MiNLO

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arXiv:1206.3572 and arXiv:1212.4504

Preliminary remark on scales

- 'Good scales' are commonly found retrospectively requiring NLO corrs be small or sensitivity minimized

- 'Bad scales' → big scale logs → big corr^s & sensitivity

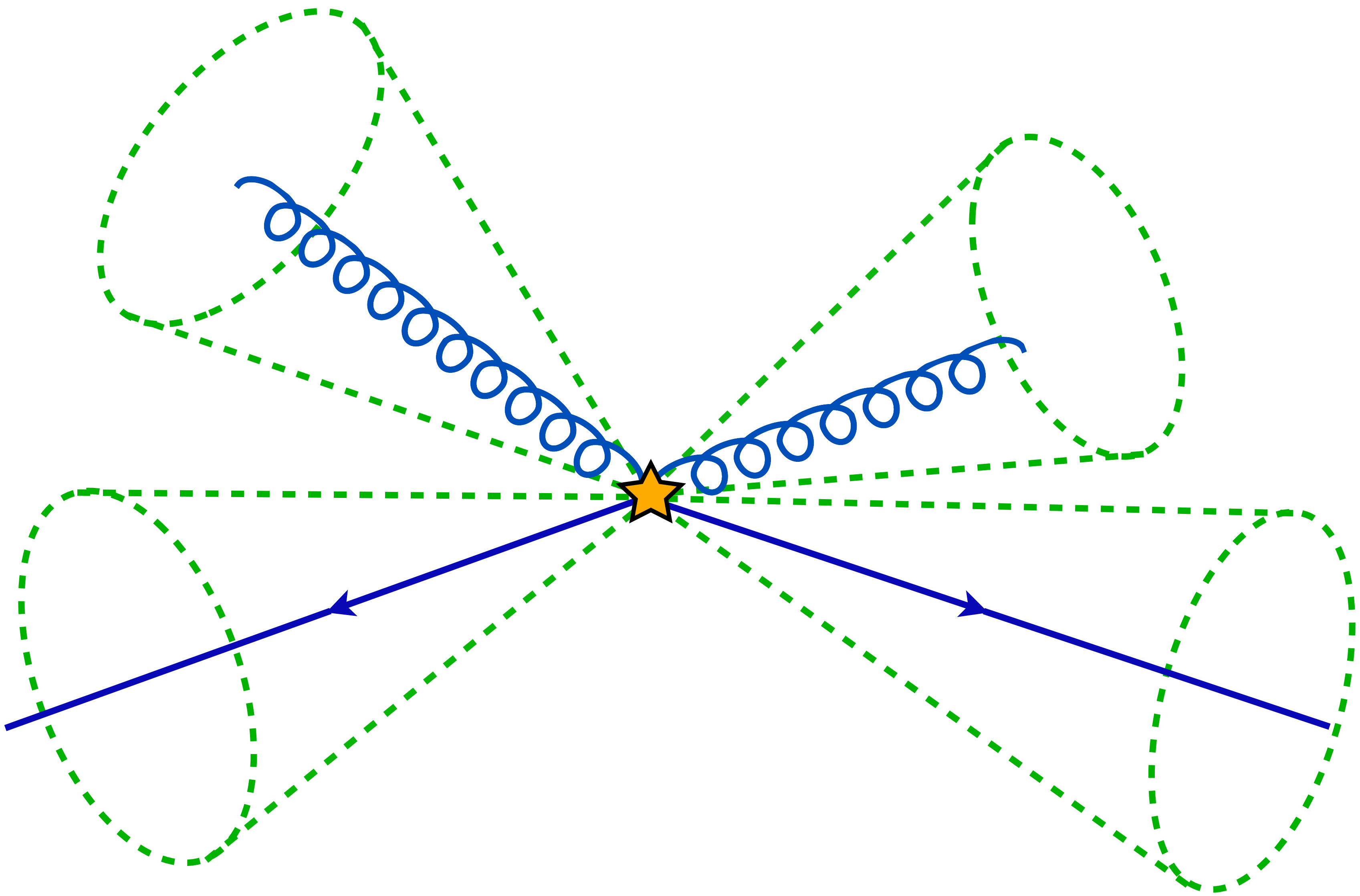
- Big corrections can have real physical origins: new production channels, I.R. logs, big colour factors, big gluon lumi ...

- Adjusting scale to make corr^s / sensitivity small can effectively 'eat' unrelated physics in scale choice

MiNLO: Multiscale improved NLO

- MiNLO only addresses processes with jets
- MiNLO recipe doesn't aim at minimizing μ sensitivity
- It's more about getting a better central value
- It's a priori i.e. there's not so much you can 'tune'
- The MiNLO scheme is just the same one used for the matrix elements in MCs using ME+PS merging ...
- with a couple of easy-to-do modificat^{n}s to keep NLO NLO
- It therefore accounts for potentially big Sudakov logs, beyond NLO, that can turn predict^{n}s to garbage

1. Take an ME generator and generate events ...

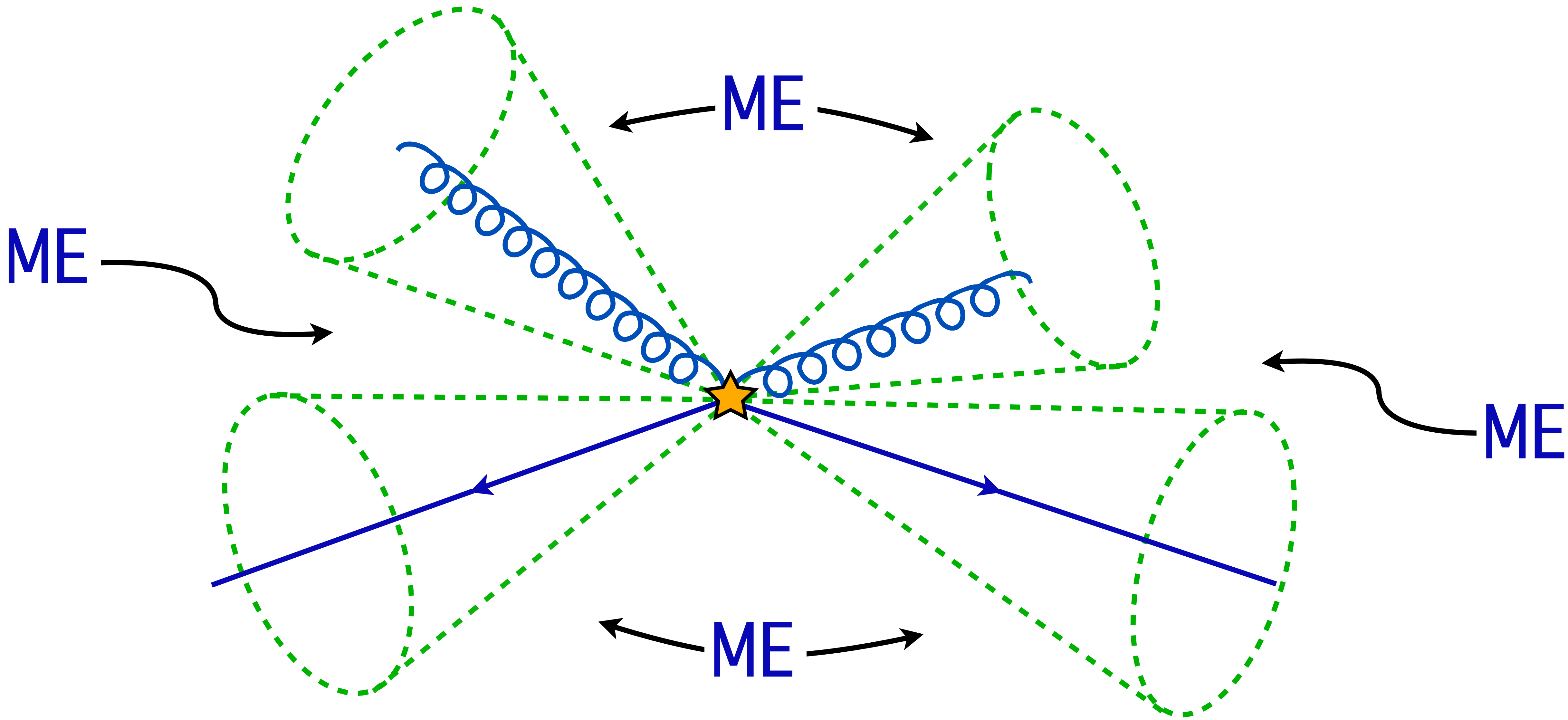


... with a cut defined in terms of a jet measure: q_0

$\alpha_s = \alpha_s(q_0), \quad \mu_F = q_0$

Reminder of ME+PS methods

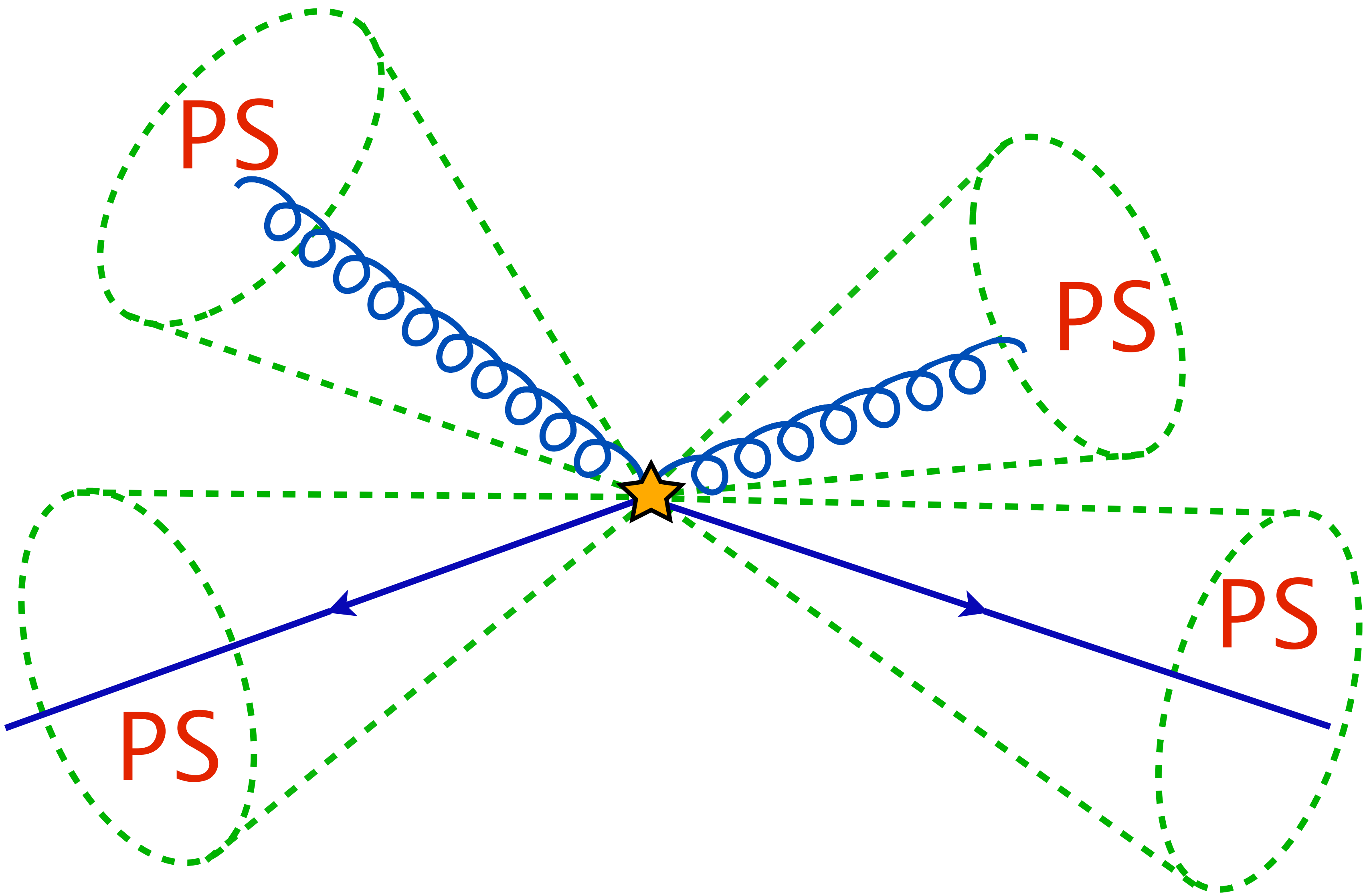
This partitions phase space into the ME region ...



