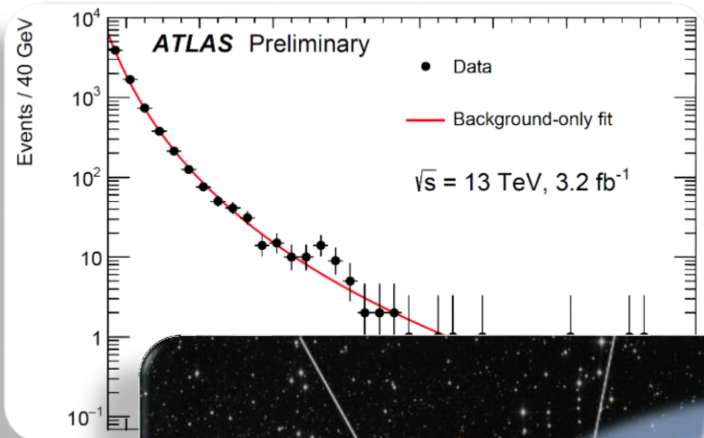
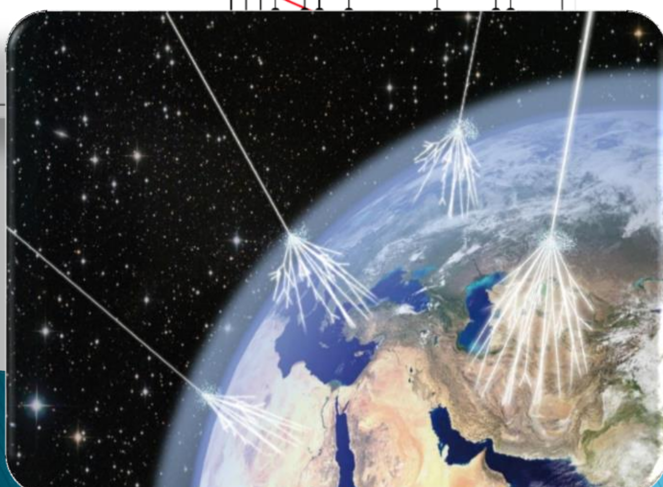
DM indirect signature & 750 GeV diphoton resonance

JCP & Seong Chan Park
[arXiv: 1512.08117]





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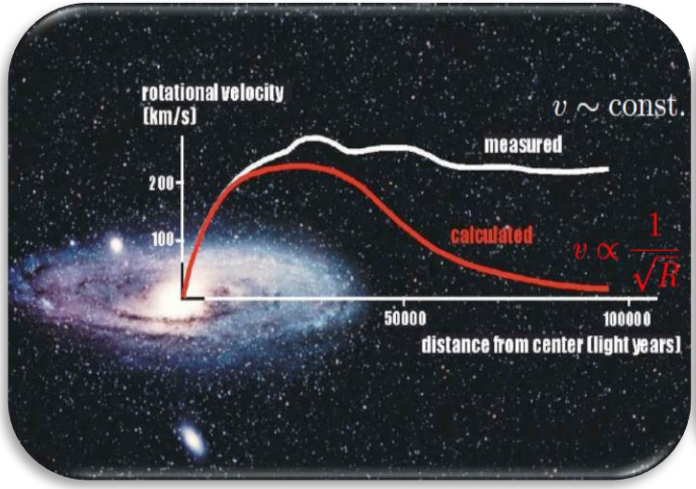
CHUNGNAM NATIONAL UNIVERSITY

January 08, 2016

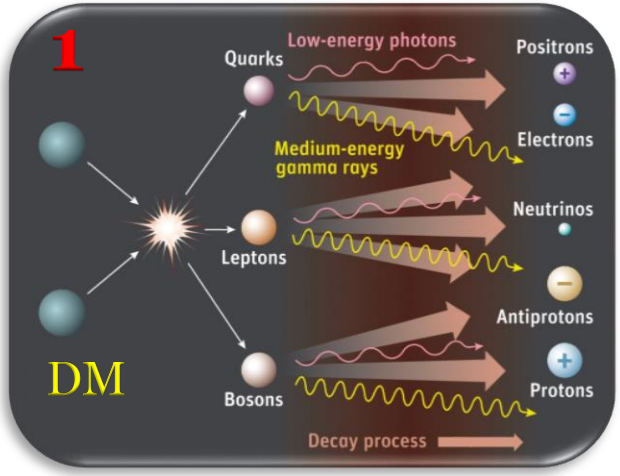
Overview on the recent di-photon excess at the LHC Run 2
@ IBS CTPU

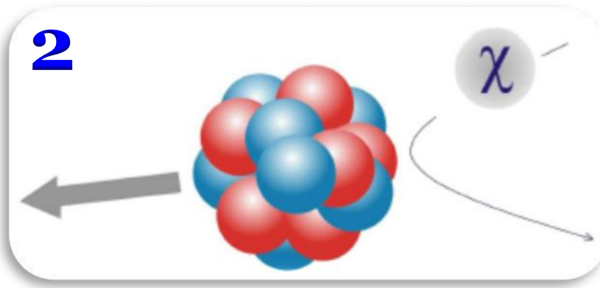
Dark Matter (DM)

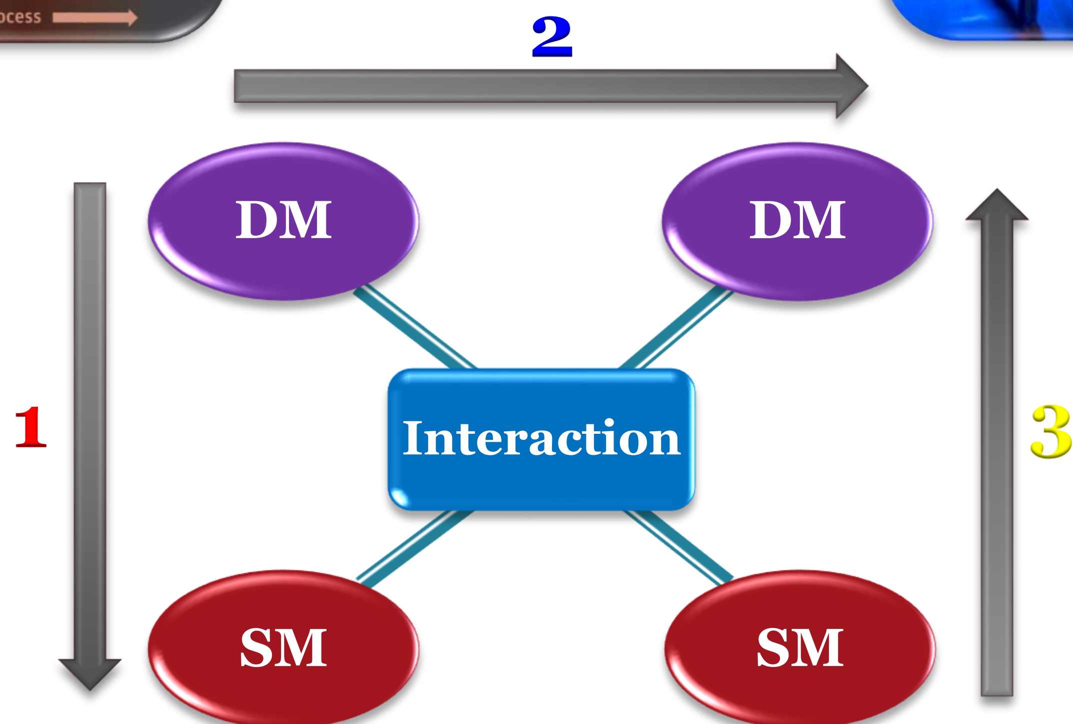
- **DM**: ~25% of our Universe
- **Compelling paradigm**:
  massive, non-luminous & stable particles
- **Evidence**
  - ✓ Galaxy rotation curve
  - ✓ Bullet cluster
  - ✓ Gravitational lensing
  - ✓ Structure formation
  - ✓ CMB
  - ✓ Coma Cluster
  - ✓ Sky surveys
  - ✓ ...



