Jets at LHC
-
a second look inside

Precision comparisons of predictions for Higgs boson + jet production at the LHC as a function of jet size
with A. Buckley, X. Chen, J. R. Currie, A. Gehrmann-De Ridder, T. Gehrmann, E. W. N. Glover, S. Höche, A. Huss, J. Huston, S. Kuttimalai, J. Pires, S. Plätzer, M. Schönherr

Determination of nonperturbative correction factors and their dependence on Monte Carlo modeling
with S. Kuttimalai

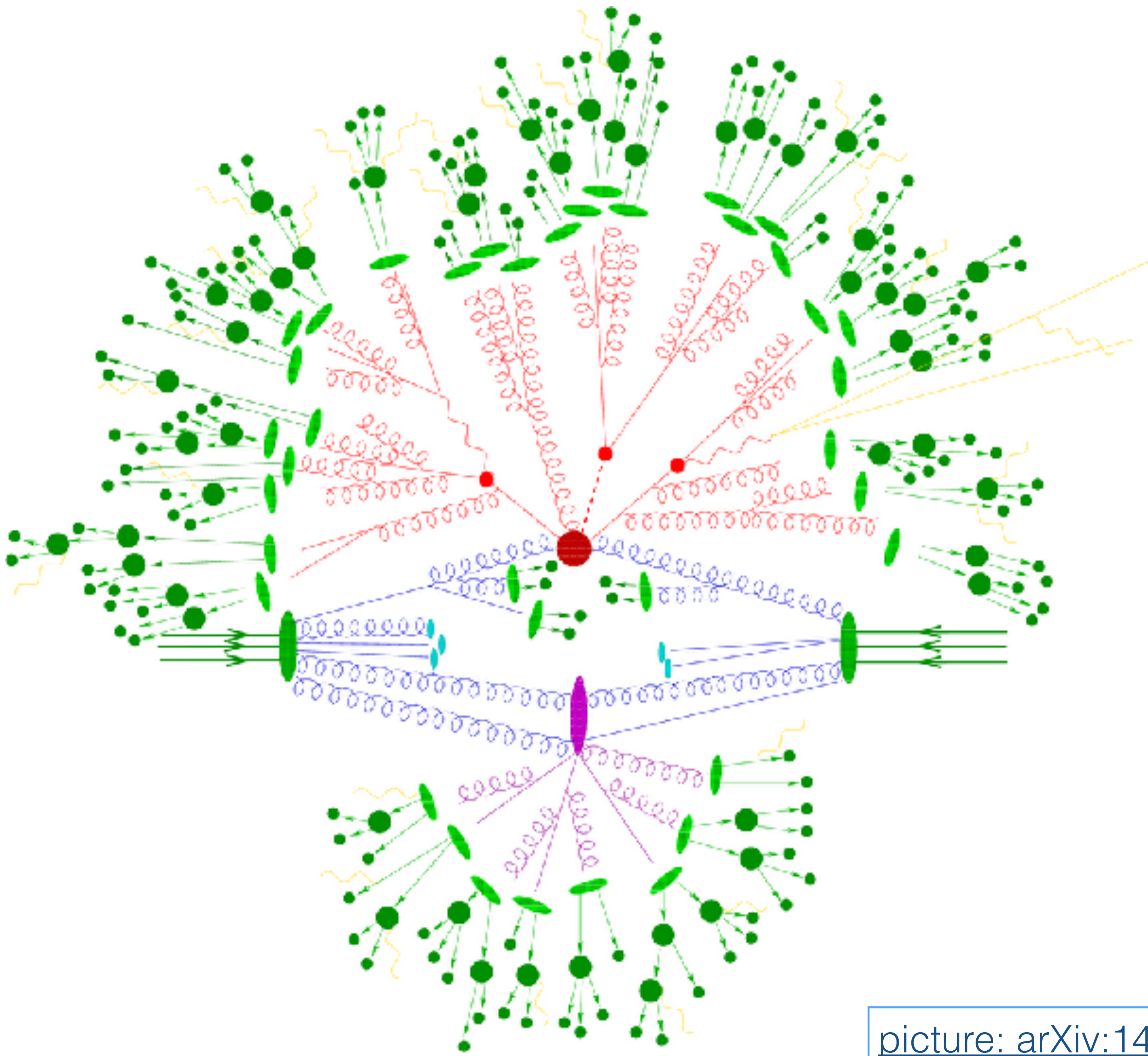
PISTA: Posterior Ion STAcking
with Ch. Bierlich

1. Motivation
2. NP-Factors
3. **R-dependence of Jets**
4. Extra: Z+J in PbPb

arXiv:1803.07977, arXiv:1807.01291 and further studies

J. Bellm (Lund U.), LoopFest, MSU, 16.7.2018

Motivation



picture: arXiv:1411.4085

Motivation

UW/PT-92-01
DOE/ER/40614-16
August 1992

Jets at Hadron Colliders at Order α_s^3: A Look Inside

Stephen D. Ellis
Department of Physics
University of Washington, Seattle, WA 98195, USA
Zoltan Kunszt
Eidgenossosche Technische Hochshule
CH-8093 Zürich, Switzerland
Davison E. Soper
Institute of Theoretical Science
University of Oregon, Eugene, OR 97403, USA

PACS numbers 12.38, 13.87

Abstract

Results from the study of hadronic jets in hadron-hadron collisions at order α_s^3 in perturbation theory are presented. The focus is on various features of the internal structure of jets. The numerical results of the calculation are compared with data where possible and exhibit reasonable agreement.

We will use the formula:

$$\sigma = A + B \ln R + C R^2$$

A: R-independent
B: leading behavior for out-of-cone radiation
C: Uncorrelated emissions collected by jet.
(area, parts of ISR or MPI)

Phenomenology shortly after Dijets at NLO.

More than 25 years later we have:

- boost invariant Jet-Algorithms
- the LHC
- more control in parton showers (matching & merging)
- and NNLO

Let's we ask similar questions:

„First, how well does the dependence on the jet definition exhibited by the theoretical jet cross section match that of the experimental jet definition?

Second, how well does the internal structure calculated at order α_s^3 compare to the internal structure of experimentally observed jets? "

---> Les Houches 2017

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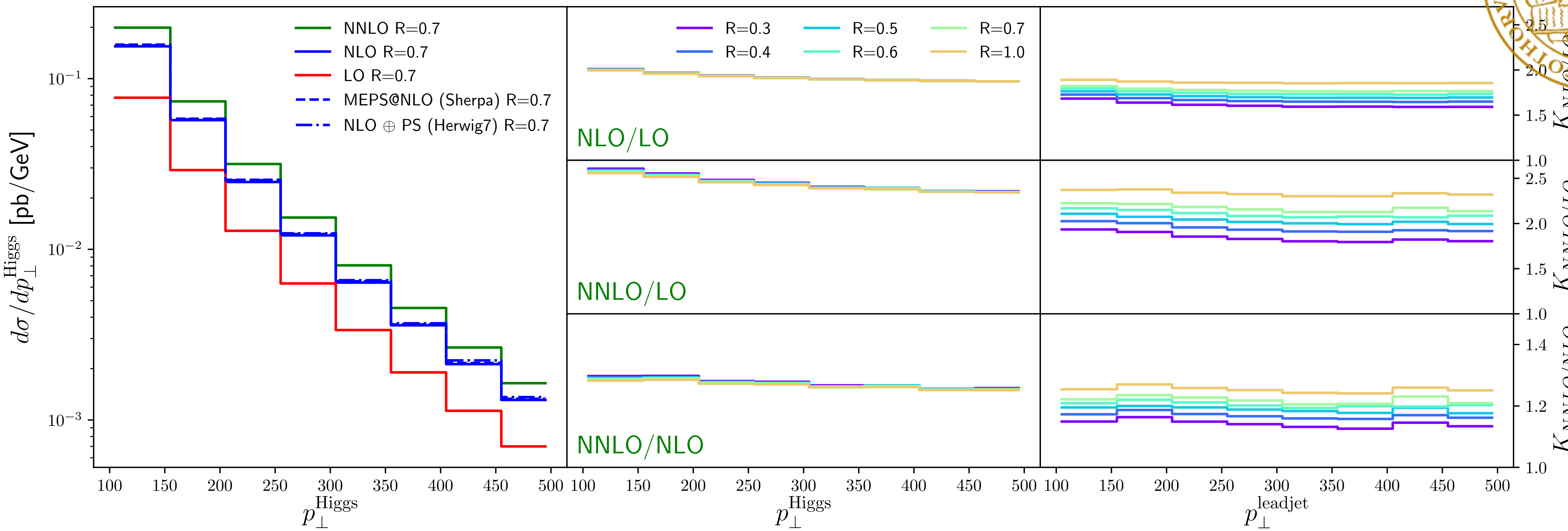
Let's we ask similar questions:

First, how well does the dependence on the jet definition exhibited by the theoretical FO jet cross section match that of the MC jet definition?

Second, how well does the internal structure calculated at order $\alpha_s{}^4$ compare to the internal structure of MC jets?

———> Les Houches 2017

Motivation



The goal is to compare:

- PS MC's matched or merged to NLO accuracy and complete events (PS/MPI/NP)
- FO LO/NLO/NNLO with high pert. accuracy, but 'jets' contain at most 3 partons.

Although no full events, FO can be used in many contexts (i.e. PDF fits)
if observable is inclusive defined.

Colourless object:
Study the objects cross section!! Either inclusive or at sufficiently high transverse momentum!!

Only coloured objects: Needs jet definition to compare to data and to define cross section.

Questions

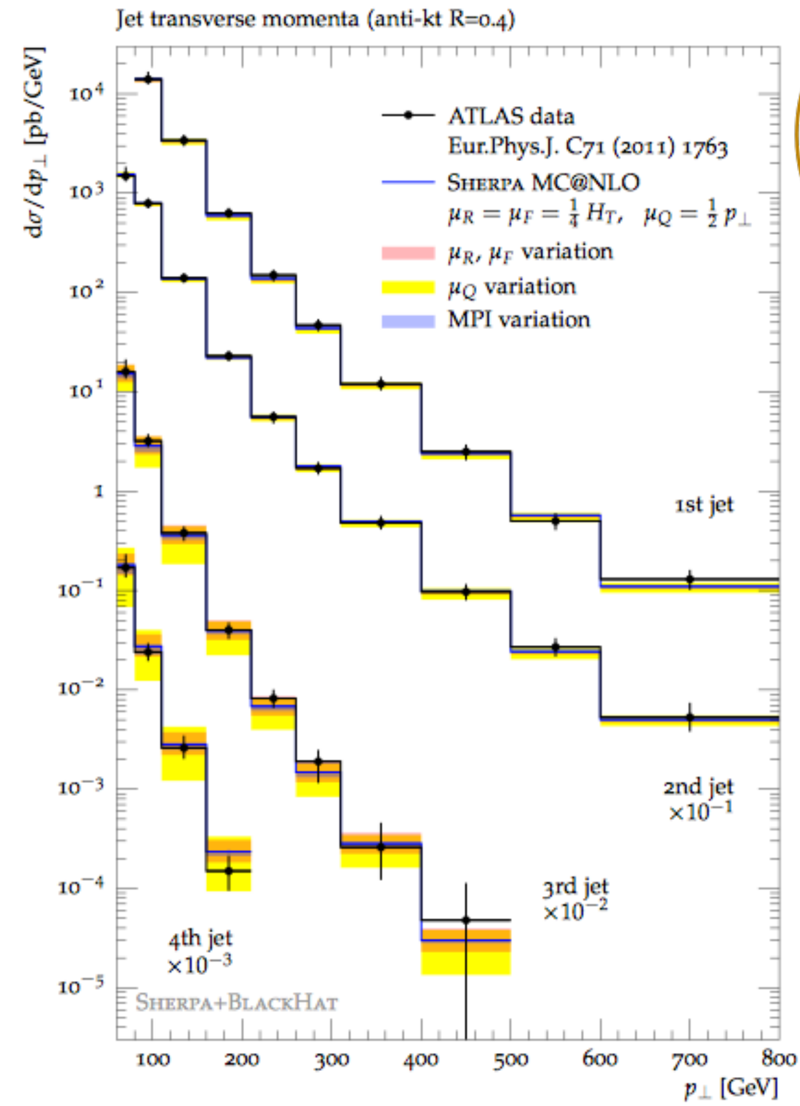
Can we use the Dijet NNLO to constrain PDFs?

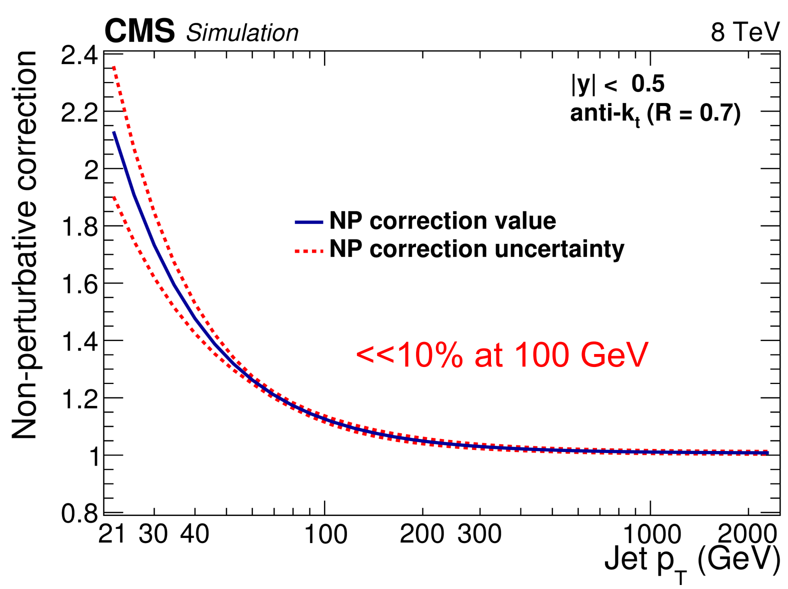
How R dependent are the cross sections at FO and MC level?

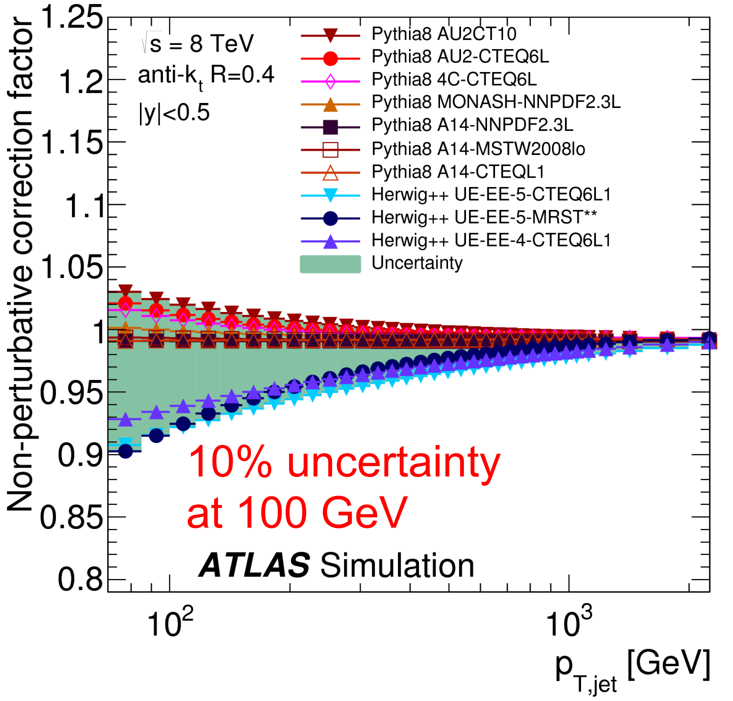
Are the observables we use stable?

Will scale variations give a realistic uncertainty estimate?

