LUND UNIVERSITY

ATLAS Higgs Group meeting
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PYTHIA – News in Recent Years

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- Timeline
- Transverse-Momentum-Ordered Showers
- Multiple Interactions and Beam Remnants
- Upgrades Relevant for Higgs Studies
- Other News
- Q & A

Timeline

PYTHIA	6.1	Mar 1997	—	Jul 2001	merge PYTHIA + JETSET
	6.2	Aug 2001	—	Jan 2005	BNV, LNV, junctions
	6.3	Jul 2003	—	Mar 2006	new showers & multiple interactions
	6.4	Mar 2006	—	??? 2008	slow upgrade path (?)
	8.0	Sep 2004	—	fall 2007	C++ experimental
	8.1	fall 2007	—		C++ standard

Currently PYTHIA 6.410 (as of last week):

- 74,800 lines of code (including comments/blanks)
- 580 page PYTHIA 6.4 Physics and Manual
  T. Sjöstrand, S. Mrenna and P. Skands,
  JHEP**05** (2006) 026 [hep-ph/0603175]
- New PYTHIA homepage on CEDAR HepForge:
  `http://projects.hepforge.org/pythia6/`
  news: fsplit $\longrightarrow$ tarballs, makefile, SVN,
  bugtracker, wiki, discussion forum, . . . (still trying our way)
- archive of older versions still available on
  `http://www.thep.lu.se/~torbjorn/Pythia.html`

PYTHIA shower improvements

Message from LEP:

ARIADNE dipole ($p_\perp$-ordered) + PYTHIA string fragmentation

$>$ PYTHIA showers (mass-ordered) + string fragmentation

$>$ HERWIG showers (angular-ordered) + cluster fragmentation

Objective:

Incorporate several of the good points of the dipole formalism (like ARIADNE) within the shower approach ($\Rightarrow$ hybrid)

$\pm$ explore alternative $p_\perp$ definitions

$+$ FSR and ISR cast in similar, but not identical, formalisms

$+$ $p_\perp$ ordering $\Rightarrow$ coherence inherent

$+$ ME merging works as before (unique $p_\perp^2 \leftrightarrow Q^2$ mapping; same z)

$+$ $\mathrm{g} \to \mathrm{q}\overline{\mathrm{q}}$ natural

$+$ well suited for ME/PS matching (still partly to be worked out)

$++$ well suited for *interleaved multiple interactions*

Transverse-momentum-ordered showers

1) *Define* $\mathrm{p}^2_{\perp\mathrm{evol}} = z(1-z)Q^2 = z(1-z)M^2$ for FSR
$\mathrm{p}^2_{\perp\mathrm{evol}} = (1-z)Q^2 = (1-z)(-M^2)$ for ISR

2) *Evolve* all partons *downwards* in $\mathrm{p}_{\perp\mathrm{evol}}$ from common $p_{\perp\mathrm{max}}$

$$\mathrm{d}\mathcal{P}_a = \frac{\mathrm{d}\mathrm{p}^2_{\perp\mathrm{evol}}}{\mathrm{p}^2_{\perp\mathrm{evol}}} \frac{\alpha_\mathrm{s}(\mathrm{p}^2_{\perp\mathrm{evol}})}{2\pi} P_{a\to bc}(z)\,\mathrm{d}z\,\exp\left(-\int_{\mathrm{p}^2_{\perp\mathrm{evol}}}^{p^2_{\perp\mathrm{max}}} \cdots\right)$$

$$\mathrm{d}\mathcal{P}_b = \frac{\mathrm{d}\mathrm{p}^2_{\perp\mathrm{evol}}}{\mathrm{p}^2_{\perp\mathrm{evol}}} \frac{\alpha_\mathrm{s}(\mathrm{p}^2_{\perp\mathrm{evol}})}{2\pi} \frac{x' f_a(x', \mathrm{p}^2_{\perp\mathrm{evol}})}{x f_b(x, \mathrm{p}^2_{\perp\mathrm{evol}})} P_{a\to bc}(z)\,\mathrm{d}z\,\exp\left(-\cdots\right)$$

