New Results from the Salt Phase at Sudbury Neutrino Observatory

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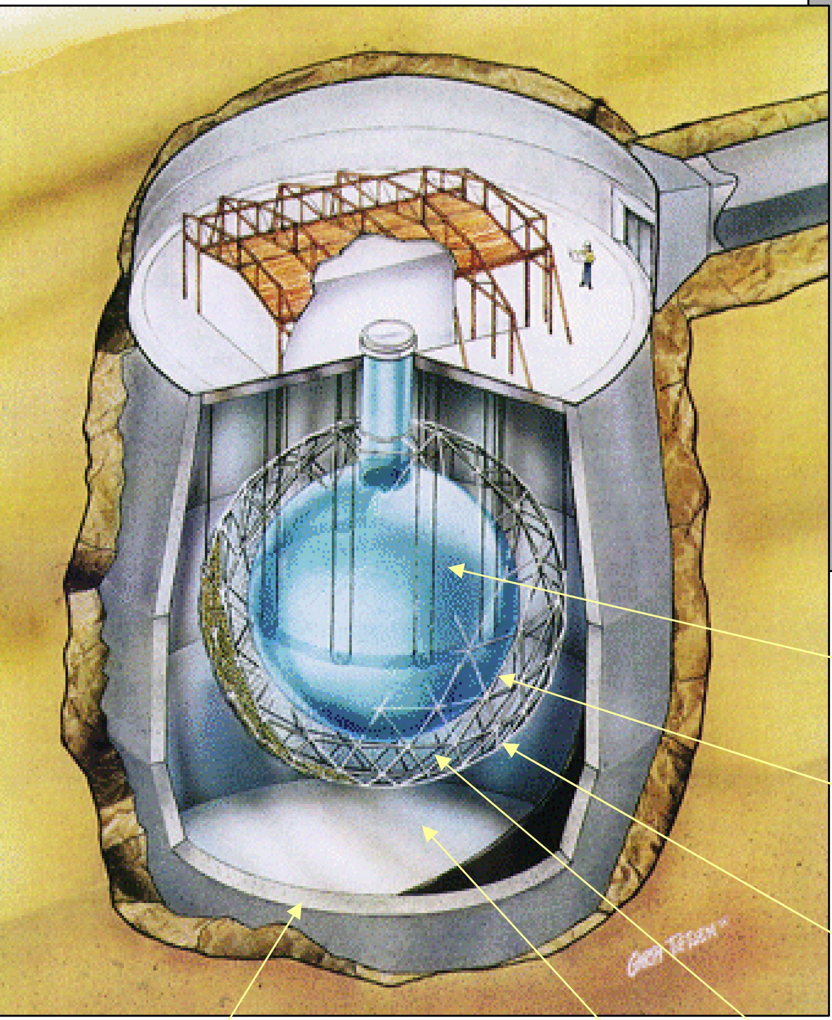
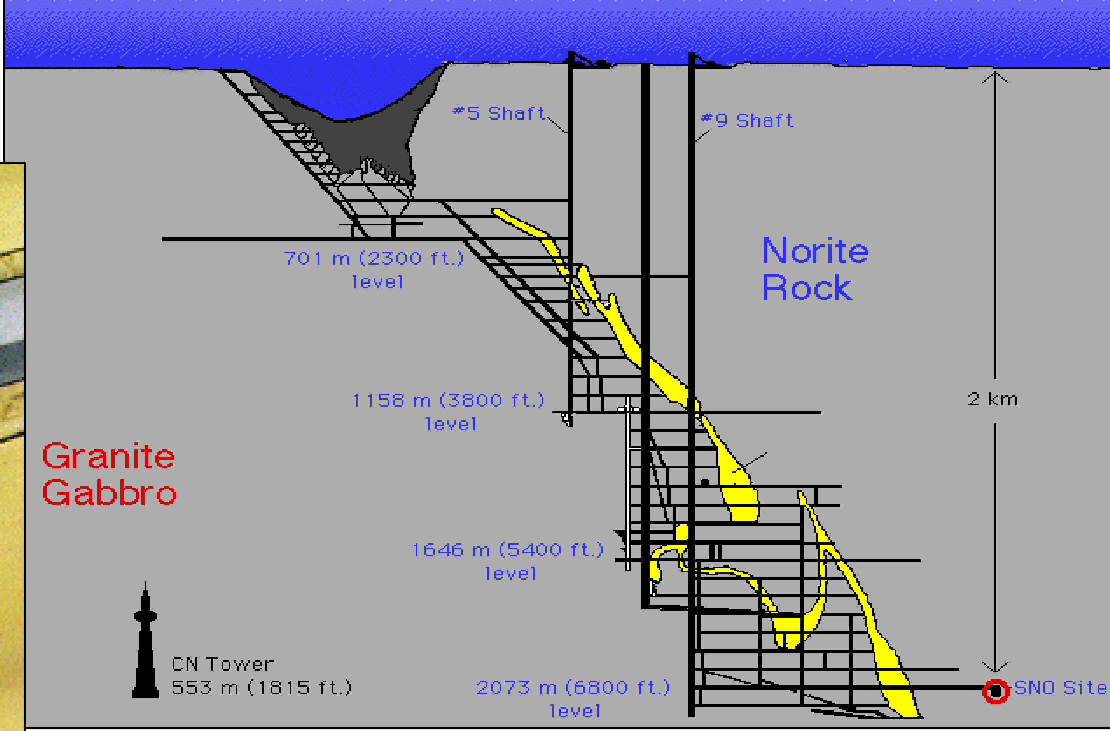
on behalf of the
Sudbury Neutrino Observatory
(SNO) collaboration

Whats New?

- First full Spectral analysis
  - Full evaluation of energy-dependent systematics
- Salt Day-Night asymmetry measurements
- Updated Flux measurements for increased statistics in Salt data set.

