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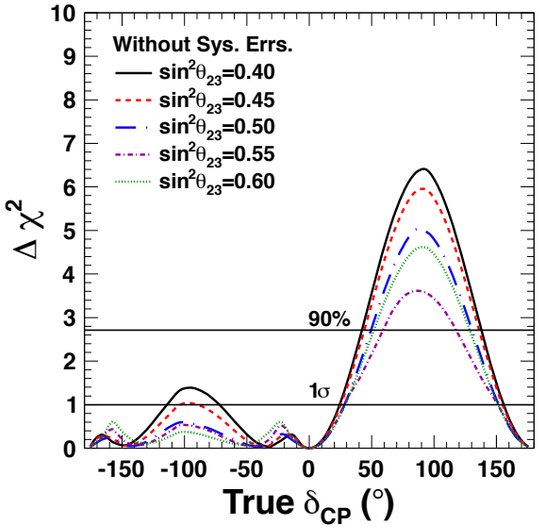
THOUGHTS ON T2K ULTIMATE SENSITIVITY

UPDATED T2K GOALS

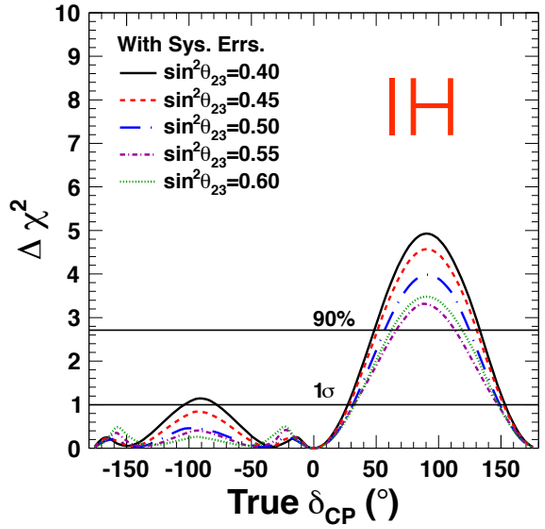
- Initial measurement of CP violation in neutrinos up to a 2.5 σ level of significance
- Precision measurement of oscillation parameters in ν_μ disappearance $\delta(\Delta m^2_{32}) \sim 10^{-4}$ eV^2, $\delta(\sin^2 2\theta_{23}) \sim 0.01$
  - n.b. $\delta(\sin^2 2\theta_{23})=0.01 \sim \delta(\sin^2 \theta_{23})=0.05$ at $\theta_{23} = \pi/4$
- Contribution to the determination of the mass hierarchy

- Can we do better in some of these goals?
  - What can we do to get to 3 σ sensitivity to CP violation in favorable cases?
  - What is the upper limit to what we can achieve?

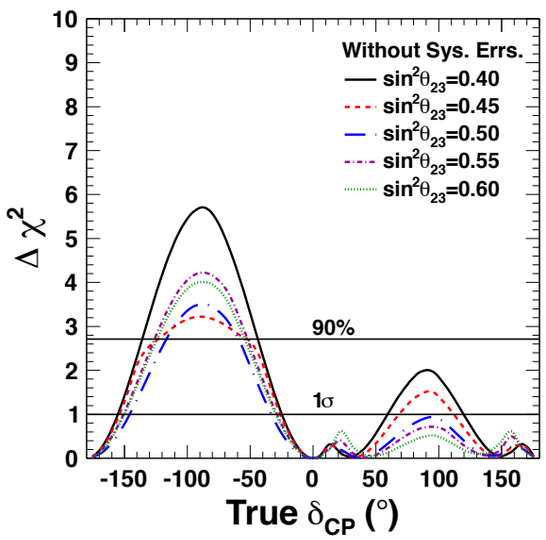
CP SENSITIVITY



(c) 50% ν, 50% $\bar{\nu}$-mode, statistical error only.



(d) 50% ν-, 50% $\bar{\nu}$-mode, with the 2012 systematic errors.



