

ATP II: Gammastrahlung

Vorlesung 4

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Leptonische Erzeugung von Gamma-Strahlen

- Bremsstrahlung & Ionisation
- Inverse Compton-Streuung
- Synchrotronstrahlung

Hadronische Erzeugung von Gamma-Strahlen

- Hadronische Pionproduktion
- Pionzerfall und erwartete Gammaspektren

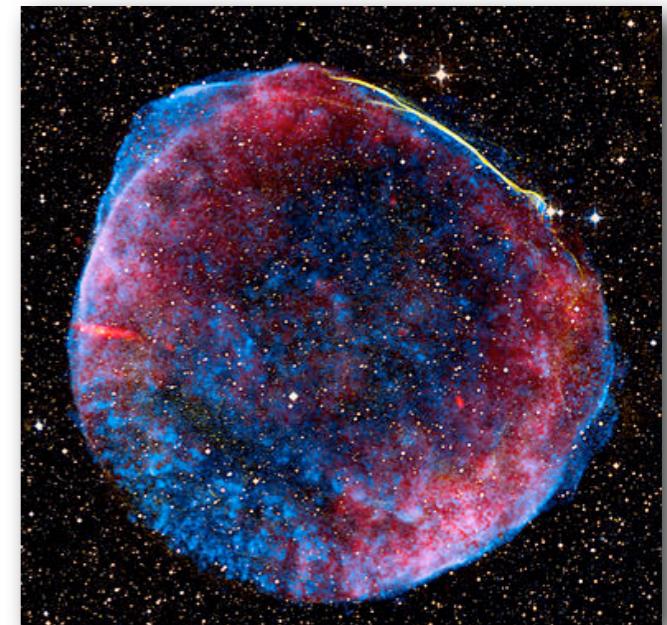
Dienstag		Donnerstag	
		23.04.2020	Vorlesung
		30.04.2020	Vorlesung
		07.05.2020	Vorlesung
12.05.2020	Übung	14.05.2020	Vorlesung
		-	Feiertag
		28.05.2020	Vorlesung
		04.06.2020	Vorlesung
09.06.2020	Übung	-	Feiertag
		18.06.2020	Vorlesung
23.06.2020	Übung	25.06.2020	Vorlesung
		02.07.2020	Vorlesung
07.07.2020	Übung	09.07.2020	Vorlesung
		16.07.2020	Vorlesung
21.07.2020	Übung	23.07.2020	Vorlesung

Bedingungen in astrophysikalischen Objekten

Schockfronten: Beschleunigung von Elektronen, Positronen, Protonen, ... Kernen
(Potenzgesetz in der Energieverteilung?)

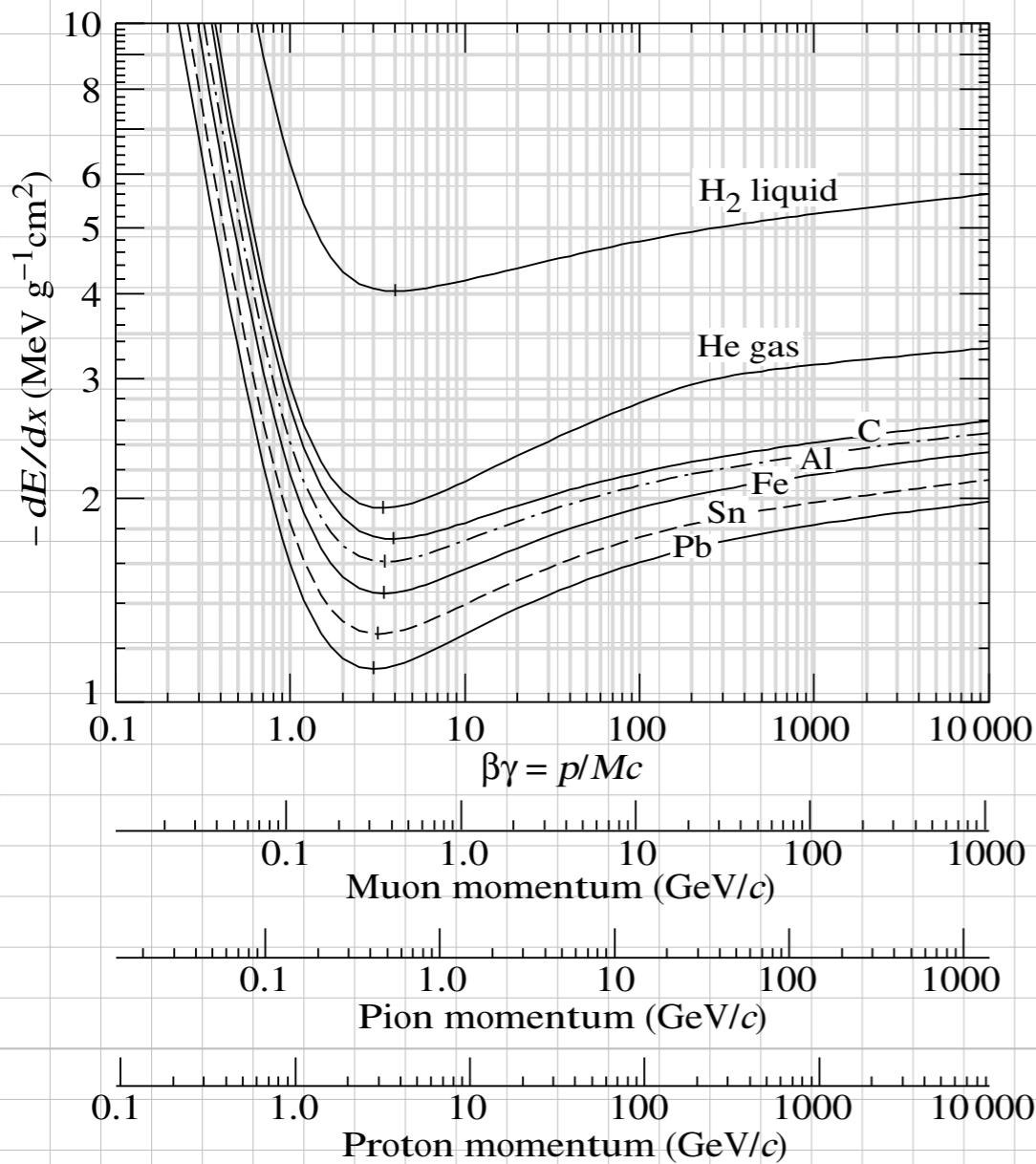
Umgebung: Restgas- und Molekülwolken, Photonen verschiedener Strahlungsfelder (CMB, Sternenlicht, lokal erzeugte Strahlung)

