

Dresden activities

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Sherpa developer meeting Milano, Jan 2020

Emmy
Noether-
Programm

Deutsche
Forschungsgemeinschaft

DFG



- ▶ **Frank's** Emmy Noether group with **Johannes** (PhD*), **Sebastian** (PhD), **Katharina** (master) + Bachelor students working on Sherpa
 - + 1 post-doc + 1 PhD student working on ATLAS

- ▶ Main Sherpa activities and responsibilities
 - Associated heavy flavour production (V+HF, tt+HF, ...)
 - Prompt photon production
 - NLO matching with resonances
 - Sherpa in ATLAS
 - Computational challenges
 - Perturbative and hadron decay cascades
 - Infrastructure and code maintenance

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Heavy Flavour Fusing

(with Stefan)

aka "Multi-jet merging in a variable flavour number scheme"

[\[1904.09382\]](#)



Three main ingredients:

1. Interpreting X+bb as merged contribution
2. Overlap removal
3. Matching 4F/5F in PDFs and α_s

Can be applied for LO and NLO merging!

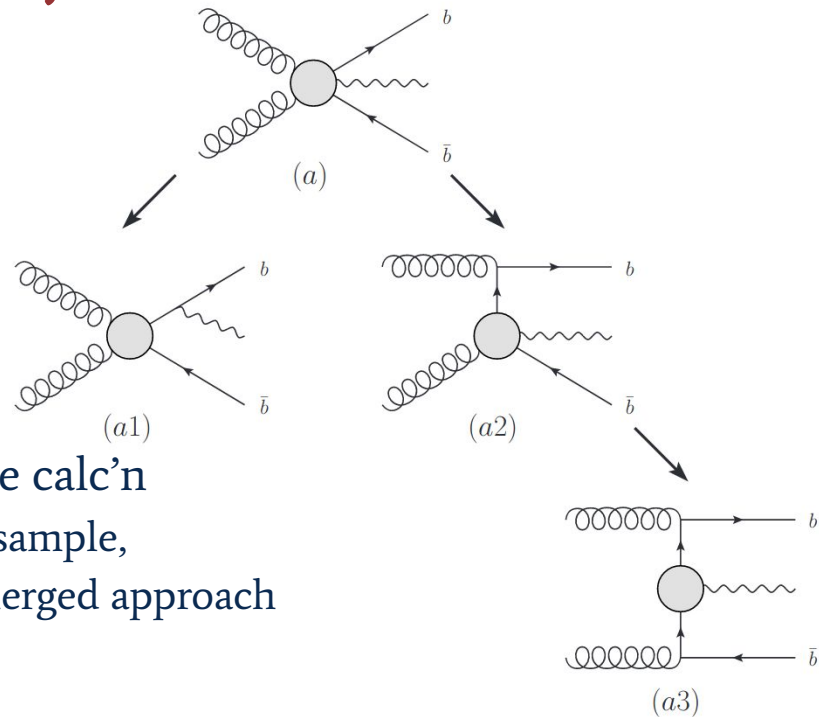
Step 1: Embedding X+bb as merged contribution

- ▶ ttj(j(...)) matrix elements treated in regular **X+jets MEPS@NLO**:

