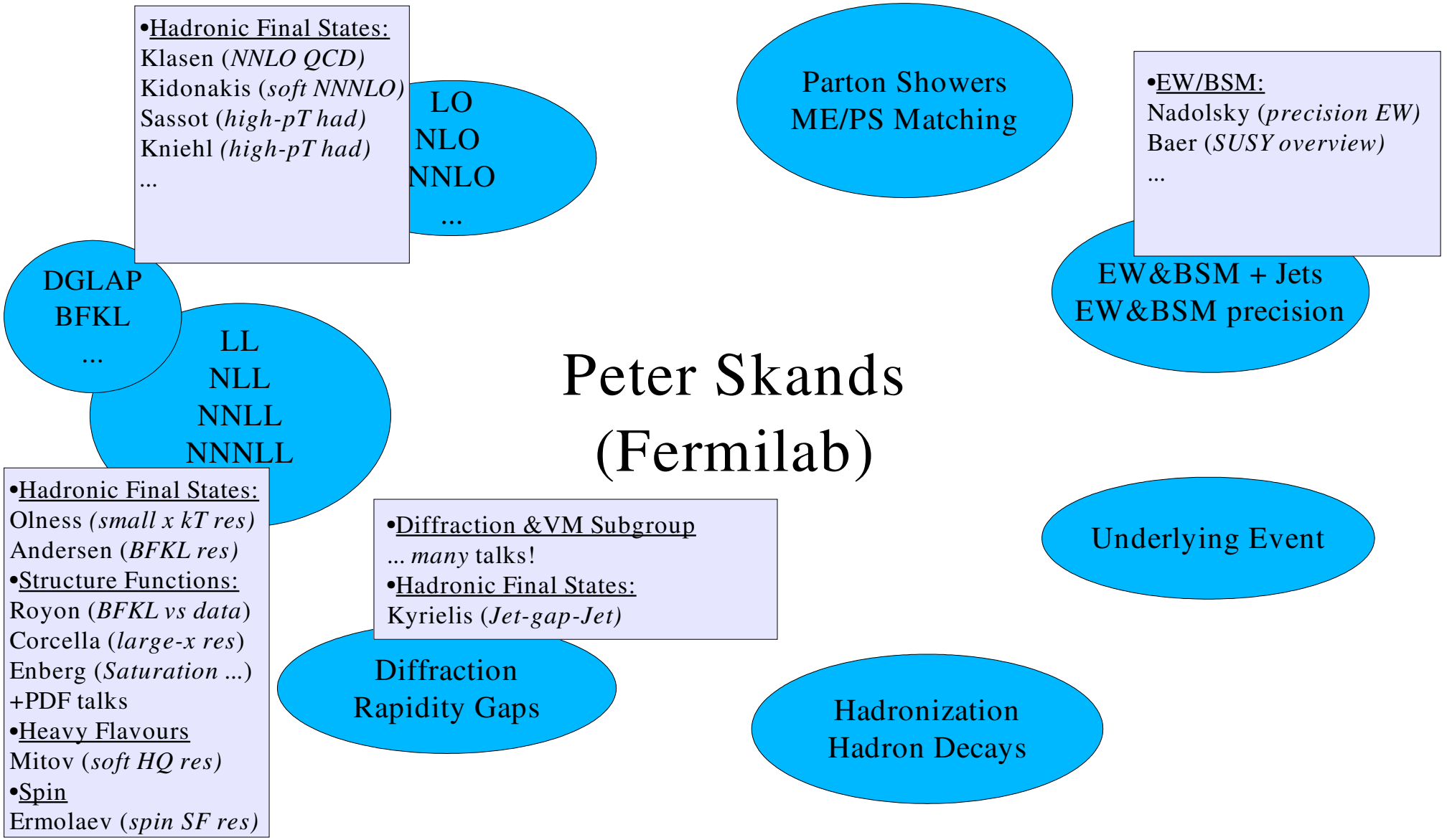
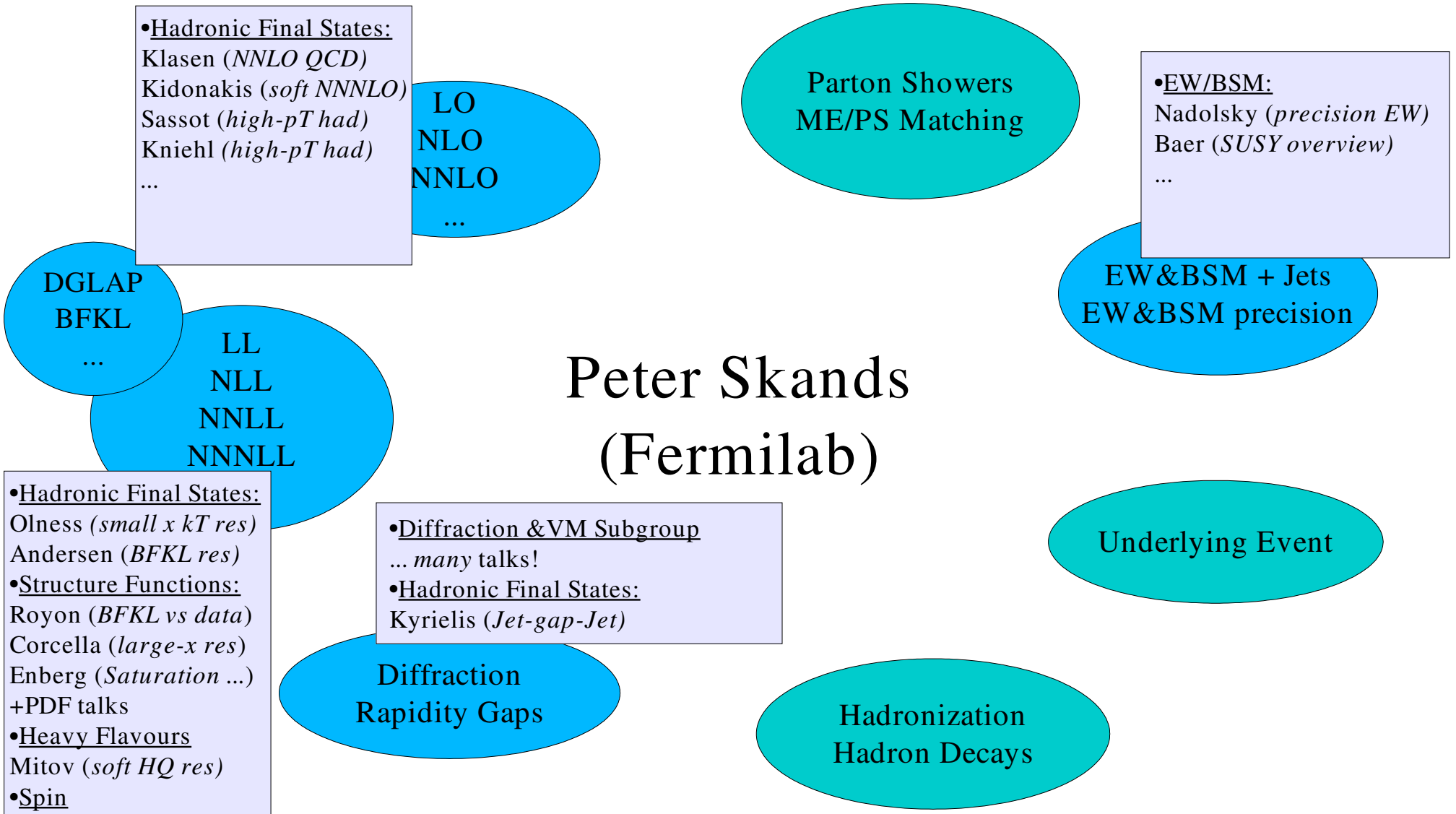
QCD (&) Event Generators

