# News from Herwig++

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on behalf of Herwig++ group:
M. Bähr, S. Gieseke, M. Gigg, D. Grellscheid, K. Hamilton, S. Latunde-Dada, S.Plätzer, Peter Richardson, M.H. Seymour, A. Sherstnev, B.R. Webber and A.S, J. Tully

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International Linear Collider ECFA Workshop
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# OUTLINE

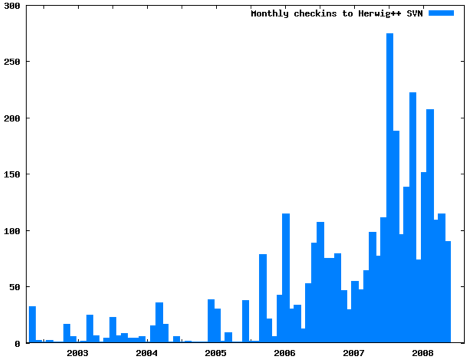
1. Herwig++ Project
2. Recent improvements/Tuning
3. Future Improvements
4. Using Herwig++
5. Summary

# 1. Herwig++ Project

# Herwig++ Project

- Hadron Emission Reactions With Interfering Gluons.
- New development, target: the successor of HERWIG (current version 6.5).
- Beginning: Cambridge/Manchester 2001.
- First version for $e^+e^-$ 2003.

S. Gieseke, P. Stephens and B. Webber, **JHEP** 0312 (2003) 045 [hep-ph/0310083]
S. Gieseke, A. Ribon, M. H. Seymour, P. Stephens and B. Webber, **JHEP** 0402 (2004) 005 [hep-ph/0311208]




- Further development in Cambridge, CERN, Durham, Karlsruhe,... (expanding)

# Herwig++ hadron collisons

- In 2006 early first version for hadron collisions (2.0$\beta$).
  - All parts of the simulation needed for hadron–hadron collisions were present
  - Some areas, in particular the underlying event, still needed improvement

S. Gieseke, *et.al.*, Herwig++ 2.0$\beta$ Release Note, [hep-ph/0602069]
S. Gieseke, Herwig++ 2.0 Release Note, [hep-ph/0609306]

- A second hadron-hadron version (2.1) was released on 20 Nov 2007 with major improvements with respect to the previous version:
  - Multiple parton-parton scattering model of the underlying event, based on the FORTRAN JIMMY program.
  - Inclusion of BSM physics including the MSSM, UED and RS models.
  - New model of meson and tau decays.
  - Tuning to LEP, SLD and B-factory data.

M. Bähr et al., Herwig++ 2.1 Release Note. [arXiv:0711.3137]

- Current Version 2.2.0 complete simulation of hadron collisions.
  - New $Zh^0$, $Wh^0$, $Z+$jet and $W+$ jet hard processes.
  - $ggh^0$ matrix element correction.

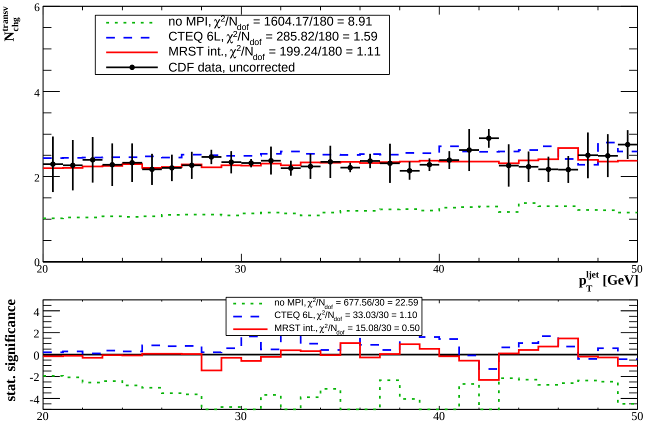
M. Bähr *et al.*, Herwig++ 2.2 Release Note. [arXiv:0804.3053]

# 2a. Recent improvements

# New MPI model in Herwig++

- Major new feature is a multiple scattering model of the underlying event.

Tevatron UE analysis fit of open parameters.



