Summary of the Flux Session

M. Friend (for the NuINT2015 Flux Session Conveners)

KEK

October 30, 2015

Flux is Important!

- You can't make a neutrino measurement without a neutrino flux

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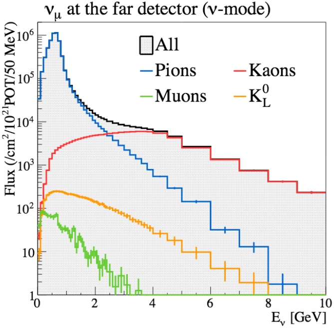
- You can't make a neutrino measurement without a neutrino flux
- You can't make a precise neutrino cross section measurement without small neutrino flux errors
  - $\rightarrow$ Flux is very important

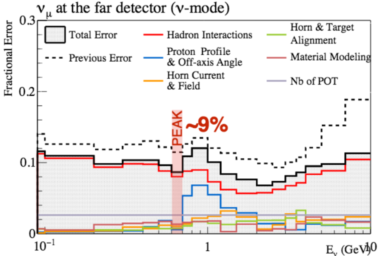
Flux Session Outline

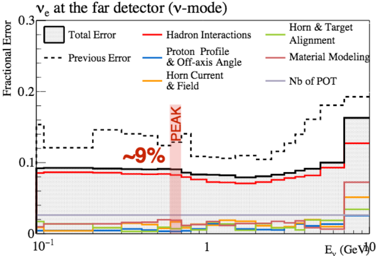
- We heard 5 talks during the flux session:
  - Recent Developments on T2K Flux and Flux Errors (L. Zambelli)
  - NuMI Flux and Flux Errors (T. Golan)
  - Hadron Production Experiments Review (A. Brvar)
  - Constraining Accelerator Flux with Muon Monitors (J. Lopez)
  - Atmospheric Neutrino Flux Calculations (M. Honda)

T2K Fluxes and Flux Uncertainties



- Need to understand interactions in the target to predict the flux
- Largest T2K flux errors come from hadron production uncertainties – constrain with external hadron production data
- Second largest T2K flux error comes from off-axis angle – error can be reduced with improved use of on-axis near detector data



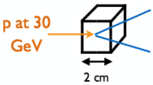


NA61/SHINE data for T2K

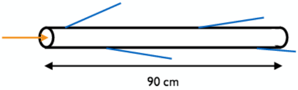
[1]: *PRC 84 (2011) 034604*, [2]: *PRC 85 (2012) 035210*,
[3]: *PRC 89 (2014) 025205*, [4]: *arXiv:1510.02703*
[5]: *NIM A701 (2013) 99-114*,
[6]: *A. Haesler's PHD (Geneva Uni., 2015)*.

NA61/SHINE provides 2 types of datasets for T2K :

JINST 9 (2014) P06005.

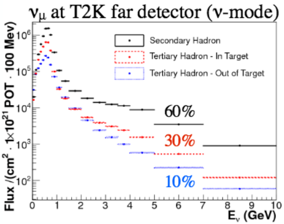


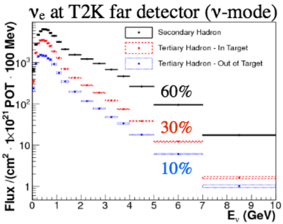
thin target :
study the primary p+C interaction



replica target :
accounts for the re-interactions in the target

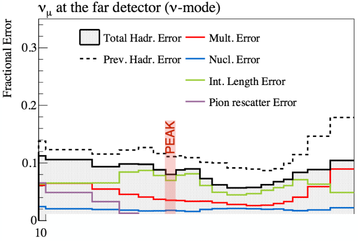
Target	Year	Stat ($\times 10^6$)	NA61 status	T2K status
Thin	2007	0.7	published : $\pi^{\pm}$[1], K^+[2], K^0_S, Λ [3]	is used (prev. tuning)
	2009	5.4	submitted : $\pi^{\pm}$, $K^{\pm}$, p, K^0_S, Λ [4]	is used **(new tuning)**
Replica	2007	0.2	published : $\pi^{\pm}$ [5]	method developed
	2009	2.8	preliminary : $\pi^{\pm}$ [6]	work ongoing
	2010	~10	analysis started	-



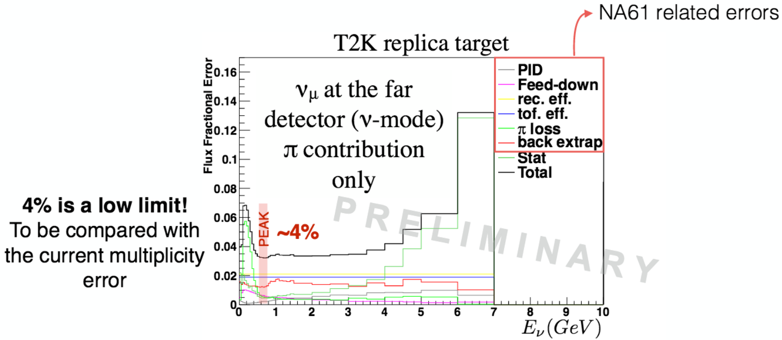


60% of the flux (at peak energy) is directly tunable with the **thin target** data.
Up to **90%** once the **replica target** data is implemented in the tuning.