QCD (&) Event Generators



QCD (&) Event Generators



See also talk by S. Frixione in Hadronic Final States, thursday 9:20!

Hard & Soft

- **Matrix Elements**

+ Fixed Order α: Exact interference, helicity, loops ...

- Present 2→5/6 ✡ multiple soft gluons significant in building event/jet structure

- Phase Space for soft emissions larger at higher energies

+ PT expansion better behaved at higher energies

For full event structure, need to go beyond fixed order

Hard & Soft

- **Matrix Elements**

+ Fixed Order α: Exact interference, helicity, loops ...

- Present 2→5/6 ✡ multiple soft gluons significant in building event/jet structure

- Phase Space for soft emissions larger at higher energies

+ PT expansion better behaved at higher energies

For full event structure, need to go beyond fixed order

- **Parton Showers**

- Approximate in wide-angle hard region

Depend on universal pheno-menological parameters

+ Exponentiate → Arbitrary number of partons in Final State

+ Match to Hadronization

Marriage Desireable!

Hard & Soft

Marriage Desireable!

- Several different ceremonies:

1) Merging (correcting first jet in X+PS to X+jet matrix element)

- PYTHIA: many ee → X + jet, pp → (h,V) + jet and most top, EW & MSSM decays
- HERWIG: many ee → X + jet (incl VV), DIS, pp → (V,h) + jet, top decay

2) LO Matching (combining LO X, X+jet, X+2jets, … with PS)

- SHERPA: "CKKW" matching for e+e- → n jets, pp → (V,VV) + jets
- PATRIOT: Pre-prepared ME/PS matched samples (using MADGRAPH with PYTHIA, stored in MCFIO format) for (W, Z) + jets (≤ 4) , for Tevatron
- ARIADNE: Vetoed Shower matching (interface to MADGRAPH) for e+e- → n jets and pp → W + jets (DIS underway)

3) NLO Matching (matching NLO matrix elements with PS)

- MC@NLO: NLO + HERWIG for: pp → (h,V,VV,QQ,ll) + jets

[+ MCFM: NLO (no PS) for pp → (V,h)+jets, VV,Vh, WBF, single top]

Underlying Event

Butch Cassidy and the Sundance Kid, copyright Twentieth Century Fox Films Inc

Motivation:

- Tevatron: 2-10 fb^{-1} by LHC turn-on, LHC: 10 fb^{-1}/dsgn yr.

- Extremely high statistics Z/W/t → precision limit = syst & theory
- Need percent-level control of (all aspects of) theory

- Large discovery potential, probe EWSB to ~ 5-6 TeV
- Not all channels produce dramatic signatures. Need good control of backgrounds, distributions, systematics.

- Use knowledge from Tevatron at LHC
- Scattering at LHC ≠ rescaled scattering at Tevatron

- Underlying Event currently not well understood component.
- Produces (large) systematic and random fluctuations in activity
- Affects isolation criteria, jet energy scale ..., omnipresent!

- Simple parametrizations are not sufficient! Physics required!

