Measuring the magnetic dipole moment of the τ lepton using bent crystals at LHC

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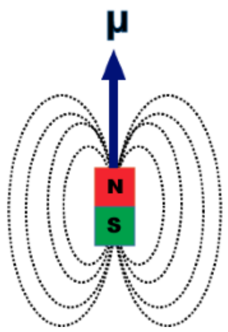
INTRODUCTION: Magnetic dipole moment (MDM) of short-living particles



$$\vec{\mu} = \frac{g}{2}\frac{e}{m}\vec{S}, \qquad \vec{S} = \frac{\hbar}{2}\vec{\sigma}$$

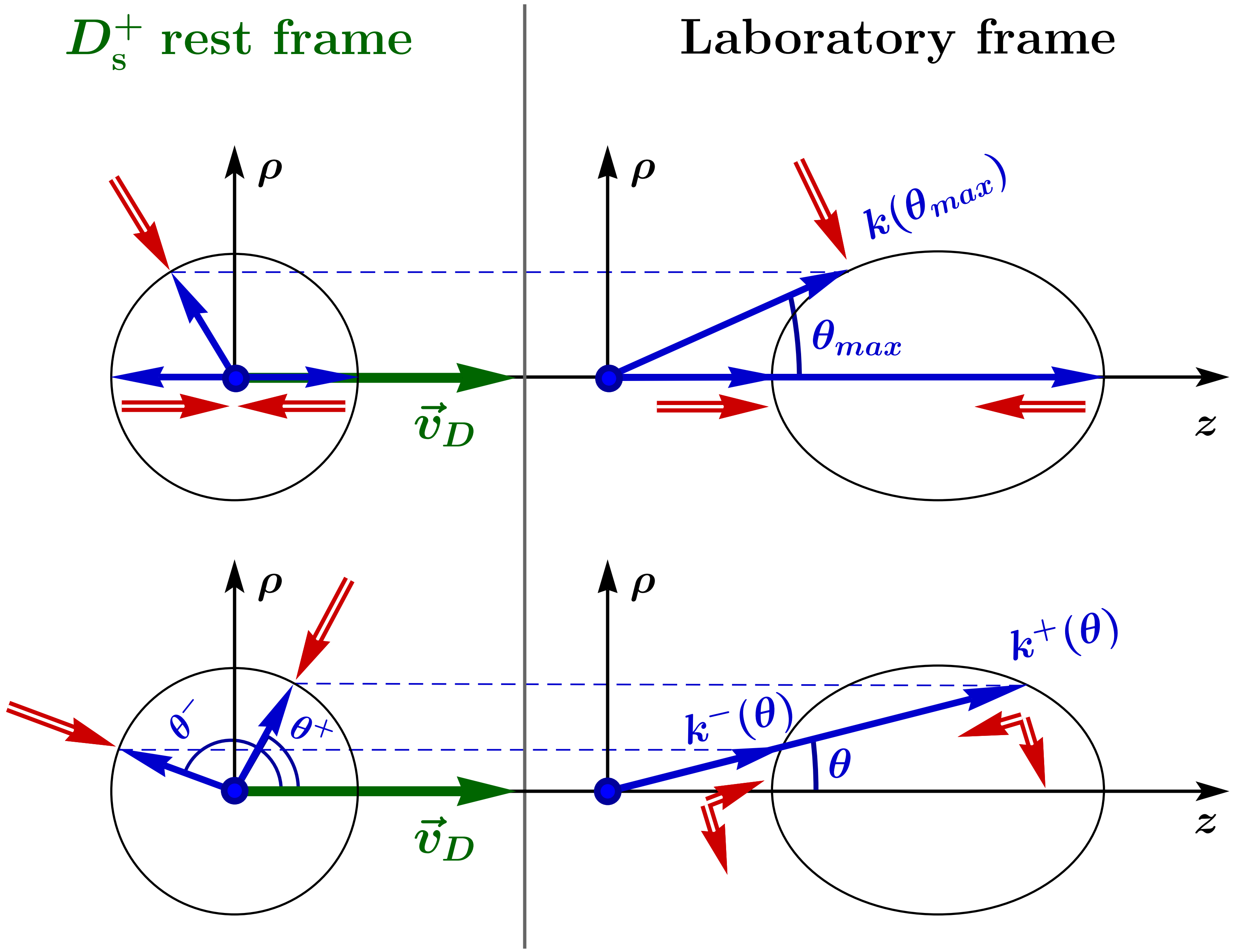
$|g| = 2$ → a point-like Dirac particle

$|g| \approx 2$ → a radiative corrections

$|g| \not\approx 2$ → a composite structure or NP

Particle	cτ	g-factor		Comments	Experiment
e^-		– 2.002 319 304 361 82 (52)	exp.	most accurate determinations of α	Harvard 2008
μ^-	659 m	– 2.002 331 8361 (10)	theor.	SM prediction	
		– 2.002 331 8418 (13)	exp.	3.4 σ deviation	BNL: E821 2006
τ^-	87 μm	– 2.002 354 42 (10)	theor.	SM prediction	
		– 2.036 (34)	exp.	$\sigma(e^+e^- \to e^+e^-\tau^+\tau^-)$	LEP2: DELPHI 2004
		– 2.002 (6)	*exp.*	*assuming EDM $_\tau$ = 0*	*from LEP and SLD 2000*
		no direct measurement	exp.	Proposed in the current study	
p		+ 5.585 694 702 (17)	exp.		
n		– 3.826 085 45 (90)	exp.		
Σ^+	2.4 cm	+ 6.233 (25)	exp.	world-average value	
		+ 6.1 $(12)_{stat}$ $(10)_{syst}$	exp.	using Bent Crystals	Fermilab 1992
Λ_c^+	60 μm	+ 1.90 (15)	theor.	assuming $g_c \approx 2$	
		not measured	exp.	Feasibility studies at LHC	

