Preliminary results from the NOMAD experiment: present and future

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OUTLINE

- **NOMAD experiment**
- **Oscillation search (principles)**
- **Diffractive $D_s^{(*)}$ production (preliminary)**
- **NOMAD-STAR prototype**
- **Physics motivation & Detector design**
- **Reconstruction algorithm**
- **Preliminary results from NOMAD-STAR**
- **Summary**

NEUTRINO OSCILLATIONS

- **Signature for lepton family number violation and** $m_\nu \neq 0$
- **flavor eigenstates:** $|\,\nu_\alpha\rangle$, $\alpha = \mu, e, \tau$
- **mass eigenstates:** $|\,\nu_i\rangle$, **i= 1,2,3**

$$\nu_\alpha = \Sigma_i\, \mathbf{U}_{\alpha i}\, \nu_i$$

$$\begin{pmatrix} \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$ **2 flavor case**

$$\mathrm{P}(\nu_\mu \to \nu_\tau) = \sin^2(2\theta)\sin^2(1.27\frac{\Delta \mathrm{m}^2 \mathrm{L}}{\mathrm{E}})$$

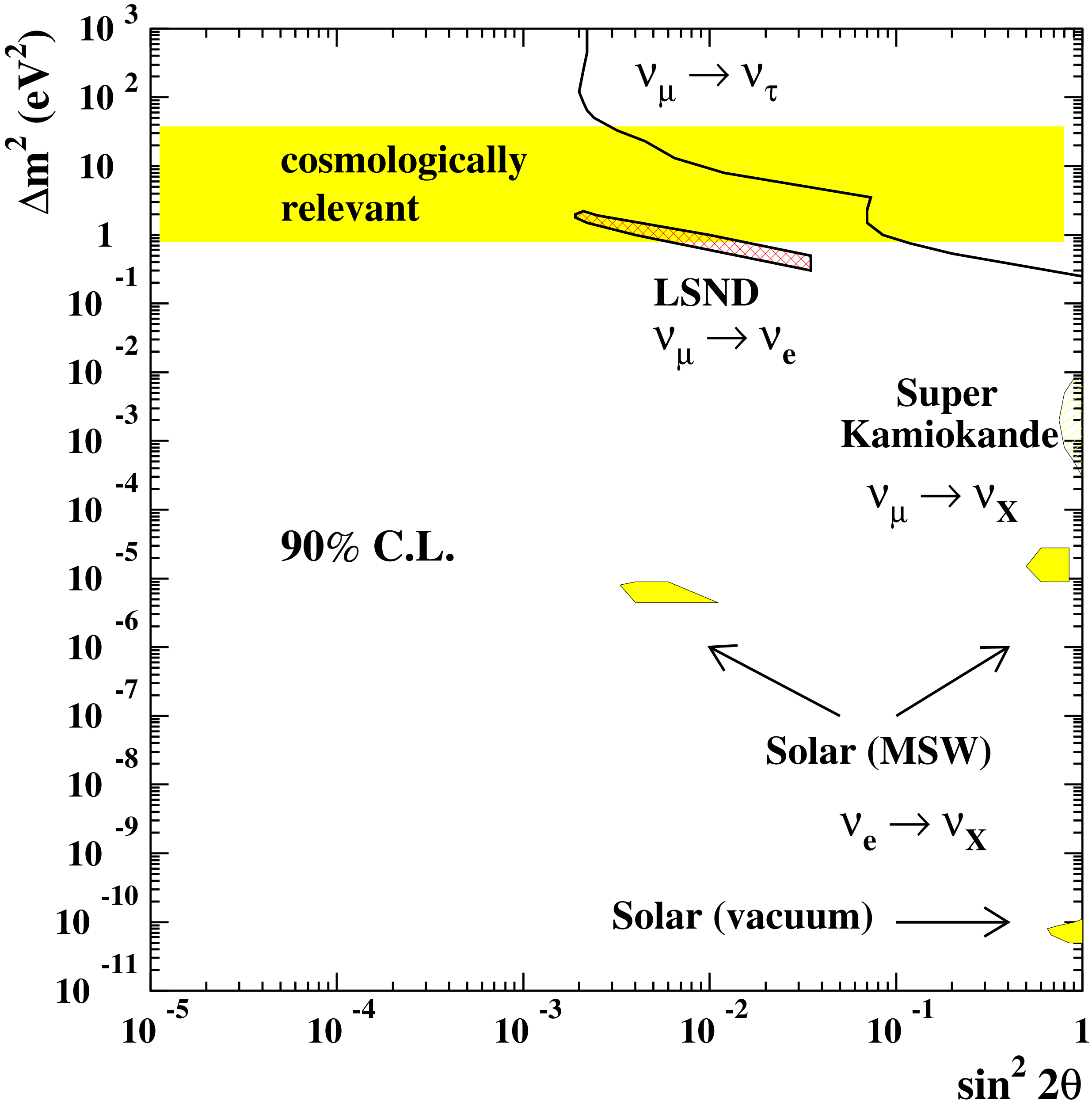
$\Delta\mathrm{m}^2 =\mid \mathrm{m}_1^2 - \mathrm{m}_2^2 \mid$ **eV^2**

L **= distance from the source in m**

E **= neutrino energy in MeV**

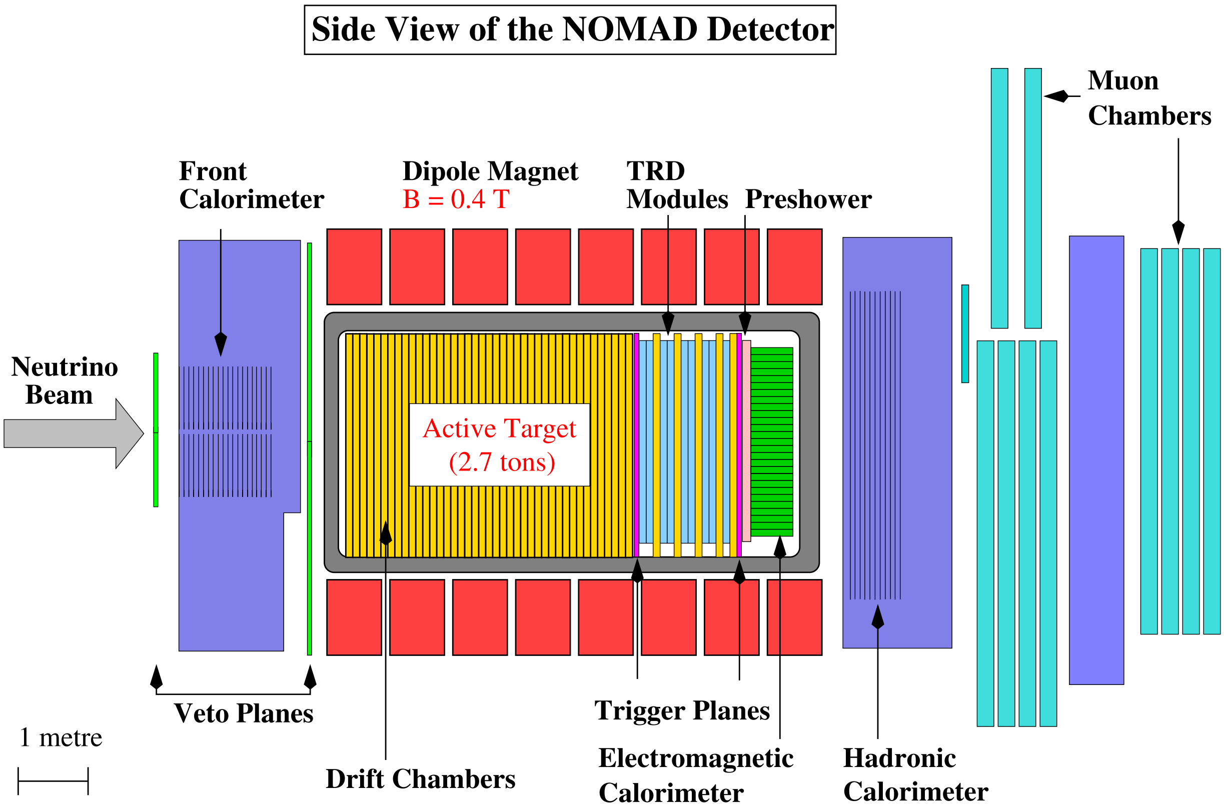
NOMAD searches at $L \sim 1$ km, $E \sim 25$ GeV and it is sensitive to $\Delta\mathrm{m}^2 \geq 10$ eV^2.

NEUTRINO OSCILLATIONS



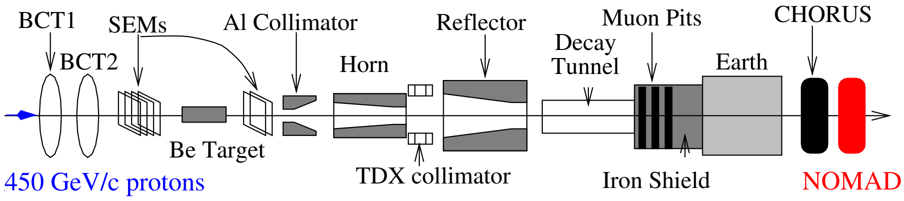
NOMAD DETECTOR

Optimized for electron identification

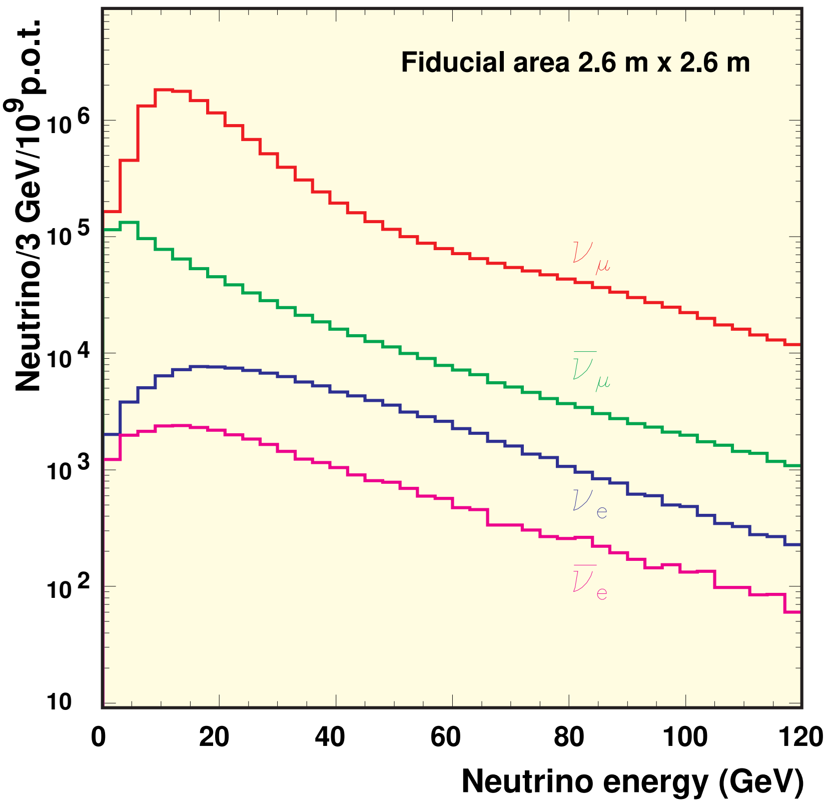


- fiducial mass 2.7 tons
- $\frac{\Delta p}{p} \sim 3 - 5\%$ ($p < 10$ GeV)
- $\frac{\sigma(E)}{E} = \frac{3.2\%}{\sqrt{E}} \oplus 1\%$
- $e^{\pm}$ identification: (π rejection $\sim 10^3$) $\varepsilon(e) \geq 90\%$ for isolated tracks in a momentum range from 1 to 50 GeV
- μ identification $\varepsilon \approx 97\%$ for $p_\mu > 5$ GeV

THE CERN NEUTRINO BEAM



- **NOMAD detector: 835 m from the target**
- **distance ν source - detector: $\langle L \rangle$ = 620 m**



	Flux		CC interactions	
Neutrino	$\langle E_\nu \rangle [GeV]$	rel. abund.	$\langle E_\nu \rangle [GeV]$	rel. abund.
ν_μ	23.6	1.0	44.1	1.0
$\bar{\nu}_\mu$	18.4	0.055	40.6	0.021
ν_e	37.5	0.009	56.6	0.015
$\bar{\nu}_e$	30.3	0.0025	50.7	0.0016
ν_τ	~ 35			$\simeq 5 \times 10^{-6}$

SEARCH FOR $\nu_\mu \leftrightarrow \nu_\tau$ OSCILLATIONS

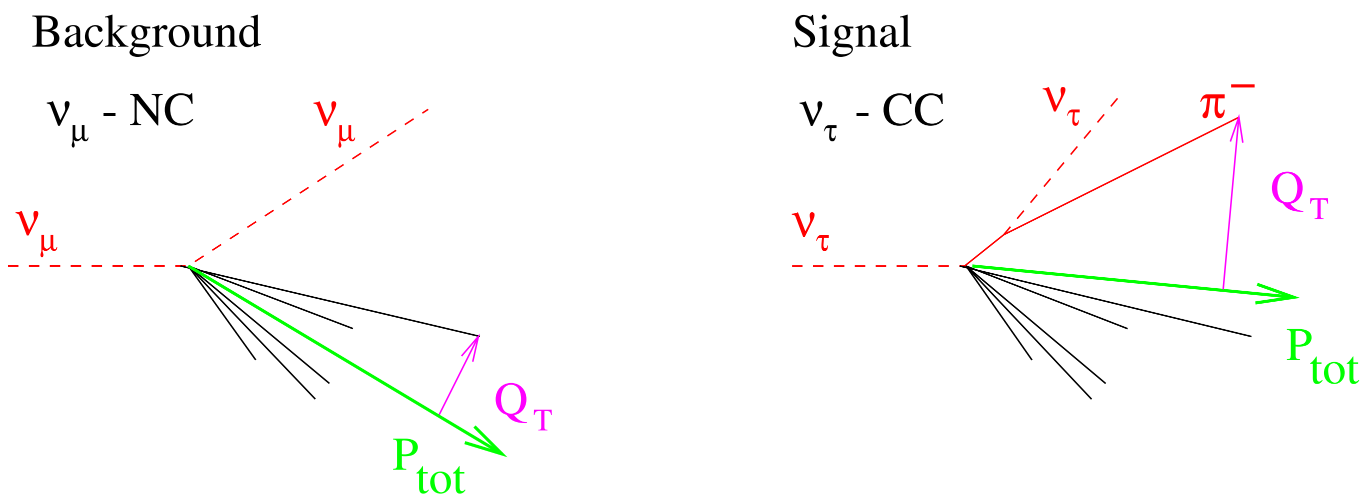
$$\nu_\mu \Longrightarrow \nu_\tau + N \rightarrow \tau^- + X$$
$$\rightarrow \textbf{(decay products)} + \nu_\tau$$

τ^- is identified from decay products:

$$\tau^- \rightarrow \mu^- \overline{\nu_\mu} \nu_\tau$$
$$\tau^- \rightarrow e^- \overline{\nu_e} \nu_\tau$$
$$\tau^- \rightarrow \pi^- \nu_\tau$$
$$\tau^- \rightarrow \rho^- (\pi^- \pi^0) \nu_\tau$$
$$\tau^- \rightarrow \pi^- \pi^+ \pi^- + n\pi^0 (n \geq 0) \nu_\tau$$

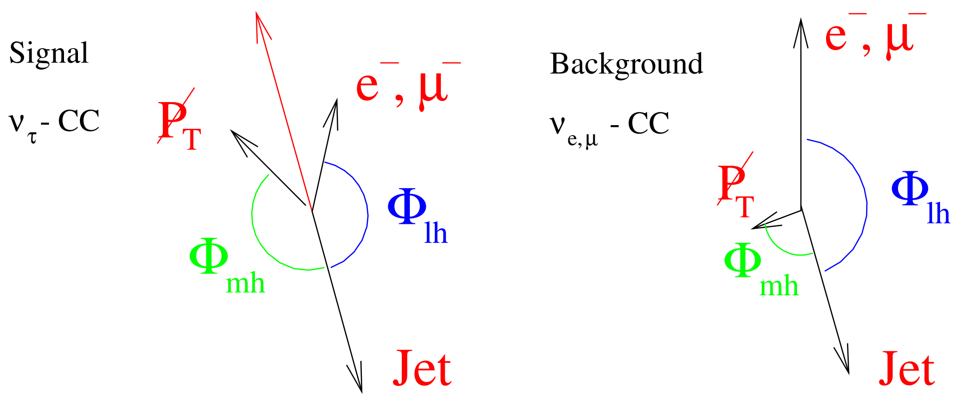
NOMAD USES A KINEMATICAL TECHNIQUE

Isolation of τ decay products from the hadronic jet



Q_T = component of the momentum of visible τ decay products perpendicular to the total visible momentum vector

Kinematical configuration in the plane perpendicular to the incoming ν direction



- **magnitude of the missing transverse momentum $\not{p}_T$**
- **direction of imbalance**
- **angle ϕ_{lh} (lepton and jet transverse momenta)**
- **angle ϕ_{mh} (missing momentum and jet transverse momentum)**

NOMAD OSCILLATION SEARCHES

Main Analysis

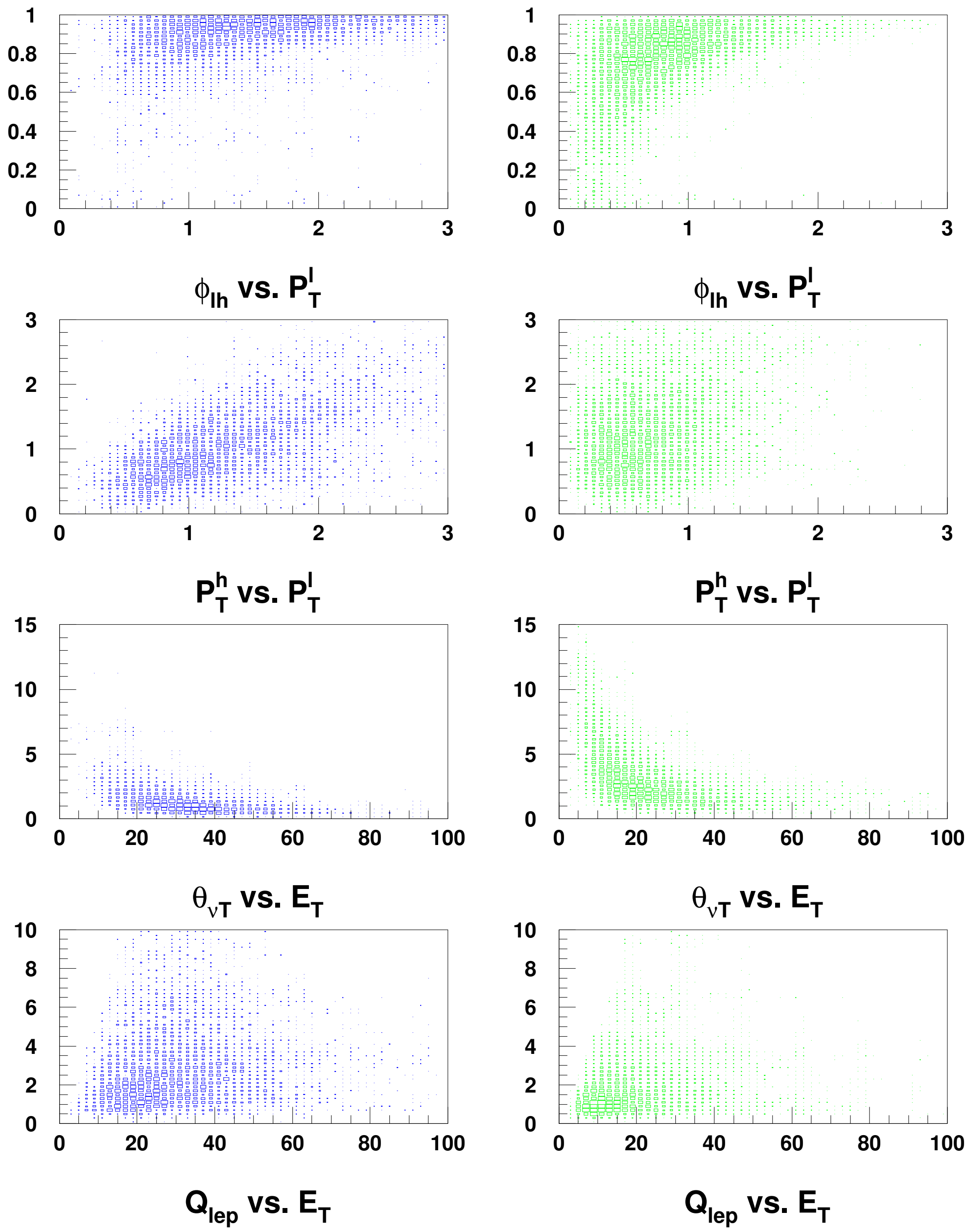
- $\tau^- \rightarrow e^- \nu_\tau \overline{\nu_e}$ **(17.8%)**
- $\tau^- \rightarrow \pi^- \nu_\tau$ **(49.8%)**
- $\tau^- \rightarrow \pi^- \pi^- \pi^+ (n\pi^0) \nu_\tau$ **(14.9%)**
- **Phys. Lett. B431 (1998) 219 $\rightarrow$ analysis of 95 data**
- **95-97 data is presented at Takayama, NEUTRINO-98**
- **95-98 data analysis is in progress**

Analysis Method

- **Separation of Signal & Background $\rightarrow$ Many variables (often correlated) $\rightarrow$ Information optimized building a Likelihood function**
- **We never look at the (τ^-) data in the signal region**
- **Compute the sensitivity to choose the signal box**
- **Choose "best" (most sensitive) analysis before opening box**
- **Open Box**

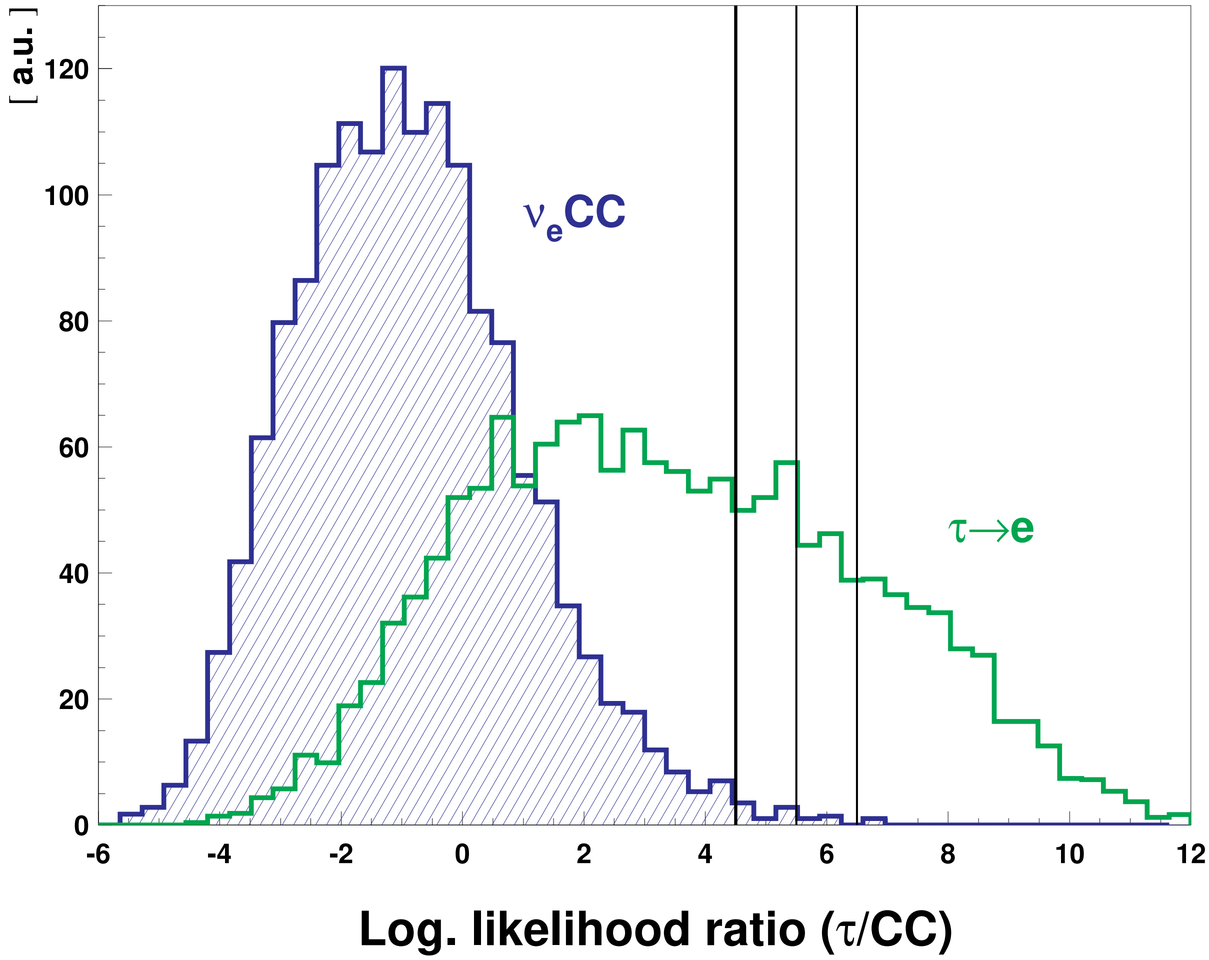
Rejection of ν_e CC interactions

ν_e **CC** $\tau \to e$



- P_T^l **: electron transverse momentum**
- P_T^h**: hadronic jet transverse momentum**
- E_T **: total visible energy in the event**
- Q_{lep} **: electron momentum component perpendicular to the hadronic jet momentum**

