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Physics Beyond Colliders

Exploring Beyond the Standard Model

J. Jaeckel

Special Thanks to all my collaborators,
the Physics Beyond Colliders Study Group,
Claude Vallee and Mike Lamont
and all participants of the PBC workshops

Many slides, pictures etc from talks at PBC workshops

What is PBC?

What is PBC?

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Study group mandated by CERN management to prepare for the next European HEP strategy update

(coordinators Mike Lamont, Claude Vallee, JJ)

"Explore the opportunities offered by the CERN accelerator complex to address some of today's outstanding questions in particle physics through experiments complementary to high-energy colliders and other initiatives in the world" (Excerpt from the mandate)

Time scale ~ 20 years

pbc.web.cern.ch

Where is the New Physics?

Exploring is (at least) 2 dimensional

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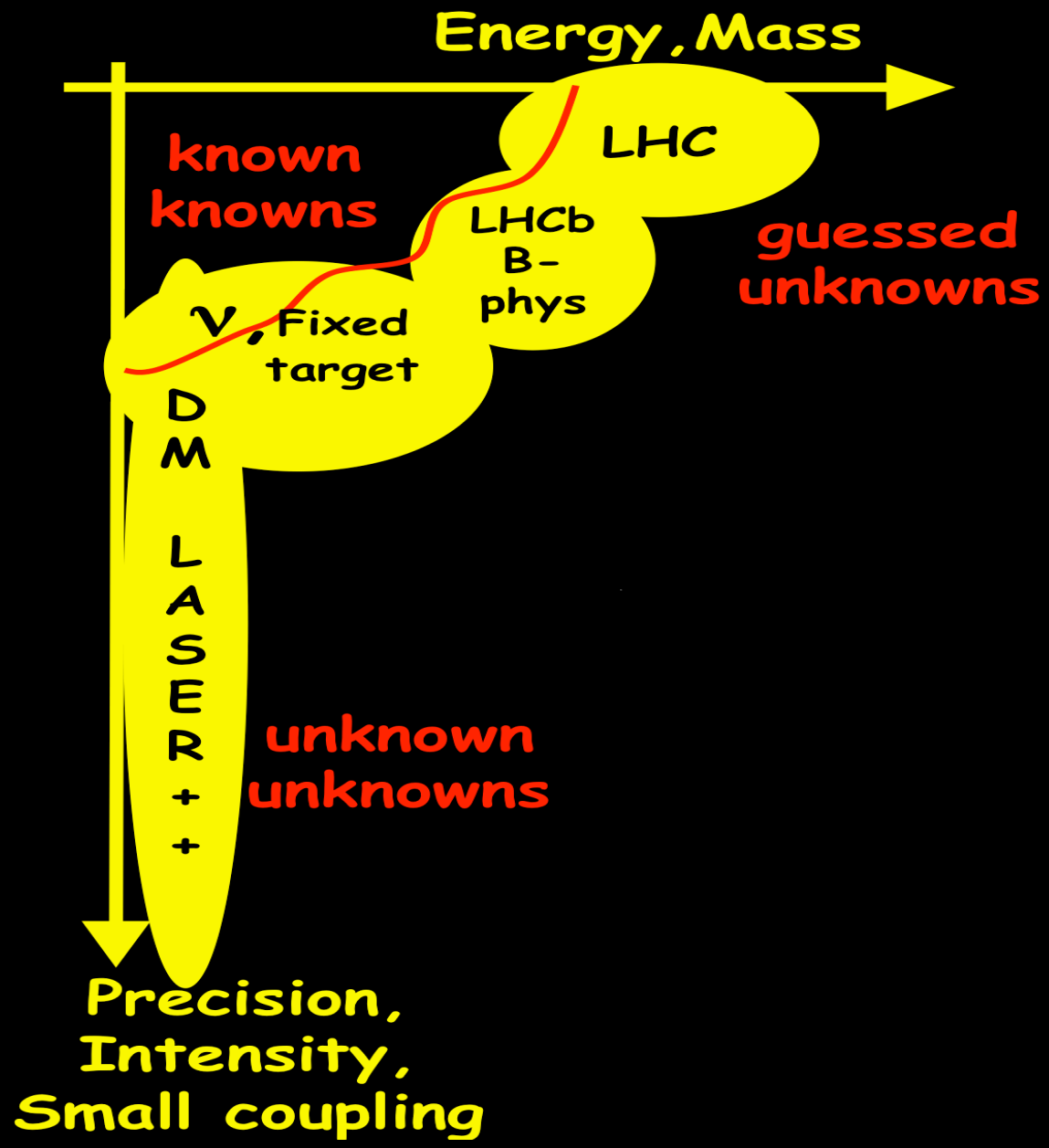

Here we want to go today…

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PBC exploration

An example:

Axions,

axion like particles,

general pseudo-Goldstone bosons

$$\mathcal{L} \supset \frac{1}{4} g_{a\gamma\gamma} \phi F^{\mu} \tilde{F}_{\mu\nu}$$

$$g_{a\gamma\gamma} \sim \frac{\alpha}{4\pi f_a}$$

This is only an example

Many more cool and interesting models to test!!!

Target space

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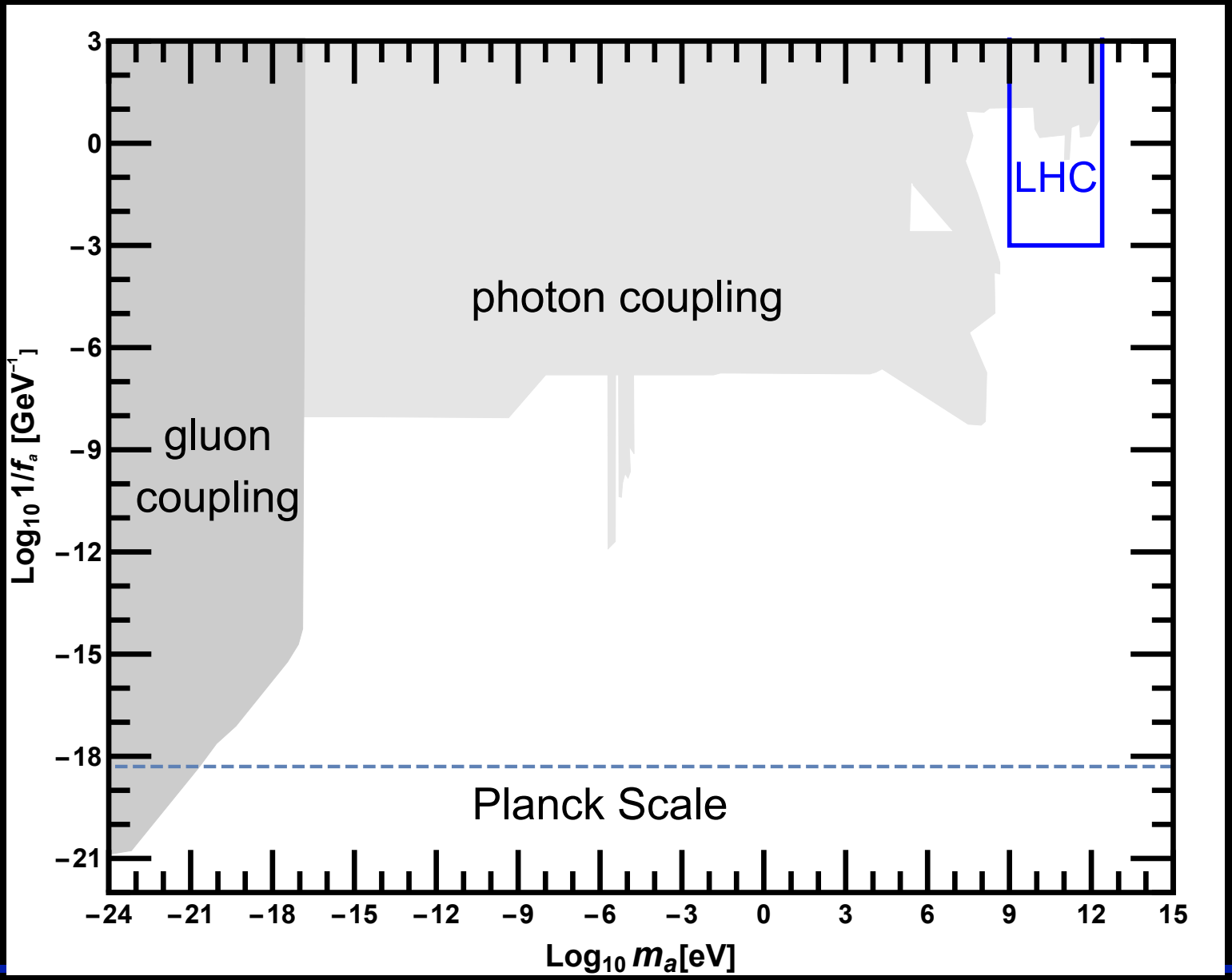

Measurement of proton EDM

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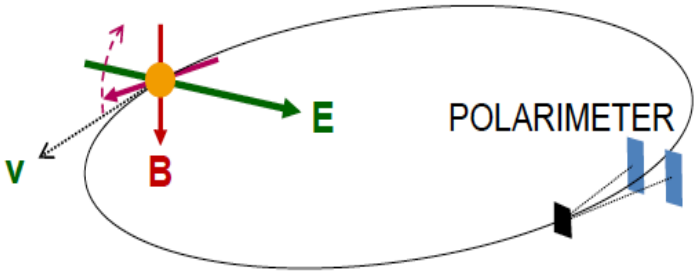
Storage ring based EDM search

- In the presence of EDM,

$$\frac{d\vec{S}}{dt} = \frac{e}{\gamma m}\vec{S} \times \left[(1+G\gamma)\vec{B}_{\perp} + (1+G)\vec{B}_{\parallel} + \left(G - \frac{\gamma}{\gamma^2-1}\right)\frac{\vec{E}\times\vec{\beta}}{c} + \boldsymbol{d}(\vec{E} + \vec{\beta}\times\vec{B})\right]$$

- **Null to remove the MDM contribution to spin motion. And glue the spin vector along the particle's velocity in the horizontal plane**
  - **Non-zero EDM results in the vertical polarization buildup**

$$\frac{d\vec{S}}{dt} = \frac{e}{\gamma m}\vec{S} \times [\boldsymbol{d}(\vec{E} + \vec{\beta}\times\vec{B})]$$



courtesy of E. Stephenson

Full Spin Frozen storage ring is the most effective way!

