New Features in Pythia (v6.420)

New Tunes to LEP data → Better Fragmentation Models

New Tunes to Tevatron data → Better Underlying-Event Models

Combined ➔ New “Professor” and “Perugia” Tunes

Outlook to Pythia 8

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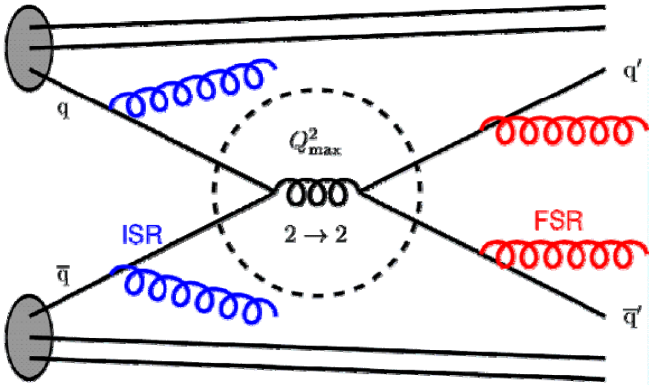
Thanks to N. Moggi, R. Field, A. Buckley, H. Hoeth

Modeling LHC



- Basic aim: improve lowest order perturbation theory by including leading corrections → exclusive event samples
  1. sequential resonance decays
  2. bremsstrahlung
  3. **underlying event**
  4. **hadronization**
  5. hadron (and τ) decays

Even the most sophisticated calculations currently only scratch the first few orders of couplings, logs, powers, twists, … → "tuning" needed. Realistic assessment of uncertainties non-trivial.

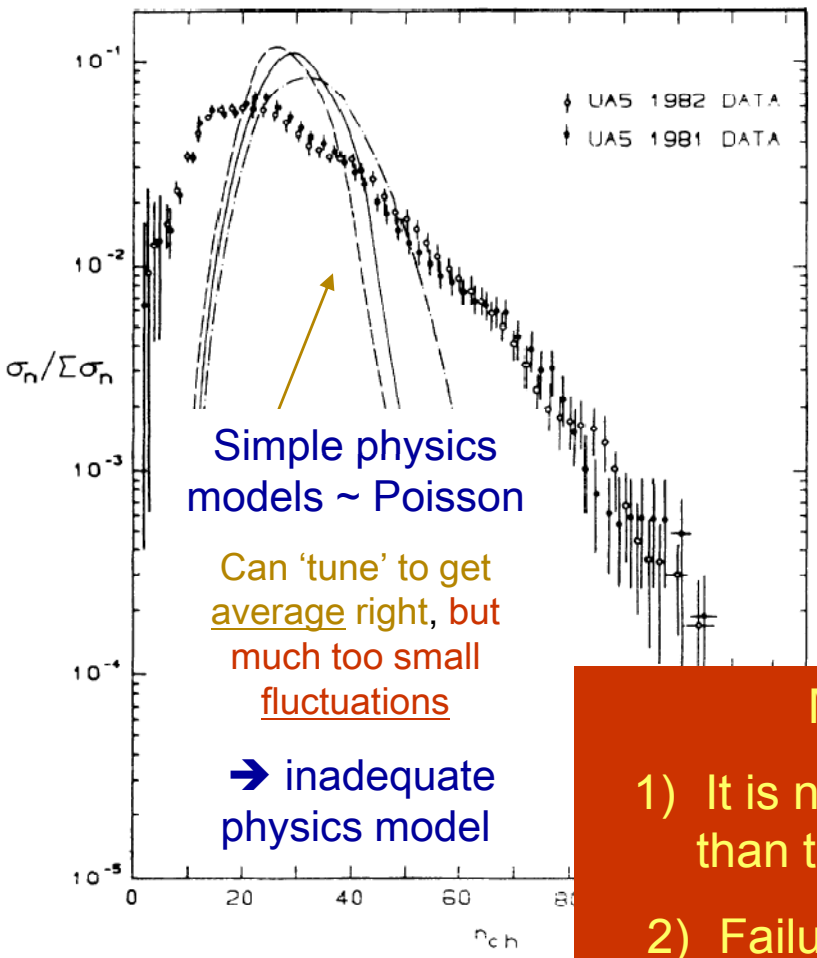
Why Study the "Underlying Event"?

