The Geneva Event Generator:

Coming soon to a collider near you!

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Jonathan Walsh, Saba Zuberi

Christopher Vermilion
University of Louisville, LBL

Fermilab Theory Seminar
June 23, 2011

Overview of Research Directions

Disclaimer: Many of these slides copied from A. Hornig

- Loops
- Logs
  - shower (LL)
  - QCD resummation
  - SCET
- Legs
  - -Madgraph
  - -Alpgen
  - -AMEGIC++
  - -calchep

MC@NLO, POWHEG = 1 NLO + 1 LO + PS

CKKW, MLM = many LO + PS

GenEvA (v0.1), MENLOPS = 1 NLO + many LO + PS

Geneva (v1.0) = many NLO + many LO + PS

Expect releases this summer!!

MC@NLO: Frixione, Webber
POWHEG: Nason et al

CKKW: Catani, Krauss, Kuhn, Webber
MLM: Mangano

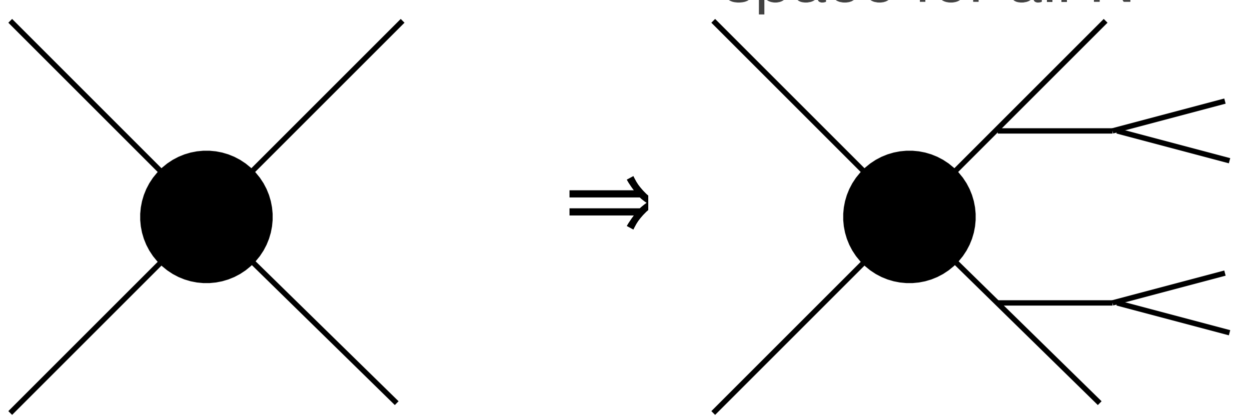
GenEvA v0.1: Bauer, Tackmann, Thaler (0801.4026, 0801.4028)
MENLOPS: Hamilton, Nason; Hoche, Krauss, Schonherr, Siegert

The Parton Shower (PS)

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

start w/ 2-2 ME
2 partons/jets

showering fills
N-body phase
space for all N

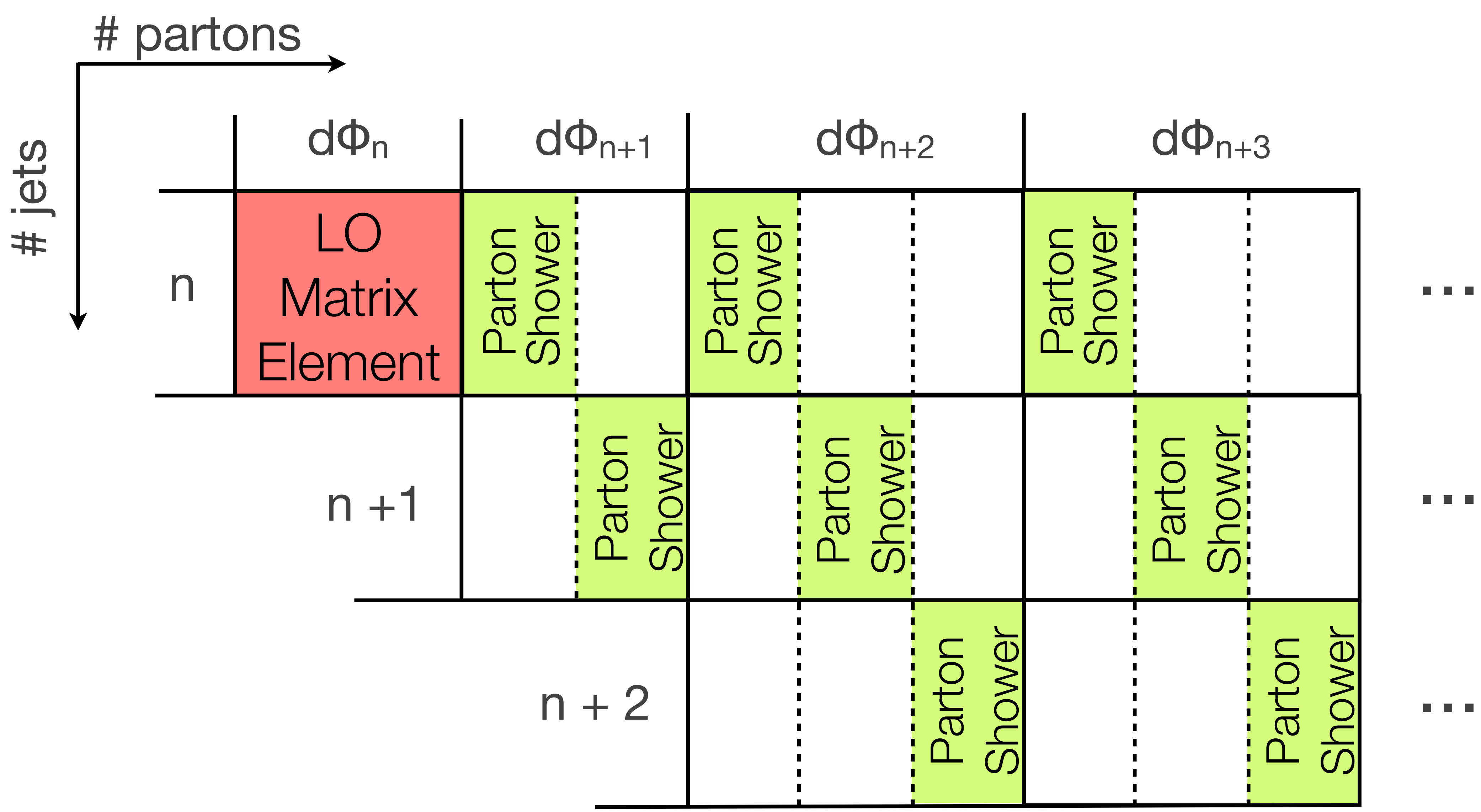


- simple phase-space picture

$d\Phi_n$	$d\Phi_{n+1}$	$d\Phi_{n+2}$	$d\Phi_{n+3}$
LO Matrix Element	Parton Shower	Parton Shower	Parton Shower

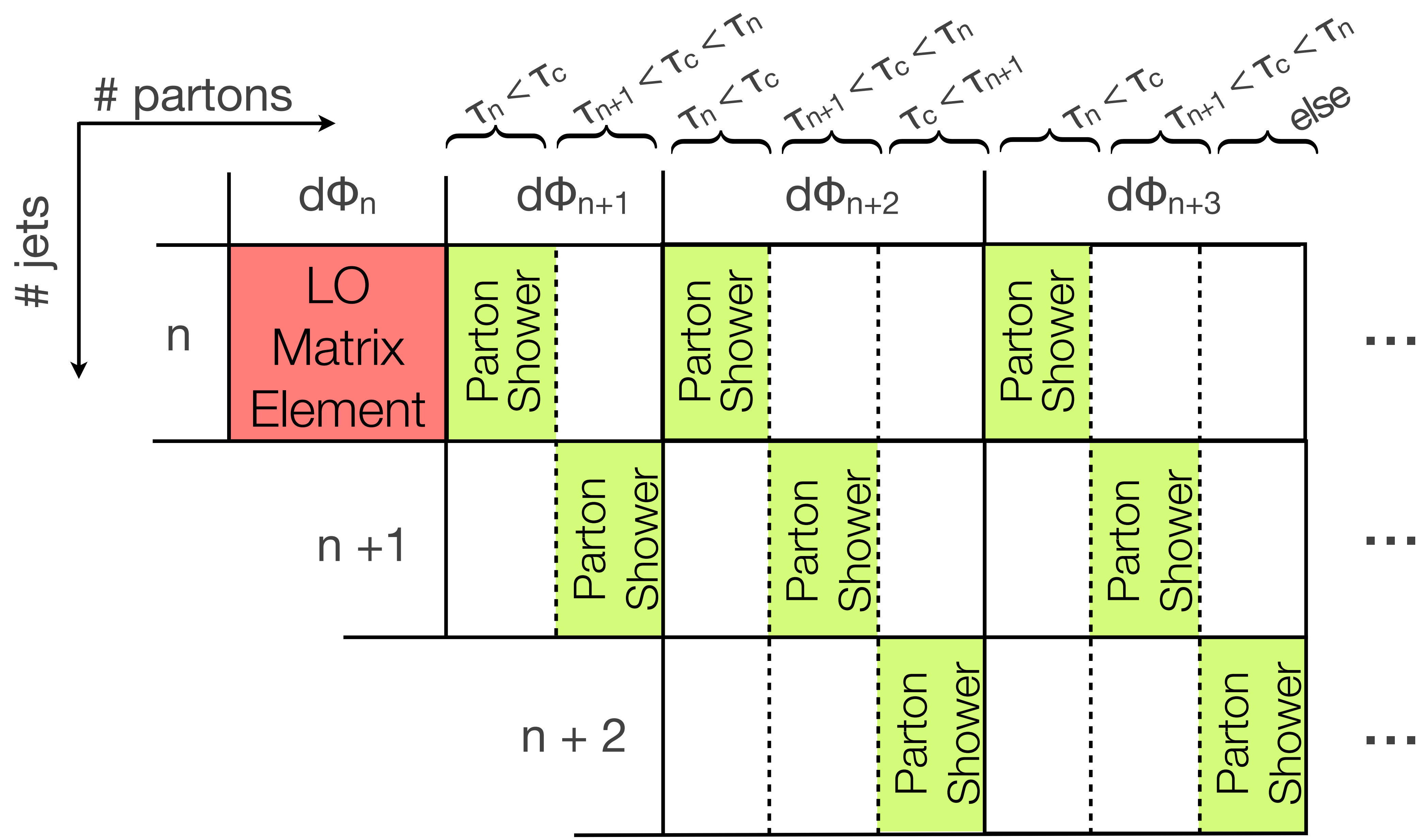
The Parton Shower (PS)

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



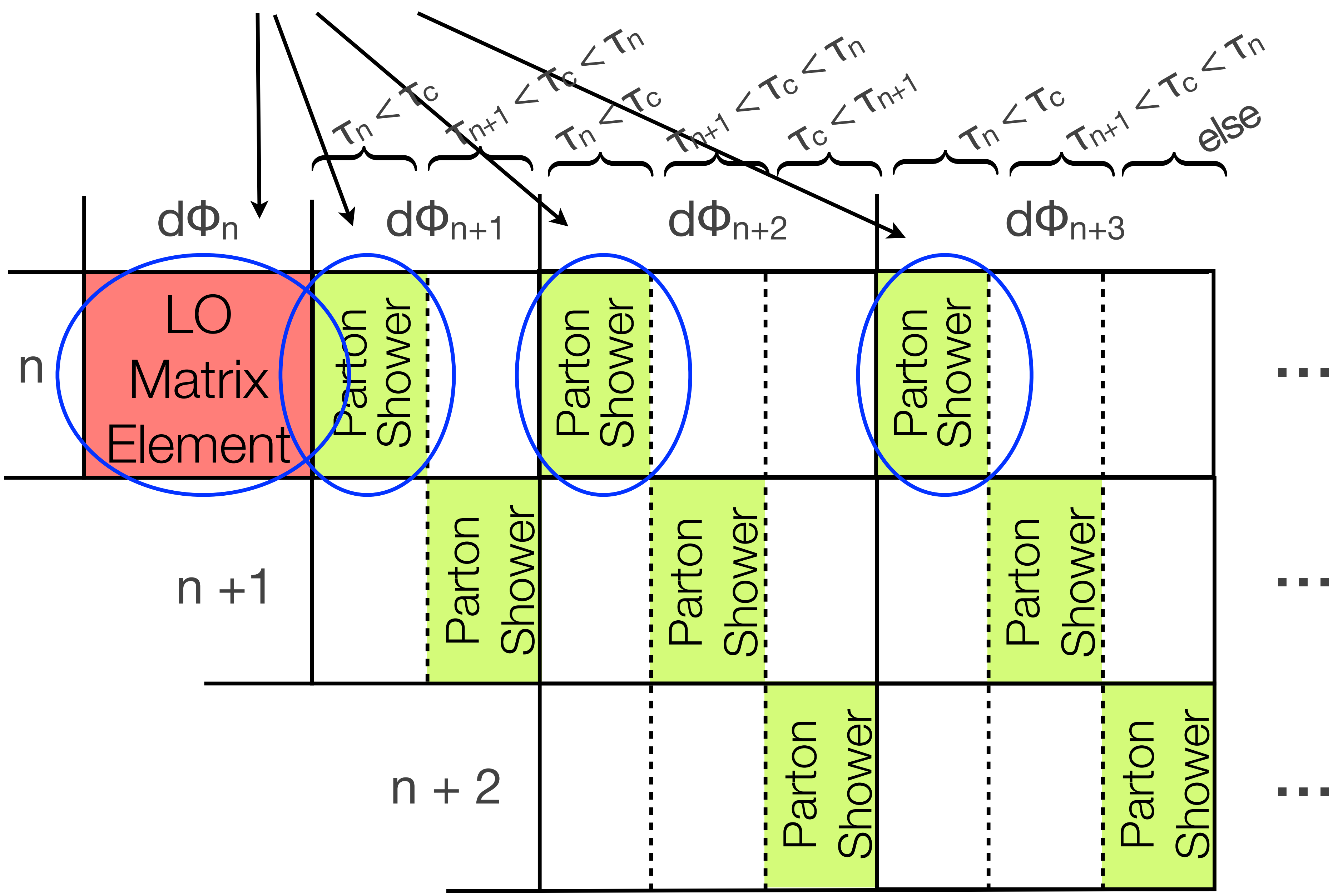
The Parton Shower (PS)

