Pythia Overview : 2013–2016

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See T. Sjöstrand et al., CPC 191 (2015) 159

MCnet Network Meeting
CERN, November 2016

2013: Freezing of the Fortran Pythia

TS, SM, PS

December 2012

Dear Pythia Users and Supporters,

…

A key request of the LHC community has been for us to transition from Fortran to C++. We have been manpower-limited, so that project has taken much longer than it ought to have. However, since some time now, the new Pythia 8 code should be able to do just about everything the old Pythia 6 code could, and then some more.

…

Development of Pythia 6 now stops. We will still provide support and urgent fixes to the code, if necessary, until 1 March 2013. At this point, the Pythia 6 code will be frozen, and a final legacy version will be released later in 2013. We will then continue to answer questions regarding the behaviour of Pythia 6 until 1 July 2013, **after which only Pythia 8 will be actively developed and supported.**

Beginning of 2013:

- Pythia 8 (C++) ~ similar level of capabilities as Pythia 6 (F77)
- (Too) Demanding to develop & support two separate large codes.
  - Decision to freeze PYTHIA 6.
    - Staggered → **September 2013**
    - First development stopped, then support

By now, usage (slowly) declining

- Pythia 6.4 remains widely used
  - Despite lack of support
- Pythia 8 usage is increasing
  - But does not appear to have overtaken Pythia 6 yet …

2014: Release of Pythia 8.2

TS et al., CPC 191 (2015) 159

CPC writeup (on arXiv: Oct 2014)

First attempt to provide more than "coversheet" for Pythia 8 release → arXiv paper expanded by ~ factor 2 (to 45 pages)

Still nowhere close to Pythia 6 manual (576p) but supplemented by extensive HTML manual

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Contents lists available at ScienceDirect

Computer Physics Communications

journal homepage: www.elsevier.com/locate/cpc

COMPUTER PHYSICS COMMUNICATIONS

An introduction to PYTHIA 8.2☆

CrossMark

Torbjörn Sjöstrand [a,*], Stefan Ask [b,1], Jesper R. Christiansen [a], Richard Corke [a,2], Nishita Desai [c], Philip Ilten [d], Stephen Mrenna [e], Stefan Prestel [f,g], Christine O. Rasmussen [a], Peter Z. Skands [h,i]

2014: Release of Pythia 8.2

Code & Build **Restructuring** PI, TS, …

Revamped configure+make (+simplify linking of external libs); Auxiliary files moved to share/Pythia; Dynamical loading of LHAPDF interface when requested (v5 or v6)

Significant News (continued on next slides)

- Weak Showers (since 8.176): **W/Z emissions** from q, ℓ, ν JC,TS JHEP 1404 (2014) 115
- Improved handling of (helicity-dependent) **tau decays** (since 8.150) PI
  - All decays with BR > 0.1% fully modelled with MEs and Form Factors (since 8.170)
    - Extended to correlations between known resonances in LHEF input (since 8.200)
    - Extended to set up tau spin information in W′ and Z′ decays (since 8.209)
- Significant extensions to colour-octet cc & bb **onium states** (since 8.185) PI
- Several New Models for **Colour Reconnections** SA,TS JHEP 1411 (2014) 043 JC,PS JHEP 1508 (2015) 003 +implementation of SK models for ee (since 8.209)
- Comprehensive update of **baseline tune**
  - From **4C** RC,TS JHEP 1103 (2011) 032 to **Monash 2013** (still default) PS et al., EPJ C74 (2014) 3024
    - Including new ee tune to (revised) LEP/SLD data & new internal NNPDF 2.3 implementation
  - \+ Several further options from ATLAS and CMS (A14 + MonashStar added in 8.205)

News cont'd: ME Matching & Merging

Stefan Prestel, with Leif Lönnblad, Steve Mrenna

+ 2014: LHEF v3
Les Houches arXiv:1405.1067,

No internal ME generator → rely on (LHEF) interfaces

8.2: aMC@NLO matching added to the list of implemented schemes

With Torielli, Frixione; required addition of "global recoil" option

→ A comprehensive suite of approaches (+ examples & tutorial)

- aMC@NLO Matching
- POWHEG Merging
- CKKW-L Merging
- NL3 Merging (~ CKKW-L @ NLO)
- **UMEPS Merging**
- **UNLOPS Merging** (~ UMEPS @ NLO)
- **FxFx** See e.g., Frederix, Frixione, Papaefstathiou, Prestel, Torrielli: JHEP 1602 (2016) 131
- Jet Matching (aka MLM)

Lönnblad & Prestel, JHEP 1302 (2013) 094,
Lönnblad & Prestel, JHEP 1303 (2013) 166

Most of this work done by SP over the last 4 years …

+ MECs (matrix-element corrections)

Often forgotten that standalone Pythia includes LO MECs for the 1st emission in all SM (and many BSM) decay processes (e.g., $t \to bW+g$)

+ a few production processes (Drell-Yan & Higgs production)

Unitarised Matching & Merging

Slides adapted from Stefan Prestel

Matrix Elements contain singularities beyond LL; not canceled by pure shower Sudakov.
Imposing detailed balance (unitarity) restores explicit real-virtual cancellation
Extreme example: choosing **very** low matching scales (~ in Sudakov peak region)