- Solving QCD requires Compromise
  - Pythia alone contains many different models, + Herwig, + Sherpa …
- Fragmentation / Hadronization
  - Hadronization can only be studied "in isolation" at LEP
    - Normal procedure: constrain fragmentation models at LEP and cross fingers
    - = EXTRAPOLATION
  - What about **in situ** constraints on fragmentation!?
    - Important to verify pion spectra, etc, **directly** in the experiment
    - At least for min-bias / UE, but ideally for processes as close as possible to signal
- Feedback to high-p_T physics
  - Reliable correction procedures
  - Without reliable models, reliable extrapolations are hard to hope for

Experimental input vital to guide construction of theory

Classic Example: Number of tracks

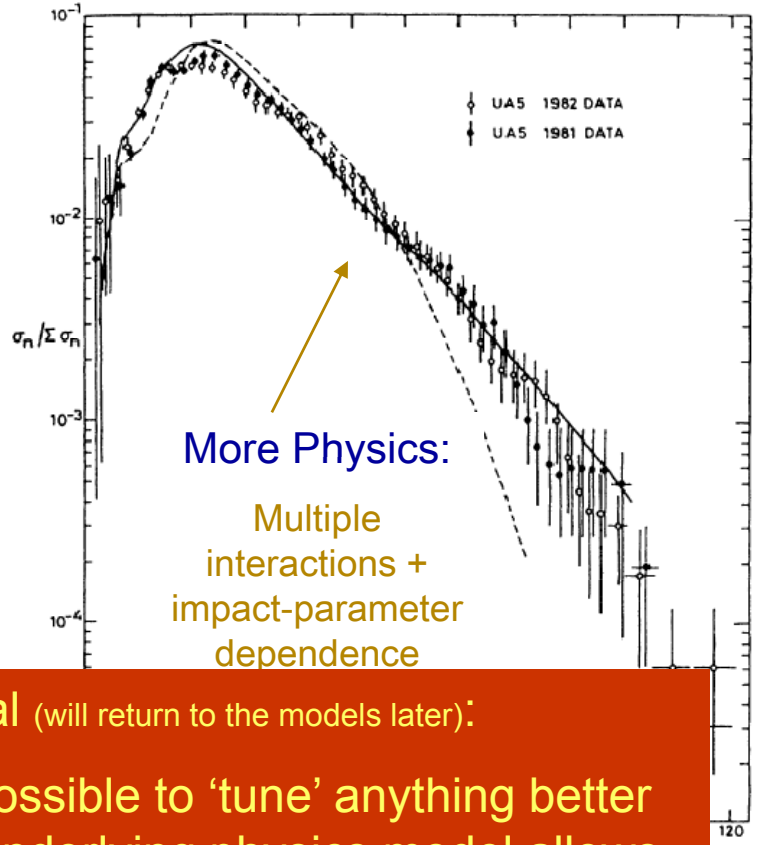
UA5 @ 540 GeV, single pp, charged multiplicity in minimum-bias events



Simple physics models ~ Poisson

Can 'tune' to get average right, but much too small fluctuations

➔ inadequate physics model



More Physics:

Multiple interactions + impact-parameter dependence

Moral (will return to the models later):

1) It is not possible to 'tune' anything better than the underlying physics model allows

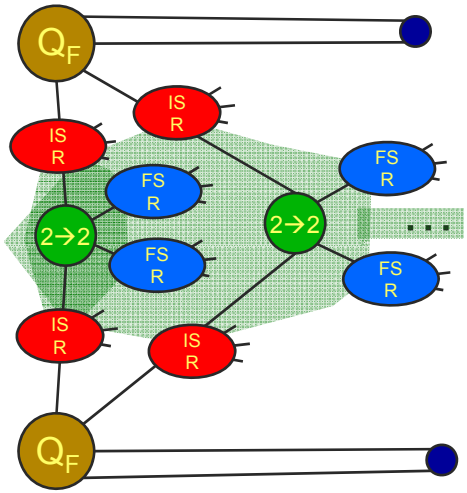
2) Failure of a physically motivated model usually points to more physics (interesting)

FIG. 3. Charged-multiplicity distributio… results (Ref. 32) vs simple models: dashed l… cluding hard scatterings, dash-dotted also including initial- and final-state radiation.

