Science Activity on IRIS: Particle Physics

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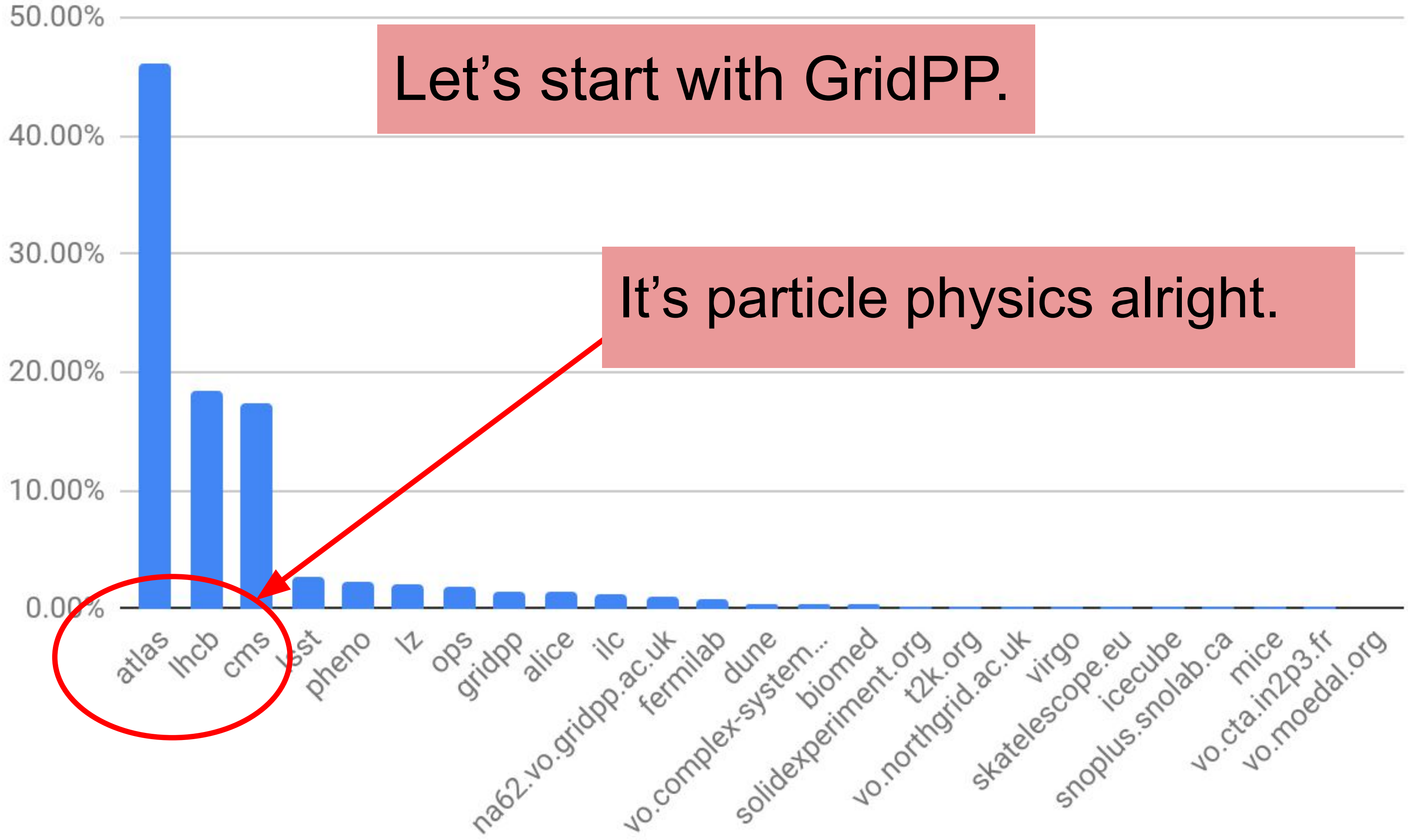
Context: GridPP
Number of running jobs by experiment Oct 2019 Oct 2020



