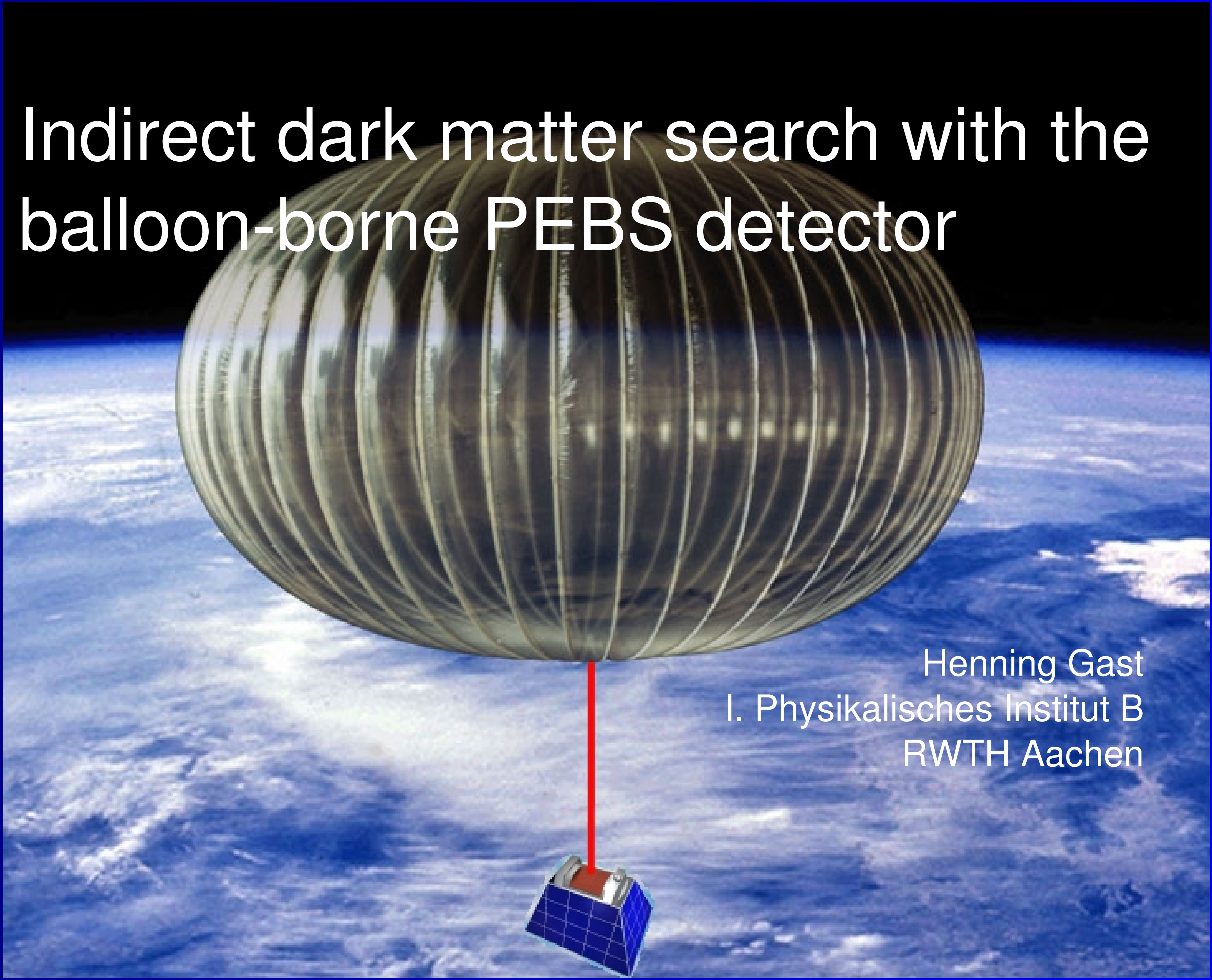
Indirect dark matter search with the balloon-borne PEBS detector



Henning Gast
I. Physikalisches Institut B
RWTH Aachen

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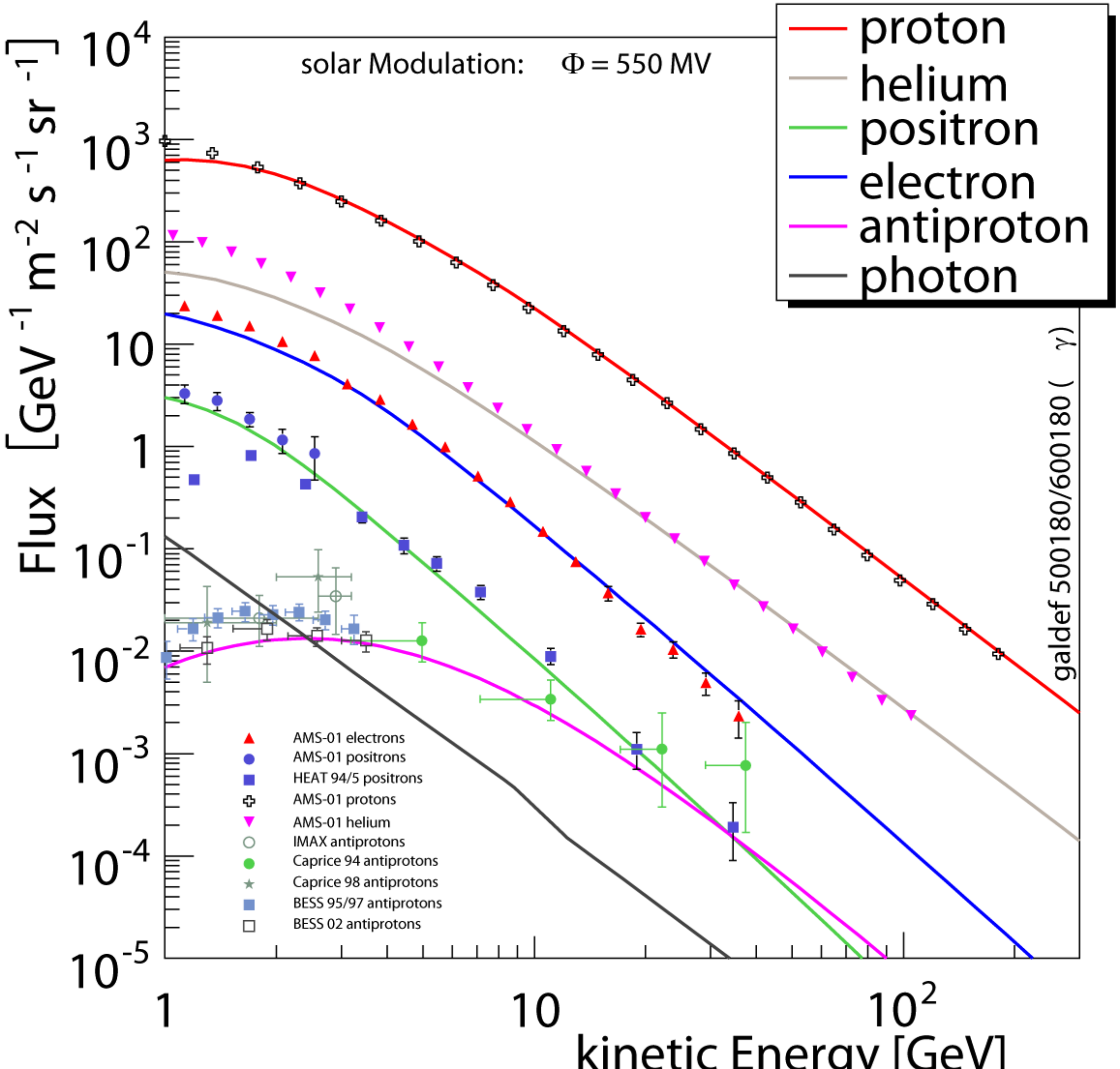
Introduction

Goal: Measure the cosmic-ray positron fraction with a balloon-borne spectrometer.

Motivation: Indirect search for dark matter. Popular scenario: WIMP annihilation in Galactic halo.

