Flux uncertainty and Flux covariance

Beam group

Contents

- Current flux uncertainty & covariance
- Update study for flux uncertainty

Latest released flux uncertainty : 11av2.1

- The first version of flux uncertainty based on 11av2 tuned flux
- Detail here http://www.t2k.org/beam/NuFlux/FluxRelease/11arelease/11av2p1covariance
  - Main topic is to update Kaon flux uncertainty by using NA61 Kaon data.
    - Already reported at last collabo. meeting
  - Release with only coarse binning for flux covariance matrix
  - Include νe-bar uncertainty for sources where it has been evaluated
  - Update the proton beam error with Run 2 y-y' uncertainties (tentatively use the different method (JReWeight) from evaluation for 2010a).
  - Include horn&target alignment and horn absolute current using variations evaluated for 2010a analysis

What is in this covariance?

- Flux covariance for ν_μ, $\bar{\nu}_\mu$, ν_e and $\bar{\nu}_e$ at ND5 and SK detector planes
- **Error Sources:**
  - Pion production – updated for 11av2 tuning
  - Kaon production – updated for 11av2 tuning

→Update from 2010a analysis

  - Secondary nucleon production – same as 10dv3
  - Production cross sections – same as 10dv3
  - Off-axis angle – no nu_e-bar errors at this time (10dv3 errors)
  - Proton beam errors – y-y' errors calculated with JReWeight
  - Horn&Target alignment – no nu_e-bar errors at this time (10dv3 errors)
  - Horn absolute current – same as 10dv3

→Basically same as 2010a analysis

Should be used with the 11av2 flux tuning

Format of 11av2.1 flux covariance matrix

- The covariance provided is the fractional covariance of the flux as a function of the true neutrino energy
- There are 20 true neutrino energy bins for each detector/flavor (GeV):

0.0-0.1, 0.1-0.2, 0.2-0.3, 0.3-0.4, 0.4-0.5, 0.5-0.6, 0.6-0.7,
0.7-0.8, 0.8-1.0, 1.0-1.2, 1.2-1.5, 1.5-2.0, 2.0-2.5, 2.5-3.0,
3.0-3.5, 3.5-4.0, 4.0-5.0, 5.0-7.0, 7.0-10.0, >10.0

- The ordering of the bins in the covariance are:

1) ND5 ν_μ bins 0-19 **2)** ND5 $\bar{\nu}_\mu$ bins 20-39

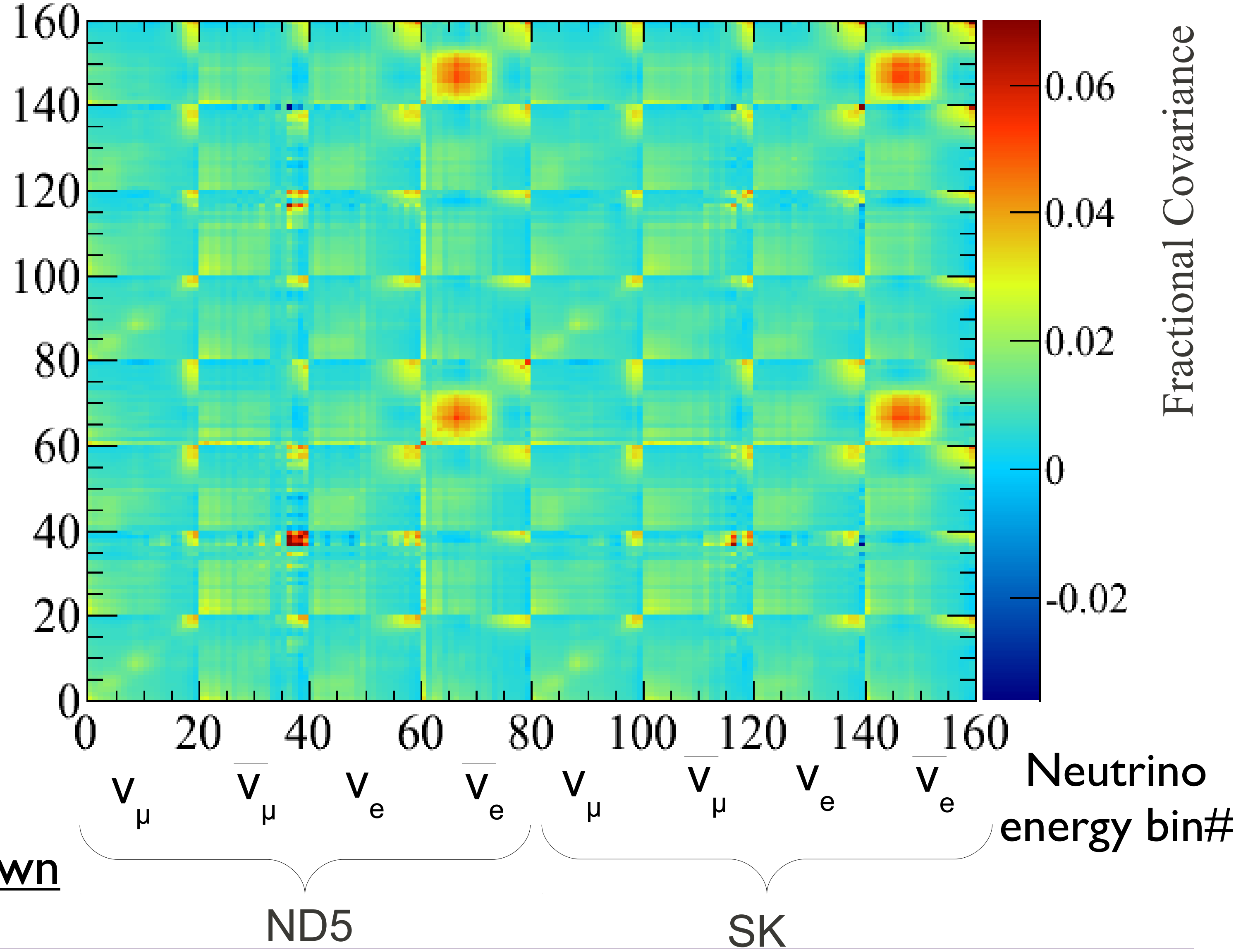
3) ND5 ν_e bins 40-59 **4)** ND5 $\bar{\nu}_e$ bins 60-79

