UNIVERSITÄT BERN

AEC
ALBERT EINSTEIN CENTER
FOR FUNDAMENTAL PHYSICS

Supplemental slides

QCD in photon production:

fragmentation, isolation, resummation, slicing

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Frontiers in precision phenomenology
CERN, August 21, 2024

Fixed-Order Pathologies

For all cross section computations we will use

$$E_T^\gamma > E_T^{\min} = 125\,\mathrm{GeV} \qquad |\eta_\gamma| < 2.37$$

$$\alpha_s(M_Z) = 0.119 \qquad \alpha_{\mathrm{EM}} = 1/132.507$$

$$\sqrt{s} = 13\,\mathrm{TeV} \qquad \mathrm{NNPDF23\_nlo\_as\_0119\_qed\_mc}$$

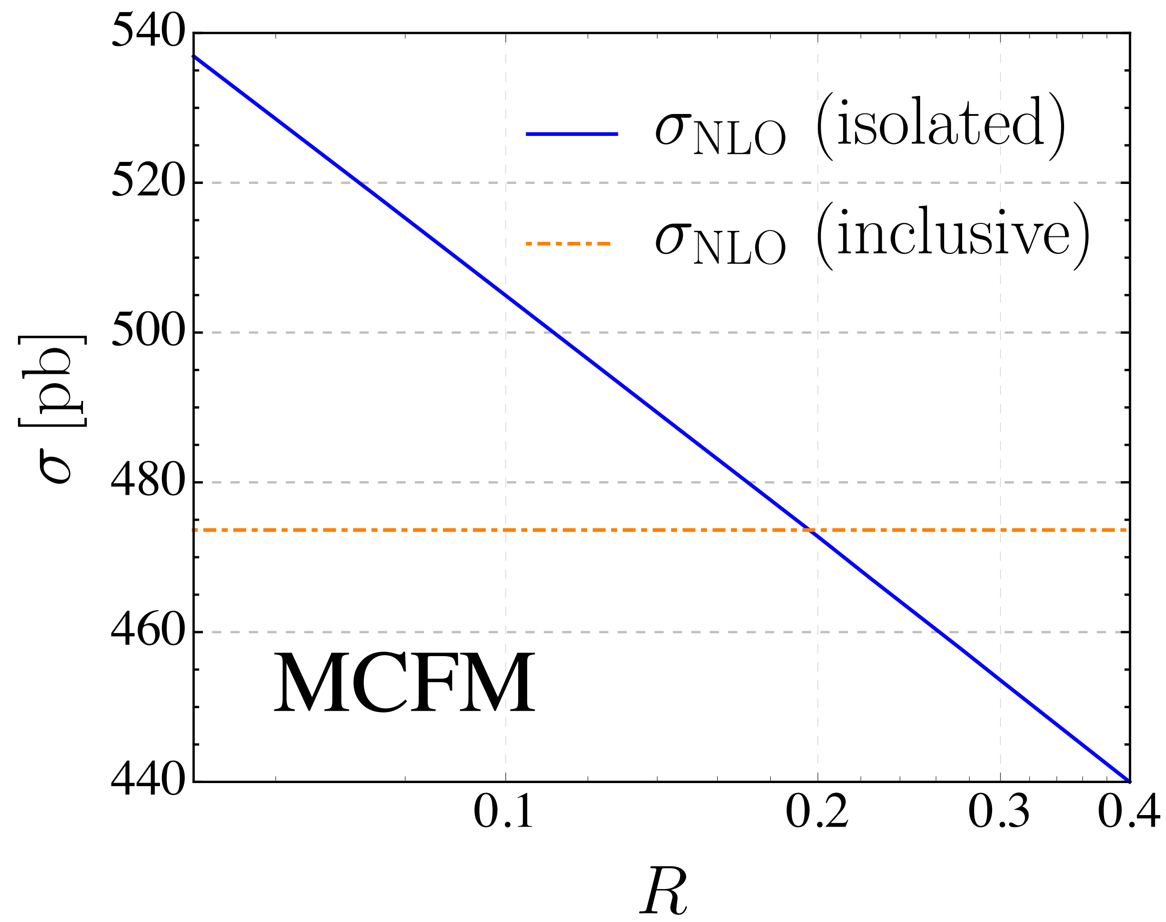
and for fixed-order results we set

$$\mu_f = \mu_r = 125\,\mathrm{GeV}$$

Fixed-cone results involve fragmentation functions and associated scale. For fixed-order, we set

$$\mu_a = 125\,\mathrm{GeV}$$

Fixed-Order Pathologies (I)



σ(isolated) with smooth-cone, n = 1, ε_γ = 1

σ(inclusive) with Gehrmann de Ridder, Glover '98 fragmentation functions

- *Should* have: σ(isolated) < σ(inclusive)
- At NLO, the isolation dependent part of cross section is proportional to ln(R)
  - breakdown of FOPT for $R \lesssim 0.2$!
  - R = 0.2 is default value for ATLAS diphoton analyses

