A modified CKKW matrix element merging algorithm for angular-ordered parton showers

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work in collaboration with Peter Richardson

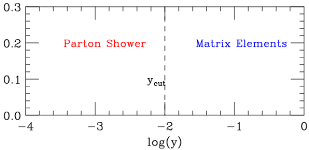
A modified CKKW algorithm in Herwig++ based around truncated showers and forced splittings.

- hep-ph/09053072

- Merging combines parton showers with exact matrix elements improving descripion of hard jets.
- NLO matching combines (N)LL PS with NLO cross sections ($\mathcal{O}(\alpha_S)$ correction only).
  - MC@NLO[5], POWHEG[3]
- Tree level merging combines (N)LL PS with all tree level MEs up to maximum multiplicity.
  - CKKW[1, 2], CKKW-L[4], MLM, Pseudo-Shower[7]
- Implementation of a modified CKKW merging algorithm based on POWHEG shower restructuring.
- Aim to avoid worst of problems with merging in angular ordered shower.

- ME merging methods split phase space into two regions: ME + PS
  - smooth coverage + no double counting
- define merging scale resolution y_{MS} in some jet measure eg Durham

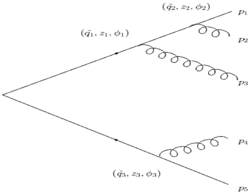
$$y_{dur} = 2\frac{\min(E_1^2, E_2^2)}{s}(1 - \cos\theta_{1,2}) \quad (1)$$



- CKKW replaces approx splitting functions with exact MEs above y_{MS}
- CKKW procedure
  1. n jet configuration generated $\propto \sigma_n(y_{MS})$
  2. n momenta clustered giving shower history
  3. reweight with appropriate Sudakov and α_S weights
  4. vetoed showers below y_{MS} from history end points.

- A number of issues/difficulties with implementing CKKW
  - Scale definition inconsistencies
  - Choice of initial shower conditions
  - Shower colour structure
- In particular problems when not using a p_T ordered shower
  - Smooth merging and y_{MS} independence not achieved
  - Shower may not produce all radiation
- Discontinuities at partonic level in the jet parameter[8]
- Herwig++ is an angular ordered shower
- Modifications aim to remove the worst of these problems

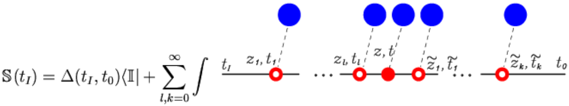
- Based on POWHEG shower restructuring with truncated showers[3, 10]
- Key element is inverse momentum reconstruction
  - Undoes rescaling boosts
  - Recursive Sudakov decomposition



momenta + shower history → shower variables $(\tilde{q}, z, \phi)$.

- Shower procedes as single shower with forced splittings and truncated showers
  - Fills gaps in shower
  - Exact mappings to shower variables
  - Unambiguous intitial shower conditions
  - Shower colour structure preserved

- POWHEG separates hardest shower emission

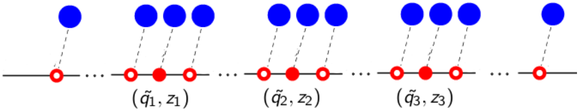


- All other emissions vetoed at $p_{\perp h}$
- Results in remnant Sudakov form factor

$$\Delta_R(t_i, t_f; p_{\perp h}) = \exp\left(- \int_{t_f}^{t_i} \mathrm{d}z\mathrm{d}t F(z,t)\Theta(k_\perp - p_{\perp h}) \right) \quad (2)$$

  - Probability for no emissions with $k_\perp > p_{\perp h}$
- shower $\rightarrow$ truncated shower + hardest emission + vetoed showers

- Generalise to shower line with set of hard emissions (above $k_{\perp_{MS}} = \sqrt{y_{MS} s}$)



- Remnant Sudakovs between hard emissions with fixed $k_{\perp_{MS}}$

$$\Delta_R(\tilde{q}_i, \tilde{q}_f; k_{\perp_{MS}}) = \exp\left(-\int_{\tilde{q}_f}^{\tilde{q}_i} \mathrm{d}z\mathrm{d}\tilde{q}F(z,\tilde{q})\Theta(p_\perp - k_{\perp_{MS}})\right) \quad (3)$$

- Sudakov factors built from shower history exactly as in standard CKKW
  - with Θ-fn since $\tilde{q} \neq k_{\perp_{MS}}$
- Multiple truncated showers between hard emissions

