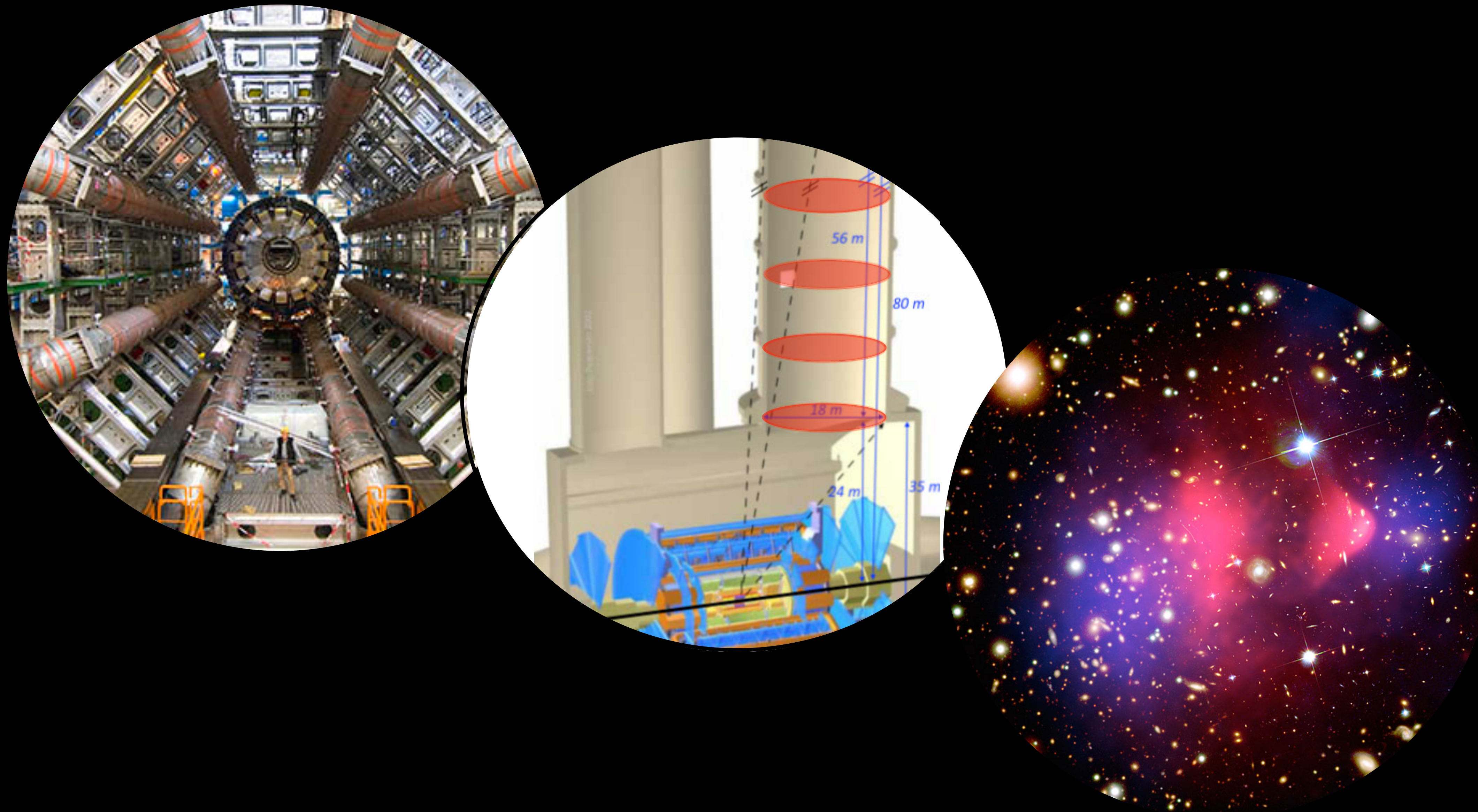

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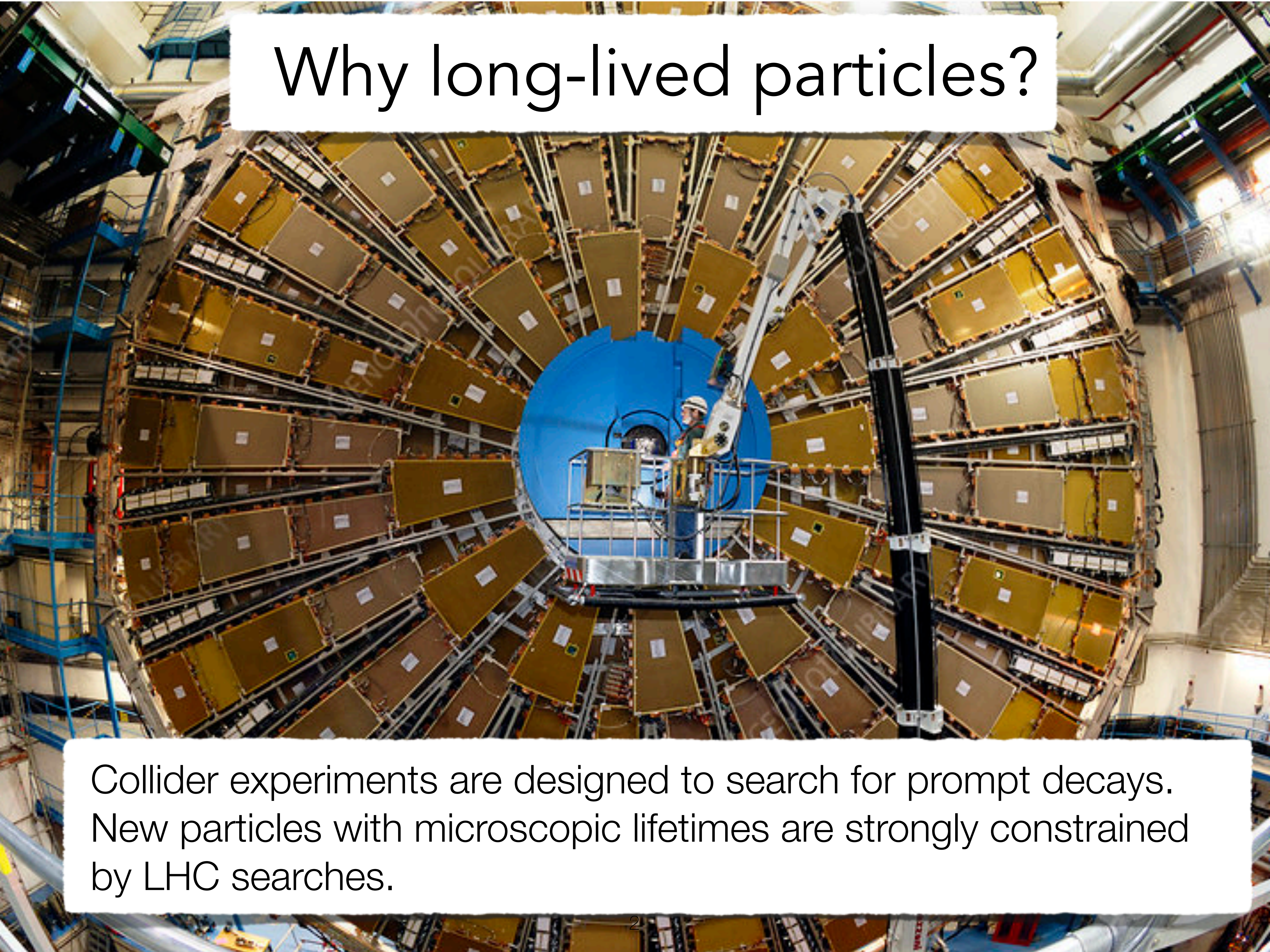
AN Underground **B**elayed **I**n-**S**haft search experiment

Martin Bauer • Oleg Brandt • Lawrence Lee • Christian Ohm

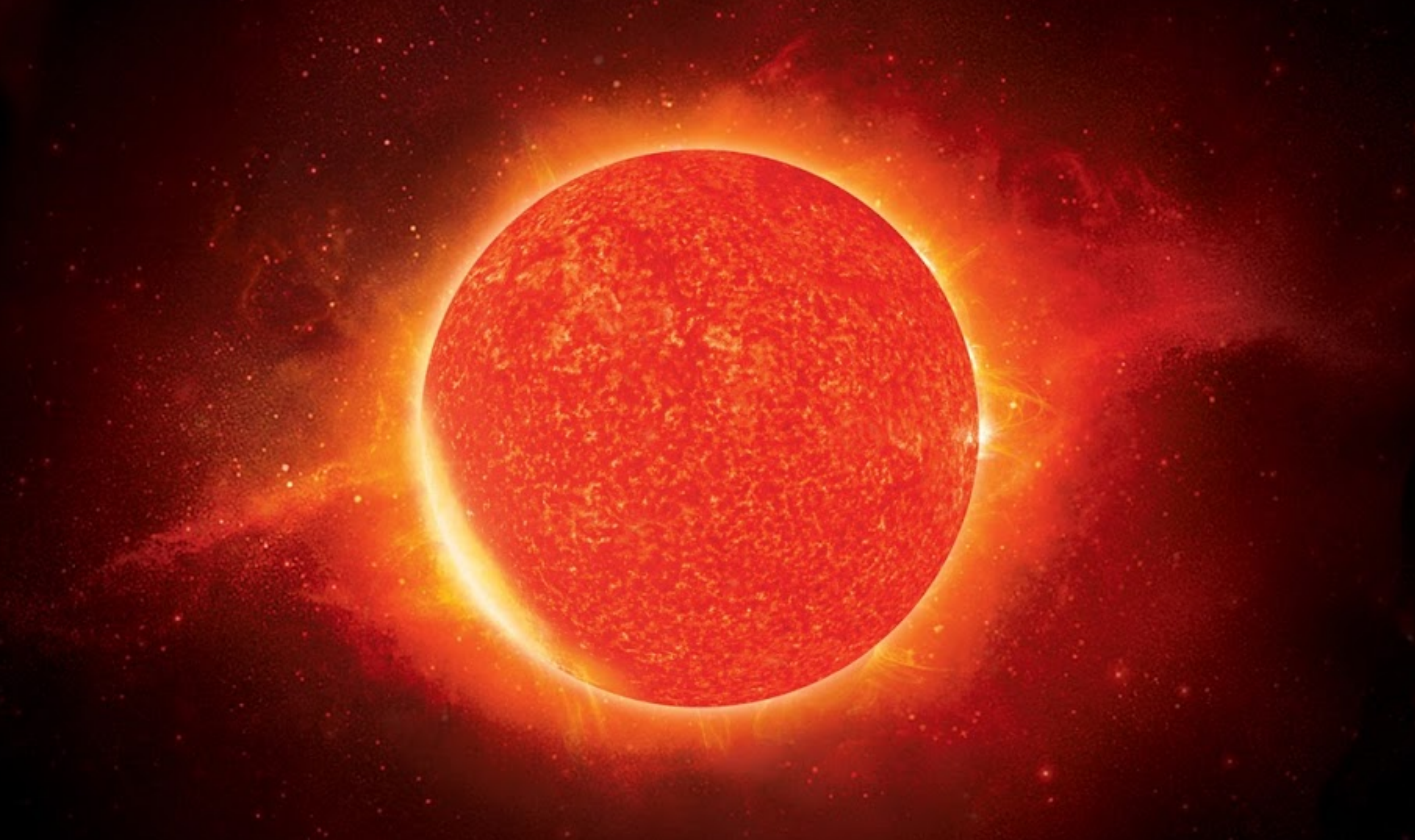
Physics Beyond Colliders Workshop 05-06.11.2019

Why long-lived particles?



Collider experiments are designed to search for prompt decays. New particles with microscopic lifetimes are strongly constrained by LHC searches.

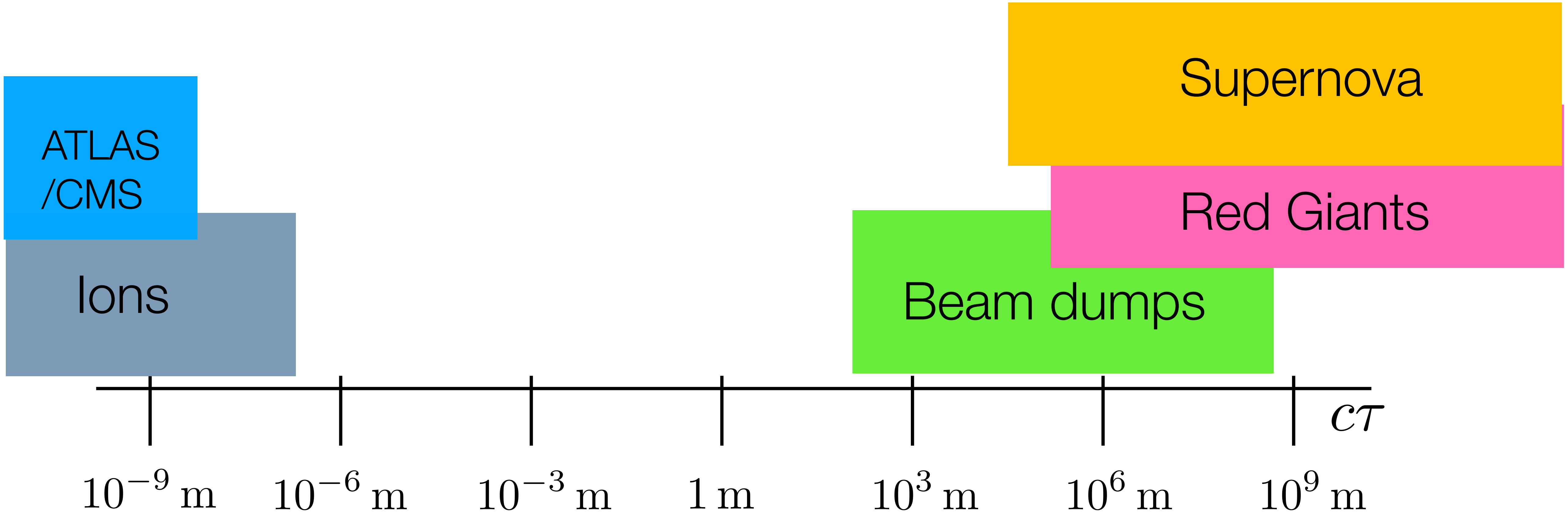
Why long-lived particles?



