Imperial College London

GAMBIT NeutrinoBit Progress Report

Chien Lin
on behalf of the NeutrinoBit WG

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GAMBIT XV, 2023/July

Active members

- Tomas Gonzalo (convenor)
- Anders Kvellestad
- Chien Lin (convenor [stepping down])
- Michele Lucente
- Roberto Ruiz de Austri Bazan
- Wilf Shorrock (convenor [stepping up])
- Martin White

Goals

- Develop `NeutrinoBit` for SM neutrino oscillation in GAMBIT
- Include a wide range of neutrino oscillation experiments
- Use publicly available data with realistic systematic models

Currently included experiments

- **Solar**
  - SNO
- **Atmospheric**
  - Super-Kamiokande
  - IceCube
- **Long baseline accelerator**
  - T2K
  - NOvA
  - MINOS
- **Reactor**
  - Daya Bay
  - KamLAND

Methodology

- GAMBIT predicts energy spectra (broadly) following the formula:

Oscillation probability

$$N_i^\alpha = N_{\mathrm{bkg},i} + \int_{E_i}^{E_{i+1}} dE_{\mathrm{rec}} \int_0^\infty dE_\nu R\left(E_{\mathrm{rec}}|E_\nu\right) \frac{d\Phi}{dE_\nu} \sigma_\alpha(E_\nu) \epsilon(E_\nu) \boxed{P_{\nu_\mu \to \nu_\alpha}(E_\nu)}$$

Reconstruction effects   Flux   Cross section   Efficiency

- GAMBIT compares predicted spectra to experimental observations
- GAMBIT searches for best-fit oscillation parameters by maximising likelihood

New since GAMBIT XIV

- **T2K**: applying PCA to reduce number of systematics to 5 (80% coverage) or 12 (95% coverage)
- **NOvA**: updating from 2018 to 2020 analysis
- **SNO**, **IceCube**: more experiments
- **PEANUTS**: a tool for solar neutrino propagation within Earth
- **Combined runs** on DiRAC

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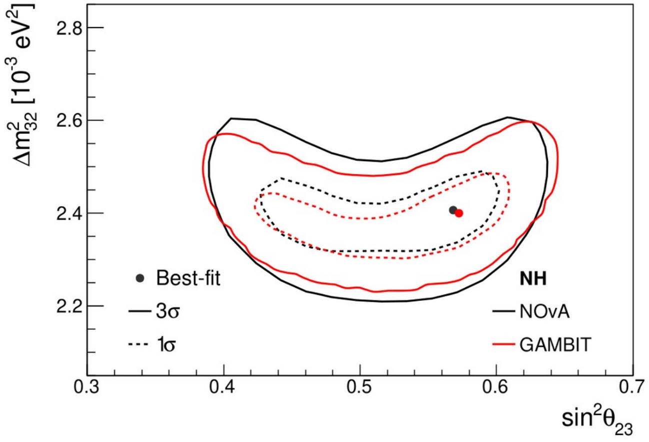
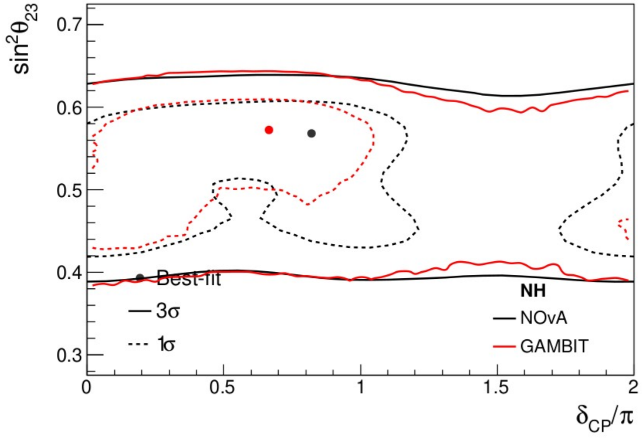
- **PEANUTS**: a tool for solar neutrino propagation with
- **Combined runs** on DiRAC





