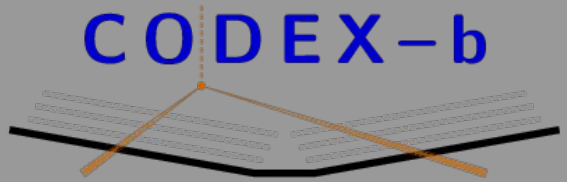
XVII CPAN Days (Valencia)
November 19th, 2025



CODEX-b (β): current status

Carlos Vázquez Sierra,
CODEX-b (and LHCb) collaboration,
Universidade da Coruña (UDC)

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Cofinanciado por la Unión Europea
AGENCIA ESTATAL DE INVESTIGACIÓN
INTALENT UDC - INDITEX

Still no New Physics?

Maybe...

Still no New Physics?

Maybe...

DISCLAIMER (@ slide 3 already, new record!):
I am not a theorist, **but I will attempt to motivate why BSM long-lived particles.**

Still no New Physics?

Maybe…

New Physics operates in *“Stealth”* mode?

EW-scale but tiny couplings and large backgrounds…

The New Physics scale is higher than expected?

Bigger colliders, higher energies, more money!

New Physics requires of unconventional search strategies?

These phenomena does not strictly happen at IP in colliders?

Still no New Phys

Maybe…

New Physics operates i

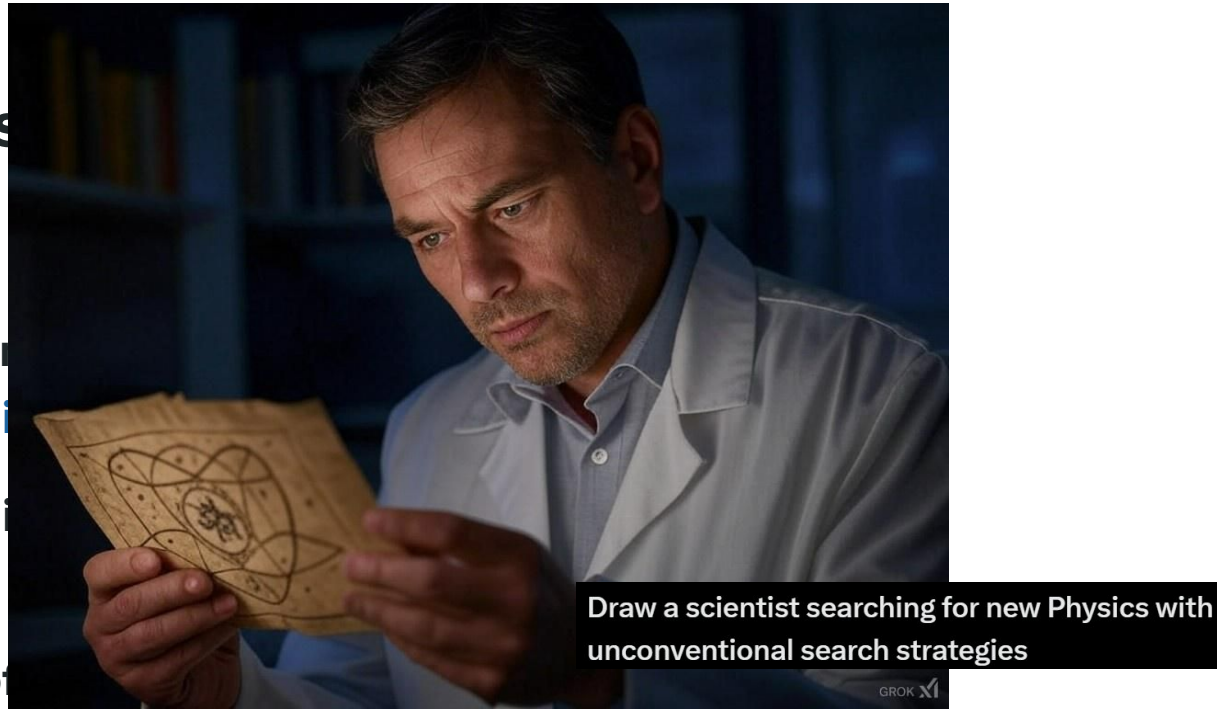
EW-scale but tiny coupli

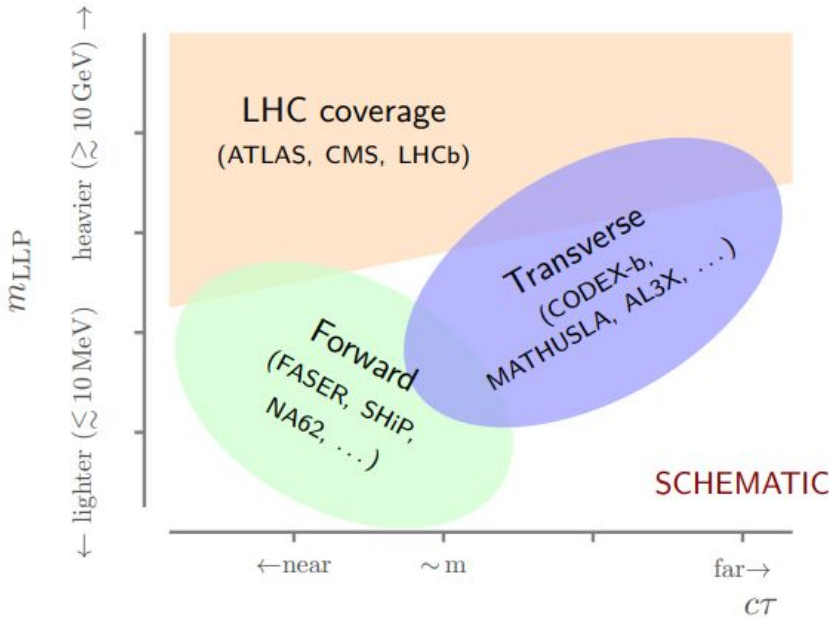
The New Physics scale i

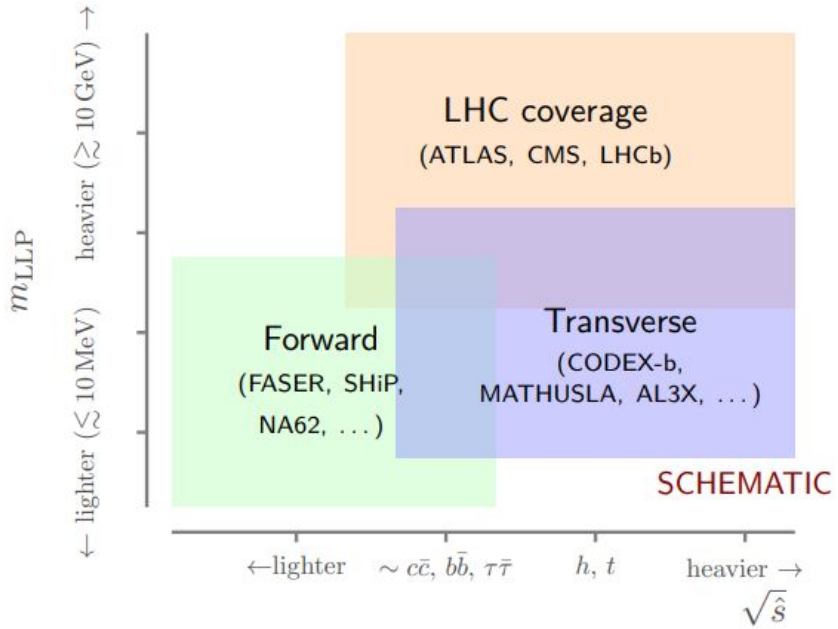
Bigger colliders, higher

New Physics requires o

These phenomena does not strictly happen at IP in colliders?

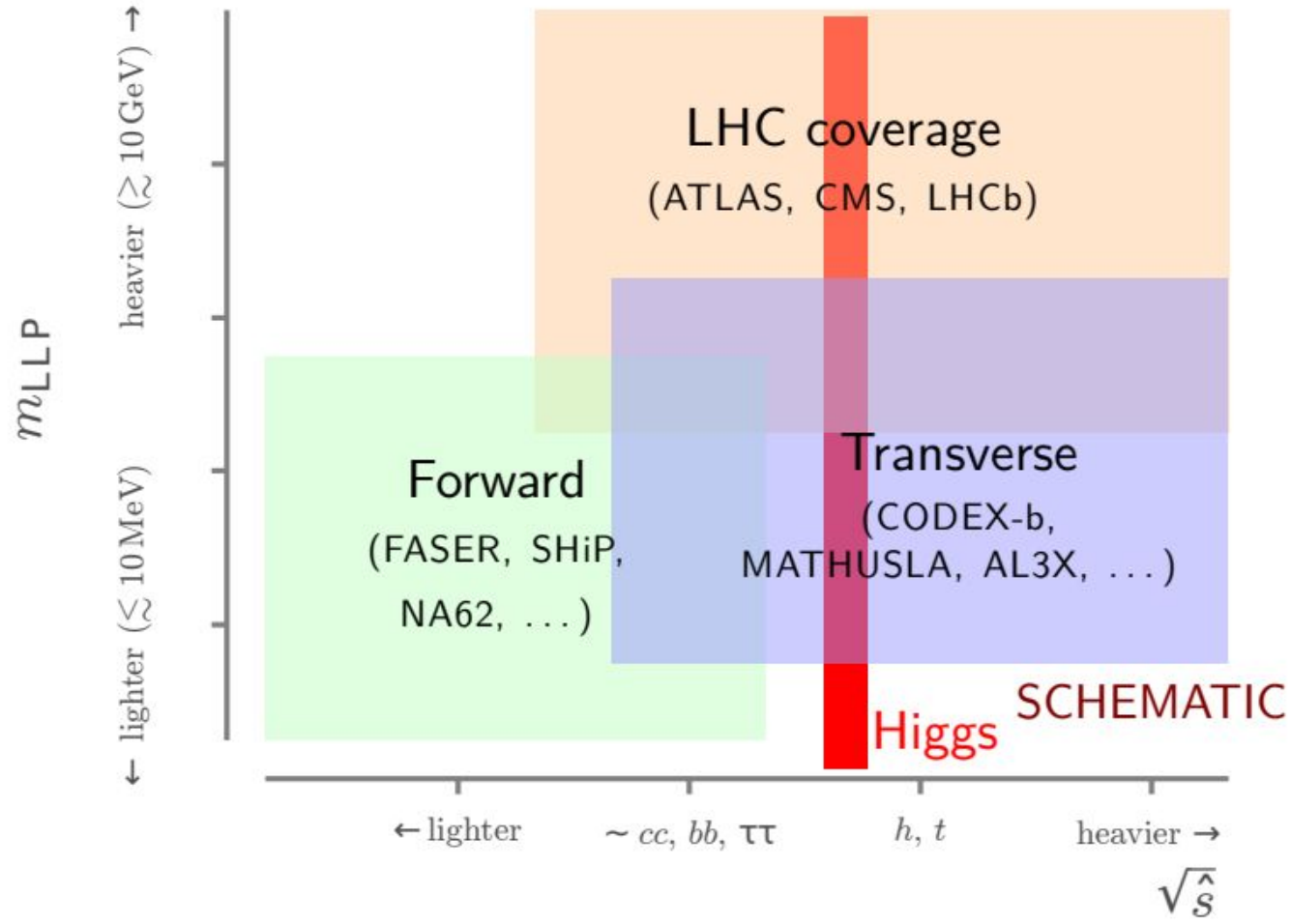






Propose new, dedicated LLP detectors to cover the inaccessible gaps of the parameter space.

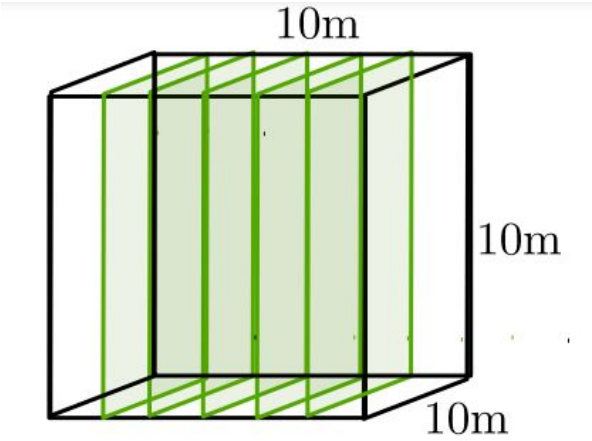
Rely on simpler reconstruction and tracking systems, much more flexible to accommodate unusual signatures.


m_{LLP}
heavier ($\gtrsim 10\,\mathrm{GeV}$) →
← lighter ($\lesssim 10\,\mathrm{MeV}$)
LHC coverage
(ATLAS, CMS, LHCb)
Forward
(FASER, SHiP,
NA62, . . .)
Transverse
(CODEX-b,
MATHUSLA, AL3X, . . .)
Higgs
SCHEMATIC
← lighter
$\sim cc,\ bb,\ \tau\tau$
$h,\ t$
heavier →
$\sqrt{\hat{s}}$

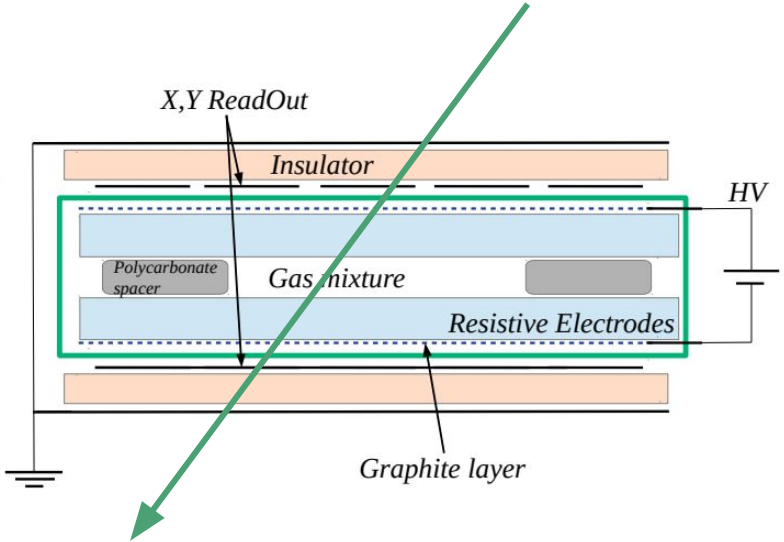
CODEX-b

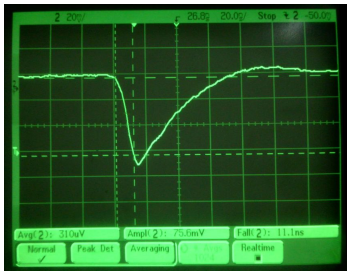
Forging a new detector

A COmpact Detector for EXotics at LHCb: CODEX-b



CODEX-b is a 10x10x10 m cube, with hundreds of **Resistive Plate Chamber (RPC) detectors** assembled in triplets and mounted in mechanical frames.





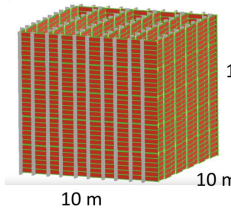
Expression of interest for the CODEX-b detector
Eur.Phys.J.C 80 (2020) 12, 1177

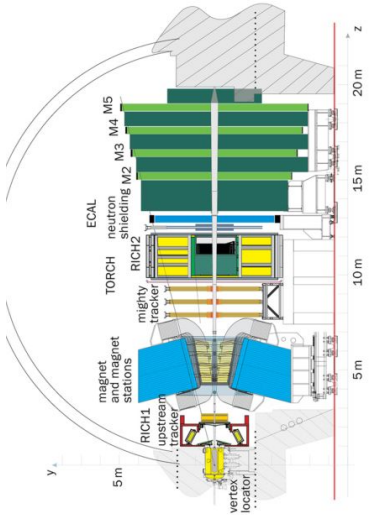
No civil work needed ➜ will make use of existing facilities in the UXA85 cavern.

