Dark matter searches at colliders



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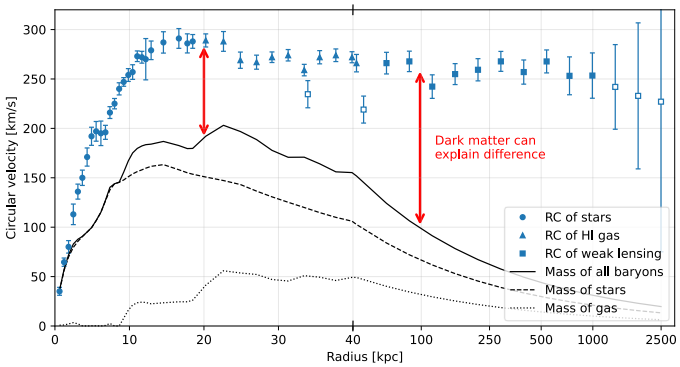
KMI Symposium 2026

What is dark matter?

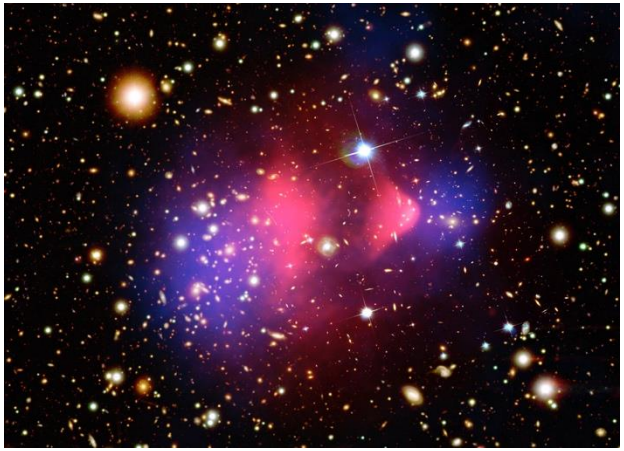
Galaxy rotation curves



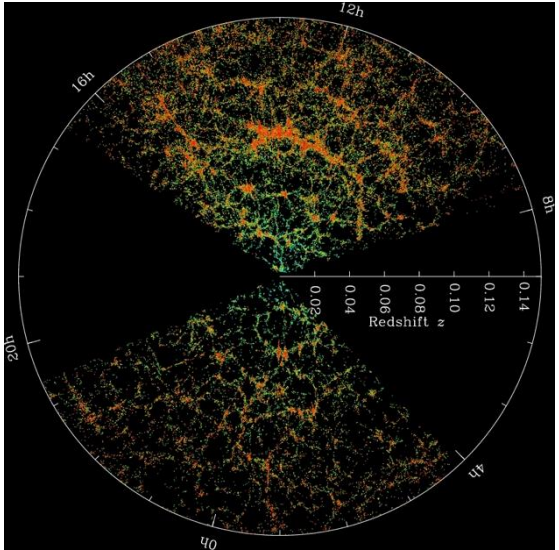
Lensing

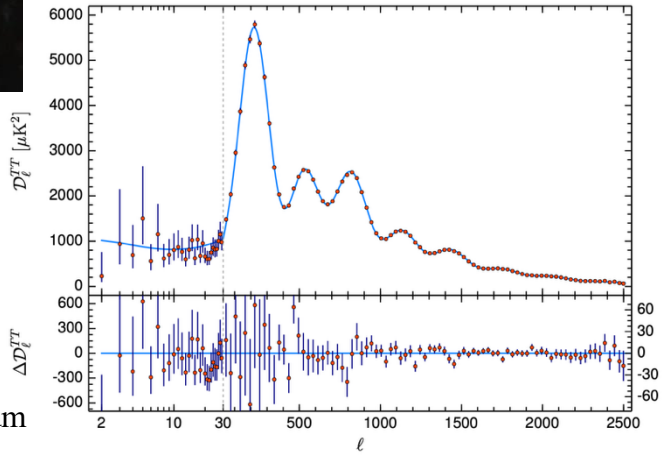


Bullet cluster



Large-scale structure





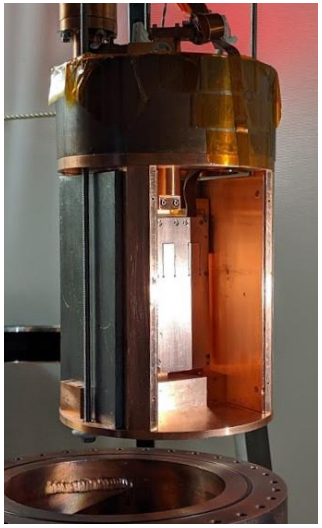
Cosmic microwave background spectrum

What is dark matter?

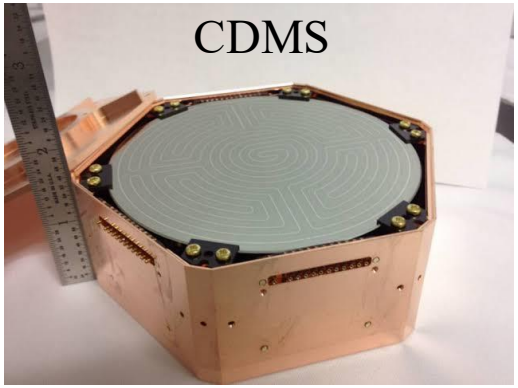


DM is searched for in direct-detection experiments

SENSEI



CDMS



LUX-ZEPLIN (LZ)



Fermi

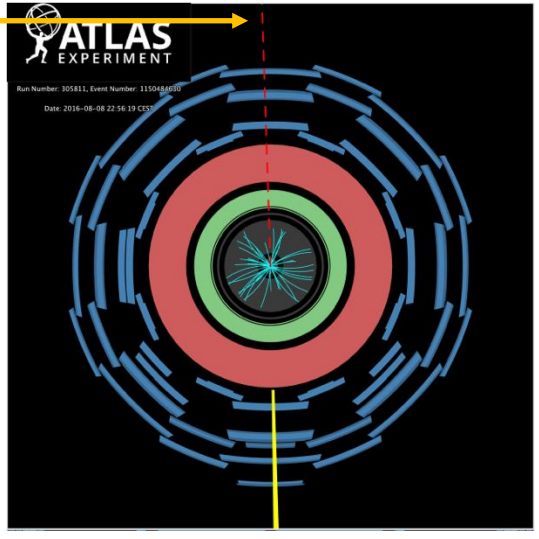


DAMA-LIBRA

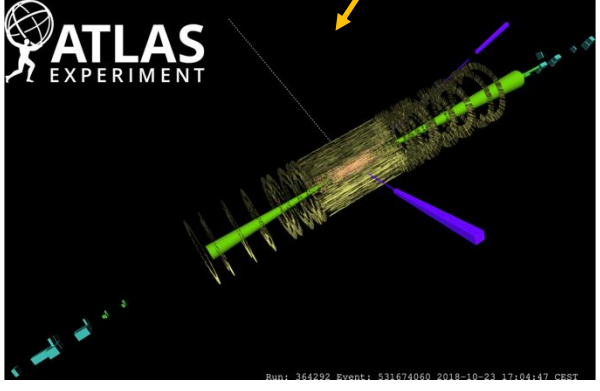


What is “dark matter” at a collider?