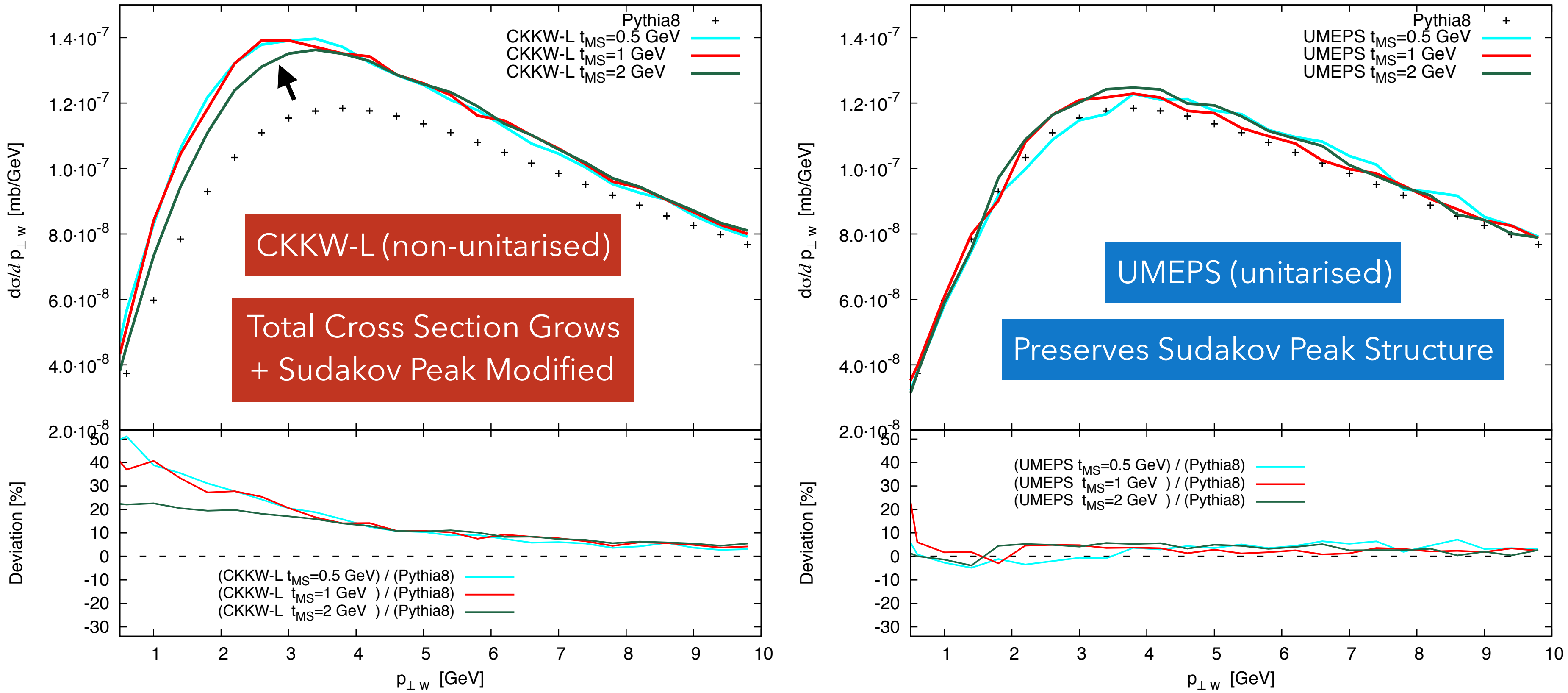


Figure: $p_\perp$ of the W-boson in the Sudakov region (for 2-jet merging, $E_{CM} = 7$ TeV).
Lower inset shows the comparison to default PYTHIA 8.

$\Rightarrow$ CKKW-L overshoots for (very) low merging scales due to uncancelled terms.

$\Rightarrow$ UMEPS describes the Sudakov peak nicely.

Unitarised Merging @ NLO

see main88.cc
example program

Slides adapted from Stefan Prestel

Lonnblad & Prestel, JHEP 1303 (2013) 166

NLO merged results for H + jets

(based on LHEF input files generated in the POWHEG framework)

