KET Strategietreffen

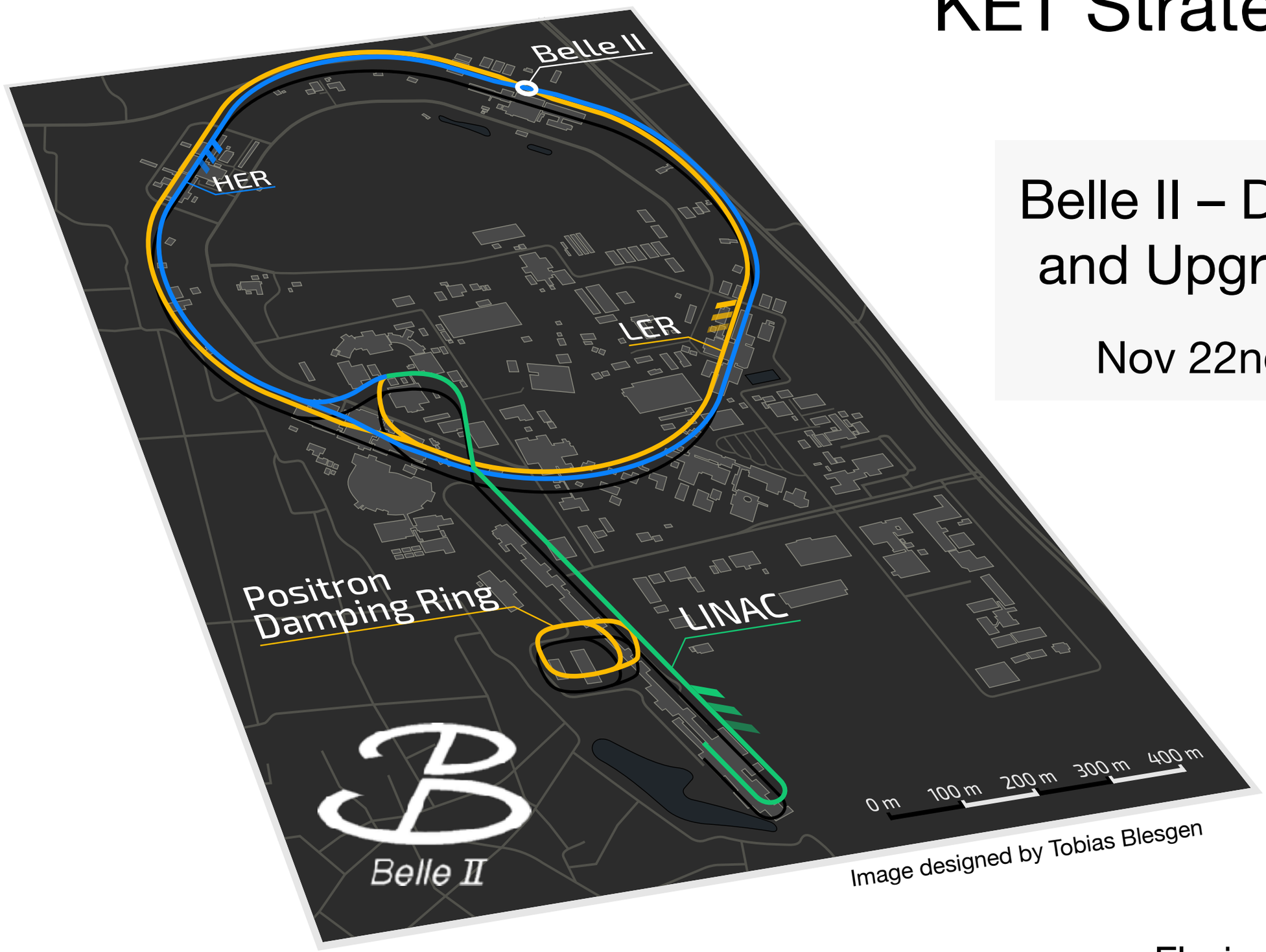


Image designed by Tobias Blesgen

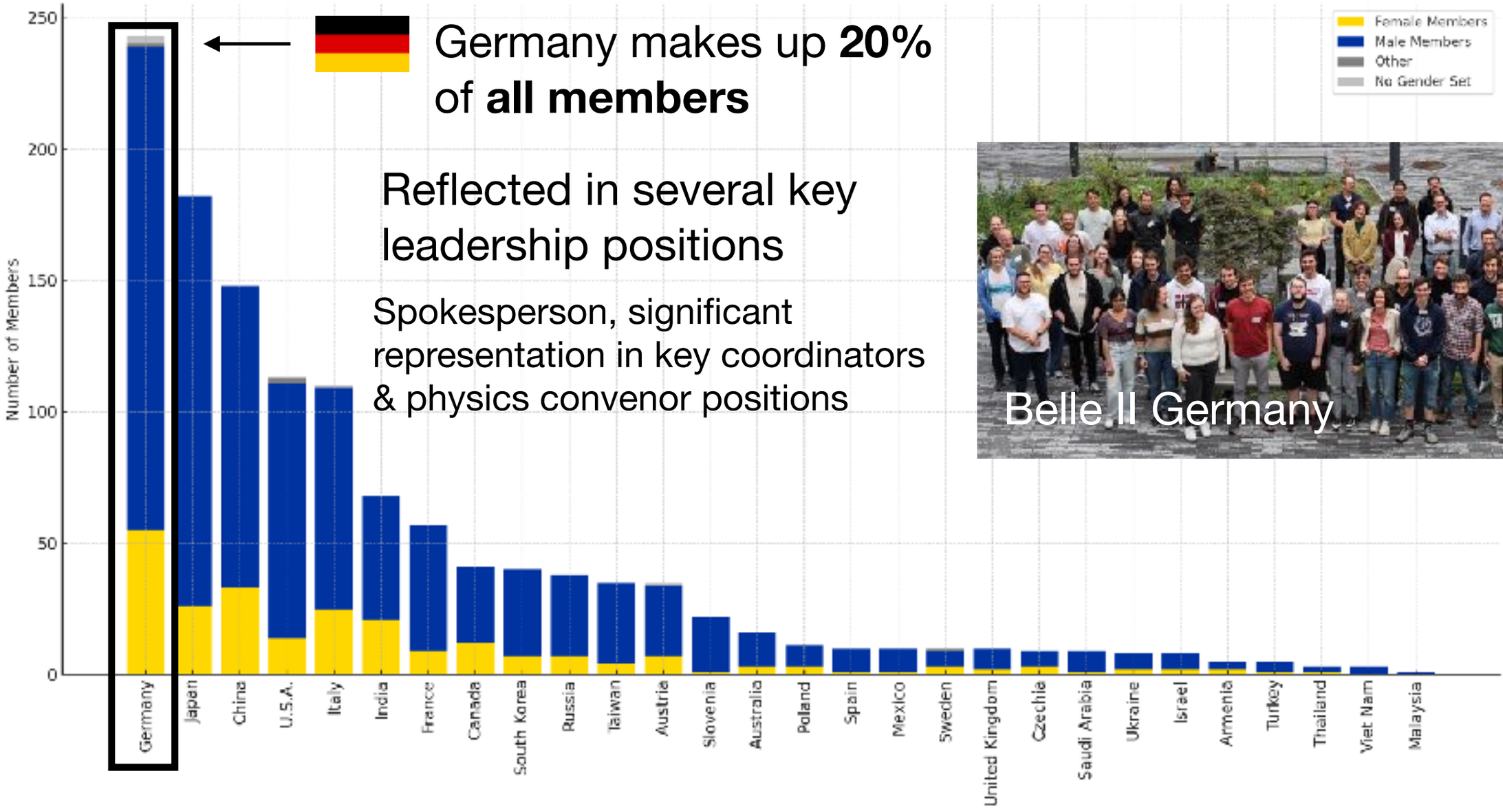
Belle II – Data Taking and Upgrade Plans

Nov 22nd, 2025

Florian Bernlochner
florian.bernlochner@uni-bonn.de

State of the Project and German Impact

1250 Members (315 Faculty, 124 PDs, 269 PhDs, 169 MSc, 94 BSc, 261 Technical)



Germany makes up **20%** of **all members**

Reflected in several key leadership positions

Spokesperson, significant representation in key coordinators & physics convenor positions

708 Scientists
(315 Faculty, 124 PDs, 269 PhDs)

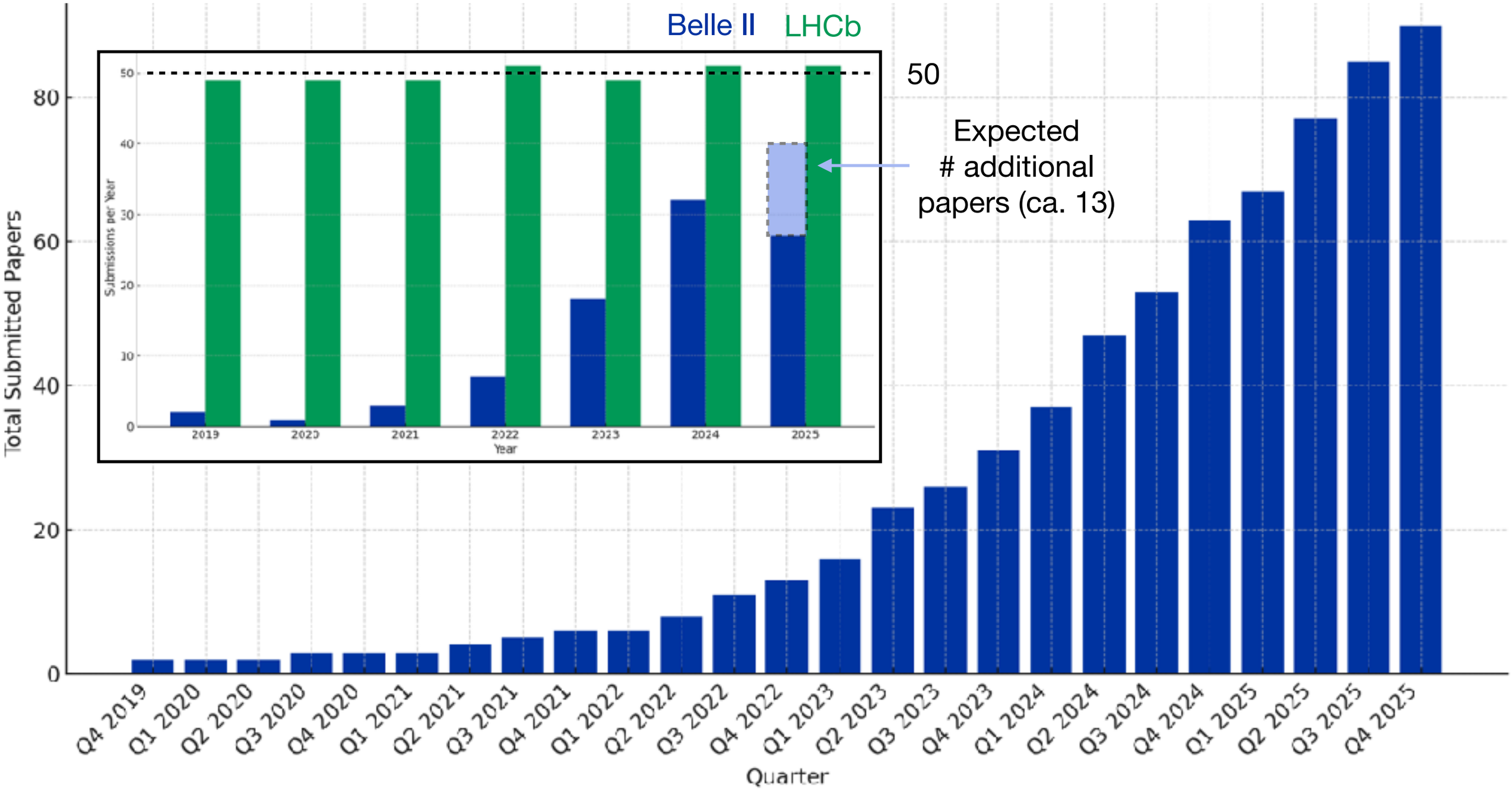
Comparison with **LHCb**:

