

Modeling the Synchrotron Polarization of Blazars with AM³

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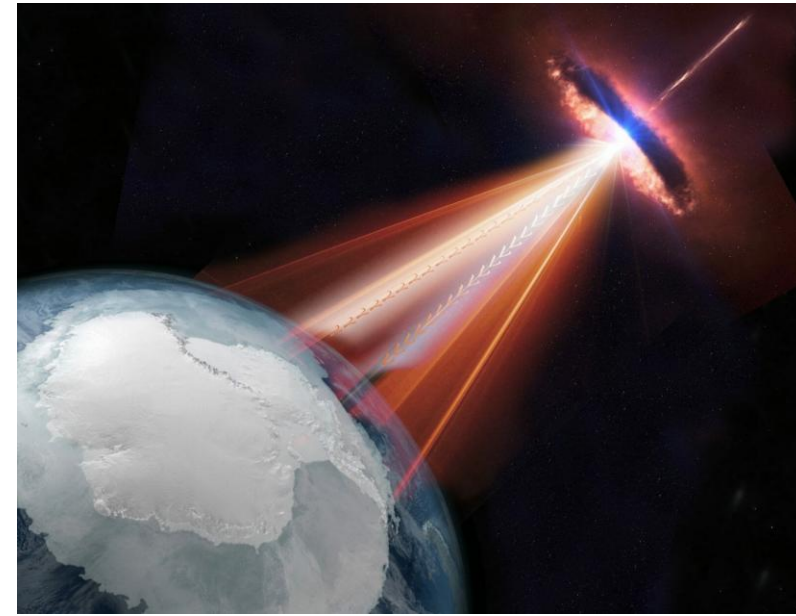
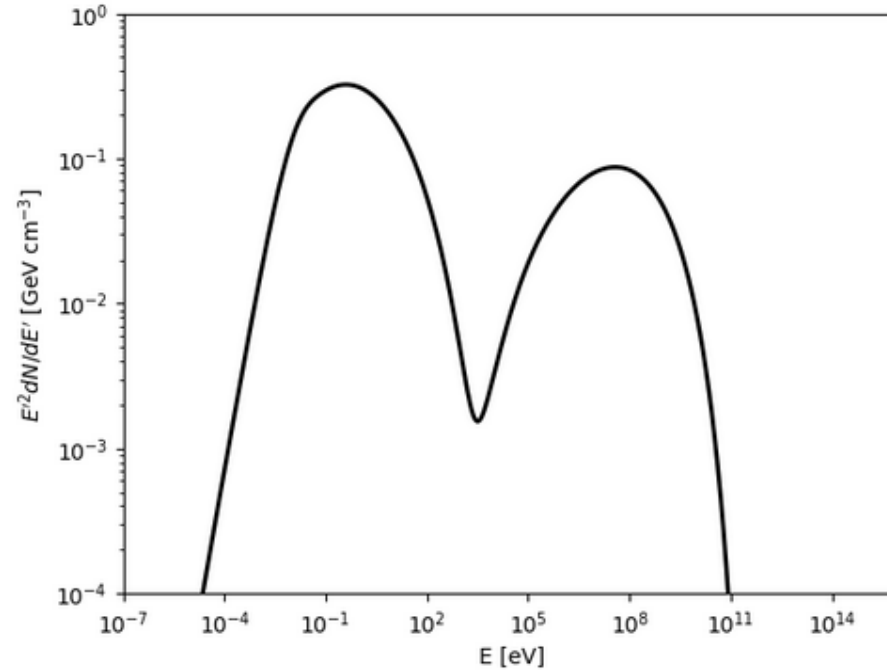


**HELMHOLTZ WEIZMANN
RESEARCH SCHOOL
MULTIMESSENGER ASTRONOMY**

Blazars

Spectral energy distribution

*Low-energy emission:
Synchrotron radiation*



IceCube/NASA

- Synchrotron radiation is linearly polarized
- Optical polarization ranges from a few % to ~30% (quiescent state)
- Time- and energy-resolved polarization provides key insights into blazar jets

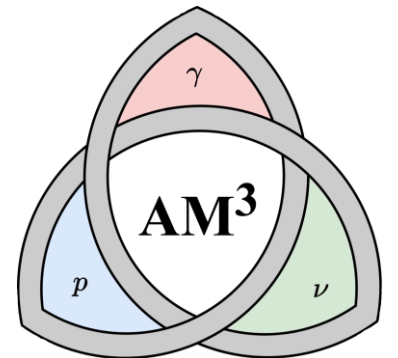
AM^3 : Astrophysical Multi-Messenger Modeling

$$\frac{\partial n(E, t)}{\partial t} = Q_E(E, t) - \frac{\partial}{\partial E} \left(\left(\dot{E}(E, t) \right) n_E(E, t) \right) - \alpha(E, t) n_E(E, t)$$

Differential number density of particles injection/source cooling/advection escape/sink

Assumption:

The particles and magnetic fields are homogeneous and isotropic.



Klinger et al. 2024

Polarization degree and polarization angle

Using polarization filters, the **polarization degree Π** and the **polarization angle χ** can be measured

Polarization degree

$$\Pi = \frac{I_{pol}}{I_{total}}$$

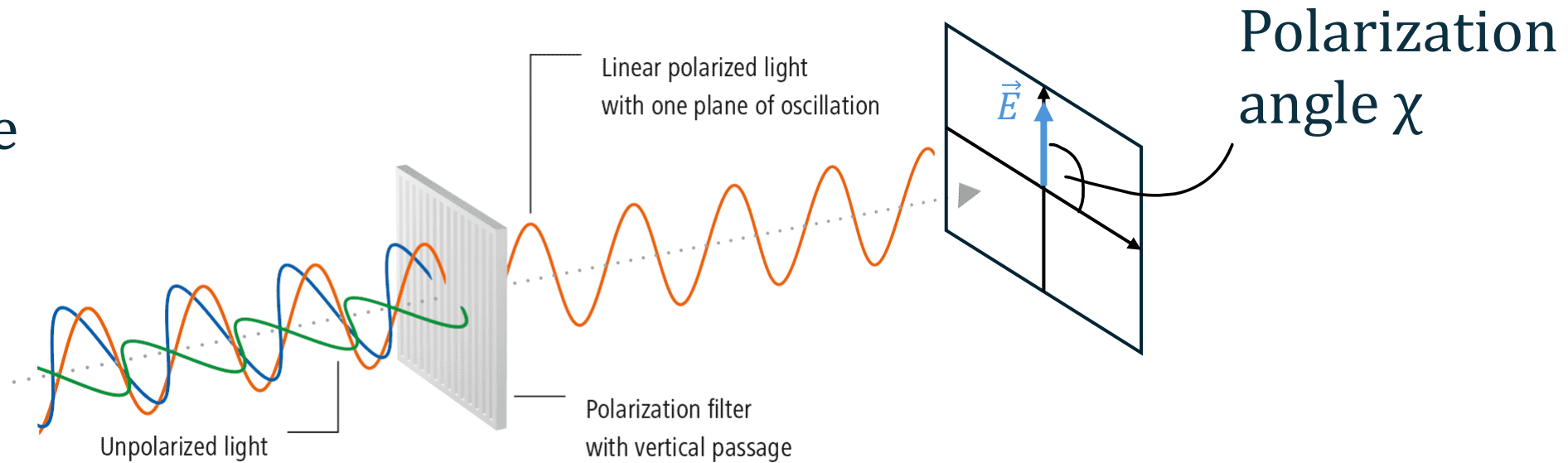
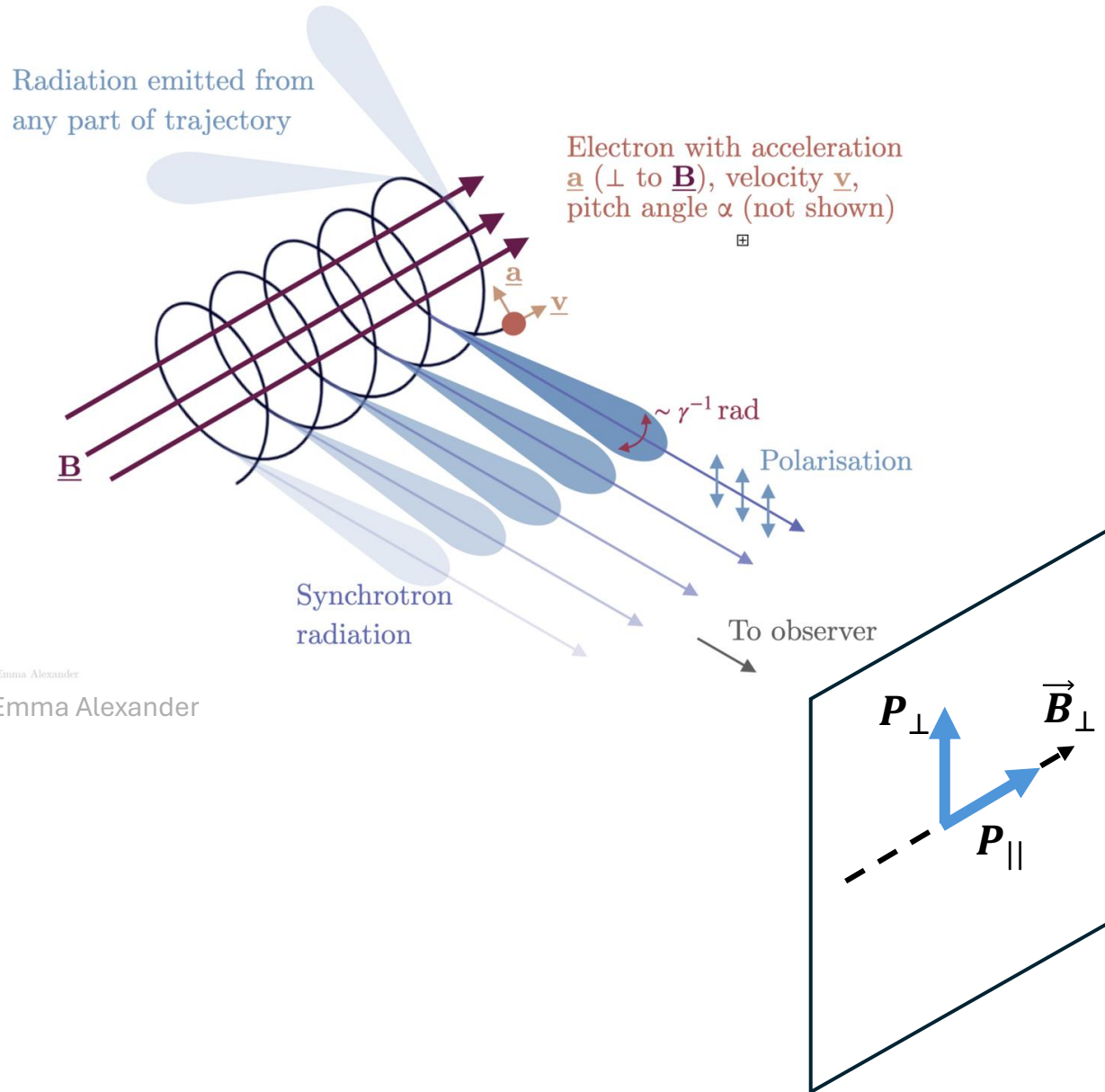


