

ORIGIN OF THE VHE γ -RAY EMISSION FROM THE CRAB PWN

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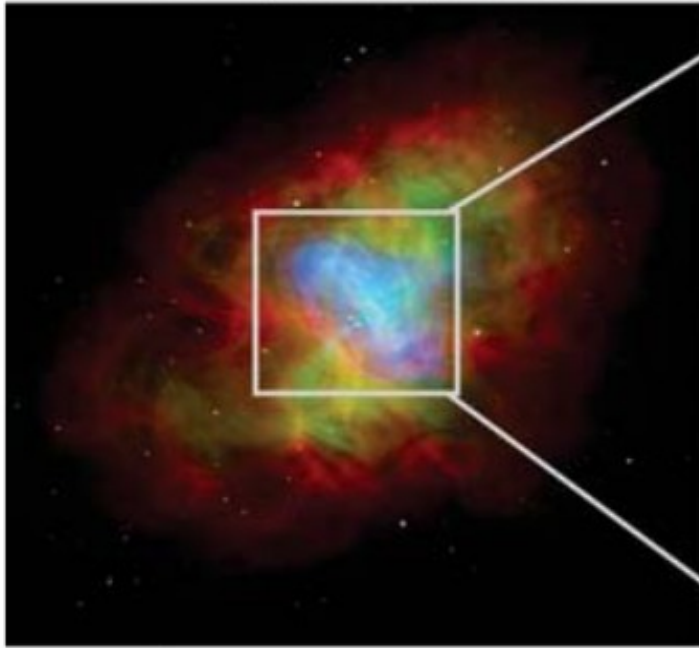
GG, Reville & Kirk, In Prep. (2021)

GG & Kirk, ApJ 863, 18 (2018) [arXiv:1804.05056]

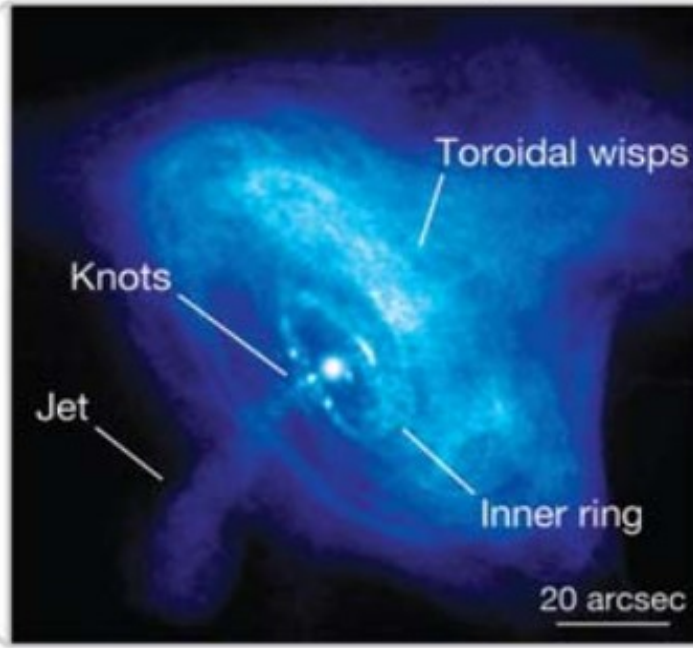
Cerutti & GG, A&A 642, A123 (2020) [arXiv:2008.07253]

Electron acceleration at the TS ?

Composite (CXC)



X-ray (CXC)



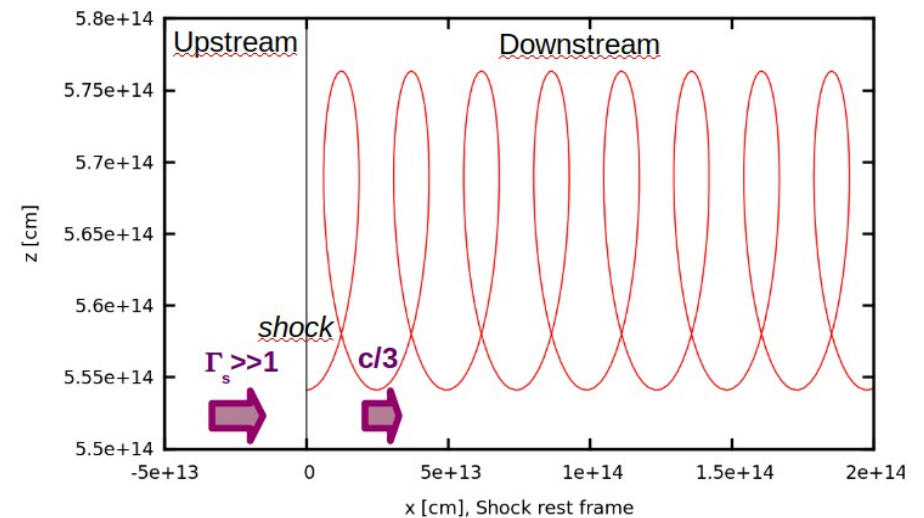
→ Electrons up to PeV.

→ Spectrum Nebula (X-rays):

