Near Detector Tasks

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Paul Soler

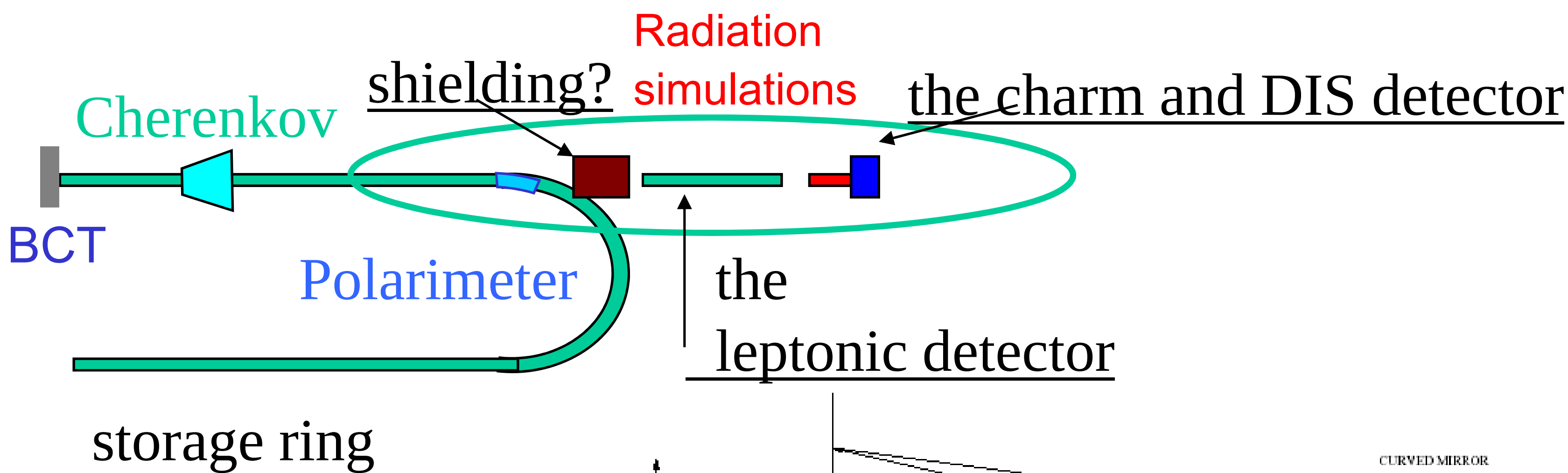
University of Glasgow

Near Detector and Beam Diagnostics aims

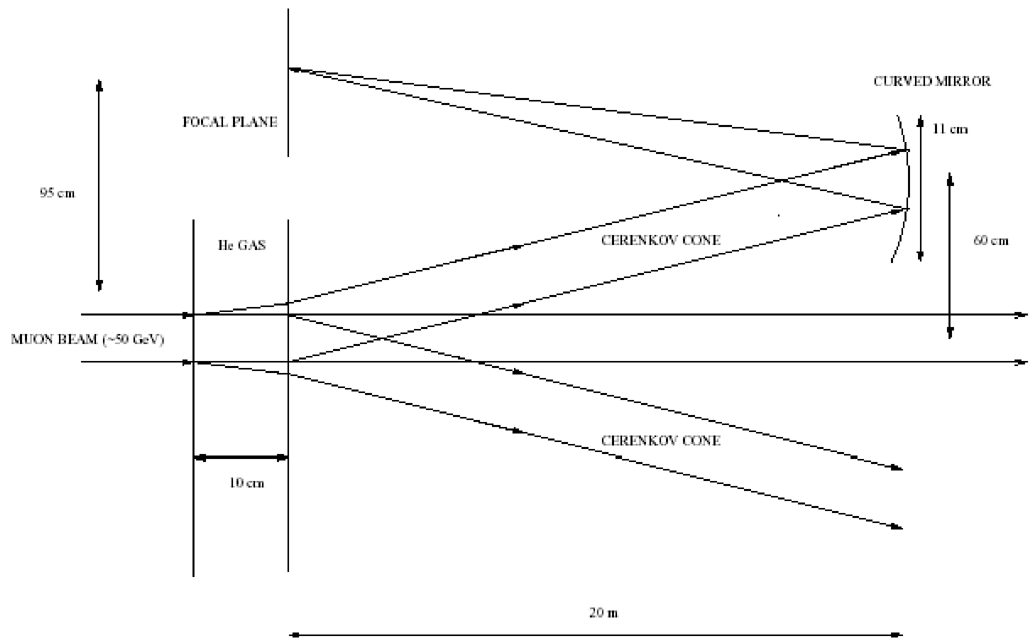
- Beam diagnostics (needed for flux measurement) – Neutrino Factory
  - Number of muon decays
  - Measurement of divergence
  - Measurement of Muon polarization
- Near detector measurements needed for neutrino oscillation systematics:
  - Flux control for the long baseline search.
  - Measurement of charm background – also search for taus from NSI?
  - Cross-section measurements: DIS, QES, RES scattering
- Other near detector neutrino physics (electroweak and QCD):
  - $\sin^2\theta_W$ - $\delta\sin^2\theta_W$?
  - Unpolarised Parton Distribution Functions, nuclear effects
  - Polarised Parton Distribution Functions – polarised target
  - Lambda (Λ) polarisation
  - α_S from xF_3 - $\delta\alpha_S$?
  - Charm production: $|V_{cd}|$ and $|V_{cs}|$, CP violation from $D^0/\bar{D}^0$ mixing?
  - Beyond SM searches – (taus?)
  - …

Beam Diagnostics (ISS report)

- Beam Current Transformer (BCT) to be included at entrance of straight section: large diameter, with accuracy ~10^{-3}.