Requirements:

- Large geometrical acceptance:
  >1000 $cm^2 sr$ for 20-day campaign
- Excellent proton suppression of $O(10^6)$
- Good charge separation
- Payload weight < 2t
- Power consumption < 1000W



e.g. at 40 GeV: $10^{-4} GeV^{-1} m^{-2} sr^{-1} s^{-1}$ x (100x24x3600)s x 0.4 $m^2 sr$ = 344 e^+/GeV

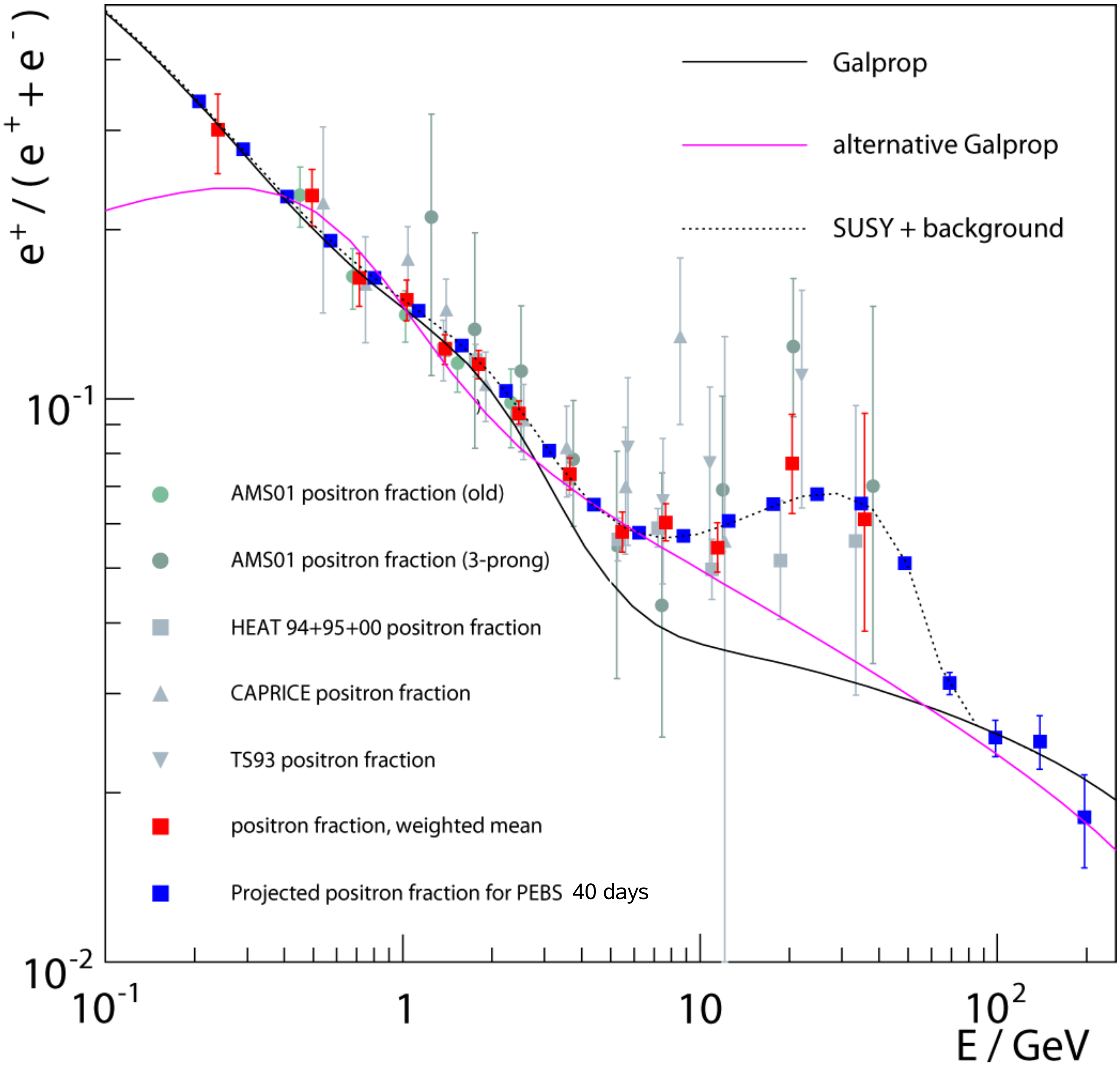
Prospective performance of PEBS detector

acceptance @100GeV and mission duration

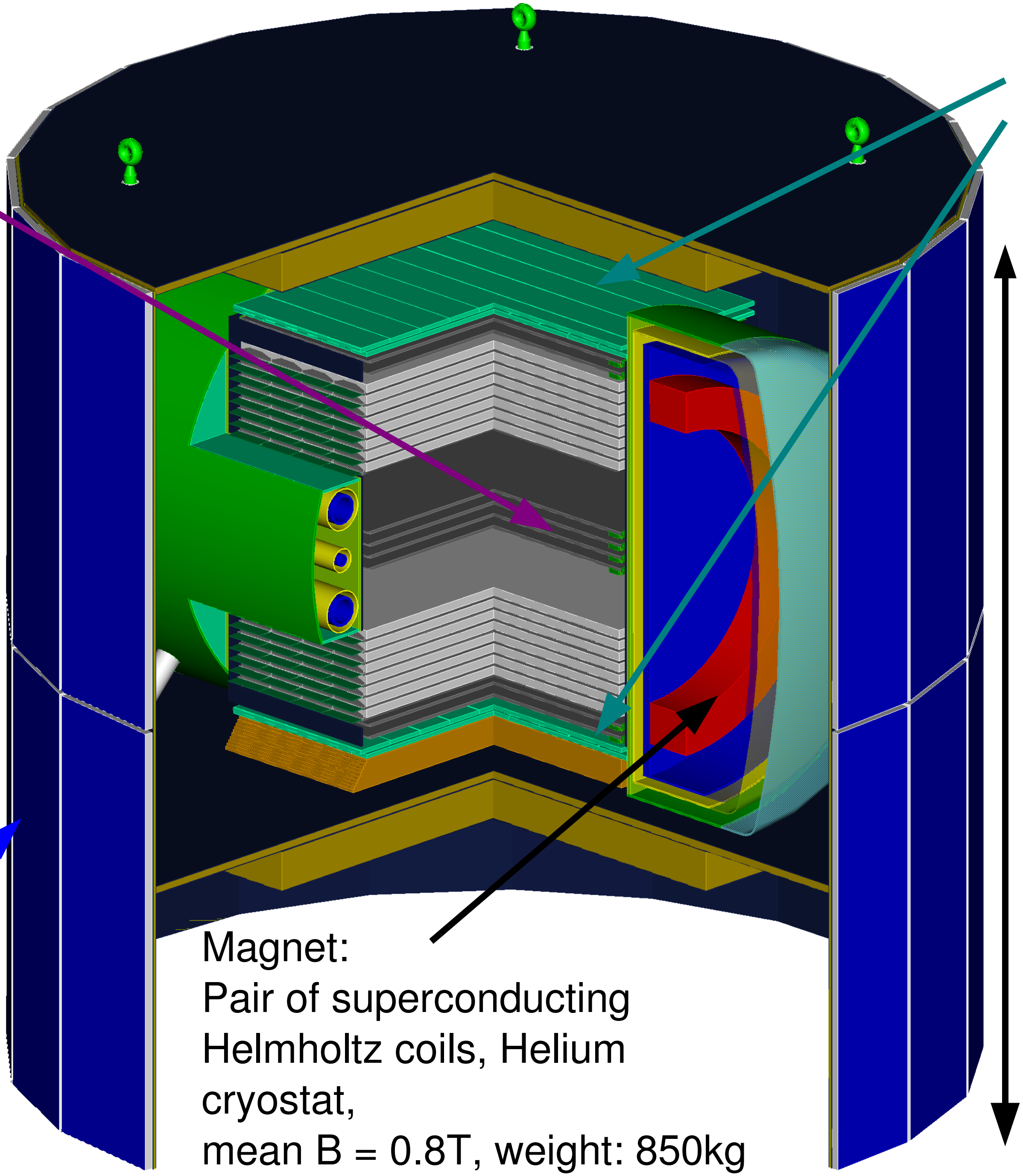
PEBS 4000 cm²sr, 100 days
AMS02 800 cm²sr, 1000 days
PAMELA 20 cm²sr, 1000 days

