Detection uncertainties at low energies

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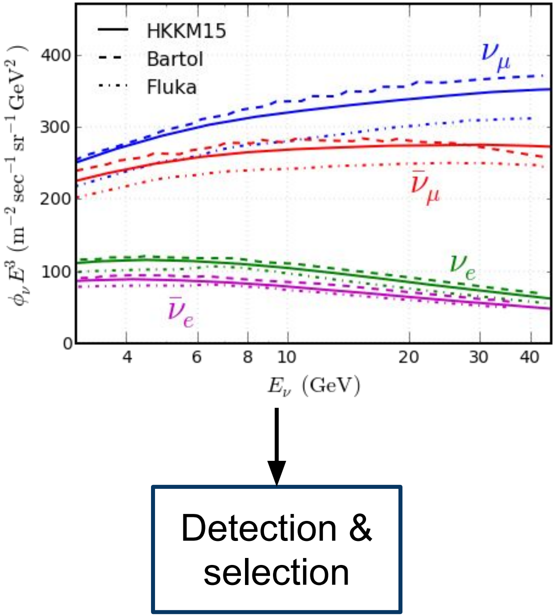
February 14th, 2017

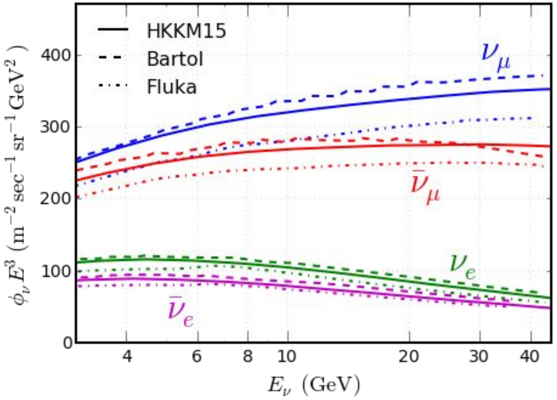
With some additions from Summer...

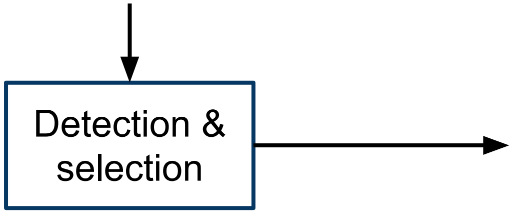
Diffuse low energy analyses

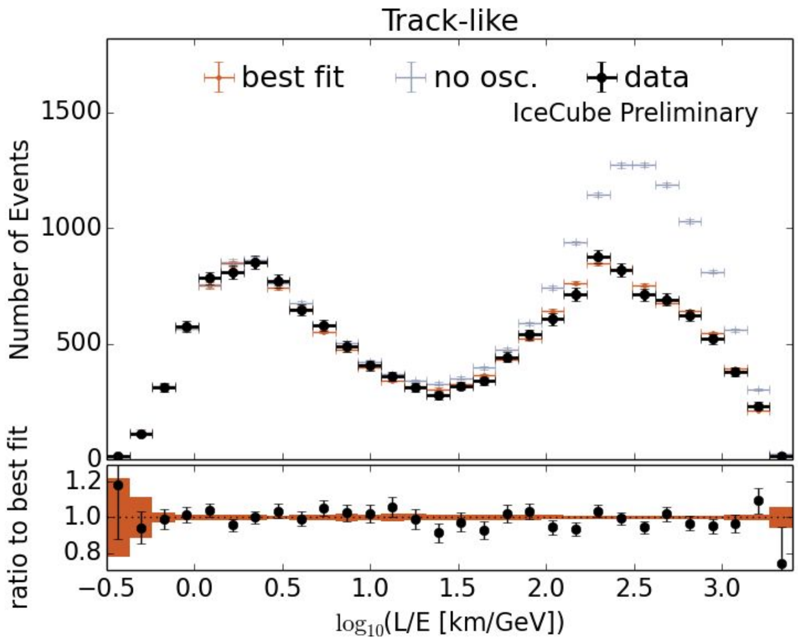


- Count neutrinos from multiple directions & energies
- Usual goal is to characterize a spectrum
- Typical strategy is **forward fold**
  - Produce simulation
  - Process simulation and data equally
  - Bin data & MC using observables, compare
- Uncertainties included in MC adjustment to data
  - Fit of physics parameters **with** nuisance parameters
- Relying heavily on MC to interpret results
  - No off-source region, test beam, near detector ...
  - Believe in a result only if data and MC **agree well**

