BEYOND THE STANDARD MODEL OPPORTUNITIES IN P-A COLLISIONS AT THE LHC

SYLVAIN FICHET

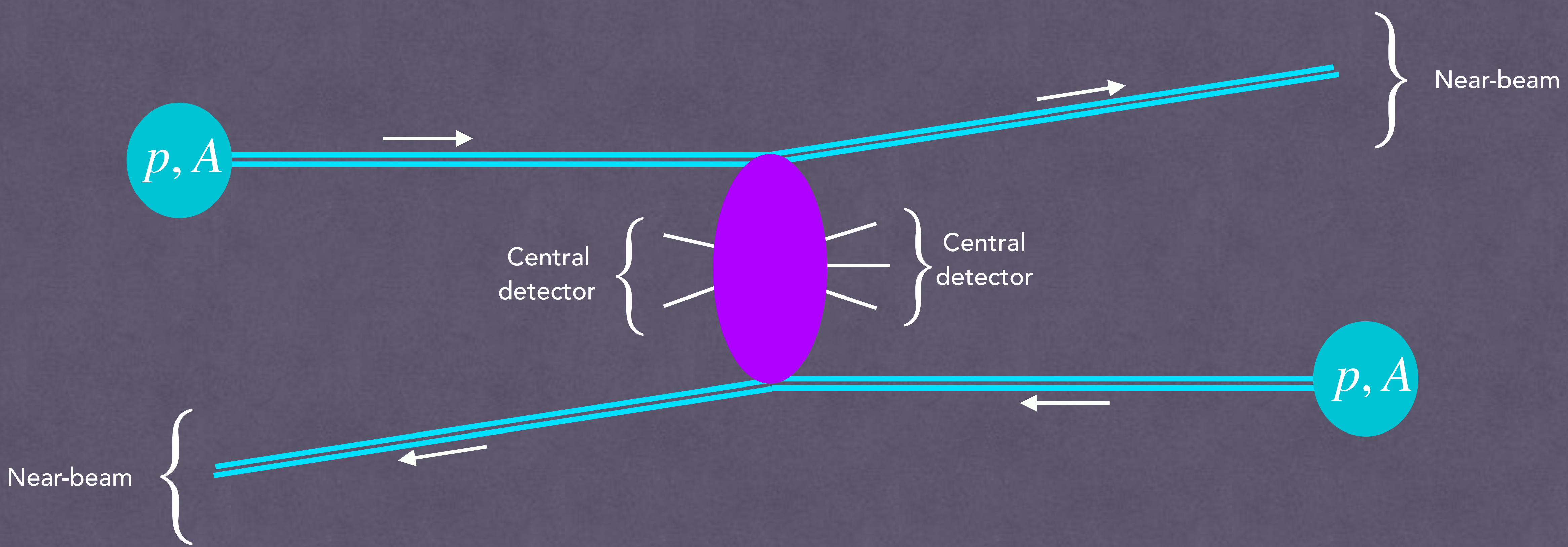
UFABC, SAO PAULO

PA@CERN WORKSHOP 05/07/24

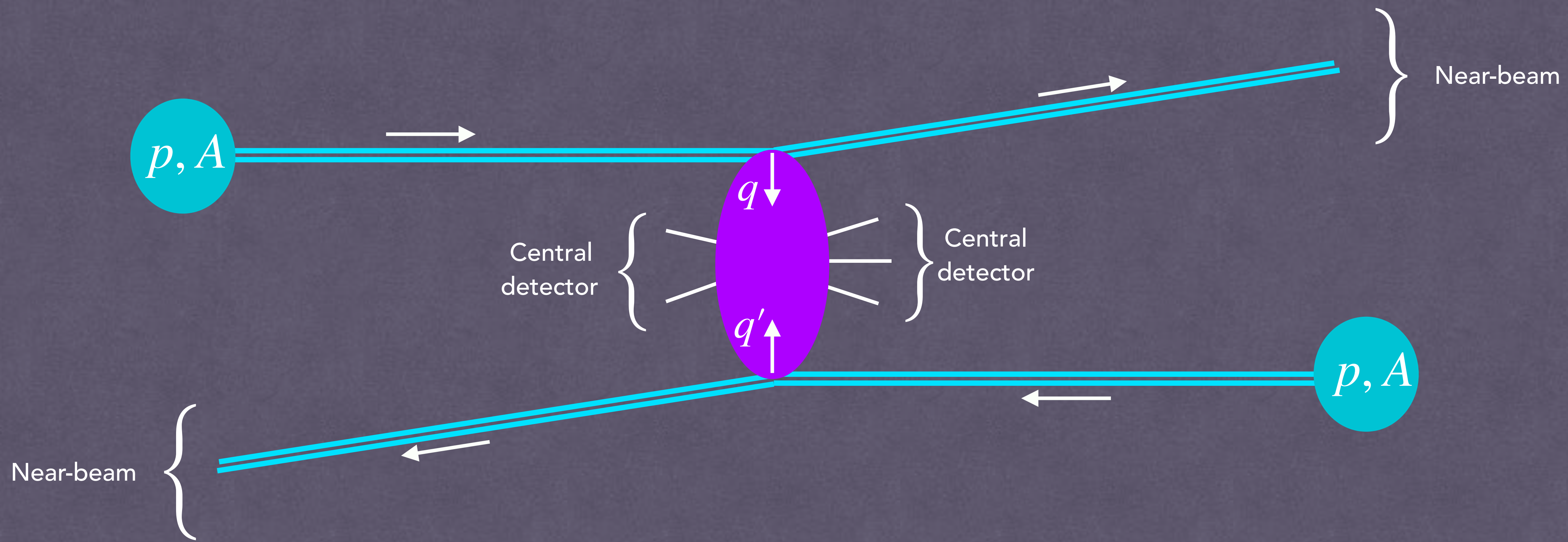
GOAL OF THIS TALK:

COMPARE THE PERFORMANCE OF THE P-A MODE
WITH RESPECT TO P-P AND A-A MODES IN BSM SEARCHES

ULTRAPERIPHERAL COLLISIONS



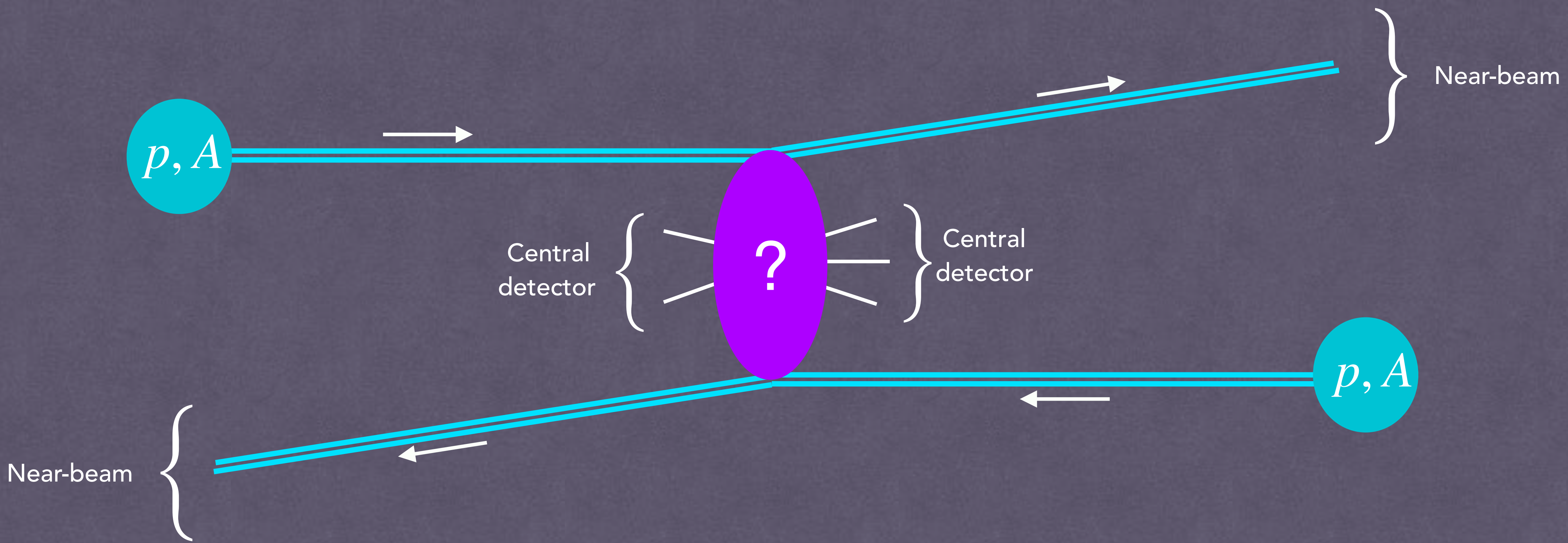
ULTRAPERIPHERAL COLLISIONS



Outgoing protons/nuclei can remain intact if $-q^2 \lesssim \frac{1}{R^2_{p,A}}$

(a ``shallow" inelastic scattering process)

