Enhanced Long-Lived Dark Photon signals @ LHC Lifetime Frontiers

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arXiv: 2111.XXXXX

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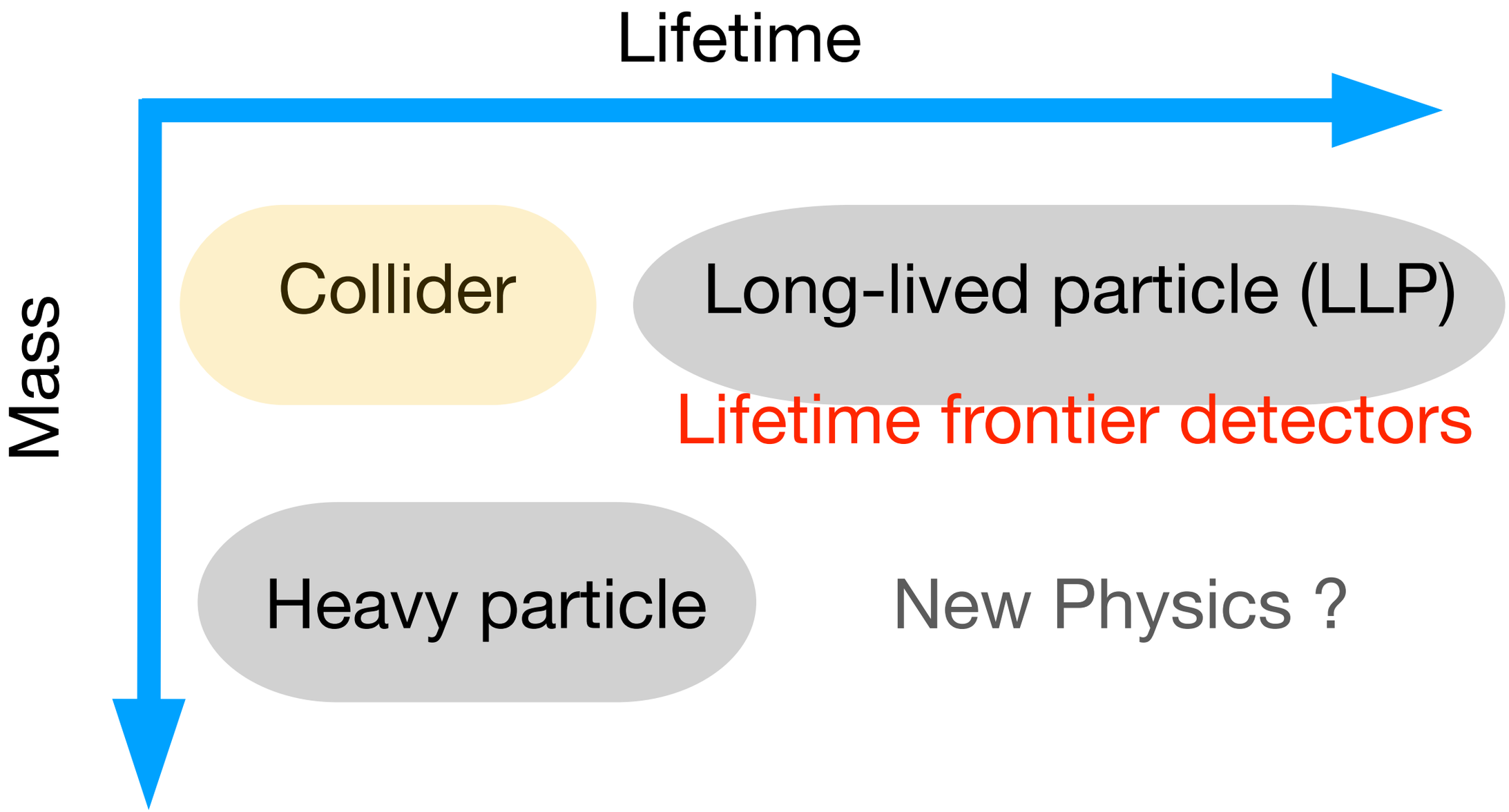
Outline

- Motivation
- Our long-lived dark photon model (LLDP)
- Experimental constraints
- Lifetime frontier detectors
- Conclusion

Motivation

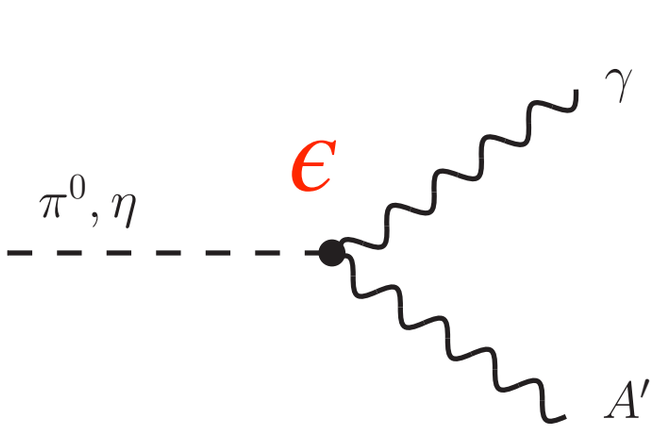

Lifetime
Mass
Collider
Long-lived particle (LLP)
Lifetime frontier detectors
Heavy particle
New Physics ?

Minimal LLDP

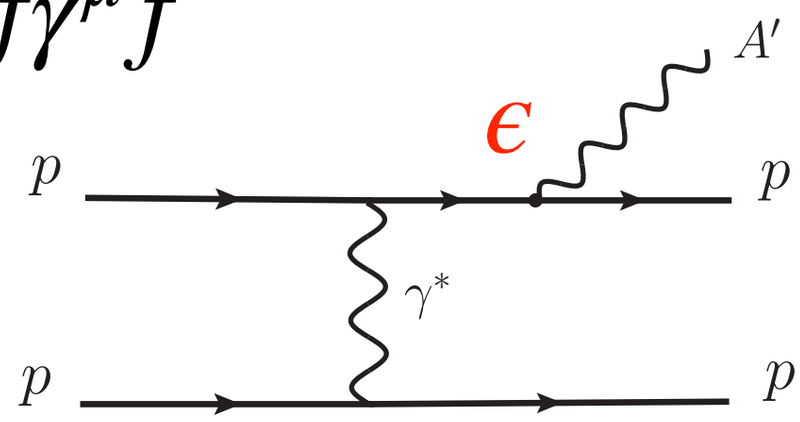
Typical LLP, the Long-lived dark photon

in the forward detector $\sim O(100m)$

$$\epsilon e Q_f A'_\mu \bar{f} \gamma^\mu f$$



Meson Decay



Proton Bremsstrahlung

Disadvantages

the far forward detector $\sim O(100m)$

Production is suppressed by ϵ

$$d \sim 100\mathrm{m}(\frac{10^{-6}}{\epsilon})^2(\frac{0.3\mathrm{GeV}}{\mathrm{m}_{A'}})^2(\frac{\mathrm{E}_{A'}}{100\mathrm{GeV}})$$

Only work for sub-GeV A', limited by proton, light meson mass

$$m_{A'} \lesssim m_{\mathrm{p}}, m_m$$

Our LLDP Model

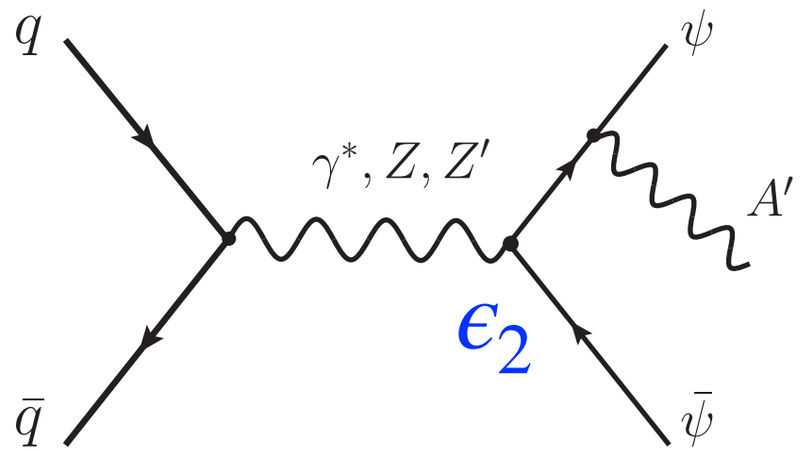
SM extended by two U(1) gauge bosons X and C

$$-4\mathscr{L}_F = X_{\mu\nu}^2 + 2\left(\partial_\mu\sigma_1 + m_1\epsilon_1 B_\mu + m_1 X_\mu\right)^2$$

$$-4\mathscr{L}_W = C_{\mu\nu}^2 + 2\left(\partial_\mu\sigma_1 + m_2\epsilon_2 B_\mu + m_2 C_\mu\right)^2$$

