Resummation in processes with jet vetoes

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partly based on work with Frank Petriello

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Chicago 2012 Workshop on LHC Physics

Outline

- Motivation
- Processes with jet vetoes
- Conclusion and Outlook

Motivation

- Cross section with jet bins
  - Higgs + 0-j, 1-j, >2-j
  - W+2-j, 3-j
  - BSM searches

Study of the dijet mass spectrum in pp $\to$ W + jets events at $\sqrt{s} = 7$ TeV

The CMS Collaboration[*]

Events are selected with one well-identified and isolated lepton (muon or electron), large missing transverse energy $\not\!E_T$, and exactly two or exactly three high-p_T jets. The selection criteria are similar to those used at the Tevatron [1, 2], but modified to adapt to the higher background rates and different experimental conditions at the LHC. We also place more stringent requirements on the jet kinematics, as suggested in Ref. [3], to enhance any signal compared to the irreducible W plus jets background. We investigate three representative models, a technicolor π_T from the decay of a technicolor ρ_T [4], a leptophobic Z' decaying to two jets [5], and the

Search for dark matter candidates and large extra dimensions in events with a photon and missing transverse momentum in pp collision data at $\sqrt{s} = 7$ TeV with the ATLAS detector

The ATLAS Collaboration

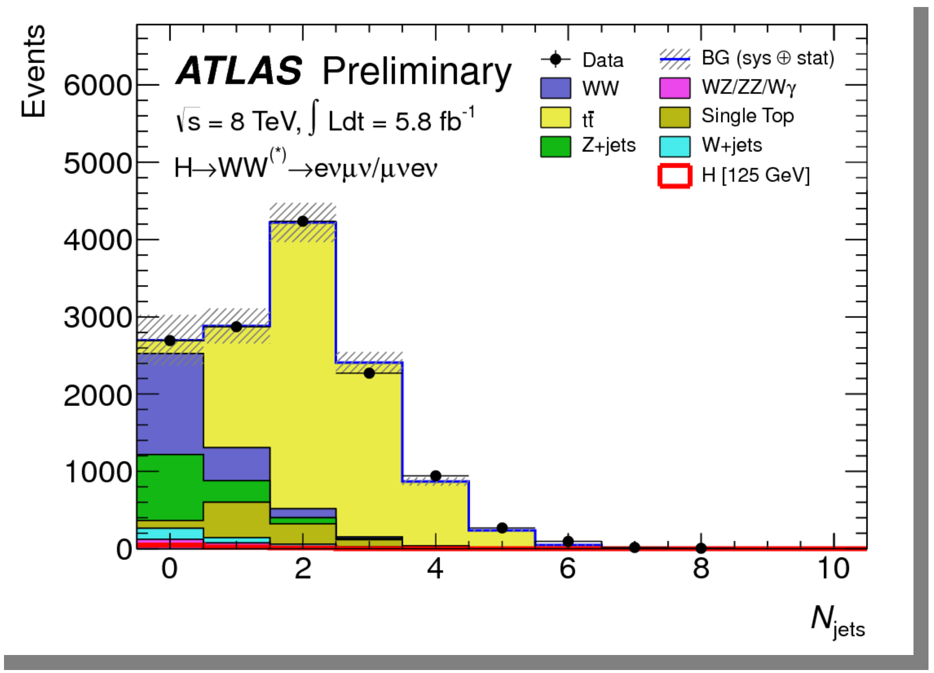
Events with more than one jet with $p_T > 30$ GeV and $|\eta| < 4.5$ are rejected. Events with one jet are retained to increase the signal acceptance and reduce systematic uncertainties related to the modeling of initial-state radiation. The reconstructed photon, E_T^{miss} vector and jets (if found) are required to be well separated in the transverse plane with $\Delta\phi(\gamma, E_T^{miss}) > 0.4$, $\Delta R(\gamma, \text{jet}) > 0.4$, and $\Delta\phi(\text{jet}, E_T^{miss}) > 0.4$. Additional quality criteria [19] are applied to ensure that jets and photons are not pro-

ATLAS [7, 8], the yields corresponding to CTEQ6.6 [31] PDFs are used, as obtained by reweighting these samples. The samples are normalized to NLO predictions [32]. The LO-to-NLO normalization factors decrease from 1.5 to 1.1 as n increases.

Simulated events corresponding to the $\chi\bar{\chi} + \gamma$ process with a minimum photon p_T of 80 GeV are generated using LO matrix elements from MADGRAPH [33] interfaced to PYTHIA 6 using CTEQ6L1 PDFs. Values for m_χ be-

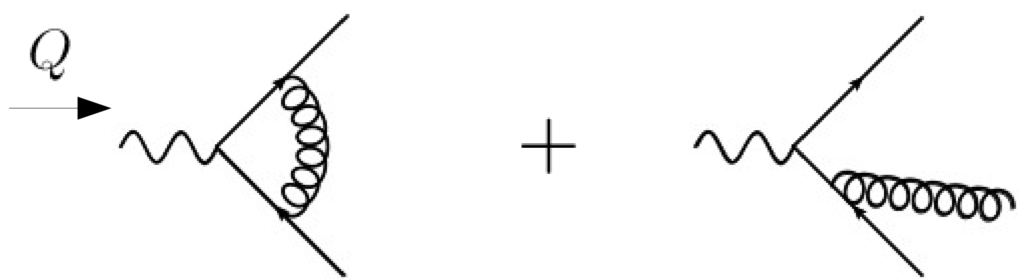
Motivation

- Cross section with jet bins
  - Advantage
    - Beat the backgrounds $p_T^{veto} \approx 25\text{GeV} - 30\text{GeV}$



Motivation

- Cross section with jet bins
  - Problems
    - Sudakov Logarithms $\sum_{n,m} C_{n,m} \alpha_s^n L^{2n-m}, \quad L = \log \frac{p_T^{veto}}{Q}$



$$\propto -\frac{1}{\epsilon_{\mathrm{IR}}^2} - \frac{1}{\epsilon_{\mathrm{IR}}} \qquad \propto \frac{1}{\epsilon_{\mathrm{IR}}^2} + \frac{1}{\epsilon_{\mathrm{IR}}} + \log^2 \frac{p_T^{veto}}{Q} + \log \frac{p_T^{veto}}{Q}$$