Event Generators
New Developments

SHERPA

HERWIG++

PYTHIA

MC@NLO

CEDAR

T. Gleisberg, S. Hoeche, F. Krauss, A. Schaelicke, S. Schumann, J. Winter

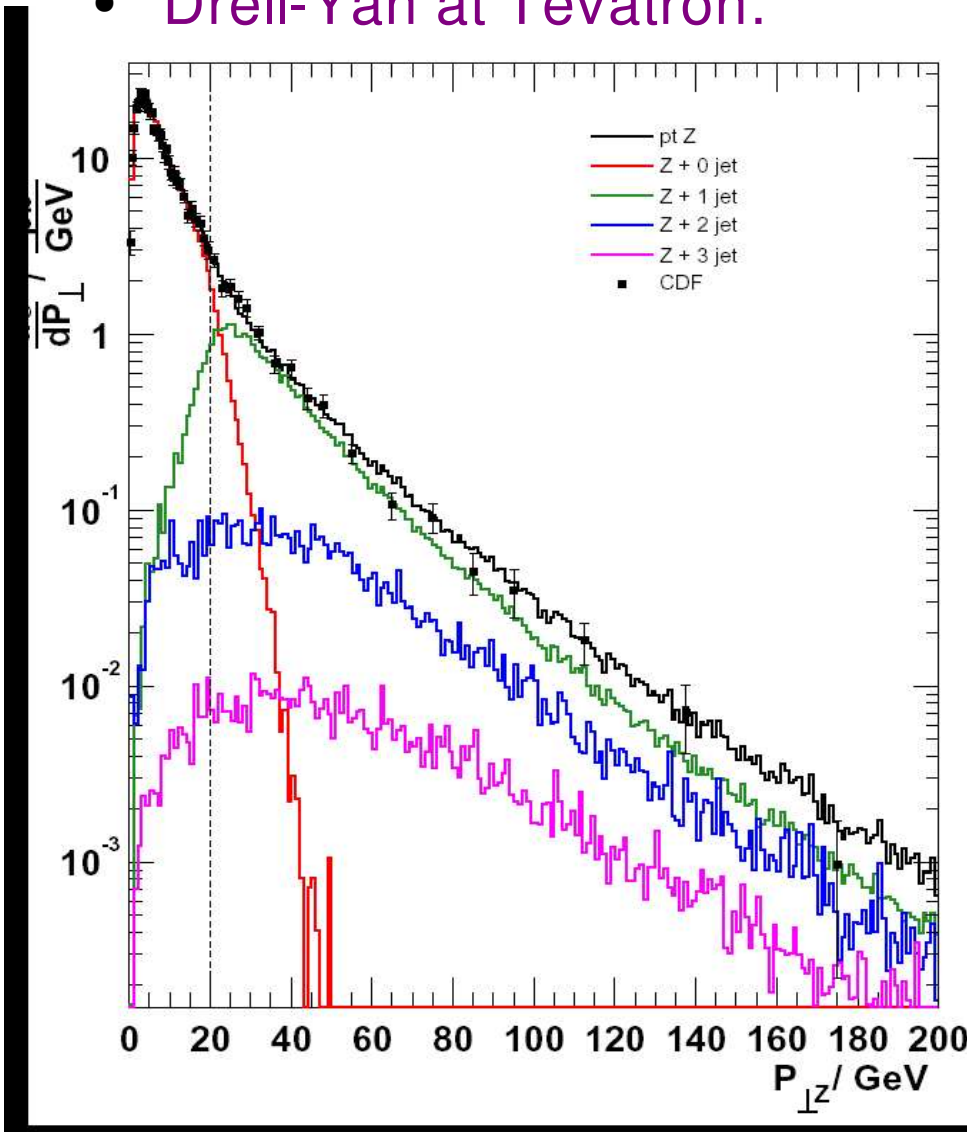
SHERPA

- Cornerstone: CKKW ME/PS matching
  (Map ME final states to (kT clustered) parton shower histories, reweight by Sudakov factors and running alpha_s, combine exclusive n-jet samples by vetoed showers)
  - Hard Matrix Elements (AMEGIC++)
  - Q2-ordered Parton Shower (APACIC++) (cf old Pythia shower)
  - Cluster Hadronization (cf HERWIG)

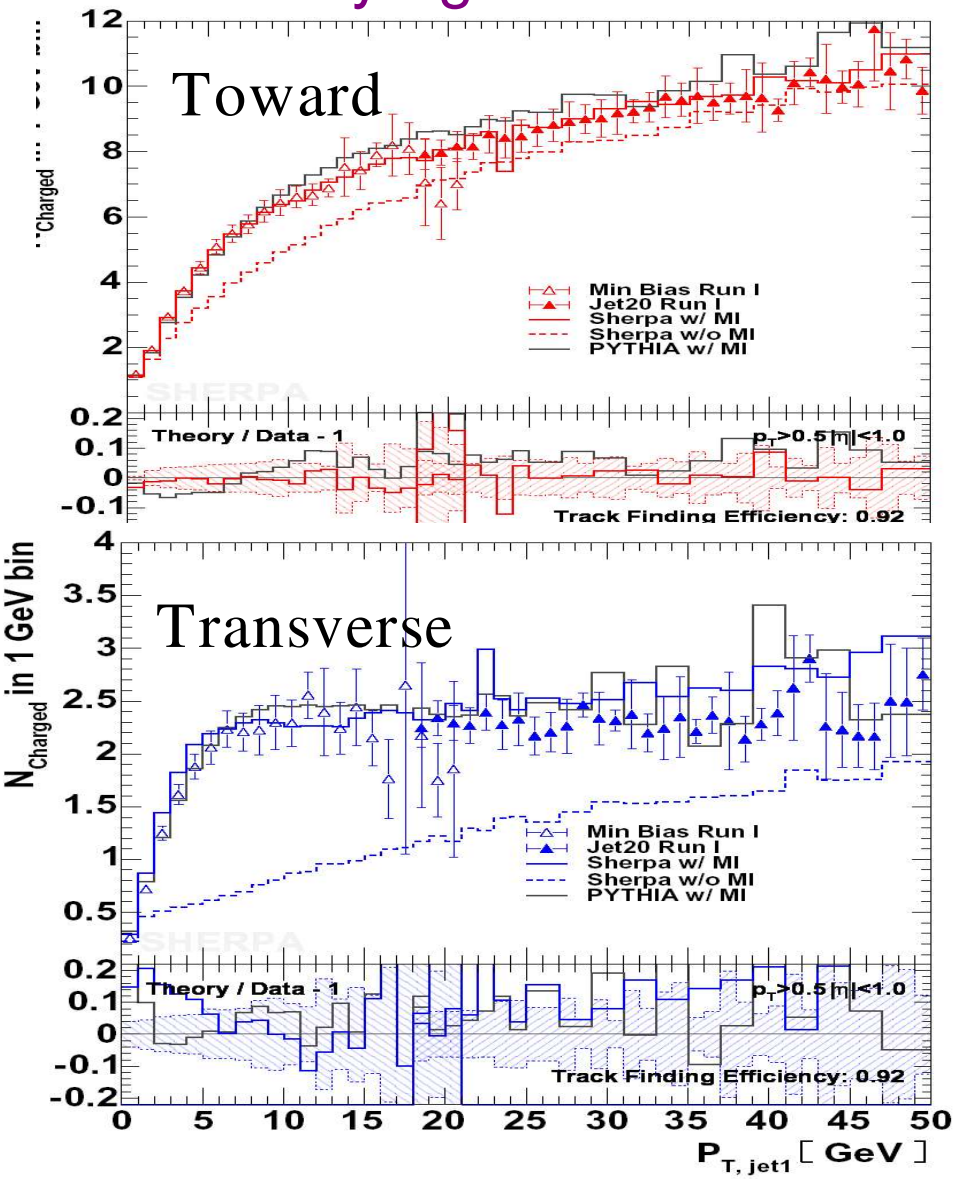
- Has progressed from infancy to adolescence
  - Implementation of Underlying Event model (Sjostrand-van-Zijl model)
  - Verification of CKKW approach for pp → V/VV
  - Ready for serious physics!