[$y_{ij} \geq q_0$ $\forall$ partons i, j]

Reminder of ME+PS methods

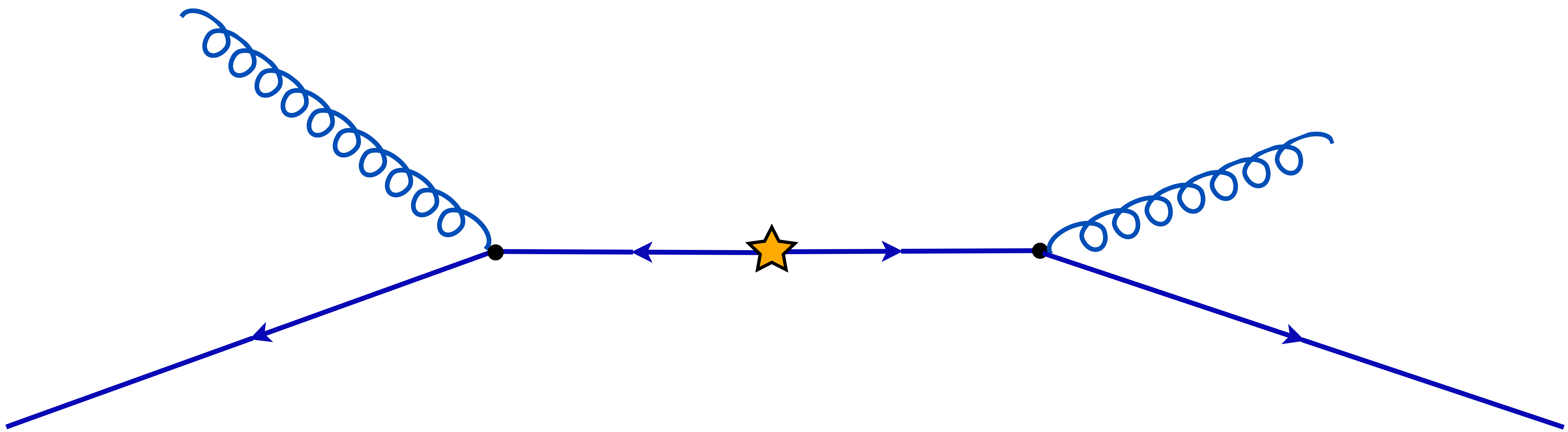
... and the PS regions of phase space.



[$y_{ij} \geq q_0 \ \forall$ partons i, j]

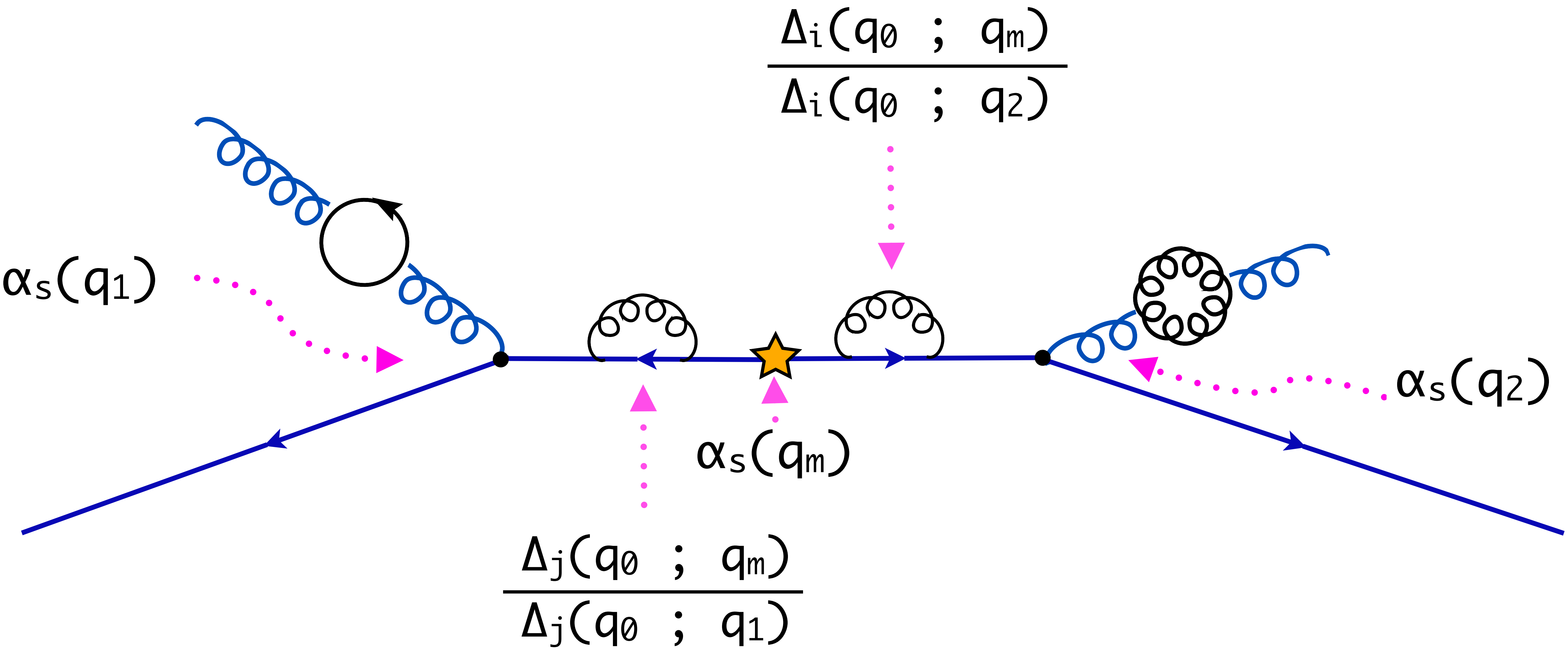
Reminder of ME+PS methods

2. Apply k_T jet-algo to get a shower history



Reminder of ME+PS methods

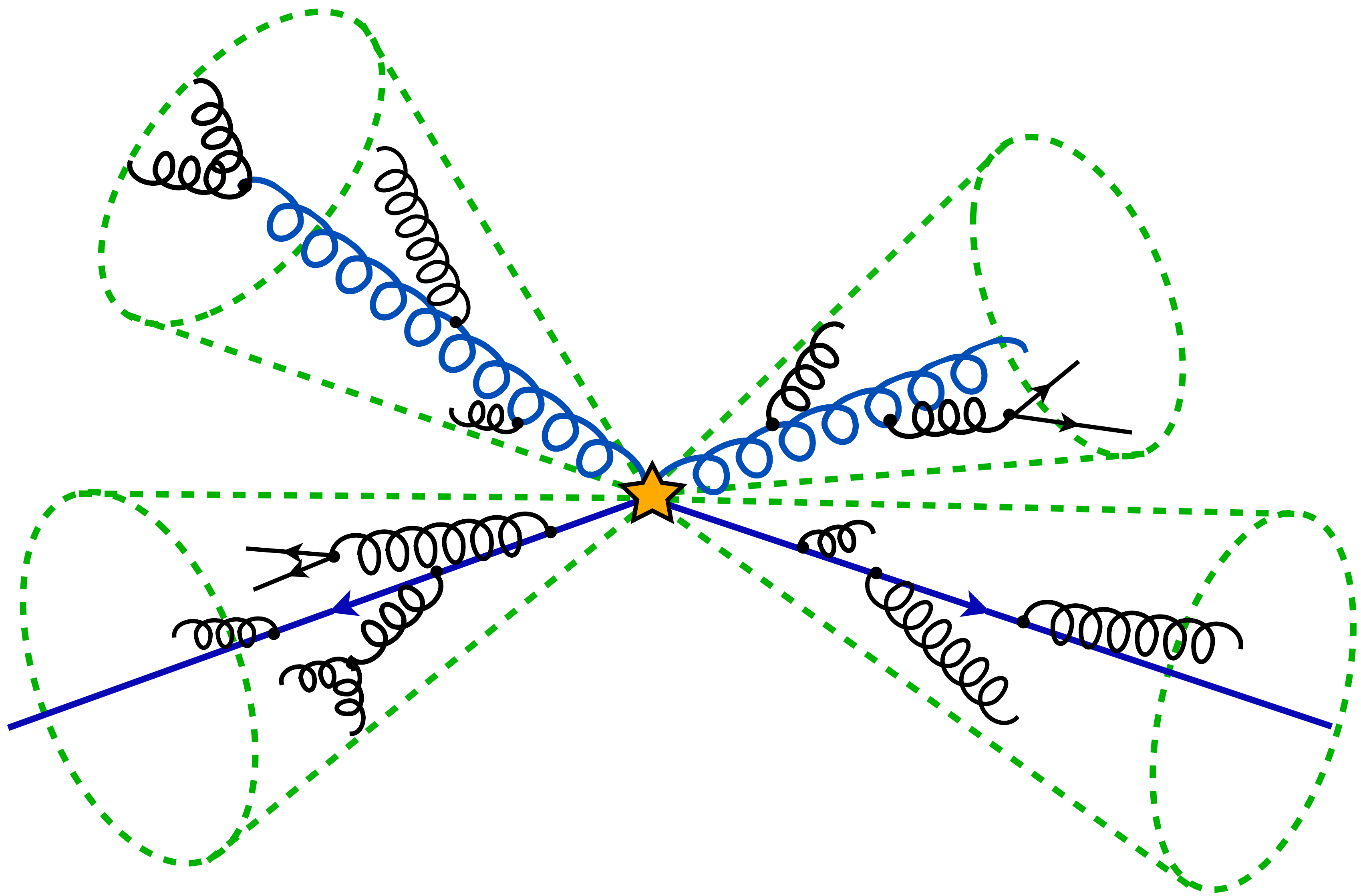
3. Include LL infrared effects [like a PS does]



- Coupling constant weighting for branching vertices
- Sudakov suppression factors for no further emission in ME region