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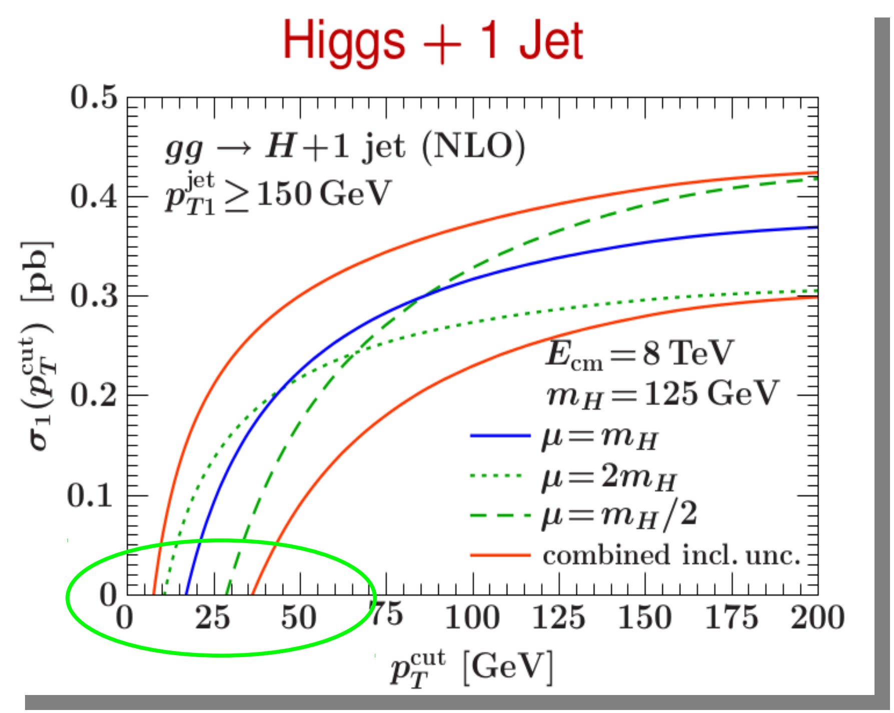
      - Breakdown of fixed-order calculations



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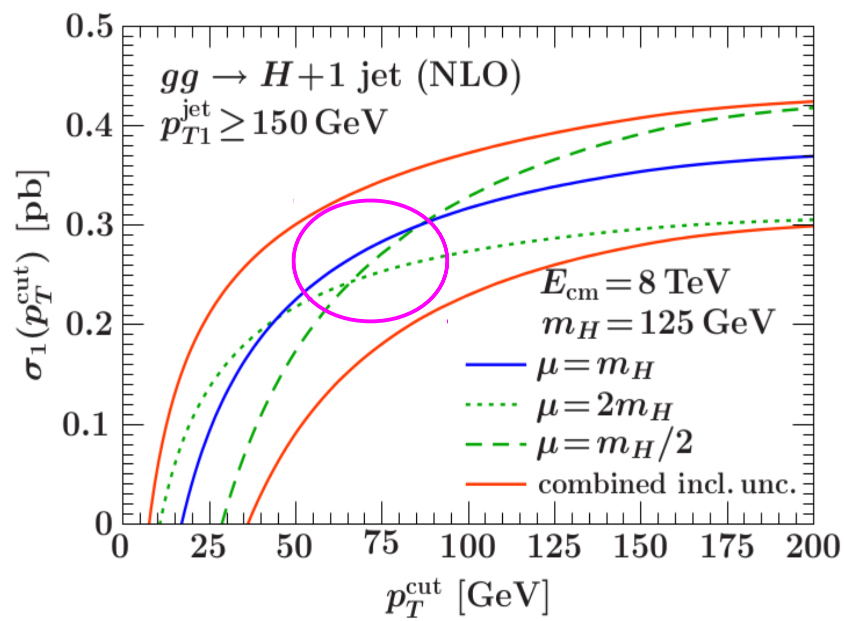
      - Unreliable uncertainty estimation (Stewart and Tackmann '11)

Large K Factor – Large Logs

Higgs + 1 Jet



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        Large K Factor – Large Logs
      - Large Uncertainties

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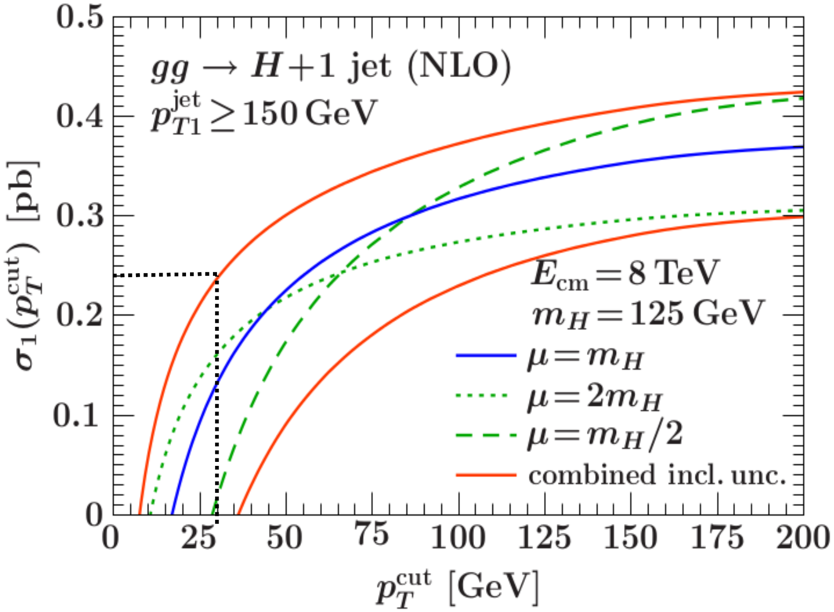
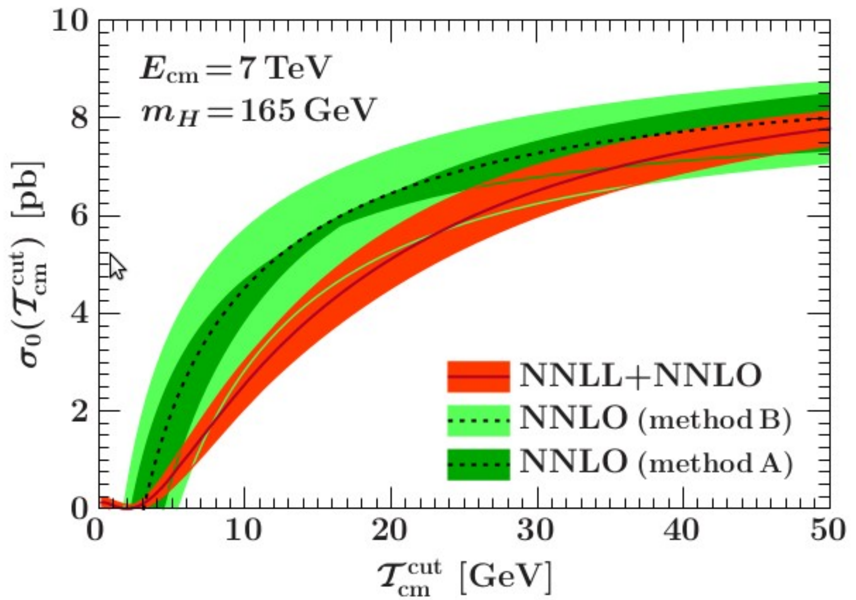


