

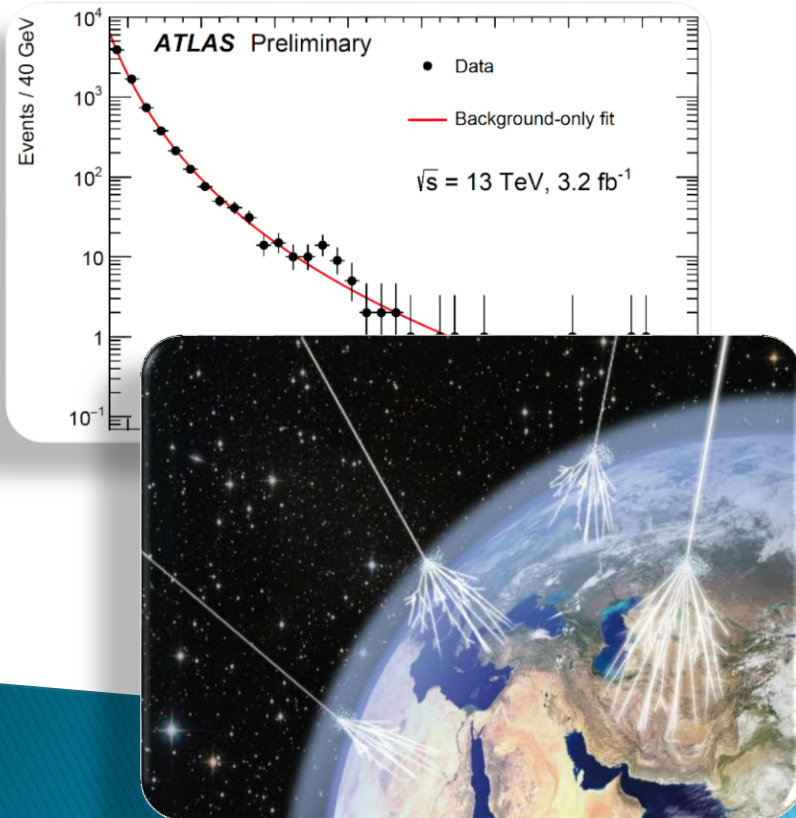
DM indirect signature & 750 GeV diphoton resonance

JCP & Seong Chan Park
[arXiv: 1512.08117]

Jong-Chul Park

CNU 충남대학교
CHUNGNAM NATIONAL UNIVERSITY

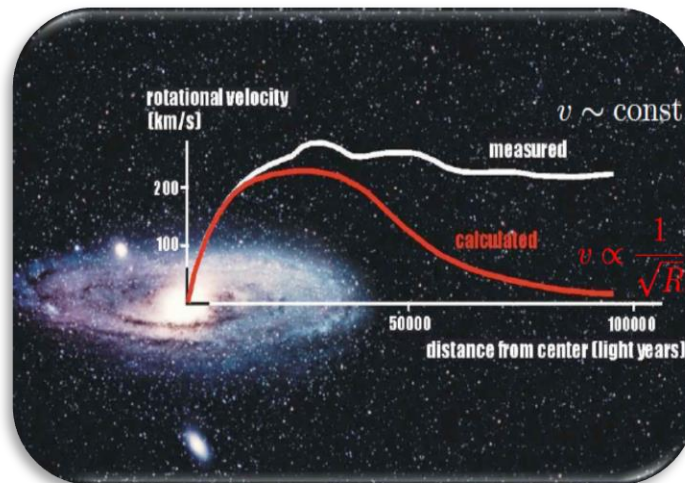
January 08, 2016



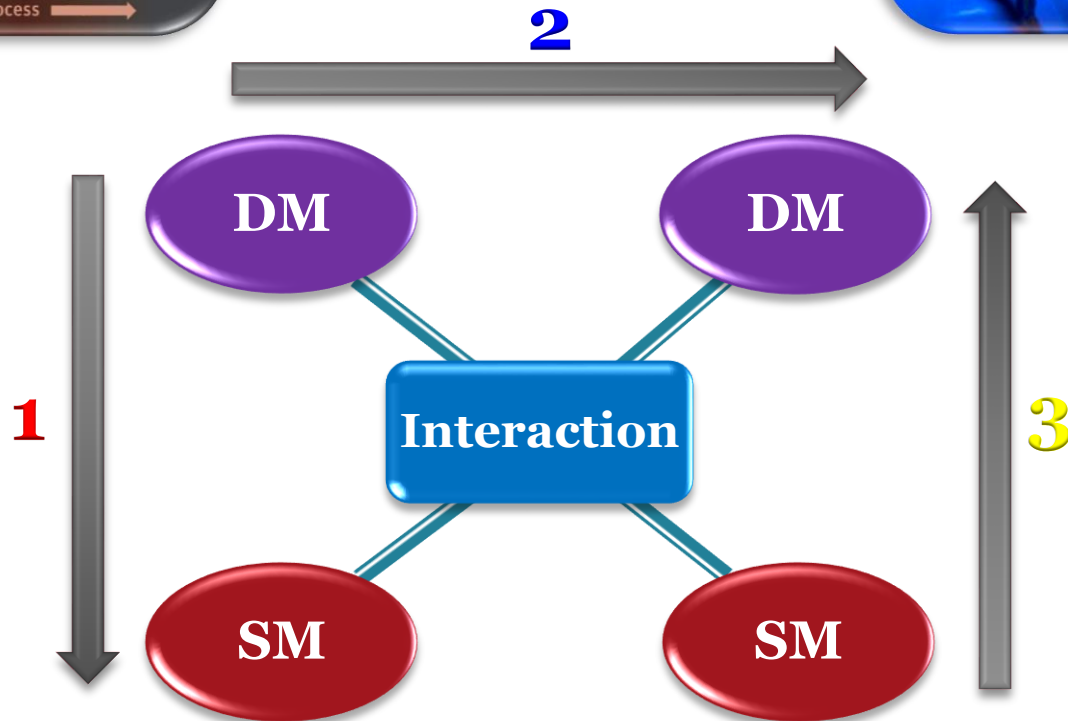
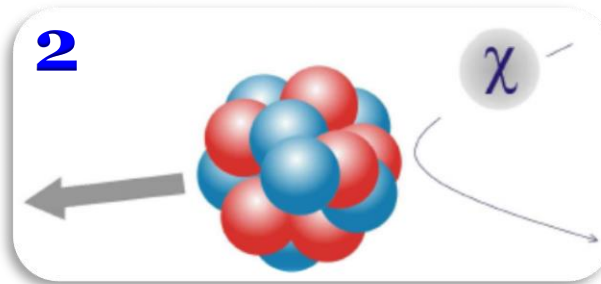
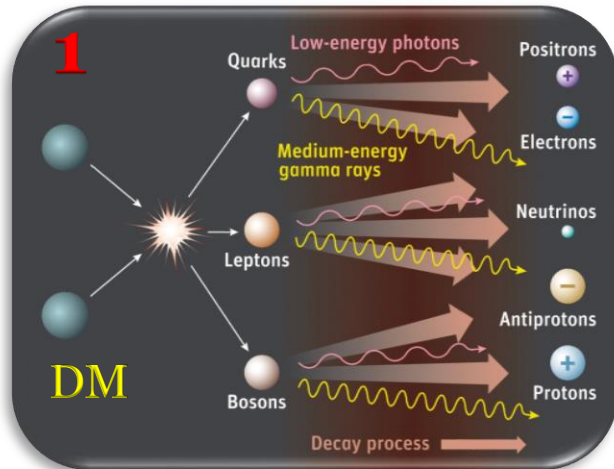
Overview on the recent di-photon excess at the LHC Run 2
@ IBS CTPU

Dark Matter (DM)