Same problem also for fixed-cone isolation

Catani, Fontannaz, Guillet and Pilon in JHEP 05, 028 (2002)

Isolation radius	Total
R	NLO
1.0	3765.1
0.7	4098.0
0.4	4524.5
0.1	5431.1
Without isolation	5217.9

Fixed-cone isolation,

$\varepsilon_\gamma = 0.133$

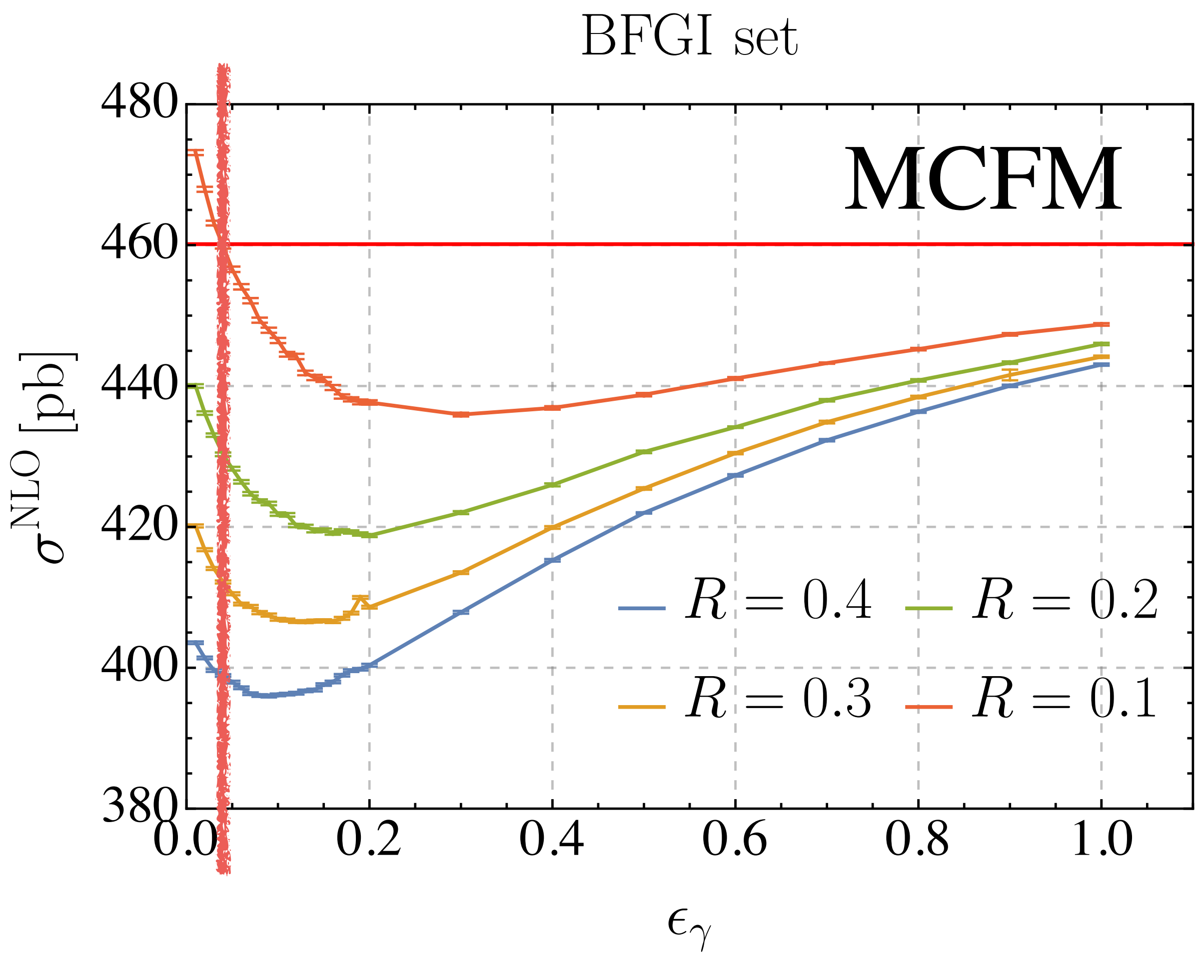
Also σ(isolated) depends fragmentation functions.

Tevatron cross section

$$\frac{d\sigma}{dE_\gamma^T}\ [\mathrm{pb/GeV}]$$

with $E_\gamma^T = 15\,\mathrm{GeV}$

Fixed-Order Pathologies (II)



σ(isolated) with fixed-cone isolation.