1165 Scientists
(459 Faculty, 282 PDs, 424 PhDs)

Source: ICHEP 2024

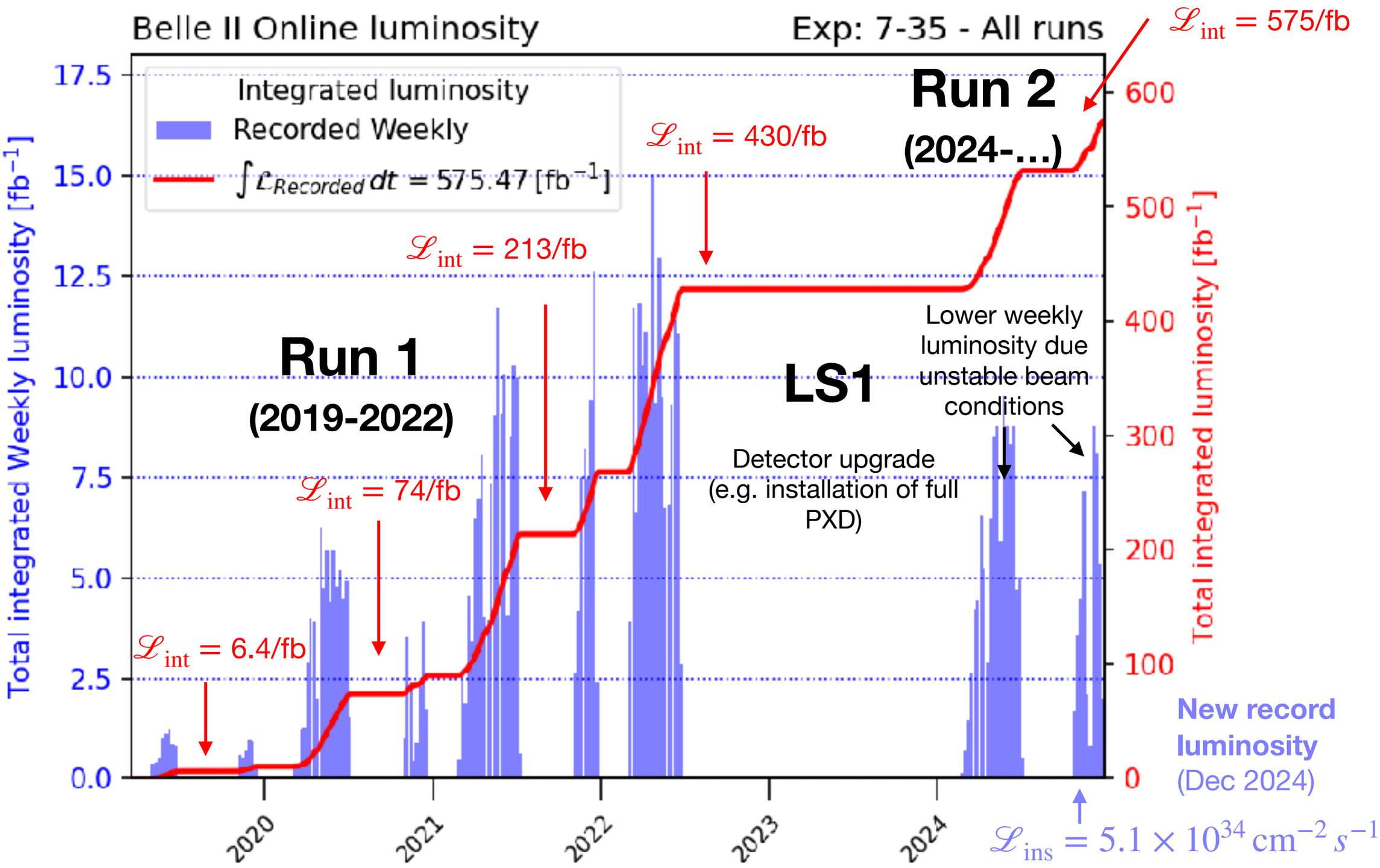
State of the Project and German Impact

90 papers submitted & 81 accepted as of last week



Our goal is to achieve **40 - 45 papers / year**

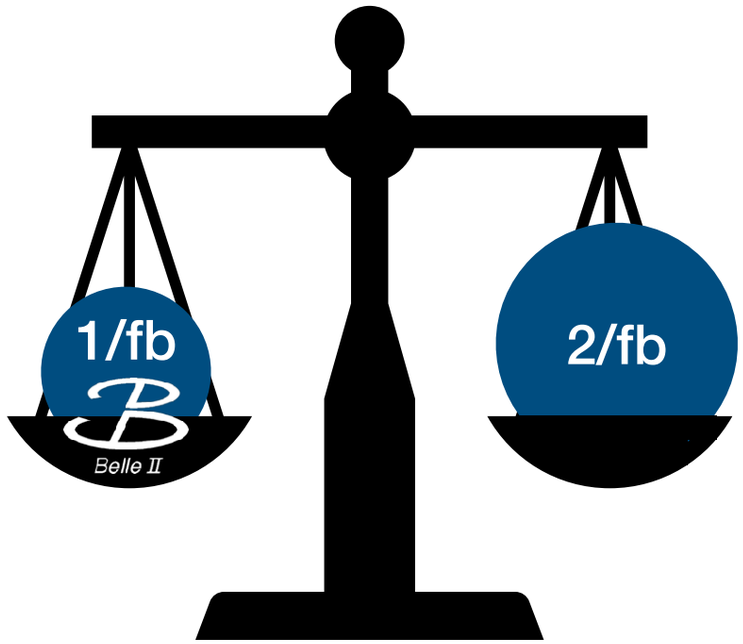
Current Status of Data Taking

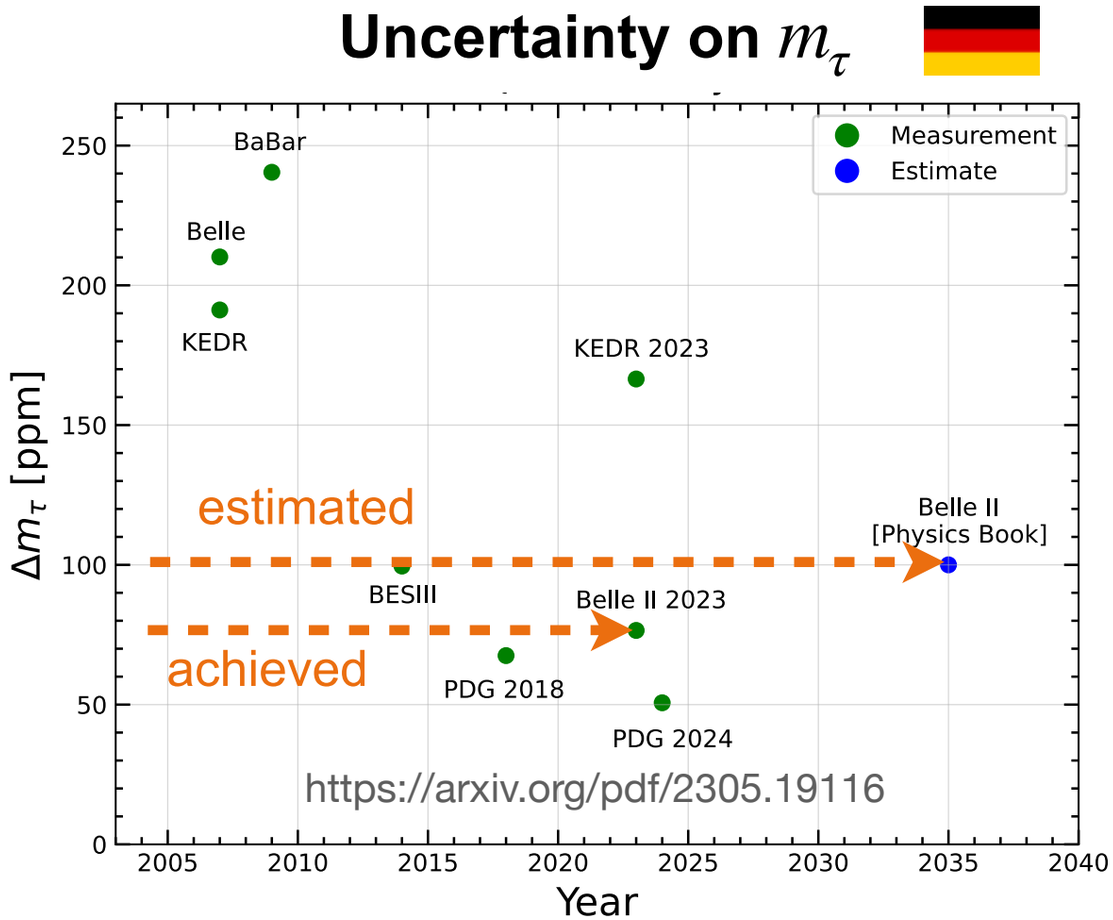


Currently Run 1 data (+ when relevant Belle data) used for **physics** ; Run 1 + 2 results in preparation

Belle II versus Belle / BaBar data

Belle II achieves **higher statistical power** than Belle & BaBar due to improved detector & modern analysis techniques.





Rough rule of thumb:

1/fb of Belle II data is **worth 2/fb of BaBar** or **Belle** data*

* exceptions of course do exist

→ Much effort ongoing to shift this fraction even further with new triggers, better reconstruction, novel ideas etc. See e.g. https://arxiv.org/pdf/2506.11196

Ongoing run: 2025c & 2026ab

Will have for the first time a continuous **7 month run**

The next run has **two goals** :

#1 Push our recorded dataset to **1/ab**

#2 Reach luminosities of **~10^{35} cm^{-2} s^{-1}**

Need close communication with SuperKEKB team to balance this; **physics (#1) will be priority** ← **80%** of running time dedicated to physics

Schedule:

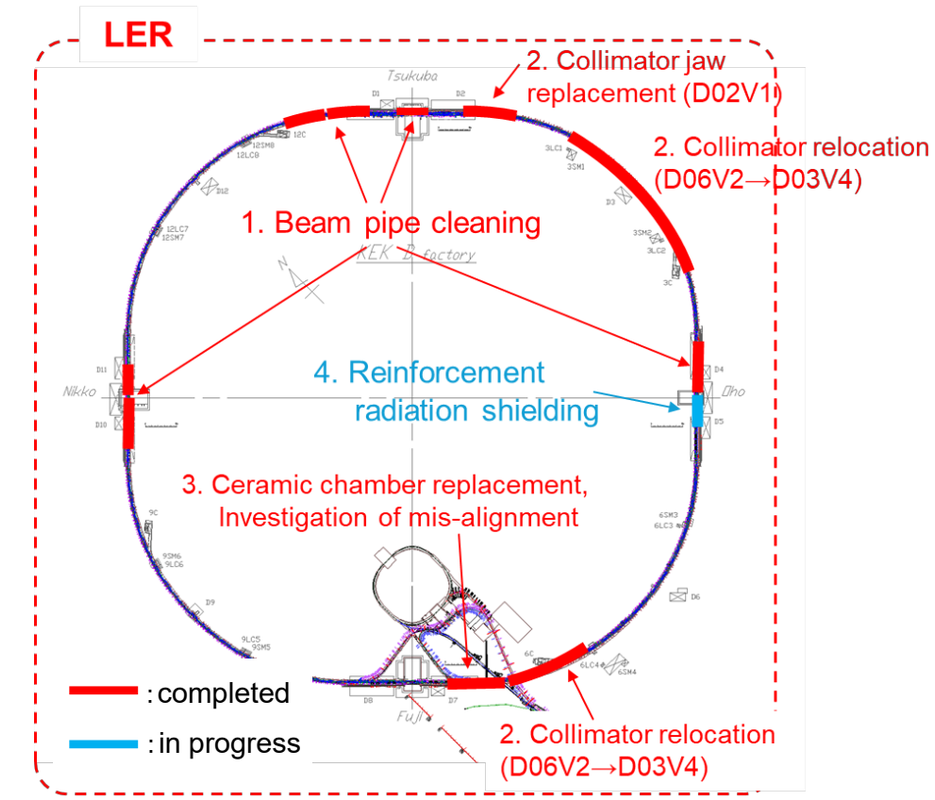
* SuperKEKB Main Ring operations started **Nov 5th**
* Brief Christmas shutdown **Dec 24th - Jan 7th**
* Continue run until **end of May**

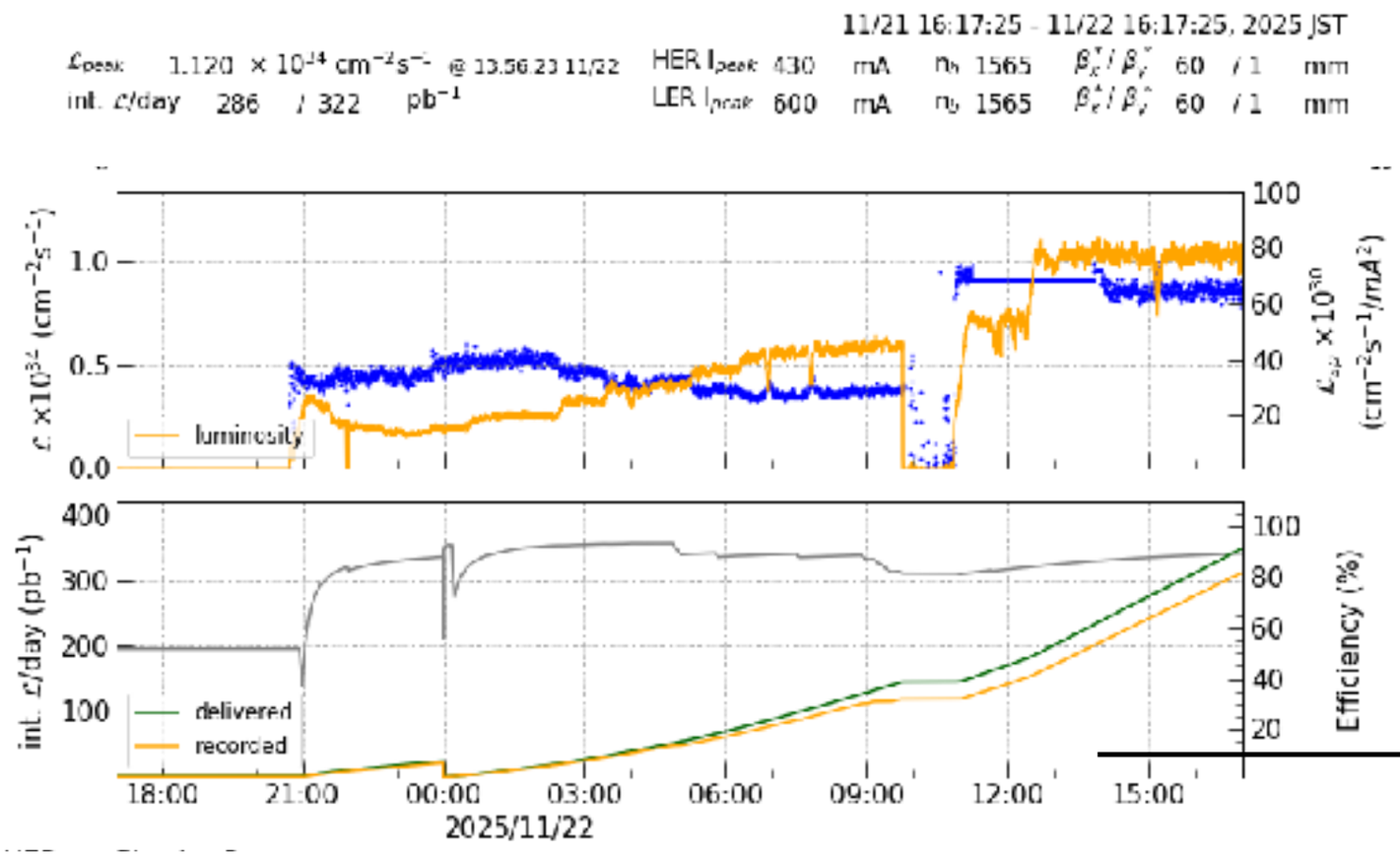
Current Status

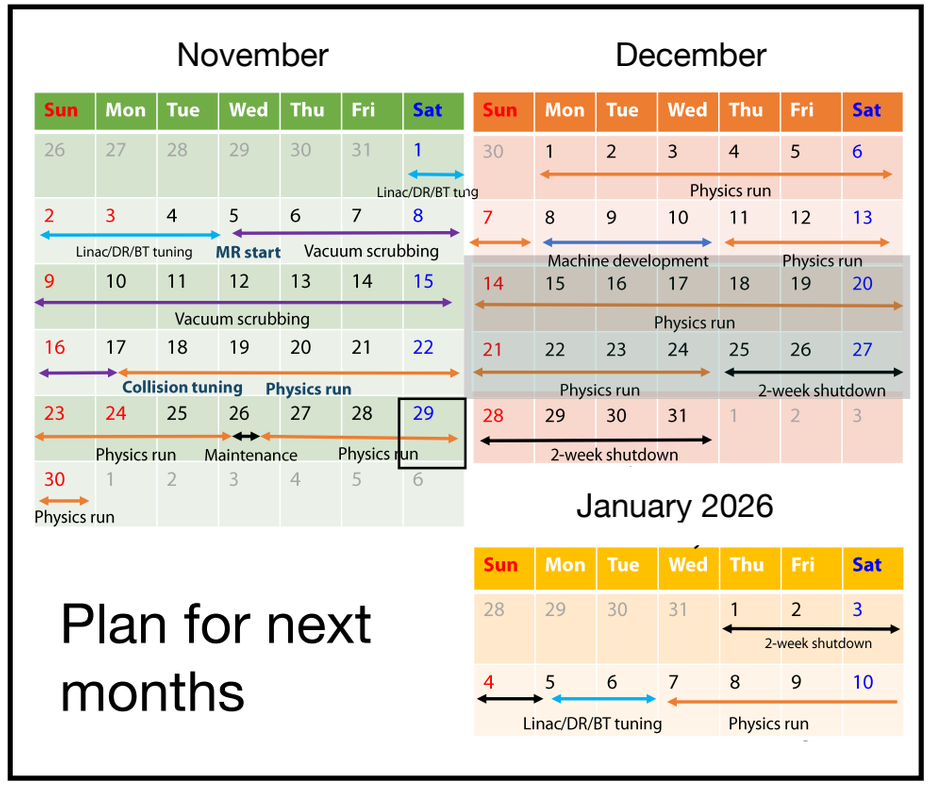
Immense effort over summer to remove vacseal residues in **LER & HER,** construction of new egun, etc.