SHERPA

- Drell-Yan at Tevatron:



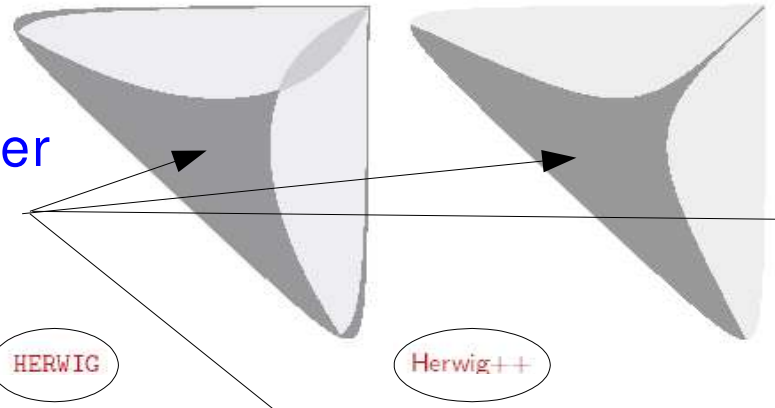
Underlying Event

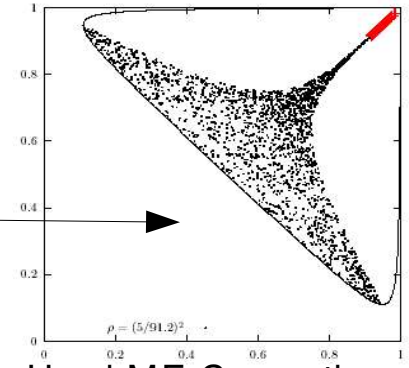


Gieseke, Richardson, Stephens, Webber

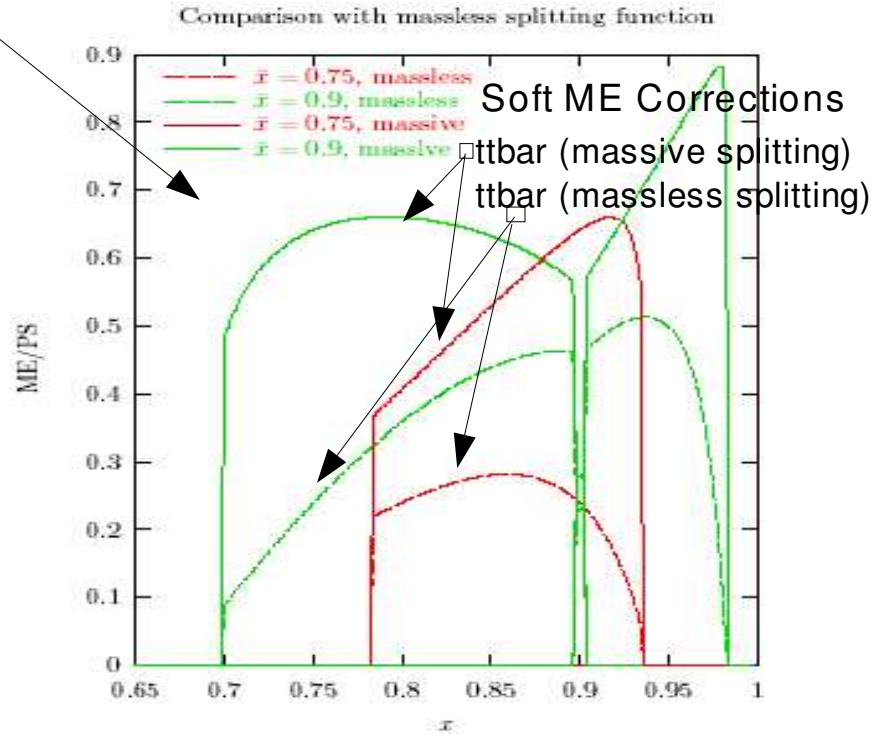
HERWIG++

- Rewritten in C++, similar to old HERWIG, ie:
  - Angular Ordered Shower (improved)
  - Cluster Hadronization
- Still mainly for e+ e-
- Hard ME's taken from ThePEG / Les Houches / AMEGIC++ / ...
  Focus is on Shower, Hadronization & Decays.
- + spin correllations