…eV, UA5 …riable im- …pact parameter. Solid line, double-Gaussian matter distribution; dashed line, with fix impact parameter [i.e., $\tilde{O}_0(b)$].

Particle Production

- Starting point: matrix element + parton shower
  - hard parton-parton scattering
    - (normally 2→2 in MC)
  - + bremsstrahlung associated with it
    - ➔ 2→n in (improved) LL approximation



$Q_F >> \Lambda_{QCD}$

- But hadrons are not elementary
- + QCD diverges at low p_T

→ multiple <u>perturbative</u> parton-parton collisions

e.g. 4→4, 3→ 3, 3→2

- No factorization theorem

➔Herwig++, Pythia, Sherpa: MPI models

Particle Production

$Q_F >> \Lambda_{QCD}$

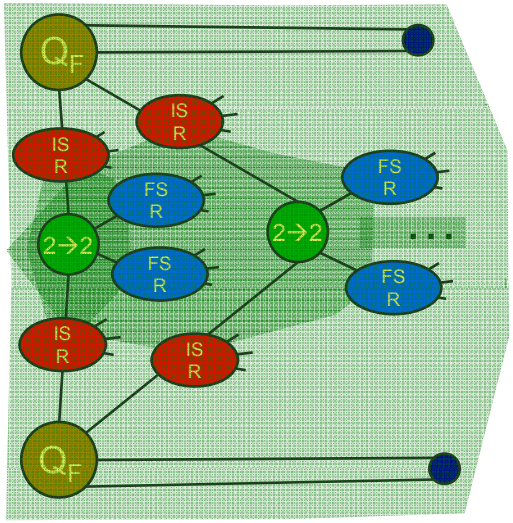
ME+ISR/FSR

+ perturbative MPI

+

Stuff at

$Q_F \sim \Lambda_{QCD}$



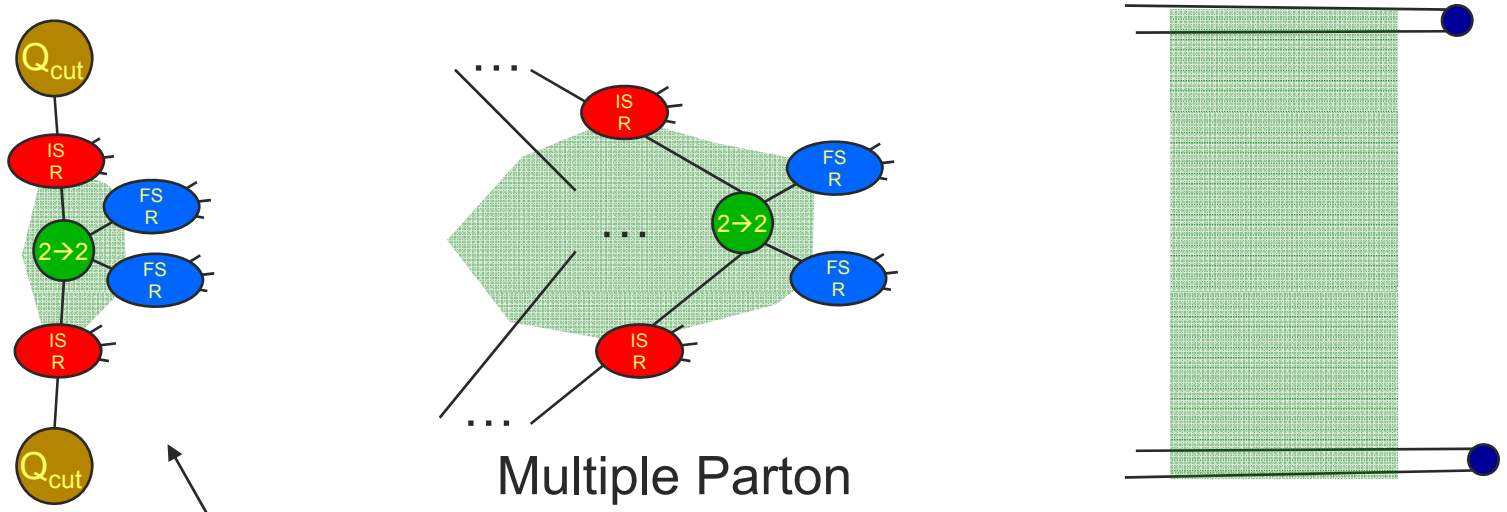
Need-to-know issues for IR sensitive quantities (e.g., N_{ch})

