« The low number of supernova remnant PeVatrons in the Galaxy »

10^{15} eV

ICRC 2021

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SWGO The Southern Wide-field Gamma-ray Observatory

cta cherenkov telescope array

« The low number of supernova remnant PeVatrons in the Galaxy »

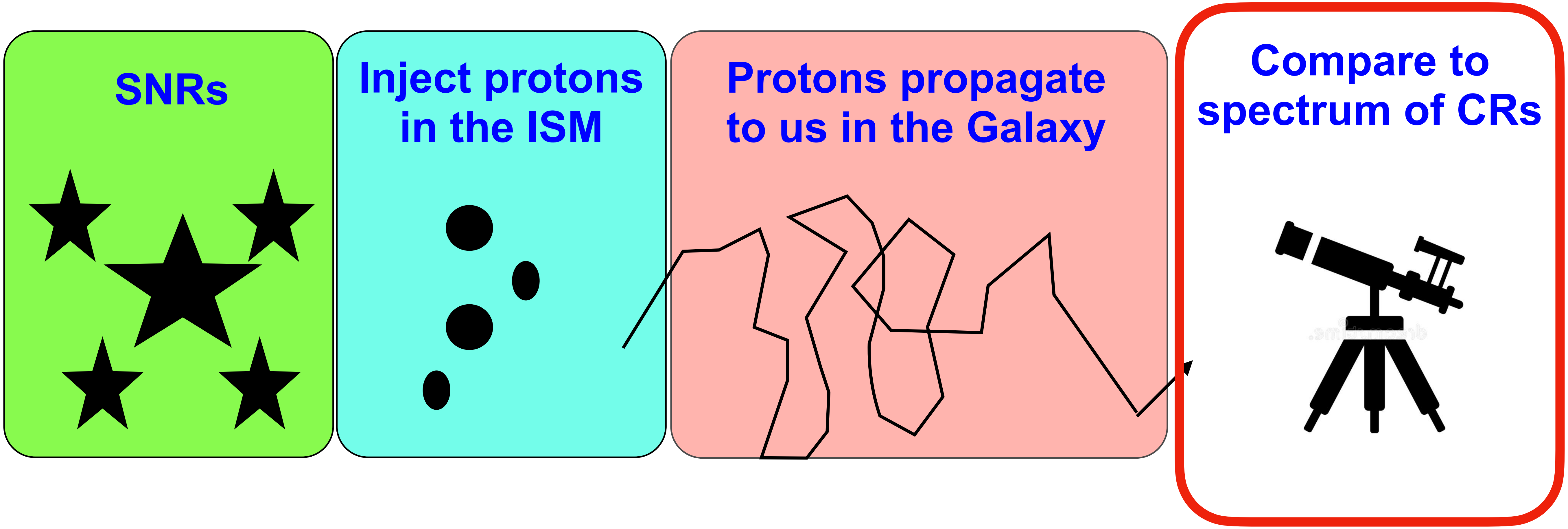
10^{15} eV

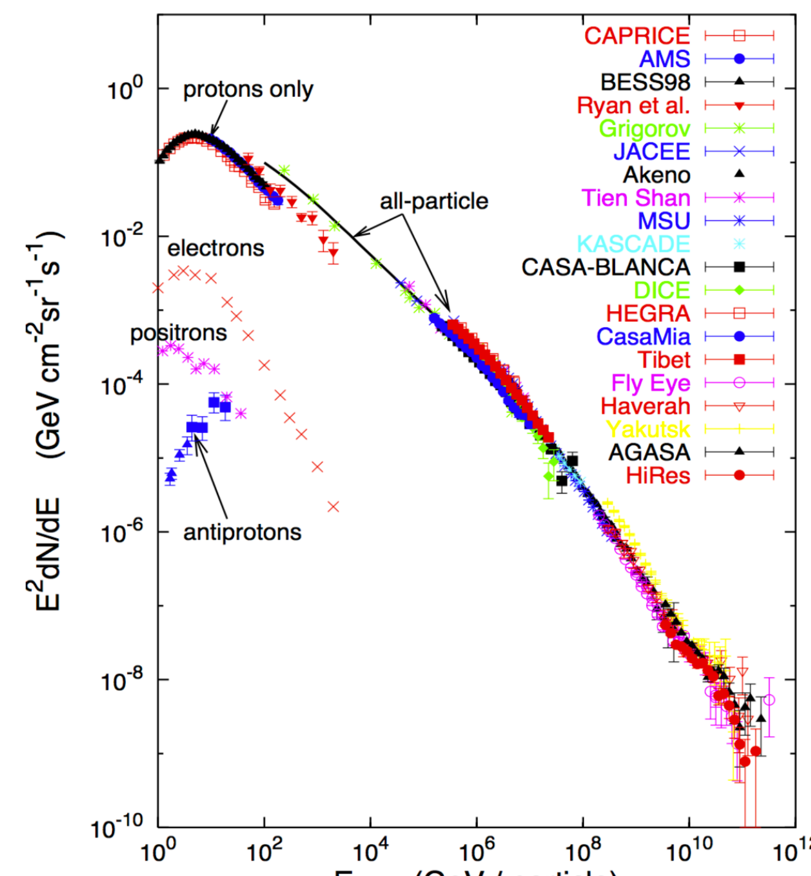
Cristofari, Blasi, Amato, Astro. Phy. , Dec. 2020
« The Low Rate of Galactic PeVatrons »

« Ultrahigh-energy photons up to 1.4 PeV from 12 gamma-ray Galactic sources »

Cao et al. (Nature 2021)

« The low number of supernova remnant PeVatrons in the Galaxy »





Why supernova remnants?