Figure from <https://www.physicshigh.com/polarisation.html>

Synchrotron Polarization



Polarization degree

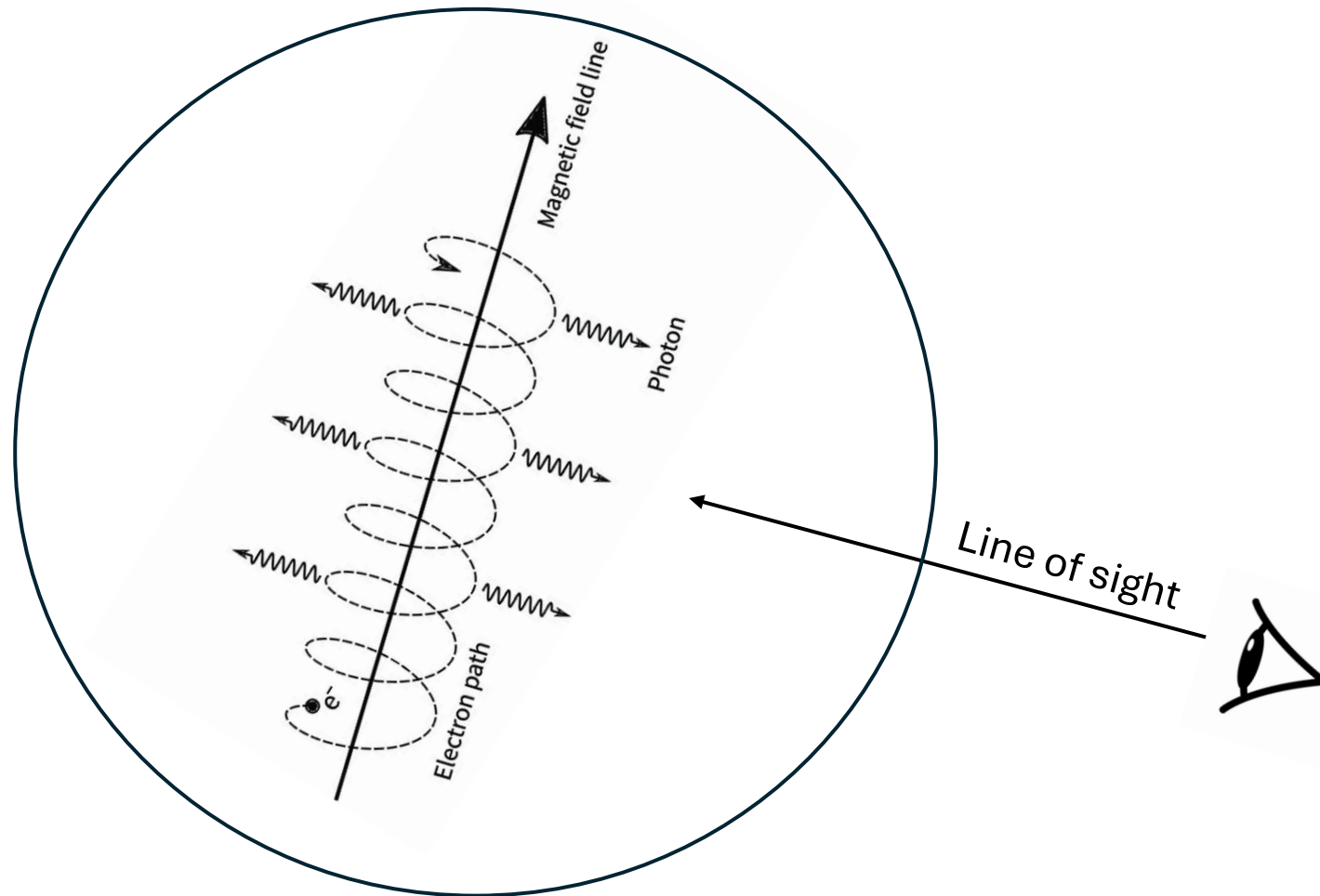
$$\Pi(\omega) = \frac{P_\perp(\omega) - P_\parallel(\omega)}{P_\perp(\omega) + P_\parallel(\omega)} = \frac{G(x)}{F(x)}$$

Theoretical maximum for particles with a power law distribution of energies $N \propto E^{-p}$