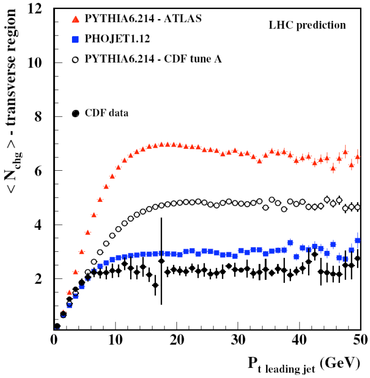

$N_{ch,T}$ - multiplicity in the transverse region

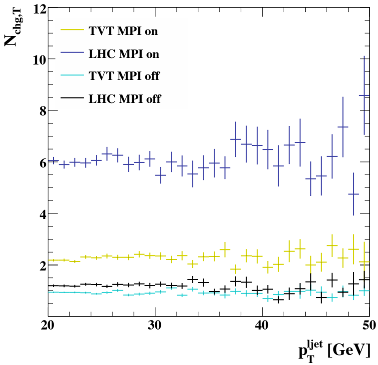
M. Bähr, S. Gieseke, M. Seymour, [arXiv:0803.3633]

# New MPI model in Herwig++

- Major new feature is a multiple scattering model of the underlying event.

Extrapolation to LHC - comparison with other models



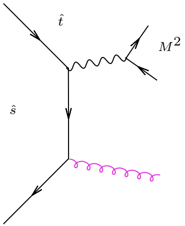




M. Bähr, S. Gieseke, M. Seymour, [arXiv:0803.3633]

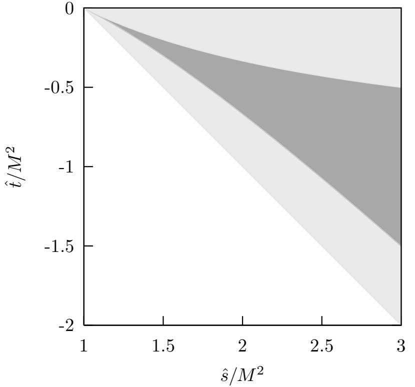
$N_{ch,T}$ - multiplicity in the transverse region

# Hard Matrix Element Correction

## Hard Matrix Element Correction in Drell-Yan

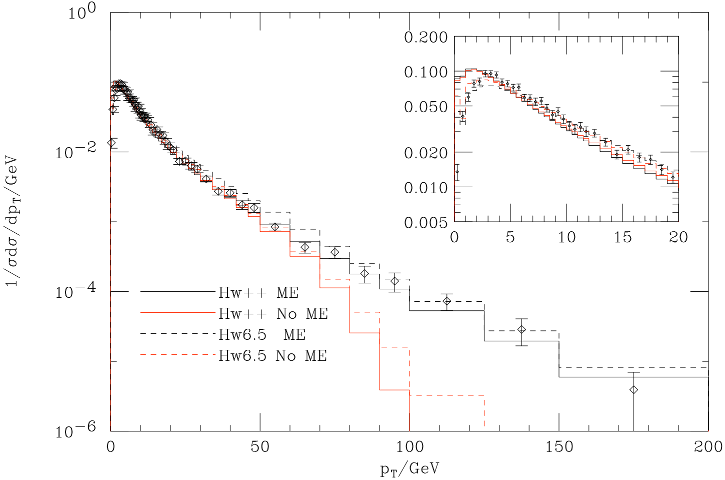



- Light: collinear/soft regions.
- Dark: Dead region, filled with extra hard emissions — not accessable by parton shower.



# Hard Matrix Element Correction

## $Z^0$ Boson $p_T$ distribution

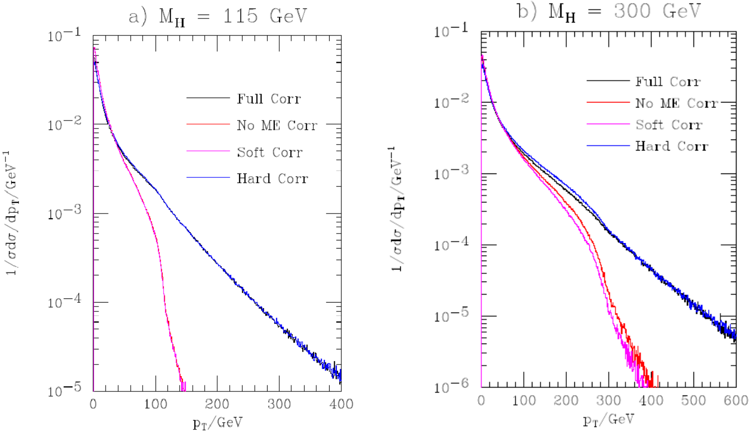



Hard ME correction in Herwig++ vs fHERWIG and CDF Run I Data.

