Near Detector at a Neutrino Factory

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Design Study Meeting
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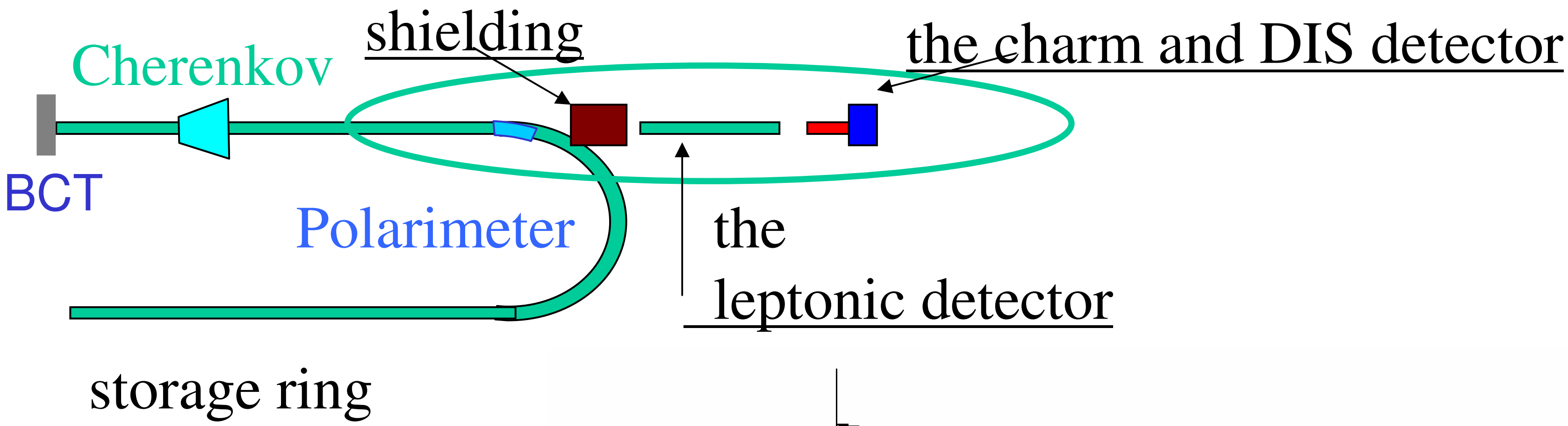
Beam Diagnostics and Near Detector aims

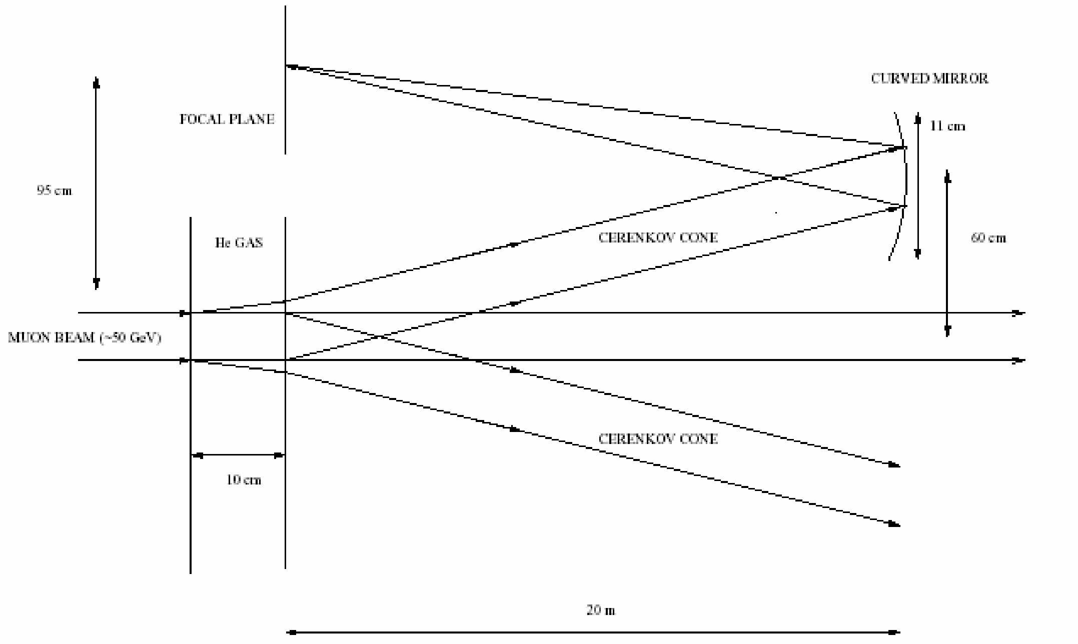
- Beam diagnostics (needed for flux measurement)
  - Number of muon decays
  - Measurement of divergence
  - Measurement of Muon polarization
- Near detector measurements needed for neutrino oscillation systematics:
  - Flux control for the long baseline search.
  - Measurement of charm background
  - Cross-section measurements: DIS, QES, RES scattering
- Other near detector neutrino physics (electroweak and QCD):
  - $\sin^2\theta_W$ - $\delta\sin^2\theta_W \sim 0.0001$
  - Unpolarised Parton Distribution Functions, nuclear effects
  - Polarised Parton Distribution Functions – polarised target
  - Lambda (Λ) polarisation
  - α_S from xF_3 - $\delta\alpha_S \sim 0.003$
  - Charm production: $|V_{cd}|$ and $|V_{cs}|$, CP violation from $D^0/\bar{D}^0$ mixing
  - Beyond SM searches
  - …

