Progress on VirCol

A Parton Shower MC based on Antenna Formalism

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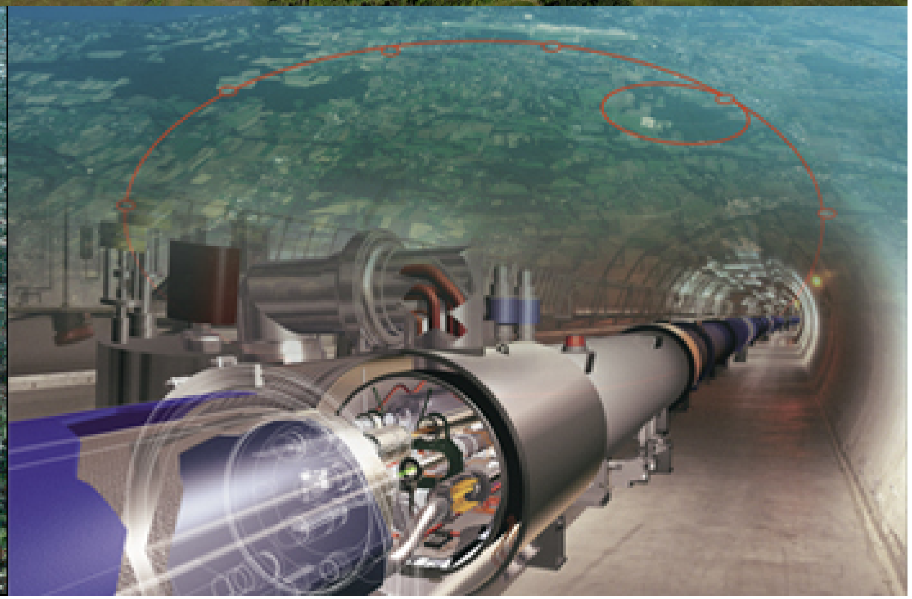
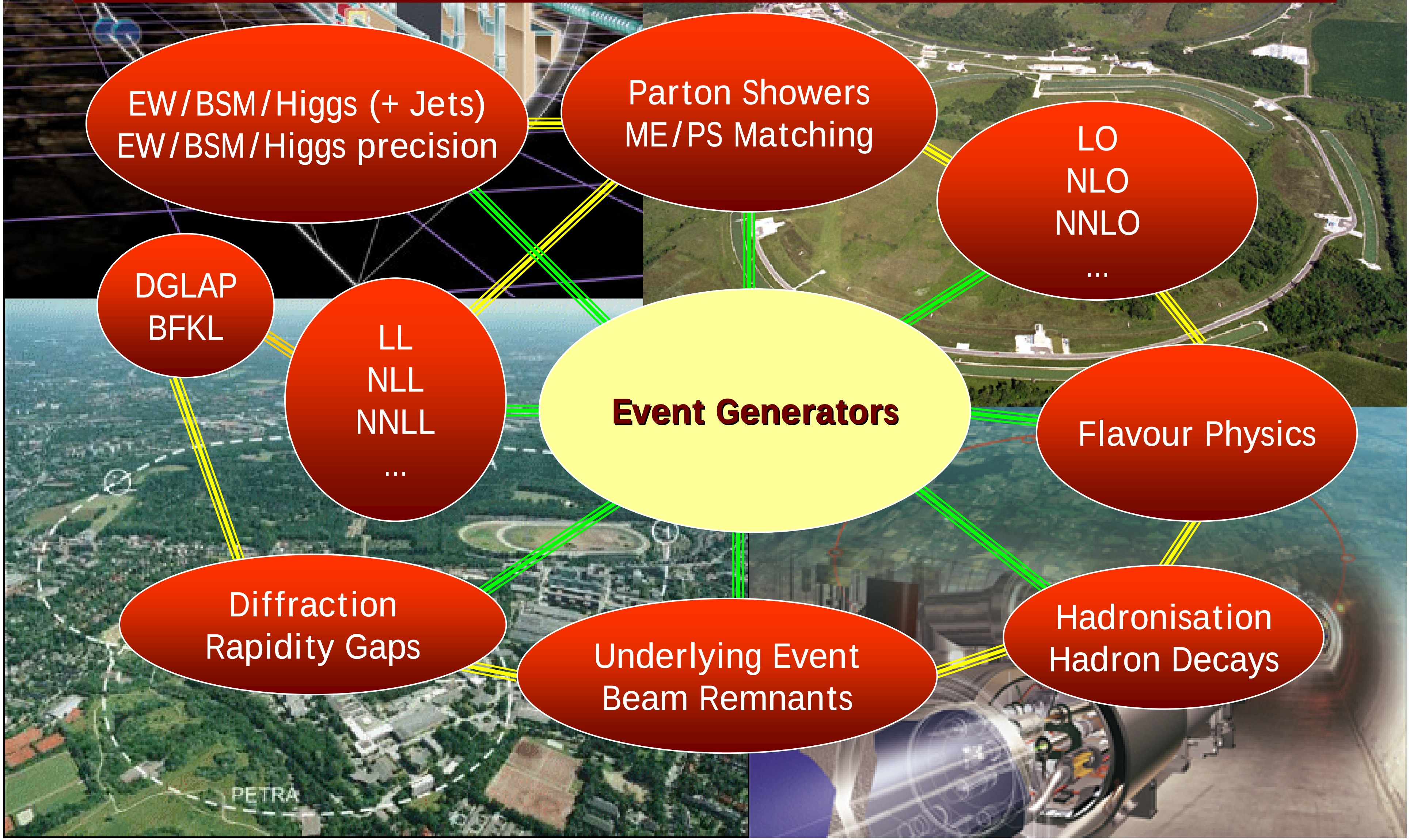
QCD at High Energies