BFG (Bourhis, Fontannaz and Guillet, '98) fragmentation functions

- σ(isolated) *should* monotonically decrease as ε_γ is lowered
- NLO isolation effects are linear in ε_γ for small ε_γ (soft quark…)
  - coefficient enhanced by ln(*R*), unphysical for small *R*
- ATLAS isolation corresponds to $\varepsilon_\gamma = 0.04$ for $E_T^\gamma = 125\,\mathrm{GeV}$

Isolation parameter dependence

Isolation parameter dependence

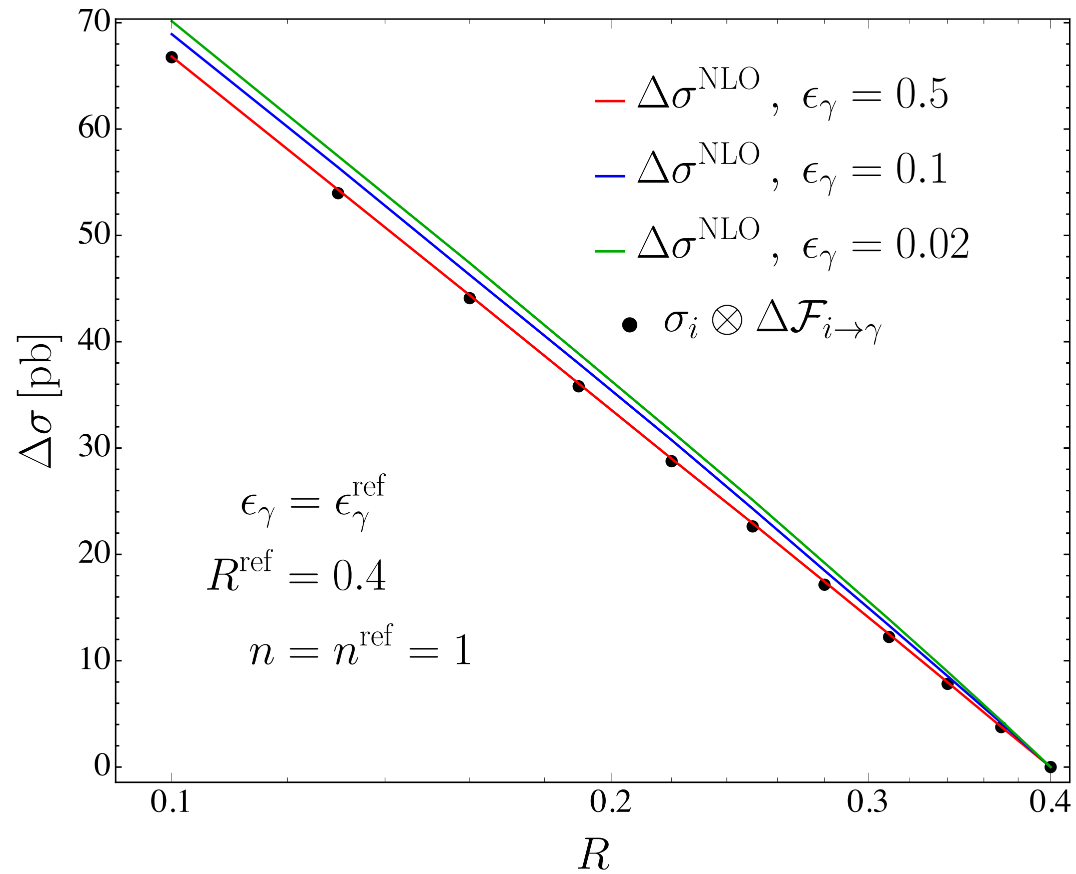
Interesting to look at difference to reference cross section

