



MATTER AND
THE UNIVERSE

Future opportunities

FPF at DESY

Elisabetta Gallo
DESY 13-14 February 2025



Future strategic developments

Strong program looking forward

Ambition to shape the scientific landscape with international partners

- Full exploitation of ATLAS, CMS and Belle-II
- Studies towards a future collider, including new technologies (HALHF, muon collider), engaged in the ESPPU (Beate Heinemann)
- A broad and world-leading theory program
- Strengthen DESY as a national hub for German Universities

Strengthen the on-site program

- A laboratory for axion-like particles (ALPS-II, MADMAX, babyIAXO)
- Strong-QED experiments (LUXE)
- Exploratory experiments for high-frequency GWs
- In general exploit our unique infrastructures (detector platform, test beam, cryoplatform,...) and unique expertise

Collider physics

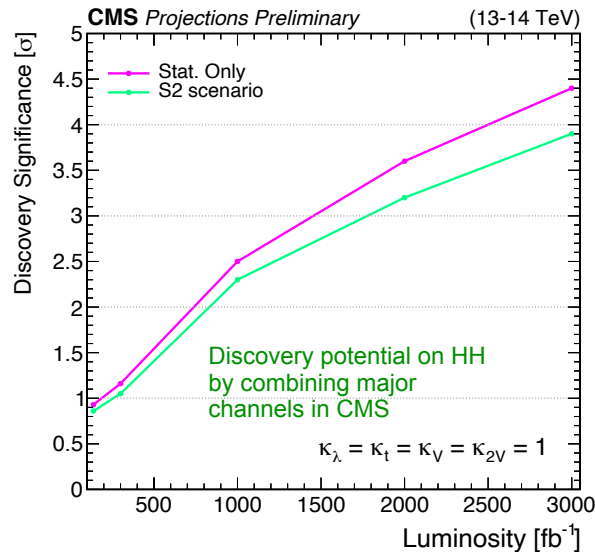
ATLAS and CMS

Full exploitation of the HL-LHC

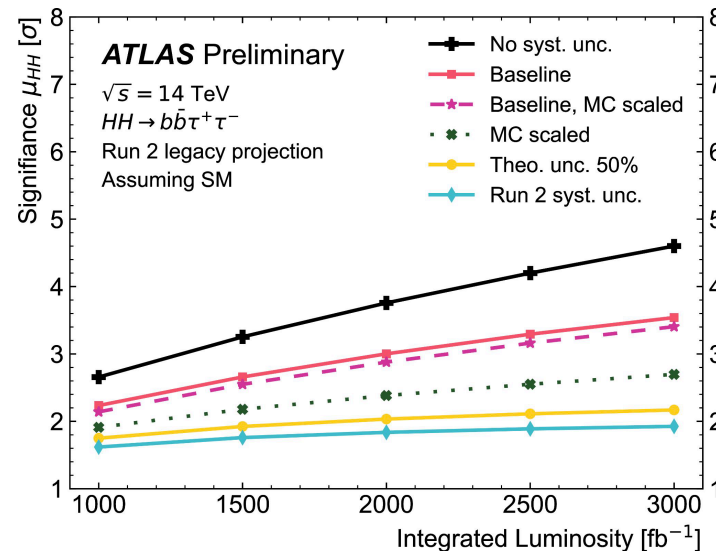
Bring to successful completion the Phase 2 upgrades (ITk in ATLAS, Outer Tracker and HGCal in CMS)

- New detectors with innovative designs will allow to keep performance as good as now (or better) but at much higher pile-up
- Major milestone will be the measurement at 4σ (or better) of the Higgs self-coupling, by combining ATLAS and CMS. DESY huge expertise in Higgs couplings and combination will play a leading role in this measurement

CMS-PAS-HIG-20-011



ATLAS-PHYS-PUB-2024-016



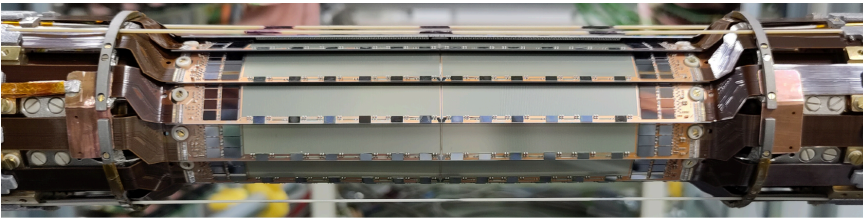
- DESY is committed to the massive effort awaiting the LHC experiments in the next years: analysis of data and HL-LHC detectors construction, installation and commissioning at the same time
- Close collaboration with German Universities on all fronts



Belle II

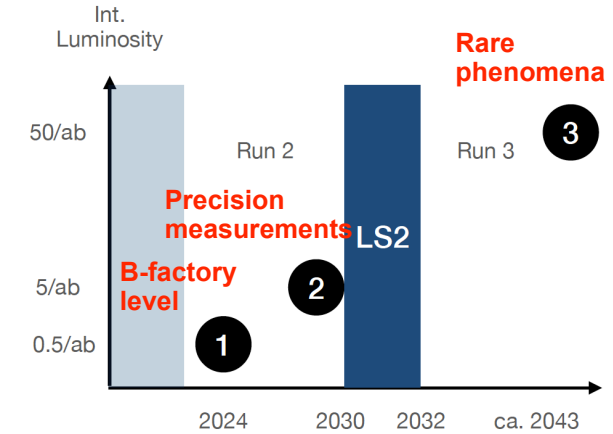
Flavour powerful tool to test BSM

- Run 2 planned for at least 4 years until the next major upgrade in LS2
- Current challenge: sudden beam losses with large doses at the IP, causing damages to PXD2