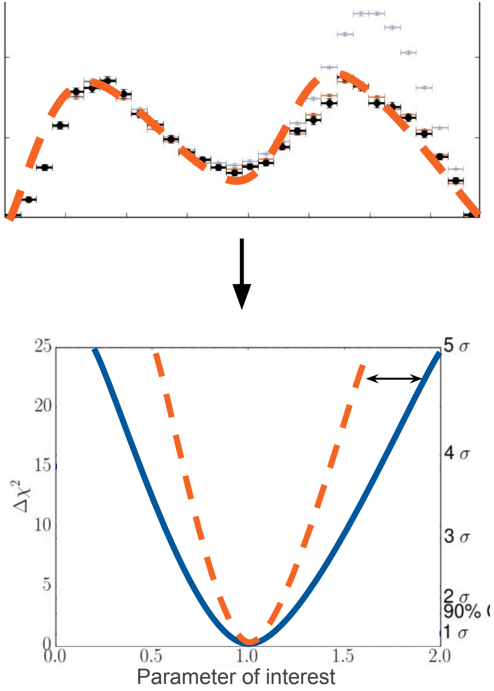
Diffuse low energy analyses







Systematic uncertainties



- Systematics are **reweighting factors** of the simulation
  - In the likelihood, λ depends on *w*

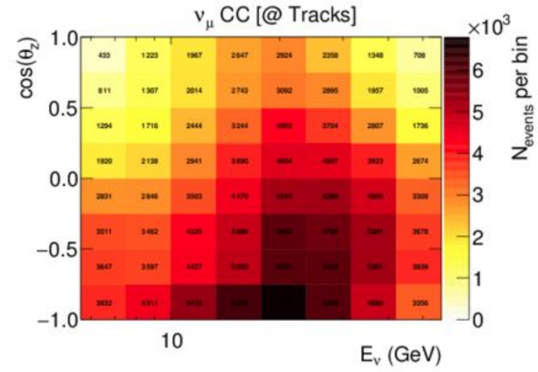
$$\mathcal{L}(\lambda, x, w; \mu, \sigma) = \prod_{i=1}^{n} \frac{\lambda_i^{x_i} e^{-\lambda_i}}{x_i} \prod_{j=1}^{m} \frac{1}{\sqrt{2\pi\sigma_j^2}} e^{-\frac{(w_j-\mu_j)^2}{2\sigma_j^2}} .$$

- We have to model and **parameterize** their impact
  - Allowed to **transition smoothly** between possibilities
  - Detection parameters = resimulation

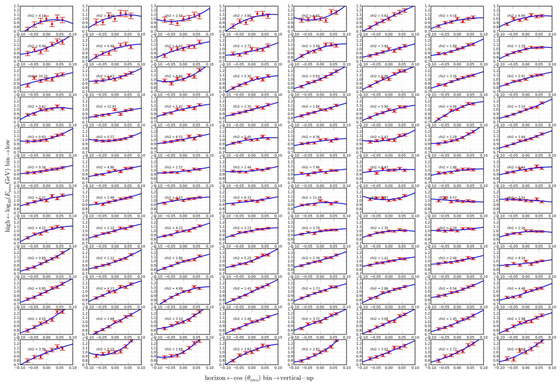
Detection uncertainties (i)

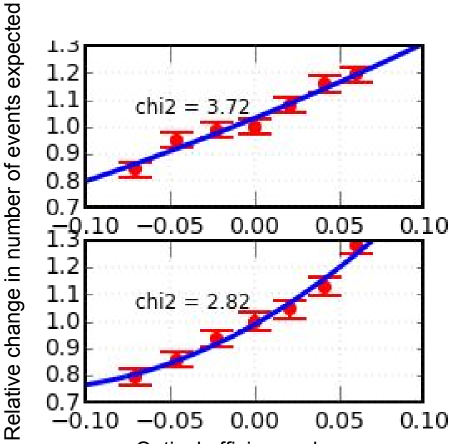
- <u>**Optical efficiency**</u>
- Bulk ice properties
- Hole ice properties