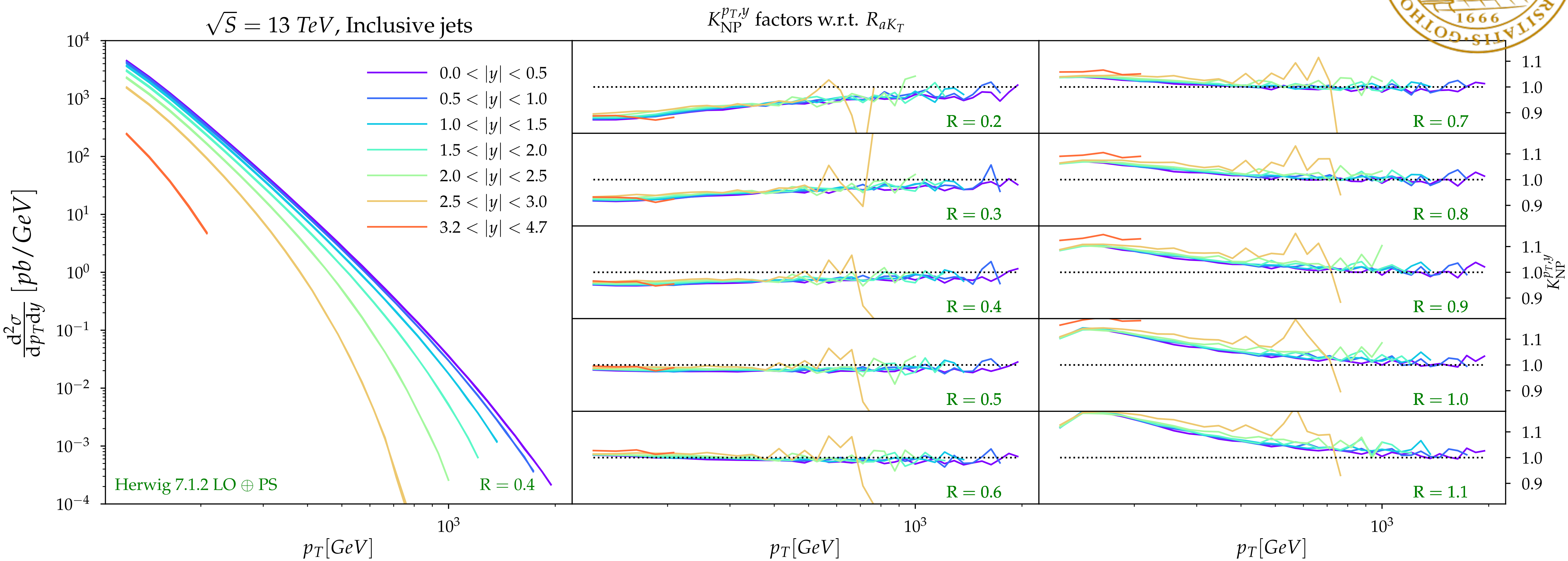
How will MC event generators react on similar input and comparable settings?





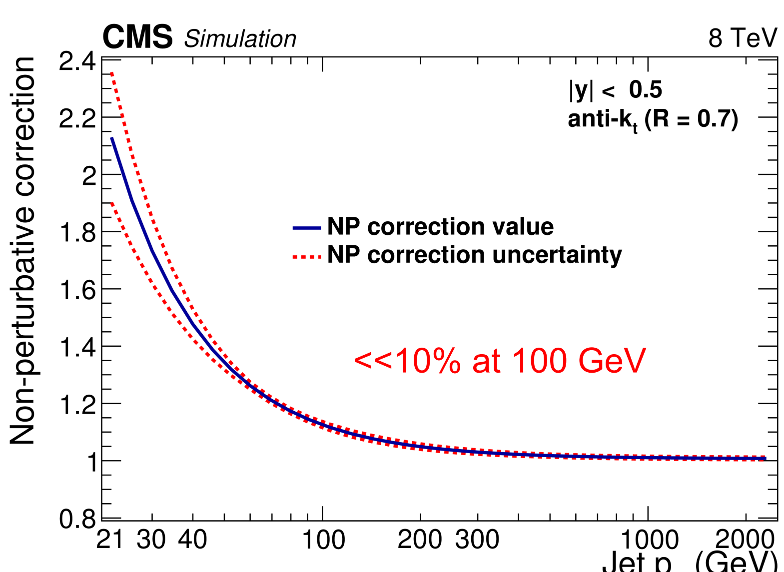


Example: NP-factors



– Observable as measured by CMS (Inclusive jets, double differential).

$$K_{\rm NP}^{\mathcal{O}} = \frac{d\sigma^{\rm PS+HAD+MPI} / d\mathcal{O}}{d\sigma^{\rm PS} / d\mathcal{O}}$$



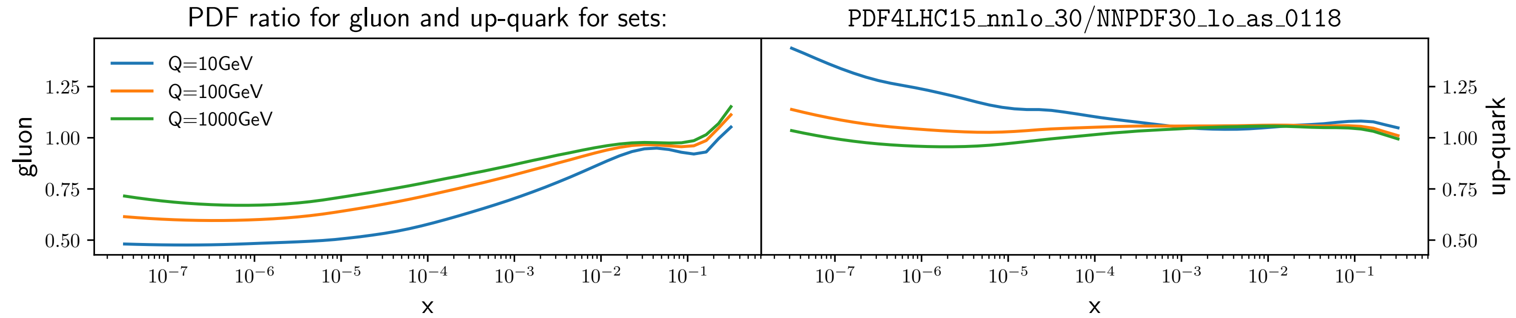
– Hadronisation: out-of-cone effect
– MPI: Uncorrelated addition ~ R^2

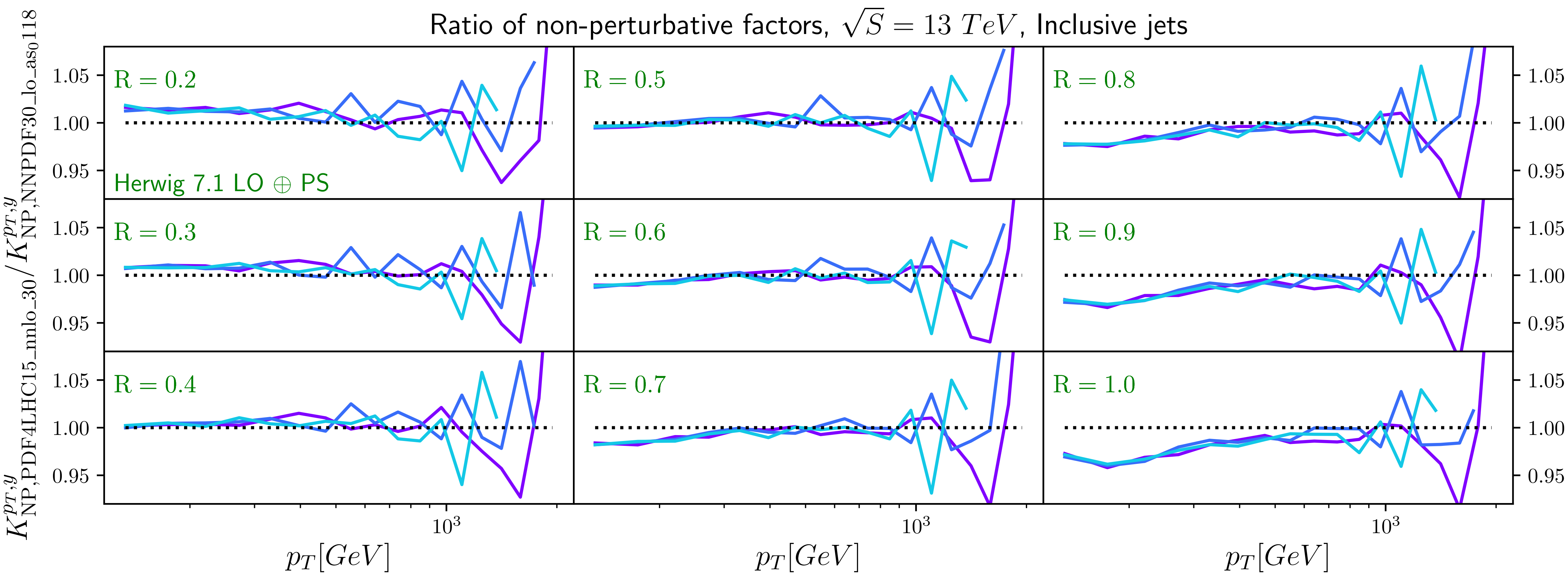
S. Ellis, Huston et al. 0712.2447

Dasgupta, Magnea, Salam 0712.3014

PDF-effects

If we measure/fit PDFs how will the PDF itself modify the NP-factor?
– Choose strongly different PDF sets (LO vs. NNLO)
– Small effect for small R –> FSR would lead to out-of-cone
– Visible (still small) effect at large R –> Less gluons == less MPI (or retune MPI)





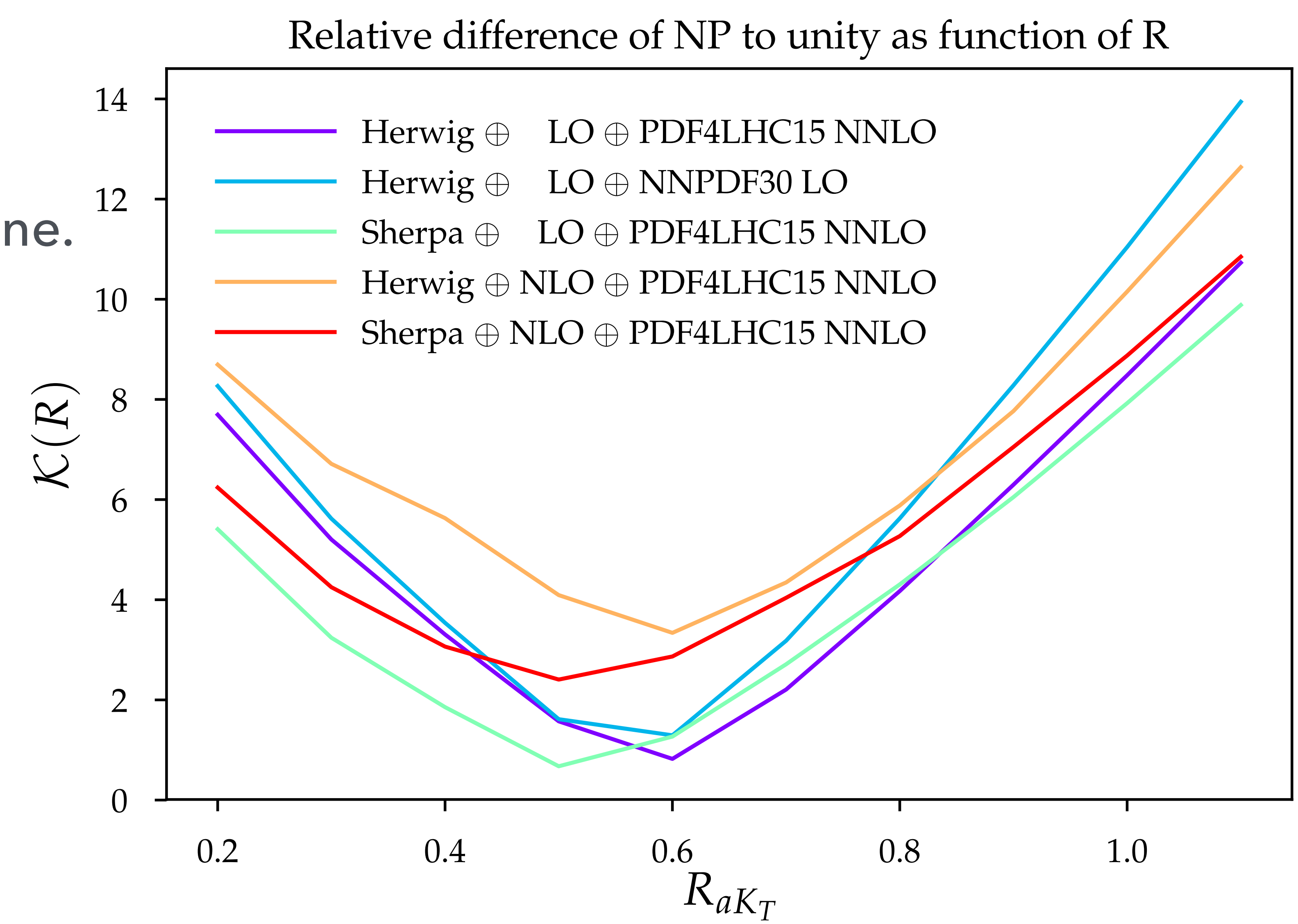
MC generator and higher Order

We can further test:
– generator dependence
– NLO stability
– find R such that NP-factors are close to one.

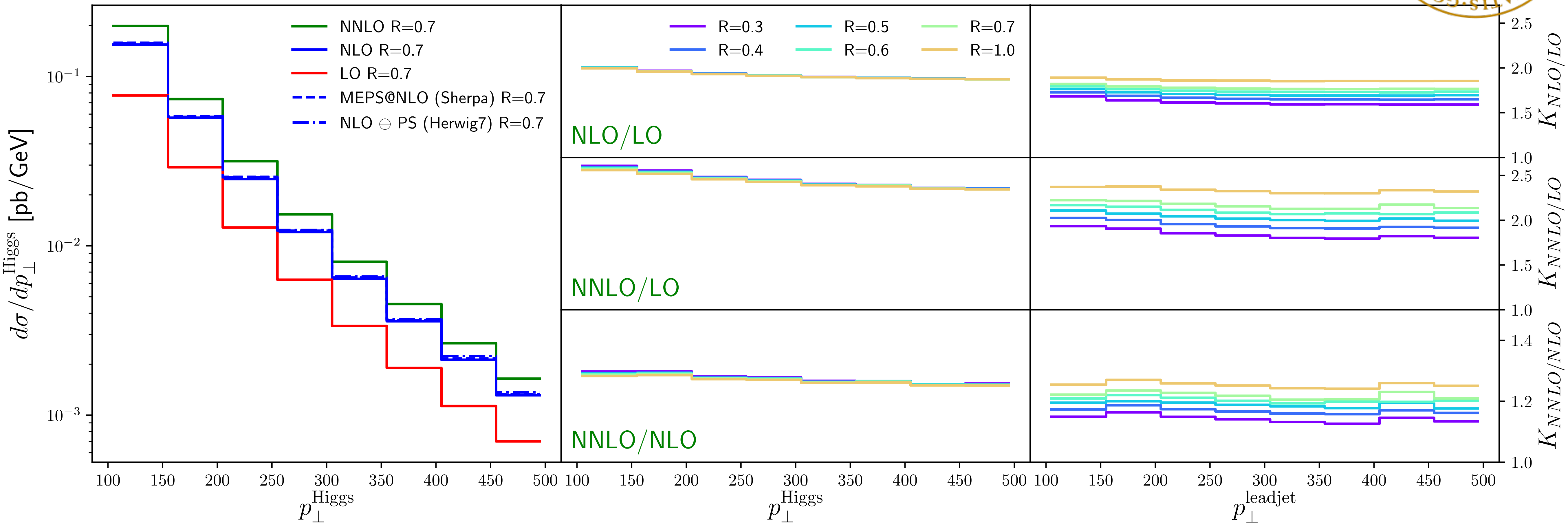
Plot:
Integrate difference of $K^{\mathcal{O}}_{\mathrm{NP}}$ and one.

Obvious questions:

What is he talking about?
Why at LoopFest?
Go to a NP physics workshop!
Give me Loops!!!