QCD at High Energies



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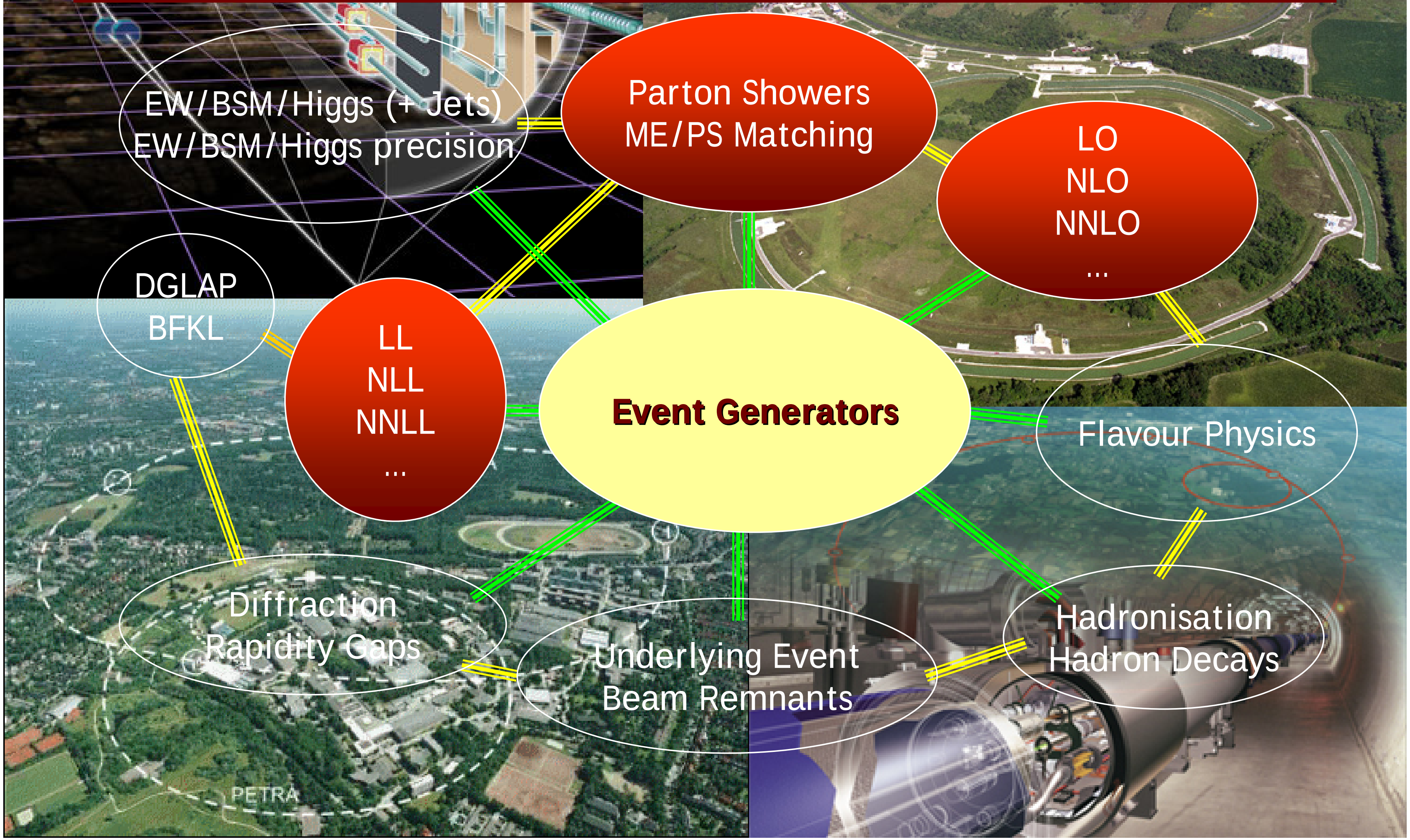

Hard & Soft

Matrix Elements (Fixed Order):

- Fixed order in α -> Exact interference, helicity, loops, …
- At present can do 2->5/6 (less with loops)
- Perturbative expansion better at higher energy (asymptotic freedom)
- Multiple soft emissions important for full event structure = exclusive observables
- Widely separated scales -> big logs / big truncation errors.
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- Derived in universal limit of QCD → depend on universal parameters
- Exponentiate→ infinite $O(\alpha)$→ ideal for widely separated scales (logs resummed)
- Arbitrary number of partons in final state→ match to hadronisation descriptions
- Derived in <u>limit</u> (collinear) of QCD→ approx. for wide-angle / hard emissions.

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Marriage desireable!!