Very long-lived particles are constrained by astrophysical observables and beam-dump experiments.

Why long-lived particles?

For particles with “intermediate lifetimes” there exists a sensitivity gap

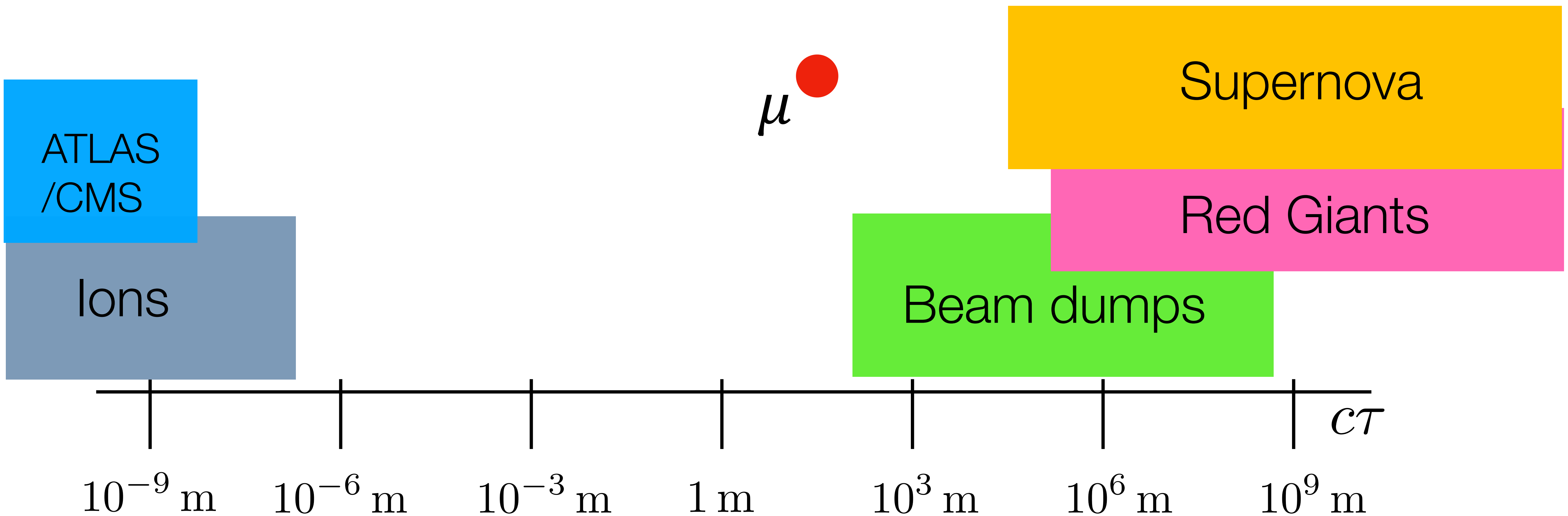


Constrains new Physics with sizeable interactions with the SM

Constrains new Physics with no (tiny) interactions with the SM (almost stable)

Why long-lived particles?

This is not a small class of exotic theories. Muons are "collider-stable" (as is the K_L, n).



Constrains new Physics with sizable interactions with the SM

Constrains new Physics with no (tiny) interactions with the SM (almost stable)

Where to look for long-lived particles?

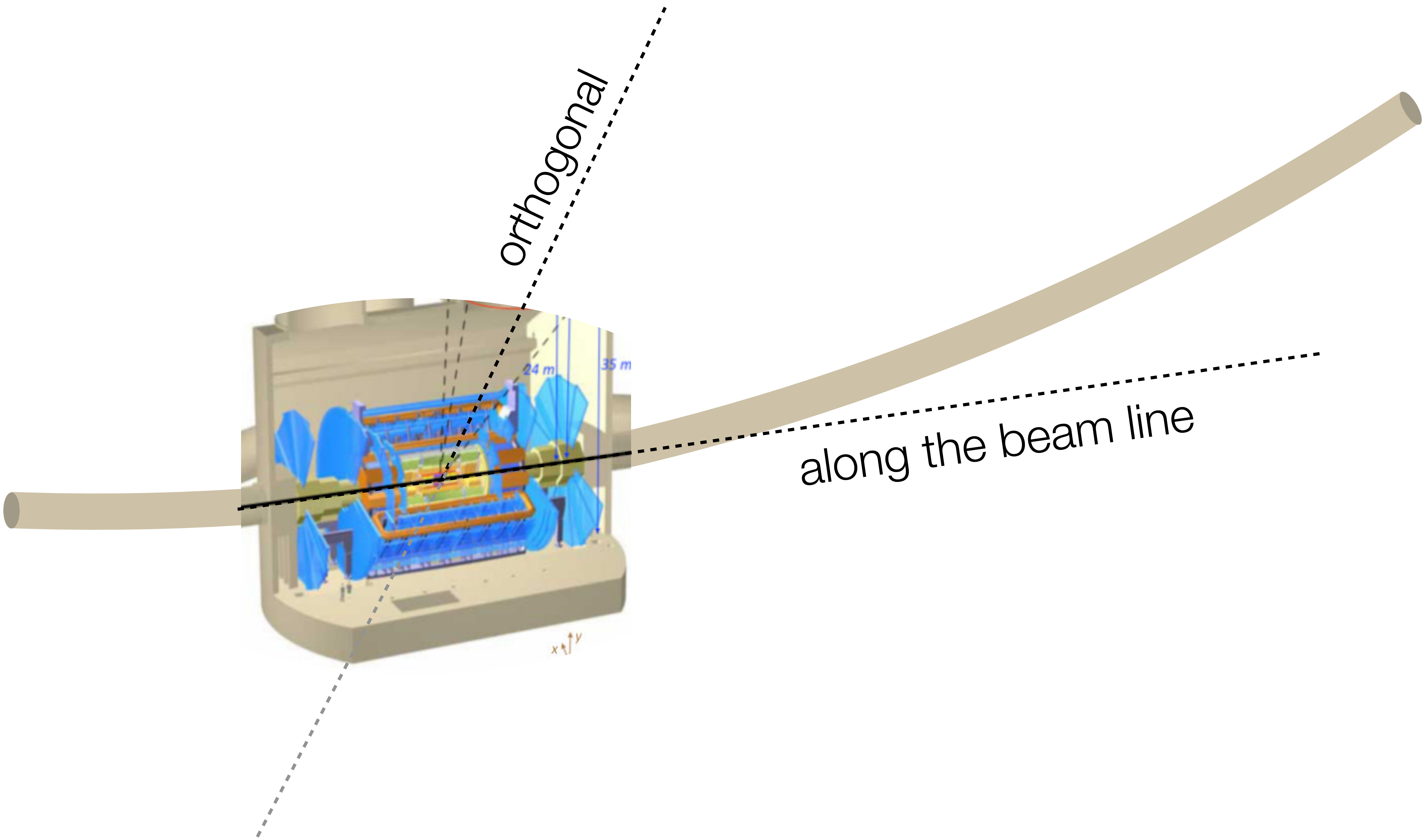
There are two different search strategies:

- Search for very weakly coupled *light particles* with high statistics
- Search for particles in the decays of *heavy states* (the Higgs, new heavy mediators)

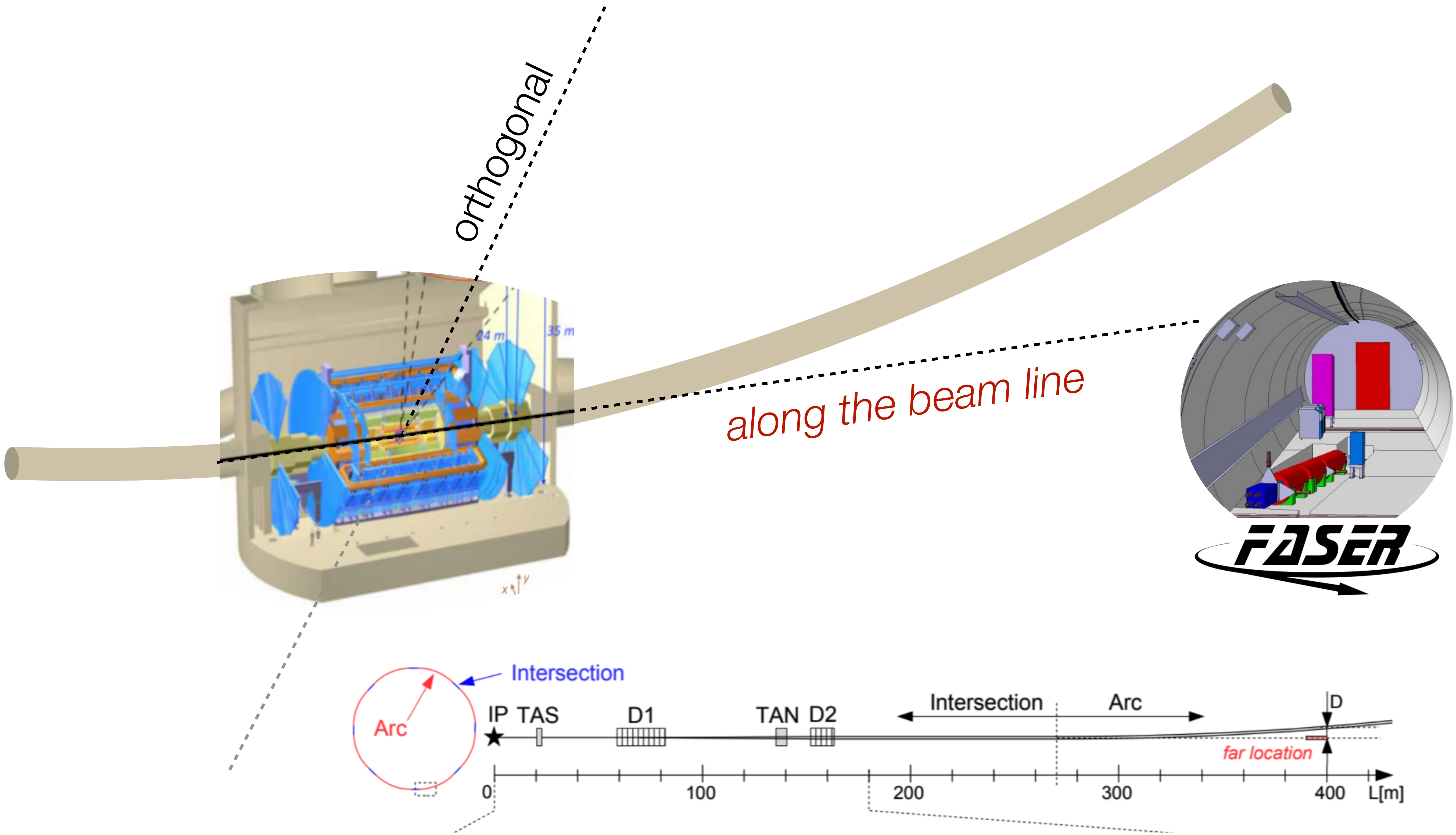
With respect to the LHC this corresponds to two different measurement regions:

- Measurements *along* the beam line (“on-axis”)
- Measurements *orthogonal* to the beam line (“off-axis”)

