Recent Highlights from Particle Physics (Topic FPF)

Kai Schmidt-Hoberg

MU Days, 14/15 September 2023

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

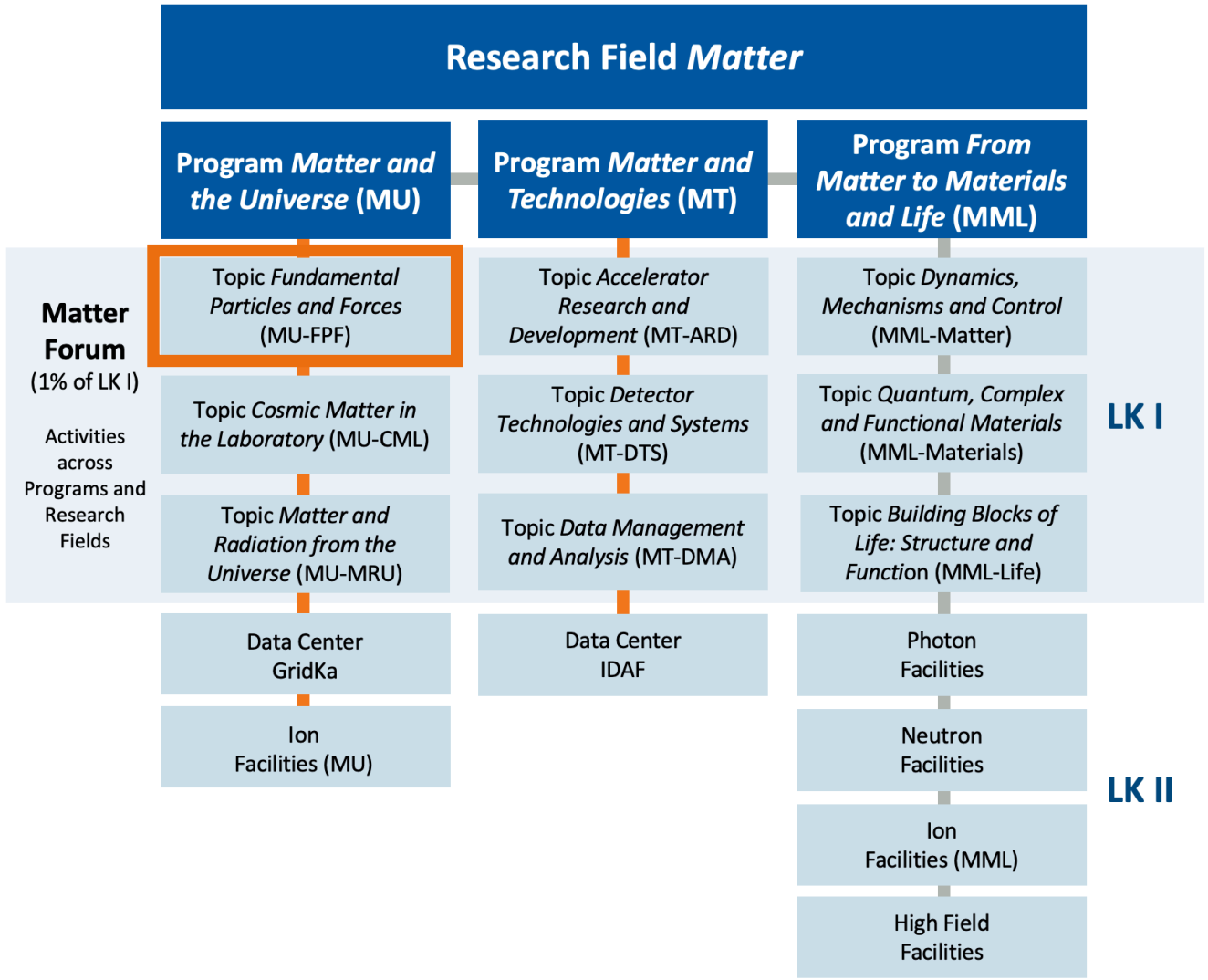
MU FPF
MATTER AND THE UNIVERSE

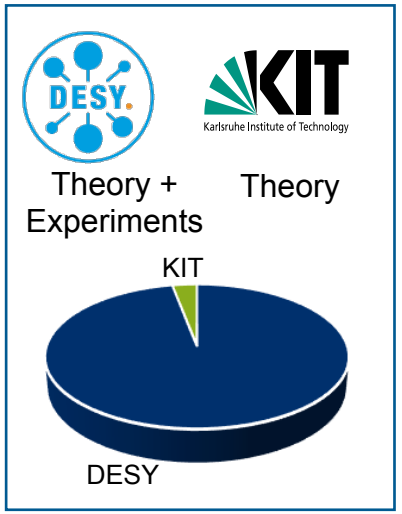
KIT
Karlsruher Institut für Technologie

DESY.

Reminder: FPF in MU

Particle physics at DESY and KIT (theory)

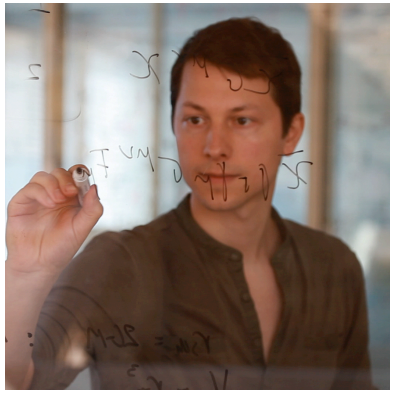




- 2 Helmholtz centres
- 3 locations
- 158 scientists
- 78 Ph.D. students
- 34 MEUR costs / a
- 42 nationalities

New topic spokespersons:
Isabell Melzer-Pellmann, Kai Schmidt-Hoberg

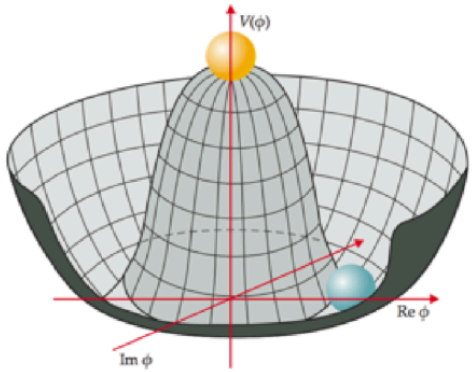
CMS



Theory

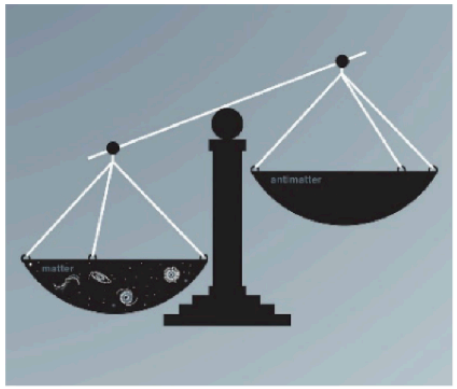
Topic structure and science drivers

Scientific questions

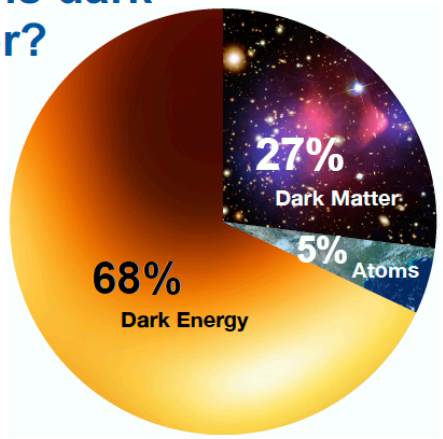


What is the structure of the vacuum?

Where did the anti-matter go?



What is dark matter?

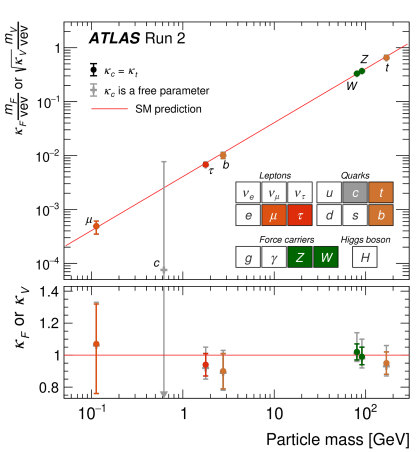


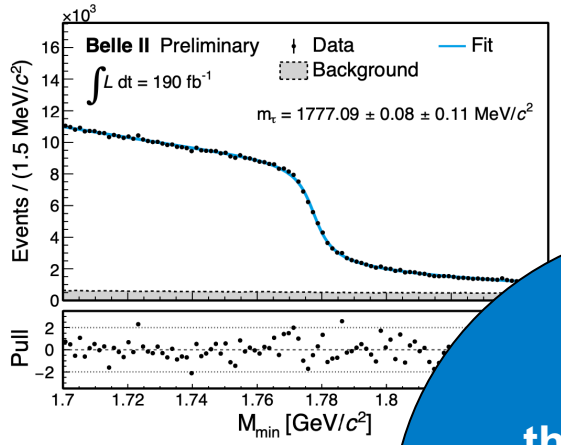
PoF IV parlance:

- Higgs and fundamental interactions at high precision
- Searches for new particles & phenomena
- Cosmology and the dark sector of the universe

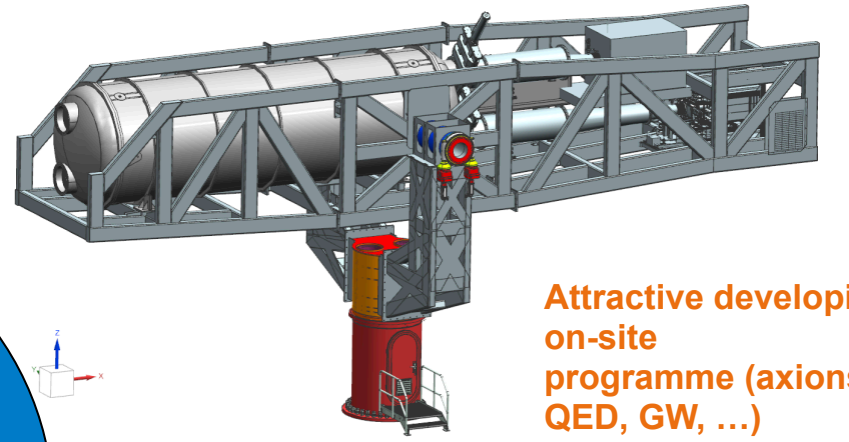
or better: why are we still here…

Tools and Activities





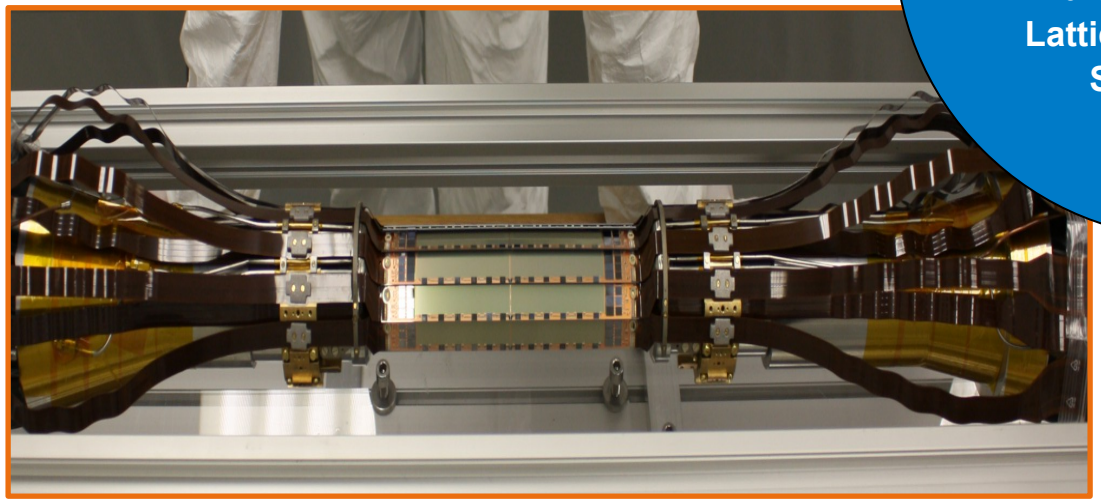
Leading contributions to global collider projects at CERN, KEK. Physics exploitation.