Note: no intrinsic $p_T$ used here but it is present in current version of Herwig++.

# Hard Matrix Element Correction

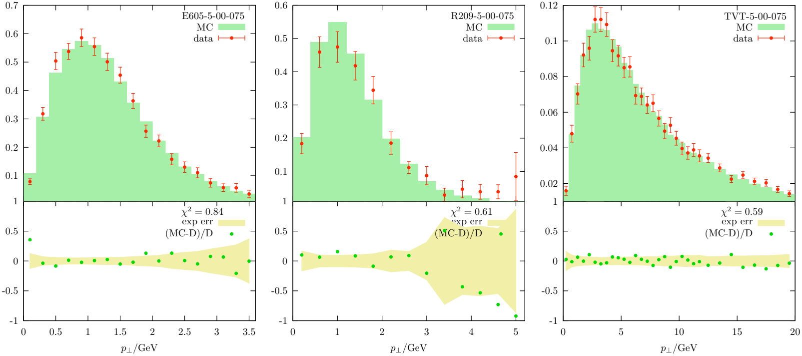
Higgs Matrix Element Correction



# Non-perturbative model

Primordial $k_T$ from soft, non-perturbative gluons

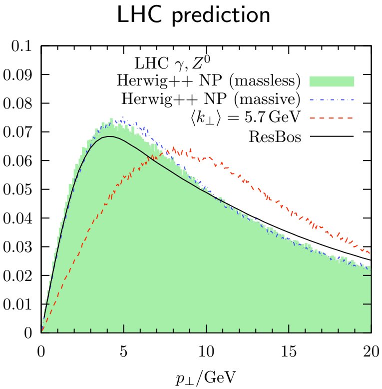
Allow for very soft gluon radiation (all cutoffs, masses $\longrightarrow \epsilon$).




Get excellent description of DY $p_T$ spectrum using only small Gaussian primordial $k_T \sim 0.4$ GeV , (allowed by Heisenberg), not $> 2$ GeV.

[S. Gieseke, M. Seymour, A. Siódmok, JHEP 06 (2008) 001]

# Non-perturbative model




More confident prediction. Similar, when cutoffs $\neq 0$ and hadronisation on.
Qualitative similarity to ResBos.

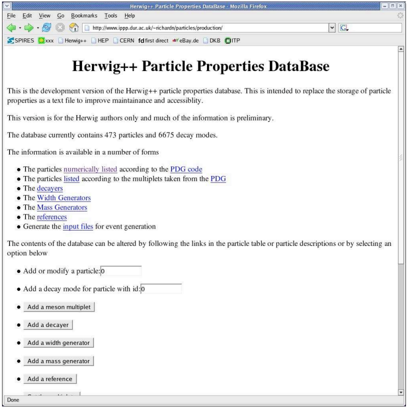
[S. Gieseke, M. Seymour, A. Siódmok, JHEP 06 (2008) 001]

# Hadronic Decays

- Better decayers have been developed for almost all decay modes (from v2.1).

- a universal database is set up.
- Spin correlations.
- Running widths.
- contains:

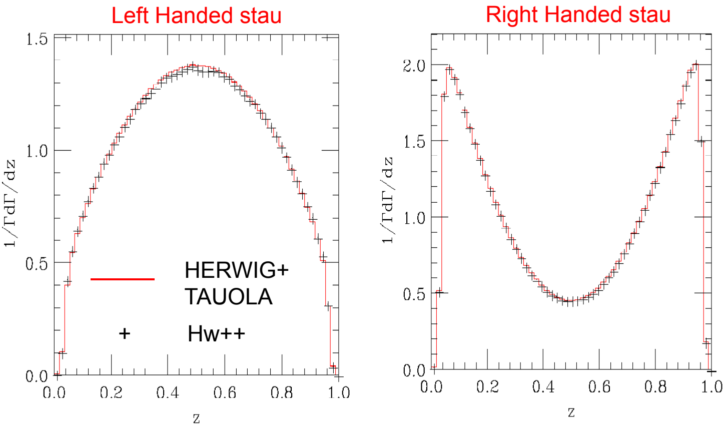
∼ 500 particles and
∼ 6500 decay modes at present.
∼ PDG '06 Particle Data Book.