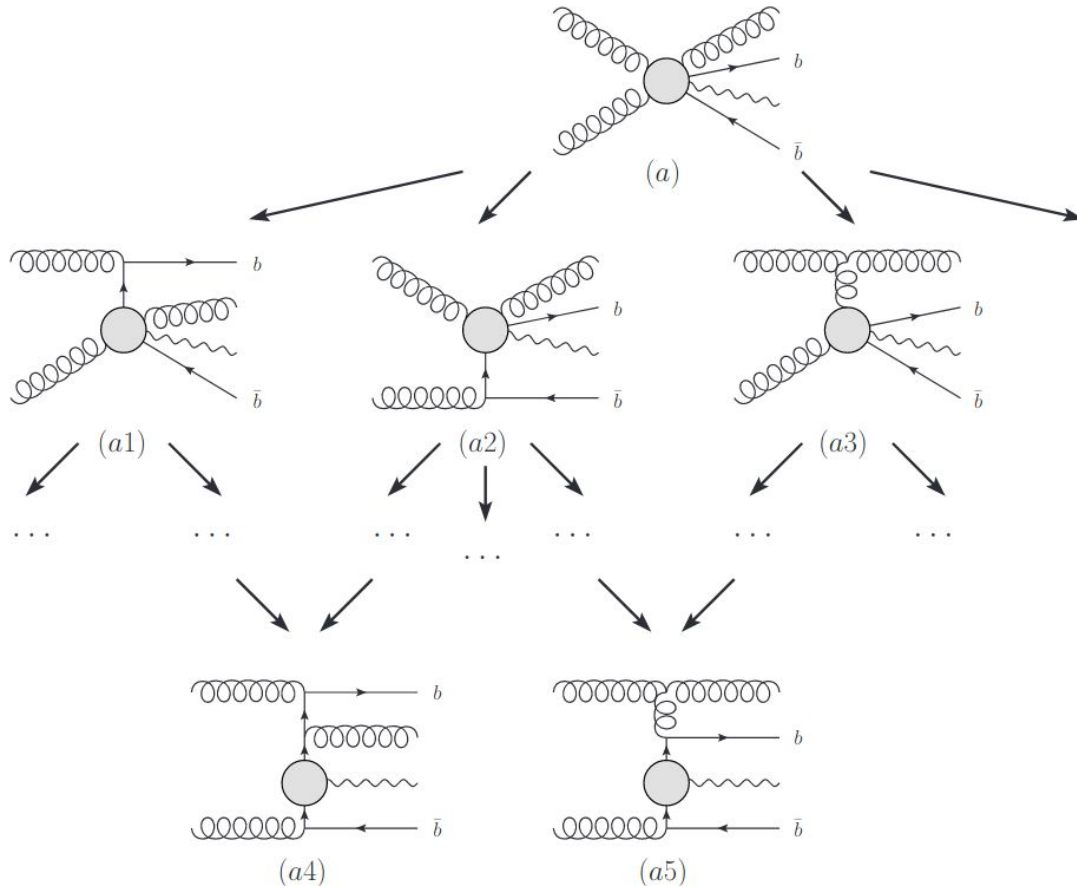
- clustering (“shower history”)
- core scale based on 2→2 process
- application of $\alpha_S(\mu_R^2) \rightarrow \alpha_S(p_T^2)$ reweighting for each emission
- application of Sudakov factors $\Delta(t_1, t_2)$ along internal lines (event vetoes) for correct resummation properties

- ▶ Now: Same applied to **ttbb NLO+PS** massive calc’n

- remains separate standalone ttbb NLO+PS sample, but generated consistently with multi-leg merged approach
 - » METS scale
 - » Fake “CKKW 100000”
 - » identical clustering and shower setup (ordered, HPS, CSS settings, ...)



- ▶ HFOR used before in experiments in simplified form
 - $dR(b,b) > 0.4 \rightarrow$ keep from ttbb ME
 - $dR(b,b) < 0.4 \rightarrow$ keep from tt ME + bb from PS
 - ▶ Here: from multi-leg merging prescription
 - Cluster **full event at PS level** using “reverse shower”
 - Look at **leading two emissions**
 - » Heavy Flavour \rightarrow keep from **ttbb NLO+PS** simulation (“**direct component**”)
 - » Light Flavour \rightarrow keep from **tt+jets MEPS@NLO** (“**fragmentation component**”)
- \Rightarrow Sub(sub)leading $g \rightarrow bb$ splittings not from ttbb ME, but from ttjjjj ME or from PS.
- ▶ (Extra: caution with b’s from “FSR” in top decay products!)



X+jets candidates:

- (a) \rightarrow (a3) \rightarrow (a5)
 “soft light jet, hard b-jets”
 \rightarrow **direct component**
 - vetoed from X+jets
- ...
 - (a) \rightarrow (a2) \rightarrow (a5)
 “soft b-jets, hard light jet”
 \rightarrow **fragmentation component**
 - kept in X+jets
 - not produced in X+bb (Sud’s)
 - (a) \rightarrow (...) \rightarrow (a4)
 \rightarrow **fragmentation component**

(At NLO all these would be direct.)