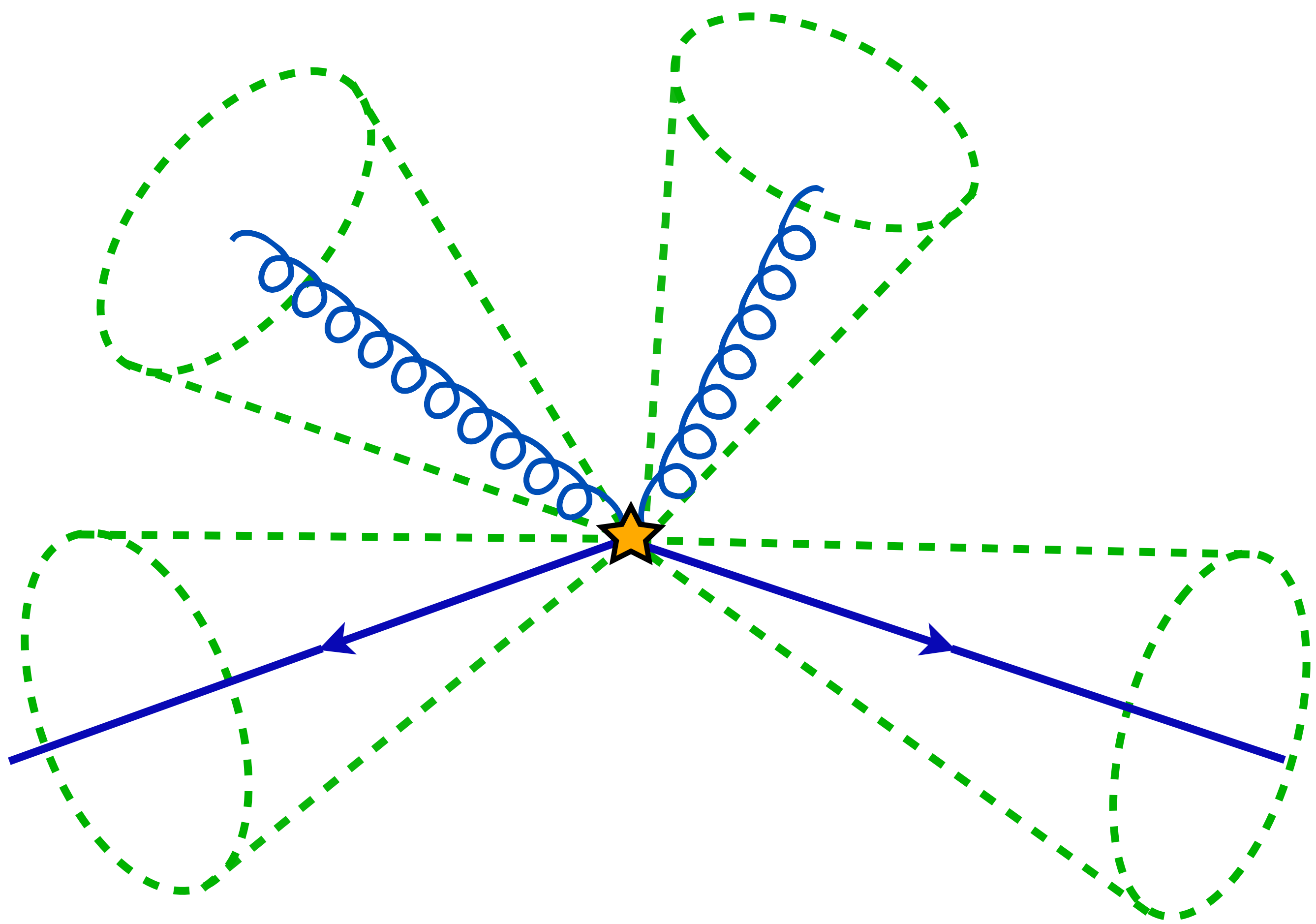
Reminder of ME+PS methods

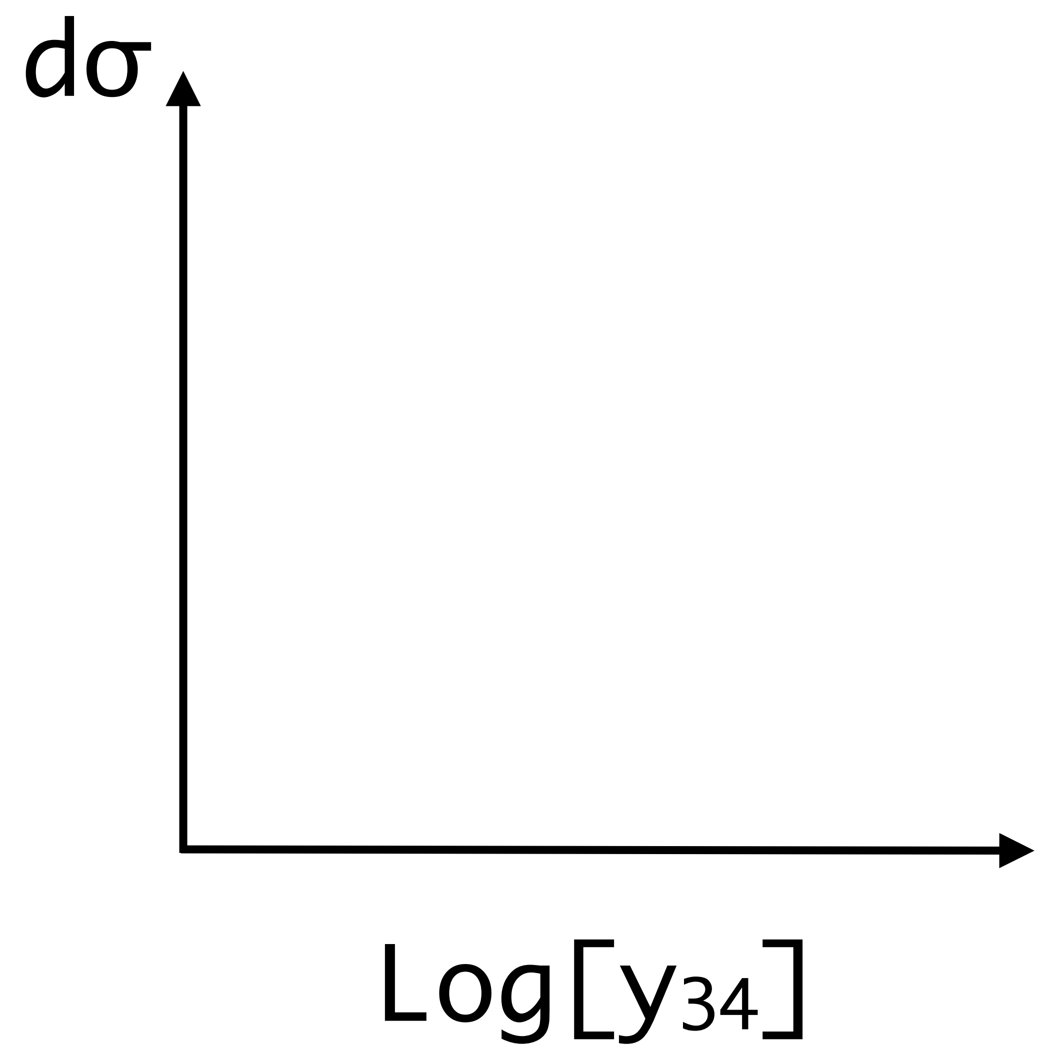
4. Fill below the q_0 cut with vetoed showers



Reminder of ME+PS methods

Gives smooth behaviour as pseudopartons get close ...