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



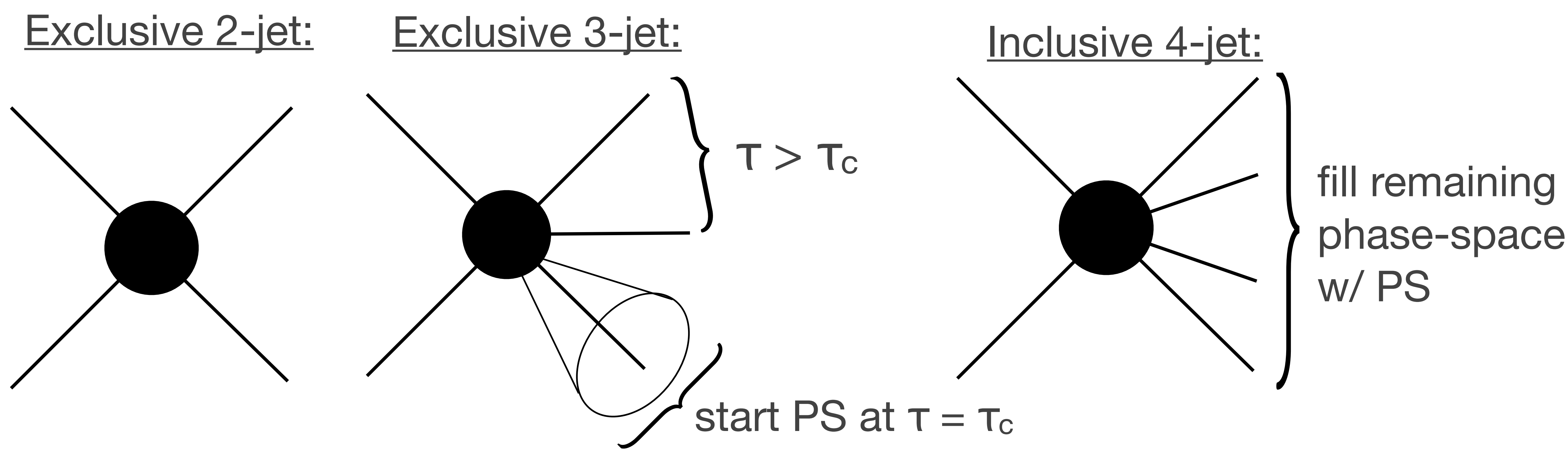
The Parton Shower (PS)

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



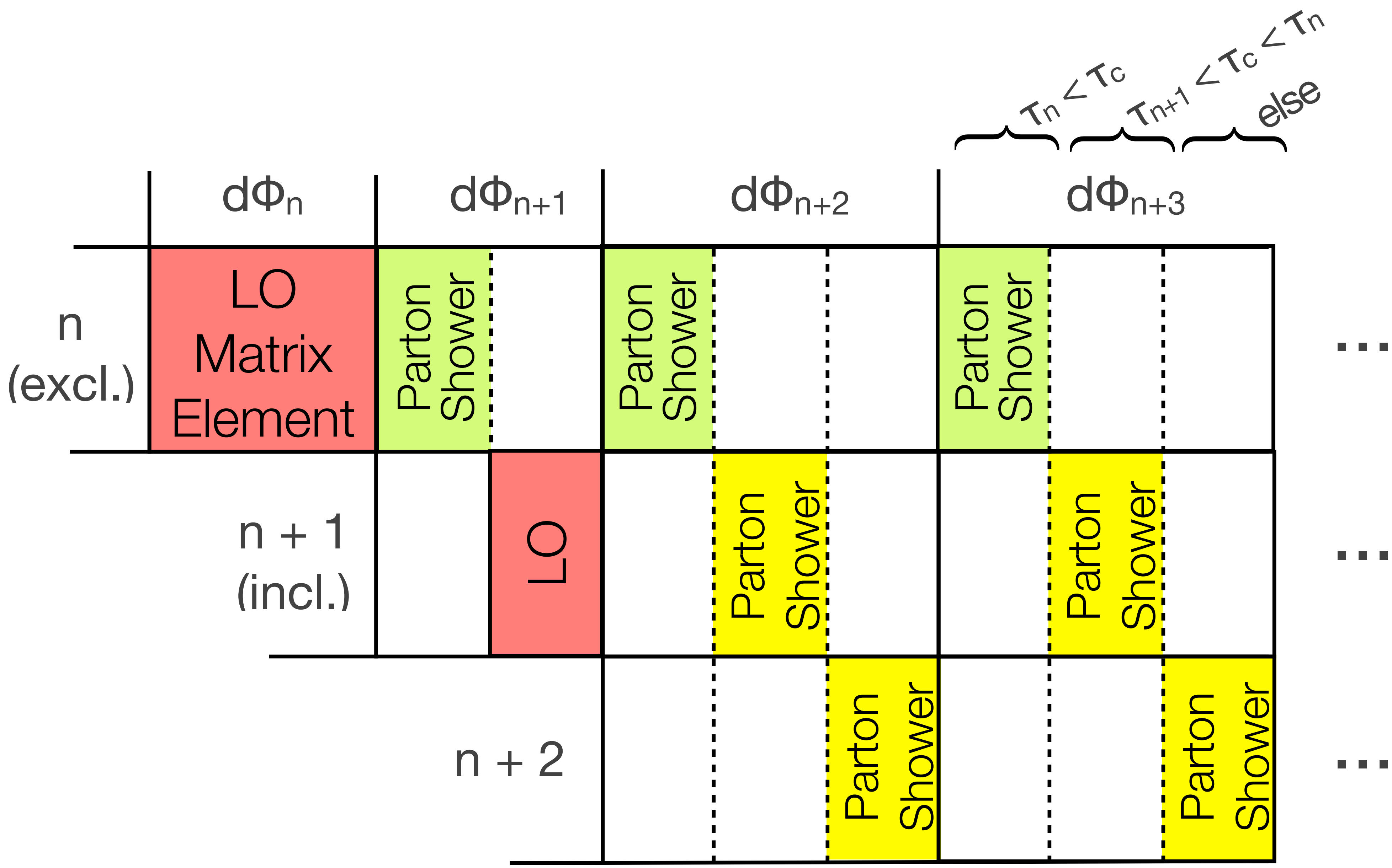
How to Merge many LO + PS (e.g., CKKW/MLM)

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



- correct at LO, LL (partial NLL)
- ME calculation needs LL resummation to match PS

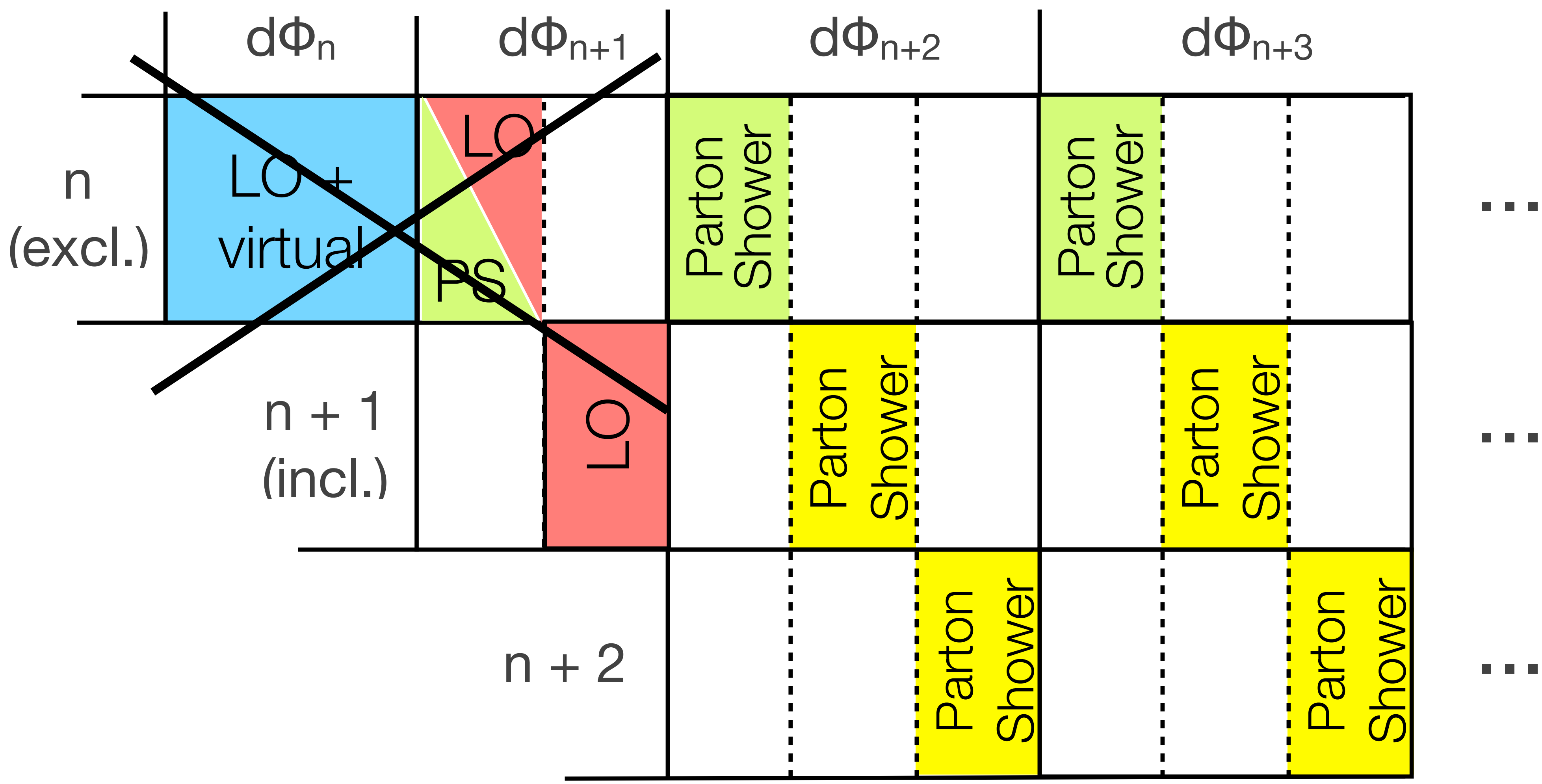
How to Merge LO + PS (e.g., CKKW/MLM)



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

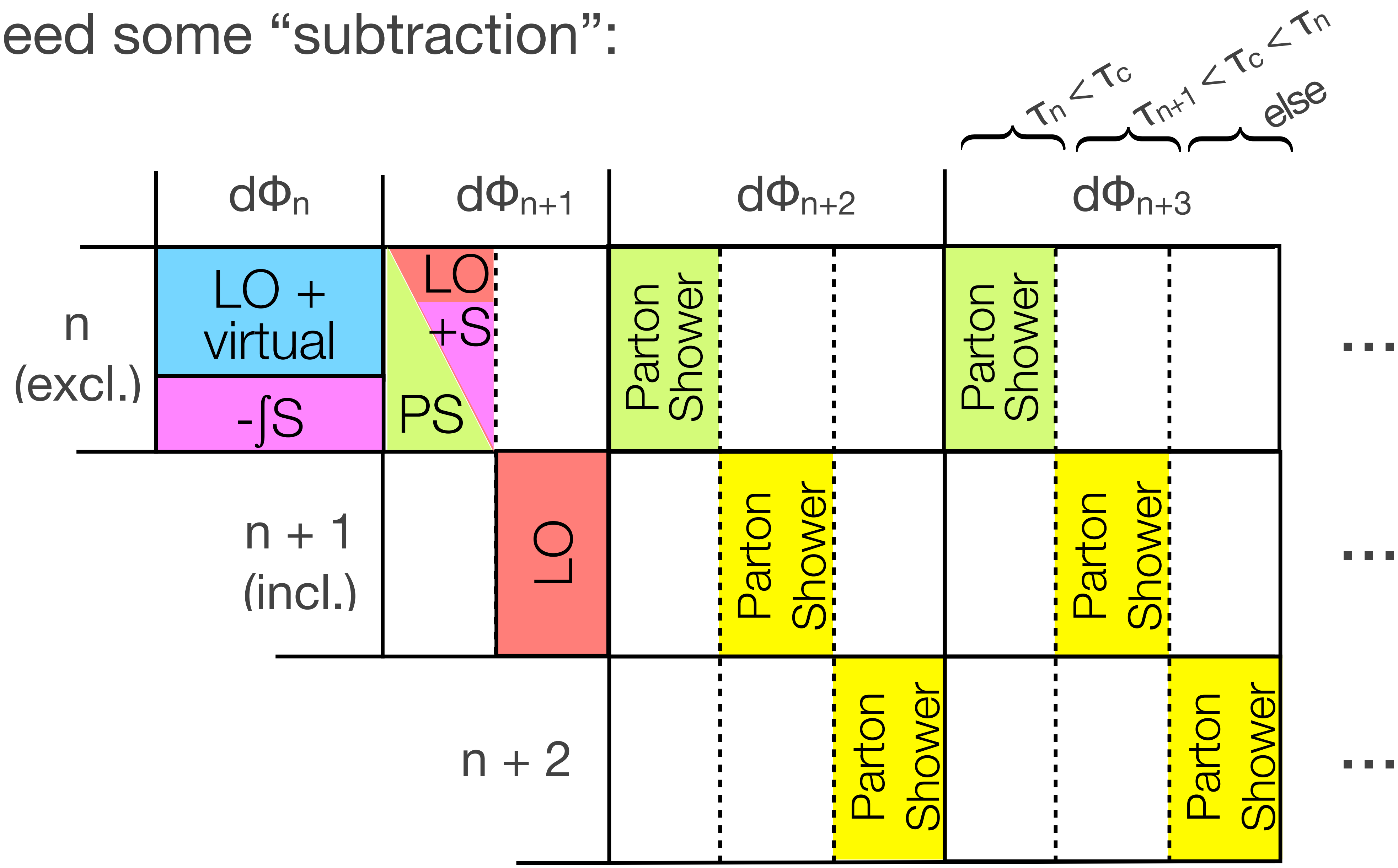
NLO + PS

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



NLO + PS: MC@NLO, POWHEG

- need some “subtraction”:

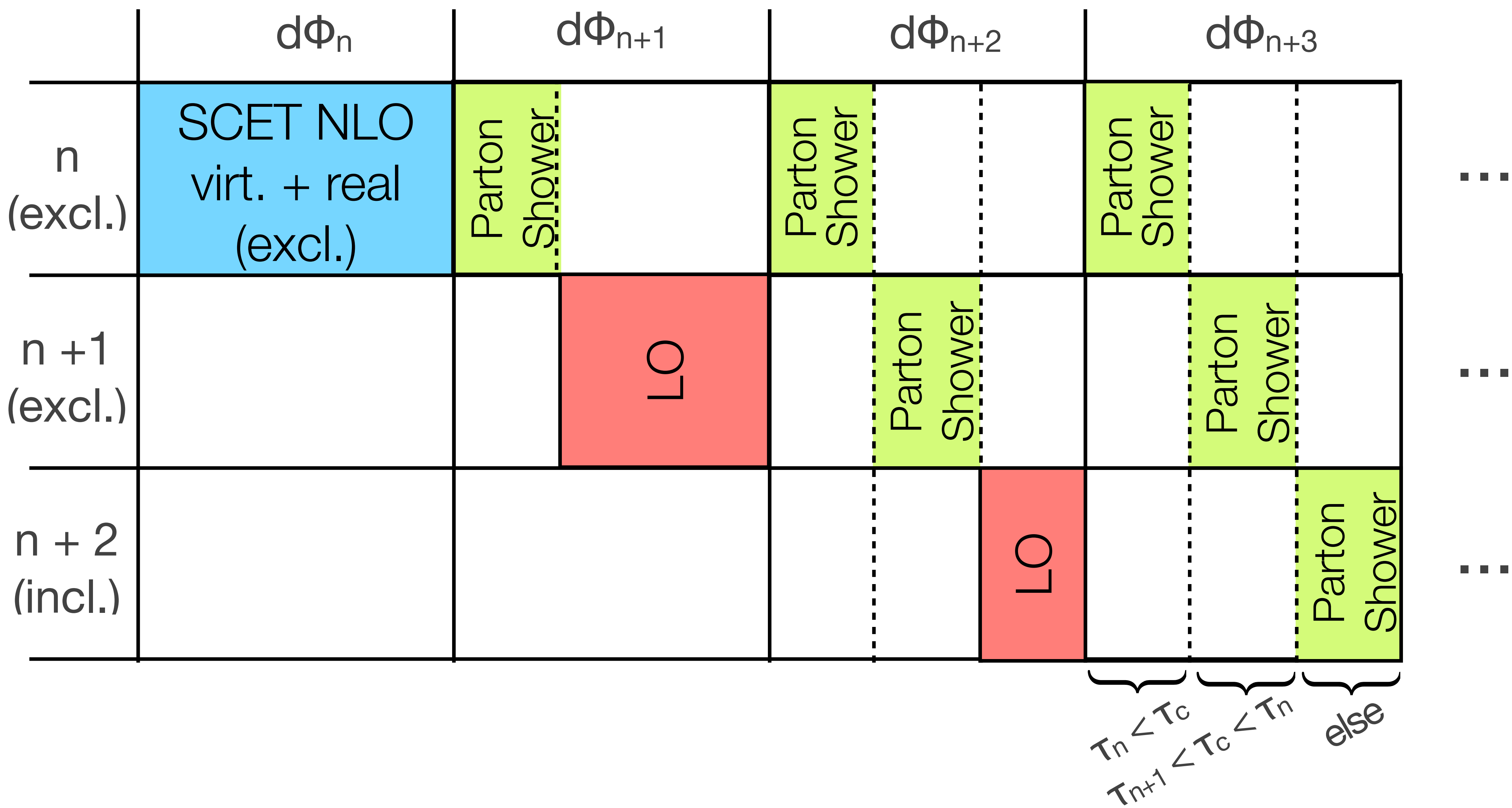


Difficulties in Merging NLO + PS

- unlike CKKW, not just one approx. is valid here:
    - need to combine (exact) real emission ($d\Phi_{n+1}$), with virtual corrections ($d\Phi_n$), at least in the singular limits
    - it's precisely in these singular (soft/collinear) limits 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

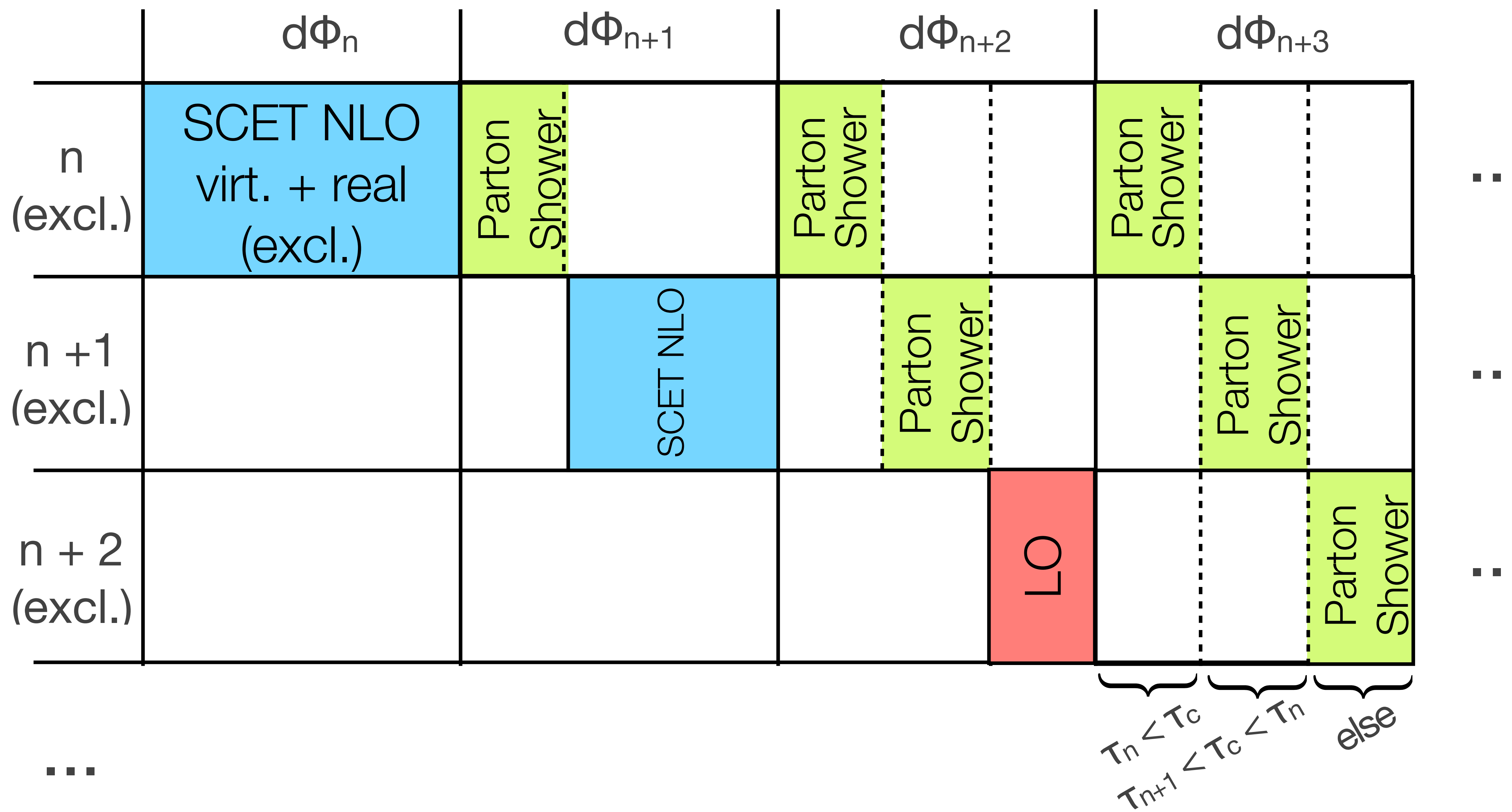
NLO + PS: Geneva (v1.0)

- Use exclusive NLO cross section for $d\Phi_n$ (calculable in SCET)



Many NLO+PS: Geneva (v1.0)

- Can have any number of NLO/LO matrix elements



Why SCET?

Woodchuck

Groundhog

(According to first hits on Google image search...)

Woodchuck

Groundhog

Actually the SAME ANIMAL.

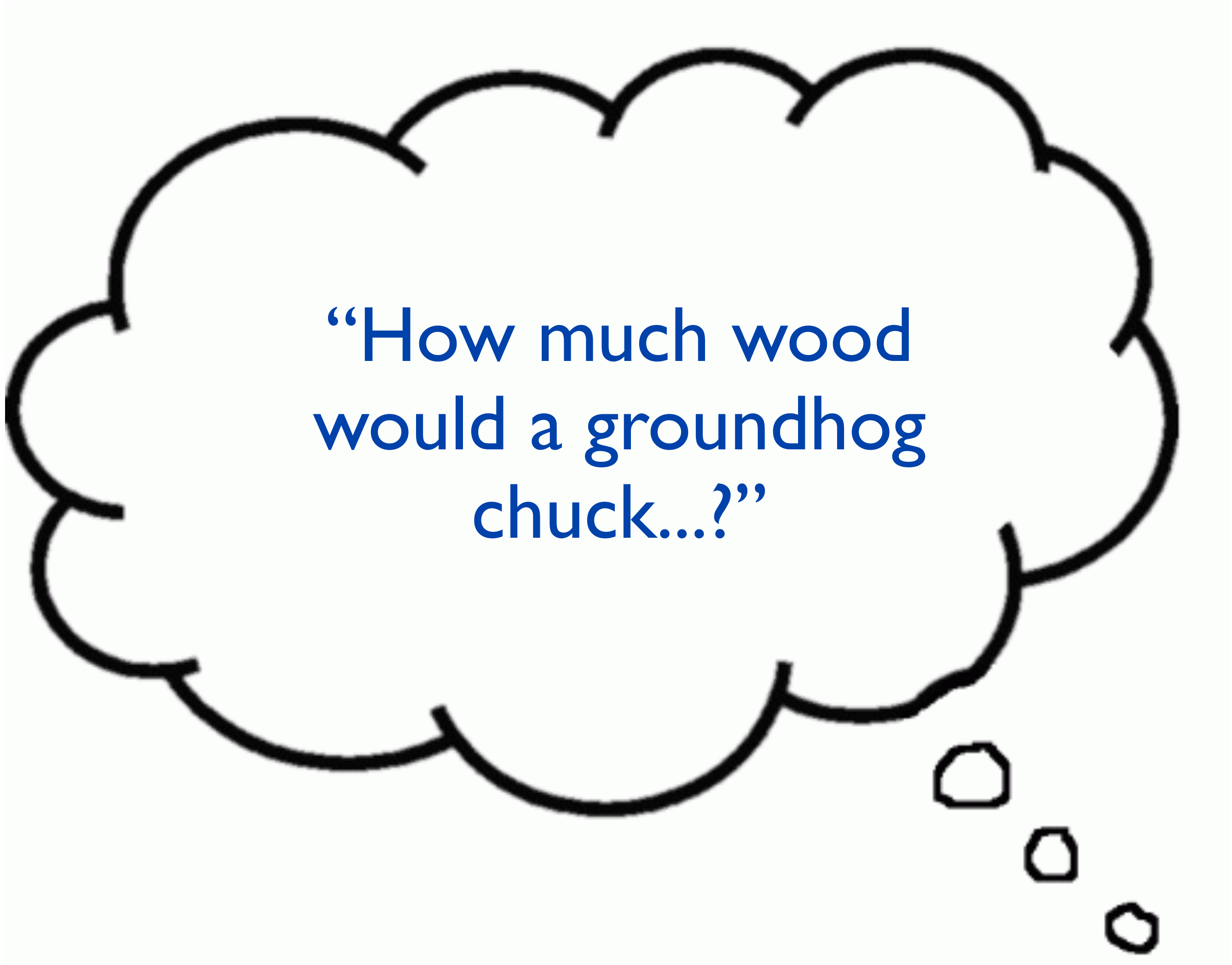


Woodchuck

Groundhog

Actually the SAME ANIMAL.