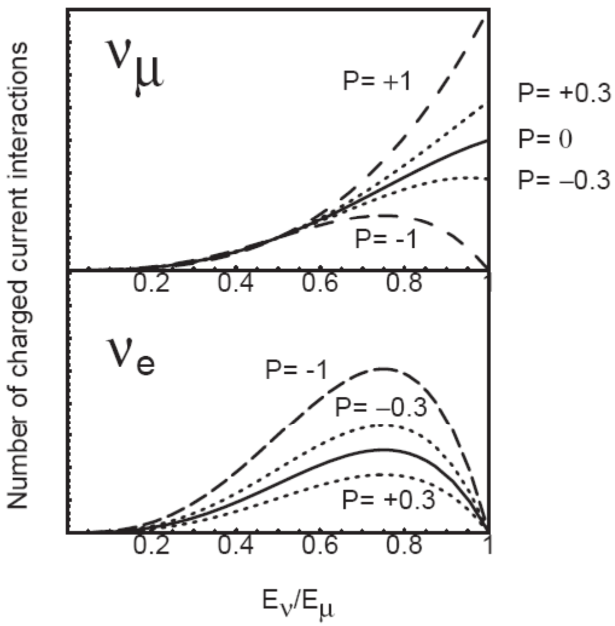
- Beam Cherenkov for divergence measurement? Could affect quality of beam.

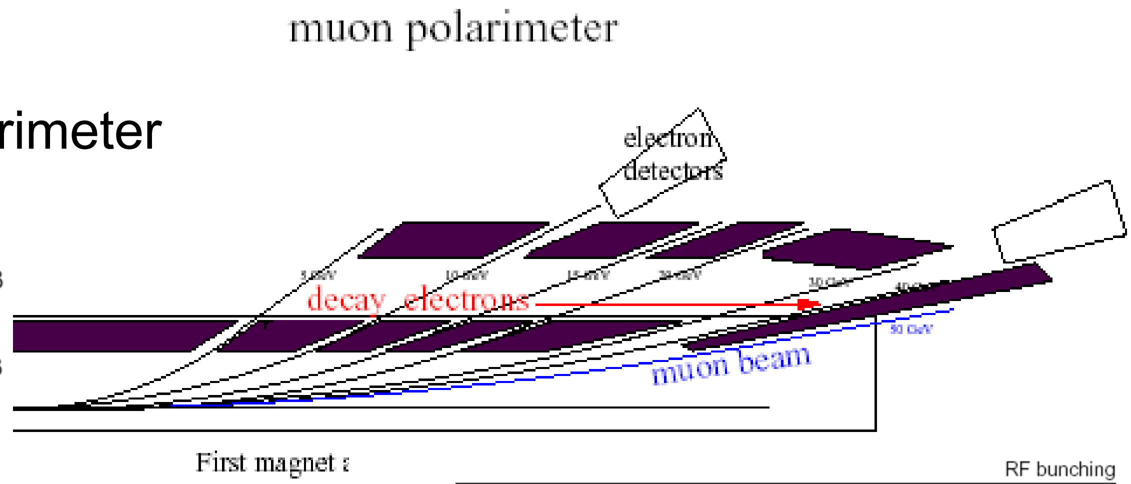


Beam Diagnostics (ISS report)

- Muon polarization:

