

Photon Fragmentation Functions extracted from Pythia stored in LHAPDF

[2608.15944]

Alexander Puck Neuwirth

Università degli Studi di Milano-Bicocca & INFN Sezione di Milano-Bicocca

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Photon Fragmentation Functions

- Just like PDFs, FFs can not be computed in perturbative theory and must be measured at an initial scale

$$d\sigma \sim \sum_{a,b,c} \int_0^1 dx_a dx_b dz \underbrace{f_{a/A}(x_a, \mu_F) f_{b/B}(x_b, \mu_F)}_{\text{PDFs}} \cdot \underbrace{d\hat{\sigma}_{cX}\left(x_a P_A, x_b P_B, \frac{P_\gamma}{z}, \mu_F\right)}_{\text{partonic cross section}} \cdot \underbrace{D_{\gamma/c}(z, \mu_F)}_{\text{fragmentation}}$$

- LO photon evolution equation, with momentum transfer z and factorization scale μ_F

$$\mu_F^2 \frac{d}{d\mu_F^2} D_{\gamma/c}(z, \mu_F) = \frac{\alpha}{2\pi} P_{\gamma c}(z)$$

$$D_{\gamma/q}(z, \mu_F) = \frac{\alpha}{2\pi} P_{\gamma q}(z) \log\left(\frac{\mu_F^2}{\mu_0^2}\right) + D_{\gamma/q}^{\text{measured}}(z, \mu_0) \quad D_{\gamma/g}(z, \mu_F) = \text{const.}$$

Motivation

- Prompt photons are clean QCD probes, but realistic isolation leaves a residual fragmentation component.
- Existing BFG/GRV/GDRG sets differ significantly and are not well constrained by data.
- Prompt photons were already studied in ep collisions at HERA [hep-ex/0608028]
 - $\Rightarrow$ EIC will study photon-production in ep and eA collisions
 - $\Rightarrow$ new sensitivity to photon FFs in $\gamma + j$ and γ -in-jet observables complementing LEP and LHC constraints.
- Better photon FFs would improve the interpretation of prompt-photon measurements as probes of proton and nuclear structure.
- Photon FFs are embeded in JetPhox, MCFM, NNLOJet, EPhox as code.
- LHAPDF grids is better because the same FF sets could be used consistently in phenomenology tools while profiting from the more advanced PDF uncertainty machinery.

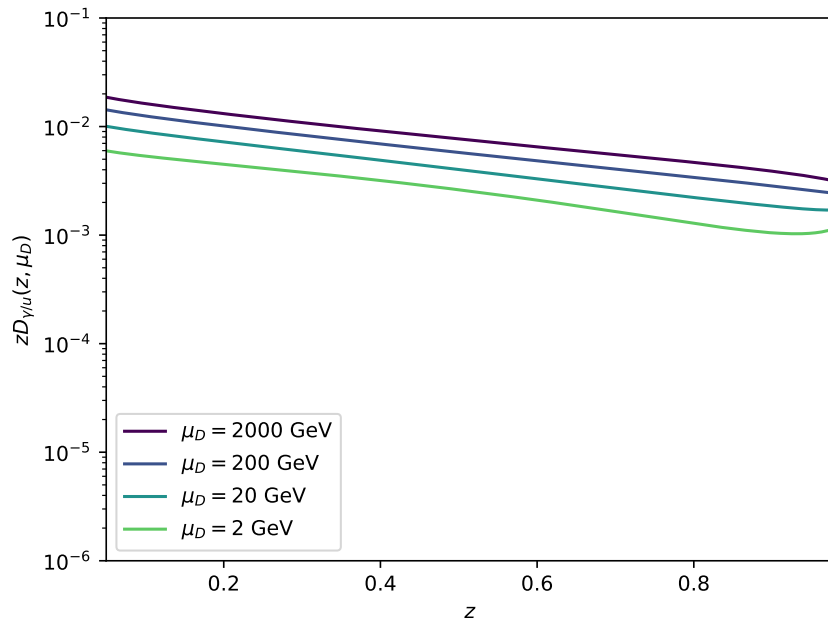
Existing Photon FFs

- Initial measurement at μ_0 in vector meson dominance (VMD) model or e^+e^- data
- No uncertainties, but large differences!

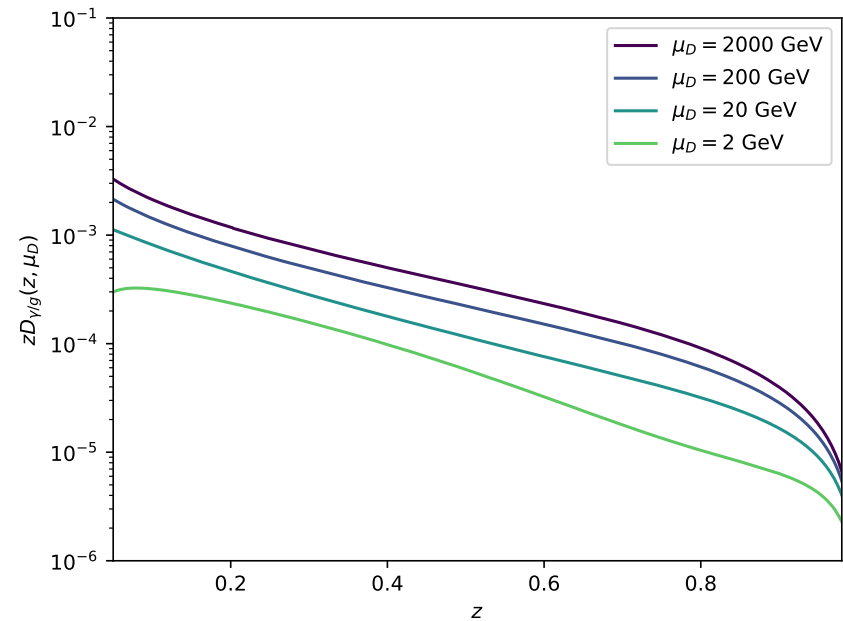
Set	Accuracy	Scheme	μ_0^2 [GeV ²], Main feature	Reference
GRV LO	LL/LO	DIS _{γ}	0.3, incoherent VMD, low-scale start	[Gluck:1992zx]
GRV NLO	BLL/NLO	DIS _{γ}	0.3, incoherent VMD, low-scale start	[Gluck:1992zx]
BFG I	BLL/NLO	$\overline{\text{MS}}$	2.0, coherent VMD, smaller gluon FF	[hep-ph/9704447]
BFG II	BLL/NLO	$\overline{\text{MS}}$	2.0, coherent VMD, larger gluon FF	[hep-ph/9704447]
GDRG LO	LO fit	—	0.14, ALEPH-based quark-only fit	[hep-ph/9806316]
GDRG NLO	NLO fit	—	0.64, ALEPH-based quark-only fit	[hep-ph/9806316]