ULTRAPERIPHERAL COLLISIONS

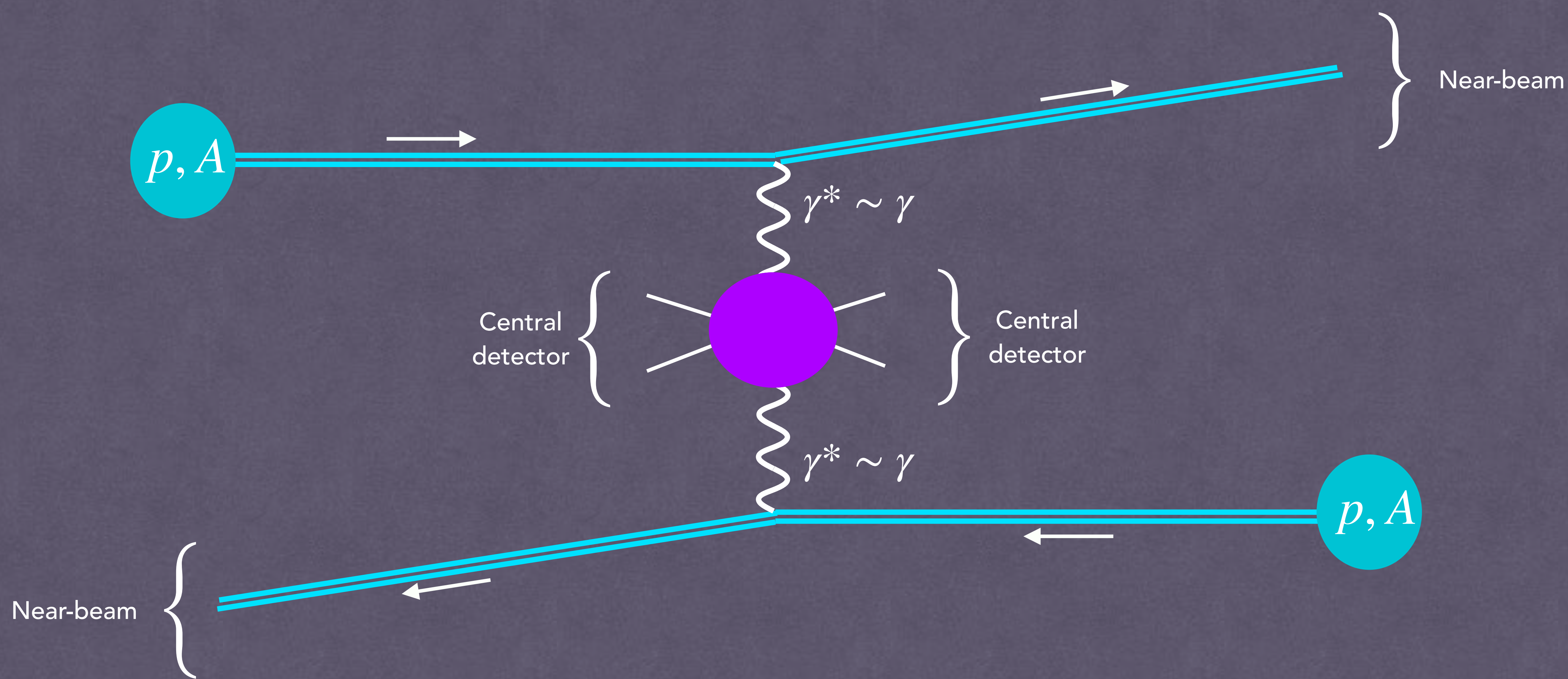


UPCs are a great place to search for physics Beyond the Standard Model (BSM):

- Little underlying activity
- Possibility of tagging the intact protons
- Huge coherent fluxes from heavy nuclei

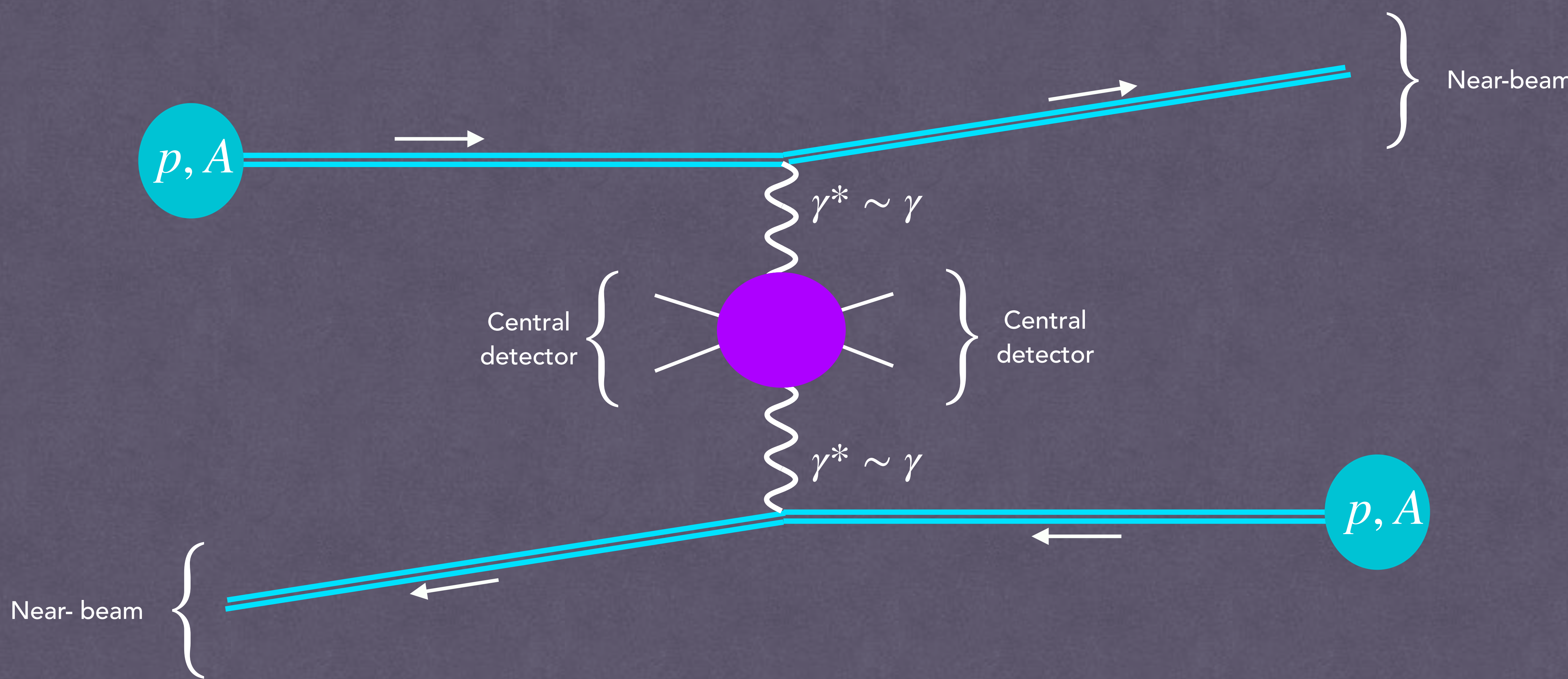
[See talks from Michael Pitt, Lucian Harland-Lang,…]

PHOTON COLLISIONS



Scalings for two identical source nuclei "A" with atomic mass A and atomic charge Z:

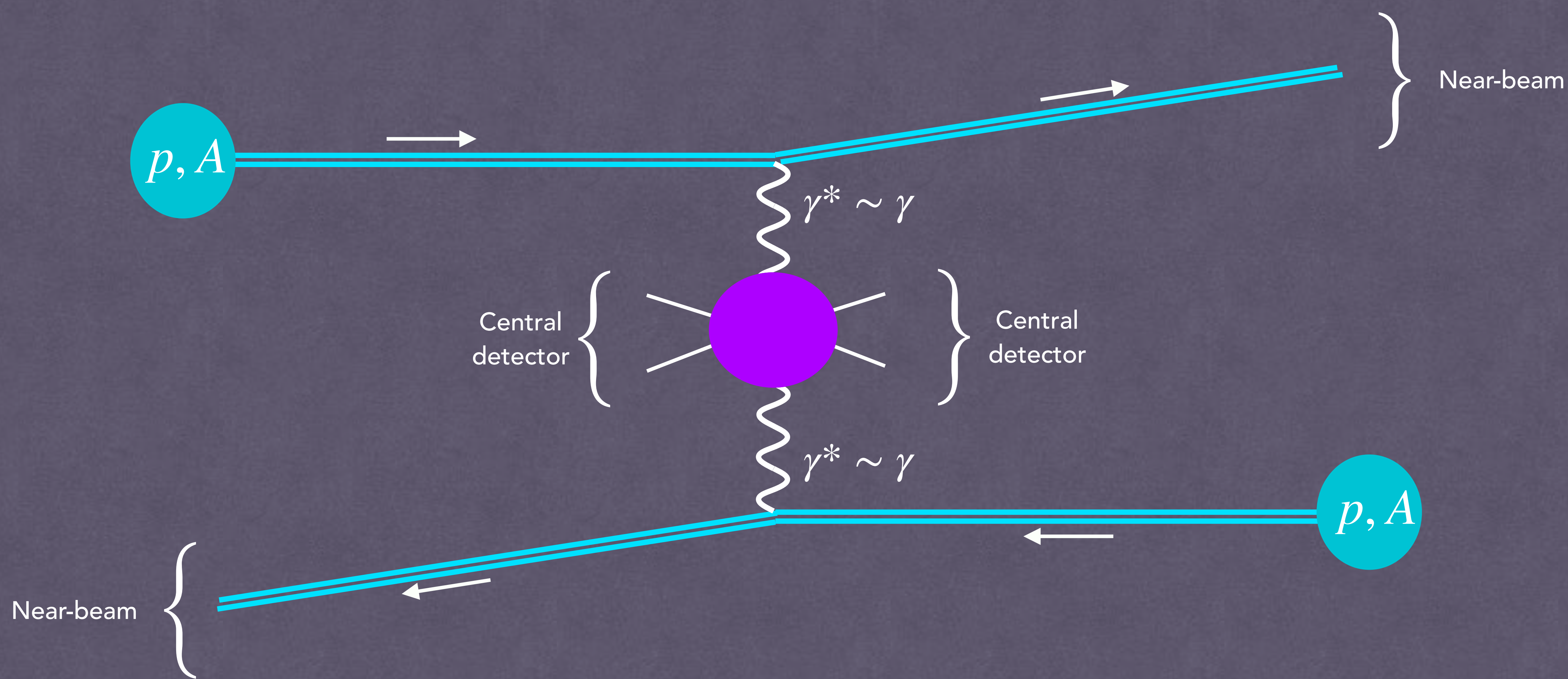
PHOTON COLLISIONS



Scalings for two identical source nuclei "A" with atomic mass A and atomic charge Z:

- Photon flux : $f_{\gamma|A} \propto Z^2$ hence $\sigma(AA \to AA + \ldots) \propto Z^4$

PHOTON COLLISIONS



Scalings for two identical source nuclei "A" with atomic mass A and atomic charge Z:

- Photon flux : $f_{\gamma|A} \propto Z^2$ hence $\sigma(AA \to AA + \ldots) \propto Z^4$
- C.o.m. energy : $\sqrt{s_{\gamma\gamma}^{\max}} \sim \frac{\sqrt{s}}{m_p R} \approx \frac{\sqrt{s}}{5.5 A^{1/3}}$

COMPARISON OF COLLISION MODES

(focusing on A=Pb from now on)

System	$\mathrm{p-p}$	$\mathrm{Pb-Pb}$
$\sqrt{s_{NN}}$	14 TeV	5.5 TeV
$\mathscr{L}_{\mathrm{int}}$	$10\ \mathrm{fb}^{-1}$ *(1 month)*	$10\ \mathrm{nb}^{-1}$ *(1 month)*
$\sqrt{s_{\gamma\gamma}^{\max}}$	4.5 TeV	160 GeV
$\langle N_{\mathrm{pile-up}} \rangle$	25	$5 \cdot 10^{-4}$
p- tagging	Yes	No

The p-p and Pb-Pb modes are complementary.

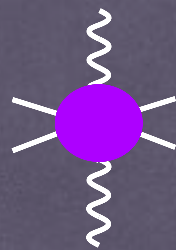
COMPARISON OF COLLISION MODES

System	$p-p$	$p-Pb$	$Pb-Pb$
$\sqrt{s_{NN}}$	$14\ \text{TeV}$	$8.8\ \text{TeV}$	$5.5\ \text{TeV}$
$\mathscr{L}_{\text{int}}$	$10\ \text{fb}^{-1}$ *(1 month)*	$1\ \text{pb}^{-1}$ *(1 month)*	$10\ \text{nb}^{-1}$ *(1 month)*
$\sqrt{s_{\gamma\gamma}^{\text{max}}}$	$4.5\ \text{TeV}$	$2.6\ \text{TeV}$	$160\ \text{GeV}$
$\langle N_{\text{pile-up}} \rangle$	25	0.05	$5 \cdot 10^{-4}$
p- tagging	Yes	Doable [See Michael's talk]	No

The p-p and Pb-Pb modes are complementary.

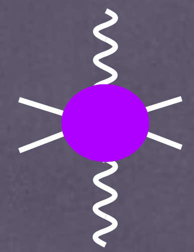
The p-Pb mode seems to draw advantages from both. Let us try to quantify that, In the context of BSM searches via UPCs.

COMPARISON OF COLLISION MODES

How to conveniently compare the BSM cross sections $\sigma_{\gamma\gamma} = \sigma\Big($  $\Big)$?

A simple ansatz: $\sigma_{\gamma\gamma,\,n}(s) \propto \frac{1}{s}\frac{s^n}{\Lambda^{2n}}$

COMPARISON OF COLLISION MODES

How to conveniently compare the BSM cross sections $\sigma_{\gamma\gamma} = \sigma\Big($  $\Big)$?

A simple ansatz: $\sigma_{\gamma\gamma,n}(s) \propto \frac{1}{s}\frac{s^n}{\Lambda^{2n}}$

Classification:

- $n = 0$ $\supset$ SM-like ($\sqrt{s} \gg m$)
  [SF/Gersdorff '12, SF/Gersdorff/Lenzi/Royon/Saimpert '12]
- $n = 1$ $\supset$ Resonant EFTs ($\sqrt{s} \gg m$)
  [SF/Gersdorff '15, …]
- $n = 2$
- $n = 3$
- $n = 4$

$n = 2, 3, 4$: Non-resonant EFTs
Ex: F^4 operators, continuum EFTs, etc
[SF/Megias/Quiros '22, …]

COMPARISON OF COLLISION MODES

System	p − p	p − Pb	Pb − Pb
$\sqrt{s_{NN}}$	14 TeV	8.8 TeV	5.5 TeV
$\mathscr{L}_{\text{int}}$	$10\ \text{fb}^{-1}$ (1 m.)	$1\ \text{pb}^{-1}$ (1 m.)	$10\ \text{nb}^{-1}$ (1 m.)
$\sqrt{s_{\gamma\gamma}^{\max}}$	4.5 TeV	2.6 TeV	160 GeV
$\langle N_{\text{pile-up}} \rangle$	25	0.05	$5 \cdot 10^{-4}$
p- tagging	Yes	Doable	No
N_{events}: $n = 0$	1 :	1 :	1300
$n = 1$	2 :	1 :	67
$n = 2$	3 :	1 :	4
$n = 3$	17 :	4 :	1
$n = 4$	490 :	64 :	1

