Two and a Half Peaks

The Phenomenology of Yoctosecond Pulses from a Quark-Gluon Plasma

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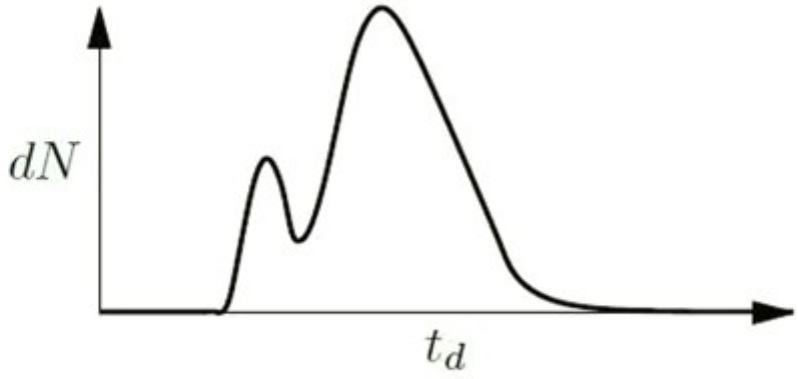


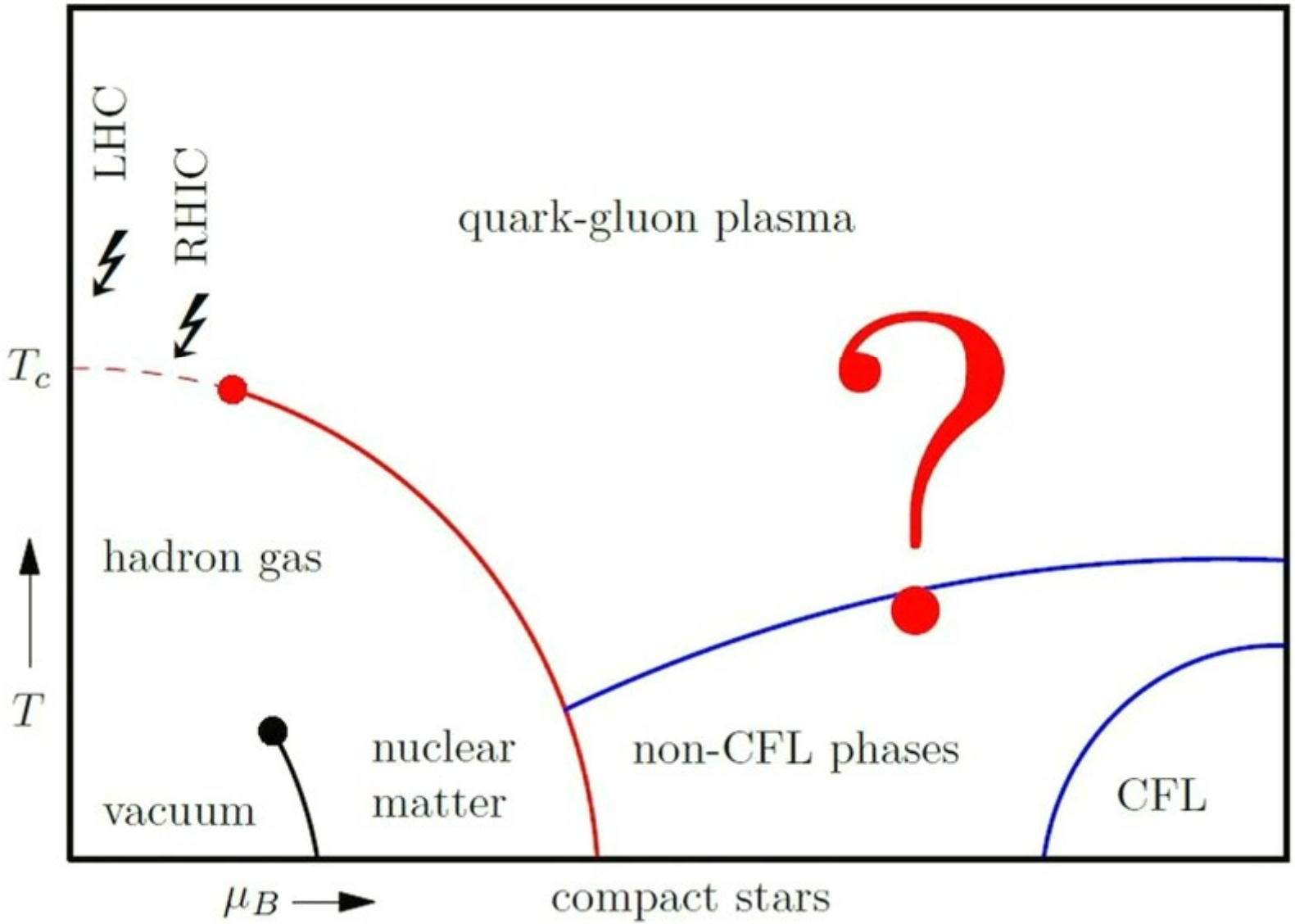
[Ipp *et al.*, 2009]

Outline

- The anisotropic quark-gluon plasma (QGP)
- Photon production rate in the QGP
- Bjorken picture and anisotropy model
- Time dependent photon signals and double pulses!

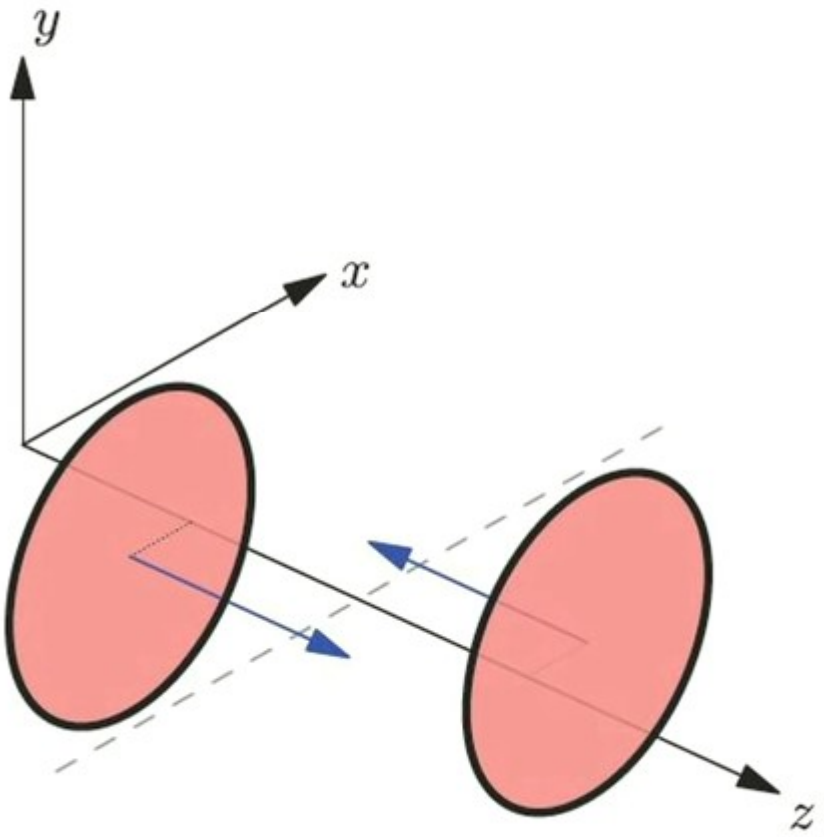
Our whole universe was in a hot, dense state ..

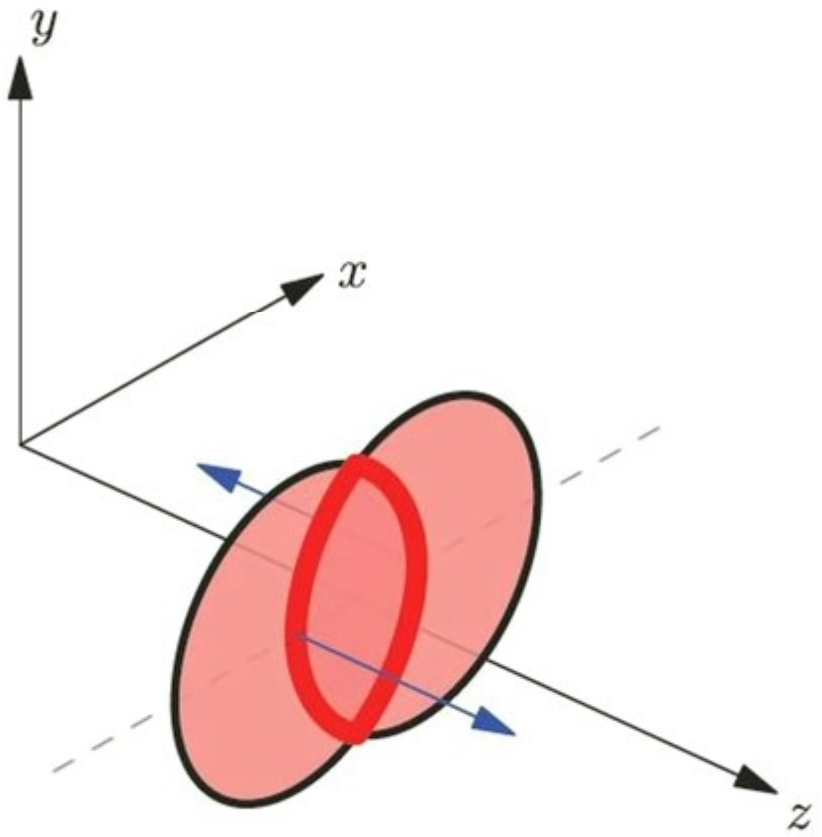
The anisotropic quark-gluon plasma
QCD phase diagram, [Hands, 2001]



