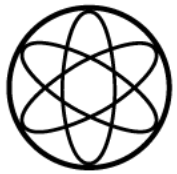
Prospects of antideuteron detection from Dark Matter annihilations or decays at AMS-02 and GAPS

Sebastian Wild (TU München)



DESY Theory Workshop, September 26, 2012

Based on arXiv:1209.5539 in collaboration with Alejandro Ibarra

Outline

1. Indirect DM detection with antideuterons
2. Constraining $\bar{d}$ prospects with PAMELA $\bar{p}/p$ data
3. Coalescence model: enhancement of $\bar{d}$ yield?
4. Conclusion

Indirect DM detection with antideuterons

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  Search for annihilation/decay products of Dark Matter in cosmic rays

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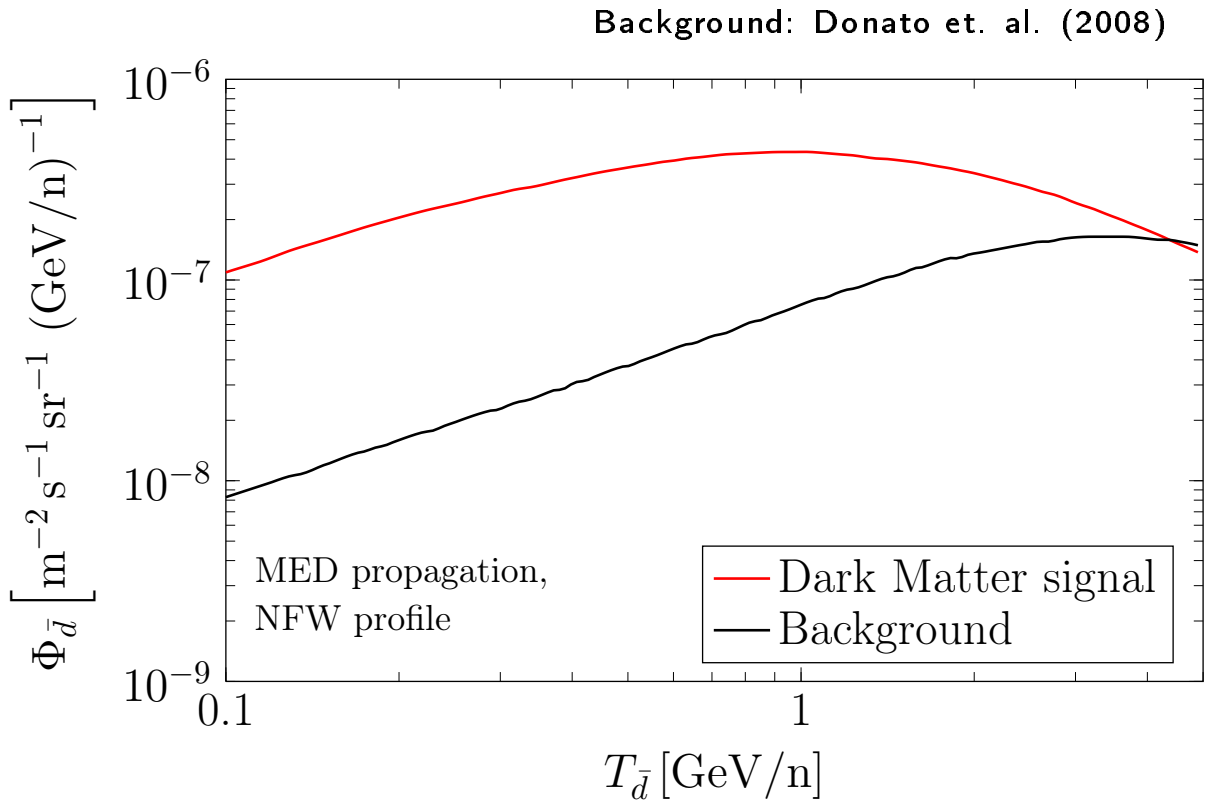
$\downarrow$

The detection of **only a few** low-energetic antideuterons therefore can be a **smoking-gun signal** for DM annihilations or decays

Indirect DM detection with antideuterons

- **Example**: $\chi\chi \to b\bar{b}$, $m_\chi = 100\,\mathrm{GeV}$, $\langle\sigma v\rangle = 3 \cdot 10^{-26}\,\mathrm{cm}^3/\mathrm{s}$



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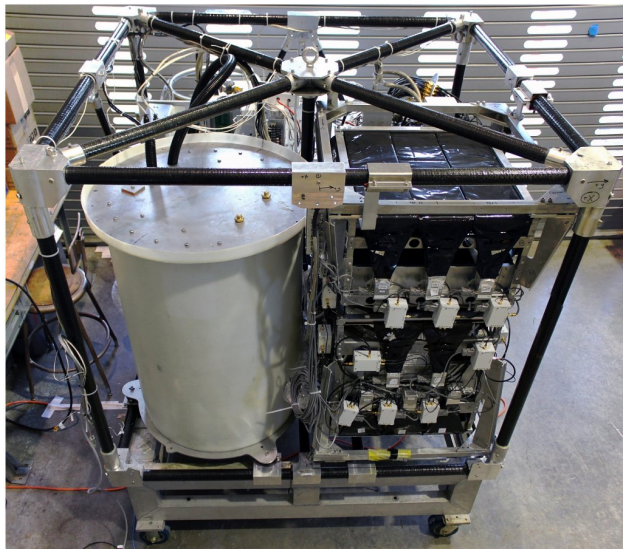

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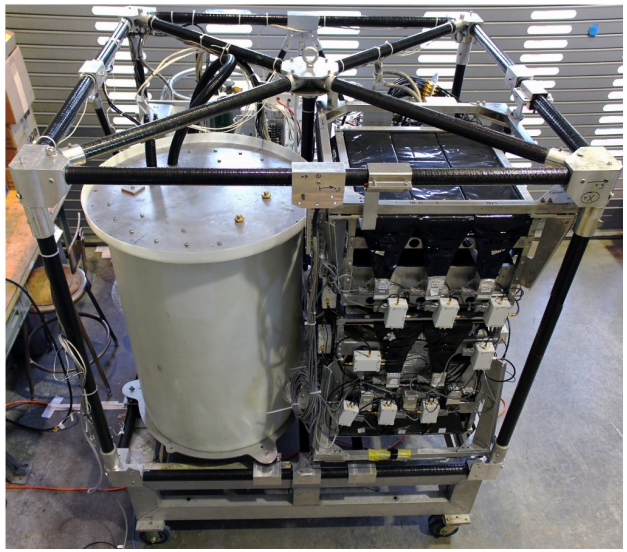
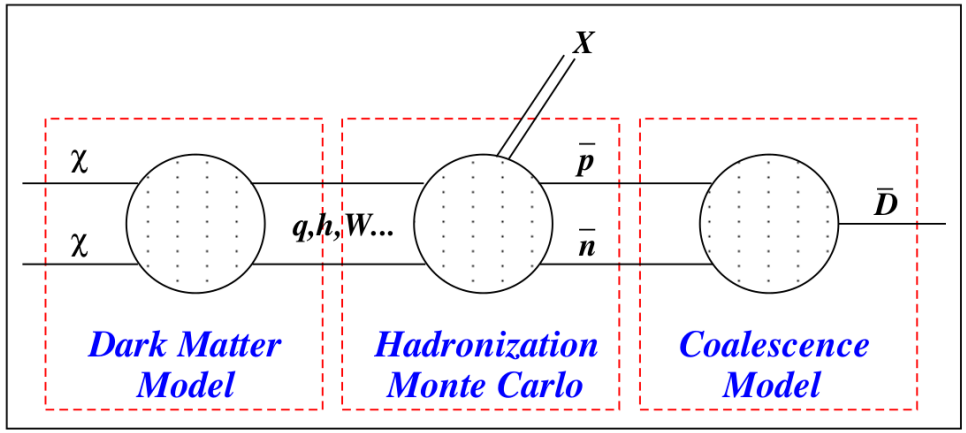


Main issue of this talk:

Prospects of DM discovery with antideuterons at AMS-02 / GAPS, taking into account $\bar{p}/p$ **constraints from PAMELA**

Production of antideuterons in DM annihilations/decays

Figure from Baer, Profumo (2005)



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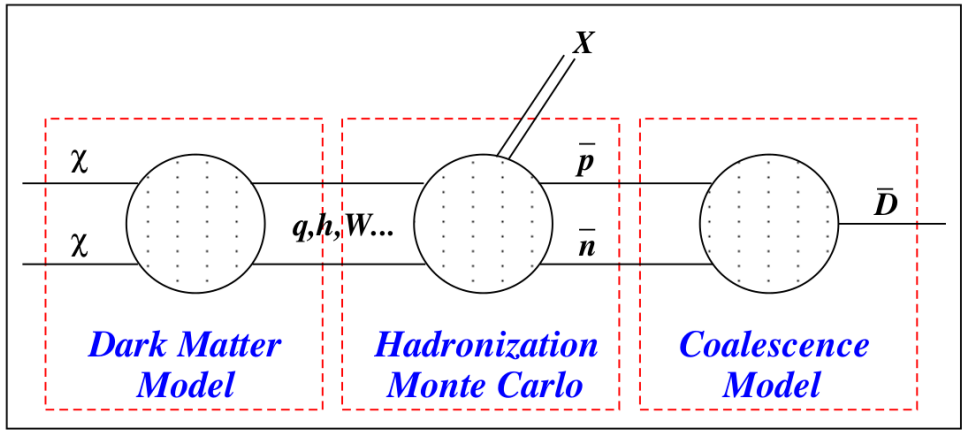