Relatively **cheap** detector, **O(10) M€**

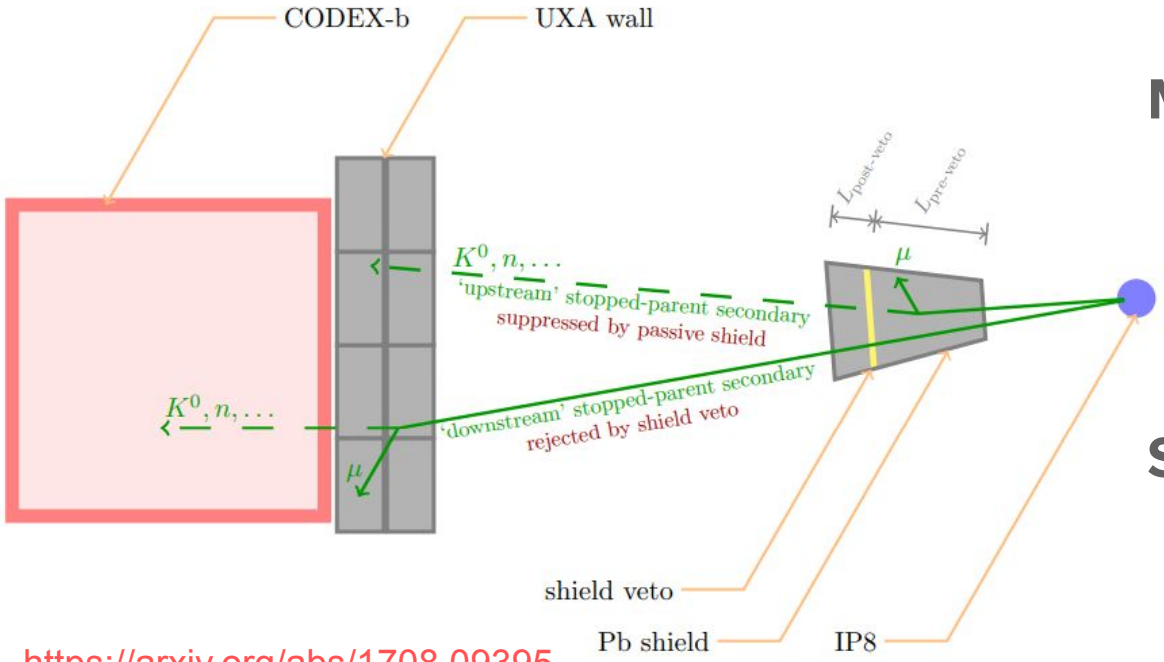
Located 25 m away from the IP8 (LHCb).

Near zero-background: wall + shield veto.





An (almost) background-free detector: shielding



https://arxiv.org/abs/1708.09395
https://arxiv.org/abs/1911.00481

Expect 10^{14} neutrons and KL^0 in 300 fb^{-1} species.

Main backgrounds:

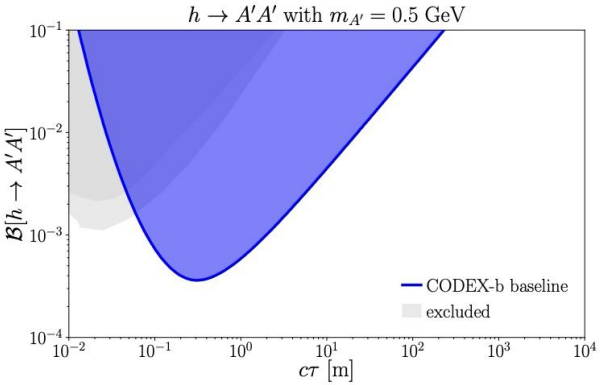
- ***n*, *KL*^{0} (main)** and ***μ*,**
- **penetrating the wall,**
- or **from secondaries or stopped-parent decays.**

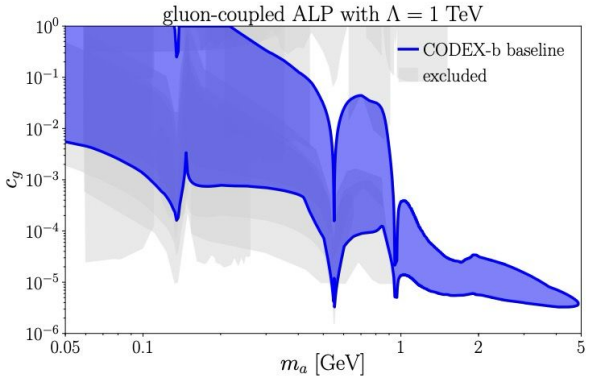
Shielding of 32λ/300 fb^{-1}:

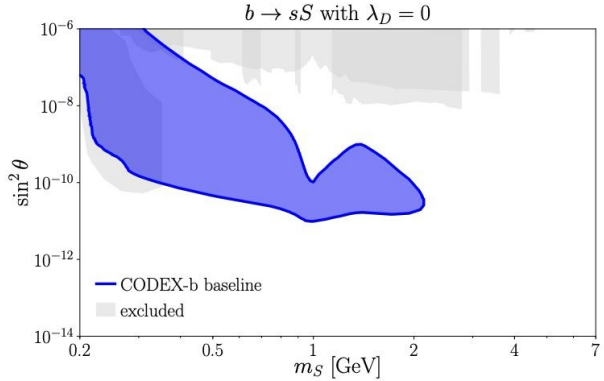
- **Pb shield (pre-veto) ~ 20λ,**
- **Active (shield) veto,**
- **Pb shield (post-veto) ~ 5λ,**
- **UXA wall ~ 7λ.**

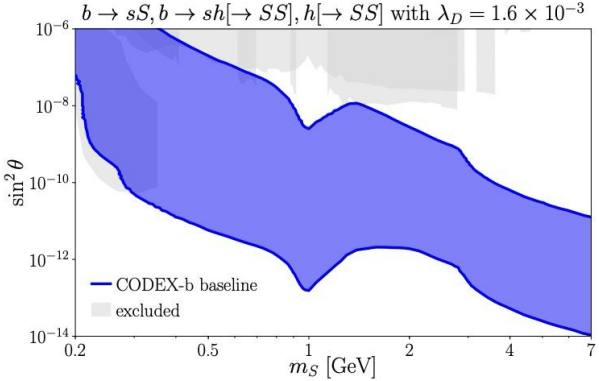
Pb shielding validated with G4 for all

Sensitivities with the nominal detector









CODEX-b ESPPU submission, **arXiv:2505.05952**

But...

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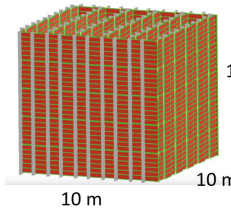

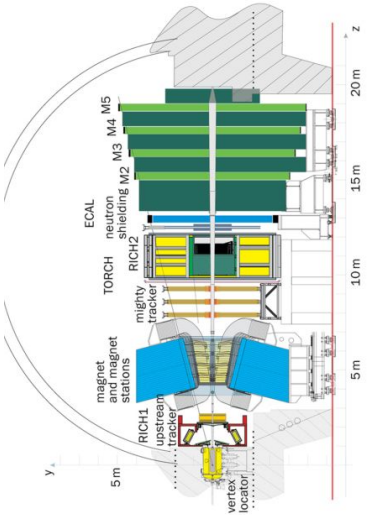

Searching for a new location

- Trigger farms moved to surface for Run 3, but, LHCb Phase-2 upgrade would **require again this space.** Impossible for system to cope with higher latency and increased bandwidth during Run 5.
- **Original CODEX-b location not feasible anymore...**

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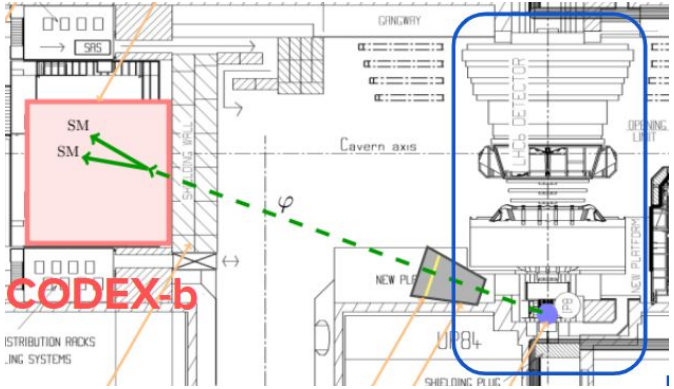
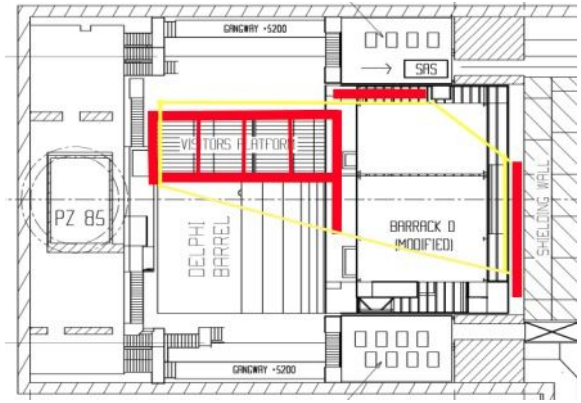
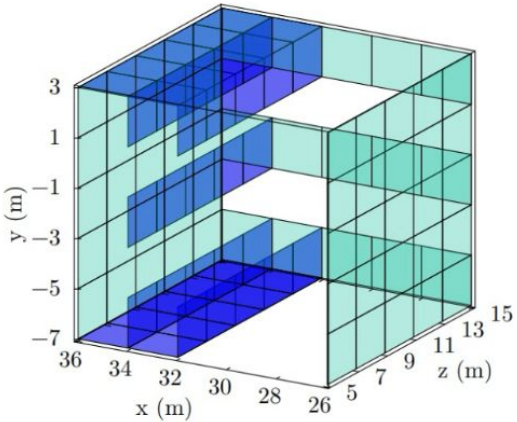
- **Original CODEX-b location not feasible anymore…**
- **But we knew this already since 2022 – 2023 (1st CODEX-b week)** 😊

Crisis = opportunities?

- Sensitivity depends on **detector volume** and **angular coverage**.
- CODEX-b does not need to be hermetic, fully instrumented… or even have cubic shape.







Based on different optimization criteria using an optimization algorithm developed by our LBNL colleagues: granularity, minimum momentum, 6 hits/track, vertex resolution, etc. [T. Gorordo et al, JINST 18 P09012]

Various new scenarios discussed in our ESSPU submission [CODEX-b collaboration, arXiv:2505.05952]

Crisis = opportunities!

- **Conversations with the LHCb management in summer 2025.**
- **Conclusion:** the CODEX-b collaboration will prepare a complete, well studied proposal with various alternative locations.

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- **Iterative process where design will change to be adapted to the potential new locations, developing a hazard score map.**

*LEXGLIMOS (Large Experiment Group Leader in Matters of Safety)
**MSO (Mechanical Safety Officer)

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- **Iterative process where design will change to be adapted to the potential new locations, developing a hazard score map.**
- **Target a negligible impact on LHCb operations and UX85 safety.**
- Aim to converge by summer 2026, with a series of proposals to be studied by the LHCb management after the end of Run 3.

Crisis = opportunities!!

- Not only a redesign and relocation… **but also a change of technology?**
- Gas cartridges and a gas system are the the most expensive budget items.
- Also, very high warming potential, very bad for the environment….

TABLE III: Construction and operational cost estimate for the CODEX-b design scenarios, including a 20% contingency. Numbers in brackets are the standard gas mixture costs (not ECO65).

component	cost [EUR×10^6]		
	baseline	scenario 1	scenario 2/3
RPC modules	14.4	9.0	6.3
power system	3.4	2.1	1.5
gas system	2.7	1.7	1.2
support structure	1.4	0.9	0.6
DAQ	0.7	0.4	0.3
shielding	1.2	1.2	1.2
tooling	1.0	1.0	1.0
gas	26.4	16.5	11.6
(non-eco gas)	3.8	2.4	1.6
total	51.2	32.8	23.6
(non-eco gas)	28.6	18.7	13.8

Crisis = opportunities!!

- Not only a redesign and relocation… **but also a change of technology?**
- Gas cartridges and a gas system are the the most expensive budget items.
- Also, very high warming potential, very bad for the environment….
- **Move from RPCs (gas flow) to sealed RPCs (no flow)? arXiv:2502.14672**
- sRPCs are not usually considered by LHC experiments because of gas degradation, but they could be for cosmic-ray experiments.
- CODEX-b will suffer from the equivalent fluence of a cosmic-ray experiment.

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- CODEX-b will suffer from the equivalent fluence of a cosmic-ray experiment.
- sRPCs experts in FiTNAE + plans to build a gaseous detectors facility.

This would reflect as a reduction on gas expenses and emissions.

CODEX-b would become the cheapest (10M), green detector.

The Physics Beyond Colliders process

- LHCC tasked PBC-BSM with an evaluation process of the transverse detectors.
- Process ongoing for various months already (X. Cid as PBC representative).
- Only one (or none will be funded): **joint agreement among detectors.**

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Main points that could be reviewed:

- Background estimations.
- Gases with carbon footprint.
- Intended location.
- Cost estimates.
- Collaboration status.

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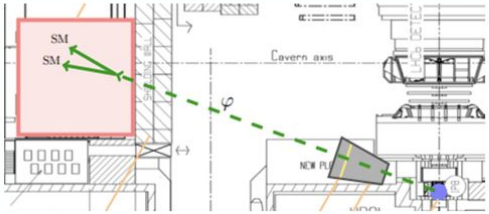
Main points that could be reviewed:

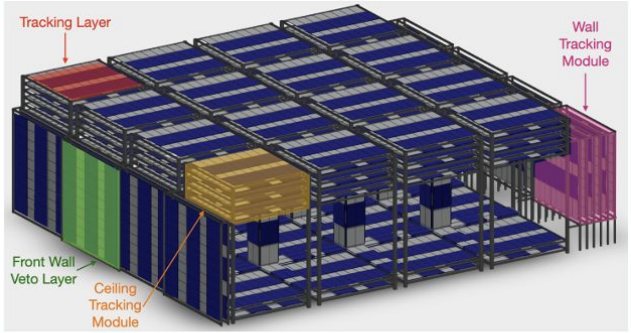
- Background estimations **[one review each other; ANUBIS reviewing CODEX now].**
- Gases with carbon footprint **[other technologies? sRPCs?].**
- Intended location **[engineers working on it!].**
- Cost estimates **[huge reduction in gas makes it become second order].**
- Collaboration status **[constitution ratified, discussions with LHCb management].**

D. Curtin, SEARCH conference

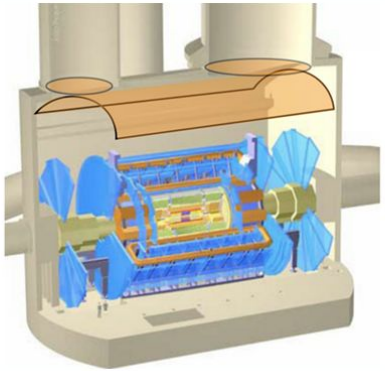
CODEX-b



MATHUSLA



ANUBIS



~ Background-free

Data-driven BG estimates

Gain most at $m_{LLP} \gtrsim$ GeV

Greatly increase LLP sensitivity for $m_{LLP} \sim$ few - 100 GeV

Investigating available room

Need a building

Needs to be in cavern

CODEX-β

The need for a demonstrator

The need for a demonstrator

CODEX-b will be a **O(10) M€, near zero SM-background detector**, composed by **hundreds of RPCs arranged in a 10x10x10 m cube**.

Purpose of a demonstrator:

- **Test the technology, design and integration with LHCb.**
- **Measure the backgrounds accurately, validate our simulations, and develop data-driven simulations based on an actual detector element response.**
- **Perform physics measurements and update sensitivities projections.**

CODEX-β, a smaller version of CODEX-b, with 42 RPCs, integrated with LHCb and taking data during Run 3 (2025), costing ~1% of the full CODEX-b detector.

The need for a demonstrator

CODEX-b will be a **O(10) M€, near zero SM-background detector**, composed by **hun**

Purp

-
- lop
-

Integration with LHCb: simultaneous trigger allows to expand the LHCb search program on BSM models (transverse region).

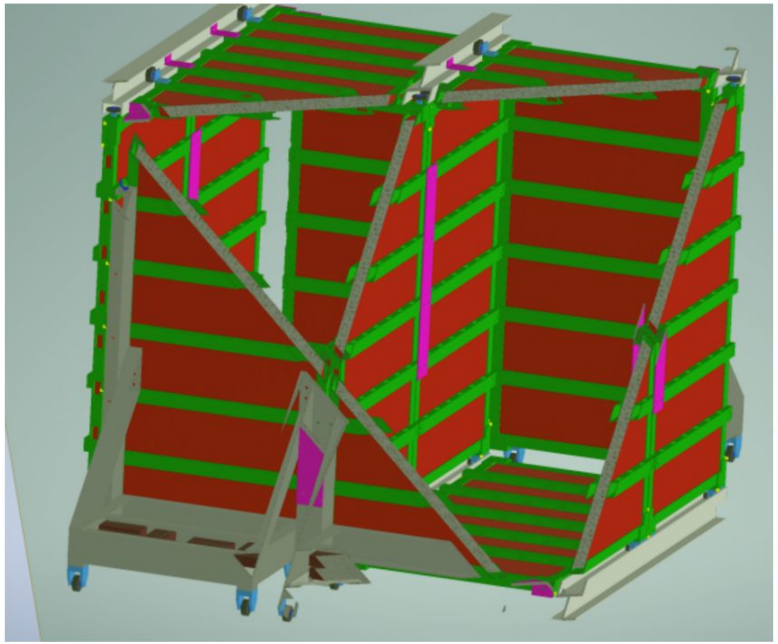
CODEX-p, a smaller version of CODEX-b, with 12 m^3, integrated with LHCb and taking data during Run 3 (2025), costing ~1% of the full CODEX-b detector.