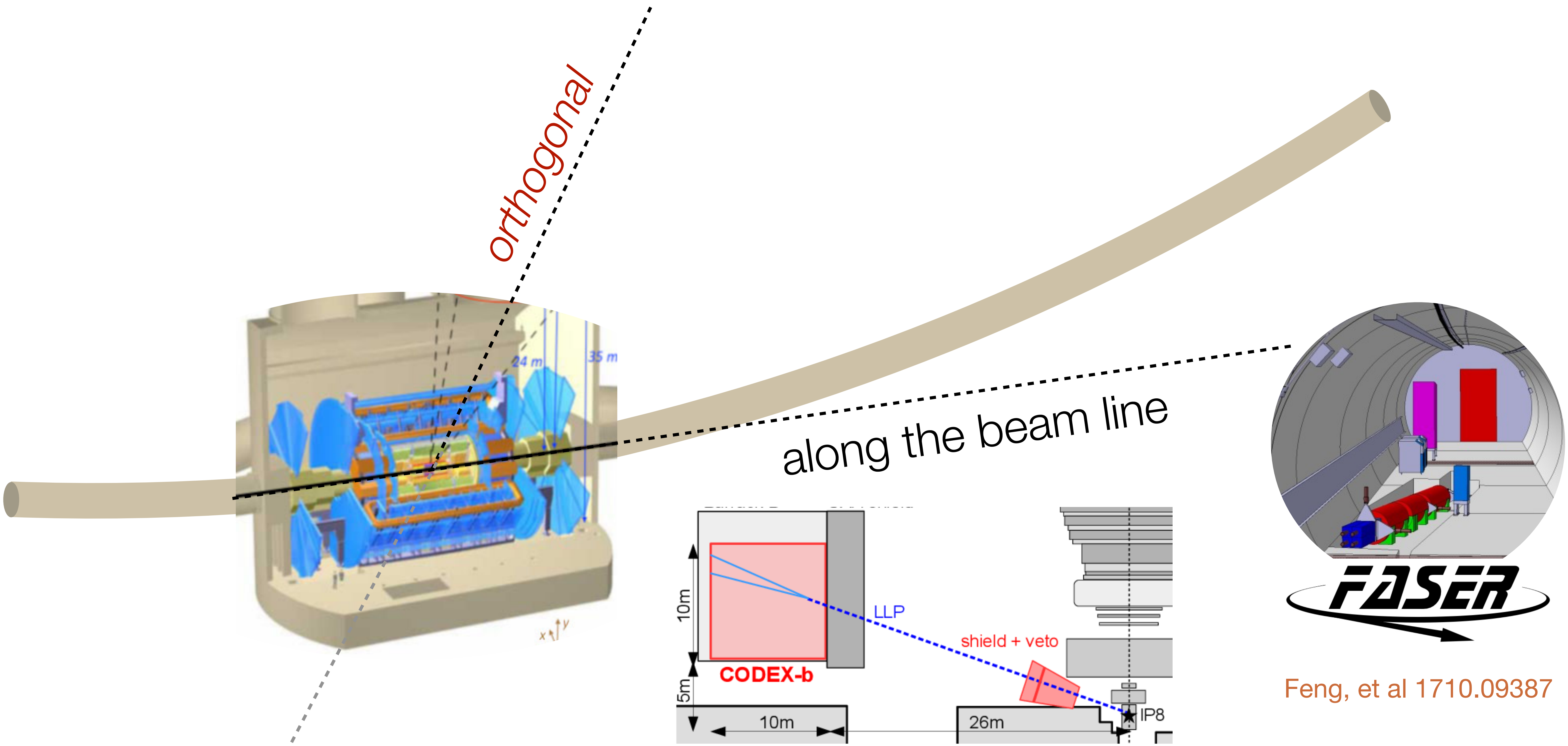
Where to look for long-lived particles?



Where to look for long-lived particles?



Where to look for long-lived particles?

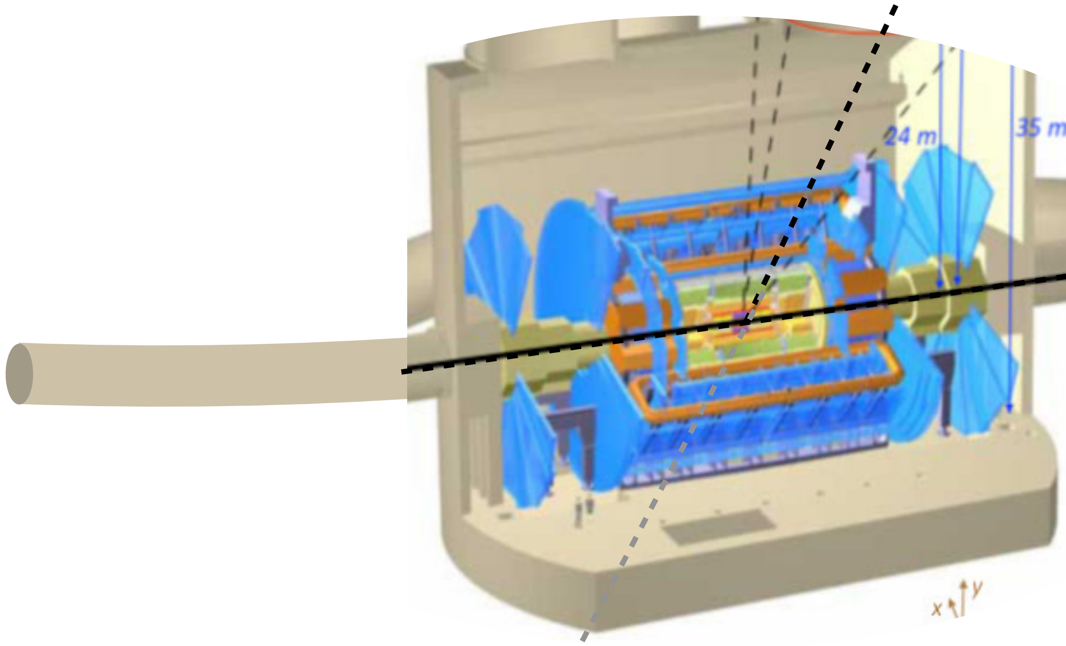


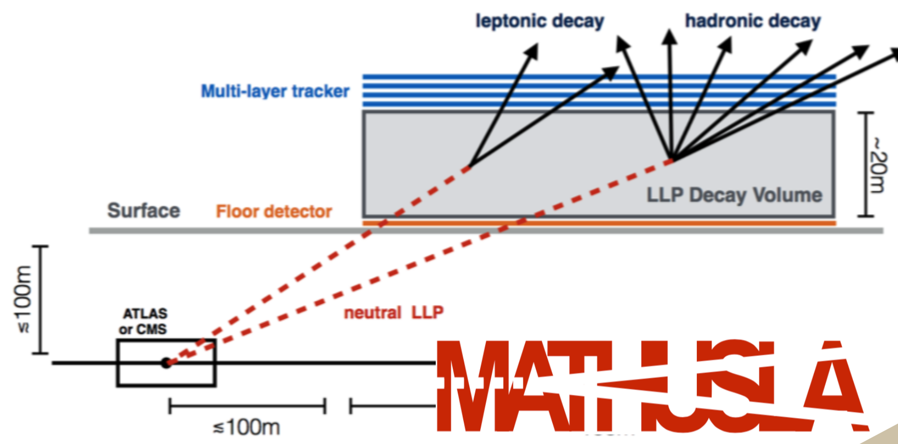
CODEX-b

Gligorov et al 1708.09395

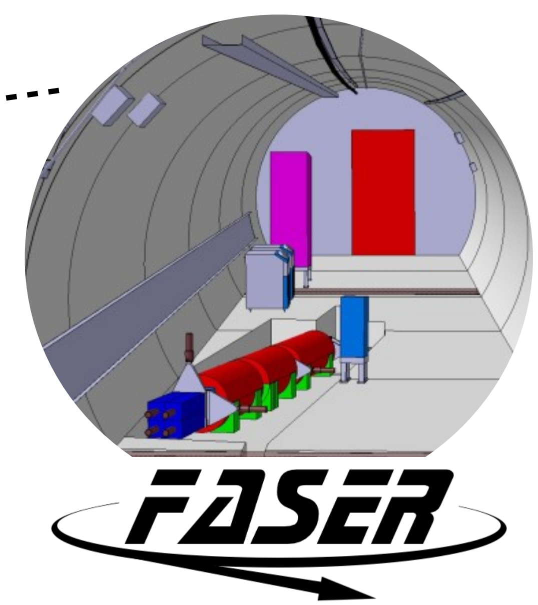
Feng, et al 1710.09387

Where to look for long-lived particles?

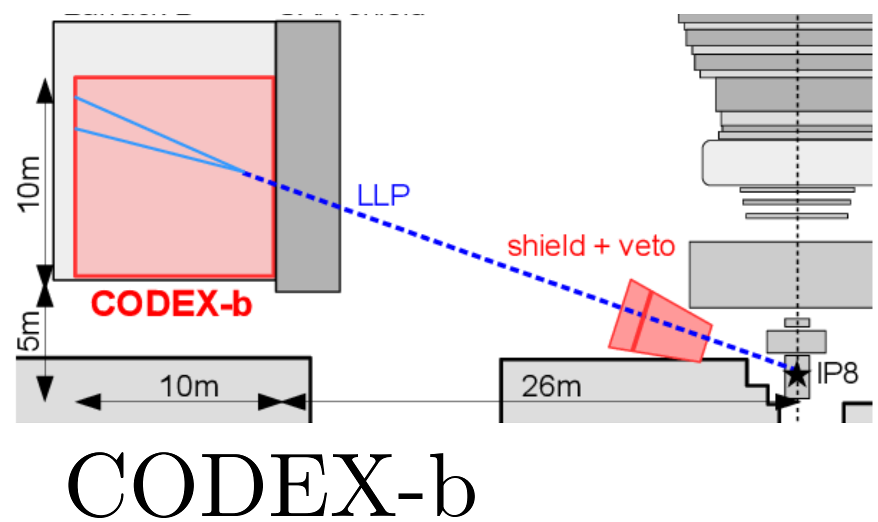




Chou et al 1606.06298



Feng, et al 1710.09387



Gligorov et al 1708.09395

Where to look for long-lived particles?

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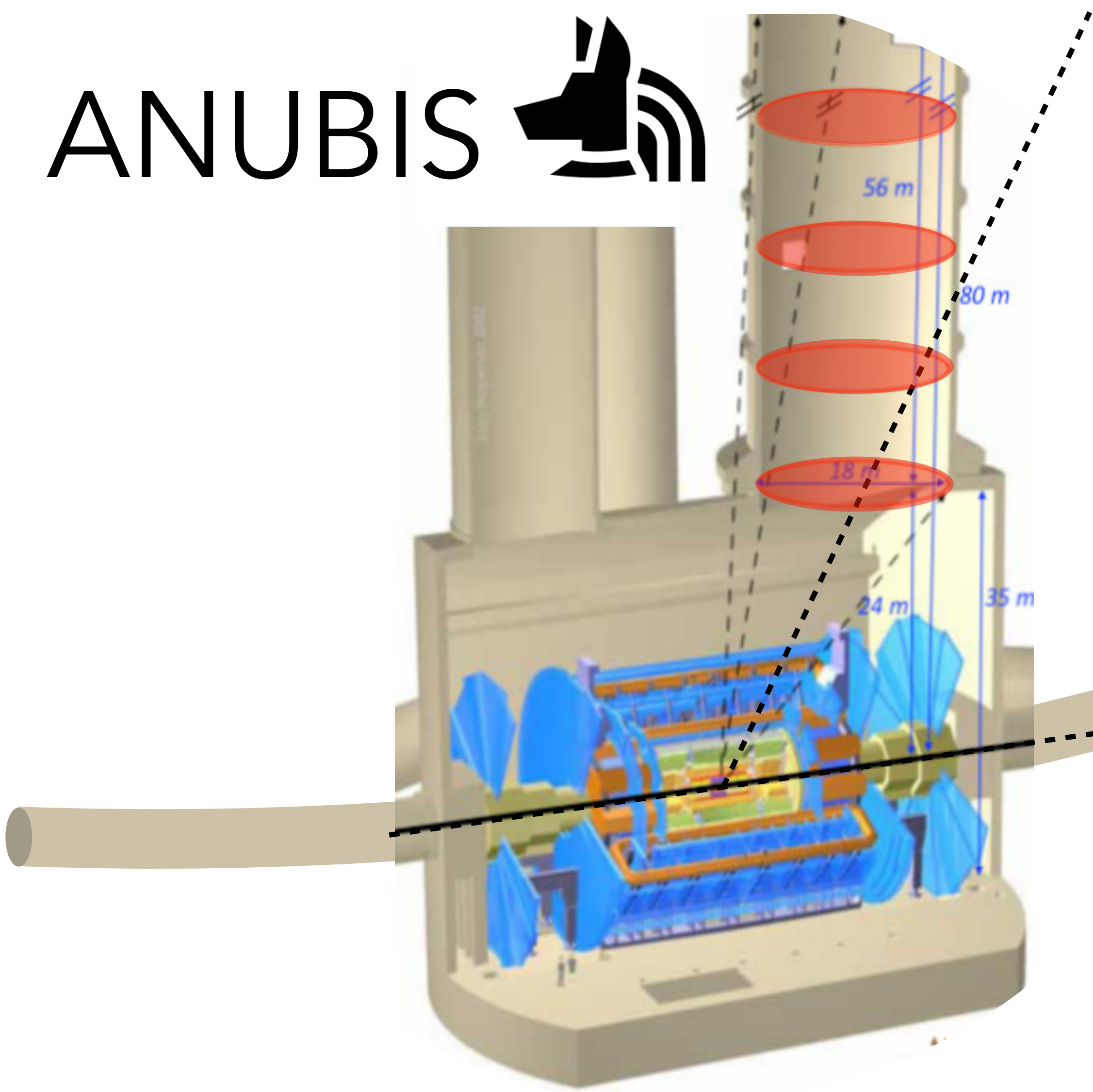
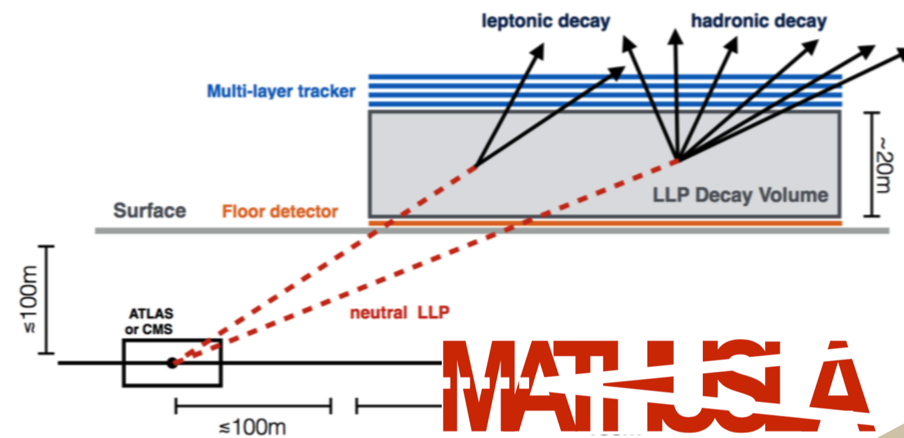