  Build prototype of polarimeter



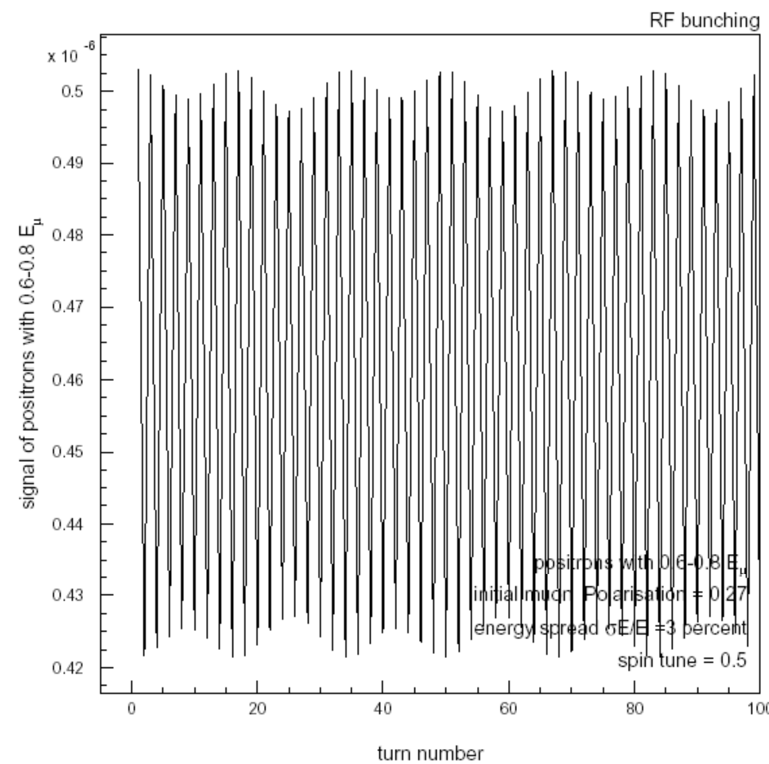


Fourier transform of muon energy spectrum

amplitude=> polarization

frequency => energy

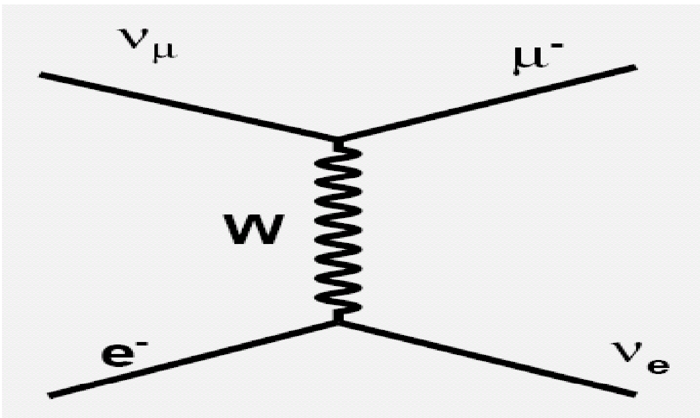
decay => energy spread.



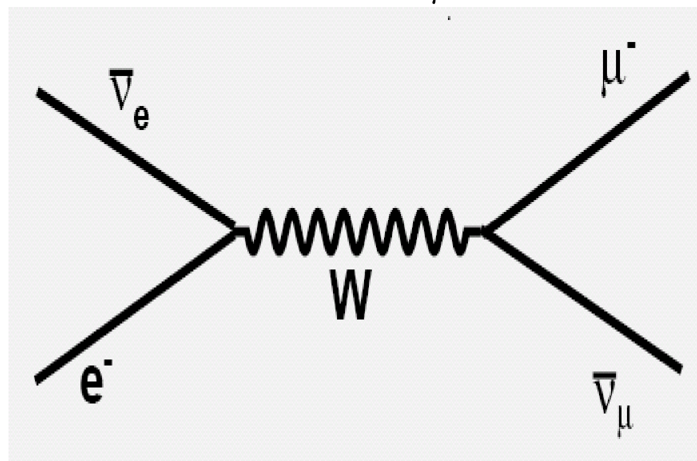
Flux Measurement at Near Detector

- Best possibility: Inverse Muon Decay scattering off electrons in the near detector

$$\nu_\mu + e^- \rightarrow \nu_e + \mu^-$$



$$\overline{\nu}_e + e^- \rightarrow \overline{\nu}_\mu + \mu^-$$



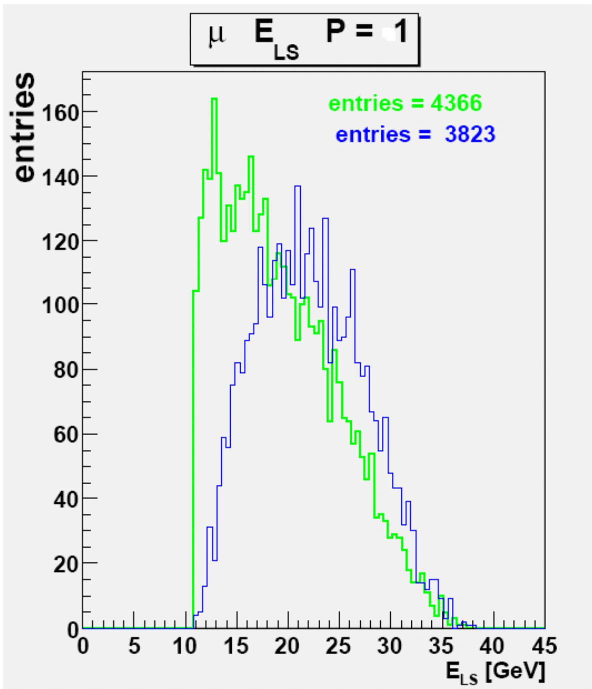
Well known cross sections in Standard Model (with 0.1% accuracy)

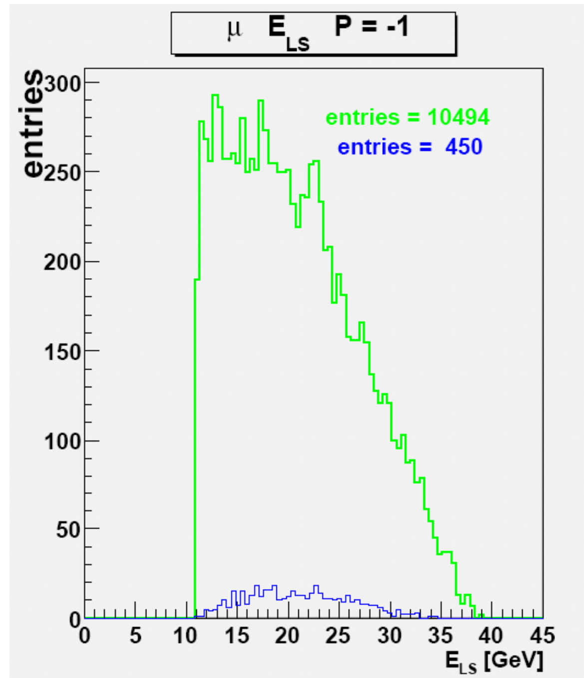
$$\sigma(\nu_\mu e^-) = \frac{G_F^2}{\pi}\frac{(s - m_\mu^2)^2}{s}$$

$$\sigma(\overline{\nu}_e e^-) = \frac{2G_F^2}{\pi}\frac{(s - m_\mu^2)^2}{s^2}\left(E_e E_\mu + \frac{1}{3}E_{\nu 1}E_{\nu 2}\right)$$

Flux Measurement at Near Detector

- Energy spectra for ν_μ (green) and anti ν_e (blue) for 10^{21} μ decays/year, Mass ~1 ton, 400 m long section.





