# Summary of WG5
# MC and Tools

*Stefan Gieseke*
*ITP*
*University of Karlsruhe*

*Part I (Part II→ P Bartalini)*

# Topics

This talk:

- New shower developments
- Matching to higher orders
- New Generators

Paolo Bartalini:

- Underlying event
- Tuning

# *Perspective*

- These topics developed throughout the HERA-LHC workshops.
- This workshop =
  good snapshot of current status of many (ongoing) projects.
- Guided by 2008 talks.

# New Shower Developments

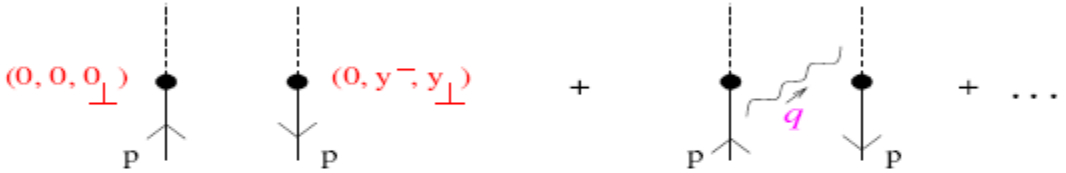
- kT factorization/CASCADE – F. Hautmann, H. Jung:
  - Evolution with NS form factor, small x effects
  - Unintegrated pdfs
  - kT kick for free
- Nagy, Soper:
  - Beyond 1/Nc
  - with interference beyond soft limit
- KRKMC - Jadach, Skrzypek
  - Constrained Markov Chain
  - MC evolution like PDF evolution
  - Path to NLO
- Dipole showers (see New Generators)

# kT factorization

Francesco Hautmann

◇ Suppose a gluon is absorbed or emitted by eikonal line:

$n = (0,\ 1,\ 0_\perp)$




$$f_{(1)} = P_R(x, k_\perp) - \delta(1-x)\,\delta(k_\perp) \int dx' dk'_\perp P_R(x', k'_\perp)$$

where $\quad P_R = \dfrac{\alpha_s\ C_F}{\pi^2} \left[ \dfrac{1}{1-x}\ \dfrac{1}{k_\perp^2 + \rho^2} + \{\text{regular at } x \to 1\} \right]$ $\quad \rho$=IR regulator

↑ endpoint singularity $(q^+ \longrightarrow 0,\ \forall\ k_\perp)$

◇ Physical observables:

$$\mathcal{O} = \int dx\ dk_\perp\ f_{(1)}(x, k_\perp)\ \varphi(x, k_\perp)$$

$$= \int dx\ dk_\perp\ [\varphi(x, k_\perp) - \varphi(1, 0_\perp)]\ P_R(x, k_\perp)$$

inclusive case: $\varphi$ independent of $k_\perp \Rightarrow 1/(1-x)_+$ from real + virtual

general case: endpoint divergences (incomplete KLN cancellation)

# kT factorization

- Alternative to collinear factorization
- Problem:

Ex. : $\int dk_\perp \; f(x,k_\perp,\mu)\;\Theta(\mu-k_\perp) \stackrel{?}{=} f^{\overline{\rm MS}}(x,\mu)$

= holds only at tree level: full relation involves coefficient function $R$

$$\int^{\mu} dk_\perp \; f(x,k_\perp,\mu) \;=\; R(x) \;\otimes\; f^{\overline{\rm MS}}(x,\mu)$$

$\diamondsuit$ $R$ calculable as a power series in $\alpha_s$, $R(x)=\delta(1-x)+\sum_k \; r_k \; \alpha_s^k$

- Applications: Cut-off regularization vs. Subtractive regularization

# kT factorization

- Monte Carlo programs based on this

Implementations:

Höche, Krauss and Teubner, arXiv:0705.4577 (KMR)

Golec, Jadach, Placzek, Stephens, Skrzypek, hep-ph/0703317 (CCFM)

LDCMC Lönnblad & Sjödahl, 2005; Gustafson, Lönnblad & Miu, 2002 (LDC)

CASCADE Jung, 2004, 2002; Jung and Salam, 2001 (CCFM)

SMALLX Marchesini & Webber, 1992 (CCFM)

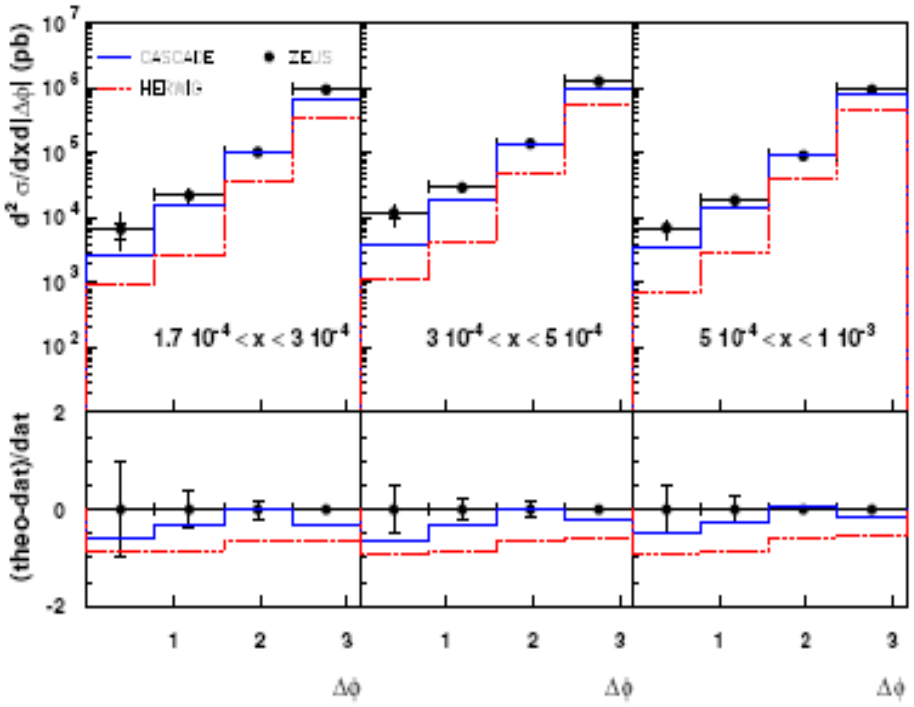
Advantages over standard Monte-Carlo like PYTHIA or HERWIG:

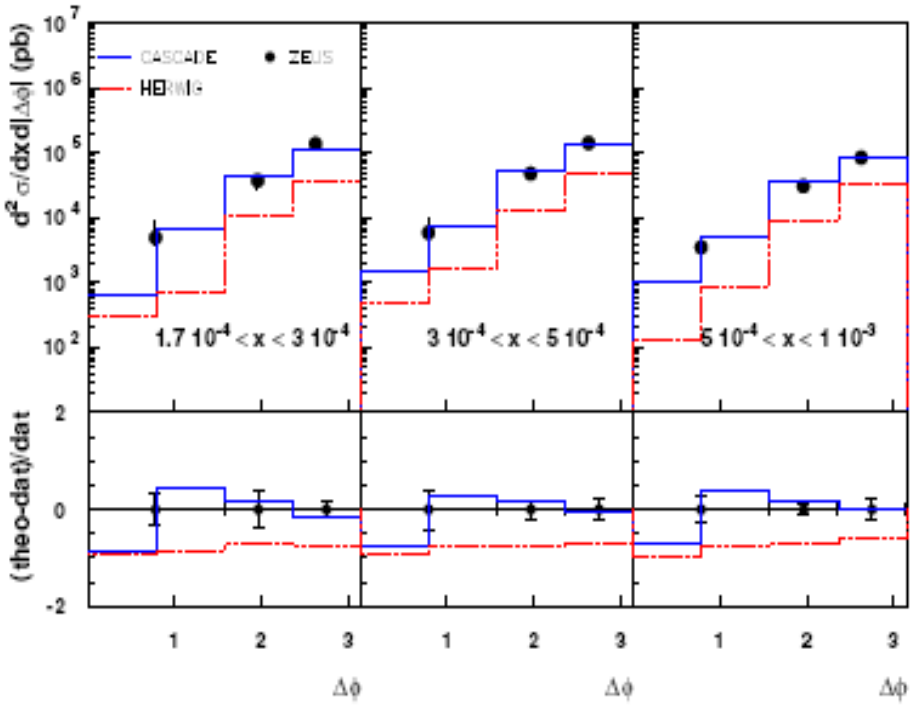
- better treatment of high-energy logarithmic effects
- likely more suitable for simulating underlying event's $k_\perp$

- Interesting for UE/multigluon environment

# kT factorization

Angular jet correlations from CASCADE and HERWIG compared with DIS data




(left) di-jet cross section; (right) three-jet cross section

Jung & H, arXiv:0712.0568 [hep-ph]

Different shapes and normalization

# Alternative showers

Z Nagy

## Motivations of Shower Development

Actually I have heard two of them...

✗ "Earn as many citations as PYTHIA does ..."

# Alternative showers

Including effects of subleading color – might be important.

Matrix element square is

$$|\mathcal{M}(\{p,f\}_m)|^2 = N_c^n \sum_{\{c\}_m} |A(\{p,f,c\}_m)|^2 + \mathcal{O}\left(\frac{1}{N_c^2}\right)$$

where $A(\{p,f,c\}_m)$ is the color subamplitudes of the color configuration $\{c\}_m$

Cross sections at $\sqrt{s} = 1960$ GeV, with structure functions, in nanobarns, $p_T > 10\text{GeV}$ $|\eta| < 2.0$.

| Process | $\sigma_0$ : Normal | $\sigma_1$ : Large Nc component | $\frac{\sigma_1 - \sigma_0}{\sigma_0}$ |
|---|---|---|---|
| ud→W+g | 0.1029(5)D+01 | 0.1158(5)D+01 | 13% |
| ud→W+gg | 0.1018(8)D+00 | 0.1283(10)D+00 | 26% |
| ud→W+ggg | 0.1119(17)D-01 | 0.1564(22)D-01 | 40% |
| ud→W+gggg | 0.1339(36)D-02 | 0.2838(71)D-02 | 120% |