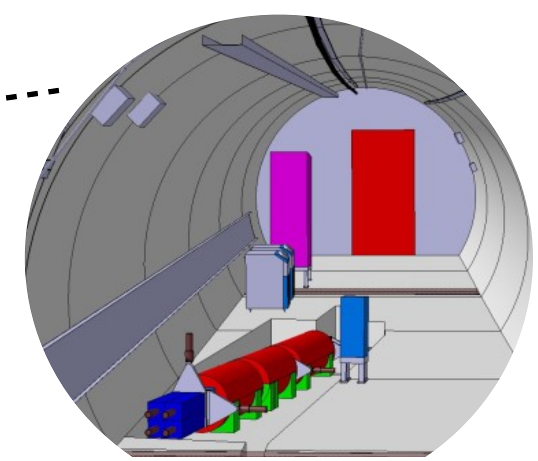
We propose to instrument the ATLAS service shaft

Bauer, OB, Lee, Ohm 1909.13022



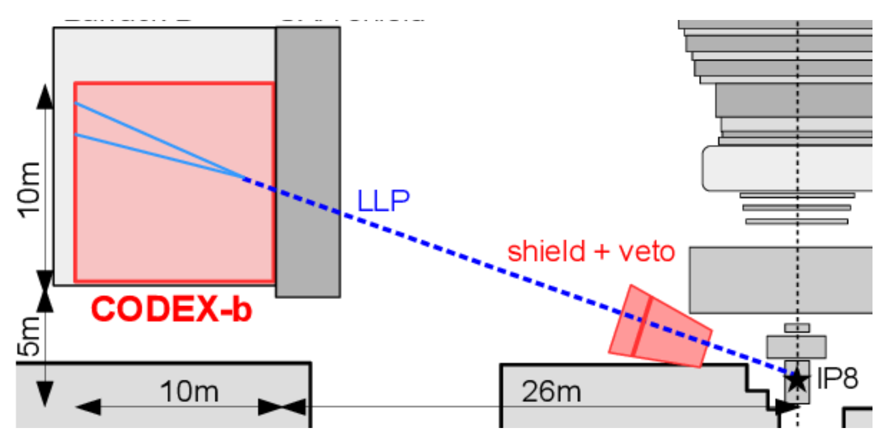
MATHUSLA

Chou et al 1606.06298



FASER

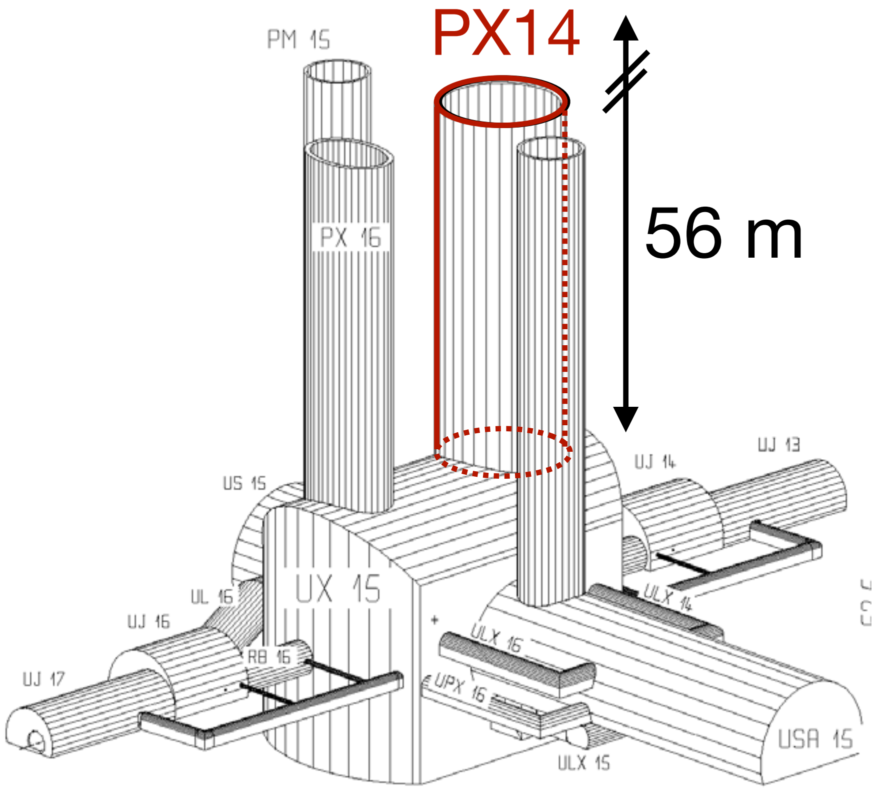
Feng, et al 1710.09387



CODEX-b

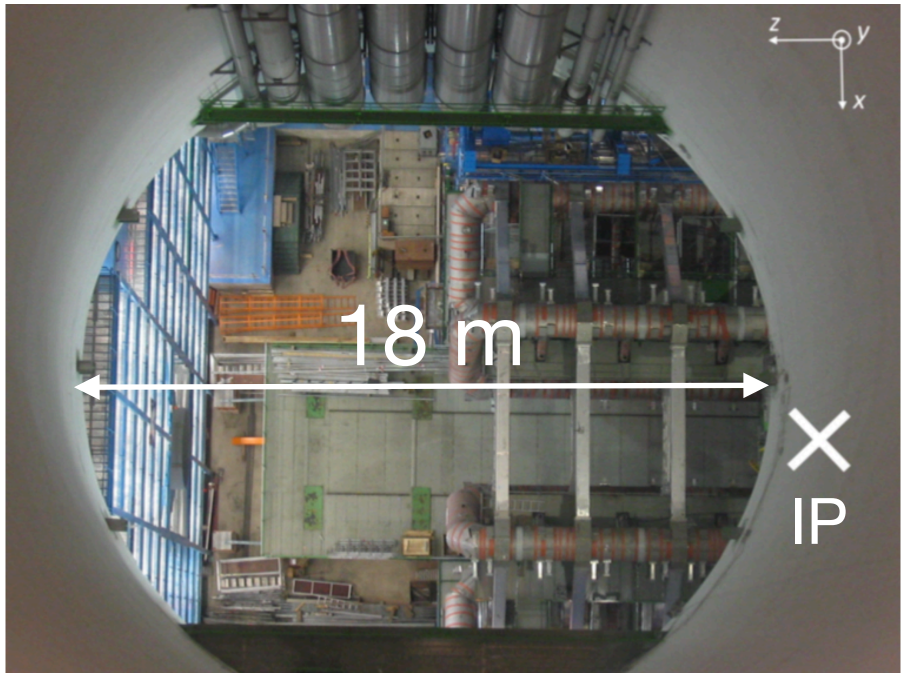
Gligorov et al 1708.09395

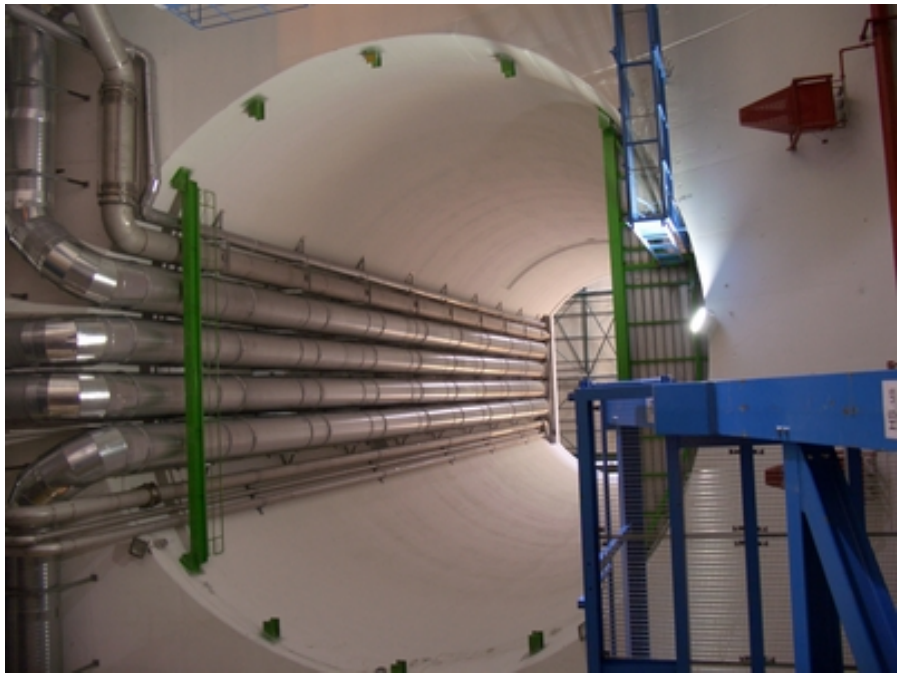
ANUBIS




cranes can support up to 270 t

- Existing geometry allows for minimal civil engineering costs
- Projective decay volume optimises acceptance for different lifetimes





