Results from CHORUS

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for

CHORUS ν_τ ν_μ

- Neutrino beam
- Principle of detection
- CHORUS detector
- Pilot analysis
- First results

XXV SLAC Summer Institute
Stanford/USA

13-15 August 1997

CHORUS Collaboration

about 150 people

Belgium	Brussels, Louvain-la-Neuve
CERN	
Germany	Berlin, Münster
Israel	Haifa
Italy	Bari, Cagliari, Ferrara, Naples, Roma, Salerno
Japan	Aichi, Gifu, Kinki, Kobe, Nagoya, Osaka, Toho, Utsunomiya
Korea	Changwon, Chonnam Gyeongsang
The Netherlands	Amsterdam
Russia	Moscow
Turkey	Adana, Ankara, Istanbul

Neutrino mixing

If neutrinos have a mass

Mass eigenstates $\neq$ flavor eigenstates

$$|\nu_e\rangle = \sum_{i=1}^{n} U_{ei}\,|\nu_i\rangle$$

For 2 state mixing:

$$U = \begin{pmatrix} \cos\Theta & \sin\Theta \\ -\sin\Theta & \cos\Theta \end{pmatrix}$$

$$|\nu_e\rangle = \cos\Theta\,|\nu_1\rangle + \sin\Theta\,|\nu_2\rangle$$
$$|\nu_\mu\rangle = -\sin\Theta\,|\nu_1\rangle + \cos\Theta\,|\nu_2\rangle$$

$$m_{\nu_e} \neq m_{\nu_\mu} \neq m_{\nu_\tau}$$

$\Rightarrow$ **Neutrino Oscillation**

CHORUS Experiment

Cern **H**ybrid **O**scillation **R**esearch apparat**US**

$\nu_\mu \rightarrow \nu_\tau$ oscillation

Search for ν_τ in a ν_μ -beam

→ direct search for decay kink of τ^-

Short baseline appearance experiment:

L ~ 0.6 km

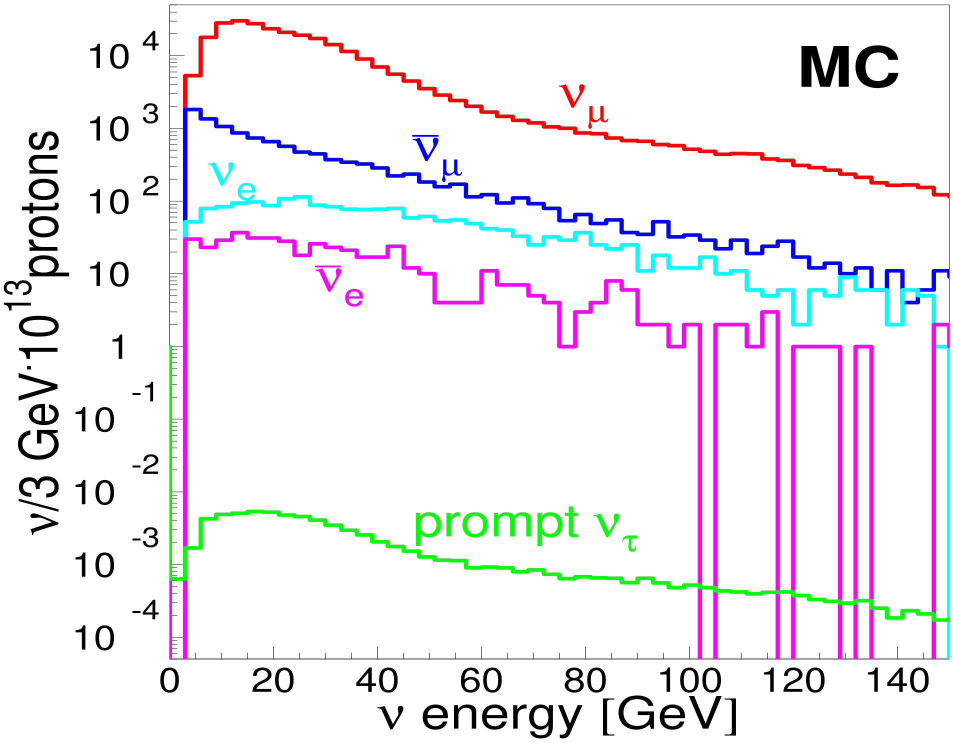
$\langle E_\nu \rangle$ ~ 27 GeV

Increased sensitivity by ~ x 20

(w. r. t. previous experiments)

→ ~ 50 ν_τ events @ present limit

CERN Wide Band ν Beam



- intensity up to 2.5×10^{13} p/pulse
- prompt ν_τ background negligible:

$$\frac{\nu_{\tau\ \text{prompt}}\ \text{CC}}{\nu_{\mu\ \text{prompt}}\ \text{CC}} = 3\text{-}4 \cdot 10^{-6}$$

$\rightarrow$ background **0.1 events**

$\nu_\mu \longrightarrow \nu_\tau$ Oscillation

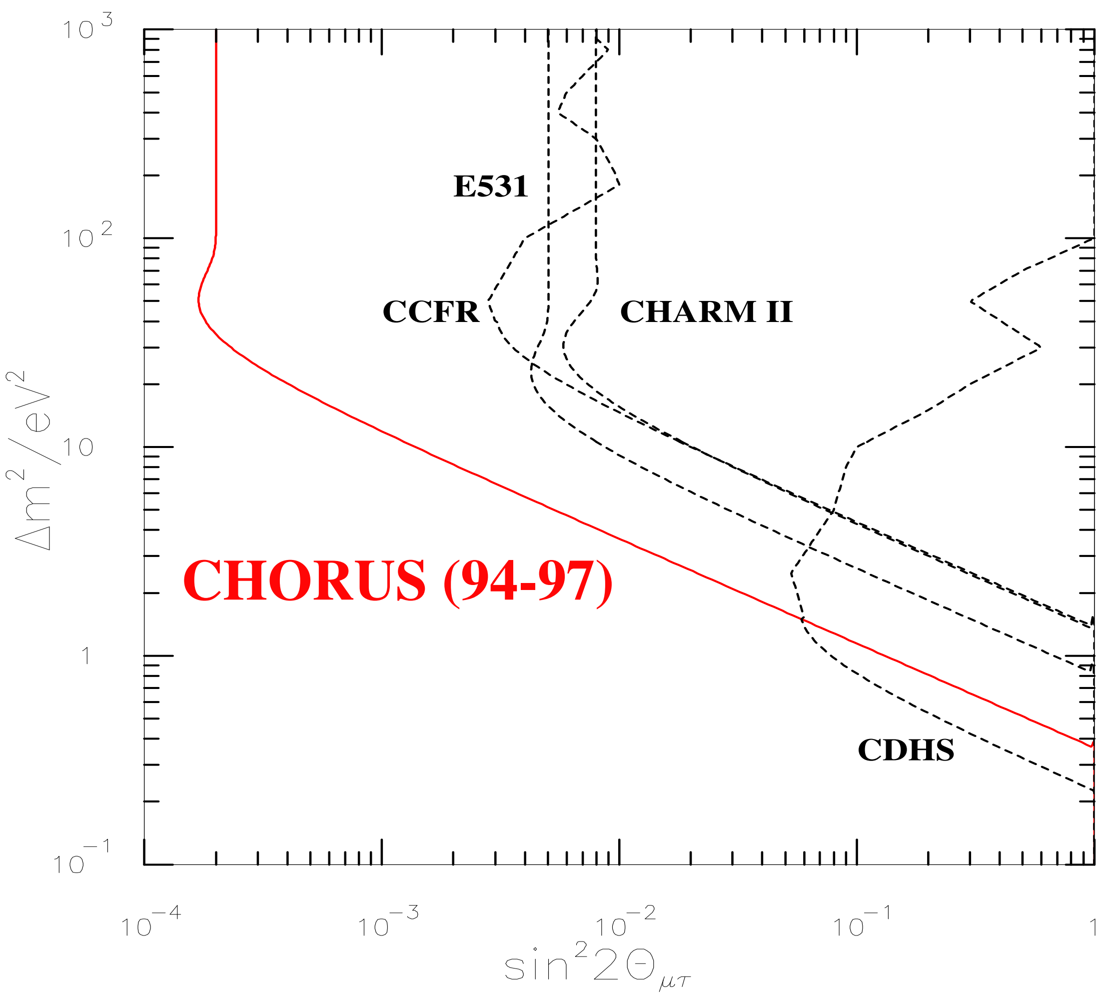
$$P(\nu_\mu \rightarrow \nu_\tau) = \sin^2(2\theta)\, \sin^2(\Delta m^2 \frac{L}{4E})$$