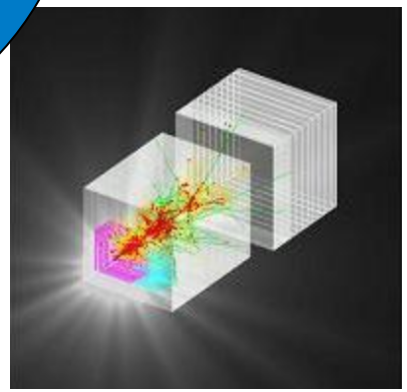
Attractive developing on-site programme (axions, QED, GW, …)

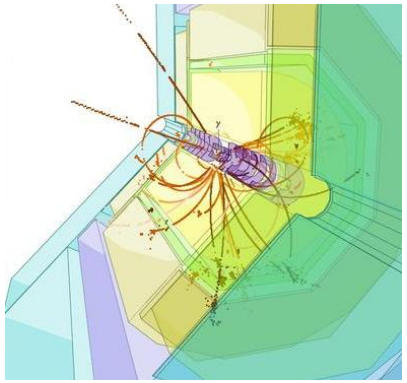
Broad theory portfolio

Collider Physics
Particle Cosmology
Lattice Gauge Theory
String Theory



Technology R&D, preparations for future projects





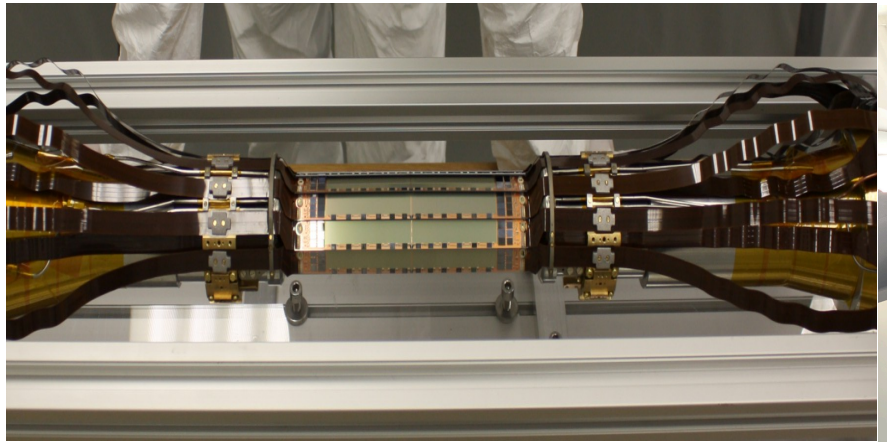
Technology

The New Belle II Pixel Vertex Detector PXD2

Endeavour with numerous German university partners

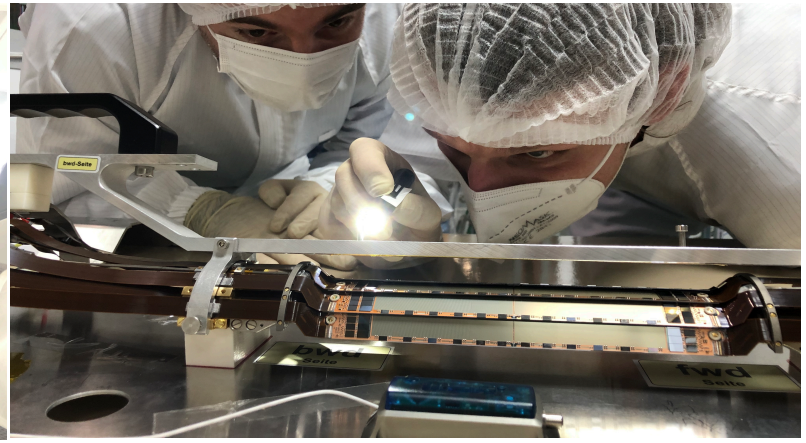
March 2023 – the end of an exciting journey: new Belle II pixel-vertex detector PXD2 delivered to KEK

- Installation and commissioning in remaining months of shutdown of SuperKEKB accelerator
- Crucial for future scientific harvest of Belle II experiment.



Installation and pre-commissioning of PXD2 @ DESY

Air transport of delicate detector to Tokyo (own business class seat)



Scrutiny of PXD2 at its designation KEK

MU profits massively from investment in global HEP flagship projects (science return, visibility, strategic impact). DESY can play its strength as national lab and hub for German contributions.
Further example -> ATLAS+CMS HL-LHC tracker endcaps

LHC Tracker End-caps Taking Shape

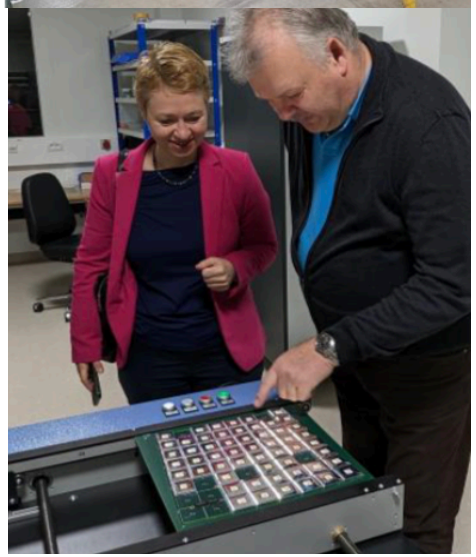
On track for installation in ATLAS and CMS until 2028

DESY builds and commissions tracker endcaps for both ATLAS and CMS

- Most important construction projects in topic FPF for the PoF IV era!
- Need to be ready for delivery to CERN according to LHC schedule.
- R&D mostly done; currently in prototyping and pre-production phase.

Additional project: CMS HGCAL

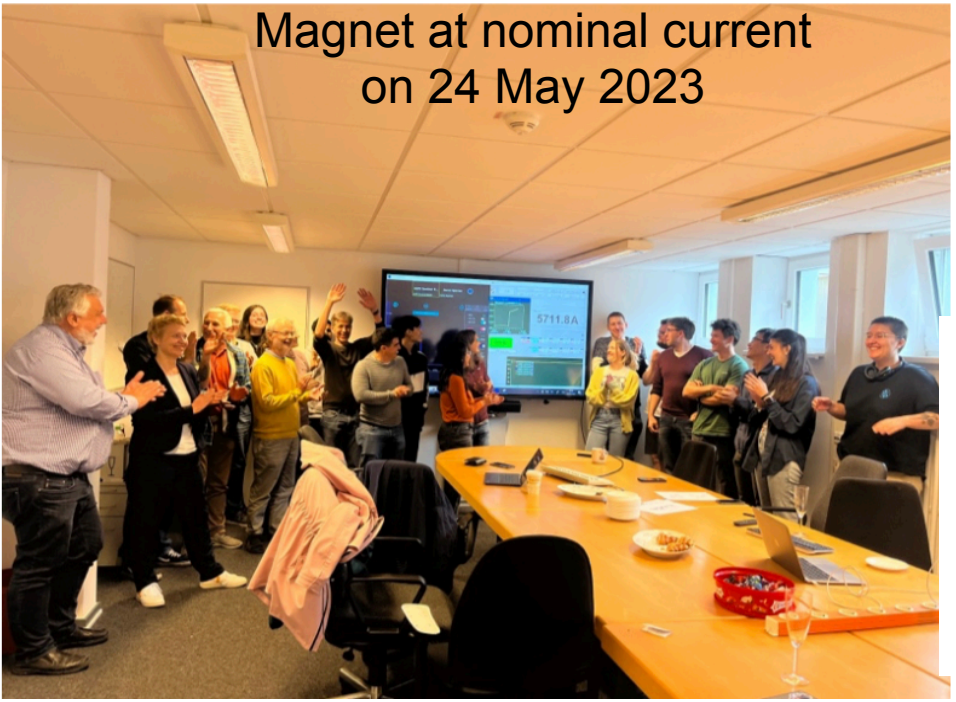
- High-granularity calorimeter based on CALICE Si-PM-on-tile technology
- Challenging project – effects of Russian war on Ukraine felt strongly.

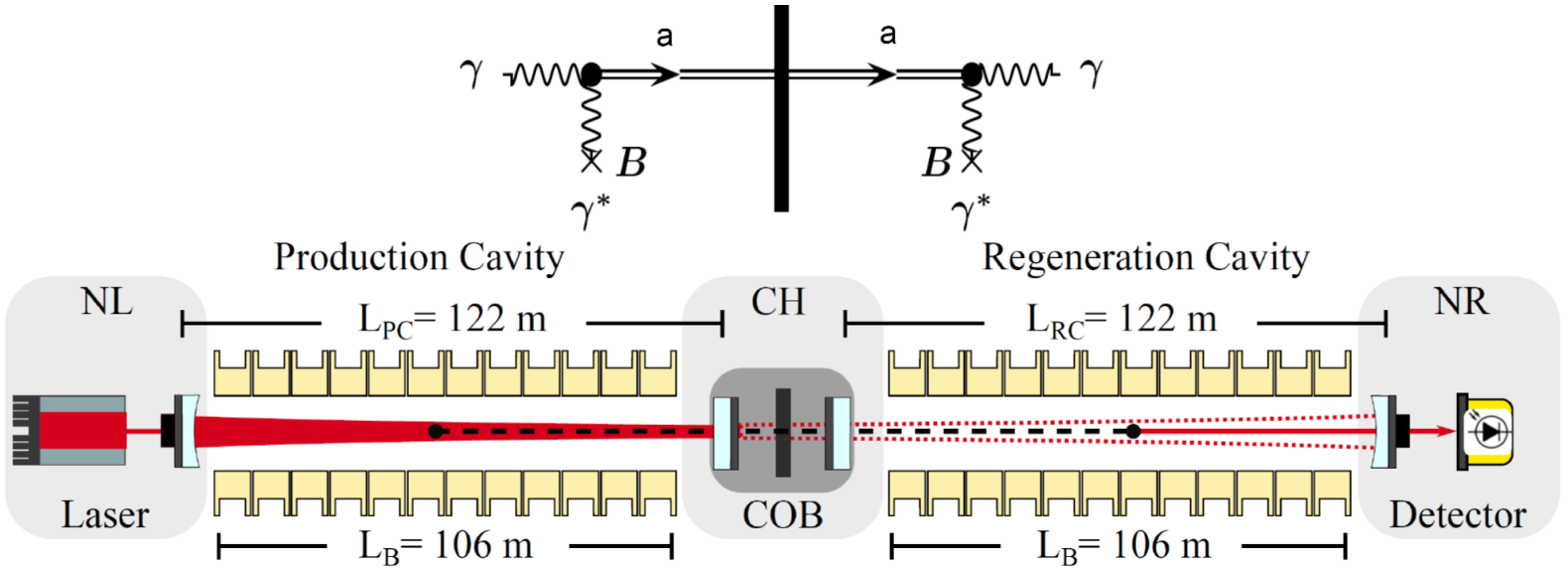


Physics

Start of ALPS II Data Taking

… after 10 years of preparation: Magnets at full current on 24 May 2023!





