SPECTRAL FEATURES
IN THE MEV-GAP

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work in collaboration with:
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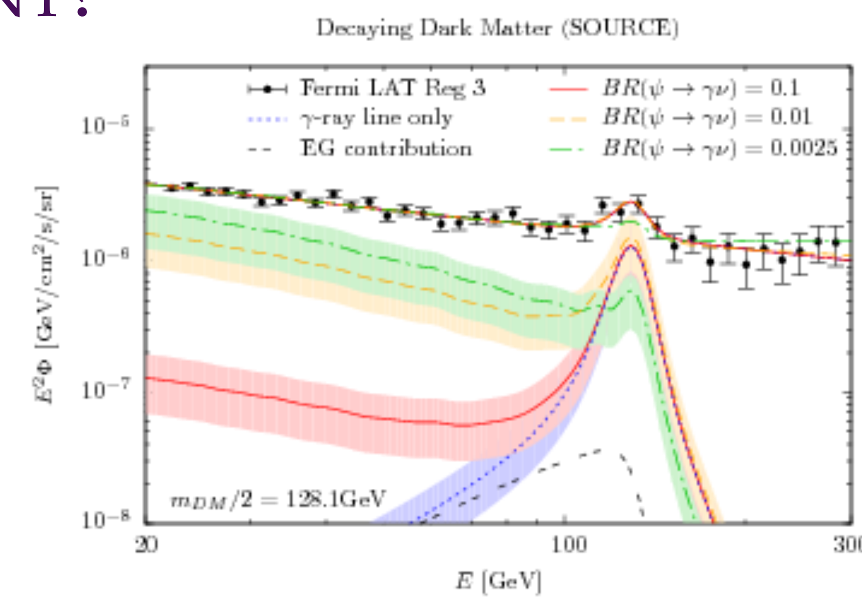
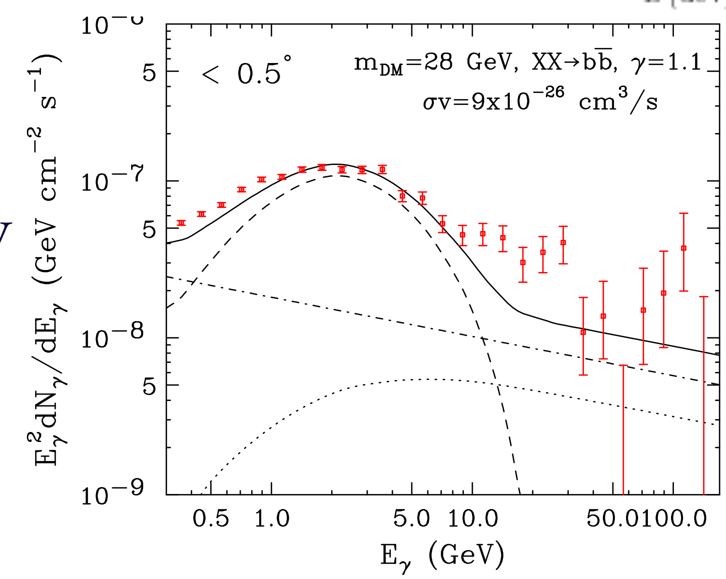
SPECTRAL FEATURES
WHY ARE THEY SO IMPORTANT?

1. Improve signal/background
   (significantly helps in spectral fits)

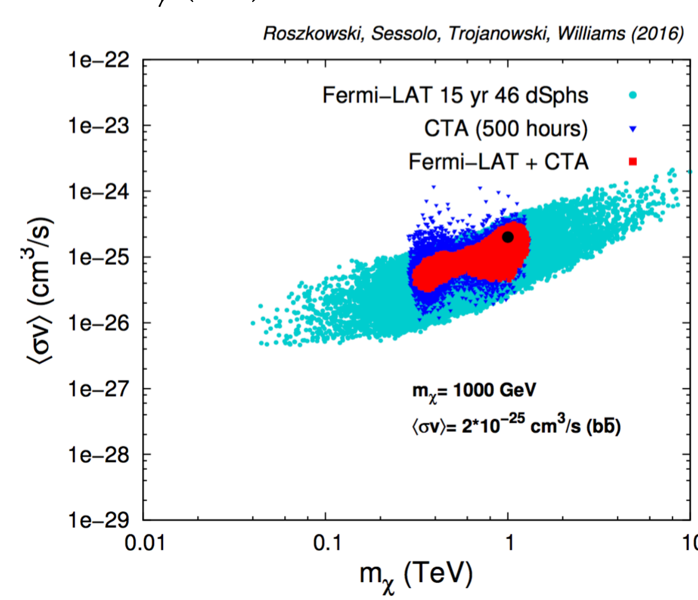


2. Hugely increase the credibility
   of the DM origin of a signal
   (systematics + interpretation)

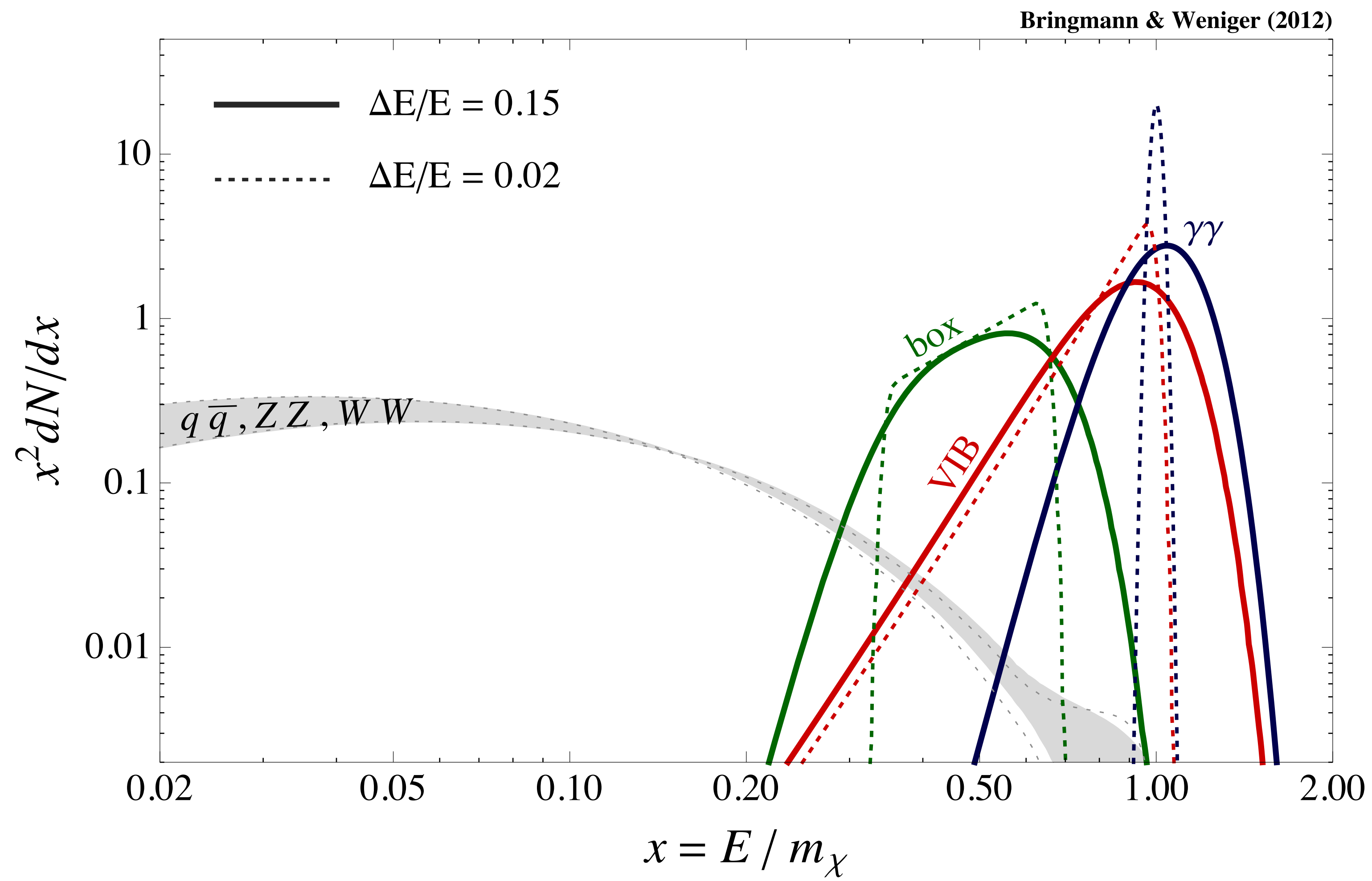
E.g. GeV excess:



3. Significantly increase possibility
   of inferring the DM properties
   from a measured signal
   (e.g. gamma line would pin-point the DM mass)



SPECTRAL FEATURES
WHAT CAN WE LOOK FOR?