PEBS schedule
2010 20 days
2011 40 days
2012 40 days

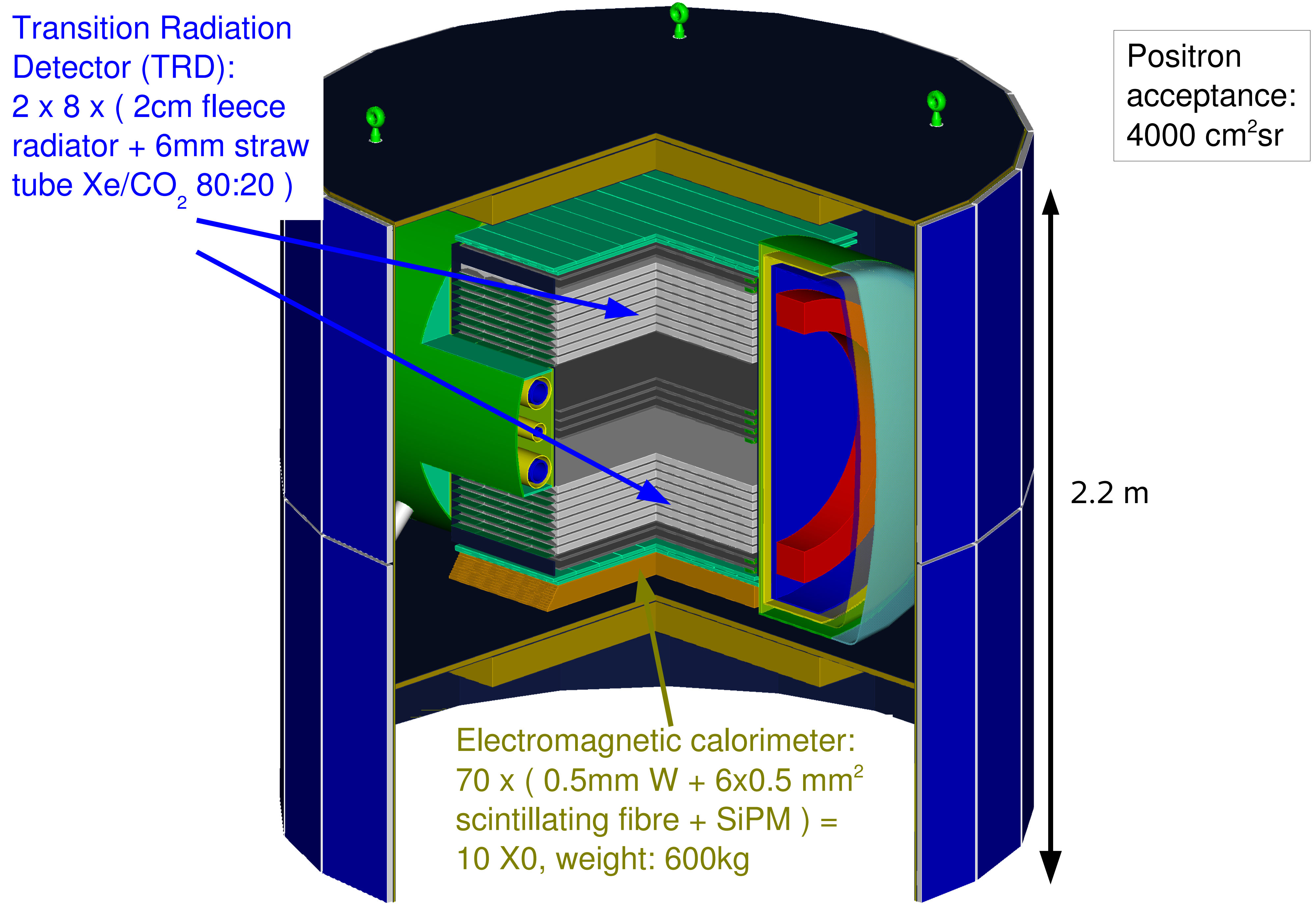
100 days PEBS=
1.4 years AMS02
55 years PAMELA



PEBS design overview



PEBS design overview

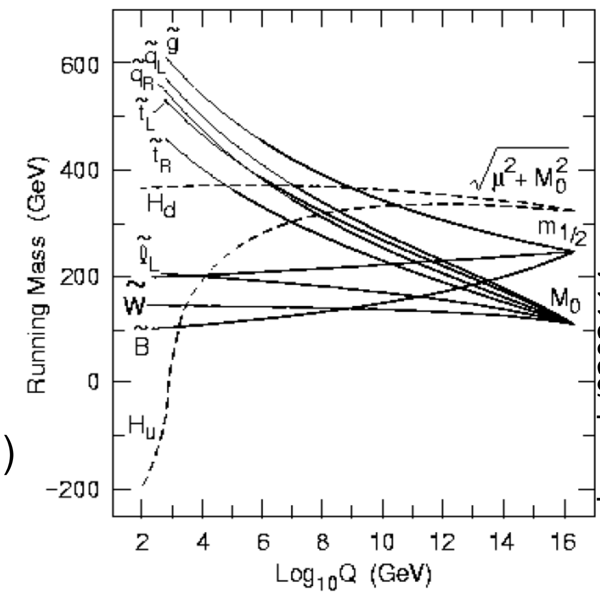


mSUGRA scan

Supersymmetry provides most popular DM candidate: the neutralino χ

Goal:

Assess constraints on mSUGRA parameter space from currently available data and improvements expected from PEBS.



hep-ph/0203114

mSUGRA parameters:

m_0	soft SUSY breaking scalar mass parameter at GUT scale
$m_{1/2}$	soft SUSY breaking fermionic mass parameter at GUT scale
$\tan\beta$	ratio of Higgs vacuum expectation values
A_0	trilinear scalar coupling at GUT scale (set to zero)
sgn μ	sign of Higgs mass parameter (set to +1 (muon magn. moment))
+ m_{top}	top quark mass

roughly 3.8 million models scanned

Tools:

ISAJET 7.75: solution of RGEs

DarkSUSY 4.1: signal fluxes, cosmological and other observables

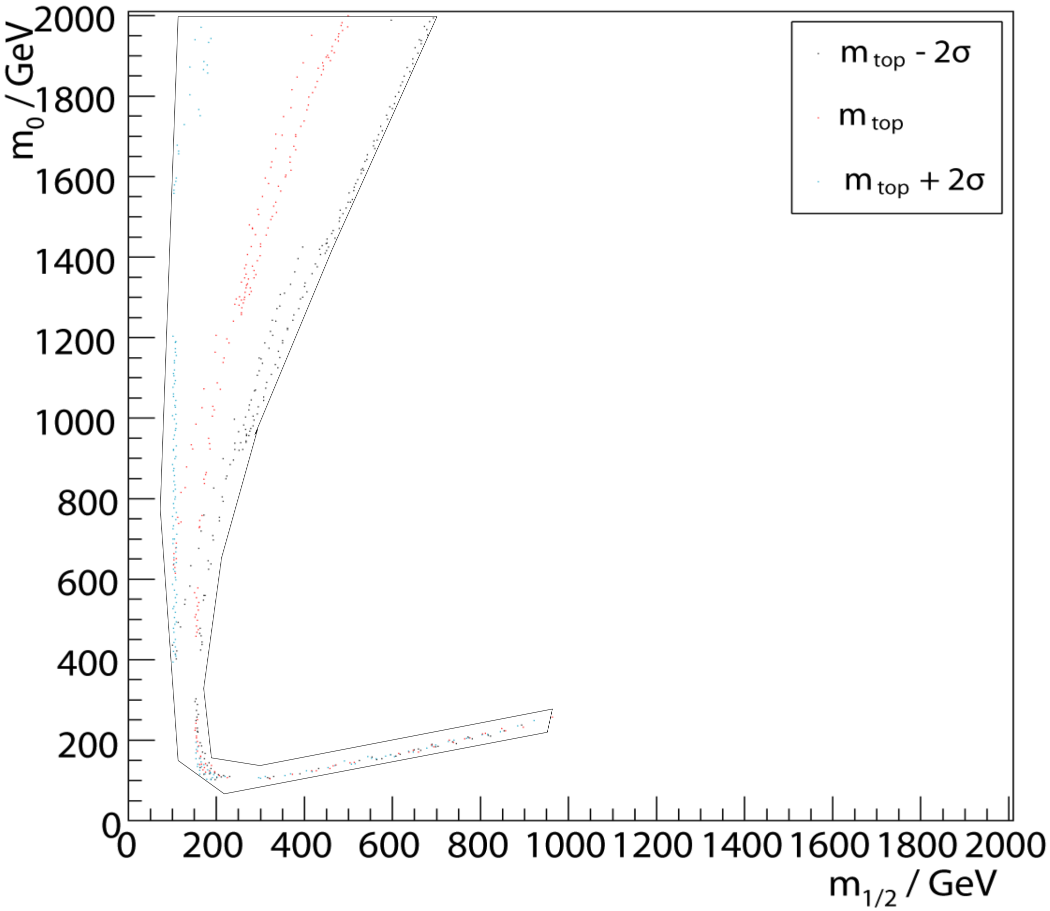
MicroMEGAS 2.0: additional observables, cross-check

