Indirect Searches for Dark Matter with AMS-02

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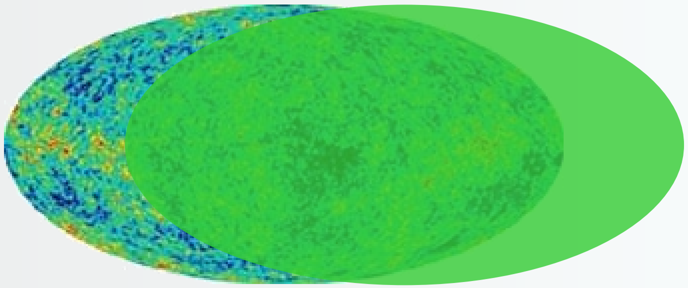
Non baryonic Dark Matter in our Universe

DM is required to understand results from cosmological probes

Example : CMB anisotropies/structure formation



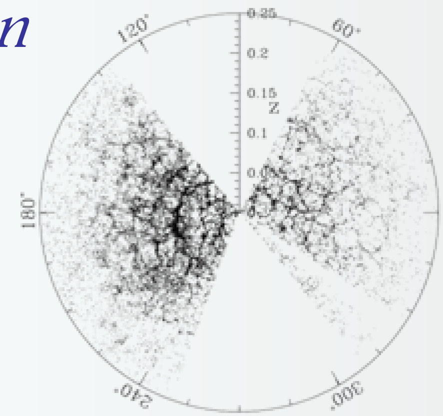
CMB is very homogeneous :

$\delta\rho/\rho = 10^{-5}$

⇔ Same Universe ≠ epochs ⇔

$\delta\rho/\rho \propto a(t)$

$a(t_{CMB})=1$ → $a(t_{galaxies})=10^3$



Blanton et al., 2003, astro-ph/0210215

∃ galaxies : $\delta\rho/\rho > 1$

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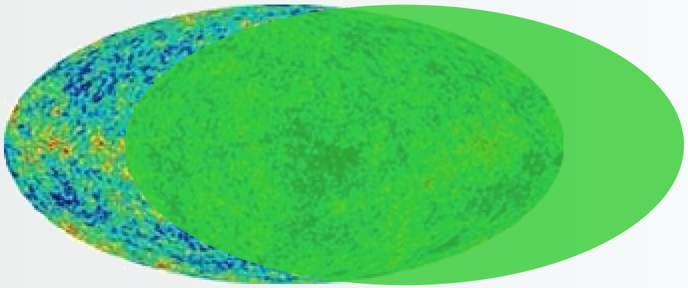
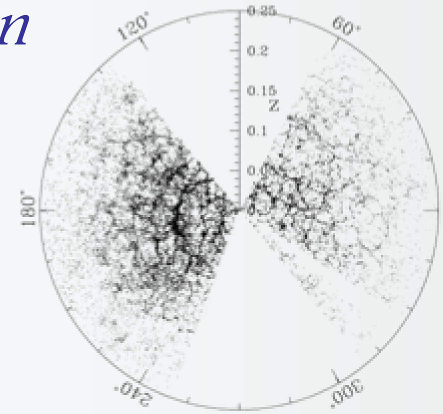


⟺ Same Universe ≠ epochs ⟺



Blanton et al., 2003, astro-ph/0210215

$\delta\rho/\rho \propto a(t)$

CMB is very homogeneous :

$\delta\rho/\rho = 10^{-5}$

$a(t_{CMB})=1$ → $a(t_{galaxies})=10^3$

$\exists$ galaxies : $\delta\rho/\rho > 1$

⇒ 84% of *non baryonic* dark matter

Standard Model photon — *Susy* → $\tilde{\chi}_1^0$ Lightest neutralino

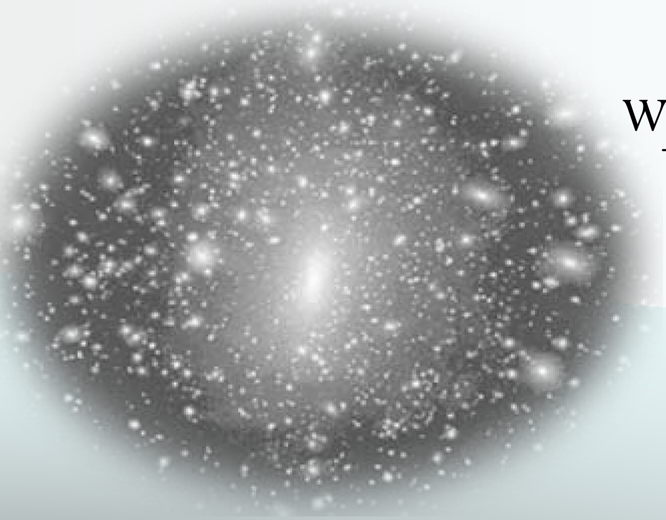
Standard Model photon — *Extra-dimensions* → $B^{(1)}$ First Kaluza-Klein U(1) boson

Primordial self-annihilations regulate cosmological density

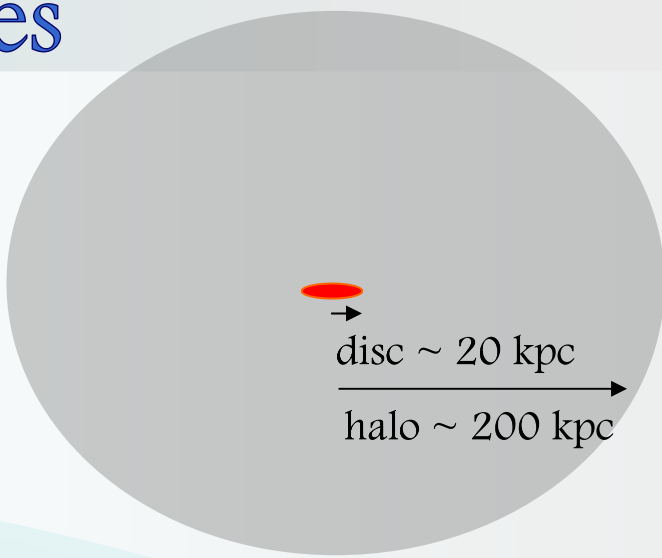
Principles of the indirect searches

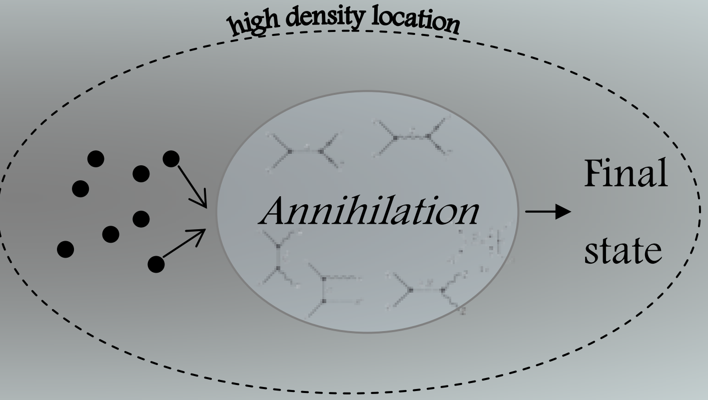
Galaxies form in DM potential wells :

B. Moore et al., ApJ Lett. 524 (1999)



We live in one of these halos





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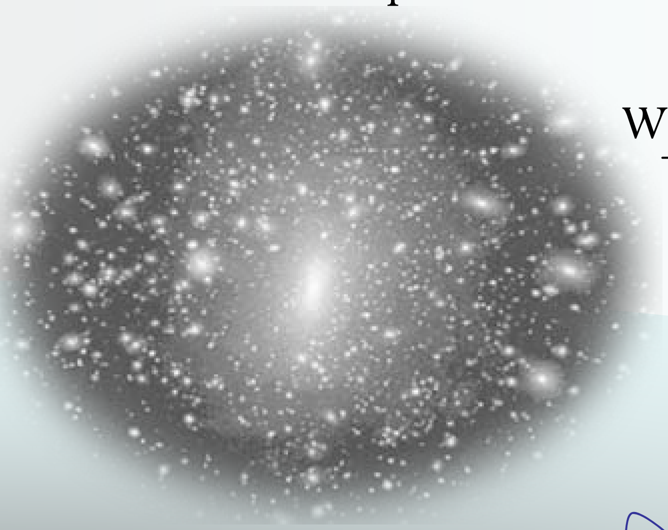