Vacuum scrubbing finished **Nov 17th**, since then collision tuning for physics run

Gradually **reduced** β_y^* to get to target optics, reached today $\mathscr{L} \simeq 10^{34}$ cm^{-2} s^{-1}







Belle II data taking eff. > **94.5%**

Belle II Timelines

Belle II project organized in **10-year plans of MEXT**

Ongoing period **2023 - 2032**

MEXT covers operational costs of SKB **(ca. 50 Mio. € / year)**, **maintenance** & partially **upgrade activities**

Goals for this period:

- ★ **Record 5-10/ab** of collision data
- ★ Establish operations with **nano-beams** at few 10^{35} **cm**$^{-2}$ **s**$^{-1}$

Project plan (as envisioned in 2022)

[Annual plan] (Japanese fiscal year)	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	
Research items	1st year	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th and later	Remarks
1. Continue operation and improve accelerator performance in parallel with accumulating physics data												Continue performance improvement efforts in later years.
Performance indicator	0.4				3					15		Integrated luminosity [/ab]
2. Maintenance/upgrade of major components												
Systematically conduct renewal of aging components to improve energy efficiency. Achieve the target performance by modifying the interaction region (IR). Improve the performance of the injector and beam transport line (BT) for efficient operation.	Main ring: Energy efficiency improvement				IR upgrade, BT remediation, High-power RF reinforcement							Minor items excluded. Search for efficient measures in terms of budget (electricity) according to collision performance and radiation dose. Flexible operation is required.
	Injector: Injector upgrade											
	Belle II: Replacement of vertex detector, photosensors, etc.											
	Measures for radiation, renewal of aging components, etc.											
Performance indicator					Start of IR upgrade		End of IR and detector upgrade			Completion of aging component renewal		
3. Report physics results obtained by analyzing the data, publish them in academic papers, and disseminate them widely. Open up a new paradigm in elementary particle physics, or show the next path necessary for that.		Results on dark matter search etc.		Results on lepton universality etc.				Results on CP violation etc.				
Performance indicator	5				40					190		Num. of publications

Mid-term review of Program in 2026 (TBC)

Preparations for Long shutdown 2 (start in 2032)

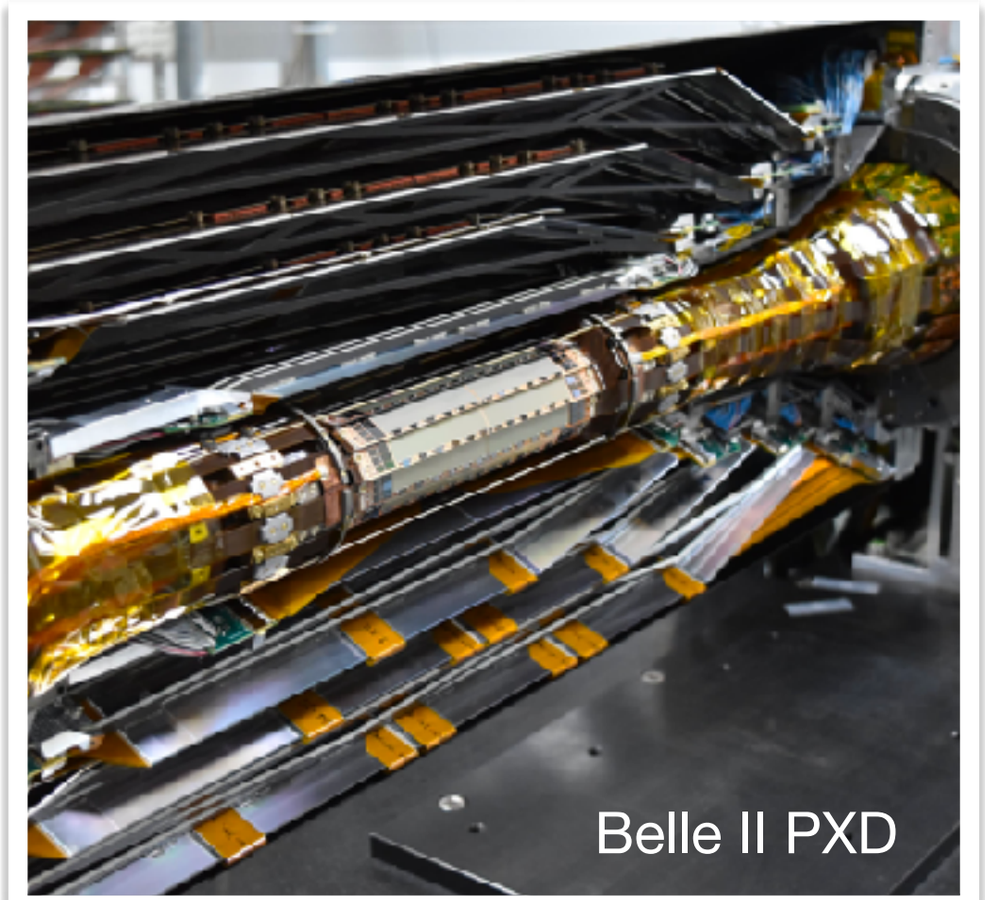
Goals for 2033-2042 period:

Reach 6 x 10^{35} cm^{-2} s^{-1}

to record **data set** of **50/ab**

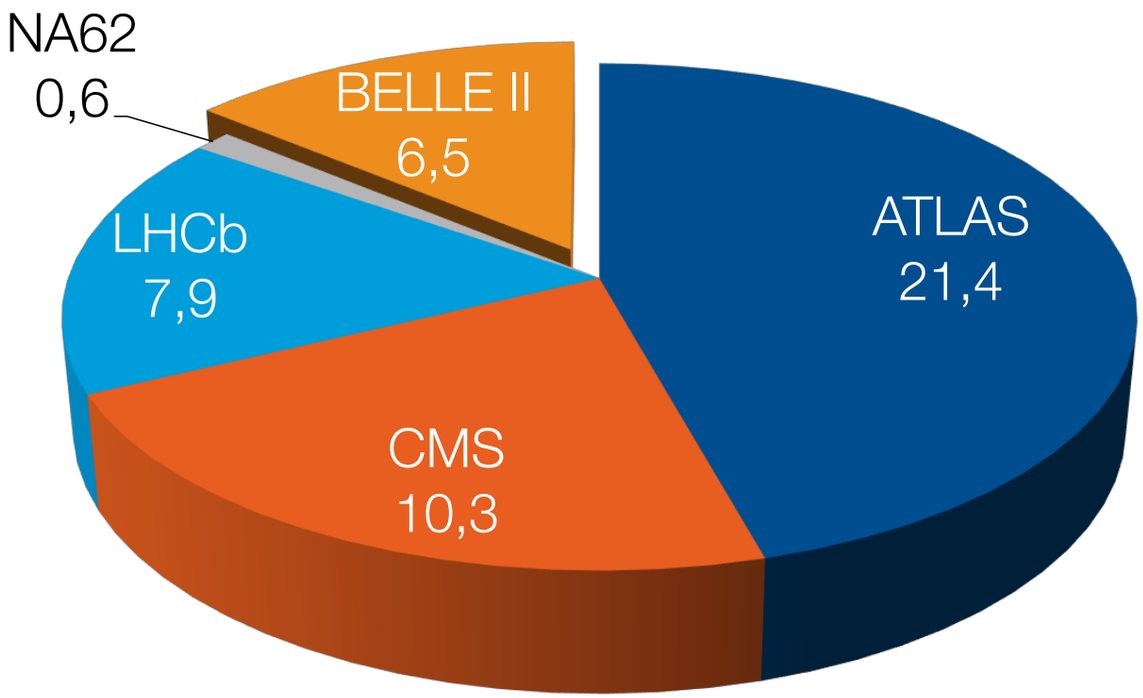
BMFTR Contributions

BMFTR and German partners (HGF via DESY, MPP) designed, constructed, and operate **crucial aspects** of the experiments:



Ongoing funding period:

total: 47 Mio. €



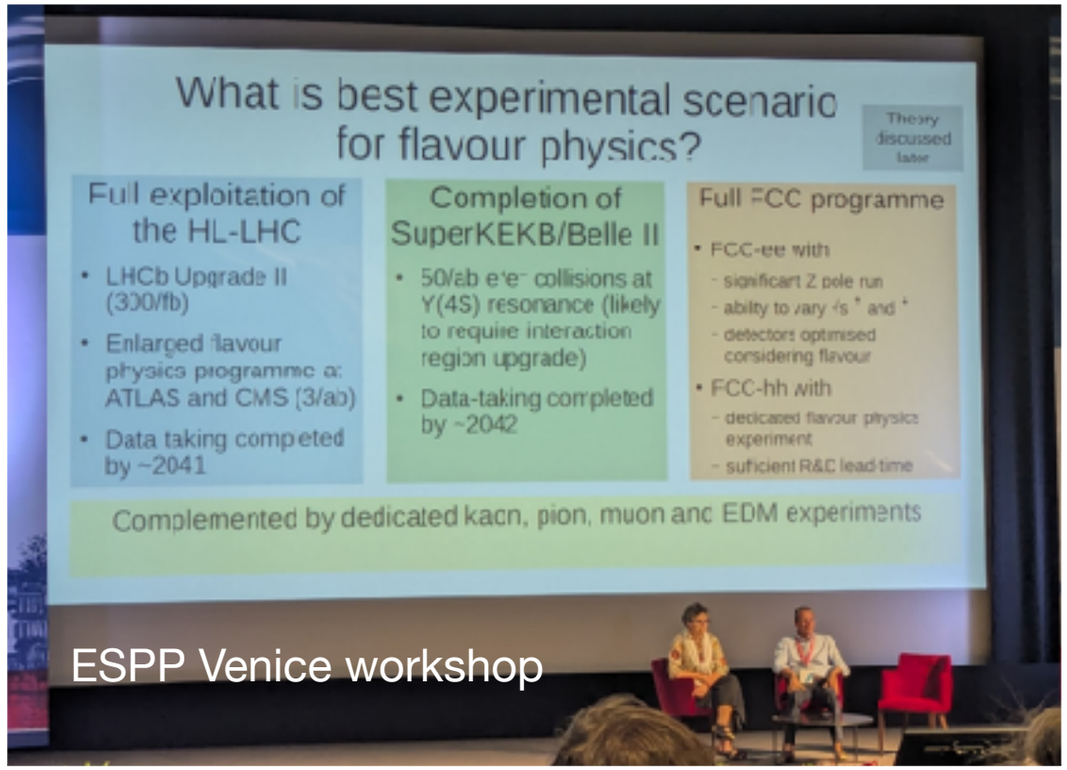
Germany hosts collaborative services, contributes heavily to reconstruction, software, trigger, etc.

status Sept. 2024

Japan will contribute **>150 Mio. €** during the ongoing funding period

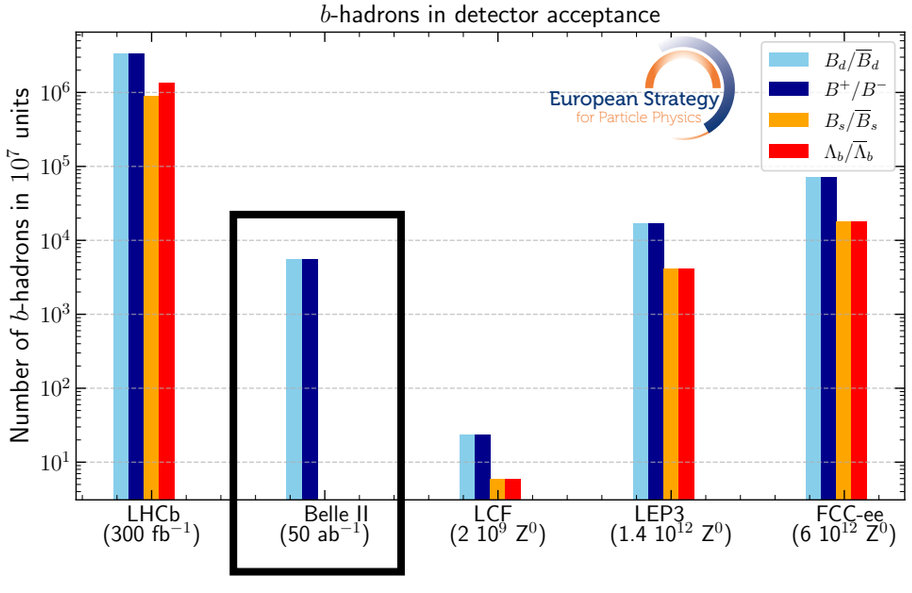
ESPP View on Flavor

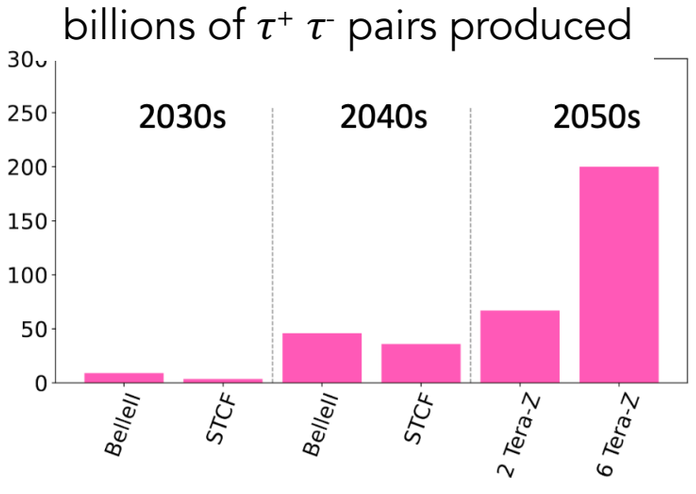
ESPP: **full exploitation** of HL-**LHC** (LHCb, ATLAS, CMS) & **Belle II** for flavor a **priority**