➔ Single global systematic shift, conceptually simple
➔ DOM-wise variations not considered
➔ Implemented at the <u>sample-level</u>



MC prediction for set of parameters


Bin-wise impact of modifying optical efficiency



Optical efficiency change

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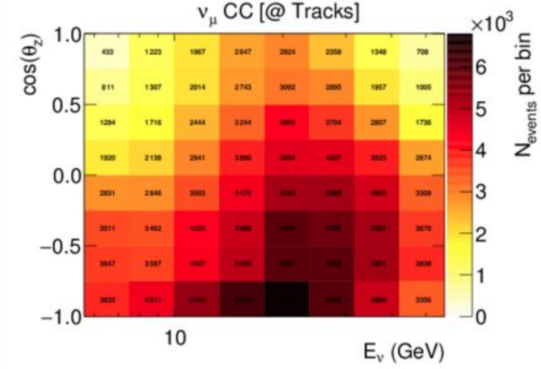

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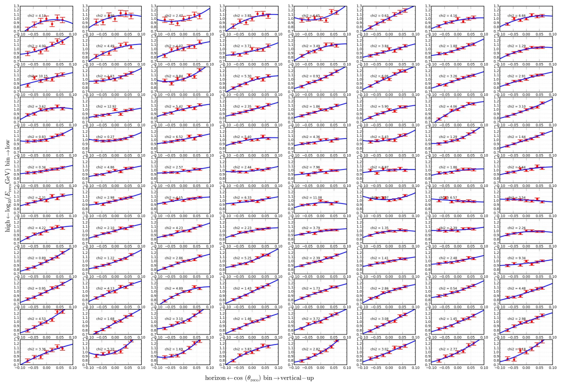
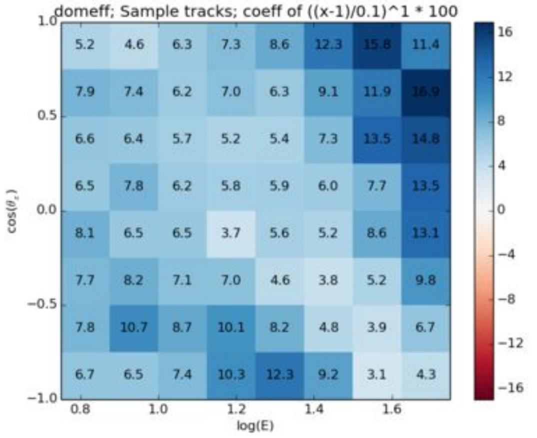