Beispiele:
SN-Überreste,
Aktive Galaxiekerne



Ionisation

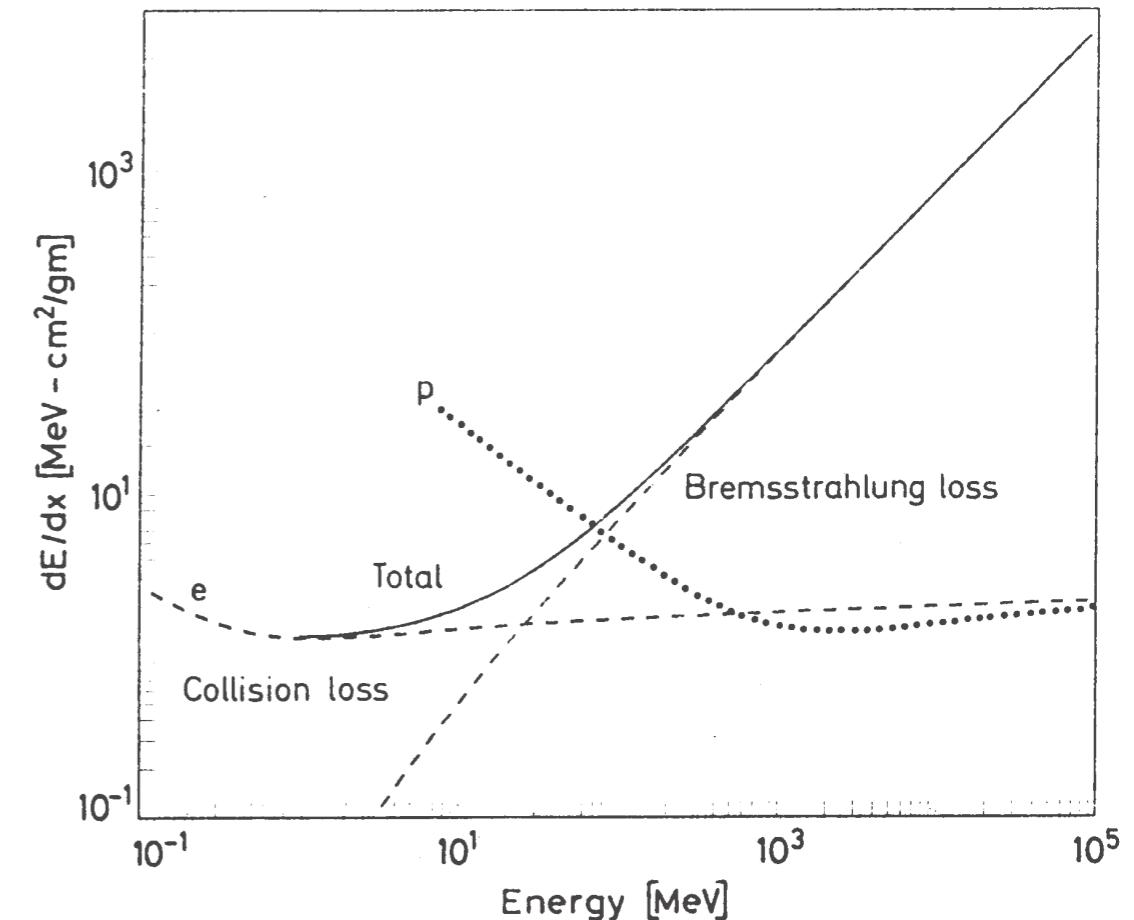
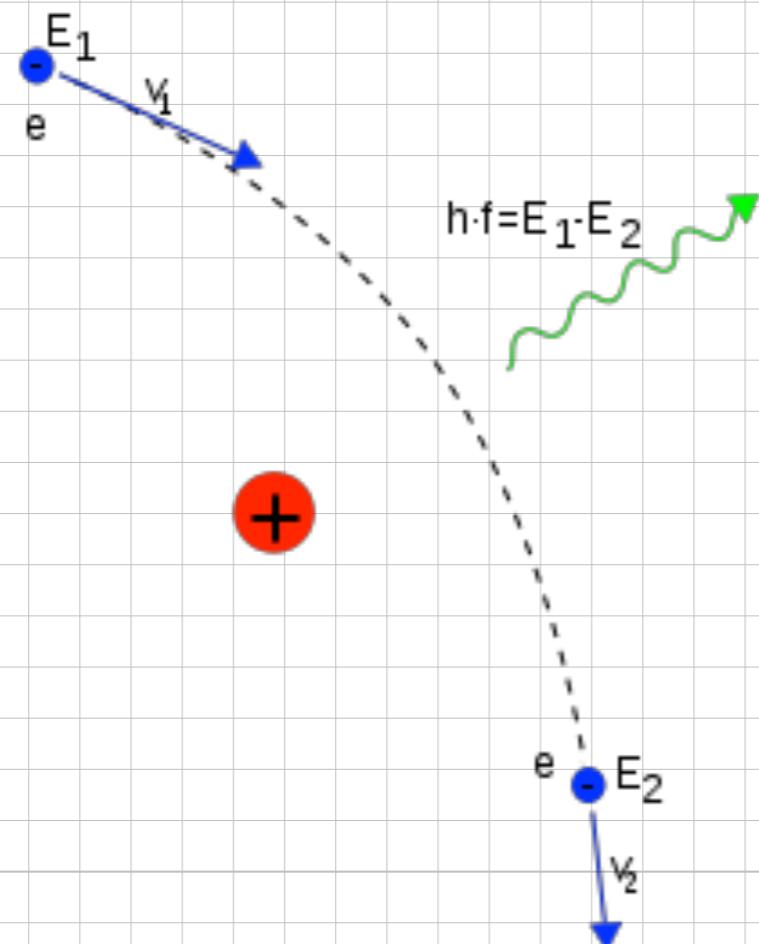
$$-\frac{dE}{dx} = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