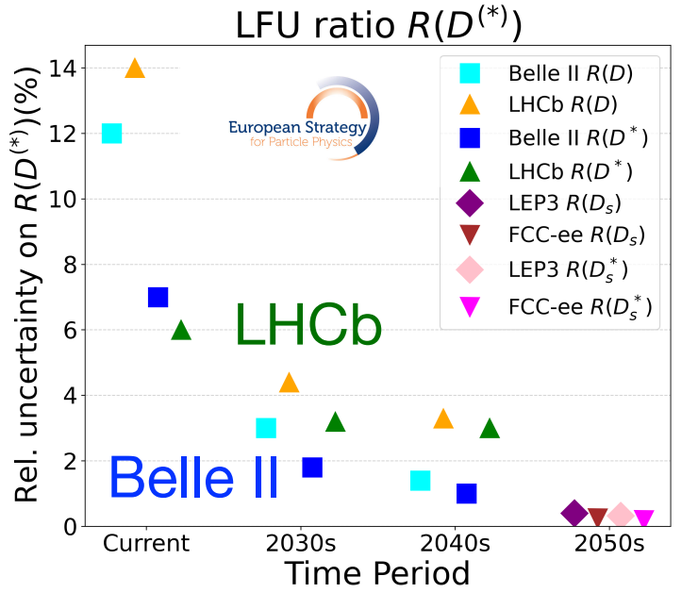


Excerpt from ESPP **Physics Briefing Book** :

> In the domain of b-hadron, c-hadron and τ-lepton physics, major progress is anticipated through the full exploitation of existing experimental facilities up to the 2040s, particularly of LHCb Upgrade II and Belle II experiments. Thanks to these programmes, this is one of the areas of particle physics where the largest gain, in terms reduced statistical and systematic uncertainties, is expected in the next 20 years.
>
> https://cds.cern.ch/record/2944678







Belle II Germany Priorities for 2027-2030

Operation of **PXD**; **key contributions** to *Software, Performance, Operations, Physics, and Trigger*

In the current funding period we have funding for R&D submissions of VTX / OBELIX and other activities

Meaningful participation to **Belle II Upgrade** in R&D & Core-Costs

Planned Activities Physics

Bonn

PXD expertise/operation, DATCON, VTX & STL upgrade, CDC R&D (test chambers, Malter mitigation), neutron ID, upgrade tracking

B-meson tagging (exclusive FEI, inclusive, deep learning), SysVar

Semileptonic, missing energy, amplitude anal.

LMU

PXD operation (incl. power supplies); tracking software maintenance and VTX development; modernization of software framework (AI/ heterogeneous computing) RunDB, PubDB

Semileptonic and generic NP searches

KIT

CDC & ECL trigger firmware and upgrades; CDC+VXD and degraded-detector tracking; PXD DHH, STL Upgrade (e.g. Interconnects)

Dark sector, LLPs.

MPP

pending succession Allen Caldwell

PXD operation, CO_2 cooling for PXD and SVD, PID, PWA, NN Trigger

tau, TDCPV, quantum coherence

Gießen

PXD operation to LS2; ROI selection, monitoring, and ML-based ROI rescue. PXD background studies (incl. synchrotron radiation; time-dependent/injection studies next). ML in SBL/MDI; ITT instrumentation (Timing for PID)

QCD exotics (next: gluon hybrids).

Göttingen

PXD shifts; VTX upgrade simulation/performance/ benchmarks; prototype characterization. STL involvement; SuperKEKB background studies, BGNet; transformer-based flavor tagging (TFlat).

Semileptonic, $B \to \tau\nu$.

Mainz

PXD expertise/operation; Run coordination, DAQ and firmware for upgrade (VTX and STL),

QCD exotics (next: gluon hybrids).

DESY

PXD operation, Performance, PID, potentially upgrade (VTX/STL, see later slides)

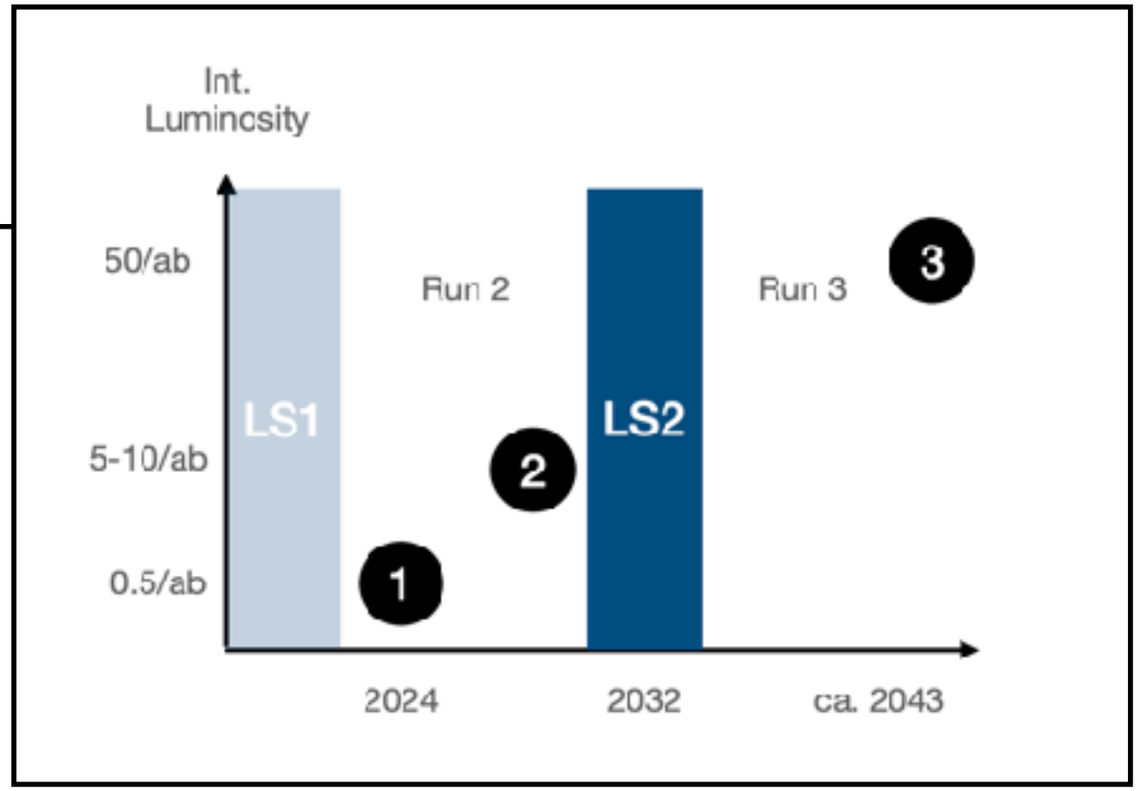
Tau, Missing Energy, TDCPV

+ immense support from German theory community (KIT, Siegen, Mainz, ..) (most not funded by BMFTR)

LS2 & Upgrade Motivation

To reach 6 x 10^{35} cm^{-2} s^{-1} & 50/ab plan for **long shutdown 2** in 2032 to upgrade IR

Redesign of final focusing magnets (QCS) essential

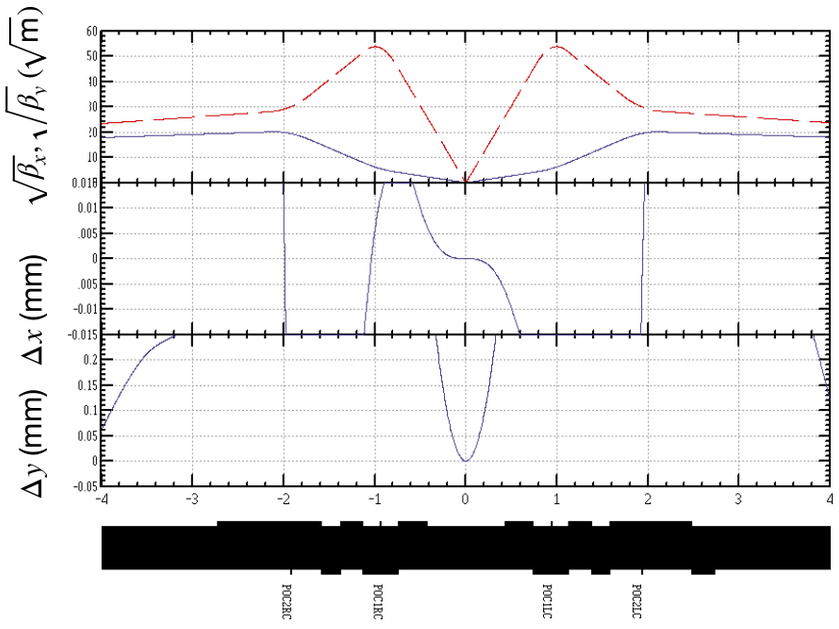


Current IR optics complicated, large chromatic xy coupling occurs when going to high luminosities

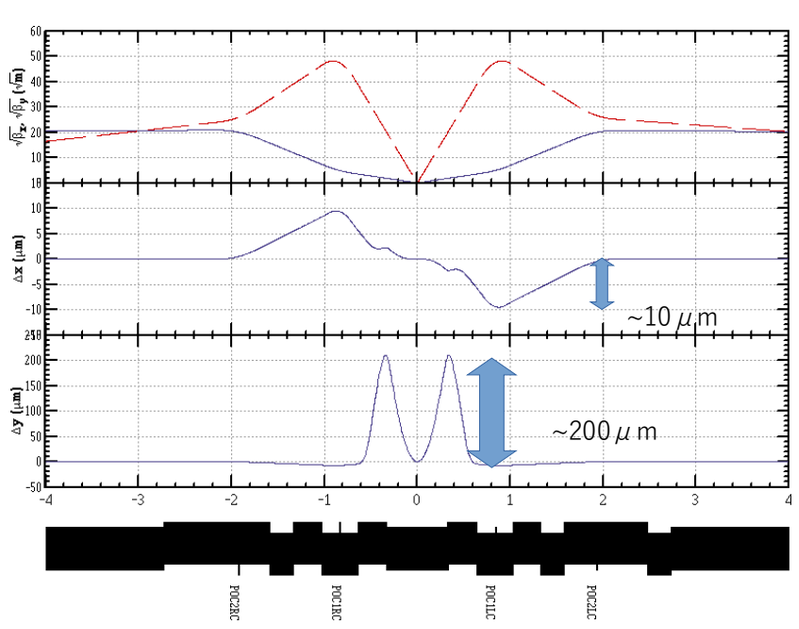
Proposed QCS modifications

- QC1P 100 mm closer to IP
  - Enlarge dynamic aperture of LER
  - Extend the beam lifetime
- Change conductor of QC1P from NbTi to **Nb_3Sn**
  - Decrease risk of beam-induced quench
- Install a compensation solenoid between the IP and QC1P
  - Simplify IR optics
  - Reduce chromatic xy coupling
  - Reduce emittance growth at IR

