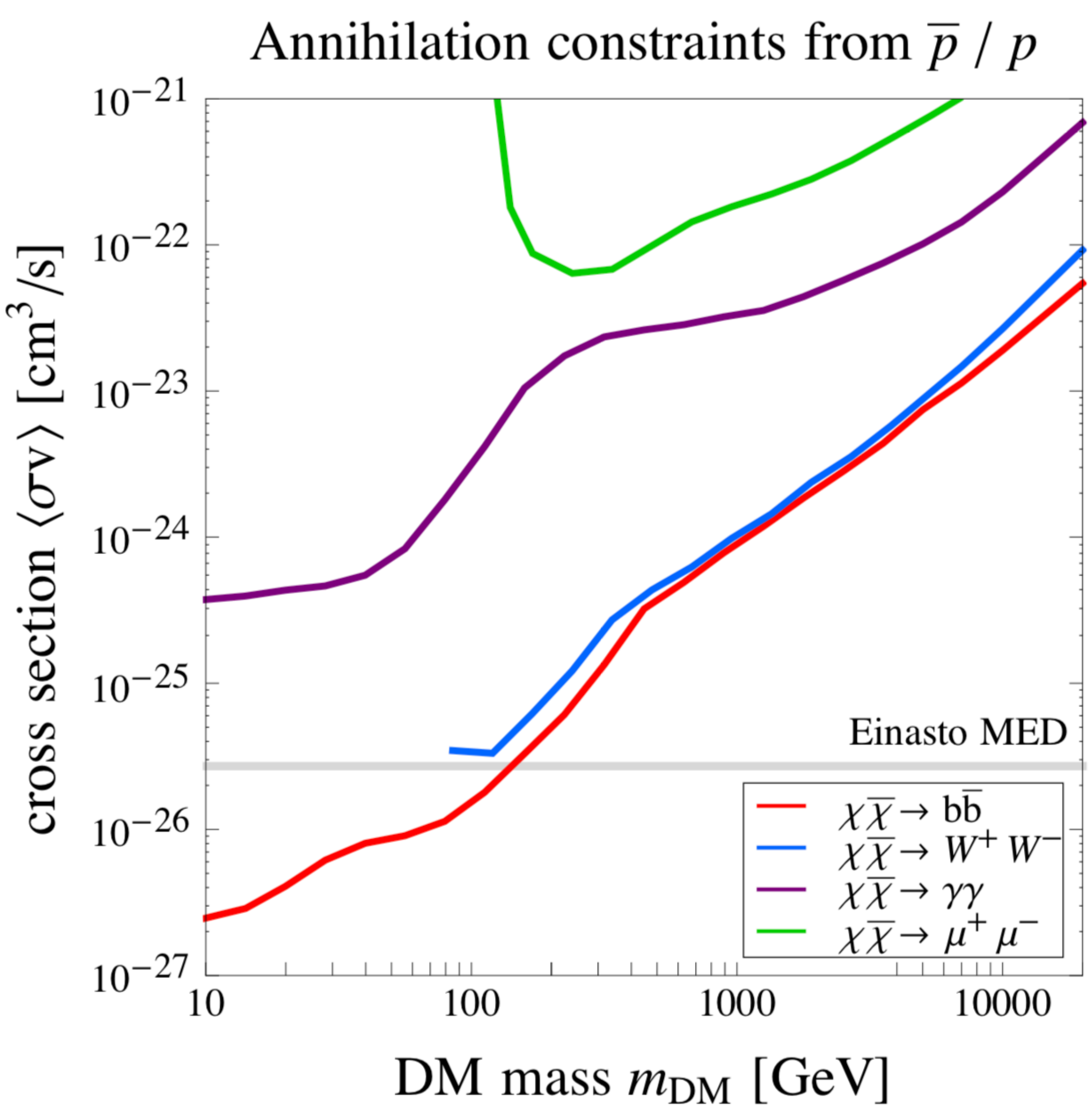
AMS-02 ANTIPROTONS
ANALYSIS STRATEGY FOR DARK MATTER

Objective

Updated limits on the DM annihilation XS <σv>



Giesen+(2015)

Antiprotons from DM: inputs

Particle physics

- DM mass m_χ and annihilation XS $<\sigma v>$
- Annihilation channels (branching ratios)
- pbar spectrum at source dN_{pbar}/dT_{pbar}

  PPPC4DMID, MicrOMEGAS (both based on Pythia)

Astrophysics

- DM halo profile in the Galaxy
  - NFW *McMillan+(2016)*
  - cored *McMillan+(2016)*
  - Einasto *Catena&Ullio(2010)*
- Transport in the Galaxy
  - BIG/SLIM/QUAINT (derived from 1D model —> 2D model from dictionary)
  - Size of the magnetic halo L (not determined by B/C, crucial for DM pbar)
  - Solar modulation