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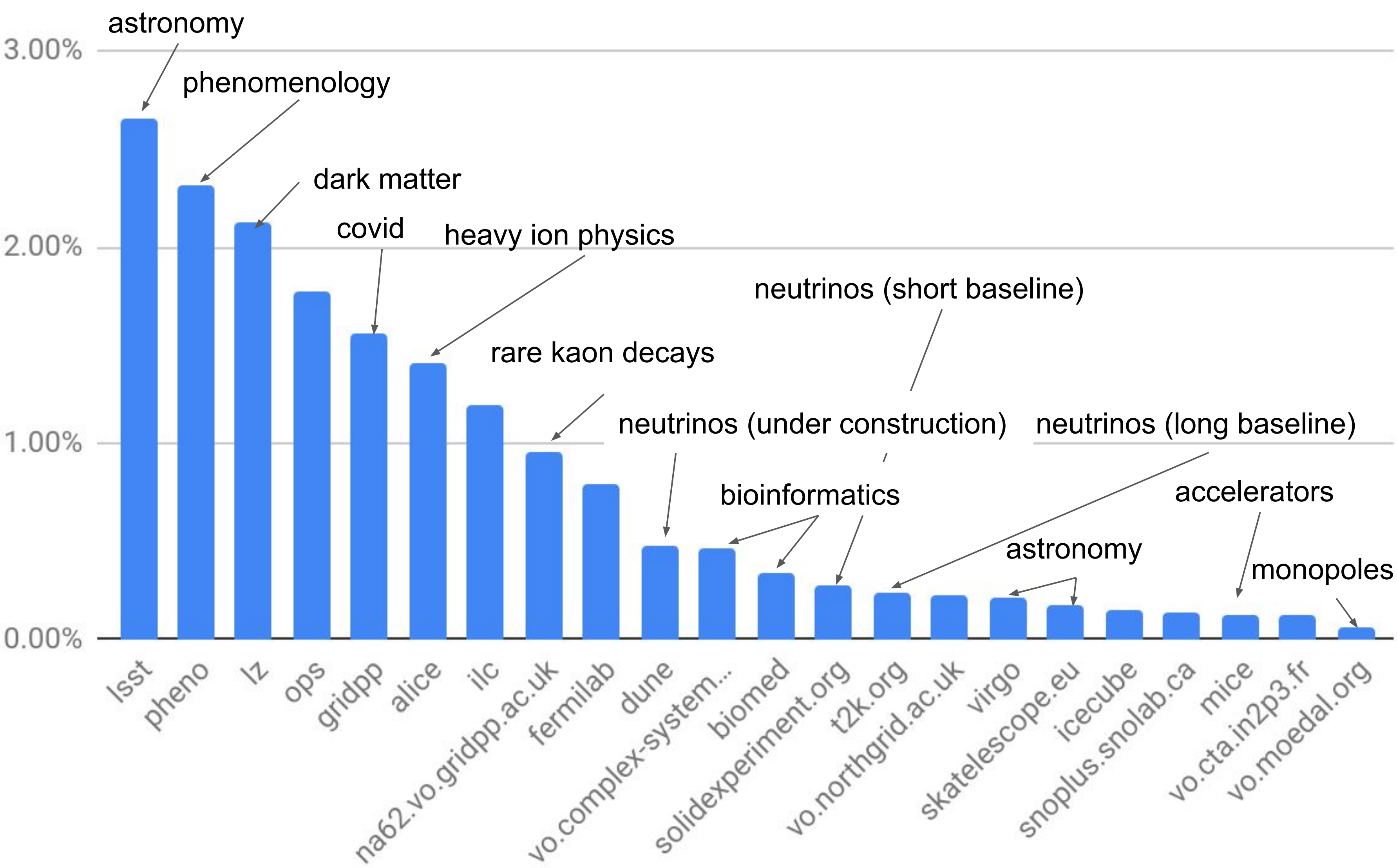
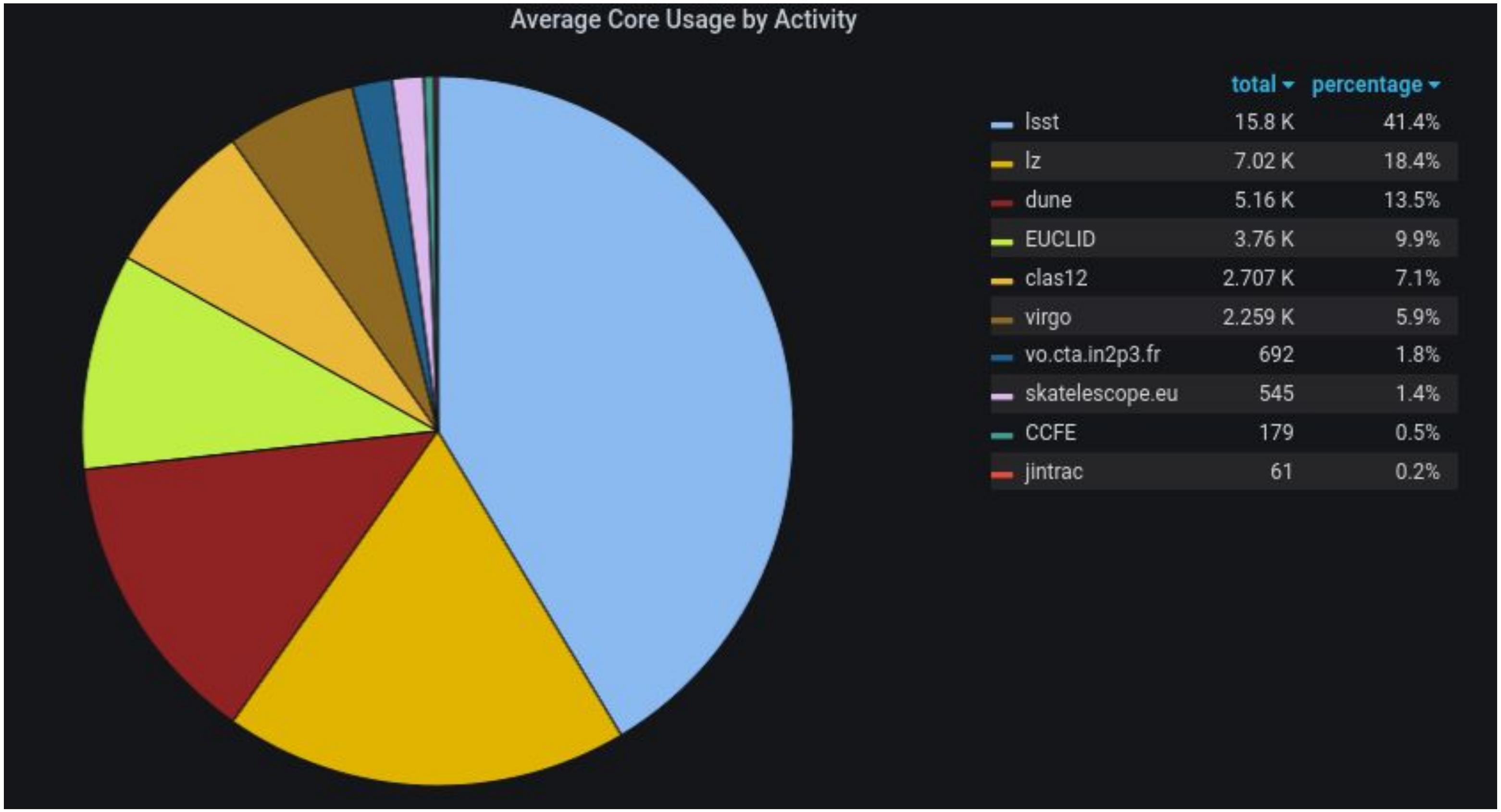
And so much more:



IRIS enhances the activities in the GridPP tail



IRIS accounting (Oct 2019 - Oct 2020)

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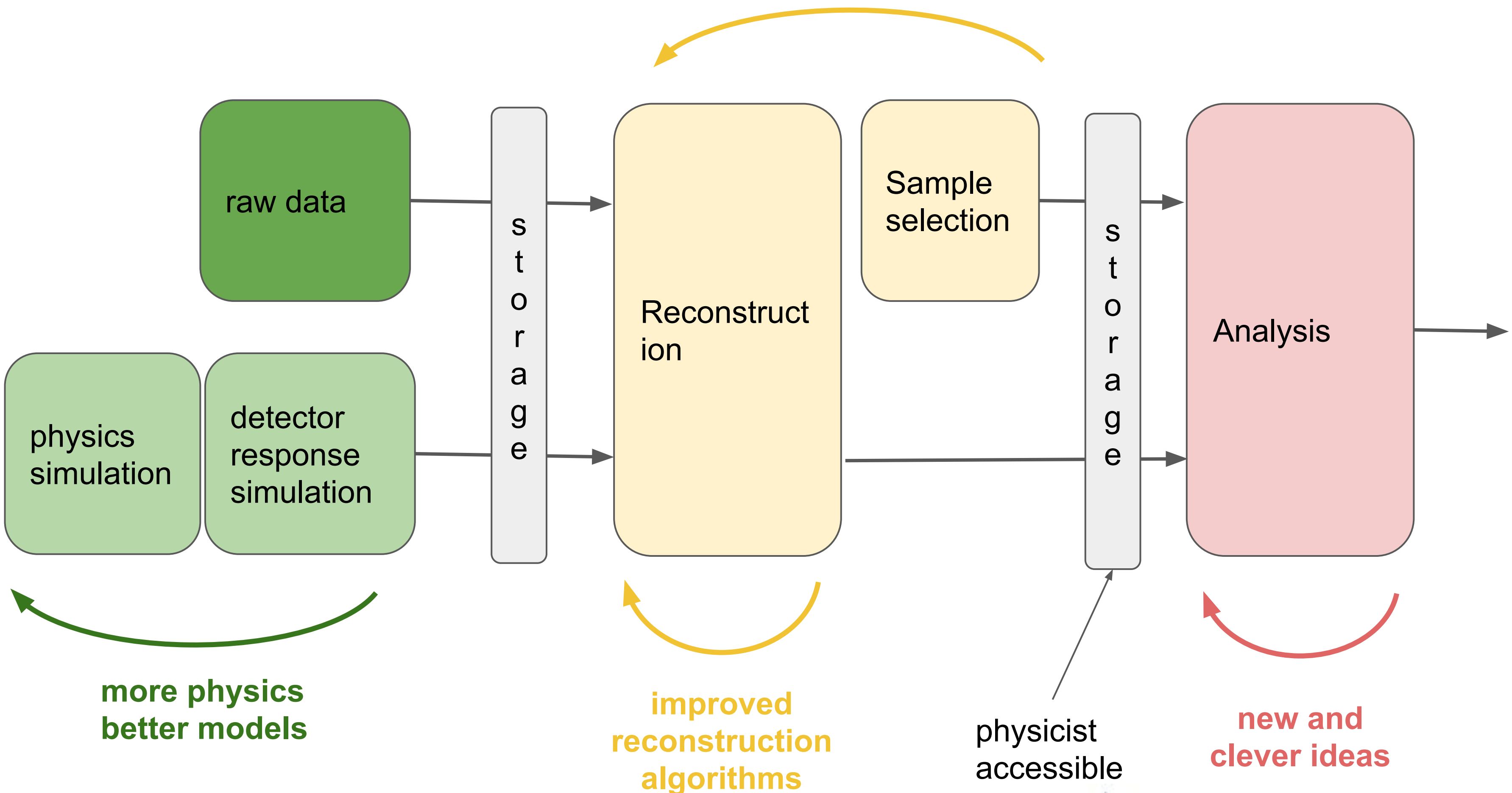
So what is HEP using all this compute for ?
The (simplified) HEP computing life cycle.