# Hadronic Decays

Example: Tau Decays

$$\tilde{\tau}^{\pm} \to \tilde{\chi}_1^0 \tau^{\pm} \to \tilde{\chi}_1^0 \rho^{\pm} \nu_{\tau} \to \tilde{\chi}_1^0 \pi^0 \pi^{\pm} \nu_{\tau}$$




Fraction of visible energy carried by the charged pion

# BSM

• New approach that is more general and lowers the amount of time needed to implement a new model.
Rather than hard coding scattering and decay we use general:

1. $2 \rightarrow 2$ matrix elements
2. $1 \rightarrow 2$ decayers

based on spins. The diagrams are evaluated using the HELAS formalism to give the value of the matrix element at the requested point in phase space.

• This leaves only the Feynman rules to be implemented for each new model which are encoded in Vertex classes.

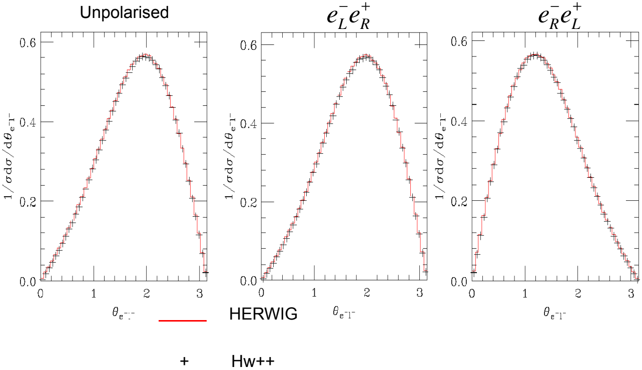
• Models implemented thus far: Randall-Sundrum Model, MSSM and MUED

[M. Gigg, P. Richardson, Eur. Phys. J. C 51, 989-1008 (2007)]
M. A. Gigg, P. Richardson, [arXiv:0805.3037]

# BSM

## Example: BSM Physics

$$e^+e^- \to \chi_2^0\chi_1^0 \to \tilde{l}_R^+ l^- \chi_1^0$$




The angle between the produced lepton and the beam in the lab frame for a centre-of-mass,

a) unpolarised incoming beams,

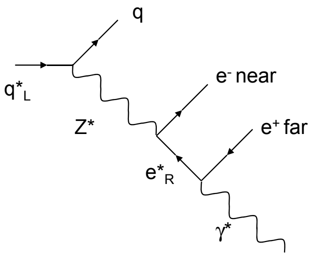
b) negatively polarised electrons and positively polarised positrons

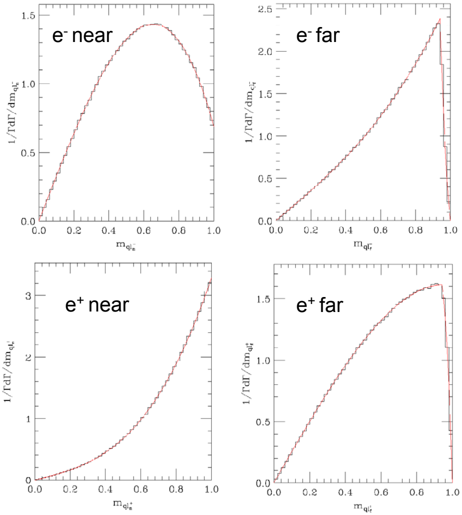
c) positively polarised electrons and negatively polarised positrons

# BSM

Example: UED

Look at the decay



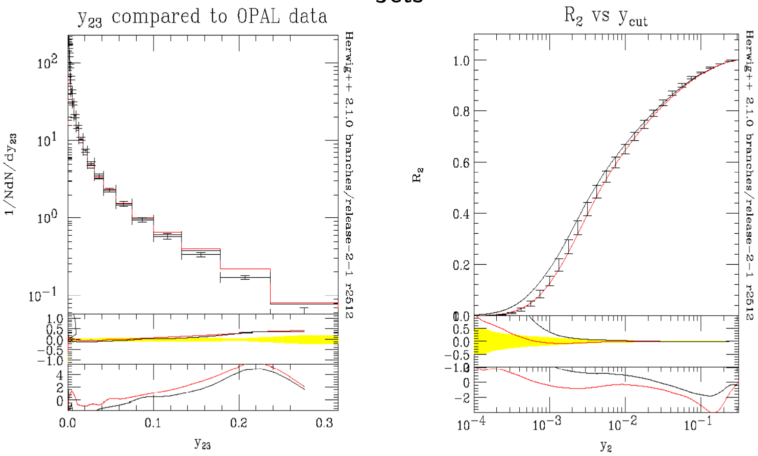



# 2b. Tuning

- The parameters of the first Herwig++ release were adjusted to improve the agreement to LEP data, not a real tuning.
- A number of significant improvements have been made since then.
- Did a retuning of the parameters to LEP, SLD and B-factory off-resonance data.