5) SK ν_μ bins 80-99 **6)** SK $\bar{\nu}_\mu$ bins 100-119

7) SK ν_e bins 120-139 **8)** SK $\bar{\nu}_e$ bins 140-159

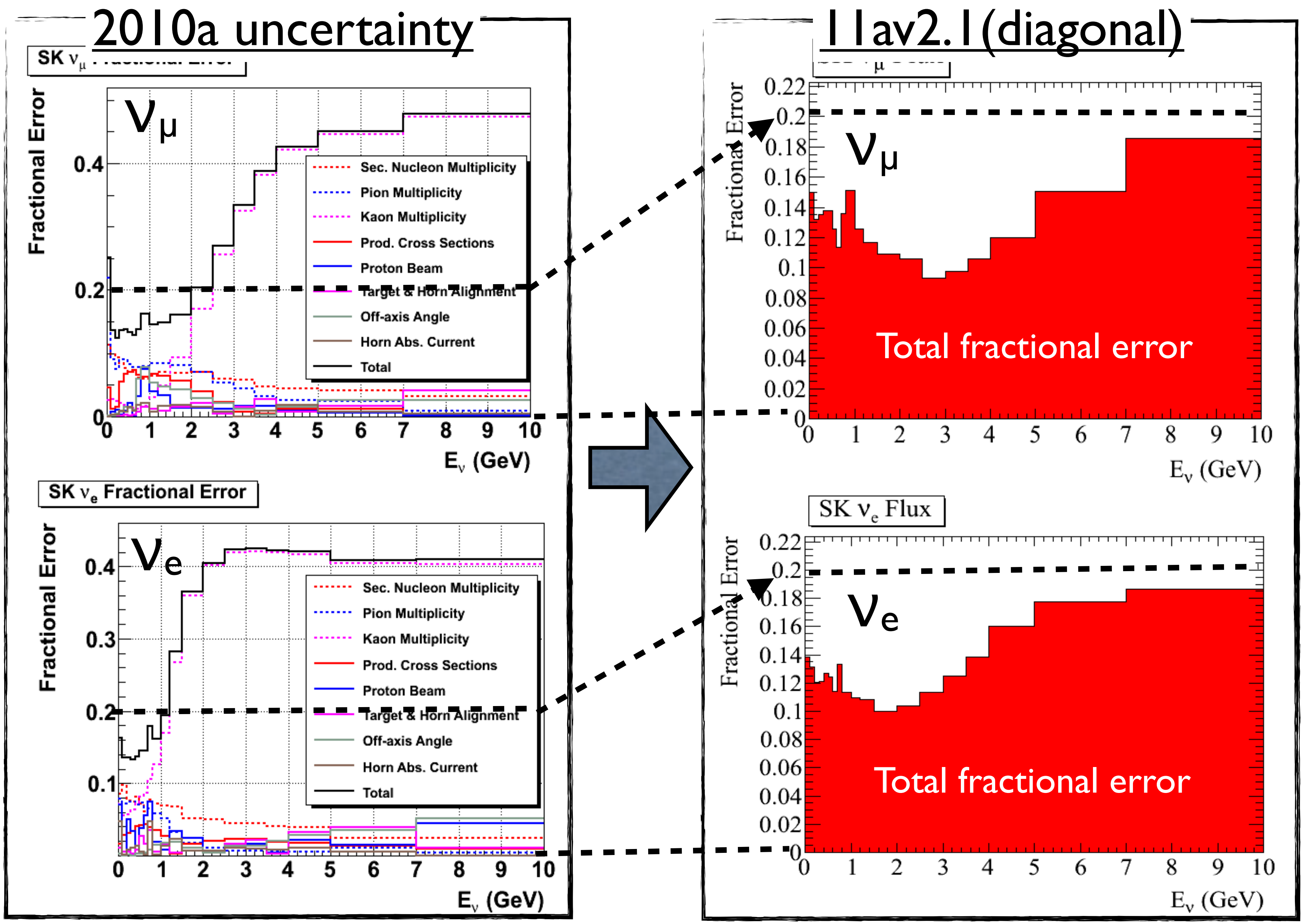
Total flux covariance matrix (11av2.1)

Fractional flux covariance matrix for ν_μ, anti-ν_μ, ν_e and anti-ν_e at ND5 and SK detector planes