Processes with jet vetoes

- Previous efforts
  - Jettiness (Stewart,Tackmann, Waalewijn '10, Berger and et al, '11)
    - Up to NNLL + NNLO accuracy

$$\sigma \propto 1 + \alpha_s L^2 + \alpha_s^2 L^4 + \alpha_s^3 L^6 \cdots \quad \text{LL}$$
$$+\alpha_s L + \alpha_s^2 L^3 + \alpha_s^3 L^5 \cdots \quad \text{NLL}$$
$$+\alpha_s n + \alpha_s^2 L^2 + \alpha_s^3 L^4 + \cdots \quad \text{N}^2\text{LL}$$
$$+\alpha_s^2 L + \alpha_s^3 L^3 + \cdots$$
$$+\alpha_s^2 n_1 + \alpha_s^3 L^2 \cdots$$



Pythia : LL + tuning
MC@NLO : NLO + LL

Processes with jet vetoes

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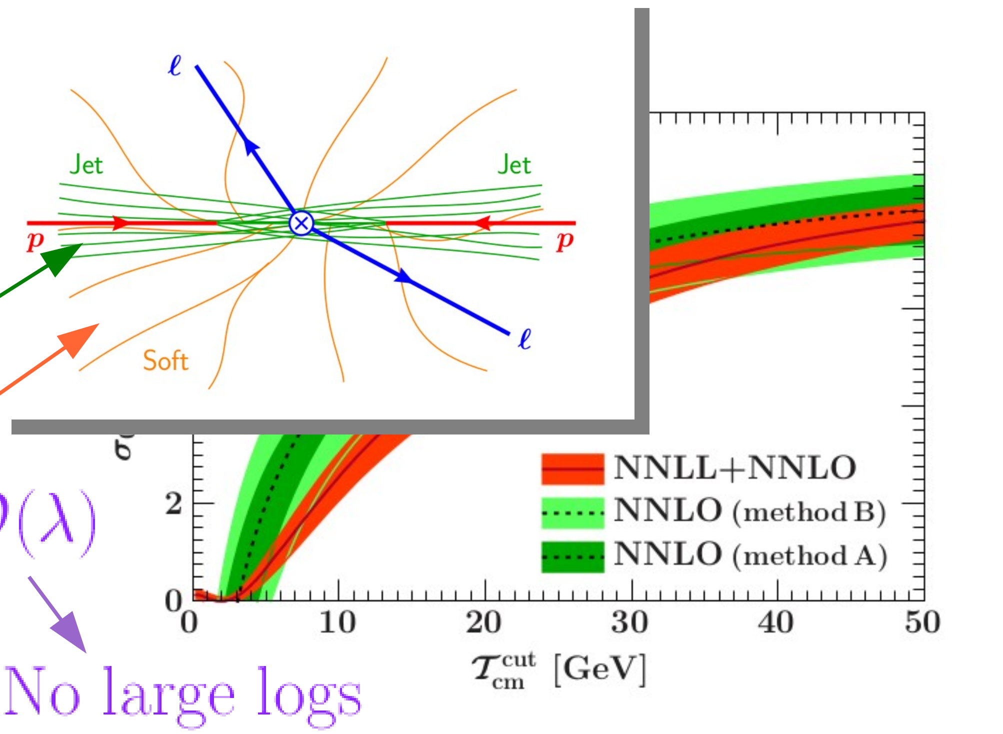
  - Jettiness (Stewart,Tackmann, Waalewijn '10, Berger and et al, '11)
    - Up to NNLL + NNLO accuracy
    - Factorization

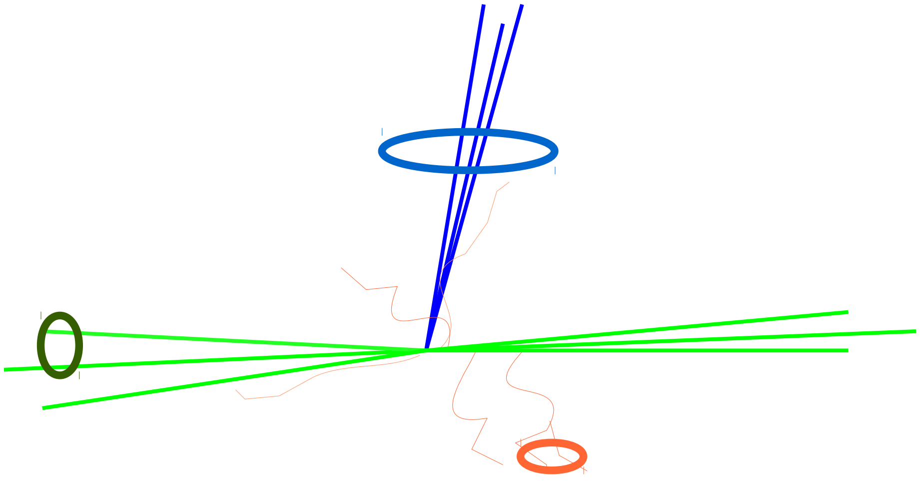


$$d\sigma \sim H\, \mathcal{B}_a\, \mathcal{B}_b \otimes S + \mathcal{O}(\lambda)$$