Limits on <σv>

$$\Phi_{\bar{p}}^{\rm tot}(m_\chi, \langle\sigma v\rangle) = \Phi_{\bar{p}}^{\rm II} + \Phi_{\bar{p}}^{\rm DM}(m_\chi, \langle\sigma v\rangle)$$

Sec. only (<σv> = 0)

$$\chi_0^2$$

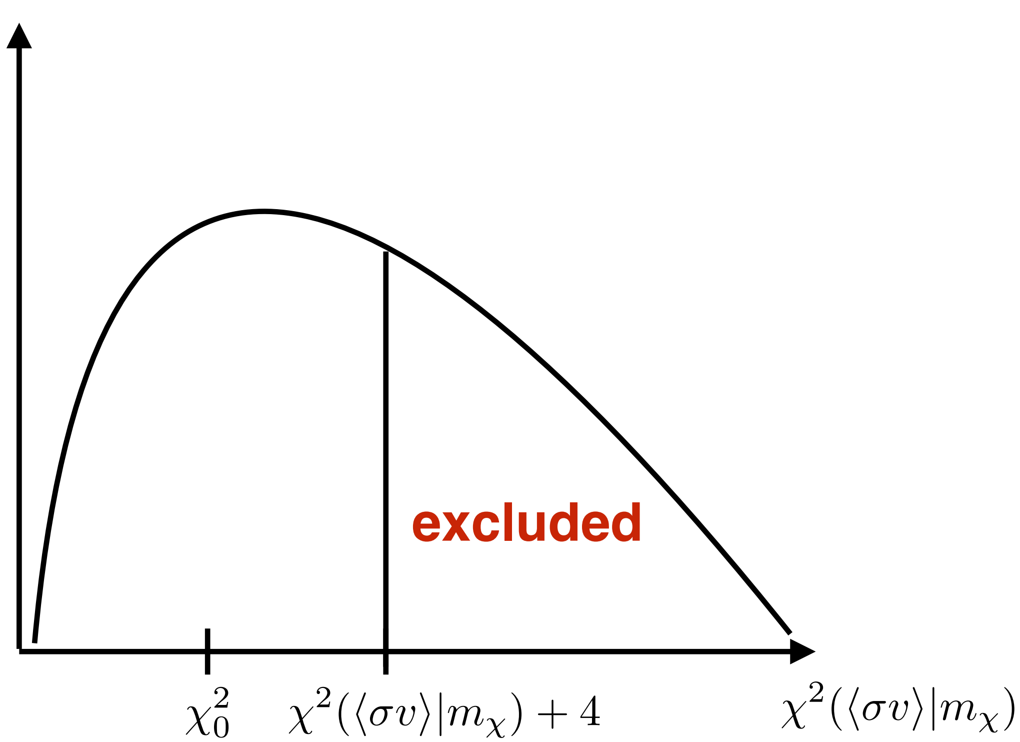
Sec + DM

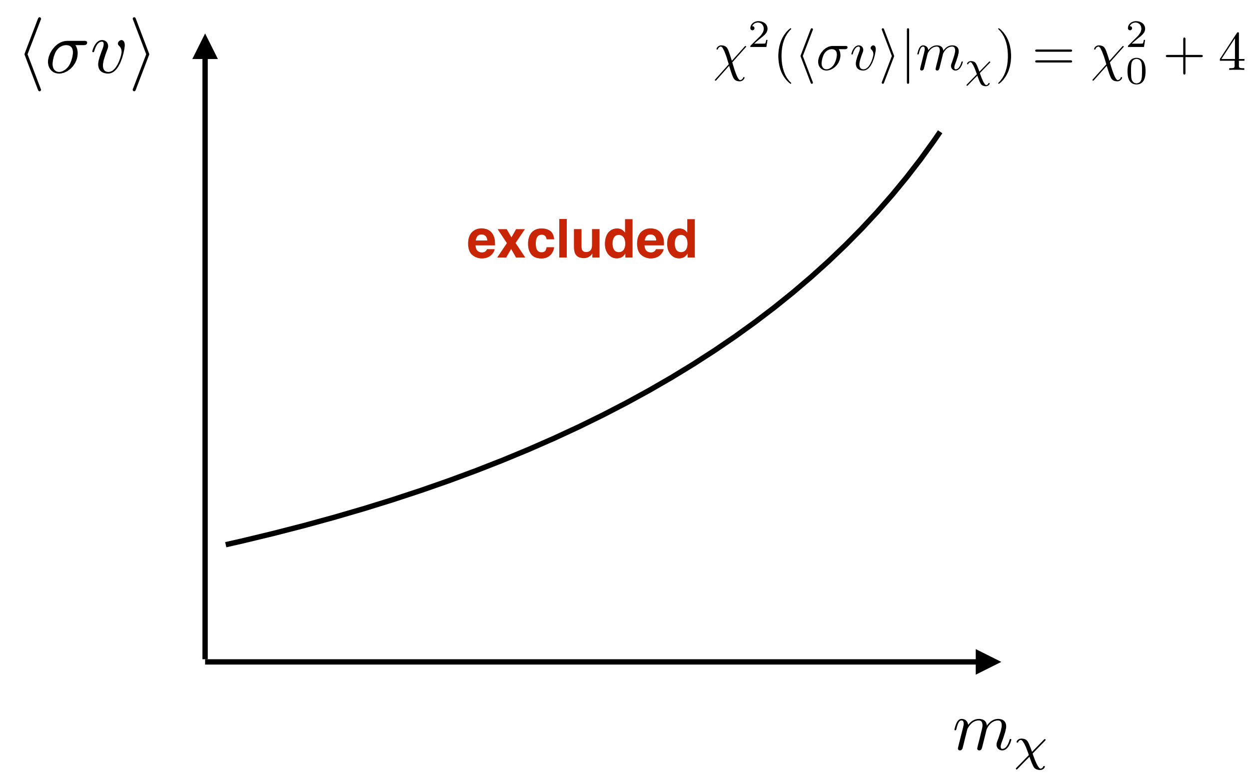
$$\chi^2(m_\chi, \langle\sigma v\rangle)$$