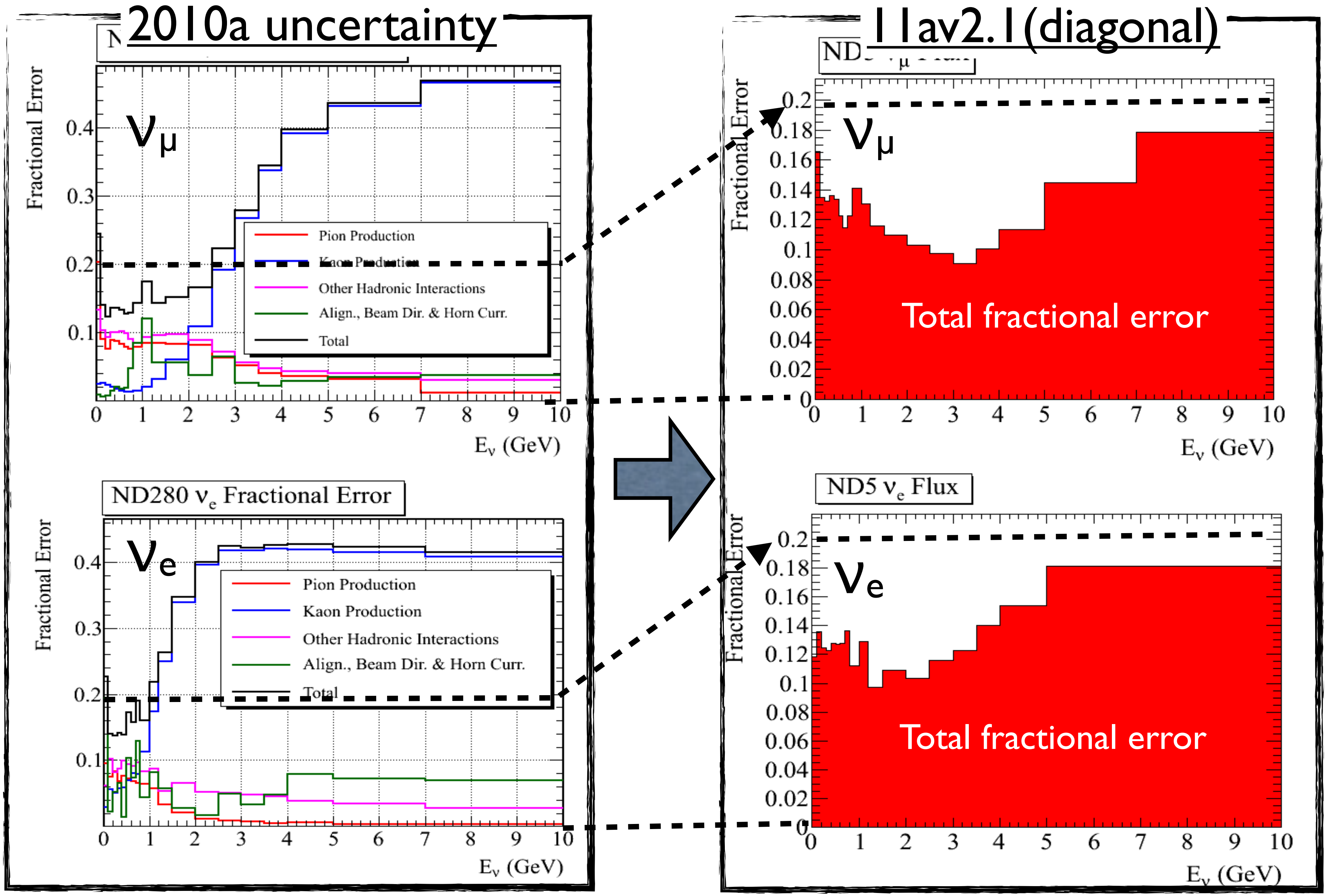
<u>No overflow bins shown</u>

SK flux uncertainty



→ Flux uncertainty at the high energy region reduced drastically

ND5 flux uncertainty



Usage

Assume we have the flux in the ith energy, detector and flavor bin: Φ_i

The value of the flux is varied through a systematic parameter b_i which has a nominal value of 1

$$\Phi_i \rightarrow b_i \Phi_i$$

The fractional flux covariance describes the covariance of the b_i

The errors from the covariance can be propagated by:

- Prior constraint on the b_i in a fit (see BANFF fits)
- Through draws of the b_i (Cholesky Decomp. Method)
- Calculation of the error propagation through the b_i dependence in the expected values of observables

Usage example is shown in BANFF or oscillation analysis talk!

What Is this release Missing?

- No νe-bar errors for off-axis angle, target alignment or horn alignment errors
- Not final proton beam uncertainty errors
- No horn field asymmetry errors
- No horn angular alignment errors

Now studies about these errors are going on.
→ Will be added in next flux uncertainty (for some parts soon after collabo.)

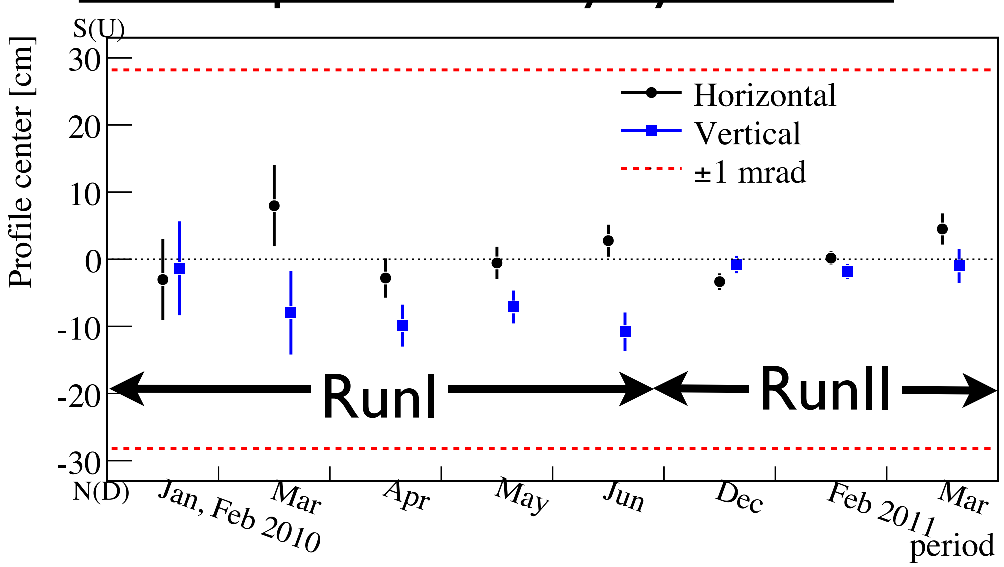
Update for flux uncertainty

- Off axis angle flux uncertainty (Minor update)
- Proton beam flux uncertainty (Minor update)
- Horn angular alignment flux uncertainty
- Horn field asymmetry flux uncertainty

Off-axis angle uncertainty

- The following factors cause flux uncertainty
  - The deviation of the beam direction from the beam-axis.
  - Stat. error of the beam direction measurement.
  - Beam direction uncertainty from INGRID detector systematic error
- Current error estimated by only RunI data.
  - We controlled neutrino beam better in RunII than RunI → Flux uncertainty will be reduced for RunII data.