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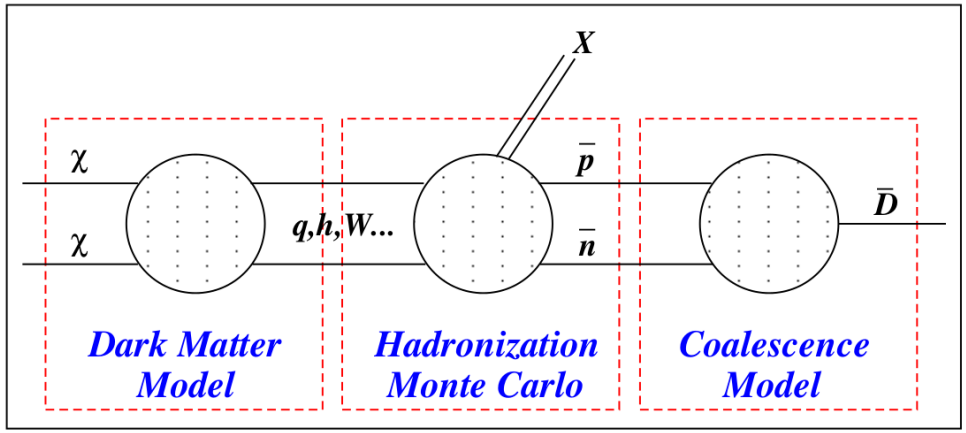
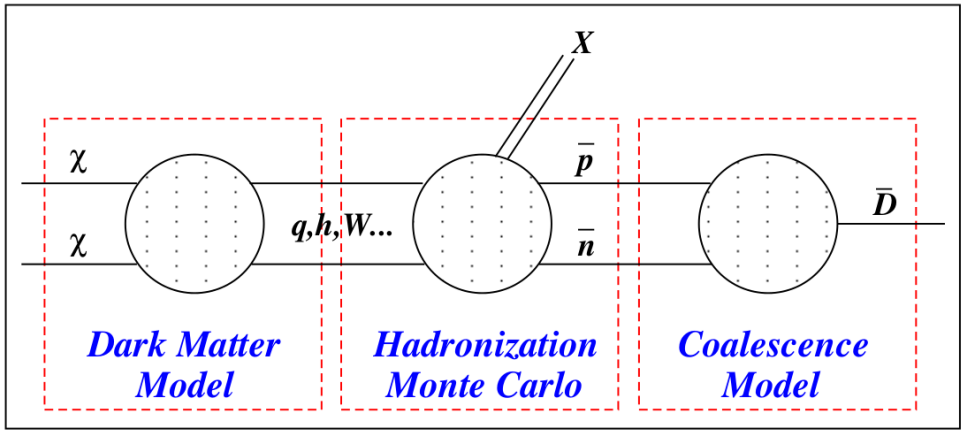


- Considered annihilation/decay channels: $\chi\,\chi \to W^+\,W^-$ and $\chi\,\chi \to b\,\bar{b}$
- Hadronization simulated with PYTHIA 8
- We use three different **halo profiles**: NFW, Einasto and Isothermal
  $\hookrightarrow$ we investige the astrophysical uncertainties regarding our results

The coalescence model

Figure from Baer, Profumo (2005)



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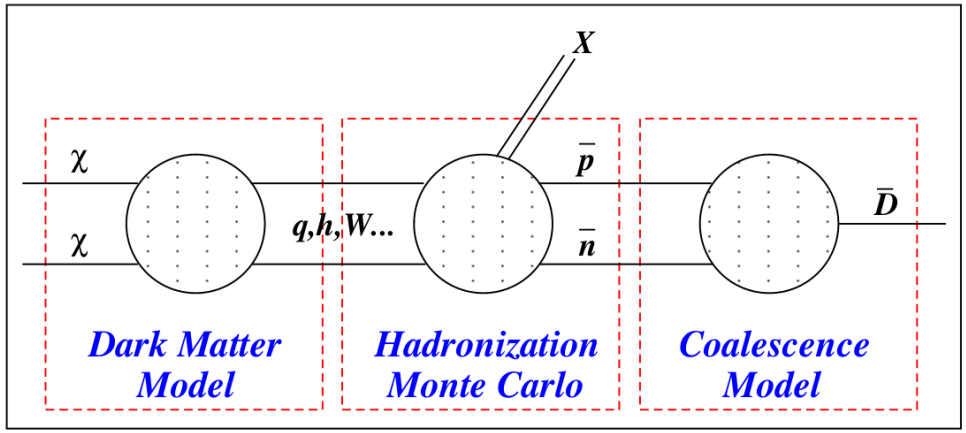

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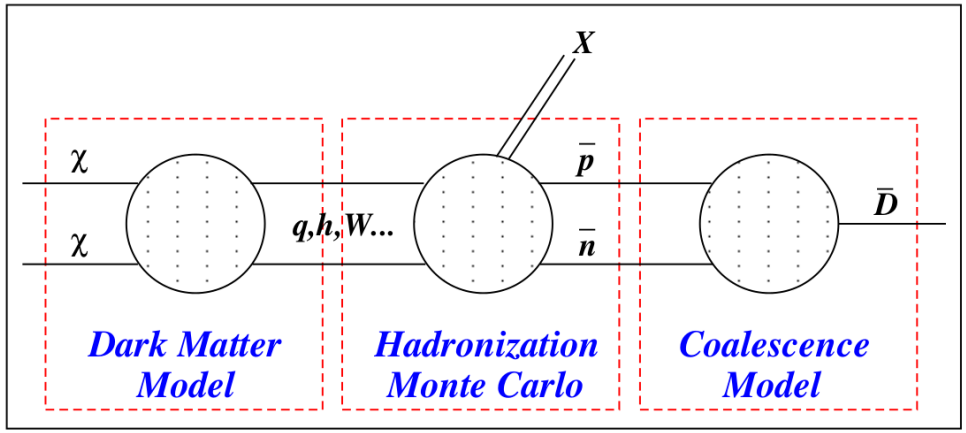

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↪ **Coalescence momentum** p_0 is tuned against measured $\bar{d}$ yield per Z decay

- We search on an event-by-event basis for $\bar{p}$-$\bar{n}$ pairs satisfying this condition

Propagation of antideuterons in the galaxy

- We employ the usual two-zone diffusion model
  $\hookrightarrow$ diffusion, convection, annihilation

- We use three sample sets of propagation parameters, covering the allowed parameter space

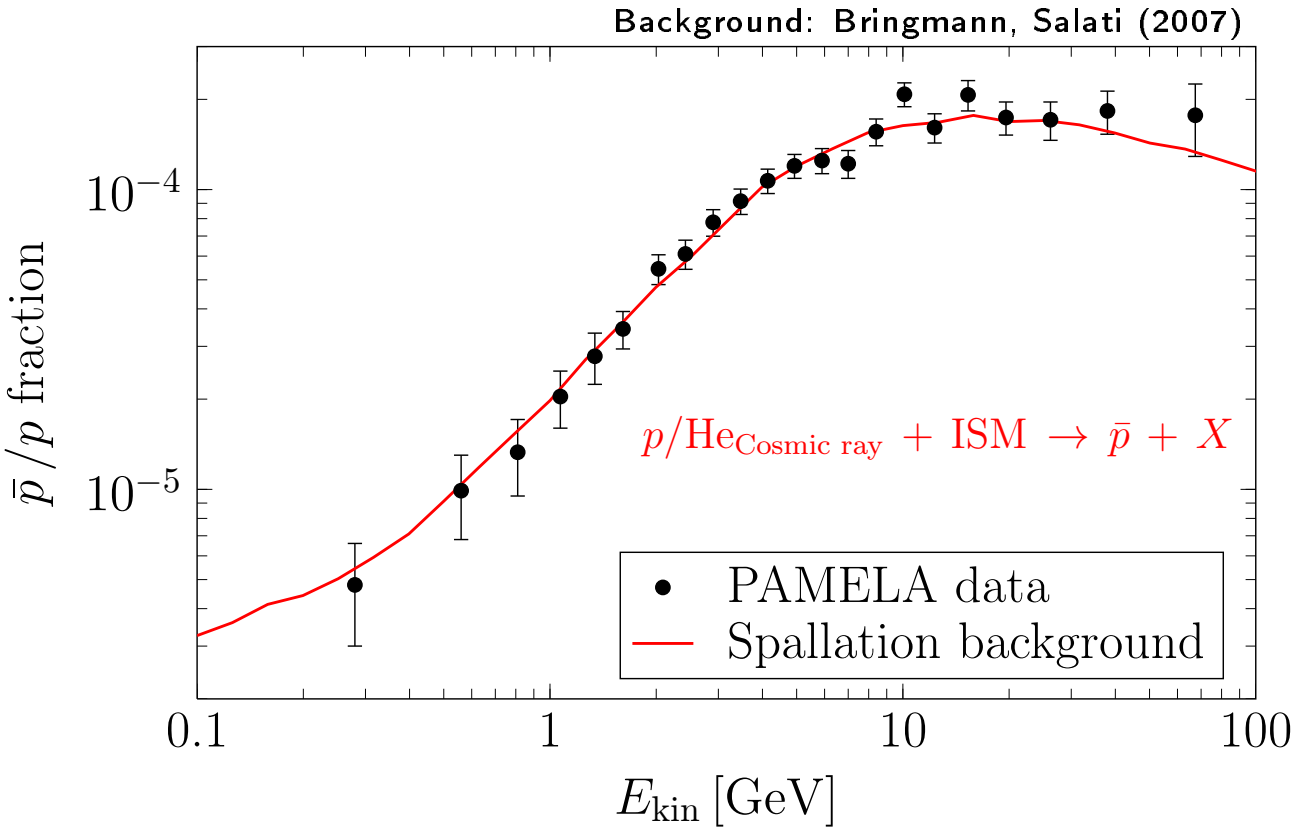
MINimial
MEDium
MAXimial
} number of antideuterons

Let's ask:

How many $\bar{d}$ events can at most be expected at AMS-02 and GAPS?