Bin-wise impact of modifying optical efficiency

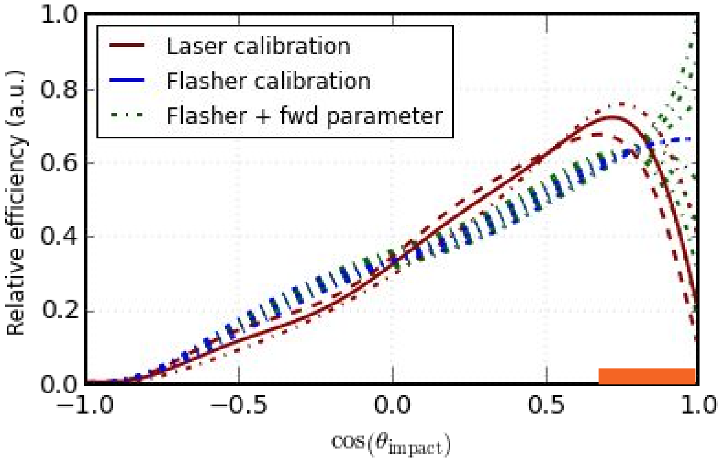
Linear component of the fit per bin

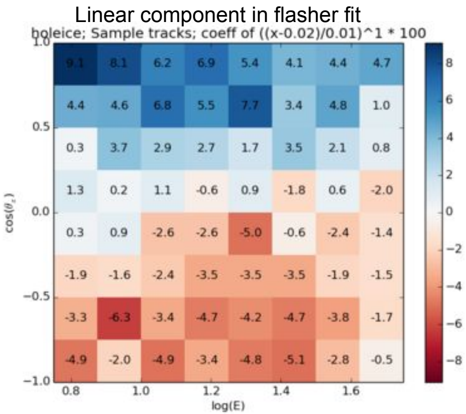


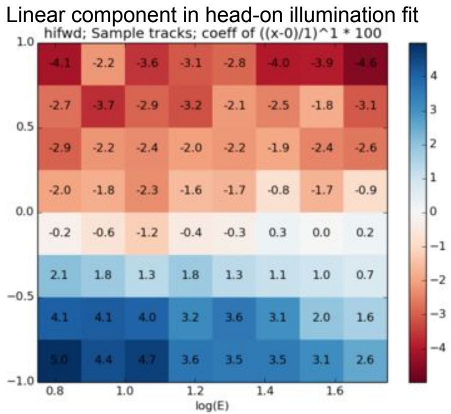
Detection uncertainties (ii)

- Optical efficiency
- Bulk ice properties
- **<u>Hole ice properties</u>**

➔ Simulated as an <u>effective</u> modulation of the angular acceptance
➔ Implemented in analysis following the <u>same scheme</u>
➔ Two models:
  - From **laser** data ("H2"): uniform scattering in all of the hole
  - From **flasher** data ("Dima"): unfolded with bulk ice
    - Nested model changes head-on acceptance ("MSU")







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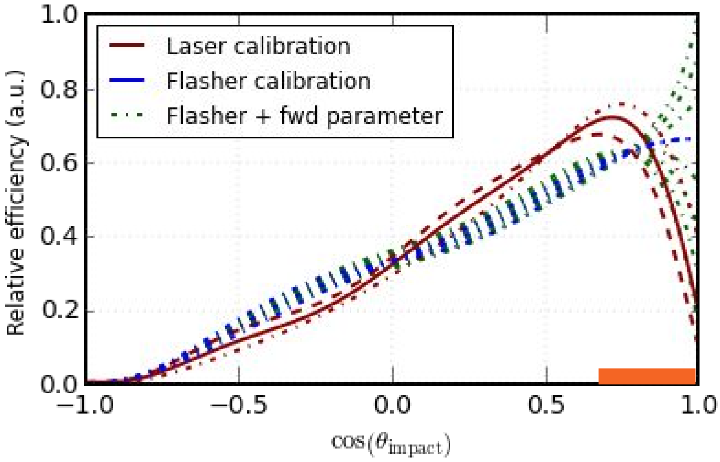

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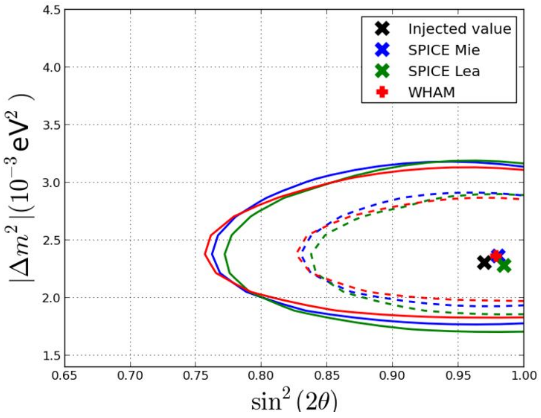
  - ◆ From **flasher** data (“Dima”): unfolded with bulk ice
    - Nested model changes head-on acceptance (“MSU”)
  - ◆ The flasher+fwd model
    - is needed for low-en data/MC agreement
    - reproduces direct hole ice simulation reasonably well

Detection uncertainties (iii)

- Optical efficiency
- **<u>Bulk ice properties</u>**
- Hole ice properties

1-year LEESARD sensitivity (not-published)



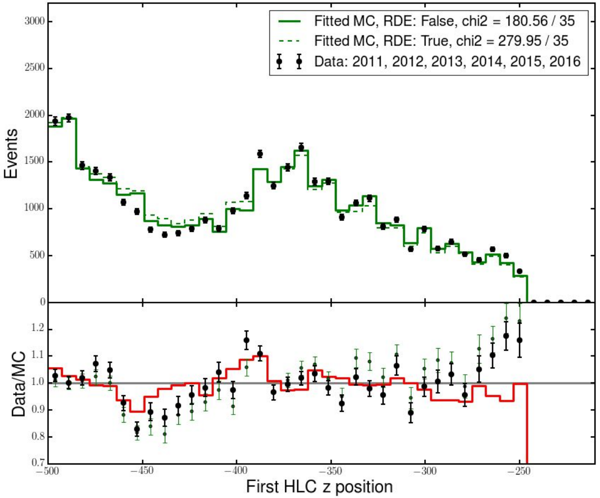
→ The ice model is a function of many (order 100) parameters
  - ◆ Not possible to include in current scheme

