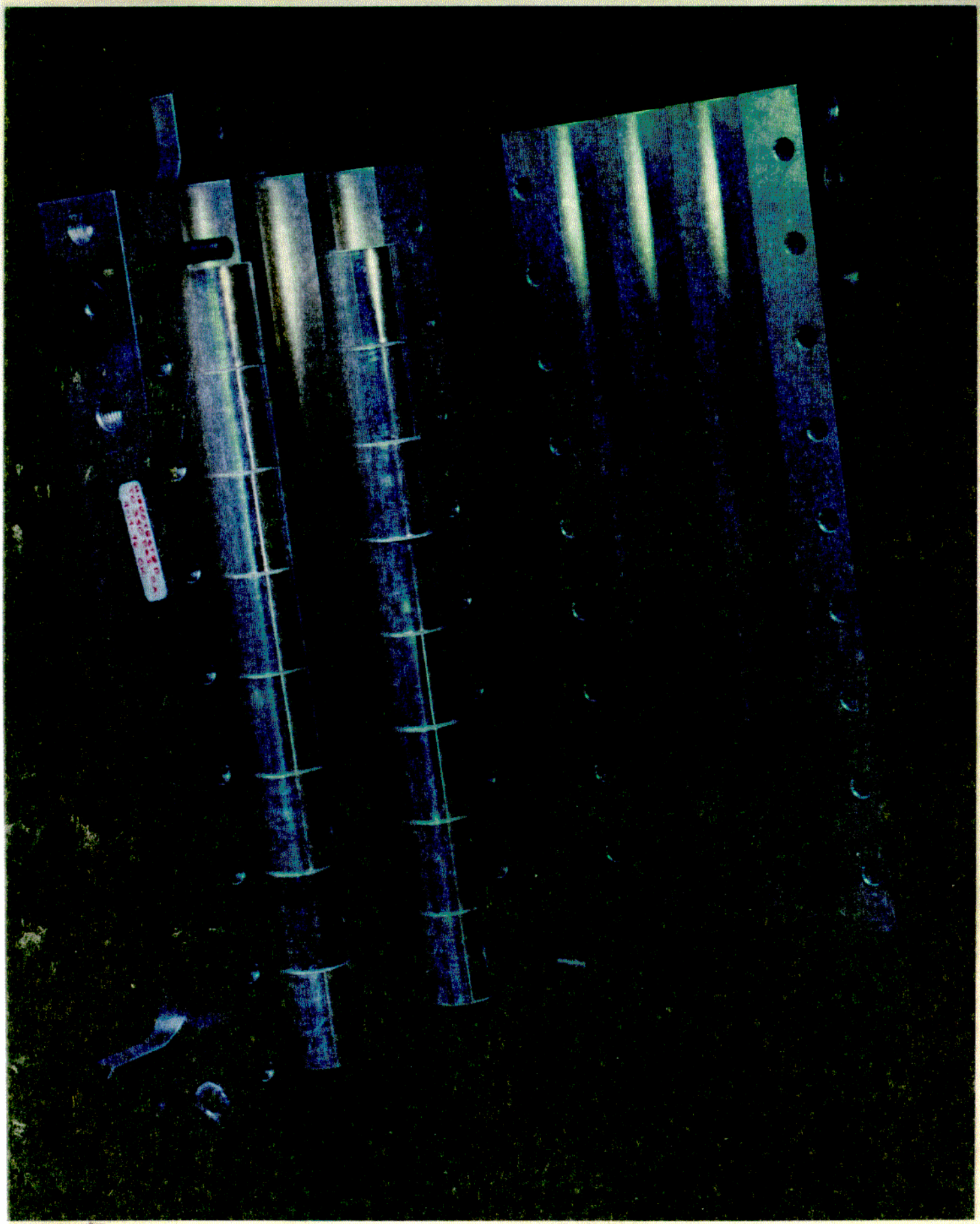
THE FNAL NCENTER BEAMLINE





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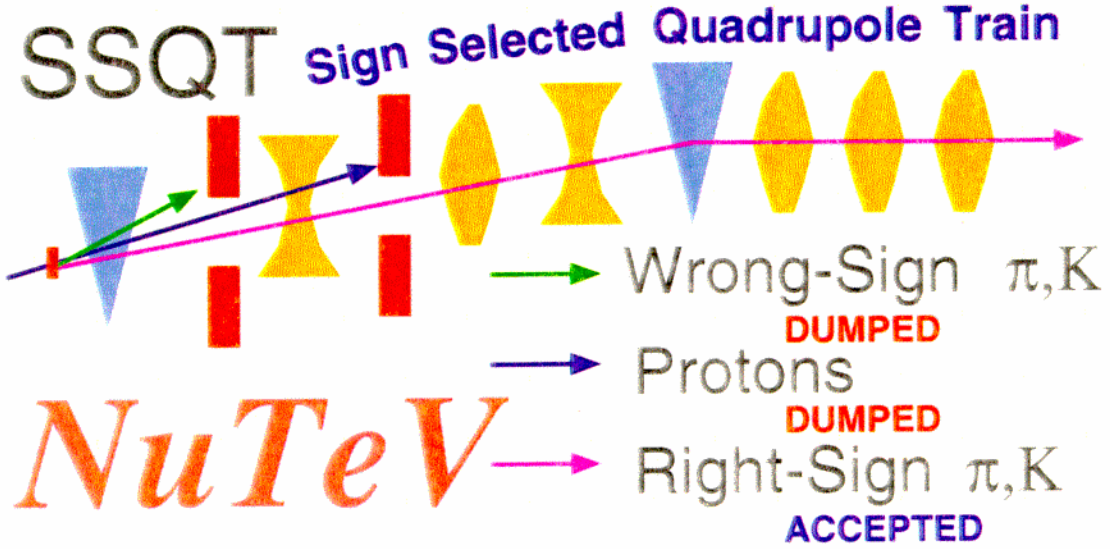
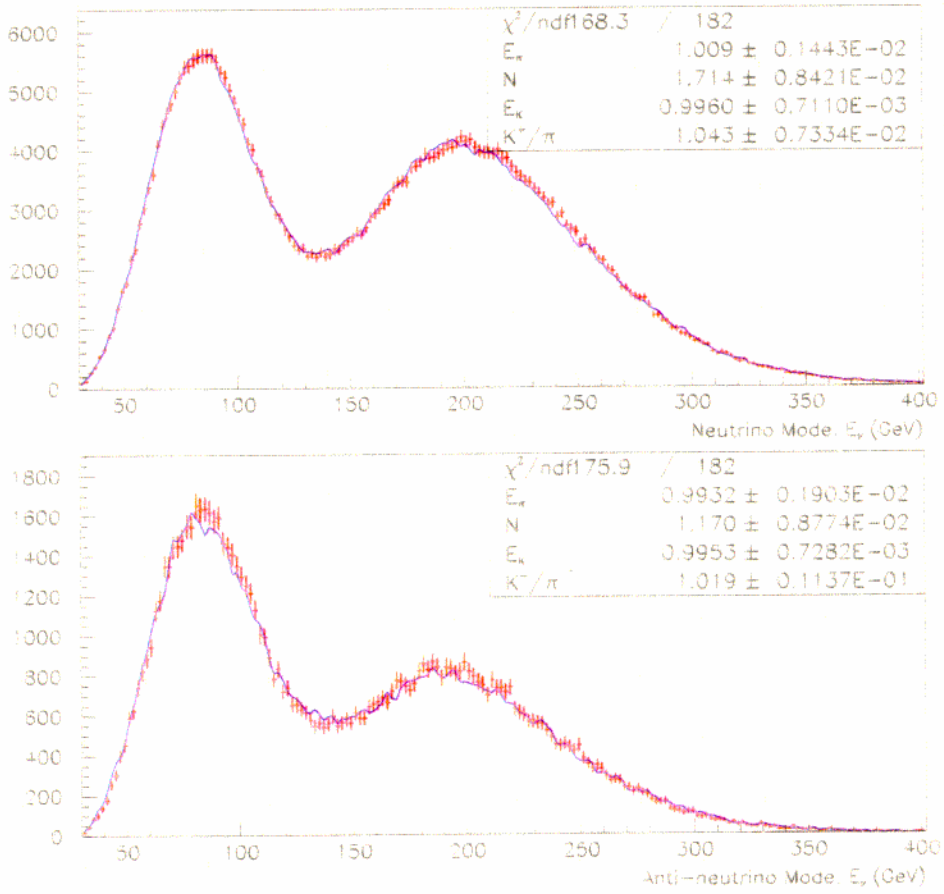
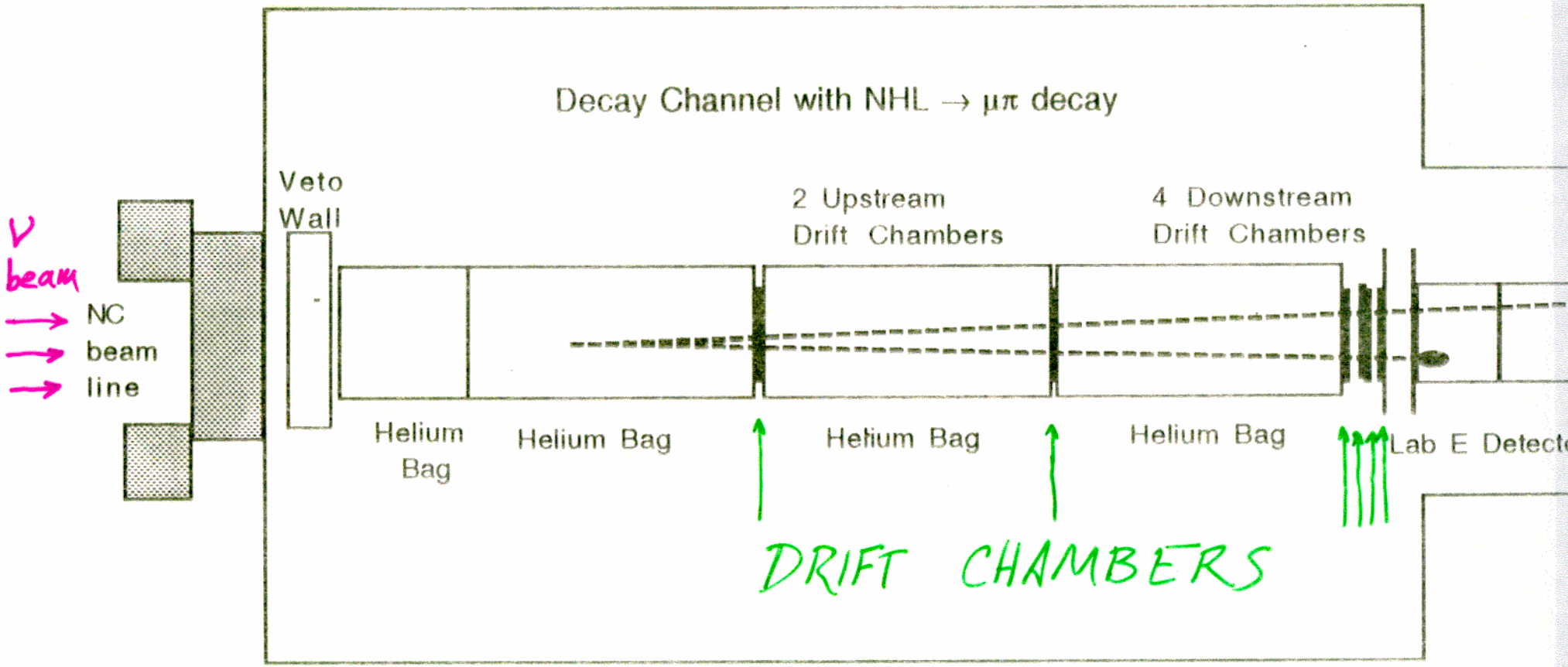
The FNAL NC neutrino beam



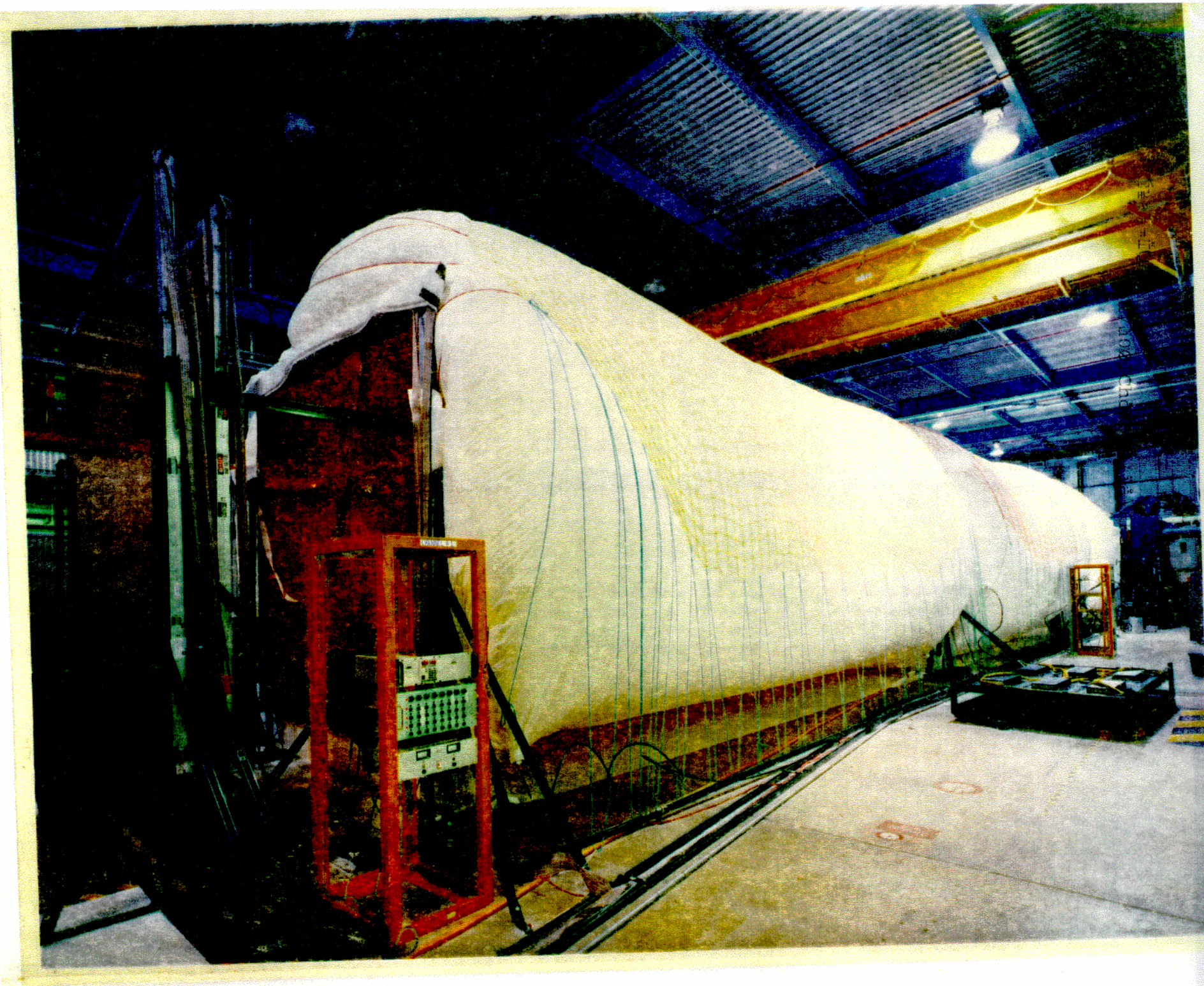
Neutrino energy distributions in ν and $\bar{\nu}$ modes:



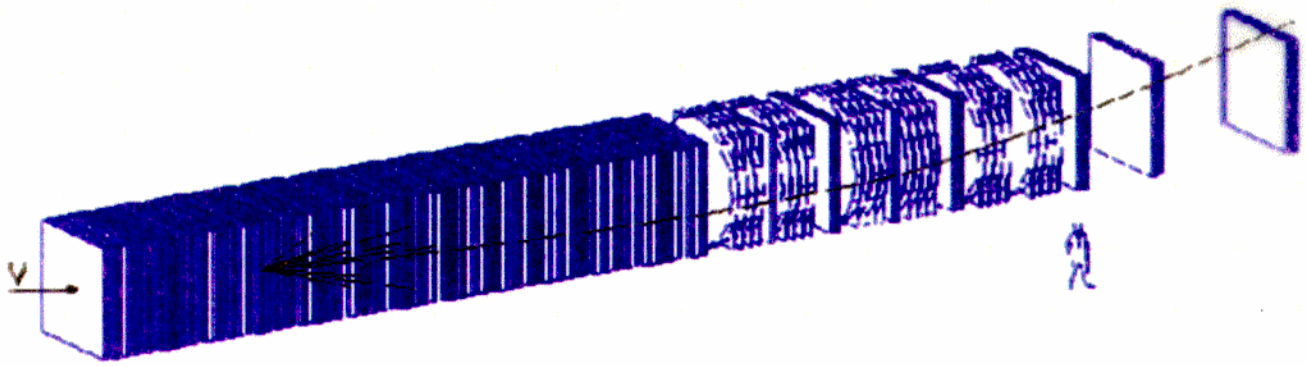
LAB F INSTRUMENTED DECAY CHANNEL



Chambers were recycled from ν detector



LAB E NEUTRINO DETECTOR



ν TARGET/SAMPLING CALORIMETER

168 STEEL PLATES (~3m × 3m × 5cm)

84 LIQUID SCINTILLATOR COUNTERS (EVERY 2 PLATES)

- UNSEGMENTED
- FAST TRIGGER
- SHOWER ENERGY MEASUREMENT

42 DRIFT CHAMBERS

- LOCALIZE TRANSVERSE POSITION OF SHOWERS
- TRACK MUONS

DOWNSTREAM TOROID SPECTROMETER

- MEASURE MOMENTUM OF HARD MUONS WHICH DON'T RANGE OUT IN STEEL

E815 PHYSICS MENU

ELECTROWEAK PHYSICS: DEEPLY INELASTIC SCATTERING

$\sin^2\theta_W$, Z', TRIDENTS *

MIXING AND OSCILLATION:

$\nu_\mu \to \nu_{e,\tau}$ APPEARANCE
$\bar{\nu}_\mu \to \bar{\nu}_{e,\tau}$ (SEPARATELY!) } ν MIXING

$|V_{cd}|$ FROM CHARM PRODUCTION } QUARK MIXING

QCD:

STRUCTURE FUNCTIONS

STRANGE SEA DISTRIBUTION

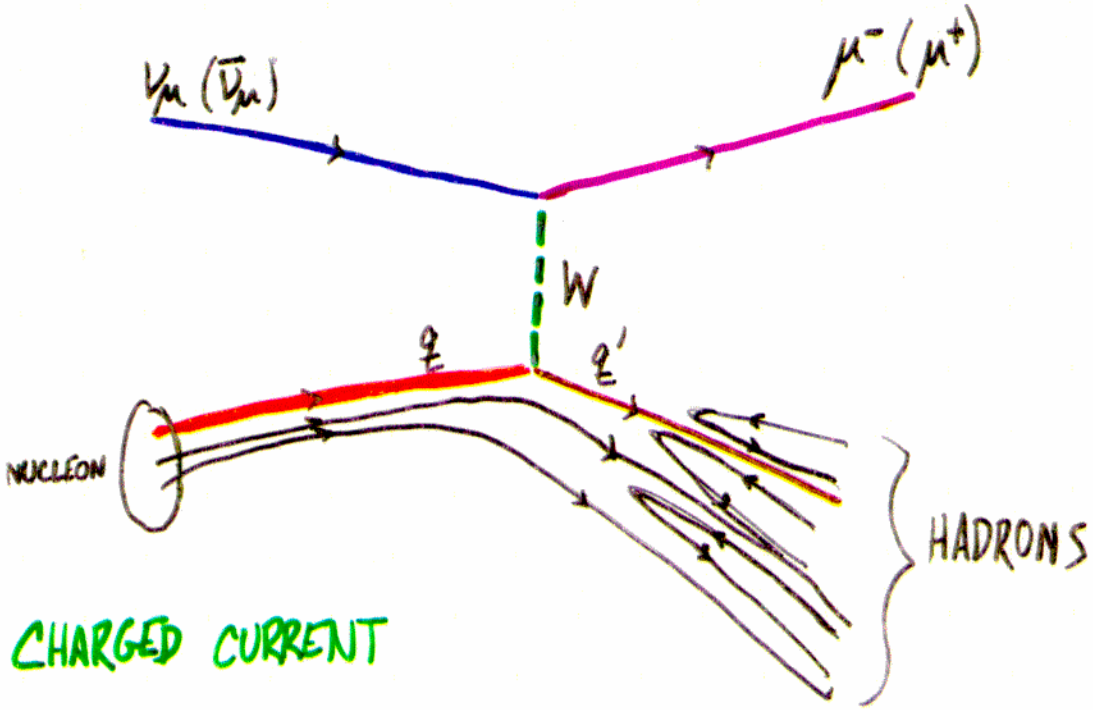
EXOTIC DECAYS:

NEUTRAL HEAVY LEPTONS *

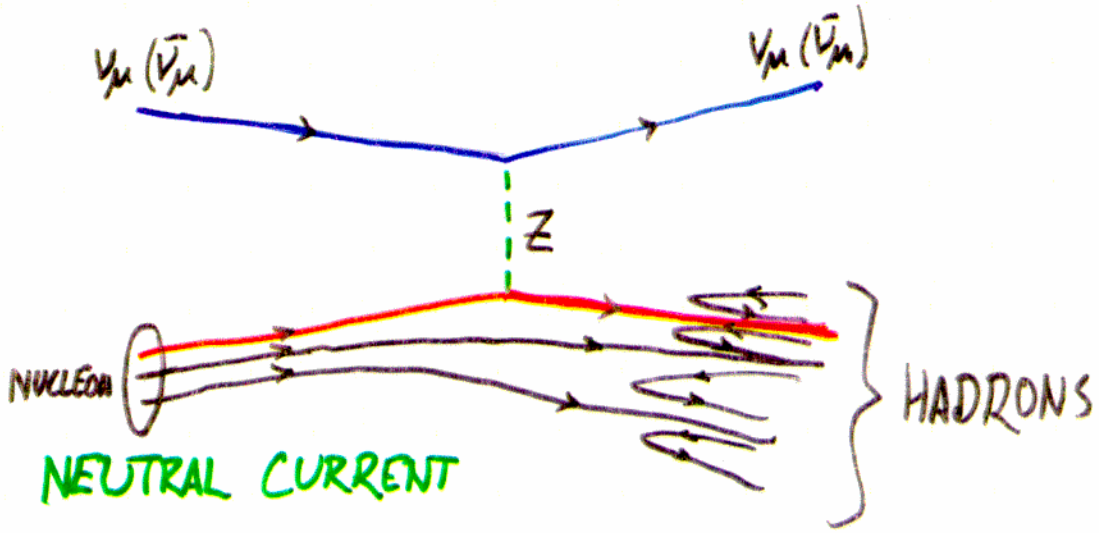
KARMEN TIMING ANOMALY *

HIGH-MASS NEUTRALS (ANOMALOUS EVENTS) *

ELECTROWEAK PHYSICS WITH NEUTRINO DEEP INELASTIC SCATTERING:



CHARGED CURRENT



NEUTRAL CURRENT

ELECTROWEAK MIXING ANGLE:

$$\sin^2\theta_W \equiv 1 - \frac{M_W^2}{M_Z^2}$$

Llewellyn Smith relation:

$$R_\nu \equiv \frac{\sigma^\nu_{NC}}{\sigma^\nu_{CC}} = \frac{1}{2} - \sin^2\theta_W + \frac{5}{9}\sin^4\theta_W\left(1 + \frac{\sigma^{\bar{\nu}}_{CC}}{\sigma^\nu_{CC}}\right)$$

Measurement of R_ν is limited by errors in charm quark mass and sea quark distributions

$\Longrightarrow$ $\Delta\sin^2\theta_W$ limited to ≈ 0.003,

not really competitive with on-shell M_W, M_Z direct measurements.

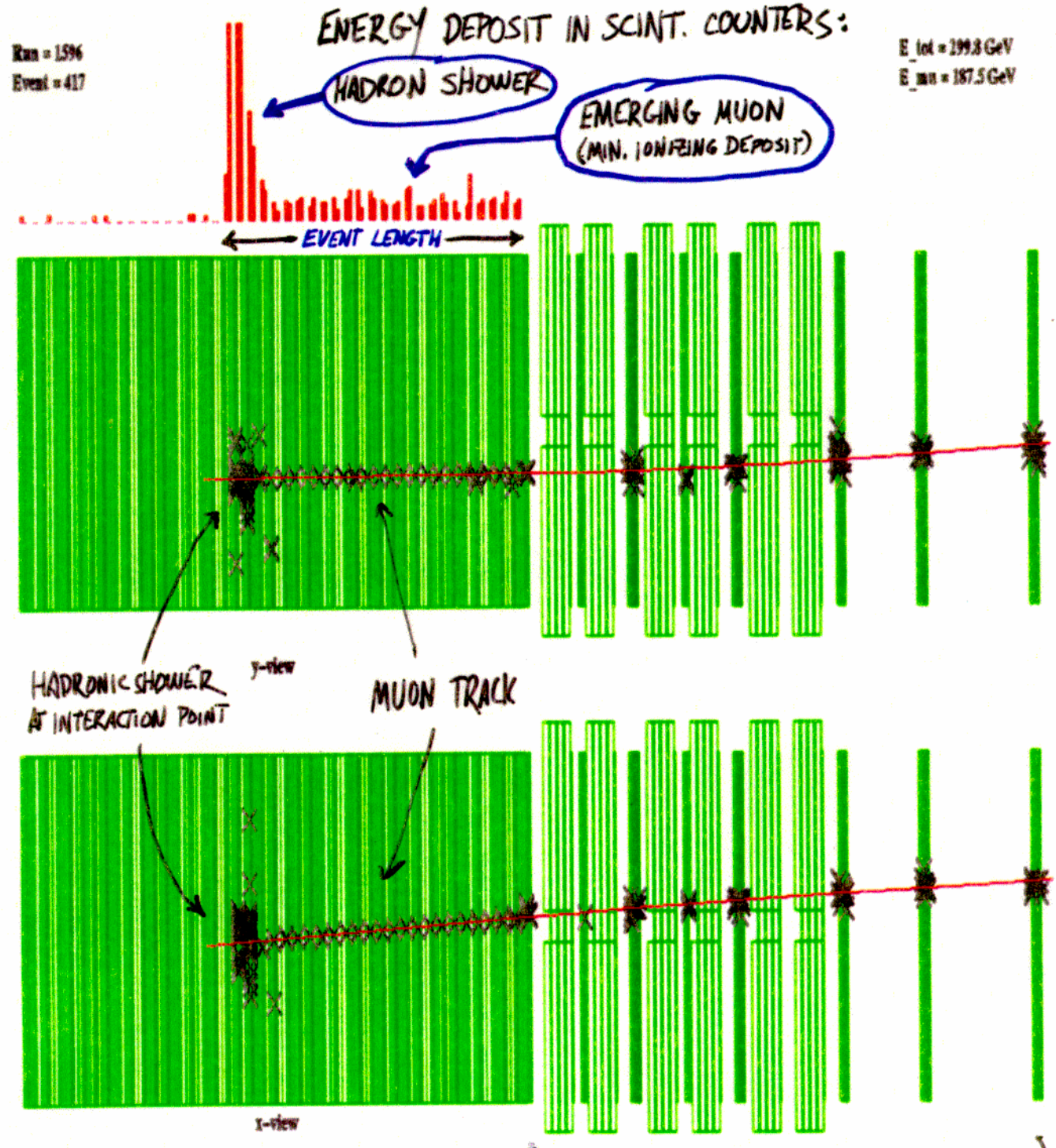
No useful sensitivity to Higgs mass.

ENTER THE PASCHOS-WOLFENSTEIN RELATION:

$$R^- \equiv \frac{\sigma^{\nu}_{NC} - \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} - \sigma^{\bar{\nu}}_{CC}} = \frac{1}{2} - \sin^2\theta_W$$

- QUARK-ANTIQUARK SYMMETRY IN SEA
  $\Longrightarrow$ SEA QUARK DEPENDENCE CANCELS IN R^-.
- CHARM PRODUCTION DEPENDENCE IS ONLY FROM CABIBBO-SUPPRESSED SCATTERS OFF $d_{VALENCE}$.
- MEASUREMENT OF R^- REQUIRES SEPARATE ν, $\bar{\nu}$ BEAMS.
- PRINCIPAL MOTIVATION FOR E815 AND THE SIGN-SELECTED QUAD TRAIN BEAM.

ANATOMY OF A CHARGED-CURRENT NEUTRINO INTERACTION



NEUTRAL CURRENT = SIMILAR SHOWER, NO MUON

A HUGE OVERSIMPLIFICATION:

- USE "EVENT LENGTH" CUT OF 20 COUNTERS (80 INCHES STEEL PENETRATION) TO STATISTICALLY SEPARATE CHARGED CURRENT, NEUTRAL CURRENT EVENTS

- DETAILED BEAM, DETECTOR MONTE CARLO TO UNDERSTAND ACCEPTANCE, BACKGROUNDS

PRELIMINARY RESULT:

$$\sin^2\theta_W^{(\text{on-shell})} = 0.2253 \pm 0.0019_{\text{stat}} \pm 0.0010_{\text{syst}}$$

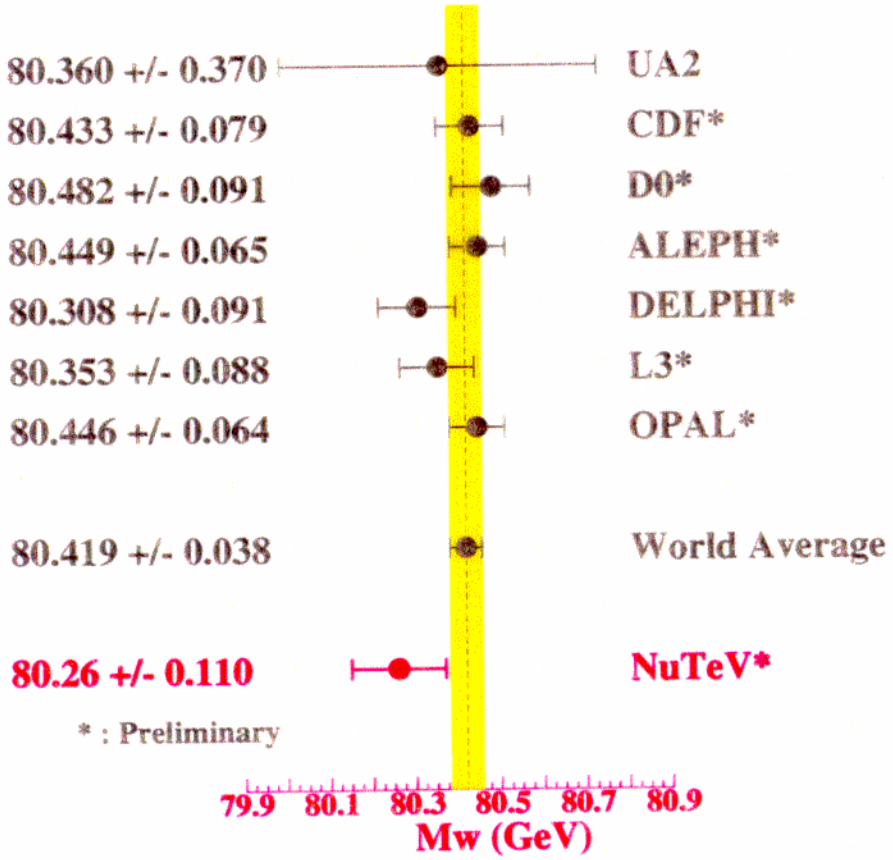
A NEW RESULT COMING SOON WITH REDUCED SYSTEMATIC ERRORS.

ALREADY:
- COMPETITIVE WITH DIRECT M_W MEASUREMENTS
- MOST PRECISE ν SCATTERING MEASUREMENT
- FIRST MEASUREMENT OF PASCHOS-WOLFENSTEIN RELATION

Converting to an M_W Measurement

$$\sin^2\theta_W^{(\text{on-shell})} \equiv 1 - \frac{M_W^2}{M_Z^2}$$

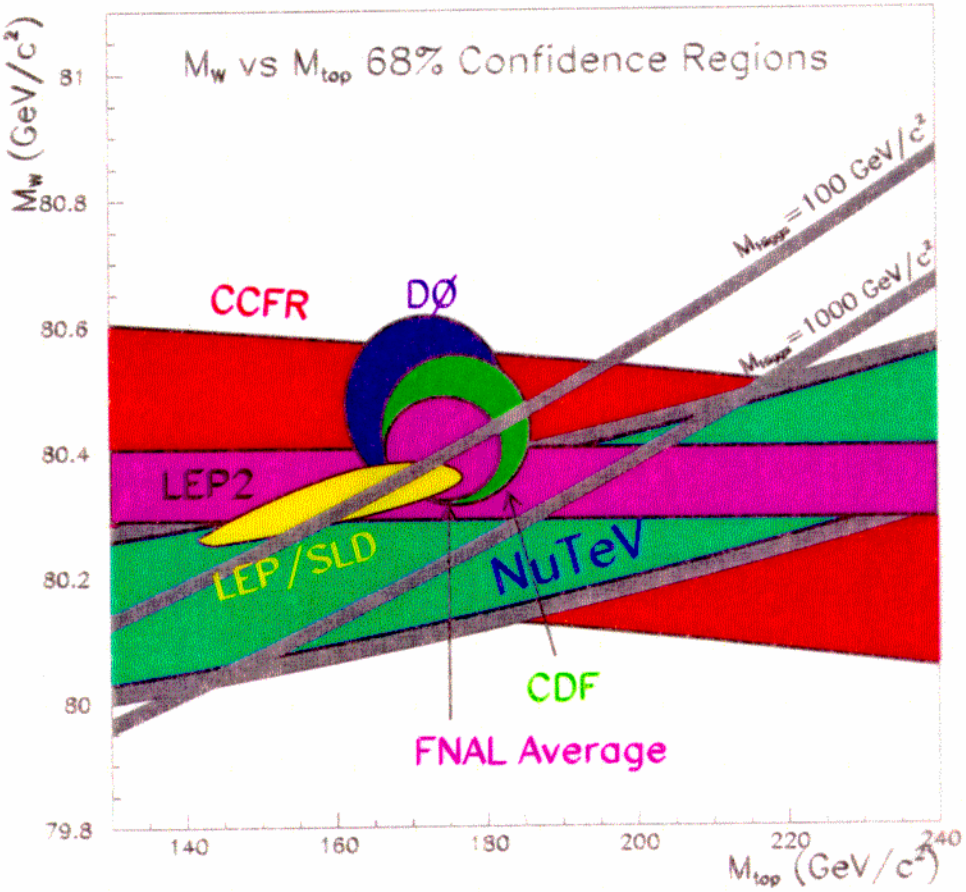
NuTeV *Preliminary*:
$M_W = 80.26 \pm 0.11$ GeV



Comparing Experiment to Theory

Within the Standard Model,

The combination M_t, M_W and M_Z predicts the Higgs Mass!



