Implications of the Lack of Sharp Spectral Features in the Local Cosmic-Ray Positron Flux

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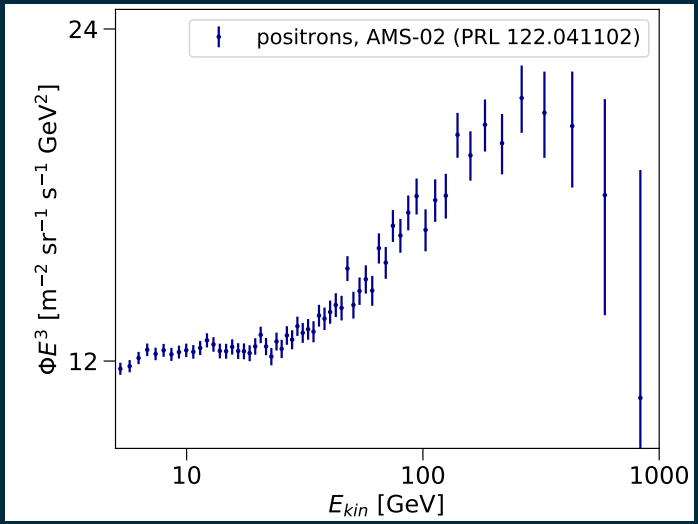
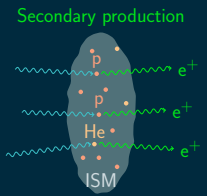
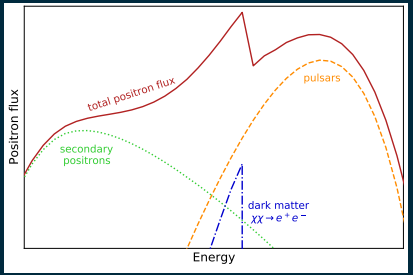
Local Cosmic-Ray Positron Flux

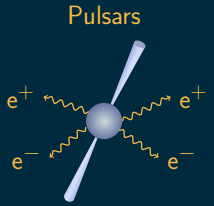
- AMS-02 provides extremely precise cosmic-ray data
- Rising positron flux above 20 GeV: contribution from pulsars favoured over dark matter
- Spectrum is very smooth

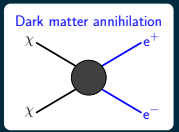


Contributions to the Local CR Positron Flux









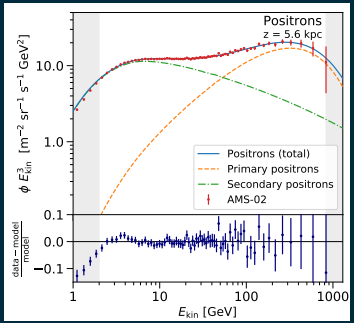
In this work:

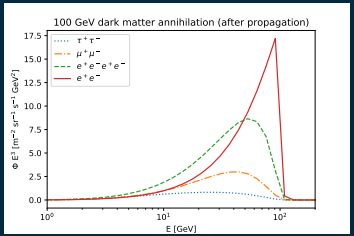
1. Dark matter: sharp spectral features from annihilating dark matter into leptonic final states
2. Pulsars: sharp spectral features in positron spectrum

CR Positrons Strongly Constrain Leptophilic DM [IJ & Linden, arXiv:2107.10261]

1. Create background model for secondary positrons and primary positrons (pulsars) using the `GALPROP` code
   - Large set of free parameters, e.g. diffusion spectrum, particle injection spectra

2. Add contribution from dark matter annihilating into four leptonic final states:
   - $\chi\chi \to \tau^+\tau^-$
   - $\chi\chi \to \mu^+\mu^-$
   - $\chi\chi \to e^+e^-$
   - $\chi\chi \to \phi\phi \to e^+e^-e^+e^-$, where ϕ is a light mediator