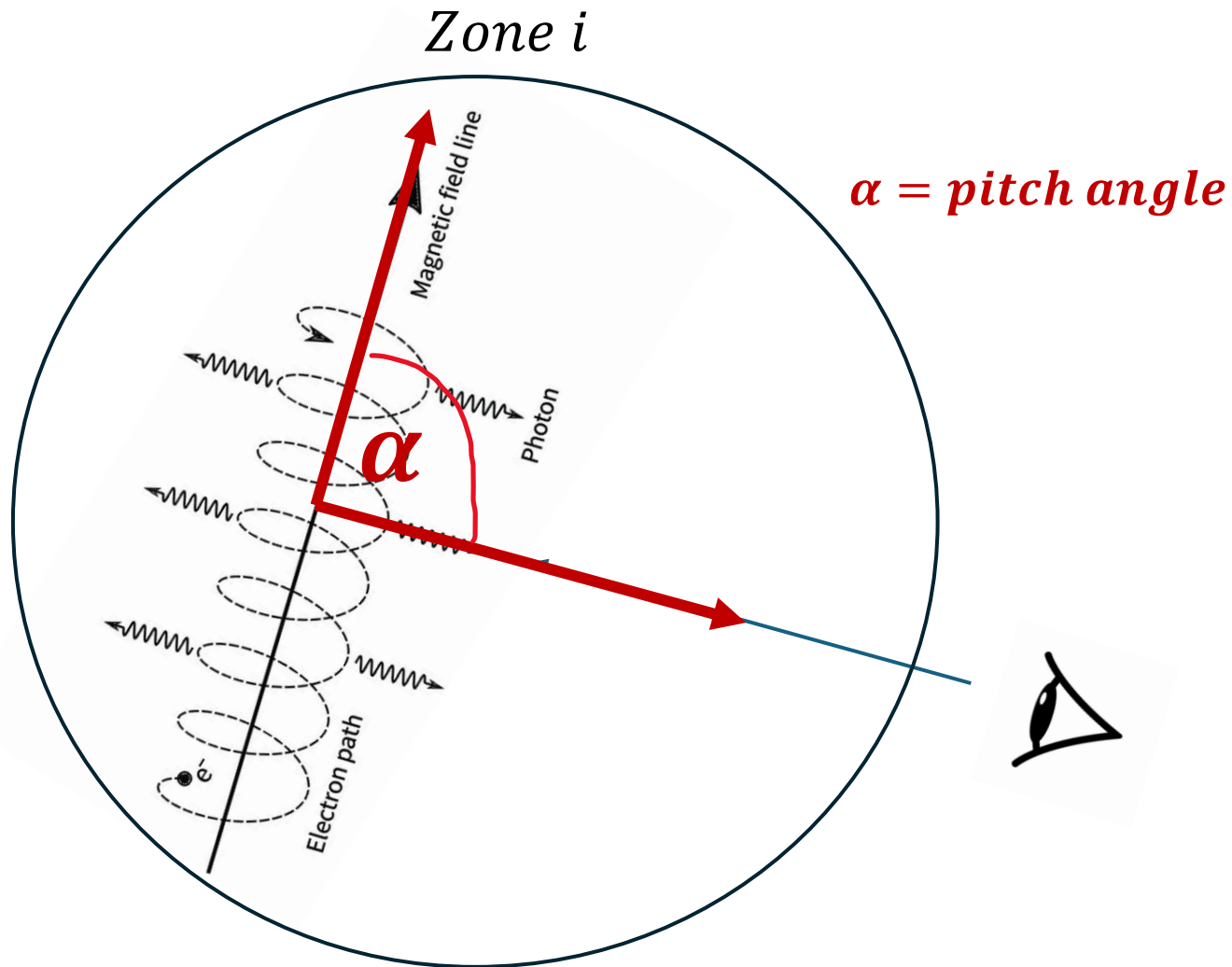
$$\Pi_{max}^{syn}(\omega) = \frac{p + 1}{p + \frac{7}{3}}$$