A light Higgs is favored!

EXOTIC PARTICLE SEARCHES

LONG-LIVED NEUTRAL PARTICLES WHICH INTERACT WEAKLY AND DECAY TO TWO CHARGED TRACKS (+ PERHAPS A NEUTRAL):

GENERICALLY, "N^0"

THREE SEARCHES FOR N^0's USING DECAY CHANNEL:

- NEUTRAL HEAVY LEPTONS
  (mass 0.2-2 GeV/c^2)
- KARMEN TIMING ANOMALY
  (mass 0.034 GeV/c^2)
- HIGHER-MASS SEARCH
  (mass >2 GeV/c^2)

NEUTRAL HEAVY LEPTONS

(NHL, L^0, "HEAVY NEUTRINOS")

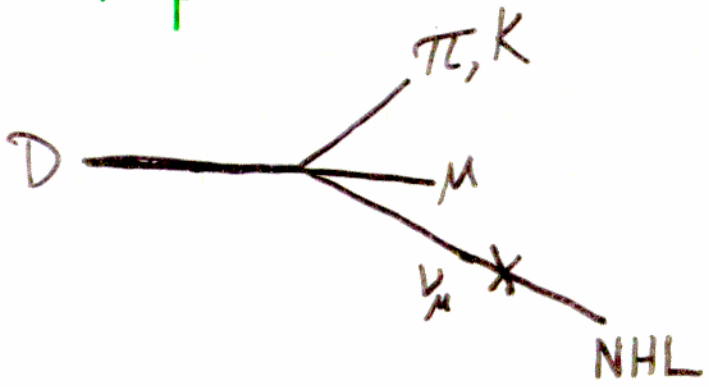
THESE ISOSINGLET PARTNERS TO THE NEUTRINOS ARE PREDICTED IN VARIOUS EXTENSIONS TO THE STANDARD MODEL (PARTICULARLY IN GUTs).

- NEUTRAL, MASSIVE FERMIONS
- DO NOT COUPLE DIRECTLY TO $W^{\pm}$, Z^0
  (DON'T CONTRIBUTE TO Z^0 WIDTH)
- PRODUCED BY MIXING WITH NEUTRINOS
- DECAY ALSO BY MIXING WITH NEUTRINOS
- LIFETIME PROPORTIONAL TO MIXING CONSTANTS U_e^2, U_μ^2, U_τ^2 AND DECAY PHASE SPACE:

- $\langle \nu_i | L^0 \rangle = U_i$ WHERE ν_i IS A LEPTON FLAVOR EIGENSTATE ($i = e, \mu, \tau$)

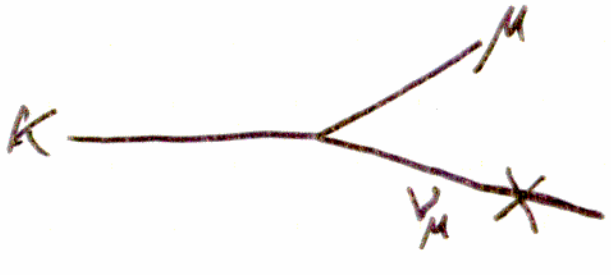
NHL PRODUCTION

1) Charmed hadron decays from prompt production in primary target, beam dumps.



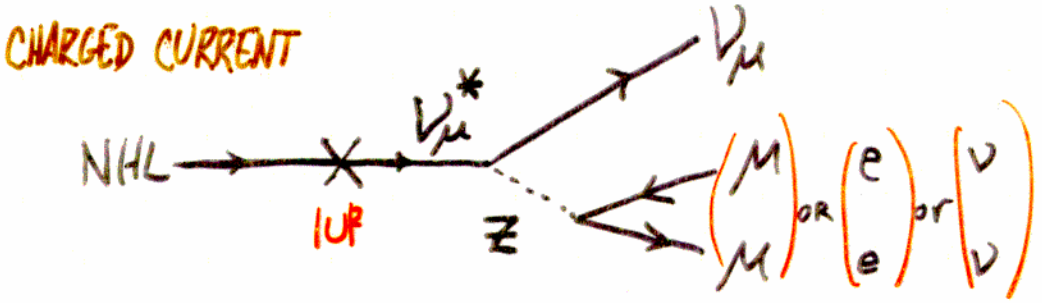
$m < 2$ GeV

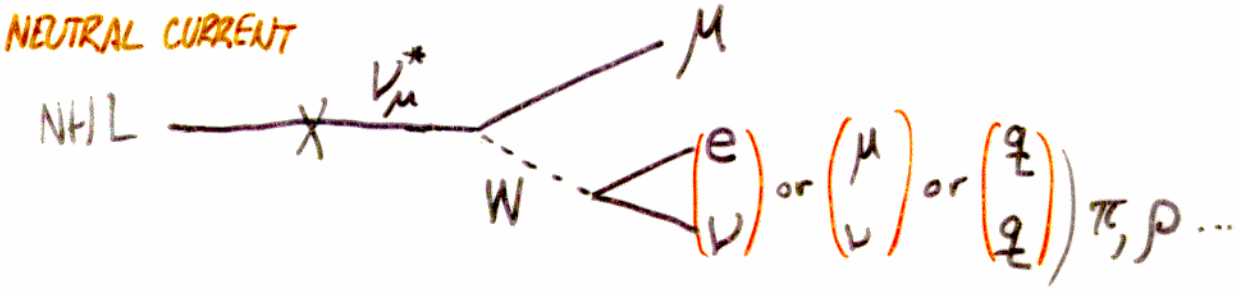
2) Kaon decays in secondary beamline (focused toward detector)



$m < 0.4$ GeV

NHL DECAYS:





WE SEARCH FOR

$\mu\mu\nu$

$e\mu\nu$

$\mu\pi$
$\mu\rho$
} No attempt to distinguish

We have searched for NHLs with mass $> 0.25\ GeV/c^2$ in muonic decay modes $NHL \to \mu e \nu,\ \mu\mu\nu,\ \mu\pi,\ \mu\rho$

EXPERIMENTAL SIGNATURE:

- UNDETECTED (NEUTRAL) PARTICLE ENTERS DECAY CHANNEL FROM BEAM
- PARTICLE DECAYS IN DECAY CHANNEL TO TWO TRACKS
- AT LEAST ONE TRACK IDENTIFIED AS A MUON (BY PENETRATION INTO CALORIMETER)

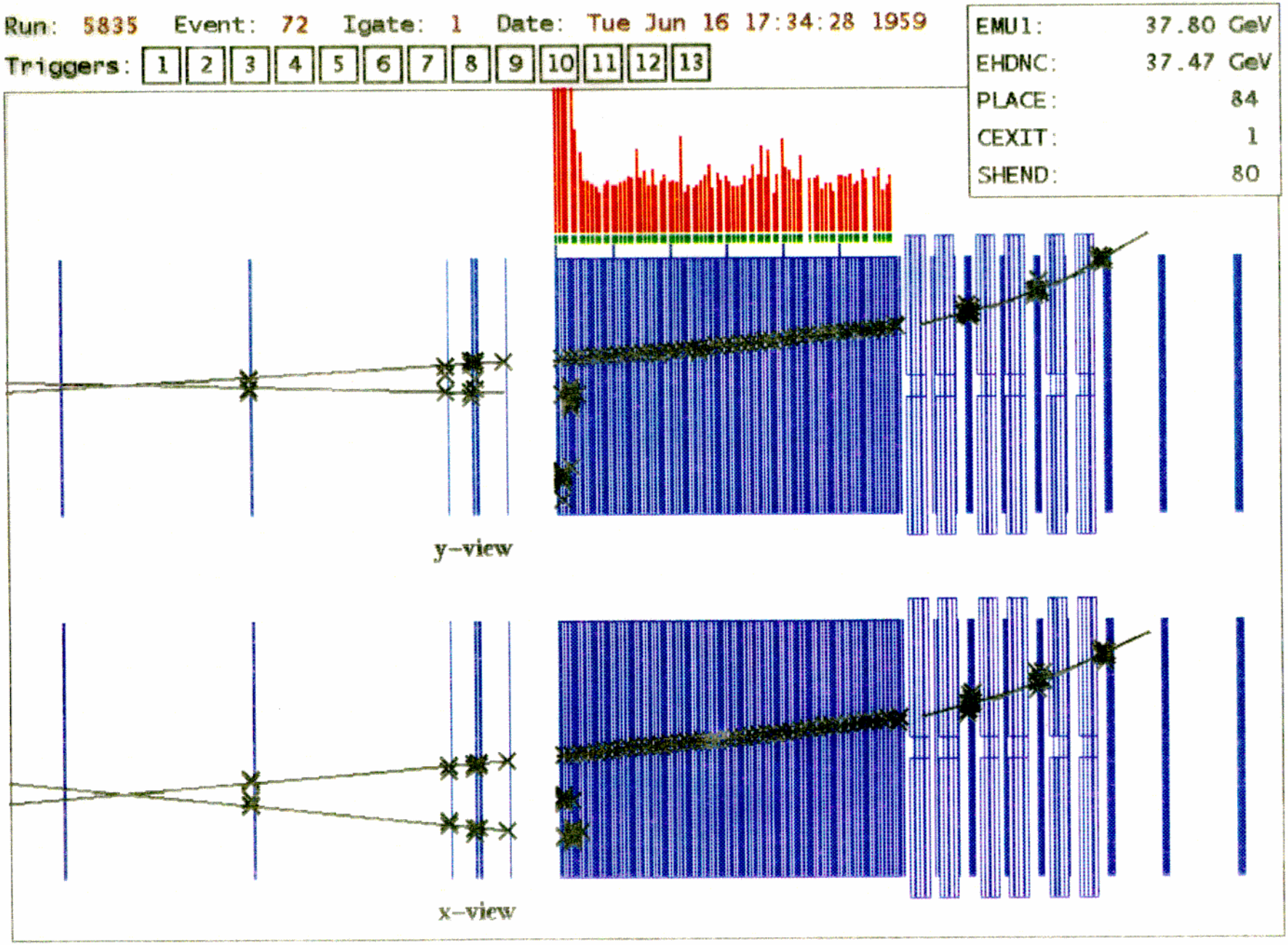
MAJOR BACKGROUND:

NEUTRINO INTERACTIONS IN HELIUM

BACKGROUND CROSS-CHECK:

NEUTRINO INTERACTIONS IN DRIFT CHAMBERS

1.15 GeV/c² NHL→μp Monte Carlo event



KEY KINEMATIC VARIABLE:

TRANSVERSE MASS (m_T)

- SINCE WE'RE LOOKING FOR 3-BODY DECAYS WITH A NEUTRAL PARTICLE IN FINAL STATE, WE CAN'T RECONSTRUCT THE ENTIRE EVENT.

- TRANSVERSE MASS: $m_T \equiv |p_T| + \sqrt{p_T^2 + m_V^2}$

  p_T = reconstructed vertex transverse momentum (transverse to beam direction)

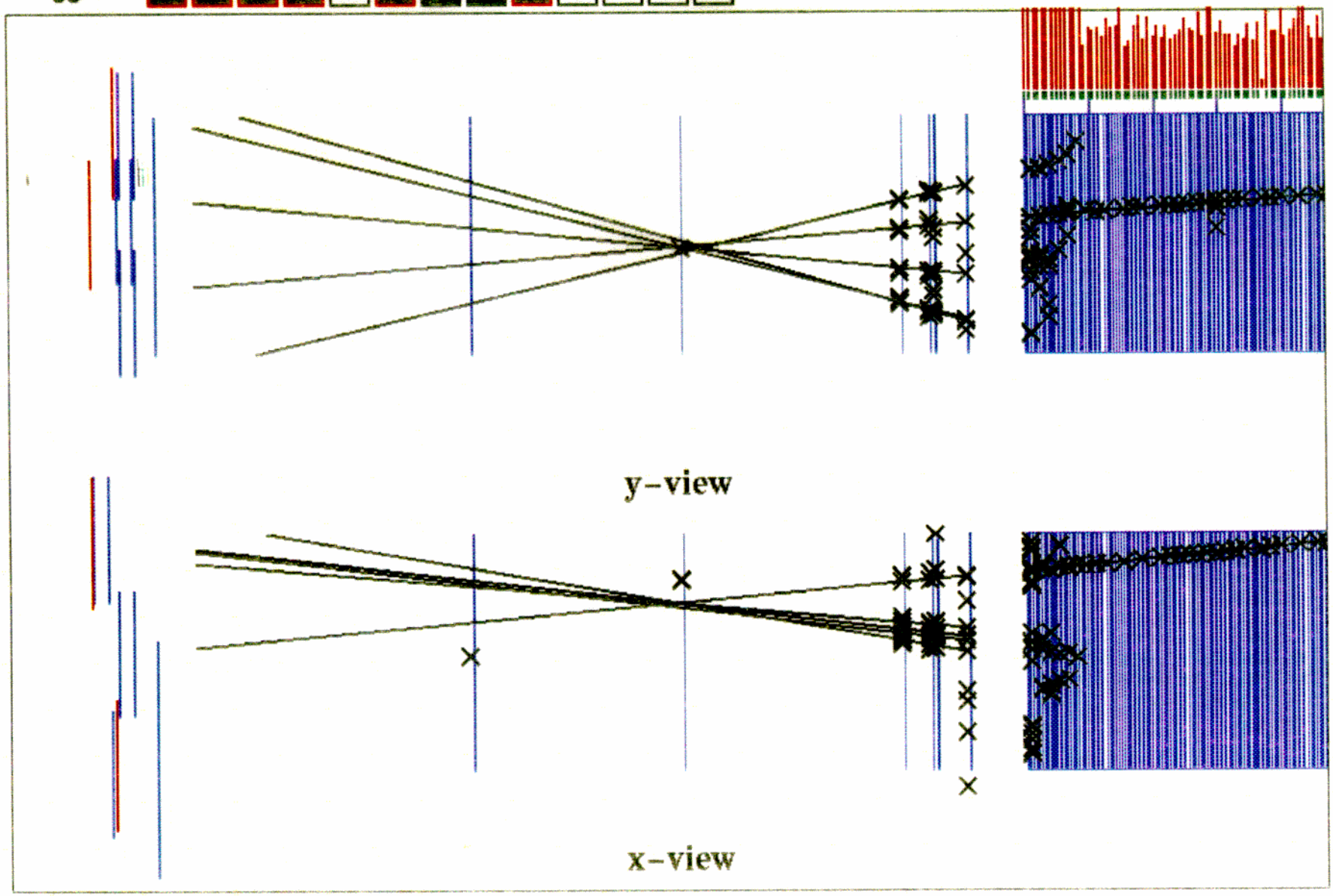
  m_V = vertex invariant mass

→ m_T represents (within resolution) the mass of the LIGHTEST particle which could have produced the event as reconstructed.

DEEP INELASTIC ν_μ CHARGED CURRENT INTERACTION IN DRIFT CHAMBER

Run: 5832 Event: 3351 Igate: 1 Date: Mon Jan 20 12:35:48 1997

Triggers: 1 2 3 4 5 6 7 8 9 10 11 12 13



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AFTER ALL CUTS....