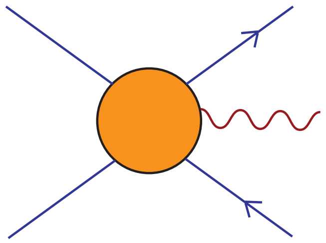
Gamma-ray lines

$$\chi\chi \to \gamma\gamma$$

generically loop-suppressed

Internal Bremsstrahlung

$$\chi\chi \to \bar{f} f \gamma$$



Box-shaped

$$\chi\chi \to \phi\phi \implies \phi \to \gamma X$$

tree-level; cascade decay

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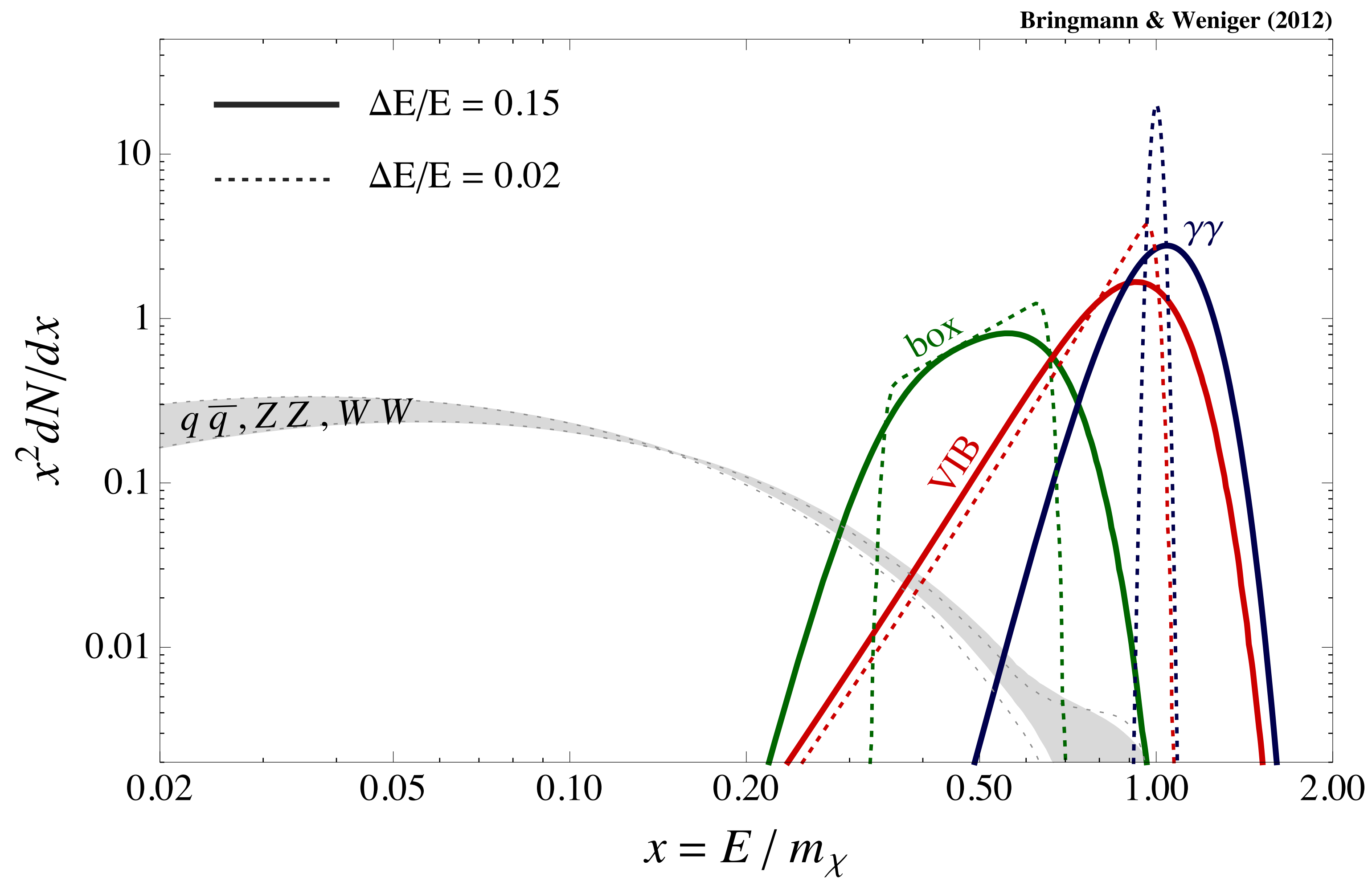

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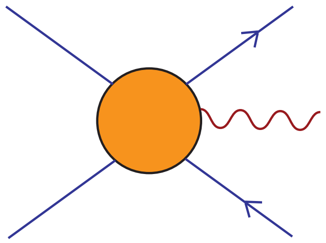

Box-shaped

$$\chi\chi \to \phi\phi \Longrightarrow \phi \to \gamma X$$

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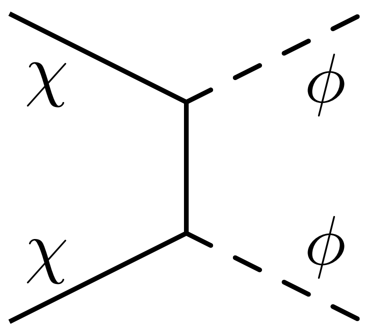
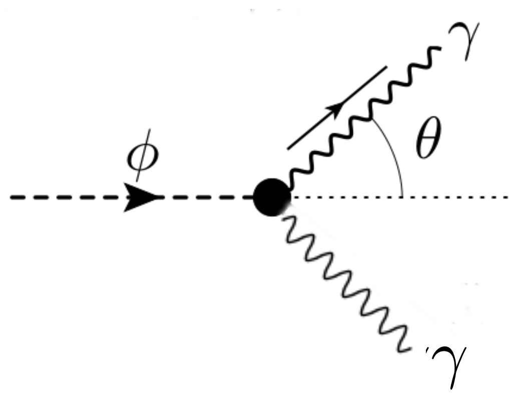
GAMMA-RAY BOXES

Consider a process: $\chi\chi \to \phi\phi \Rightarrow \phi \to \gamma\gamma$





In the LAB frame:

$$E_\gamma = \frac{m_\phi^2}{2\,m_{DM}}\left(1 - \cos\theta\sqrt{1 - \frac{m_\phi^2}{m_{DM}^2}}\right)^{-1}$$

If ϕ produced at rest $\longrightarrow$ monochromatic line...

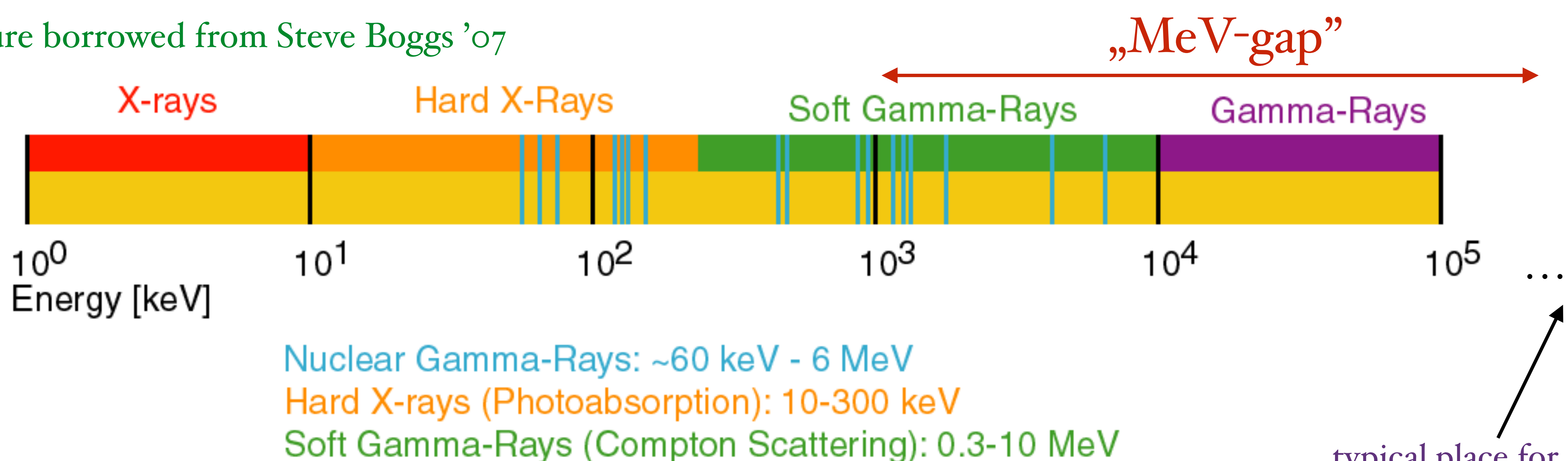
...if not, boosted to give a box shaped spectrum:

$$\frac{dN_\gamma}{dE} = \frac{2}{\Delta E}\left[\Theta(E - E_-) - \Theta(E - E_+)\right]$$

(For narrow boxes I may use the box and line terms interchangeably...)