→ Reasonable ice model variants not available
  - ◆ "Error ellipse" models are too different
  - ◆ Ice model sampling by Jakob could work, so far not used
  - ◆ Efforts at Texas Arlington try to tackle this issue

→ Previous strategies (using WHAM, Mie & Lea)
  - ◆ Estimate potential biases by
    - MC tests, fitting one with the other
      - ○ If bias is small, ignore
    - Fitting the data with all models
      - ○ marginalize the LLH (tested, not used), or
      - ○ pick the one with the largest error (used in PRD)
  - ◆ No "best-fit" for ice model. Results produced with a single model.

Detection uncertainties (iii)

- Optical efficiency
- **<u>Bulk ice properties</u>**
- Hole ice properties



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➔ Current strategy
  - ◆ Ignore for most
  - ◆ EXCEPT GRECO sample (very high stats)

- Ice model discrepancies show up in variables connected to depth
  - **LEESARD**: First HLC position
  - Most other selection variables show **very good** agreement

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- Optical efficiency
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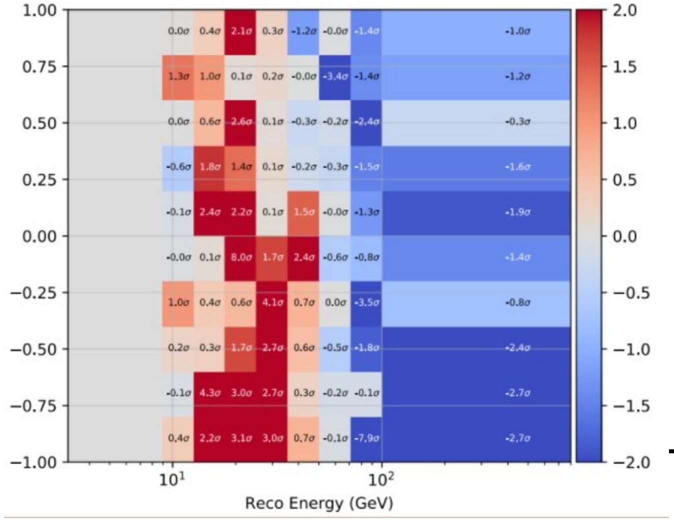
Numu CC, GRECO, +10% absorption



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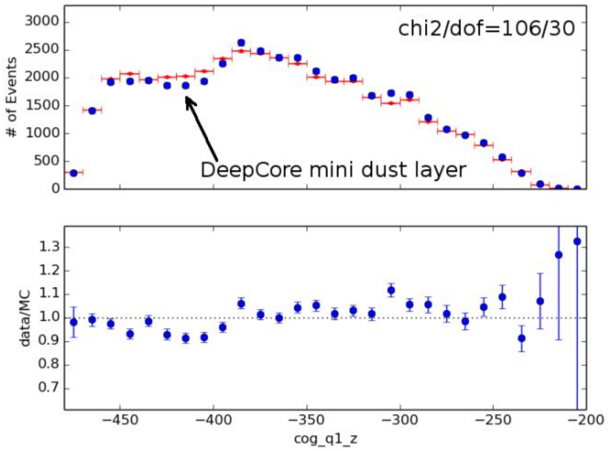

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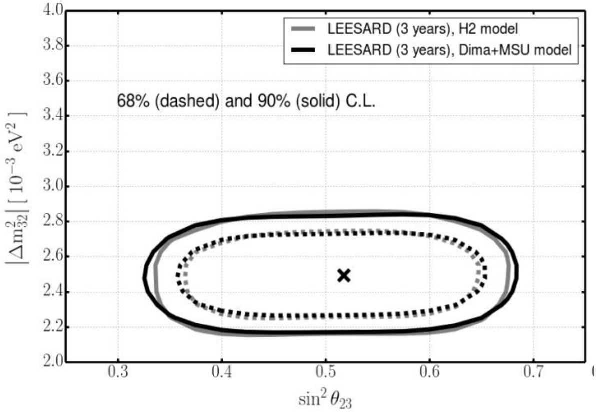
➔ Current strategy
  - Ignore

- Ice model discrepancies show up in variables connected to depth
  - **DRAGON**: cog q1 z
  - Chi squared 106 / 30 bins (p-value < 10^(-5))
  - Mixed agreement in other variables

Why do we care? In oscillations ...