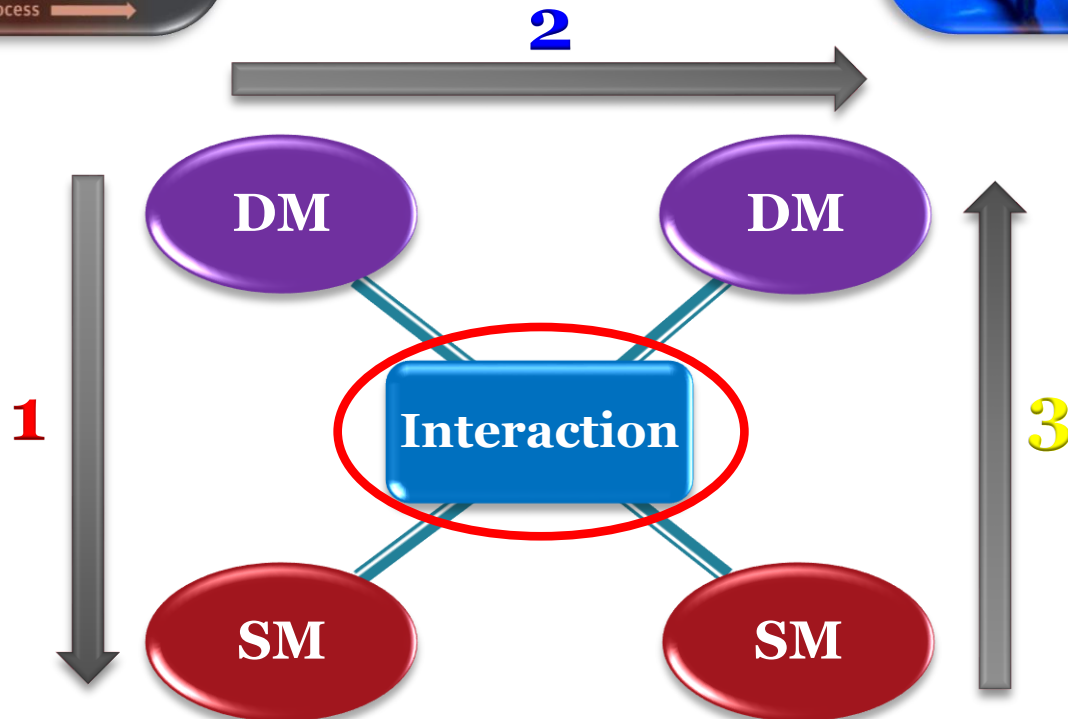
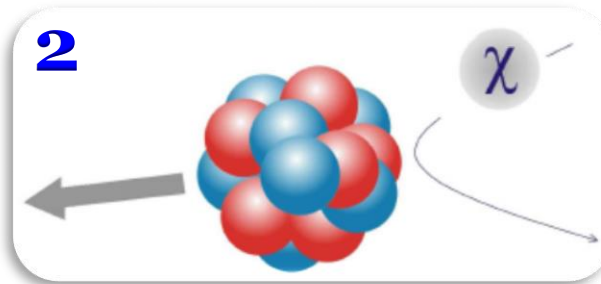
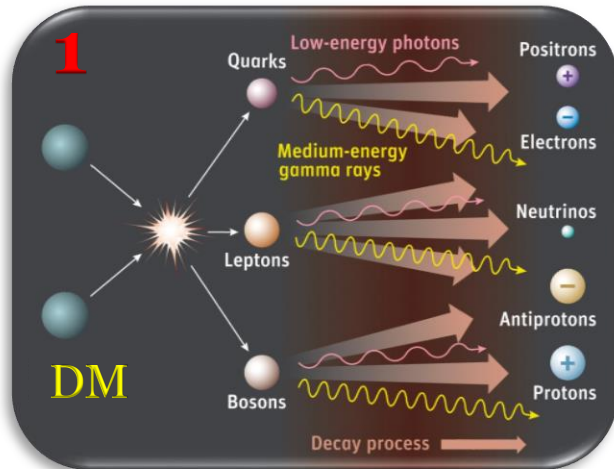
- ❖ **DM**: ~25% of our Universe
- ❖ **Compelling paradigm**:
massive, non-luminous & stable particles
- ❖ **Evidence**
 - ✓ Galaxy rotation curve
 - ✓ Bullet cluster
 - ✓ Gravitational lensing
 - ✓ Structure formation
 - ✓ CMB
 - ✓ Coma Cluster
 - ✓ Sky surveys
 - ✓ ...



DM Search Strategies

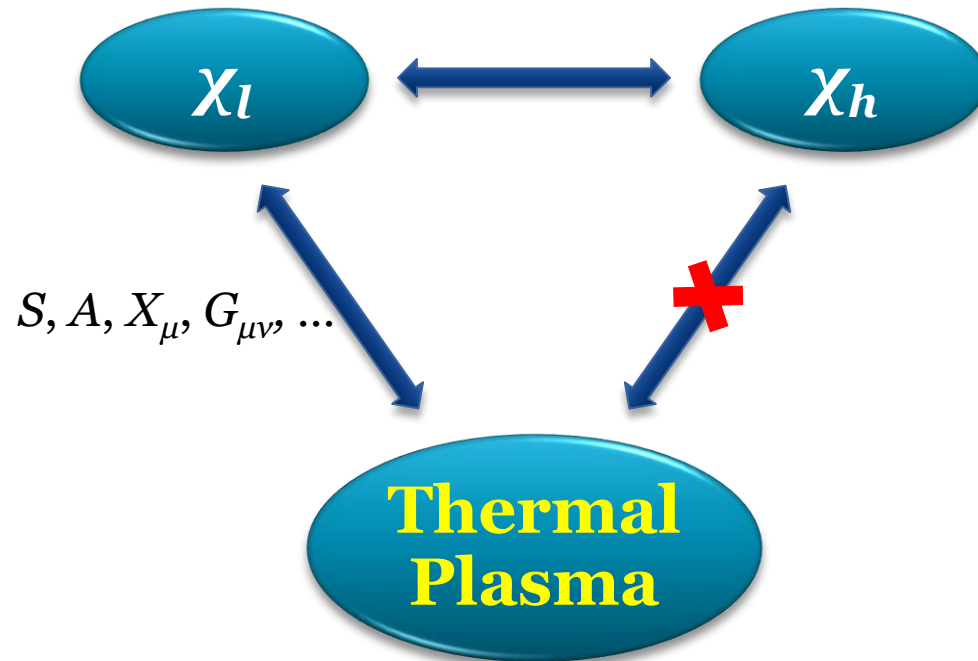


DM Search Strategies

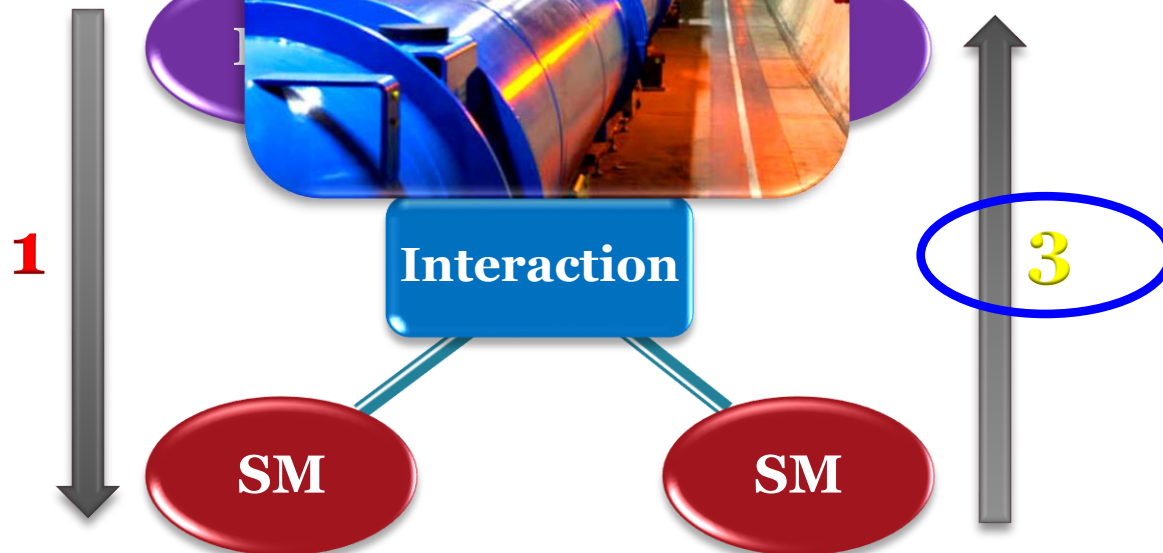
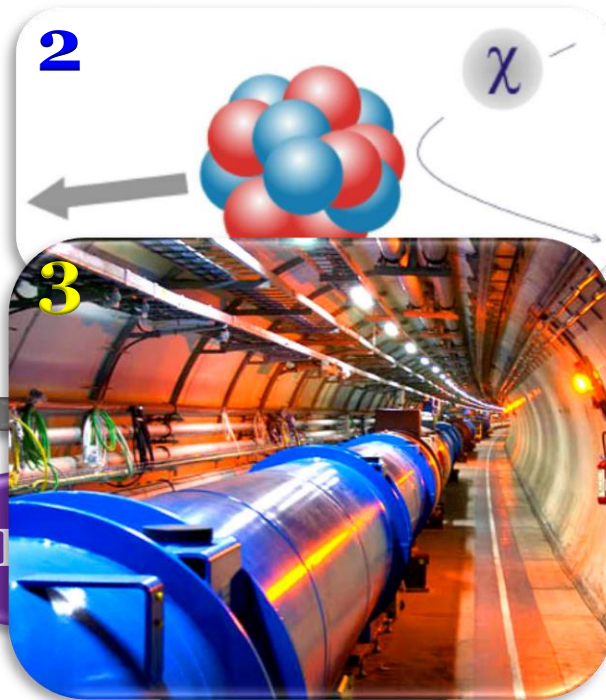
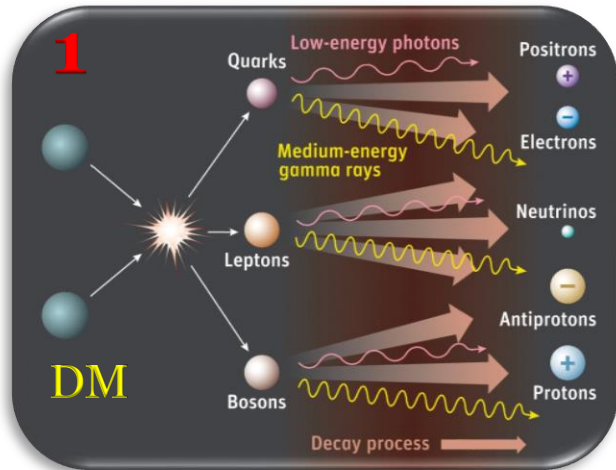


Mediator between Dark & SM

- ❖ DM sector: maybe complicated
- ❖ Require **at least one mediator** between DM & SM sectors