Du, Liu, Tran, 1912.00422

Gauge eigenstates $\left(C, X, B, A^3\right)$ → Mass eigenstates (Z', A', Z, A)

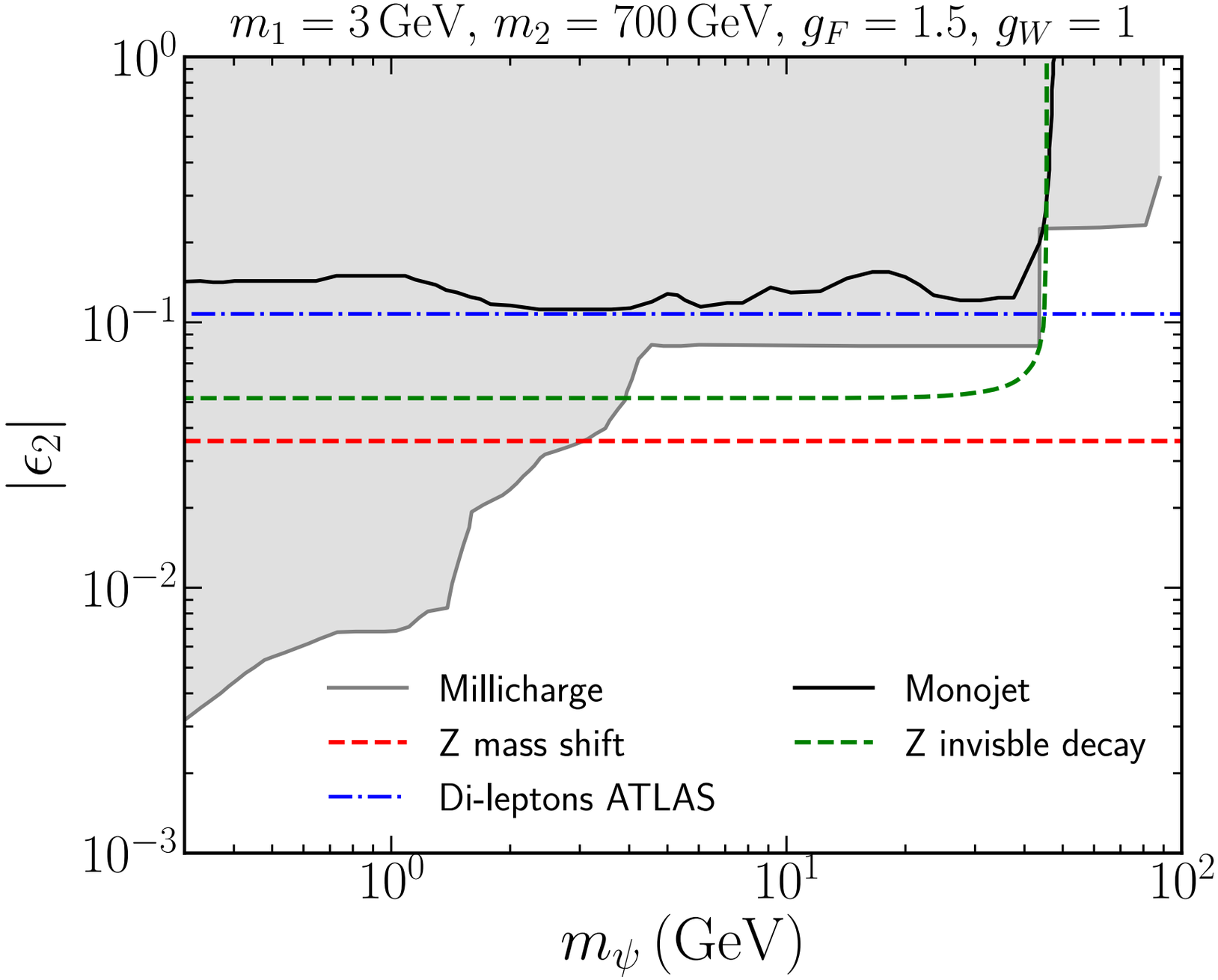


Hidden Radiation

$$\left(g_F X_\mu + g_W C_\mu\right)\bar{\psi}\gamma^\mu\psi$$

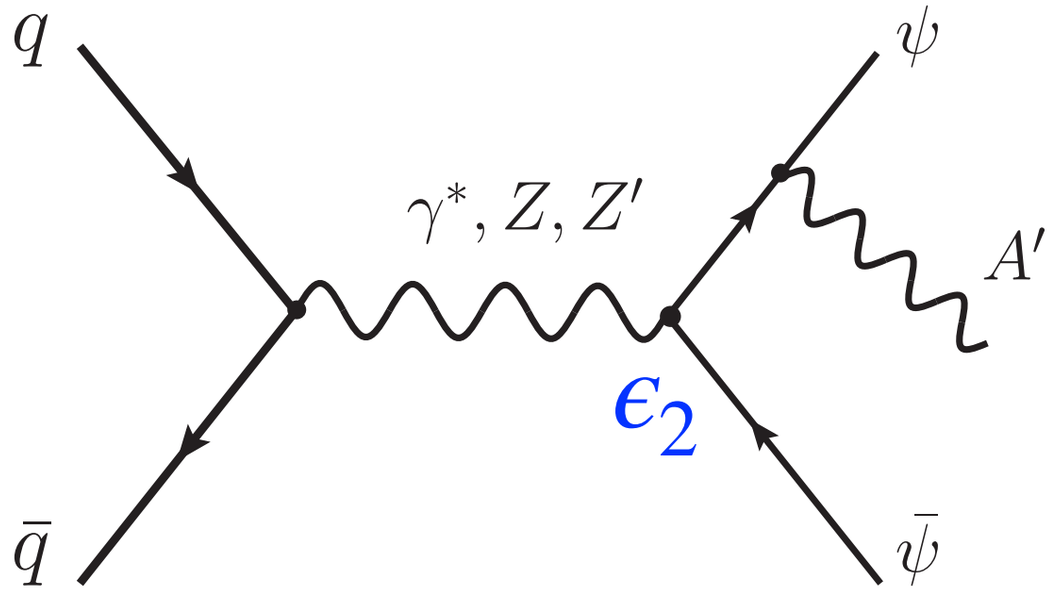
If $\epsilon_2 \gg \epsilon_1 \sim 1.1\epsilon \sim 10^{-6}$, A' is LLDP and its signal can be enhanced

Experimental constraints



Difficulties gone

Hidden Radiation



suppressed by ϵ ?