- Precision gain by removing a systematic uncertainty at a time - **LEESARD**
  - Low statistics, nice events, straight cuts, little ice model dependence



Mixing angle

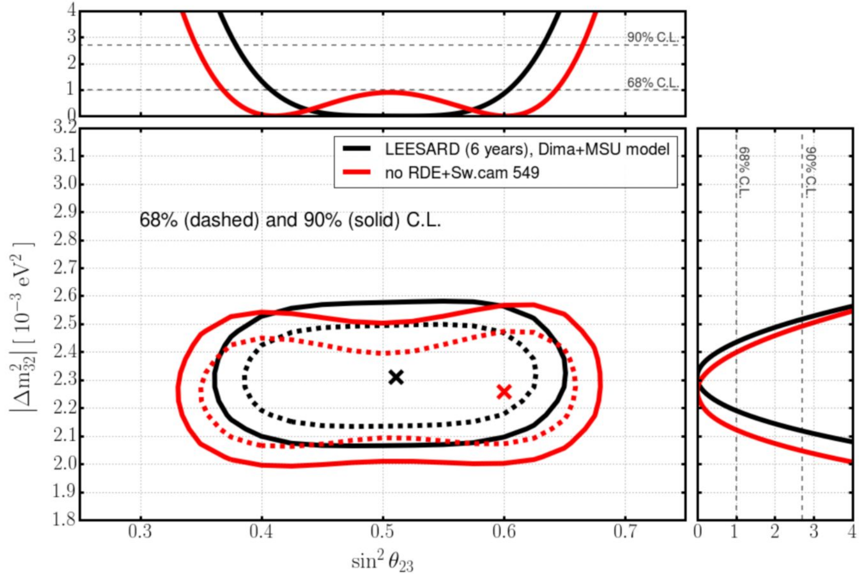
Parameter	H2	Dima+MSU
DOM eff	3.3%	4.2%
Hole ice	2.9%	0.4%
HI fwd	–	0.4%
Up/hor ratio	0.42%	1.0%
Atm. muons	0.27%	0.1%
gamma	0.16%	0.03%
Norm NC	0.08%	0.3%
Nu/nubar	0.04%	0.04%
MA (QE)	0.007%	0.03%
MA (res)	0.004%	0.01%
Norm nue	<0.001%	<0.002%

Mass splitting

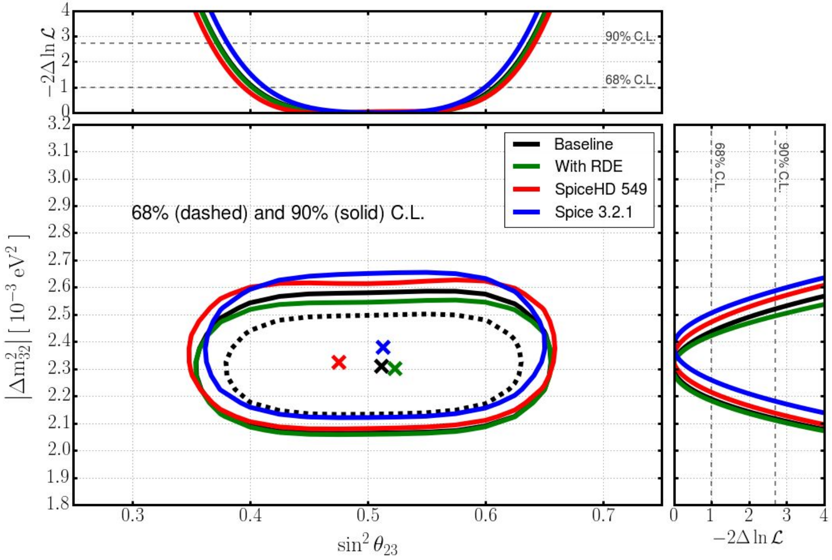
Parameter	H2	Dima+MSU
DOM eff	14.9%	6.9%
Hole ice	5.1%	2.8%
HI forward	–	6.9%
Up/hor ratio	3.5%	6.8%
gamma	2.4%	3.1%
MA (res)	1.8%	1.1%
Norm NC	0.47%	0.023%
MA (QE)	0.31%	0.28%
Norm nue	0.24%	~0%
Atm. muons	0.23%	1.5%
Nu/nubar	0.22%	0.09%

Why do we care? In oscillations ...