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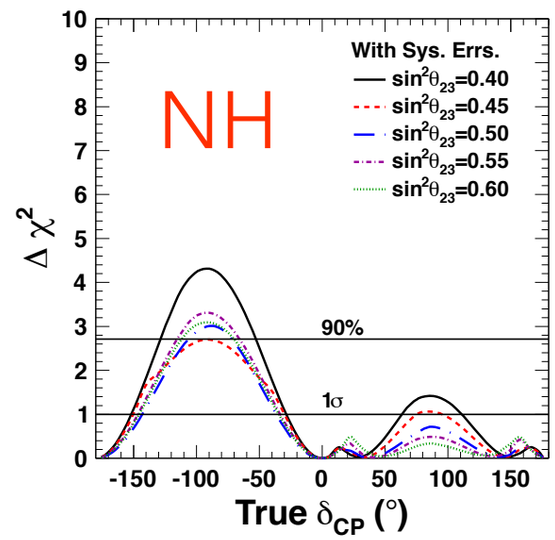


(d) 50% ν-, 50% $\bar{\nu}$-mode, with the 2012 systematic errors.

- (Obvious) T2K's sensitivity to CPV depends heavily on the underlying true parameters.
- Systematic uncertainties have a significant impact (~30% on $\Delta\chi^2$)
  - making significant progress
  - assume progress continues . .
- Even in the absence of systematic errors, the sensitivity is <2.5 σ in even the most favorable cases.
  - Higher effective statistics in SK is needed (roughly x2.5)

HEADROOM FOR IMPROVEMENT

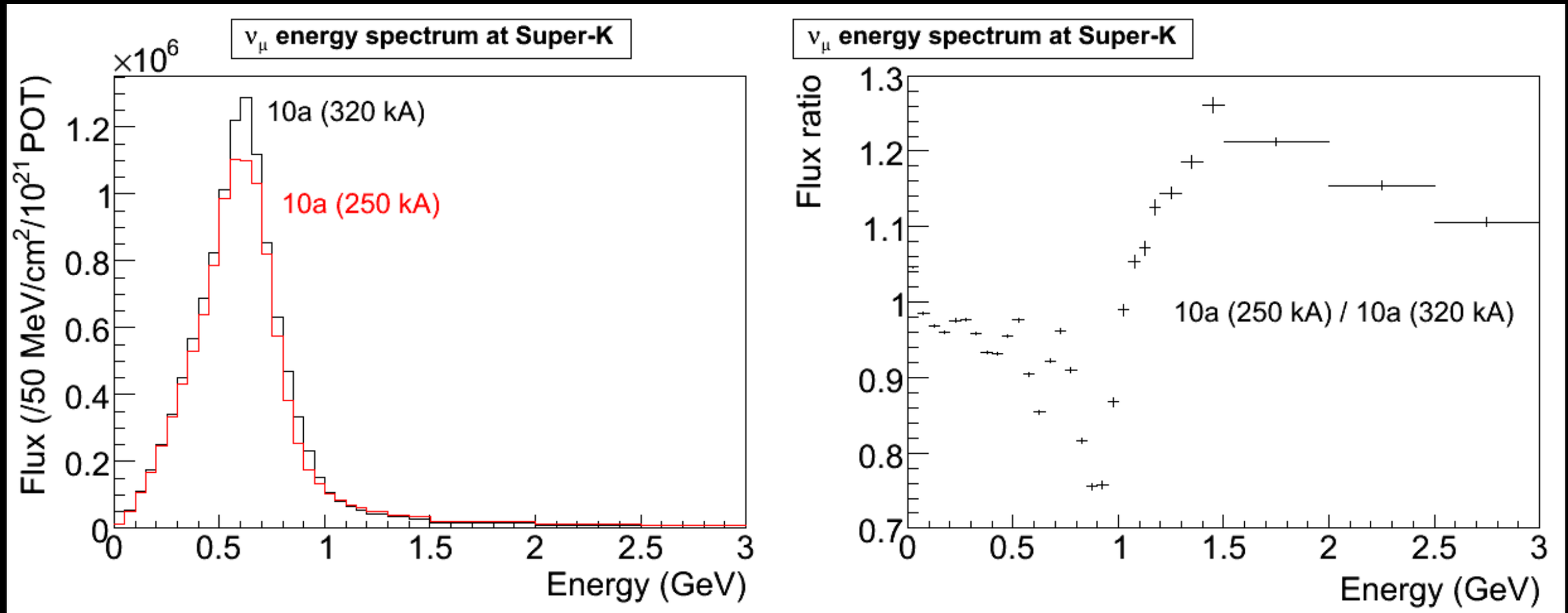
RUN1+2+3+4 ($\sin^2 2\theta_{13} = 0.1$)	Expected					Data
	$\nu_\mu + \overline{\nu}_\mu$ CC	$\nu_e + \overline{\nu}_e$ CC	NC	BG total	$\nu_\mu \to \nu_e$ CC	
Interactions in FV	325.67	15.97	288.11	629.75	27.07	-
FCFV	247.75	15.36	83.02	346.13	26.22	377
Single-ring	142.44	9.82	23.46	175.72	22.72	193
Electron-like PID	5.63	9.74	16.35	31.72	22.45	60
$E_{\rm vis} > 100$MeV	3.66	9.68	13.99	27.32	22.04	57
No decay-e	0.69	7.87	11.84	20.40	19.63	44
$E_\nu^{\rm rec} < 1250$MeV	0.21	3.73	8.99	12.94	18.82	39
fiTQun π^0 cut	0.07	3.24	0.96	4.27	17.32	28
Efficiency from Interactions [%]	0.0	20.3	0.3	0.7	64.0	-
Efficiency from FCFV [%]	0.0	21.1	1.2	1.2	66.0	-