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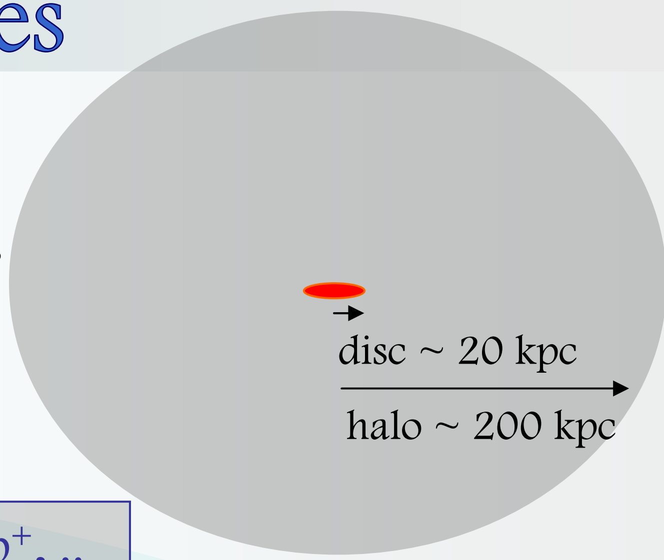
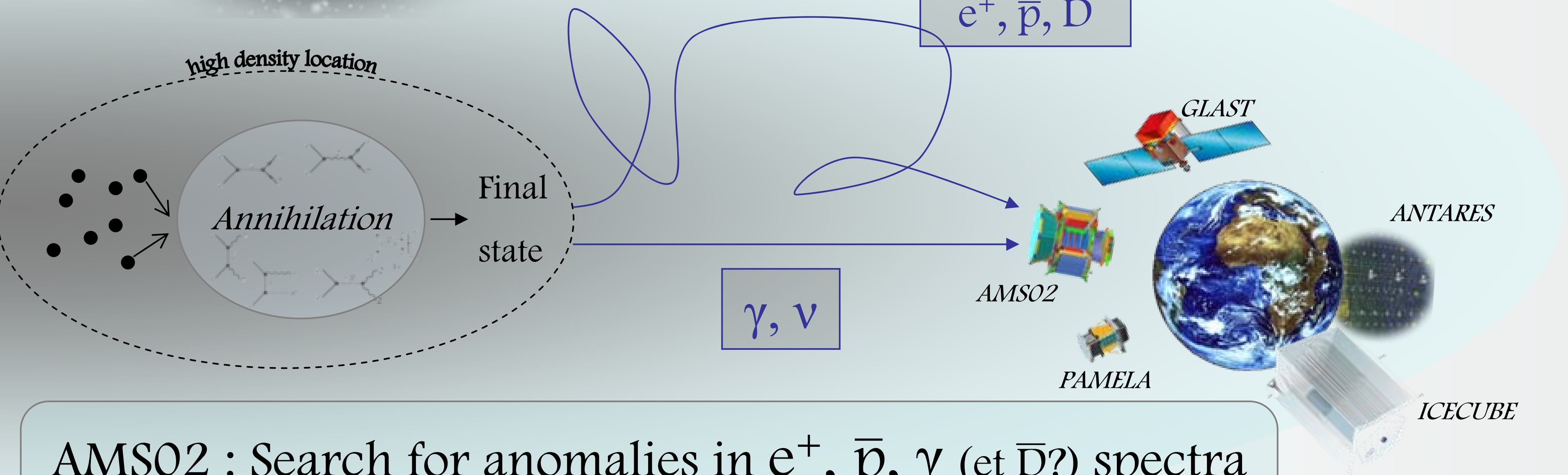
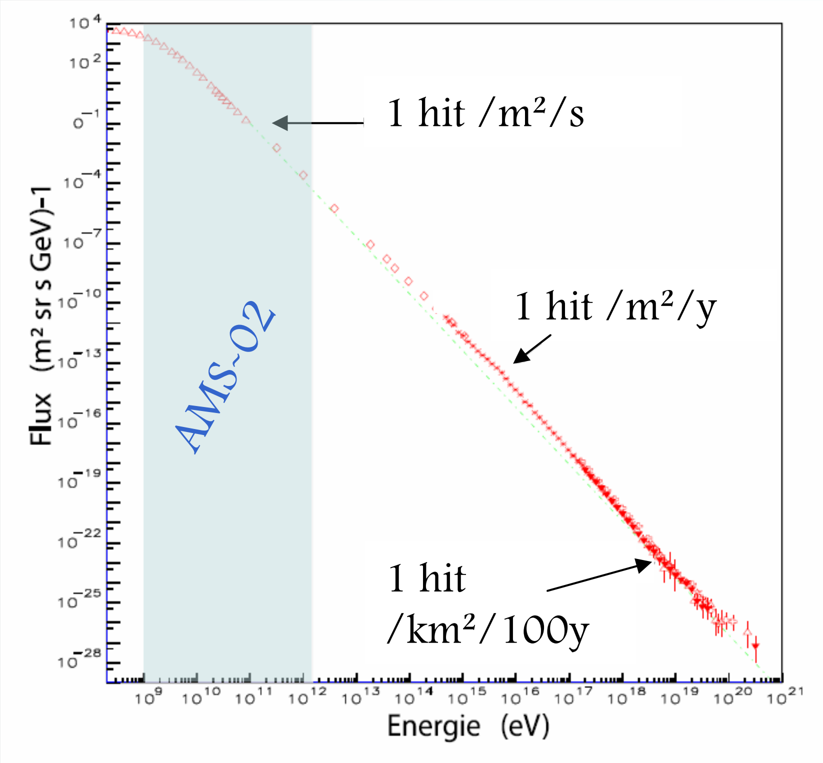
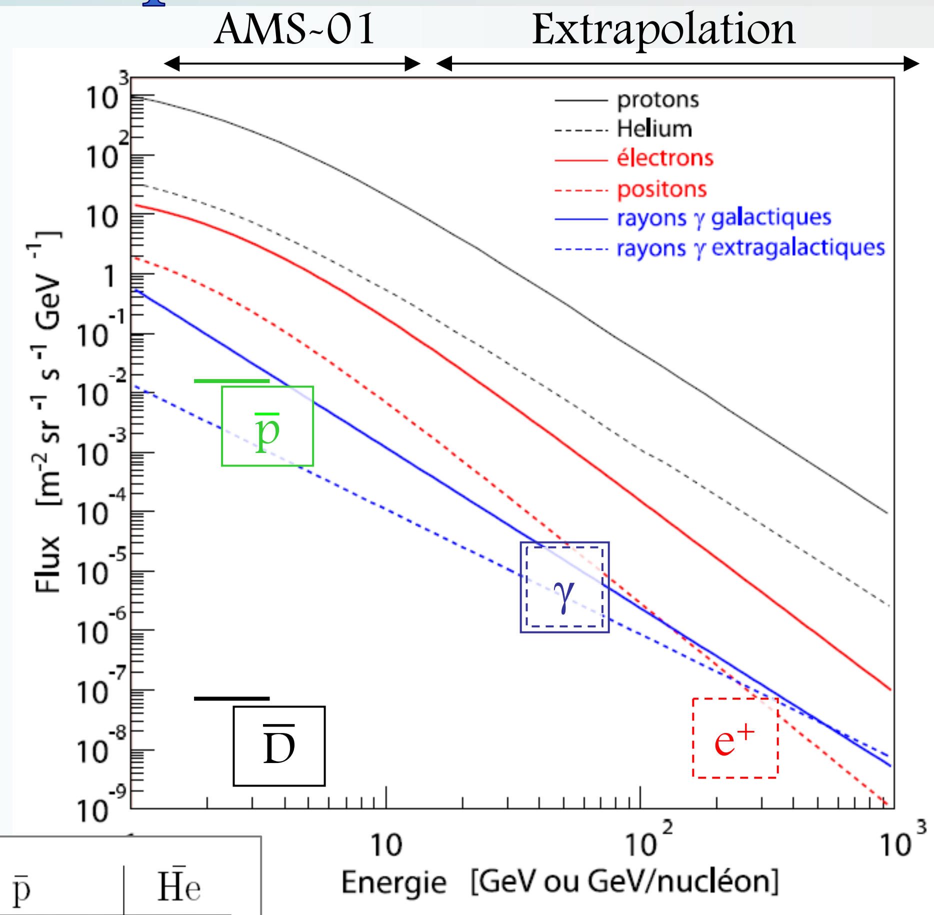




AMS02 : Search for anomalies in e^+, $\bar{p}$, γ (et $\bar{D}$?) spectra
at typical electroweak scale : 1 GeV ~ 1 TeV

Required identification capabilities





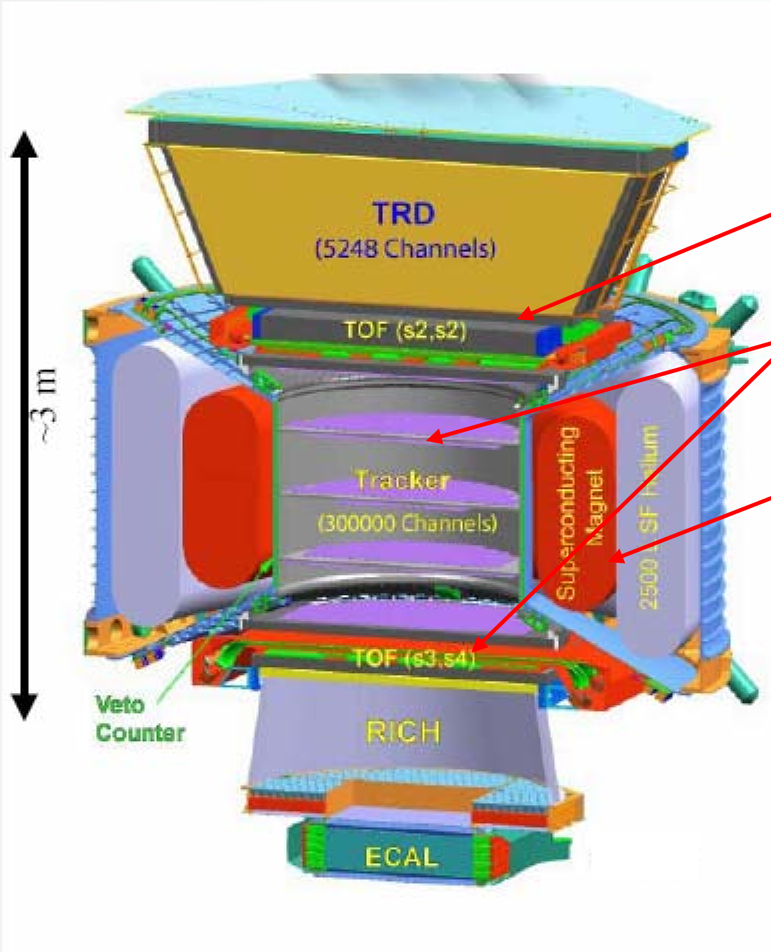
	He	e^-	e^+	γ	$\bar{p}$	$\bar{He}$
Main background	p	p	p	p	p et e^-	He
Flux ratio	10	10^2	10^3	10^5 à 10^7	10^5 et 10^3	?
Required rejection factor	10^3	10^4	10^5	10^9	10^7 et 10^5	10^{10}