SM-like ($n = 0$)

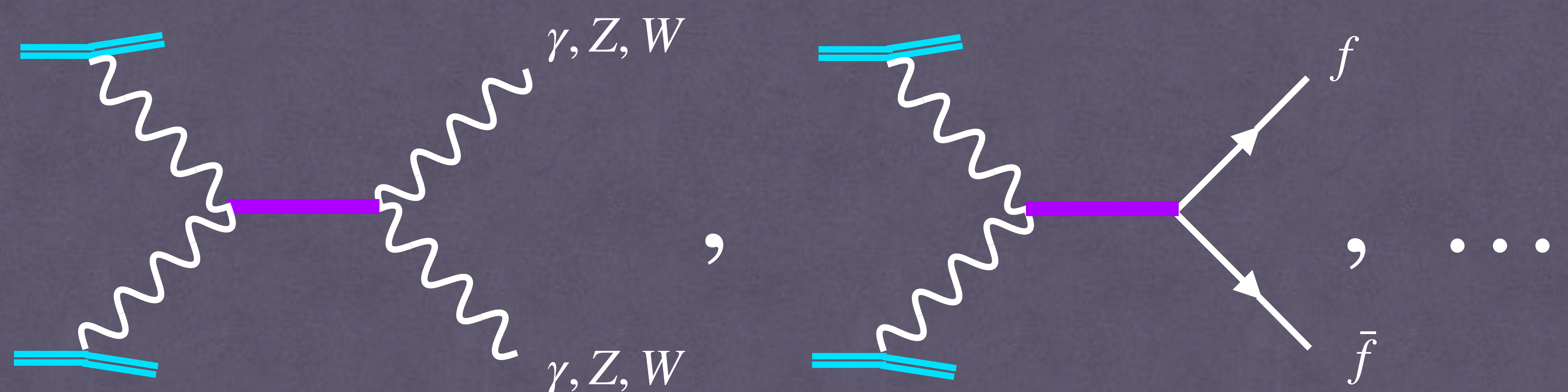
Resonant EFTs ($n = 1$)

Non-resonant EFTs ($n = 2, 3, 4$)

$$\sigma_{\gamma\gamma, n}(s) \propto \frac{1}{s} \frac{s^n}{\Lambda^{2n}}$$

1) RESONANCES

RESONANT EFTS



EFTs of particles linearly coupled to the SM:

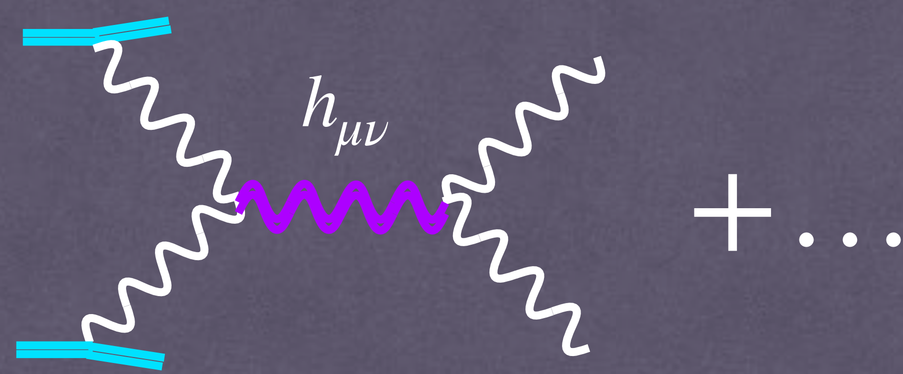
CP-even Spin 0 | CP-odd Spin 0 | Spin 2

$$\mathscr{L}_{\text{eff}}^{\gamma\gamma} = \frac{1}{f_{\mathbf{0}^+}^{\gamma\gamma}}\varphi(F_{\mu\nu})^2 + \frac{1}{f_{\mathbf{0}^-}^{\gamma\gamma}}aF_{\mu\nu}\tilde{F}_{\mu\nu} + \frac{1}{f_{\mathbf{2}}^{\gamma\gamma}}h^{\mu\nu}\left(-F_{\mu\rho}F^{\rho}{}_{\nu} + \frac{1}{4}\eta_{\mu\nu}(F_{\rho\sigma})^2\right)$$

$$\mathscr{L}_{\text{eff}}^{\bar{t}t} = \frac{m_t}{f_{\mathbf{0}^+}^{\bar{t}t}}\varphi\bar{t}t + i\frac{m_t}{f_{\mathbf{0}^-}^{\bar{t}t}}a\bar{t}\gamma_5 t + i\frac{1}{f_{\mathbf{2}}^{\bar{t}t}}h^{\mu\nu}\bar{t}\gamma_\mu D_\nu t$$

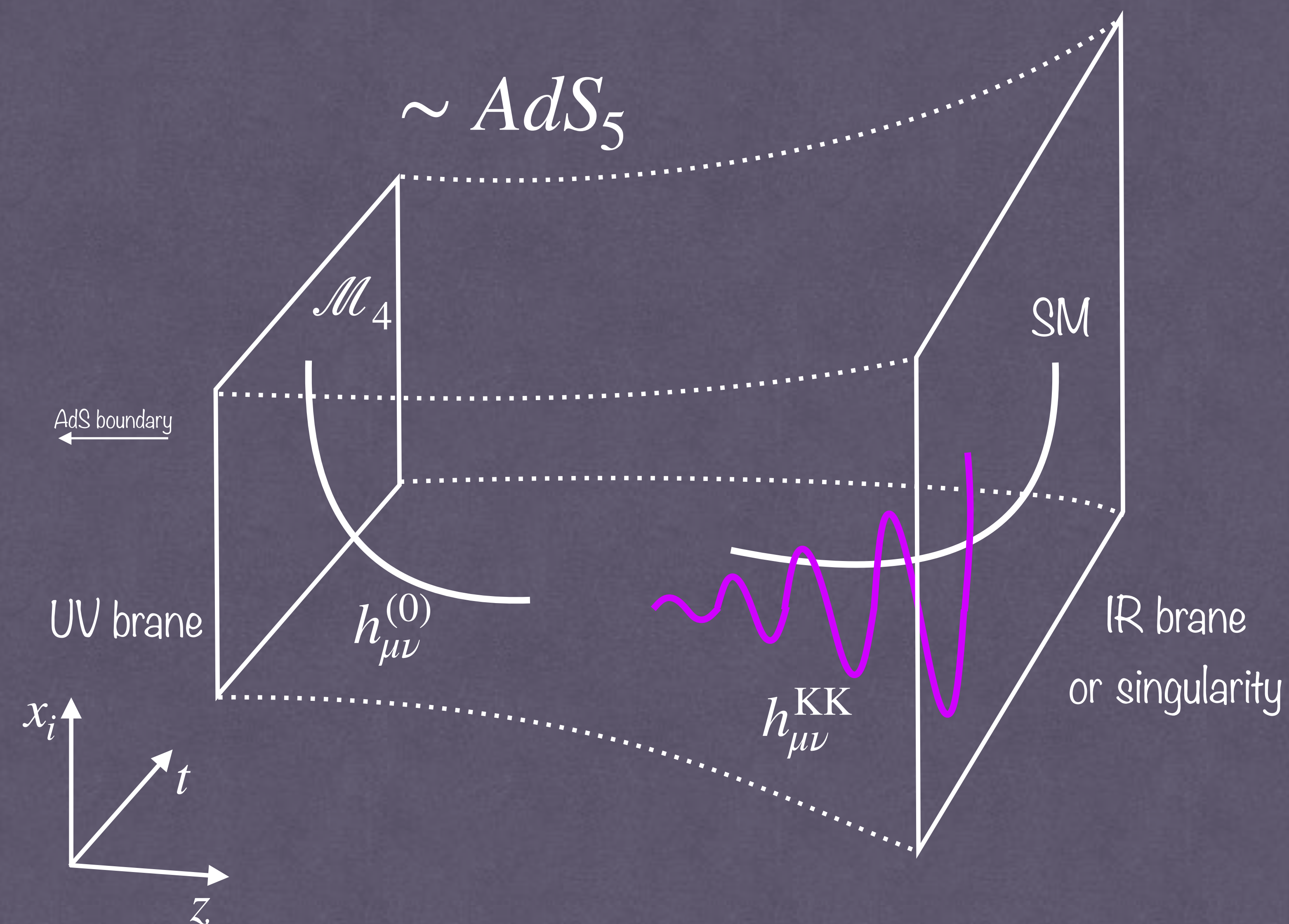
[Baldenegro/Bellora/SF/Gersdorff/Royon/Pitt '22,...]