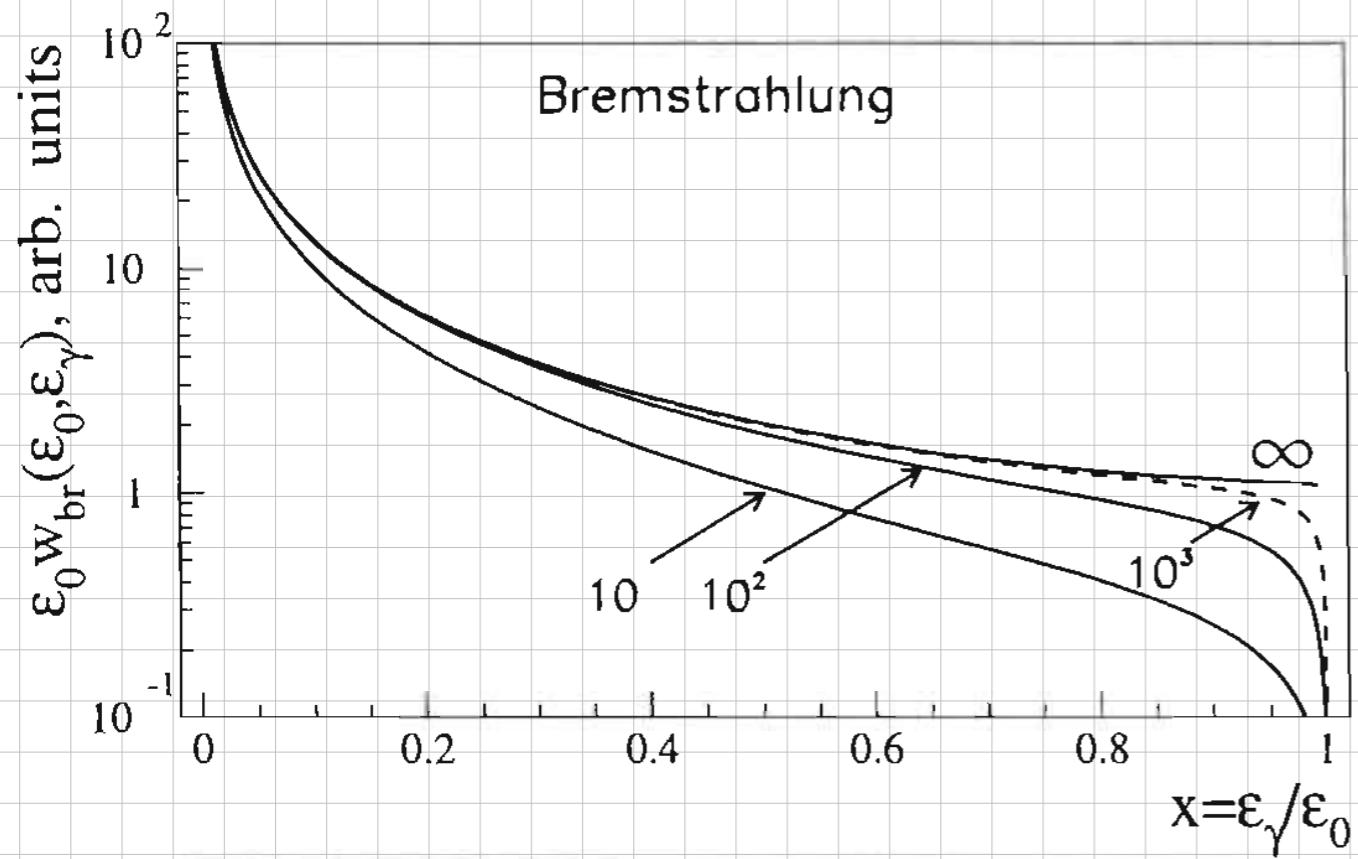


- K – $4\pi N_A r_e^2 m_e c^2 \approx 0.307 \text{ MeV}/(\text{g/cm}^2)$,
- N_A – Avogadro's number,
- r_e – classical electron radius ($\approx 2.82 \text{ fm}$),
- $m_e c^2$ – electron rest energy ($\approx 511 \text{ keV}$),
- z – charge number of the incident particle,
- Z, A – target charge number and target mass number,
- β – velocity ($= v/c$) of the incident particle,
- γ – $1/\sqrt{1 - \beta^2}$,
- T_{\max} – $\frac{2m_e p^2}{m_0^2 + m_e^2 + 2m_e E/c^2}$
maximum energy transfer to an electron,
- m_0 – mass of the incident particle,
- p, E – momentum and total energy
of the projectile,
- I – average ionization energy of the target,
- δ – density correction.

Bremsstrahlung

Schnelle geladene Teilchen verlieren zusätzlich zu ihrem Energieverlust durch **Ionisation (Bethe-Bloch)** Energie durch Wechselwirkung mit dem **Coulombfeld der Kerne**.