RGE $\quad \log\frac{Q}{\mu} \quad \log\frac{\sqrt{Q\mathcal{T}}}{\mu} \quad \log\frac{\mathcal{T}}{\mu}$ No large logs

Processes with jet vetoes

- Real life
  - anti-kT $R \sim 0.4 - 0.5$
  - pT veto $p_T^{veto} \sim 25 - 30\mathrm{GeV}$



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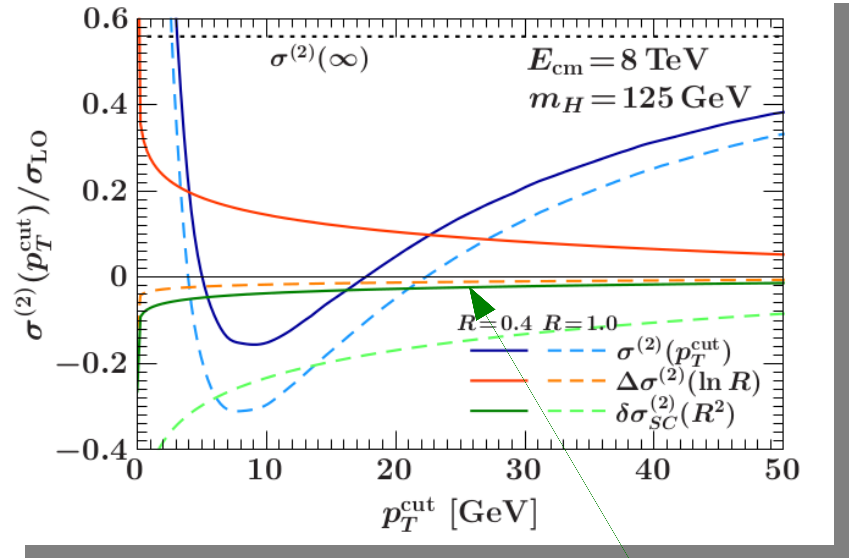
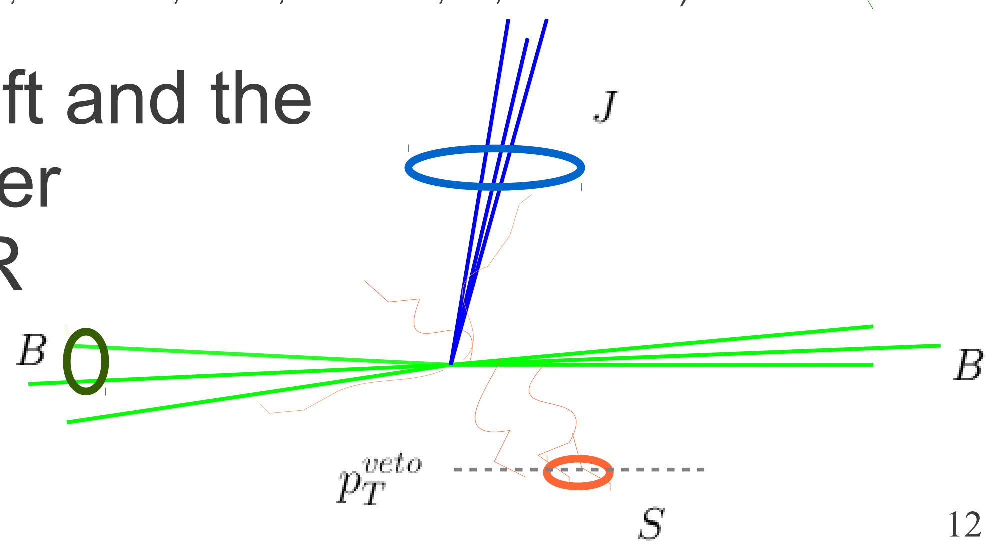


- Factorizability (Becher, Neubert '12, Tackmann, Walsh, Zuberi '12, XL, Petriello '12)
  - Mixing between the soft and the beam sectors are power suppressed for small R



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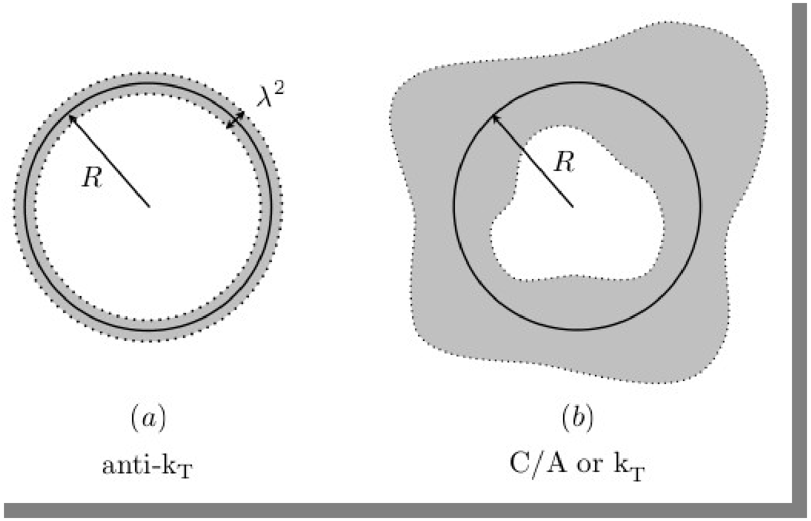
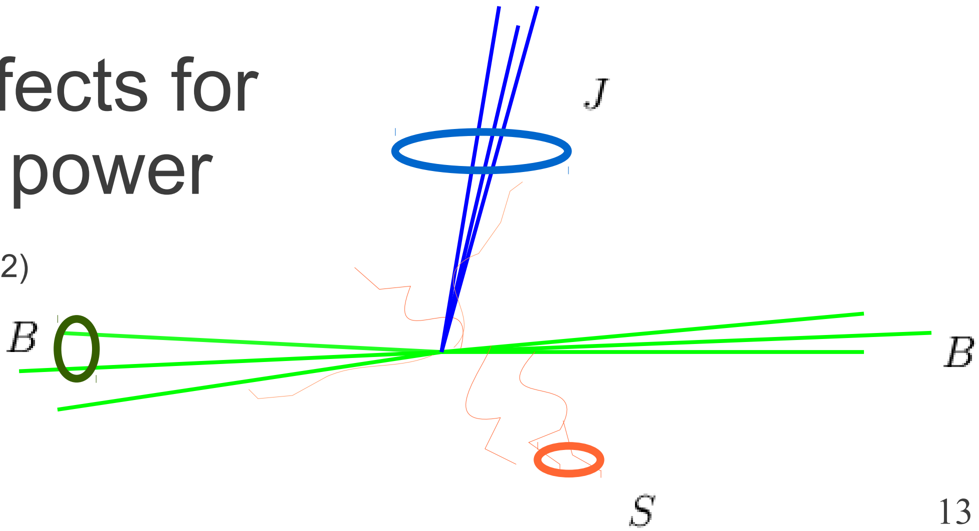