- Hadronization
- Remnants from the incoming beams
- Additional (non-perturbative / collective) phenomena?
  - Bose-Einstein Correlations
  - Non-perturbative gluon exchanges / color reconnections ?
  - String-string interactions / collective multi-string effects ?
  - "Plasma" effects?
  - Interactions with "background" vacuum, remnants, or active medium?

Naming Conventions

See also **Tevatron-for-LHC Report of the QCD Working Group, hep-ph/0610012**

- Many nomenclatures being used.
  - Not without ambiguity. I use:



Inelastic, non-diffractive

Note: each is colored ➔ Not possible to separate clearly at hadron level

MPI Models in Pythia 6.4

- **Old Model: Pythia 6.2 and Pythia 6.4**
  - "Hard Interaction" + **virtuality-ordered** ISR + FSR
  - p_T-ordered MPI **without ISR/FSR**
  - Momentum and color explicitly conserved
  - Color connections: **PARP(85:86) → 1** in Rick Field's Tunes
  - No explicit color **re**connections

MPI create kinks on existing strings, rather than new strings

- **New Model: Pythia 6.4 and Pythia 8**
  - "Hard Interaction" + **p_T-ordered** ISR + FSR
  - p_T-ordered MPI + **p_T-ordered** ISR + FSR
    - ISR and FSR have **dipole kinematics**
    - **"Interleaved"** with evolution of hard interaction in one common sequence
  - Momentum, color, and **flavor** explicitly conserverd
  - Color connections: random or ordered
  - Toy Model of Color reconnections: **"color annealing"**

Hard System + MPI allowed to undergo color reconnections

Developments in Perugia 2008

- October 2008: Perugia Workshop

http://www.pg.infn.it/mpi08/

  - Huge model building and tuning efforts by many groups (Herwig, Professor, Pythia, Sherpa, …)

- From Pythia Side:

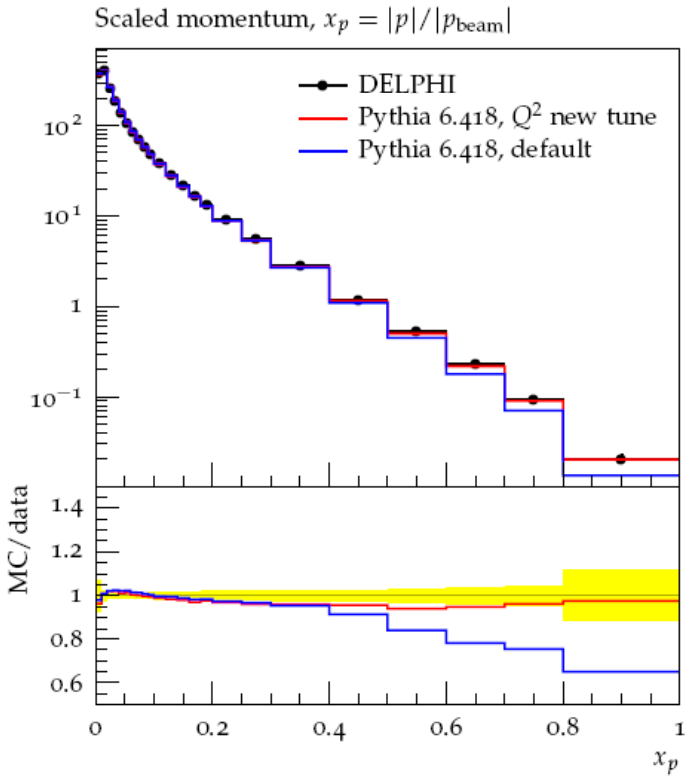
  - LEP data revisited → better fragmentation tunes
  - More Tevatron data included → better underlying-event tunes
  - LEP + Tevatron tunes combined: new generation of tunes
    - Both old-fashioned tuning (Rick Field, me) but now also first set of tunes using fully automated approach ("Professor")
    - Updated tunes available for BOTH new and old MPI models!
    - + Systematic HARD / SOFT / CR / PDF variations (incl LO*)
  - All included in Pythia 6.4.20, available via PYTUNE
    - See 6.4.20 Update Notes for full documentation