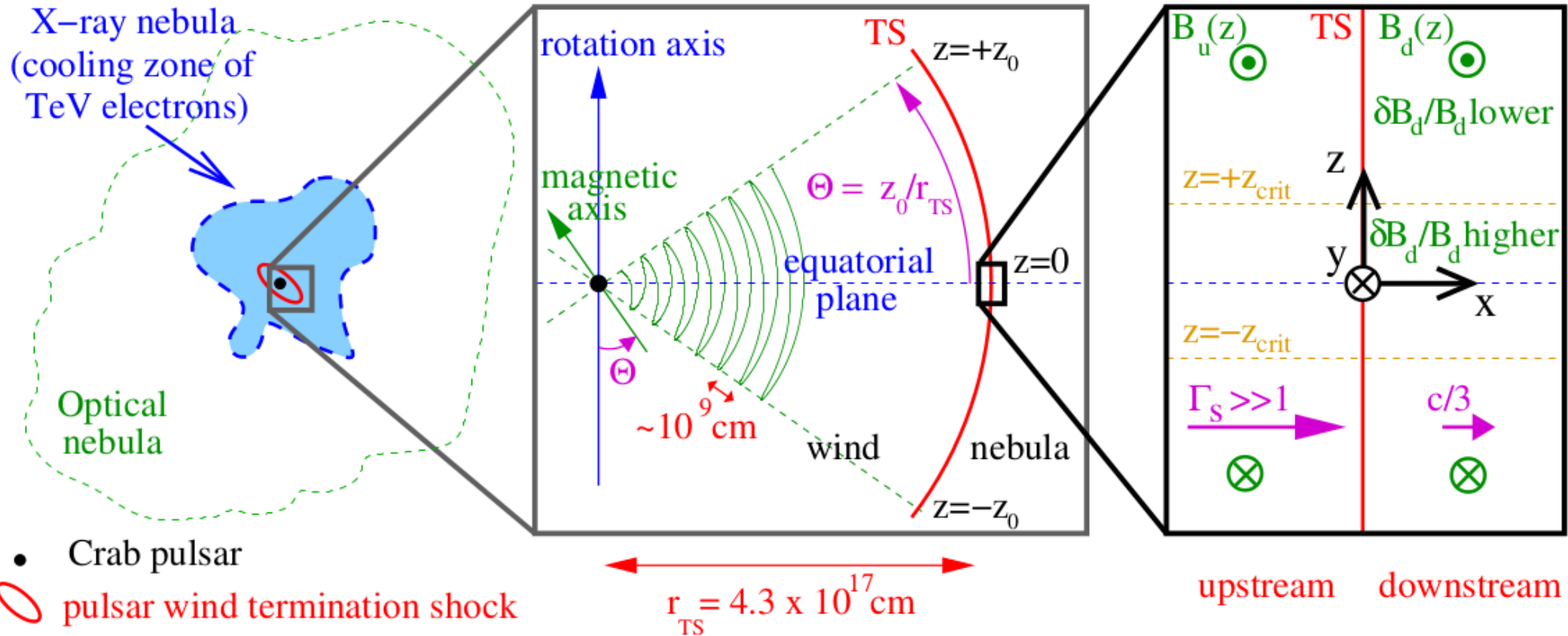
$$\nu F_{\nu} \propto \nu^{-0.1}$$

Part. spect.: $\sim E^{-2.2}$

**BUT perpendicular shock
=> 1st order Fermi
should NOT work !**



Model

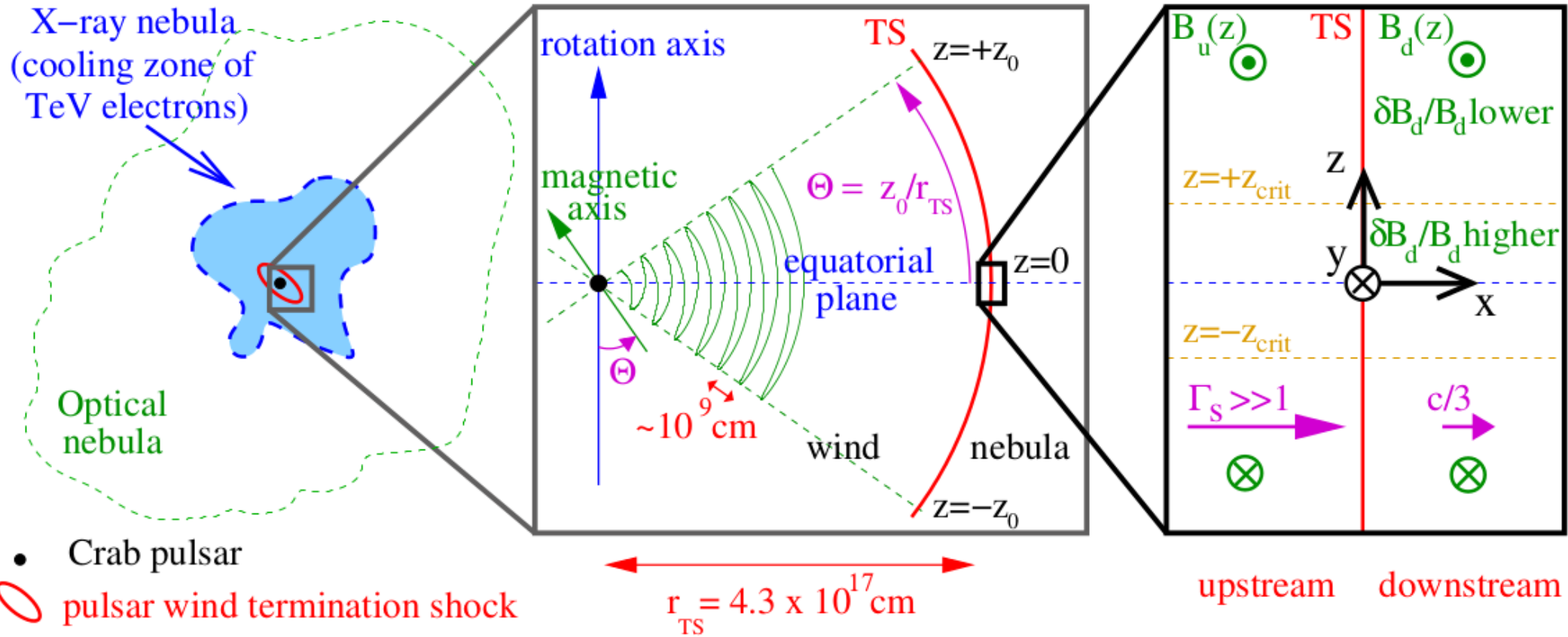


Fluid flow and B field model based on Crab MHD simulations from Porth *et al.* (2014, 2016)

$$\mathbf{B}_d(z) = -B_{d,0}(z/z_0)\hat{y} \quad \text{if } |z| \leq z_0$$

$$B_{d,0} = +1\text{mG}$$

Model

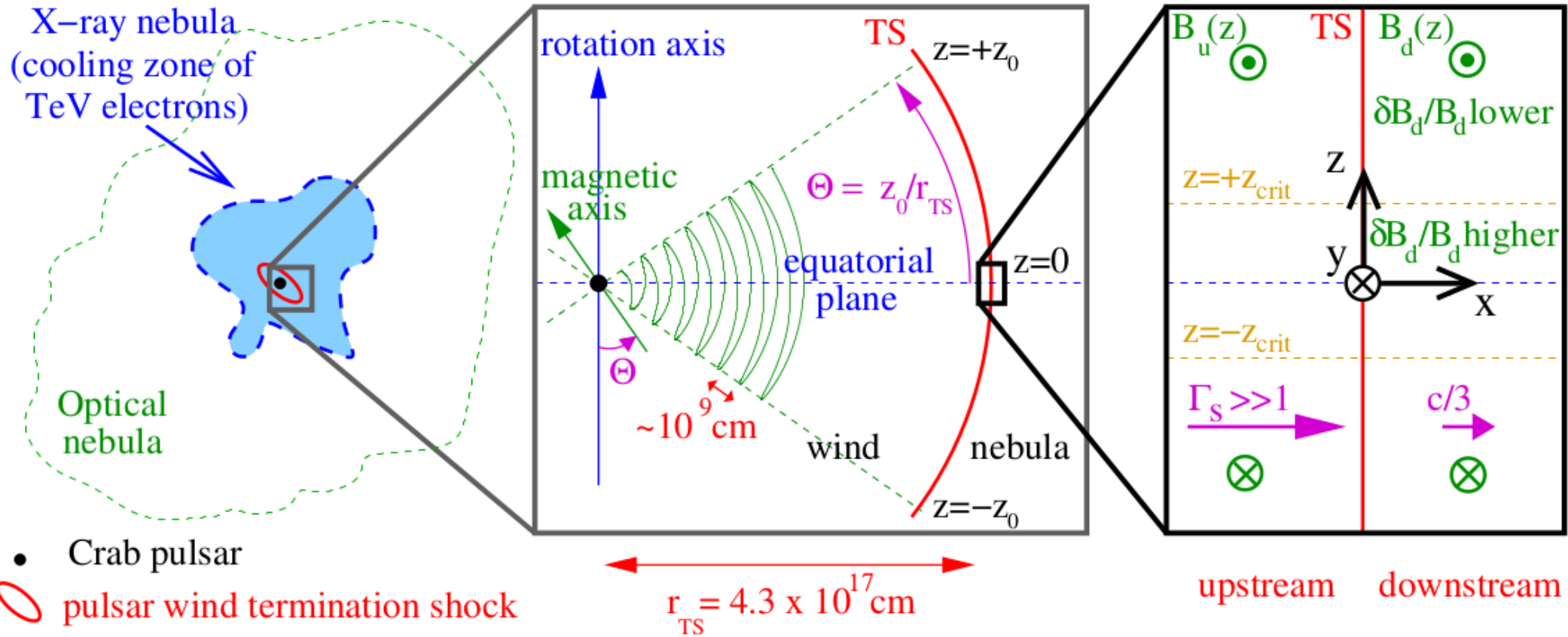


$$\mathbf{B}_u(z) = -B_{u,0}(z/z_0)\hat{y} \quad \text{if } |z| \leq z_0$$

Jump conditions: $B_{u,RF} = (\Gamma_d/3\Gamma_u)B_{d,RF}$

+ 3D turbulent magnetic field on nested grids.