- Factorizability (Becher, Neubert '12, Tackmann, Walsh, Zuberi '12, XL, Petriello '12)
  - Boundary clustering effects for anti-kT central jets are power suppressed (Kelley, Walsh, Zuberi '12)

$$\rho_{ij} = \min\left(p_{T,i}^{-1}, p_{T,j}^{-1}\right)\frac{\Delta R_{ij}}{R}, \quad \rho_i = p_{T,i}^{-1}$$

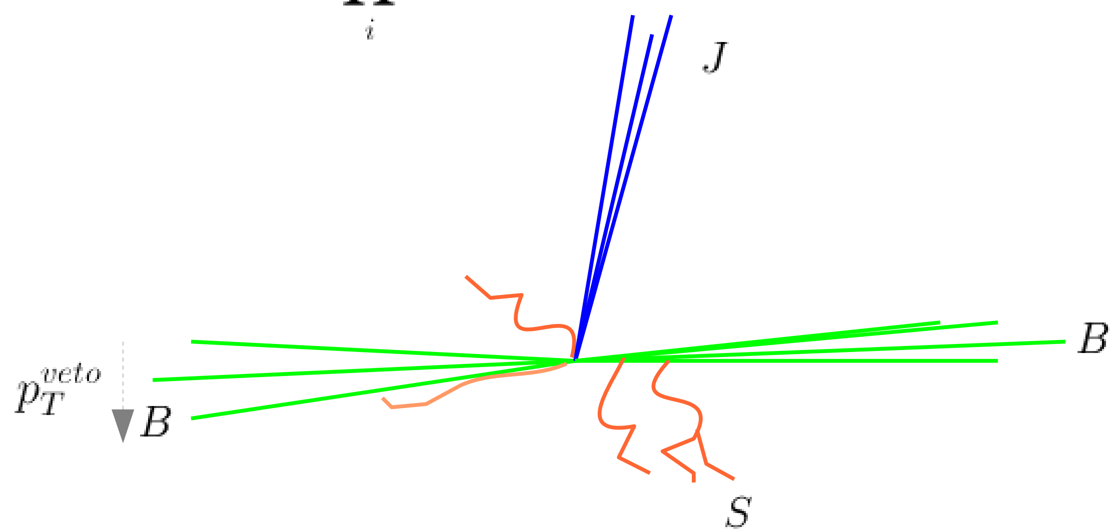


Processes with jet vetoes

- N(H/W/Z) + n-j (XL and Petriello, '12, Becher and Neubert, '12 for 0-jet bin)
  - Factorization

$$d\sigma = d\Phi_N d\Phi_{J_i}\, \mathcal{F}(\Phi_N, \Phi_{J_i}) \sum_{a,b} \int dx_a dx_b \frac{1}{2\hat{s}} (2\pi)^4 \delta^4 \left(q_a + q_b - \sum_i^n q_{J_i} - q_N \right)$$

$$\times \bar{\sum_{\text{spin}}} \bar{\sum_{\text{color}}} \text{Tr}(H \cdot S)\, \mathcal{I}_{a,i_a j_a} \otimes f_{j_a}(x_a)\, \mathcal{I}_{b,i_b j_b} \otimes f_{j_b}(x_b) \prod_i^n J_{J_i}(R)$$



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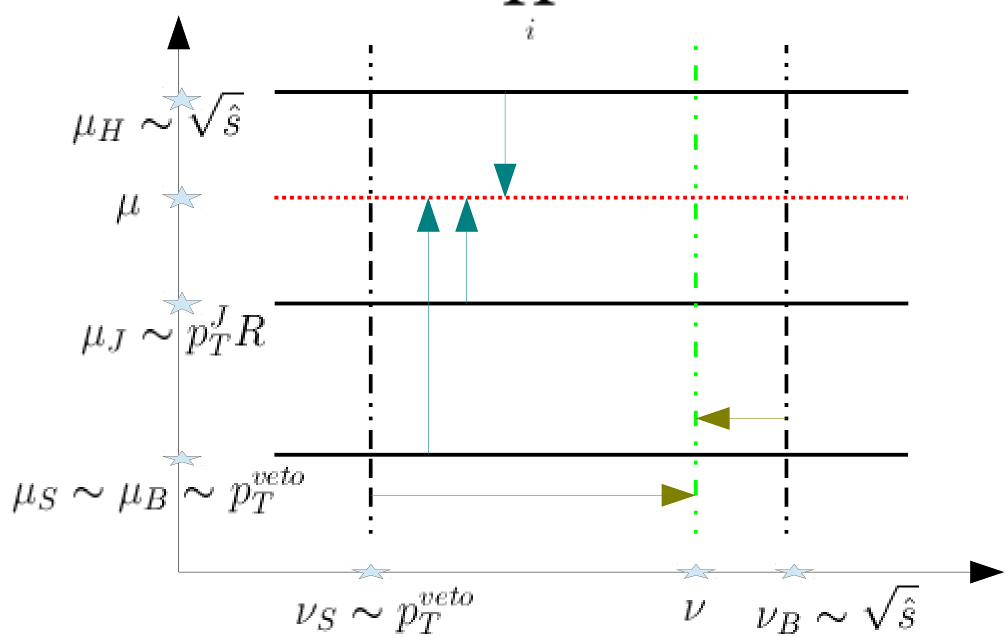
  - Resummation