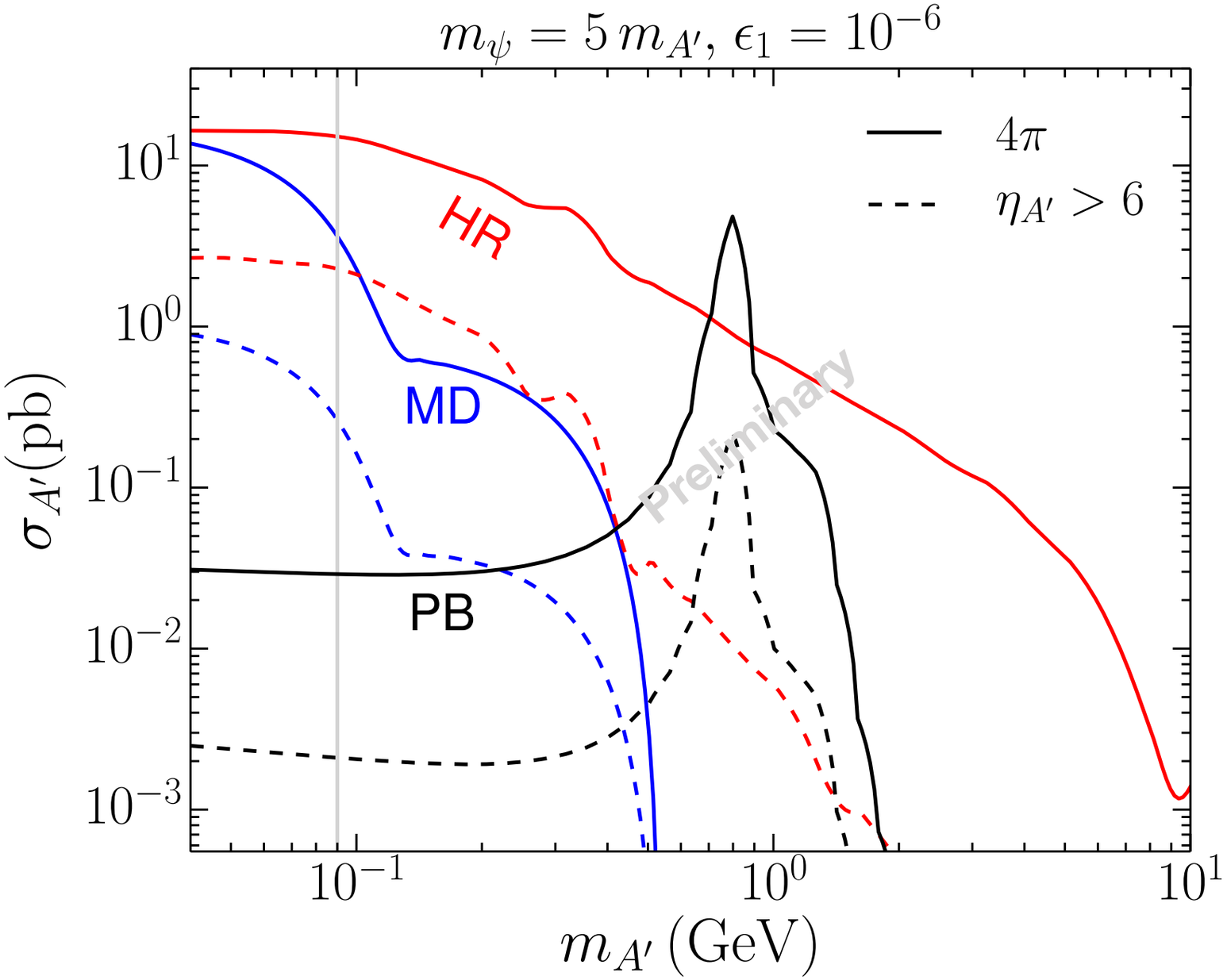
$\epsilon_2 \sim 10^{-2} \gg \epsilon_1 \sim 10^{-6}$,

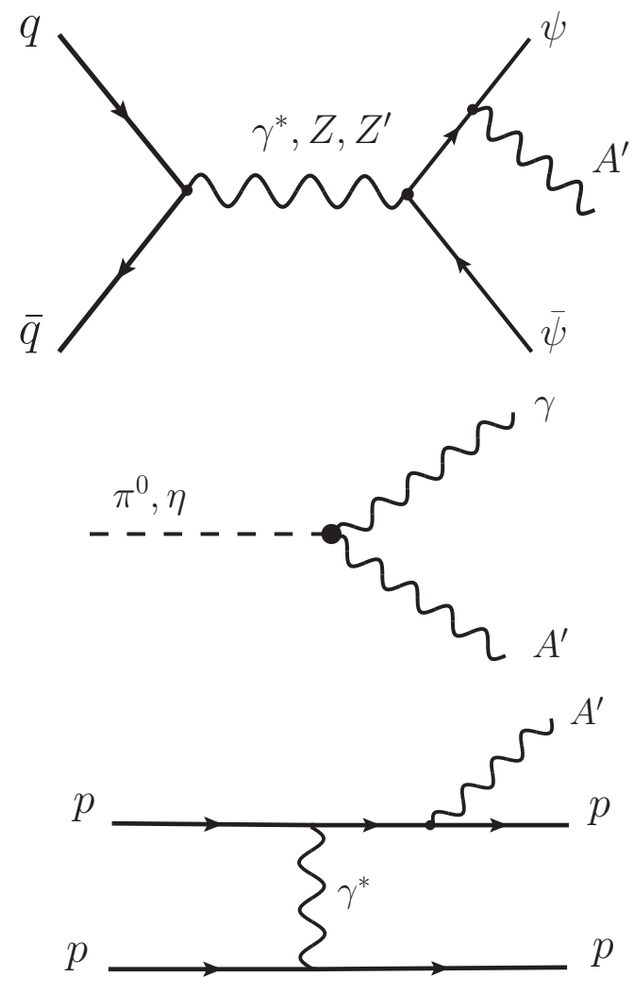
A' signal can be enhanced

$m_{A'} \lesssim m_{\rm p}, m_m$?