KNOWN GAMMA-RAY LINES

figure borrowed from Steve Boggs '07

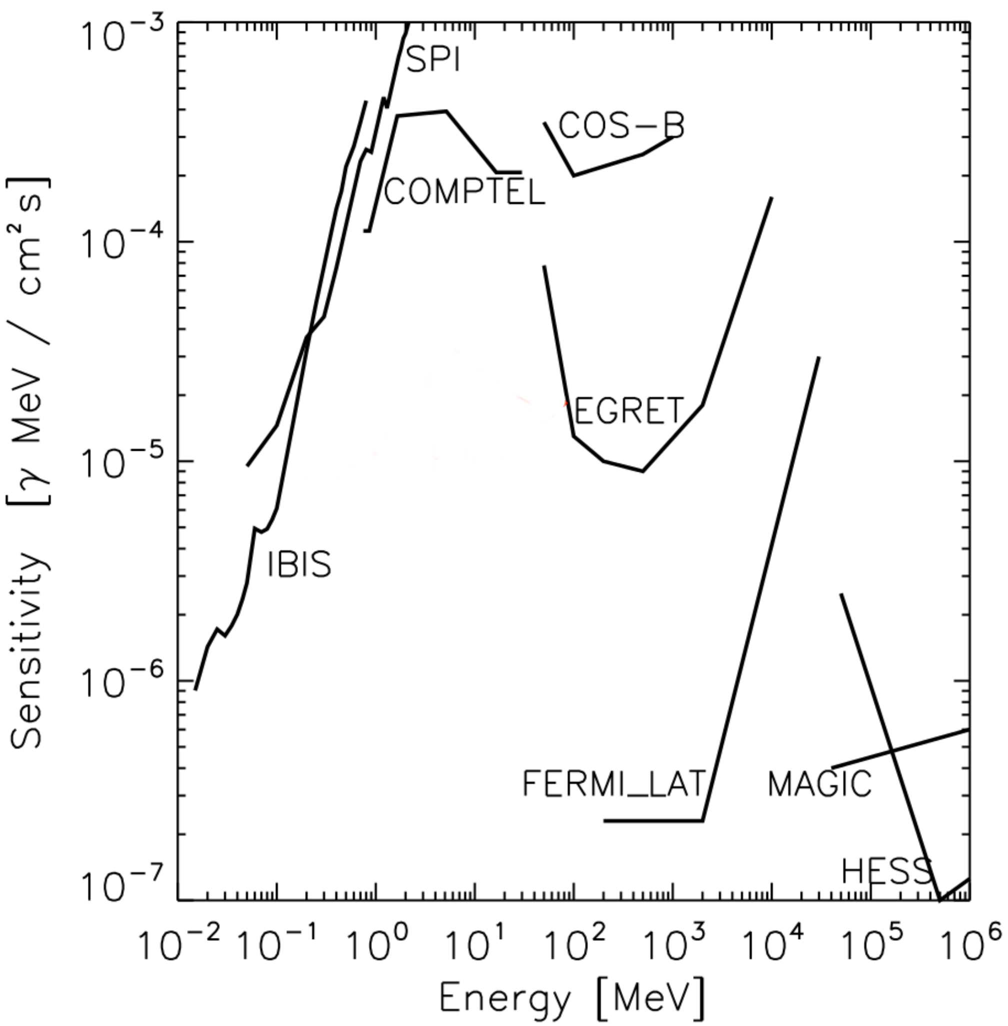


typical place for gamma-line searches;

quite constrained, especially for low masses, from other ID channels

The MeV-gap contains a timely sweet spot for spectral features searches: no background lines + scarce complementary data

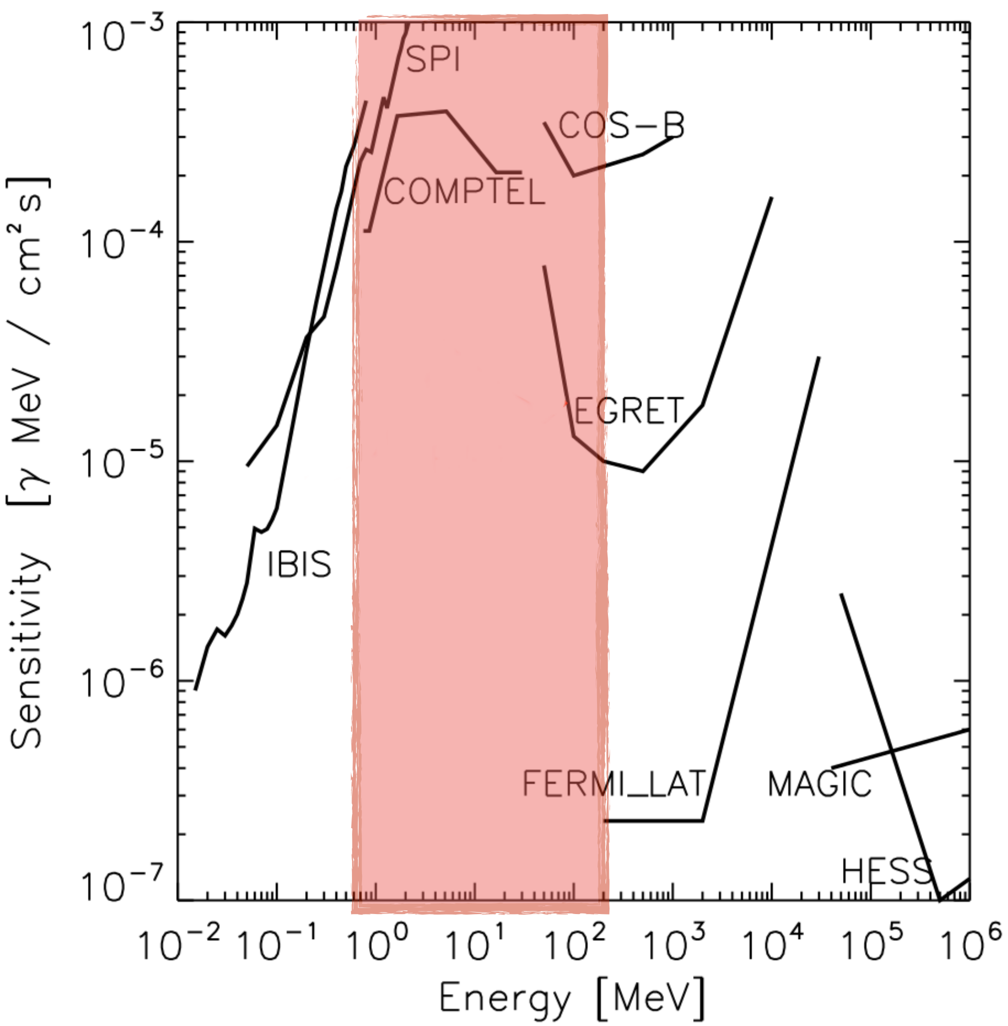
MeV-gap



Experiment	E range	Characteristics
GAMMA-400	100 MeV - 3 TeV	A_{eff} = 3000cm^2, dE optimized for high E
APT	100 MeV -100 GeV	A_{eff} = 3-4 x10000cm^2
AdEPT	5 - 200 MeV	PSF ~ 0.5deg, dE ~ 15-30%
ASTROGAM	0.3 MeV - 1 GeV	dE ~ 1%, PSF < 1deg
GAMMA-LIGHT	10 MeV - 10 GeV	PSF ~1deg, A_{eff} ~ few 100cm^2
GRIPS	200 keV - 80 MeV	dE ~ 1%, PSF ~ 1.5deg, A_{eff} = 195cm^2
PANGU	10 MeV - 1 GeV	PSF ~ 0.3deg, dE like *Fermi*
...		

At this energy range: ID is the best available strategy + high backgrounds from astrophysics = are there any spectral features that would help?

MeV-gap



„MeV-gap”

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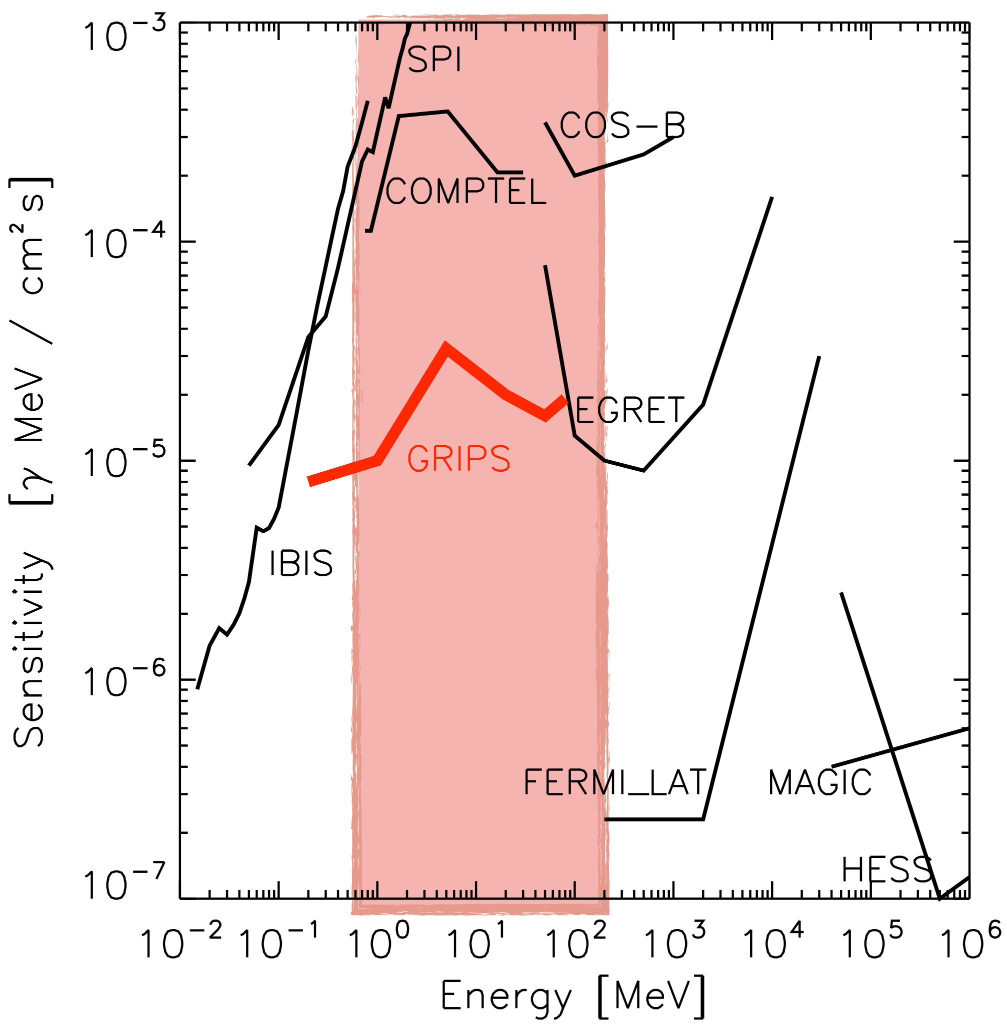