Higgs+Jet @ NNLO

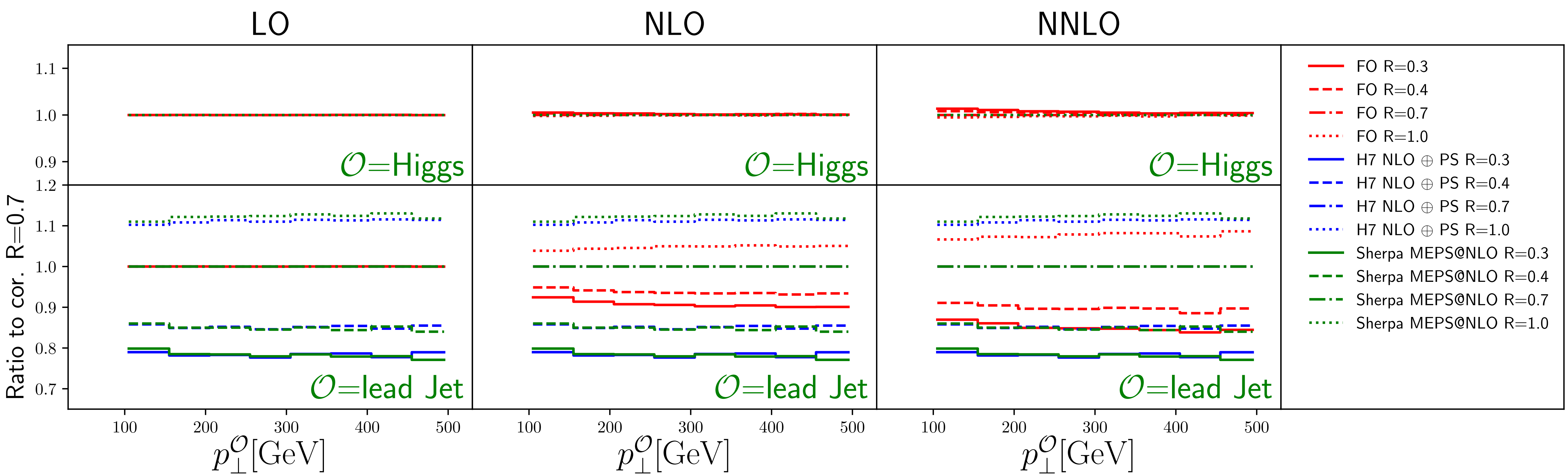


Idea: Use processes with electroweak bosons to study the first jet.

Compare fixed order (FO) and FO+PS results.

Later apply to dijets.

Higgs+Jet @ NNLO

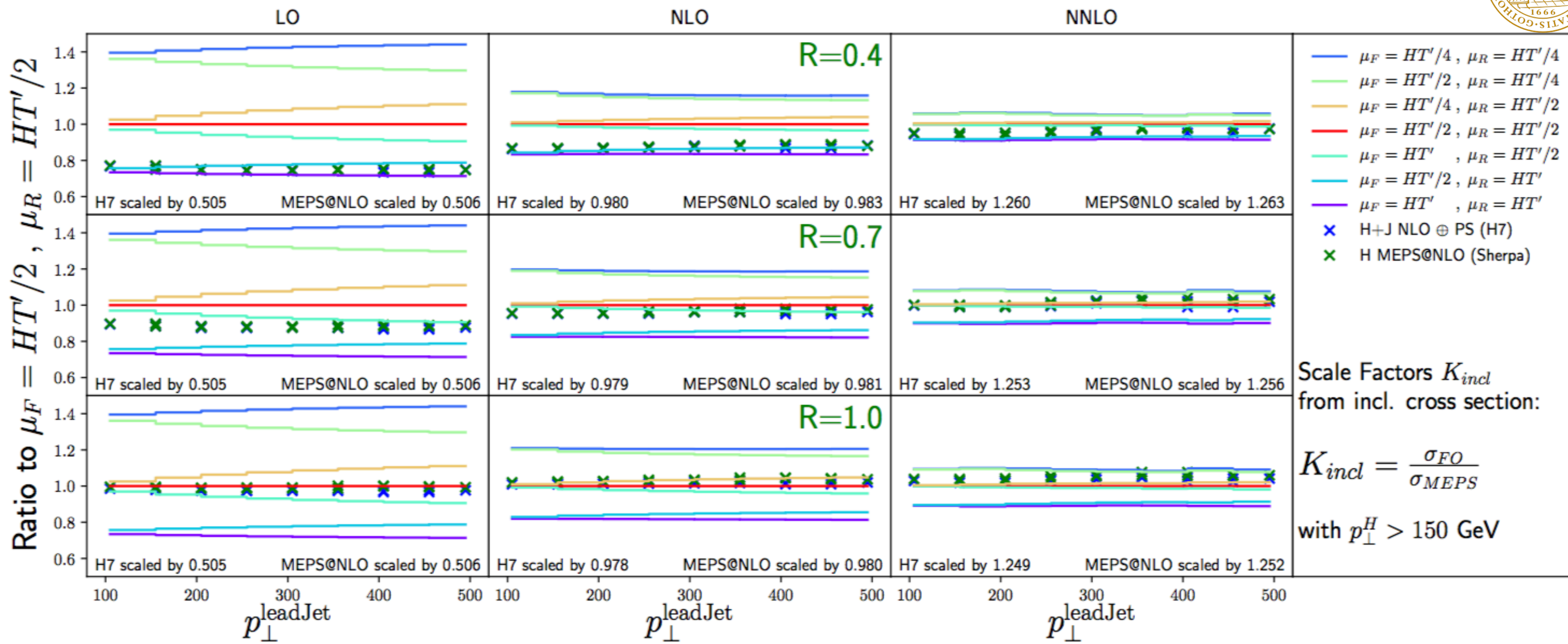


Observable: Higgs and leading jet transverse momentum.

Ratio of various R values w.r.t. respective R=0.7 at LO/NLO/NNLO.
Parton shower as reference.

As expected, the ratio of FO approaches the PS results (additional emissions).

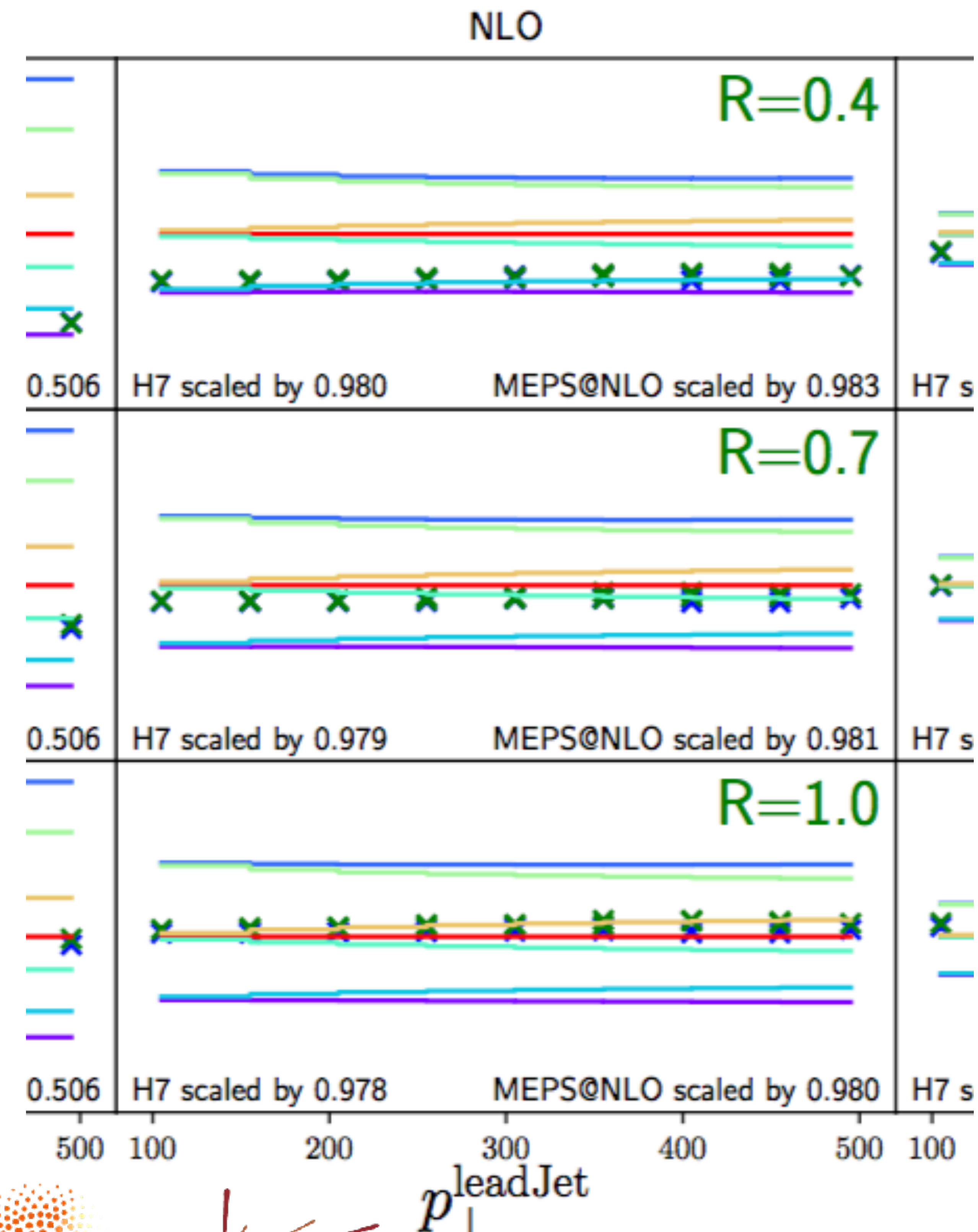
Higgs+Jet @ NNLO



We are interested here in modification of jets.
We use an incl. factor extracted from boson to rescale (pT > 150 GeV).

For various radii (commonly used 0.4/0.7) we can be at the edge of scale variations but better agreement with higher orders.

Higgs+Jet @ NNLO



Shower jets loose more transverse momentum for smaller R.
(out-of-cone radiation)

-> different jet shape between NLO and shower.

We observe a very flat behaviour ratio for different R.

Higgs+Jet @ NNLO

A standard observable to measure the R dependence is the integrated jet shape:

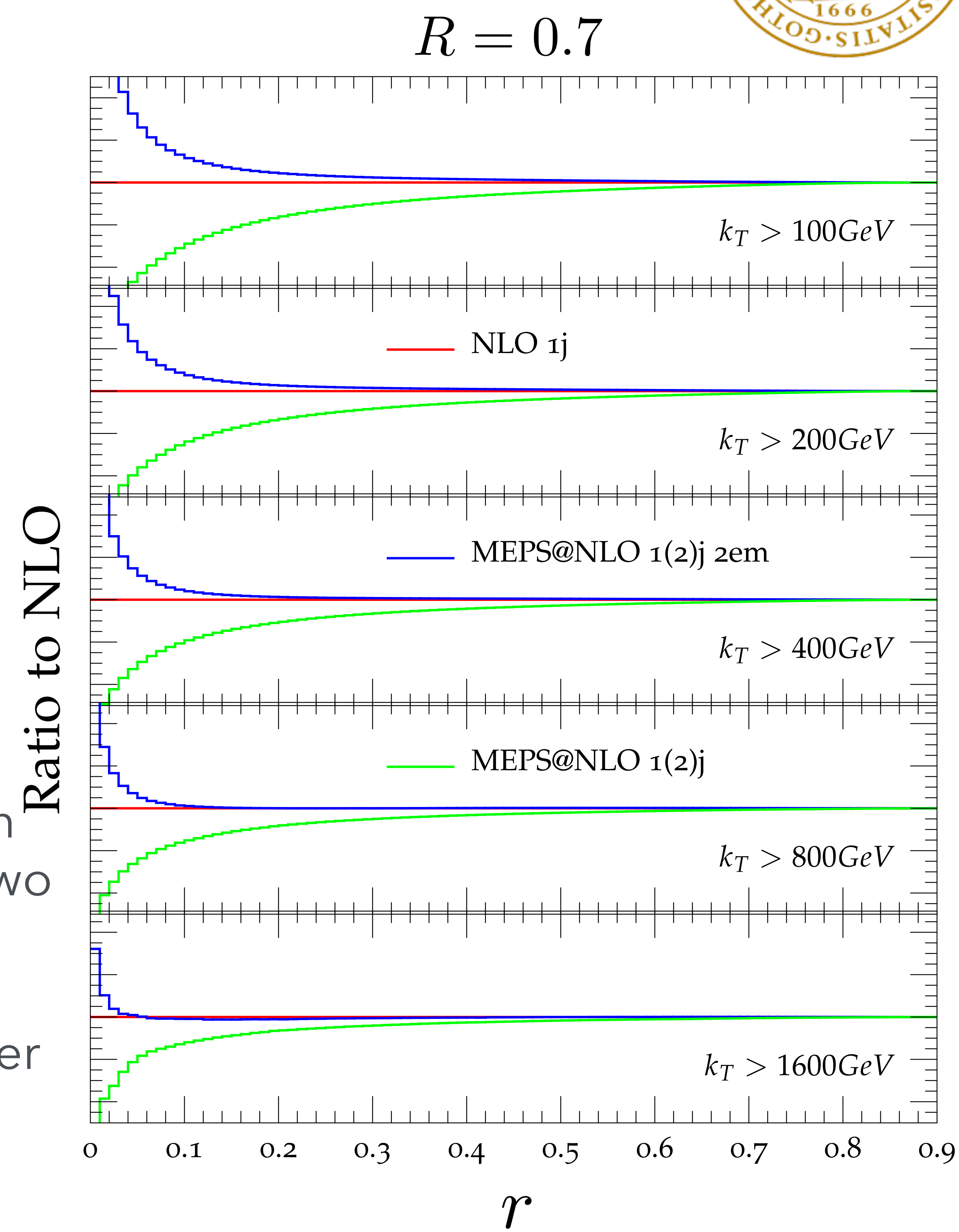
$$\Psi(r) = \frac{1}{N^{\text{jet}}} \sum_{\text{jets}} \frac{p_{\text{T}}(0,r)}{p_{\text{T}}(0,R)}$$

If all jets contain only one parton this observable is one.

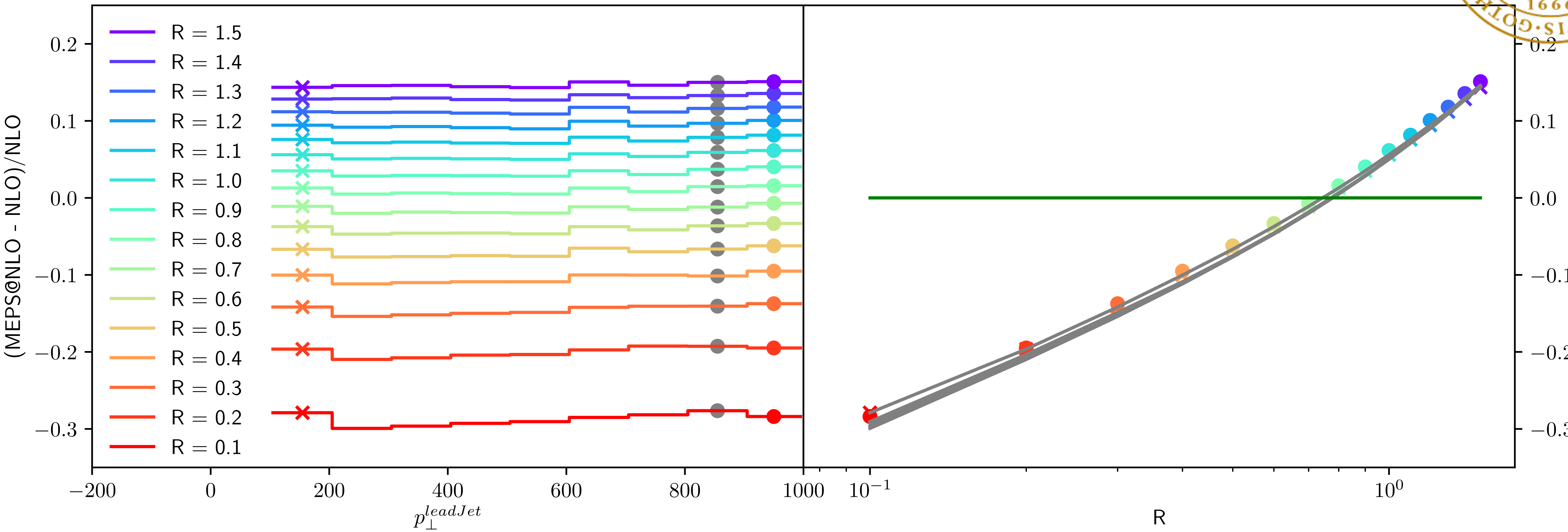
It measures the loss of transverse momentum as a function a smaller radius.

