ABOUT SYSTEMATICS

near detector constraints for CP violation

Superbeam:

$$\frac{P(\nu_\mu \rightarrow \nu_e) - P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)}{P(\nu_\mu \rightarrow \nu_e) + P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)} = A_{CP} \; \alpha \; \frac{\sin\delta \, \sin(\Delta m^2_{12} L/4E) \, \sin\theta_{12} \, \sin\theta_{13}}{\sin^2\theta_{13} + \text{solar term}\ldots}$$

Near detector gives ν_μ and $\bar{\nu}_\mu$ diff. cross-section*detection-eff *flux
and ibid for bkg

BUT: need to know also ν_e, $\bar{\nu}_e$ diff. cross-section* detection-eff

with small (relative) systematic errors.

→knowledge of cross-sections (relative to each-other) required
→knowledge of flux!

interchange role of ν_e and ν_μ for superbeam

maximum T asymmetry for sin δ = 1

!

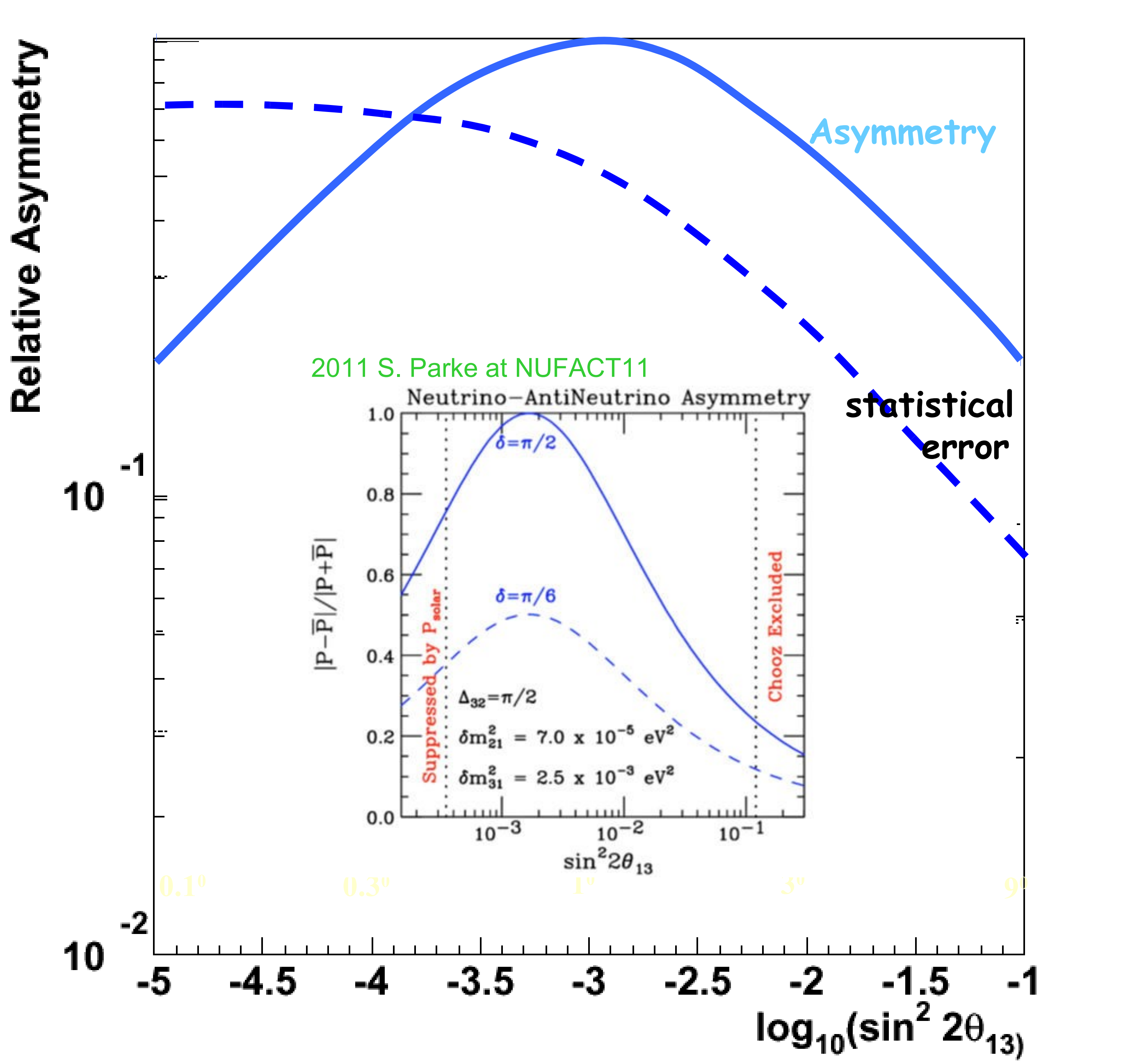
asymmetry is
a few %
and requires
excellent
flux normalization
(neutrino fact., beta beam
or
off axis beam with
not-too-near
near detector)