SIGNAL ACCEPTANCE 23%

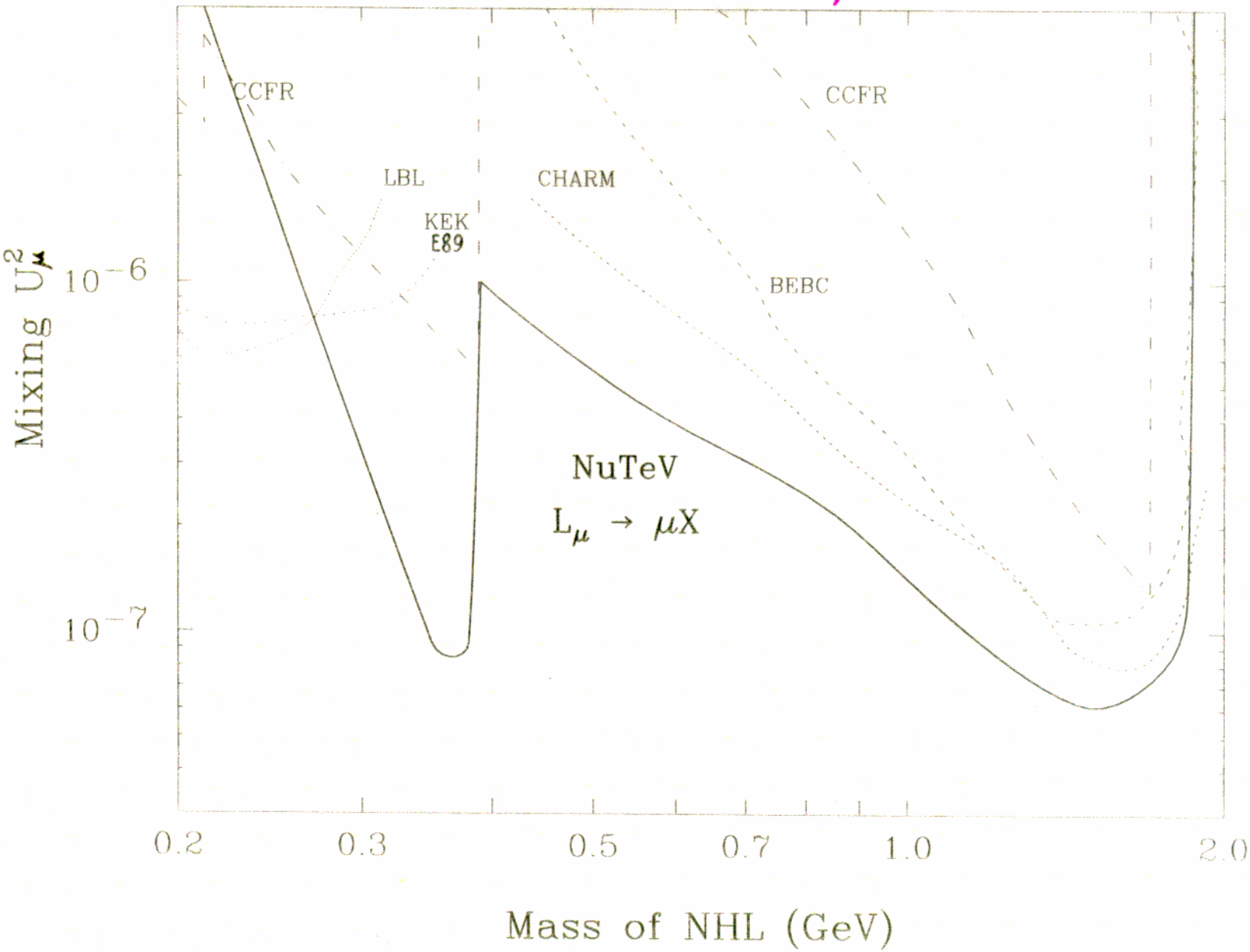
(AVERAGED OVER MASSES 0.25-2.0 GeV)

EXPECT 0.57±0.15 BACKGROUND EVTS.

(NEARLY ALL FROM ν INTERACTIONS IN HELIUM)

NO EVENTS WERE OBSERVED.

90% CONF. LIMITS ON U_μ^2



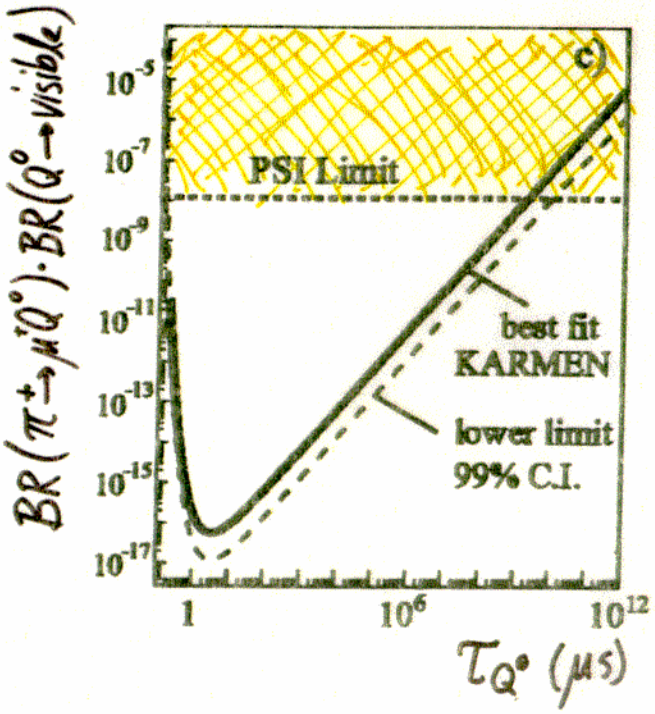
PUBLISHED: A. Vaitaitis et al., "Search for Neutral Heavy Leptons in a High Energy Neutrino Beam," PRL 83 (1999) 4943

THE KARMEN TIMING ANOMALY

- ~4σ ANOMALY IN ARRIVAL TIME DISTRIBUTION OF NEUTRINOS FROM A BEAM STOP SOURCE
- INTERPRETED AS AN N^0 WITH MASS 33.9 MeV/c^2. PRODUCED IN $\pi \to \mu Q^0$.
  → WE CALL THIS PARTICLE Q^0.
- DETECTED BY DECAY $Q^0 \to e^+e^-\nu$
- COULD BE A NHL, COULD BE AN R-PARITY VIOLATING NEUTRALINO, (COULD BE A FLUCTUATION!), COULD BE SOMETHING COMPLETELY DIFFERENT.

The allowed region is described by a curve in branching ratio vs. Q^0 lifetime; lowest BR is ~5×10^{-17}, at $\tau \sim 3.6\ \mu s$.

PSI limit is from direct search for $\pi^+ \to \mu^+ +$ heavy particle.

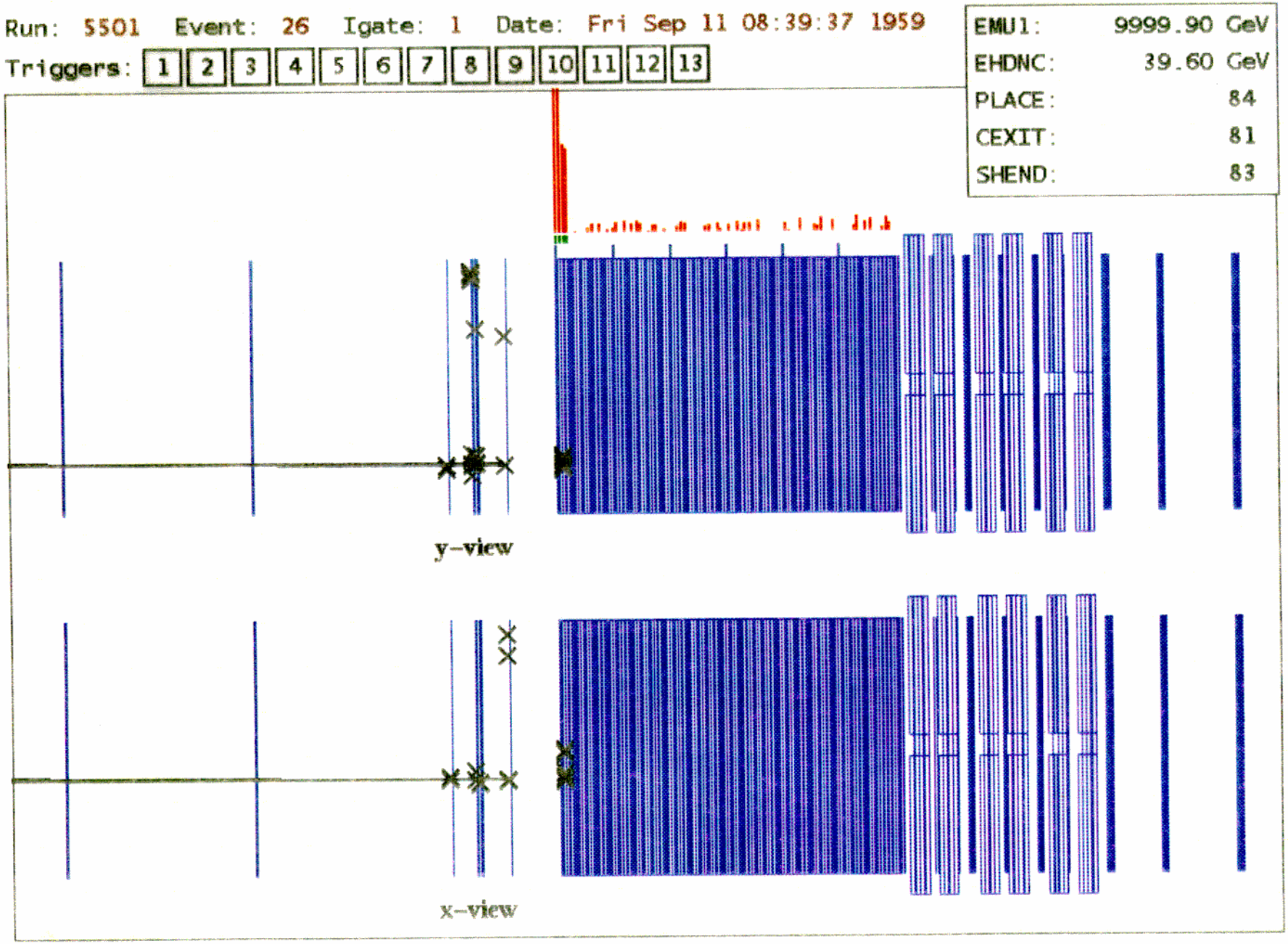


At E815, we would expect Q^0 to be produced by π decays in flight — similar to NHLs.

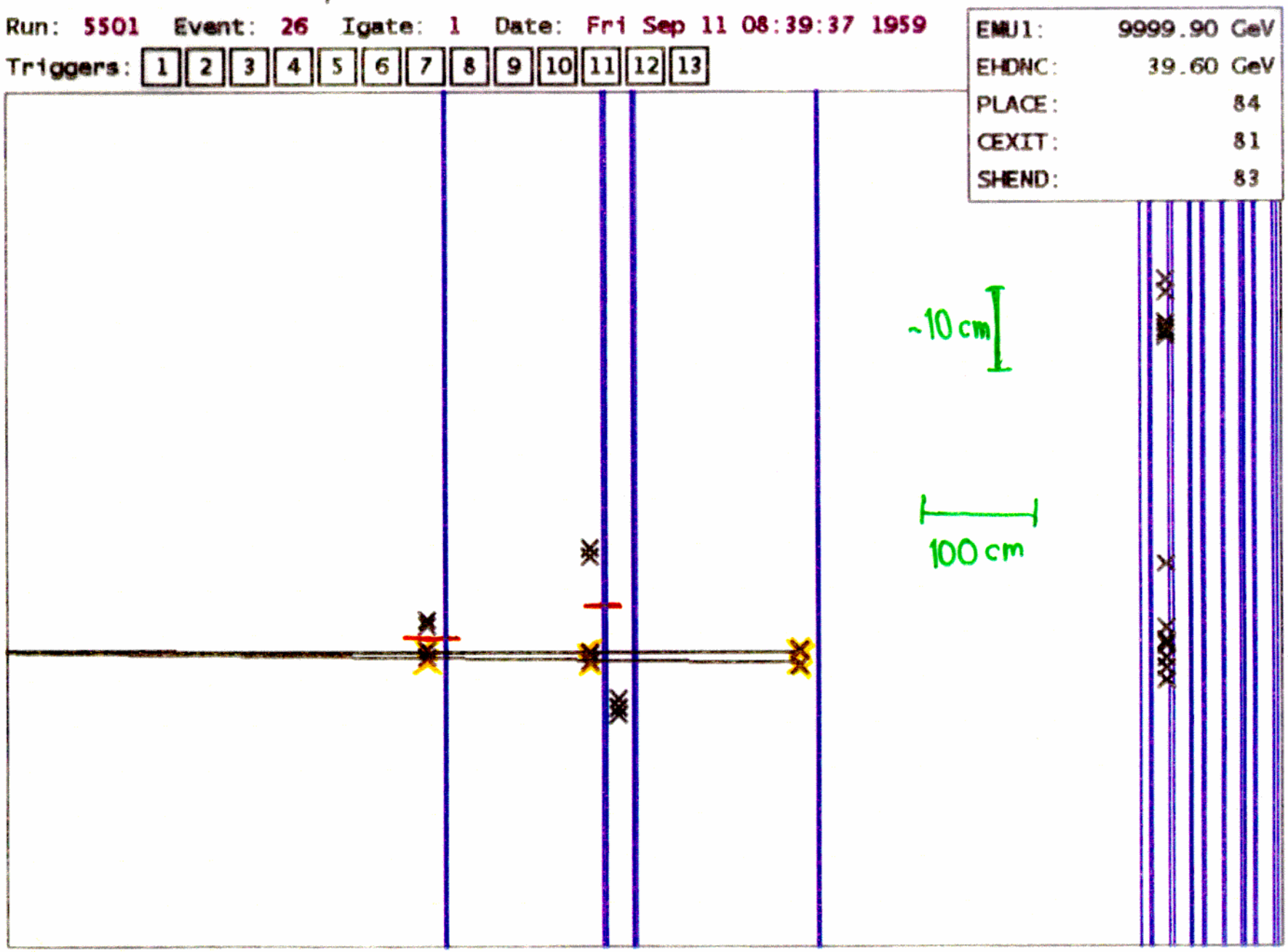
- EXPERIMENTAL SIGNATURE OF Q^0 DECAY IS THE SPONTANEOUS APPEARANCE OF AN e^+e^- PAIR IN THE DECAY CHANNEL.

- DUE TO OUR HIGH BEAM ENERGY, Q^0's ARE HIGHLY BOOSTED IN OUR LAB FRAME. THIS GIVES US HIGHER SENSITIVITY THAN KARMEN TO THE SHORT-LIFETIME SOLUTION — BUT OUR SMALLER NUMBER OF PION DECAYS ($\sim 10^{16}$ vs. $\sim 10^{20}$) MEANS WE WILL NOT HAVE ACCESS TO THE LONG-LIFETIME SOLUTION.

$Q^{\circ} \rightarrow eev$ Monte Carlo event



Close-up of x-view — $Q^0 \to eeV$ Monte Carlo event



REALITY CHECKS

THE ENTIRE ANALYSIS WAS PERFORMED BLIND.

THE CUTS WERE DETERMINED AND THE BACKGROUNDS ESTIMATED USING MONTE CARLO SIMULATIONS AND DATA FROM THE COSMIC RAY TRIGGER GATE ONLY.

WHILE IT'S DIFFICULT TO FIND "CLEAN" EVENTS IN THE DECAY CHANNEL, WE HAVE EXAMINED A FEW TEST SAMPLES OF BEAM DATA:

Sample 1: 2e events with wrong kinematics:

$(M_T > 0.5\ \mathrm{GeV}/c^2)$ .OR. $(E_{vis} < 15\ \mathrm{GeV})$

Expected 2.0 ± 0.3 events, observed 1.

Sample 2: 2-track $\mu\pi$ events (mostly CC DIS)

$(p_\mu > 2.2\ \mathrm{GeV}/c)$ .AND. $(p_\pi > 5\ \mathrm{GeV}/c)$ .AND. $(x_{eff} < 0.1)$ .AND. $(M_T < 2\ \mathrm{GeV}/c^2)$

Expected 4.1 ± 0.6 events, observed 3.

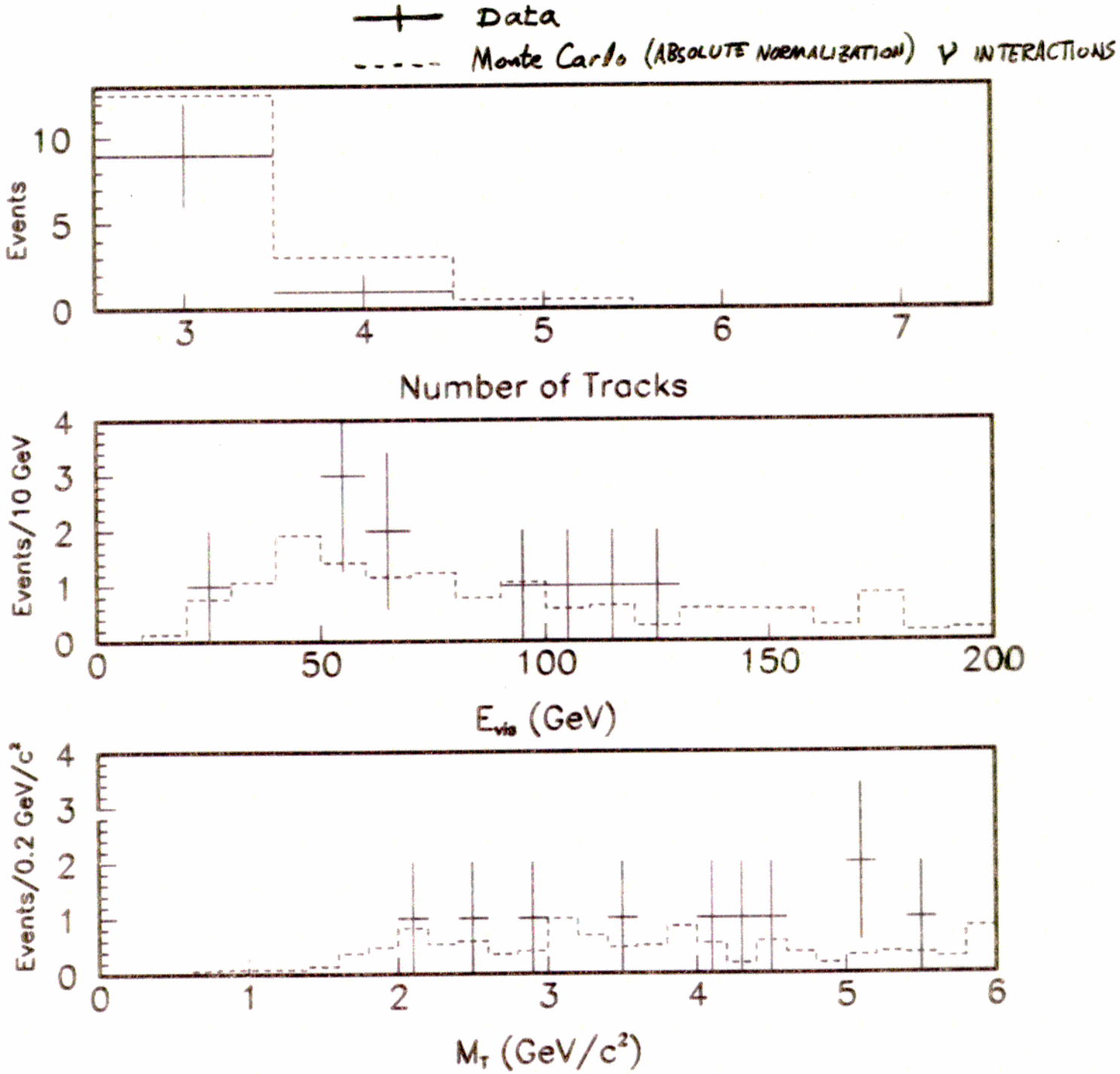
Sample 3: Higher multiplicity events

(≥3 tracks) .AND. $(M_T < 10\ \mathrm{GeV}/c^2)$ .AND. $(E_{vis} > 15\ \mathrm{GeV})$ .AND $(W_{eff} > 2\ \mathrm{GeV}/c^2)$

Expected 13.7 ± 1.8, observed 10.

