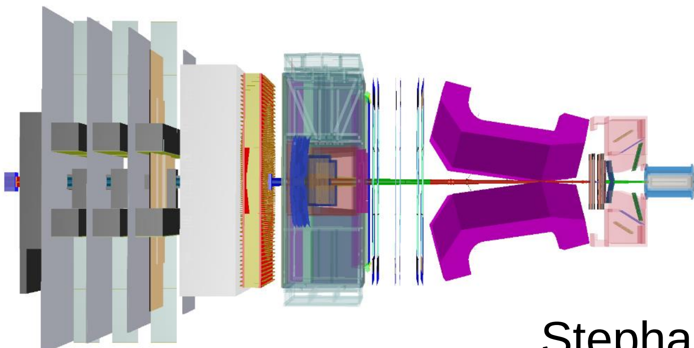
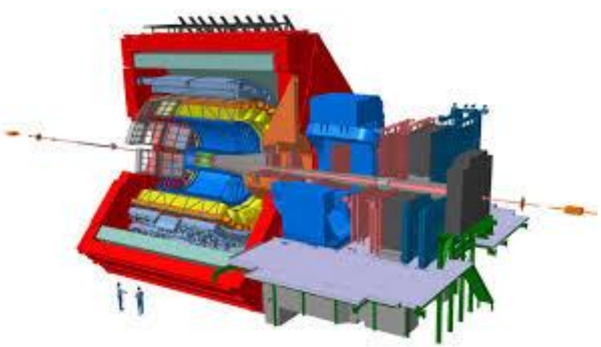
UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

Exploiting the full potential of the LHC and the HL-LHC

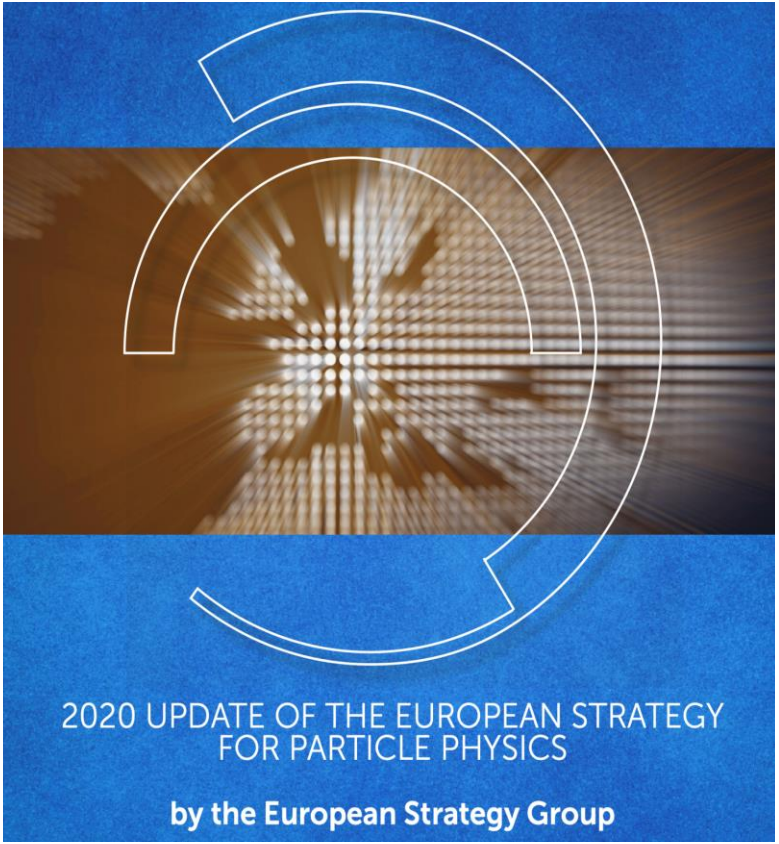


Stephanie Hansmann-Menzemer
with input from
Wolfgang Wagner, Alexander Schmidt, Laura Fabbietti



German strategy workshop
The future of collider physics
DESY, Nov 27-29 2024

European Strategy 2020



„The successful completion on the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques. The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited."

Time Scale – The Past

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

Run 1 | LS1 | Run 2 | LS2 | Run 3

L_{peak} = 7.5 x 10^{33} $cm^{-2}s^{-1}$

(delivered to ATLAS and CMS)

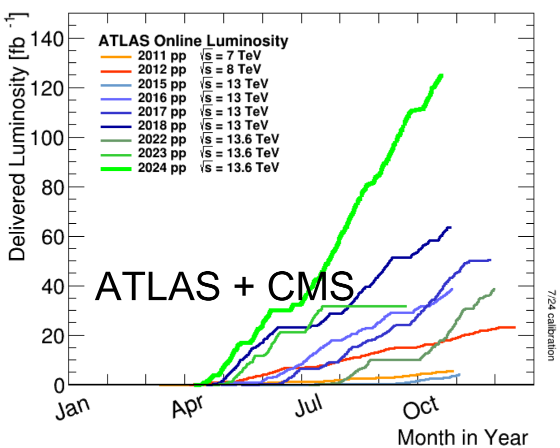
L_{peak} = 2 x 10^{34} $cm^{-2}s^{-1}$

LHC Phase-I upgrade
of the machine

medium upgrade for ALICE, ATLAS
and CMS, significant upgrades for LHCb

today

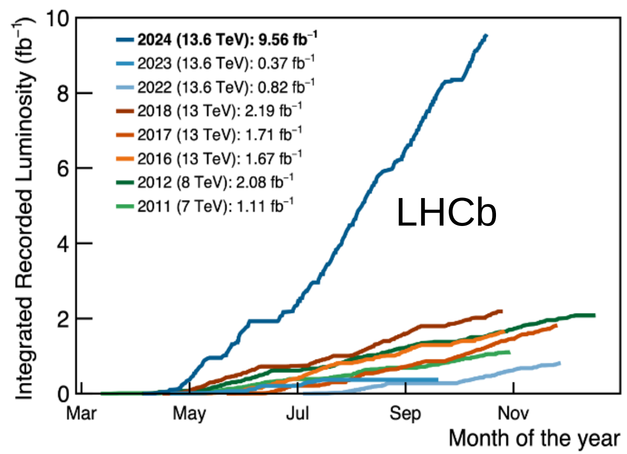
Data taking in 2024 delivered for all experiments more data than in Run1+Run2 together.



L_{int} ~300 fb^{-1}

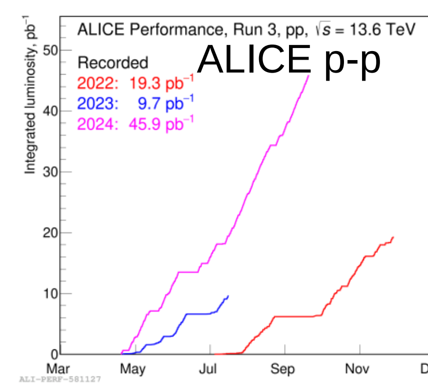
L_{int} ~18 fb^{-1}

(not running at same peak luminosity as ATLAS and CMS)

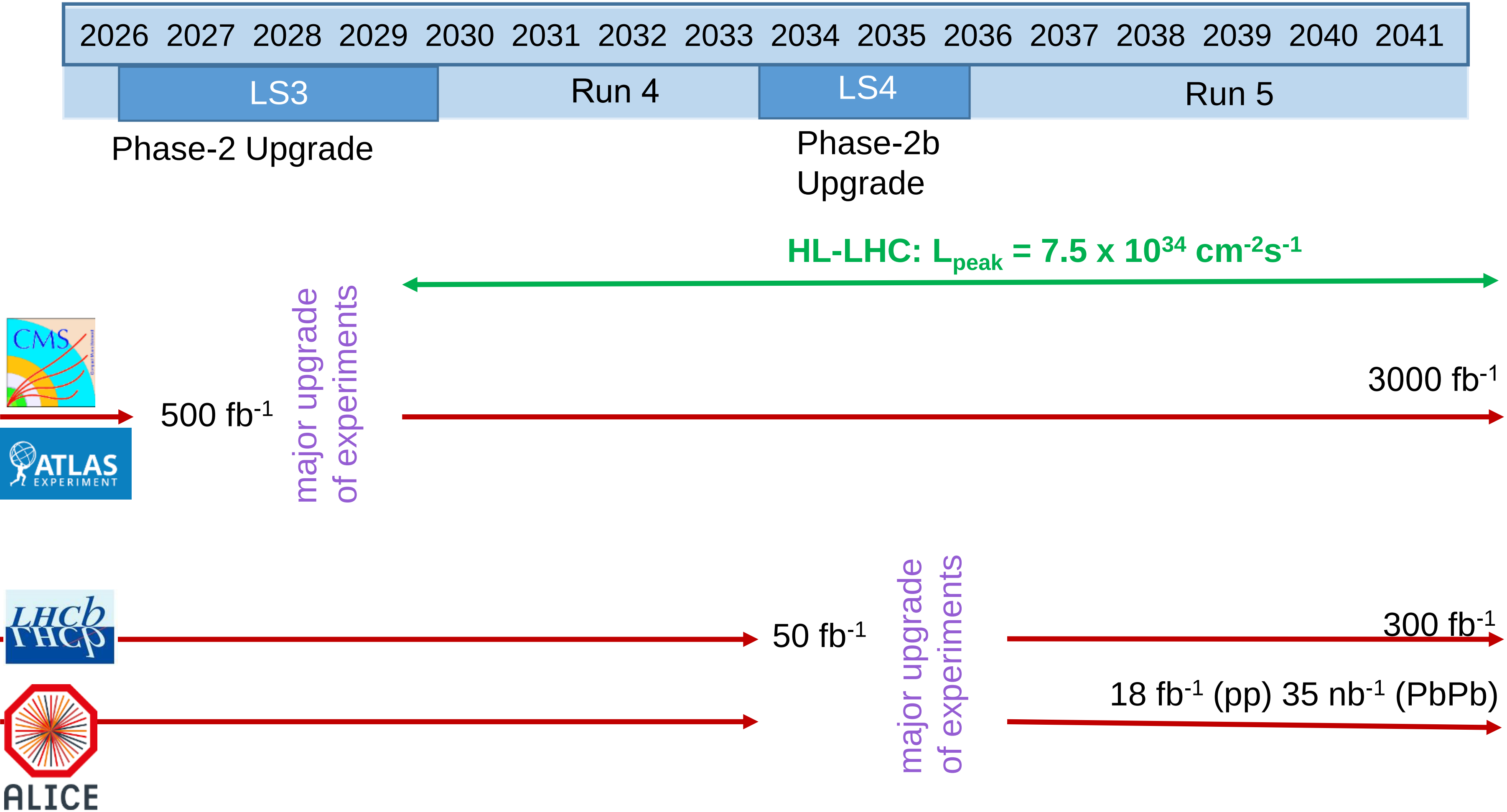


L_{int-pp} ~96 pb^{-1}

$L_{int-PbPb}$ ~ 3.7 nb^{-1}

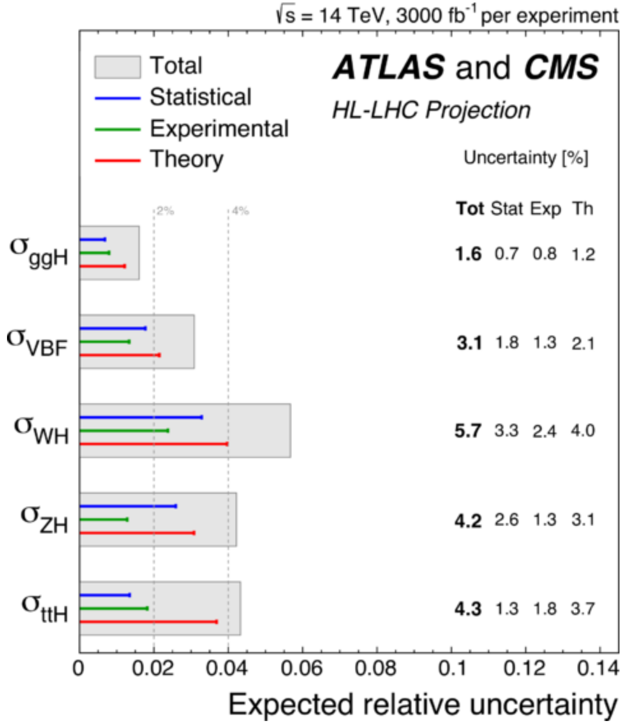


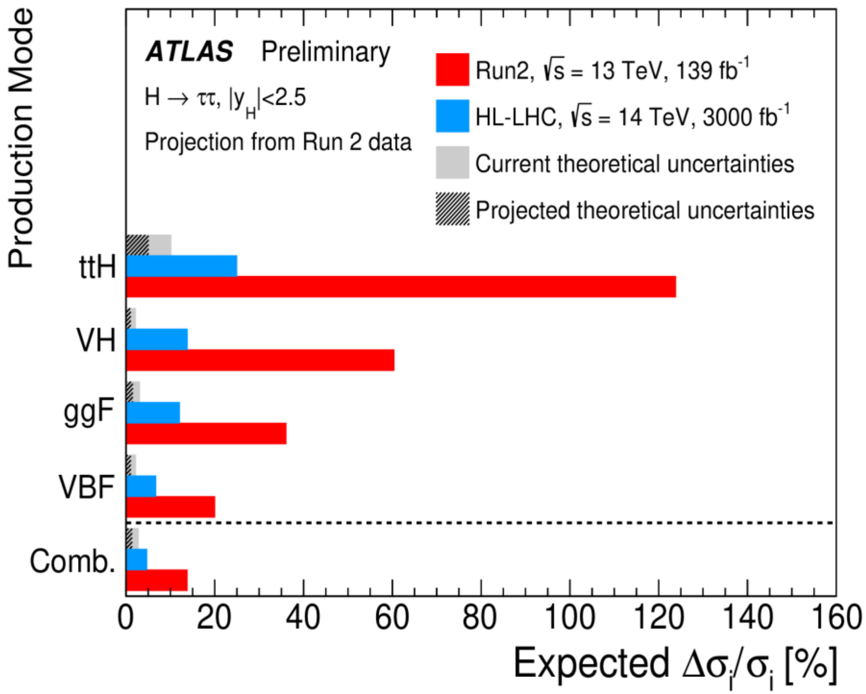
Time Scale – The Future



We are only at the very beginning of a very exciting LHC physics programme.
More than 10 times more data still to come for all four experiments.

Phase-2 Upgrade: Huge Physics Potential





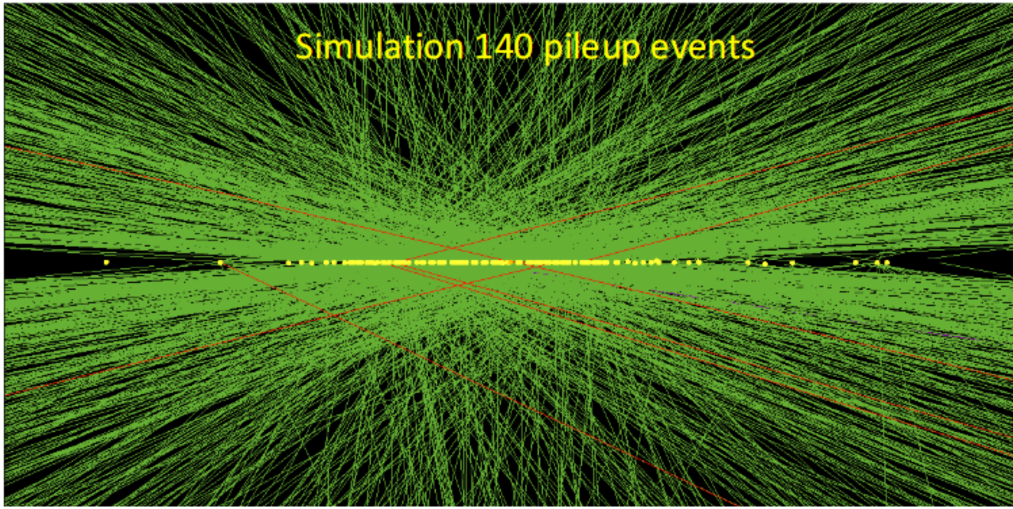
Many more exciting physics sensitivity projections in yesterdays talk.

Phase-2 Upgrade: Huge Technical Callenge

- Peak luminosity 7.5 x 10^{34} cm^{-2} s^{-1} (about 3.5 x times compared to LHC)
- Up to 200 events per bunch crossing (pile up)

- Higher particle and track densities
- Increased radiation levels

- Highly segmented detectors needed
- Increased readout bandwidth
- More selective triggers
- Radiation hard solutions required



To achieve the same efficiency/quality despite the harscher conditions is already a challenge.