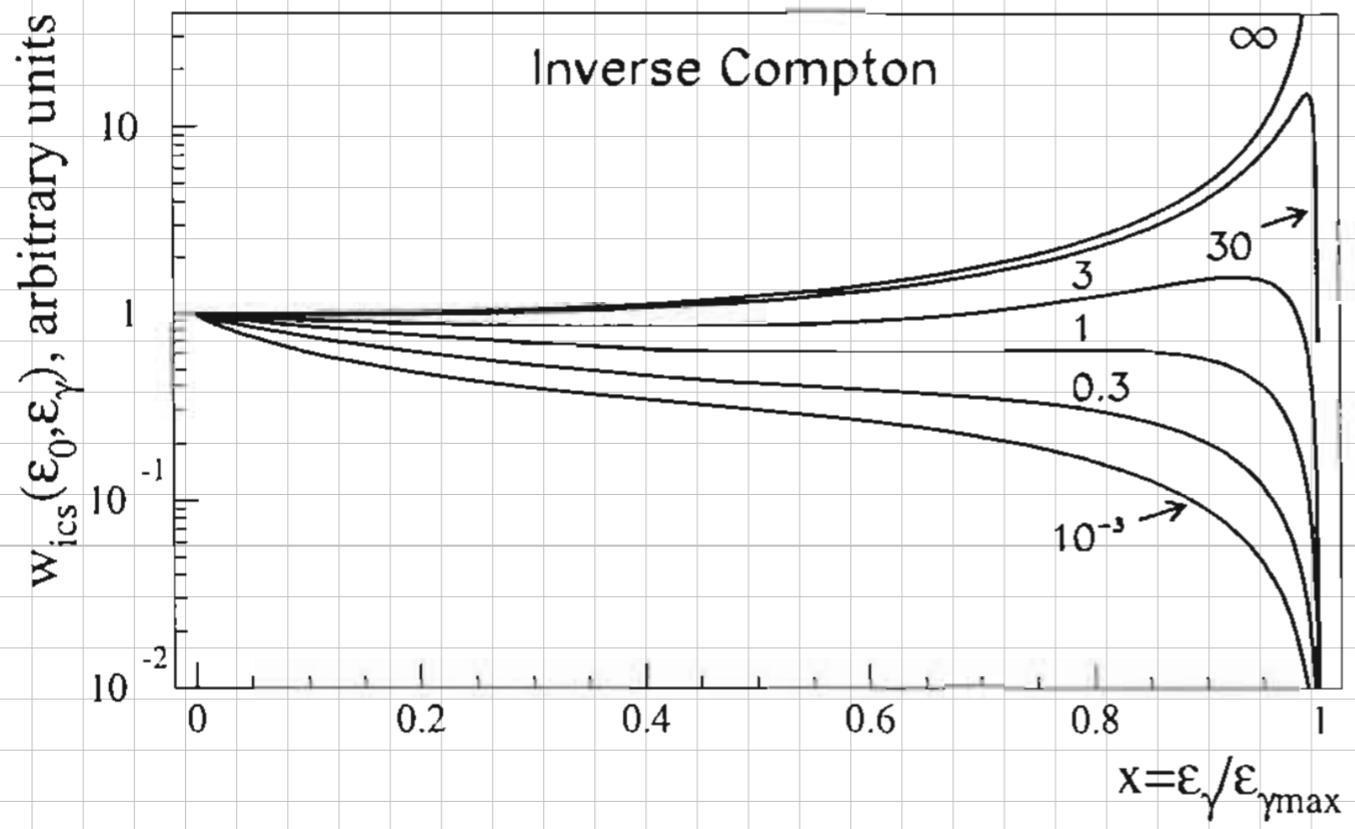


$$\sigma_0 = 4\alpha_{\text{em}} r_e^2 Z(Z+1) \frac{\ln(183Z^{-1/3})}{1 + 0.12(Z/82)^2}$$