ν beam profile history by INGRID



Summary of INGRID beam profile measurements

Beam center from the INGRID center	X center[cm]	Y center[cm]
RUN1 + RUN2	-0.4 ± 0.7 ± 9.2	-3.0± 0.7 ± 10.4
RUN1 only	0.4 ± 1.4 ± 9.2	-8.6± 1.5
RUN2 only	-0.7± 0.8 ± 10.4	-1.4± 0.8

Update of off-axis angle

Beam profile center in RunI for 2010a flux uncertainty

	x	y
Profile center (cm)	$0.2 \pm 1.4(\text{sta.}) \pm 9.2(\text{sys.})$	$-6.6 \pm 1.5(\text{sta.}) \pm 10.4(\text{sys.})$
Beam direction (mrad)	$0.01 \pm 0.05(\text{sta.}) \pm 0.33(\text{sys.})$	$-0.24 \pm 0.05(\text{sta.}) \pm 0.37(\text{sys.})$

Beam profile center in INGRID technote (#41, v7.2)

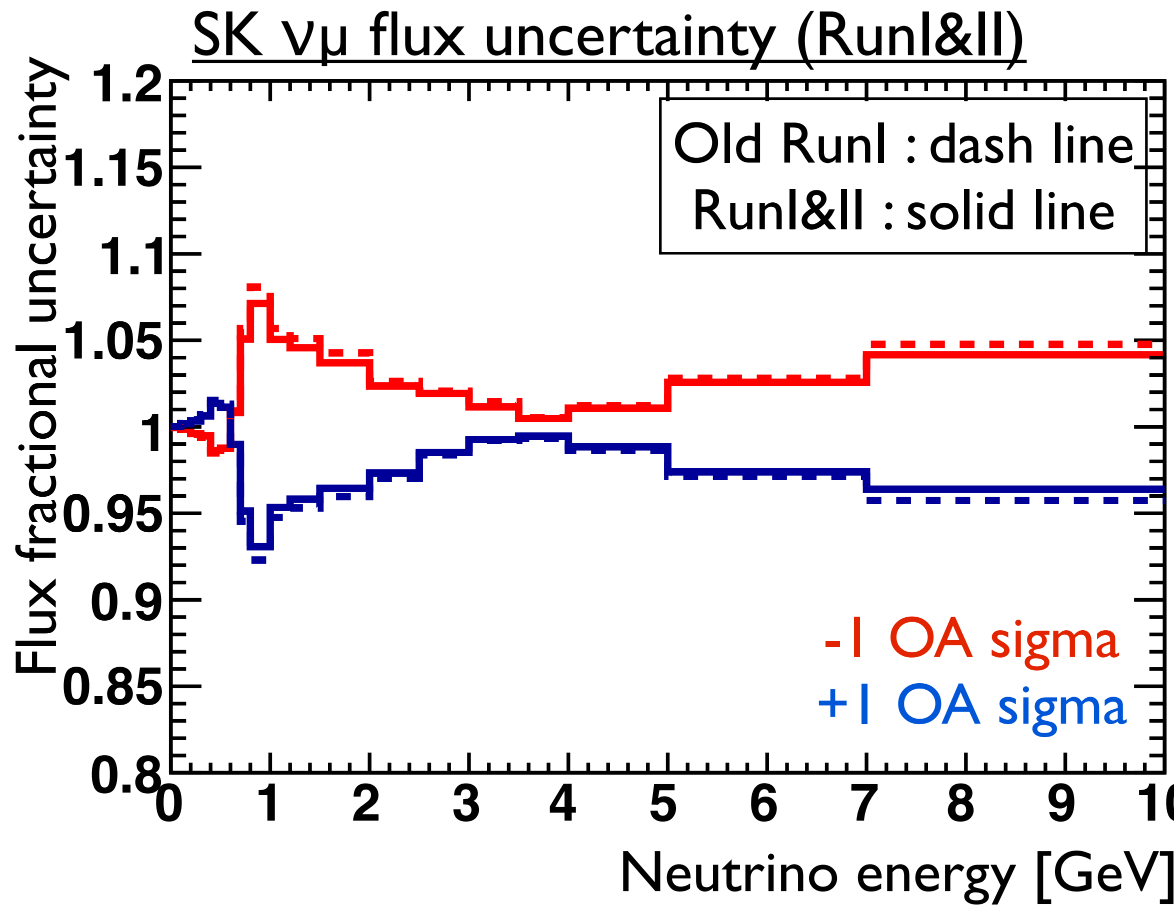
Beam center from the INGRID center	X center[cm]	Y center[cm]
RUN1 + RUN2	-0.4 ± 0.7 ± 9.2	-3.0± 0.7 ± 10.4
RUN1 only	0.4 ± 1.4 ± 9.2	-8.6± 1.5
RUN2 only	-0.7± 0.8 ± 10.4	-1.4± 0.8

- Difference of RunI beam profile center between two tables. → INGRID latest tech-note are correct.
- Correct values written in technote#54 ("Beam update for 2010a"), but used values for 2010a flux uncertainty are still old (incorrect).
  - Transfer of information might not work well.

Estimate flux uncertainty by using corrected off-axis angle uncertainties

Updated flux uncertainty

	OA angle uncertainty [mrad]	Diff. from 2010a
2010a	0.44	
RunI only	0.47	0.07
RunII only	0.37	-0.16
RunI&II	0.38	-0.14



- Off-axis uncertainty decreases from Old to RunI&II : 1~2% (absolutely)
  - For ND νμ, flux uncertainty also decrease by this level

Proton beam uncertainty

- Only RunI proton beam position/angle uncertainty was considered for 2010a flux uncertainty.
  - For 11av2.1, use the different method (JReWeight)
- Uncertainties of beam center position/angle during RunII are larger than RunI → Consider this effect by same method as 2010a analysis's.
  - Mass production to estimate this by using special wide proton beam flux samples going on → finish in few days.