Beam Diagnostics

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

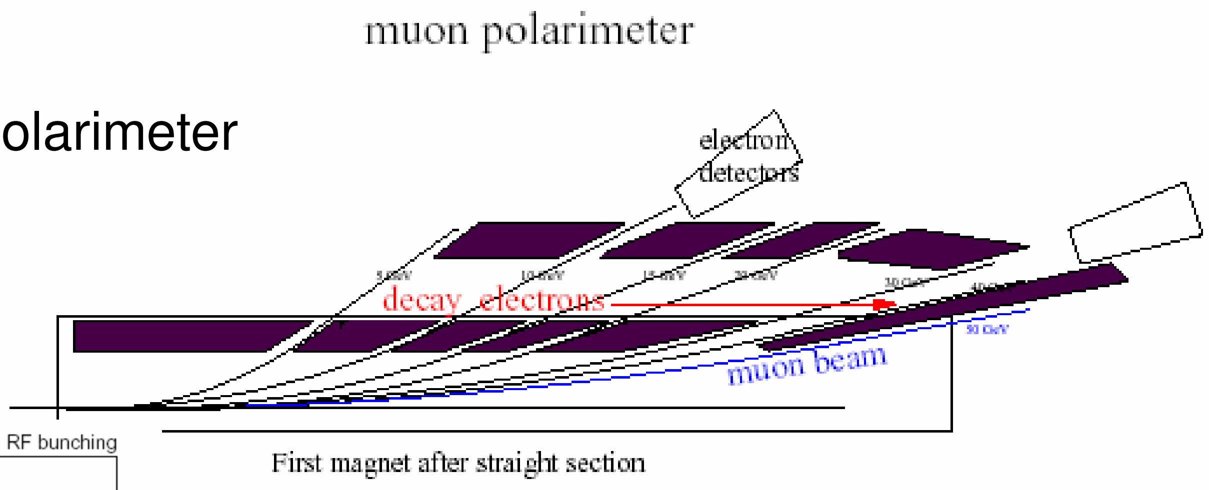


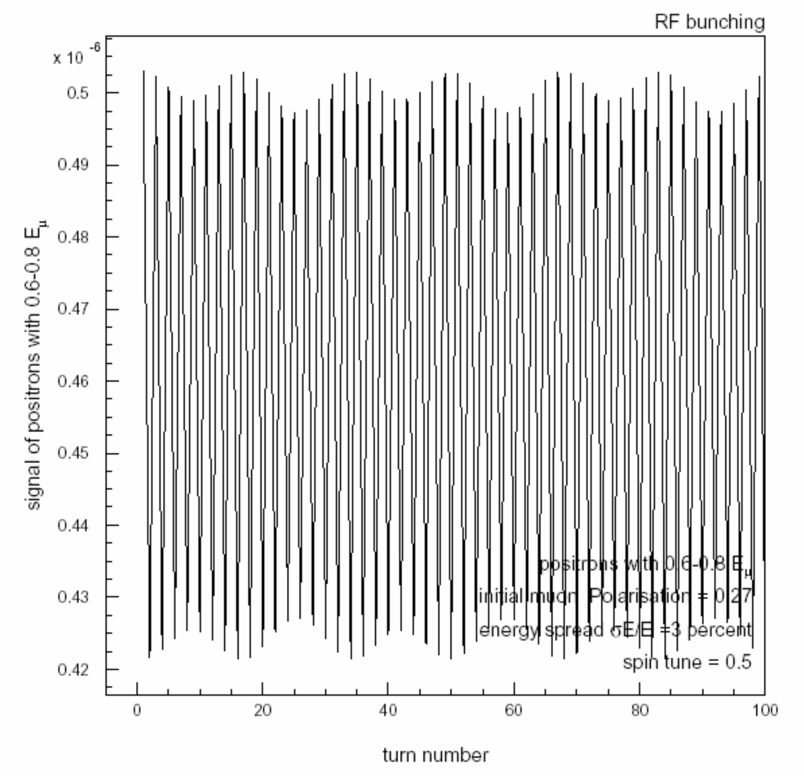
- Beam Cherenkov for divergence measurement? Could affect quality of beam.



Beam Diagnostics

- Muon polarization:
  Build prototype of polarimeter





Fourier transform of muon energy spectrum

amplitude=> polarization

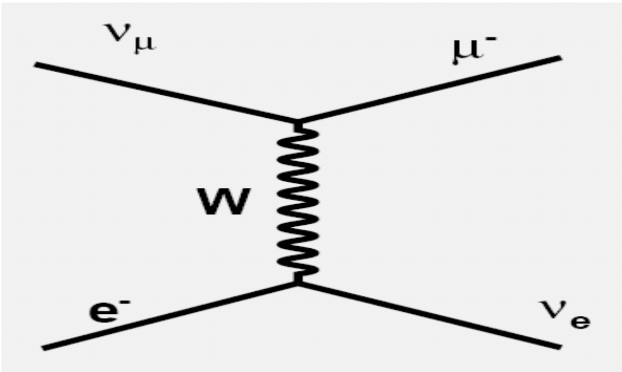
frequency => energy

decay => energy spread.