θ: mixing angle

Δm^2: mass difference

L: distance

E: neutrino energy



Principle of Detection

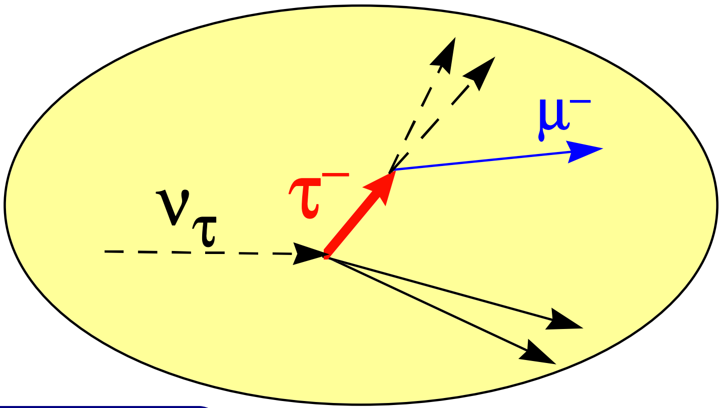
τ^- observed through 3 decay modes:

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

$\to \mu^- \bar{\nu}_\mu \nu_\tau$	17%
$\to h^-(n\pi^0)\nu_\tau$	50%
$\to \pi^+\pi^-\pi^-(n\pi^0)\nu_\tau$	14%

τ identification method:

$\gamma \cdot c \cdot t \sim 1$ mm

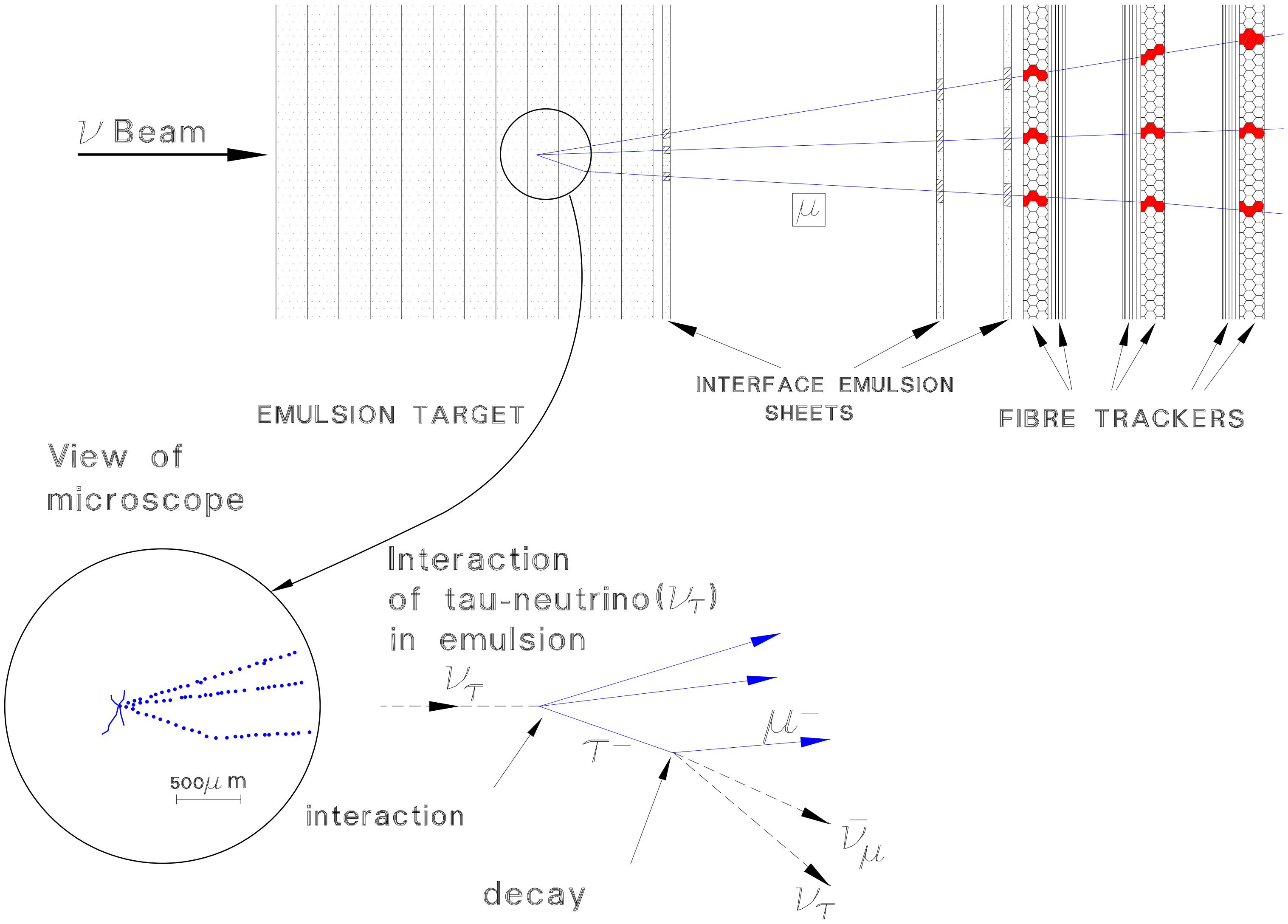


Nuclear emulsion

3D-resolution: ~ 1 μm

800 kg / RUN

ν–Target and Fiber Tracker



The CHORUS Detector

Calorimeter

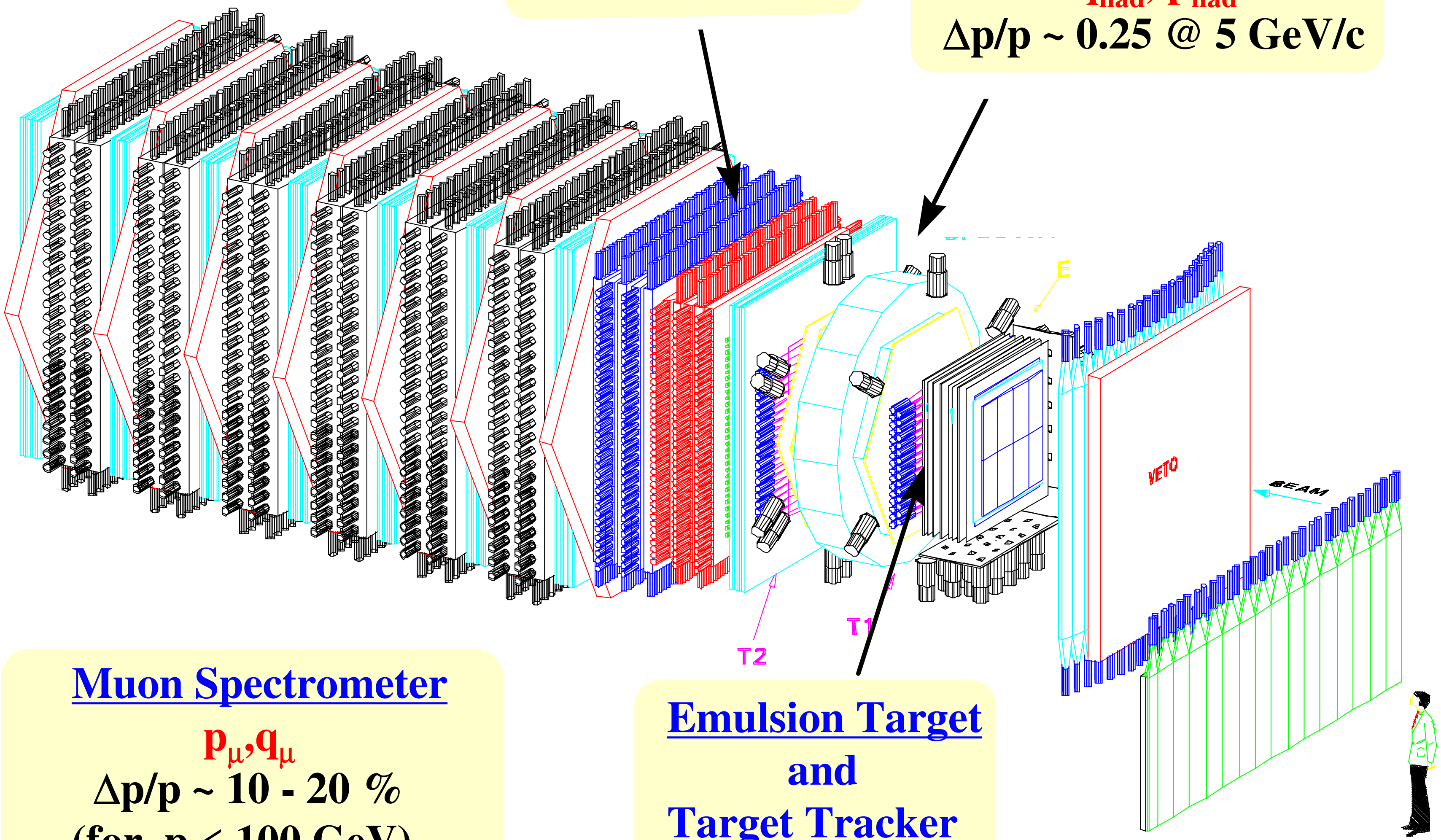
E_{had}, Θ_{had}

$\Delta E/E \sim 0.35/\sqrt{E}$

Magnet Spectrometer

q_{had}, p_{had}

$\Delta p/p \sim 0.25$ @ 5 GeV/c



Muon Spectrometer

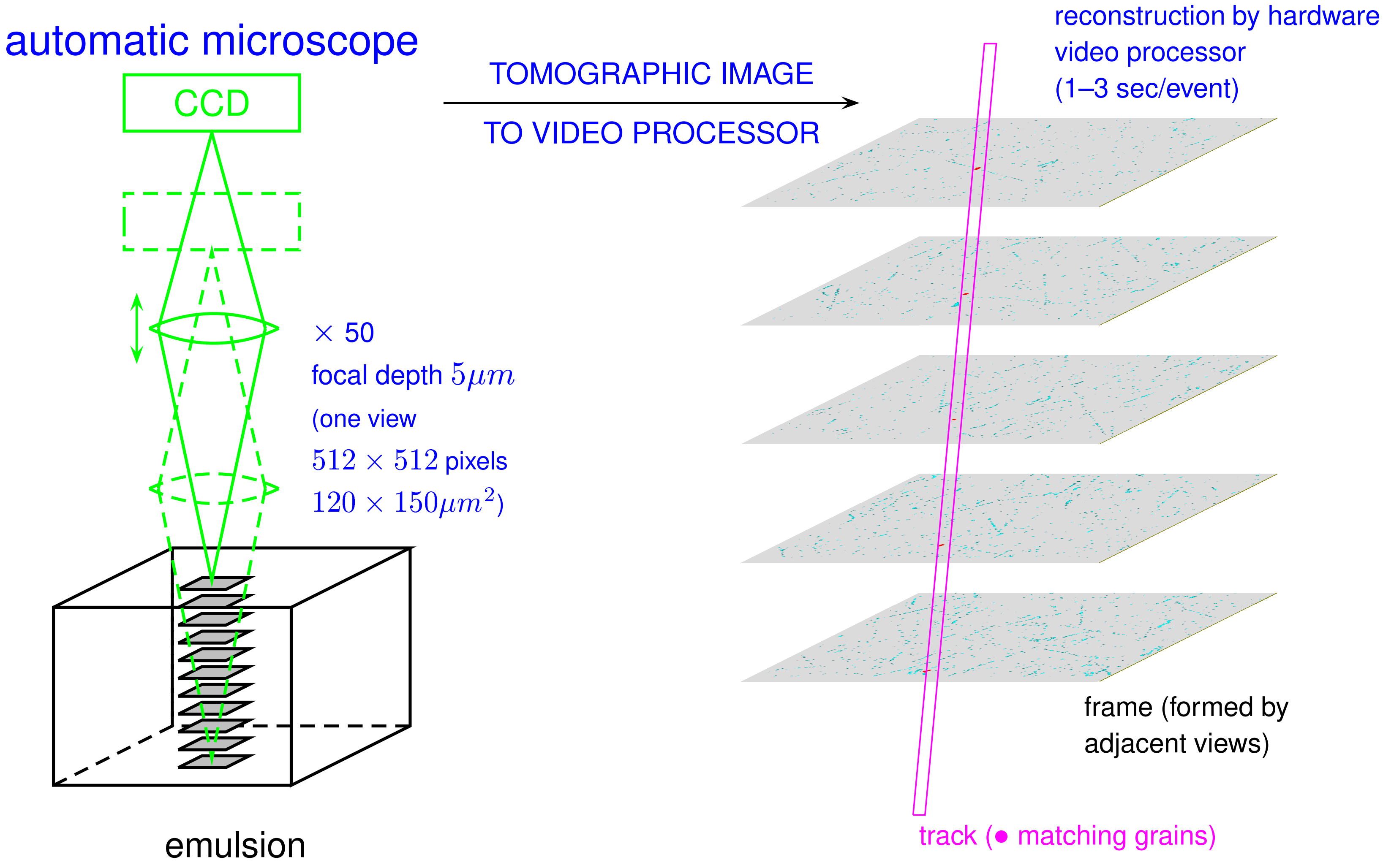
p_μ, q_μ

$\Delta p/p \sim 10 - 20$ %

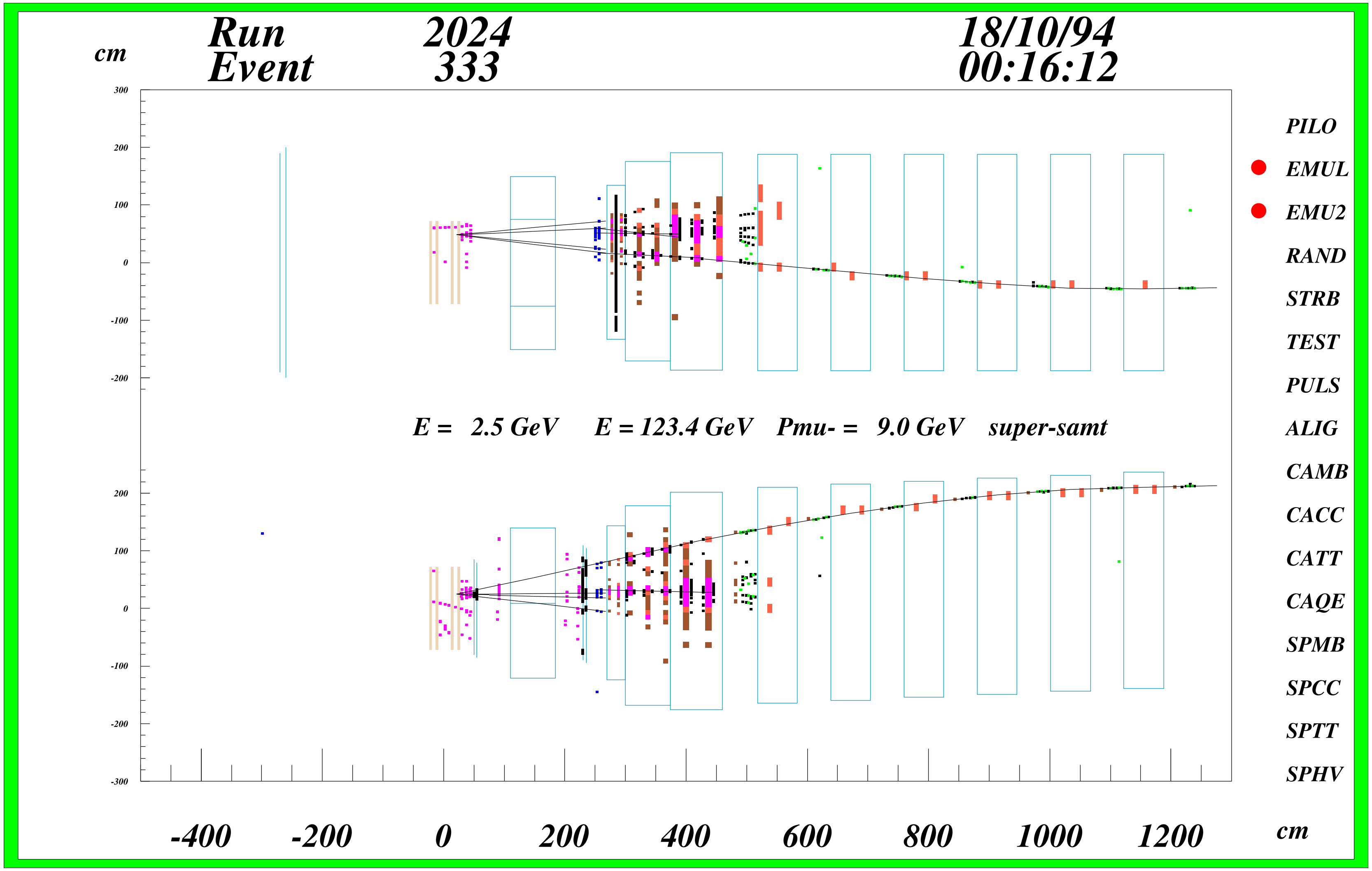
(for $p < 100$ GeV)