NOTES:

1. sensitivity is more or less independent of θ_{13} down to max. asymmetry point

2. This is at first maximum! Sensitivity at low values of θ_{13} is better for short baselines, sensitivity at large values of θ_{13} is better for longer baselines (2d max or 3d max.)

3. sign of asymmetry changes with max. number.



near detector constraints for CP violation

beta-beam or nufact:

$$\frac{P(\nu_e \to \nu_\mu) - P(\bar{\nu}_e \to \bar{\nu}_\mu)}{P(\nu_e \to \nu_\mu) + P(\bar{\nu}_e \to \bar{\nu}_\mu)} = -A_{CP} \ \alpha \ - \frac{\sin\delta \ \sin(\Delta m^2_{12} L/4E) \sin\theta_{12} \sin\theta_{13}}{\sin^2\theta_{13} + \text{solar term}\ldots}$$

Near detector gives ν_e diff. cross-section*detection-eff *flux and ibid for bkg

BUT: need to know ν_μ and $\bar{\nu}_\mu$ diff. cross-section* detection-eff

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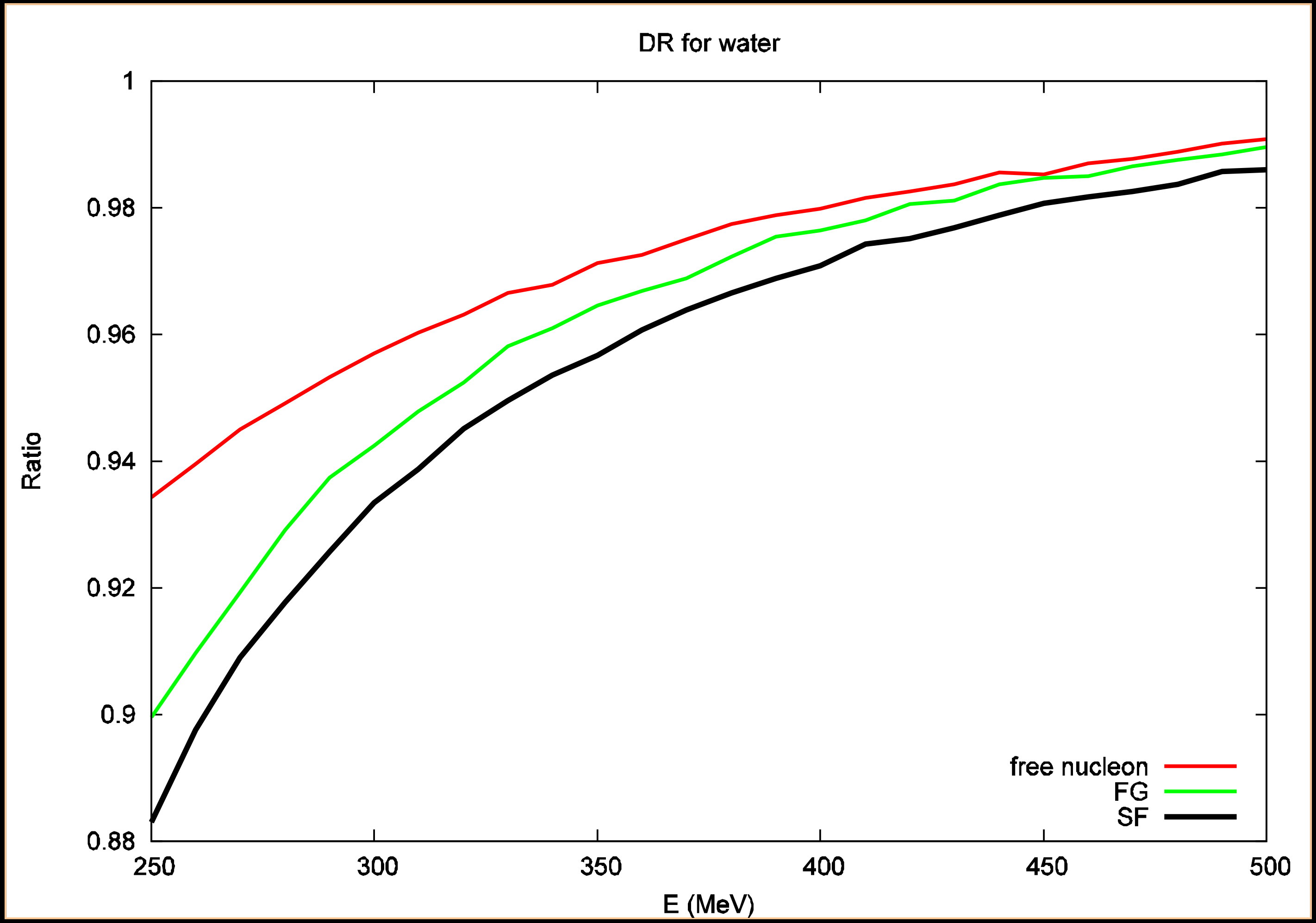