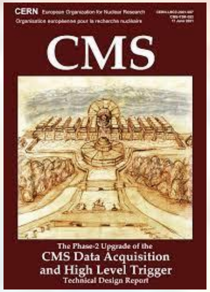
But aim for more than luminosity scaling

CMS Phase-2 Upgrade

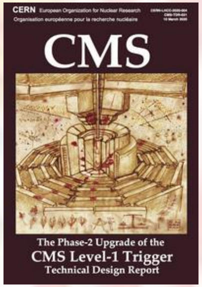
- LoI in 2012
  Technical Proposal + Scoping Document in 2015
  followed by TDRs 2017-2022


CERN-LHCC-2015-10
LHCC-P-008
CMS-TDR-15-02
ISBN 978-92-9083-417-5
1 June 2015

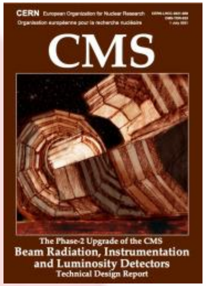
TECHNICAL PROPOSAL
FOR THE
PHASE-II UPGRADE
OF THE
COMPACT MUON SOLENOID



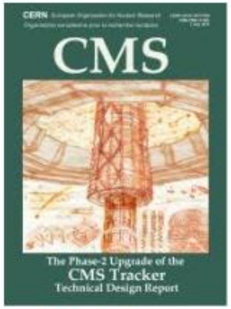
HLT & DAQ



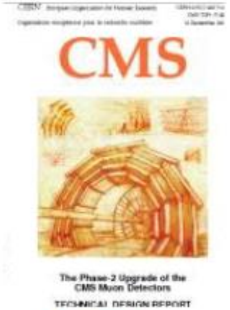
Level 1 Trigger



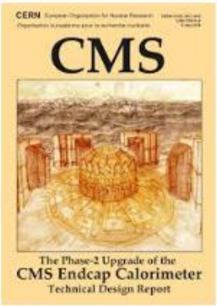
BRIL: Beam radiation, Instrumetnation, lumi



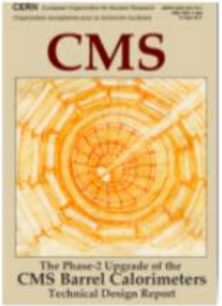
Tracker



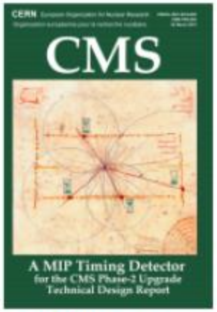
Muons



Endcap Calo.



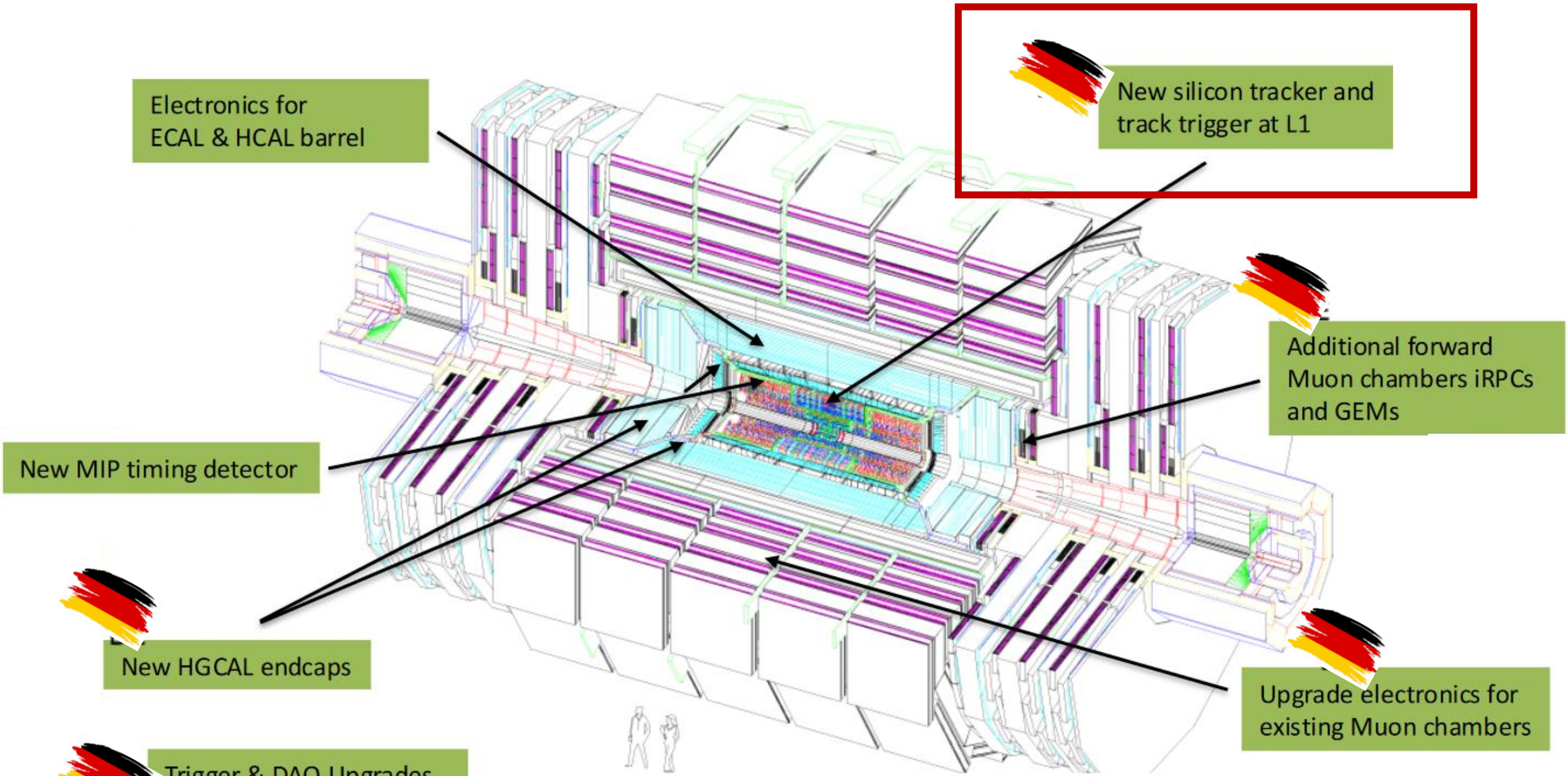
Barrel Calo.



MIP Timing

18 years from LoI to start of data taking In 2030 for a major upgrade of an already established collaboration

CMS Phase 2 Upgrade



Upgrade coordinator: Frank Hartmann (KIT)

CMS Tracker for Phase-2 Upgrade

Current CMS tracker will reach end of its lifetime after Run 3 (500 fb-1)

New tracker

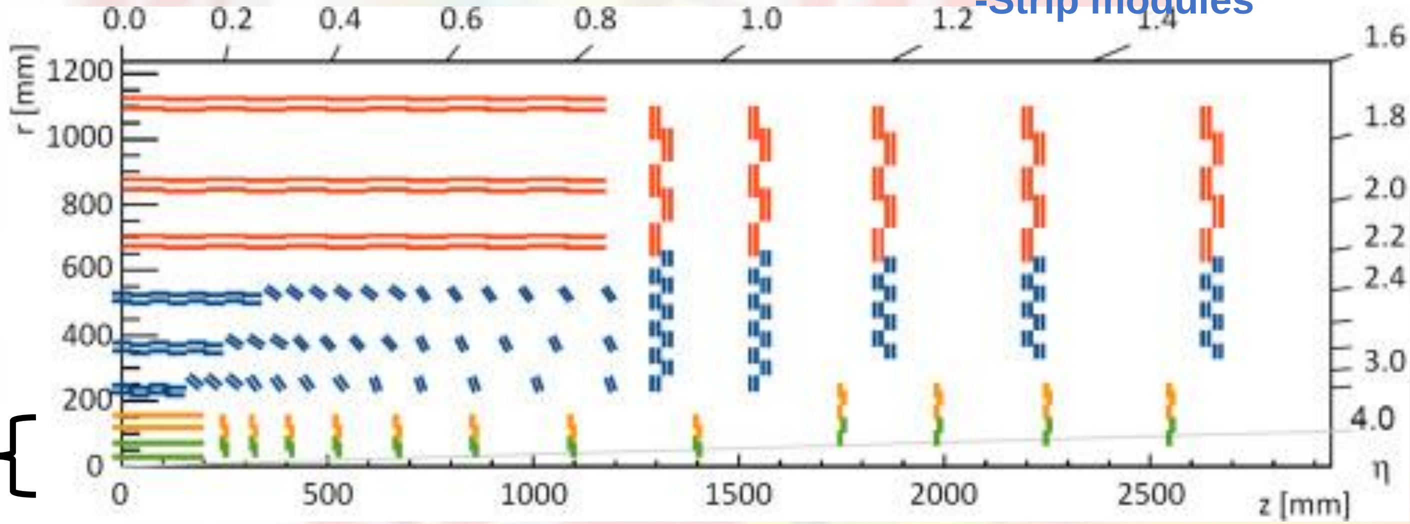
- Able to operate at up to 7.5 10^{34} $cm^{-2}s^{-1}$
- Radiation tolerance up to 1.9 10^{16} 1 MeV neq cm^{-2}
- Acceptance up to $|\eta| < 4$
- Level 1 Tracker Trigger using OT

7608 Strip-Strip modules

5592 Macro-Pixel -Strip modules

OT
190 m²
213 M channels

IT
5 m²
1.9 G channels

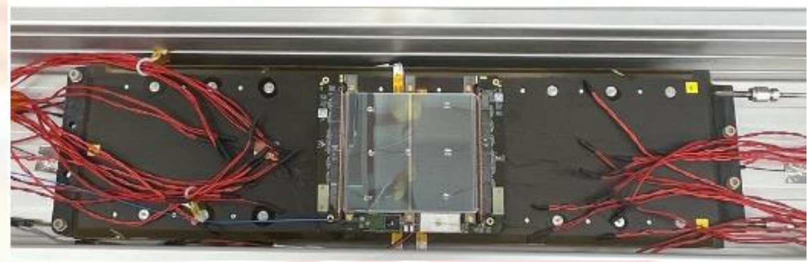


3892 Pixel-Modules
1x2 and 2x2 readout chips

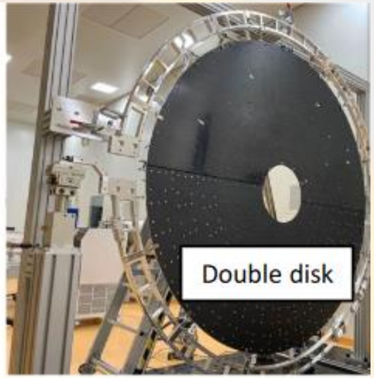
CMS Tracker for Phase-2 Upgrade

Hamburg: Inner Tracker Endcap Pixel (TEPX) Module production

Aachen: OuterTracker Endcap Double Disks (TEDD) Module production and test



DESY: Outer Tracker Module and encap intergration



KIT: Quality Controll OuterTracker Module assembly, system tests, and DAQ boards

Funding-Matrix (status 2021)

BMBF + Helmholtz

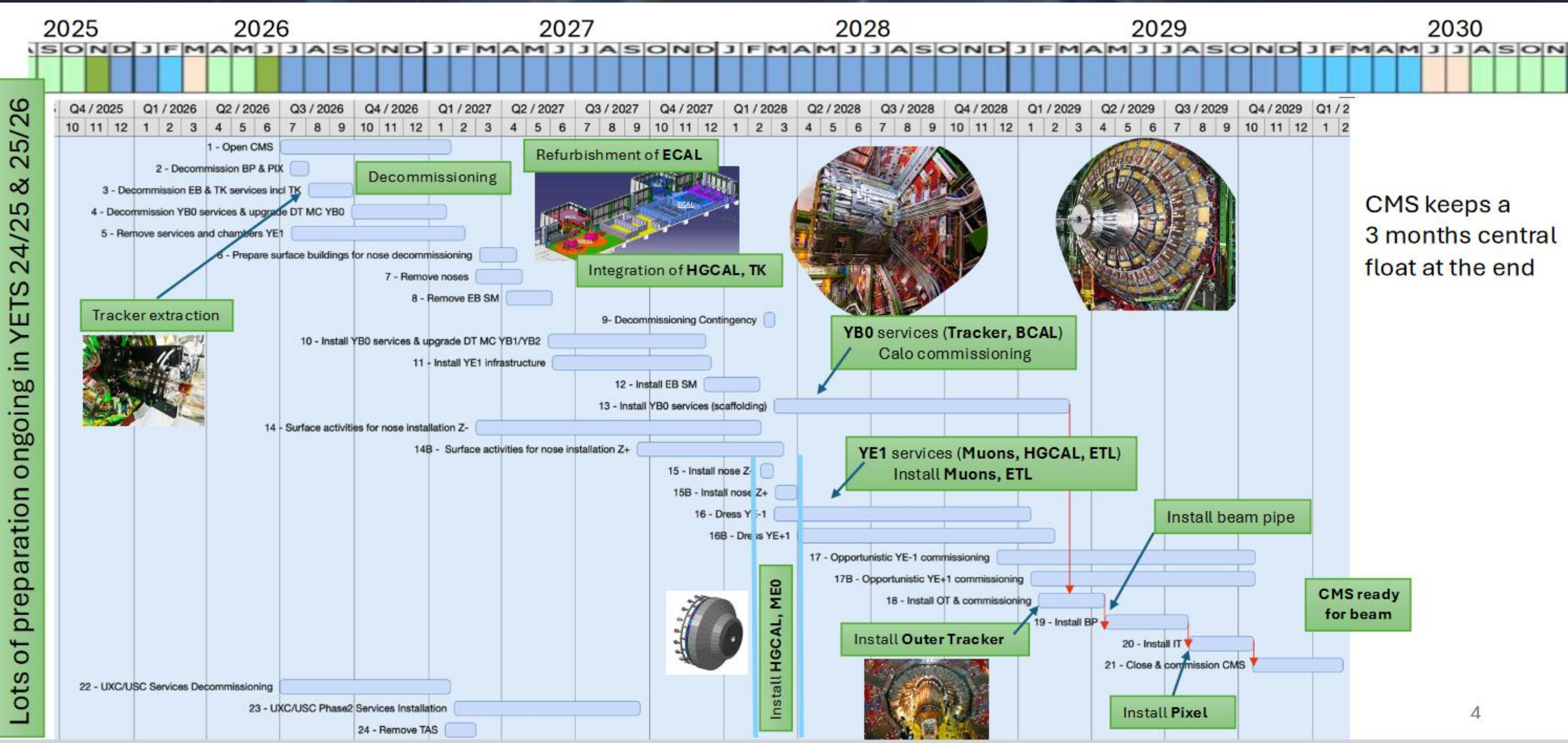
subsystem	Total [kCHF]	German contribution [kCHF]
Endcap-Calo	67.125	100
Barrel-CALO	13.255	
Muons	25.187	1.920
Tracker	111.900	18.557
MID-TD	20.685	500
BRIL	2.600	
L1-Trigger	7.058	
DAQ/HLT	10.737	
Common funds	25.000	2.120
Total	**283.549**	**24.590**

- 4800 members, 247 institutes
- Significant German contributions to the Tracker
- German contribution 8.7% funded via FIS (about half from Helmholtz, half from BMBF)
- Increase of costs compared to original proposal due to inflation, corona and war in the Ukraine

Status of today:
25% of the project costs have been spent
62% of all procurements have been contracted (which makes future planing more reliable)

True for all LHC-experiments:
Costs for staff are about factor 2-4 higher than invest costs.
Typically they are shared about 1:1 between BMBF and Universities.

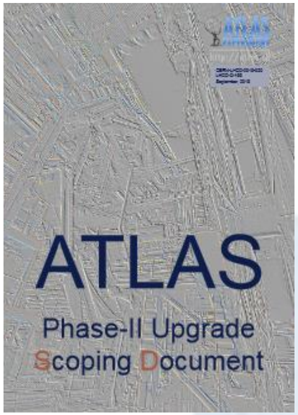
Shedule for CMS Phase-2 Upgrade



Tight shedule (despite the shift of start of Run 4 by one year), detector components need to be ready mid 2026 to start installation, only 3 months contingency.

LHCC strongly recommends to put priority on finishing the Phase-2 Upgrade in time, which at the same time means putting less priority on Run 3 operation, analysis and future upgrades.

ATLAS Phase-2 Upgrade

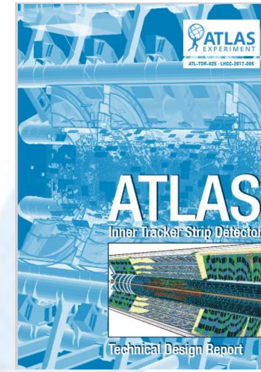


2015

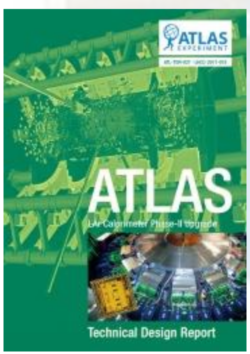
Time scale very similar to CMS

- 2012 LoI
- 2015 Scoping Document
- TDRs written 2017-2022

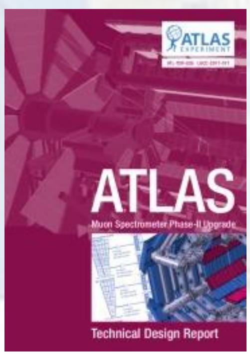
18 years from LoI to start data taking for a major upgrade of an established collaboration.