# Tuning

## Jets

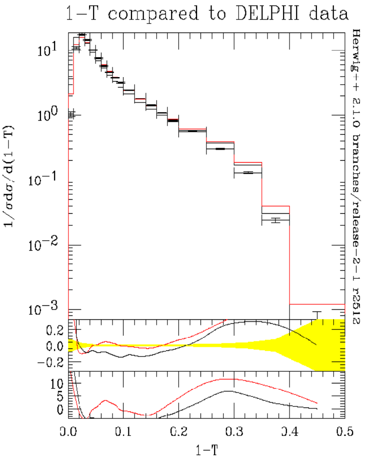


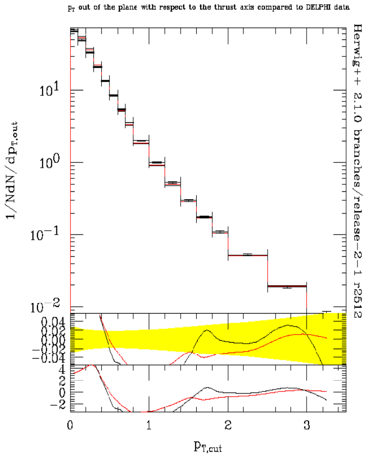

Before tune

After Tune

# Tuning

## Event Shapes

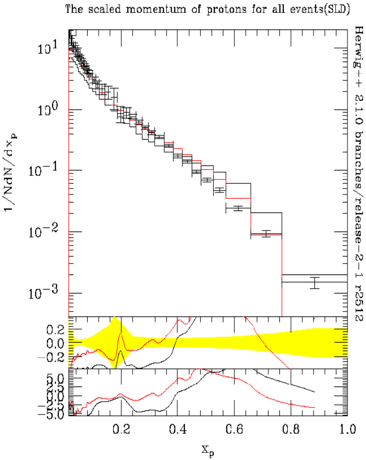


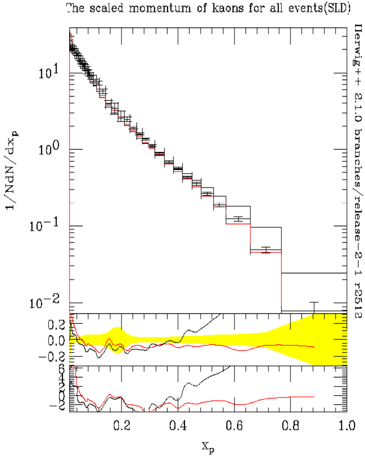




Before tune After Tune

# Tuning

## Kaons and Protons



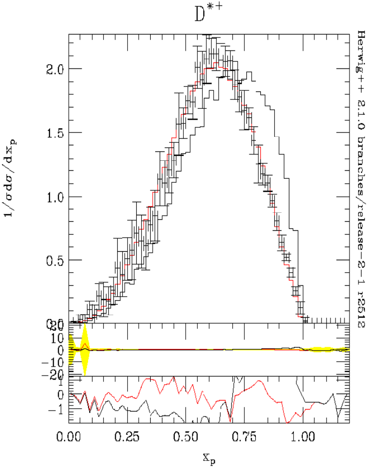



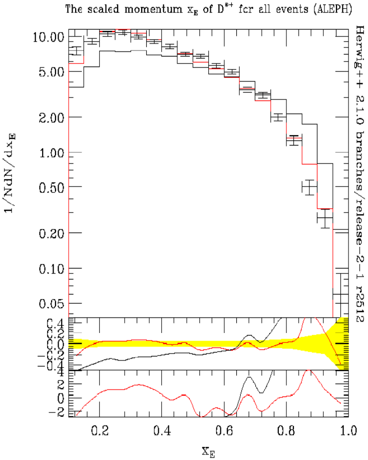

Before tune

After Tune

# Tuning

## Charm Fragmentation



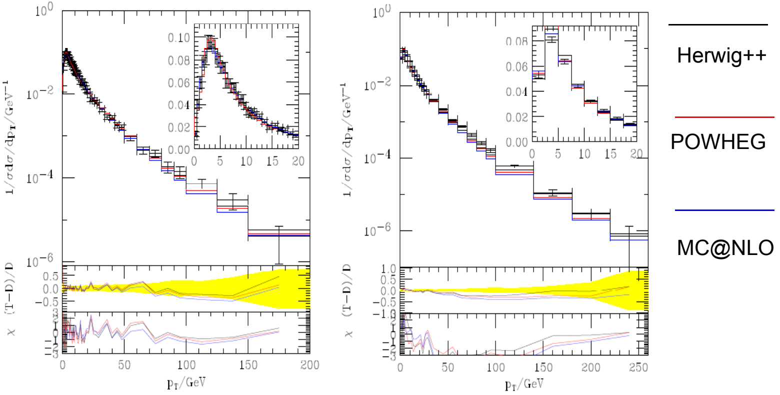

Before tune — After Tune

# 3. Future Improvements

- CKKW matrix element matching;
- MC@NLO; [Seyi Latunde-Dada, 0708.4390]
- The Nason approach to MC@NLO; (next slide)
- The multi-scale shower;
- Additional new physics models and better simulation of off-shell effects.
- Improved modelling of baryon decays;
- Model for non-perturbative scatters in the underlying event (enables simulation of min bias events);

# POWHEG

The Nason approach to MC@NLO;




CDF Run I Z $p_T$

D0 Run II Z $p_T$

O. Latunde-Dada, S. Gieseke, B. Webber, [hep-ph/0612281]
K. Hamilton, P. Richardson, J. Tully, [arXiv:0806.0290]