+ anni. channel

- Statistical criterion to compare these two χ^2 ⟹ derive an upper limit on <σv> **see Pierre's talk**

e.g: if $\chi^2(m_\chi, \langle\sigma v\rangle) - \chi_0^2 > 4$ ⟹ <σv> is excluded at 2σ CL (1 free parameter (<σv>))





Limits on <σv>

$$\Phi_{\bar{p}}^{\rm tot}(m_\chi, \langle\sigma v\rangle) = \Phi_{\bar{p}}^{\rm II} + \Phi_{\bar{p}}^{\rm DM}(m_\chi, \langle\sigma v\rangle)$$

Sec. only (<σv> = 0)	Sec + DM
χ_0^2	$\chi^2(m_\chi, \langle\sigma v\rangle)$

Strategy 1 - no fit

- Sec. only: baseline from Boudaud+(2019) $\Longrightarrow \chi_0^2$
- Sec. + DM: scan on <σv>, m_χ $\Longrightarrow \chi^2(m_\chi, \langle\sigma v\rangle)$

Pro: easy to implement, fast calculation

Cons: Transport uncertainty computed only for sec.

Strategy 2 - fit sec. pbar

Fit sec. pbar data (prod. XS parameters in nuisance (accounting for correlations))

- Sec. only: fit pbar data $\Longrightarrow \chi_0^2$
- Sec. + DM: scan on <σv>, m_χ and fit pbar data $\Longrightarrow \chi^2(m_\chi, \langle\sigma v\rangle)$

Pro: account for uncertainty in pbar prod. XS

Cons: fit for each couple (<σv>, m_χ), long running time

Strategy 3 - combined fit

Fit: B/C (transport parameters) & H, He, C, O (Parents) & sec. pbar (XS parameters)

- Sec. only: fit B/C, H, He, C, O, pbar $\Longrightarrow \chi_0^2$
- Sec. + DM: scan on <σv>, m_χ and fit B/C, H, He, C, O, pbar $\Longrightarrow \chi^2(m_\chi, \langle\sigma v\rangle)$

Pro: account for uncertainty in pbar prod. XS, Parents, Transport

Cons: fit for each couple (<σv>, m_χ), **very very** long running time, fit convergence?