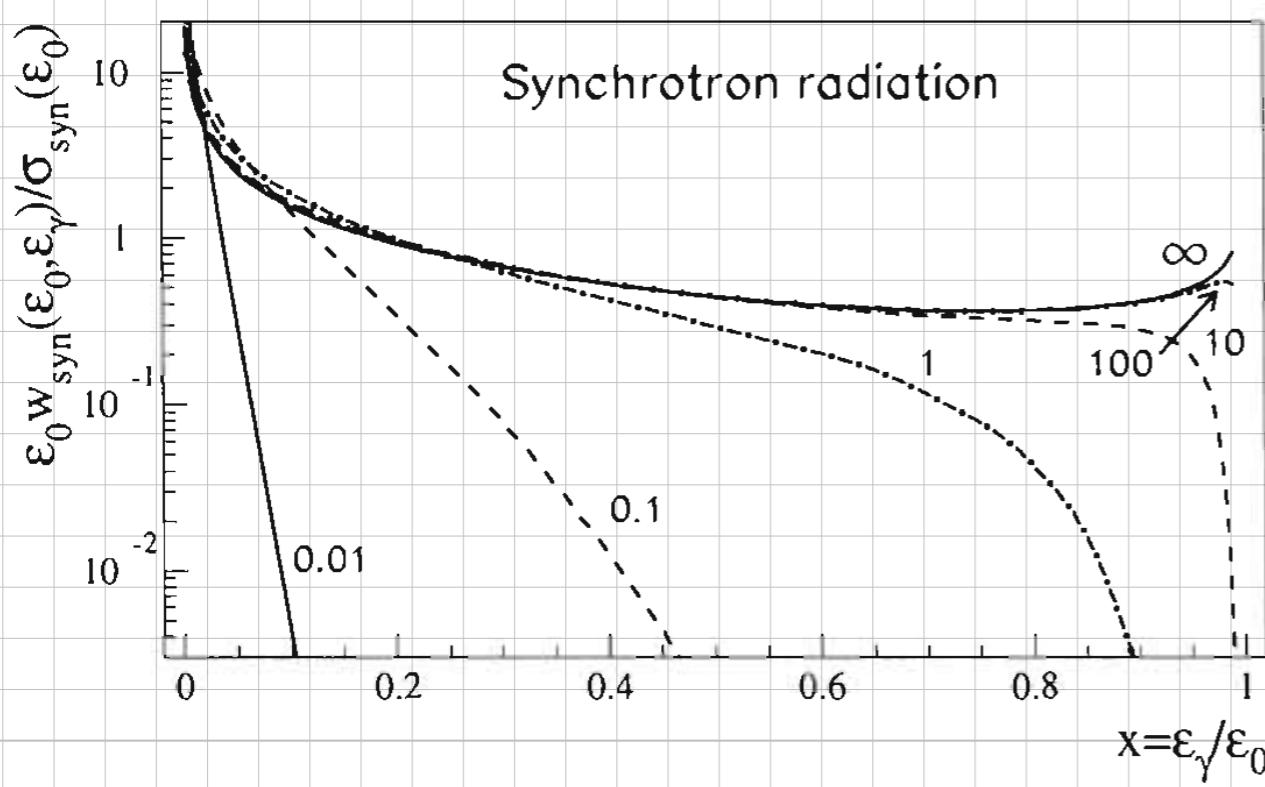
Anwendung: erwartetes Photonspektrum

Compton-Streuung

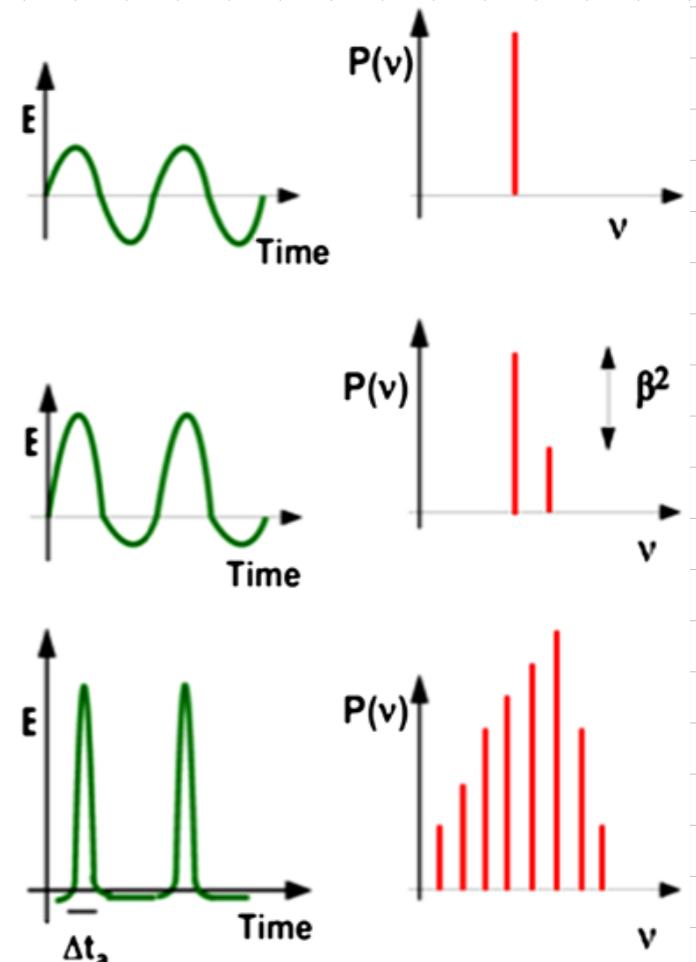
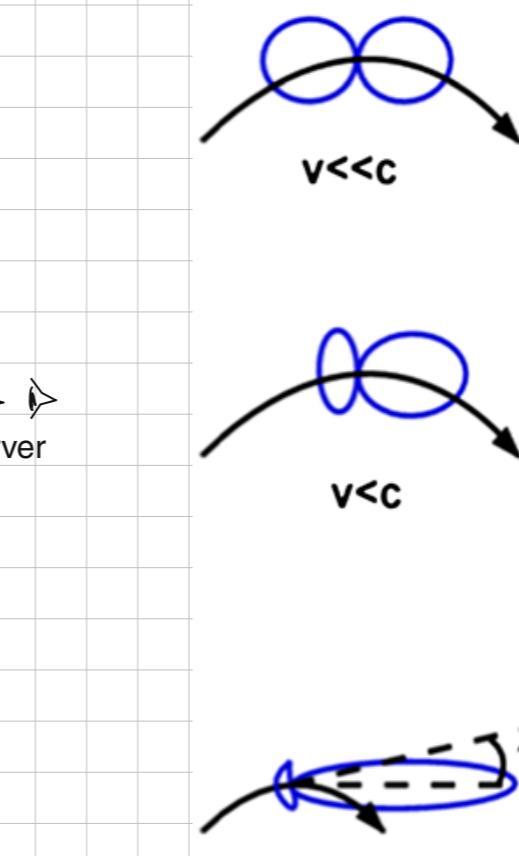
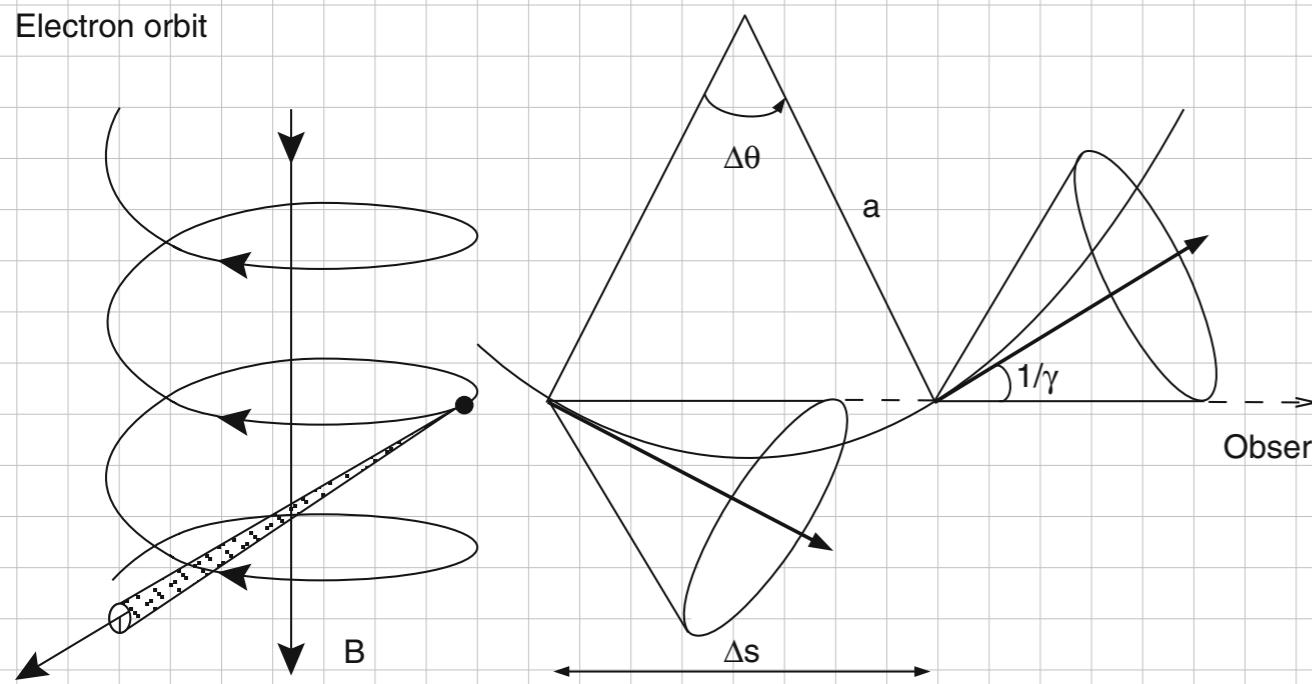
Inverse Compton-Streuung