→ Particle physics detector

The AMS-02 space spectrometer

Geometrical acceptance :
0.5 m^2.sr

To be placed aboard the International Space Station



Time of flight

120 ps

Silicon Tracker

Rigidity at few %, charge sign

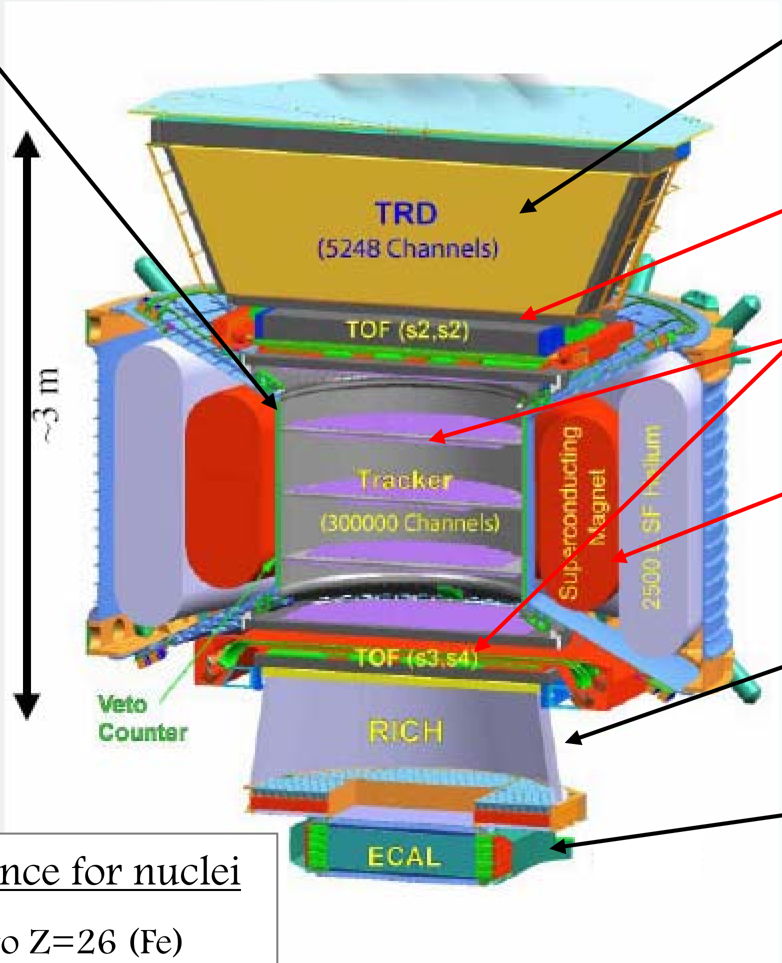
Superconducting magnet

BL^2 = 0.86 T

The AMS-02 space spectrometer

+ star tracker and GPS

Veto scintillators



Transition radiation detector

e/p separation (10^2-10^3)

Time of flight

120 ps

Silicon Tracker

Rigidity at few %, charge sign

Superconducting magnet

$BL^2 = 0.86$ T

Cerenkov detector

charge & β (0.1%)

Electromagnetic calorimeter

e/p separation (10^3-10^4)

$e^{\pm}$,γ energy

γ trigger from 1 GeV to 1 TeV

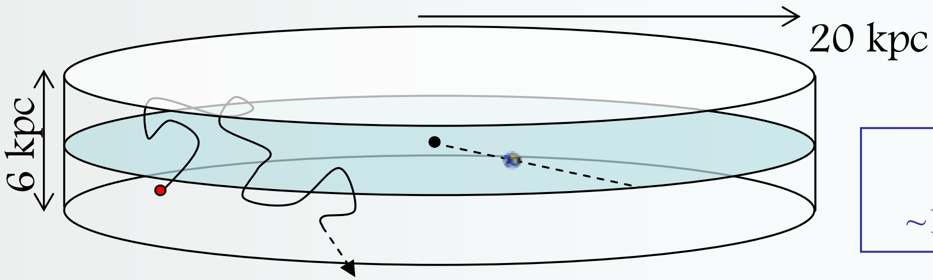
Performance for nuclei

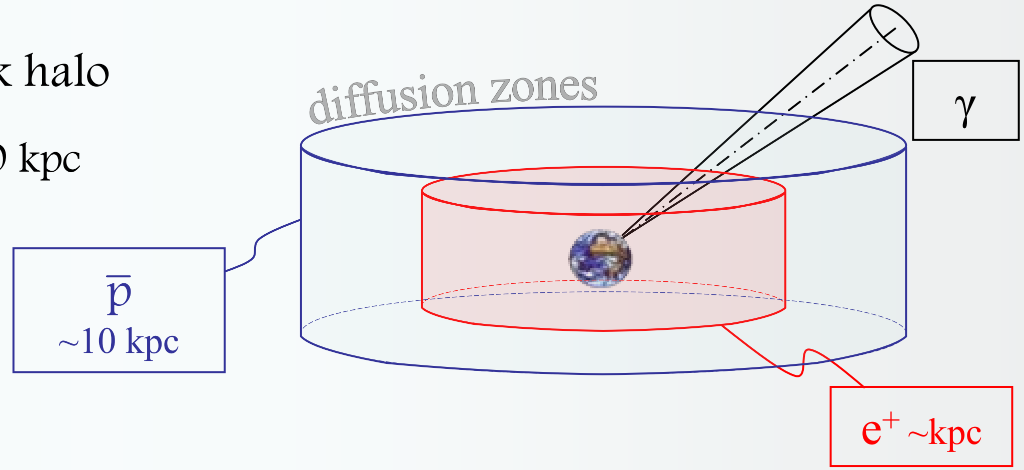
ID up to Z=26 (Fe)

Isotopes up to A=25 (Al)

AMS-02 observables

Diffusive zone ~10× smaller than the dark halo





Each channel has its own relevance :

Gamma

Untouched energy spectrum

Sources localization

No uncertainty / propagation

Antiprotons

Probe a large part of the halo

Known uncertainties

Positrons

Clear final state correspondence

« local » effect

Observed excess (AMS01, HEAT)

multi-channel analysis

⇒ Principle of AMS02 !

Normalization of the signal is unknown (boost factors) ⇒ focus on the spectral features

Performance for DM signals detection

- Sensitivity to DM signals :

→ main reducible backgrounds :

$\Phi(\gamma) \approx 10^{-4 \text{ to } -6} \times \Phi_{protons}$

$\Phi(e^{+}) \approx 10^{-3} \times \Phi_{protons}$

$\Phi(\bar{p}) \approx 10^{-4} \times \Phi_{protons}$

→ with specific selections / sub-detectors :

$A_{\gamma} / A_{p} \sim 10^{7}$

γ : 3 GeV ~ 1 TeV

$A_{e+} / A_{p} \sim 10^{5}$

e^{+} : 1 GeV ~ 300 GeV

$A_{\bar{p}} / A_{p} \sim 10^{6}$

$\bar{p}$: 0.8 GeV ~ 600 GeV

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- Key sub-detectors :

e^+, γ

Calorimeter :

☺ Standalone γ trigger

☻ 16.5 X_0

☼ $\sigma_E/E \approx 5\%$ at 50 GeV

$\bar{p}$

Tracker :

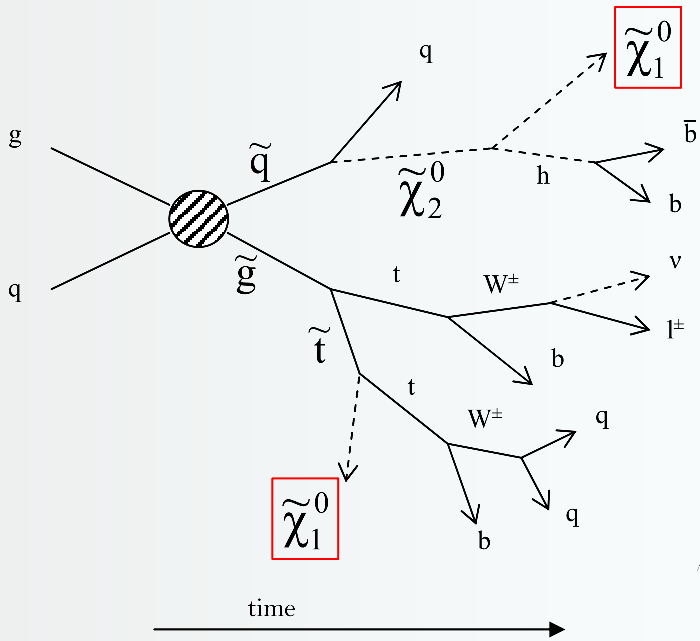
☺ Very high sensitivity

☻ 8 μm spatial resolution

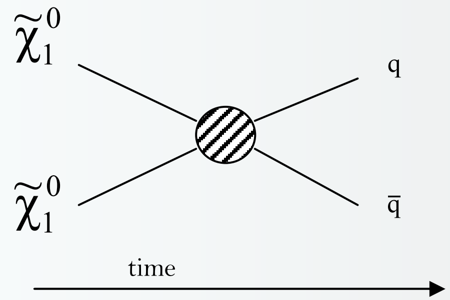
☼ $\sigma_p/p \approx 1.5\%$ at 10 GeV

Links to new physics models

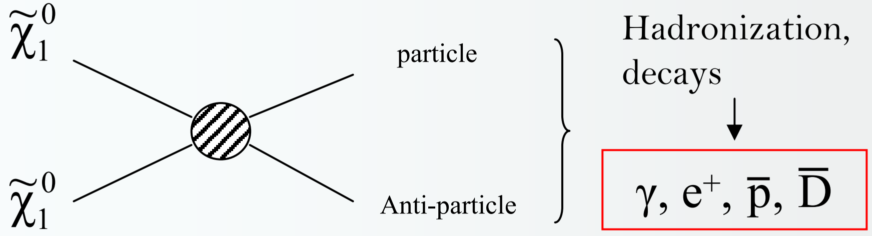
DARK MATTER SEARCHES IN COLLIDER EXPERIMENTS