Approach & Application Examples

Calculate polarization with AM3 - Approach



Calculate polarization with AM3 - Approach



set pitch angle for Zone i



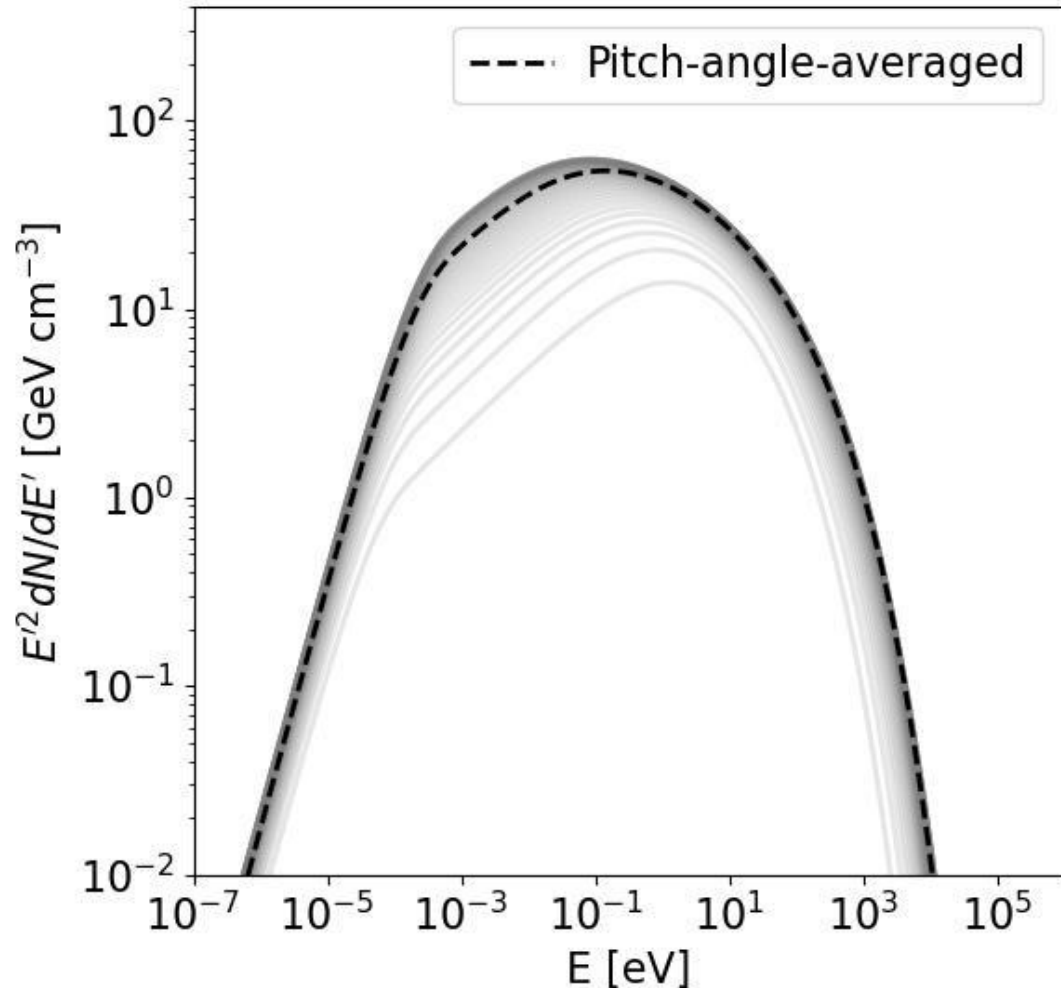
AM3 calculates
 $G(x)$ and $F(x)$



$$\Pi(E, t) = \frac{G(x)}{F(x)}$$

Effects of the geometry on synchrotron emission

$$P_{tot} = P_{\perp}(E, t) + P_{\parallel}(E, t) = F(x)$$



set pitch angle for *Zone i*

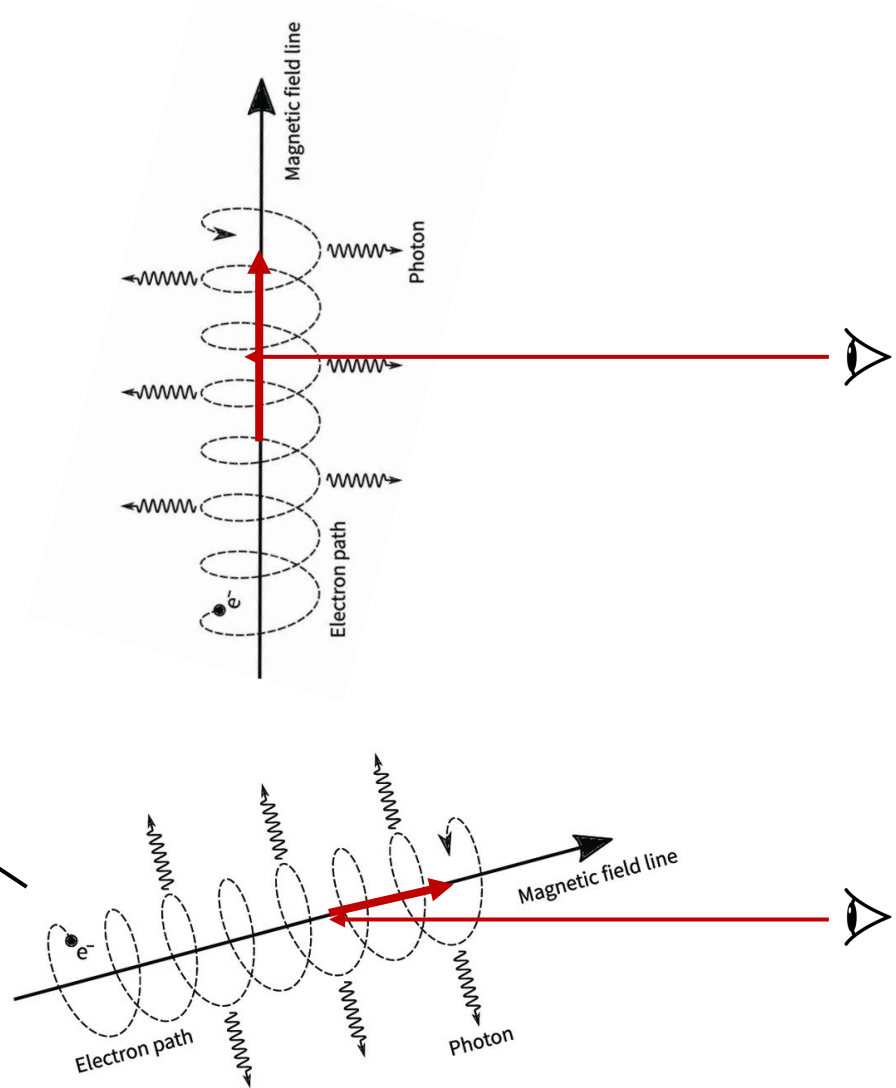
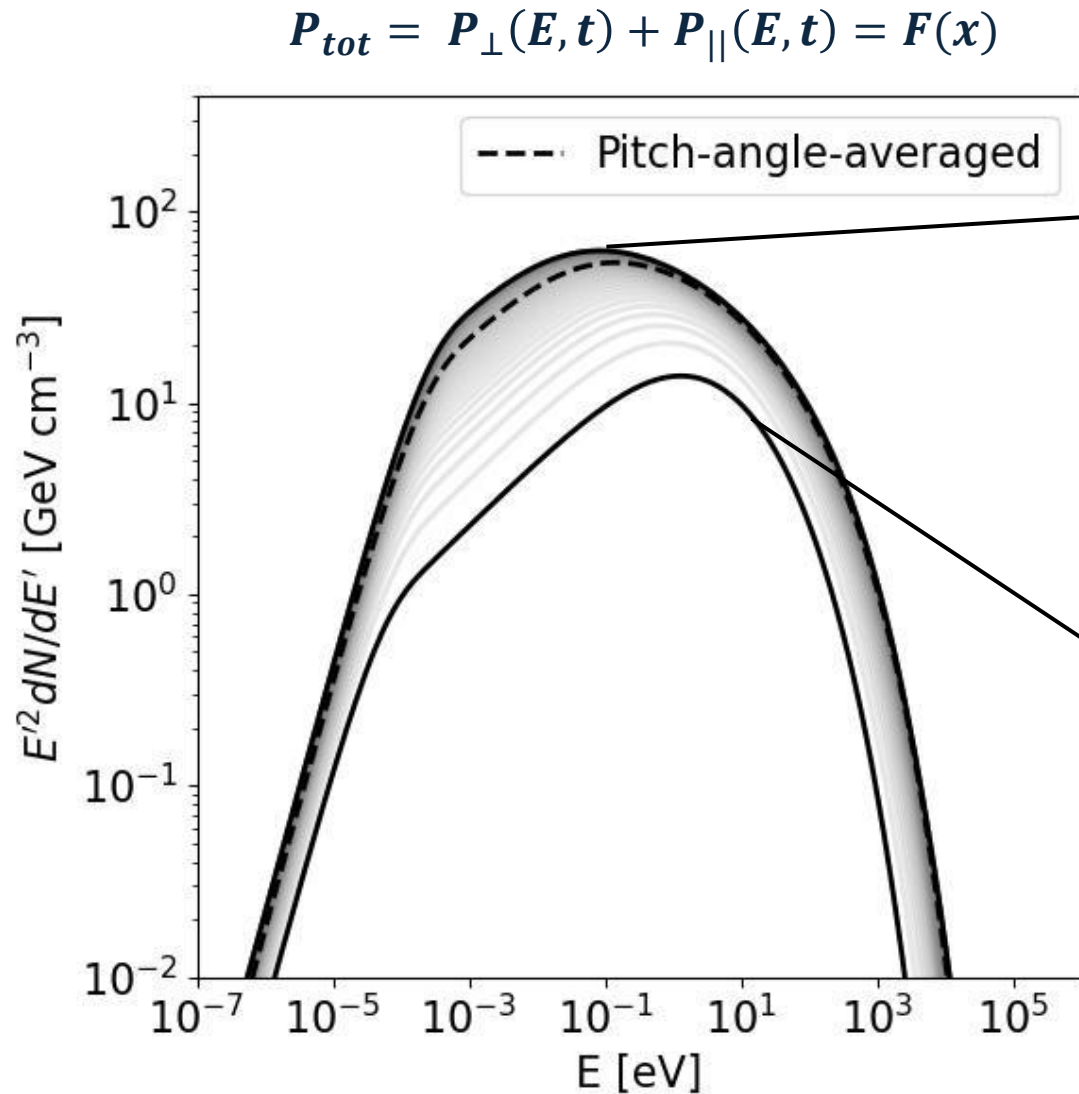


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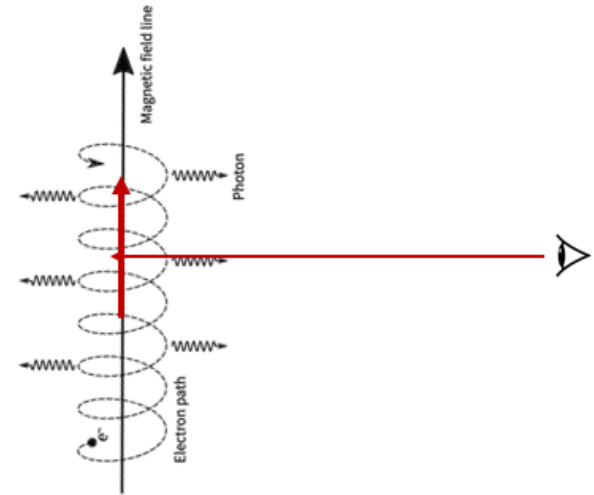
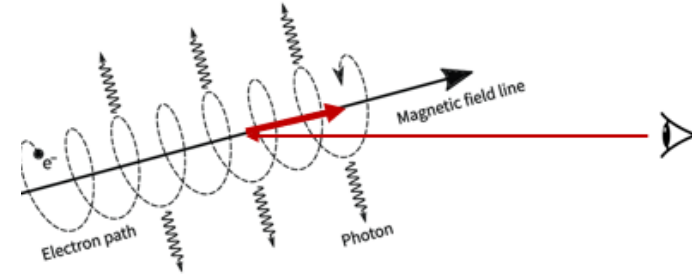
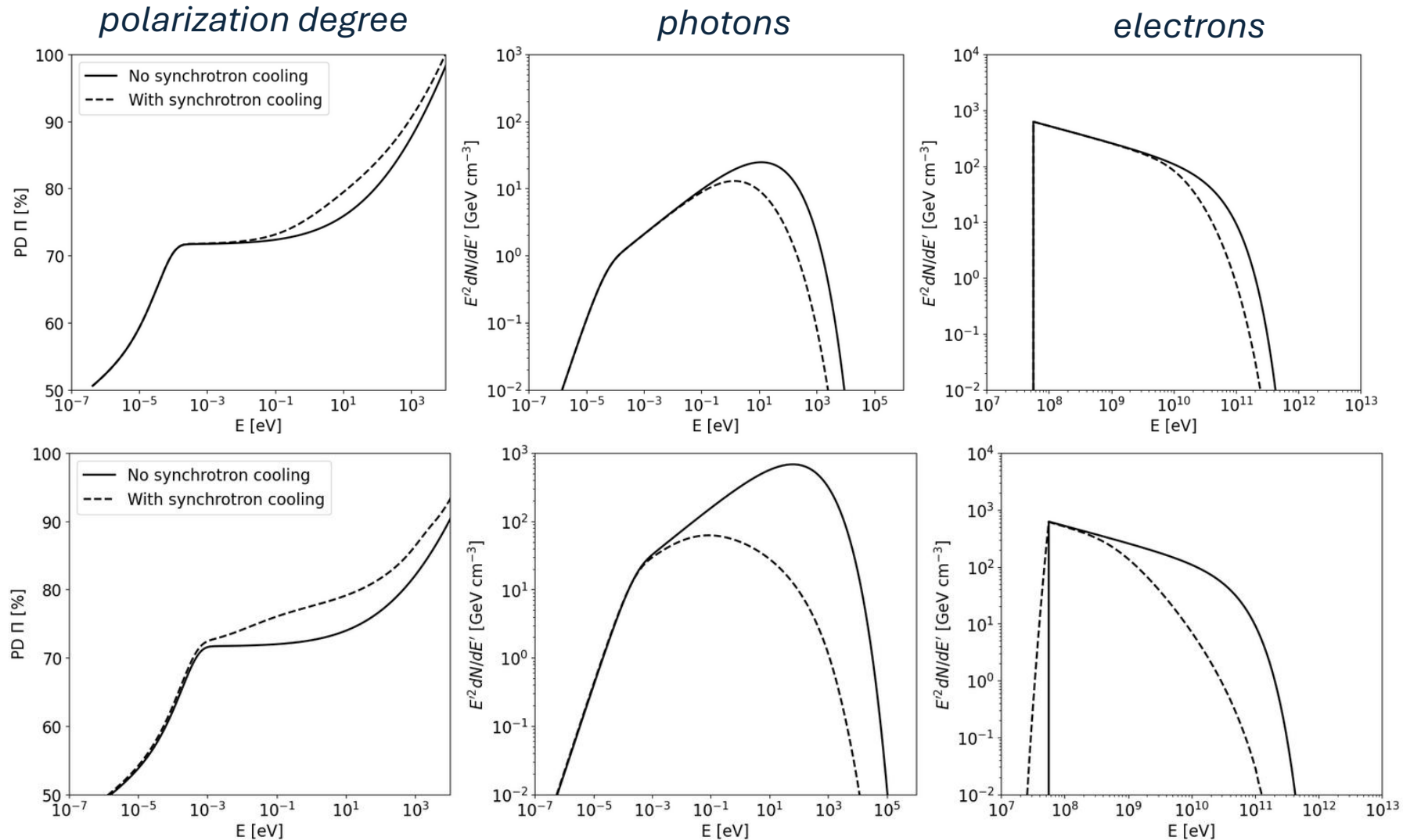
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Effects of the geometry on synchrotron emission

