Requirements and design options for a vertex detector (Si tracker)

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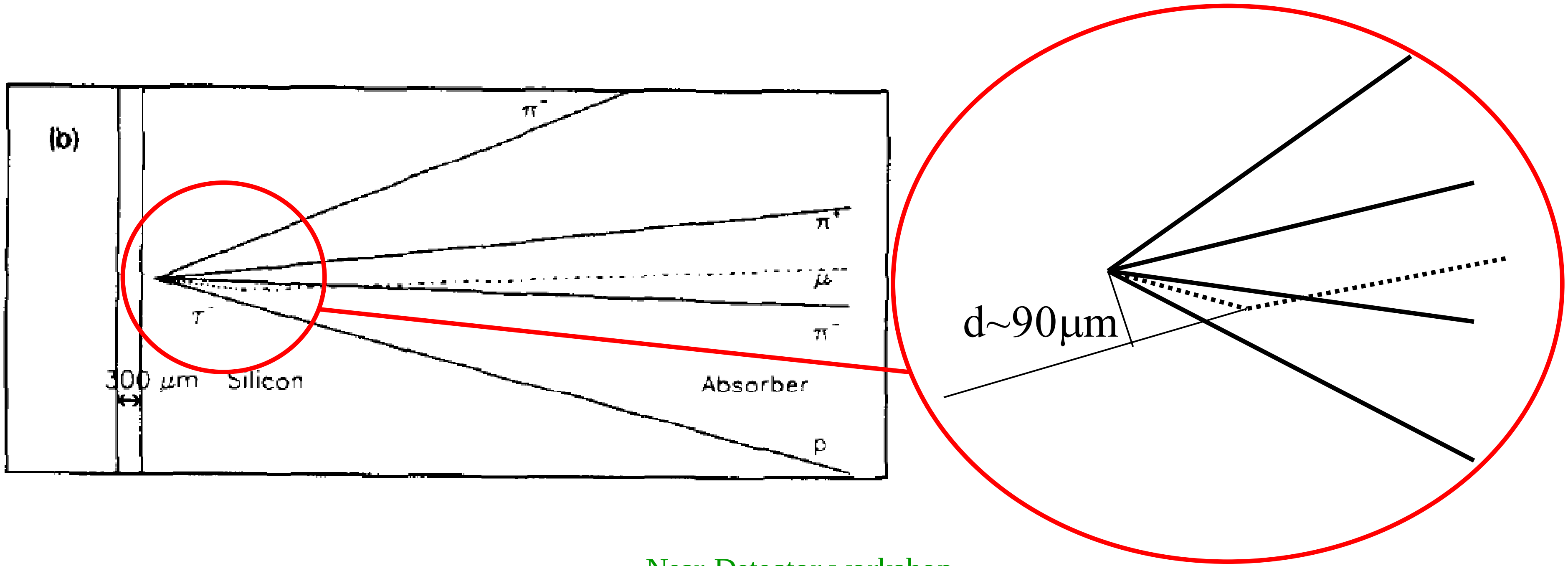
VIA VERITAS VITA

Tau detection techniques

- Currently there are three possible techniques for detecting taus (that I know of):
  - Observation of decay kink of tau: emulsion technique (already discussed by P. Migliozzi) like in OPERA or CHORUS
  - Kinematic technique: used by NOMAD to identify taus through the kinematic analysis of the tau decay
  - Reconstruction of the impact parameter with a dedicated vertex detector (ie. Silicon detector, prototyped by NOMAD-STAR)
- Pasquale has already covered the emulsion technique
- I think that a combination of the two other techniques can be used at a near detector of a neutrino factory.

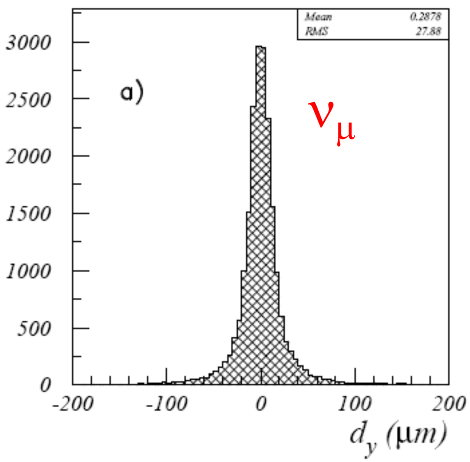
Impact parameter detection of taus

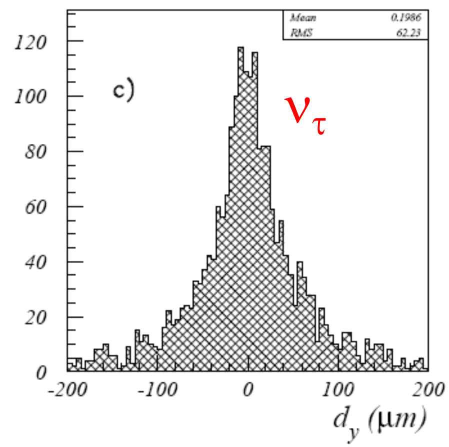
- This was invented by Gomez Cadenas et al.
  - NAUSICAA: (Si vertex detector): NIM A 378 (1996), 196-220
  - ESTAR (Emulsion-Silicon Target): NIM A 381 (1996), 223-235
- Identify tau by impact parameter (for one prong decay of τ) and double vertex (for 3 prong decays)