SNO





1000 tonnes D_2O

12m Diameter Acrylic Vessel

Support Structure for 9500 PMTs, 60% coverage

Urylon Liner and Radon Seal

5300 tonnes Outer Shield H_2O

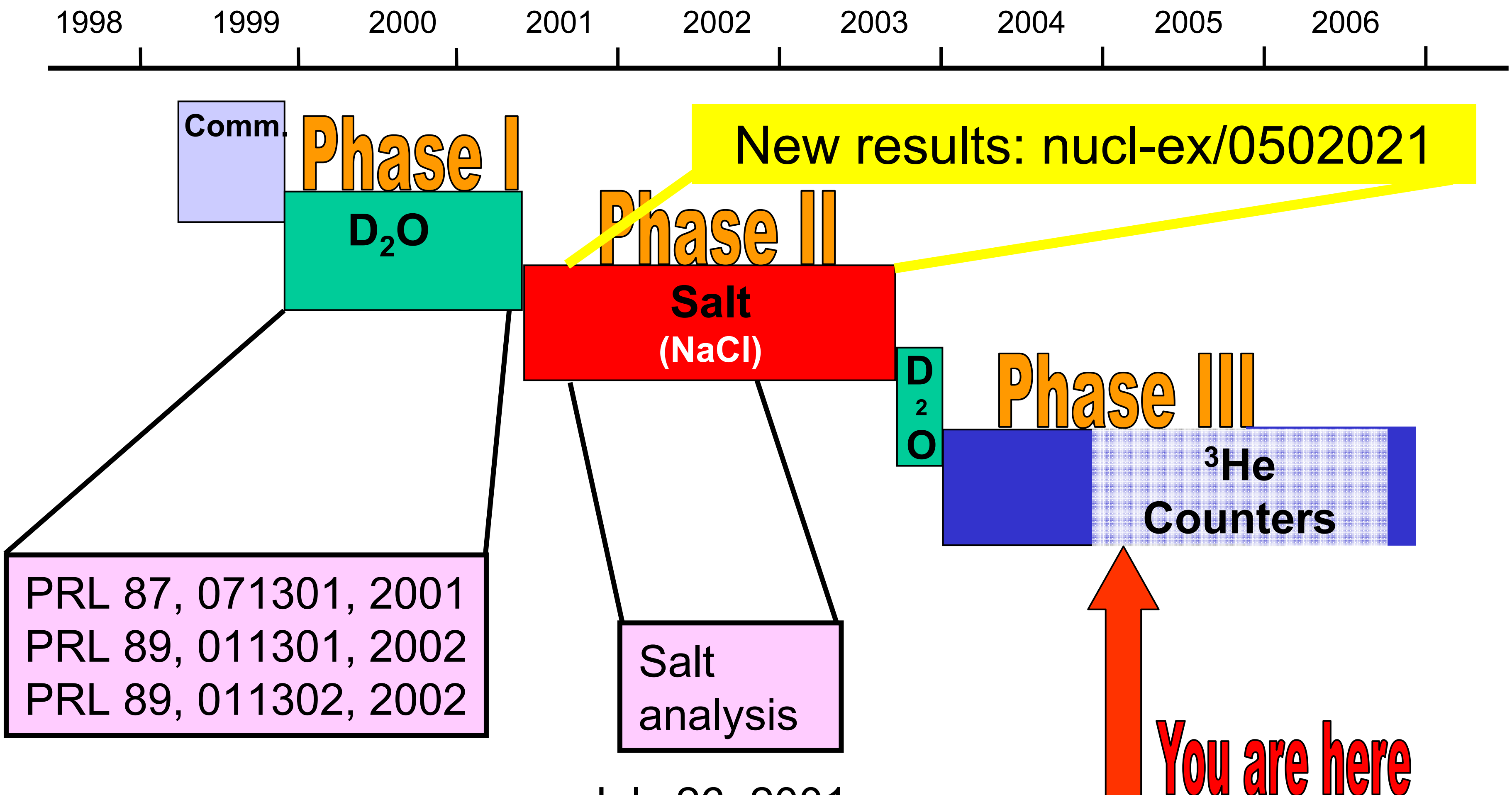
1700 tonnes Inner Shielding H_2O

CC: $\nu_e + d \rightarrow p + p + e^-$

NC: $\nu_x + d \rightarrow p + n + \nu_x$

ES: $\nu_x + e^- \rightarrow \nu_x + e^-$

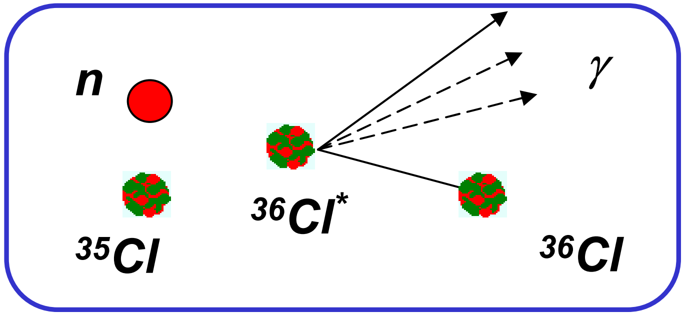
SNO Program

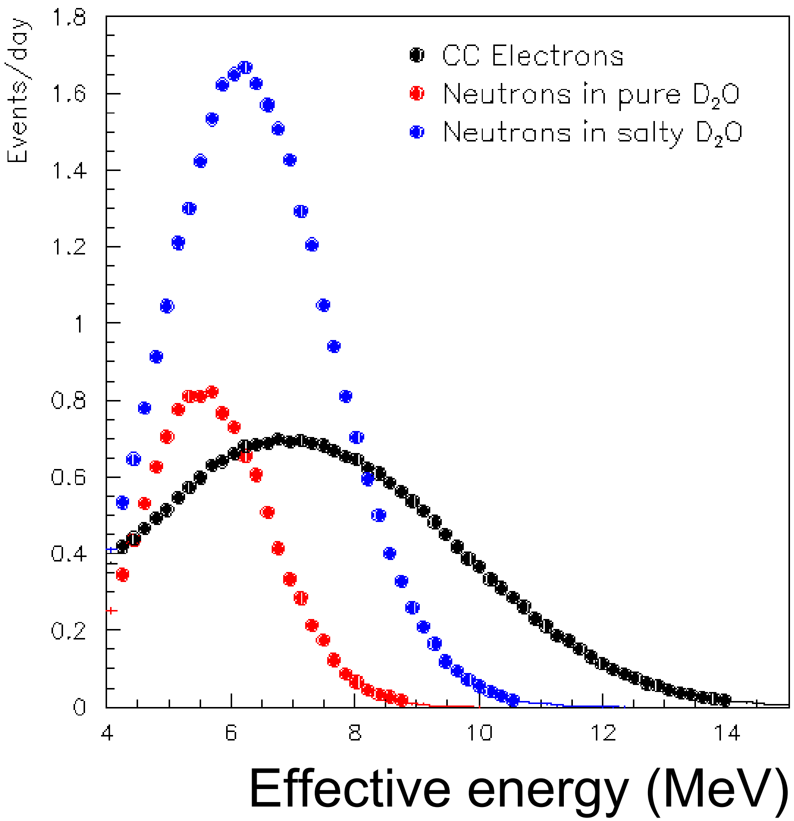


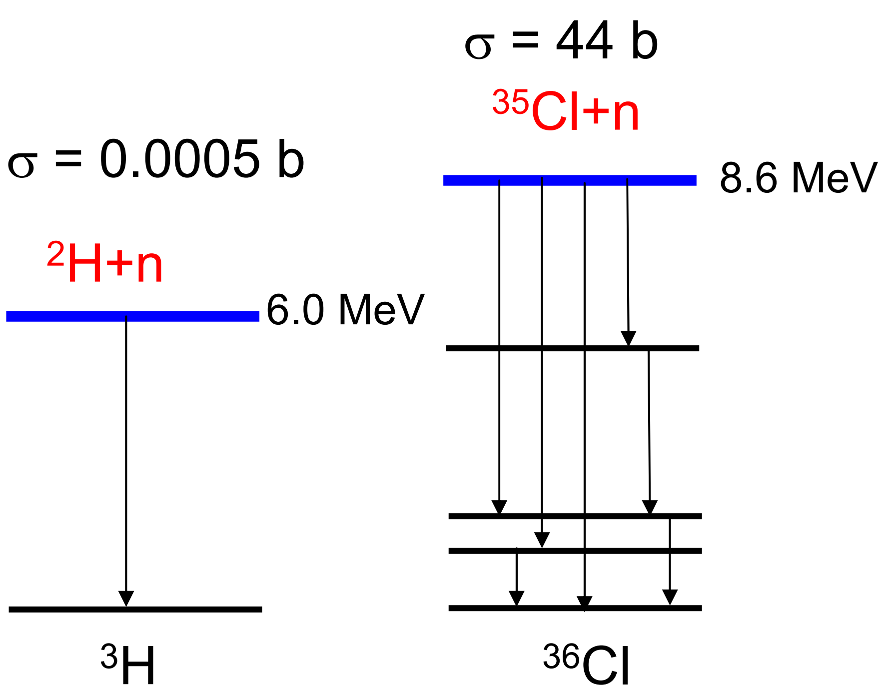
July 26, 2001 –
October 10, 2002
PRL 92, 181301, 2004

Advantages of NaCl for Neutron Detection

- Higher capture cross section
- Higher energy release
- Many gammas







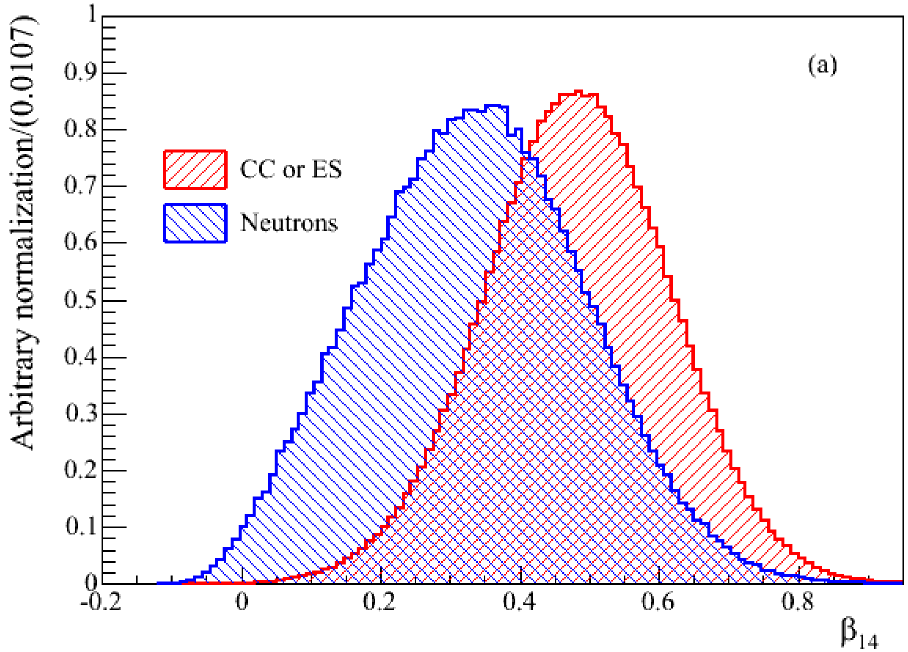
Event Isotropy

Define the parameters β_l as

$$\beta_l \approx \left\langle P_l\left(\cos\theta_{ij}\right)\right\rangle_{i \neq j}$$

where P_l is the l^{th} order Legendre Polynomial.

θ_{ij} = angle between pair of hits subtended at event vertex.