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“events” are independent ➞ HTC

Result ! Atlas: $H \rightarrow \mu^+\mu^-$

The Higgs - the last missing building block in the standard model - was discovered in 2012.

The focus since then has been on characterizing the Higgs boson.

In summer 2020 **Atlas** presented results from the search of $H \rightarrow \mu^+\mu^-$ to explore Higgs interactions with second-generation fermions: https://arxiv.org/pdf/2007.07830.pdf

Looks straight forward, so why all the compute and storage ?

Run II data set: 139 fb^{-1} (~1.1 x 10^{16} proton collisions) [Storage] [Reconstruction]

Actual number of candidate events (spread over 20 categories, according to Higgs production mechanism and reconstructed quantities): ~ 450 000 [Sample Selection]

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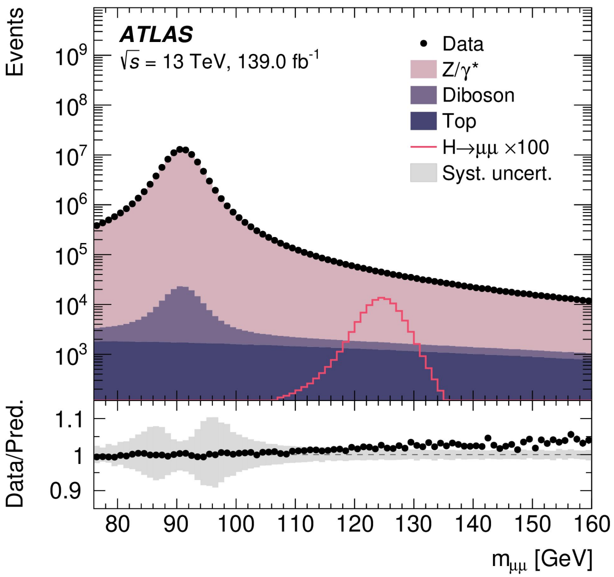
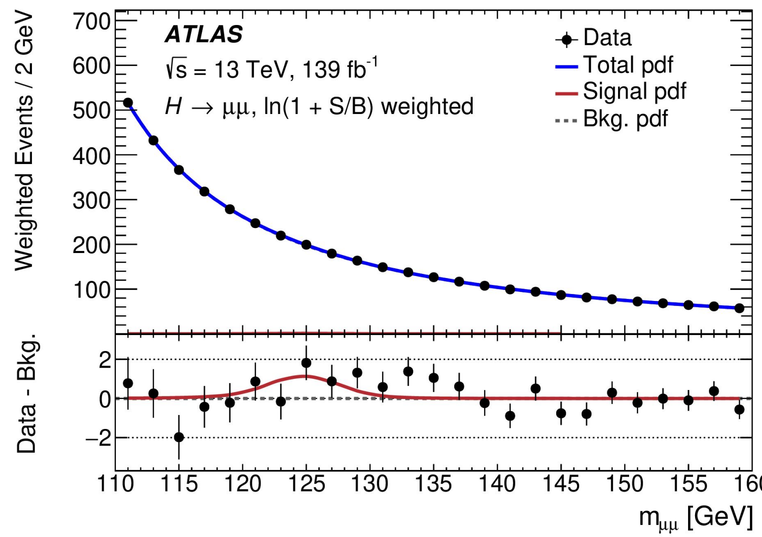
Result ! Atlas





Nothing (apart from lots of *Z*) to see here.

Finally:
The observed significance over the background-only hypothesis for a Higgs boson with a mass of 125.09 GeV is 2.0σ (expected: 1.7σ).

Many boosted decision trees later…. [Analysis]
To train your BDT you need lots of Monte Carlo.
[Simulation] [Storage]

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Result ! CMS: $H \rightarrow \tau^+\tau^-$

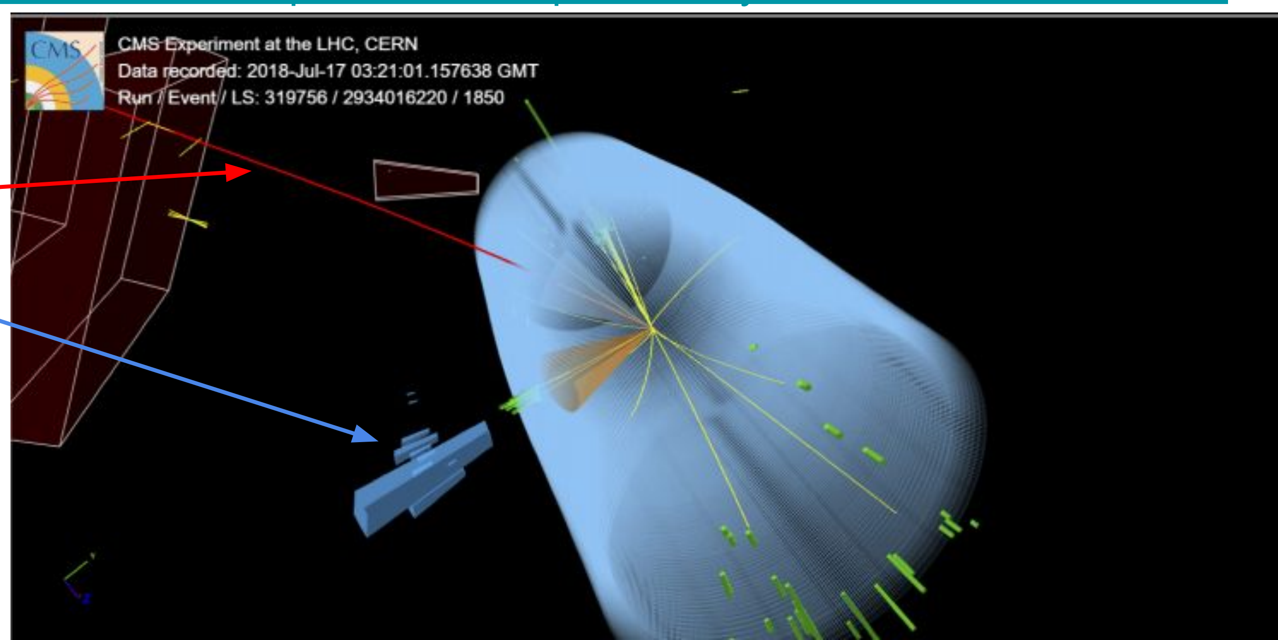
$H \rightarrow \tau^+\tau^-$ has been measured by CMS and Atlas