$$D_s^+ \to \tau^+ \; \nu_\tau$$



$$|\vec{P}_\perp| = \frac{m_\tau p_D}{M_D k_\tau^*} \sin\theta,$$

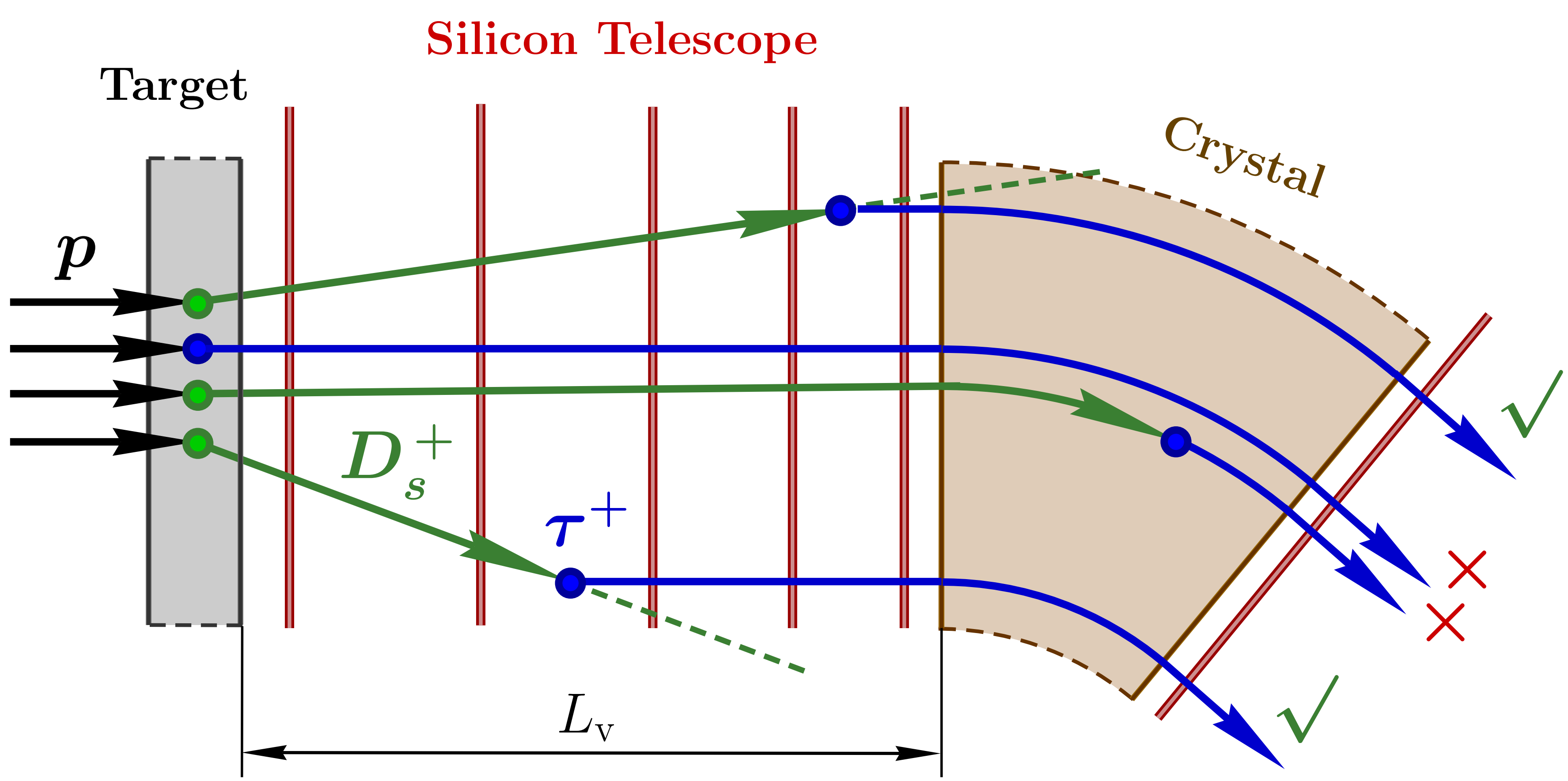
$$\vec{P}_\parallel^2 = 1 - \vec{P}_\perp^2$$

$$\theta_{max} \approx \frac{0.1025}{\gamma_D} \quad (\gamma_\tau \gg 1)$$

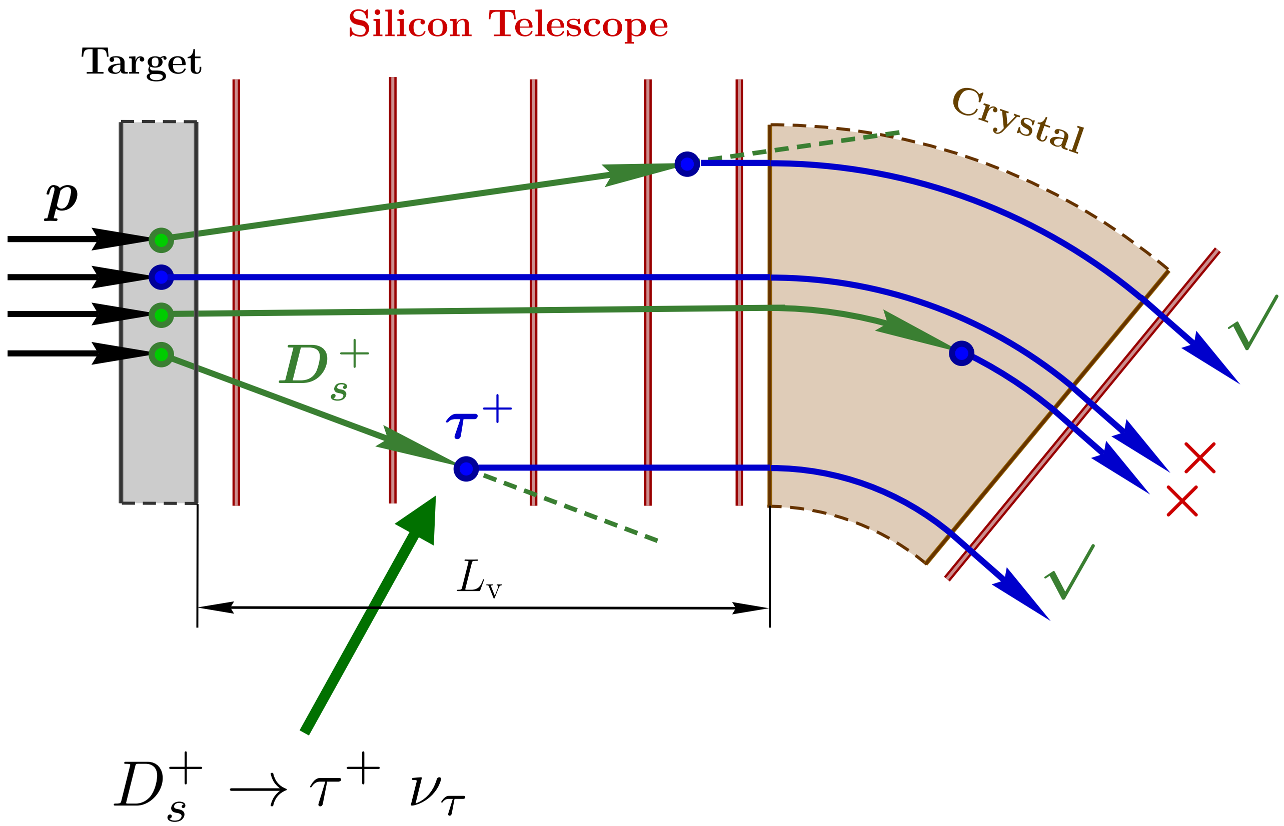
$$\vec{P}_\perp(\theta, 0) \approx -\vec{P}_\perp(\theta, \pi).$$