Model



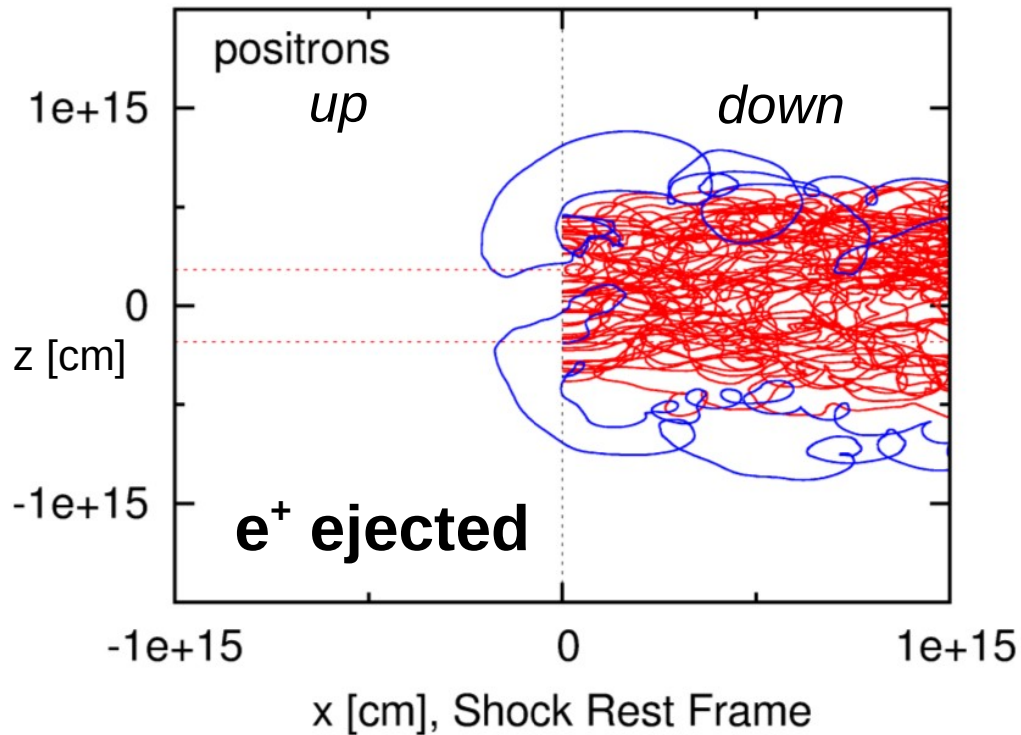
→ **INJECTION** : e.g. Giacchè & Kirk (2017):

$$E_{inj,d} = 1 \text{ TeV}$$

- Integrate the **trajectories of individual particles in 3D (test particle limit)**,
- Integrate in the Upstream or Downstream RFs; Shock crossing: Do the Lorentz transfo.

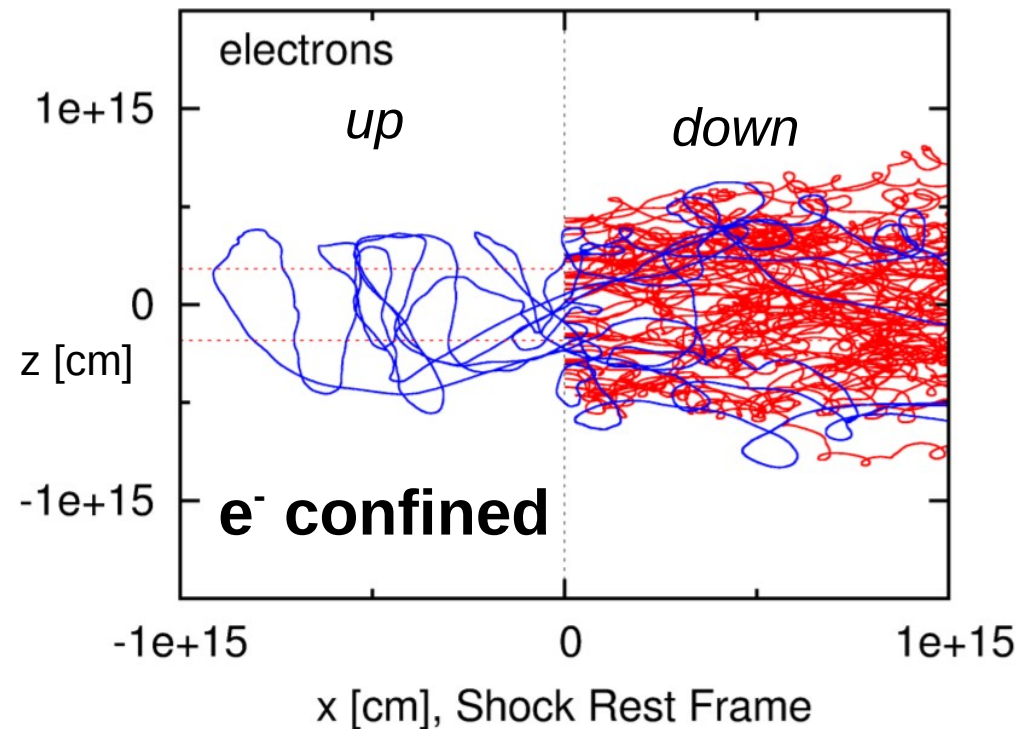
Numerical simulations

Positrons :



No/little acceleration

Electrons :