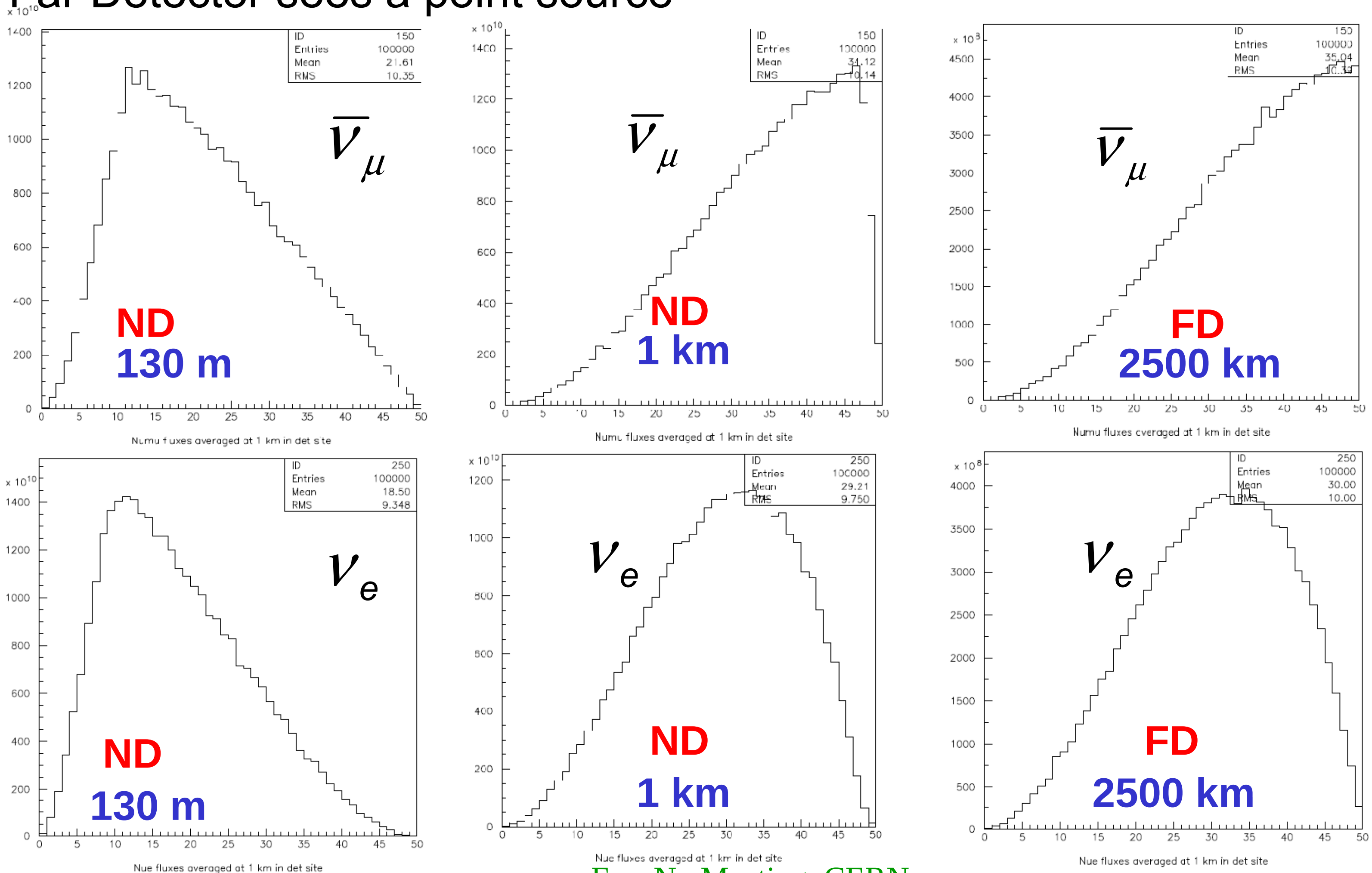
E_μ = 40 GeV.

Need to redo:
- **E_μ=25GeV**
- **Baseline storage ring straight section (755 m)**
- **Perform proper event selection**

	$\nu_\mu + e^- \rightarrow \nu_e + \mu^-$	$\overline{\nu_e} + e^- \rightarrow \overline{\nu_\mu} + \mu^-$	$\nu_\mu N$
E = 40GeV , P = 1	6.87×10^5	5.81×10^5	1.92×10^9
E = 40GeV , P = -1	1.67×10^6	6.97×10^4	2.81×10^9
E = 30GeV , P = 1	2.02×10^5	1.97×10^5	1.32×10^9
E = 30GeV , P = -1	5.89×10^5	1.60×10^4	1.91×10^9
E = 20GeV , P = 1	1.83×10^4	1.14×10^4	8.07×10^8
E = 20GeV , P = -1	7.83×10^4	7.76×10^2	1.14×10^9

Flux Observed by Near Detector

- Near Detector sees a line source (755 long decay straight)
- Far Detector sees a point source