*Results were calculated by HELAC*

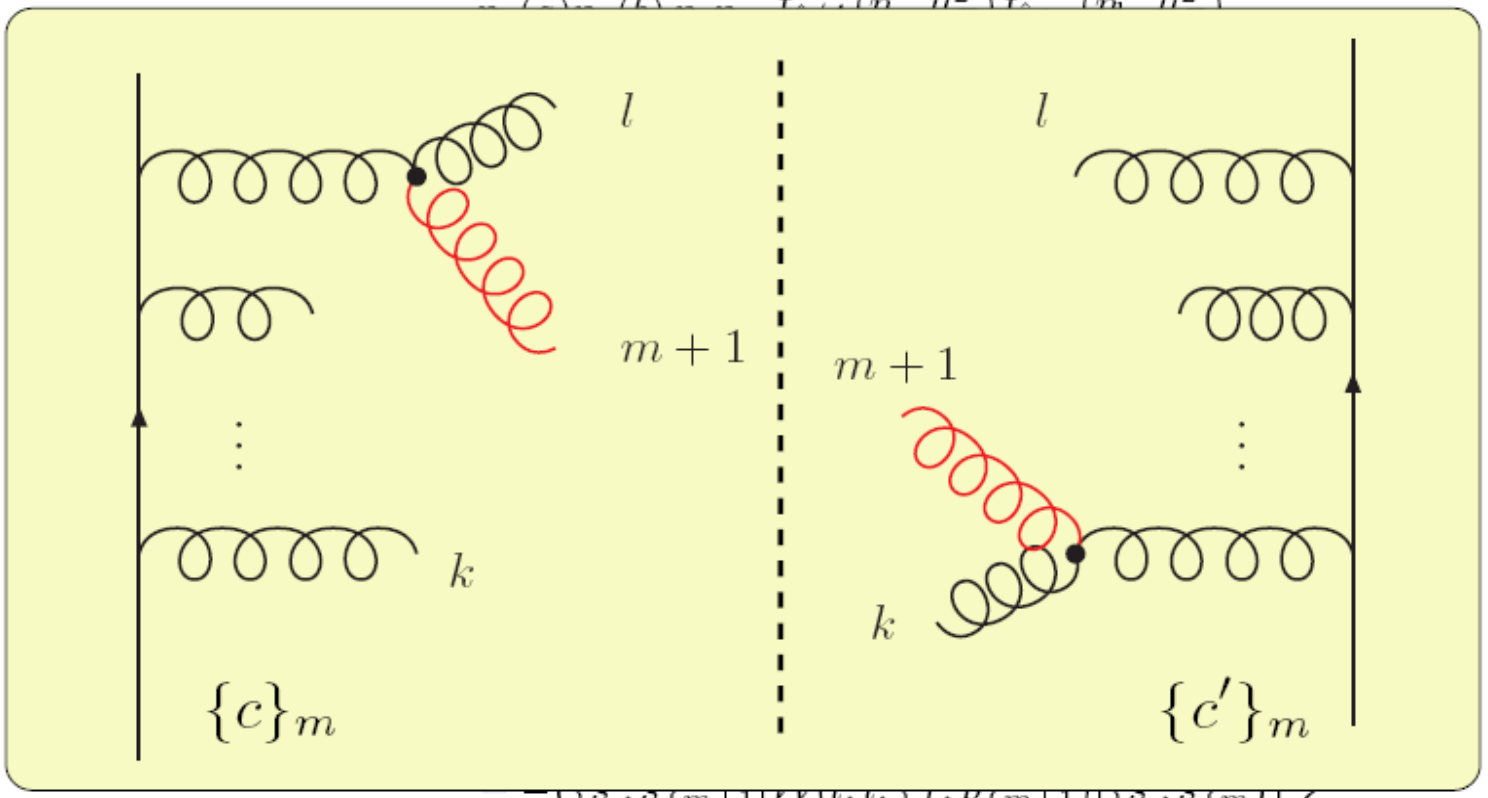
Large on ME level!

*Yes, we need.*

# Alternative showers

## Full Splitting Operator

$$\left(\{\hat{p},\hat{f},\hat{s}',\hat{c}',\hat{s},\hat{c}\}_{m+1}\middle|\mathcal{H}_{\rm I}(t)\middle|\{p,f,s',c',s,c\}_m\right)$$




$$+\,\theta(\hat{f}_{m+1}\neq \mathrm{g})\ \left(\{\hat{c}',\hat{c}\}_{m+1}\middle|\mathcal{G}(l,l;\{\hat{f}\}_{m+1})\middle|\{c',c\}_m\right)\mathcal{W}(l,l;\{\hat{f},\hat{p}\}_{m+1})\Big]$$

# KRKMC

## Subtracted NLO splitting function for *NLO MC!*

M Skrzypek, S Jadach

In the subtracted expression the NLO kernels comes form the integral in which we may set $\epsilon \to 0$

$$F^{(2)}(\bar{C}_0 \mathbf{P} K_0 (1-\mathbf{P}) K_0) = \left(C_F \frac{\alpha}{\pi}\right)^2 \frac{1}{2\epsilon} \int_\alpha \frac{\alpha_1}{\alpha_1^2+\delta^2} \frac{\alpha_2}{\alpha_2^2+\delta^2} \int_0^1 dy \int_0^{2\pi} \frac{d\varphi_{21}}{2\pi}$$

$$\times \left[ \frac{1}{U^2(y,1,\varphi_{21})} \left\{ \frac{T_1(\alpha_1,\alpha_2)}{\alpha_1\alpha_2} + \frac{T_2(\alpha_1,\alpha_2,0)}{\alpha_2^2} \left(\frac{1}{y}\right)_+ + \frac{T_3(\alpha_1,\alpha_2)}{\alpha_2} 2\cos(\varphi_{21}) \frac{1}{\sqrt{y}} \right\} \right.$$

$$+ \frac{1}{U^2(1,y,\varphi_{21})} \left\{ \frac{T_1(\alpha_1,\alpha_2)}{\alpha_1\alpha_2} + \frac{T_2(\alpha_1,\alpha_2,0)}{\alpha_2^2} y + \frac{T_3(\alpha_1,\alpha_2)}{\alpha_2} 2\cos(\varphi_{21}) \sqrt{y} \right\}$$

$$\left. + \delta(y) \frac{T_2'(\alpha_1,\alpha_1) - 2T_2'''(\alpha_1,\alpha_1)}{x_1^2} \right] + \mathcal{O}\left(\frac{1}{\epsilon^2}\right).$$

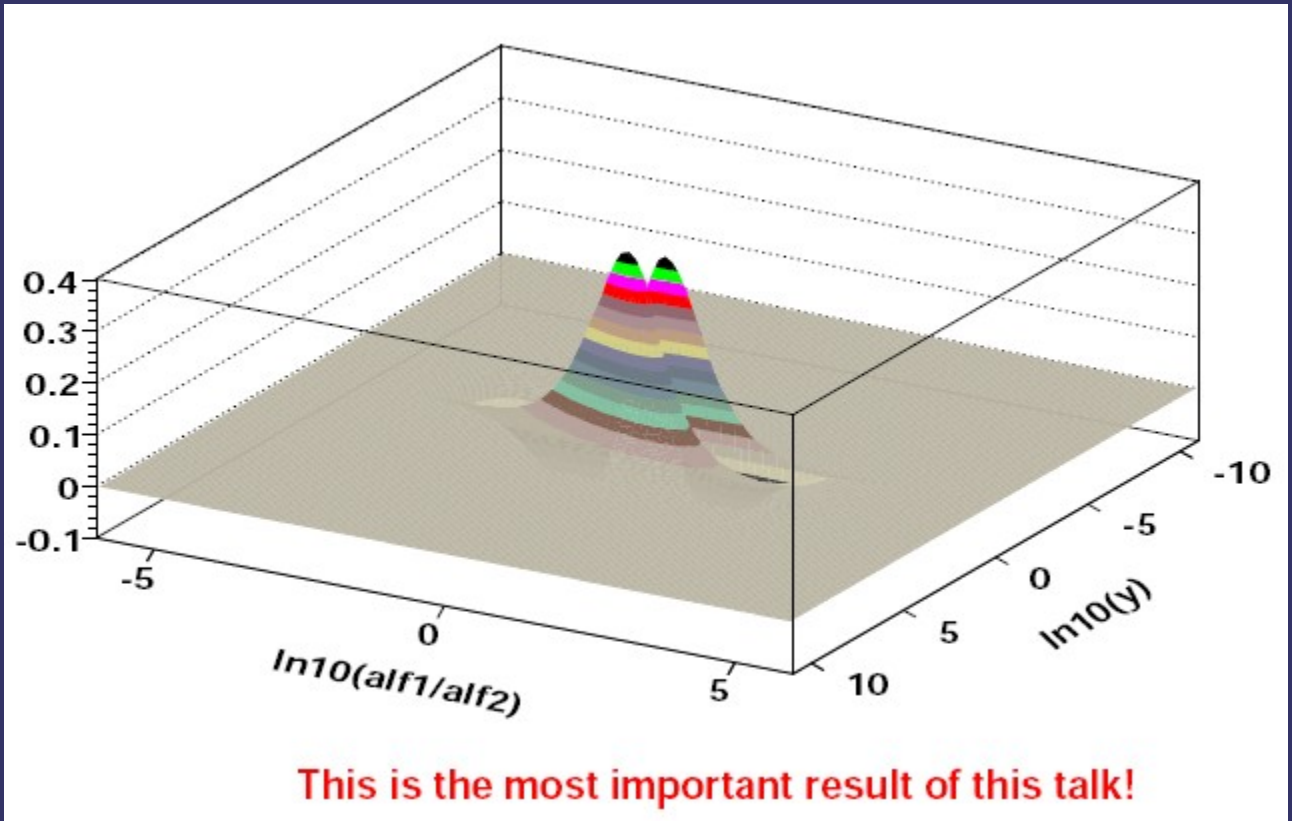
Explicit regularization of the IR singularity in the lightcon variables $\alpha_i$ using $\delta \ll 1$. (Dim. reg. is not used here!). $T_2' - 2T_2'''$ comes from $\epsilon$ terms in $\gamma$-traces.

The above is ready to go for analytical and/or numerical 3-dim. integration.

# KRKMC

”Short range correlation”
Only important when leading logs are small!