- Missing transverse energy (MET) or missing mass
- This signature is almost never directly related to actual DM
- It can also result from other BSM sources
  - Neutralino
  - Sterile neutrino
  - Axion
- Or background: neutrinos in the SM



$pp \rightarrow \mu X$ candidate



VBF $H \rightarrow WW \rightarrow eev\nu$ candidate

- The DM particle can have any mass in the range

$$10^{-22}\ \text{eV} < m_{DM} < 5\ M_{\text{sun}}$$

- Colliders can discover weakly-interacting massive-particle (WIMP) DM particles, approximately

$$10\ \text{MeV} < m_{DM} < 2\ \text{TeV}$$

- Models for collider searches are more specific

"Dark-sector" particles

- Dark-matter particles have very little (if any) interaction with SM particles
- But they may be just part of a "dark sector" that contains different particles
  - The SM particle spectrum is rich. Why would the dark sector have only 1 particle type?
- These dark-sector fields may interact with the SM fields:
  - Dark photon: kinetic mixing $\frac{\epsilon}{2} F'_{\mu\nu} F^{\mu\nu}$
  - Dark scalar: scalar mixing $\frac{\epsilon}{2} S^2 |H|^2$
  - Dark pseudoscalar (axion): $\frac{1}{f}\, a \frac{g^2}{32\pi^2} \left(F_{\alpha\beta} \epsilon^{\alpha\beta\mu\nu}\right) F_{\mu\nu}$
- These interactions enable production of DM in colliders and its detection in direct-detection experiments
- Experimental searches for new particles sometimes refer to them as "dark", but in most searches there is no direct relation to dark matter

Some collider-search paper statistics

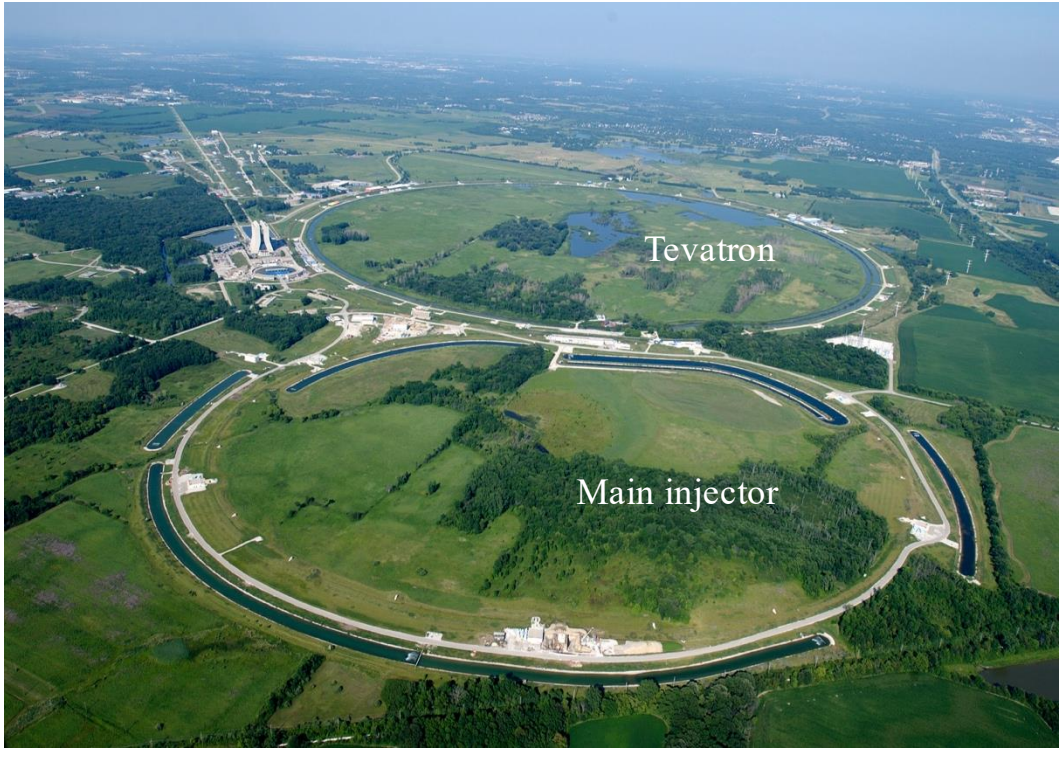
Collider-experiment papers with "dark matter" in the title:

- LEP experiments (ALEPH, DELPHI, L3, OPAL): 0
- D0 @ Tevatron: 0
- CDF @ Tevatron: 2
- ATLAS @ LHC: 34
- CMS @ LHC: 33
- BABAR: 2
- Belle: 1
- Belle II: 1

There are many additional papers with missing particles (could be DM) in the final state but without "dark matter" in the title.

CDF @ Tevatron: $p\bar{p} \rightarrow t\chi$

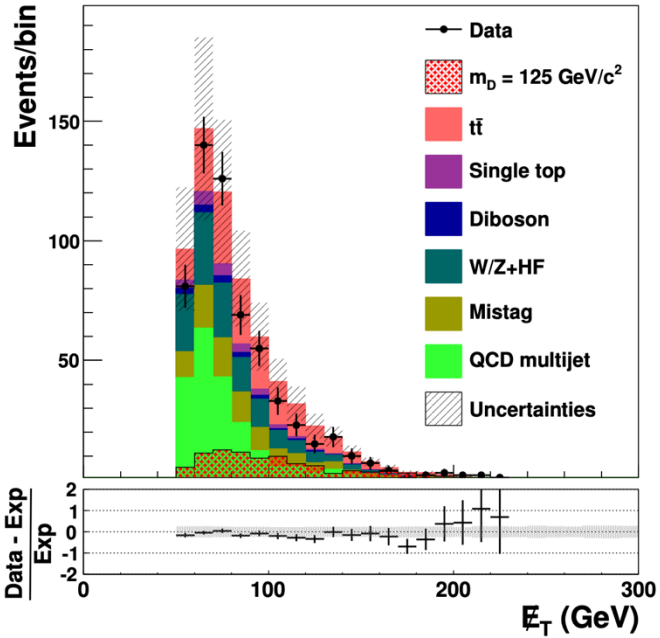
- Tevatron collided $p\bar{p}$ at up to 1.96 TeV, 1983-2011, in Illinois, USA