CMS recently presented results looking at the CP (charge parity) structure of the Yukawa coupling between the Higgs boson and τ leptons:

- The standard model predicts the Higgs to be a scalar boson (CP even).
- Any deviation from this would be a hint for new physics.
- Requires looking at the decay geometry.
- Analysis relies heavily on machine learning.

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-20-006/index.html

$H \rightarrow \tau(\mu\nu\nu)\ \tau(\text{hhh}\nu)$



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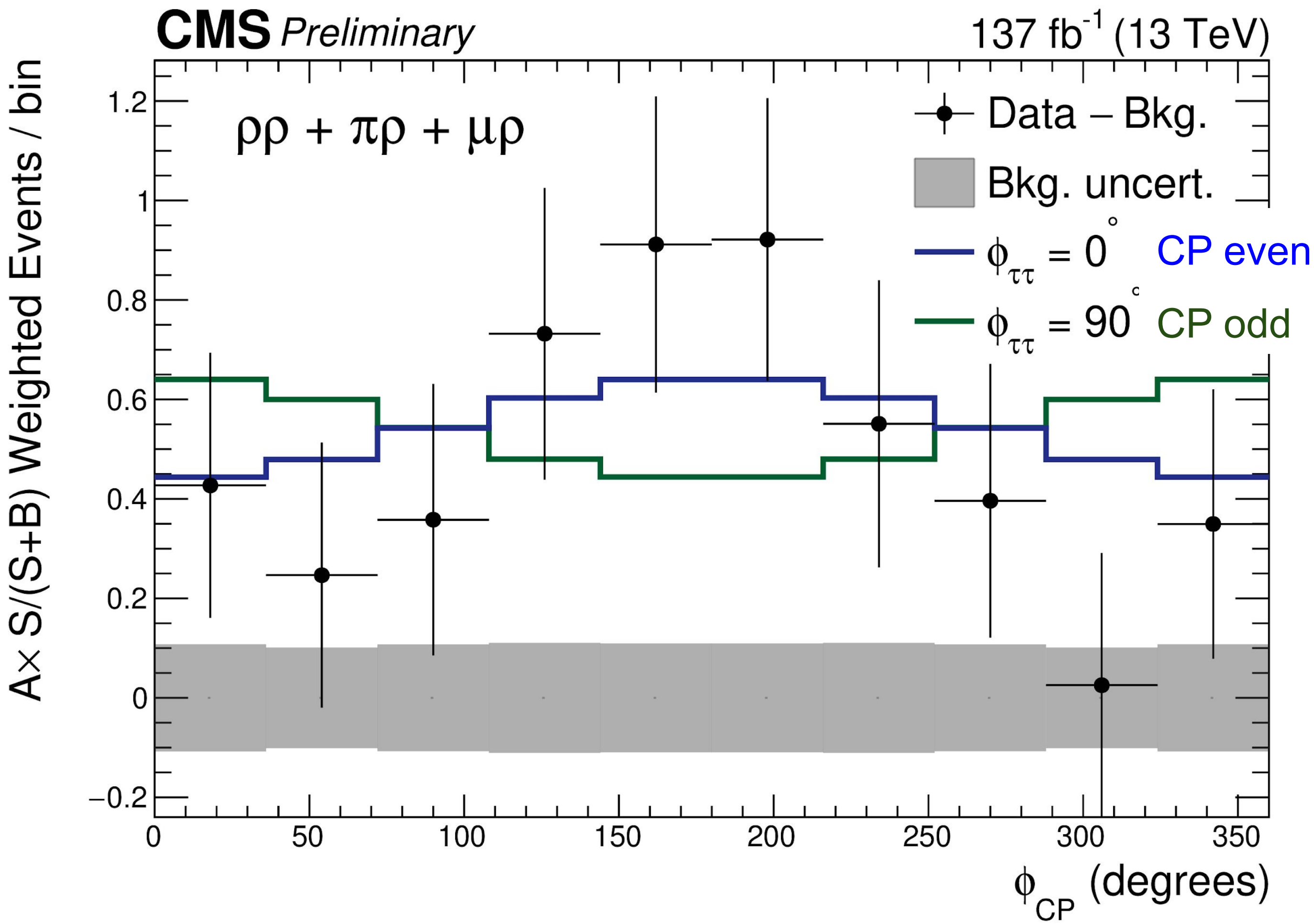
Result ! CMS



The Standard Model holds.

Result ! LHCb

October 2020: The first observation of time-dependent CP violation in B_s^0 decays.

CERN seminar: Time-dependent CP violation in B0s decays at LHCb

What is LHCb looking for and why is it interesting ?

- CP (charge-parity) violation in the quark sector can help explain the difference between matter (why is there so much ?) and anti-matter (why is there so little?)
- B_s^0 mesons 'oscillate' (turn into their anti-particle and back) ~ $3*10^{12}$ times per second: ~ 9 times during their lifetime
- So now there's plenty of opportunity for CP violation:
  - direct: different decay widths: $\Gamma\left(B \to f\right) \neq \Gamma\left(\overline{B} \to \overline{f}\right)$
  - in mixing: $\Gamma\left(B \to \overline{B}\right) \neq \Gamma\left(\overline{B} \to B\right)$
  - in mixing and decay: $\Gamma\left(B \to f_{CP}\right) \neq \Gamma\left(\overline{B} \to f_{CP}\right)$