$m_{A'}$ can be larger than GeV

Difficulties gone

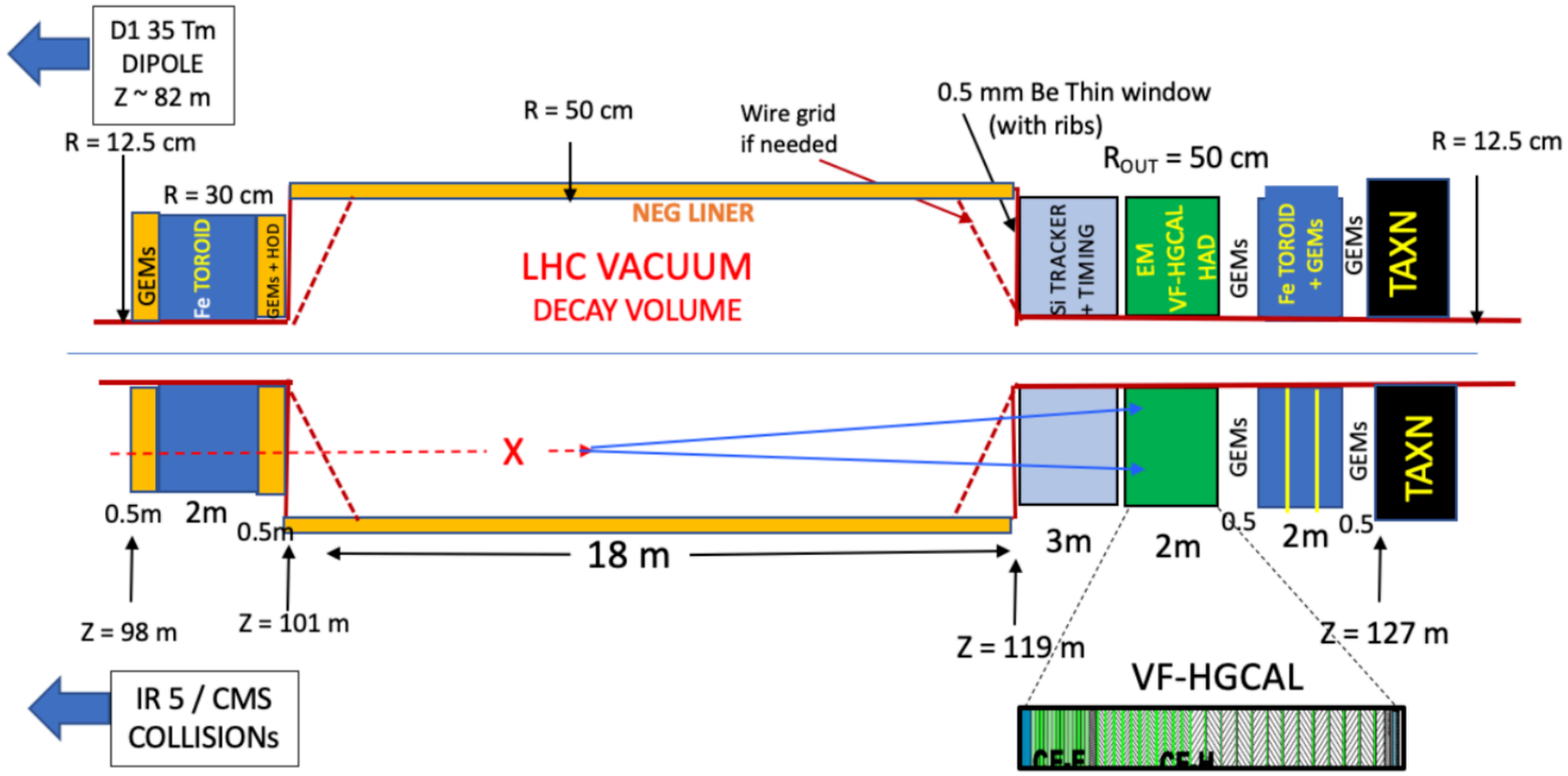




Lifetime frontier detectors

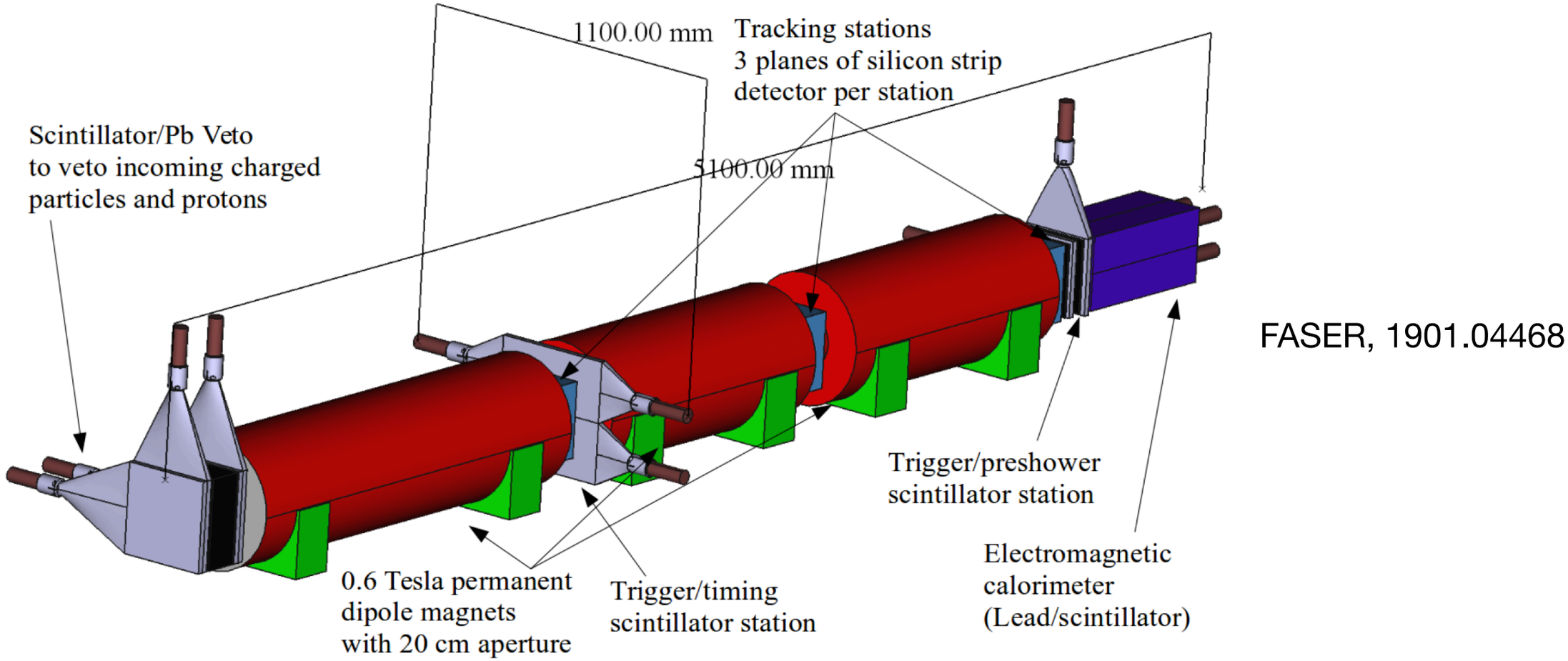
- Far forward detectors
- Far transverse detectors
- Timing detectors

Forward-Aperture CMS ExTension (FACET)

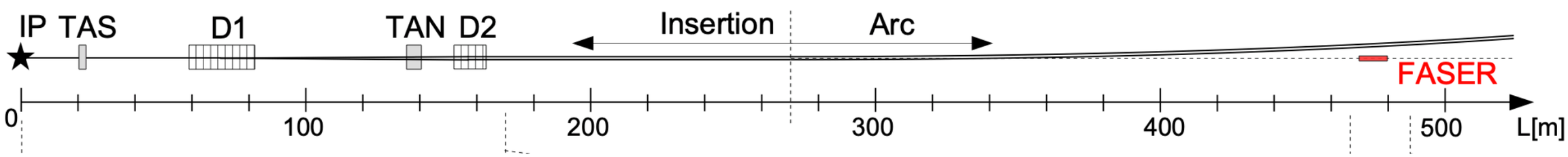


G. Landsberg,"Searches for new physics with FACET: Forward-Apertrue CMS ExTension". https://indico.cern.ch/event/994582/

ForwArd Search ExpeRiment (FASER)



FASER, 1901.04468



FACET better

Detector	Distance from IP d (m)	Decay volume V (m^3)
FACET	100	12.3
FASER	480	0.047
FASER2	480	15.7

