UNIVERSITÄT **BERN**

AEC ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

Supplemental slides

QCD in photon production:

fragmentation, isolation, resummation, slicing

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Fixed-Order Pathologies

For all cross section computations we will use 1 cos *R* (*r*) = ✓ ¹ cos *^r* ◆*ⁿ* utations we w 1 cost cost cost cost cost cost cost <u>cost cost cost cost cost cost cost cost cost cost cost</u>
2 cost ◆*ⁿ*

$$
E_T^{\gamma} > E_T^{\min} = 125 \,\text{GeV}
$$
\n
$$
\alpha_s(M_Z) = 0.119
$$
\n
$$
\alpha_{\text{EM}} = 1/132.507
$$
\n
$$
\sqrt{s} = 13 \,\text{TeV}
$$
\nNNPDF23_nlo-as_0119_qed_m

and for fixed-order results we set and for fixed-order results we set \overline{u} $\overline{$

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

Fixed-cone results involve fragmentation functions and associated scale. For fixed-order, we set *a* ie. For tixeu-or $\frac{1}{2}$ the involve fraamentat IX CU-CUILE I COL

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

Fixed-Order Pathologies (I)

σ(isolated) with smooth-cone, $n=1, \varepsilon_{\rm V}=1$

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 \bullet proportional to $\ln(R)$
	- breakdown of FOPT for $R \le 0.2!$
	- $R = 0.2$ is default value for ATLAS diphoton analyses

Same problem also for fixed-cone isolation Catani, Fontannaz, Guillet and Pilon in JHEP 05, 028 (2002) Same problem also for fixed-cone isolation **Canno prodicin also ion fixed cone isolation** Same problem also for fixed-co **Canno propioni are reference with the results with an experience with the report is with the report of the repo**

Fixed-cone isolation, *ε*^γ = 0.133

1.0 1764.6 3318.4 265.0 446.7 3765.1 Also σ(isolated) depends fragmentation functions.

$$
\frac{\text{Without isolation}}{\text{d}E_{\gamma}^{T}} \left[\text{pb}/\text{GeV} \right]
$$

It is interesting to note that the HO contributions, both to the direct and to the direct and to the fragmentations, $\mathcal{L}_{\mathcal{A}}$ with $\; E_\gamma^T = 15 \, {\rm GeV}$

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 $\varepsilon_{\rm v}$ for small $\varepsilon_{\rm v}$ (soft quark...) \bullet
	- coefficient enhanced by $ln(R)$, unphysical for small R
- ATLAS isolation corresponds to $\varepsilon_{\rm V}$ = 0.04 for $E_T^{\gamma} = 125\,{\rm GeV}$

Isolation parameter dependence

Isolation parameter dependence

Interesting to look at difference to reference cross section parameters listed in Table 1 throughout the paper. In the paper of the paper of the paper. In the paper of the
Table 1 throughout the paper. In the paper of the paper of the paper of the paper. In the paper of the paper o To depend the dependence on the dependence on its smooth-cone is a consider smooth-cone is a consider smooth-c (1.2) and compute the di↵erence to a reference cross section Interesting to look at difference to reference

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

since direct part drops out: In the direct photon part in (2.1) drops out so that it is given by a state photon part in (2.1) drops out so
It is given by a state it is given by a s convolution part are position. convolution of the partonic cross section with the fragmentation function. At this order, of fragmenting part of the parton is equal.

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

R-dependence (smooth cone)

- **•** Good agreement between full NLO (lines) and fragmentation approach (dots) the full NLO cross sections. For the lines labeled *g/* in the right plot gluons inside the isolation ragfieriation approach (dots)
	- difference must vanish for $R \rightarrow 0$
- Right plot without *R*-suppressed contribution of gluons inside the cone said the same scale is sensible. Note that this is the opposite of *^F*out *^q*! in (??). In the absence of the isolation energy $\bullet\quad$ Hight plot without κ -suppressed contribution of constraint, the isolation becomes trivial and the entire fragmentation reduces to the non-

*ε*γ-dependence (smooth cone)

• Fragmentation approach becomes exact as $R \rightarrow 0.$ the full NLO cross sections. The dots represent = *i*⌦*Fⁱ*! computed with the fragmentation • Fragmentation approach becomes exact as

Smooth- vs fixed-cone isolation

- For fixed cone also inside part of $\mathcal{F}_{i\rightarrow \gamma}$ has $\ln(R)$ contribution, which is ε _γ dependent. show the full NLO cross sections, the dots correspond the the result obtained using the cone • For fixed cone also inside part of $\mathcal{F}_{i\to\gamma}$ has $\ln(R)$ contribution which is sudenandent contribution, which is $\varepsilon_{\operatorname{\gamma}}$ dependent.
- For $\varepsilon_y \rightarrow 0$ inside part vanishes and one recovers smooth-cone R-dep! For $\epsilon_{\gamma} \rightarrow 0$ inside part vanishes and one recovers ✏ = 0*.*02 414*.*56 *±* 0*.*34 413*.*31 *±* 0*.*36 410*.*41 *±* 0*.*37 **•** For $\varepsilon_v \rightarrow 0$ inside part vanishes and one recovers

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

- In(*R*) dependence only from outside part
- All isolation prescriptions become identical!

but at NNLO differences from out-in terms!

Resummation

- Resum both ln(εγ) and ln(*R*). \bullet Resum both $\mathsf{In}(\varepsilon_v)$ and $\mathsf{In}(R)$. part of the compact (and slightly more general) way of writing $\frac{1}{2}$
	- Lowest scale is $R E_0 \ge 1$ GeV for ATLAS! d*E* $\overline{1}$ $\overline{0}$ +*X* **DWEST SCAIE IS** *H E*o ≳ 1 (d*Eⁱ Fi*!(*z, E, E*0*, R*)*.* (2.2) – 19 –

Resummation of ln(*R*) and ln(*ε*γ)

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

Resummation of ln(*R*) and ln(*ε*γ)

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