Antiprotons from DM: ranking uncertainties

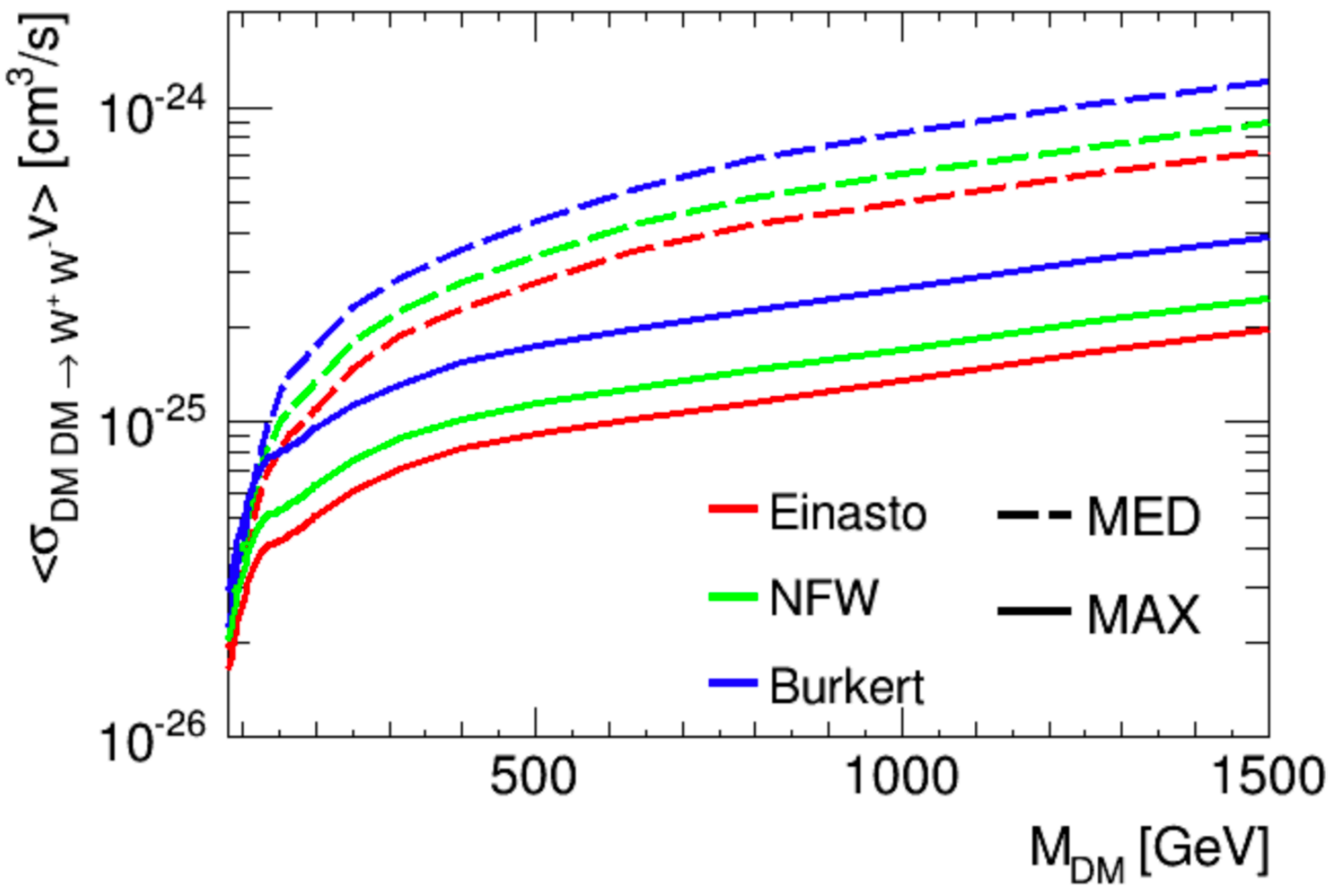
1. **Size of the magnetic halo L**
   ~ factor 10 (m_χ~1 TeV, $\chi\chi \to W^+W^-$)