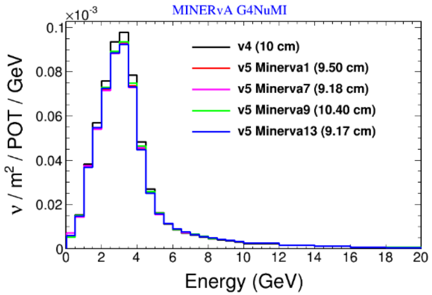
Improvement of T2K Flux Uncertainties w/ Replica Target Data

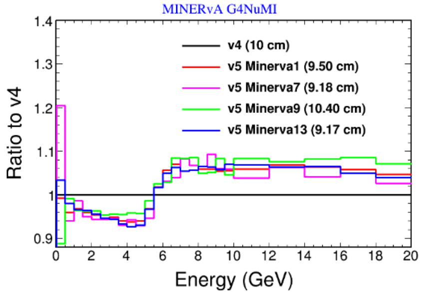


- Uncertainties on the T2K flux can be reduced with T2K replica target data (now under analysis)
- Multiple methods being considered to incorporate replica target data in T2K flux estimation



NUMI Flux Update – Geometric Update

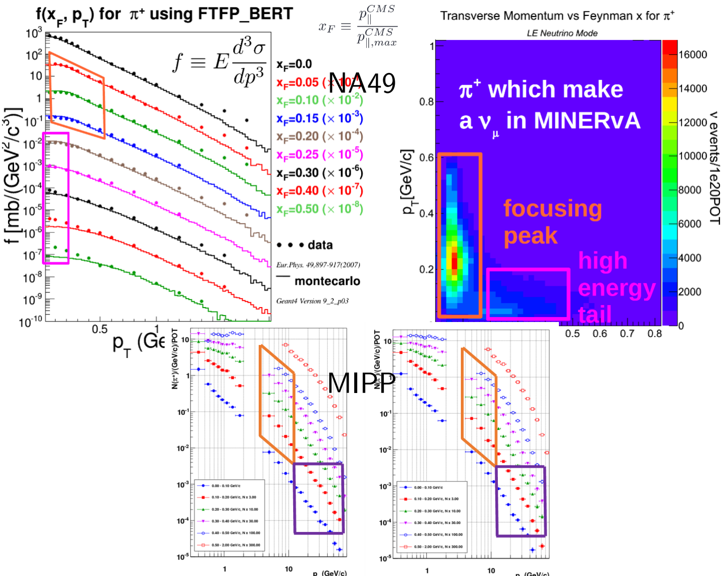




Heard about major updates to NUMI flux estimation for MINERvA

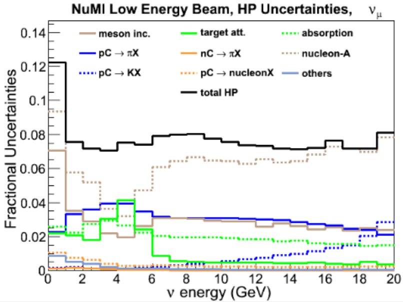
- Changes to geometry inputs
  - Horn cooling water has major impact on predicted flux
- Inclusion of new external hadron production data
  - NA49
  - MIPP

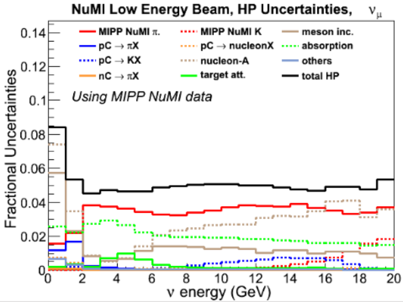
NUMI Flux Update – External Hadron Production Constraints



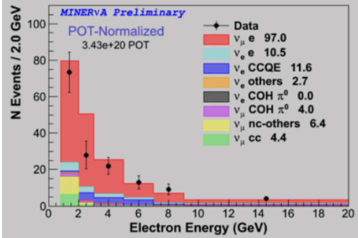
NUMI Flux Update – Flux Errors Reduced

- Flux errors reduced substantially by using this new hadron production data



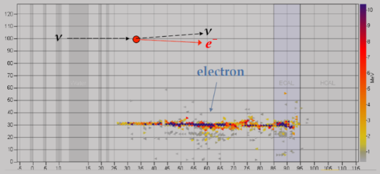


NUMI Flux – Interesting New Ways to Constrain the Flux



Predicted number of signal events is higher than indicated by data (weighting up universes that agree better with data)