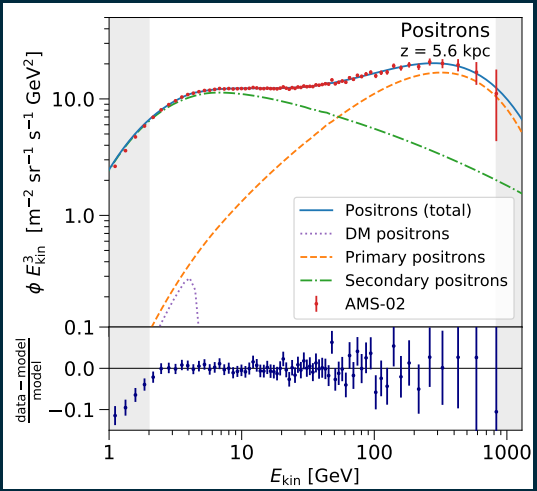




CR Positrons Strongly Constrain Leptophilic DM [IJ & Linden, arXiv:2107.10261]

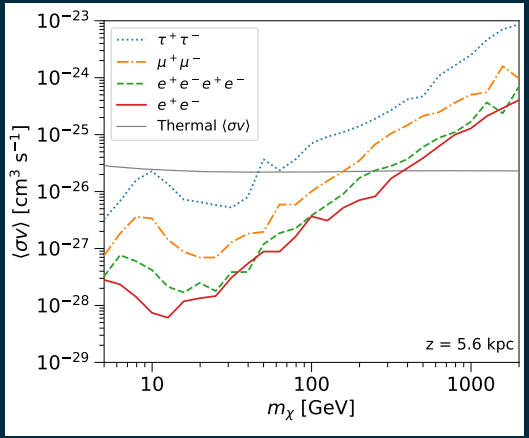
3. Re-fit model with relevant model parameters

4. Compute constraints on the DM annihilation cross section for DM masses between 5-2000 GeV



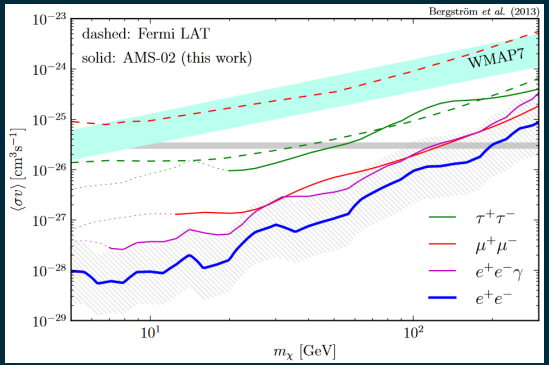
CR Positrons Strongly Constrain Leptophilic DM [IJ & Linden, arXiv:2107.10261]

- Background model fits AMS-02 data to within a few percent ($\chi^2/\mathrm{dof} = 0.88$)
- Derive strong constraints, 95% upper CL
- At small masses (~ 30 GeV), constraints significantly below the thermal cross section ($\sim 2.5\times10^{-28}$ cm^3/s) for annihilations into e^+e^- rule out even subdominant dark matter contributions

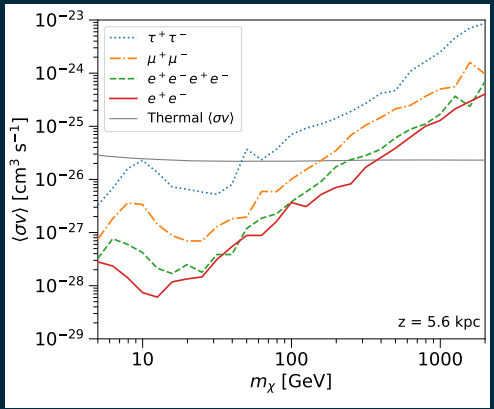


CR Positrons Strongly Constrain Leptophilic DM [IJ & Linden, arXiv:2107.10261]

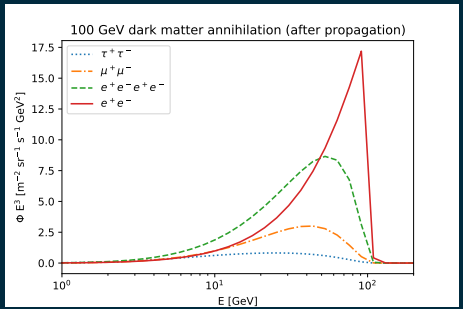
- Improvement on previous limits by Bergström *et. al* (2013) by a factor of ≈ 2