Severe constraints from PAMELA measurement of **antiprotons**

PAMELA data on $\bar{p}/p$ flux ratio



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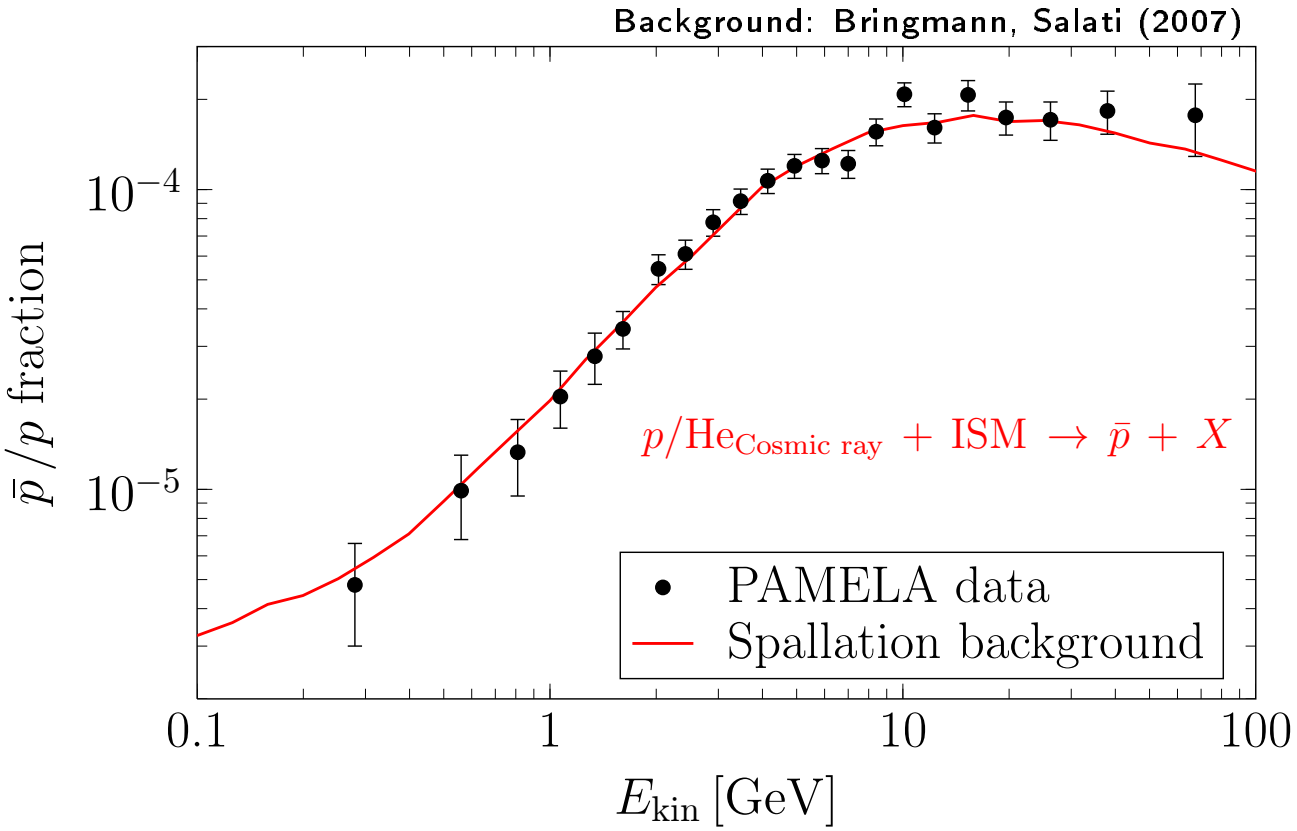
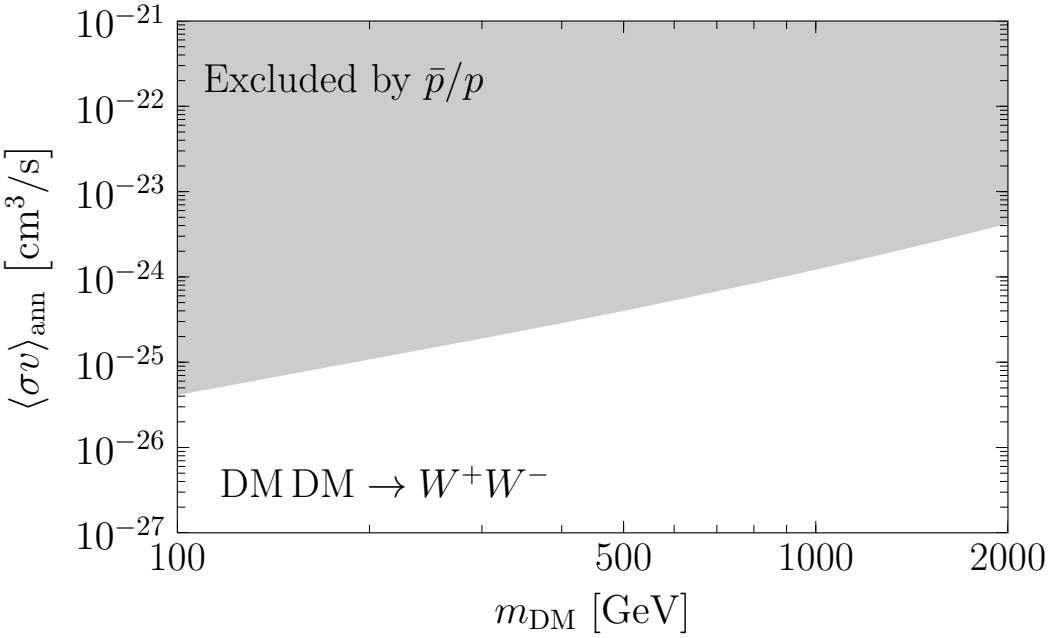
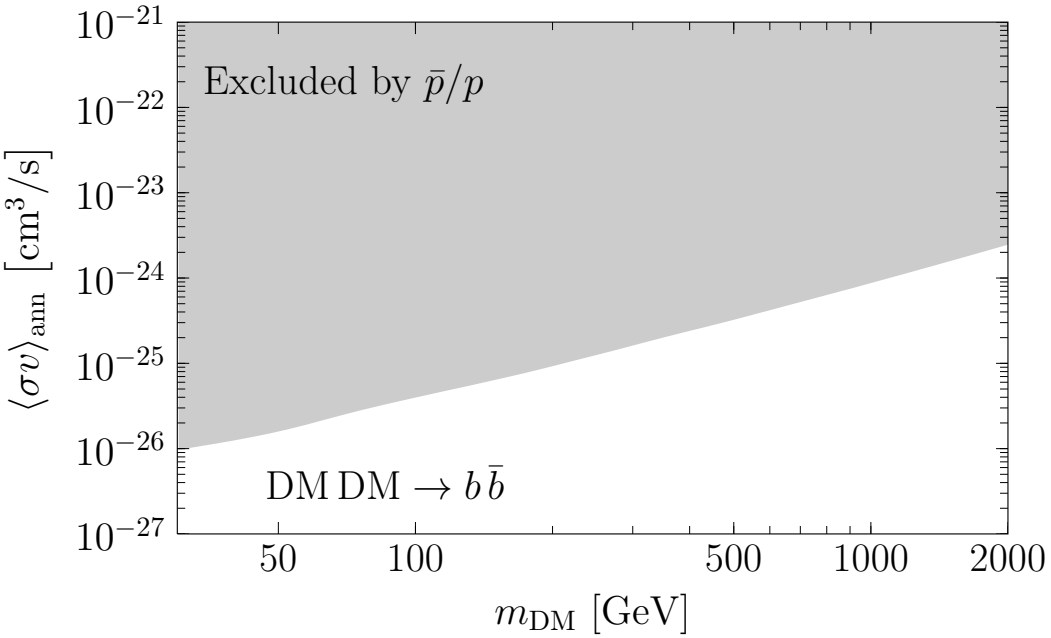