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Possible Ceremonies

1. Merging (old) (HERWIG, PYTHIA, ARIADNE)
   - C… hower to X+jet rate fr…

2. Tre… …DNE, SHERPA, PATRIOT)
   - In… 3j, … by Sudakov re… LO normalisation.
3. NLO…
   - M… arton shower. Only 1 … nvar… hardwired to HERWIG + formalism som… cumbersome.
4. + new ideas … (Kramer+Soper, Nagy, Collins et al

Vircol – Basic SKETCH

- Perturbative expansion for some observable J,
  $d\sigma = \Sigma_{m=0} d\sigma_m$; $d\sigma_m = d\Pi_m |M|^2 \delta(J - J(k_1, k_2, \ldots, k_m))$
- Assume we know some Matrix Elements
  $d\sigma_0$, $d\sigma_1$, … $d\sigma_n$ (w or w/o loops)
- And we have some approximation $T_{n \to n+1}$, so that
  $d\sigma_{n+1} \sim T_{n \to n+1} d\sigma_n$ (~ parton shower)
- A 'best guess' cross section is then:
  $d\sigma \sim d\sigma_0 + d\sigma_1 + \ldots + d\sigma_n (1 + T_{n \to n+1} + T_{n \to n+1} T_{n+1 \to n+2} + \ldots)$
  $\Rightarrow$ $d\sigma \sim d\sigma_0 + d\sigma_1 + \ldots + d\sigma_n S_n$; $S_n = 1 + T_{n \to n+1} S_{n+1}$
- For this to make sense, the $T_{n \to n+1}$ have to at least contain the correct singularities (in order to correctly sum up all logarithmically enhanced terms), but they are otherwise arbitrary.
- We will now reorder this series in a useful way …

Reordering example: $h \to gg$

- Assume we know ME for $H \to gg$ and $H \to ggg$. Then reorder:

Use $1 = S_n - T_{n \to n+1} S_{n+1}$

- $d\sigma \quad \sim d\sigma_{gg} + d\sigma_{ggg}\, S_{ggg}$
  $= S_{gg} d\sigma_{gg} + S_{ggg} (d\sigma_{ggg} - T_{gg \to ggg} d\sigma_{gg})$
  $= S_{gg} d\sigma_{gg} + S_{ggg}\, d\chi_{ggg}$ (generalises to n gluons)

- I.e shower off gg and <u>modified</u> ggg matrix element.

- Double counting avoided since singularities/shower subtracted in $d\chi_{ggg}$.

What IS THE Difference?

CKKW (& friends) in a nutshell:

1. Generate a n-jet Final State from n-jet (singular) ME.
2. Construct a “fake” PS history.
3. Apply Sudakov weights on each “line” in history → from inclusive n-jet ME to exclusive n-jet (i.e. probability that n-jet FS remains n-jet above cutoff) ➔ gets rid of double counting when mixed with other ME’s (Sudakov wt dampens singularity).
4. Apply PS with no emissions above cutoff.

VirCol in a nutshell:

1. Subtract PS singularities from n-jet ME (antenna subtraction)
2. Generate a n-jet Final State from the subtracted (finite) ME.
3. Apply PS → Leading Logs resummed.

\+ full NLO: divergent part already there = unitarity of shower assumption → just include extra finite contribution in $d\sigma_0$:

$$d\sigma = d\sigma_0^{(0)} + d\sigma_1^{(0)} + \text{sing}[d\sigma_0^{(1)}] + F^{(1)} + \ldots$$

\+ now NNLO/NLL possible → talks by Gehrmann, Gehrmann-De Ridder

The ANTENNA Shower

- So far, we have written a C++ code that (for the moment) generates a pure gluon cascade ordered in:

  $y_R = 4s_{a1}s_{1b}/s^2_{a1b} = 4p^2_{T;ARIADNE}/s_{a1b}$

- …with the antenna / subtraction function:

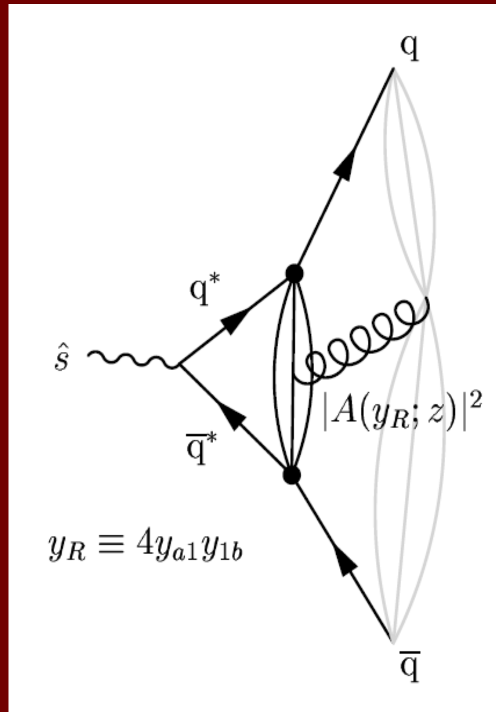
  $|A(a,b \rightarrow a,1,b)|^2 =$

  $2(s_{a1b}(s_{a1}+s_{1b})+s_{ab}^2)^2/(s_{a1}s_{1b}(s_{a1b}s_{ab}+s_{a1}s_{1b})s_{a1b})$

  → "usual" collinear limit, but different outside.