DM Search Strategies







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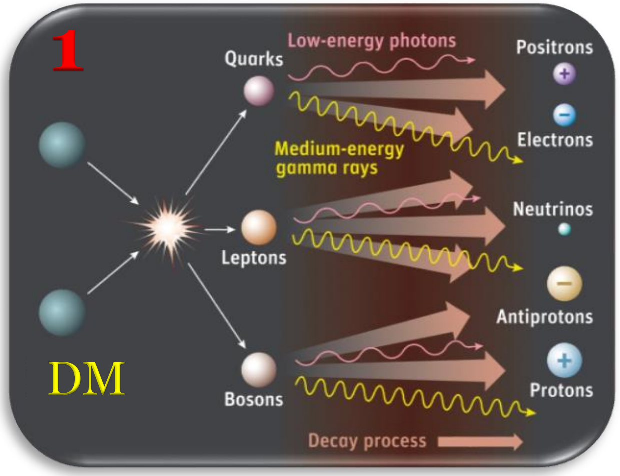
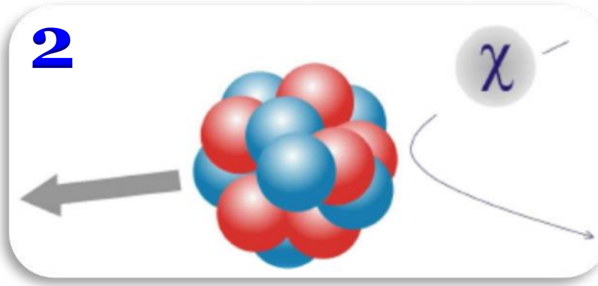
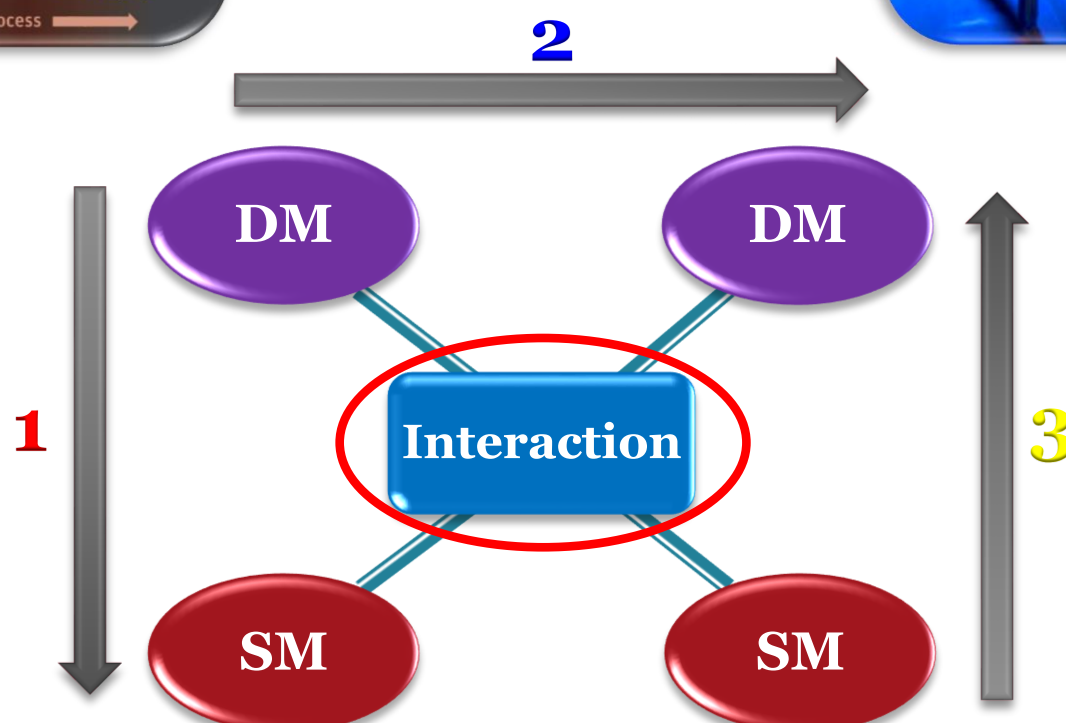
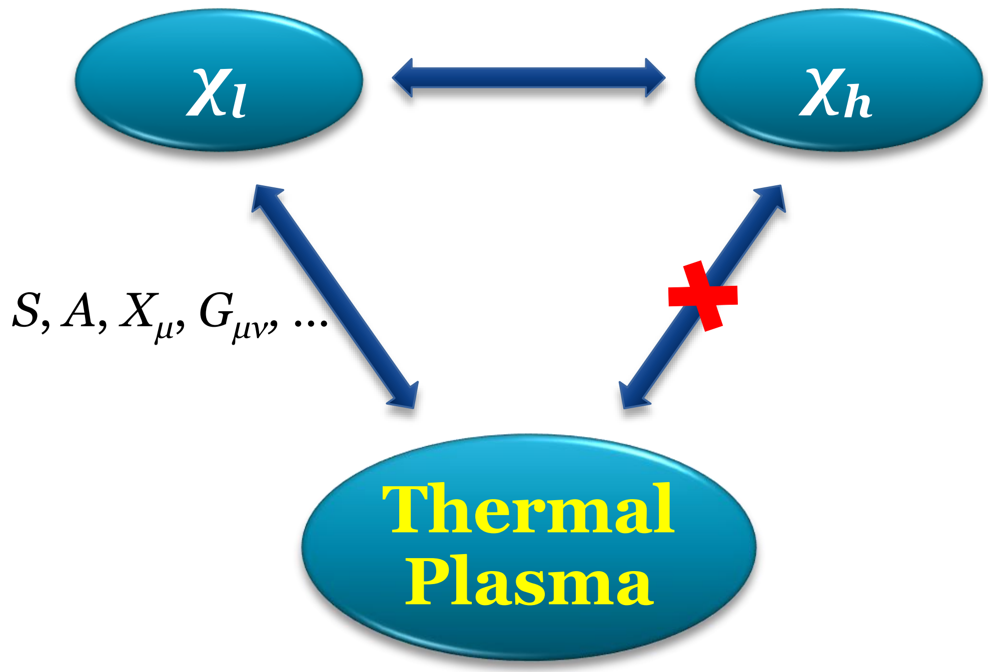