at 250 MeV (first maximum in Frejus expt) prediction varies from 0.88 to 0.94 according to nuclear model used. (= +- 0.03-0.05?)

Hope to improve results with e.g. monochromatic k-capture beam

Challenge of precision

-- if $\sin^2 2\theta_{13}$ is very small : challenge is

--- signal statistics

--- background level and subtraction

-- if $\sin^2 2\theta_{13}$ is large: challenge is signal systematics

Asymmetry is at most 25% and 5% systematics on each of neutrino and antineutrino leads to

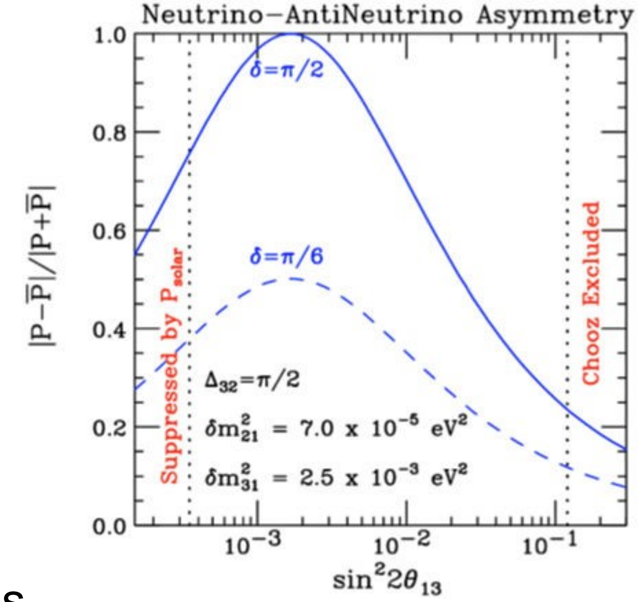
a) signal cross-section systematics (including selection cuts!)

$$\frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} \Rightarrow \Delta A_{CP} = 2\,\Delta \frac{\sigma^{signal,far}(\bar{\nu}_e) / \sigma^{signal,near}(\bar{\nu}_\mu)}{\sigma^{signal,far}(\nu_e) / \sigma^{signal,near}(\nu_\mu)}$$

b) near-far flux systematics

c) systematic errors e.g. coming from uncertainty in matter effect.