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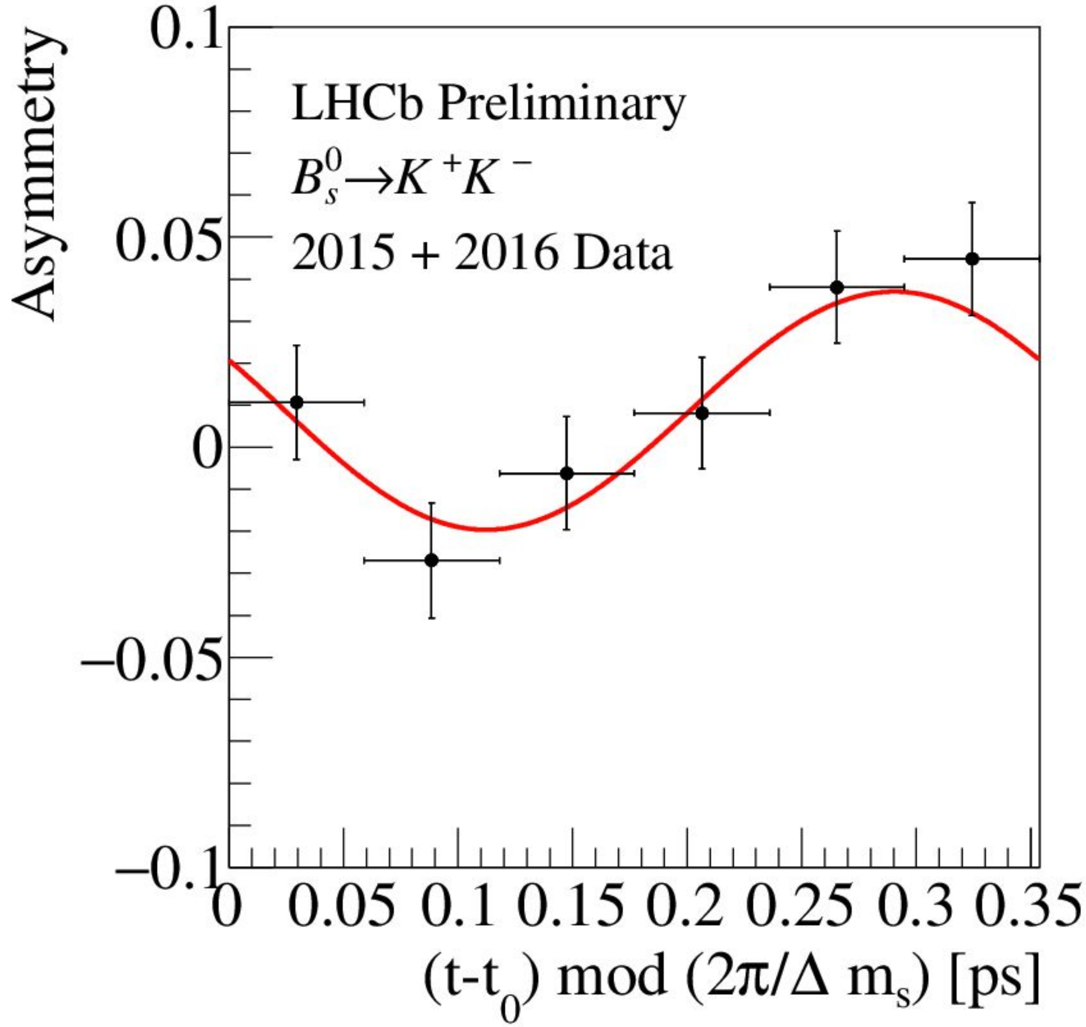
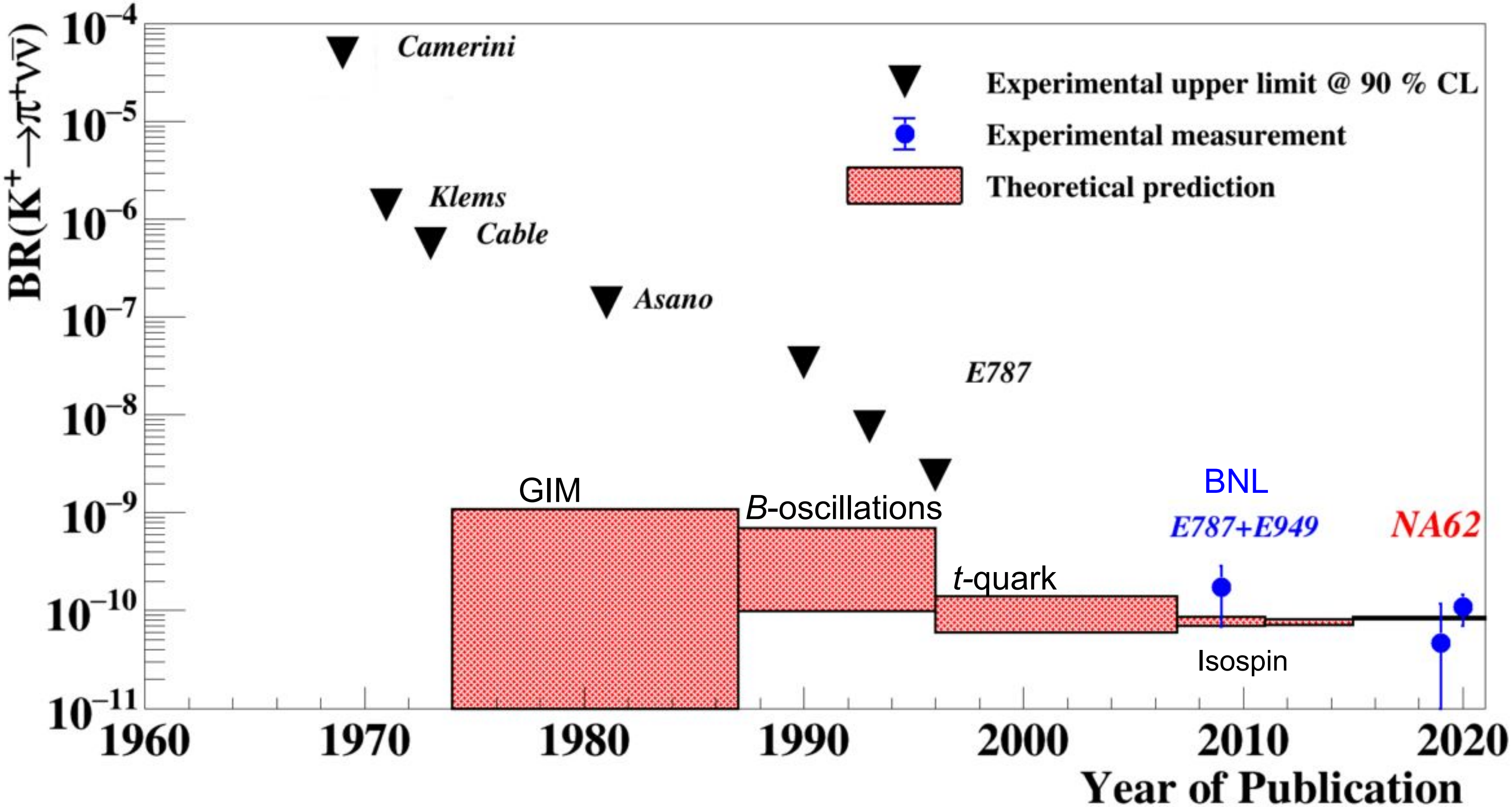
Result ! LHCb: CP asymmetry vs B_s^0 meson decay time