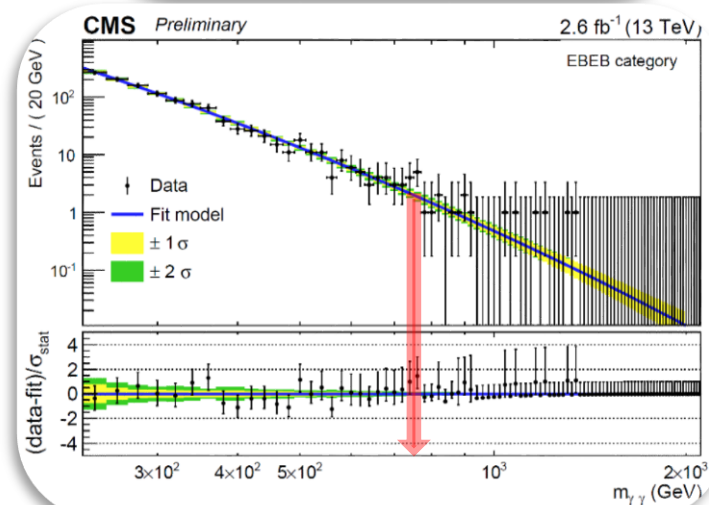
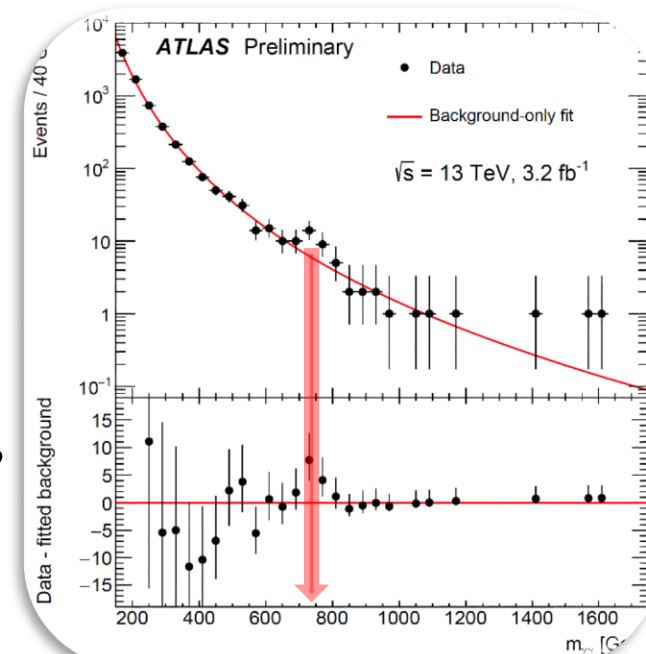
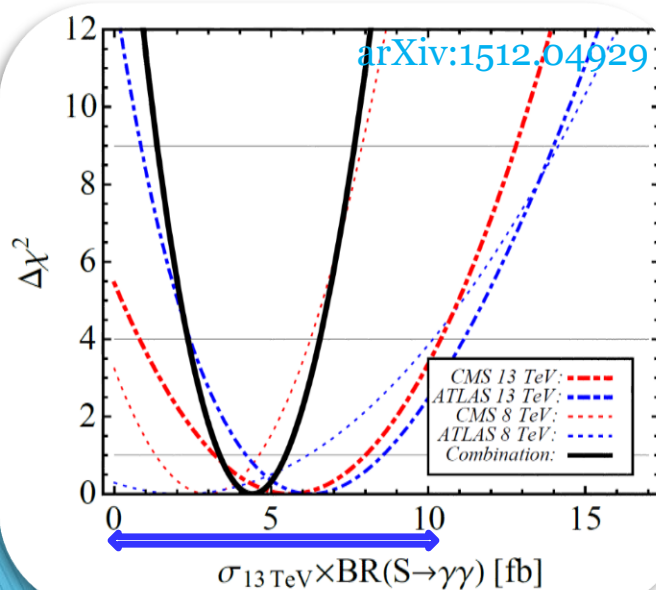
Collider Search: LHC



**New Resonance
@ ~ 750 GeV ?**

New Resonance at ~ 750 GeV?

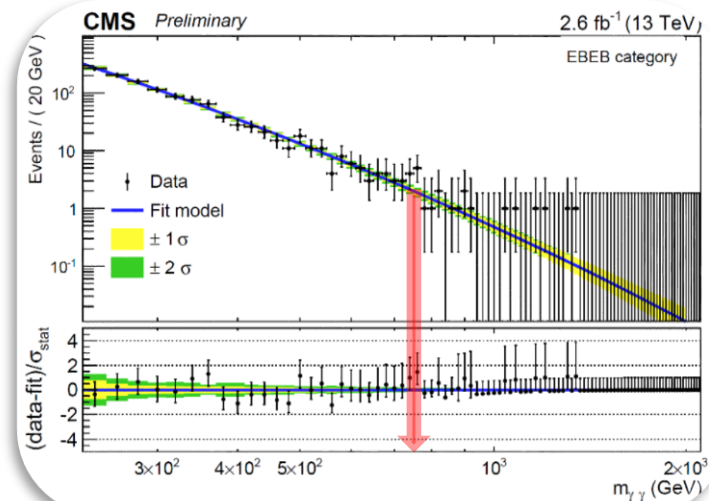
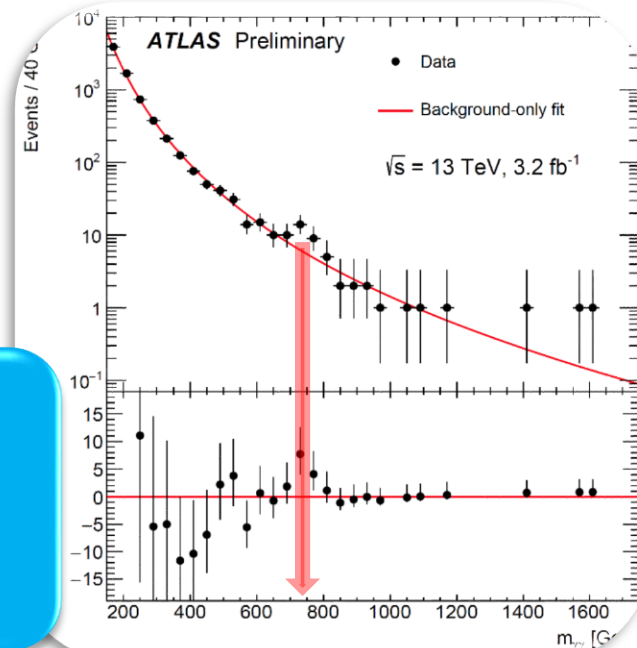
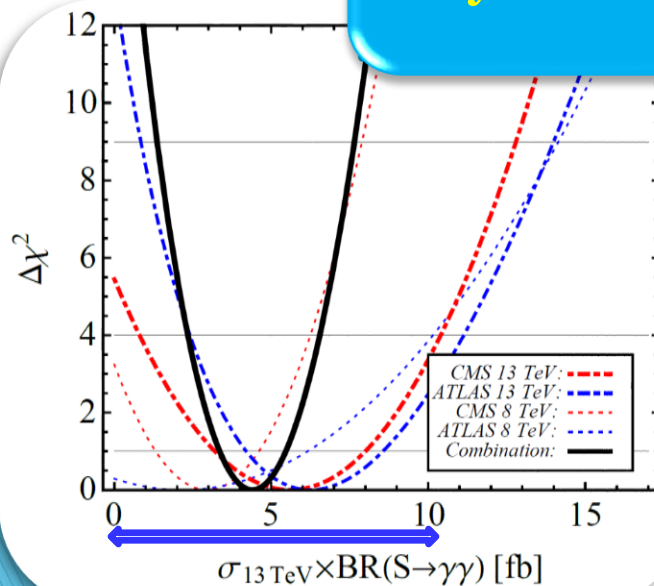
- ❖ **LHC** at **13 TeV**
- ❖ **ATLAS** (3.2 fb^{-1} , $\sim 750 \text{ GeV}$)
signal significance: 3.9σ (local), 2.3σ (global)
- ❖ **CMS** (2.6 fb^{-1} , $\sim 760 \text{ GeV}$)
signal significance: 2.6σ (local-narrow width),
 2.0σ (local-wide width), 1.2σ (global)



New Resonance at ~ 750 GeV?

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signal significance: 3.9σ (local), 2.3σ (global)
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Well covered
by other speakers



New Resonance at ~ 750 GeV?

❖ Up to yesterday more than 123 papers

The screenshot shows the INSPIRE website interface. At the top, the INSPIRE logo is on the left, and a welcome message is on the right. Below the logo is a navigation bar with links: HEP, HEPNames, Institutions, Conferences, Jobs, Experiments, Journals, and Help. The search bar contains the text 'ATLAS-CONF-2015-081'. To the right of the search bar are dropdown menus for 'Brief format' and a 'Search' button. Below the search bar, there are links for 'find in "Phys.Rev.Lett.105"' and 'more'. The 'Sort by' section has dropdowns for 'earliest date', 'desc.', '- or rank by -', '25 results', and 'single list'. The 'Display results' section has a dropdown for '25 results' and a dropdown for 'single list'. The search results section shows '1 records found' and 'Search took 0.09 seconds.' The first result is '1. Search for resonances decaying to photon pairs in 3.2 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector'. Below this title, it says 'The ATLAS collaboration. Dec 15, 2015. ATLAS-CONF-2015-081'. There are links for 'References', 'BibTeX', 'LaTeX(US)', 'LaTeX(EU)', 'Harvmac', and 'EndNote'. Below these links, there is a link for 'CERN Document Server' and a link for 'Link to Fulltext'. The 'Detailed record' link is circled in red, and it shows 'Cited by 123 records' with a '00+' icon. At the bottom, there is a yellow box with the text 'Interested in being notified about new results for this query? Subscribe to the RSS feed.'