Ring of fire

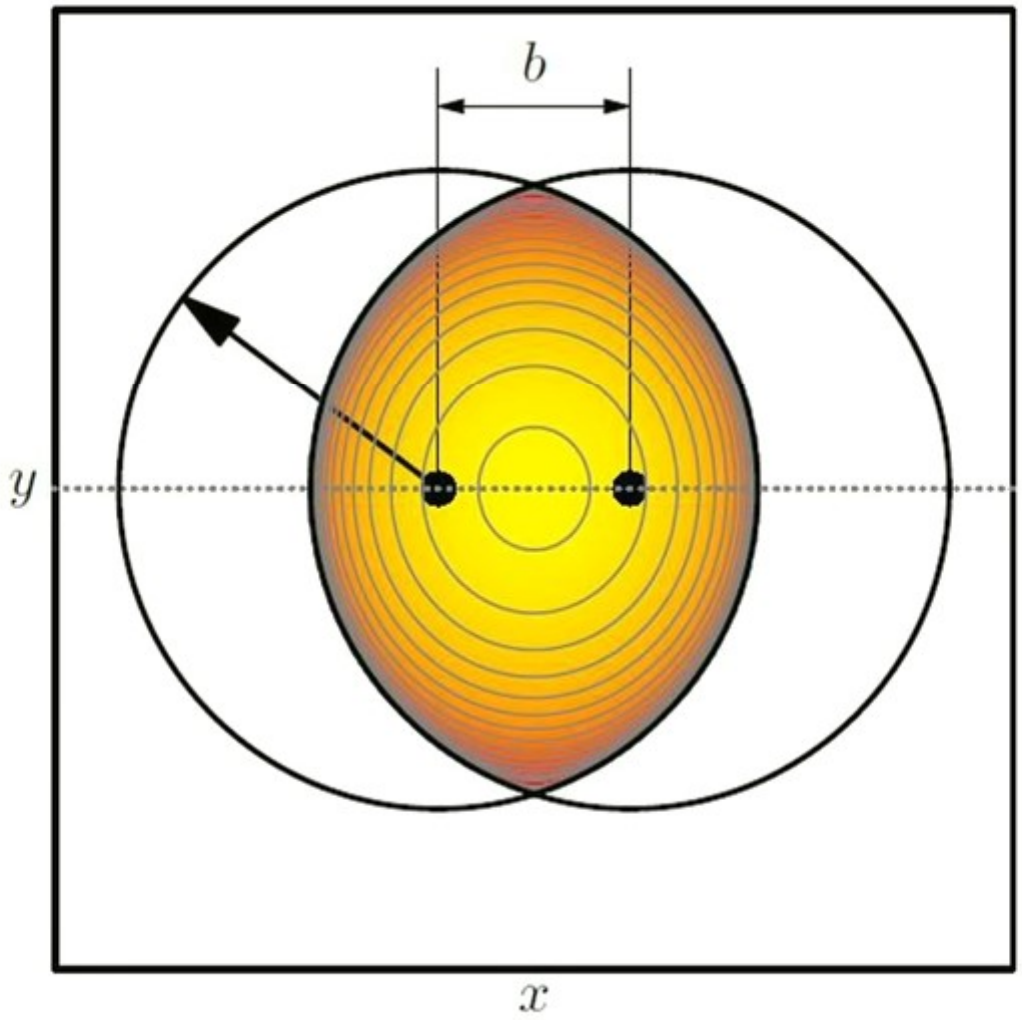
The QGP in a heavy-ion collision





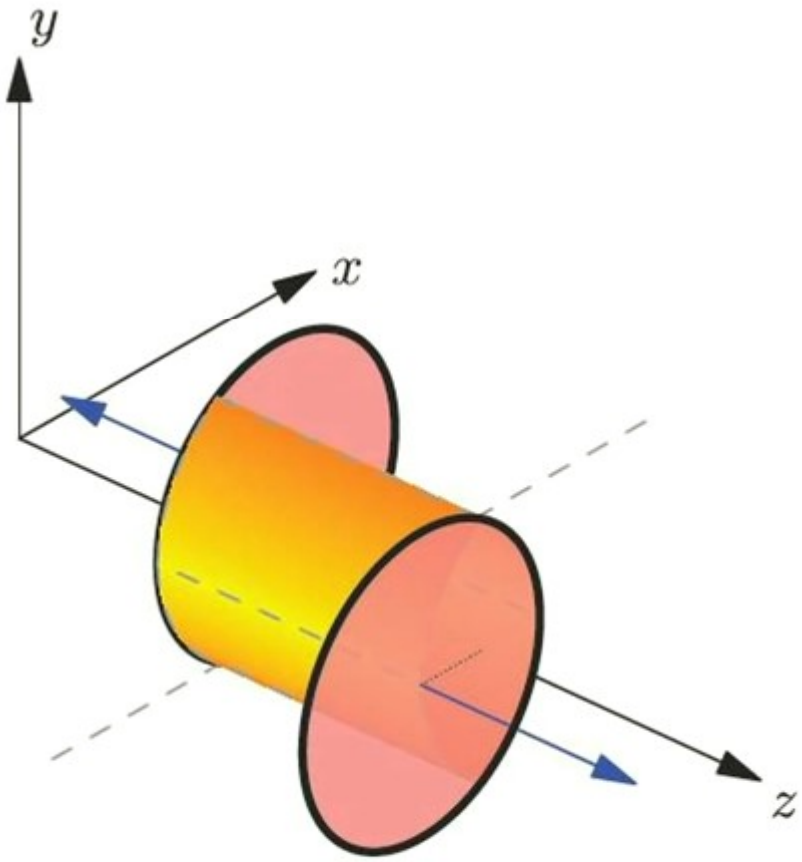
Along the beam axis

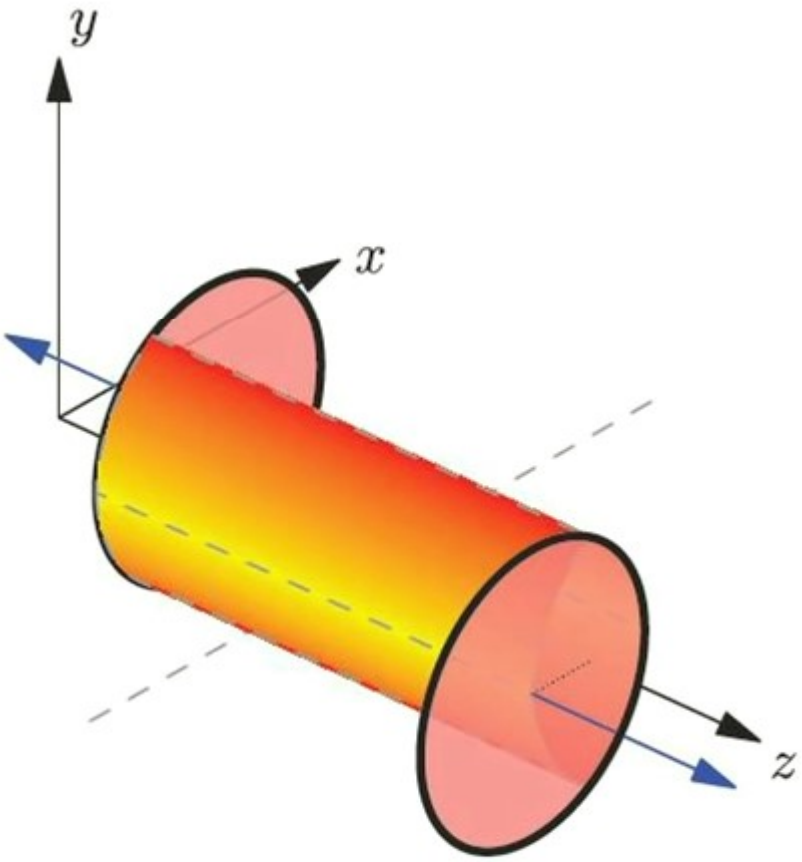
The QGP in a heavy-ion collision



Hot stuff

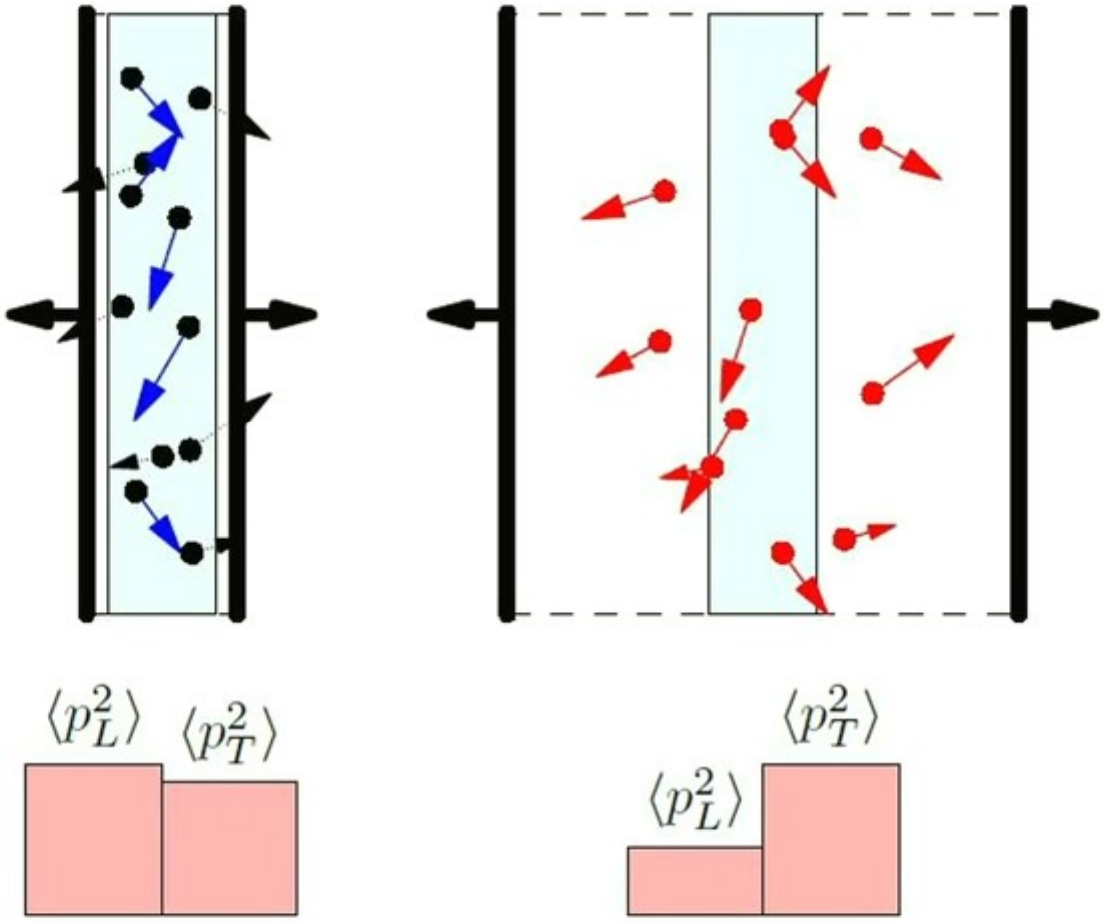
The QGP in a heavy-ion collision





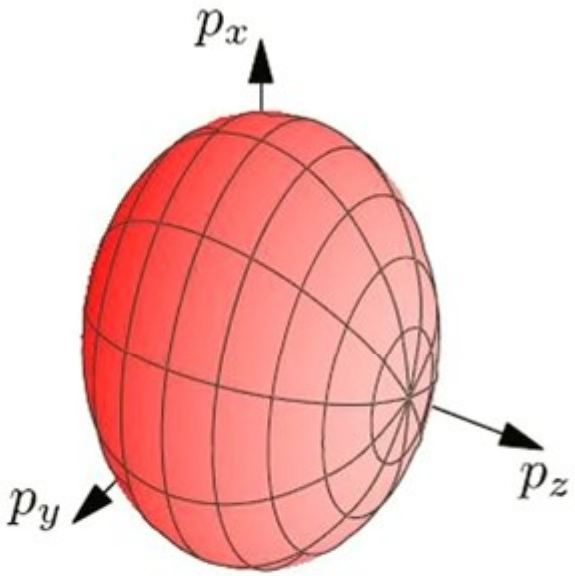
Anisotropy buildup

Central rapidity region, [Bjorken, 1983]