RECONSTRUCTION/KINEMATIC VARIABLES

- MULTITRACK STUDY SAMPLE



EXPECTED BACKGROUND

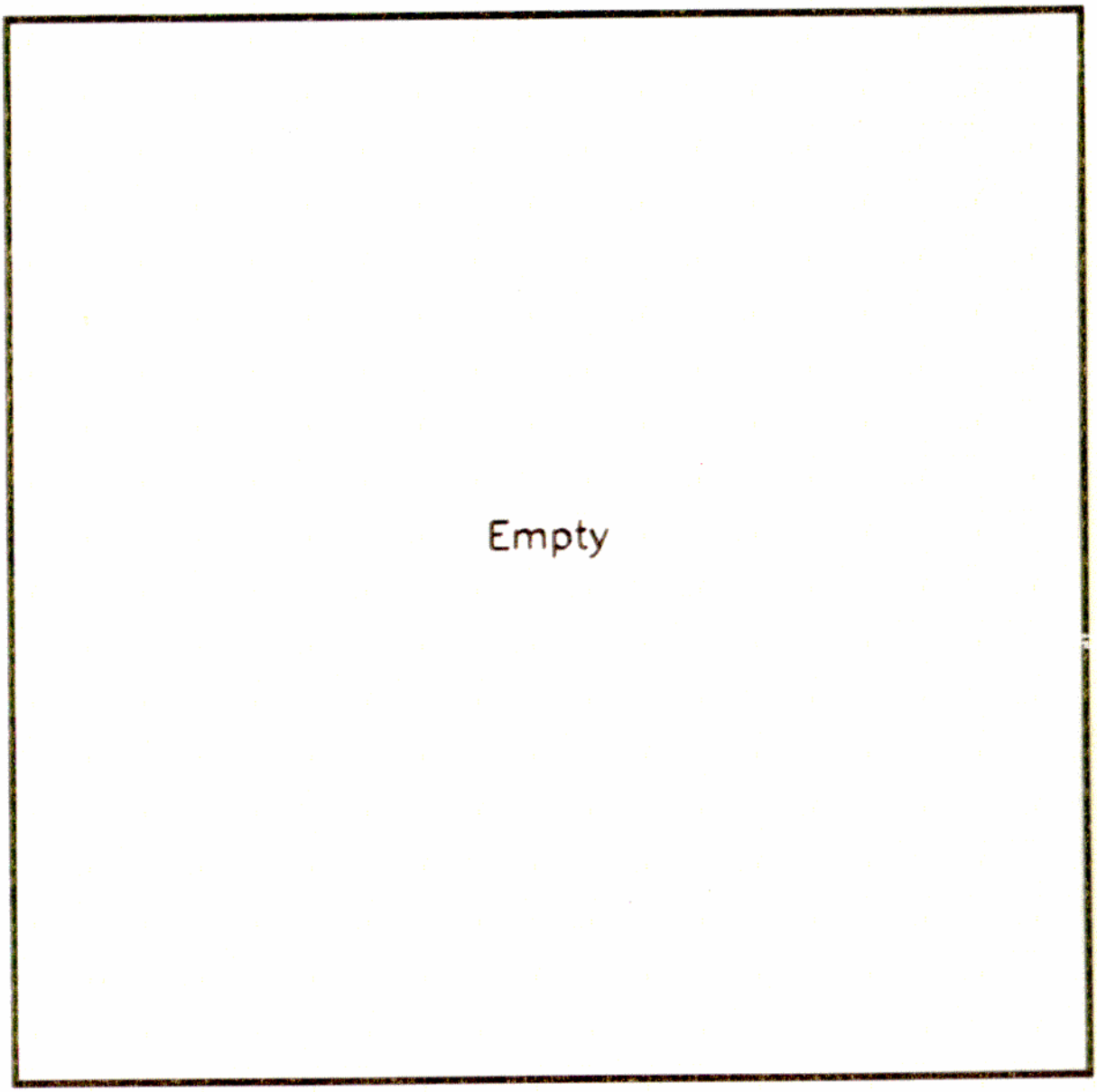
SOURCE	# OF EVENTS EXPECTED AFTER ALL CUTS
PHOTON PUNCH-THROUGH	0.007 ± 0.007
$K_{L,S}$ PUNCH-THROUGH	$\ll 10^{-3}$
VETO WALL INTERACTIONS	$0.036 \pm {}^{0.018}_{0.036}$
CHARGED CURRENT DEEP INELASTIC	0 ± 0.040
NEUTRAL CURRENT DEEP INELASTIC	0.020 ± 0.020
QUASIELASTIC CHARGED CURRENT	0 ± 0.008
NEUTRAL CURRENT RESONANCE PRODUCTION	0 ± 0.003
DIFFRACTIVE PIONS	$\ll 10^{-3}$
e^+e^- "TRIDENT" PRODUCTION	$\ll 10^{-3}$
TOTAL	0.06 ± 0.05

(PROBABILITY OF THIS FLUCTUATING ABOVE ZERO EVENTS IS 6%.)

SIGNAL ACCEPTANCE: 0.156

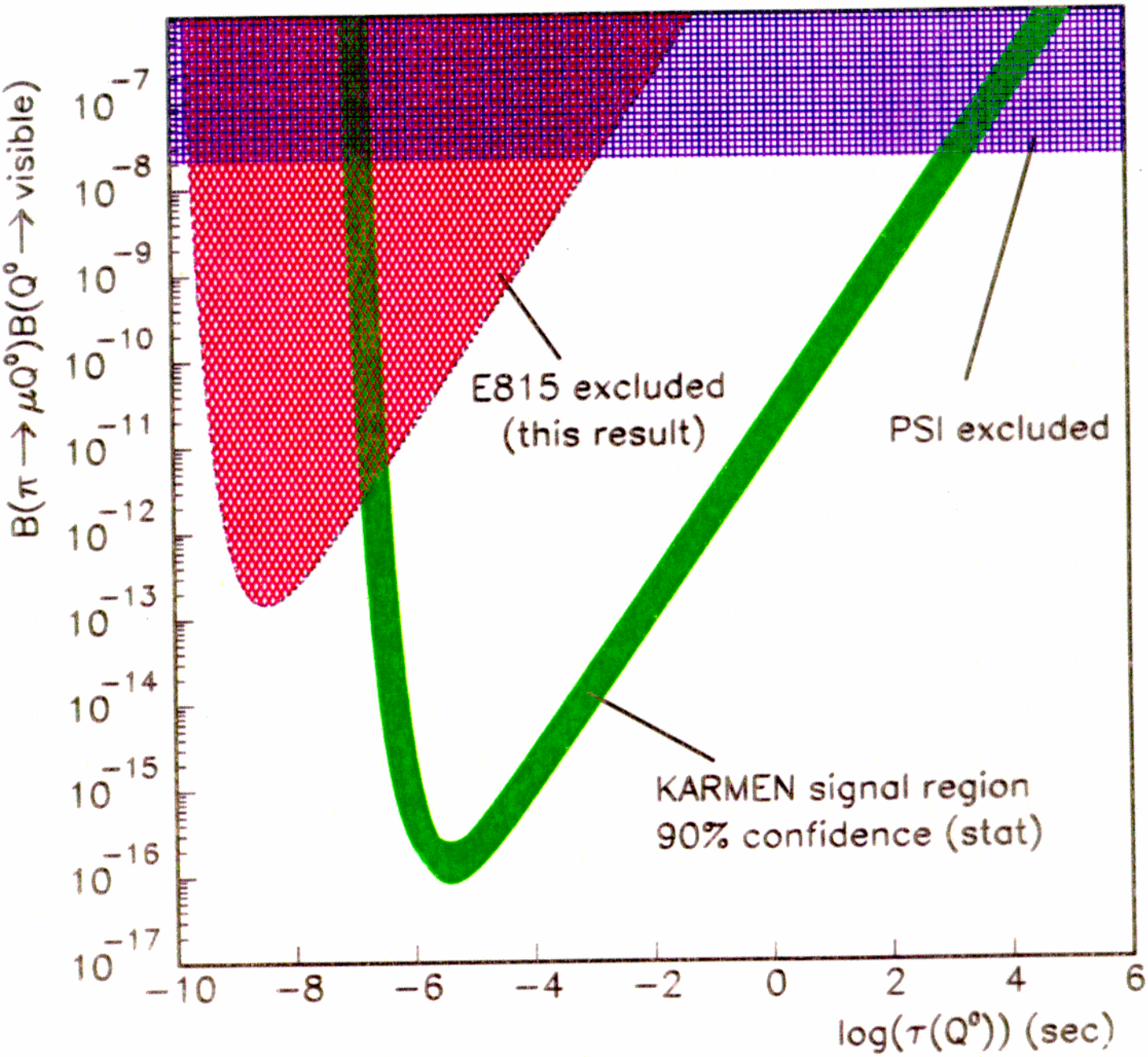
SYST. ERROR ON SENSITIVITY 12.1%

THE Q^0 SIGNAL REGION



SO WE SET A LIMIT...

Limits on Q^0 from $\pi \to \mu$ decay



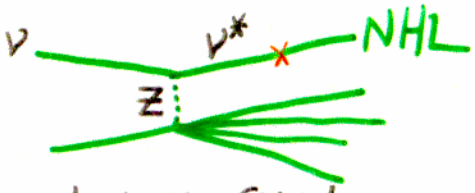
PUBLISHED: J. A. Formaggio et al., "Search for a 33.9 MeV/c^2 Neutral Particle in Pion Decay," PRL 84 (2000) 4043.

SEARCH FOR HIGH-MASS N° DECAYS

$$m_{N^\circ} > m_{D_s}$$

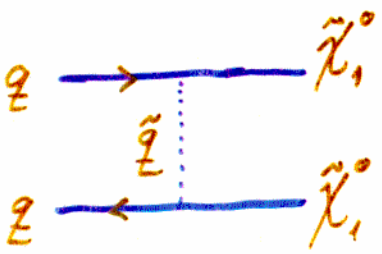
POSSIBLE SOURCES:

- **NHL:** Similar sensitivity as DELPHI in this mass range
  - B meson decays in target
  - Direct production by neutrino interaction in berm shielding

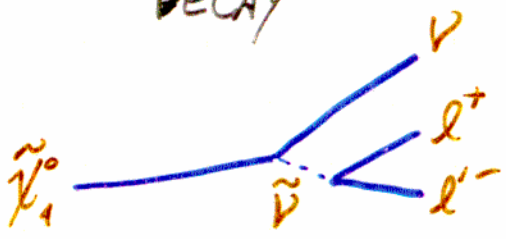


- **Neutralino:** Permitted in unconstrained SUSY
  - Pair-produced in primary target
  - R-parity violating $\tilde{\chi}_1^\circ \to \mu\mu\nu$, $\mu e\nu$ decays would be visible in decay channel

PRODUCTION



DECAY



WHY IS THIS SEARCH DIFFERENT?

1) WE'RE SEARCHING FOR A GENERIC $N^0 \to \mu X$
   $\Rightarrow$ AVOID KINEMATIC CUTS.

2) WE EXPECT MORE ν INTERACTION BACKGROUND AT HIGH TRANSVERSE MASS.

3) PRIOR KNOWLEDGE:

IN 1997, DURING DATA QUALITY STUDIES, A CANDIDATE 2μ EVENT WAS OBSERVED WITH HIGH TRANSVERSE MASS. (OOPS)

TO RECOVER FROM THIS AND MINIMIZE BIAS:

- DEFINE EXCLUDED SIGNAL REGION FOR SUBSEQUENT ANALYSIS STUDIES
- STICK TO CUTS IN PROPOSAL AS MUCH AS POSSIBLE; STRONG MC-BASED MOTIVATION FOR ANY NEW CUTS
- BRING NEW PEOPLE INTO ANALYSIS GROUP
- SET UP BLIND "STUDY BOXES" TO TEST MONTE CARLO

HIGH-MASS N^0 SEARCH REQUIREMENTS

TO ISOLATE 2-TRACK EVENTS WITH GOOD VERTEX IN HELIUM:

- **GOOD TRACK, VERTEX RECONSTRUCTION**

  Pseudo-$\chi^2_{trk.}$/DOF < 10, X-Y TRACKS MATCH, Pseudo-χ^2_{vert} < 10

- **TWO TRACKS ONLY, NO VETO HIT**

  Third downstream track from δ-ray is allowed.

- **ENERGY, PARTICLE ID**

  $E_\mu > 2.2$ GeV, $E_{\pi \text{ OR } e} > 10$ GeV, $\Sigma E_{TRACKS} > 12$ GeV

- **FIDUCIAL VOLUME**

  Vertex $|x|, |y| < 50$ inches, z at least 40 inches AND 3σ

  From any drift chamber material

- **HIGH MASS: $M_T > 2.2$ GeV/c^2**

- **"CLEAN CUTS:" USE HIT MULTIPLICITY TO REMOVE ν SCATTERS**

  - No extra neutral clusters in calorimeter
  - ≤ 4 hits/view downstream of vertex
  - ≤ 7 hits total in 2 chambers DS of vertex in at least one view

EXPECTED BACKGROUND:

- DOMINATED BY A FEW THOUSAND ν-DIS INTERACTIONS IN THE DRIFT CHAMBERS.

PLUS:

~ 150 INTERACTIONS IN THE HELIUM BETWEEN CHAMBERS

... AND LESS IMPORTANT:

INTERACTIONS IN SURROUNDING MATERIAL (MOSTLY THE UPSTREAM VETO AND LABORATORY FLOOR) $\Rightarrow$ WIDE-ANGLE K_L (NEGLIGIBLE)

PUNCH-THROUGH OF MUONS (MOSTLY VETOED) OR NEUTRALS FROM INTERACTIONS IN UPSTREAM BERM (NEGLIGIBLE BACKGROUND)

NON-DEEP-INELASTIC INTERACTIONS: QUASIELASTIC SCATTERS, RESONANCES, "TRIDENTS," DIFFRACTIVE PRODUCTION
(ALL OF THESE PROVE NEGLIGIBLE IN THE END)

COSMIC RAYS, MULTIPLE INTERACTIONS, ... (NEGLIGIBLE)

ABOUT THE INTERACTION MONTE CARLO:

- INCLUDES DEEPLY INELASTIC SCATTERING
  QUASIELASTIC SCATTERING
  RESONANCE PRODUCTION
  DIFFRACTIVE PRODUCTION
  TRIDENTS

- FRAGMENTATION BY LEPTO/JETSET, CHECKED AGAINST DATA FROM BEBC, EMC, CCFR, NuTeV

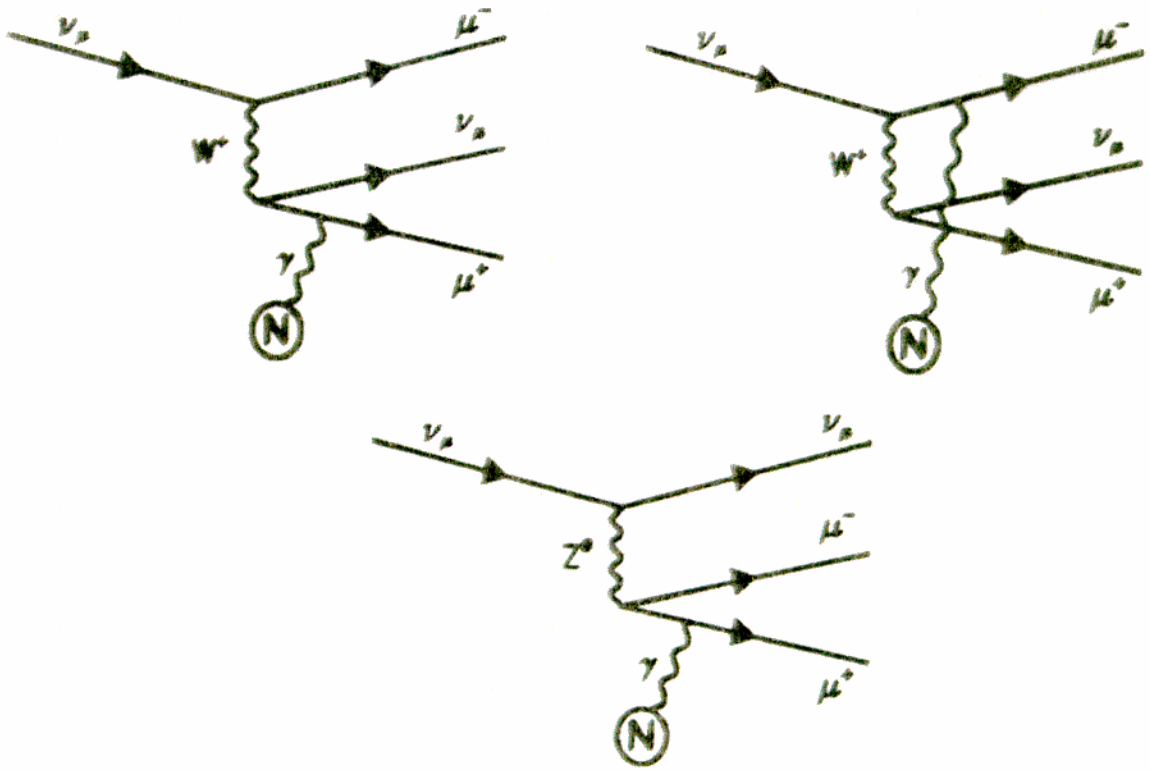
- INTERFACED TO GEANT HIT-LEVEL MONTE CARLO