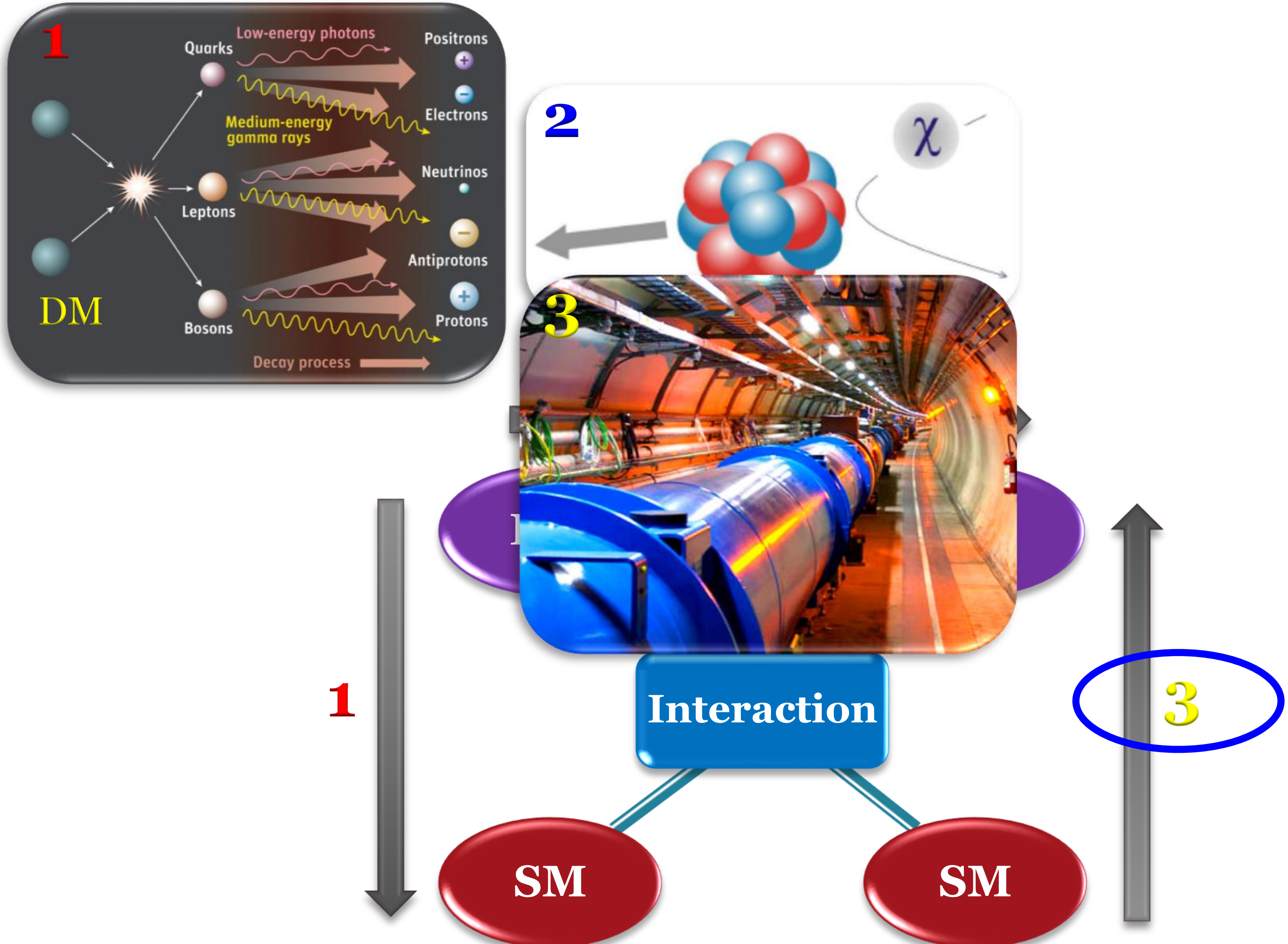


Mediator between Dark & SM

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



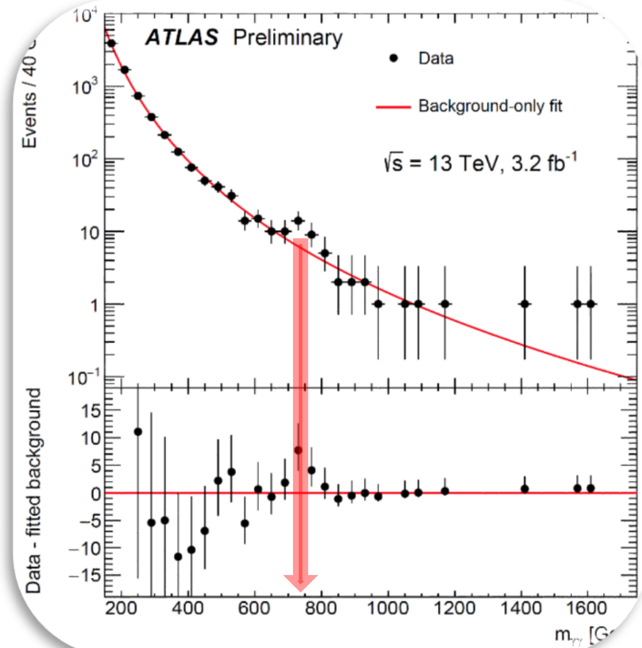
Collider Search: LHC

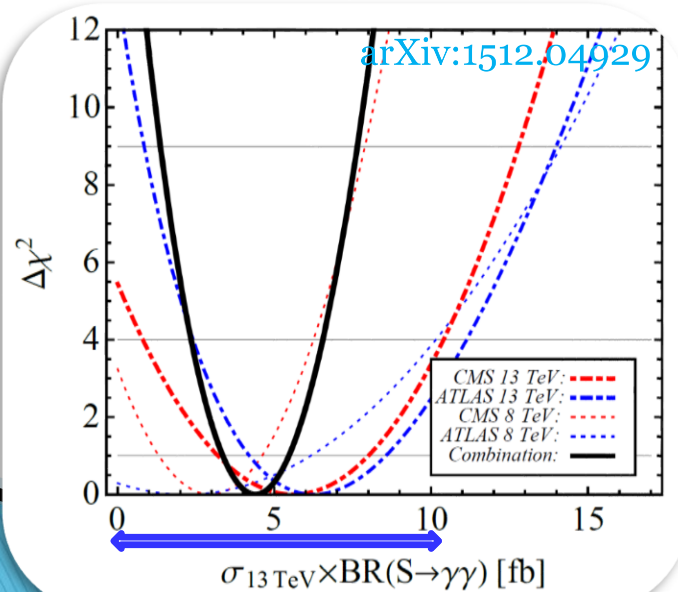


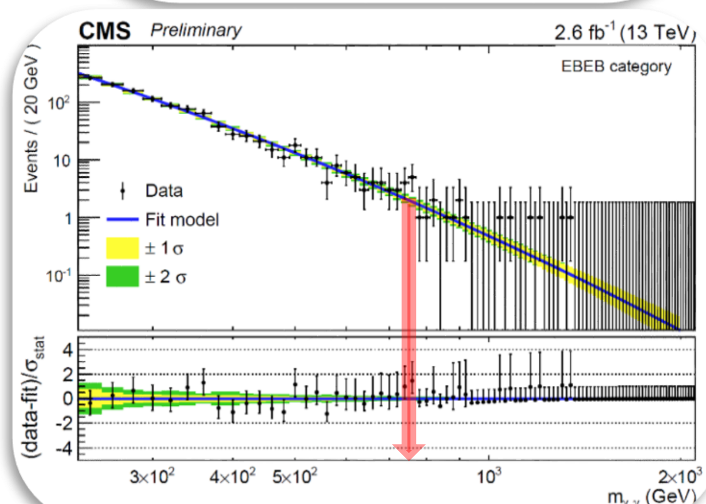
New Resonance @ ~750 GeV ?

New Resonance at ~750 GeV?

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







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- **LHC** at 13 TeV
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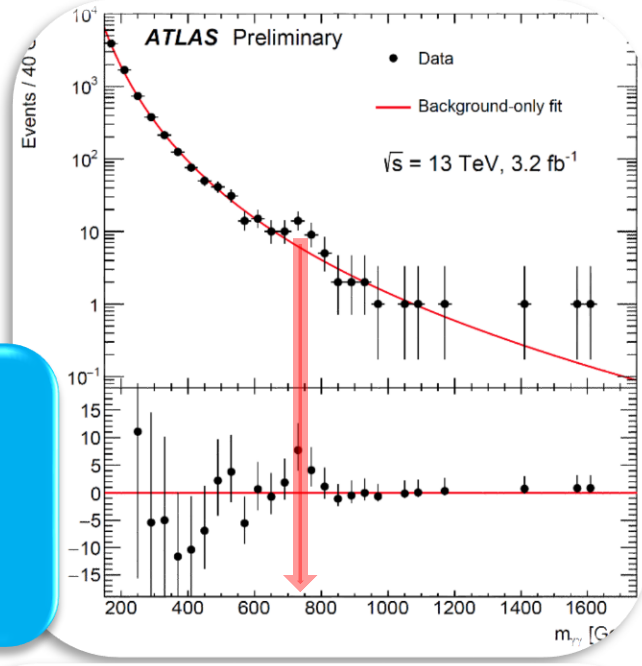
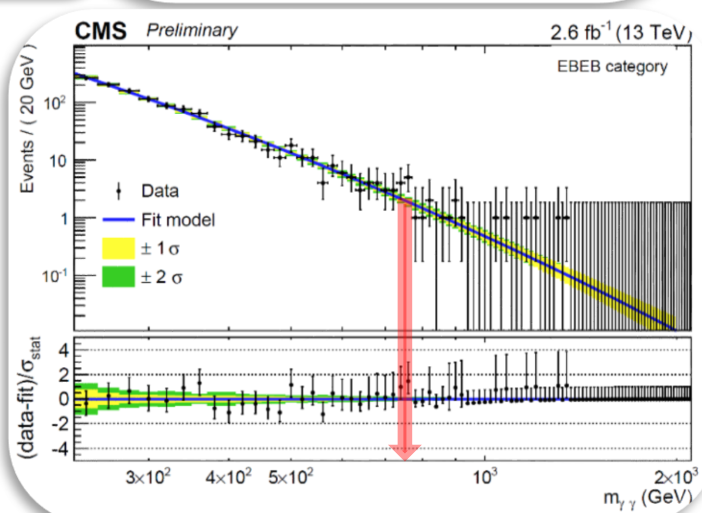
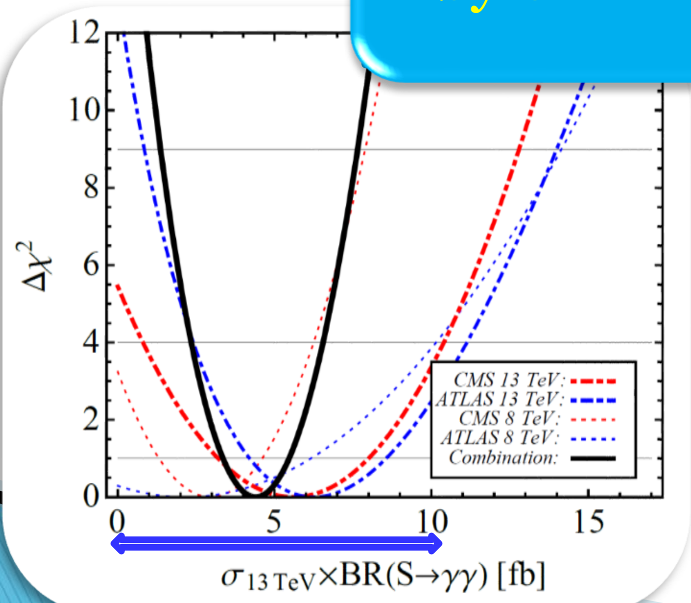
- **CMS** (2.6 fb^{-1}, ~760 G
  signal significance: 2
  2.0 σ (local-wide wid