Processes with jet vetoes

- N(H/W/Z) + n-j (XL and Petriello, '12)
  - NLL

$$\mathrm{d}\sigma_{\mathrm{NLL}} = \sum_{ab} \int \mathrm{d}x_a \mathrm{d}x_b \, \mathrm{Tr}\left[H_{\mathrm{LO}}^{ab\to N\{J_i\}}(\mu_H)\, S\, U_{H,\{J_i\}}(\mu,\mu_H)\, U_{S,\{J_i\}}(\mu,\nu,\mu_S,\nu_S) \right]$$
$$\times f_a(\mu_B,x_a) f_b(\mu_B,x_b) \mathcal{I}_{B,a,b}(\mu,\nu,\mu_B,\nu_B,x_a,x_b) \prod_i \mathcal{R}_{J_i}(\mu,\mu_J,R)\,.$$

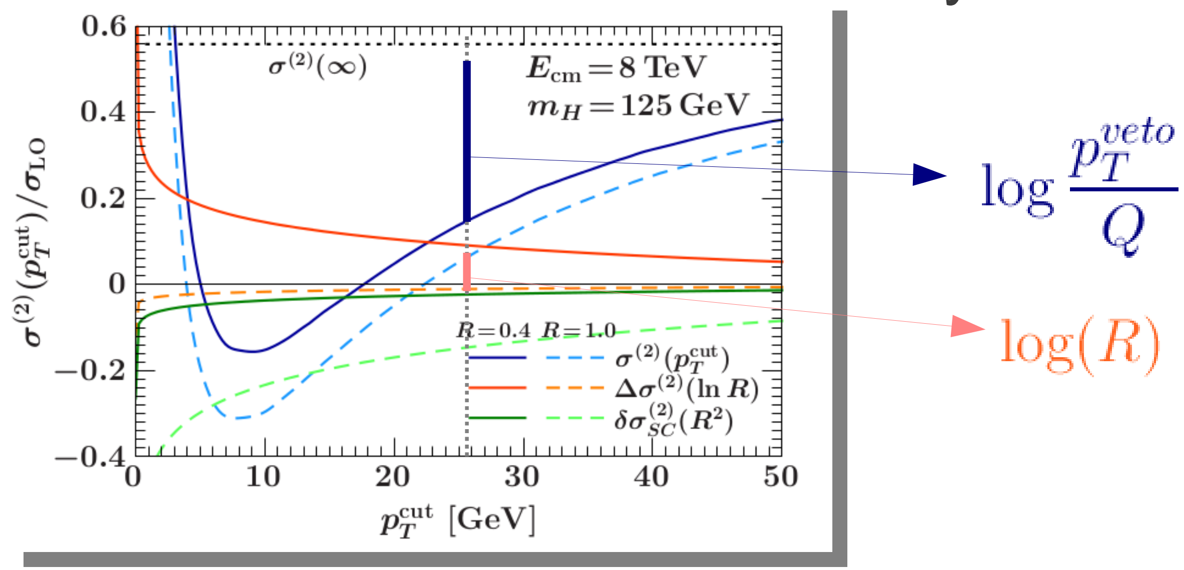
    - Resummation at the fully differential cross section level
    - Very compact analytic expressions (examples in the backup slides)
    - Easy to supplement MCFM with these corrections
    - Can improve the accuracy systematically

Processes with jet vetoes

- Other Approach
  - NNLL+NNLO formula (not fact. thm.) for 0-jet bin

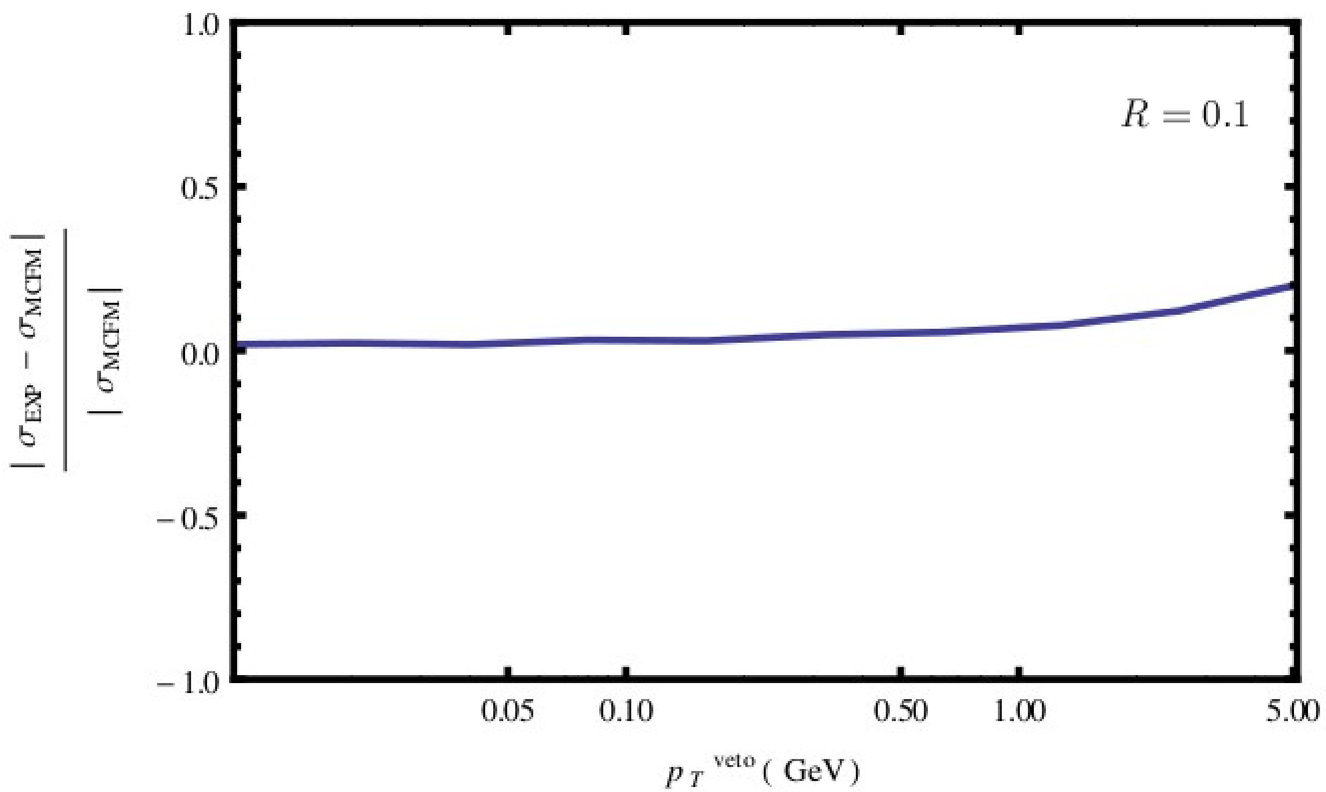
(Banfi, Monni, Salam, Zanderighi, '12)