Sensitivity

$$d_p \sim 4 \times 10^{-29} e\,\mathrm{cm}$$

Sensitivity

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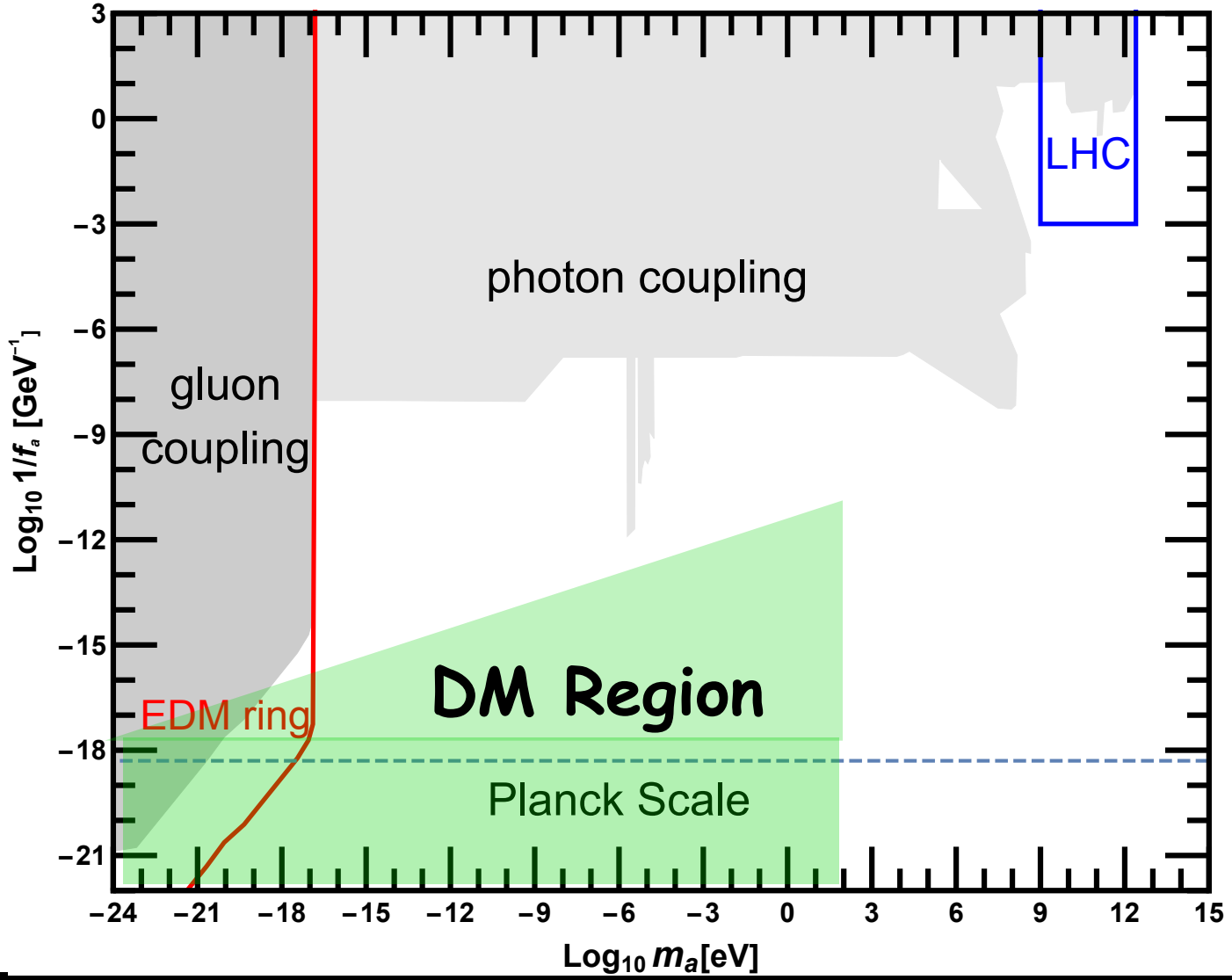

International Axion Observatory = IAXO

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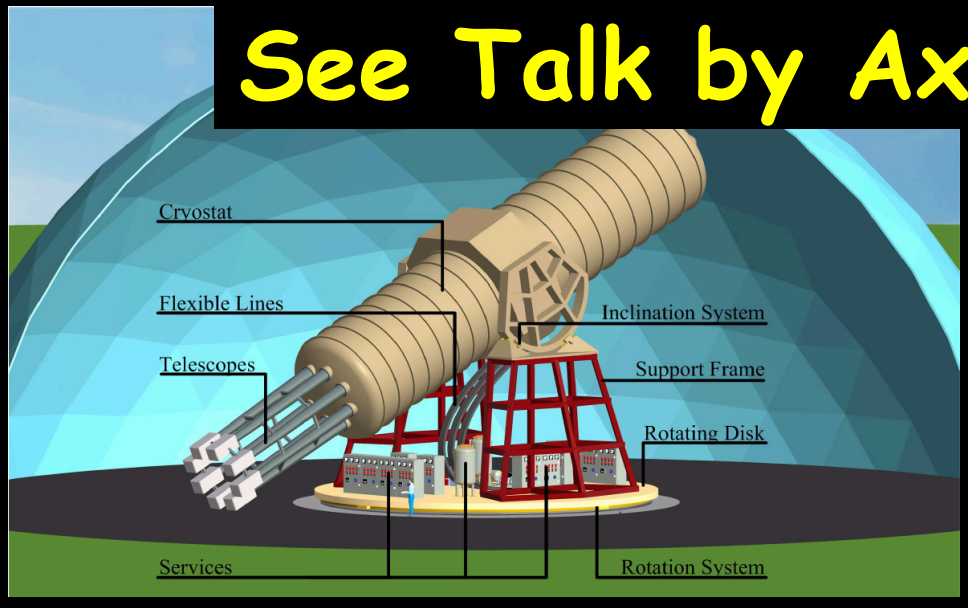
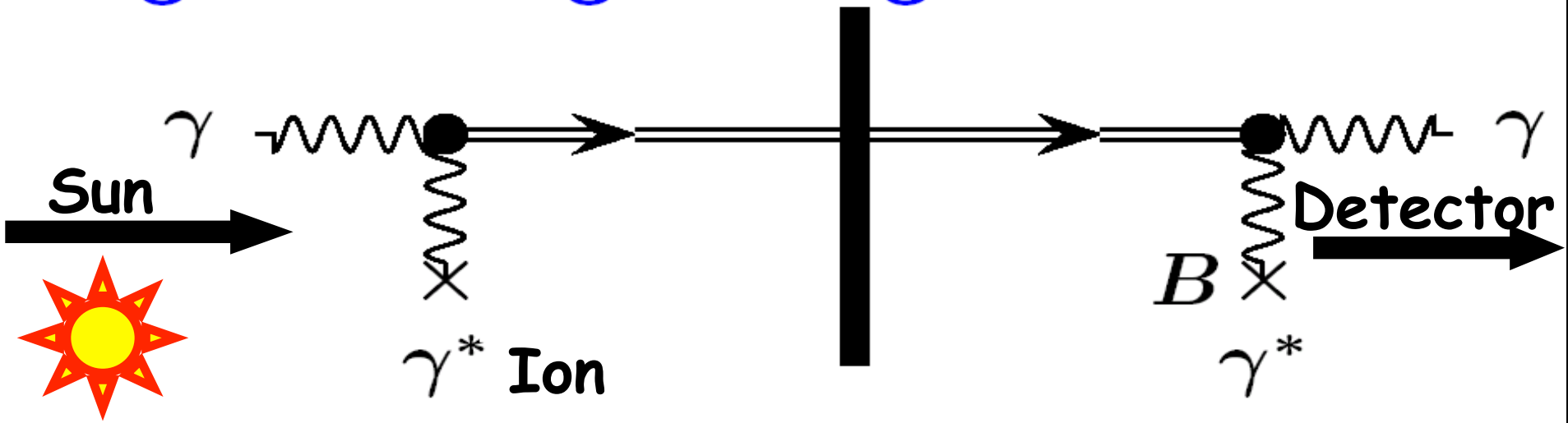
See Talk by Axel Lindner



$$\mathcal{L} \supset \frac{1}{4} g_{a\gamma\gamma} \phi F^{\mu} \tilde{F}_{\mu\nu}$$