$\Rightarrow$ No need for an exotic component

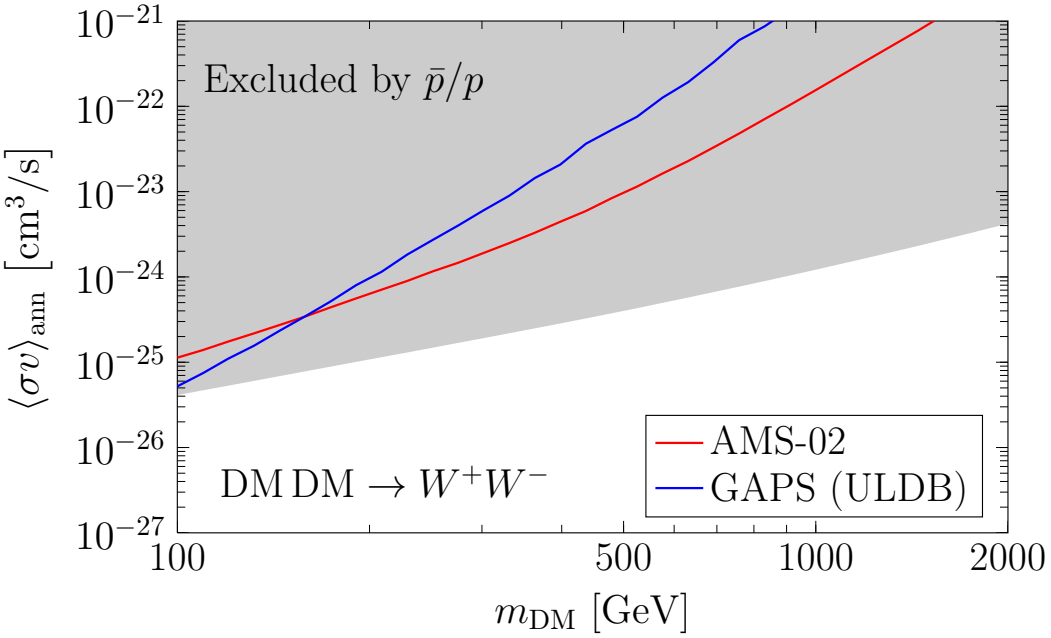
$\Rightarrow$ **Antiproton constraints** on Dark Matter models:

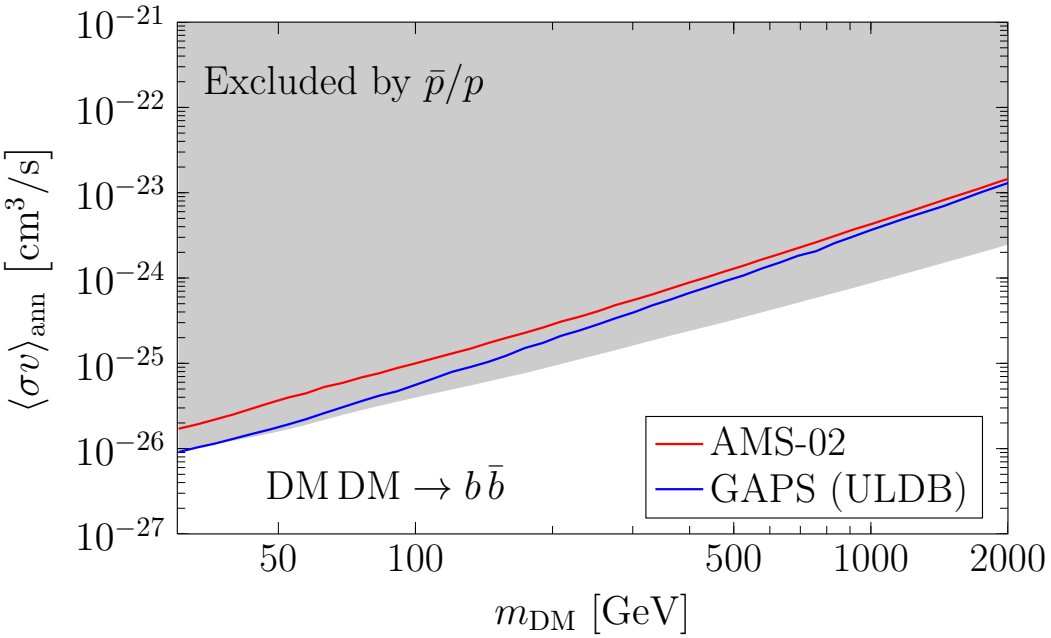
Spallation background + DM induced flux $\leq$ PAMELA data





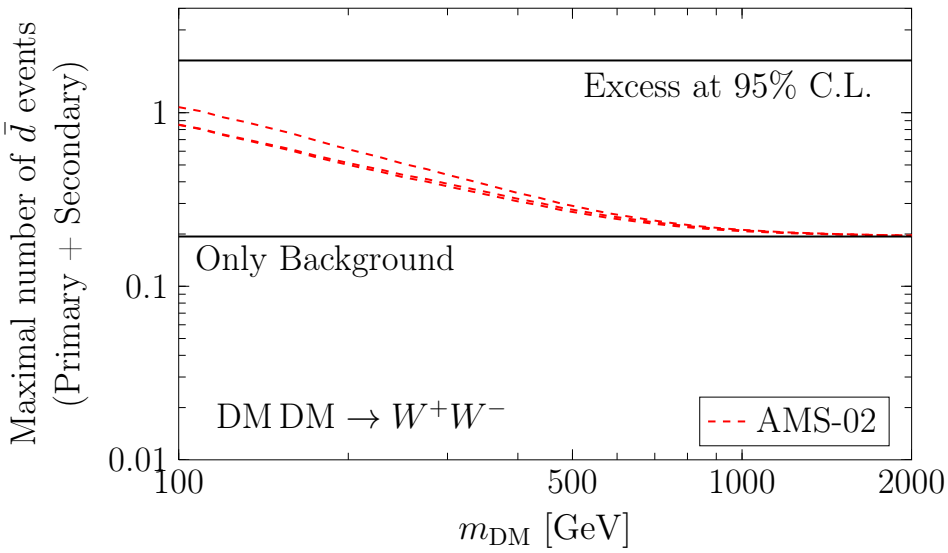
- Shaded regions: 95% C.L. exclusion from PAMELA $\bar{p}/p$
  $\hookrightarrow$ using NFW profile, MED propagation parameters

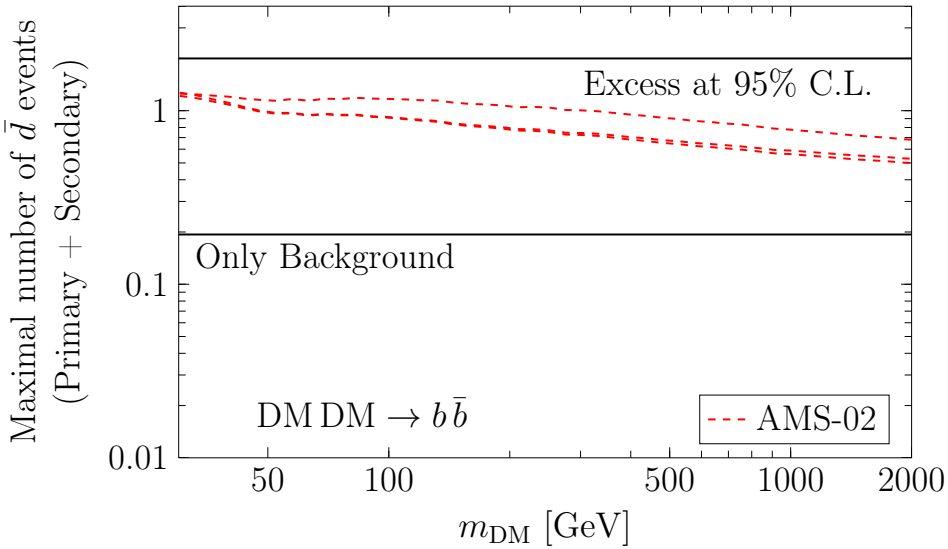




- Shaded regions: 95% C.L. exclusion from PAMELA $\bar{p}/p$
  $\hookrightarrow$ using NFW profile, MED propagation parameters
- Red and blue: cross sections necessary for an expectation of a primary $\bar{d}$ signal at 95% C.L.