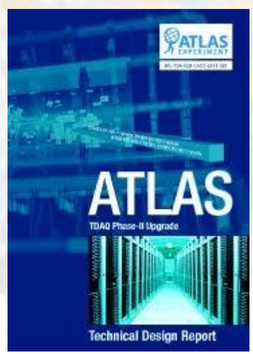
Inner Strip Detector



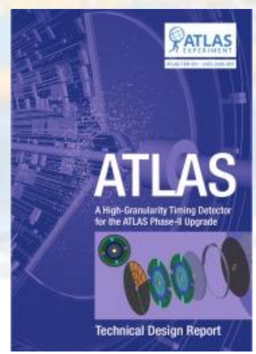
LAr Calo



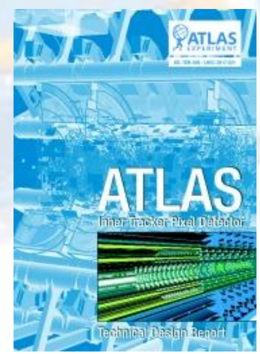
Muon Spektrometer



Trigger & DAQ



Timing Detector



Inner Pixel

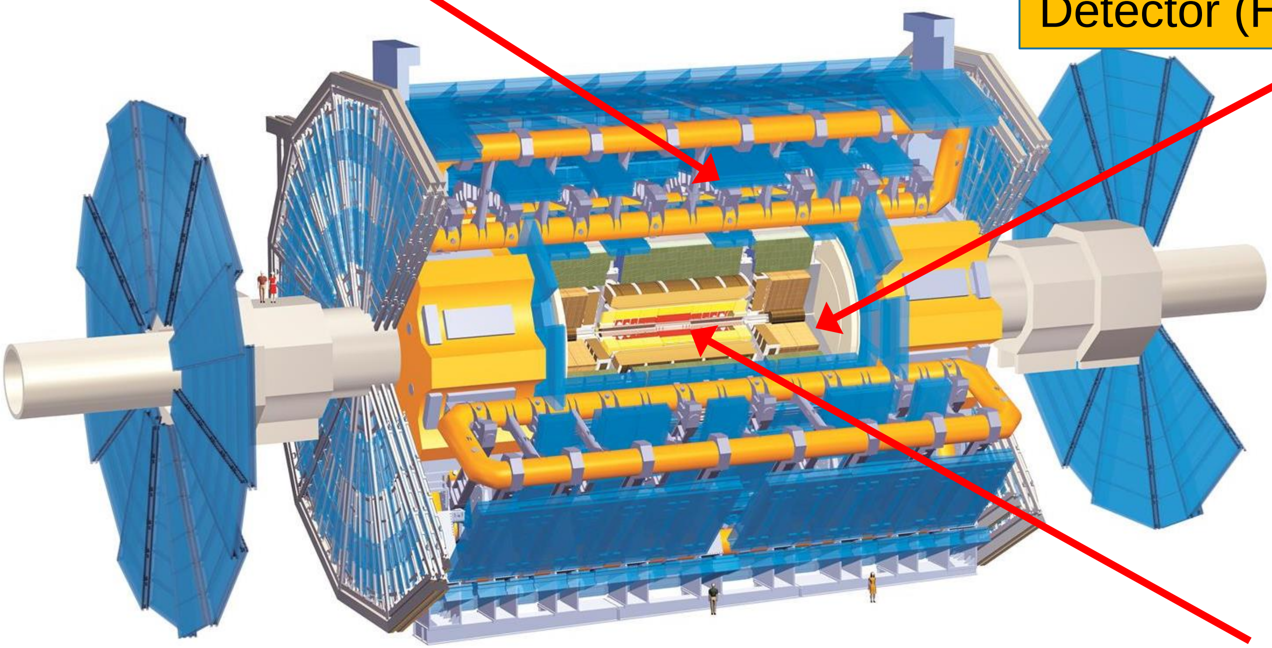
Tile Calo

ATLAS Phase-2 Upgrade

Trigger and DAQ
- Level-0-Trigger with 1 MHz

Muon system
- Resistive Plate Chambers
- Monitored Drift Tubes

High Granular Timing Detector (HGTD)



Electronic for calorimeter and muon detectors

Inner Tracker (ITk)
Silicon pixel + strips

Funding Matrix

including Helmholtz

Upgrade Project	CORE Costs [kCHF]	German contribution [kCHF]
TDAQ	34,821	3,395
ITk Pixel	49,009	6,420
ITk Strips and Common	75,395	12,137
LAr Calorimeter	28,851	1,801
Tile Calorimeter	11,561	450
Muon System	28,485	4,466
HGTD	10,138	300
Common	373	33
Total	**238,633**	**29,002**

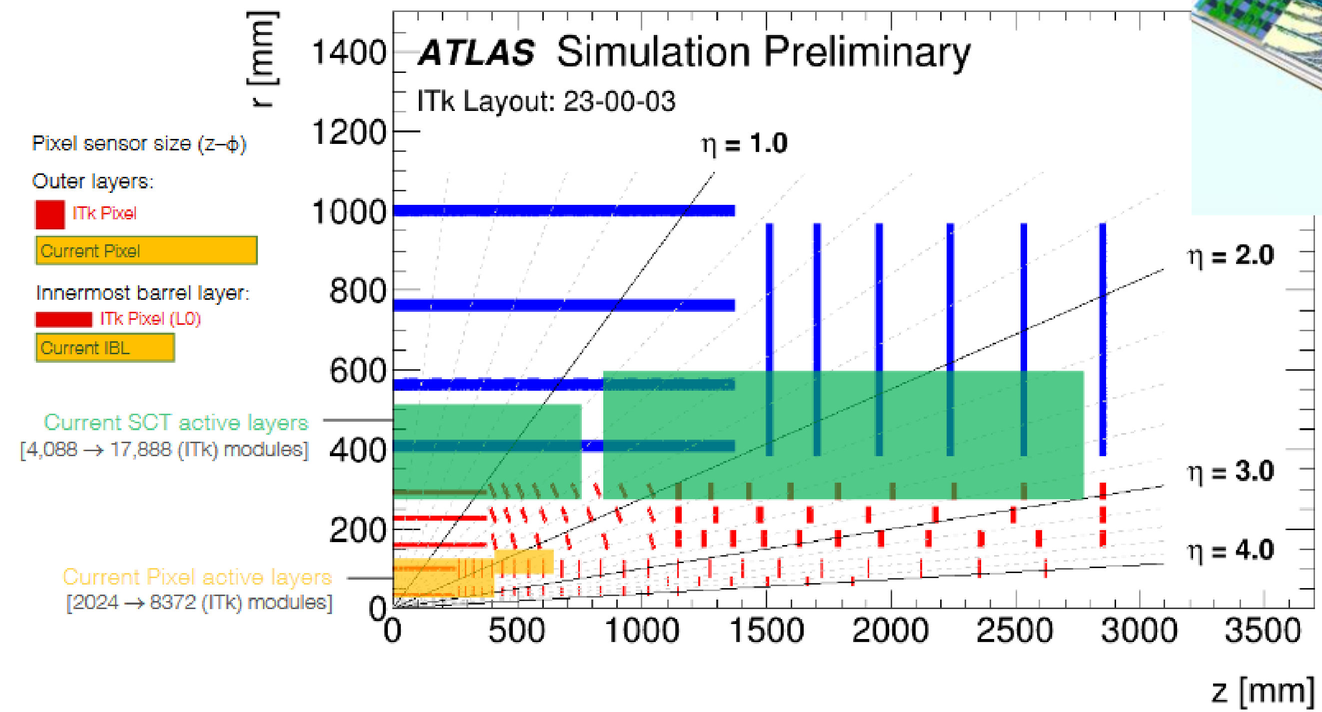
- ~6000 members, 185 institutes
- German groups are involved in all upgrade projects with strong focus on ItTk, Muon System and TDAQ
- German contribution 12.2% funded via FIS
- Increase of costs compared to original proposal due to inflation, corona and war in the Ukraine

Status of today:

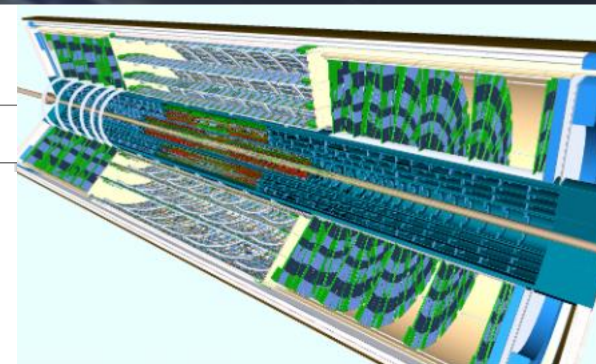
- About 5% of the invest is spend

True for all LHC-experiments:
Costs for staff are about factor 2-4 higher than invest costs.
Typically they are shared about 1:1 between BMBF and Universities.

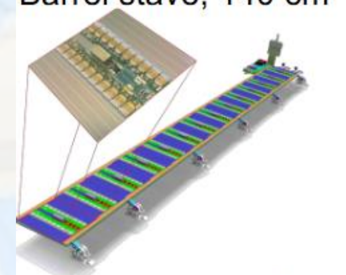
ATLAS ITk Upgrade



ITk: ~13 hits in barrel (incl. 2 hits per Strip module), minimum ~9 Pixel hits in forward region

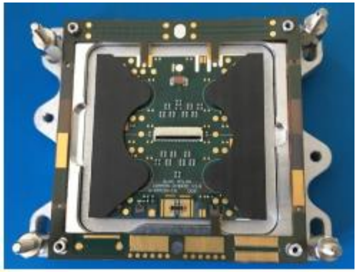


Barrel stave, 140 cm



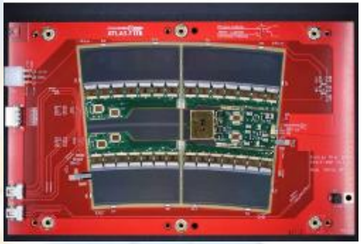
- ➢ Significant larger coverage of acceptance, less material, finer segmentation
- ➢ All silicon: **13 m^2 of silicon pixels - 5G pixels, 168 m^2 of silicon strips**

ATLAS: Transition from final design to production



ITk Pixel [Bonn, FH+TU Dortmund, Göttingen, MPI München, Siegen, Wuppertal]

- 1/3 of sensor production is completed
- currently in first stage of module production readiness review
- start of production phase in 2025
- A lot of progress made, but schedule very tight, even including delayed LS3



ITk Strips [HU Berlin, DESY, TU Dortmund, Freiburg]

- Sensor cracking and cold noise investigation
- Module production start early 2025
- Production of other components progressing well

High Granularity Timing Detector:
[TU Dreseden, Mainz, Giessen, MPI München, Heidelberg]

- ASIC PRR and module assemply FDR planned for November 2024

Myonsystem [Freiburg, Mainz, LMU+MPI München, Würzburg]

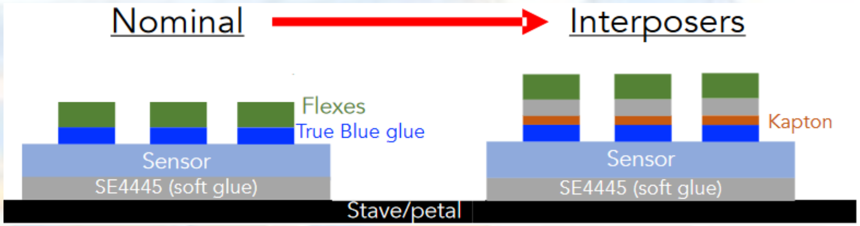
- Production of readout electronics progressing well

Technical and Organisatorial Challenges

Several technical and organisatorial challenges causing loss of contingency in the shedule.

ITk – sensor cracks:

- Sensor cracks at glue/flexes boundary at low temperature
- Cured by intermediate kapton layer
  Tests up to -70C so far promising.
  (operation in the pit at -45C)



- Industrial solution well advanced for the barrel, more complicated for endcap due to different hybrid layouts

IpGBT failure rate (affects several CERN experiments):

(IpGBT: trasceiver ASIC used in many ATLAS detector systems, among other ITk)

- Resubmission of improved ASIC
- Extended radiation tests

Export restrictions with radiation hard ASICs from China
discussion with CERN legal department started

A comment on delays ....

Old shedule:

Run 3		LS3			Run 4				LS4		Run 5				LS5	Run 6	
2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041

New shedule:

Run 3		LS3				Run 4				LS4		Run 5					
2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041

New shedule leaves more time for ATLAS and CMS to construct and install the upgrade detectors, which is very welcome.

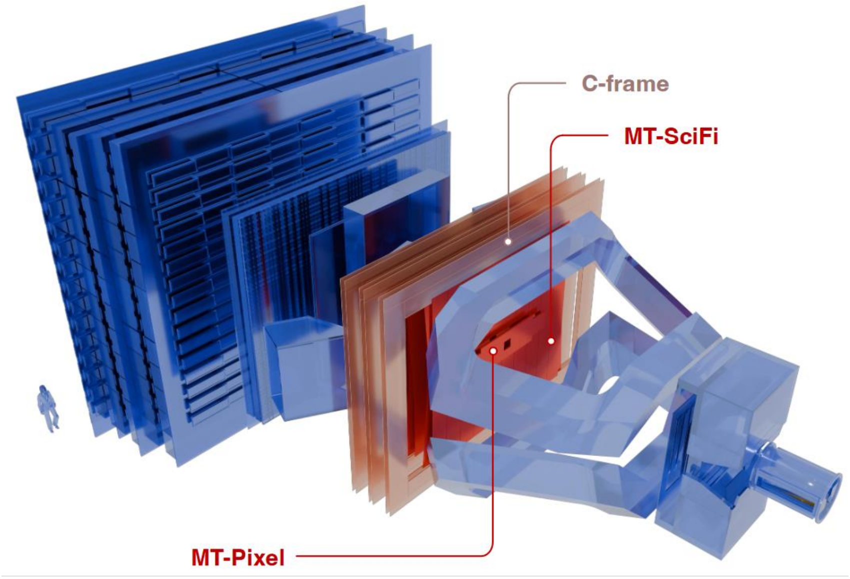
Any further shifts in the shedule of Phase-II Upgrade will cut into Run5 and thus the physics exploitation of LHCb (and ALICE3).

Depending how installation/commissioning of the four significantly upgraded experiments/almost new exepriment goes, one should consider to extend HL-LHC beyond 2041.

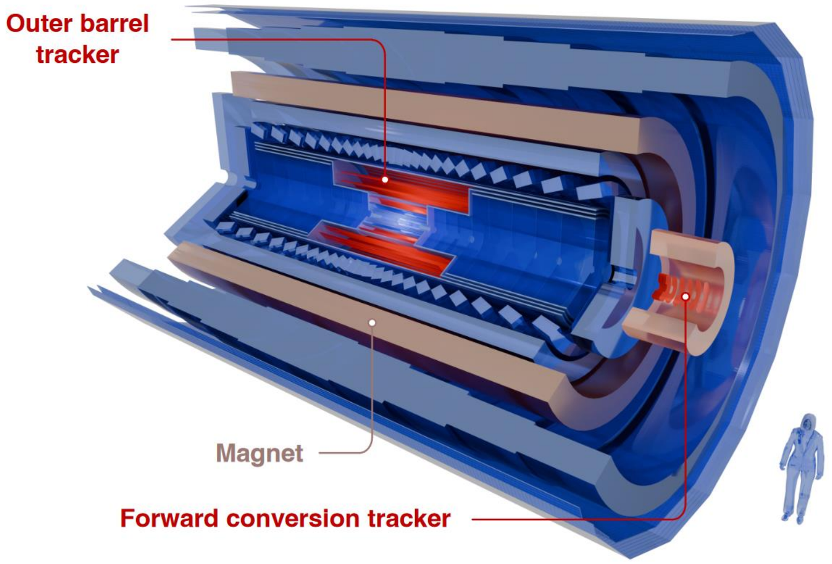
Excluding this option harms already now LHCb (and ALICE3).

Phase-2b Upgrade

LHCb-UII



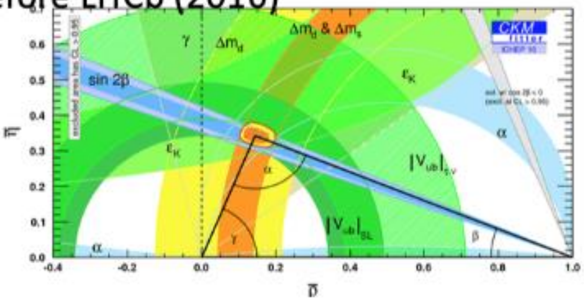
ALICE3



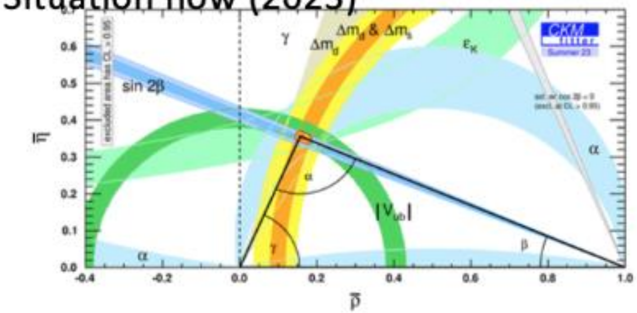
European Strategy 2020:
The full physics potential of the LHC and the HL-LHC, **including the study of flavour physics and the quark-gluon plasma,** should be exploited."