Sometimes one description is preferable:



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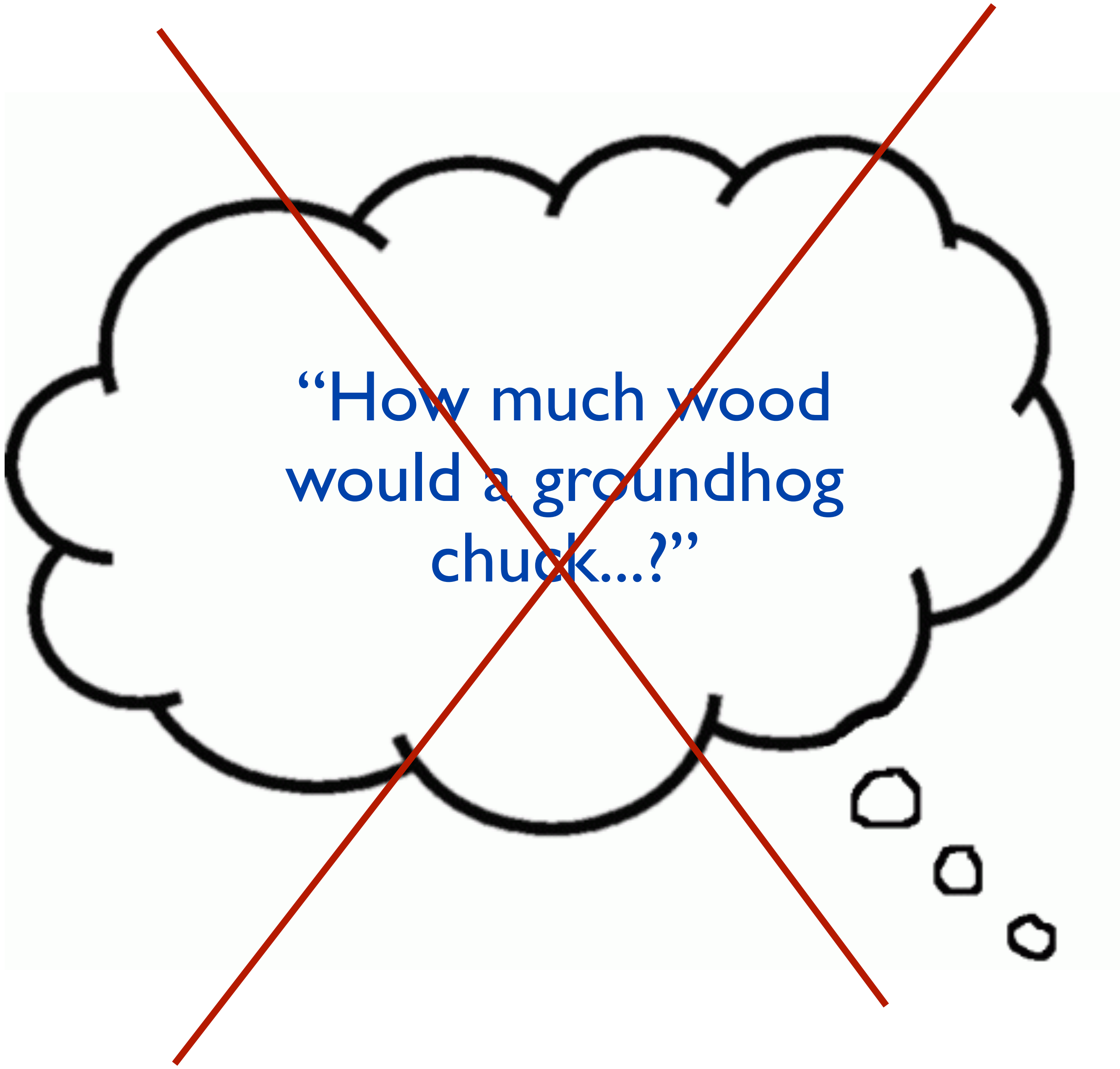
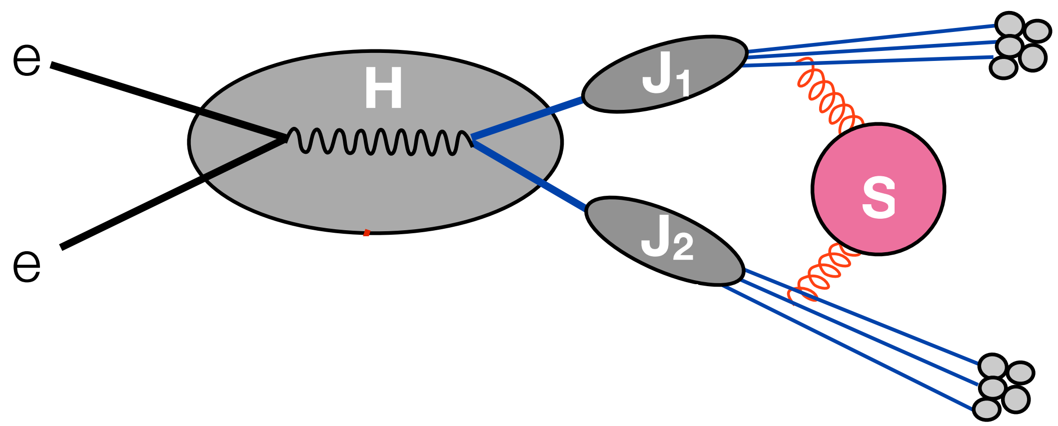
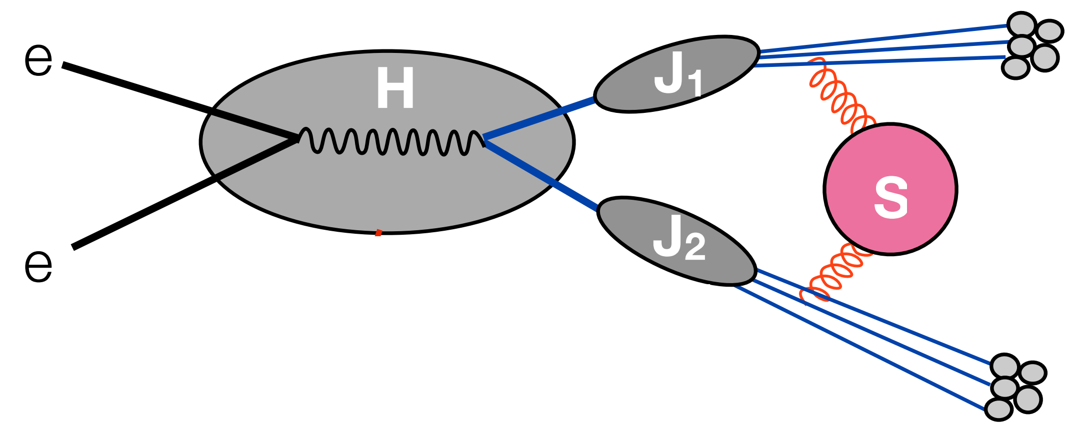




SCET



QCD

Same physics!

SCET just makes certain calculations easier.

Soft-Collinear Effective Theory

Bauer, Fleming, Luke:
Phys Rev D63, 014006 (2000)
Bauer, Fleming, Pirjol, Stewart:
Phys Rev D63, 114020 (2001)
Bauer, Stewart:
Phys Lett B516, 134-142 (2001)
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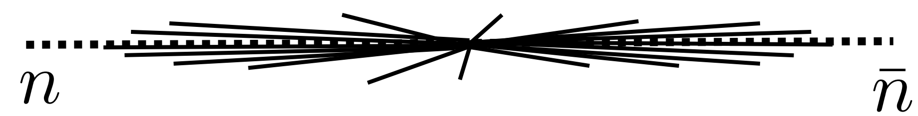
Phys Rev D65, 054022 (2002)

- Soft-collinear effective theory (SCET) is an effective theory of QCD at high energies
- SCET separates dynamics at different energy/distance scales
  - Soft and collinear modes become different fields in SCET, matching to QCD with hard modes
- Can prove factorization theorems more easily in SCET
  - Hard (H), jet (J1,J2), and soft (S) functions are separately calculable
  - Each function incorporates physics at a different distance scale



$$n = (1, 0, 0, 1) \qquad \bar{n} = (1, 0, 0, -1)$$

$$p = (n \cdot p, \bar{n} \cdot p, p_\perp)$$

(SCET slides from J. Walsh)

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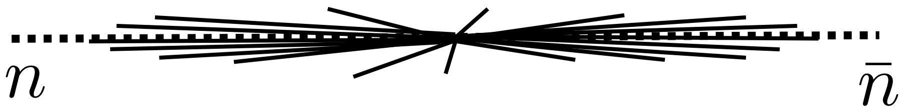

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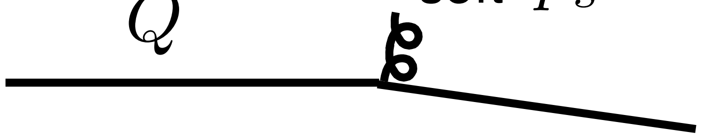
$$p = (n \cdot p, \bar{n} \cdot p, p_\perp)$$

$$\lambda \equiv \frac{p_\perp}{Q} \ll 1$$

soft $p_s \sim Q(\lambda^2, \lambda^2, \lambda^2)$



collinear $p_c \sim Q(\lambda^2, 1, \lambda)$

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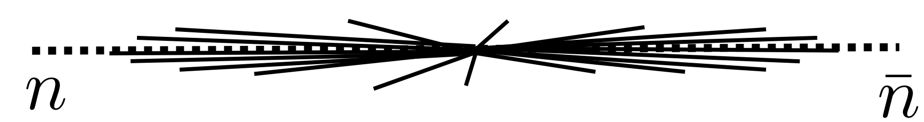

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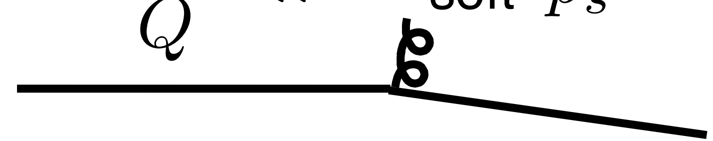

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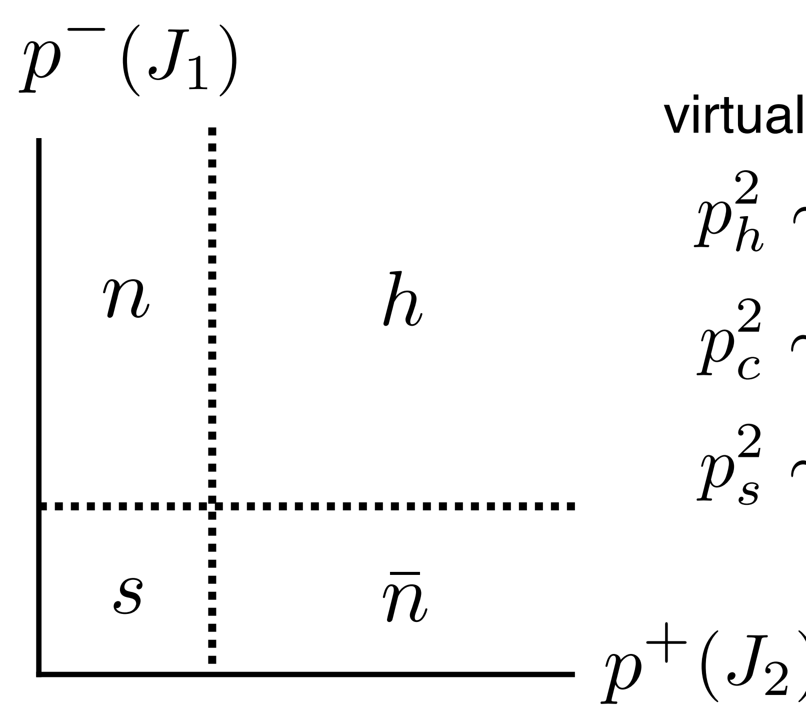

virtuality of modes:

$p_h^2 \sim Q^2$

$p_c^2 \sim Q^2\lambda^2$

$p_s^2 \sim Q^2\lambda^4$

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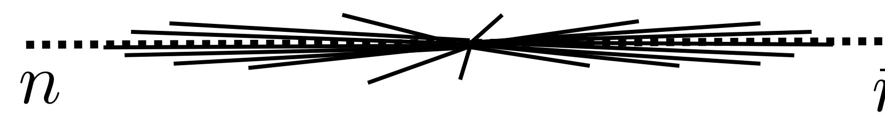

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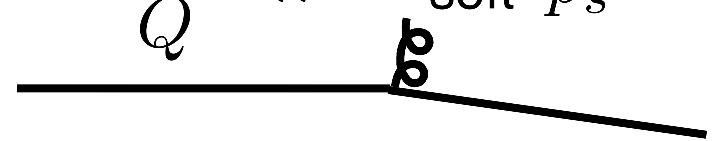

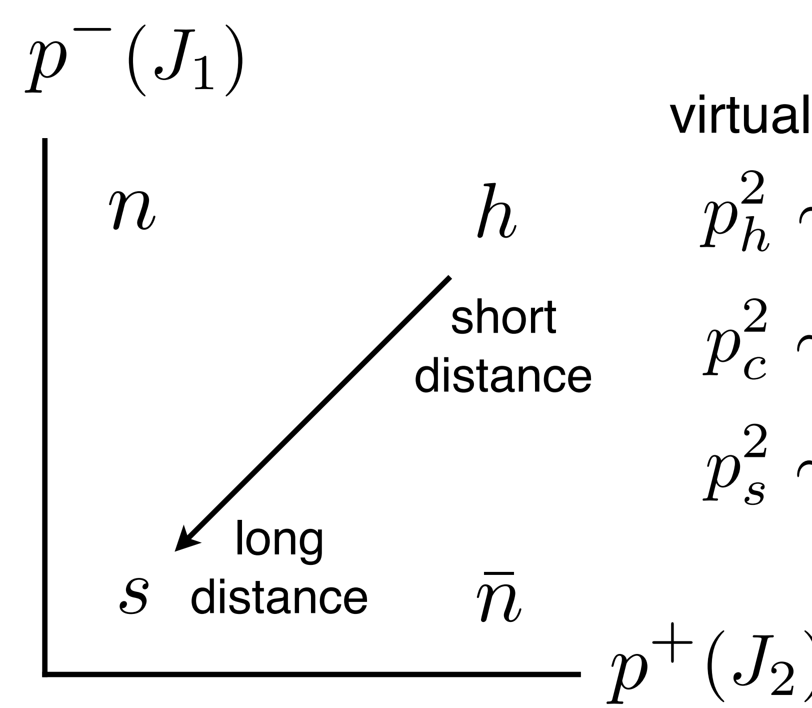

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$p_h^2 \sim Q^2$

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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):

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

↖ Born cross-section

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

- H (“hard” func.): QCD virtual corrections ($\overline{\mathrm{MS}}$)
- J, S (“jet”/“soft” funcs.): real emission corrections in collinear, soft limits
- RGE of H/J/S from μ to $Q/Q\tau^{1/2}/Q\tau$ 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^3LL/NNLO) Becher, Schwartz ‘08

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

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

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:

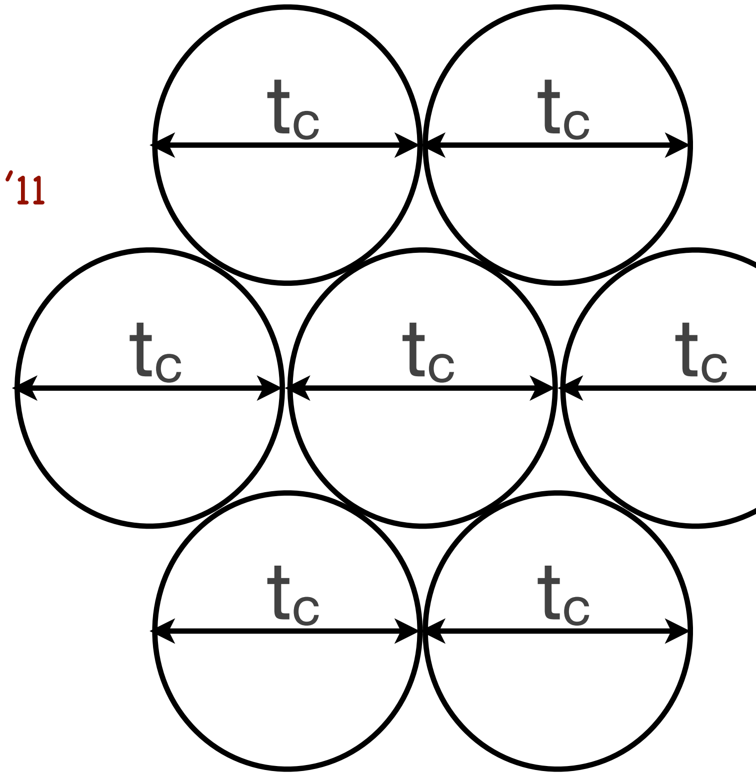
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\tau} = \int \mathrm{d}k \left(\frac{\mathrm{d}\hat{\sigma}_{\mathrm{s}}}{\mathrm{d}\tau} + \frac{\mathrm{d}\hat{\sigma}_{\mathrm{ns}}}{\mathrm{d}\tau}\right)\left(\tau - \frac{k}{Q}\right) S^{\mathrm{mod}}(k)$$

- 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

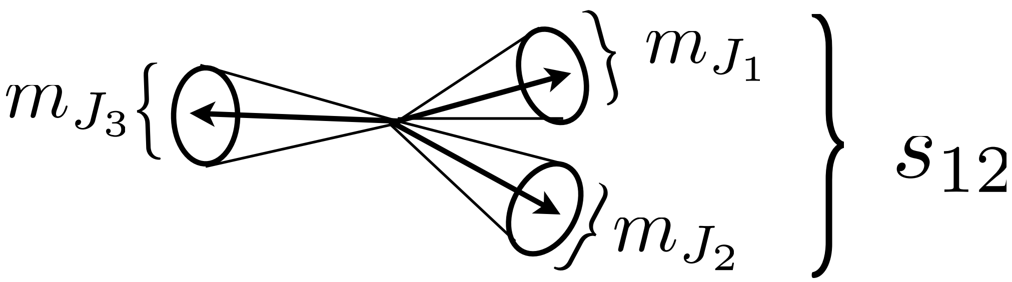
  ⇒ generate other soft funcs numerically   Bauer, Dunn, AH '11



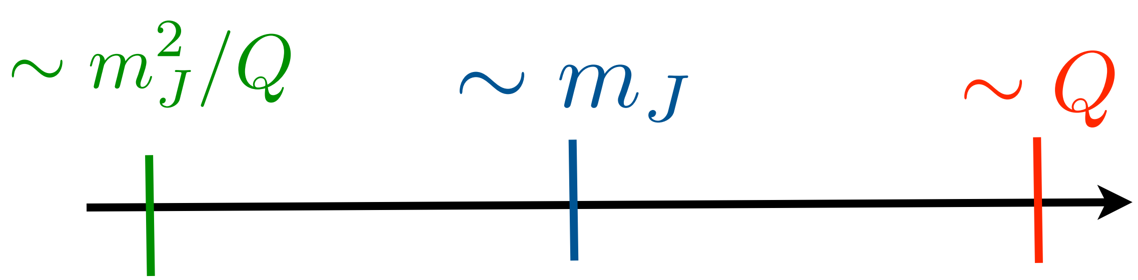
Ongoing work...

Kinematic Logs in SCET (generalized CKKW)

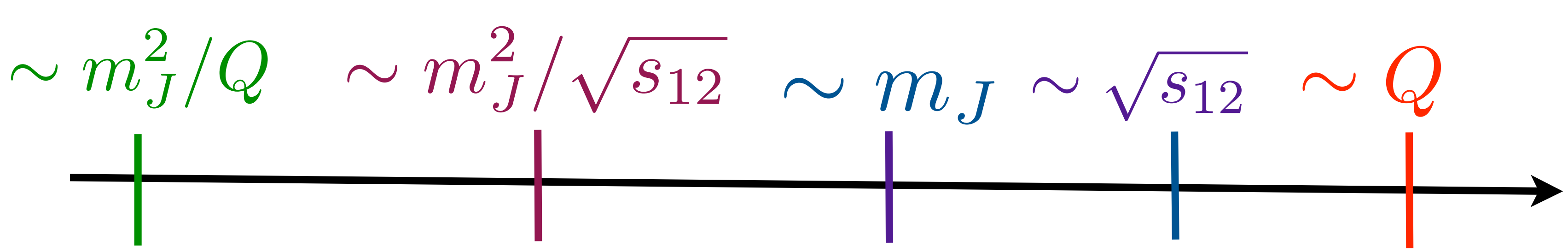
Bauer, Tackmann, Walsh, Zuberi



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

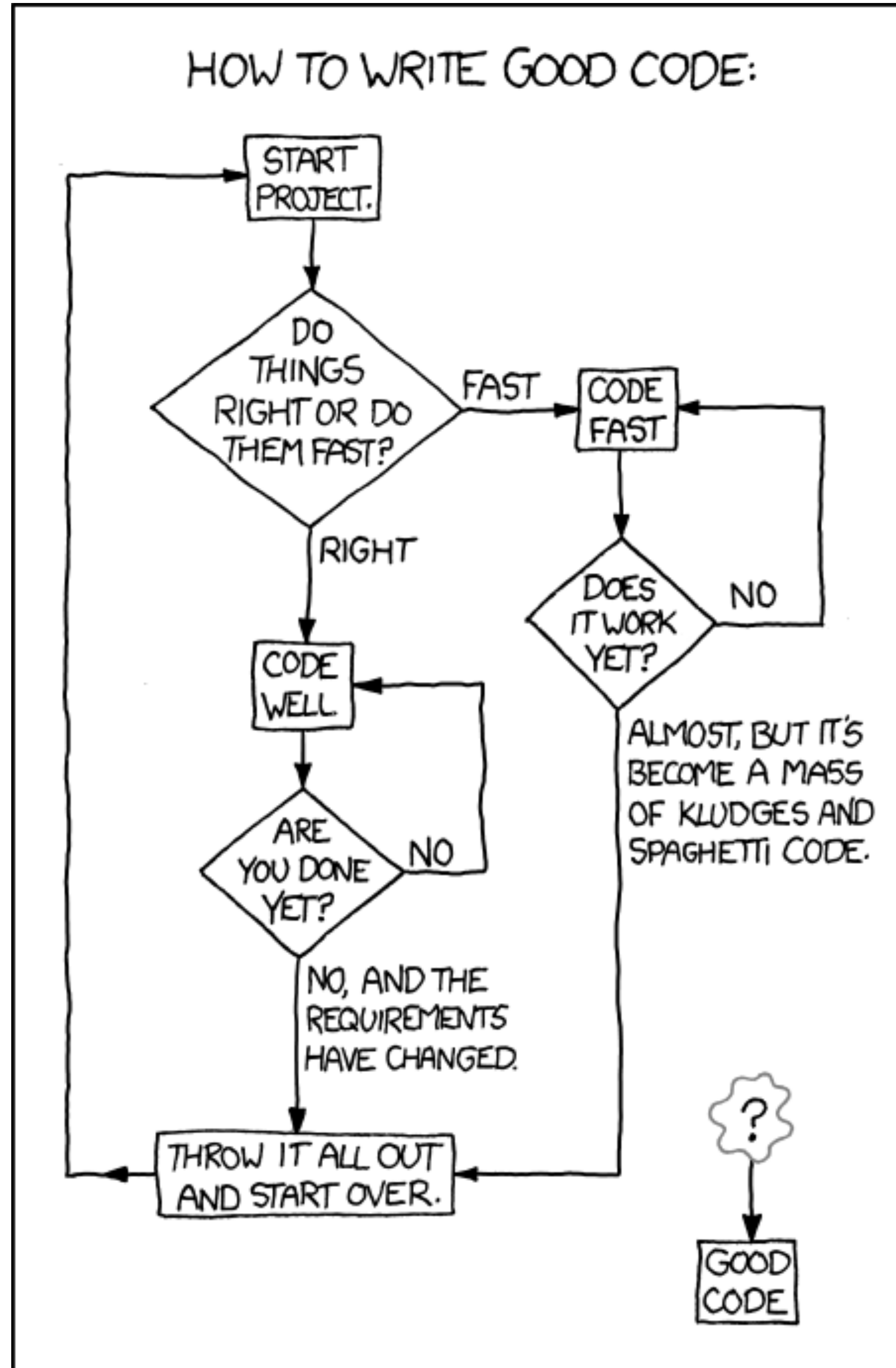


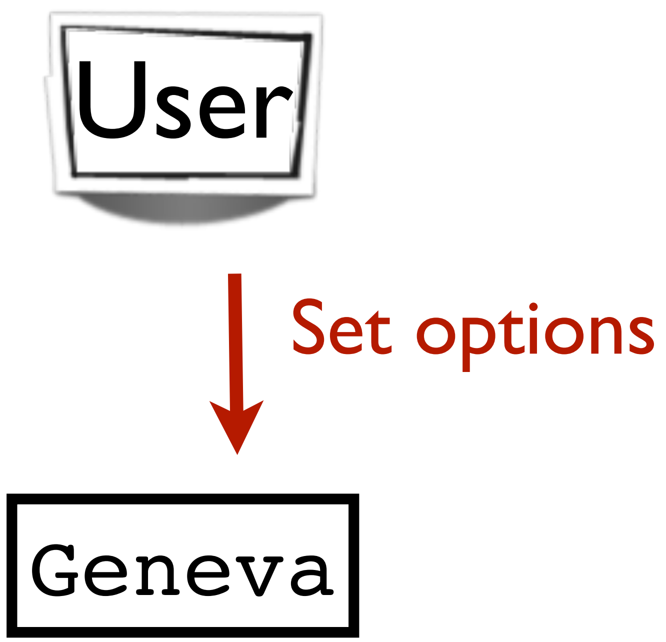
- “SCET+”: Q >> s_{12} >> m_{J1} ~ m_{J2}~ m_{J3}