- NOISE/ACCIDENTALS FROM DATA OVERLAYS

- NORMALIZED TO ≥2 TRACK DATA WITH HARD μ

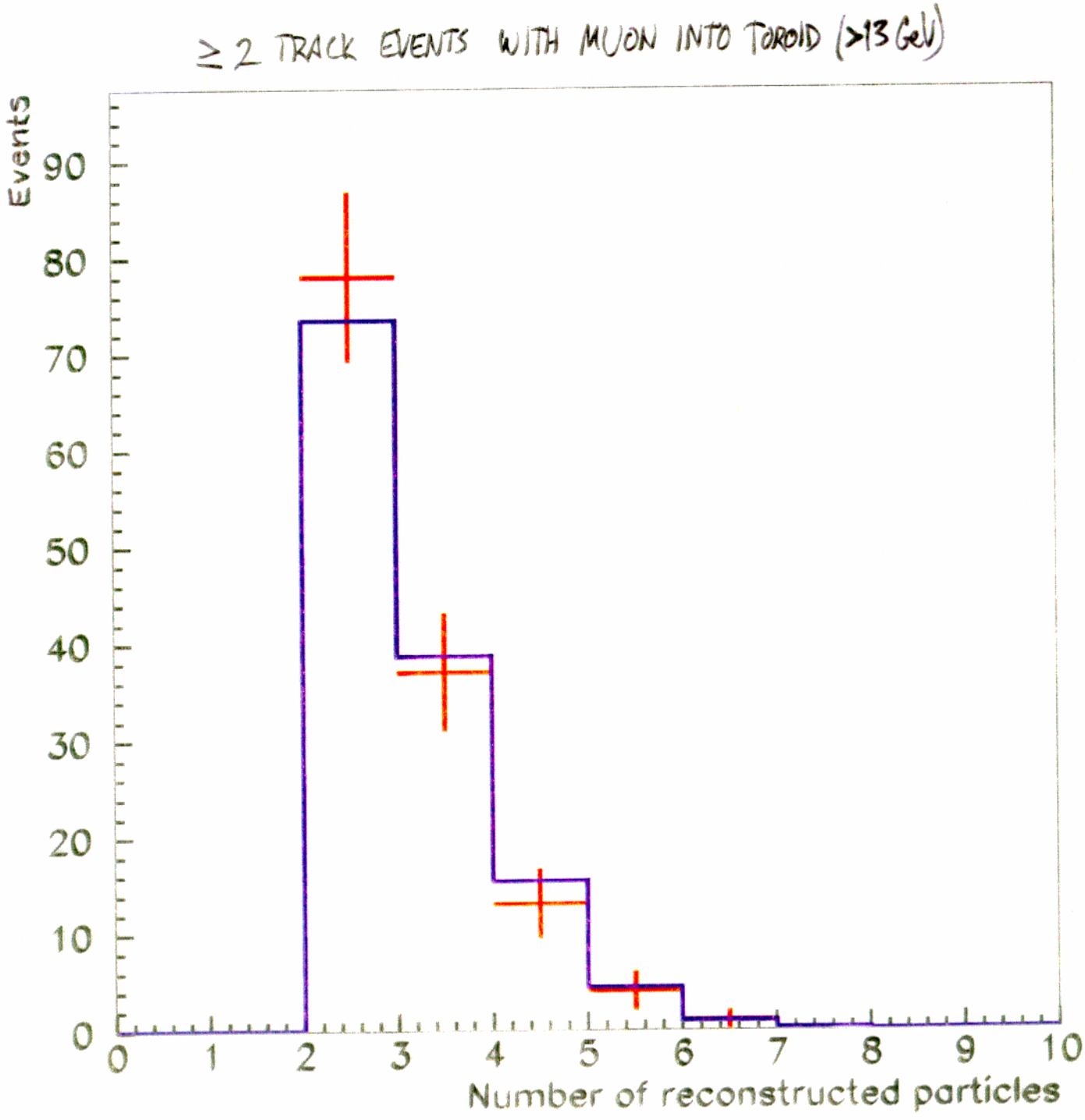
- MONTE CARLO ANALYZED WITH FULL DATA RECONSTRUCTION.

"TRIDENTS"

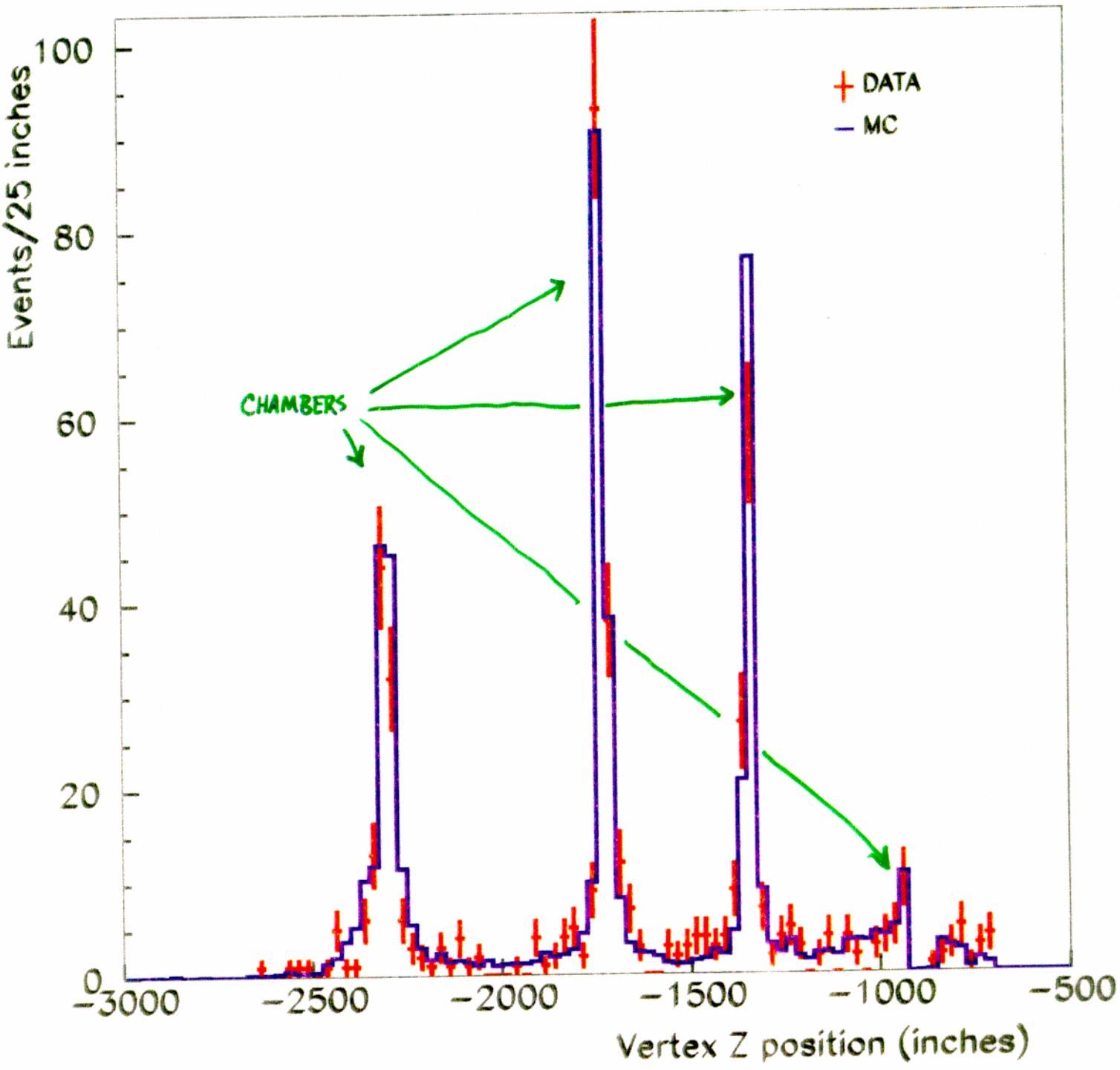


CROSS-SECTION TAKEN FROM MEASUREMENT IN TARGET-CALORIMETER

Does the Monte Carlo model track multiplicity correctly?



EVENTS WITH ≥2 GOOD TRACKS:



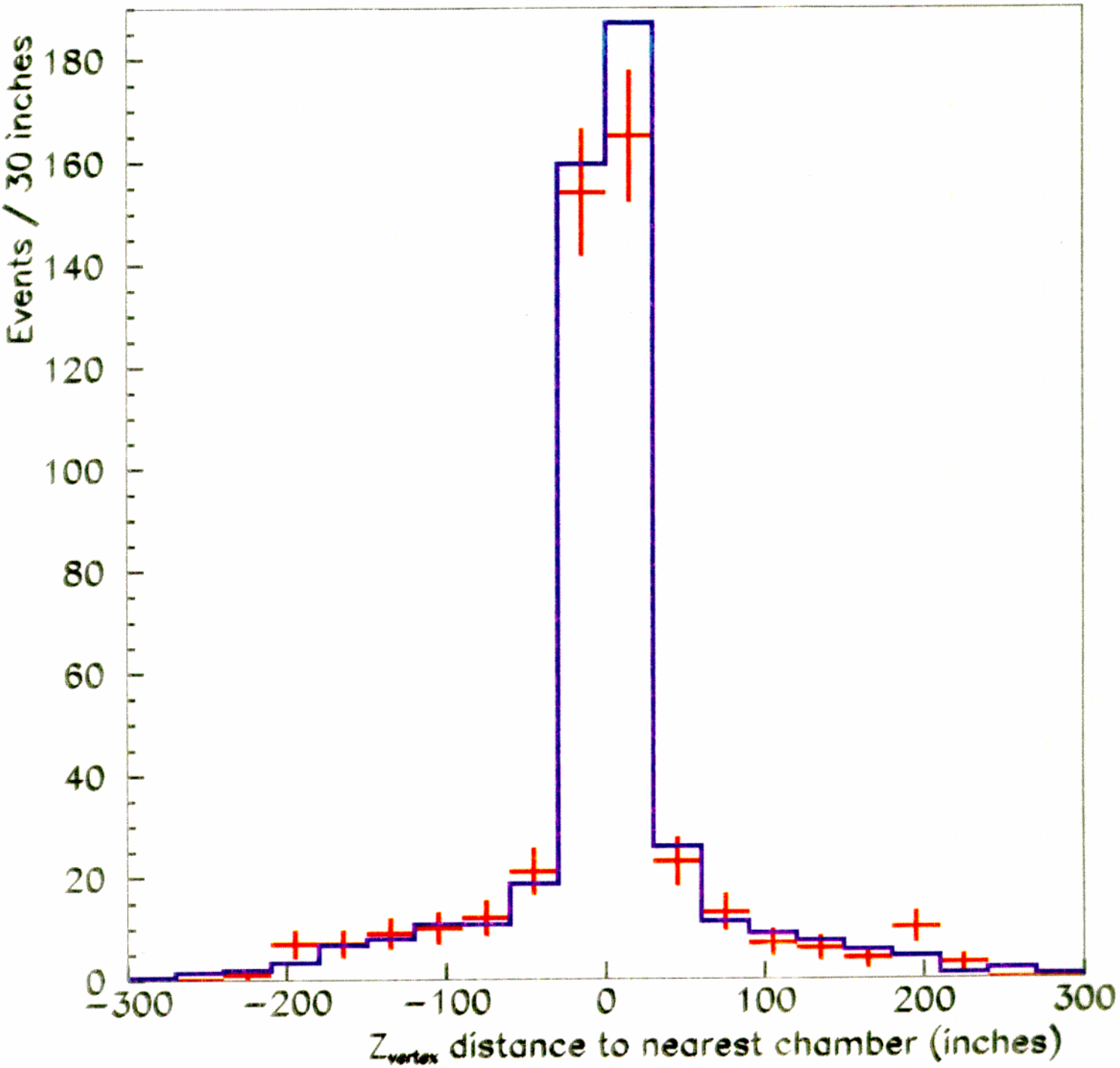
GOOD AGREEMENT BETWEEN DATA, MC

EVENTS:

502 observed

525±80 expected

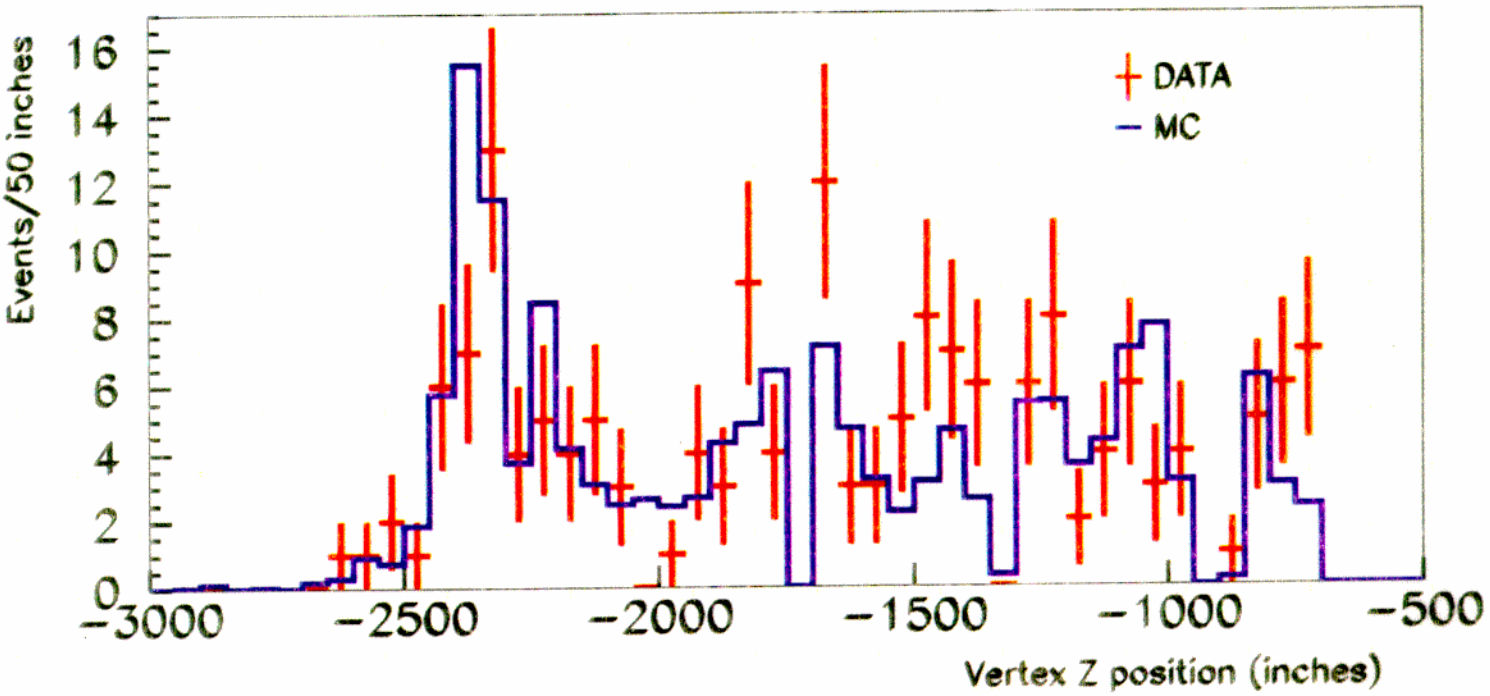
EVENTS WITH ≥2 GOOD TRACKS

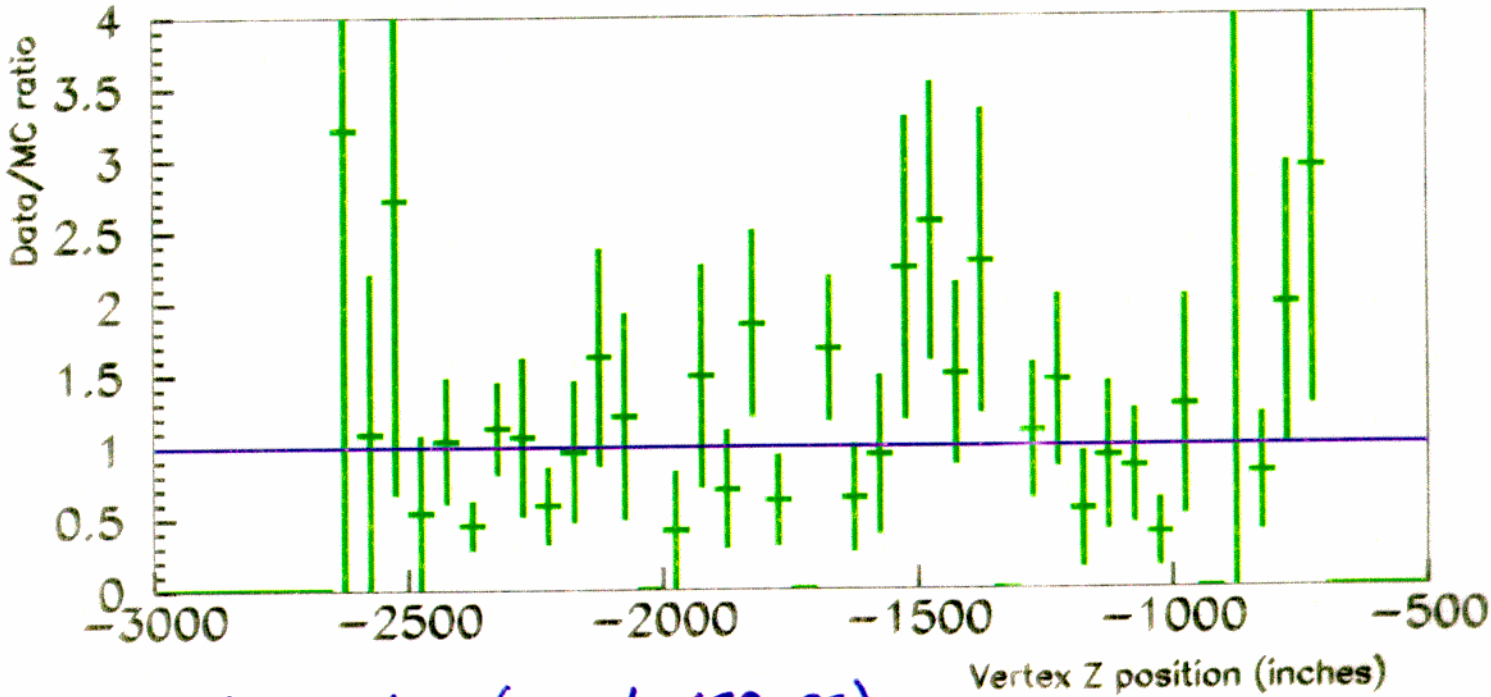


TAIL OF MISRECONSTRUCTED CHAMBER INTERACTIONS IS WELL MODELED.

CHAMBERS SURGICALLY REMOVED:

EVENTS WITH VERTICES RECONSTRUCTED IN HELIUM





data: 169 events (expect 159±25)

→ only 23 expected to be true He interactions; rest are misreconstructed chamber + floor + veto....

BLIND STUDIES

- **CHAMBER REGION:** ("ANTIBOX")

  ALL SIGNAL ANALYSIS CUTS, INVERTED FIDUCIAL CUT:

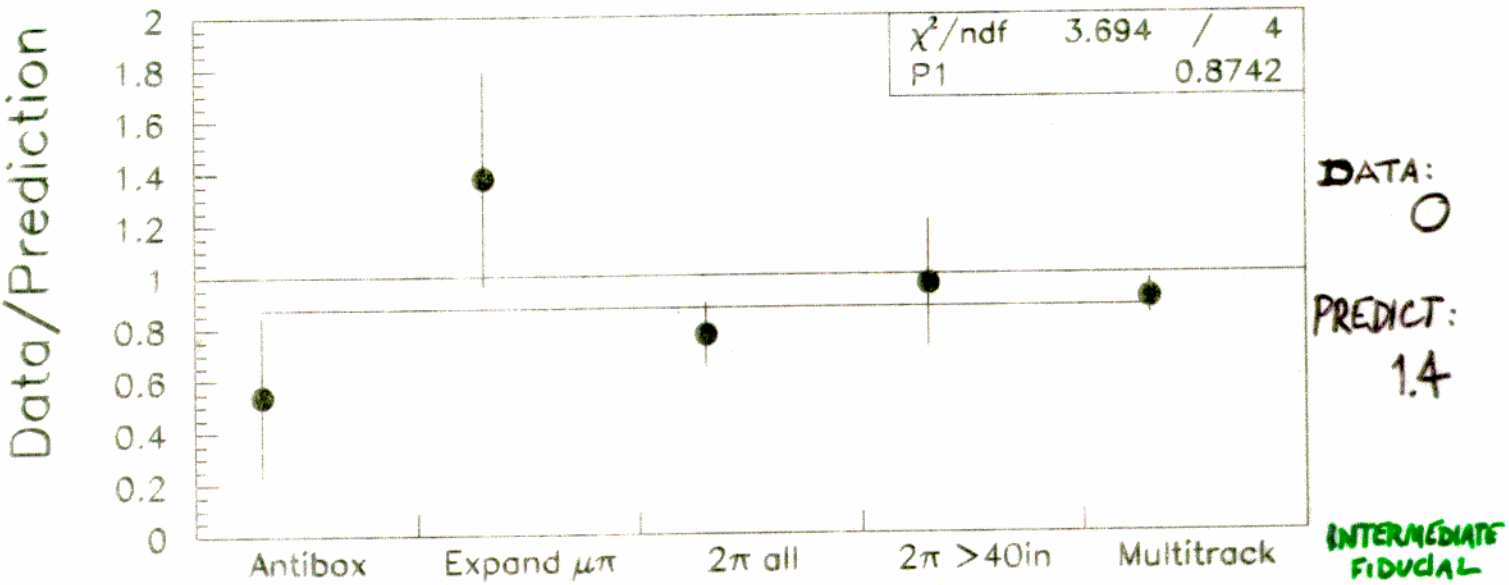
  $|\Delta z_{CHAMBER}| < 6$ inches.

MODE	MC EXPECT	OBSERVED
$\mu\mu$	1.6	0
μe	1.8	1
$\mu\pi$	2.7	2

MC NORMALIZED BY "FIRST PRINCIPLES" → 16% SYST. ERROR

- "ANTIBOX" WITH REDUCED π CUTS
- 2π VERTICES ANYWHERE
- 2π VERTICES IN HELIUM
- >2 TRACK VERTICES
- "INTERMEDIATE" FIDUCIAL REGION: $6'' < |\Delta z_{CHAMBER}| < 40''$

How well did studies agree?



OVERALL, PRETTY WELL. BACKGROUND ESTIMATES ROBUST.

SOME EVIDENCE OF ~13% DEFICIT IN DATA; CONSISTENT WITHIN 16% SYSTEMATIC ERROR ON "FIRST PRINCIPLES" NORMALIZATION.

FOR FINAL RESULTS, NORMALIZE TO A DATA SAMPLE WITH 9% STATISTICAL ERROR.

Summary of the Sources of Background

OBSERVED

$\mu\mu$

3

Source	$\mu\mu$ Events
DIS Events, all sources	$(3.9 \pm 0.9) \times 10^{-2}$
Diffractive Charm	$(1.1 \pm 0.1) \times 10^{-3}$
Diffractive $\mu\pi$	$(1.7 \pm 0.1) \times 10^{-4}$
K_L decays from berm	$(3.9 \pm 3.9) \times 10^{-4}$
Diffractive μK	$(3.3 \pm 0.3) \times 10^{-7}$
Other Sources	$< 2.5 \times 10^{-4}$
Total $\mu\mu$ Background:	0.040 ± 0.009 events

Preliminary

μe

0

Source	μe Events
DIS Events, all sources	$(1.4 \pm 0.2) \times 10^{-1}$
Diffractive Charm	$(1.5 \pm 0.1) \times 10^{-3}$
Diffractive $\mu\pi$	$(1.0 \pm 0.1) \times 10^{-4}$
K_L decays from berm	$(3.9 \pm 3.9) \times 10^{-4}$
Diffractive μK	$(2.5 \pm 0.2) \times 10^{-7}$
Other Sources	$< 1.6 \times 10^{-4}$
Total μe Background:	0.14 ± 0.02 events

Preliminary

$\mu\pi$

0

Source	$\mu\pi$ Events
DIS Events, all sources	$(1.3 \pm 0.2) \times 10^{-1}$
Diffractive Charm	$(1.1 \pm 0.1) \times 10^{-3}$
Diffractive $\mu\pi$	$(3.5 \pm 0.3) \times 10^{-4}$
K_L decays from berm	$(3.9 \pm 3.9) \times 10^{-4}$
Diffractive μK	$(8.7 \pm 0.8) \times 10^{-7}$
Other Sources	$< 1.6 \times 10^{-4}$
Total $\mu\pi$ Background:	0.13 ± 0.02 events

Preliminary

Errors are Systematics $\otimes$ Monte Carlo Statistics.

CHECKING "SIDEBAND" AGREEMENT:

IS THERE A MAJOR BACKGROUND LEAKING IN FROM JUST BEYOND THE CUTS?

ADDRESS THIS BY REMOVING CUTS SEQUENTIALLY:

NO "FLOOD" OF UNSIMULATED BACKGROUND APPEARS:
⇒ THE BACKGROUND ESTIMATES ARE ROBUST.

- Remove "Clean Cuts"

Event Type	Data Events	MC Predict
μμ	3 + 1	0.25
μe	0	0.25
μπ	0	0.13

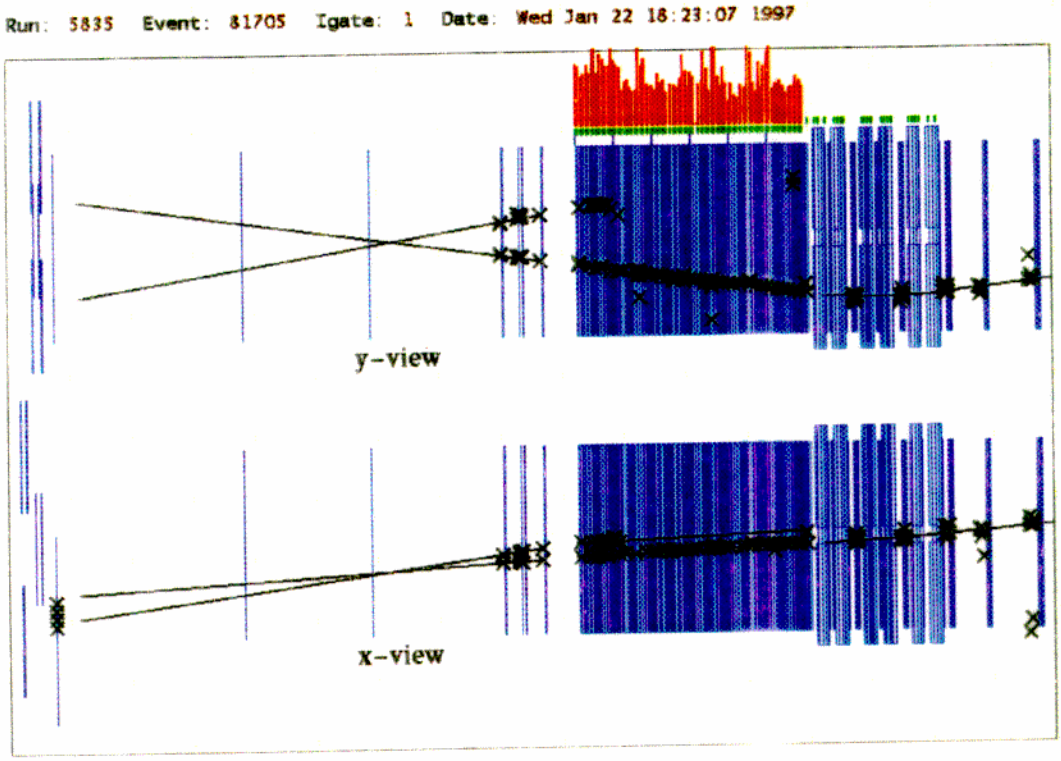
- Expand fiducial region to include chambers

Event Type	Data Events	MC Predict
μμ	3 + 2	1.4
με	7	6.3
μπ	5	5.5

- Remove all energy and PID cuts

Event Type	Data Events	MC Predict
μμ	3 + 3	2.5
με	10	13.8
μπ	10	13.8

Event 1



- Transverse Mass: 5.1 GeV
- Track information:

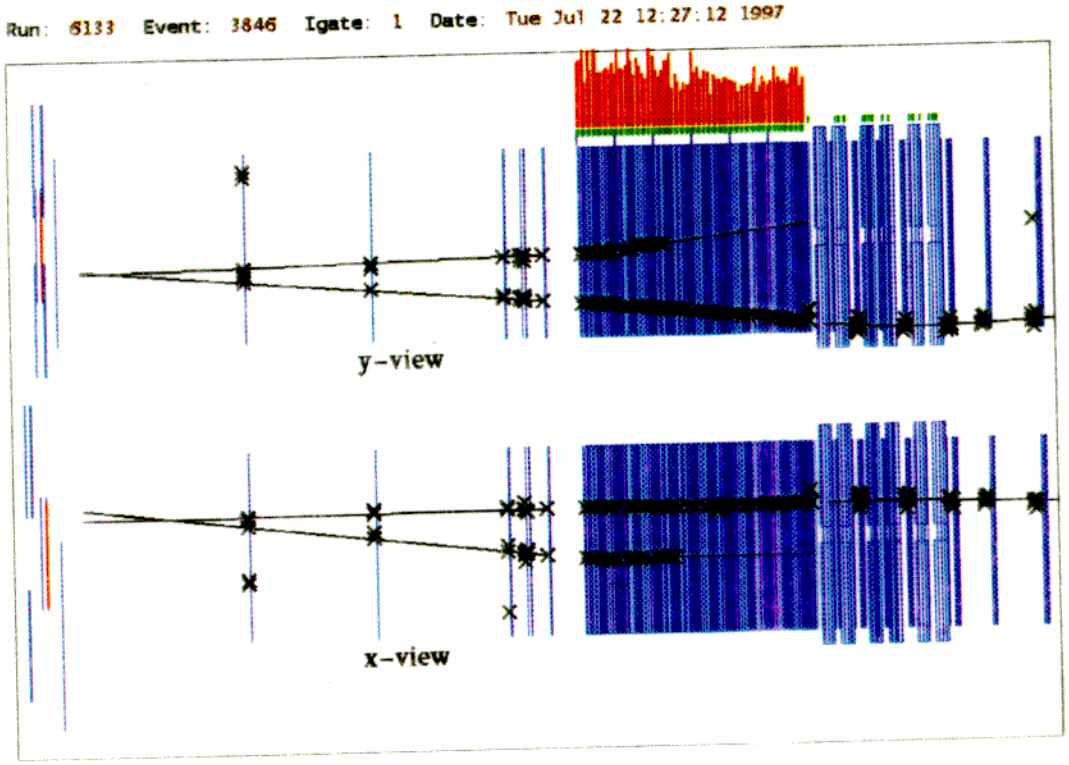
	Momentum	Pseudo-χ^2/DOF $(x;y)$	Charge
Track 1:	77.7 GeV	0.2/2; 2.4/2	negative
Track 2:	2.6 GeV	0.3/2; 3.1/2	unmeasured

- Vertex Information:

(x, y, z) in inches	$\Delta_z^{chamber}$	Pseudo-χ^2/DOF	error in z
$(-18.4, 1.4, -1265.9)$	77 inches (DK4)	6.3/9 (Prob=62%)	± 9.5 inches

- Veto hit-time from trigger: +404, +536 ns

Event 2



- Transverse Mass: 3.1 GeV
- Track information:

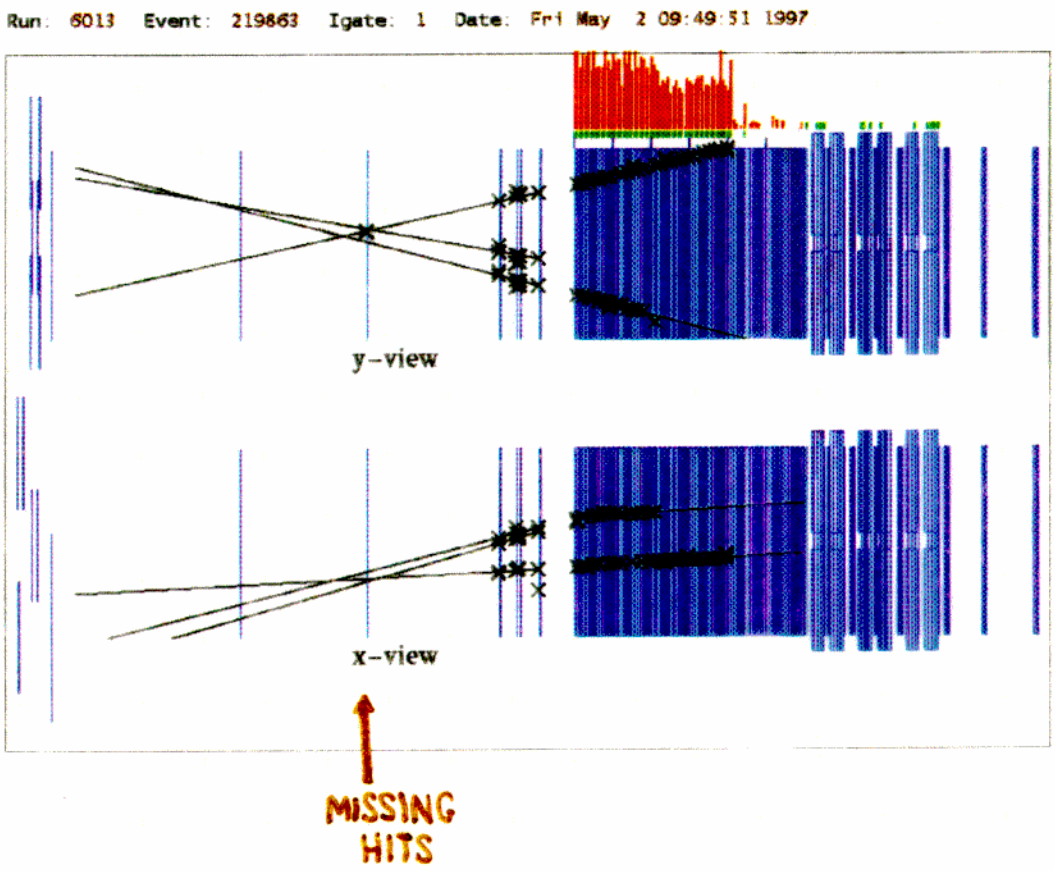
	Momentum	Pseudo-χ^2/DOF	Charge
Track 1:	92.0 GeV	1.8/4; 2.8/4	negative
Track 2:	5.8 GeV	5.1/4; 4.5/4	unmeasured