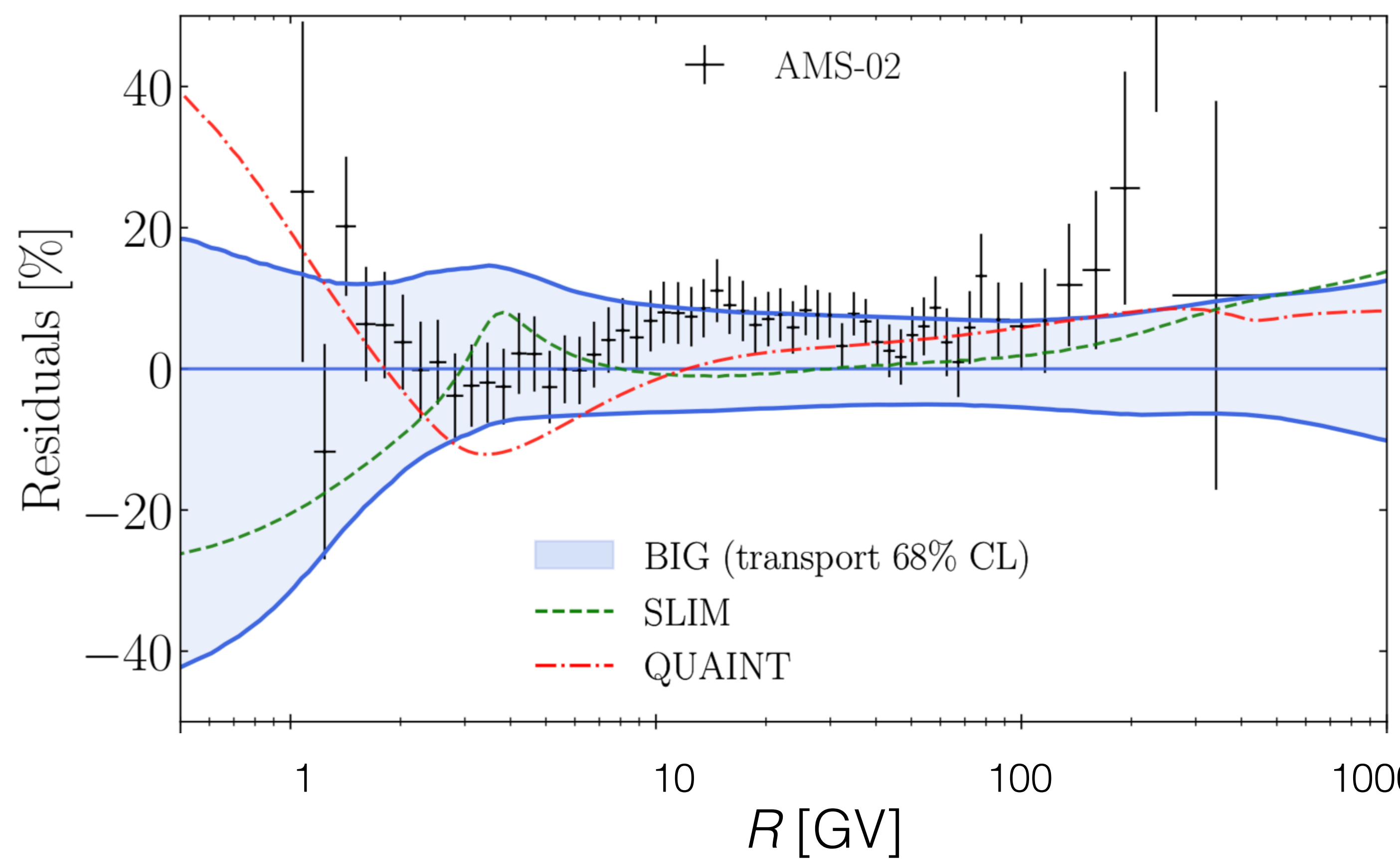
2. **DM halo profile (core vs cusp)**
   ~ factor 2 (m_χ~1 TeV, $\chi\chi \to W^+W^-$)

3. **Transport in the Galaxy**
   < 10% for secondary pbar

4. **Solar modulation**
   - charged sign dependance of ϕ_F (±50% ?)
   - important only for low masses (<10 GeV)

5. **PPPC4DMID, Pythia?**





Strategy 1: propagation of uncertainties

$$\chi^2 = \sum_{i,j} x_i \left(\mathcal{C}^{-1}\right)_{ij} x_j, \qquad x_i = \mathrm{data}_i - \mathrm{model}_i \qquad \mathcal{C} = \mathcal{C}^{\mathrm{data}} + \mathcal{C}^{\mathrm{model}}$$