M Skrzypek, S Jadach

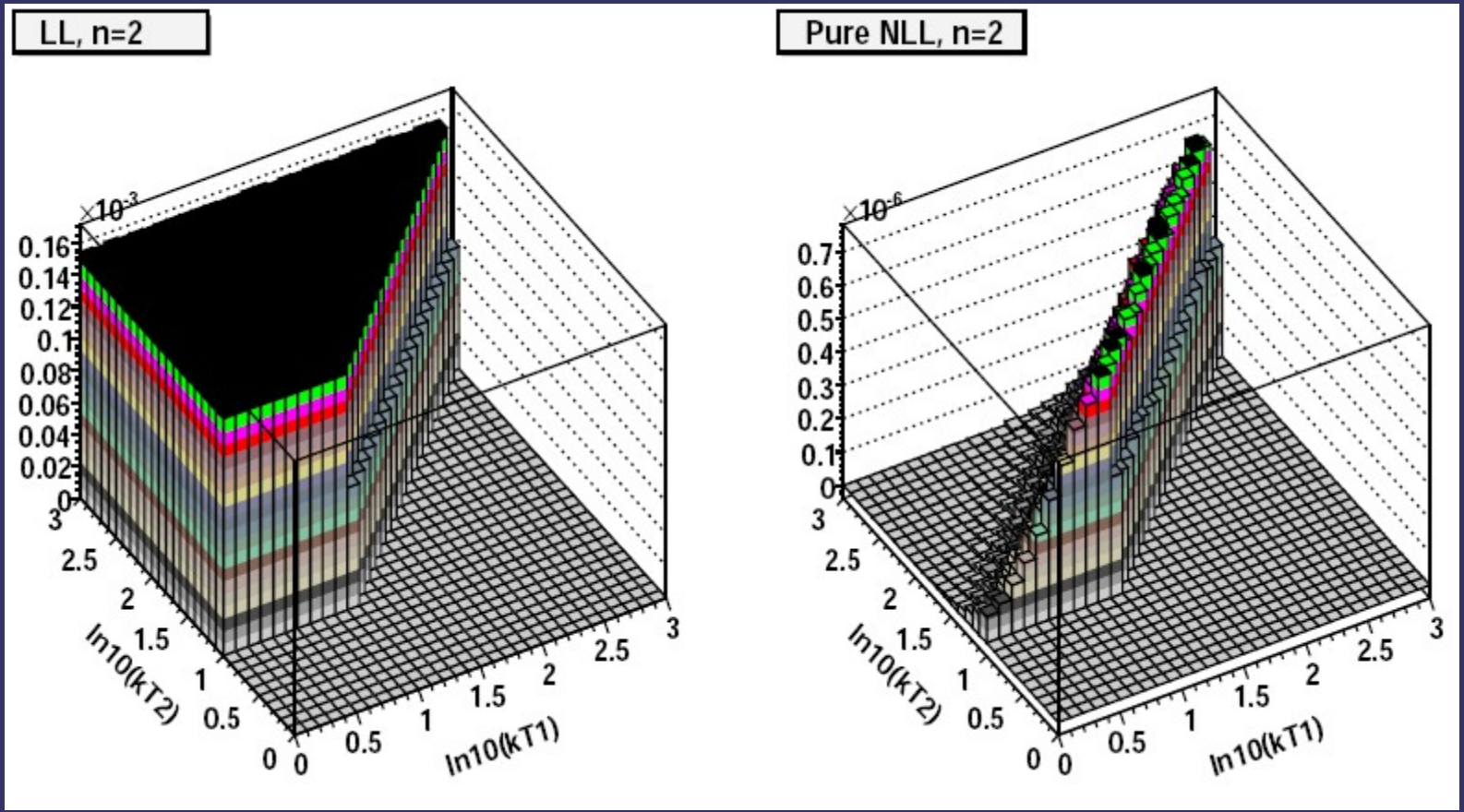



Final numerical result after many (large) cancellations, highly nontrivial!

# KRKMC

## Prototype MC implementation

M Skrzypek, S Jadach




1+1 emssion from LL, 2 emssions from NLL, more emissions understood

# *Alternative showers*

- New phase space opened for kT factorization? (→ *HERA!*)
- Full colour+quantum interference?
  → Progress, implementation will be interesting!
- Full NLO MC from Krakow?
  Lots of progress! Many questions solved on conceptual *and* practical level
  – much work remains!

# Matching to higher orders

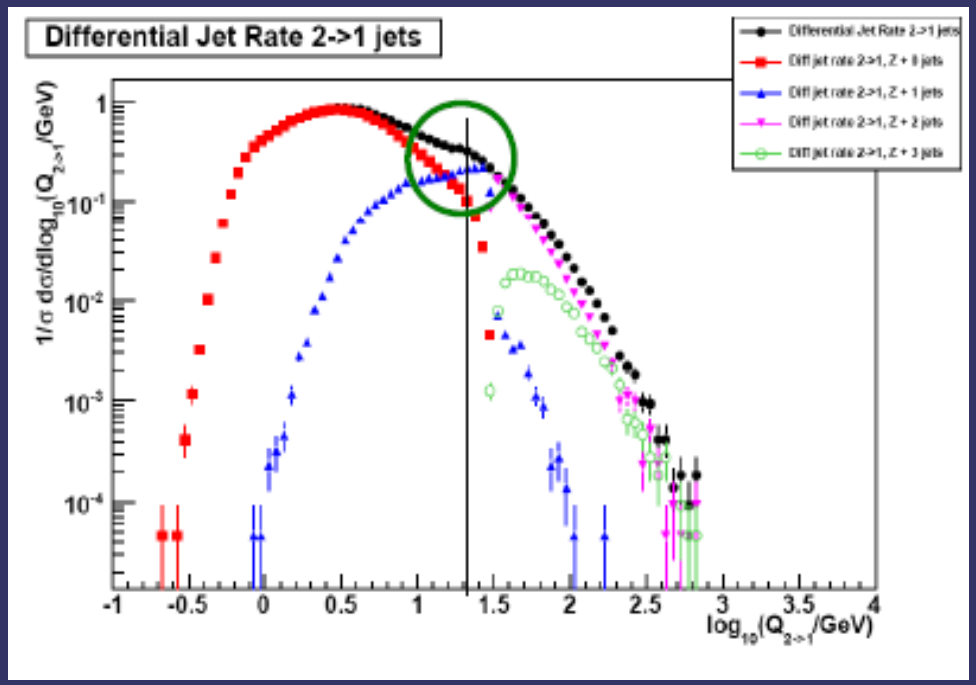
- Want to add information from ME to PS
- Multileg matching
  - (n+1, n+2,... in FS), tree level
  - CKKW – Sudakov weights
  - MLM - phase space vetos
- Matching to full NLO
  - 1 extra hard emission
  - Full virtual corrections