- Vertex Information:

(x, y, z) in inches	$\Delta_z^{chamber}$	Pseudo-χ^2/DOF	error in z
$(18.3, -15.2, -2041.2)$	312 inches (DK5) 260 inches (TB)	166/17 (Prob=5%)	± 7.2 inches

- Veto hit-time from trigger: +24 ns

Event 3



- Transverse Mass: 4.7 GeV
- Track information:

	Momentum	Pseudo-χ^2/DOF (x, y)	Charge
Track 1:	47.9 GeV	2.5/2; 0.8/2	unmeasured
Track 2:	4.3 GeV	13/2; 2.4/2	unmeasured
Downstream Track:	unmeasured ($< 2GeV$)	0.8/2; 1.2/2	unmeasured

- Vertex Information:

(x, y, z) in inches	$\Delta_z^{chamber}$	Pseudo-χ^2/DOF	error in z
$(-23.3, 5.8, -1416.7)$	73 inches (DK4)	23/10 (Prob=21%)	± 5.3 inches

- Veto hit-time from trigger: -256, $+320$, $+320$, $+1192$ ns

WHAT SUPPORTS N° DECAY EXPLANATION?

* THE EVENTS PASS THE CUTS!

  BACKGROUND IS 0.04 EVENTS AND ESTIMATE SUPPORTED BY ALL CROSS-CHECKS

  FLUCTUATION PROBABILITY IS 1.2×10^{-5}.

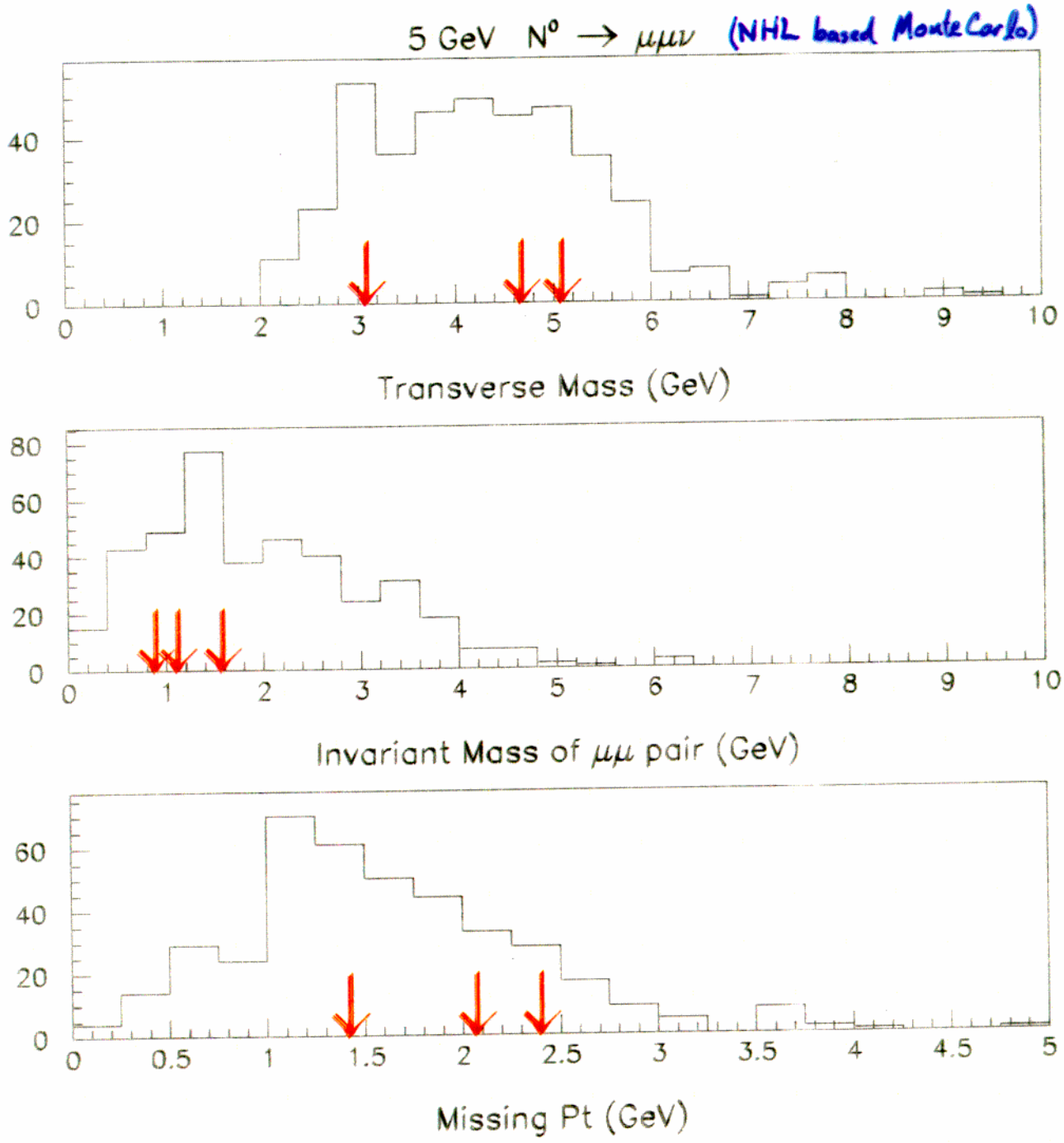
* EVENTS WELL DISTRIBUTED IN Z

* VERTICES FAR FROM CHAMBERS

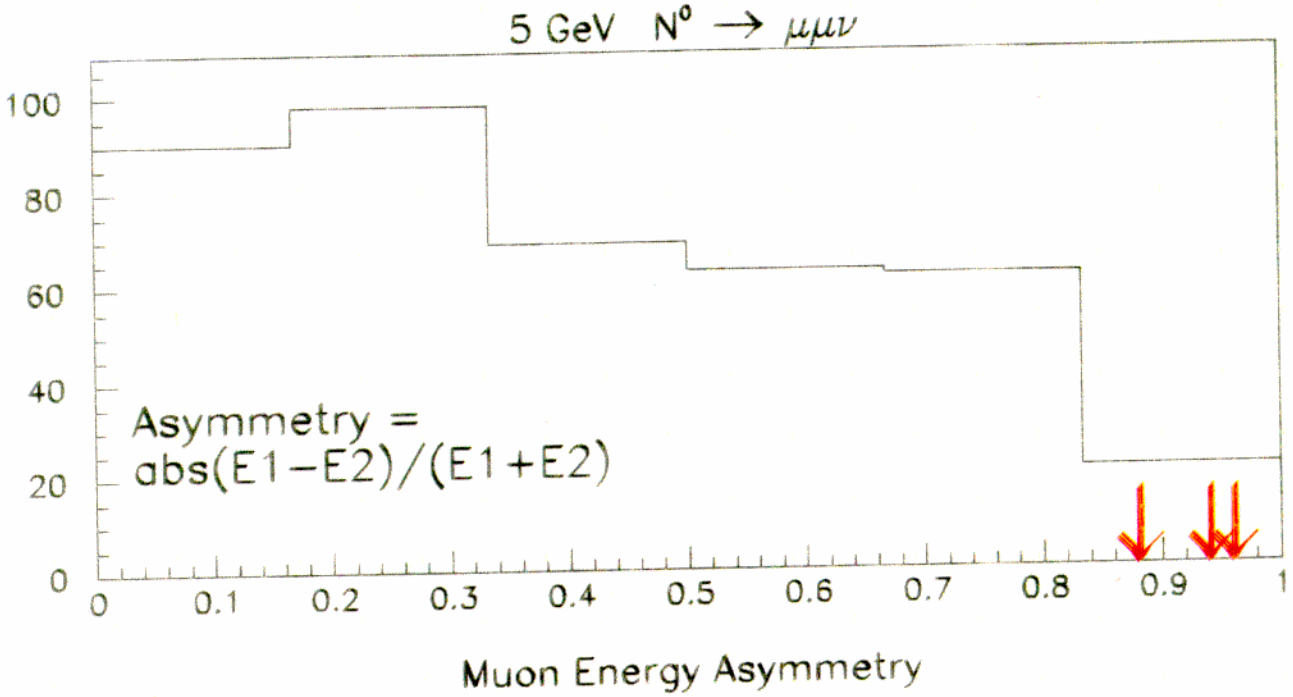
KINEMATICS?

MIXED BAG:

How do the kinematics compare to N° expectation?



... BUT IN ONE VARIABLE THEY LOOK VERY STRANGE FOR DECAYS!



EVENTS HIGHLY ASYMMETRIC IN μ ENERGY.

PROBABILITY OF A>0.85 FOR 3 EVENTS:

NHL DECAY: $\lesssim 0.5\%$

DIS: $25\sim35\%$

How to express result?

- Origin of events very unclear ⇒ hesitant simply to use Feldman-Cousins approach and give signal band.

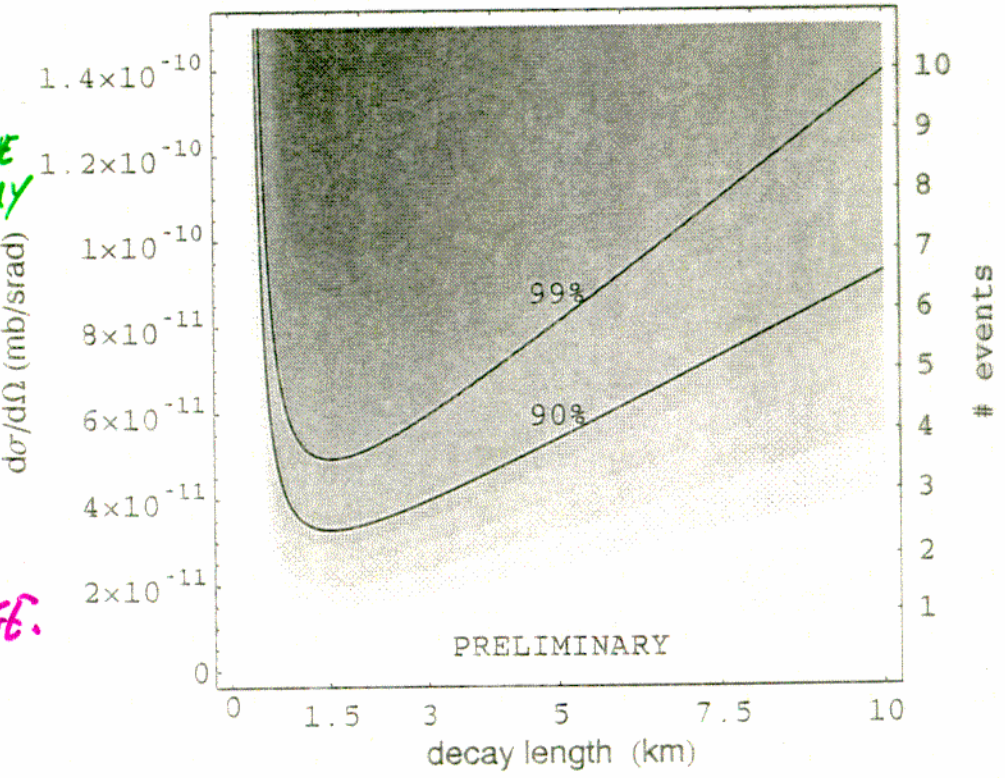
- So, use classic frequentist approach and force a one-sided 90% C.L. limit assuming 3 events with no background subtraction:

Rate < 6.6 events at 90% C.L.

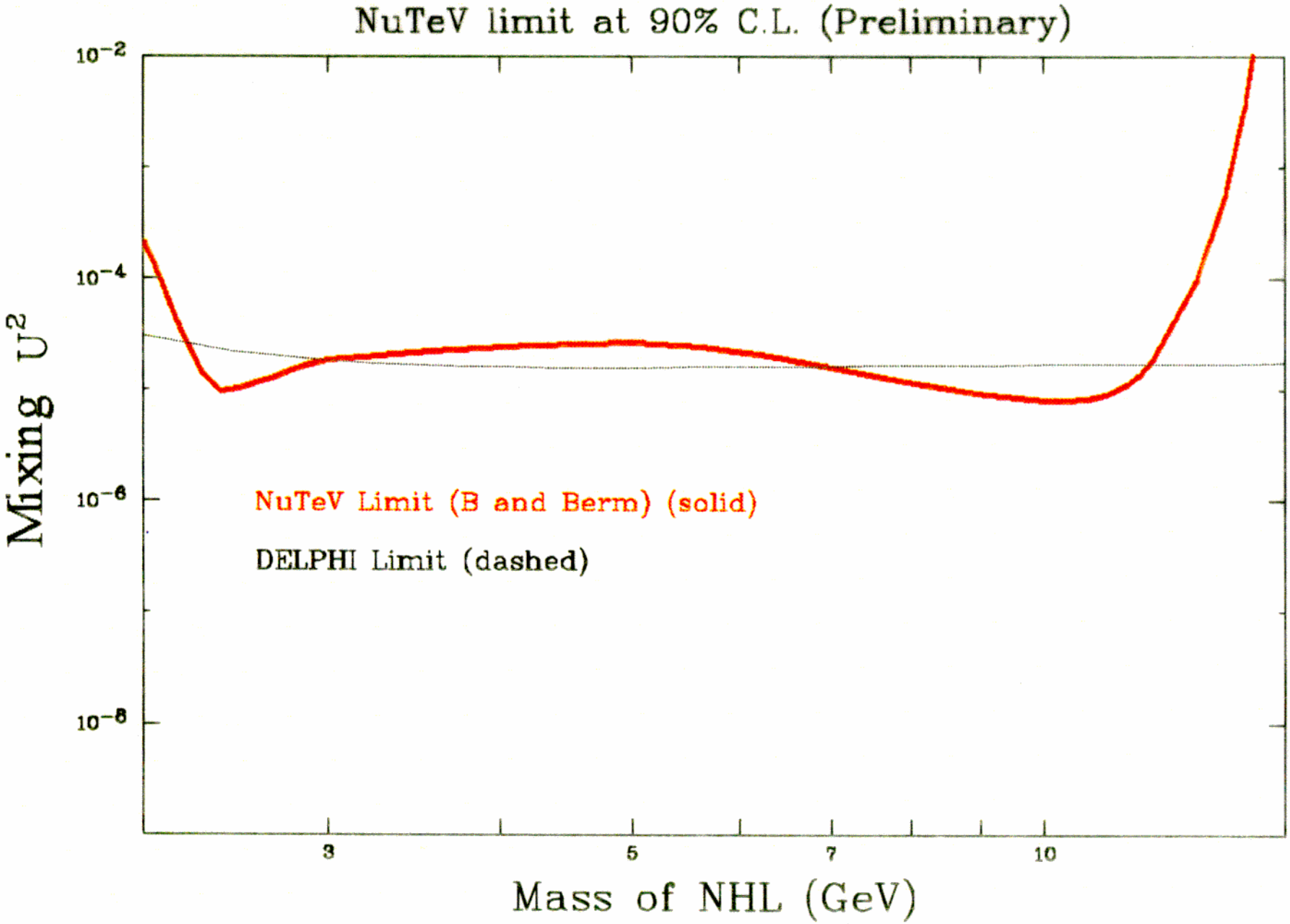
- Limit in terms of $\gamma c\tau$, $\frac{d\sigma}{d\Omega}$ for neutralino (or other N°)

- Choose $\tilde{\chi}^0_1$ couplings to give only $\mu\mu\nu$ decay

- First direct search for long-lived $\tilde{\chi}^0_1$ in mass range.



MODEL-SPECIFIC LIMIT ON NEUTRAL HEAVY LEPTONS



Conclusions:

* Electroweak Physics:

Competitive $\sin^2\theta_W$ result; final number soon

* Searches:

- Neutral heavy lepton sensitivity well beyond other experiments
- KARMEN timing anomaly limit reduces available parameter space by ~4 orders of magnitude (but doesn't rule out Q°)
- Anomalous high-mass events intriguing!
  Able to set limits on NHLs
  First search for long-lived few-GeV neutralino.