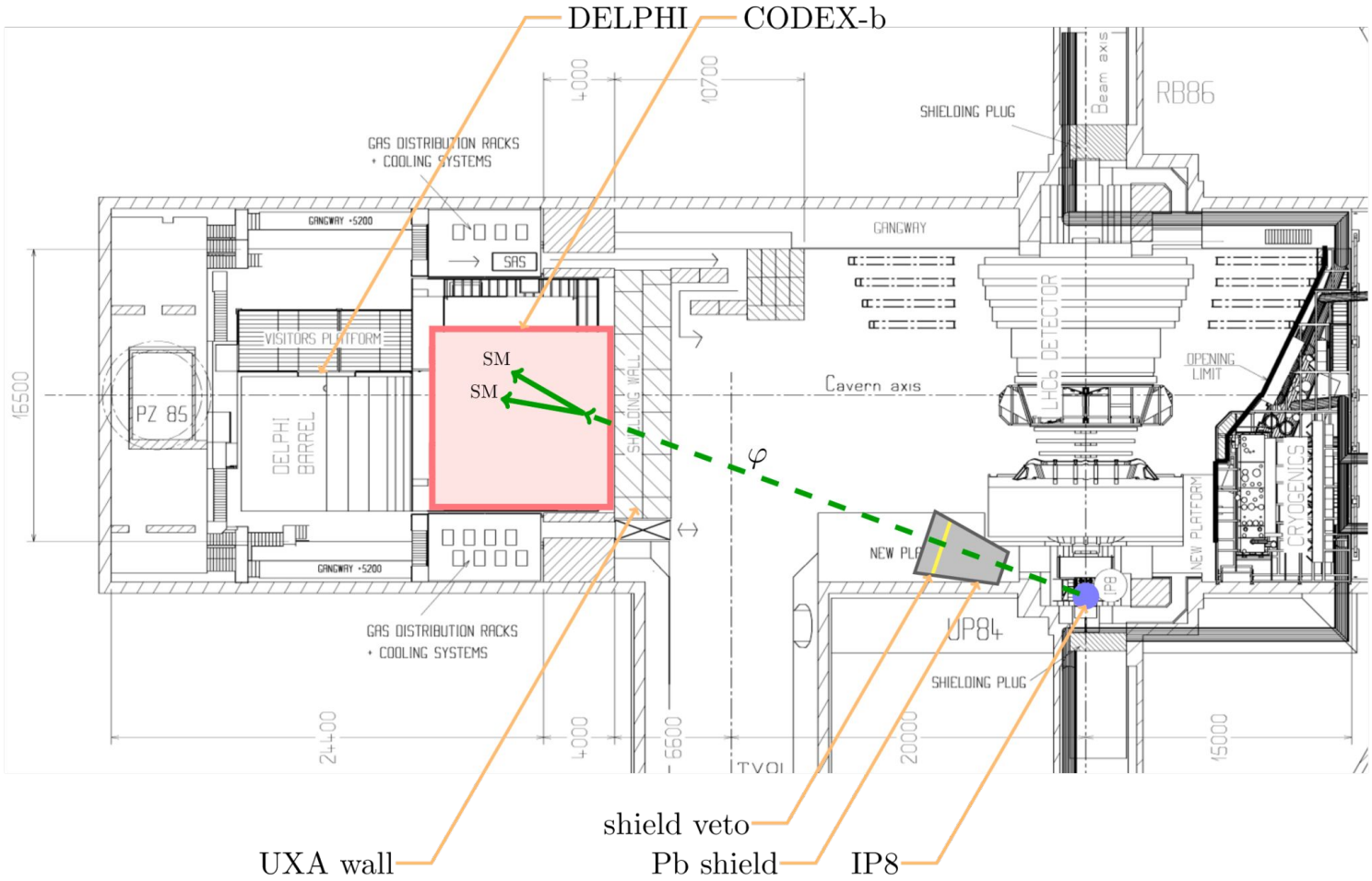
The need for a demonstrator

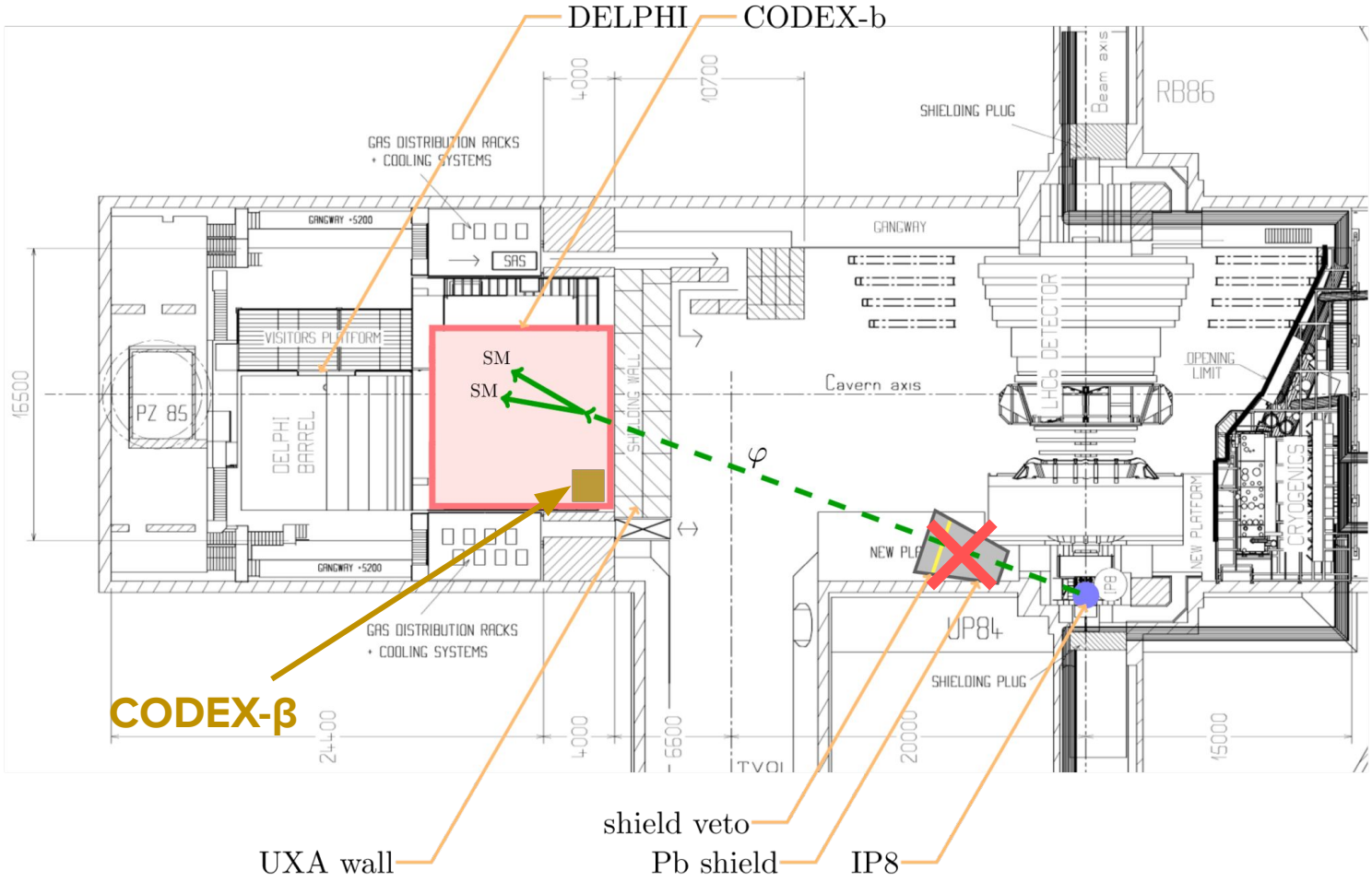
CODEX-β is a 2 x 2 x 2 m cube:

- Each side is composed by 2 panels, 1 x 2 m each ➜ **2x6 = 12 panels,**
- 2 panels inside ➜ 12+2 = **14 total panels.**
- Each panel consists of a RPC triplet (3 singlets),
- **Design from BIS78 ATLAS upgrade project (as for CODEX-b).**

Mechanical frames completely redesigned by the CODEX-b team, built in the University of Cincinnati workshop.




DELPHI
CODEX-b
4000
10700
Beam axis
RB86
SHIELDING PLUG
GAS DISTRIBUTION RACKS
+ COOLING SYSTEMS
GANGWAY +5200
SAS
GANGWAY
VISITORS PLATFORM
SM
SM
LHCb DETECTOR
OPENING
LIMIT
16500
PZ 85
DELPHI
BARREL
SHIELDING WALL
Cavern axis
φ
NEW PLATFORM
CRYOGENICS
NEW PLA
IP8
UP84
GAS DISTRIBUTION RACKS
+ COOLING SYSTEMS
SHIELDING PLUG
24400
4000
6600
20000
15000
UXA wall
shield veto
Pb shield
IP8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SM
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φ
NEW PLA
NEW PLATFORM
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UP84
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SHIELDING PLUG
CODEX-β
24400
4000
6600
20000
15000
shield veto
UXA wall
Pb shield
IP8

Road to data-taking (I)

CODEX-β installation

Installation TDR [JINST 20 (2025) T07007]

Road to data-taking (II)

Details on backup

Road to data-taking (III)

Details on backup
Targets mid-Dec '25

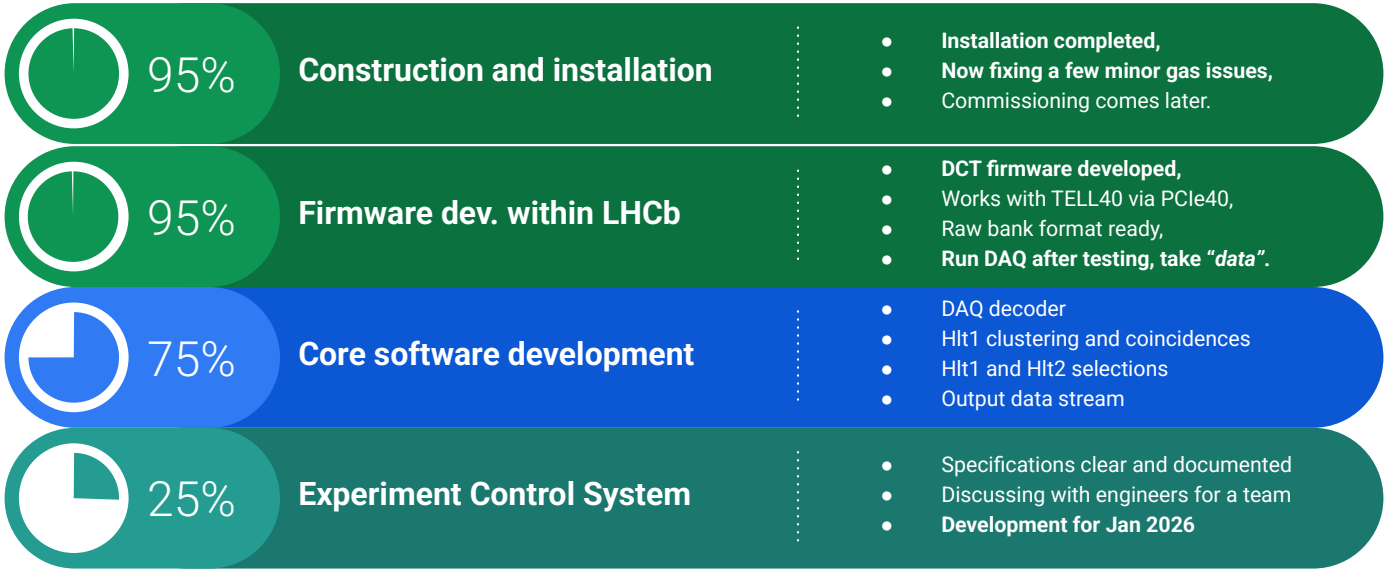
What about simulation?

Geometry almost completely implemented. **But still needs to be validated.** We are able to obtain hits from Simulation, but, **we still need to model the complete infrastructure: CODEX is in a side of the cavern never fully considered for G4.**

Contribute to this and help the LHCb simulation project with the development of the infrastructure in DD4hep (Run 4 and 5). Digitisation also to be developed. **Planned for 2026.**

For now – fast simulation and digitisation frameworks **fully functional. Plan to make them public and available in conda in the next months.**

Road to data-taking (IV)



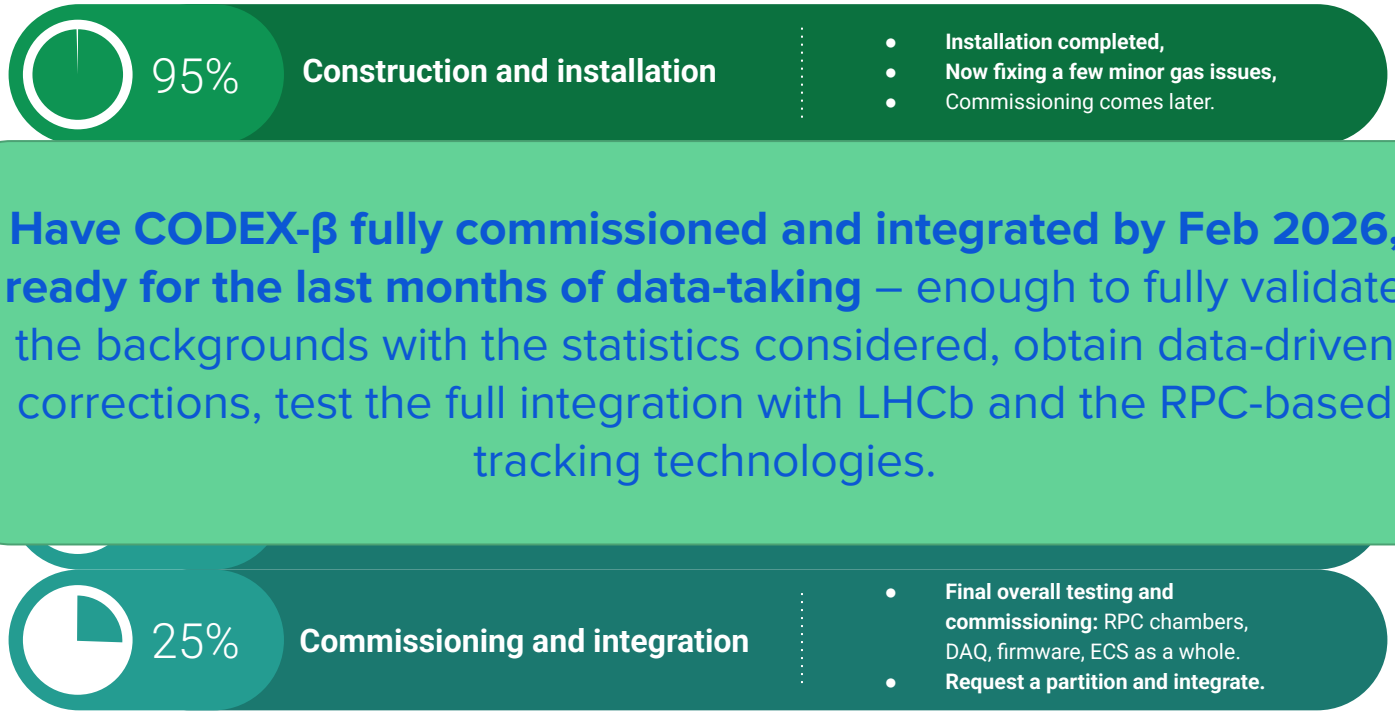
Road to data-taking (V)

Six PhD students from USC contributed to construction and installation!