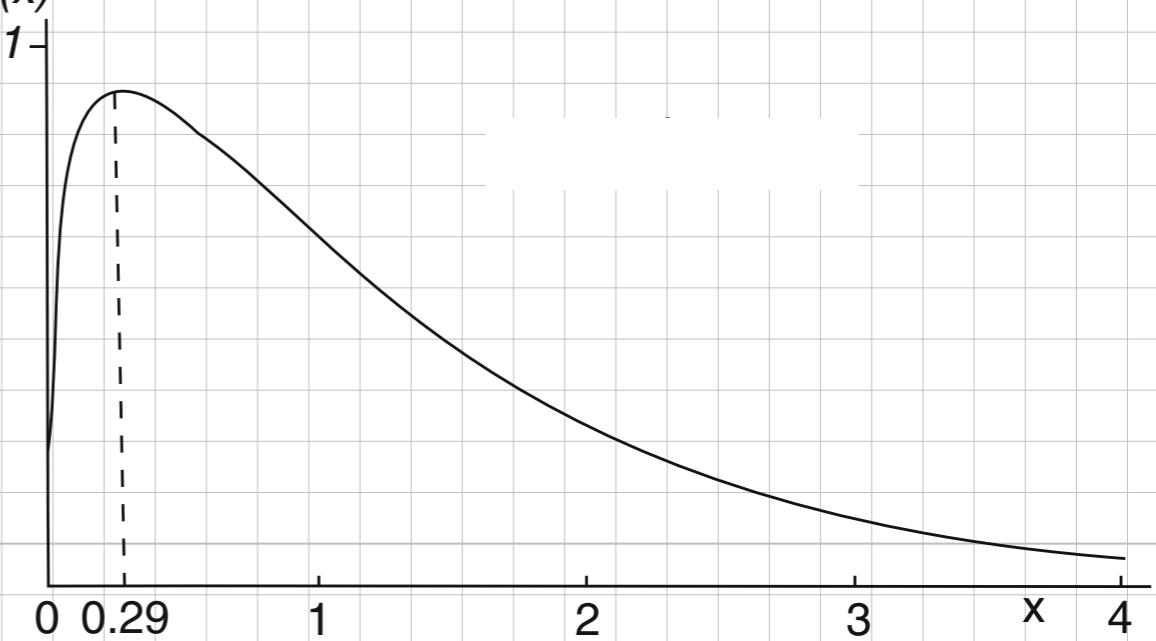
Synchrotronstrahlung

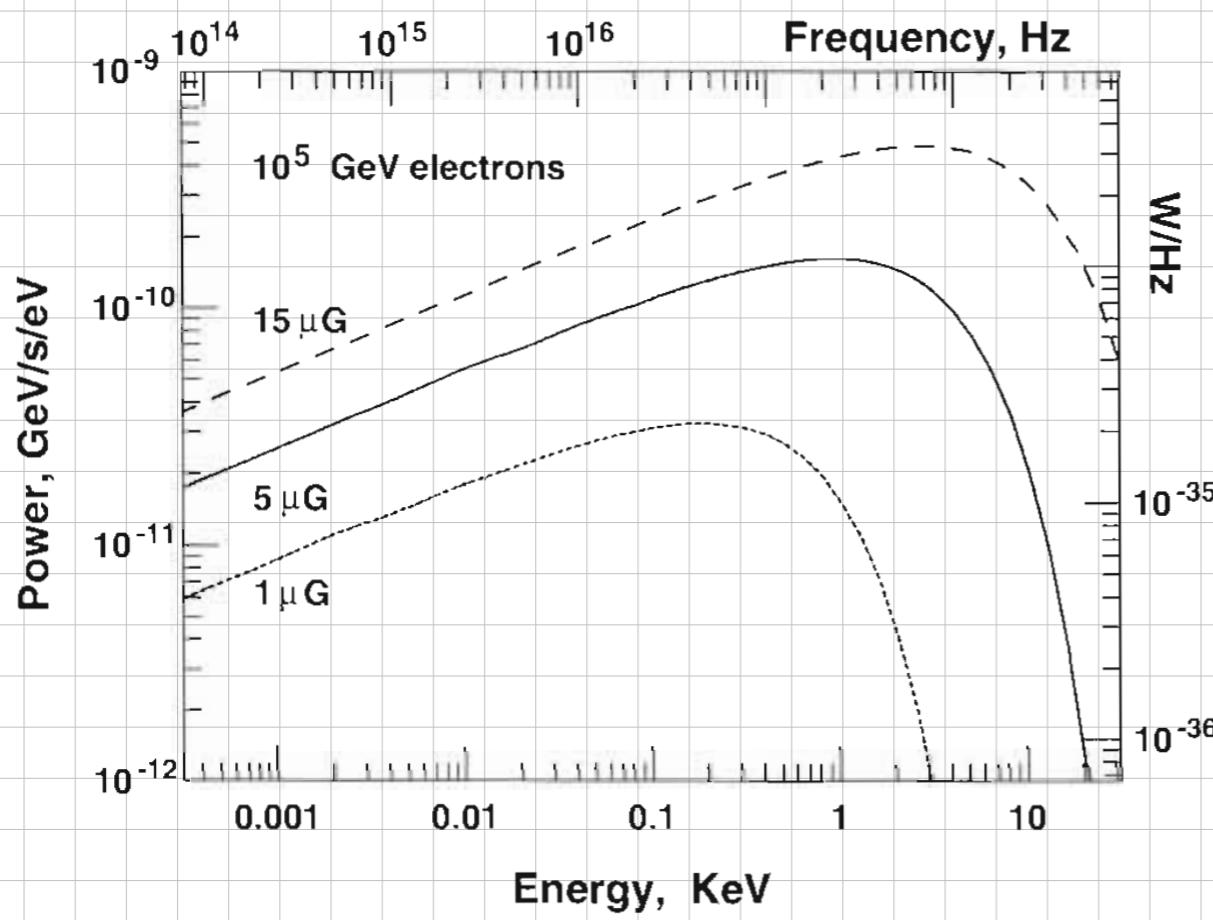


Electron orbit



$$F(x)$$





$$v_c = \frac{3}{4\pi} \gamma^2 \frac{eB_{\perp}}{m_e c}$$

Synchrotronstrahlung von Protonen

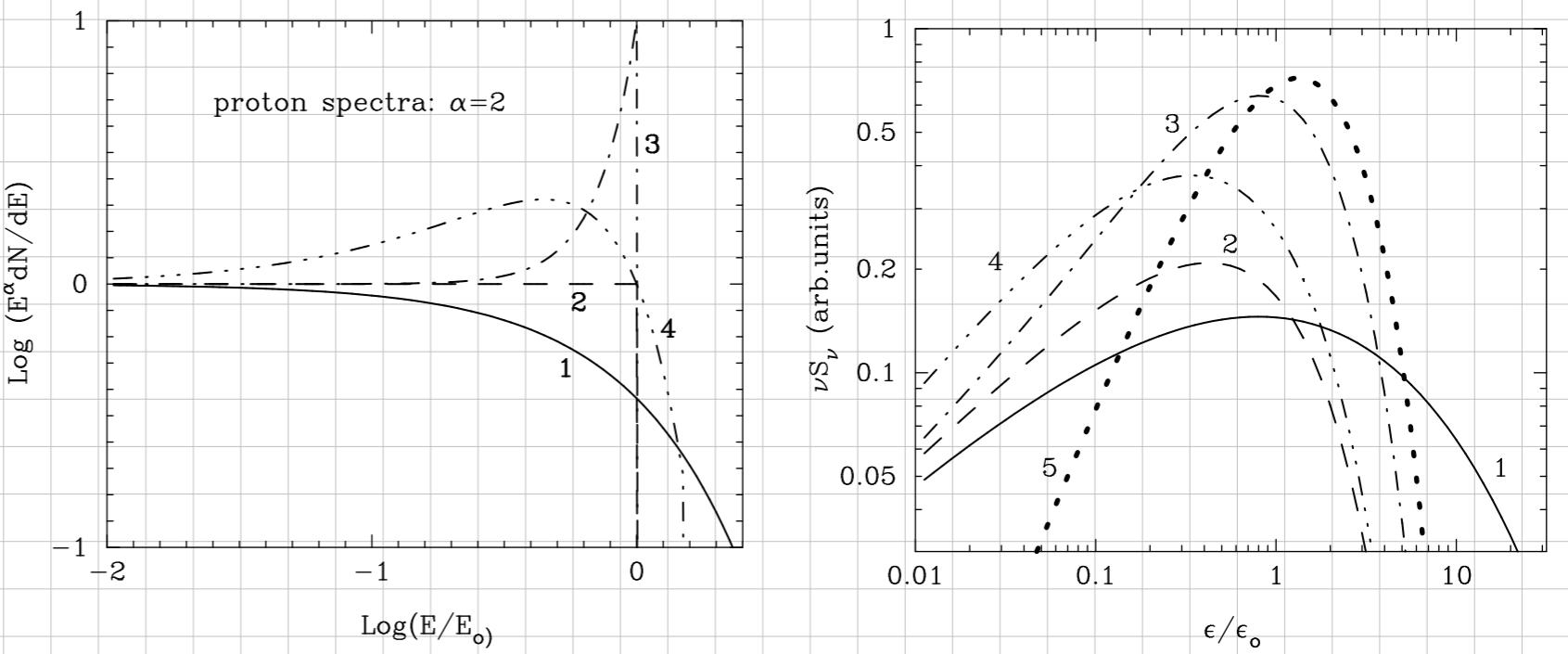


Fig. 3.8 (a) Possible spectra of accelerated protons (left panel), and (b) the corresponding Spectral Energy Distributions of their synchrotron radiation (right panel). At energies $E \ll E_0$ all proton spectra have power-law behaviour with $\alpha_p = 2$, but in the “cutoff” region around E_0 they have very different shapes. Curve 1 corresponds to the proton spectrum