Displaced vertex signatures of Pseudo-Dirac Dark Matter

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with Andrea De Simone, Alessandro Davoli, Veronica Sanz
arXiv:1706.08985

2017-07-27
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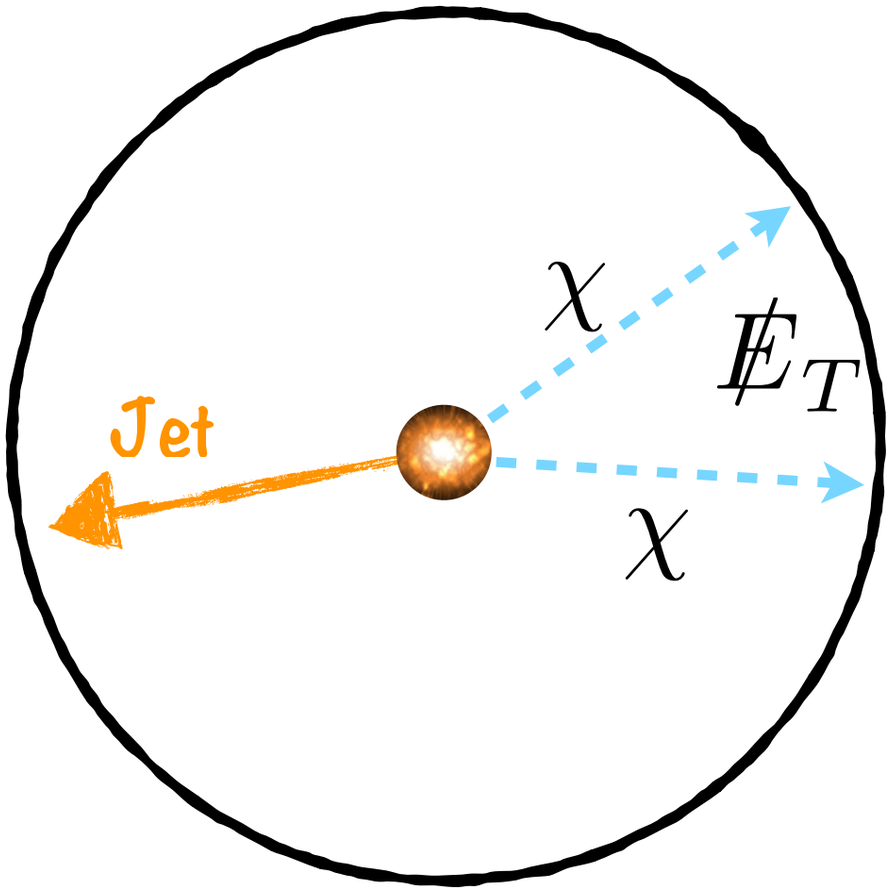
ma per seguir virtute e canoscenza
SISSA

Displaced vertices

Thomas Jacques



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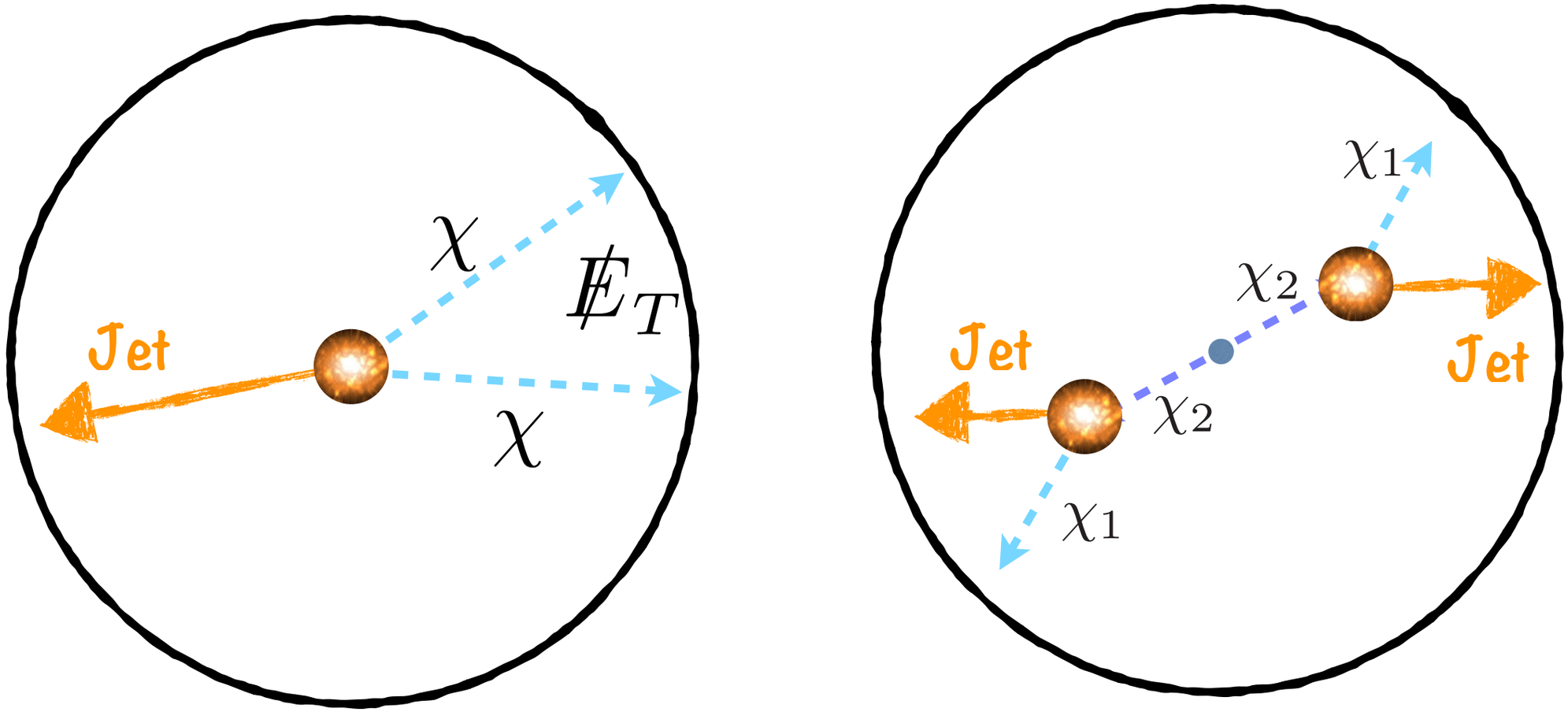