Photon FF evolution

- Larger scale $\Rightarrow$ higher fragmentation contribution



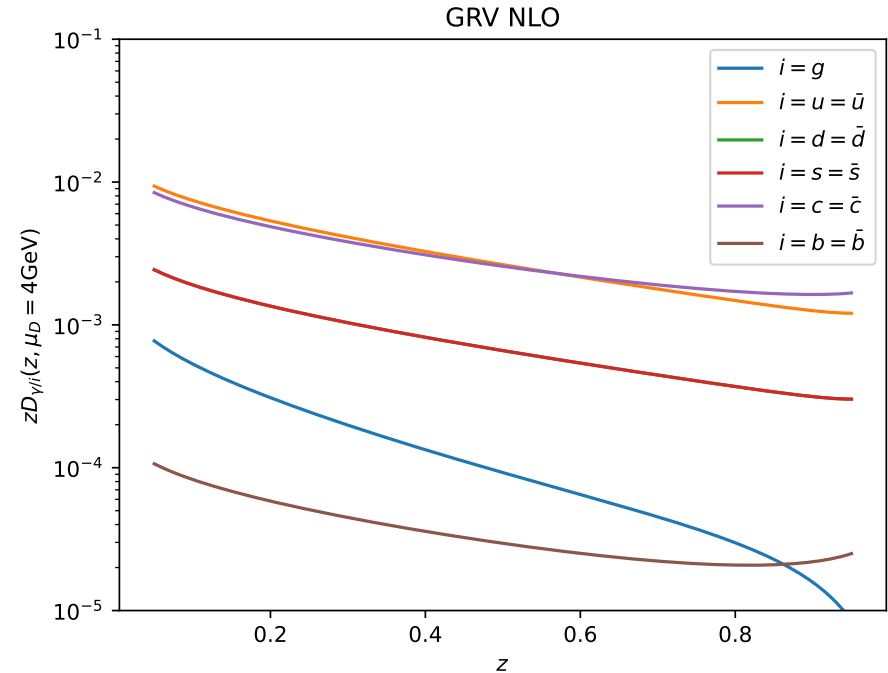
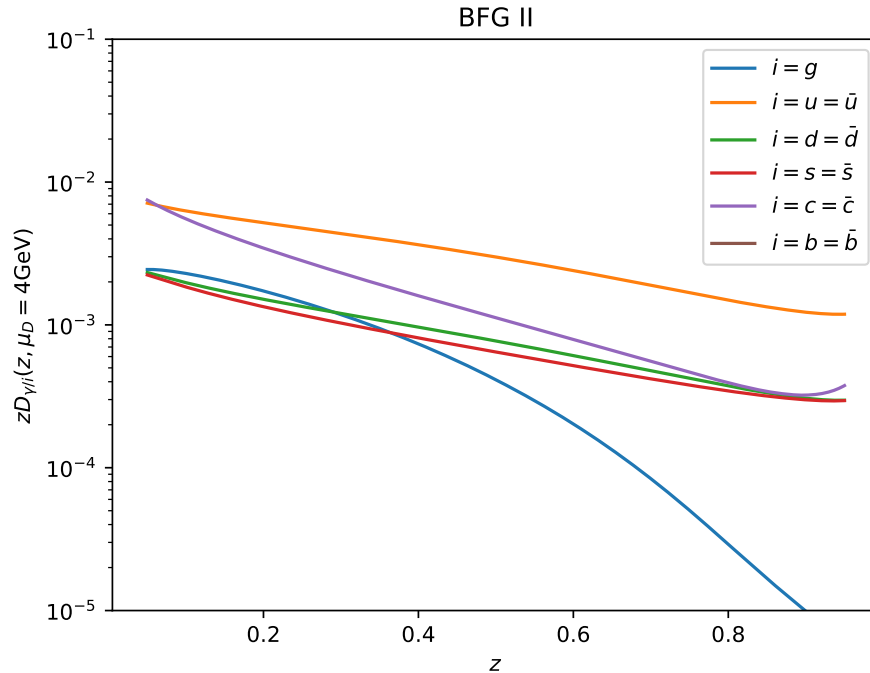
BFG I: up quark