GALPROP 50p: model of cosmic-ray propagation and secondary production

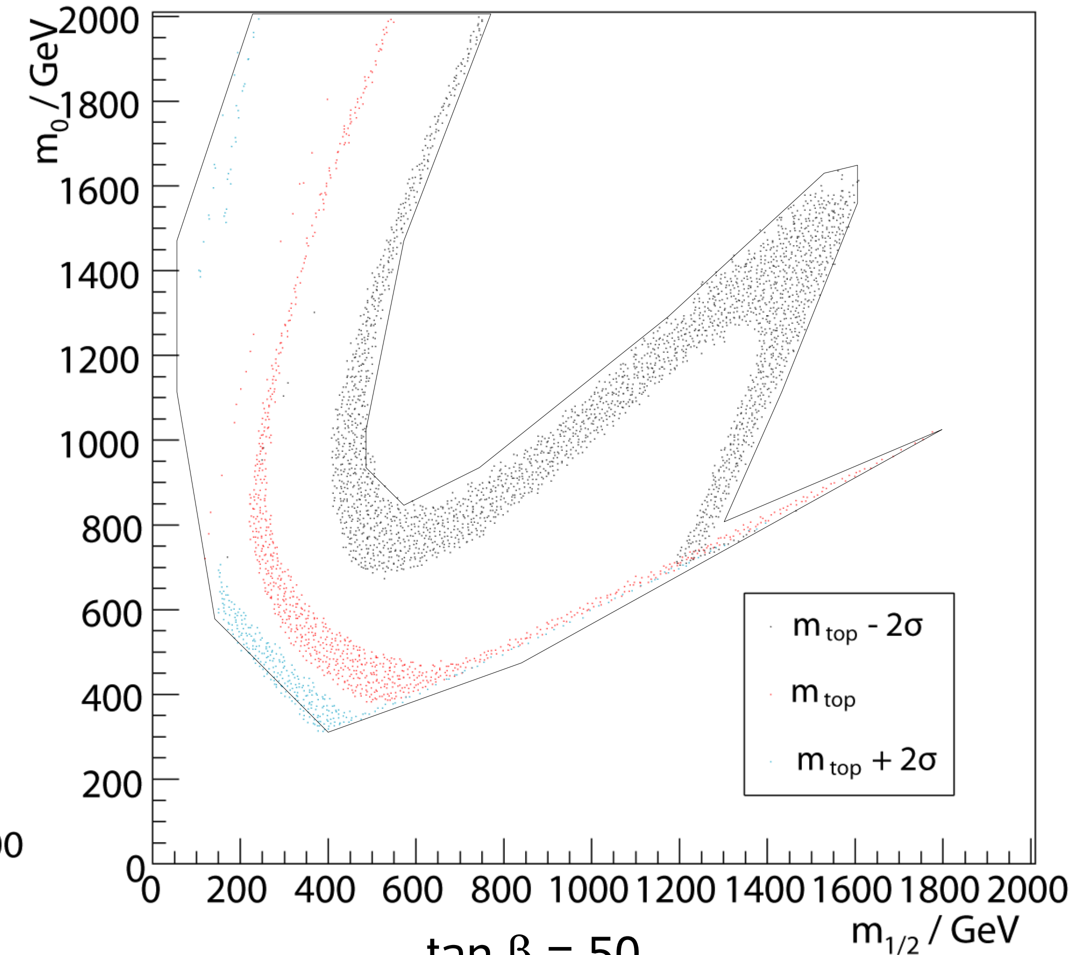
} all linked into one executable (only one call of ISAJET), considerable effort because of Fortran limitations

Relic density constraint for different m_{top}

$\Omega_\chi h^2$ with coannihilations



tan β = 20



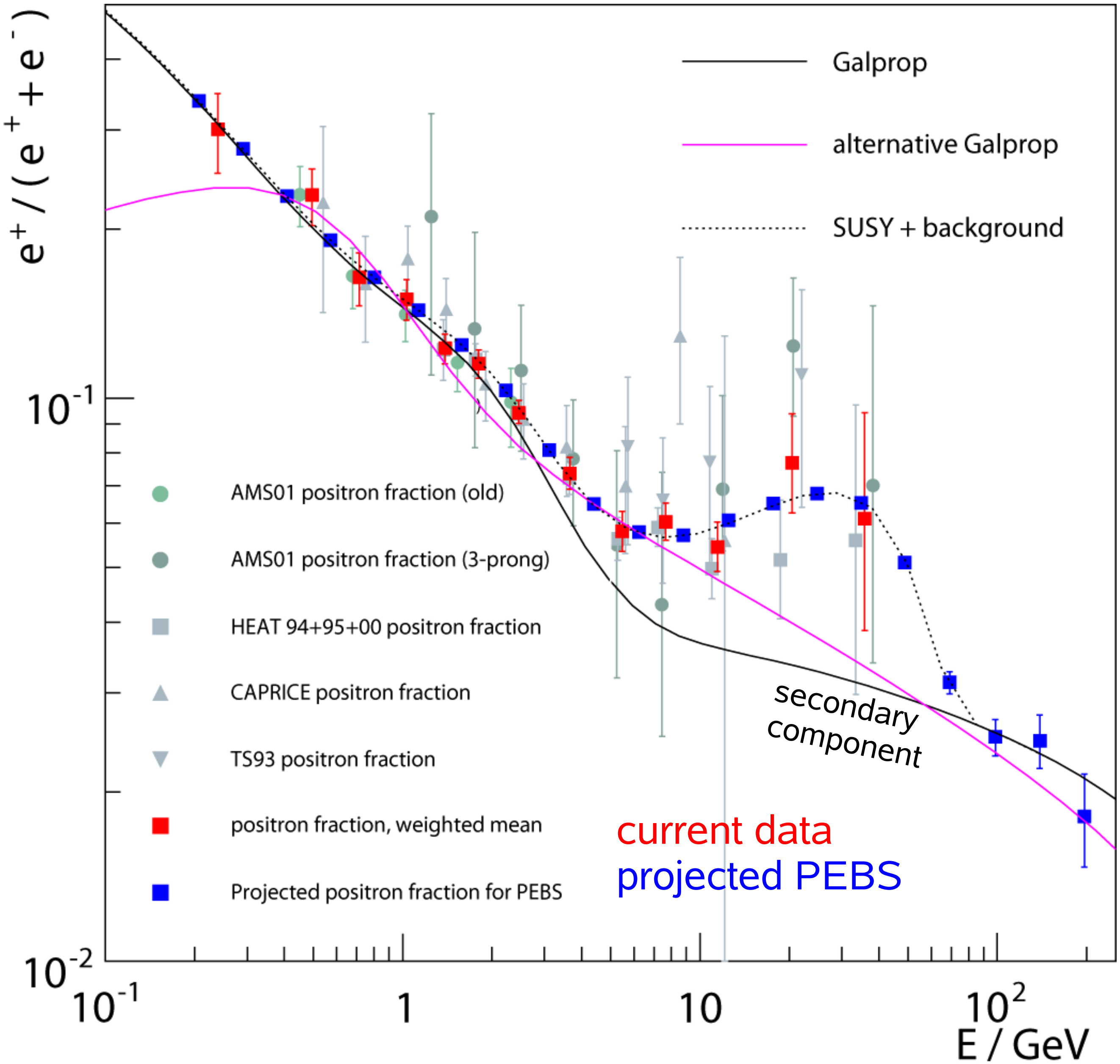
tan β = 50

Region allowed by relic density constraint (CMB+large scale structure) depends strongly on tan β and m_{top}.