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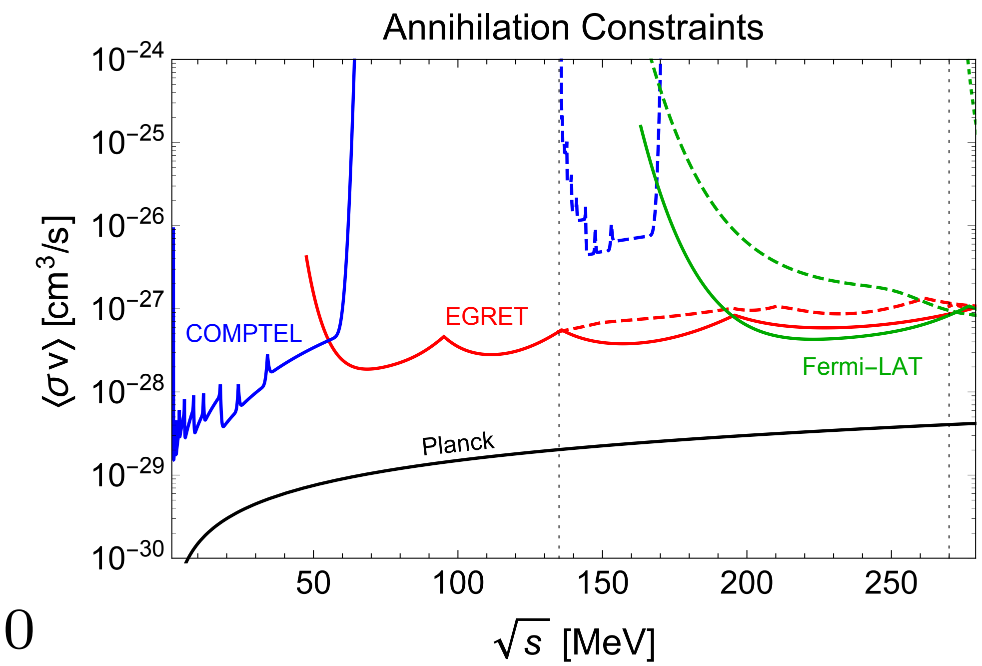
How to get O(MeV) line?

Typically gamma-lines at such small DM masses have to be extremely weak, otherwise would be already excluded

One possibility to evade it:
Boddy & Kumar '15

- low mass $\sqrt{s} < 2m_{\pi^\pm}$
- annihilating/decaying
- coupled to first generation quarks



→ possible final states: $\gamma\gamma \quad \gamma\pi^0 \quad \pi^0\pi^0$

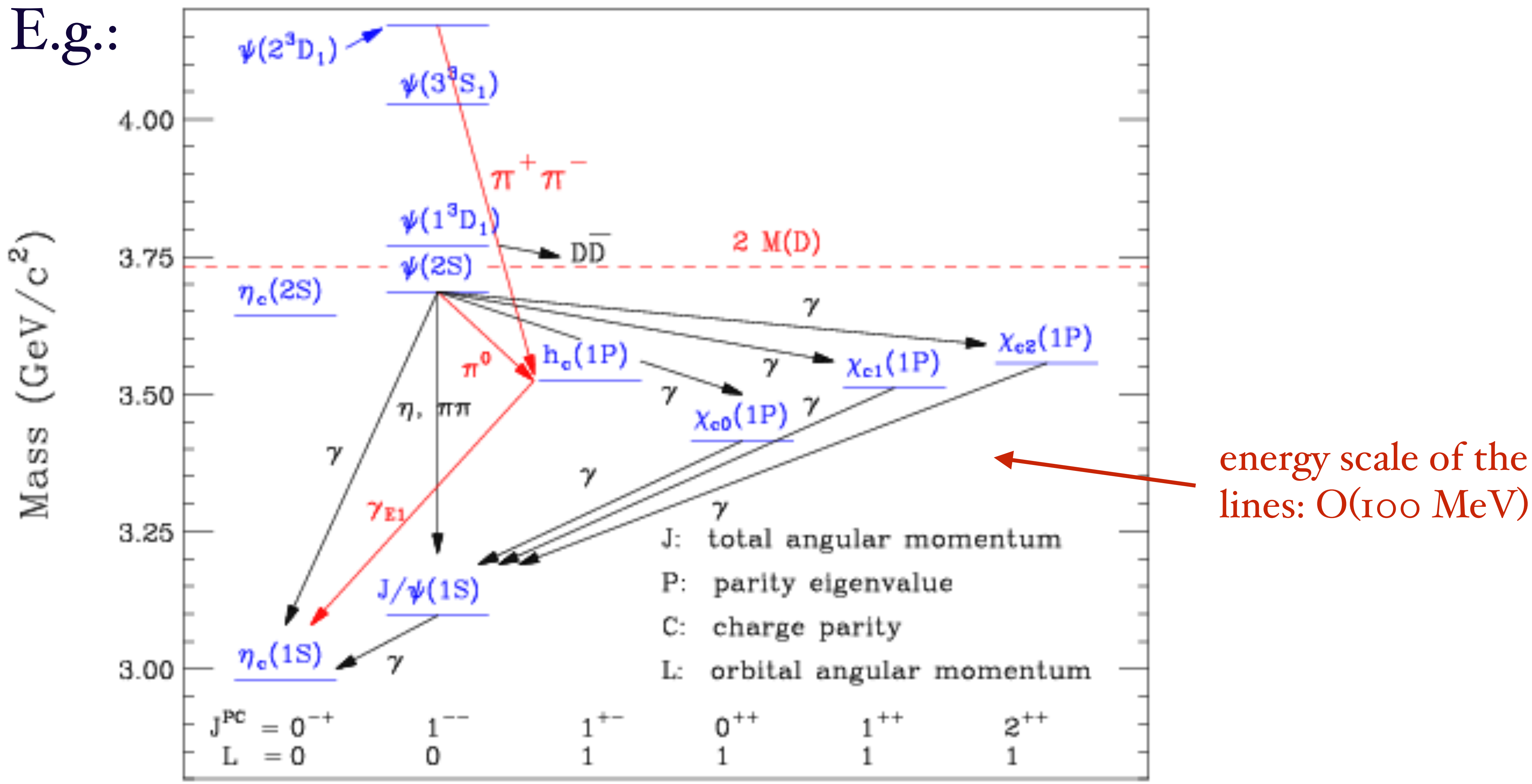
produced nearly at rest:
decay to nearly monochromatic photons

But there is also another, quite striking possibility...

