Event Generation at NLO

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Loopfest X
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Overview of Research Directions

- Loops

- Logs
  - shower (LL)
  - QCD resummation
  - SCET

- Legs
  - -Madgraph
  - -Alpgen
  - -AMEGIC++
  - -calchep

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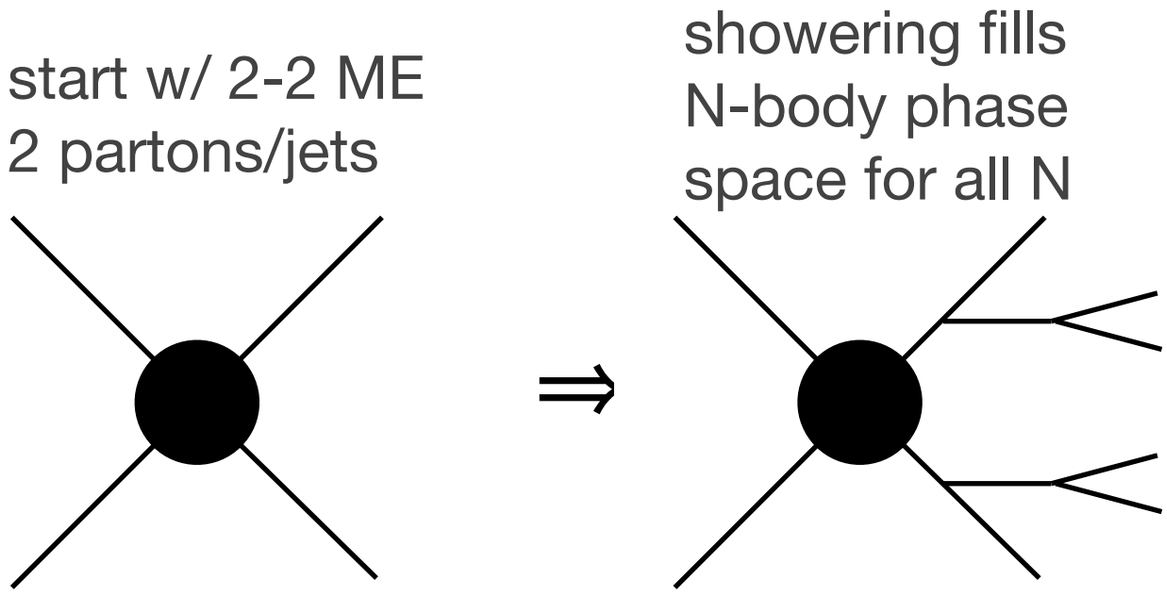
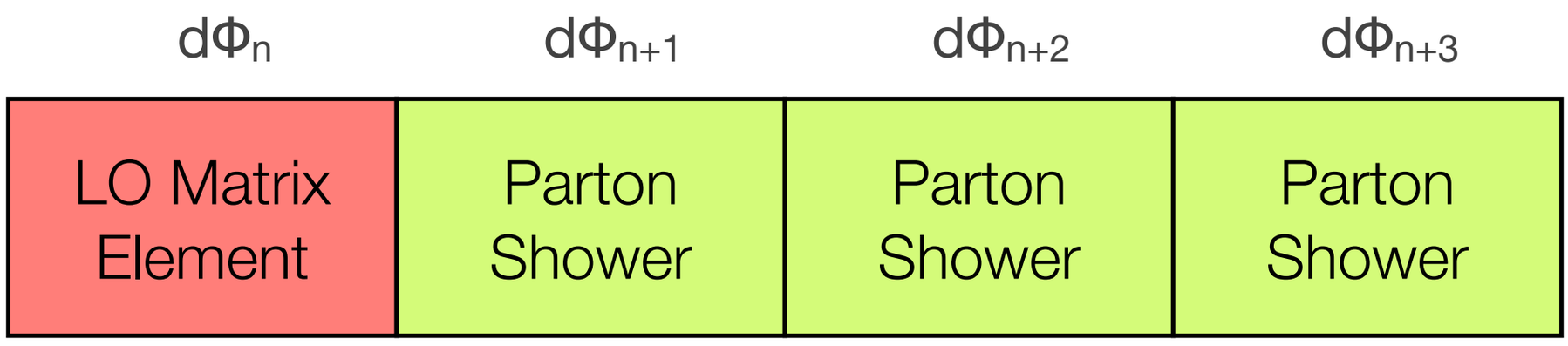
GenEvA v0.1: Bauer, Tackmann, Thaler
MENLOPS: Hamilton, Nason; Hoche, Krauss, Schonherr, Siegert

The Parton Shower (PS)

- LO for lowest multiplicity, higher mult. filled w/ parton splittings

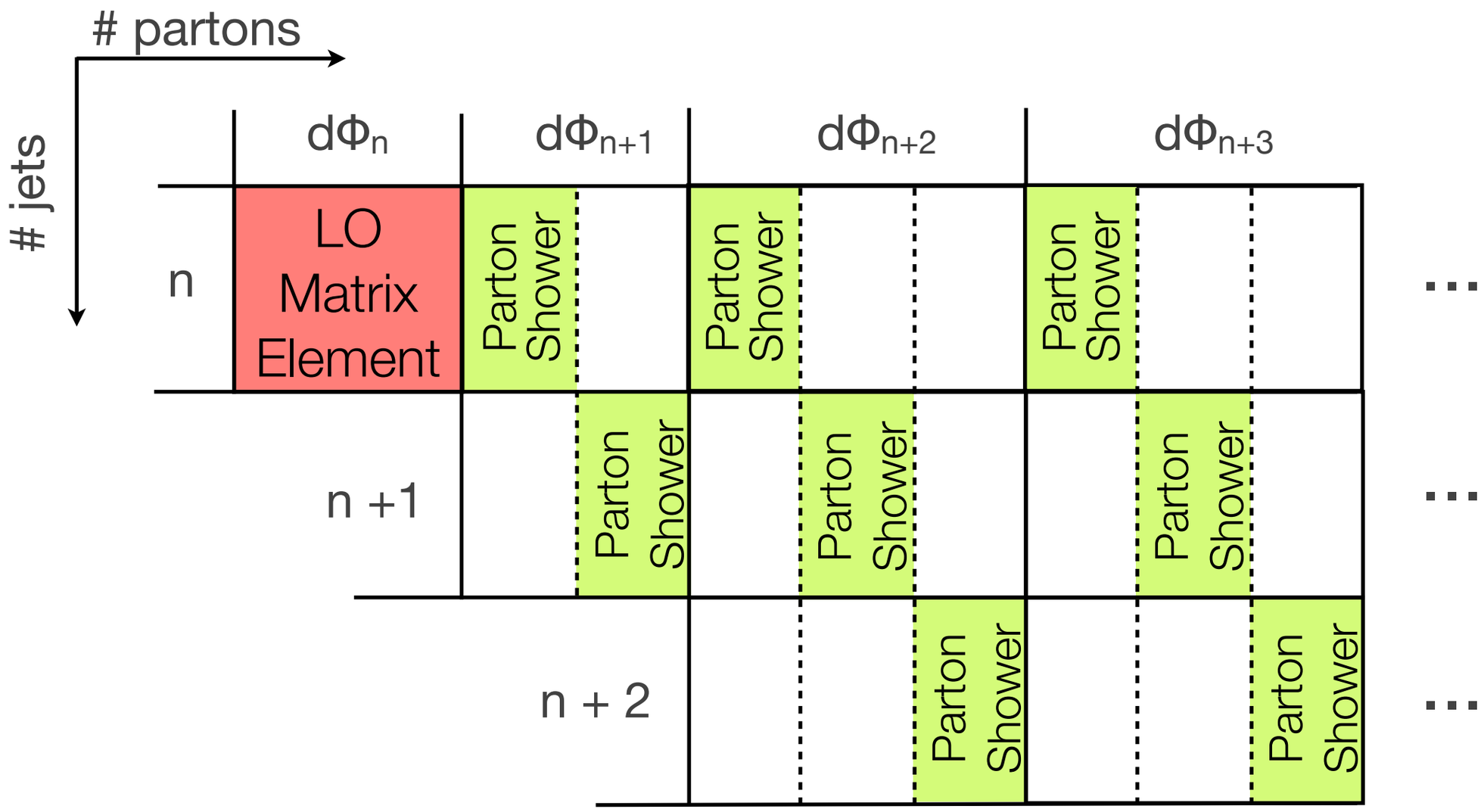


- simple phase-space picture



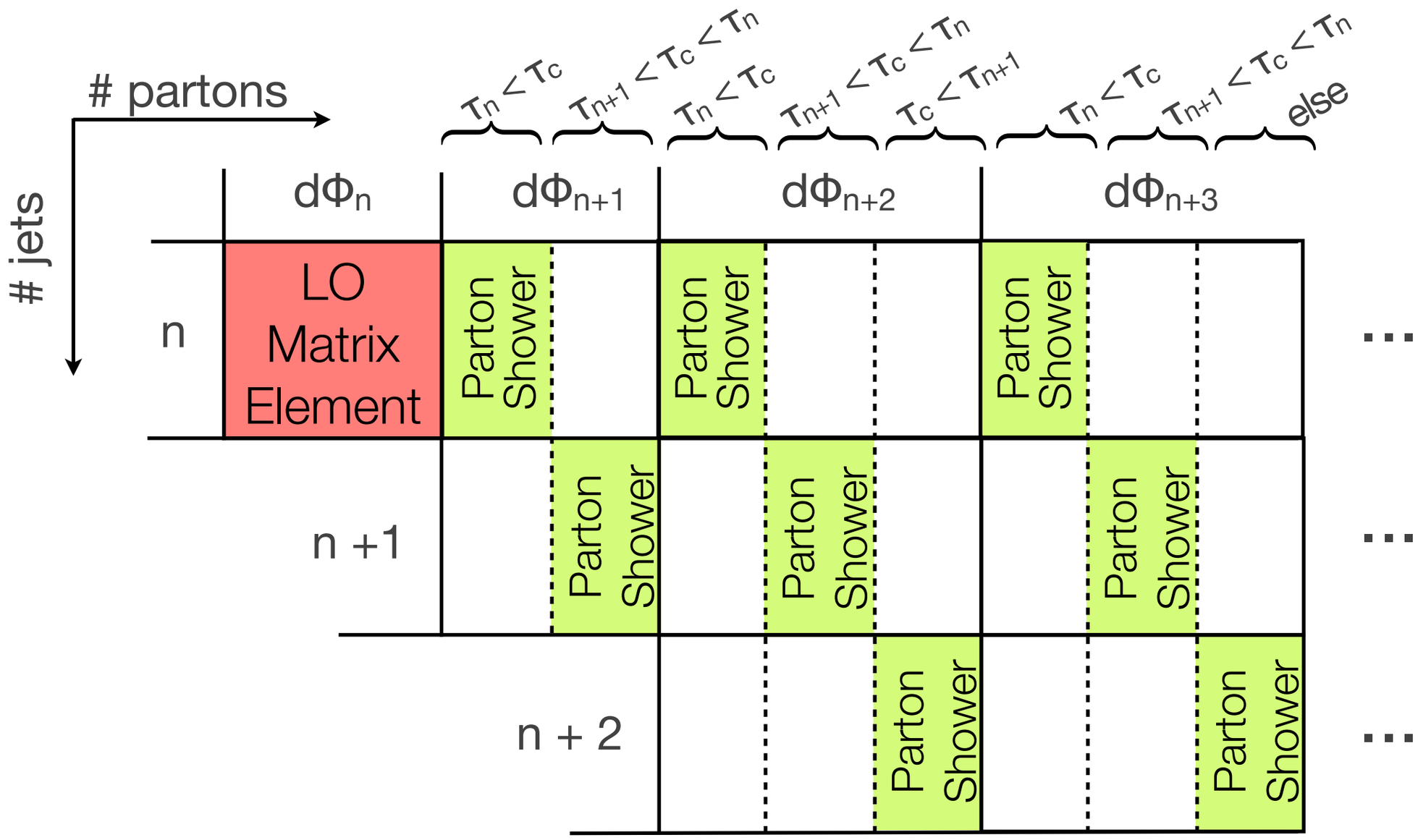
The Parton Shower (PS)

- beyond tree level, will need partons ≠ jets!!