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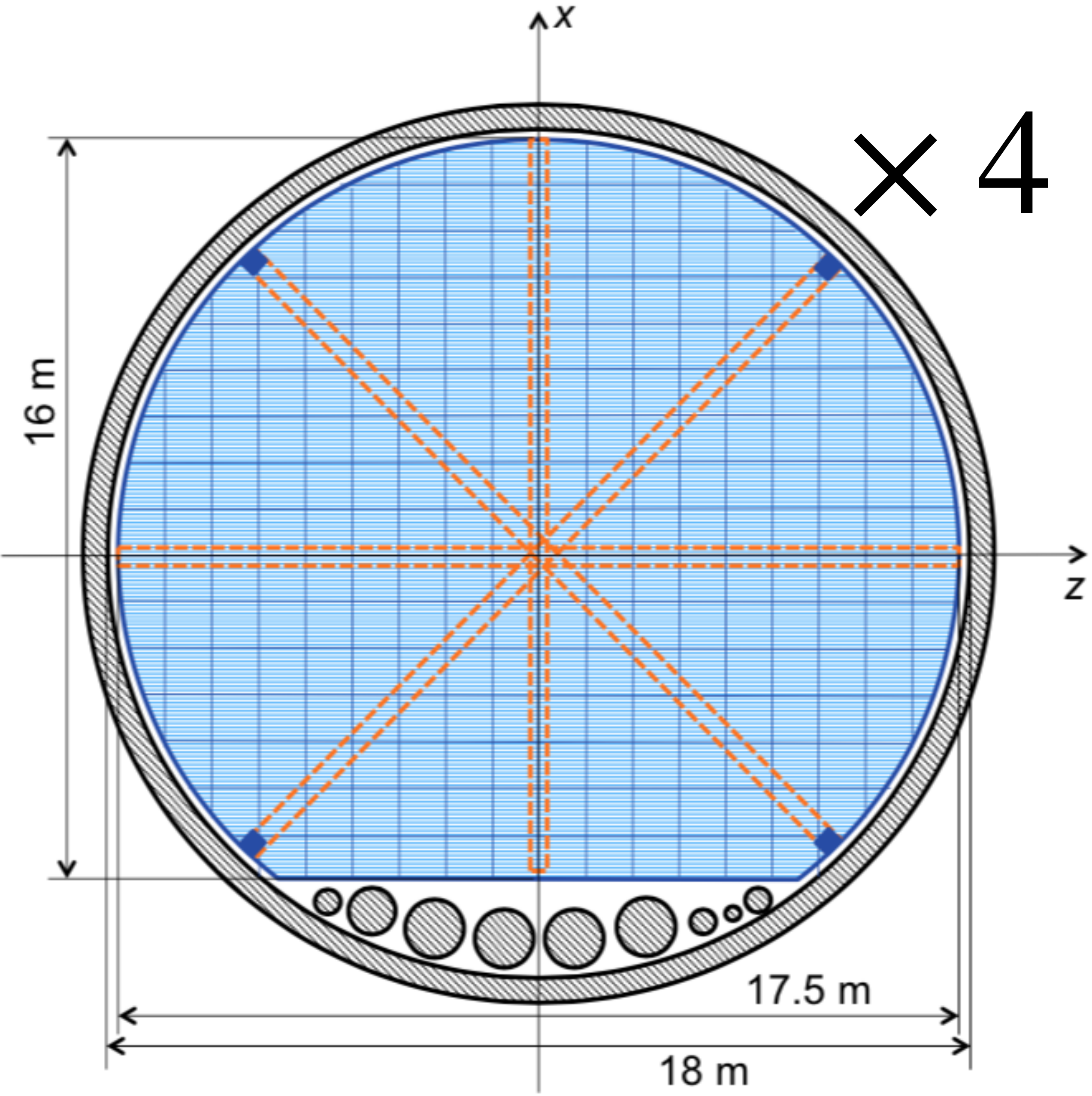
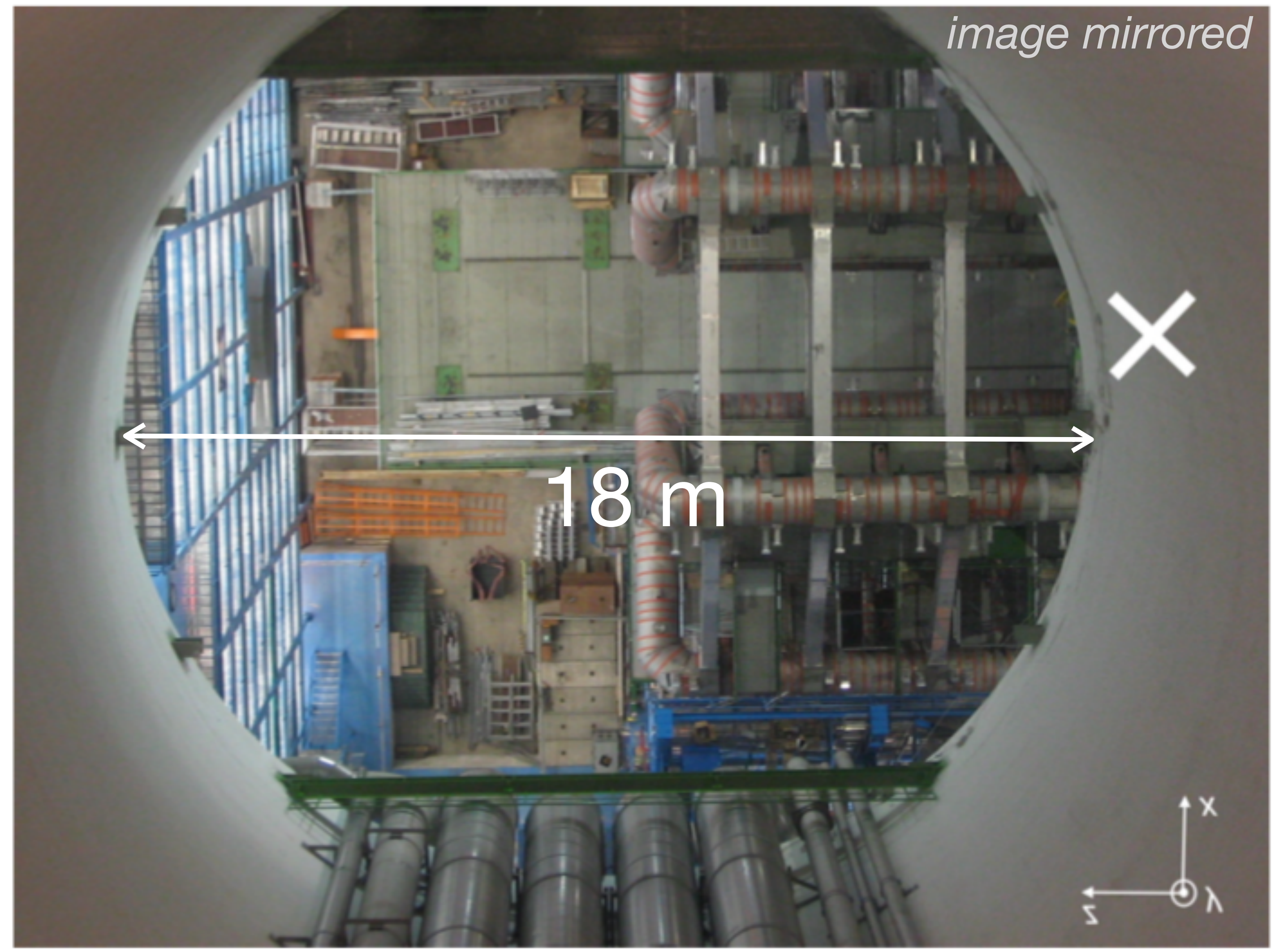
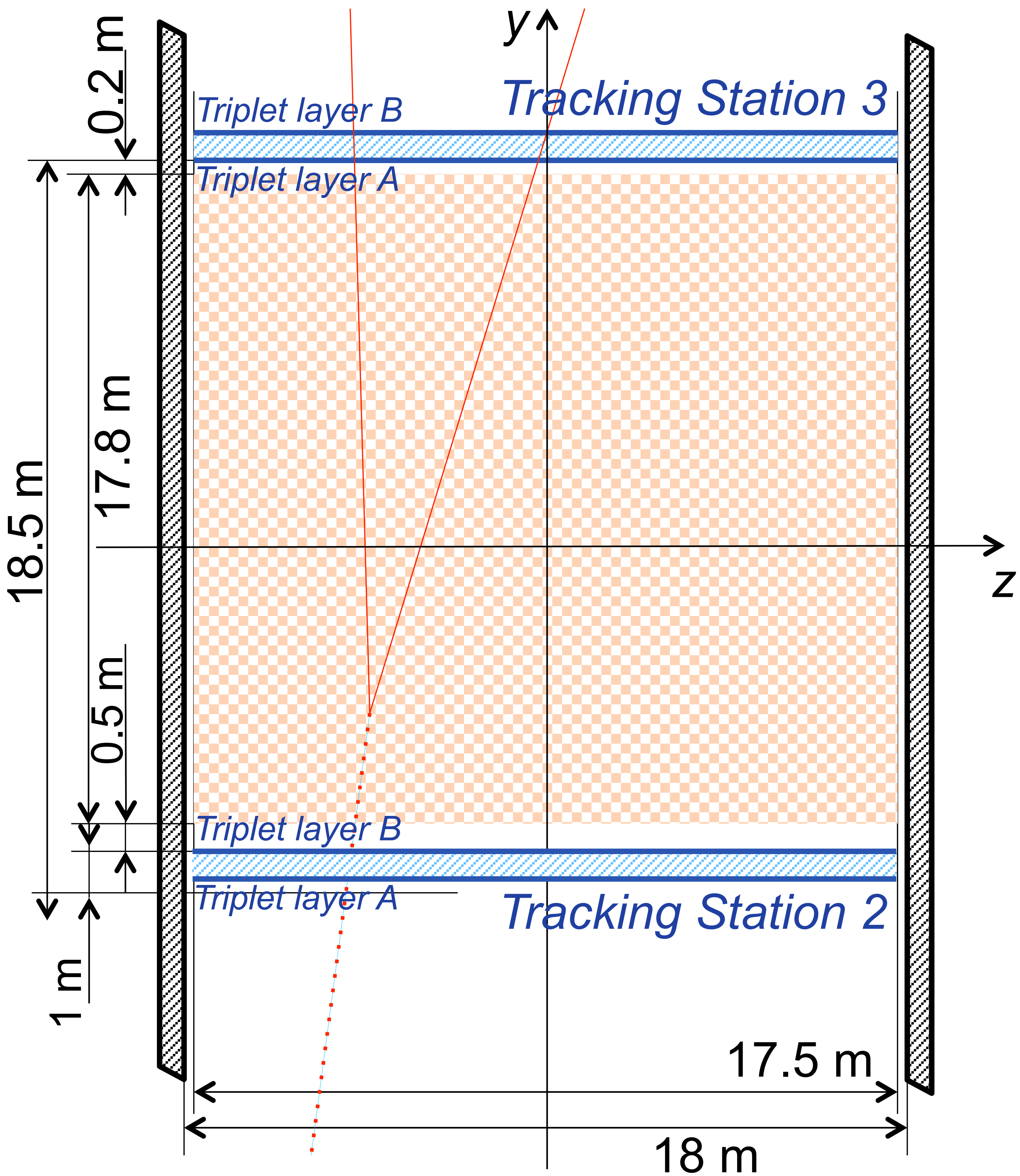




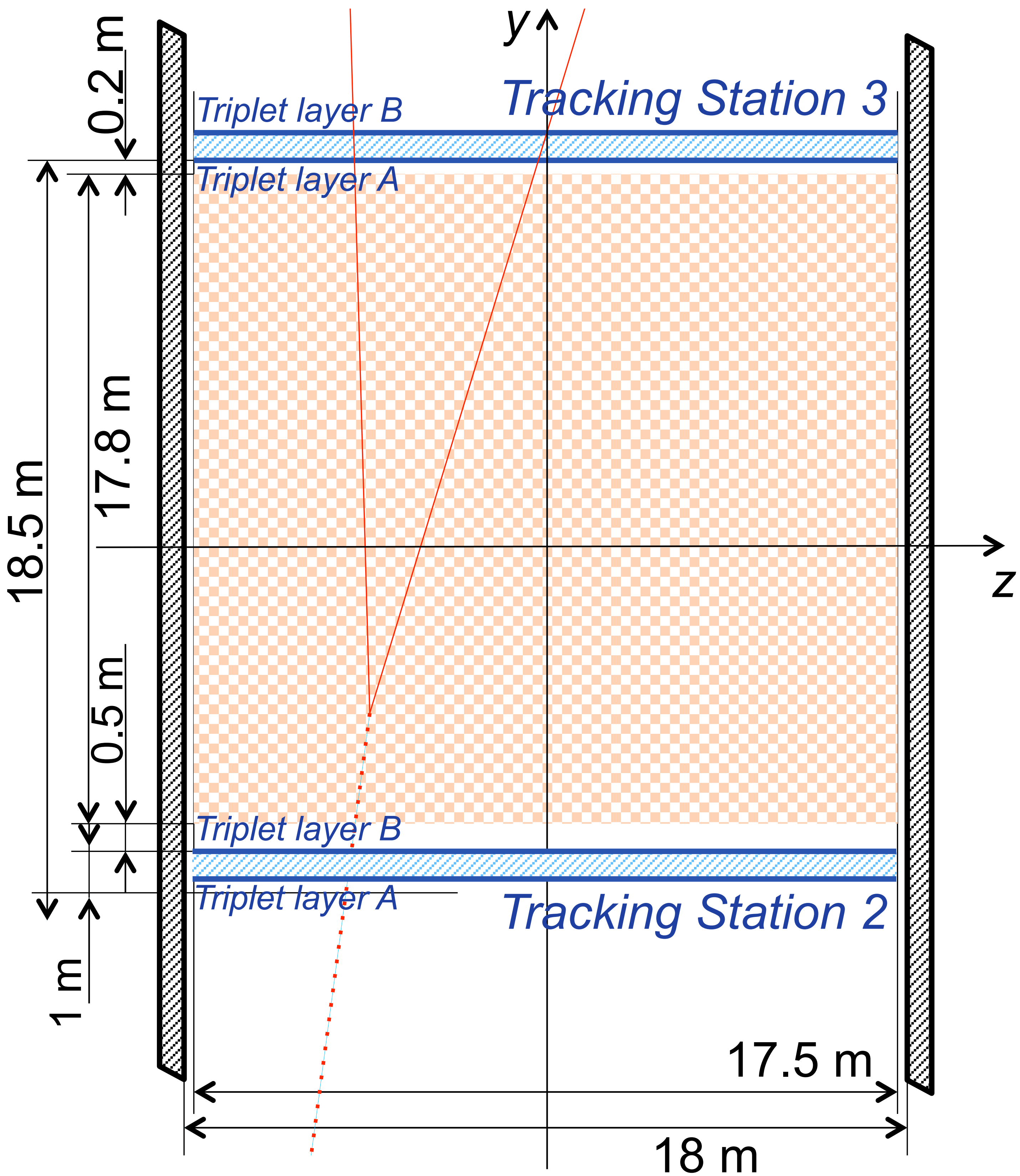
Current proposal:
Four evenly spaced tracking stations with a cross-sectional area of 230 m^2 each

ANUBIS



Parameter	Specification
Time resolution	$\delta t \lesssim 0.5$ ns
Angular resolution	$\delta\alpha \lesssim 0.01$ rad
Spatial resolution	$\delta x, \delta z \lesssim 0.5$ cm
Per-layer hit efficiency	$\varepsilon \gtrsim 98\%$