Tevatron: m_{top}=170.9 ± 1.86 GeV

PDG: $\Omega_{nbm}h^2 = 0.106 \pm 0.008$

Positron fraction and boost factors

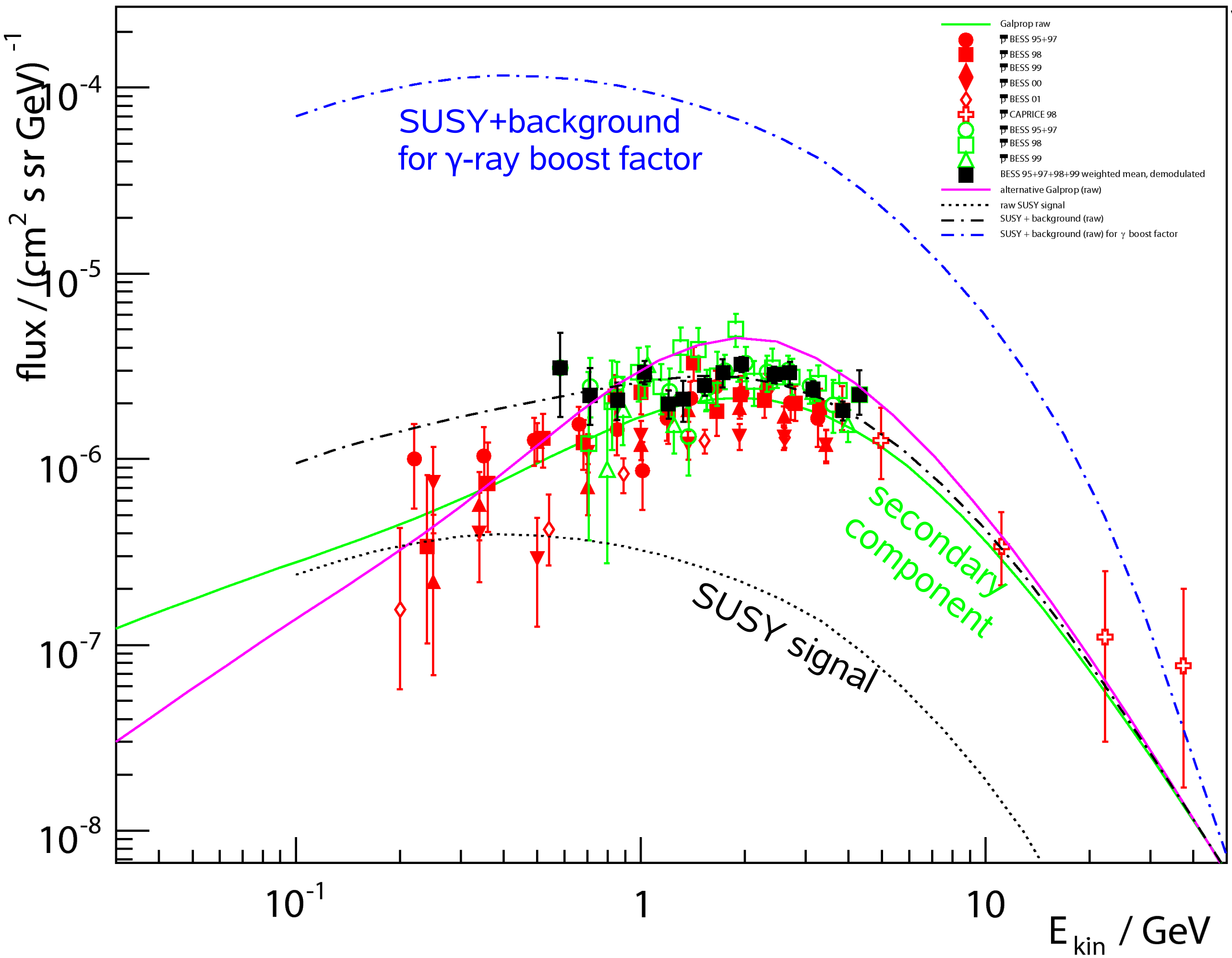


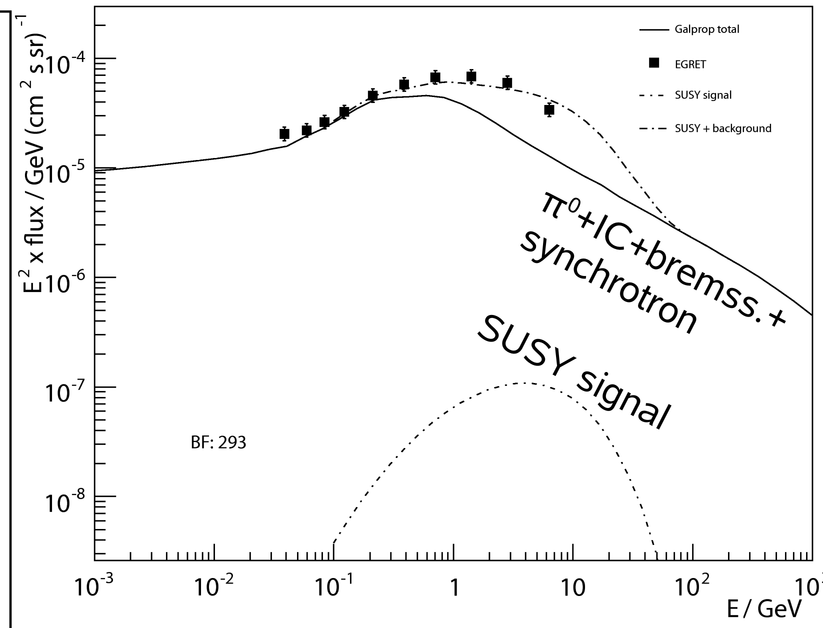
comparison of current data to projected PEBS data for

m_0=1300 GeV,
$m_{1/2}$=270 GeV,
tan β = 40,
m_{top} = 170.9 GeV

χ^2 minimization of SUSY+background curve with respect to data:
1 free parameter: “boost factor” of SUSY signal
→ clumpiness of dark matter halo

Antiprotons and diffuse gamma-rays

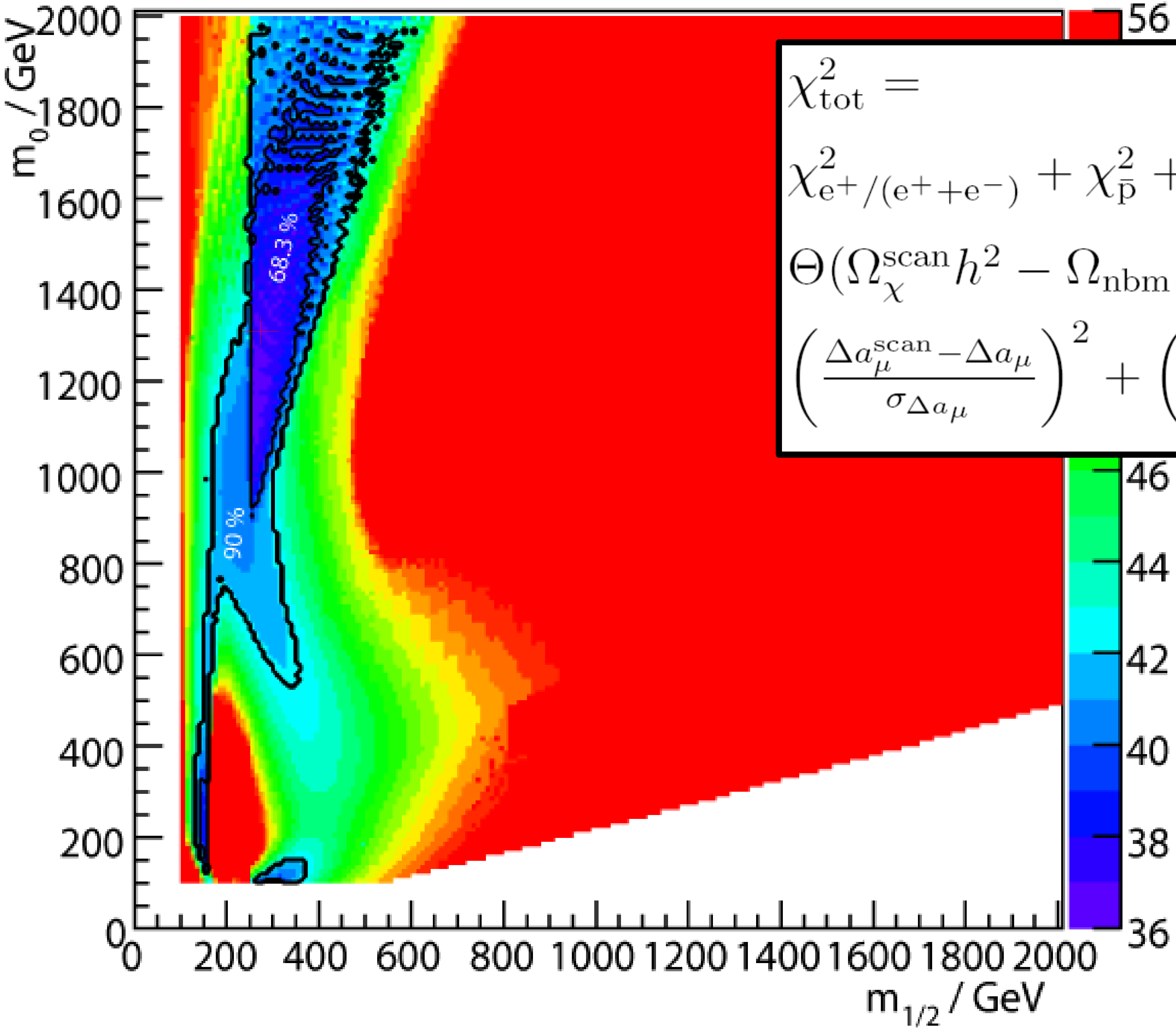




DM explanation of EGRET data from inner Galaxy: large boost factor required → overproduction of antiprotons

no need for signal component apparent in antiprotons

Preferred region from current knowledge



$$\chi^2_{\rm tot} =$$

$$\chi^2_{\rm e^+/(e^+ + e^-)} + \chi^2_{\rm \bar{p}} + \chi^2_{\gamma} + \left(\frac{m_t^{\rm scan} - m_t}{\sigma_{m_t}}\right)^2 +$$