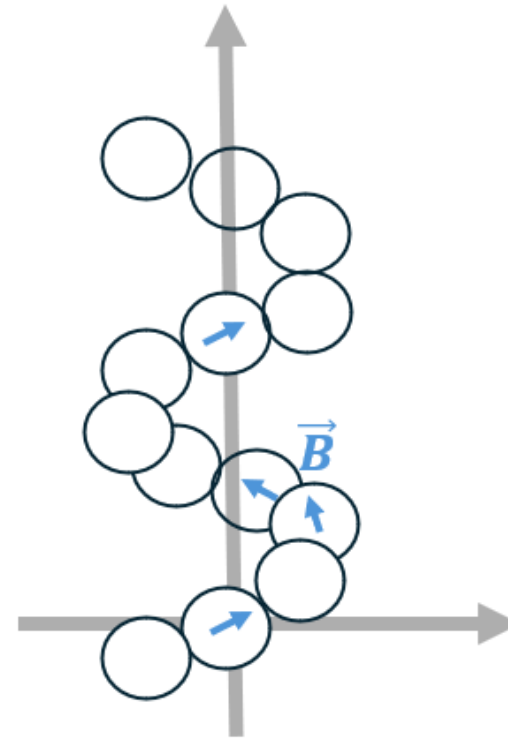
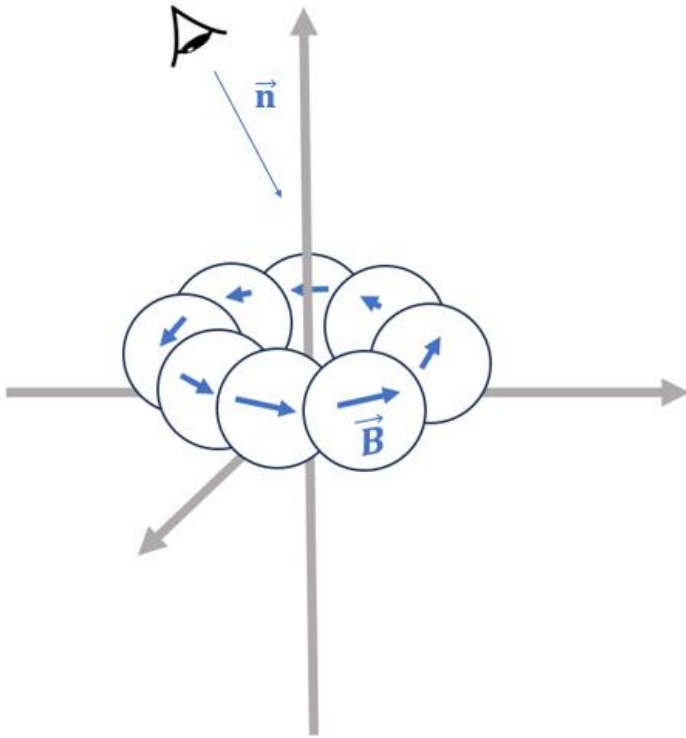


Synchrotron polarization

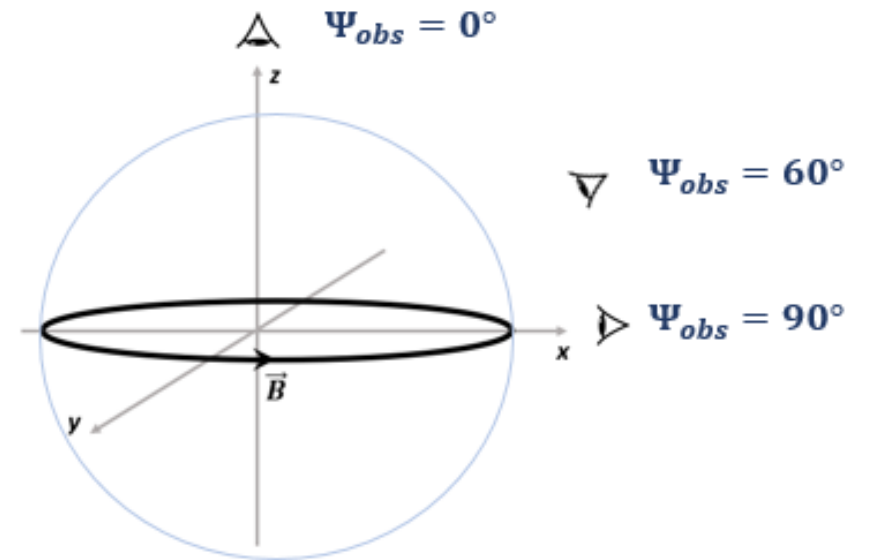
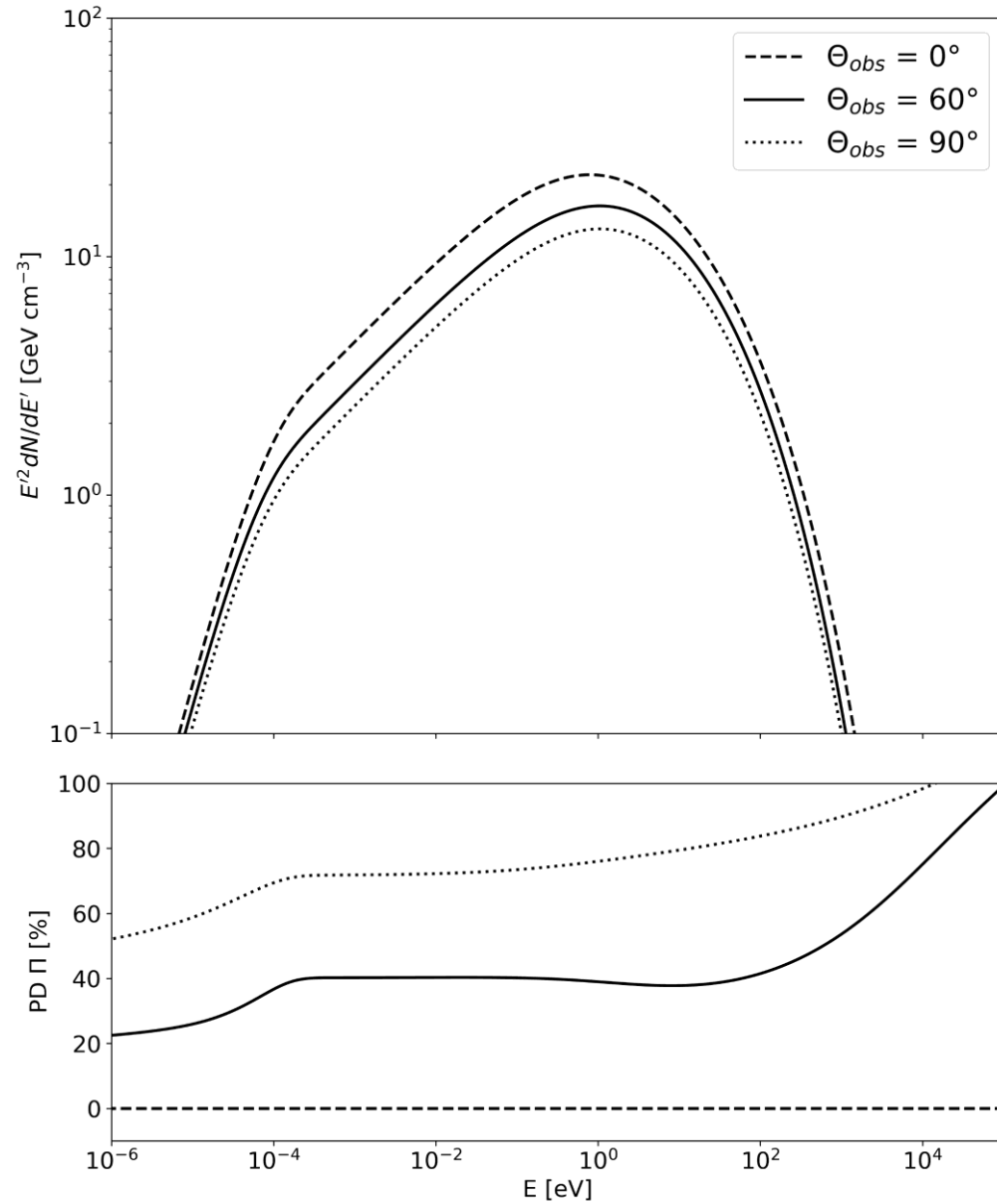
$$\Pi_{\max}^{\text{syn}}(\omega) = \frac{p+1}{p+\frac{7}{3}} \sim 71\% \text{ with } p = 2.3$$