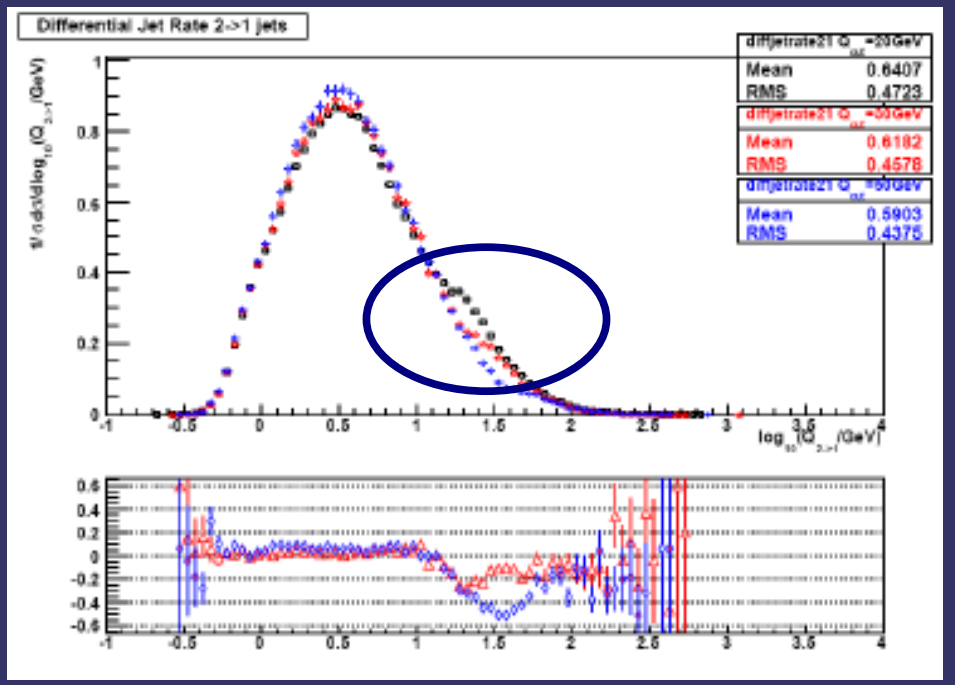
# Multileg

CKKW vs MLM – Differential jet rates **@LHC**

*Systematic matching scale dependence*

Piergiulio Lenzi

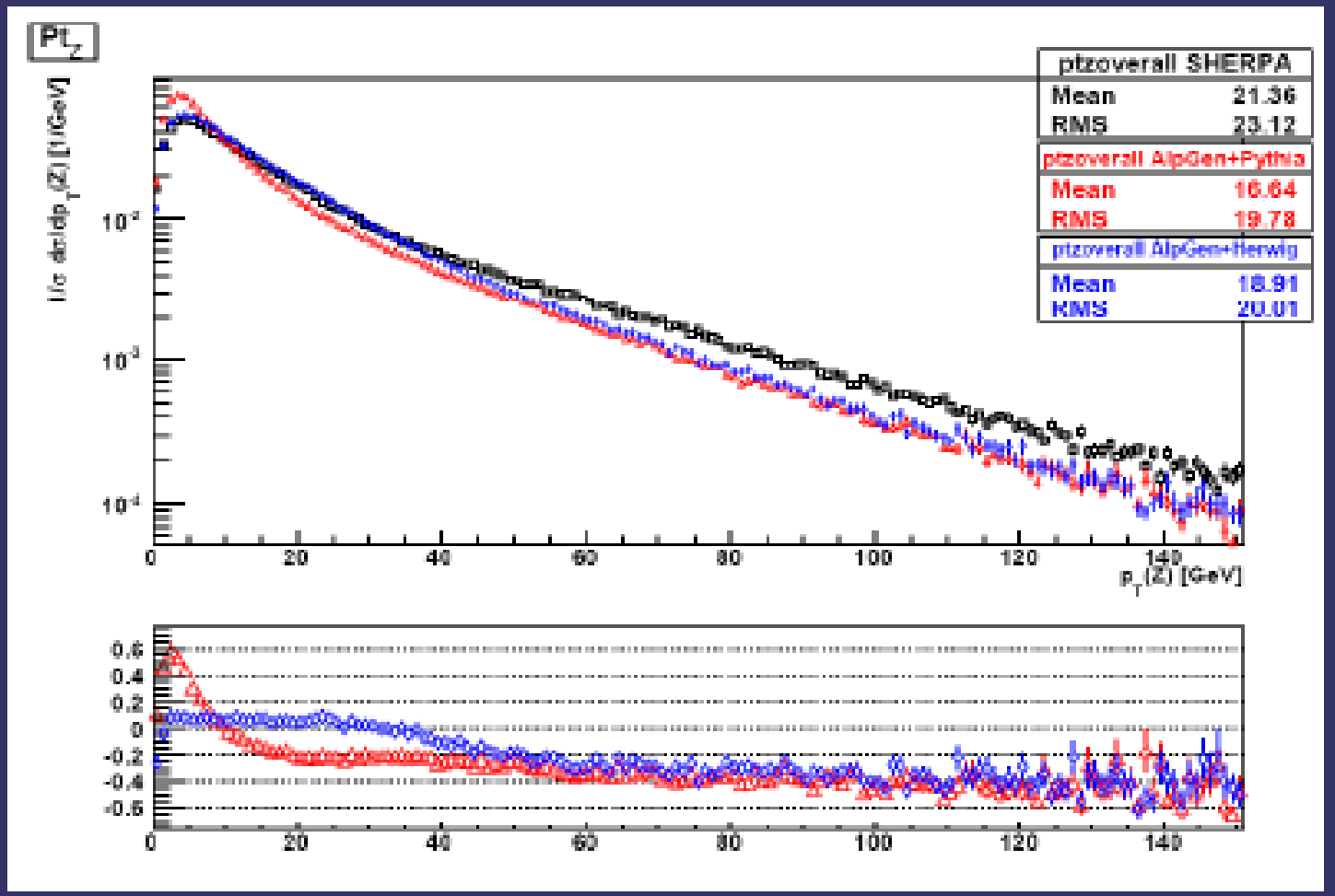



*CKKW* *D(2→1)* *MLM*

# Multileg

CKKW vs MLM (+Herwig/+Pythia) *Z transverse momentum*

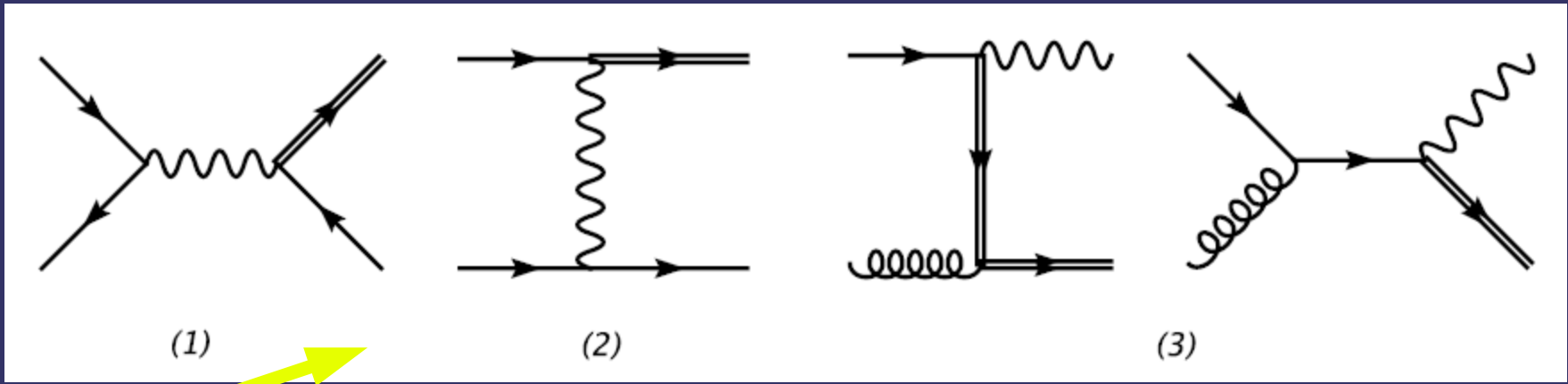



Large deviations! *More work needed to understand.*

# NLO

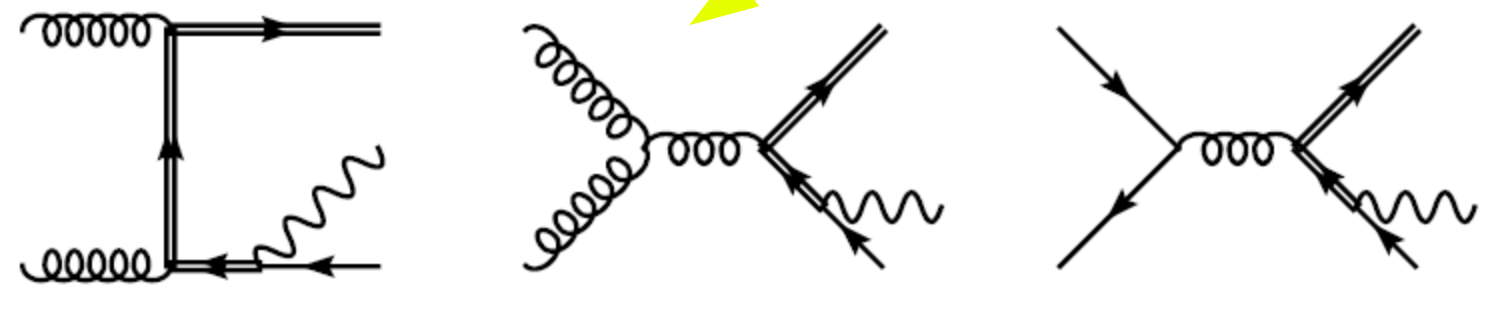
Single top in the Wt mode with MC@NLO

Chris White




LO

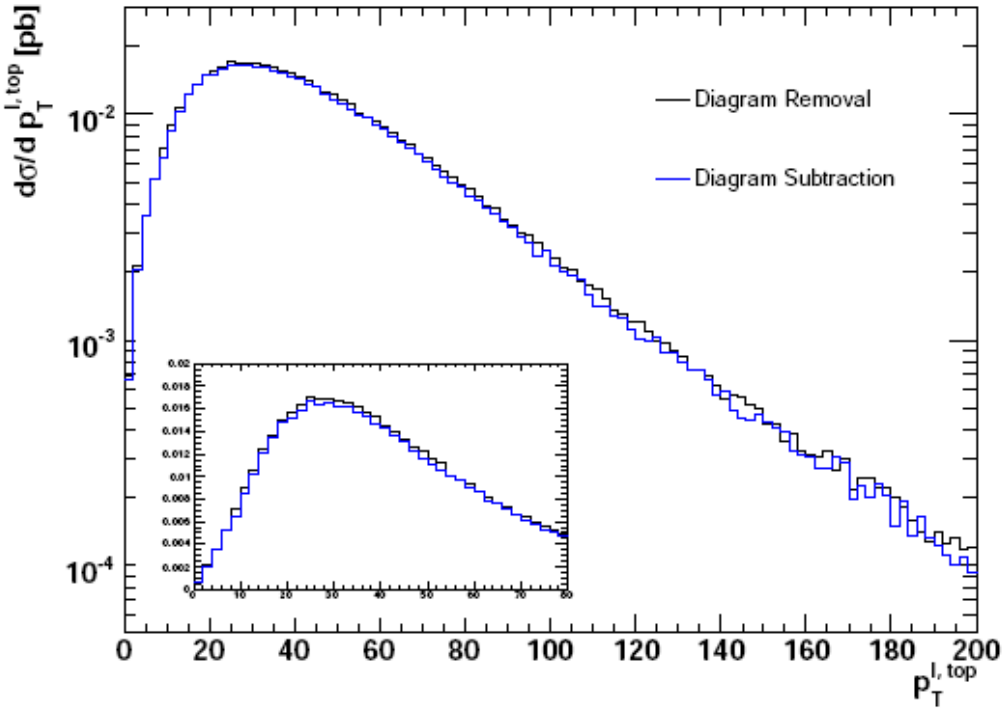
NLO real – contains resonant top

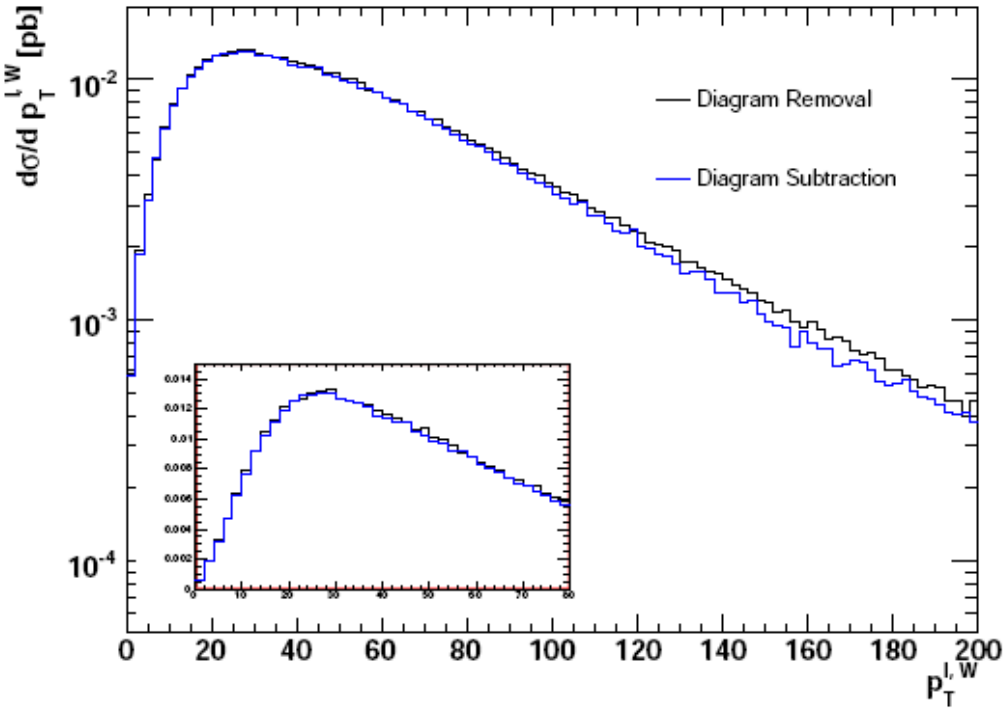


# NLO

## Two Methods working in MC@NLO

Chris White




- Subtraction and Removal give very similar results, except at very high $p_t$ (here $p_{t,veto} = 50\text{GeV}$).
- Here the cross-section is very small.

# Matching to higher orders

- Multileg matching
  - Quite well established
  - Systematic problems?
- Matching to full NLO
  - Much progress
  - MC@NLO established
  - More methods (POWHEG, Dipoles, KRKMC...)