Secondaries

Transport, Parents and XS uncertainties from cov. matrix

Primaries

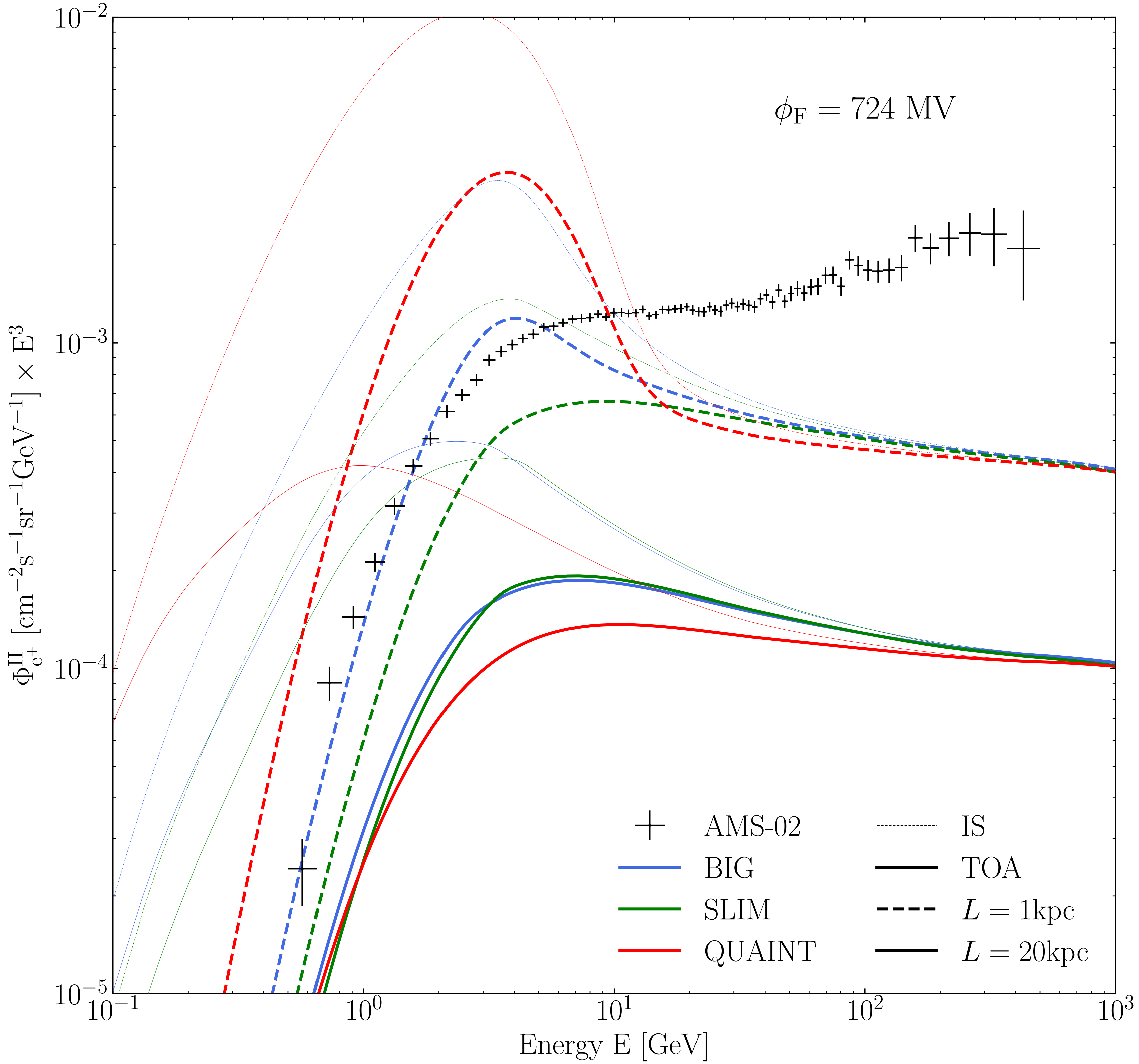
- Halo size L: constraints from radioactive nuclei and/or e+
  - bracket uncert. w/ L_{min}=1kpc and L_{max}=R=20kpc
  - determine a pdf for L w/ radioactive nuclei

- DM profile: bracket uncert. w/ cored and Einasto

- Transport: not computed for primaries
  - could be assed for each couple (<σv>, m_χ) and each annihilation channel
    ⟶ long process, we don’t want to do that
  - assume the same uncertainty as for secondary (subdominant uncertainty)

Constraining the halo size L w/ low energy e^+

Lower bound on K_0 —> lower bound on L, *Lavalle+(2014) (PAMELA), Boudaud+(2016) (AMS-02)*