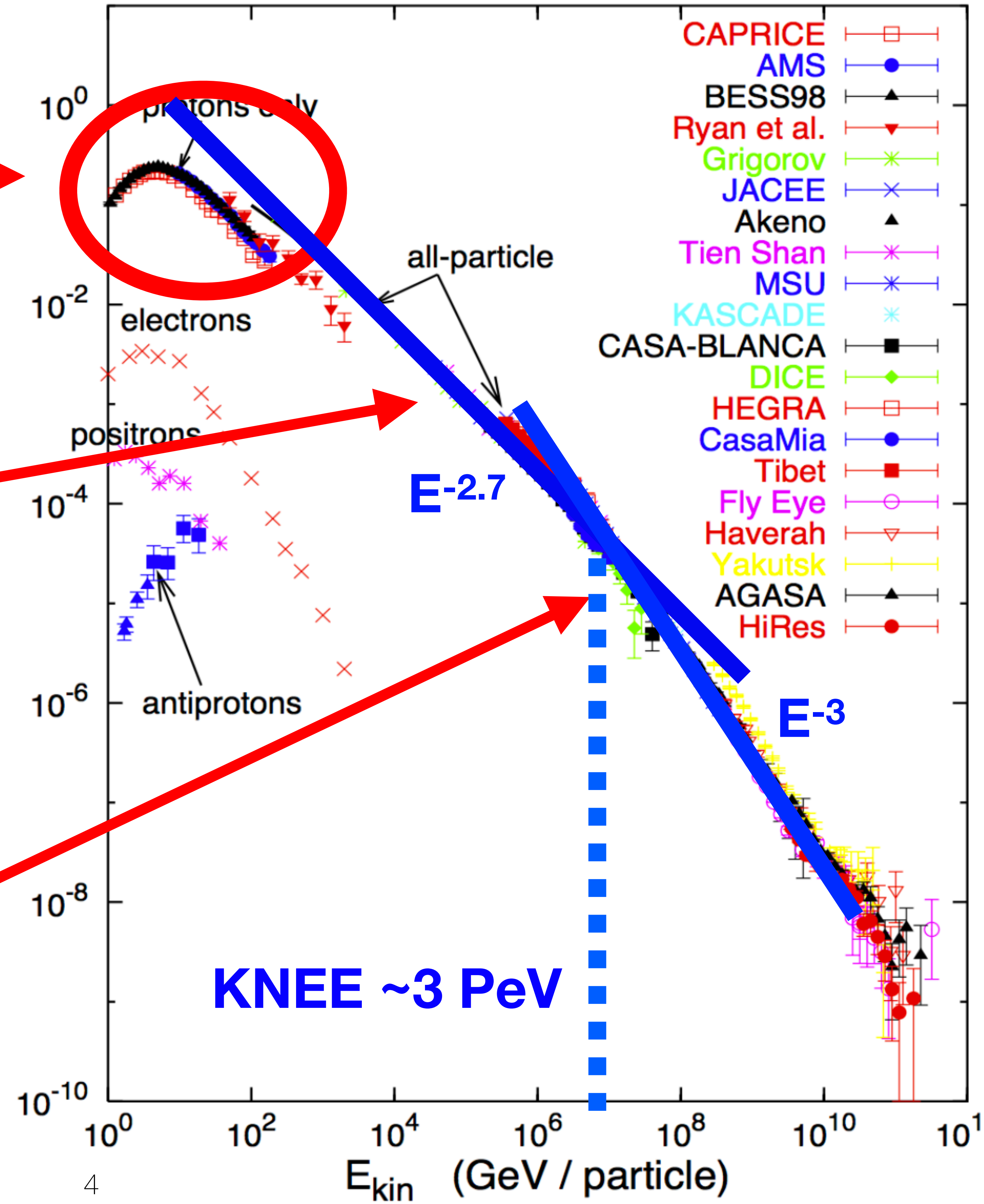
1. Bulk of CRs
Energy density ~1 eV/cm3
10% of SNR total explosion energy

2. Slope $E^{-2.7}$
Diffusive shock acceleration

$$E^{-(2.4..2.1)} \times E^{-(0.3..0.6)} = E^{-2.7}$$

Injection **Propagation**

3. Magnetic field amplification - pevatrons!



Non-resonant streaming of CRs

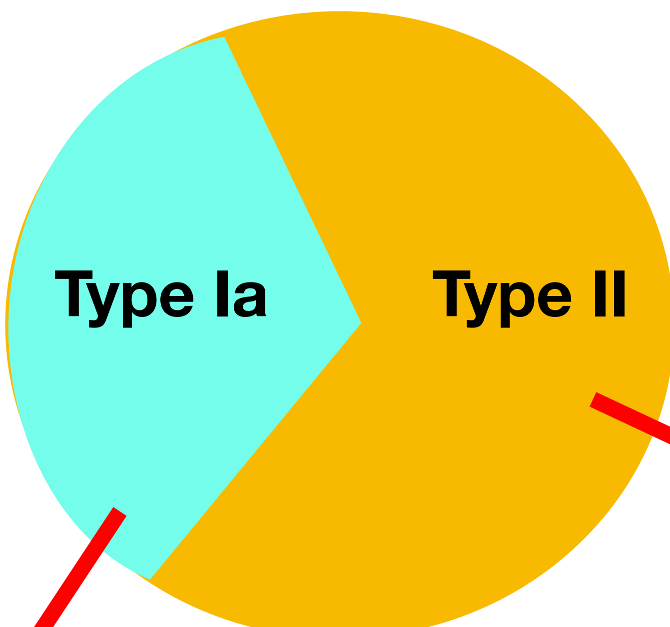
$$\int_0^t dt' \gamma_{\max}(t') \simeq 5$$

Growth rate of the non-resonant streaming instability

$$p_{\max}(t) \approx \frac{r_{\rm sh}(t)}{10} \frac{\xi e \sqrt{4\pi\rho(t)}}{\Lambda} \left(\frac{u_{\rm sh}(t)}{c}\right)^2$$