MESON SPECTROSCOPY

Transitions between meson states lead to monochromatic pions or photons:

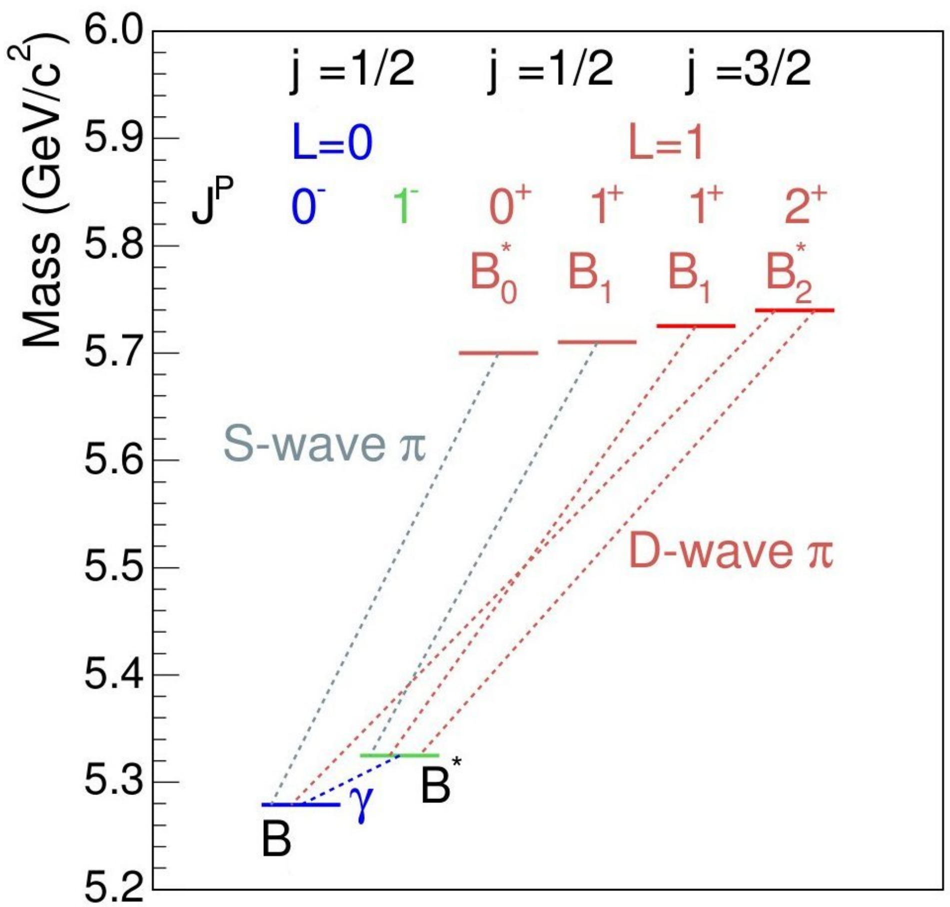
E.g.:

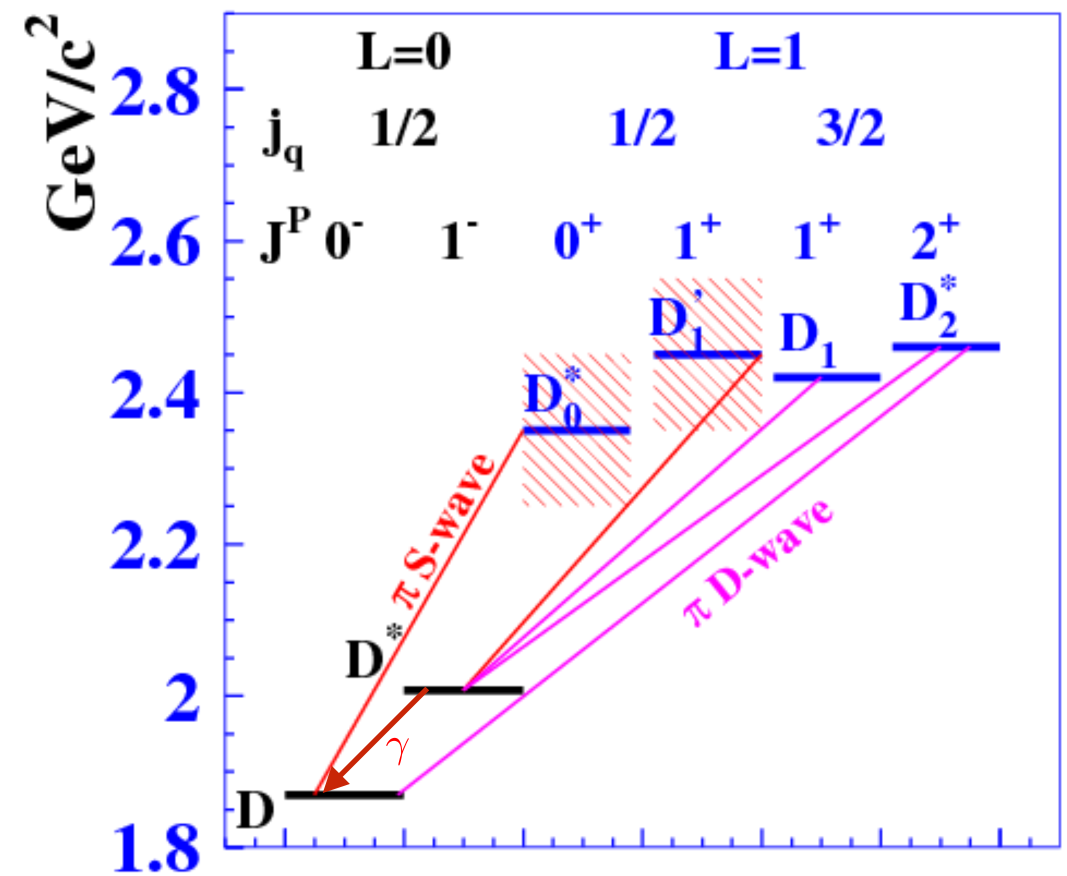


Can such states be produced in DM annihilation?

Can such lines be detected?