SPIN 2 EXAMPLE: A KK GRAVITON



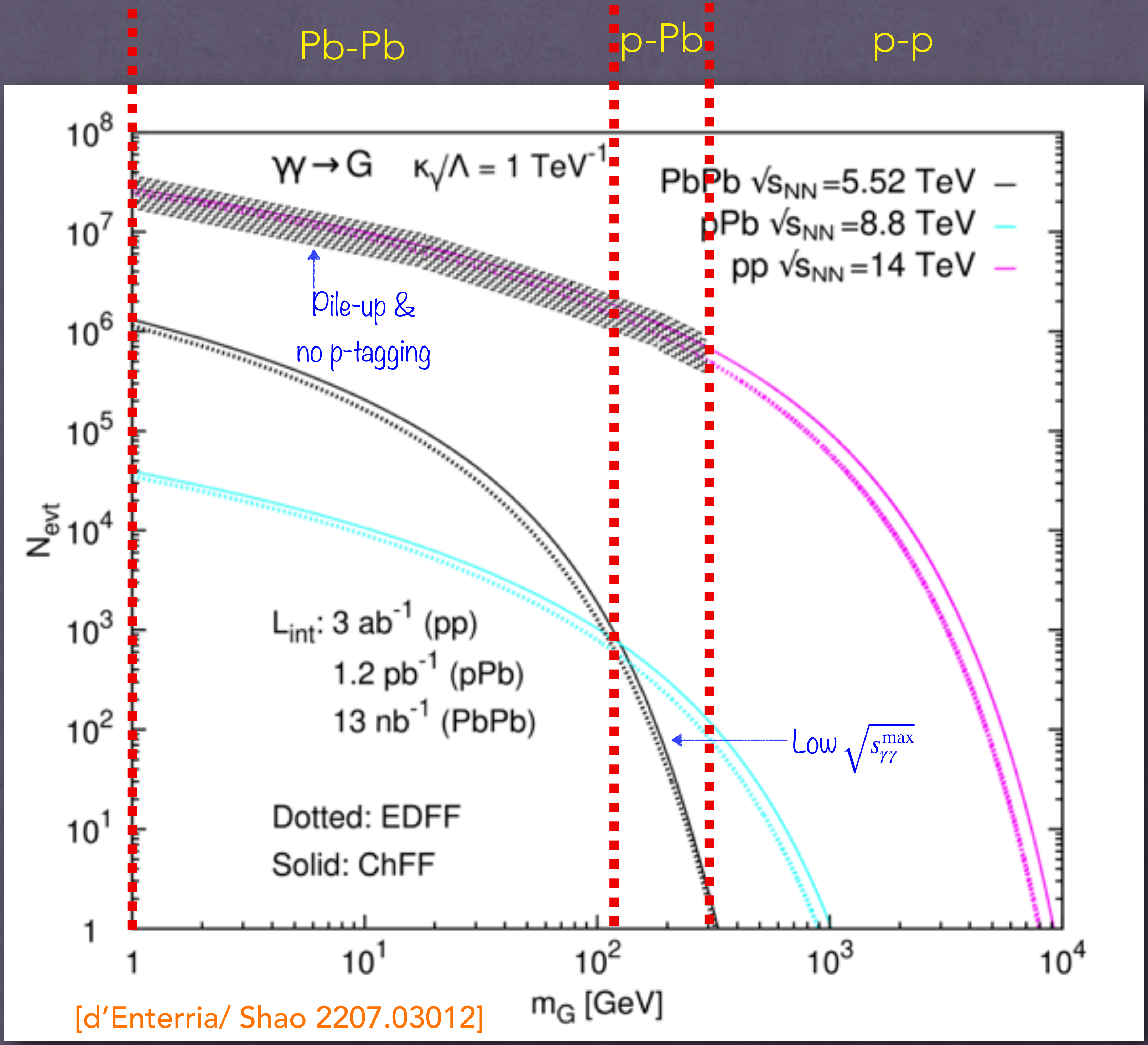
Warped extra dimensions

[Randall/Sundrum '99,
Csaki '04 (review),
Gherghetta '10 (review),
Cabrer/Gersdorff/Quiros '09,
and many many more, see e.g.
Agashe, Pomarol, …]



SPIN 2 PRODUCTION IN UPCS

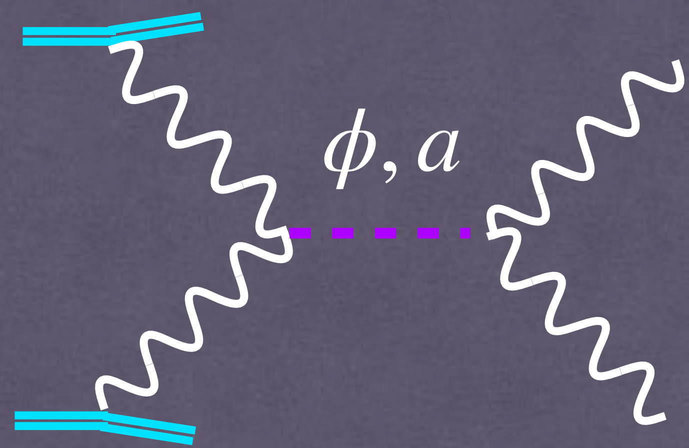
Highest rate
at equal running time:



p-Pb is competitive in the
$m_G \sim (100 - 300)$ GeV range

At lower mass, Pb-Pb performs
better by a factor ~ 30

SPIN-0 EXAMPLES



$+\ldots$

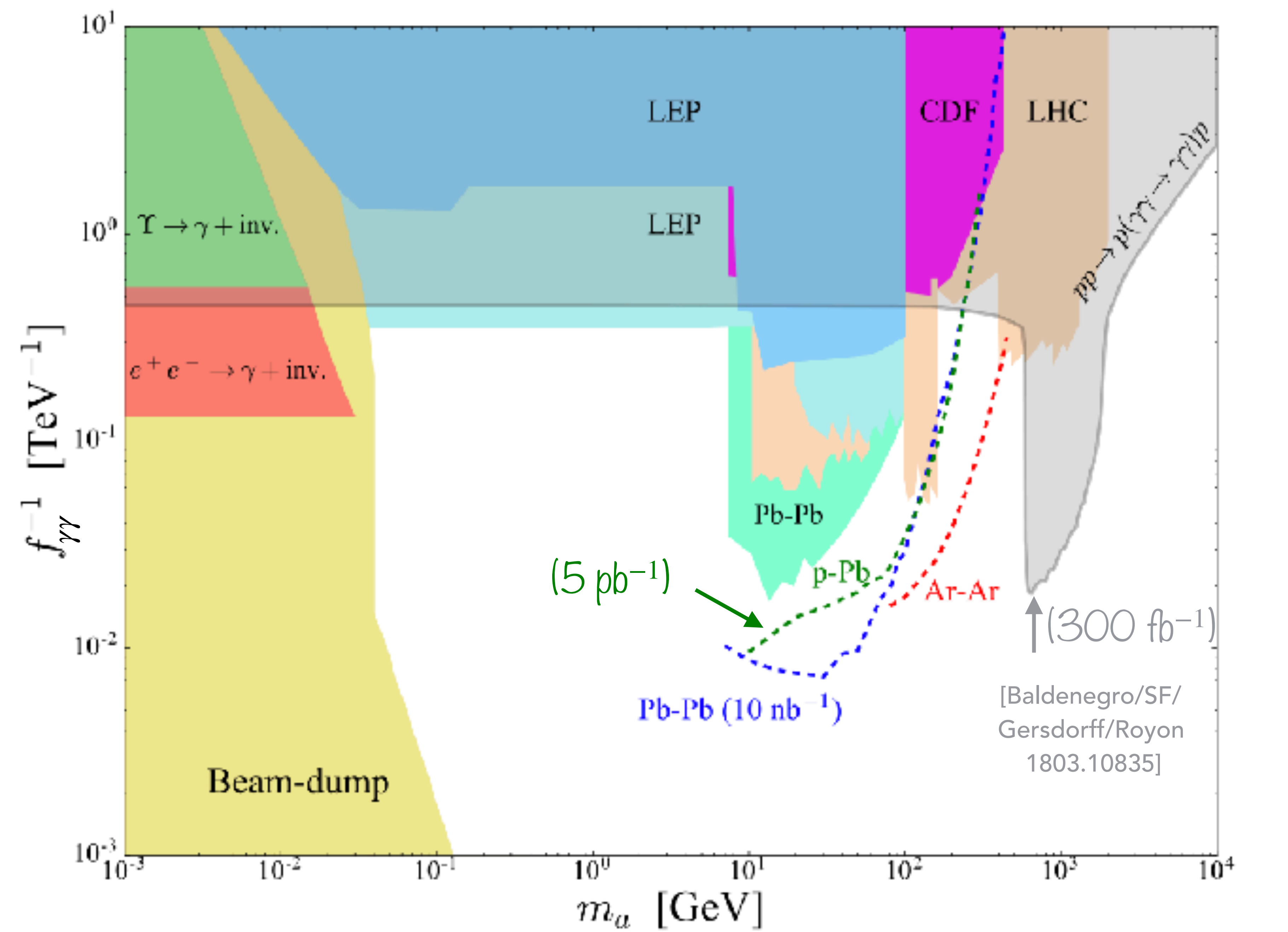
Many UV motivations:

CP-odd
- PQ Axion [Peccei/Quinn '77, …]
- GBs from Composite Higgs models [Kaplan/Georgi/Dimopoulos '84, …]
- String Landscape [Svrcek/Witten '06, Arvanitaki/Dimopoulos/Dubovsky/Kaloper/March-Russell '10, …]

CP-even
- Radion from Extra Dimensions [Csaki/Hubisz/Lee '07, Randall/Sundrum '99,…]
- Dilaton [Conlon '06, Goldberger/Grinstein/Skiba '08,…]
- Radial Mode in Composite Higgs models [SF/Gersdorff/Pontón/Rosenfeld '16, …]
- Extension of Higgs Sector [Lee, Fayet, Flores/Sher, …]
- Higgs Portal [Schabinger/Wells '05, …]

⋮

AXION PRODUCTION IN UPCS

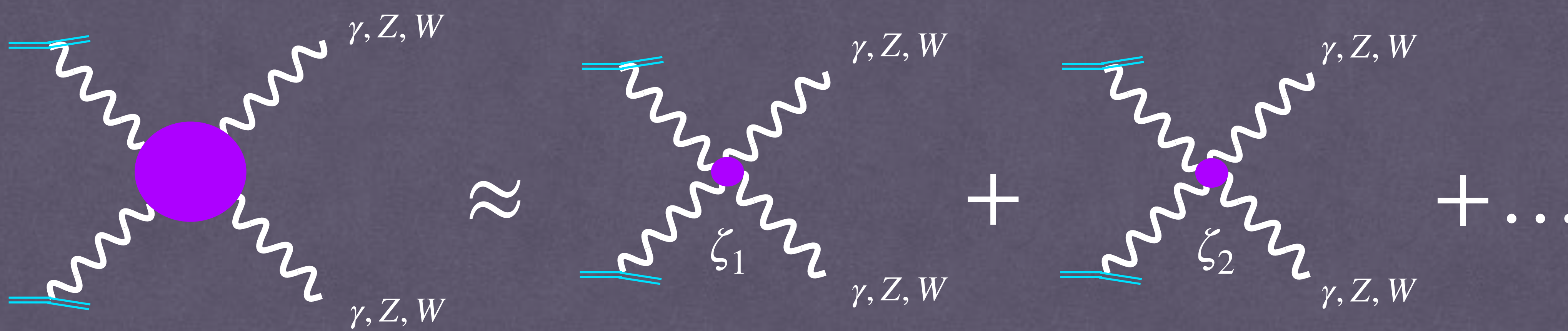


[Baldenegro/Hassani/Royon/Schoeffel, 1903.04151]

➡ p-Pb performs below Pb-Pb by a factor 2-4 in $f_{\gamma\gamma}$

2) NON-RESONANT EFTS

F^4 EFT $\quad (n = 4)$



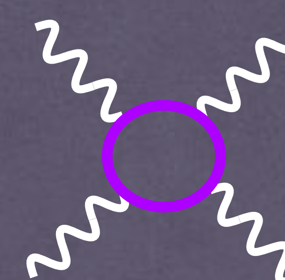
Many UV motivations:

Linear coupling to SM

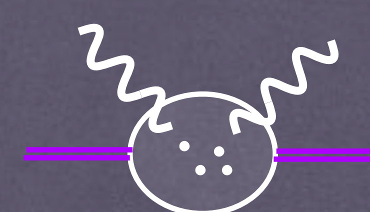
- All heavy neutral particles shown before
  [SF/Gersdorff '12, SF/Gersdorff/Lenzi/Royon/Saimpert '12]

Quadratic coupling to SM

- Charged particles [SF/Gersdorff '12, …]



- Polarizable dark particles [SF '16]

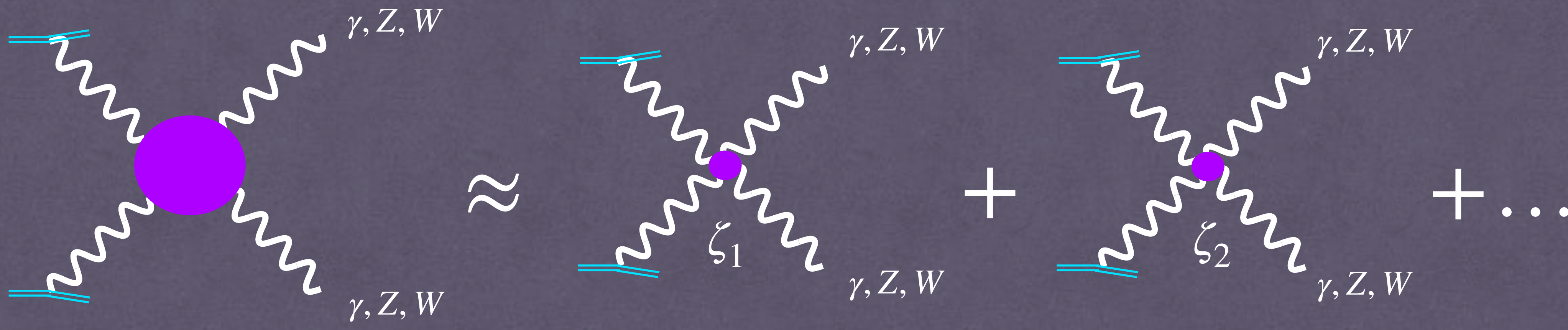


String-motivated

- Born-Infeld QED [Fradkin/Tseytlin '85 …]

⋮

F^4 EFT $\quad (n = 4)$



Cross section goes as $\sigma_{\gamma\gamma}(s) \propto \dfrac{s^3}{\Lambda^8}$.

At equal running time, $\dfrac{N_{\mathrm{pp}}}{N_{\mathrm{pPb}}} = O(10)$.