Likelihood signal vs. CC background



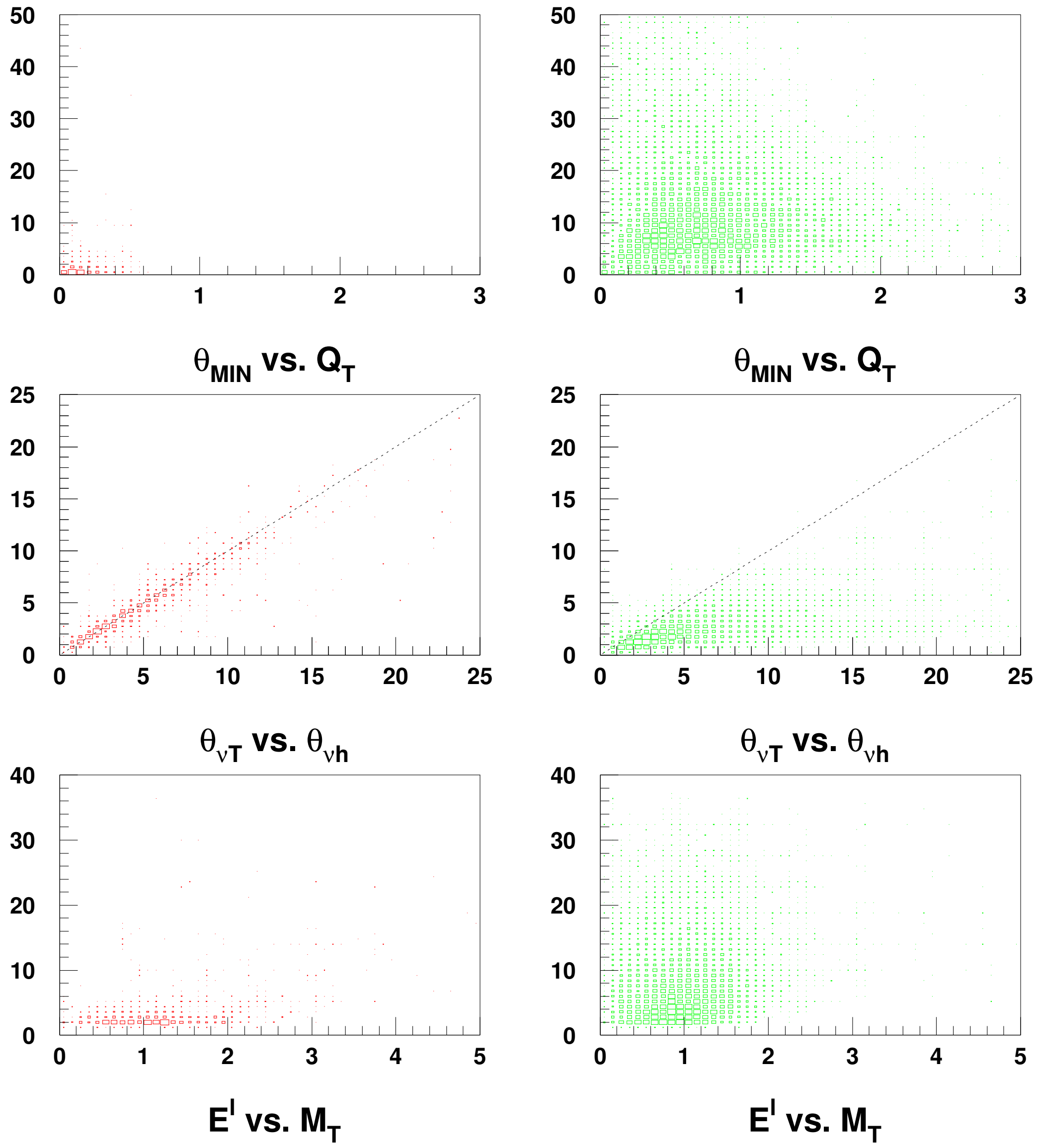
$$L = \Pi_{i=1}^{N} P(X_i)$$

are formed for signal and background, with $P(X_i)$ the 1 or n-dimen sional probability density function of the variable X_i.

$$L(\tau/\nu_e CC) = [p_T^l, p_T^h, \phi_{lh}][E_T,\ \theta_{\nu T}, Q_{lep}]$$

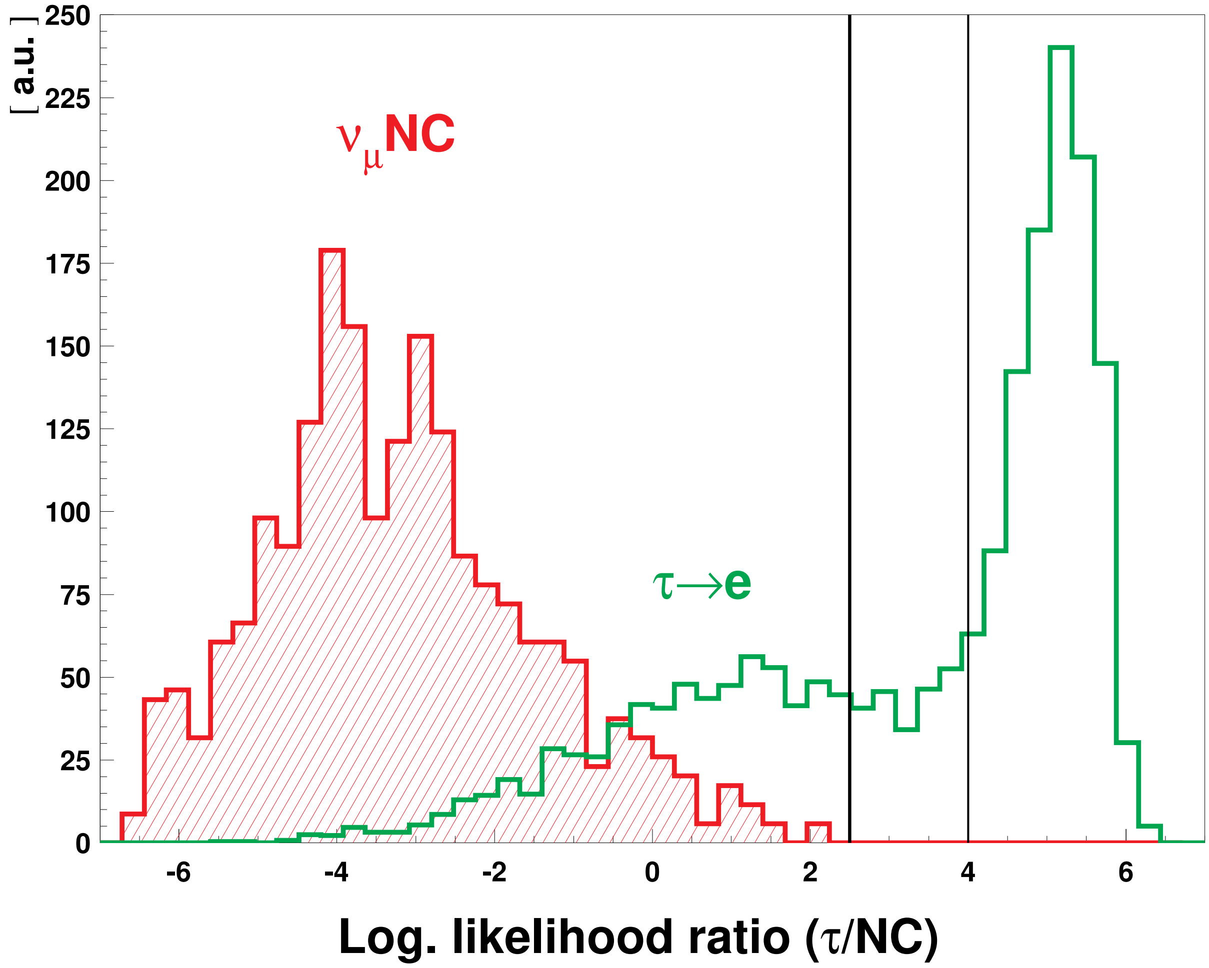
Rejection of NC interactions

ν_μ **NC** $\tau \rightarrow e$



- θ_{MIN} **: minimum angle between $\vec{p}_{ele}$ and any $\vec{p}_h$ of the hadronic system**
- $\theta_{\nu T}$ **: angle between the incident ν direction and the total momentum of the event**
- $\theta_{\nu h}$ **: angle between the incident ν direction and the total hadron momentum**
- $\mathbf{E}^l$ **: electron energy**
- $\mathbf{Q}_T$ **: electron momentum component perpendicular to the hadronic jet momentum**
- $\mathbf{M}_T$ **: transverse mass of the hadronic system**

Likelihood - signal vs. NC background

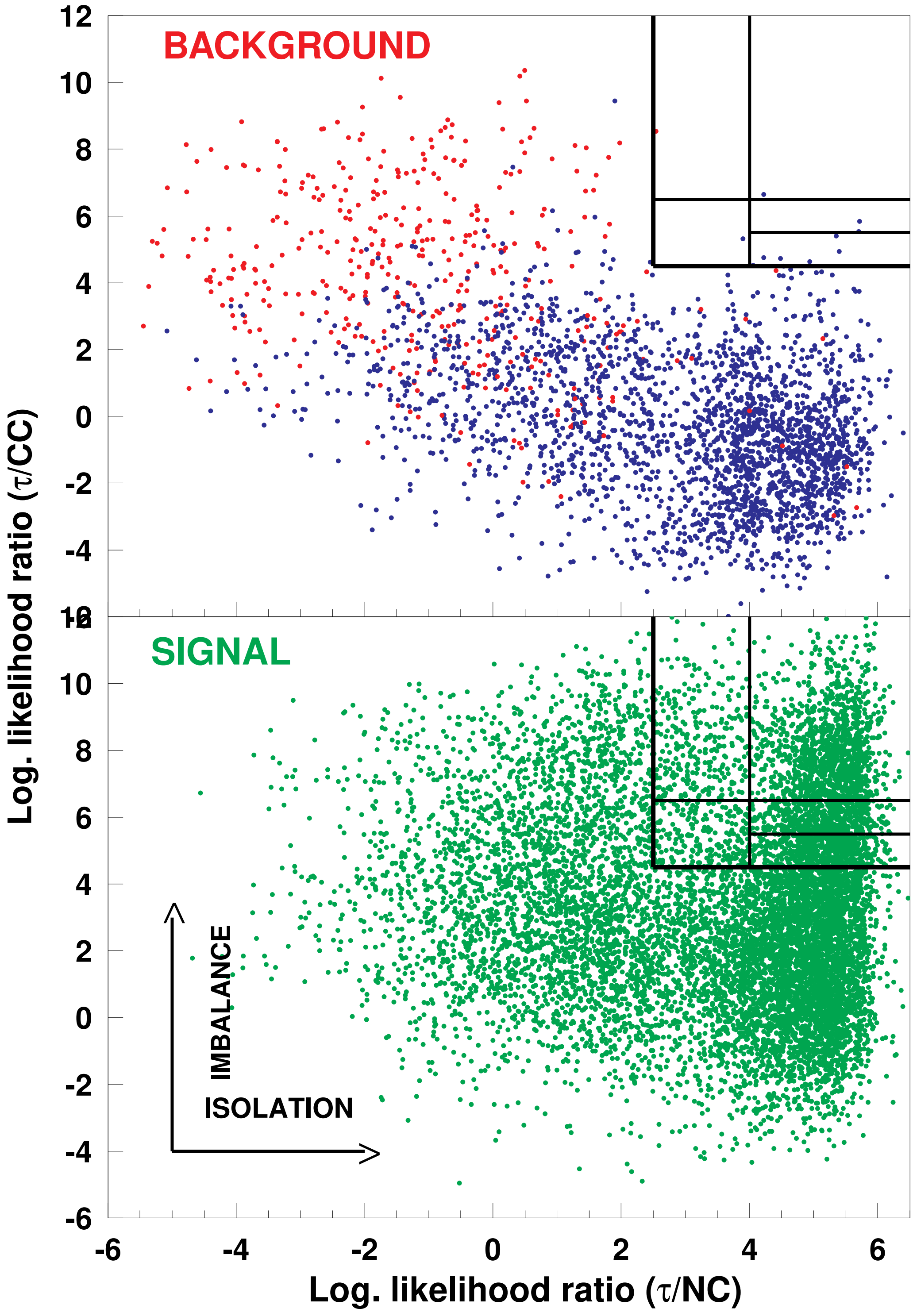


$$\mathrm{L} = \Pi_{i=1}^{N} \mathrm{P}(\mathrm{X}_i)$$

are formed for signal and background, with $\mathrm{P}(\mathrm{X}_i)$ the 1 or n-dimen sional probability density function of the variable X_i.

$$L(\tau/\nu NC) = [[[\theta_{\nu T}, \theta_{\nu h}], \theta_{MIN}, Q_T], E^l, m_T]$$

Definition of the 'signal region'

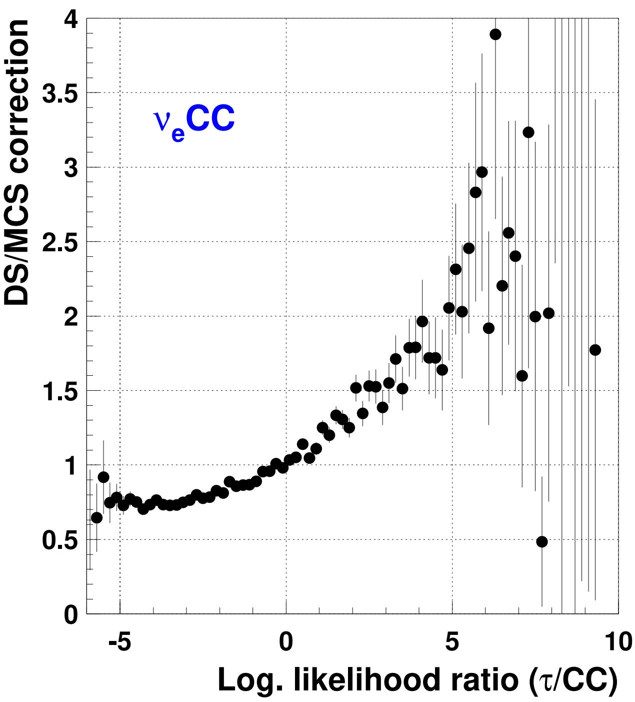


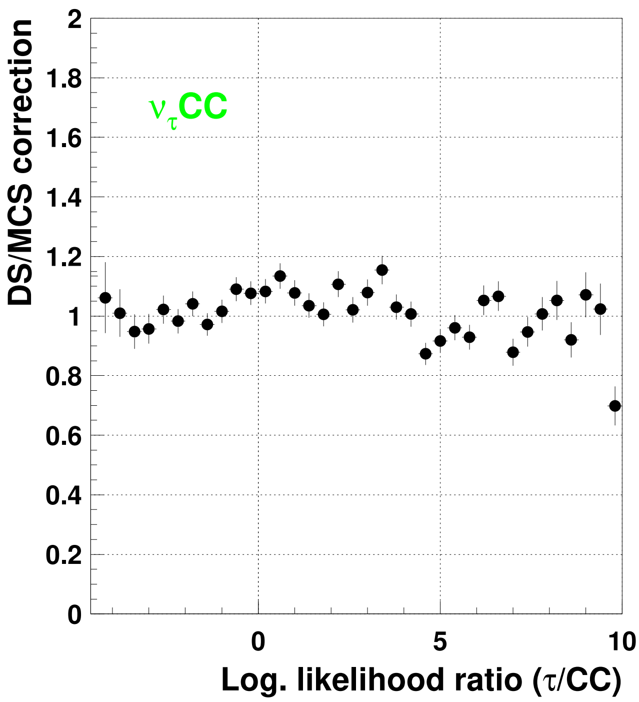
Data simulator

Back-Up

- **The hadronic system is not well simulated in the Monte Carlo**
- **Replace a muon from a ν_μ CC event in the data , by another lepton (tau, electron, ν) from either MC or data**
- **Estimate signal and background efficiencies (except for ν_μ CC events), from**

$$\epsilon = \epsilon_{MC} \times \frac{\epsilon_{DS}}{\epsilon_{MCS}}$$

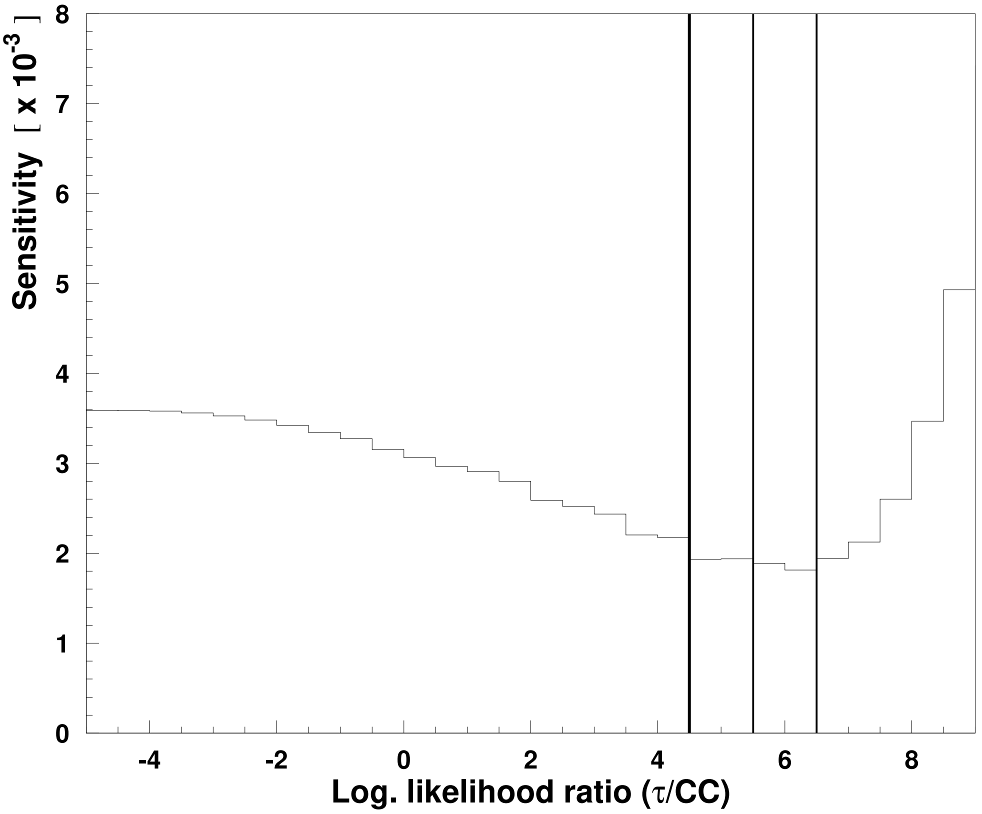




A blind analysis method

Back-Up

- Compute the sensitivity to choose the signal box
  'The sensitivity is defined as the average upper limit one would get from an ensemble of experiments with the expected background and no true signal' , from G.J.Feldman and R.D.Cousins Phys. Rev. D 57 (1998) 3873.
- In order to avoid biases
  $\Longrightarrow$ do not look at the data in the signal box before a full understanding of the sensitivity of the analysis based on MC and Data Simulator



A blind analysis method

Back-Up

- Make sure to be able to predict the background in the signal box $(L(\tau/\nu NC) > 2.5, L(\tau/\nu_e CC) > 4.5)$

Survival fraction from MC					
e^+ sample			e^- sample		
ν_μ CC	ν NC	$\overline{\nu}_e$ CC	ν_μ CC	ν NC	ν_e CC
2.8×10^{-6}	2.1×10^{-6}	3.6×10^{-4}	$< 4 \times 10^{-7}$	$< 1 \times 10^{-6}$	2.3×10^{-4}

Background and efficiencies DS corrected			
ν NC + ν_μ CC bkgrnd	ν_e CC bkgrnd	ϵ_τ	N_τ
$0^{+0.4}$	6.6 ± 0.8	$4.1 \pm 0.3\%$	2904

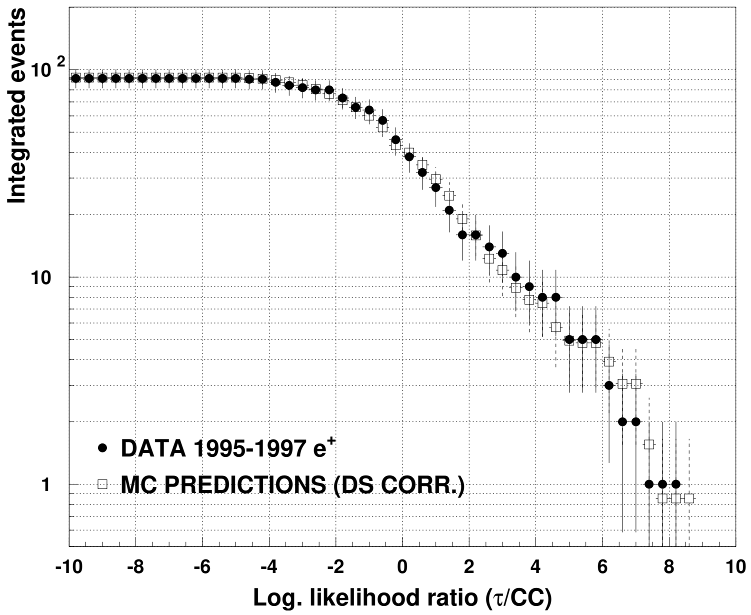
$$N_\tau = N_\mu \times (\sigma_\tau/\sigma_\mu) \times Br \times \epsilon_\tau$$