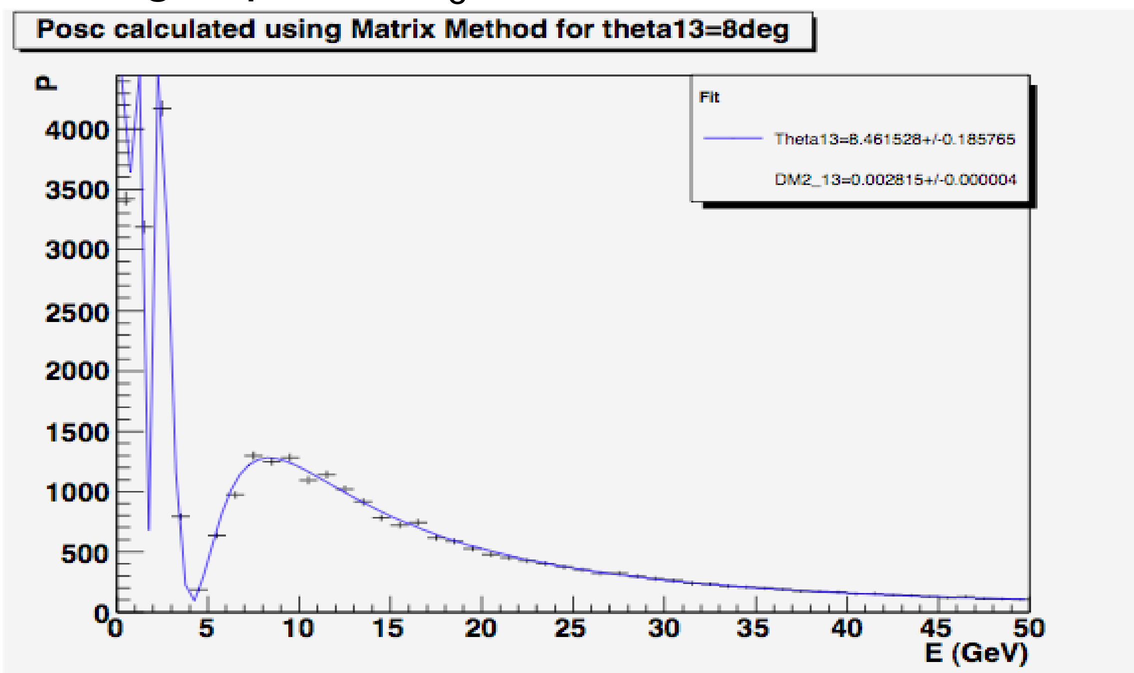
Near Detector flux used to extract $P\nu_e\nu_\mu$

- Original idea: use matrix method with Near Detector data (even if spectrum not identical in near and far detector!) to extract oscillation probability:

$$P_{\nu_e \nu_\mu} = M_2^{-1} M M_1 M_{nOsc}^{-1}$$

Two matrix inversions!

- Where: M_1=matrix relating event rate and flux of ν_e at ND (x-section + det)
  M_2=matrix relating event rate and flux of ν_μ at FD (x-section + det)
  M=matrix relating measured ND ν_e rate and FD ν_μ rate (measured!)
  M_{nOsc}=matrix relating expected ν_e flux from ND to FD (extrapolation)
- Method works well but two inversions affects fit convergence



Probability of oscillation determined by matrix method under "simplistic" conditions. Need to give more realism to detector and matter effects.

Near Detector flux used to extract $P\nu_e\nu_\mu$

- Now we calculate in stages: ND simulated data to predict ND flux

$$\Phi_{ND,predict} = M_1^{-1} N_{ND}$$

$\sigma_{ND}/E \sim 35\%/\sqrt{E}$

where: M_1=matrix relating event rate and flux of ν_e at ND

- Extrapolate ND flux to FD: M_{nOsc}=matrix relating ν_e flux from ND to FD

$$\Phi_{FD} = M_{nOsc} \Phi_{ND,predict}$$

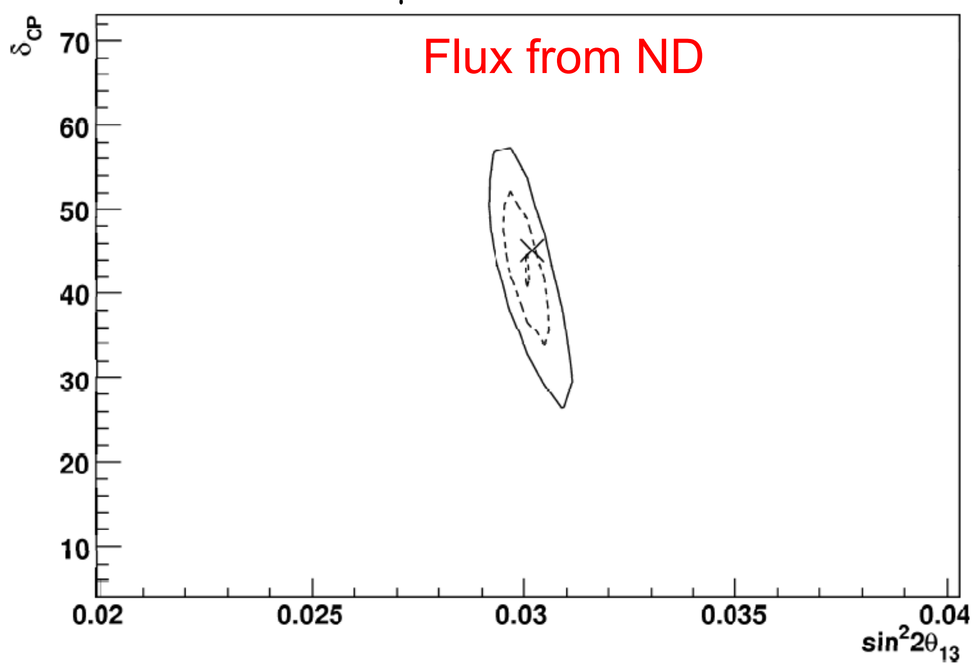
No oscillations

- Extract FD interaction rate: $N_{FD} = M_2 P_{\nu_e \nu_\mu} \Phi_{FD}$

M_2=matrix relating event rate and flux of ν_μ at FD, $\sigma_{FD}/E \sim 55\%/\sqrt{E}$