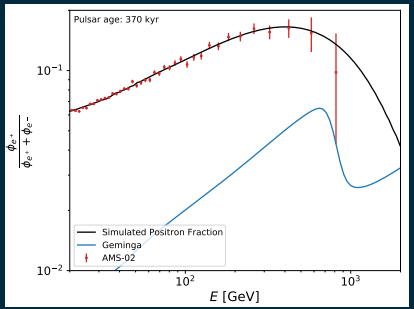
Bergström *et. al*, arXiv:1306.3983



Sharp Spectral Features in the CR Positron Flux



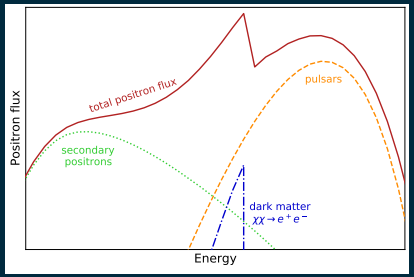
- Sharp spectral features from annihilating dark matter

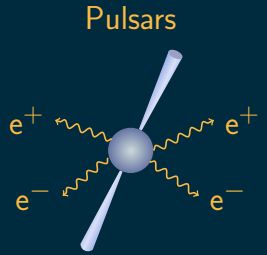


- Models of individual pulsars produce sharp spectral features as well
- Example: Geminga, a nearby ($\sim$ 250 pc) middle-aged ($\sim$ 370 000 years) pulsar

In this work: How robust is this spectral feature suggested by simple pulsar models?

Cosmic-Ray Positron Contribution From Pulsars

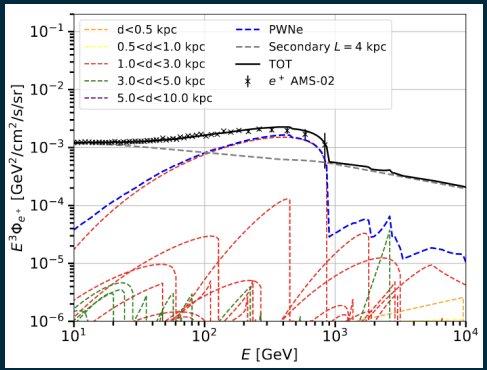




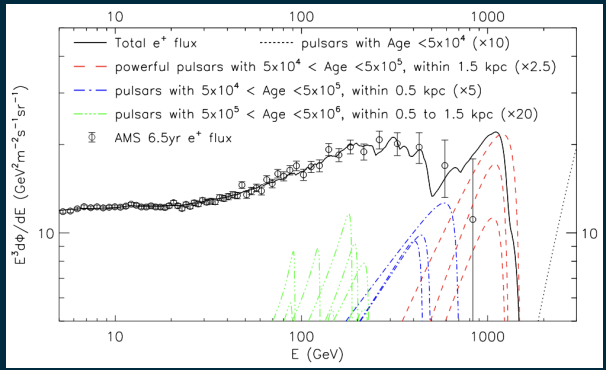
- Pulsars: rapidly rotating neutron stars that convert their spindown energy into electron-positron pairs $\Rightarrow$ dominant contribution to the local CR positron flux at $\sim$ 50 GeV to TeV energies
- Pulsar birth rate: 1 per century in Milky Way $\Rightarrow$ contribution from potentially $\sim$ 1000 pulsars

Cosmic-Ray Positron Spectrum From Pulsars

- Recent papers that focused on fitting the positron data used models where the contribution from each pulsar has sharp spectral features