FASER, 1901.04468

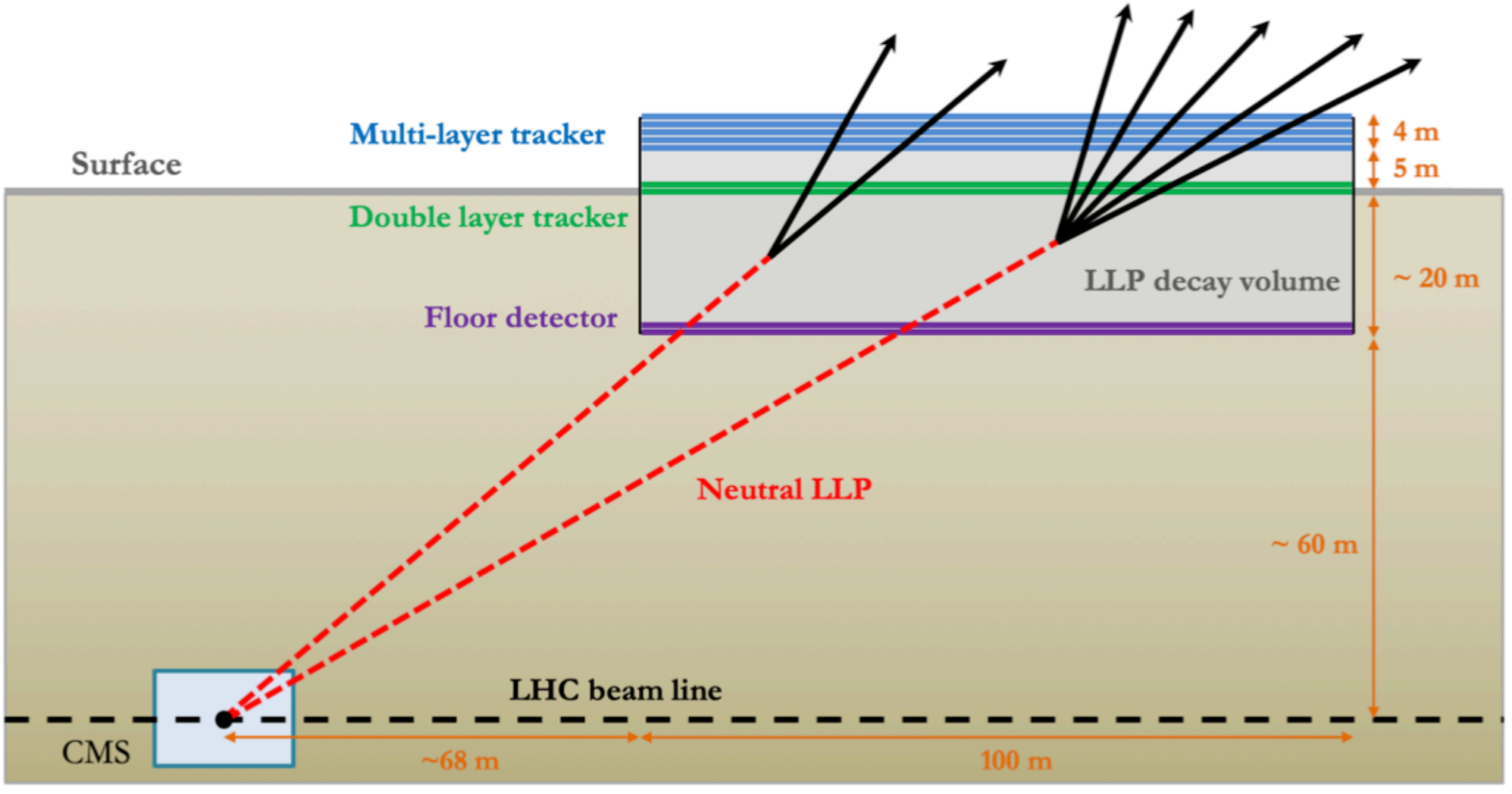
FACET larger decay volume

$$N_{A'} \propto \frac{V}{d^2 l_{A'}} e^{-\frac{d}{l_{A'}}}$$

if BG is under control

FACET smaller distance

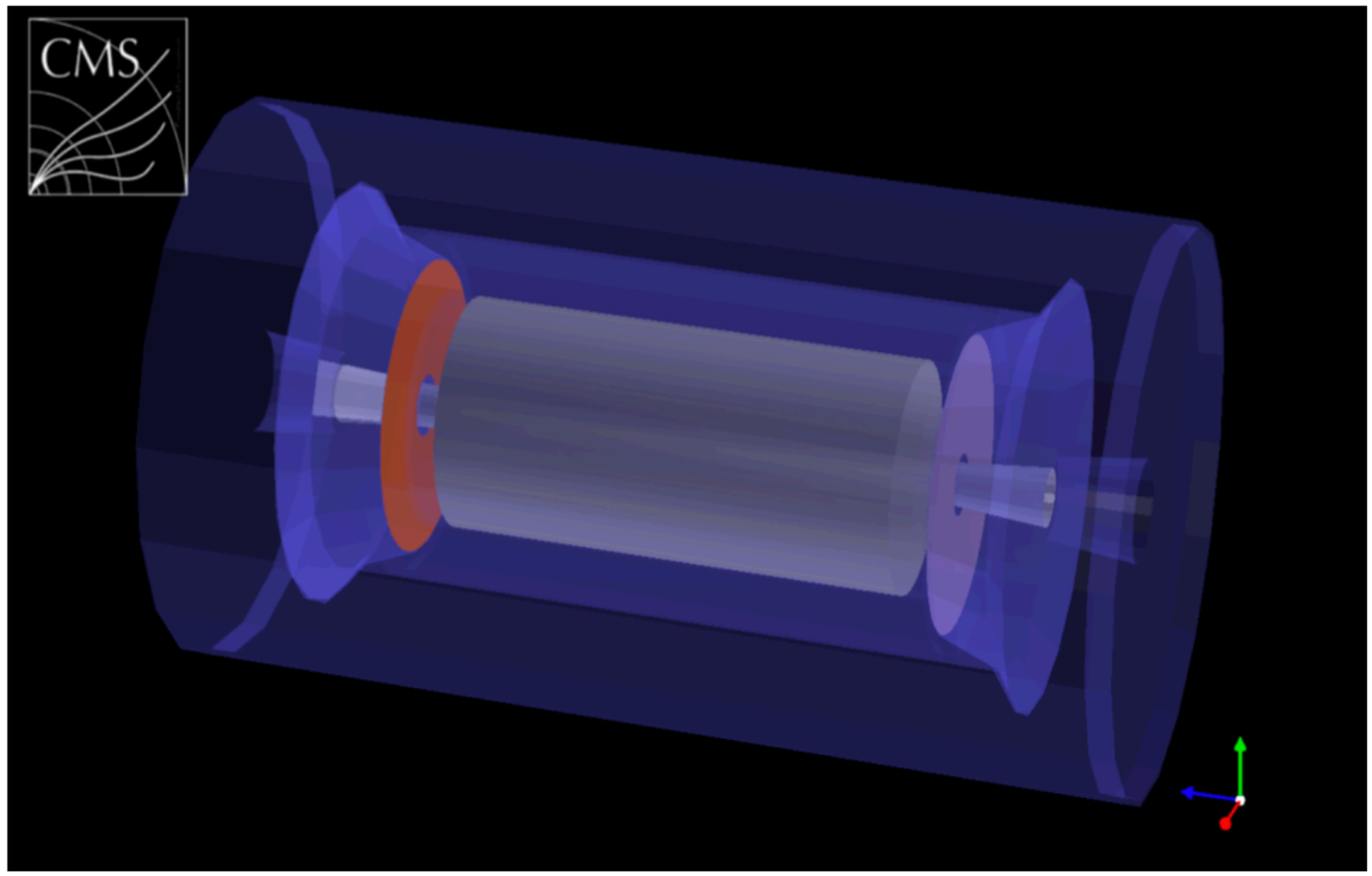
Massive Timing Hodoscope for Ultra-Stable neutral pArticles (MATHUSLA)



MATHUSLA, 2009.01693

Timing Detector

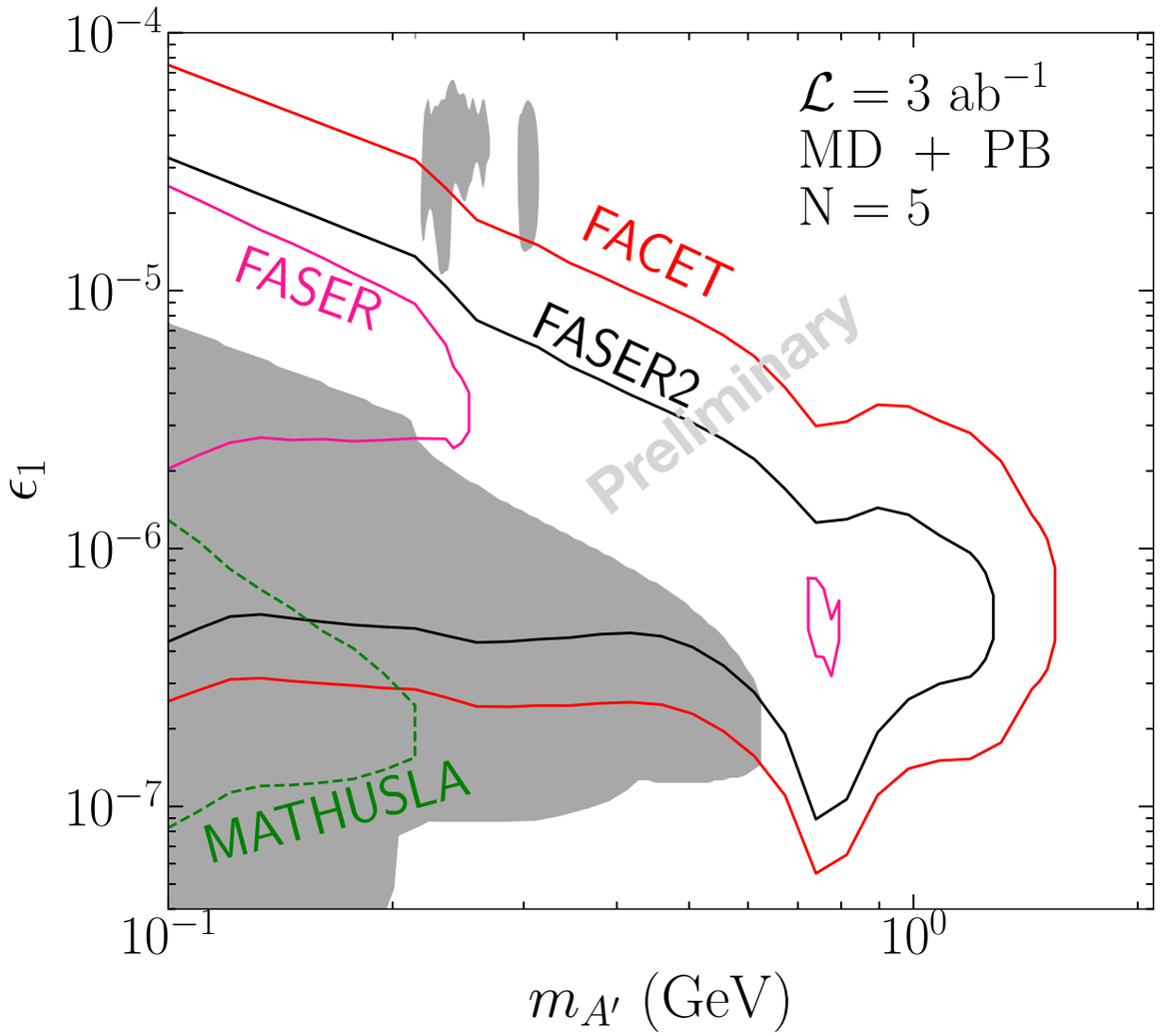
CMS timing detector (phase 2)