"Light shining through a wall"



Sensitivity

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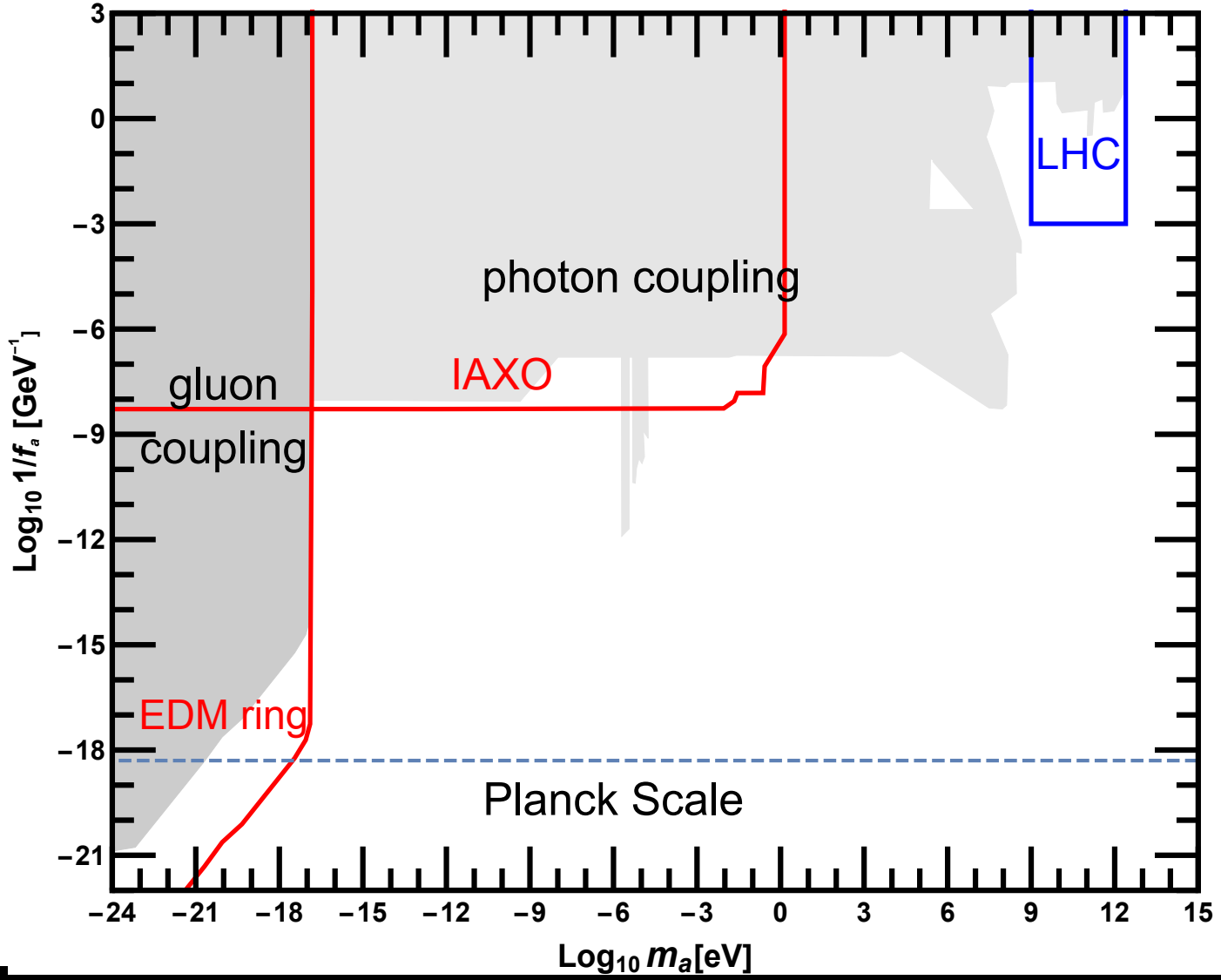

Sensitivity

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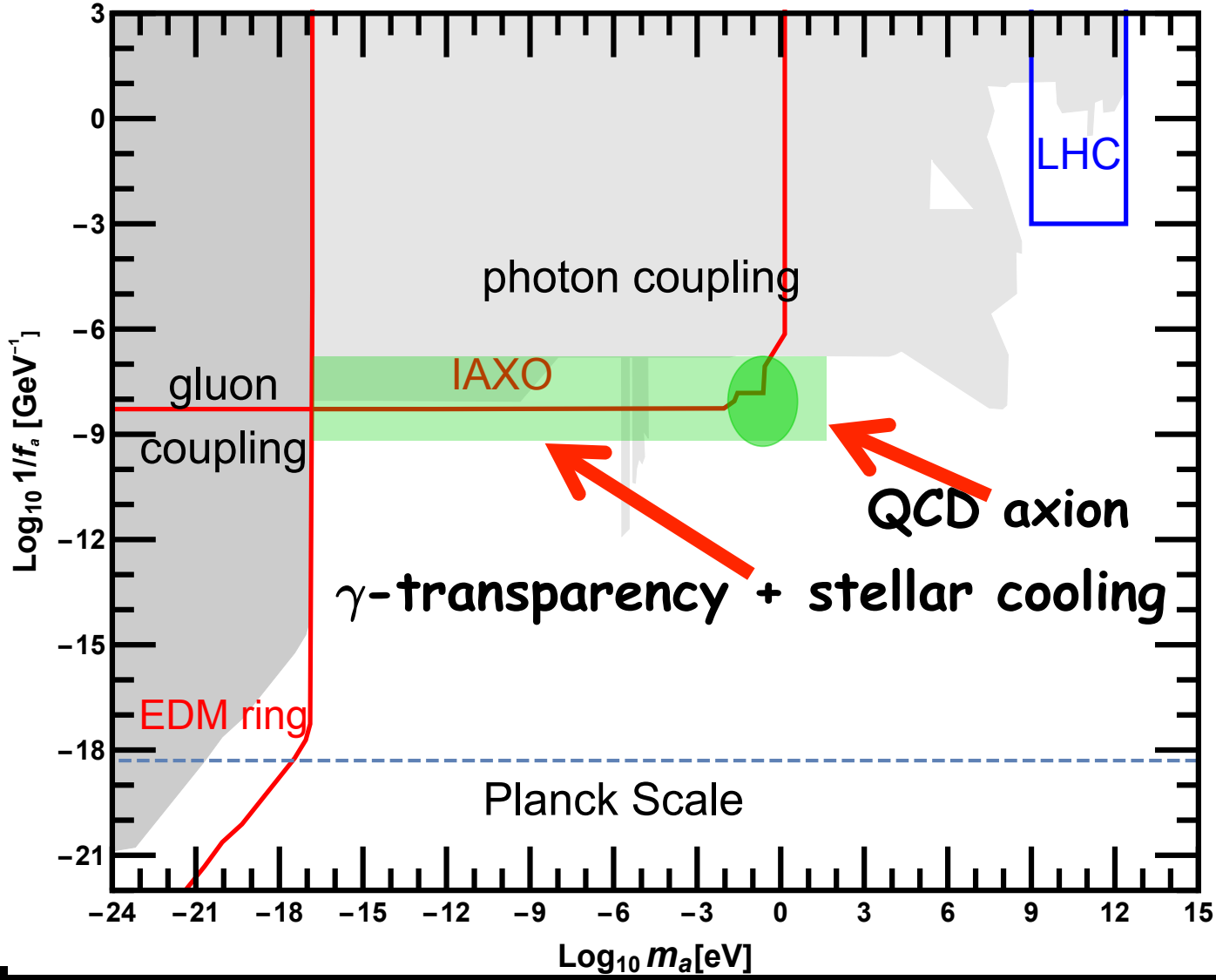