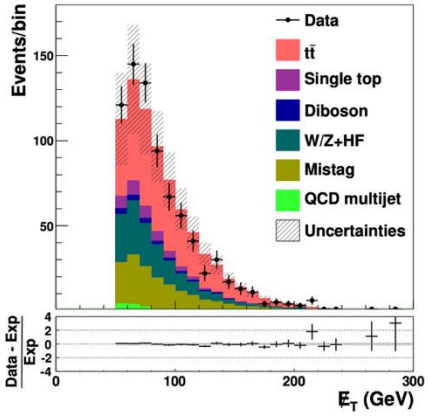
CDF @ Tevatron: $p\bar{p} \rightarrow t\chi$

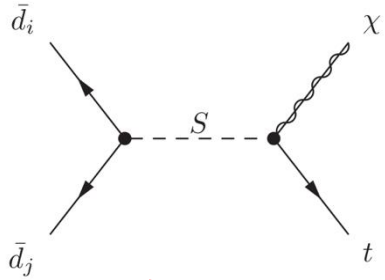
PRL 108 (2012) 201802, 7.7 fb^{-1} @ 1.96 TeV

Identified a top quark, plot MET distribution

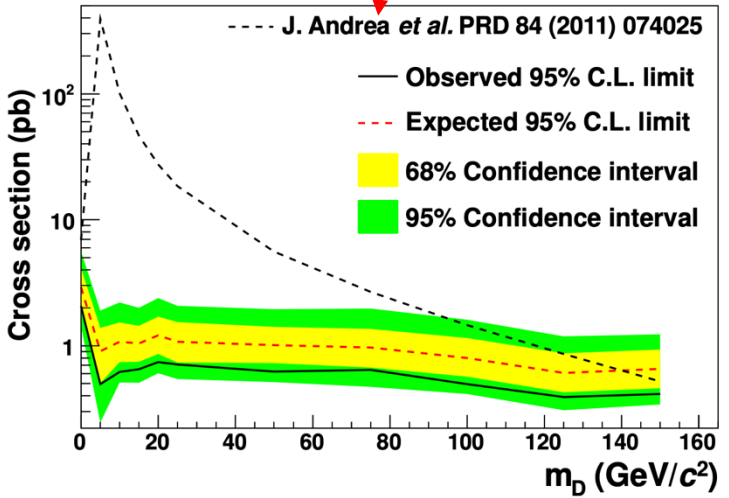


Validated on a control sample



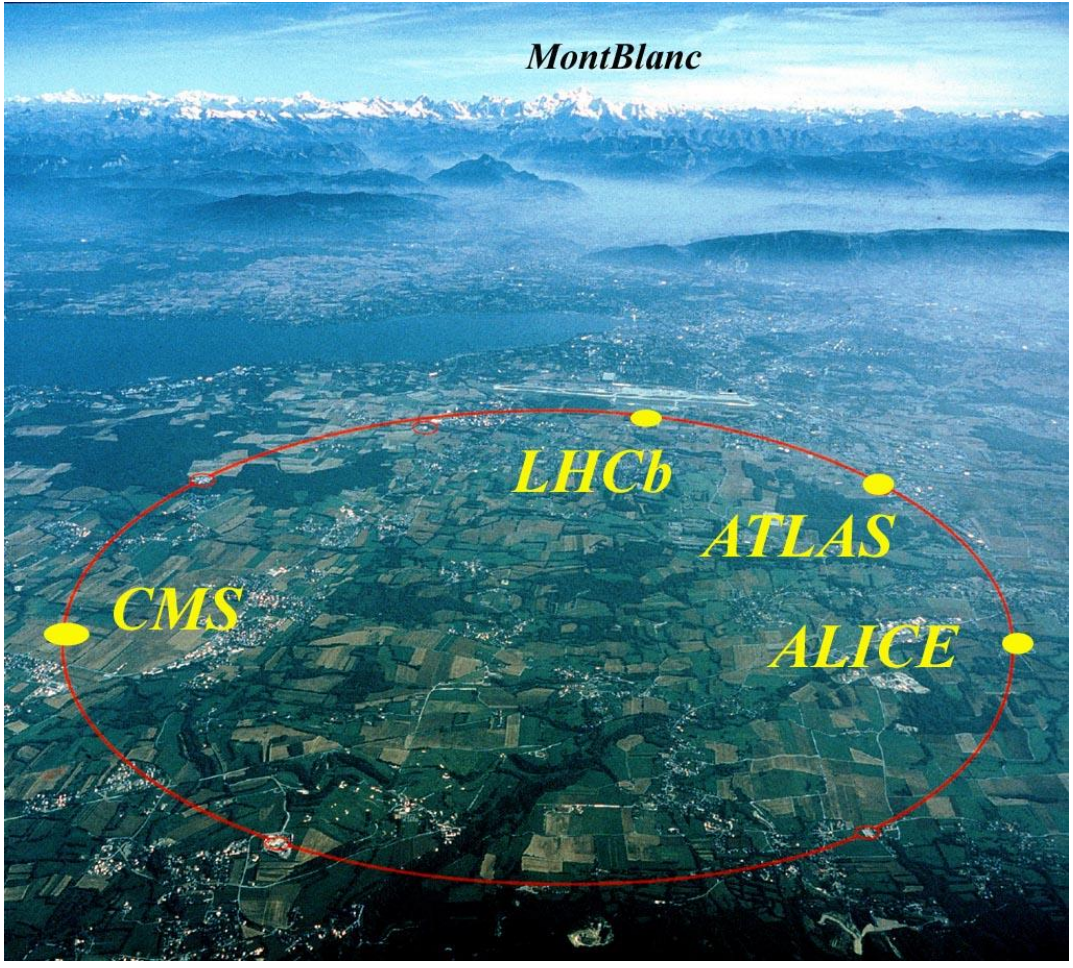


Cross-section limit & model comparison



LHC searches

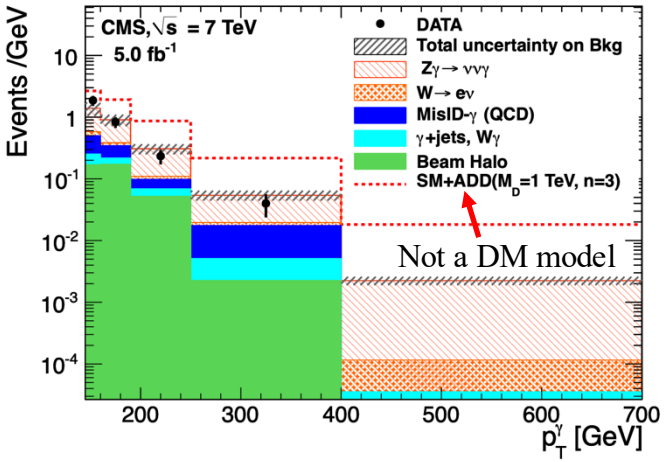
pp collisions at 7, 8, 13, 13.6 TeV