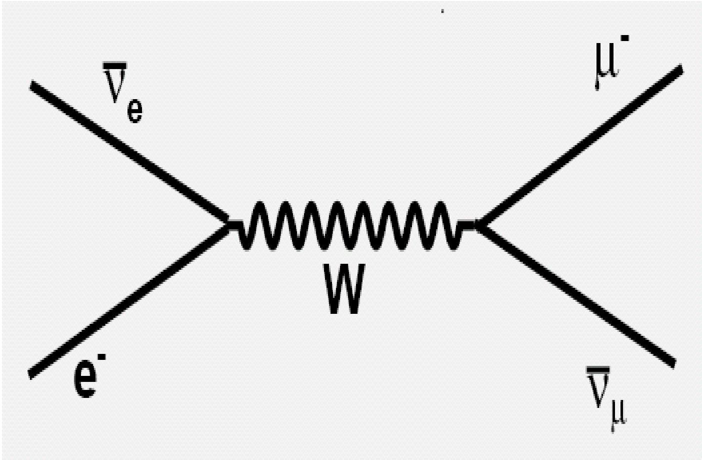
Flux Measurement at Near Detector

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

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



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



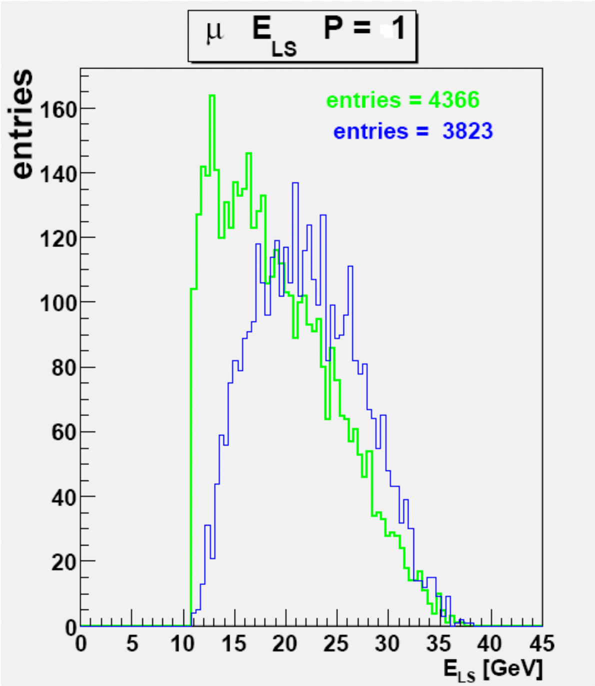
Known cross sections in Standard Model

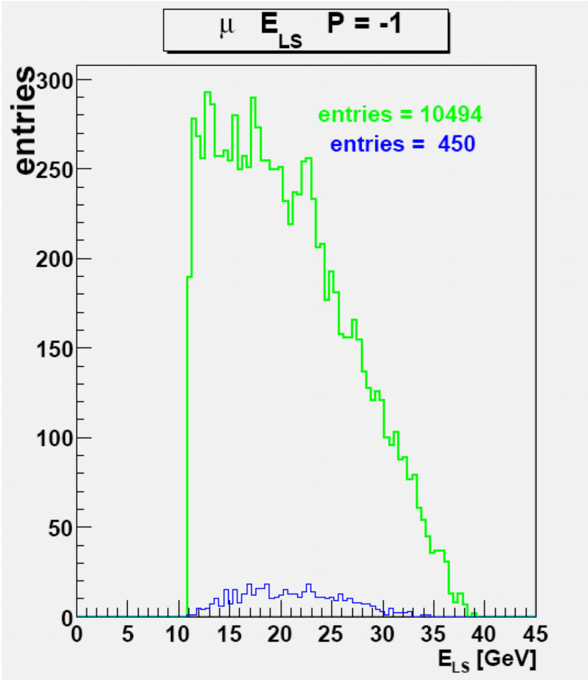
$$\sigma = \frac{G_F^2}{\pi}\frac{\left(s - m_\mu^2\right)^2}{s}$$

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

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.

	$\nu_\mu + e^- \to \nu_e + \mu^-$	$\overline{\nu_e} + e^- \to \overline{\nu_\mu} + \mu^-$	$\nu_\mu N$
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

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

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

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

- Where: M_1=matrix relating event rate and flux of ν_e at ND
  M_2=matrix relating event rate and flux of ν_μ at FD
  M=matrix relating measured ND ν_e rate and FD ν_μ rate
  M_{nOsc}=matrix relating expected ν_e flux from ND to FD
- Method works well but need to extract syst errors of method:

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

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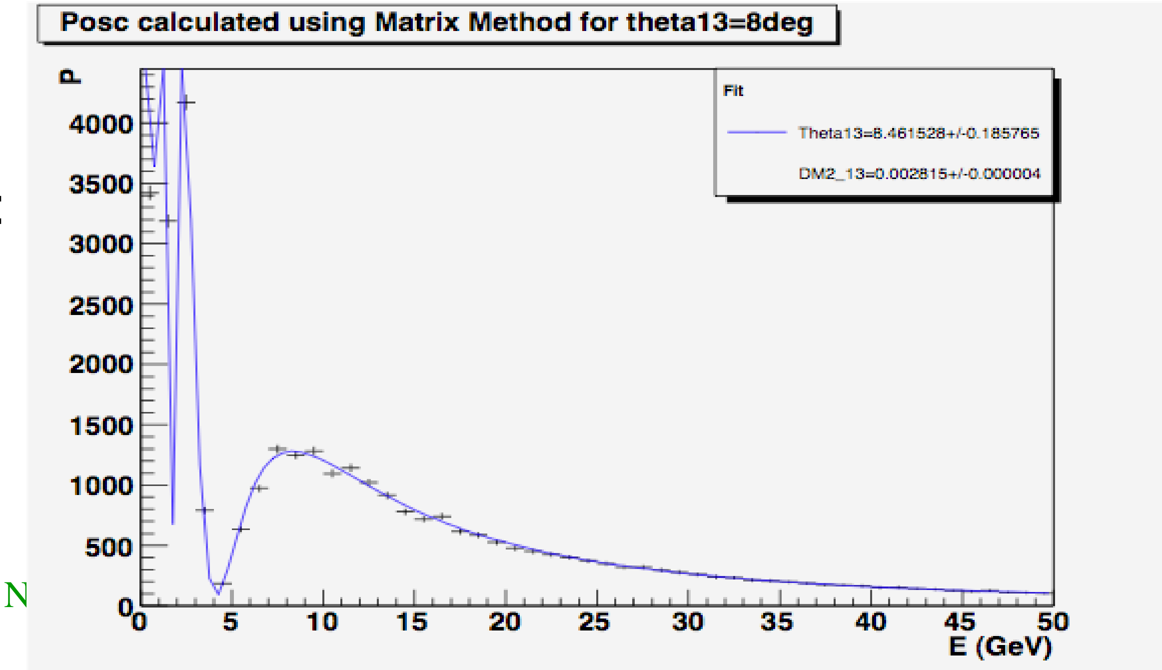
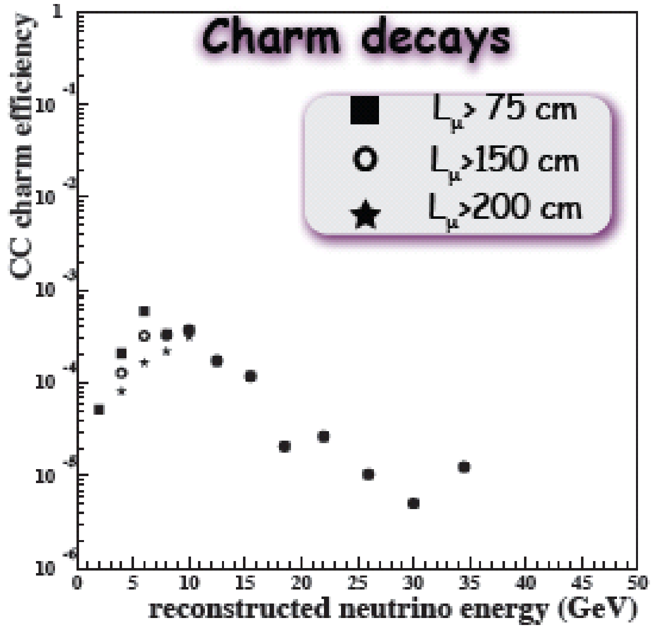
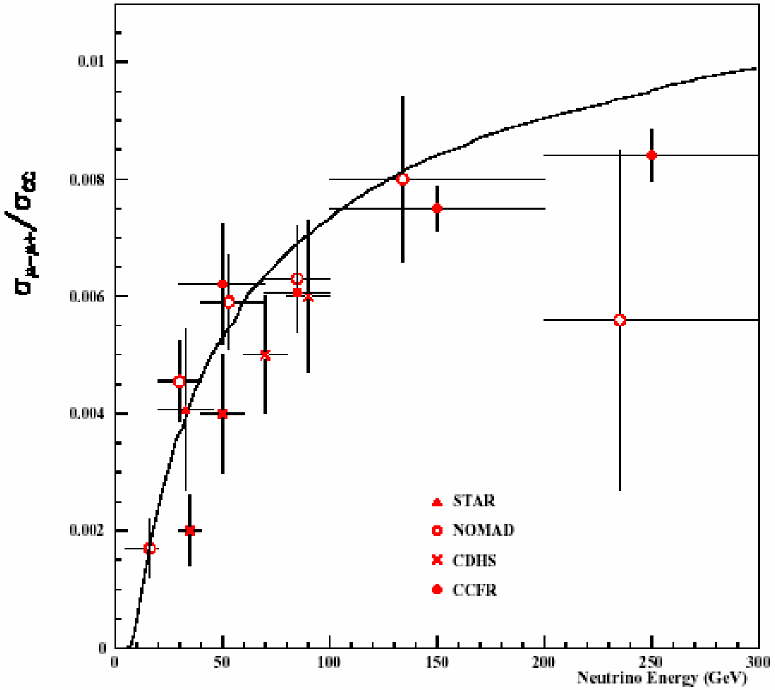