- This gives an analytical Sudakov integral
  = [Mathematica output] .

- (No Matrix Elements yet … but work in progress).



The ANTENNA Shower

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  $y_R = 4s_{a1}s$

- ...with th

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  → "usual

- This give
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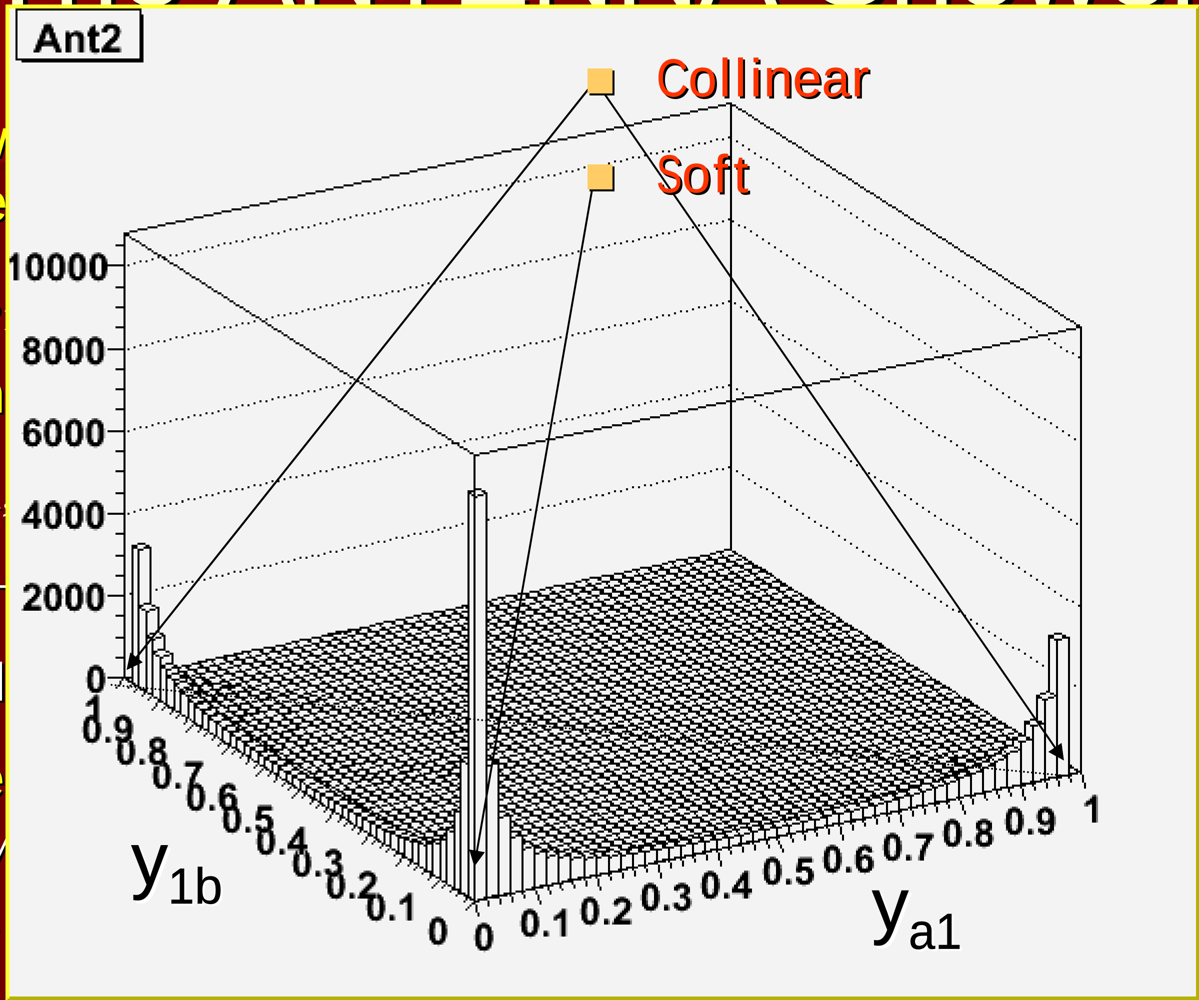
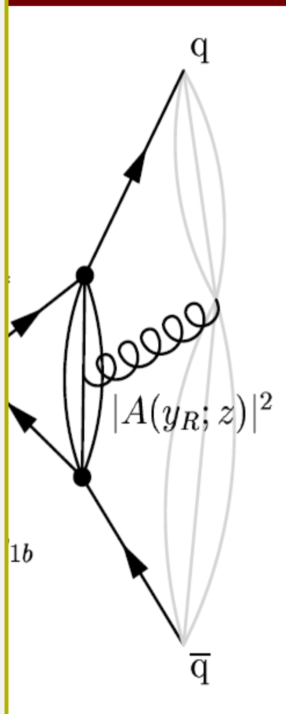
- (No Matr





Resolution & sharing

- Sudakov → y_R for next branch → select phase space point along iso-y_R contour:
  1. Rewrite Antenna function in terms of $y^2=y_R$; $\xi=(s_{a1}+s_{1b})/y$:

$$\int_0^1 dy \, \frac{1}{y} \int_1^{1/y} d\xi \, \frac{(\xi y + (1-\xi y)^2)^2}{1+y^2/4-\xi y} \, \frac{1}{\sqrt{\xi^2-1}}$$