BFG I: gluon

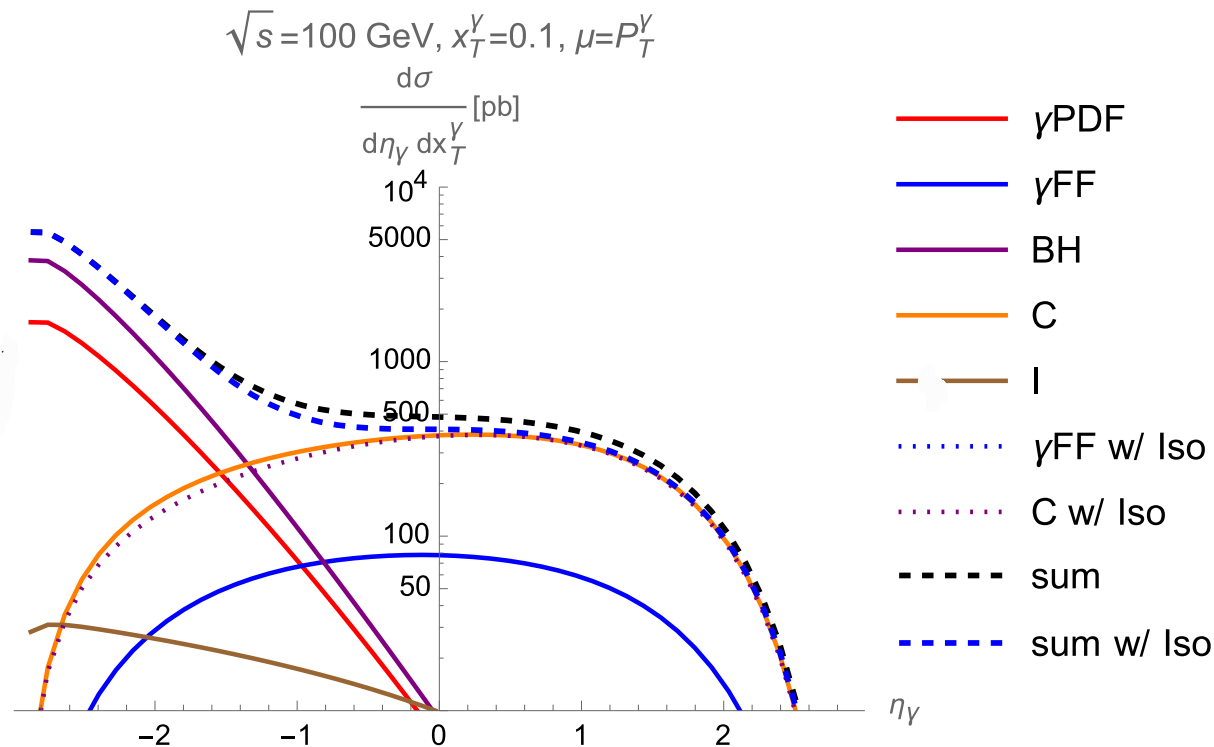
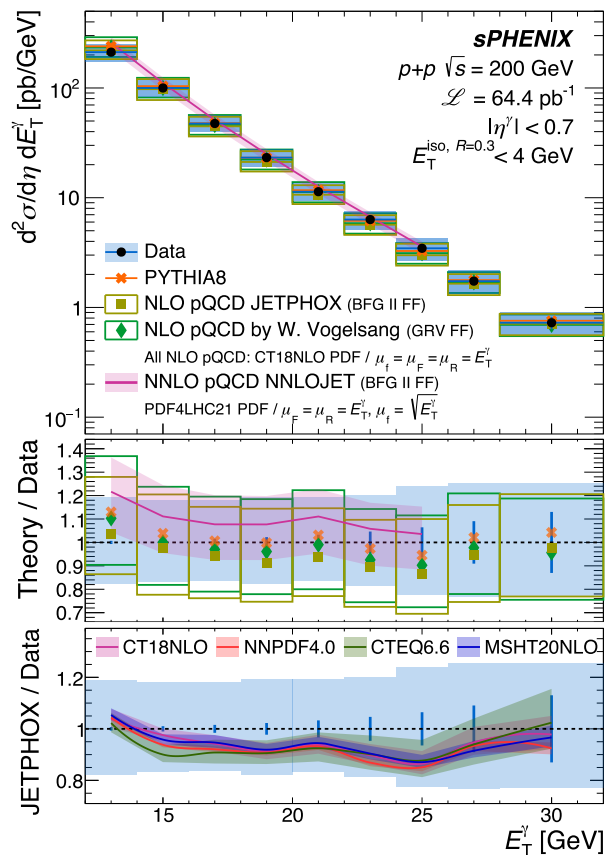
Existing Photon FFs (cont.)

- $zD_i(z, \mu_D = 4 \text{ GeV})$
- Anti-quarks are identical to quarks



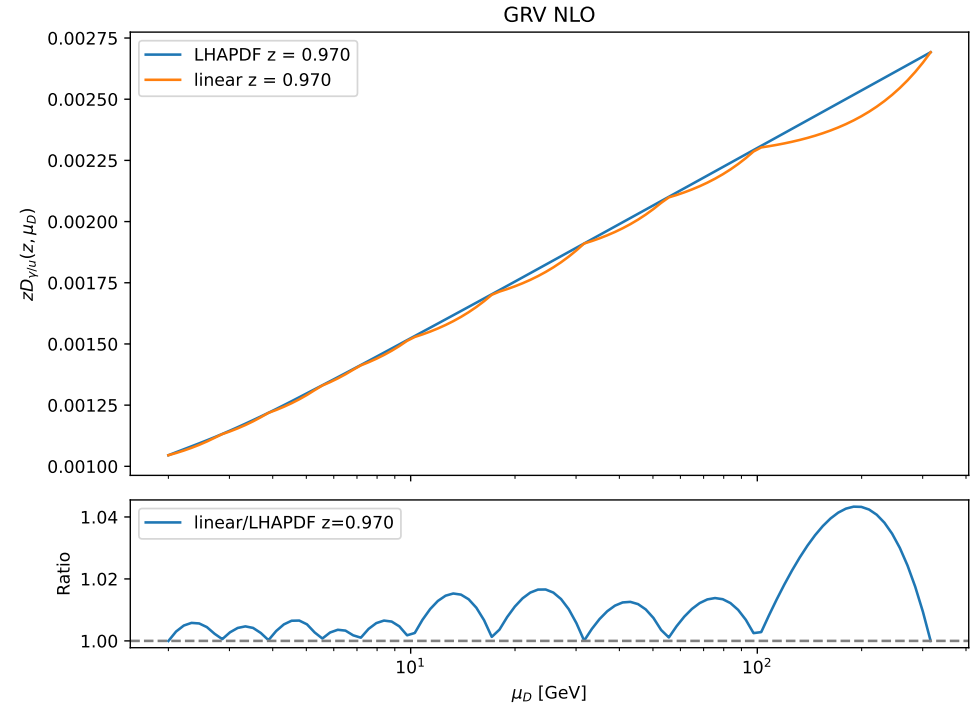
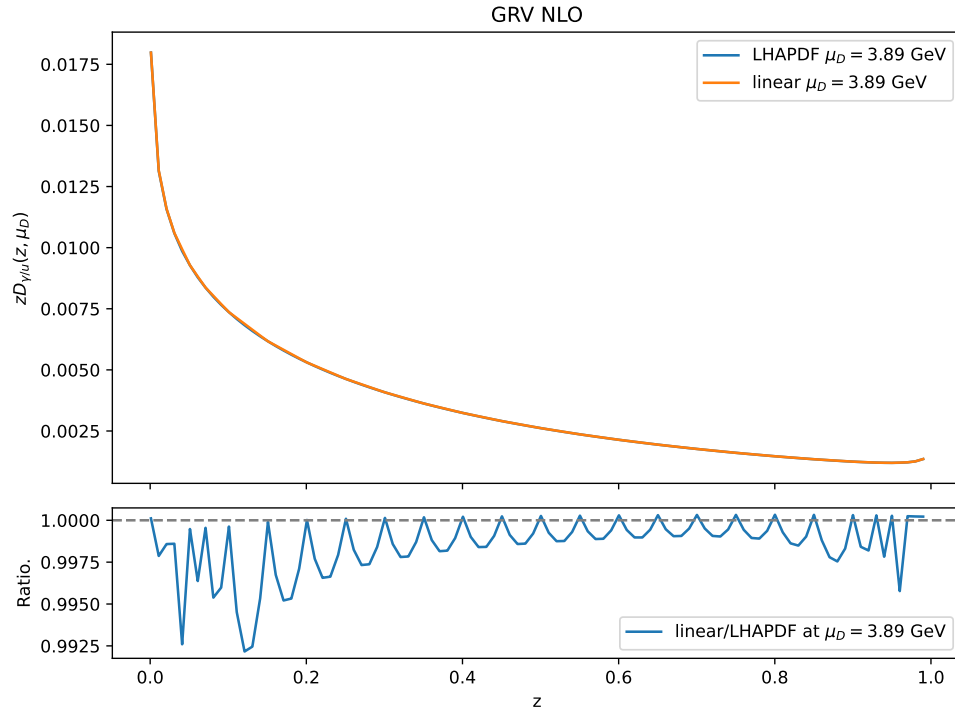
Recent Photon FF usage [2607.03892] [2405.04232]