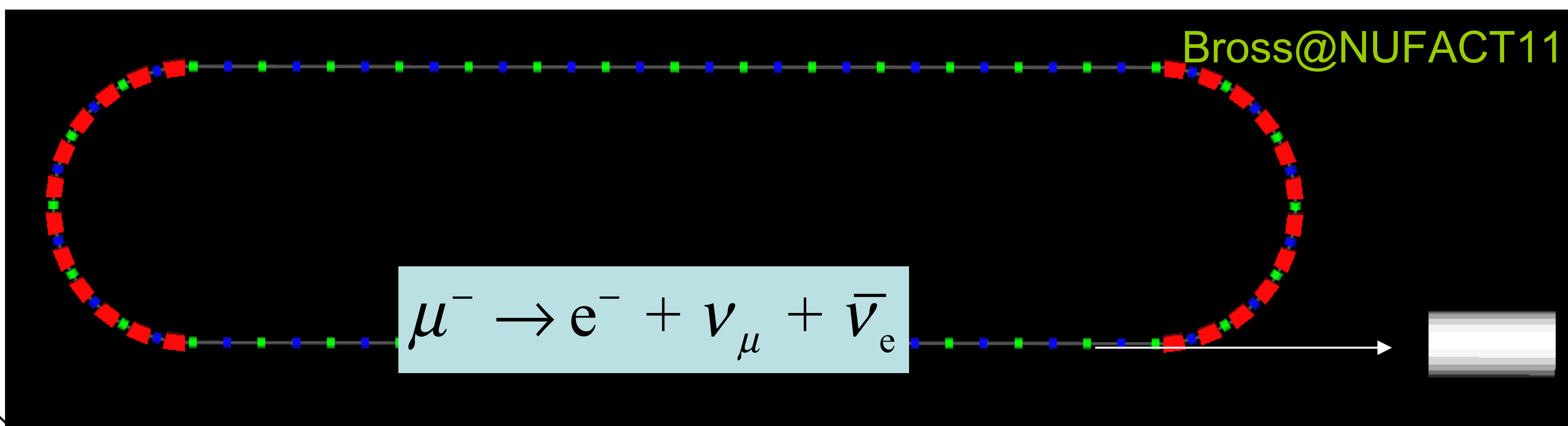
CP asymmetry decreases as $\sin^2 2\theta_{13}$ increases… Systematics!



- Challenge of precision!
- Flux and cross-sections must be known to <<5%

- ➔hadro production experiments (NA61@CERN) + near detectors → cross-sections to 5%

- if needed to measure $\nu_\mu;\bar{\nu}_e;\bar{\nu}_\mu;\nu_e$ cross-sections to 1% precision ➔ mini neutrino factory (first step muon storage ring)



TASD, LArg…

Neutrino factory flux control

Preamble: near detector does not measure flux.

Near detector can measure cross-sections (including exp. cuts) provided flux is well known.

the cross-sections are *essential* for the interpretation of far detector measurements in terms of oscillations.

the near detector provides a fixed candle ($\nu_\mu e^- \rightarrow \mu^- \nu_e$ and $\bar{\nu}_e e^- \rightarrow \mu^- \nu_\mu$) which cross-checks the flux calculations for stored μ^- beam. (!not μ^+!) constraint can be expressed as a line in (divergence, intensity) plane because of strong kinematics limit its basically one measurement point.

We still need to control neutrino factory flux.

System where one stores a beam of decaying particles
Neutrino Factory,
□potential for excellent neutrino flux control

Main parameters to MONITOR

1. Total number of muons circulating in the ring,
2. muon beam polarisation, OK
3. muon beam energy and energy spread, OK
4. muon beam angle and angular divergence.
5. Theory of μ decay, including radiative effects OK

two parameters pose a little bit of problem

-- beam intensity monitor
-- beam divergence monitor

Absolute number of muons in the ring: maybe the most difficult?