Well covered
by other speakers

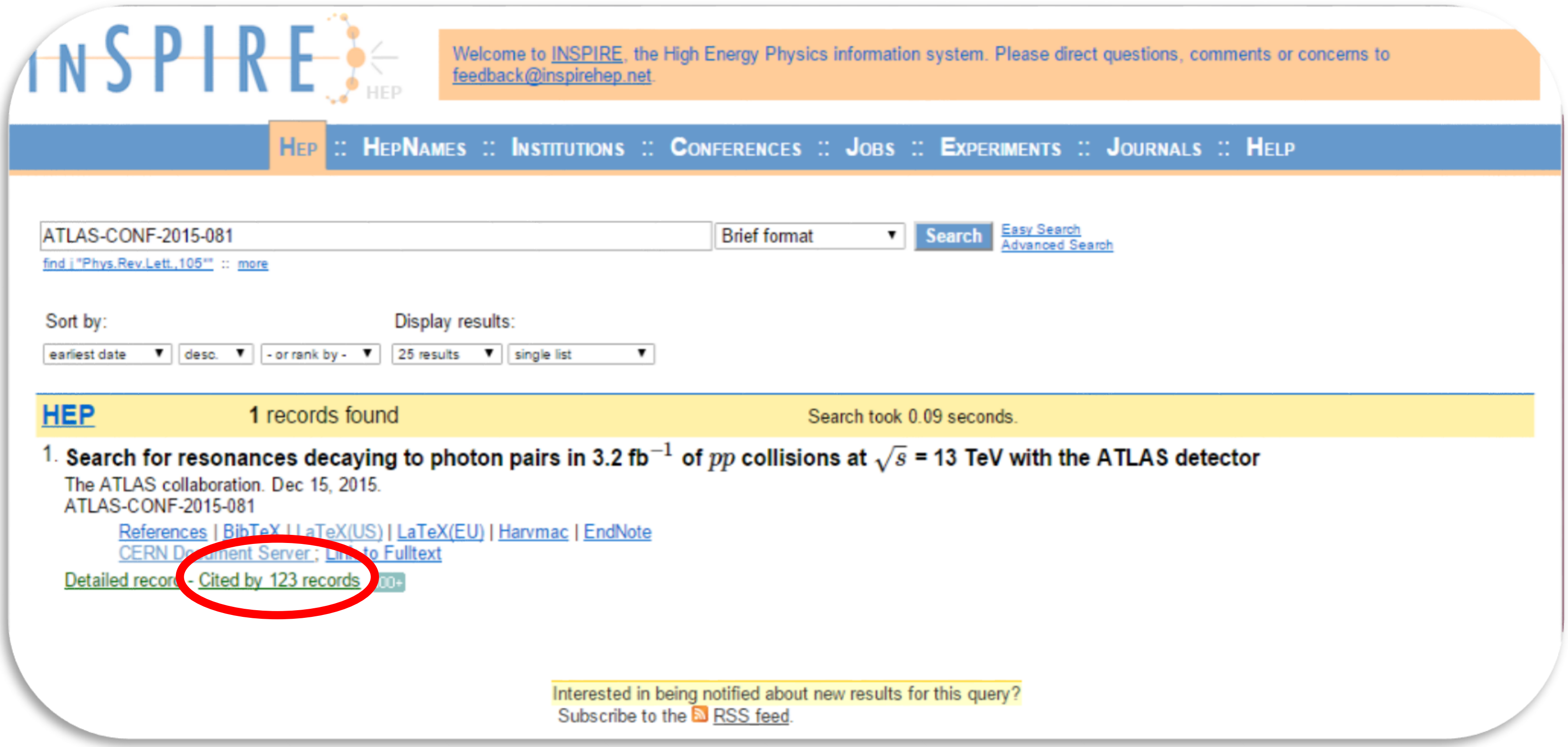






New Resonance at ~750 GeV?

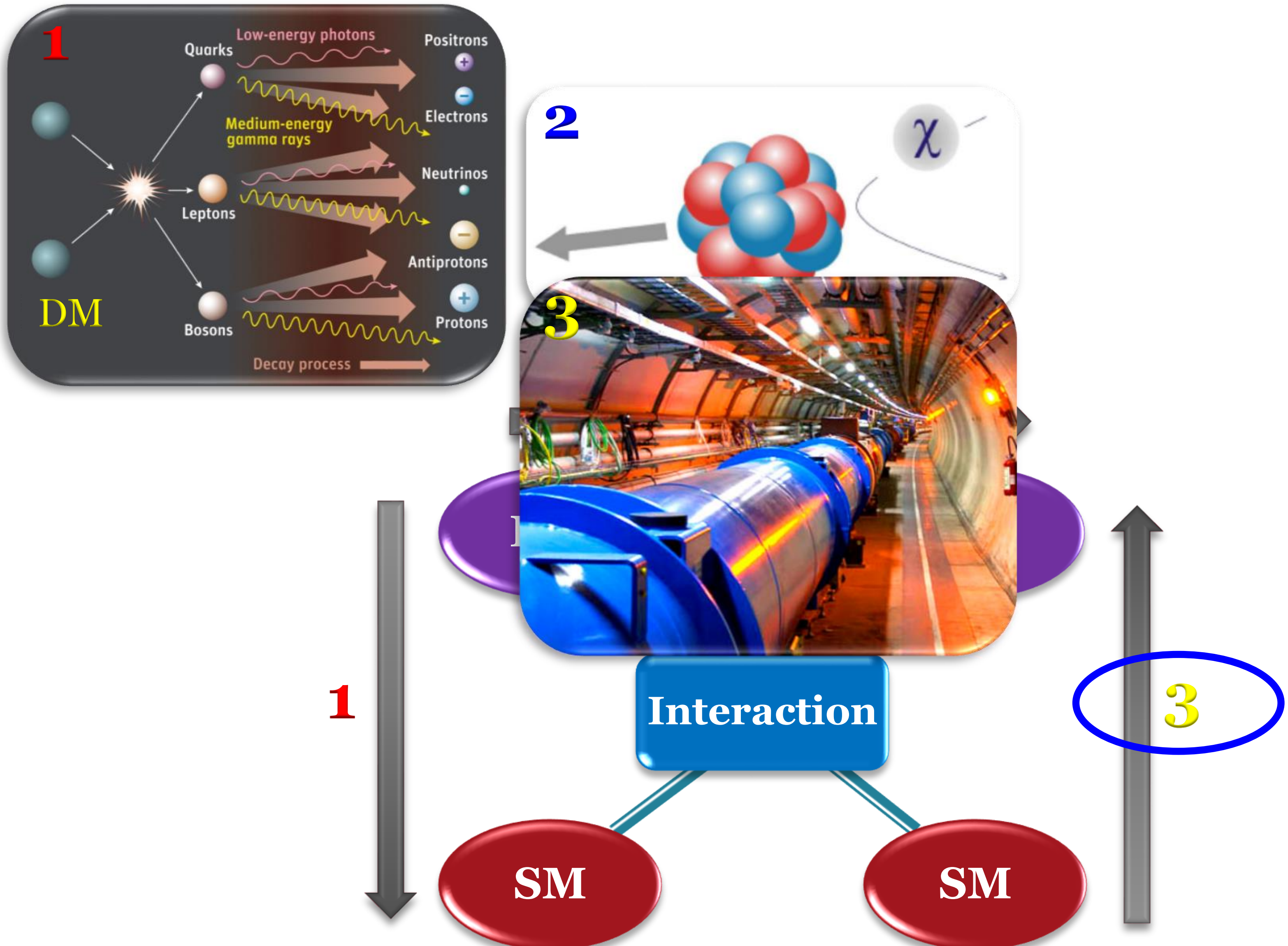
- **Up to yesterday** more than 123 papers



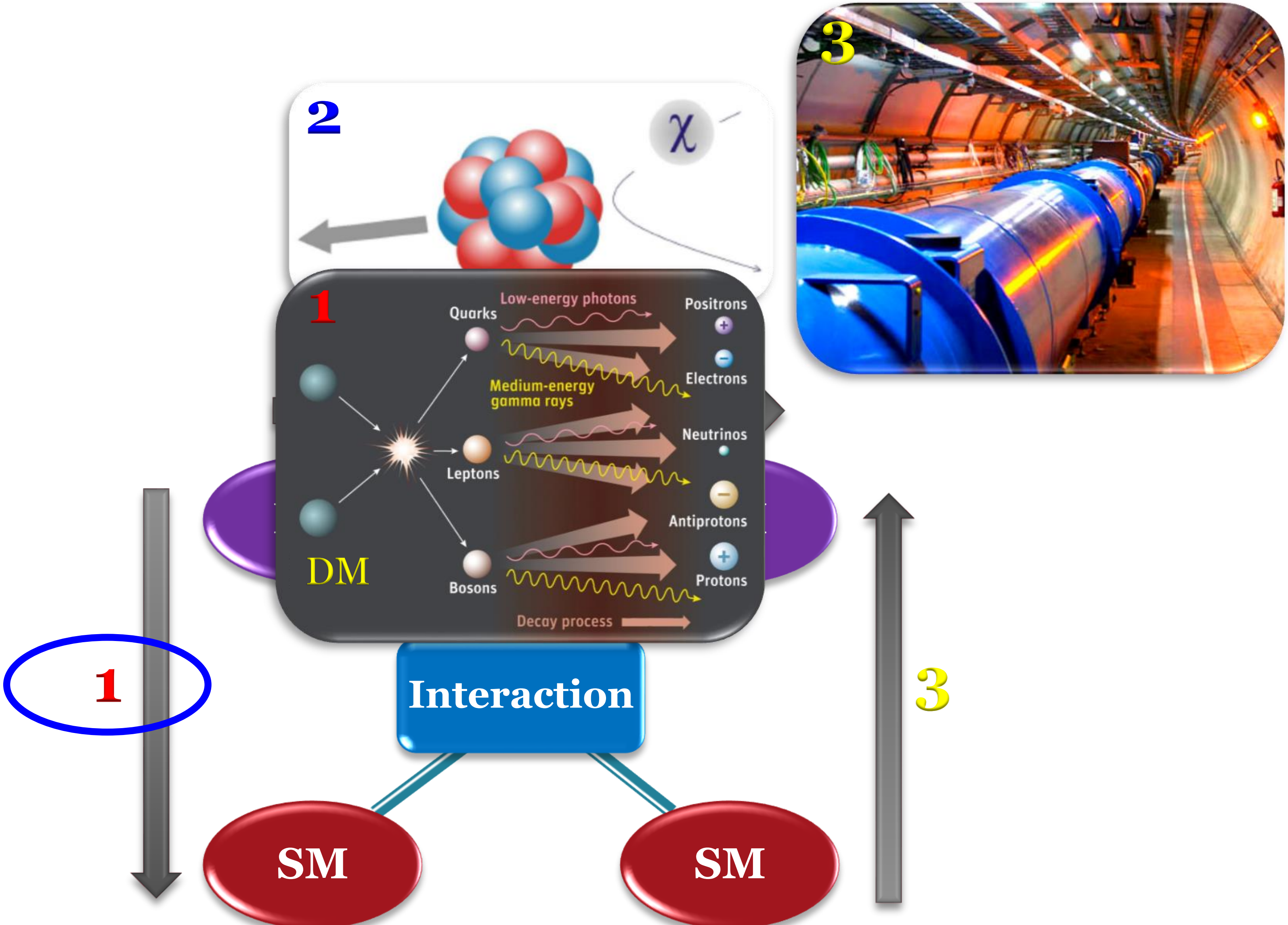
~750 GeV Dark Messenger?