Emulsion Target and Target Tracker

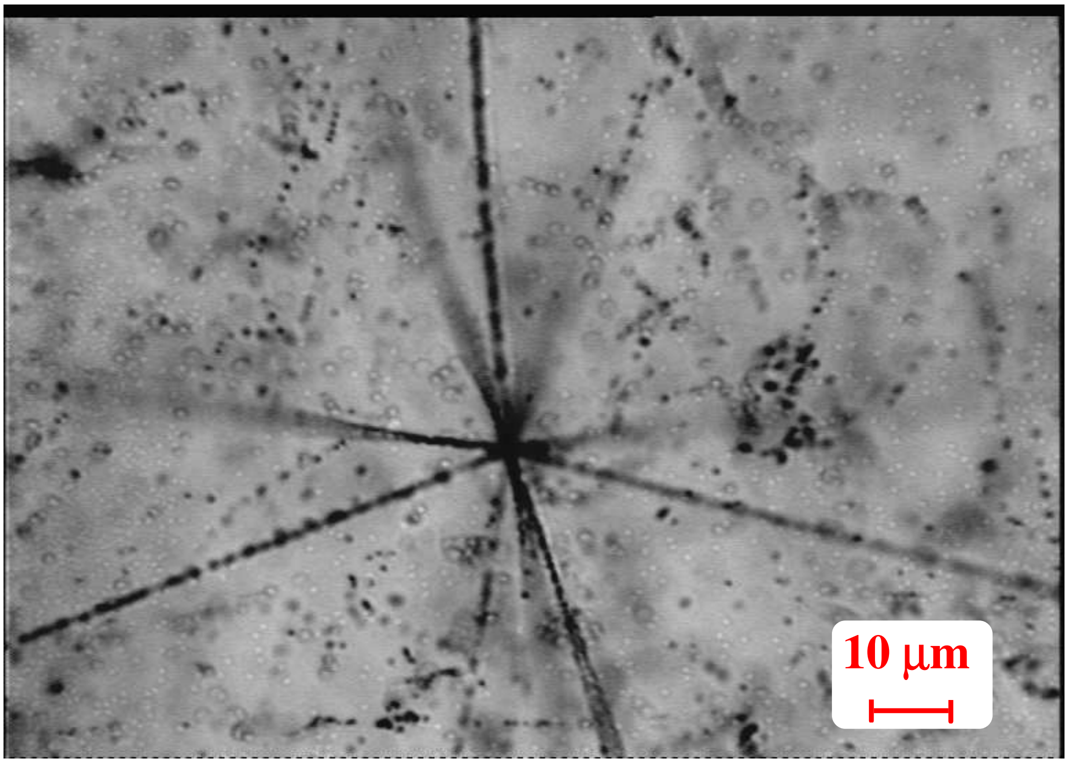
Automatic Scanning



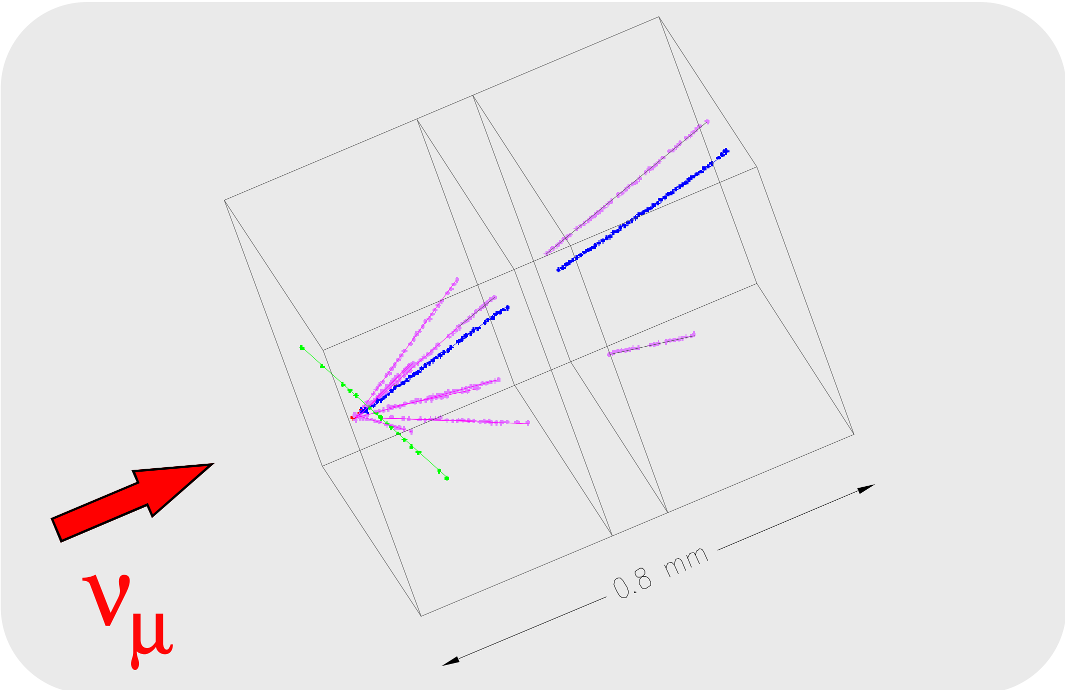
Event in CHORUS



ν Interaction in the Emulsion



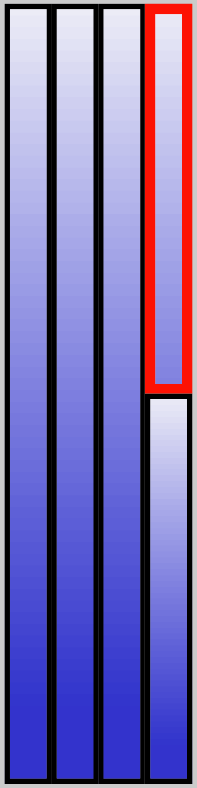
... and after digitisation and reconstruction



CHORUS Runs

Run I

Σ CC



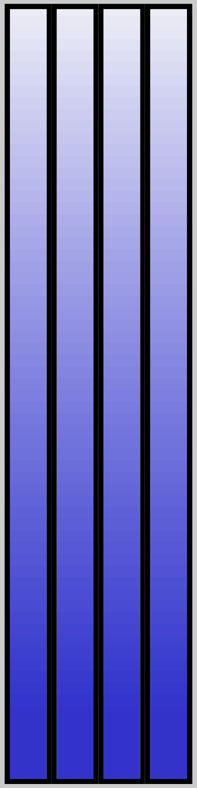
May 94 Start of data taking
(Proposal 1991)

Oct 94 Stack 4 developed and replaced
➔1st pilot analysis
120 k

Oct 95 All emulsion developed
320 k

Run II

Σ CC



Apr 96 New emulsion

Sep 96 3.4×10^{19} pot
550 k

Nov 97 End of data taking
730 k

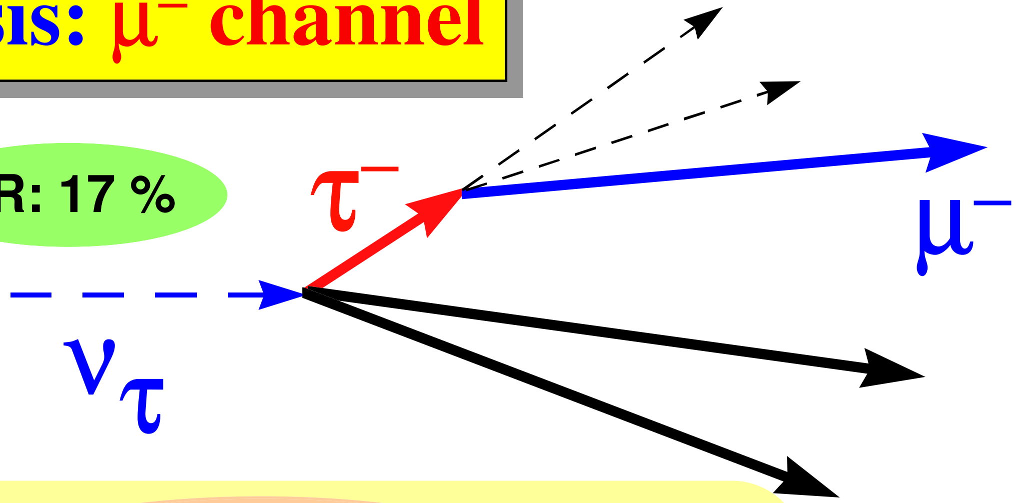
Pilot Analysis: μ^- channel

Based on:

$\nu_\tau N \longrightarrow \tau^- X$

$\quad\quad\quad\quad \llcorner\!\longrightarrow \mu^- \bar{\nu}_\mu \nu_\tau$

BR: 17 %



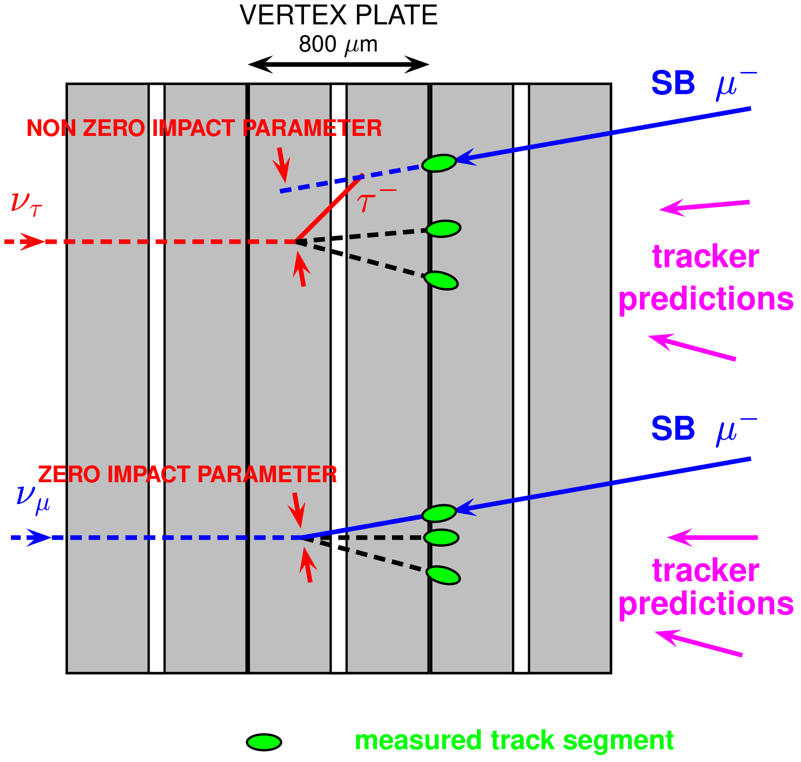
- kink candidate is μ^- : no kink $\longrightarrow$ no τ^-
- no other lepton at primary vertex
- $p_\mu <$ 30 GeV/c
- decay $p_\perp \geq$ 250 MeV/c