- Potential Issue
  - Clustering Log(R) (Tackmann, Walsh, Zuberi, '12)
    - Moderate and well controlled for experimentally interesting R



Processes with jet vetoes

- Higgs + 1-j (XL and Petriello, '12)
  - Catches the NLL structures



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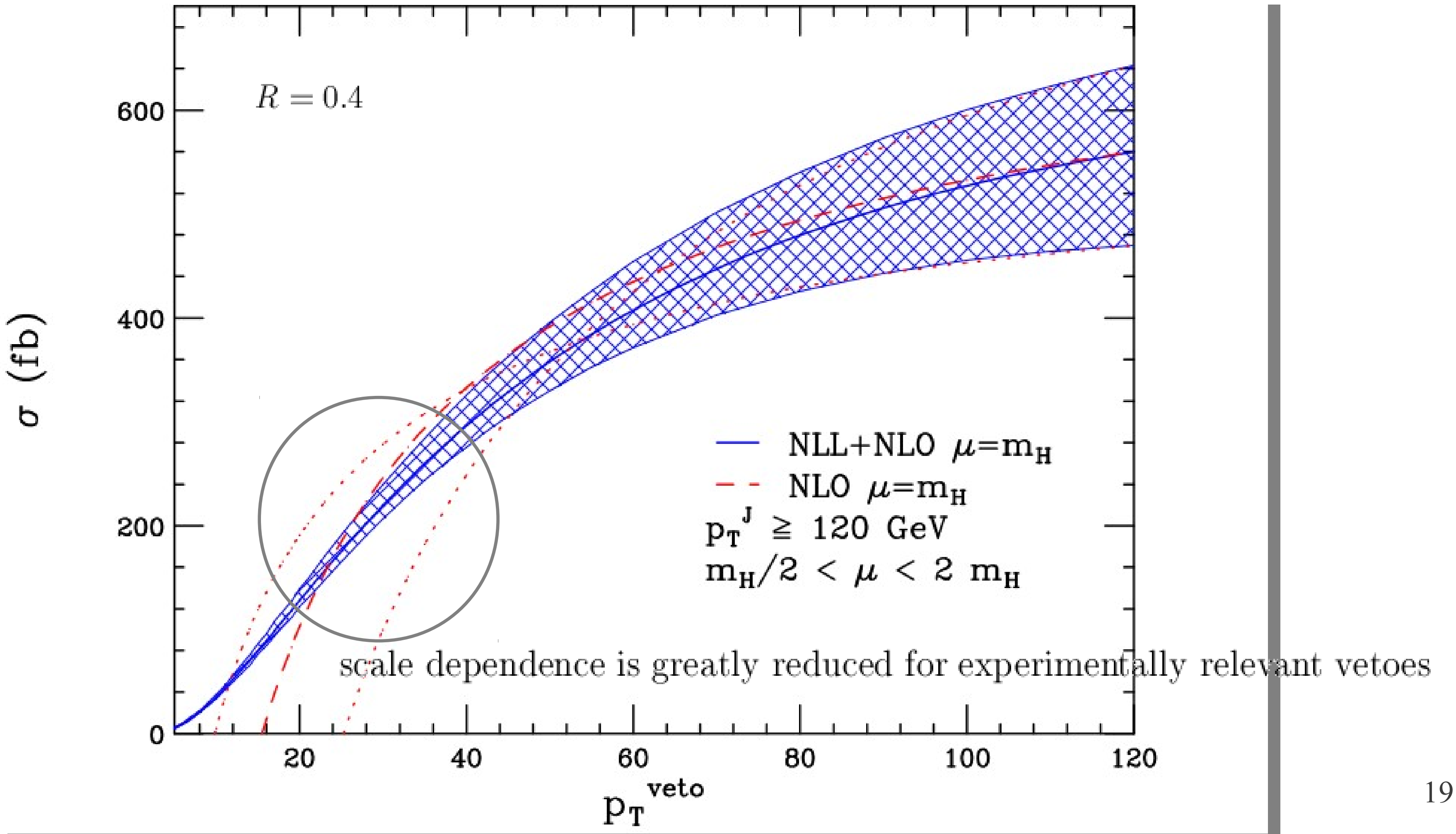