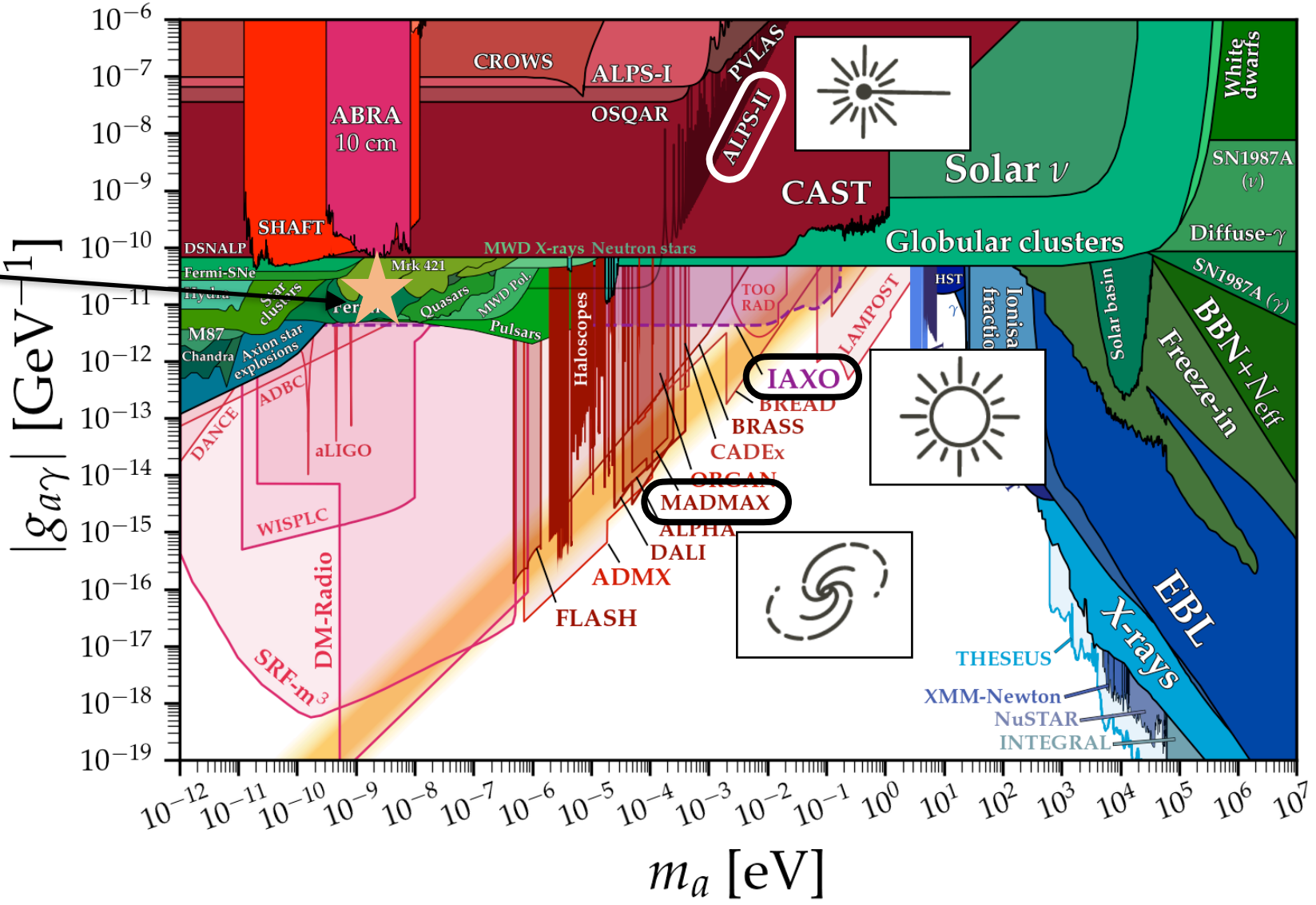
- Smooth data run in May & June with an initial configuration w/o resonating cavity on the production side.
- Since then, work on optimisation of the configuration + automation of data taking
  ➔ achieve an integrated amount of one million seconds of good data as basis for first physics publication on axion searches with ALPS II.
- In 2024, the entire optics system will be installed, leading to a further improvement of the sensitivity.

The Axion landscape

Axions interesting as DM candidates and solution to strong CP problem (yellow QCD band)…

Some astrophysical hints in the reach of ALPS-II

IAXO and **MADMAX** update from Isabell tomorrow



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IAXO and **MADMAX** upd
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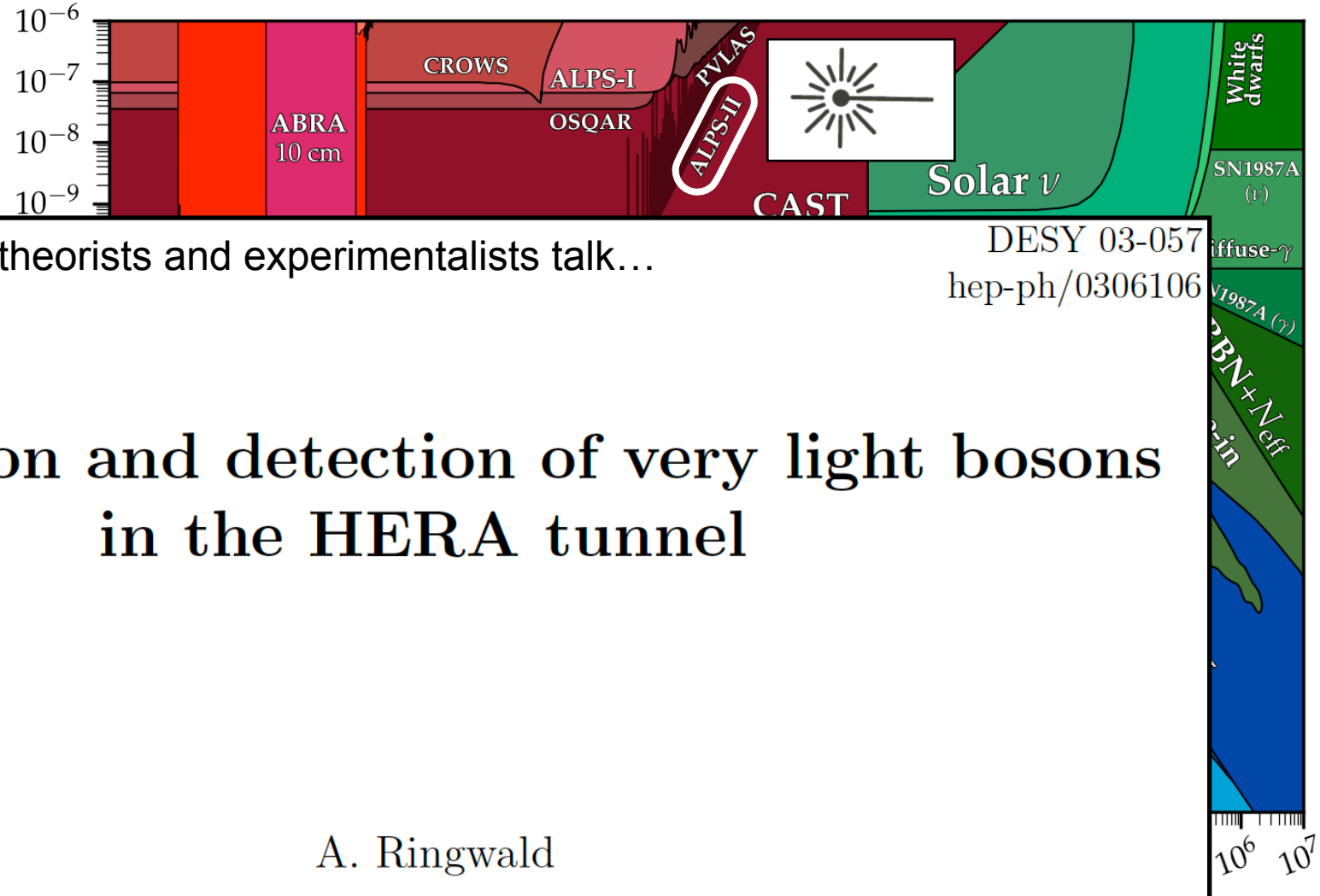