- If new dark particle decays to jets in LHC with decay length o(cm), jet origin may be displaced from center of detector
- **Smoking-gun signature** at the LHC: no irreducible SM background
- Existing searches mostly limited to SUSY: **under-exploited channel**

Model

De Simone, Sanz, Sato
Phys.Rev.Lett. 105 (2010) 121802

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- General Lagrangian with **both Dirac & Majorana masses**

$$\mathcal{L}_0 = \bar{\Psi}(i\partial\!\!\!/ - M_D)\Psi$$
$$- \frac{m_L}{2}\left(\overline{\Psi^c} P_L \Psi + \text{h.c.}\right) - \frac{m_R}{2}\left(\overline{\Psi^c} P_R \Psi + \text{h.c.}\right)$$

- Coupling to Standard Model via **Z'**:

$$\mathcal{L}_{\text{int}} = \bar{\Psi}\gamma^\mu(c_L P_L + c_R P_R)\Psi\, Z'_\mu + \bar{f}\gamma^\mu(c_L^{(f)} P_L + c_R^{(f)} P_R) f\, Z'_\mu$$

- Take **'Pseudo-Dirac'** limit, $M_D >> m_L, m_R$;
  At $O(|m_L - m_R| / M_D)^0$, Majorana eigenstates:

$$\chi_1 = \frac{i}{\sqrt{2}}\left(\Psi - \Psi^c\right), \qquad \chi_2 = \frac{1}{\sqrt{2}}\left(\Psi + \Psi^c\right)$$

with $m_{1,2} = M_D \mp (m_L + m_R)/2$

Model

Thomas Jacques

- ‘Pseudo-Dirac’ DM:
  Introduce simplified model with two Majorana eigenstates, χ_1 and χ_2
- χ_2 decays to χ_1, which is DM candidate

$$\mathcal{L}_{\text{int}} = \frac{c_f}{2}\,\bar{f}\gamma^\mu\left(1-\gamma^5\right) f\, Z'_\mu$$

$$+\,\frac{c_R - c_L}{4}\,\bar{\chi}_1\gamma^\mu\gamma^5\chi_1\, Z'_\mu$$

$$+\,\frac{c_R - c_L}{4}\,\bar{\chi}_2\gamma^\mu\gamma^5\chi_2\, Z'_\mu$$

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Pure axial-vector χ_1-χ_1, χ_2-χ_2 coupling

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Pure vector χ_1-χ_2 coupling

Features

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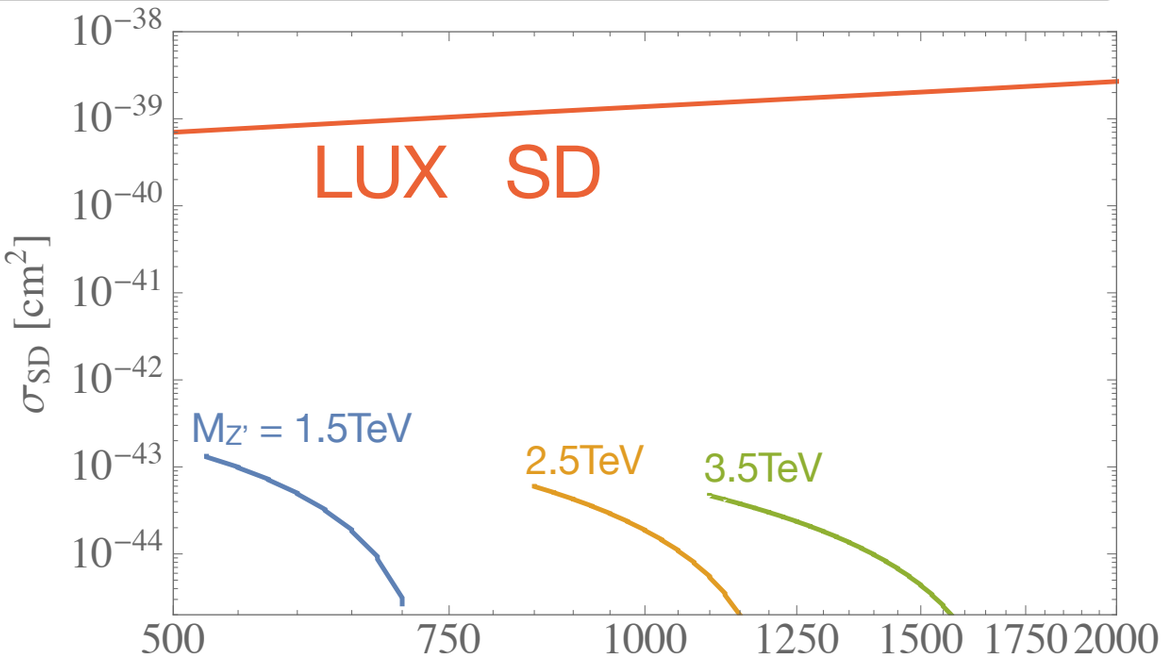
- **Axial-vector** $\chi_i\chi_i Z'$ coupling: **Spin-suppressed** direct detection rate



- **Vector** $\chi_1\chi_2 Z'$ coupling: **unsuppressed** coannihilation

→ 'Thermal Relic' couplings evade direct & indirect detection

- **Vector** $\chi_1\chi_2 Z'$ coupling controls both relic density and decay length:

$$\frac{\Omega h^2}{0.1194} \simeq \frac{L_0}{10\,\mathrm{cm}} \left(\frac{100\,\mathrm{GeV}}{m_1}\right)^2 \left(\frac{\Delta m}{1\,\mathrm{GeV}}\right)^5$$

- Correct relic density → χ_2 can decay within detector

Choice of parameters

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- Use basis: $M_{Z'}$, m_1, $\Delta m (\equiv m_2 - m_1)$, c_f, c_L, c_R
- Masses:
  - **Scan** over m_1, Δm plane,
    - benchmark mediator masses: $M_{Z'}$=1.5, 2.5, 3.5 TeV
- Couplings:
  - Assume coupling to quarks only
  - Choose max allowed value for c_L, c_R, c_f
  - c_f from **dijet**, c_L, c_R from **relic density**