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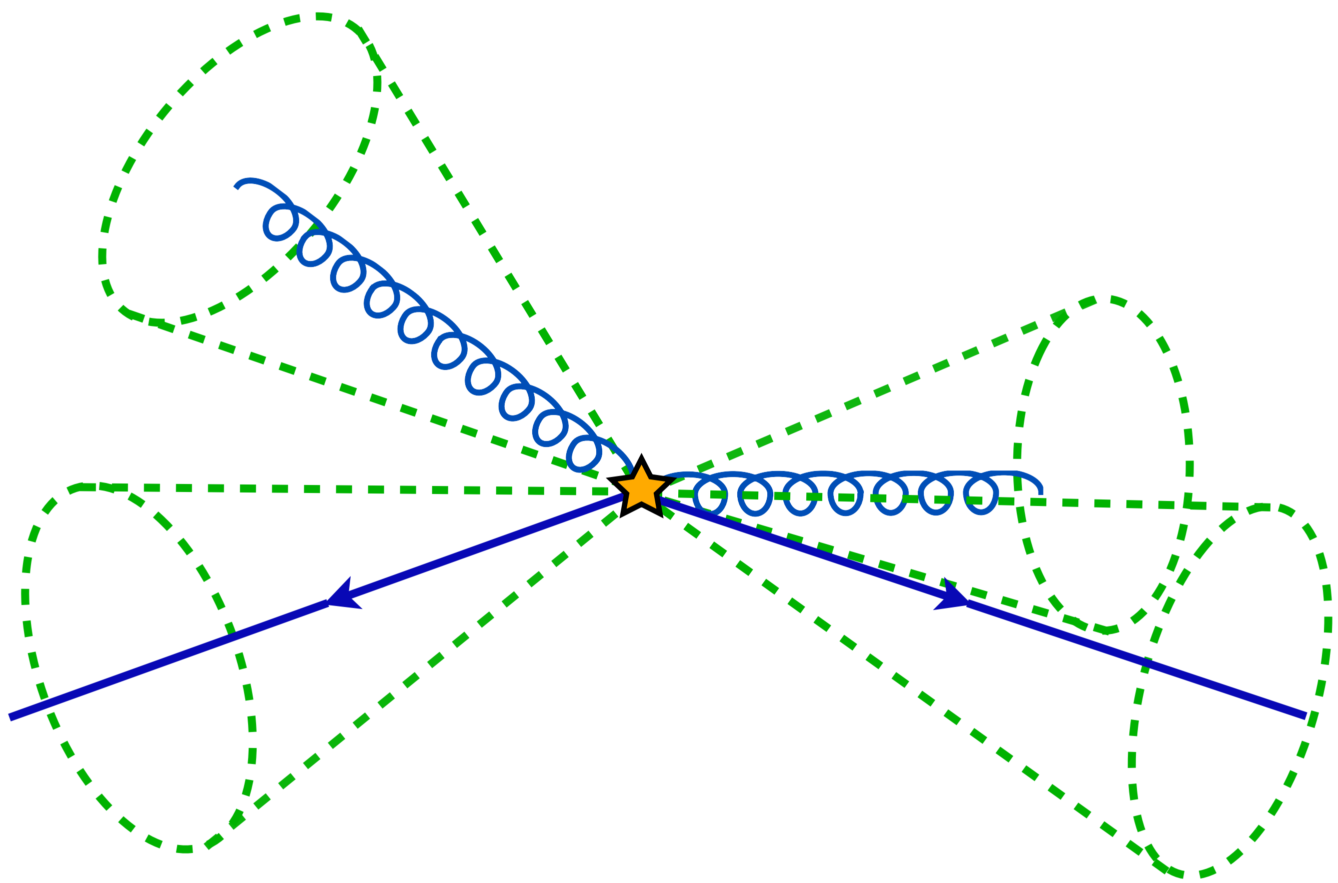
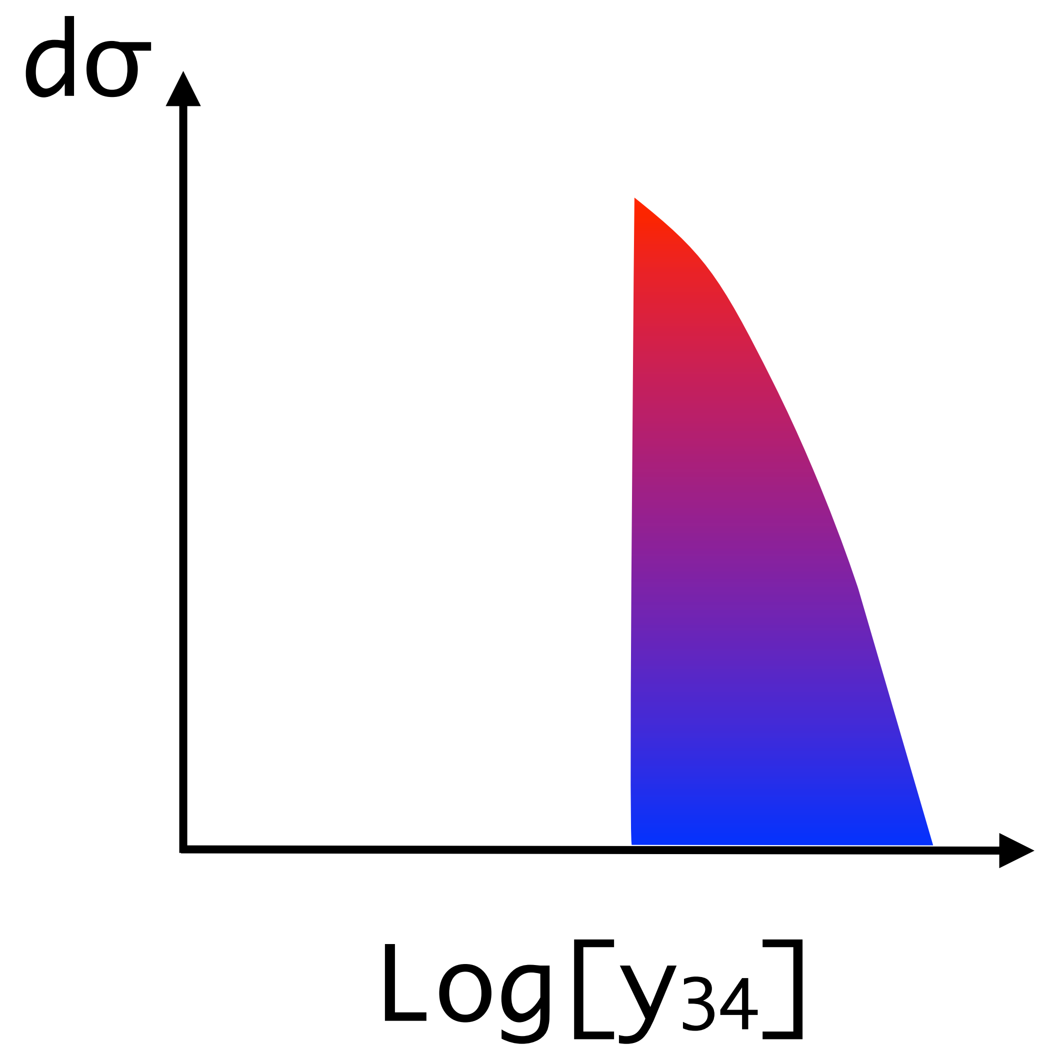
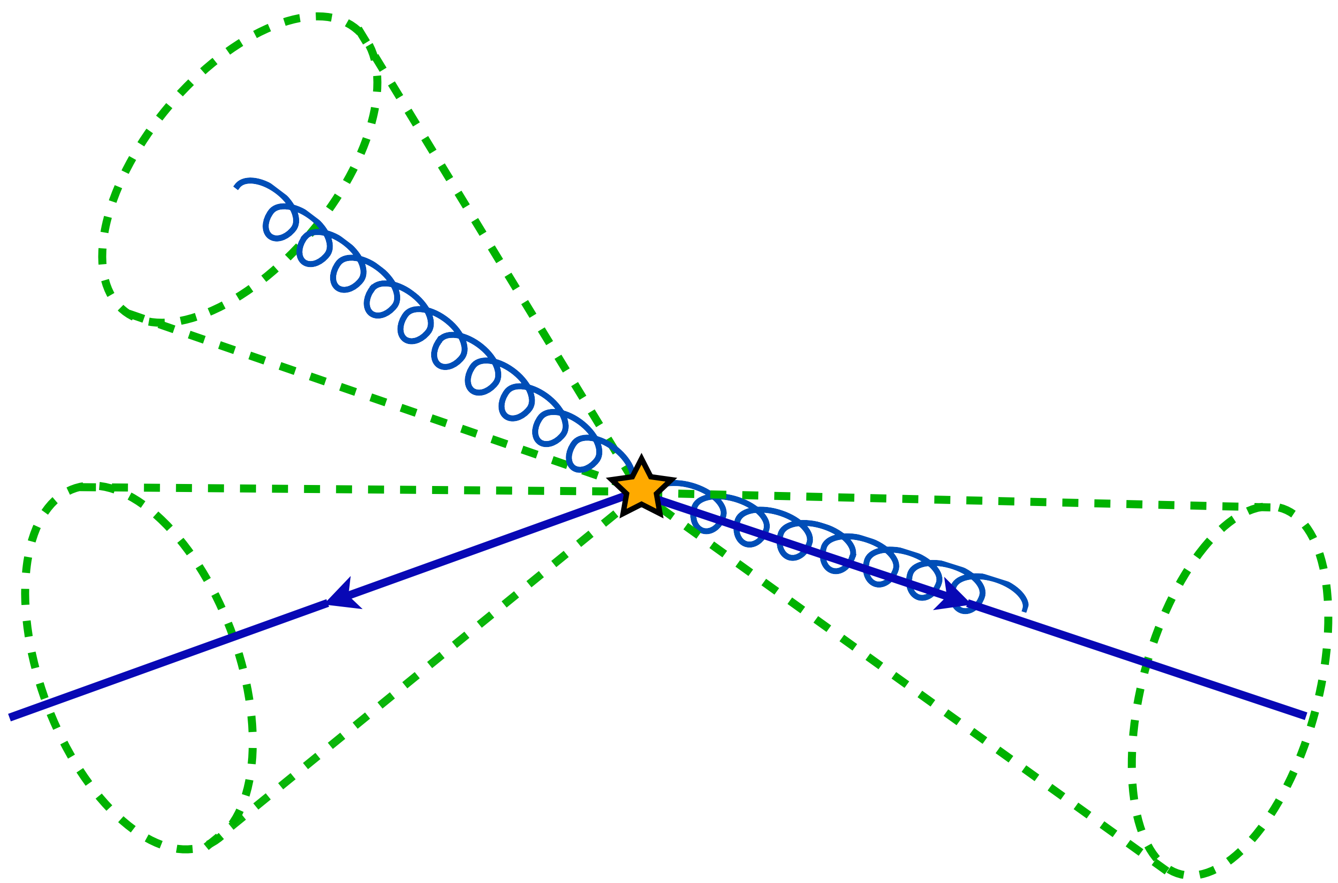
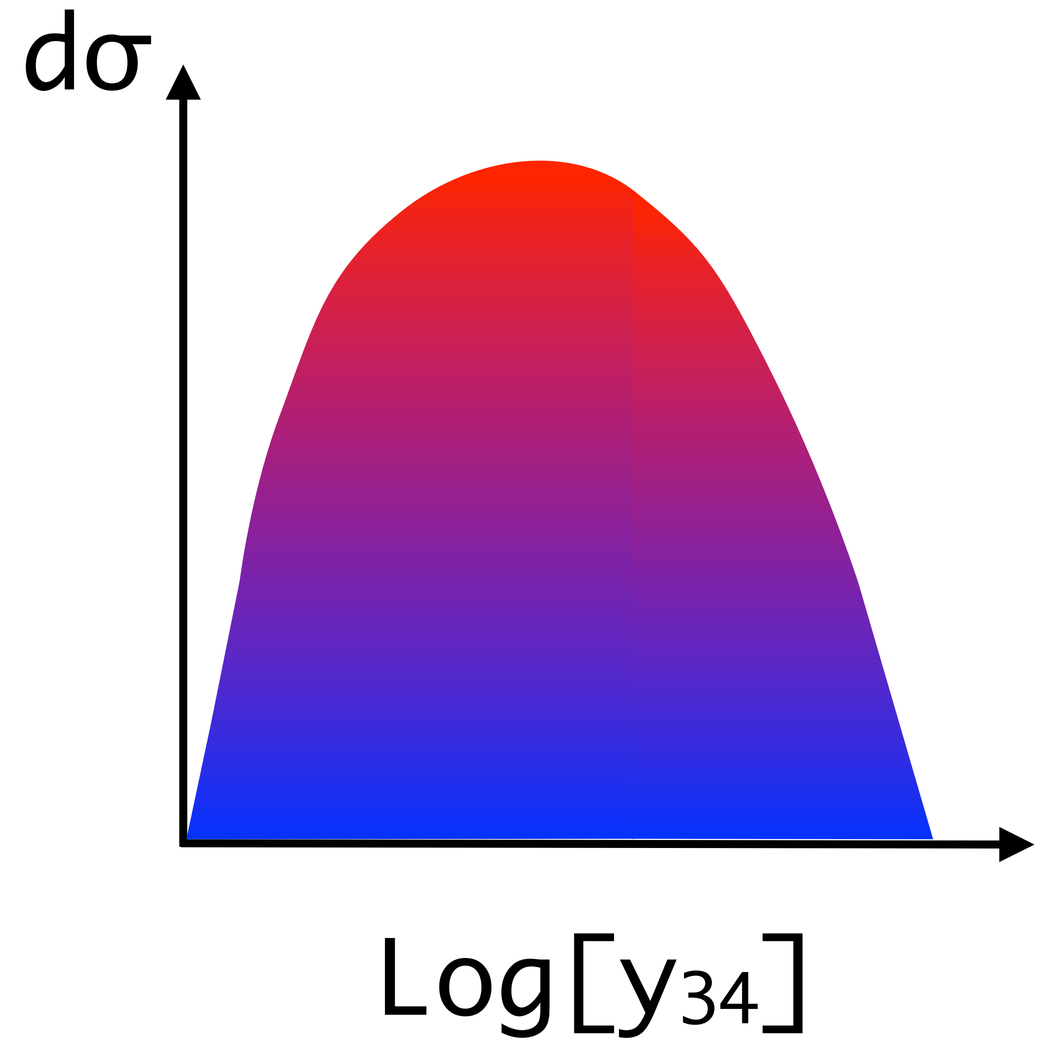




Reminder of ME+PS methods

Gives smooth behaviour as pseudopartons get close ...





Extension 1: don't break scale compensation

- NLO x-secs have the generic form:

$$\frac{d\sigma}{d\Phi} = \alpha_S^N(\mu_R)\,B + \alpha_S^{N+1}(\mu_R)\left[V + N\,b_0\,\log\frac{\mu_R^2}{Q^2}\,B\right] + \alpha_S^{N+1}(\mu_R)\,R$$

- Vary $\mu_R \to \mu_R'$ in Born & you get back Born + $O(\alpha_S^{N+1})$

$$\alpha_S^N(\mu_R)\,B + N\,b_0\,\alpha_S^{N+1}(\mu_R)\,\log\frac{\mu_R^2}{\mu_R'^2}\,B + \mathcal{O}\left(\alpha_S^{N+2}\right)$$

- Vary $\mu_R \to \mu_R'$ in virtual & you get back virtual + $O(\alpha_S^{N+1})$

$$\alpha_S^{N+1}(\mu_R)\left[V + N\,b_0\,\log\frac{\mu_R^2}{Q^2}\,B\right] - N\,b_0\,\alpha_S^{N+1}(\mu_R)\,\log\frac{\mu_R^2}{\mu_R'^2}\,B + \mathcal{O}\left(\alpha_S^{N+2}\right)$$

- The net variation is $O(\alpha_S^{N+2})$ → scale compensation

Extension 1: don't break scale compensation

- For this to hold when using multiple different scales in Born α_S's input a fancy choice of μ_R to the virtuals:

$$\mu_\mathrm{R} = \left(\prod_{i=1}^{N} \mu_i\right)^{\frac{1}{N}}$$

- This way virt. $\mu \to \mu'$ $O(\alpha_S^{N+1})$ variat^n cancels that of Born

$$\alpha_\mathrm{S}^{N+1}(\mu_R)\left[V + N\, b_0 \log \frac{\left(\prod_{i=1}^{N} \mu_i^2\right)^{1/N}}{Q^2} B\right] - b_0\, \alpha_\mathrm{S}^{N+1}(\mu_R) \sum_{i=1}^{N} \log \frac{\mu_i^2}{\mu_i'^2} B + \mathcal{O}\left(\alpha_\mathrm{S}^{N+2}\right)$$

- Equivalently, use some fixed μ & subtract 'by hand' a [scale] compensating term derived from the α_S^N wgts

- Latter can be viewed as undoing the spurious NLO effect coming from reweighting the Born with MEPS α_S's

Extension 2: don't overcount Sudakov logs

- Multiplication of Born by Sudakovs generates NLO IR logs

$$\Delta_f(Q_0, Q) = 1 + \Delta_f^{(1)}(Q_0, Q) + \mathcal{O}(\alpha_S^2),$$

$$\Delta_f^{(1)}(Q_0, Q) = -\frac{C_f}{\pi}\alpha_S \left[\frac{1}{4}\log^2\frac{Q^2}{Q_0^2} - \log\frac{Q^2}{Q_0^2}B_f\right]$$