Here we compare NLO FO to the full merged result and a mimicking NLO shower result with limiting the number of additional patrons to two (counting from inclusive Higgs).

The mimicking contribution hits the NLO earlier and additional radiation is responsible for additional loss.



Higgs+Jet @ (N)NLO



Come back to flat behaviour in ratio PS vs. FO holds for large variety of R in Higgs*.

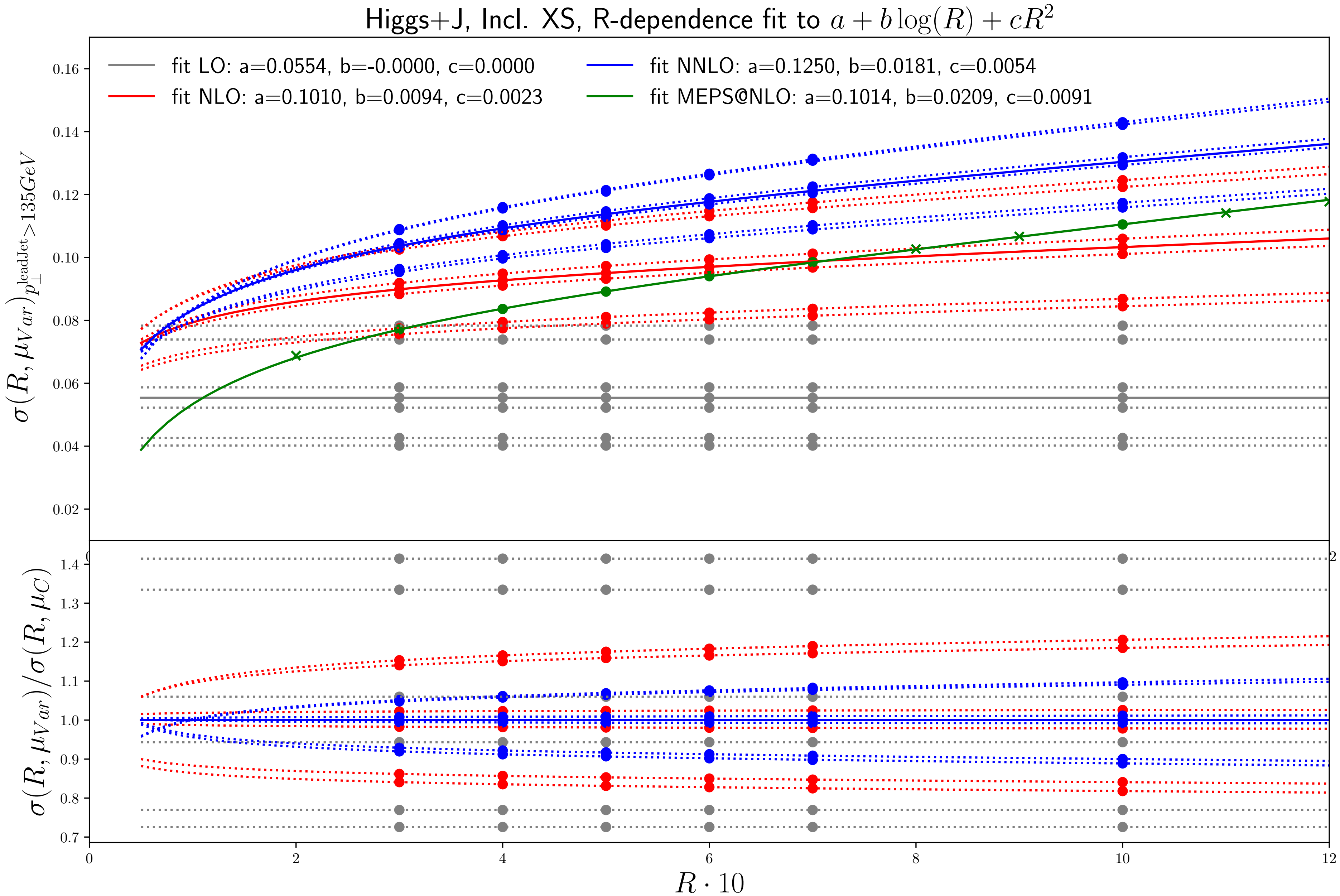
Here we plot difference normalized to NLO.

Right: different p_T^J-bins as function of R.

Difference minimal for R~0.7-0.8 as in old comparison for Jets in EKS.
Can be argued to have similar additional emissions out as in cone.

*Note: This is for EFT in NLO and PS.

Higgs +Jet @ NNLO

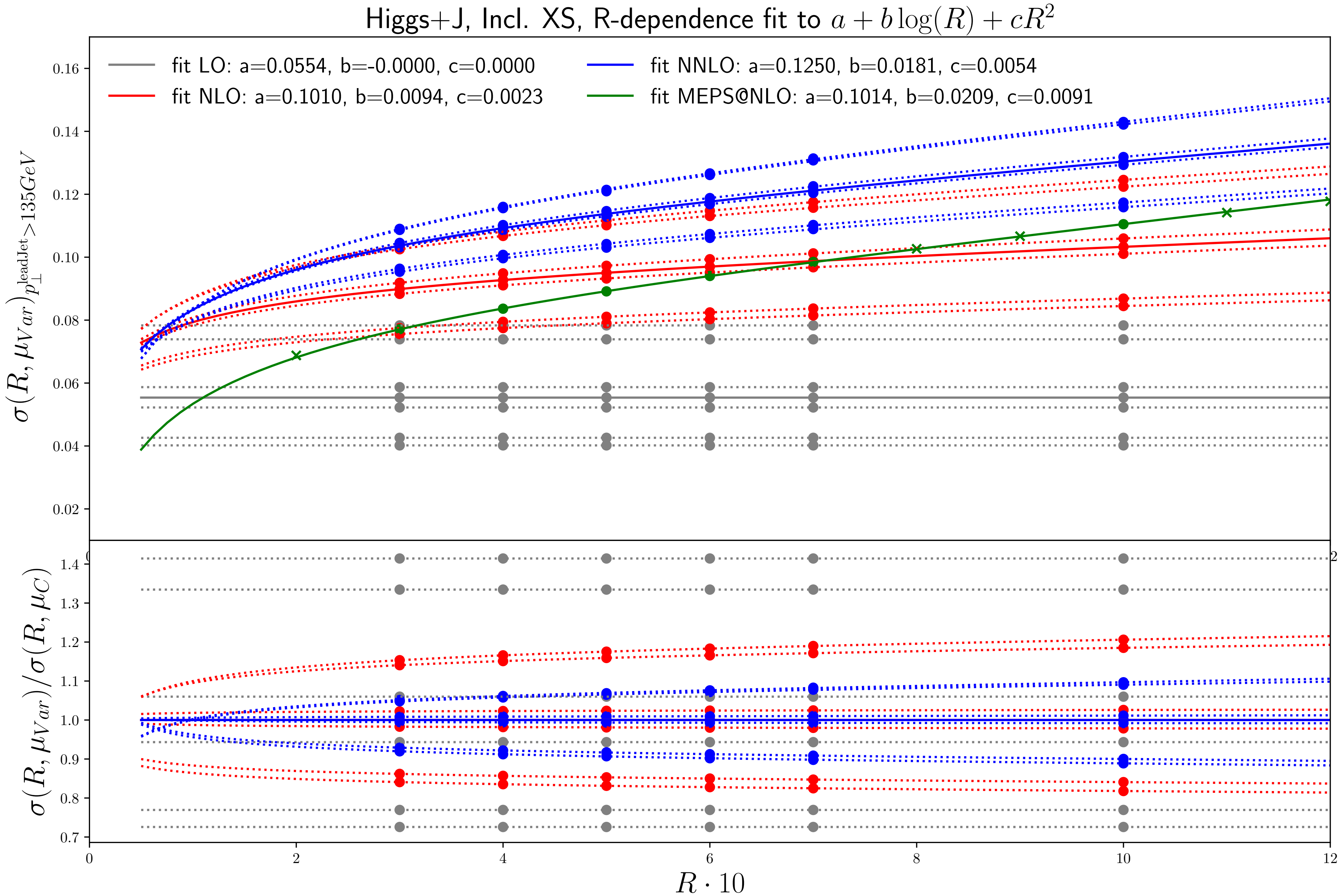


XS defined by cut on Jet.

Cut at $p_T^J(R)$ 135 GeV, above Higgs mass to exclude Higgs+PS scale setting issues.

Fit funktional form: $\sigma = A + B \ln R + C R^2$

Higgs +Jet @ NNLO

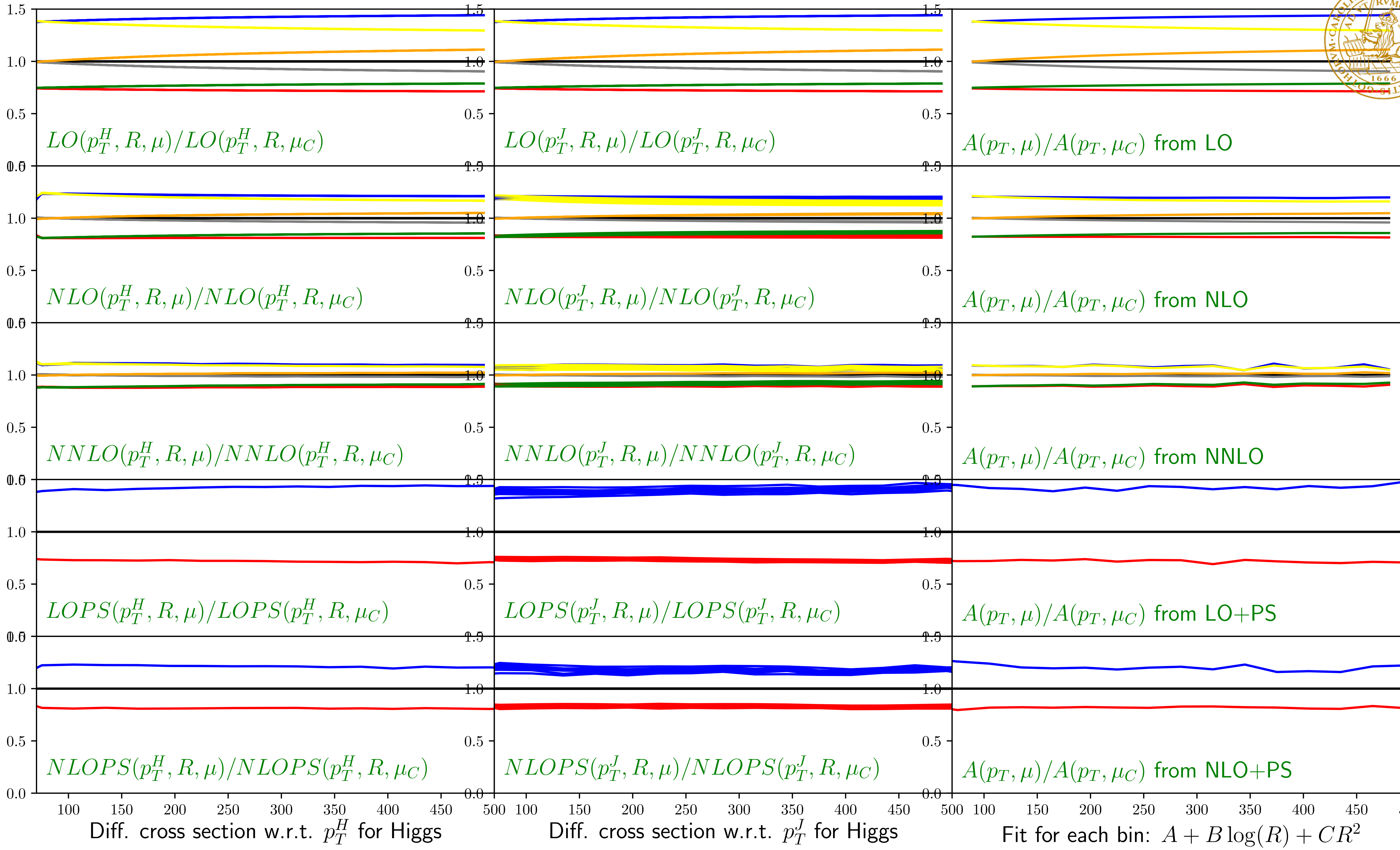


Note: Scale uncertainty grows with R, crossing for very small R

Same as "accidental" scale compensation in vetoed cross section? It is a vetoed XS!

R introduced a new scale. At NLO emissions outside of Jet are LO with monotonic μ_R dependence (same as LO only). Virtual parts with compensating μ_R-dependence stay in cone. Virtuals should compensate for LO scale dependence, not the out-of-cone of real emissions. Varying R therefore can lead to "accidental" scale compensation.

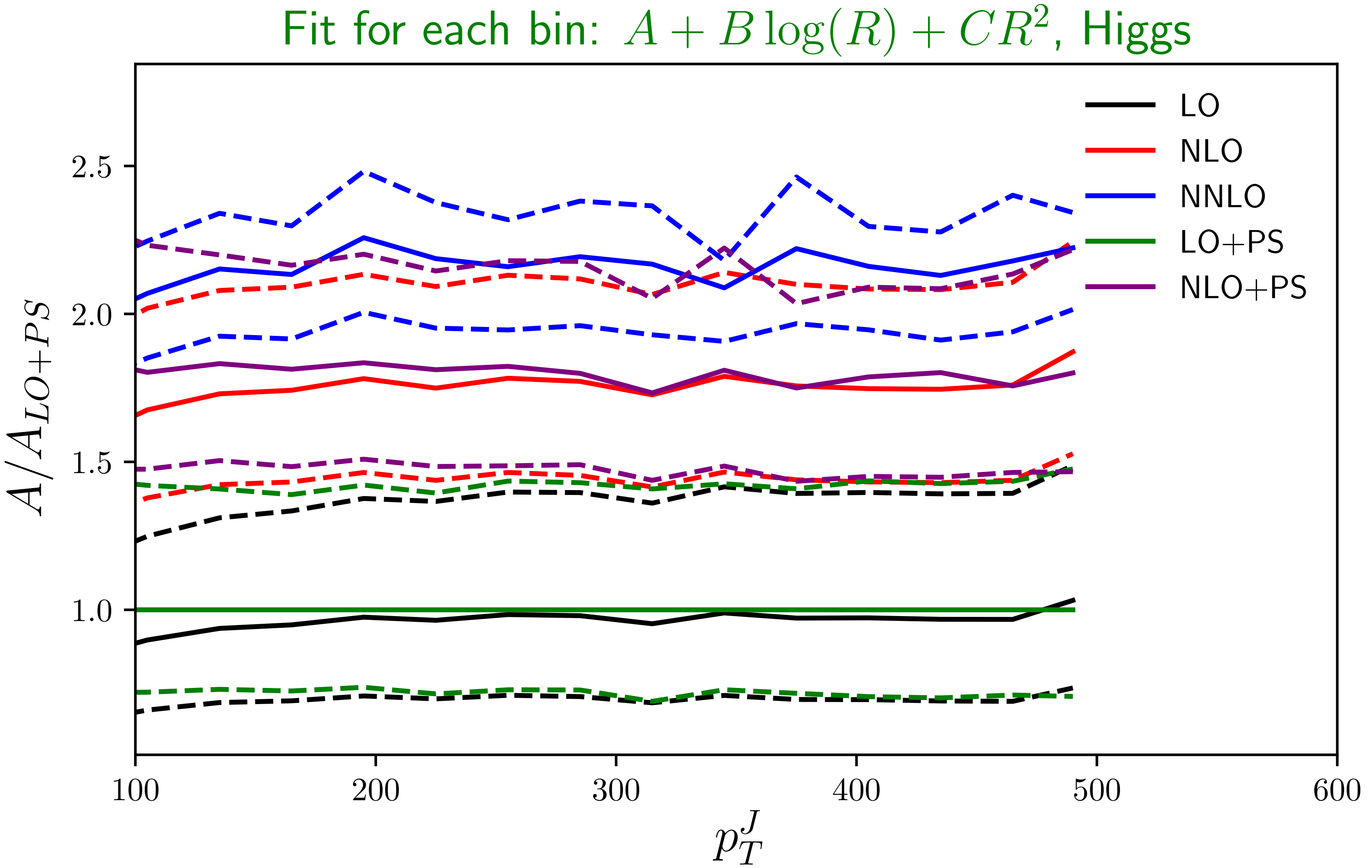
Similar to Stewart,Tackmann 1107.2117



Fit funktional form: $\sigma = A + B\ln R + CR^2$ now differential in p_T^J.