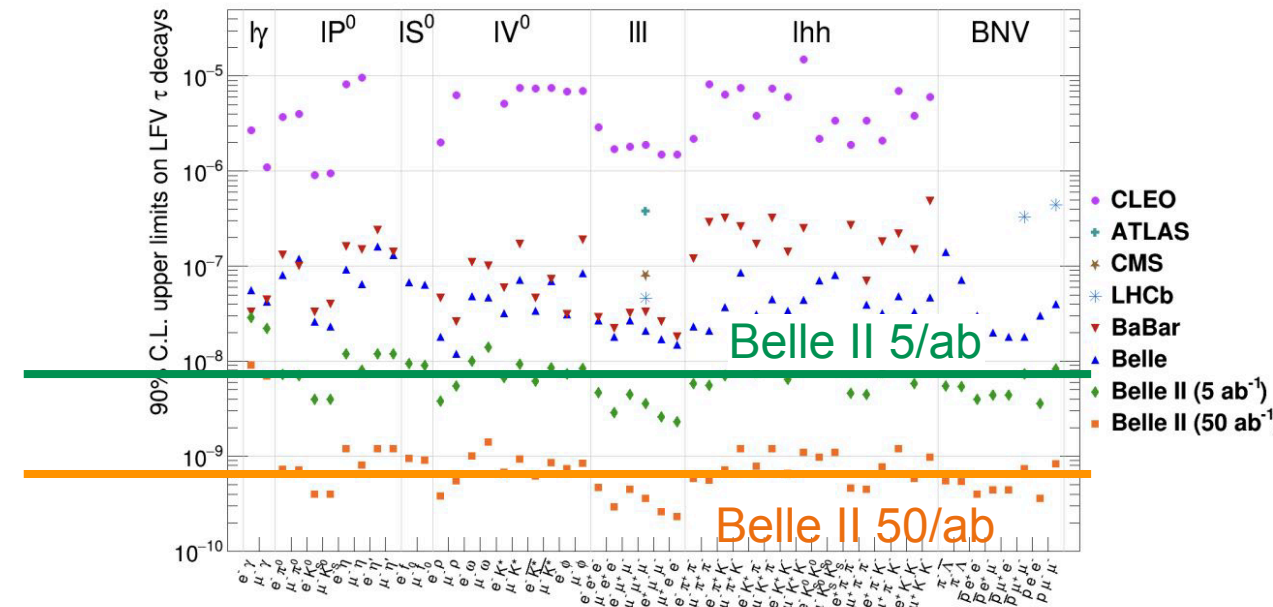


To fully exploit Belle II needs design integrated L up to 50/ab, vital for accessing rare phenomena

- Example: test of the SM in 52 tau decays
- To reach the design luminosity of $6 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ likely a redesign of IP needed
- New CMOS-based tracking VTX being studied



[arXiv:2203.14919](https://arxiv.org/abs/2203.14919), contribution to Snowmass



Future Collider studies

A future Higgs factory

DESY scientists **strongly contributing, also with highly visible responsibility roles** in the decision of the next Higgs factory (P5 process in the US, ECFA studies, ESPPU).

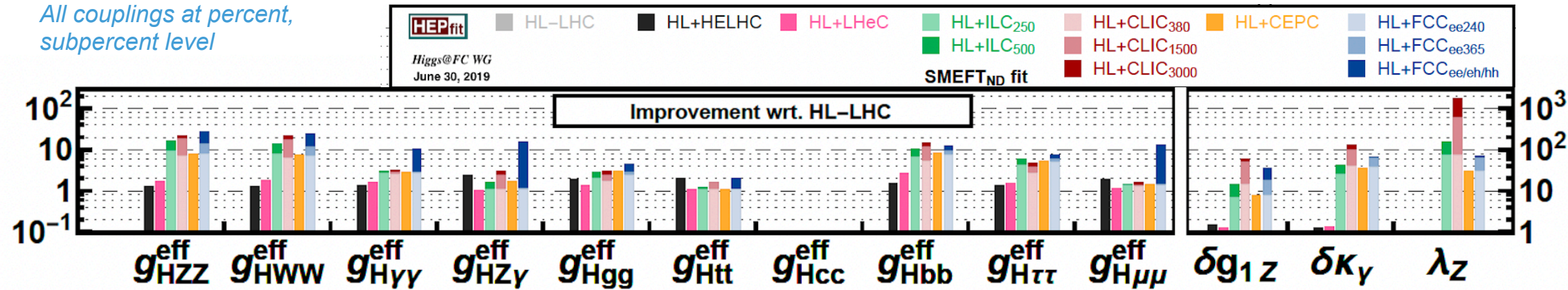
Driving developments on all fronts:

- Examine the physics case
- Detector concepts
- Software ecosystem

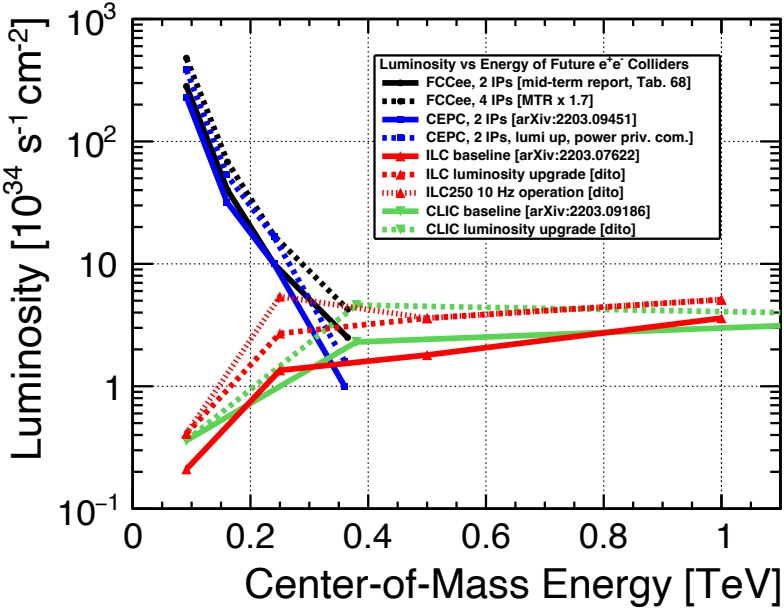
Experimental projections on Higgs couplings based on an SMEFT framework
All couplings at percent, subpercent level

$$g = g_{SM}[1 + \Delta] : \Delta = O(v^2/\Lambda^2)$$

C. Grojean, arXiv:2206.08326
input for Snowmass



Plot by Jenny List



Linear collider

Higgs projections

- **DESY one of the leading institutes** in the ILC
- Precise measurements of Higgs couplings, especially b, c, g at few % level
- **The measurement of the Higgs potential** will be one of the main goals at the next Higgs factory
 - Higgs trilinear coupling can be measured at the ILC directly with 20% precision at $\sqrt{s} = 500 \text{ GeV}$ (10% at 1 TeV)
 - Main channels are $4b, bb\tau\tau, bbWW$. Good reconstruction of $m_{b\bar{b}}$ and regression are essential (DESY contribution)