# *Do we have all the tools?*

# New MC generators

New Event generators in MCnet

- Sherpa
- Pythia8
- ThePEG/Ariadne
- Herwig++


”Special guest”

- Cascade

# Sherpa

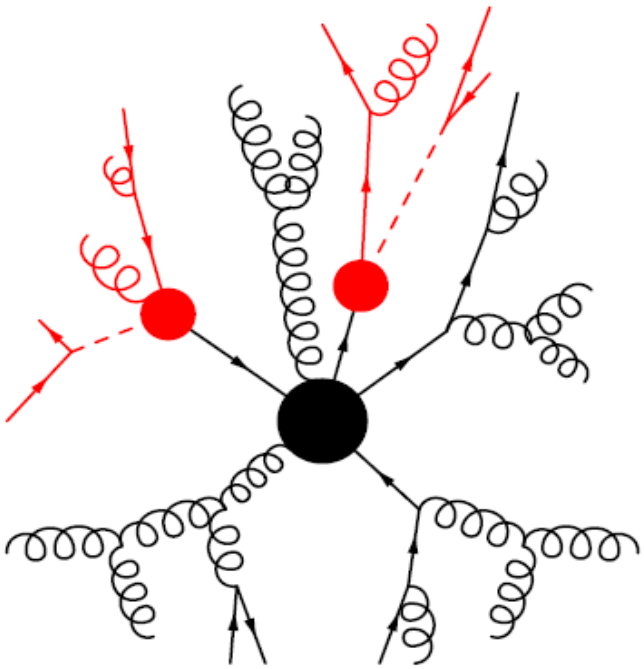
Frank Siegert

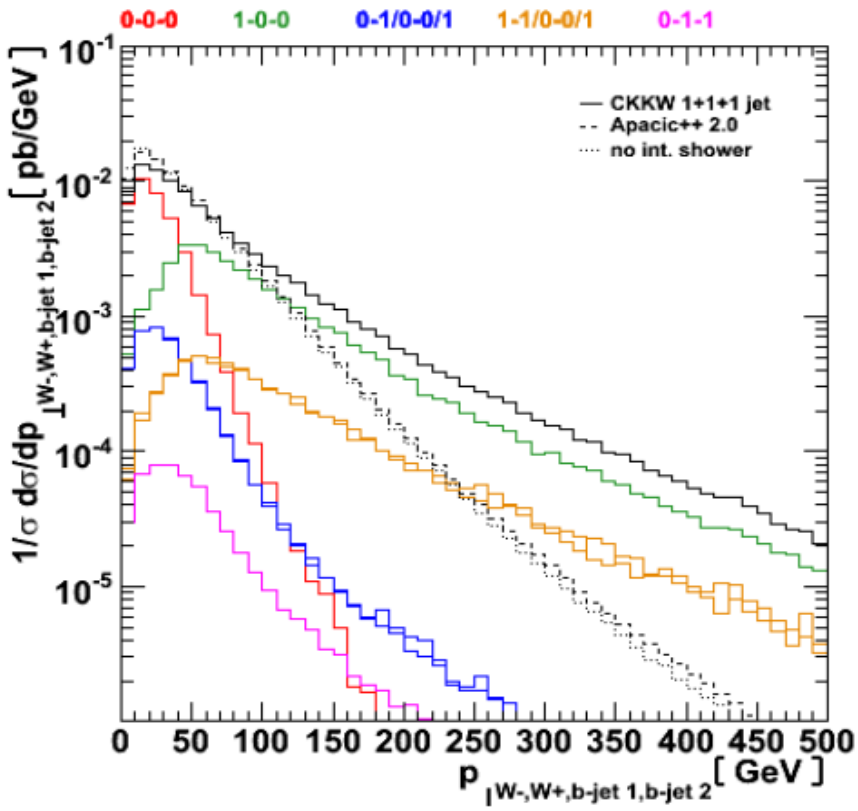
SHERPA release 1.1

## New features

- AHADIC++ – Cluster fragmentation module
- HADRONS++ – Complete hadron and $\tau$ decay module
- PHOTONS++ – QED radiation in the YFS formalism

CKKW in ttbar



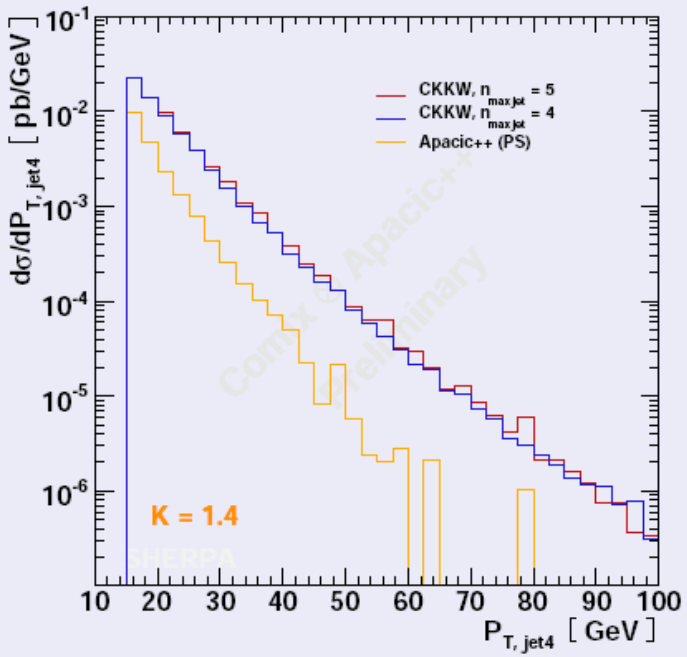


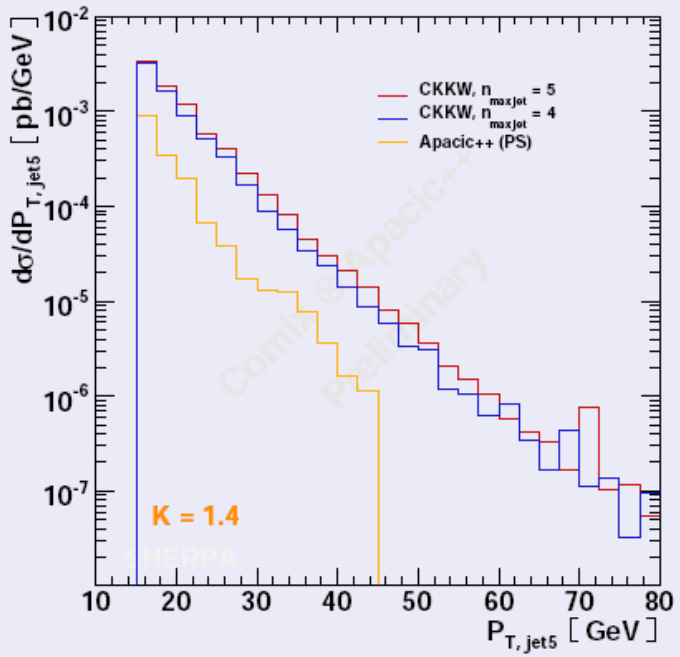
# Sherpa

## Example from MC4LHC comparison vs. COMIX

| $\sigma$ [pb] | Number of jets | | | | | | |
|---|---|---|---|---|---|---|---|
| $e^-e^+$ + QCD jets | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| COMIX | 723.5(4) | 187.9(3) | 69.7(2) | 27.14(7) | 11.09(4) | 4.68(2) | 2.02(2) |
| ALPGEN | 723.4(9) | 188.3(3) | 69.9(3) | 27.2(1) | 10.95(5) | 4.6(1) | 1.85(1) |
| AMEGIC++ | 723.0(8) | 188.2(3) | 69.6(2) | 27.21(6) | 11.1(1) | | |

## Inclusive jet $p_T$ in Z+jets production at the Tevatron

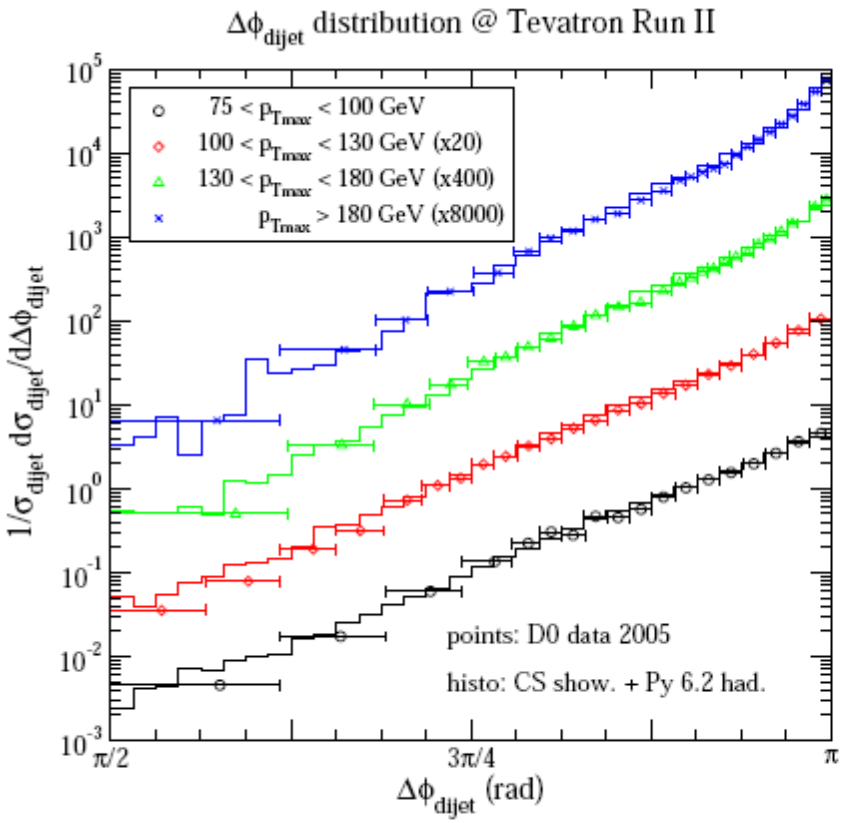


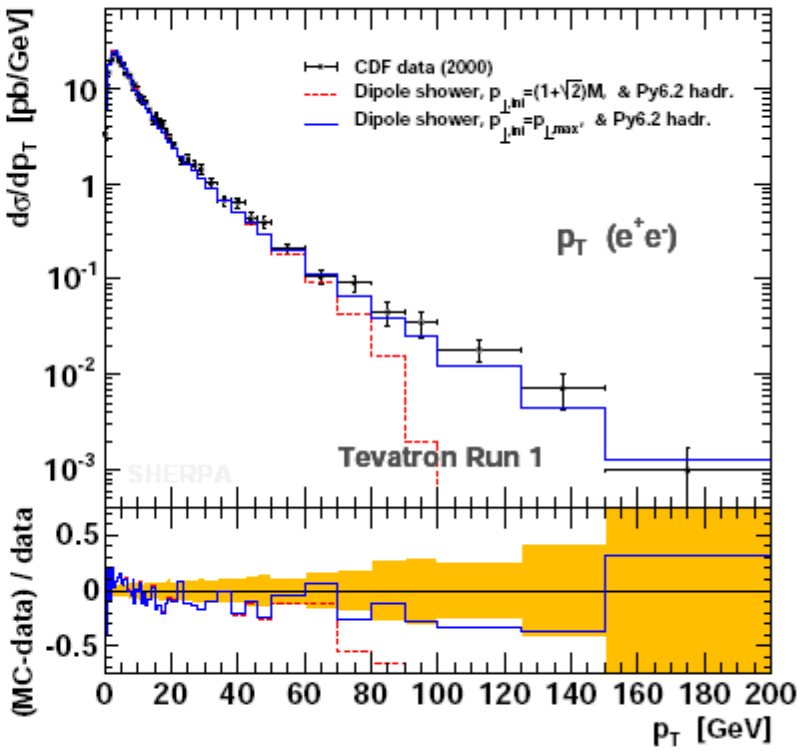

With CKKW matching

# Sherpa

- Two new dipole showers under development:




CSSHOWER++: Inclusive Jet production




ADICIC++: Boson $p_T$ in Drell-Yan

# Pythia8

Torbjorn Sjostrand

- Complete new event generator

New features, not found in 6.4:

- interleaved $p_\perp$-ordered MI + ISR + FSR evolution
- richer mix of underlying-event processes ($\gamma$, J/$\psi$, DY, ...)
- possibility for two selected hard interactions in same event
- possibility to use one PDF set for hard process and another for rest
- elastic scattering with Coulomb term (optional)
- updated decay data

Plans for the future:

- rescattering in multiple interactions (with Florian Bechtel & Richard Corke)
- more ME/PS matching (with Richard Corke)

# News since PYTHIA 8.100

- Acolliner beams and beam momentum spread.
- Beam vertex spread.
- Reduced use of `static`:
  possibility to have several almost separate `Pythia` instances,
  e.g. signal + background events in pileup.
- Combine event records with new = and += methods.
- Updated `SusyLesHouches` interface handles SLHA version 2.
- Neutralino pair production now operational.
- Updated routine for HepMC conversion; support for version 1 dropped;
  bug fix for onium $\longrightarrow$ ggg or $\gamma$gg.
- Improved capability for standalone hadronization.
- Improved handling of Higgs width.
- Safety checks on $\alpha_S$ at small scales.
- Changed for compilation with gcc 4.3.0 and with `-Wshadow` option.
- Some further minor improvements and bug fixes.

# PYTHIA 8 status

| task | status |
|---|---|
| administative structure | operational; extensions planned |
| hard processes, internal | much of PYTHIA 6; SUSY & TC & more to do |
| resonance decays | much of PYTHIA 6; SUSY & TC & more to do |
| hard processes, external | interfaces to LHA F77, LHEF, PYTHIA 6 |
| SUSY(+more) parameters | SLHA2; more needed |
| initial-state showers | operational |
| final-state showers | operational |
| matching ME's to showers | some exists; much more needed |
| multiple interactions | operational; extensions planned |
| beam remnants & colour flow | operational; alternatives to come |
| parton densities | only 2 internal, but interface to LHAPDF |
| string fragmentation | operational; improvements planned |
| decays & particle data | operational; may need updates |
| Bose-Einstein | operational; off by default (tuning) |
| analysis | some simple tools; may be enough |
| graphical user interface | operational; could be extended |
| tuning | major task for MCnet postdocs! |
| testing | major task for experimentalists! |
| ep, $\gamma$p, $\gamma\gamma$ | not in the foreseeable future |

# ThePEG/Ariadne

Leif Lonnblad

ThePEG = framework used by Herwig++ & Ariadne

- New developments:

(since last MCnet meeting at CERN in January 2007)

- No longer depends on CLHEP
- Only dependence is the GNU scientific library
- Compile-time checking of units
- Les Houches Event Files
- Helicity classes for construction of matrix elements.

- Leifs status page:

- Current version 1.2.0 (`www.thep.lu.se/ThePEG`)
- Reasonably stable piece of software

# ThePEG/Ariadne

- About Ariadne
  - Completely rewritten in C++ using THEPEG Main work by Nils Lavesson
  - Almost all components are in place
  - Simple CKKW(L) matching
  - Modified model for initial-state radiation needed
  - $q \rightarrow g$ splitting included
  - String fragmentation with PYTHIA7
  - Validated for $e^+e^-$
- But unfortunately...
  - ARIADNE will not be ready for LHC startup

# Herwig++

Peter Richardson

- Current version: 2.2.0 released Apr/08

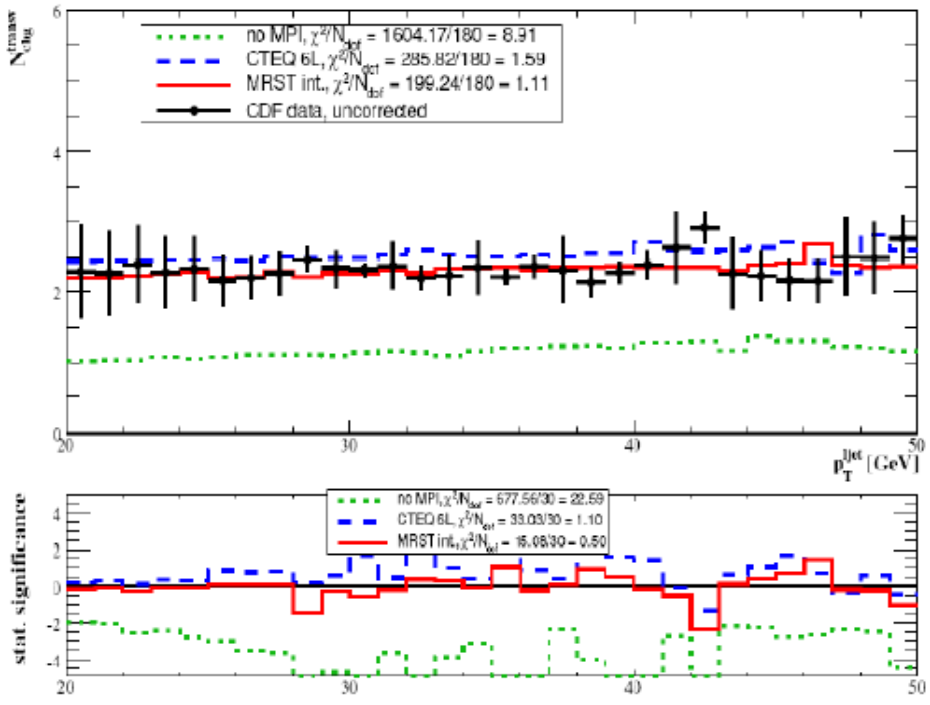
– Multiple parton-parton scattering model of the underlying event, based on the FORTRAN JIMMY program.
– New model of meson and tau decays.
– Inclusion of BSM physics including the MSSM, UED and RS models.
– Tuning to LEP, SLD and B-factory data.

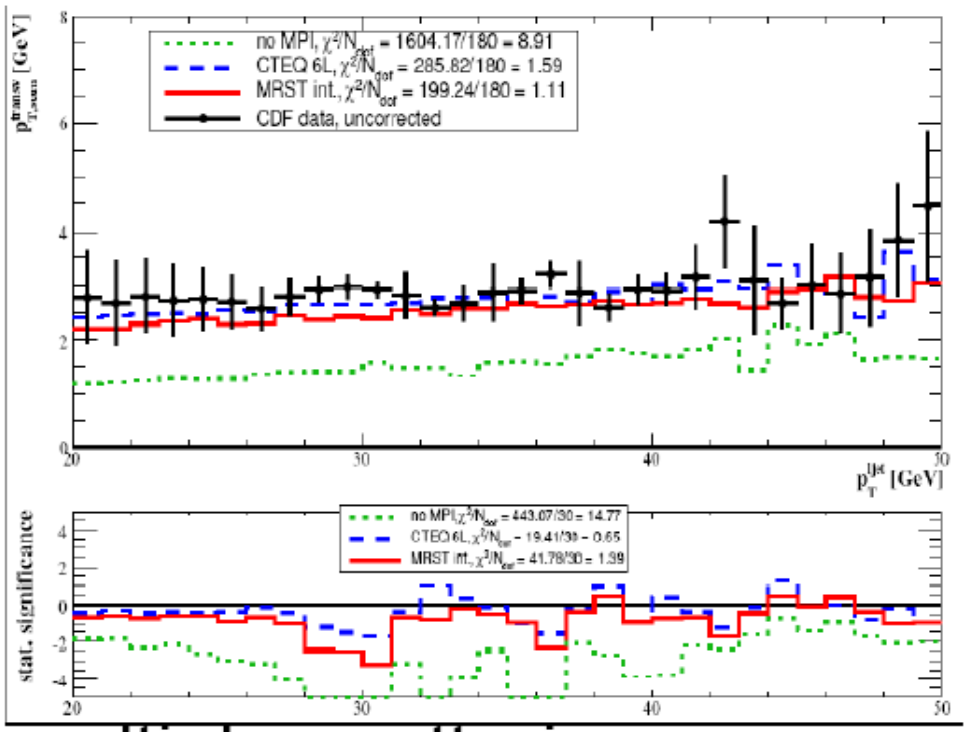
– New $Zh^0$, $Wh^0$, Z+jet and W+jet hard processes.
– $gg \to h^0$ matrix element correction.