Recover scale dependence of Higgs ($\mu_C = p_T^J$).

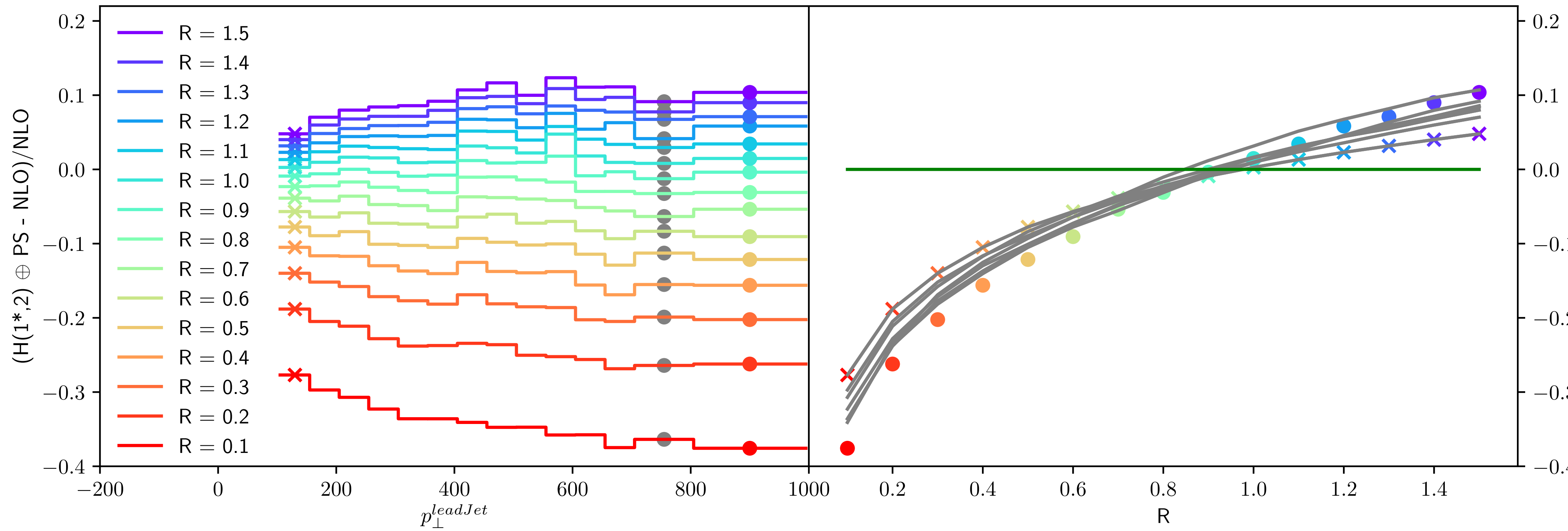
Higgs+Jet @ NNLO



While “A” is already defined at LO, “B“ and “C“ appear a NLO.

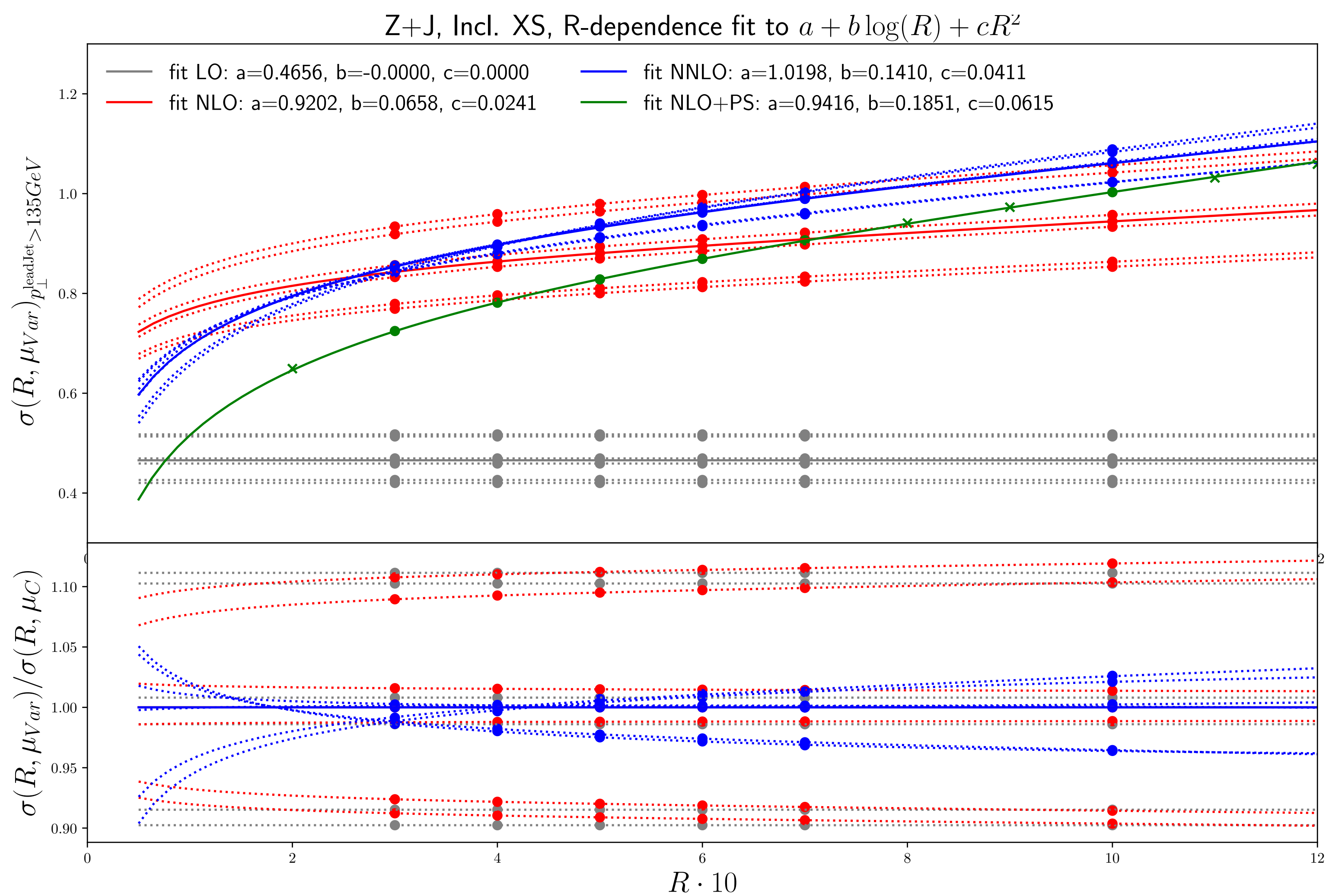
Not just scale dependence is restored, also absolute values with and without PS are comparable!

Z+Jet @ NNLO



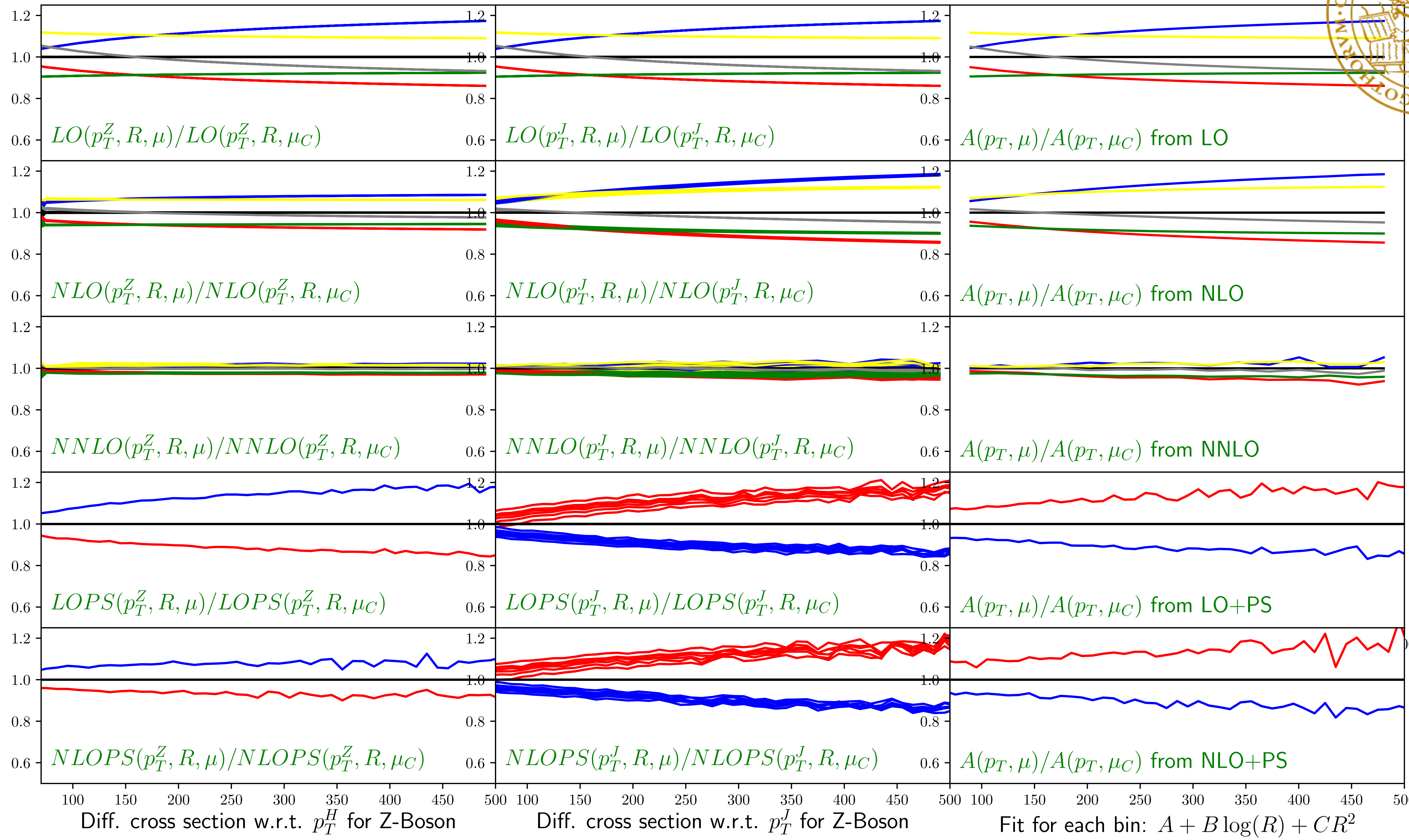
Same game, different process!!

- Not as flat!
- Still good fit to a,b,c parametrisation.



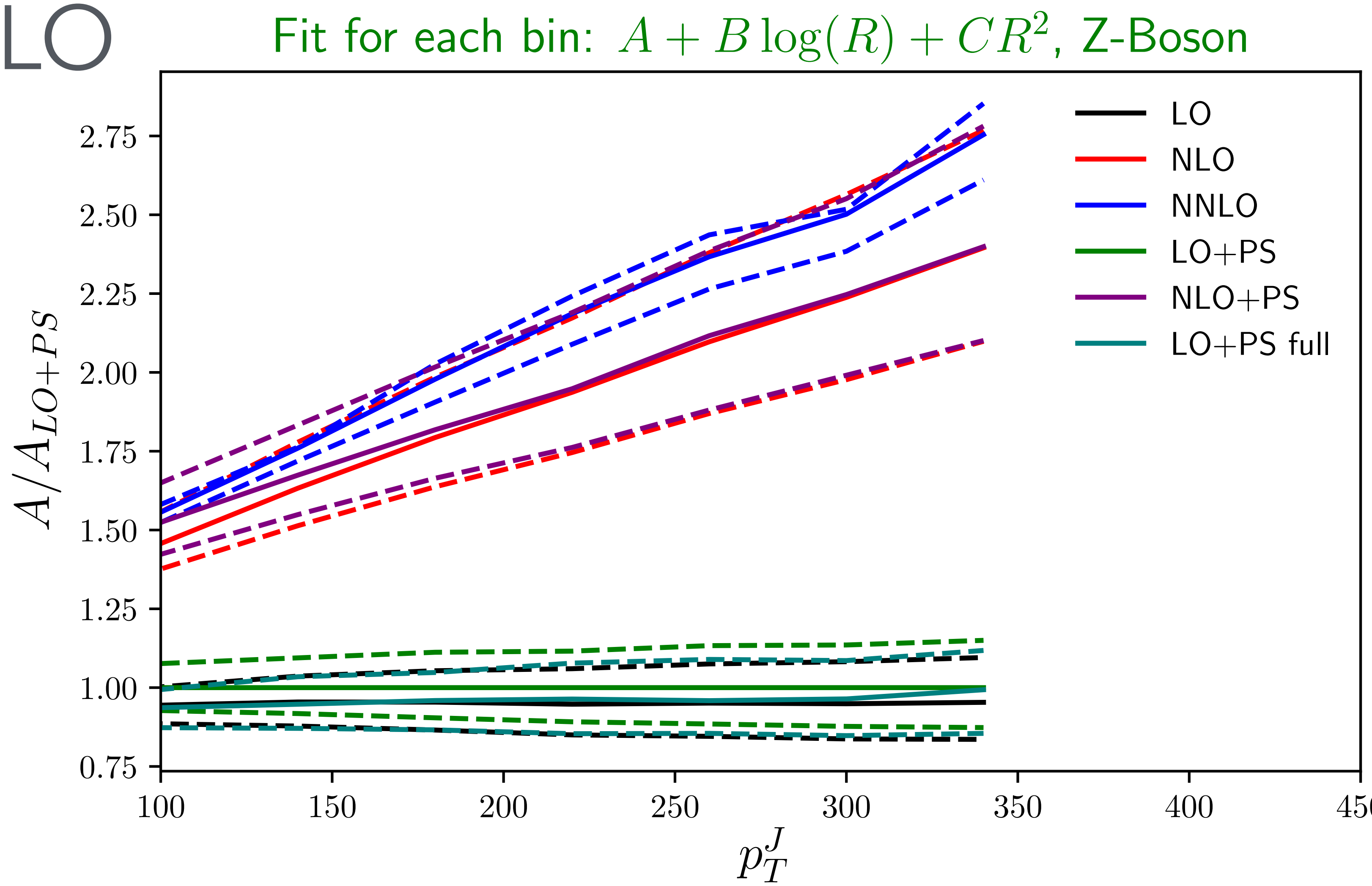
J. Bellm (Lund U.), LoopFest, MSU, 16.7.2018

Z+Jet @ NNLO



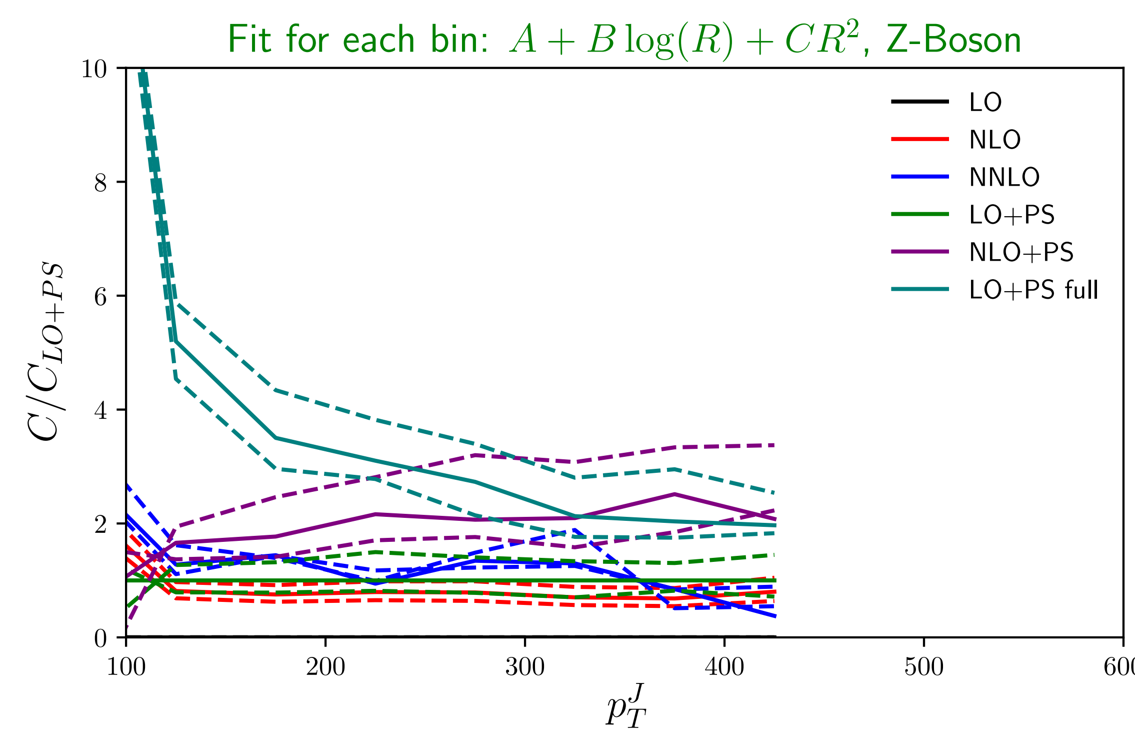
- H vs. Jet pt show different scale uncertainties
- Indicates new important contribution.