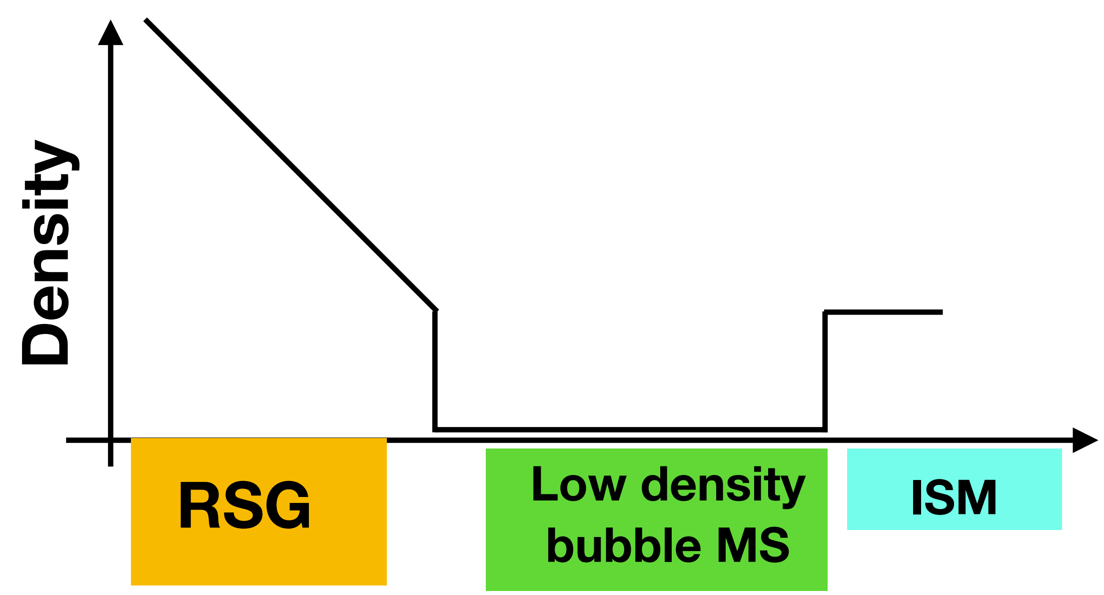
Bell et al. (2013), Schure et al. (2014)

Different for different SNRs/SNe



ISM

$$n_0$$



$$\dot{M}_{\rm RSG}, u_{\rm RSG}, E_{\rm SN}$$

$$\dot{M}_{\rm MS}, u_{\rm MS}, n_0, M_{\rm ej},$$

Non-resonant streaming of CRs

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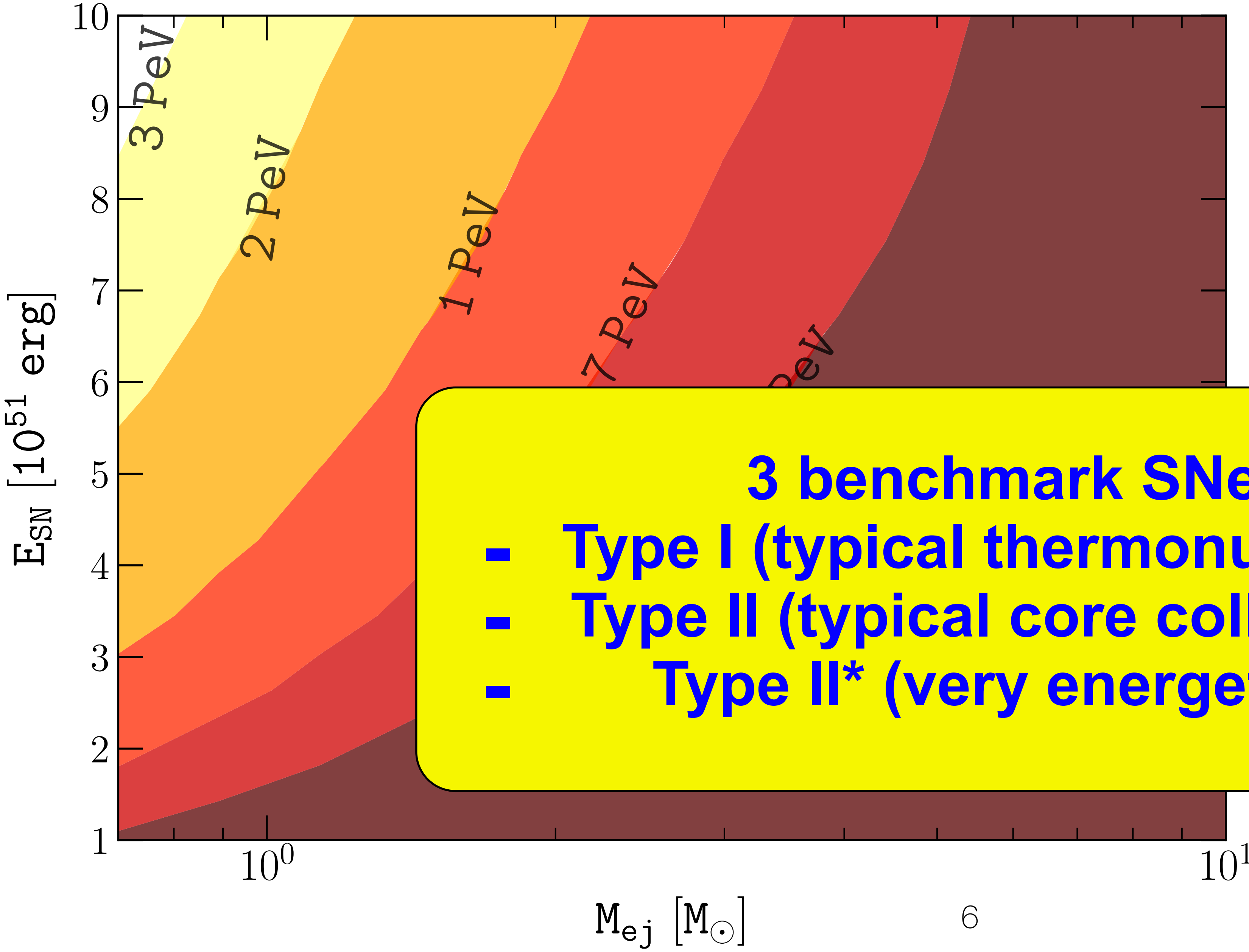