Coordination

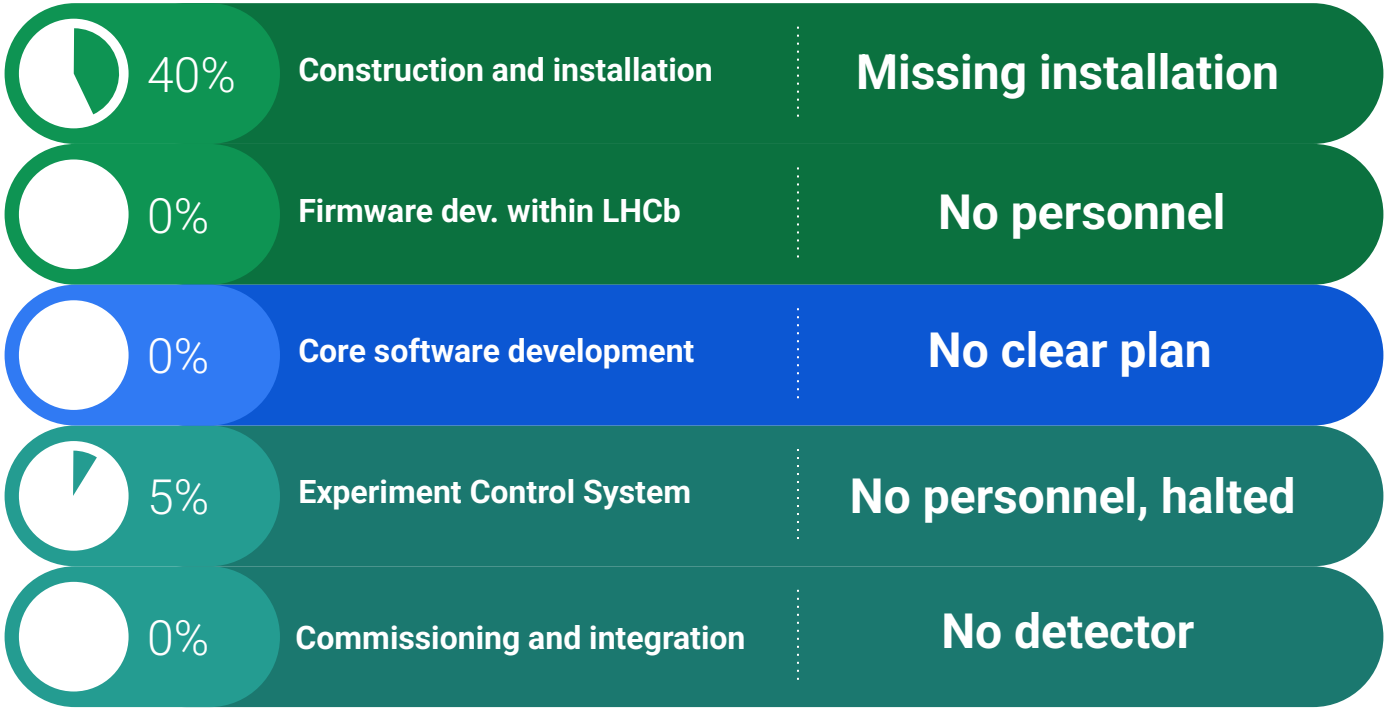
USC, CINCINNATI	95%	**Construction and installation**	• **Installation completed,** • **Now fixing a few minor gas issues,** • Commissioning comes later.
CERN, CINCINNATI	95%	**Firmware dev. within LHCb**	• **DCT firmware developed,** • Works with TELL40 via PCIe40, • Raw bank format ready, • **Run DAQ after testing, take "*data*".**
UNIVERSIDADE DA CORUÑA	75%	**Core software development**	• DAQ decoder • Hlt1 clustering and coincidences • Hlt1 and Hlt2 selections • Output data stream
UNIVERSIDADE DA CORUÑA	25%	**Experiment Control System**	• Specifications clear and documented • Discussing with engineers for a team • **Development for Jan 2026**
USC, CINCINNATI	25%	**Commissioning and integration**	• **Final overall testing and commissioning:** RPC chambers, DAQ, firmware, ECS as a whole. • **Request a partition and integrate.**

Road to data-taking (now)



Road to data-taking (now)

Road to data-taking (the past)



Final considerations

Report of the first FIPPAN review on CODEX-β by LHCb (Sep 2023):

- That Codex-β be considered as a time-limited R&D project of LHCb until June 2026. The project is being hosted by LHCb and should be kept independent of LHCb where possible.

The CODEX-b collaboration follows and enforces the minimal-impact-on-LHCb rule, as well as complies with LHCb technical guidelines and operations, trying also to find solutions to the environmental issues caused by the employ of RPCs using gases with warming potential.

The collaboration

Organigram and contributions

CODEX-b

Spokesperson
Phil Ilten

Deputy SP and CC
Juliette Alimena

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

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UC CINCINNATI

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Daniel Johnson

Technical coordinator
Titus Mombächer

Simulation convener
Biplab Dey

Reconstruction convener
Bingxuan Liu

Installation and commissioning convener
Michael K. Wilkinson

Future design convener
Dean Robinson

Contributions from Spanish institutions

USC [Xabier Cid as PI, 2020–2022 + CVS as co-PI since 2023] → 180k€ in total (45% for PhD students expenses and salaries, 55% for instrumentation). Various funding sources (XuntaGal, PID2023, IGFAE MdM).

UDC [Carlos Vázquez as PI, 2025 only] → 24k€ in total (almost full spent in instrumentation), from RyC, InTalent, XuntaGal. Around 6k€ from XuntaGal FiTNAE GPC.

Rest of the expenses mostly funded by University of Cincinnati (approx. 50%), having the other half funded by USC and UDC. Contributions from ELTE, Paris-Saclay and Birmingham, among others.

One PhD thesis defended (first CODEX thesis in Spain), second one to be defend in December, and **four** more ongoing (all USC). One MSc on CS ongoing, and two BSc in Nanoscience next year (UDC), one BSc and one MSc in Physics (USC). **Highly prolific!**

Summary

Growing team with 18 institutes and 60 members, including theorists, engineers, and members of ATLAS, CMS and LHCb

https://codex-b.web.cern.ch/

Summary

- New design and location studies for CODEX-b. All efforts towards minimising the impact on LHCb, on the environment and on the wallet. All transverse detectors under PBC/LHCC scrutiny.
- CODEX-β to be completed for the end of the year, and commissioned for 2026 mid-Q1. Data-taking from then until the end of Run 3 (July 2026).
- Enormous effort from collaborators (especially PhD students) on both hardware and software task. Coordination efforts are also crucial.
- Leading contributions (personnel and equipment) to CODEX from UDC and USC. Spain as one of the top hubs on LLP searches and dedicated LLP detectors: CODEX-b, MoEDAL, MATHUSLA, etc.

Summary

- New design and location studies for CODEX-b. All efforts towards minimising the impact on LHCb, on the environment and on the wallet. All

CODEX has an enormous potential to become one of the cheapest, green dedicated LLP detectors, allowing for not only BSM searches in the transverse region with near-zero background, also for combined LHCb+CODEX searches.

USC. Spain as one of the top hubs on LLP searches and dedicated LLP detectors: CODEX-b, MoEDAL, MATHUSLA, etc.

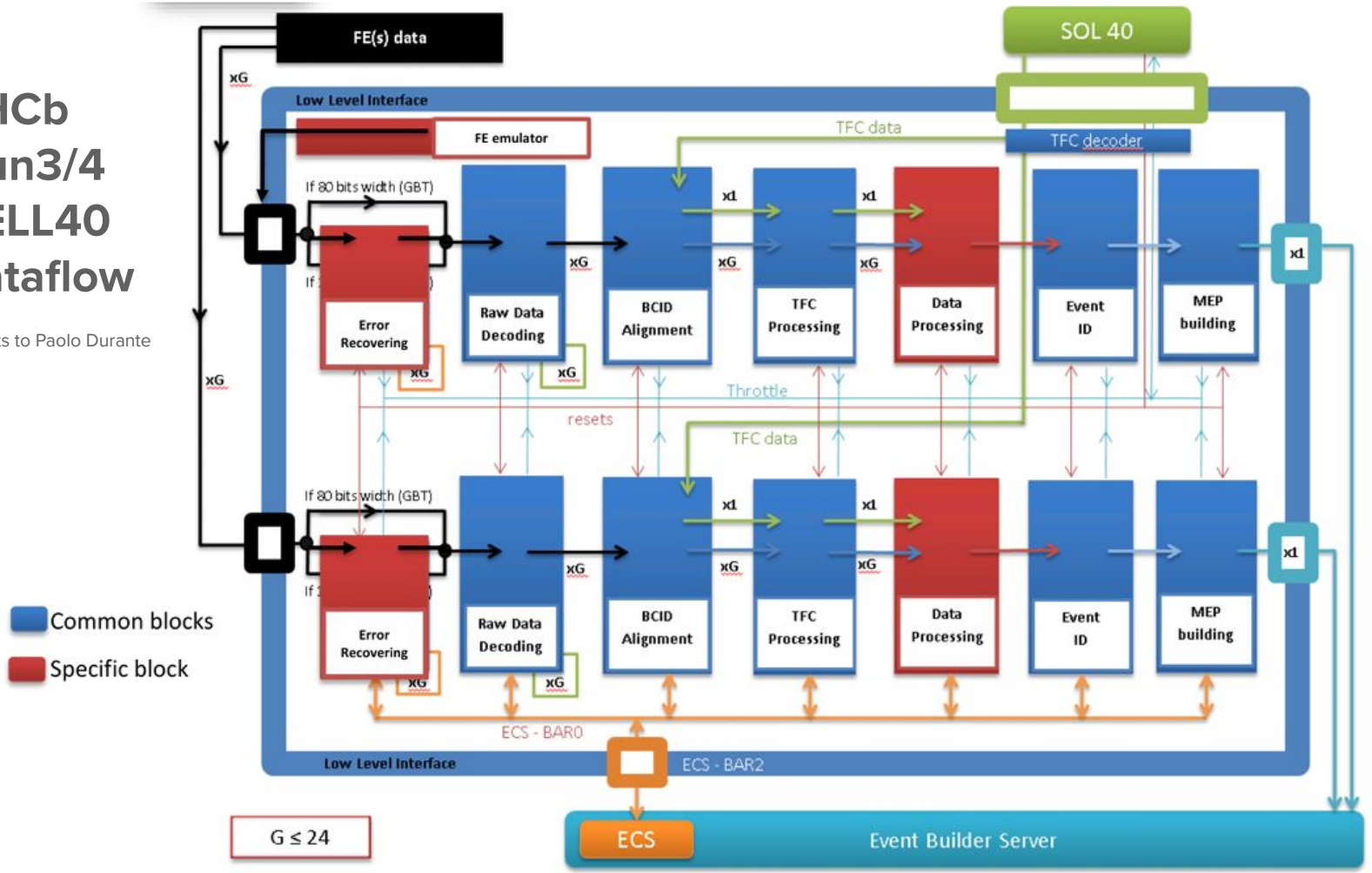
Here are the Victorian-era particle physicist images you requested, capturing the moment of discovering dark matter in CODEX-b. If you need any adjustments or additional elements, feel free to let me know!

Thank you for listening!

Backup

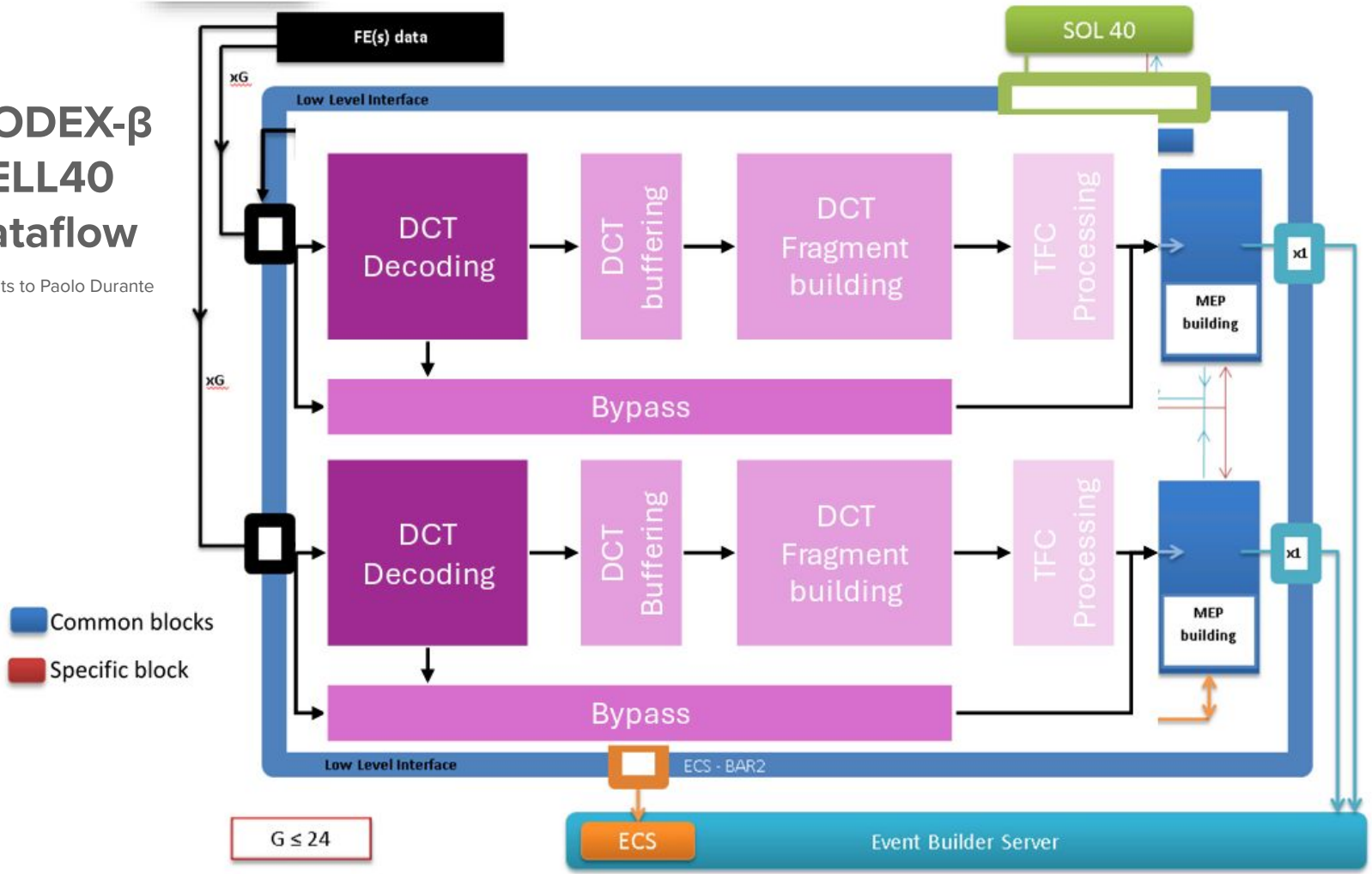
LHCb Run3/4 TELL40 dataflow

Credits to Paolo Durante



CODEX-β TELL40 dataflow

Credits to Paolo Durante



Core software: data processing and triggers

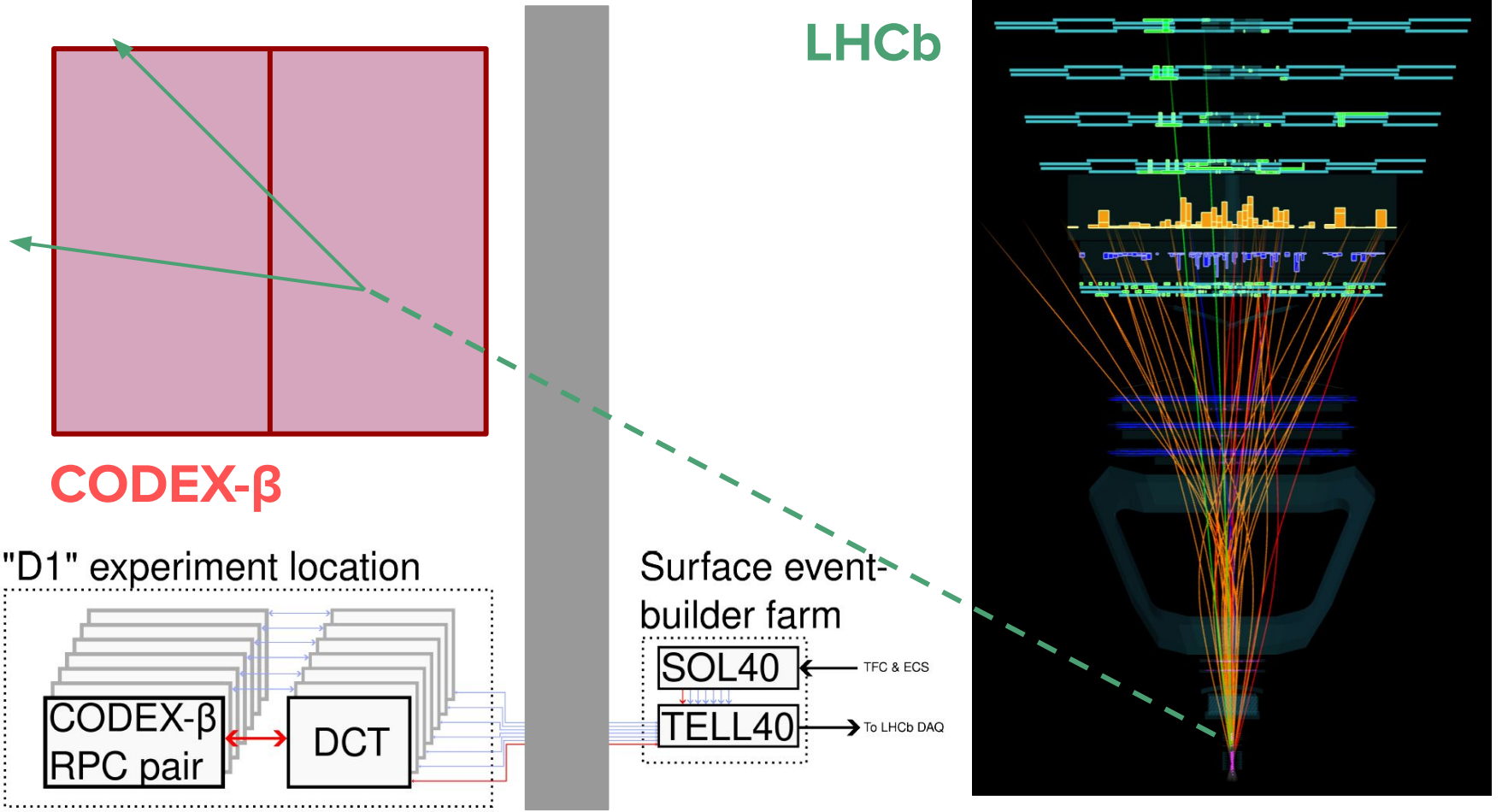
DAQ decoder | Hlt1 (GPU) | Hlt2 (CPU)