Oscillating non-zero asymmetry indicates the presence of *time-dependent CP violation in B_s^0 decays*



“Small” HEP experiments: NA62

- It’s not just the Higgs that proved elusive over decades. Here’s the hunt for **K → πνν** (flavour changing neutral current)



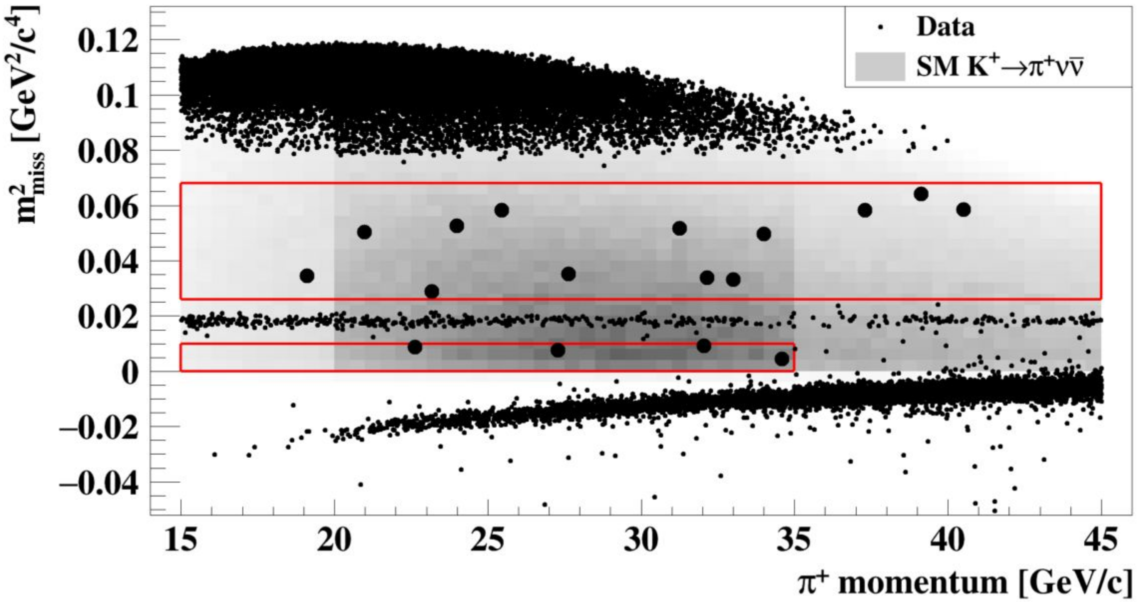
NA62: $K^+ \to \pi^+ \nu\nu$

Fixed target experiment (protons on Beryllium target).

Blinded analysis.

Presented August 2020:

[Evidence for the decay K+→π+νν from the NA62 experiment at CERN]



5.3 background + 7.6 SM signal events expected: 17 events observed

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = (11.0^{+4.0}_{-3.5}{}_{stat.} \pm 0.3_{syst.}) \times 10^{-11} (3.5\sigma \text{ significance})$$

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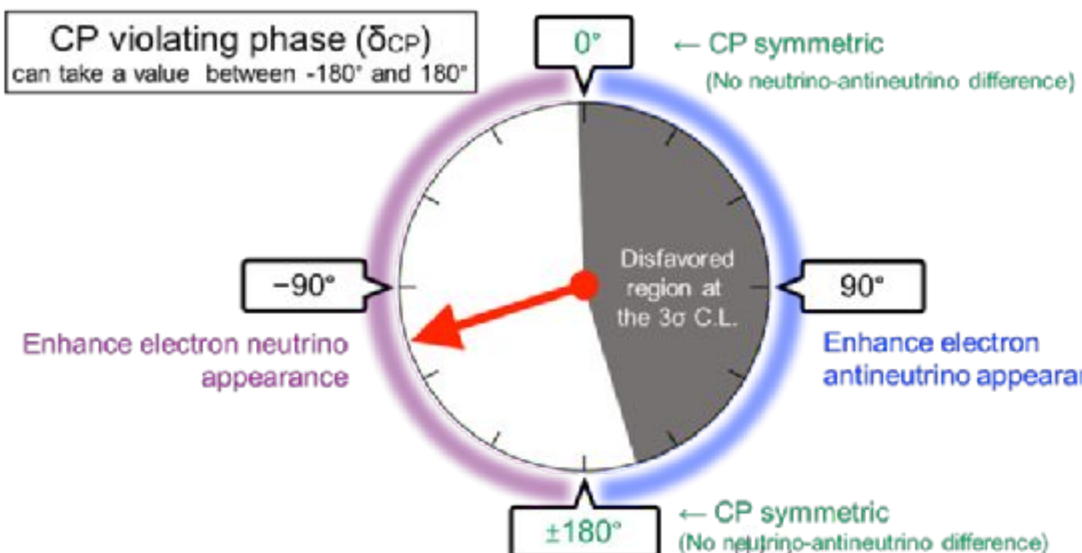
Neutrino Physics

- Neutrino first postulated by Pauli in 1930 to explain energy and momentum conservation in β decays $n \rightarrow p\, e^- \, \nu$
- Discovery of the electron neutrino by Clyde Cowan, Frederick Reines in 1956.
- Three flavours of neutrino within the Standard Model: e, mu, tau
  - Z-Boson life-time measurement (1989 onwards) confirms this hypothesis
- Initially assumed to be massless, 1998 the Super-Kamiokande collaboration found $\nu_\mu \leftrightarrow \nu_\tau$ oscillations (Nobel prize to Takaaki Kajita and Arthur B. McDonald)
- What are we currently exploring ?
  - T2K experiment (ongoing): oscillations
  - SoLid (ongoing - special thanks to IRIS for providing extra diskspace for all those data): sterile neutrinos
  - DUNE (under construction):
    - oscillations
    - supernova (if nature cooperates)

T2K (Tokai to Kamioka)

- Long baseline neutrino experiment (295 km between near and far detector)
- Using (anti-) muon neutrino to (anti-)electron neutrino oscillations
- **CP violation in the quark sector is not sufficient to explain the discrepancy between matter and anti-matter in the universe**
- Constraint on the matter–antimatter symmetry-violating phase in neutrino oscillations: https://www.nature.com/articles/s41586-020-2177-0

So close….