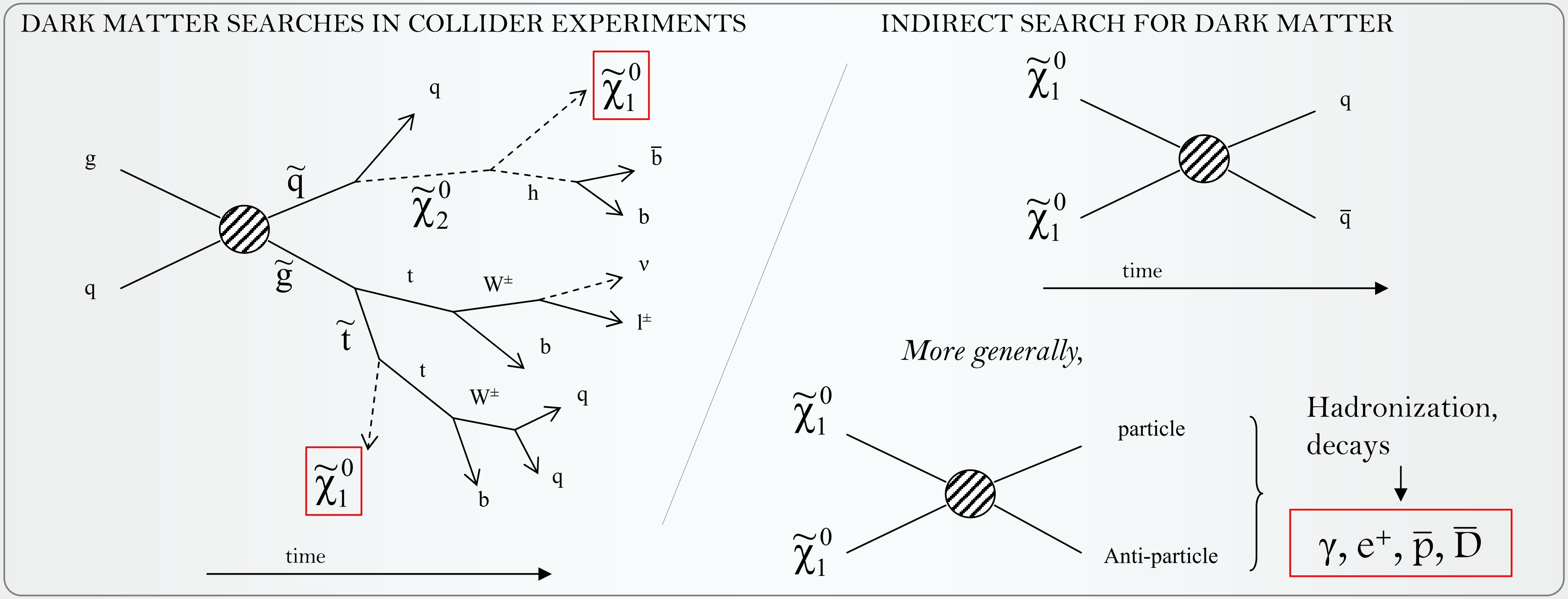
INDIRECT SEARCH FOR DARK MATTER



More generally,

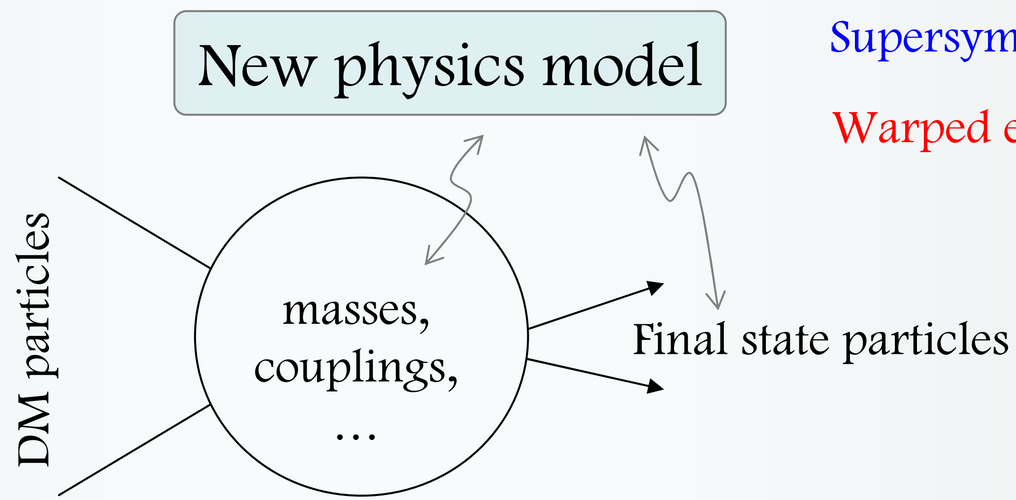


Links to new physics models



Supersymmetry

Warped extra-dimensions



Lightest neutralino (LSP)

Kaluza-Klein boson (LZP)

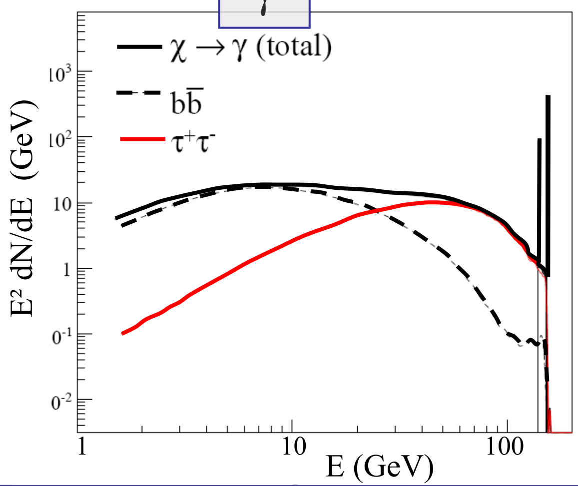
LSP (Susy) vs. LZP (X~dim) : at the source