One Slide on Physics

Before LHCb (2010)



Situation now (2023)



Many more physics motivation
In Gudruns Talk yesterday

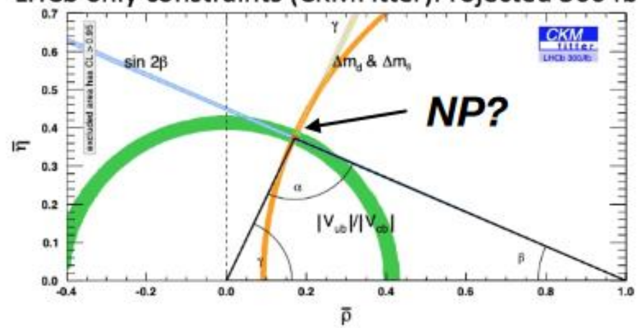
from S.Malde 22/2/24

Sometimes our work can feel incremental

But on the timescale of an experiment the progress can reach the holy grail of paradigm shifting…

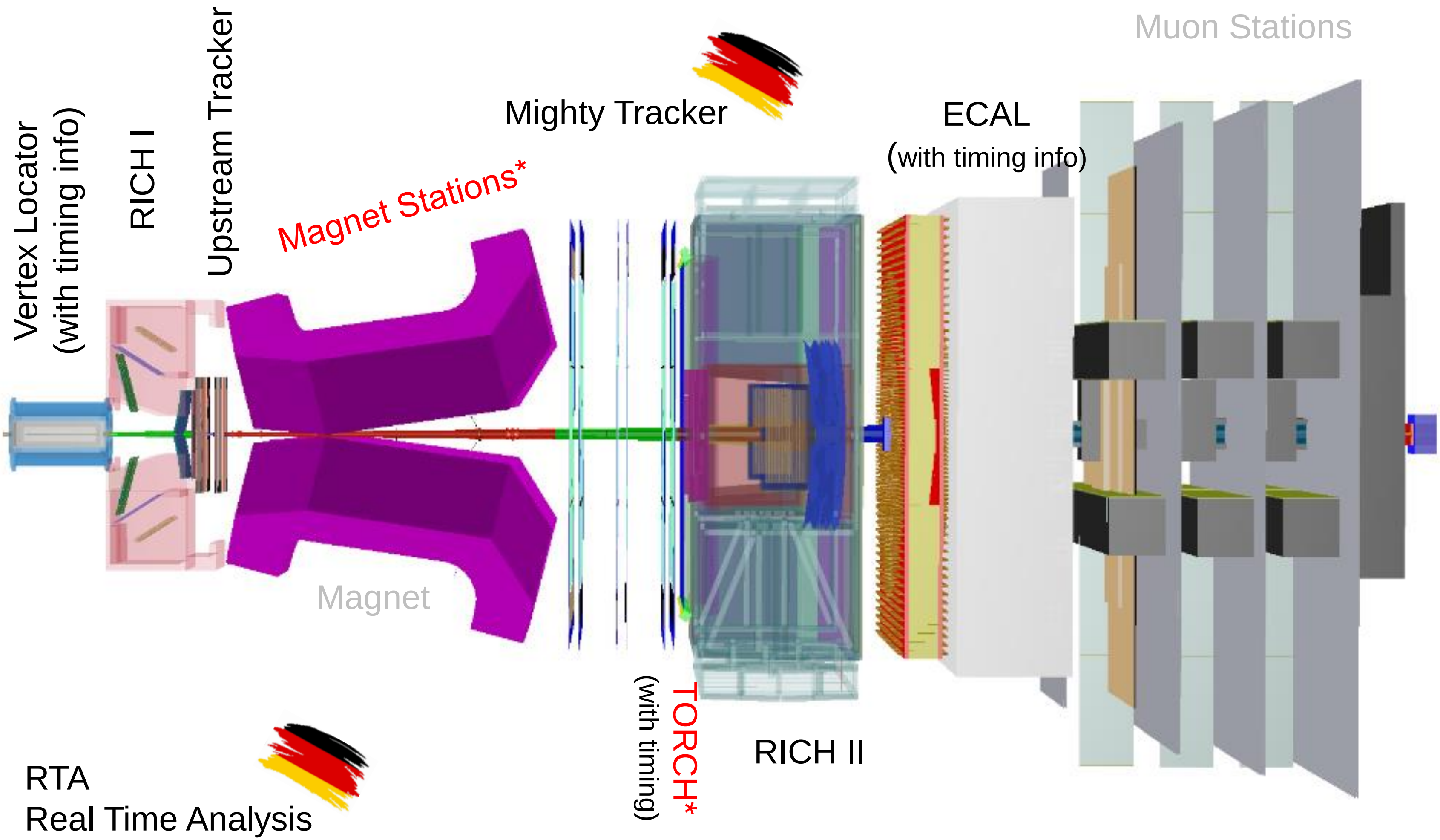
..and, independent of NP discovery, our experimental effort will produce a genuine knowledge leap in the Standard Model theory

LHCb only constraints (CKMFitter)Projected 300 fb

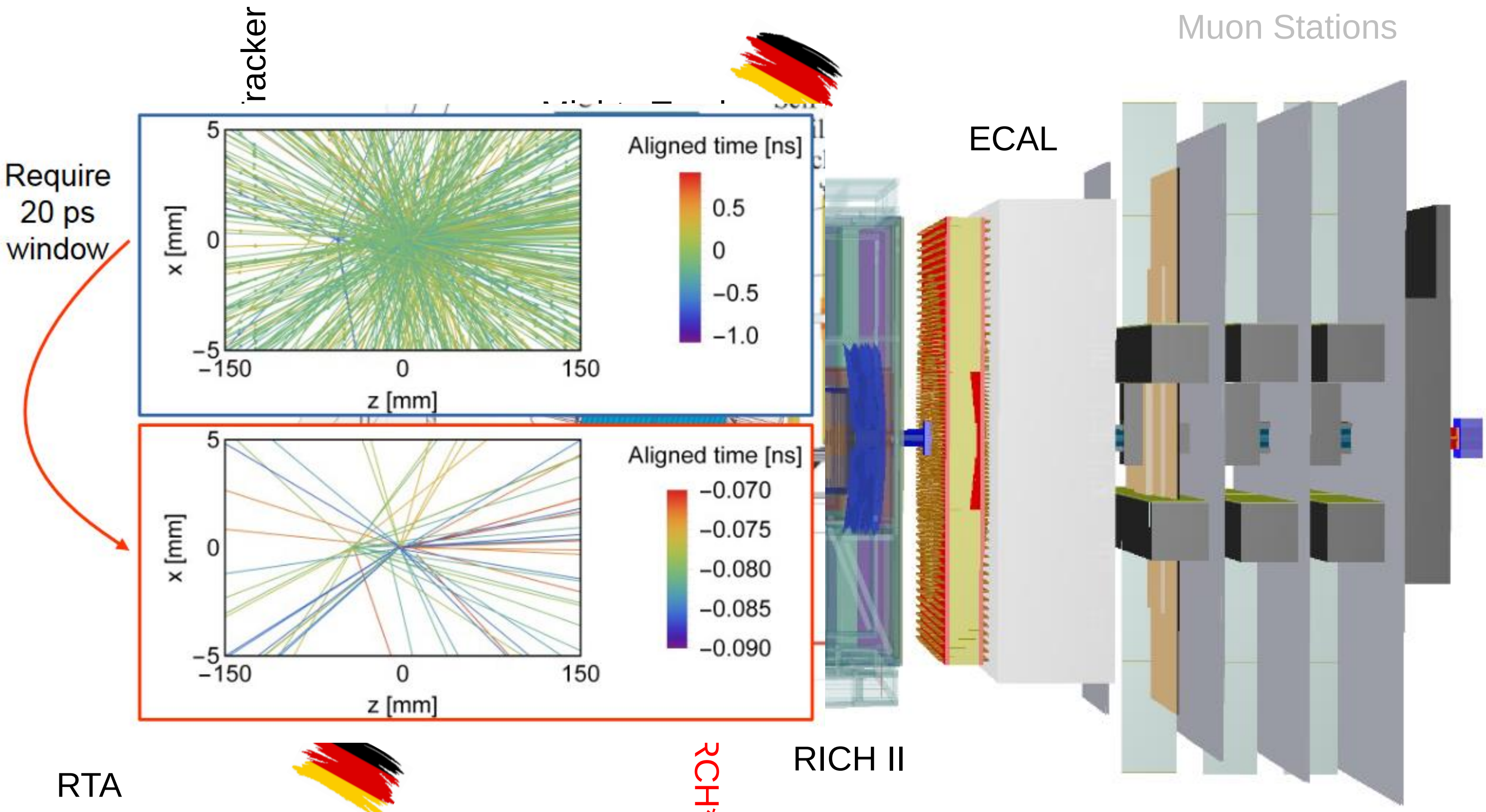


If we miss this opportunity we may not get another one

LHCb-UII



*not part of all detector versions



RTA
Real Time Analysis

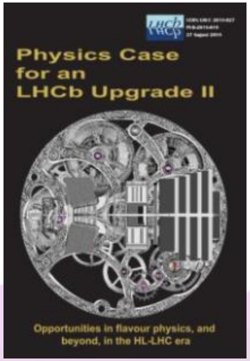
*not part of all detector versions

Towards LHCb-UII

EoI

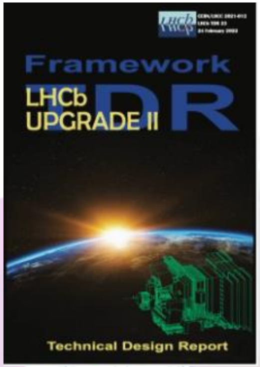
LHCC-2017-003

Physics Case



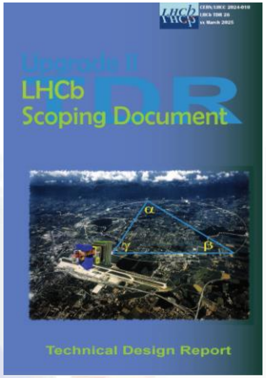
LHCC-2018-027

Framework TDR



LHCC-2021-012

Scoping Document



Sept. 2024 handed over to the LHCC

Currently under review:

- detector design and technology options
- R&D program and shedule
- cost for basline and options for descoping
- national interests

next steps:

- discussion with funding agencies ongoing
- initial money matrix forseen for march 2025
- approval for one of the three version by April 2025
- finalize signing MoUs in 2026
- 2025-26: write TDRs

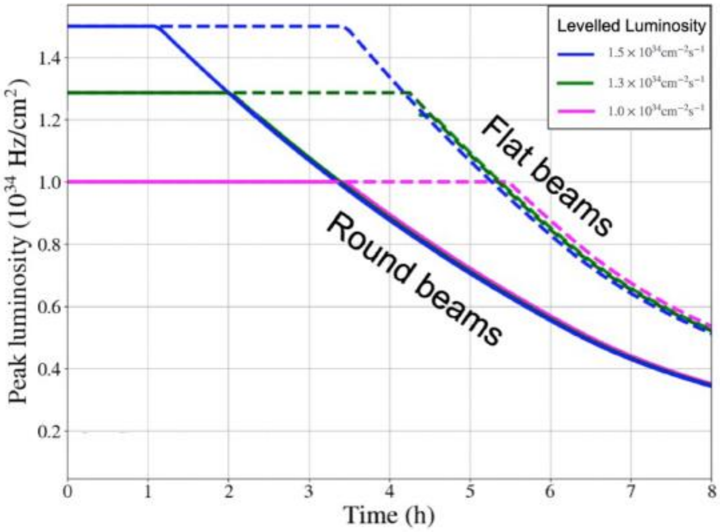
Although all funding agencies welcome the propose project
The financial situation is tight in many coutnries

8 years between scoping document and start of data taking in 2036

(compared to 13 for ATLAS and CMS)

Luminosity Scenarios

- Detector requirements scale with peak luminosity (radiation hardness, granularity)
- Physics performance scales with integrated luminosity



Round optics (present HL-LHC baseline)

49 fb^{-1}/year at L_{peak} = 1.5 10^{34} cm^{-2} s^{-1}

42 fb^{-1}/year at L_{peak} = 1.0 10^{34} cm^{-2} s^{-1}

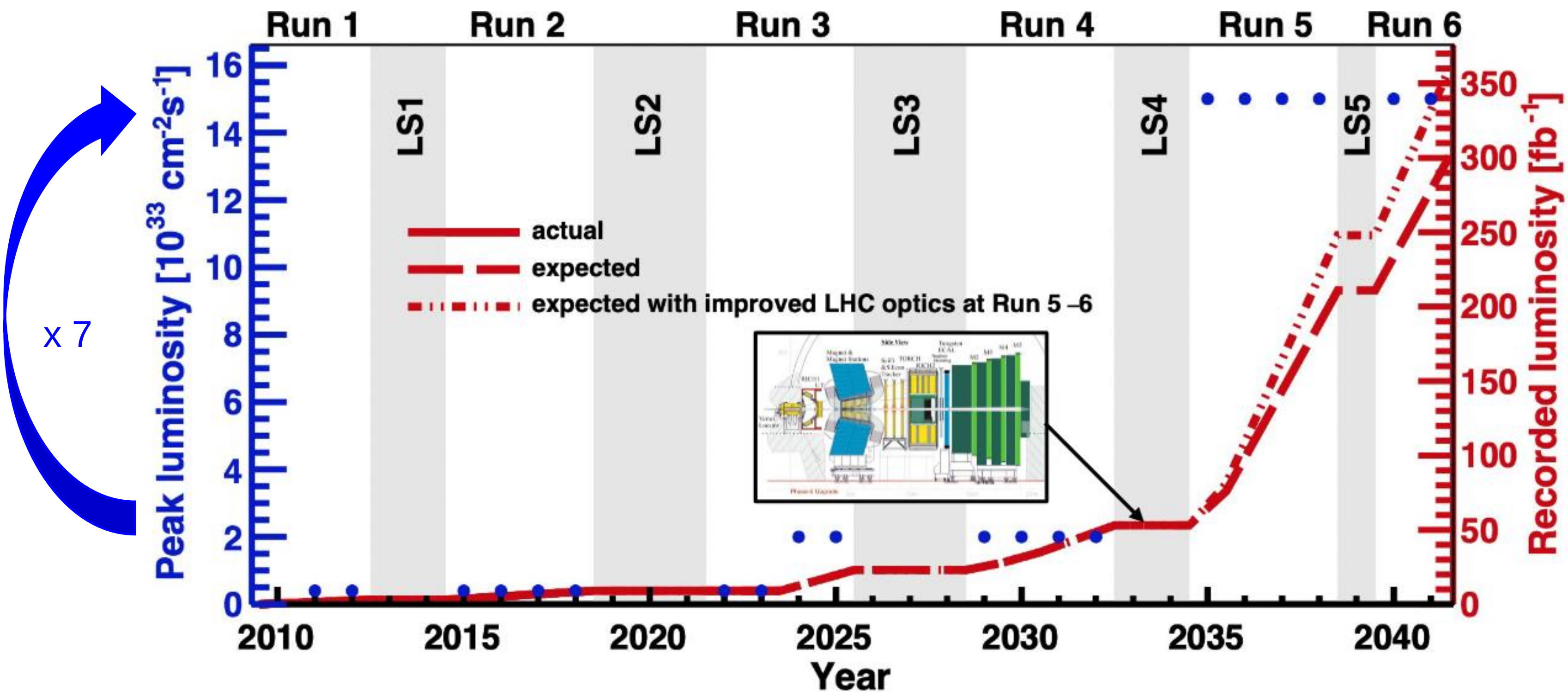
Flat optics (need further R&D)

63 fb^{-1}/year at L_{peak} = 1.5 10^{34} cm^{-2} s^{-1}

49 fb^{-1}/year at L_{peak} = 1.0 10^{34} cm^{-2} s^{-1}

Flat optics cleary preferable for LHCb. Awaiting results of machine tests.

Luminosity



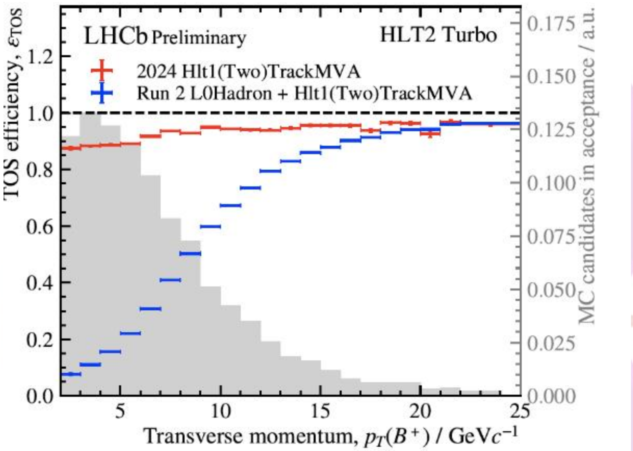
Expected intergrated luminosity by end of Run4: **50 fb^{-1}**

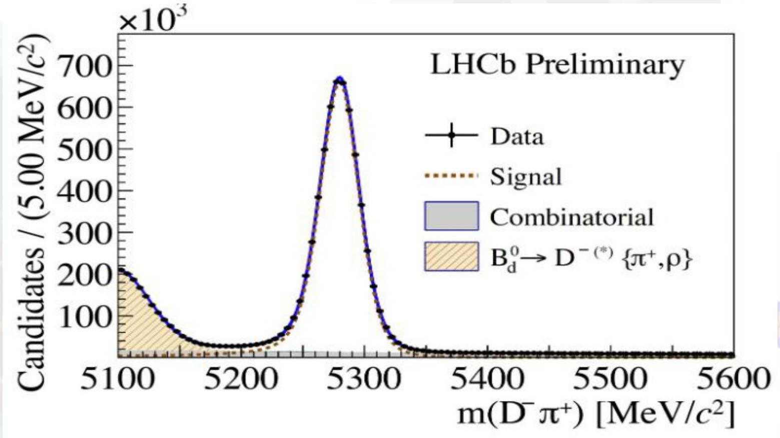
Baseline scenario for UII with round/**flat optics**: 300 fb^{-1}/**350fb^{-1}**

x 6-7 integrated luminosity

Beyond Luminosity Scaling

Example from Run 3 ($B^+ \rightarrow D^- \pi^+$):





transverse momentum distribution of B^+ candidates

efficiency with Run 2 L0 trigger

efficiency with Run 3 trigger (RTA - real time analysis)