(simplified analysis result's illustration from the University of Warwick)

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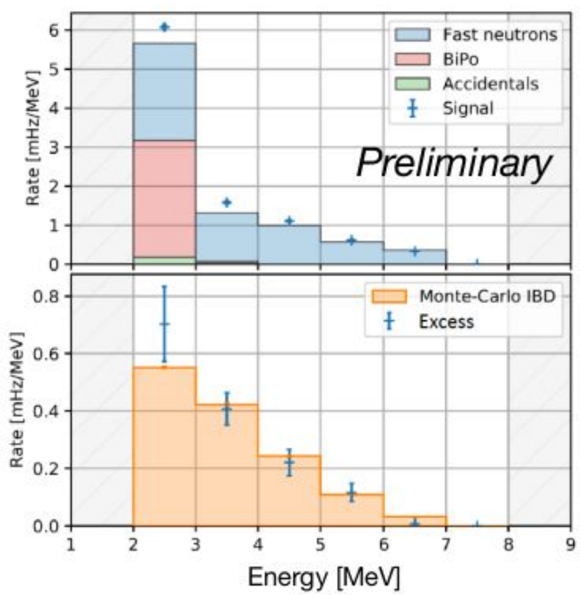
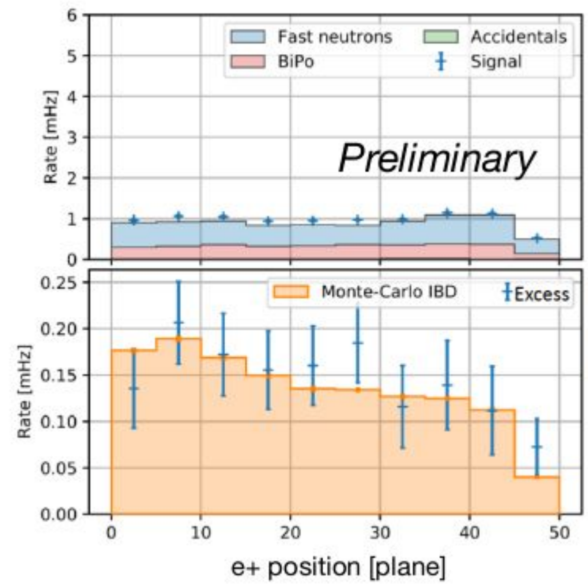
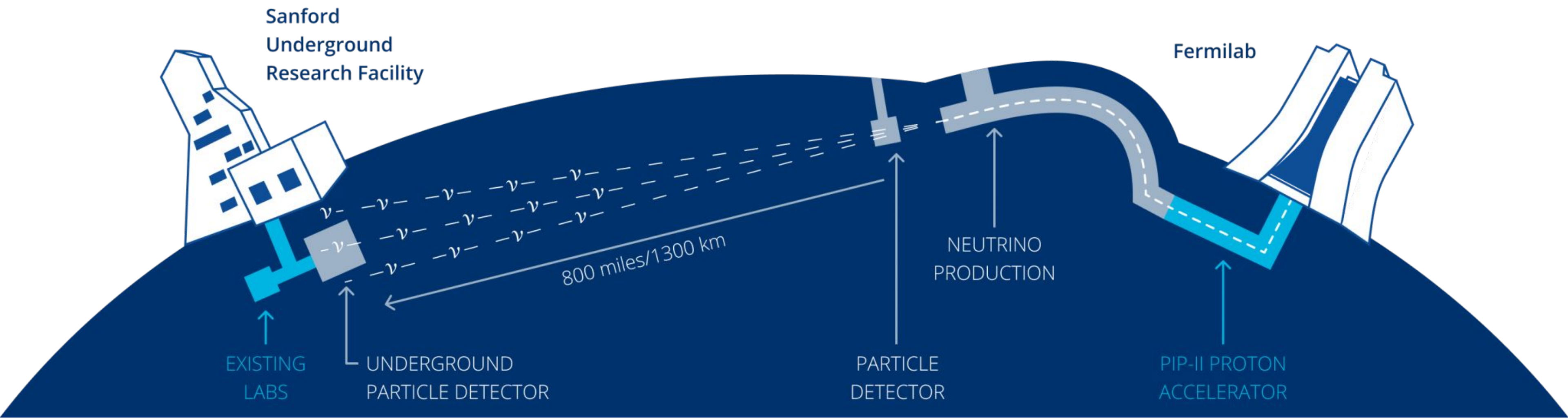
SoLid: a short baseline (~ 6m) neutrino experiment

- Searching for oscillations of anti-ν_e to previously undetected flavour states ("sterile neutrinos").
- Neutrinos generated at the Belgian BR2 reactor.
- Detection based on anti-ν_e+p→e^++n ("inverse beta decay")
- Detector consists of 1.6 tons of 5cm x 5cm x 5cm plastic scintillator cubes, which have neutron captures screens (ZnS(Ag) + LiF) mounted on two sides
- Oscillation result expected next year





DUNE (under construction)



Long baseline: 1300 km between near and far detector

Near detector: Liquid and Gaseous Argon, plus beam monitor

Far detector: Liquid Argon (the biggest ever)

ProtoDUNE: Liquid Argon Time Projection Chamber Prototype

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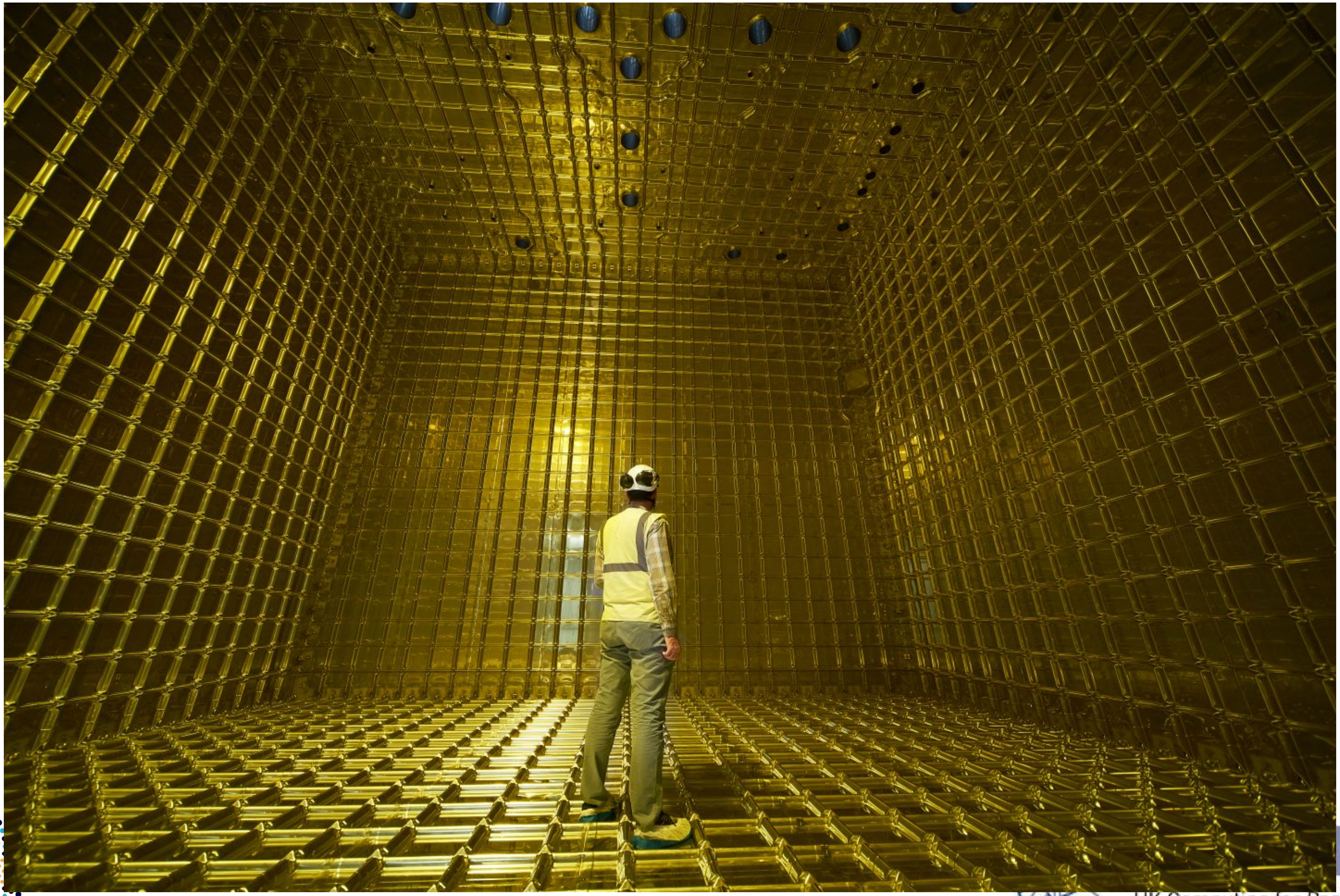
Proto DUNE: Make sure LAr technology works at scale