Monte Carlo vs. DATA

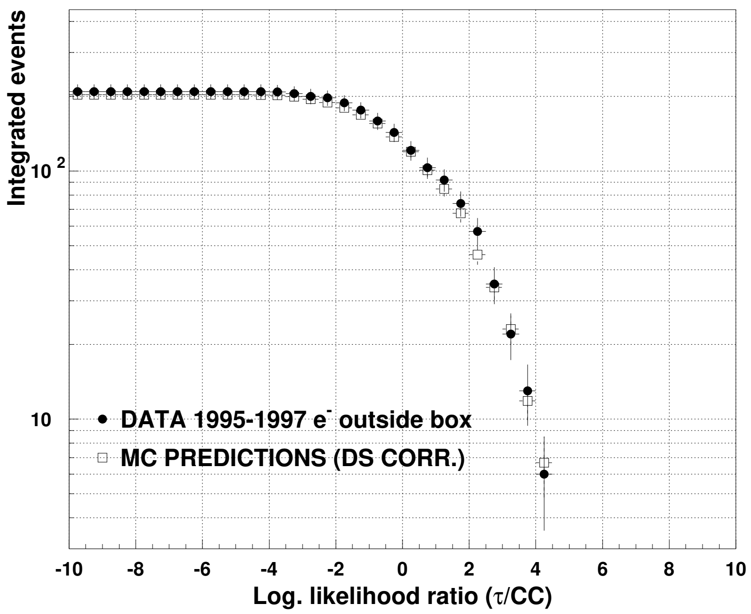
Good agreement

Back-Up

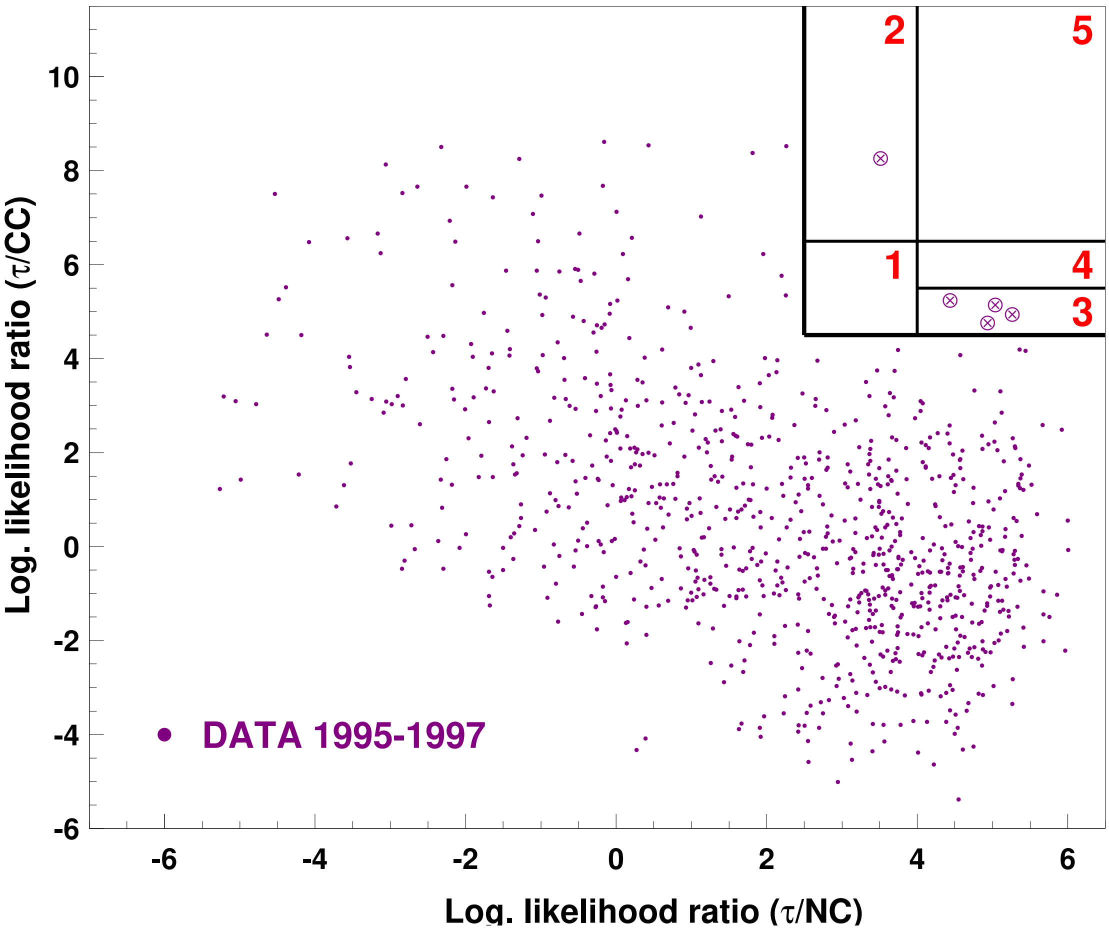
- the τ^+ candidates, where no signal is expected in NOMAD



- the (‘τ^-’) data outside the ‘signal box’



DATA

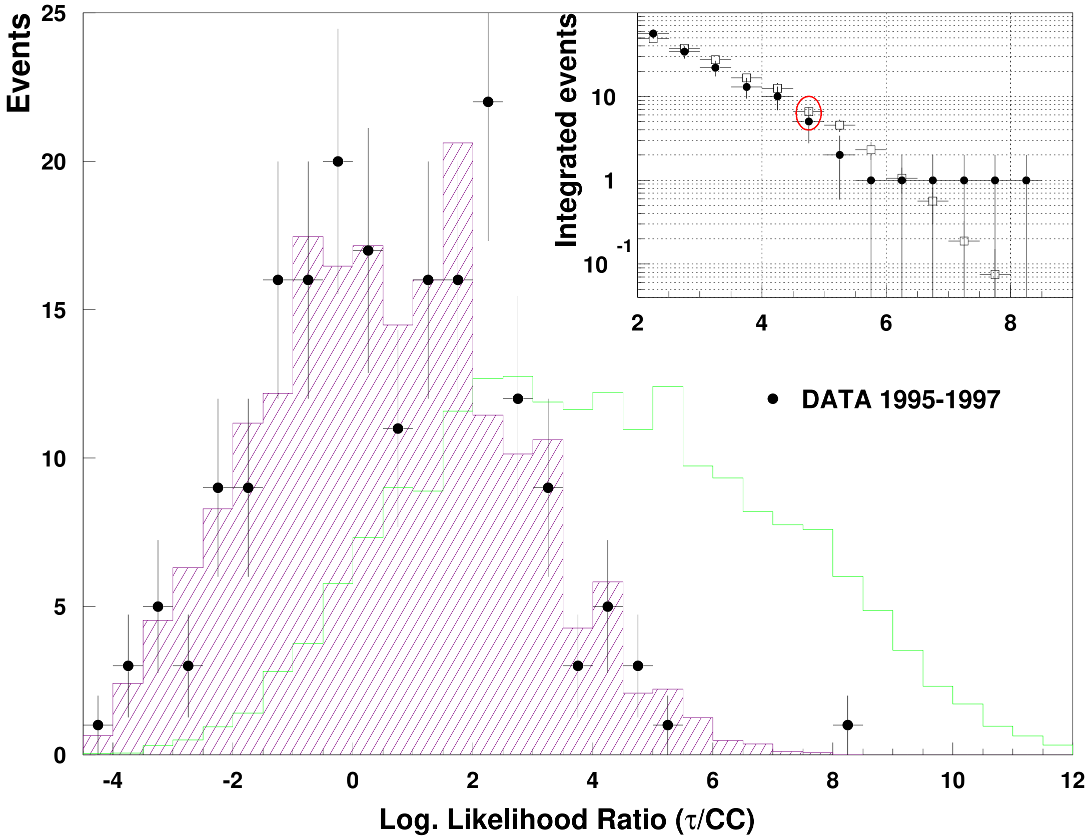


Bin	N_τ	Exp. Bkgnd	Data
1	240	1.52 ± 0.38	0
2	273	0.23 ± 0.16	1
3	646	3.10 ± 0.57	4
4	543	1.31 ± 0.40	0
5	1202	0.46 ± 0.27	0
Tot	2904	6.6 ± 0.8	5

No evidence
for oscillation

LIKELIHOOD - DATA vs. MONTE CARLO

Back-Up

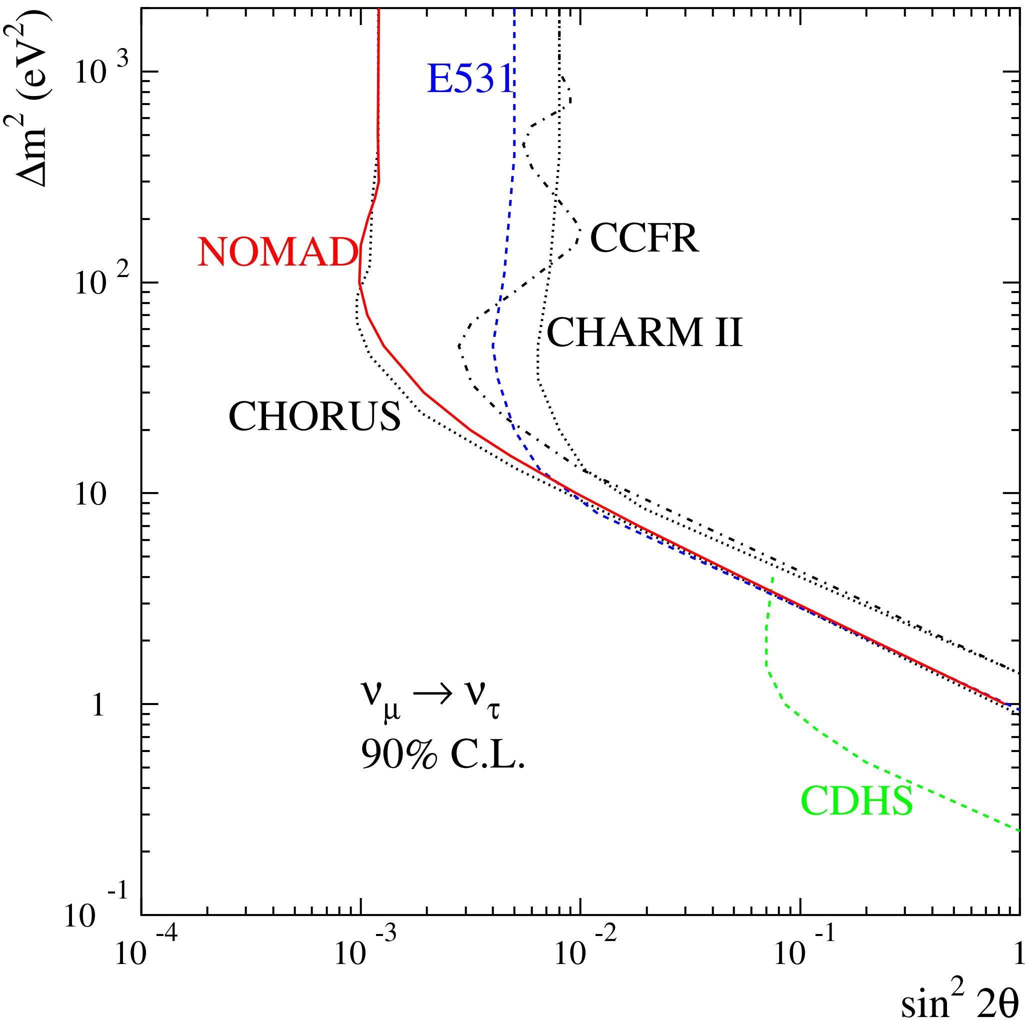


Channel	Data	est. backg.	N_{obs}
$\tau^- \rightarrow e^- \nu_\tau \overline{\nu_e}$ DIS	95-97	6.6 ± 0.8	5

Year	ν_μ CC
95	180,000
96	380,000
97	382,000
98	?
total 95-97	942,000

PRESENT NOMAD RESULTS

$$P(\nu_\mu \to \nu_\tau) < 0.6 \times 10^{-3}$$



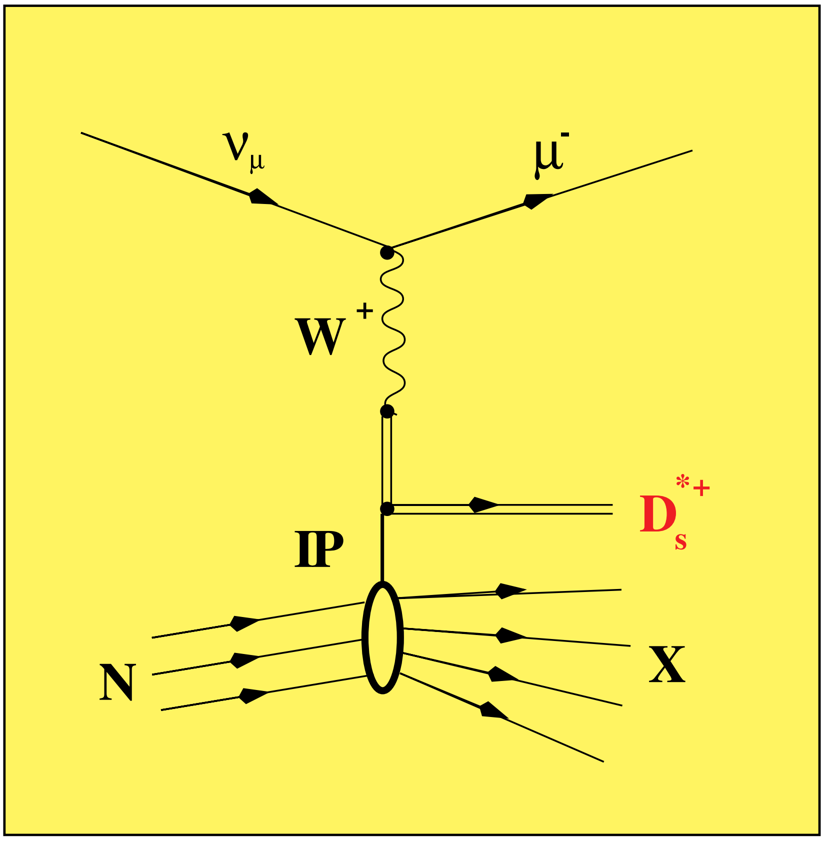
Results based on 942,000 ν_μCC (95-97 data)

All channels are included

Data taking has been completed in 1998

and we expect additional $\simeq$ 300,000 ν_μCC

DIFFRACTIVE PHYSICS



$$D_s^{*+} \to D_s^+ \gamma$$

$$D_s^+ \to \tau^+ \nu_\tau$$

VERY PRELIMINARY !

PHYSICS MOTIVATION

Measure the production rate of $D_s^{(*)}$

PRESENT KNOWLEDGE

total of 6 events in 57,000 ν CC and 52,000 $\bar{\nu}$ CC interactions (bubble chambers)

- **2 events in WA59**
- **3 events in WA21**
- **1 event in E180**

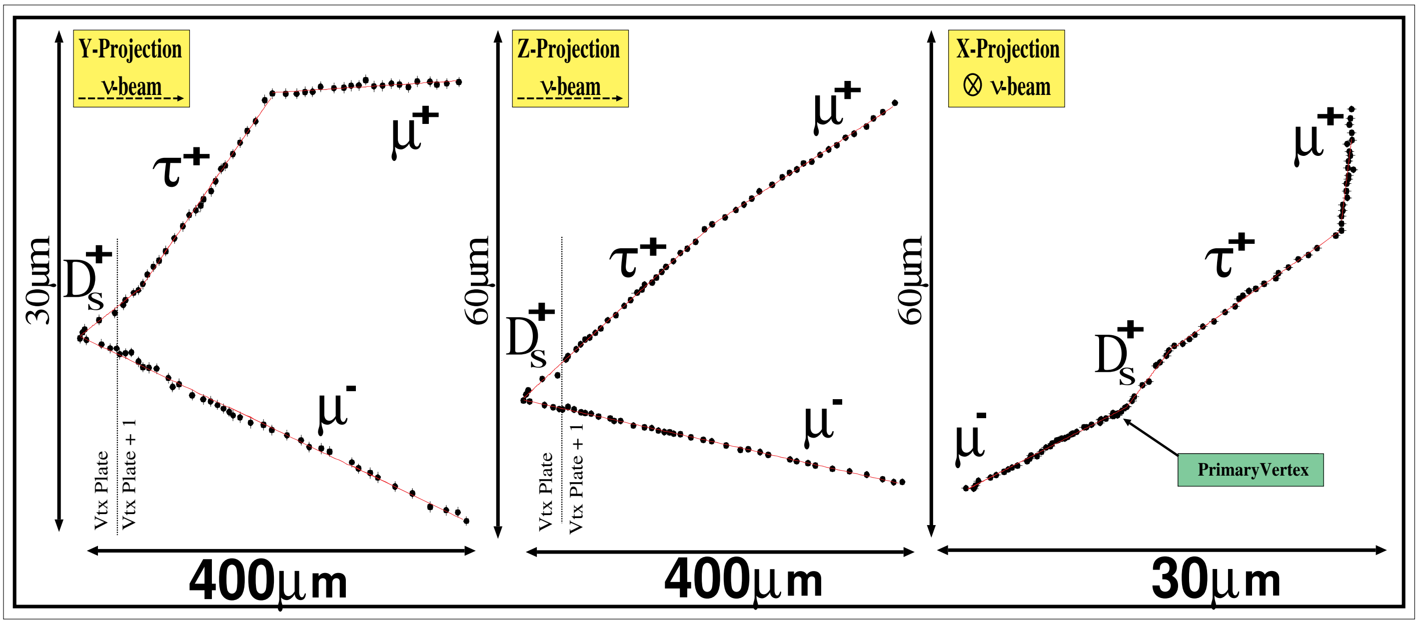
84,000 ν CC (nuclear emulsion)

- **1 event in CHORUS**

A CANDIDATE IN CHORUS ?

Back-Up

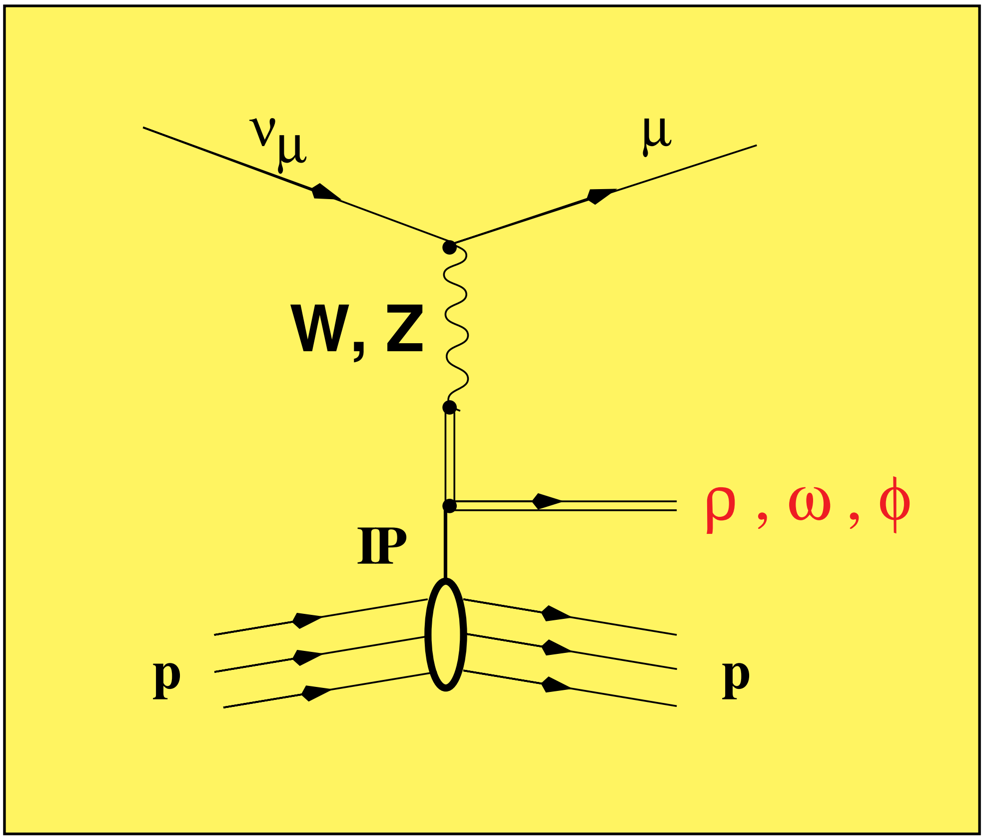
Out of 84,000 ν_μ CC interactions



WEAK DECAYS

Back-Up

$$\nu p \to \mu^- p \rho^+$$
$$\nu p \to \mu^- p \rho^0$$



To transfer the knowledge from electromagnetic to weak decays...

Vector Meson Dominance

$$|W > or |Z >= | >_{bare} + | >_{vector,axialvector} + \ldots$$

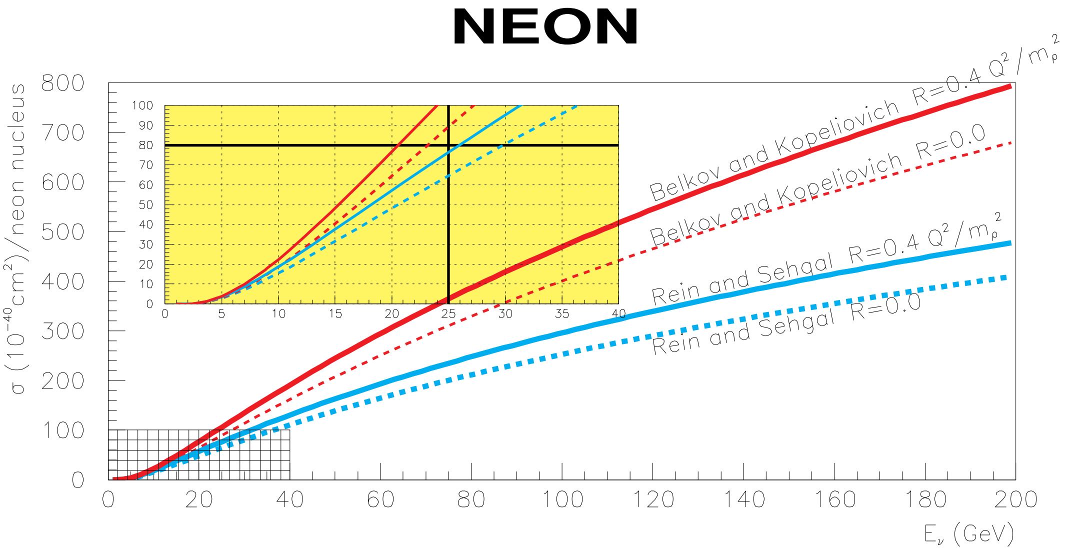
Piketty and Stodolosky used CVC to obtain cross sections

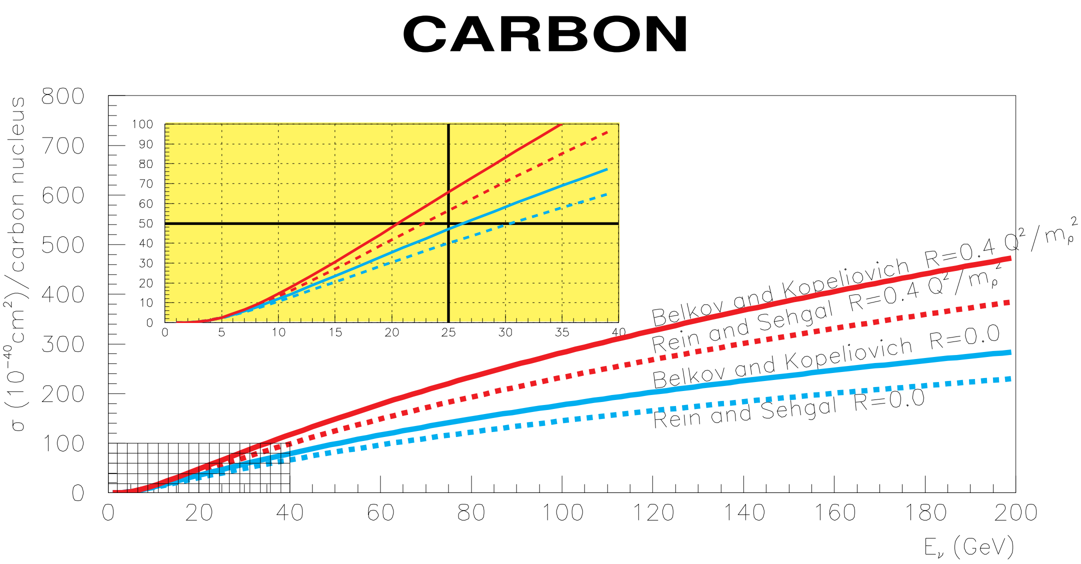
Can we extrapolate up to $D_s^{(*)}$ masses ?