RunI beam parameters

	center position (cm)	center angle (mrad)	profile width (RMS)(cm)	emittance (π mm.mrad)	Twiss parameter α
X	-0.037	0.044	0.4273	2.13	0.60
Y	0.084	0.004	0.4167	2.29	-0.09

RunII beam parameters

	center position (cm)	center angle (mrad)	profile width (RMS)(cm)	emittance (π mm.mrad)	Twiss parameter α
X	-0.0149	0.080	0.4037	5.27	0.16
Y	-0.0052	-0.007	0.4083	5.17	0.14

TN054(v2.3)

Proton beam uncertainty

	Run I	Run II
width in X (mm)	0.11	0.26
width in Y (mm)	0.97	0.82
Twiss α in X	0.32	0.26
Twiss α in Y	1.68	0.49
position in X(mm) (x)	0.38	0.27
position in Y(mm) (y)	0.58	0.62
angle in X (mrad) (x')	0.056	0.064
angle in Y (mrad) (y')	0.286	0.320
$\mathrm{cov}(x, x')$	0.011	0.013
$\mathrm{cov}(y, y')$	0.065	0.079

Horn angular alignment uncertainty

Martin Tzanov

Alignment surveys have been done in 2009 – TN-039.

Axis	Unertainty
X	0.3 mm
Y	1.0 mm
Z	1.0 mm

- For Horn-2 and Horn-3 angular uncertainty is less than 1 mrad. however we will use 1 mrad to study the effect.

- For Horn-1 the uncertainty in the Y-axis is obtained with respect to the main beamline. We will use 0.3mm as 1σ uncertainty in Y since Horn-1 main beamline misalignment is accounted also by beam angle uncertainty.

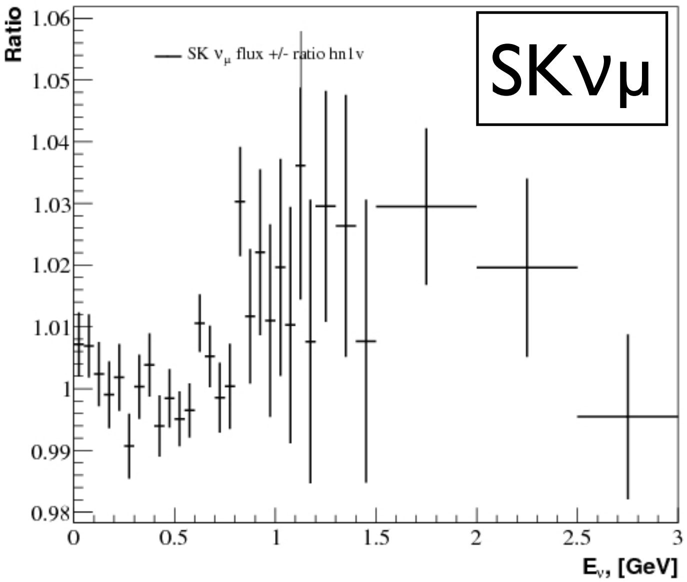
- Rotation of Horn-1 causes rotation of the Target since they are firmly attached. Expect sizable effect.

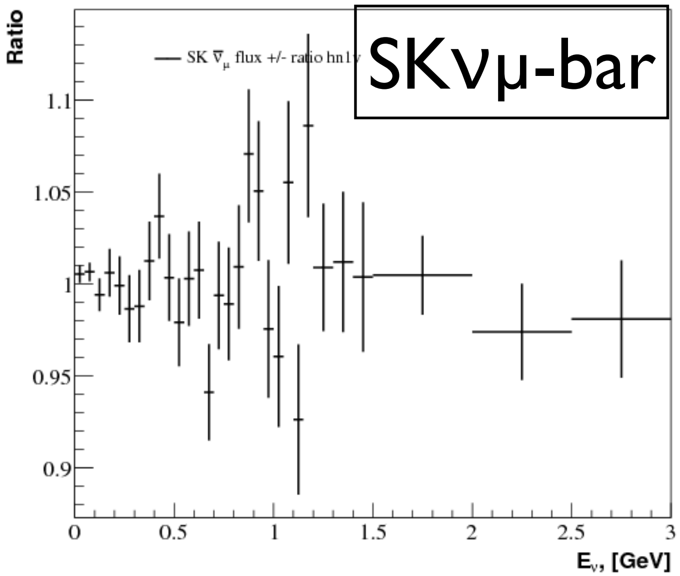
→ Estimate this effect by JNUBEAM (GCALOR)