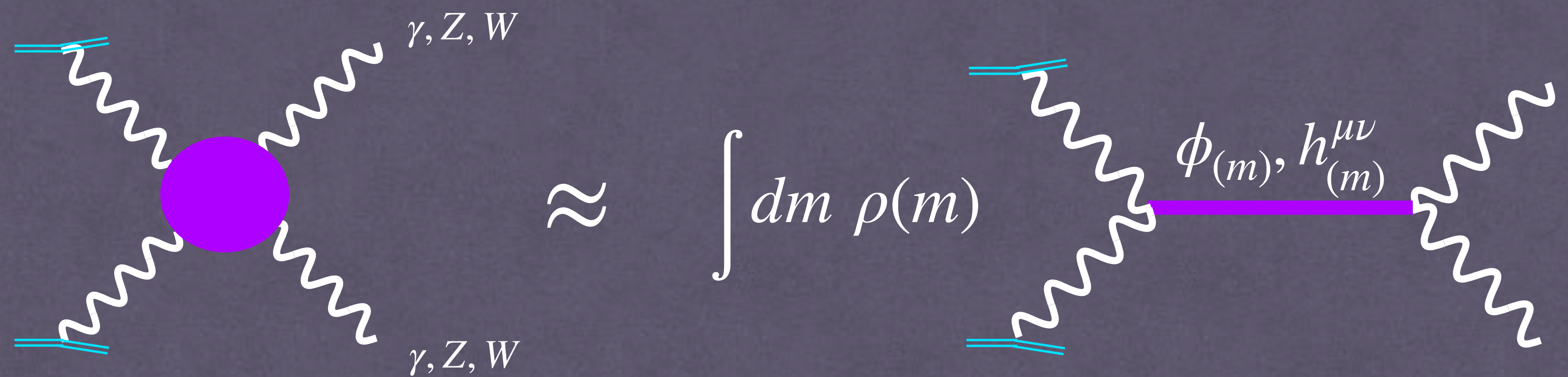
Other characteristics do not produce a clear favorite:

$\langle N_{\text{pile-up}} \rangle$	25	0.05
p- tagging	Yes	Doable

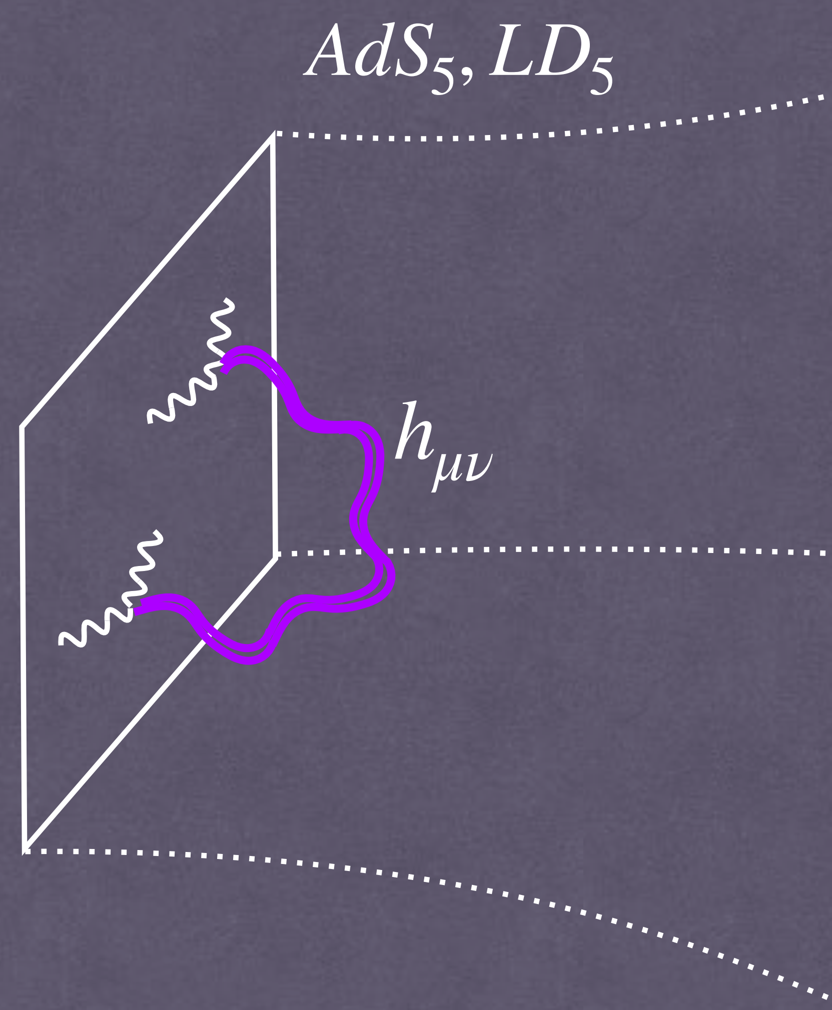
➡ p-Pb performance for F^4 operators search may be close to p-p.

A detailed analysis would be welcome!

CONTINUUM EFT



Examples:



- Graviton continuum from AdS braneworld:

$$\sigma_{\gamma\gamma}(s) \propto \frac{s^3}{\Lambda^8} \quad \text{(n=4)}$$

[Brax/SF/Tanedo '19, …]

- Graviton continuum from linear dilaton braneworld:

[SF/Megias/Quiros '22, …]

$$\sigma_{\gamma\gamma}(s) \propto \frac{s^2}{\Lambda^6} \quad \text{(n=3)}$$

At equal running time, $\frac{N_{\rm pp}}{N_{\rm pPb}} = O(1)$.

SUMMARY

We classified BSM scenarios to be searched in UPCs into (roughly) two types.

SUMMARY

We classified BSM scenarios to be searched in UPCs into (roughly) two types.

Low-mass resonances: The p-Pb mode competes with Pb-Pb mode.
p-Pb performs better for $m \sim (100 - 300)$ GeV, while p-Pb event yields is lower than Pb-Pb by up to O(30) for lower masses.

SUMMARY

We classified BSM scenarios to be searched in UPCs into (roughly) two types.

Low-mass resonances: The p-Pb mode competes with Pb-Pb mode.
p-Pb performs better for $m \sim (100 - 300)$ GeV, while p-Pb event yields is lower than Pb-Pb by up to O(30) for lower masses.

Non-resonant EFTs: The p-Pb mode competes with p-p mode.
p-Pb event yields is only moderately smaller than in p-p. There seems to be no strong favorite based on the other characteristics of the modes. A detailed study of effective operators searches in p-Pb would be useful.

SUMMARY

We classified BSM scenarios to be searched in UPCs into (roughly) two types.

Low-mass resonances: The p-Pb mode competes with Pb-Pb mode.
p-Pb performs better for $m \sim (100 - 300)$ GeV, while p-Pb event yields is lower than Pb-Pb by up to O(30) for lower masses.

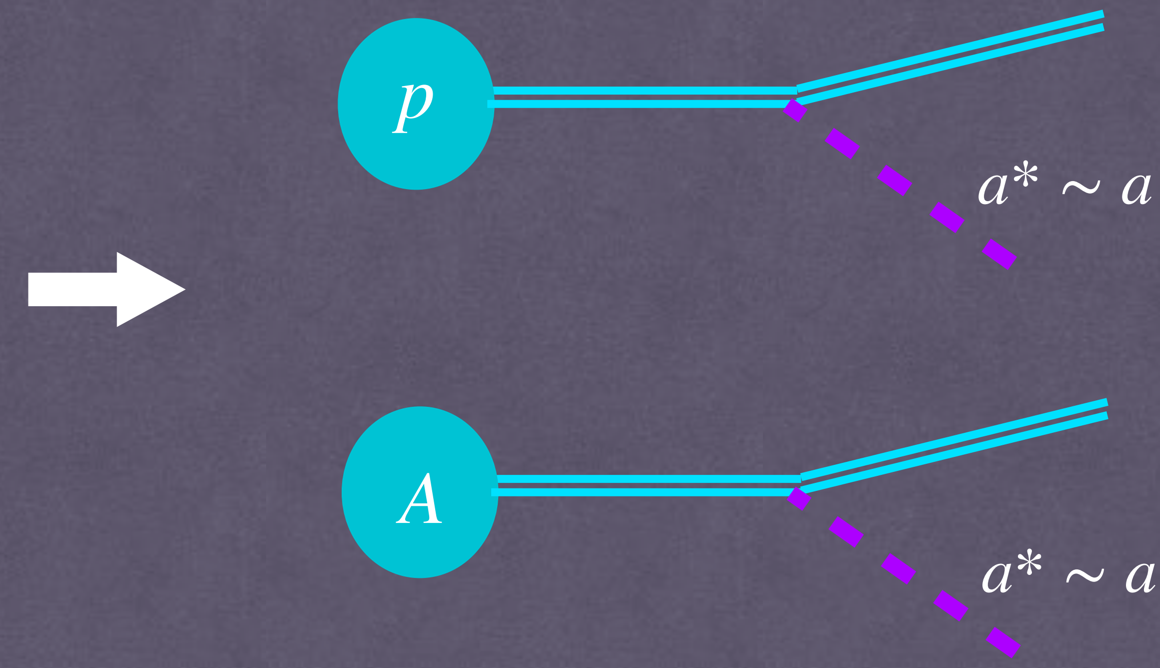
Non-resonant EFTs: The p-Pb mode competes with p-p mode.
p-Pb event yields is only moderately smaller than in p-p. There seems to be no strong favorite based on the other characteristics of the modes. A detailed study of effective operators searches in p-Pb would be useful.