CROSS SECTION

Back-Up

Use model from ρ and π diffractive production. Models differ on the nuclear form factor (absorption effects)



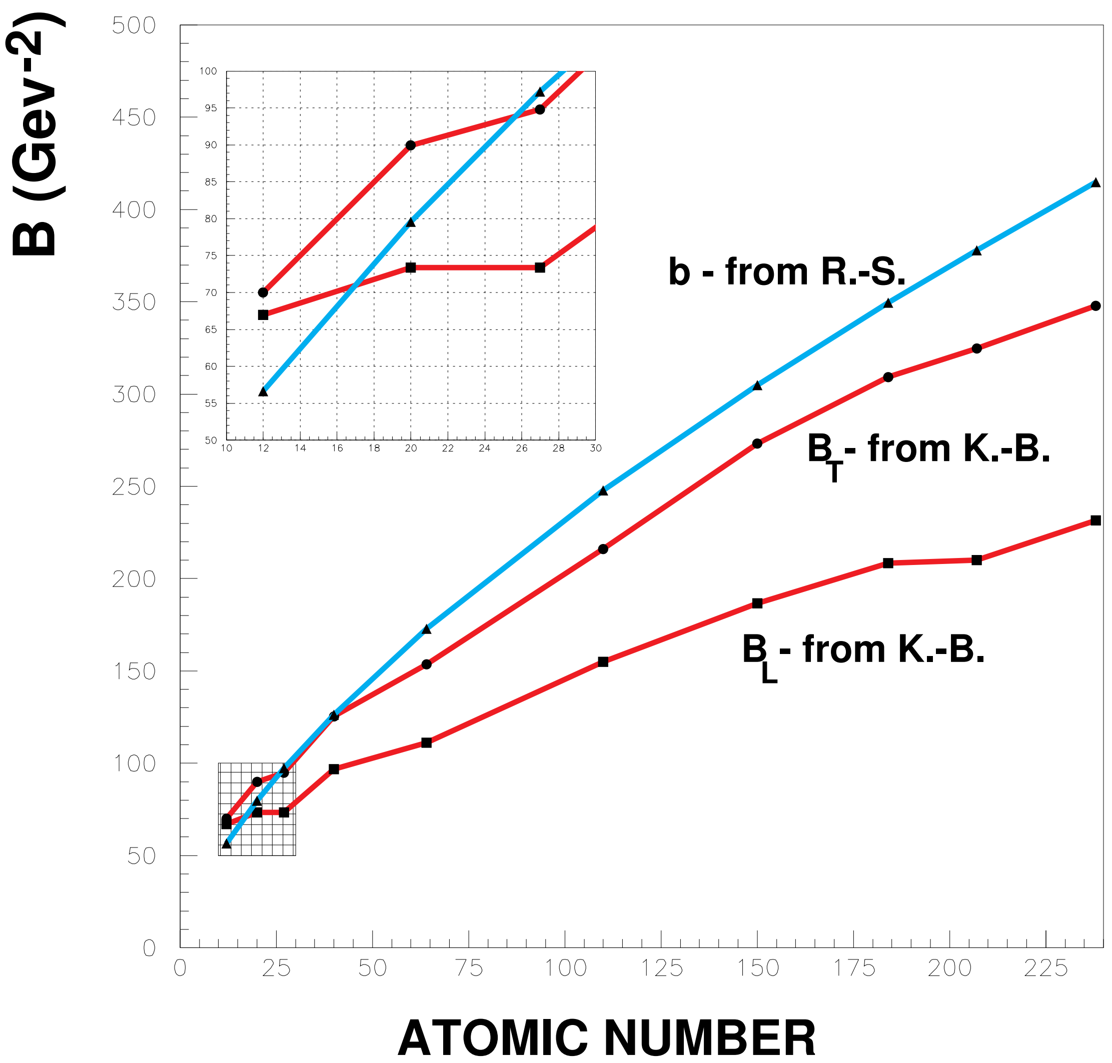


The target in NOMAD is mostly CARBON, so we need to scale down the cross section obtained from previous measurements

CROSS SECTION

Back-Up

It is not clear what is the dependance on the momentum transfer is



$$t_{min} = t_{min}(Q^2, M_V, \nu)$$

DECAY CHANNELS

$D_s^* \rightarrow D_s\gamma$ (94.20 ± 2.50) %

Leptonic channels

Decay	Branching ratio
$D_s \rightarrow \tau\nu_\tau$	(7 ± 4) %
$\tau \rightarrow \mu\nu_\mu\nu_\tau$	(17.37 ± 0.09) %
$\tau \rightarrow e\nu_e\nu_\tau$	(17.81 ± 0.07) %

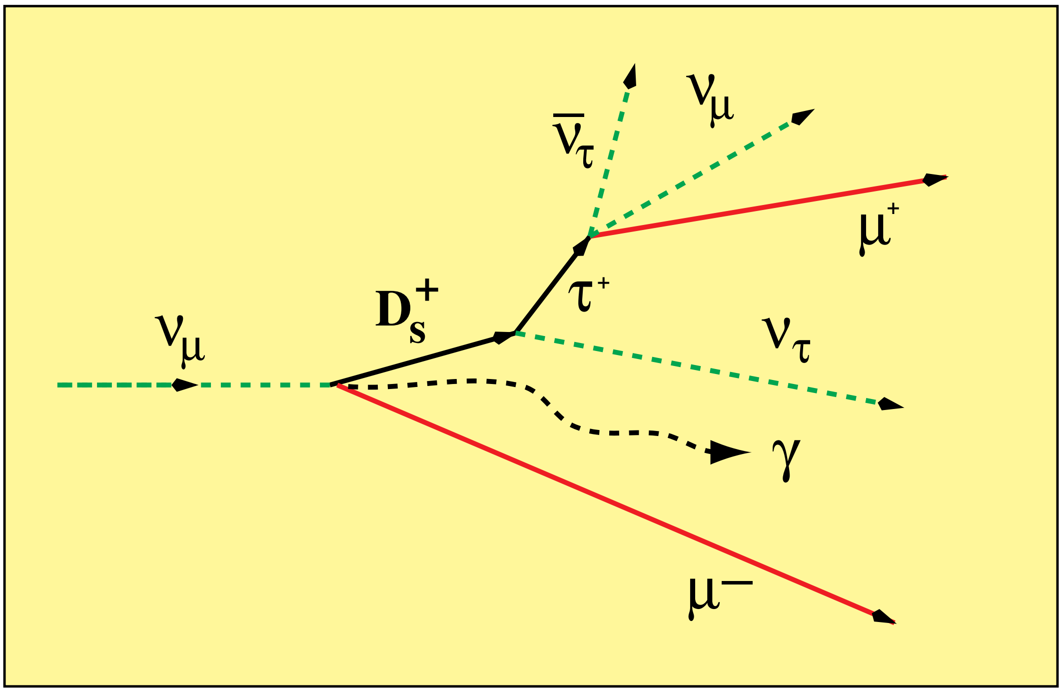
Hadronic channel (our normalization)

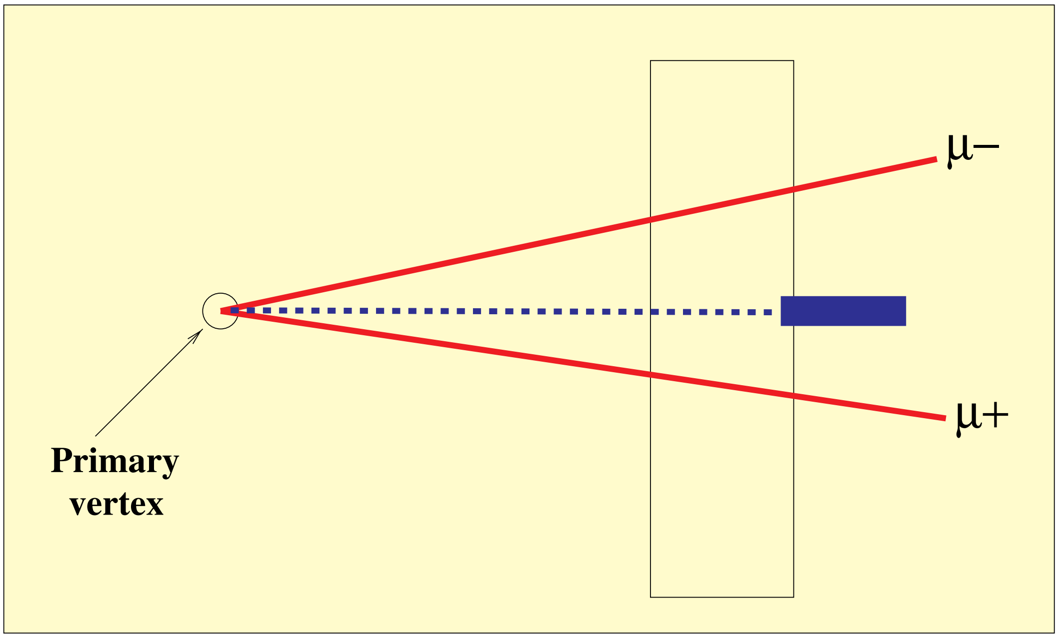
Decay	Branching ratio
$D_s \rightarrow \phi\pi$	(3.6 ± 0.9) %
$D_s \rightarrow \eta\pi$	(2.0 ± 0.6) %

- **836389 ν_μ CC events selected in our data**
- **D_s diffractive production = 2.8 $\times$ 10^{-3}/CC**

Expect $\simeq$ 10 events (assuming $\epsilon \simeq 10\%$)

TOPOLOGY





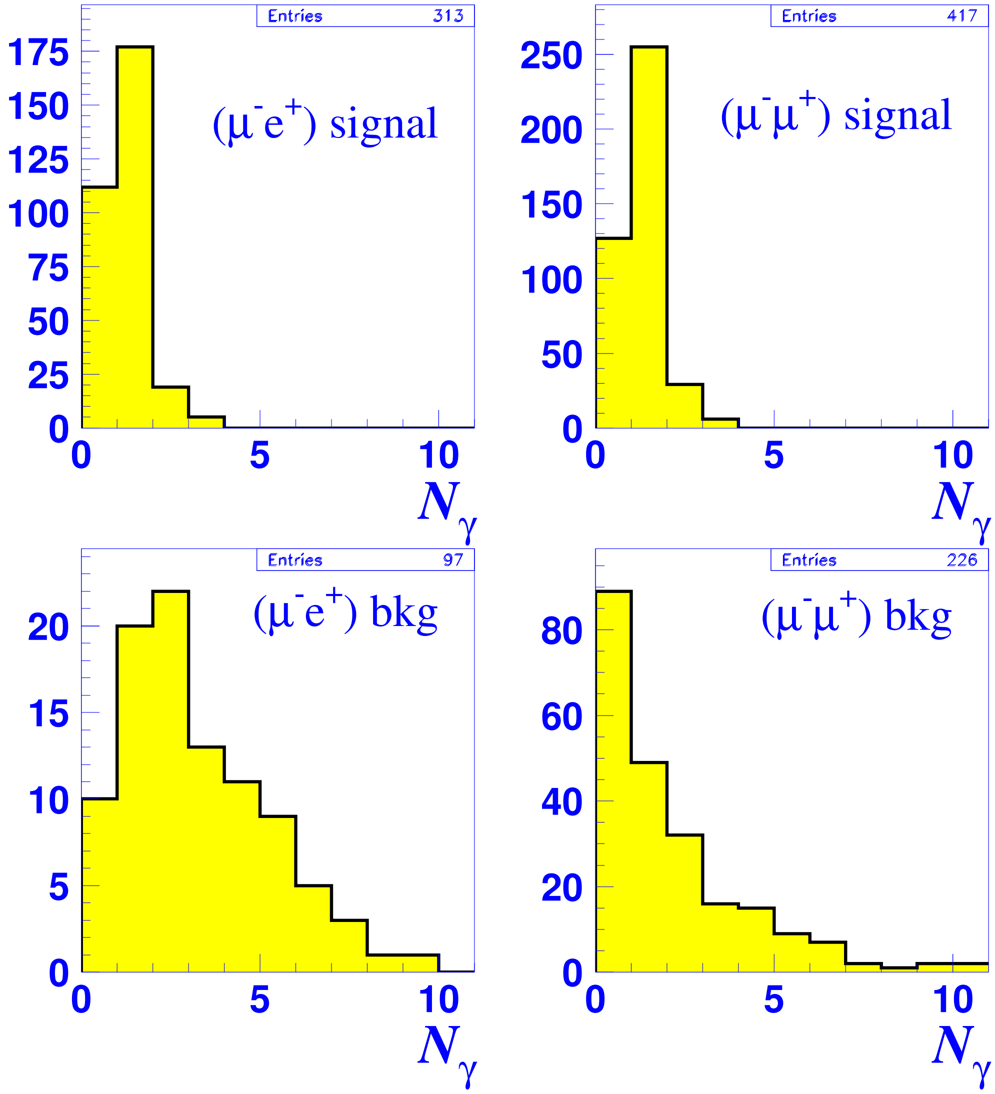
- Primary tracks: Within a box of ± 5 cm in x and y, and ± 15 cm in z of the primary vertex. These tracks are further required to have at least 100 MeV of momentum and 7 hits to be included.
- Photon candidates: All ECAL clusters of at least 100 MeV which are not associated to tracks.

Monte Carlo Background

- **Charm decays: track multiplicity cut**
- **For ($\mu^-\mu^+$): decays in flight of π (65%)**
  decays in flight of K (18%)
- **For (μ^-e^+): uncertanties in bremsstrahlung algorithm (under investigation).**

NUMBER OF PHOTONS

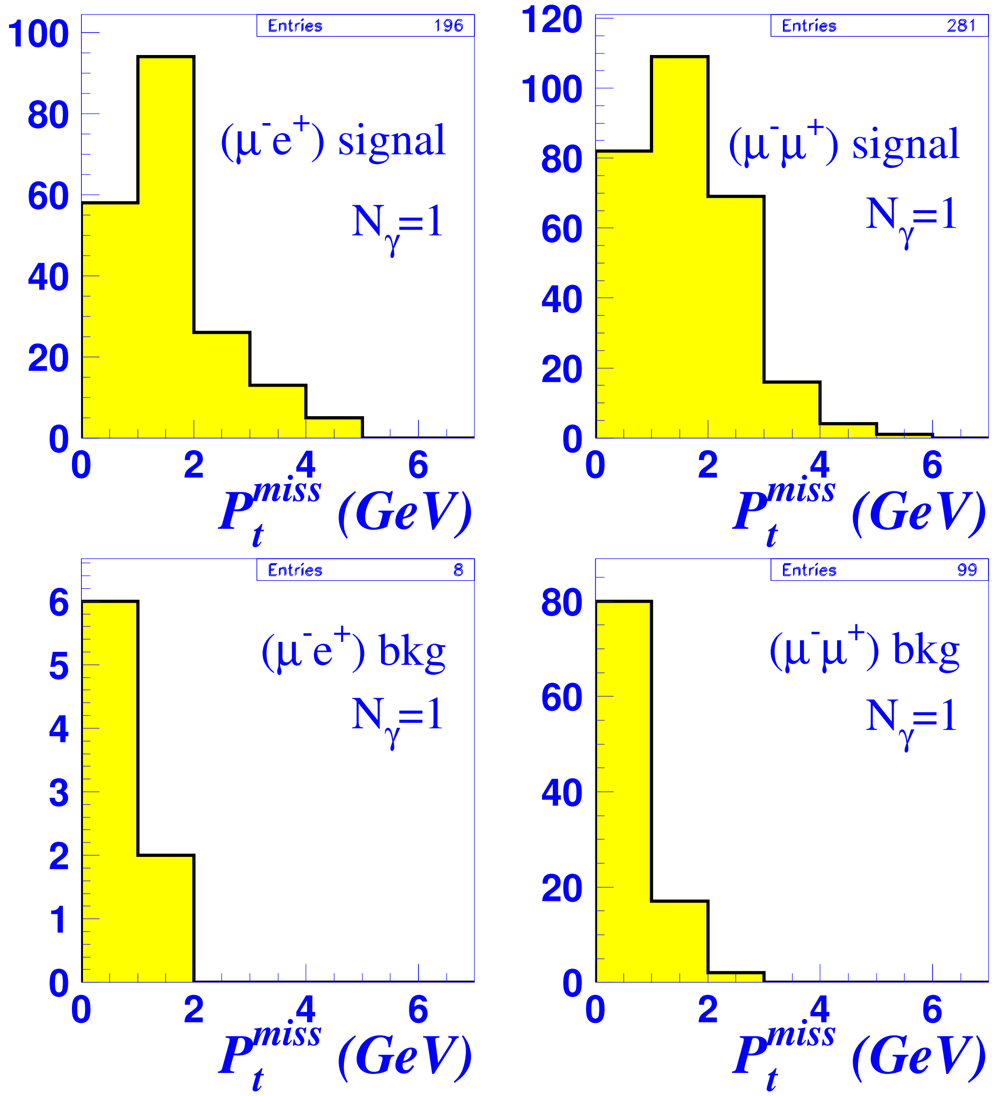
Monte Carlo



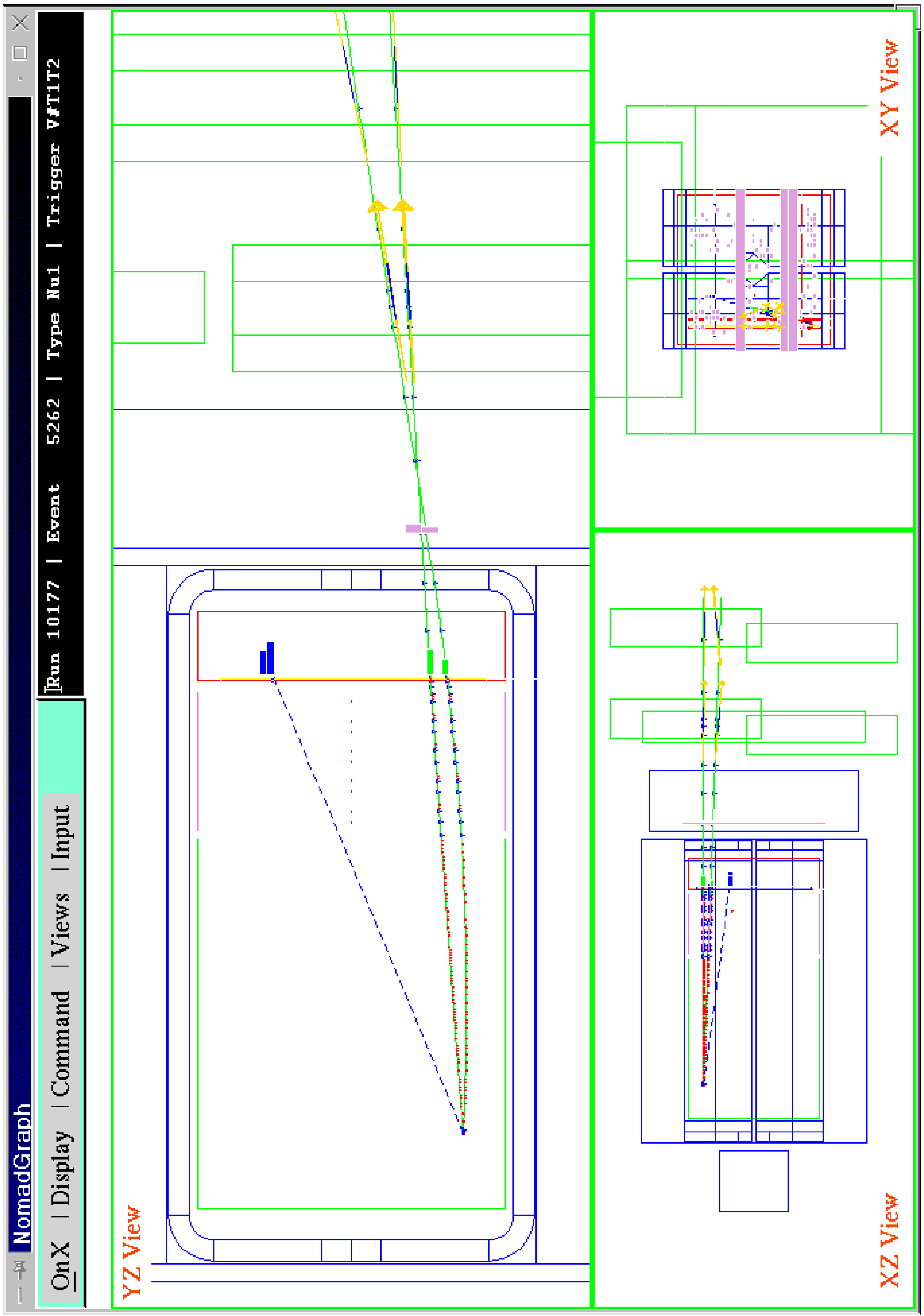
therefore we require only one γ per event ...