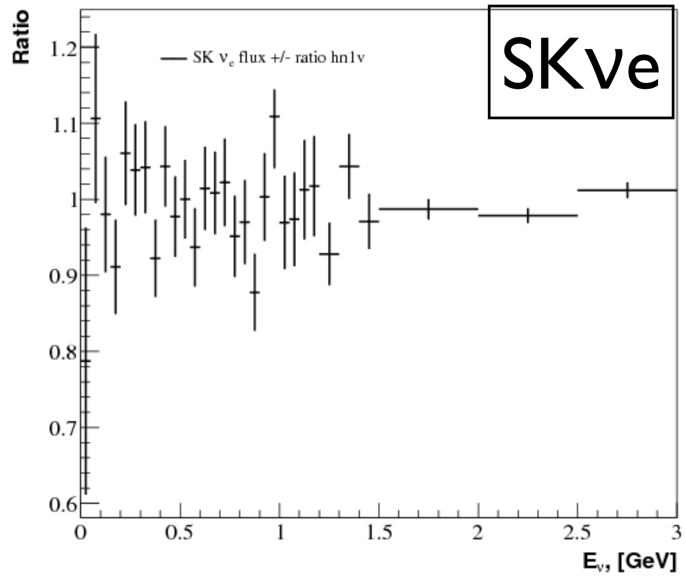
Horn 1 :Vertical ± 0.3 mrad

- Calc. +1σ/-1σ varied flux ratio

Martin Tzanov





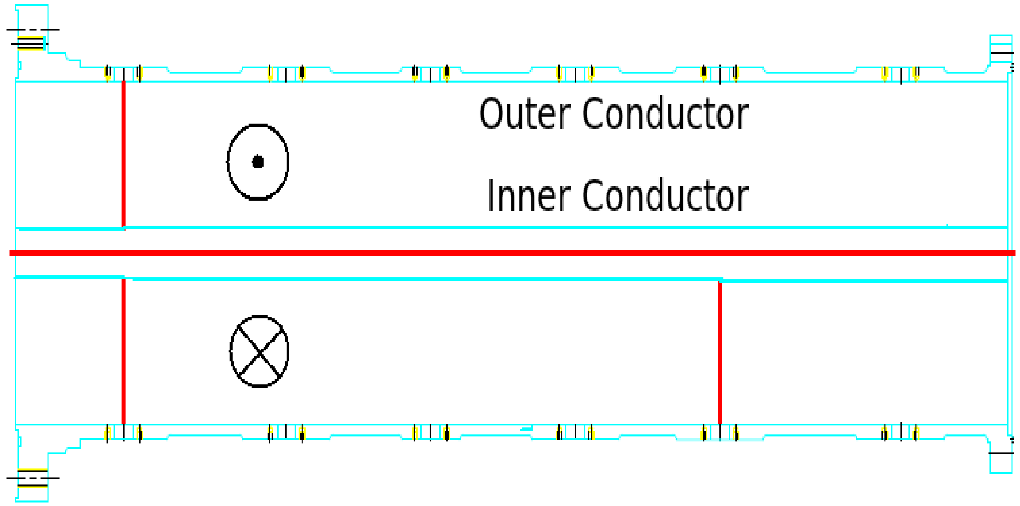


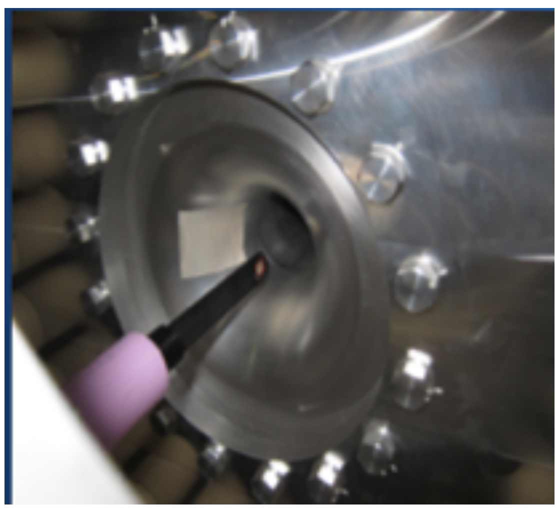
- About 2-3% shape difference for the νμ flux. Perhaps partially due to the tilt of the target.
  - For horizontal change, 2~3% shape difference around 1~2GeV
- About horn2&3, flux not change significantly
- About ND flux, same results as SK
- Next: Estimate this effect by FLUKA

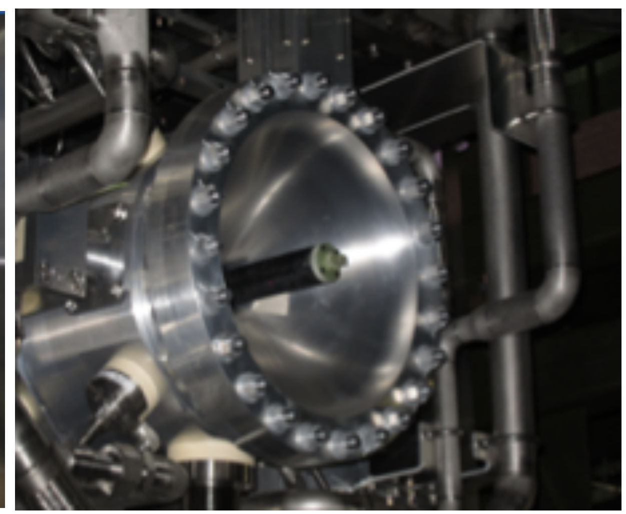
Horn field asymmetry

Andrew Missert

- Measurements made to verify replacement horn 1 field and check for asymmetry.
- Nominal azimuthal field tested at instrumentation ports with 3-axis Hall probe, and asymmetry field tested on-axis with Hall probe and pickup coil.
- Found instead "anomalous" field with unusual time dependence