Maximimal number of $\bar{d}$ events at AMS-02





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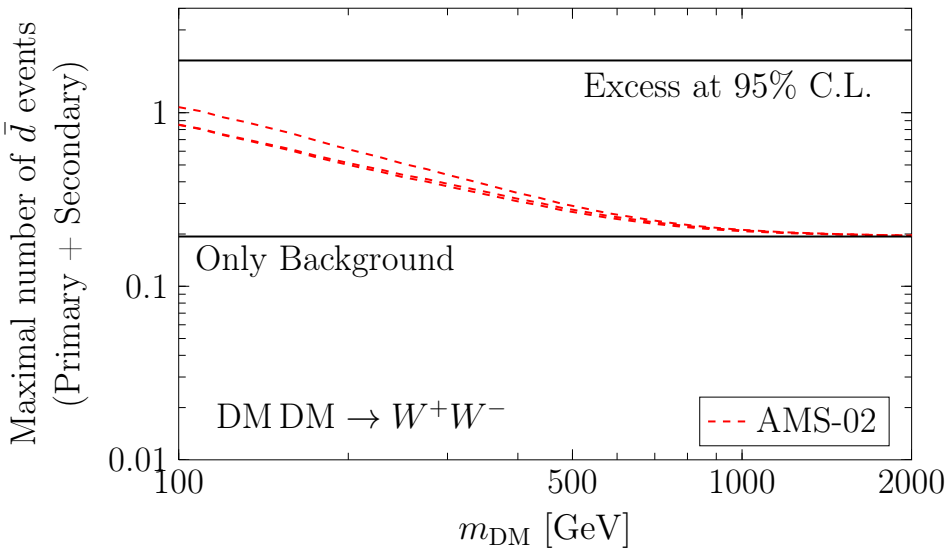

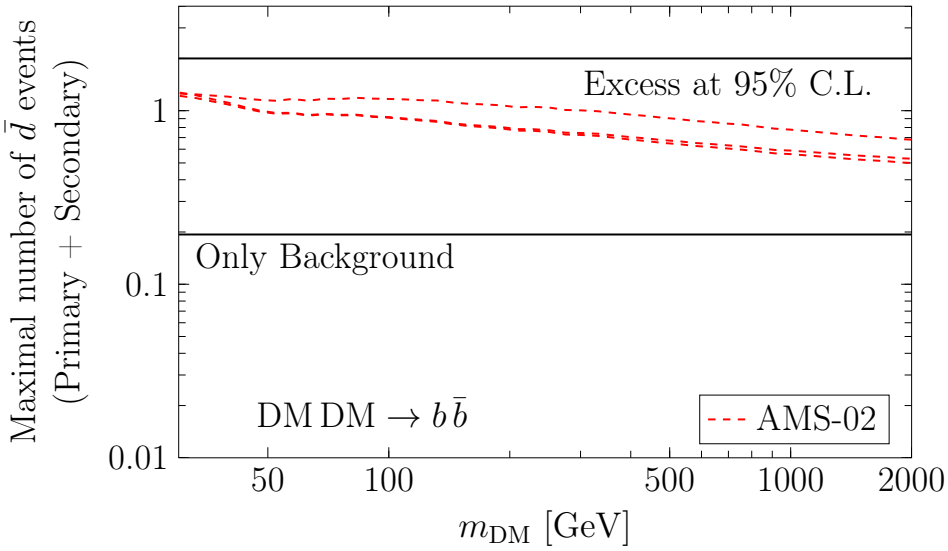

- Red curves:
  Maximal number of $\bar{d}$ at AMS-02 compatible with $\bar{p}/p$ constraints (MIN, MED, MAX)

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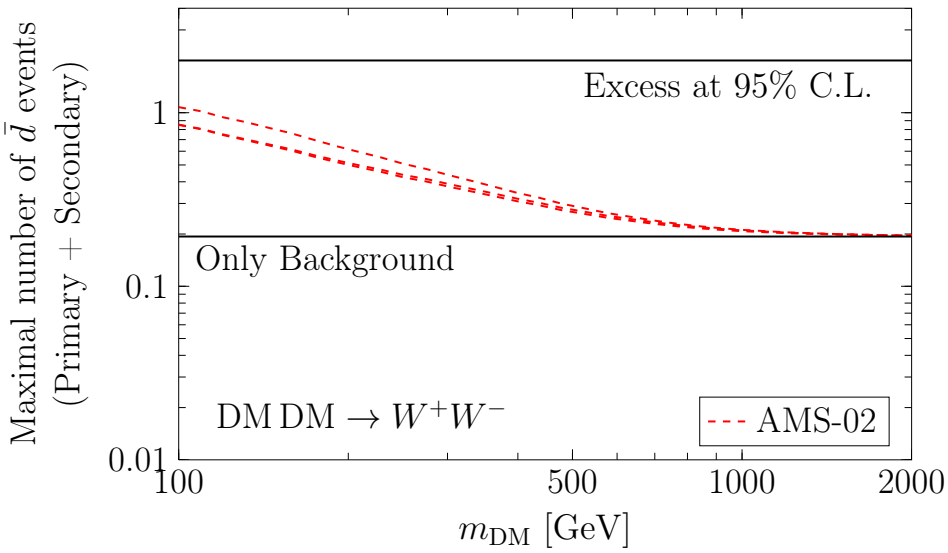

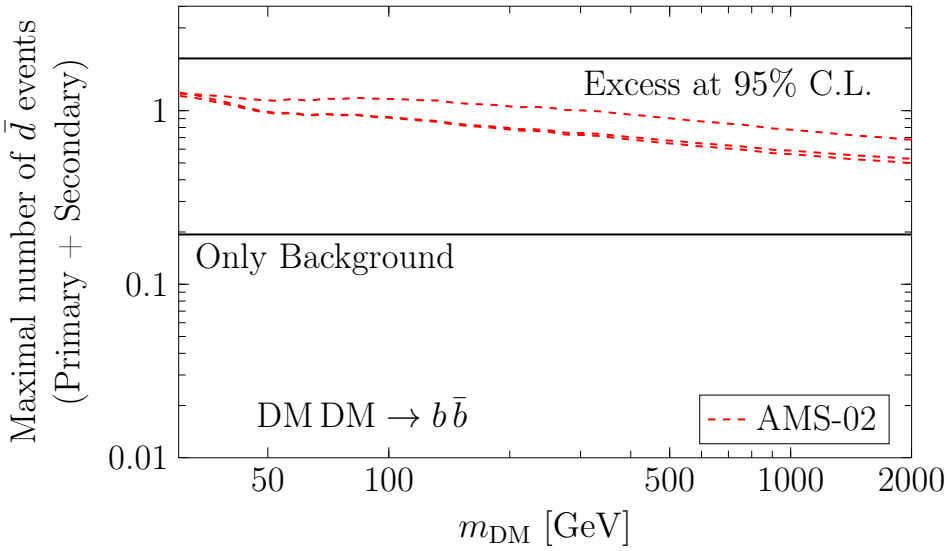

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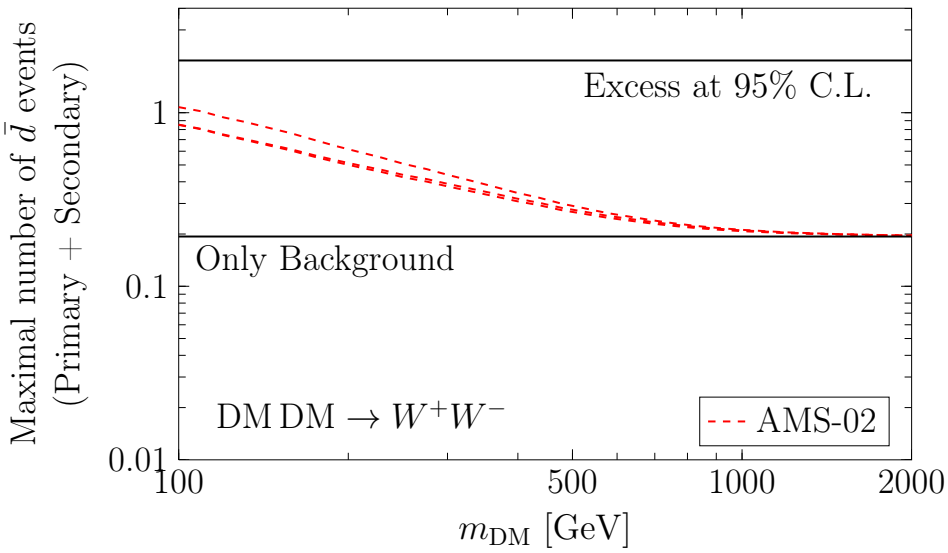