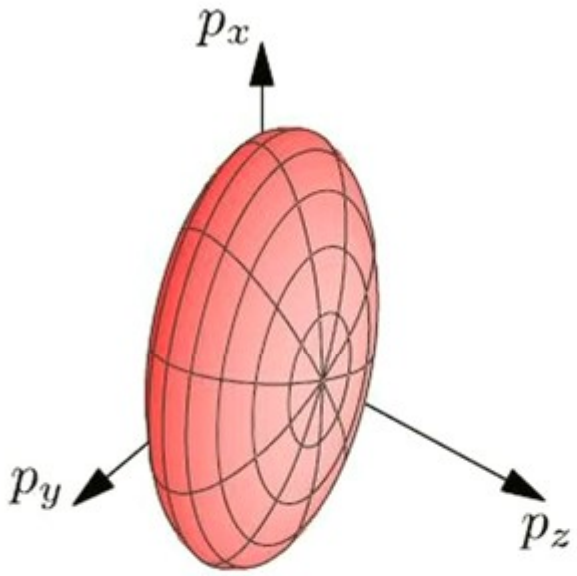


Squeeze my lemon

Modified distribution function, [Romatschke & Strickland, 2003]



a) $\xi = 0$



b) $\xi = 5$

$$f(\mathbf{p}) = f_{\text{iso}}(\sqrt{\mathbf{p}^2 + \xi(\hat{\mathbf{z}} \cdot \hat{\mathbf{p}})^2})$$

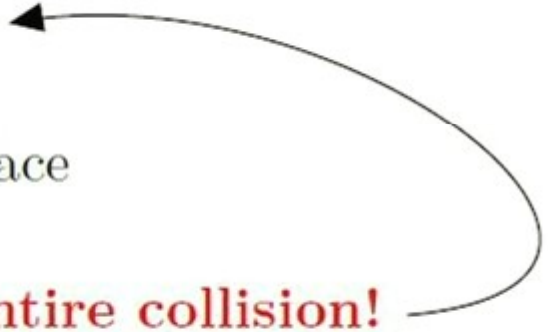
ξ .. anisotropy parameter

We repeat

- QCD predicts deconfined phase at asymptotically high energies
- quark-gluon plasma is (probably) created in heavy-ion collisions
- the QGP expands primarily in the longitudinal direction
- momentum-space anisotropy (ξ) due to expansion

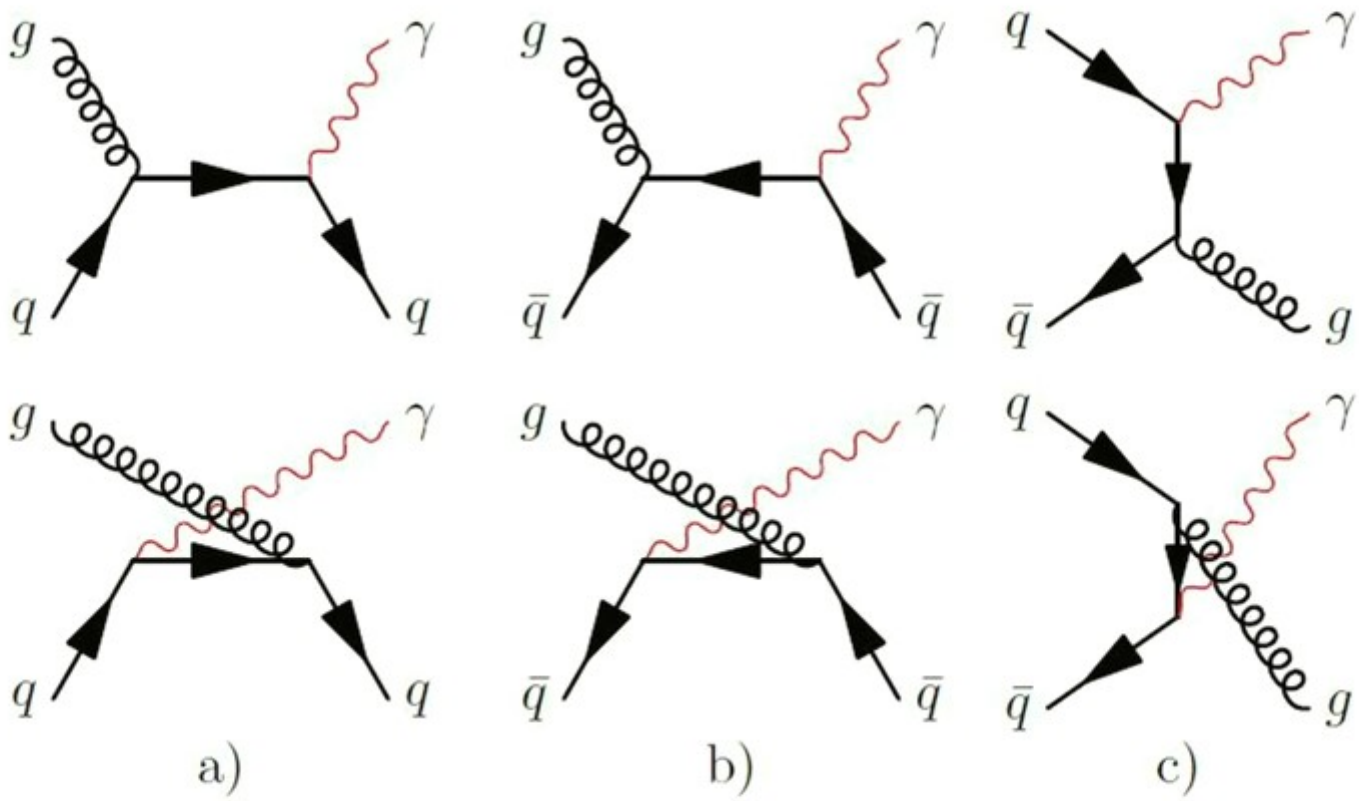
Why photons?

- QGP undergoes time evolution until freezeout
- Hadrons can teach us about the freezeout surface
- **Photons are produced throughout the entire collision!**
- QGP lifetime: $\approx 13\,\mathrm{fm}/c$ or $\approx 40 \cdot 10^{-24}\,\mathrm{s} = 40\,\mathrm{ys}$!



Photon production rate

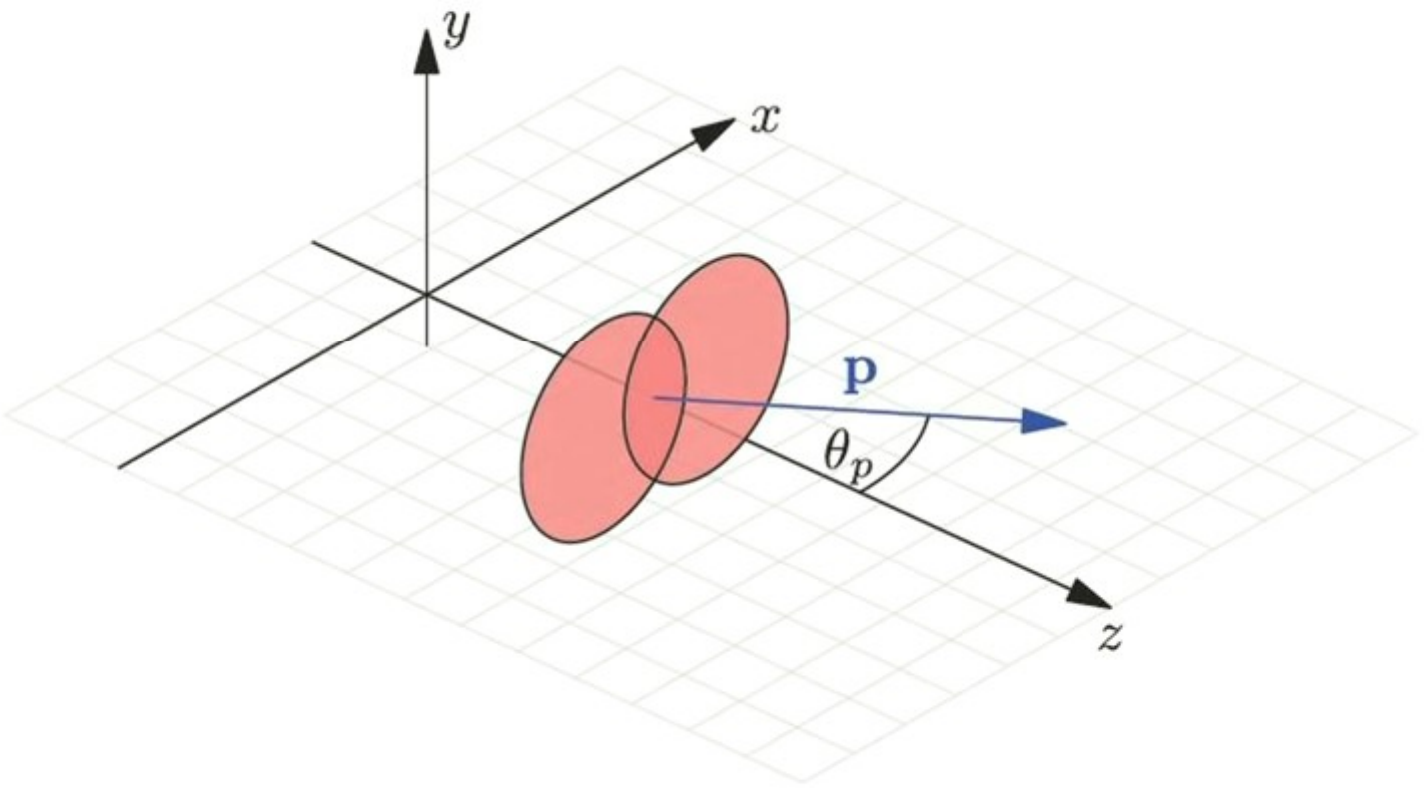
Processes contributing to photon production at leading order in α_s