Idea to take away:
From the viewpoint of BSM searches, the p-Pb mode is relatively competitive with BOTH p-p and Pb-Pb modes. Hence, in the context of BSM searches, assuming no prior on the type of BSM scenario, it could make sense to extend the duration of the p-Pb run.

THE END

AXION FLUXES (PRELIMINARY) [da Silveira/SF/Machado/…]

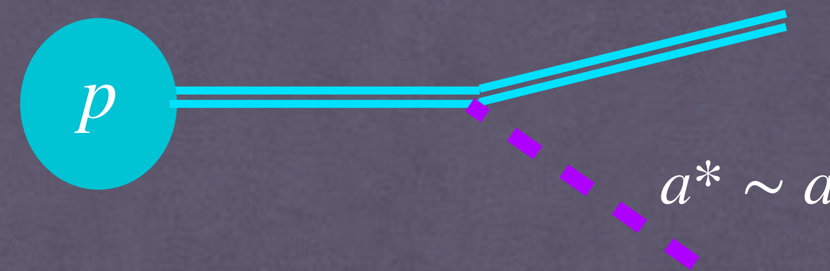
$$\mathscr{L}_a \supset \frac{a}{f_{NN}} \bar{N} i \gamma_5 N$$

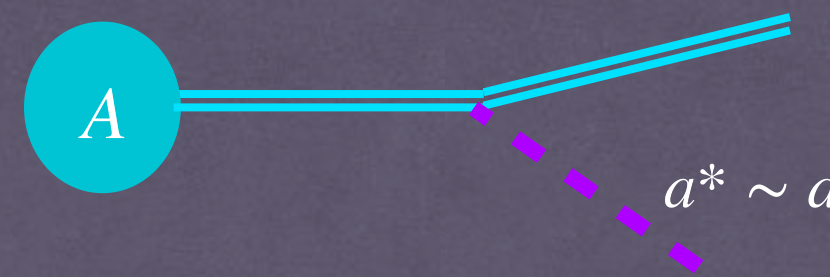


$\propto \frac{A^2}{\gamma^2}$ Very suppressed

AXION FLUXES (PRELIMINARY) [da Silveira/SF/Machado/…]

$$\mathscr{L}_a \supset \frac{a}{f_{NN}} \bar{N} i \gamma_5 N$$

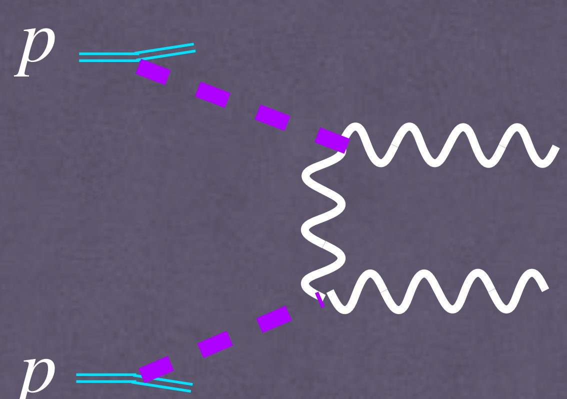




$$\propto \frac{A^2}{\gamma^2}$$

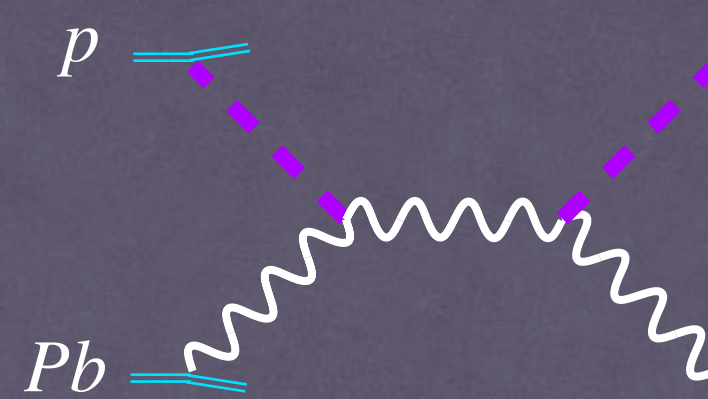
Very suppressed

Some processes:



$+ \ldots$

$\propto f_{NN}^{-2} f_{\gamma\gamma}^{-4}$



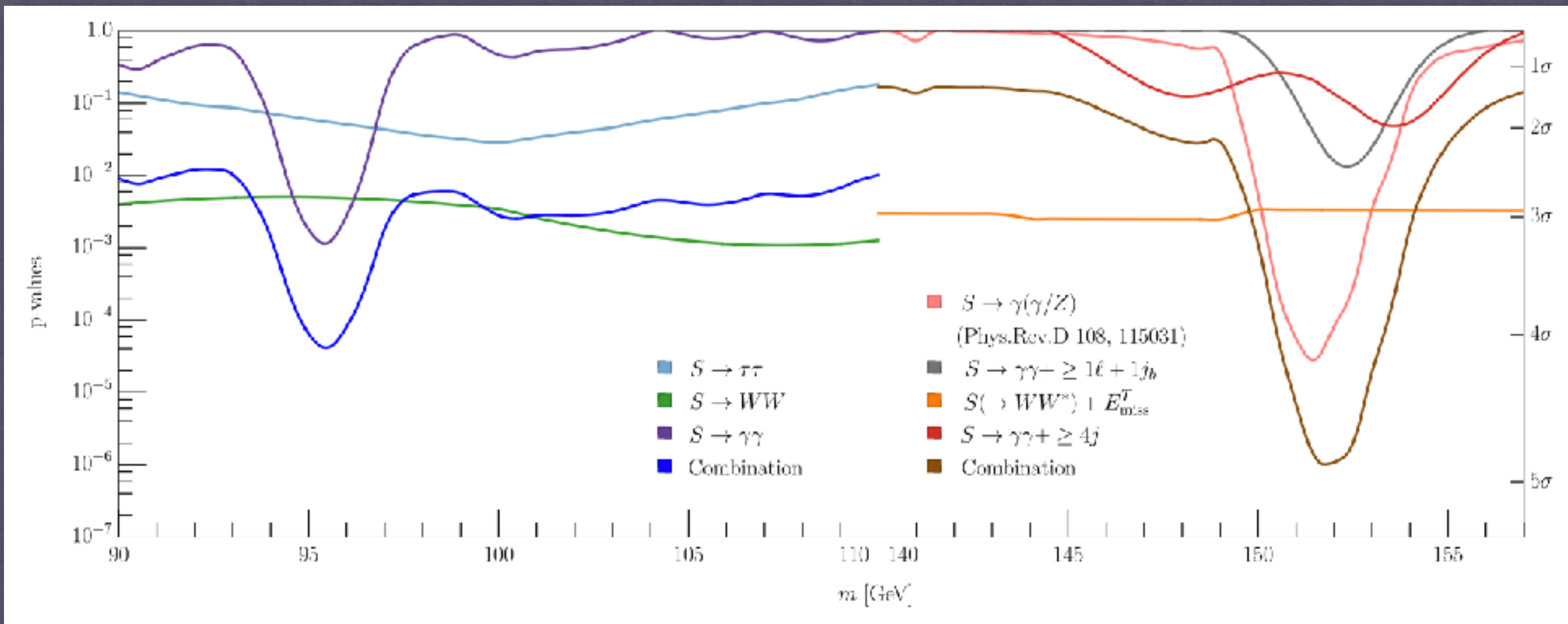
$+ \ldots$

$\propto e f_{NN}^{-1} f_{\gamma\gamma}^{-2}$

[Currently under analysis]

[Less suppressed, benefits from p tagging]

A MOTIVATION FROM DATA ?



Taken from [Crivellin 2405.15933]. None of these excesses are statistically significant.