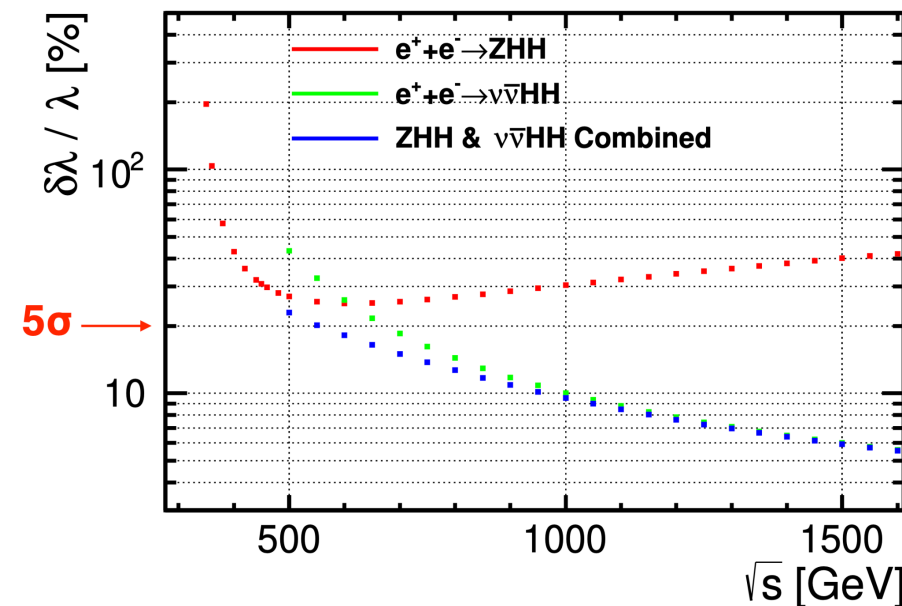
Jenny List, co-leading the LCVision document for the ESPPU, chair of IDT for an ILC in Japan



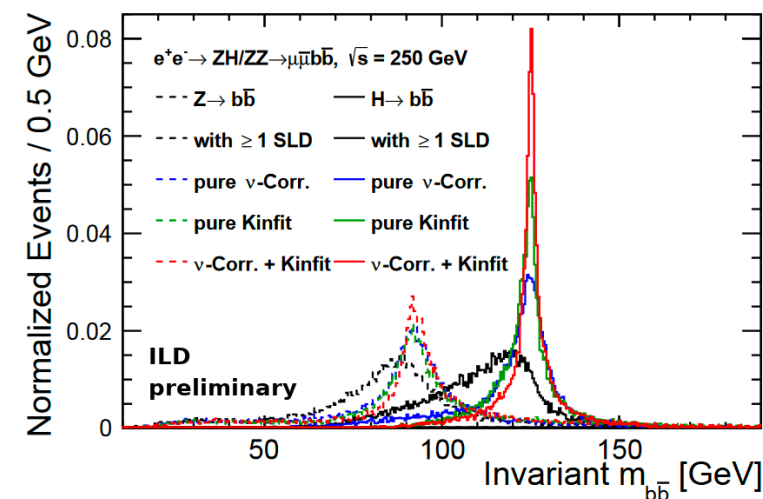
Ties Behnke, ILD spokesperson



J. List, G. Moortgat-Pick, mG. Weiglein et al., arXiv:2410.1619



U. Einhaus et al., PoSa ICHEP2022, 538 (2022)



FCC

Higgs couplings and BSM at FCC

DESY involved in the FCC feasibility studies and H/EW/top studies at FCC-ee:

- Higgs couplings at percent or sub percent precision, Higgs trilinear coupling via NLO in single Higgs (at 20% precision)
- Example: cutting-edge strange tagger at the moment, eventually measure the Higgs to strange coupling (120% precision in present projections)

Leading contributions to the CDR and Mid-term feasibility study report



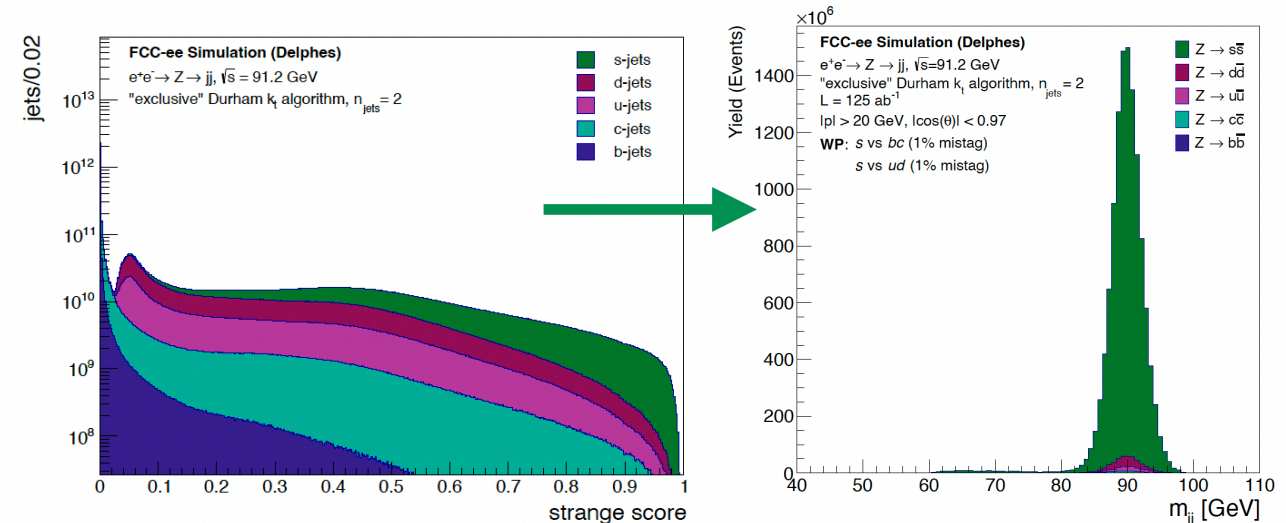
Christophe Grojean, FCC-ee Physics Coordinator



Felix Sefkow, convener detector concept



arXiv:2406.08590, F. Blekman et al



Software

Inside the activities of the FH Scientific Computing Platform

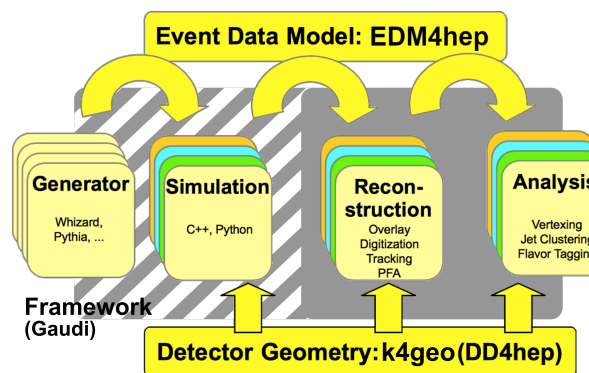
Software Ecosystem Key4HEP:

- HEP community decided 5 years ago to develop a common turn-key software stack for future colliders
- Involved communities by now: ILC, CLIC, CEPC, FCC-ee, FCC-hh, EIC, LUXE, Muon Collider
- A recognized success of the ECFA Higgs/EWTop Factory WG physics analysis tools, based on work started at DESY!