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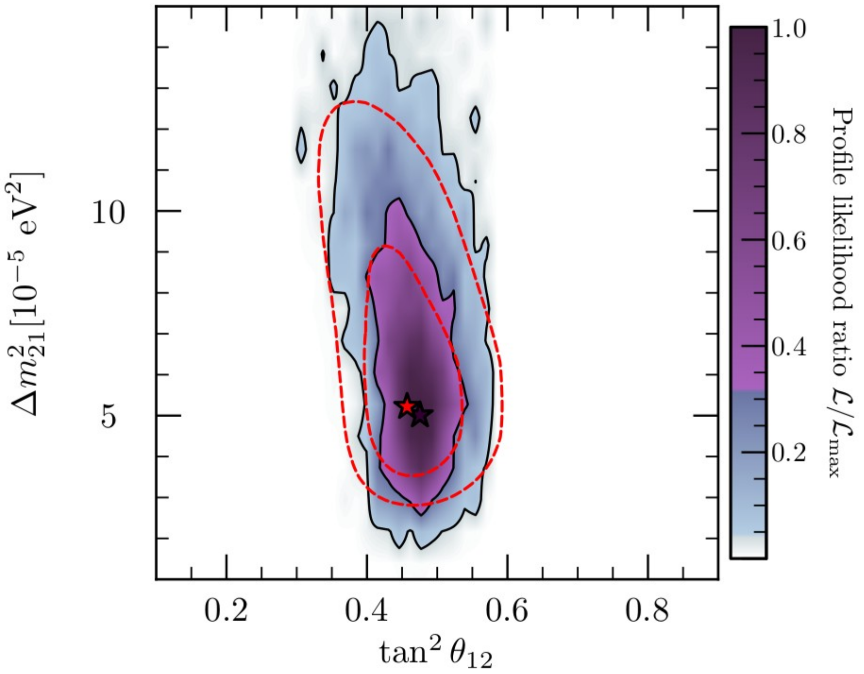

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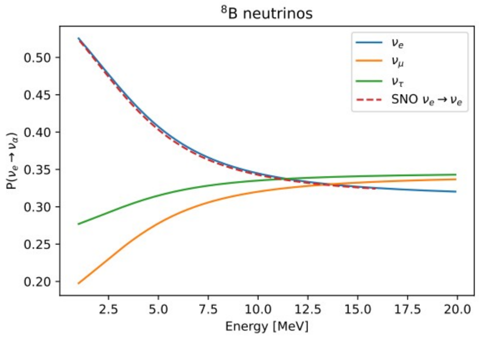