Hard scattering contributions
+ soft parts

Photon production rate

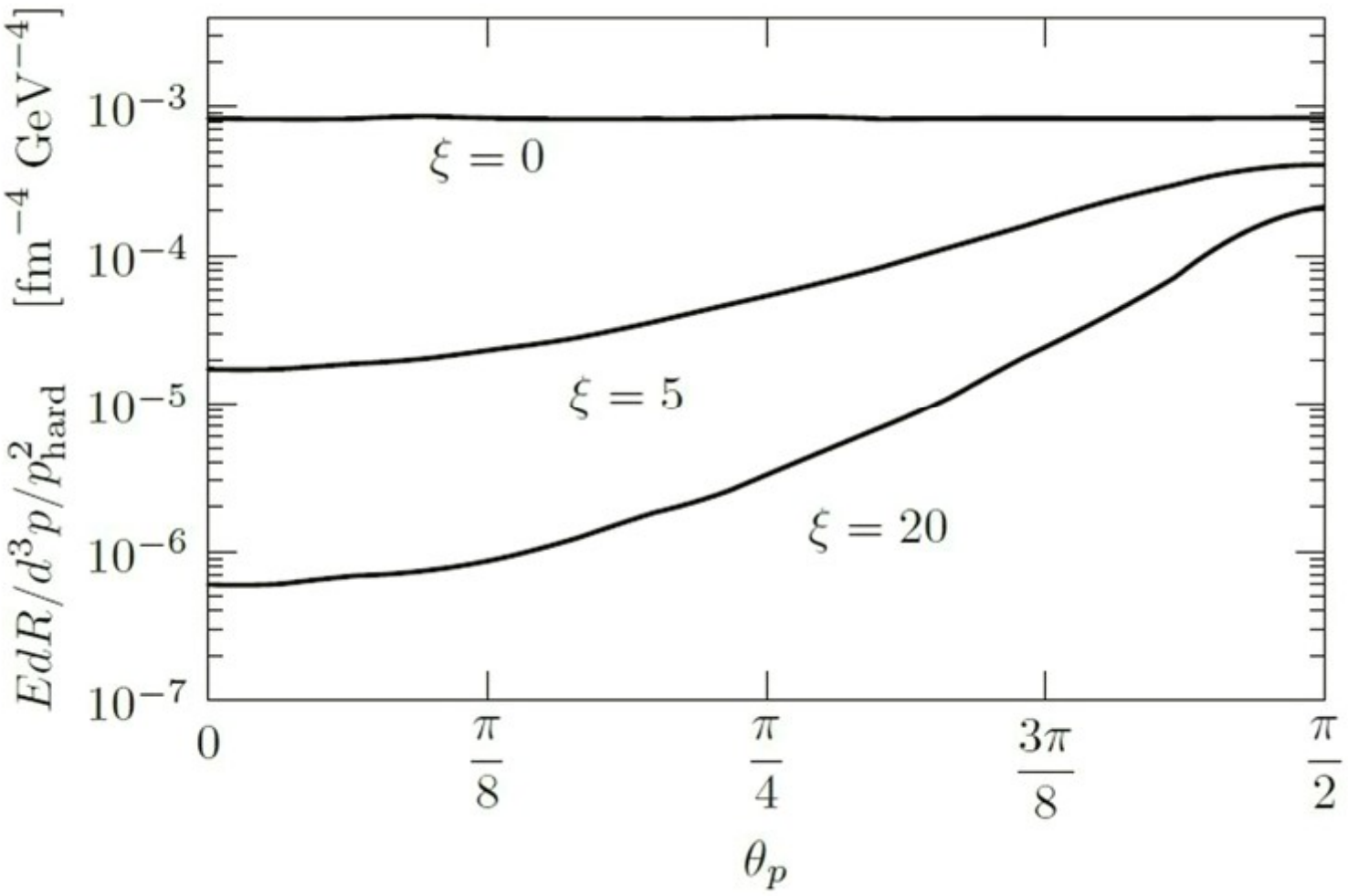
The setup



θ_p: Photon emission angle (detector position)

Photon production rate

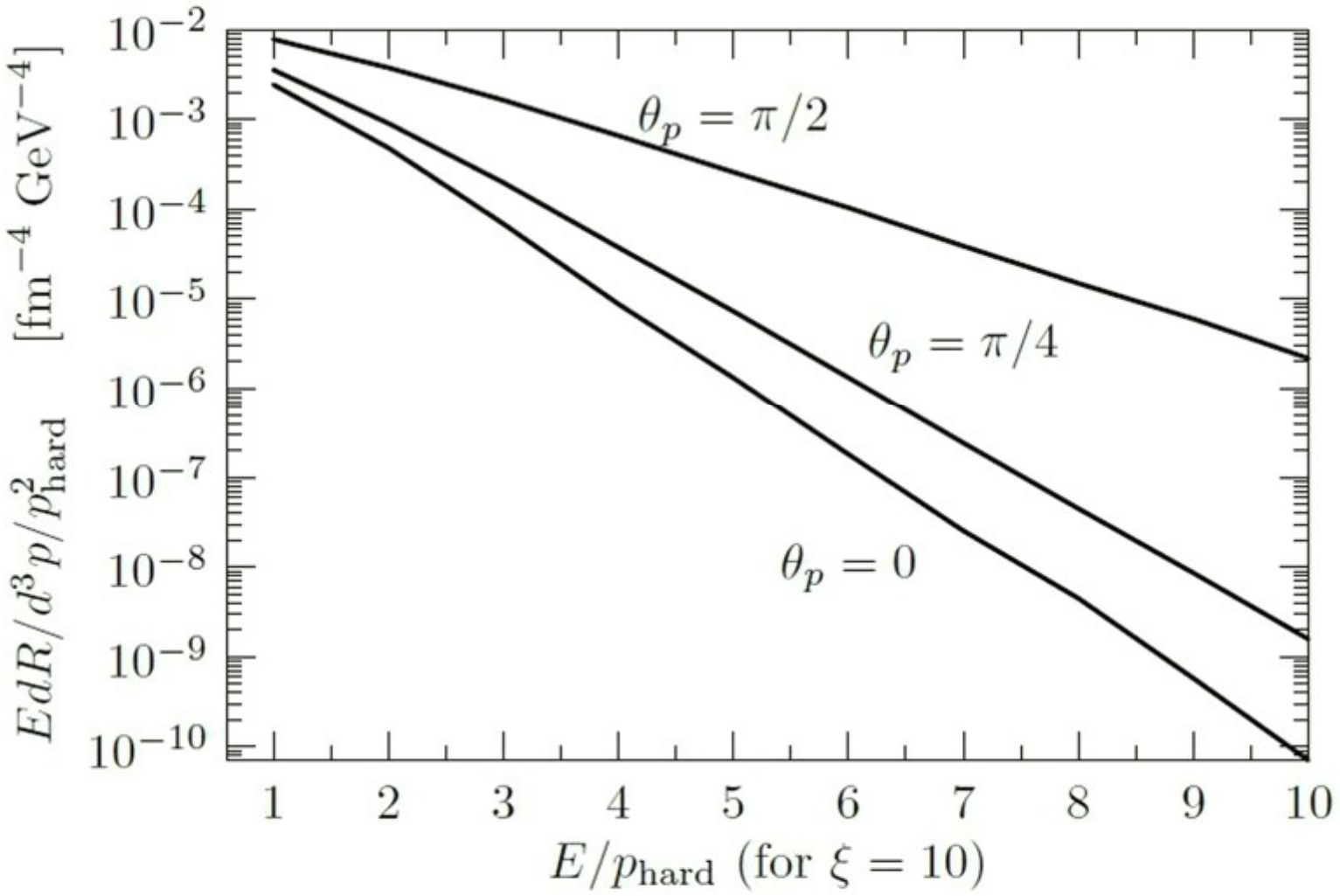
[Schenke & Strickland, 2007]



Strong angle dependence!