Missing Momentum

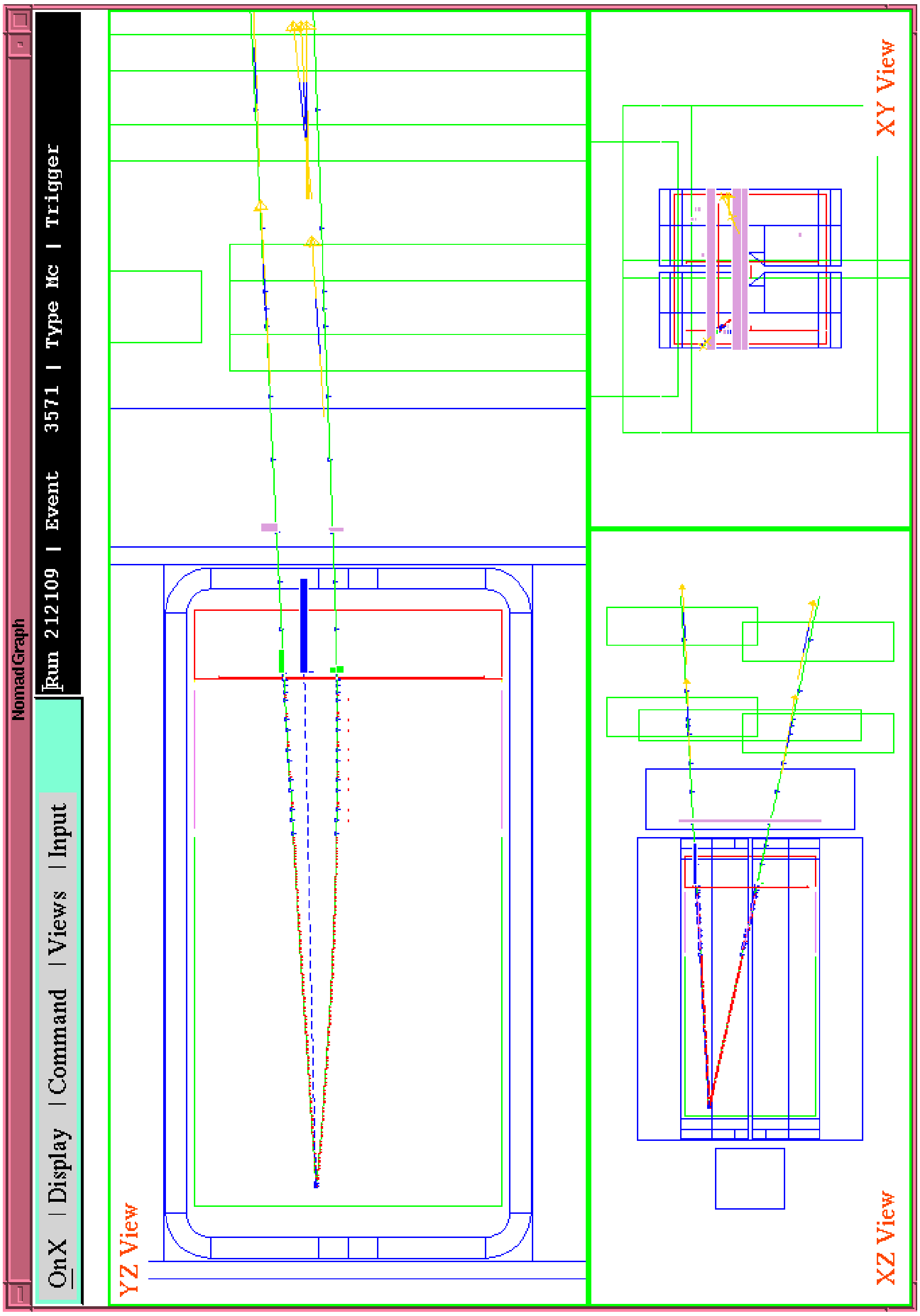
Monte Carlo



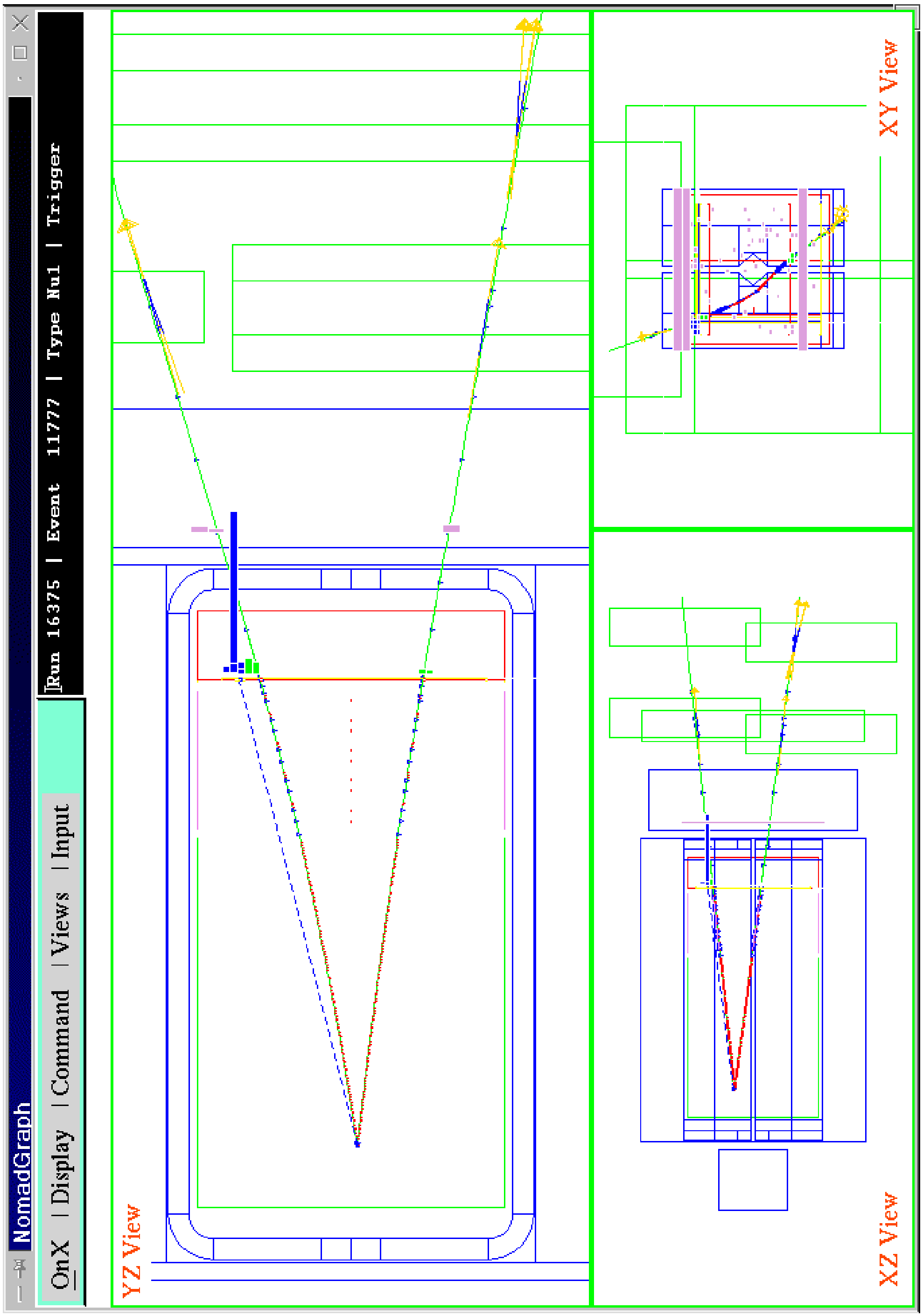
DATA - PRELIMINARY



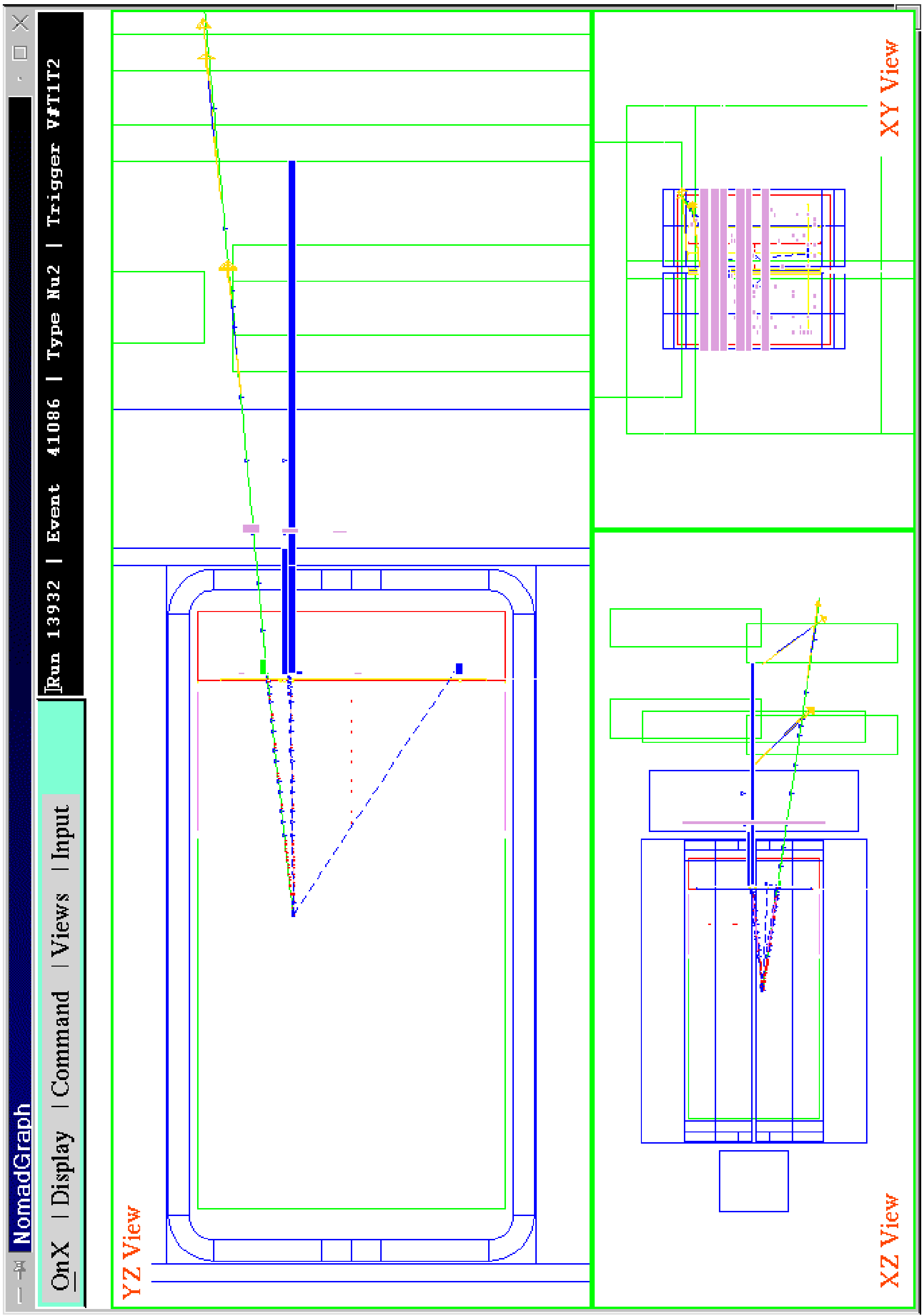
MC - BACKGROUND



DATA - PRELIMINARY



DATA - PRELIMINARY



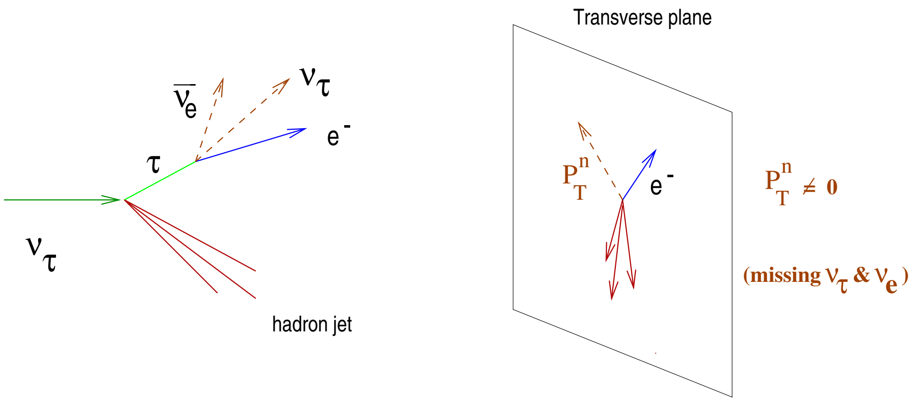
A NEXT STEP OF

Short-Base-Line (SBL) EXPERIMENTS

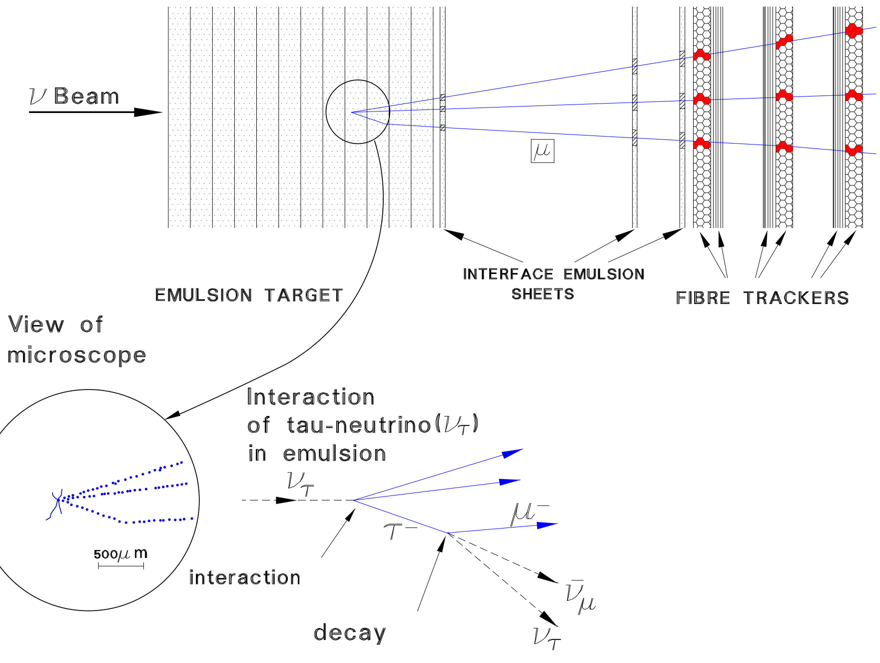
- Study neutrino oscillations & standard physics (e.g. charm search)
- Aim to improve the sensitivities of current experiments
- Search for the τ signature using both kinematical and vertex criteria simultaneously
- Detector requirements:
  - Compact detector with very high acceptance
  - Good kinematics capability
  - Very good μ and e identifications
  - Vertex information

PRESENT SBL EXPERIMENTS

Kinematics criteria - NOMAD



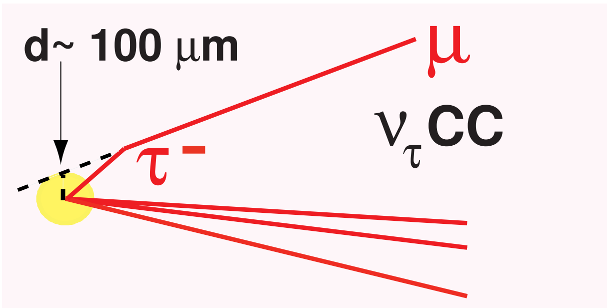
Vertex criteria - CHORUS

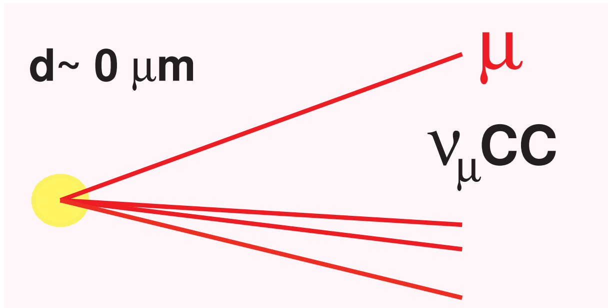


NEW IDEAS, NEW TECHNIQUES

- **Two different techniques based on vertex (CHORUS) and kinemematic (NOMAD) selection criteria exists**
- **Is it possible to combine them?**
- **Let us try SILICON**

WHY SILICON DETECTORS ?





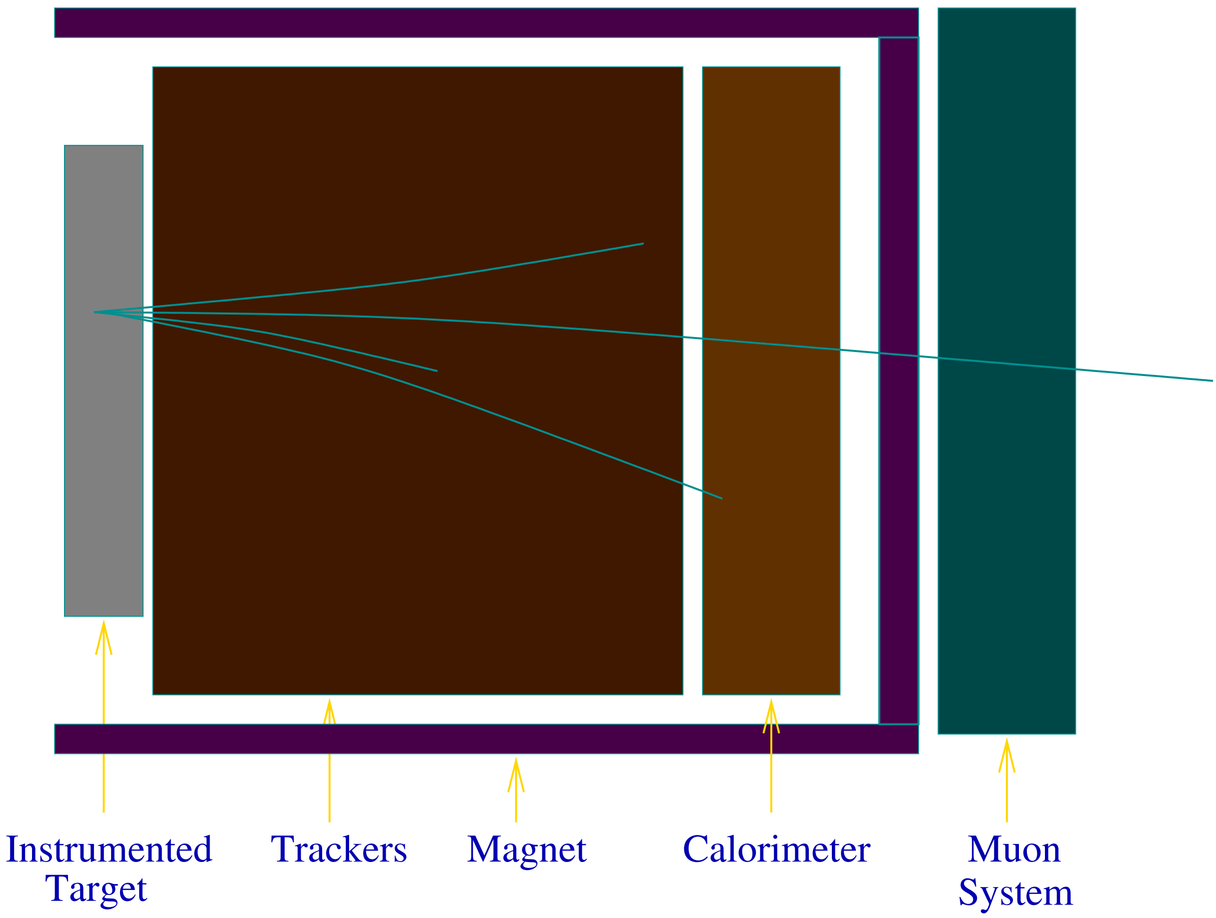
- **Spatial resolution of a few microns**
- **It is a "mature" technology**
- **Reliability**

Two possibilities:

- Passive material & Silicon
- Nuclear emulsion & Silicon

NAUSICAA (Simplest design)

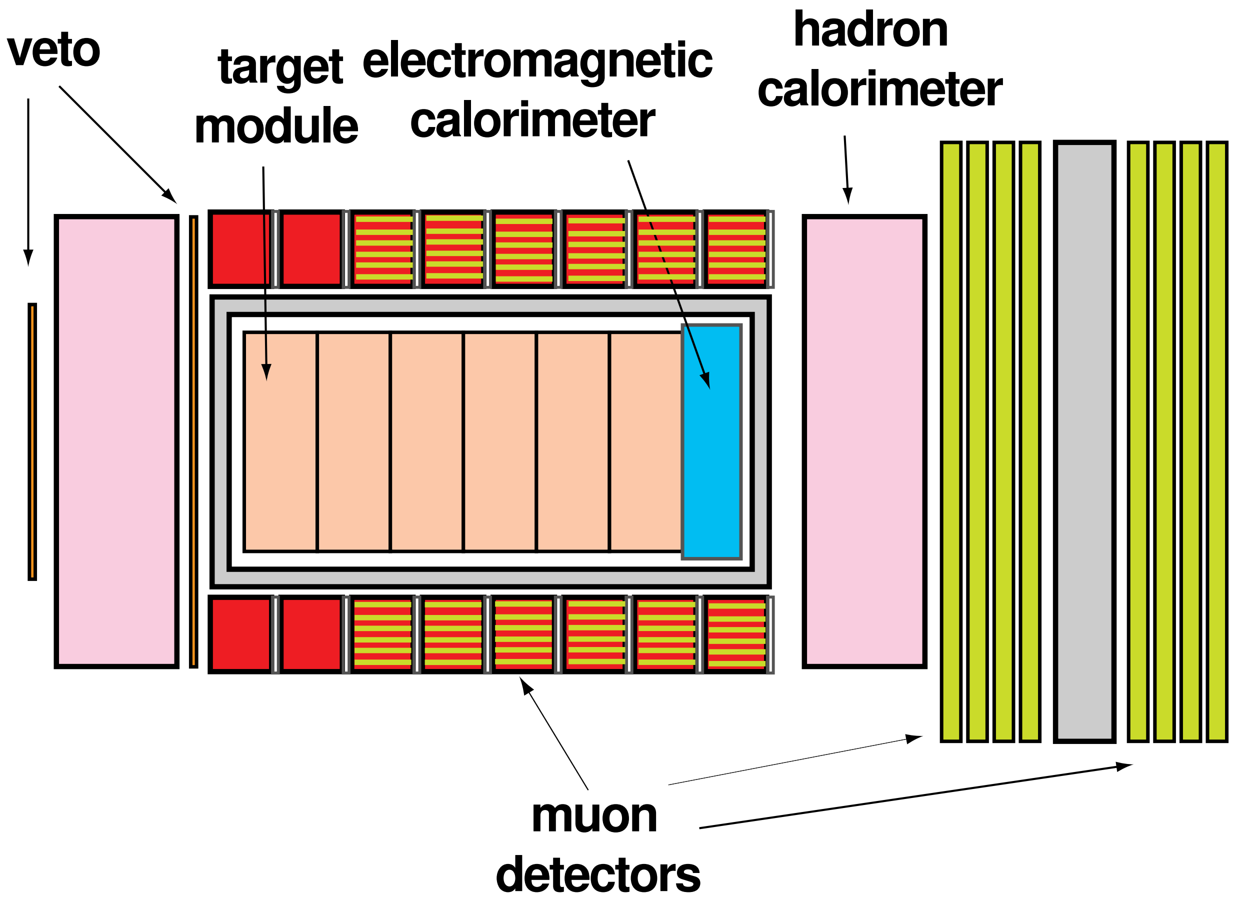
Back-Up



- **Two possibilities:**
  - **Passive material & Silicon**
  - **Nuclear emulsion & Silicon**
- **Modular construction**
- **Could take data at ν_μ beam**

TOSCA DETECTOR

Back-Up

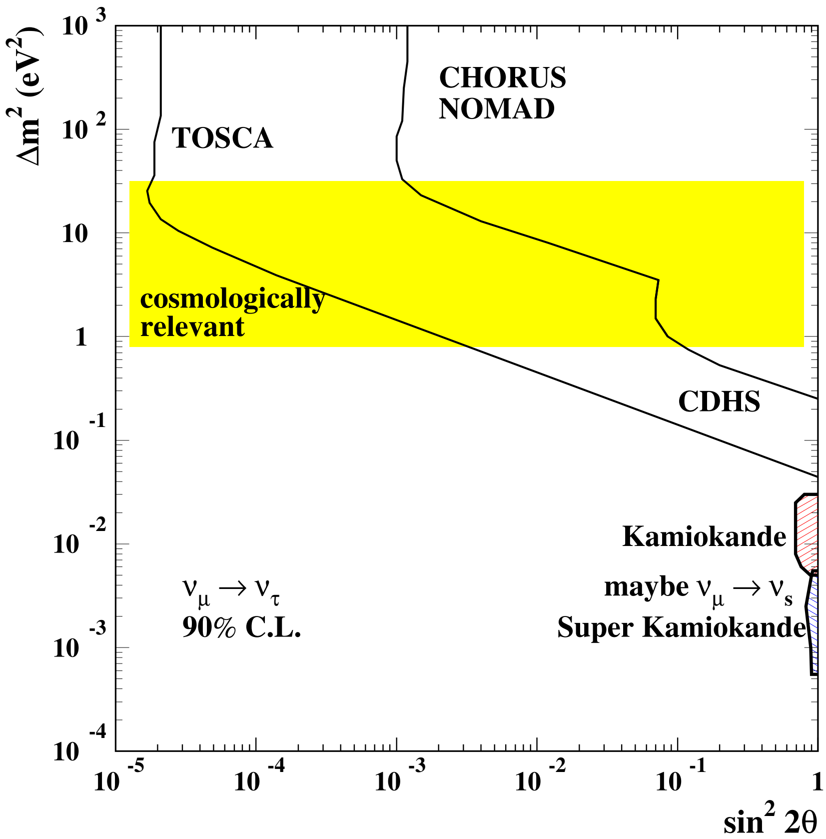


- Hybrid detector combining emulsions and silicon
- 2400 kg of emulsion target
- Measuremnt of "kink" topologies and kinematical variables
- Optimized for neutrino oscillations
- But: heavy scanning

A. S. Ayan et al., CERN/SPSC/97-5.

$\nu_\mu \rightsquigarrow \nu_\tau$ oscillations search with TOSCA detector (Topological Oscillation Search with kinematiCal Analysis)

Back-Up

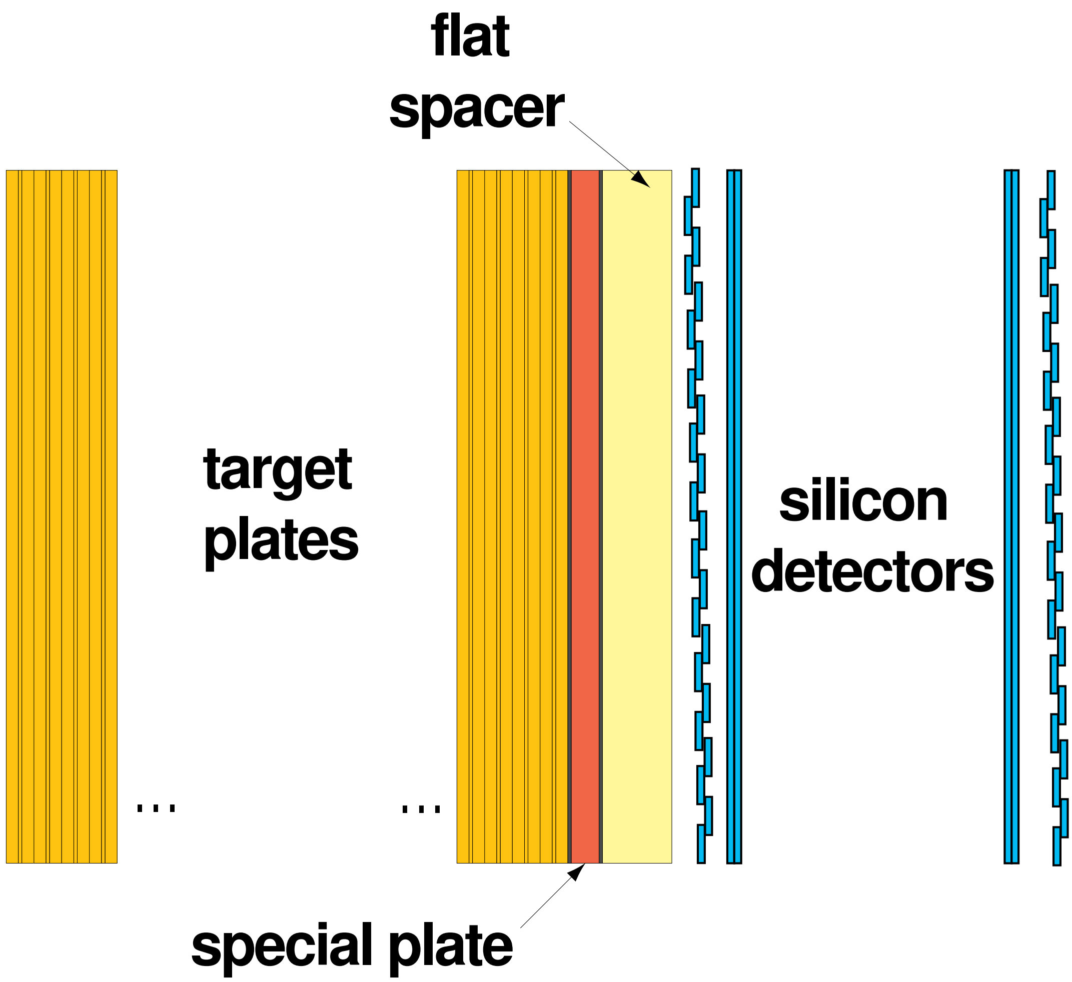


WHY TOSCA ?