Before “spiciness”...



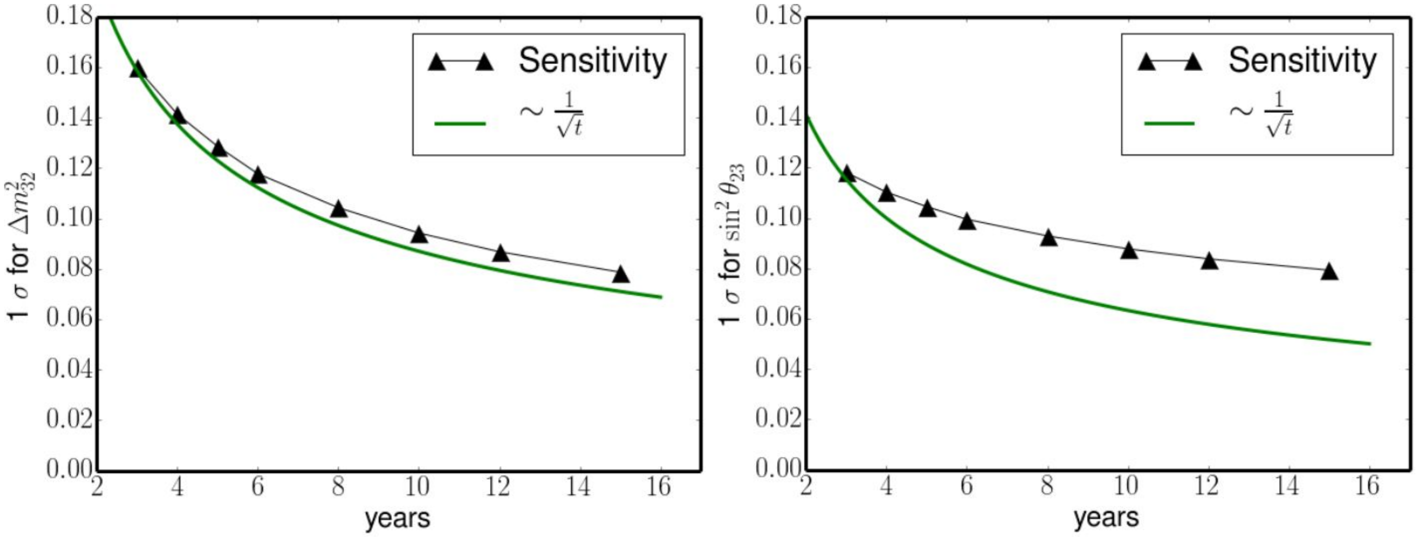
After “spiciness”...



- Off maximal pull is about about 0.9 in 2 Delta LLH
- Less then 1 sigma

Why do we care? In oscillations ...

- Precision improvement with statistics - **LEESARD**
  - Low statistics, nice events, straight cuts, little ice model dependence



Why do we care? In oscillations ...

- Sensitivity lost for not knowing a systematic uncertainty at a time- **DRAGON**
  - Medium statistics, all events, nested BDTs, reconstructing using tables
- Conclusion differs from LEESARD case
  - DOM efficiency takes most of the toll here
  - Hole ice has very small impact, but ...
- Data/MC agreement
  - With H2: p-value < 0.01
  - <u>With Flasher+Fwd: p-value ~0.65</u>

Systematic Removed	Reduction of sensitivity from Δm^2_{32} (%)	$sin^2(\theta_{23})$ (%)
DOM_{eff}	20.27	0.32
$\nu/\bar{\nu}$ ratio	3.03	0.22
HI forward	2.22	0.55
M_A^{RES}	1.23	0.03
Atmospheric μ fraction	0.82	0.65
Up/Horizontal ratio	0.61	1.93
$norm_e$	0.32	0.015
θ_{13}	0.32	0.0040
γ	0.091	0.24
$norm_{NC}$	0.060	0.10
Hole ice	0.046	0.80
M_A^{QE}	0.0043	0.0053