- **Up to yesterday** less than 10 papers

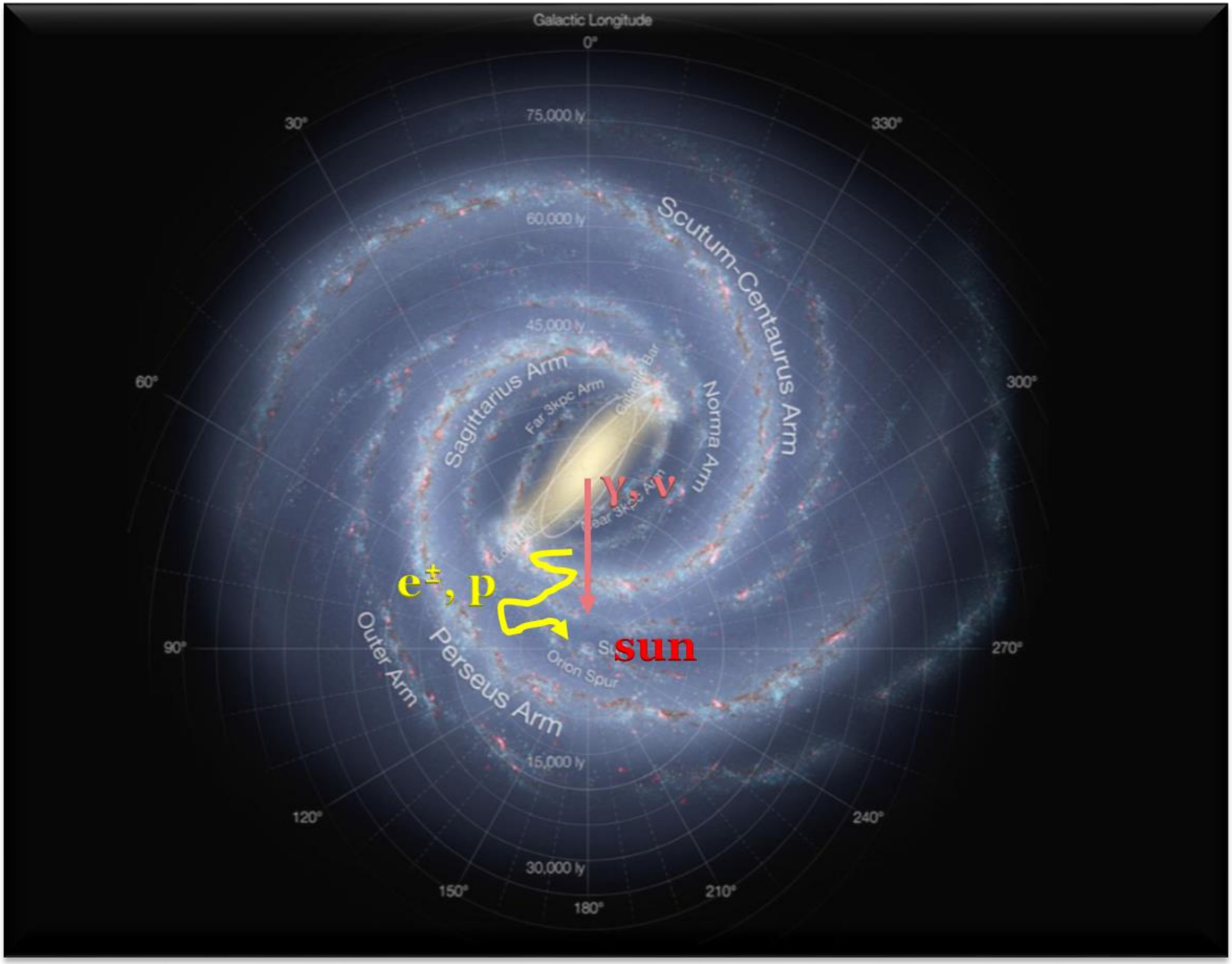
Collider Search: LHC



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

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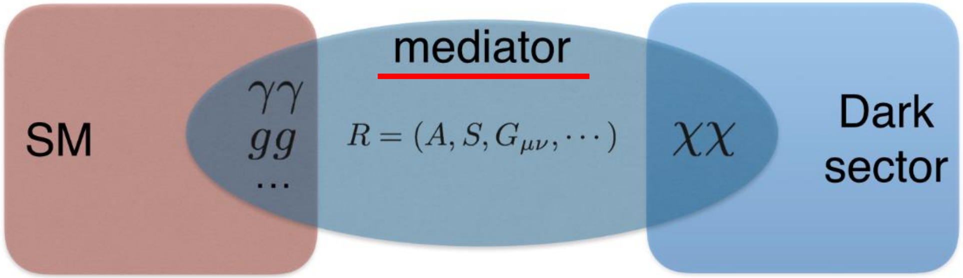
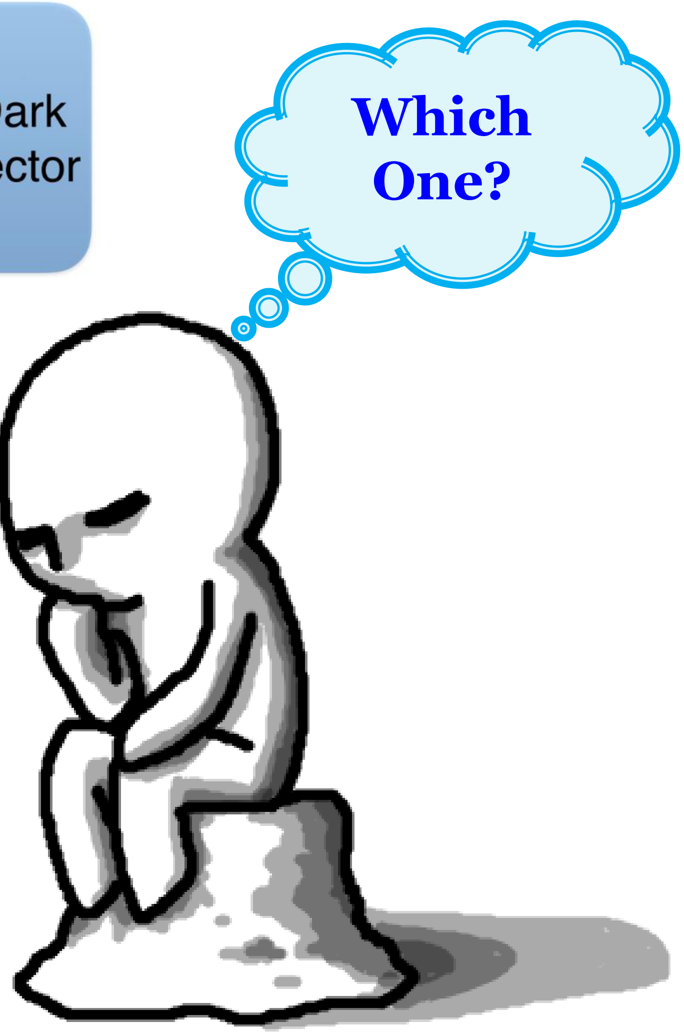
DAMPE (Dec 17, 2015)


mediator
SM
$\gamma\gamma$
gg
$\cdots$
$R = (A, S, G_{\mu\nu}, \cdots)$
$\chi\chi$
Dark
sector


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

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

❖ Pseudo-scalar *A* can be produced via gluon fusion: $\sigma(pp \to A) \propto (a_3/\Lambda)^2$,

decaying into a pair of SM gauge bosons: *γγ, Zγ, 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

JCP & S. C. Park, arXiv: 1512.08117

Model Set-up II

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

$$\langle \sigma v_{\rm rel}\rangle_{\gamma\gamma} = \frac{\lambda_\chi^2 a_{\gamma\gamma}^2}{4\pi\Lambda^2}\frac{16 m_\chi^4}{(4m_\chi^2 - m_A^2)^2 + \Gamma_A^2 m_A^2} + \mathcal{O}(v_{\rm rel}^2)$$

$$\langle \sigma v_{\rm rel}\rangle_{Z\gamma} = \frac{\lambda_\chi^2 a_{Z\gamma}^2}{8\pi\Lambda^2}\frac{16 m_\chi^4}{(4m_\chi^2 - m_A^2)^2 + \Gamma_A^2 m_A^2}\left(1 - \frac{m_Z^2}{4m_\chi^2}\right)^3 + \mathcal{O}(v_{\rm rel}^2)$$

$$\langle \sigma v_{\rm rel}\rangle_{ZZ} = \frac{\lambda_\chi^2 a_{ZZ}^2}{4\pi\Lambda^2}\frac{16 m_\chi^4}{(4m_\chi^2 - m_A^2)^2 + \Gamma_A^2 m_A^2}\left(1 - \frac{m_Z^2}{m_\chi^2}\right)^{3/2} + \mathcal{O}(v_{\rm rel}^2)$$

$$\langle \sigma v_{\rm rel}\rangle_{WW} = \frac{\lambda_\chi^2 a_{WW}^2}{8\pi\Lambda^2}\frac{16 m_\chi^4}{(4m_\chi^2 - m_A^2)^2 + \Gamma_A^2 m_A^2}\left(1 - \frac{m_W^2}{m_\chi^2}\right)^{3/2} + \mathcal{O}(v_{\rm rel}^2)$$

$$\langle \sigma v_{\rm rel}\rangle_{gg} = \frac{2\lambda_\chi^2 a_{gg}^2}{\pi\Lambda^2}\frac{16 m_\chi^4}{(4m_\chi^2 - m_A^2)^2 + \Gamma_A^2 m_A^2} + \mathcal{O}(v_{\rm rel}^2)$$

$$\Gamma_A(\gamma\gamma) = \frac{m_A^3}{4\pi\Lambda^2}\, a_{\gamma\gamma}^2$$

$$\Gamma_A(Z\gamma) = \frac{m_A^3}{8\pi\Lambda^2}\, a_{Z\gamma}^2\left(1 - \frac{m_Z^2}{m_A^2}\right)^3$$

$$\Gamma_A(ZZ) = \frac{m_A^3}{4\pi\Lambda^2}\, a_{ZZ}^2\left(1 - \frac{4m_Z^2}{m_A^2}\right)^{\frac{3}{2}}$$