Z+Jet @ NNLO



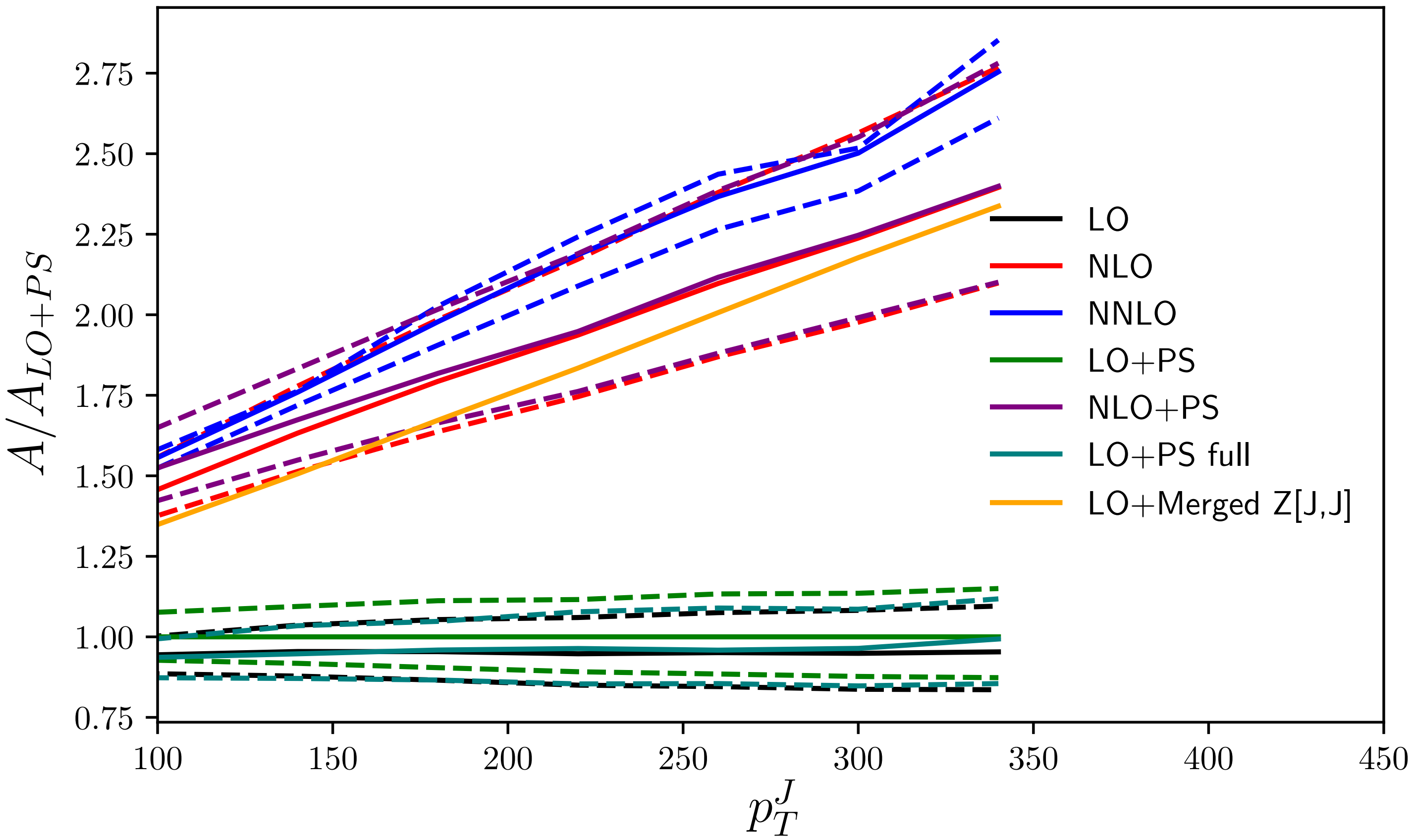
Same game, different process!!

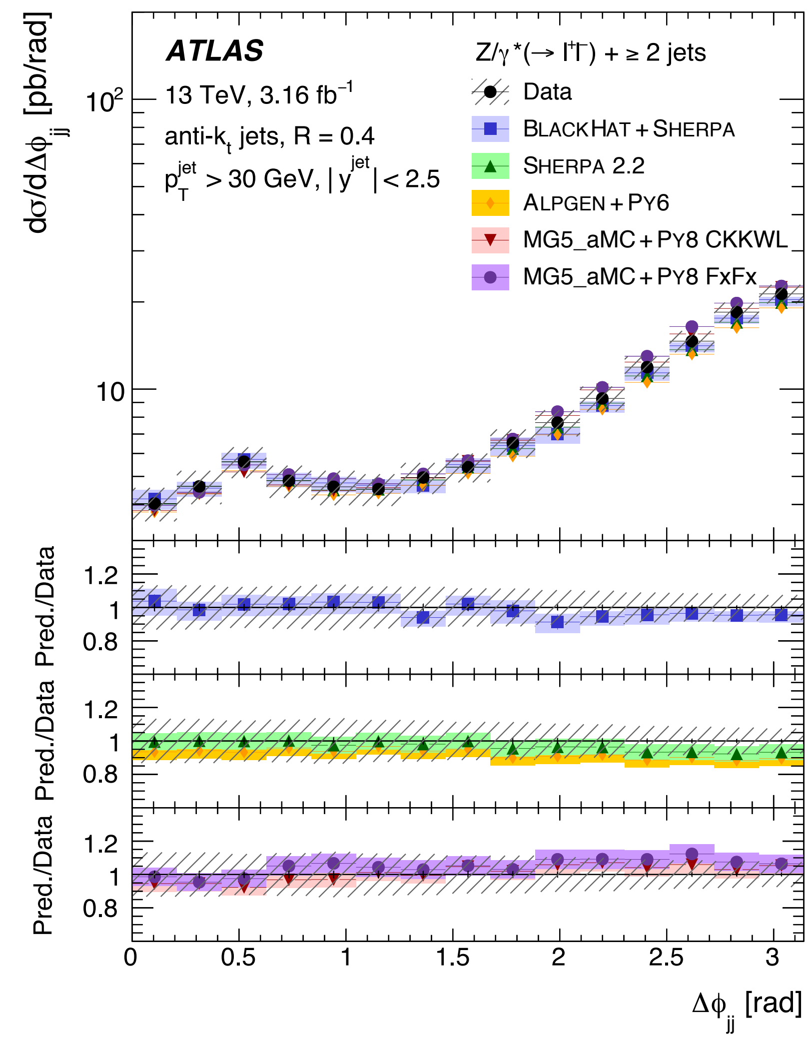
- No flat K-factor for "A"!
- Still LO vs. LO+PS and NLO vs. NLO+PS very comparable.
- Moderate from NLO to NNLO.
- Also including MPI and hadronisation is stable
- "C" compensates MPI for small p_T^J (MPI ~ R^2)
-



Z+Jet @ NNLO

Fit for each bin: $A + B\log(R) + CR^2$, Z-Boson





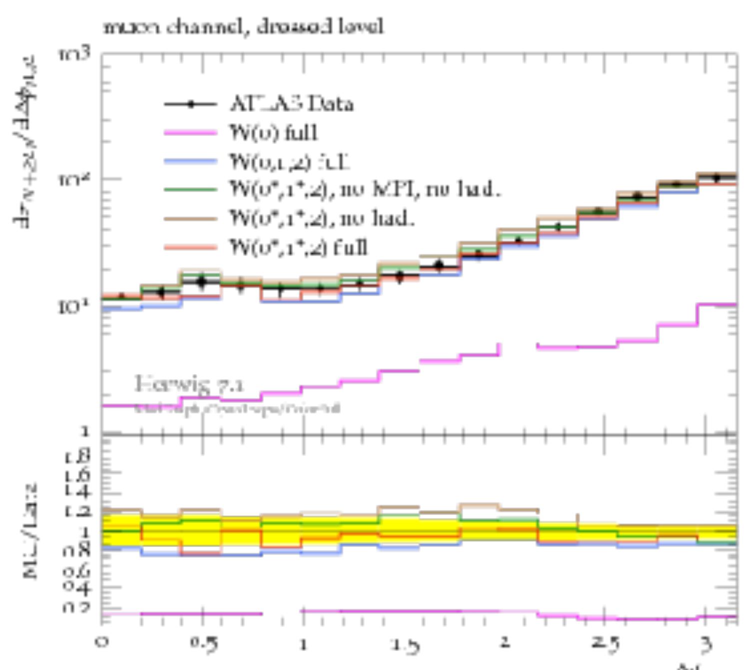
LO merging Z+ZJ+ZJJ = Z[J,J]
shows similar behavior by adding
„unordered“histories (not PS-like).

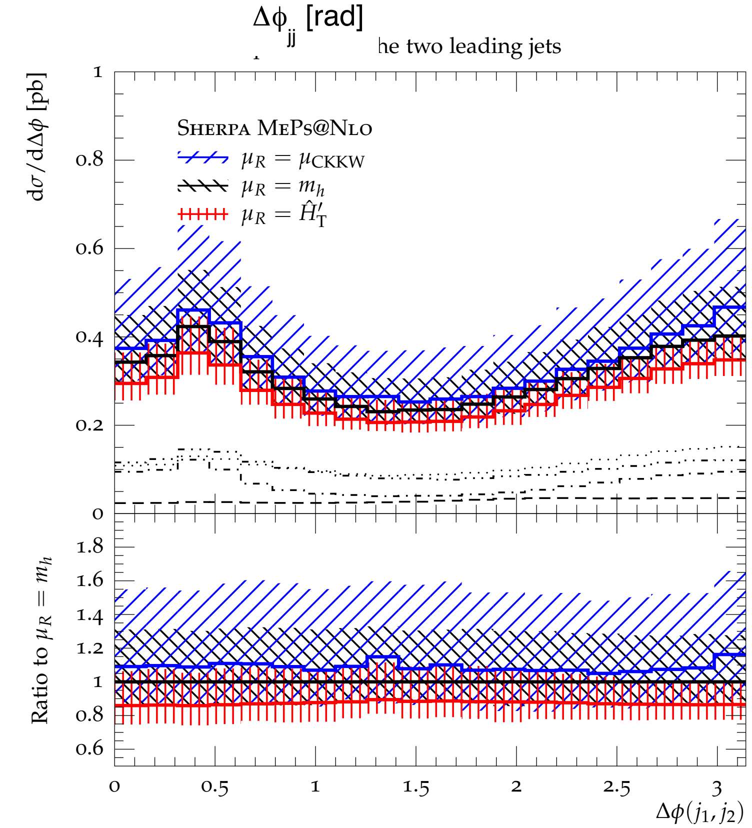
Mainly back-to-back with soft boson.

Might consider additional cut on

$$r = p_T^Z / p_T^J$$

-> new uncertainty





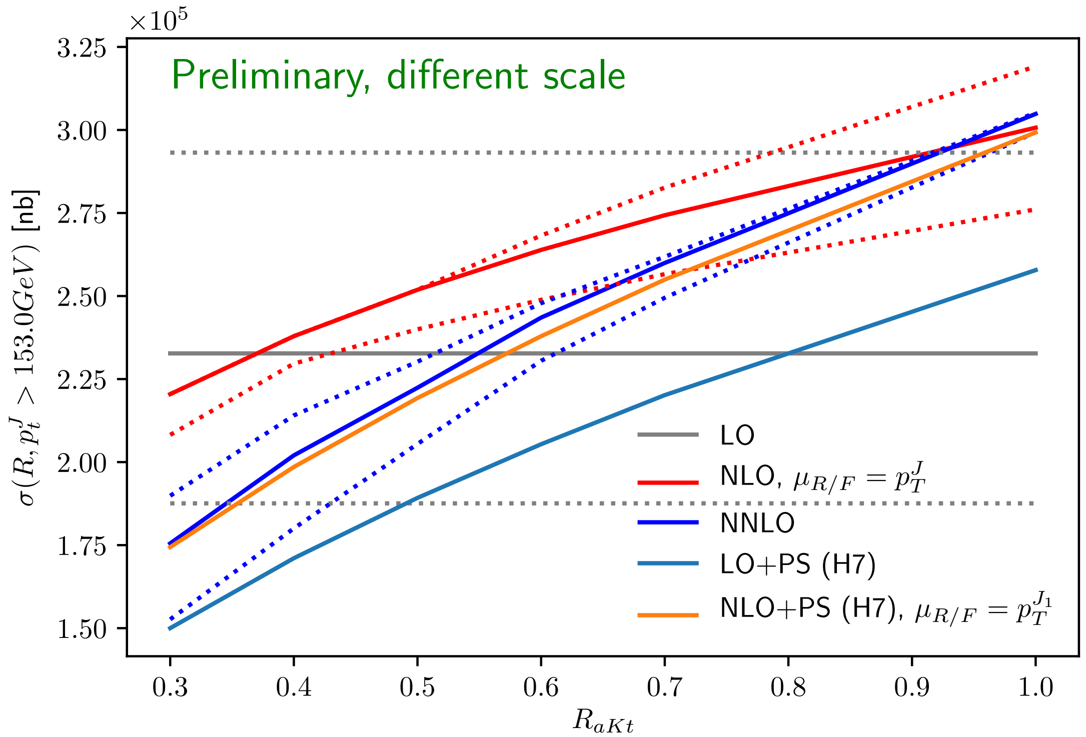
Jets @ NNLO

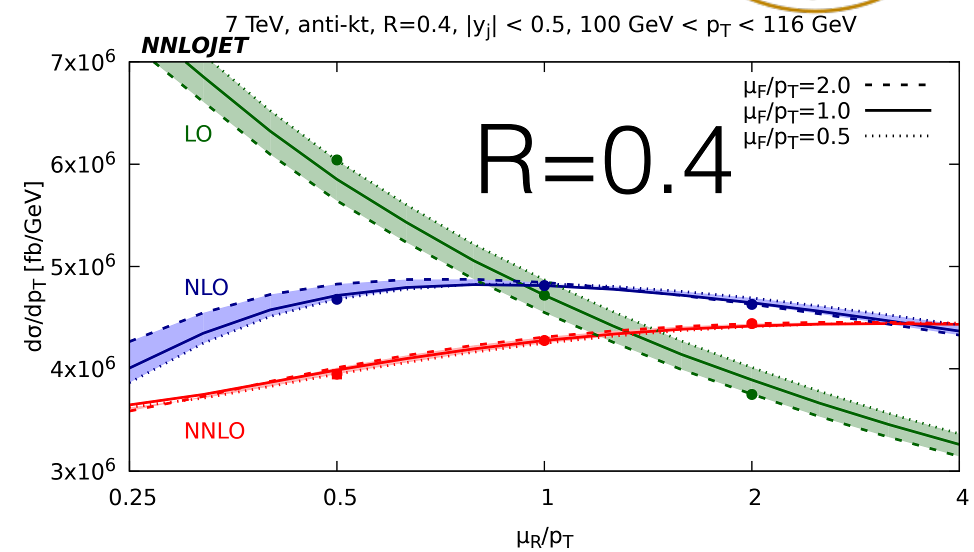
Same game, different process!!