Hard ME Corrections



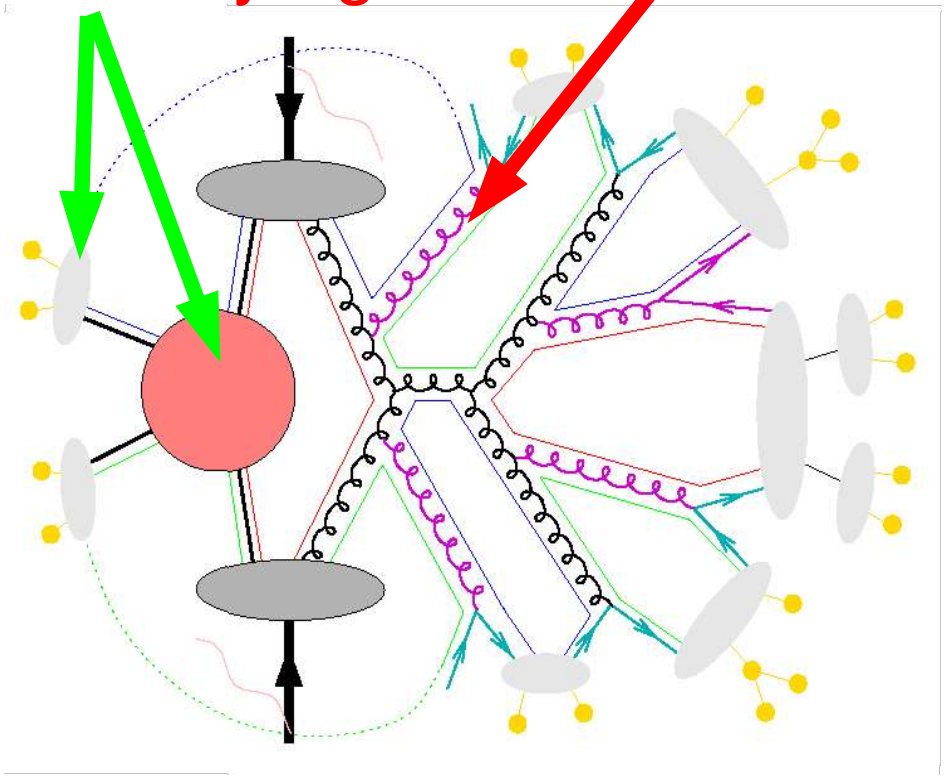
Soft ME Corrections

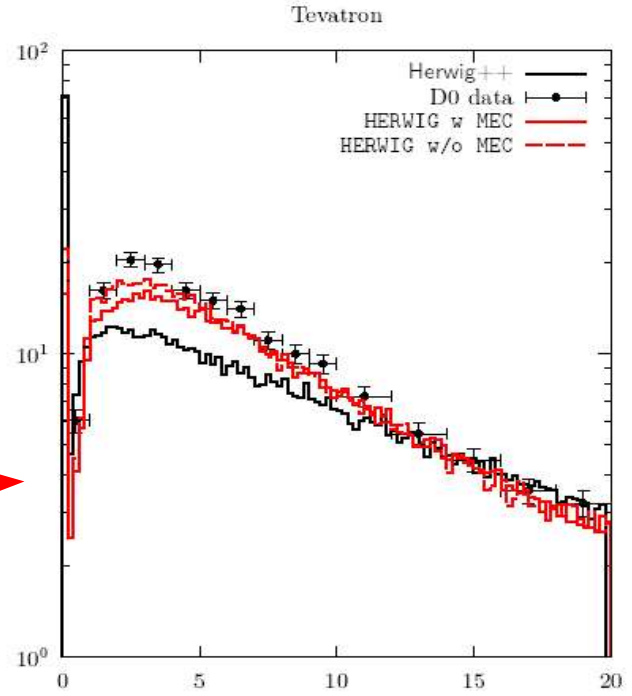
ttbar (massive splitting)

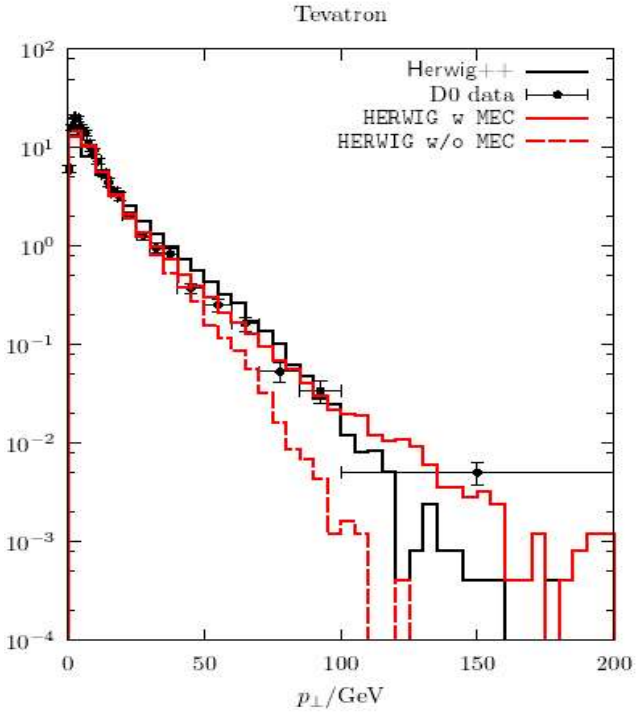
ttbar (massless splitting)

HERWIG++

- Towards Hadronic Collisions:
  - Initial State Radiation
  - Underlying Event





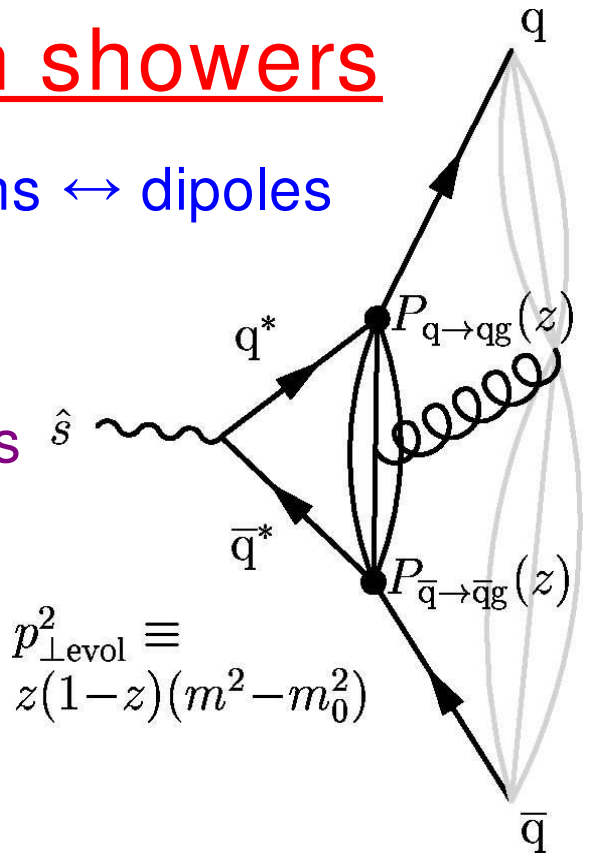


HERWIG++

- What's Next? cf Gieseke, TeV4LHC @ BNL
  - Complete ISR + pp Drell-Yan studies/tunes
  - Refine e+ e-:
    - CKKW ME+PS matching
    - Precision tunes to LEP data
  - Underlying Event
  - Hadronic Decays (τ decays, spin corr)
- Schedule?
  - Ready for LHC