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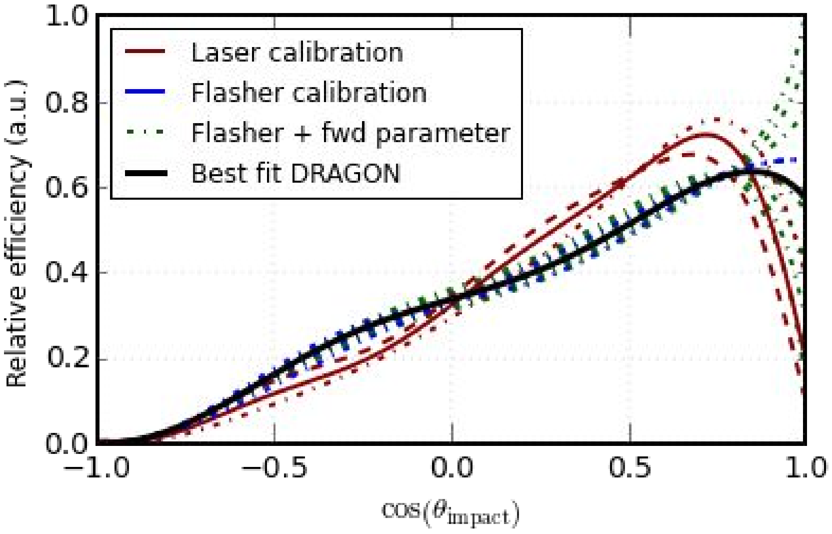
- Data/MC agreement
    - With H2: p-value < 0.01
    - With Flasher+Fwd: p-value ~0.65
- Head-on illumination region matters



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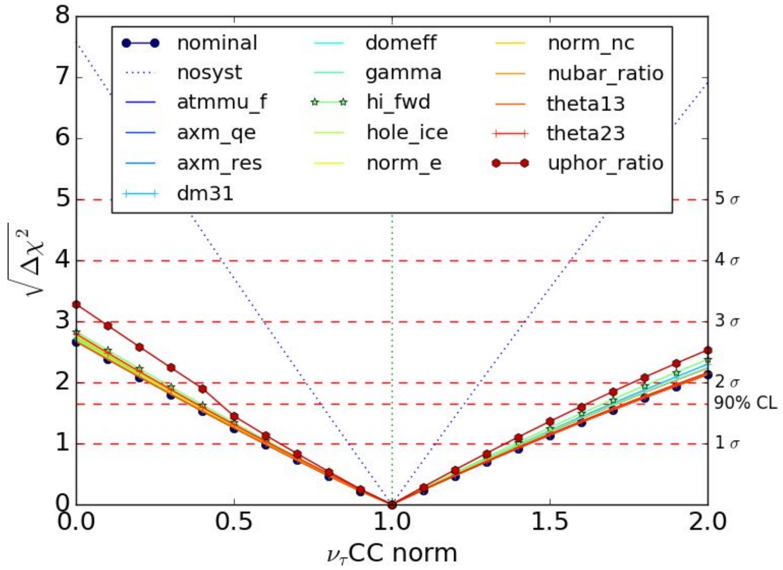

***Tab 6.2.A* Change in 1σ width for each systematic (in %) for ν_τ CC measurement.**

Systematic Removed	$\Delta\nu_\tau$CC
Barr flux parameter up:horizontal ratio	15.1
Forward hole ice parameterization	8.2
Δm^2_{31}	4.7
Scattering in the hole ice	4.2
Atmoshperic μ normalization	4.1

Summary

- Detection uncertainties (detector + medium) dominate error budget in diffuse low energy studies
- LowEn studies pushing the systematic barrier
  - To obtain acceptable goodness of fit
  - To keep on improving our measurements
- Lots of work going towards DOM eff & hole ice
  - We might be sensitive enough to resolve/reject SPICE HD models
- Don’t know when will the bulk ice kick
  - Disagreement is visible, but can still achieve decent GoF
  - Is the result biased? How much? How to test it?
- DOM-wise efficiency not considered thus far

Backup

From M. Rongen