EIC $ep \rightarrow \gamma X$ using GRV NLO FF



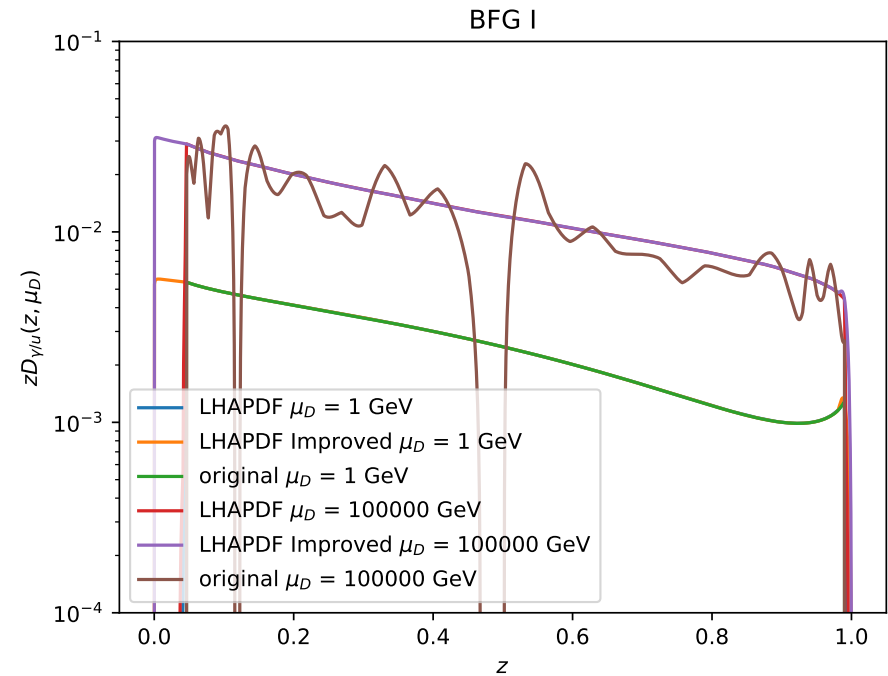
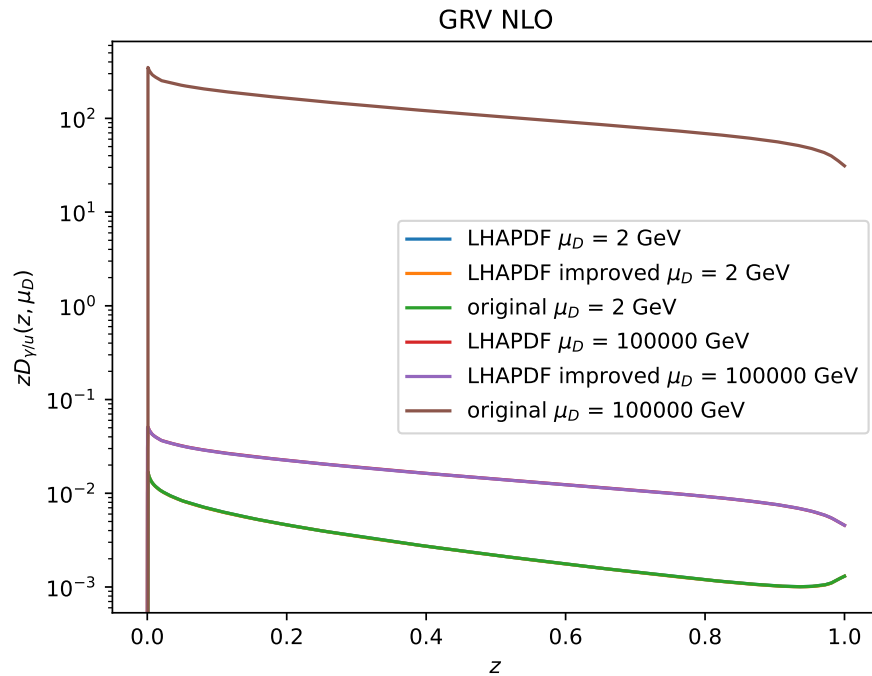
Interpolation: linear vs logcubic