PYTHIA 6.3

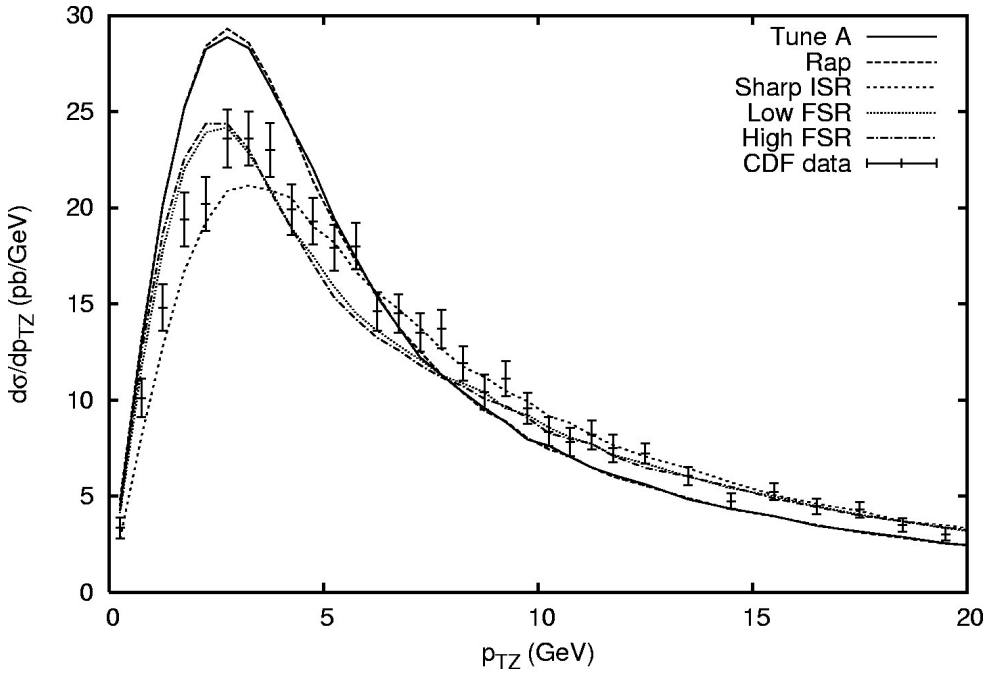
- "0'th" approach to matching: improve parton shower algorithm itself
  (if doable, gives fast results for "all" processes)
- ⇨ Completely rewritten parton showers
  - Based on dual description of QCD: partons ↔ dipoles
  - Ordered in (lightcone) pT of branchings
    Sudakovs ⇨ Priority to high-pT branchings
  - ISR + FSR, QCD + QED

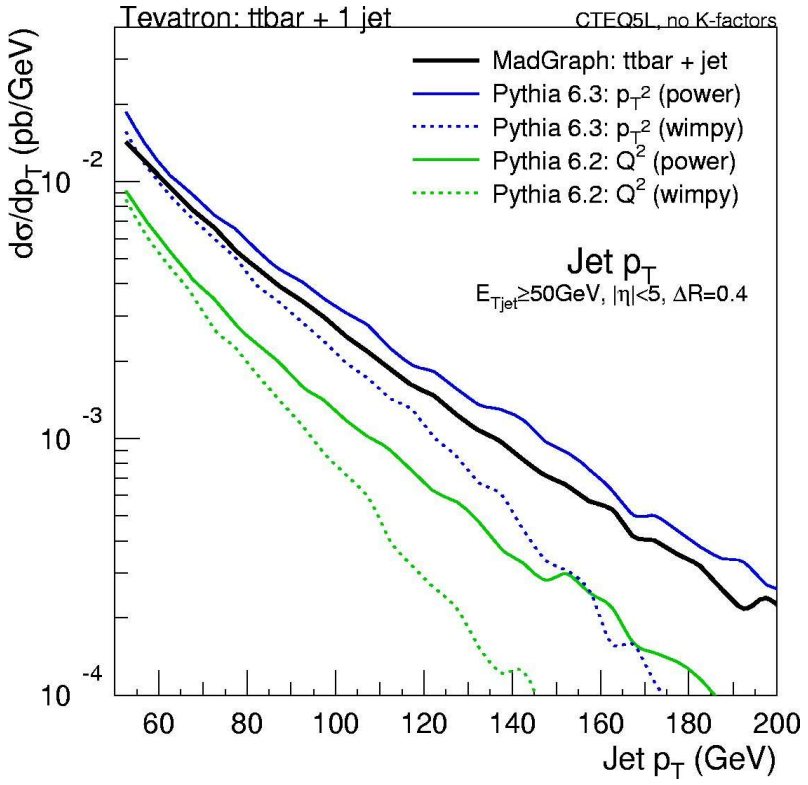


(old Q2-ordered showers also still kept as option)

PYTHIA 6.3

- FSR algorithm compared to LEP data G. Rudolph (ALEPH) 2004
  ⇨ Improved description (generator "correct" to ~ 1%)
- ISR algorithm: pp DY, ttbar+jets Plehn, Rainwater, PS
  Huston, Mrenna, Sjostrand, PS