- Background from charmed mesons ~ 10^{-6}

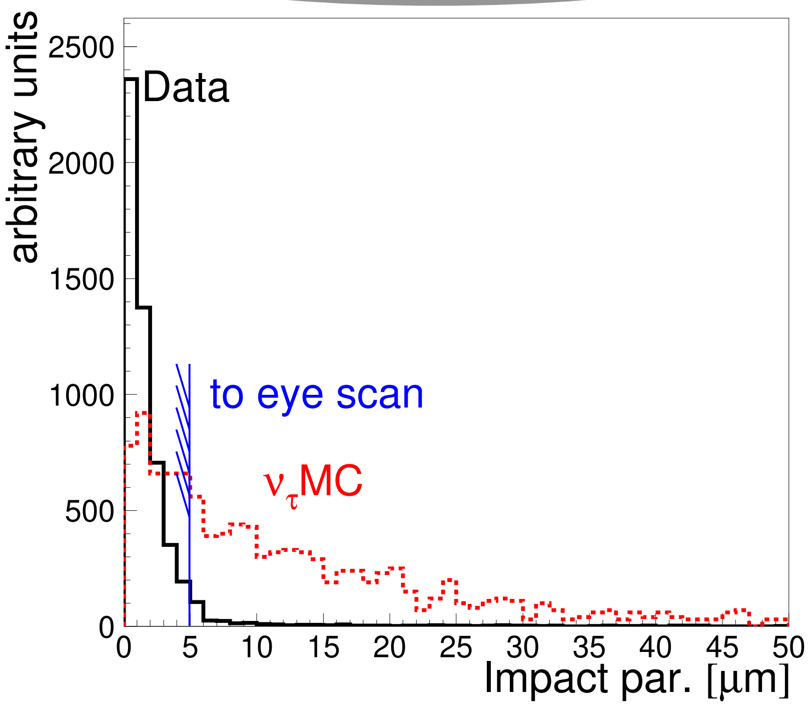
$D^- \rightarrow \mu^-$ from $\bar{\nu}_{\mu,e}$ CC ; μ^+, e^+ not identified

“Short” Decay (27 %)

vertex and decay in same plate

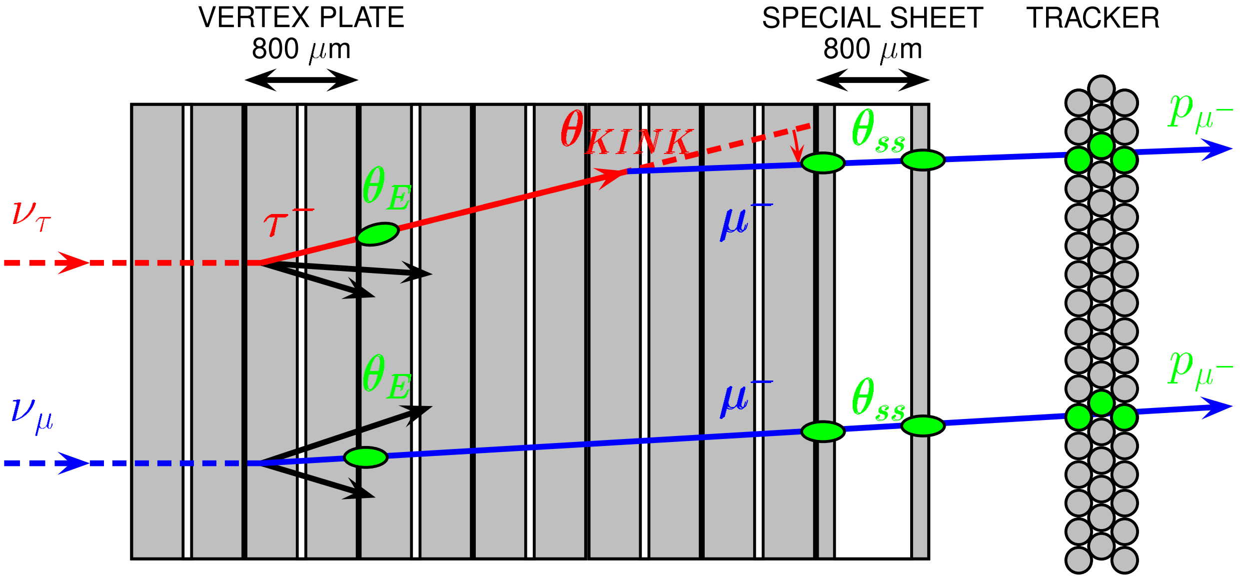


impact parameter cut

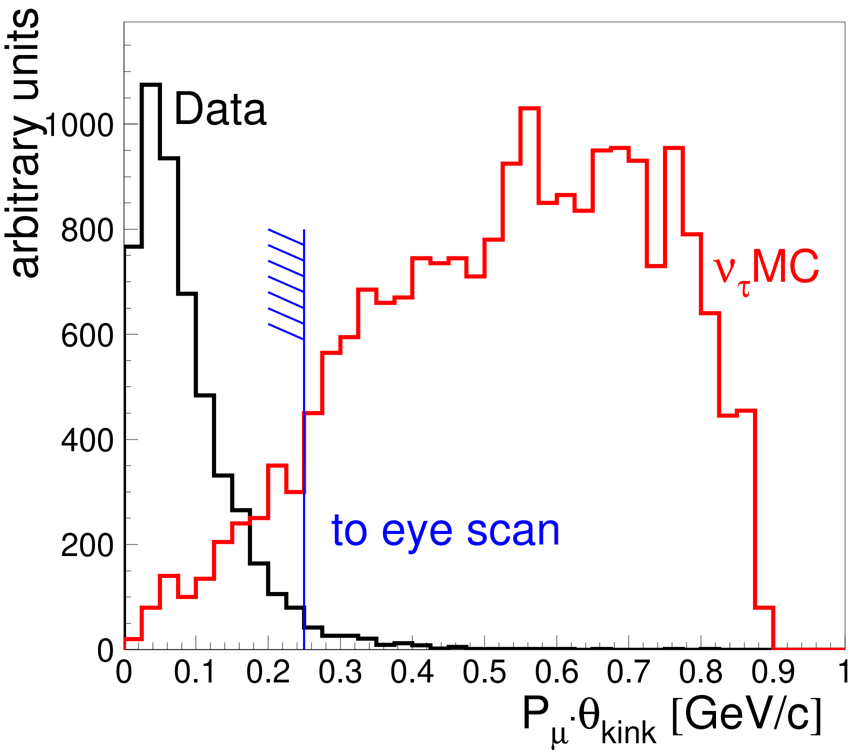


“Long” Decay (73 %)

vertex and decay not in same plate



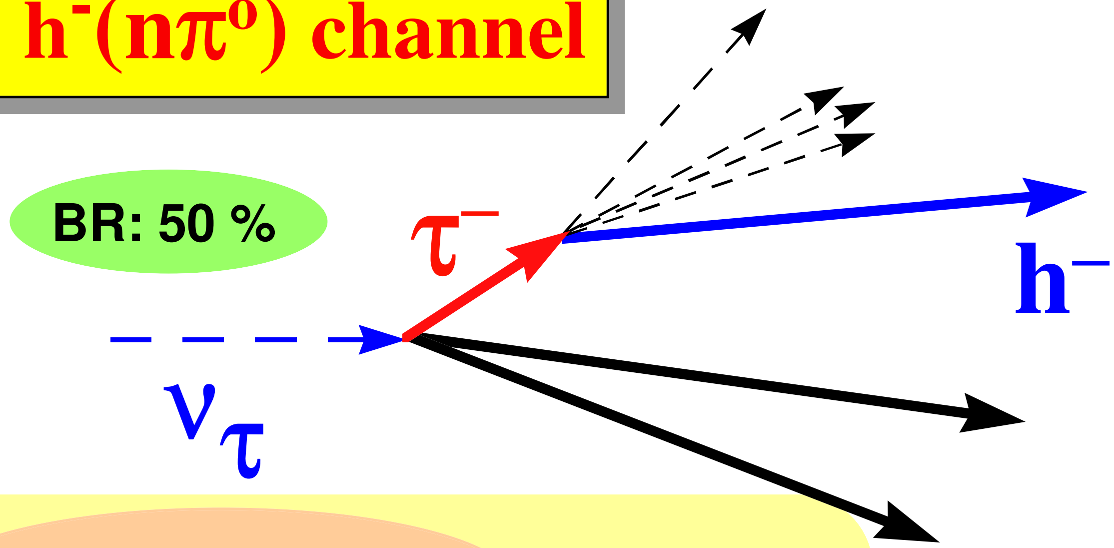
Cut on $p_\mu \cdot \theta_{kink}$



Pilot Analysis: $h^{-}(n\pi^{o})$ channel

Based on:

$$\nu_\tau N \longrightarrow \tau^- X$$
$$\hookrightarrow h^-(n\pi^0)\nu_\tau$$



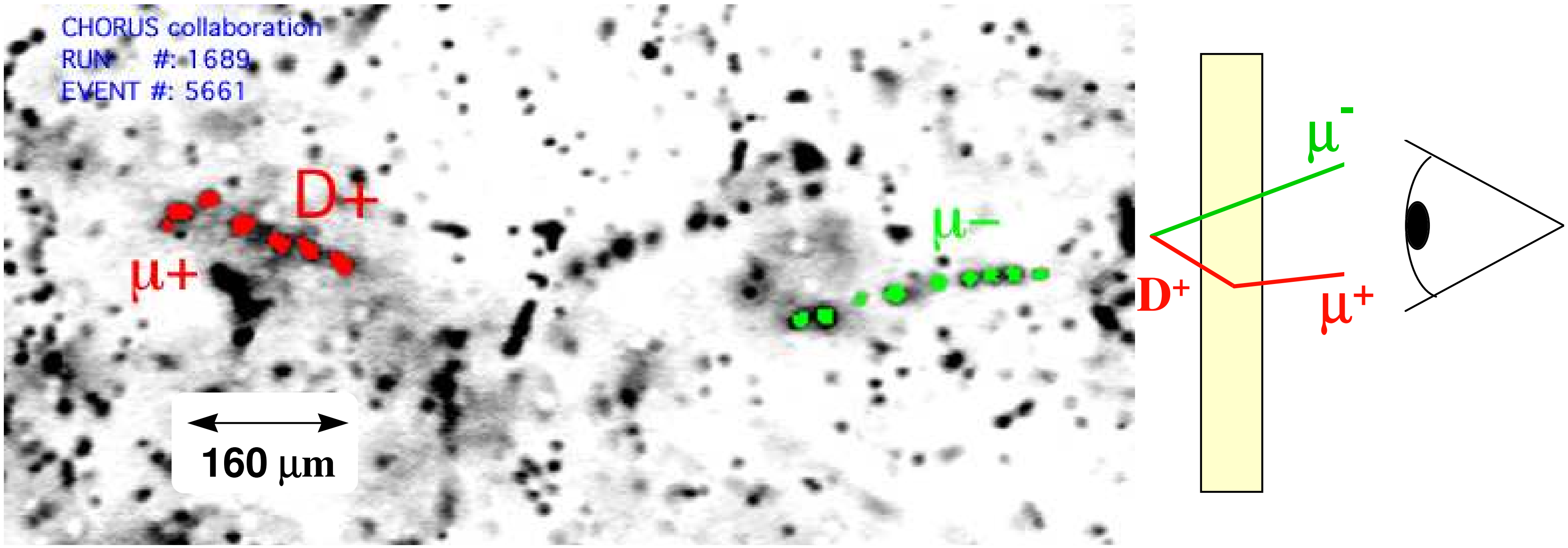
- **kink candidate is h^- : no kink $\longrightarrow$ no τ^-**
- **no other leptons at primary vertex**
- **$1 < p_h < 20$ GeV/c**
- **decay $p_\perp \geq 250$ MeV/c**
- **background :**

  $\sim 10^{-6}$ events from charm production

  $\sim 10^{-5}$ events from kinks due to recoilless elastic scattering of a hadron on a nuclei (white kink)

Dimuon Event in the Emulsion

$$\nu\, N \rightarrow D^{+}\, \mu^{-}\, X$$
$$\hookrightarrow \mu^{+} + \text{neutrals}$$



Status of Pilot Analysis:

For large Δm^2:

$$P(\nu_\mu \rightarrow \nu_\tau) = \tfrac{1}{2}\sin^2(2\theta)$$

$$\sin^2(2\theta) = \frac{2\cdot 2.3}{N(\nu_\mu)}\cdot\frac{\sigma(\nu_\mu)}{\sigma(\nu_\tau)}\cdot\frac{1}{\sum\limits_{i=\mu^-,h^-}\frac{A_i(\nu_\tau)}{A(\nu_\mu)}\cdot BR_i\cdot\varepsilon_i\cdot r_i}$$

$\sigma_\mu/\sigma_\tau = 1.89$

A	acceptance and efficiency
N_μ	number of scanned $\nu \rightarrow \mu$ events with vertex located in emulsion
ε_i	kink finding efficiency
r_i	fraction of events of this class w. r. t. the μ channel

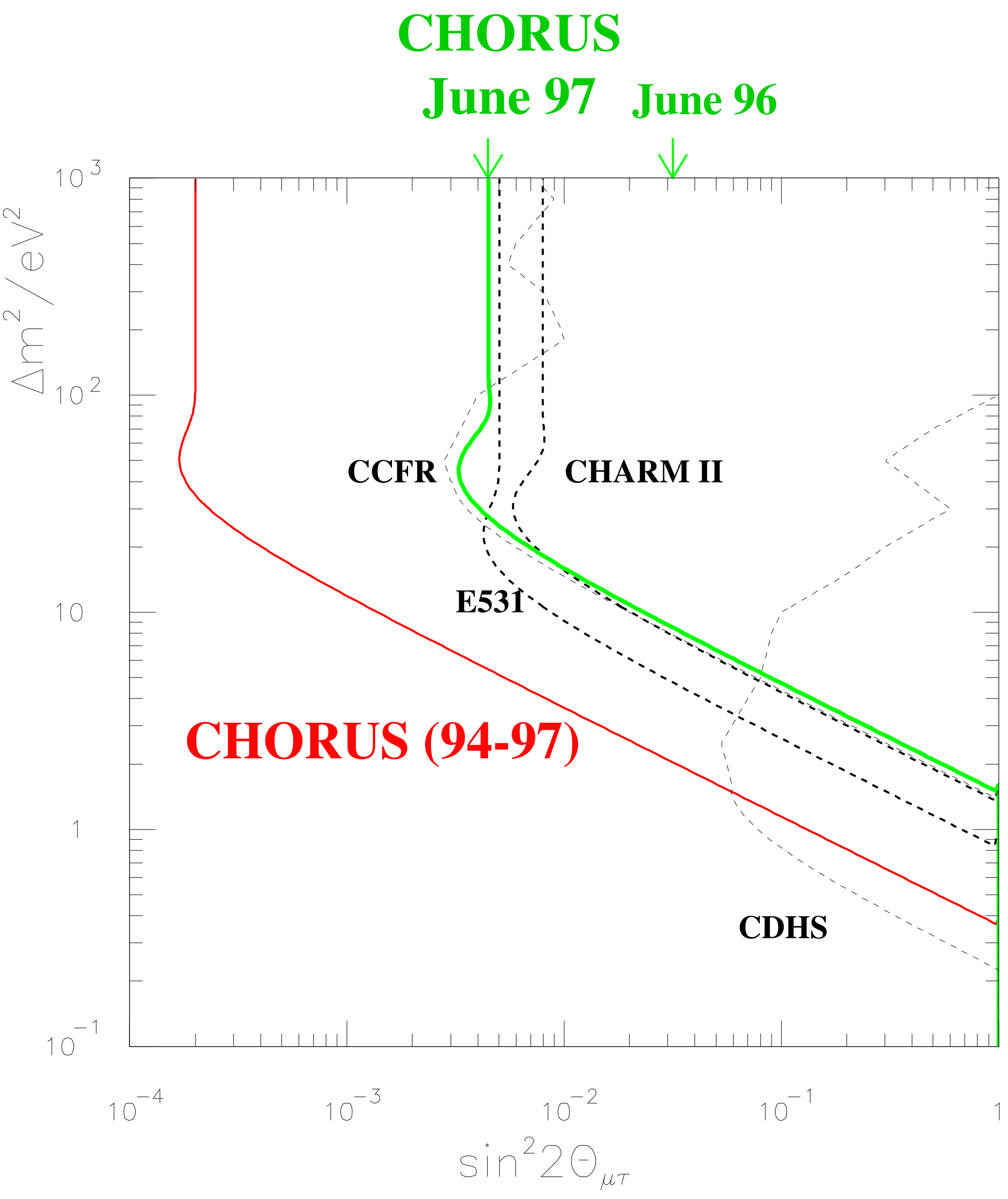
decay mode	$\frac{A_i}{A}$	BR_i	ε_i	r_i
$\tau^- \rightarrow \mu^- \nu_\tau \bar{\nu}_\mu$	1.07	0.17	0.55	1
$\tau^- \rightarrow h^-(nh^0)\nu_\tau$	0.36	0.50	0.26	0.44

Status of Pilot Analysis:

PRELIMINARY

	N	$\sin^2(2\theta)$
June 96	2 622	$3.0 \cdot 10^{-2}$
October 96	7 637	$1.0 \cdot 10^{-2}$
January 97	10 084	$8 \cdot 10^{-3}$
June 97	14 897 (μ) + 1 343 (h^-)	$4.5 \cdot 10^{-3}$

Exclusion Plot



Outlook

Now: ~6 • 10^5 ν-CC events on tape

End of 1997: ~7.3 • 10^5 ν-CC events expected

Expected improvements:

x **10.0** — 1μ: gain due to statistic

x **1.5** — 0 μ included with present efficiency $= (1 + 0.17 \cdot 2.8)$

$\varepsilon_h / \varepsilon_\mu$ — BR_h / BR_μ

x **1.7** — efficiency
vertex location, kink finding...