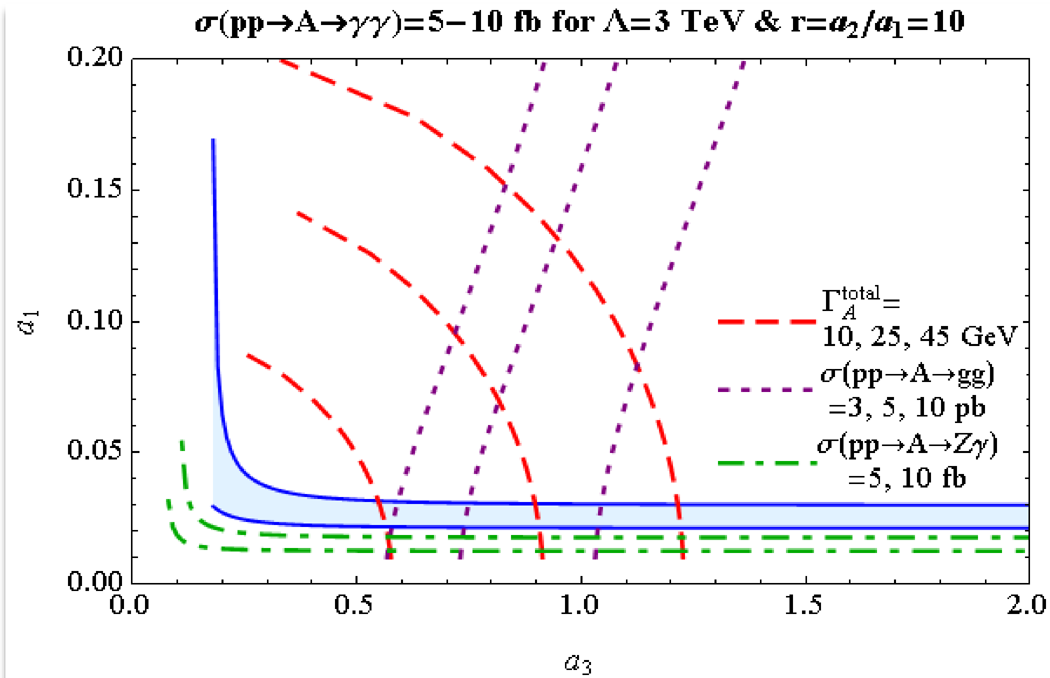
$$\Gamma_A(WW) = \frac{m_A^3}{8\pi\Lambda^2}\, a_{WW}^2\left(1 - \frac{4m_W^2}{m_A^2}\right)^{\frac{3}{2}}$$

$$\Gamma_A(gg) = \frac{2m_A^3}{\pi\Lambda^2}\, a_{gg}^2$$

$$\Gamma_A(\bar\chi\chi) = \frac{\lambda_\chi^2 m_A}{8\pi}\left(1 - \frac{4m_\chi^2}{m_A^2}\right)^{\frac{3}{2}}\theta\left(\frac{m_A}{2m_\chi} - 1\right)$$

A. Ibarra, H. M. Lee, et al., arXiv: 1303.6632

Scenario-I: $a_2 >> a_1$



$$\boxed{\sigma(pp \to A \to XX) \equiv \sigma_A \times \mathrm{Br}_{XX}}$$

- Relative branching fractions
  - → stringent limit on $\sigma(pp \to A \to Z\gamma)$

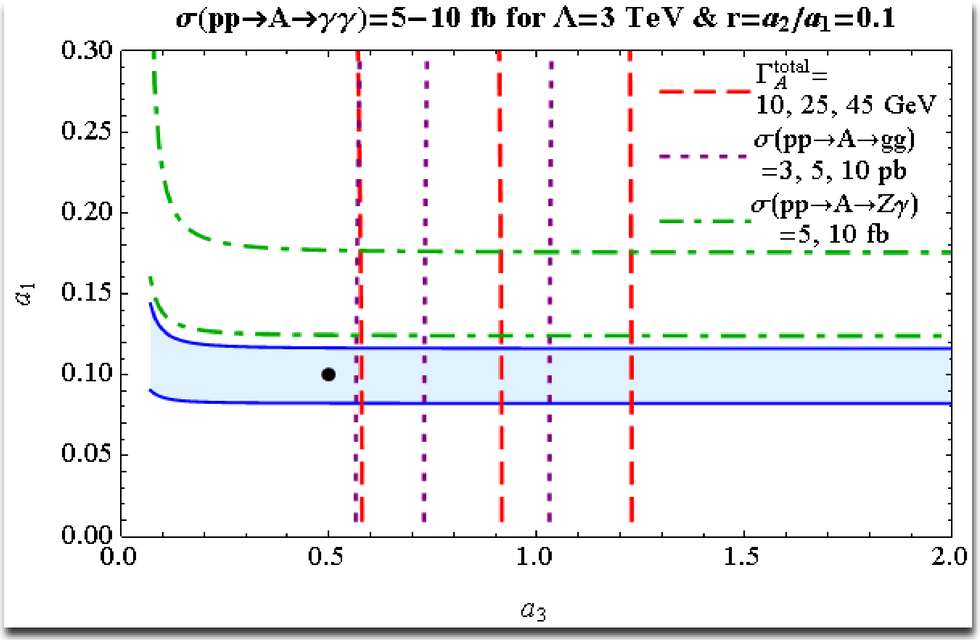
$$\gamma\gamma : \underline{\gamma Z : ZZ : WW} : gg$$

$$\approx 1 : \frac{2}{\tan^2\theta_W} : \frac{1}{\tan^4\theta_W} : \frac{2}{\sin^4\theta_W} : \frac{8}{\sin^4\theta_W}\left(\frac{a_3}{a_2}\right)^2$$

$$\approx 1 : \underline{7 : 11 : 38} : \frac{150}{r^2}\left(\frac{a_3}{a_1}\right)^2$$