- Oscillations back to the input grid points in both μ_D and z



Extrapolation

- At $\mu_D = 100$ TeV GRV NLO blows up and BFG I is unstable

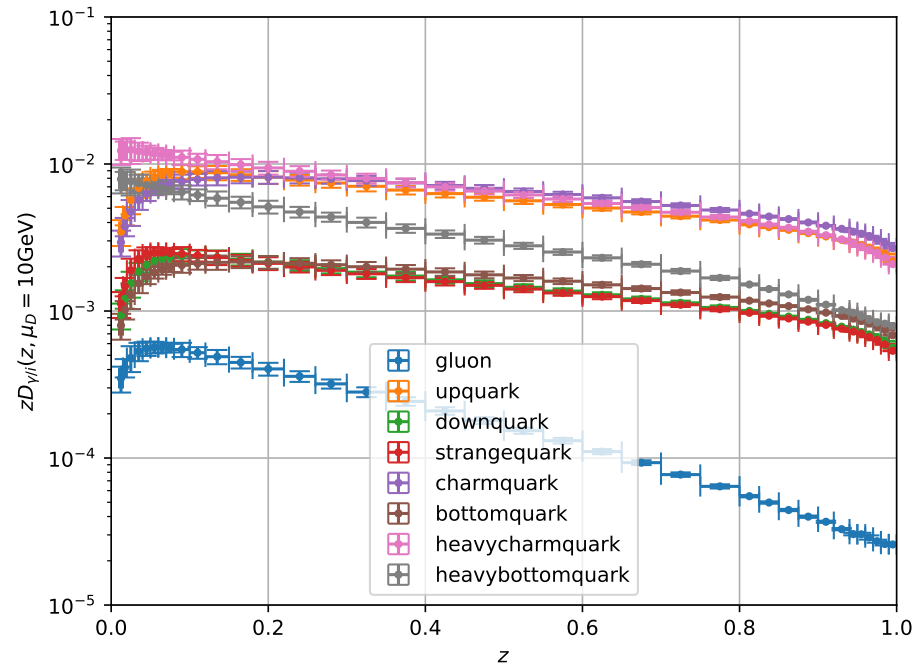


Extraction from a parton shower

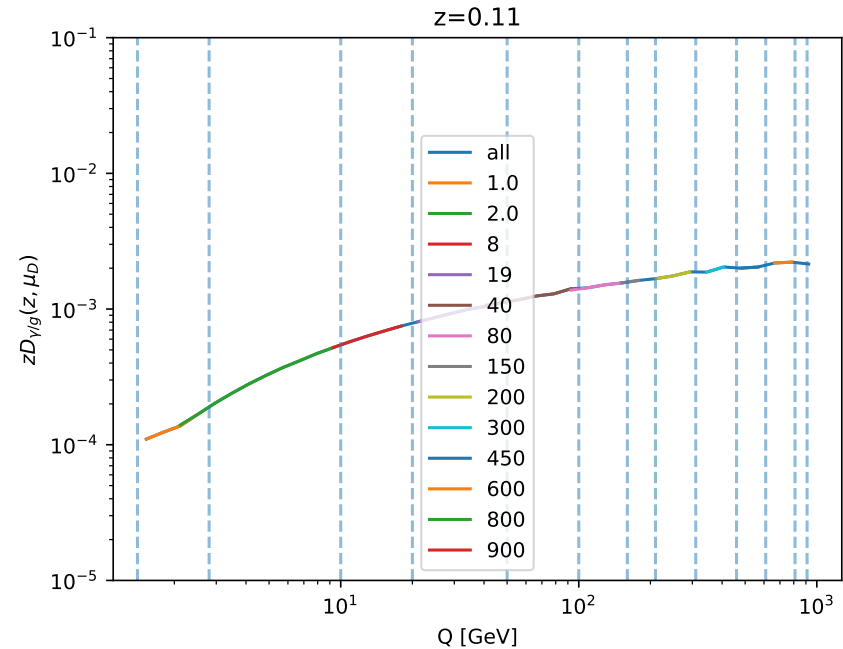
- Goal: construct an effective shower-level photon fragmentation function, $D_{\gamma/i}^{\text{PS}}(z, \mu_D)$, in similar variables as standard FF sets.
- Use Pythia final-state QED radiation: photons are traced back to the initiating parton flavour in the HepMC record.
- Define the fragmentation scale from the hard parton: $\mu_D = p_{T, \text{parton}}$, with light-cone photon momentum fraction $z = \frac{E_\gamma + \vec{p}_\gamma \cdot \hat{n}_i}{E_i + \vec{p}_i \cdot \hat{n}_i}$.
- Fill flavour-dependent histograms: $D_{\gamma/i}^{\text{PS}}(z, \mu_D) = \frac{1}{N_{i, \text{tot}}(\mu_D)} \frac{dN_{i \rightarrow \gamma+X}(z, \mu_D)}{dz}$.
- Combine several hard-process p_T slices to cover the full (z, μ_D) plane, then export the result as the LHAPDF grid.

Pythia Photon FF

- one slice at $\mu_D = 10 \text{ GeV}$



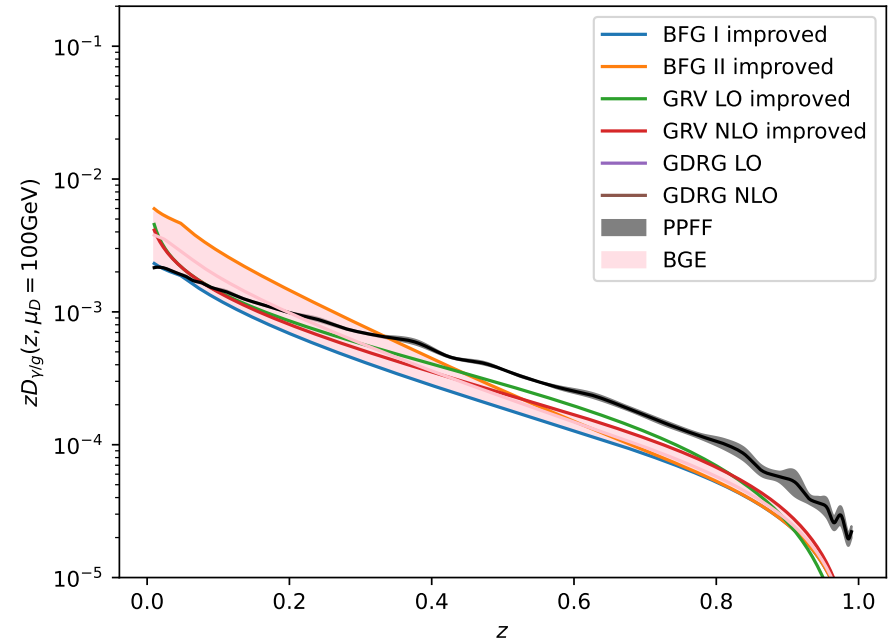
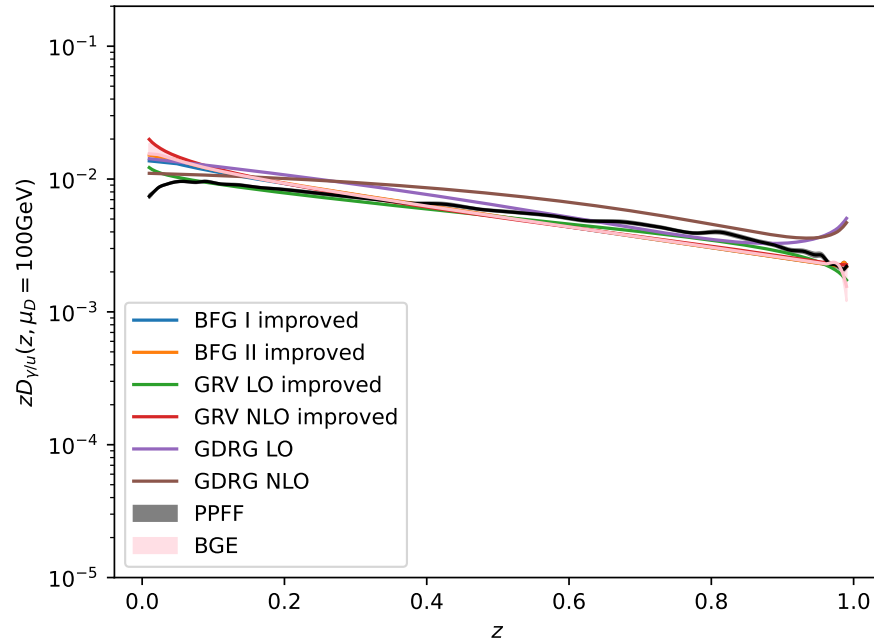
- slices stitched together