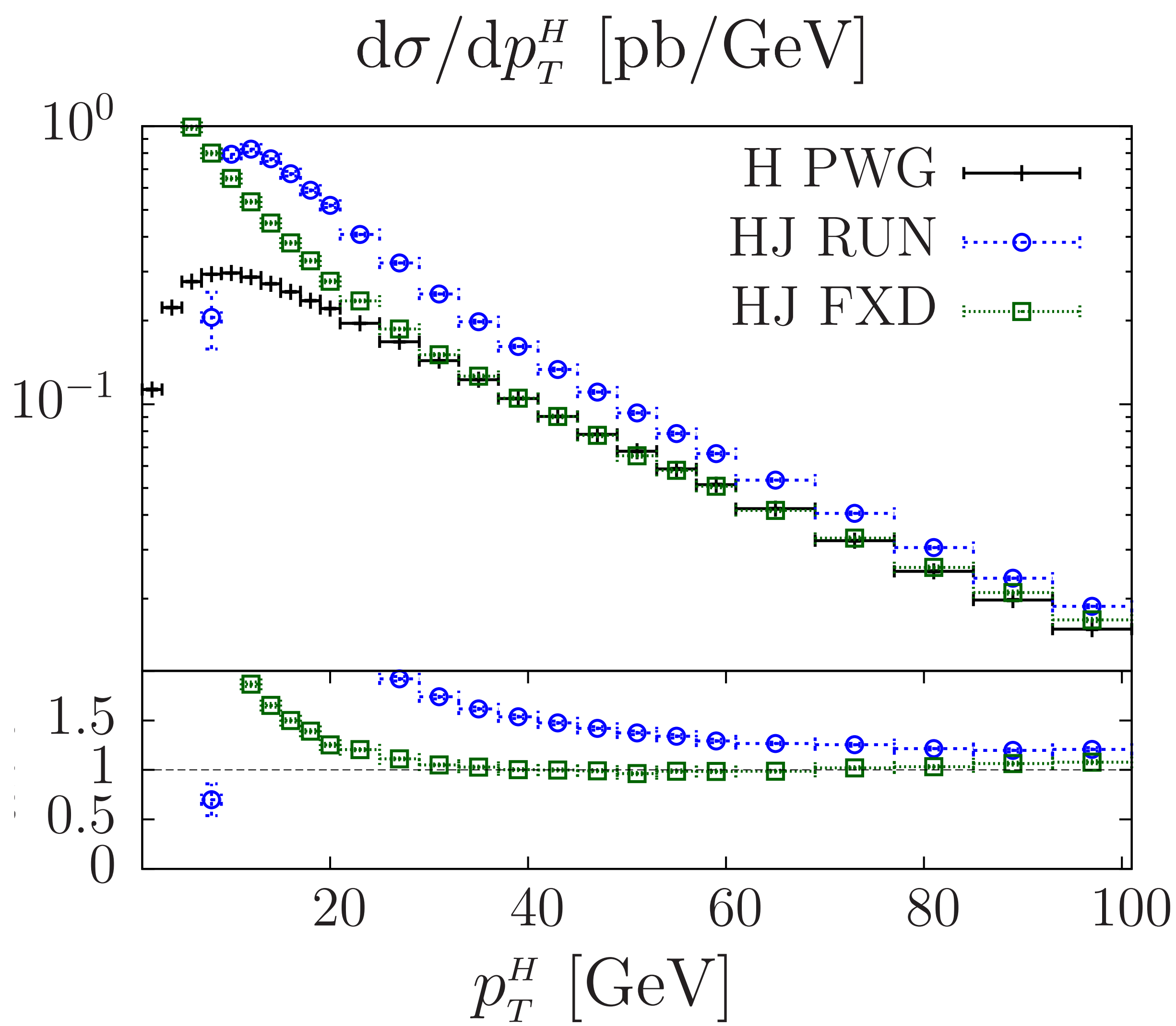
- But NLO was NLO so it already had them in it

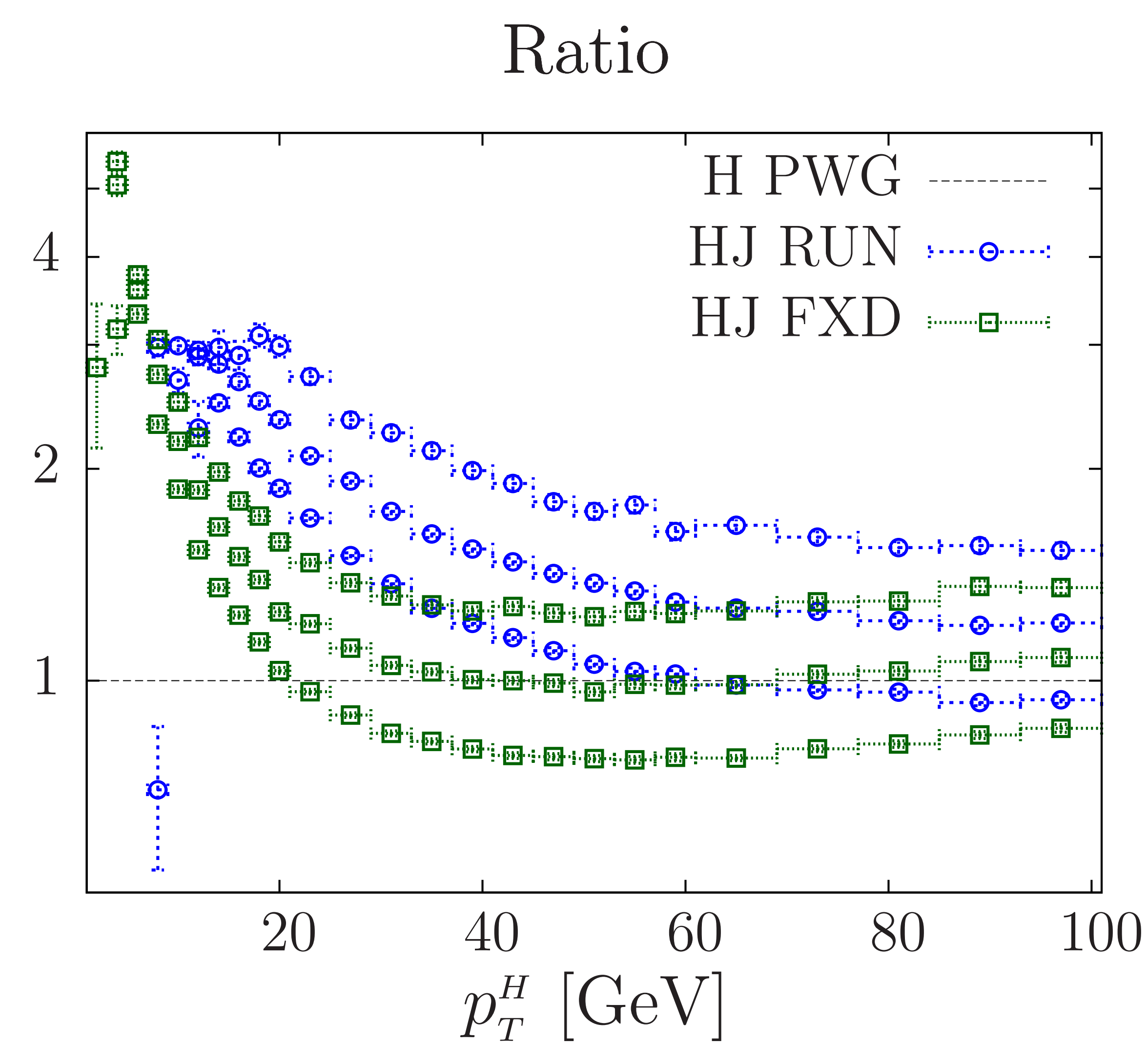
- So as well as deleting NLO terms generated by α_S wgts we delete $O(\alpha_S)$ expansion of all Sudakov wgts * Born

Properties of MiNLO

- MiNLO is always NLO accurate - same as NLO up to NNLO
- For sufficiently inclusive observables MiNLO is also NLL accurate
- When used as starting point for Powheg / MC@NLO the scope of the resummation greatly extended ; multiple emissions are explicitly accounted for.