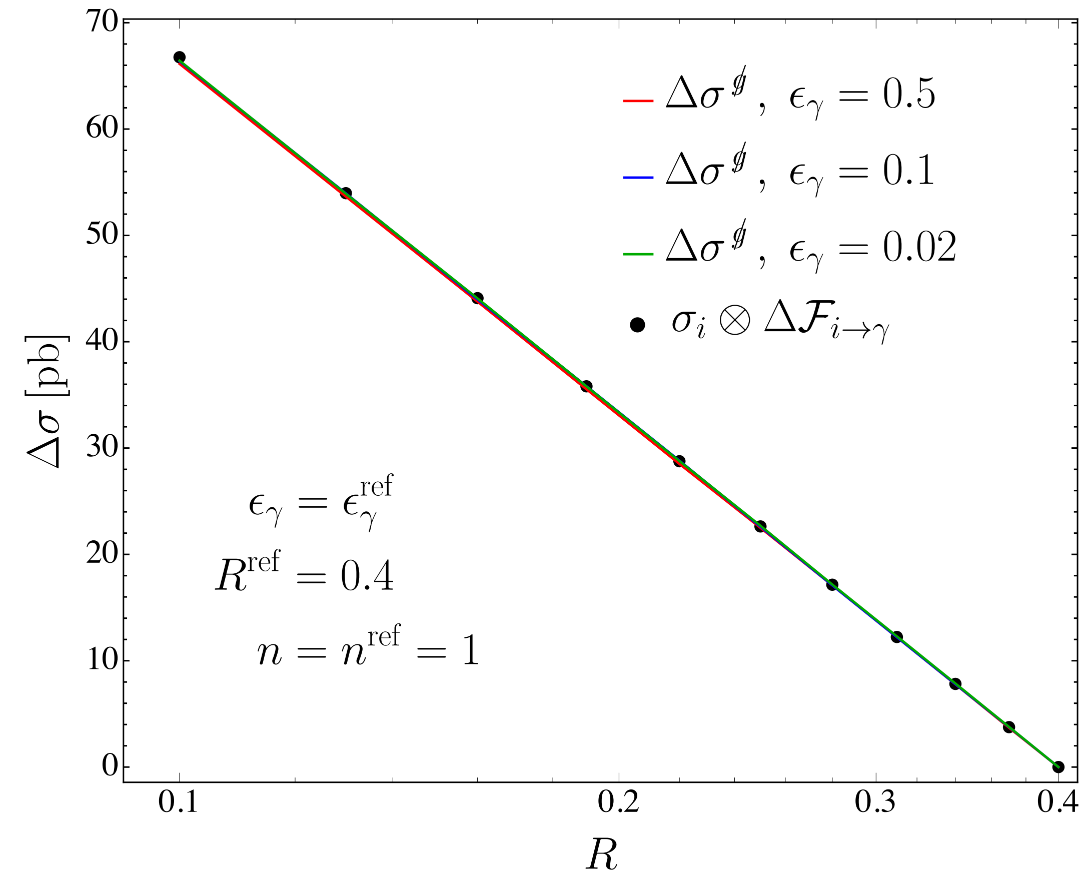
$$\Delta\sigma = \sigma\left(\epsilon_\gamma, n, R\right) - \sigma(\epsilon_\gamma^{\mathrm{ref}}, n^{\mathrm{ref}}, R^{\mathrm{ref}})$$

since direct part drops out:

$$\Delta\sigma = \sum_{i=q,\bar{q}} \int_{E_T^{\mathrm{min}}}^{\infty} dE_i \int_{z_{\mathrm{min}}}^{1} dz \frac{d\sigma_{i+X}}{dE_i} \Delta\mathcal{F}_{i\to\gamma}$$

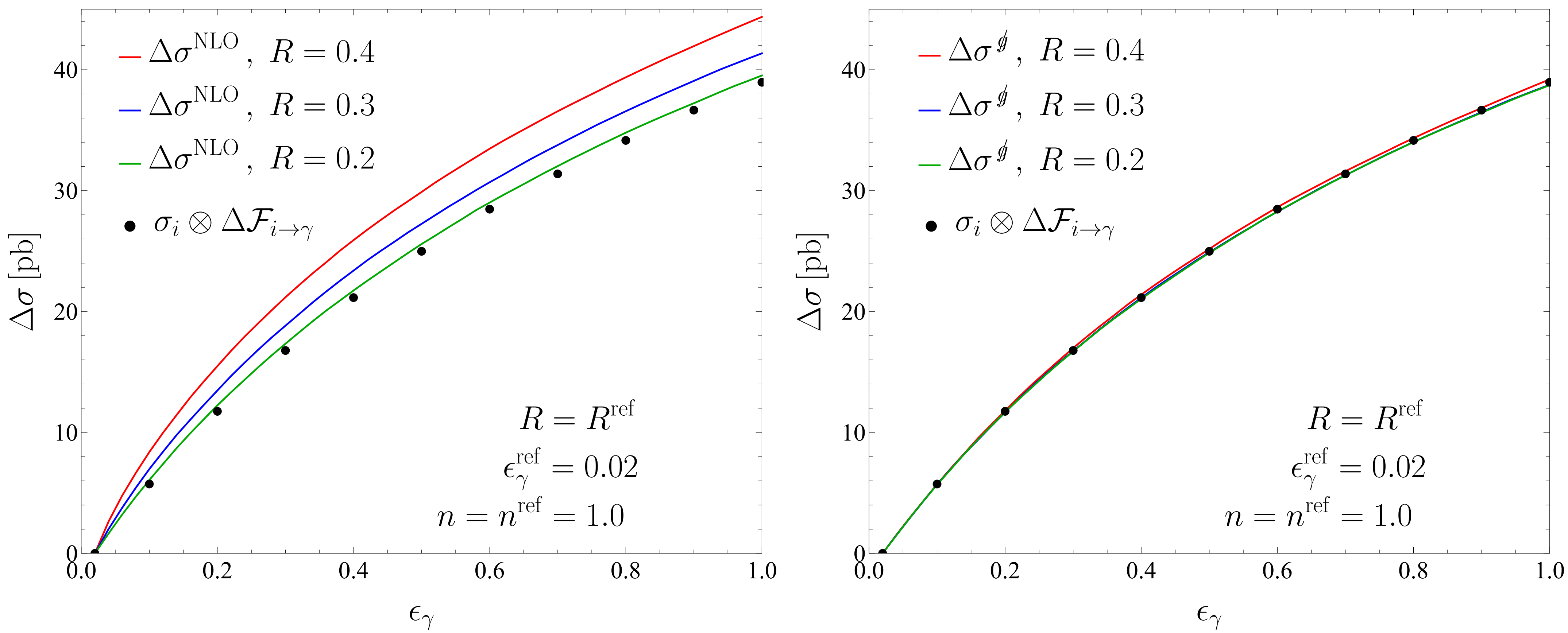
R-dependence (smooth cone)