full manual arXiv:0803.0883

# Herwig++

- Multiple parton interaction model for UE

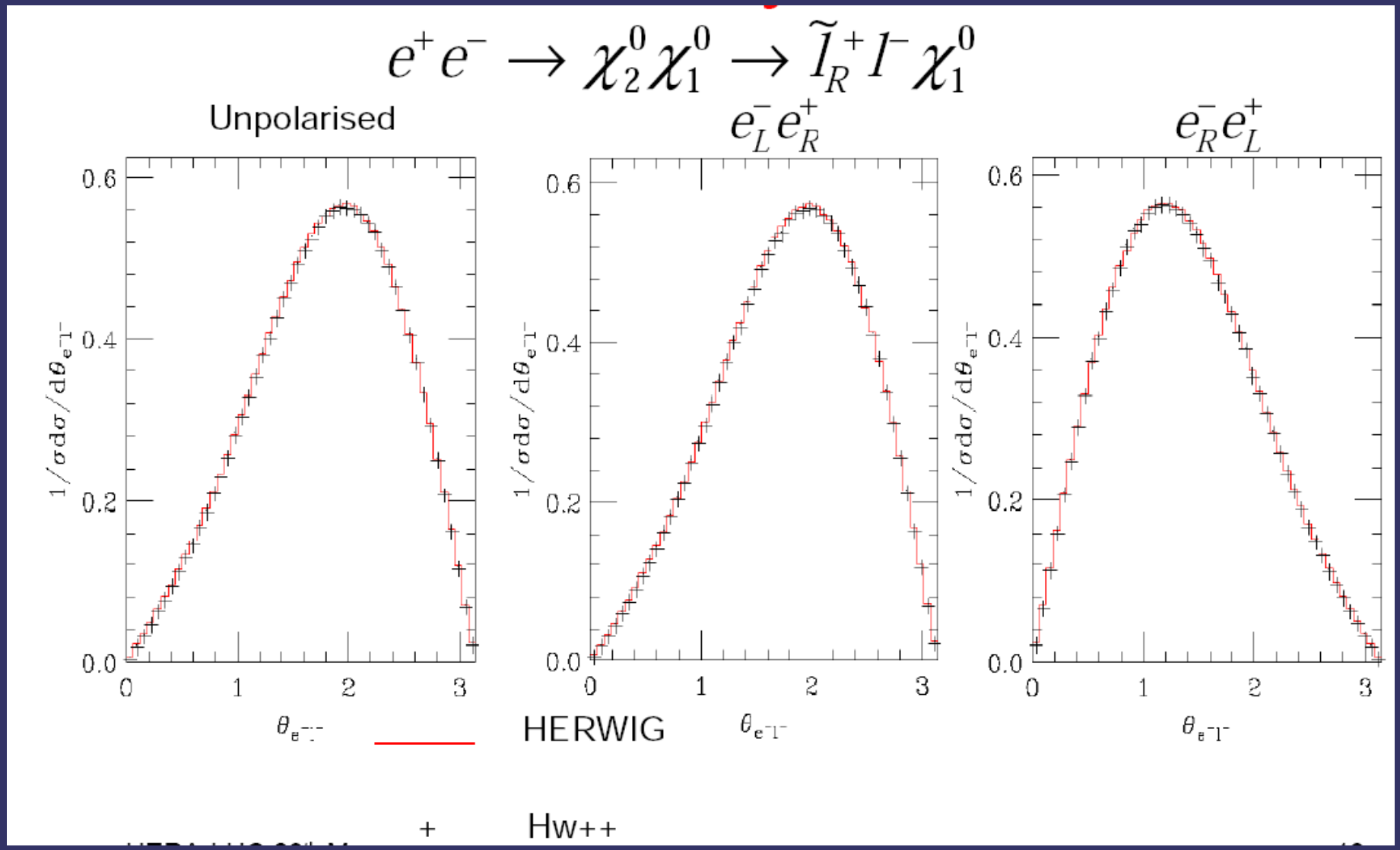



- Major new feature is a multiple scattering model of the underlying event.
- In good agreement with CDF data on the underlying event.

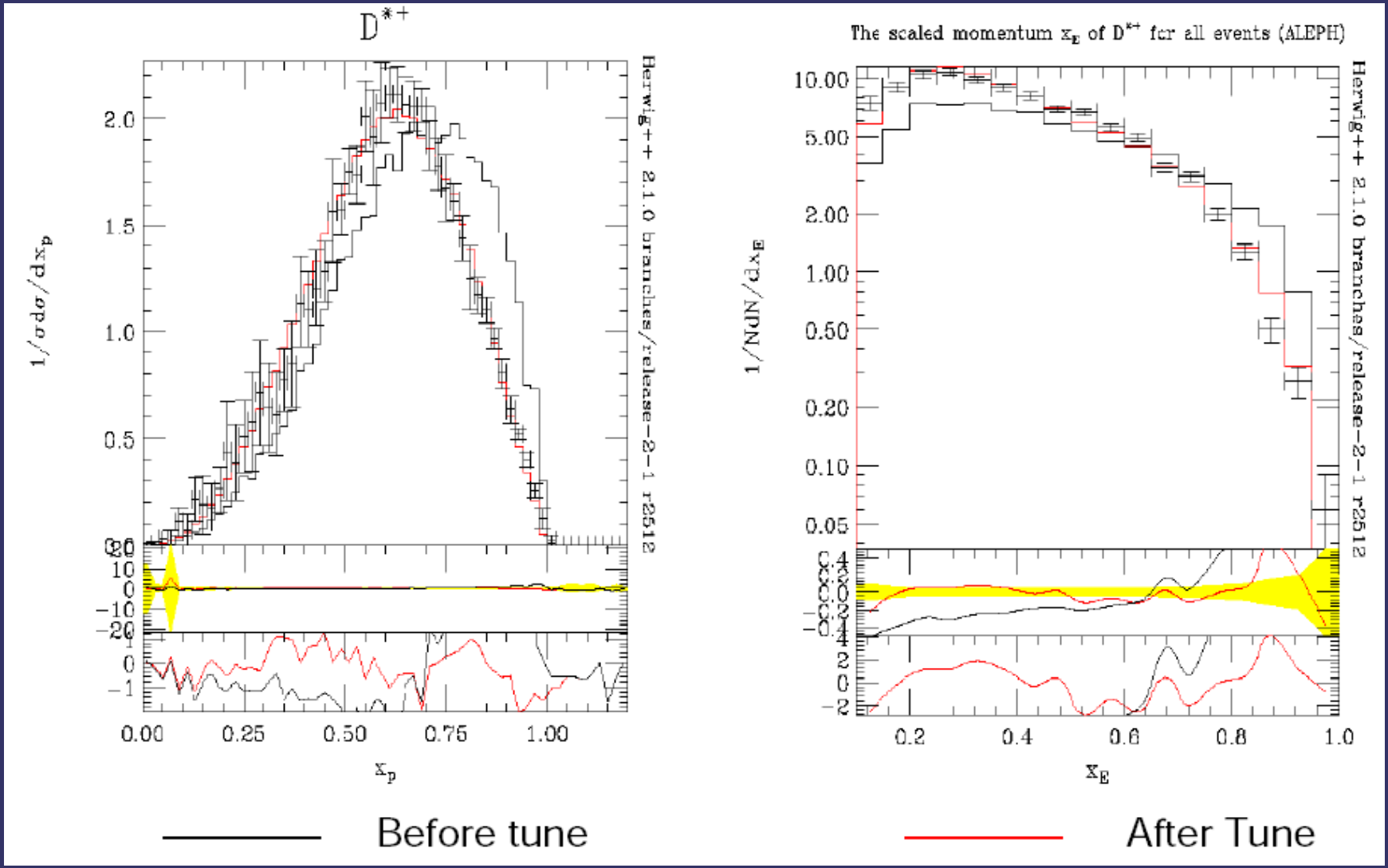
# Herwig++

- MSSM (here e+e-, also works for LHC)



# Herwig++

- Tuning



# Cascade



## CASCADE ...

... is a hadron level

Monte Carlo event generator for

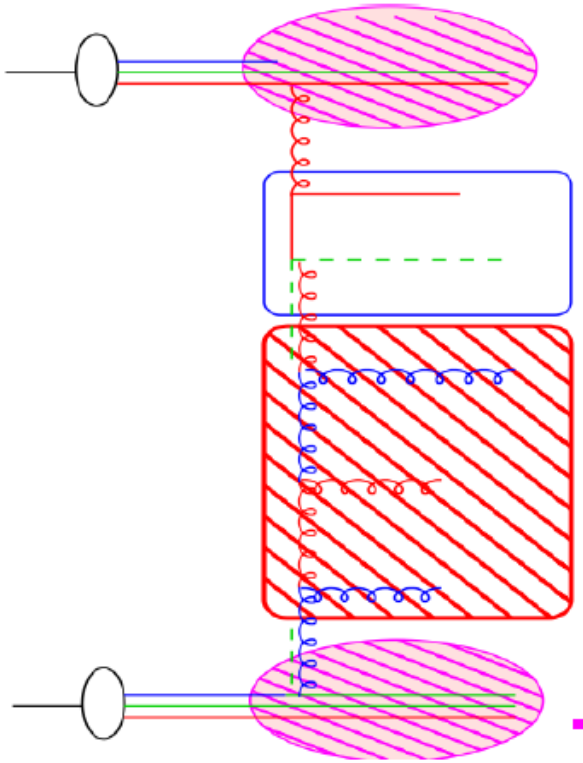
QCD type processes

with emphasis on the

initial state parton evolution

# Cascade

CASCADE: H.Jung and G.P.Salam, Eur.Phys.J. **C19** (2001) 351



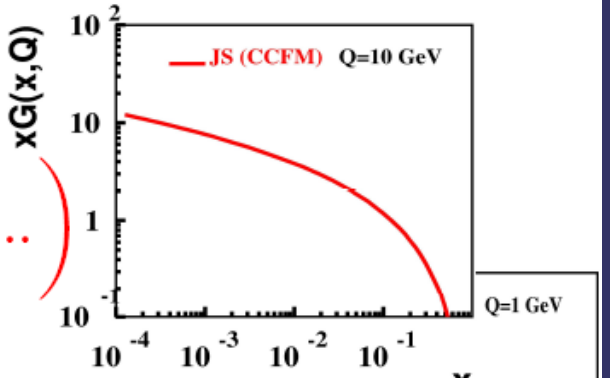
matrix element
off shell

CCFM (all loops)