Photon production rate

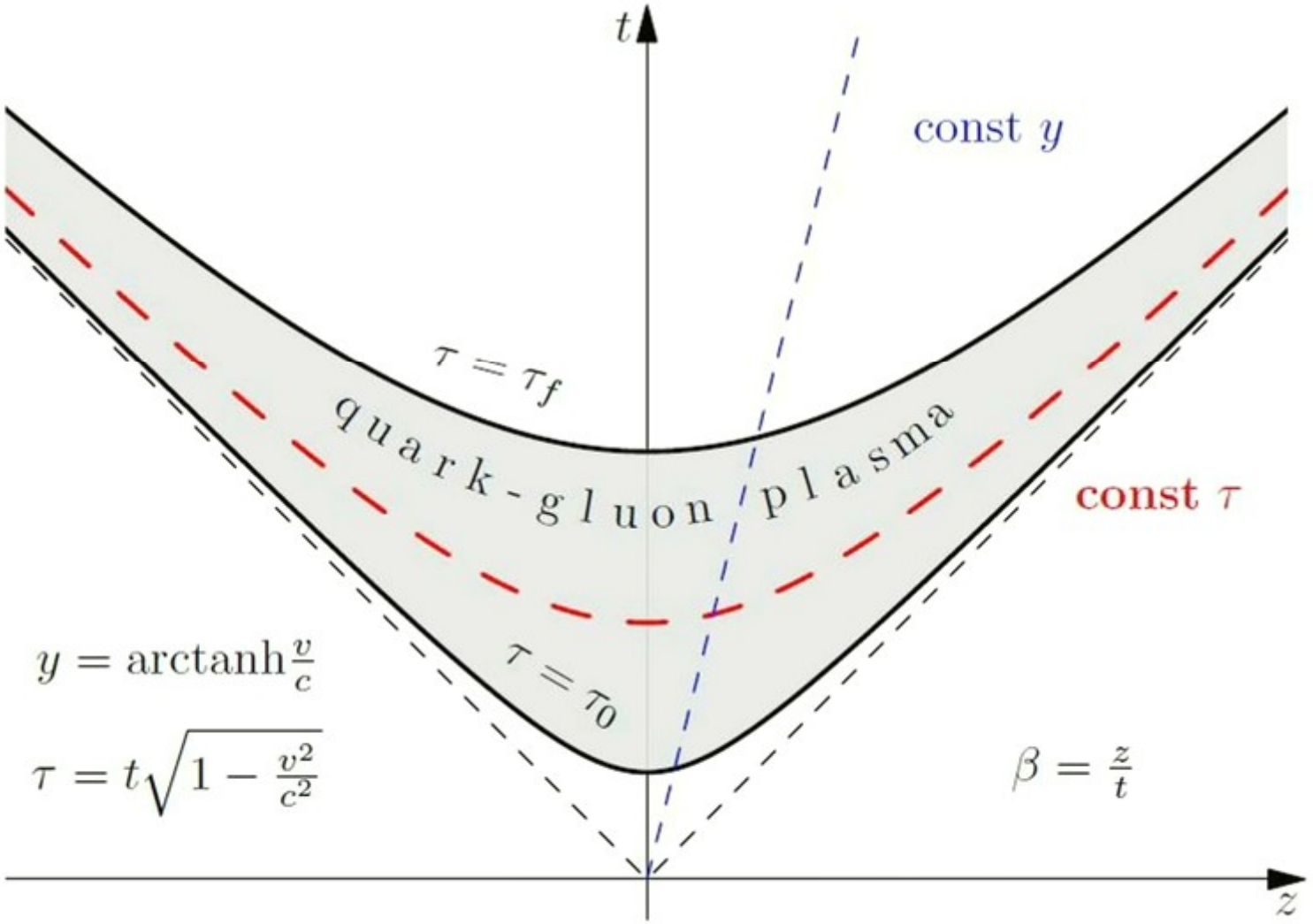
[Schenke & Strickland, 2007]



Strong energy dependence!

Bjorken picture for the QGP

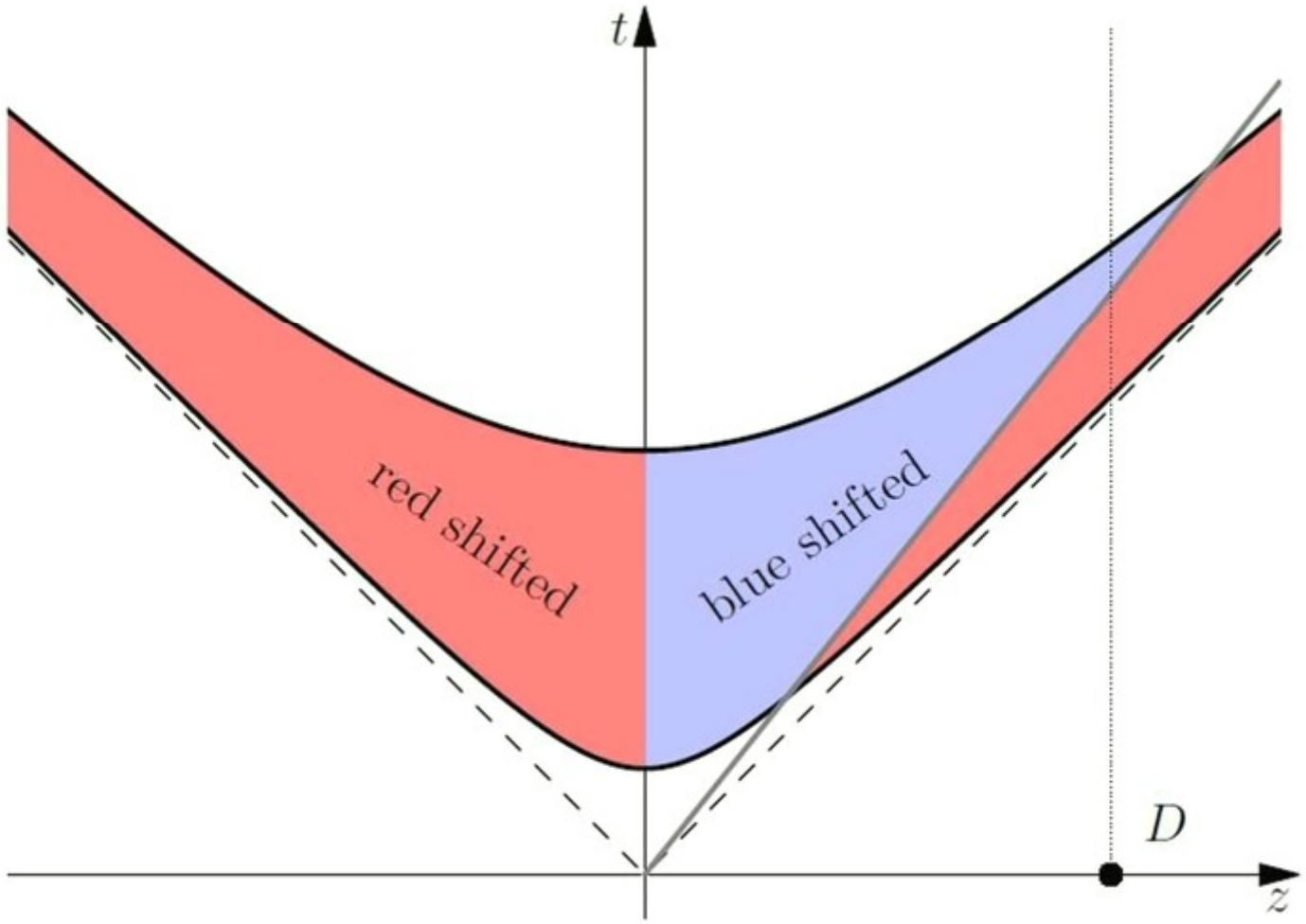
Assumption: QGP is rapidity invariant



I see a red part and I want it painted blue

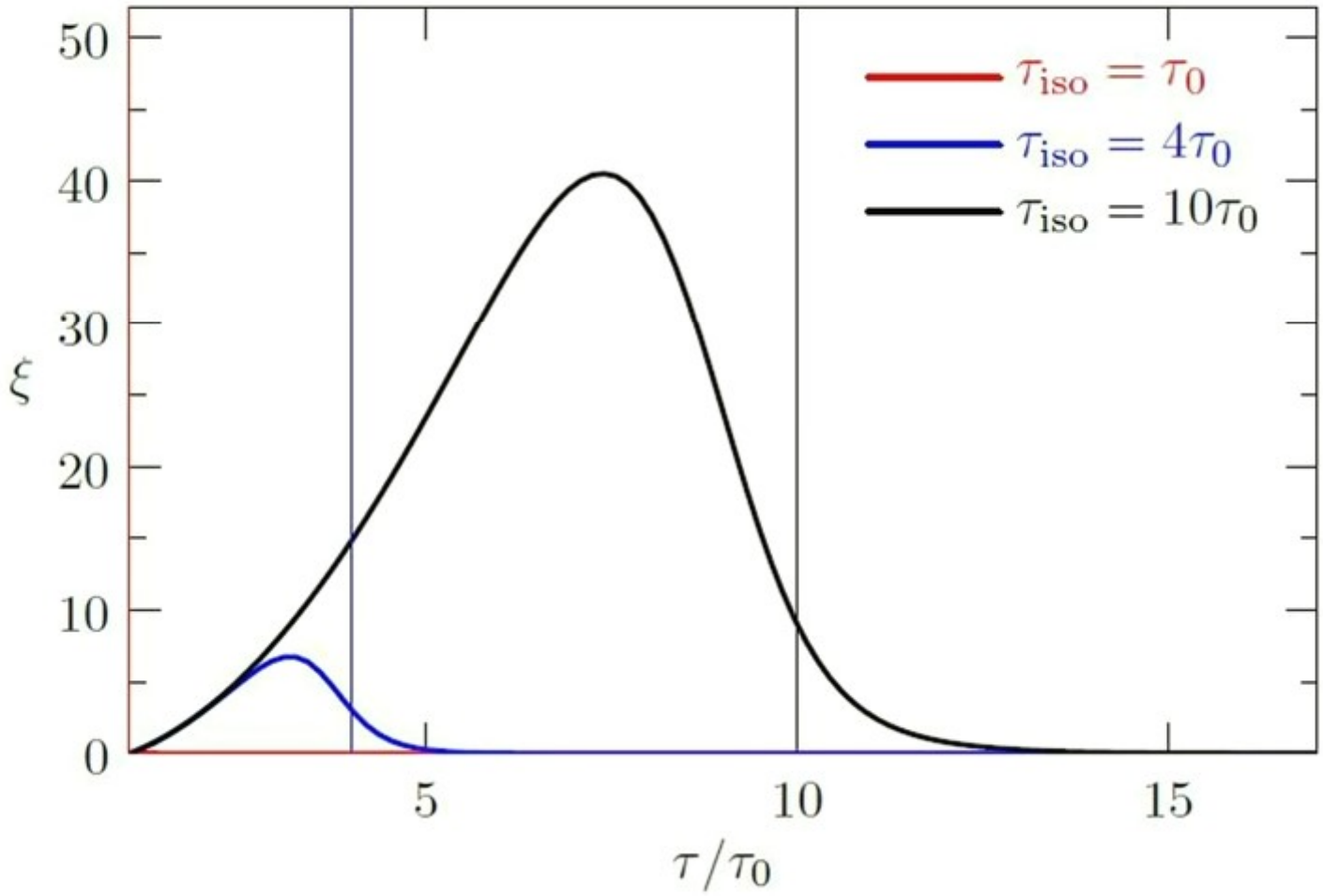
Doppler shift!