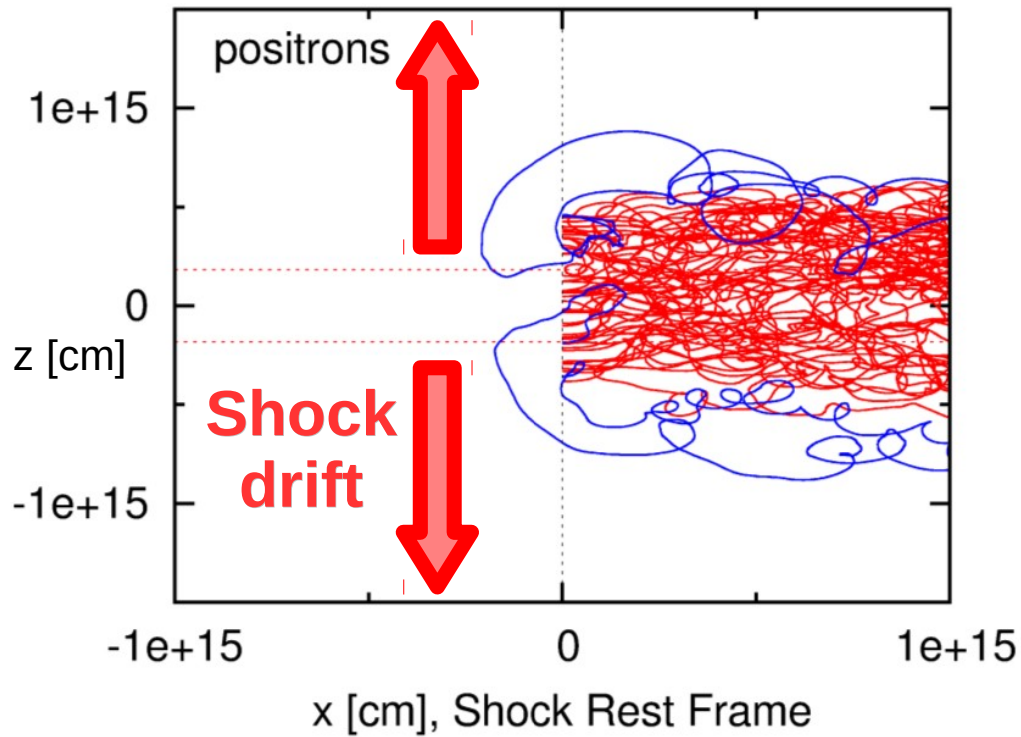


Acceleration

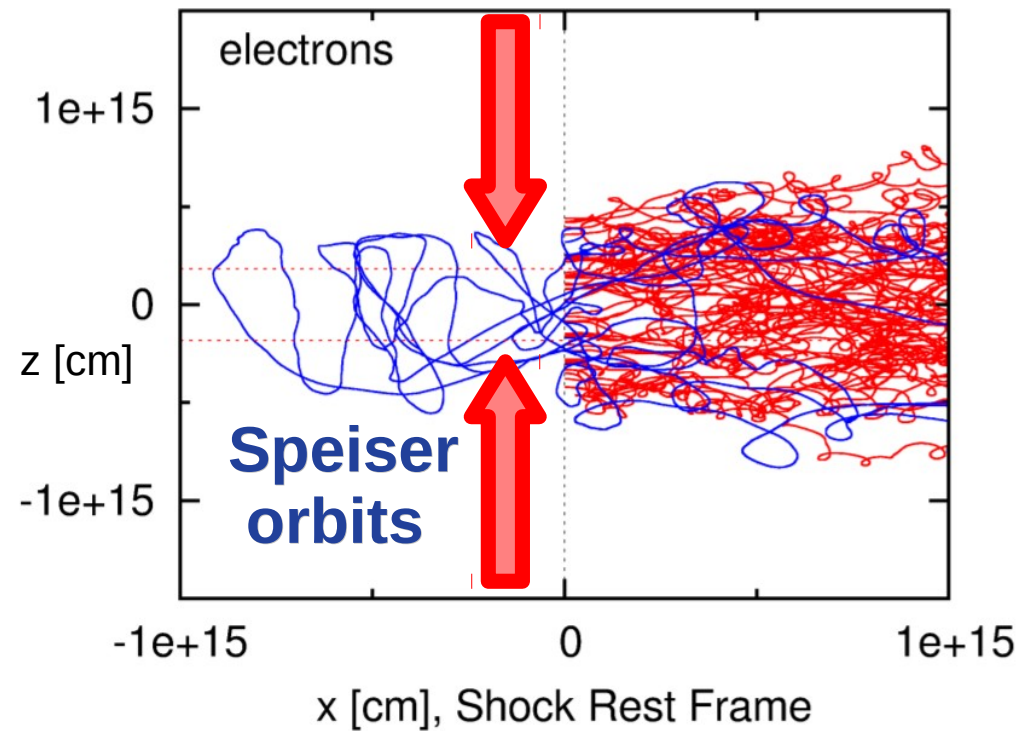
(... or vice versa, depending on the polarity)

Numerical simulations

Positrons :

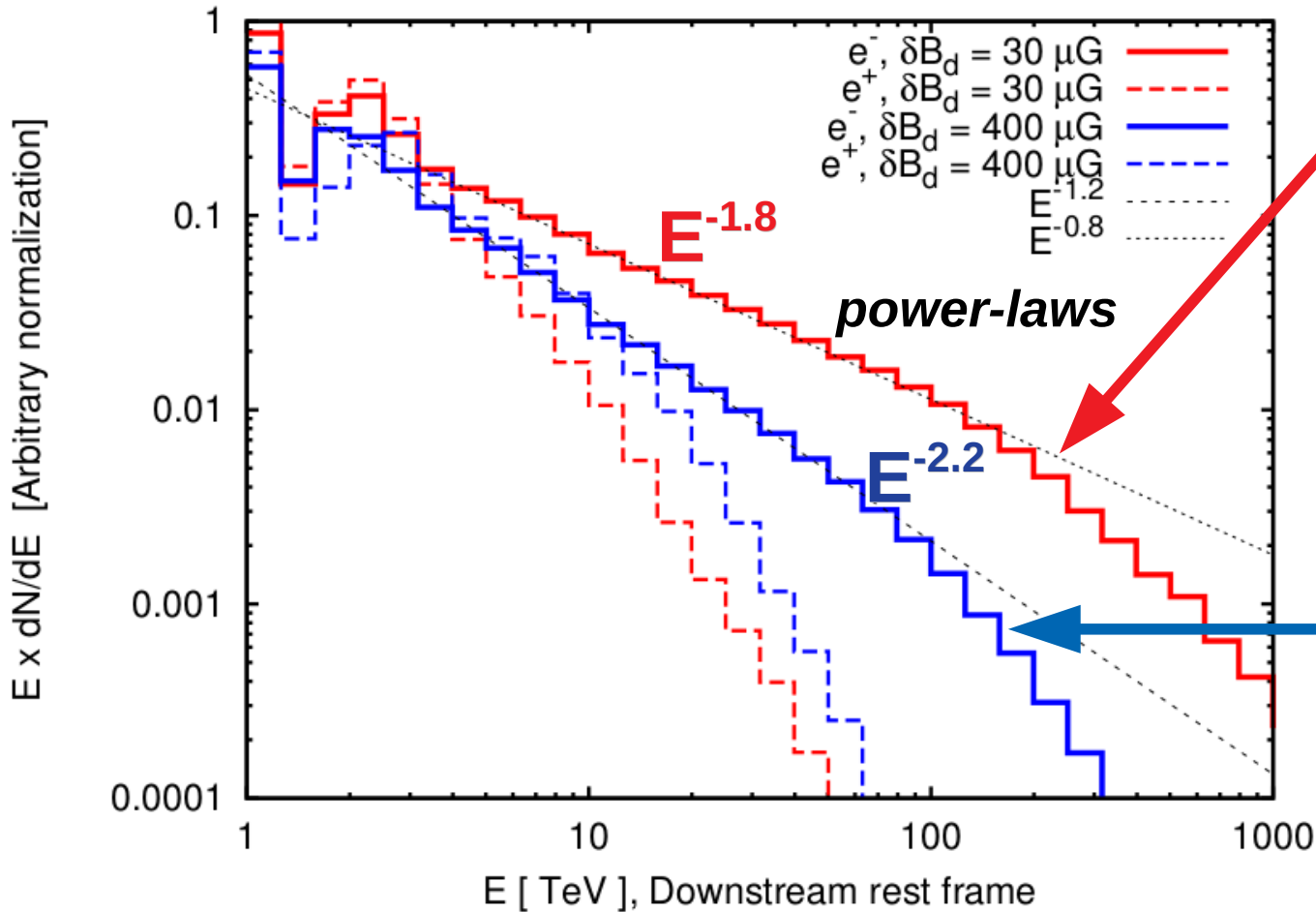


Electrons :



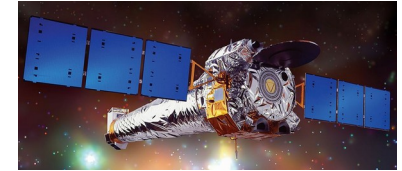
Effects of drift motions on the shock surface

e^+ , e^- spectra vs Observations



CENTER

Chandra

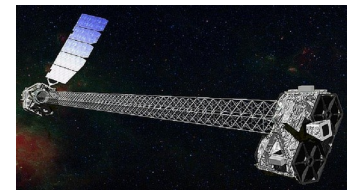


Photon index $s \sim 1.9$
Mori et al. (2004)