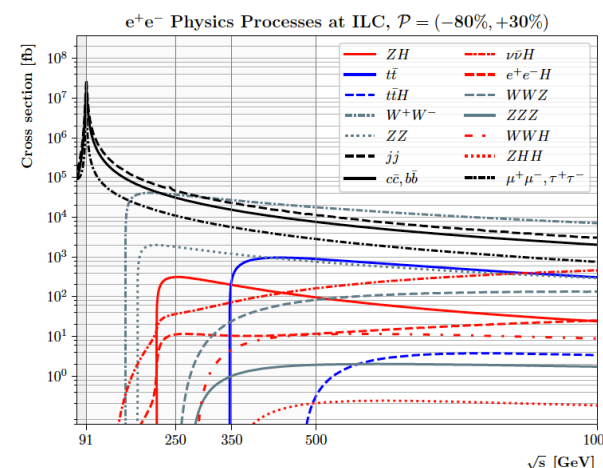
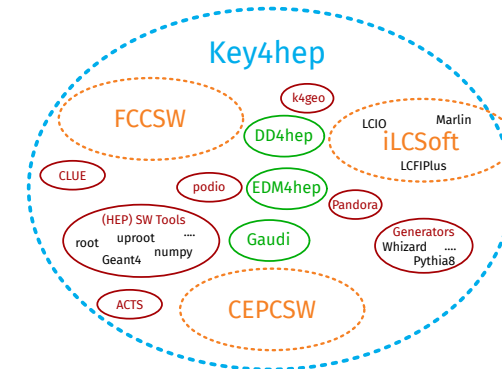
Modern generators for e^+e^- :

- Whizard, workhorse for all e^+e^- machines (and high-energy muon collider)
- Parallelization of the core phase-space integration and simulation achieved (30 to 50 times more speed)
- Automation of NLO QCD and EW (and mixed) corrections completed, up to 6-jets at NLO QCD

Frank Gaede,
Key4HEP
initiator and
leader



arXiv:2203.07622,
ILC at Snowmass



Juergen Reuter,
Whizard author



HALHF and Muon Collider

New attractive far future technologies

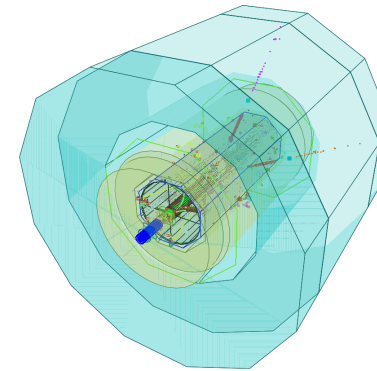
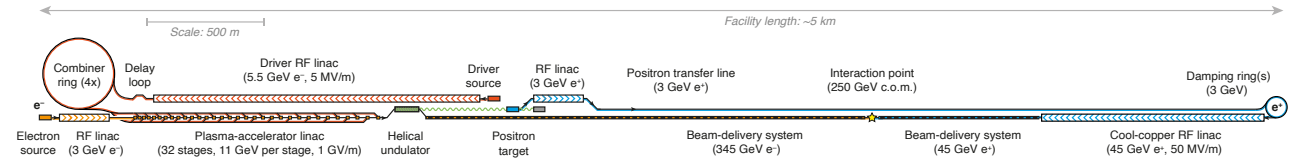
An Hybrid Asymmetric Linear Higgs Factory

- Only 5 km, plasma for e^- (550 GeV), conventional RF for e^+ (31 GeV)
- Initiated by DESY, strong synergies with DESY accelerator division
- Luminosity $L \simeq 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, similar to an ILC machine
- Working towards adapted, asymmetric version of ILD detector, so far no fundamental issues in achieving ILC-like detector performance

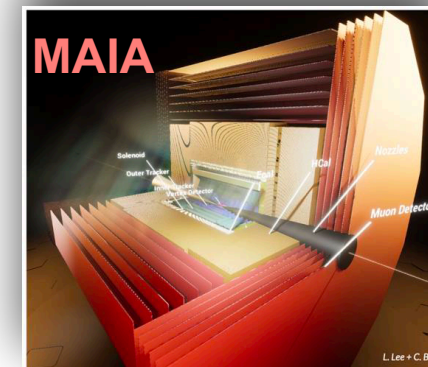
Muon Collider

- DESY leading the MAIA detector concept
- Federico Meloni chair of the editorial team for the ESPPU submission