~ **25.0** — (w. r. t. current 1μ result)

If no candidate

$$\sin^2 2\theta \leq 2 \cdot 10^{-4}$$

can be achieved

Summary

- **Run I successfull (1994/95)**
  - **Emulsion of 1994/95 was developed and is being analysed**
  - **320 000 CC events taken**
  - **Vertex located:** **1μ channel 14 897**
    $1h^-$ channel 1 343

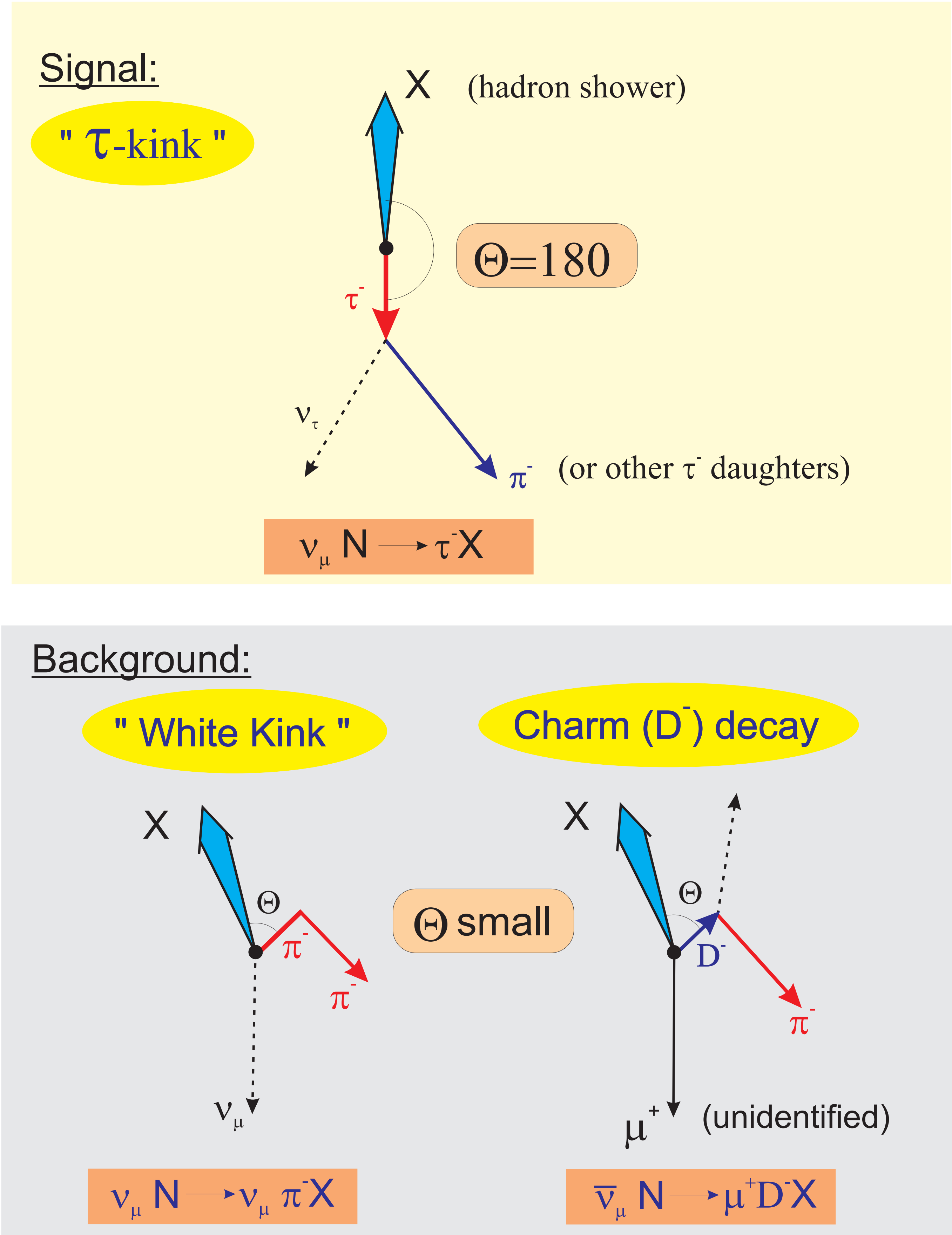
present limit

$$\sin^2(2\theta) \text{ for large } \Delta m^2\text{: } 4.5 \cdot 10^{-3}$$

- **Run II started April 1996**
  - **Intense and stable beam**
  - **High CHORUS efficiency (> 94 %)**
  - **410 000 CC events expected**