Before propagation

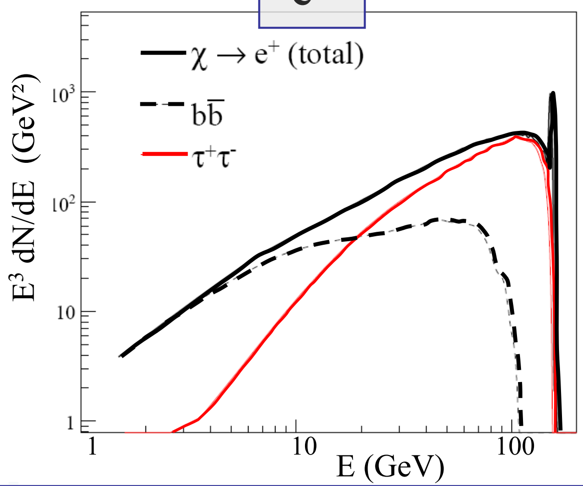
Top : LSP (SUSY) ~ 151 GeV

Bottom : LZP (X~dim) ~ 150 GeV

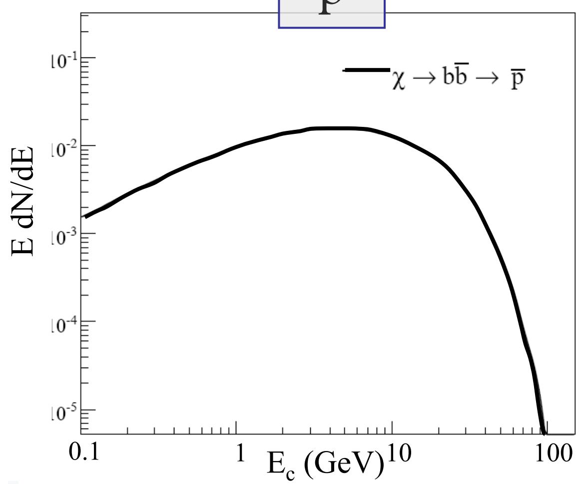
γ

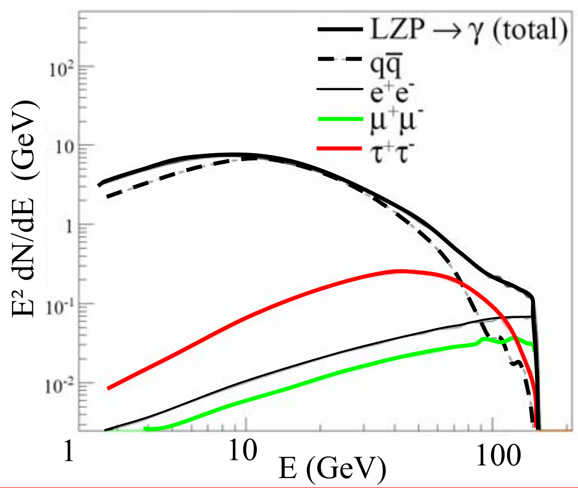


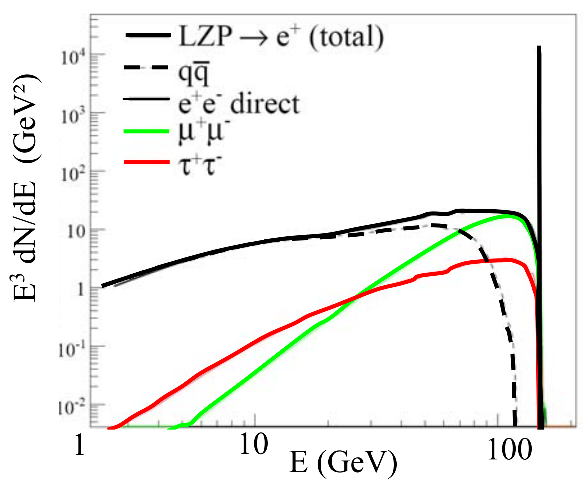
e^+

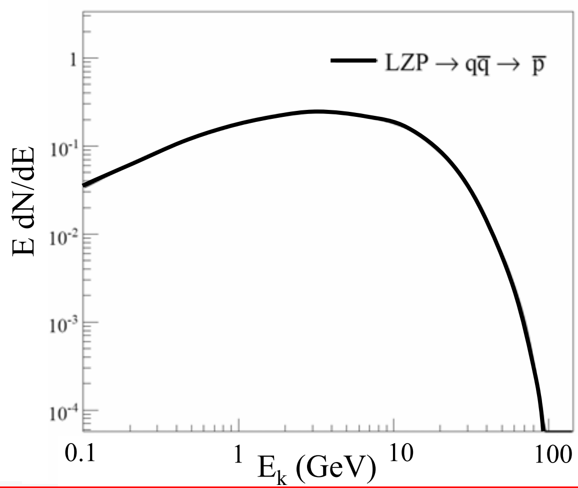


$\bar{p}$









Computed with micrOMEGAs

LSP (Susy) vs. LZP (X~dim) : at the Earth

After propagation

Top : LSP (SUSY) ~ 151 GeV

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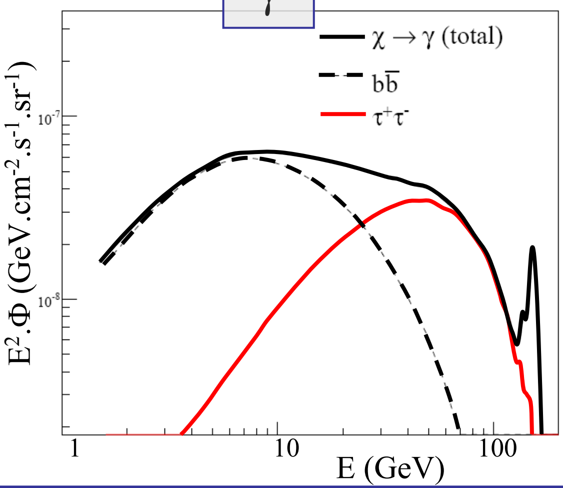
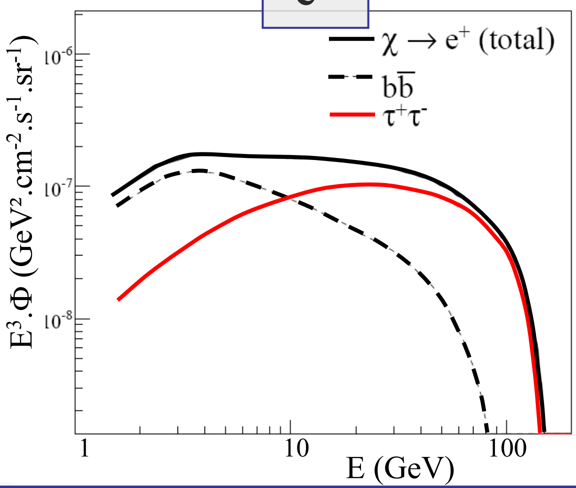
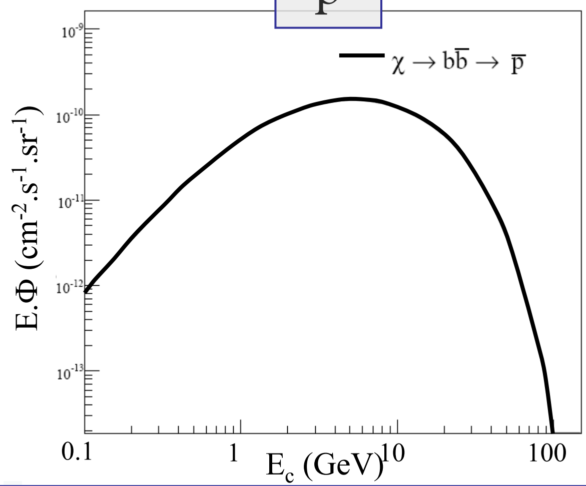
γ

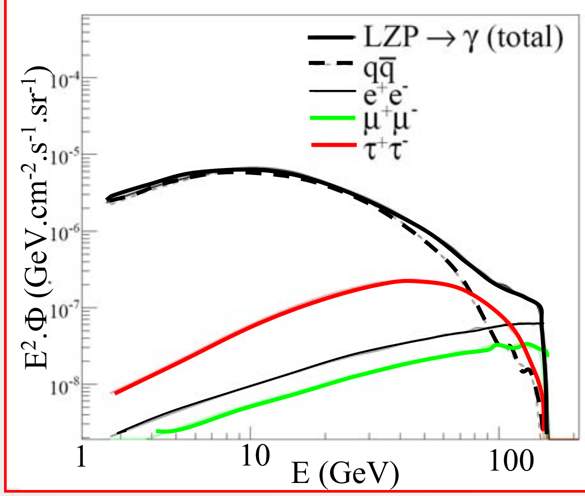


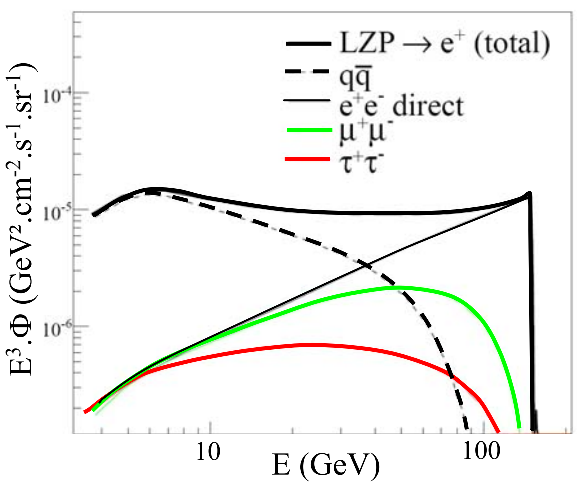
e^+

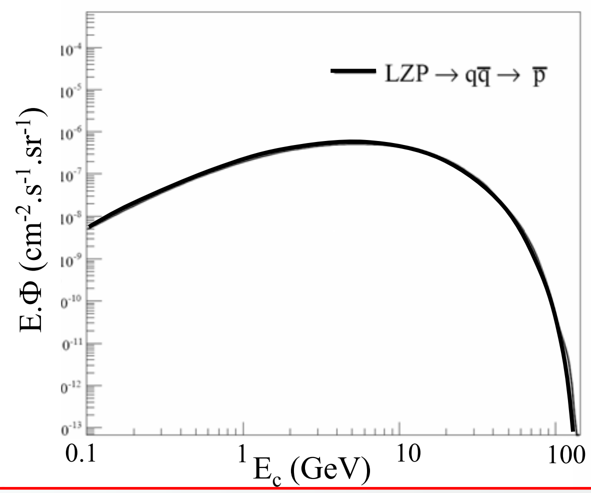


$\bar{p}$









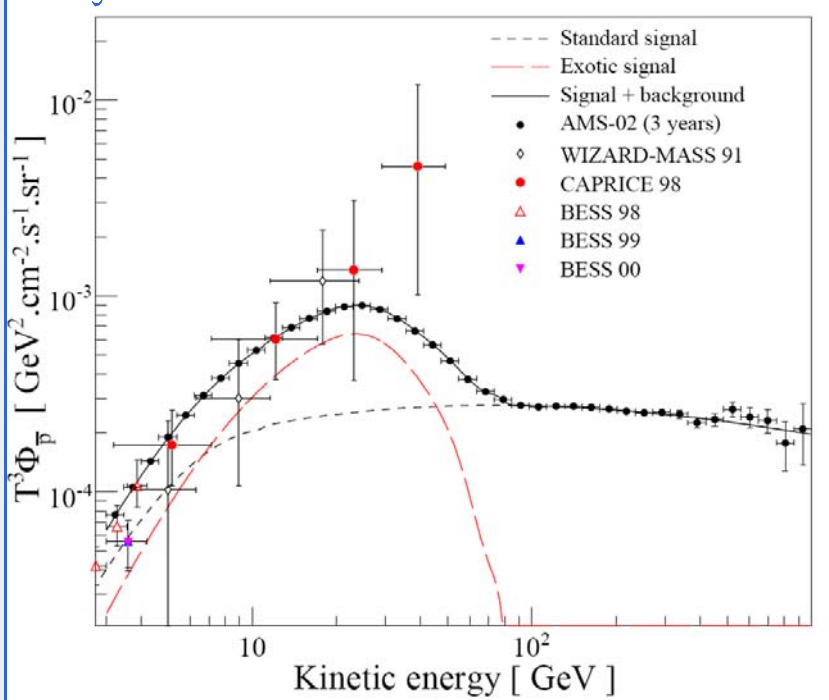
Computed with micrOMEGAs

LSP (Susy) vs. LZP (X-dim) : observed by AMS-02

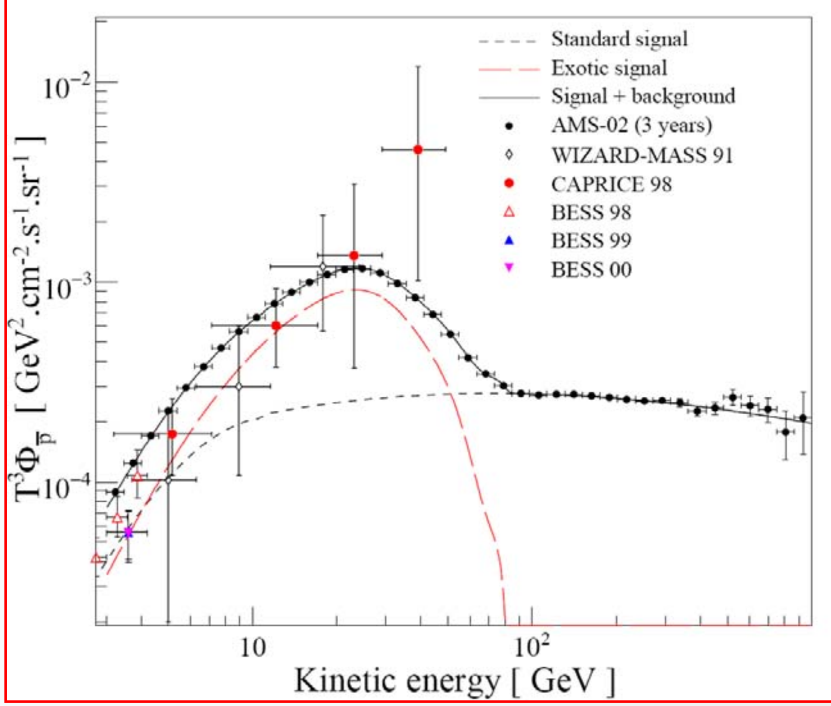
- Major assumption : the measured e^+ excess is due to DM annihilation
  - → boost (*clumpiness*) factors are set to required values
  - → no spectral distortion due to clumpiness effects
- 3 years of data taking