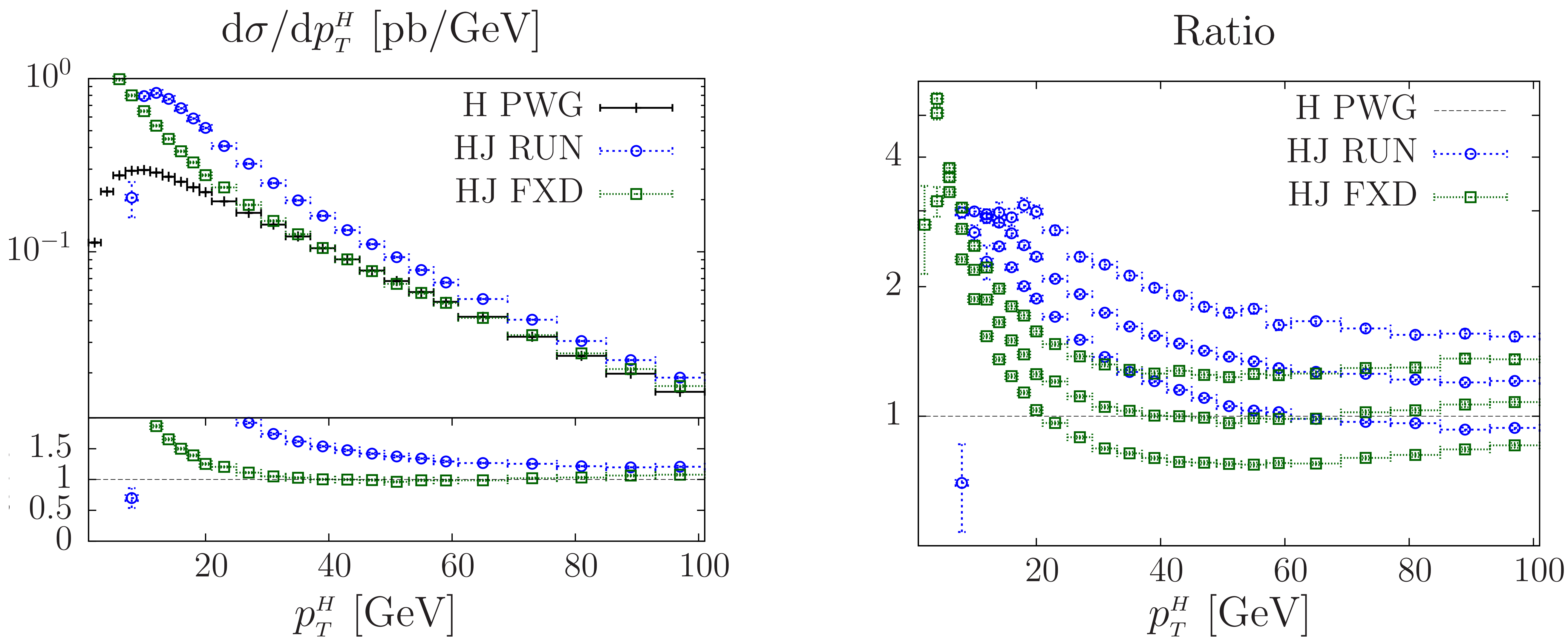
Case study: NLO Higgs + 1 jet





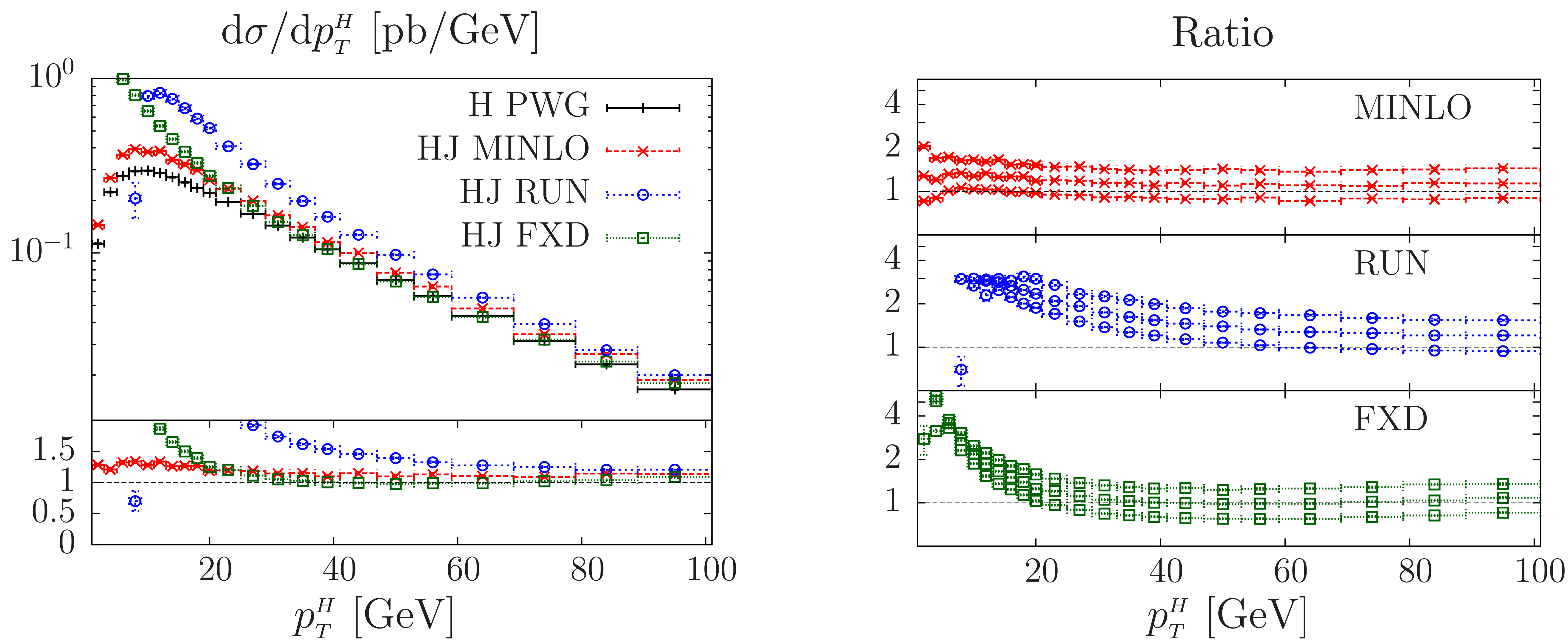
- H PWG: gg → Higgs at NLO Powheg+Pythia
- HJ RUN: NLO H+1 jet with $\mu_R = \mu_F = p_{T,H}$
- HJ FXD: NLO H+1 jet with $\mu_R = \mu_F = M_H$
- The ref. line for ratios is NLO gg → H Powheg+Pythia

Case study: NLO Higgs + 1 jet



- HJ RUN above HJ FXD : $\alpha_S(p_T) > \alpha_S(m_H)$
- NLO H+1 jet calcs outside each other's envelopes by 60 GeV
- HJ RUN [$\mu_R=\mu_F=p_{T,H}$] departs from resummed H PWG at 60 GeV
- HJ FXD's high μ_R makes up for missing Sudakov a bit longer
- Uncertainty envelopes shrink on way down from 40-60 GeV :-/

Case study: NLO Higgs + 1 jet



- MiNLO agrees w.other H+1 jet NLOs at high p_T as promised
- MiNLO within 40% of H PWG in deep Sudakov region
- MiNLO's scale uncertainty does not shrink towards low p_T
- 'Normal' bands shrink to 0 by having 1st Sudakov log only
- Shrinking envelope as $p_T \to 0$ is surely a bad sign

MiNLO in NLO & NLOPS

- Theoretically well motivated scale setting recipe for procs with light jets, based on that used in ME+PS
- Unlike std. NLO it doesn't break when Born kinematics approach soft / collinear configurations
- Scale uncertainties are also more reliable
- The same as conventional NLO up to NNLO terms
- Agrees better with conventional NLO using higher scales e.g. $H_T/2$ [... but not H_T]
- It's a prerequisite for merging NLO+PS's together
- It's pretty simple to implement ...

MiNLO Mk2

- First MiNLO paper claims MiNLO Boson+jet is LO accurate for inclusive Boson predictions

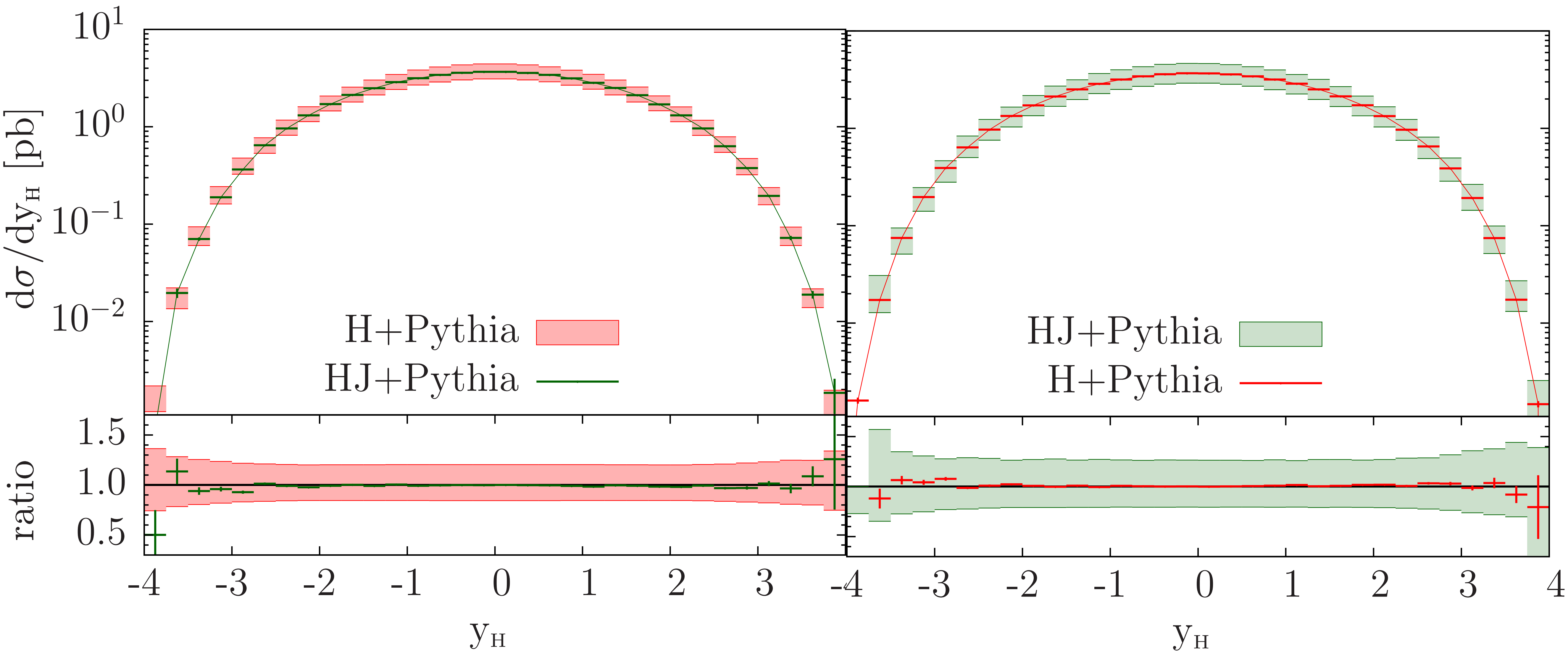
- Rigorous investigat^{n} in arXiv:1212.4504 [Nason et al.]

- Reveals claim to be true ...

- It improved MiNLO s.t. NLO Boson+jet alone also gives NLO for incl. boson observables

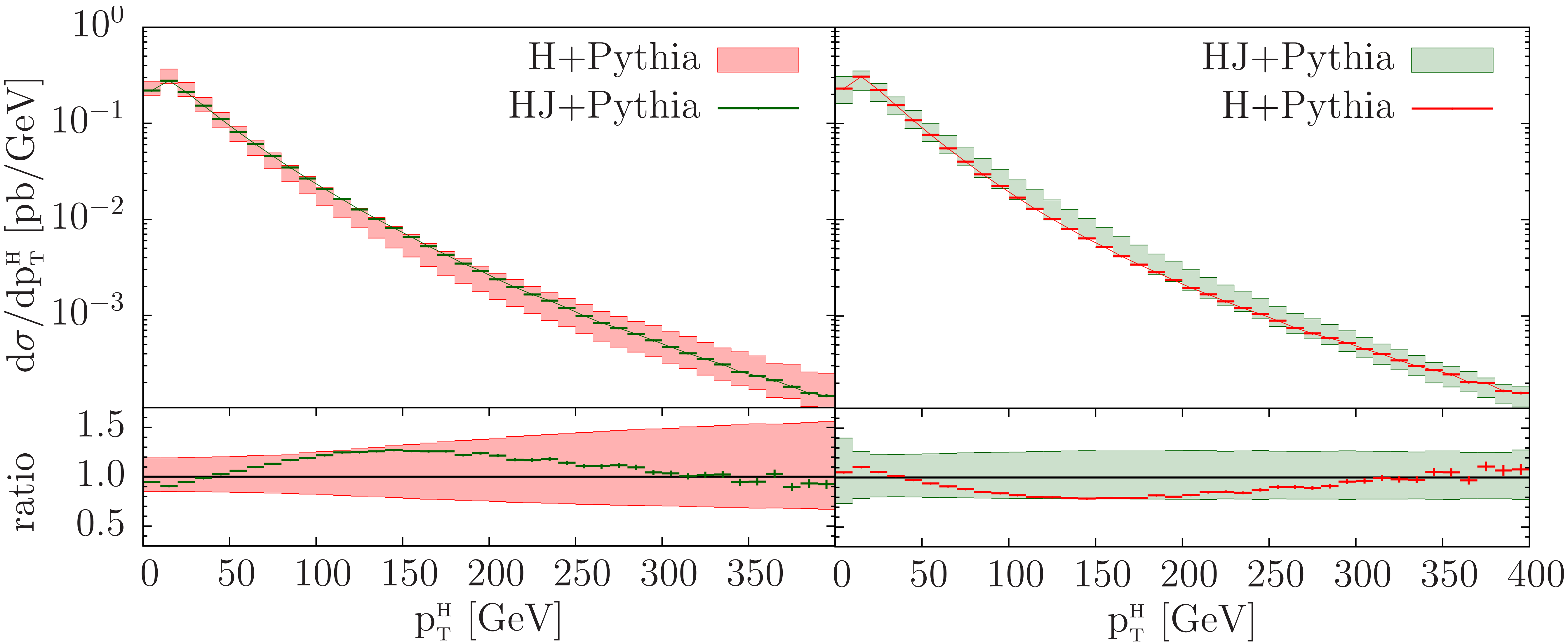
- Like CKKW, at NLO level, but w/o any actual merging