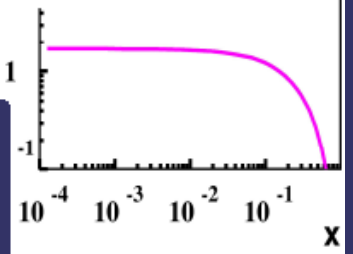
- angular ordering
- non - Sudakov $\Delta_{ns}$

evolution of parton
cascade:

$$\tilde{P} = \bar{\alpha}_s \left( \frac{1}{1-z} + \frac{1}{z}\Delta_{ns} + ... \right)$$




initial distribution
~ flat



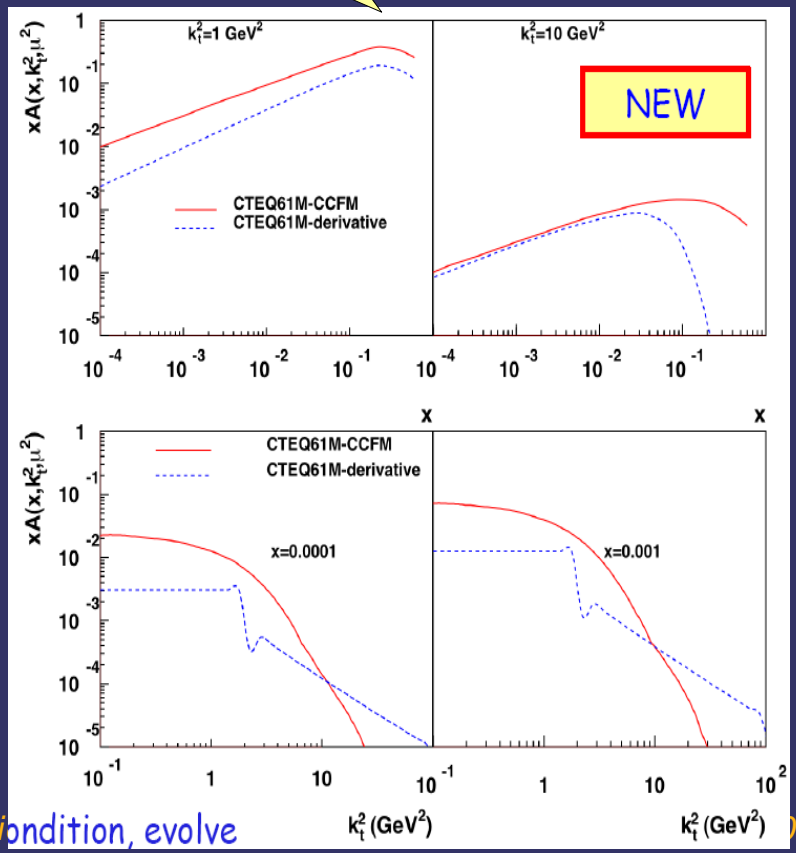

$$\sigma(pp \to q\bar{q} + X) = \int \frac{dx_{g1}}{x_{g1}} \frac{dx_{g2}}{x_{g2}} \int d^2k_{t1} d^2k_{t2} \hat{\sigma}(\hat{s}, k_t, \bar{q}) \times x_{g1}\mathcal{A}(x_{g1}, k_{t1}, \bar{q}) x_{g2}\mathcal{A}(x_{g2}, k_{t2}, \bar{q})$$

$$\int d^2k_t x_g \mathcal{A}(x_g, k_t, \bar{q}) \simeq x_g G(x_g, Q^2)$$

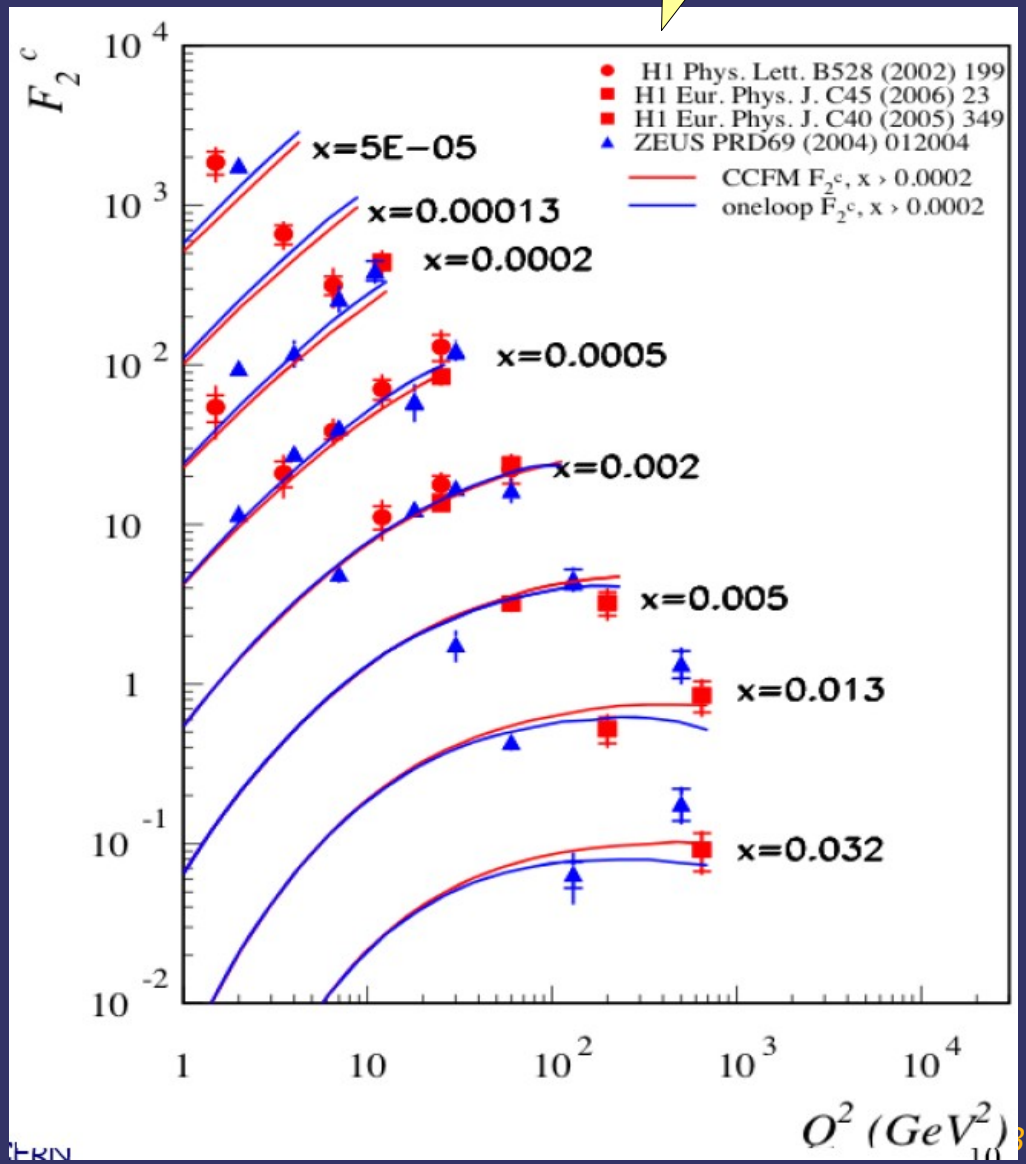
# Cascade

## Own fits of uPDFs

New: valence quarks (only first steps...)

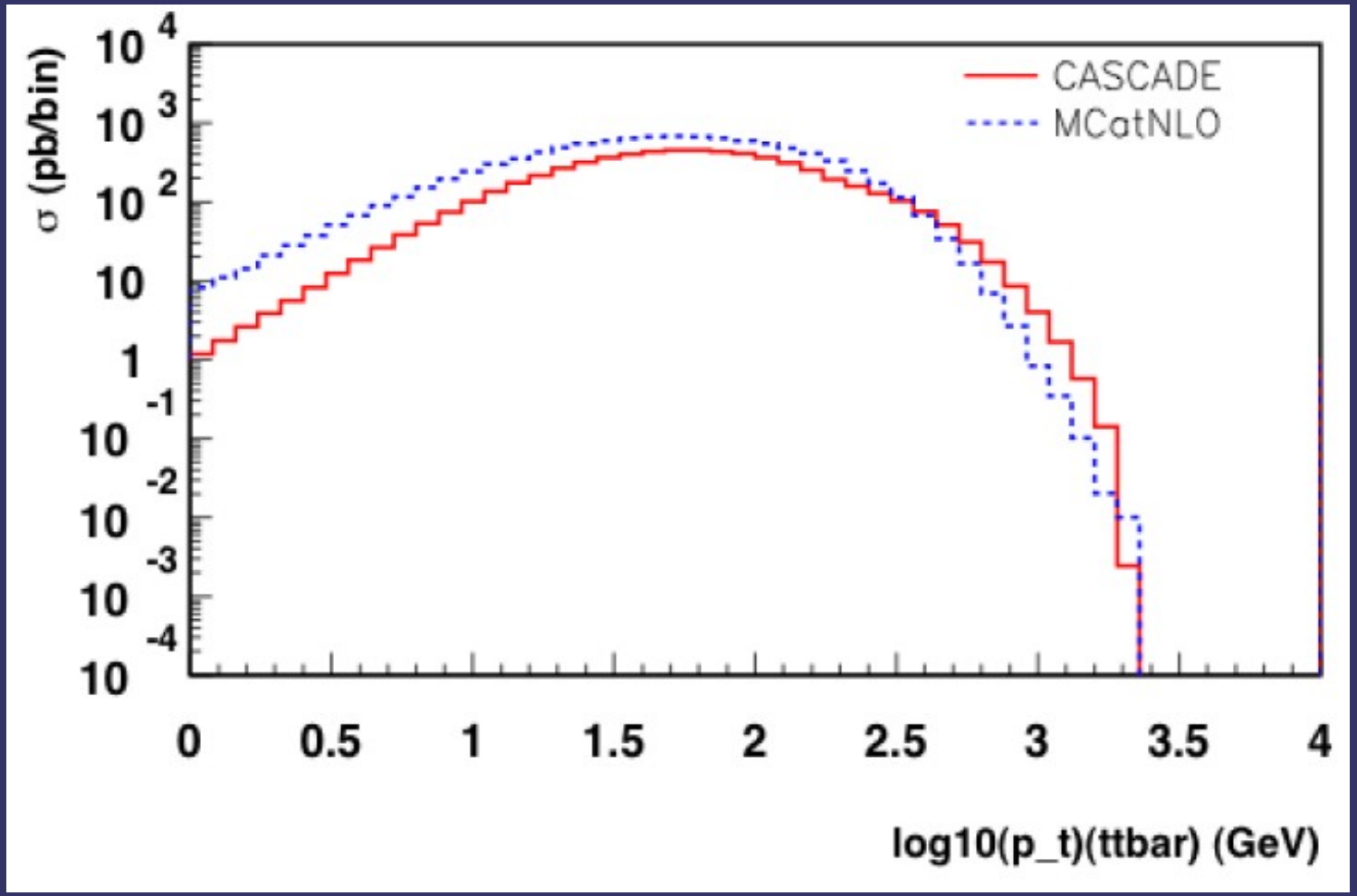



Fit to inclusive data



# Cascade

Comparison to other programs (ttbar at the LHC)



# *New MC generators/MCnet*

- Much progress in the last years
- Tuned or at least well tested versions of Pythia8, Sherpa, Herwig++
  → *matured programs!*
- First use in physics studies seen
  (UE studies, first LHC physics)
- *Ready for the LHC!*
- *Much more usage/feedback needed from experiments at this stage*

# *Do we have all the tools?*

***Yes!***

***Much progress has been made.***

***Many new exciting developments.***

***Now they need to be used -***

***Your feedback is important!***