B and D mesons



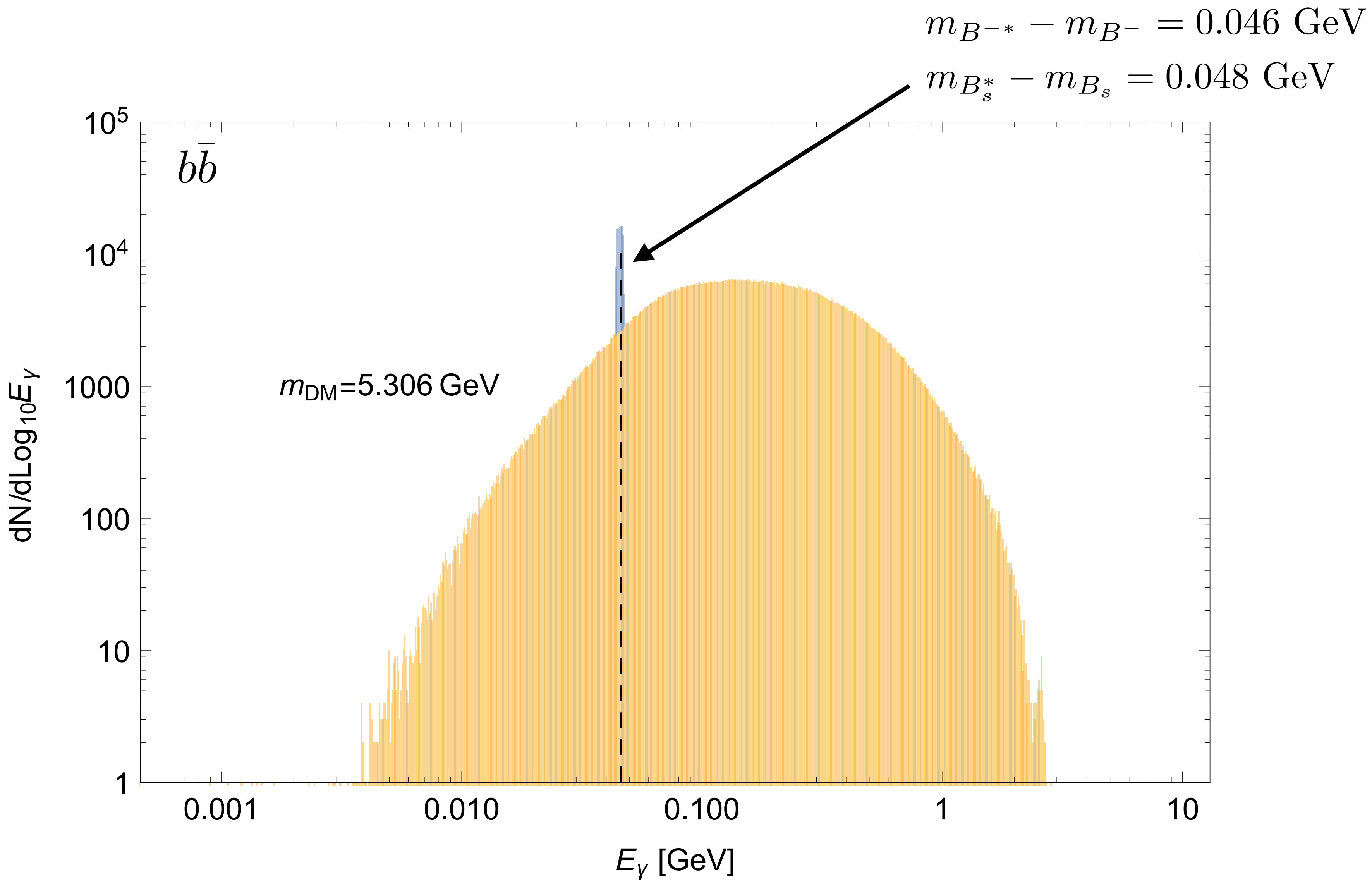


B and D mesons are composed from one light and one heavy quark

→ can be produced in annihilation to $b\bar{b}$ and $c\bar{c}$

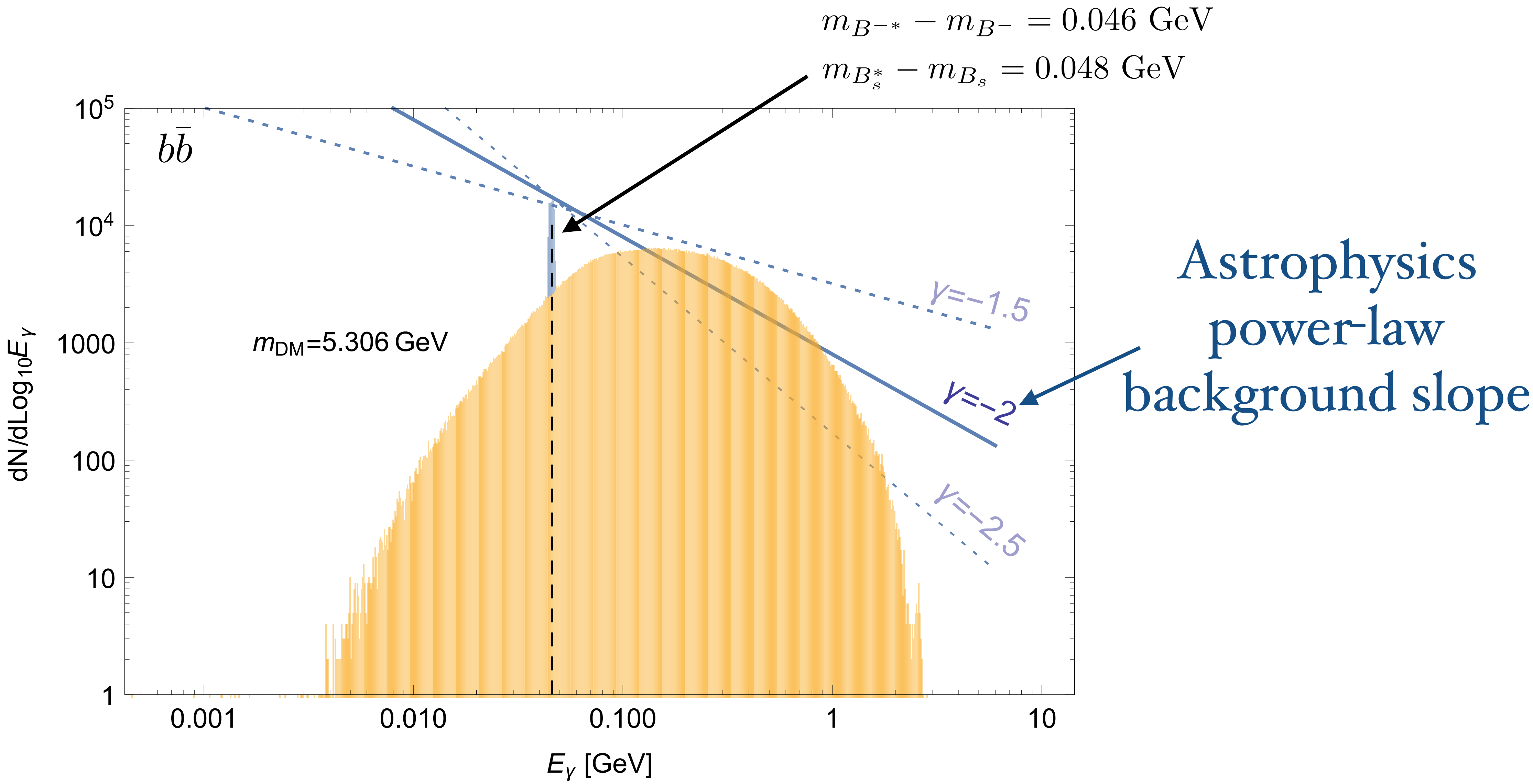
→ do not show up in astrophysical background

SPECTRA
DM ANNIHILATION INTO B-QUARKS



Close to threshold: very narrow box features ⟶ effectively a line

SPECTRA
DM annihilation into b-quarks



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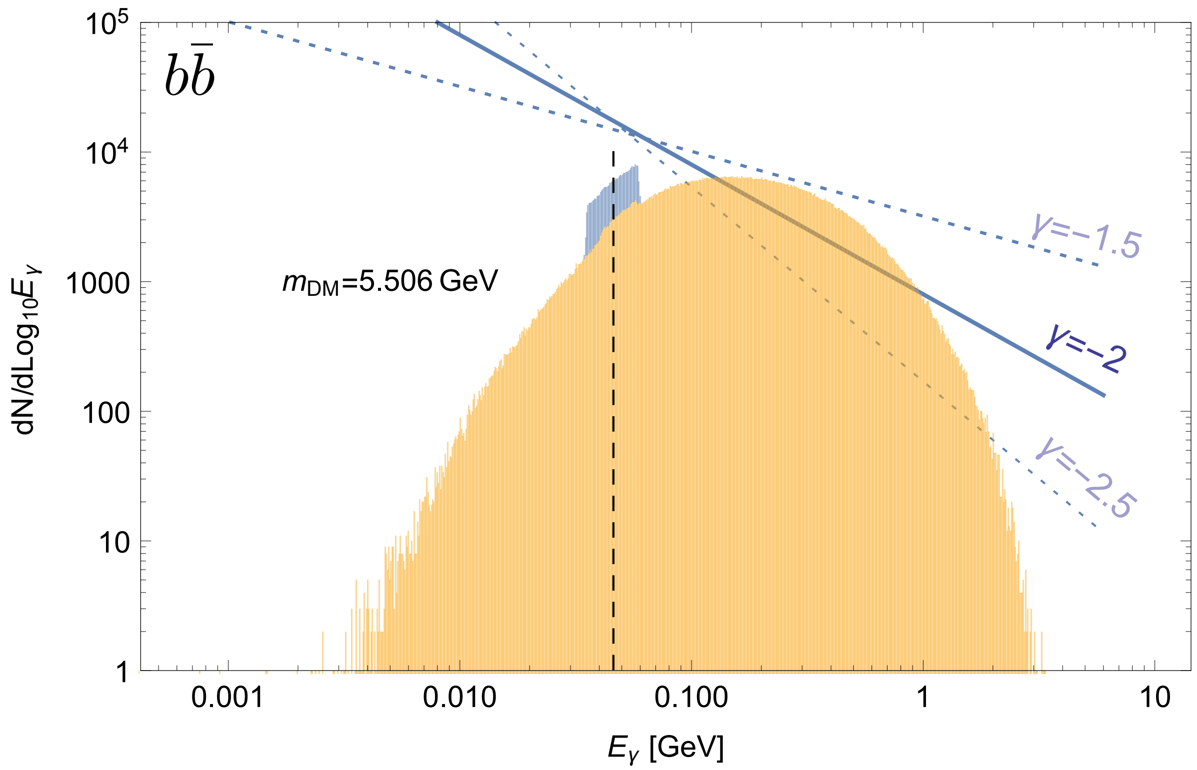
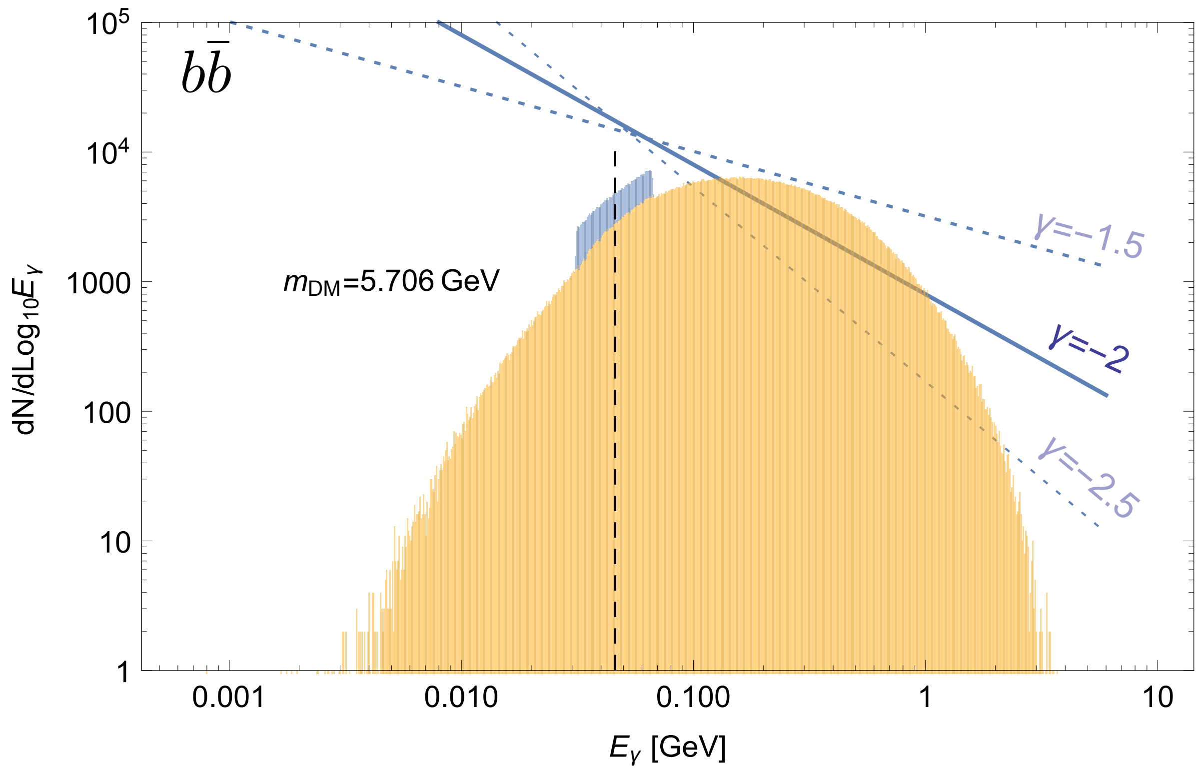