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ATLAS-CONF-2015-081 Brief format Search [Easy Search](#) [Advanced Search](#)

[find in "Phys.Rev.Lett.105"](#) :: [more](#)

Sort by: Display results:

earliest date desc. - or rank by - 25 results single list

HEP 1 records found Search took 0.09 seconds.

1. Search for resonances decaying to photon pairs in 3.2 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS collaboration. Dec 15, 2015.
ATLAS-CONF-2015-081

[References](#) | [BibTeX](#) | [LaTeX\(US\)](#) | [LaTeX\(EU\)](#) | [Harvmac](#) | [EndNote](#)
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~750 GeV Dark Messenger?

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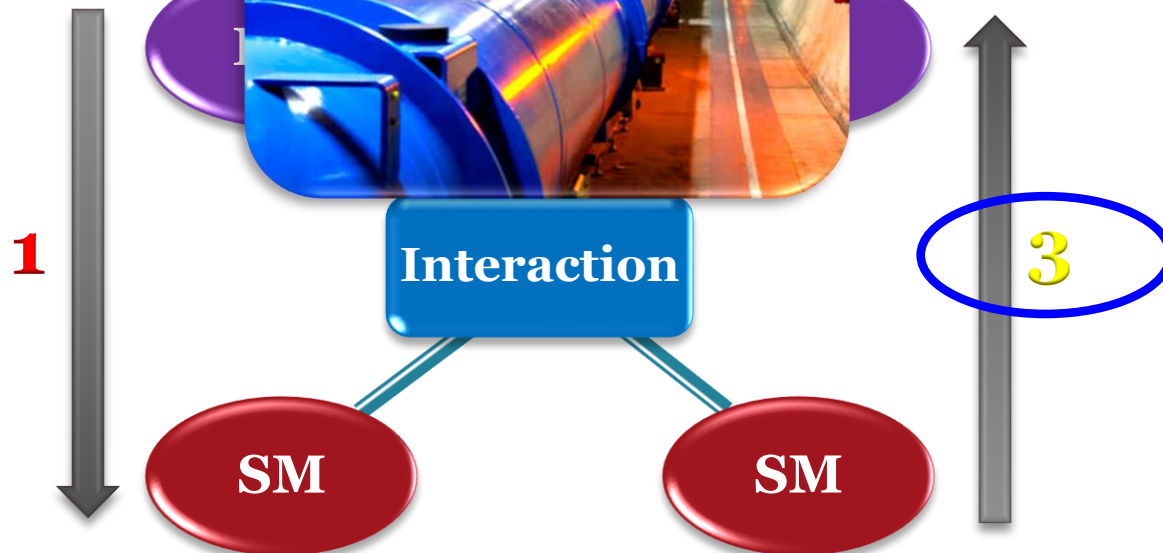
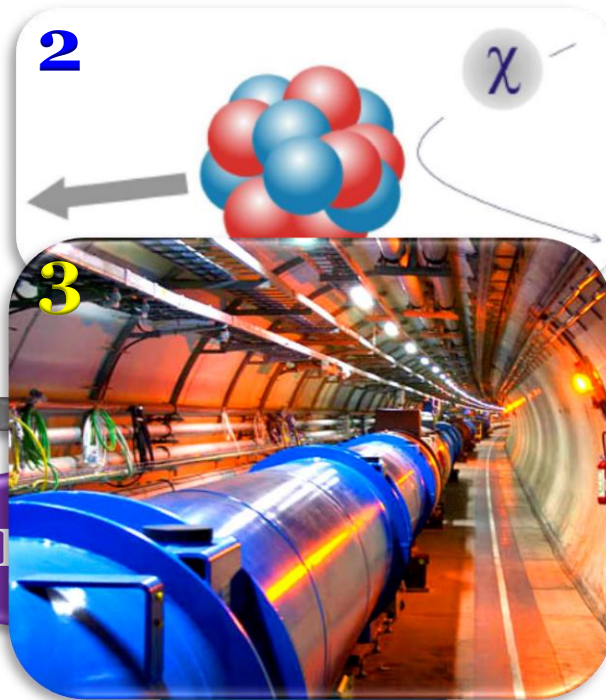
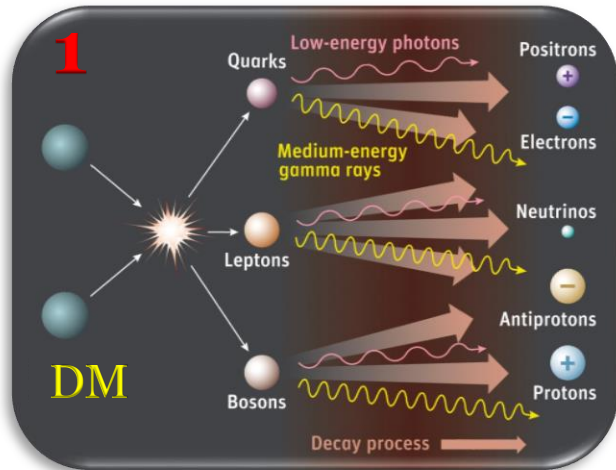
[find i "Phys.Rev.Lett.,105"](#) :: [more](#)

Sort by: earliest date desc. - or rank by - Display results: 25 results single list

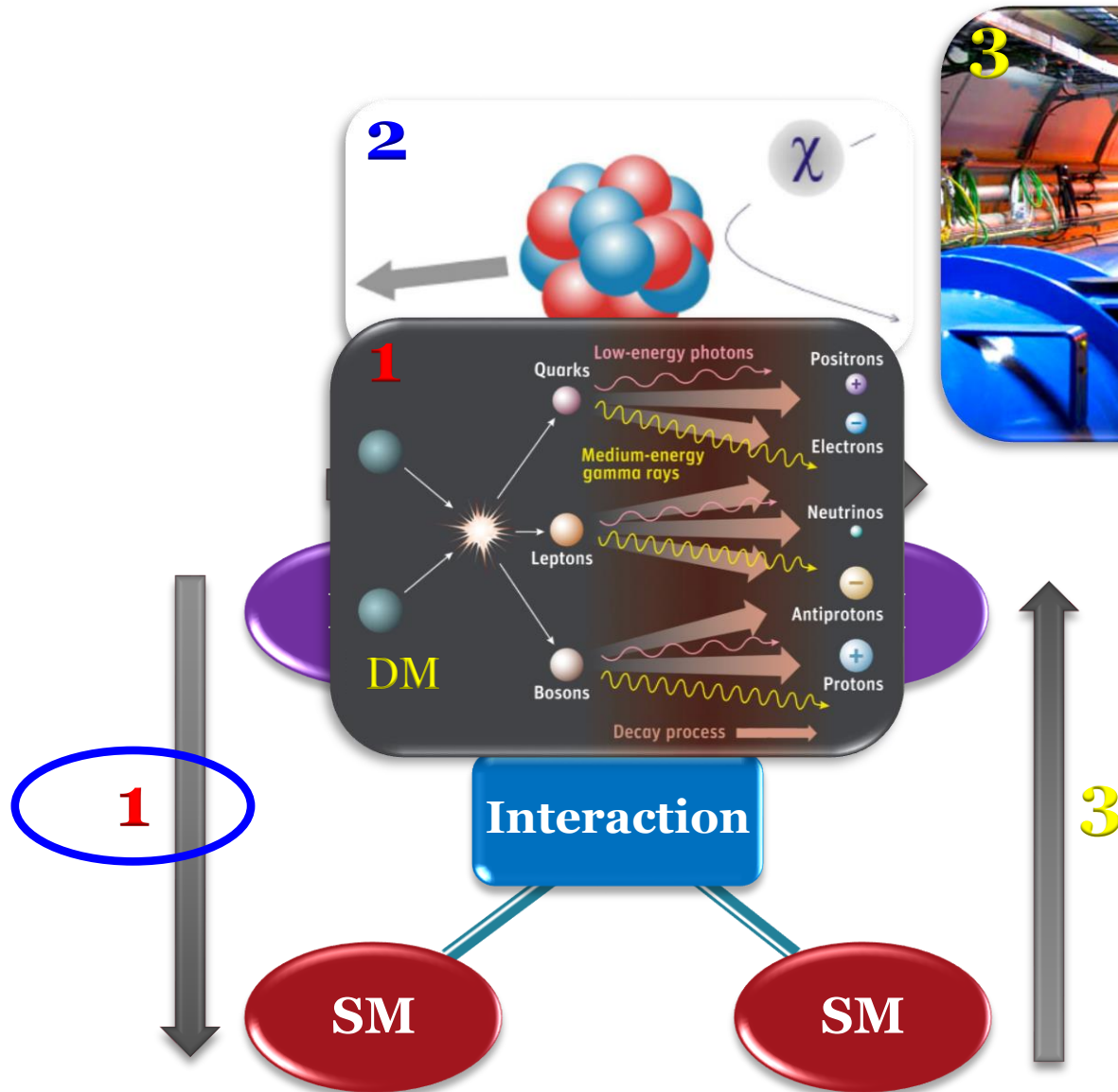
HEP **9 records found** Search took 0.13 seconds.