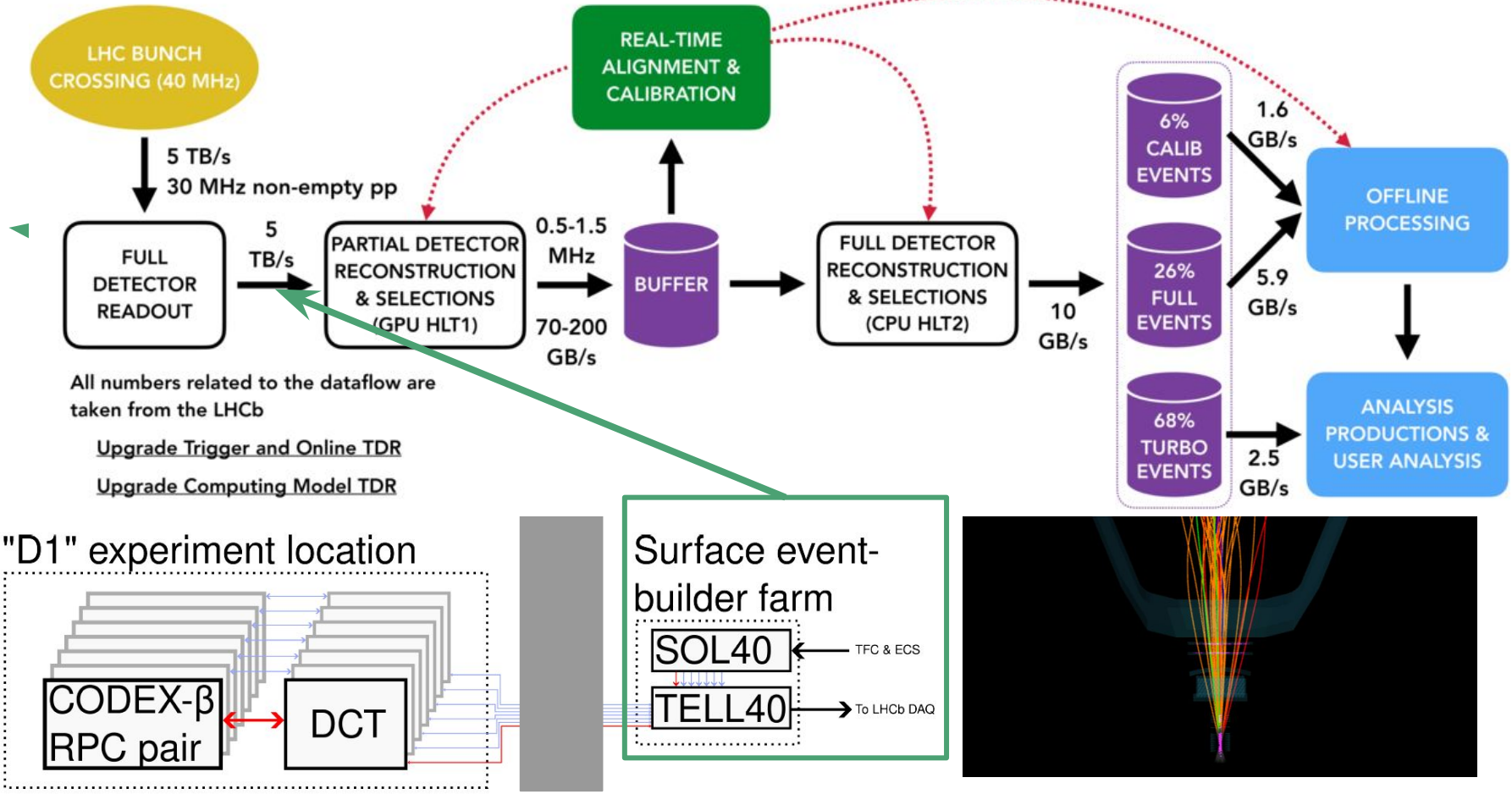
- Convert the raw bank information into an meaningful, usable object in the Hlt1 level.
- **Prototype ready, need to come up with a final output version of the decoder.**

- Develop a CUDA algorithm to form clusters and obtain coincidences.
- A complete CUDA algorithm has been developed, **now being integrated in the Allen framework.**

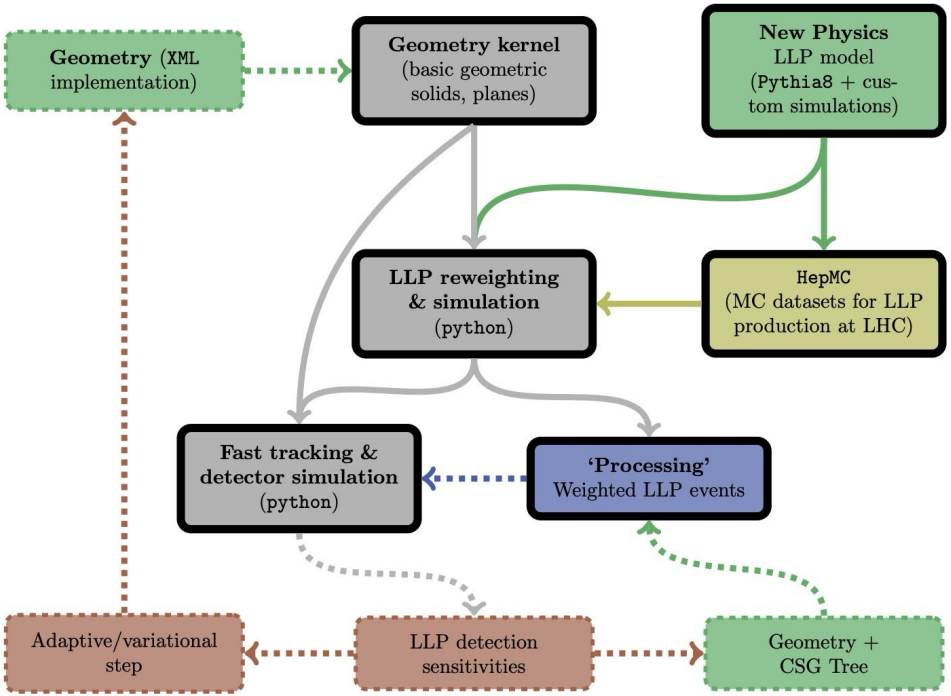
- Passthrough trigger lines for CODEX, perhaps with some specific cases saving also LHCb data.
- Own output data stream, small (1-5 Tb) of data expected.
- **Last, very easy step.**

Target: mid-December (xmas break)

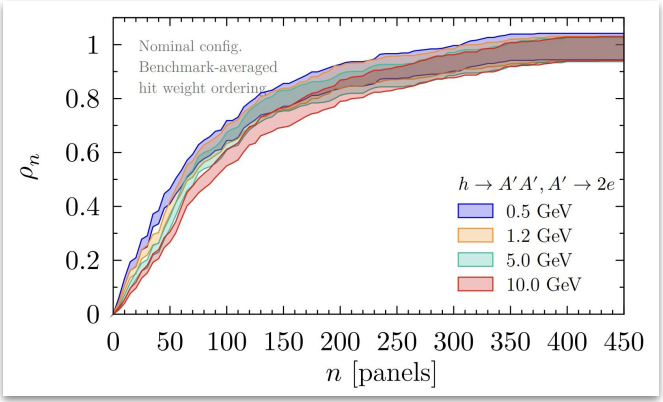

LHCb
CODEX-β
"D1" experiment location
CODEX-β
RPC pair
DCT
Surface event-
builder farm
SOL40
TFC & ECS
TELL40
To LHCb DAQ


LHC BUNCH CROSSING (40 MHz)
5 TB/s
30 MHz non-empty pp
FULL DETECTOR READOUT
5 TB/s
PARTIAL DETECTOR RECONSTRUCTION & SELECTIONS (GPU HLT1)
0.5-1.5 MHz
70-200 GB/s
BUFFER
REAL-TIME ALIGNMENT & CALIBRATION
FULL DETECTOR RECONSTRUCTION & SELECTIONS (CPU HLT2)
10 GB/s
6% CALIB EVENTS
26% FULL EVENTS
68% TURBO EVENTS
1.6 GB/s
5.9 GB/s
2.5 GB/s
OFFLINE PROCESSING
ANALYSIS PRODUCTIONS & USER ANALYSIS
All numbers related to the dataflow are taken from the LHCb
Upgrade Trigger and Online TDR
Upgrade Computing Model TDR
"D1" experiment location
CODEX-β RPC pair
DCT
Surface event-builder farm
SOL40
TFC & ECS
TELL40
To LHCb DAQ

Optimization algorithm



arXiv:2211.08450



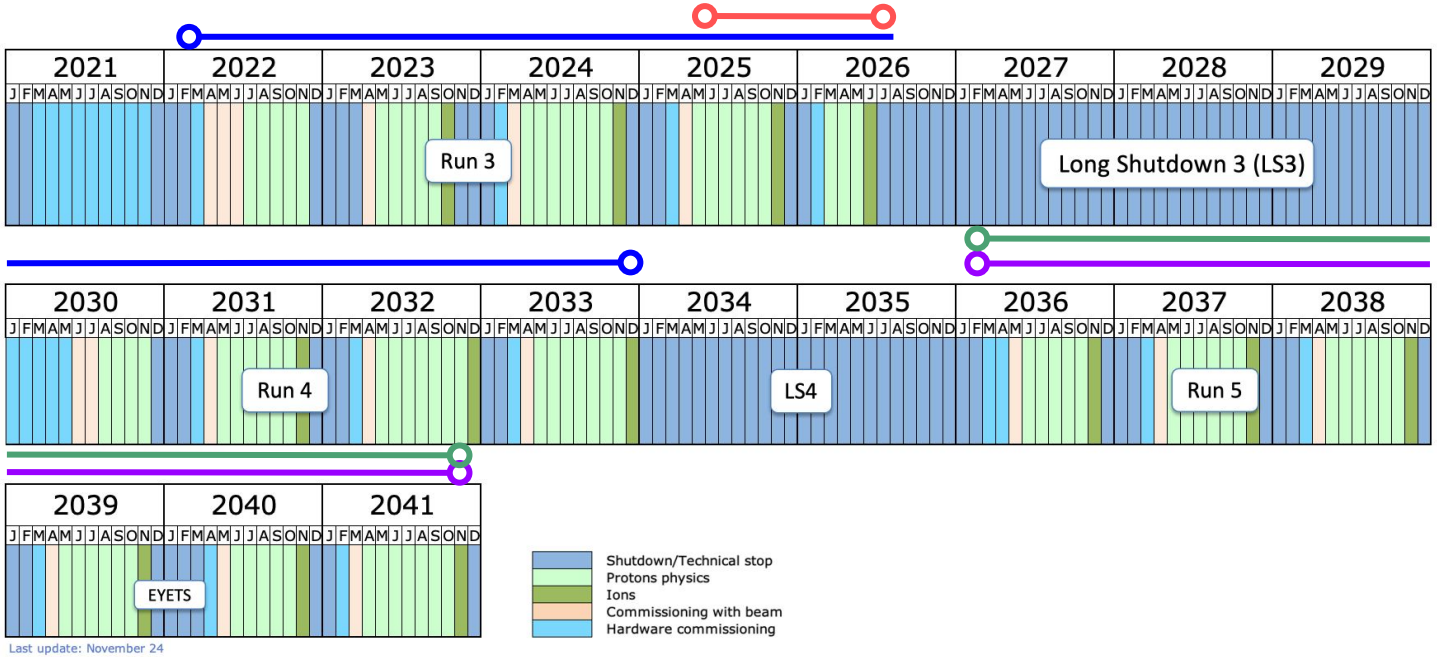
- Algorithmic optimization, provides **best possible detector design**, averaged over different BSM models. Branch-and-bound technique.
- Includes fast tracking and detector simulation
- AI (MODE) approach also under study

Experiments and timescales

LHCb-U1 (2022-2032): 50 fb^{-1} (A)
LHCb-U2 (2035-2041): 300 fb^{-1}

A = approved.

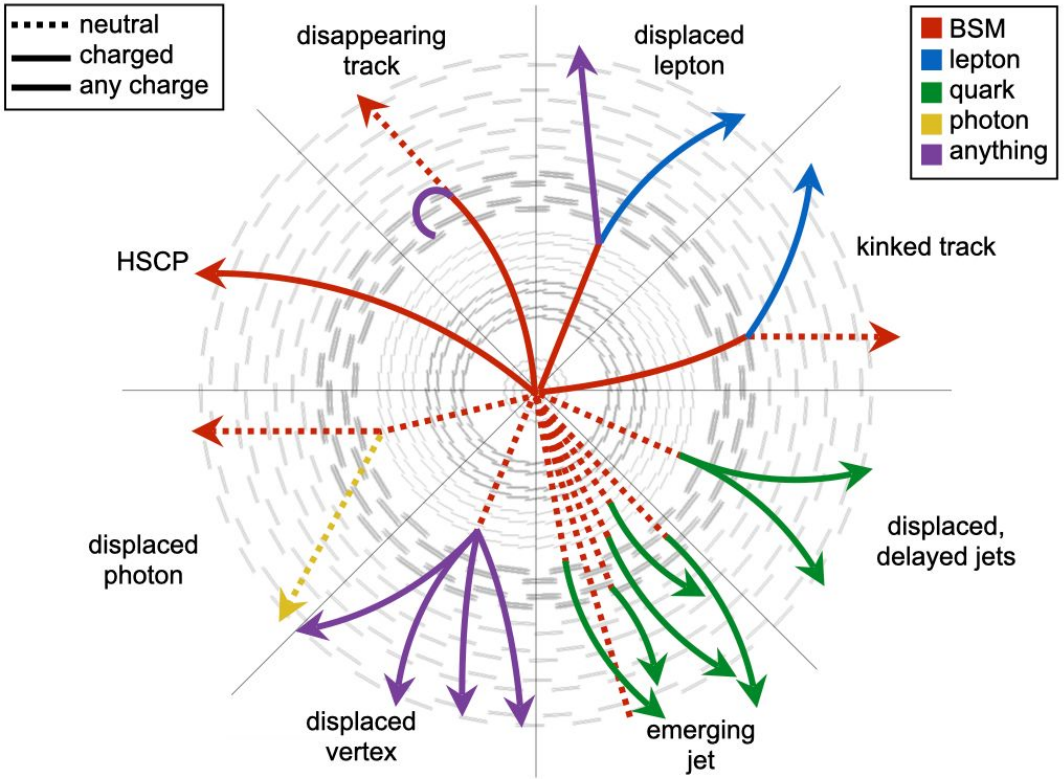
CODEX-β (2025-2026): >10 fb^{-1} (A)
CODEX-b (2036-2041): 300 fb^{-1}
SHIP (2031-2046): 6×10^{26} ppot (A)



Complex and diverse model space → sometimes very complicated signatures.