always good if theorists and experimentalists talk…

DESY 03-057
hep-ph/0306106

Production and detection of very light bosons in the HERA tunnel

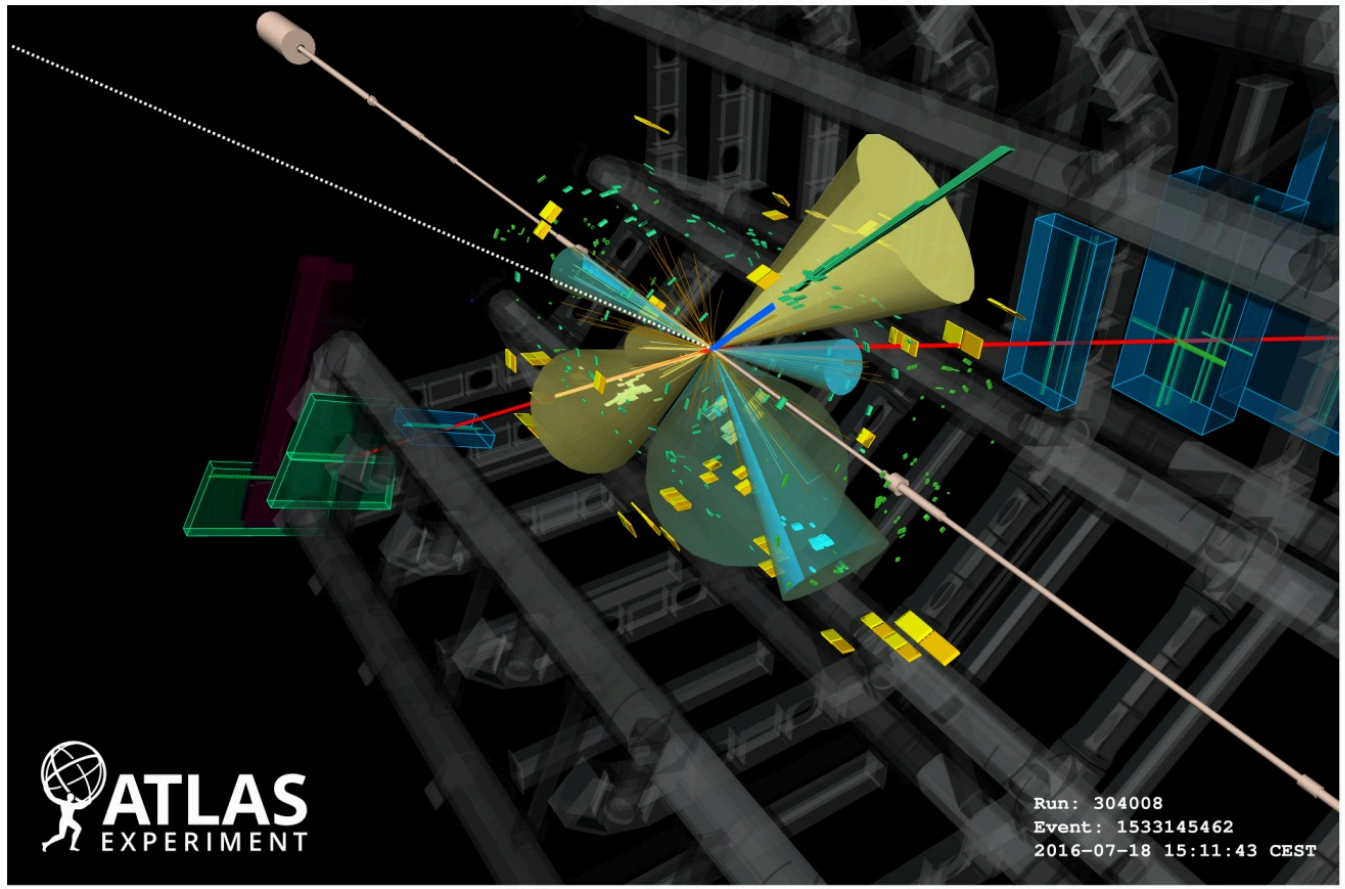
A. Ringwald

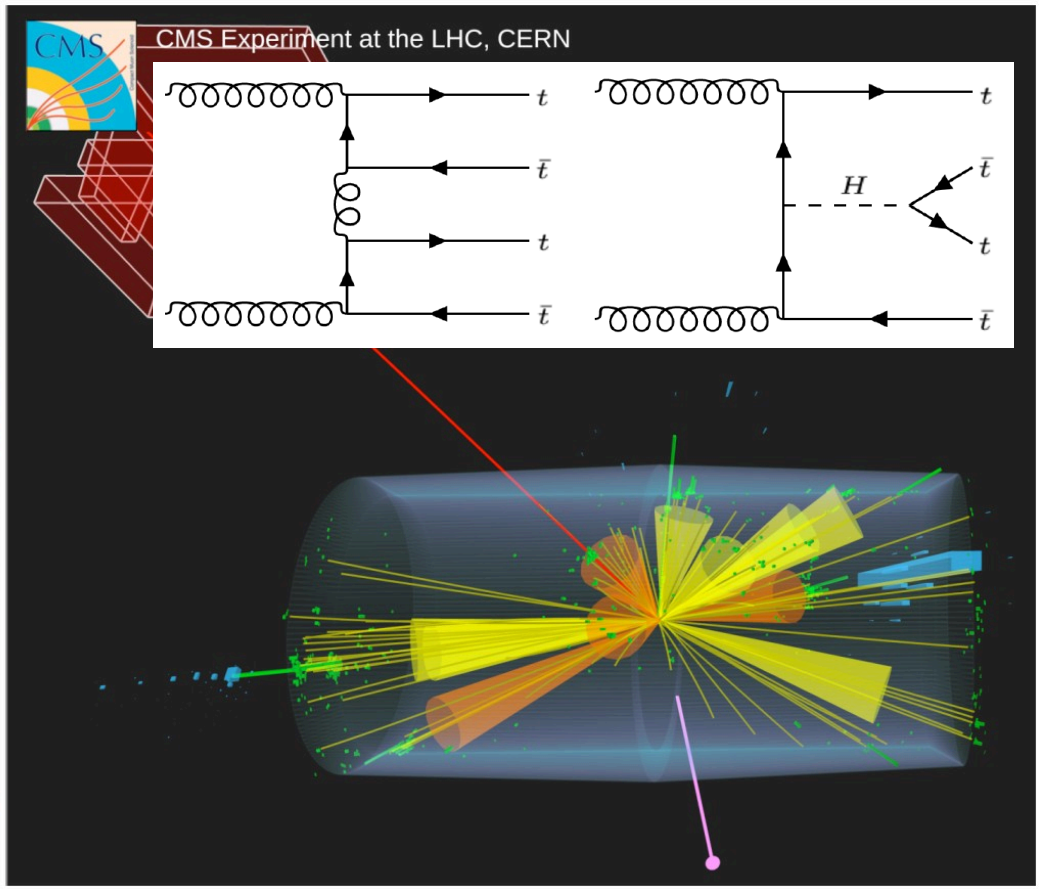
Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany

Physics Highlights: LHC

4-Top Observation with ATLAS and CMS

arXiv:2303.15061
arXiv:2305.13439





Significances above 5 sigma for both ATLAS and CMS; measured cross sections in agreement with SM expectation of about 12 fb. LHC is exploring ever smaller cross sections, scrutinising SM predictions.

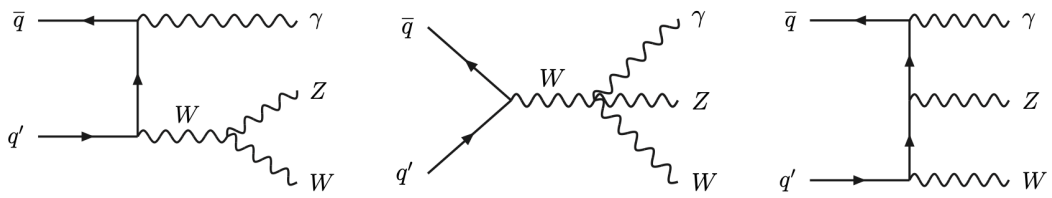
arXiv:2305.16994

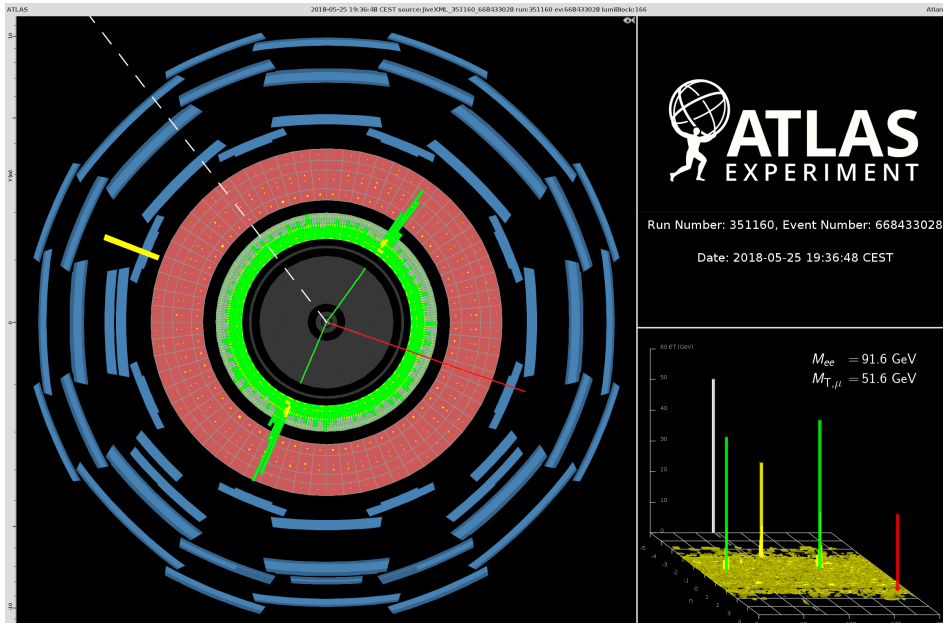
Physics Highlights: LHC

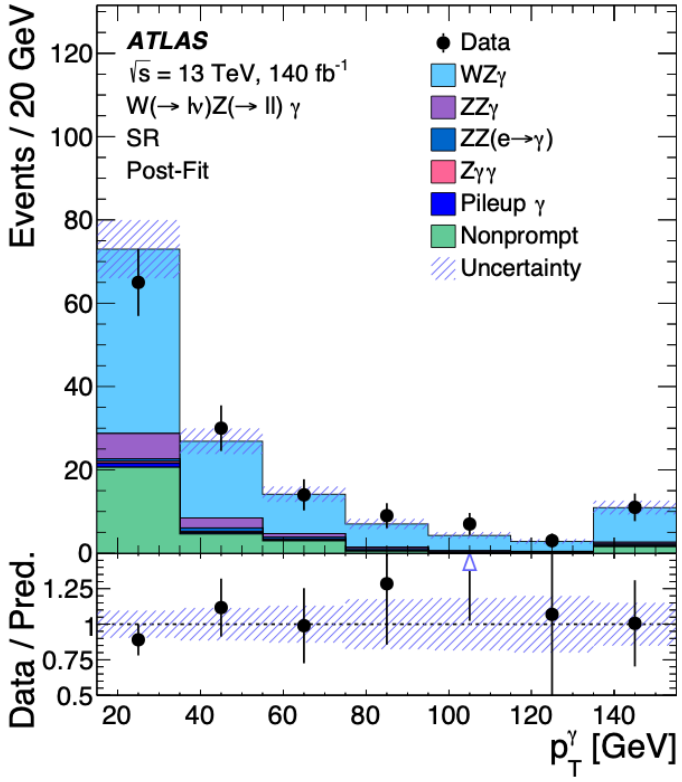
Multi-boson final states: $WZ\gamma$ observation by ATLAS

Multi-boson production as another example of small cross section measurements at the LHC, confronted with precision SM predictions.

Most recent example: $WZ\gamma$ observation in ATLAS!