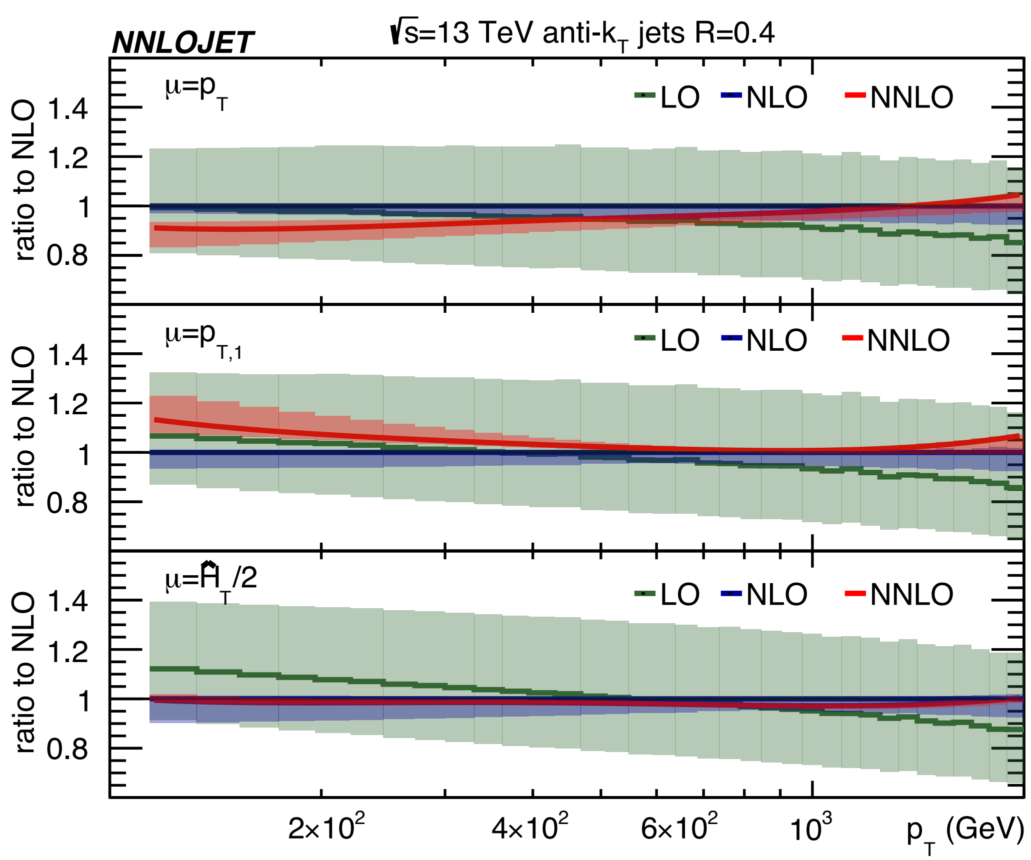
Different scale in NNLO (miscommunication)

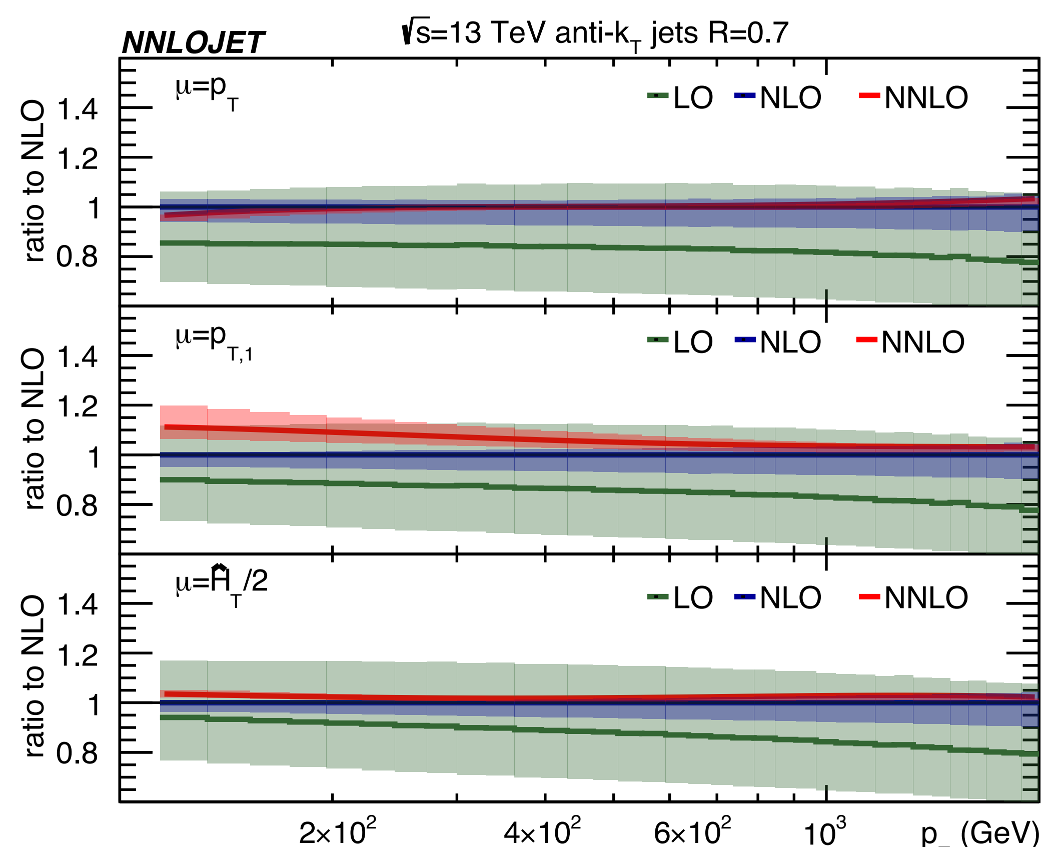
Scale variation are R-dependent

NLO: small R
NNLO: large R



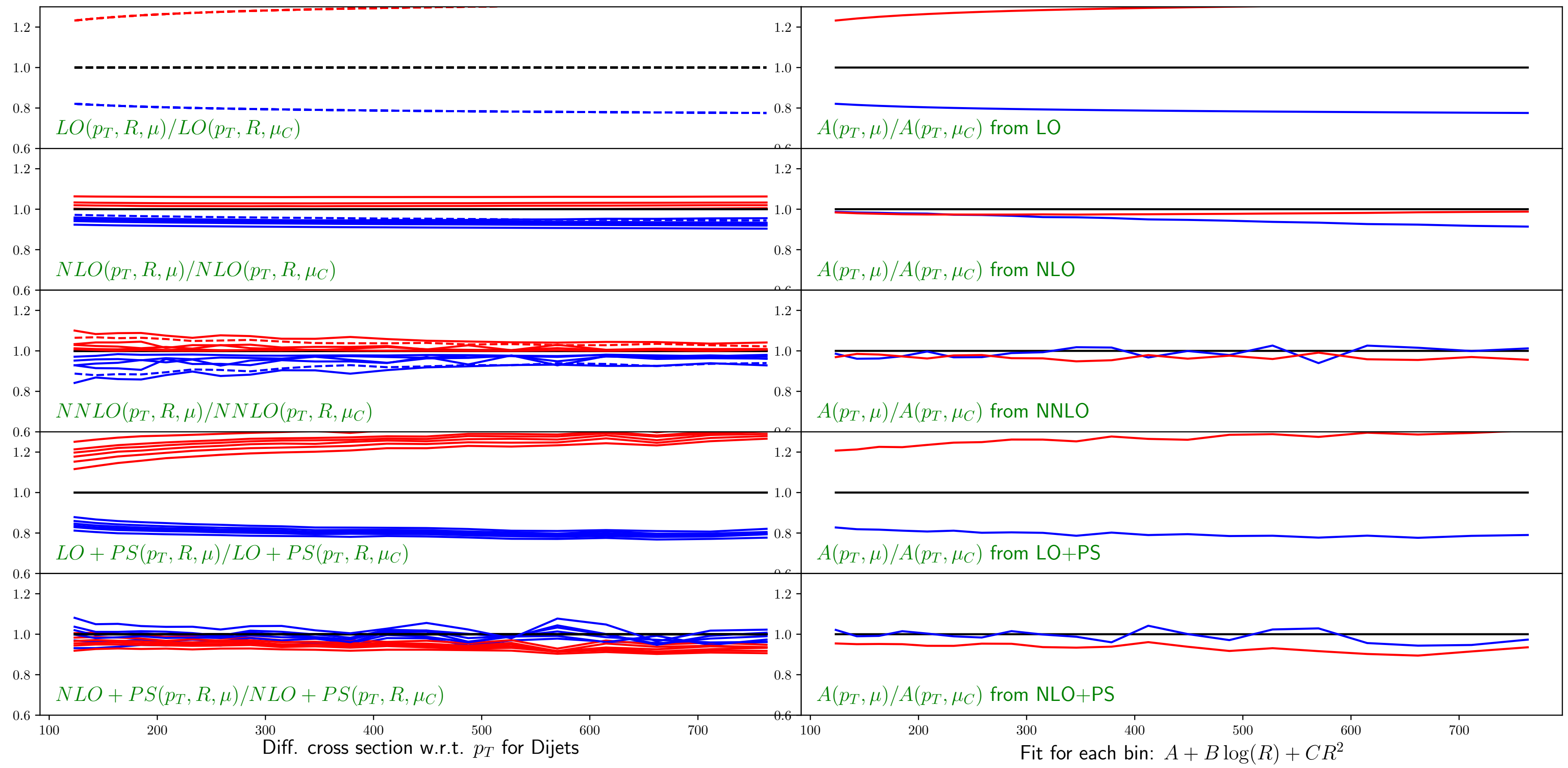






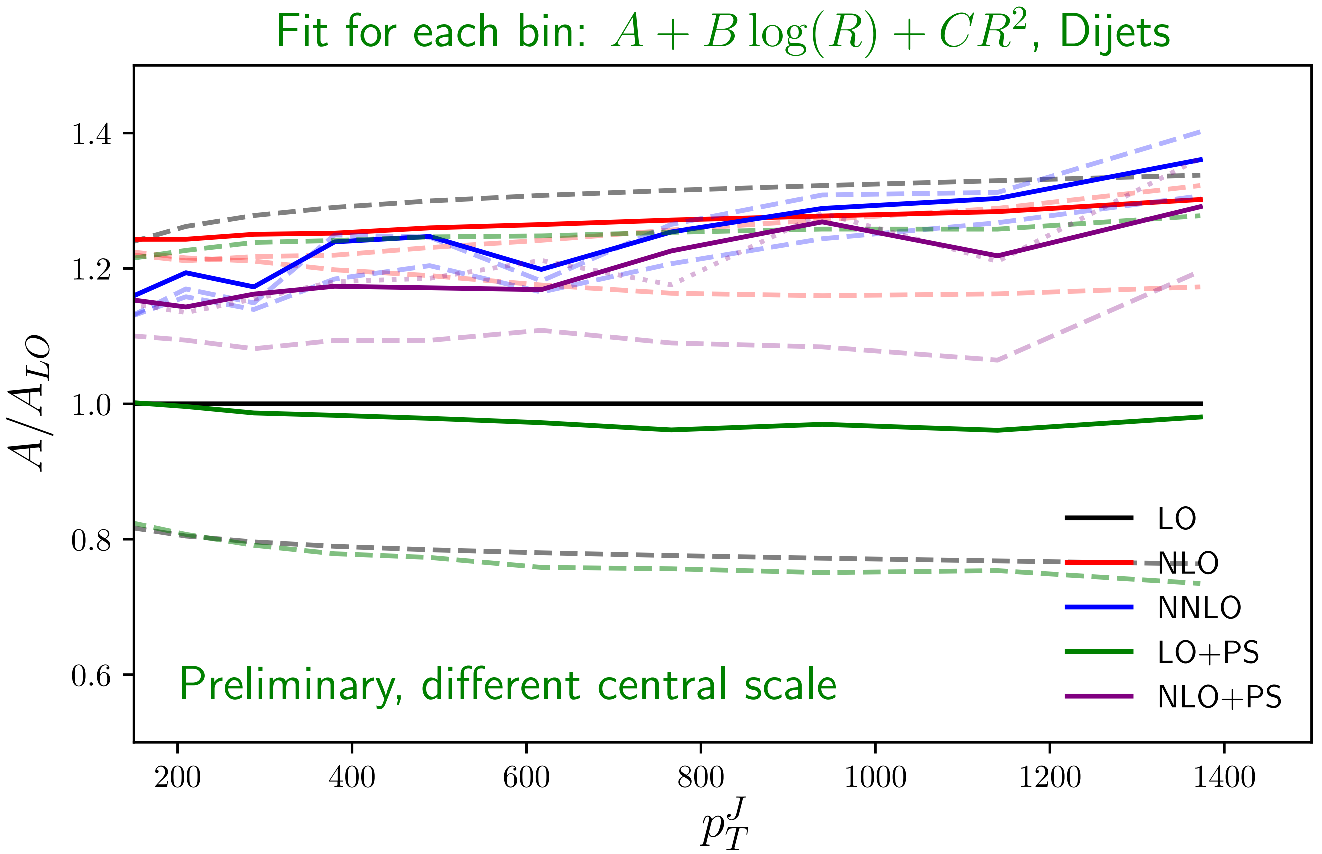
NNLOJET 1807.03692

Jets @ NNLO



Same game, different process!!

- Dashed line is R=0.4
- At LO+PS recover scale uncertainty band of FO
- Again NLO+PS and NLO comparable K factor
- Good perturbative convergence.



Heavy Ion @ LoopFest

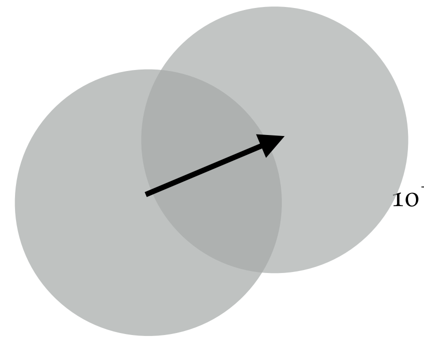
At the end:

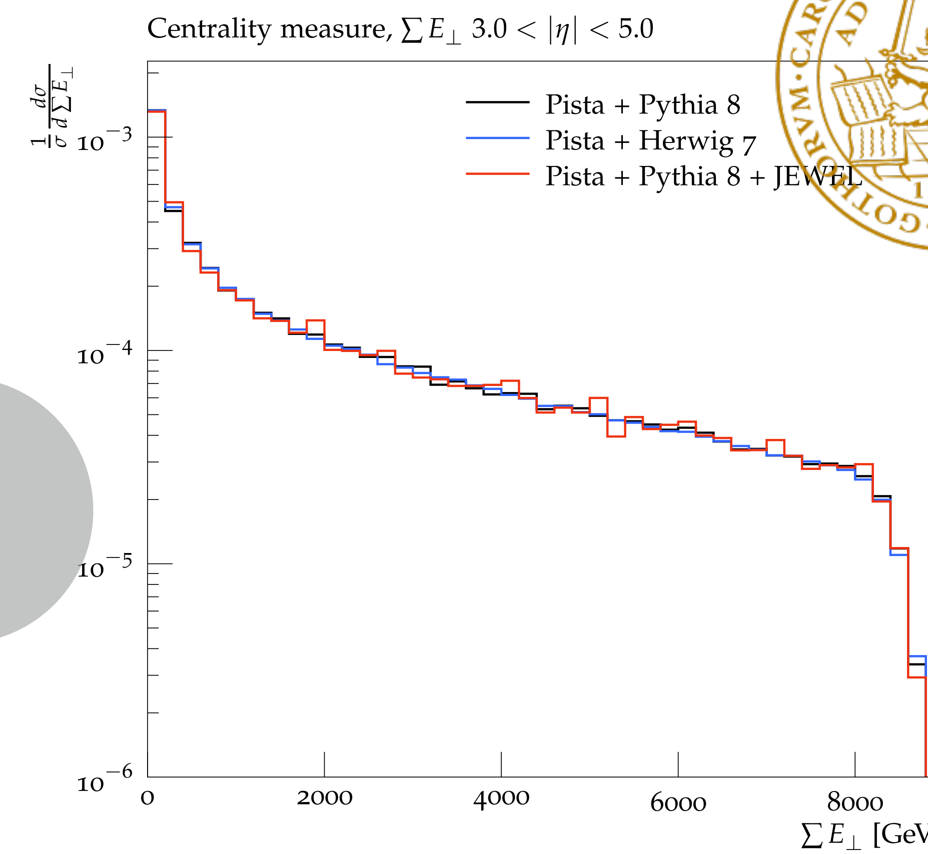
So much about R-dependence.