  2. Partial-fraction singular structure + overestimate numerators → generate uniform R and solve for ξ_R :

$$R=\int_1^{\xi_R} d\xi \left(\frac{A(y;\xi)}{1-\xi y+y^2/4} + \frac{B(y;\xi)}{\sqrt{\xi^2-1}} \right)$$

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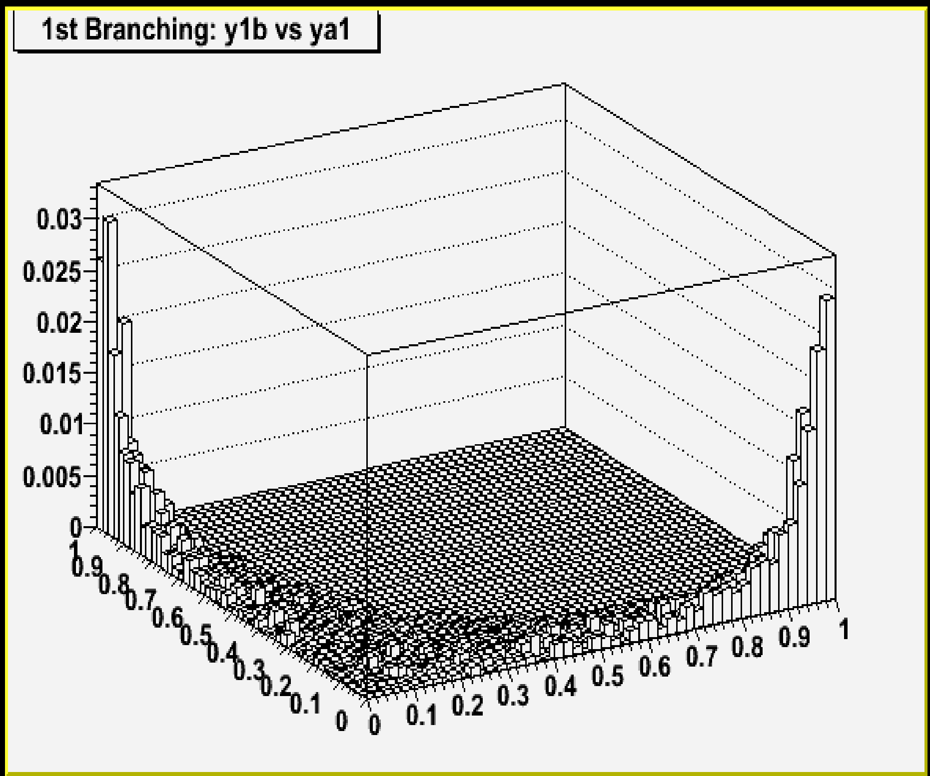
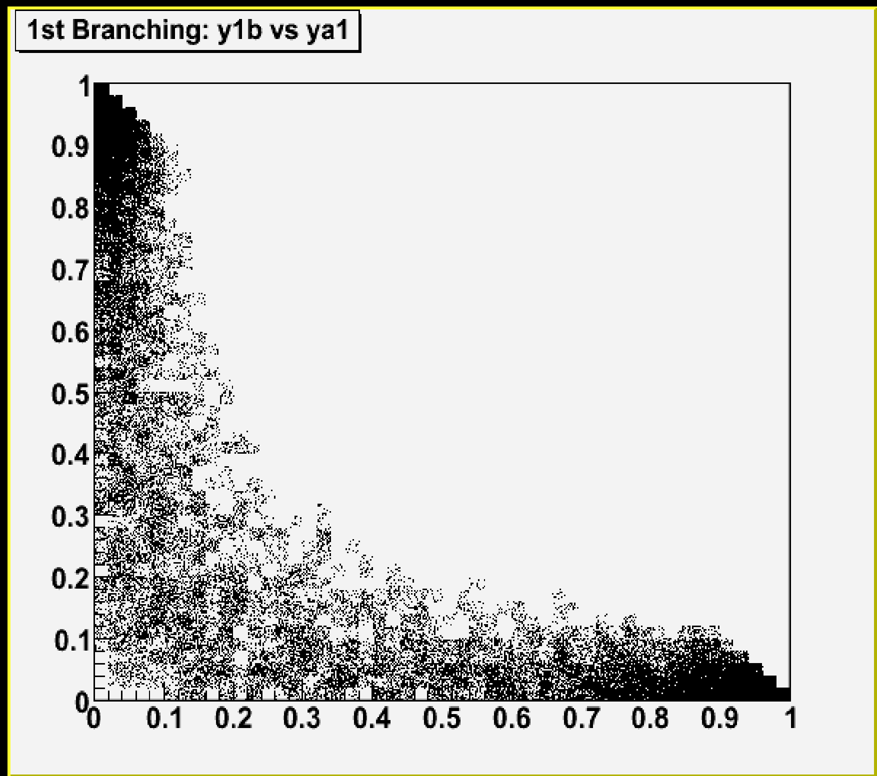
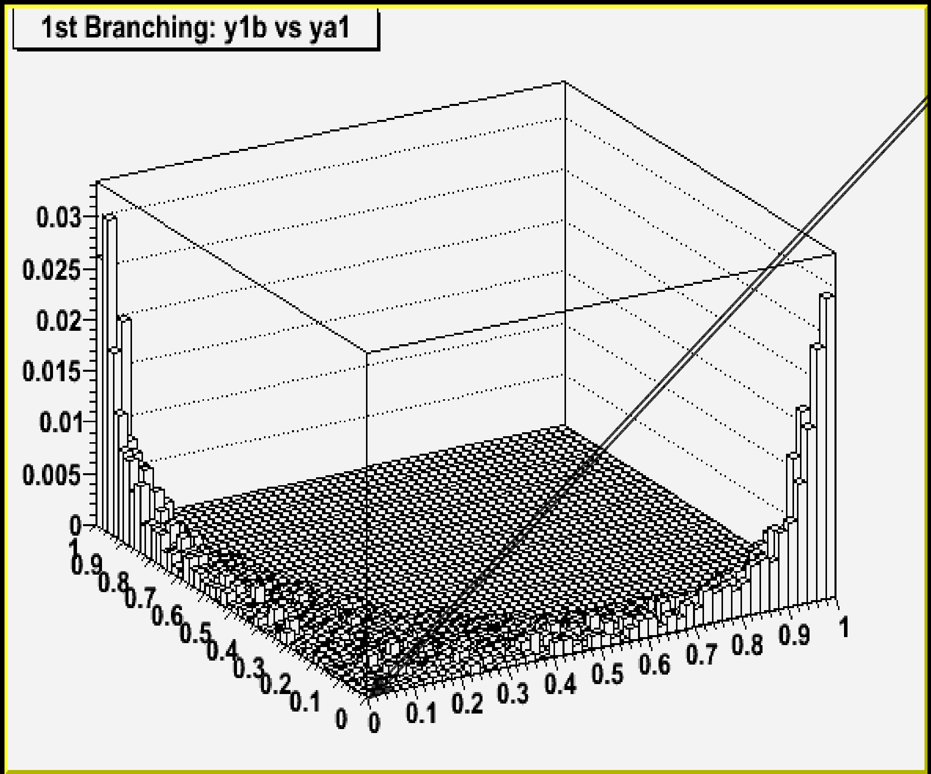