GOOD FIT

TOTAL NEBULA

NuSTAR

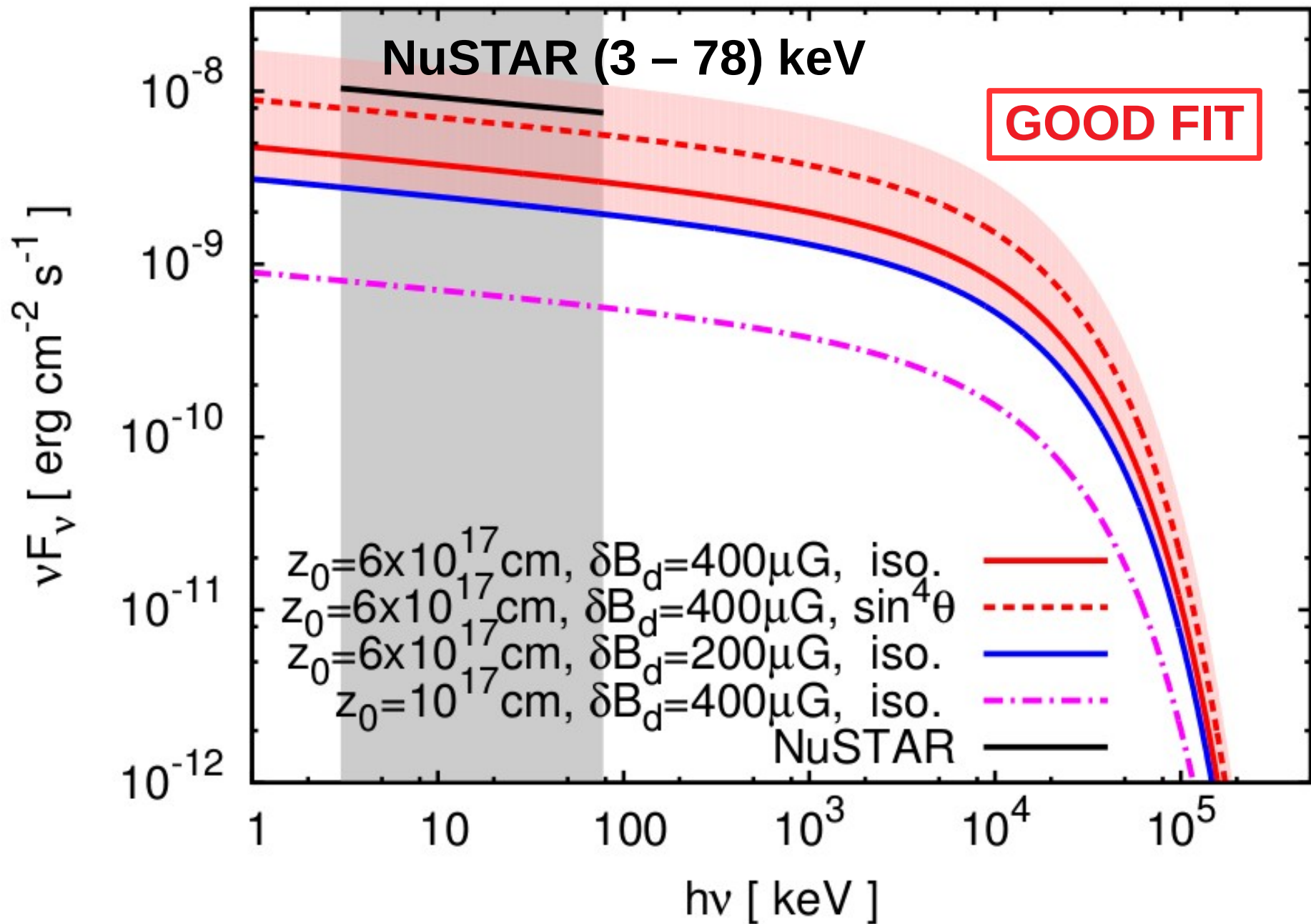


$$\nu F_\nu \propto \nu^{-0.1}$$

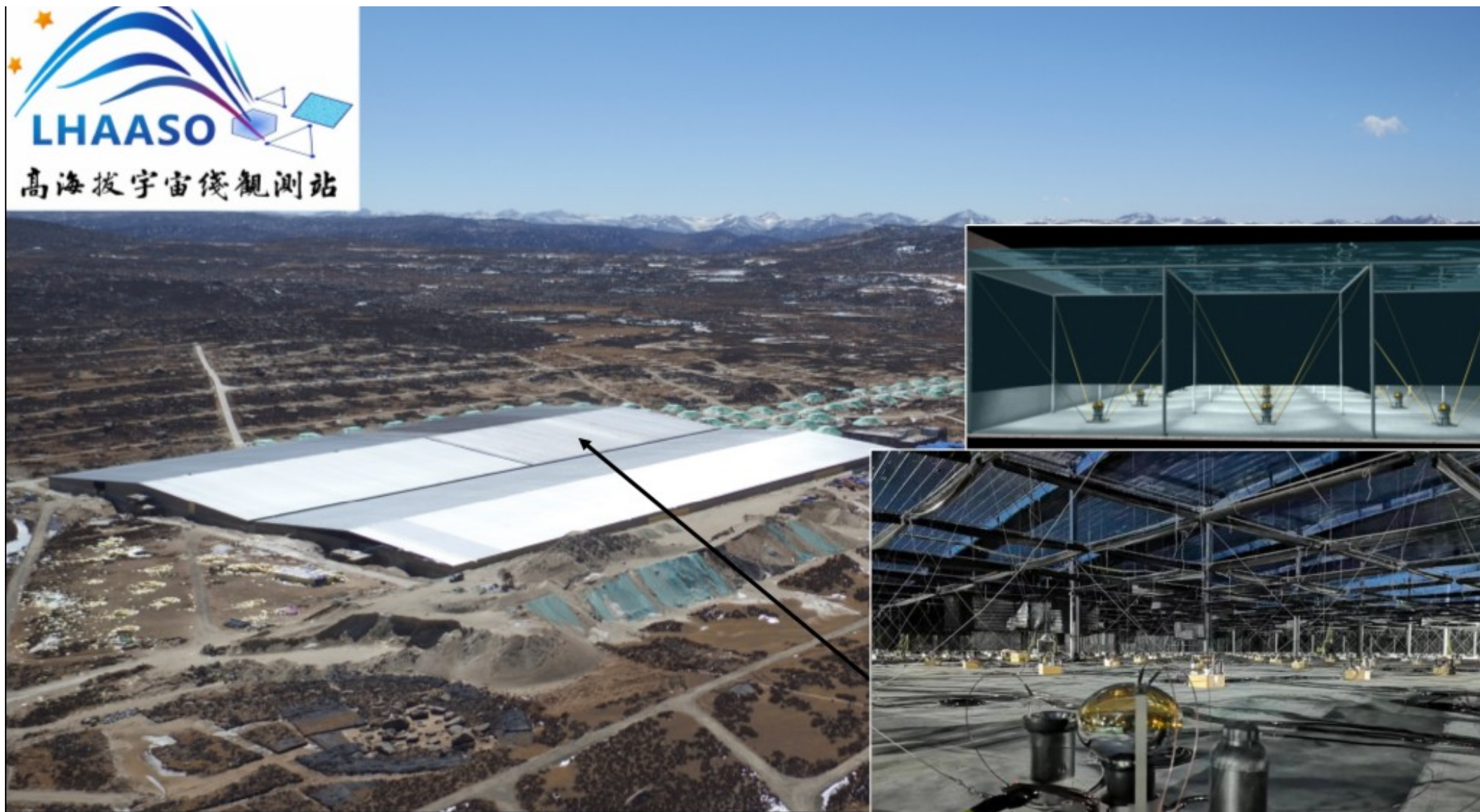
GOOD FIT

Spectral index $\sim -2.4 \dots -1.8$