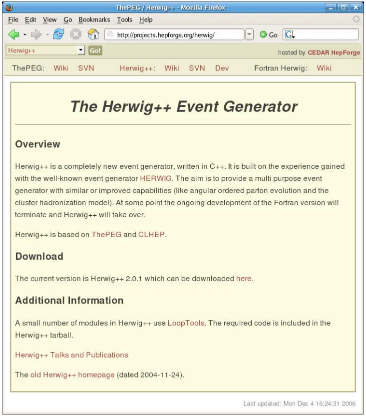
# 4. Using Herwig++

# Manual

http://projects.hepforge.org/herwig/

(wiki, news, bug tracker/tickets)

mailto: herwig@projects.hepforge.org




Current version is 2.2.0.

- Need ThePEG and gsl.
- Builds with autotools.
- ./configure, make, make install.
- Successfully built with gcc's from 3.4.0 to 4.3.0.
- Also MacOS

- Physics and Manual.
  - contains a full description of the physics together with the overall structure of the code and is designed to supplement the Doxygen documentation of the code and all parameters.
  - The PDF of the manual is linked to the Doxygen to make finding things easy.

M. Bähr *et al.*, Herwig++ Physics and Manual, [arXiv:0803.0883]

- Examples of using various Herwig++ features in the manual and on the wiki

# 4. Summary

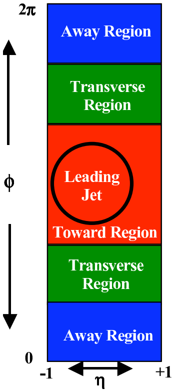
- Herwig++ group made a lot of progress in the last year
- The generator is now fully ready for hadron collisions
- A comprehensive manual is now available
- Support of experiments: herwig@projects.hepforge.org
- Further improvements will follow. News on wiki!

Thank you for the attention!