Antiproton spectra are not so discriminating :

Susy



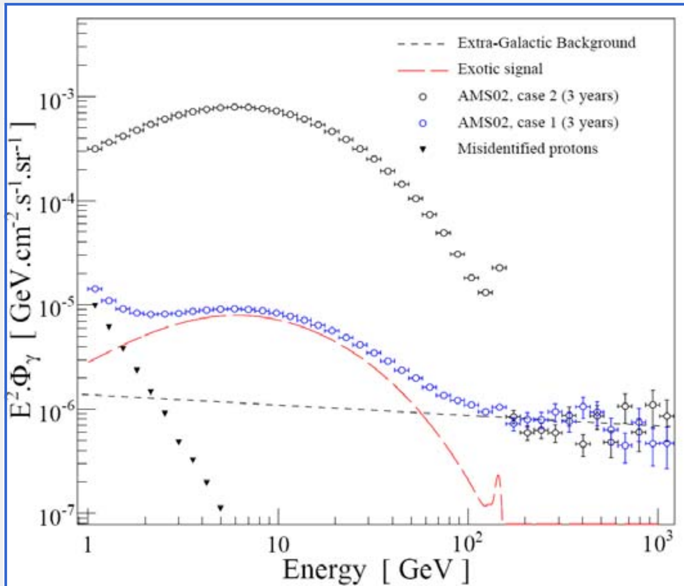
Kaluza-Klein

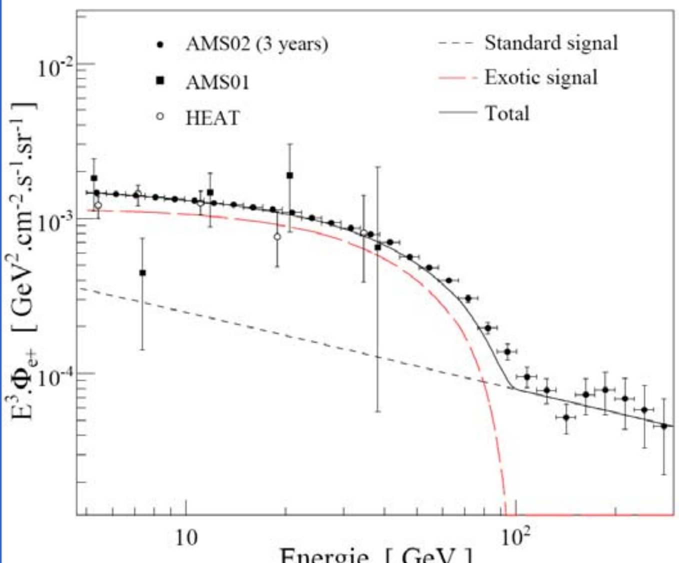


LSP (Susy) vs. LZP (X-dim) : observed by AMS-02

γ : 2 cases of clumps off the Galactic plane

Susy

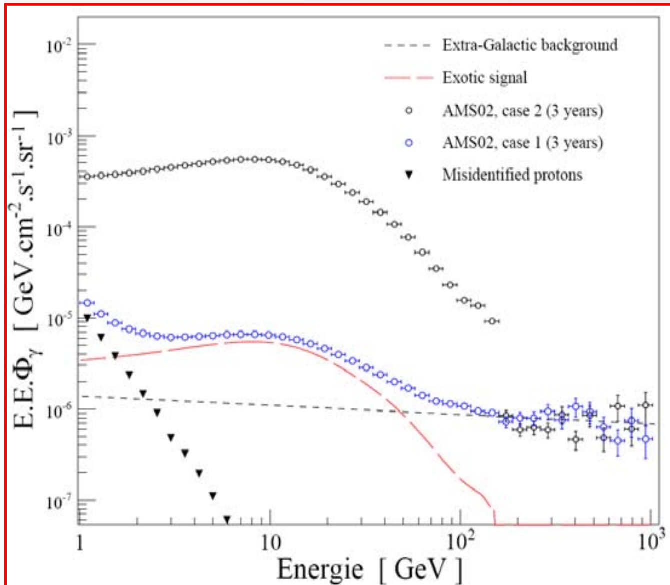


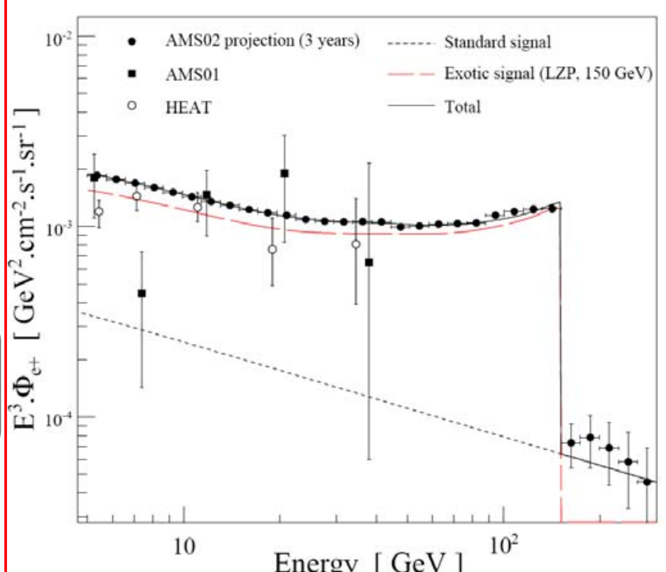


γ Line (Ecal)

Very distinctive cut-off

Kaluza-Klein





Probing the Majorana structure of the DM particle

Precise spectral shape measurement

Access to Majorana nature through *polarization* effects

Annihilation through gauge boson pairs

- Some UED models
- Susy with anomaly-mediated breaking (AMSB)

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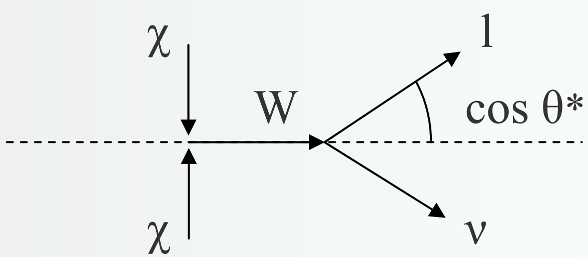
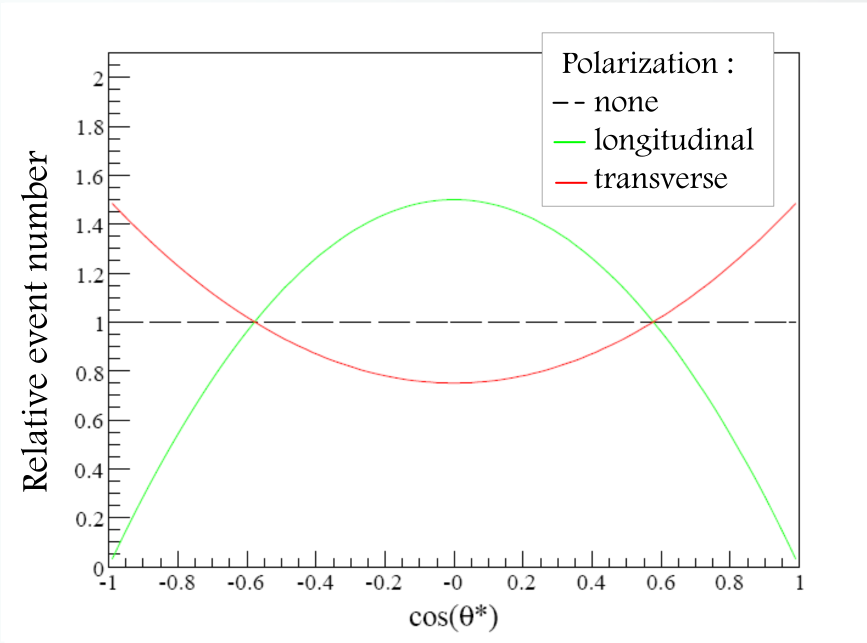
Pair annihilation at rest of DM particles :