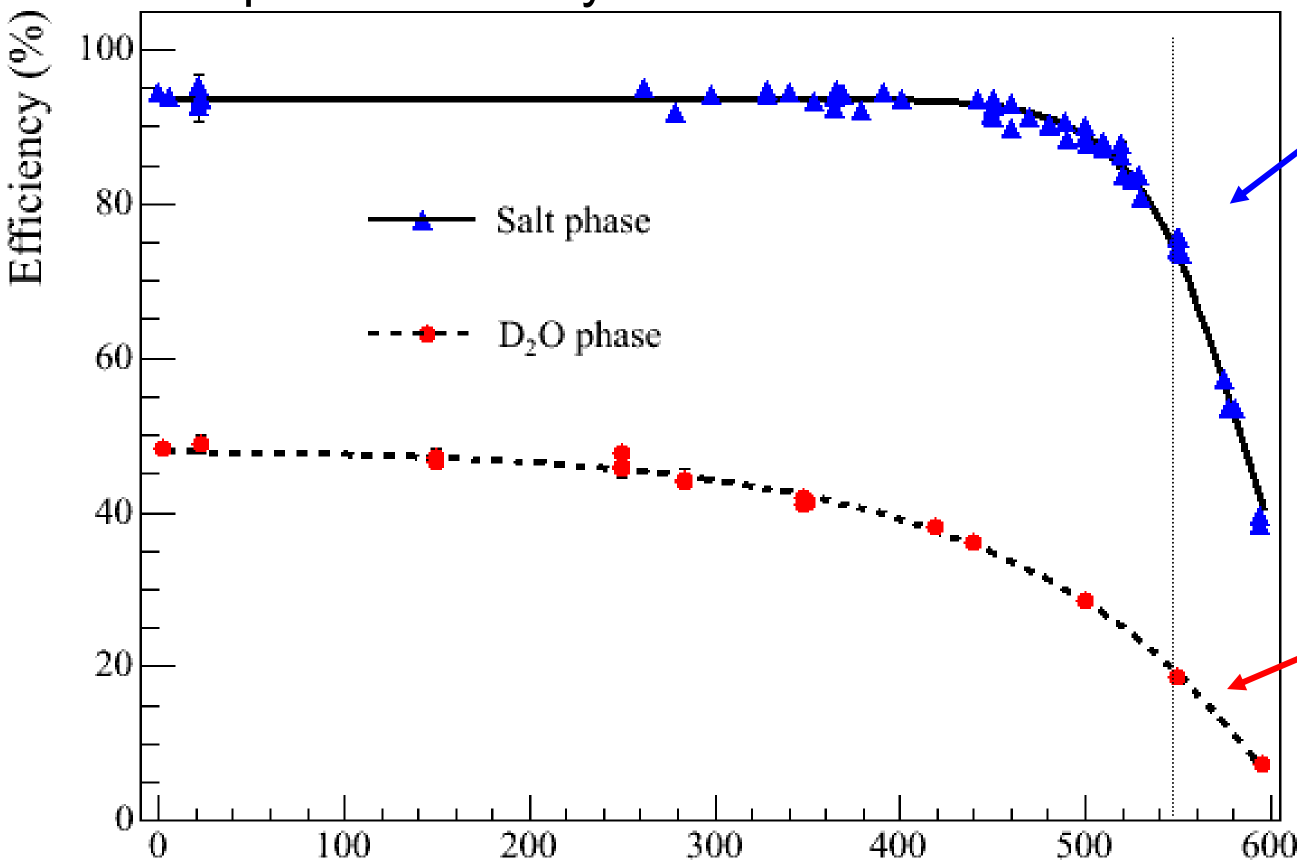


$$\beta_{14} = \beta_1 + 4\beta_4$$

is found to give good CC/NC separation

Neutron Capture Efficiency in SNO

Capture Efficiency

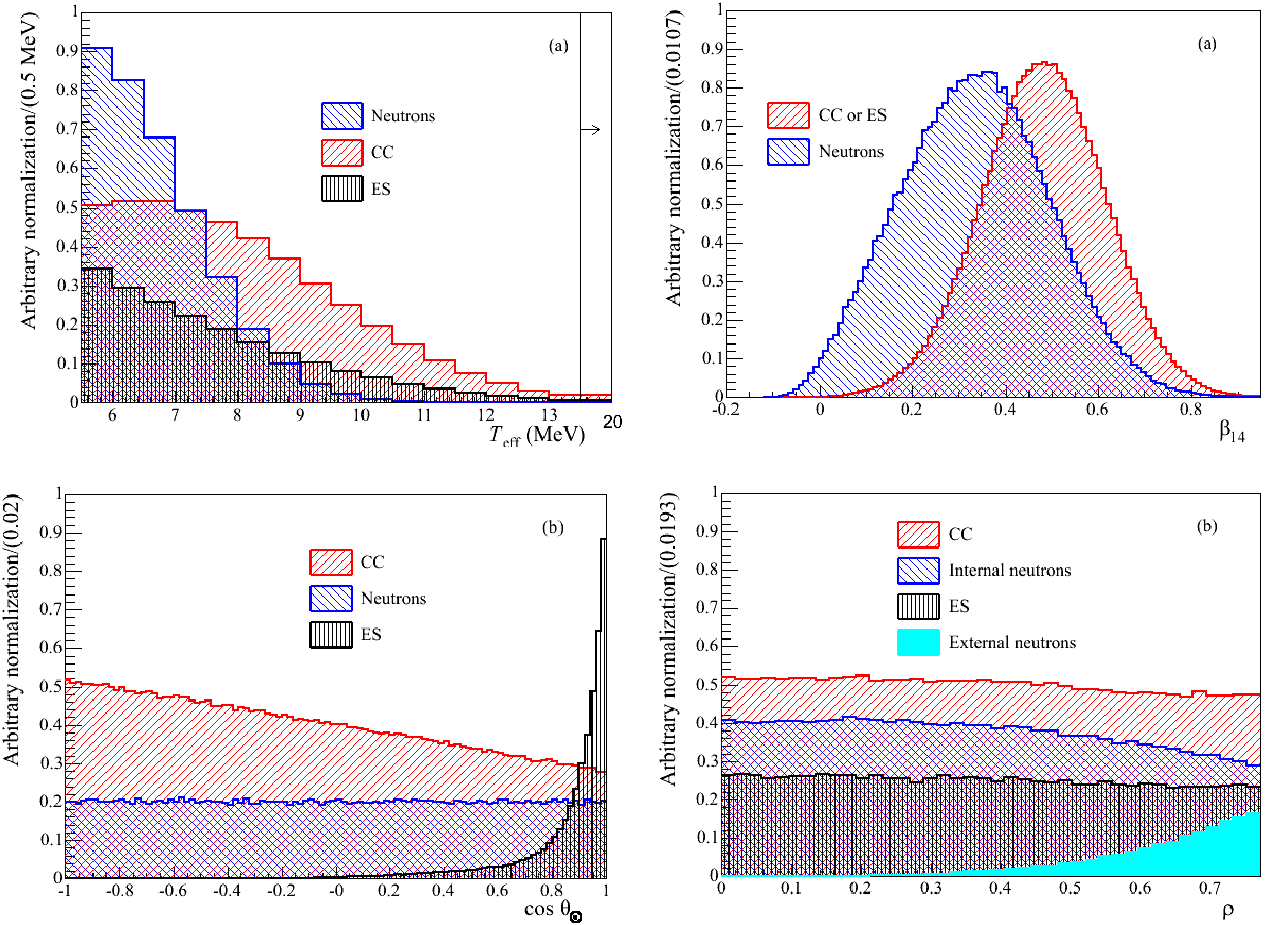


Radial Position of ^{252}Cf Source (cm)

Detection Efficiency

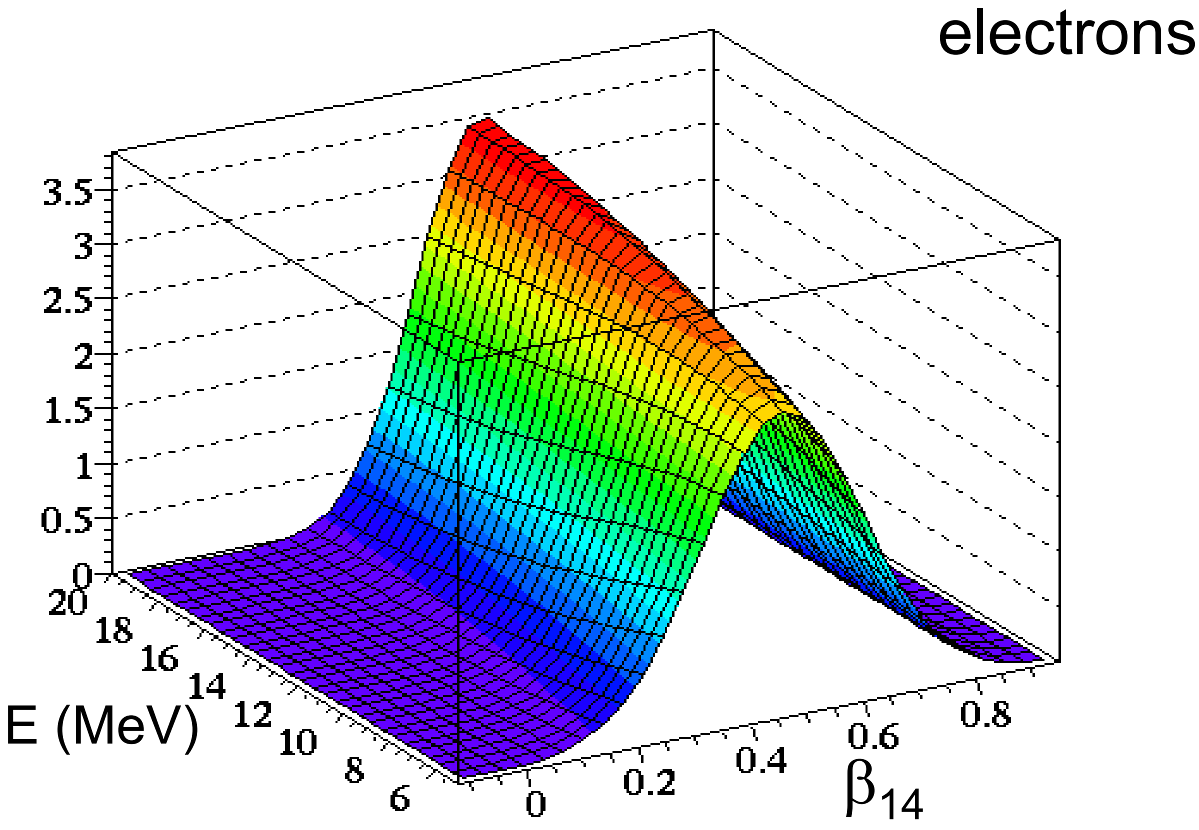
^{35}Cl(n,γ)^{36}Cl
Average Eff. =
0.407
$T_{eff} \geq 5.5$ MeV and
R ≤ 550 cm

^{2}H(n,γ)^{3}H
Average Eff. =
0.144
$T_{eff} \geq 5.0$ MeV and
R ≤ 550 cm



Arbitrary normalization/(0.5 MeV)
(a)
Neutrons
CC
ES
T_{eff} (MeV)
20
Arbitrary normalization/(0.0107)
(a)
CC or ES
Neutrons
β_{14}
Arbitrary normalization/(0.02)
(b)
CC
Neutrons
ES
$\cos\theta_{\odot}$
Arbitrary normalization/(0.0193)
(b)
CC
Internal neutrons
ES
External neutrons
ρ

Correlated Parameters



Correlated Parameters

- Ideal scenario – 4 dimensional PDF
  - Statistical limitations
- Signal extraction procedure tested on 100 simulated data sets.
- Small bias (~0.8% on CC) seen using:

$$P(T_{eff},\beta_{14},R^3,\cos\theta)=P(T_{eff},\beta_{14}).P(\cos\theta).P(R^3)$$

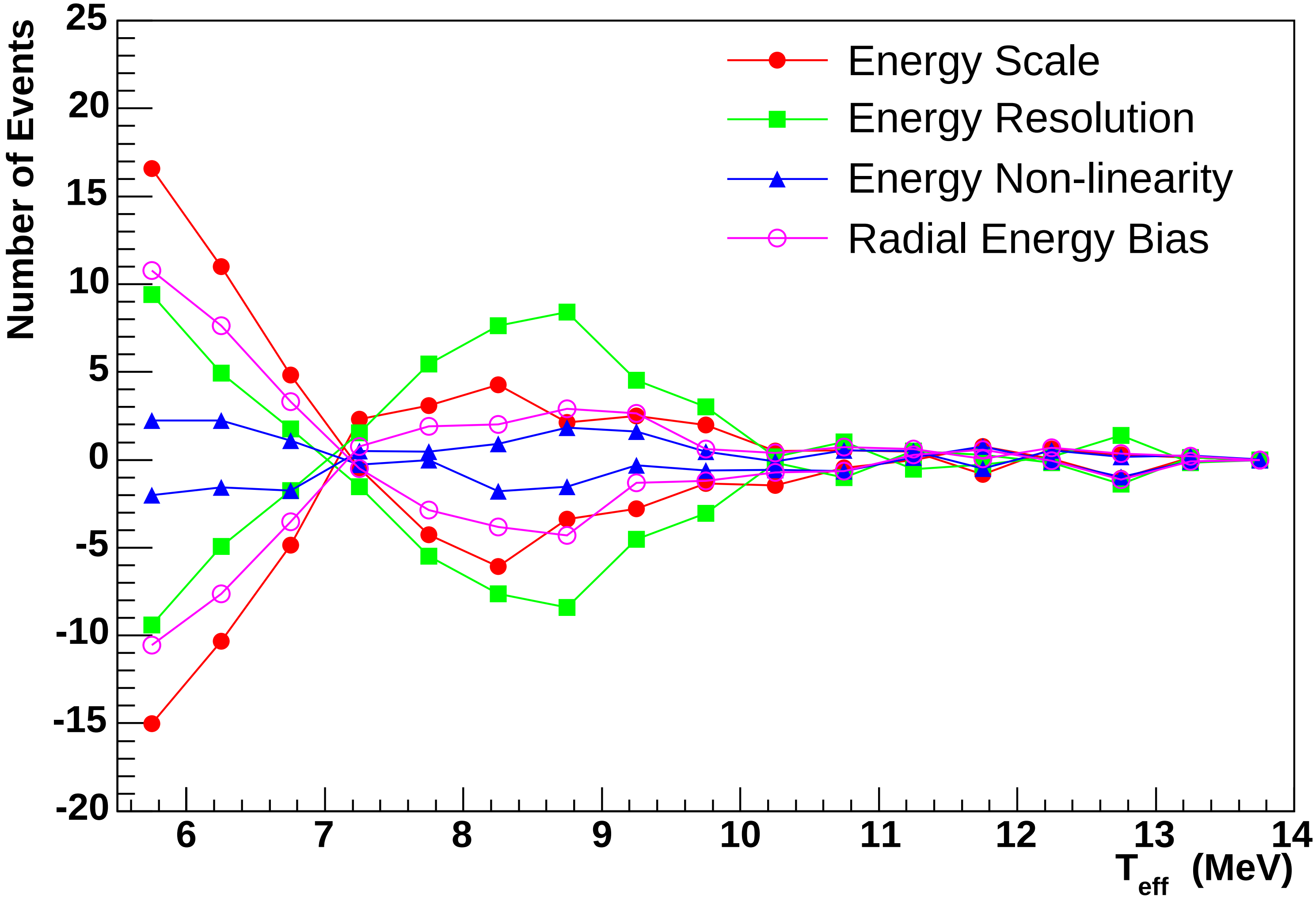
- Bias becomes insignificant using:

$$P(T_{eff},\beta_{14},R^3,\cos\theta)=P(T_{eff},\beta_{14},R^3).P(\cos\theta/T_{eff},R^3)$$