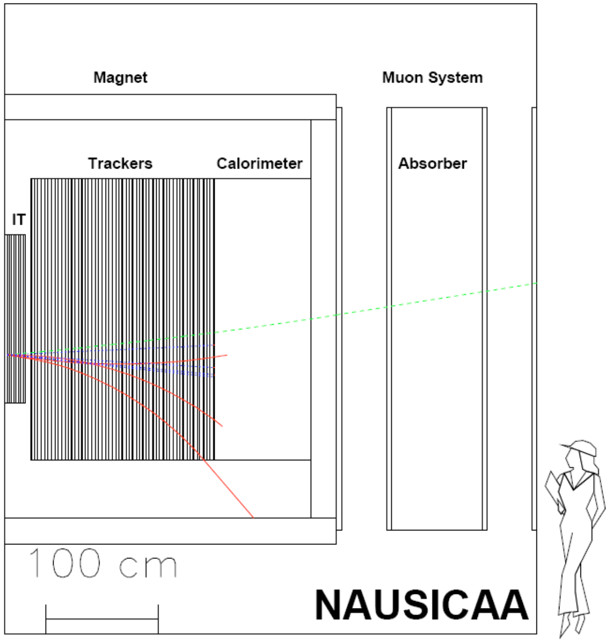


NAUSICAA

- NAUSICAA proposal:
  - Impact parameter resolution ν_μ-CC=28μm
  - Impact parameter resolution ν_τ-CC=62μm







- Efficiencies:
  - $\tau \rightarrow \mu$: ε=10%
  - $\tau \rightarrow \pi(n\pi^0)$: ε=10%
  - $\tau \rightarrow \pi\pi\pi(n\pi^0)$: ε=23%
  - Total eff:

ε=0.85x10%+0.15x23%=12%

  - σ_τ/σ_μ=0.29

- Sensitivity at Main Injector with $2\text{x}10^7$ ν_μ CC interactions (MINSIS):

$$P_{osc}(\nu_\mu \rightarrow \nu_\tau) < \frac{2.48}{2\times10^7\times0.12\times0.29} = 3.6\times10^{-6}$$

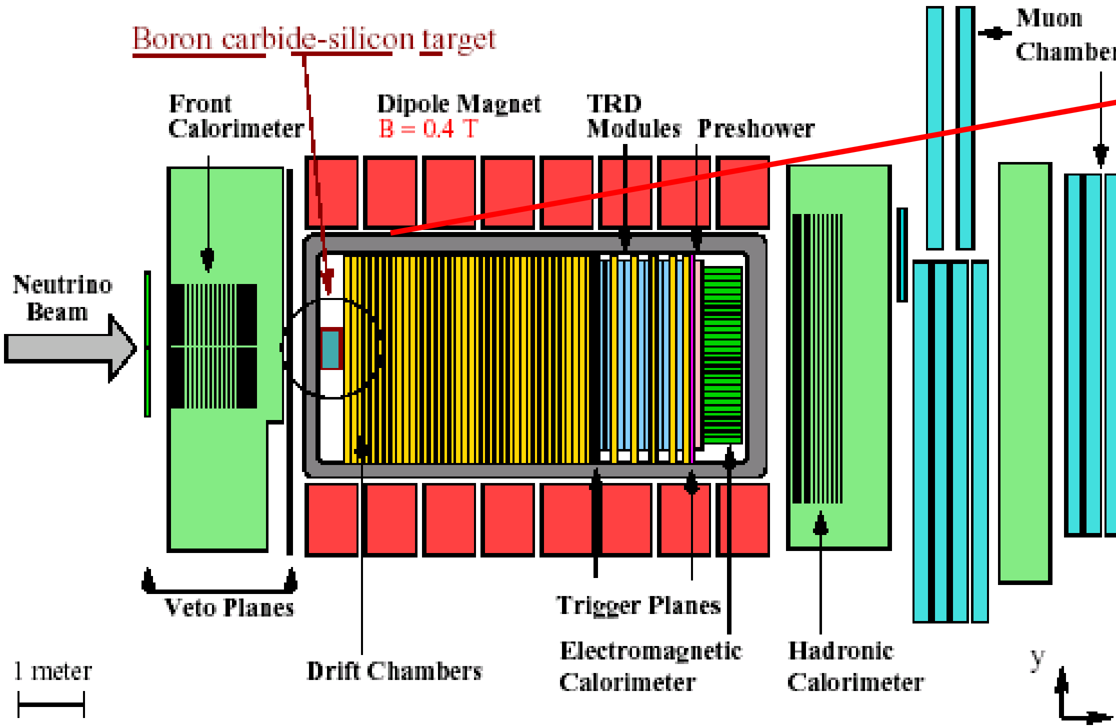
- Intrinsic limit tau production $D_s \rightarrow \tau\nu_\tau$:
  - $3.5\text{x}10^{-6}$ at 450 GeV
  - $1.3\text{x}10^{-6}$ at 350 GeV
  - $9.6\text{x}10^{-8}$ at 120 GeV

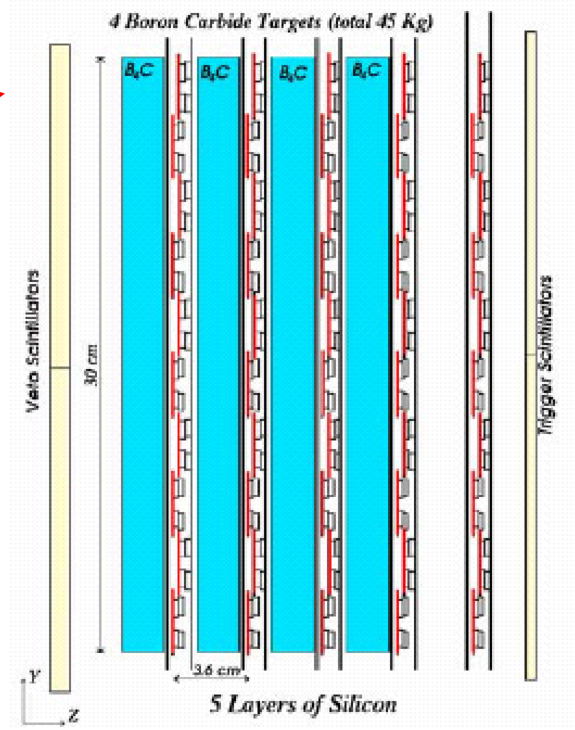
PRD 55, (1997),1297. NIMA 385 (1997), 91.