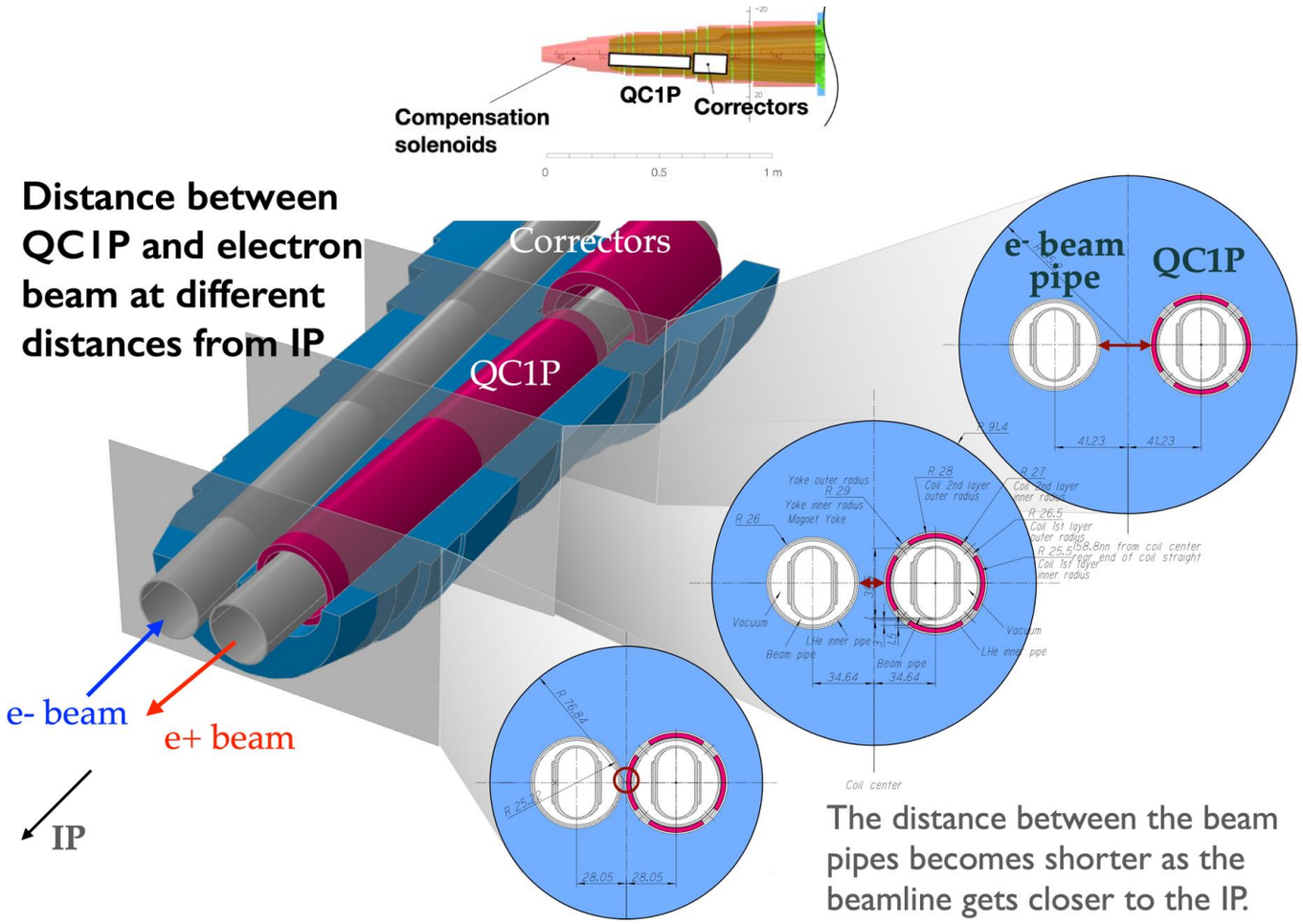
Y. Arimoto @ARC Dec. 2024



Orbit with Current Design



Candidate for new Design

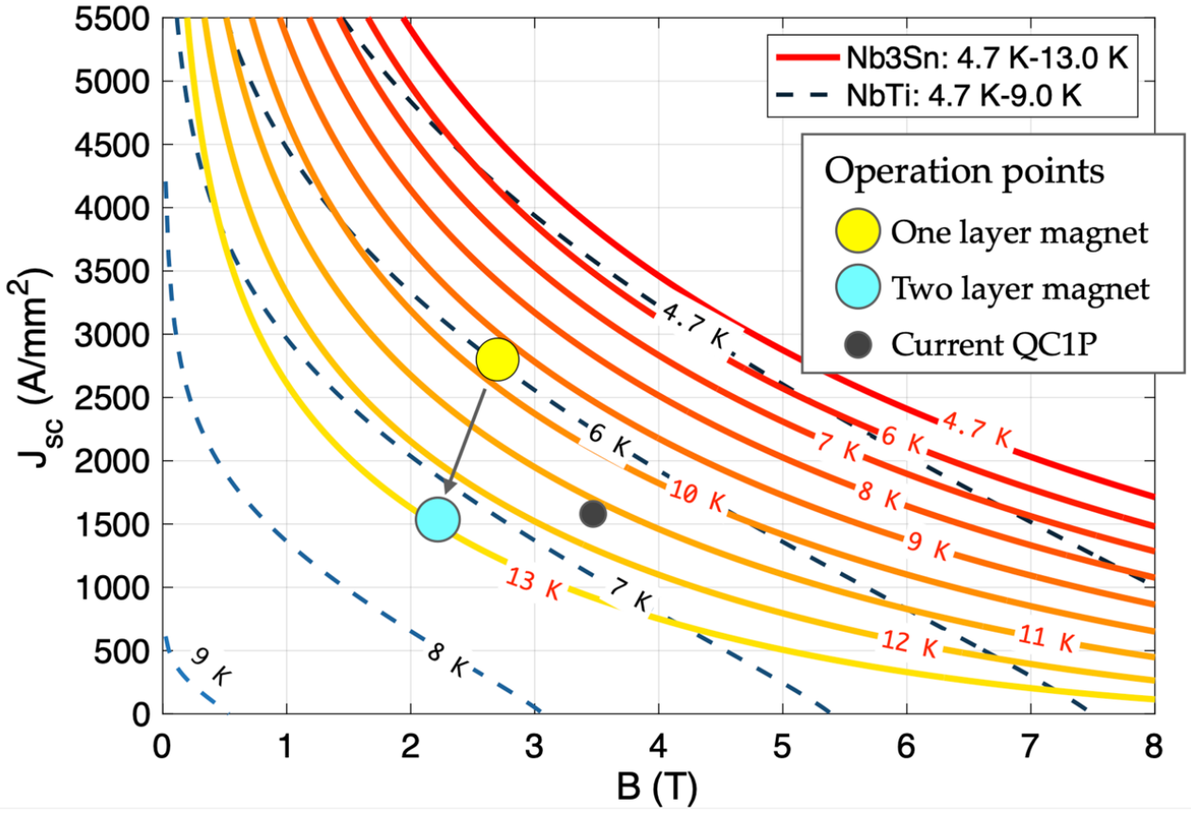


Limited space, need to produce thin coil with large packing factor

Ideally use new material (**Nb3Sn** versus **NbTi**) to gain larger quenching temperature margin

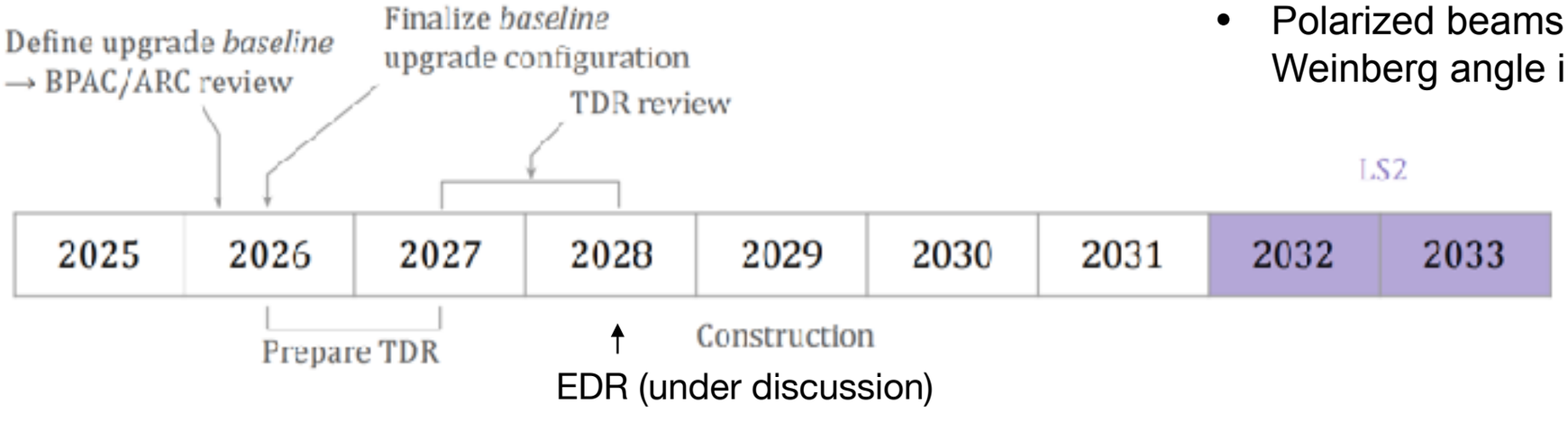
	New QC1P		New QC1P		Present QC1P
	Nb_3Sn		NbTi		
# of layer	1	2	1	2	2
Temp. margin	4K	8K	1K	2.5K	2K

Y. Arimoto @ARC Dec. 2024



Belle II Upgrade Program

Timeline:



Upgrade intends to push the state-of-the-art, e.g.

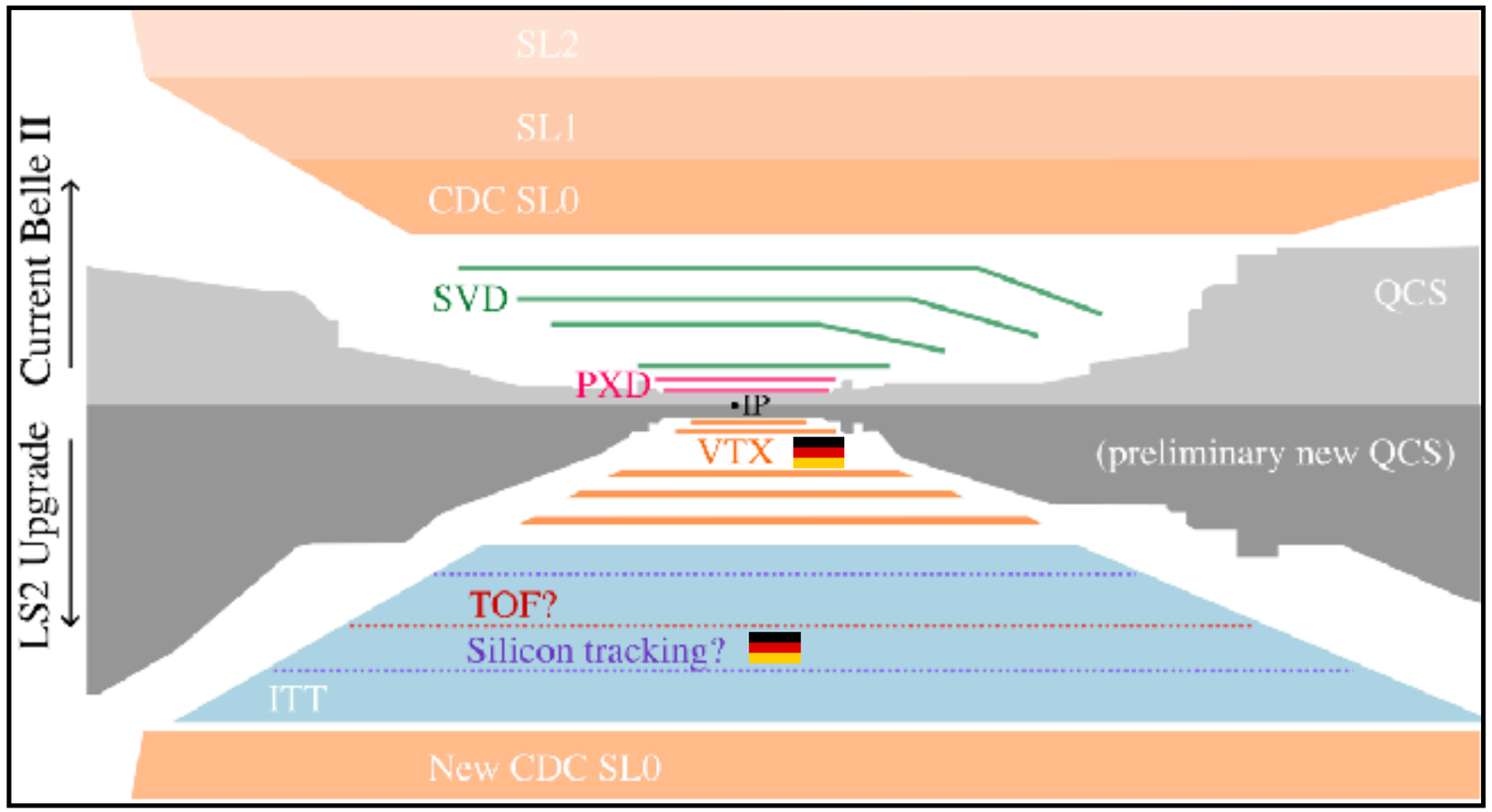
- CMOS-based pixel and strip detectors
- Polarized beams for measurement of Weinberg angle in running region

Upgrade Working Scenario:

- QCS envelope change
- **VTX** (5 layers)
- **ITT** (TOF = Time of Flight, **STL = Strip Transition Layer)**
- CDC replacement w/o SL0/1
- ECL electronics
- TOP electronics & PMTs
- KLM New RPC frontend
- Trigger
- ChiralBelle

= German Groups are **interested** in **participating**

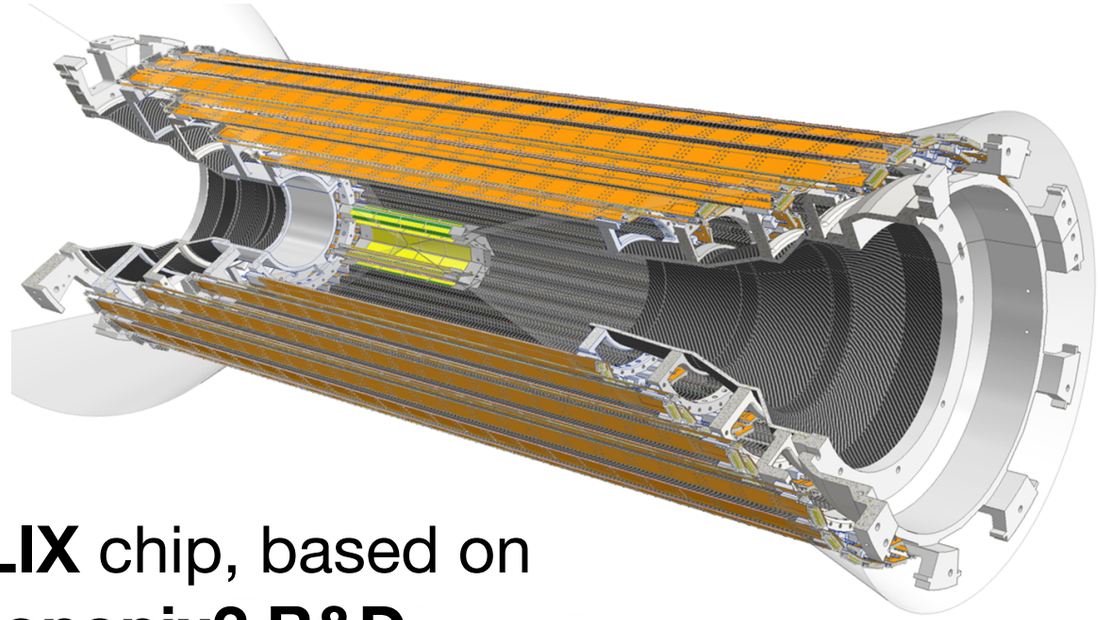
Costs: ca. 40 Mio. € / 7.2 BYen

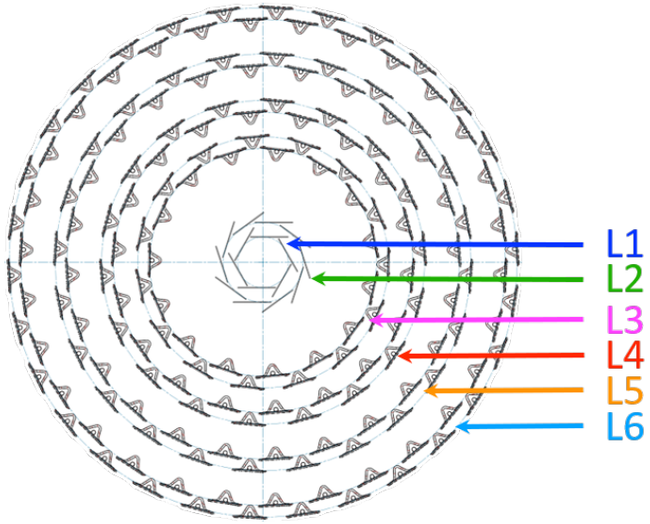


Belle II Vertex Detector Upgrade: VTX

Hit rate up to 120 MHz / cm²
Fast time stamping 50 - 100 ns
Resolution < 15 μm → pitch of 30-40 μm
TID ~ 1 MGy
NIEL fluence ~ 5×10^{14} neq/cm²
200-300 mW/cm²
Total material budget < 3.5% X_0