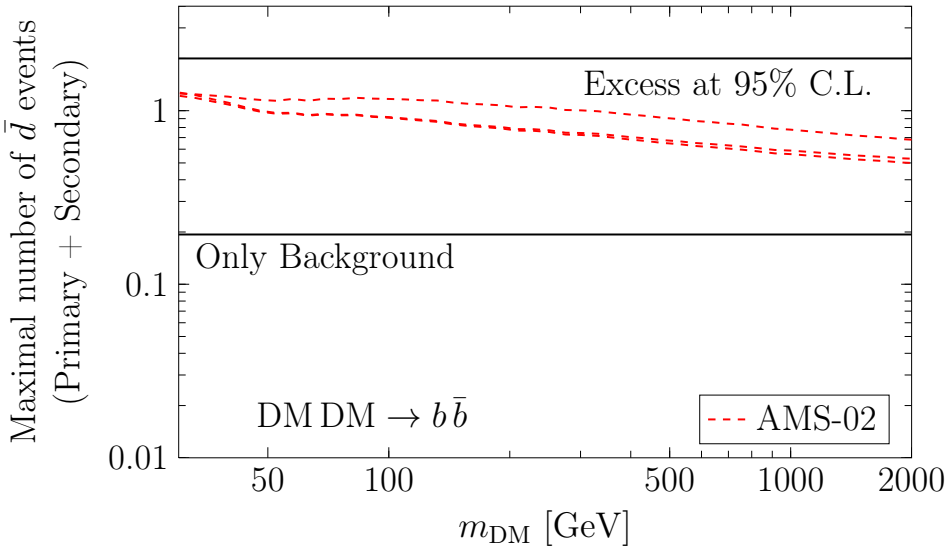

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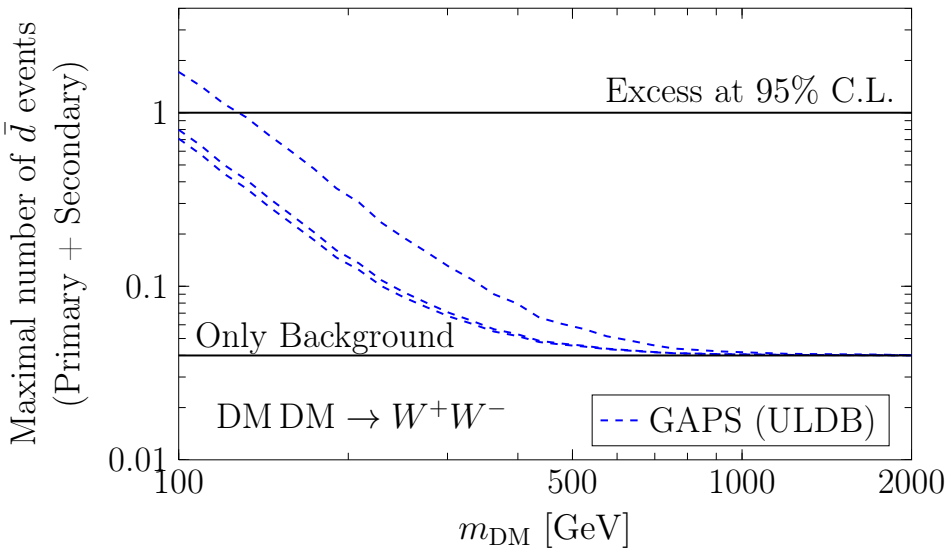
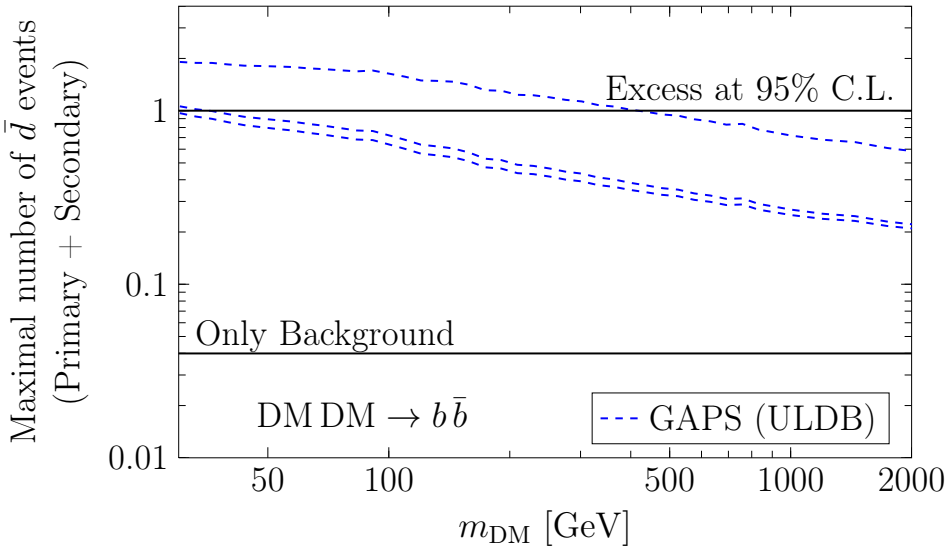
↓

Excess at 95% C.L. (= 2 events) is in **strong tension** with $\bar{p}/p$ constraints!

Maximimal number of $\bar{d}$ events at GAPS (ULDB)





- Blue curves:
  Maximal number of $\bar{d}$ at GAPS (ULDB) compatible with $\bar{p}/p$ constraints (MIN, MED, MAX)

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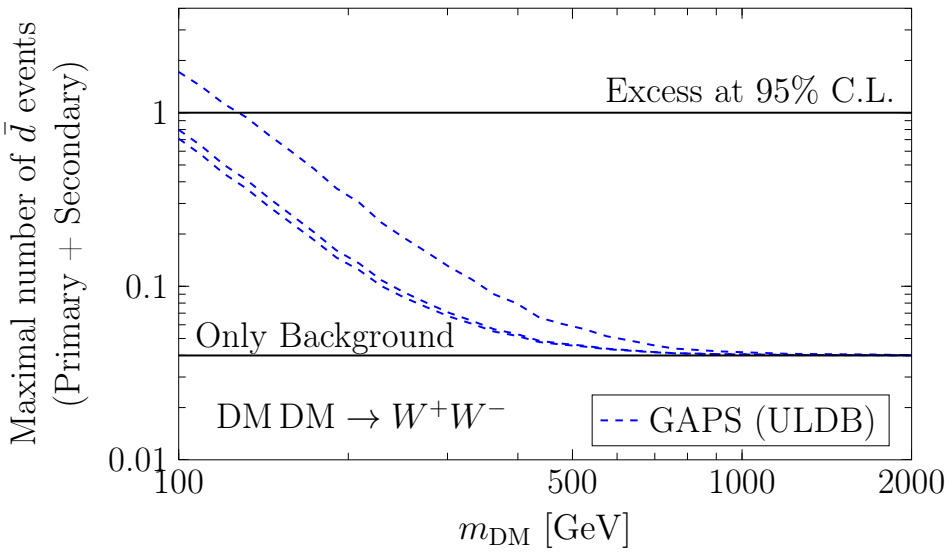