Resolution & sharing

- Q1: Where's the soft singularity?



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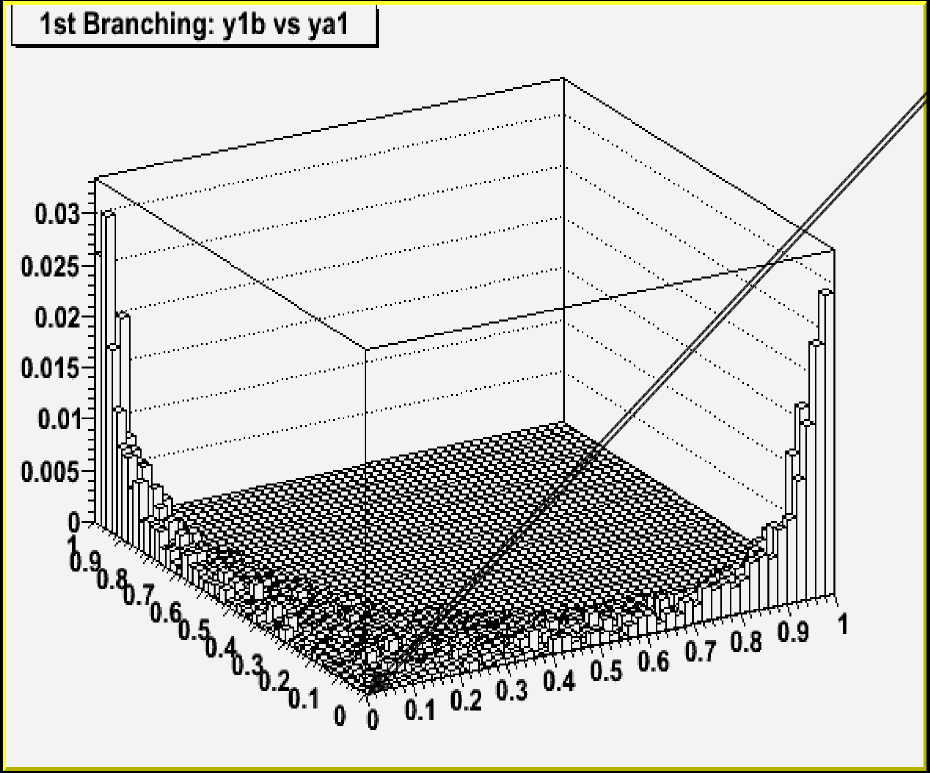
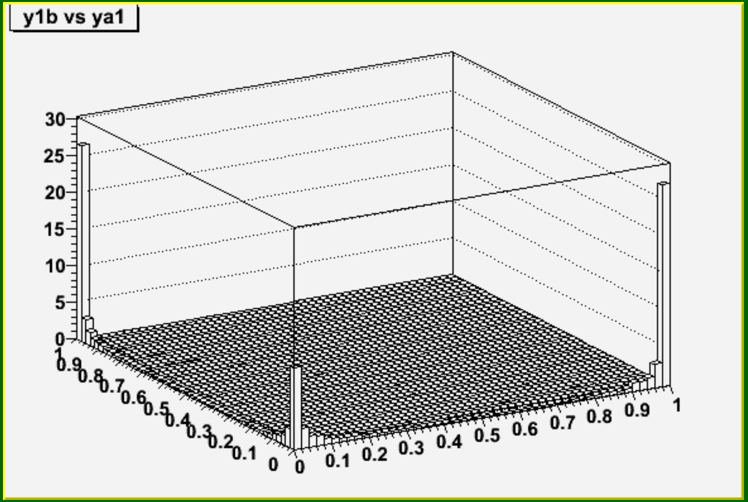
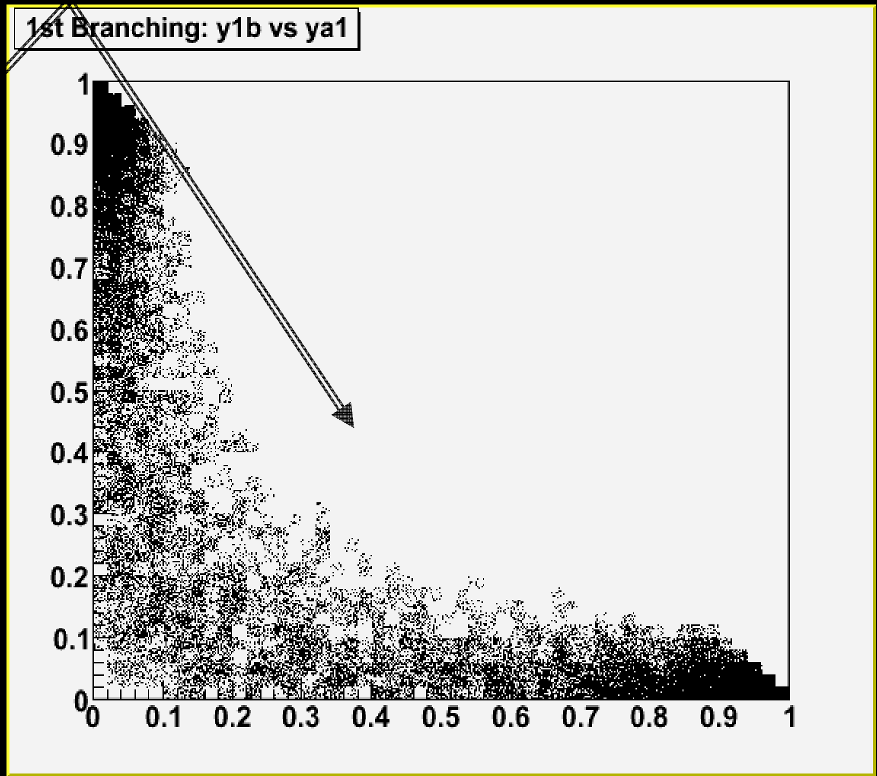