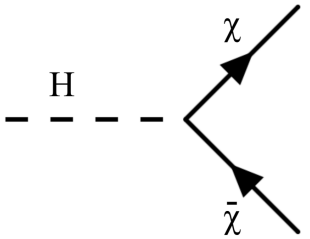
$\sigma_{obs} = 2.01 \pm 0.3 \pm 0.16$ fb, **observation at 6.3 sigma!**

arXiv:2301.10731

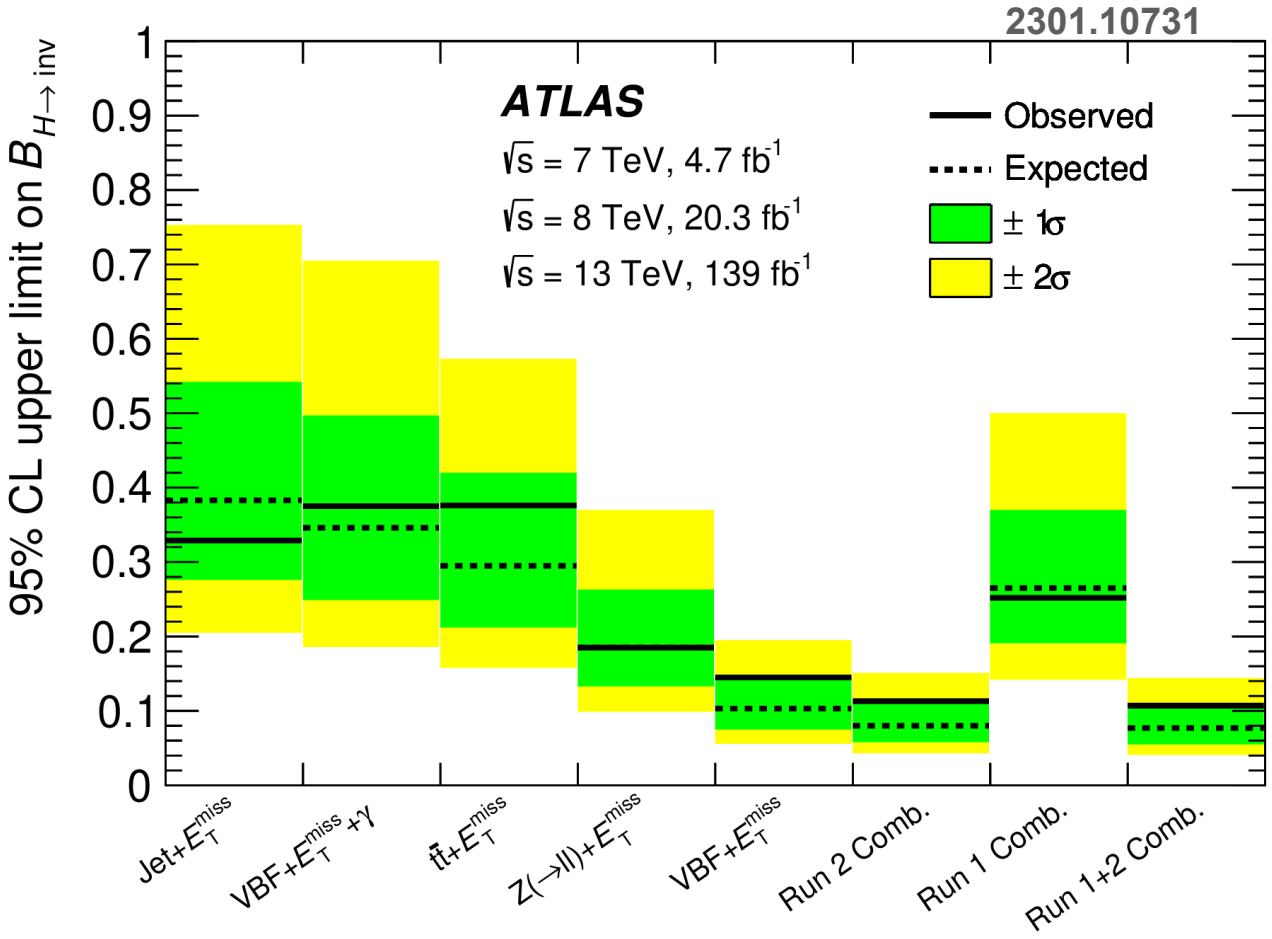
Physics Highlights: LHC

Does the Higgs talk to the dark sector?

- **Light dark matter: Potentially new Higgs decays** $h \to \chi\chi$

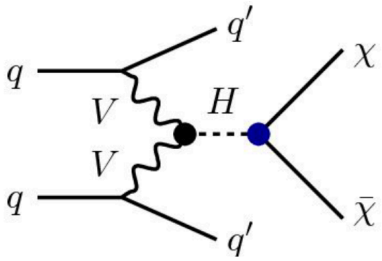


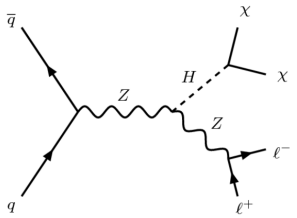
ATLAS full Run 2 result: different channels and combination



$$\mathrm{BR}(h \to \mathrm{inv}) < 0.107 \; (0.077^{+0.030}_{-0.022})$$

at 95% CL



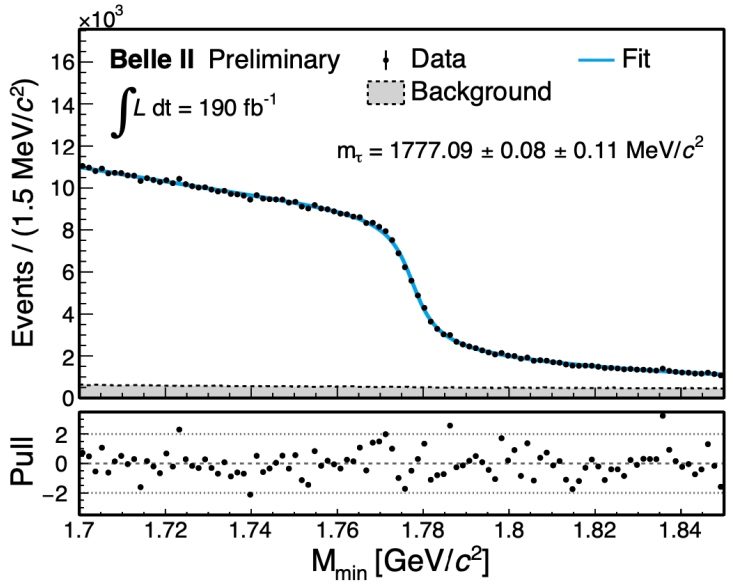


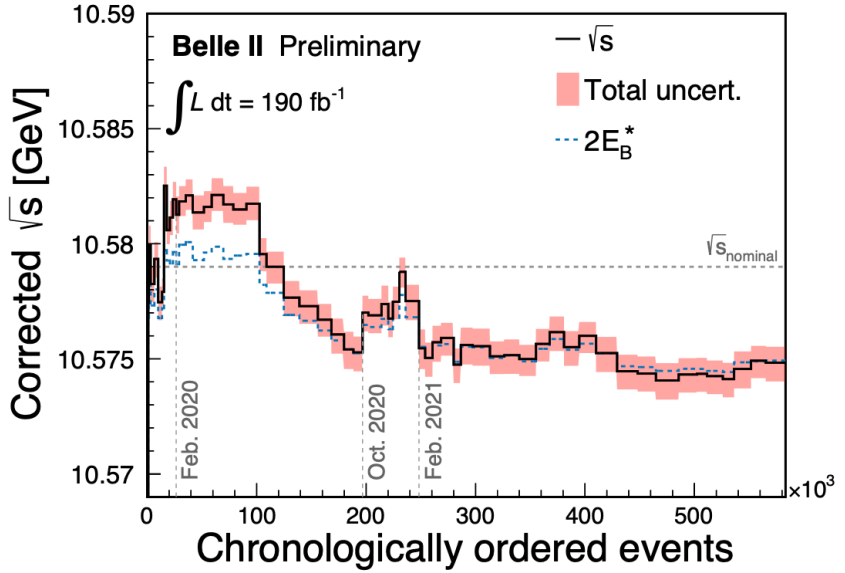
arXiv:2305.19116

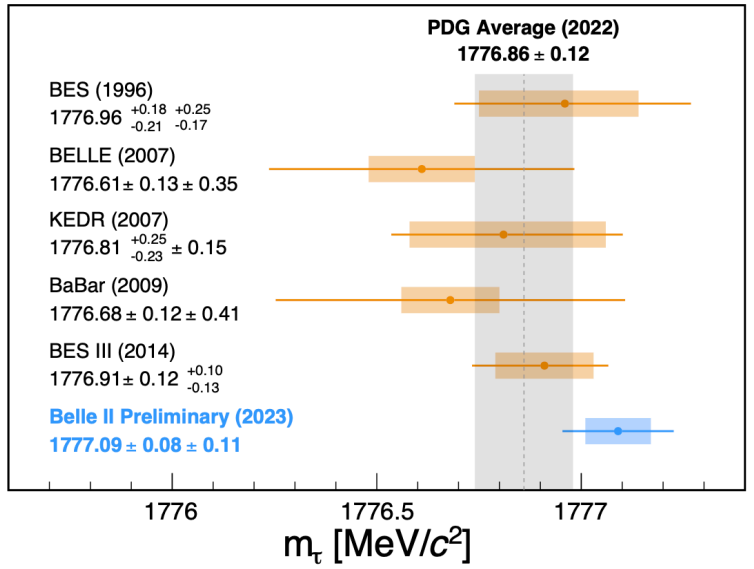
Physics Highlights: Belle II

World's most precise tau mass measurement

$$M_{\min} = \sqrt{M_{3\pi}^2 + 2(\sqrt{s}/2 - E_{3\pi}^*)(E_{3\pi}^* - p_{3\pi}^*)} \leq m_\tau .$$







- Large samples of τ pairs
- Using pseudo-mass method to determine tau lepton mass with unprecedented precision.

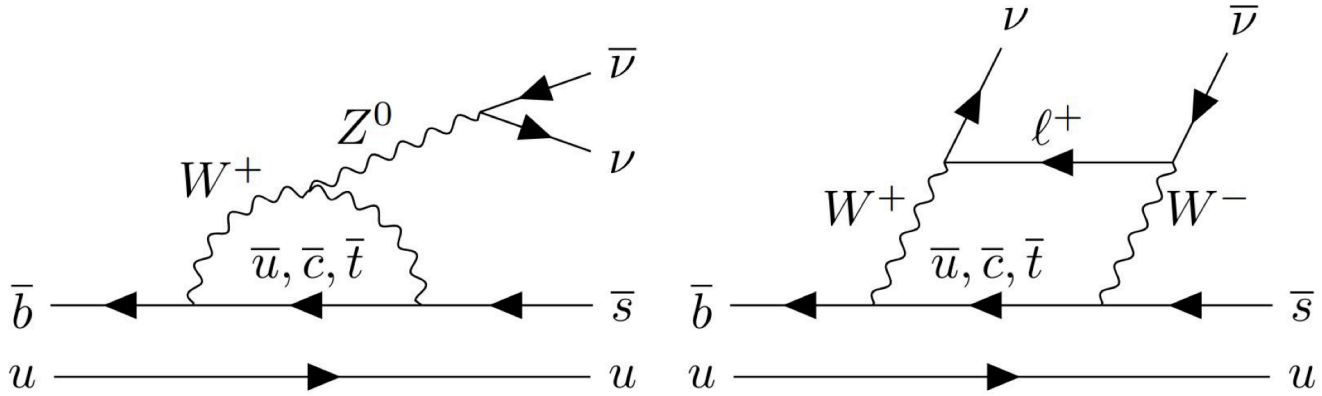
Requires excellent knowledge of energy scales at SuperKEKB.