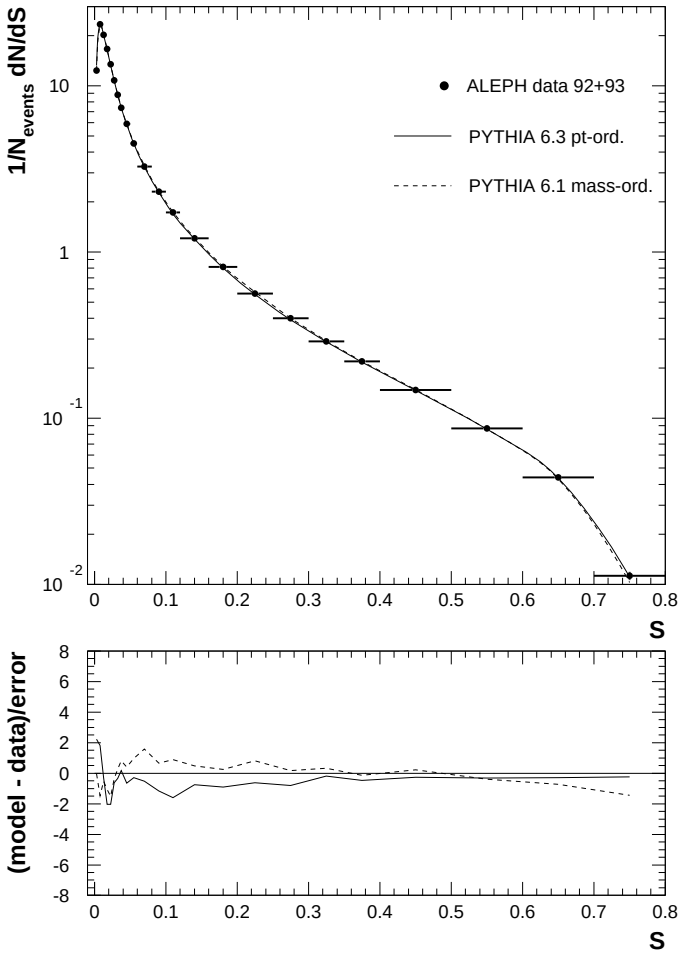
Pick the one with *largest* $\mathrm{p}_{\perp\mathrm{evol}}$ to undergo branching; also gives z.

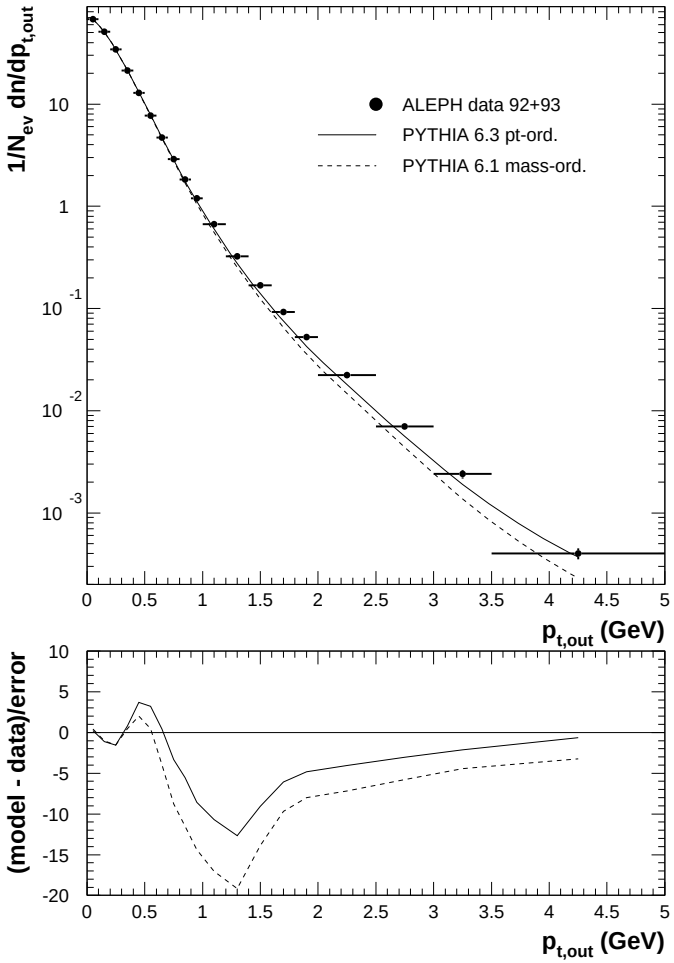
3) Kinematics: *Derive* $Q^2 = \pm M^2$ by inversion of 1), but then
interpret z as *energy fraction* (not lightcone) in "dipole" rest frame,
so that *Lorentz invariant* and matched to matrix elements.
Assume yet unbranched partons on-shell and shuffle $(E, \mathbf{p})$ inside dipole.