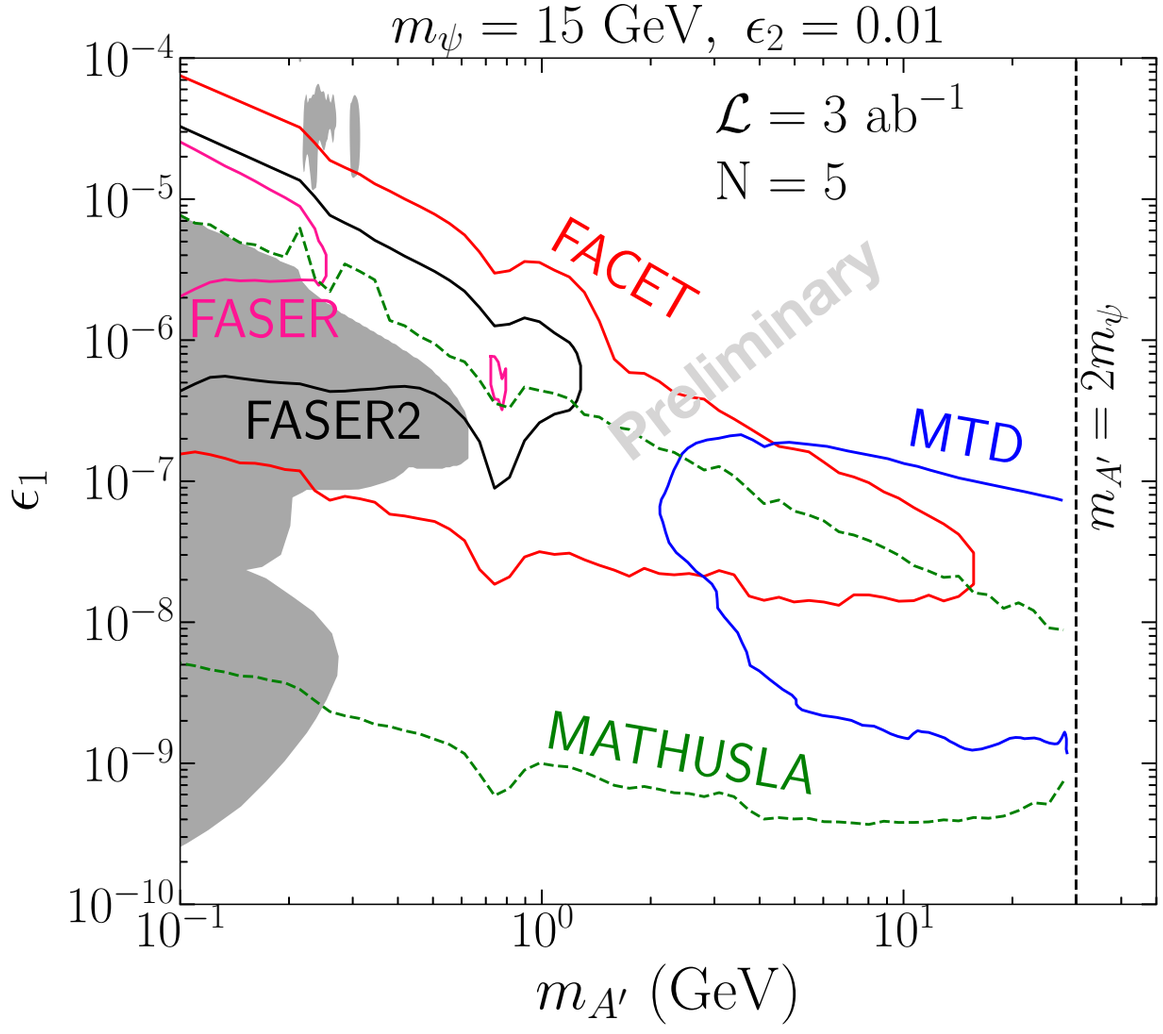


- between the tracker and calorimeter
- $\delta t = 30\text{ps}$
- $1.17\text{m} \sim \text{O(ns)}$ away from the beam axis

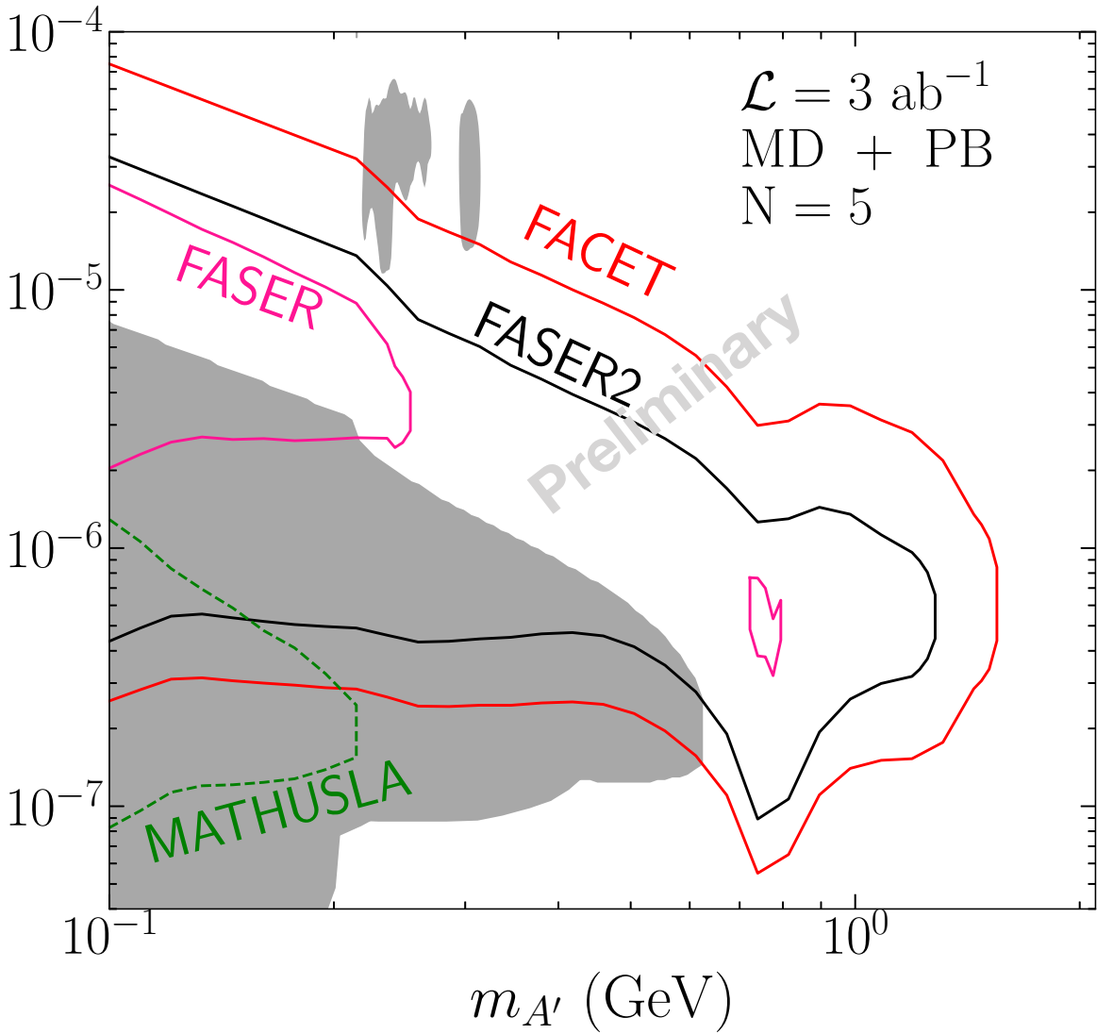
hsps://cds.cern.ch/record/2296612/files/LHCC-P-009.pdf