Result agrees well with former determinations, but with reduced uncertainties. More Belle II data to come!

$$m_\tau = 1777.09 \pm 0.08\,(\text{stat}) \pm 0.11\,(\text{syst})\ \text{MeV}/c^2$$

Physics Highlights: Belle II

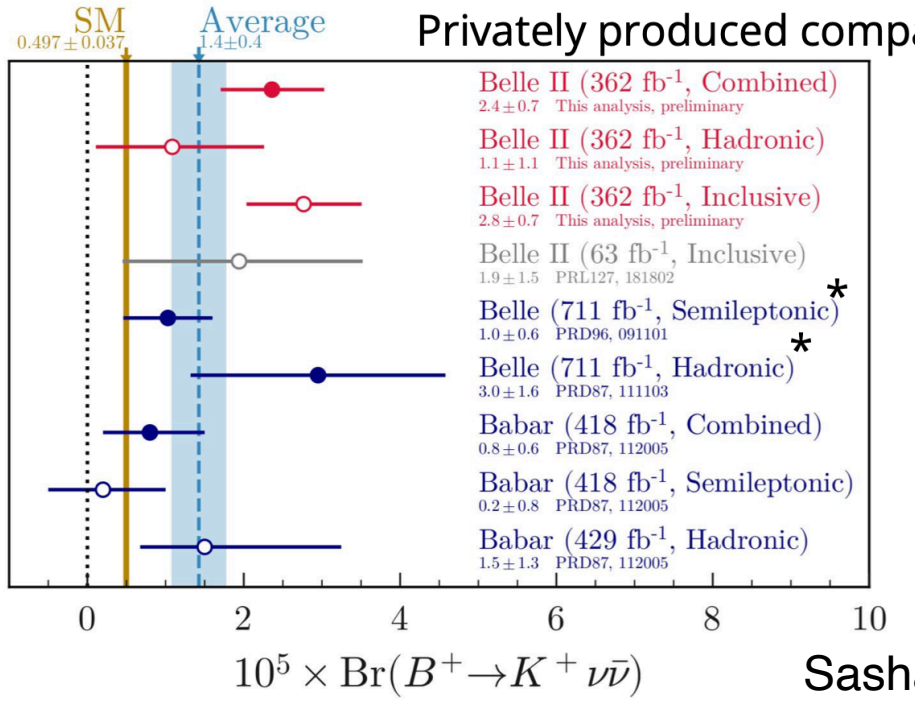
Evidence for $B \to K\bar{\nu}\nu$ decays



Motivation: Process $B \to K\bar{\nu}\nu$ extremely well understood in SM:

$B(B \to K^+ \nu\nu) = (5.6 \pm 0.4) \times 10^{-6}$ (arXiv:2207.13371)

BSM contributions might raise rate considerably…



Privately produced comparison

Sasha Glazov@EPS

Results:

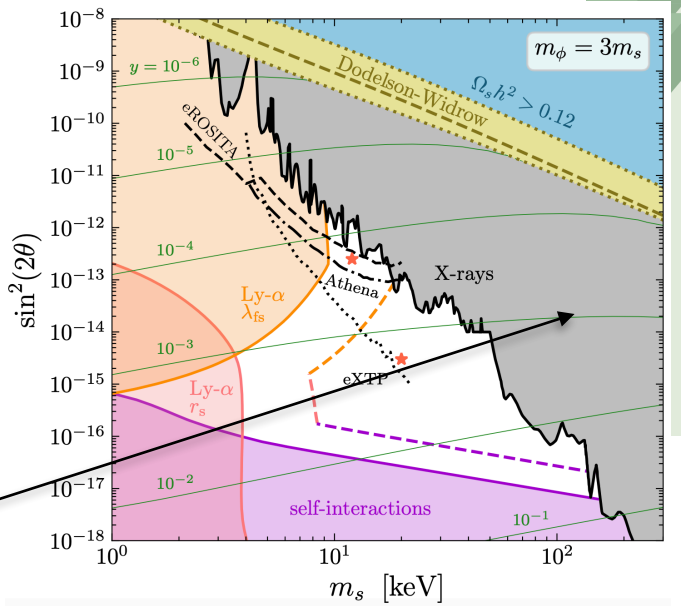
- Experimentally measured branching fraction is **$B(B^+ \to K^+\nu\nu) = (2.4 \pm 0.7) \times 10^{-5} = [2.4 \pm 0.5(\mathrm{stat})^{+0.5}_{-0.4}(\mathrm{syst})] \times 10^{-5}$**
- The **significance of the observation is 3.6σ**; the result is **within 2.8σ of the SM prediction**
- should we get excited? awaiting publication!

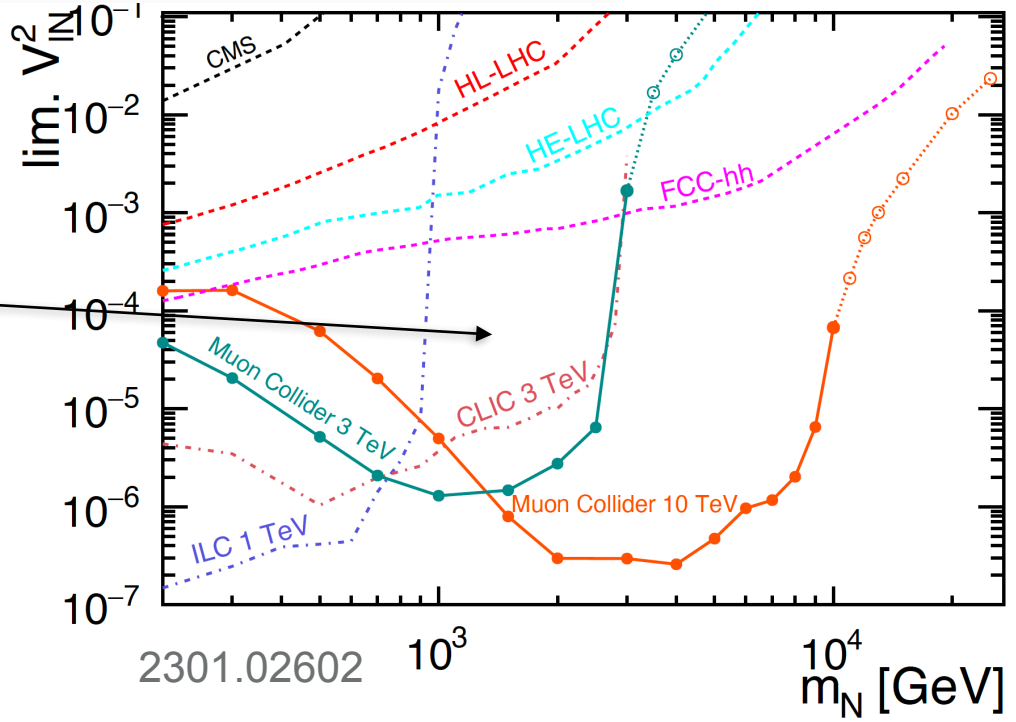
Physics Highlights: theory

100++ theory papers in the last 12 months

- Precise predictions for Standard Model physics and beyond
- Coherent interfaces between theory and experiments for Higgs physics, B-physics and new particles models
- String theory and mathematical physics
- Exploration of dark sectors
  - **DM production mechanisms**
  - phenomenological, astrophysical and cosmological implications
- Predictions for **future colliders**
- Cosmology, including inflation, gravitational waves, …

2206.10630

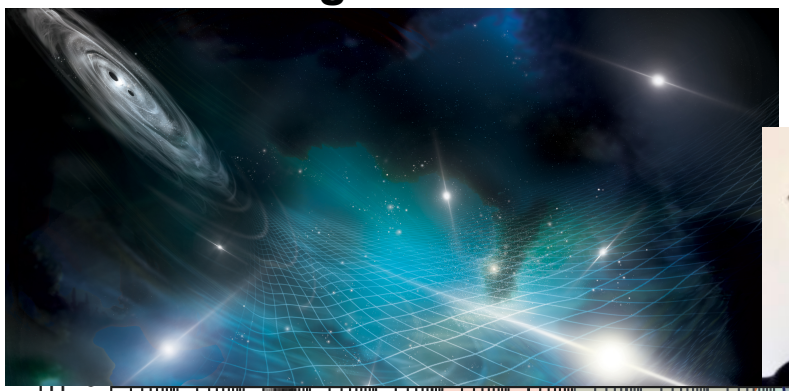




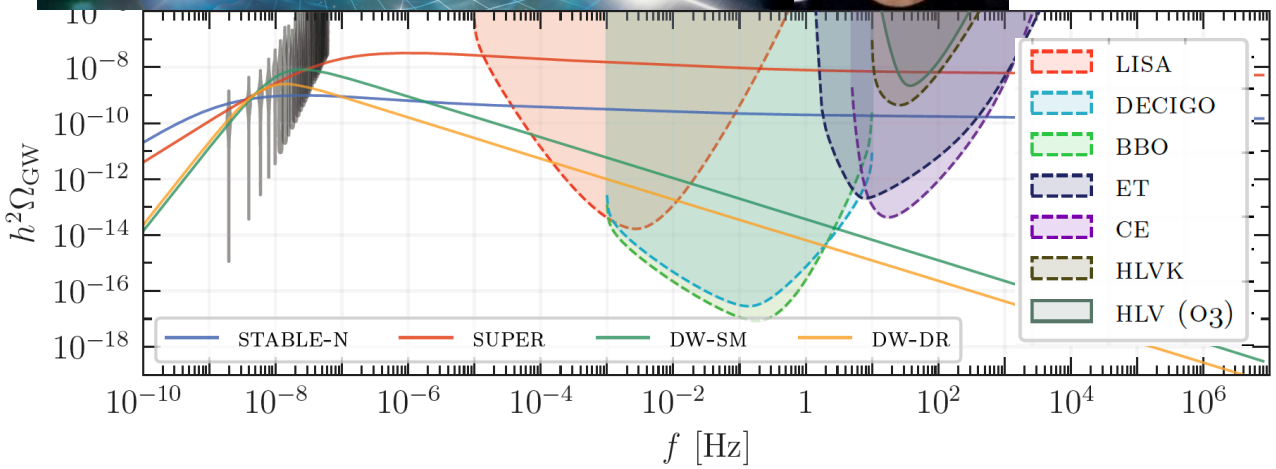
2301.02602

Physics Highlights: GWs

Stochastic gravitational wave background

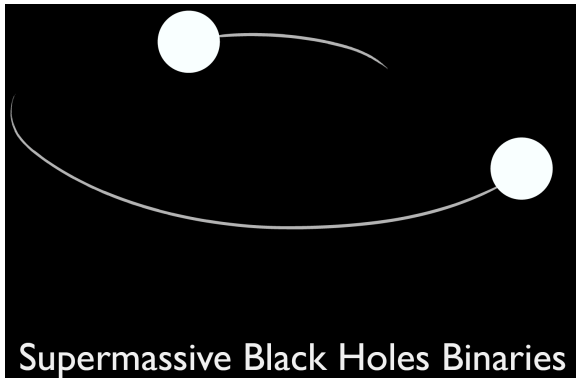


2306.16219



NANOGrav Collaboration sees evidence for low-frequency (~years) gravitational waves using a 15-year data set of pulsar data.
Crucial question: what is the source?

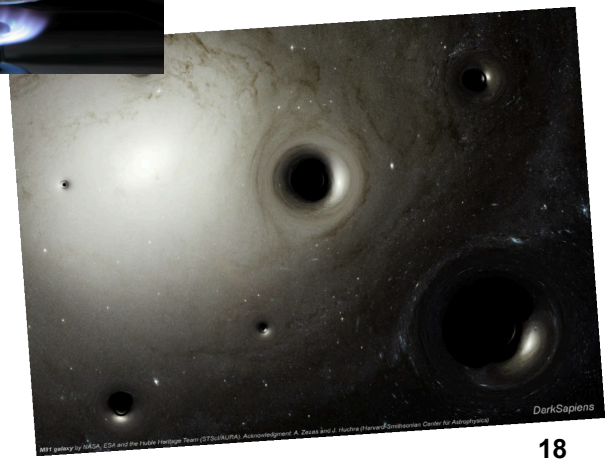
Vanilla explanation:
but also the best?