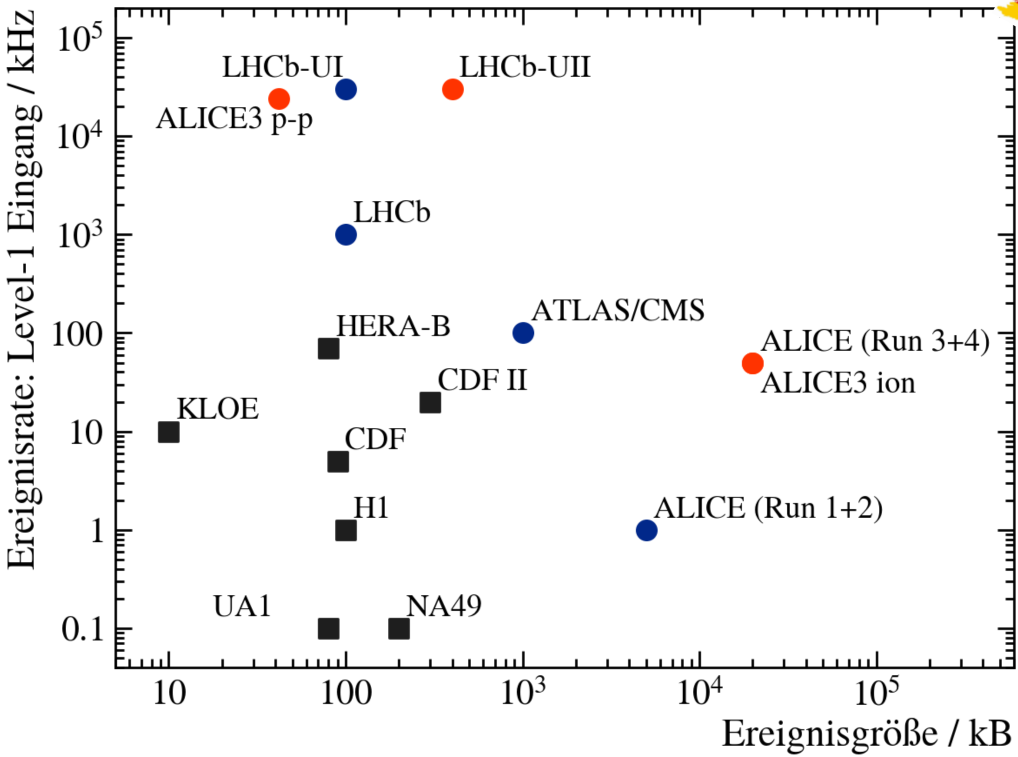
yield/fb^{-1} = 1.1 x 10^8

2.6 larger than in Run2

(yield for all hadronic B and D channels 2-4 times larger)

Ready to address the next challenge

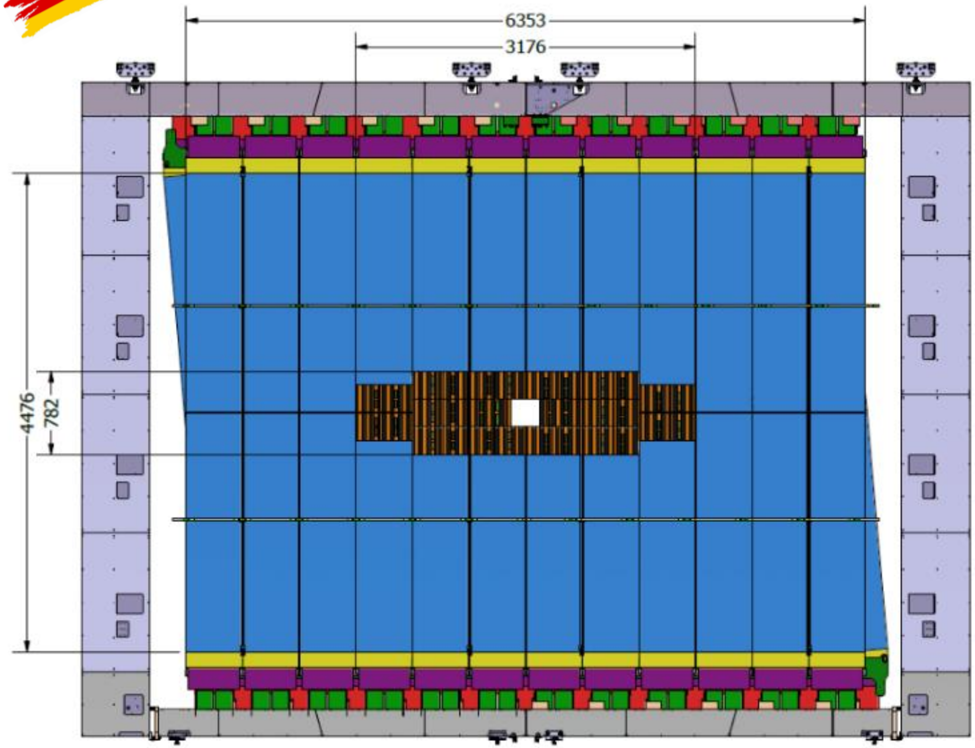
LHCb and ALICE3 are pioneering novel regimes in event rate and event size



The smarter the algorithms, the more compressed/reduced the information in an event, the more processing is done at an early stage (FPGA, GPU, …) , the more physics we get per bandwidth.

[Dortmund, Heidelberg, Freiburg, Bonn]

Mighty Tracker



- Fiber technology used in the outer region, pioneered in Germany
- Just successfully finished the commissionong of a 99% efficient detector with 12 x 30 m^2 detection planes with a single hit resolution < 100 μm under German leadership (despite covid in time and financial budget)
- HV-CMOS technology in the high occupancy, region developped at HD and KIT, many synergies with Mu3e total area: 12.6 m^2
- Operation of SiPMs at cryogenic temperaturs

[Dortmund, Heidelberg, Freiburg, Bonn, Aachen, Bochum, KIT]

Detector Scenarios of the Scoping Document

Baseline scenario (182 MCHF = 194.2 MEuro)

sub-detector	total costs [MEuro]	German contribution [MEuro]
Vertex Locator	17.8	0
Upstream Tracker	8.6	0
Magnet Stations	2.8	0
RICH	23.0	0
TORCH	13.4	0
Calorimeter	29.5	0
Muon System	10.5	0
Online	12.6	0
Infrastructure	15.5	0
Mighty Tracker	40.4	11.7
RTA	20.1	2.9
total	194.2	14.6

table from FIS proposal

- 1700 members, 75 institutes
  (steadily increaseing by 5-10% per year for the last 8 years)
- German fair share 7.5%: 14.6 MEuro
- General support of BMBF, but not yet clear how to fund German contribution.
- UK was the first (and sofar only) country with firm committments
- German groups focus on key-expertise
  - **Main tracking system**
  - **Real time analysis (full software trigger)**

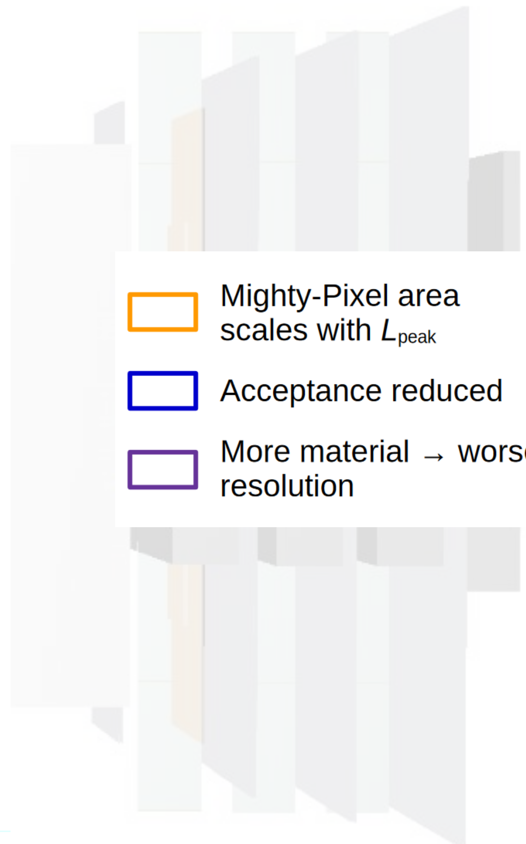
Alternative options:

Middle (156 MCHF): same performance as baseline, reduced peak luminosity,
12-20% less intergrated luminosity,
lower costs due to less granularity and less radiation hardness

Low (125 MCHF): 12-20% less integrated luminosity, significant loss in detector performance

Tracking Systems in the Different Scenarios

Baseline	Middle	Low
$1.5 \times 10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$	$1.0 \times 10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$	$1.0 \times 10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$
	VELO	
32 stations, $\eta < 4.8$	32 stations, $\eta < 4.8$	28 stations, $\eta < 4.7$
module 0.8% X_0	module 0.8% X_0	module 1.6% X_0
RF foil 75 µm	RF foil 75 µm	RF foil 150 µm
	UP	
4 planes pixel $\times 1.7\,\mathrm{m}^2$	as baseline	remove corners
	Magnet Stations	
4 panels fibres $\times 3.5\,\mathrm{m}^2$	as baseline	remove
	Mighty-Pixel	
6 planes pixel $\times 2.1\,\mathrm{m}^2$	6 planes pixel $\times 1.3\,\mathrm{m}^2$	6 planes pixel $\times 1.3\,\mathrm{m}^2$
	Mighty-SciFi	
12 planes fibres	12 planes fibres	12 planes fibres
$25.9\,\mathrm{m}^2$/plane	shorter, $23.7\,\mathrm{m}^2$/plane	narrower, $18.9\,\mathrm{m}^2$/plane



Mighty-Pixel area scales with L_{peak}

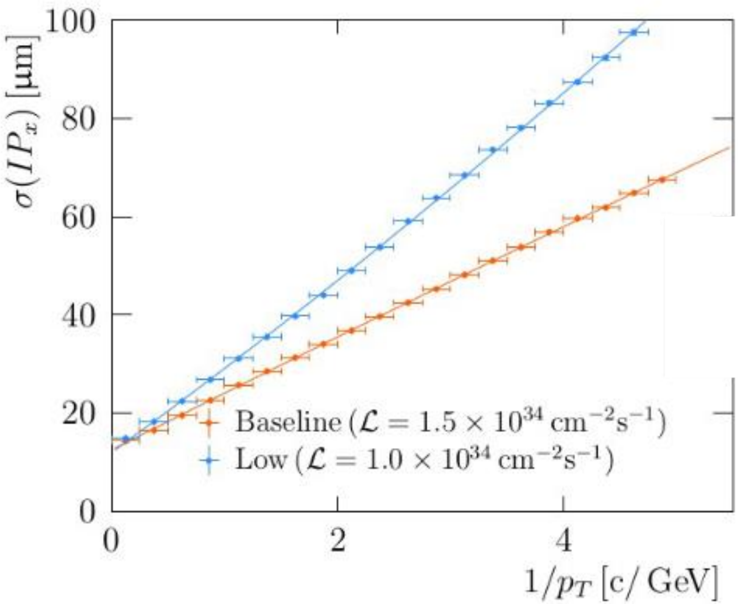
Acceptance reduced

More material → worse resolution

Baseline versus Low

Vetex-Locator: Impact Parameter Resolution

Baseline, Low: more material



Reduced SciFi acceptance impacts different channels differently: 5-15%

Channel	Relative acceptance %	
	Middle	Low
$B_s^0 \to \mu^+\mu^-$	99.3 ± 0.1	95.3 ± 0.1
$B_s^0 \to \phi(\to K^+K^-)\phi(\to K^+K^-)$	99.4 ± 0.1	90.6 ± 0.2
$D^0 \to K_S^0(\to \pi^+\pi^-)\pi^+\pi^-$	99.7 ± 0.1	84.8 ± 0.8

Low option results in significant loss of physics performance.

Schedule

2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
Run 3			LS3			Run 4				LS4		Run 5					
TDR phase			Construction phase							Installation		Exploitation					

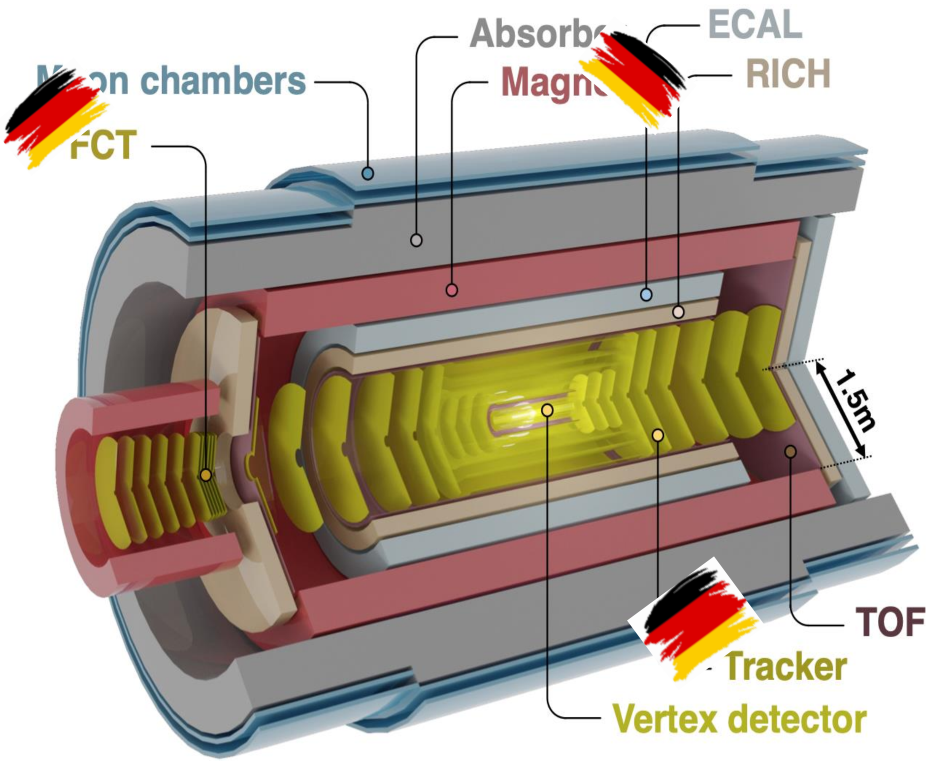
- TDRs completed in 2026
- 7 years construction time; all subdetectors ready for installation end of 2033
- **2 years (including removal of current detector)**
  - Important to do as much as possible preparatory work on the infrastructure in advance
  - Slice tests up-front on surface
- Start exploitation in 2036; **6 years of operation of a brand new detector**
  (first 1-2 years will be devoted to commissioning)

Shedule is ambitious but LHCb has a track record to stay in budget an in time.

A downscoped/simpler detector might be more realistic for the given time scale.

Any further changes in the shedule of the LHC which impact LS4 or Run 5 is endangering LHCb-UII (and ALICE3).

ALICE3 – a complete new detector



+ DAQ and Computing

- Compact and lightweight all-silicon tracker
- Retractable vertex detector (R: 5-16mm)
- Extensive particle identification
- Large acceptance
- New superconducting magnet system
- Continous read-out and online processing

EoI 2019

LoI: CERN-LHC-2022-009

Scoping Document handed over to LHCC September 2024

Money-Matrix fall 2025

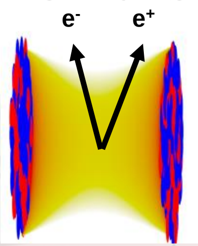
MoUs signed 2026

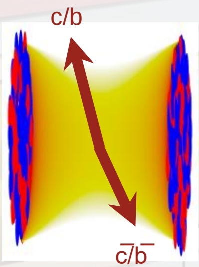
2025-2026 TDRs

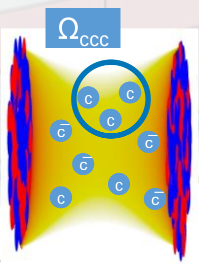
same time line as LHCb

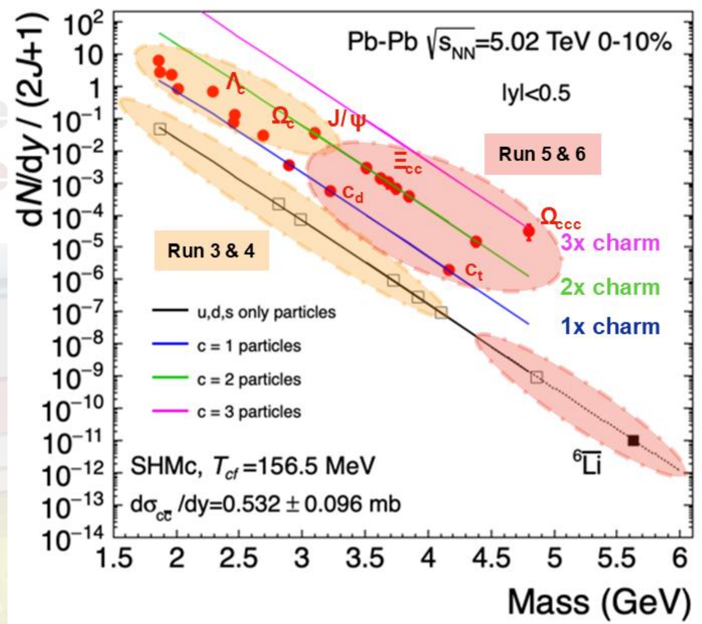
ALICE3: Heavy Ion Physics in Run 5

- **Precision measurements of dileptons**
  - ➟ evolution of the quark gluon plasma temperature
  - ➟ mechanisms of chiral symmetry restoration in the quark-gluon plasma
- **Systematic measurements of (multi-)heavy-flavoured hadrons**
  - ➟ transport properties in the quark-gluon plasma
  - ➟ mechanisms of hadronisation from the quark-gluon plasma
- **Hadron correlations**
  - ➟ hadron-hadron interaction potentials
  - ➟ net-baryon and net-charm fluctuations
- …