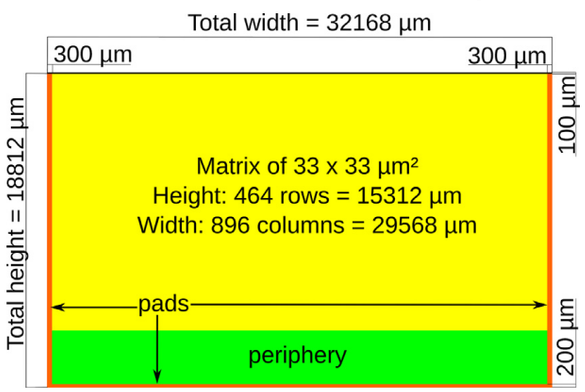
CMOS DMAPS based new vertex detector, building on BMFTR and German R&D → cf. Talk from Jochen Dingfelder



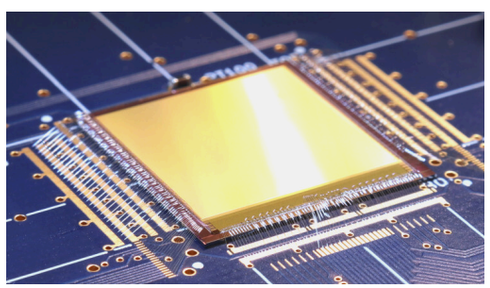


OBELIX chip, based on **TJ-Monopix2 R&D** first submission imminent

Sketch of OBELIX chip

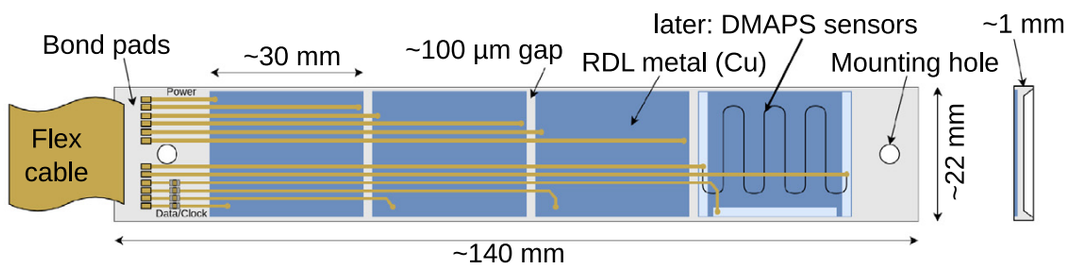


TJMonopix2



2 Inner layers (iVTX) 16 ladders with 4 sensors each

Full silicon modules



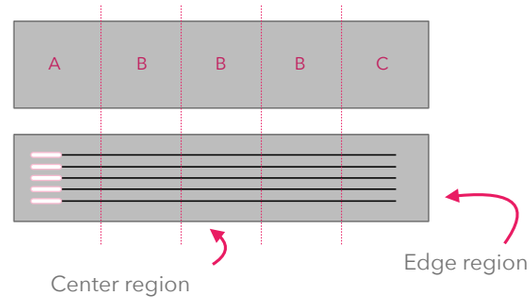
3-4 Outer layers (oVTX)

VTX collaboration forming (More official steps will be taken in December meeting in Pisa)

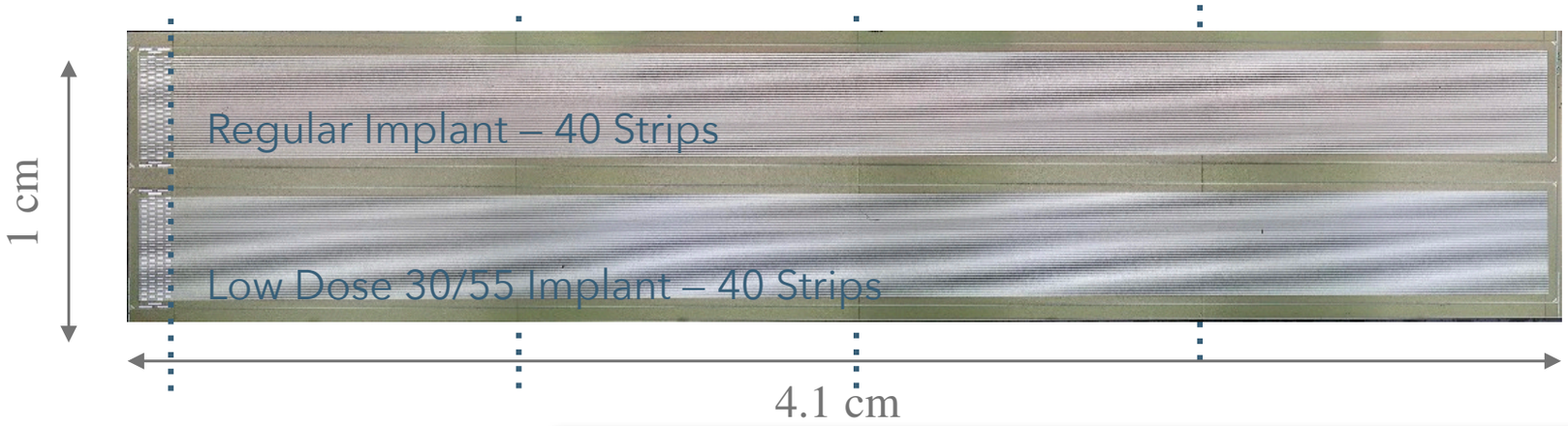
Belle II CMOS Strip Transition Layer: STL

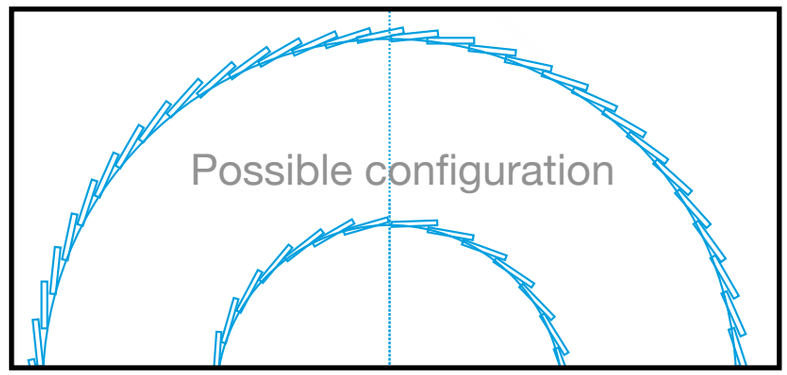
Requirements: (WIP)
Hit rate up to 30 MHz / cm²
Fast time stamping 50 - 100 ns
TID ~ 0.25 MGy
NIEL fluence ~ 1.5×10^{14} neq/cm²
200-300 mW/cm²
Total material budget < 1-2% X_0

CMOS strip detectors to instrument former inner drift chamber layers along with timing detector, building on BMFTR and German R&D → cf. Talk from Jochen Dingfelder



150 nm LFoundry passive prototype Pitch 75.5 um, Thickness 150 um

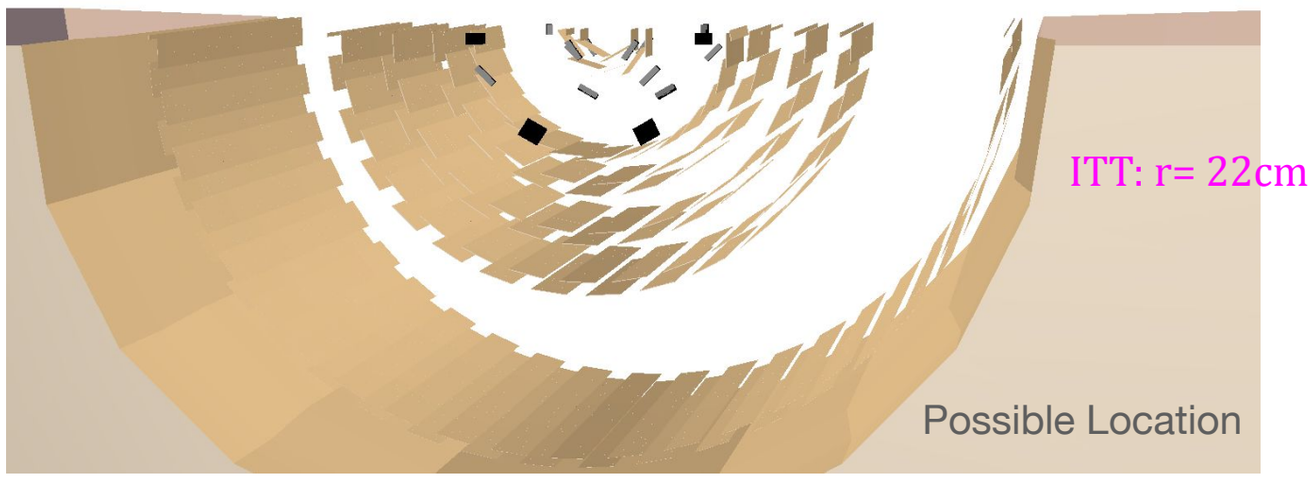




Up to 5 stitches have been successfully used to achieve strip lengths of up to 4.1 cm

More detailed studies with full-silicon sensor prototypes planned next year
(by Dortmund, Bonn, DESY, Freiburg)

Belle II studying **placement** and tracking **performance**



German and **international Groups** interested in project (In discussions with Valencia, Nikhef)

Partners for the next Funding Period

German Universities

Bonn, KIT, Mainz, LMU, Göttingen, Gießen

are interested in continuing LS2 Upgrade Activities on VTX, STL and Trigger + Continued Operation of PXD and other activities

New **Dortmund** (Prof. Kevin Kröninger, maybe NN)

Interested in contributing to silicon strip / STL

Bonn new Professorship planned color meets flavor

Project partners of *ongoing* funding period

Projektpartner	
(Bemerkung: Die jeweiligen **Projektleiter** sind in Fettdruck markiert.)	
Rheinische Friedrich-Wilhelms-Universität Bonn	**Prof. Dr. Florian Bernlochner** Prof. Dr. Jochen Dingfelder **Prof. Dr. Slavomira Stefkova** Dr. Markus Prim
Justus-Liebig-Universität Gießen	**Apl. Prof. Dr. Sören Lange** Prof. Dr. Claudia Höhne
Georg-August-Universität Göttingen	**Prof. Dr. Ariane Frey**
Karlsruhe Institut für Technologie (KIT)	**Prof. Dr. Torben Ferber** Dr. Pablo Goldenzweig Prof. Dr. Frank Simon Prof. Dr. Jürgen Becker
Johannes Gutenberg-Universität Mainz	**Prof. Dr. Concettina Sfienti** Prof. Dr. Wolfgang Gradl
Ludwigs-Maximilians-Universität München	**Prof. Dr. Thomas Kuhr**
Deutsches Elektronen-Synchrotron	**Dr. Armine Rostomyan** Dr. Carsten Niebuhr Prof. Dr. Kerstin Tackmann Jun.-Prof. Dr. Thibaud Humair
Halbleiterlabor der Max-Planck-Gesellschaft	**Dr. Jelena Ninkovic**
Max-Planck-Institut für Physik München	**Dr. Hans-Günther Moser** Prof. Dr. Christian Kiesling

DESY Prof. Ulrich Husemann, Director of Particle Physics at DESY

DESY ist daran interessiert, die Möglichkeit eines Beitrags zum Belle II-Upgrade basierten auf der Performance von SuperKEKB und Belle II zu evaluieren. DESY betrachtet dabei eine Beteiligung im Bereich der geplanten CMOS-Strip- (oder Pixel-)Lagen in Kooperation mit weiteren deutschen Instituten nach Abschluss der Arbeiten an den HL-LHC-Detektoren als vielversprechend und inhaltlich sehr gut anschlussfähig.