NOMAD-STAR

- R&D in NOMAD for short baseline ν_τ detector based on silicon:
  NOMAD-STAR (NIMA 413 (1998), 17; NIMA 419 (1998), 1; NIMA 486 (2002), 639; NIMA 506 (2003), 217.)

Silicon TARget - STAR



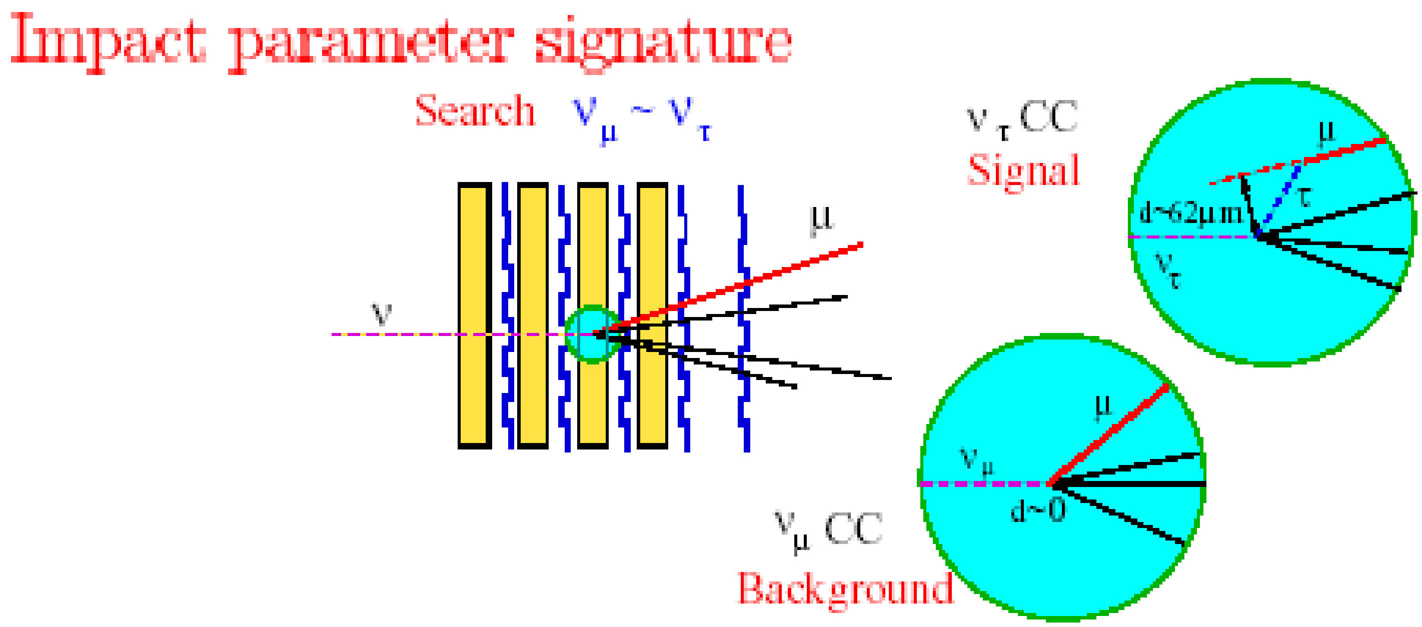


- Total mass: 45 kg of B_4C target (largest density 2.49 g cm^{-3} for lowest X_0=21.7 cm.)

1.14 m^2 silicon area

NOMAD-STAR

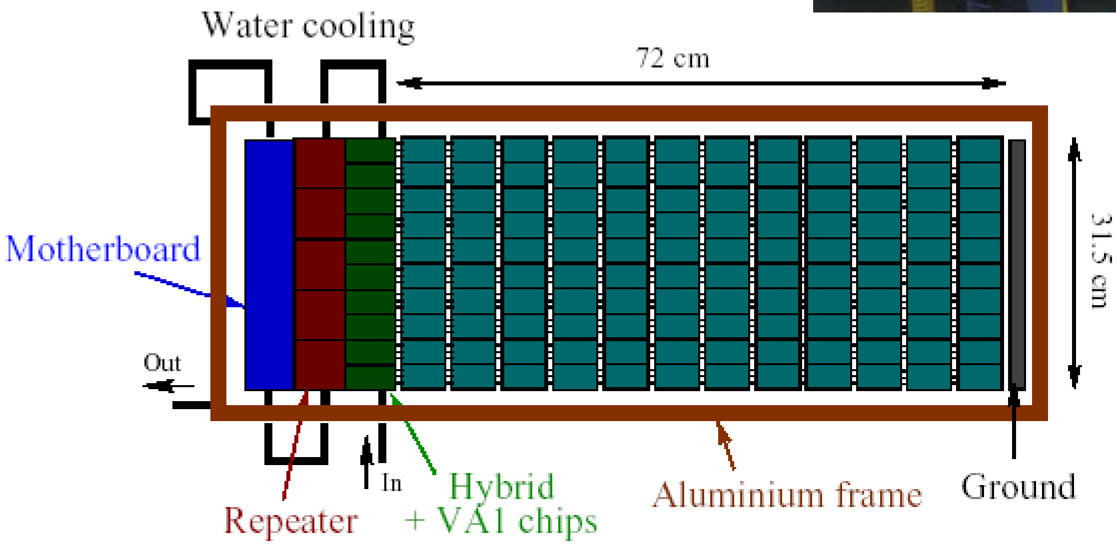
- Aim of NOMAD-STAR: reconstruct short lived particles in a neutrino beam to determine capabilities ν_τ detection: use impact parameter signature of charm decays to mimic ν_τ