Sensitivity

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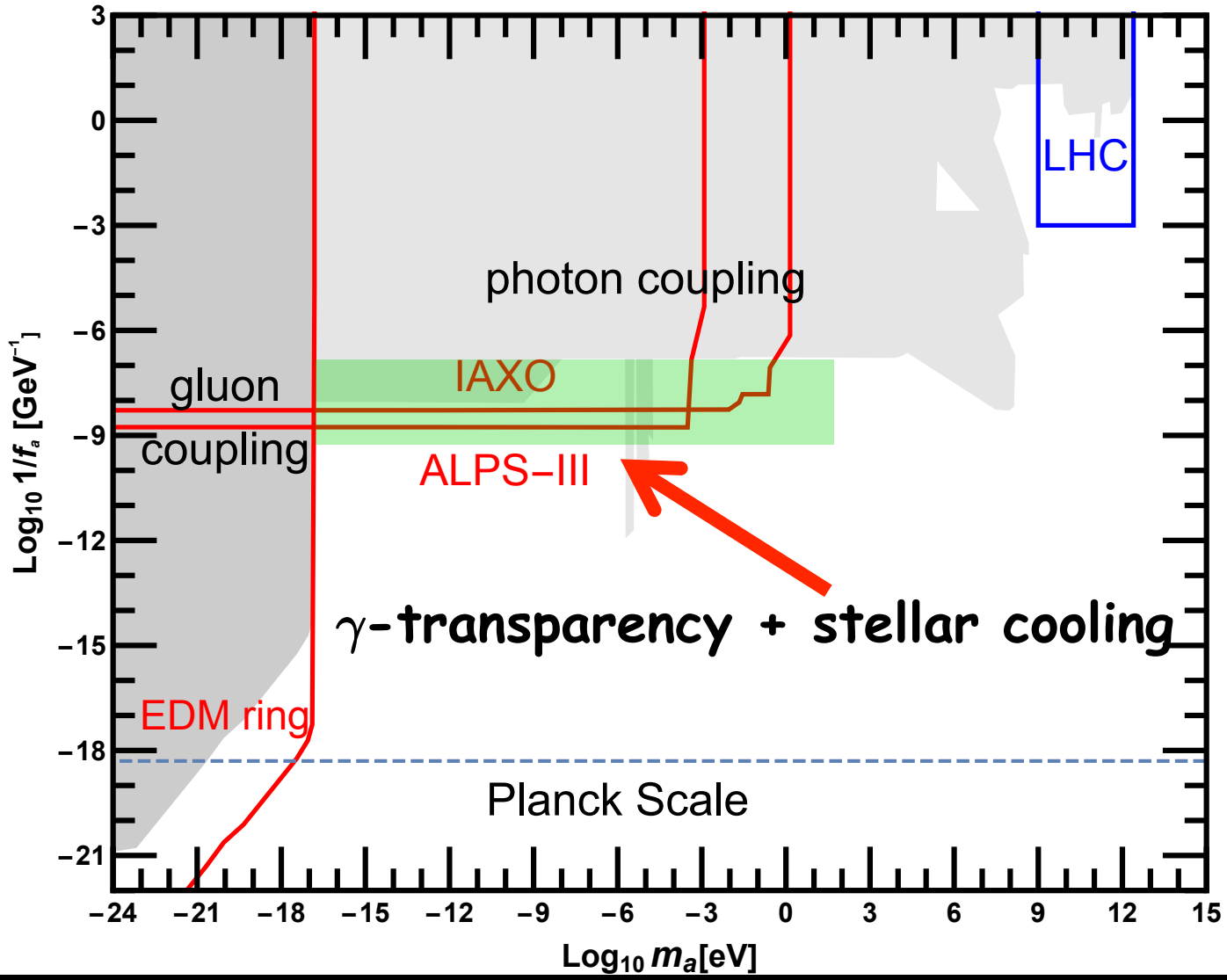

Search for Hidden Particls = SHiP

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SHiP
Search for Hidden Particles

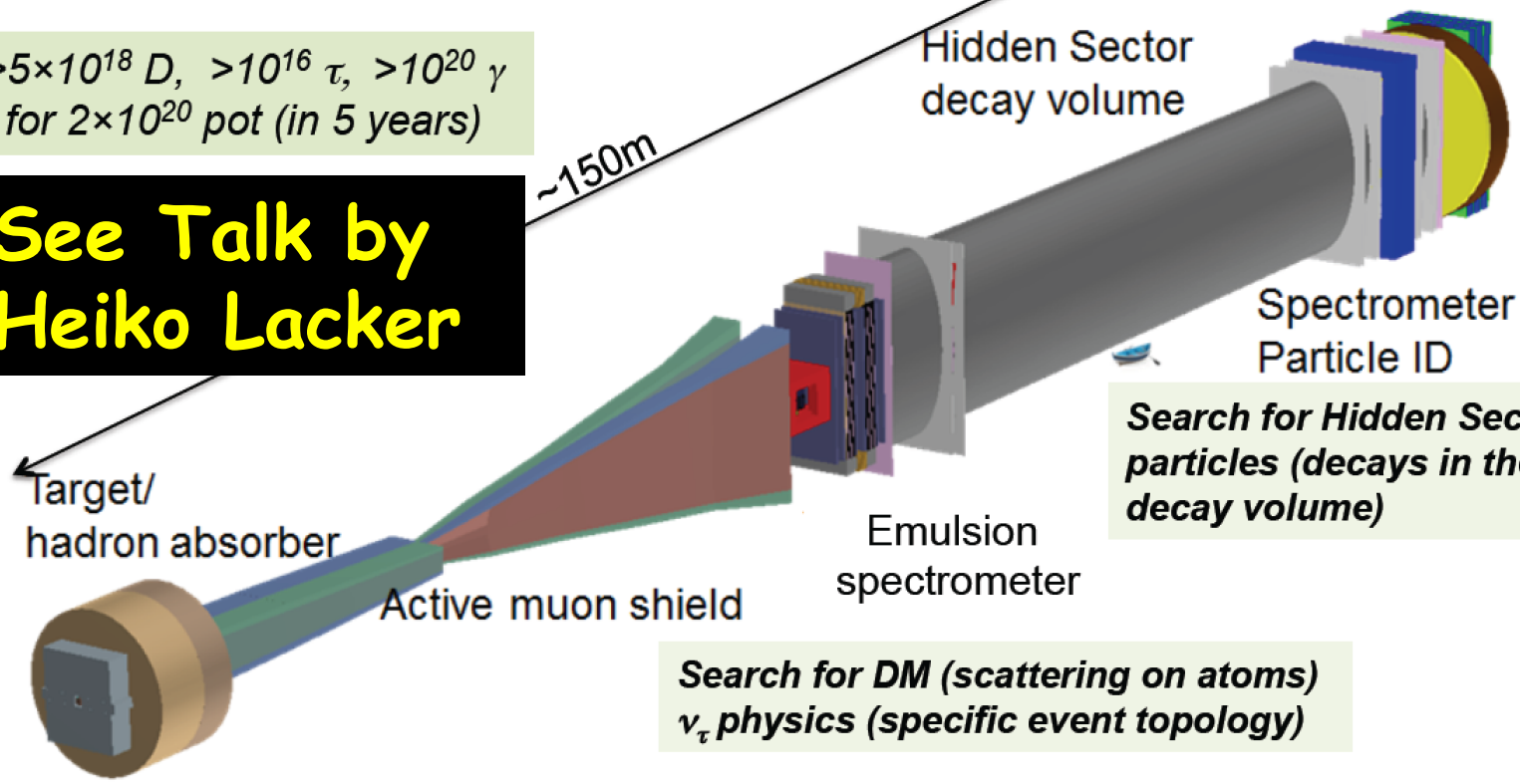
The SHiP experiment at SPS
(as implemented in Geant4 for TP)

SHiP Technical Proposal: 1504.04956

"Zero background" experiment
- *Muon shield*
- *Surrounding Veto detectors*

$>5\times10^{18}$ D, $>10^{16}$ τ, $>10^{20}$ γ
for 2×10^{20} pot (in 5 years)