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Constraints: Dijet

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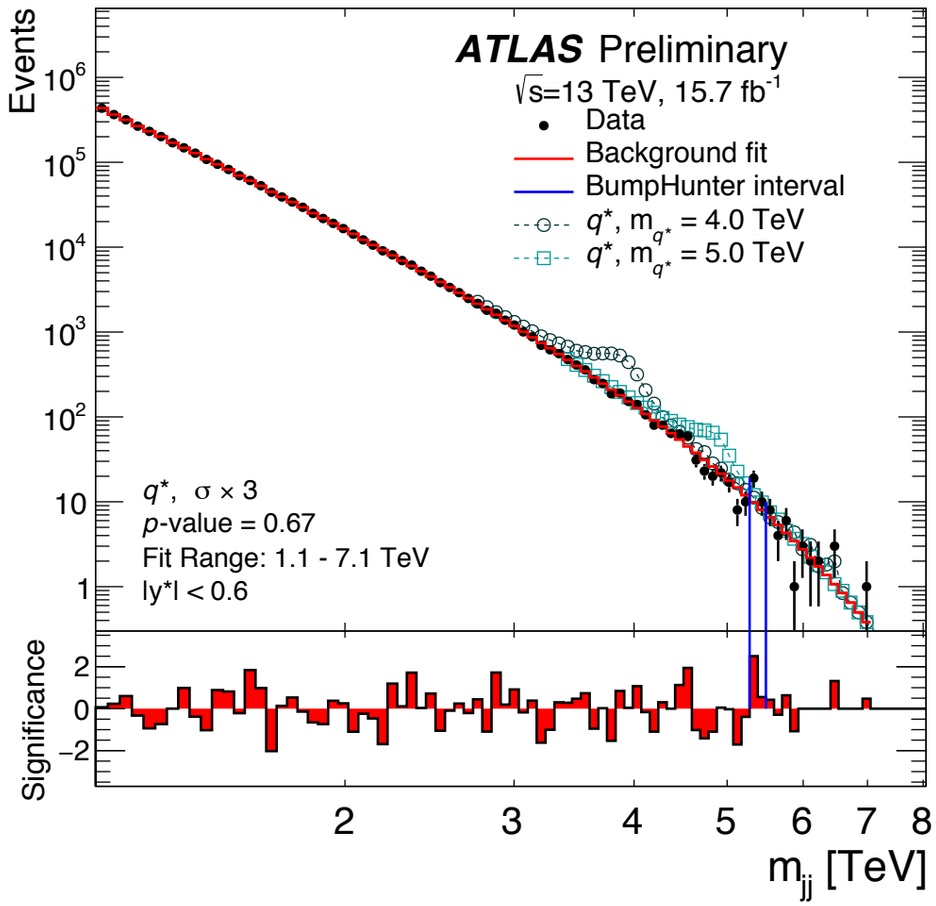

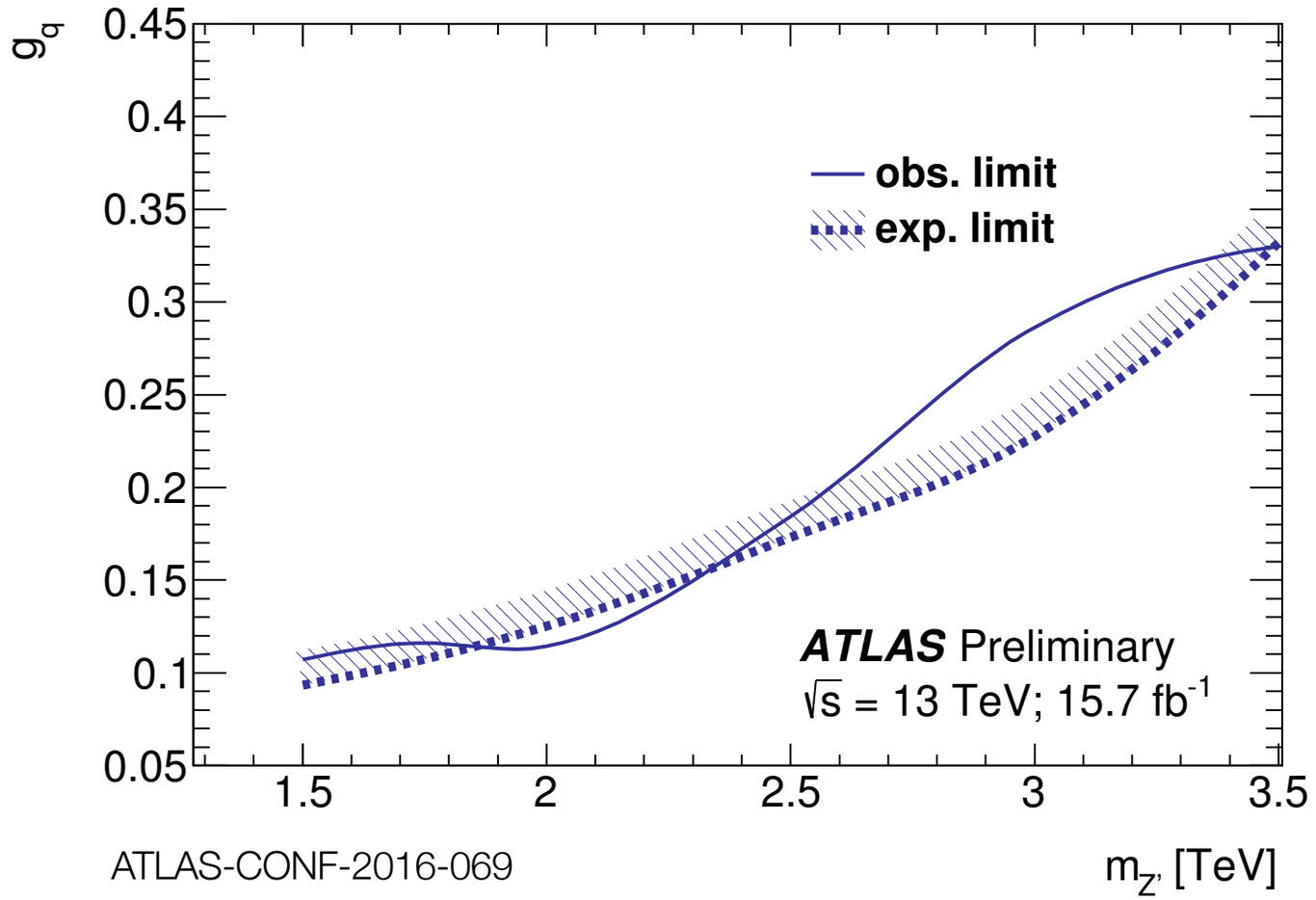

- Dijet searches place strong constraint on mediator decay to SM particles
- Constrains c_f; Use max allowed value

Constraints: Relic density

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- Enforce correct relic density

$$\Omega h^2 = \frac{8.7 \times 10^{-11} \mathrm{GeV}^{-2}}{\sqrt{g_*} \int_{x_F}^{\infty} dx \, \frac{\langle \sigma v \rangle_{\mathrm{eff}}}{x^2}}$$