- τ impact parameter ~ 62 μm, normal ν_μ charged current (CC) interactions ~30 μm

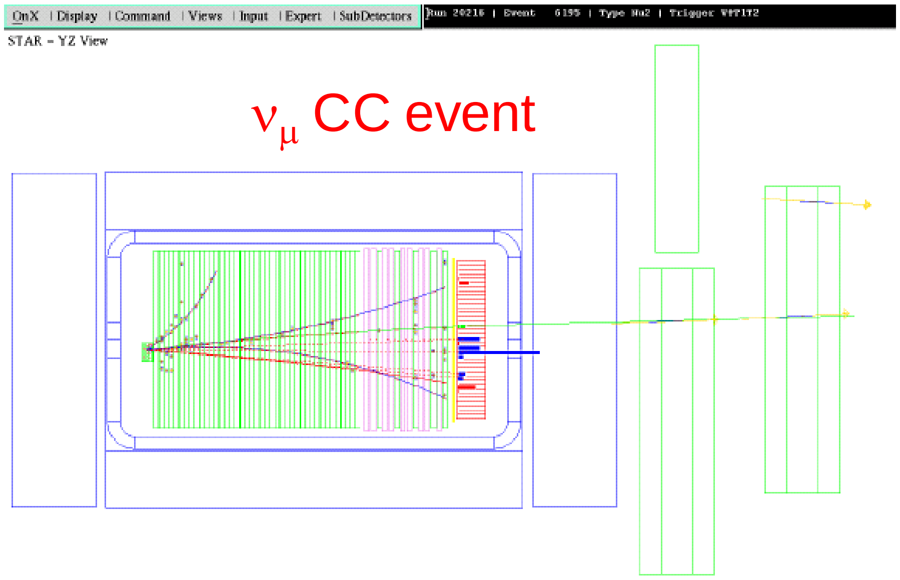
NOMAD-STAR

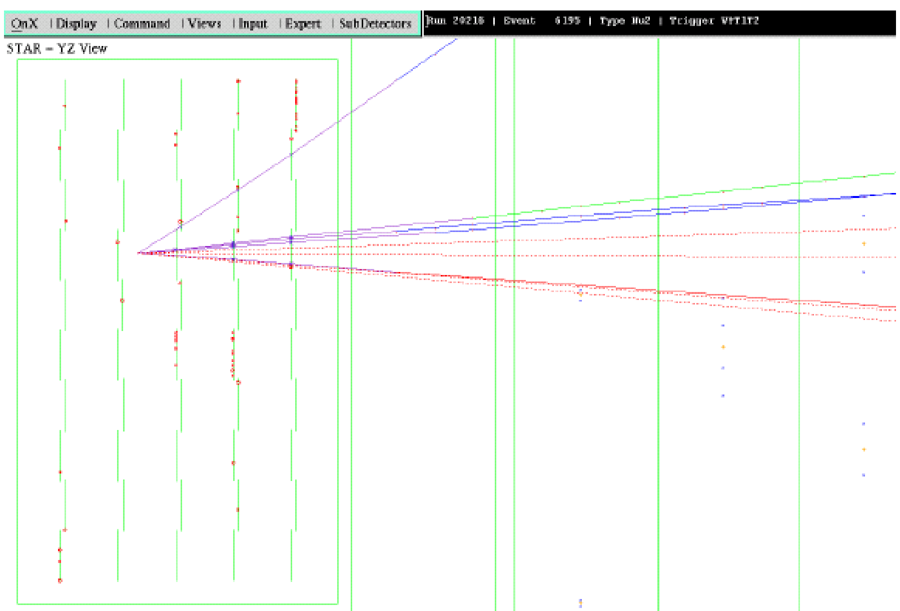
- Longest silicon microstrip detector ladders ever built: 72cm, 12 detectors, S/N=16:1
- Hamamatsu Si Detectors: 300 μm thick, 25 μm pitch, 50 μm readout (640 channels) – total 32,000 channels
- VA1 readout: 3 μs shaping



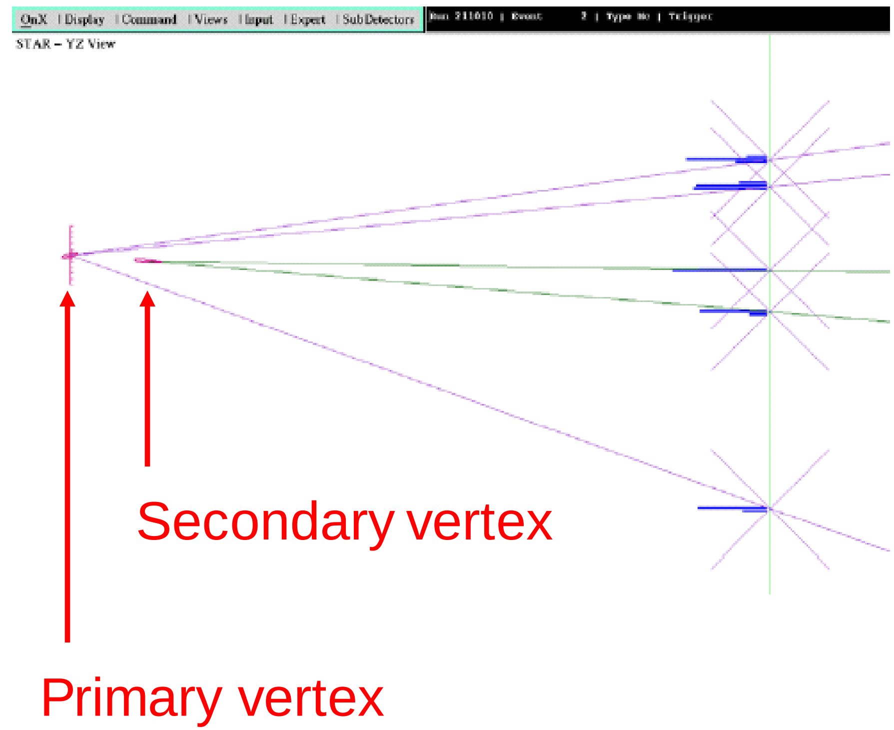
1990s technology: could do much better with LHC type technology and readout