- **Hot Dark Matter region shifted from 100 eV to $\simeq$ 1 eV**
- **Superkamiokande can not tell whether their signal is from $\nu_\mu \rightarrow \nu_\tau$ or $\nu_\mu \rightarrow \nu_s$**
- **If TOSCA sees a signal, then Superkamiokande has to be $\nu_\mu \rightarrow \nu_s$**

TOSCA TARGET

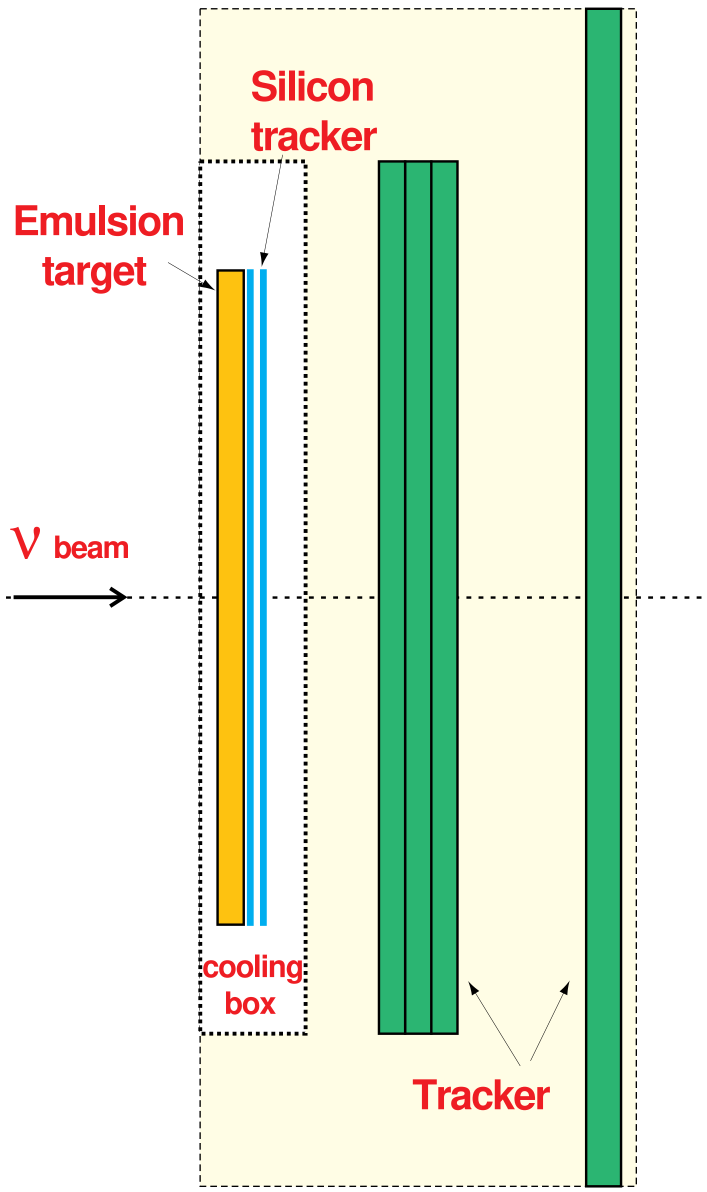
Back-Up



- Special emulsion plate provides **high angular resolution**
- **Precise prediction** of the exit point in the emulsion.
- A factor of 100 **reduction** (w.r.t. CHORUS) in the **area to be scanned**

TOSCA MODULE

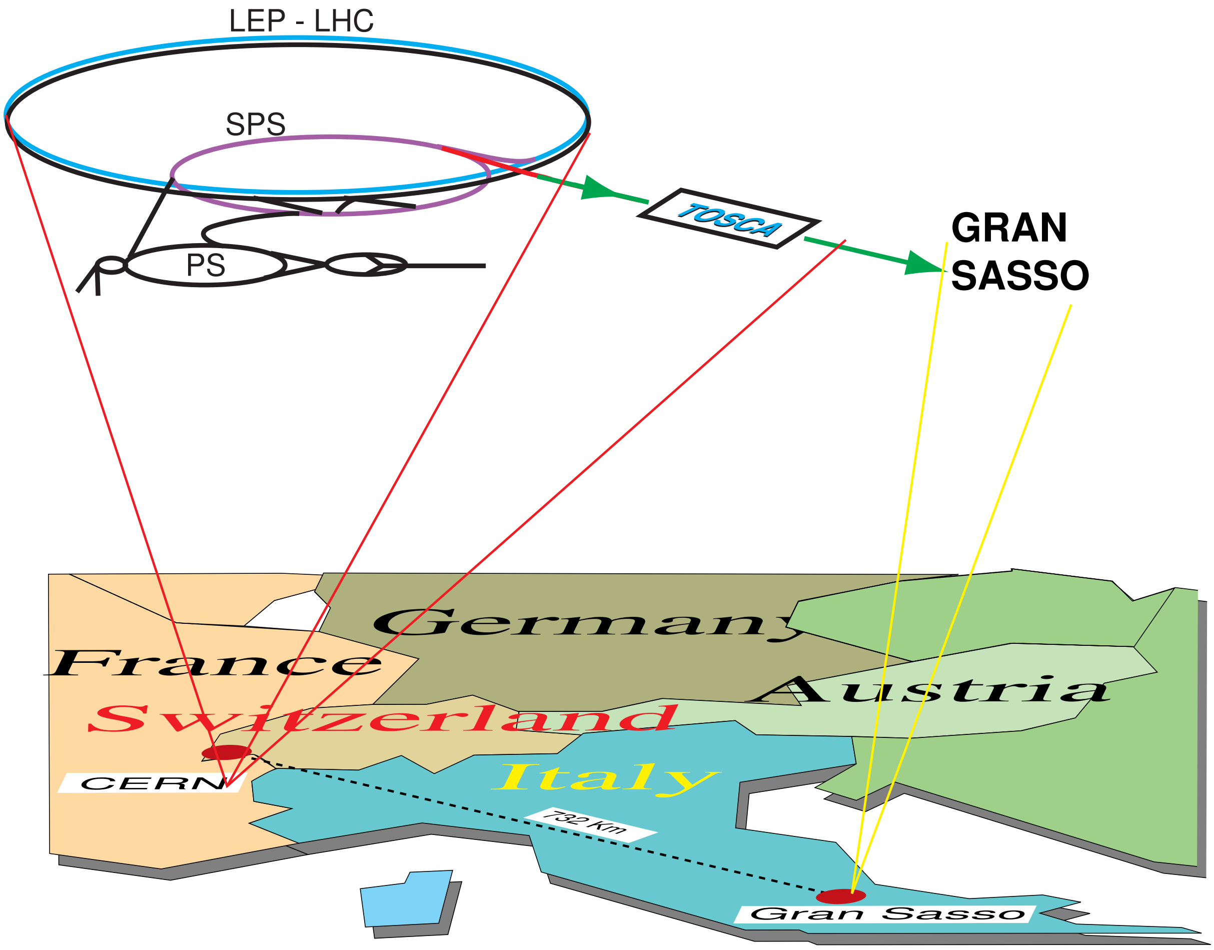
Back-Up



- 1 module = active mass of 400 Kg
- 1 module = emulsion target, silicon trackers, tracker
- Total number of modules is 6.

Back-Up

CERN TO GRAN SASSO NEUTRINO BEAM



$L \simeq 1858$ m (Target$-$TOSCA distance)

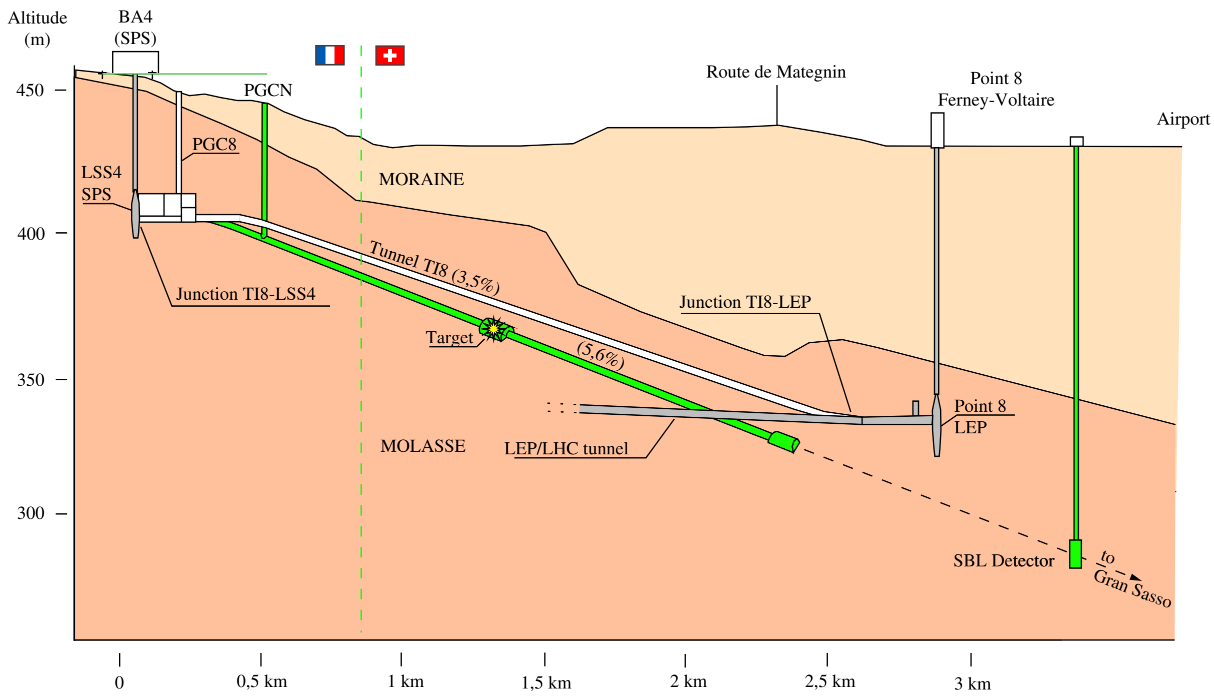
400 GeV proton beam

10 μs spills

3.0×10^{19}/pot/year

Back-Up

CERN TO GRAN SASSO NEUTRINO BEAM



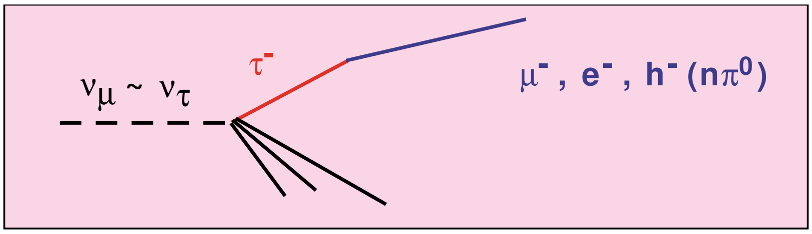
Neutrino	Relative composition
ν_μ	1.00
$\bar{\nu}_\mu$	0.02
ν_e	0.009
$\bar{\nu}_e$	0.0007
ν_τ	0.7×10^{-6}

$$< E_\nu > = 24.1 \text{ GeV}$$

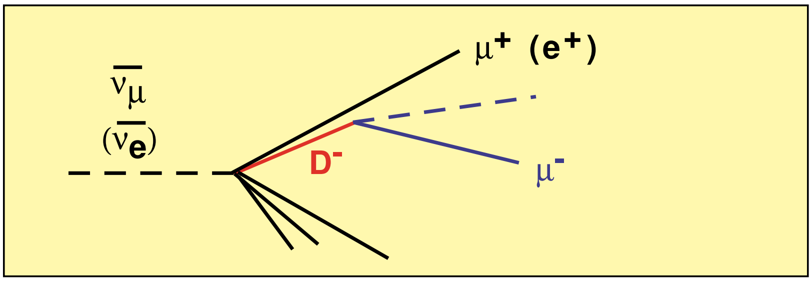
DECAY CHANNELS

Back-Up

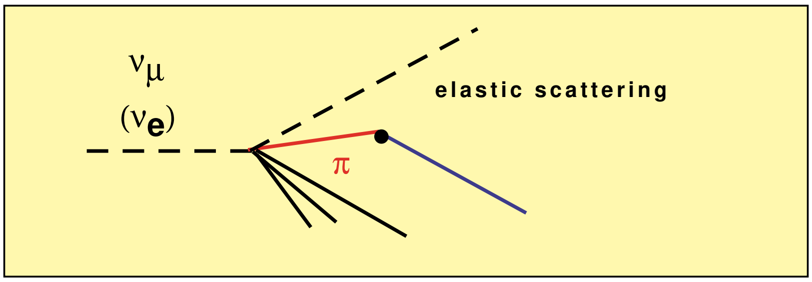
SIGNAL



CHARM BACKGROUND



WHITE KINK



and...

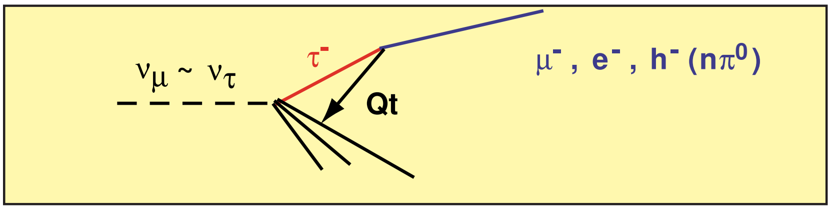
prompt ν_τ from the beam

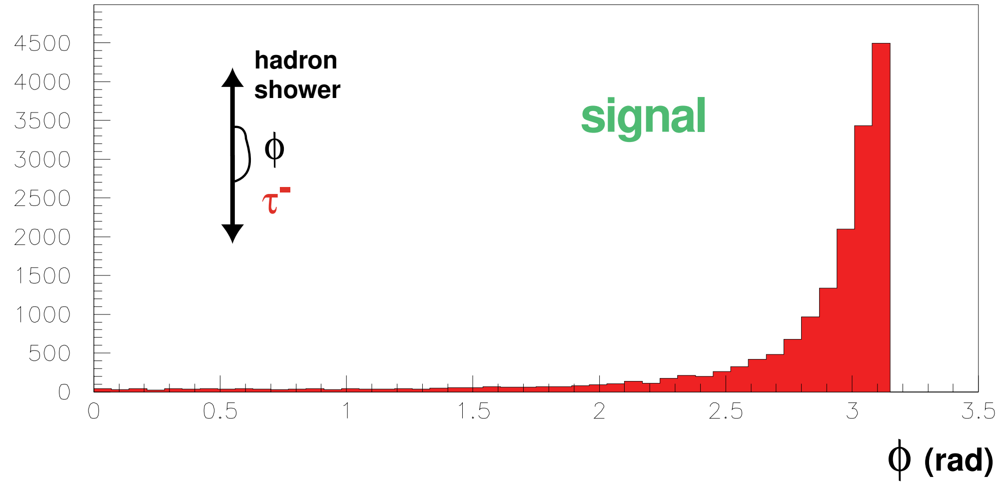
τ decay channel	BR (%)	Oscillation Sensitivity
$e\,\bar{\nu}_e\,\nu_\tau$	~ 18	0.026
$\mu\,\bar{\nu}_\mu\,\nu_\tau$	~ 18	0.006
$\pi^-\,\nu_\tau$	~ 12	0.038
Total	~ 48	0.070

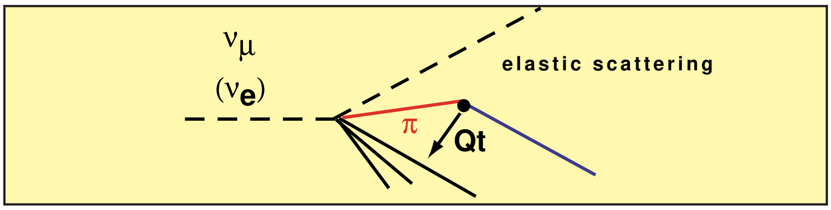
Only 1 prong decays are shown

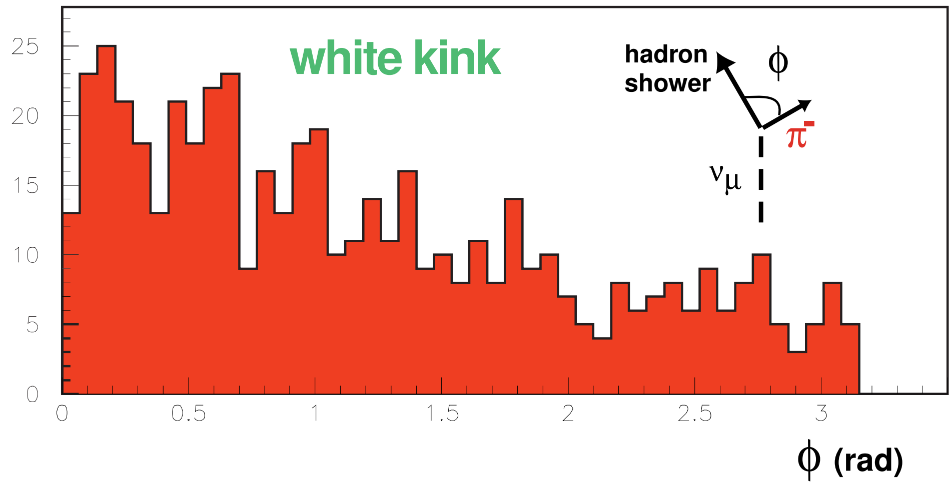
WHITE KINK

Back-Up









Charm supression can be achieved by a Q_t cut (transverse momentum of the shower w.r.t. to the kink parent) and the angle of the candidate w.r.t. to the beam.

SOME NUMBERS...

Back-Up

Efficiencies

EFFICIENCY	CHORUS	TOSCA	REASON
μ^- identification	0.65	0.90	better coverage
scanning	0.45	0.75	silicon & less edge effects
kink finding	0.61	0.75	less edge effects
kinematic cuts	-	0.70	-
Total	0.18	0.35	-

Backgrounds (WANF)

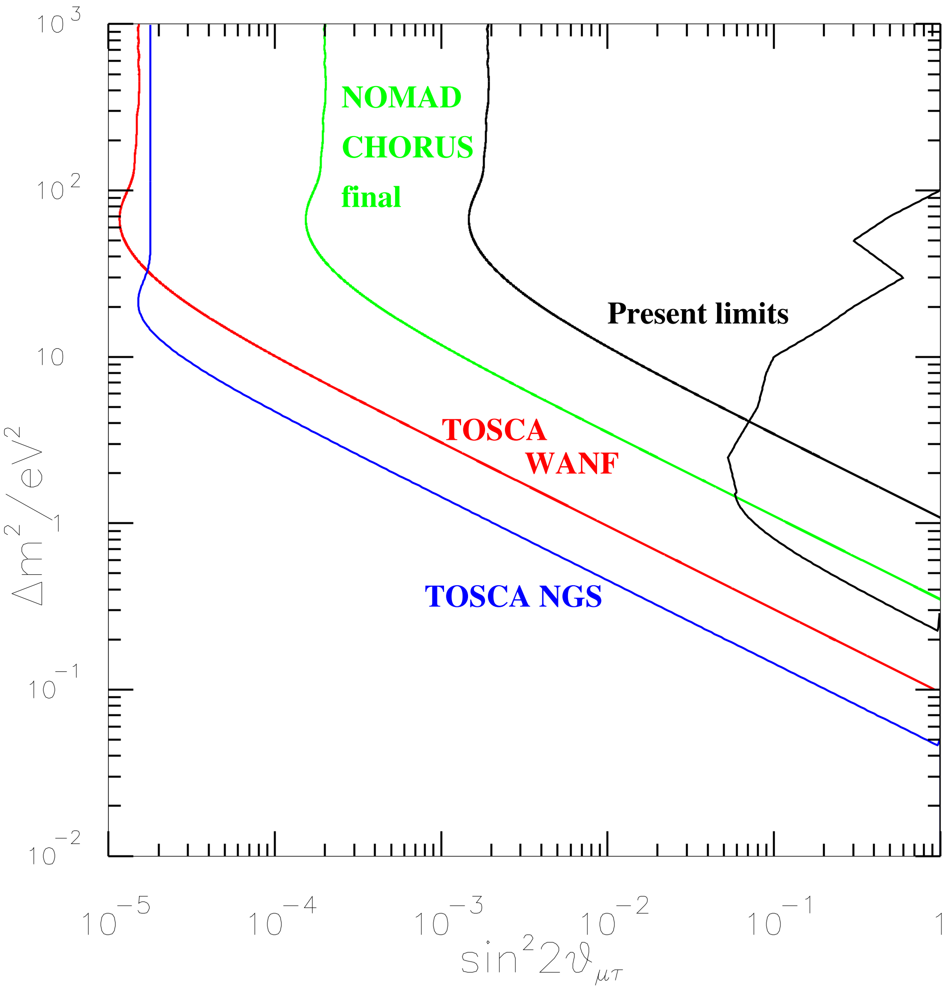
3 year run: 1.3×10^{20} p.o.t. $\simeq 6\times 10^{6}$ ν_μ CC events

τ DECAY MODE	CHARM	WHITE KINK	PROMPT ν_τ	TOTAL
μ	0.08	-	0.29	0.37
e	0.02	-	0.07	0.09
$h(n\pi^0)$	0.11	0.38	0.36	0.85