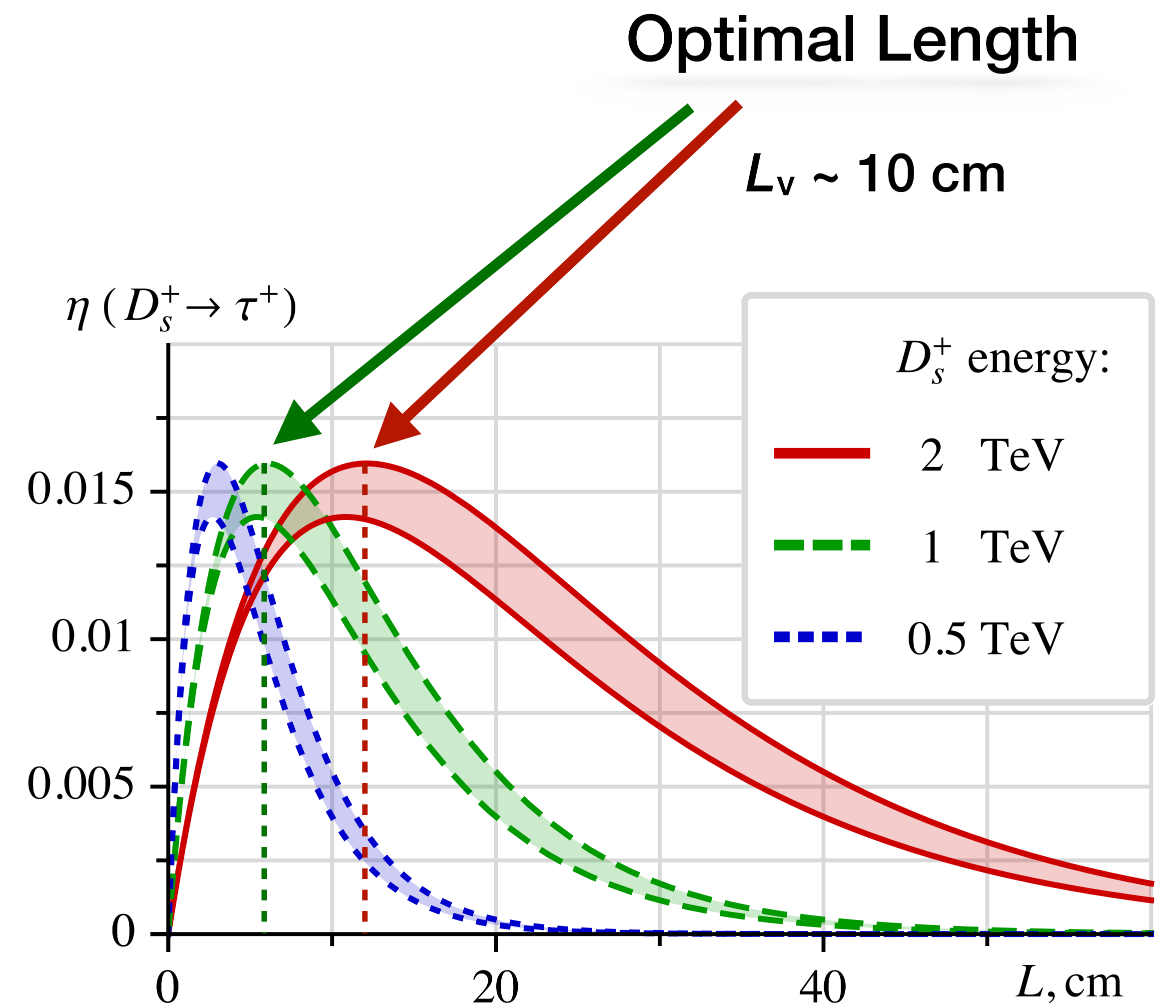
$$\theta_{max}(E_D = 2\,\text{TeV}) \approx 100\,\mu rad$$

$$p\,p \to D_s^+ \ldots \to \tau^+ \ldots \to 2\pi^+\,\pi^- \ldots$$



- we need to select events: $D_s^+ \Rightarrow \tau^+ \Rightarrow 2\pi^+\,\pi^-$ out of the background: $X^+ \Rightarrow 2\pi^+\,\pi^-$
- directions of D_s^+ and τ^+ momenta should be measured very accurately $\Delta\theta < 100$ μrad





$$\eta^*(L_v, E_D, \varepsilon_\tau^*) = Br_i \, \frac{e^{-L_v / T_D} - e^{-L_v / T_\tau}}{T_D / T_\tau - 1}$$

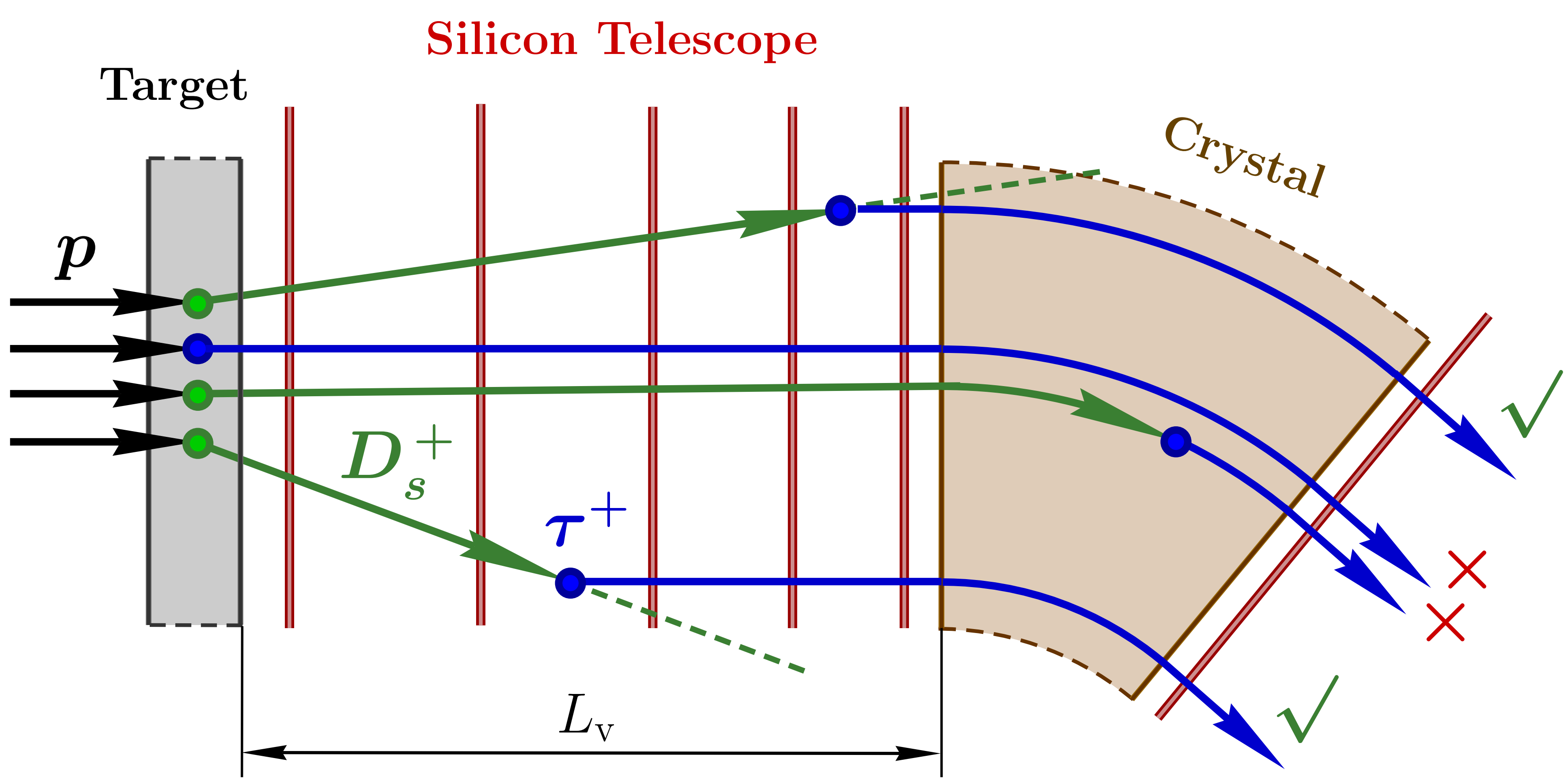
$$T_i = c\,\tau_i \gamma_i \qquad c\,\tau_D \approx 150\,\mu\text{m}$$

$$c\,\tau_\tau \approx 87\,\mu\text{m}$$

$$Br_j \approx 0.055$$

$$\eta(L_v, E_D) = \frac{\int_{\varepsilon_\tau^{min}}^{\varepsilon_\tau^{max}} d\varepsilon_\tau \, \frac{\partial N_\tau}{\partial \varepsilon_\tau} \int_0^{L_v} dx \, \frac{\partial N_{\text{prod}}}{\partial x} \, N_{\text{dec}}\,(L_v - x)}{\int_{\varepsilon_\tau^{min}}^{\varepsilon_\tau^{max}} d\varepsilon_\tau \, \frac{\partial N_\tau}{\partial \varepsilon_\tau}}$$

$$p\,p \to D_s^+ \ldots \to \tau^+ \ldots \to 2\pi^+\,\pi^- \ldots$$



- we need to select events: $D_s^+ \Rightarrow \tau^+ \Rightarrow 2\pi^+\,\pi^-$ out of the background: $X^+ \Rightarrow 2\pi^+\,\pi^-$
- directions of D_s^+ and τ^+ momenta should be measured very accurately