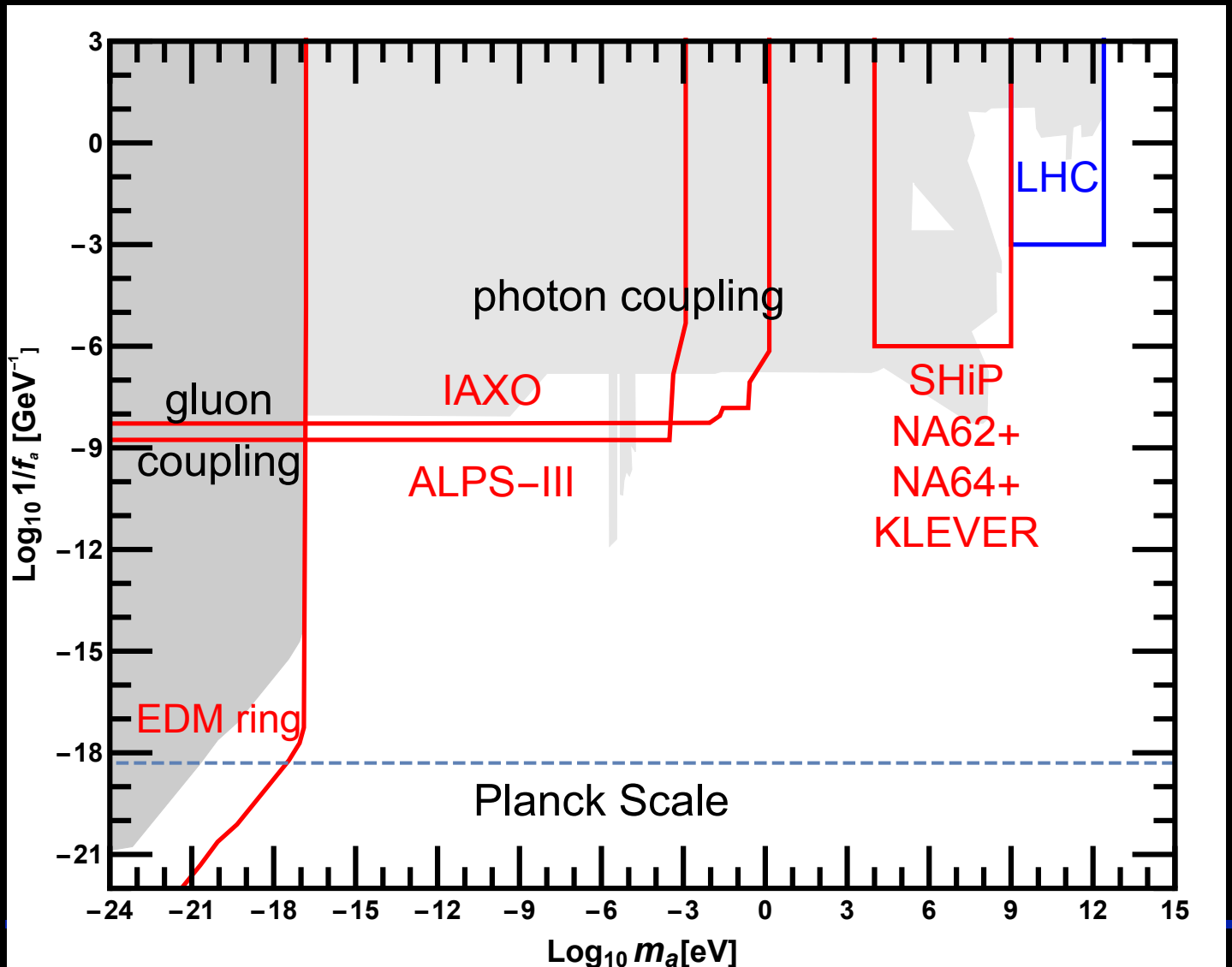
See Talk by Heiko Lacker



Search for Hidden Sector particles (decays in the decay volume)

Search for DM (scattering on atoms)
ν_τ physics (specific event topology)

SHiP + NA62+, NA64+ and KLEVER



"Seeing" the dark stuff NA 64+

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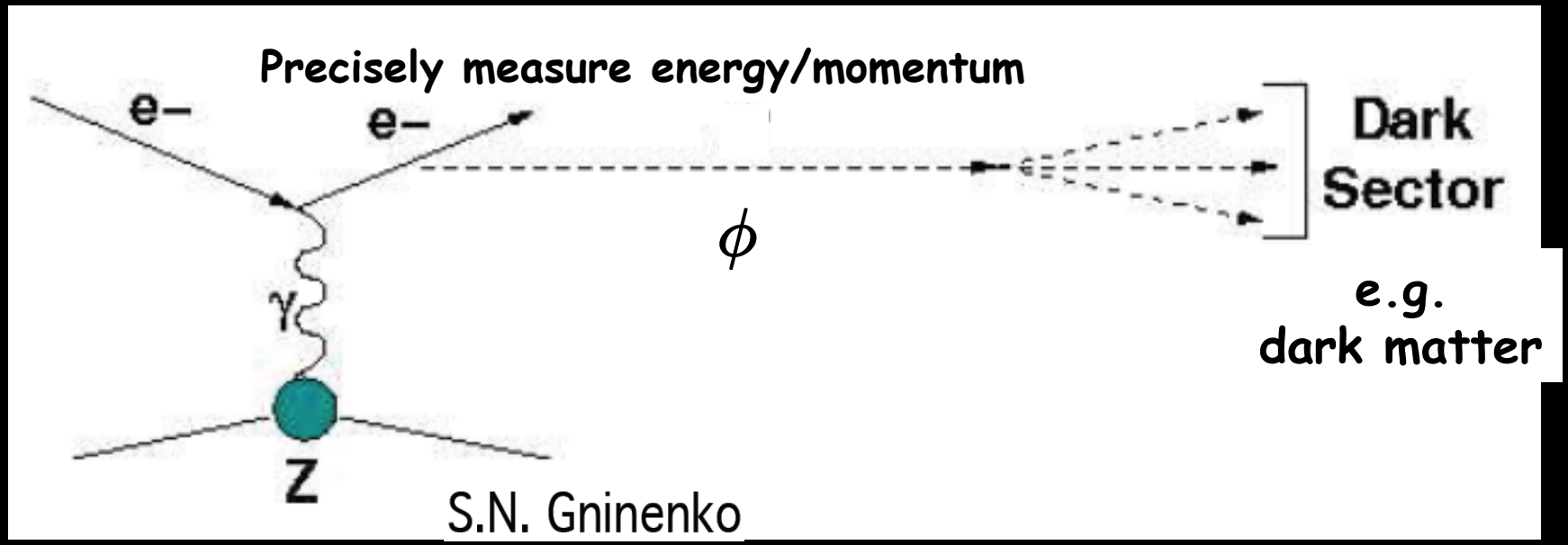
$$\mathcal{L} \supset \frac{\partial_\mu \phi}{f_a} \bar{\psi} \gamma^\mu \gamma^5 \psi$$



+ "dark matter" detector @ SHiP

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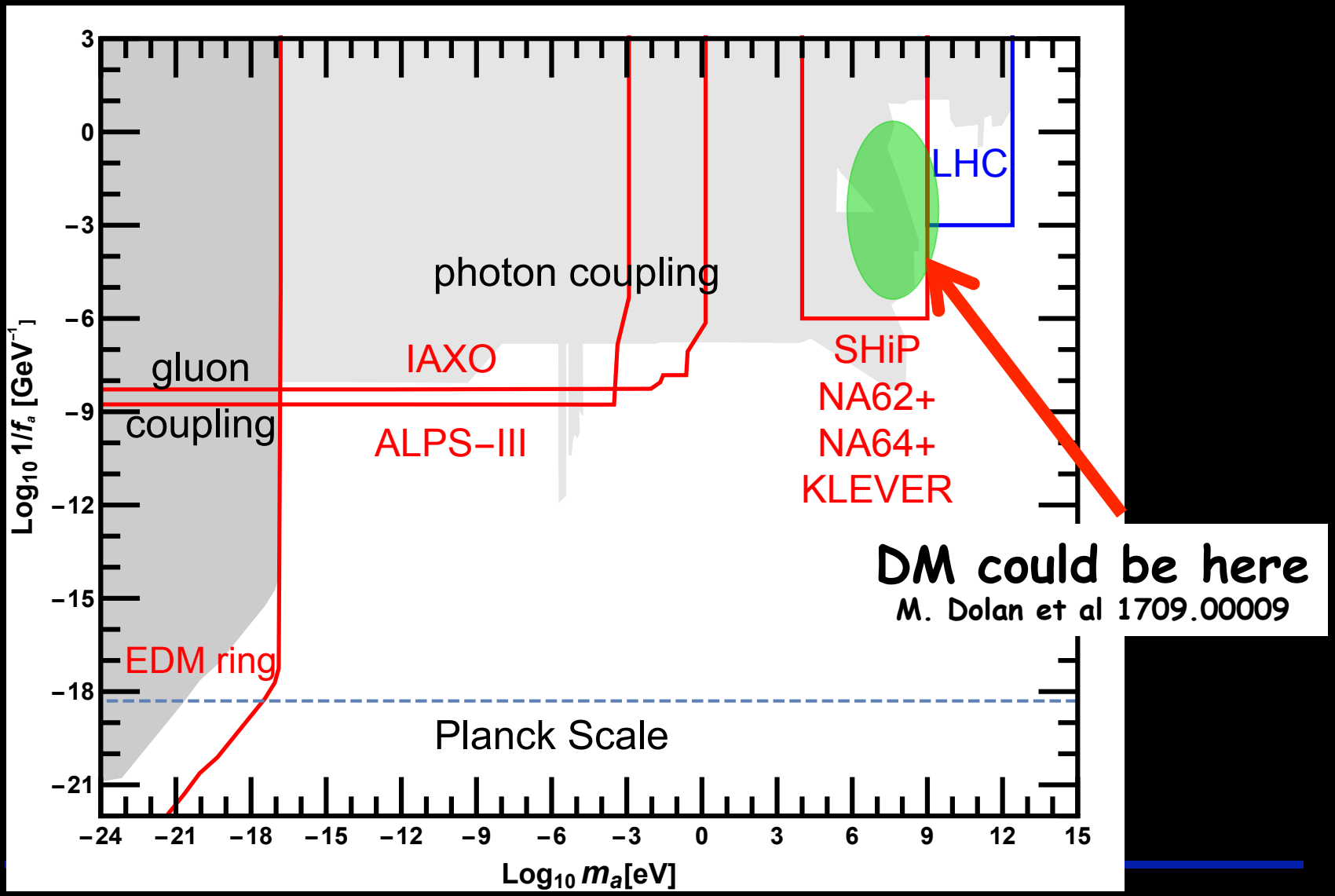
Messengers for dark matter?