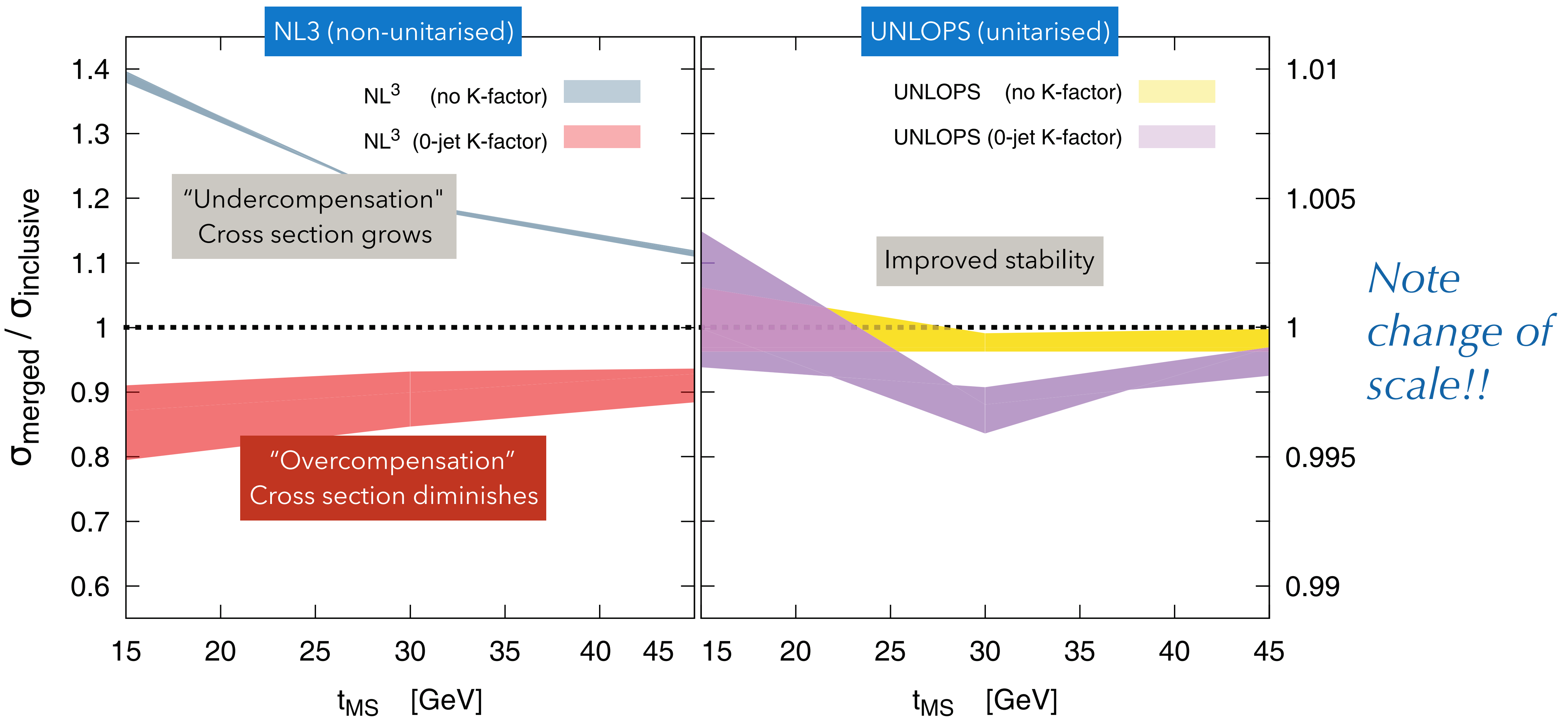


Figure: Ratio of the inclusive cross section for gg→H after merging (H+0)@NLO, (H+1)@NLO and (H+2)@LO, compared to the NLO inclusive cross section.

⇒ NL^3 (=CKKW-L@NLO) has problems for processes with large, loop-driven NLO corrections. UNLOPS does not.

NLO merged results for H + jets

(based on LHEF input files generated in the POWHEG framework)

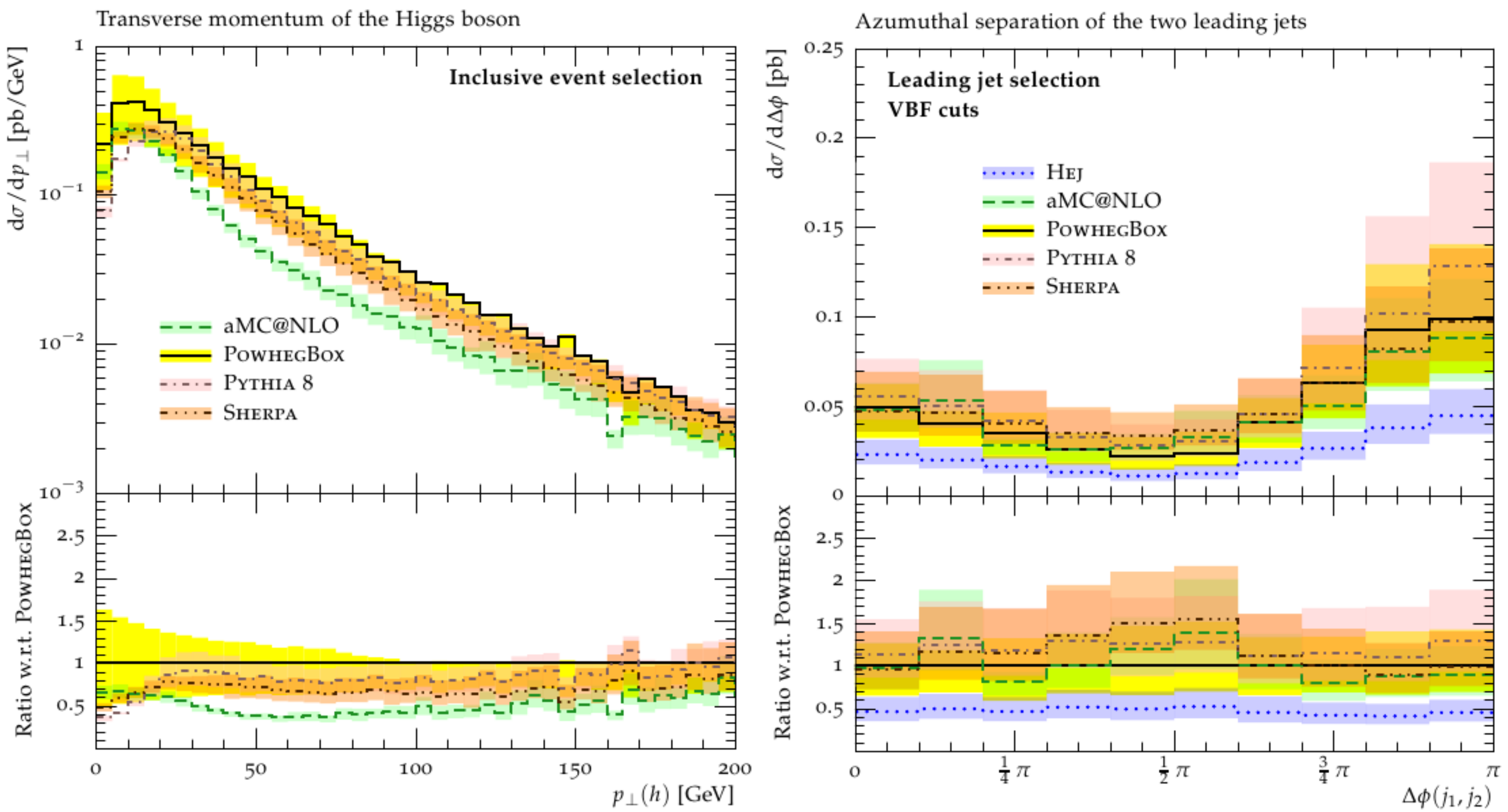


Figure: $p_{\perp,H}$ and $\Delta\phi_{12}$ for gg$\to$H after merging (H+0)@NLO, (H+1)@NLO, (H+2)@NLO, (H+3)@LO, compared to other generators.