Total beam current: Beam Current Transformer

-- difficulties:

1. presence of decay electrons in the ring?

Keil CERN-NUFACT Note 54 (2000), showed that the electrons are swept in the arcs and destroyed. Since the lifetime is 200 turns, the maximum fraction of electrons is 0.3/200 = 1.6 10^{-3} at the ***end*** *of a straight section, much less at the entrance of it.*

NOT really a problem!

→ <u>Monitor should be placed at entrance of straight section</u>

2. absolute calibration? 10^{-3} difficult, impossible?

3. the most practical way to cross-normalize μ^+ vs μ^- fluxes

alternative: count the electrons or photons at the exit of a straight.

this has a nice feature of counting the decays

the acceptance of the monitor (see polarimeter later) is tricky

More on BCT:

-- absolute calibration is performed by injecting calibrated pulses

-- noise can be an issue for slow pulses

-- really need ratio of mu+ to mu-…

investigated LHC who care about currents for luminosity prediction:

Strategy for 2011

BCT DC will remain our main source of absolute calibration in 2011. We will push their performance as much as we can with the current hardware and we reasonably think to be able to **push their absolute scale uncertainty below 1%** .

systematic error on μ^+ / μ^- is dependent on this number, since there is no absolute calibration signal for the μ^+ decay

The number of bunches is not an issue, rather a help!

Absolute normalisation (ctd)

-- Near detector will measure product of flux X cross-section for individual channels

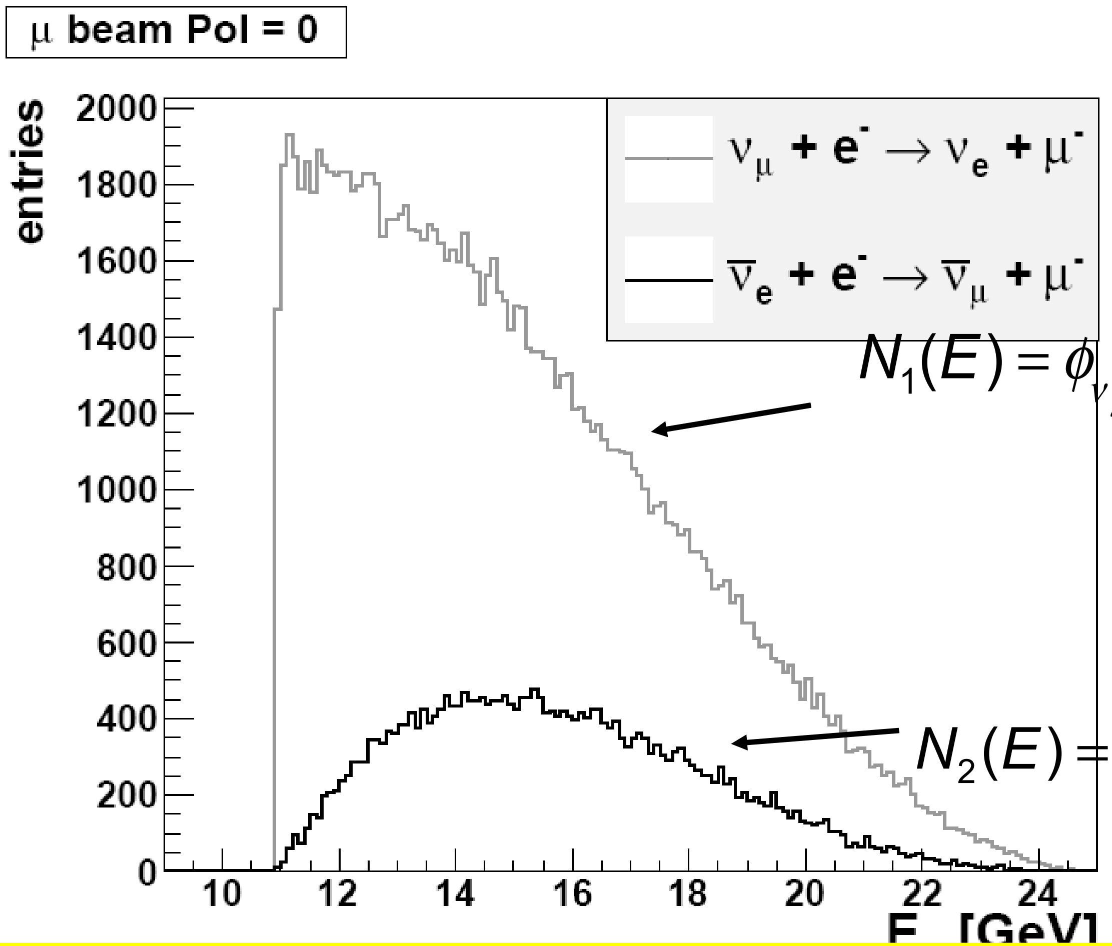
-- better: $\nu_\mu\ e^- \rightarrow \mu^-\ \nu_e$ in a dedicated near detector. IMD