- Currently, we select 17.3 events out of 27.1 ν_e CC in the FV
  - 64% efficiency to select ν_e CC in 22.5 kt FV
  - most of the "efficiency" loss is in 1R (86%) and decay-e (89%) to select CCQE from CC1π and other more complicated topologies
- At best, we can hope to recover these remaining events, maintain S/B
  - ~56% increase in effective statistics

FIDUCIAL VOLUME:

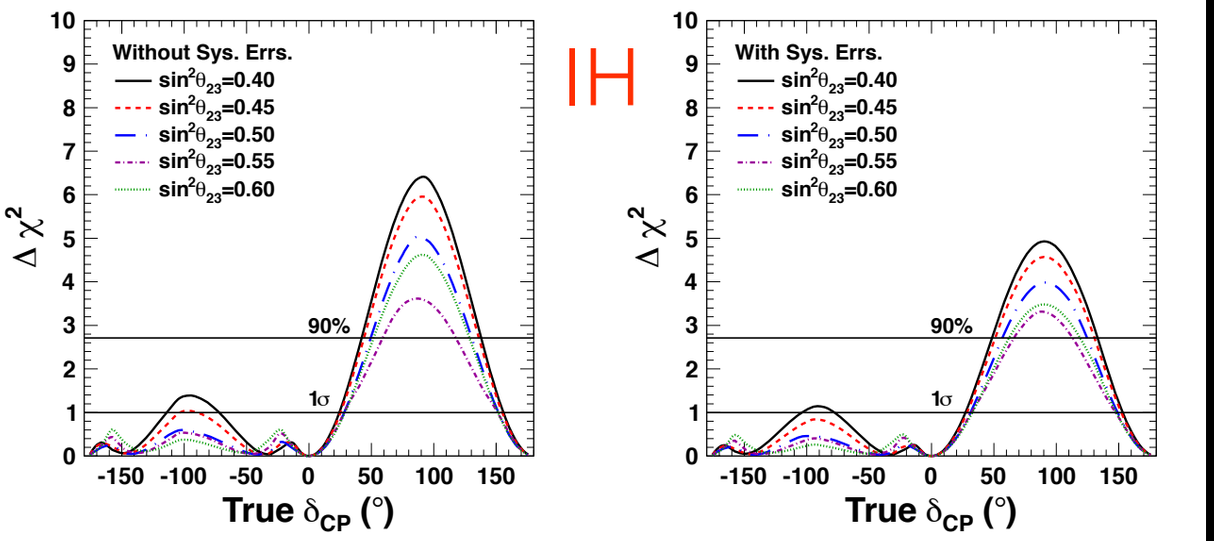
- The current FV is defined by a 2m cut from the wall of the SK inner detector
  - 2 meters from 33.8 m diameter, 36.2 m cylinder
  - Total 31.9 kT (somewhat less due to PMTs, etc.) (42%)
- Could be relaxed and more events brought in.
  - 1 m from the wall (or a similar effective increase) leads to 21% increase in FV (27.2 kT)

HORN CURRENT



- Recall that we are running with reduced horn current with respect to design (250 kA vs. 320 kA)
- If we can return to design current, we can recover ~10-15% of the flux at the off-axis peak

HOW FAR DO WE GET?