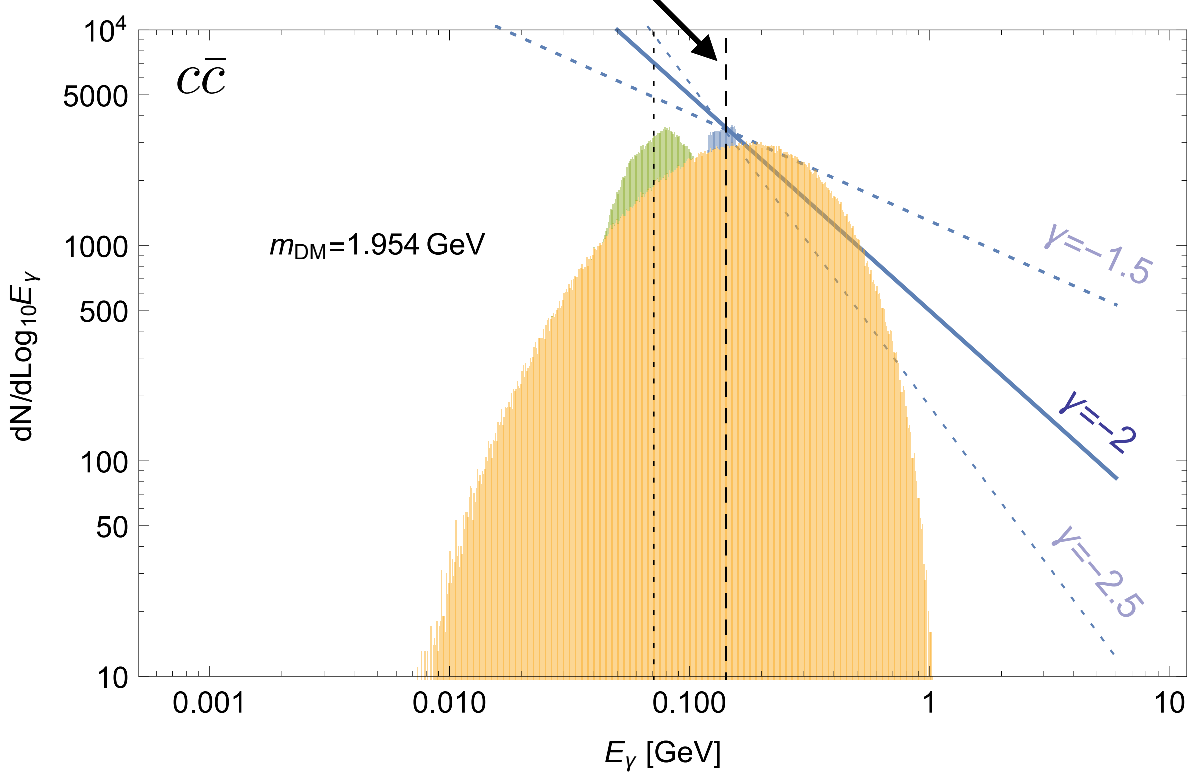


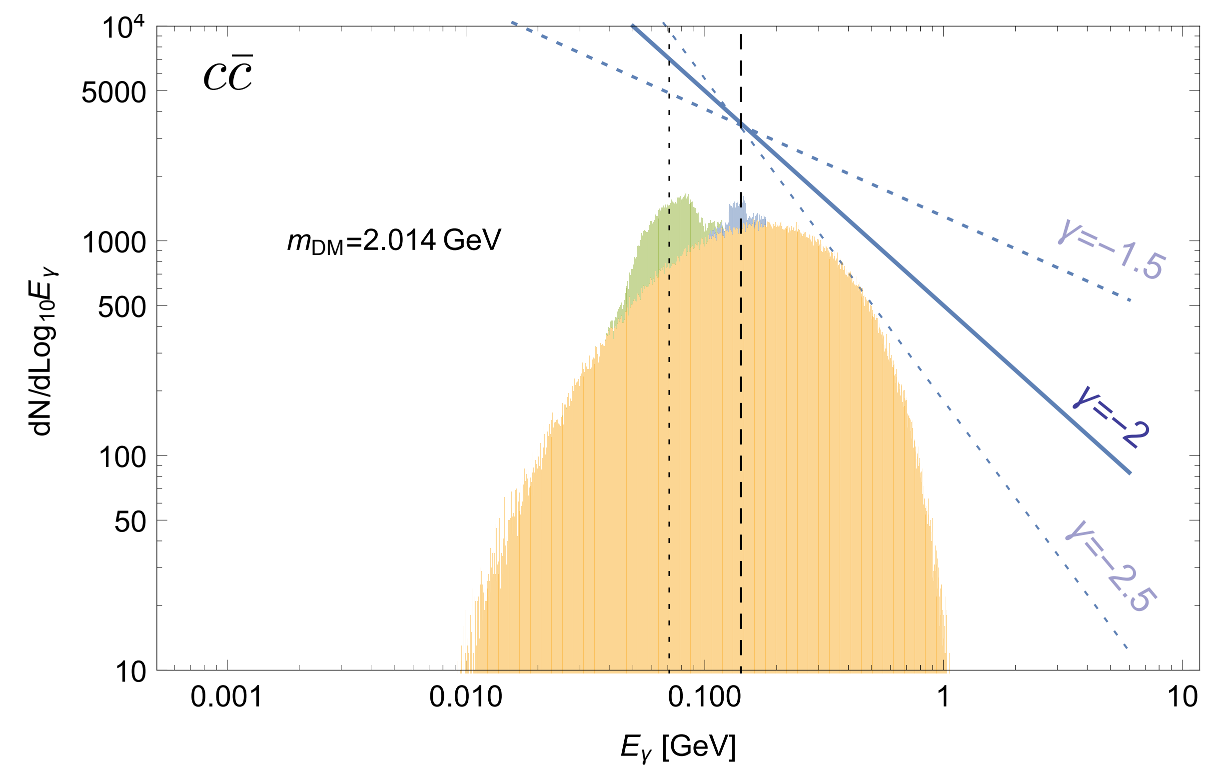
More above the threshold:
box feature becomes wider and less pronounced

feature thickness strongly dependent on the mass
⟶ possibility of accurate mass determination

SPECTRA
DM ANNIHILATION INTO C-QUARKS

$m_{D^{-*}} - m_{D^-} = 0.140$ GeV
$m_{D^*} - m_D = 0.142$ GeV
$m_{D_s^{-*}} - m_{D_s^-} = 0.144$ GeV





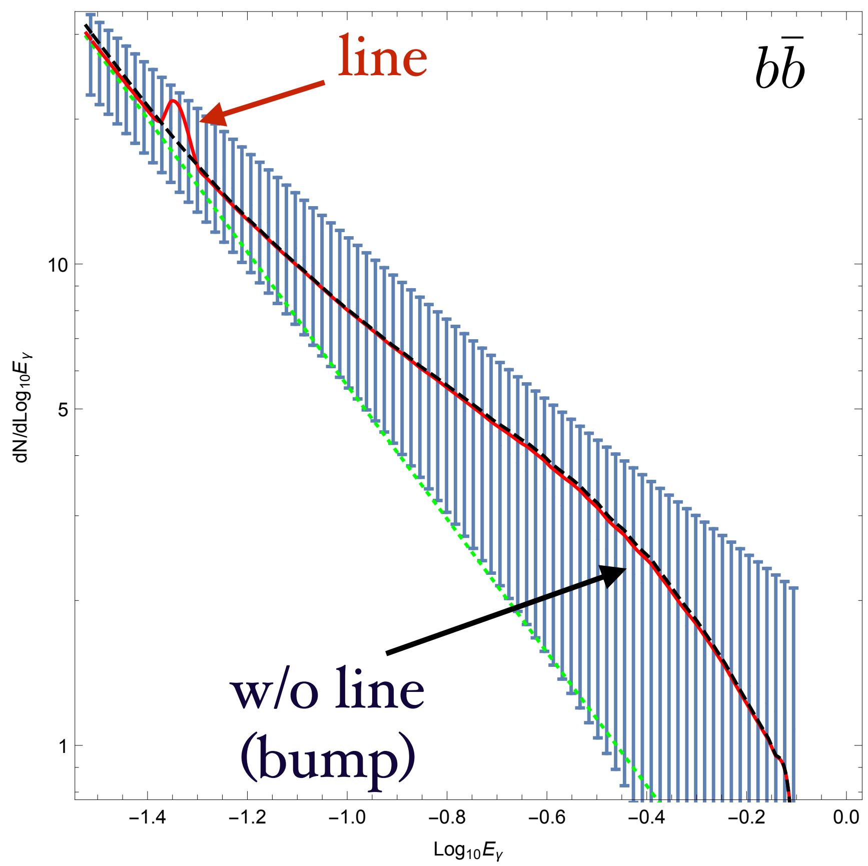
$D^* \rightarrow \pi^0 D$ BR ~ 2/3
$D^* \rightarrow \gamma D$ BR ~ 1/3