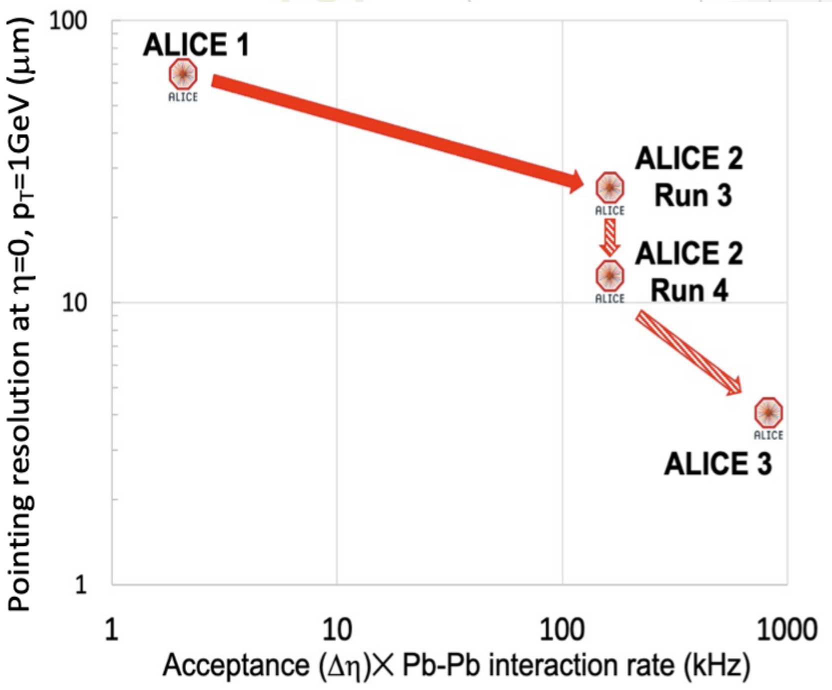






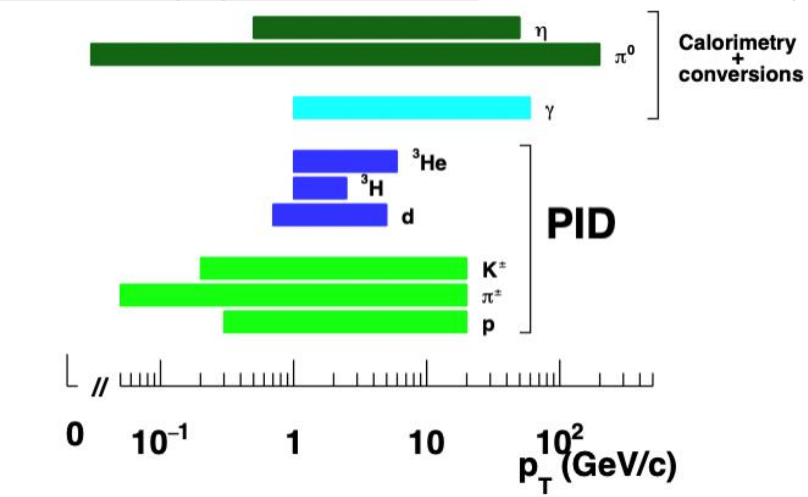
ALICE3 – Key Features

Large steps in pointing precision and "effective acceptance"



+

Keep/strengthen ALICE unique reach in particle identification



ALICE3 – Funding Plans

Baseline scenario
(148.2 MCHF = 167.9 MEuro)

sub-detector	total costs [MEuro]	German contribution [MEuro]
Inner Tracker	14.6	0
Outer Tracker	29.6	9.0
Forward Conversion Tracker	3.7	1.7
TOF	19.2	0
RICH	25.8	0
MID	4.3	0
FD	1.2	0
Superconducting Magnet	26.6	5.0
Online Computing	19.5	4.0
Infrastructure	23.4	2.7
total	167.9	22.4

table from FIS proposal

ALICE collaboration:

~2000 members, 171 institutes
12.5% German authors

Current planing:

- German share (Helmholtz+BMBF):
  22.4 MEuro invest (13.3%)
- General support from BMBF, but not yet clear how to fund the German contribution.
- German groups focus on key-expertise
  - **Tracker including magnet**
  - **Online Computing (full software trigger)**

Alternative descoped options for individual subsystems under discussion

ALICE3 - Tracker

Ultra-thin larger curved MAPS
(less than 0.05% radiation length per layer)

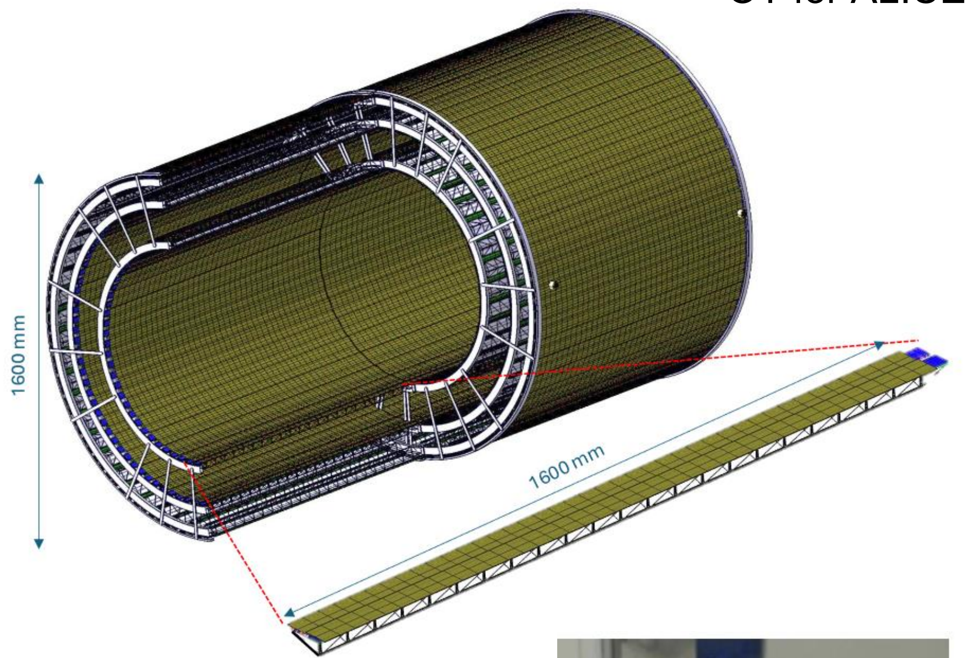
- CMOS technologies developed with significant German contributions for ITS3 (to be installed in LS3)

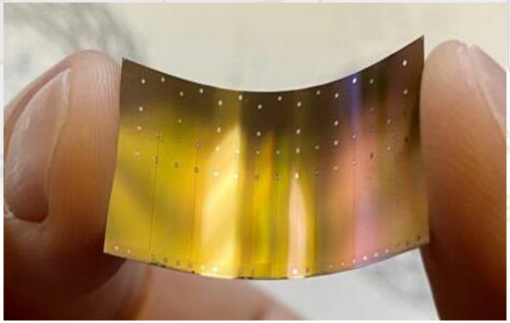
- IT and OT together: 60 m^2 pixel detector

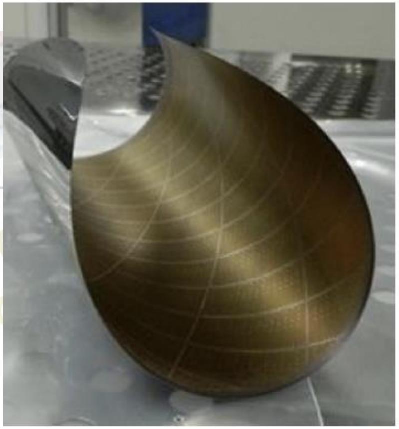
- Germany in charge for 3 barrels of the outer tracker and several disks of the forward conversion tracker (FCT)

- 64000 sensors for 3 OT barrel layers
  5000 modules equipped with sensors
  → industrialisation of production process
  (close collaboration with industry partners)

OT for ALICE3







Photos: ITS3

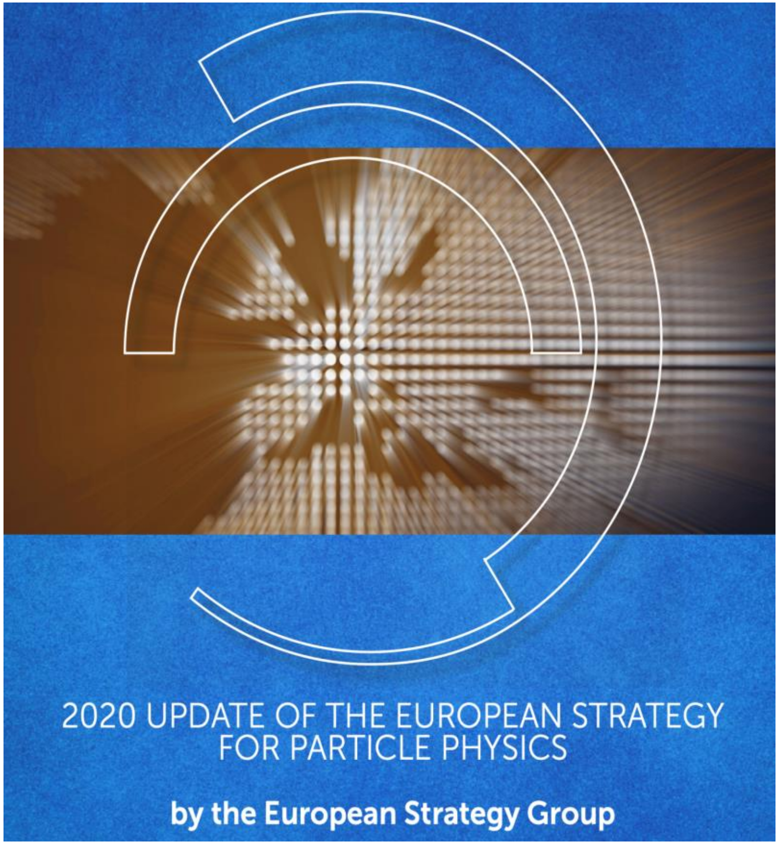
ALICE3 – Time Scale

- **2023-25**: Scoping Document, selection of technologies, small-scale prototypes (~25% of R&D funds)
- **2026-27**: large-scale engineered prototypes (~75% of R&D funds) → TDRs and MoUs
- **2028-31**: construction and testing
- **2032-33**: contingency and pre-commissioning
- **2034-35**: preparation of cavern, installation

Still need to do some R&D efforts, technology choice not yet concluded.

Ambitious time plan for the construction of the detector & tight time plan for installation in the caverne.

Sustainability



„ The environmentail impact of particle physics Activities should continue to be carefully Studied and minimised. A detailed plan for the Minimisation of environmental impact and for the saving and re-use of energy should be part of the approval process for any major project. Alternatives to travel should be explored and encouraged.“

This recommendation is adopted by CERN. Both LHCb-II and ALICE3 did include/will have to include a detailed environmental report in their TDRs.

Most imortant first step, be aware about your foot print.

Enironmental Impact has many facetts

Sustainability has many dimensions (see Environmental Report 2021-22)

ENERGY
1215 GWh

The Laboratory is committed to limiting rises in electricity consumption to 5% up to the end of Run 3 compared to the 2018 baseline year, which corresponds to a maximum target of 1314 GWh, while delivering significantly increased performance of its facilities. It is also committed to increasing energy reuse.

In 2021 and 2022, CERN consumed 991 GWh and 1215 GWh of electricity respectively.

In addition, the Organization consumed 67 GWh (240 TJ) and 51 GWh (184 TJ) of energy generated from fossil fuels in the two years respectively.

WASTE
69% recycled

CERN's aim has been to increase its recycling rate for non-hazardous waste. The recycling rate rose from 56% in 2018 to 69% in 2022.

In 2021 and 2022 respectively, CERN disposed of 5111 tonnes and 8812 tonnes of non-hazardous waste, and of 1544 tonnes and 1295 tonnes of hazardous waste, including 307 and 519 tonnes of radioactive waste.

EMISSIONS
184 173 tCO_2e

CERN's objective is to reduce direct emissions by 28% by the end of Run 3 compared to the 2018 baseline year, which corresponds to a maximum target of 138 300 tCO_2e.

The scope 1 emissions in 2021 and 2022 were 123 174 and 184 173 tonnes of CO_2 equivalent (tCO_2e) respectively.

The total amount of scope 2 greenhouse gas emissions due to CERN's electricity consumption was 56 382 and 63 161 tCO_2e in 2021 and 2022 respectively.

Total scope 3 emissions arising from business travel, personnel commuting, catering, waste treatment and water purification amounted to 7813 and 8956 tCO_2e in 2021 and 2022 respectively.

Scope 3 emissions arising from procurement, which are reported for the first time, amounted to 98 030 tCO_2e and 104 974 tCO_2e in 2021 and 2022 respectively.

NOISE
45 dBA at night

CERN is committed to restricting noise at its site perimeters to 70 dBA during the day and 60 dBA at night.

Over this reporting period, CERN implemented measures to improve its noise management, including the installation of an online real-time monitoring system at Point 2 of the LHC and Point 4 of the SPS. Average noise levels measured on the boundaries of CERN's sites are typically around 50 dBA during the day and 45 dBA at night.

WATER AND EFFLUENTS
3234 ML

The Laboratory is committed to keeping the increase in its water consumption below 5% up to the end of Run 3 compared to the 2018 baseline year, which corresponds to a maximum target of 3651 ML, despite a growing demand for water cooling at the upgraded facilities.

In 2021 and 2022, CERN used 2661 and 3234 megalitres of water respectively.

BIODIVERSITY
18 species of orchids

Inventories of flora and fauna were conducted in 2022. A further two species of orchid were identified, bringing the total on the CERN sites to 18, as well as 62 species of Lepidoptera and 32 species of Orthoptera.

IONISING RADIATION
< 0.01 mSv

The European annual dose limit for public exposure to artificial sources is 1 mSv. CERN is committed to keeping its contribution to no more than 0.3 mSv per year.

The actual dose received by any member of the public living near the Laboratory was less than 0.01 mSv in the reporting period, which is more than 100 times lower than the average annual dose received from medical exposure per person in Switzerland.

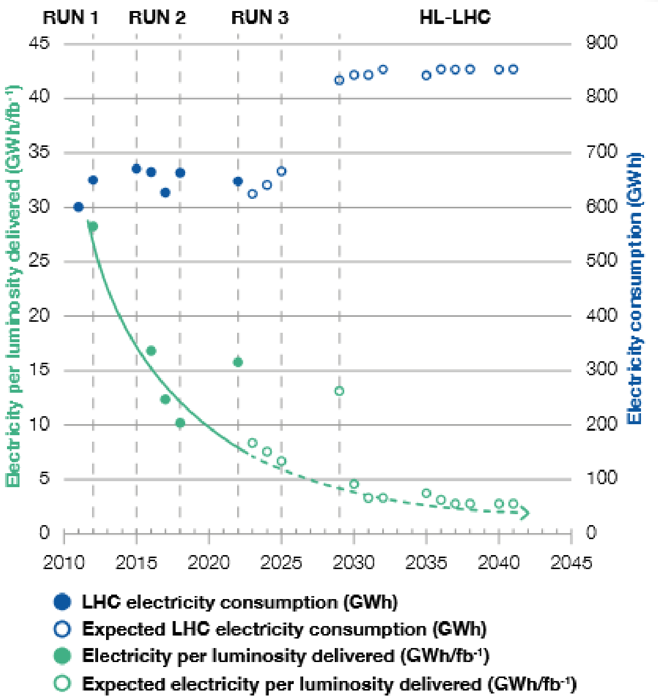
KNOWLEDGE TRANSFER
8 environmental projects

In 2022, CERN launched the Innovation Programme on Environmental Applications (CIPEA), which spans four focus areas where CERN's know-how can be of use, namely renewable and low-carbon energy; clean transportation and future mobility; climate change and pollution control; and sustainability and green science.

Eight projects were selected for implementation with the financial support of external partners or the CERN Knowledge Transfer fund.

Electricity

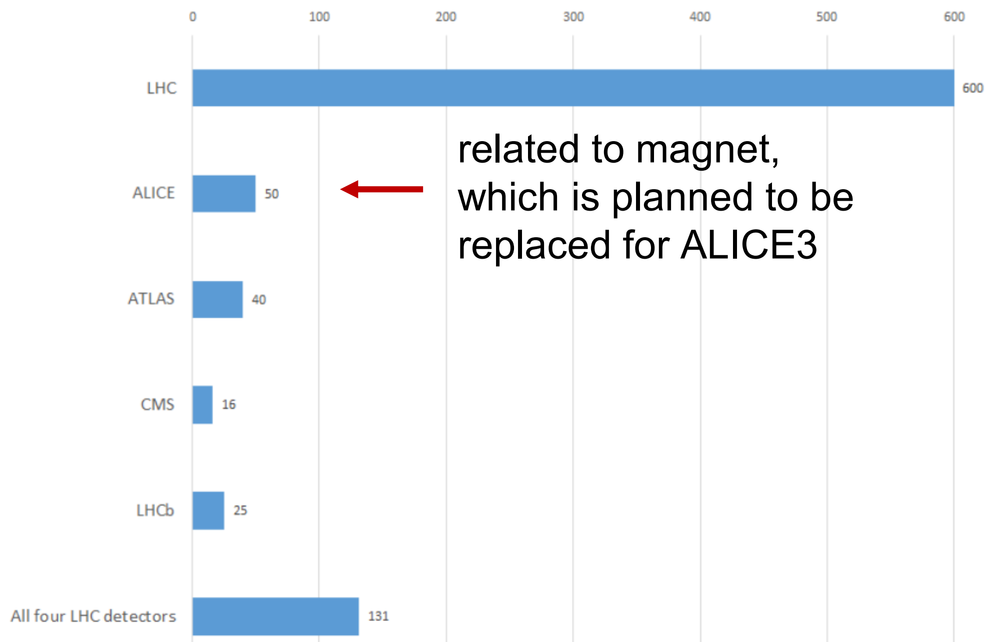
Energy efficiency of the LHC improved by a factor of three from start of Run 1 till end of Run2 and another factor 4 expected for HL-LHC



Grid computing is not part of the evaluation at CERN!