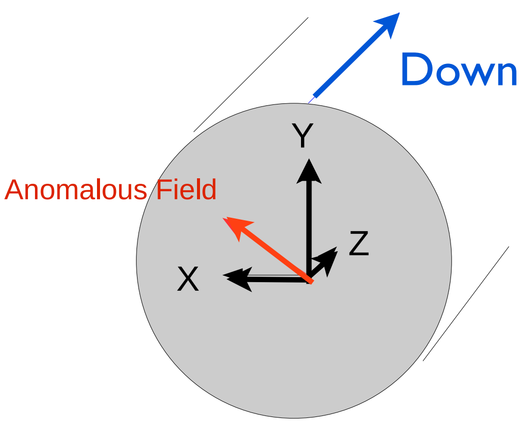




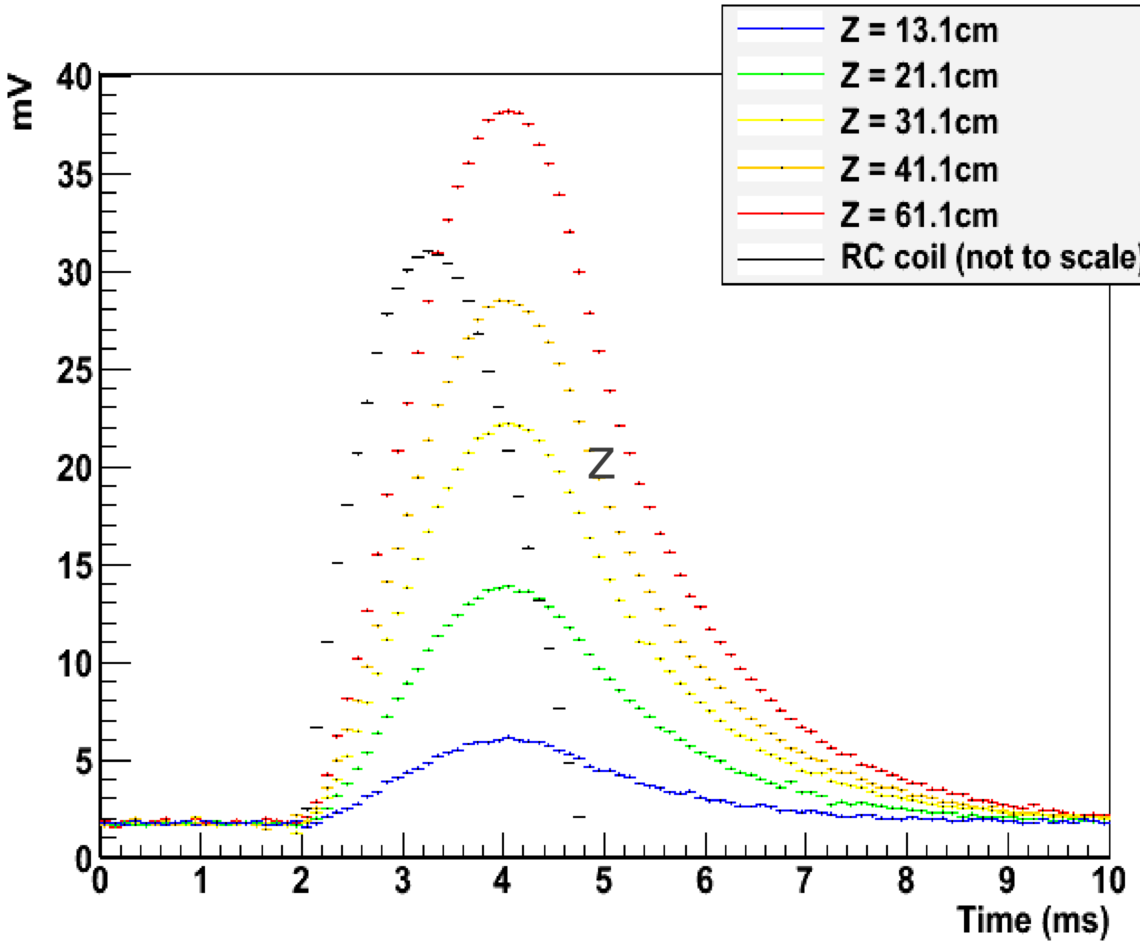
Anomalous On-Axis Field: Time Dependence

Andrew Missert

- Peak field on-axis offset from peak current by 0.7ms
- Decays exponentially with time constant 0.826 (1/ms) after shaped current pulse.

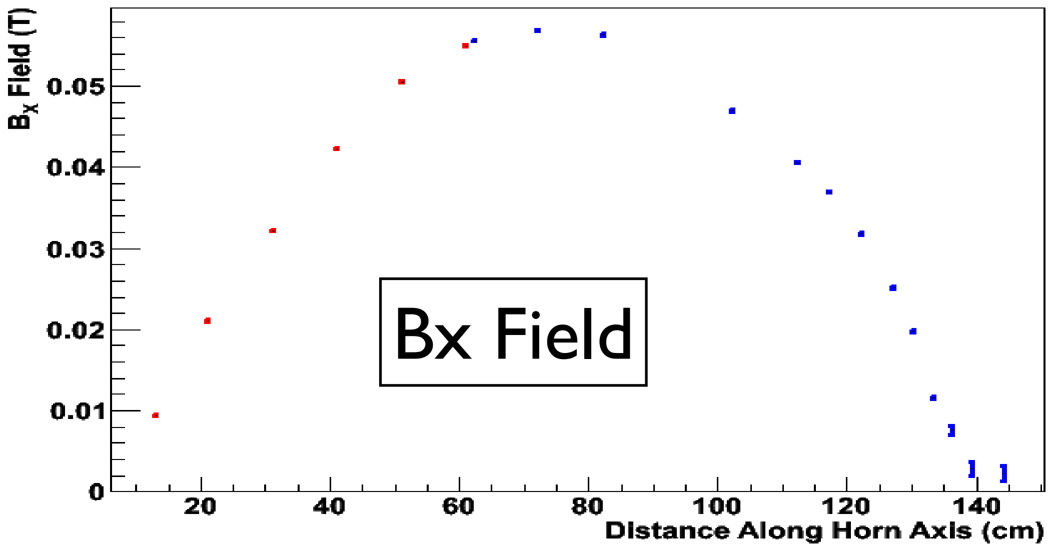


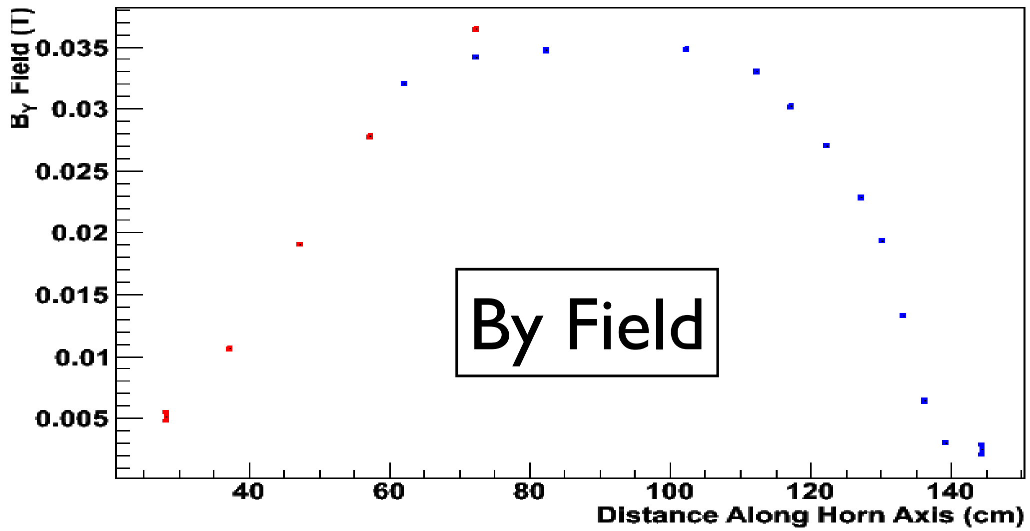
On-axis Coordinate Definitions



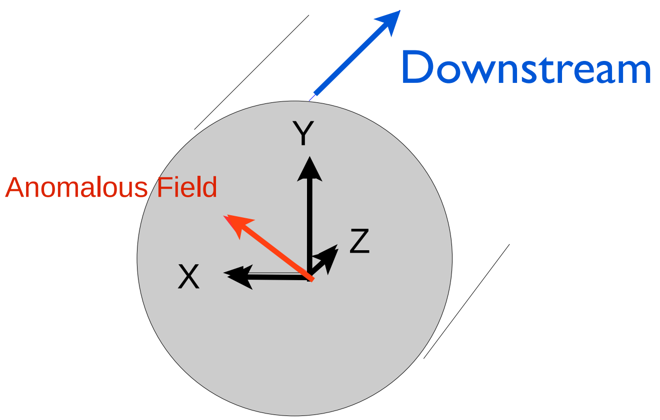
Anomalous On-Axis Field: Variation along horn axis