- **Axial-vector** $\chi_1\chi_1$ & $\chi_2\chi_2$ annihilation **suppressed**: Temp-suppressed *p*-wave, helicity-suppressed *s*-wave

- Annihilation rate **enhanced** and relic density achieved by **unsuppressed vector** $\chi_1\chi_2$ co-annihilation

- Constrains a contour in c_L, c_R plane

Choice of parameters

Thomas Jacques

- Final free parameter: $k = c_L/c_R$
- Strong effect on phenomenology

$$\frac{c_R - c_L}{4}\,\bar{\chi}_1\gamma^\mu\gamma^5\chi_1\,Z'_\mu$$

$$\frac{c_R - c_L}{4}\,\bar{\chi}_2\gamma^\mu\gamma^5\chi_2\,Z'_\mu$$

$$i\,\frac{c_R + c_L}{2}\,\bar{\chi}_1\gamma^\mu\chi_2\,Z'_\mu$$

- Best case: k close (but not equal!) to -1
  → **Enhances $\chi_2\chi_2$ production rate and extends χ_2 decay length**
- Choose k = -0.8 and 0

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Pure axial-vector: No decay

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k=1 ($c_L = c_R$):
Pure vector: No $\chi_2\chi_2$ production

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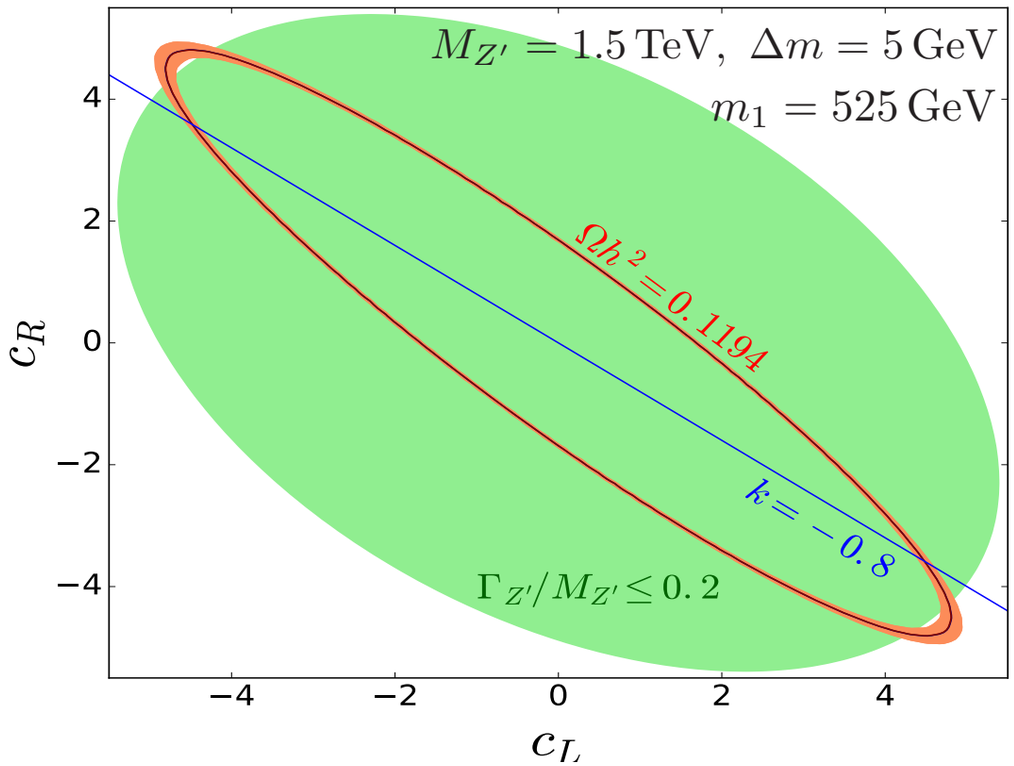