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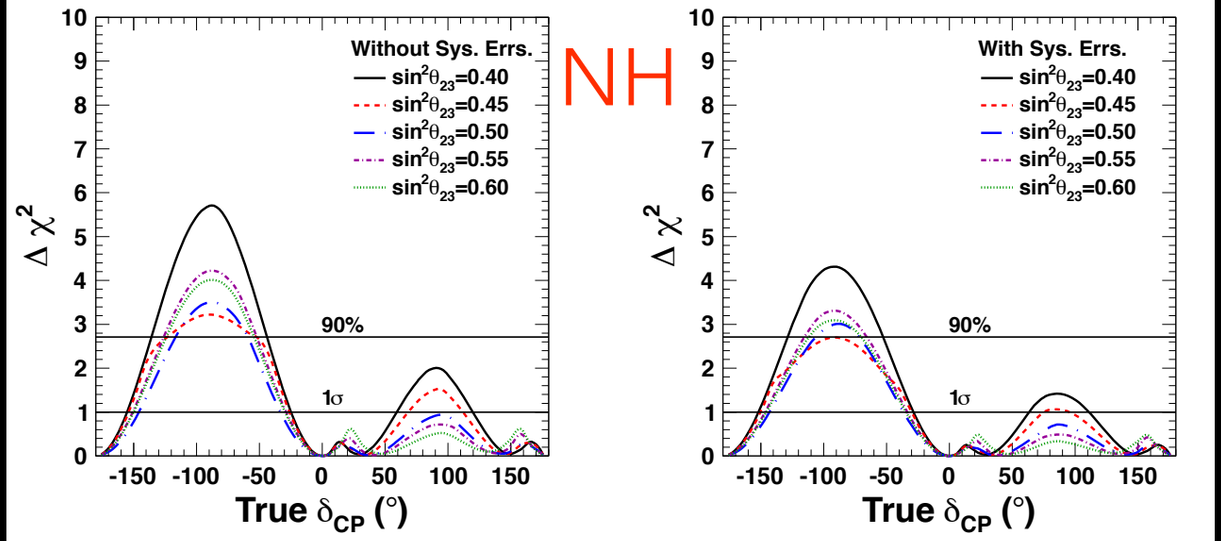

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(d) 50% ν-, 50% $\bar{\nu}$-mode, with the 2012 systematic errors.

- If we take our δ_{CP}=-π/2 "hint" seriously, we can expect $\Delta\chi^2$~3-4 depending on $\sin^2\theta_{23}$
- Assume maximum from recovering efficiency, increasing FV:
  - 1.21-1.42(FV) x 1.56 (Eff) x 1.10 (flux) ~ 2.0-2.4 increase in effective statistics
- This gets us close to 3 σ ($\Delta\chi^2$ ~9)