Andrew Missert





- Pickup Coil on 1m probe mount
- 3-axis Hall probe on 2m probe mount



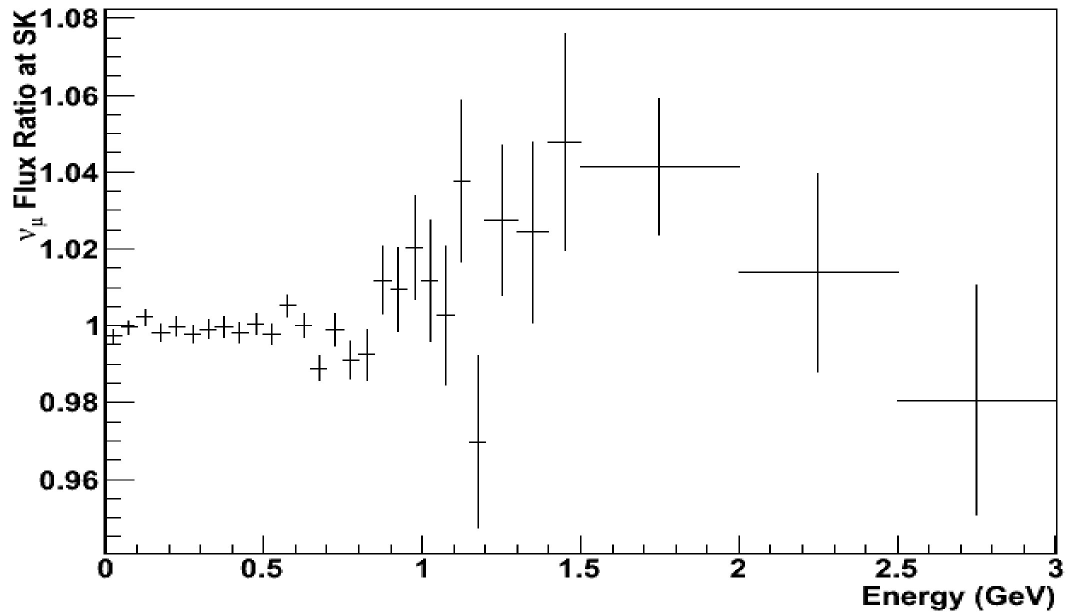
On-axis Coordinate Definitions

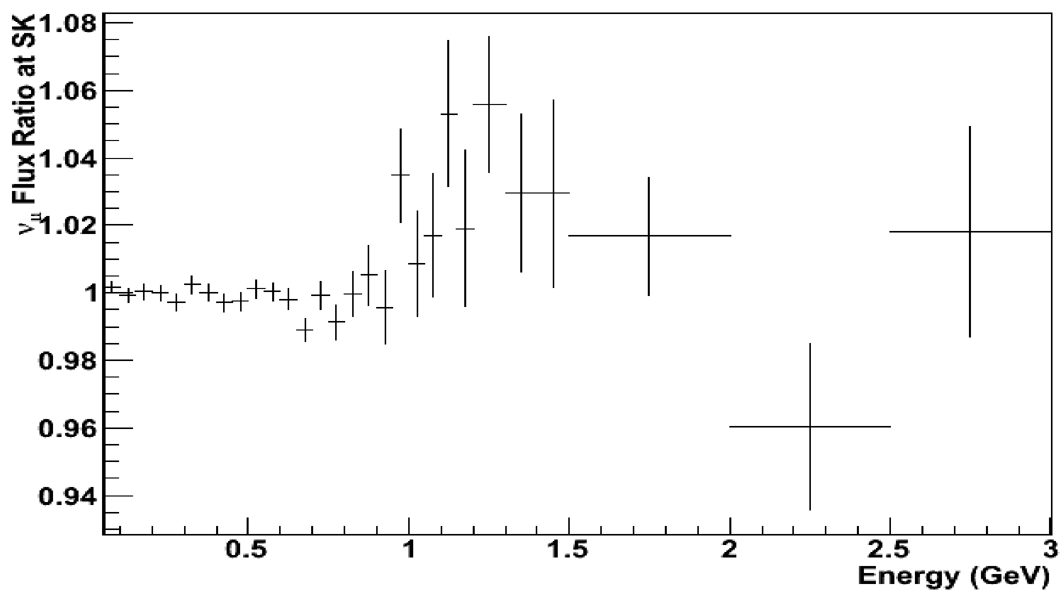
- Field measured along entirety of horn axis with long axial probe mount.
- Field reaches maximum value of (0.057,0.035,0)T near middle of horn.

Anomalous On-Axis Field: Effect on Neutrino Flux

Andrew Missert

- Upper bound of effect on neutrino flux found by implementing in beam MC maximum measured field (0.057, 0.035,0.0)T everywhere inside inner conductor of just horn 1 (top) and all 3 horns (bottom) . Effect less than 2% for most energy bins.
- Now progress in study → Will add flux uncertainty (next next version)





Summary

- Already provide latest flux uncertainty (11av2.1) and covariance for oscillation analysis.
- Plan to finalize next release of flux uncertainty (11av3.1) toward 2011 oscillation analysis.
  - Include errors from updated NA61 Kaon results.
  - Update about Off axis angle & proton beam flux uncertainty
  - Include flux uncertainty related horn angular alignment and asymmetric field.
- Tech-note(#99) about flux uncertainty for 2011 analysis nearly complete and under internal review.