- ▶ For consistent combination with X+jets we produce the massive **X+bb** **NLO+PS** with a 5F PDF

→ m_b mismatch with massive NLO matrix elements

Looking at ideas from **FONLL** [Forte, Napoletano, Ubiali 2016] based on

$$\sigma^{\text{FONLL}} = \sigma^{(5)} - \sigma^{(4),(0)} + \sigma^{(4)}$$

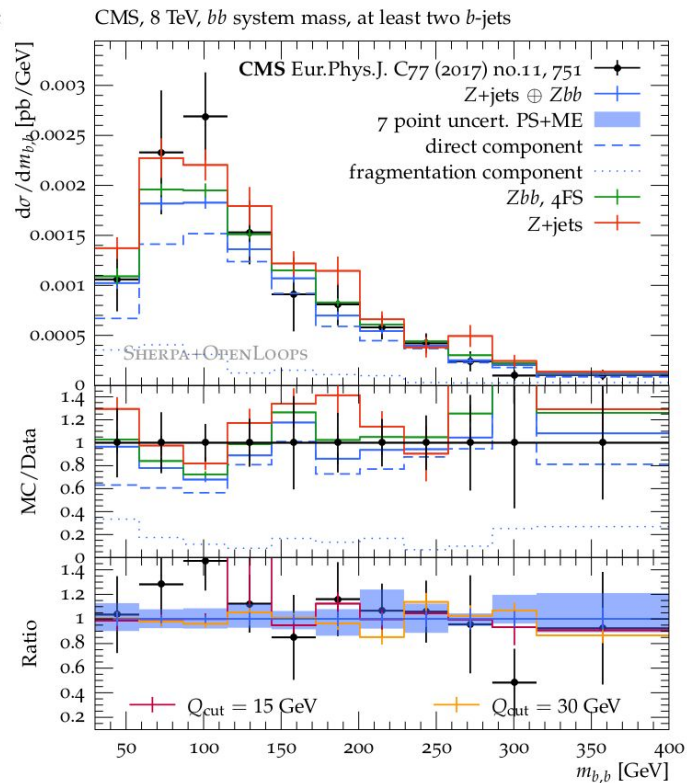
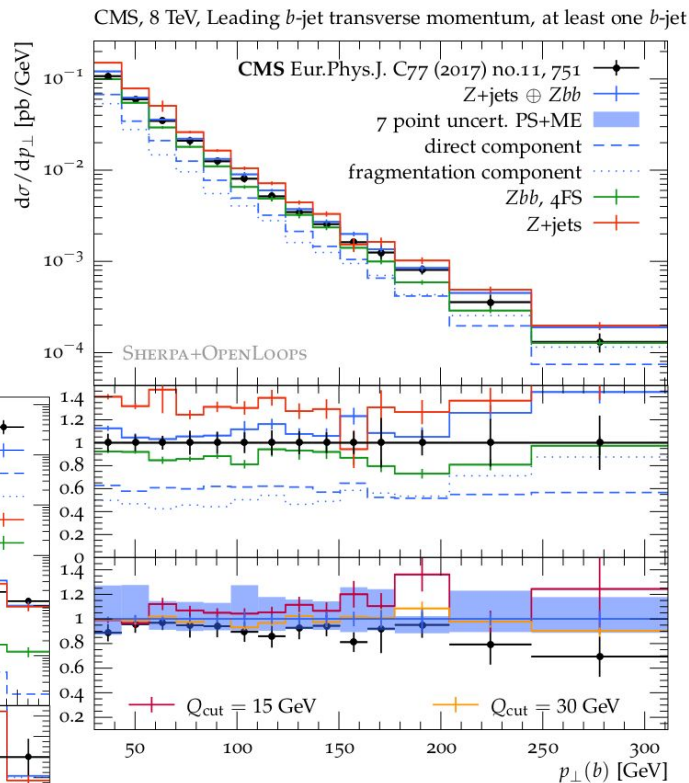
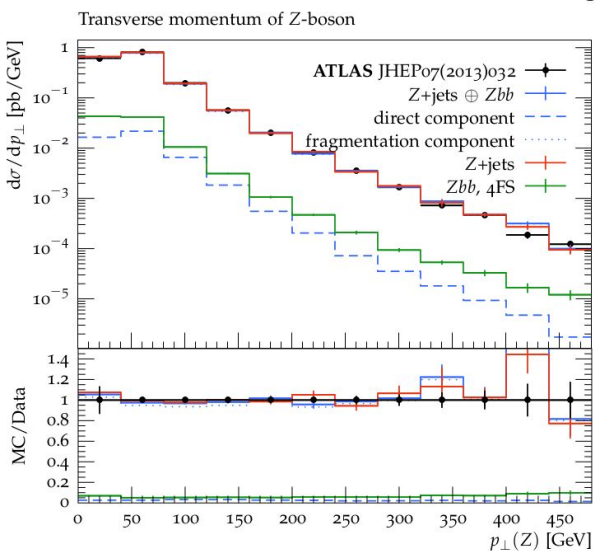
we find that they are generated by prescription above!