Other possible sources:

- First order phase transitions

- Primordial black holes



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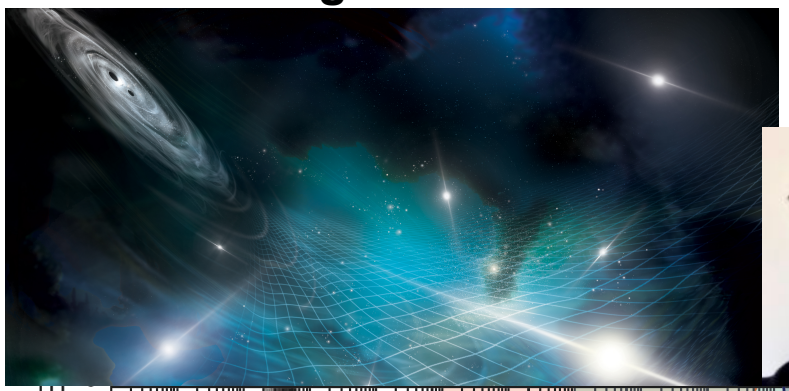

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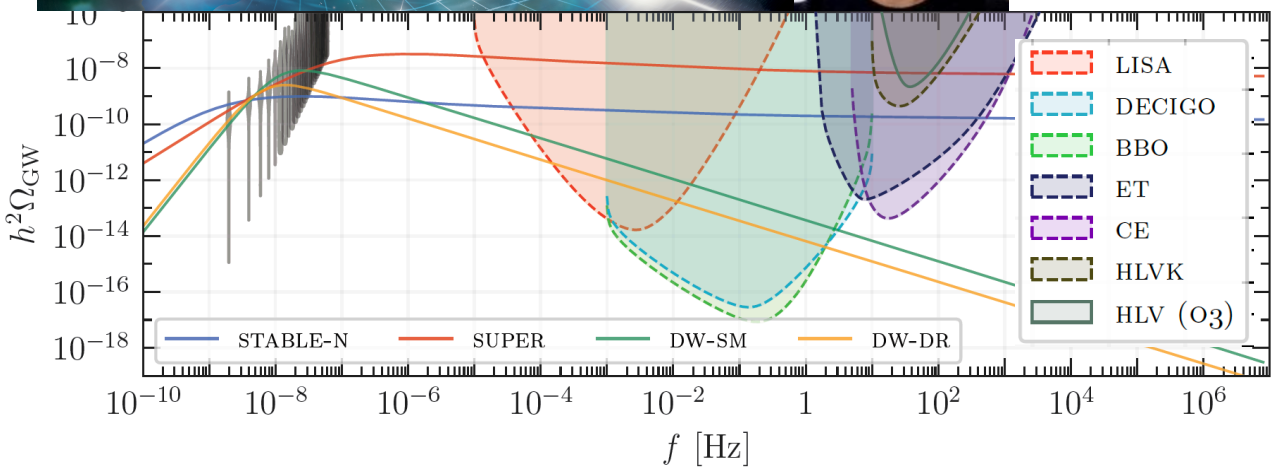

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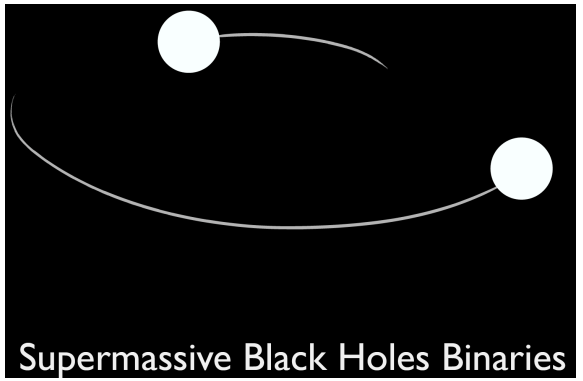

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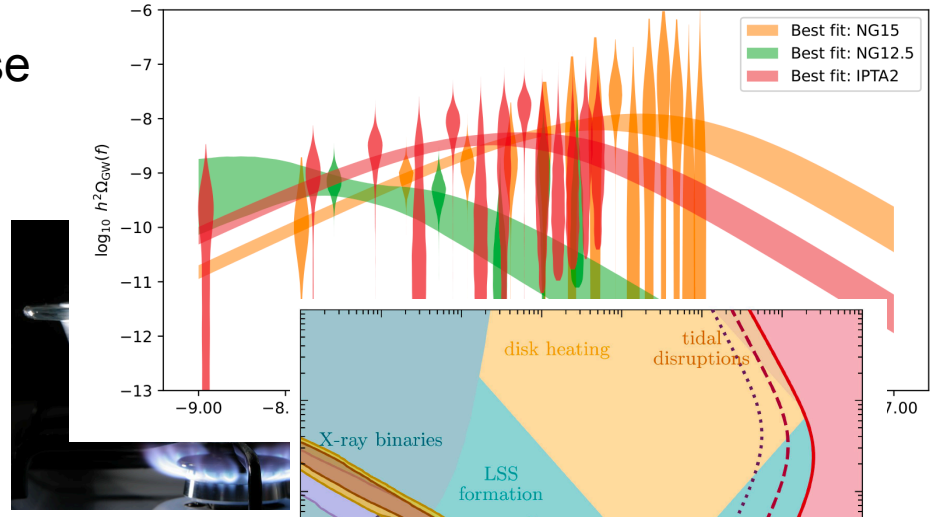
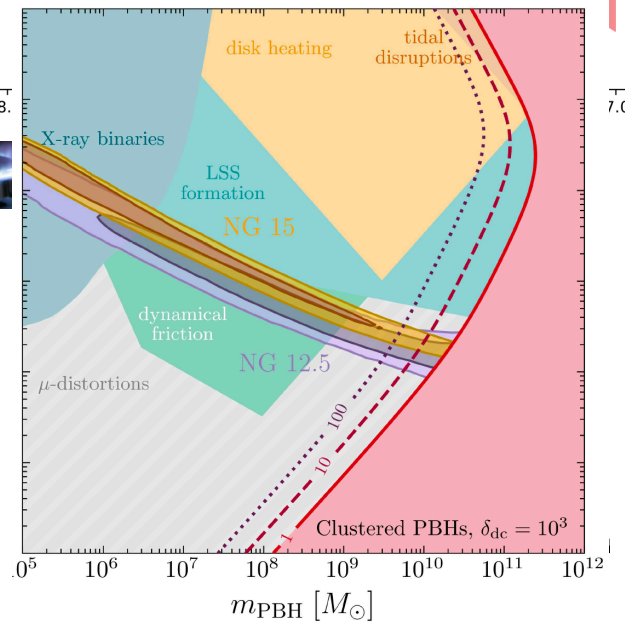
2306.09411



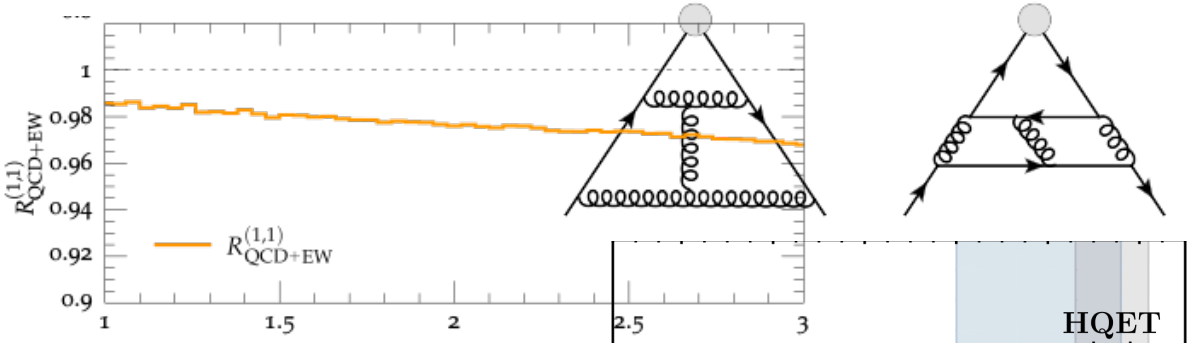
- Primordial black holes

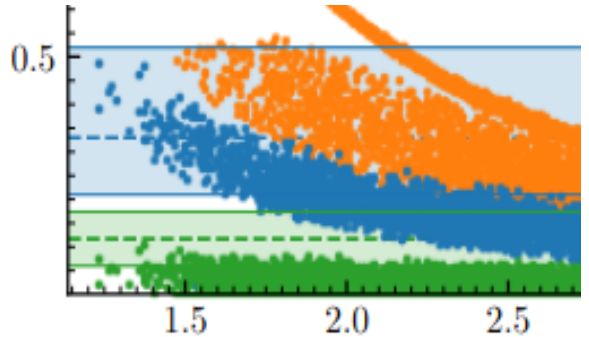
2306.17836

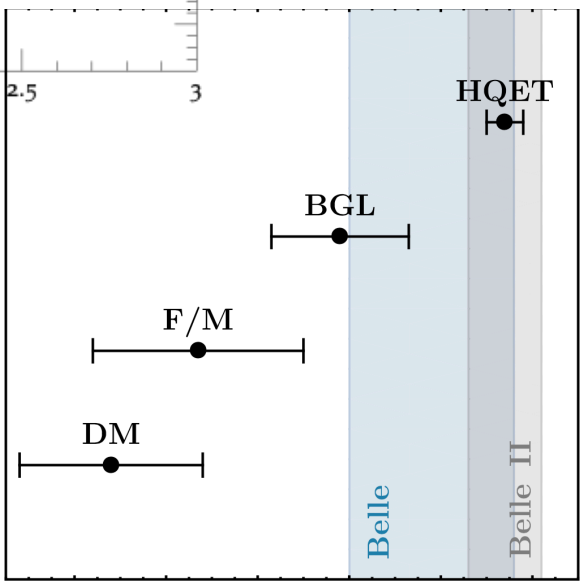


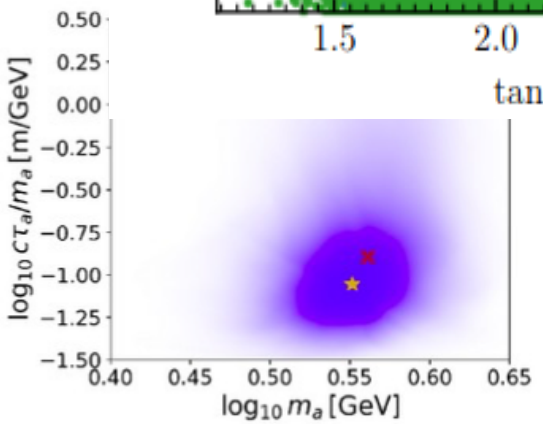
Highlights of topic FPF at KIT

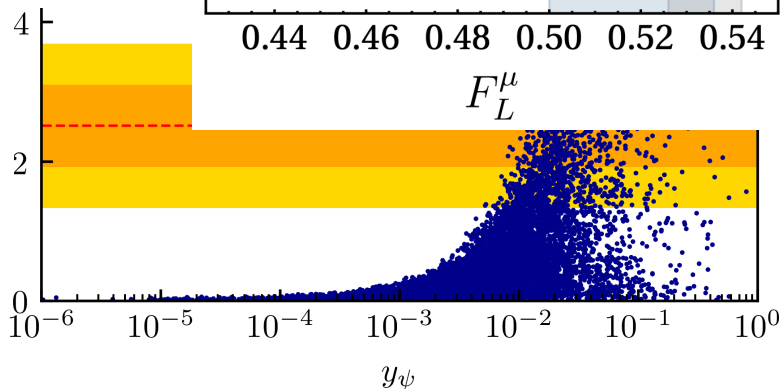
- form factors at three loops in QCD for Higgs decays and $e^-\mu^-$ scattering
- mixed QCD-electroweak corrections to Drell-Yan process at LHC
- $B \to D^* \ell \bar{\nu}$ form factor analysis and $B \to D^{(*)} \tau \bar{\nu}$ flavour anomaly
- study of CMS diphoton excess at 95 GeV in a model with two Higgs doublets
- searching axion-like particles with machine learning
- analysis of lepton-flavoured dark matter signatures at LHC