Problems:
- the background overload,
- the telescope should have a very high angular resolution $\Delta\theta < 100$ μrad on a rather short base $L_{\rm v} \sim 10$ cm.

Crystal 1:

Ge: L = 3 cm R = 10 m

Si: L = 4.5 cm R = 15 m

Θ_D = 3 mrad

θ_p = 0.1 mrad

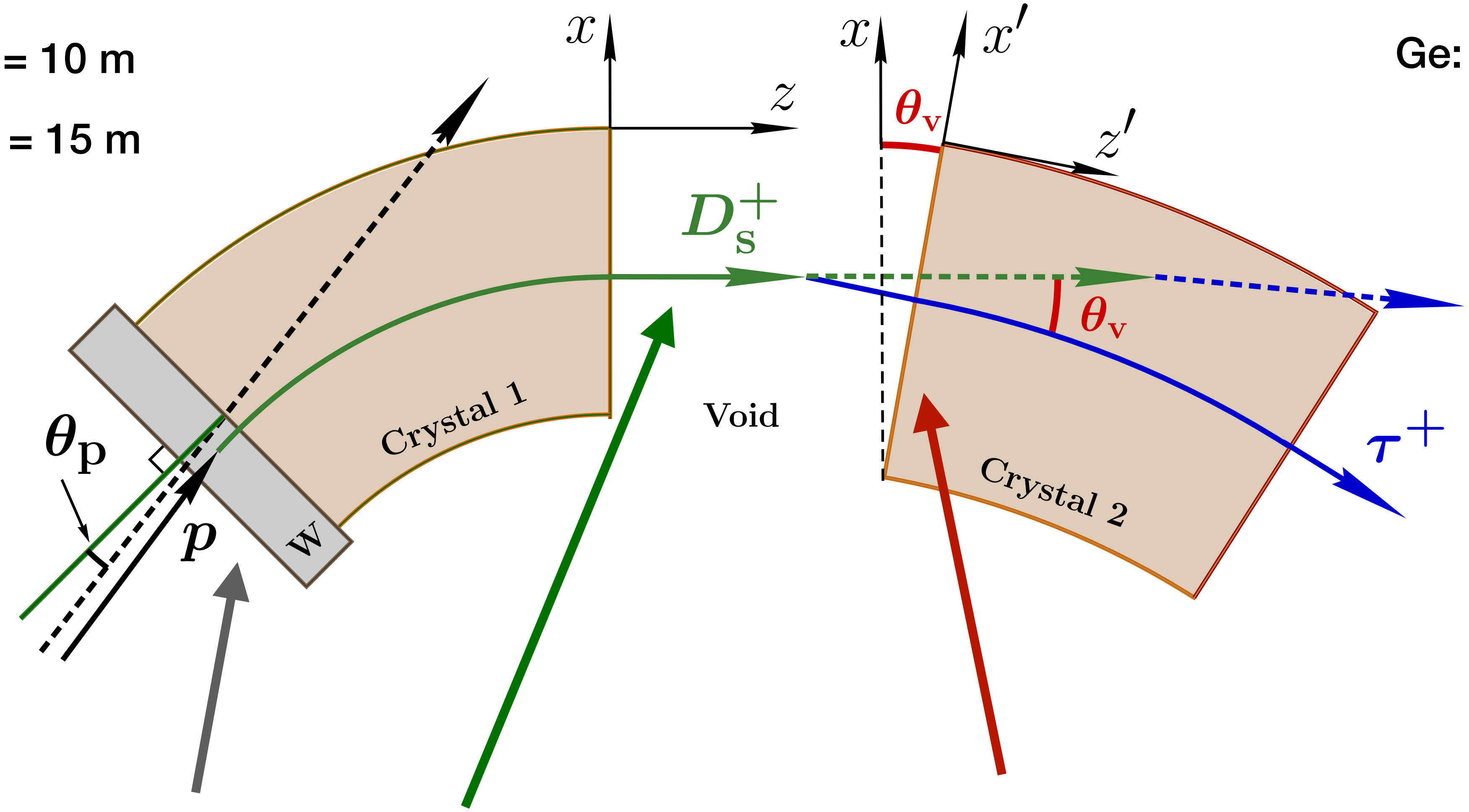
Crystal 2:

Ge: L = 10 cm R = 7 m

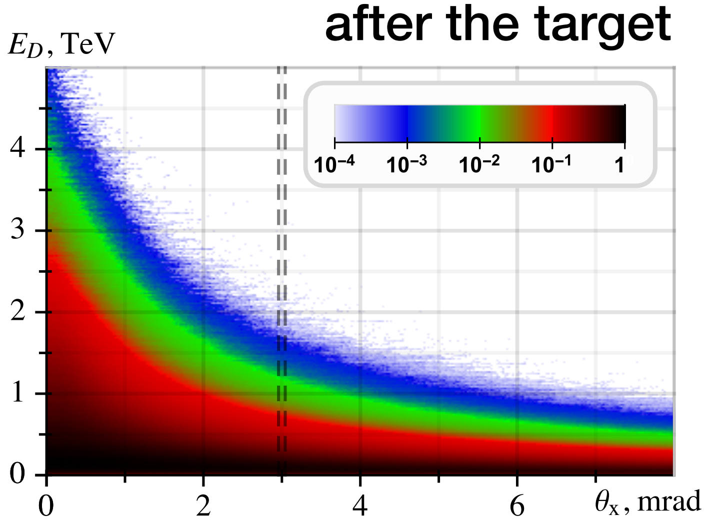
Θ_τ = 14 mrad

θ_v = 0.08 mrad

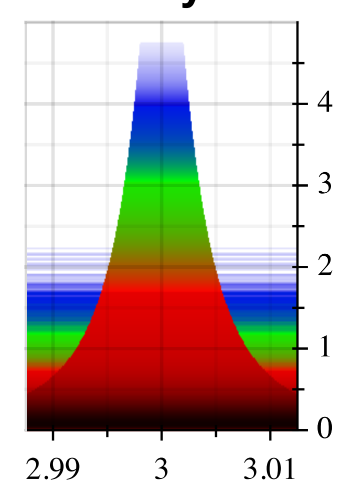
L_v = 10 cm



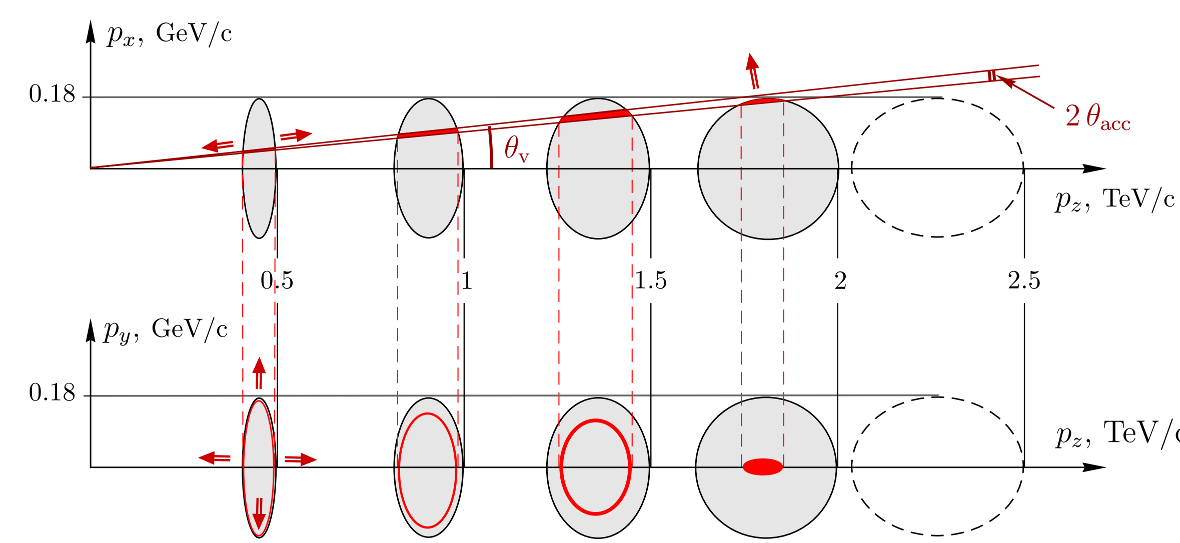
Sp.-ang. distribution of Ds after the target