- NLO accuracy preserved from input matrix elements
- LL/NLL accuracy according to shower used
 - » Overlap removal and embedding of X+bb as merged contribution with LL shower automatically generates leading log matching term
 - » Next-to-leading log would need explicit counterterms as event weights (complicated) or comes **automatically with NLL showers** in the future
- ▶ Additional event weights for mismatch between α_s evolution with $m_b = 0$ and virtuals with $m_b \neq 0$

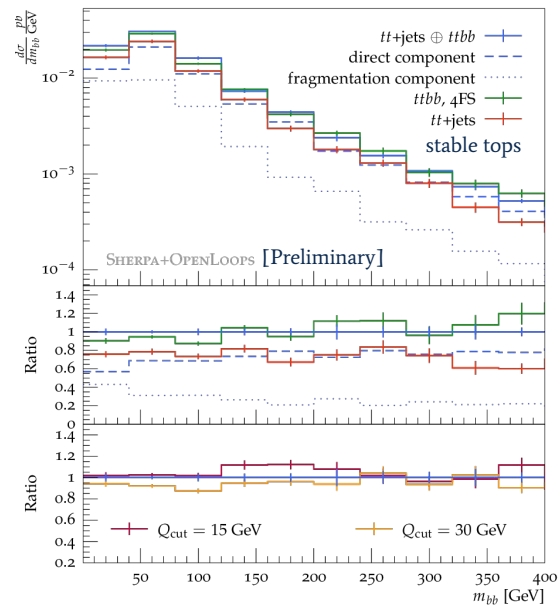
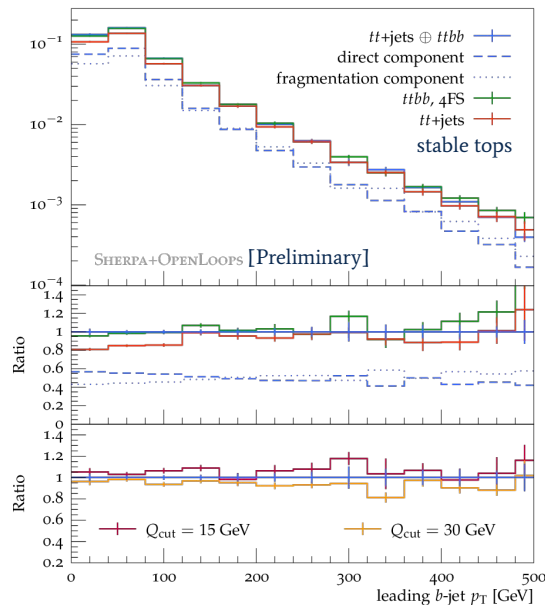
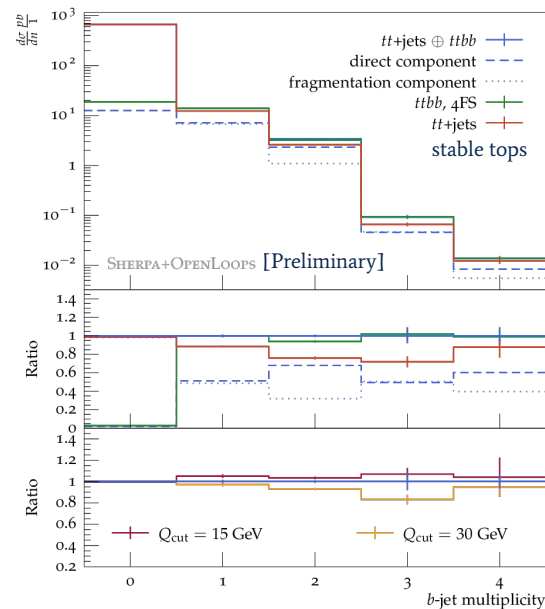
$$w_{q\bar{q}}^{\text{new}} = w_{q\bar{q}} \left(1 - \frac{4}{3} T_R \ln \frac{\mu_R^2}{Q^2} \frac{w^{\text{Born}}}{w^{\text{ME}}} \right)$$

$$w_{gg}^{\text{new}} = w_{gg} \left(1 - \frac{4}{3} T_R \ln \frac{\mu_R^2}{m_b^2} \frac{w^{\text{Born}}}{w^{\text{ME}}} \right)$$

- ▶ Implementation in Sherpa 2.2
- ▶ First application to Z+HF, compared to CMS 8 TeV data



- ▶ Also applied as fusion of **MEPS@NLO tt + 0,1j@NLO + 2,3j@LO** and **massive ttbb@NLO**
- ▶ 2-bjet production dominated by direct component, but 1-bjet observables with equal contributions from direct and fragmentation configurations!