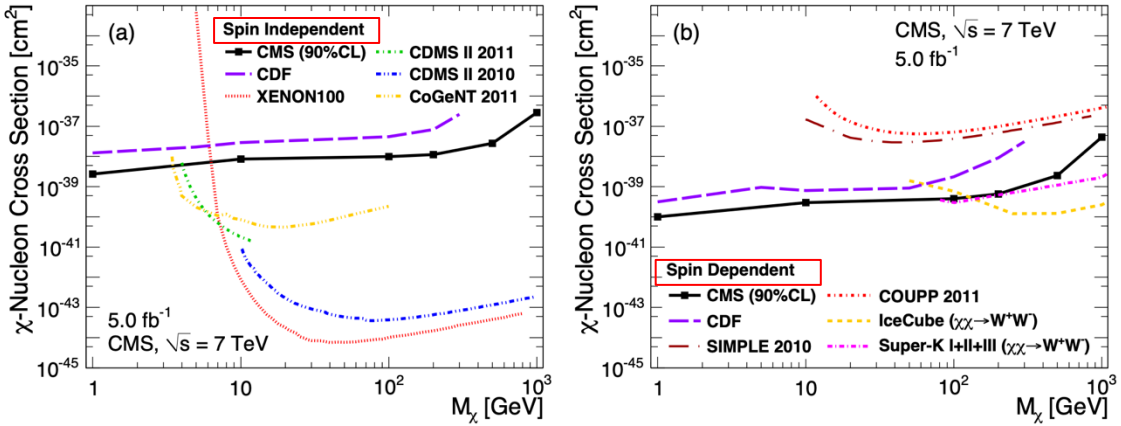
The first LHC search, $pp \to \gamma\chi\chi$

CMS, PRL 108 (2012) 261803, 7 TeV, 5 fb^{-1}

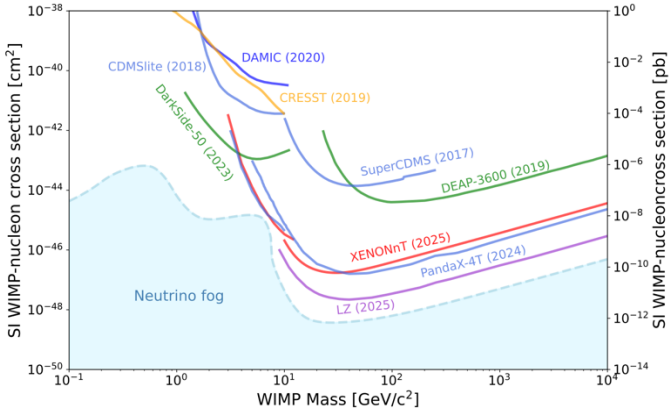
Plot photon p_T



Limits (@ 95% CL,) compared with direct-detection-experiment limits

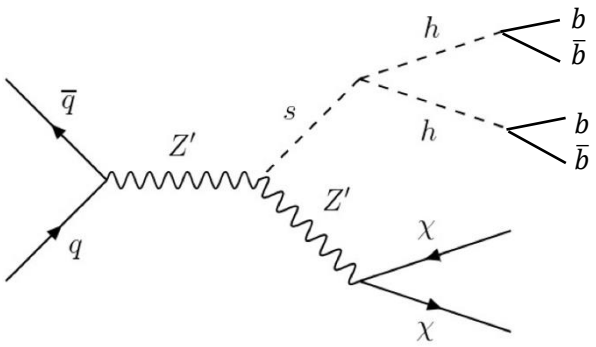


Compare to current limits (PDG 25)

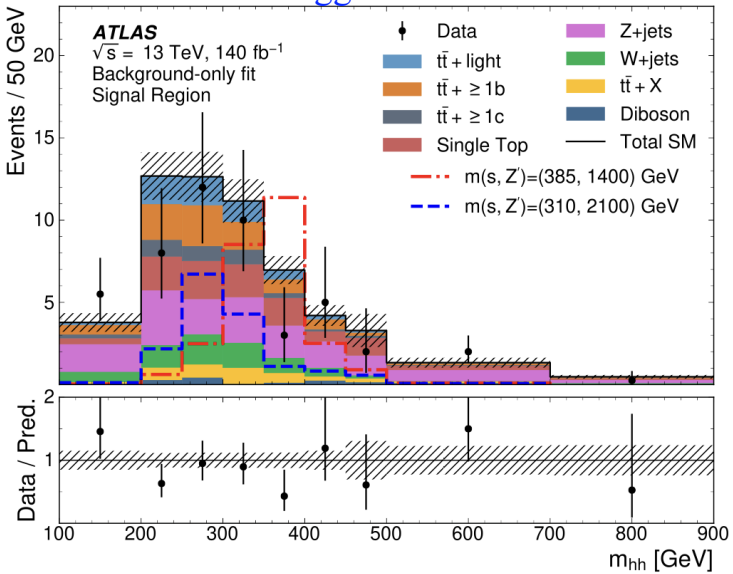


The (almost) most recent LHC search

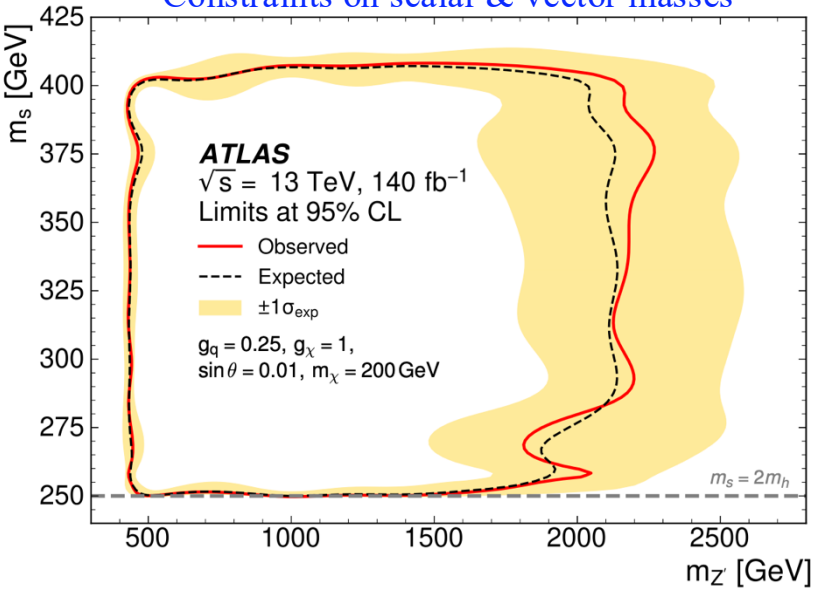
ATLAS, JHEP 06 (2026) 014, 13 TeV, 138 fb^{-1}