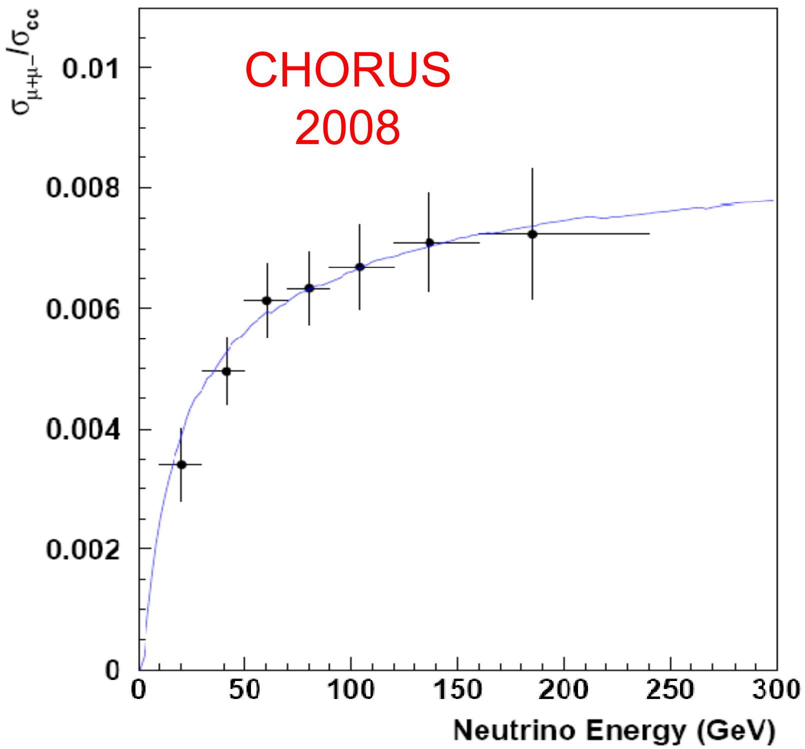
$P_{\nu_e \nu_\mu}$ = prob oscillation

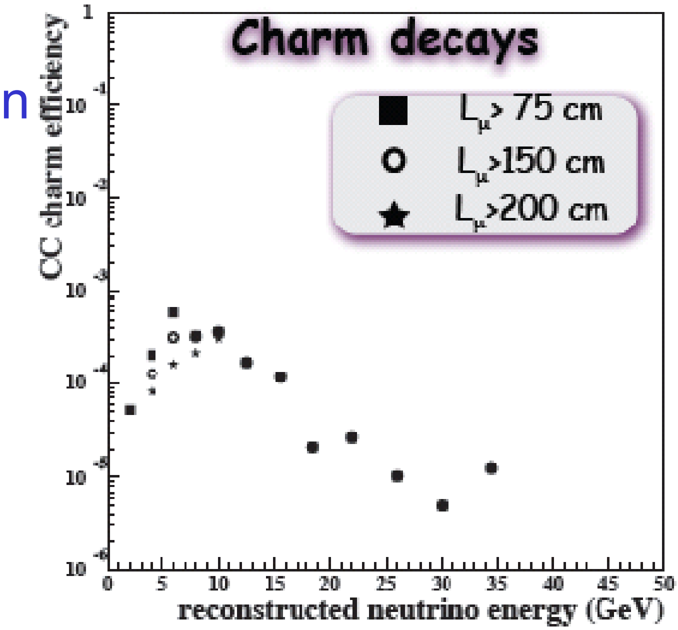
- There is only one matrix inversion and fit to $P\nu_e\nu_\mu$ seems to be more robust.
- Hardly any change in error contours by adding ND information.
- Still need to extract syst error from method