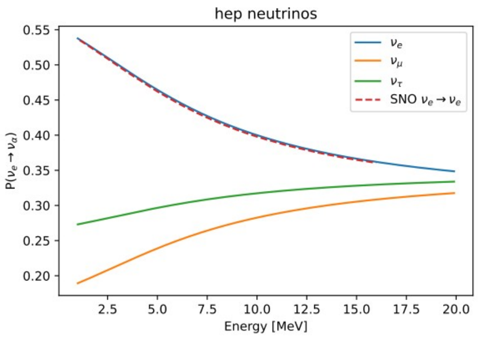

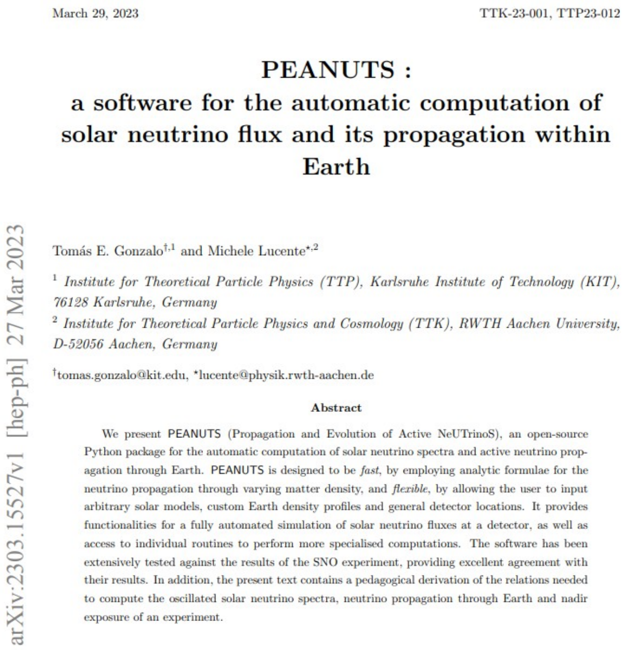

March 29, 2023 TTK-23-001, TTP23-012

PEANUTS : a software for the automatic computation of solar neutrino flux and its propagation within Earth

arXiv:2303.15527v1 [hep-ph] 27 Mar 2023

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[2] Institute for Theoretical Particle Physics and Cosmology (TTK), RWTH Aachen University, D-52056 Aachen, Germany

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Abstract

We present PEANUTS (Propagation and Evolution of Active NeUTrinoS), an open-source Python package for the automatic computation of solar neutrino spectra and active neutrino propagation through Earth. PEANUTS is designed to be *fast*, by employing analytic formulae for the neutrino propagation through varying matter density, and *flexible*, by allowing the user to input arbitrary solar models, custom Earth density profiles and general detector locations. It provides functionalities for a fully automated simulation of solar neutrino fluxes at a detector, as well as access to individual routines to perform more specialised computations. The software has been extensively tested against the results of the SNO experiment, providing excellent agreement with their results. In addition, the present text contains a pedagogical derivation of the relations needed to compute the oscillated solar neutrino spectra, neutrino propagation through Earth and nadir exposure of an experiment.

New since GAMBIT XIV

- **T2K**: applying PCA to reduce number of systematics to 5 (80% coverage) or 12 (95% coverage)
- **NOvA**: updating from 2018 to 2020 analysis
- **SNO**, **IceCube**: more experiments
- **PEANUTS**: a tool for solar neutrino propagation within Earth
- **Combined runs** on DiRAC
  - Example test run includes T2K, NOvA, Daya Bay, KamLAND, MINOS
  - More improvements have been implemented since the test run
  - Had not reached convergence

Comparison with NuFIT

- NuFIT paper: "*The fate of hints: updated global analysis of three-flavor neutrino oscillations*" [JHEP 09 (2020) 178] [arXiv:2007.14792]
- Uses a different list of experiments
- Uses a different method to represent systematic uncertainties

PREPARED FOR SUBMISSION TO JHEP IFT-UAM/CSIC-112, YITP-SB-2020-21

The fate of hints: updated global analysis of three-flavor neutrino oscillations

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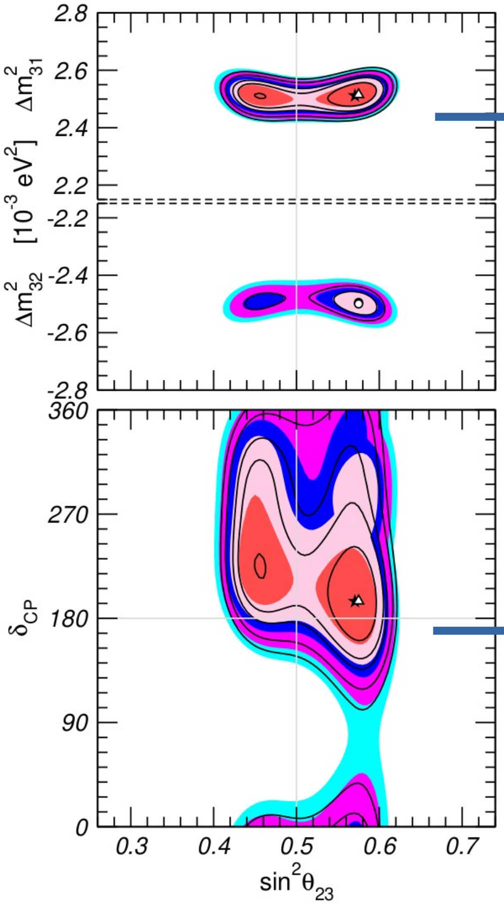
ABSTRACT: Our herein described combined analysis of the latest neutrino oscillation data presented at the Neutrino2020 conference shows that previous hints for the neutrino mass ordering have significantly decreased, and normal ordering (NO) is favored only at the 1.6σ level. Combined with the χ^2 map provided by Super-Kamiokande for their atmospheric neutrino data analysis the hint for NO is at 2.7σ. The CP conserving value $\delta_{CP} = 180°$ is within 0.6σ of the global best fit point. Only if we restrict to inverted mass ordering, CP violation is favored at the $\sim 3\sigma$ level. We discuss the origin of these results – which are driven by the new data from the T2K and NOvA long-baseline experiments–, and the relevance of the LBL-reactor oscillation frequency complementarity. The previous 2.2σ tension in Δm^2_{21} preferred by KamLAND and solar experiments is also reduced to the 1.1σ level after the inclusion of the latest Super-Kamiokande solar neutrino results. Finally we present updated allowed ranges for the oscillation parameters and for the leptonic Jarlskog determinant from the global analysis.