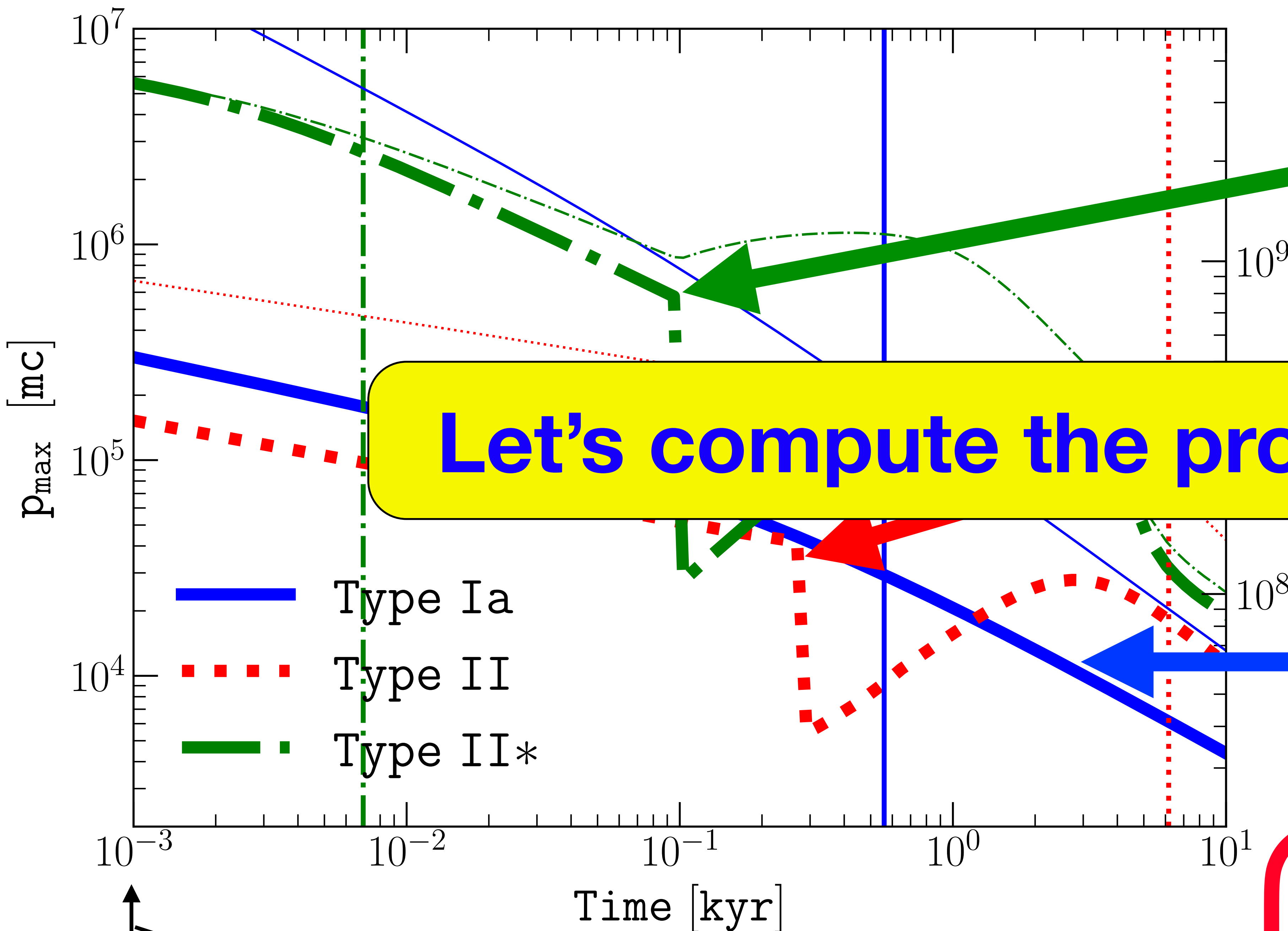
$$\dot{M}_{\rm RSG} = 10^{-4} M_\odot/{\rm yr}$$

$$\zeta = 0.1$$

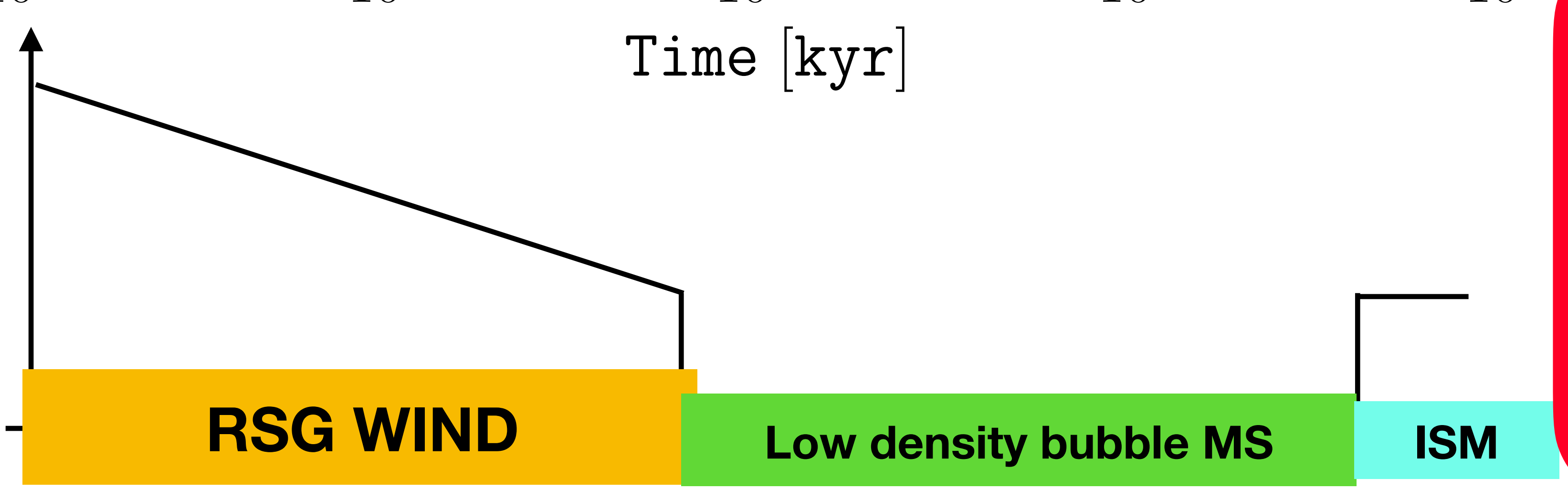
3 benchmark SNe:

- **Type I (typical thermonuclear SN)**
- **Type II (typical core collapse SN)**
- **Type II* (very energetic SN)**

Type Ia, type II, type II*

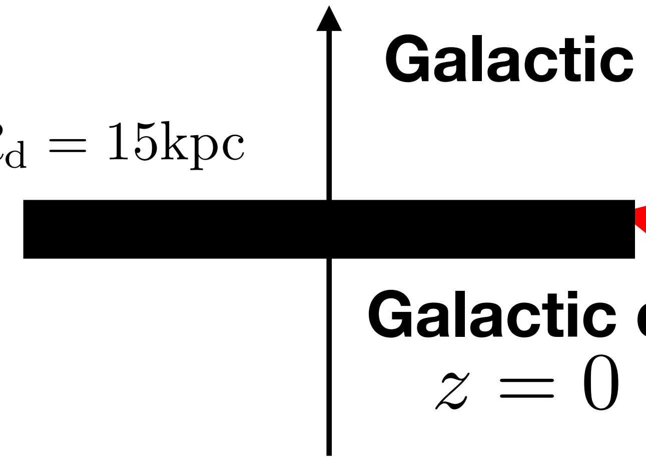


Let's compute the protons!



Type	Ia	II	II*
M_{ej} [$M_\odot$]	1.4	5	1
E_{SN} [10^{51} erg]	1	1	10
$\dot{M}$ [10^{-5} $M_\odot$/yr]	–	1	10
u_w [10^6 cm/s]	–	1	1
r_1 [pc]	–	1.5	1.3

Protons after propagation in the Galaxy



Galactic Halo $H = 4\ \mathrm{kpc}$

$R_{\rm d} = 15\mathrm{kpc}$

SNRs injecting particles

Galactic disk
$z = 0$

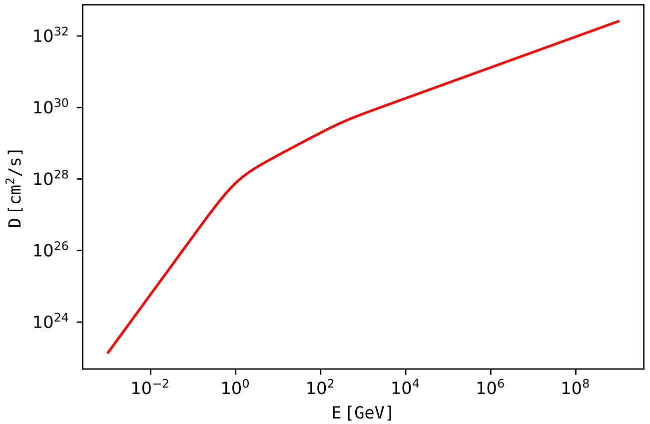
1D Galactic transport

$$-\frac{\partial}{\partial z}\left[D(p)\frac{\partial f}{\partial z}\right] + u\frac{\partial f}{\partial z} - \frac{du}{dz}\frac{p}{3}\frac{\partial f}{\partial p} + \frac{1}{p^2}\frac{\partial}{\partial p}\left[p^2\left(\frac{dp}{dt}\right)_{\rm ion} f\right] = q(p,z)$$

Diffusion **Advection** **Ionisation losses** **Injection from SNRs**

$$D(p) = D_0 \frac{v(p)}{c}\frac{(p/mc)^{\delta}}{\left[1+(p/p_{\rm b})^{\Delta\delta/r}\right]^r}$$

In agreement with AMS-02 measurements
Evoli (2019)



Trapped

$$q_{\rm acc}(p)dp = \frac{\nu_{\rm SN}}{\pi R_{\rm d}^2}\int_{t_0}^{T_{\rm SN}} dt \frac{4\pi}{\sigma} r_{\rm sh}^2(t) u_{\rm sh}(t) f_0(p',t)dp'$$

Escaping

$$q_{\rm esc}(p) = \frac{\nu_{\rm SN}}{\pi R_{\rm d}^2}\int_{t_0}^{T_{\rm SN}} dt \frac{4\pi}{\sigma} r_{\rm sh}^2(t) u_{\rm sh}(t) f_0(p,t)\delta(p, p_{\rm max}(t))$$

Protons from supernova remnants

List of parameters:

$\dot{M}_{\rm wind}, u_{\rm wind}, E_{\rm SN}, M_{\rm ej}$

$\xi_{\rm CR}, \nu_{\rm SN}$

Injection from SNRs

Galactic dimensions

Diffusion coef

$H, R_{\rm d}, h, D$ n_0

Transport

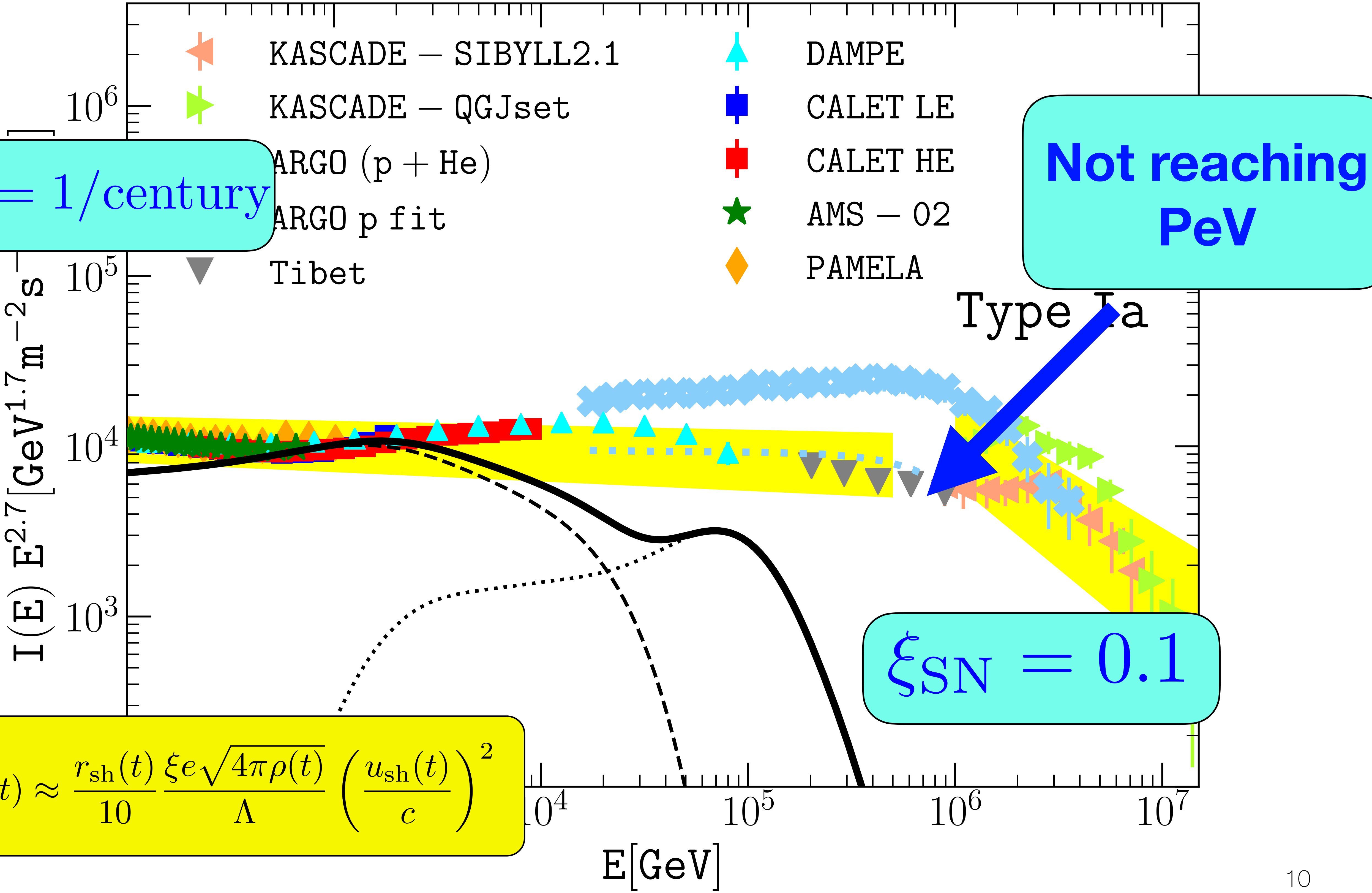
Rate of SNe

Efficiency of particle acceleration

$$E_{\rm max} \propto \xi_{\rm CR}$$

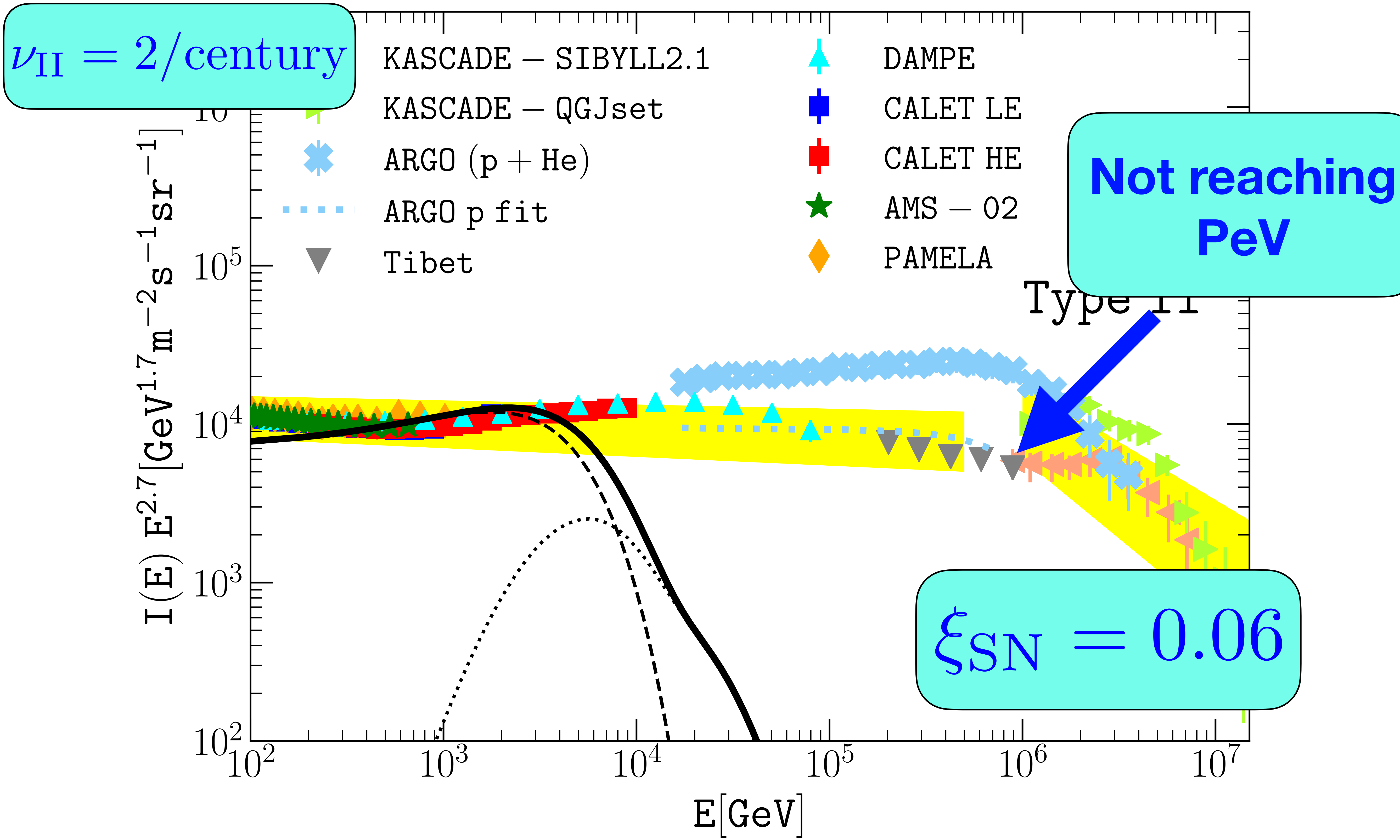
$$\rm Norm \propto \xi_{\rm CR} \times \nu_{\rm SN}$$