Final state leptons energy spectrum is changed

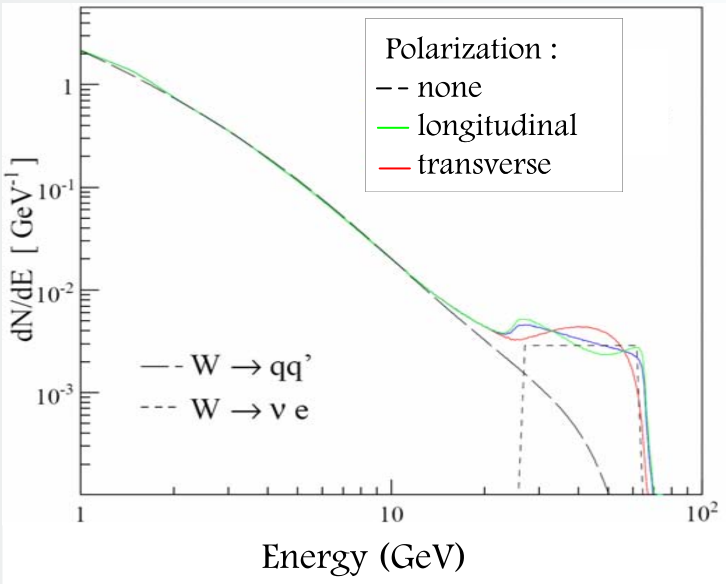
⇓

Effects on e^+ et ν spectra

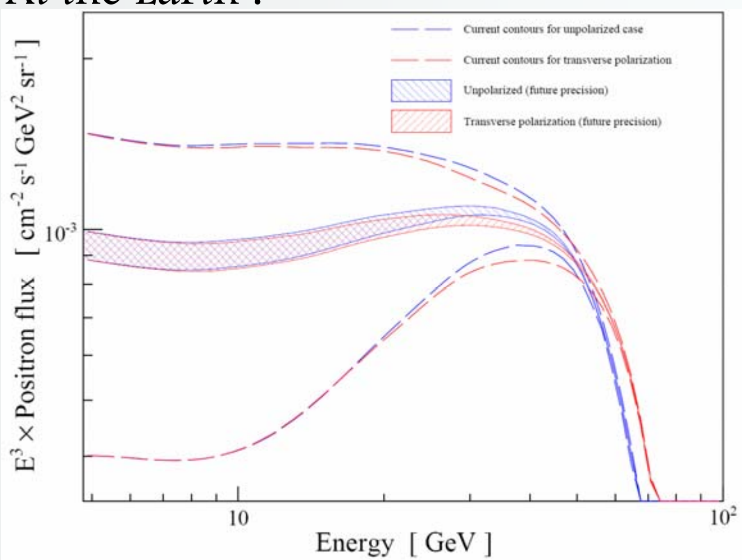


Probing the Majorana structure of the DM particle

At the source :

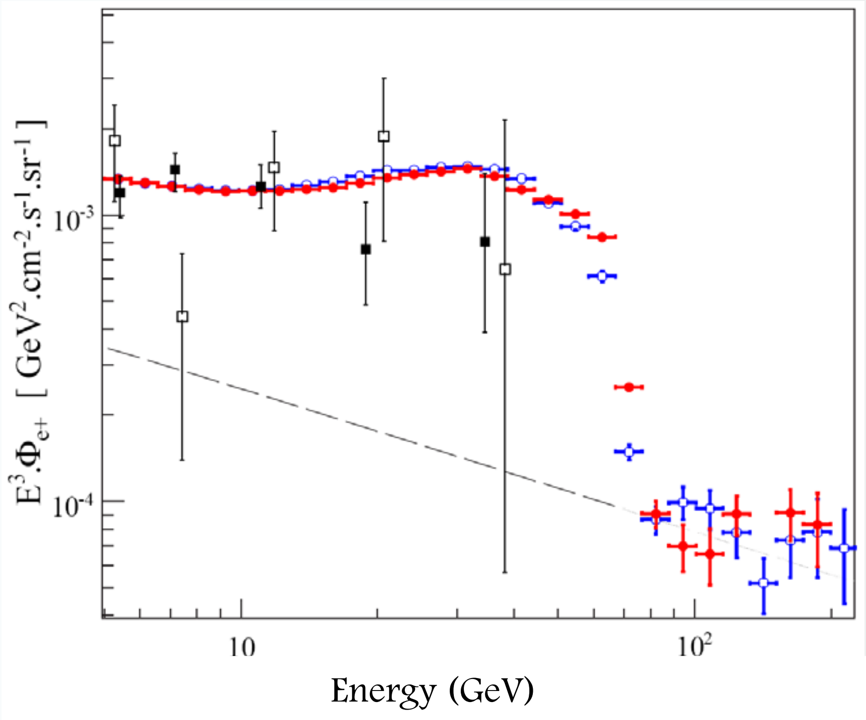


At the Earth :



Assumptions :

- annihilation into W
- e^+ excess = DM signal
- 3 years of data taking

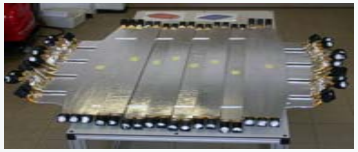


Observable difference with AMS-02

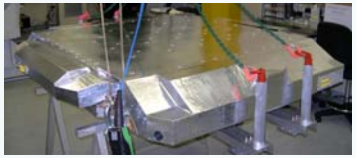
Summary & conclusions

- AMS02 sub-detectors are being integrated at CERN, ready for launch in 2009

TRD

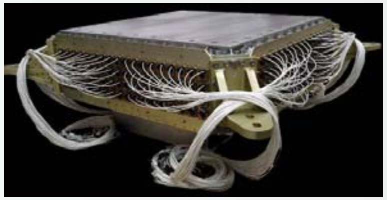


ToF



RICH

Ecal

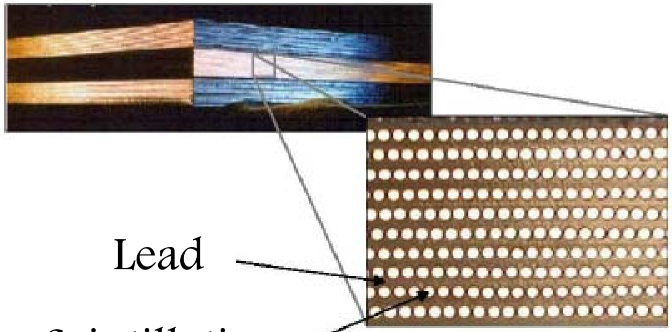


Tracker

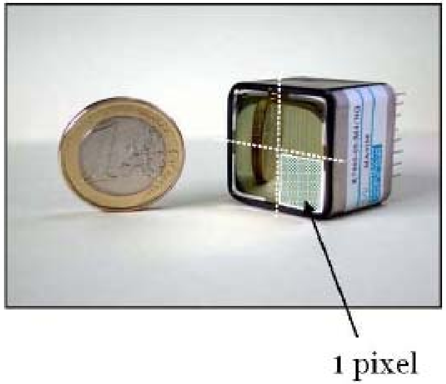
Magnet & structure

- For what concerns Dark Matter searches :
  - → Very high particle identification capabilities
  - → Searches in antiprotons, positrons, gamma rays, antideuterons
  - → Combined analyses
- Possible model discrimination through final state identification
- Access to subtle effects (e.g. polarization of the produced gauge bosons)

The AMS-02 calorimeter

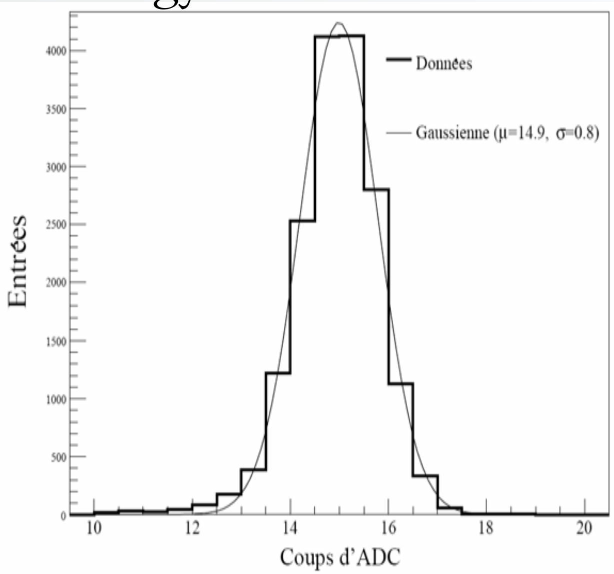


324 photomultipliers

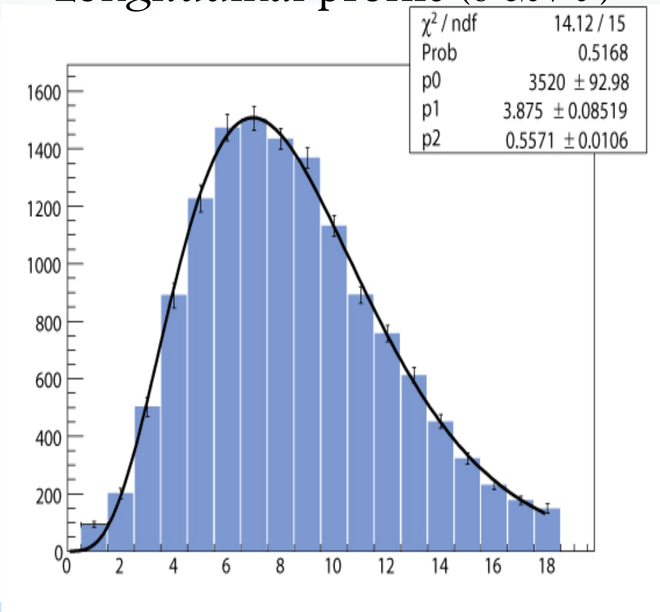


Test beam data (2007)