B. Foster, R. D'Arcy, A. Lindstroem
New J. Phys. 25 (2023) 9, 093037
Newest layout



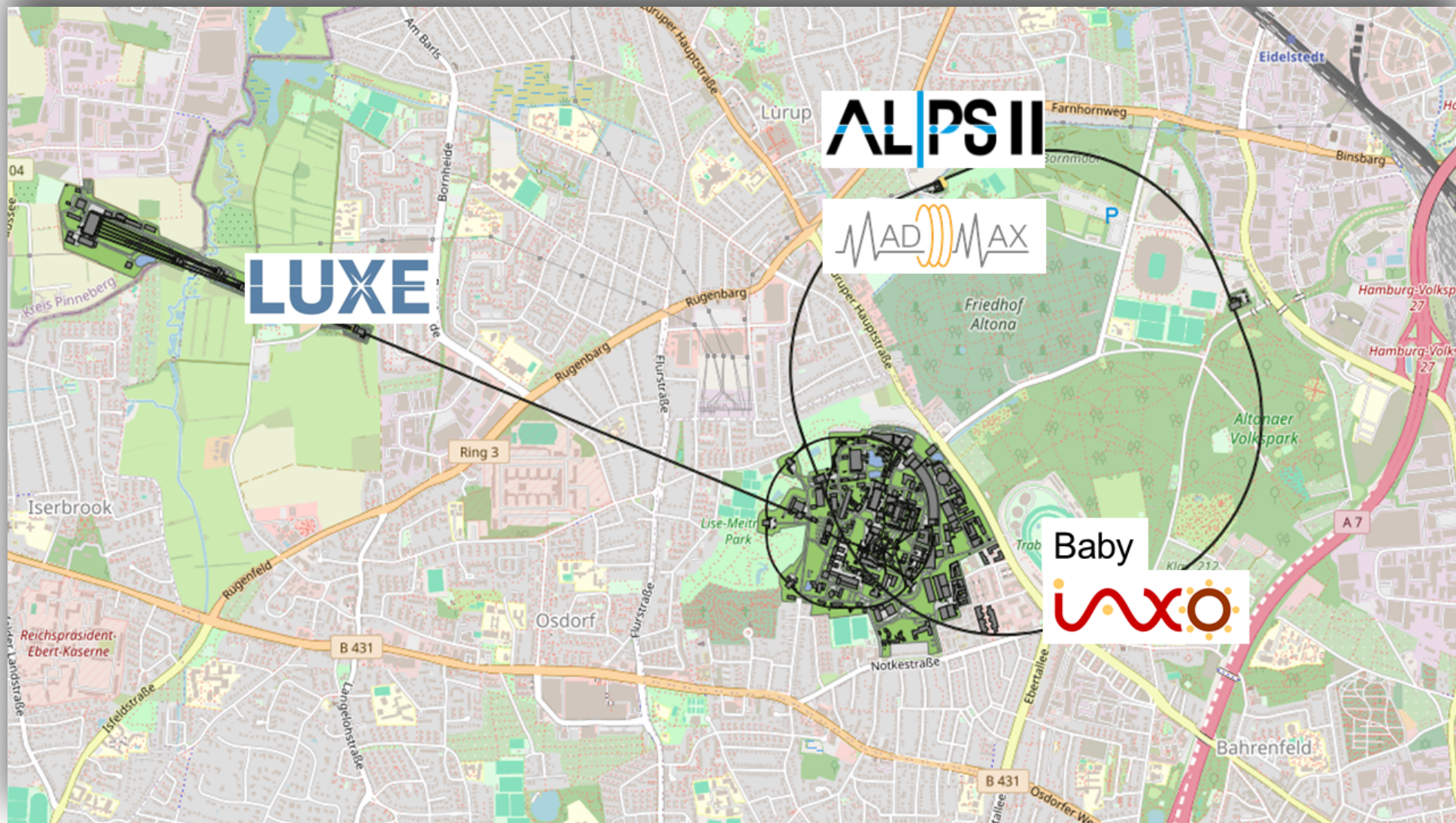
An $e^+e^- \rightarrow \mu^+\mu^-H$
event in the adapted
asymmetric ILD detector



On-site experiments

On site experiments

A map of on-site experiments (see Axel Lindner's talk)



GWs detection at higher frequencies

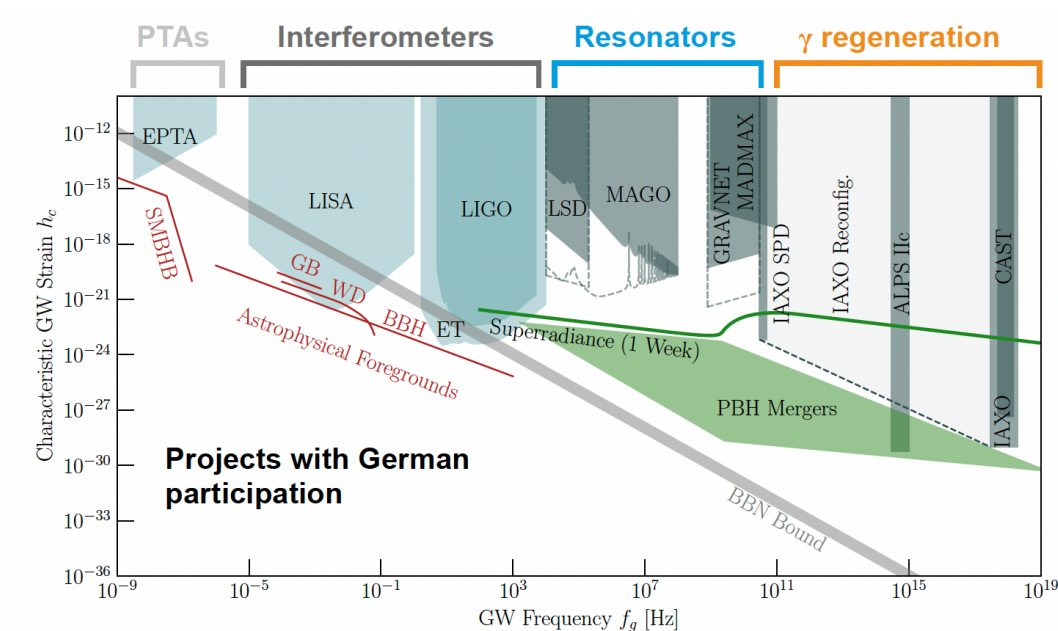
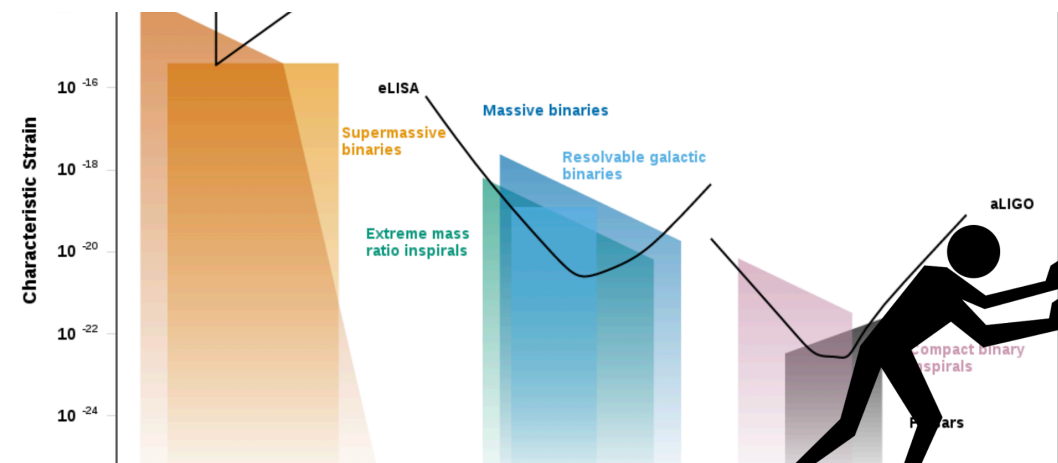
Opportunity to explore GWs at higher frequencies

Universe expected to be populated by GWs over many frequencies

- Push the boundary and extend to high frequency
- No known astrophysical objects over O(kHz): if detected, points to BSM physics
- Understand the origin of stochastic GWs
- High risk, high return!