Orusa *et. al*, 2021, arXiv:2107.06300

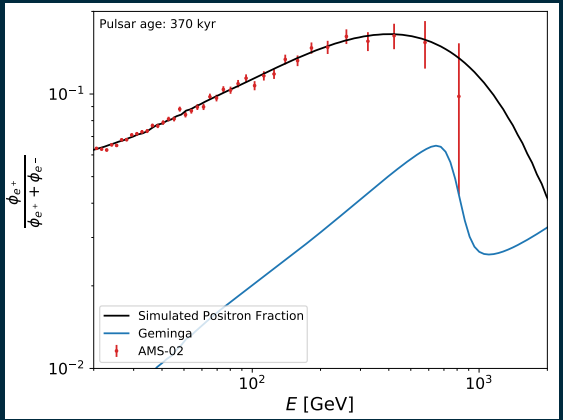


Cholis & Krommydas, 2021, arXiv:2111.05864

Spectral Features From Pulsars

- Large fraction of positrons are produced when pulsar is very young
- High-energy positrons are cooled faster than low-energy positrons

$\Rightarrow$ These initial positrons create sharp cutoff in positron fraction

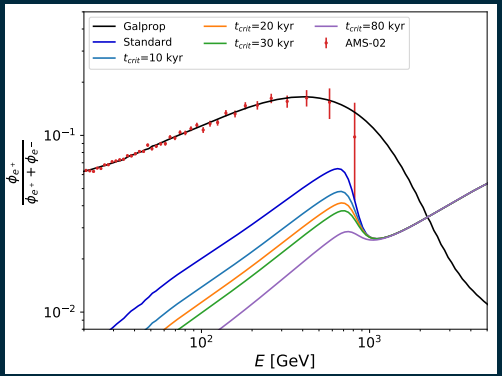


Are there mechanisms that can minimize this cutoff?

1. Efficiency of positron production
2. Cooling of positrons as they propagate through galaxy

Pulsar Models: Efficiency [Preliminary]

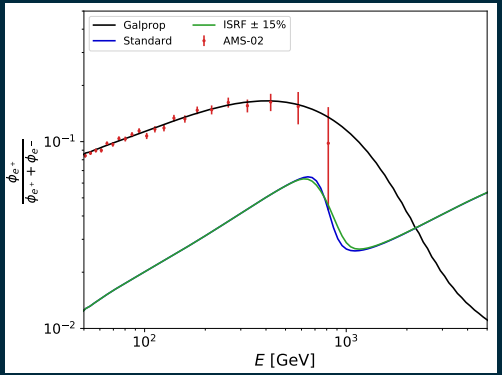
- Pulsar efficiency: fraction of spindown power converted into e^+e^- pairs, $\sim 10\%$
- In simple models: efficiency is assumed to be constant over pulsar age
- But observations suggest that efficiency increases over time



- Pulsar models with increasing efficiency show strong reduction ($\sim$ 30-60%) of the cutoff

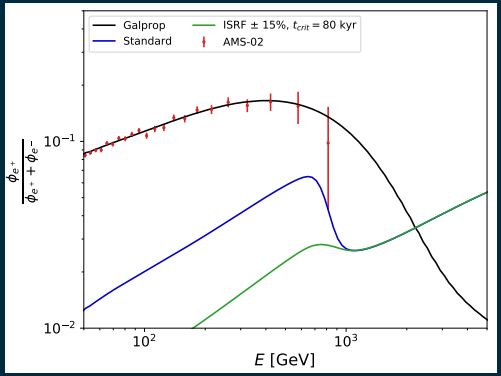
Pulsar Models: Cooling [Preliminary]

- Cooling of particles depends on interstellar radiation field (ISRF) and magnetic fields
- Simple models assume same path for all particles, but there are variations on small scales $\Rightarrow$ particles cool at different rates



- Here: introduced variations in ISRF $\pm \sim 15\%$
- Cutoff is somewhat stretched out

Sharp Spectral Features From Pulsars? [Preliminary]



- Sharp spectral features associated with simple pulsar models can be significantly reduced
- Consistent with smooth CR positron spectrum

Summary and Conclusion

- Local cosmic-ray positron spectrum is measured to great precision by AMS-02 and looks very smooth
  - Set strong constraints on dark matter models
  - Constrain pulsar models

- Leptophilic dark matter can produce sharp spectral features
  - We set strong constraints on the DM annihilation cross section, e.g. 2 orders of magnitude below thermal cross section for annihilation into e^+e^- at for 20 GeV dark matter mass

- Simple pulsar models suggest sharp spectral features
  - There exist mechanisms that can strongly reduce sharp features [preliminary]