Rapidity invariance implemented as $\beta = z/t$



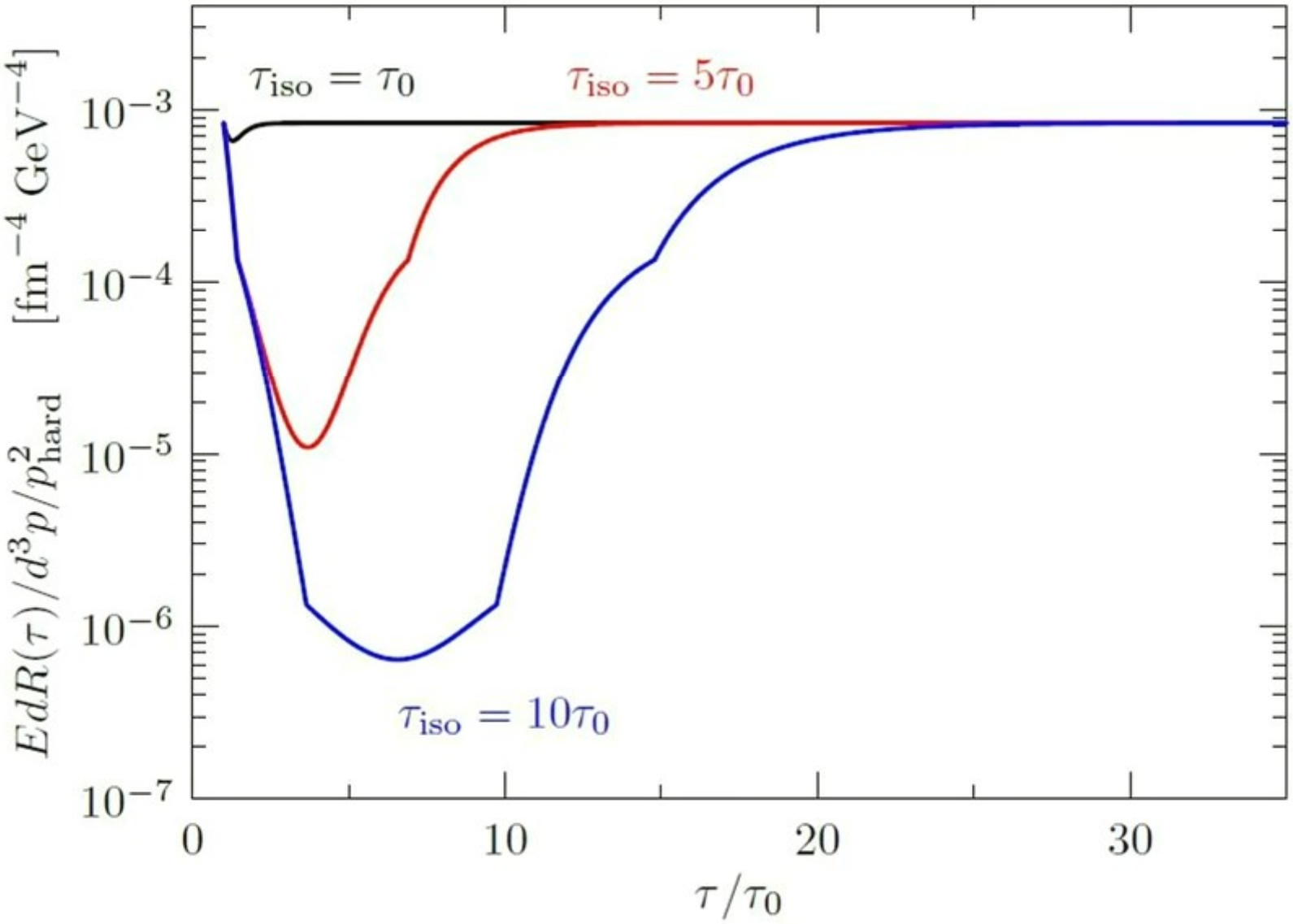
Time evolution of anisotropy parameter ξ

Transition parameter γ, [Martinez & Strickland, 2008]



Evolution of the photon rate at $\theta_p = 0$

(without plasma cooling)

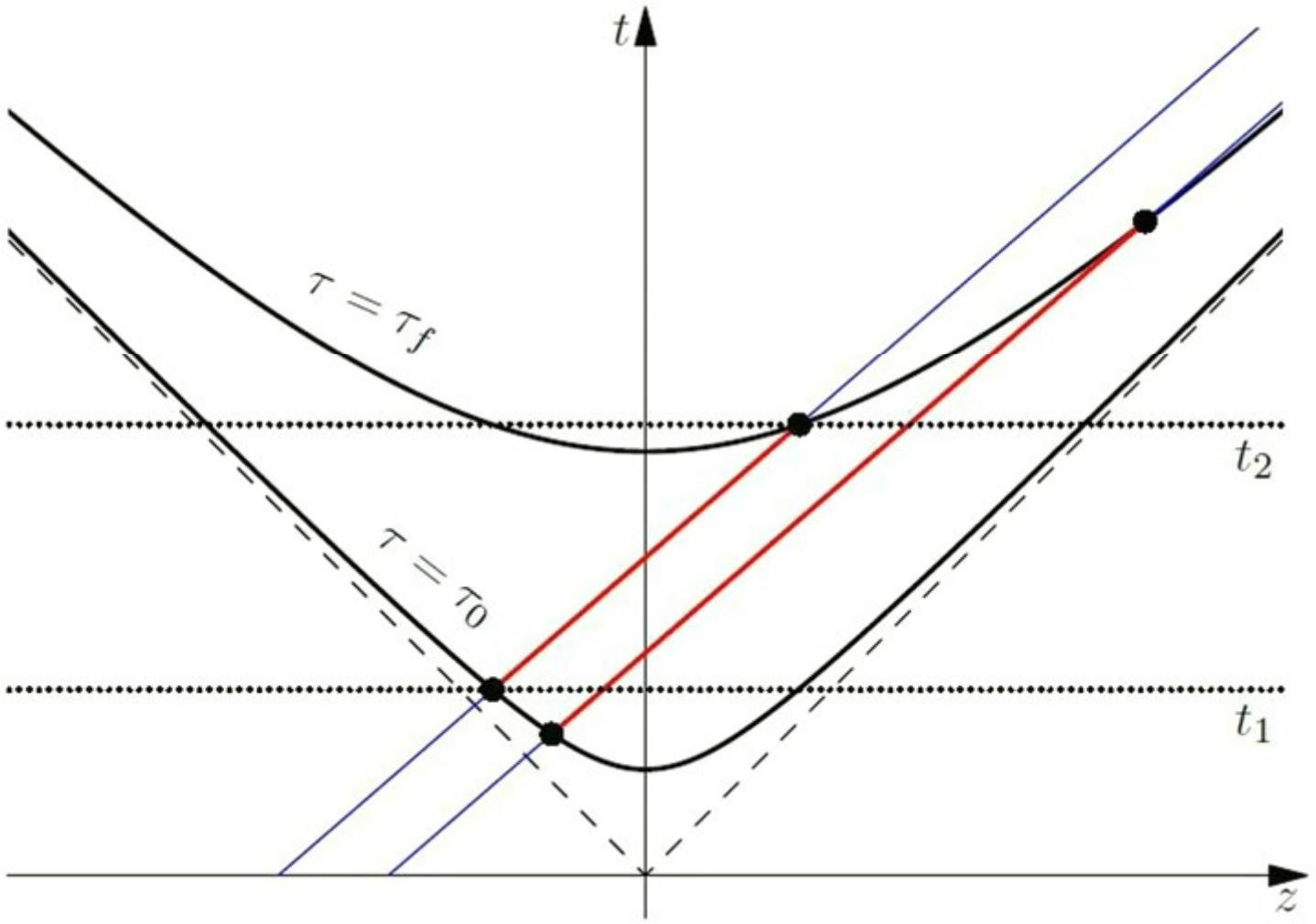


We repeat again

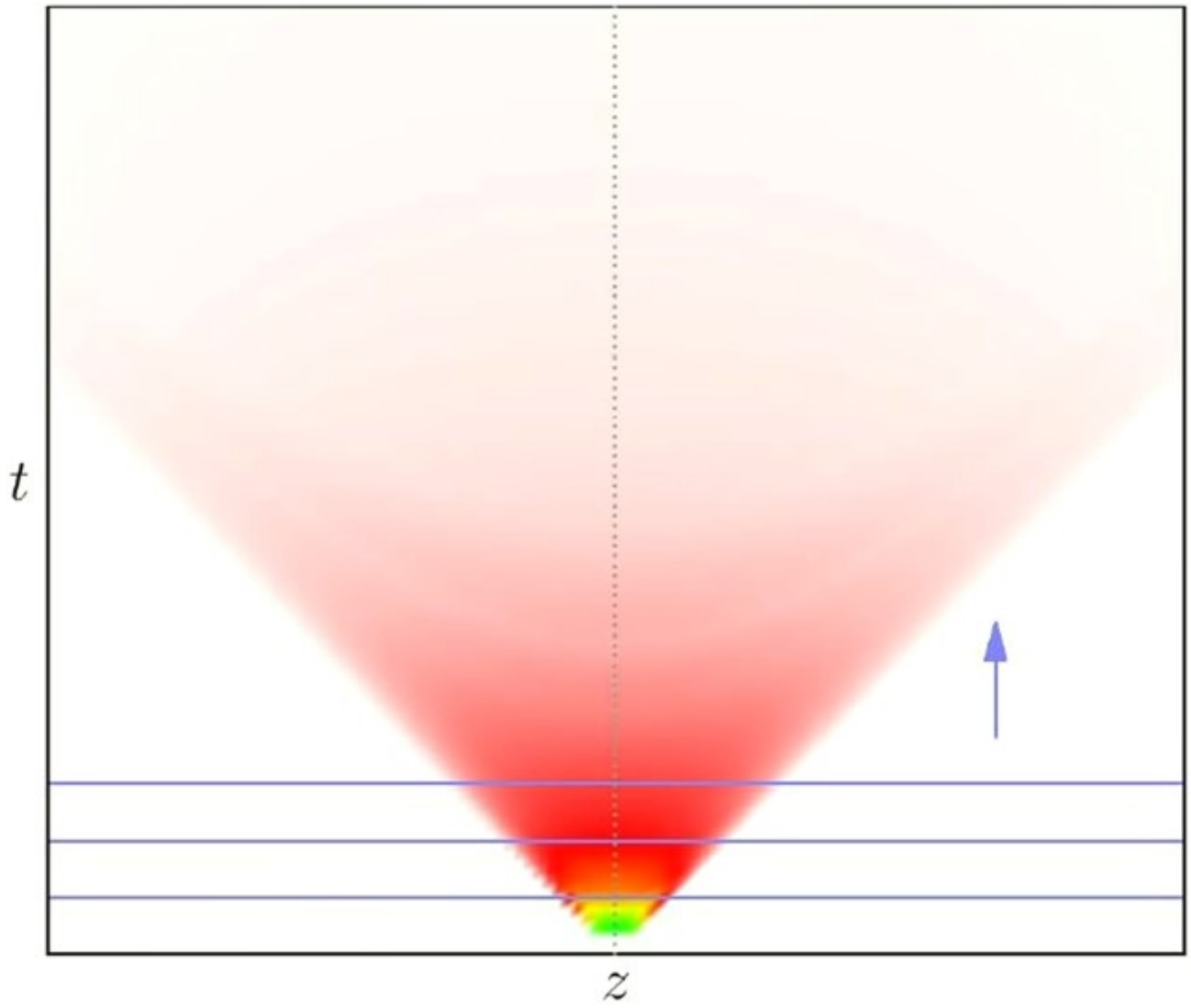
- Photon rate depends on anisotropy (ξ), energy (E) and angle (θ_p)
- QGP is rapidity invariant: hyperbolas in Minkowski diagram
- Time evolution of anisotropy $\rightarrow$ time evolution of photon rate!