4)*Iterate* $\Rightarrow$ combined sequence $p_{\perp\mathrm{max}} > p_{\perp 1} > p_{\perp 2} > \ldots > p_{\perp\mathrm{min}}$.

Testing the FSR algorithm

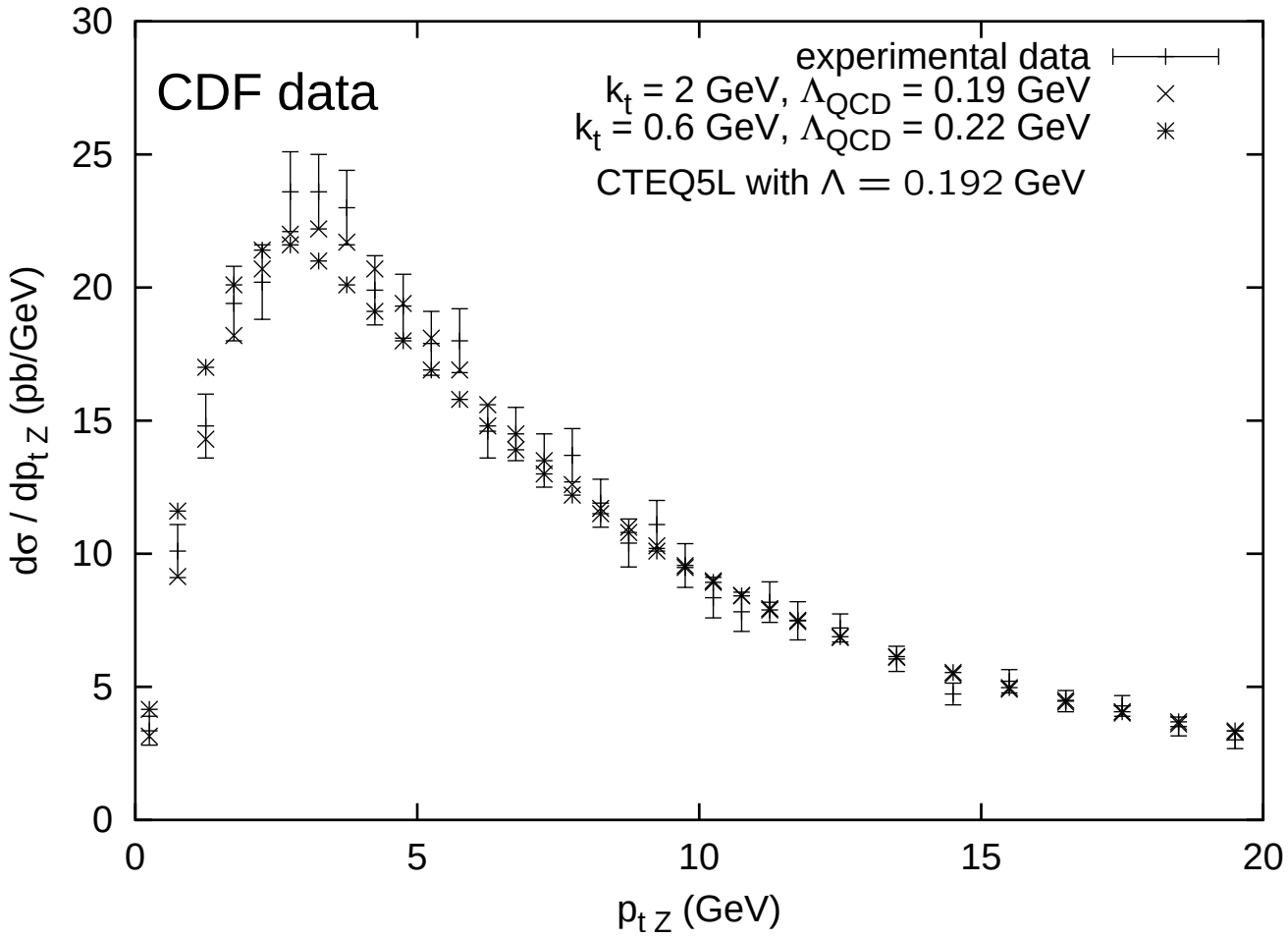
Tune performed by Gerald Rudolph (Innsbruck)
based on ALEPH 1992+93 data:



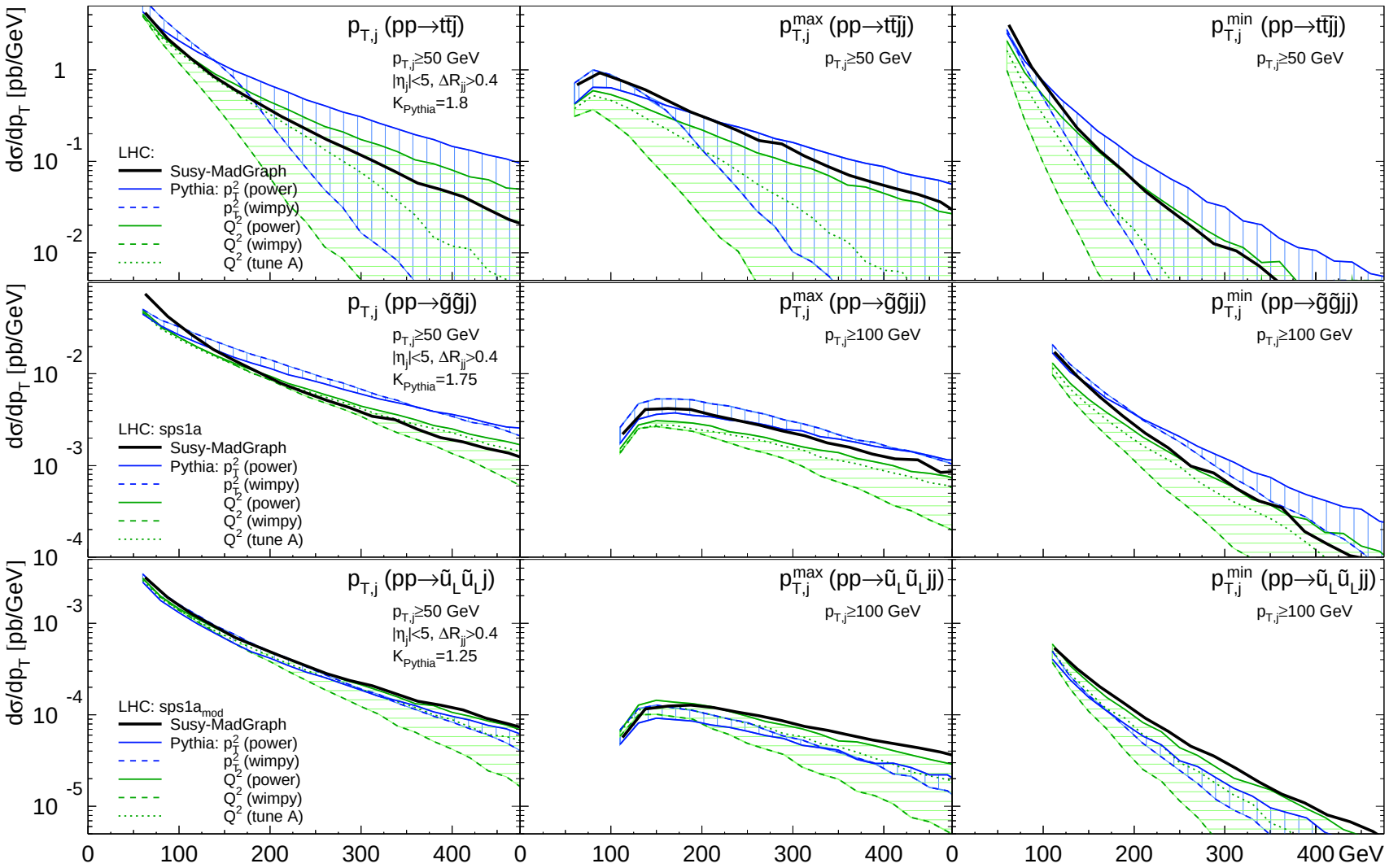


Testing the ISR algorithm

Still only begun. . .