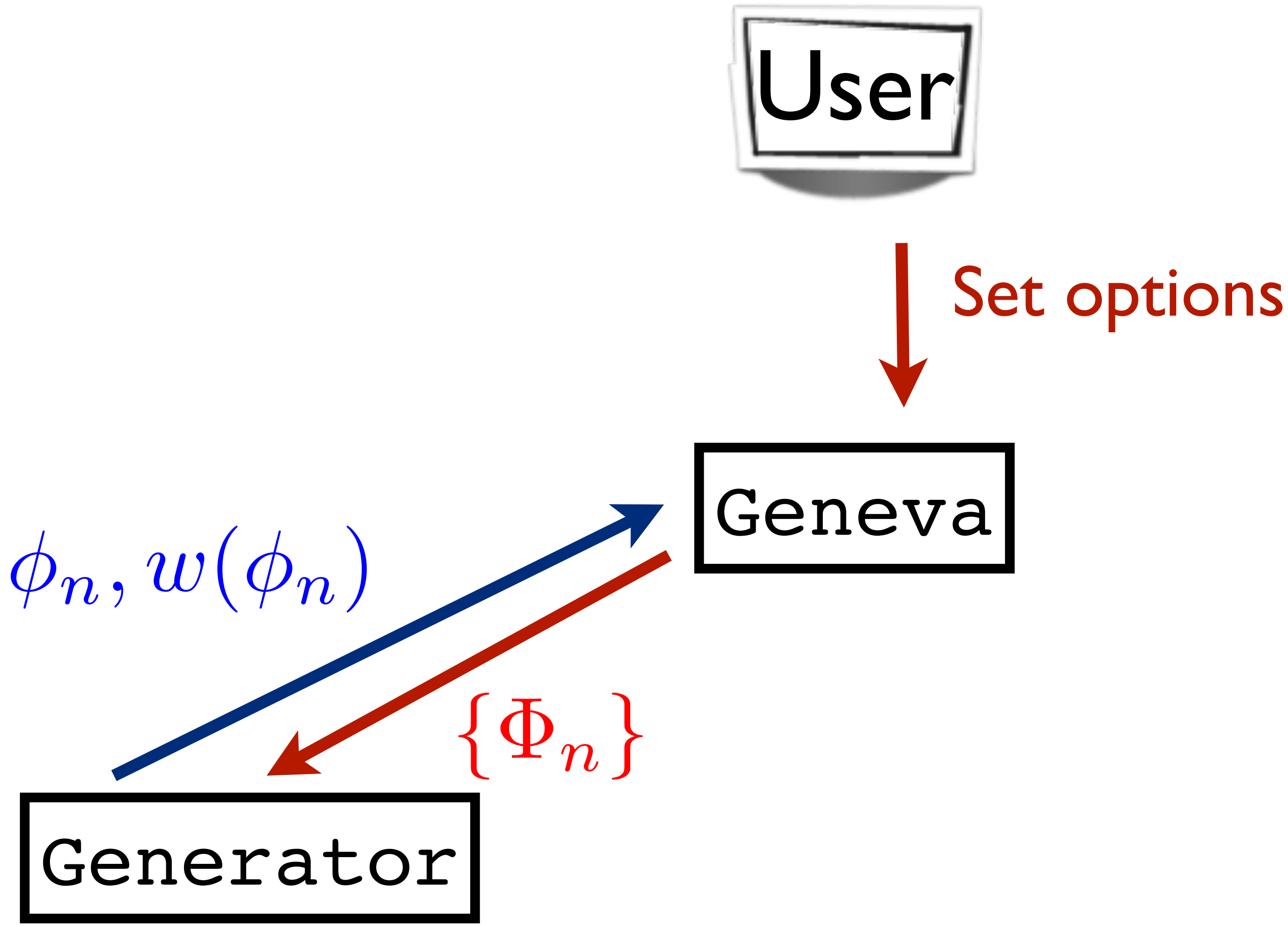


GenEvA Code

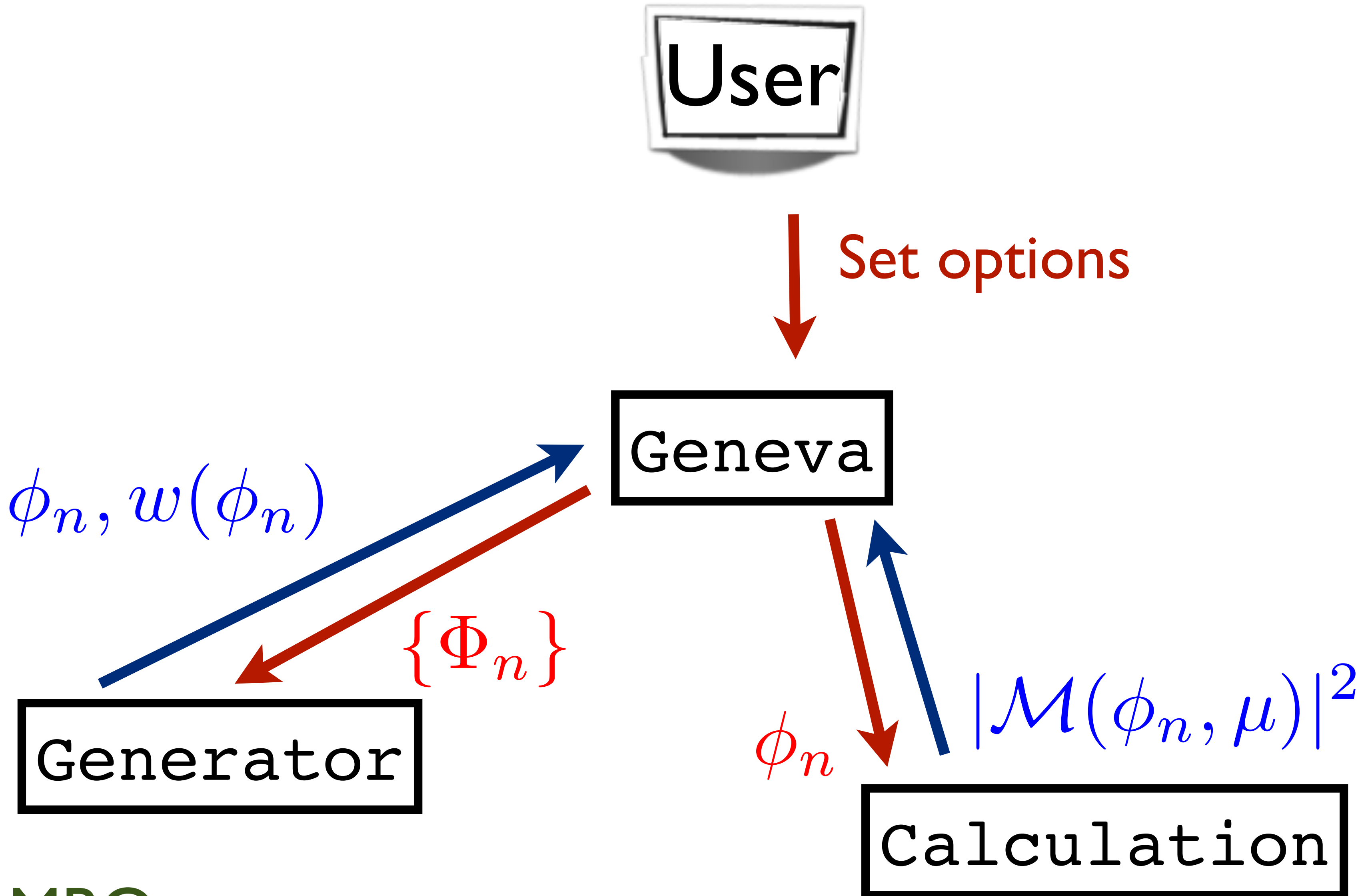
- "Pure" C++
- Modular
- Easy to read (objects ↔ physics)
- Fully Doxygenated
- (Hopefully) proving xkcd wrong!
    - Usual story of physicists trying to work out project management, software design, etc. *do novo*...




User
Set options
Geneva

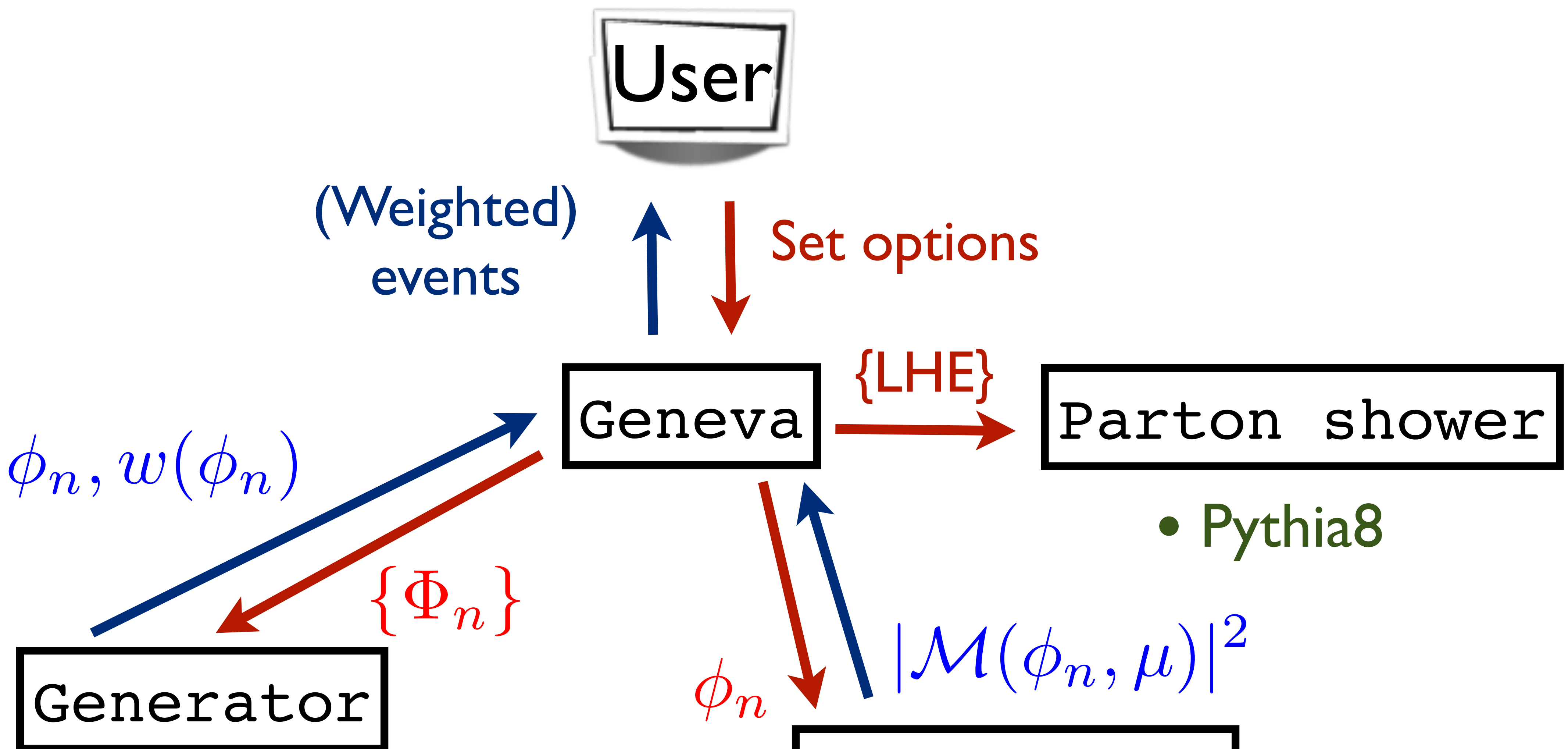


- RAMBO
- "Analytic Shower"
  ("GenEvA algorithm")



- RAMBO
- "Analytic Shower" ("GenEvA algorithm")

- LO
- LO/LL
- LO/LL (SCET)
- LO/LL (Shower)
- NLO (SCET)
- NLO_2/LL (SCET)
- NLO_3/LL (SCET)*

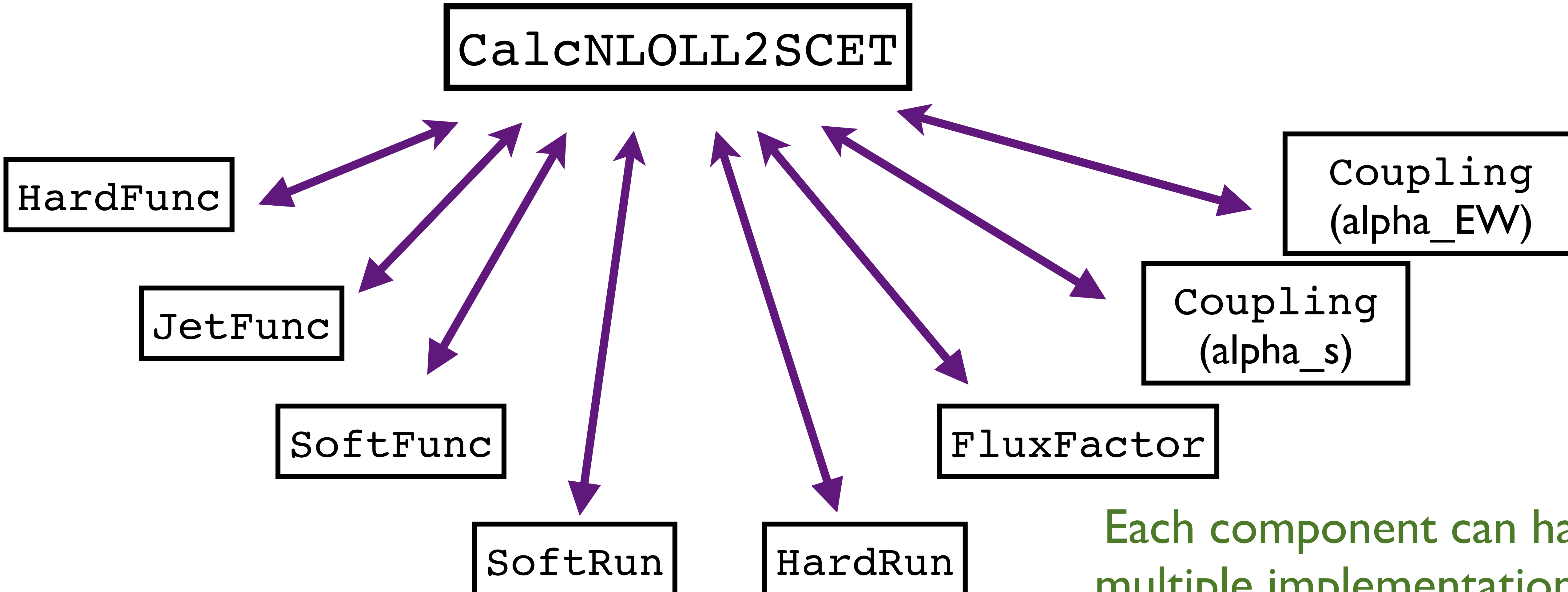


- Pythia8

- RAMBO
- "Analytic Shower" ("GenEvA algorithm")

- LO
- LO/LL
- LO/LL (SCET)
- LO/LL (Shower)
- NLO (SCET)
- NLO_2/LL (SCET)
- NLO_3/LL (SCET)*

Calculations built up from components

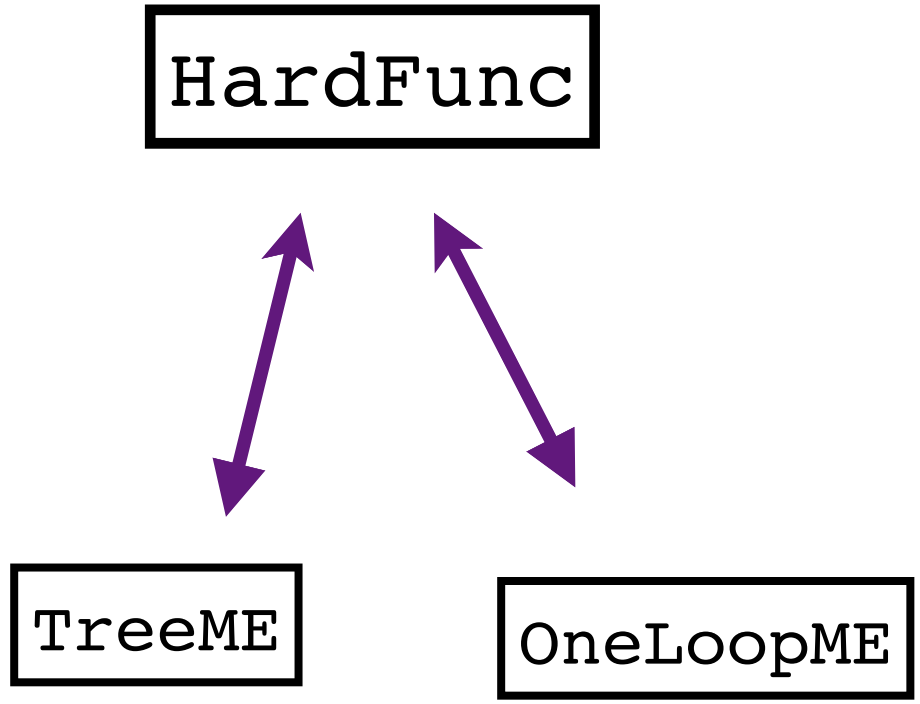


Each component can have multiple implementations...