Returning to the Minkowski diagram..

Space-like curve: photons produced will reach detector at same time t_d!

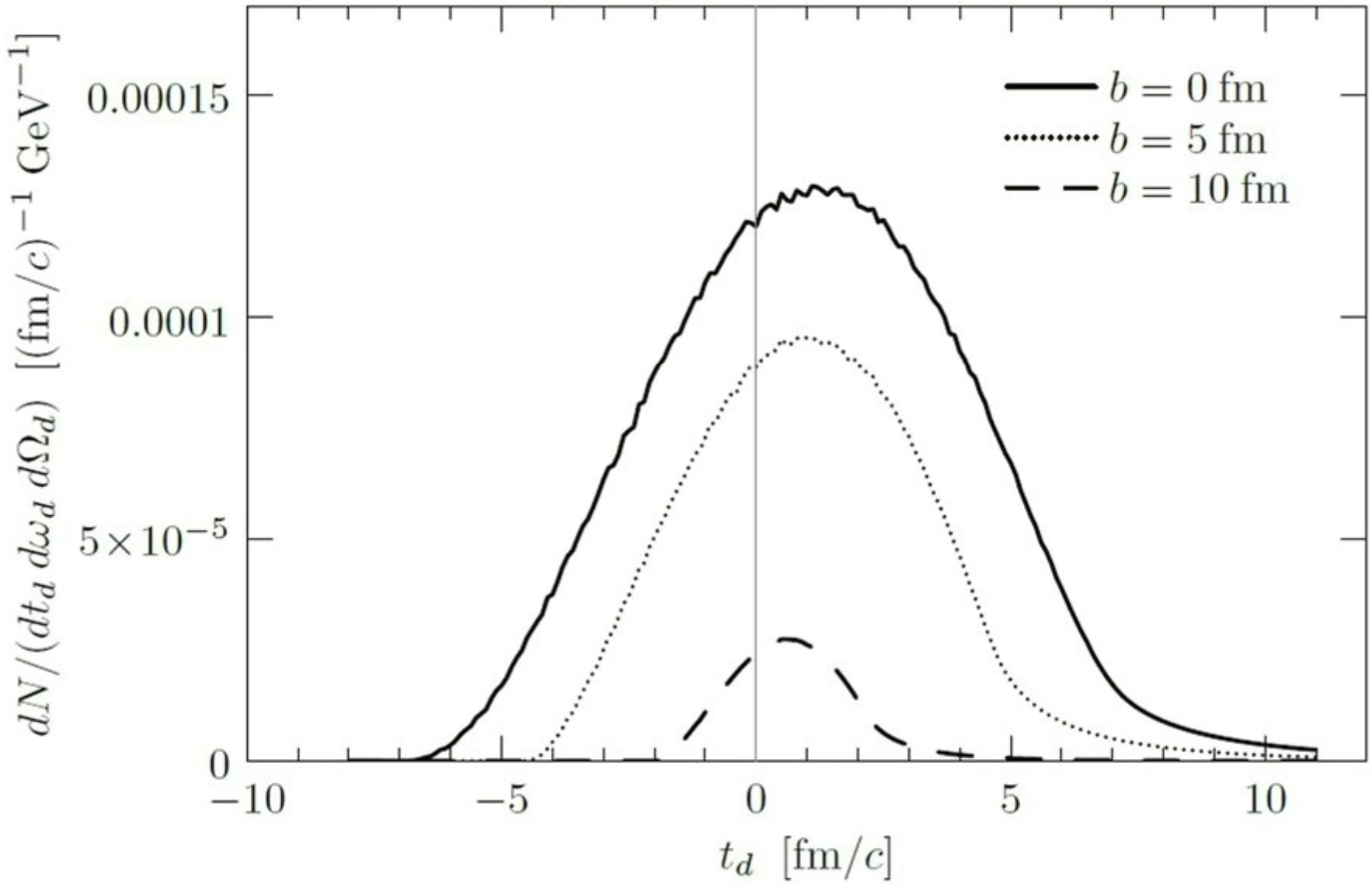


Photon rate at $\theta_p = \pi/2$



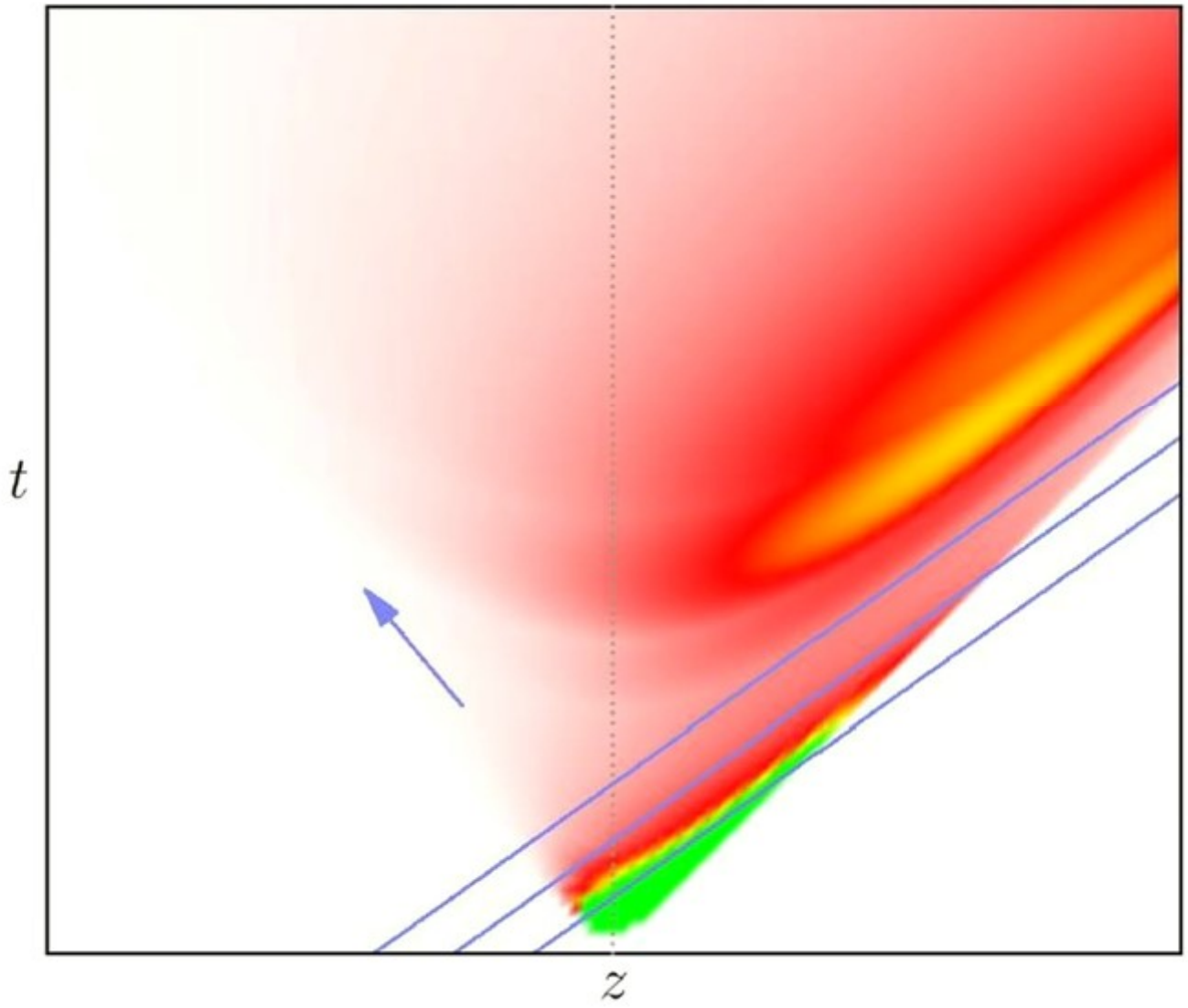
Photon pulses at $\theta_p = \frac{\pi}{2}$