NOMAD-STAR



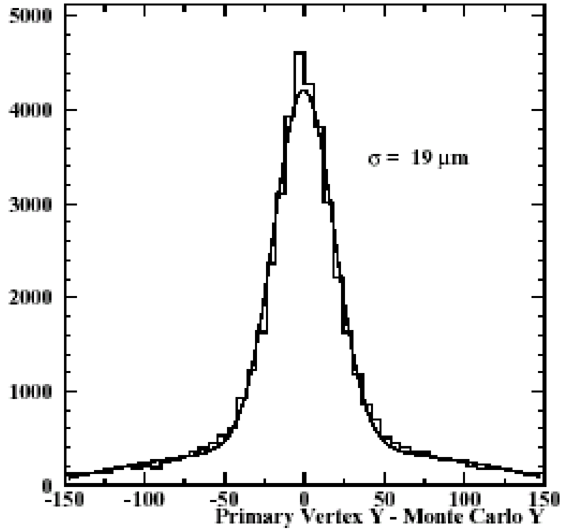


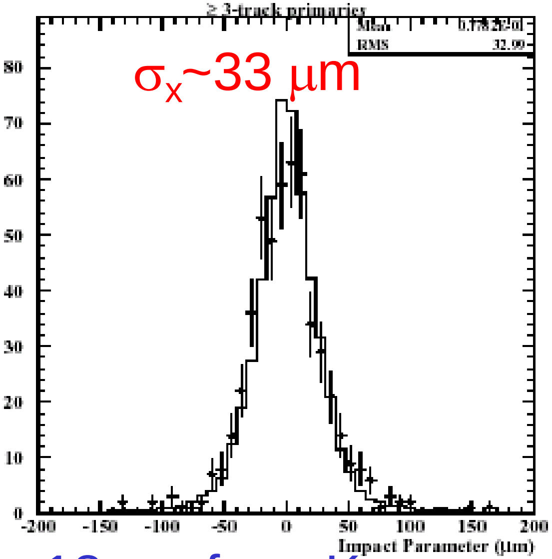
D^0 Monte Carlo Event

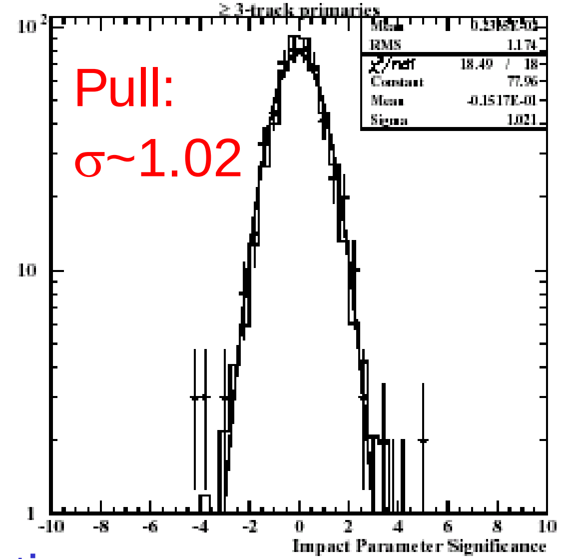


NOMAD-STAR

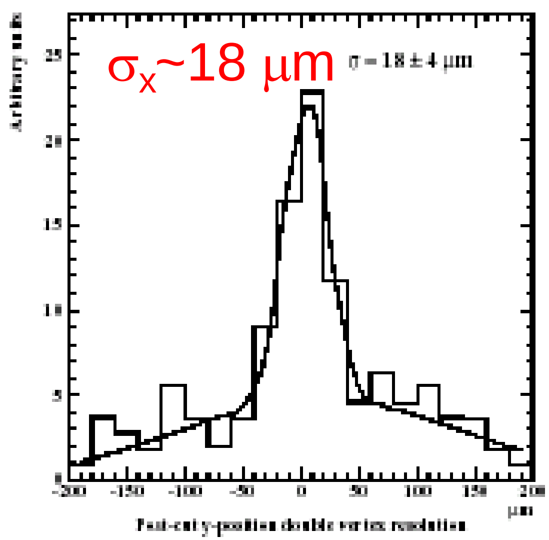
- Vertex resolution: σ_y = 19 μm
- Impact parameter resolution: 33 μm