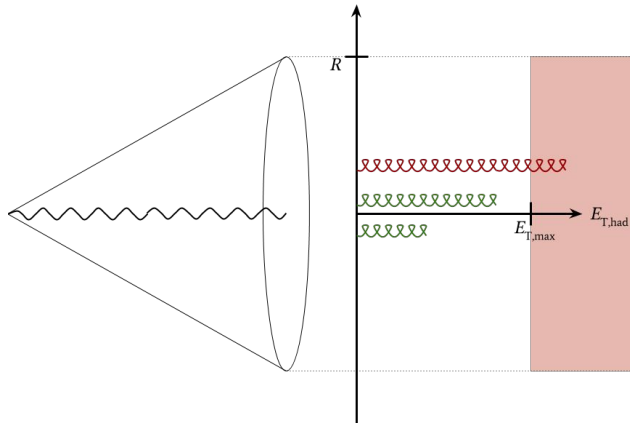


Prompt photon production and photon isolation

- Construction principles for photon isolation criteria:
 - Detector: discrete resolution in energy and angular distance
 - Theory: infrared safety needed, ideally no fragmentation functions

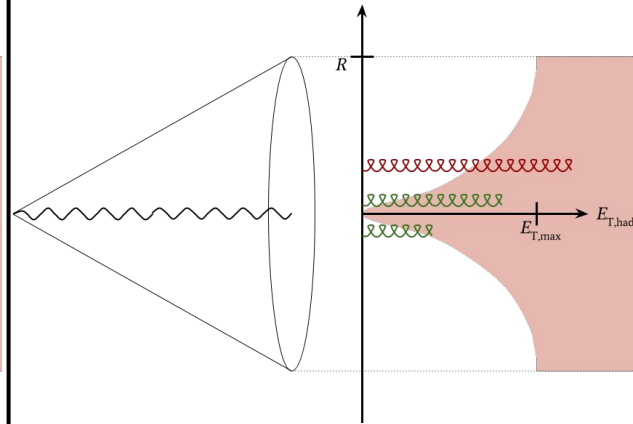
Experimental cone

→ Needs FF



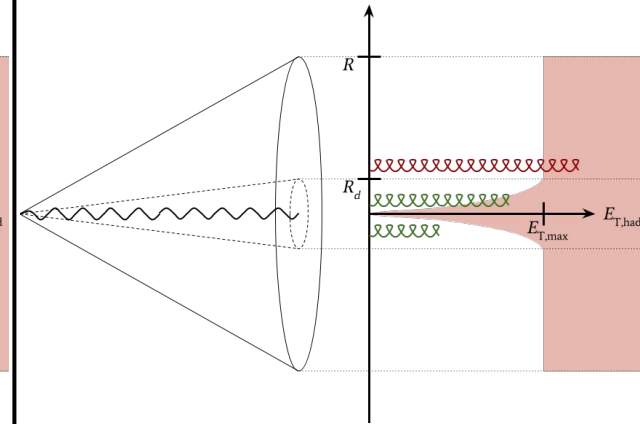
Smooth cone

→ Bias



Hybrid isolation

→ Smaller bias



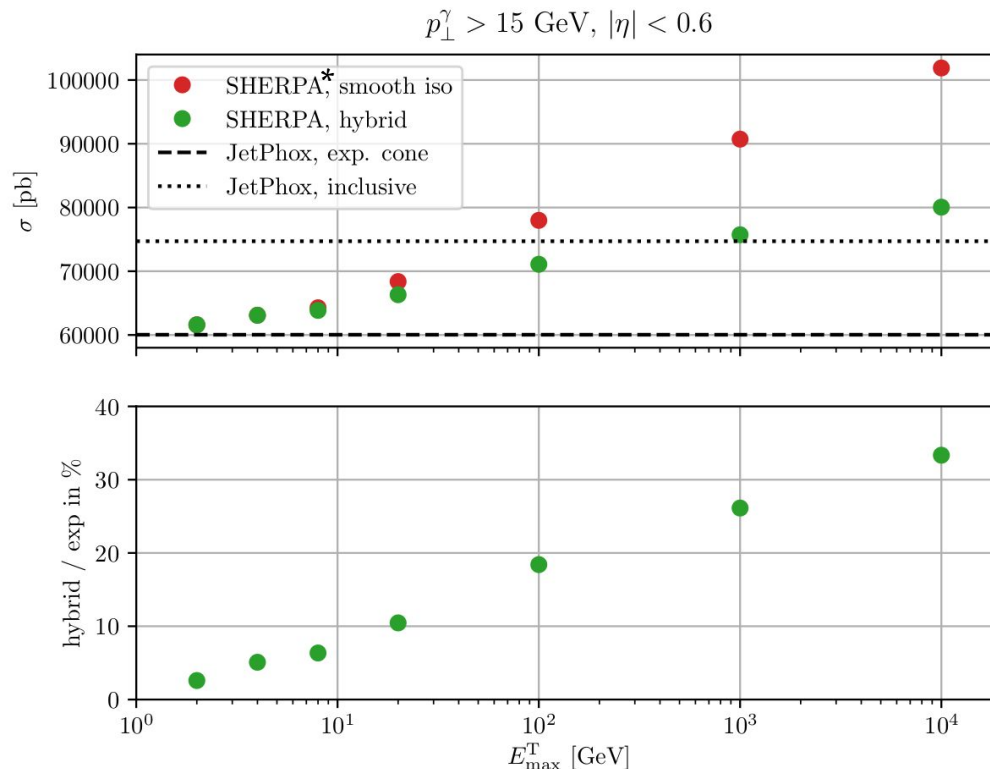
But careful: fixed-order breaking
down for very small cones! 13