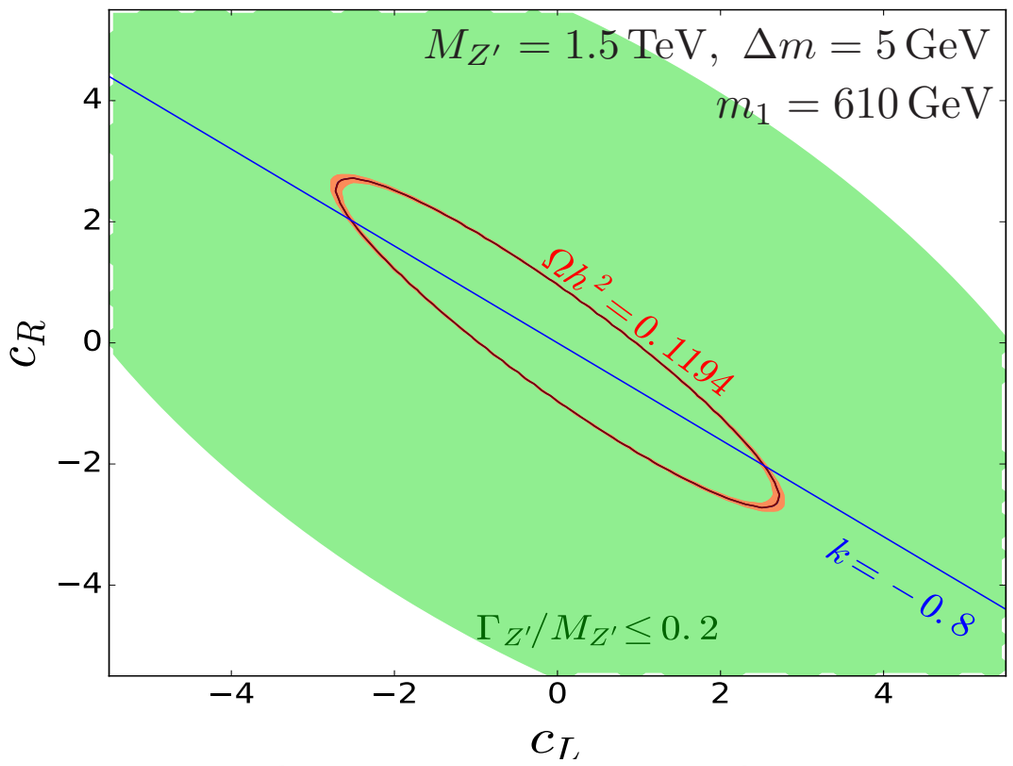

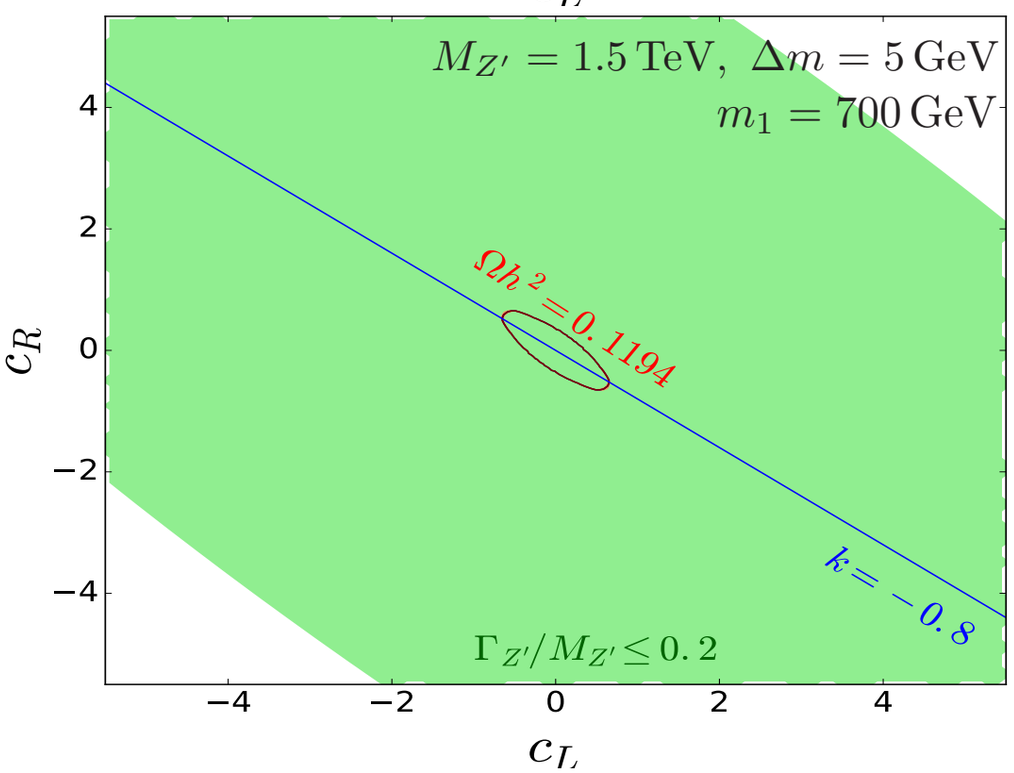

- For each (m_1, Δm, $M_{Z'}$), intercept of relic density and k contours fixes c_L, c_R
- In all observables, c_L, c_R appear together as $|c_L - c_R|^2$ or $|c_L + c_R|^2$, so four quadrants are equivalent

Displaced vertices

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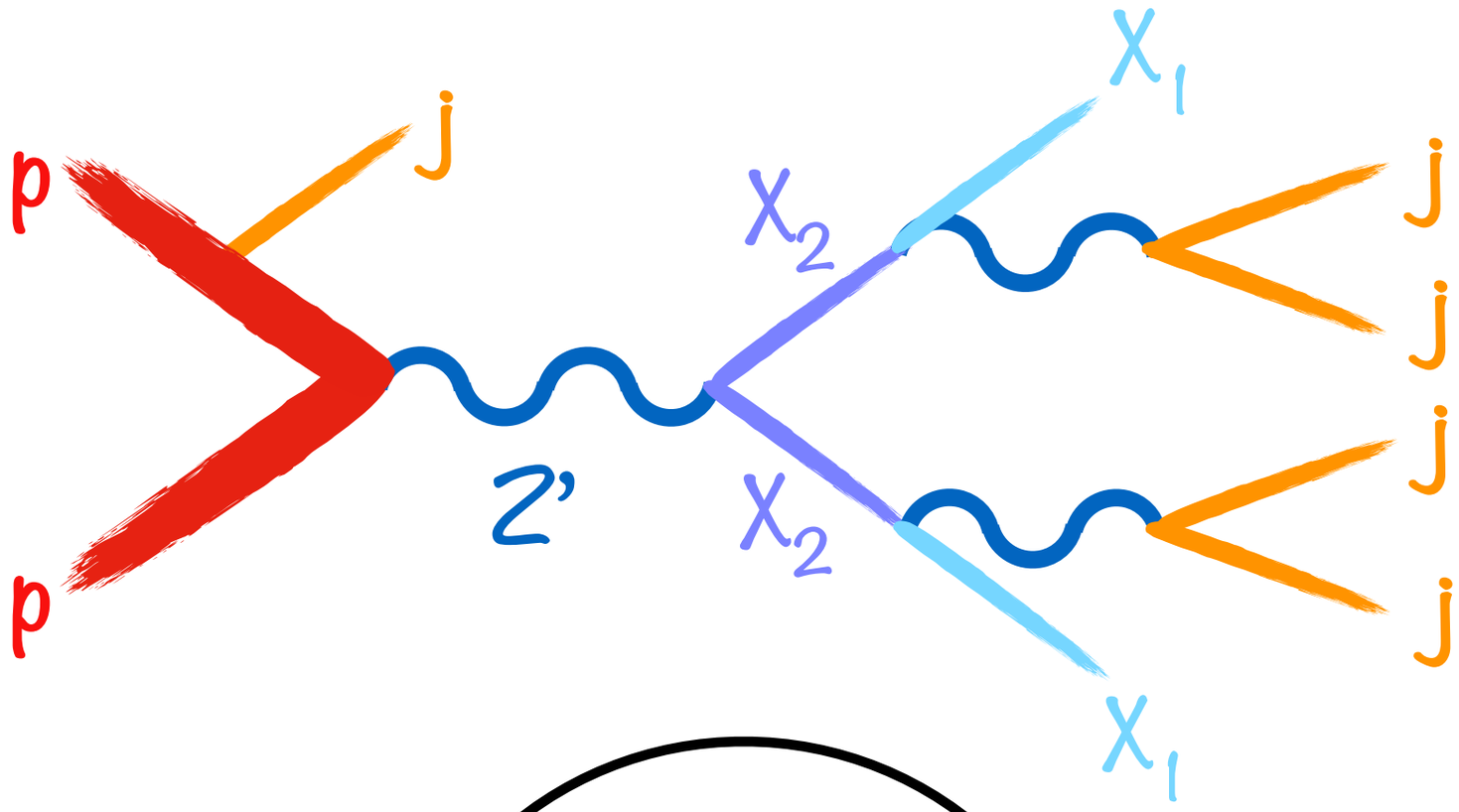
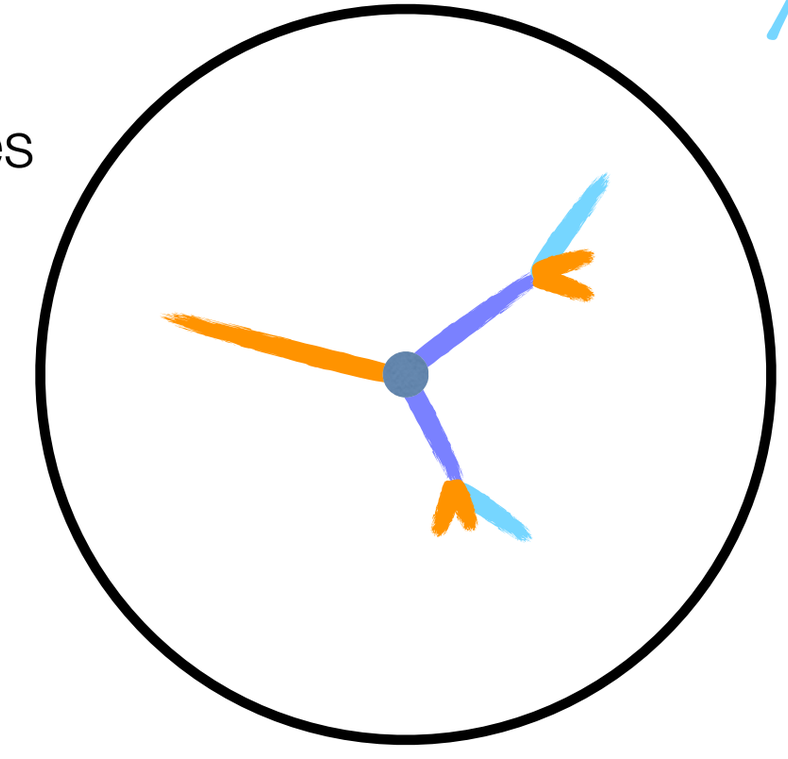