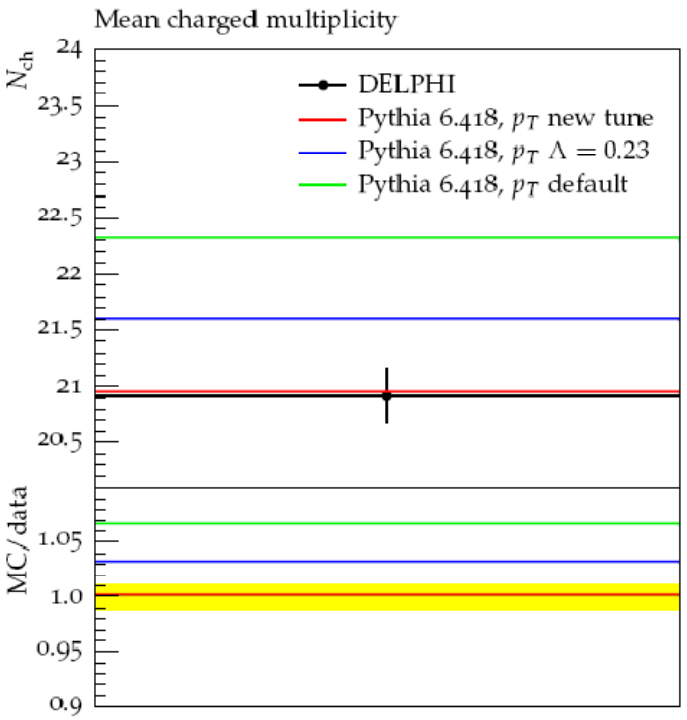
The New Tunes

- Old Framework
  - Tune 103: Rick Field's "old" best Tevatron tune: "DW"
  - Tune 113: "DW-Pro"
    - Revamped to include Professor tuning of fragmentation parameters.
    - Useful to estimate how big difference is between old and new fragmentation tuning
  - Tune 129: "Pro-Q2O" Professor tune of Q2-ordered showers and old MPI model
    - Currently recommended "best" tune of old model.
    - Includes Professor's LEP and Tevatron 630-1800-1960 tunes.
- New Framework
  - Tune 320: "Perugia 0" tune of pT-ordered showers and new MPI
    - Currently recommended "best" tune of new model
    - Includes both LEP and Tevatron 630-1800-1960 data (+ some UA5 data)
    - + also includes Tune 321 – 326: HARD / SOFT / PDF / etc variations
  - Tune 329: "Pro-pTO" Professor tune of pT-ordered model
    - Alternative to Perugia 0 obtained with fully automated tuning

Jet Fragmentation : LEP

- Improvements in descriptions of LEP spectra
  - E.g., momentum spectra and particle multiplicites