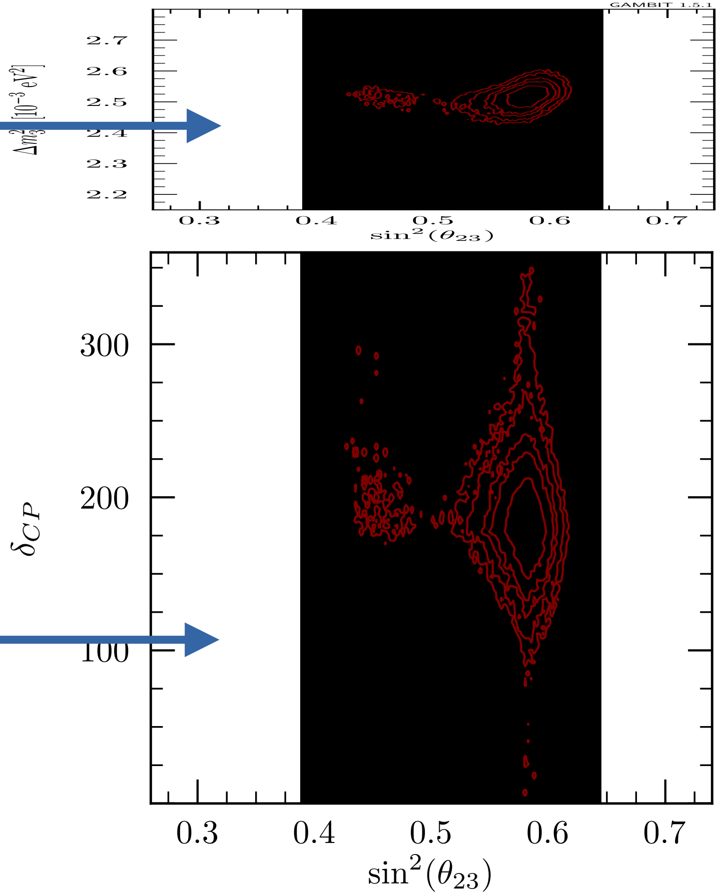
KEYWORDS: neutrino oscillations, solar and atmospheric neutrinos

Comparison with NuFIT

NuFIT (coloured regions)



GAMBIT



(Colours regions are without SK-atm)

(1σ, 90%, 2σ, 99%, 3σ)