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Phi_2}(t_{\mathrm{cut}}) = B_2(\Phi_2)\Big[1+H_2(\Phi_2)+J+S_2(\Phi_2)+\mathrm{NLL}_H+\mathrm{NLL}_S\Big]\Pi_2^H(Q,\sqrt{t_{\mathrm{cut}}})\Pi_2^S(t_{\mathrm{cut}}/Q,\sqrt{t_{\mathrm{cut}}})\,. \tag{42}$$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Phi_3} = \frac{16\pi^2}{3}\frac{1}{Q^2-3t_{\mathrm{min}}}\frac{\mathrm{d}}{\mathrm{d}t_{\mathrm{min}}}\left[\frac{\mathrm{d}\sigma}{\mathrm{d}\Phi_2}(t_{\mathrm{min}}) - \frac{\mathrm{d}\sigma_{\mathrm{exp}}}{\mathrm{d}\Phi_2}(t_{\mathrm{min}})\right] + B_3(\Phi_3)$$

Components all the way down



Each component can have multiple implementations...

- MadGraph
- Analytic (ee to 2, 3 jets)

- Analytic (ee to 2, 3 jets)

Goal: Build code/physics out of existing blocks when possible!

Dependency > Redundancy

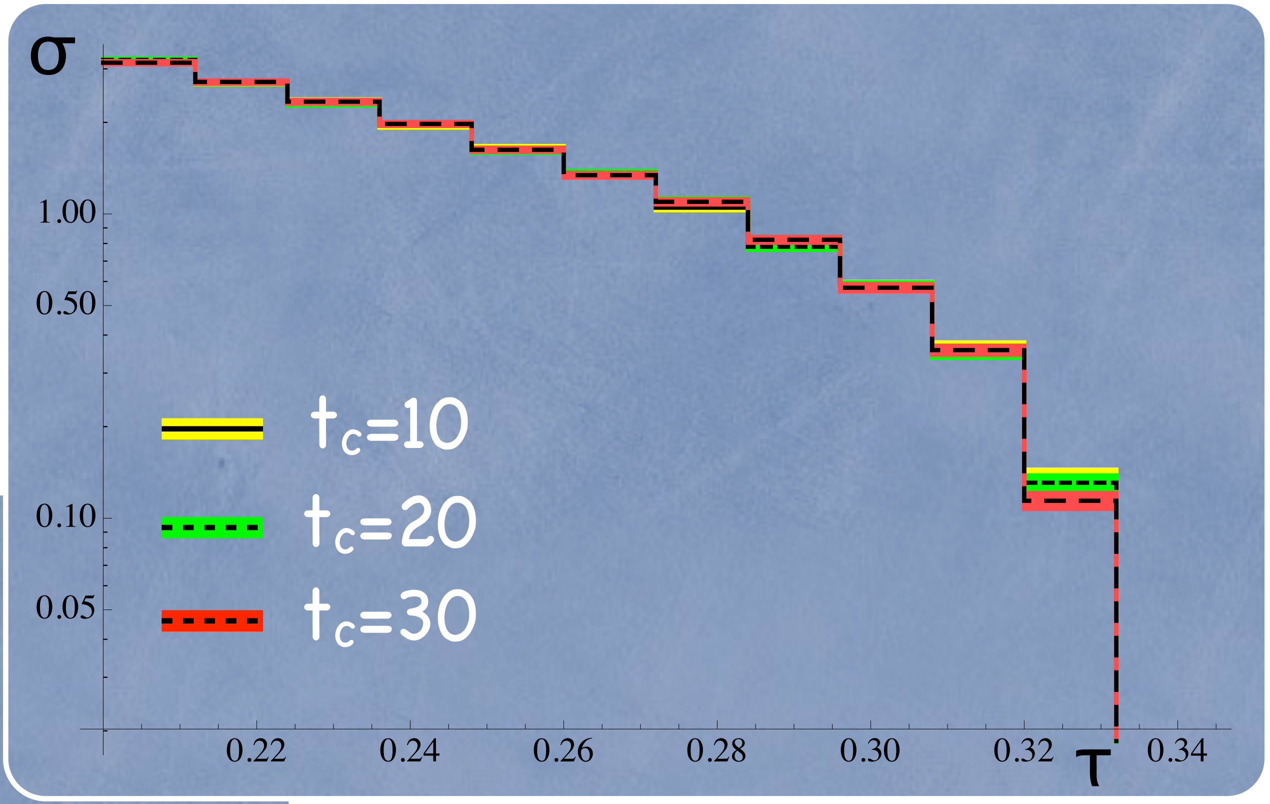
Some interesting features of GenEvA 0.1
(that may or may not survive to 1.0)

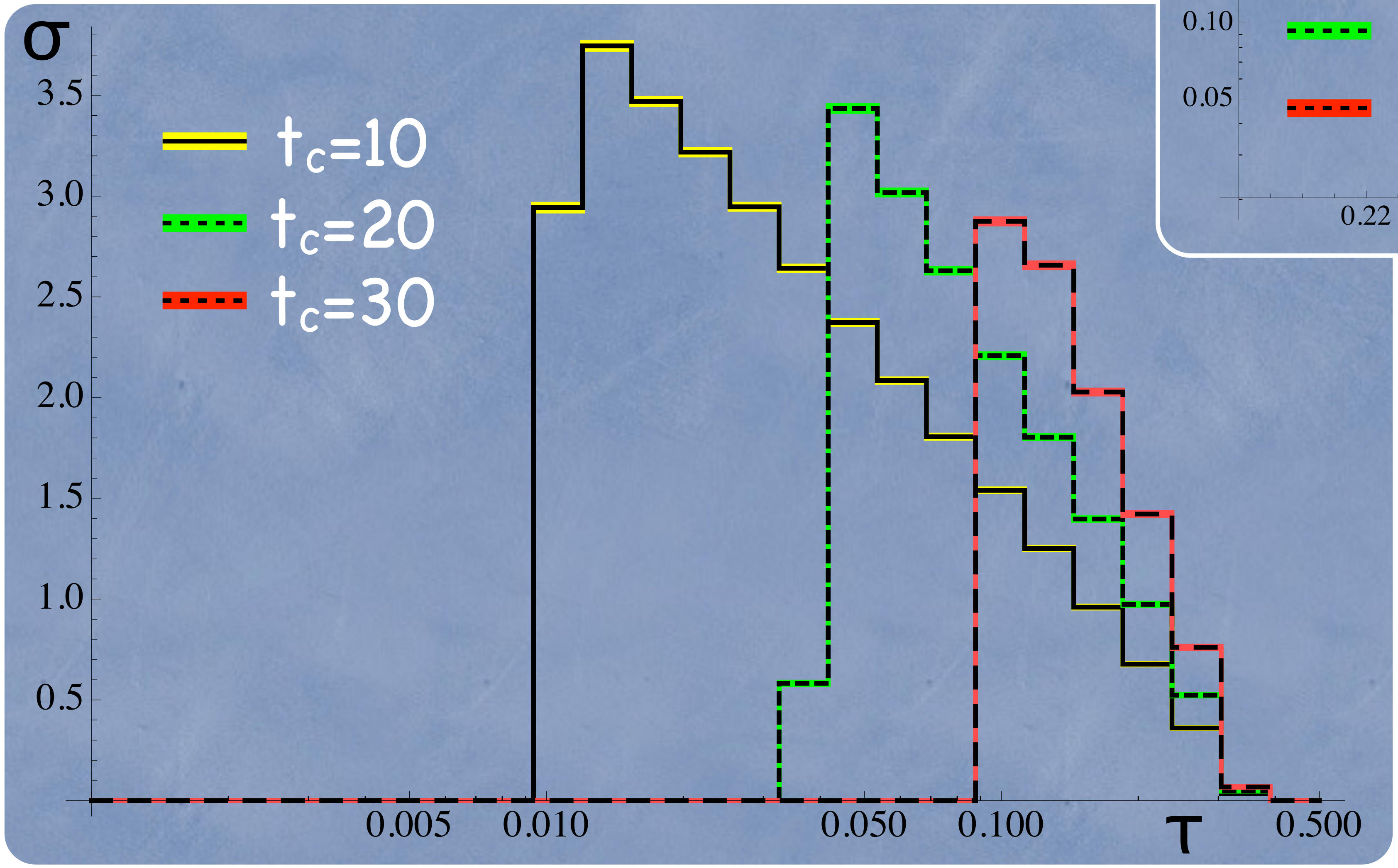
- Analytic parton shower
  - Change how splitting functions work to eliminate momentum re-shuffling -- means that branching probabilities independent
  - Leads to analytic shower weight
    - Re-weightable events! Can re-weight according to better ME, even for a different multiplicity (NLO_2 -> NLO_3, e.g.), even after detector simulation.
  - Not sure if we can extend this to hadron collisions
- Parton shower as phase space generator
  - Requires analytic shower; very efficient for QCD events

(Preliminary) Results: LO only (no shower)

e^+e^- -> qq~g

no events in low thrust region or for τ > 1/3





(Preliminary) Results: LO/LL (no shower)

- LO only:
  - no events in low thrust region or for $\tau > 1/3$
- LO/LL (no shower):
  - double log dependence on t_c

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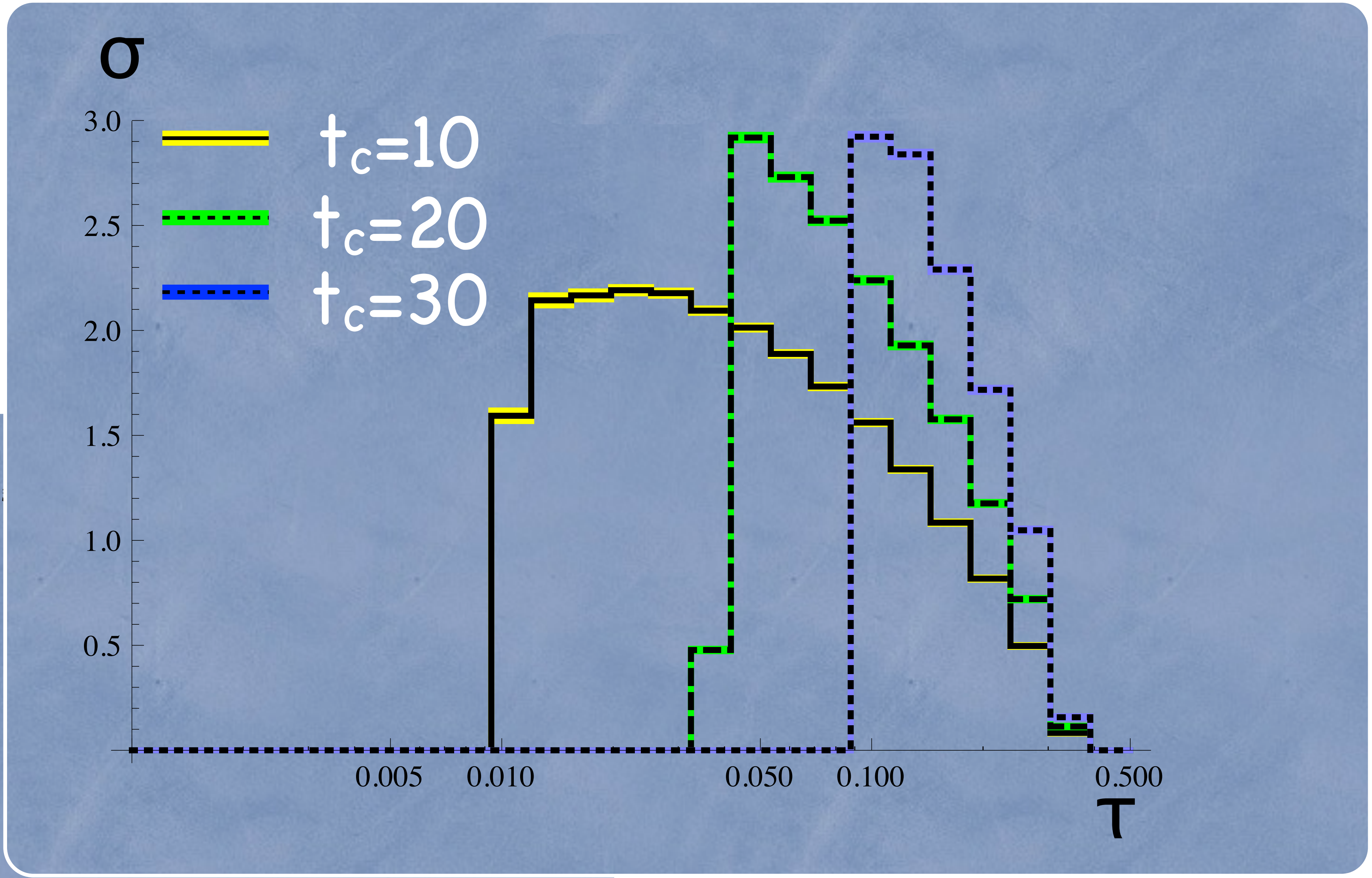
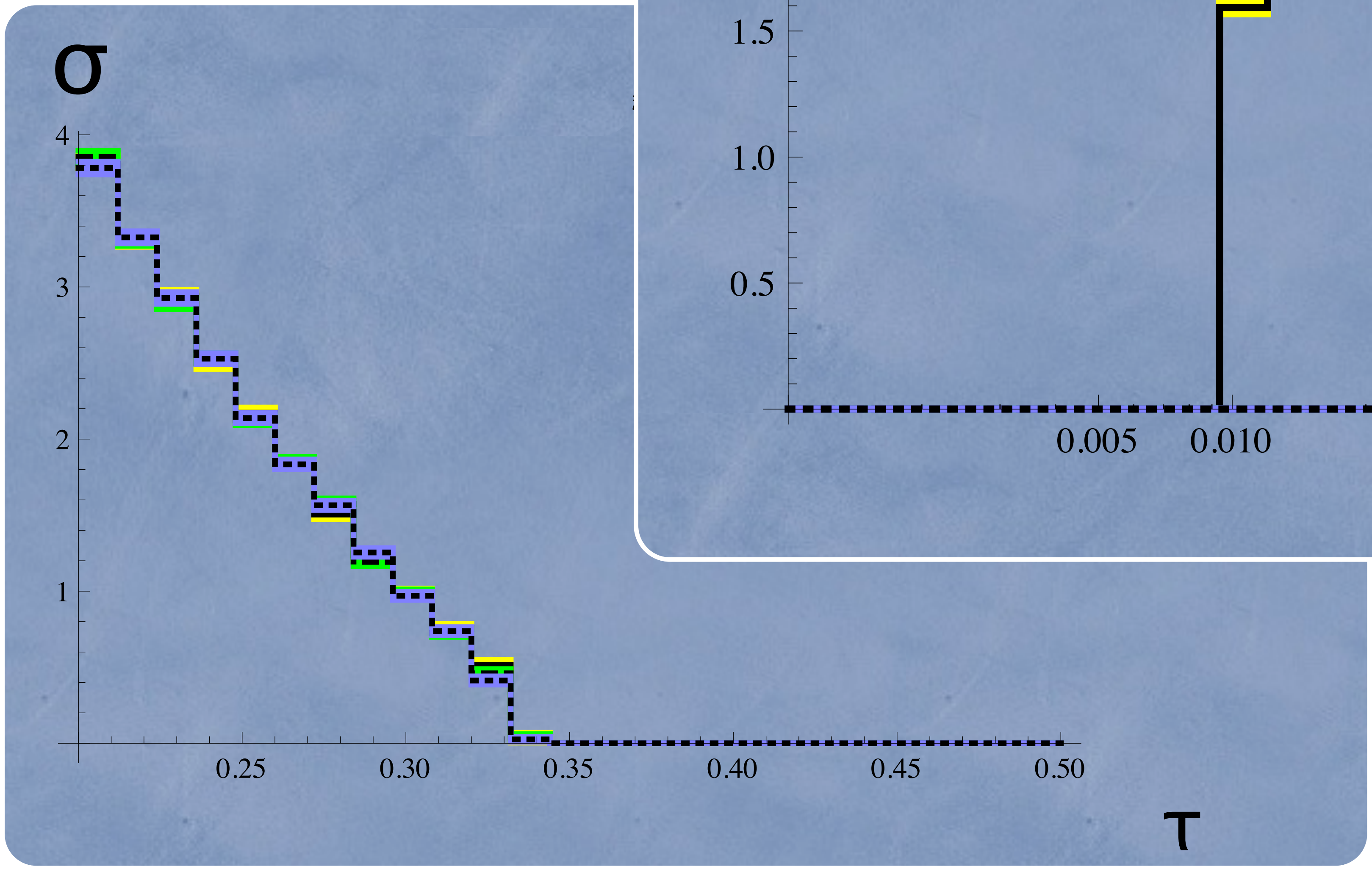