Analysis

- $P_{T,\text{photon}} > 15 \text{ GeV}$
- isolation:
 - $E_{T,\text{threshold}} = 4 \text{ GeV}$
 - $dR = 0.4$

Prediction

- smooth / hybrid cone
 - $r_0 = 0.4$, $n = 1$
 - $2 \text{ GeV} < E_{T,\text{max}} < 10000 \text{ GeV}$
 - effects shape below
- $E_{T,\text{threshold}}$

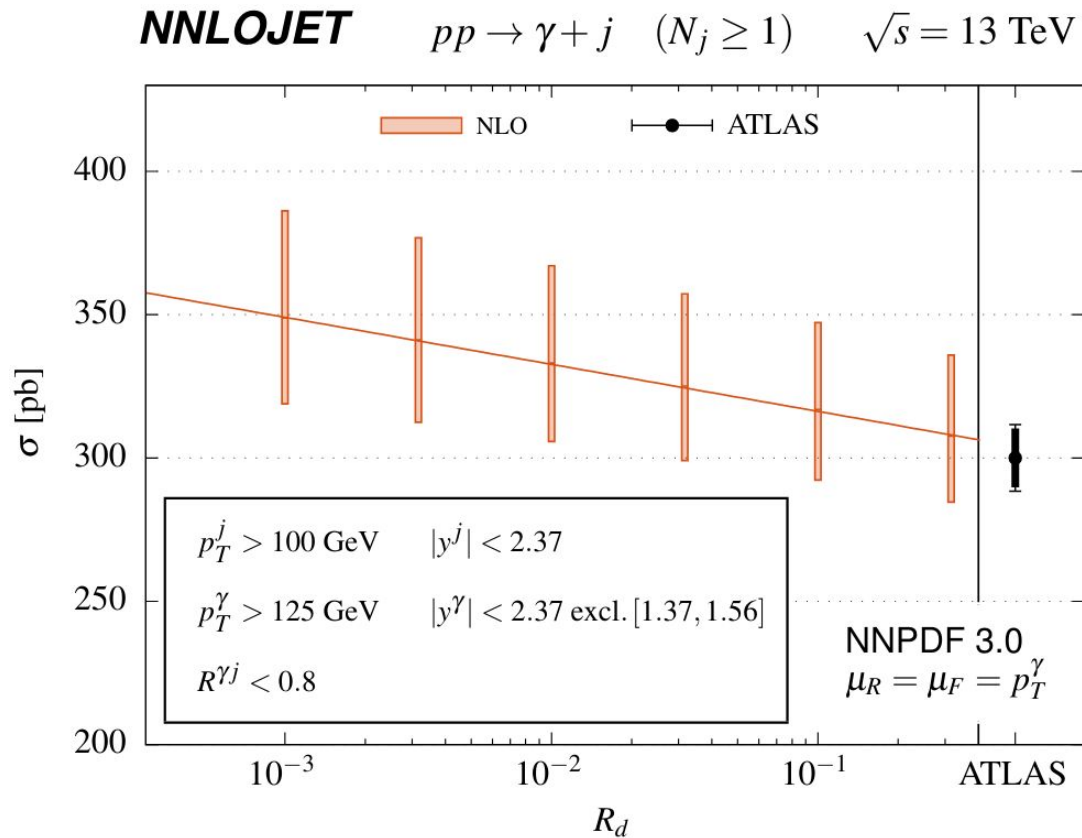


* Sherpa results cross checked with Jetphox,
thanks to Gudrun Heinrich for providing an implementation!