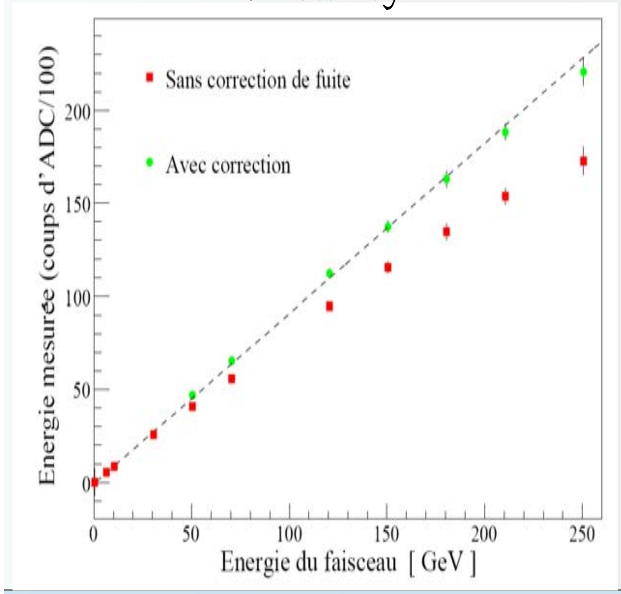
Energy resolution at 6 GeV



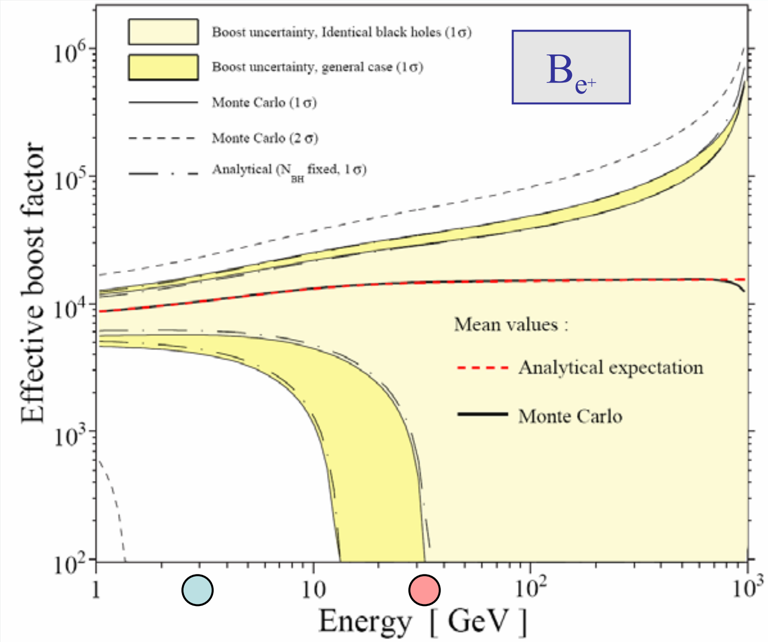
Longitudinal profile (6 GeV e⁻)

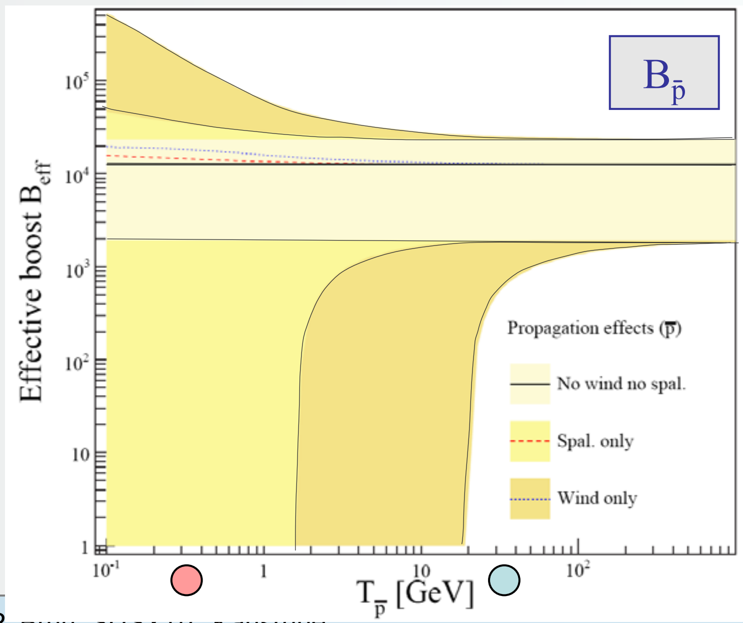


Linearity



Exact computation of boost factors

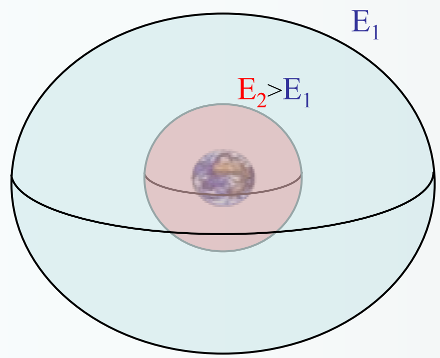


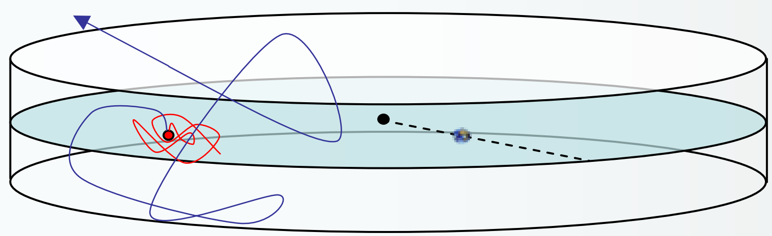


Example :

- DM spikes around IMBHs
- Generic 1 TeV DM particle
- High boost factors and variance

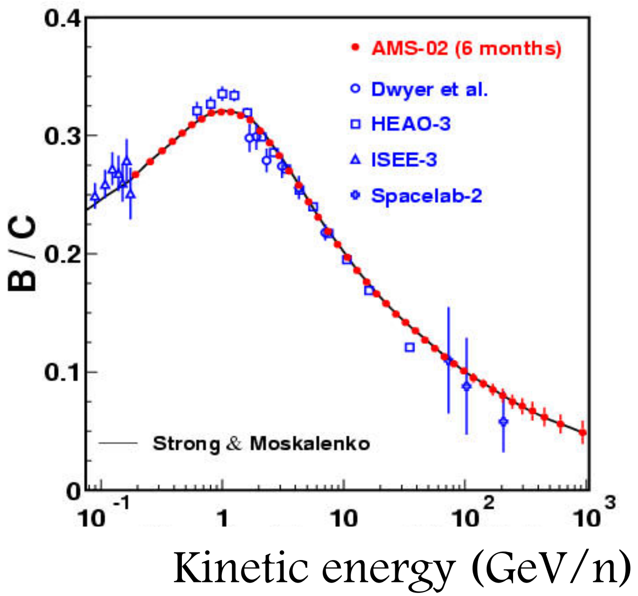
P. Brun et al., 2007, PRD, arXiv:0704.2543

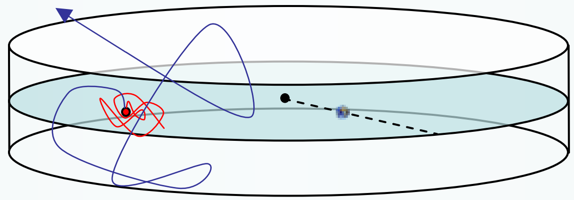




Constrains on the propagation model

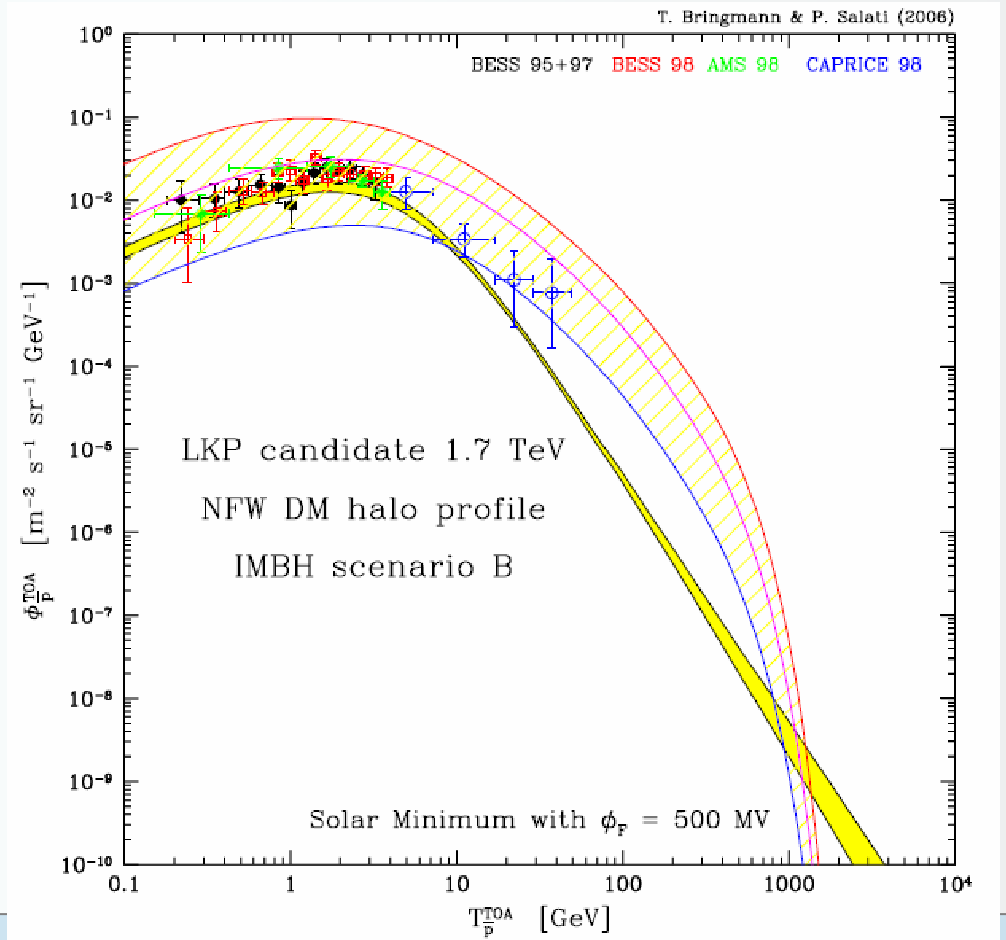
Identification up to Z=26 (Fe), isotope separation up to A=25 (Al)





Propagation parameters :

K_0, δ, τ_E, L, ρ_H, ρ_{He}, V_c, V_a



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$\tau \approx 10^6$ y