- A1: Sudakov suppressed, (sum of ordered branching probs → unordered probability)



Resolution & sharing

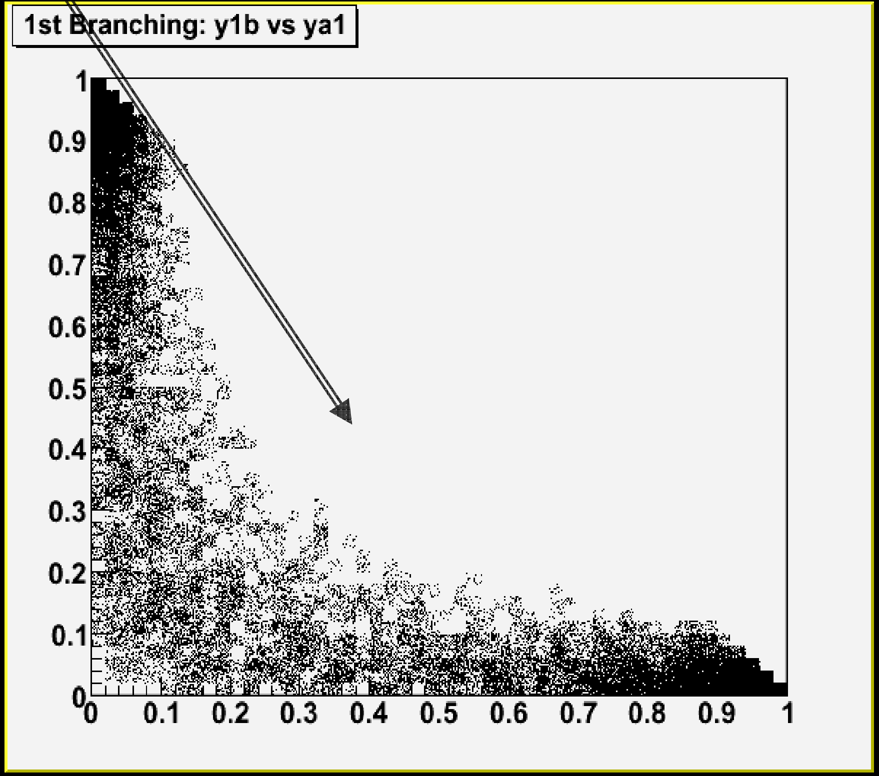
- Q1: Where's the soft singularity?
- Q2: Is that a 'dead region' ?