$\Rightarrow$ The generators come closer together if enough fixed-order matrix elements are employed. The uncertainties after cuts are still very large.

Slides adapted from Stefan Prestel

Combining resonant “signals” and non-resonant “backgrounds”

(a.k.a. “resonance-aware” matching)

Recent exploration for single-top production

JHEP1606(2016)027

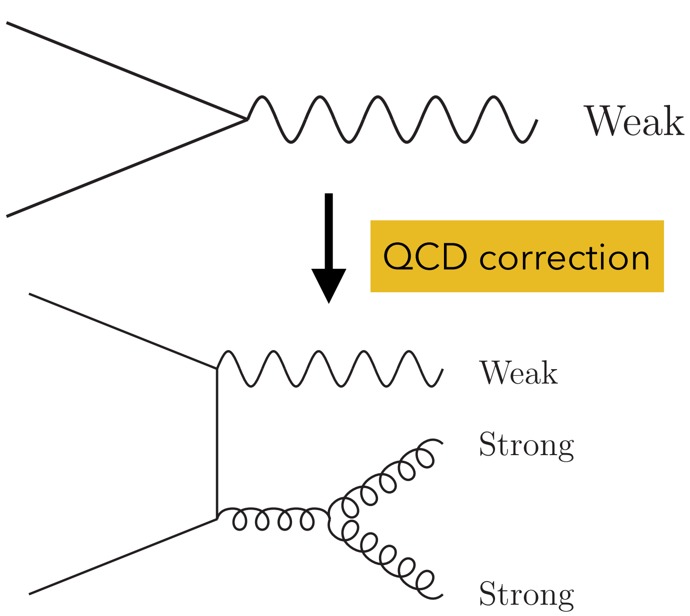
Matching *Wbj* with MC@NLO

Introducing “resonance histories” (from kinematical considerations, or from partial amplitudes)

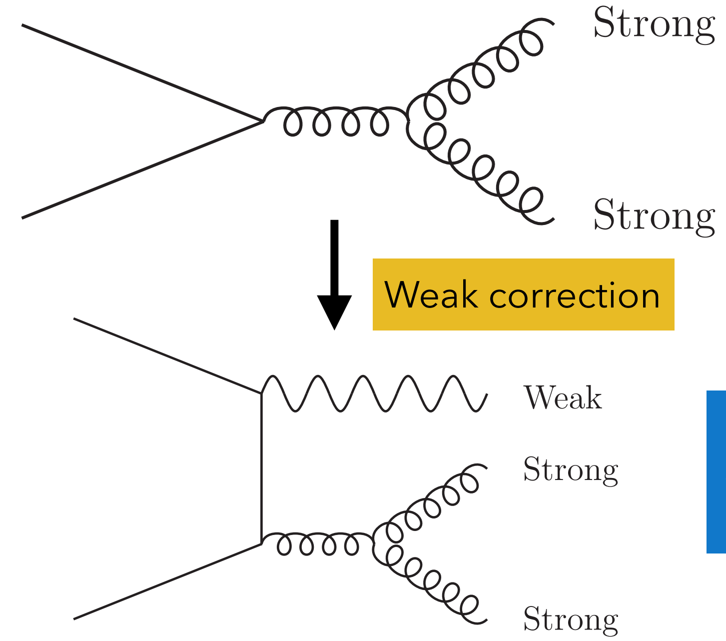
Electroweak Merging

JC & SP EPJC 76 (2016) 1, 39

Drell-Yan



Dijet



Weak Showers JC,TS JHEP 1404 (2014) 115

Assumption that every jet is a correction to Drell-Yan not reliable.

New Colour-Reconnection Models

Brief History

1980'ies: MPI + CR : rise of <p_T> vs N_{ch} — TS, v Zijl Phys.Rev. D36 (1987) 2019

(+ not mentioned here: rapidity gaps, onium production, …)