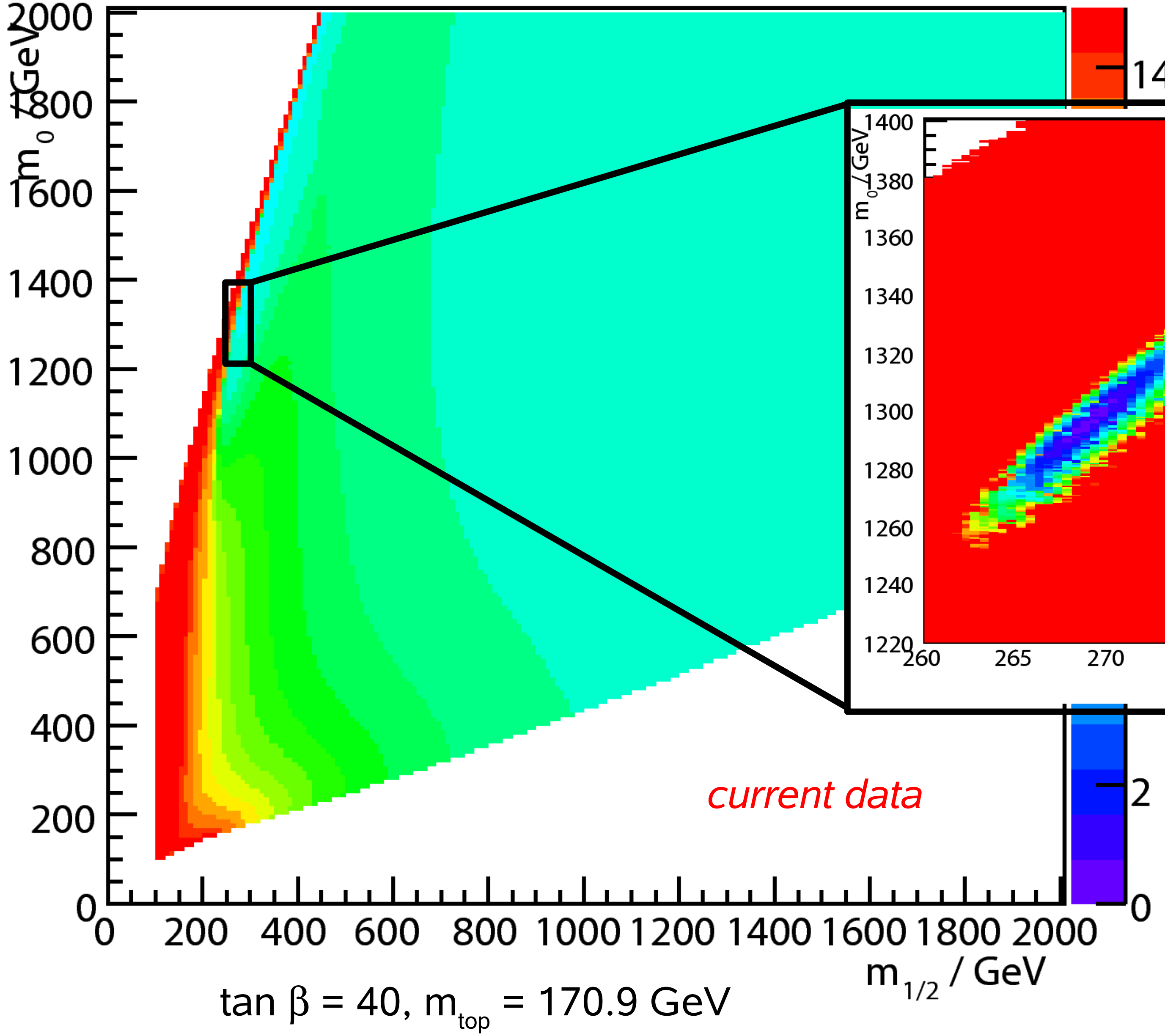
$$\Theta(\Omega_\chi^{\rm scan} h^2 - \Omega_{\rm nbm} h^2) \cdot \left(\frac{\Omega_\chi^{\rm scan} h^2 - \Omega_{\rm nbm} h^2}{\sigma_{\Omega_{\rm nbm} h^2}}\right)^2 +$$

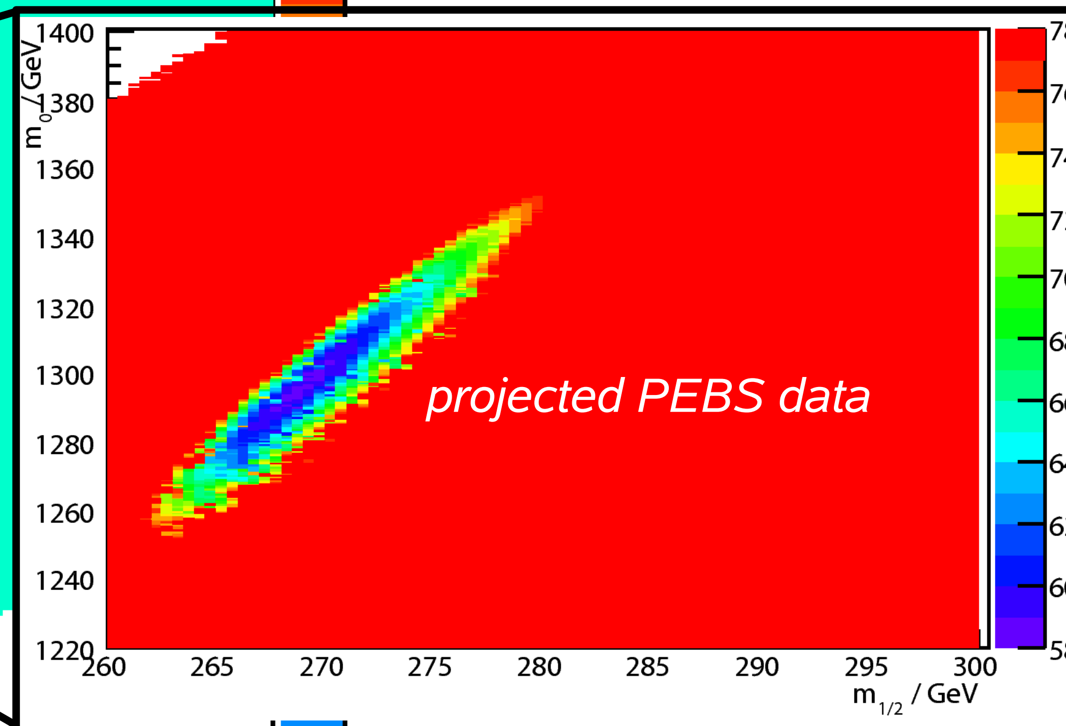
$$\left(\frac{\Delta a_\mu^{\rm scan} - \Delta a_\mu}{\sigma_{\Delta a_\mu}}\right)^2 + \left(\frac{BR^{\rm scan}_{b\to s\gamma} - BR_{b\to s\gamma}}{\sigma_{BR(b\to s\gamma)}}\right)^2$$

Ingredients:
- CR positron fraction
- CR antiprotons
- CR gamma-rays
- top quark mass
- relic density of dark matter
- anomalous magnetic moment of the muon
- $b \to s\gamma$ branching ratio