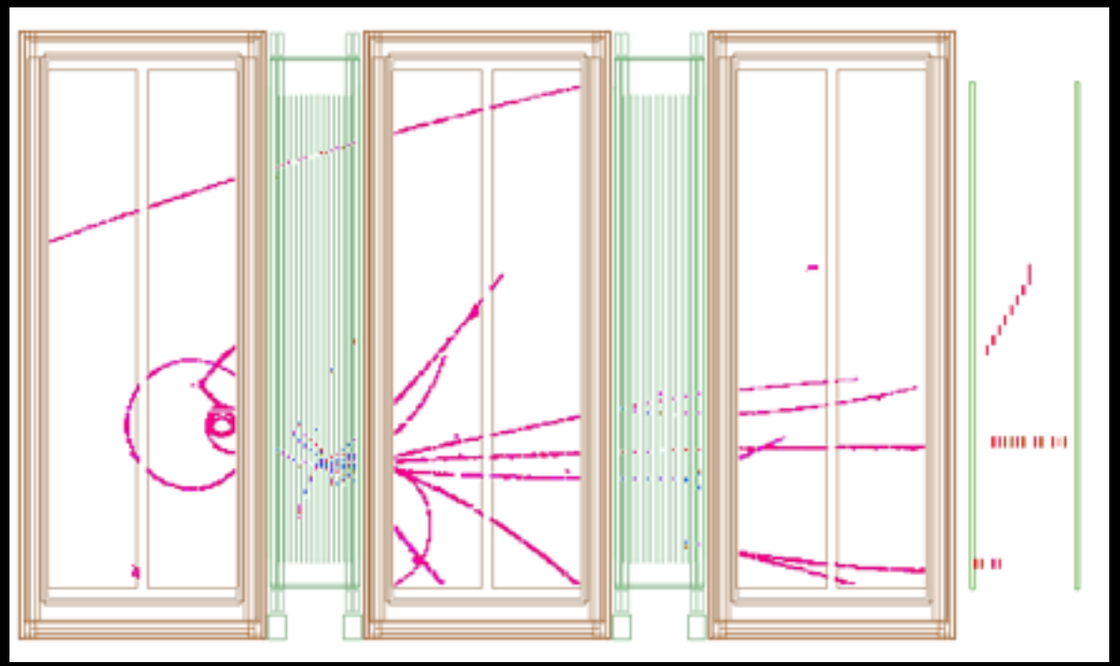
CONCLUSIONS

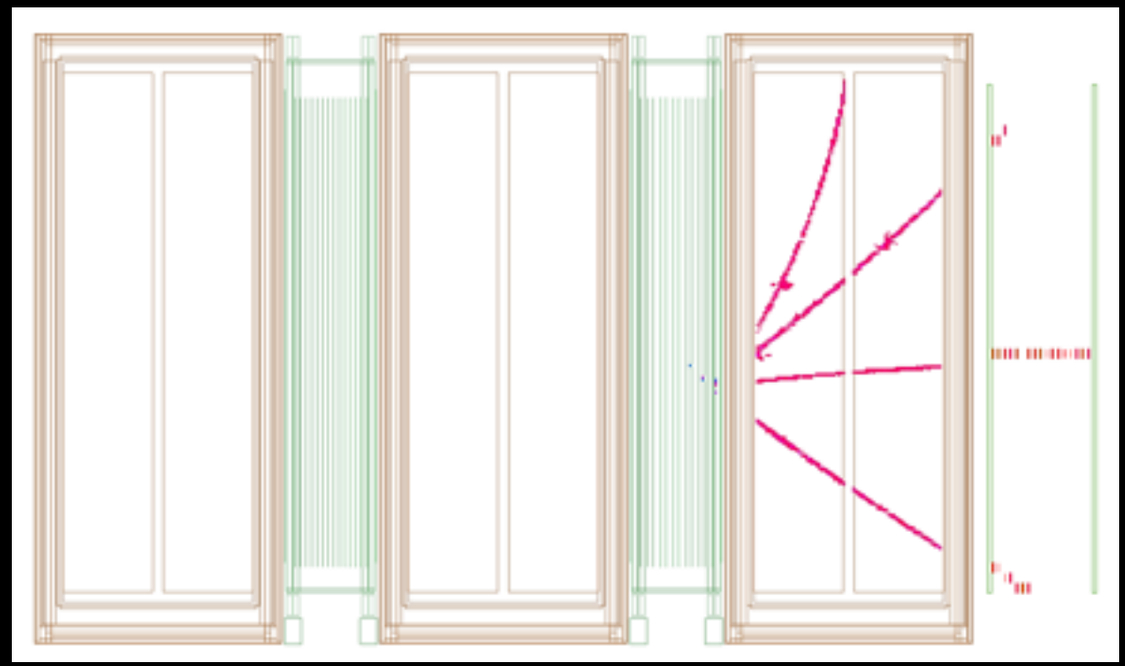
- Upper limit on improvements in SK:
  - Up to 56% in selecting ne interactions by expanding topologies
  - Up to 42% in fiducial volume (21% if we got to D_{wall}=1 m)
  - How close can we get to ultimate performance while:
    - keeping backgrounds under control
    - keeping systematic errors under control
- With these “improvements”, and with a little help from elsewhere (horn, extra POT, etc.) 3 s is within reach.
  - But it’s very tough!