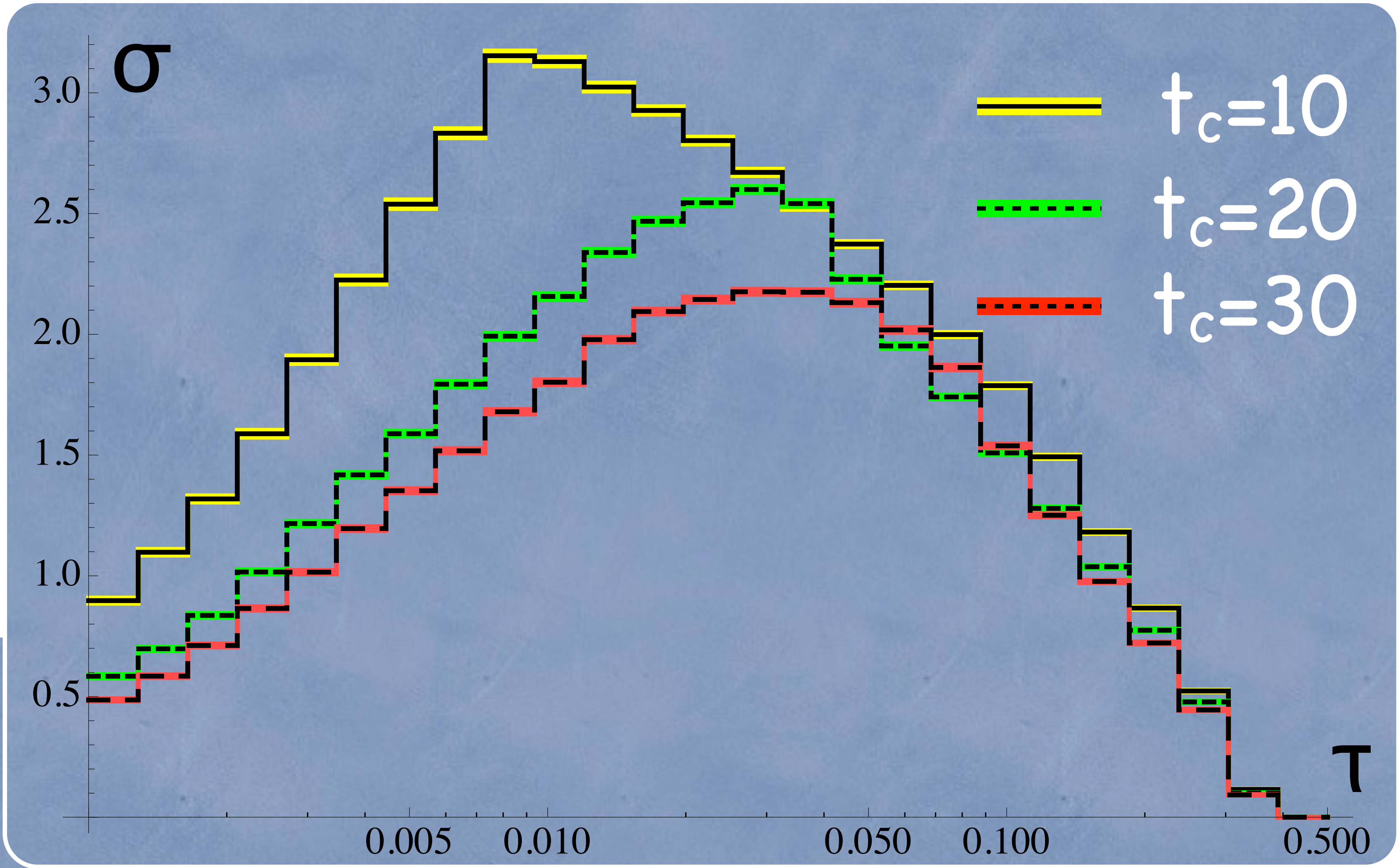
(Preliminary) Results: LO + Pythia (LL)

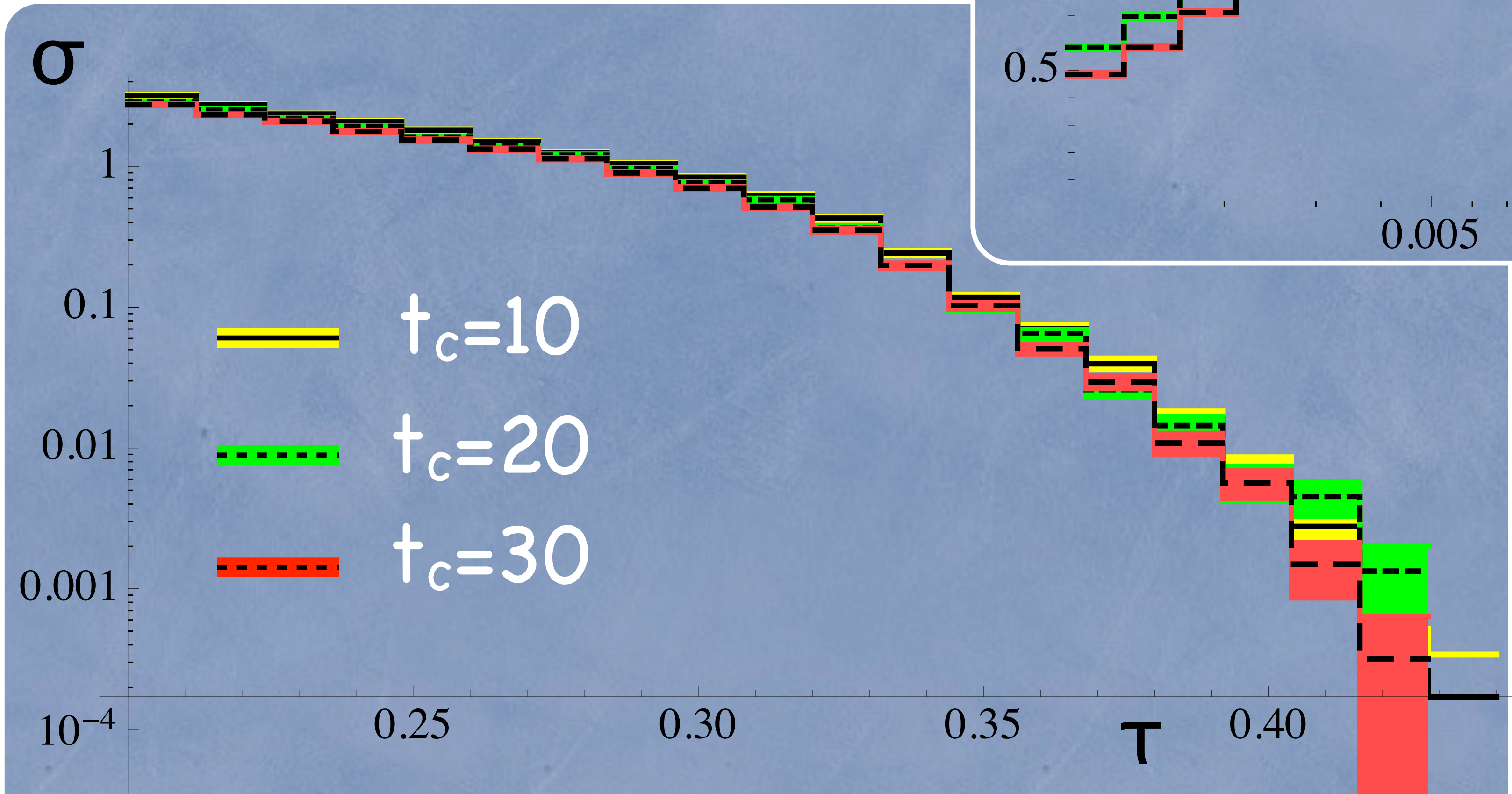
- LO only:
  - no events in low thrust region or for $\tau > 1/3$
- LO/LL (no shower):

  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

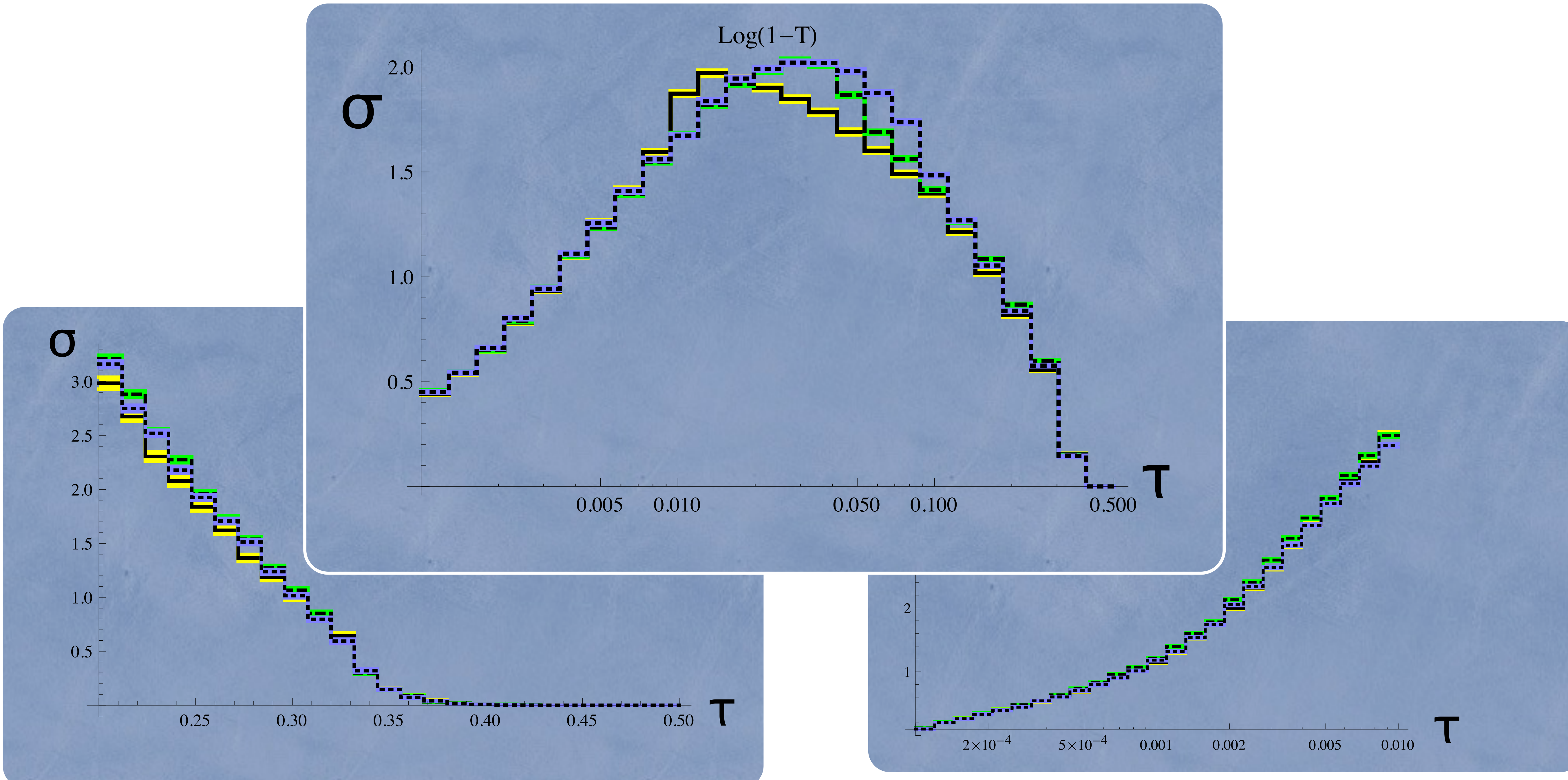
(Preliminary) Results: LO + Pythia (LL)





(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 2 jet rate independent of B_3



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?)

Thank you!