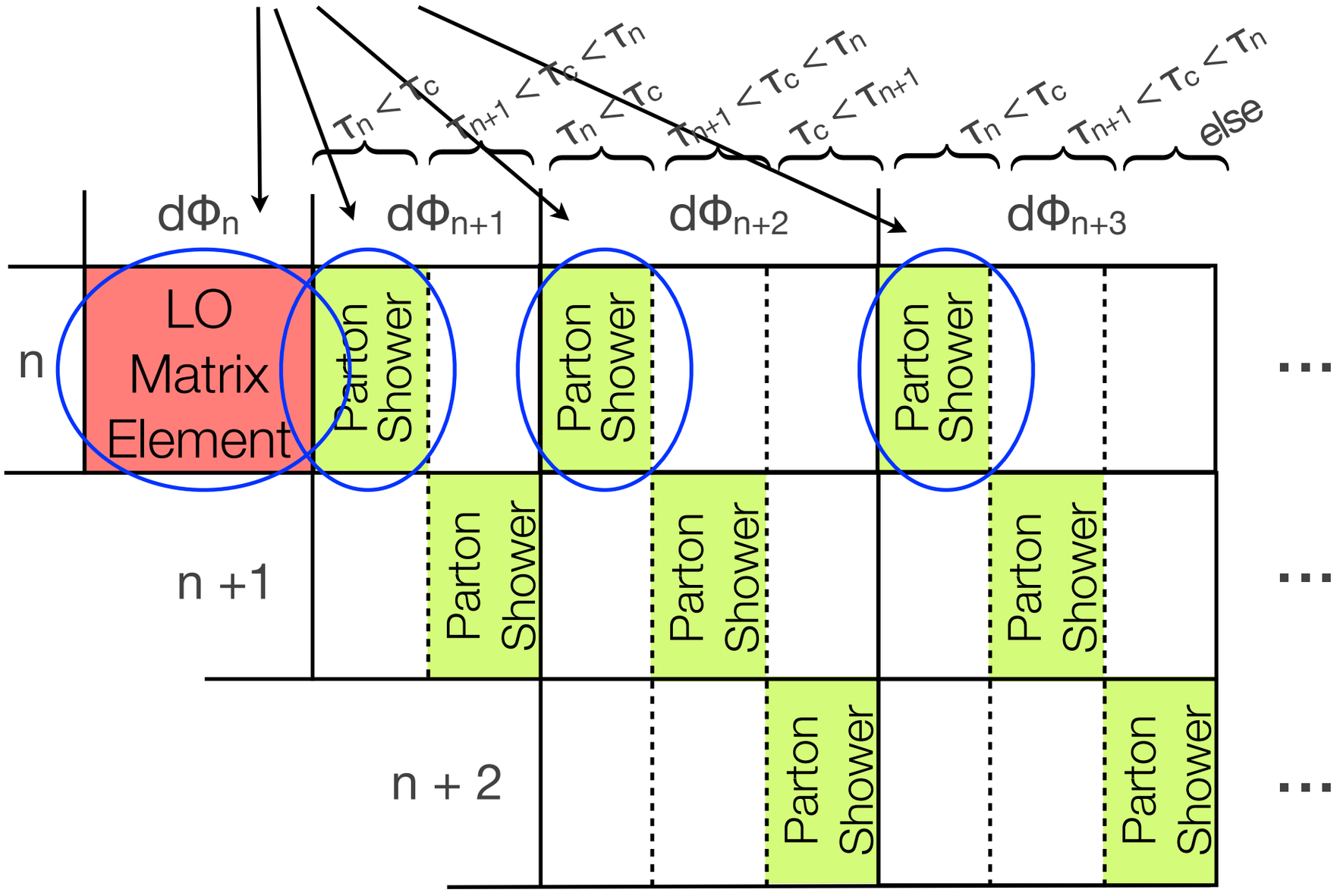
The Parton Shower (PS)

- divide phase-space w/ (a set of) resolution variable(s), (e.g., the min virtuality t or the n-jettiness parameters τ_n)



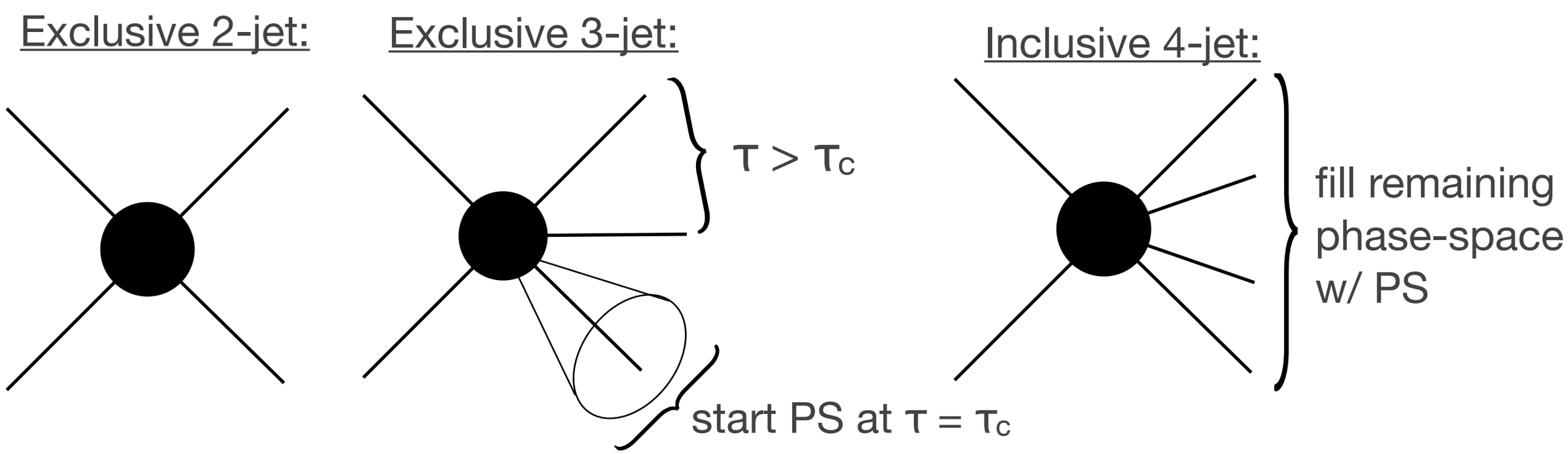
The Parton Shower (PS)

- in PS, only $\tau_n < \tau_c$ good approx. (n-body singular region)



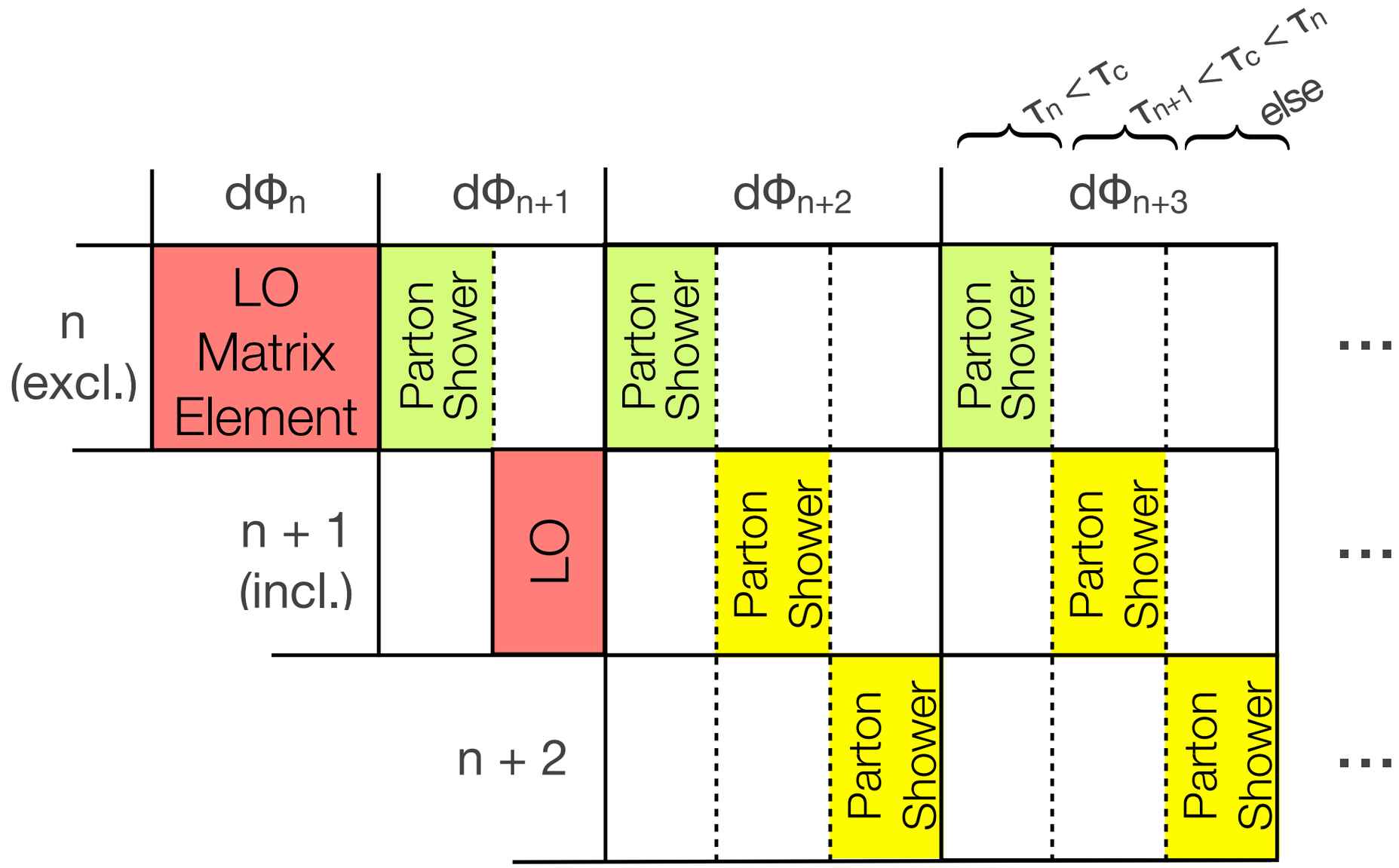
How to Merge many LO + PS (e.g., CKKW/MLM)