described by a power-law with exponential cutoff; curve 2 corresponds to the truncated proton spectrum; curve 3 corresponds to the proton spectrum with a sharp pile-up and an abrupt cutoff at E_0 ; curve 4 corresponds to the proton spectrum with a smooth pile-up and a super-exponential cutoff. For comparison, in the right panel the spectrum of the synchrotron radiation of mono-energetic protons, $x F(x) \propto x^{4/3} \exp(-x)$, is also shown (curve 5).

$$v_c = \frac{3}{4\pi} \gamma^2 \frac{eB_\perp}{m_e c}$$

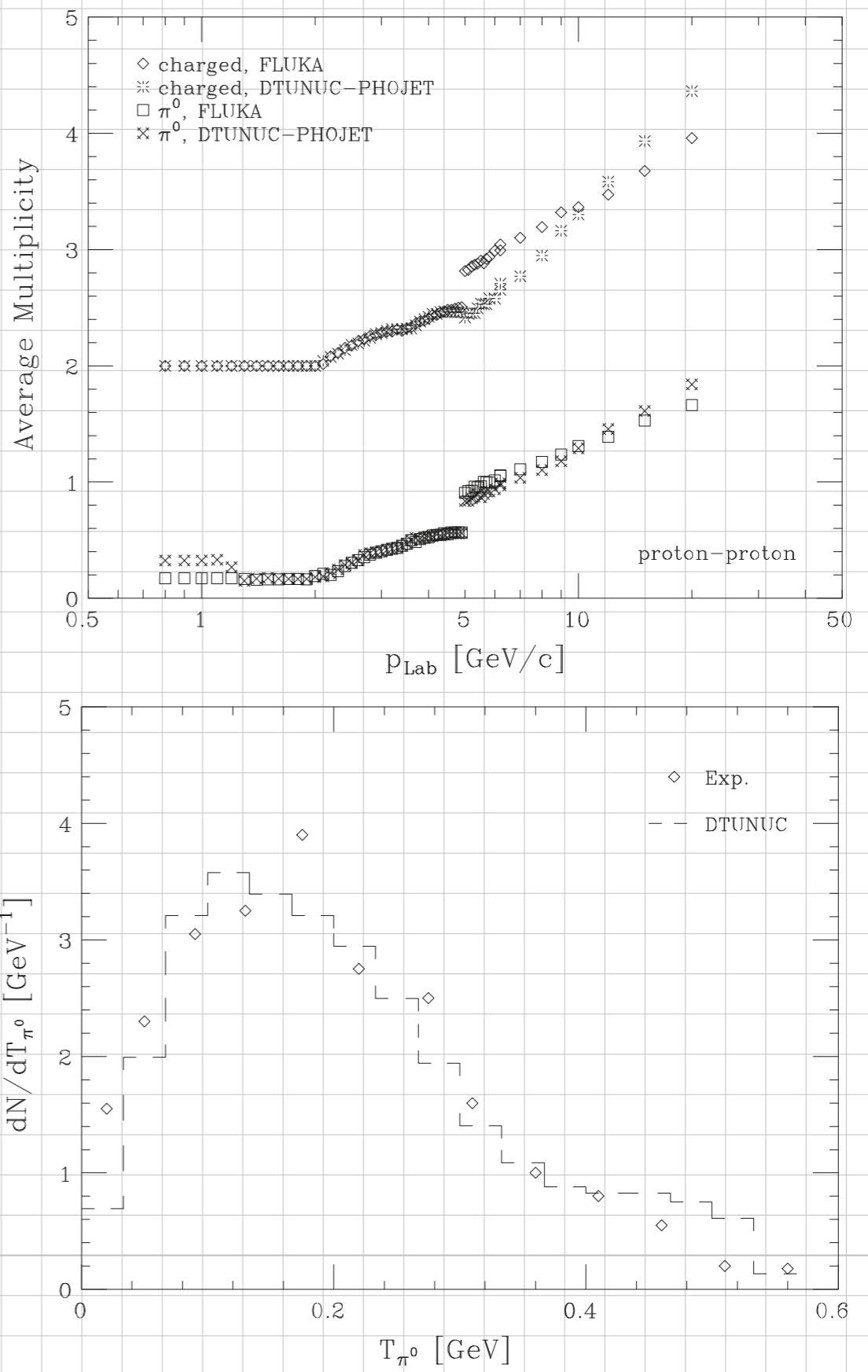
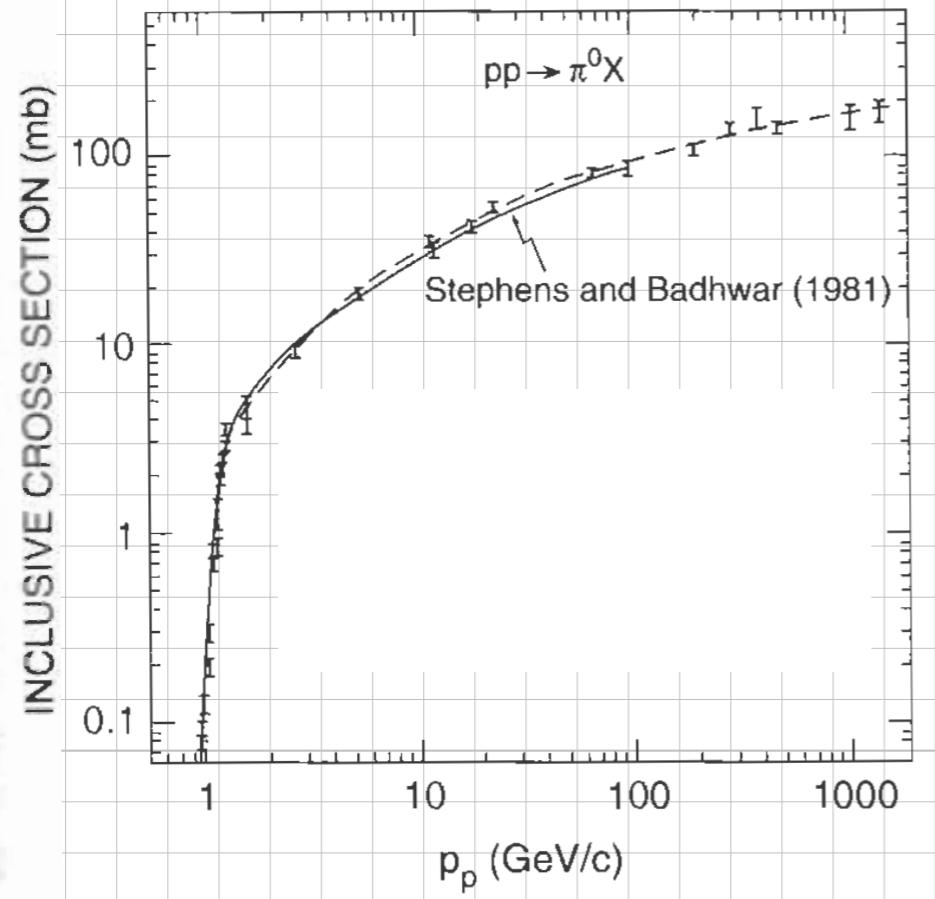
Zusammenfassung: leptonische Erzeugungsprozesse