Case study: NLO H vs MiNLO Mk2 HJ



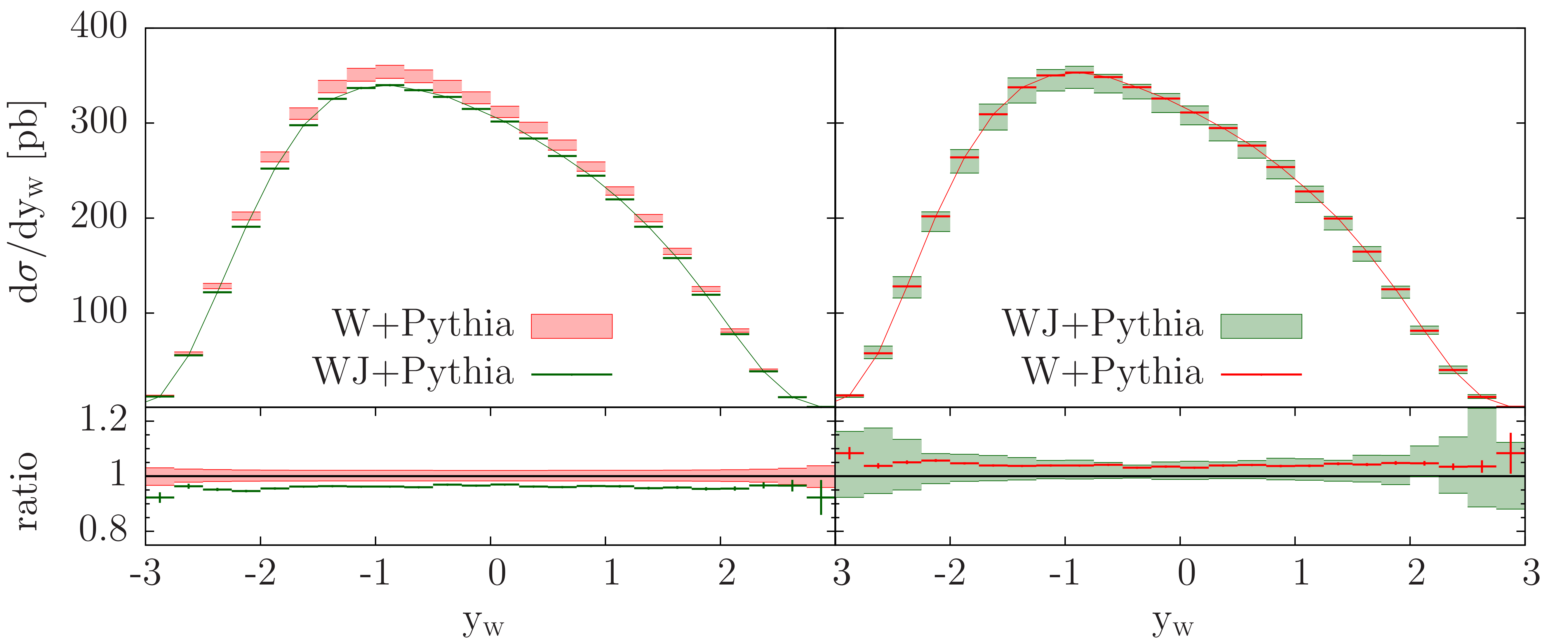
- Left NLO H PWG uncertainty w. MiNLO HJ inset as green +'s
- Right MiNLO HJ uncertainty w. NLO H inset in red +'s
- Both 7 pt independent μ_R , μ_F scale variation bands

Case study: NLO H vs MiNLO Mk2 HJ



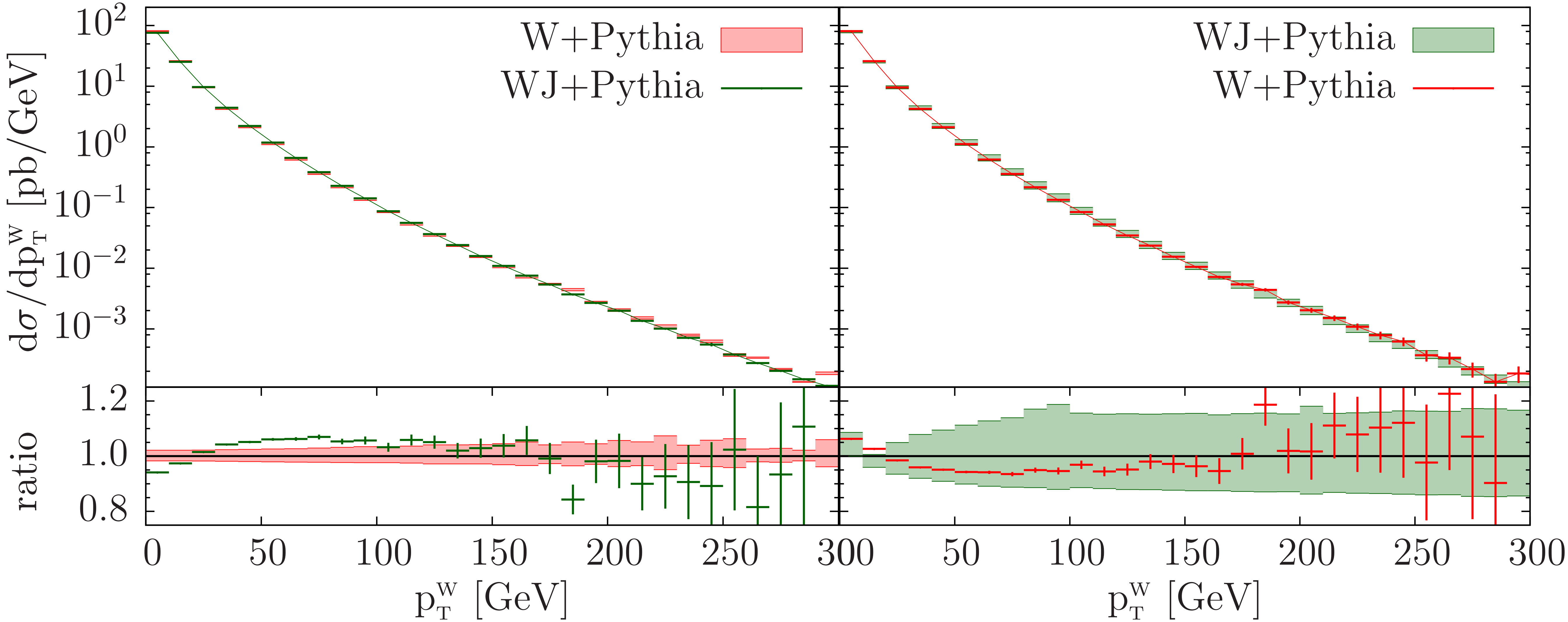
- Again central values in good agreement
- MiNLO HJ is NLO for H+jet and H inclusive
- Powheg H only NLO for H inclusive
- Hence MiNLO HJ band is expectedly smaller at high p_T

Case study: NLO W vs MiNLO Mk2 WJ



- W^- @ Tevatron with 3-pt. symmetric scale unc. bands
- MiNLO WJ low w.r.t Powheg W by 4-5%, band larger by ~2% in central region and gets wider toward large y_W
- Powheg W uncertainty is pretty small < 3% ...
- NO shape differences

Case study: NLO W vs MiNLO Mk2 WJ

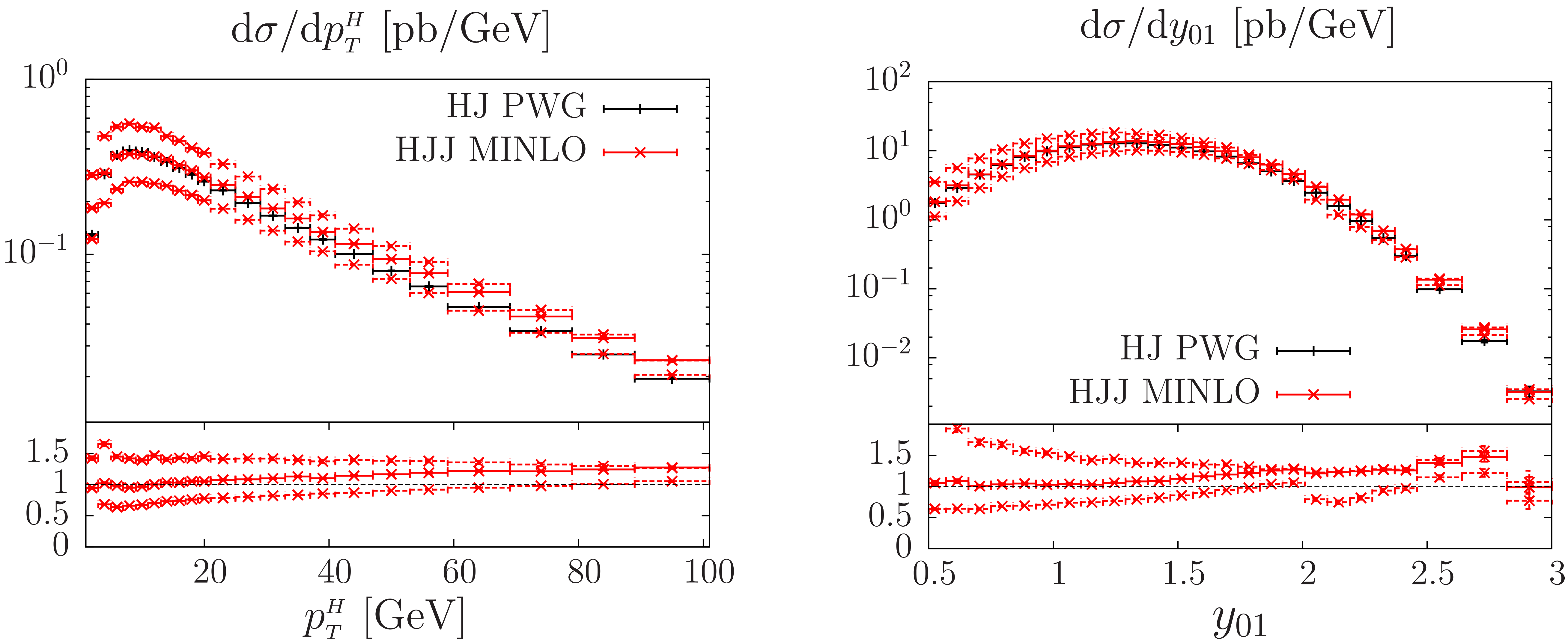


- As with Higgs case differences in Sudakov f.f.s manifest in the low p_T part of the spectrum
- Powheg W error band is highly spurious for p_T >~ m_W [LO]
- MiNLO WJ band looks pretty reasonable [NLO]

Conclusions on MiNLO Mk2

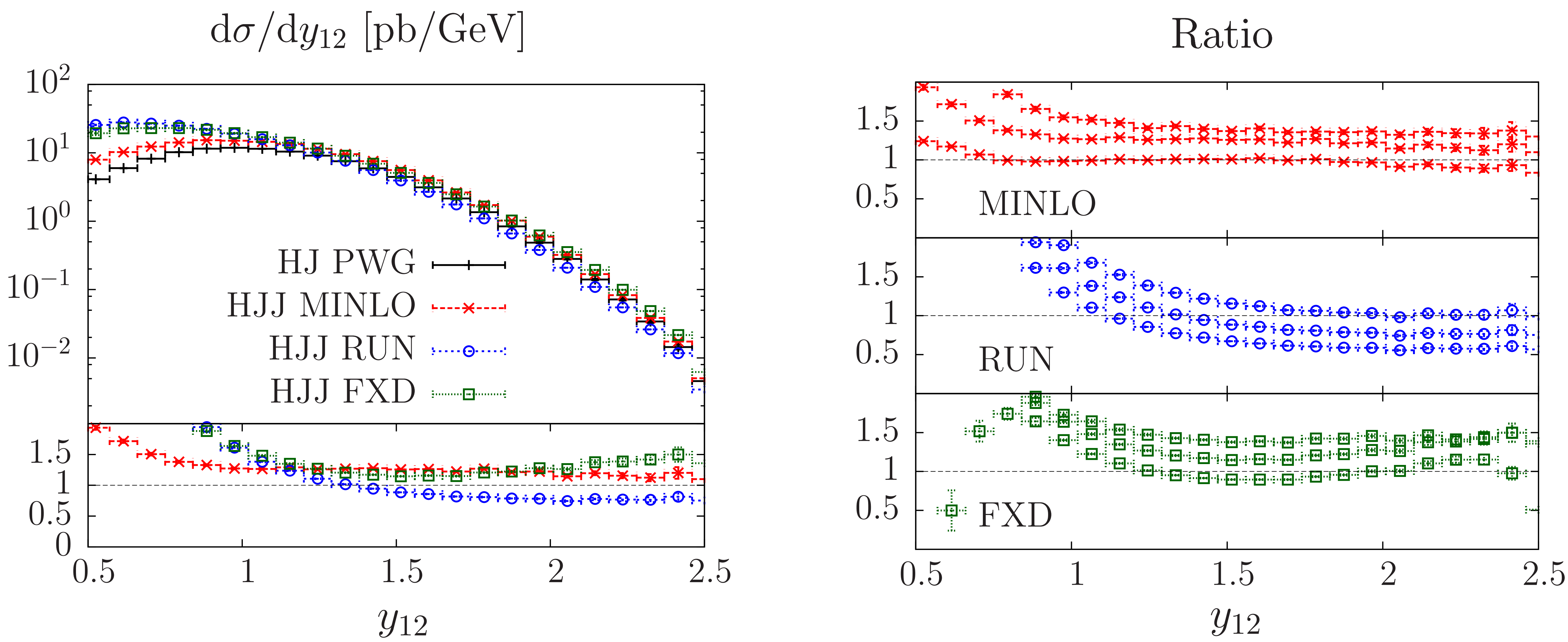
- MiNLO for NLO boson+jet, alone, refined to return, simultaneously, NLO predictions for incl. boson prod^n
- Log accuracy is the same as before
- 'CKKW at NLO' without actual merging
- Trivial rwgt of events [NNLO ÷ MiNLO] gives NNLO+PS
- Work needed to clarify rel^n of scale variation in conventional NLO inclusive w.r.t MiNLO for inclusive
- Applicat^n to other white-stuff+jet goes the same way
- Applicat^n to higher jet multiplicities requires we learn more resummation technology [O(yearS)]