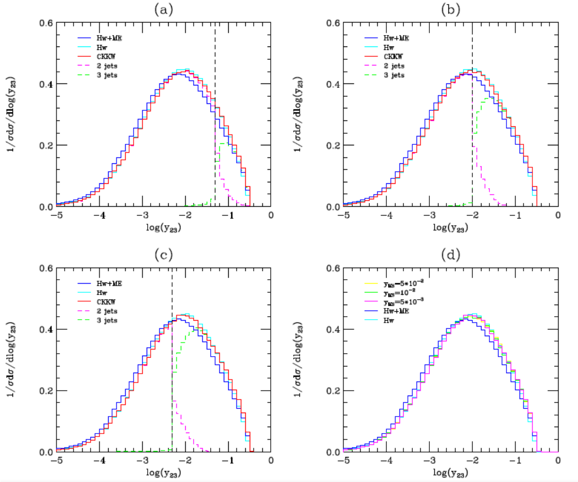
1. n-jet configuration generated $\propto \sigma_n(y_{MS})$ (MadEvent[9])
2. Momenta clustered giving shower history
3. Shower variables to produce shower history calculated
   - Defines a set of 'hard emissions'
4. Reweighting with Sudakov and α_S weights
   - Analytically calculated with exact shower variables
5. Shower begins from clustered $q\bar{q}$ state
6. Truncated showers evolve along each line
   - With $k_{\perp_{MS}}$ veto, no flavour changing
7. Hard emissions forced when get to relevant scales
   - If there is another hard emission along line go to 7.
8. Vetoed showers evolve to hadronization scale

- Shower restructuring assumes angular-ordered hard emission history.
- Create all possible histories from allowed branchings resulting in a LO configuration.
- Keep only histories satifying angular-ordering

$$z_i \tilde{q}_i > \tilde{q}_{i+1}. \quad (4)$$

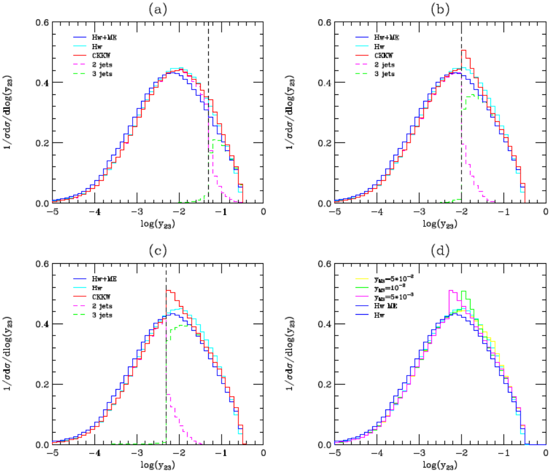
- Choose 'most likely' of these histories
  - Lowest $\sum |p_\perp|$
- If no angular-ordered histories choose an unordered history.

$e^+e^- \rightarrow$ hadrons with 2 and 3 jets.



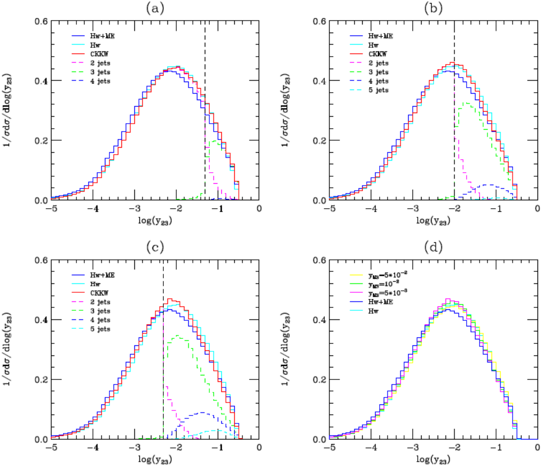
(a) $y_{MS} = 5 \times 10^{-2}$, (b) $y_{MS} = 10^{-2}$, (c) $y_{MS} = 5 \times 10^{-3}$, (d) comparison.

$e^+e^- \to \mathrm{hadrons}$ with 2 and 3 jets, no truncated shower.



(a) $y_{MS} = 5 \times 10^{-2}$, (b) $y_{MS} = 10^{-2}$, (c) $y_{MS} = 5 \times 10^{-3}$, (d) comparison.

$e^+e^- \rightarrow$ hadrons with up to 5 jets.

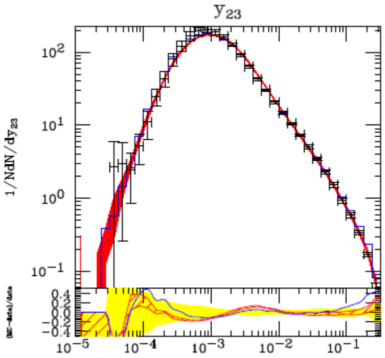


(a) $y_{MS} = 5 \times 10^{-2}$, (b) $y_{MS} = 10^{-2}$, (c) $y_{MS} = 5 \times 10^{-3}$, (d) comparison.