Plot di-Higgs invariant mass



Constraints on scalar & vector masses



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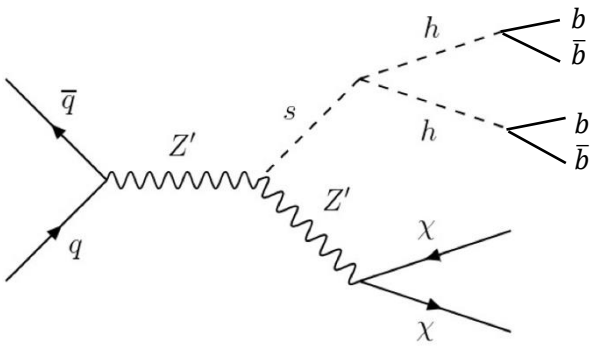
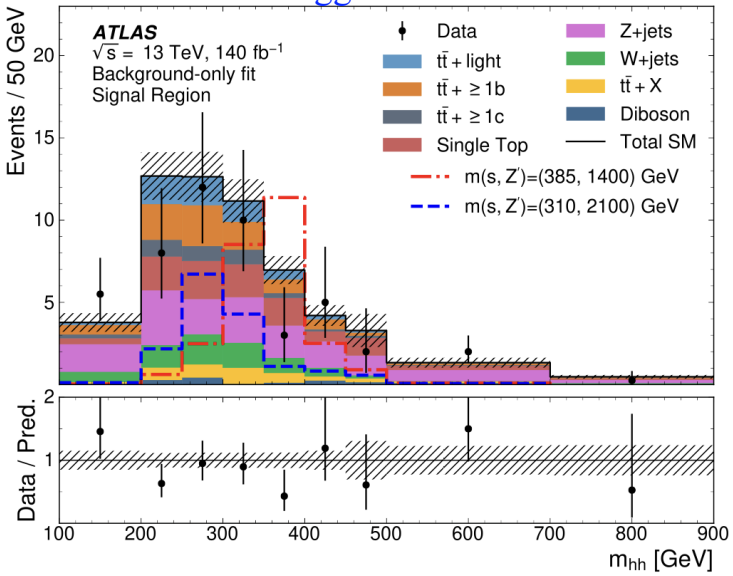
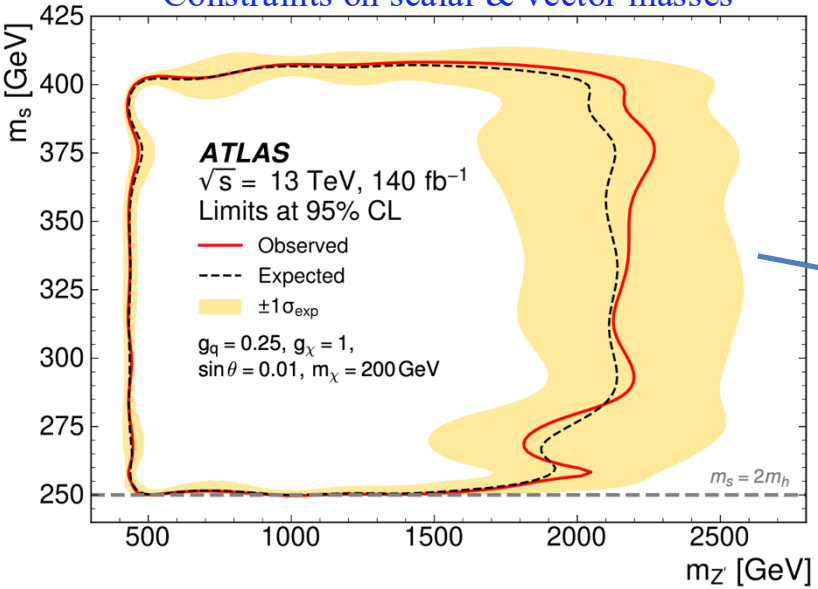


Plot di-Higgs invariant mass



Constraints on scalar & vector masses



Doesn't it look like.

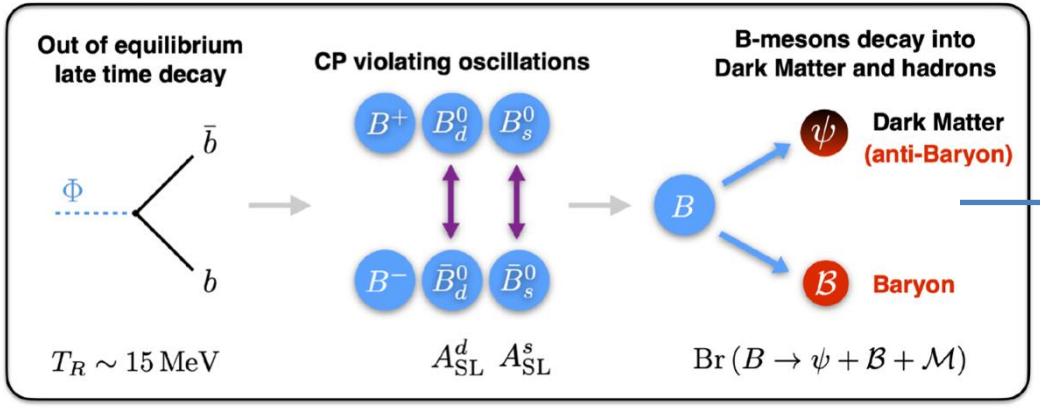


BABAR search for $B^+ \to p\psi$ in B-mesogenesis

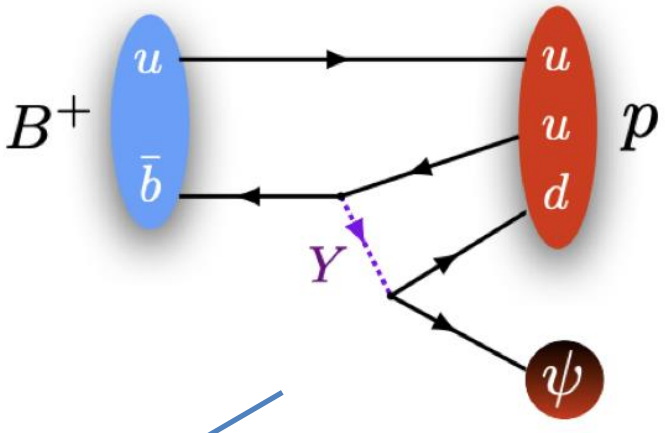
A collider search where the invisible particle actually is DM in a specific model