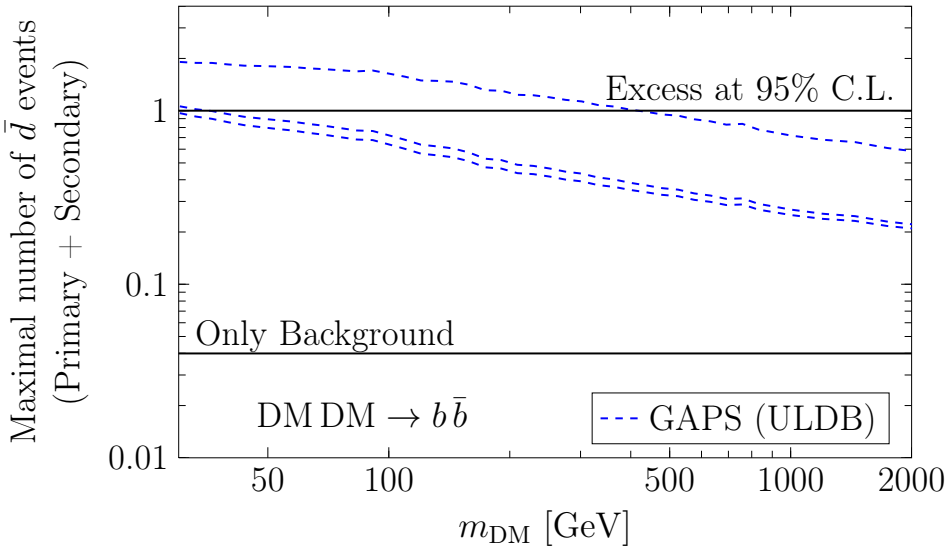

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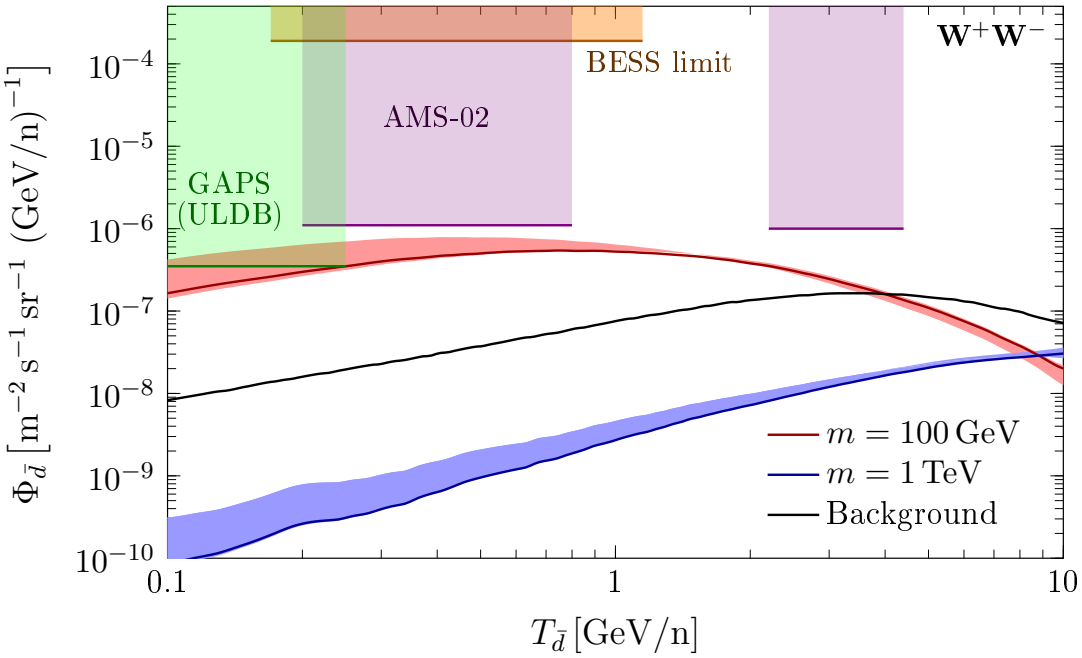
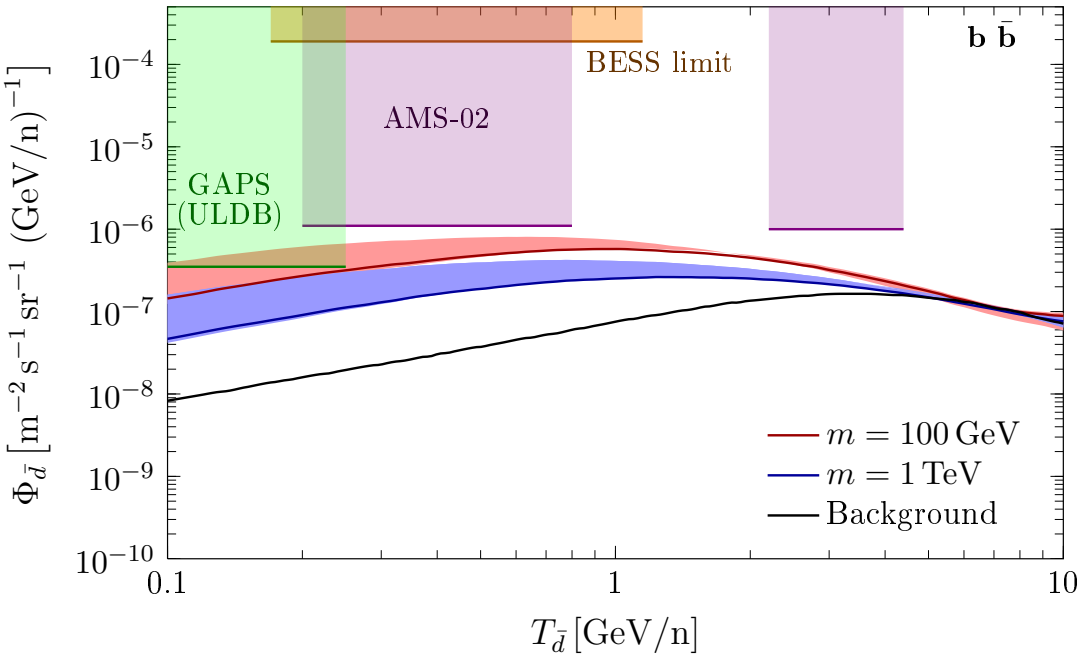
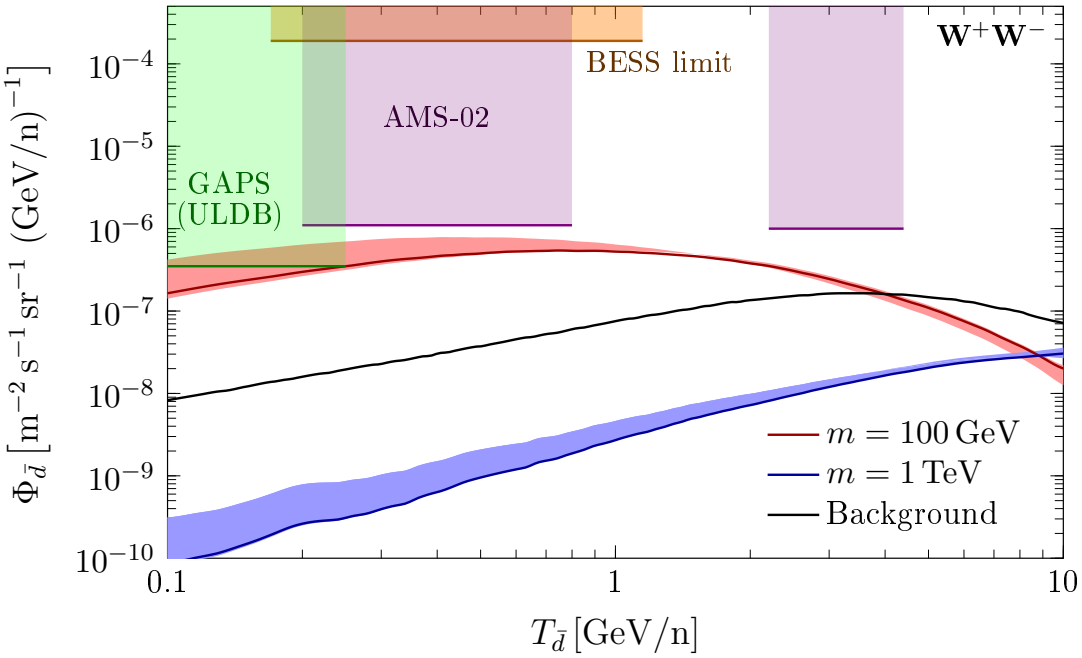
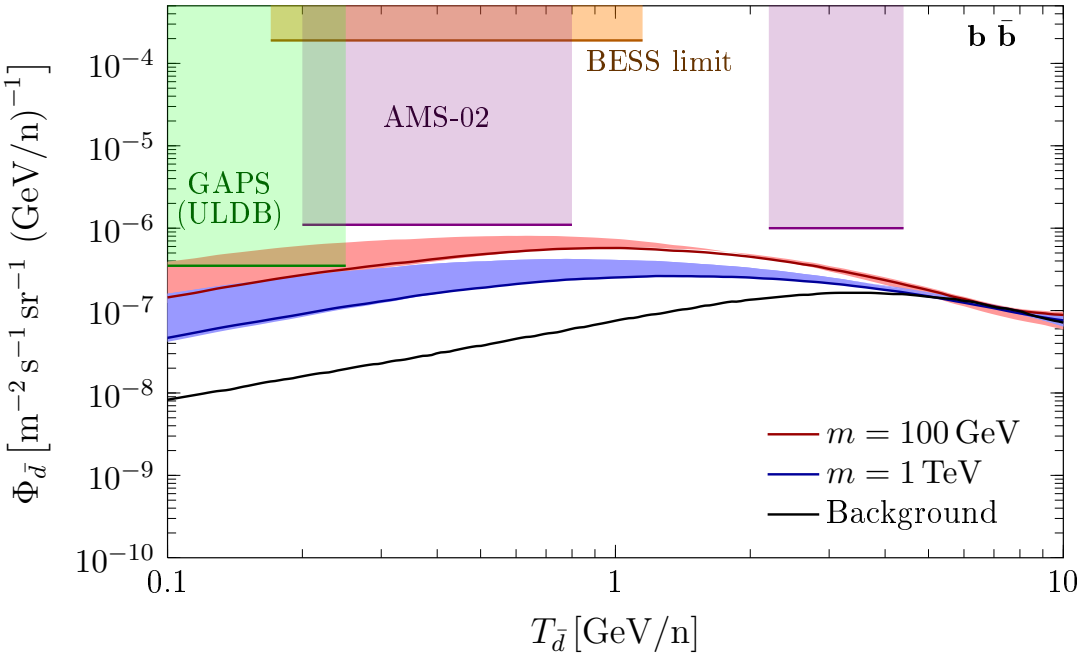
Excess at 95% C.L. (= 1 event) **only possible** for MAX propagation and
$m_{\rm DM} < 125\,{\rm GeV}\ (W^+W^-)$
$m_{\rm DM} < 400\,{\rm GeV}\ (b\bar{b})$





- Red and blue curves: Maximally allowed $\bar{d}$ fluxes ($m_{\mathrm{DM}} = 0.1/1\,\mathrm{TeV}$)





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$\Downarrow$

More sensitive experiments could detect antideuterons!

Coalescence model: enhancement of $\bar{d}$ yield?

- **Standard calculation**: $\bar{d}$ forms if $\left|\vec{k}_{\bar{p}} - \vec{k}_{\bar{n}}\right| \leq p_0 = 192\,\mathrm{MeV}$
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- However: By calibrating p_0 against several other experiments ($p\,p$, Υ decay, $e^-\,p$) we find a **significant dependence of p_0 on the process and the energy**: $133\,\mathrm{MeV} \leq p_0 \leq 236\,\mathrm{MeV}$
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Coalescence model needs further investigation!
More lab experiments with antideuterons are needed for a better understanding of the coalescence process!