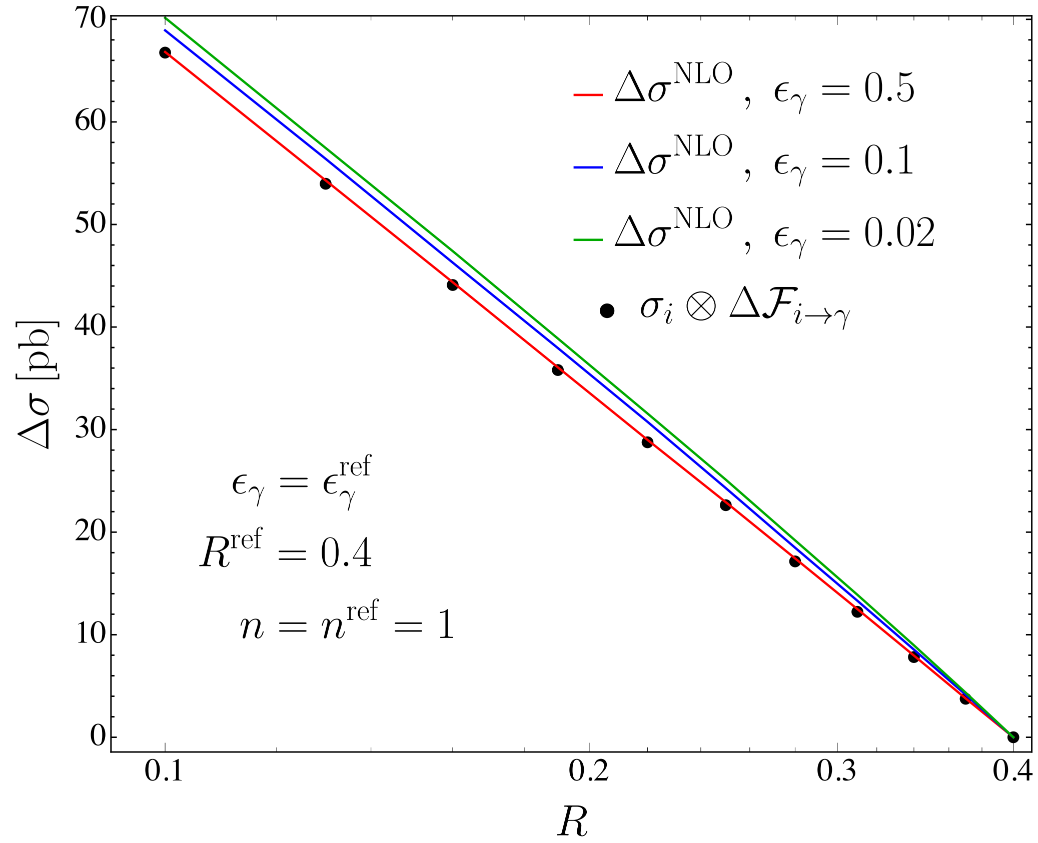
- Good agreement between full NLO (lines) and fragmentation approach (dots)
  - difference must vanish for R → 0
- Right plot without *R*-suppressed contribution of gluons inside the cone