- Signal of 2 displaced vertices + missing energy (MET) + hard jet
- Zero SM background; Background entirely from mismeasurement



- Statistics limited search
- Good complement to monojet
- Hard to recast

Displaced vertices: k = 0

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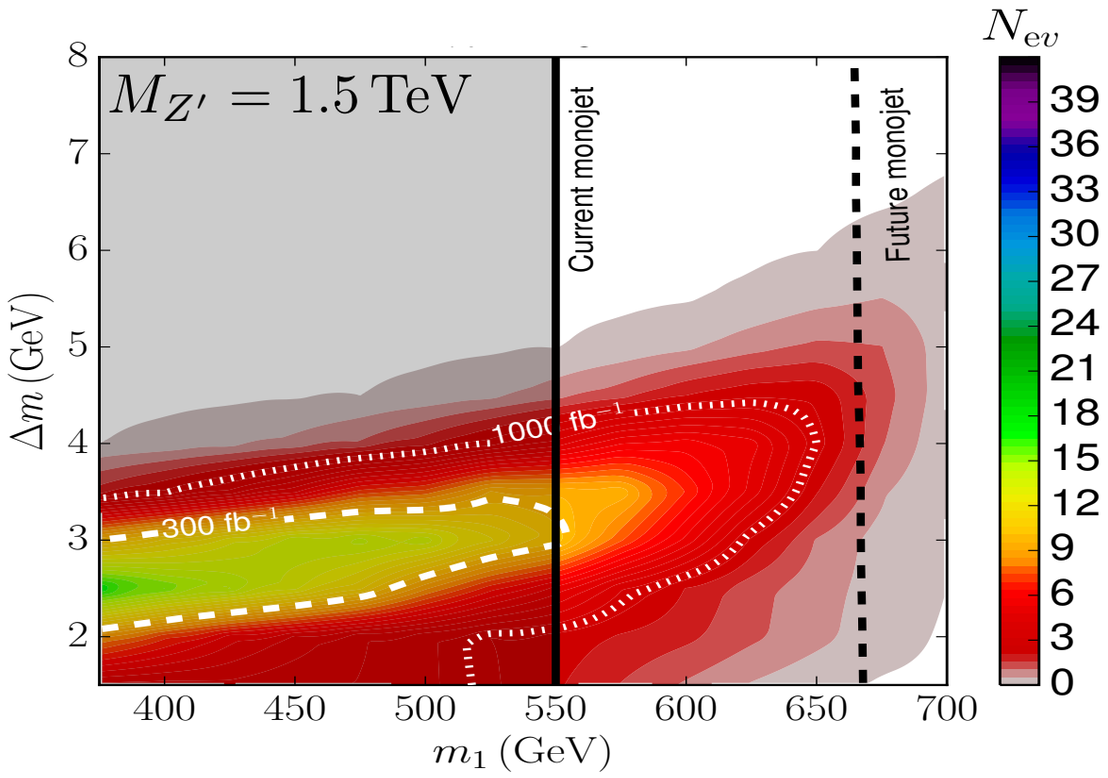