Protons from type Ia

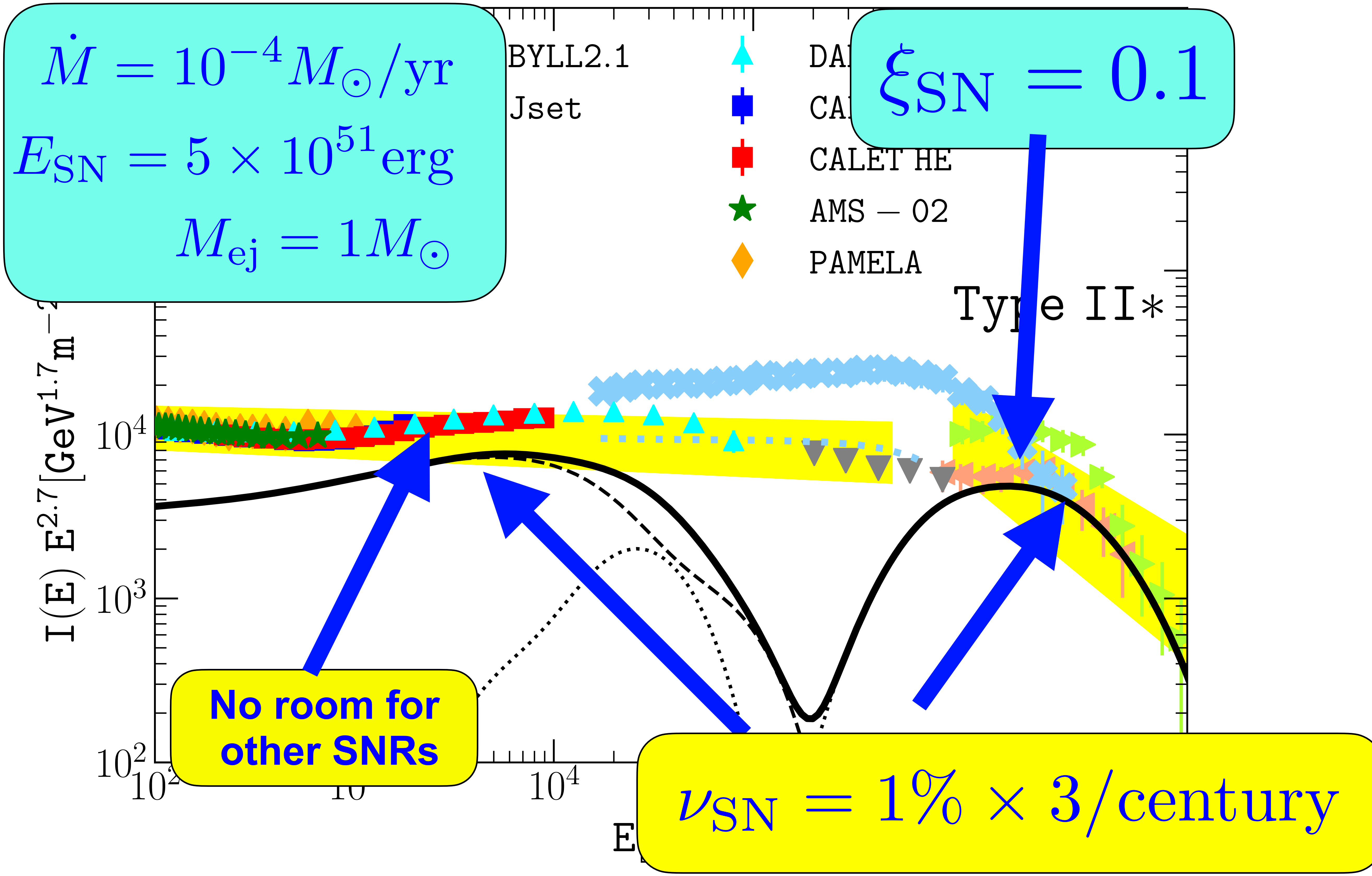


$$p_{\max}(t) \approx \frac{r_{\rm sh}(t)}{10}\frac{\xi e\sqrt{4\pi\rho(t)}}{\Lambda}\left(\frac{u_{\rm sh}(t)}{c}\right)^2$$