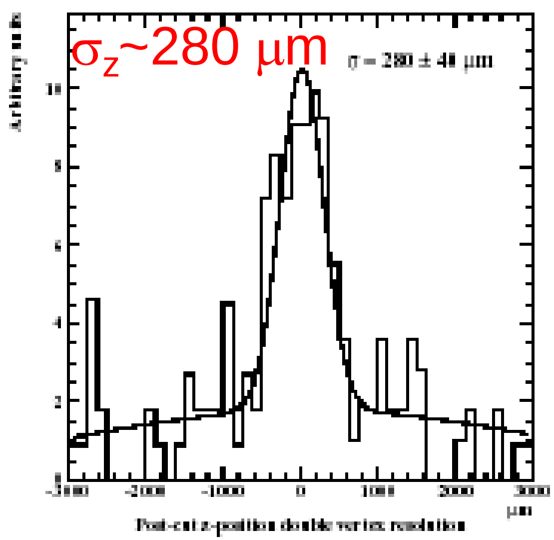






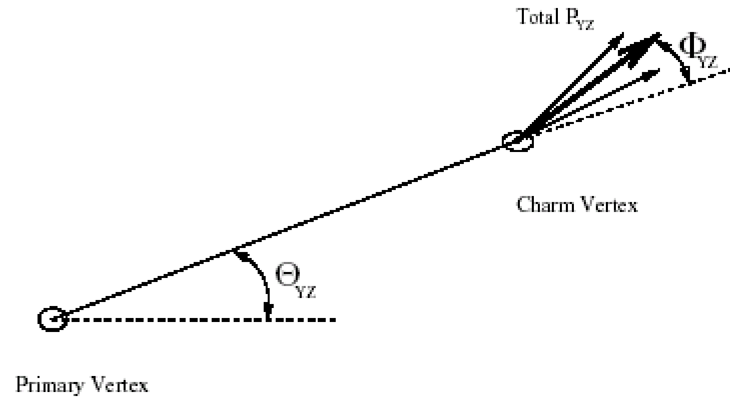
- Double vertex resolution: 18 μm from K_s reconstruction



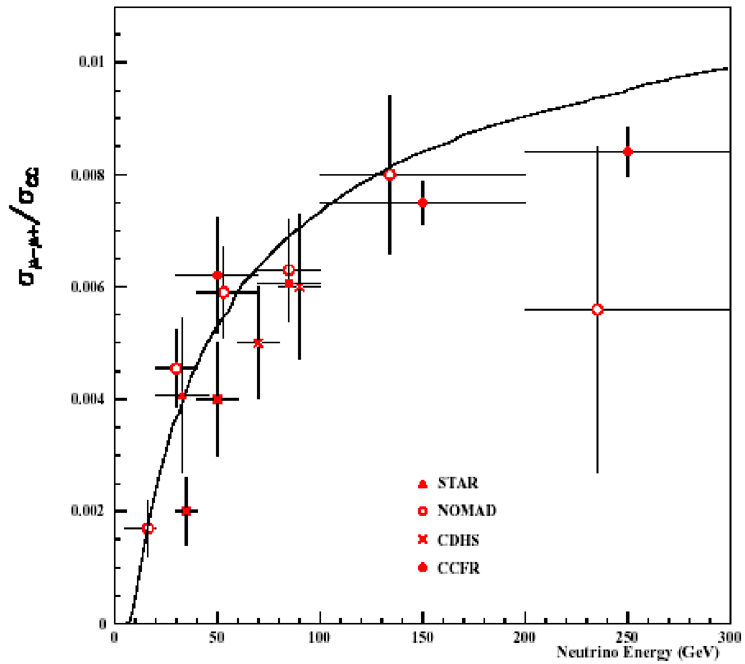


NOMAD-STAR

- Charm event reconstruction:
  - Implementation of Kalman filter
  - Constrained fit method: extract charm signatures for each charm mass
- Used NOMAD-STAR to search for charm events: marginal statistical accuracy, but was a good proof of principle