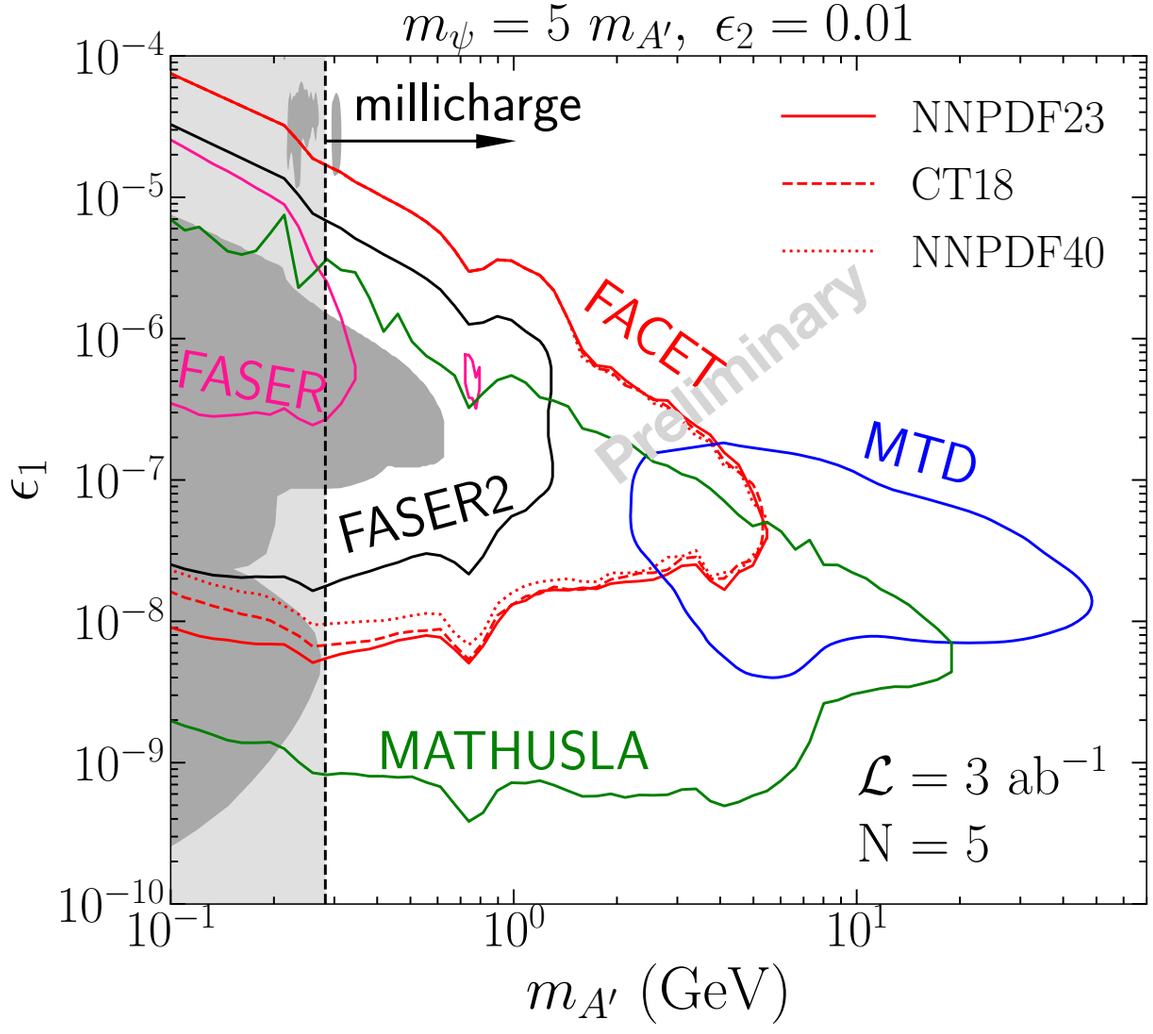
Lifetime frontier detectors



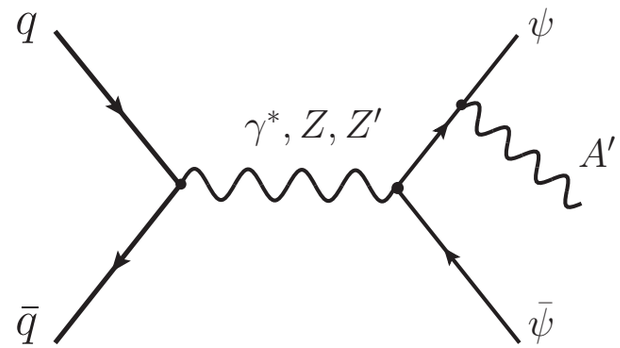


Lifetime frontier detectors





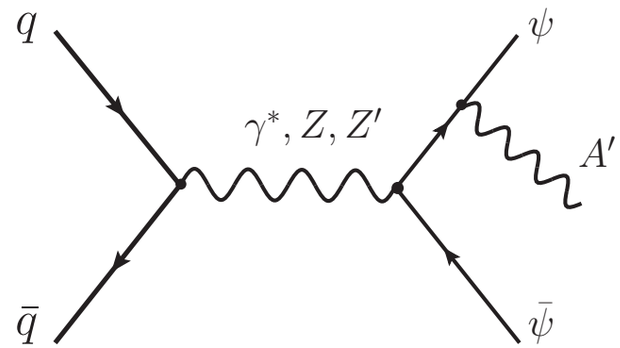
Conclusion



- LLPs escape the current collider search
- Minimal LLDP signals are suppressed by ϵ, and insensitive to GeV or heavier DP
- our model has additional HR process

  $\propto \epsilon_2 \sim 10^{-2} \gg \epsilon_1 \sim 10^{-6}$, probing GeV or heavier DP
- Sensitivity to the LLDPs in the FACET, FASER, MATHUSLA, CMS-MTD
- FACET is better than FASER due to the larger decay volume and closer distance
- CMS-MTD is a good complementary

Conclusion



- LLPs escape the current collider search
- Minimal LLDP signals are suppressed by ϵ, and insensitive to the GeV or heavier DP
- our model has an unique additional HR process

  $\propto \epsilon_2 \sim 10^{-2} \gg \epsilon_1 \sim 10^{-6}$, probing GeV or heavier DP

- We calculated sensitivities of the LLDPs in the FACET, FASER, MATHUSLA, CMS-MTD
- FACET is better than FASER due to the larger decay volume and closer distance
- CMS-MTD is a good complementary

Thank you!