Charm measurement

- Motivation: measure charm cross-section to validate size of charm background in wrong-sign muon signature
- Charm cross-section and branching fractions poorly known

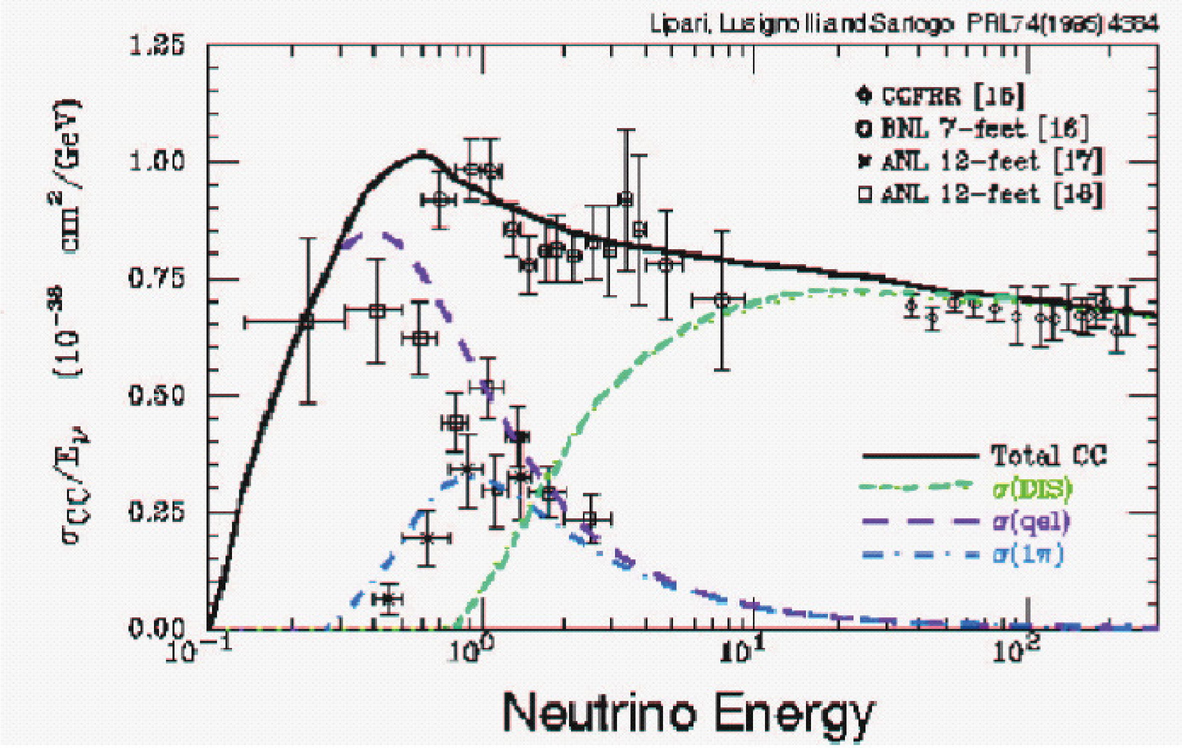




- Semiconductor vertex detector only viable option in high intensity environment (emulsion too slow!)