0.37 + 0.09 + 0.85 = 1.3 background events

Back-Up

TOSCA SENSITIVITY



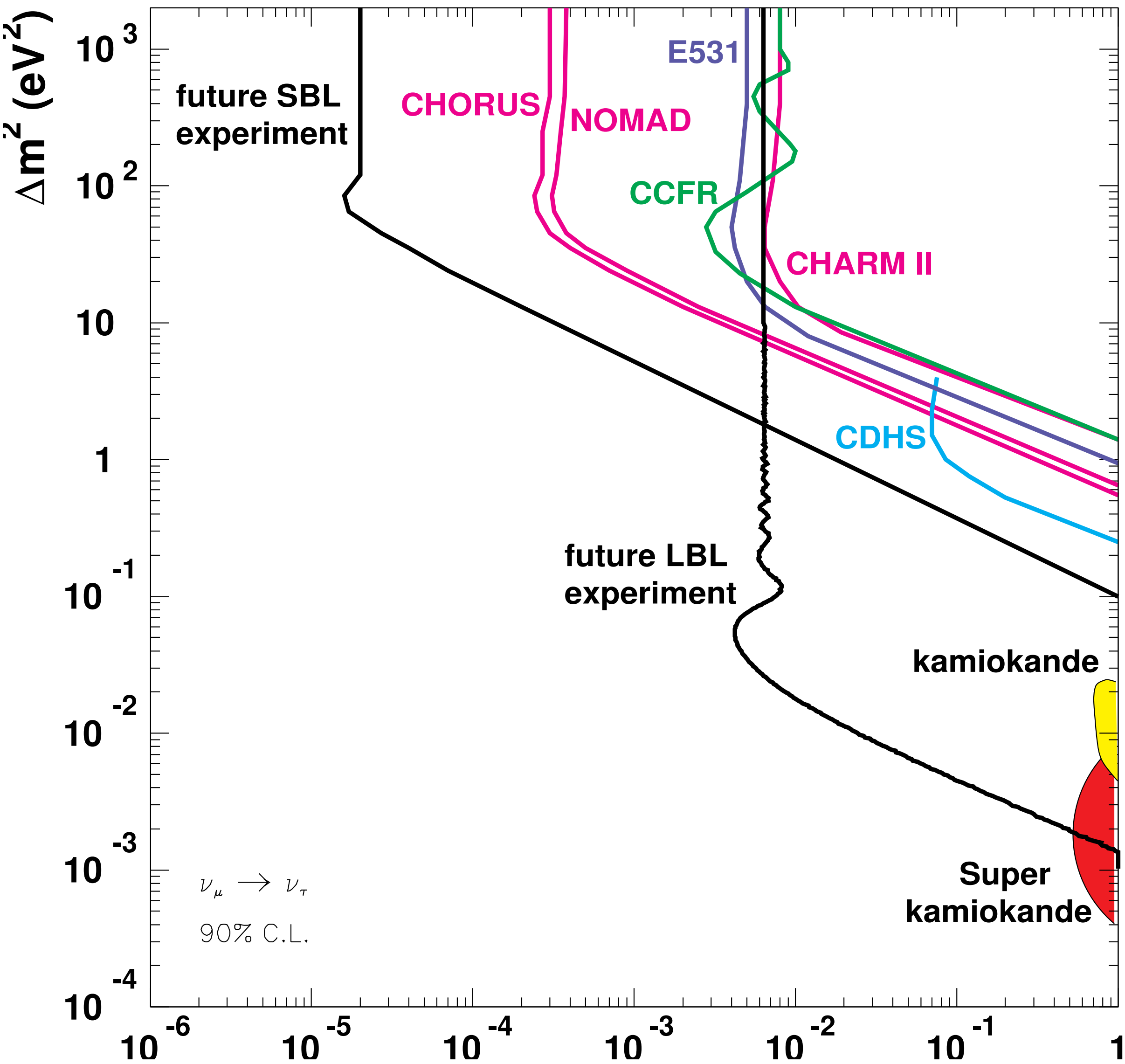
90% C.L. limits

	WANF	NGS
$\sin^2 2\theta$ (high Δm^2)	1.5×10^{-5}	2.5×10^{-5}
Δm^2 ($\sin^2 2\theta$=1)	0.1 eV^2	0.04 eV^2

WANF : $\simeq$ 1.3 background events

NGS : $\simeq$ 0.7 background events

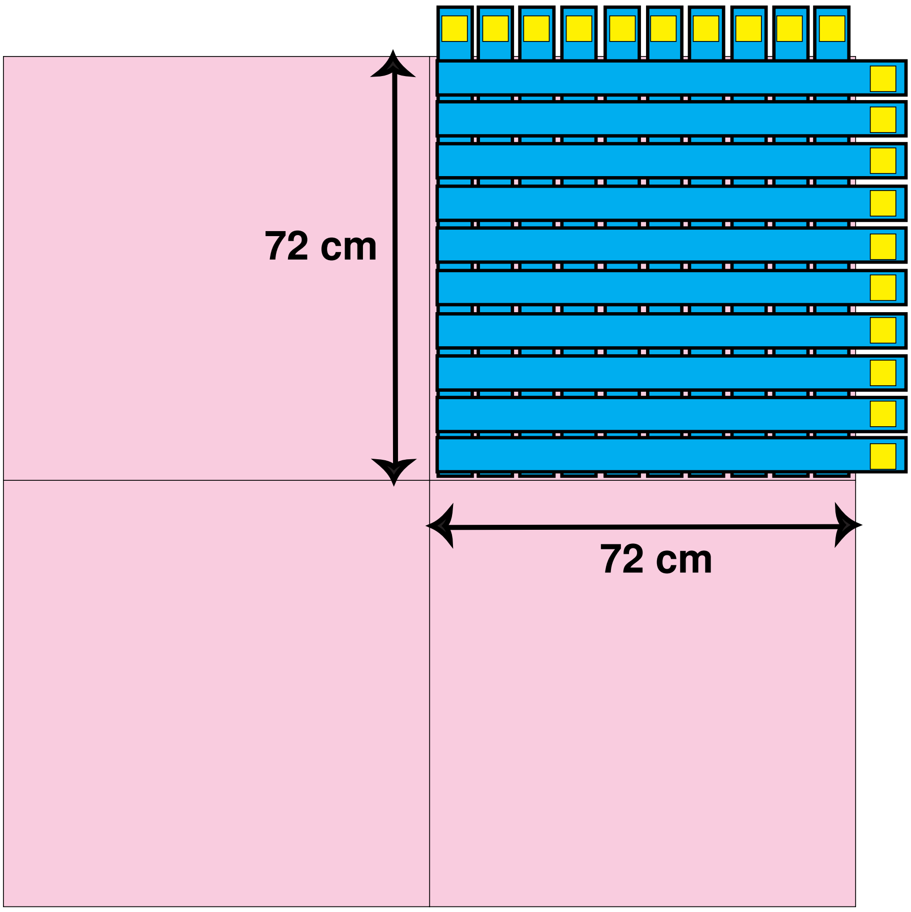
LIMITS


Δm^2 (eV^2)
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
future SBL experiment
CHORUS
NOMAD
E531
CCFR
CHARM II
CDHS
future LBL experiment
kamiokande
Super kamiokande
$\nu_\mu \rightarrow \nu_\tau$
90% C.L.

SILICON DETECTORS FOR FUTURE

SBL NEUTRINO EXPERIMENTS

silicon detectors are used to locate the position of particles in nuclear emulsions



NOMAD-STAR (Silicon TARget prototype)

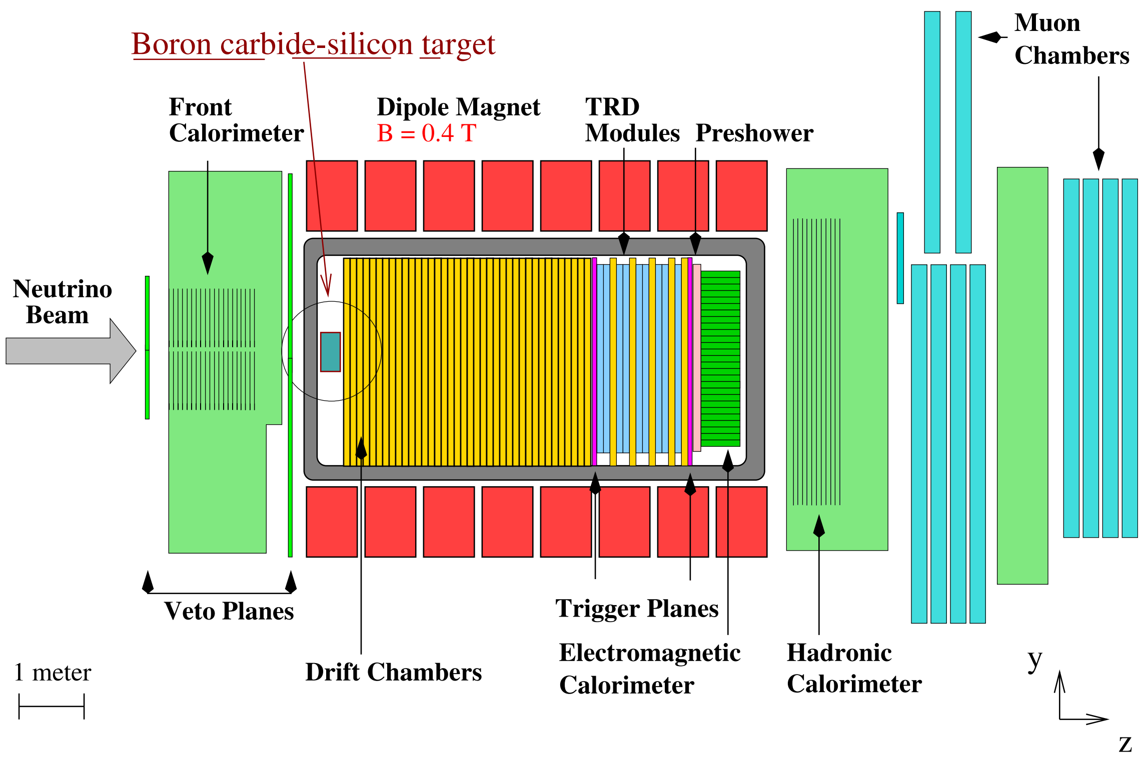
WHAT?

A prototype for the simplest silicon-B_4C detector

WHY?

We want to demonstrate a new technique to explore neutrino physics: measurement of impact parameter & charm search

WHERE?



GOALS

Back-Up

Demonstrate the ability to build a robust & cheap silicon detector (NAUSICAA requires ~ 50 m^2 of silicon)

Demonstrate a new technique: measurement of impact parameter, charm search

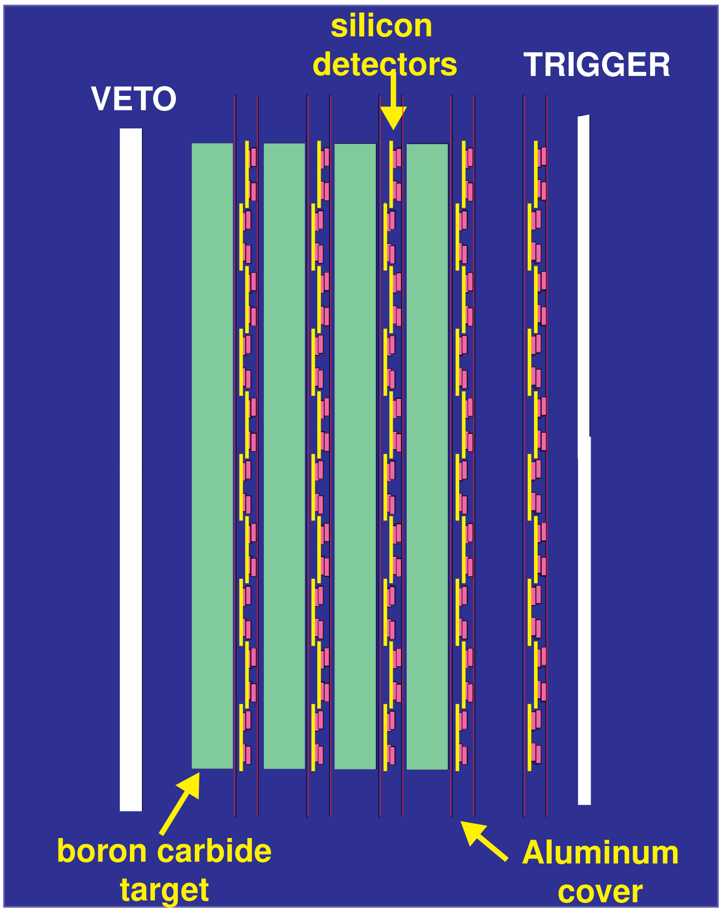
CONSTRAINTS

Budget $\simeq$ 350,000 USD
Only 7 months to build 1.14 m^2 (as big as AMS)
Few people with experience with silicon

RESULTS

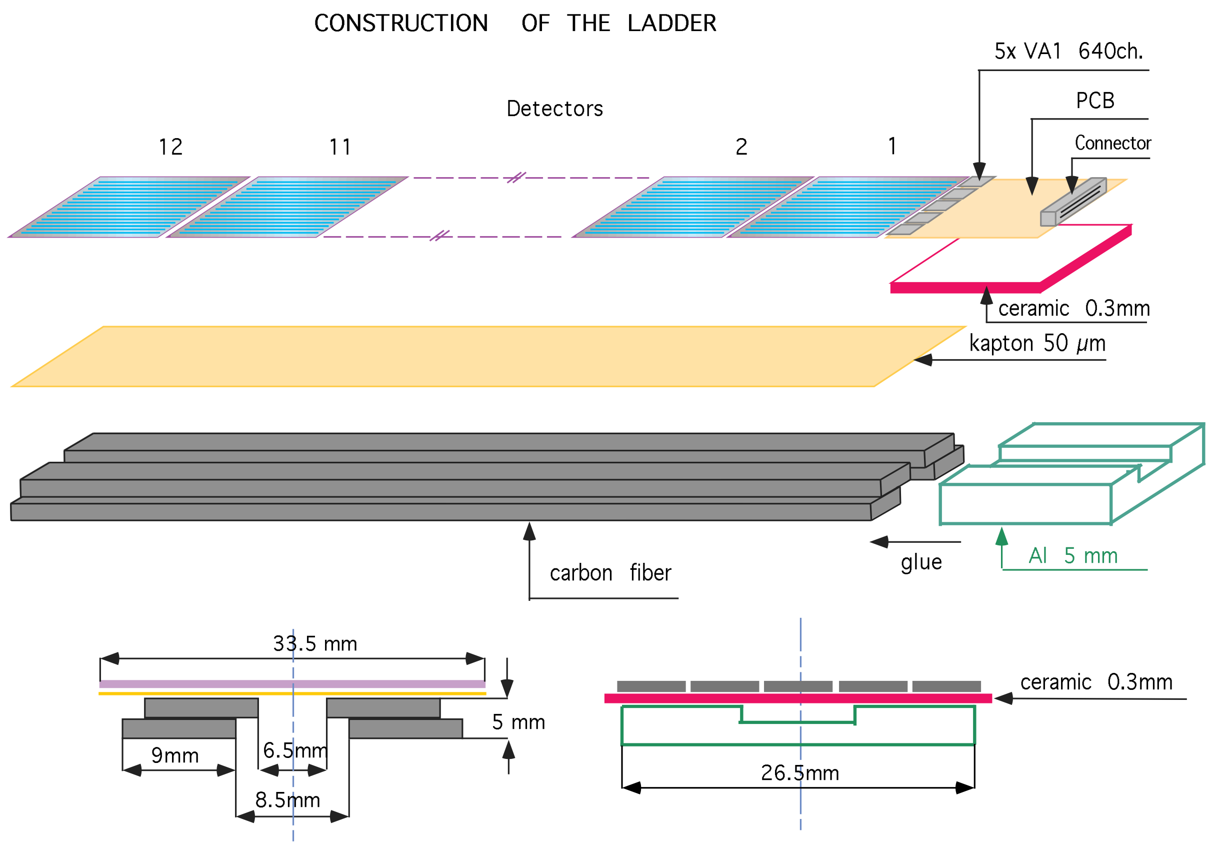
- **we built the simplest detector design, the Silicon TARget (STAR) with B_4C 45 kg passive material**
- **data taking during 1997 (998 events) & 1998 (~ 10000 events)**

NOMAD-STAR DETECTOR



- 5 planes of silicon detectors with 10 ladders each
- 4 planes of passive material (45kg of B_4C)
- 12 silicon detectors per ladder
- Overall dimensions $32 \times 72 \times 18$ cm^3.

NOMAD-STAR LADDER



- **50 ladders**
- **single sided - FOXFET biased detectors**
- **strip pitch = 25 μm, readout pitch = 50 μm.**
- **600 single-sided microstrip detectors with a total area of 1.14 m^2**
- **32,000 readout channels**

WHY IS IT FUN?

NOMAD-STAR has 3 times more readout data then NOMAD!!!

NOMAD-STAR has 1/60 mass of NOMAD!!!

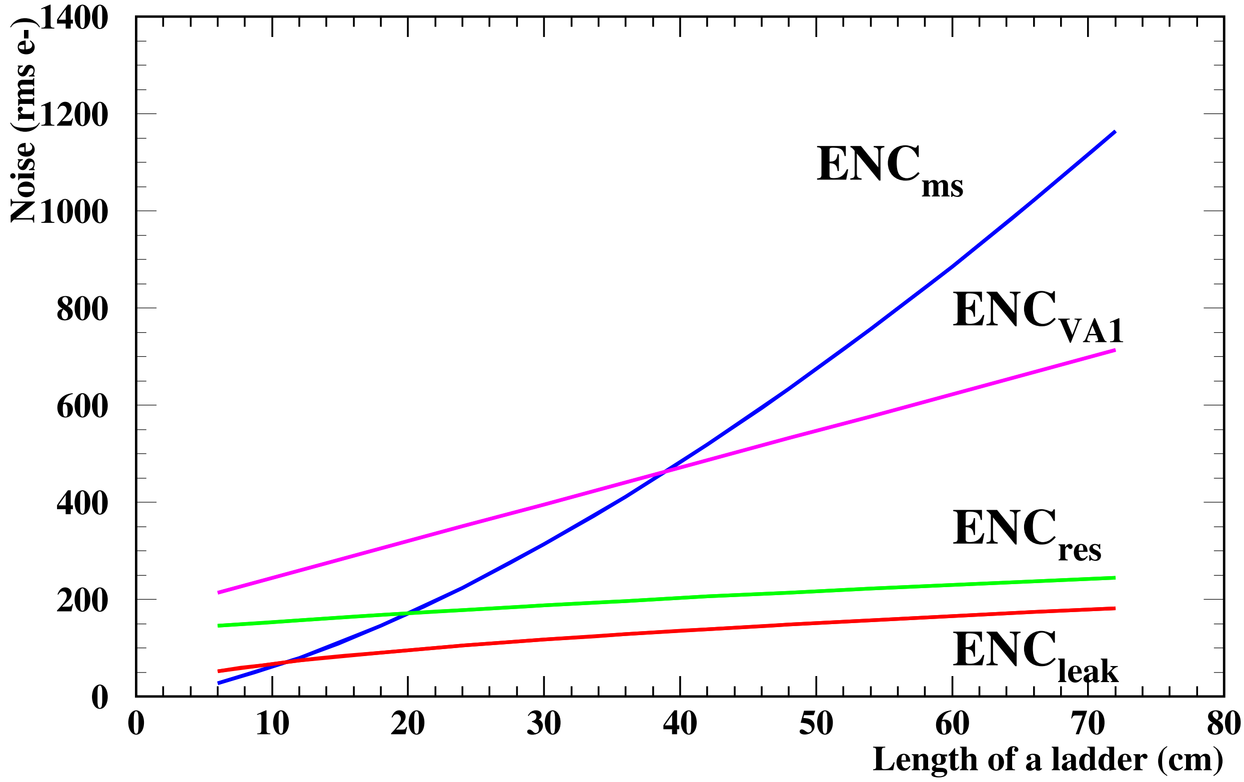
NOMAD-STAR is a prototype (very small budget) but NOMAD is a real experiment

NOMAD-STAR has single PC/Linux, NOMAD has $\sim$ 50 workstation

SOURCES OF NOISE

Back-Up

Dominant source of noise comes from the strip resistance



metal trace resistance - $\mathrm{ENC}_{ms} = \frac{eC_t}{q}\sqrt{\frac{kTR_{eq}}{6T_p}}$

input capacitance - $\mathrm{ENC}_{VA1} = 169e^{-} + 5.6\mathrm{e}^{-}\mathrm{C}_t/\mathrm{pF}$

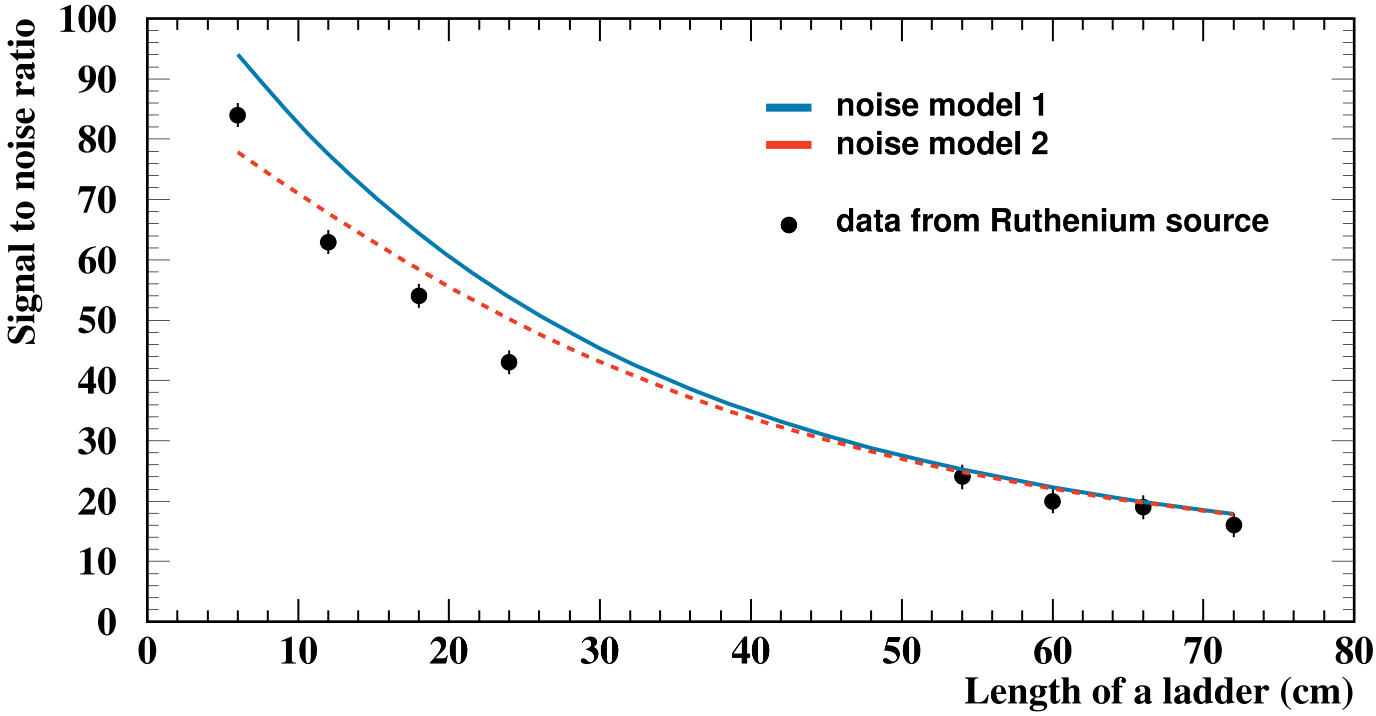
biasing resistance - $\mathrm{ENC}_{res} = \frac{e}{q}\sqrt{\frac{kTT_p}{2R_p}}$

leakage current - $\mathrm{ENC}_{leak} = \frac{e}{q}\sqrt{\frac{qI_{leak}T_p}{4}}$