Case study: NLO Higgs + 2 jets



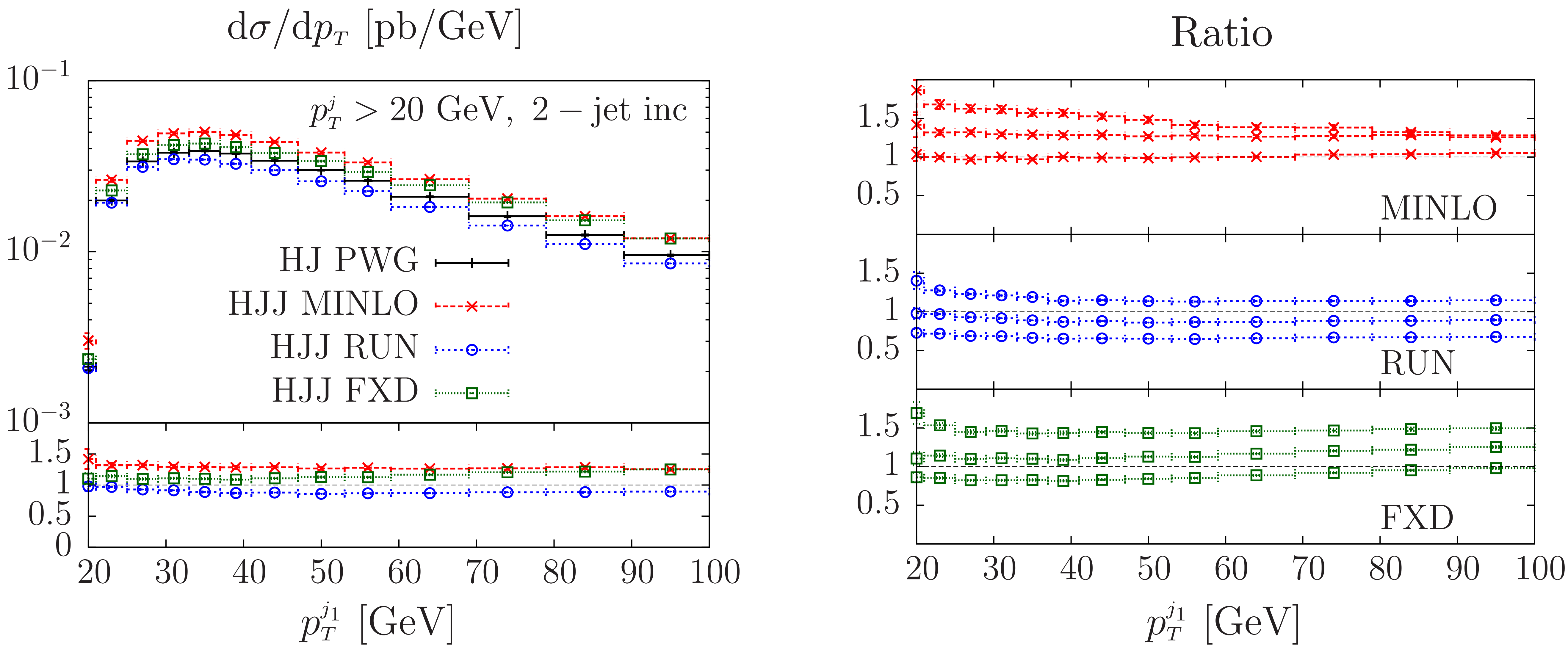
- HJ PWG MiNLO Higgs + 1 jet feeding Powheg+Pythia
- HJJ MINLO MiNLO H+2 jets
- As before conventional NLO returns nonsense towards low p_T
- HJJ MINLO follows MiNLO H+1 jet [w.shower] down to $p_T = 0$

Case study: NLO Higgs + 2 jets



- HJ PWG — MiNLO Higgs+1 jet feeding Powheg+Pythia [ref line]
- HJJ MINLO — MiNLO H+2 jets
- HJJ RUN — NLO H+2 jets with $\mu_R = \mu_F = H_T$
- HJJ FXD — NLO H+2 jets with $\mu_R = \mu_F = M_H$

Case study: NLO Higgs + 2 jets



- Conventional NLO with $\mu_R = \mu_F = H_T$ outside MiNLO envelope
- Conventional NLO with $\mu_R = \mu_F = H_T/2$ in better agreement
- $H_T/2$ is a preferred choice nowadays in multi-jet NLO,
- apparently giving increased scale stability
- [So far] MiNLO HJJ & ZJJ results agree OK with $H_T/2$

MiNLO Mk2 3-slide scant explanation

- LO $d\sigma / dy\, dp_T$ x-sec of Boson+jet is $O(\alpha_S)$

- It has a $p_T \to 0$ finite bit which naturally integrates to $O(\alpha_S)$ over p_T

- It also has a $p_T \to 0$ singular bit

$$\frac{d\sigma_S}{dy dp_T^2} = \frac{\hat{\sigma}_0}{p_T^2} \left[\alpha_S\, A \ln \frac{m^2}{p_T^2}\, f_i f_j + \alpha_S\, B\, f_i f_j + p_T^2 \frac{d}{dp_T^2} \left(f_i f_j\right)\right]$$

- Now do MiNLO ["@LO"] i.e. multiply by a Sudakov and take scale in PDFs and α_S to be p_T

$$\Delta\left(p_T\right) = \exp\left[-\int_{p_T^2}^{m^2} \frac{dq^2}{q^2} \alpha_S\left(p_T\right) \left[A \ln \frac{m^2}{q^2} + B\right]\right]$$

MiNLO Mk2 3-slide scant explanation

- Using $\frac{d\Delta}{dp_T^2} = \Delta \frac{d\ln\Delta}{dp_T^2}$ we can write exactly

$$\Delta \frac{d\sigma_{\mathcal{S}}}{dy dp_T^2} = \hat{\sigma}_0 \frac{d\Delta}{dp_T^2} f_i f_j + \hat{\sigma}_0 \Delta \frac{d}{dp_T^2} (f_i f_j) = \hat{\sigma}_0 \frac{d}{dp_T^2} (\Delta f_i f_j)$$

- Integrating from $p_T = 0$ [$\Delta = 0$] to $p_T = m$ [$\Delta = 1$] gives the LO Boson rapidity dist^n:

$$\frac{d\sigma_{\mathcal{S}}}{dy} = \hat{\sigma}_0 f_i f_j$$

- Imagine we forgot the B-term in the Sudakov, we would not be able to make the exact differential and get

$$\frac{d\sigma_{\mathcal{S}}}{dy} \simeq \hat{\sigma}_0 f_i f_j + \int dp_T^2 \frac{\hat{\sigma}_0}{p_T^2} \Delta \alpha_S B f_i f_j$$

- $1/p_T^2$ factor promotes integral from $O(\alpha_S)$ to $O(\sqrt{\alpha_S})$

MiNLO Mk2 3-slide scant explanation

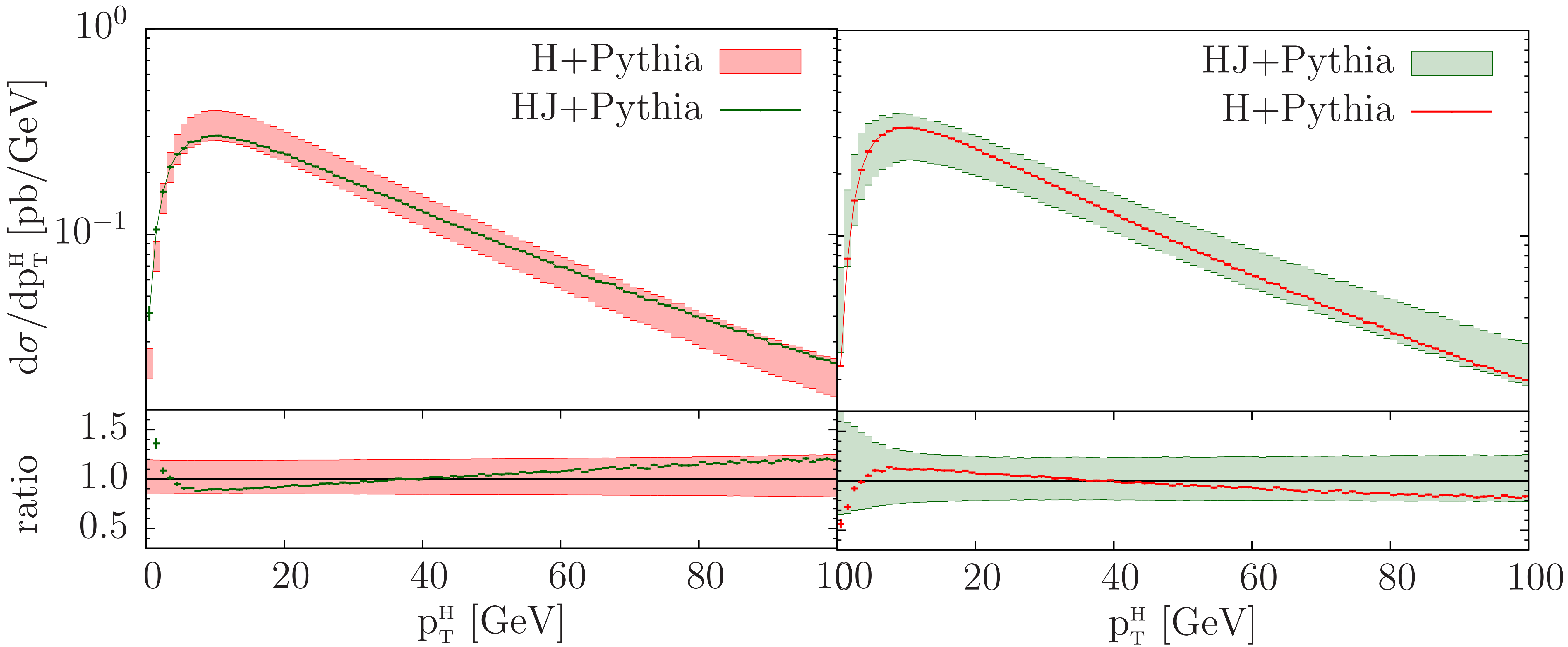
- By not having the B term in the Sudakov you get LO+O($\sqrt{\alpha_S}$) : this is not LO accuracy, LO + O(α_S) is.

- Message : for LO B+jet to give LO B-incl. Sudakov exponent must have same $f_i f_j$ singularities as what it multiplies, or you get leftover Sudakov junk in B-incl.

- Same thing holds at NLO level : mandates original MiNLO formulation be refined to include the NLO correction to the B term in the Sudakov.

- In MiNLO B+jet, on p_T integration, the Sudakov logs and PDF evol^n terms disappear leaving behind NLO B

Case study: NLO H vs MiNLO Mk2 HJ



- MiNLO HJ band widens at p_T ; approaching strong coupling
- H band not realistic as $p_T \to 0$; reflects tot. x-sec unc.
- Difference in shape as $p_T \to 0$ due to different Sudakovs: extra NNLL terms in MiNLO HJ, finite ones in Powheg H