B-mesogenesis explains the baryon asymmetry of the universe (baryogenesis) with CP-violation in $B\bar{B}$ mixing + decay to antibaryon DM

(PRD 104 (2021) 3, 035028)



Example decay to search for



Invisible DM

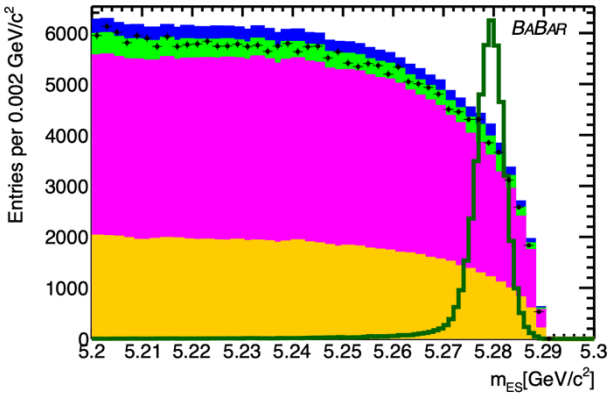
A single baryon isn't enough to identify signal.

So reconstruct the baryon + the other B in the $e^+e^- \to B\bar{B}$ event & study the missing mass

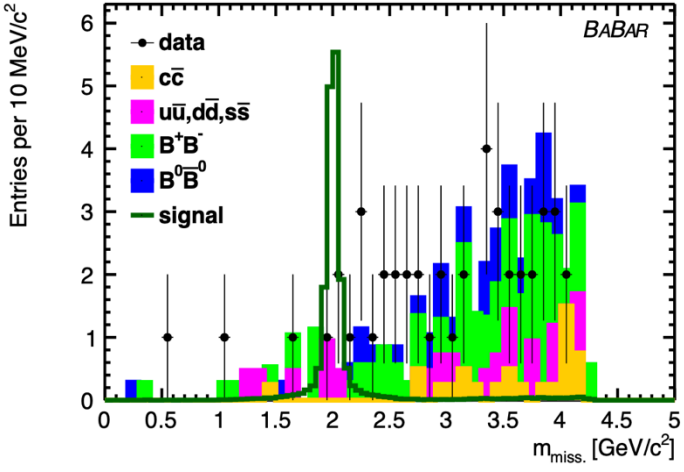
BABAR search for $B^+ \to p\psi$ in B-mesogenesis

PRD 131 (2023) 20, 201801

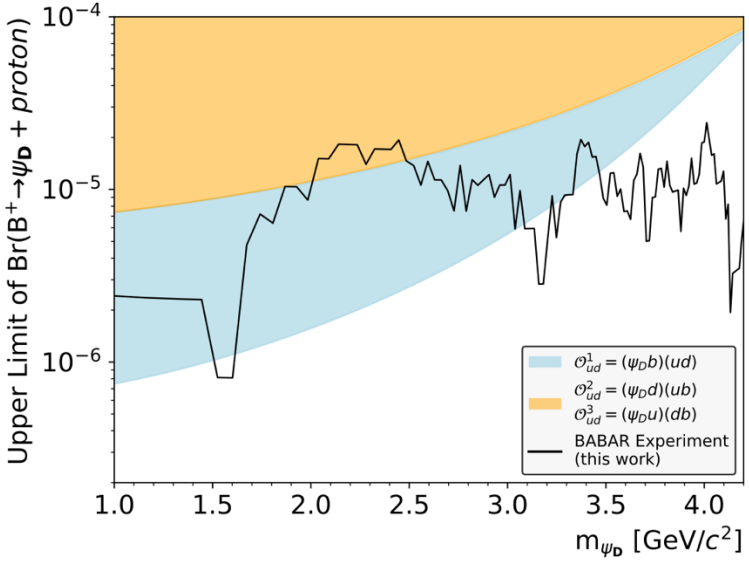
Reconstruct the other B

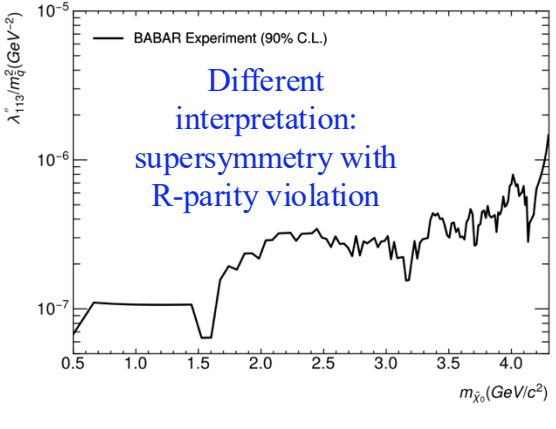


Plot the missing mass $\sqrt{(p_{ee} - p_B - p_p)^2}$



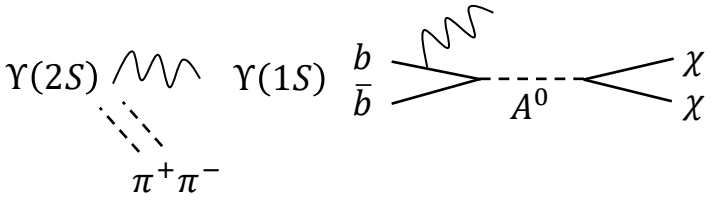
Branching-fraction limit & comparison to model expectation