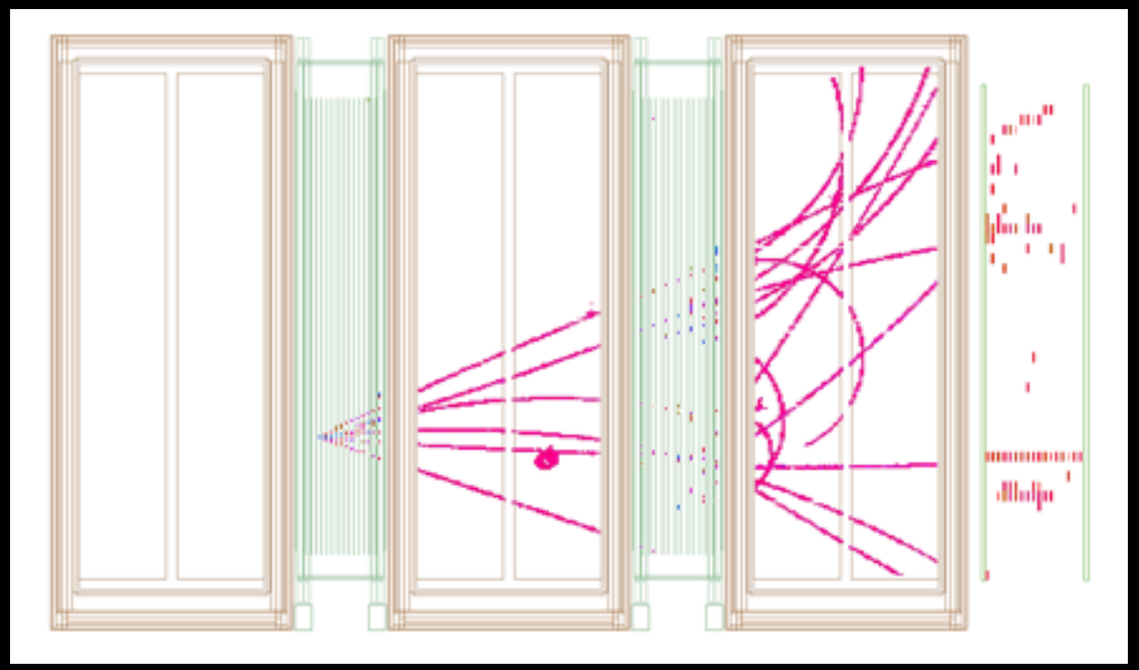
BEYOND CCQE

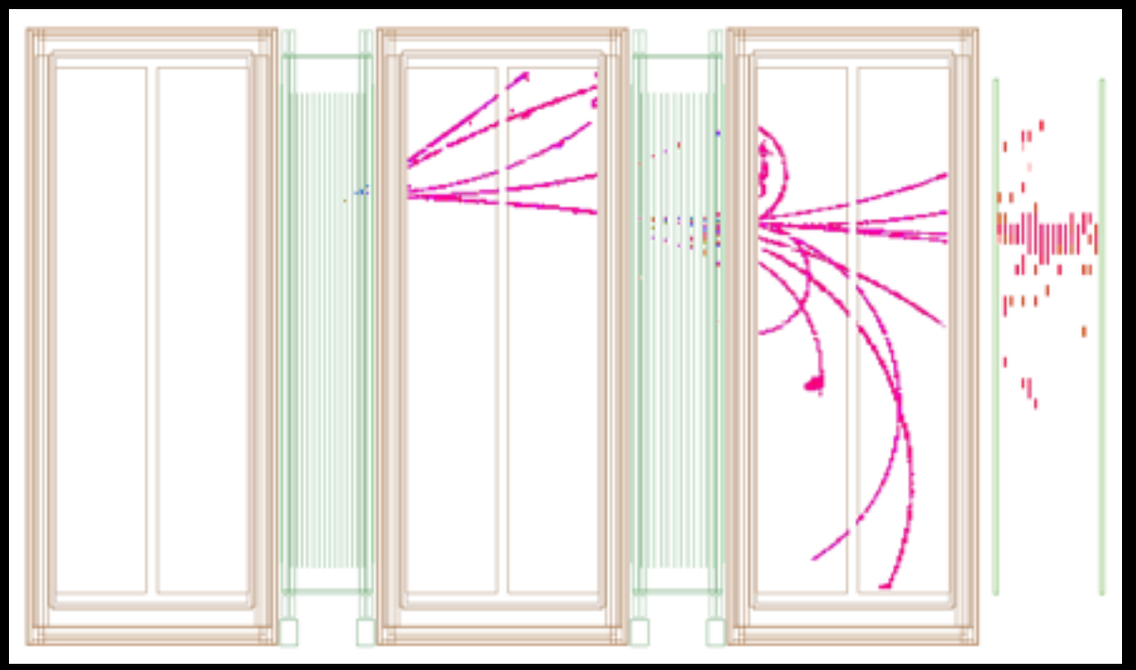
- Much of our discussion focusses on how we go beyond “1R”/“CCQE” events in the T2K-SK sample
- That means confronting pion production
  - more complicated topologies
  - more complications in understanding:
    - particles that actually emerge from the interaction
    - secondary interactions
    - relation between “Np” interactions and “Nring” events
- What is our strategy for understanding the Np interactions?
  - necessary ingredient towards using these samples
  - lots of preparatory work (multiplicity tuning, etc.)