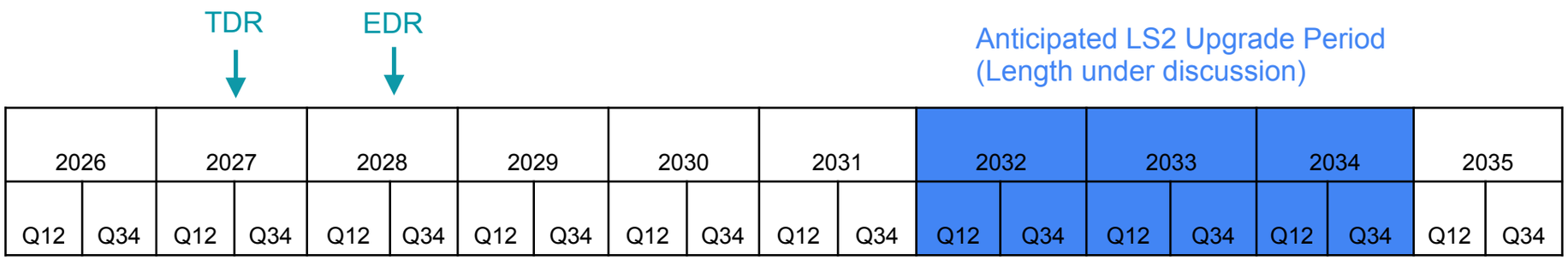
MPP / HLL More clear after new Director positions are filled

Core-Invest Needs for next Funding Period(s)

Current Belle II funding is ca. **6.5 Mio. € / period**

German Key **Upgrade Activities**: **VTX + STL + Trigger**

VTX	Total Cost 5.9 Mio. € 5 Layer Option	BMFTR Participation 20% 2027-2030 555 T €	1.18 Mio. € 2030-2033 625 T €
STL	Total Cost 3.7 Mio. €	BMFTR Participation 33% 2027-2030 560 T €	1.23 Mio. € 2030-2033 670 T €
Trigger	Total Cost 1.05 Mio. €	BMFTR Participation 20% 2027-2030 70 T €	0.21 Mio. € 2030-2033 140 T €



∑ 2.62 Mio. €

Split across funding periods

27-30 **1.185 Mio. €**

30-33 **1.435 Mio. €**

Dringlichkeit & Bundesinteresse

ESPP recommends **“full exploitation of flavor”**

German groups played significant part in the experiment in the past; intend to keep this role

Given the current timelines, **meaningful participation** in the upgrade only possible within the next two funding periods, with contribution needed in the 2027-2030 period

Japan is a long term **strong** and **reliable** partner in our international research landscape ; they are pivoting to also think of playing a role in future CERN projects (FCC-ILC collaborations)

Japan is **Wertepartner**, i.e. a democracy with joint interests on the global stage

The **full operational budget** for **SuperKEKB** is **provided** by **Japan**

Belle II upgrade transforms **important R&D lines** into tools that are needed to answer urgent scientific questions (cf. ESPP assessment on the impact of Flavor)

Connection to Hightech agenda via R&D, pixel and education of young talent

Without funding from the **Federal Ministry of Research, Technology, and Space** financing the **German activities** are **not possible** ; there exist no funding possibilities for the proposed research and upgrade activities from other institutions

Sustainability & Technology Transfer

Belle II is **actively working** in **evaluating &** committed to **reduce** its **carbon footprint**

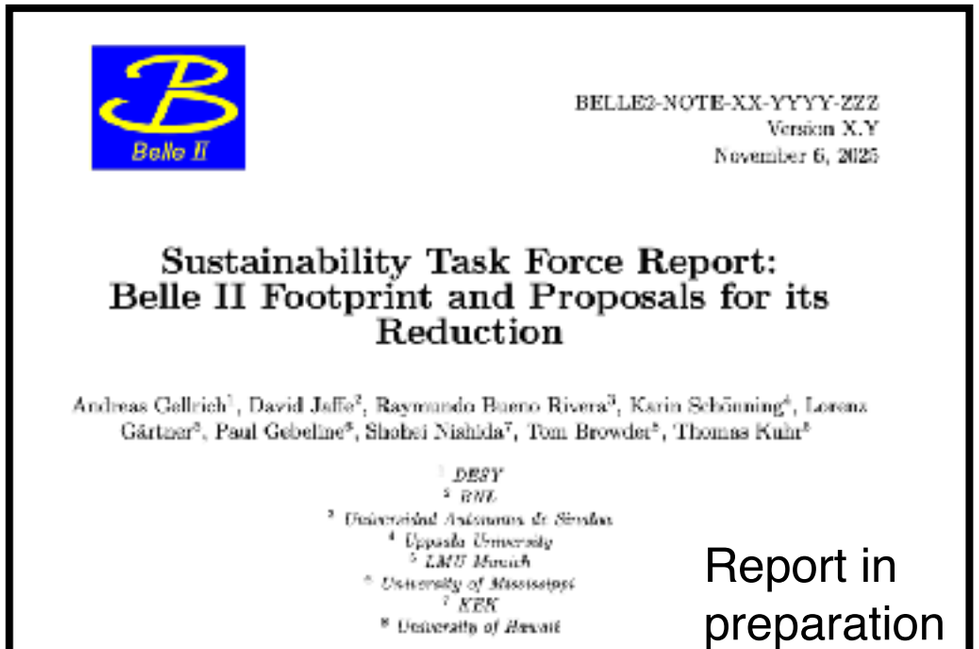
Sustainability Task Force

Mandate:

- Gather data to quantify the overall carbon footprint of our Belle II related activities;
- Propose measures to reduce emissions and improve sustainability to the management and the collaboration.

Members:

- Andreas Gellrich, David Jaffe, Raymundo Bueno Rivera, Karin Schönning, Lorenz Gärtner, Paul Gebeline, Shohei Nishida (KEK contact), Tom Browder, Thomas Kuhr (chair)



BELLE2-NOTE-XX-YYYY-ZZZ
Version X.Y
November 6, 2025

Sustainability Task Force Report: Belle II Footprint and Proposals for its Reduction

Andreas Gellrich[1], David Jaffe[2], Raymundo Bueno Rivera[3], Karin Schönning[4], Lorenz Gärtner[5], Paul Gebeline[6], Shohei Nishida[7], Tom Browder[8], Thomas Kuhr[5]

[1] DESY
[2] BNL
[3] Universidad Autónoma de Sinaloa
[4] Uppsala University
[5] LMU Munich
[6] University of Mississippi
[7] KEK
[8] University of Hawaii

Report in preparation

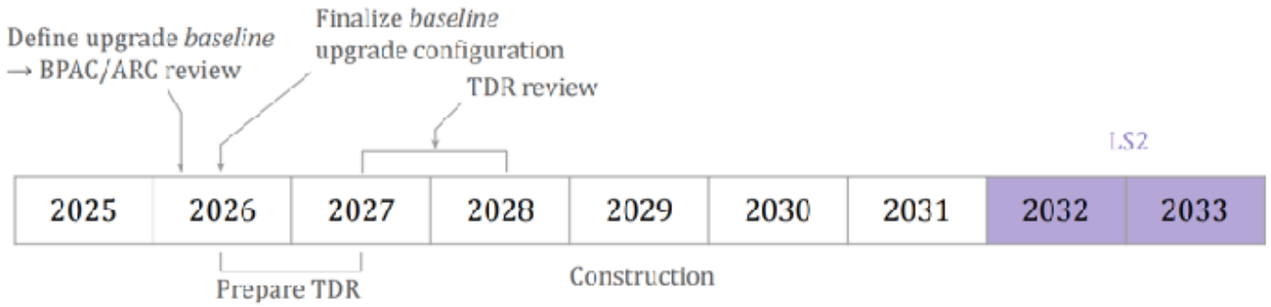
The technology developed as part of **FSP T09 Belle II and the Belle II Upgrade** have strong potential to be used **beyond particle physics.**

The DEPFET and CMOS sensor have excellent spatial resolution and low-noise performance, making them applicable for future accelerator experiments, X-ray satellite missions, autoradiography, digital radiography, and Free-Electron Laser (XFEL) applications. Other applications could be found in medical imaging (e.g. proton therapy and proton CT), for which high radiation tolerance is a must. Mature manufacturing could also enable broader spin-off innovations.

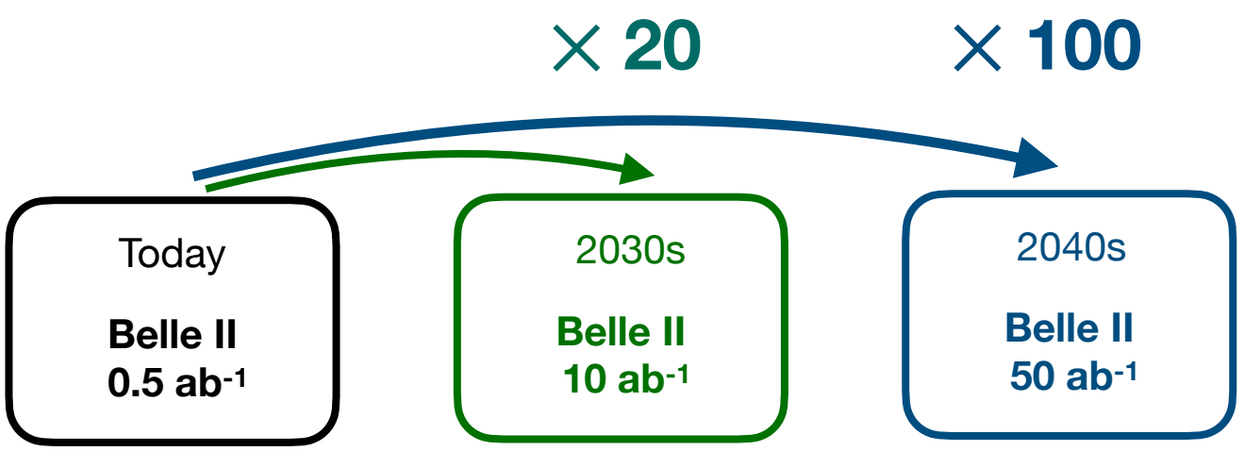
Summary

Belle II & SKB have **started operations** after summer shutdown ; in physics collisions ; goal is to **double data set** by Summer 2026

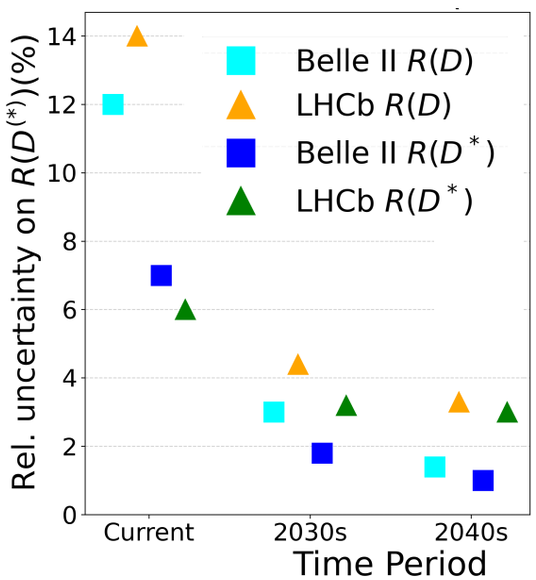
Both are pursuing upgrade by 2032 to prepare for high luminosity operation



Need federal funding to continue fulfilling German **pledges** to operate Belle II detector & **meaningful participate** in **upgrade**



[Source ESPP PBB]



Envisioned German contributions to core cost **2.62 Mio. €** **~1.2 Mio. € in 27-30**

Backup

Publications Meta-Analysis

Belle II only: 64
Belle II + Belle: 17
Belle only: 4

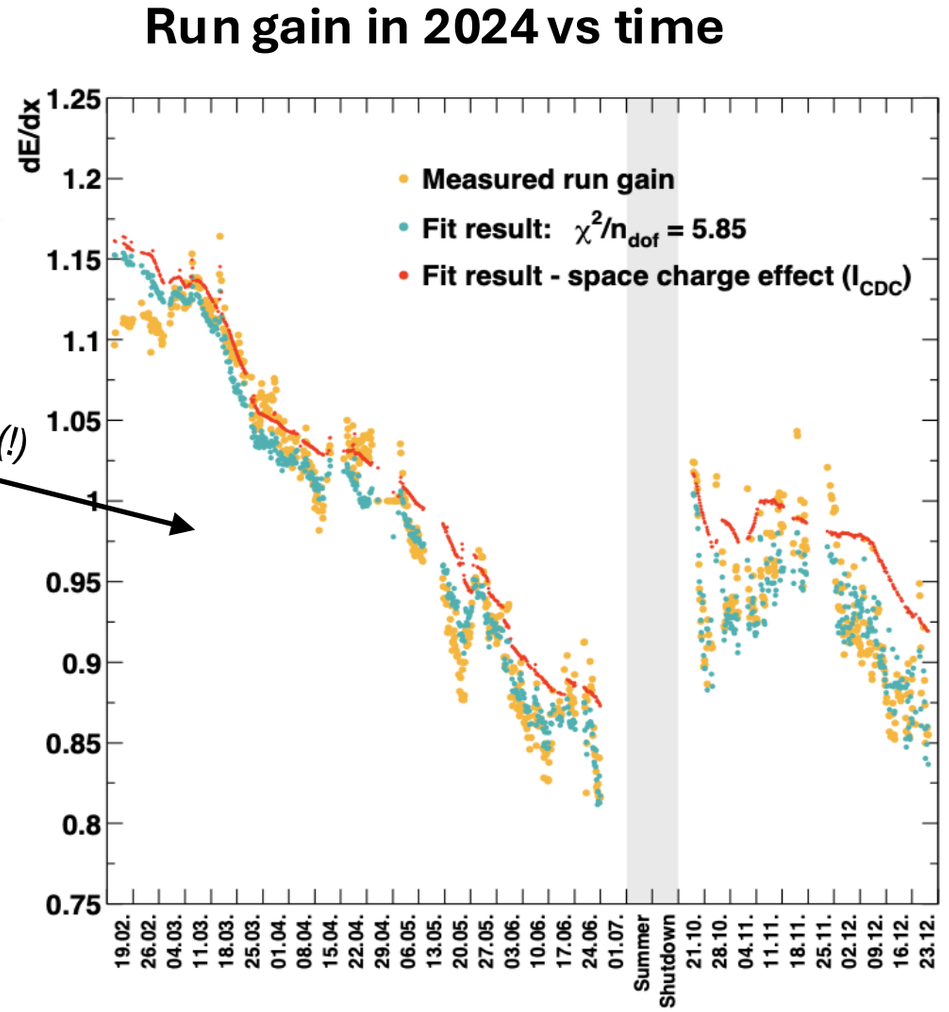
Topic	# of Publications	Dataset
b → s $\nu\nu$ / X	**1 PRL, 3 PRD**	Belle II
R(D/D*) & R(X)	**1 PRL, 2 PRD**	Belle II
Other LFU/LFV	**3 PRL, 1 PRD**	Belle II,
Dark Matter / Dark Photon / ALPs	**7 PRL, 1 PRD, 1 JHEP**	7 Belle II, 1 Belle
g-2	**1 PRD**	Belle II
Exotic and non-exotic Hadrons	**2 PRL, 1 PRD, 1 JHEP, 1 PRD (submitted)**	4 Belle II, 1 Belle + Belle II
Lifetimes	**3 PRL, 2 PRD**	Belle II