using 3 different boost factors

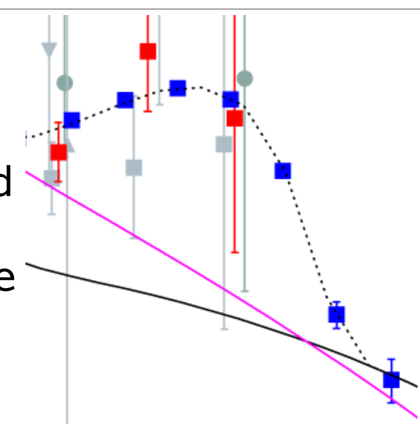
Positron fraction χ^2



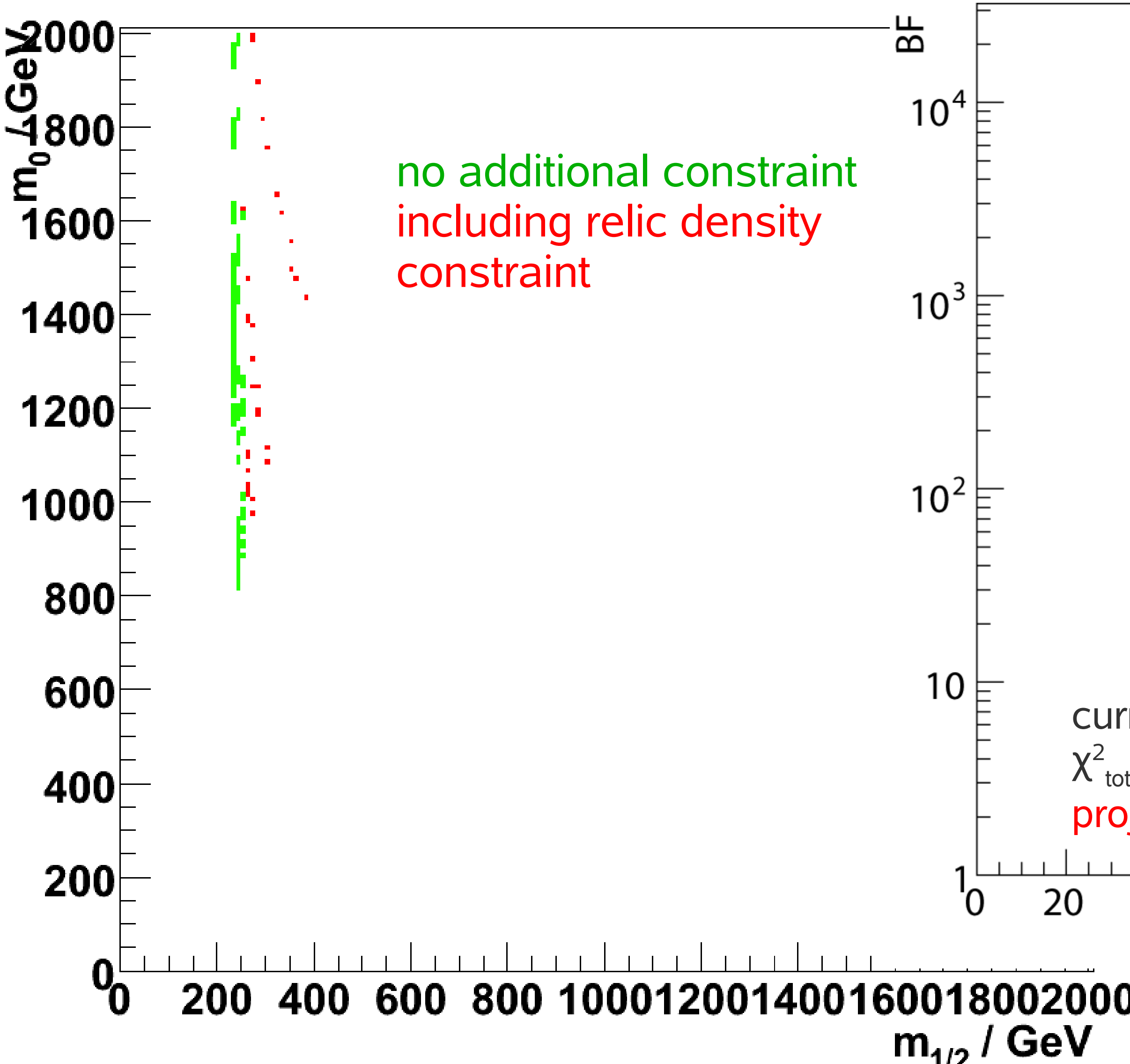


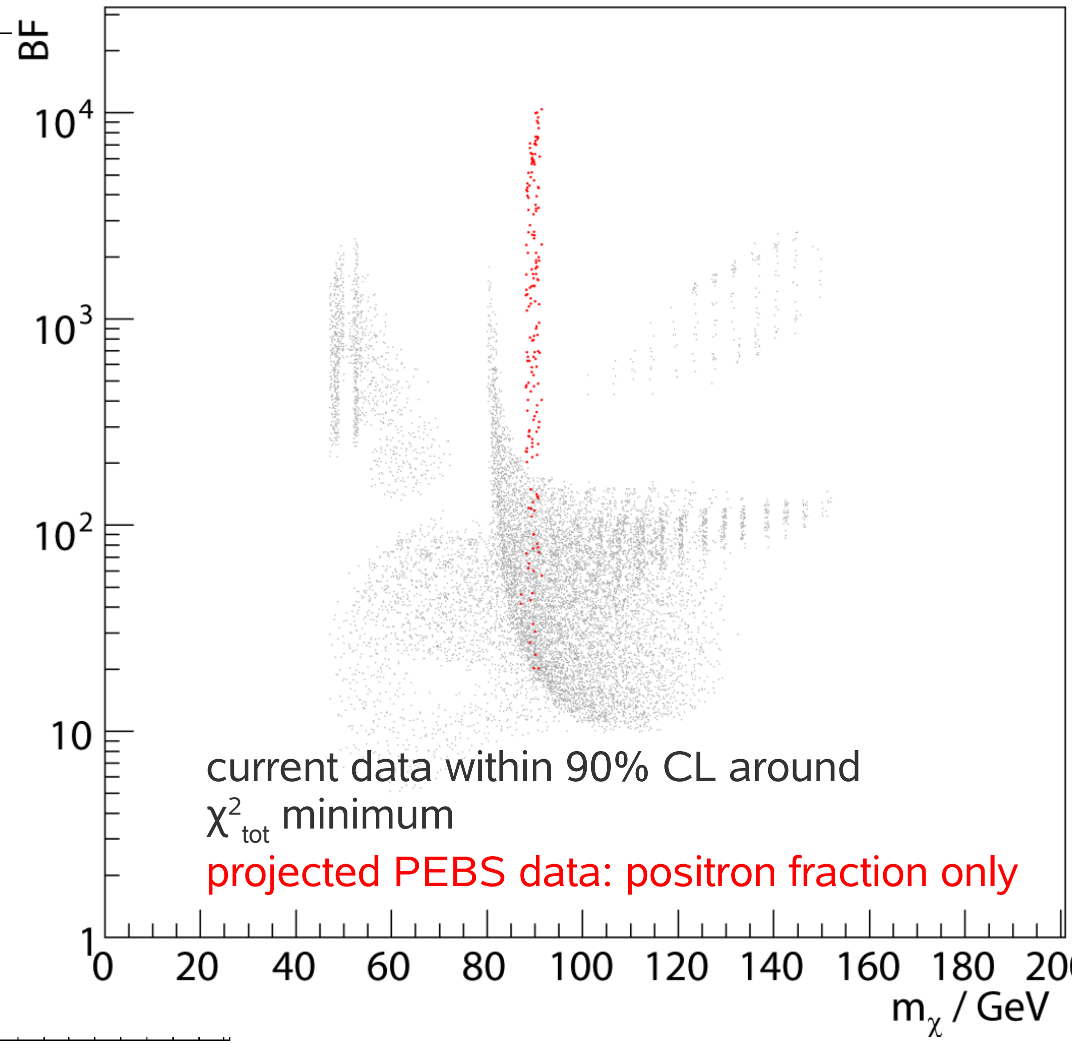
PEBS:

- vastly improved statistics and
- extended energy range



Projected constraints on mSUGRA parameter space



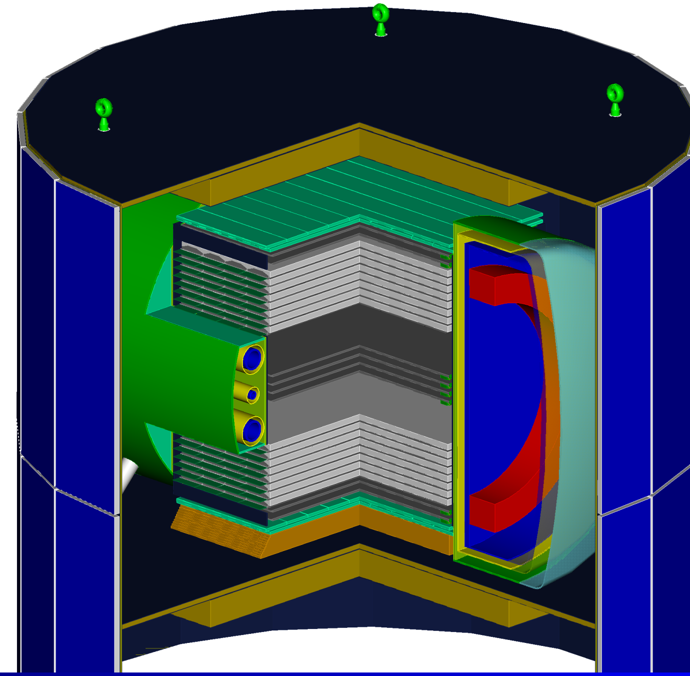


PEBS projected positron fraction data only: points (from entire scan) within 90% CL interval around χ^2 minimum.

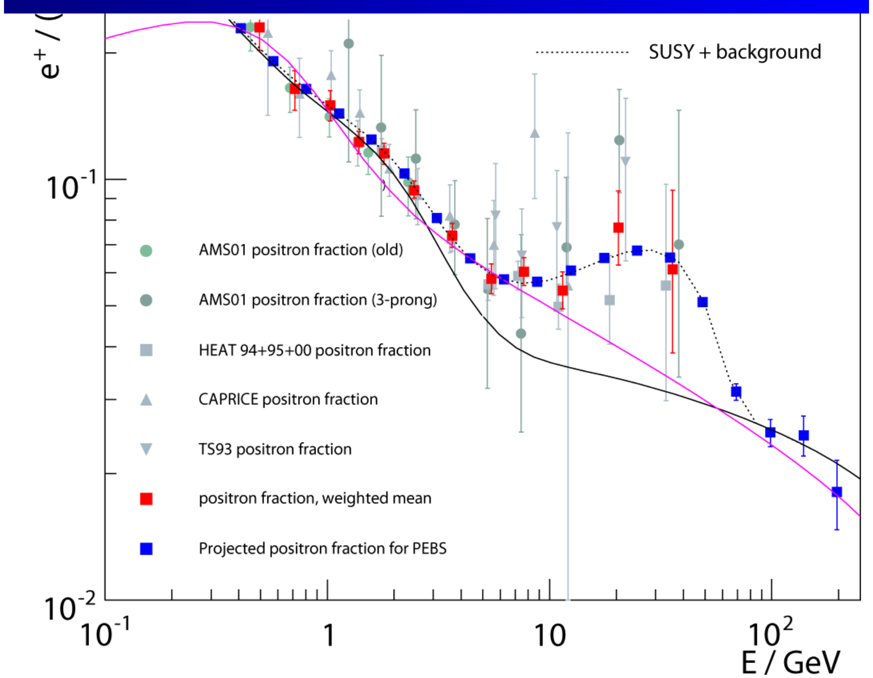
corresponding resolution in neutralino mass