Bremsstrahlung

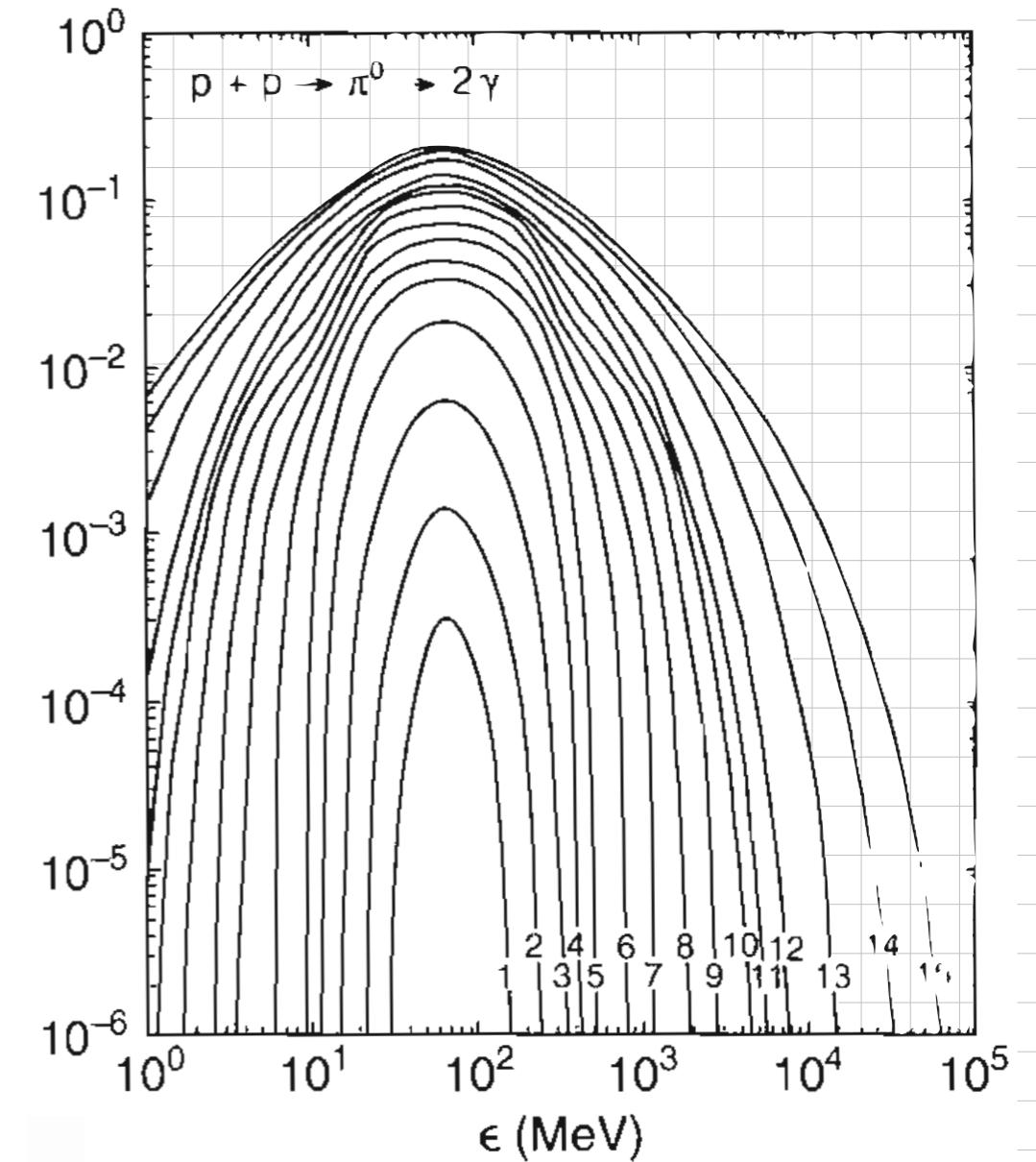
Inverse Comptonstreuung

Synchrotronstrahlung

Hadronische Erzeugung von Gamma-Strahlen



Hadronische Erzeugungsspektren



<u>E (MeV)</u>	<u>E (MeV)</u>
1	3.16×10^2
2	3.83×10^2
3	4.64×10^2
4	5.62×10^2
5	6.61×10^2
6	1.00×10^3
7	1.47×10^3
8	2.15×10^3
9	3.16×10^3
10	4.64×10^3
11	6.81×10^3
12	1.00×10^4
13	2.15×10^4
14	4.64×10^4
15	1.00×10^5
16	