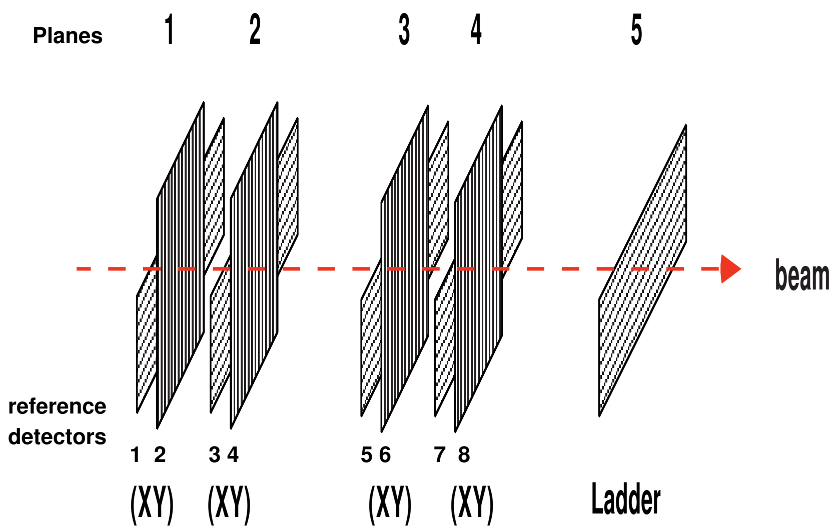
LADDER STATISTICS

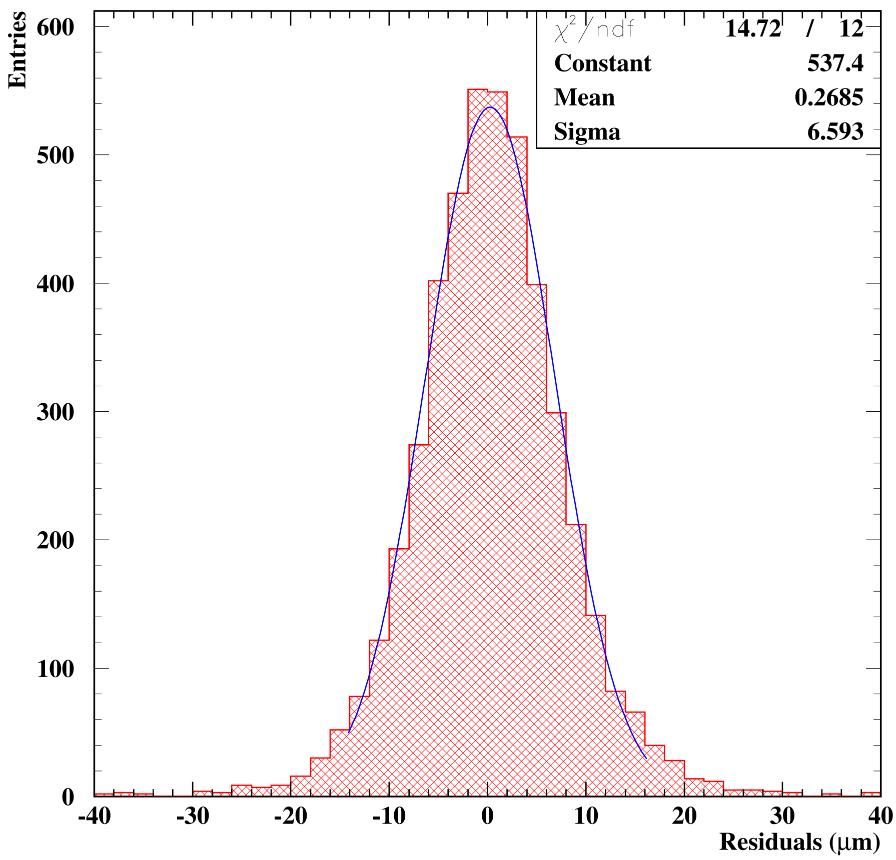
Back-Up

- average signal–to–noise ratio ($\simeq 16$)
- spatial resolution ($< 10\ \mu$m)
- hit–finding efficiency (test beam) ($\simeq 99\%$)
- average leakage current 2 μA.
- average 1.4% defective channels.



SPATIAL RESOLUTION





long ladder in a test beam (plane 5)

RECONSTRUCTION (NOMAD approach)

- **Object-oriented approach: hit, track are interpreted as different objects**
- **C-language, GNU-software, OnX graphics interface**
- **Independent subdetector reconstruction (each NOMAD subdetector has its own hit, track & reconstruction algorithm)**
- **Matching between detectors**
- **Vertex Search & selection**
- **analysis**

Track Building (PART I, DC→Si Approach)

Back-Up

- Build tracks in Drift Chambers (DcTracks)
- Extrapolating DcTracks to STAR region
- Hits inside of Roadwidth are included to track (depends on p)
  - Critirea: $p > 100$ MeV/c; x, y within volume of STAR; only one missing SiHit per track
- The best hit is allocated to each track for each plane
- Using pointers SiHit knows DcTrack information and now it contains x position, so detector is known
- Upgrade exact x, y, z from survey & alignment data for that datector in a ladder.
- DcVertex builds Dc Primary Vertex with DC resolution.

Track Building (Part II, building silicon tracks)

- Use prediction from DcTracks to build SiTracks
- Two measurements coordinates → 2D Kalman filter
- Two track model is investigated:
  - linear track model (stright lines), $y = a + bz$, (a & b are fitted parameters)
  - parabola track model, $y = a + bz + cz^2$, (a & b are fitted parameters, c comes from momentum of DcTrack).
- We can use this part in stand-alone mode to look for secondary interactions.

Vertex Search

Back-Up

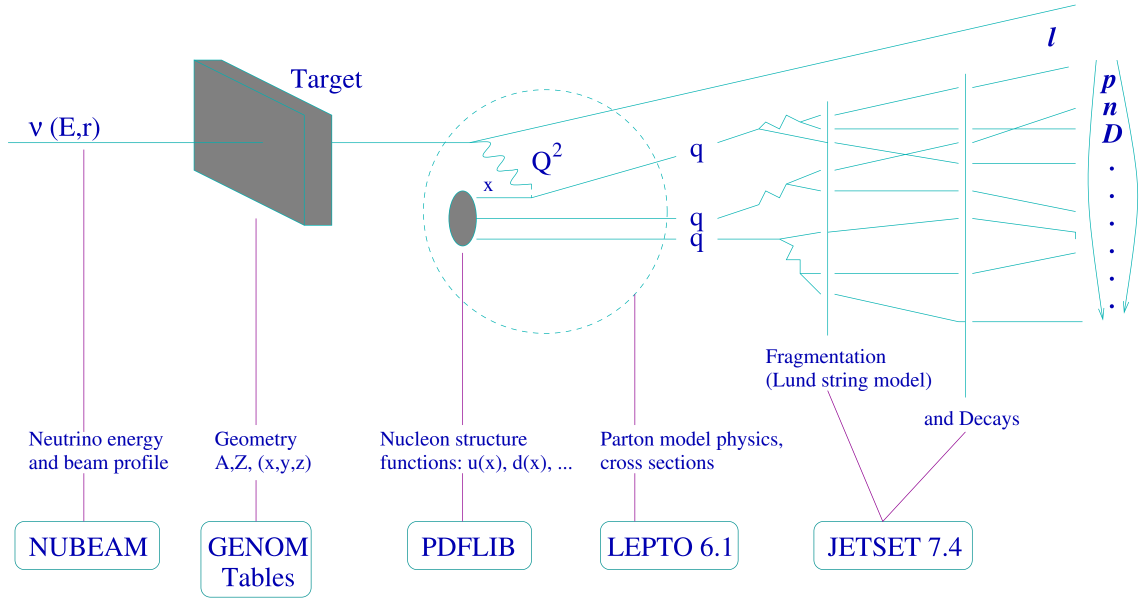
Using DC code we can build DcPrimaryVertex with spatial resolution: $\sim 600\mu$m in x, $\sim 100\mu$m in y, and $\sim 800\mu$m in z.

Building verteces with Silicon

- **Initial vertex guess: point where two tracks of highest momentum cross**
- **Vertex Kalman filter:**
  - **All SiTracks used to find vertex**
  - **χ^2 test, if it is above threshold, then remove track which contributes most to χ^2**
  - **Process stops when χ^2 less than threshold or only two tracks left.**
- **Candidates for "good" vertex:**
  - **Covariance matrix $\sigma_y < 25\mu$m.**
  - **$z_{vertex} < z$ (first hit of SiTrack)**
  - **Vertex inside of STAR volume**
  - **For two tracks: $y_{extrap.DC} - y_{vertex} < \delta$**

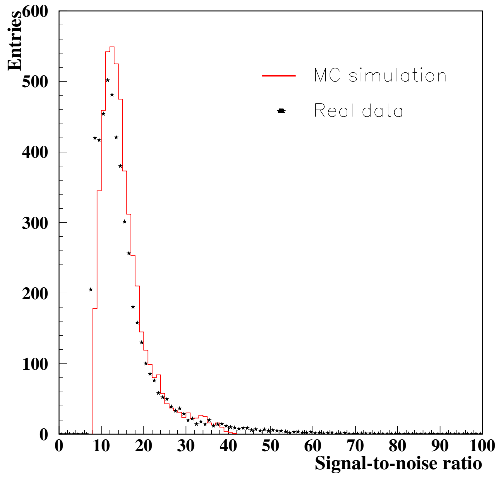
Using Silicon vertex search we achive the resolution of $\sim (20-25)\mu$m in y-direction and $\sim (200-250)\mu$m in z-direction.

Monte Carlo



Silicon Part

- Geometry simulation
- Raw hits & Digitization algorithm



- Clusterization

Back-Up

MC ν_τCC EVENT

Silicon vs MC (before discarding muon)

$|\Delta y| = 113 \pm 12\mu$**m,** $|\Delta z| = 1249 \pm 68\mu$**m**

Silicon vs MC (after discarding muon)

$|\Delta y| = 73 \pm 13\mu$**m,** $|\Delta z| = 1032 \pm 76\mu$**m**

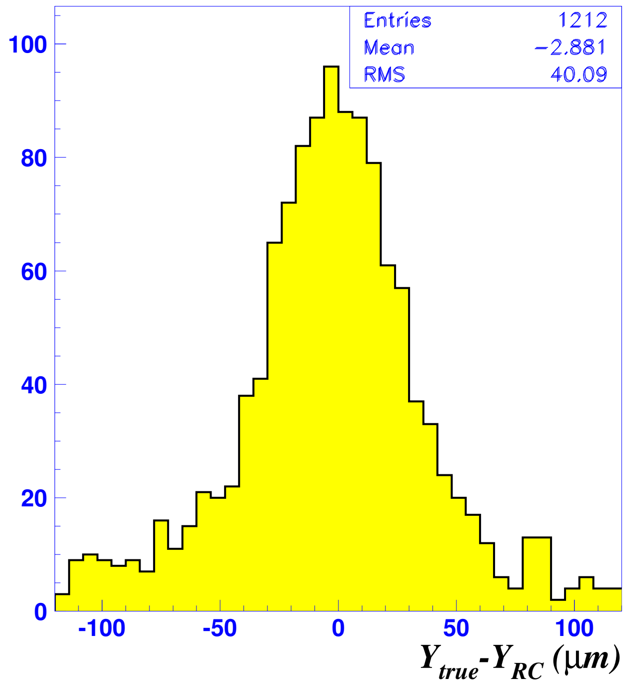
Impact parameter equal to 298μ**m**

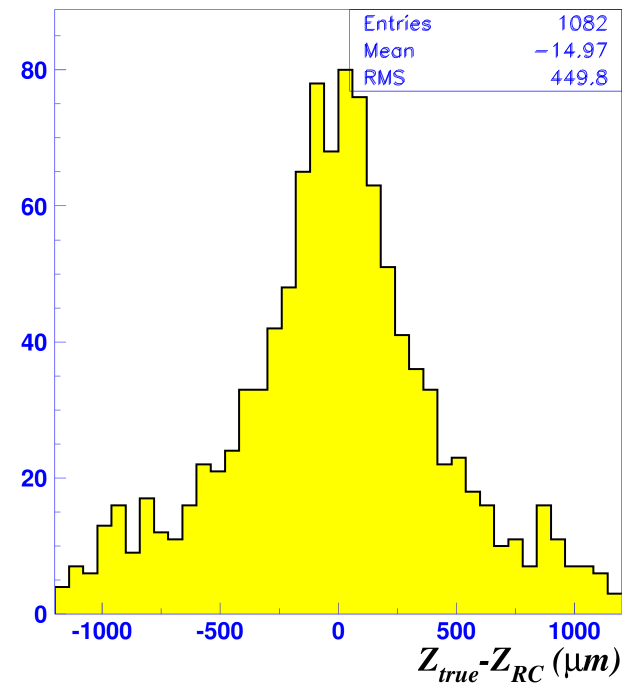
DC vs MC

$|\Delta y| = 1474\mu$**m,** $|\Delta z| = 2410\mu$**m**

Have two vertices (wrong)

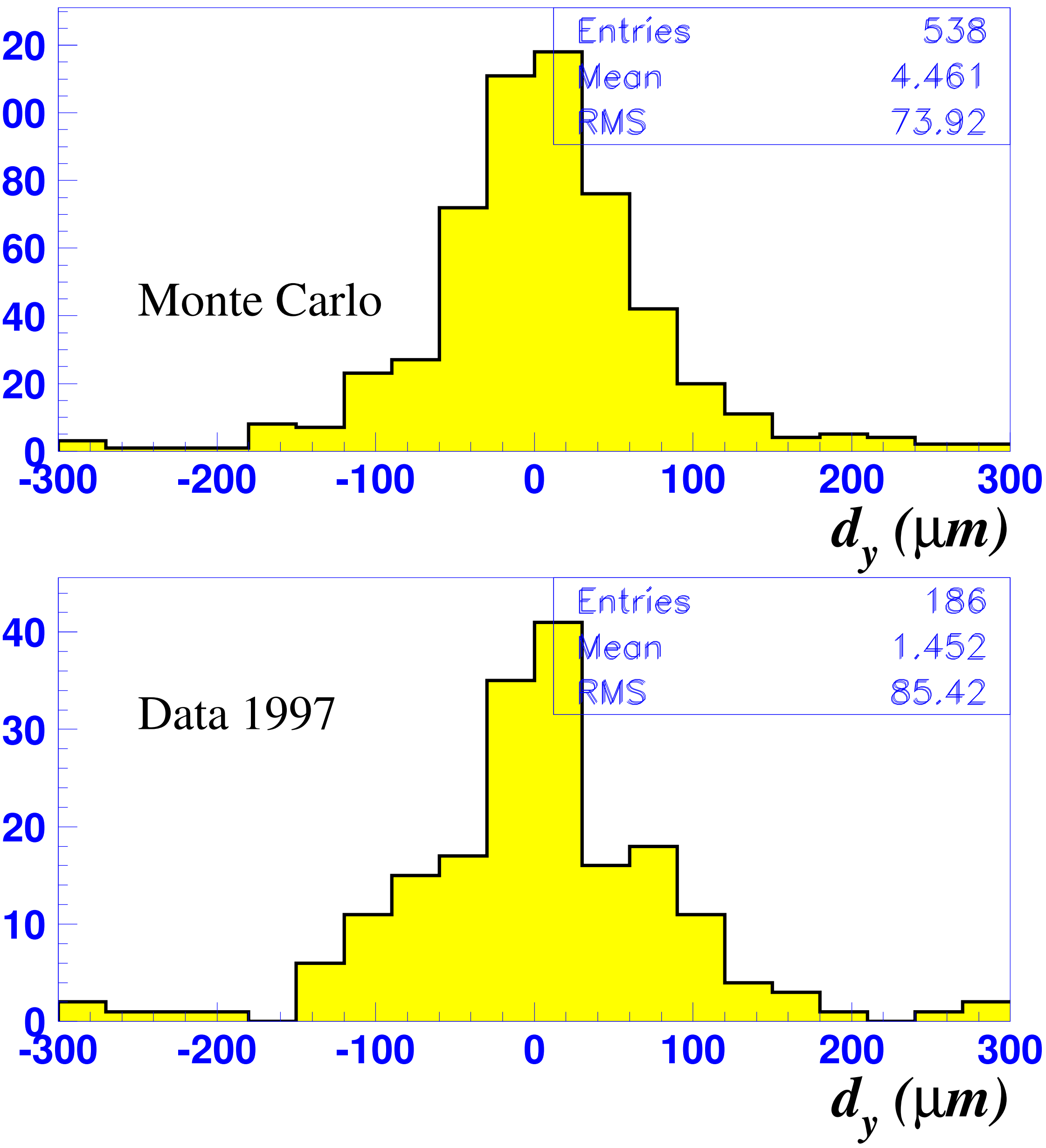
VERTEX RESOLUTION





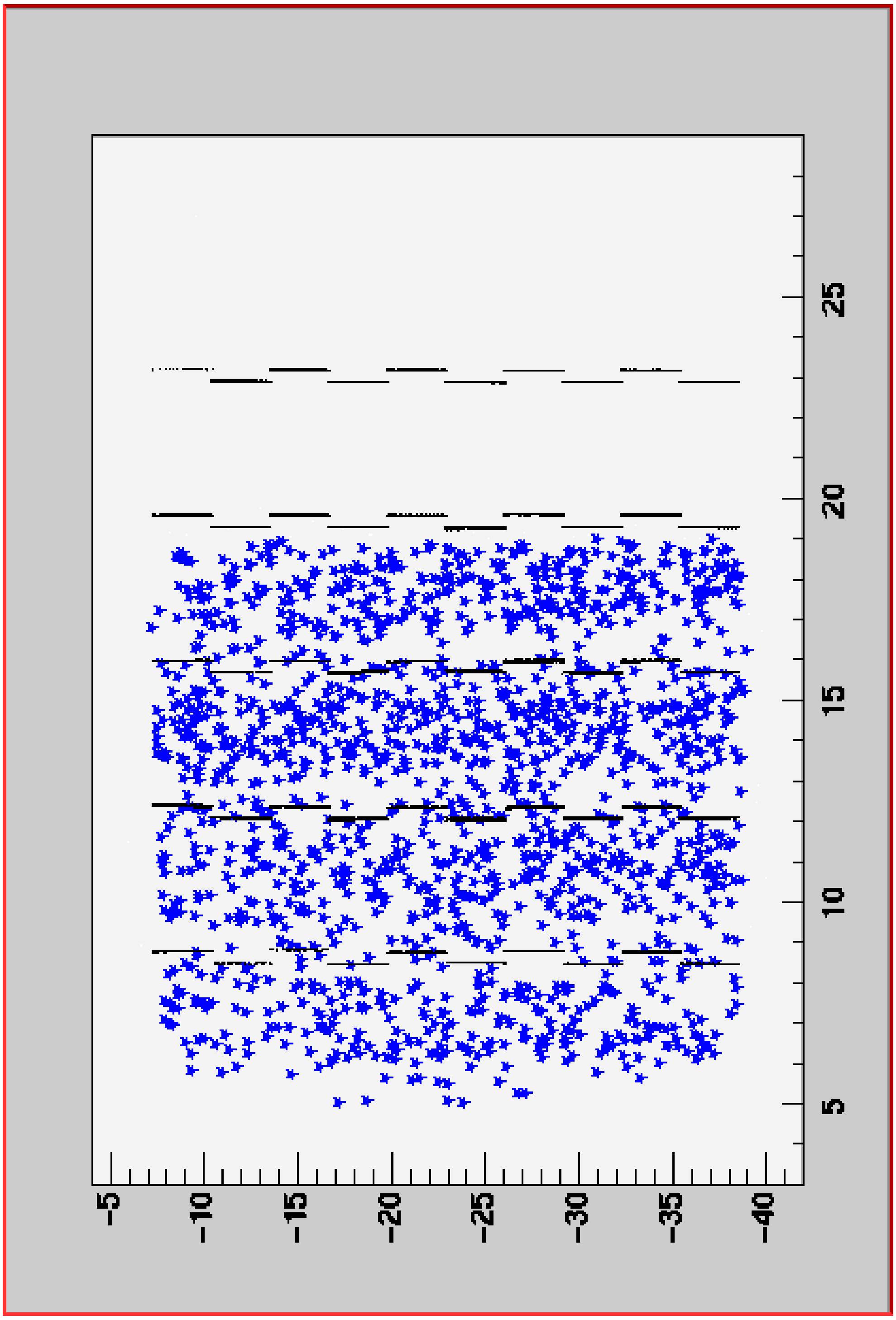
PRELIMINARY

IMPACT PARAMETER DISTRIBUTION



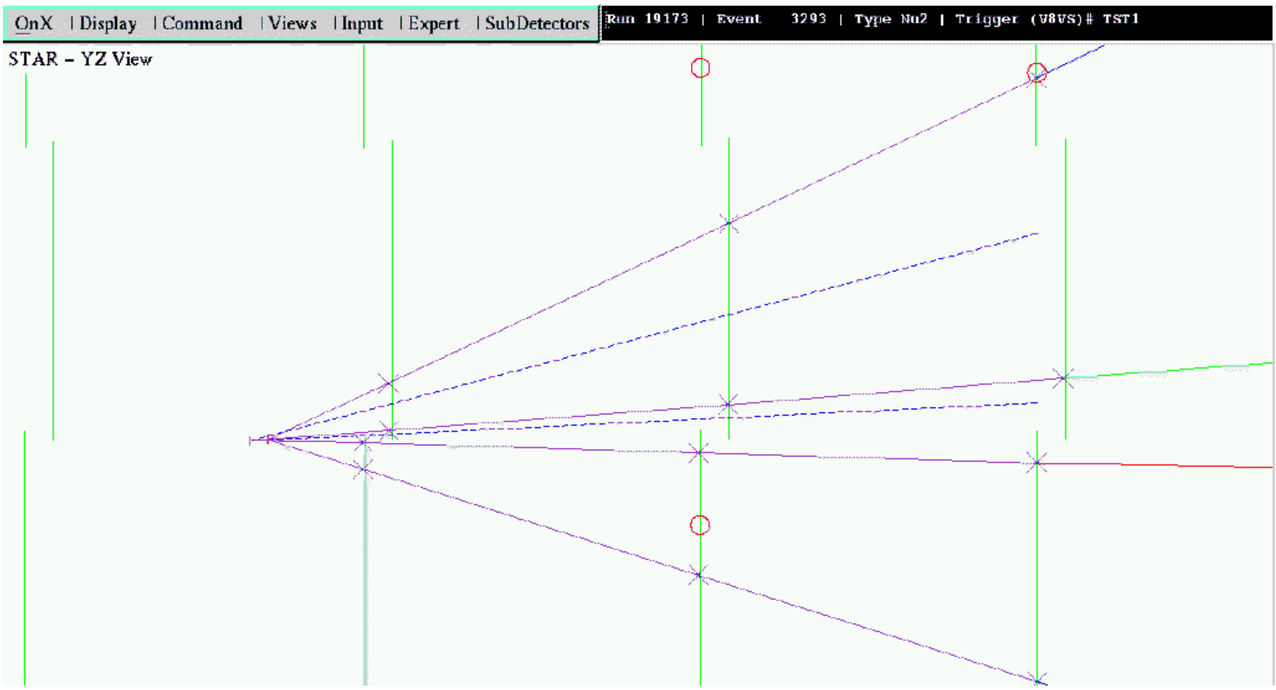
PRELIMINARY

NOMAD-STAR tomography



Charm candidate in NOMAD-STAR

- **STAR vertex code can separate double vertex events.**
- **No systematic charm search done yet**
- **First attempt was done for simplest case: $D^0 \to K^- \pi^+$ (3.89%)**
  - **Two vertices: primary with μ^-, secondary with $+-$ tracks**
  - **Invariant mass ~ 1865 MeV**



SUMMARY

OSCILLATIONS: **NOMAD finds no indication for $\nu_\mu \leftrightarrow \nu_\tau$ oscillations and sets a limit of $P(\nu_\mu \to \nu_\tau) < 0.6 \times 10^{-3}$. Data taking period is completed and some data still remain to be analyzed.**

DIFFRACTIVE: **Very preliminary results on the search for $D_s^{(*)}$ diffractive production have also been presented.**

NEXT STEP: **a new idea to use silicon for future oscillation neutrino experiments based on a large are silicon tracker is discussed.**

NOMAD–STAR: **a prototype instrumented silicon target has been built to measure impact parameter distributions of tau (charm) decays. Data taking period is completed and we have recorded about 10000 neutrino interactions. Details of reconstruction algorithm is discussed. Analysis is in progress.**