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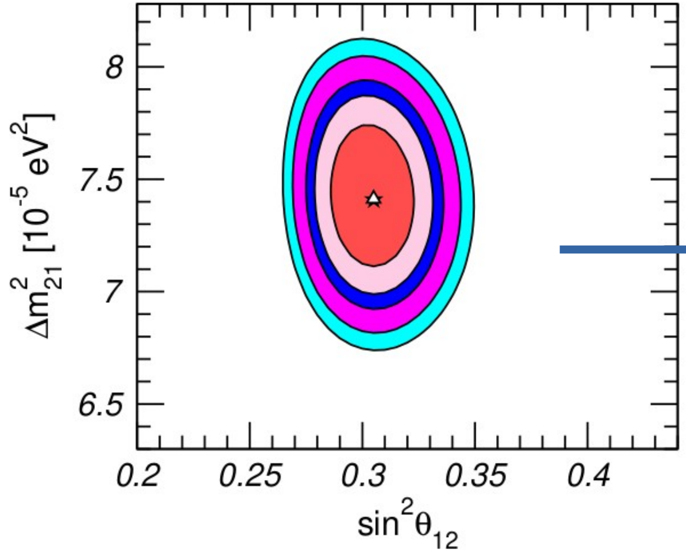

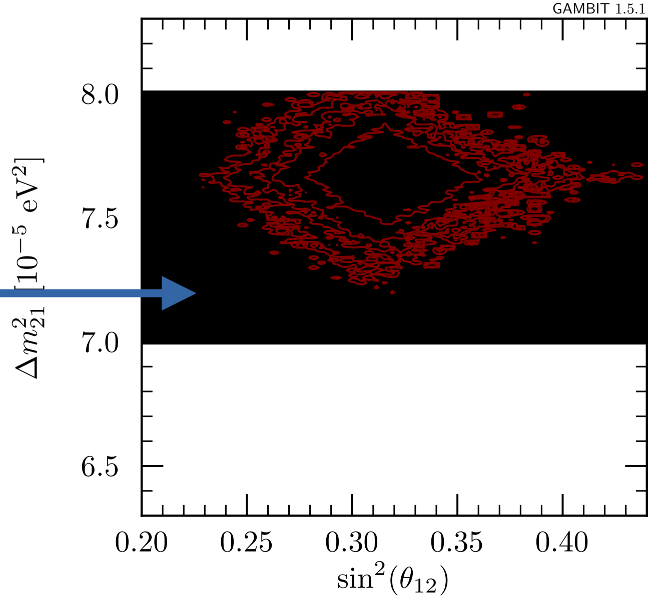

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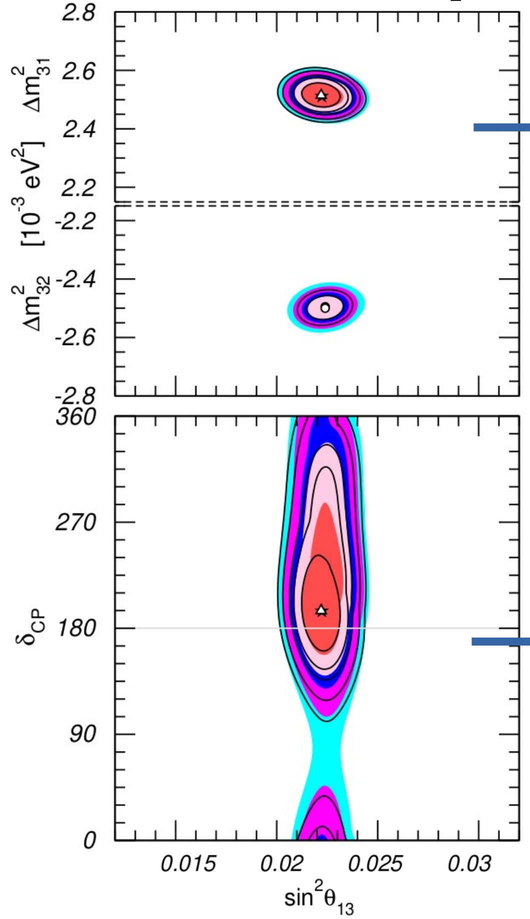