- In the following only massless quarks are used from $pp \rightarrow jj$ at $\sqrt{s} = 13 \text{ TeV}$

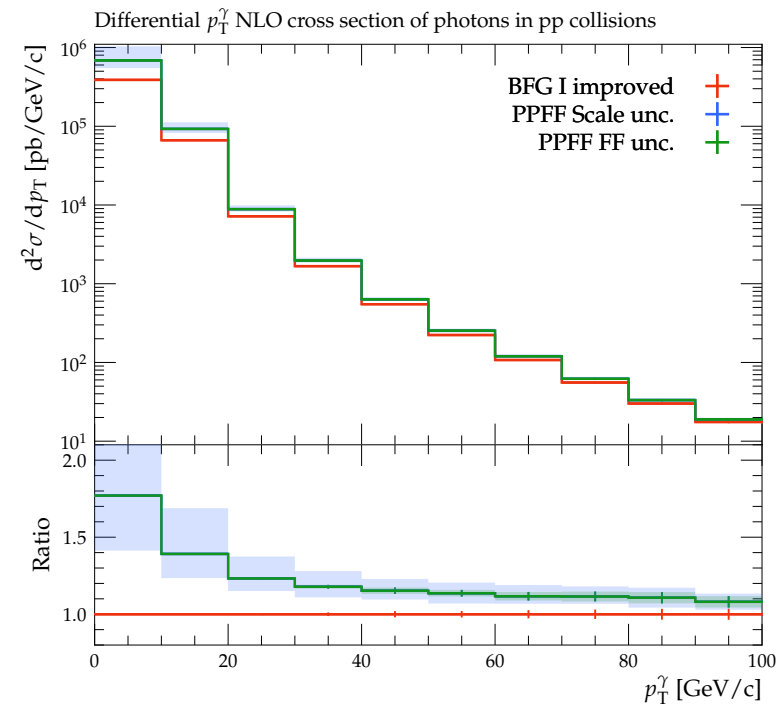
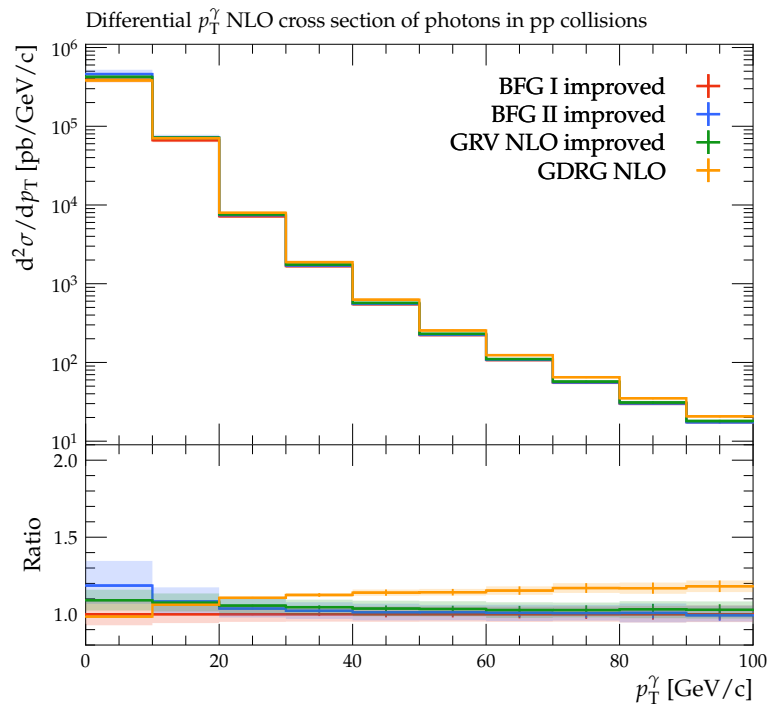
Comparison of FFs

- New demo sets: BFG_GRV_ENVELOPE (BGE) and Pythia Photon FF (PPFF)
- PPFF decreases towards small z due to shower cutoff (TimeShower:pTminChg)