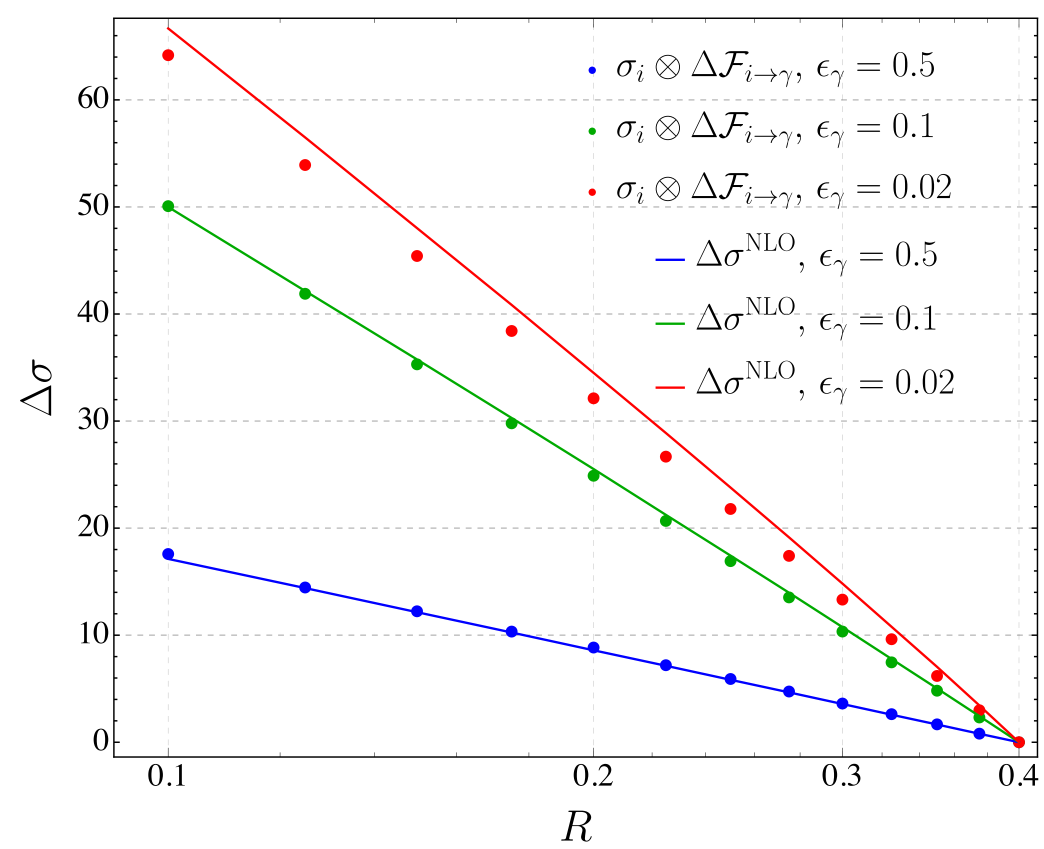
ε_γ-dependence (smooth cone)



- Fragmentation approach becomes exact as $R \to 0$.

Smooth- vs fixed-cone isolation





- For fixed cone also inside part of $\mathcal{F}_{i\to\gamma}$ has ln(*R*) contribution, which is ε_γ dependent.
  - For $\varepsilon_\gamma \to 0$ inside part vanishes and one recovers smooth-cone *R*-dep!

More generally: for small ε_γ the inside part becomes small

- Non-perturbative fragmentation suppressed by ε_γ

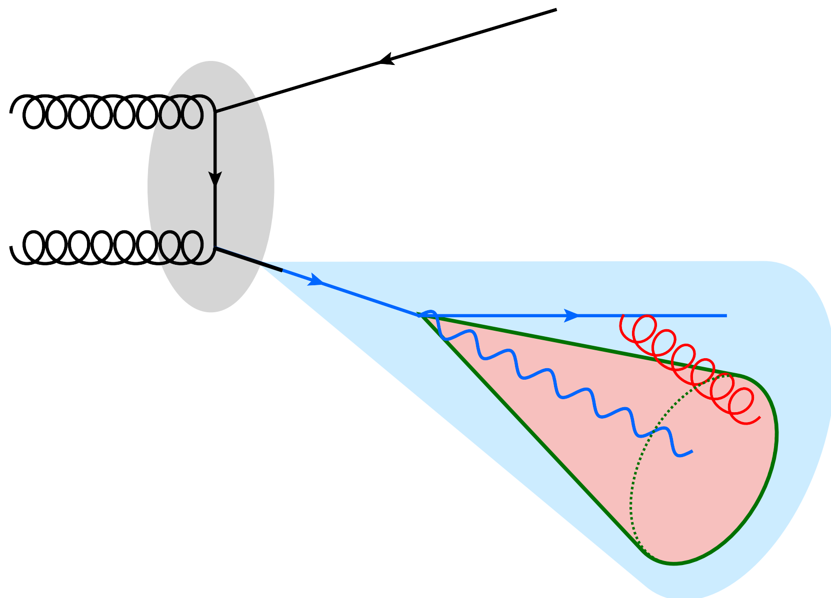
and at NLO the following properties hold

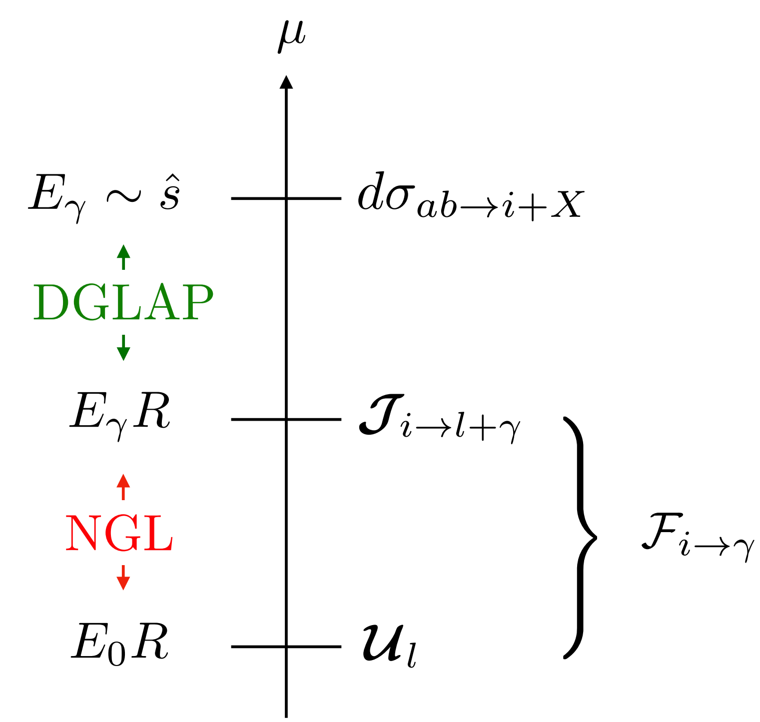
- $\ln(R)$ dependence only from outside part
- All isolation prescriptions become identical!