for different impact parameters b, $E = 2\,\mathrm{GeV}$



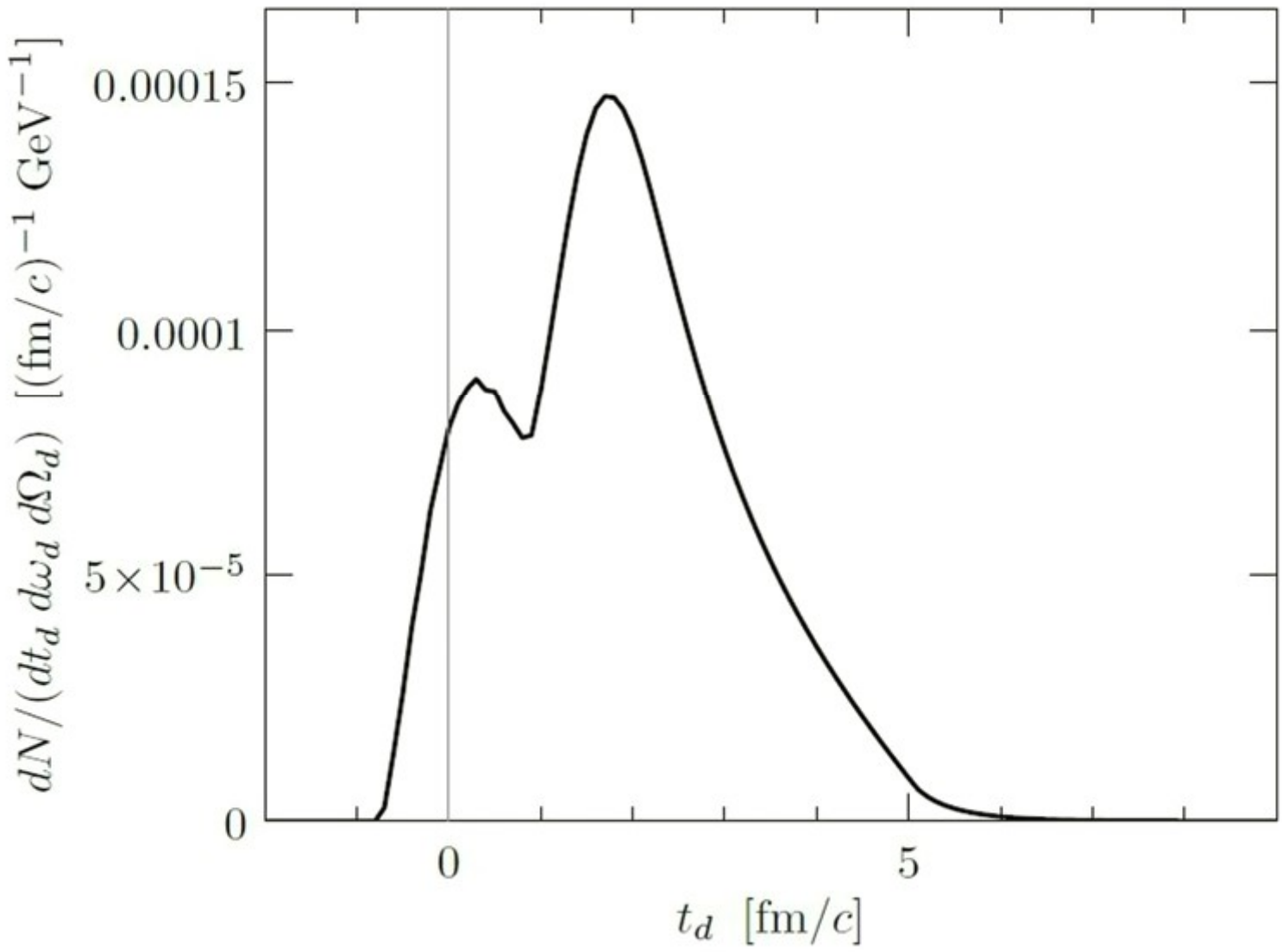
A tale of two pulses

Photon rate at $\theta_p = \pi/4$ and $\tau_{\mathrm{iso}} = 2\,\mathrm{fm}/c$



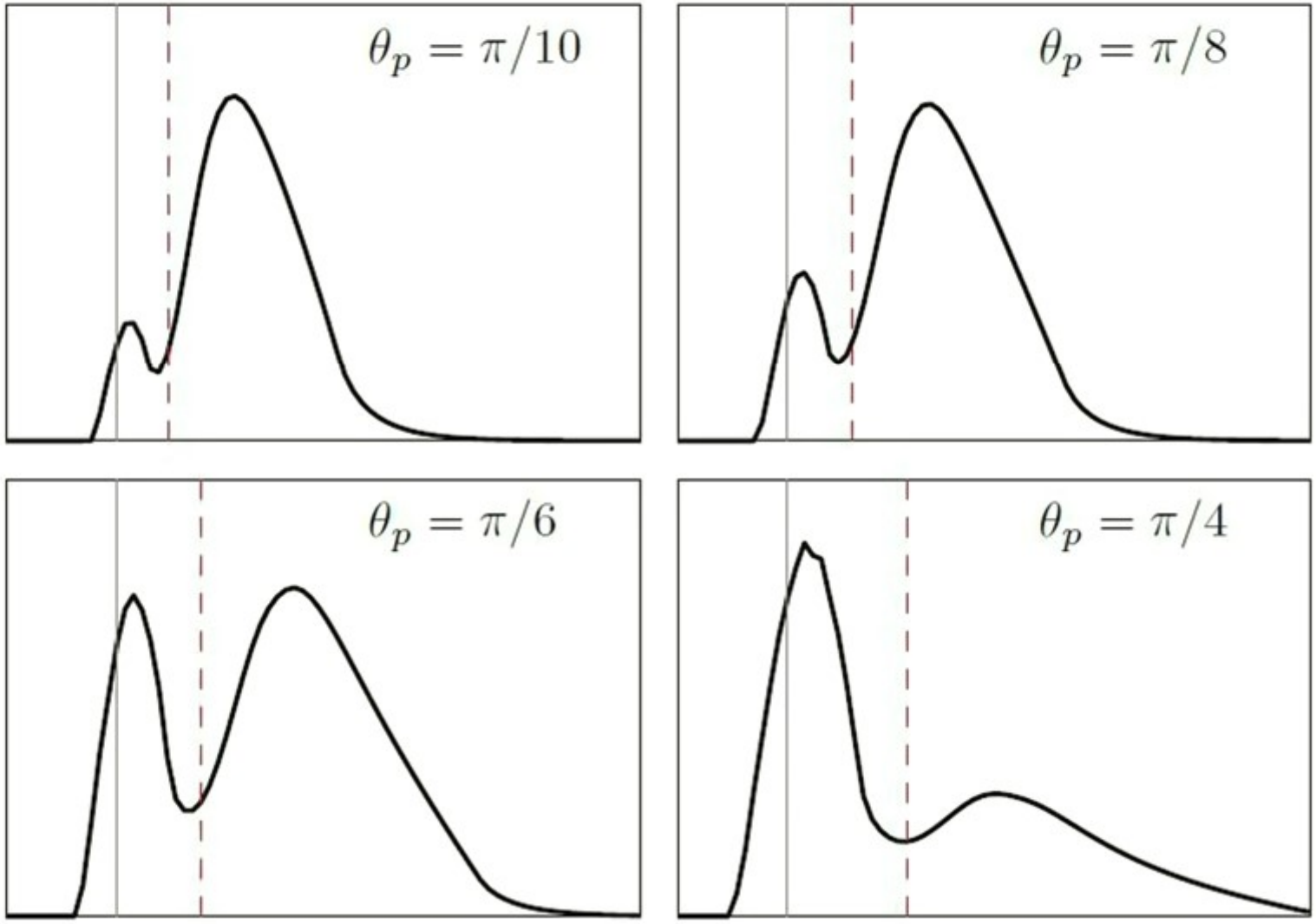
Photon pulse at $\theta_p = \frac{\pi}{8}$

$b = 10\,\mathrm{fm},\ E = 3\,\mathrm{GeV},\ \tau_{\mathrm{iso}} = 2\,\mathrm{fm}/c$

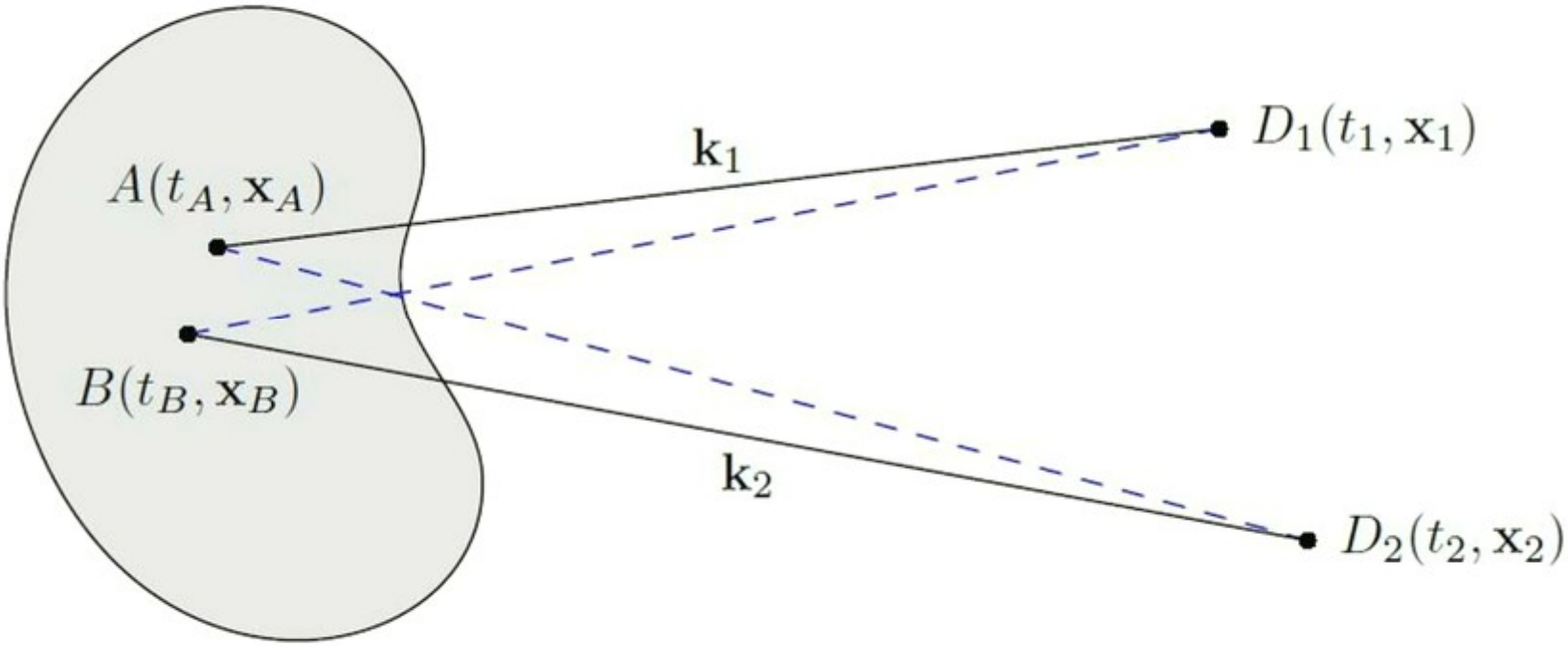


Photon pulses at different emission angles

$b = 10\,\mathrm{fm}$, $E = 2\,\mathrm{GeV}$, $\tau_{\mathrm{iso}} = 2\,\mathrm{fm}/c$. Ordinates are differently scaled!



Hanbury Brown - Twiss correlations



$$C_2(\mathbf{k}_1, \mathbf{k}_2) = \frac{P(\mathbf{k}_1, \mathbf{k}_2)}{P(\mathbf{k}_1)P(\mathbf{k}_2)}$$

Hanbury Brown - Twiss correlations

Collinear configuration: $\mathbf{k}_1 \parallel \mathbf{k}_2$.