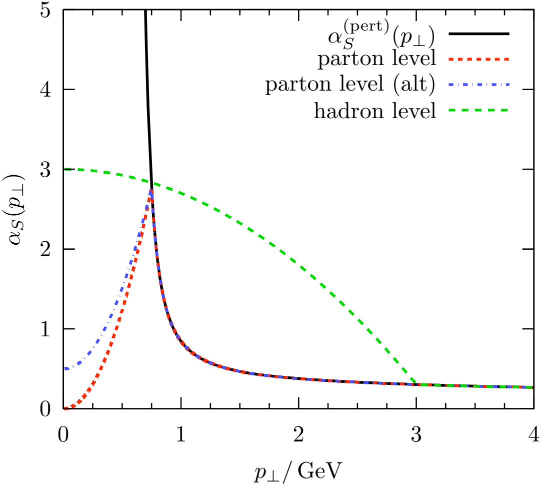
# Backup slides

## Exp. analysis
R. Field's TVT analysis; PRD65,092002

- non standard jet algorithm used to reconstruct the jet with the largest scalar ptsum from charged particle tracks: leading jet
- define 3 regions with respect to $\phi$ of the leading jet: towards, transverse, away
- plot $\langle N^{chg} \rangle$ and $\langle p_{T,sum}^{chg} \rangle$ for each of these regions
- comparison of `Herwig++ 2.1.3` to detector level data by applying 92% track efficiency (like the original experimental analysis)



# Non-perturbative model



# Tuning

### Thrust

$$F(\boldsymbol{n}) = \frac{\sum_\alpha |\boldsymbol{p}_\alpha \cdot \boldsymbol{n}|}{\sum_\alpha |\boldsymbol{p}_\alpha|}$$

Find $\boldsymbol{n}$, such that thrust

$$\begin{aligned} T &= \max_{\boldsymbol{n}} F(\boldsymbol{n}) \\ &= F(\boldsymbol{n}_T) \ , \end{aligned}$$

thrust major

$$\begin{aligned} M &= \max_{\boldsymbol{n} \perp \boldsymbol{n}_T} F(\boldsymbol{n}) \\ &= F(\boldsymbol{n}_M) \ , \end{aligned}$$

thrust minor

$$\begin{aligned} \boldsymbol{n}_m &= \boldsymbol{n}_T \times \boldsymbol{n}_M \\ m &= F(\boldsymbol{n}_m) \end{aligned}$$

### Sphericity

$$Q_{ij} = \frac{\sum_\alpha (\boldsymbol{p}_\alpha)_i (\boldsymbol{p}_\alpha)_j}{\sum_\alpha \boldsymbol{p}_\alpha^2}$$

Diagonalize, eigenvalues

$$\begin{aligned} &\lambda_1 > \lambda_2 > \lambda_3 \\ &\lambda_1 + \lambda_2 + \lambda_3 = 1 \end{aligned}$$

Then

$$\begin{aligned} S &= \tfrac{3}{2}(\lambda_2 + \lambda_3) \\ P &= \lambda_2 - \lambda_3 \\ A &= \tfrac{3}{2}\lambda_3 \end{aligned}$$

Eigenvector $\boldsymbol{n}_S$ sphericity axis etc.

### $C$, $D$ parameter

$$L_{ij} = \frac{\sum_\alpha (\boldsymbol{p}_\alpha)_i (\boldsymbol{p}_\alpha)_j / |\boldsymbol{p}_\alpha|}{\sum_\alpha |\boldsymbol{p}_\alpha|}$$

Diagonalize, eigenvalues

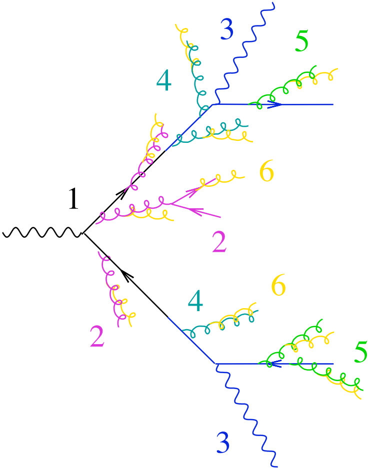
$$\lambda_1 + \lambda_2 + \lambda_3 = 1$$

and define

$$\begin{aligned} C &= 3(\lambda_1\lambda_2 + \lambda_2\lambda_3 + \lambda_3\lambda_1) \\ D &= 27\lambda_1\lambda_2\lambda_3 \end{aligned}$$

# The multi-scale shower;

## Multiscale Showering




Example: $t\bar{t}$ production & decay

1. Hard process (scale $\sim \hat{s}$)
2. Showers from $t, \bar{t}$ ($\hat{s} \longrightarrow \Gamma_t$)
3. Decays $t \longrightarrow Wb$, $\bar{t} \longrightarrow W\bar{b}$
4. ISR from $t, \bar{t}$ ($m_t \longrightarrow \Gamma_t$)
5. FSR from $b, \bar{b}$ ($m_t \longrightarrow \Gamma_t$)
6. Global showering ($\Gamma_t \longrightarrow \Gamma_b$)

etc.