JCP & S. C. Park, arXiv: 1512.08117

Scenario-II: $a_2 << a_1$

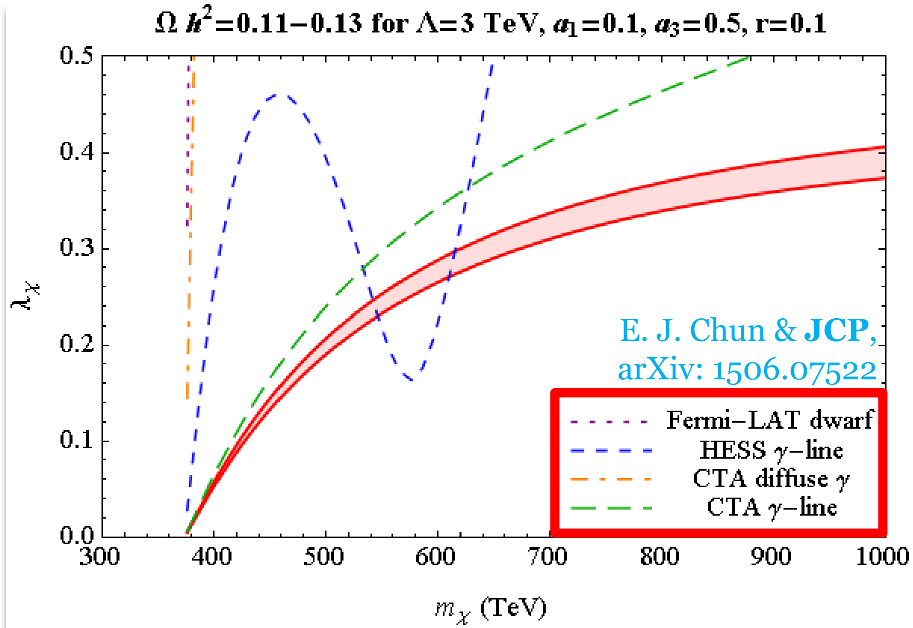


- Relative branching fractions

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

JCP & S. C. Park, arXiv: 1512.08117

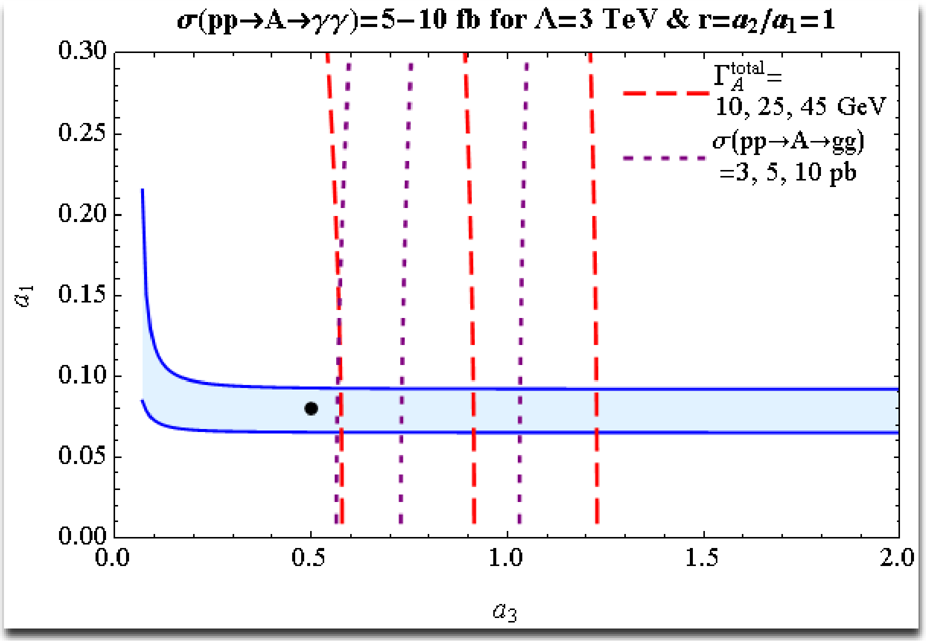
Scenario-II: $a_2 << a_1$



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

JCP & S. C. Park, arXiv: 1512.08117

Scenario-III: $a_2 \approx a_1$

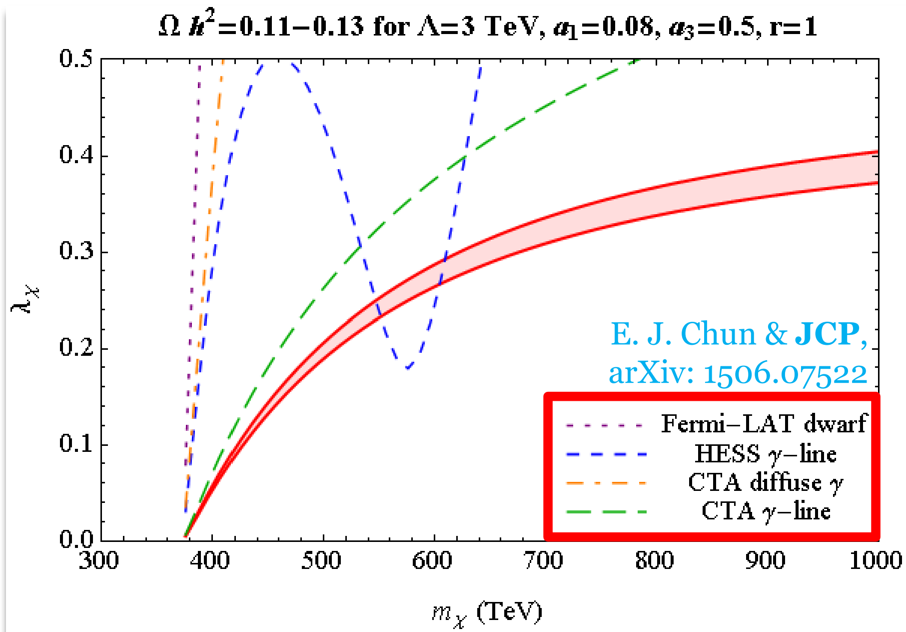


- Relative branching fractions

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

JCP & S. C. Park, arXiv: 1512.08117

Scenario-III: $a_2 \approx a_1$



$$\underline{\gamma\gamma : \gamma Z} : \underline{ZZ : WW} : gg$$

γ-line

γ-bump

JCP & S. C. Park, arXiv: 1512.08117

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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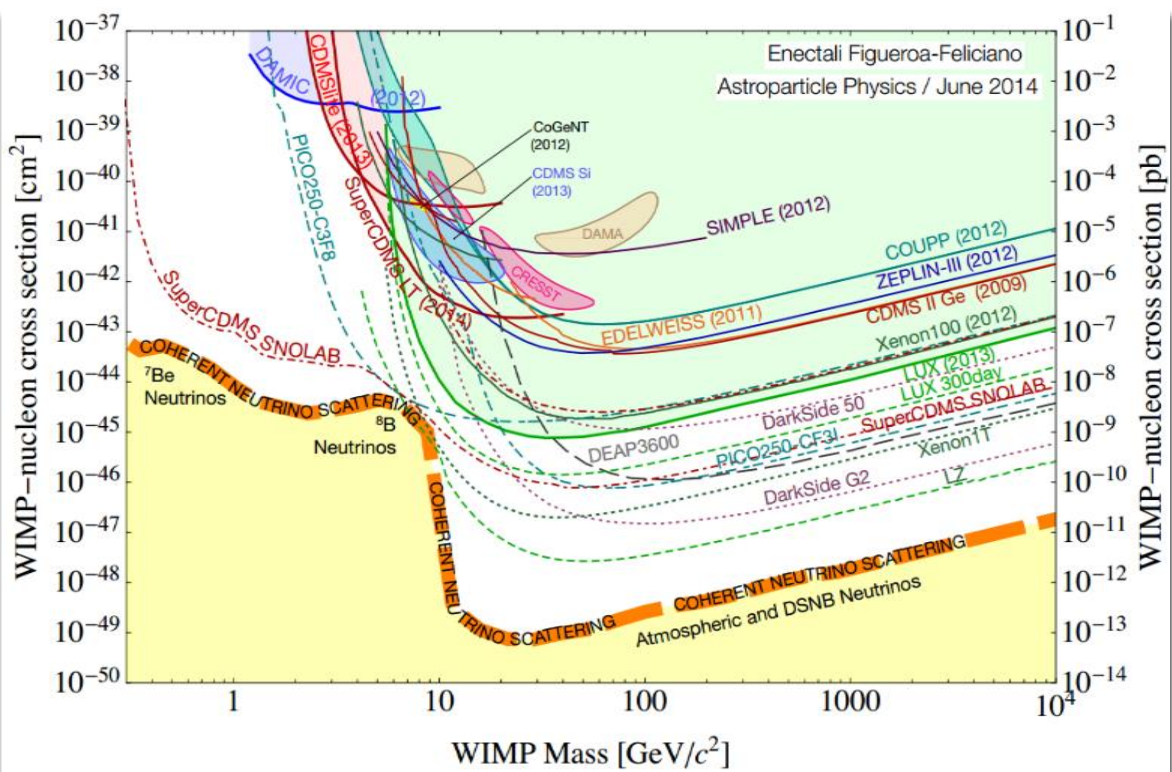
If Real, we Really need 100 TeV machine!!

Thank you

Back-Up

Direct Detection

❖ DM-N scattering X-section on contact operators

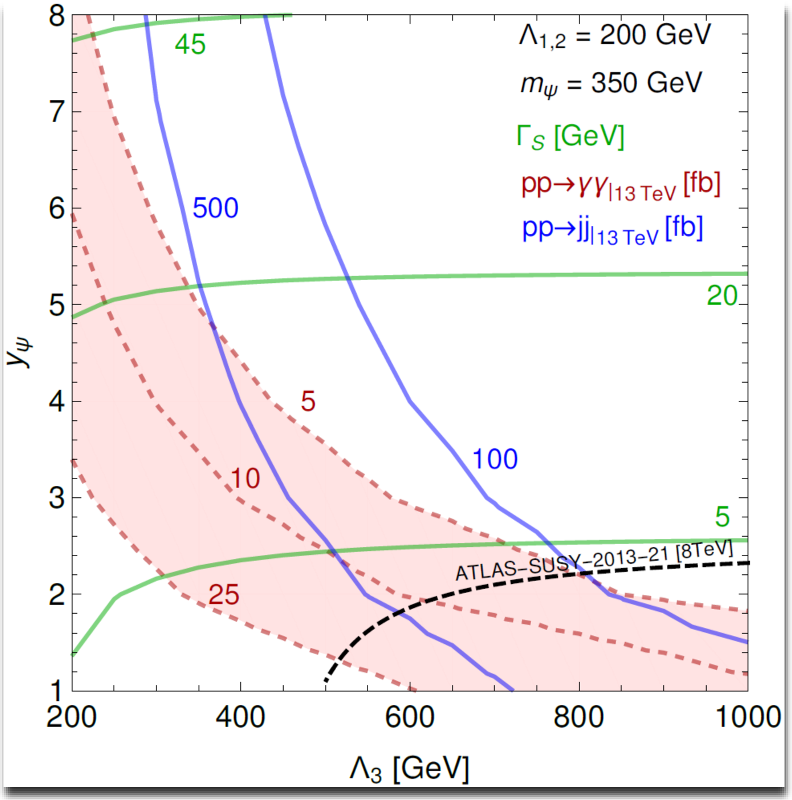


$\Delta\mathscr{L}$		Int.	Suppression
$\mathcal{O}_s^\phi$:	$\frac{1}{\Lambda}\phi^\dagger\phi\overline{f}f$	SI	1
$\mathcal{O}_v^\phi$:	$\frac{1}{\Lambda^2}\phi^\dagger\partial^\mu\phi\overline{f}\gamma_\mu f$	SI	1
$\mathcal{O}_{va}^\phi$:	$\frac{1}{\Lambda^2}\phi^\dagger\partial^\mu\phi\overline{f}\gamma_\mu\gamma^5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