this study has been described by R. Tsenov et al in the IDR report – can do better than 1% (statistical) on fraction of exposure.

➔ numbers to be consistent with far detector for a given exposure.
Increase volume of detector if needed to reach absolute normalization to 10^{-3}

This only works for neutrinos above threshold of 10.6 GeV
– what is the constraint on the flux at oscillation maximum
(e.g. 4.5 GeV for Pyhasalmi)
This only works for the μ^- beam. What about the μ^+ beam?

Inverse Muon Decay



$$N_1(E) = \phi_{\nu_\mu e^-}(E)\sigma^{CC}_{\nu_\mu e^-}(E)$$

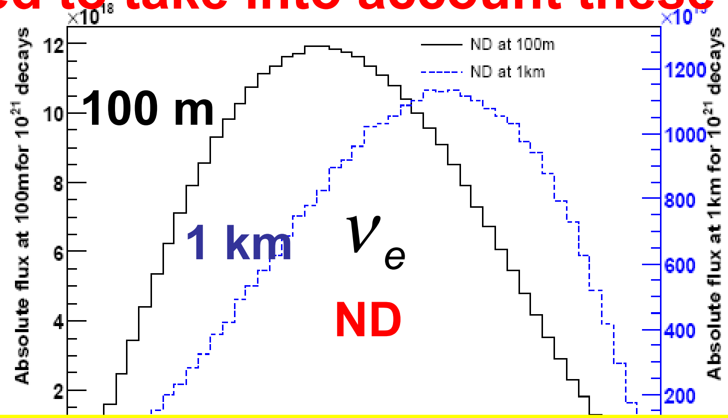
$$N_2(E) = \phi_{\bar{\nu}_e e^-}(E)\sigma^{CC}_{\bar{\nu}_e e^-}(E)$$

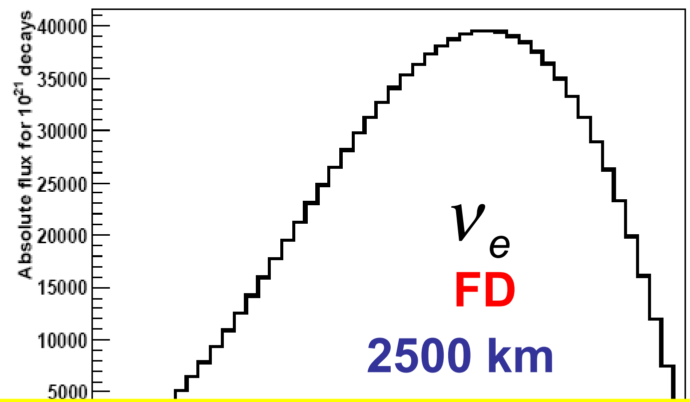
But this calibration depends on fraction of flux situated above 10 GeV