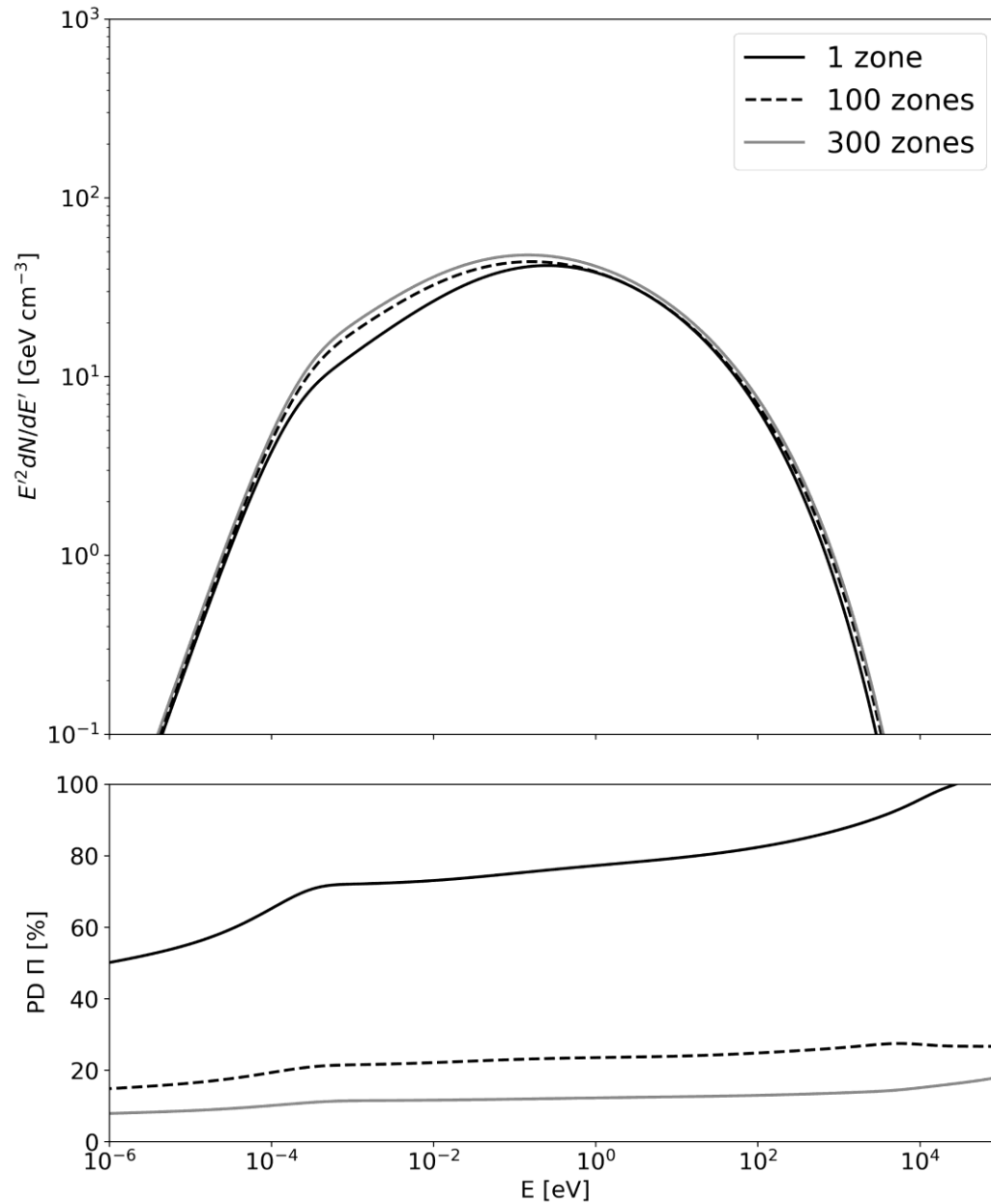
From here we can build more complex structures using multiple zones