1990'ies: CR at LEP2: string drag effect on m_W

2000's: Tevatron "Tune A": needed ~ 100% colour correlations

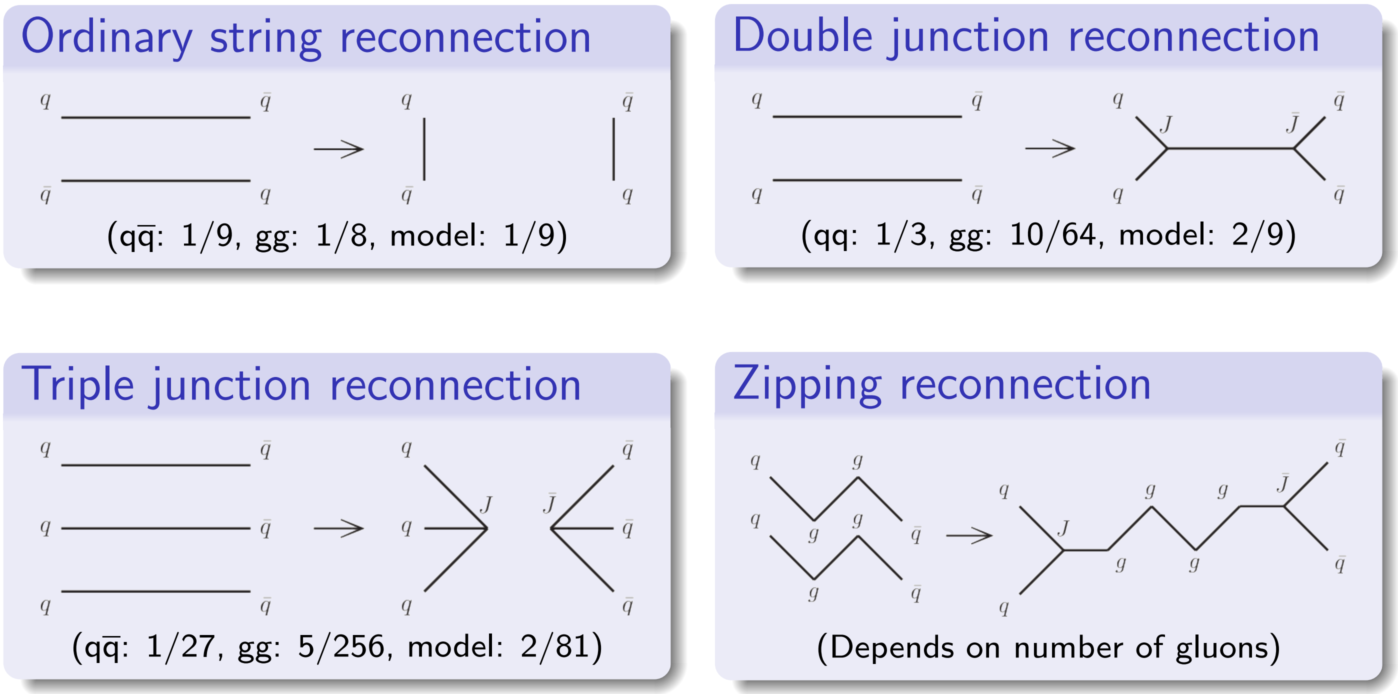
+ O(0.5 GeV) CR uncertainty on Tevatron top quark mass

Best LEP2 fit (2013) excluded no-CR at 99.5% CL

J. Christiansen & P. Skands, JHEP 1508 (2015) 003:

New model relies on two main principles

⋆ **SU(3)** colour rules give allowed reconnections



⋆ minimal λ measure gives preferred reconnections

+ "Gluon-Move Model" (and a few variants) mainly intended for conservative (maximal) effect on top quark mass:

SA,TS JHEP 1411 (2014) 043

Still ⇒ Δm_t ~ 500 MeV

ATLAS & CMS : ~ 100 MeV ?

+ Superconductor-inspired SK-I and SK-II models re-implemented in Pythia 8

(Since 8.209)

2015-2016: Further Recent News

Runtime interface to POWHEG BOX (PI)

Can run MadGraph5_aMC@NLO from within Pythia (PI)

New machinery for hard diffraction + physics studies

- Partonic substructure of Pomeron: diffractive jets
- MPI-based gap survival probability

CR & TS JHEP 1602 (2016) 142

Extended options for damped ISR/FSR above hard scale

Reweighting machinery for ISR/FSR branchings (SP)

Interface to the Python programming language (PI)

Various PDF upgrades (TS) & SUSY/SLHA updates (ND)

Thermal Hadronisation, Close-Packing Effects, and Hadron Rescattering Options NF & TS arXiv:1610.09818

See talk by Nadine Fischer

New: Automated Shower Uncertainties

S. Mrenna, P. Skands, S. Prestel

Based on original proposal for VINCIA: Giele, Kosower, PS PRD84 (2011) 054003

Pythia 8 implementation (+ All-orders proof) SM, PS Phys.Rev. D94 (2016) no.7, 074005

(~ Simultaneously with same principle in Herwig++, Sherpa)

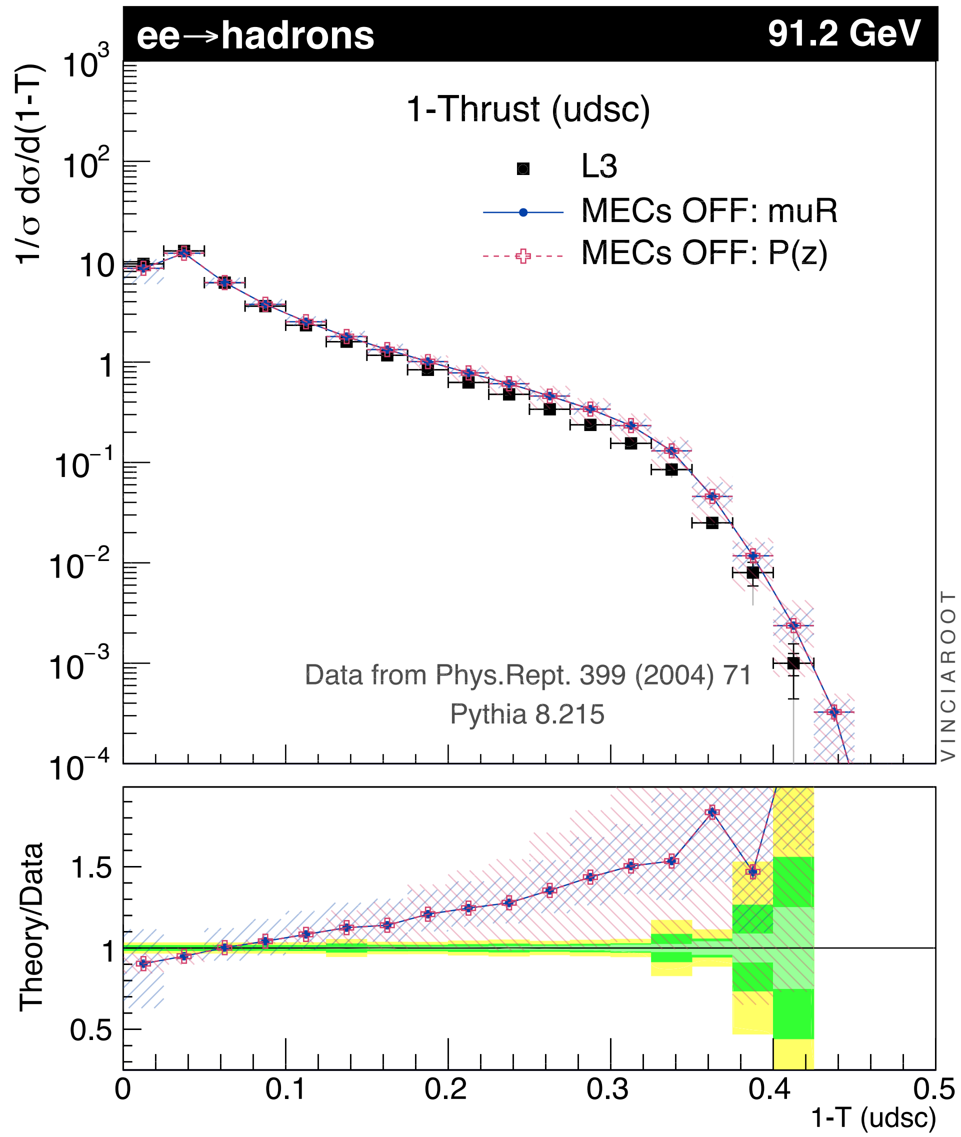
For each trial branching, with splitting variables, {t}:

If accepted, compute alternative weight for different α_s or splitting kernel:

$$R'_{\mathrm{acc}}(t) = \frac{P'_{\mathrm{acc}}(t)}{P_{\mathrm{acc}}(t)} = \frac{P'(t)}{P(t)}$$

If rejected, compute alternative no-emission weight:

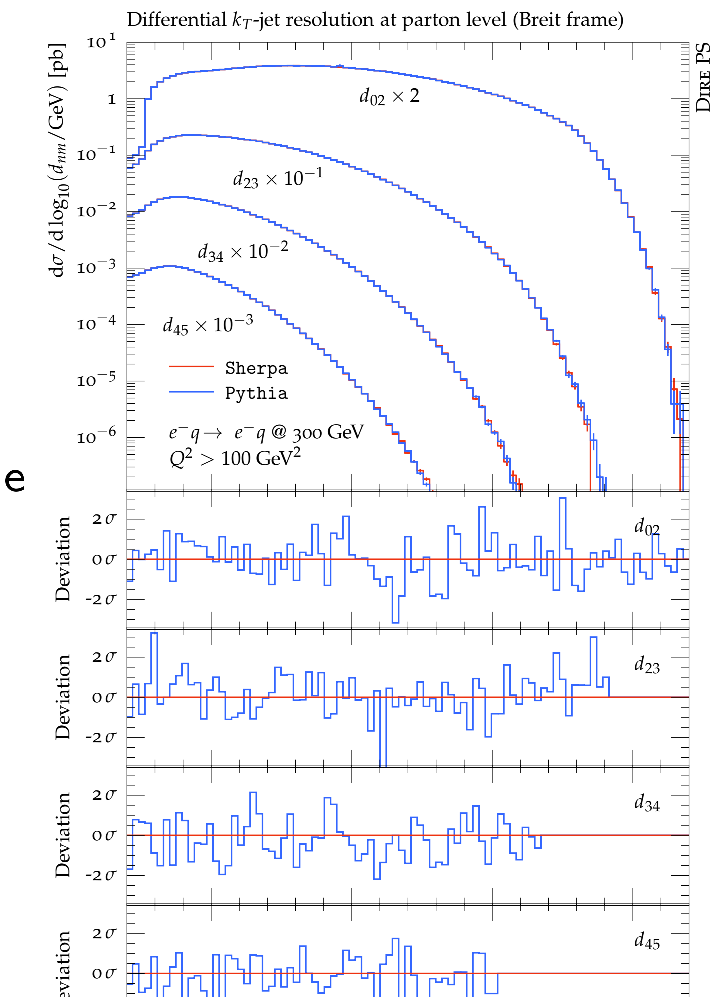
$$R'_{\mathrm{rej}}(t) = \frac{P'_{\mathrm{rej}}(t)}{P_{\mathrm{rej}}(t)} = \frac{1 - P'_{\mathrm{acc}}(t)}{1 - P_{\mathrm{acc}}(t)} = \frac{\hat{P}(t) - P'(t)}{\hat{P}(t) - P(t)}$$



New Shower Plug-Ins: DIRE & VINCIA

Slides adapted from Stefan Prestel

Cross-validation example: Jet scales in DIS



DIRE is a new shower for both PYTHIA and SHERPA

Combines "traditional" *parton* showers and *dipole* showers:

Ordering in "soft" dipole-antenna $p_\perp$. $1/p_\perp^2$ contains all divergences.
Antenna radiation pattern still partial-fractioned into parton shower kernels
$\Rightarrow$ Kernels act to project collinear enhancements out of $1/p_\perp^2$.

Ensure wide phase space coverage

Choose two-particle symmetric ordering variable, normalized to the *largest* scale in the branching.

Use simple phase space boundaries:

Phase space integration manageable $\to$ hopefully allows comparison to known anomalous dimensions.