Spectra at Near Detector

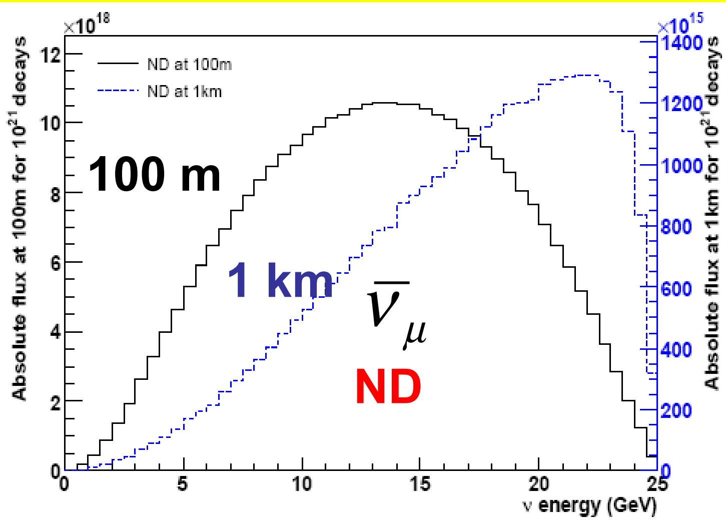
- Near Detector sees a line source (600 m long decay straight)
- Far Detector sees a point source

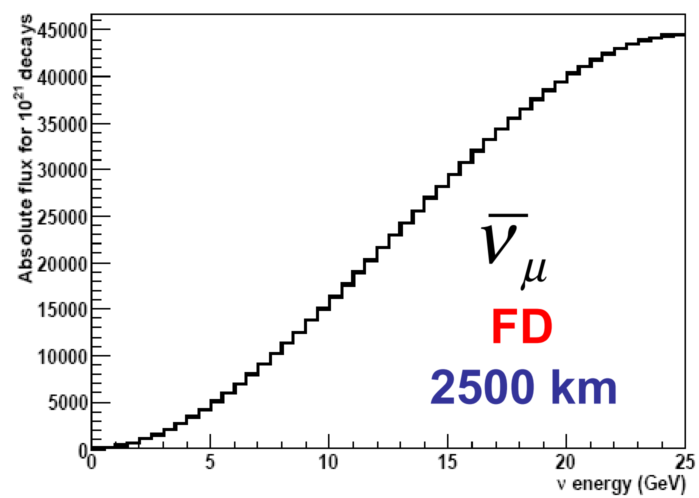
Need to take into account these differences for flux measurement





➔ Flux weighted by inverse muon decay cross-section will be dependent on beam divergence…..





Beam divergence monitor

We are still scratching our heads with this – don't give up!
Cherenkov is difficult (it would need to exceedingly thin)
Transition radiation monitor is not demonstrated, and also beam disruptive.

Idea was proposed to use the (god-given) photons from radiative muon decays
I include two slide from NUFACT about it.
These photons are there and need to be taken into account in any case.

there is not much coming out of the muon beam pipe except PHOTONS (everything else is swept by magnetic field)

μ^- DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$e^- \overline{\nu}_e \nu_\mu$		$\approx$ 100%		53
$e^- \overline{\nu}_e \nu_\mu \gamma$	[d]	(1.4 ± 0.4) %		53
$e^- \overline{\nu}_e \nu_\mu e^+ e^-$	[e]	$(3.4 \pm 0.4) \times 10^{-5}$		53

[d] This only includes events with the γ energy > 10 MeV. Since the $e^- \overline{\nu}_e \nu_\mu$ and $e^- \overline{\nu}_e \nu_\mu \gamma$ modes cannot be clearly separated, we regard the latter mode as a subset of the former.