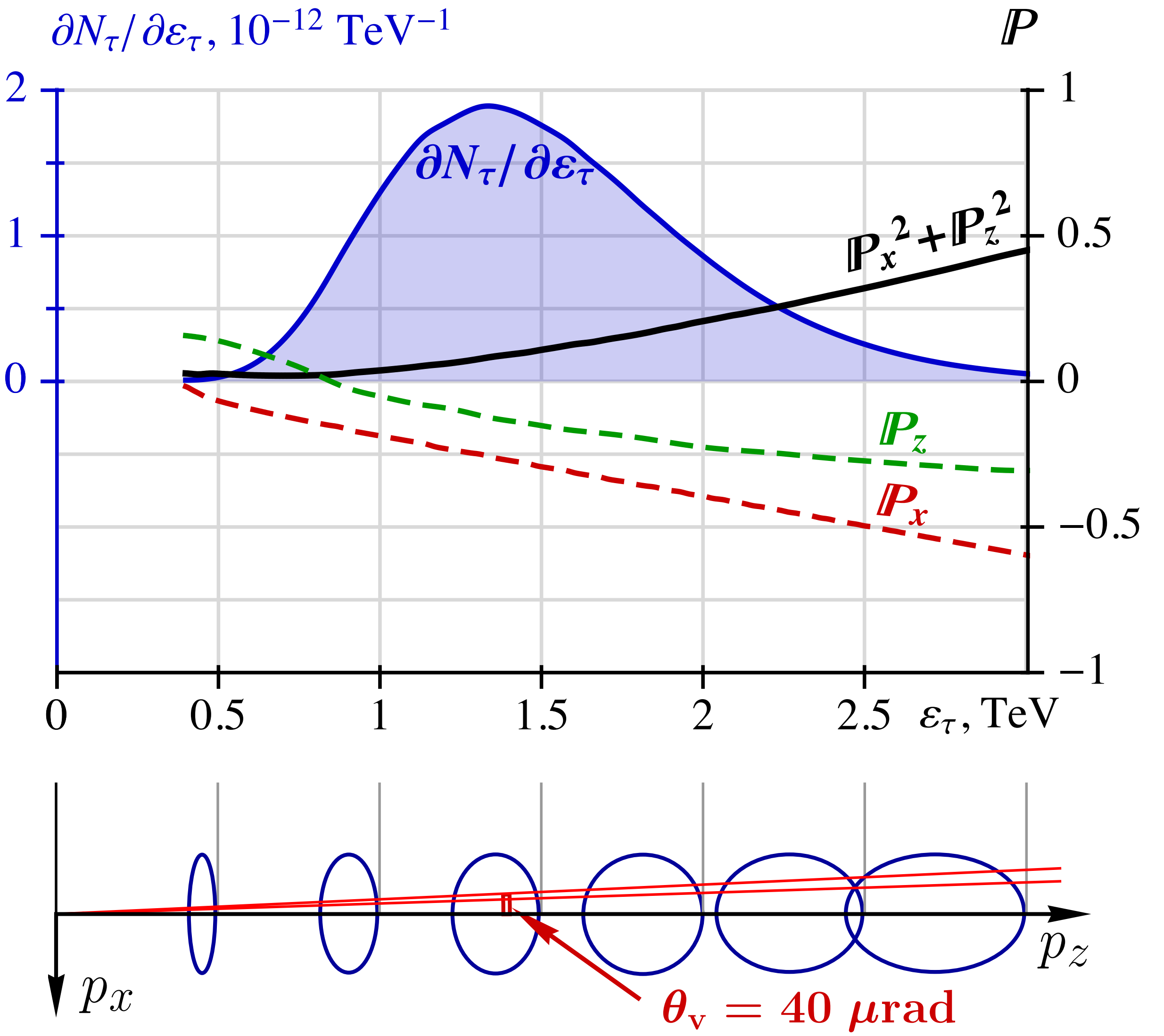


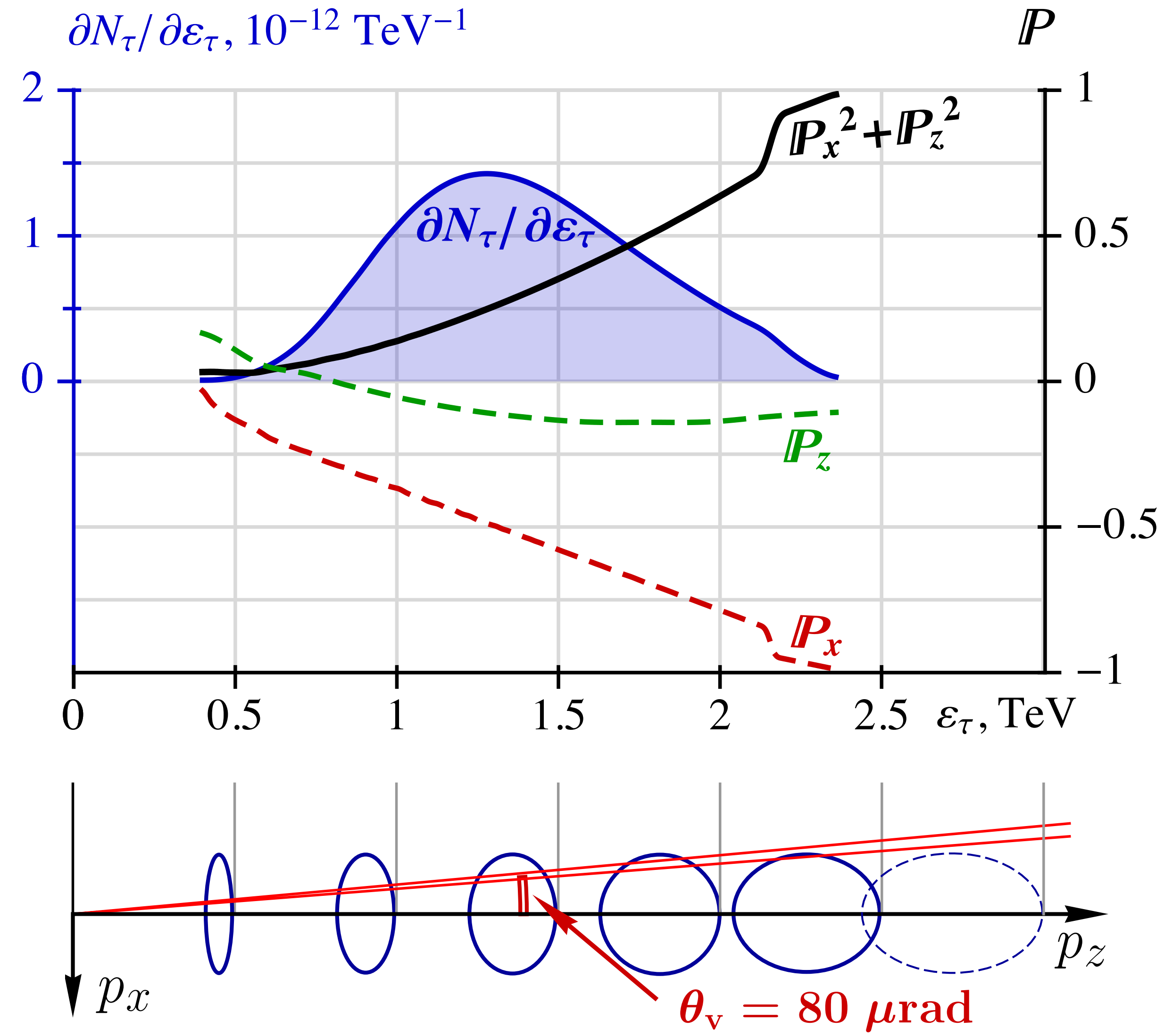
after Crystal 1



Angular collimation of τ by Crystal 2







Spectra:

$$\frac{\partial N_\tau^{\rm def}}{\partial \varepsilon_\tau} = \int_0^{\varepsilon_{\rm max}} dE_D \, \frac{\partial N_D}{\partial E_D} \, \eta\left(L_{\rm v}, E_D\right) \, \frac{\partial N_\tau}{\partial \varepsilon_\tau}(E_D) \, \eta_{\rm coll}(E_D, \varepsilon_\tau) \, \eta_{\rm chan}\left(\varepsilon_\tau\right)$$

Polarisation:

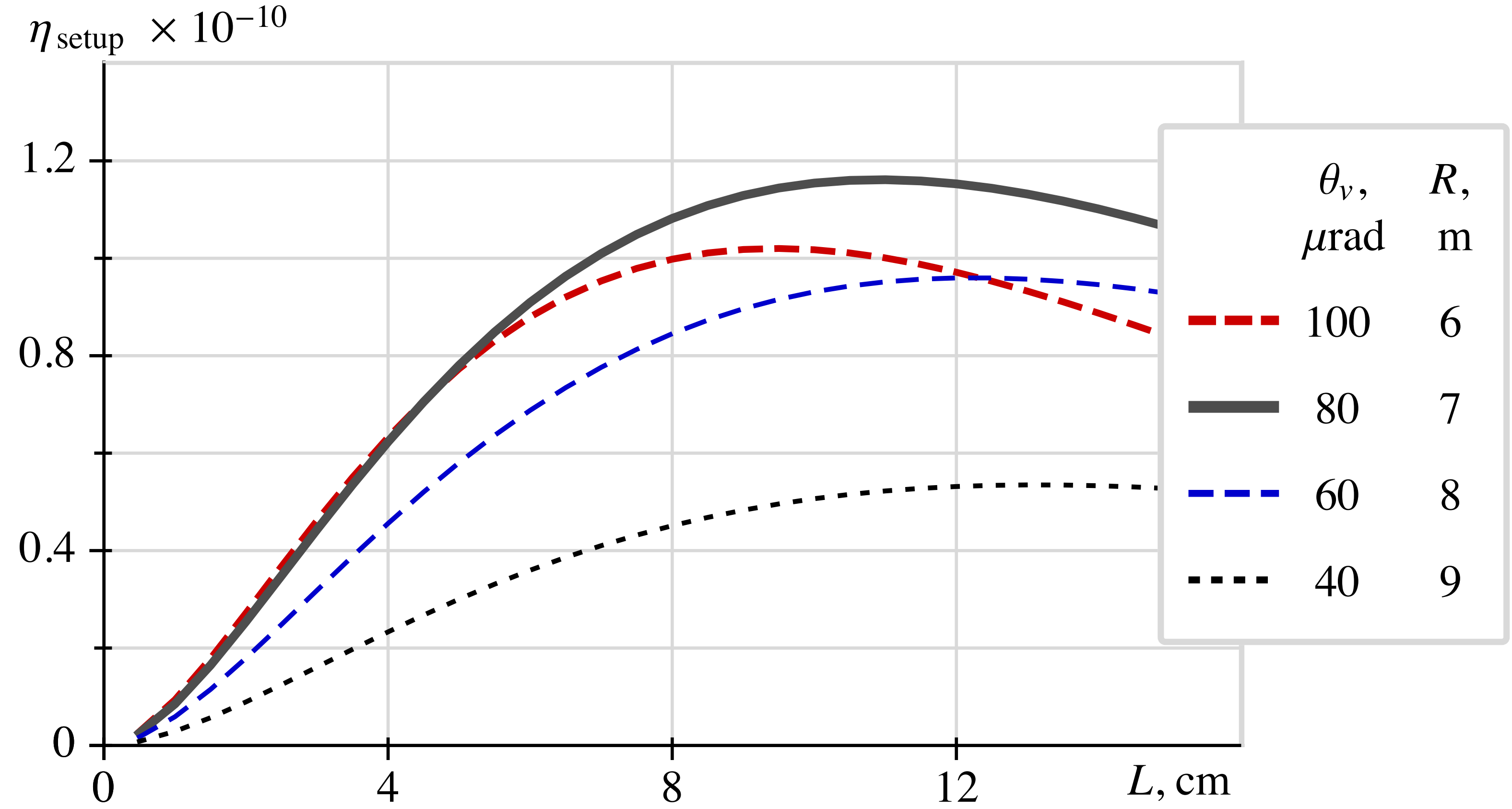
$$\mathrm{P_z}(\varepsilon_\tau) = \frac{1}{\partial N_\tau^{\rm def}/\partial \varepsilon_\tau} \int dE_D \, \frac{\partial N_D}{\partial E_D} \, \frac{\partial N_\tau^{\rm def}}{\partial \varepsilon_\tau}(E_D) \, \mathrm{P_z}(E_D, \varepsilon_t)$$

$$\mathrm{P}_x(\varepsilon_\tau) = \frac{1}{\partial N_\tau^{\rm def}/\partial \varepsilon_\tau} \int dE_D \, \frac{\partial N_D}{\partial E_D} \, \frac{\partial N_\tau}{\partial \varepsilon_\tau}(E_D) \, \mathrm{P}_\perp(E_D, \varepsilon_\tau) \, \frac{1}{\pi} \int_{\phi_{min}(\varepsilon_\tau)}^{\phi_{max}(\varepsilon_\tau)} \sin\phi \, d\phi.$$