Resolution & sharing

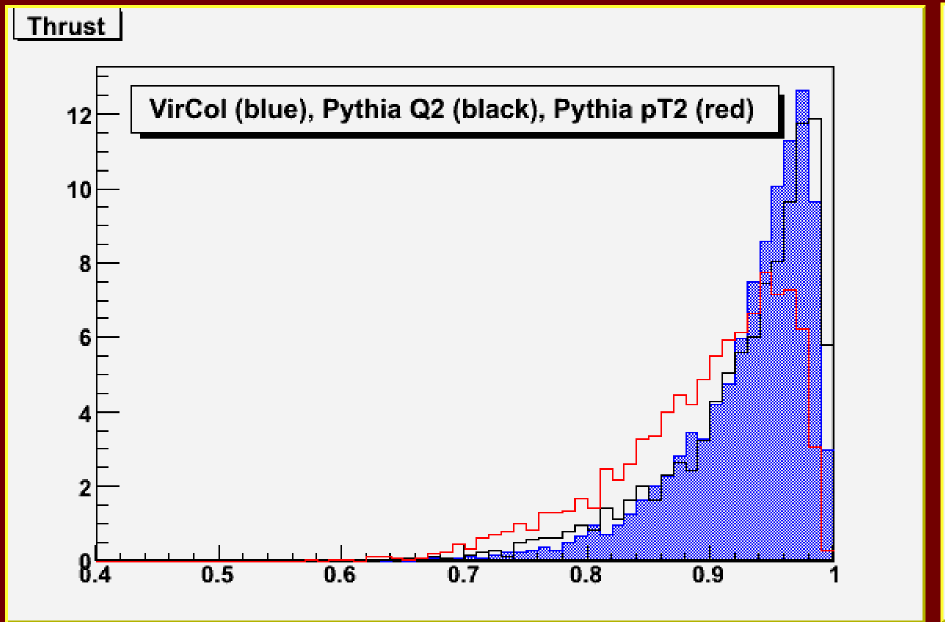
- Q1: Where's the soft singularity?
- Q2: Is that a 'dead region' ?

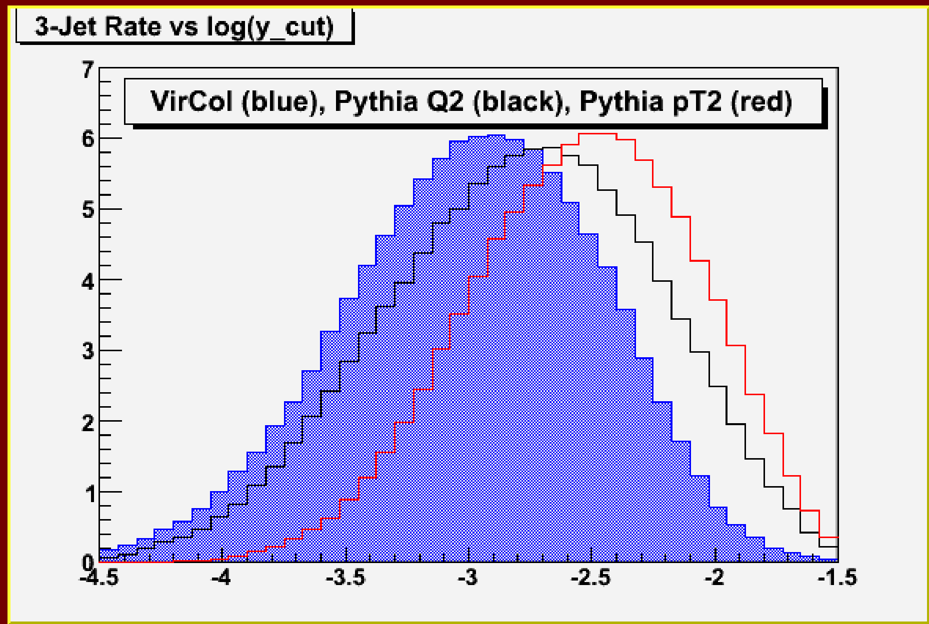
- A2: Yes, it is cut out by 'unresolution criterion', i.e. that neighbour dipoles remain resolved after branching.
- Due to H→gg in colour singlet state! (pathological)
- Eventually, could be filled by Matrix Elements and/or by changing evolution var.



Preliminary Results

- Thrust and 3-jet rate, compared to Q^2-ordered and $p_T{}^2$-ordered PYTHIA showers.





- Preliminary: matrix elements should be added and parton-level matched to hadronisation models eventually + all showers only include gluons here…

Conclusion & Outlook

- Construction of VIRCOL shower monte carlo:
  - gluons shower MC (based on LO, done!)
  - gluons shower MC (based on NLO)
  - parton shower MC (LO/NLO(/NNLO))
  - parton shower MC (NLL + NLO/NNLO)
  - Hadron collider shower MC's
  - Higher order Sudakov factor calculations(this will reduce a lot of implicit and explicit uncertainties: e.g. renormalization scale, choice of subtraction function,…)