1. **A 750 GeV dark matter messenger at the Galactic Center**
Xian-Jun Huang, Wei-Hong Zhang, Yu-Feng Zhou. Dec 30, 2015. 12 pp.
e-Print: [arXiv:1512.08992](#) [hep-ph] | [PDF](#)
[References](#) | [BibTeX](#) | [LaTeX\(US\)](#) | [LaTeX\(EU\)](#) | [Harvmac](#) | [EndNote](#)
[ADS Abstract Service](#)
[Detailed record](#) - **Cited by 4 records**

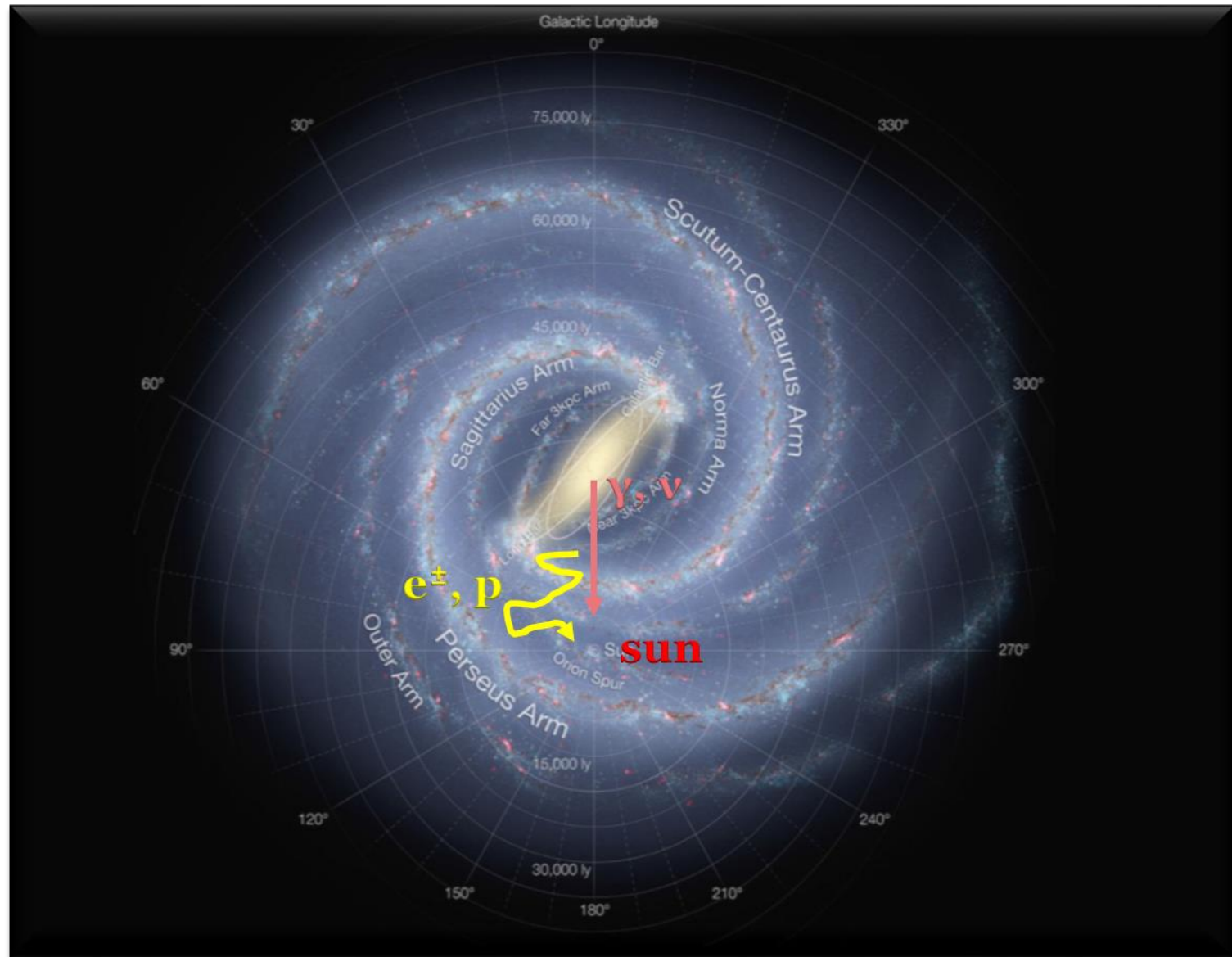
Collider Search: LHC



DM Indirect Detection



Indirect Detection: Cosmic-rays



Experiments

❖ Ground-based

→ MAGIC, HESS, CTA,
Super-K, IceCube, ...



❖ Balloon-based

→ PPB-BETS, ATIC, ...

❖ Satellite-based

→ PAMELA, Fermi-LAT, AMS,
DAMPE, ASTROGAM, ...



- ✓ **Great sensitivity** to cosmic-ray signals
- ✓ Better chance to have the information for **extracting DM properties**

Experiments

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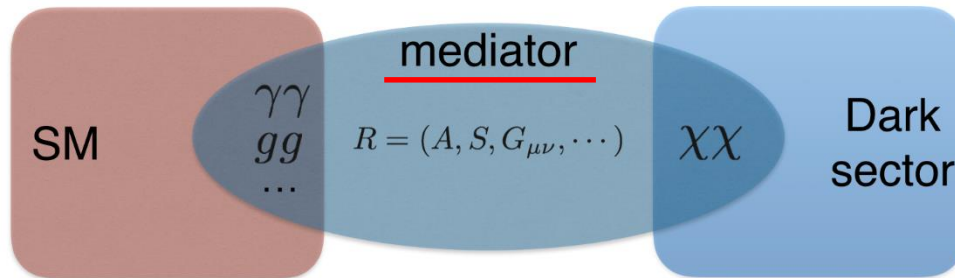
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- ✓ **Great sensitivity** to cosmic-ray signals
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Which One?



750 GeV Resonance & Mediator

- ❖ We take the resonance as a mediator between SM & Dark sectors.
 - Spin=1 (vector): **X** (Landau-Yang theorem or Furry's theorem)
 - Spin=0⁺ (scalar): **No indirect detection** (v^2 suppression)
 - Spin=2 (tensor): **No indirect detection** (v^2 suppression) (Hyun Min's talk)
 - Spin=0⁻ (pseudo-scalar): **Our choice!**
 - Other possibilities: See e.g. Wonsang's talk.

Model Set-up I

- ❖ **Effective Lagrangian** for a Dirac fermion DM

$$\mathcal{L}_A = -\frac{A}{\Lambda} \left(a_1 F_{\mu\nu}^Y \tilde{F}^{Y\mu\nu} + a_2 W_{\mu\nu} \tilde{W}^{\mu\nu} + a_3 G_{\mu\nu} \tilde{G}^{\mu\nu} \right) - i\lambda_\chi A \bar{\chi} \gamma^5 \chi$$

- ❖ **Pseudo-scalar A** can be **produced via gluon fusion**: $\sigma(pp \rightarrow A) \propto (a_3/\Lambda)^2$,
decaying into a pair of SM gauge bosons: $\gamma\gamma, Z\gamma, ZZ, WW, gg$.

$$a_{\gamma\gamma} = a_1 \cos^2 \theta_W + a_2 \sin^2 \theta_W$$

$$a_{Z\gamma} = (a_2 - a_1) \sin(2\theta_W)$$

$$a_{ZZ} = a_1 \sin^2 \theta_W + a_2 \cos^2 \theta_W$$

$$a_{WW} = 2a_2$$

$$a_{gg} = a_3$$

- ❖ For generic spin & CP states which couple to dibosons:

See e.g. D. Kim, KC Kong, H. M. Lee & S. C. Park, arXiv: 1507.06312

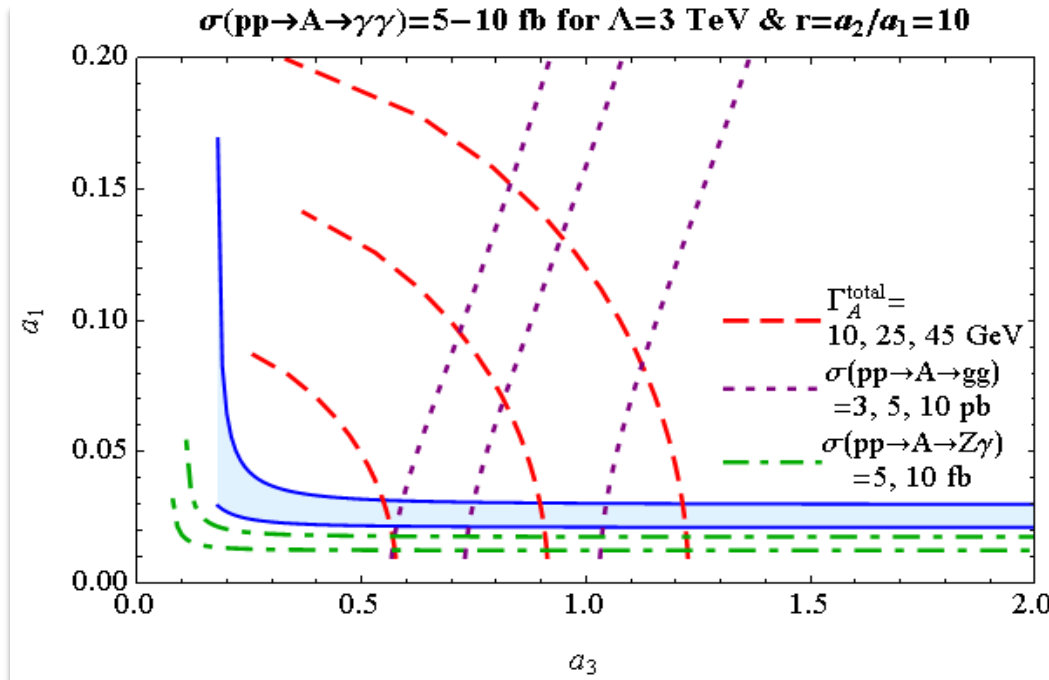
Model Set-up II

❖ Annihilation X-sections of DM & Decay rates of A

$$\begin{aligned}
 \langle \sigma v_{\text{rel}} \rangle_{\gamma\gamma} &= \frac{\lambda_\chi^2 a_{\gamma\gamma}^2}{4\pi\Lambda^2} \frac{16m_\chi^4}{(4m_\chi^2 - m_A^2)^2 + \Gamma_A^2 m_A^2} + \mathcal{O}(v_{\text{rel}}^2) \\
 \langle \sigma v_{\text{rel}} \rangle_{Z\gamma} &= \frac{\lambda_\chi^2 a_{Z\gamma}^2}{8\pi\Lambda^2} \frac{16m_\chi^4}{(4m_\chi^2 - m_A^2)^2 + \Gamma_A^2 m_A^2} \left(1 - \frac{m_Z^2}{4m_\chi^2}\right)^3 + \mathcal{O}(v_{\text{rel}}^2) \\
 \langle \sigma v_{\text{rel}} \rangle_{ZZ} &= \frac{\lambda_\chi^2 a_{ZZ}^2}{4\pi\Lambda^2} \frac{16m_\chi^4}{(4m_\chi^2 - m_A^2)^2 + \Gamma_A^2 m_A^2} \left(1 - \frac{m_Z^2}{m_\chi^2}\right)^{3/2} + \mathcal{O}(v_{\text{rel}}^2) \\
 \langle \sigma v_{\text{rel}} \rangle_{WW} &= \frac{\lambda_\chi^2 a_{WW}^2}{8\pi\Lambda^2} \frac{16m_\chi^4}{(4m_\chi^2 - m_A^2)^2 + \Gamma_A^2 m_A^2} \left(1 - \frac{m_W^2}{m_\chi^2}\right)^{3/2} + \mathcal{O}(v_{\text{rel}}^2) \\
 \langle \sigma v_{\text{rel}} \rangle_{gg} &= \frac{2\lambda_\chi^2 a_{gg}^2}{\pi\Lambda^2} \frac{16m_\chi^4}{(4m_\chi^2 - m_A^2)^2 + \Gamma_A^2 m_A^2} + \mathcal{O}(v_{\text{rel}}^2)
 \end{aligned}$$

$$\begin{aligned}
 \Gamma_A(\gamma\gamma) &= \frac{m_A^3}{4\pi\Lambda^2} a_{\gamma\gamma}^2 \\
 \Gamma_A(Z\gamma) &= \frac{m_A^3}{8\pi\Lambda^2} a_{Z\gamma}^2 \left(1 - \frac{m_Z^2}{m_A^2}\right)^3 \\
 \Gamma_A(ZZ) &= \frac{m_A^3}{4\pi\Lambda^2} a_{ZZ}^2 \left(1 - \frac{4m_Z^2}{m_A^2}\right)^{\frac{3}{2}} \\
 \Gamma_A(WW) &= \frac{m_A^3}{8\pi\Lambda^2} a_{WW}^2 \left(1 - \frac{4m_W^2}{m_A^2}\right)^{\frac{3}{2}} \\
 \Gamma_A(gg) &= \frac{2m_A^3}{\pi\Lambda^2} a_{gg}^2 \\
 \Gamma_A(\bar{\chi}\chi) &= \frac{\lambda_\chi^2 m_A}{8\pi} \left(1 - \frac{4m_\chi^2}{m_A^2}\right)^{\frac{3}{2}} \theta\left(\frac{m_A}{2m_\chi} - 1\right)
 \end{aligned}$$

Scenario-I: $a_2 \gg a_1$



$$\sigma(pp \rightarrow A \rightarrow XX) \equiv \sigma_A \times \text{Br}_{XX}$$

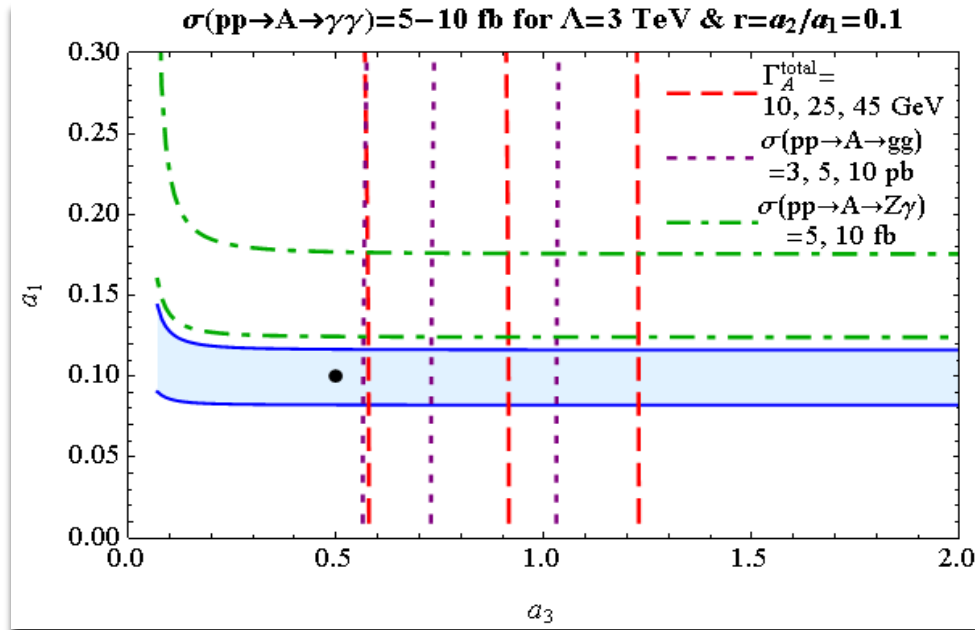
➤ Relative branching fractions

→ **stringent limit** on

$$\sigma(pp \rightarrow A \rightarrow Z\gamma)$$

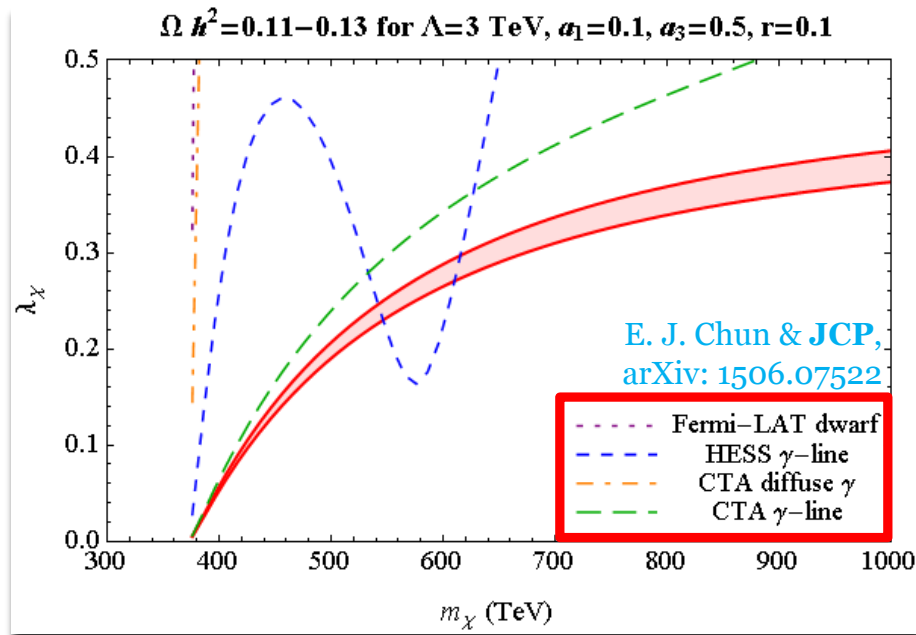
$$\begin{aligned} & \gamma\gamma : \gamma Z : ZZ : WW : gg \\ & \approx 1 : \frac{2}{\tan^2 \theta_W} : \frac{1}{\tan^4 \theta_W} : \frac{2}{\sin^4 \theta_W} : \frac{8}{\sin^4 \theta_W} \left(\frac{a_3}{a_2} \right)^2 \\ & \approx 1 : \underline{7} : \underline{11} : \underline{38} : \frac{150}{r^2} \left(\frac{a_3}{a_1} \right)^2 \end{aligned}$$