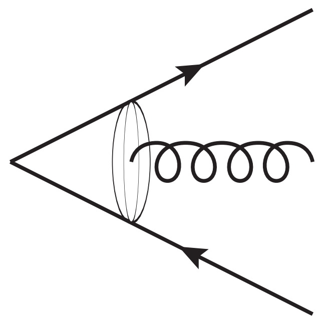
Extensive cross-validation possible

…and done at permille-level for each individual splittting.

S Höche, SP Eur.Phys.J. C75 (2015) no.9, 461

New: PYTHIA 8 showers now capable of handling DIS vincia.hepforge.org

Splittings are fundamentally 2→3



Each colour **antenna** undergoes a sequence of splittings

Proof of concept for one-loop corrections Hartgring, Laenen, PS JHEP 1310 (2013) 127

+ Framework for 2nd-order kernels, implementation of *2→4* Li & PS, arXiv:1611.00013

See talk by Hai Tao Li

E.g., **VINCIA** (also ARIADNE)

Antenna radiation functions & phase-space factorisations

Collinear Limits → **DGLAP kernels** (→ collinear factorisation)

Soft Limits → **Eikonal factors** (→ Leading-Colour coherence)

2→3 phase-space maps = **exact, on-shell factorisations of the (n+1)/n-parton phase spaces** (→ Lorentz invariant, p_μ conserving, and valid over all of phase space - not just in limits)

+ Non-perturbative limit of colour dipoles/antennae → **string pieces**
→ natural matching onto (string) hadronisation models

What's new in our approach? (e.g., not in ARIADNE)

+ Iterated (tree-level) MECs: matrix-element corrections (since v1.x)
+ Backwards antenna evolution for ISR (new in v2.0) N Fischer, Ritzmann, SP, PS arXiv:1605.06142
+ Automated uncertainty bands/weights (& runtime ROOT displays)

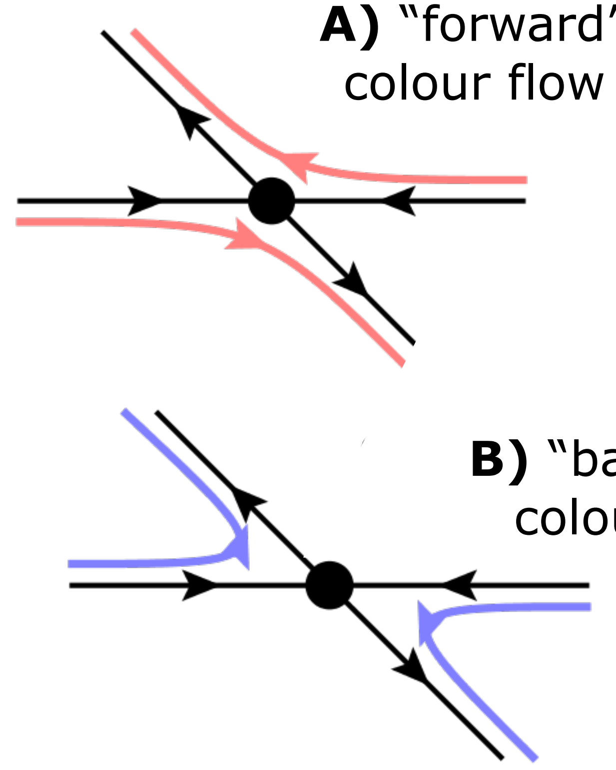
Giele, Kosower, PS PRD84 (2011) 054003 (same principle as now in Herwig++, Pythia 8, Sherpa)

Example taken from: Ritzmann, Kosower, PS, PLB718 (2013) 1345

Example: quark-quark scattering in hadron collisions

Consider one specific phase-space point (eg scattering at 45°)