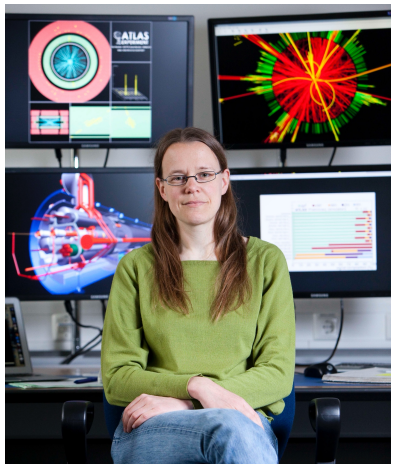




Awards: selected highlights from 2023

Left to right: Freya, Sandra, Jonas, Mathias, Younes, Karla
CMS outstanding achievements (credit: S. Hurst / CMS)

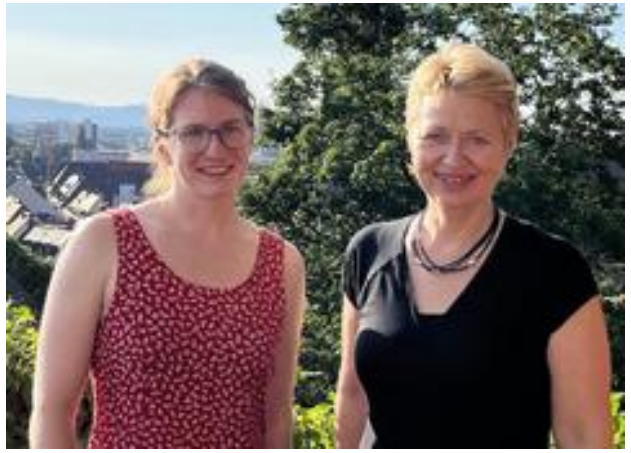
Frauke Poblotzki
DESY exceptional ach.



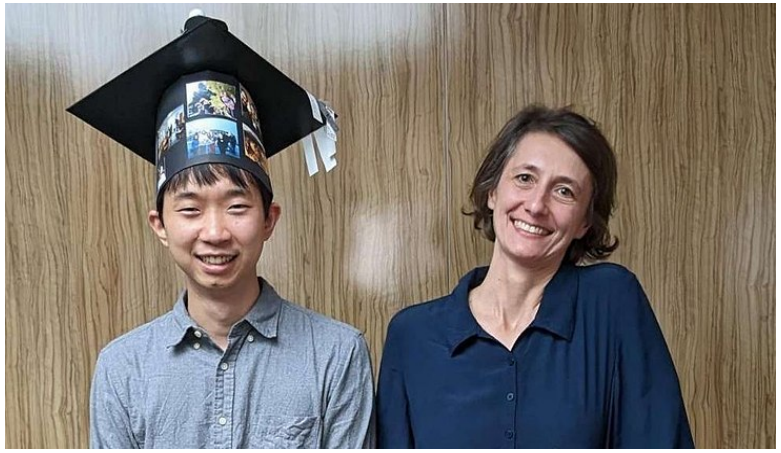
Kerstin Tackmann
Miller Fellowship

Adinda De Wit
Hertha Sponer Prize

T. Novak
ATLAS outstanding achievement



Emily Tompson
ATLAS thesis award



Peera Simakachoorn
Helmholtz Promotionspreis

Carl Lindstroem
Simon van der Meer Prize

New funding: selected highlights from the past 12 months

ERC Elli Pomoni (Theory)

ERC Andrea Caputo (Theory)

YIG Thibaut Humair (Belle II)

YIG Lydia Beresford (ATLAS)

Machine learning methods for resource-efficient simulations

KISS (1 Mar 2023)

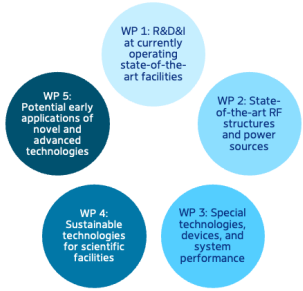
Transnational access to European accelerator facilities

EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

Euro-Labs (1 Sep 2022)

Marie Curie Staff Exchange Action with USA, Canada, Japan

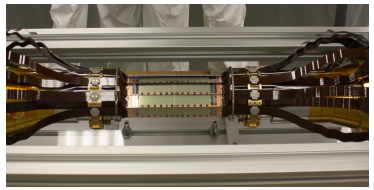
EAJADE
Europe-America-Japan Accelerator Development Exchange Programme

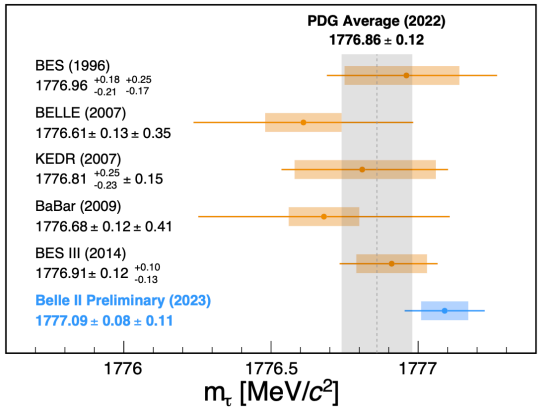


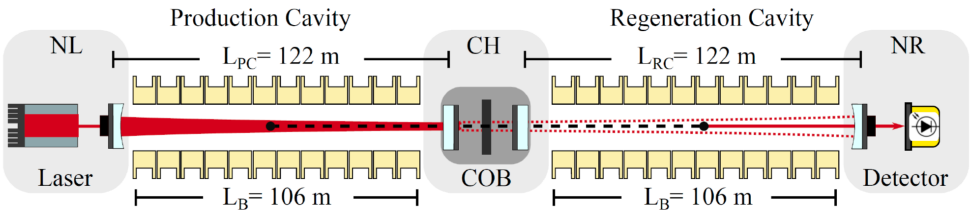
EAJADE (1 Mar 2023)

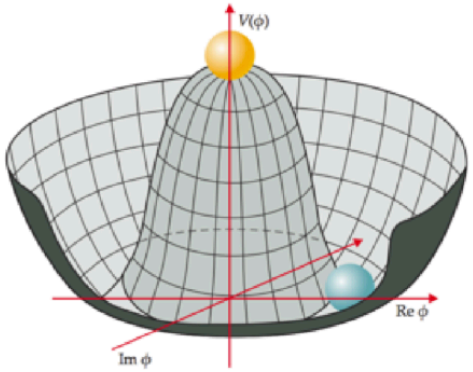
Summary

Scientific questions

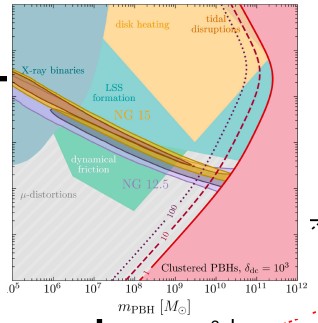


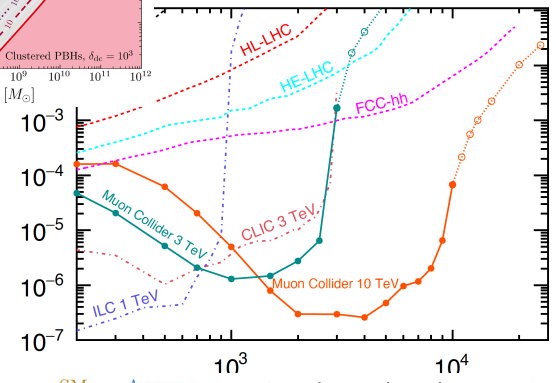






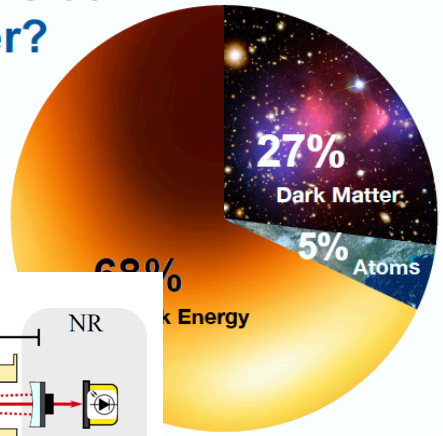
What is the structure of the vacuum?

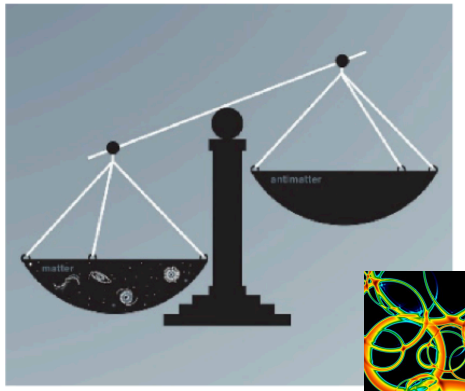


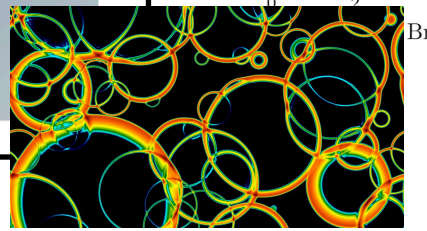


Where did the anti-matter go?

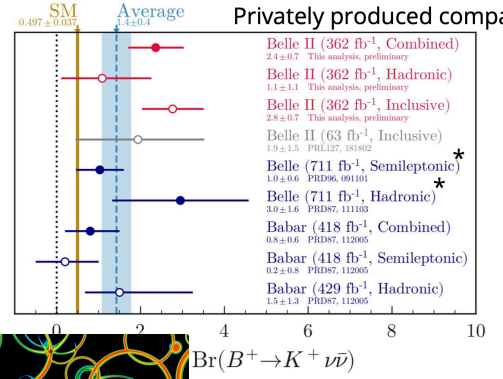
What is dark matter?







Privately produced comparison



We are attacking from all angles — but still work left to do for PoF V…