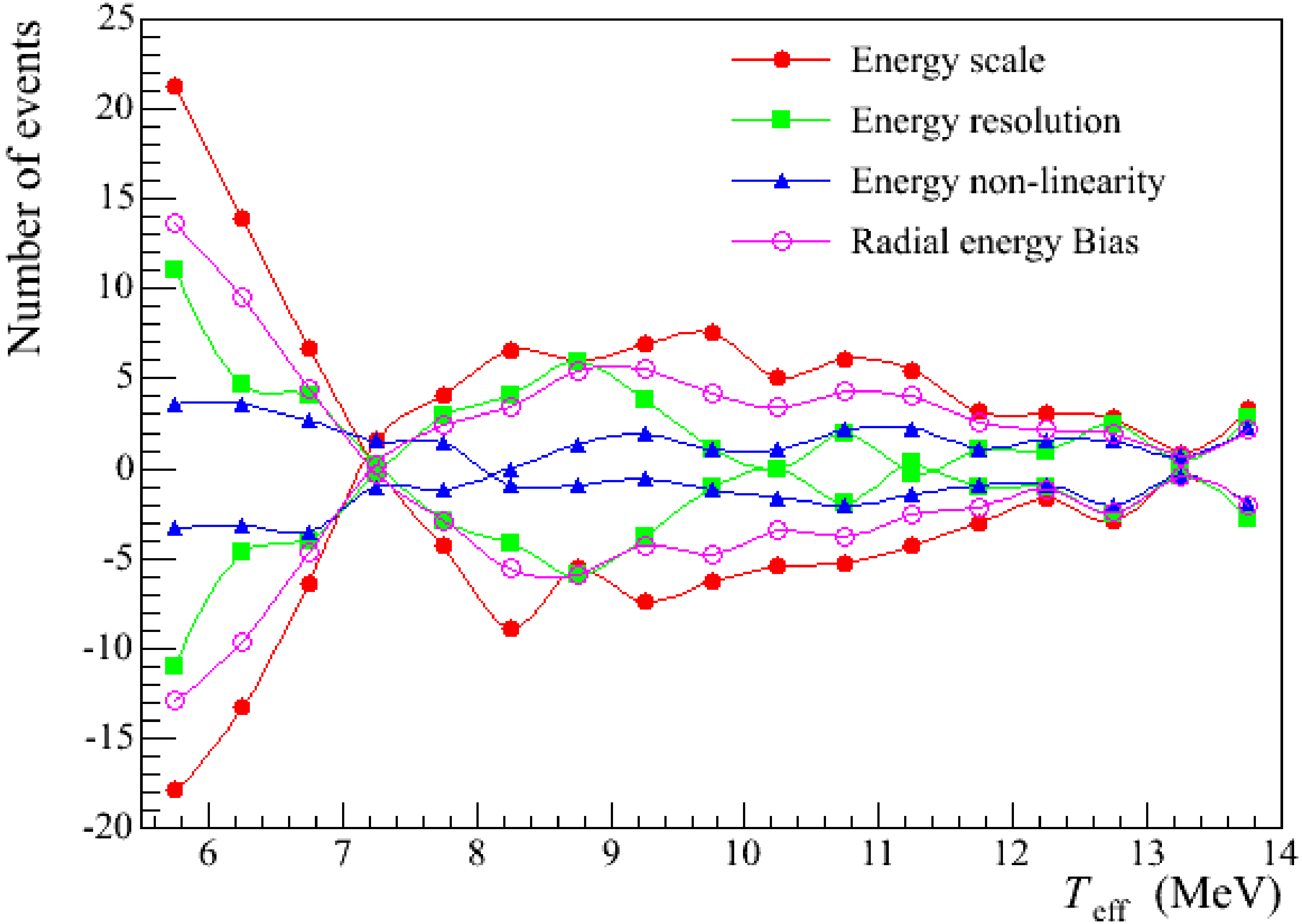
Major Systematic Uncertainties

- A number of systematics re-evaluated for possible differential effects in energy.
  - Energy systematics
  - β_{14} systematics
  - Fiducial volume
  - Selection efficiency
- High(er) energy calibration data used to parameterise non-linear contributions to systematic uncertainty.
  - ^{8}Li, ^{252}Cf in addition to ^{16}N