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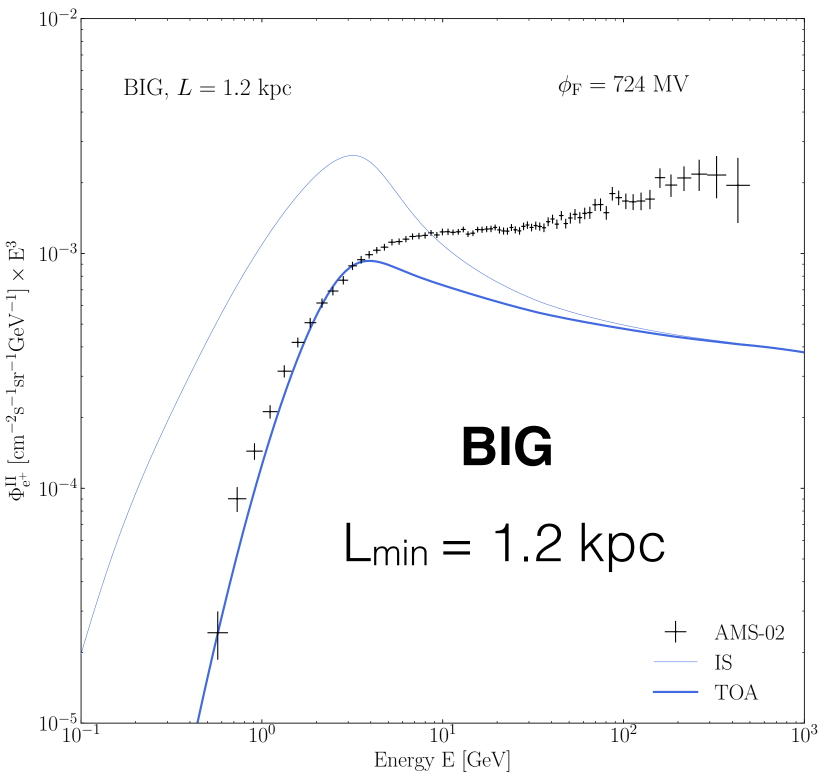
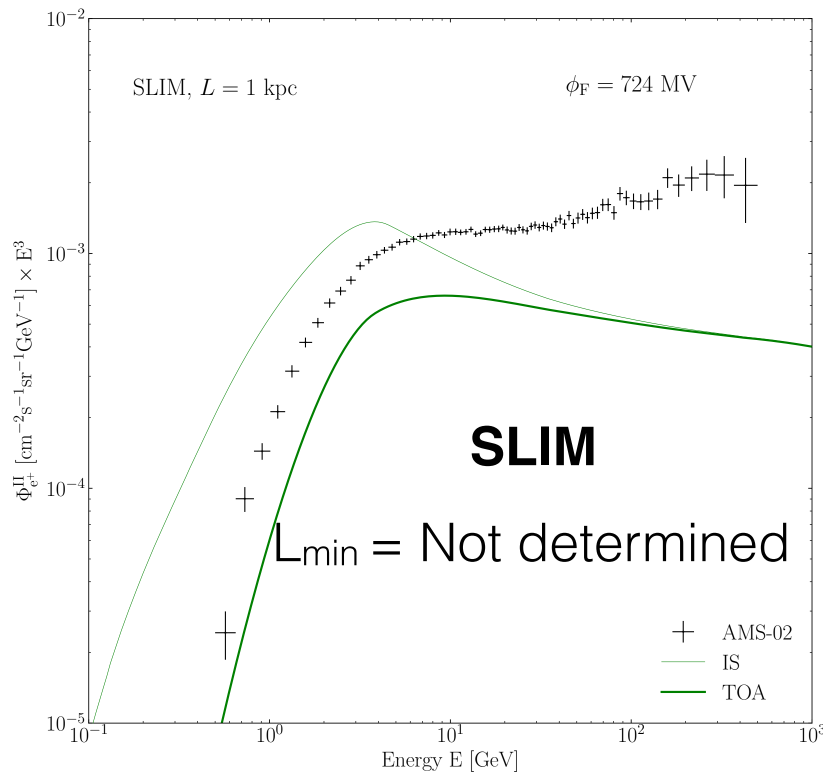
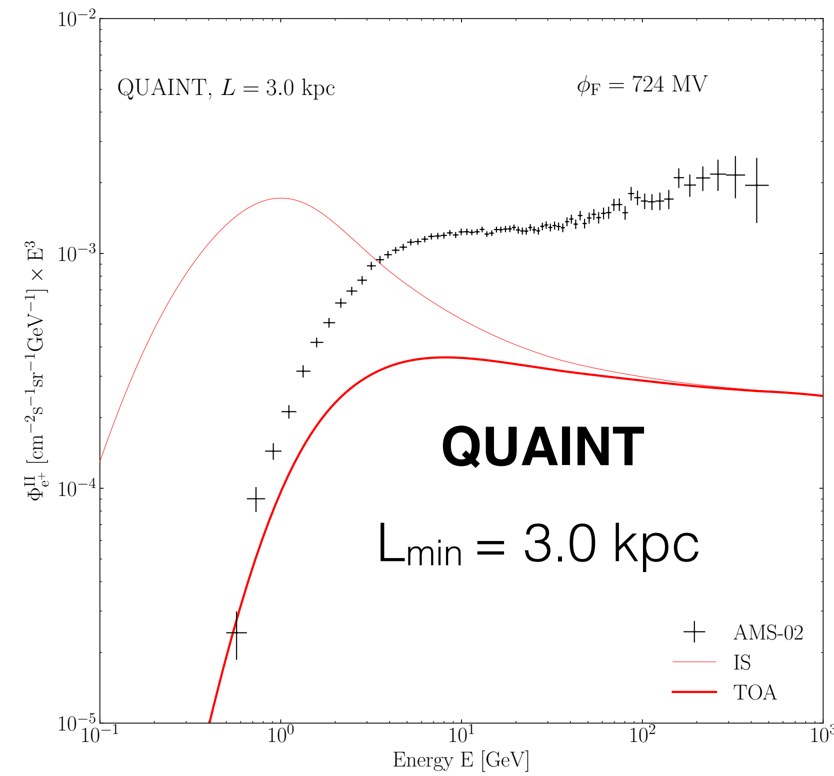