- multiple LO ME's + shower
- double-counting avoided by dividing phase-space w/ some resolution parameter τ_n)



- correct at LO, LL (partial NLL)

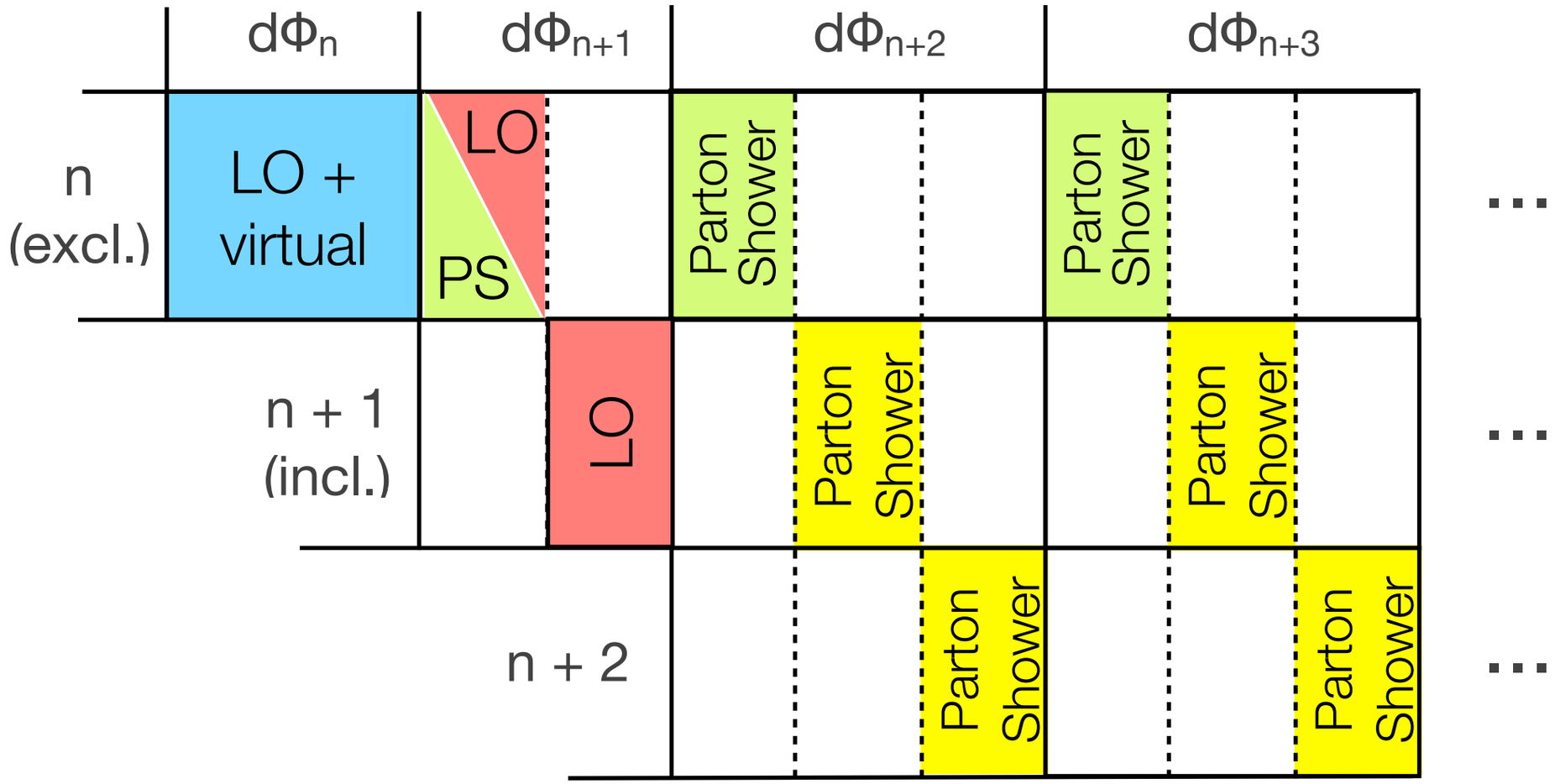
How to Merge LO + PS (e.g., CKKW/MLM)



- can have many exclusive jets at LO (not shown)

NLO + PS

- rows are IR-safe, finite quantities, but not columns!



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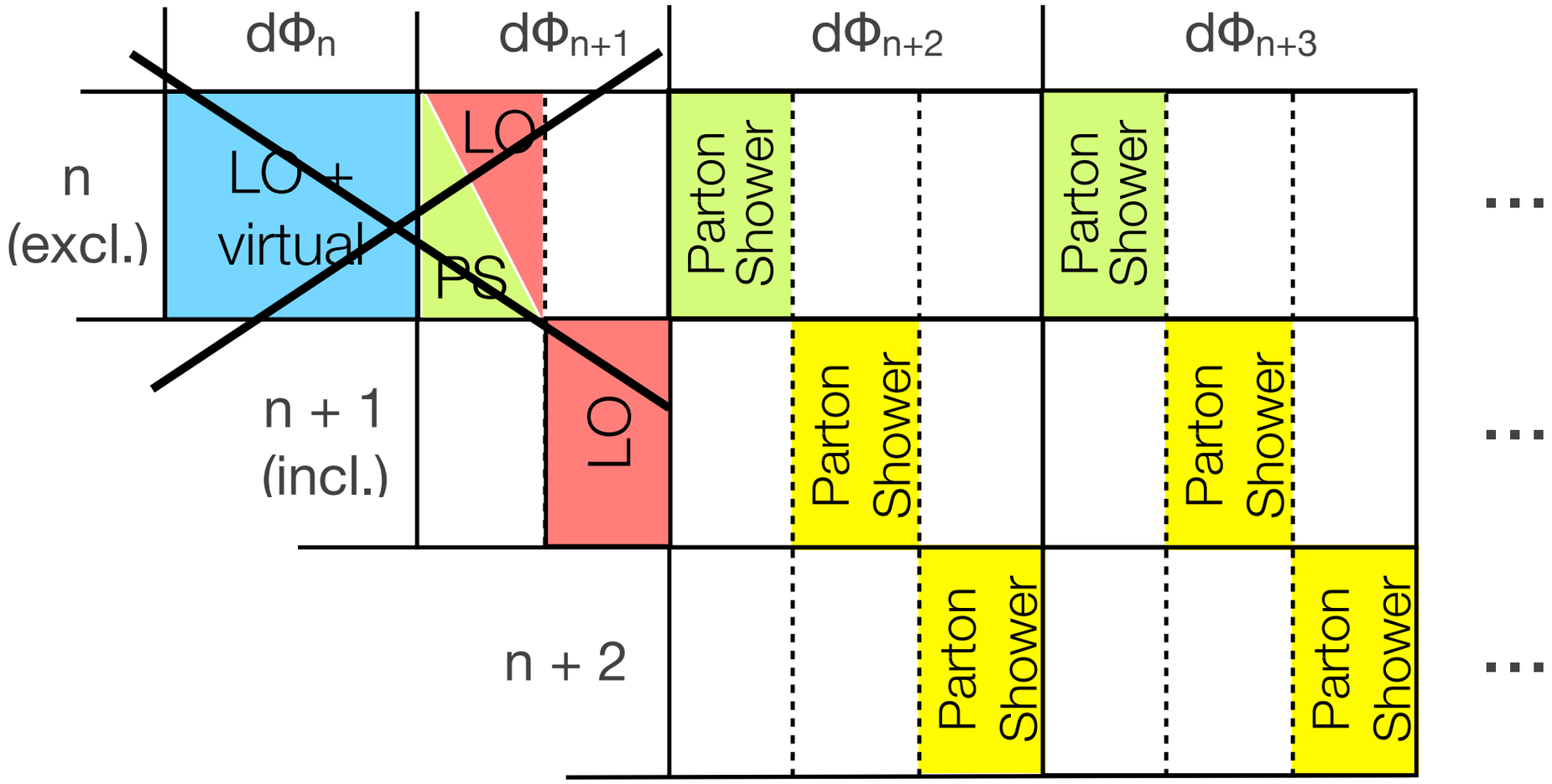
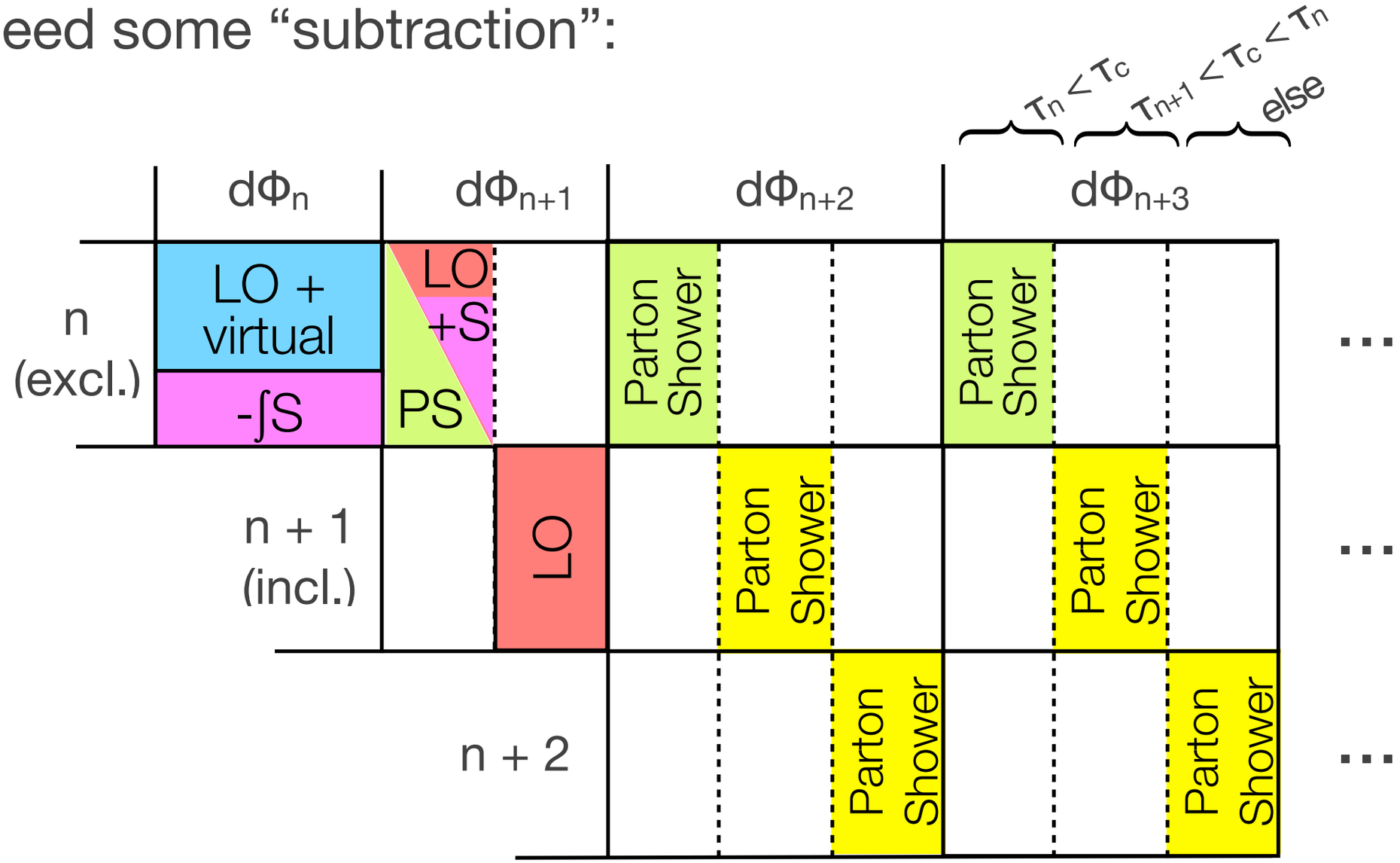