We can push the boundaries with relative small experiments:

- MAGO SRF cavity sensitive to frequencies 4-20 kHz

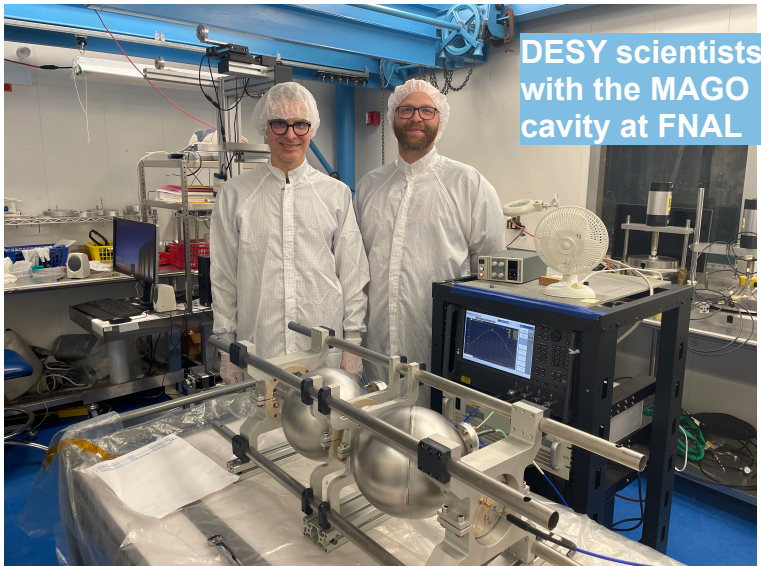


Plot from Tom Krokotsch

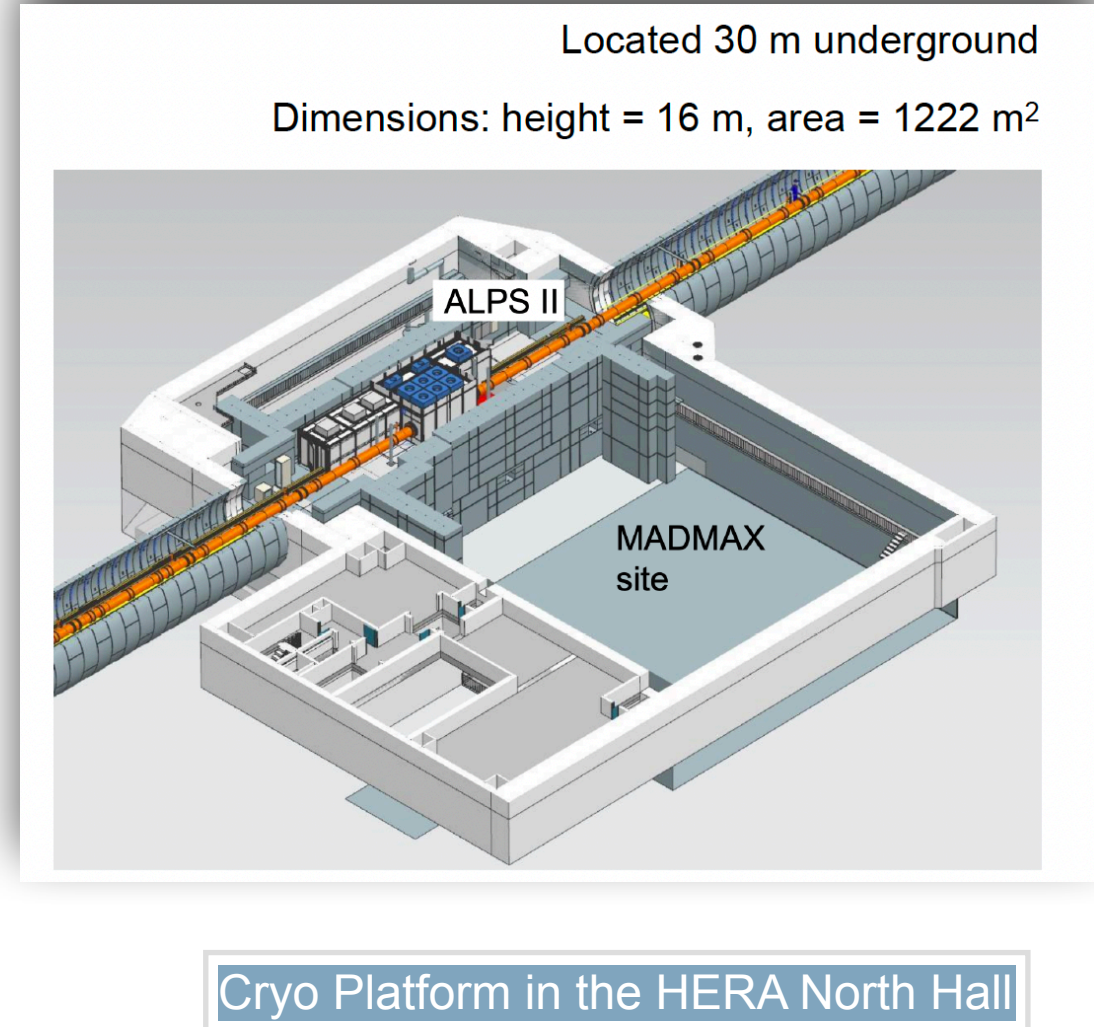
HF GW experiments

Revival of the MAGO activity in collaboration with UHH and FNAL

- R&D on cavity going on now
- DESY has unique expertise and ideal infrastructure:
 - The cryoplatfom can supply up to 3 experiments (achieved in this POF period)
 - In construction, operation from 2026



Christoph Reinhard,
Innovation Award
for levitated
sensors



Summary

Summary

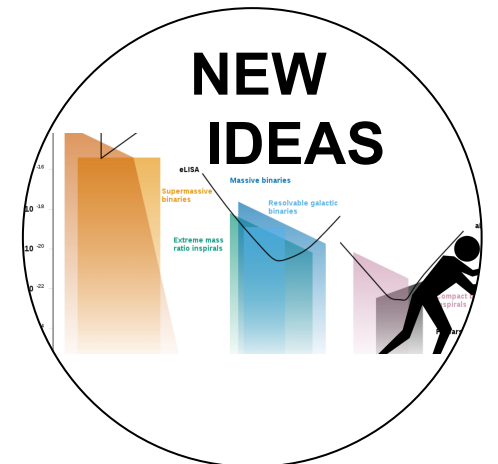
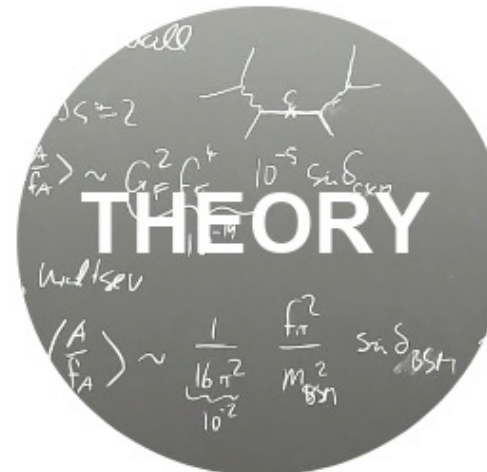
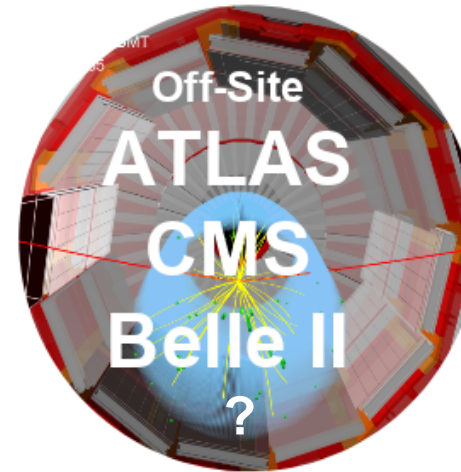
A mixture of on-site and international experiments, very attractive also for the young generation