Huge efforts at major collaborations (ATLAS, CMS, LHCb) required to design and develop dedicated triggers, reconstruction algorithms, and even complicated simulation models.

These detectors were not originally designed for these kind of searches.



CMS schematic,
J. Antonelli (ICHEP 2016)

3.2 Measurement of the LLP mass

Now we discuss the determination of the LLP mass. It is crucial that the decay vertex can be precisely located within the MATHUSLA decay volume. Since the LLP X originates from the nearby LHC collision region, the vector from the point of origin to the decay vertex is very well known. This allows the velocity β_X of the LLP to be found from the geometry of the decay.

Consider first a decay to 2 final-state charged particles, such as ee or $\mu\mu$. Let θ_1 and θ_2 be the angles of the two decay products with respect to the X direction, as shown in Fig. 3. The 4-vectors of the two products then have the form

$$p_i = E_i(1, \pm\beta_i \sin\theta_i, 0, \beta_i \cos\theta_i) \quad , \qquad i = 1, 2 \tag{1}$$

with θ_1 and θ_2 both positive quantities and $E_1\beta_1 \sin\theta_1 = E_2\beta_2 \sin\theta_2$ by momentum balance. Since all components are known up to a an overall prefactor, we can boost both p_i back along the direction of p_X until they are back-to-back, recovering the LLP rest frame. This yields

$$\beta_X = \frac{\beta_1\beta_2 \sin(\theta_1 + \theta_2)}{\beta_1 \sin\theta_1 + \beta_2 \sin\theta_2} \, . \tag{2}$$

Since the distance of the LLP decay to the LHC interaction point is much greater than the distance to the tracking planes, the precision of the measured angles θ_1, θ_2 is simply the precision of the measured angles between the tracks and the trackers, about 0.2% for $\theta_i \sim \mathcal{O}(1)$ and approximately independent of the uncertainty on the displaced vertex location [51]. For the two-body decays we consider, the products will be relativistic, with β_i close to 1. This makes the error induced by assuming

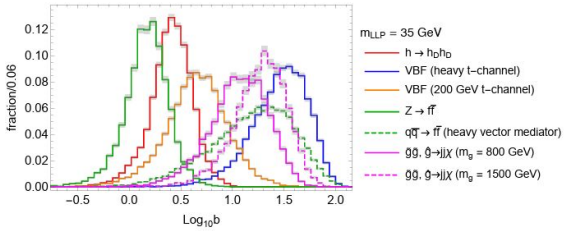


Figure 7: Truth-level boost distribution of a 35 GeV LLP produced in a variety of different production modes, from left to right: $Z \to XX$, $h \to XX$, vector boson fusion through a 200 GeV mediator in the t-channel, decay of gluinos with mass 800 and 1500 GeV, vector boson through through a $WW \to XX$ contact interaction, and $q\bar{q} \to XX$ through a vector contact interaction.

Curtin, Peskin, https://arxiv.org/abs/1705.06327

An overview of minimal models

https://arxiv.org/abs/1708.09395
https://arxiv.org/abs/1911.00481
https://arxiv.org/abs/2203.07316

Vector (A')	$hA'A'$	$F'F$
$F'F$	yes	no reach

Scalar (S)	$SH^\dagger H$	$S^2H^\dagger H$
$SH^\dagger H$	yes	yes

HNL (N)	HLN
HLN	yes

ALP (a)	$\partial_\mu a\bar{q}\gamma^\mu\gamma^5 q$	$a\tilde{G}G$
	yes	yes

Production portal
Decay portal
UV operator

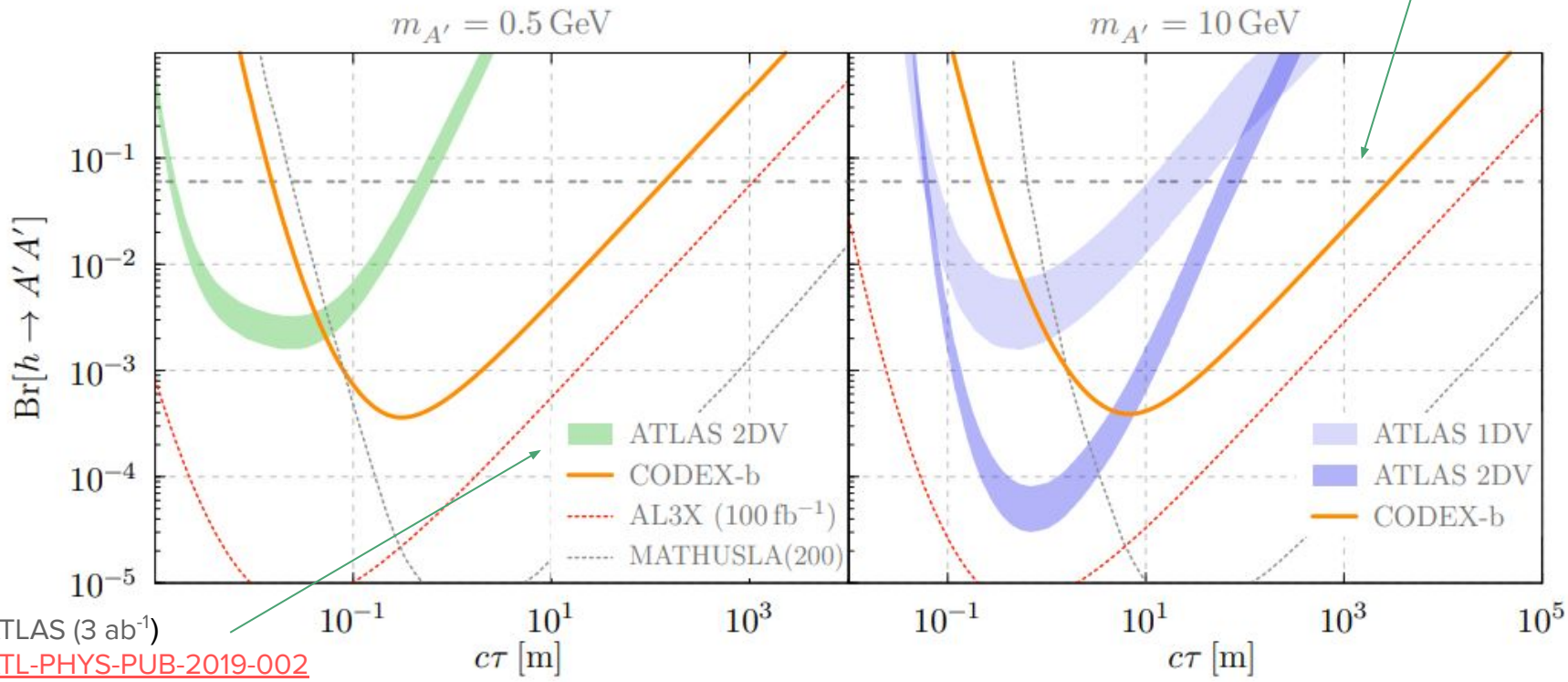
C. Minimal models

1. Abelian hidden sector
2. Scalar-Higgs portal
3. Axion-like particles
4. Heavy neutral leptons

(Only published studies)

Abelian hidden-sector: *dark photon*

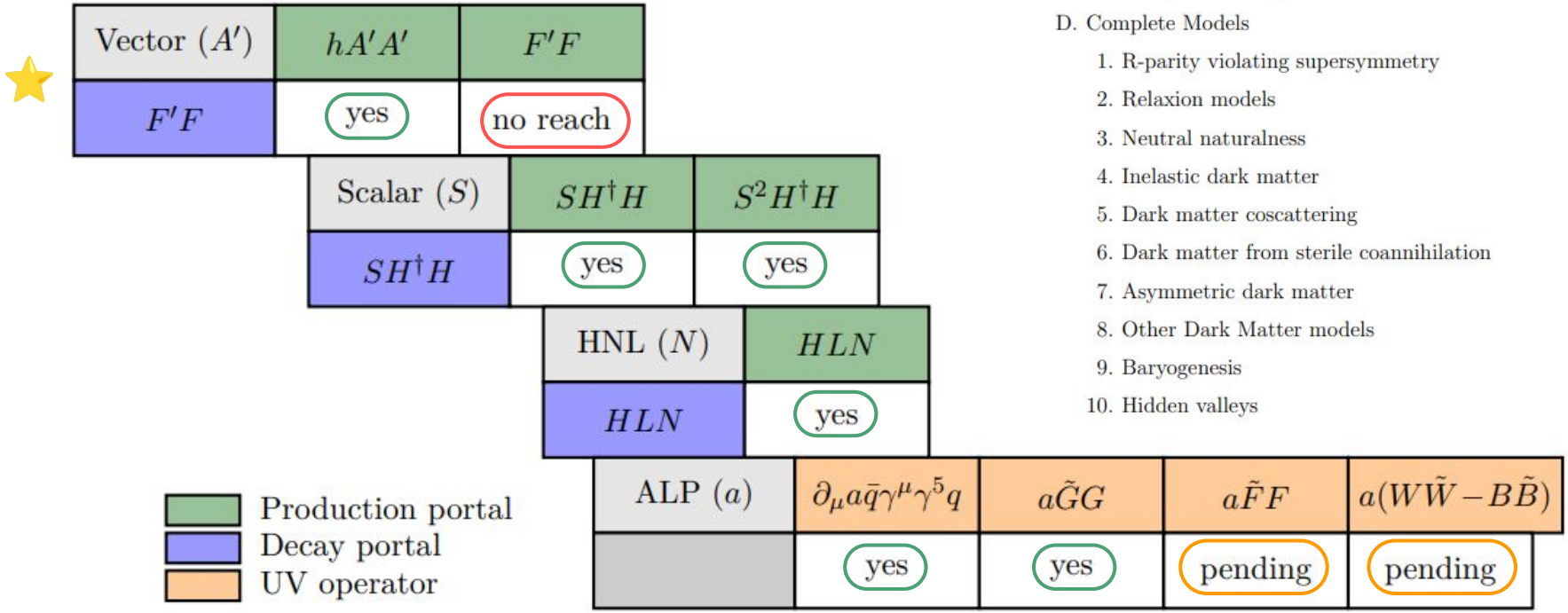
Higgs to invisible (HL-LHC) limit
arXiv:1902.00134



ATLAS (3 ab^{-1})
ATL-PHYS-PUB-2019-002
Phys. Rev. D 99, 052005

An overview of (minimal) models

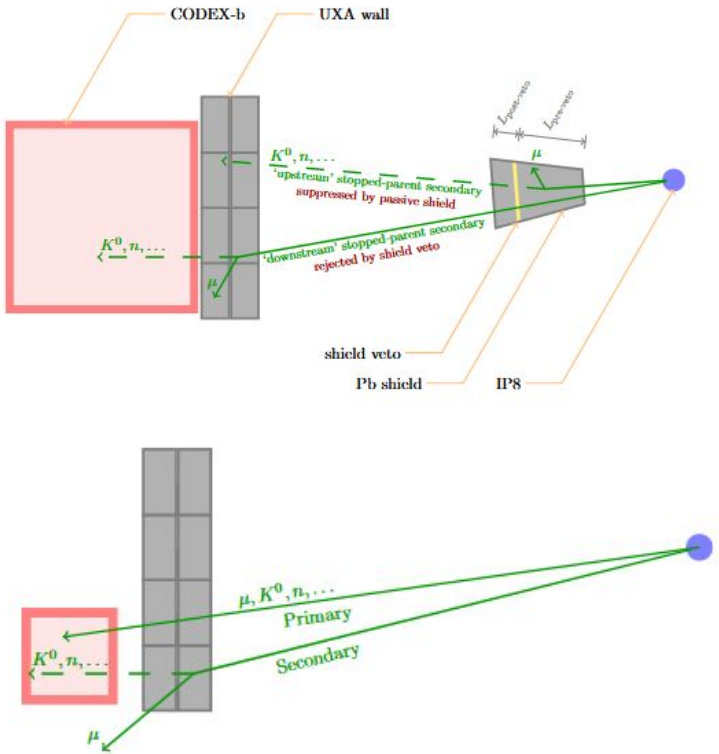
https://arxiv.org/abs/1911.00481

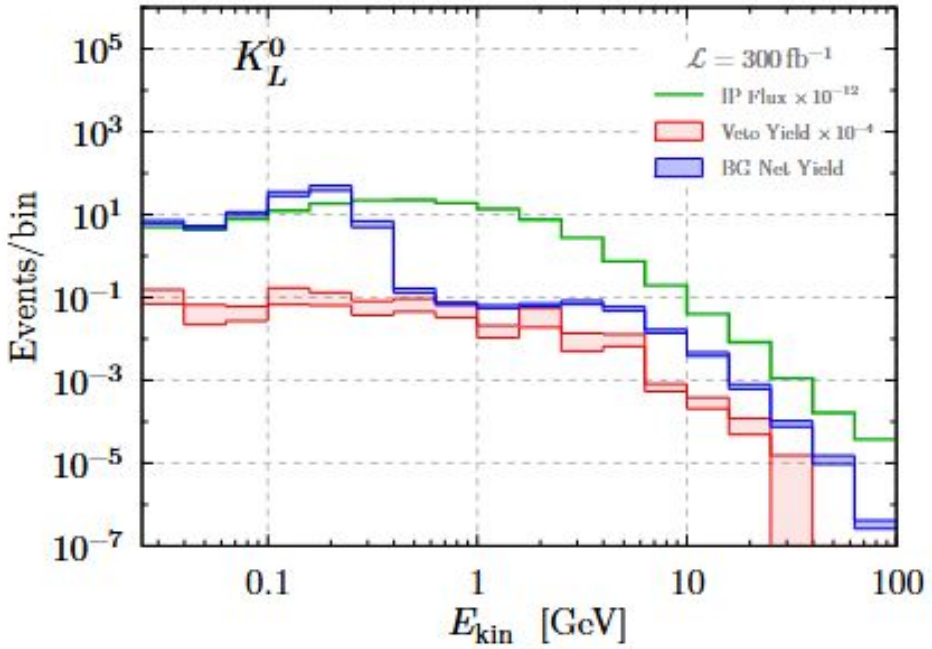


C. Minimal models
   1. Abelian hidden sector
   2. Scalar-Higgs portal
   3. Axion-like particles
   4. Heavy neutral leptons

D. Complete Models
   1. R-parity violating supersymmetry
   2. Relaxion models
   3. Neutral naturalness
   4. Inelastic dark matter
   5. Dark matter coscattering
   6. Dark matter from sterile coannihilation
   7. Asymmetric dark matter
   8. Other Dark Matter models
   9. Baryogenesis
   10. Hidden valleys

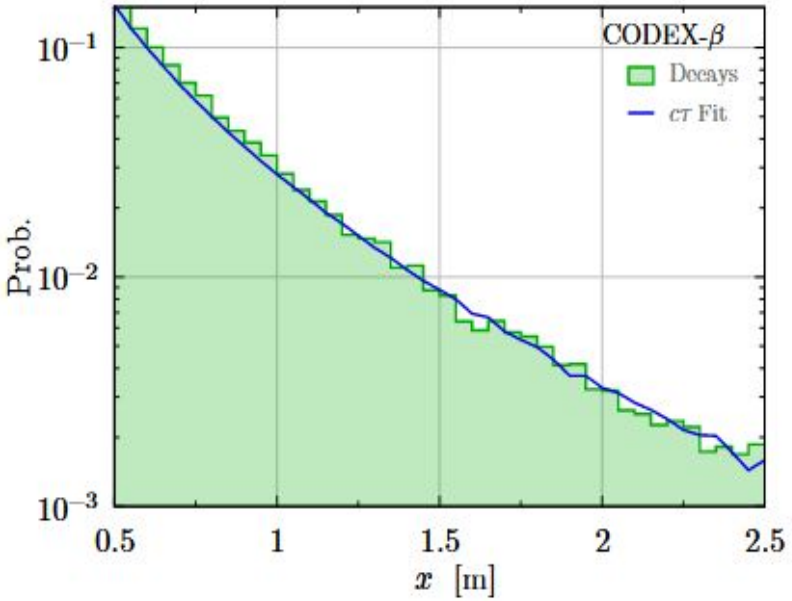
Physics with CODEX-β: Background studies