Scenario-II: $a_2 \ll a_1$



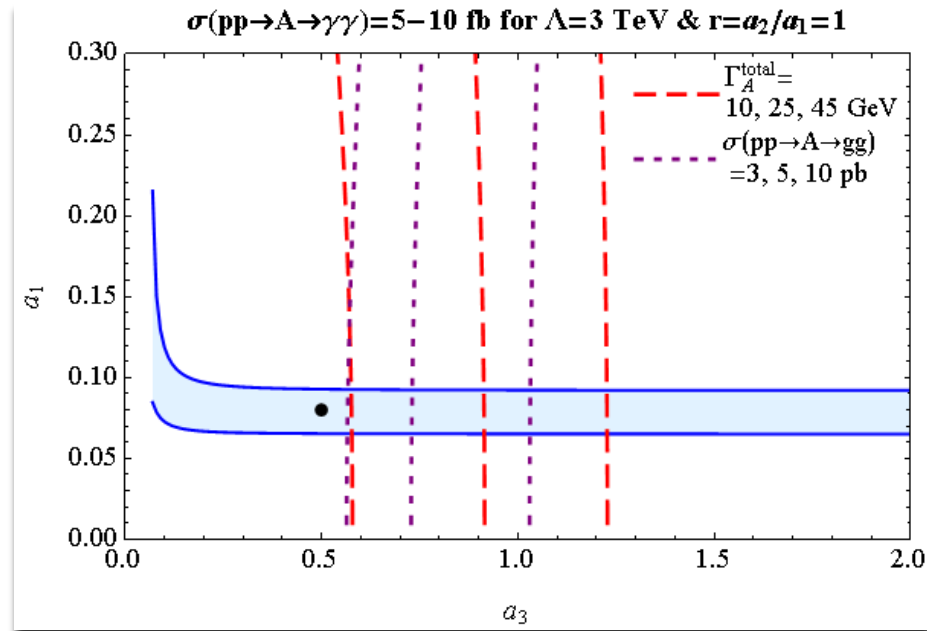
- Relative branching fractions
- $$\gamma\gamma : \gamma Z : ZZ : WW : gg$$
- $$\approx 1 : 2 \tan^2 \theta_W : \tan^4 \theta_W : \left(\frac{a_2}{a_1} \right)^2 : \frac{8}{\cos^4 \theta_W} \left(\frac{a_3}{a_1} \right)^2$$
- $$\approx 1 : \underline{0.6} : \underline{0.09} : \ll 1 : 13.5 \left(\frac{a_3}{a_1} \right)^2$$

Scenario-II: $a_2 \ll a_1$



$$\underbrace{\gamma\gamma : \gamma Z : ZZ : WW : gg}_{\gamma\text{-line}} \quad \underbrace{\gamma\gamma : \gamma Z : ZZ : WW : gg}_{\gamma\text{-bump}}$$

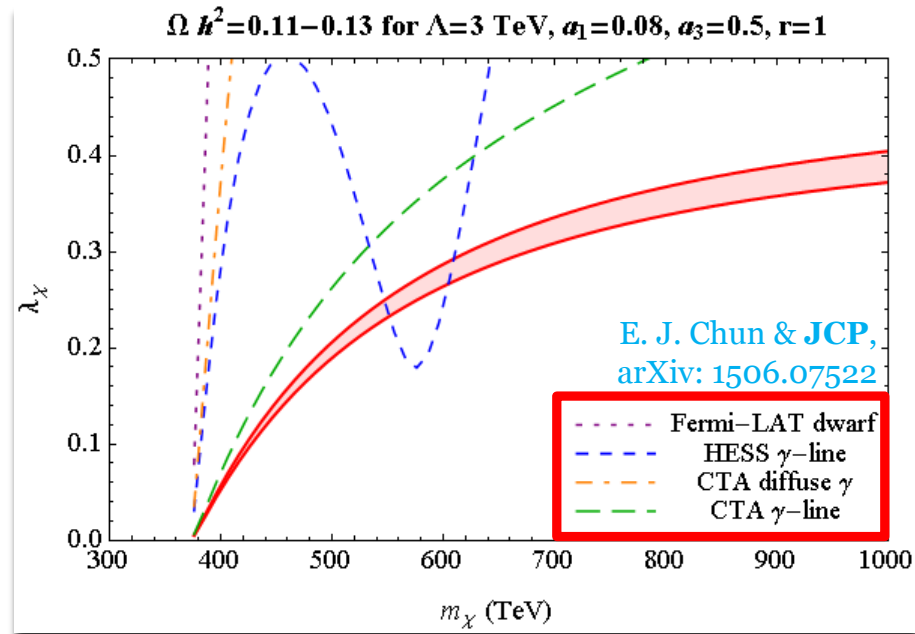
Scenario-III: $a_2 \approx a_1$



➤ Relative branching fractions

$$\begin{aligned}
 & \gamma\gamma : \underline{\gamma Z} : ZZ : WW : \underline{gg} \\
 & \approx \underline{1 : 0 : 1 : 2 : 8} \left(\frac{a_3}{a_1} \right)^2
 \end{aligned}$$

Scenario-III: $a_2 \approx a_1$



$\gamma\gamma : \gamma Z : ZZ : WW : gg$

γ -line

γ -bump

Conclusions

- New resonance at ~ 750 GeV via diphoton channel?
- If yes, it can be a mediator connecting Dark & SM sectors.
- Pseudo-scalar mediator with LHC constraints
- DM indirect signature: Fermi-LAT, HESS, CTA, ...

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**If Real, we Really need
100 TeV machine!!**

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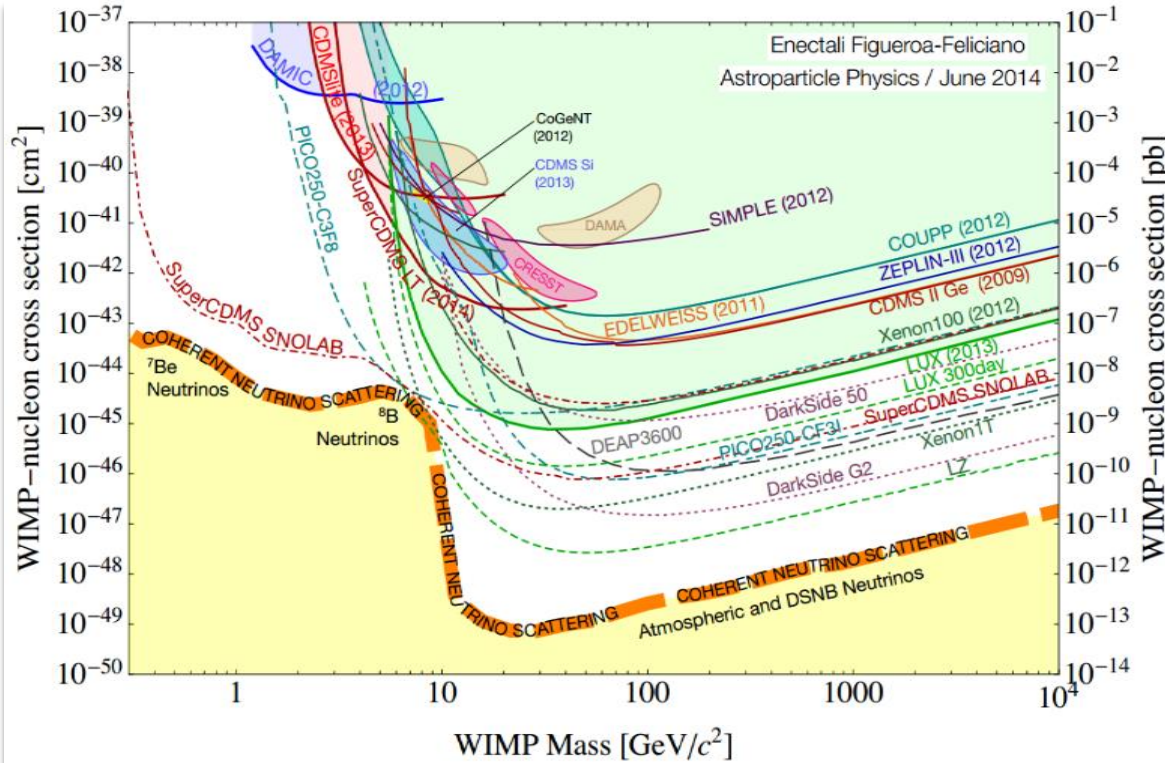
**If Real, we Really need
100 TeV machine!!**