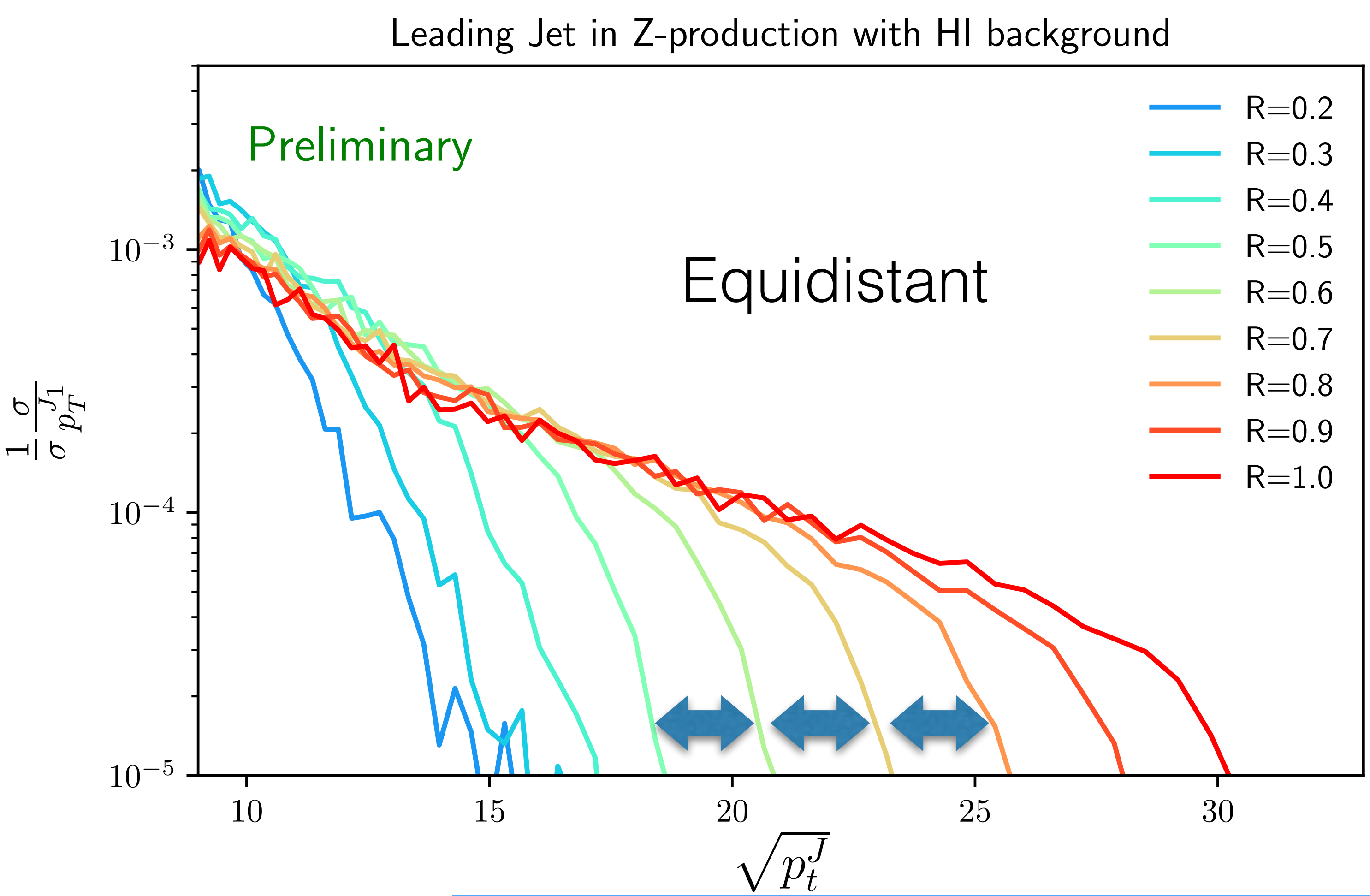
What happens at PbPb collisions?

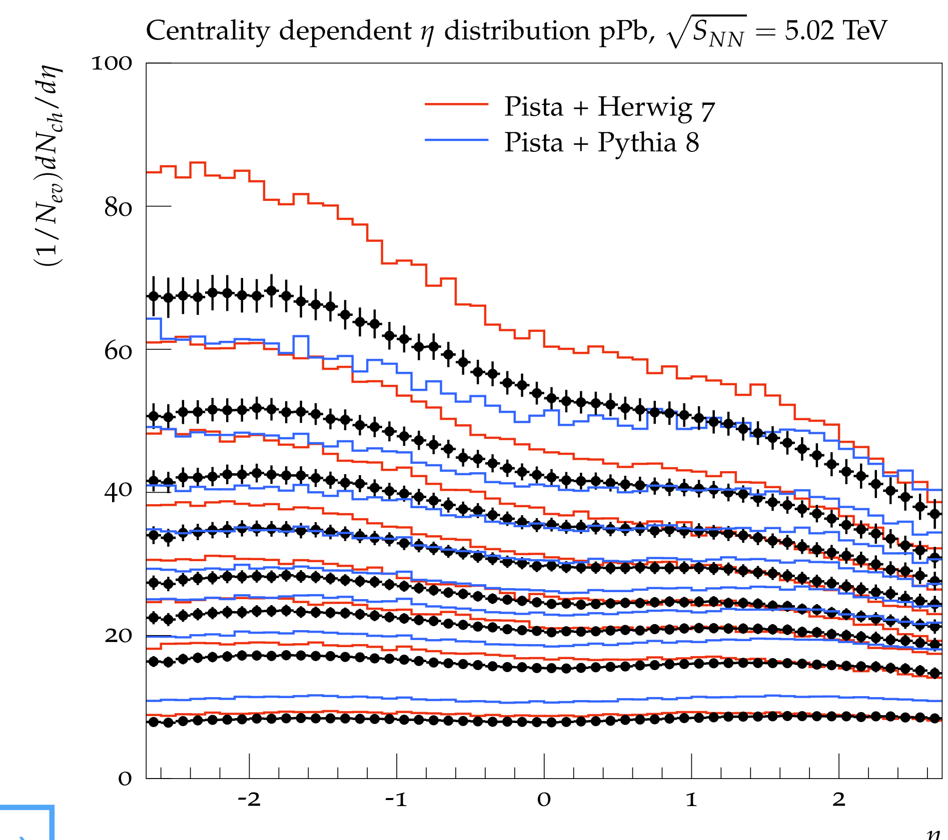
Here "C" -term becomes dominant!

Large R: $N_{part} \sim R^2 \sim p_T^J$









Based on arXiv:1807.01291 (JB, Bierlich)

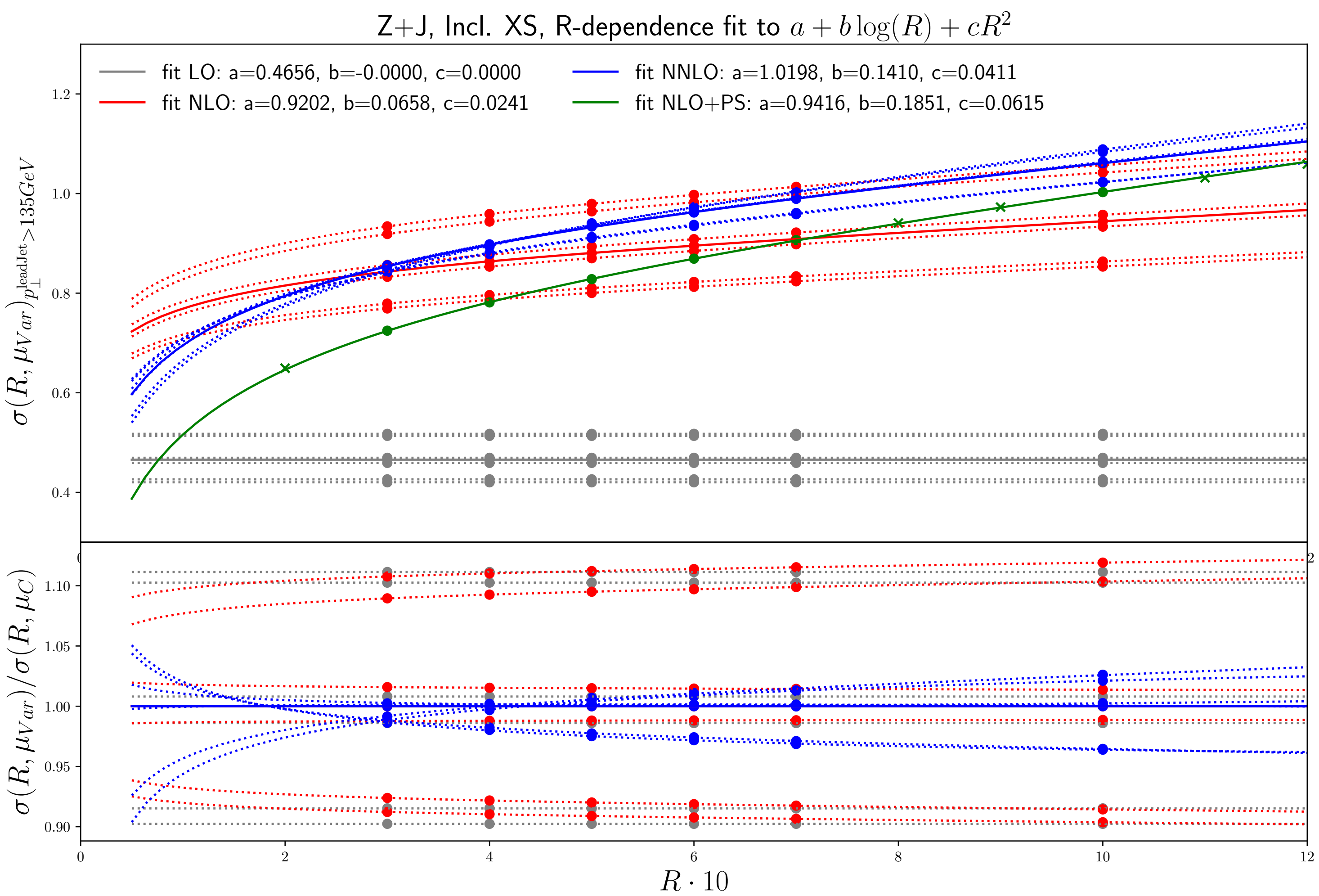
Conclusions

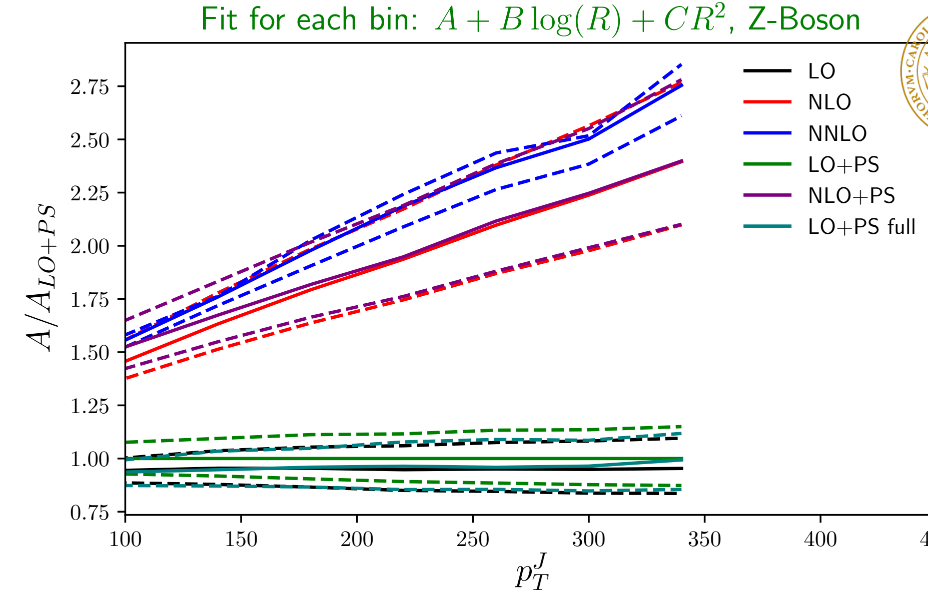
- The measurement of cross sections including jets depend on R.
- We compared for various scenarios the effects in the event generation (NP, MPI, PDF, higher orders).
- Numerical studies still needed with comparable tune to same data.
- The jet radius intrinsically produces a vetoed cross section.
  –> Scale variation can be misleading.
- Fit to simple functional behavior can remove parts of contributions beyond FO.
- Still need to quantify in numerical studies beyond MC generators how model dependent.
- Reconsider to build observables that allow more stable FO to data comparisons. Then need to test the MC dependence.
- Also in HI the R-dependence is important and needs good background simulations.

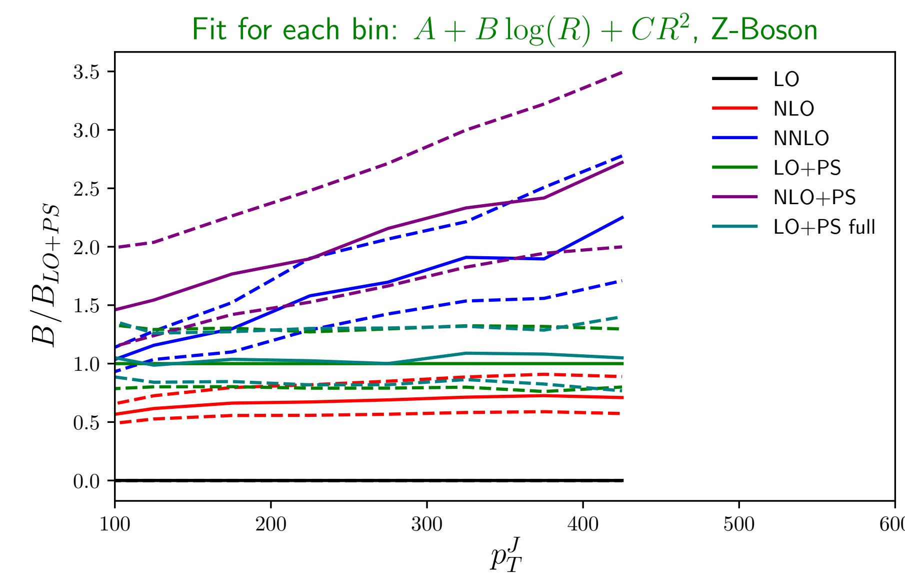
The End

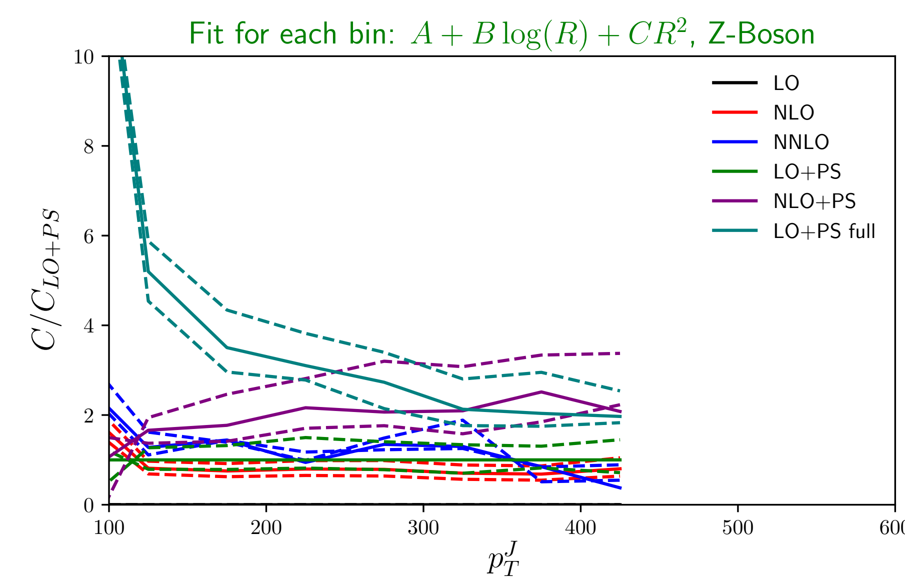
Thank you!

Backup









- Same as Higgs plot for Z-bosons.
- Right: A, B and C ratios to LO+PS for Z.

Backup

- Need for higher statistic with same scale choice.
- NNLO behaves as NLP+PS
- Both jets can radiate and collect ISR.