Differential Systematic Effects

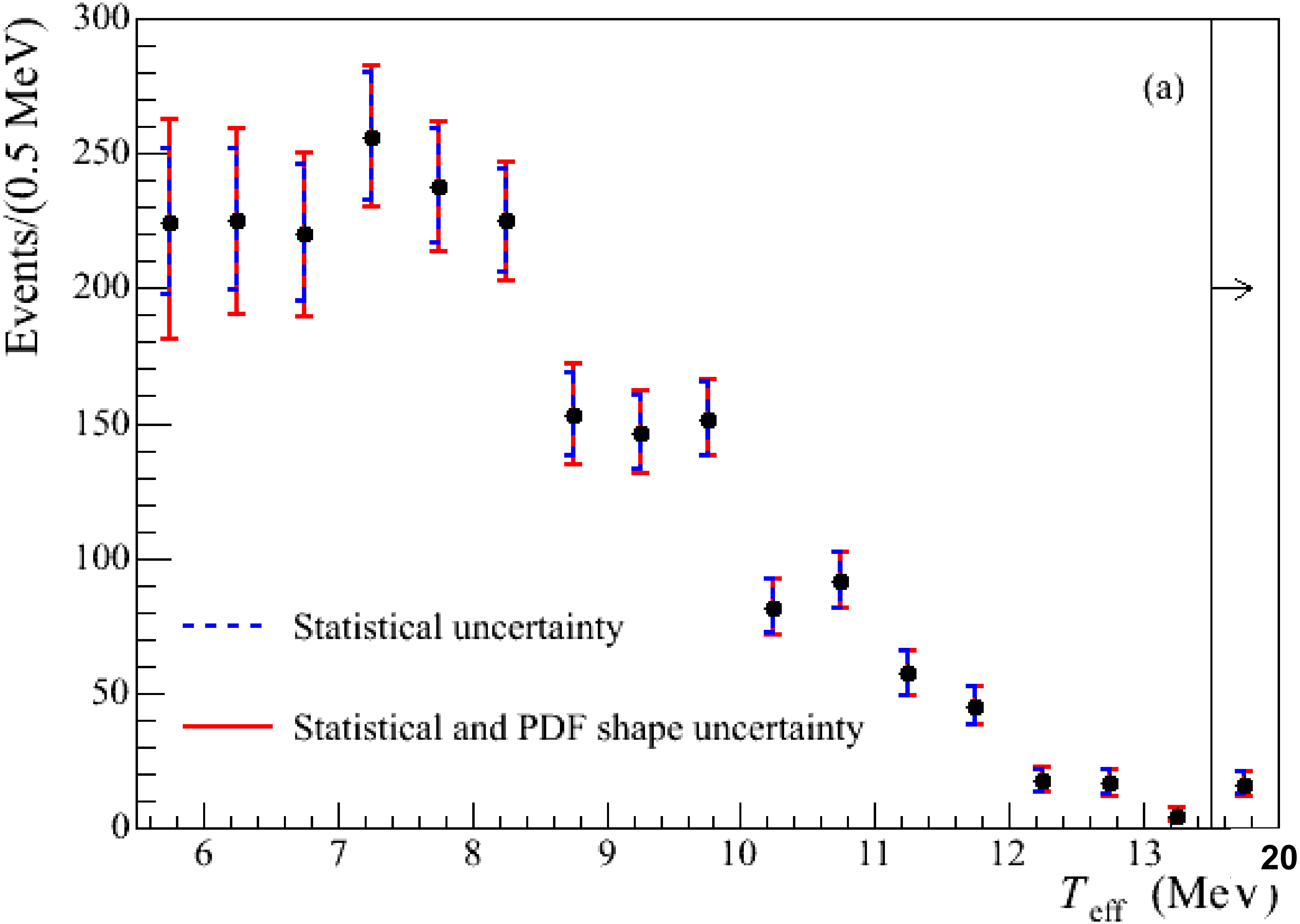


Differential Systematic Effects

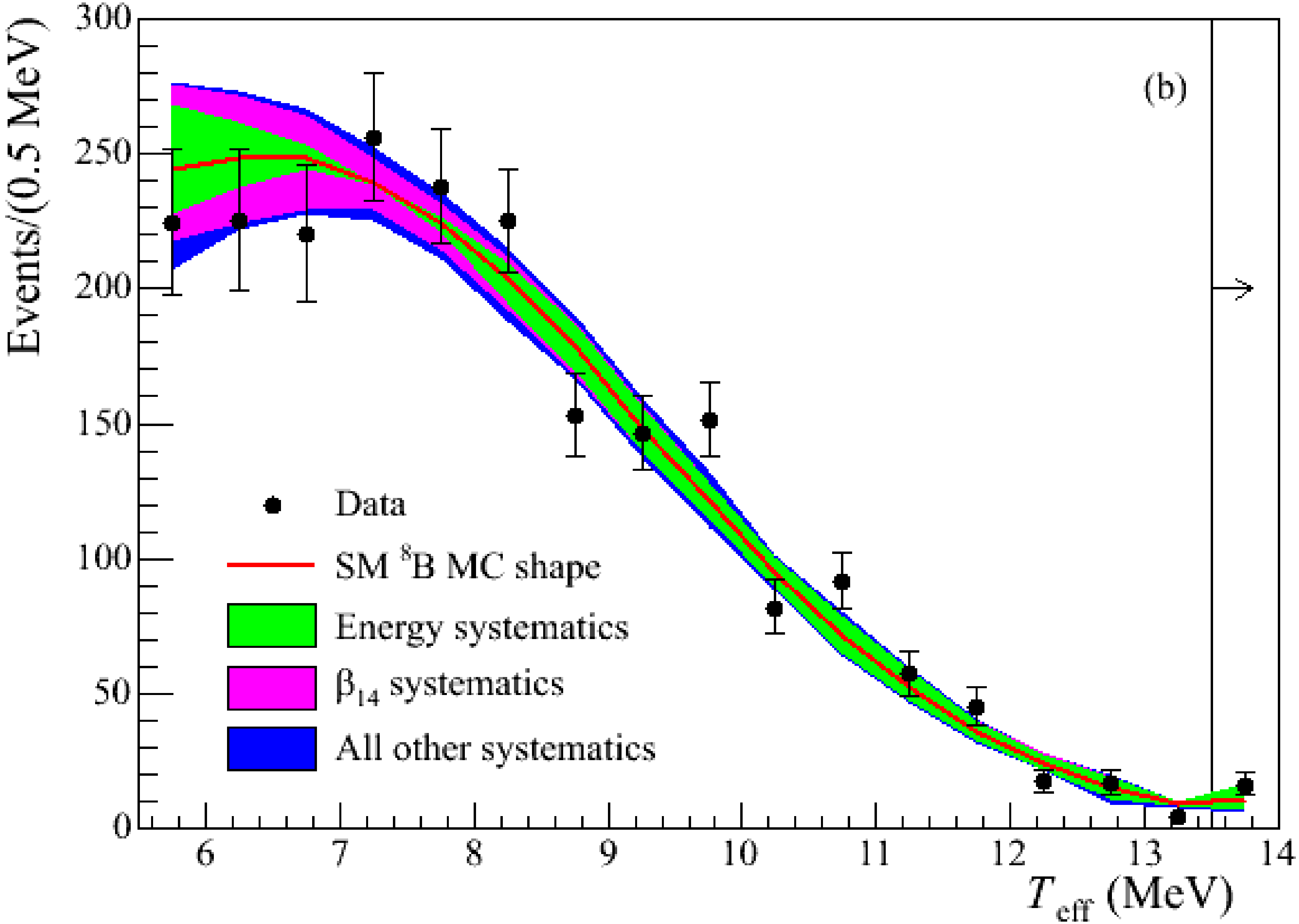


Spectrum

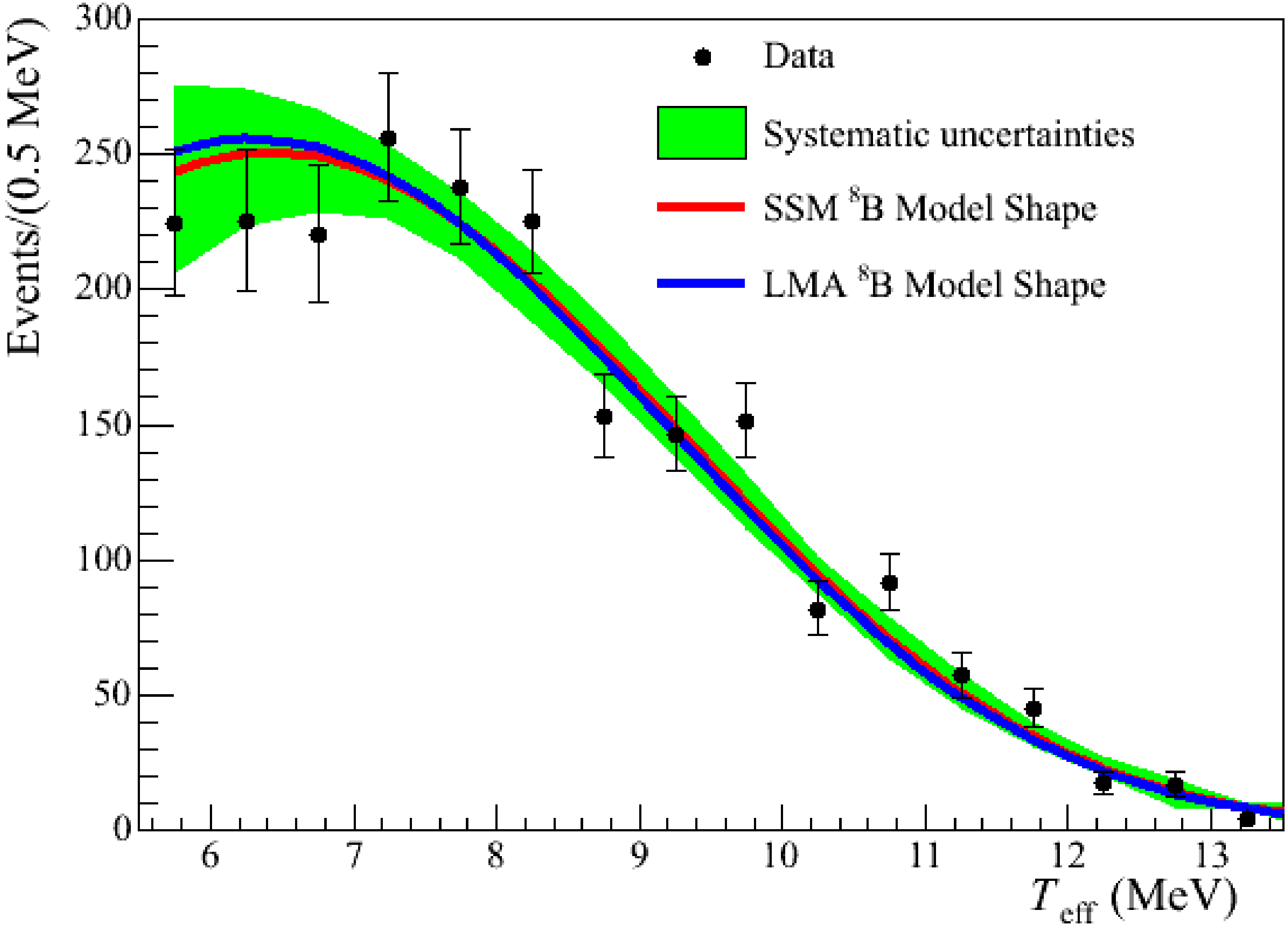
Charged Current Spectrum



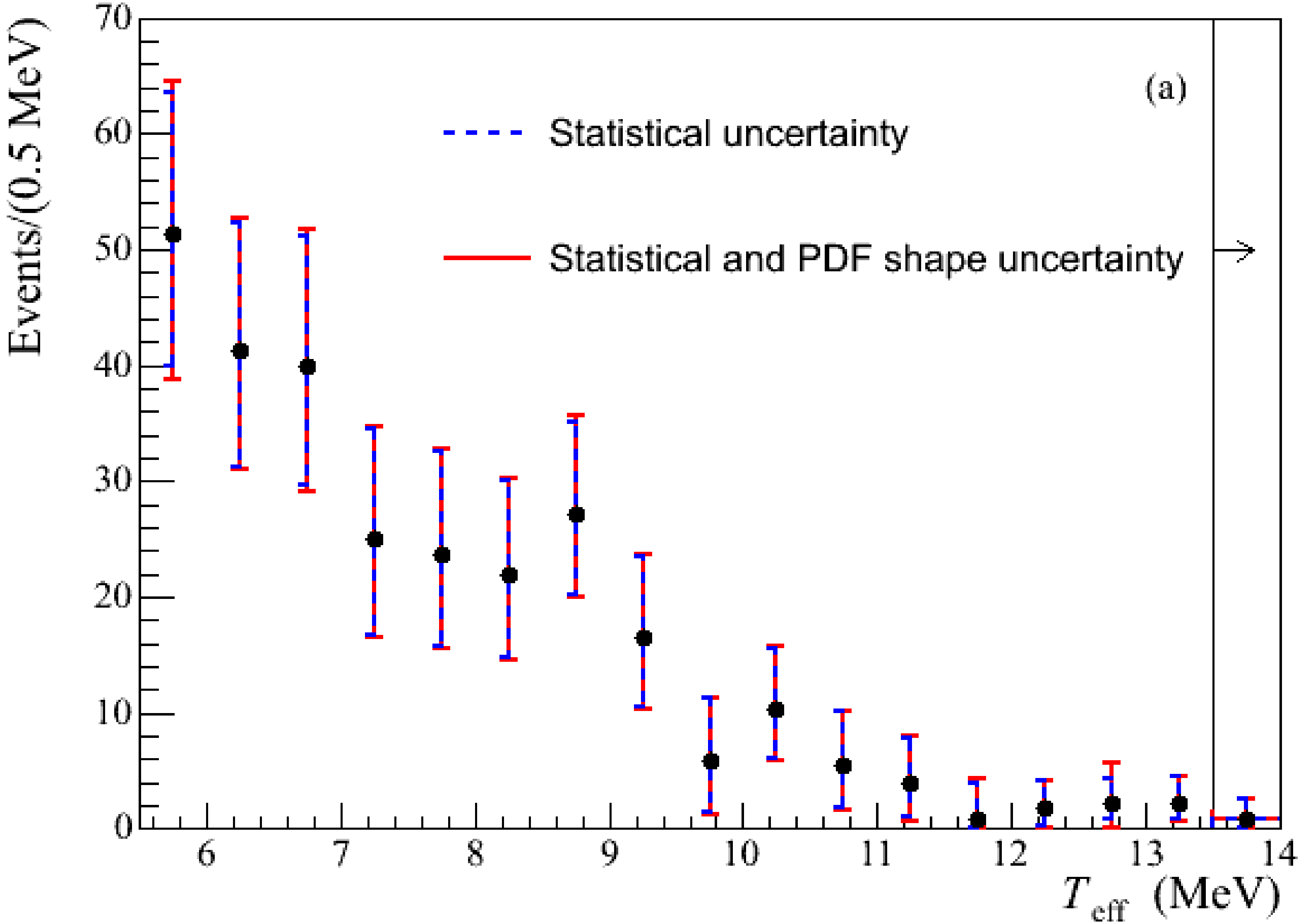
Charged Current Spectrum



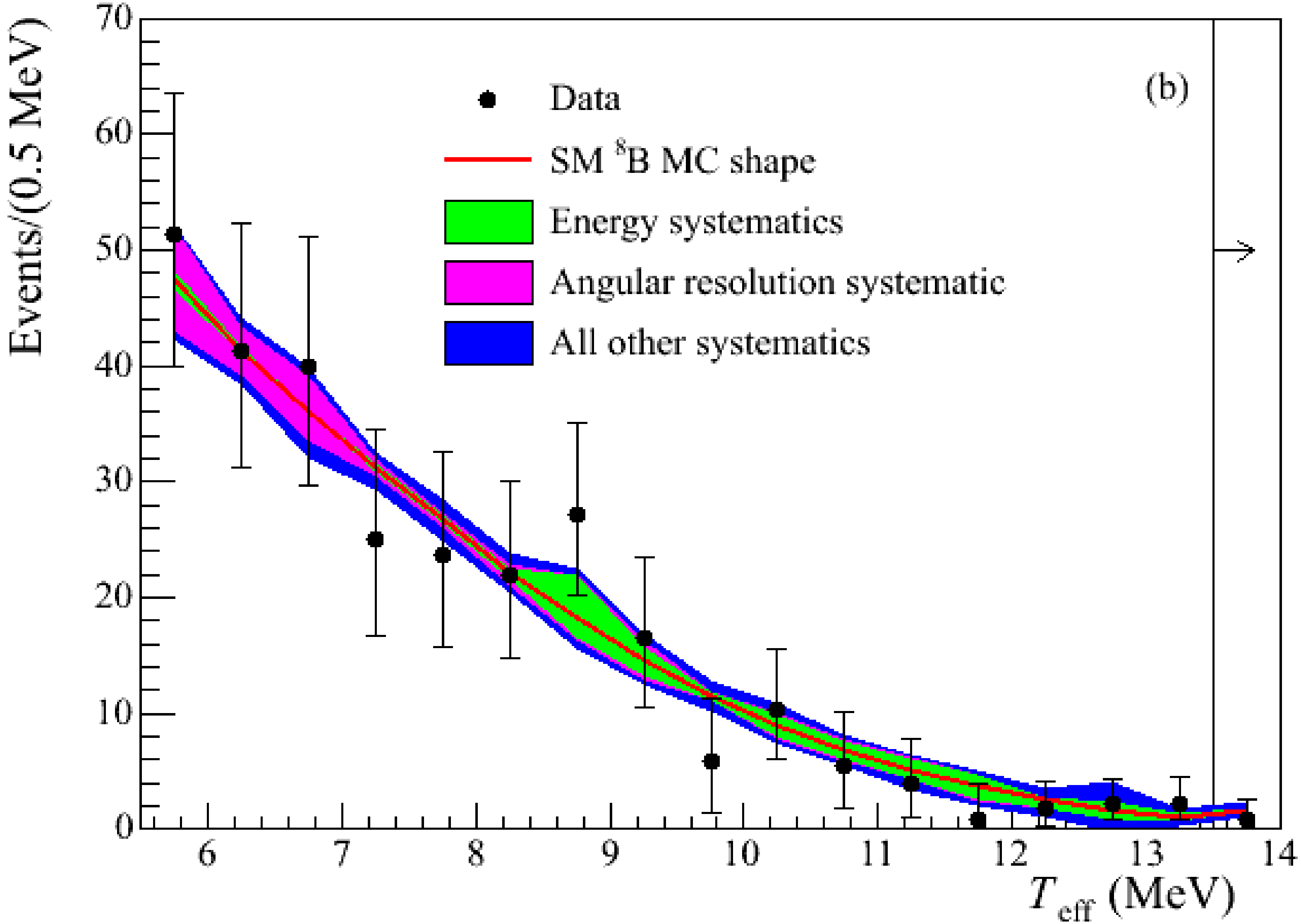
Predicted LMA spectral distortion



Elastic Scattering Spectrum



Elastic Scattering Spectrum




Day Night

Day Night Asymmetry

CC,ES asymmetry

ν_e regeneration inside the Earth