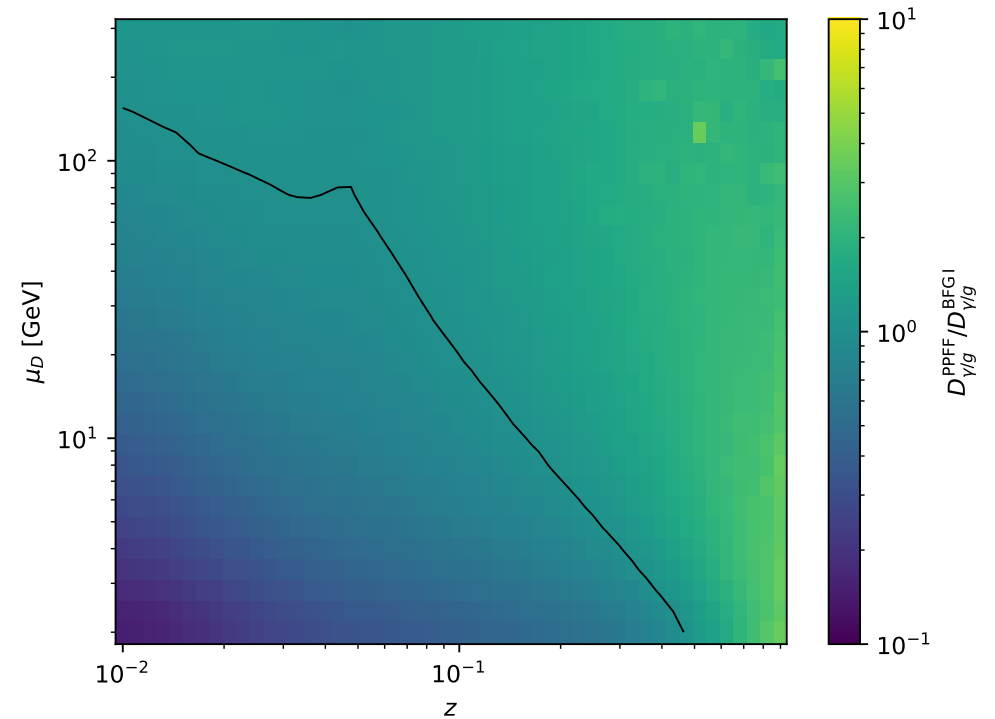
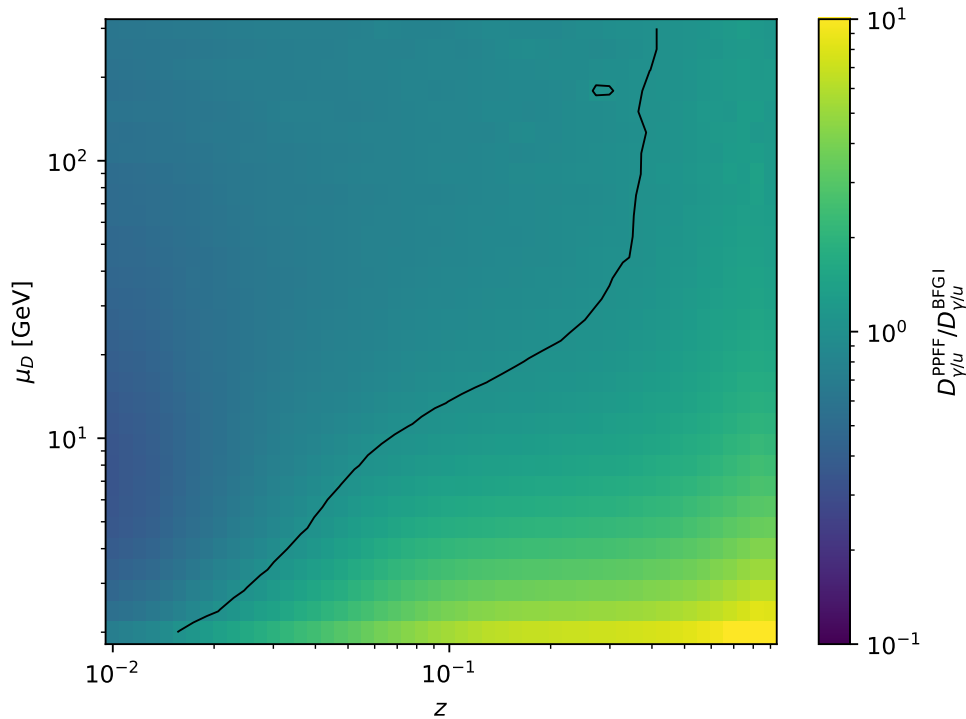
Unisolated photons from MCFM @ 7 TeV

- Uncertainty from different sets (BFG I vs BFG II) is larger than the factor 2 scale variation
- No visible difference between improved and original (after MCFM bug fix!)

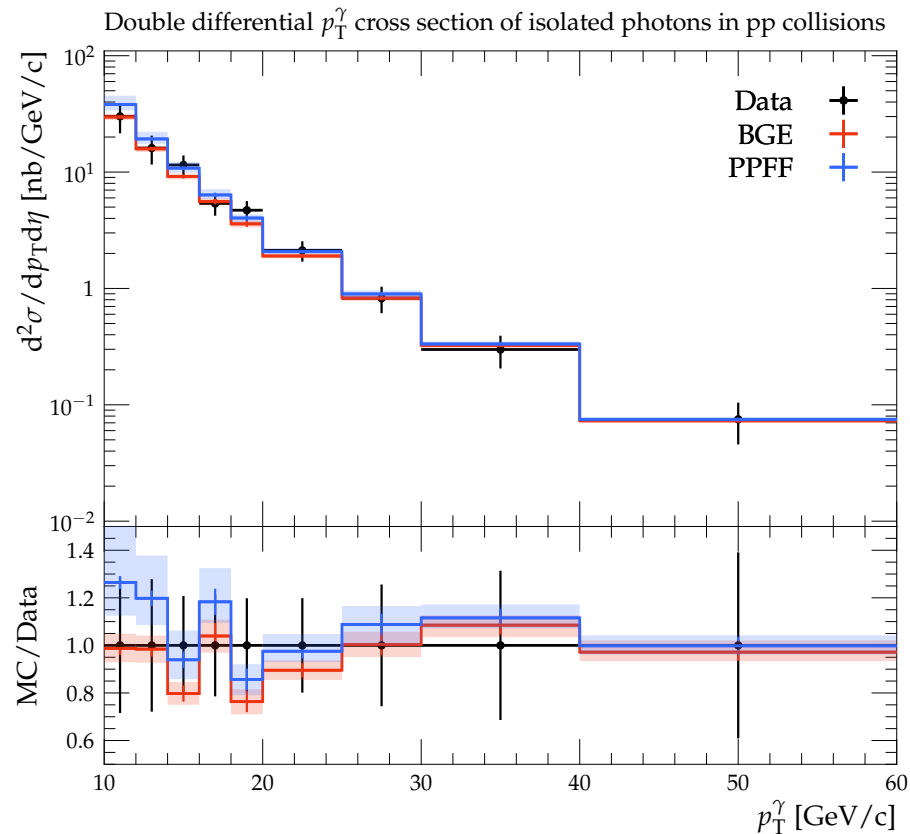
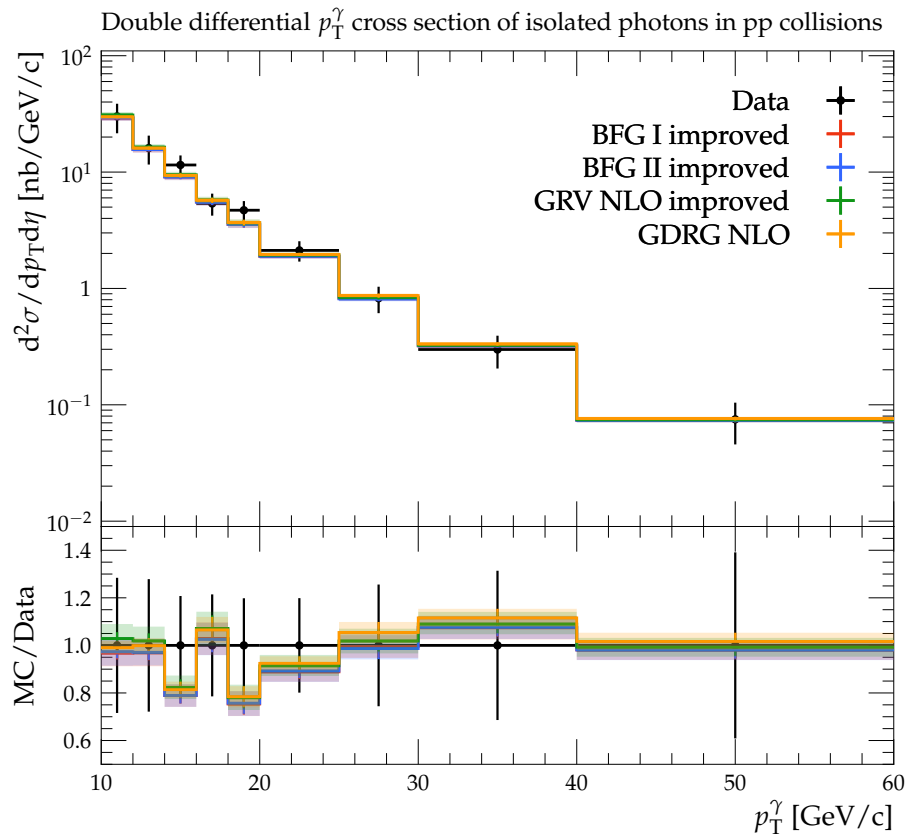