The setup efficiency (target + two crystals)

$$\Delta a_\tau = \sqrt{\frac{1}{N_p \;\; \eta_{\det} S^2 \;\; \eta_{\text{setup}}}}$$

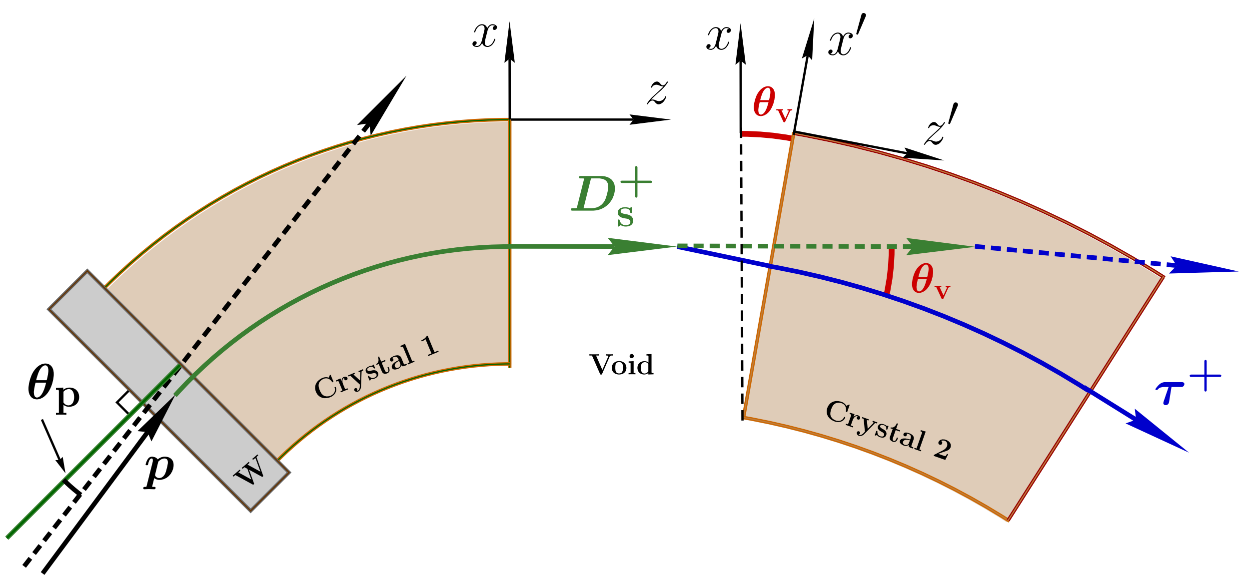
$$\eta_{\text{setup}} = \Theta^2 \int d\varepsilon \, \frac{\partial N_\tau^{\text{def}}}{\partial \varepsilon} \; \gamma_\tau^2 \;\; \mathrm{P}^2$$



N_p is the integral number of protons,

$\eta_{\det}$ is the detector efficiency

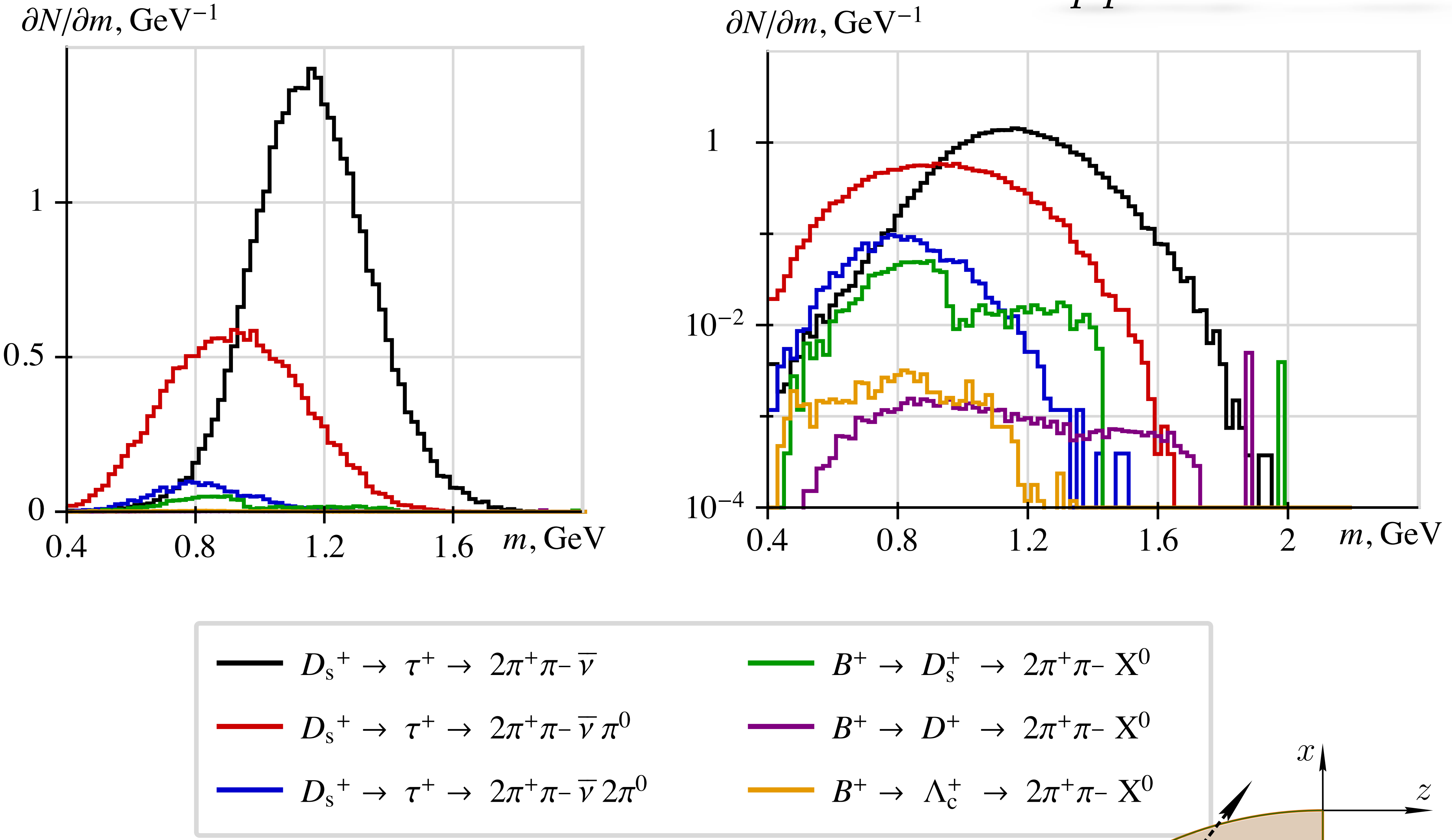
S is the sensitivity of polarisation reconstruction by the analysis of τ decay[(1)]