NC asymmetry

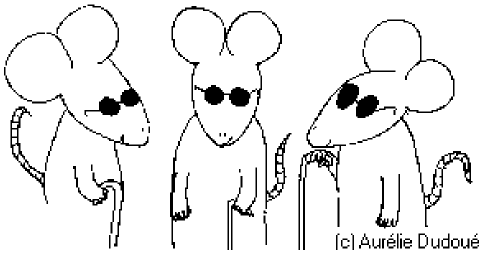
Admixture of sterile neutrinos or unexpected matter interactions inside the Earth

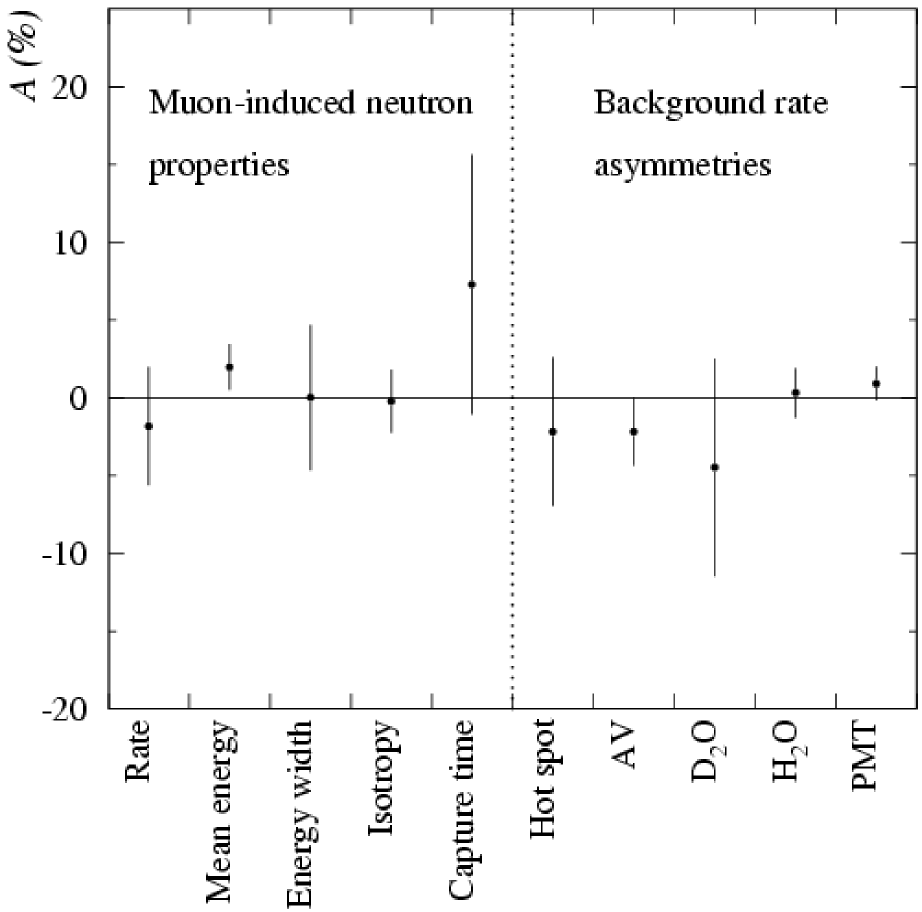
LMA→ small A_{CC}, A_{ES}
$A_{NC} = 0$

$$A = \frac{2(\Phi_N - \Phi_D)}{(\Phi_N + \Phi_D)}$$

Day Night Asymmetry

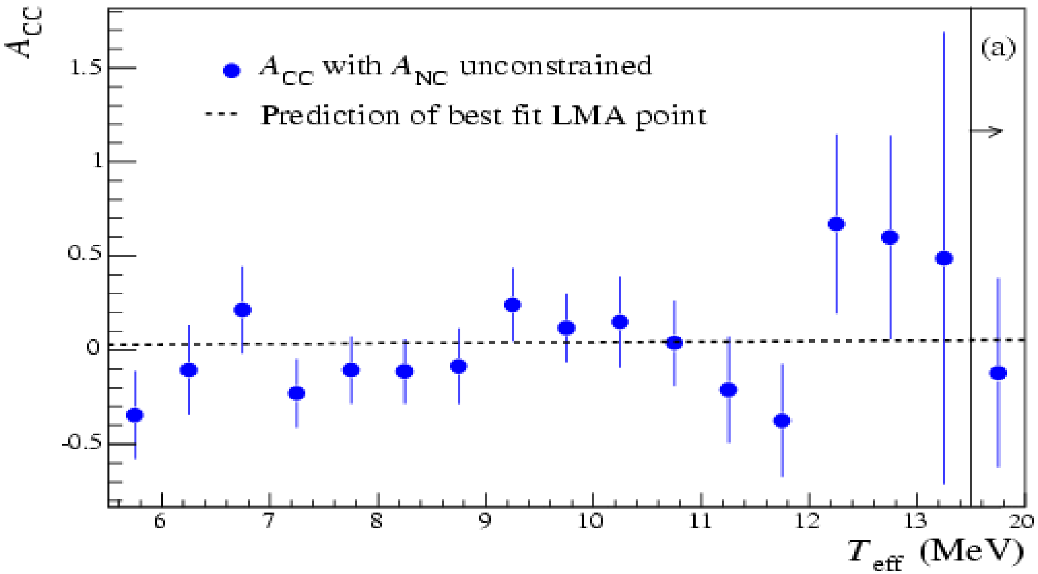
- Blind analysis to avoid statistical bias (analysis developed on 20% of data)





Constant background sources used to investigate diurnal systematic effects.