ANUBIS



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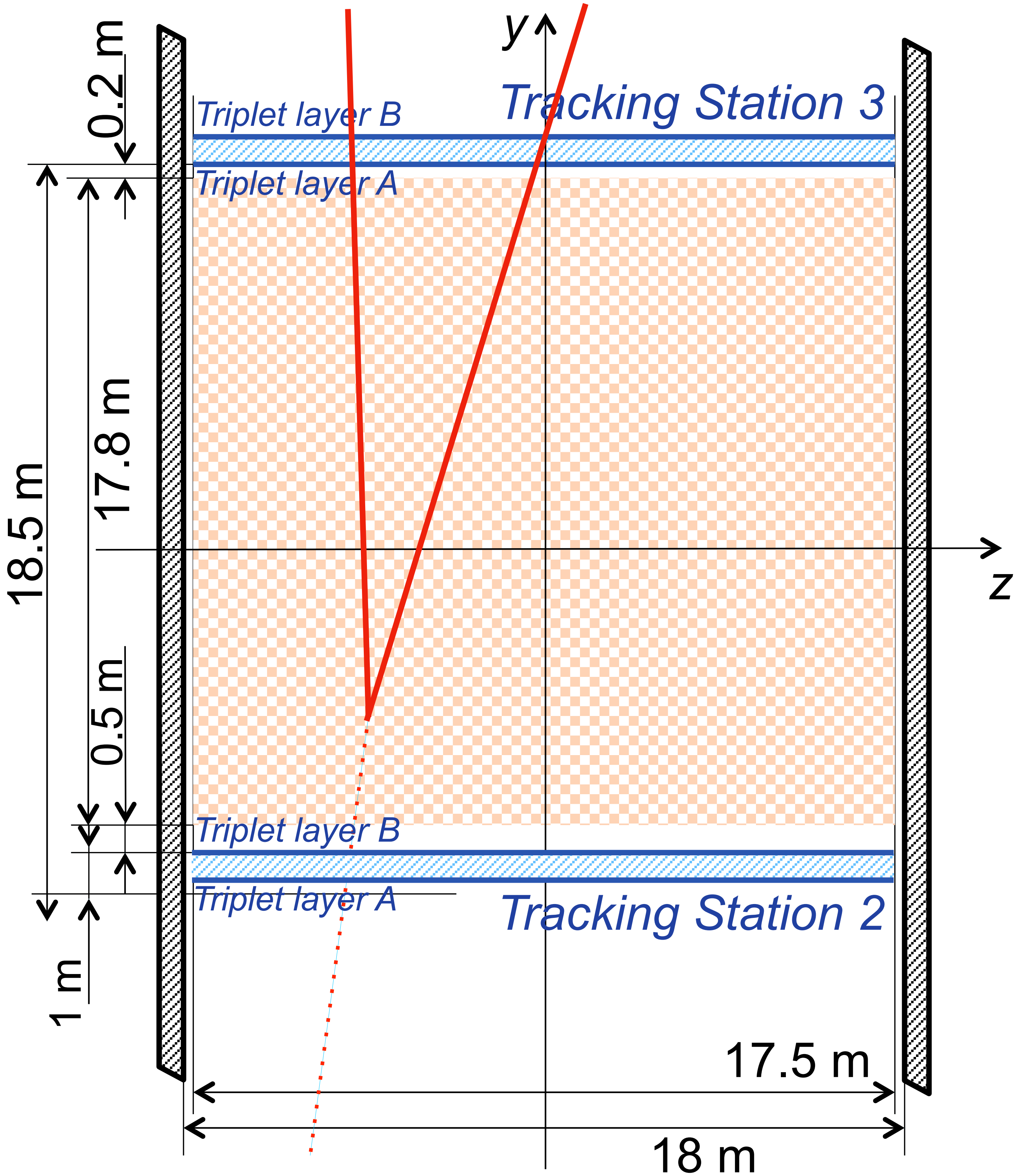
Per-layer hit efficiency	$\varepsilon \gtrsim 98\%$

Timing:

- Fiducialise volume:
  $\delta y_{\mathrm{DV}} \approx 15$ cm
- Eliminate backgrounds
  e.g. cosmics, non-collision
- measure β

ANUBIS



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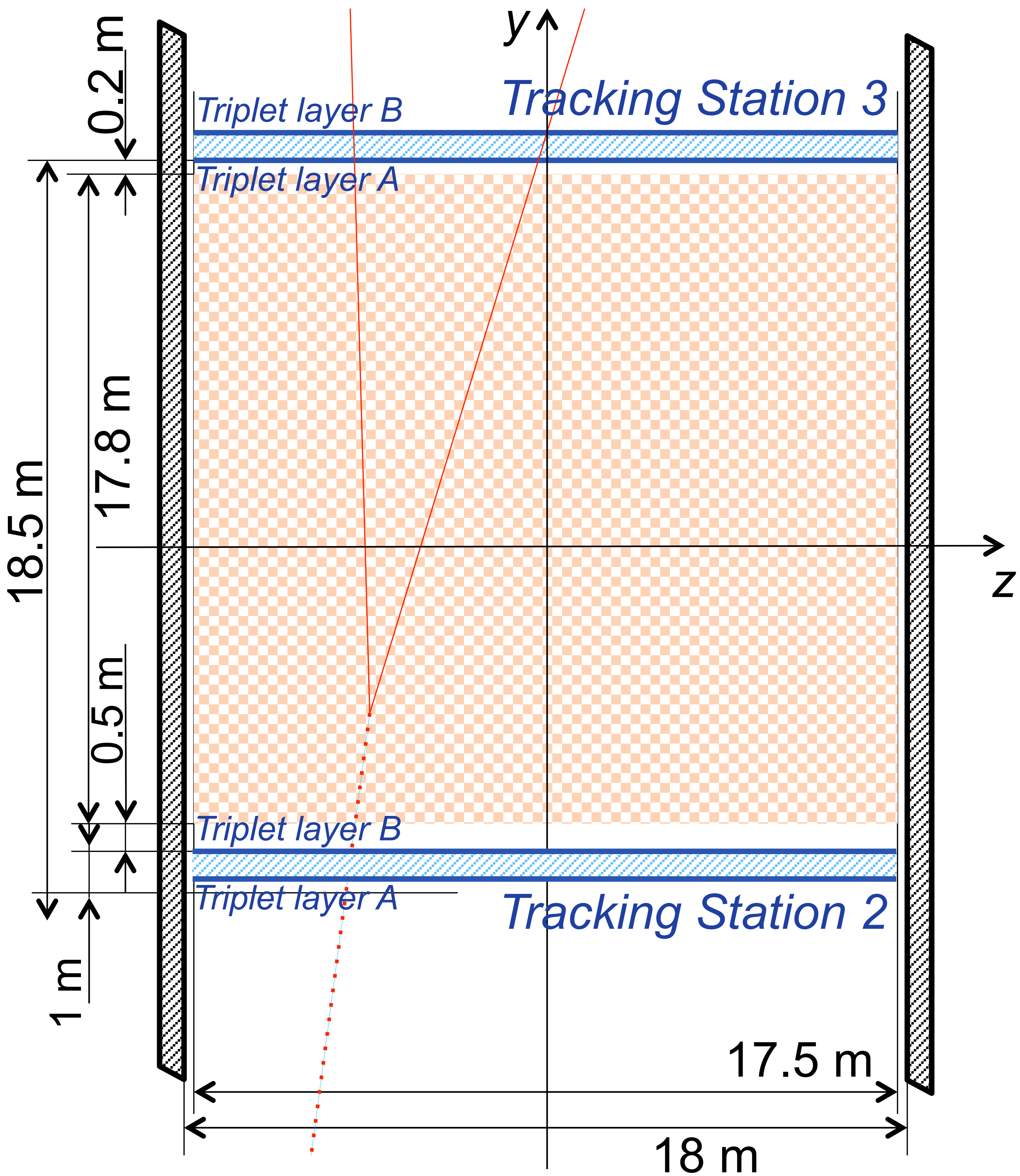
Spatial resolution	$\delta x, \delta z \lesssim 0.5$ cm
Per-layer hit efficiency	$\varepsilon \gtrsim 98\%$

Angular & spatial resolution:

- Reconstruct displaced vertices: reach $m_{\mathrm{LLP}} \gtrsim K_L$ for $m_{\mathrm{mediator}} \approx 100$ GeV
- Fiducialise volume

ANUBIS



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Efficiency:

- Detect signal
- Reject backgrounds

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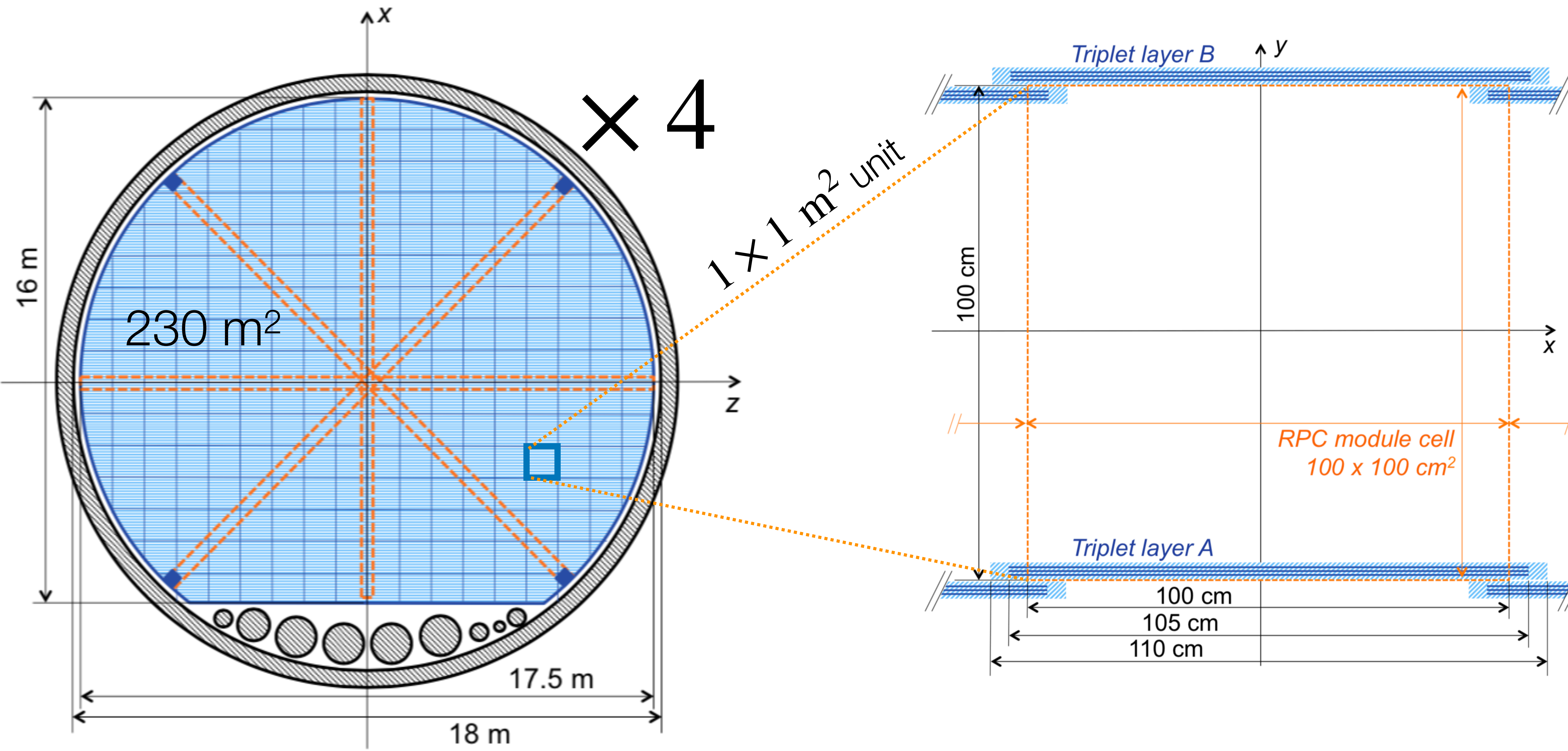

Tracking stations affixed with cams: extract tracking stations to surface quickly & easily in an emergency

Parameter	Specification
Time resolution	$\delta t \lesssim 0.5$ ns
Angular resolution	$\delta\alpha \lesssim 0.01$ rad
Spatial resolution	$\delta x, \delta z \lesssim 0.5$ cm
Per-layer hit efficiency	$\varepsilon \gtrsim 98\%$

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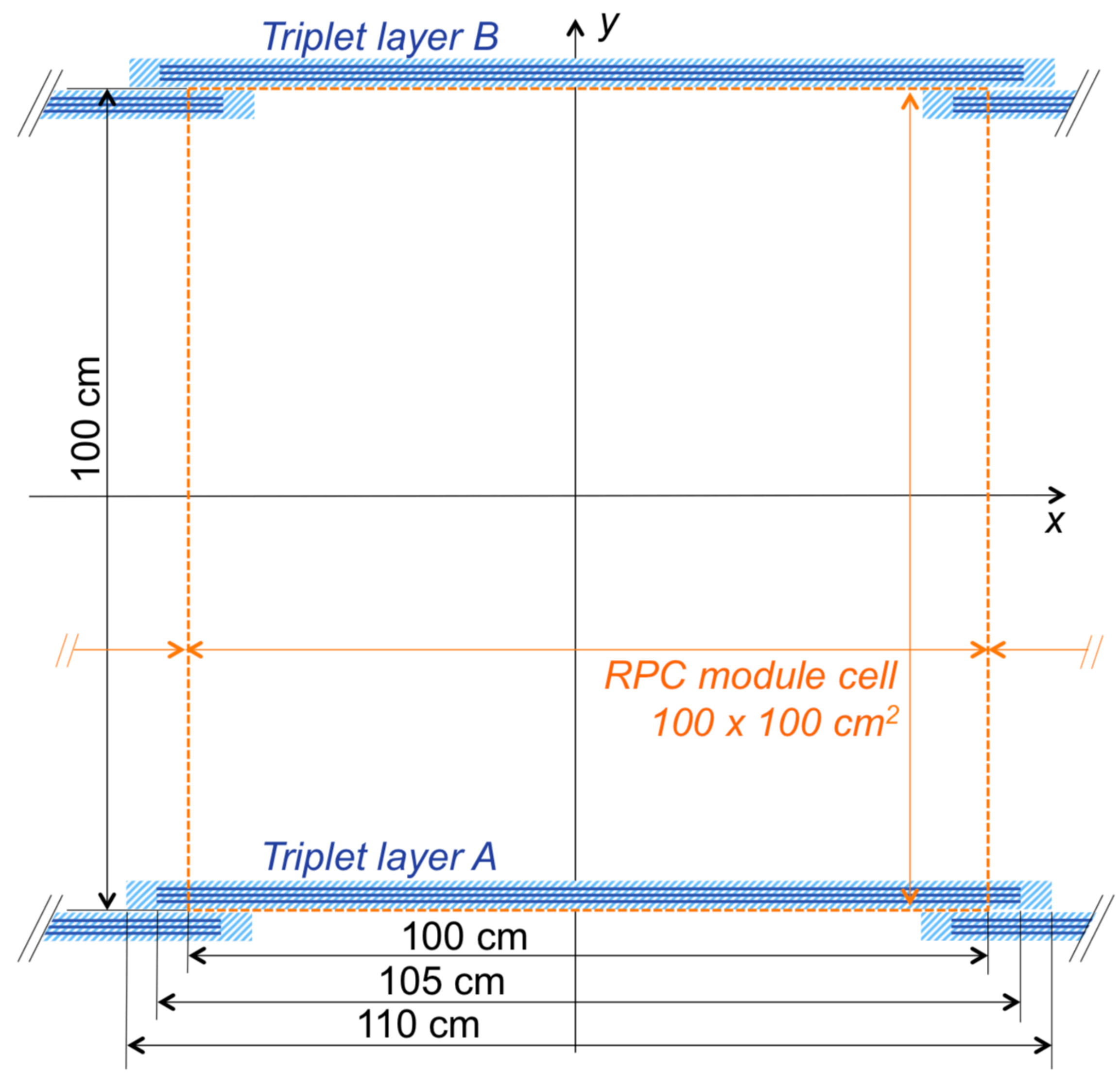
Possible detector technology:

- Resistive Plate Chamber technology; ANUBIS performance specifications met by ATLAS *BIS-78 prototype* (ongoing upgrade): triplet of layers with 0.4 ns time resolution, 0.1 cm spatial resolution

- *2.3 x 10^3 m^2* total instrumented area @3.1k€/m^2 (including mechanics, gas gap, strips, front-ends and production yield): *7.2 M€ (total < 10 M€, scales with m^2)*
  Each tracking station weighs
  230 m^2 x 51 kg/m^2 ~ 30 tons

- Other possibilities like finely granulated scintillators, scintillating fibres to explore
  - Potential further cost reductions



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Per-layer hit efficiency	$\varepsilon \gtrsim 98\%$

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It should be possible to dramatically reduce backgrounds.
The ATLAS detector serves:

- as a passive shield:
  calorimeters account for ~10 nuclear interaction lengths λ_I
- as an *active veto*:
  high-p_T neutral particles (n, K_L) typically come with energetic jets

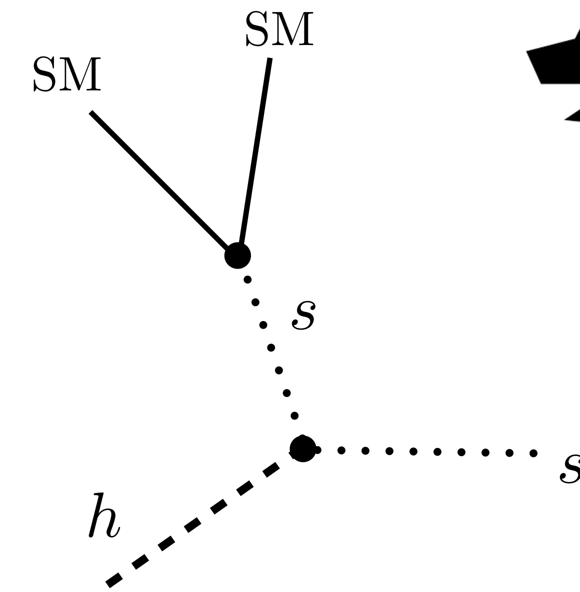
Almost background-free by requiring isolation in $\Delta R(\mathrm{DV}, x)$

- from inner detector tracks
- from calorimeter jets
- from muon spectrometer tracks

Achieve this by *triggering readout of ATLAS*

Additional shielding by rock between the interaction point and some regions of the tracking stations - useful as control region

ANUBIS

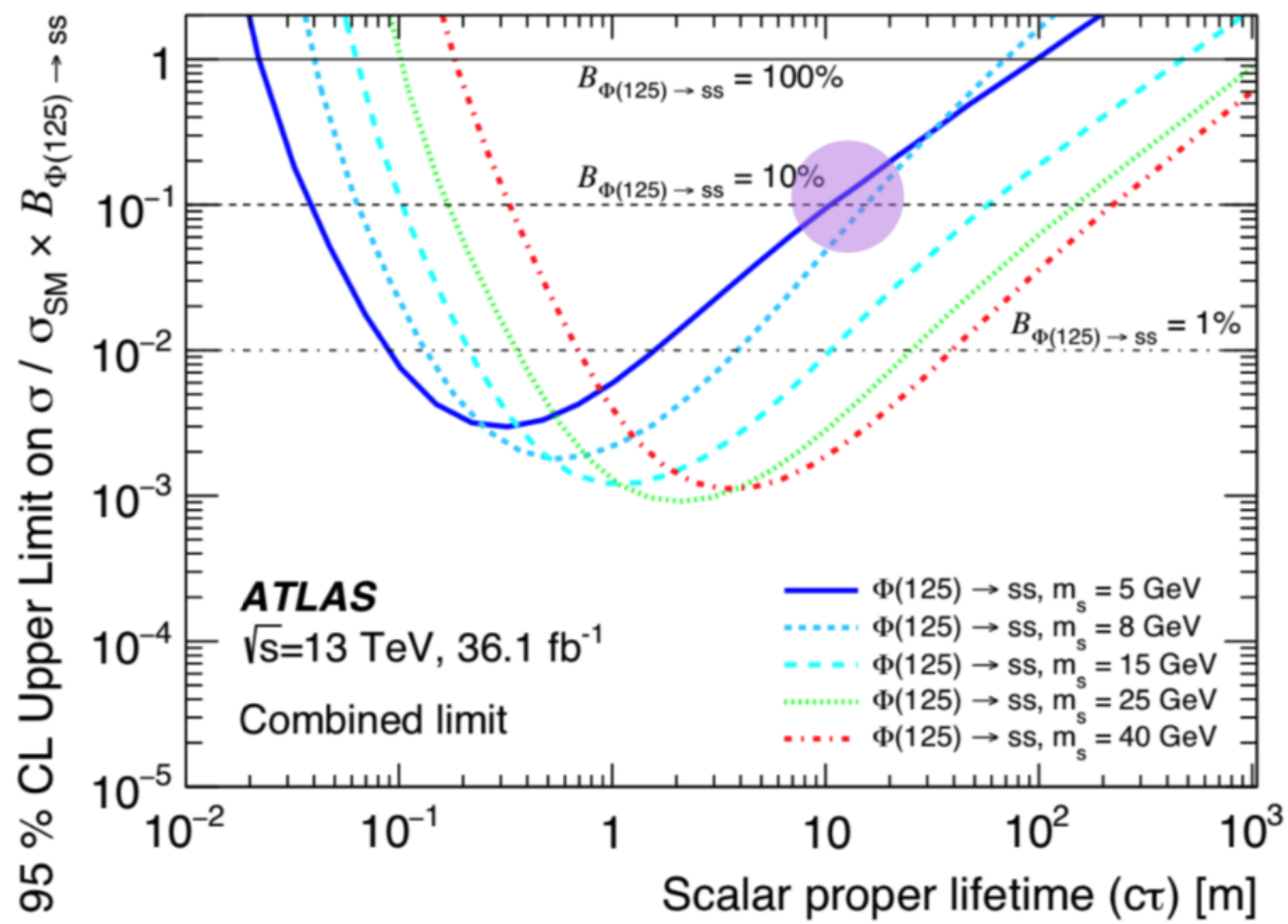


Sensitivity study for exotic Higgs decays

$$\mathcal{L} = \lambda s^2 H^\dagger H \qquad h \to ss, s \to \mathrm{SM\,SM}$$

ATLAS searched for displaced vertices in the muon spectrometer.

ATLAS 1811.07370



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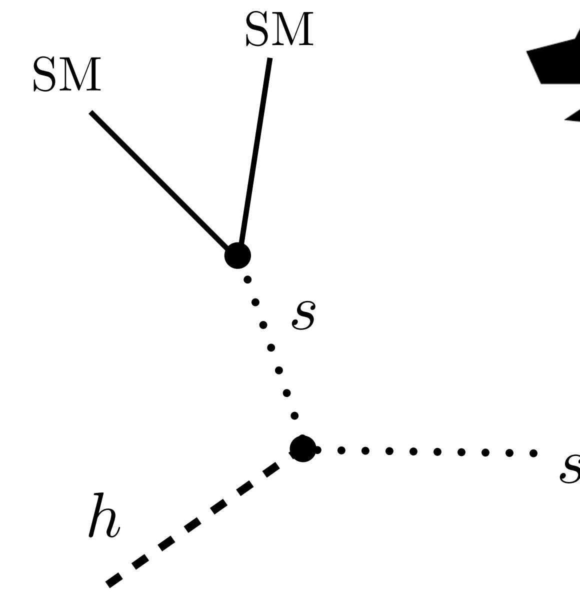


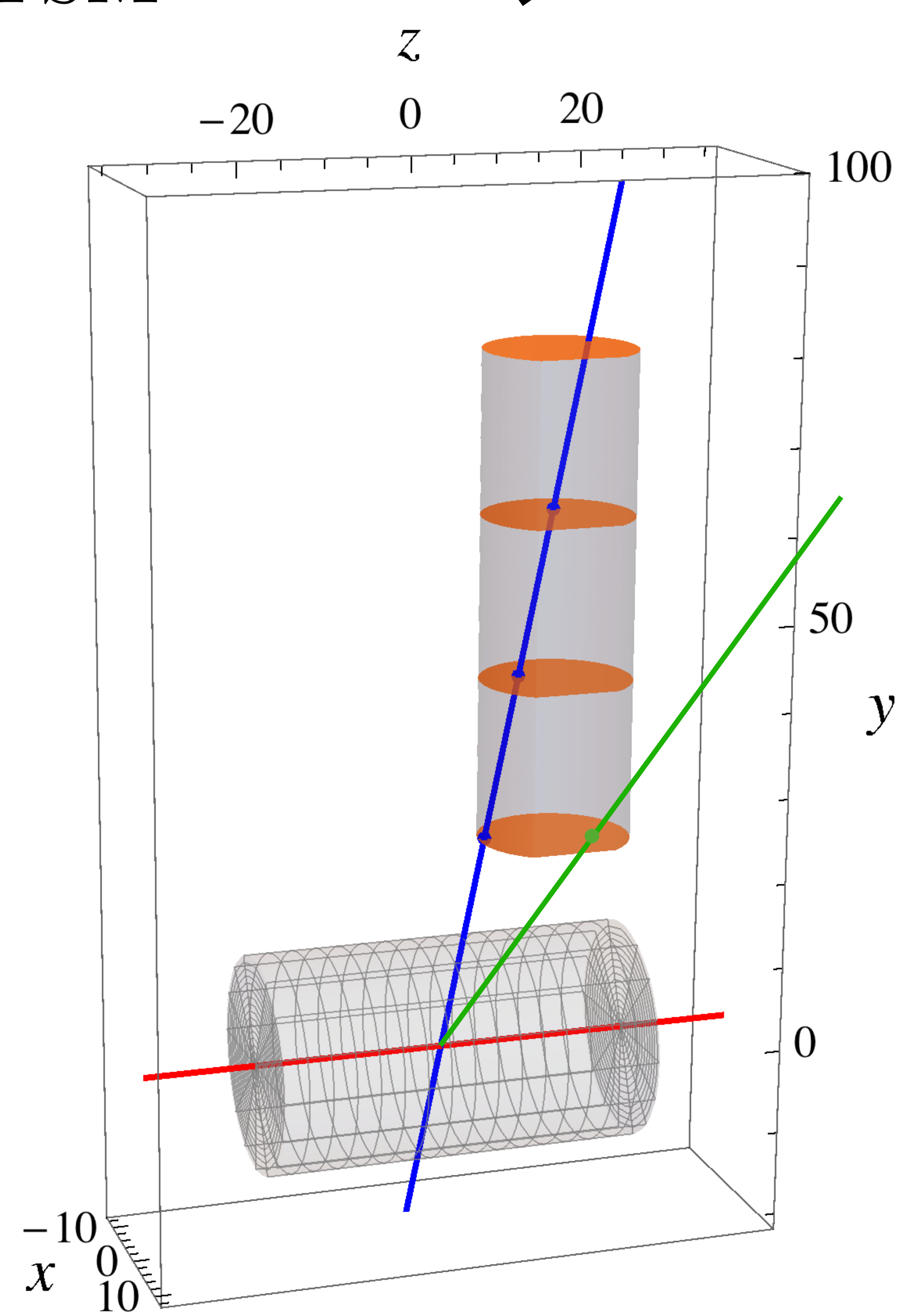
Sensitivity study for exotic Higgs decays

$$\mathcal{L} = \lambda s^2 H^\dagger H \qquad h \to ss, s \to \mathrm{SM\,SM}$$

We simulated the signal with MadGraph and require the LLP to penetrate at least 1 (2) tracking stations

We consider two scenarios:

- optimistic (requiring 4+ events - similar to MATHUSLA)
- conservative (requiring 50+ events - similar to ATLAS muon spectrometer search)