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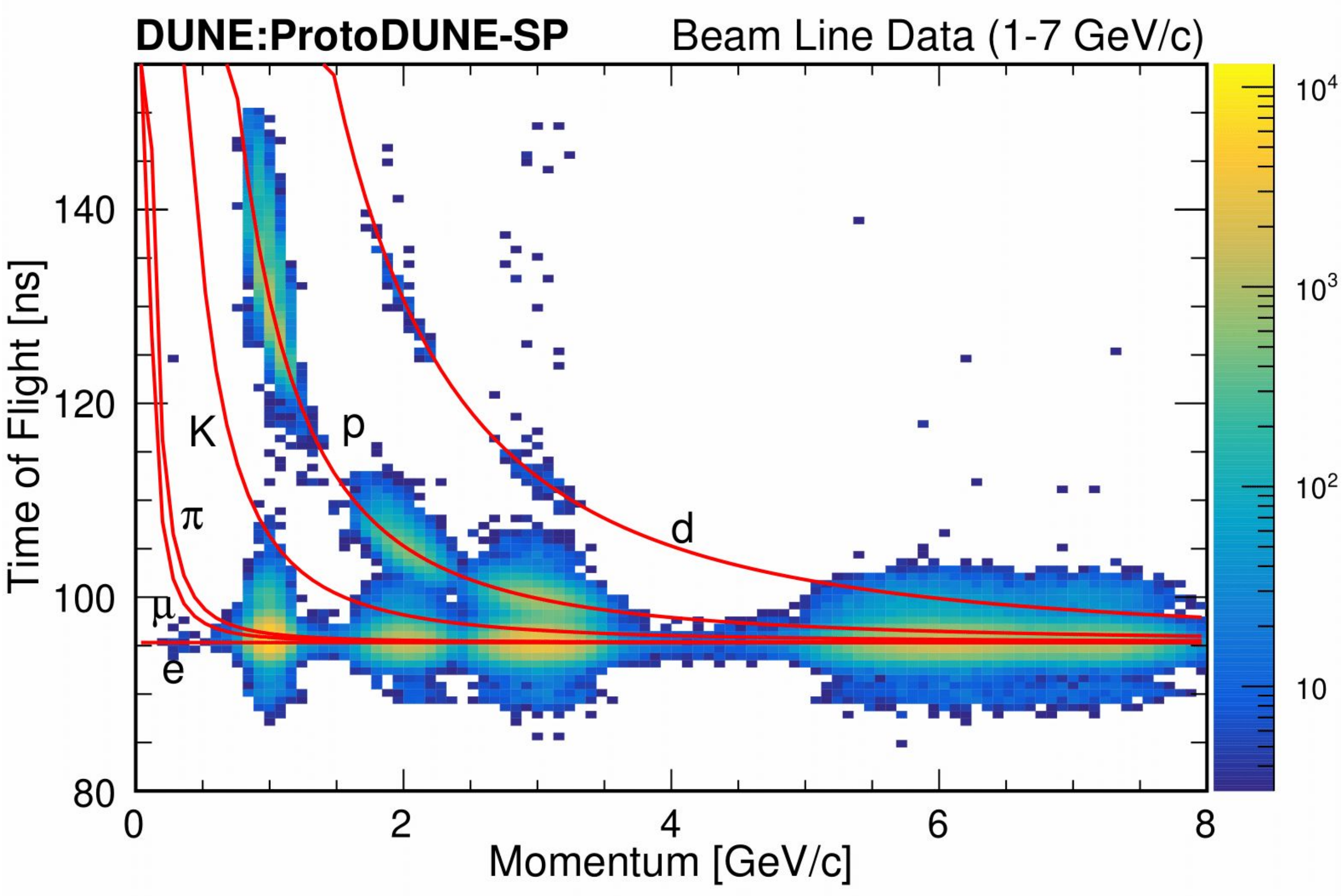
Proto-DUNE results

https://arxiv.org/abs/2007.06722



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DUNE: The Future (on ~30 PB/year+near detector)

- Measurement of δ_{CP} and potential *CP* violation by neutrinos
- Neutrino mass hierarchy determination, Δm^2
- Measurements of the mixing angles θ_{23} and θ_{13}

The Future: How much bandwidth for a supernova ?

- Estimated data size for a Supernova in the DUNE detector ~ 115 TB.
- Takes about 3 hrs to read out over 100 Gbps.
- If DUNE can get some of it analyzed within a few hours, there could be a result before the light of the supernova reaches Earth.
    - Cue endless “faster than light analysis” jokes.

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The End.

I hope you enjoyed the tour.

Bonus slides

T2K result (Nature)

a, Two-dimensional confidence intervals at the 68.27% confidence level for δ_{CP} versus $\sin^2\theta_{13}$ in the preferred normal ordering. The intervals labelled T2K only indicate the measurement obtained without using the external constraint on $\sin^2\theta_{13}$, whereas the T2K + reactor intervals do use the external constraint. The star shows the best-fit point of the T2K + reactors fit in the preferred normal mass ordering. **b**, Two-dimensional confidence intervals at the 68.27% and 99.73% confidence level for δ_{CP} versus $\sin^2\theta_{23}$ from the T2K + reactors fit in the normal ordering, with the colour scale representing the value of negative two times the logarithm of the likelihood for each parameter value. **c**, One-dimensional confidence intervals on δ_{CP} from the T2K + reactors fit in both the normal and inverted orderings. The vertical line in the shaded box shows the best-fit value of δ_{CP}, the shaded box itself shows the 68.27% confidence interval, and the error bar shows the 99.73% confidence interval. We note that there are no values in the inverted ordering inside the 68.27% interval.