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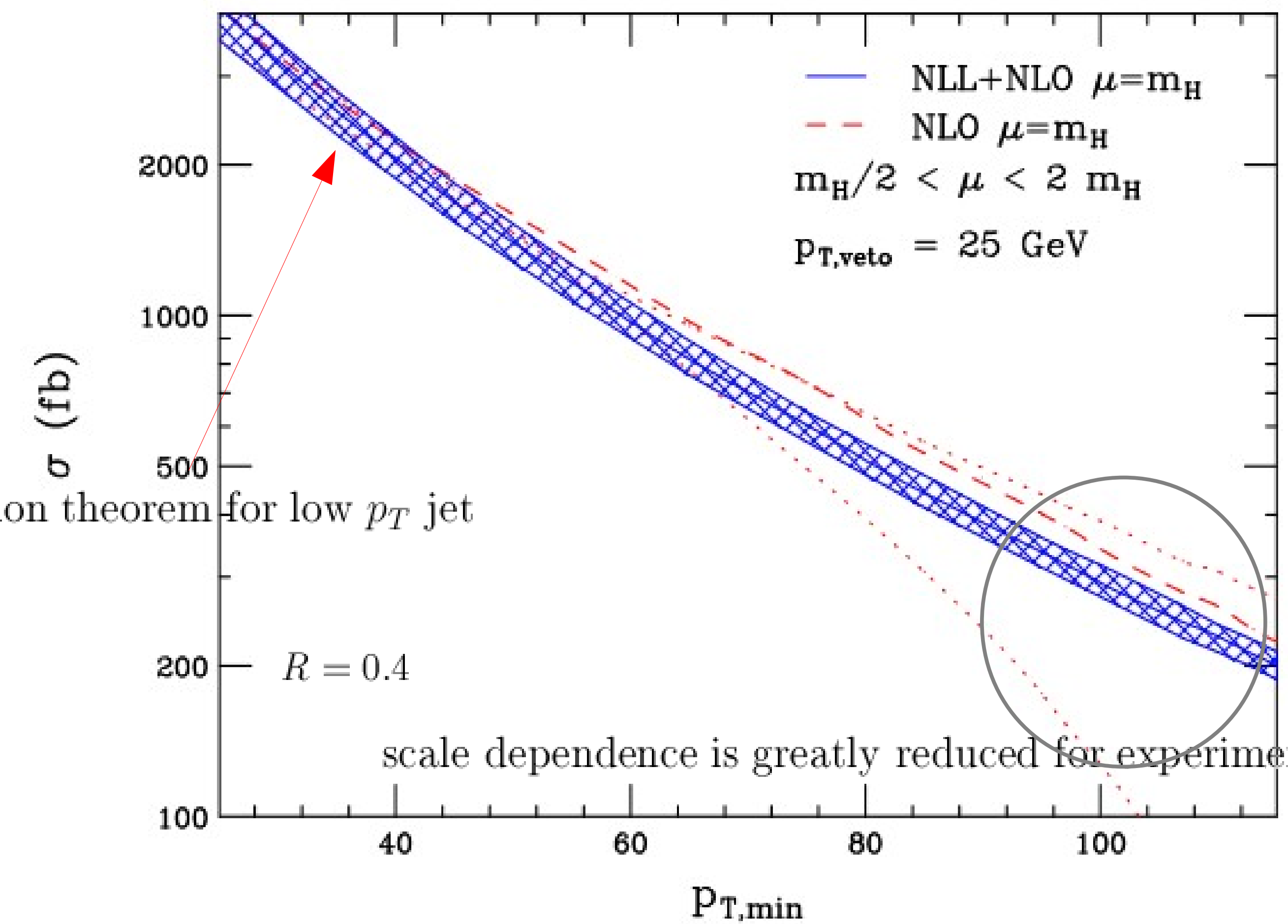


new factorization theorem for low p_T jet

scale dependence is greatly reduced for experimentally relevant vetoes

Conclusion and Outlook

- Resum NLL for exclusive multi-jet events
  - Neat analytic expressions
  - Reliable prediction
  - Reduced scale dependence
- Things to do
  - NLL' (within reach) and beyond
  - Entire spectrum (low jet pT)
  - Matching schemes and uncertainties
  - Compare with parton shower

Thanks

Backup

- Neat expressions   arXiv:1210.1906

$$\mathcal{R}_{J_i} = \exp\left[-2T_i^2 S(\mu_J, \mu) - A_{J_i}(\mu_J, \mu)\right] \left(\frac{\mu_J}{p_T^{J_i} R}\right)^{-2T_J^2 A_\Gamma(\mu_J, \mu)},$$

For the NLL resummation, we need

$$A_\Gamma(\mu_i, \mu_f) = \frac{\Gamma_0}{2\beta_0}\left\{\log r + \frac{\alpha_s(\mu_i)}{4\pi}\left(\frac{\Gamma_1}{\Gamma_0} - \frac{\beta_1}{\beta_0}\right)(r-1)\right\}, \tag{38}$$

and

$$S(\mu_i, \mu_f) = \frac{\Gamma_0}{4\beta_0^2}\left\{\frac{4\pi}{\alpha_s(\mu_i)}\left(1 - \frac{1}{r} - \log r\right) + \left(\frac{\Gamma_1}{\Gamma_0} - \frac{\beta_1}{\beta_0}\right)(1 - r + \log r) + \frac{\beta_1}{2\beta_0}\log^2 r\right\}, \tag{39}$$

Backup

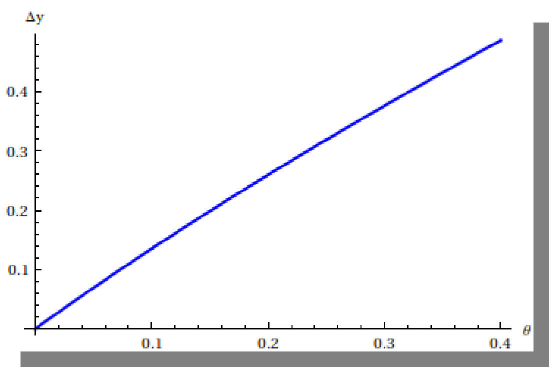
- Log counting

	matching (singular)	nonsingular	γ_x	Γ_{cusp}	β	PDF
LO	LO	LO	-	-	1-loop	LO
NLO	NLO	NLO	-	-	2-loop	NLO
NNLO	NNLO	NNLO	-	-	3-loop	NNLO
LL	LO	-	-	1-loop	1-loop	LO
NLL	LO	-	1-loop	2-loop	2-loop	LO
NNLL	NLO	-	2-loop	3-loop	3-loop	NLO
NLL′+NLO	NLO	NLO	1-loop	2-loop	2-loop	NLO
NNLL+NNLO	(N)NLO	NNLO	2-loop	3-loop	3-loop	NNLO
NNLL′+NNLO	NNLO	NNLO	2-loop	3-loop	3-loop	NNLO
N^3LL+NNLO	NNLO	NNLO	3-loop	4-loop	4-loop	NNLO

Table from Berger, Marcantonini, Stewart, Tackmann and Waalewijn '11

Backup

- Q
  - Why the clustering between the soft and the central collinear radiations is not a problem?
- A
  - The clustering does NOT depend on how the collinear mode splits



$$\text{small } \theta \rightarrow \text{small } \Delta y$$

$$d_{SC_i} \sim d_{SC_j} \sim d_{SJ}$$

Backup

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  - Why the clustering between the soft and the beam collinear radiations is a problem?
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  - The clustering DOES depend on how the beam mode splits