Source of differences

- Contour line at $\frac{D^{\text{PPFF}}}{D^{\text{BFGI}}} = 1$
- Strongest differences at low μ_D and large z for quarks (due to $p_T^{\text{hard}} \neq p_T^\gamma$)

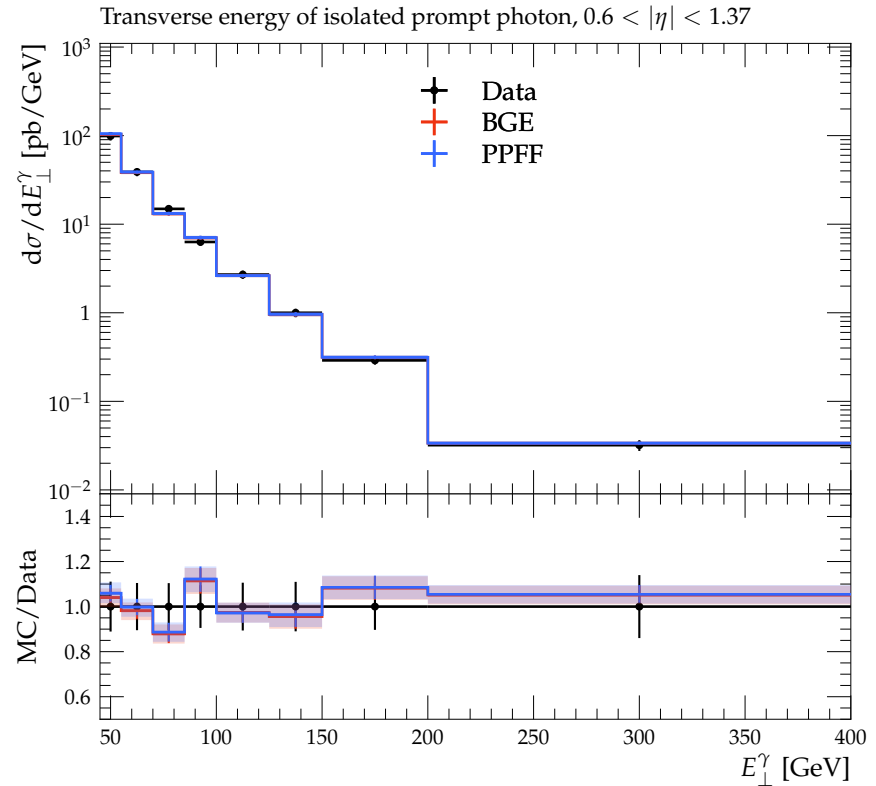
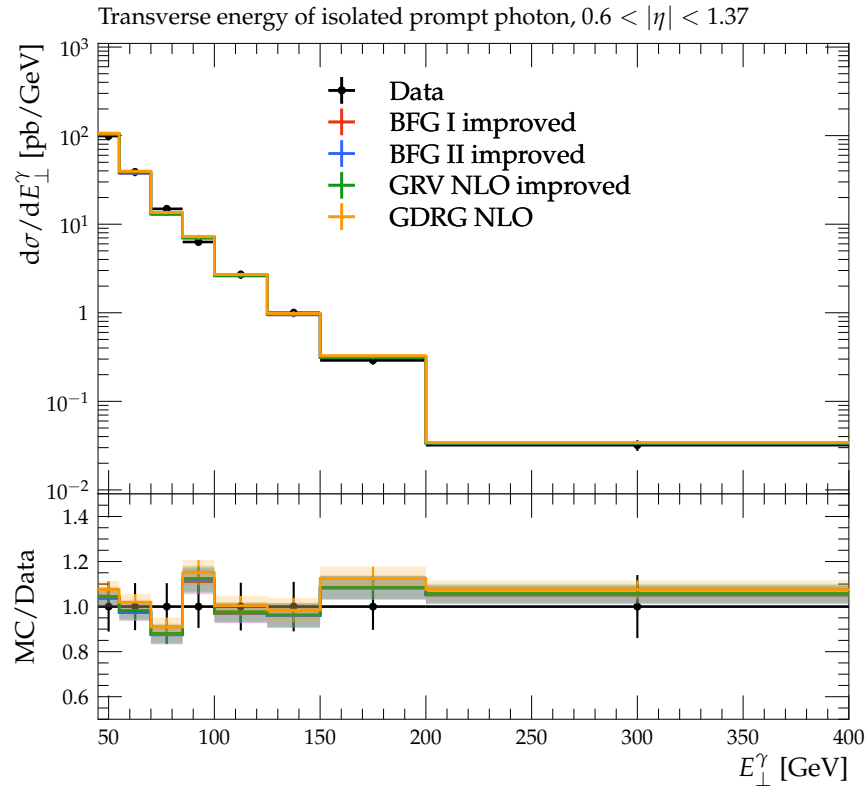


Isolated photons ALICE @ 7 TeV [1906.01371]



Isolated photons ATLAS @ 7 TeV [1108.0253]

- Isolation and higher photon p_T reduce the sensitivity to FFs



Conclusion and Outlook

- Photon FFs were packaged in LHAPDF, giving a portable and consistent interface for BFG, GRV, GDRG, the BFG-GRV envelope, and PPFF.
- Pythia-extracted PPFF shows the expected qualitative behaviour: quark dominance, small gluon contribution, and increasing yield with scale.
- FF choices matter most for non-isolated or low- p_T^γ prompt photons; realistic isolation strongly suppresses the sensitivity.
- Repeat the extraction with NLO-matched events for a more systematic treatment of hard radiation, include MPI and hadronization.
- Extend evolution tools such as γ EKO or APFEL++ to support photon FF evolution and compare against showers.

Good lunch and trip home!