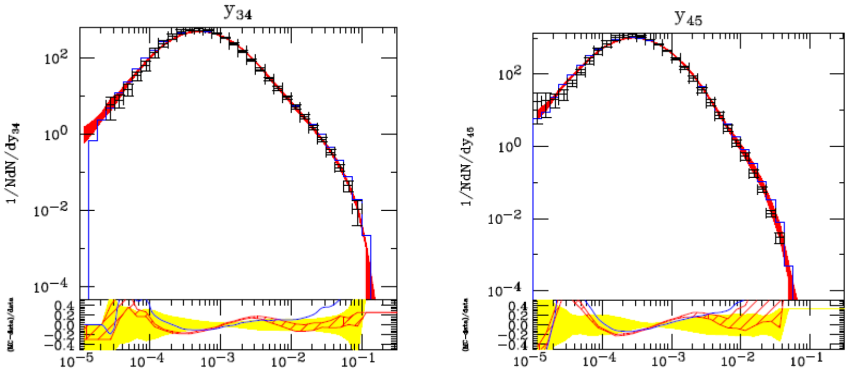
Tune of Herwig++ parameters for to LEP data[13, 14, 15] for CKKW with $y_{MS} = 10^{-2}$ in Durham measure.

Red band gives variation with $y_{MS} = 10^{-2}$, $y_{MS} = 5 \times 10^{-3}$ in Durham and LUCLUS measures.

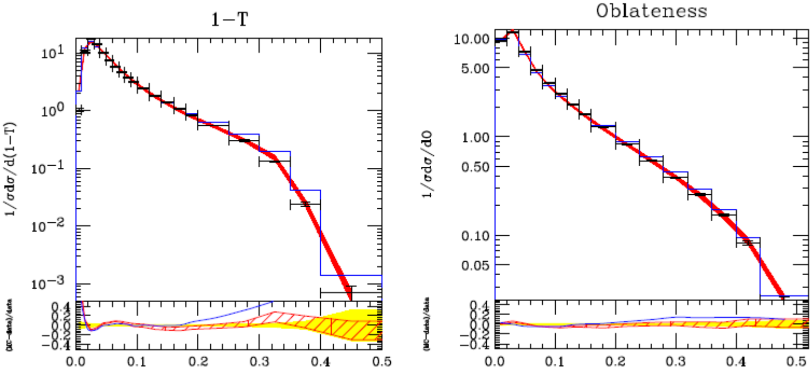
3 jet resolution



4 and 5 jet resolution



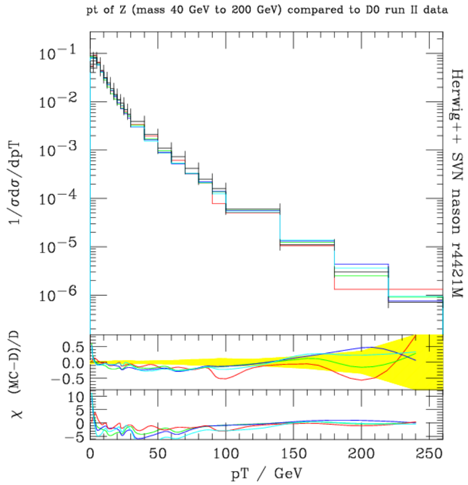
Thrust and oblateness



- Requires merging with initial-state (backwards) parton shower.
- Backwards clustering along initial-state line.
- Initial state inverse momentum reconstruction.
- PDF factors in branching probability.
- Sudakov factors generated dynamically (CKKW-L).
  - Required Sudakov weight is probability of no emissions with $k_\perp > p_{\perp_{MS}}$ in showering around hard emissions.
  - Veto events that generate an event with $k_\perp > p_{\perp_{MS}}$ in truncated and vetoed showers.

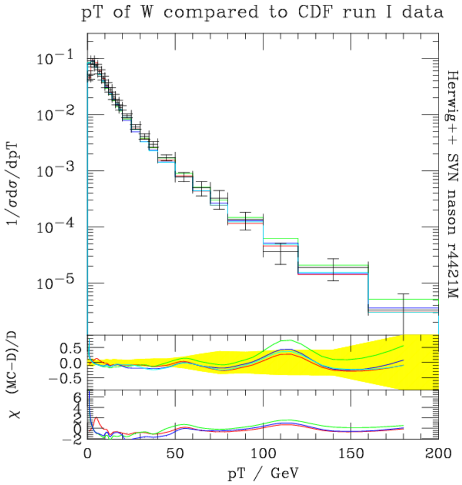
Z/γ $p_\perp$ spectrum for CKKW with one extra jet compared to D0 run II data[12].

CKKW $p_{\perp_{MS}}$ =10GeV, 20GeV,30GeV and Hw+ME



W $p_\perp$ spectrum for CKKW with one extra jet compared to CDF run I data[11].

CKKW $p_{\perp_{MS}}$ =10GeV, 20GeV,30GeV and Hw+ME



Summary

- Modified CKKW algorithm implemented in Herwig++
  - POWHEG style restructuring with truncated showers
  - Exact mappings to shower variables avoiding scale mismatches
- Sensitive partonic plots appear free of discontinuities
- Tuned plots demonstrate improved description of LEP data
- Drell-Yan implementation in progress.

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