Toroidal magnetic field

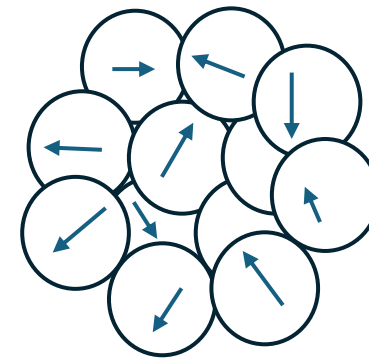


Chaotic fields

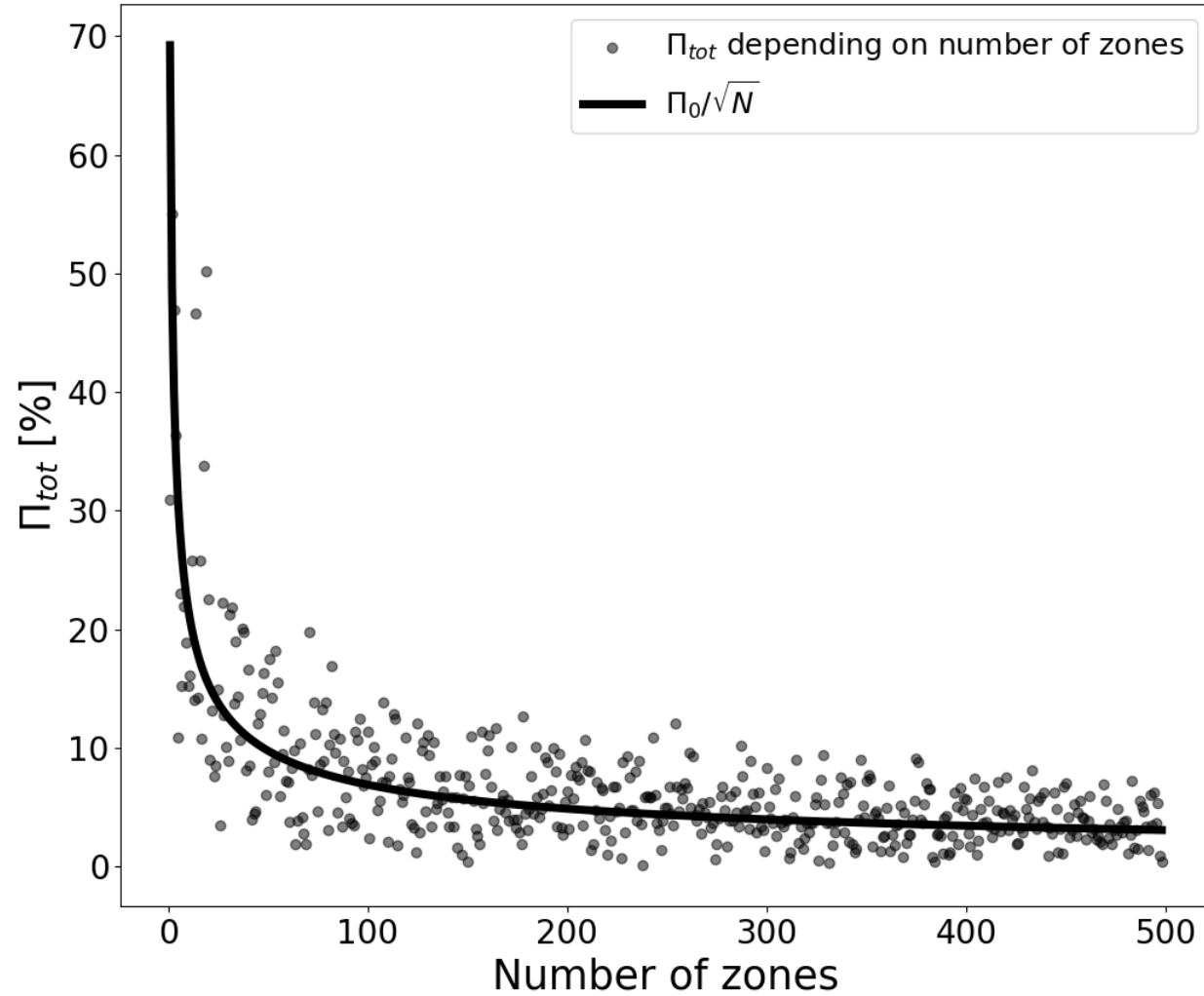


Depolarization

$$\Pi_{tot} = \frac{\Pi_{max}}{\sqrt{N}}$$

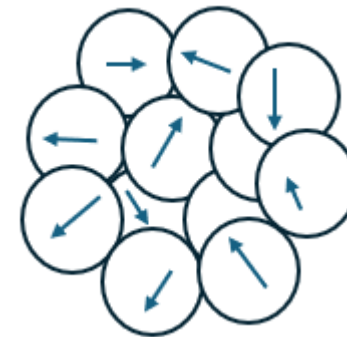


Chaotic fields



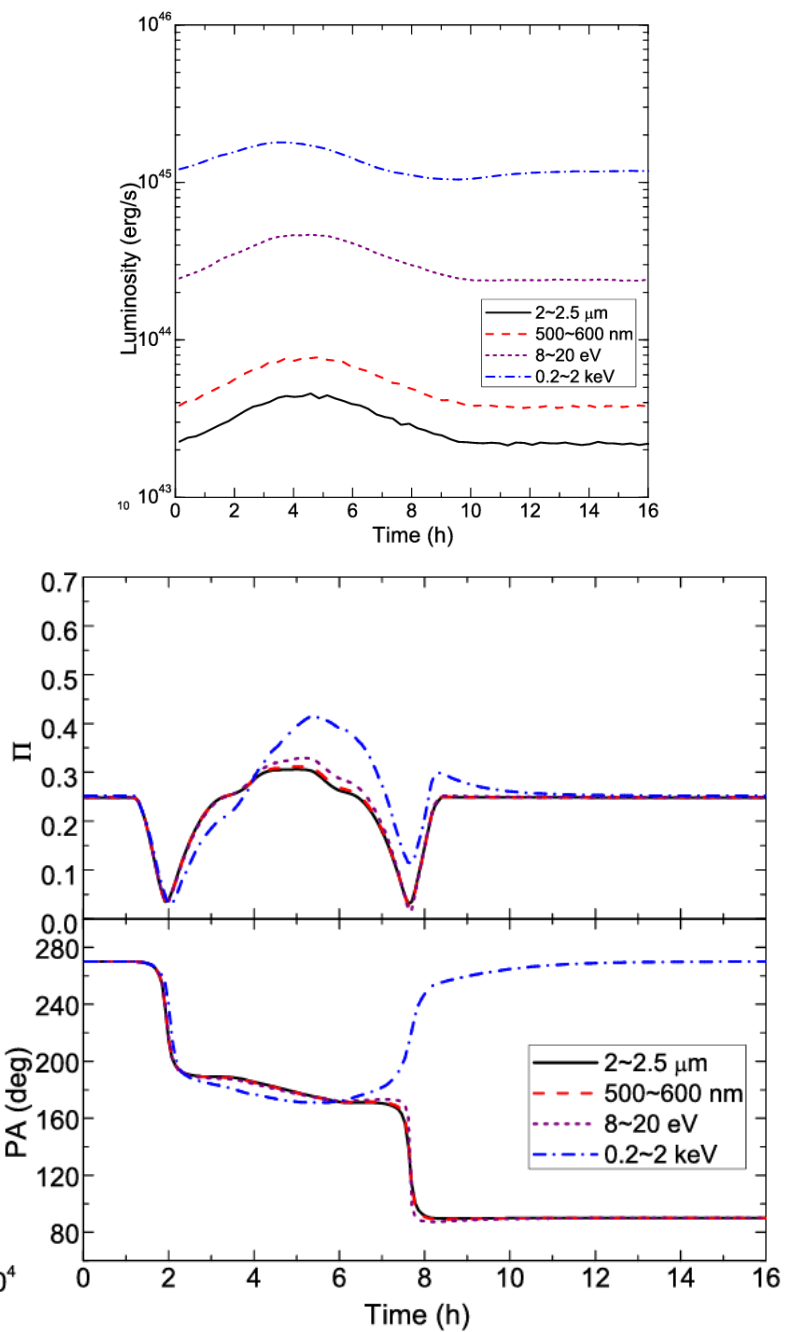
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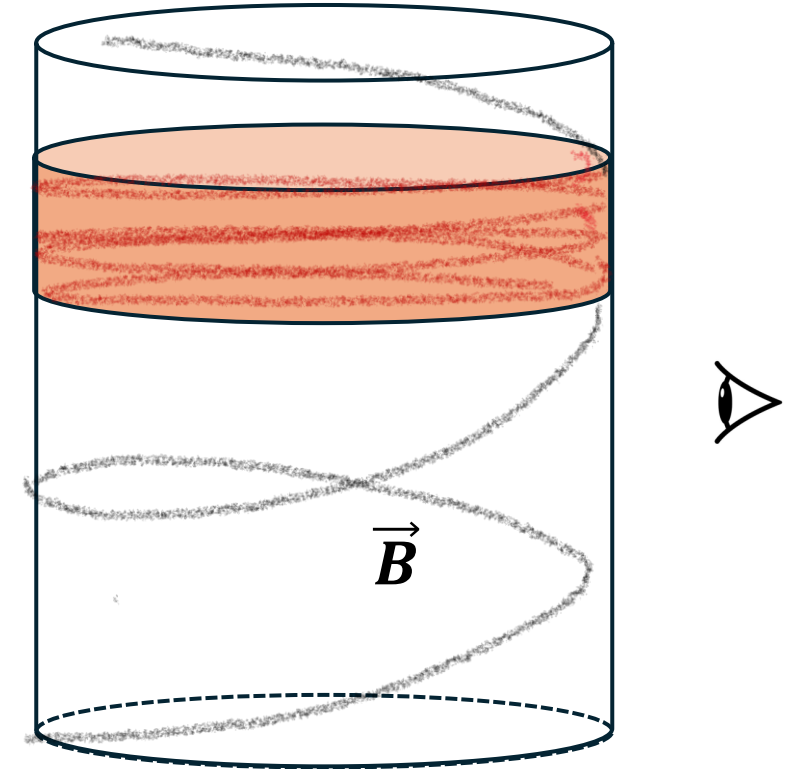
Shock-in-jet model

inspired by
„Synchrotron Polarization in Blazars“ (Zhang et al. 2014)