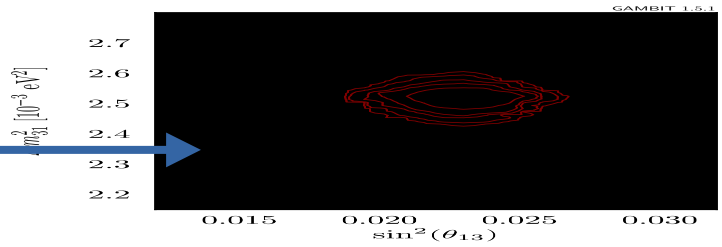

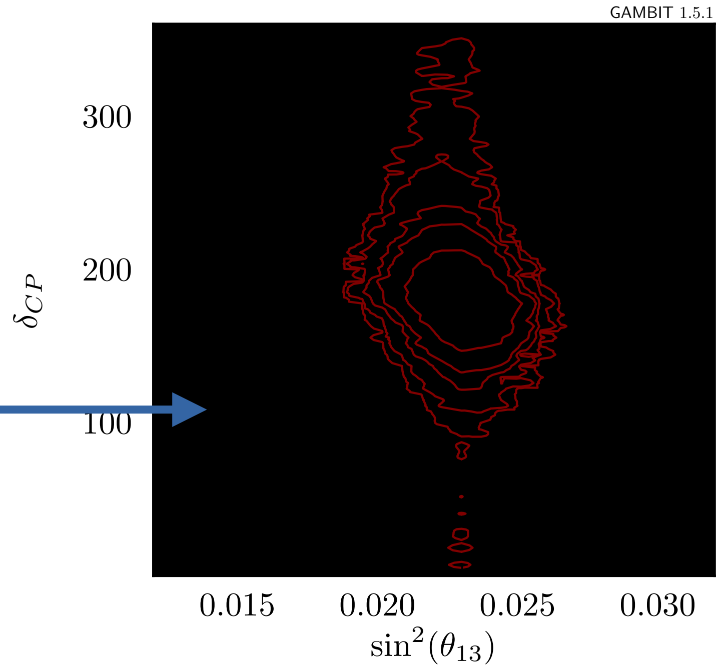

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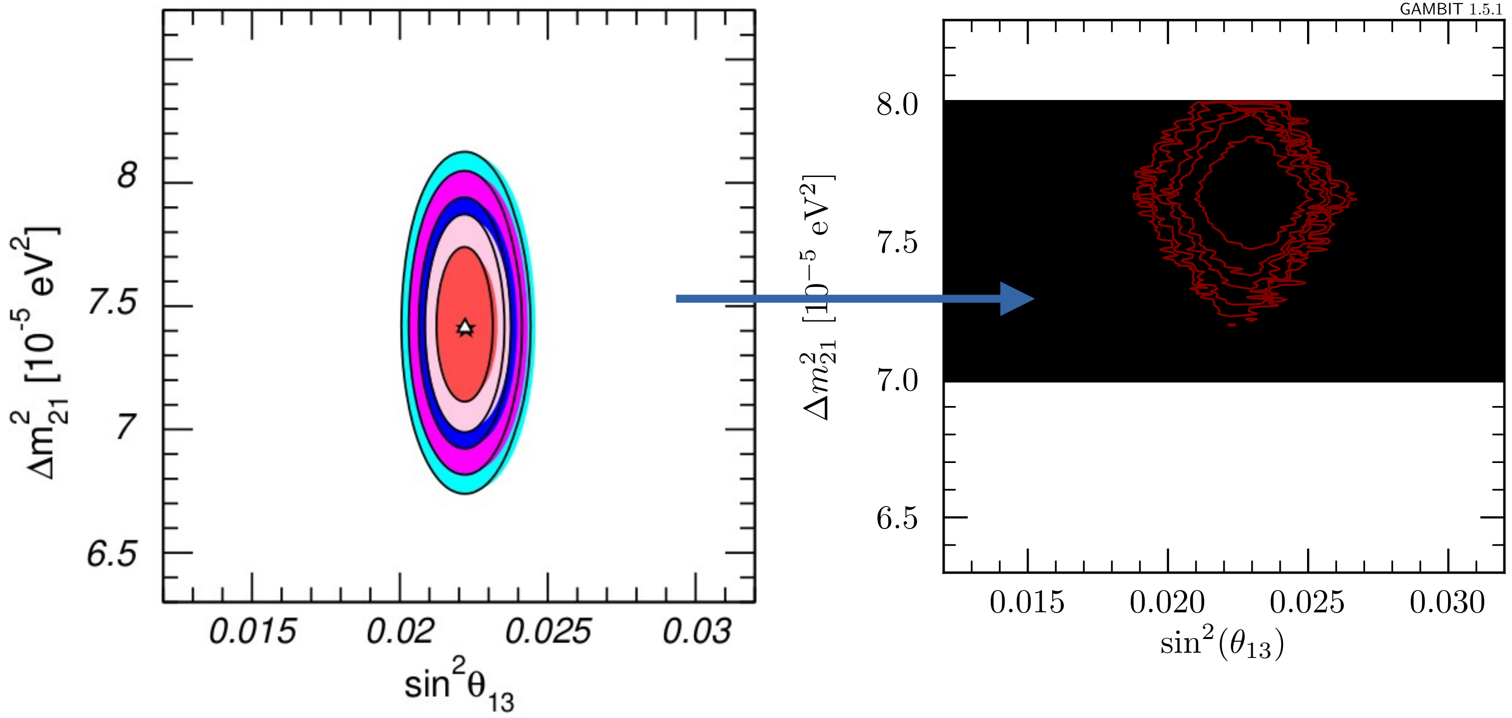