Nπ EVENTS IN ND280

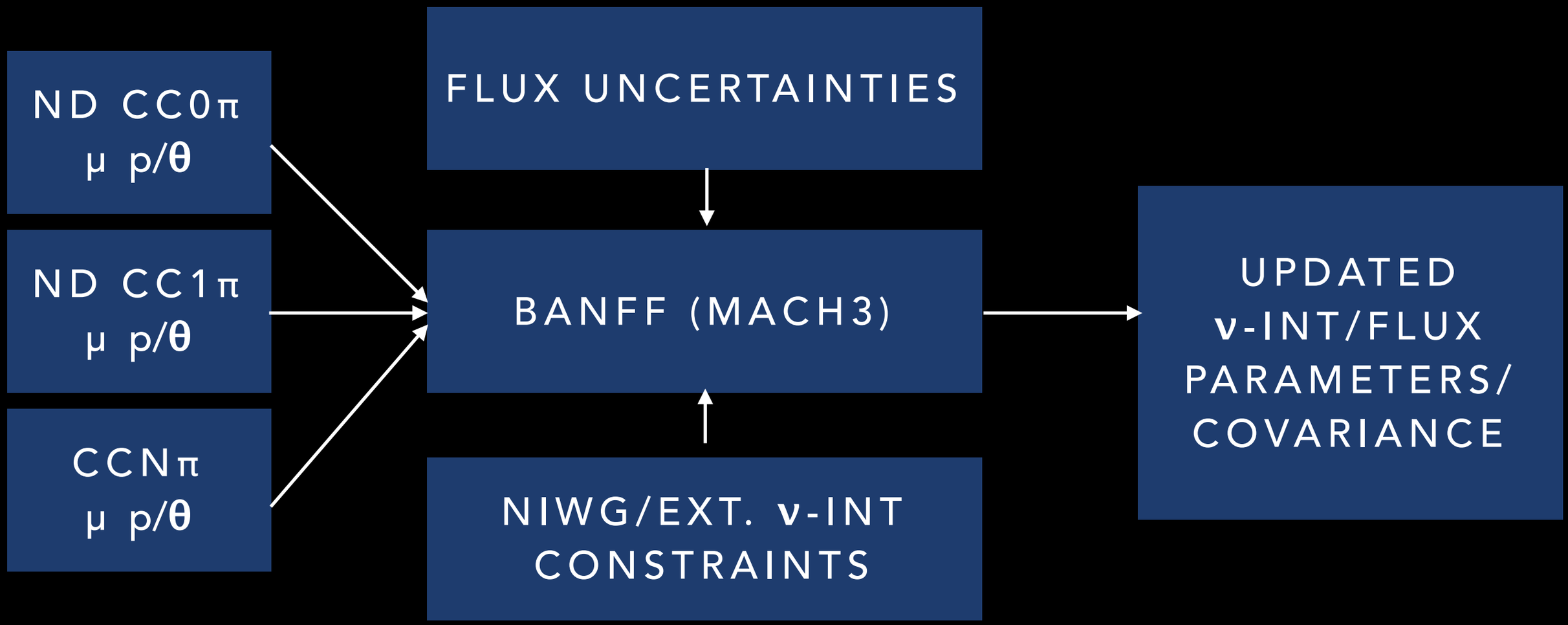








BANFF



- Current formalism incorporates topology in a limited way:
  - migration between three ND280 topological configurations
  - doesn’t resolve details of Nπ topologies in any detail
  - Works fine (great!) since the impact of these events on the analysis is limited due to our focus on 1R events.

MORE DIRECT WAY?

- Can we embed ND280 topologies directly into skdetsim to simulate interactions?
  - Perhaps restrict phase space, or limit attention to highest momentum track, etc.
- Can we isolate multitrack ν-H_2O interactions in FGD2 without subtraction?
  - vertex directly into water with multiple tracks.