NLO + PS: MC@NLO, POWHEG

- need some “subtraction”:



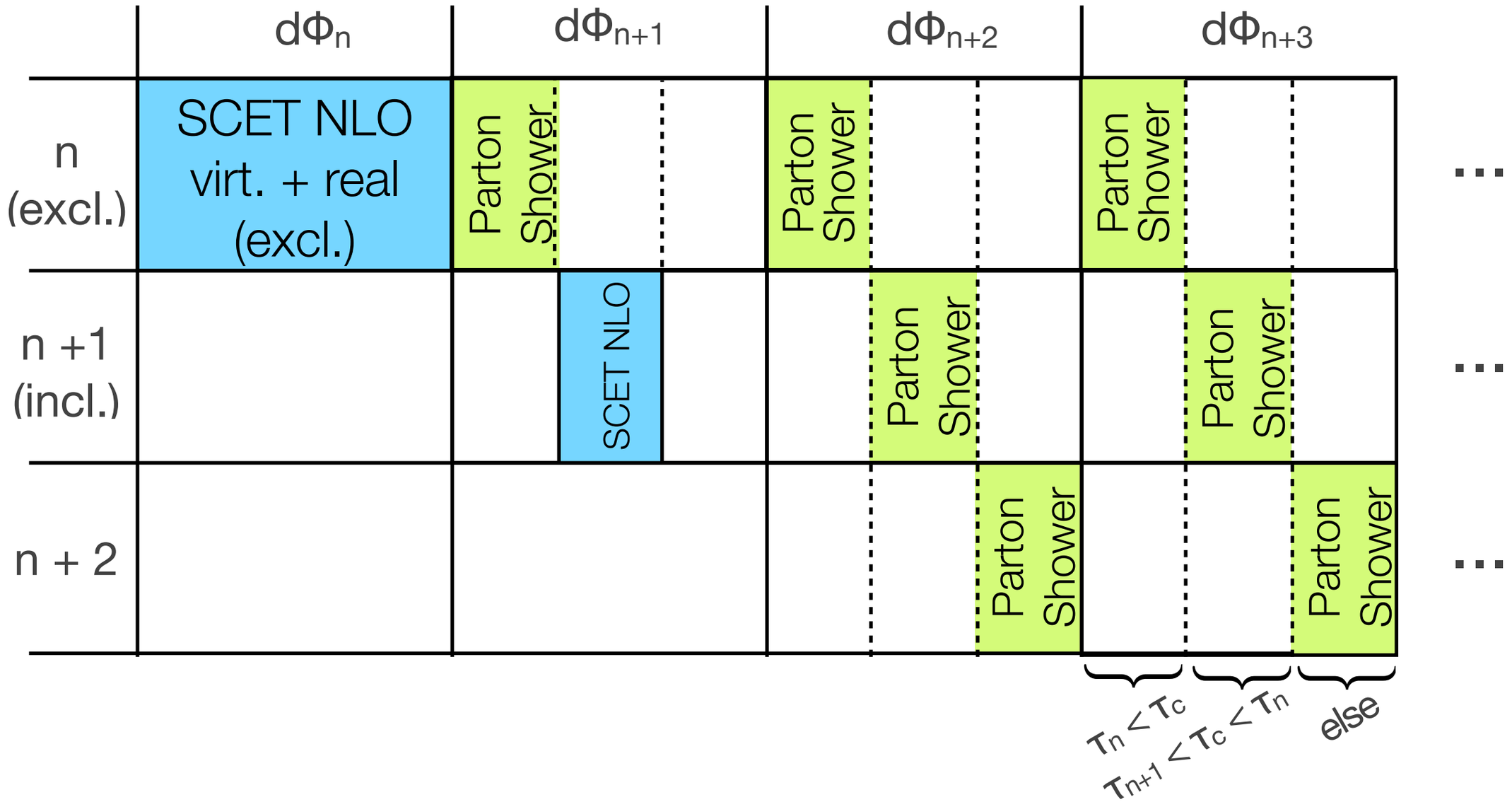
Difficulties in Merging NLO + PS

- unlike CKKW, not just one approx. is valid here:
  - need to combine (exact) real emission ($d\Phi_n$) with virtual corrections ($d\Phi_{n+1}$), at least in the singular limits
    - its precisely in these singular (coll. + soft) that we need resummation
- Q: how to have both resummation and correct real emission when they live in same part of phase-space?
- most current solutions make it difficult to have multiple NLO

GenEvA (v1.0)

rev.

- many NLO + PS



Soft-Collinear Effective Theory & Resummation

- SCET separates hard/collinear/soft (& pert. from non-pert.)

- classic example = thrust (here, τ = 1-thrust → 0 for pencil-like jets):

$$\frac{\mathrm{d}\hat{\sigma}_{\mathrm{s}}}{\mathrm{d}\tau} = \sigma_0 H(\mu, Q) \int d\tau_n d\tau_n J_n(\mu, Q\sqrt{\tau_n}) J_{\bar{n}}(\mu, Q\sqrt{\tau_{\bar{n}}}) S(\mu, Q(\tau - \tau_n - \tau_{\bar{n}}))$$

born cross-section

$$H, J, S = 1 + \alpha_s + \cdots$$

- H ("hard" fnc.): QCD virtual corrections ($\overline{\mathrm{MS}}$)

- J, S ("jet"/"soft" fncs.): real emission corrections in collinear, soft limits

- RGE of H/J/S from μ to Q/Qτ$^{1/2}$/Qτ resums logs of τ

SCET Approach to "Merging"

- tail region matching for to get exact NLO when $\tau \sim 1$:

SCET resummed calc. of "singular" terms ($\tau \ll 1$), terms like $\alpha^m \log^n(\tau)/\tau$ (currently N^{3}LL/NNLO) Becher, Schwartz '08

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\tau} = \frac{\mathrm{d}\hat{\sigma}_{\mathrm{s}}}{\mathrm{d}\tau} + \frac{\mathrm{d}\hat{\sigma}_{\mathrm{ns}}}{\mathrm{d}\tau}$$

$$\frac{d\hat{\sigma}_{\mathrm{ns}}}{d\tau} = \frac{d\hat{\sigma}_{\mathrm{QCD}}}{d\tau} - \left[\frac{d\hat{\sigma}_{\mathrm{ns}}}{d\tau}\right]_{\mathrm{exp.}}$$

difference of QCD and SCET expanded to fixed-order in α_s (terms like $\alpha^m \log^n(\tau)$, $\alpha^m \tau^n$)

- include non-pert. corrections:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\tau} = \int \mathrm{d}k \left(\frac{\mathrm{d}\hat{\sigma}_{\mathrm{s}}}{\mathrm{d}\tau} + \frac{\mathrm{d}\hat{\sigma}_{\mathrm{ns}}}{\mathrm{d}\tau}\right)\left(\tau - \frac{k}{Q}\right) S^{\mathrm{mod}}(k)$$

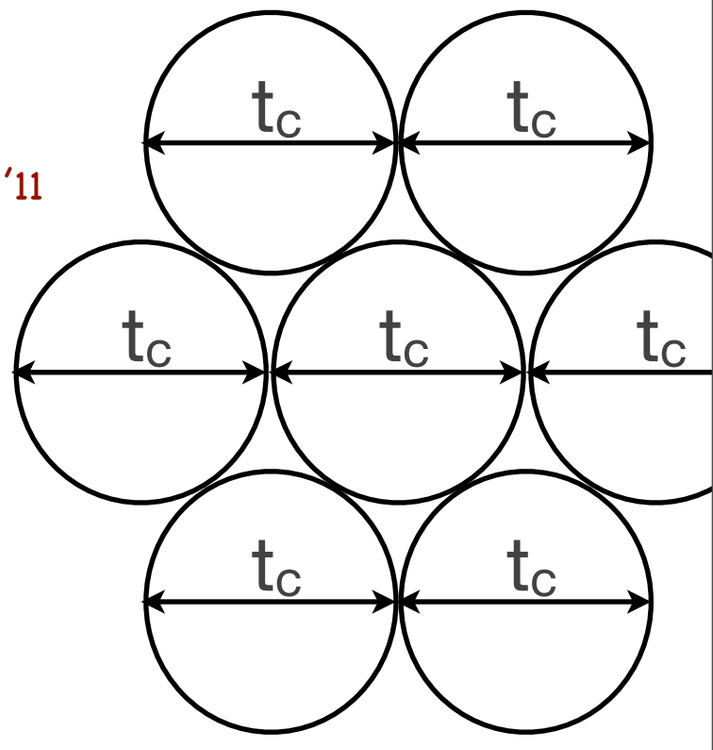
- works for particular observables, need generic for Event Generator