10 MeV in the center of mass → 5 GeV in lab!

$>10^{11}$ photons per straight section per second!

ntative conclusions

50 X_0 = 28 cm of lead (to minimize neutrino interactions)
cessary to shield near detector (that is not 100m!)

hoton spot contains information on beam properties

obably somewhat obscured by the beamline magnets
200m = 1m…

n this be used to *monitor* divergence? possible strategy:
sure beam divergence in dedicated expt, and track it with the photons

n the radial distribution of neutrino events across the near detector
lso used to monitor variations of the divergence?
bably not in absolute terms since this implies assumption on σ(E))

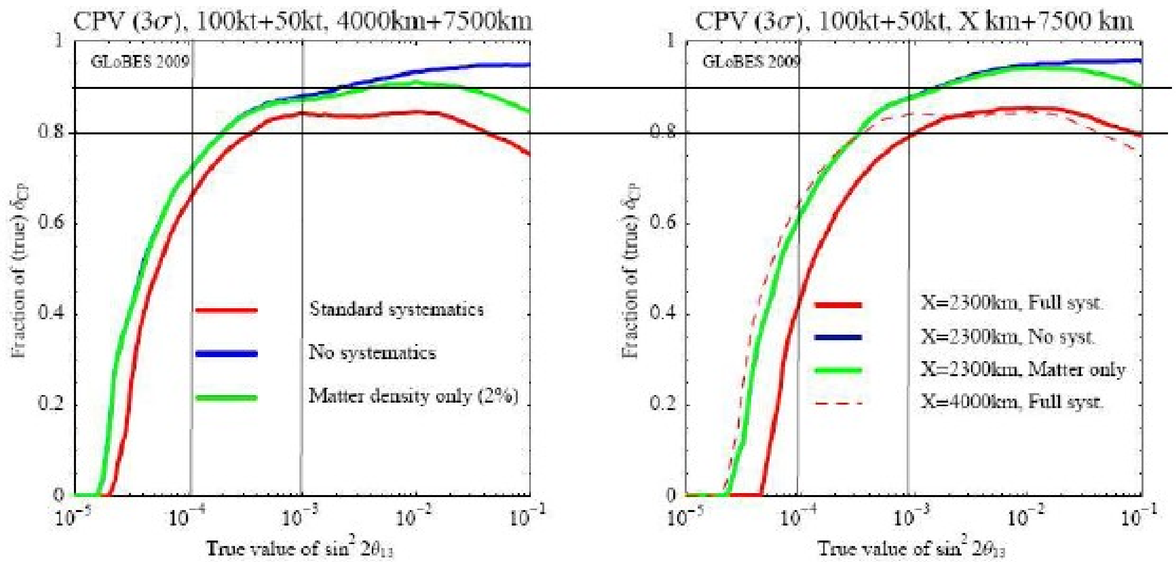
still need to measure and monitor the beam divergence
bsolute value of flux below 1%!

Nevertheless neutrino factory has the tools to already promise the normalisation to better than one percent.

How sensitive is the CP violation reach to this number?

Walter Winter, private communication

NB 95% at 3sigma means
$\Delta\delta$= 360*0.05/12= 1.5° !
(near δ=0)



???

this poing is critical in the difference between NUFACT…

…and the superbeams

NB here X=2285 km i.e. CERN-Pyhasalmi

from IDS-NF 4 in Mumbai

It is really important to understand the worsening of errors on δ_{CP}

-- factor 3 at $\sin^2 2\theta_{13}$ = 0.01 !

may I suggest that we for clarity we express measurement as

sinδ (or δ) = ….± stat ± syst (flux) ± syst (bkg) ± syst (xsec) ± …

Conclusions

-- keep investigating the flux prediction systematics limitations
  -- present standpoint is 1% absolute from
    -- BCT to ~< 1% ➔ aim is 0.1%
    -- a-priori (optics) knowledge of beam divergence
      ➔ aim is to measure and monitor.
  -- ultimate aim is 0.1% (one permil)
  -- near detector will provide
    -- a fixed candle (IBD) for μ^- stored beam
      very very precious cross check of the above!
    -- measurements of cross-sections to ~achieved flux precision
      -- should design near detector with aim of 0.1%

-- systematics on signal are very important at large values of θ_{13},
I keep being surprised by the 80-85% CP coverage of NUFACT in [0.1 – 0.01] range. Should be almost 95%.
keep investigating what is going on and where errors come from.