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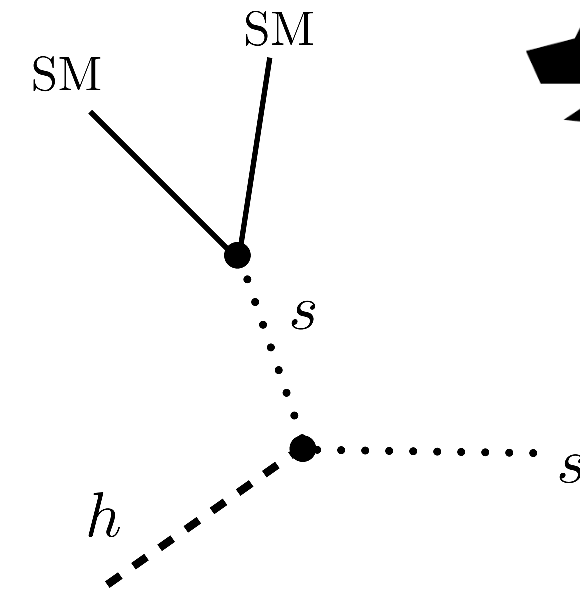

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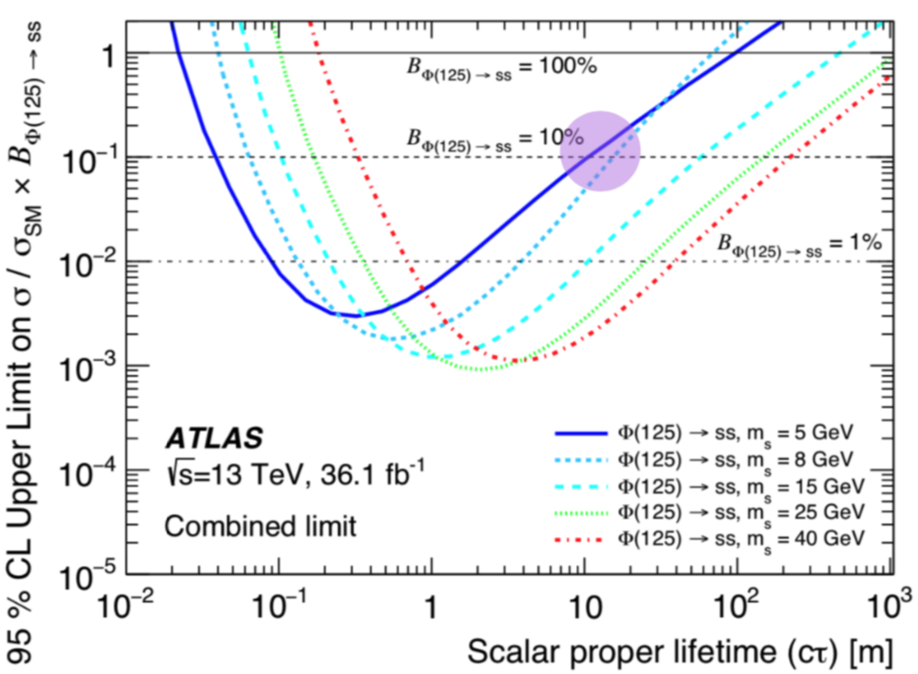
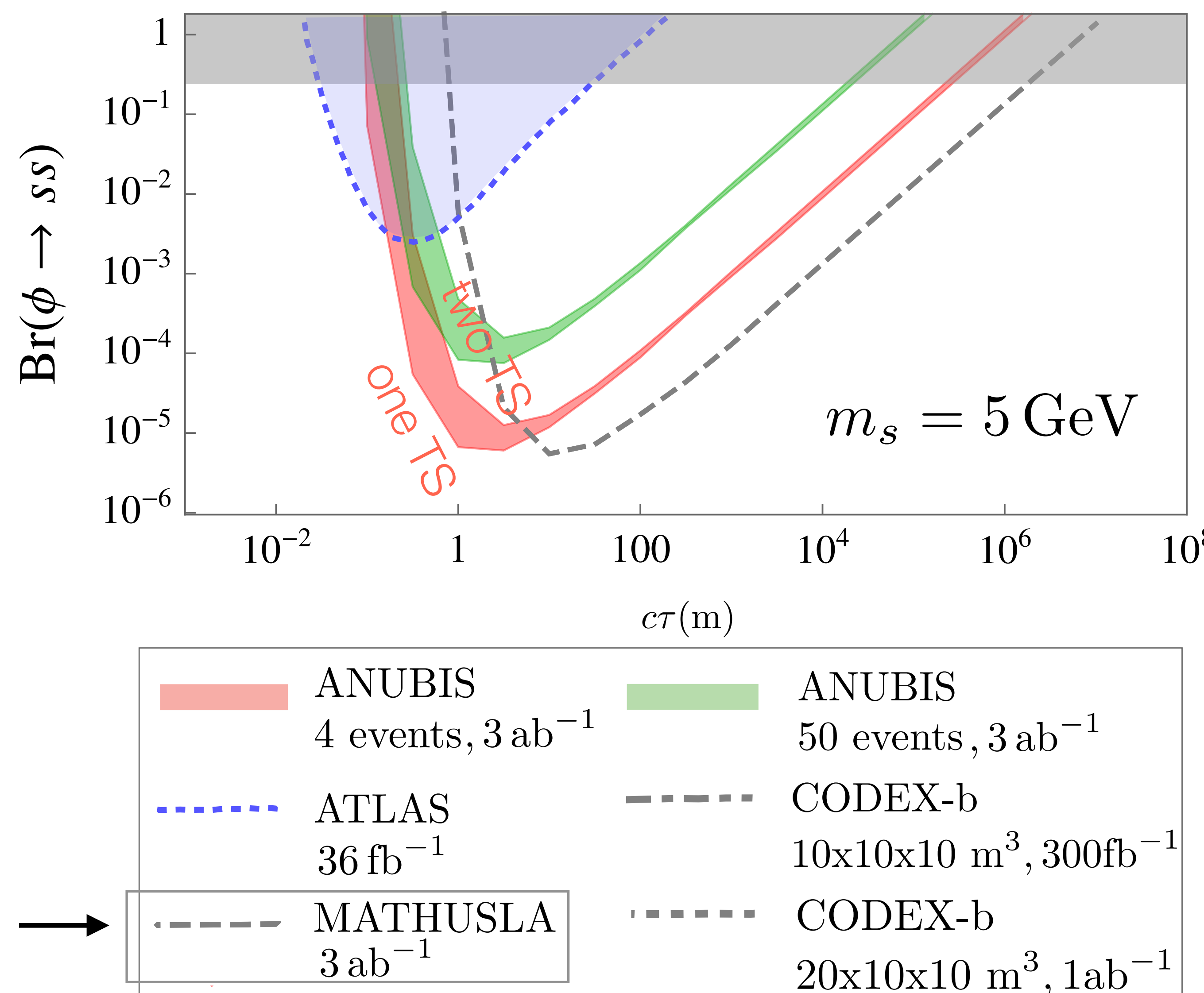
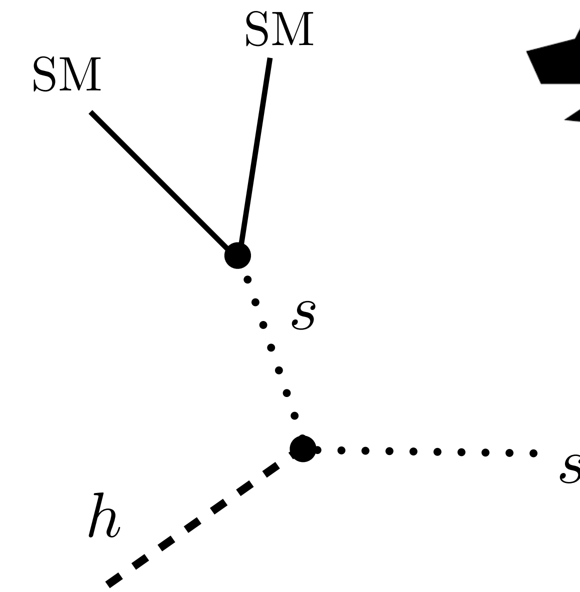




200 x 200 x 20 m³ decay volume →

ANUBIS



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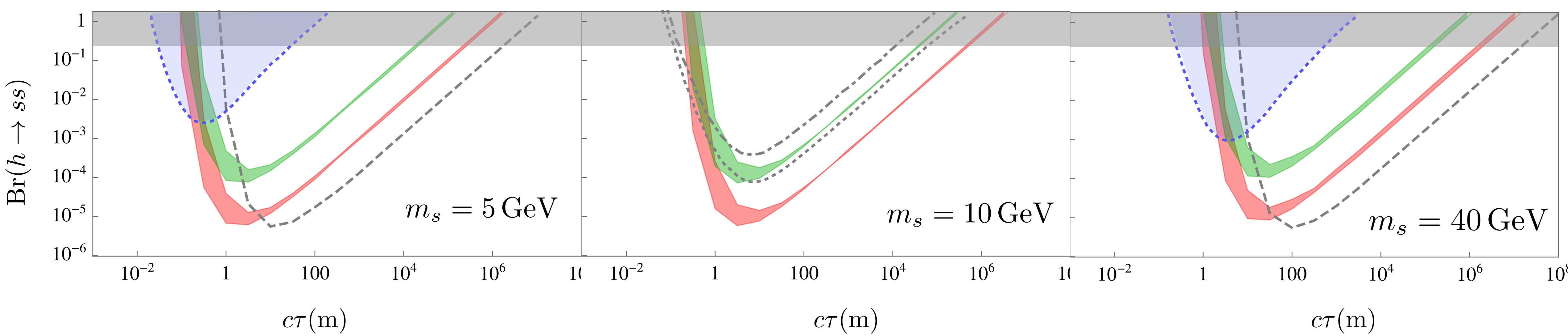

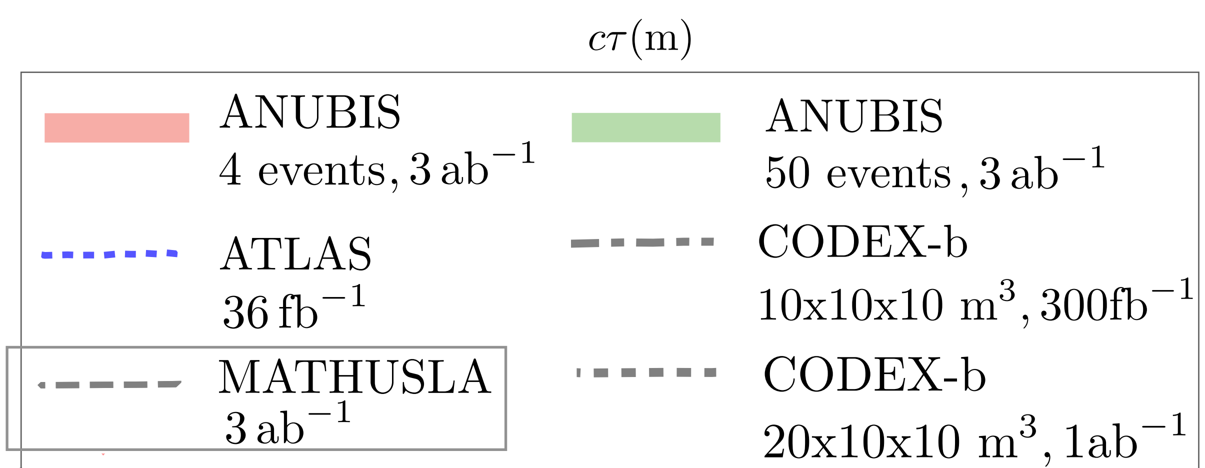

200 x 200 x 20 m³ decay volume →

Conclusions

- **AN U**nderground **B**elayed **I**n-**S**haft search experiment is a cost-effective (< 10M€) alternative to optimise the LHC reach searching for LLPs produced orthogonal to the beam direction

- Existing geometry and infrastructure minimise civil engineering

- ANUBIS physics reach is comparable to CODEX-b and MATHUSLA

- We propose to construct two $1 \times 1\ \mathrm{m}^2$ prototypes to be suspended at the top and bottom of the PX14 shaft during Run III
  - E.g. $1 \times 1\ \mathrm{m}^2$ units using two BIS-78 resistive plate chambers

- ANUBIS is 1:1 transferrable to CMS using its main PX56 shaft

- ANUBIS combinable with other search strategies

Thank you!

ANUBIS - other backgrounds

- Background from cosmic ray muons negligible:
veto using timing and directional requirements

- Non-collision backgrounds negligible:
ANUBIS is ~orthogonal to the beam line, while non-collision backgrounds feature a pronounced boost along the beam line

- Background from thermal neutrons decays negligible:
too little energy

- Once >2 tracks required for the displaced vertex, any residual backgrounds from n, KL are rendered negligible

- Certainly background-free when 2 displaced vertices required:
- one within ANUBIS for triggering
- one can be in ANUBIS or anywhere in ATLAS

ANUBIS - Angular resolution

- Consider decay into two particles — this is the most challenging case!
  - Higher multiplicity → easier reconstruction & (even) lower backgrounds
- Assume mediator at EW scale (e.g. 125 GeV Higgs):

$$m_{\rm med} \approx 100 \ {\rm GeV}$$

- Average boost from pure kinematics:

$$\frac{m_{\rm med}}{2m_{\rm LLP}} \quad \Rightarrow \quad m_{\rm LLP} \approx \frac{1}{2} m_{\rm med} \cdot \omega$$

- Assume symmetric LLP decay

$$\delta\omega \ \approx \ \sqrt{2} \cdot \delta\alpha$$