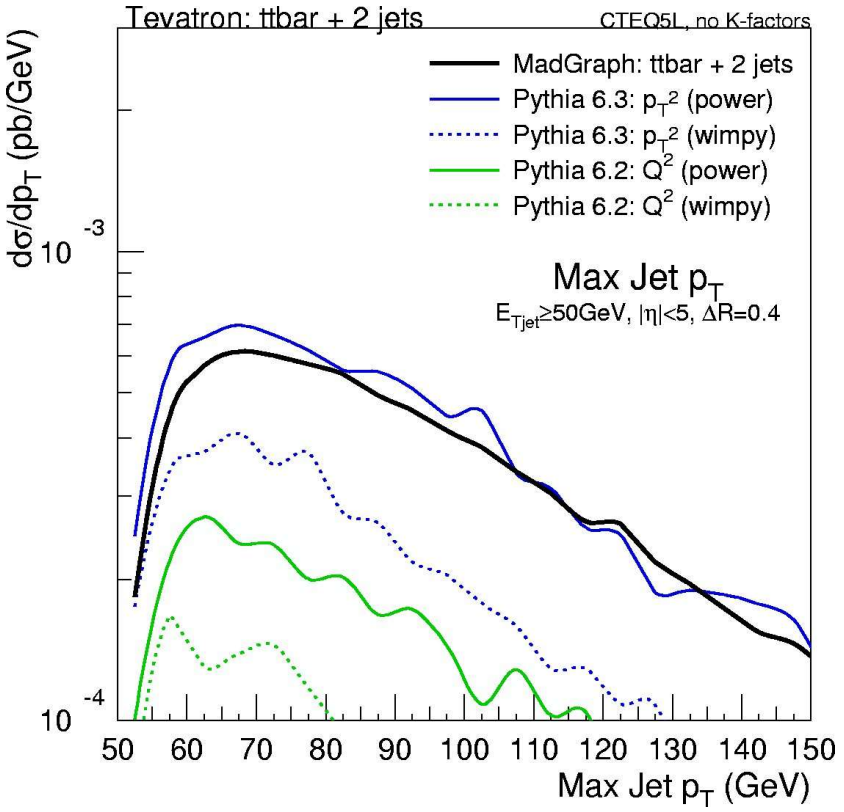


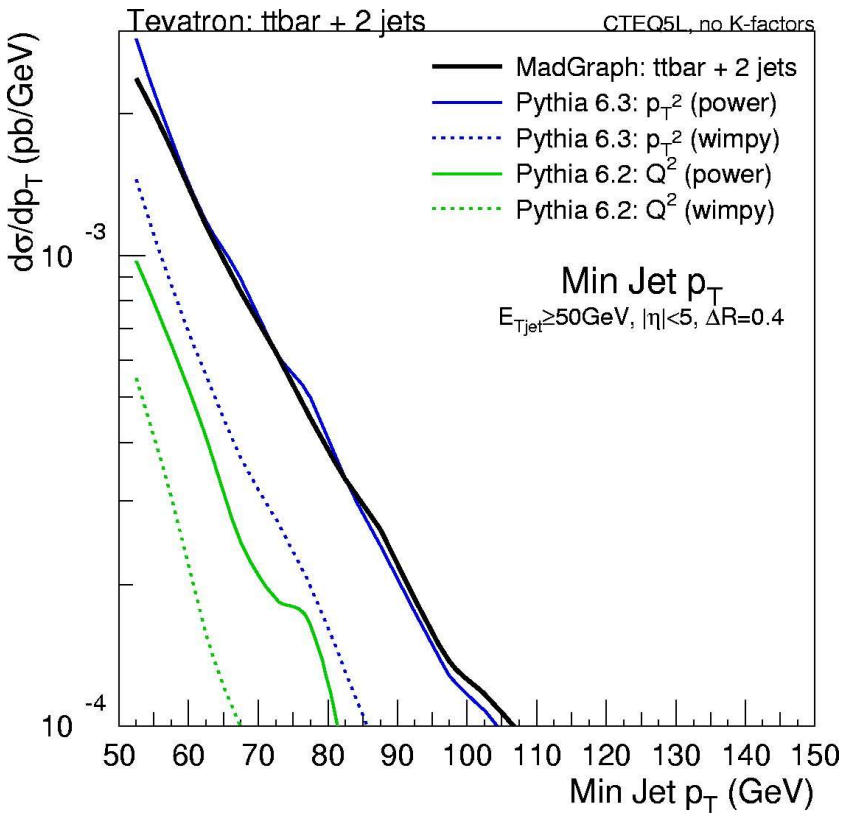


PYTHIA 6.3

Max shower scale (hat or no hat) is very important

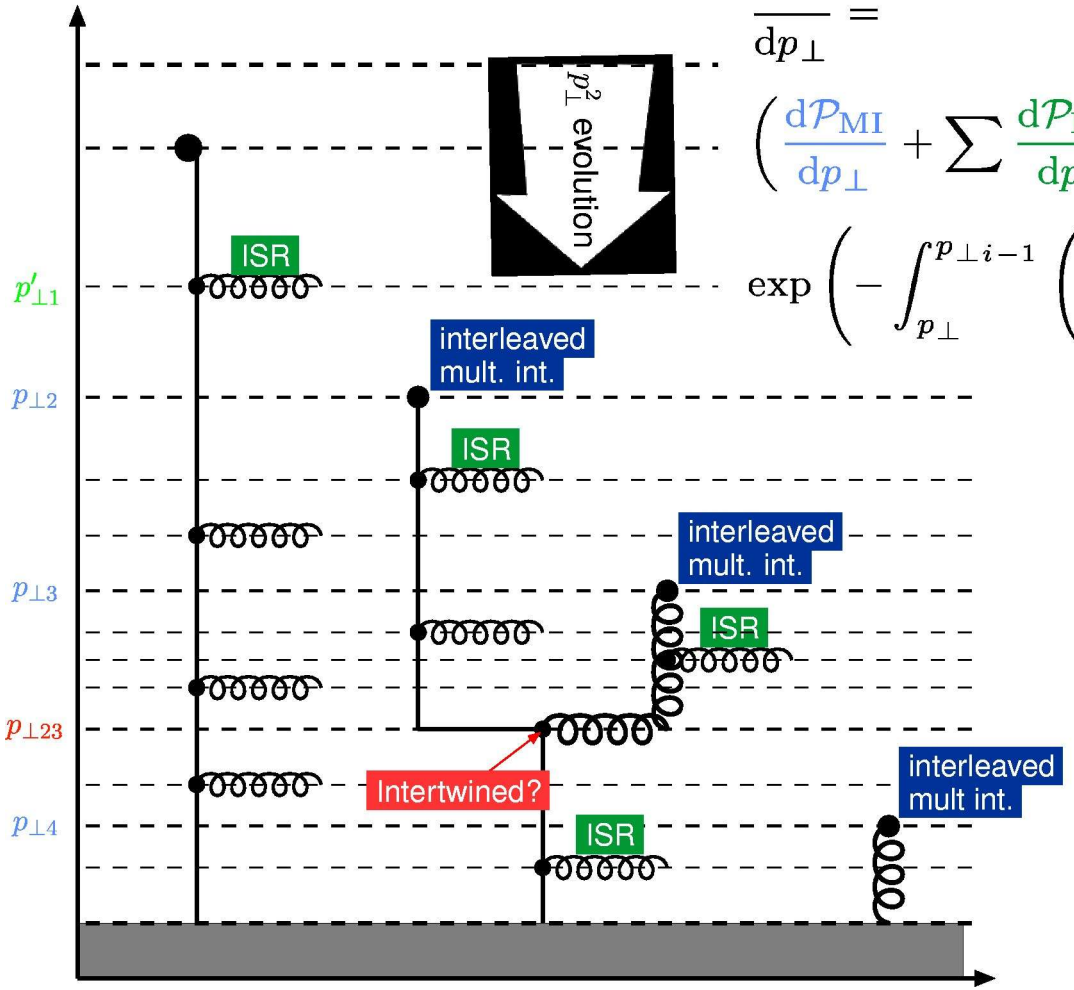
⇨ “power showers” vs “wimpy showers”