GAMBIT

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Some issues

- **Compiling GAMBIT on DiRAC** [solved] – detailed instructions are updated on the GAMBIT wiki now
- **Memory leak** [solved] – a numba bug that leaks memory every time a jitted function with a string literal argument is called
- **Running GAMBIT with MPI and OpenMP** [solved] – DiRAC distributes number of jobs that exceed physical core count per node
- **icc GAMBIT and gcc GAMBIT behave differently** [solved] – relates to the use of arrays whose lengths are defined using non-const varibles
- **Resuming runs killed by DiRAC** – several potential solutions proposed; need verification
- **Processes killed without clear reasons** – not sure why this happens; jobs with more cores are killed sooner

```
===================================================================================
=   BAD TERMINATION OF ONE OF YOUR APPLICATION PROCESSES
=   RANK 220 PID 1333155 RUNNING AT cpu-q-95
=   KILLED BY SIGNAL: 9 (Killed)
===================================================================================

===================================================================================
=   BAD TERMINATION OF ONE OF YOUR APPLICATION PROCESSES
=   RANK 221 PID 1333156 RUNNING AT cpu-q-95
=   KILLED BY SIGNAL: 6 (Aborted)
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===================================================================================
=   BAD TERMINATION OF ONE OF YOUR APPLICATION PROCESSES
=   RANK 222 PID 1333157 RUNNING AT cpu-q-95
=   KILLED BY SIGNAL: 9 (Killed)
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===================================================================================
=   BAD TERMINATION OF ONE OF YOUR APPLICATION PROCESSES
=   RANK 223 PID 1333158 RUNNING AT cpu-q-95
=   KILLED BY SIGNAL: 9 (Killed)
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===================================================================================
=   BAD TERMINATION OF ONE OF YOUR APPLICATION PROCESSES
=   RANK 224 PID 1333159 RUNNING AT cpu-q-95
=   KILLED BY SIGNAL: 9 (Killed)
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===================================================================================
=   BAD TERMINATION OF ONE OF YOUR APPLICATION PROCESSES
=   RANK 225 PID 1333160 RUNNING AT cpu-q-95
=   KILLED BY SIGNAL: 9 (Killed)
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===================================================================================
=   BAD TERMINATION OF ONE OF YOUR APPLICATION PROCESSES
=   RANK 226 PID 1333161 RUNNING AT cpu-q-95
=   KILLED BY SIGNAL: 9 (Killed)
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```

Summary

- Most of the experiments are finished or close to finished
- PEANUTS was developed and released
- Preparing and testing for the production run on DiRAC
- Investigating issues arising from the test runs
- Paper writing

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Backup slides