J. March-Russell, J. Unwin, S. M. West, arXiv: 1203.4854

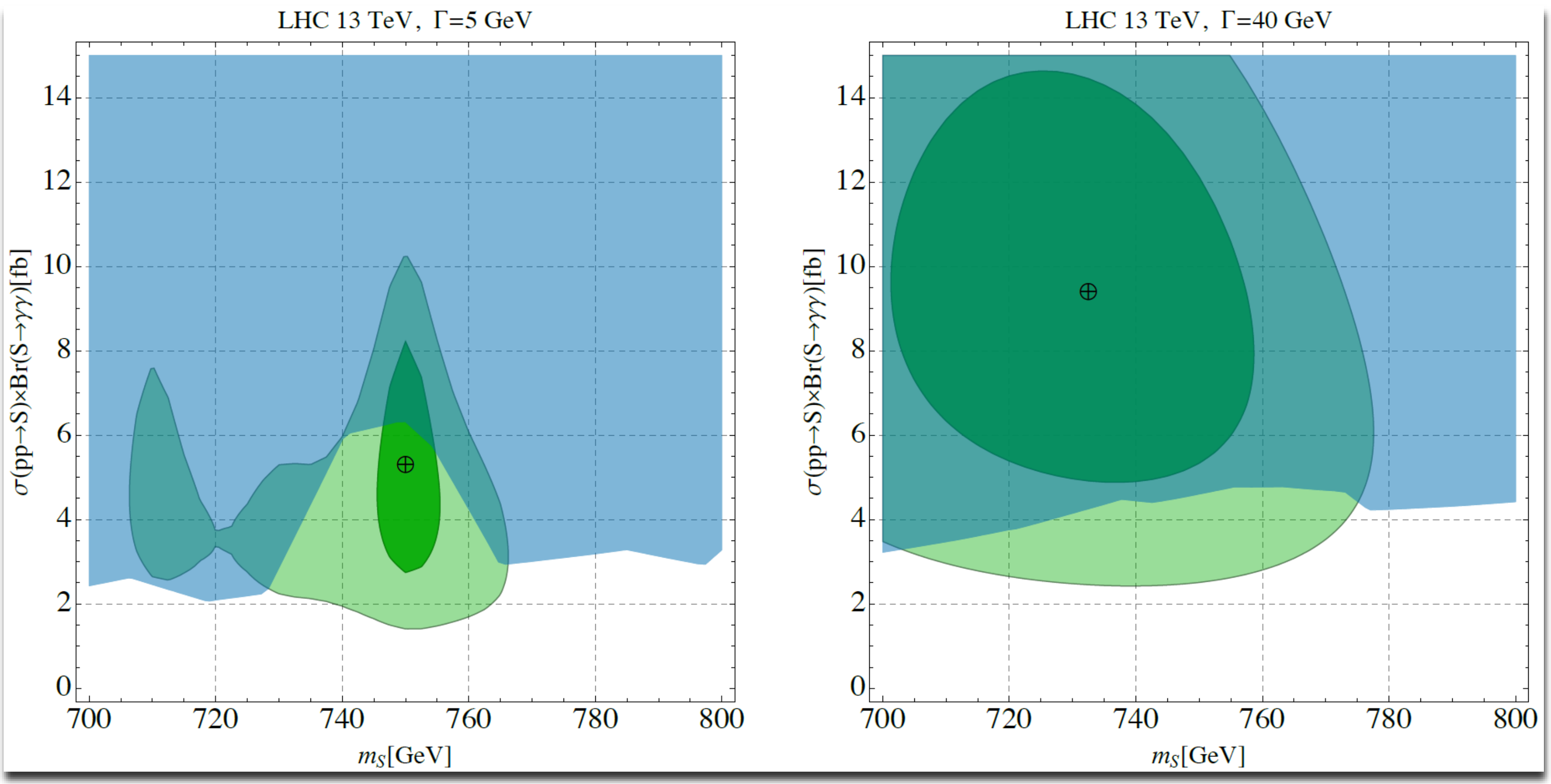
Mono-jet constraint

$$\mathcal{L}_{\rm NP,CPE} = \frac{1}{2}(\partial_\mu s)^2 - \frac{\mu_s^2}{2}s^2 + \frac{1}{2}\bar{\psi}(i\partial\!\!\!/_\mu - m_\psi)\psi - \frac{y_\psi}{2}s\bar{\psi}\psi$$
$$- \frac{g_1^2}{4\pi}\frac{1}{4\Lambda_1}s\ B_{\mu\nu}B^{\mu\nu} - \frac{g_2^2}{4\pi}\frac{1}{4\Lambda_2}s\ W_{\mu\nu}W^{\mu\nu} - \frac{g_3^2}{4\pi}\frac{1}{4\Lambda_3}s\ G_{\mu\nu}G^{\mu\nu}$$



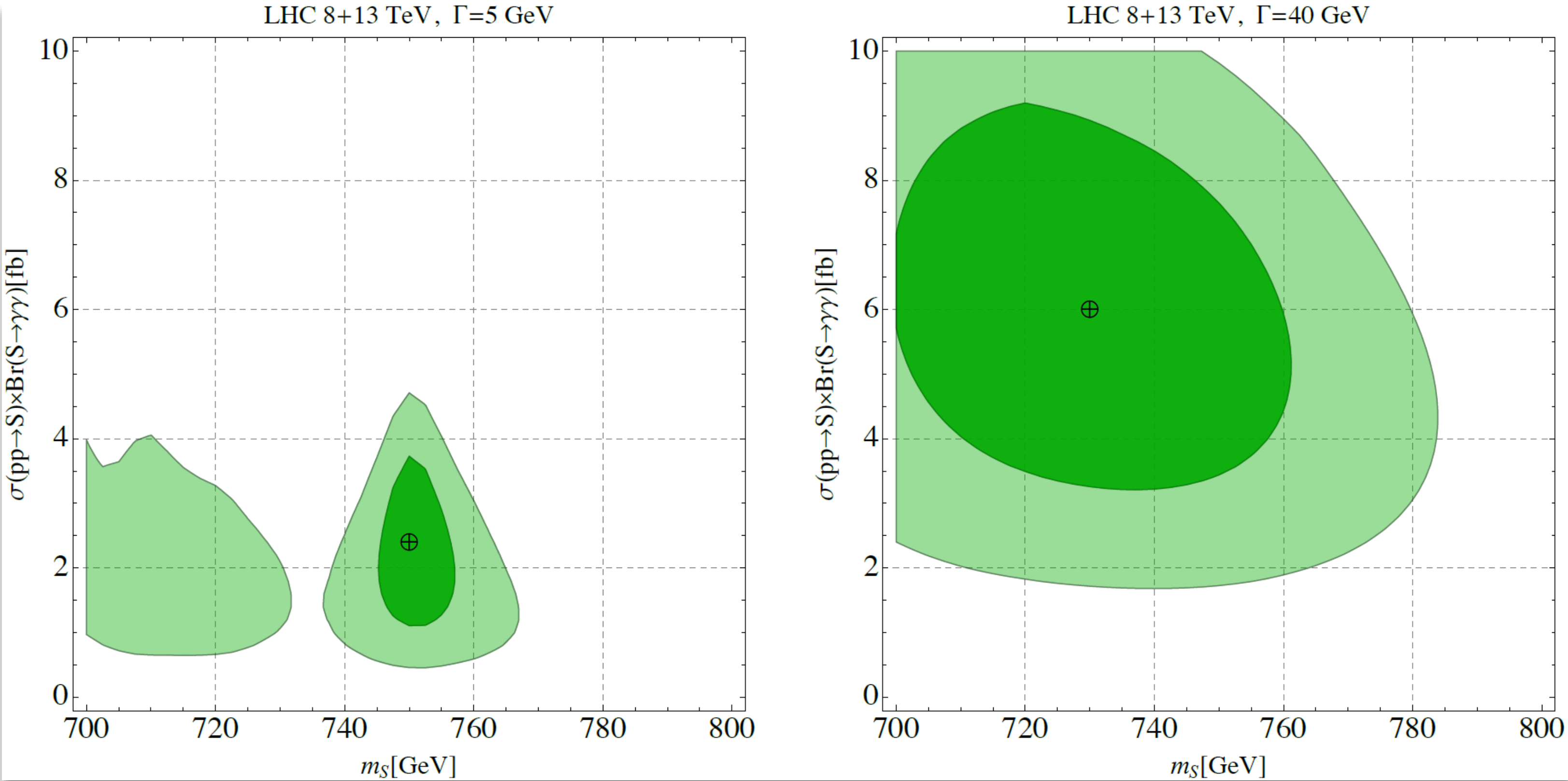
Barducci, Goudelis, Kulkarni & Sengupta, arXiv: 1512.06842

Wide vs Narrow ? (13 TeV)



A. Falkowski, O. Slone & T. Volansky, arXiv: 1512.05777

Wide vs Narrow ? (8+13 TeV)



A. Falkowski, O. Slone & T. Volansky, arXiv: 1512.05777