⟶ the box is fainter + secondary pion bump appears

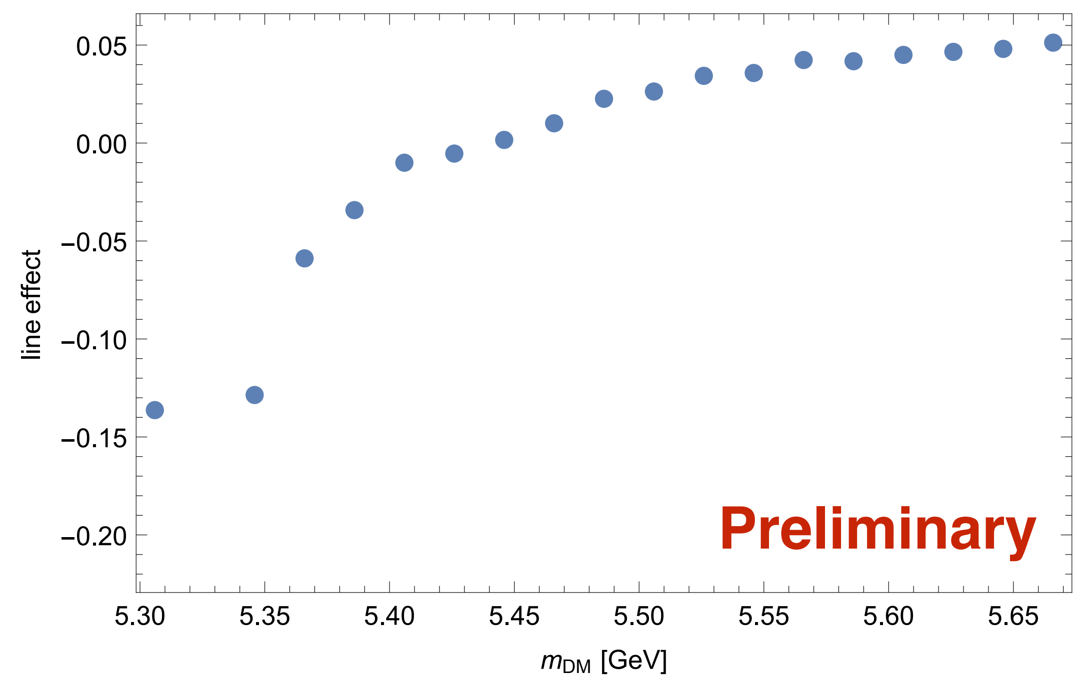
still interesting, since less hidden behind the main component

PHENOMENOLOGY
LIMITS EXAMPLE

fake data power-law with index = -2



if no systematics:



the line has mild effect…

Instrument:

- A_{eff} = 1000 cm²
- dE = 1%
- E range = 30-800 MeV

ROI:

- Draco
- ang. size 0.25°
- J-factor = $10^{18.8}$ GeV^2 cm^{-5}

… but with systematics included

↓

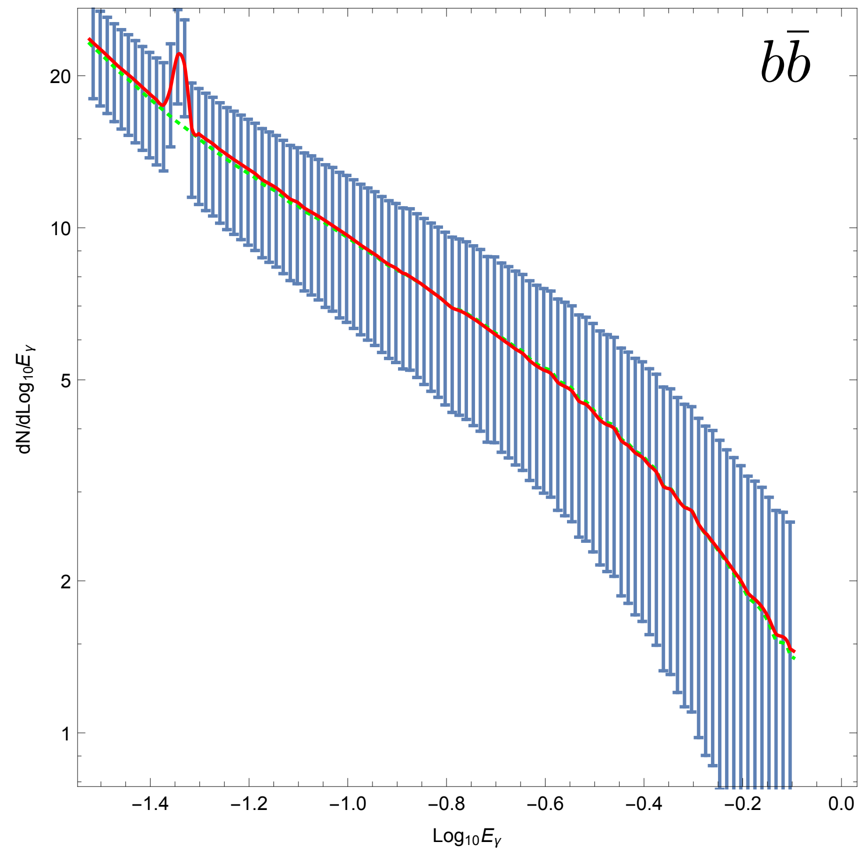
limits on the „bump" much weaker, but not for the line

work in progress…

PHENOMENOLOGY

SENSITIVITY FOR LINE DETECTION

fake data: Astro+DM signal



m_{DM} = 5.326 GeV
Draco, no systematics

case	σv sensitivity
dE = 1%, t = 1 year	4.02 x 10^{-26} cm^3/s
dE = 1%, t = 10 years	8.10 x 10^{-28} cm^3/s
dE = 5%, t = 10 years	1.17 x 10^{-26} cm^3/s

Preliminary

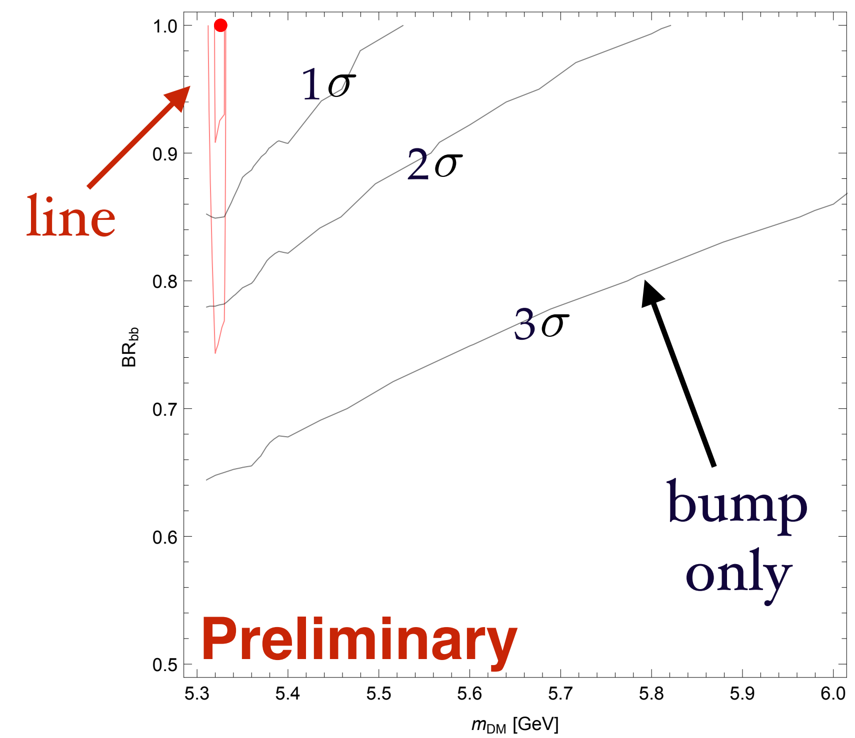
example of parameter determination:
line vs. bump only

generated fake data: m_{DM} = 5.326 GeV, 100% $b\bar{b}$

signal reconstruction: free m_{DM} and $BR_{bb\ vs\ uu}$

line significantly helps in inferring DM parameters

(if strong enough to be detected)



CONCLUSIONS

1. We identified new spectral features in gamma-ray DM searches

   from transitions between meson states, with potentially interesting phenomenology

2. Based on SM physics alone, they are present for generic DM model

   however, they are pronounced only in close to threshold scenarios

3. For B and D mesons, the box is hiding behind extended component

   but still can help in detection & determination of the DM parameters

Takeaway:

Meson spectral features could significantly increase robustness of light DM detection and help in determination of its parameters