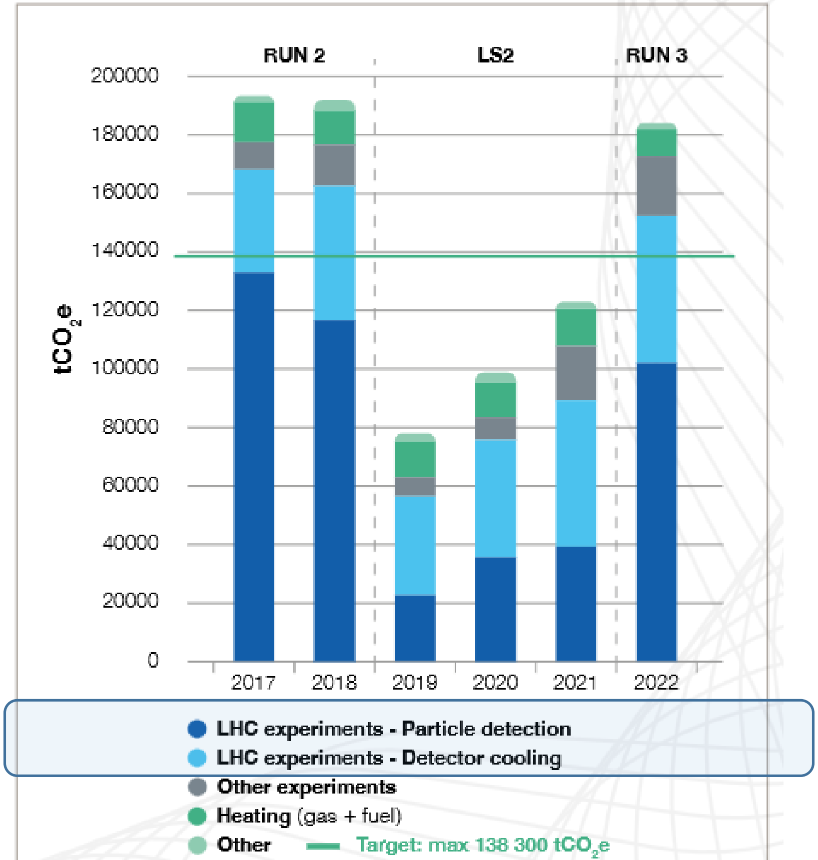
LHC

650 GWh per year → $30ktC0_2e$ rather modest foot-print as power from atomic power plants from France are 88% carbon-free



related to magnet, which is planned to be replaced for ALICE3

Gas Emission



CERN SCOPE 1 EMISSIONS FOR 2017–2022 BY CATEGORY
"Other" includes air conditioning, electrical insulation, emergency generators and the fuel consumption of the CERN vehicle fleet.

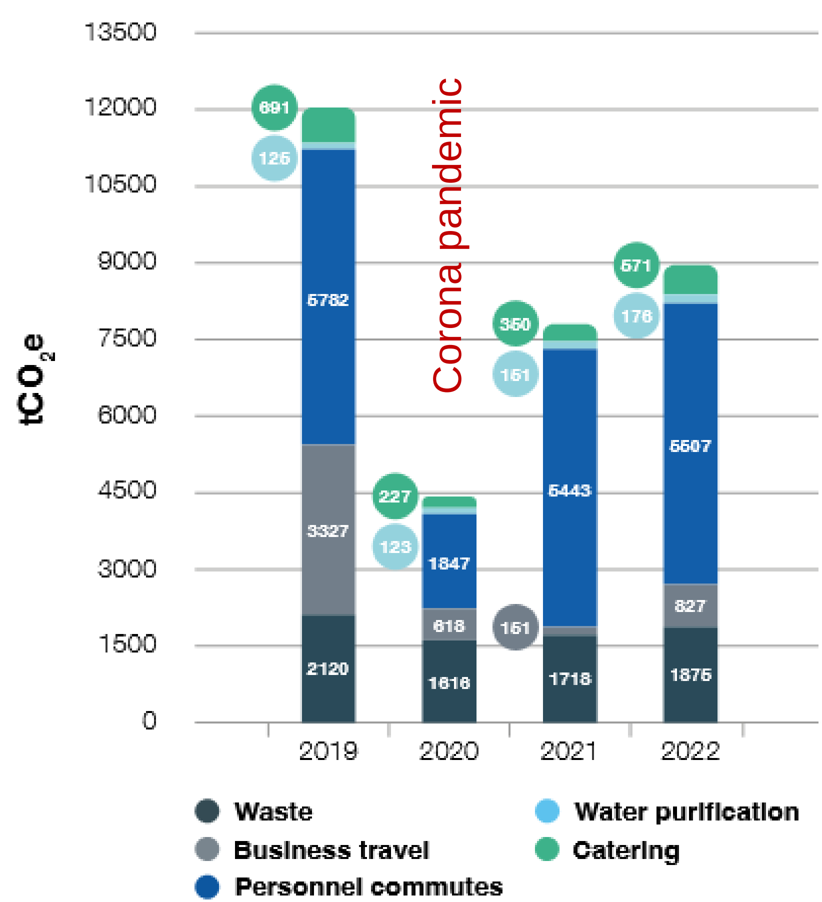
LHCb -- 4.4 ktC0$_2$e
50% gas emission ← recopuration system for RICH detectors
25% electricity
25% travel

ALICE – 15 ktC0$_2$e
70% gas emission ← **ALICE3** no gas detectors
13% electricity
7% travel

CMS and ATLAS worked on gas tightness of detectors during LS2 (effort will continue during LS3)

low GWP gas tested for cooling.
e.g. C0$_2$ or air-cooling for ALICE3

Travel



CERN'S SCOPE 3 EMISSIONS 2019–2022
(EXCLUDING PROCUREMENT)

Only for CERN employers,
but trend is clear.

All of us can make a difference by taking the bike or public transport to work.

Next step to include procurement and take this into account when placing orders

Summary

- We are just at the beginning of the exploitation of the LHC physics potential.
  About a factor 10 in luminosity still to be taken till the end of LHC in 204x.

- Technology (fine granular detectors, lager acceptance, smart trigger and analysis Procedures) can extend the reach beyond pure lumionosity scaling.

- Larges scale projects need time from LoI till data taking … 15-20 years
  This experience should be taken into account in the planing of ALICE3, LHCb-UII as well as for any future experiment at a future collider

- The HL-LHC data will be the largest data sets we have in hand before the start of any future collider.

- A successfull upgrade of the machine and the experiments for the HL-LHC in LS3 and LS4 are mandatory for any future planning.
  A successfull Phase-II upgrade must have highest priorities.

- **Potential further shifts in shedule and/or longer commissioing times must be compensated by a longer run-time of the LHC to not endanger the full exploitation** of the LHC physics programme.

- Funding situation currently tight in Germany as well as in all other countries.
  Reliable time and cost plans are most important.

Summary

In a world with increasing demand on limited resources and undergoing climate change
it is mandatory to consider energy consumption, sustainability and efficiency
when discussiong scientific proposals.

CERN and its experiments are on a good way,

Particle physics/CERN is a driver of technology and should be a role model for
sustainable use of resoures.

Back-Up

LHCb-UII in a Nutshell

- **Unique science programme with BSM discovery potential**
  - Only way to achieve European Strategy of full HL-LHC exploitation
  - Broad physics programme
    - Unique forward acceptance
    - Unprecendented sensitivity for flavour physics in the B and D systems, probing potential new physics beyond energy frontier
    - Spectroscopy, EW precision measurements, top quark and Higgs physics, dark sector heavy ions and fixed target physics
  - Beyond luminosity scaling with new subdetectors and reconstruction techniques
- **Exciting technology roadmap**
  - High granularity, fast timing, extreme radiation hardness, novel trigger and computing strategies

see talks yesterday

Phase IIb Upgrade

107 institutes, 19 associate in 25 countries

1784 members

1160 authors

7 German institutes

6.5% German autors

157 member institutes, 24 associate in 40 countries

1944 members

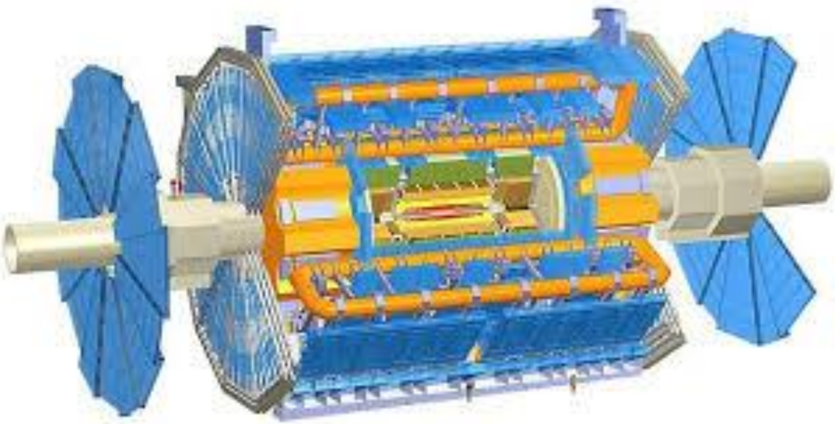
1070 authors

Xxx German institute

Xx% German autors

LHCb and ALICE took part in Phase-I Upgrade and just restarted with significantly upgraded (almost new) experiments

Phase-2 Upgrade

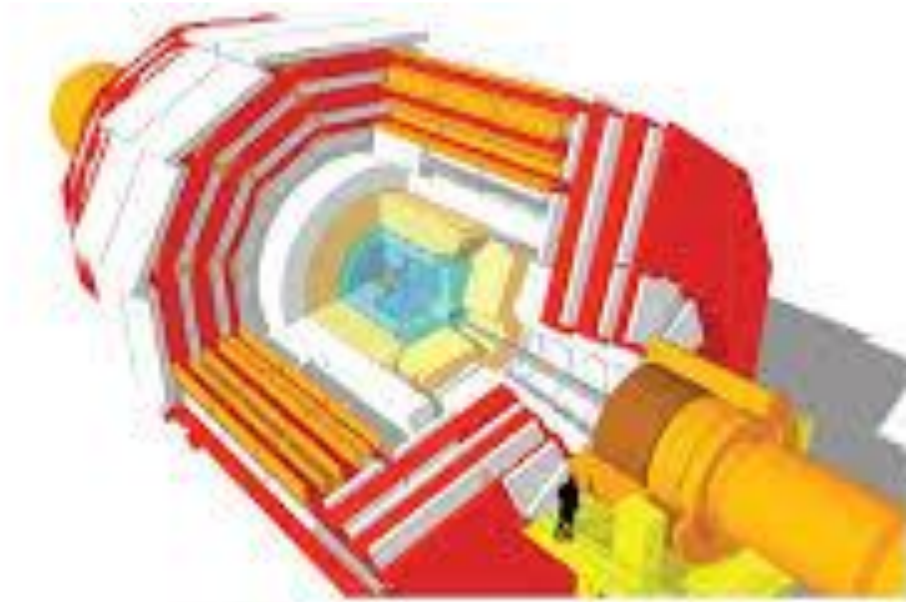


185 institutes in 41 countries

~6000 members, ~2900 authors

Xxx deutsche Institute

Xx% deutsche Autoren



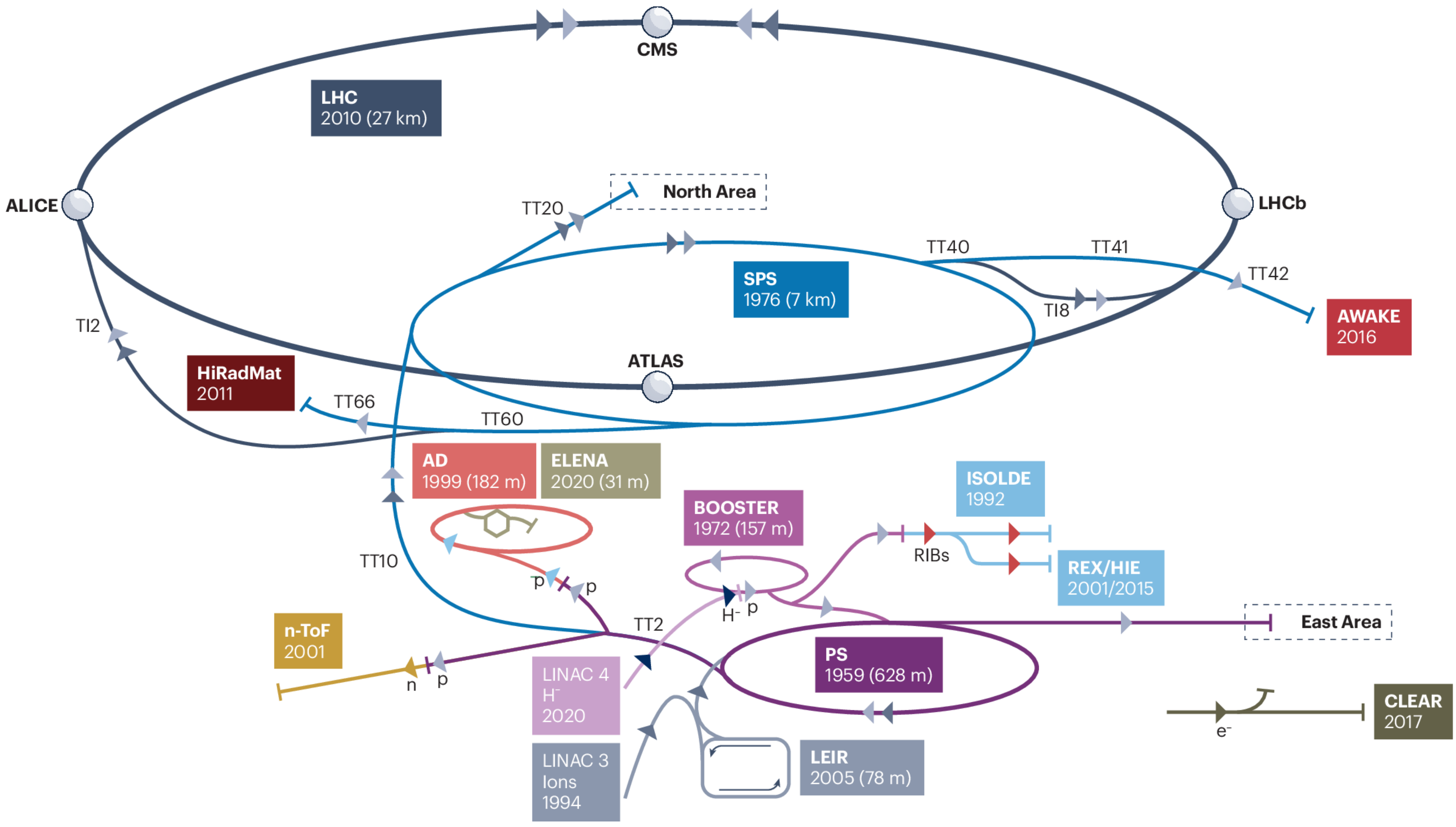
Xxxx institutes   in xxx countries

Xxx members

Xxx deutsch Institute

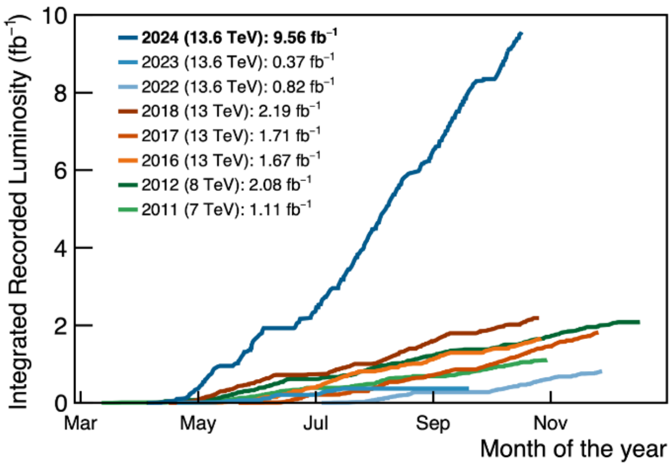
Xx% deutsche Autoren

The LHC and its Pre-Accelerators



LHCb-UI erfolgreich in Betrieb!