Shape Unconstrained Analysis

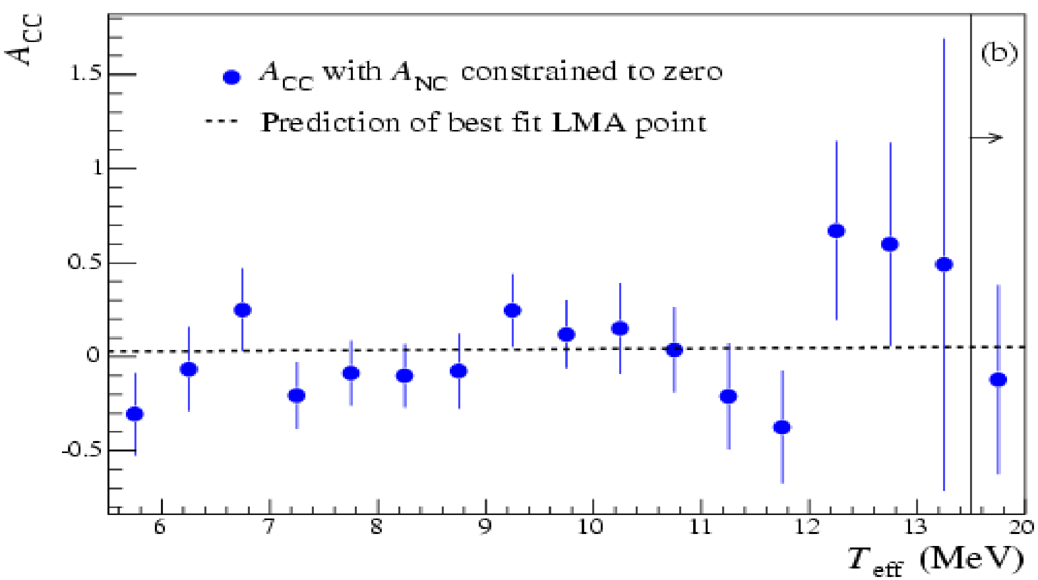


No constraint on A_{NC}

A_{cc}= -0.056±0.074±0.051

A_{NC}= 0.042±0.086±0.067

A_{ES}= 0.146±0.198±0.032



A_{cc}= -0.037±0.063±0.032

A_{ES}= 0.153±0.198±0.030

A_{NC} = 0

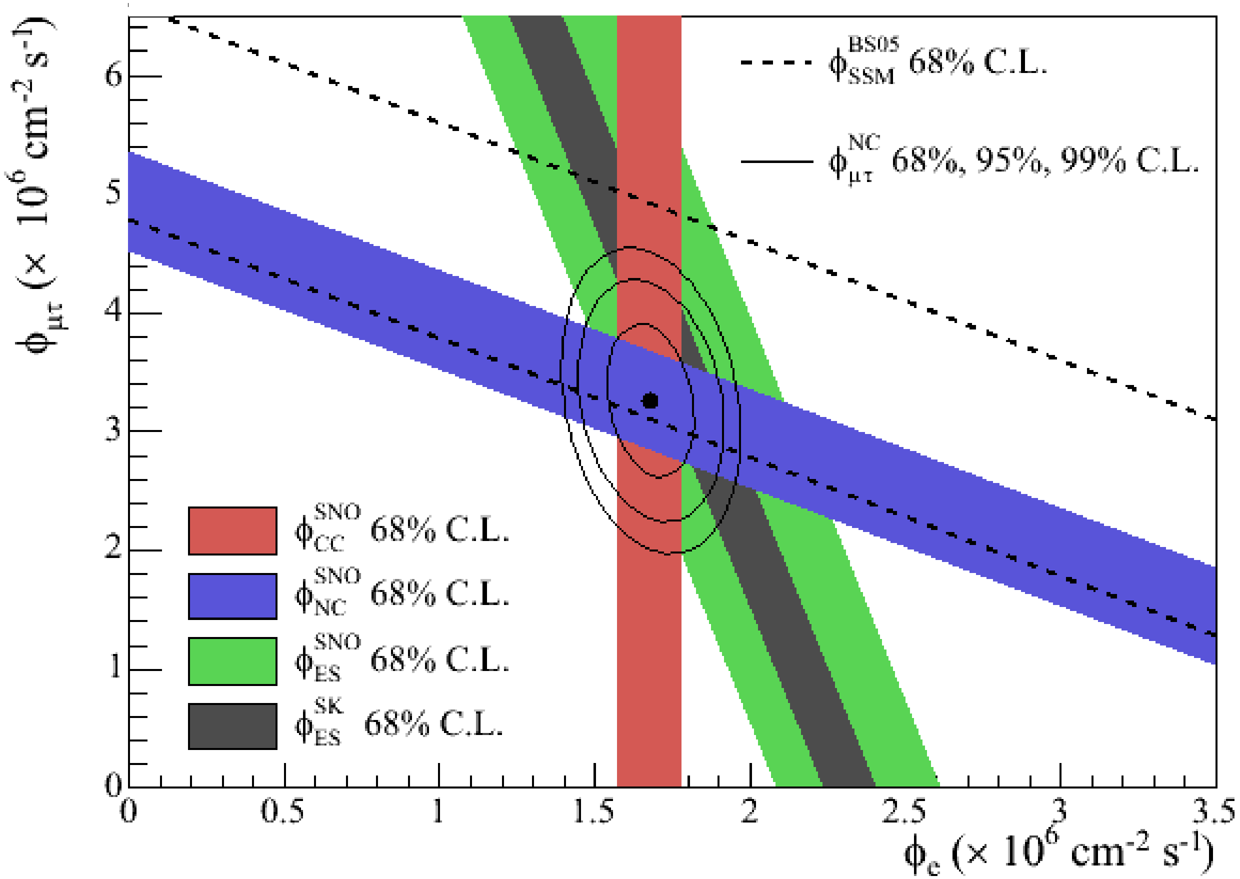

Updated Flux

Energy-Unconstrained Fluxes

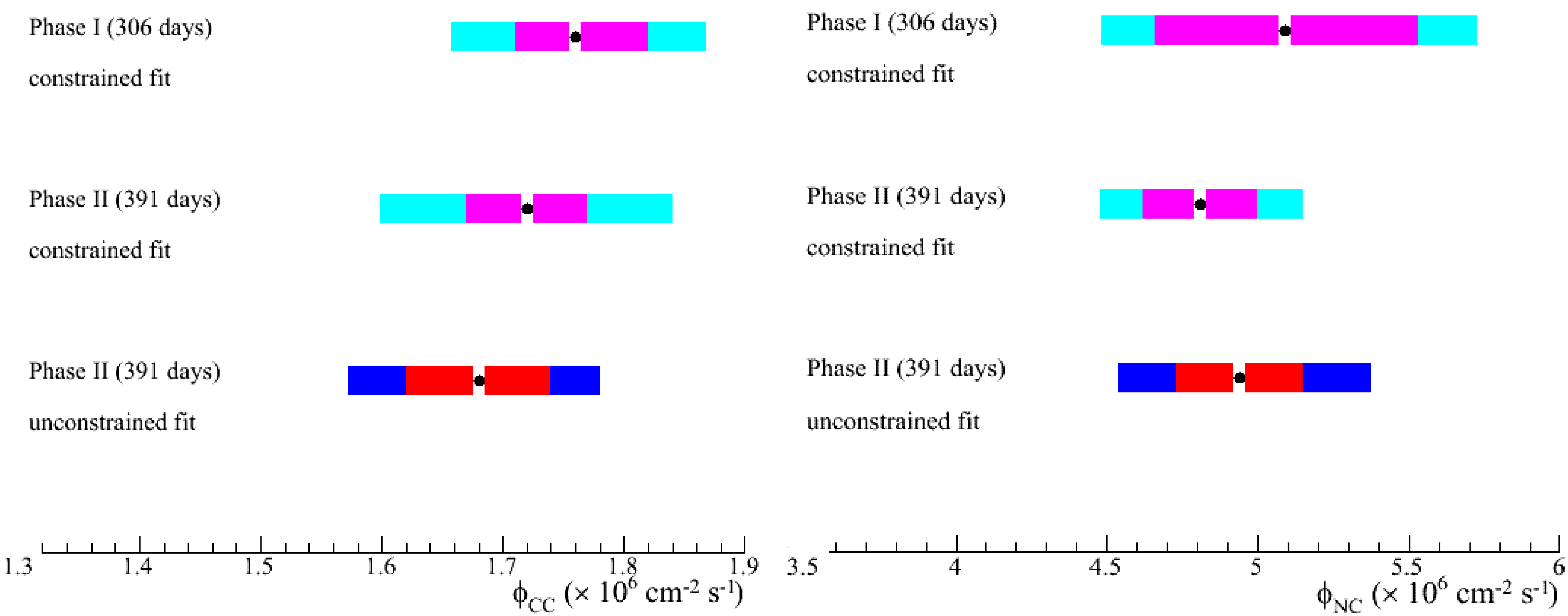
$\Phi_{CC} = 1.68 \pm 0.06 \pm ^{0.08}_{0.09}$

$\Phi_{ES} = 2.35 \pm 0.23 \pm ^{0.15}_{0.14}$ $\times 10^6$ cm^{-2} s^{-1}

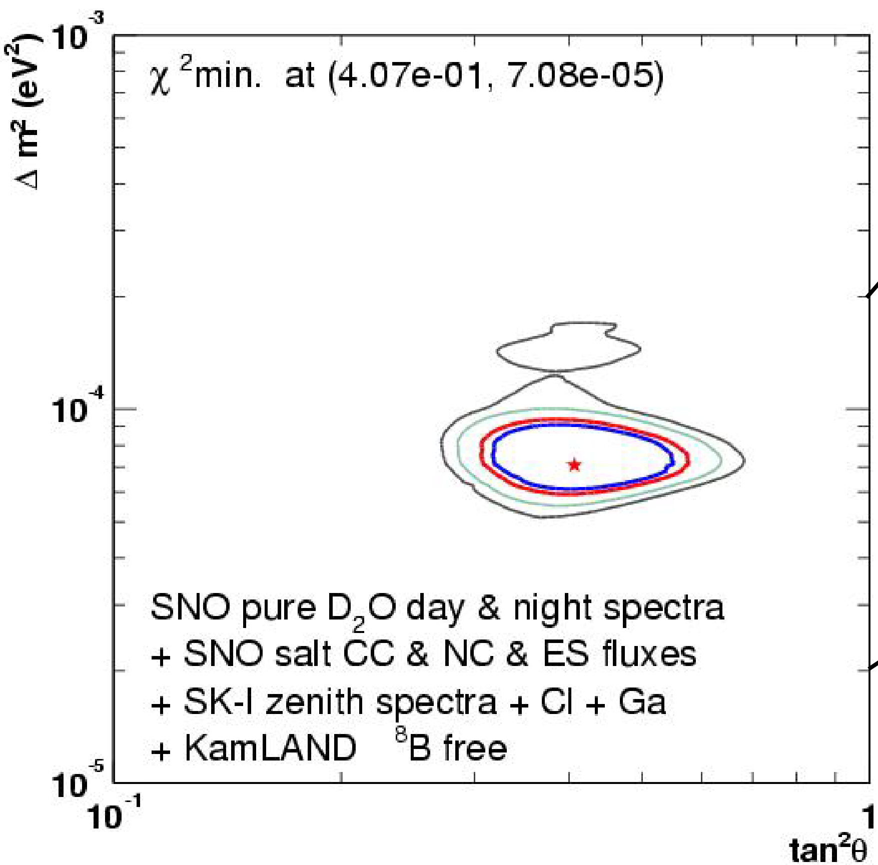
$\Phi_{NC} = 4.94 \pm 0.21 \pm ^{0.38}_{0.34}$