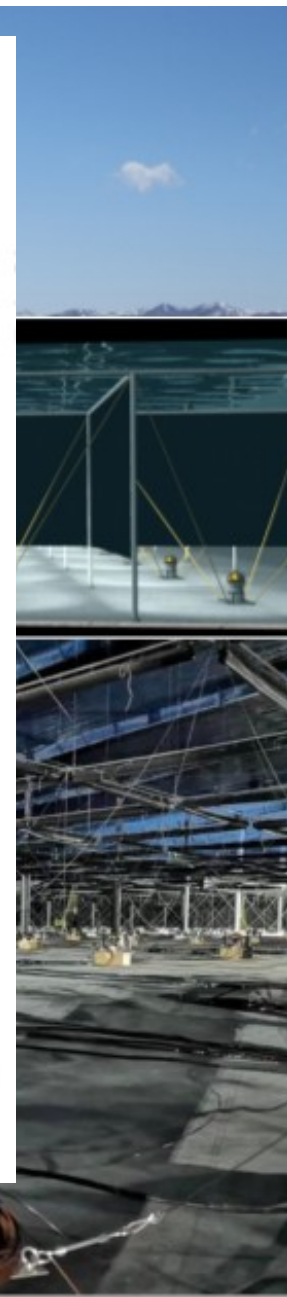
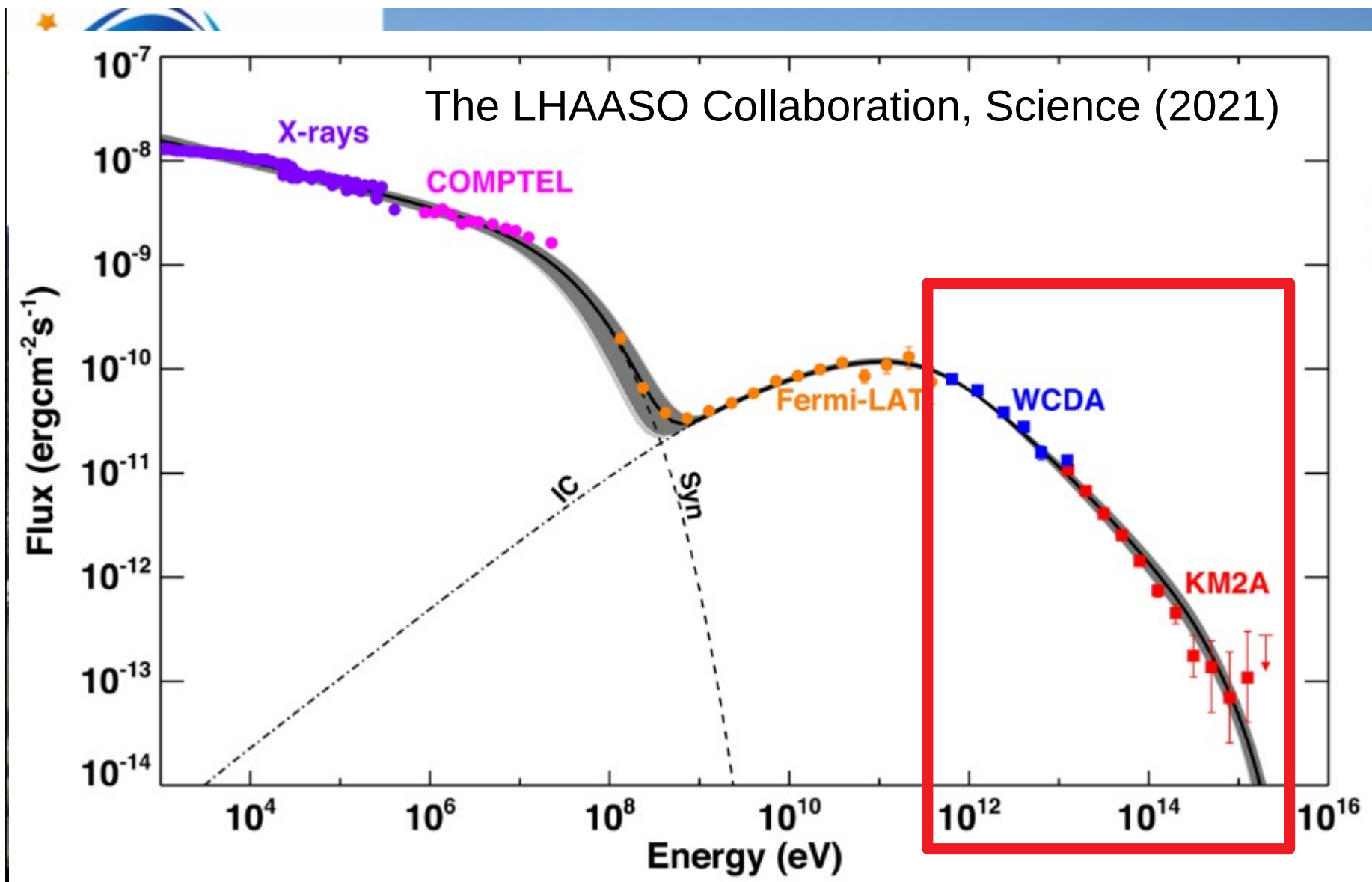
Synchrotron emission (X-rays)



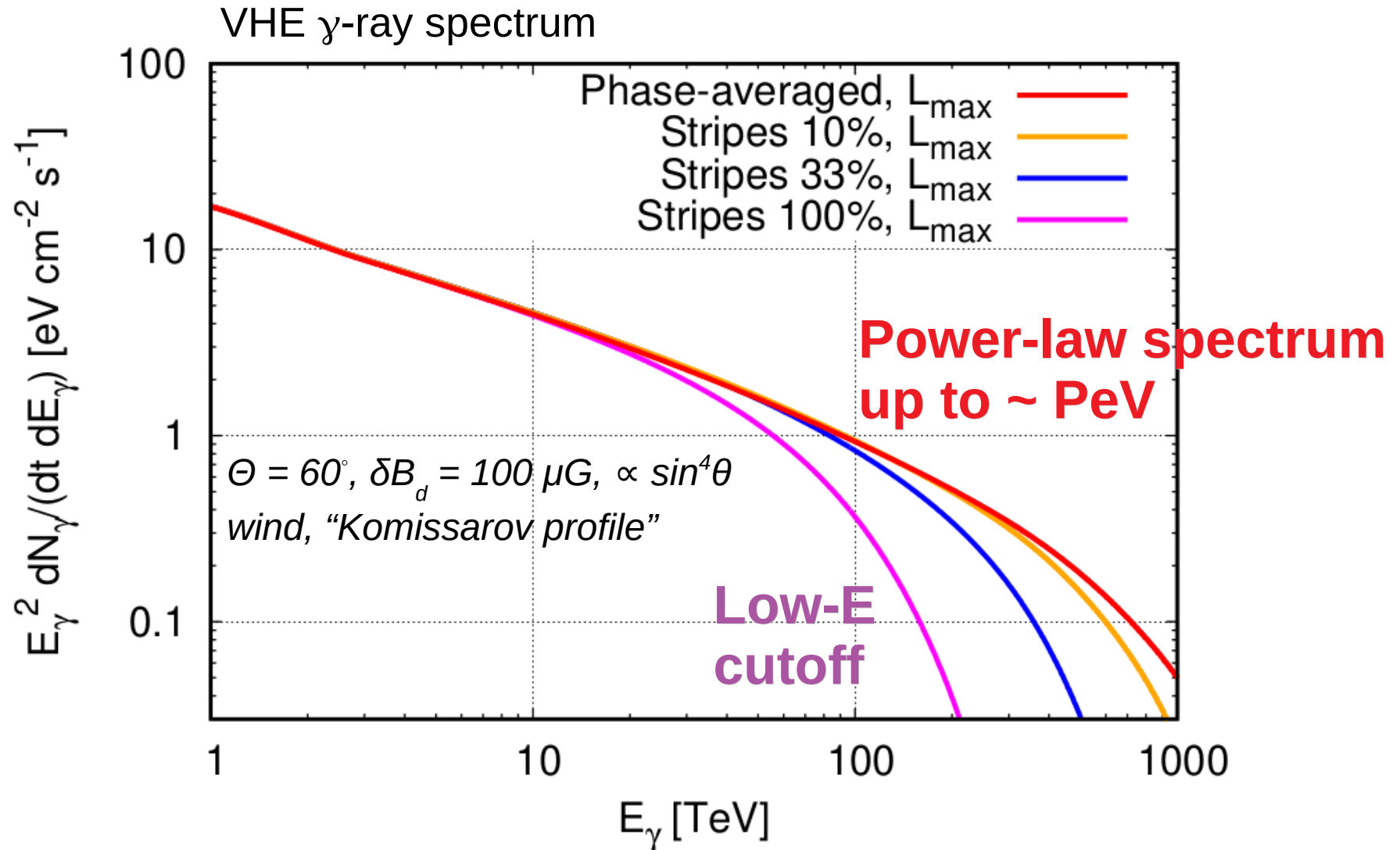
LHAASO (高海拔宇宙线观测站)