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

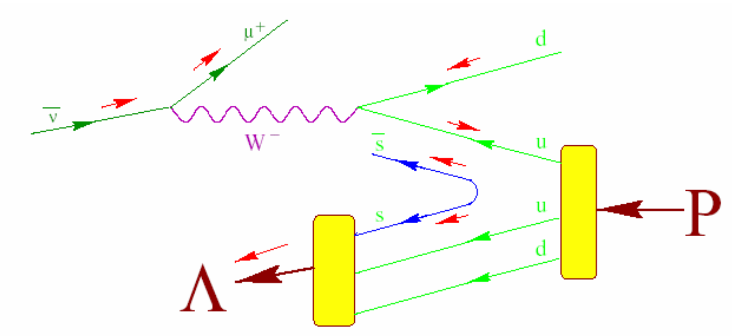


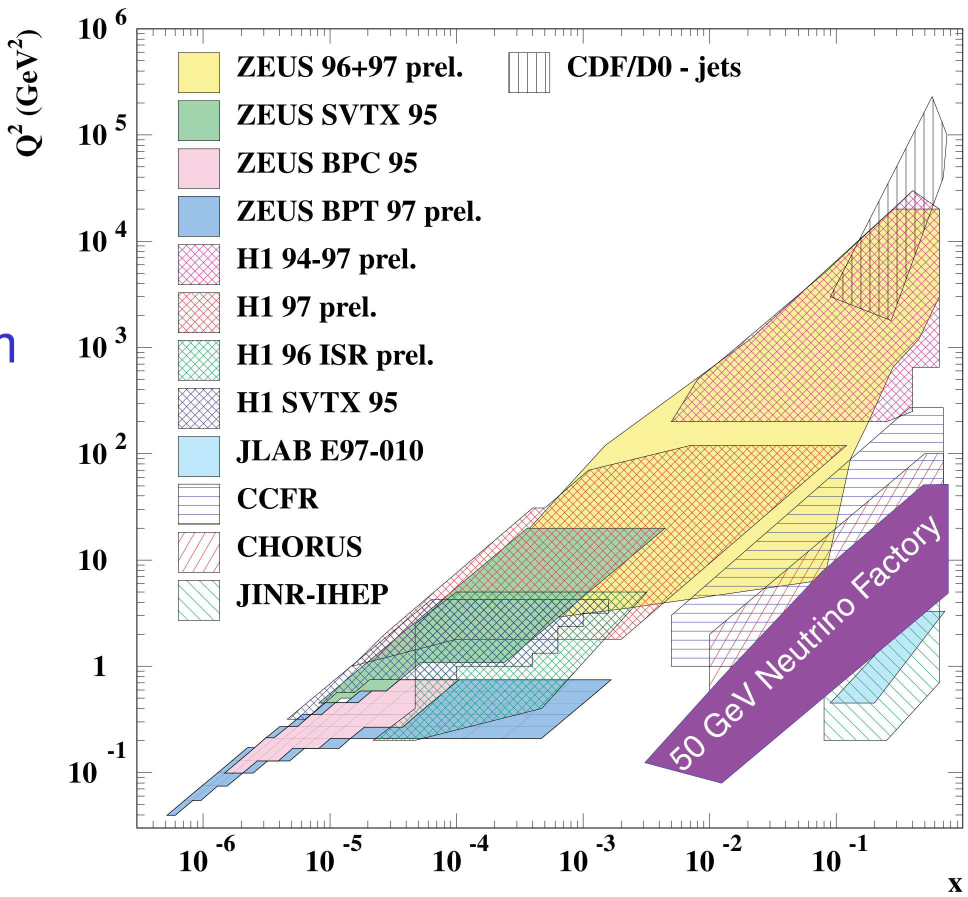
What is expected cross-section errors from MiniBoone, SciBoone, T2K, Minerva, before NUFACT?