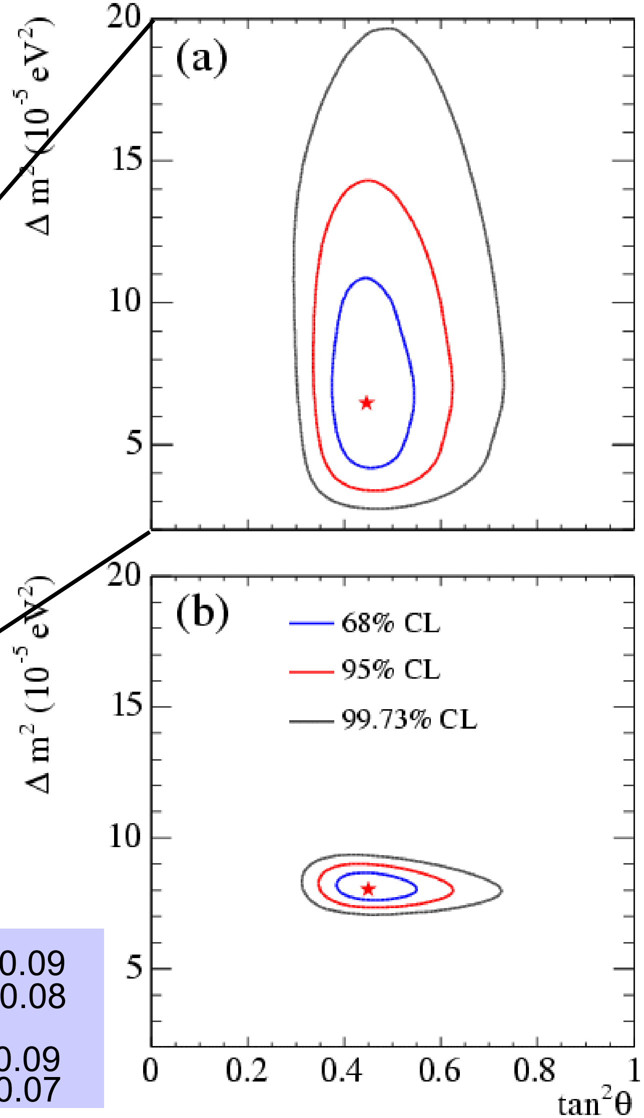


SNO flux results - Summary



MSW interpretation of Results





a) $\Delta m^2 = 6.5^{+4.4}_{-2.3} \times 10^{-5}$ eV^2, $\tan^2\theta = 0.45^{+0.09}_{-0.08}$

b) $\Delta m^2 = 8.0^{+0.6}_{-0.4} \times 10^{-5}$ eV^2, $\tan^2\theta = 0.45^{+0.09}_{-0.07}$

Current Status

Where next?

- Lower energy threshold
- Combined analysis of the full salt and D_2O data sets.
- NCD phase ....

SNO Phase III (NCD Phase)

- ^{3}He Proportional Counters (“NC Detectors”) now installed
- Production data taking underway

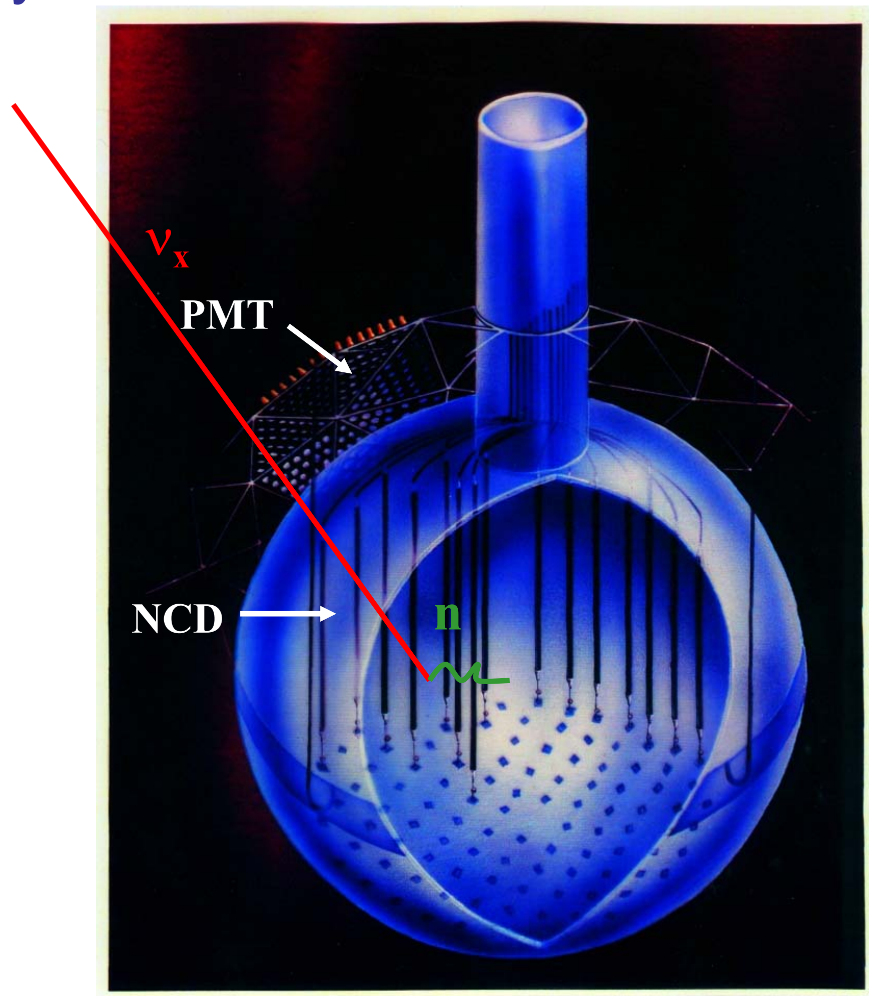
40 Strings on 1-m grid

440 m total active length

Detection Principle

$^2H + \nu_x \rightarrow p + n + \nu_x - 2.22$ MeV (NC)

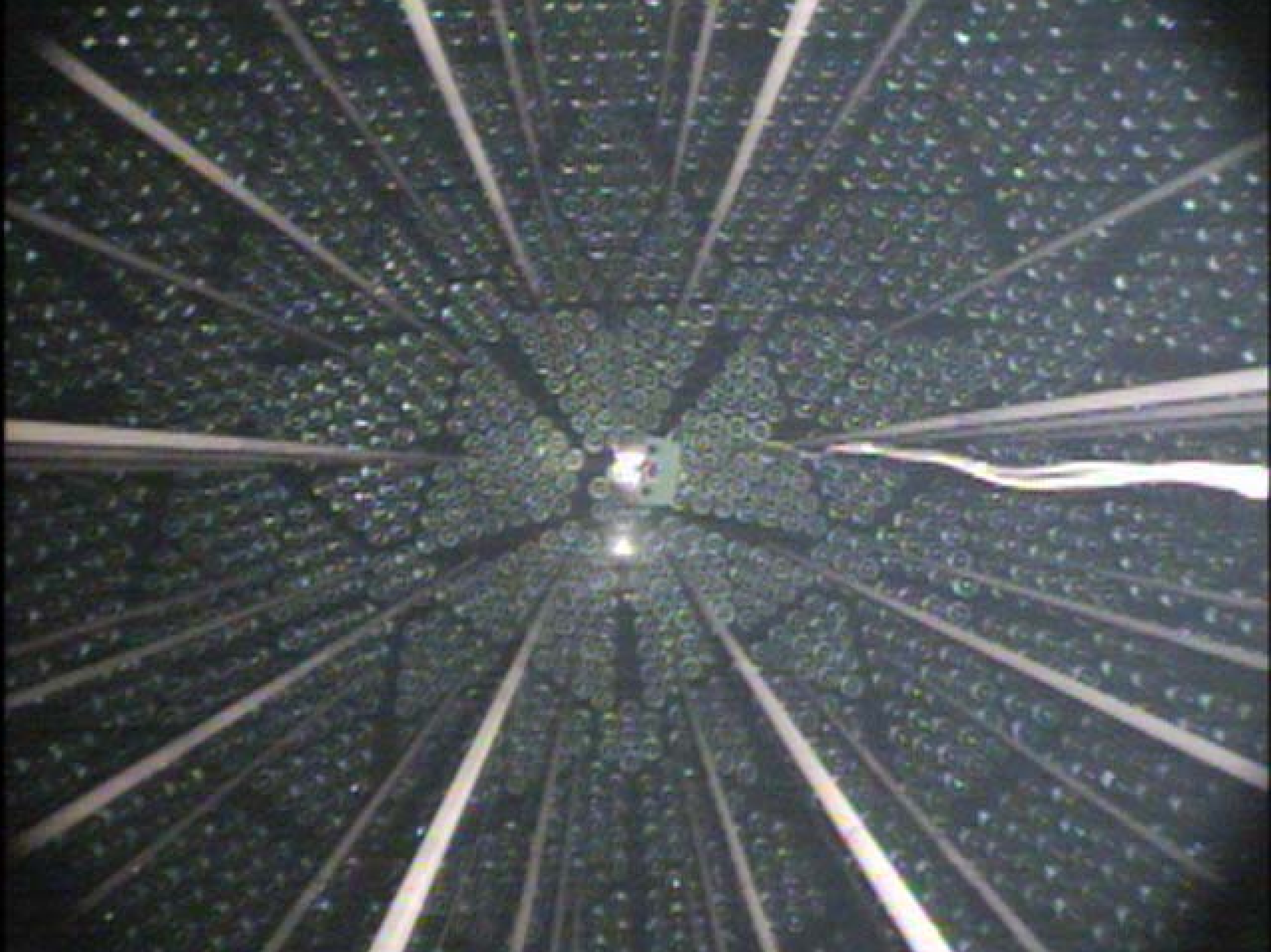
$^3He + n \rightarrow p + {^3H} + 0.76$ MeV



Physics Motivation

Event-by-event separation. Measure NC and CC in separate data streams.

Different systematic uncertainties than neutron capture on NaCl.



Summary

- 4722 candidate neutrinos in 391 days data
- New salt results confirm and improve previous SNO data
- First full CC spectrum presented
  - consistent with best fit LMA
- First salt day:night measurements
  - A_{cc} consistent with zero and LMA prediction
- Best fit mixing parameters

$$\Delta m^2 = 8.0^{+0.6}_{-0.4} \times 10^{-5}\ \mathrm{eV}^2, \quad \tan^2\theta = 0.45^{+0.09}_{-0.07}$$