PYTHIA 6.3

- Parton Showers “interleaved” with Underlying Event



$$\frac{\mathrm{d}\mathcal{P}}{\mathrm{d}p_\perp} = \left(\frac{\mathrm{d}\mathcal{P}_{\mathrm{MI}}}{\mathrm{d}p_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{ISR}}}{\mathrm{d}p_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{JI}}}{\mathrm{d}p_\perp}\right) \times \exp\left(-\int_{p_\perp}^{p_{\perp i-1}} \left(\frac{\mathrm{d}\mathcal{P}_{\mathrm{MI}}}{\mathrm{d}p'_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{ISR}}}{\mathrm{d}p'_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{JI}}}{\mathrm{d}p'_\perp}\right) \mathrm{d}p'_\perp\right)$$

⇨ successive ”finegraining” of all perturbative activity

+ correlated multiparton pdfs (with flavour/momentum cons)
+ Impact parameter dependence
+ String fragmentation developed for baryonic colour topologies ⇨ improved description of beam remn.

PYTHIA 8

Currently Fortran PYTHIA6 is successfully being used,
also in C++ environments, hidden under wrappers

Q: Why rewrite?

A1: Need to clean up!
A2: Fortran 77 is limiting **Fortran 90**
A3: Young experimentalists will expect C++

Problem: PYTHIA7 project $\Longrightarrow$ ThePEG, physics stalled, no manpower
Solution?: T. Sjöstrand has taken a sabbatical to work "full-time"!
($\Rightarrow$ baseline model, S. Mrenna & P. Skands join later ?)

Tentative schedule:

time	date	processes	final states
0 =	1 Sept. 2004	—	—
1 =	1 Sept. 2005	LHA-style input	incomplete draft
2 =	1 Sept. 2006	a few processes	complete, buggy(?)
3 =	1 Sept. 2007	more processes	stable, debugged

So far according to plan, with first public "proof-of-concept" version
planned for July (but don't forget Murphy's law)

Warning: top priority is LHC; ep/γp/$\gamma\gamma$ is not on current "roadmap"!

Frixione, Webber, + collaborators

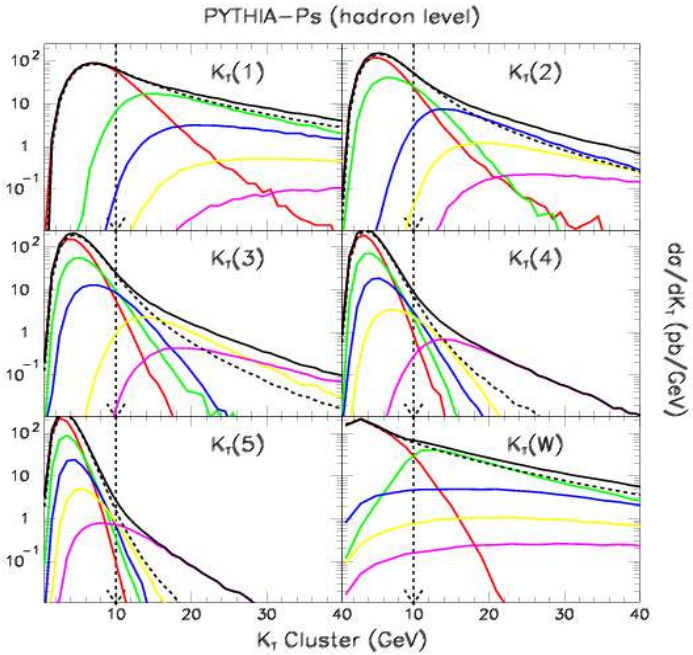
MC@NLO

- Consistent match of NLO QCD to parton showers!
  (Makes full use of analytical real-virtual cancellation of divergences)
- Generates events including “K”-factors by construction
  (unweighted events, weights = +/- 1: negative weights ~ destructive interference)
- Uses HERWIG 6.5 for showers (hard-wired)
  (if you use another shower, you get wrong results)
- Many processes = pp → (h,V,VV,QQ,ll) +X now implemented
  (in progress/being finished: study of WBF)
- Works identically to HERWIG, uses LHA for event information, features self-contained PDF library
  (LHAPDF will eventually be implemented)

See also talk by S. Frixione in Hadronic Final States, thursday 9:20!

TOOLS: PATRIOT

- LO ME/PS matched samples
  - Z/γ + jets (≤ 3)
  - W + jets (≤ 4)



- Different from CKKW:
  - Matching a la ARIADNE Lonnblad et al: Instead of using analytic Sudakov, computes Sudakov directly from "pseudo-showers" ⇨ more exact matching
  - History clustering done in relative pT instead of kT (since relative pT is renormalization scale for alpha_s in both PYTHIA and HERWIG)
  - Uses colour and flavour information in clustering
  - Unweighted hadron-level events available in MCFIO format

Butterworth, Butterworth, Waugh, Stirling, Whalley, Buckley

TOOLS: CEDAR

Combined E-Science DAta Resource for Particle Physics

- Compare MC models ↔ data:
  - JetWeb ("on-line" comparison between data and MC predictions)
  - HEPDATA (comprehensive compilation of up-to-date scattering data)
- CEDAR is newly funded project to merge these projects,
  - JetWeb ⇨ "super-JetWeb" = CEDAR
  - Incl code repository (HEPCODE), GRID tech, integrate C++ Monte Carlos...

http://cedar.ac.uk/

http://jetweb.hep.ucl.ac.uk/

http://durpdg.dur.ac.uk/hepdata/

Conclusions

- With the emergence of many sophisticated tools for 2->n
  (ALPGEN, COMPHEP, GRACE, MADGRAPH, MCFM, AMEGIC++, ...),
  the focus of the traditional Monte Carlo Generators
  (ARIADNE, HERWIG, ISAJET, PYTHIA, ...)
  is increasingly "returning" to parton showers & hadronization, with hard processes interfaced externally.
- Do not expect many new processes implemented directly in the MC programs in the future.
- We are becoming increasingly confident how to treat perturbative multi-parameter expansions consistently (ME/PS matching)
  (ARIADNE, SHERPA, PATRIOT, MC@NLO ...)
- LEP and HERA did(do) not teach us everything we need to know about hadron collisions. Several big white spots still on the map!
  (Tools like CEDAR welcome; need to make optimal use of existing data, now!)