Exclusive Cross-Sections in SCET

- just use calculation of some exclusive multijet measure (e.g., N-jettiness)
- shower fills $t < t_c$
- integrate up to get other observables at LL

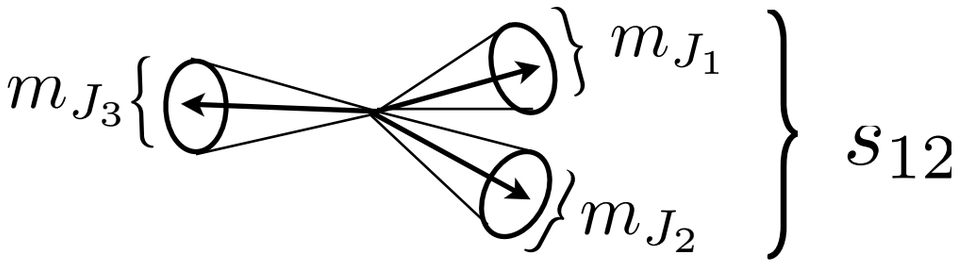
- beyond leading logs, need other soft functions

  ⇒ generate other soft funcs numerically Bauer, Dunn, AH '11

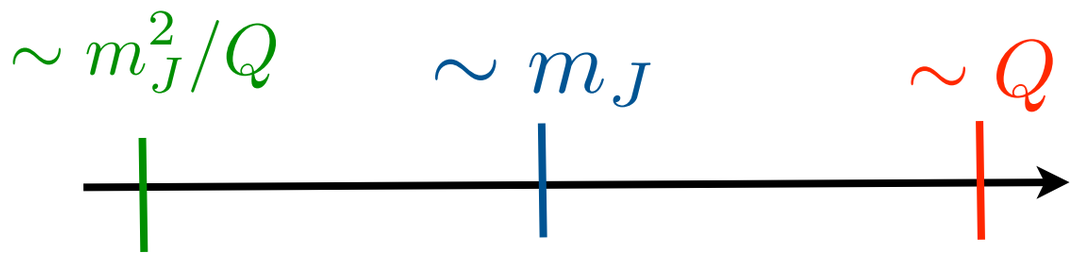


Kinematic Logs in SCET (generalized CKKW)

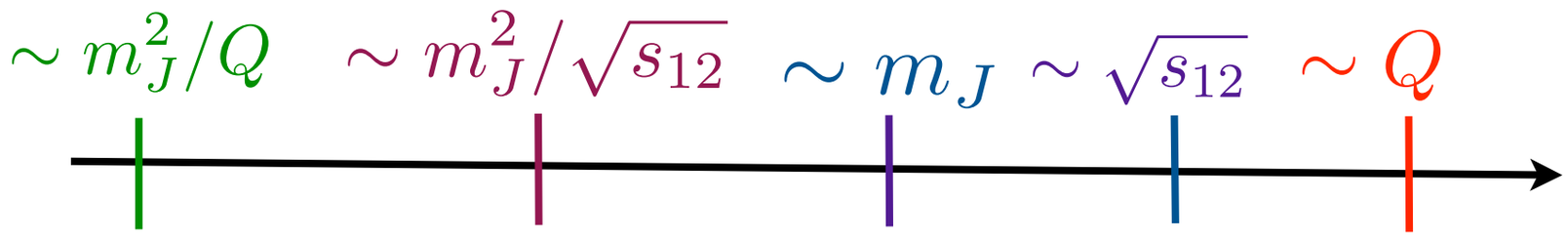
Bauer, Tackmann, Walsh, Zuberi



- traditional SCET: Q ~ s_{ij} >> m_{J1} ~ m_{J2}~ m_{J3}

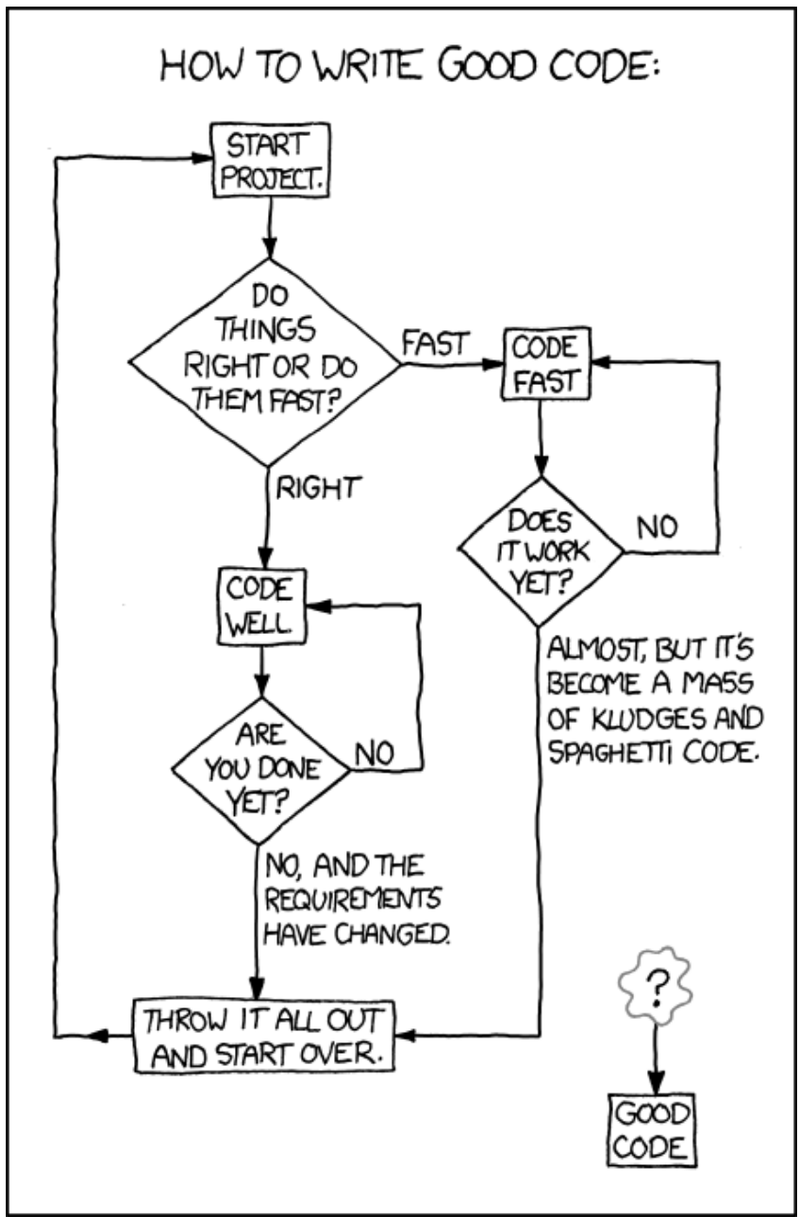


- "SCET+": Q >> s_{12} >> m_{J1} ~ m_{J2}~ m_{J3}



GenEvA Code

- c++
- modular
- easy to read (objects ↔ physics)
- (hopefully) proving xkcd wrong!



(Preliminary) Results: LO only

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  - no events in low thrust region or for $\tau > 1/3$

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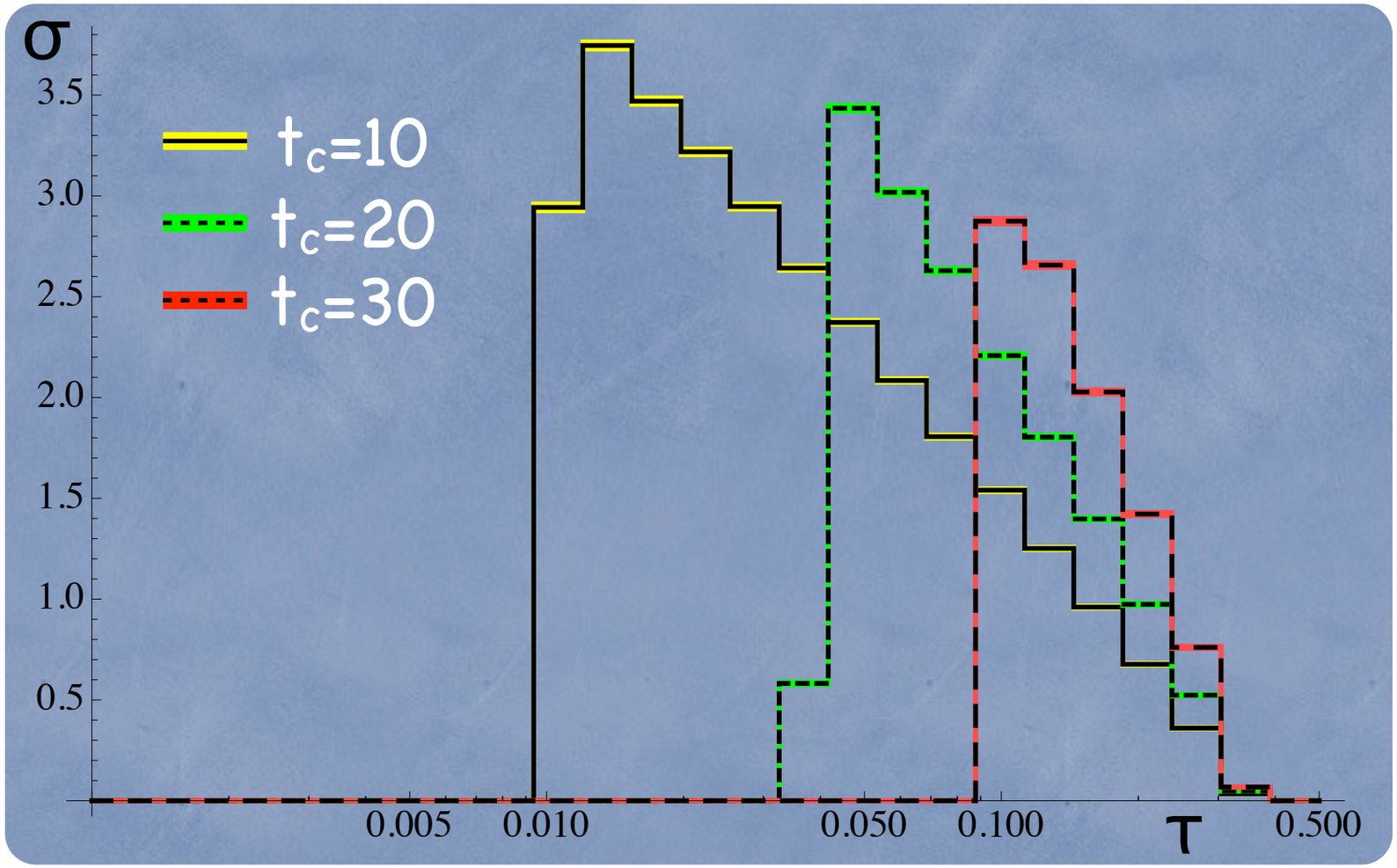