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

Other physics: Parton Distribution Functions

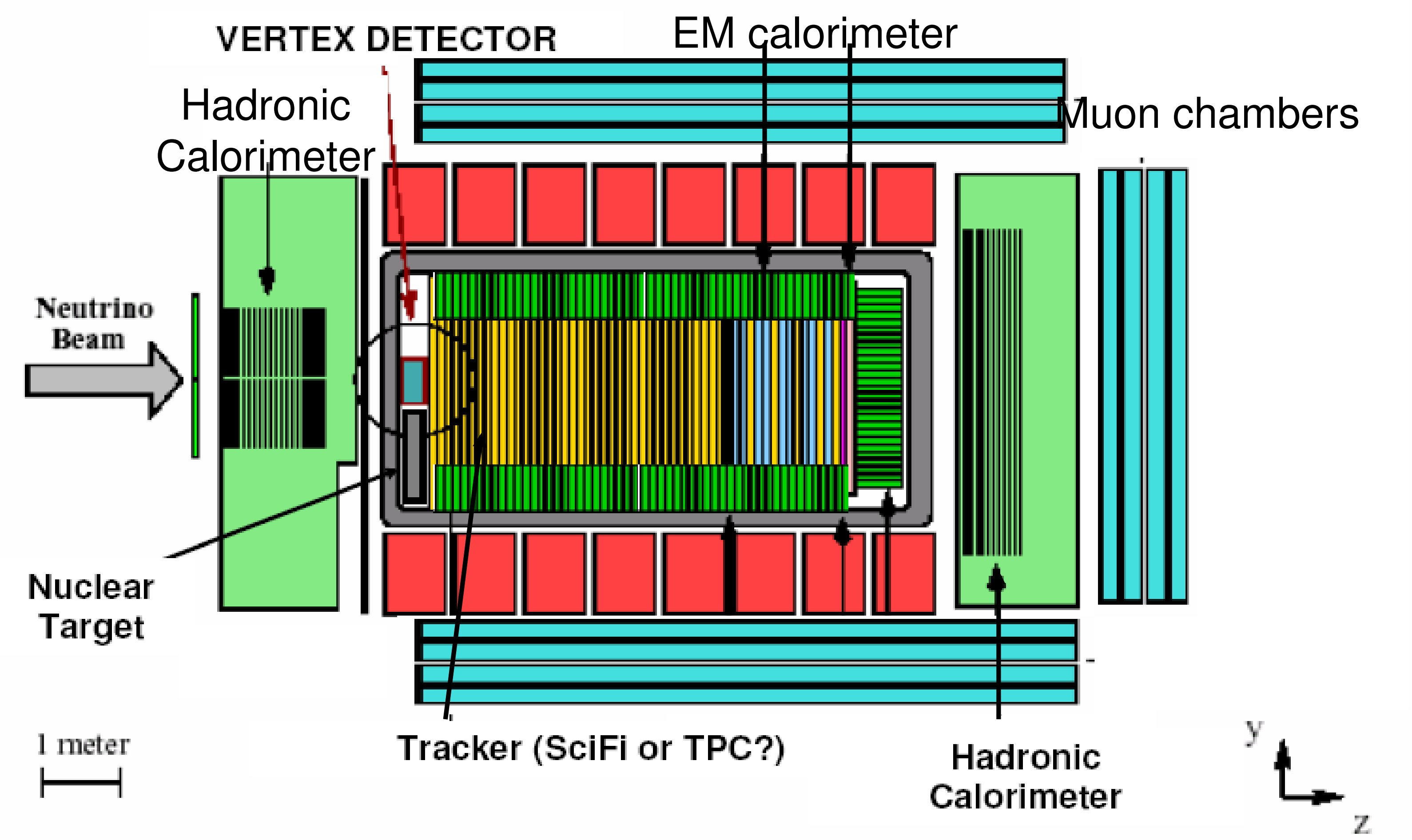
- Unpolarised and Polarised Parton Distribution Functions
- α_S from xF_3 - $\delta\alpha_S$~0.003
- Sum rules: e.g. Gross-Llewelyn Smith
- Λ polarization: spin transfer from quarks to Λ
  - NOMAD best data
  - Neutrino factory 100 times more data





Near Detector Design

- Overall design of near detector(s):
  - 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 (MAPS), DEPFET; 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: could 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)