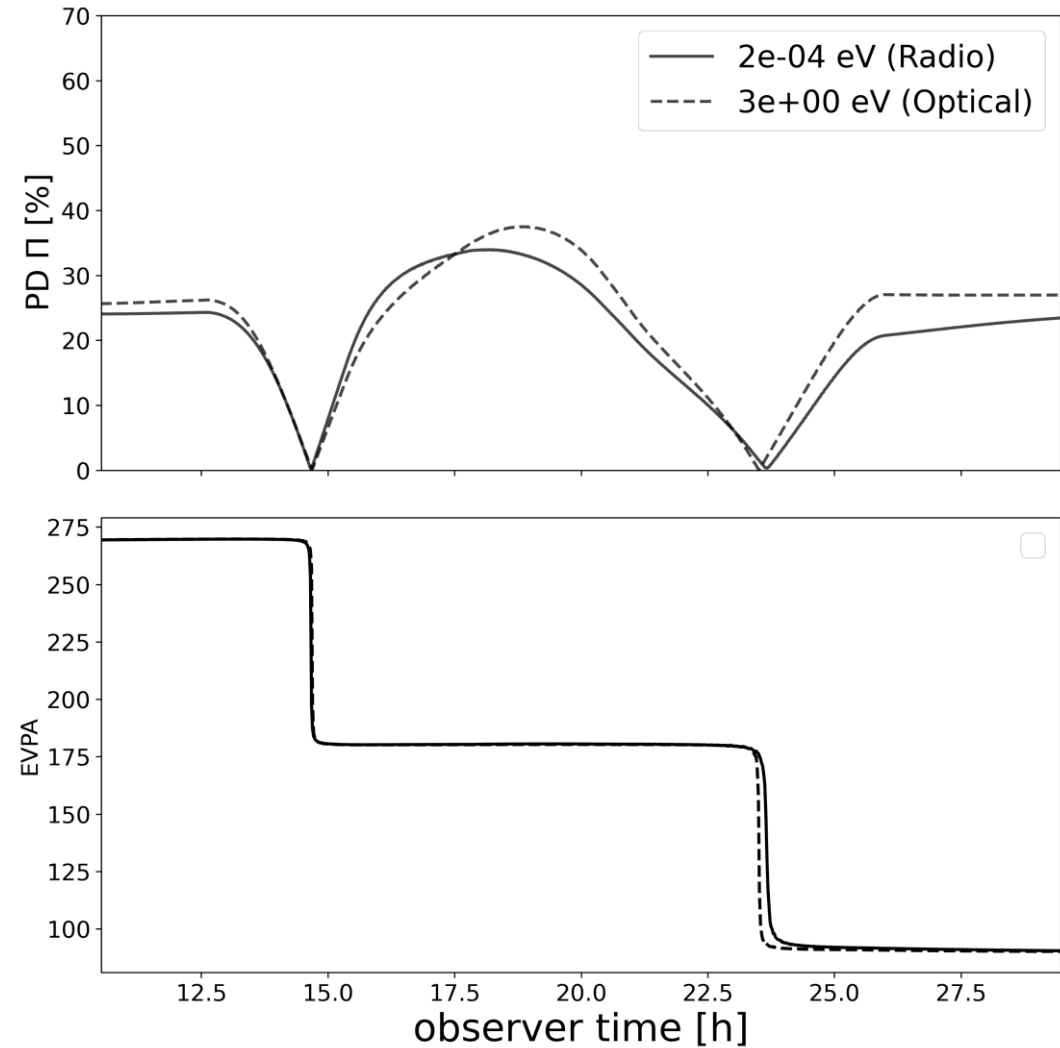
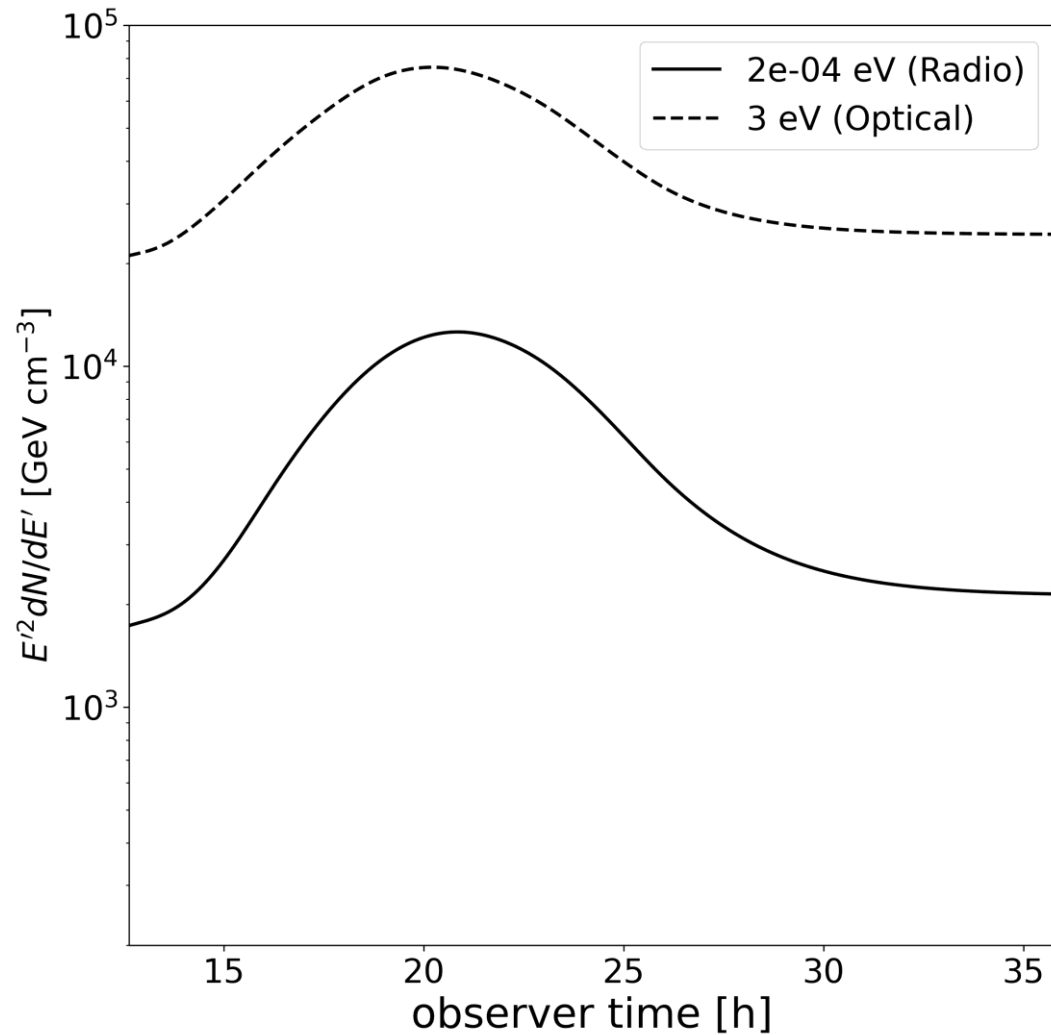


Figures taken from Zhang et al. 2014

*Shock propagates
through the
emission region*

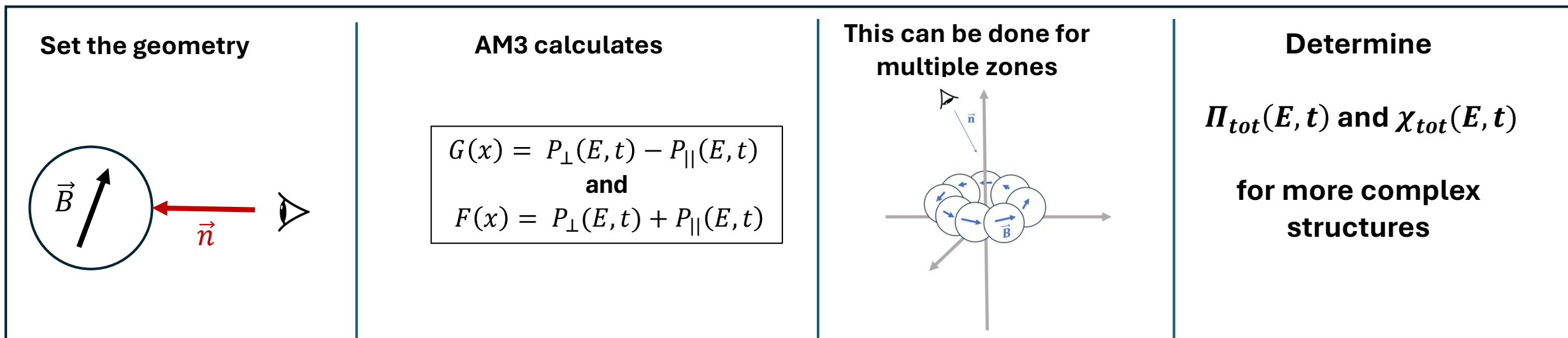


Shock-in-jet model using AM^3



Summary

We have implemented a method to model synchrotron polarization with AM³.

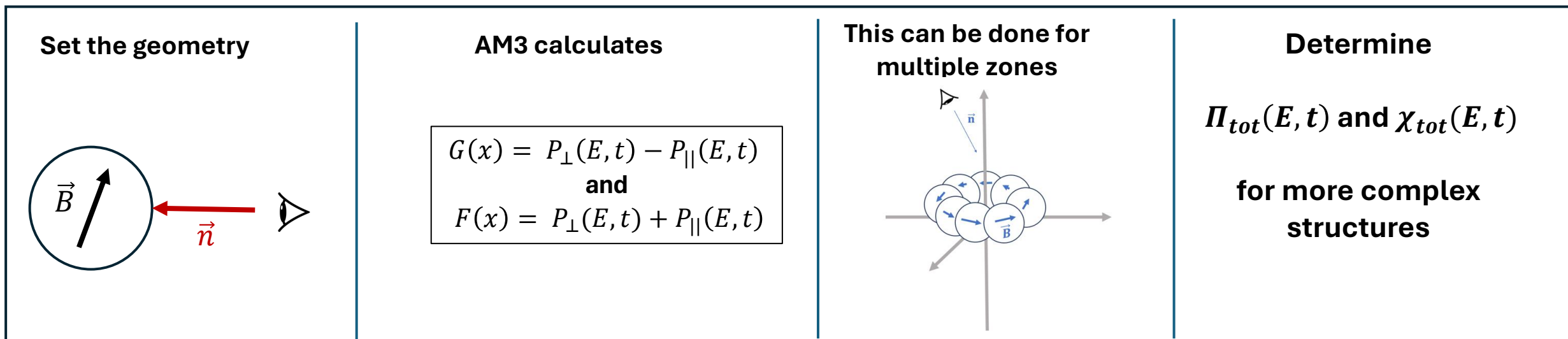


Outlook

- Investigate the impact of synchrotron self-absorption on polarization
- Enable public access to this feature
- Compare models with observed polarization data
- Consider high-energy polarization

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We have implemented a method to model synchrotron polarization with AM³.



Outlook

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Thank you!

Stokes Parameters

- I : Total intensity
- Q : Measures horizontal/vertical polarization
- U : Measures diagonal polarization
- V : Measures right-handed/left-handed circular polarization