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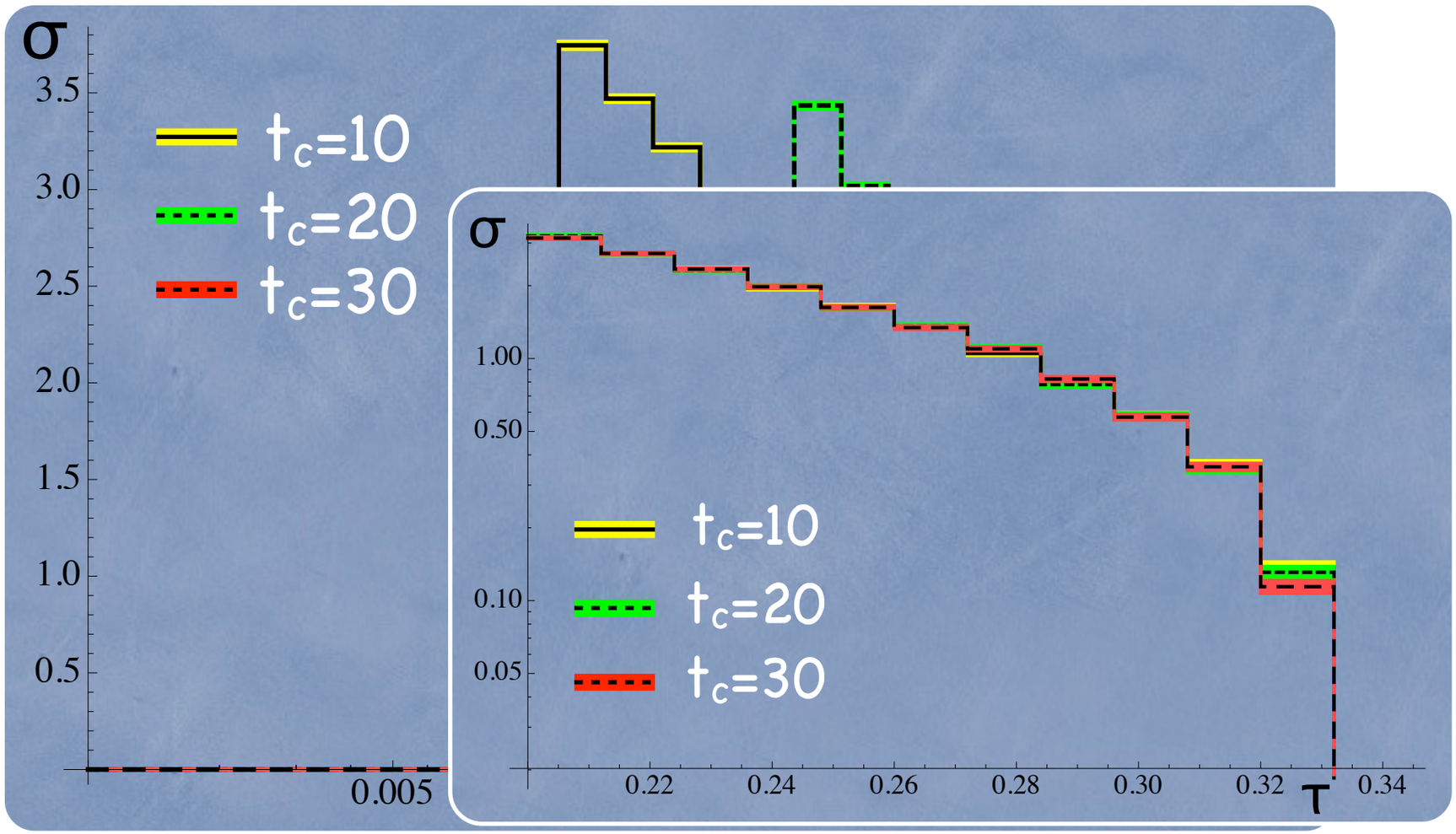

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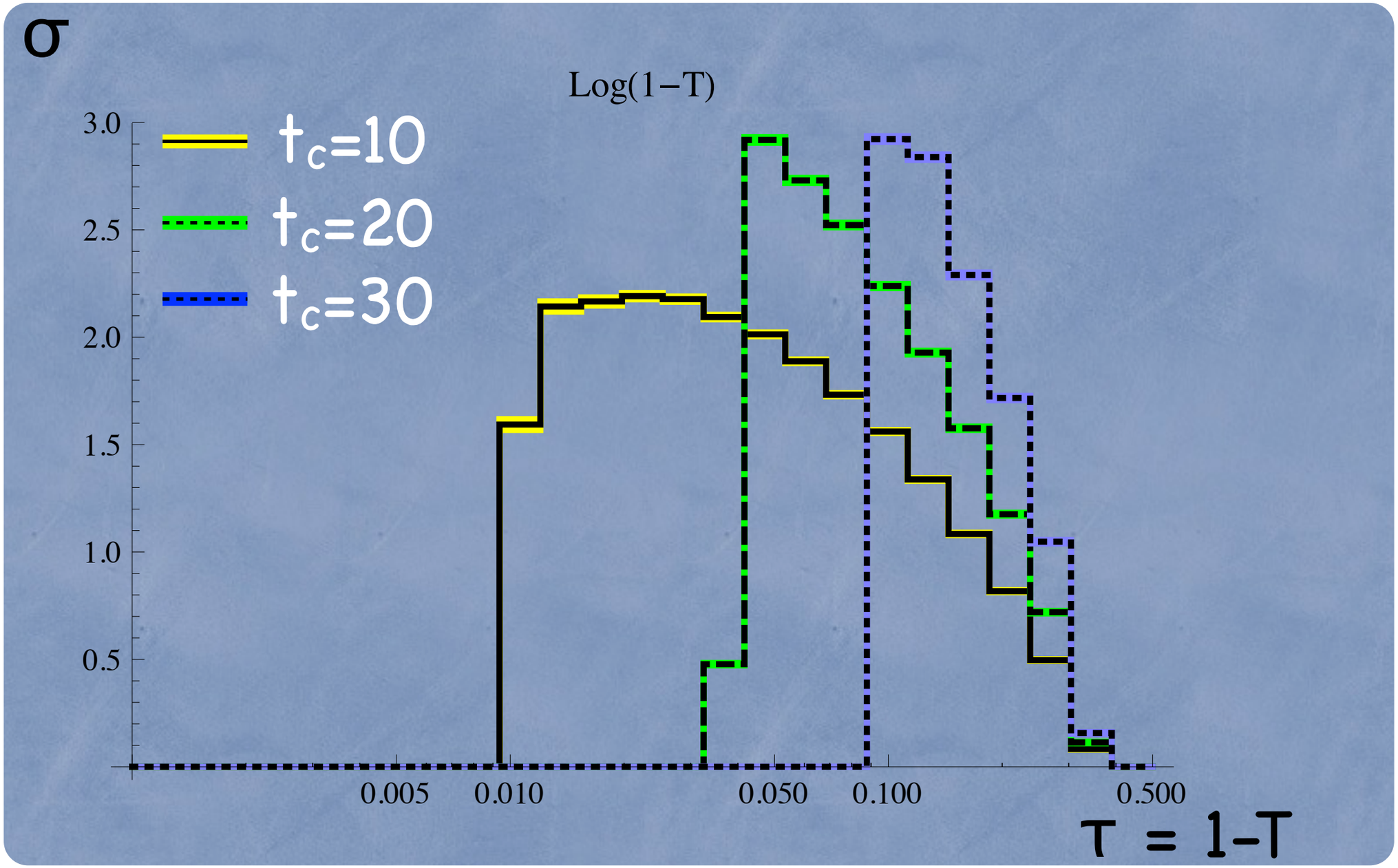

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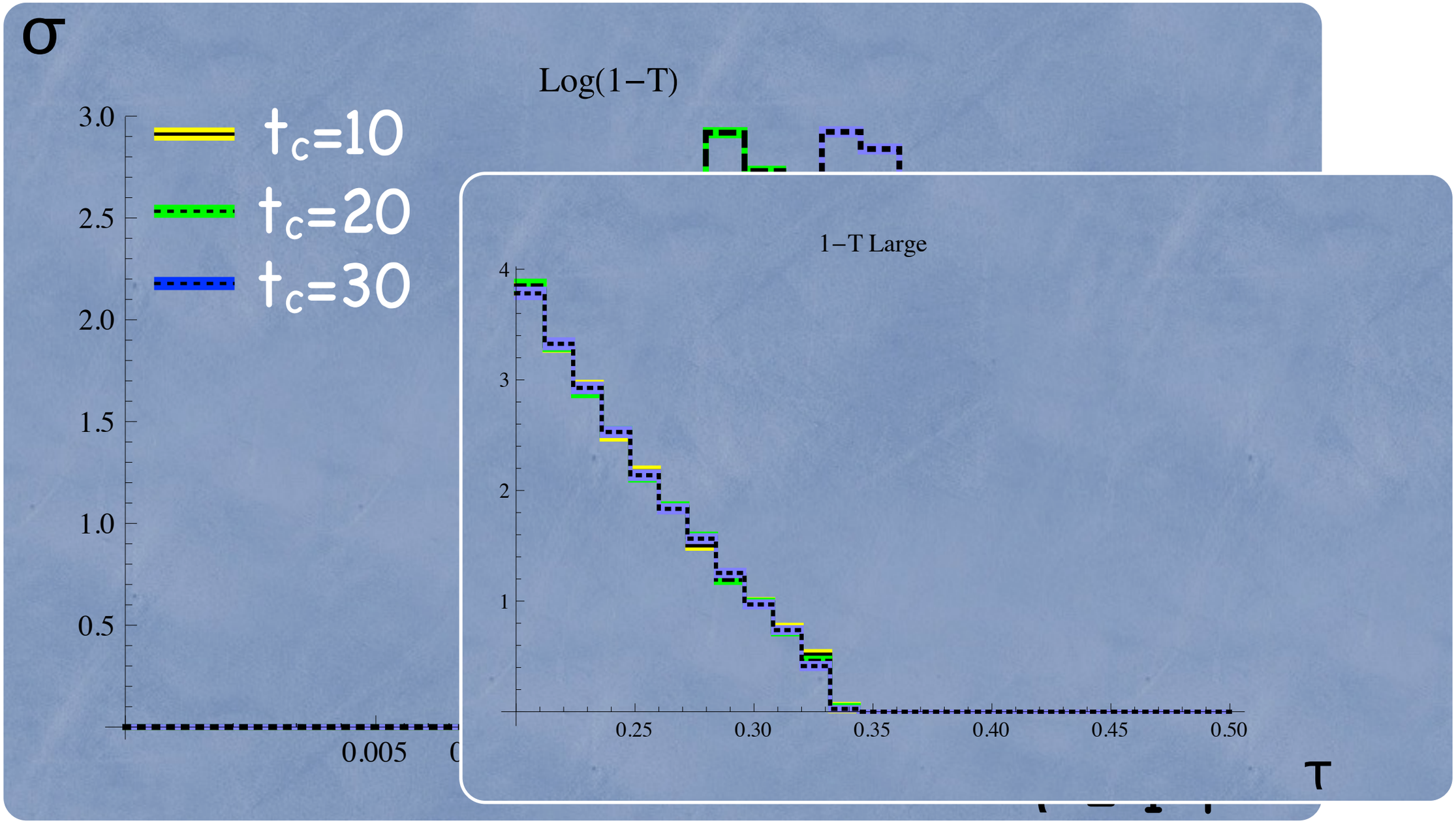