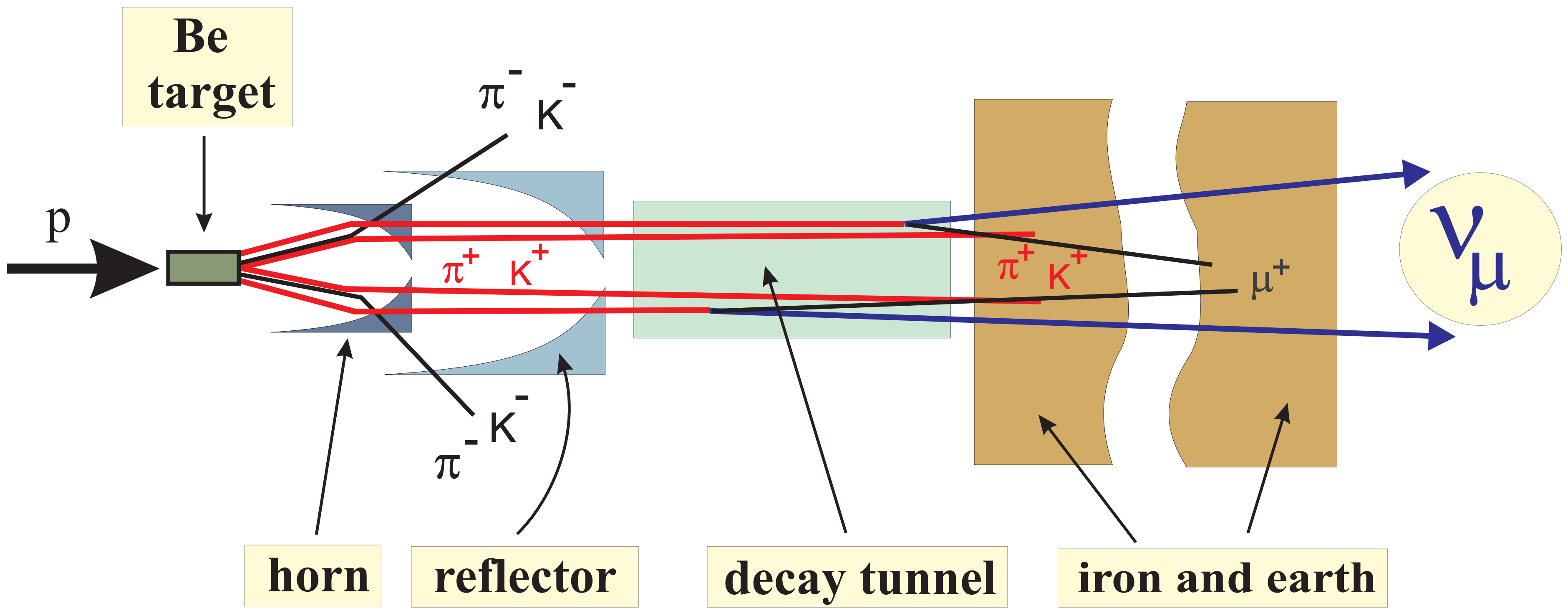
If negative result **RUN I & II**

$$\sin^2(2\theta) \text{ for large } \Delta m^2\text{: } \leq 2 \cdot 10^{-4}$$



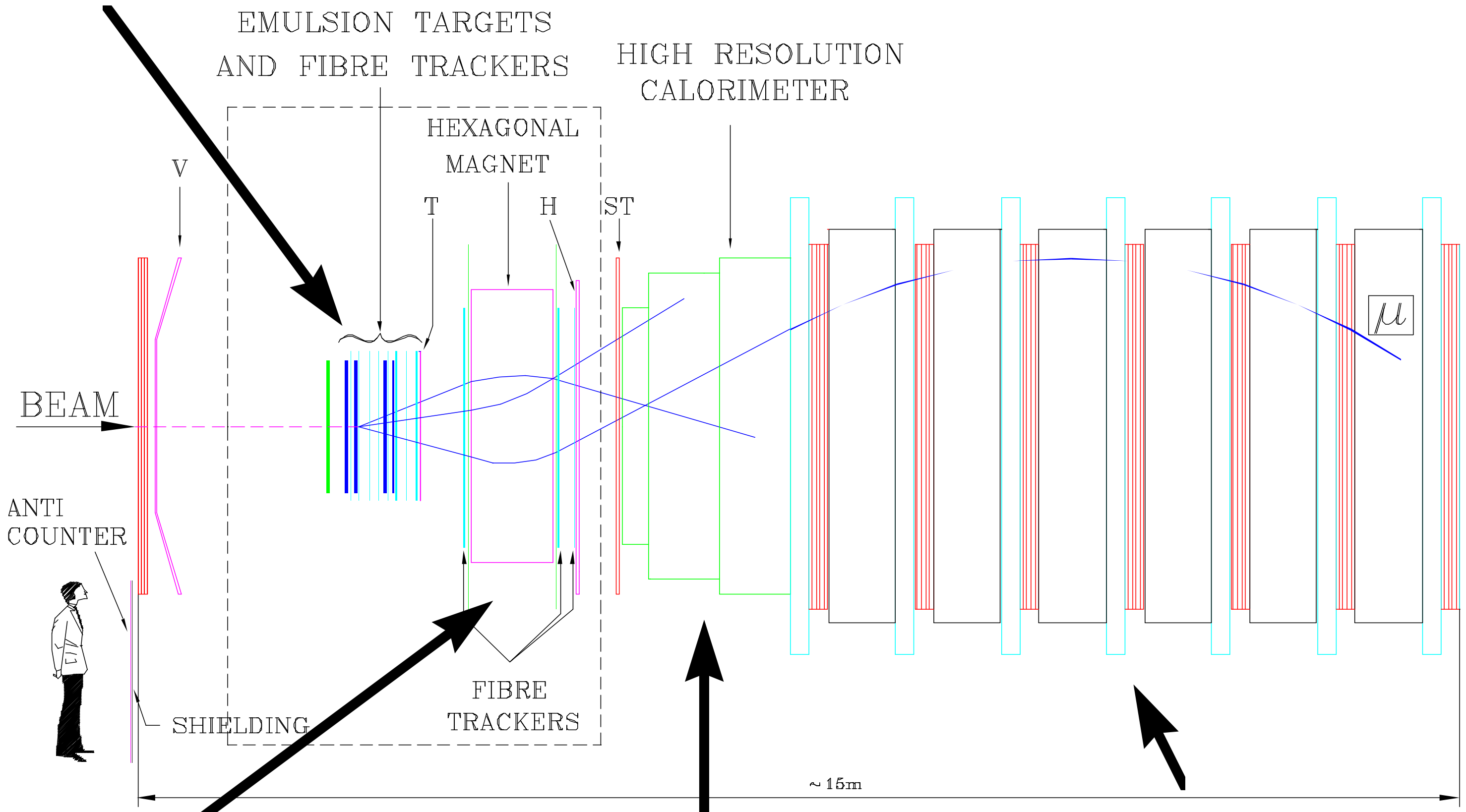
Signal:
" τ-kink "
X
(hadron shower)
Θ=180
τ^-
ν_τ
π^-
(or other τ^- daughters)
$\nu_\mu N \longrightarrow \tau^- X$
Background:
" White Kink "
X
Θ
π^-
π^-
ν_μ
$\nu_\mu N \longrightarrow \nu_\mu \pi^- X$
Θ small
Charm (D^-) decay
X
Θ
D^-
π^-
μ^+
(unidentified)
$\bar{\nu}_\mu N \longrightarrow \mu^+ D^- X$

CERN Wide Band Neutrino Beam



CHORUS Detector

Emulsion Target and Target Tracker



Magnet Spectrometer

q_{had}, p_{had}

$\Delta p/p \sim 0.25$@ 5 GeV/c

Calorimeter

E_{had}, Θ_{had}

$\Delta E/E \sim 0.35/\sqrt{E}$

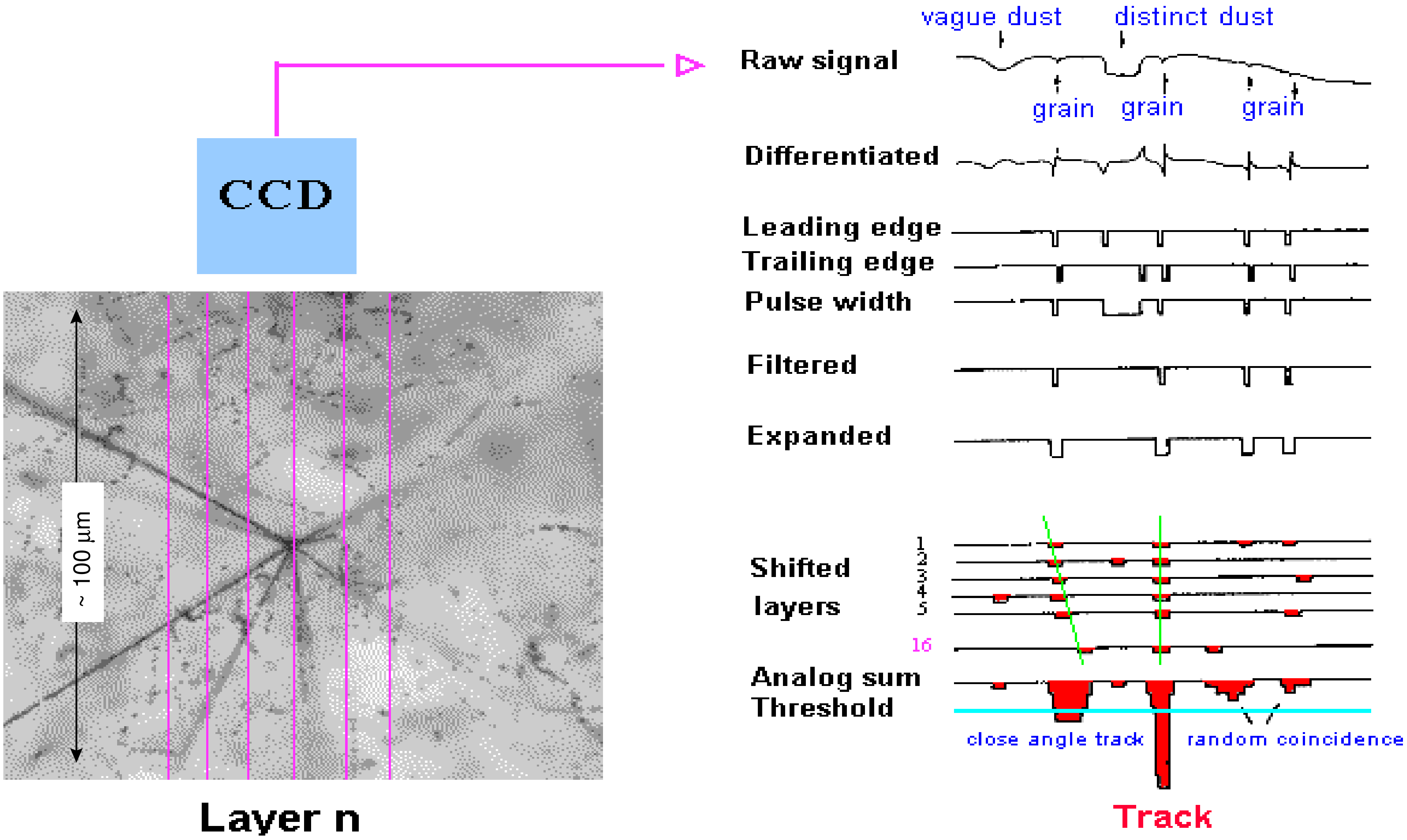
Muon Spectrometer

p_{μ},q_{μ}

$\Delta p/p \sim 10 - 20$

(for p< 100 GeV)

Track Reconstruction



Data taking 1994 - 1996

	1994	*1995*	*1996*
Pot/10^{19}	0.81	1.20	1.38
Chorus efficiency	0.77	0.88	0.94
Potato/10^{19} *)	0.62	1.06	1.30
Deadtime	0.10	0.10	0.13
CC events	120 k	200 k	230 k
main triggers	422 k	547 k	620 k
Trigger rate/10^{13} p	0.68	0.52	0.48
CC per main trigger	0.28	0.37	0.37

*) Protons On Target And Tape On