Belle: Light Higgs decay to DM

PRL 122, 011801 (2019), 24.9 fb^{-1} ~ 157×10^3 $\Upsilon(2S)$



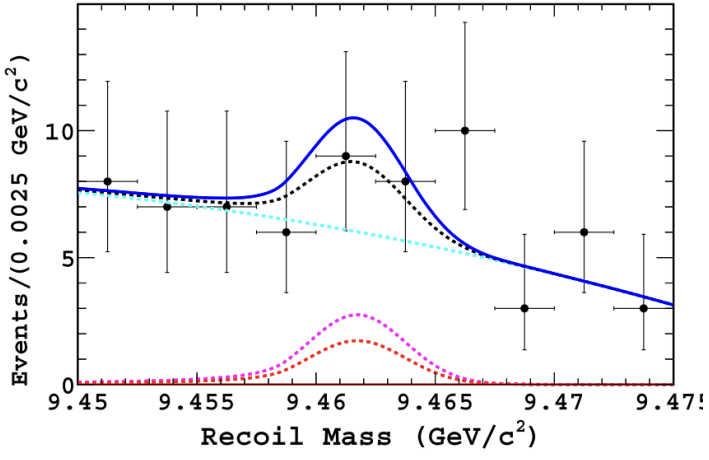
2D fit to

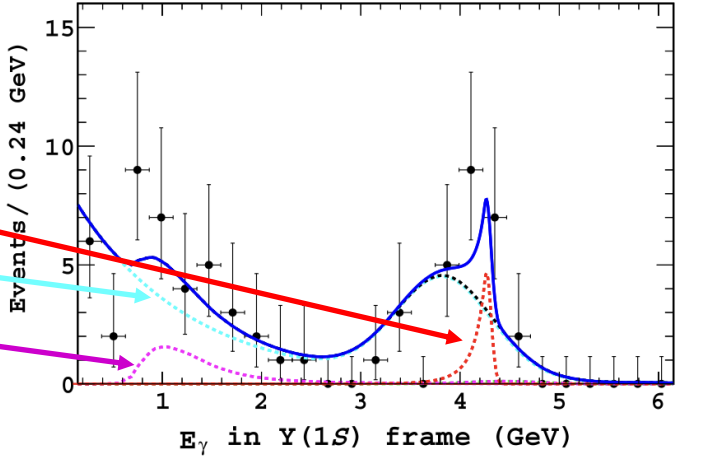
- $M_{\text{recoil}} = \sqrt{(p_{ee} - p_{\pi\pi})^2}$
- E_γ in $\Upsilon(1S)$ frame

Fit function includes

- Signal with A^0-mass hypotheses
- Background from $e^+e^- \to q\bar{q}$
- Background from $\Upsilon(1S)$

Also perform an off-shell A^0 fit
where the $\Upsilon(1S)$ decay is modelled with phase space

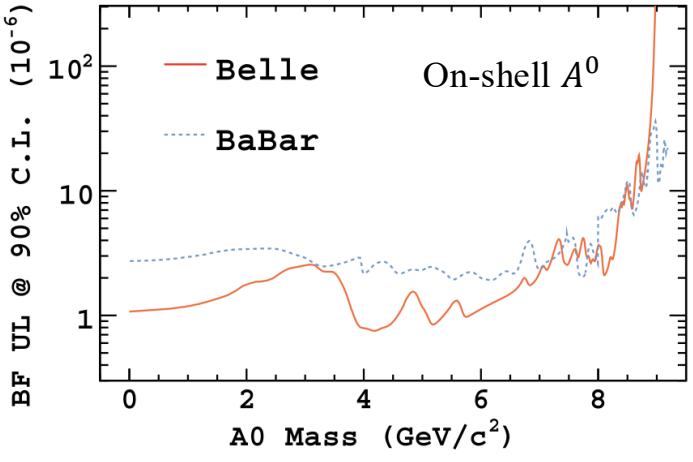


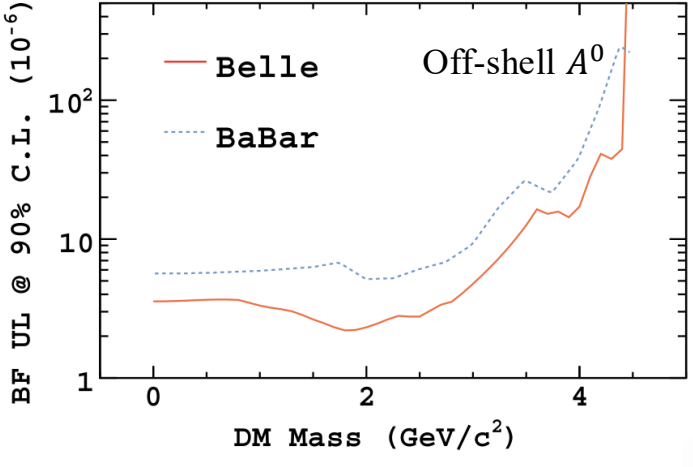


Belle: Light Higgs & DM

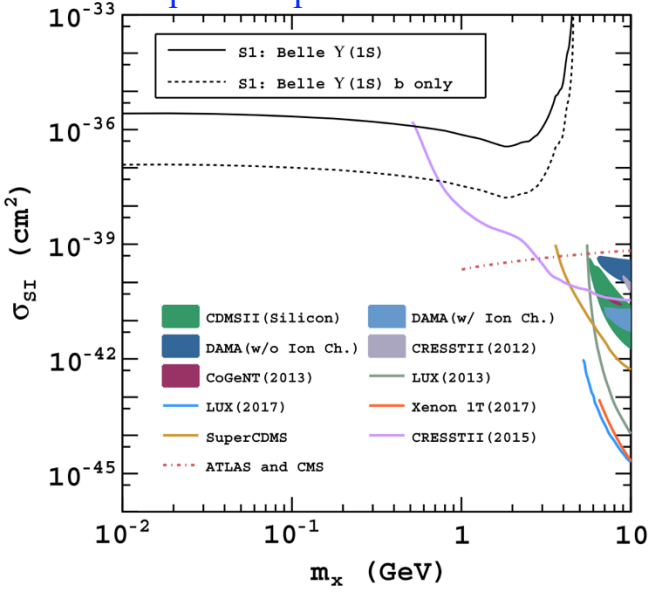
PRL 122, 011801 (2019), 24.9 fb^{-1} ~ 157×10^3 $\Upsilon(2S)$

Branching-fraction limits



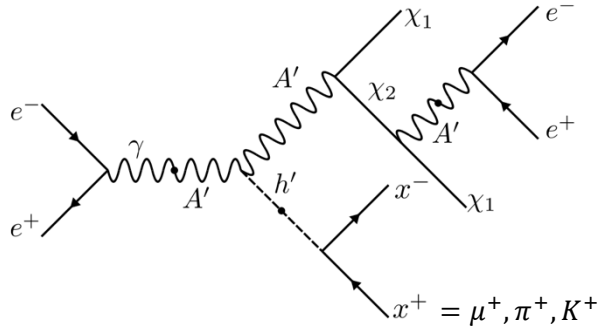


Limits on DM-nucleon spin-independent cross section



Belle II: Dark Higgs & photon + inelastic DM

PRL 135 (2025) 13, 131801, 365 fb^{-1}



Inelastic DM:

- Ground state χ_1 (DM)
- Excited state χ_2 can decay via $\chi_2 \rightarrow \chi_1 A'$

Small mixing b/w dark Higgs/photon & SM Higgs/photon
→ h' or A' is long-lived, respectively.