$$\Phi^{II}_{e^+} \propto \frac{1}{\lambda_D} \propto \frac{1}{\sqrt{K(R)}}$$

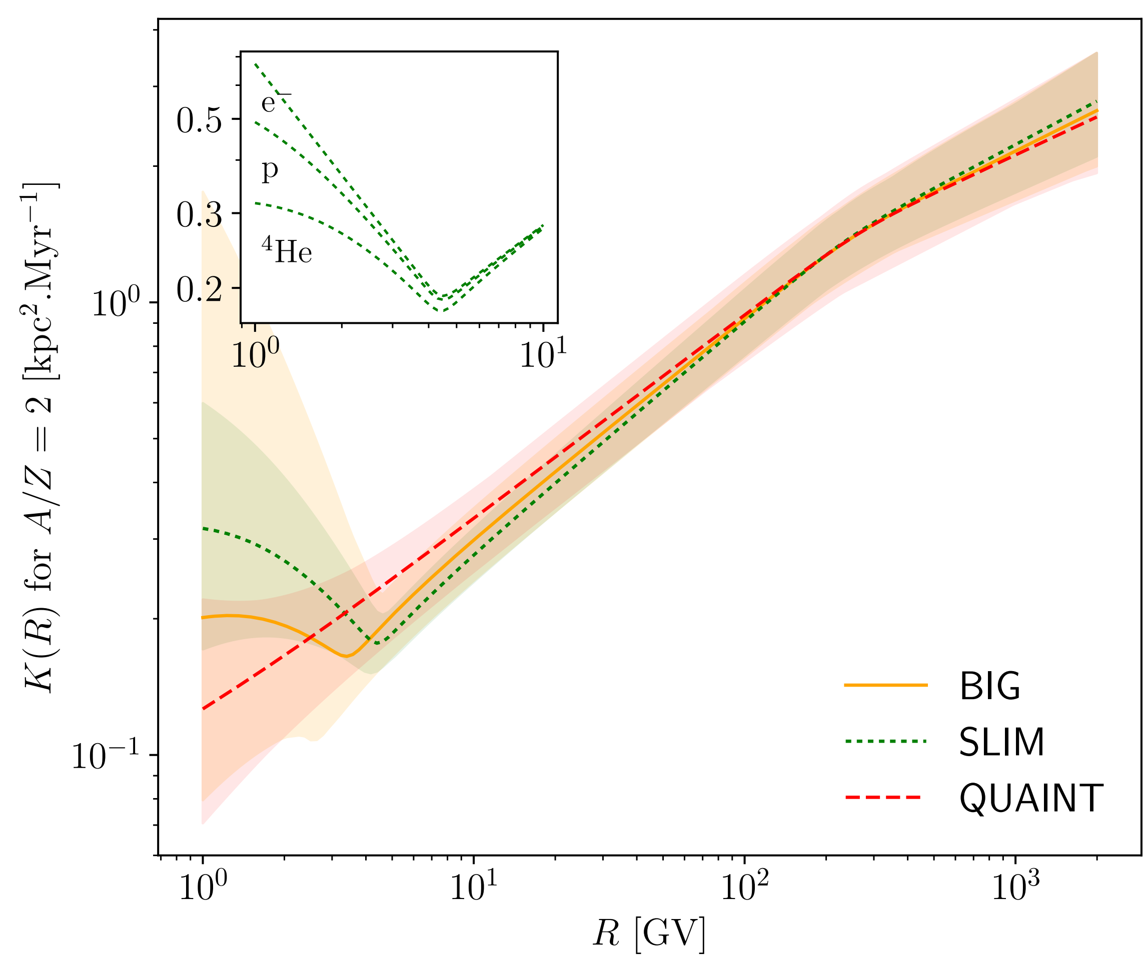
BIG, SLIM: R ↘ ⟹ K ↗ ⟹ flux ↘

- no uncertainty on transport parameters
- no uncertainty on solar modulation (ϕ_F = 724 MV fixed)
- Accounting for more uncertainties ⟹ L_{min}↘

Not possible to constraint L with e^+

What about radioactive species?

see David's, Nathanael's and Gilles's talks



DM constraints from AMS-02 pbar - a roadmap

- Transport of primary pbar in USINE (almost done)
- Import DM pbar spectra at source from e.g.: PPPC4DMID
- Propagation of uncertainties: depend on the strategy
  - First step: fixed L
  - PDF for L: updated MIN-MED-MAX

  ⟶ analysis on the halo size L could be done in parallel
- Define the statistical test to use to derive upper limits on $<\sigma v>$
  - chi2 distribution
  - KS distance distribution?
- Derive constraints for each annihilation channel