PRD: 41
PRL: 21
JHEP: 20
EPJC: 1
CPC: 1

CDC Status

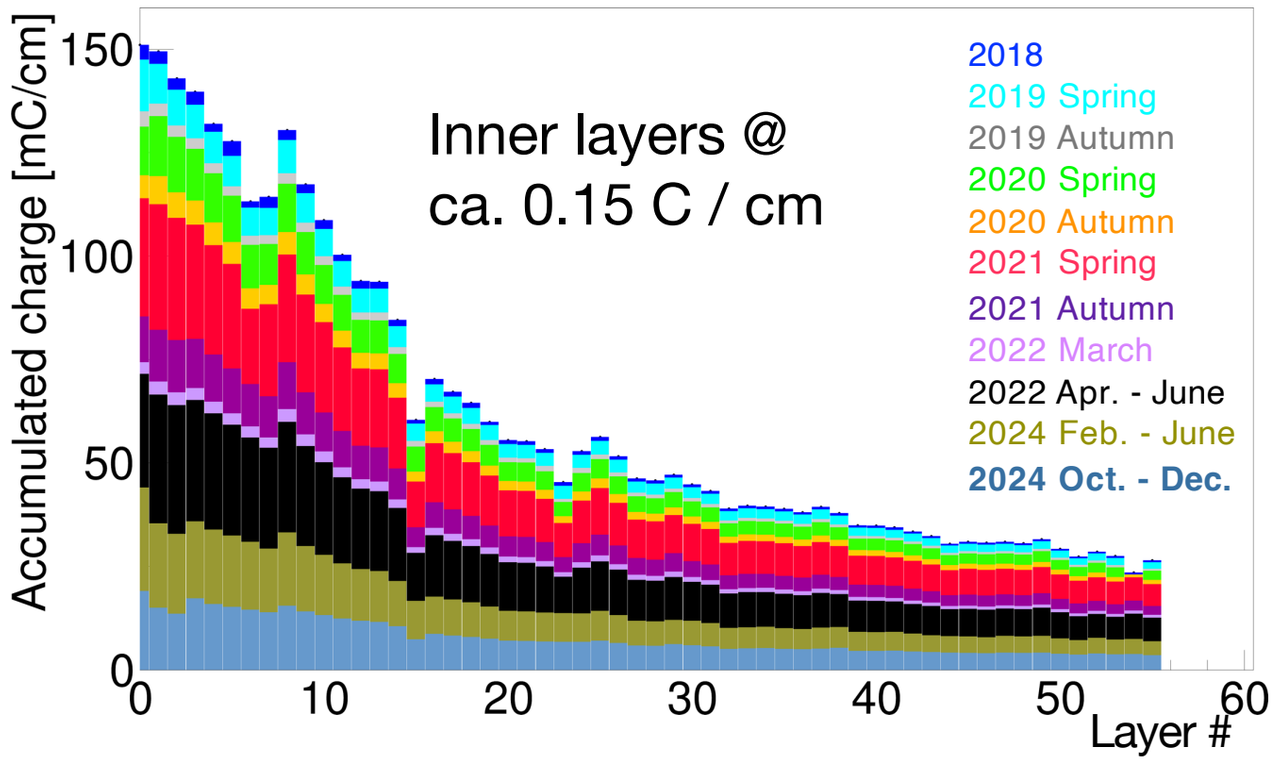
Observed significant gain drop & instabilities that affect performance

Gain does depend on **Gas conditions**, **background**, **contaminations**, **aging effects**



See indications that **aging** progressing **faster than expected**

Dedicated cosmic run ongoing with controlled gas conditions to clarify situation



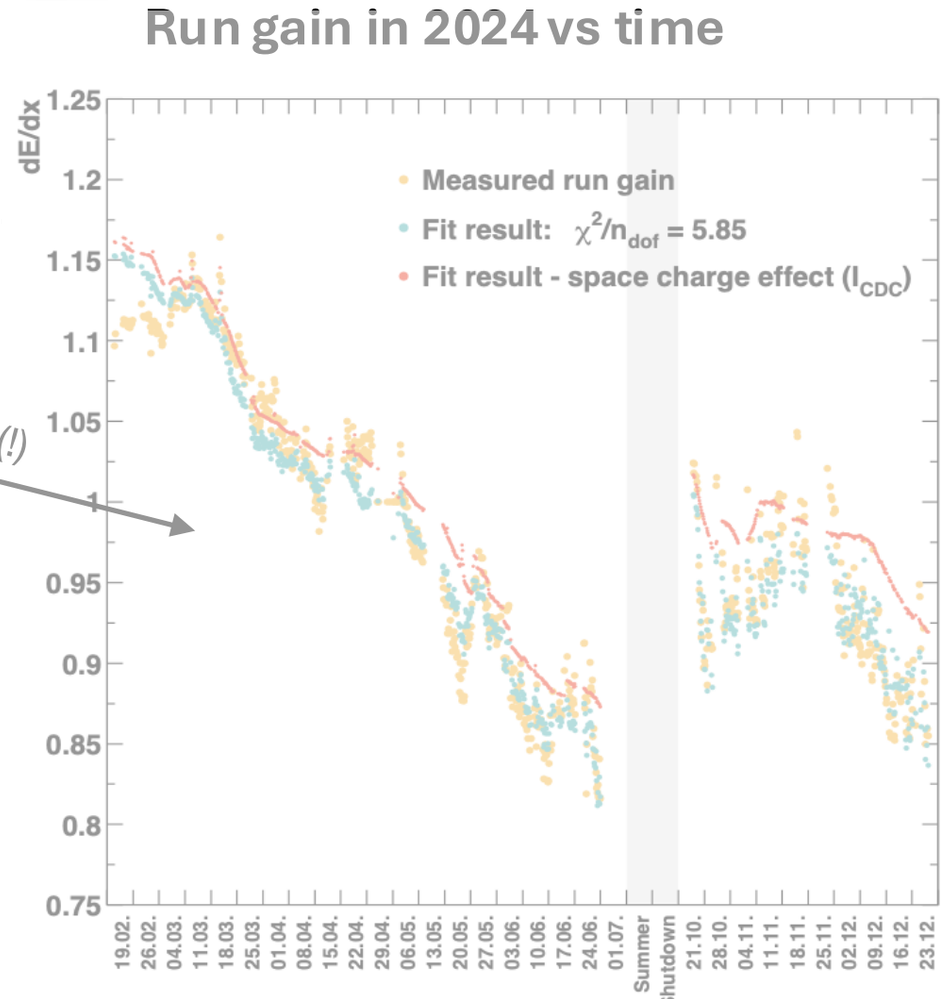
→ **Expect ~6% gain drop at 1 C / cm**

Estimated from Belle drift chamber

CDC Status

Observed significant gain drop & instabilities that affect performance

Gain does depend on **Gas conditions**, **background**, **contaminations**, **aging effects**



Single run (!)

See indications that **aging** progressing **faster than expected**

Dedicated cosmic run ongoing with controlled gas conditions to clarify situation

→ Prepare for **lower HV operation** to **reduce risk of Malter & aging**

Performance impact of this under study

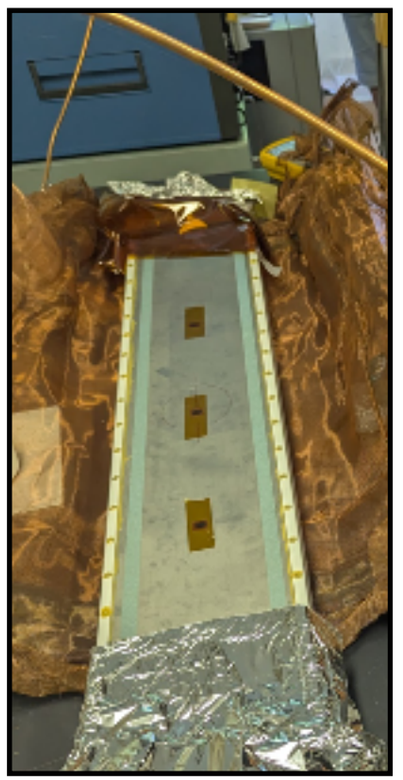
Change entire gas volume in under 3 days, instead of 28 days

→ **Increase gas flow** by **factor of 10 & cosmic studies**

→ **Aging** studies with **test chamber ongoing**

Investigations if intense electron beam facility at Tohoku University can be used for irradiation

Effort to engage new groups ongoing (IHEP, Bonn gas detector group, Hawaii, UPenn, …)



VTX Cost Estimate

Total Cost for different options

	Sensors	Ladders	Assembly	System	Instal	TOTAL
5 layers	1,600	2,000	800	1,400	100	**5,900**
6 layers	1,800	2,500	800	1,700	100	**6,600**

Unit = k€

Time profile for 5 layers With 10% contingency costs

S1 2028	S2 2028	S1 2029	S2 2029	S1 2030	S2 2030	S1 2031	S1 2031	S1 2032	S2 2032
895	0	270	895	180	535	2,415	535	90	90

Sensor pre-prod

Sensor prod

System parts 1/2

Ladder struct. fab

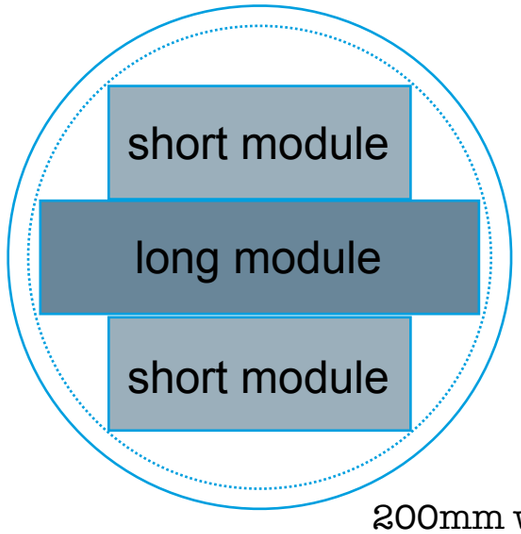
System parts 2/2

Cost Split

Austria	China	France	Germany	Italy	Japan	Spain	UK
10%	10%	20%	20%	20%	10%	10%	10%
590	590	1180	1180	1180	590	590	590

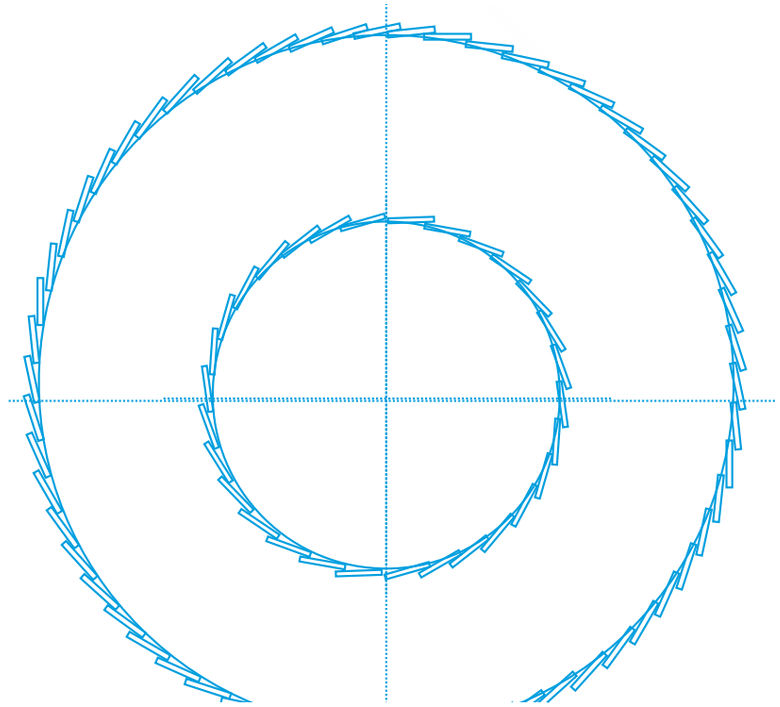
= 110% to cover contingency costs

STL Cost Estimate



200mm wafer

Radius	Length	Staves	Modules
17 cm	0,85m	30	**6x30**
34 cm	1,58 m	60	**11x60**



Long stave for outer layer

Short stave for inner layer

Total cost: **ca. 3.7 Mio €**

- Silicon
  - 1680 modules (both versions) plus 20% yield results in about 670 wafers
  - 160k Submission x 2 = 320kEUR
  - Production 3,5kEUR per Wafer -> 2,35 Mio
- Assembly/testing of sensor-modules (sensors=modules)
  - 100kEUR
- Power boards and bus tapes
  - 100kEUR
- Staves (carbon structure with kapton tapes on top)
  - 250kEUR
- Global support
  - 150kEUR
- Power Supplies & air Cooling etc
  - 400kEUR

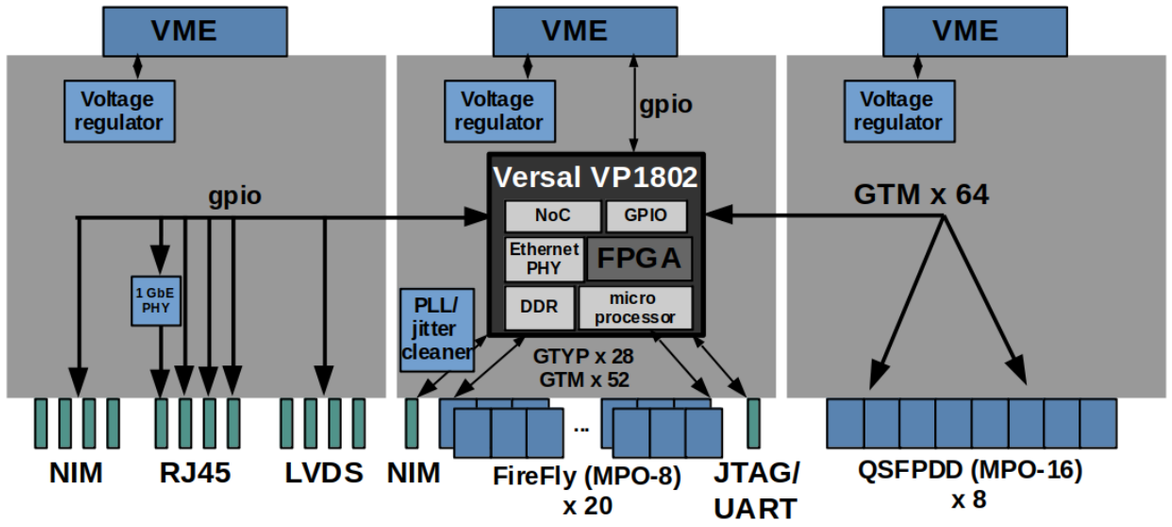
Trigger Board Cost Estimates

Belle II UT3

Belle II UT4

New design: UT5

Preliminary block diagram



And for LS2: **UT6 board**

Require 15 boards with a cost of ca. 70 k€ per board

→ German contribution **20%** (3 boards) **= 210 k€**