Charm measurement

- Motivation: 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

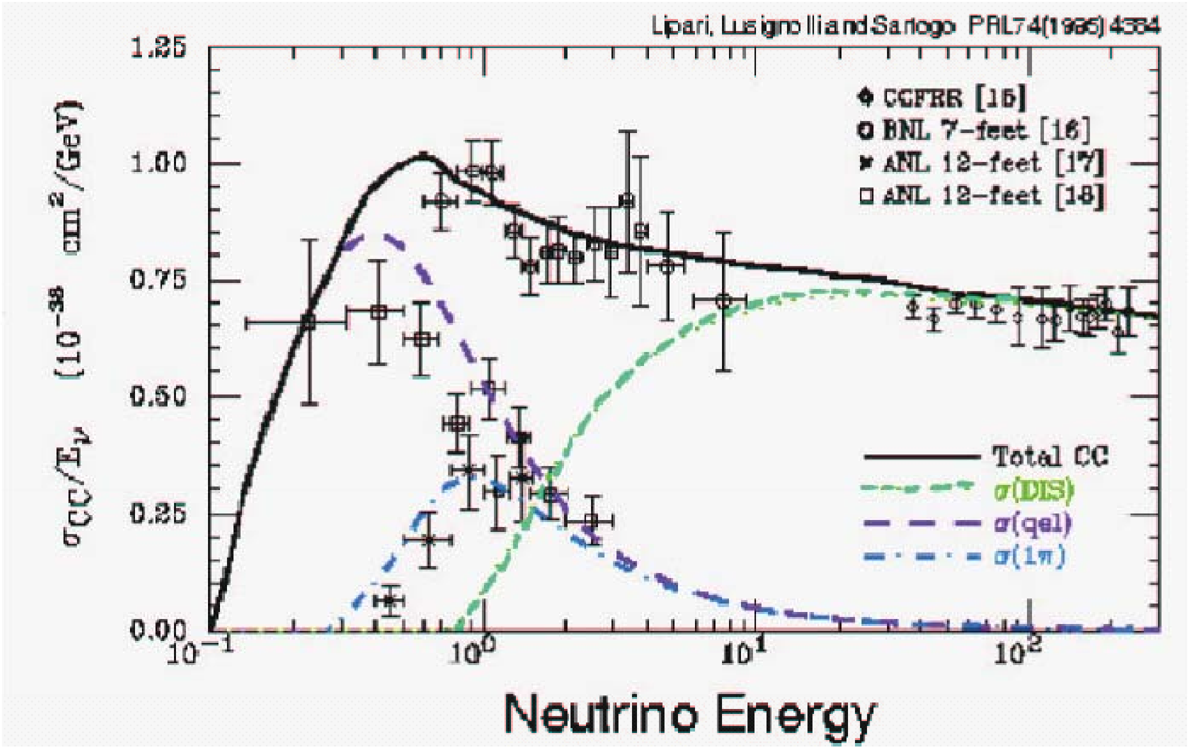




- Semiconductor vertex detector only viable option in high intensity environment (emulsion too slow!)

Cross section measurements

- Measure of cross sections in DIS, QE and RES.
- Coherent π
- Different nuclear targets: H_2, D_2
- Nuclear effects, nuclear shadowing, reinteractions

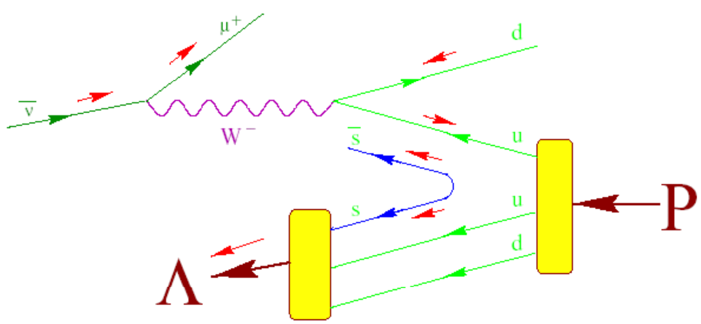


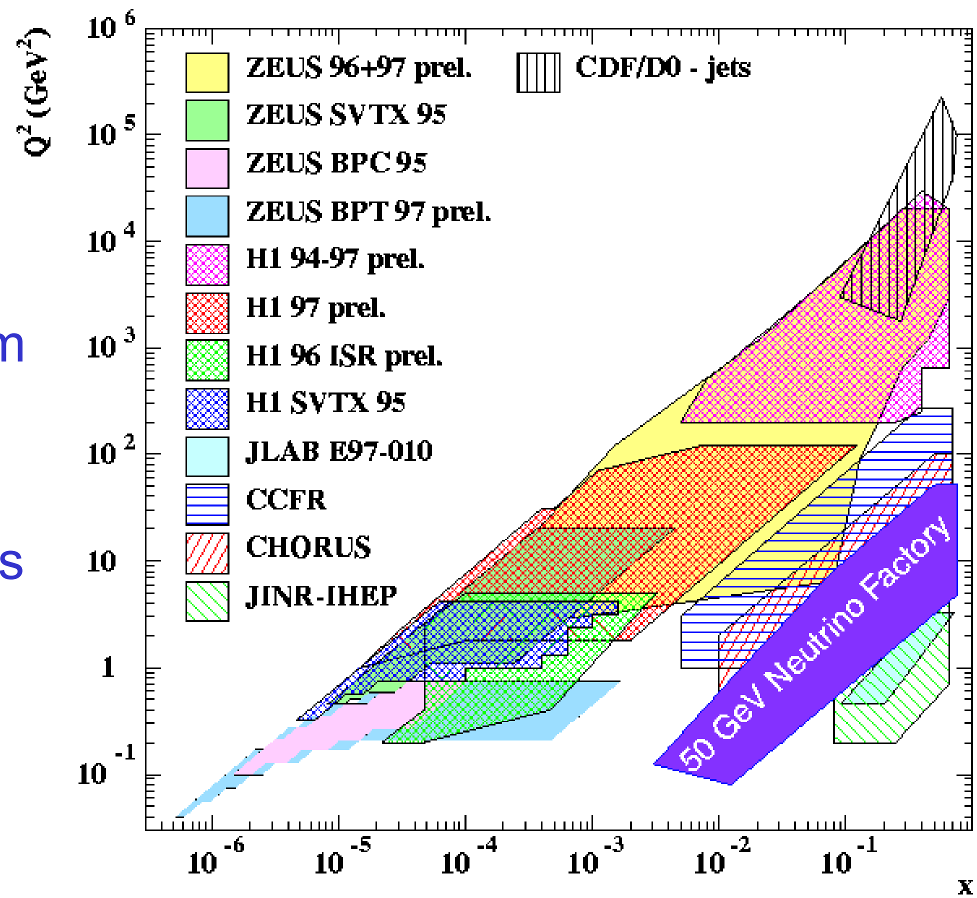
What is expected cross-section errors from MiniBoone, SciBoone, T2K, Minerva, before NUFACT?