- Electroweak theory predicts precisely cross section for neutrino-electron scattering
- Experimental signature is a very forward single electron in the finale state



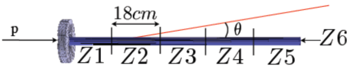
- ν-e scattering (which has a very well-known cross section) to constrain the flux
- Use low ν (energy transfer) CC events
  - Cross section looks like: $\frac{d\sigma}{d\nu} = A(1 + \frac{B}{A}\frac{\nu}{E} - \frac{C}{A}\frac{\nu^2}{2E^2})$ – higher order terms cancel at $\nu/E \to 0$
    - Constrain flux shape (w/ normalization A)

Hadron Production Measurements

- Many types of dedicated hadron production experiments
  - NA61/SHINE, NA49, MIPP, HARP & CERN-PS214, etc
  - For conventional, non-conventional beams, atmospheric, MC inputs
  - T2K replica target analysis by NA61/SHINE is currently under way

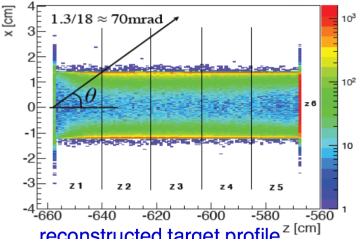
NA61 Replica Target Analysis:

Hadron multiplicities are measured at the target surface in bins of {p, θ, z}



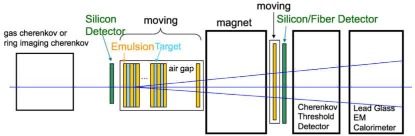
Tracks are extrapolated backwards to the target surface (point of closest approach)

the target is sliced in 5 bins in z
+ downstream exit face



reconstructed target profile

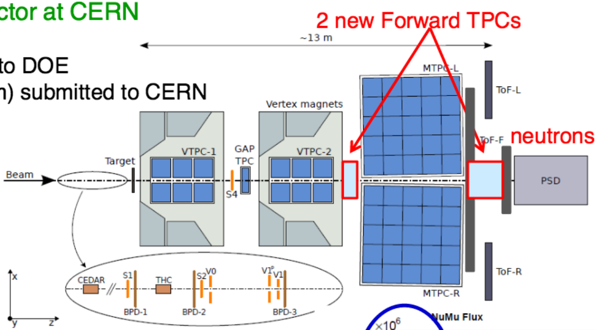
New Idea – Use Emulsion:



NA61 for FNAL ν beams (USNA61)

Perform hadroproduction measurements to characterize the NuMI ν beam using the NA61 detector at CERN

- mainly US groups
- proposal submitted to DOE
- proposal (addendum) submitted to CERN

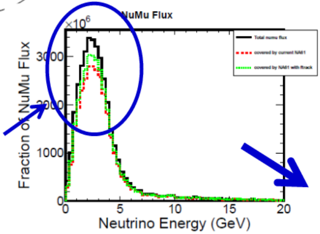


data taking to start this fall
~ 5 year program

Upgrades:

- add forward tracking
- forward calorimetry (neutrons)
- new DAQ based on the DRS
- improved trigger
- new beam tracking-SciFi detectors

improved coverage

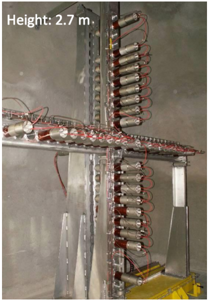


Sandro's Observations on Hadron Production Measurements

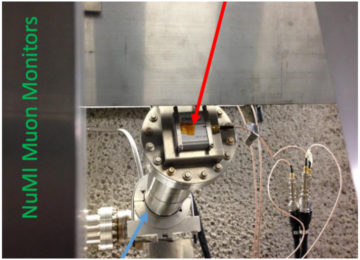
- Hadroproduction measurements require
  - Large acceptance detectors
  - Excellent PID over whole kinematical range
  - Good vertexing (replica targets!)
  - Large statistics
  - Different nuclear targets to study various particle production effects
- None of the existing hadroproduction models describes satisfactorily the ensemble of NA61 data (same for NA49, MIPP ...)!
- Systematic uncertainties due to small contributions from various sources
  - There is not a particular error dominating over others $\rightarrow$ Beginning to be true for full beam flux errors as well?
- Some kinematical regions still dominated by statistical uncertainties
- To improve on existing results:
  - Increase statistics by a factor of 10
  - Better understanding of interaction and production cross sections
  - Forward acceptance
  - Vertexing (replica targets)

Constraining the Flux w/ Muon Monitors

CNGS:



New Ideas for LBNF/DUNE:



T2K:

Silicon PIN Photodiodes

Ion Chambers

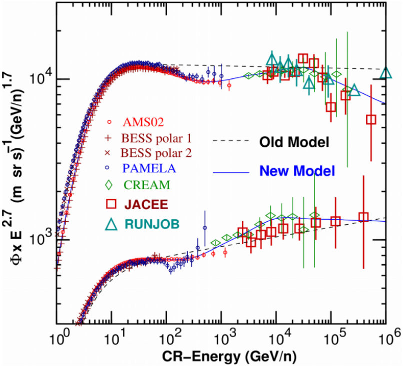
Constraining the Flux w/ Muon Monitors

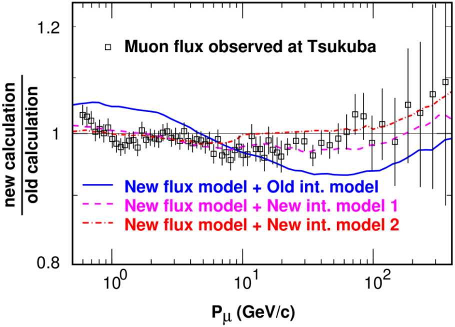
Comment from Megan:

- Need to start seriously thinking how we can use this kind of measurement to constrain the flux/as an input into flux simulation
  - Does it actually add a useful constraint?
    - T2K off-axis angle, beam position constraint
  - Difficulties?
    - Beam dump material, backgrounds (delta production), etc

Atmospheric Neutrino Flux

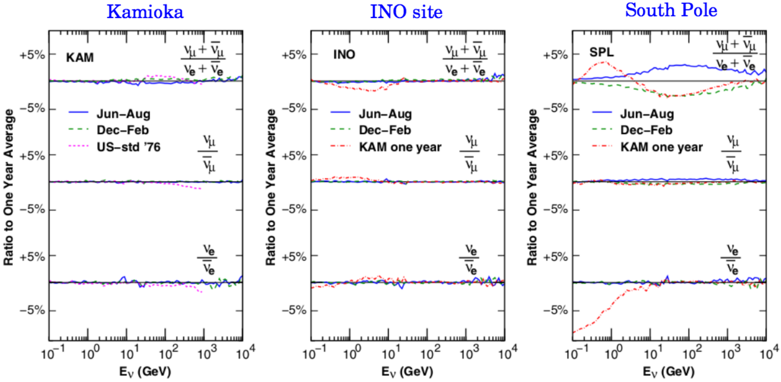
Heard about update to muon calibration of hadronic interaction model going into atmospheric flux calculation to include AMS02 and BESS-polar data in model constraint





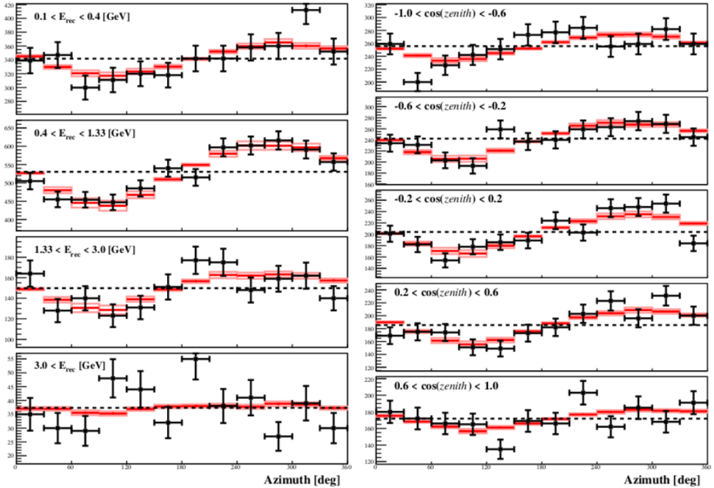
Atmospheric Neutrino Flux – Seasonal Variation

New calculations including seasonal variations in atmospheric pressure



Atmospheric Neutrino Flux – SK Data-MC Comparison

Observed Azimuthal Variation of ν_e flux (from PHD thesis of E.Richard)



Energy Binned All Azimuth angles

Zenith Angle Binned All Energies

Comments from Mike (I guess everyone can agree..)

- We need to worry about flux measurements for future experiments (DUNE, HK) now and not later
  - If (since) dedicated experiments are required and take a long time to set up/analyze, need to work on this NOW
- Need redundant flux measurements using different methods as much as possible
  - Now there are discrepancies that we need to understand for next generation experiments
  - Let's take as much data as possible to understand the flux

Some Things to Think About for Fluxes

- How precisely can we predict the flux?
  - New ideas for hadron production measurements? How precise can these get?
    - What should we do when systematics come from a variety of small errors rather than one dominant one?
  - Possible to achieve a precision good enough to check well-known cross sections (such as ν-e scattering)?
- Other novel ways to constrain fluxes?
  - Existing measurements/monitors can be used in new ways?