Backups

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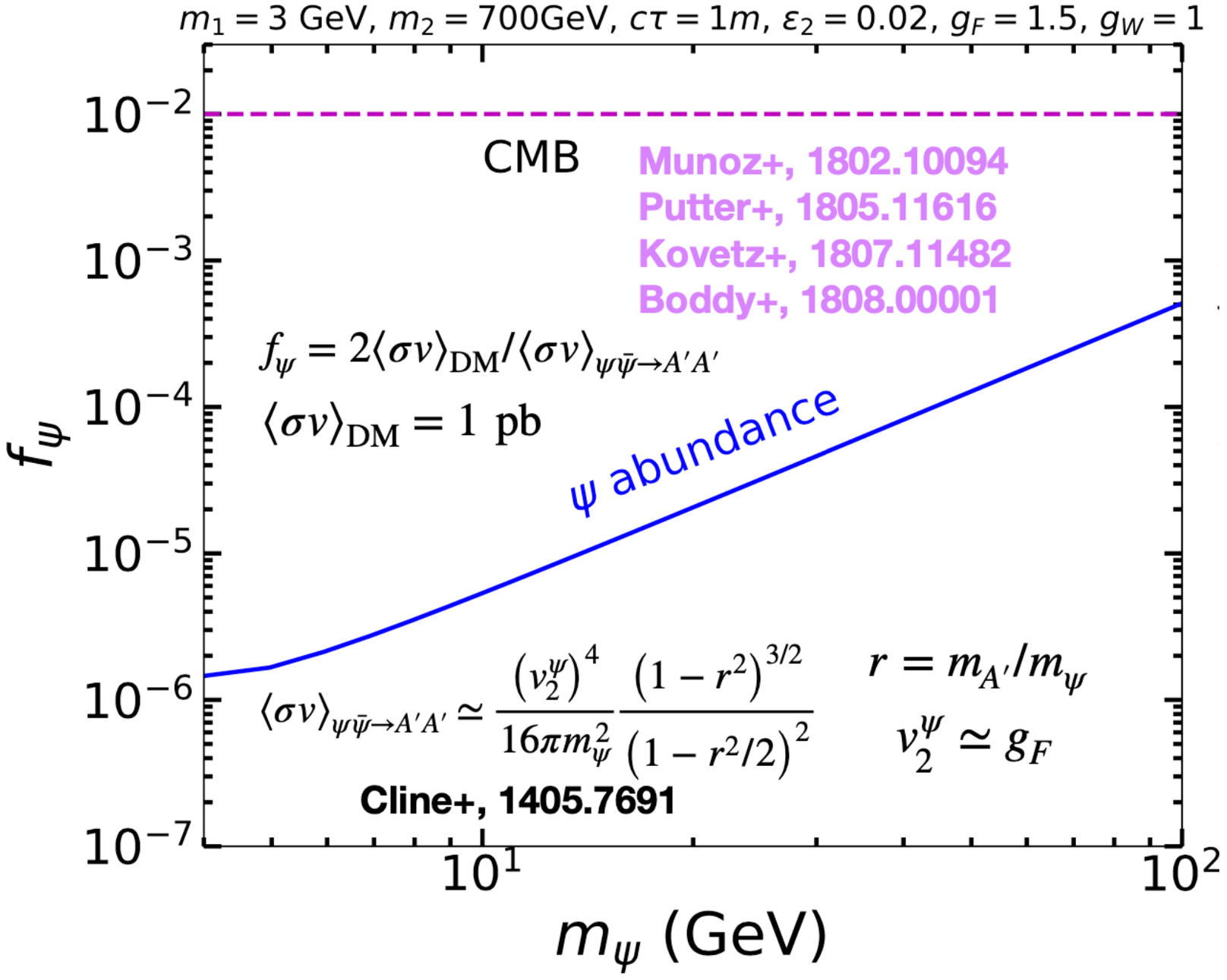
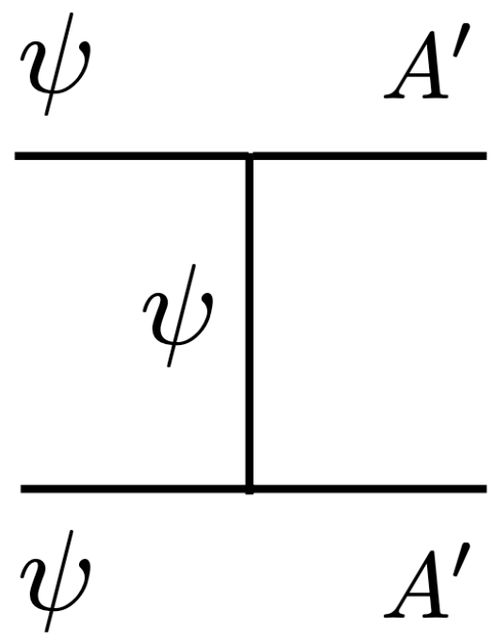
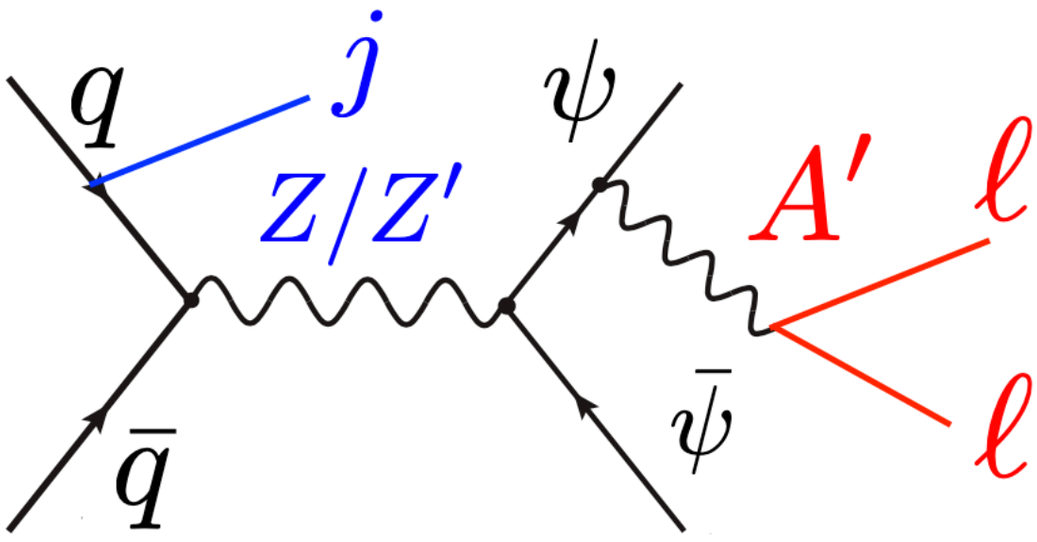
CMB constraint

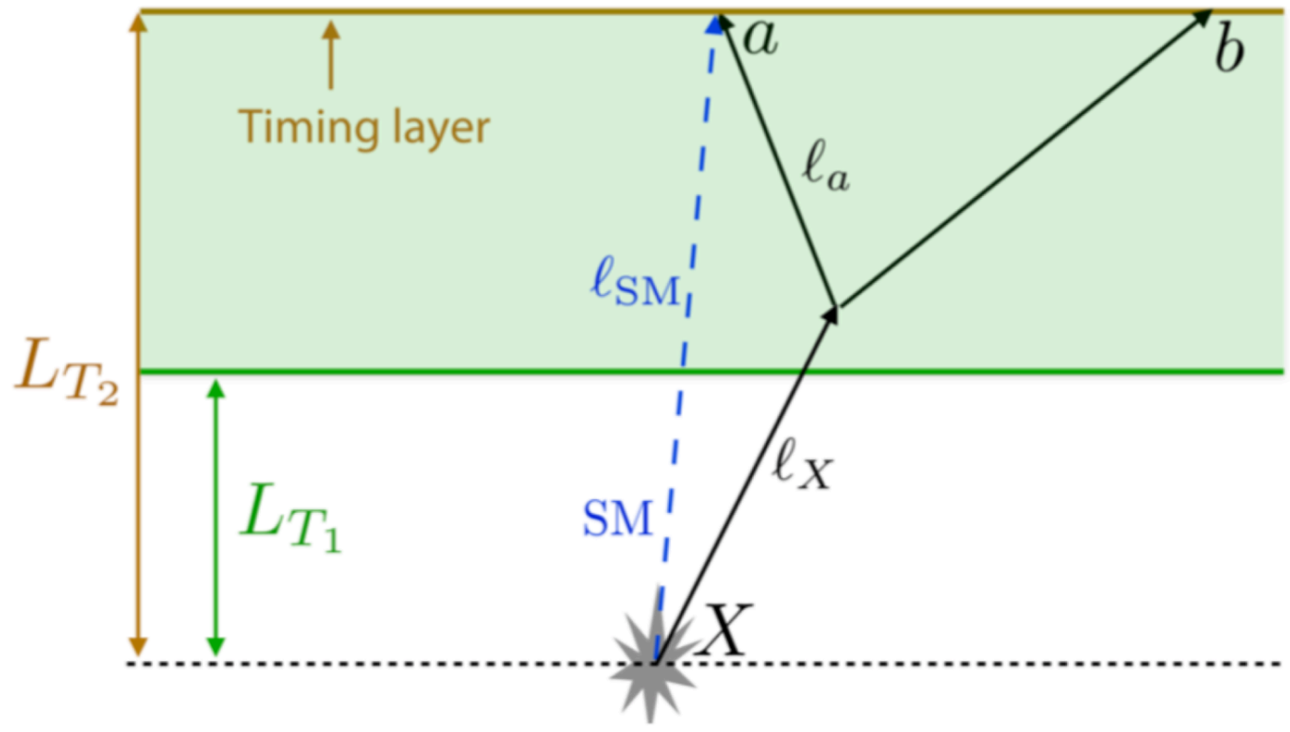


$\sim 1\,\%$ of DM
can be charged



Time delay for LLP





$$\Delta t = \frac{\ell_X}{\beta_X} + \frac{\ell_a}{\beta_a} - \frac{\ell_{\rm SM}}{\beta_{\rm SM}} \quad \beta_a \simeq \beta_{\rm SM} \simeq 1$$

Liu, Liu, Wang, 1805.05957