Similar findings by NNLOJET

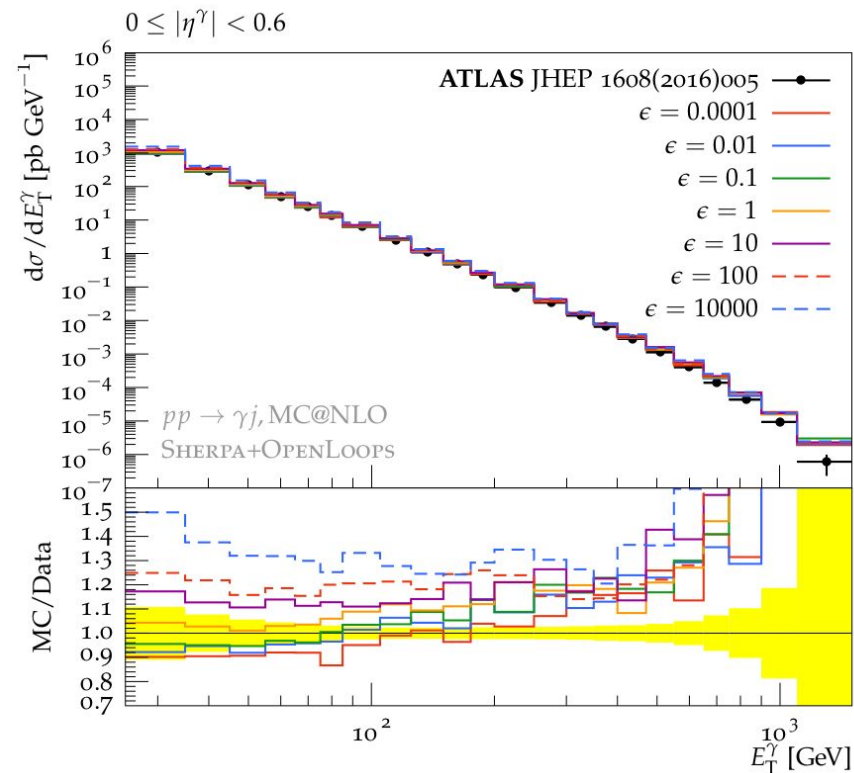
- expected $\log(1/r_0)$ dependence

[1904.01044](#)