A vibrant diverse portfolio, addressing the main questions in Nature now, under guidance of theory:

- Structure of the vacuum and its relation of the evolution of the Universe
- Matter-antimatter asymmetry
- Nature of dark matter and strong CP problem
- QED at the extreme
- Gravitational waves in an unexplored region

Ambition to shape the field and the future collider decision

On-site, shorter-term experiments, attractive for our national and international collaborators



Thank you

Contact

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Backup

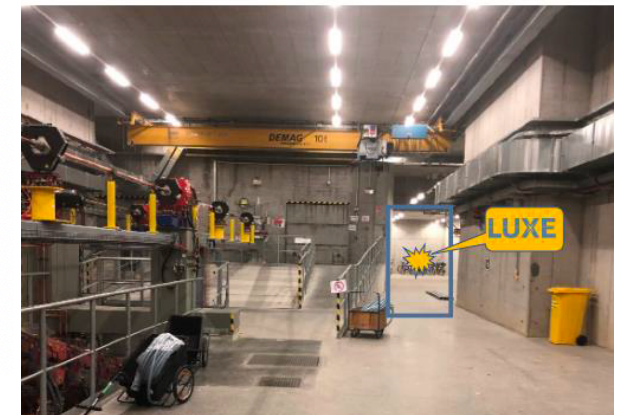
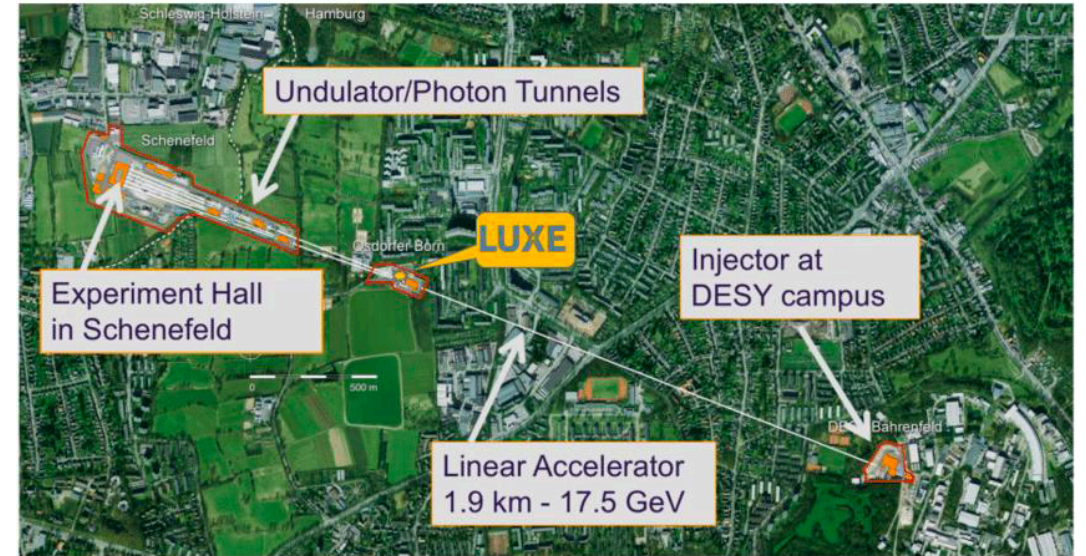
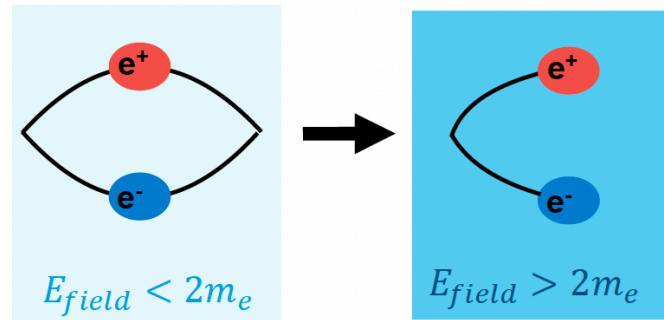
LUXE

Laser Und XFEL Experiment

Proposed new experiment at DESY and XFEL

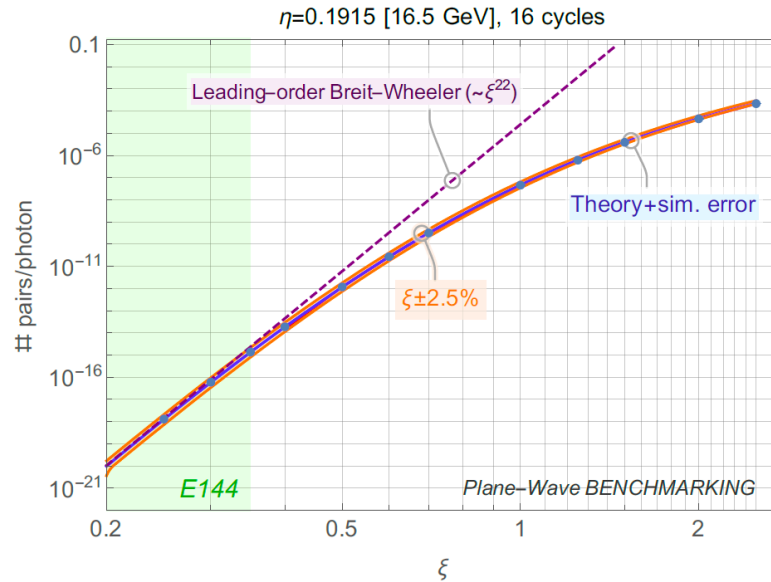
- Test QED in non-perturbative regime (Schwinger limit) in collision of electron beam from XFEL and high-intense laser
- Synergy between particle, accelerator and laser physics