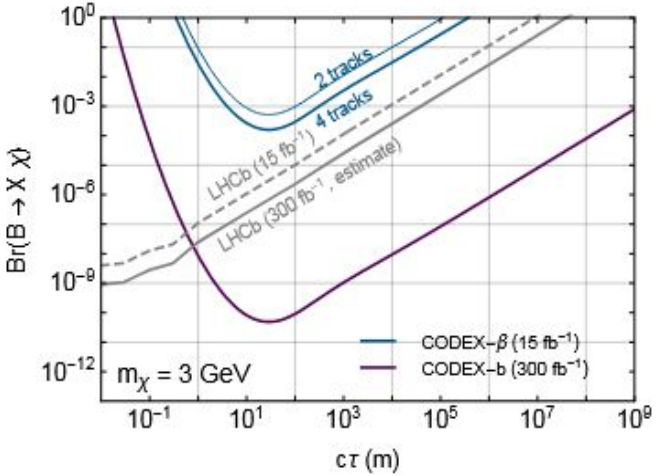
Physics with CODEX-β: Trial NP analysis

K_s meson lifetime measurement



Example of NP sensitivity

- Example: χudd interaction, $\chi \to 4h$ decay (Motivated by baryogenesis scenario)



Preparing the D1 barracks

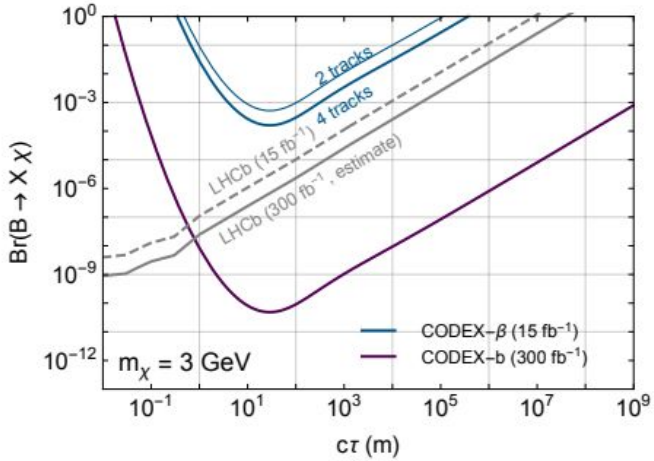
Gas system:

- **Mixer + recirculation system.** Extensive discussions with CERN gas group. 64% R134a, 30% CO2, 5% isobutane, 1% SF6.
- **GHG emissions not scalable for CODEX-b → R&D in search for an ecomixture.**

Multitrack production from LLPs

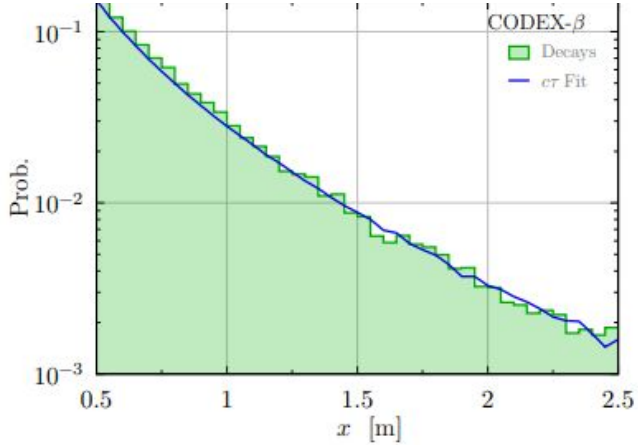
Tracks	Total	K_L^0 contribution
1	$(3.9 \pm 0.1) \times 10^8$	$(2.9 \pm 0.1) \times 10^8$
2	$(4.1 \pm 0.1) \times 10^7$	$(3.7 \pm 0.1) \times 10^7$
3	$(6 \pm 1) \times 10^5$	$(2.9 \pm 0.4) \times 10^5$
4+	$(9 \pm 2) \times 10^4$	$(7 \pm 2) \times 10^4$

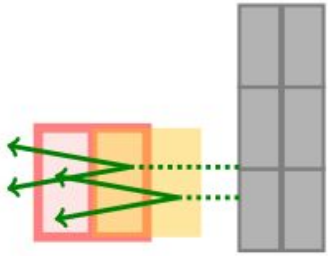
- Example: χudd interaction, $\chi \to 4h$ decay (Motivated by baryogenesis scenario)



Can conduct a trial NP analysis with CODEX-β

KS0 lifetime measurement



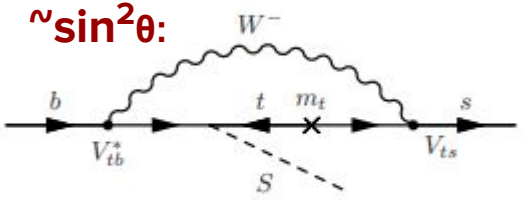


Toy CODEX-β example: **(Ks0 lifetime measurement)**

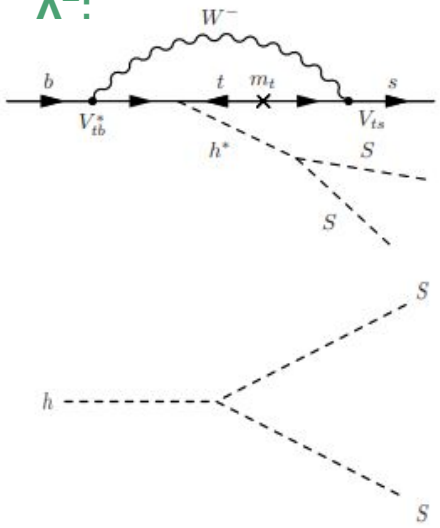
- Azimov dataset of 10^6 events (i.e. $\sim 10\%$ efficiency) binned with 5 cm resolution
- Vertexing $0.5 \leq x \leq 2.5$ m from UXA wall (assumes vertexing in 'detector shadow')
- Toy χ^2 fit: Recover $c\tau = 0.030^{+0.003}_{-0.007}$ cf. $c\tau = 0.02686(1)$ m.

Scalar-Higgs portal

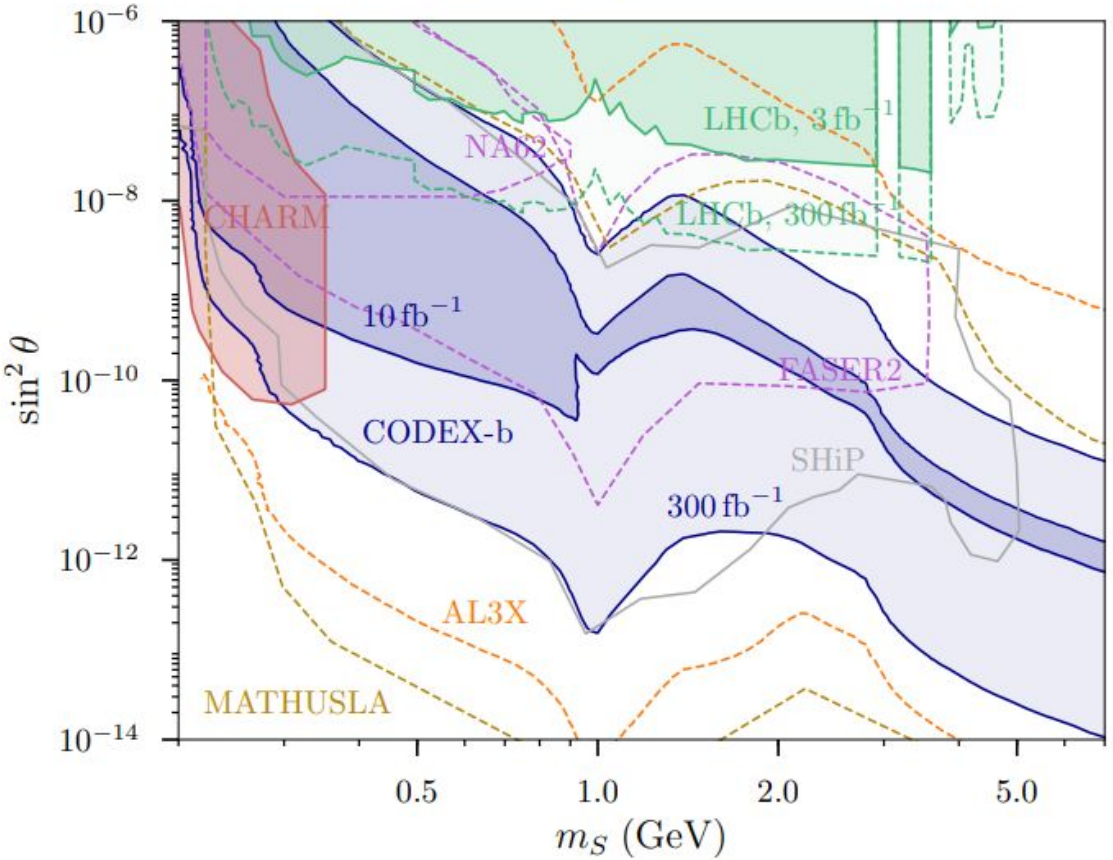
~$\sin^2\theta$:

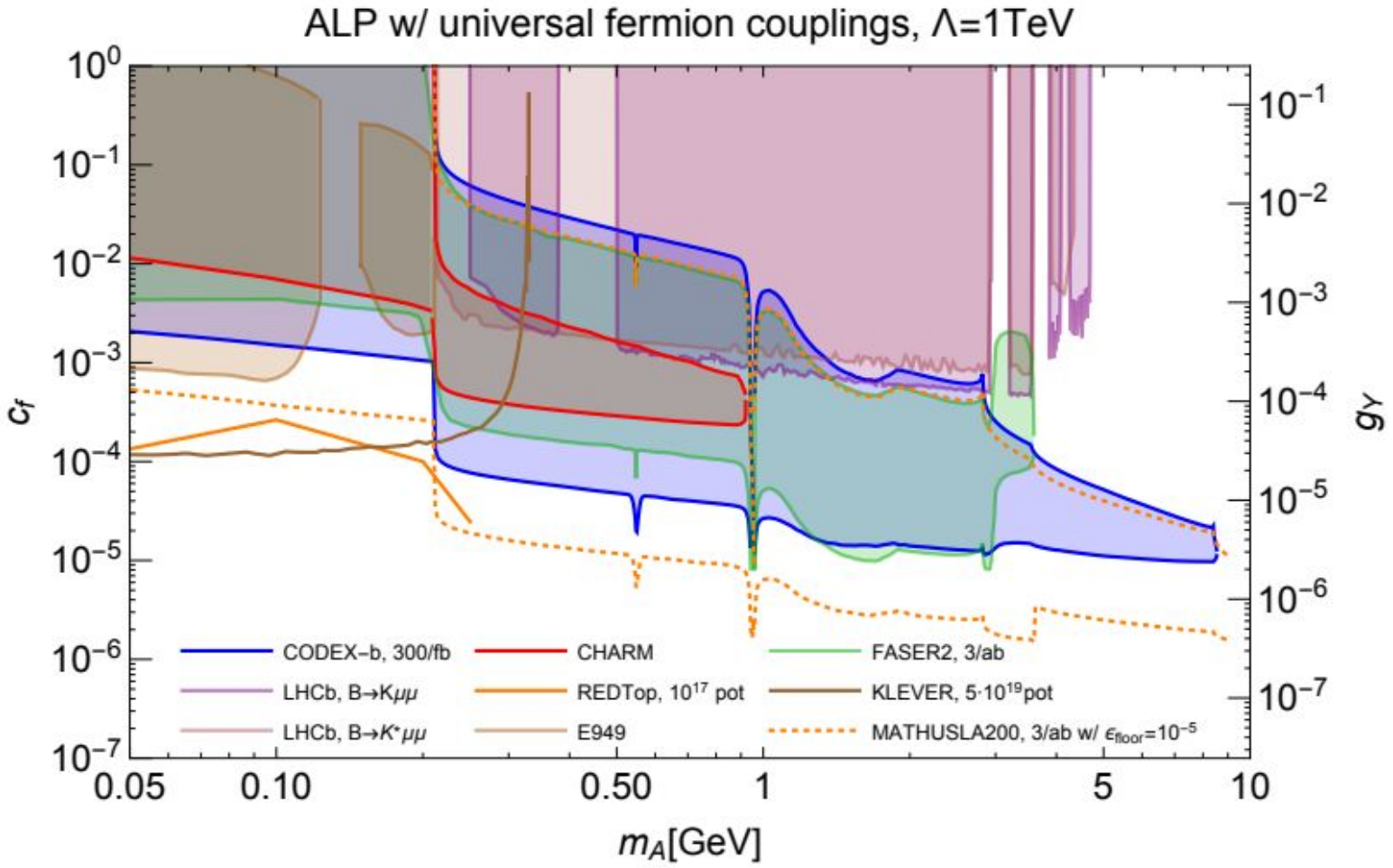


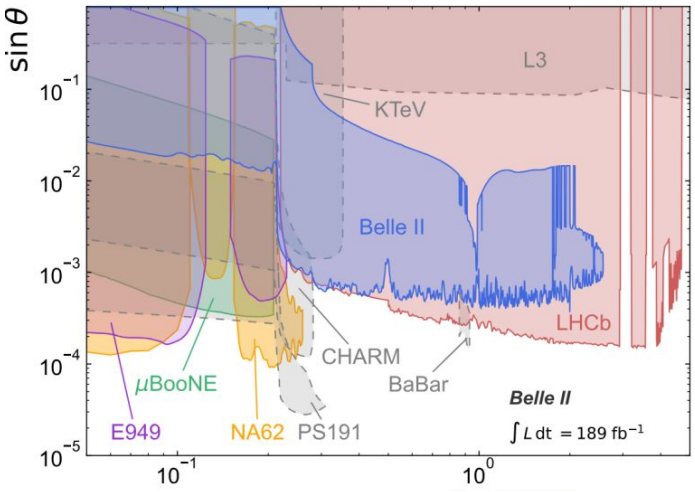
~λ^2:

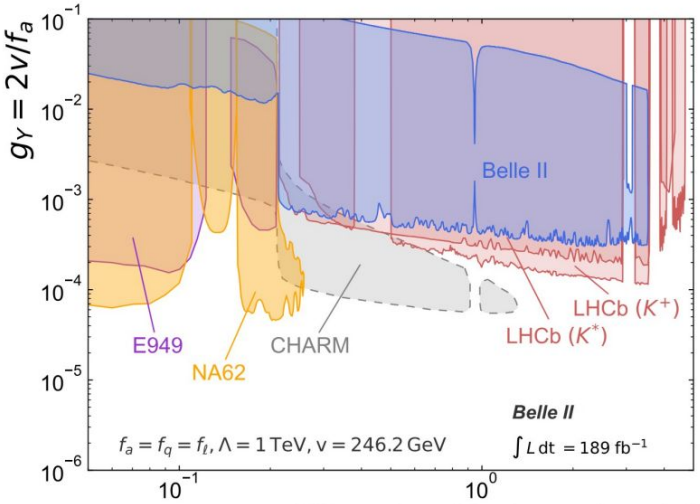


$\lambda = 1.6 \times 10^{-3}$ **From b-hadron decays**

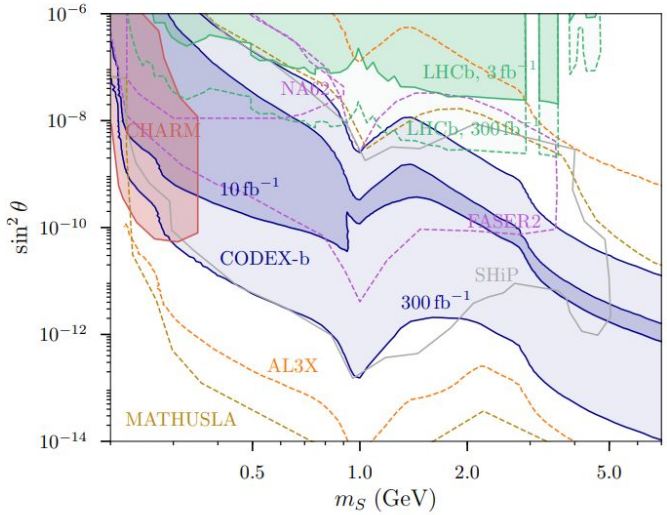


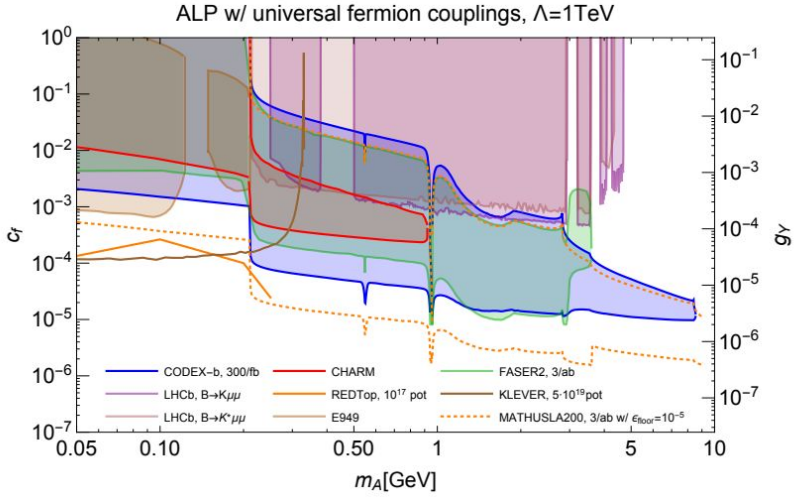

ALP w/ universal fermion couplings, Λ=1TeV
c_f
g_γ
m_A[GeV]
CODEX−b, 300/fb
CHARM
FASER2, 3/ab
LHCb, B→Kμμ
REDTop, 10^{17} pot
KLEVER, $5{\cdot}10^{19}$pot
LHCb, B→K*μμ
E949
MATHUSLA200, 3/ab w/ $\epsilon_{floor}=10^{-5}$