(Preliminary) Results: LO + Pythia (LL)

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  - no events in low thrust region or for $\tau > 1/3$
- LO/LL (no shower):

  double log dependence on t_c
- LO + pythia:
  - fills low thrust region and $\tau > 1/3$
  - however, it resums LL of t_c, but LO does not

    $\Rightarrow$ double log sensitivity on t_c

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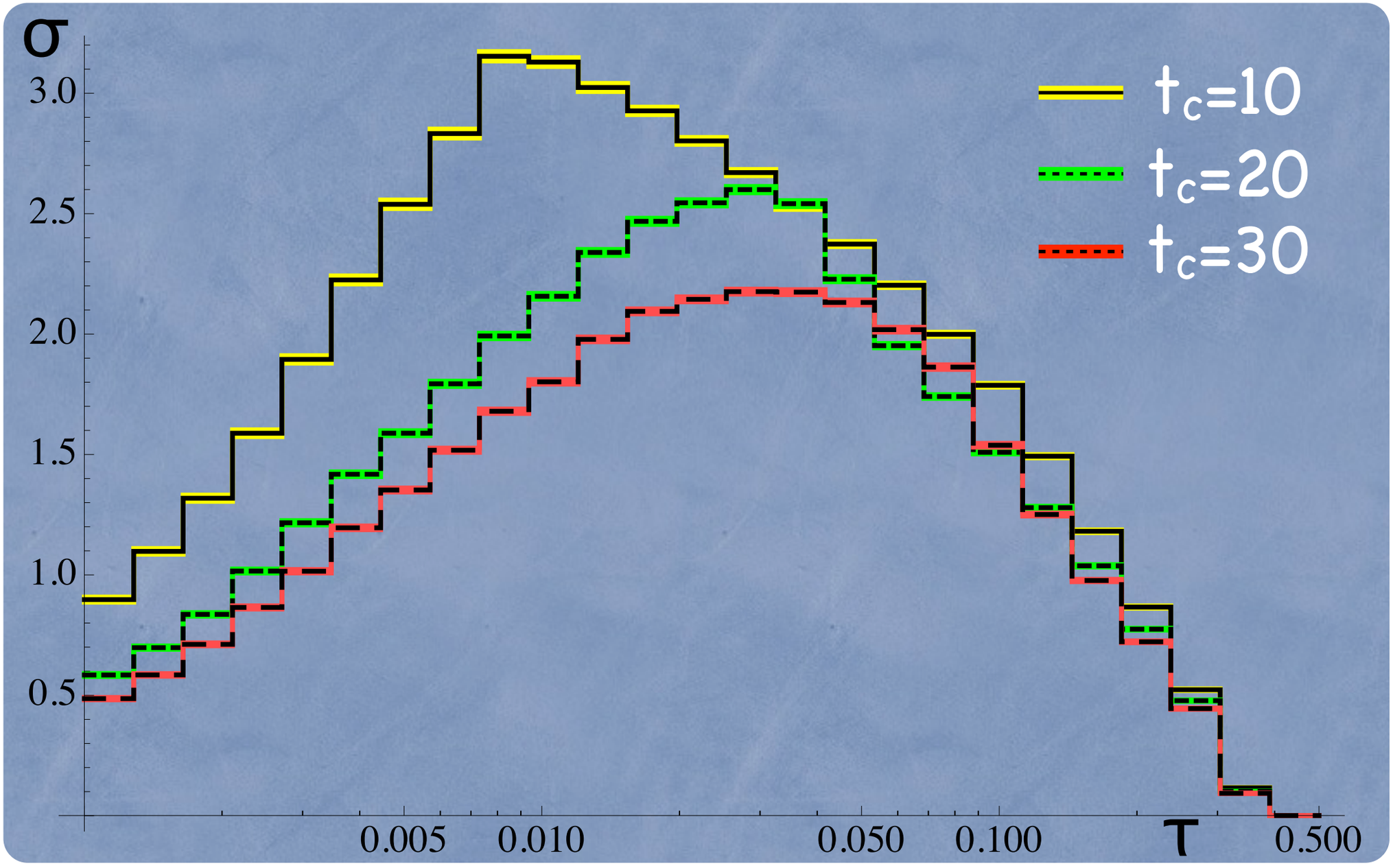

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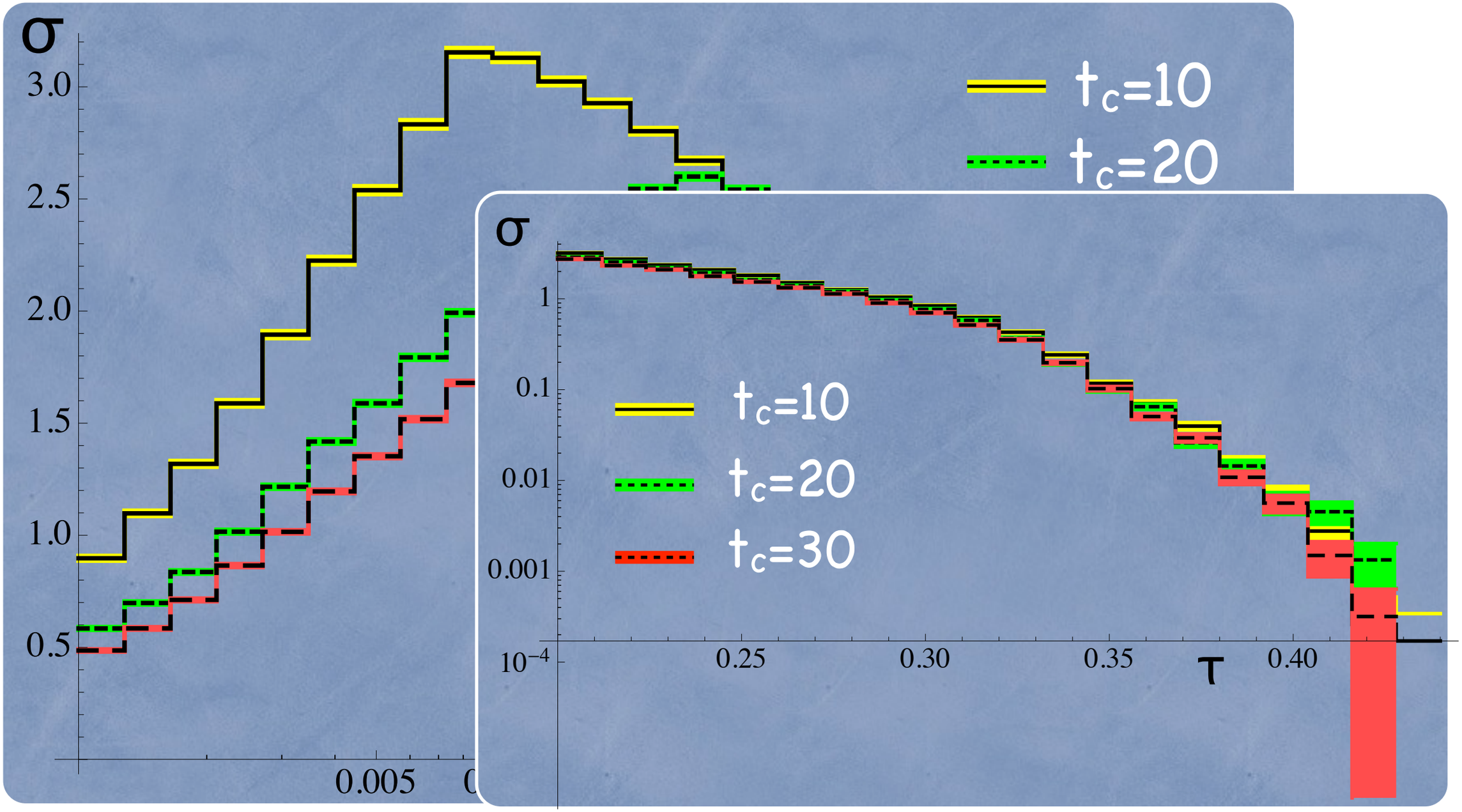
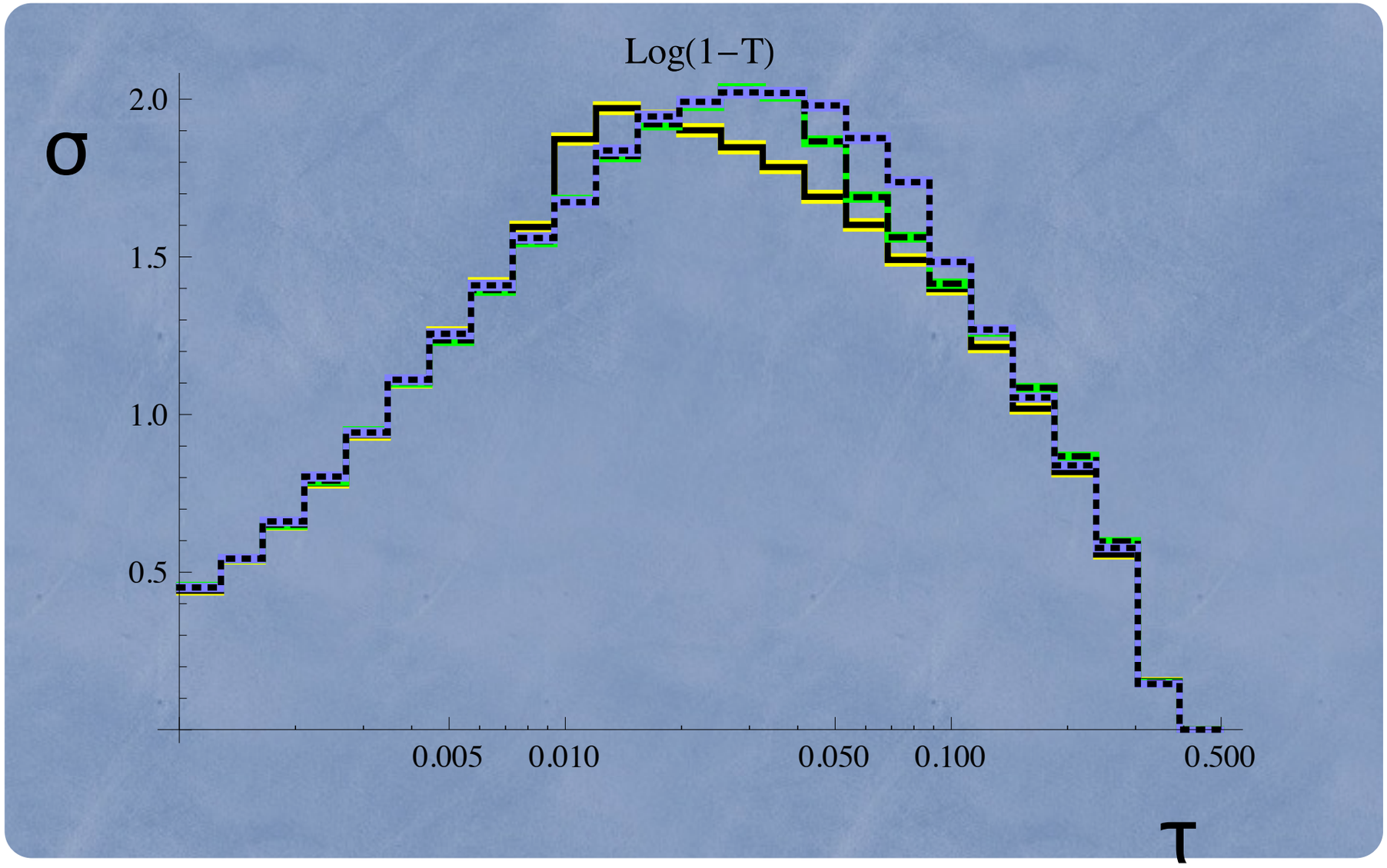