. . . but so far no showstoppers

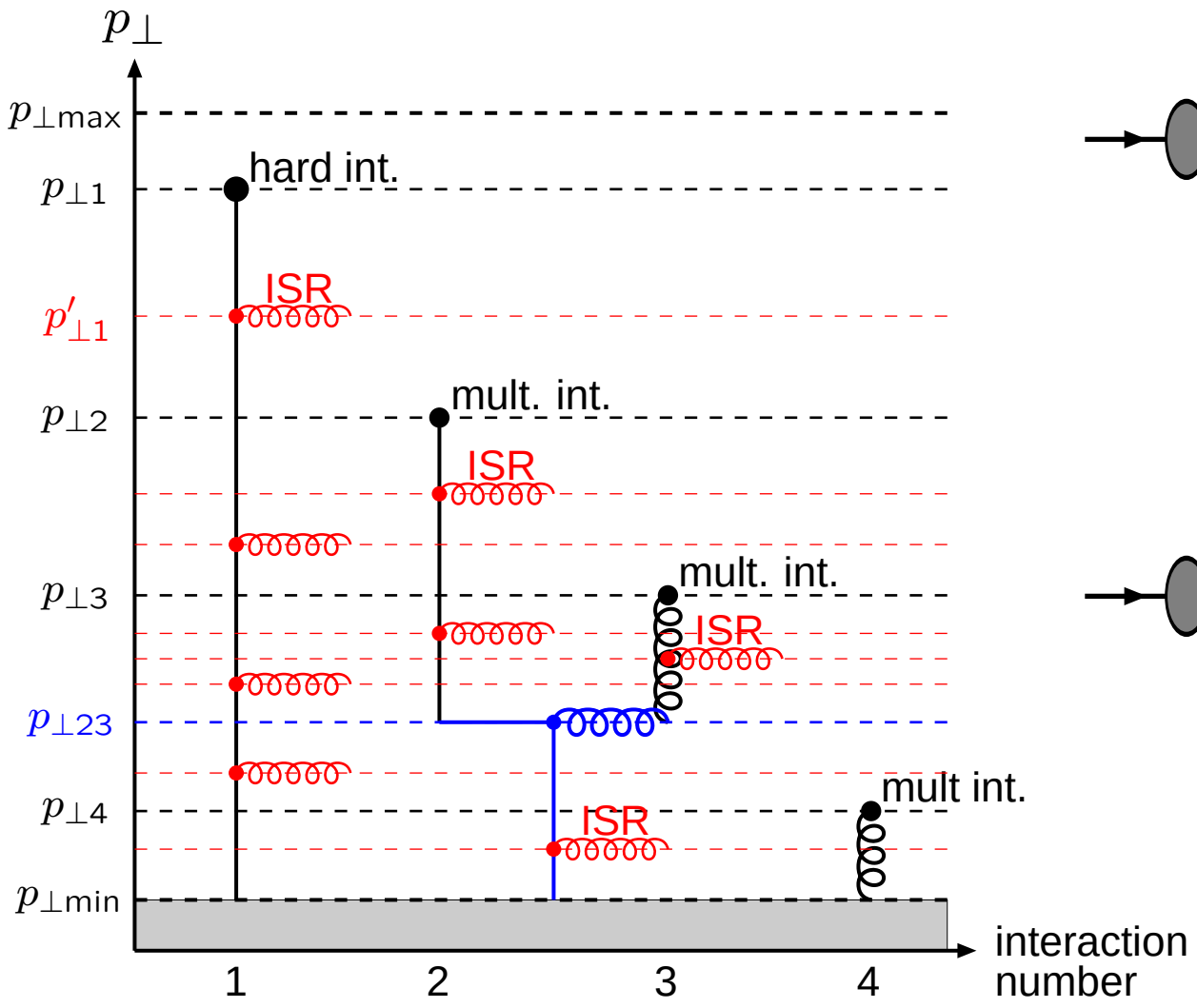


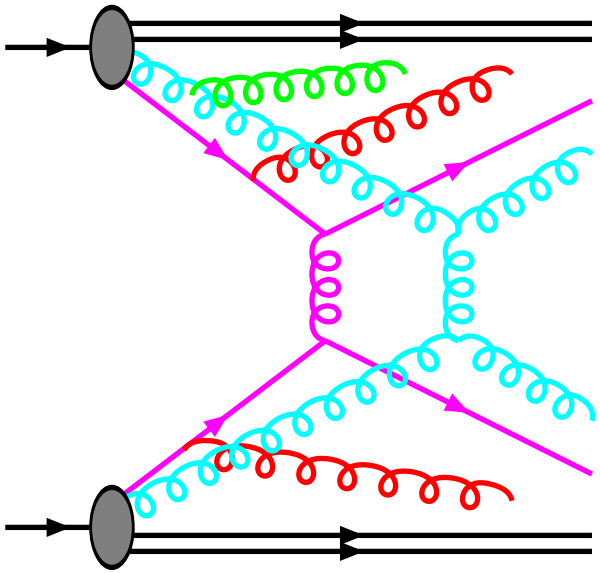
power: $Q^2_{\text{max}} = s$; wimpy: $Q^2_{\text{max}} = m_\perp^2$; tune A: $Q^2_{\text{max}} = 4m_\perp^2$

$m_{\text{t}} = 175$ GeV, $m_{\tilde{\text{g}}} = 608$ GeV, $m_{\tilde{\text{u}}_L} = 567$ GeV

(T. Plehn, D. Rainwater, P. Skands)

Key Objective: Interleaved Multiple Interactions





Competition

"Evolution" equation, only Multiple Interactions:

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