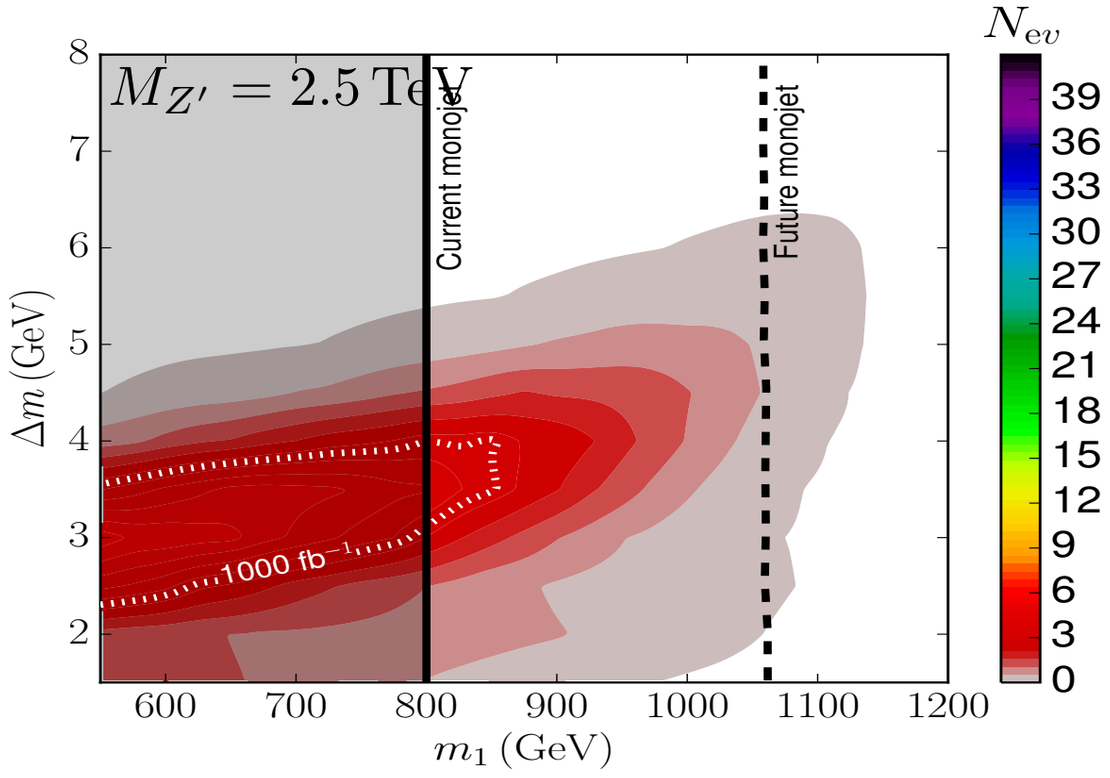

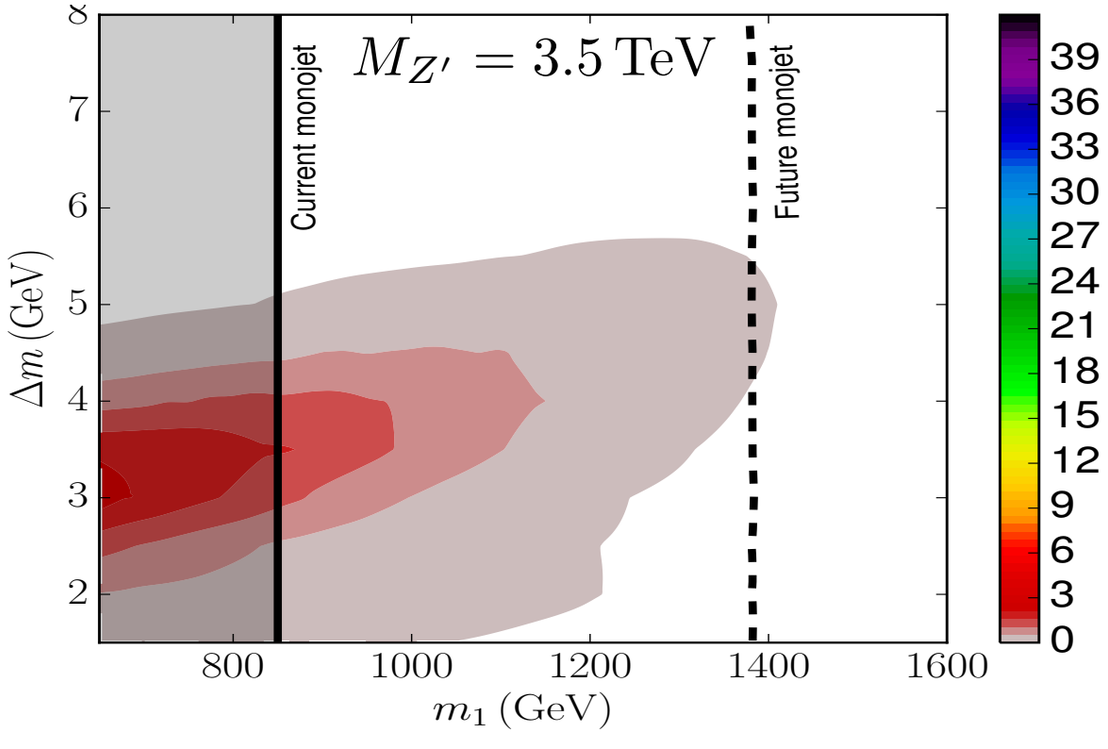

- Colour contours: expected number of events @ 1000 fb^{-1}
- White: potential 95% exclusions with 0 observed events
- Black: Statistical limit of monojet

Displaced vertices: k = -0.8

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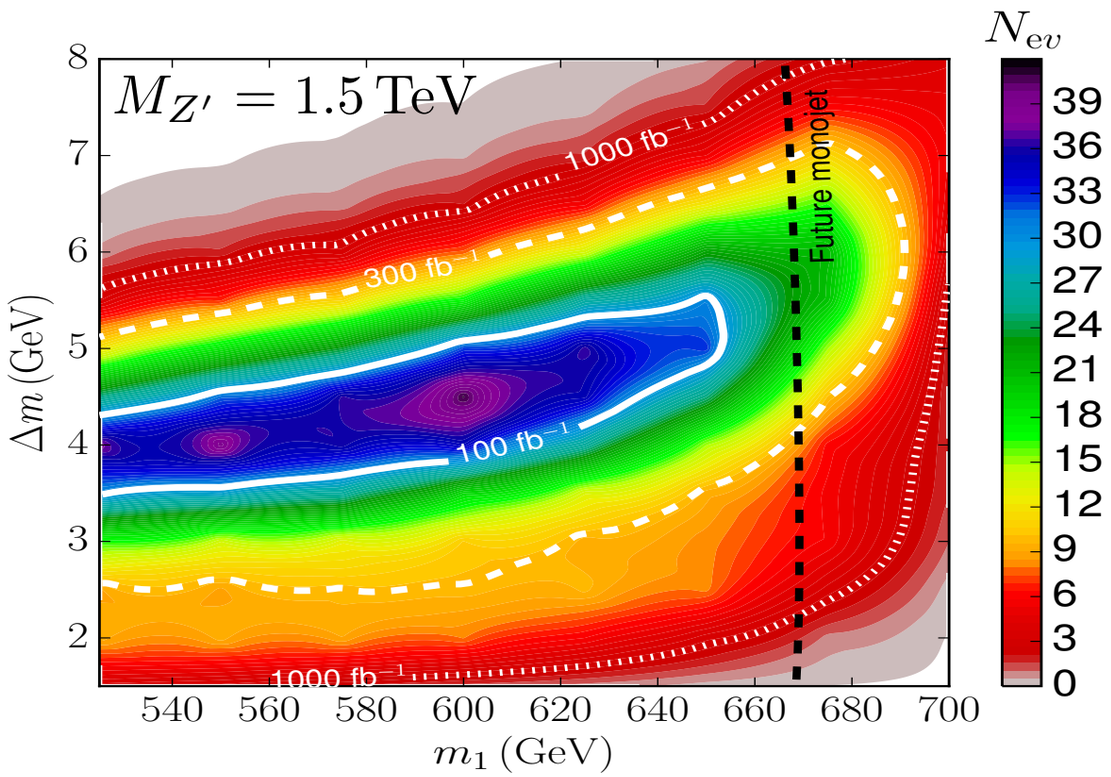