2 possible colour flows: **A** and **B**



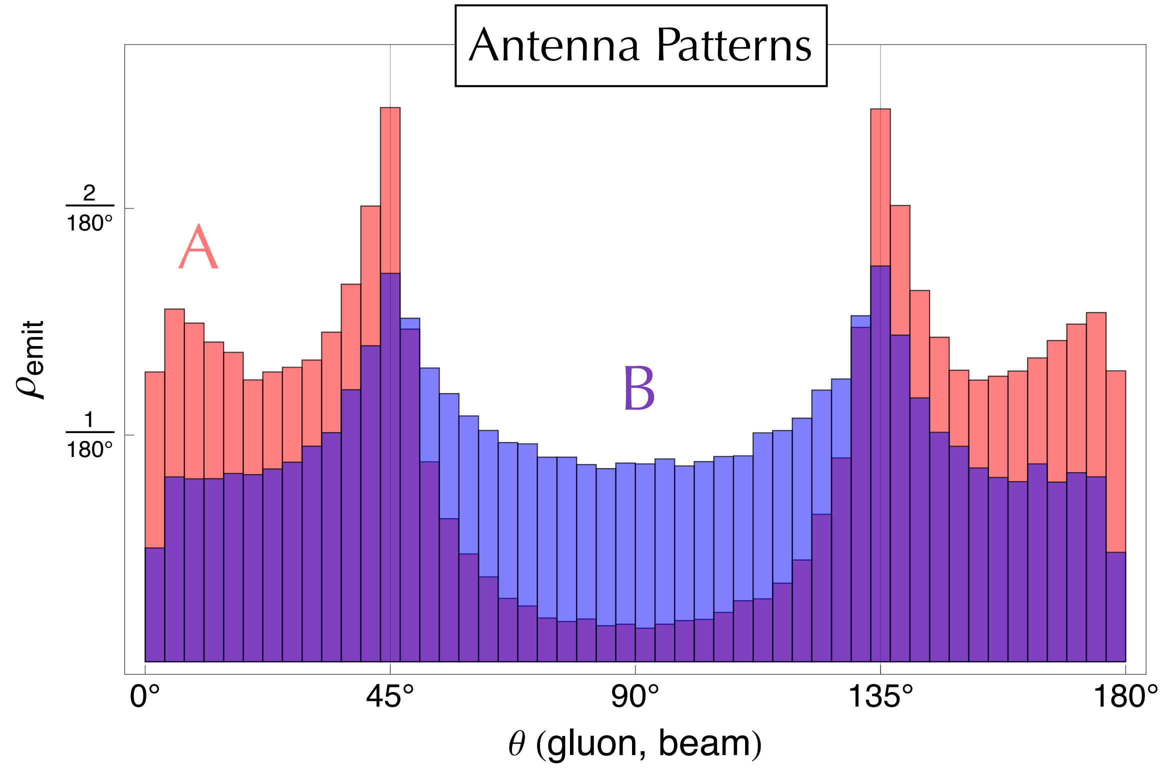


Figure 4: Angular distribution of the first gluon emission in $qq \to qq$ scattering at 45°, for the two different color flows. The light (red) histogram shows the emission density for the forward flow, and the dark (blue) histogram shows the emission density for the backward flow.

Kinematics (e.g., Mandelstam variables) are identical. The only difference is the colour-flow assignment.

PS: coherence also influences the Tevatron top-quark forward-backward asymmetry: see PS, Webber, Winter, JHEP 1207(2012)151

(New: Photon-Photon Interactions)

Ilkka Helenius

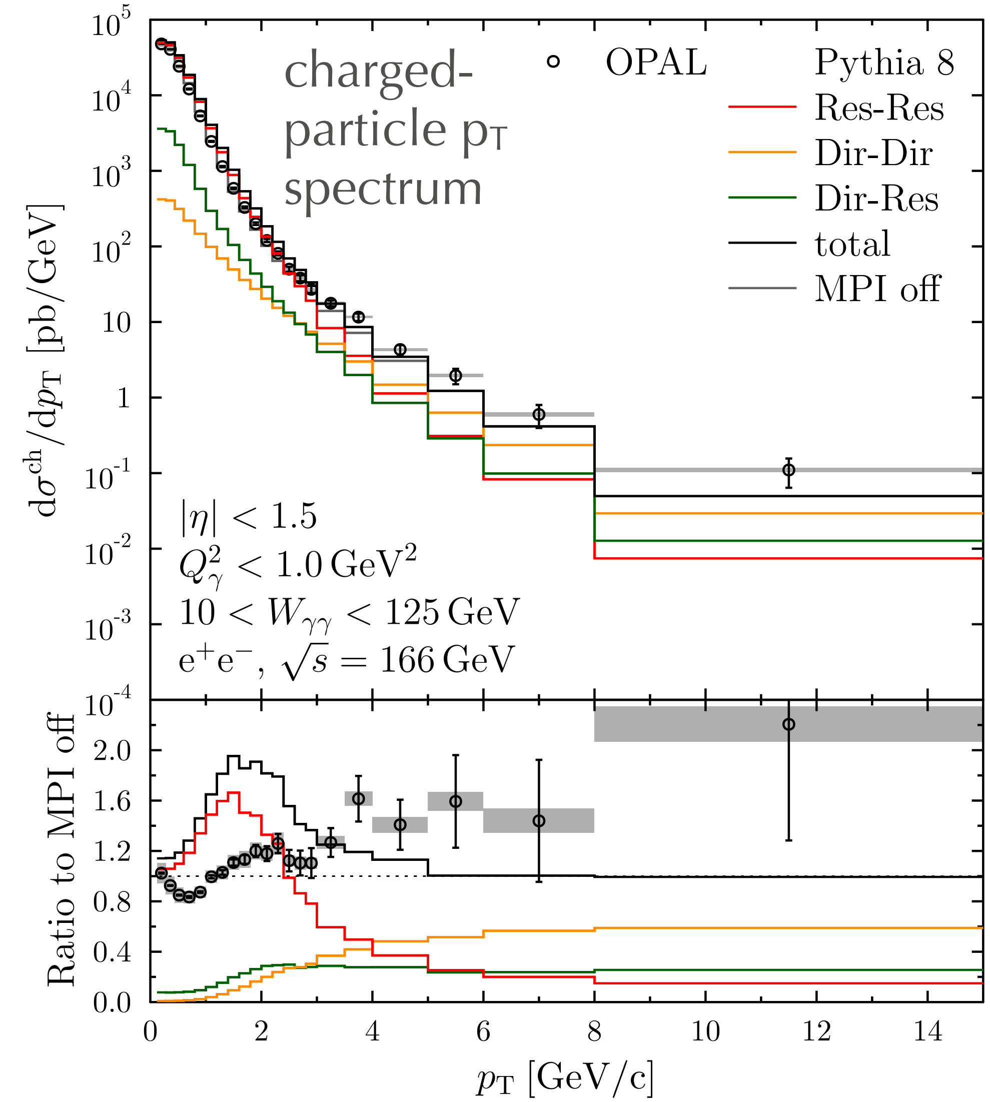
Currently included (version 8.219):

- Hard processes in resolved photon-photon collisions of real photons : γγ→X; with parton showers and beam remnants
    - Hard processes in resolved γγ interactions can also be generated in e^+e^- collisions by convolution of EPA and photon PDFs
- One set of PDFs for resolved photons (CJKL)

Will be included soon (next version):

- Further kinematic cuts (e.g. on $m_{\gamma\gamma}$)
- Direct (unresolved) processes with scattered leptons
- Soft processes and MPIs for resolved photon-photon collisions including also these processes in e^+e^- collisions

See talk by Ilkka Helenius



Summary