Thank you

Back-Up

Direct Detection

❖ DM-N scattering X-section on contact operators

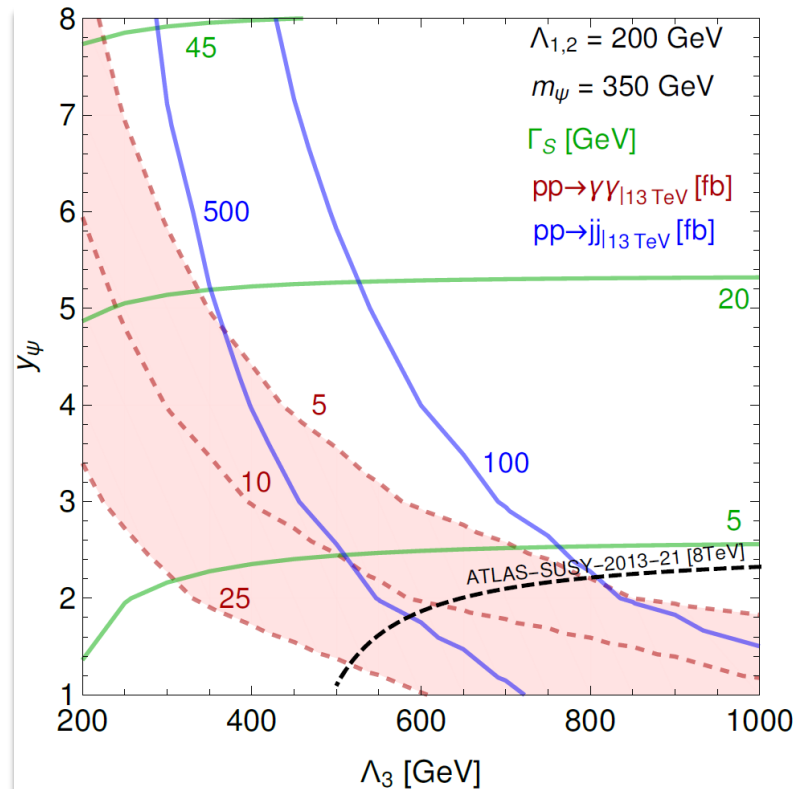


$\Delta\mathcal{L}$	Int.	Suppression
$\mathcal{O}_s^\phi : \frac{1}{\Lambda} \phi^\dagger \phi \bar{f} f$	SI	1
$\mathcal{O}_v^\phi : \frac{1}{\Lambda^2} \phi^\dagger \partial^\mu \phi \bar{f} \gamma_\mu f$	SI	1
$\mathcal{O}_{va}^\phi : \frac{1}{\Lambda^2} \phi^\dagger \partial^\mu \phi \bar{f} \gamma_\mu \gamma^5 f$	SD	v^2
$\mathcal{O}_p^\phi : \frac{1}{\Lambda} \phi^\dagger \phi \bar{f} i \gamma^5 f$	SD	q^2
$\mathcal{O}_s^\psi : \frac{1}{\Lambda^2} \bar{\psi} \psi \bar{f} f$	SI	1
$\mathcal{O}_v^\psi : \frac{1}{\Lambda^2} \bar{\psi} \gamma^\mu \psi \bar{f} \gamma_\mu f$	SI	1
$\mathcal{O}_a^\psi : \frac{1}{\Lambda^2} \bar{\psi} \gamma^\mu \gamma^5 \psi \bar{f} \gamma_\mu \gamma^5 f$	SD	1
$\mathcal{O}_t^\psi : \frac{1}{\Lambda^2} \bar{\psi} \sigma^{\mu\nu} \psi \bar{f} \sigma_{\mu\nu} f$	SD	1
$\mathcal{O}_p^\psi : \frac{1}{\Lambda^2} \bar{\psi} \gamma^5 \psi \bar{f} \gamma^5 f$	SD	q^4
$\mathcal{O}_{va}^\psi : \frac{1}{\Lambda^2} \bar{\psi} \gamma^\mu \psi \bar{f} \gamma_\mu \gamma^5 f$	SD	v^2, q^2
$\mathcal{O}_{pt}^\psi : \frac{1}{\Lambda^2} \bar{\psi} i \sigma^{\mu\nu} \gamma^5 \psi \bar{f} \sigma_{\mu\nu} f$	SI	q^2
$\mathcal{O}_{ps}^\psi : \frac{1}{\Lambda^2} \bar{\psi} i \gamma^5 \psi \bar{f} f$	SI	q^2
$\mathcal{O}_{sp}^\psi : \frac{1}{\Lambda^2} \bar{\psi} \psi \bar{f} i \gamma^5 f$	SD	q^2
$\mathcal{O}_{av}^\psi : \frac{1}{\Lambda^2} \bar{\psi} \gamma^\mu \gamma^5 \psi \bar{f} \gamma_\mu f$	SI SD	v^2 q^2
$\hat{\mathcal{O}}_s^\phi : \frac{m_q}{\Lambda^2} \phi^\dagger \phi \bar{f} f$	SI	1
$\hat{\mathcal{O}}_s^\psi : \frac{m_q}{\Lambda^3} \bar{\psi} \psi \bar{f} f$	SI	1
$\hat{\mathcal{O}}_p^\psi : \frac{m_q}{\Lambda^3} \bar{\psi} \gamma^5 \psi \bar{f} \gamma^5 f$	SD	q^4

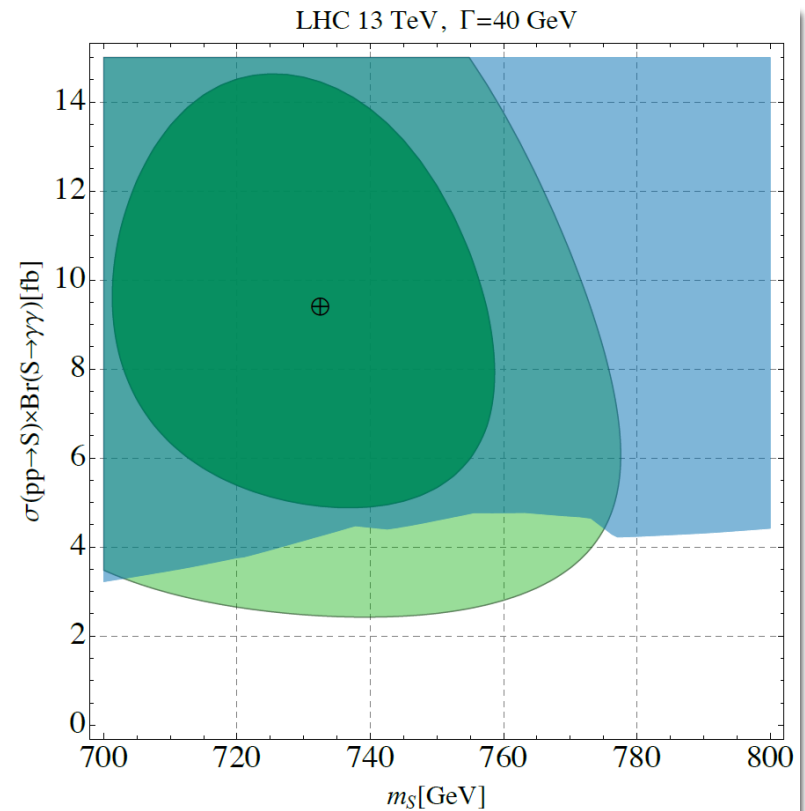
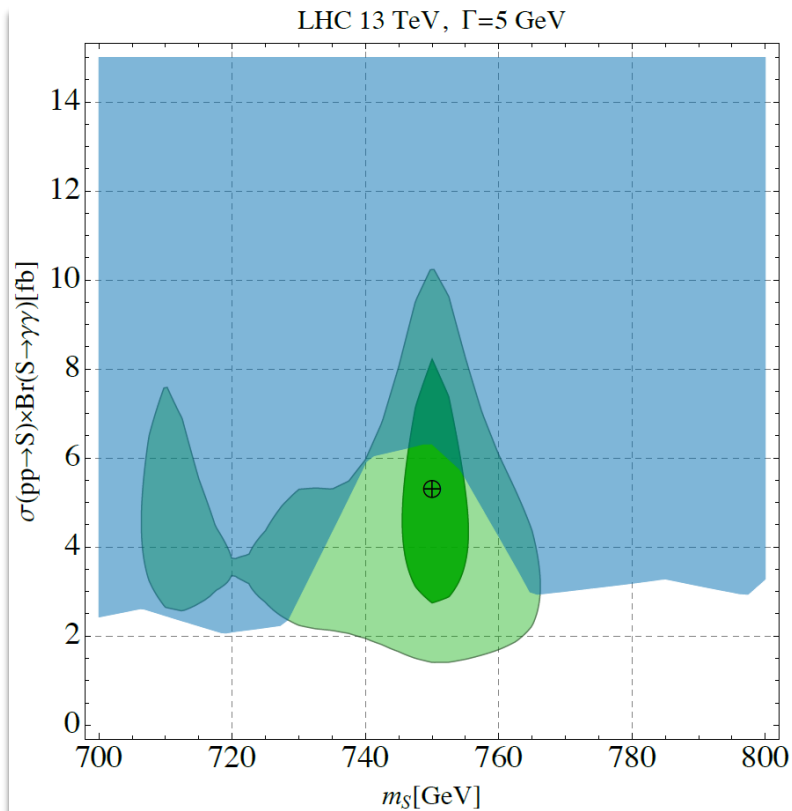
Mono-jet constraint

$$\mathcal{L}_{\text{NP,CPE}} = \frac{1}{2}(\partial_\mu s)^2 - \frac{\mu_s^2}{2}s^2 + \frac{1}{2}\bar{\psi}(i\not{\partial}_\mu - m_\psi)\psi - \frac{y_\psi}{2}s\bar{\psi}\psi$$

$$- \frac{g_1^2}{4\pi} \frac{1}{4\Lambda_1} s B_{\mu\nu} B^{\mu\nu} - \frac{g_2^2}{4\pi} \frac{1}{4\Lambda_2} s W_{\mu\nu} W^{\mu\nu} - \frac{g_3^2}{4\pi} \frac{1}{4\Lambda_3} s G_{\mu\nu} G^{\mu\nu}$$



Wide vs Narrow ? (13 TeV)



Wide vs Narrow ? (8+13 TeV)