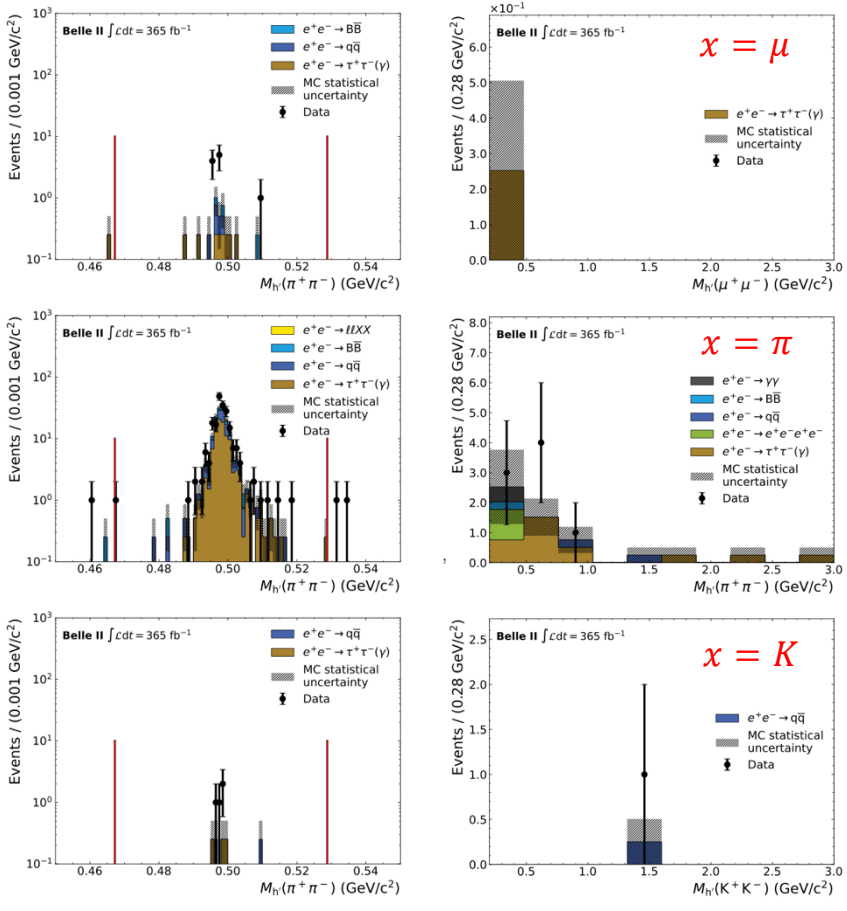
So require at least one displaced vertex.

Signature summary:

- e^+e^- vertex and x^+x^- vertex, at least one is displaced
- Missing energy from the two χ_1

Veto h' if consistent with K_S

$m(x^+x^-)$ distribution

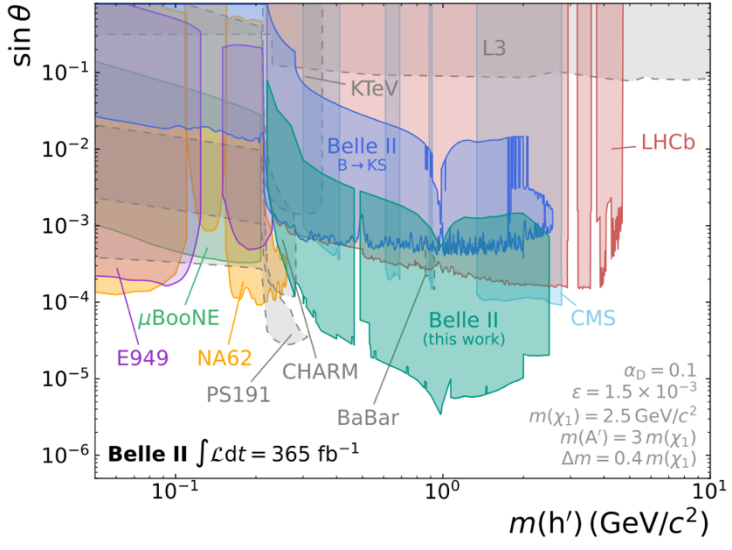


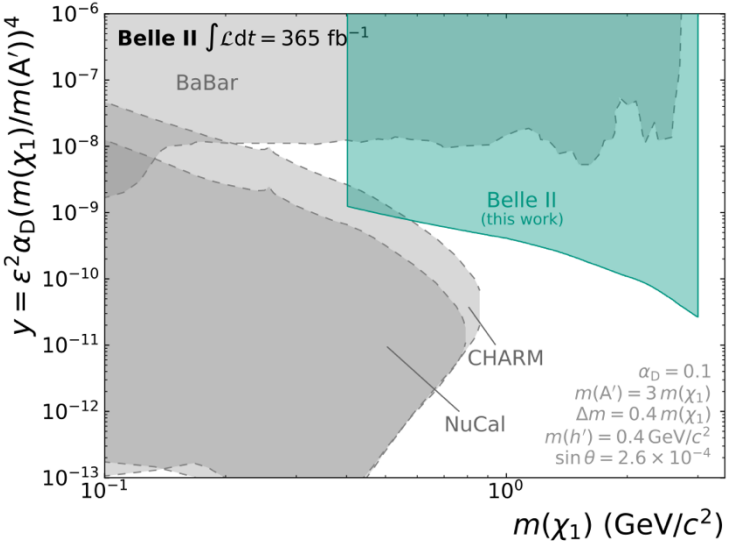
Belle II: Dark Higgs & photon + inelastic DM

Model parameters:

- $m_{h'},\ m_{\chi_1}, m_{A'}$
- $\Delta m = m_{\chi_2} - m_{\chi_1}$
- $\varepsilon =$ dark photon kinetic mixing w. SM photon
- $\theta =$ dark Higgs mixing w. SM Higgs
- $\alpha_D =$ dark U(1) interaction strength

Limits on 2 parameters with the rest fixed





Other experiments' limits are from A' & h' without inelastic DM

Summary

- There are many collider searches for dark-matter particles
  - Mostly from LHC but also from other experiments
- Limits reported in the $10\ \text{MeV} < m_D < 2\ \text{TeV}$ range
- These searches utilize specific models to explain DM production
  - Results are often presented in the same way as direct-search limits
- In some cases the limits are tighter for low DM masses
- These searches are sensitive also to non-DM BSM scenarios