Evolution equation, only Initial State Radiation:

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

Evolution equation, MI + ISR, with competition for PDF and phase space:

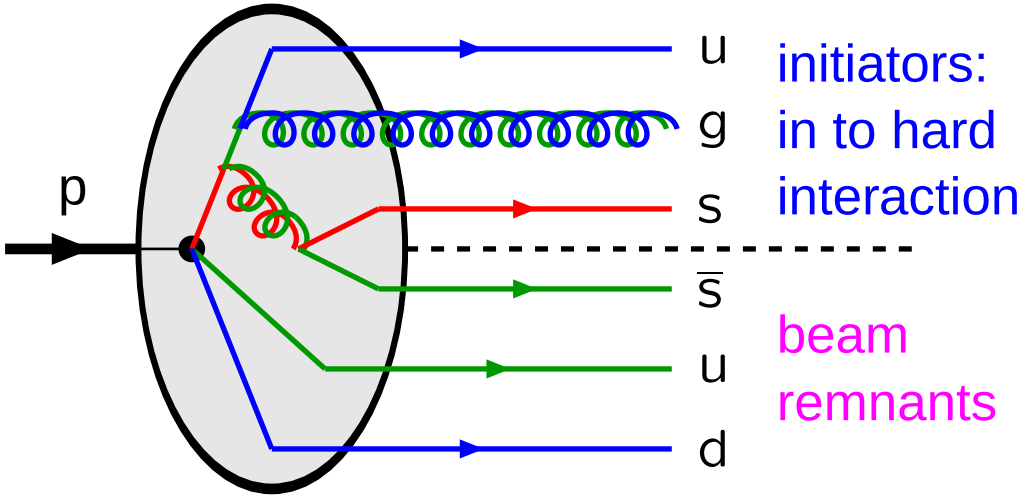
$$\frac{\mathrm{d}\mathcal{P}}{\mathrm{d}p_\perp} = \left(\frac{\mathrm{d}\mathcal{P}_{\mathrm{MI}}}{\mathrm{d}p_\perp} + \sum \frac{\mathrm{d}\mathcal{P}_{\mathrm{ISR}}}{\mathrm{d}p_\perp}\right) \exp\left(-\int_{p_\perp}^{p_{\perp i-1}} \left(\frac{\mathrm{d}\mathcal{P}_{\mathrm{MI}}}{\mathrm{d}p'_\perp}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