Conclusion

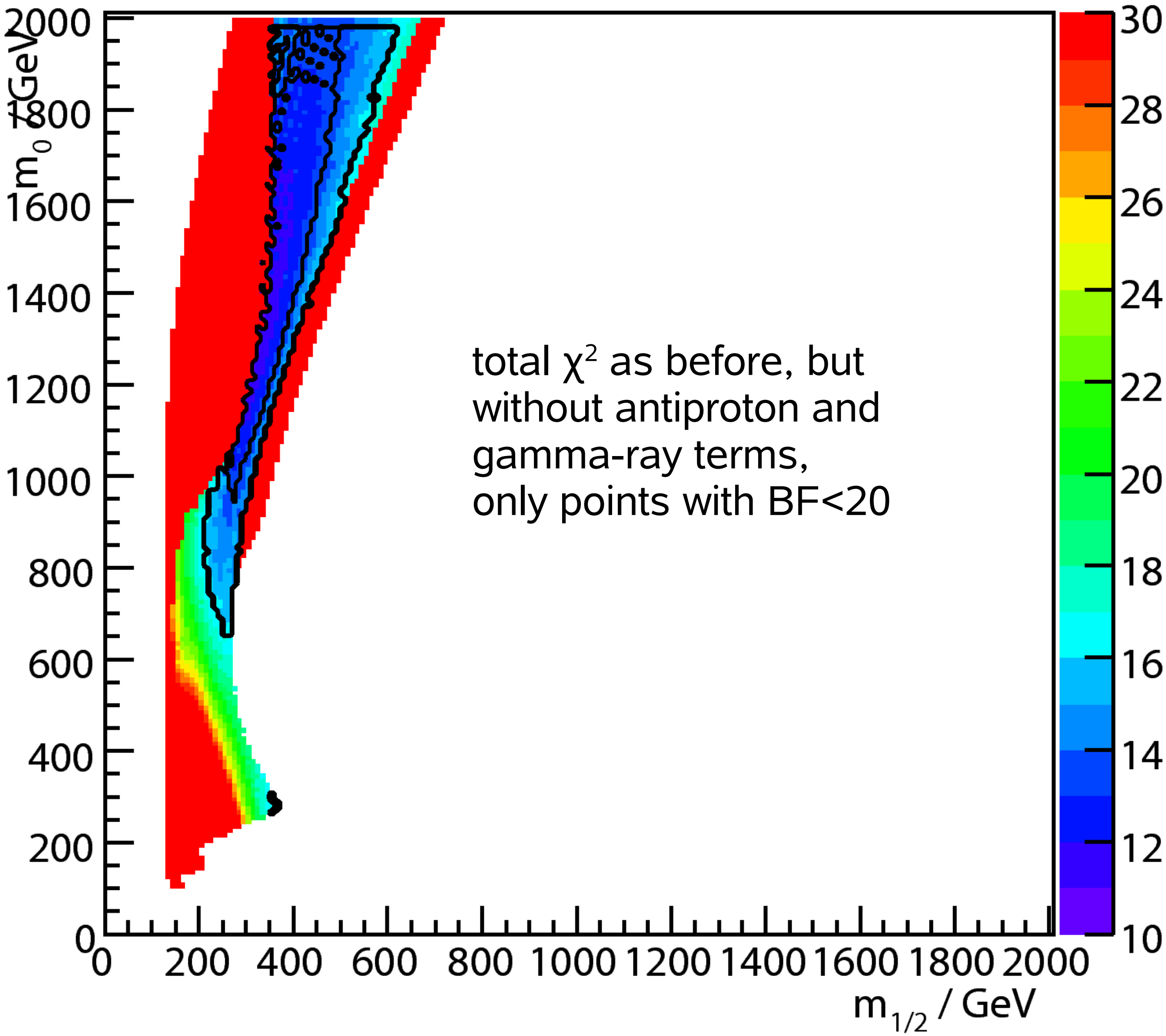
- Design study to build a balloon-borne spectrometer to measure the cosmic-ray positron fraction, in the context of indirect search for dark matter
- Extensive scan of mSUGRA parameter space: present data show preference for $m_{1/2}$<~600 GeV
- Corresponding neutralino masses are favourable for upcoming positron experiments
- PEBS data will greatly enhance our knowledge about dark matter, as well as about cosmic-ray propagation



Anomaly in the positron spectrum? PEBS can answer the question!



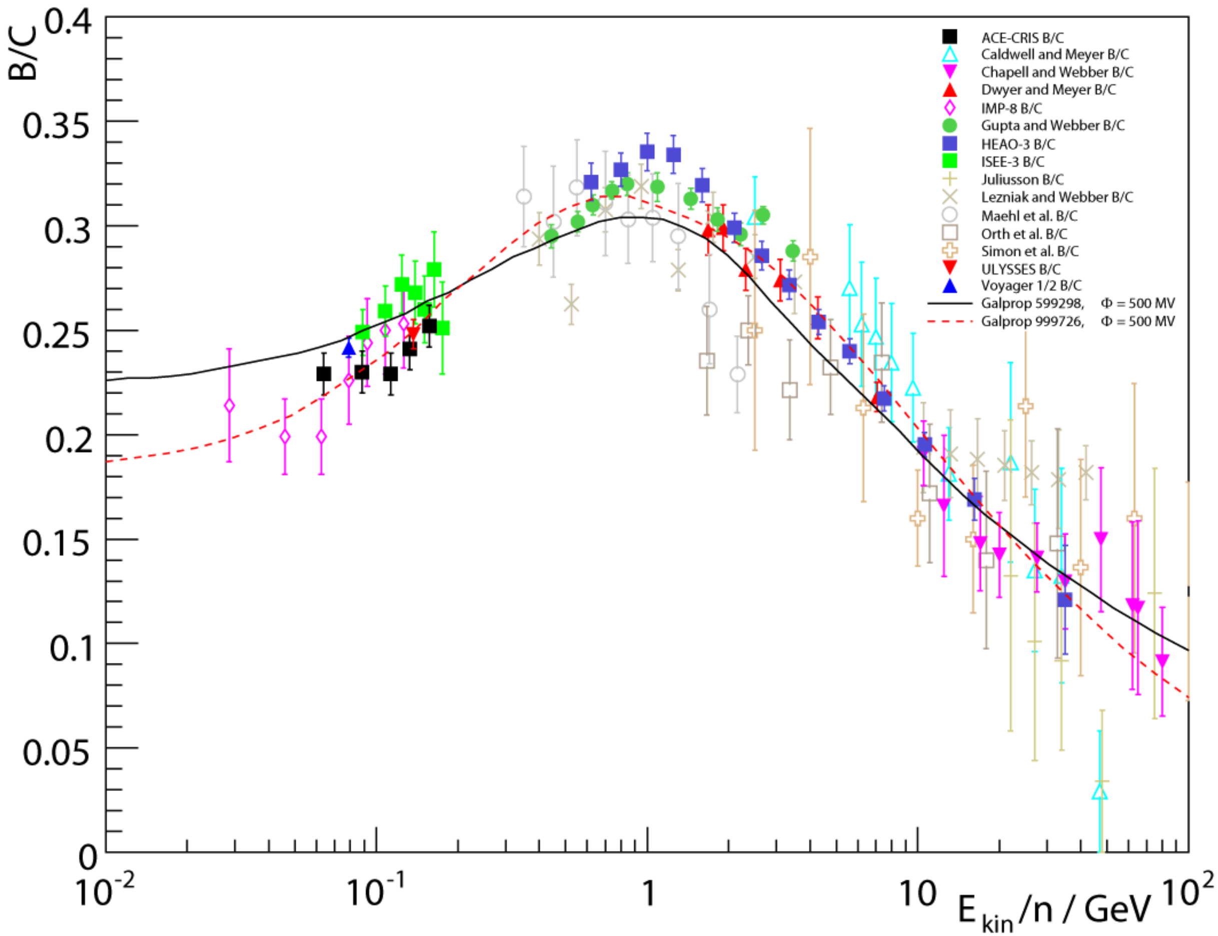
Impact of ΛCDM N-body simulations



Recent results for structure and distribution of dark matter clumps:
boost factors close to unity

In the preferred region:
Subdominant neutralino dark matter with
$\Omega_\chi h^2 \sim 0.015$ and
$m_\chi \sim 100$ GeV

B/C-ratio



B/C ratio: important test for propagation models, good description by both Galprop models (conventional vs plain diffusion)