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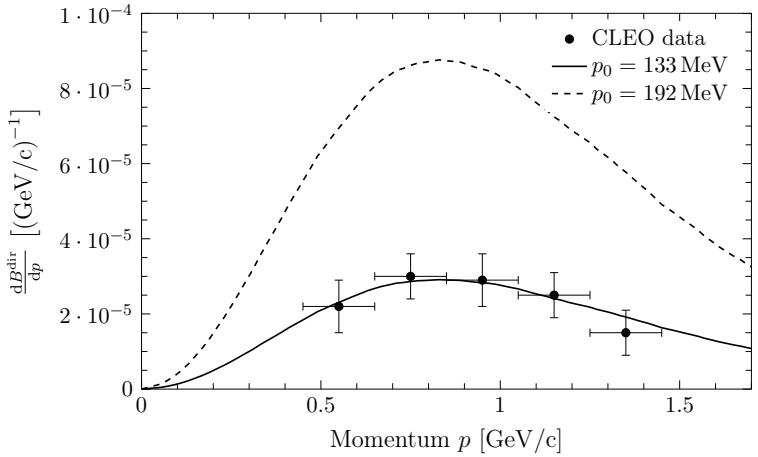
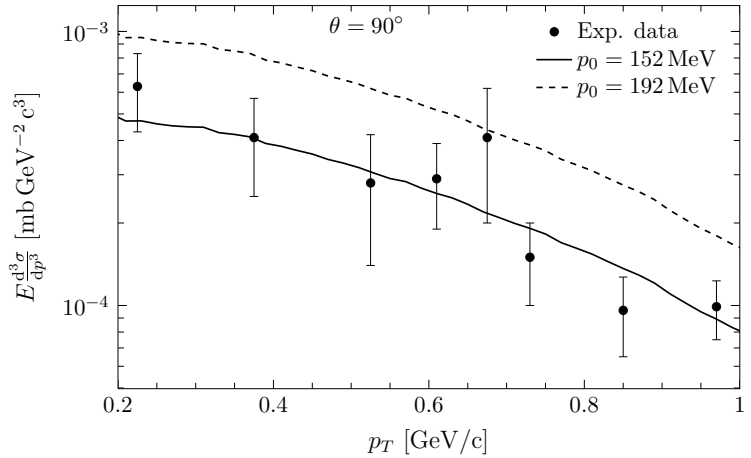
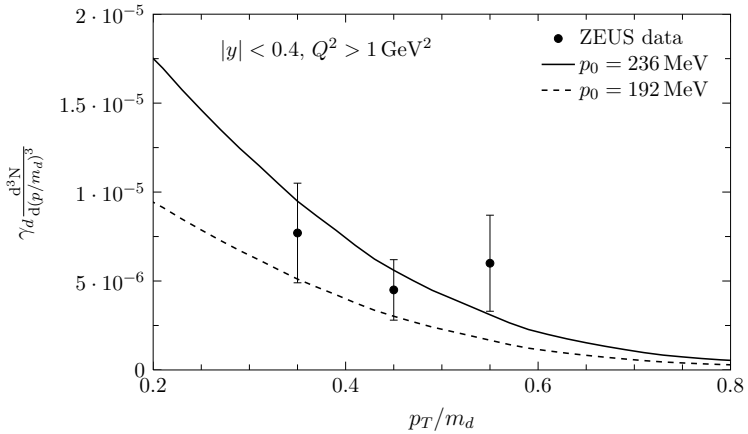
- We found an energy and process dependent coalescence momentum p_0
  - $\hookrightarrow$ Coalescence model seems not to be fully understood!
  - $\hookrightarrow$ Further investigations necessary!

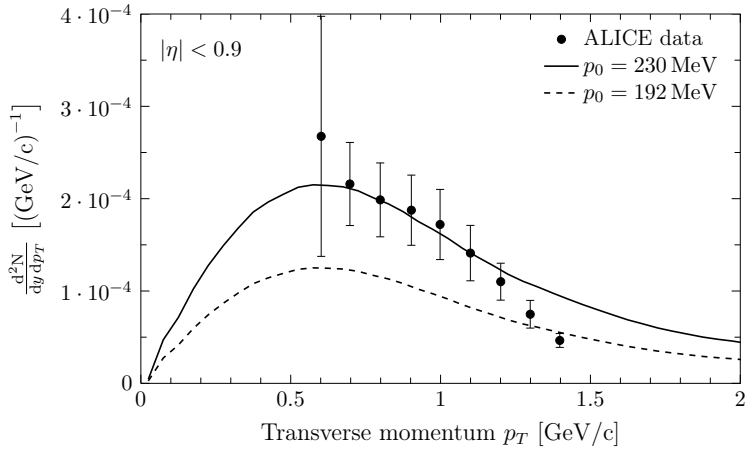
Backup slides

Determination of the coalescence momentum p_0



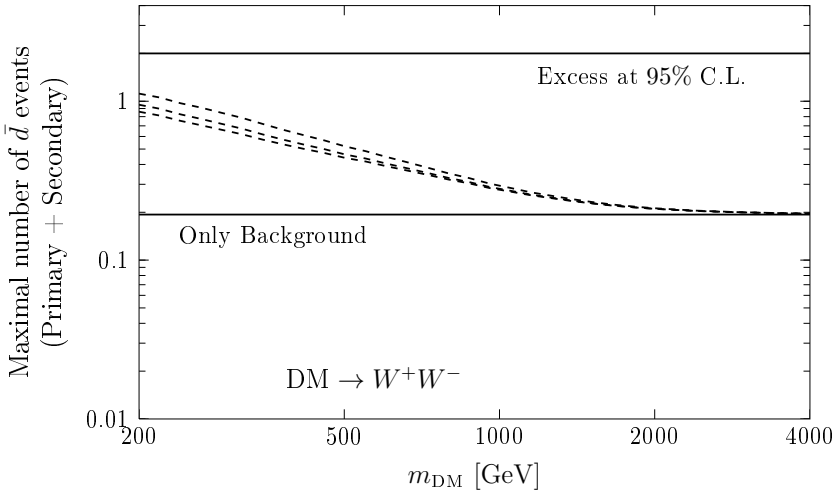


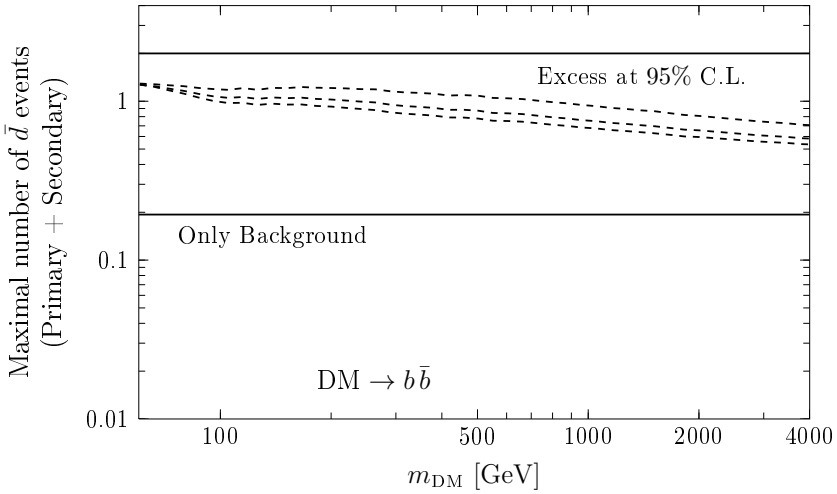


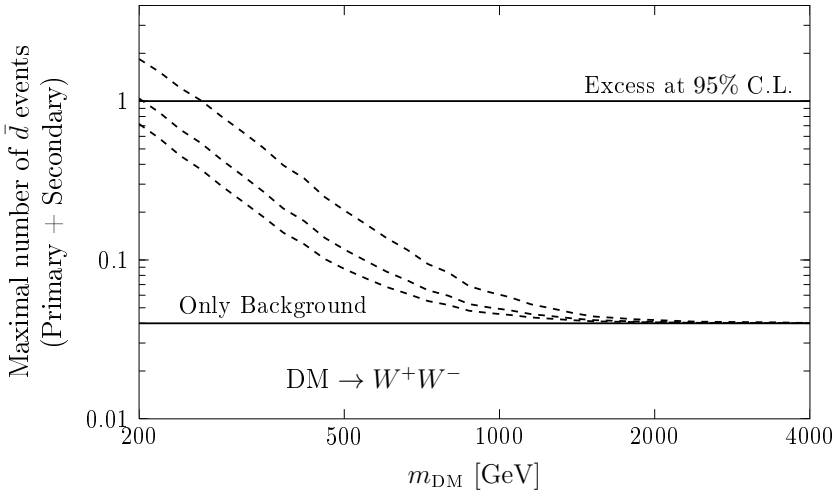


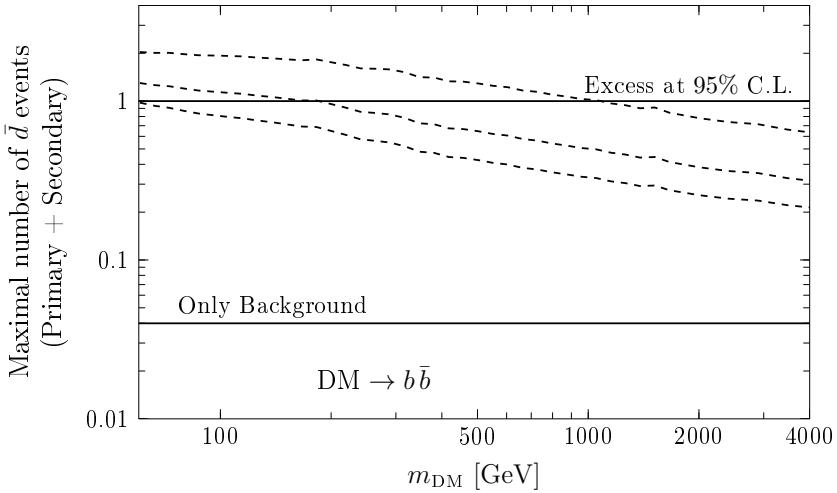
Top left: Υ decay, *top right*: pp collisions at $\sqrt{s} = 53$ GeV (CERN ISR), *bottom left*: $e^- p$ collisions at $\sqrt{s} = 318$ GeV (ZEUS), *bottom right*: pp collisions at $\sqrt{s} = 7$ TeV (ALICE, deuteron spectrum)

Maximal number of events for decaying Dark Matter









Upper panel: AMS-02, lower panel: GAPS (ULDB)