with ISR sum running over all previous MI

$\Rightarrow$ one interleaved sequence of MI and ISR

FSR: no competition so not required (but nice for ME merging)

Initiators and Remnants



Need to assign:

- correlated flavours
- correlated $x_i = p_{zi}/p_{z\mathrm{tot}}$
- correlated primordial $k_{\perp i}$
- correlated colours
- correlated showers

- **PDF after preceding MI/ISR activity:**

0) Squeeze range $0 < x < 1$ into $0 < x < 1 - \sum x_i$ (ISR: $i \neq i_{\mathrm{current}}$)

1) Valence quarks: scale down by number already kicked out

2) Introduce companion quark $\mathrm{q}/\overline{\mathrm{q}}$ to each kicked-out sea quark $\overline{\mathrm{q}}/\mathrm{q}$, with x based on assumed $\mathrm{g} \to \mathrm{q}\overline{\mathrm{q}}$ splitting

3) Gluon and other sea: rescale for total momentum conservation

Upgrades Relevant for Higgs Studies

Bug from PYTHIA 6.321 - PYTHIA 6.406:
procedure for setting maximum scale of shower rewritten from scratch,
but did not consider gauge-boson-fusion or prompt-photon processes;
for former scale became s rather than M^2_{W},
("right choice" for $\mathrm{q\overline{q}} \to \gamma^*/\mathrm{Z}^0/\mathrm{W}^\pm$; also $\mathrm{gg} \to \mathrm{h}^0$ for $m_{\mathrm{t}} \to \infty$)
so much too much extra jet activity, also in central region

- SUSY Les Houches Accord: allows generic input of
  masses and couplings, including NMSSM support ($\Rightarrow$ more Higgses)
- interface to FeynHiggs for better Higgs masses
- IsaSusy interface upgraded in several steps
- Diffractive Higgs $\mathrm{pp} \to \mathrm{ppH}^0$ with LHA input `PDFGUP(i) = -9`

- $\Gamma(\mathrm{h}^0 \to \mathrm{W}^+\mathrm{W}^-, \mathrm{Z}^0\mathrm{Z}^0) \propto M^2_{\mathrm{h}}\sqrt{\hat{s}}$
  $\Gamma(\mathrm{h}^0 \to \mathrm{others}) \propto \hat{s}^{3/2}$
- $\mathrm{h}^0 \to \mathrm{W}^+\mathrm{W}^-, \mathrm{Z}^0\mathrm{Z}^0 \to 4$ fermions angular correlations
  with mixture CP-even + CP-odd + interference
- $\mathrm{gg}/\mathrm{q\overline{q}} \to \mathrm{tbH}^\pm$ implemented (Johan Alwall)
- wider selection of process scales

Other News

- Les Houches Event Files provides standard input fomat,
  e.g. from MadGraph
- `UPVETO` routine allows rejection of parton-level events
  for MLM matching to Alpgen (MadGraph on the way)
- New processes for J/Ψ and Υ production
  through colour-singlet and colour-octet mechanisms
- Technicolor Strawman model

- Tune A of Rick Field made default, but with `PARP(90) = 0.16`
- Several different models for colour reconnection
- `PYTUNE` routine allows simple setup of several tunes
  to old and new shower/MI framework

- Many further small additions and bug fixes

Questions

Q1 (Bill Murray): Momentum is not conserved in top decay if you study the documentation section of the event record. Why?