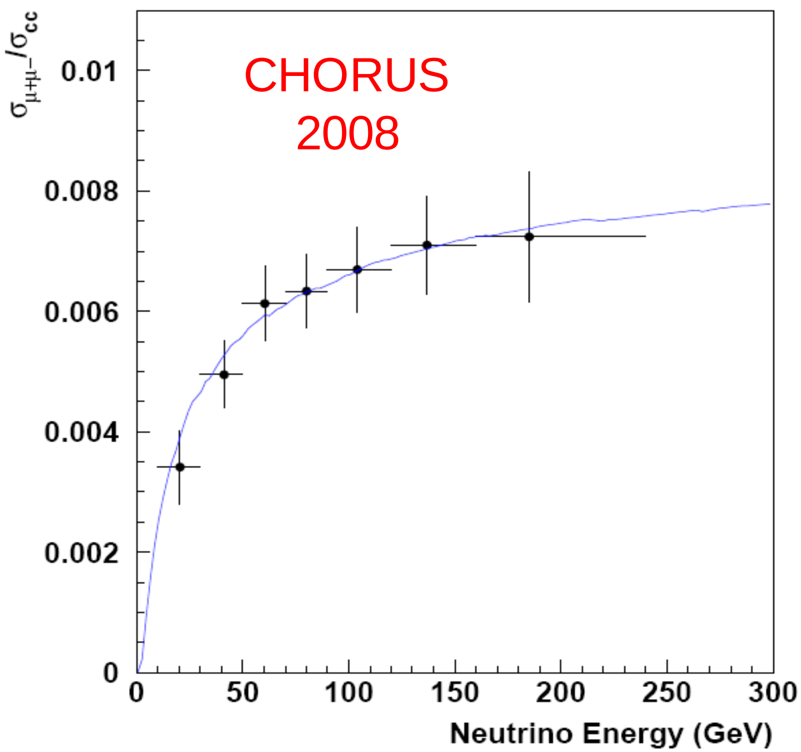


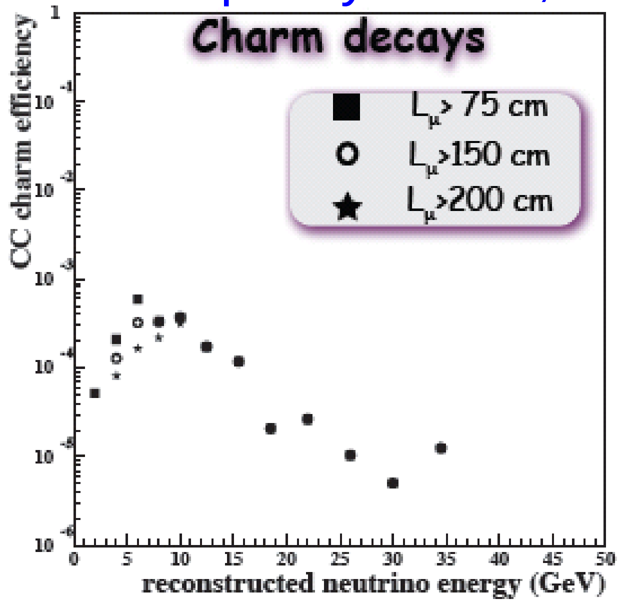
Meson	Num events	Back-ground	Production Rate	Efficiency
D^0	24	13.3	13.3±1.0%	3.5%
D^+	10	3.8	3.8±0.5%	3.5%
D_s^+	11	5.2	5.2±0.6%	12.7%
Total	45	22.3	7.2±2.4%	



Charm measurement at Near Detector

- Amongst other things, we need to measure charm cross-section to validate size of charm background in wrong-sign muon signature
- Charm cross-section and branching fractions poorly known, especially close to threshold

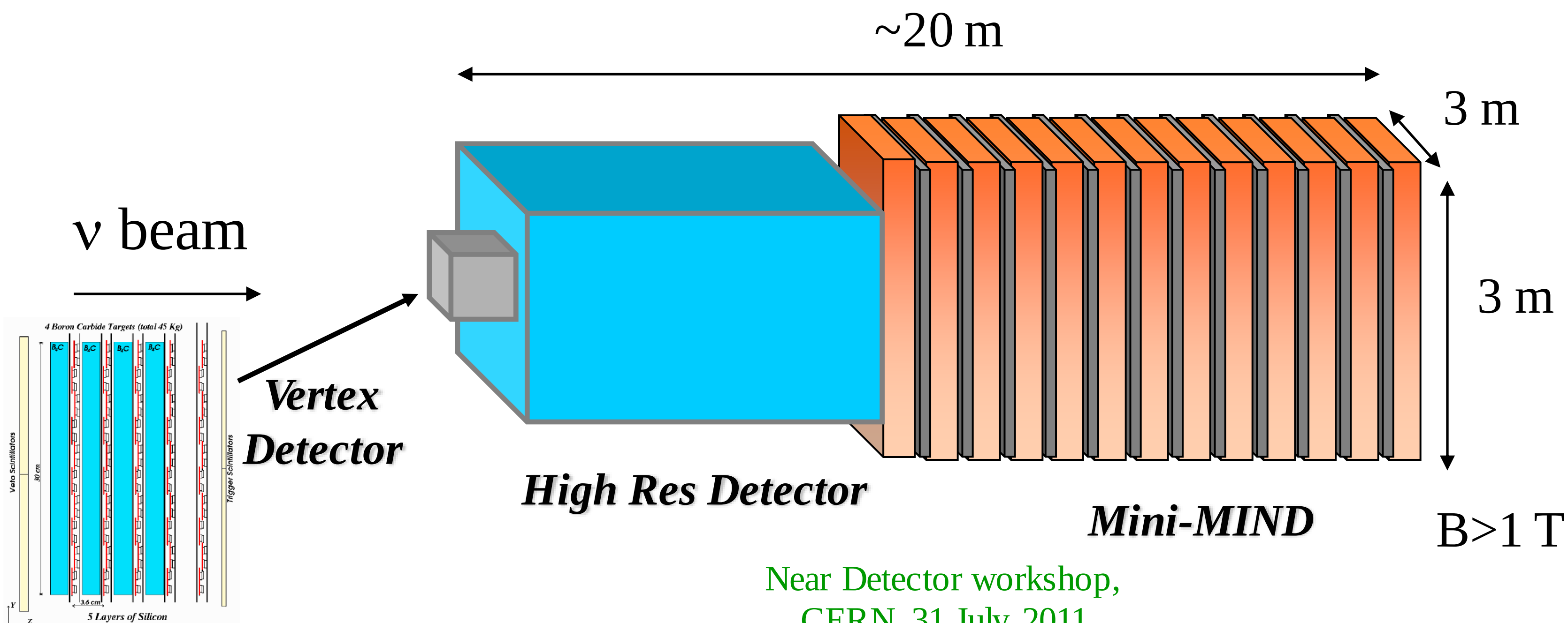




- Semiconductor vertex detector only viable option in high intensity environment (~10^9 ν_μ CC events/year)
- Very hard for emulsion and liquid argon TPC, since rate so high