(Preliminary) Results: SCET NLO/LL+ Pythia (LL)

- pythia + NLO/LL SCET (3 jet = LO, rate = NLO, t_3 & t_c = LL)
- can extend to higher orders since 2j rate indep. of B_3



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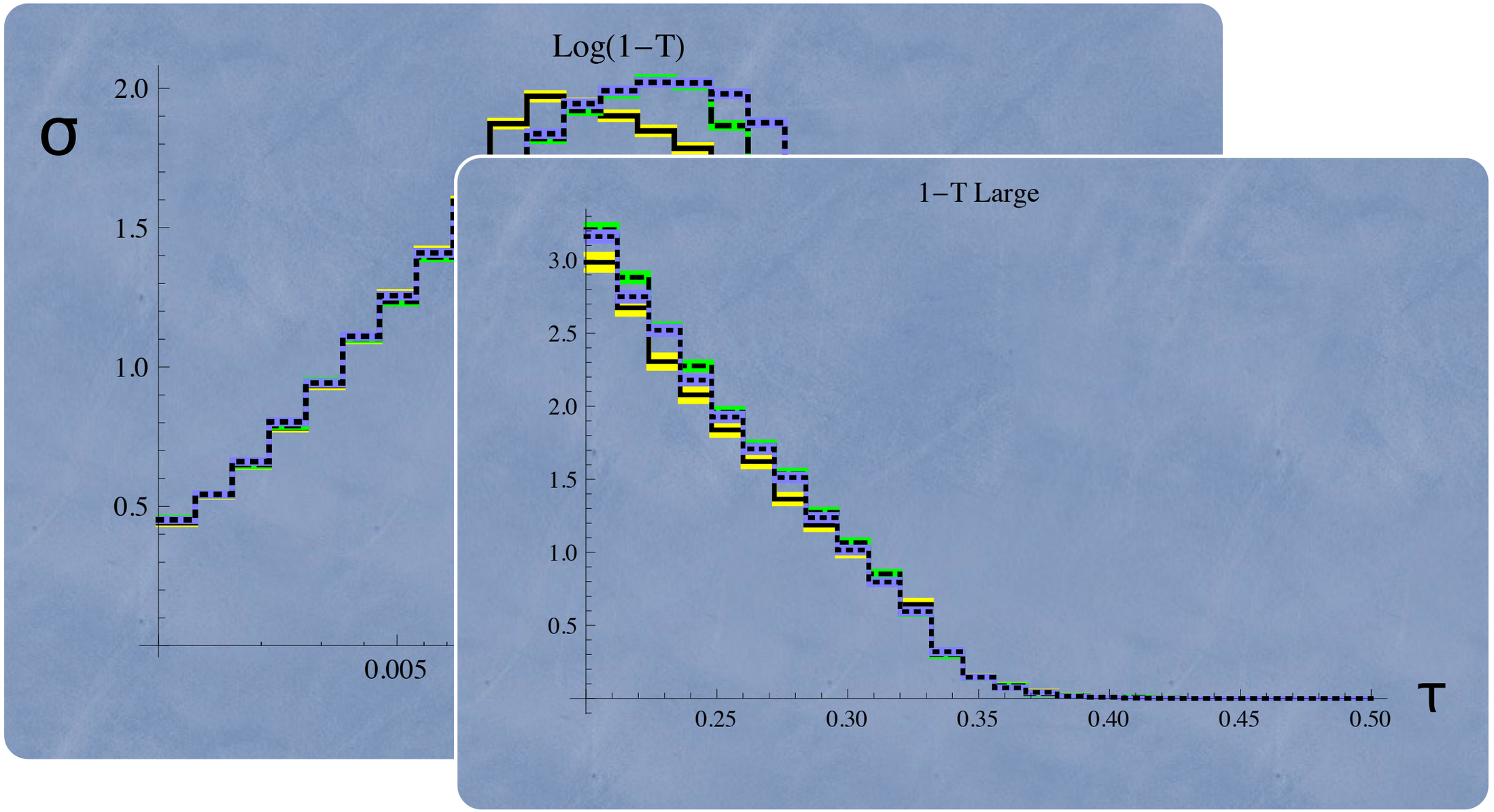

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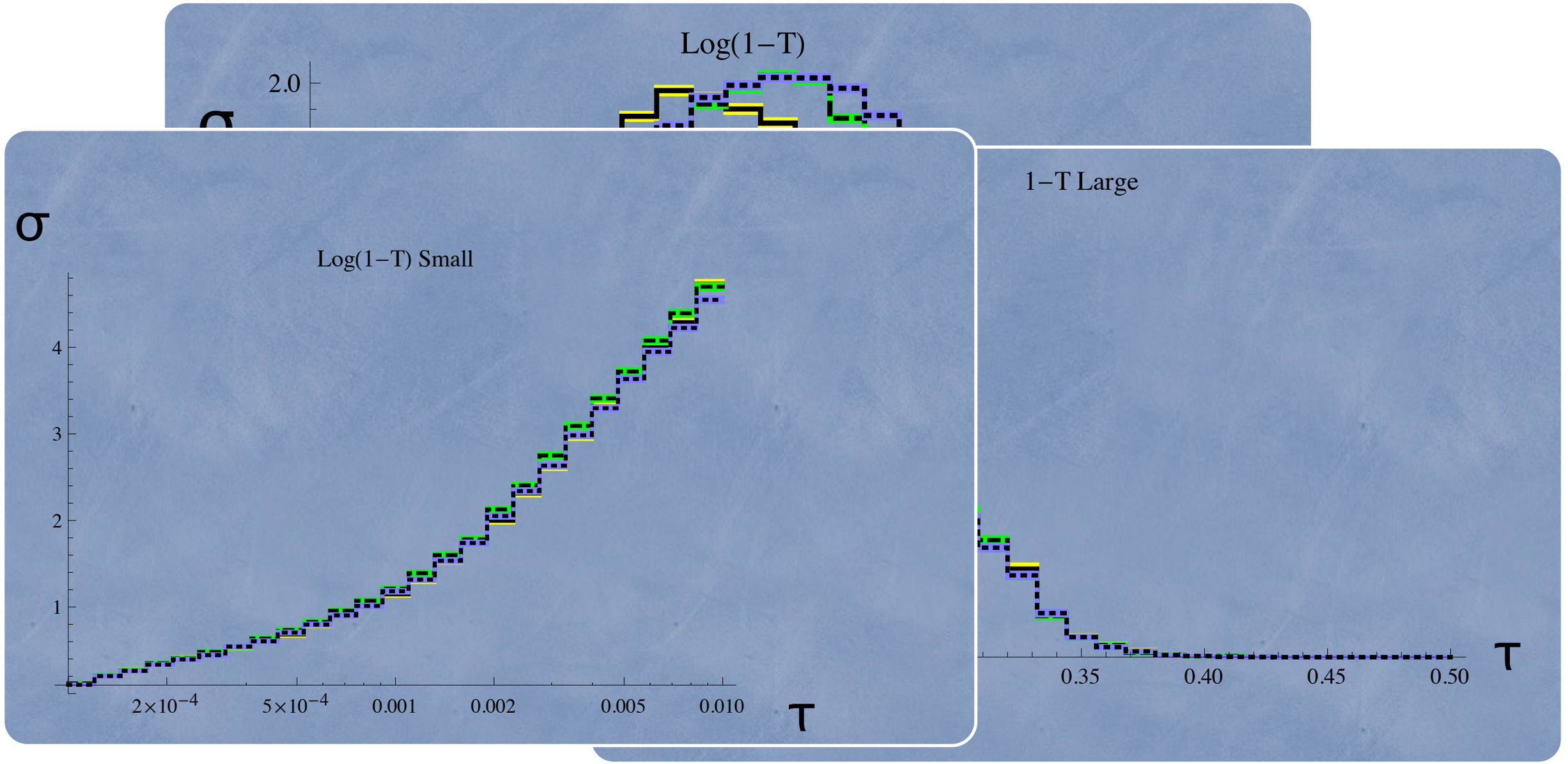

Conclusions/Status of Project/Future Timeline

- event generators crucial to connect precision calculations to experiment
- goal: many NLO + shower
- method: exclusive cross-sections (SCET)
- have debugged LO/LL (CKKW) and $NLO_2/LO_6/LL$ (GenEvA v0.1/ MENLOPS)
- working on debugging NLO_n/LL, starting with e+e-
- expect W+0,1 jets (both at NLO) soon (end of summer?)