A1: the documentation section corresponds to "snapshots"
taken at different times of the event evolution.

line	particle	time
7	t	after initial-state radiation, but before $\mathrm{t} \to \mathrm{tg}$ and top decay
9	W^+	after top decay, but before $\mathrm{b} \to \mathrm{bg}$ and W^+ decay
10	b	ditto
13	u	after W^+ decay but before $\mathrm{u} \to \mathrm{ug}$ and $\overline{\mathrm{d}} \to \overline{\mathrm{d}}\mathrm{g}$
14	$\overline{\mathrm{d}}$	ditto

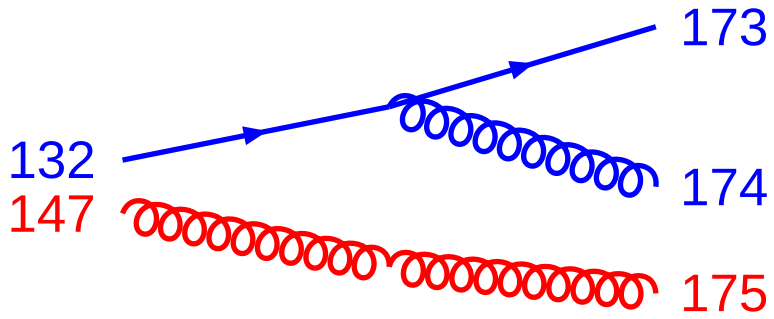
Thus $p_9 + p_{10} \neq p_7$ but $(p_9 + p_{10})^2 = p_7^2 = m_{\mathrm{t}}^2$
and $p_{13} + p_{14} \neq p_9$ but $(p_{13} + p_{14})^2 = p_9^2 = m_{\mathrm{W}^+}^2$.

The top you would hope to reconstruct corresponds to $p_9 + p_{10}$.

If you look in the main part of the event record with full documentation, `MSTP(125) = 2`, it also corresponds to the last copy of t.

Q2 (Markus Schumacher): How should one read the event record with the new showers, e.g. for tagging jets in VBF?

A2a) Yes, it is messy, and there is no simple tagging-jet identification, aside from the functional one of jet clustering.
A2b) The quarks in the documentation section may be as good as anything you can get at by tracing showers.
A2c) Key difference is that in the new showers partons are on shell until they branch, and therefore you need a recoiler to conserve momentum.



$$p_{173} + p_{174} \neq p_{132}$$

. . . but . . .

$$p_{173} + p_{174} + p_{175} = p_{132} + p_{147}$$

For search generate events with `MSTP(125) = 2`.
Then start with tagging jet in slot 7 (or 8),
look for `K(I,3) = 7`, gives `I = 103`,
look for `K(I,3) = 103`, gives 2 or 1 new "daughters",
iteratively look for two or one replacement(s) of existing list.
Worse with initial-state radiation, since works backwards:
two daughters above mother.

Q3 (Markus Warsinsky): Why did the hardness of the b jets in $gg/q\bar{q} \to b\bar{b}h^0$ change so much between 6.3 and 6.4?
(Francesca Sarri): Also VBF changed!

A3: presumably same bug as noted above, that

6.321 – 6.402 used as maximum scale for ISR

s in both $b\bar{b}h^0$ and VBF

(– 6.405 for γ's)

6.403 & 6.2 uses

$\max(m^2_{\perp b}, m^2_{\perp \bar{b}})$ for $b\bar{b}h^0$ (see `MSTP(39)` for options)

m^2_W or m^2_Z for VBF (no main options, but see `MSTP(68)`)

Of course 6.4 new showers $\neq$ 6.2 old showers.
For old showers `PARP(67)` was changed from 1 to 4 for Tune A, which affects $2 \to 2$ processes such as $q\bar{q} \to Z^0h^0$ or $gb \to h^0b$.