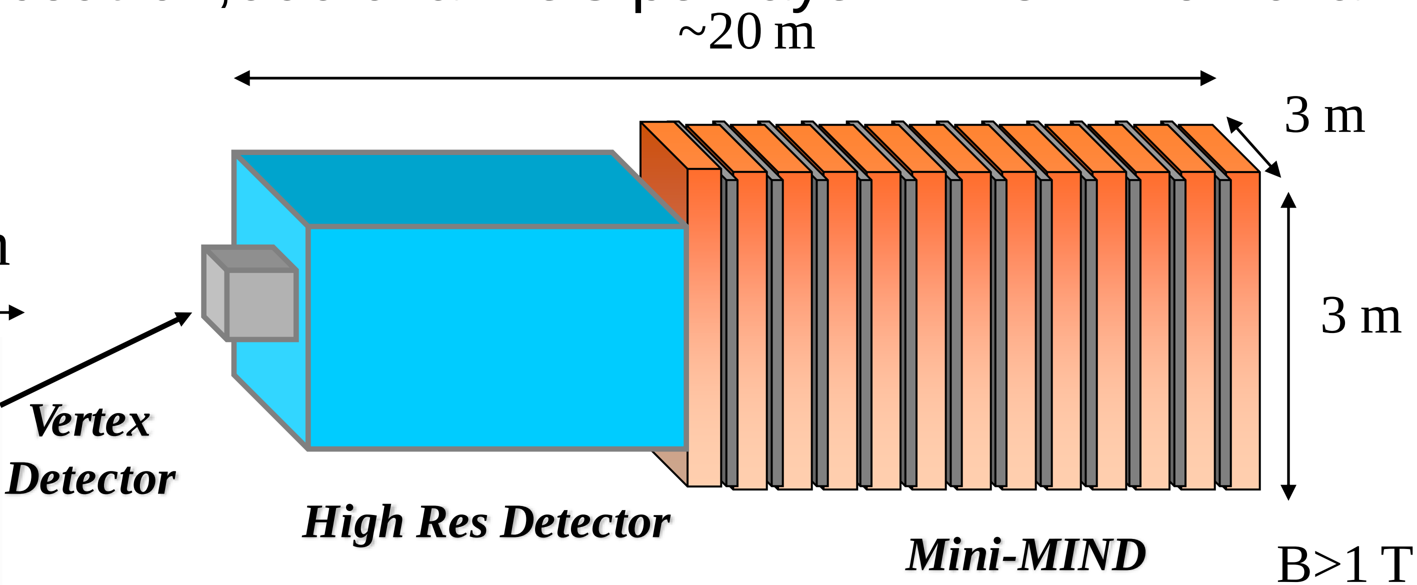
Near Detector Block Diagram

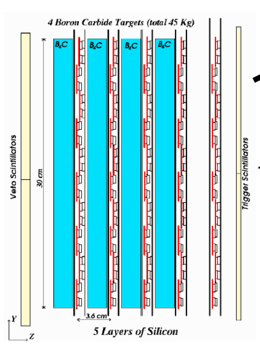
- Near Detector design will need three sections:
  - Vertex detector for charm/tau measurement at the front.
  - High resolution section (SciFi tracker or TRT tracker) for leptonic flux measurement
  - Mini-MIND detector for flux and muon measurement



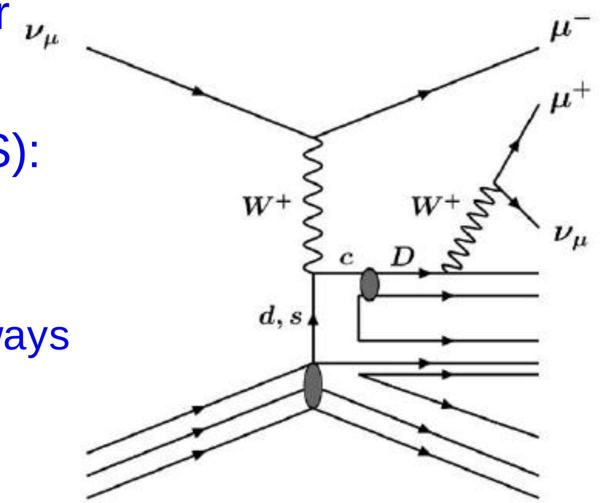
Vertex detector dimensions

- Vertex detector:
  - Assume: $150 \times 150 \times 2\,cm^3$ per layer of B_4C ($2.49\ g/cm^3$) and 18 layers: total mass = 2.02 tonnes
  - Assume 20 layers of silicon: $45\ m^2$ of silicon
  - Assume silicon strip detectors but could be pixels
  - About 64,000 channels per layer: 1.28 million channels





Charm and tau measurements



- Rates: approx 10^9 ν_μ CC events/year in 1 ton detector
- Assume 12% eff from NAUSICAA
- Inclusive charm production at 27 GeV (from CHORUS): 6.4±1.0%
  - From 10-30 GeV: ~4%→4x10^7 charm events!!
  - Charm produced in CC reaction with d or s quark so always have lepton
  - Associated charm in NC interaction (see charm review De Lellis et al. Phys Rep 399 (2004), 227-320)
- For tau measurement we would use the same analysis
  - We would do a search for $\nu_\mu \rightarrow \nu_\tau$ and search for τ^-
  - However, there is anti-ν_e background that can create D^- which looks like signal, but need to identify e^+ to reject background!!!
- So, very important to have light detector with B-field (ie Scintillating Fibre tracker) behind vertex detector to identify positron with high efficiency:
  - We would have to reject positron background using a similar analysis to that used for MIND: use a mixture of isolation and kinematic techniques to reject background (ie. In MIND we rejected ν_e background at 10^{-6} but this was in iron. Assuming no background:

$$P(\nu_\mu \rightarrow \nu_\tau) < \frac{2.48}{10^9 \times 0.12 \times 0.29} = 7.1 \times 10^{-8}$$

Very tough: probably overestimate in efficiency since background rejection will affect it

Conclusions

- We can use a vertex detector to identify charm at a NF near detector
- Use impact parameter for for one prong events and vertex detection for two prong events
- Efficiencies and proof of principle demonstrated in NOMAD-STAR: successful detection of charm
- Can achieve two tons of a passive target with silicon strip detectors (45 m^2 of silicon, 1.3M channels): not overly challenging in LHC era
- No problems at all to measure charm and charm species
- More challenging to do tau searches due to charm background, but need to perform full analysis to determine sensitivities to NSI: $P_{\mu\tau} < 7 \times 10^{-8}$?