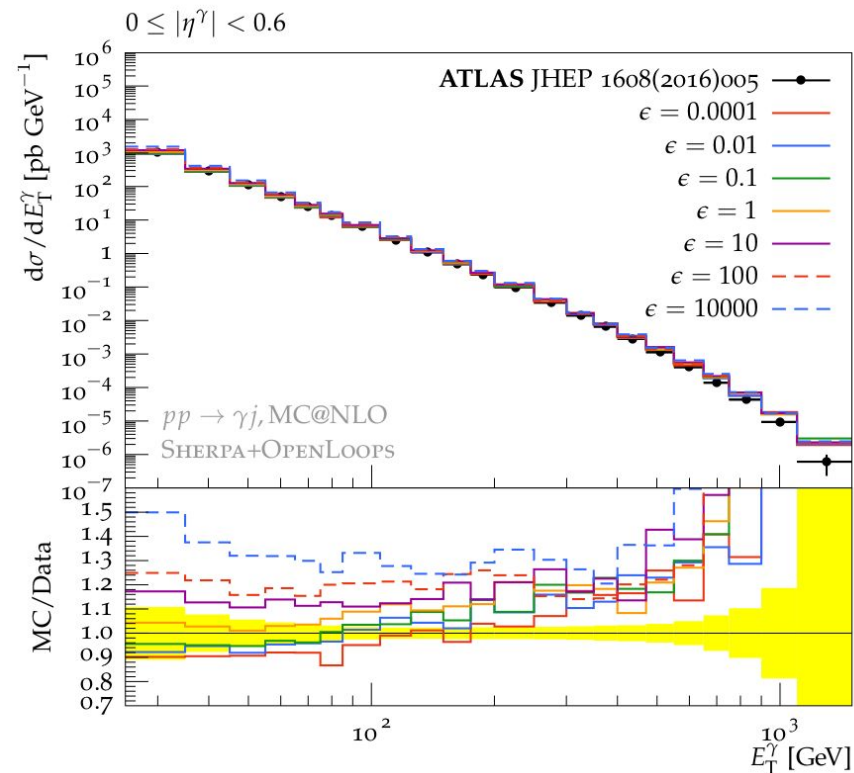
- ▶ Problem propagates to NLO+PS

- ▶ Solutions and alternatives for prompt photon predictions?
 - Fixed-order: fragmentation functions (not available beyond NLO)
 - QCD+QED merging at LO [arXiv:0912.3501](https://arxiv.org/abs/0912.3501)
 - QED NLO+PS [[arXiv:1709.04154](https://arxiv.org/abs/1709.04154), [arXiv:1610.02275](https://arxiv.org/abs/1610.02275)]
 - » only for single photon!



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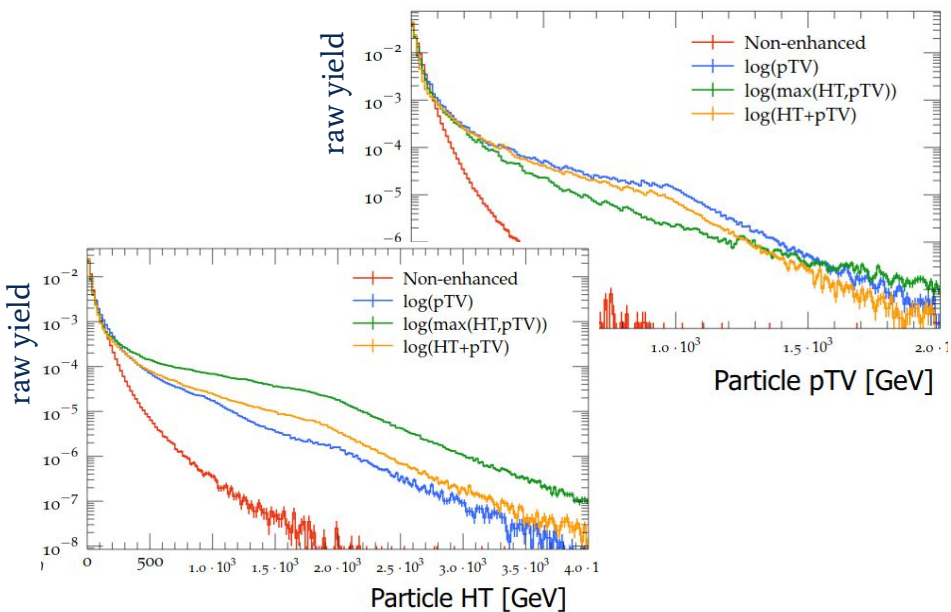
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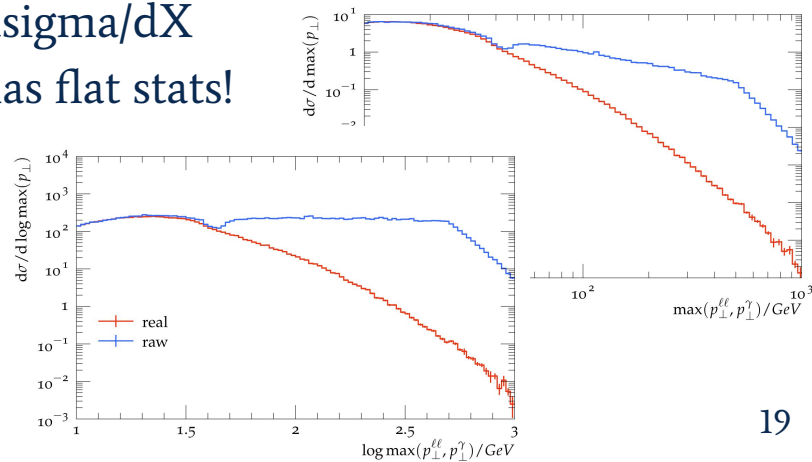
Computational Challenges

- ▶ Experiments slice samples (e.g. in $p_{T,V}$) to populate non-bulk regions
- ▶ Alternative: Enhance_Observable for (otherwise) unweighted events
- ▶ (Re-)Implemented in Sherpa 2.2.8 and master
- ▶ Tested extensively in preparation of ATLAS samples (V+jets, $V\gamma$ +jets, ttbar)

later



Watch out: enhancement in $\log(X)$ does **not** mean that a logarithmically binned $d\sigma/dX$ has flat stats!



→ continued in Katharina's slides