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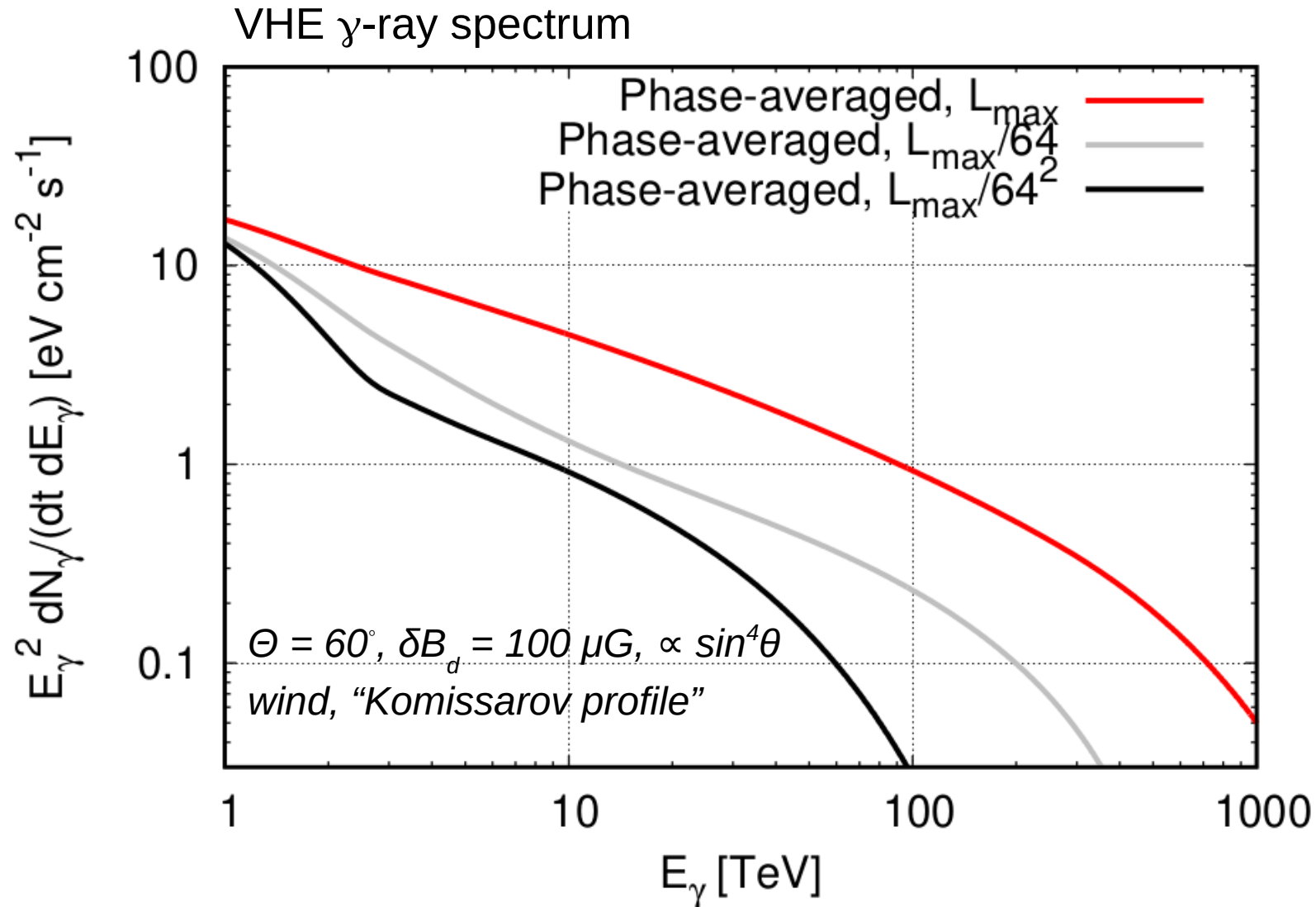
PeV γ -rays from the Crab Nebula ?



Our model fits the data for some parameters, but not for others.

=> LHAASO already constrains the Crab WIND's parameters with its measurements at ~ 1 PeV !

PeV γ -rays from the Crab Nebula ?