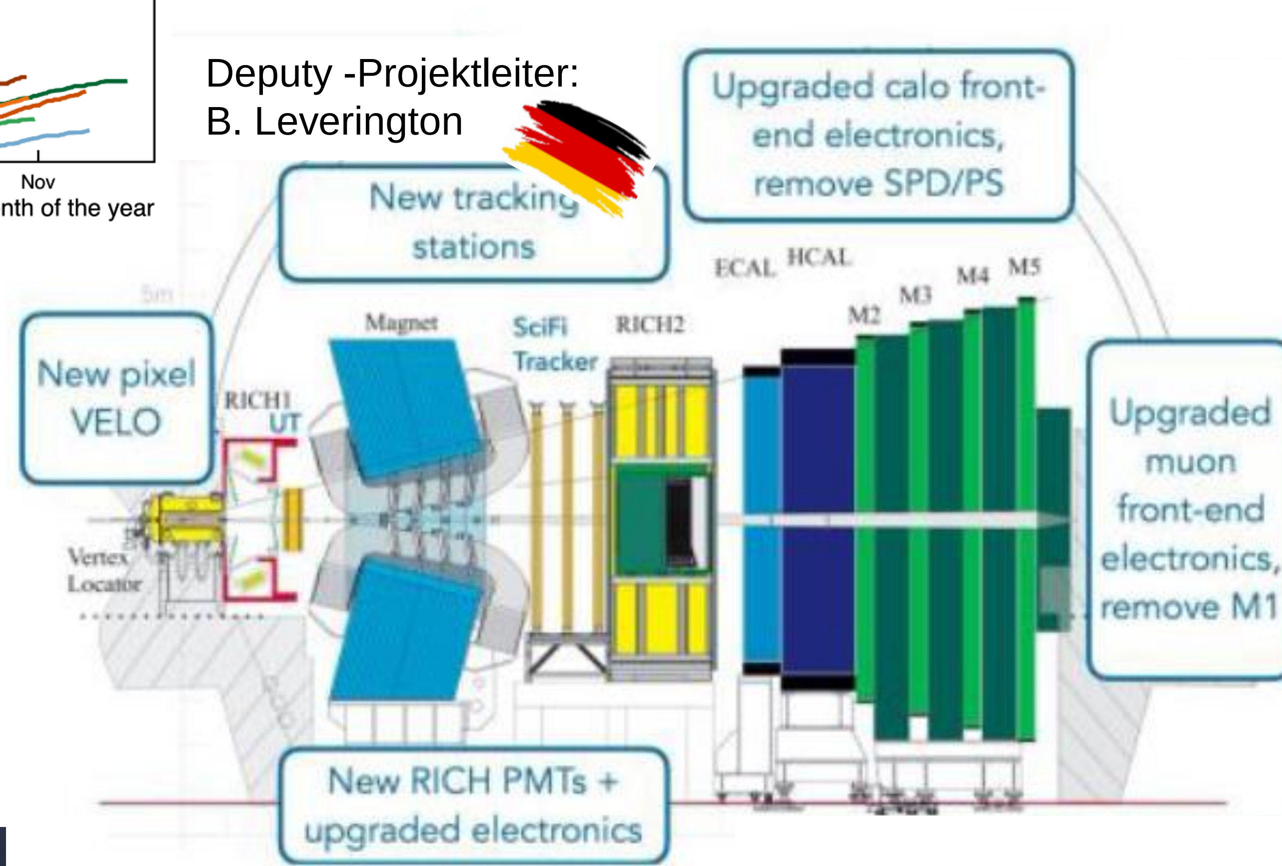
In 2024 mehr Daten als in Run1+2



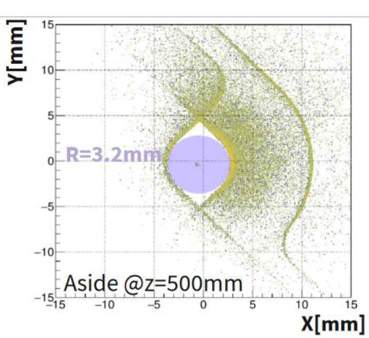
Projektleiter: M. de Cian

+ neuer Software Trigger
für 40 MHz readout (RTA)

Deputy -Projektleiter:
B. Leverington



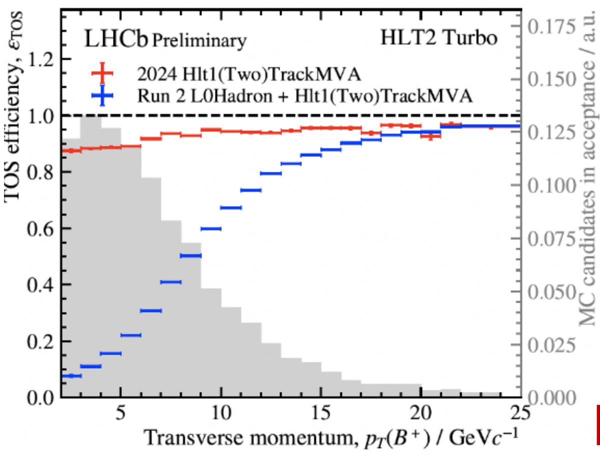
Velo Detektor nach 2023
LHC-Vakuum-Incident
wieder voll funktionsfähig!



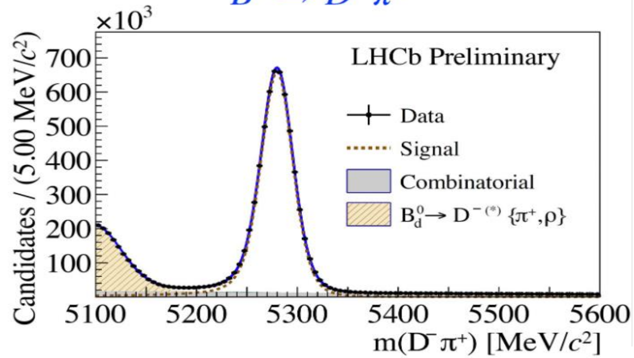
Software Trigger (RTA)

Signalraten pro Luminosität um einen Faktor 2-4 höher als in Run 2

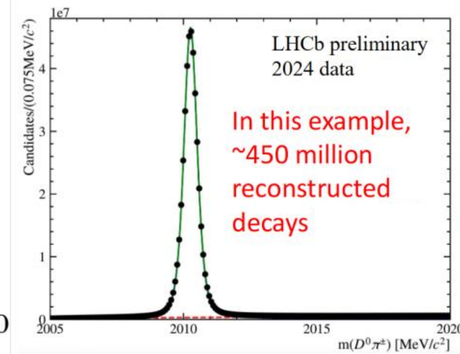
$B^+ \to D^0\pi^+$



$B^0 \to D^-\pi^+$

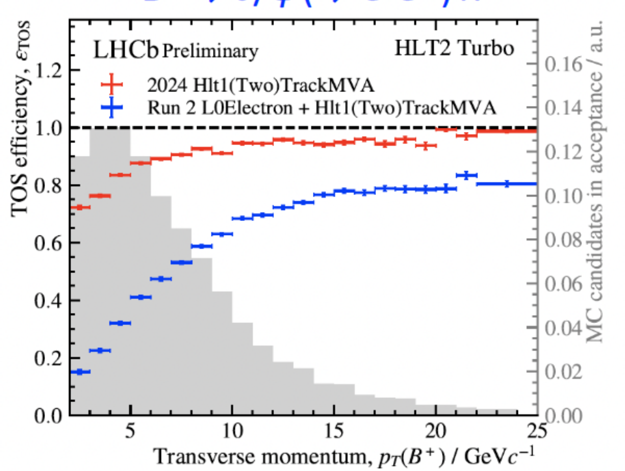


yield/fb^{-1} = 1.1 x 10^6
(x 2.6 Run2)

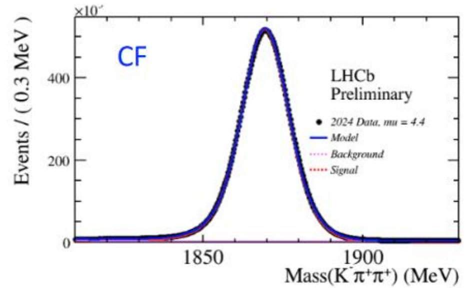


yield/fb^{-1} = 1.9 x 10^8
(x 2.1 Run2)

$B^+ \to J/\psi(\to e^+e^-)\,K^+$

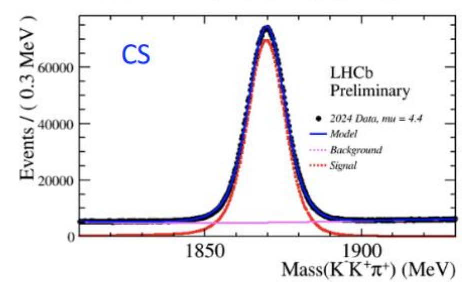


$D^+ \to K^-\pi^+\pi^+$



yield/pb^{-1} = 1.84×10^6
($\times$ 2.8 Run2)

$D^+ \to K^-K^+\pi^+$

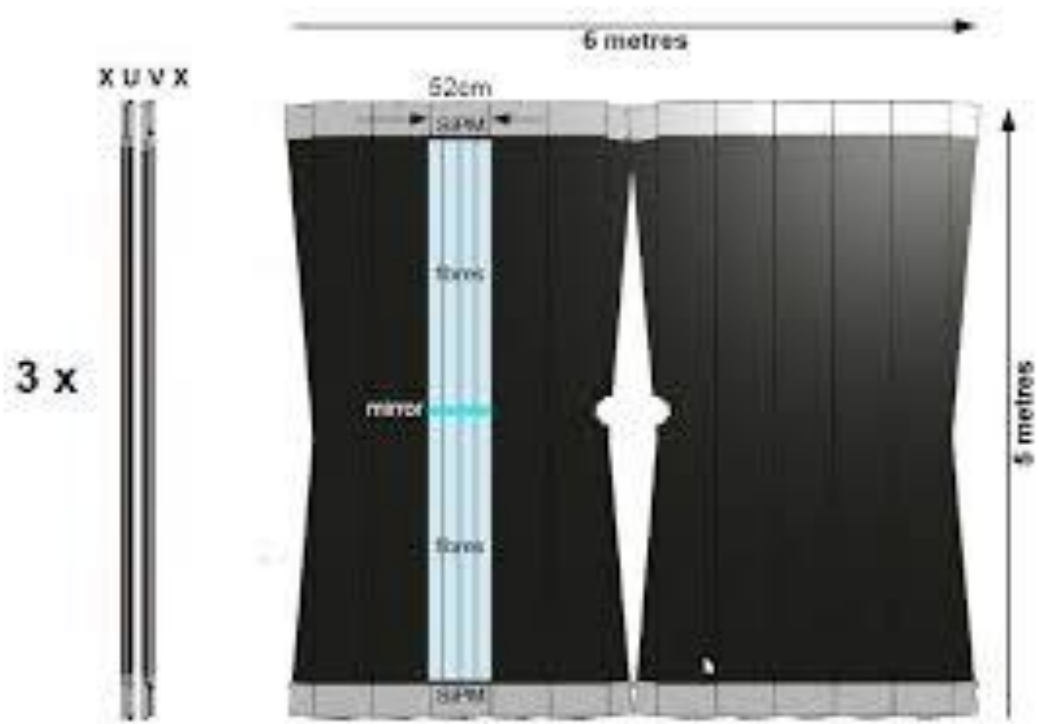


yield/pb^{-1} = 1.97×10^5
($\times$ 3.2 Run2)

Scintillating-Fiber-Tracker

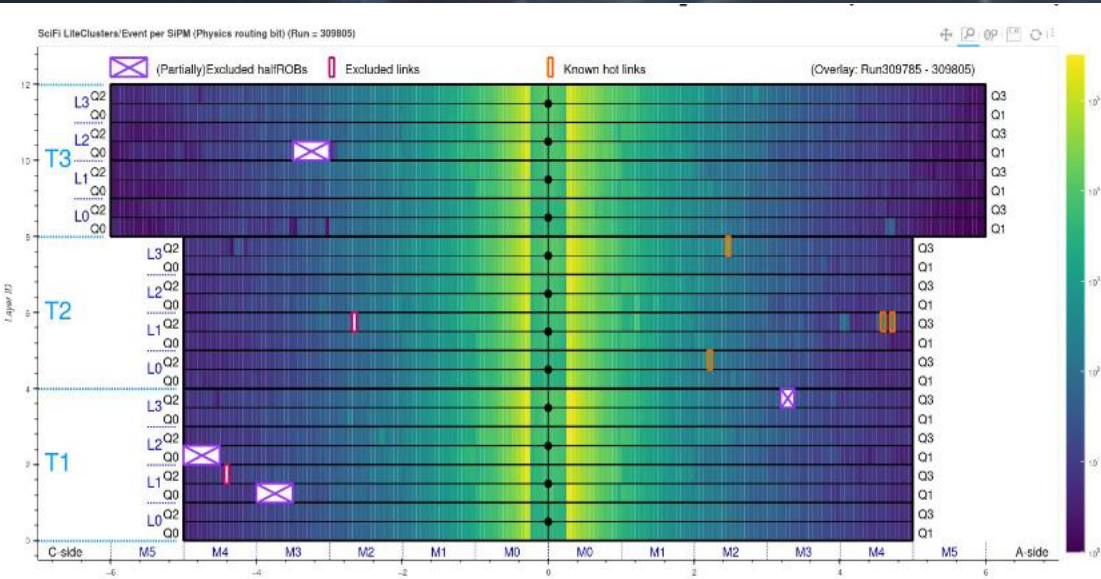
Hauptspursystem nach dem Magente,
12 Lagen zu je 5 x 6 m^2 each;

besteht aus 11.000 km Fasern



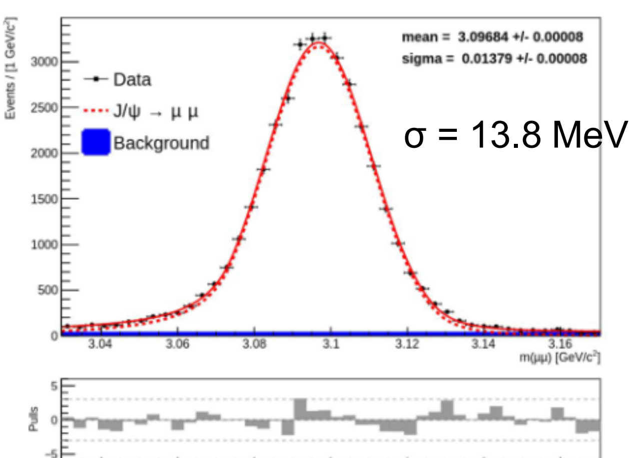
Maßgeblich von deutschen Gruppen entwickelt, gebaut und betrieben.

SciFi-Performance



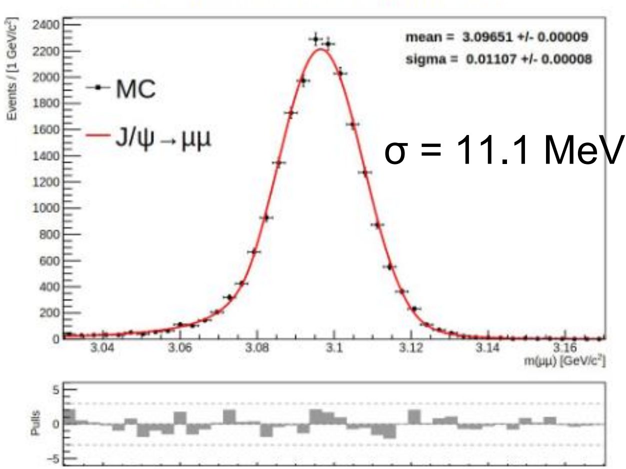
Single hit efficiency in the SciFi: > 99%

Data with new alignment

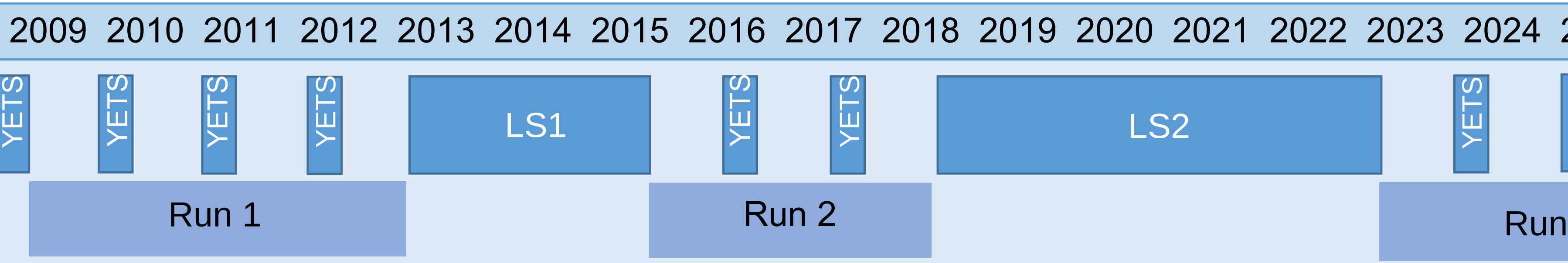


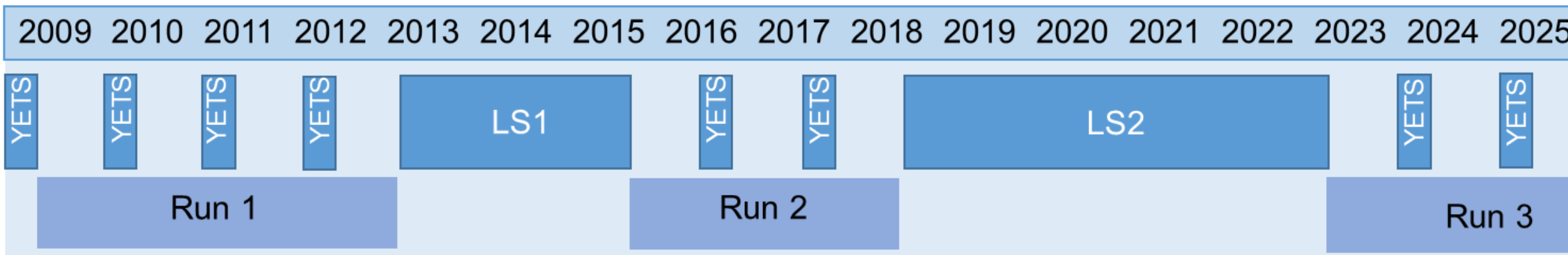
Mass resolution better than in Run 2 and almost as good as in 2024 simulation!

Realistic-2024 simulation



Time Scale


2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024
YETS
YETS
YETS
YETS
LS1
YETS
YETS
LS2
YETS
Run 1
Run 2


2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025
YETS
YETS
YETS
YETS
LS1
YETS
YETS
LS2
YETS
YETS
Run 1
Run 2
Run 3