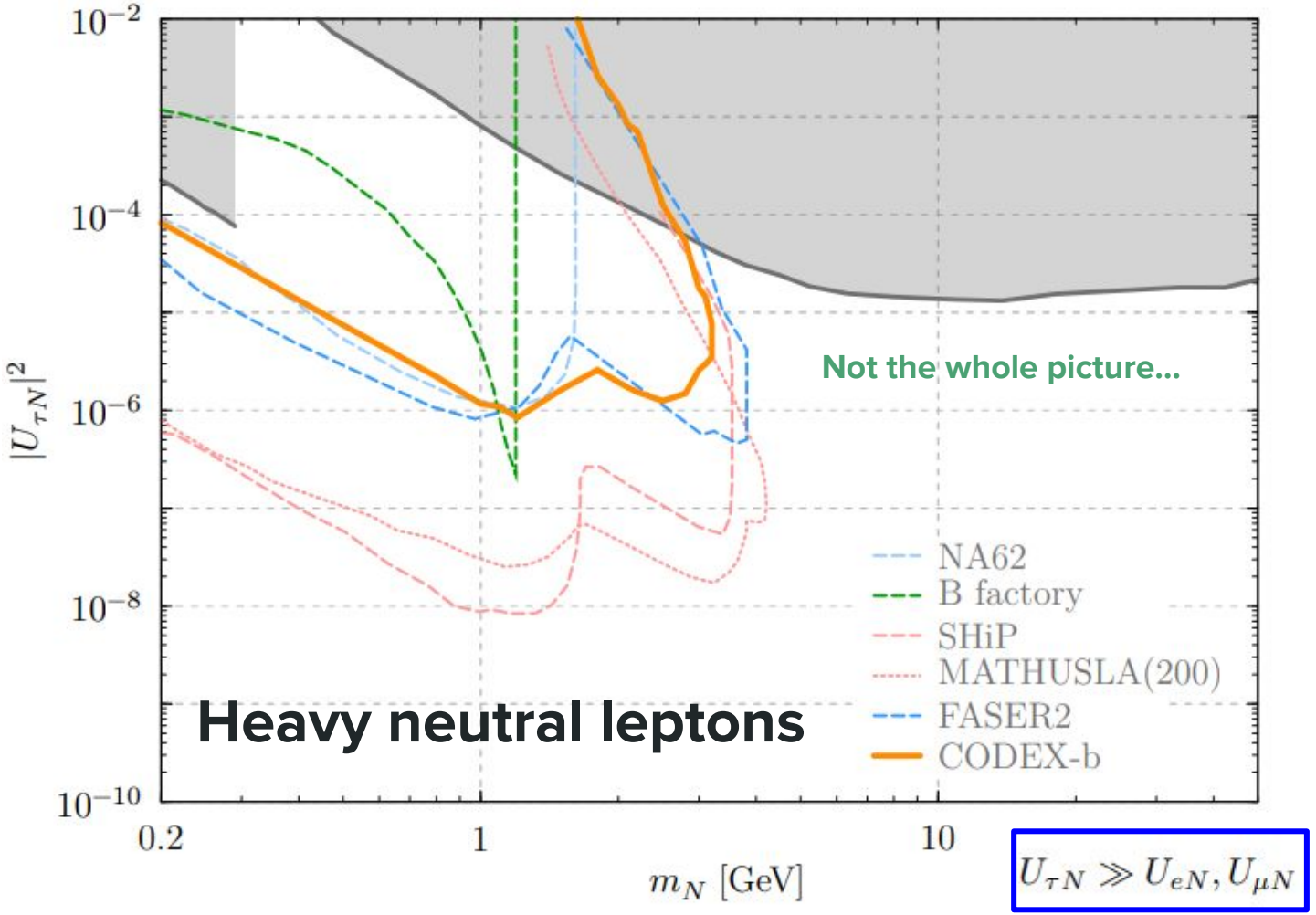


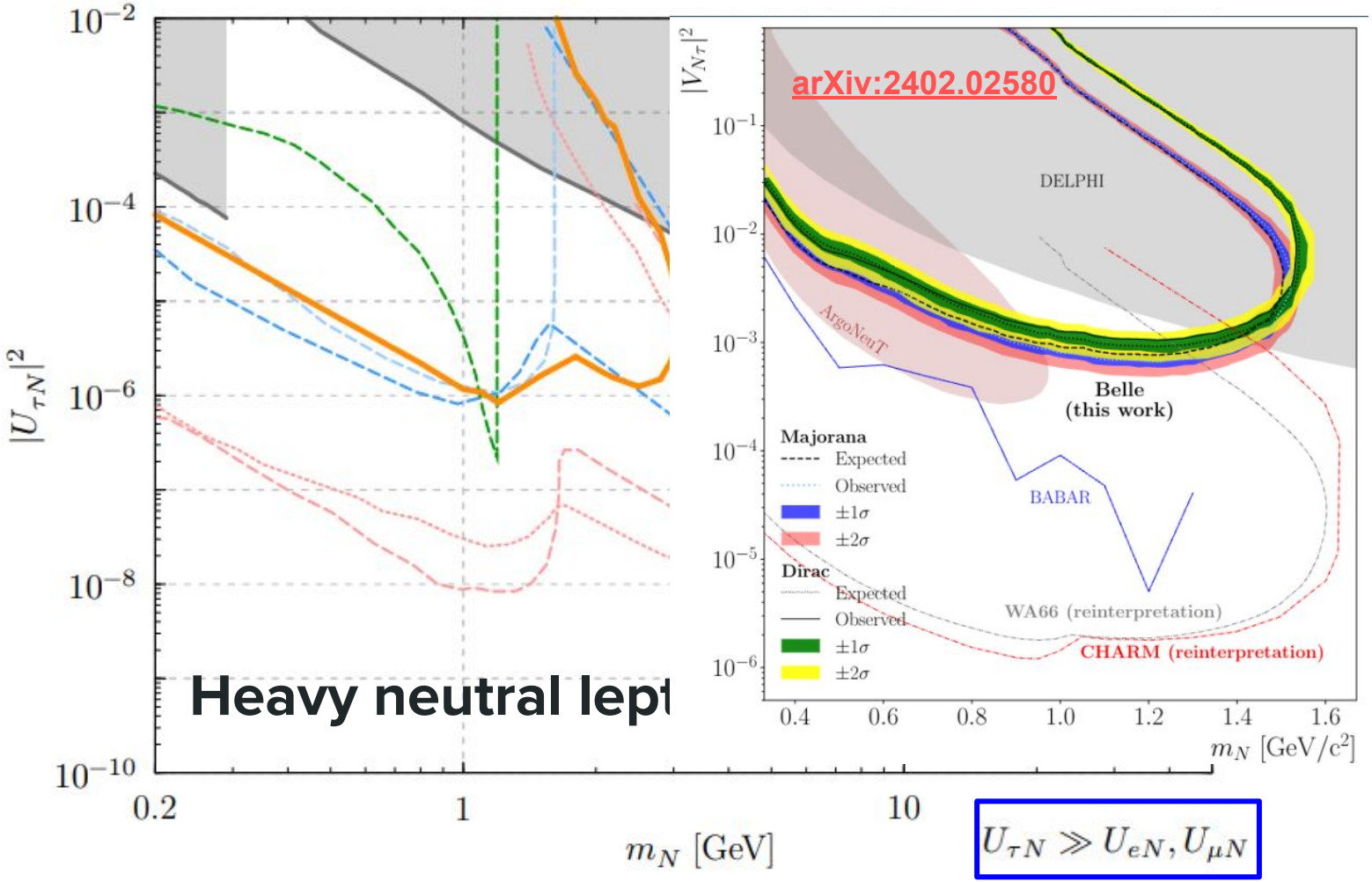


arXiv:2306.02830





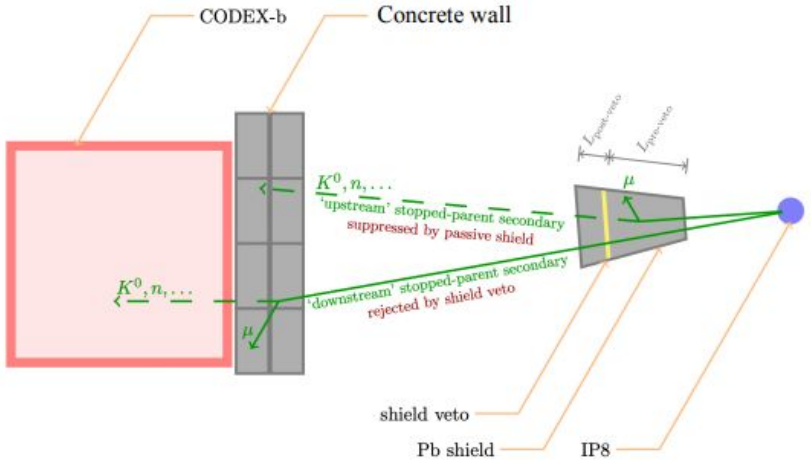

Not the whole picture...
Heavy neutral leptons
NA62
B factory
SHiP
MATHUSLA(200)
FASER2
CODEX-b
$|U_{\tau N}|^2$
m_N [GeV]
$U_{\tau N} \gg U_{eN}, U_{\mu N}$



Heavy neutral lept

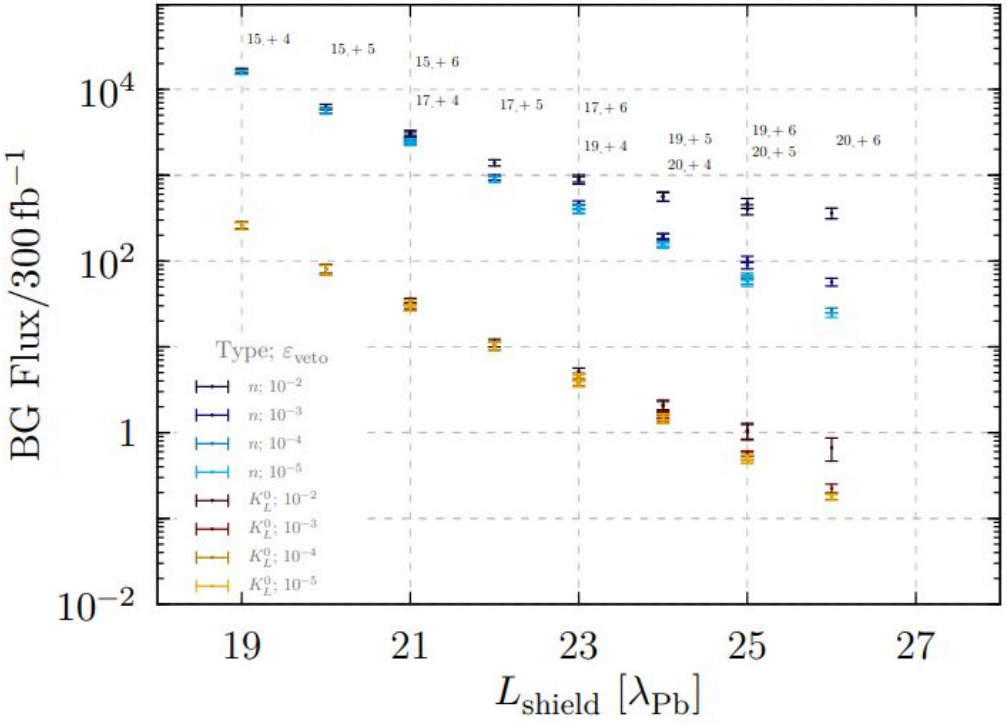
Backgrounds in CODEX-b

- **Main backgrounds:**
  - μ (primary or secondary) that can penetrate concrete+Pb shield
  - n/$\pi^{\pm}$/$K^{\pm}$/K_L^0
- **Additional potential sources:**
  - LHC machine-induced, Thermal neutrons, Neutrinos



- **Detailed bkg simulation:**
  - arXiv:1708.09395, arXiv:1911.00481
  - **Bkg levels reduced to < $\mathcal{O}$ (1 event) in 300 fb^{-1} with shields + active/ topological vetoes**
- Shield + 3.2m concrete wall crucial to achieve 0 backgrounds
- Measured backgrounds in D1 area in 2018:
  - arXiv:1912.03846
- FLUKA campaign from CERN Radiation Protection validated Pythia simulation

A background-free detector: shielding



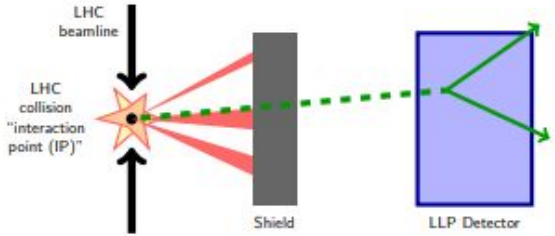
Measurement campaign of backgrounds in D1 barracks during 2018.
https://arxiv.org/abs/1912.03846

Detailed simulations with Pythia, **consistent with FLUKA predictions by CERN Radiation Protection.**

Background studies

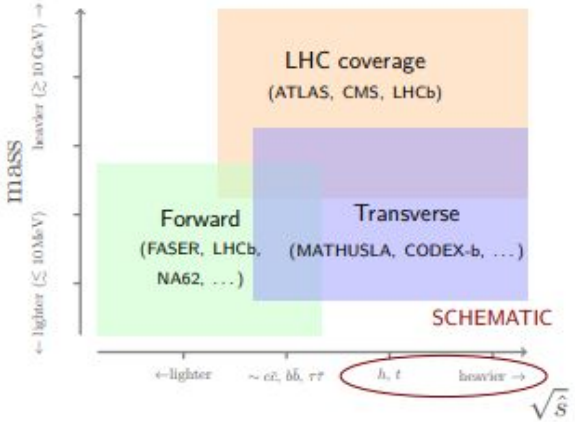
Main LHC experiments will efficiently probe 'heavy' ($m \gtrsim 10\,\text{GeV}$) LLPs, but backgrounds become impossible for lighter states.

Comprehensive LHC search for LLPs requires new, special purpose, shielded detectors

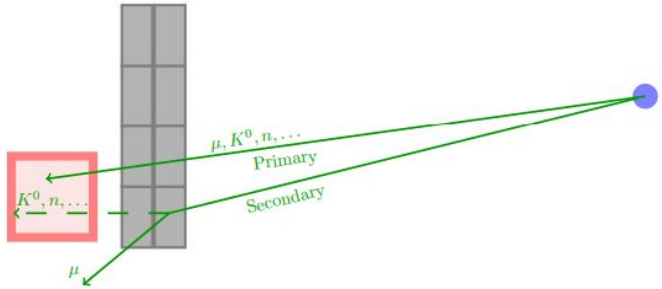


Background-free environment: searches beyond LHC main experiments' capability

Transverse detectors are needed to probe heavy mediators (including the Higgs)



Background studies



- Fluxes of SM LLPs from IP over log(E_{kin}) with Pythia + G4 for shield response.
- Measure fluxes of **primary plus secondary** backgrounds versus **simulation.**
- Generate data-driven background sim framework ➜ **optimize shielding design.**