but at NNLO differences from out-in terms!

Resummation

Factorization of $\mathcal{F}_{i\to\gamma}$





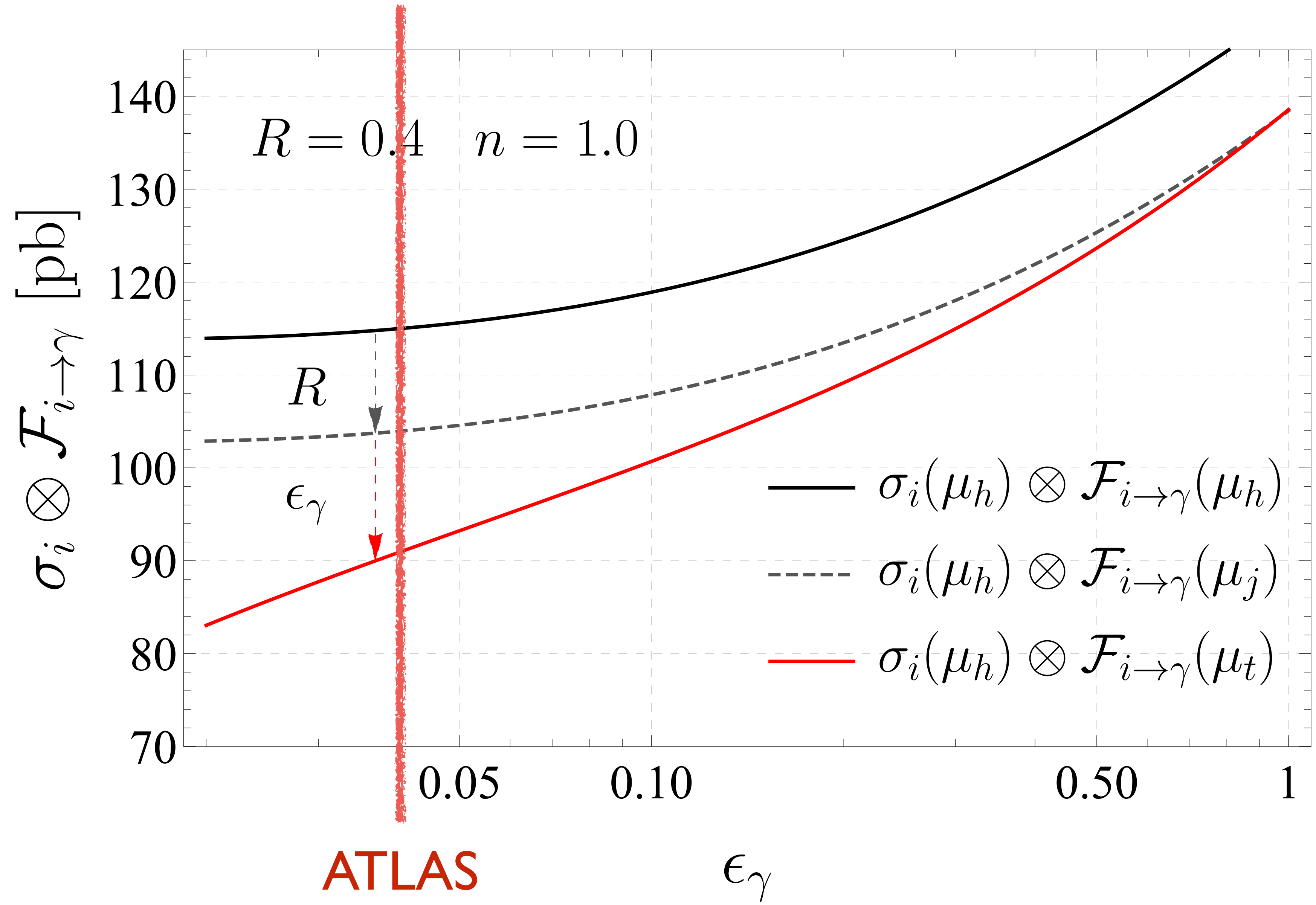
$$\mathcal{F}_{i\to\gamma}(z, R\,E_\gamma, R\,E_0, \mu) = \sum_{l=1}^{\infty} \langle \boldsymbol{\mathcal{J}}_{i\to\gamma+l}(\{\underline{n}\}, R\,E_\gamma, z, \mu) \otimes \boldsymbol{\mathcal{U}}_l\,(\{\underline{n}\},\, R\,E_0, \mu)\rangle$$