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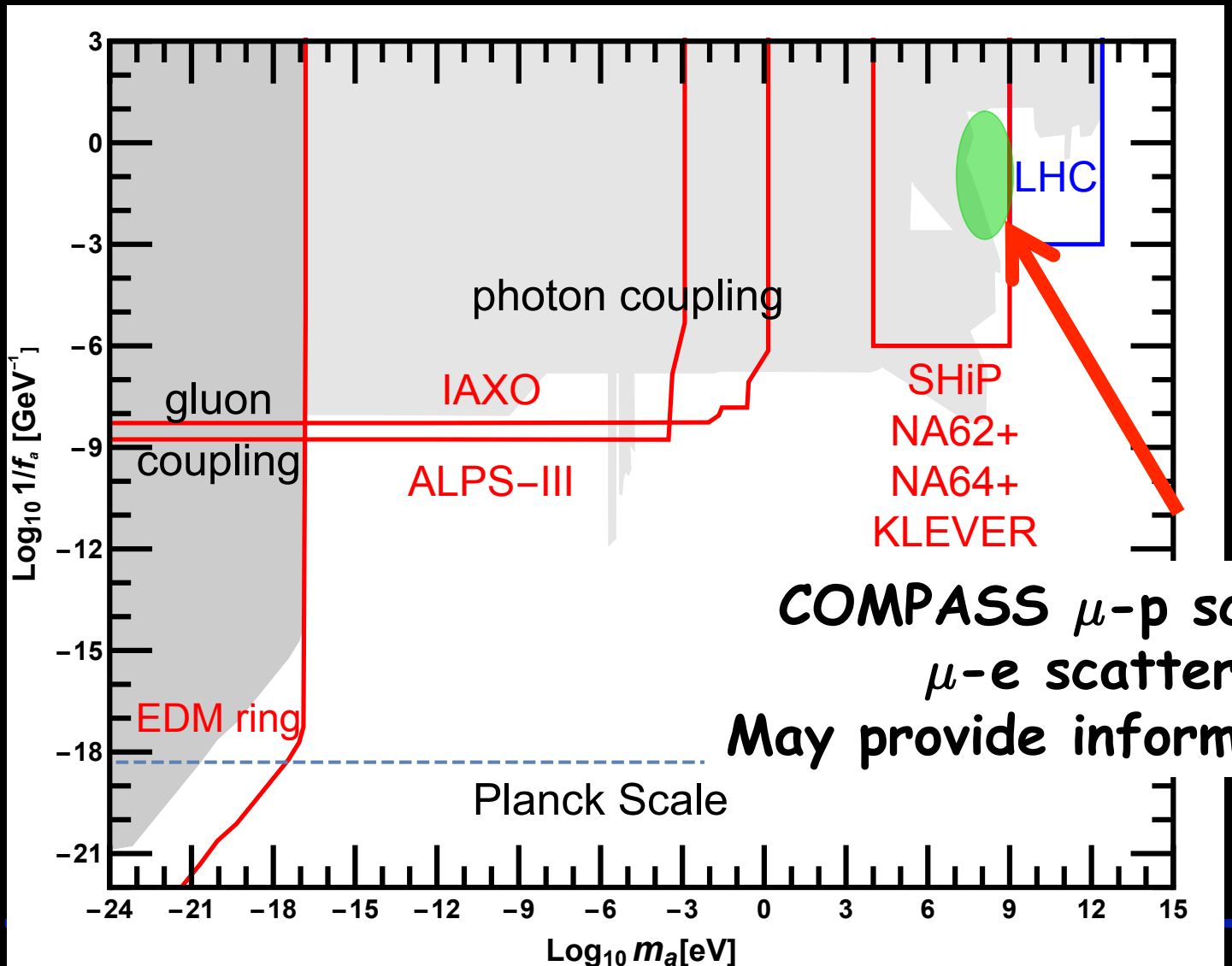
$(g-2)_\mu$ and proton radius anomaly



COMPASS μ-p scattering
μ-e scattering
May provide information here

Long Lived Particles @ LHC

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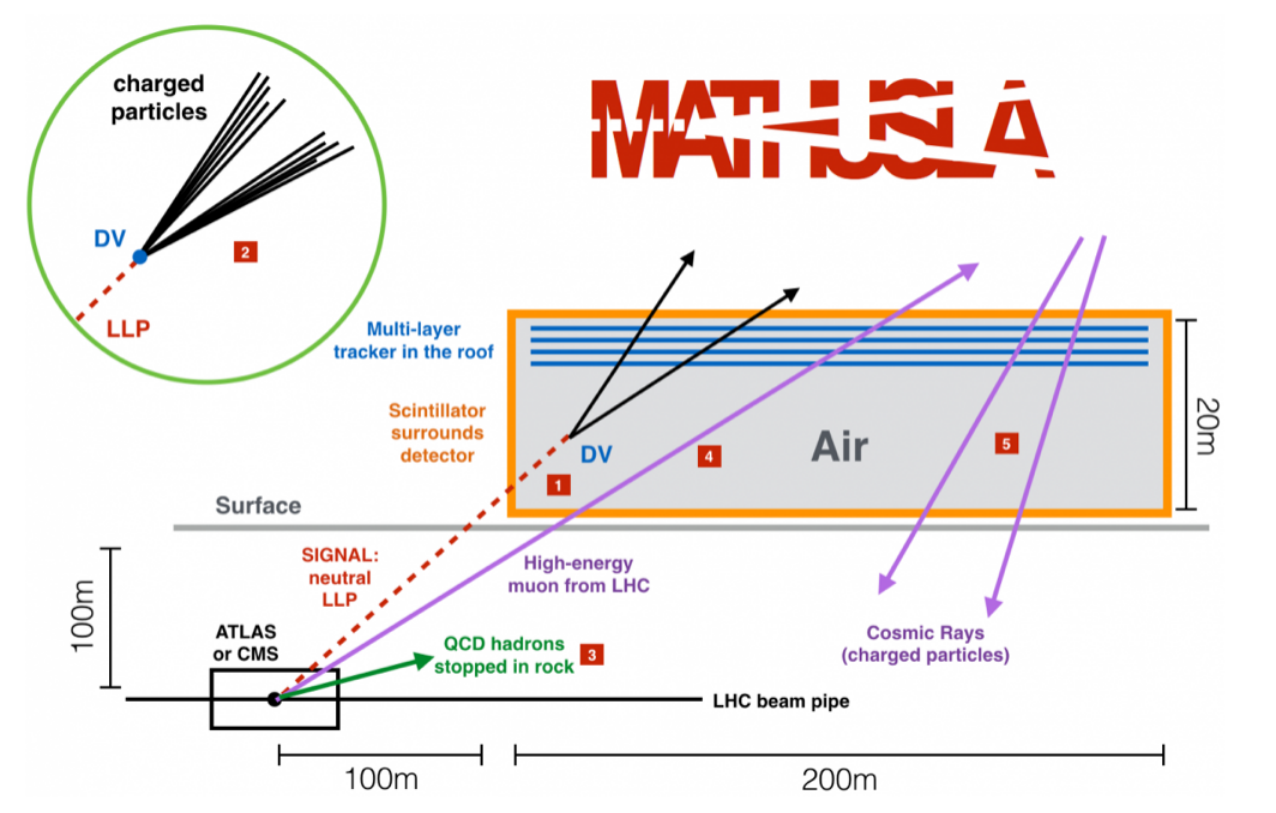
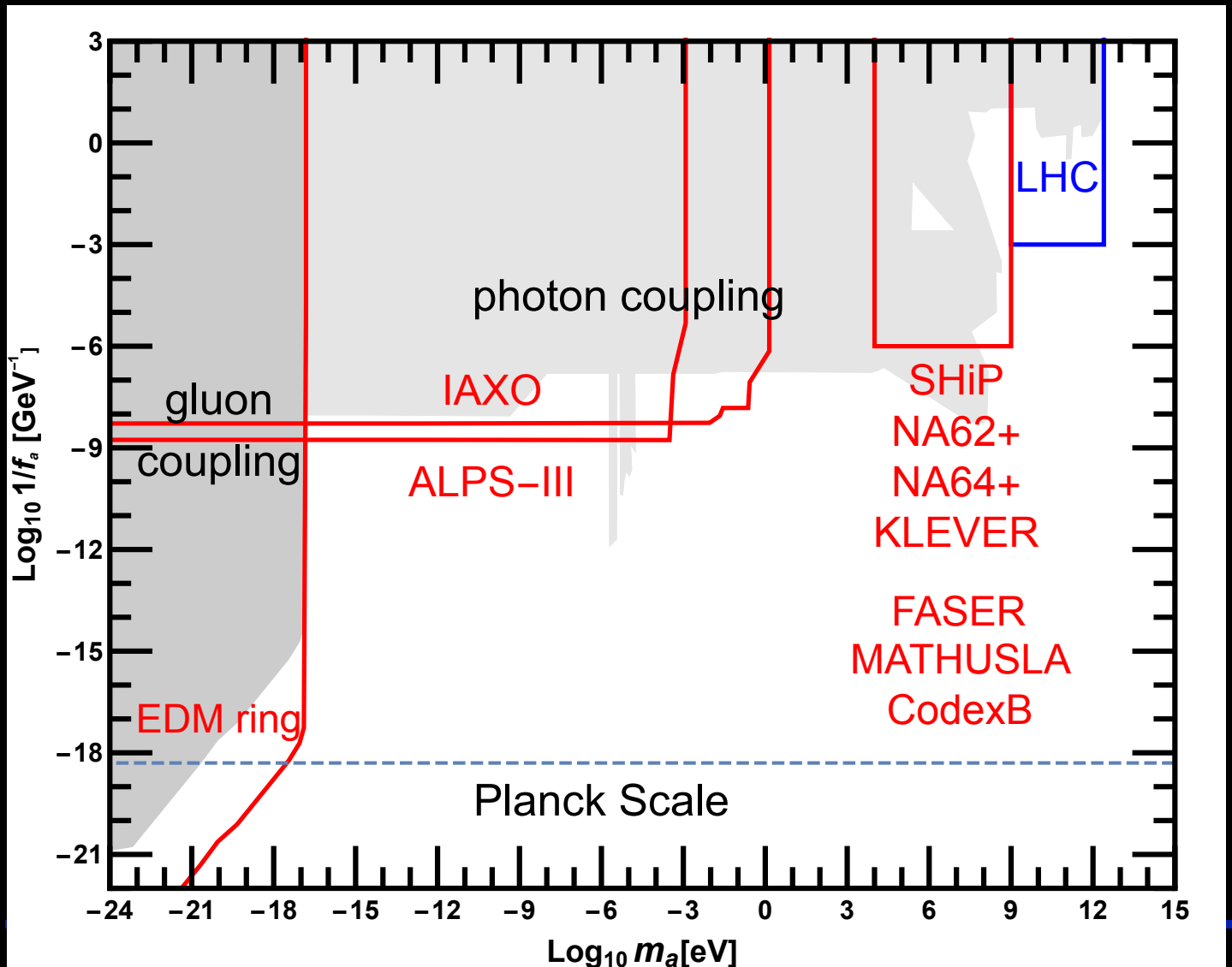
- Idea: Look for very long lived particles produced in LHC collissions
- Recent proposals:

  MATHUSLA, FASER, CodexB



Long Lived Particle searches also explore MeV-GeV region



Many more particles to test!!!

A few words on QCD

LHC fixed target studies

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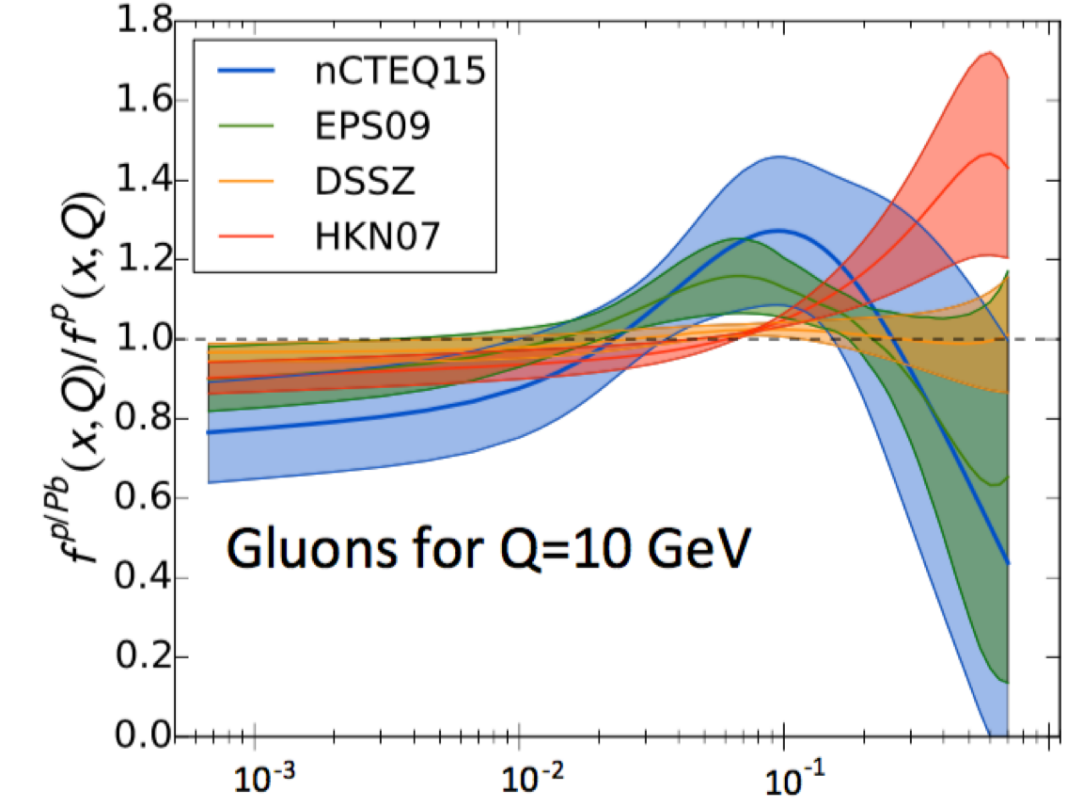
- AFTER but also @LHCb and ALICE

- Example measure parton densities in p, Pb etc.!



see Gunar Schnell @ PBC Workshop Nov. 2017

mu on e

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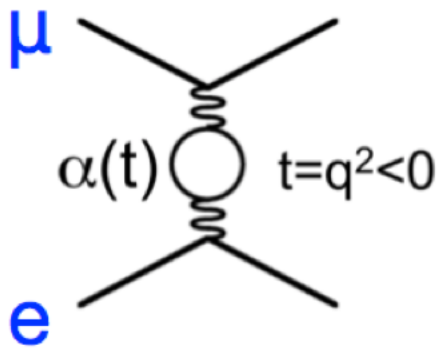
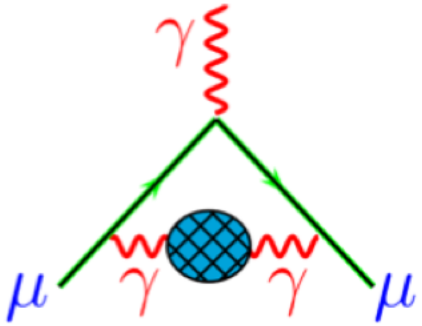
- Measure hadronic corrections for $(g-2)_\mu$
- New way: Measure scattering of μ on e



sum rule

→



see Gunar Schnell @ PBC Workshop Nov. 2017

COMPASS

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- Measure μ-p scattering at Q~0
- This allows to determine the "muonic" proton radius
- Investigate proton radius puzzle

NA60 + NA61

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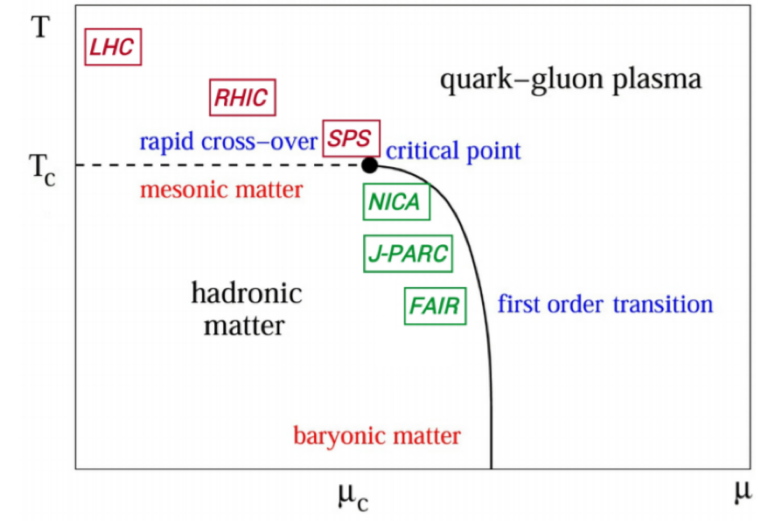
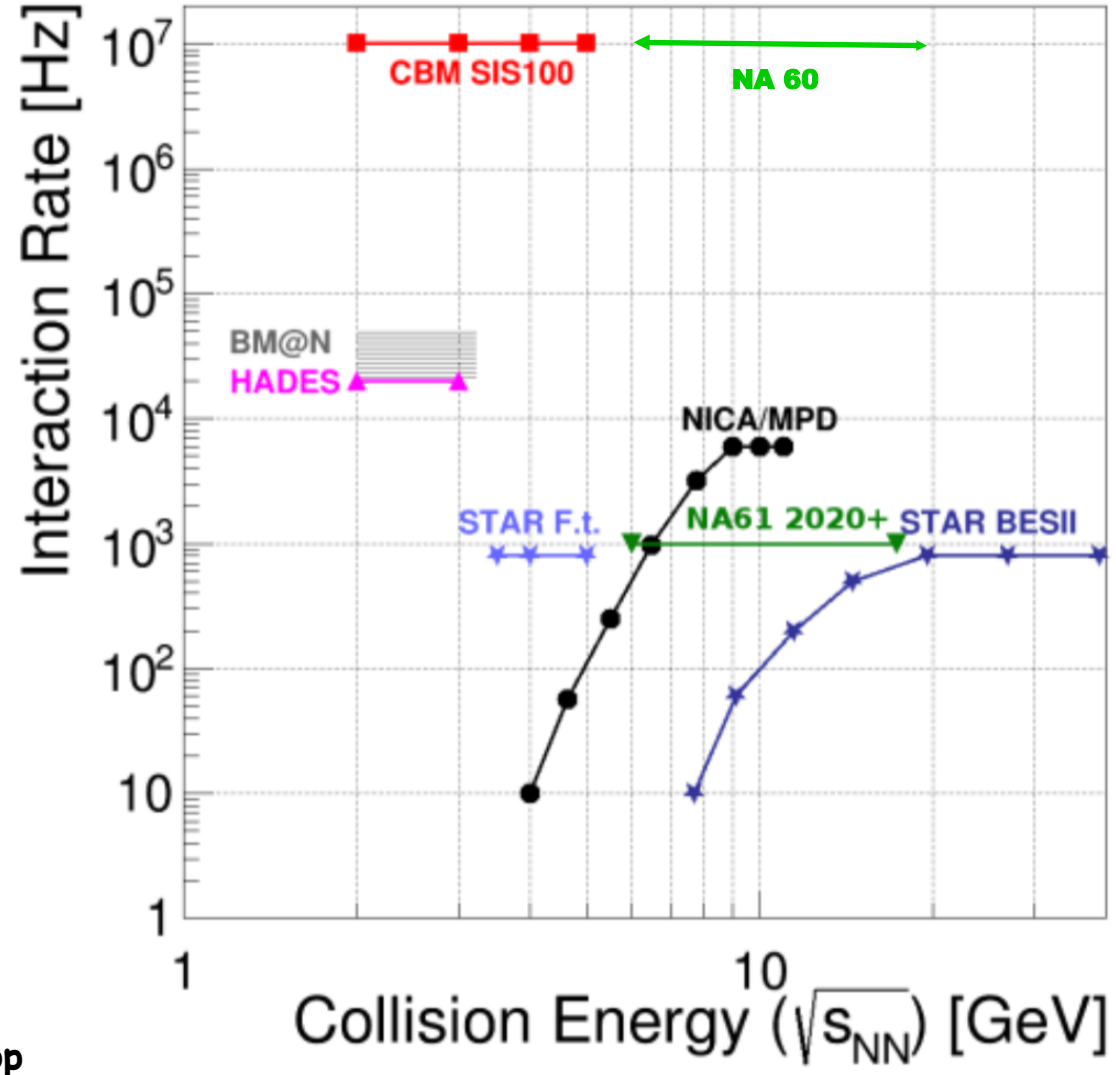
- Explore QCD phase diagram