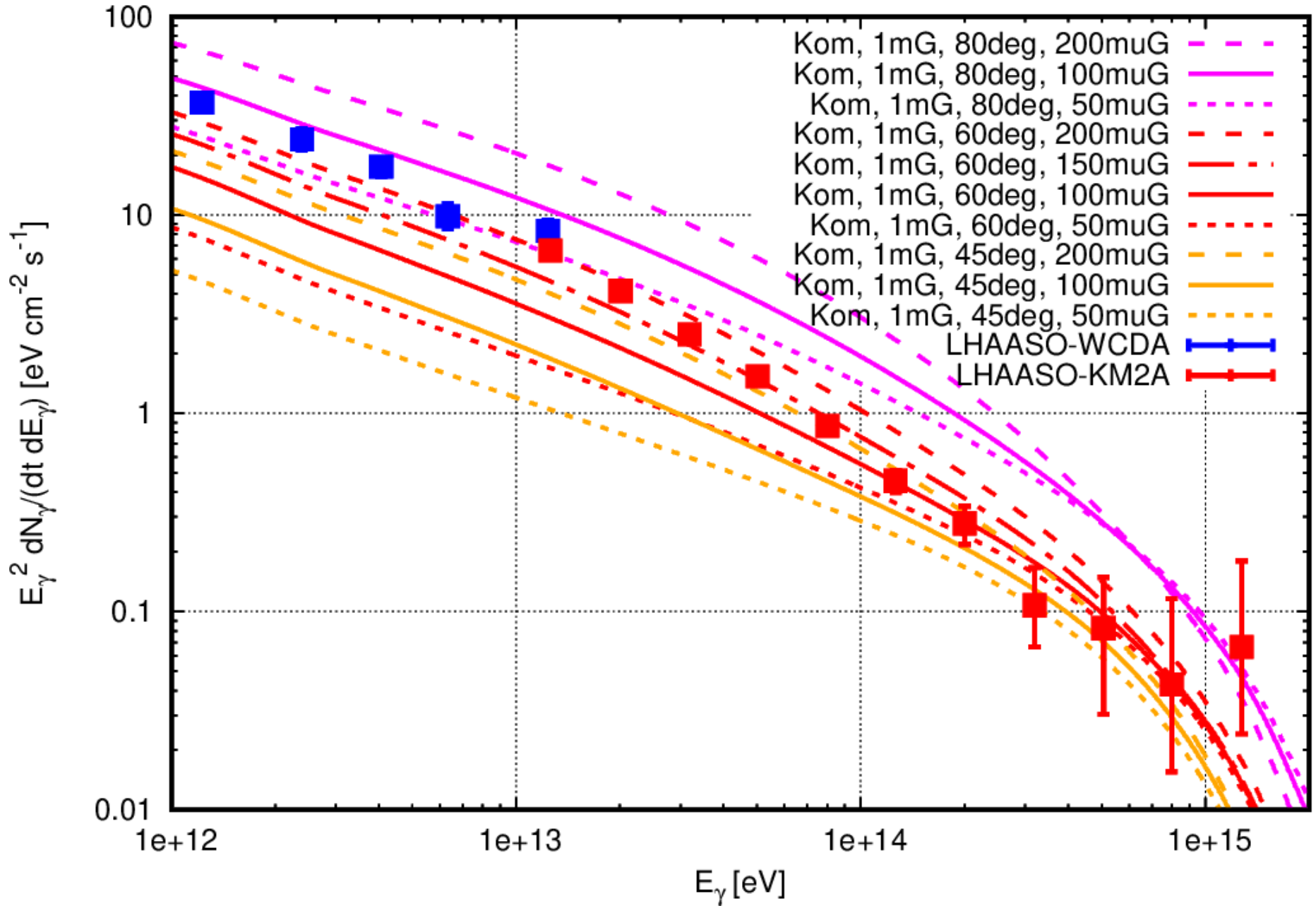


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PeV γ -rays from the Crab Nebula ?

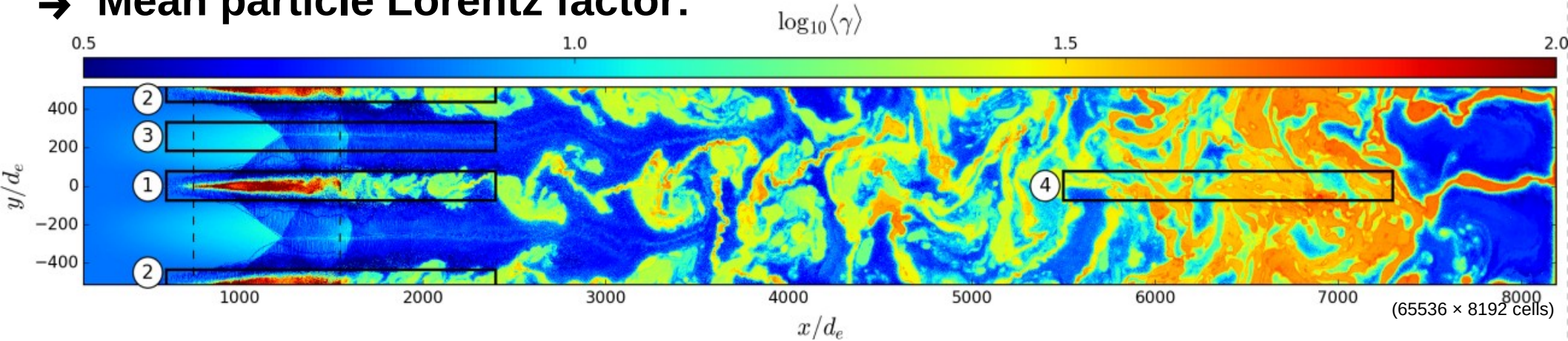
Comparison with LHAASO data :



Particle-In-Cell (PIC) simulations

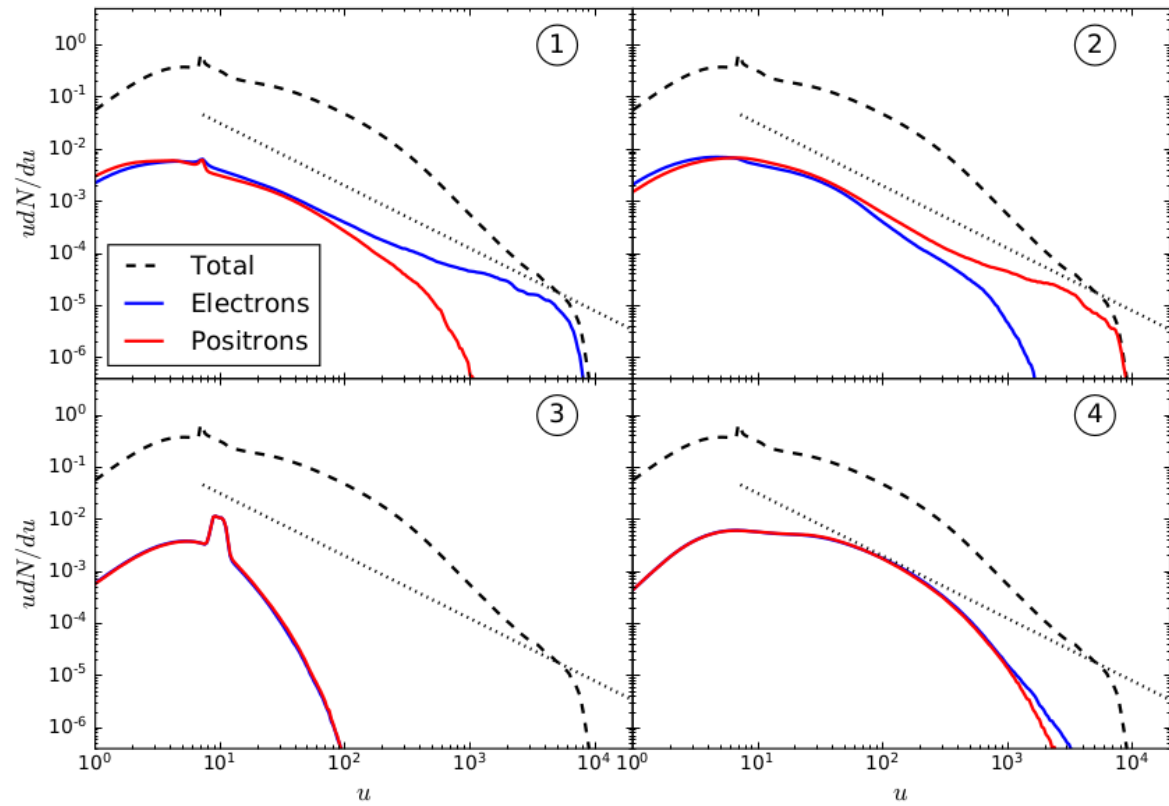
Cerutti & Giacinti, A&A **642**, A123 (2020), arXiv:2008.07253

→ Mean particle Lorentz factor:



→ Local e^+ , e^- spectra :

Very efficient e^+ OR e^- acceleration !



Conclusions:

- **1st numerical 'proof' of e^- acceleration to $> \text{PeV}$ at pulsar wind termination shocks via 1st order Fermi,**
- **Large-scale anisotropy of the transverse B-field profile** allows for efficient particle acceleration close to the eq. plane,
- **Speiser orbits around the eq. Plane; Shock-drift,**
- Fits the X-rays and γ -rays from the Crab Nebula,
- New constraints on pulsar winds from PeV data !
- **LHAASO** already constrains striped pulsar wind parameters,
- **Either e^- or e^+ acc. to HE** (depending on the pulsar **polarity**)
=> Crucial implications for the **positron excess.**

Thank you! 谢谢!

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