energetic collinear outside cone

soft radiation inside cone

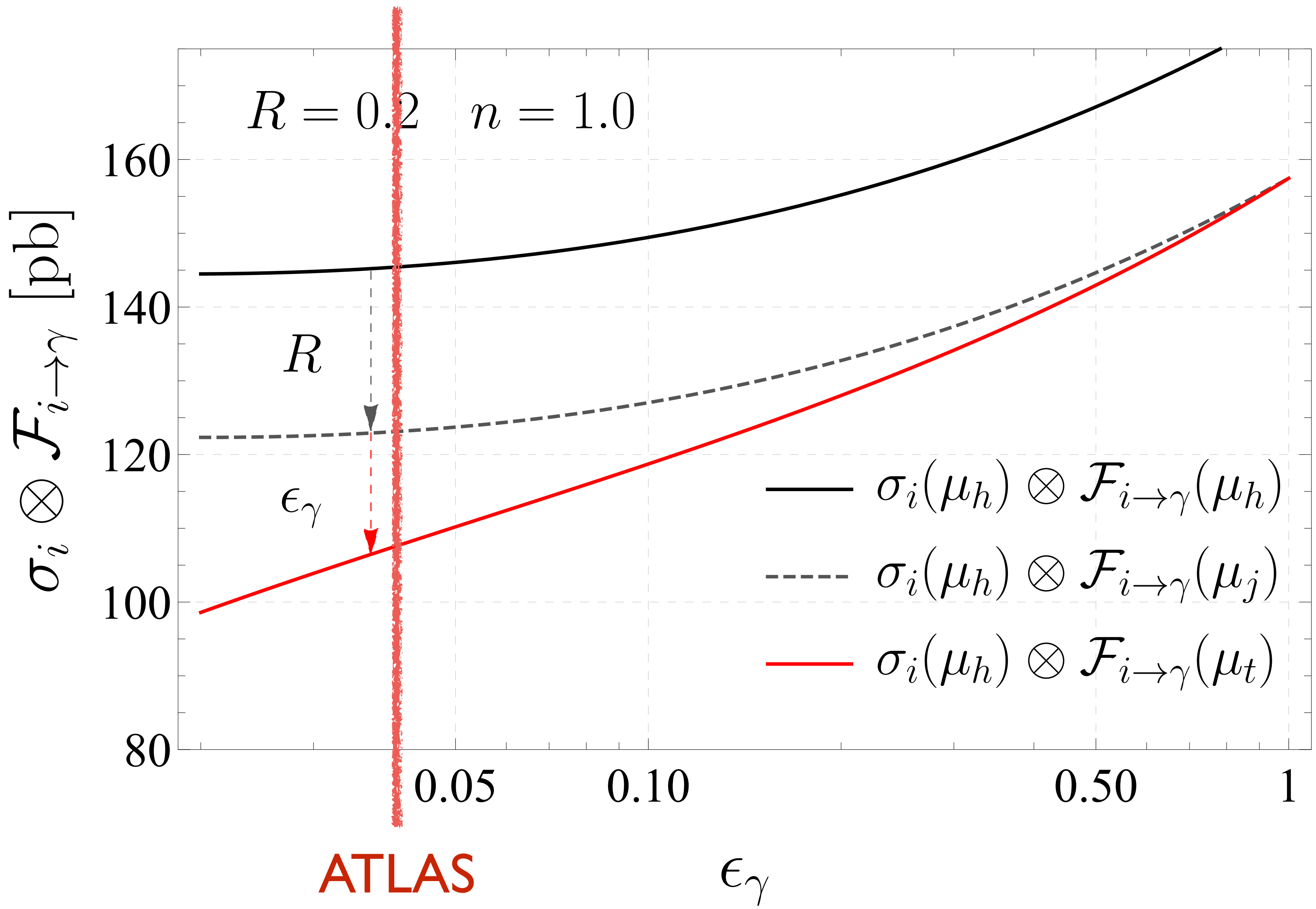
- Resum both ln(ε$_\gamma$) and ln(R).
- Lowest scale is $R\,E_0 \gtrsim 1$ GeV for ATLAS !

Resummation of ln(R) and ln(ε_γ)



- For the full cross section, add direct part $\sigma^{\mathrm{dir}} \approx 290\,\mathrm{pb}$

Resummation of ln(R) and ln(ε_γ)



- For the full cross section, add direct part $\sigma^{\rm dir} \approx 290\,{\rm pb}$