Adapted from
Szymon Pulawski @ internal PBC Workshop

Many more cool things out there!

Cool things…

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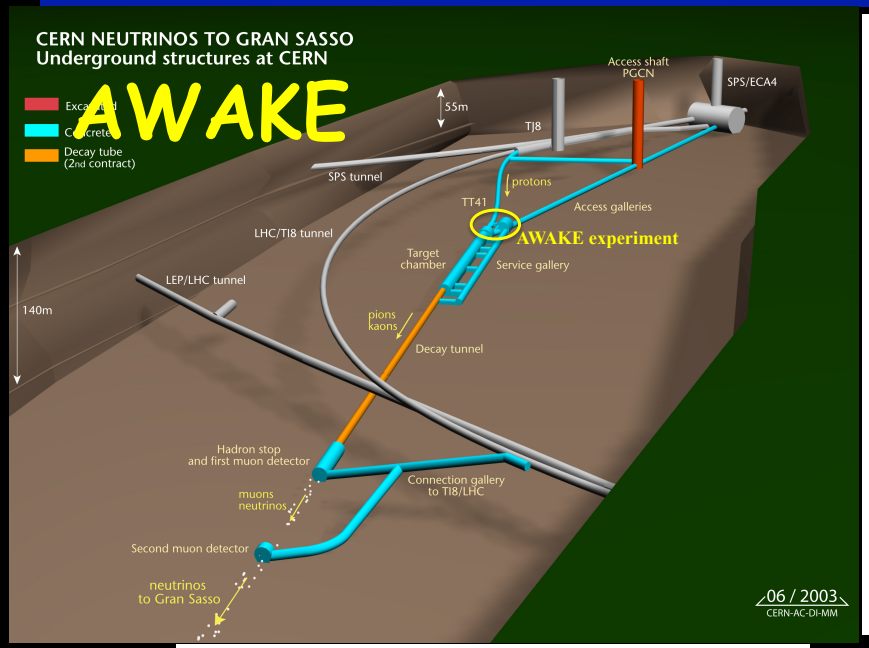
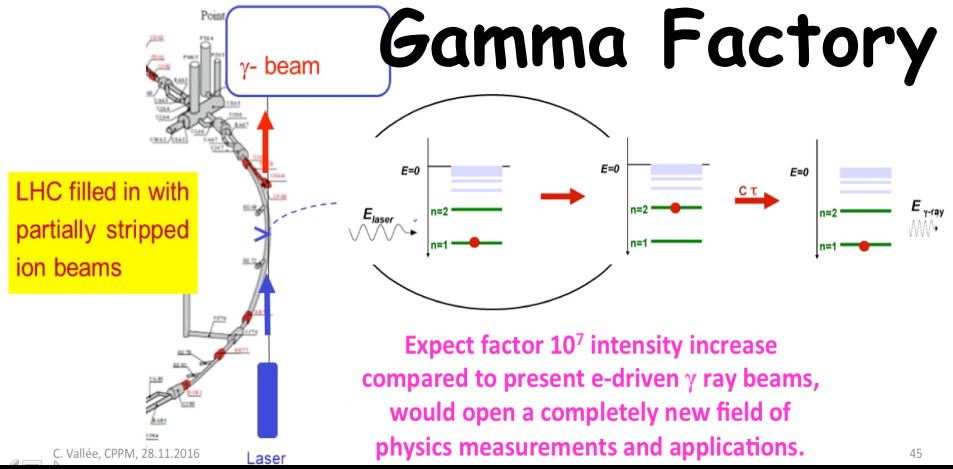


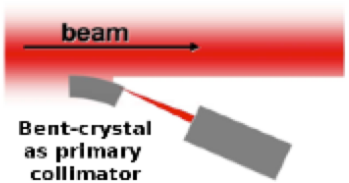
New idea: Gamma Factory

Use LHC beam to convert laser photons into 0.1 - 400 MeV γ rays



Expect factor 10^7 intensity increase compared to present e-driven γ ray beams, would open a completely new field of physics measurements and applications.

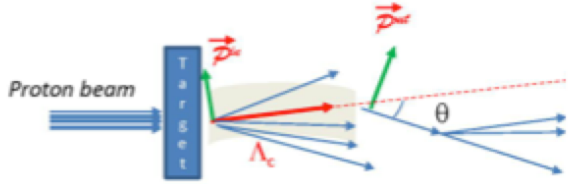
Crystal extraction



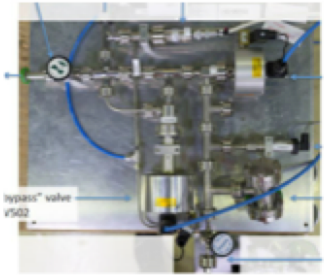
UA9

Upstream of LHCb and/or ALICE

$$\frac{dN_i}{N_{0i}\,d\cos\theta_i} = \frac{1}{2}(1+\alpha P_i \cos_i\theta_i)$$



Internal gas target (AFTER)



e.g. SMOG

Upstream of LHCb and/or ALICE

p-p: High precision TMD measurements (polarized target) and charm at high x

p-A: Nuclear PDFs

Conclusions

Conclusions

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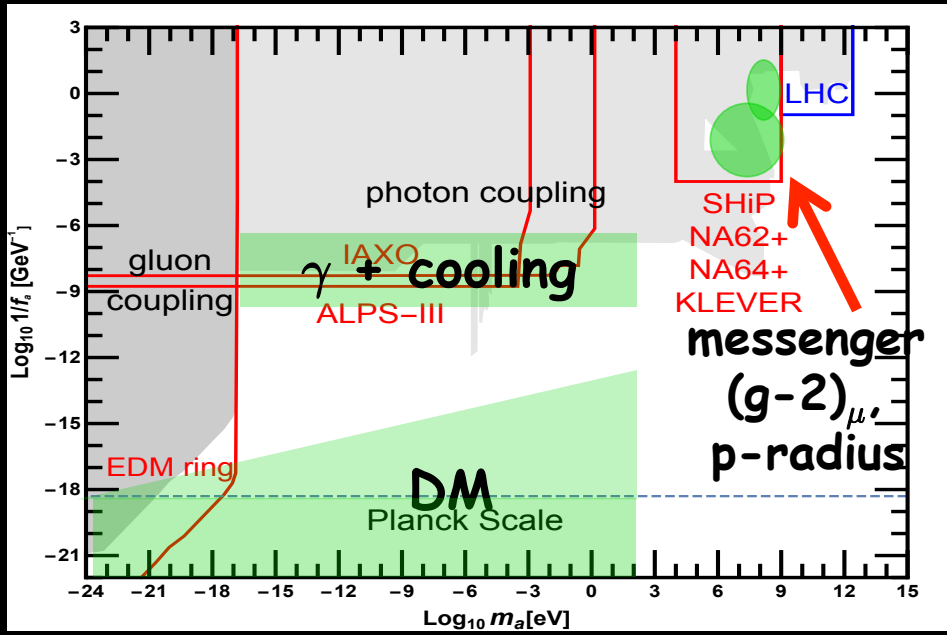
- Exploration for New Physics benefits from both high energy as well as high sensitivity

➔Different experiments complement each other

➔Interesting Hints



Many (more) cool things to explore!

More things going on @ PBC

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- Here mostly direct BSM searches but more things going on…

- QCD experiments
- Technology development

- This can also have crucial impact on BSM searches, e.g.
  - mu-e scattering ➔ essential for $(g-2)_\mu$

  - Fixed target measurements with LHC beam
    ➔ PDF's for collider searches