- When $\epsilon_{critical} = \frac{m_e^2 c^3}{e \hbar}$ reached
($1.32 \times 10^{18} \text{ V/m}$) can create $e^+ e^-$ pairs from vacuum
- Explore QED from the perturbative to the non-perturbative regime



LUXE

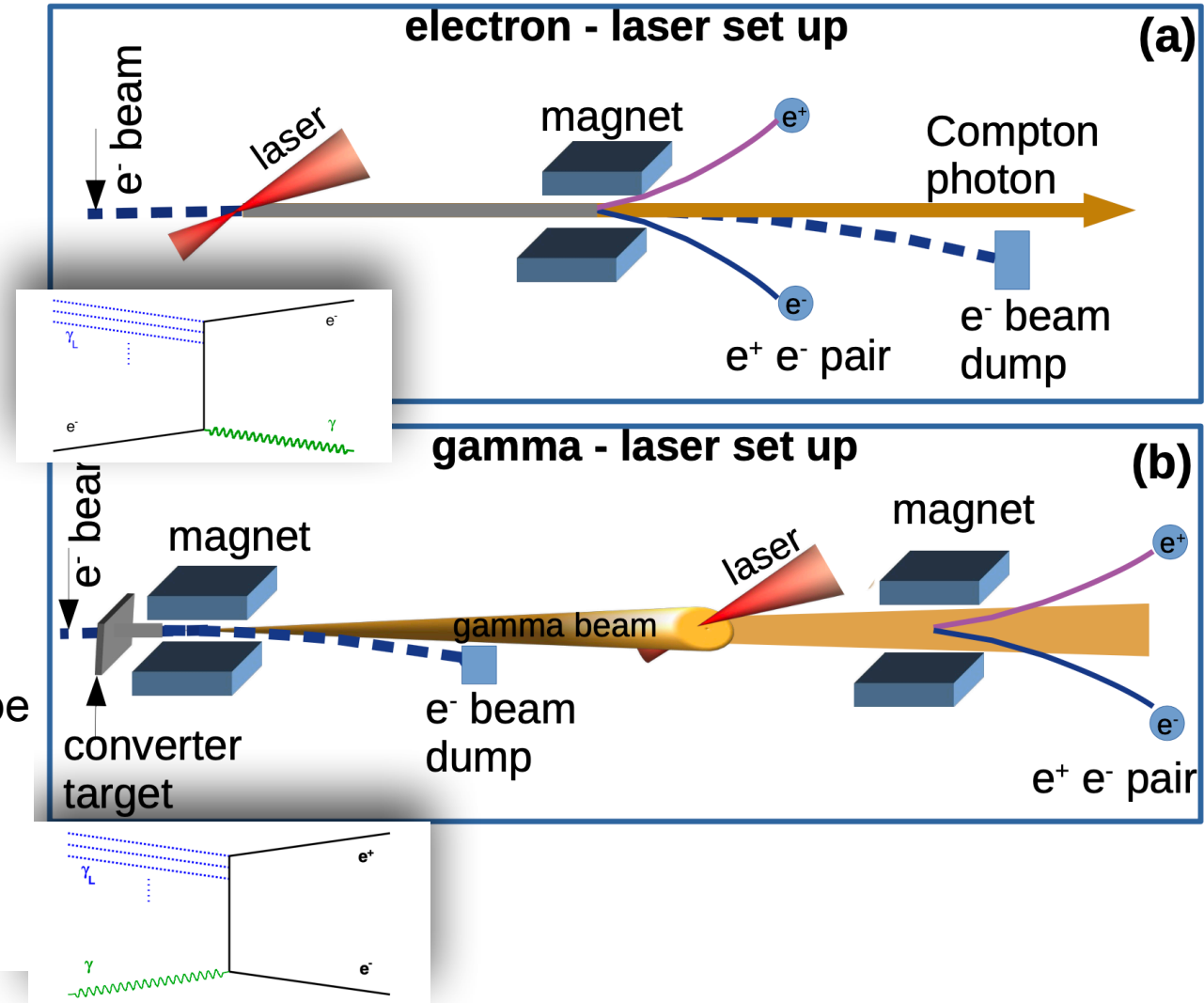
Experimental setup



Status:

- Collaboration of ~100 people
- T20 beam extraction line financed by Horizon Europe (ELBEX)
- JETI40 laser to be loaned by Jena University
- Experiment could start in 2030

Two setups: Compton and Breit-Wheeler



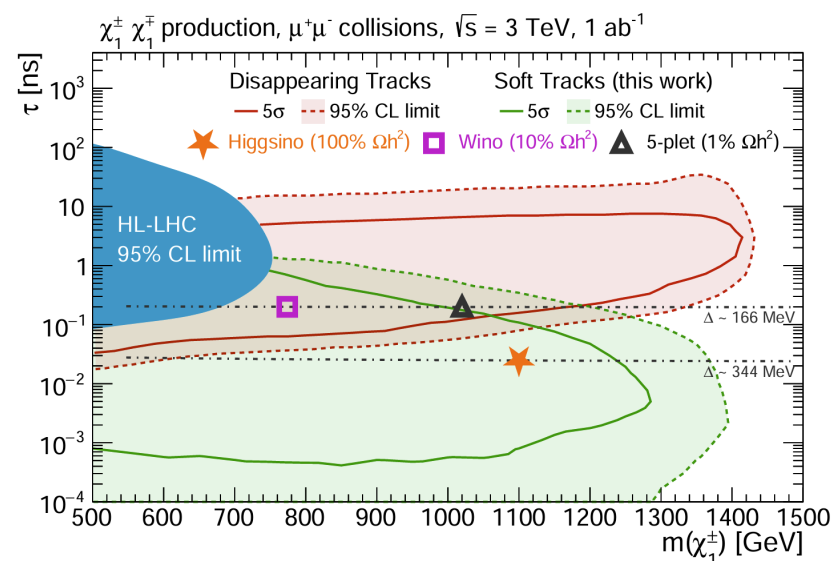
Muon Collider

New attractive looking-forward technologies

Muon Collider

- Energy staging from 3 TeV to 10 TeV (baseline) and higher, supported by P5 (“Muon Shot”)
- **DESY** member of the International Muon Collider Collaboration:
 - design of the MAIA detector concept
 - development of track reconstruction algorithms (synergies with key4hep)
 - Federico Meloni chair of the editorial team for the ESPPU submission
 - BSM studies on minimal dark matter in a signature with disappearing tracks

DESY will host the IMCC2025 week



F. Meloni et al.,
arXiv:2405.08858