At NUFACT, with modest size targets can obtain very large statistics, but is <1% error achievable?

Other physics: Parton Distribution Functions

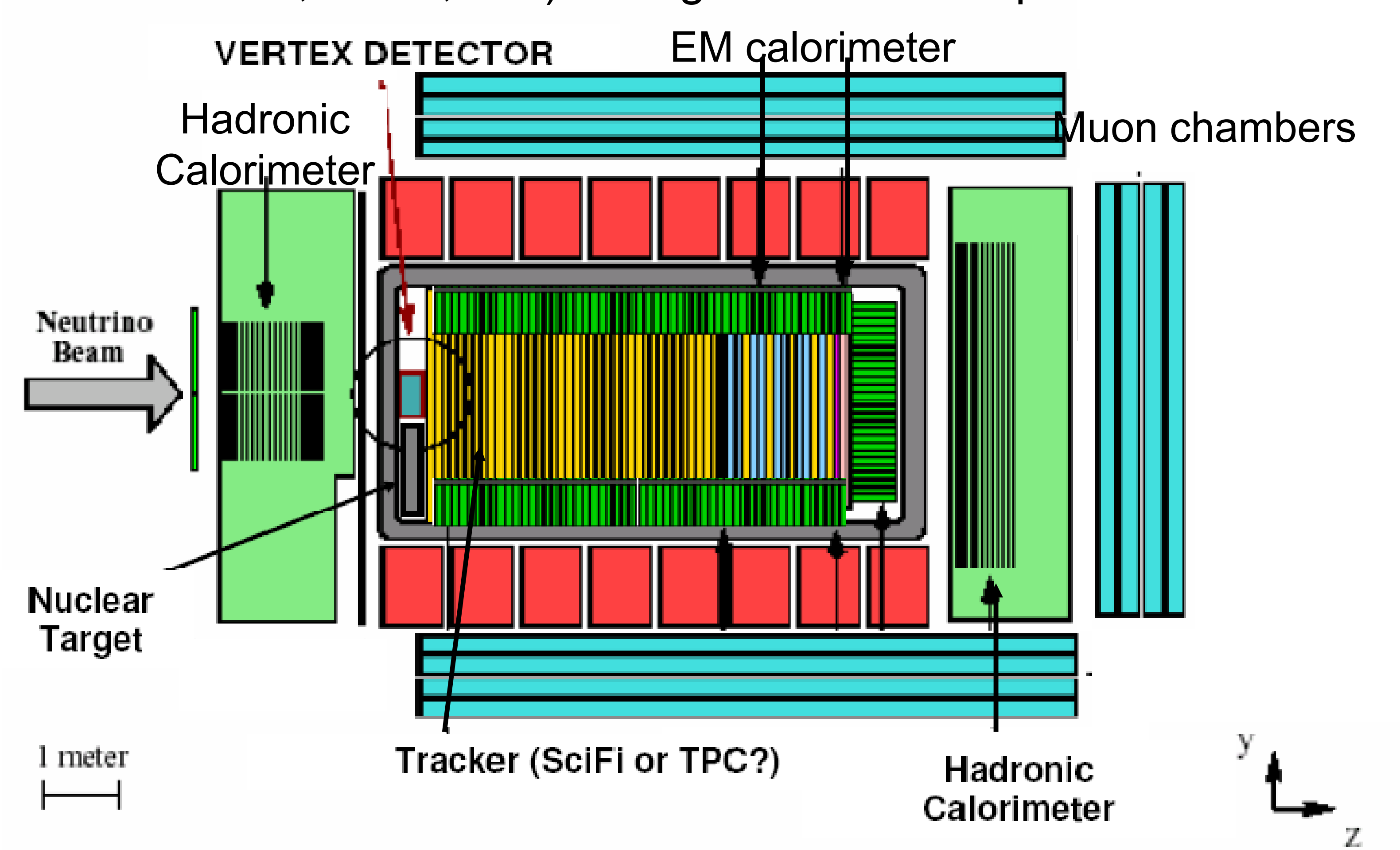
- Unpolarised and Polarised Parton Distribution Functions
- α_S from xF_3
- Sum rules: e.g. Gross-Llewelyn Smith
- Λ polarization: spin transfer from quarks to Λ
  - NOMAD best data
  - Neutrino factory ~1000 times more data





Near Detector Design

- Overall design of near detector(s): more than one detector?
  - Near Detector could be a number of specialised detectors to perform different functions (ie. lepton and flux measurement, charm measurement, PDFs, etc.) or larger General Purpose Detector



Near Detector Design

- Near Detector elements:
  - Vertex detector: Choice of Pixels (eg. Hybrid pixels, Monolithic Active Pixels …) or silicon strips
  - Tracker: scintillating fibres, gaseous trackers (TPC, Drift chambers, …)
  - Other sub-detectors: PID, muon ID, calorimeter, …
- Tasks:
  - Simulation of near detector and optimisation of layout: benefit from common software framework for Far Detector
  - Flux determination with inverse muon decays, etc.
  - Analysis of charm using near detector
  - Determination of systematic error from near/far extrapolation
  - Expectation of cross-section measurements
  - Test beam activities to validate technology (eg. vertex detectors)
  - Construction of beam diagnostic prototypes
  - Other physics studies: PDFs, etc. (engage with theory community for interesting measurements)