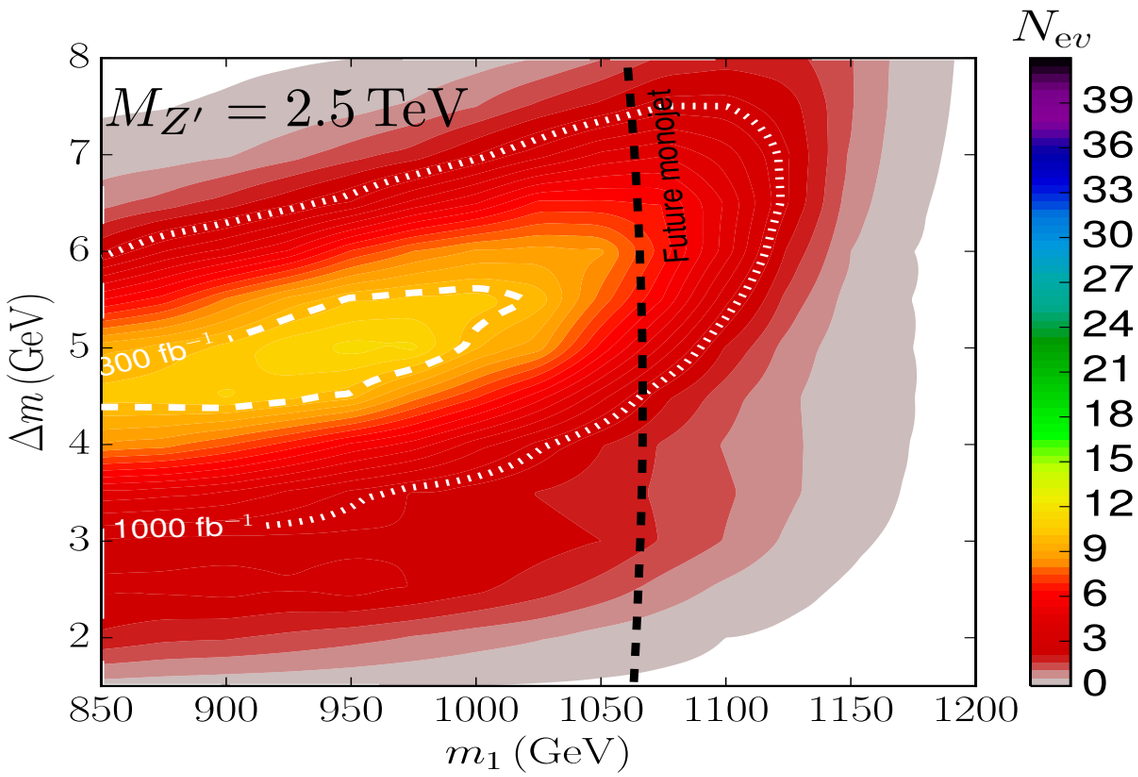

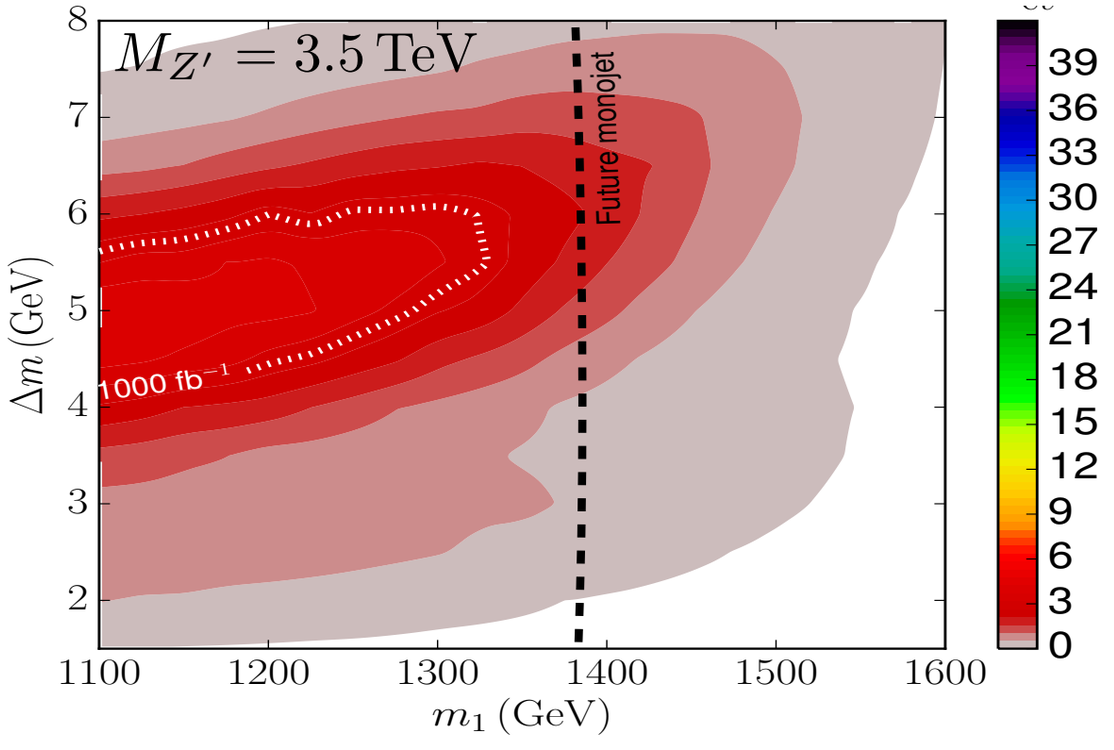

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Conclusion

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- Pseudo-Dirac Dark Matter has many attractive features:
  - Avoids direct & indirect detection constraints
  - Yields correct relic abundance
  - Gives displaced vertices at LHC
- Displaced vertex signal complementary to Monojet:
  Monojet initially stronger but can be overtaken at large luminosity
- Prospects for under-exploited signature of dark sector at LHC
- Looking forward to published displaced vertex identification efficiencies as function of kinematic variables in the future