Protons from type II

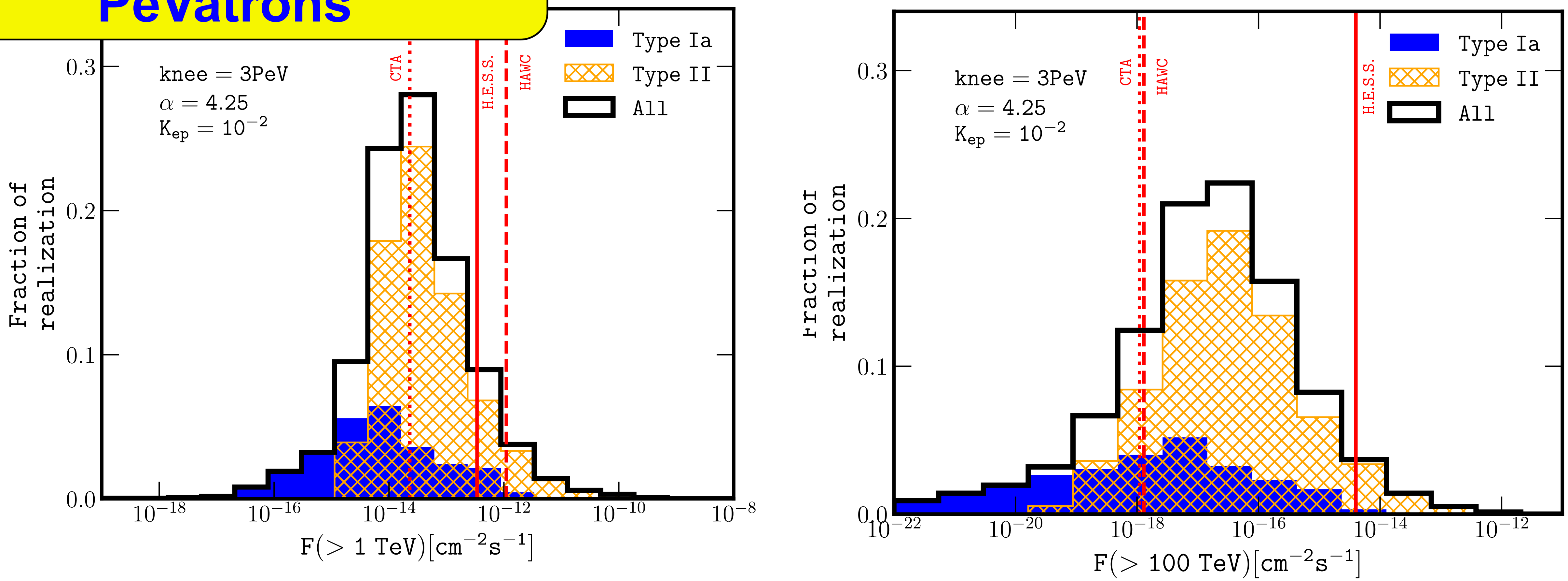


Protons from type II*



Pevatrons with CTA

Assuming all SNRs are PeVatrons



If only Type II* are Pevatrons

$$\nu_{\mathrm{SN}} = 1\% \times 3/\mathrm{century}$$

$$\rightarrow 0$$

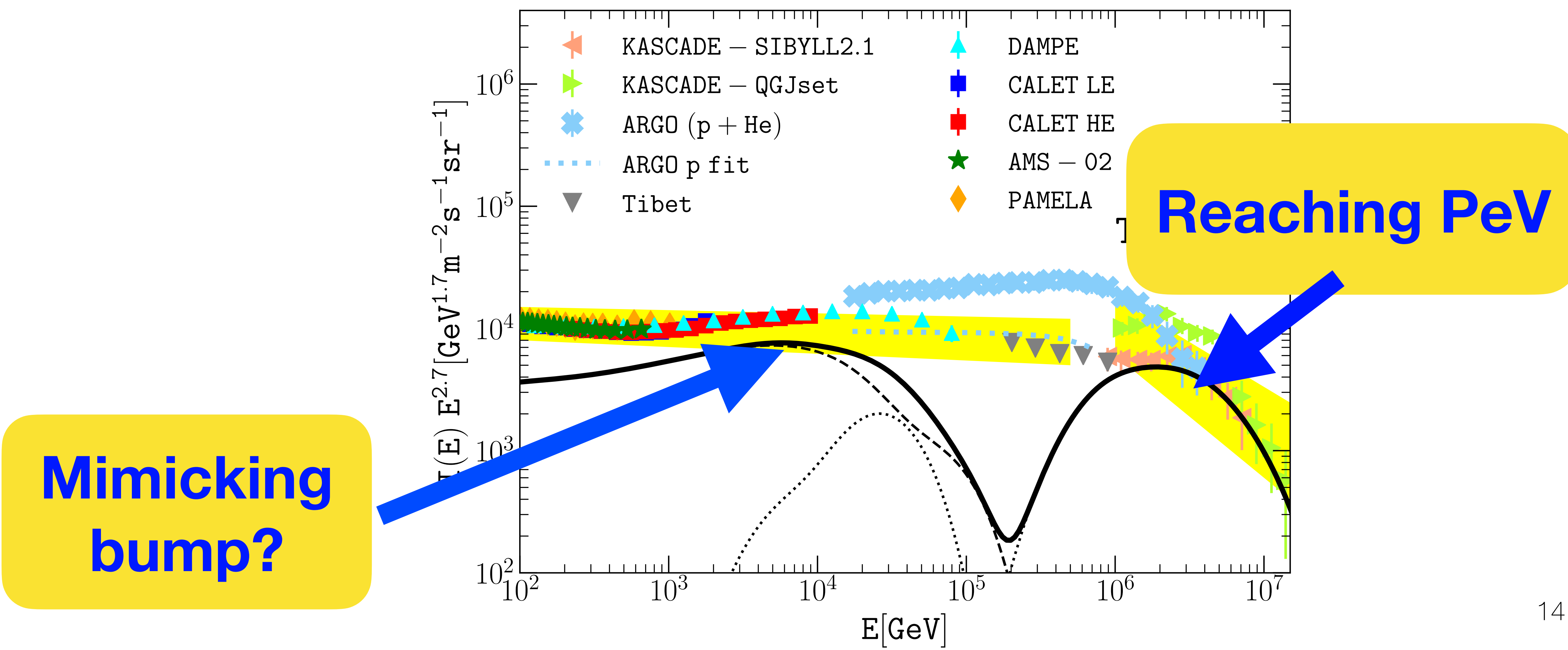
PC, Blasi, Amato (Astro. Part. Phy. 2020)

PC, Gabici, Terrier, Humensky (MNRAS, 2018)

MAYBE:

What does this mean?

1. SNRs are OK but we won't see any PeVatrons with CTA
2. Another instability (not Bell) comes into play
3. Strong temporal dependance on one/several parameters
4. SNRs are not dominant sources of CRs up to the knee (role of other objects/stellar clusters/ massive stars/?)



Conclusions : the hunt for pevatrons, closing the SNR case?

SNR PeVatrons with gamma-ray instruments (HAWC, H.E.S.S, CTA, LHAASO recent detection 12 pevatrons, SWGO)

Not detected

- That's OK
- What role for SNRs?
- Really PeV? Knee? Composition?
- DAMPE bump?

Detected

- What mechanism? (Bell?)
- xi_CR/ Mdot function of time?
- When? How many?
- Other Astrophysical objects?

Thank you!

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