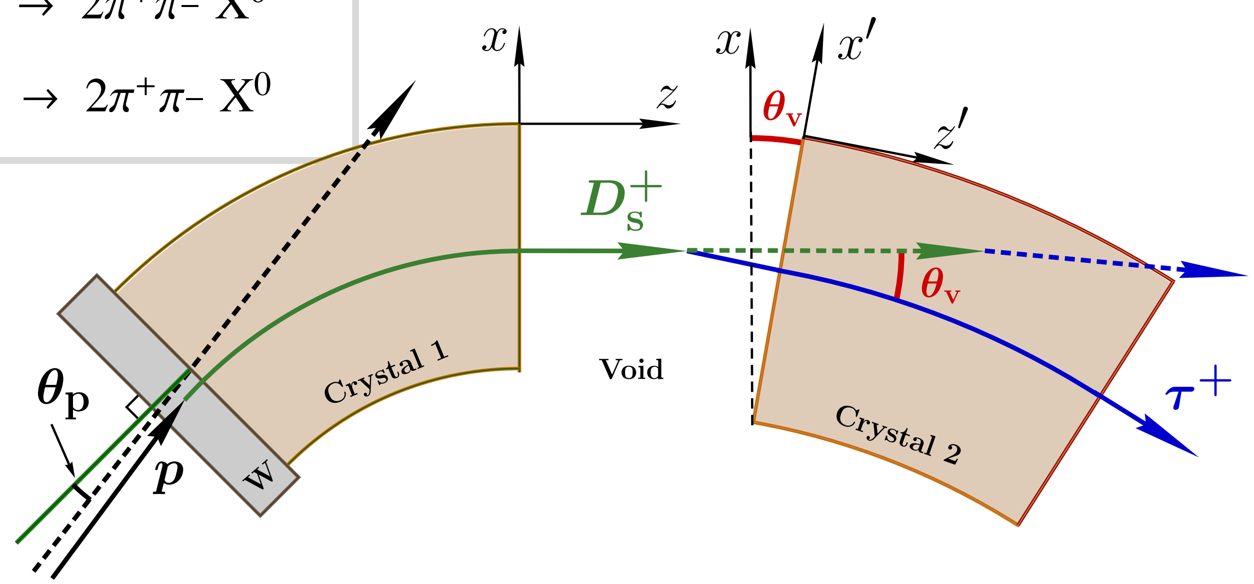
(1) J. Bernabeu et al., JHEP, 01:062, 2009

Background from other decay channels.

$$p\,p \to X^+ \dots \to Y^+ \dots \to 2\pi^+\,\pi^- \dots$$



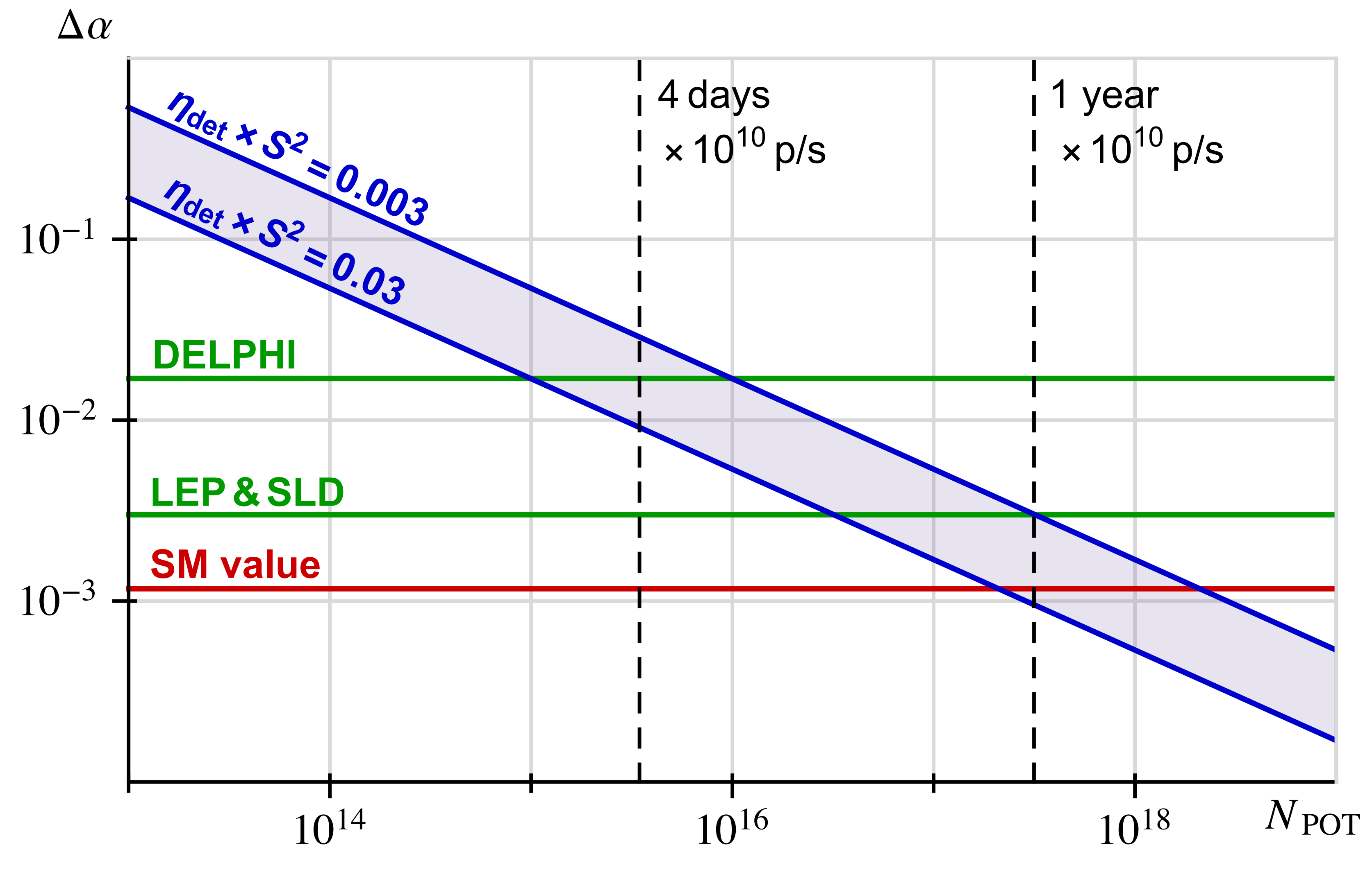
The main source of the background is the decay $\tau^+ \to 2\pi^+\pi^-\,\nu_\tau\,\pi^0$



$$\Delta a_\tau = \sqrt{\frac{1}{N_p \;\; \eta_{\rm det} S^2 \;\; \eta_{\rm setup}}}$$

- Target (W)
  L_{tar} = 1 cm
- Crystal 1 (Ge)
  L_D = 3 cm,
  R_D = 10 m,
  θ_p = 100 μrad
- Crystal 2 (Ge)
  L = 10 cm,
  R = 7 m,
  θ_v = 80 μrad

$\eta_{setup} = 10^{-10}$ per incident proton



Double Crystal Setup at LHC $D_s^+ \to \tau^+ \nu_\tau \to 2\pi^+ \pi^- \bar{\nu}_\tau$

DELPHI: error of aMDM from LEP2 experiment $\gamma\gamma \to \tau^+ \tau^-$
J. Abdallah et al. Eur. Phys. J., C35:159–170, 2004

LEP & SLD: error of aMDM from various LEP and SLD experiments.
G. A. Gonzalez-Sprinberg, et al. Nucl. Phys., B582:3–18, 2000.

SM value: aMDM value predicted by a Standard Model
S. Eidelman et al. Mod. Phys. Lett., A22:159–179, 2007.