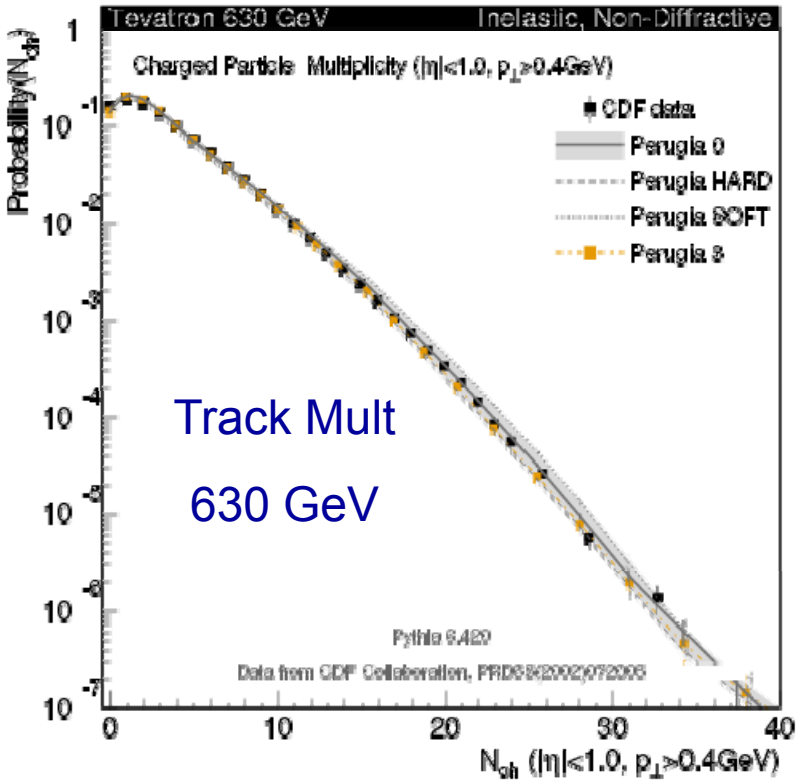


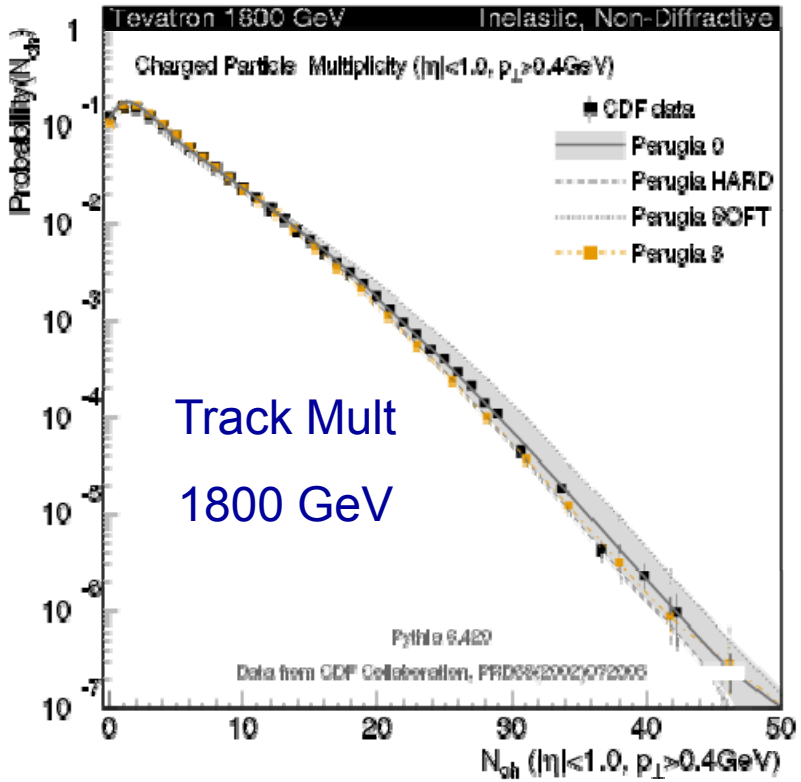


https://users.hepforge.org/~holsch/wiki/tune_flavour/comparisonplots.html

Hadron Collisions : Tevatron

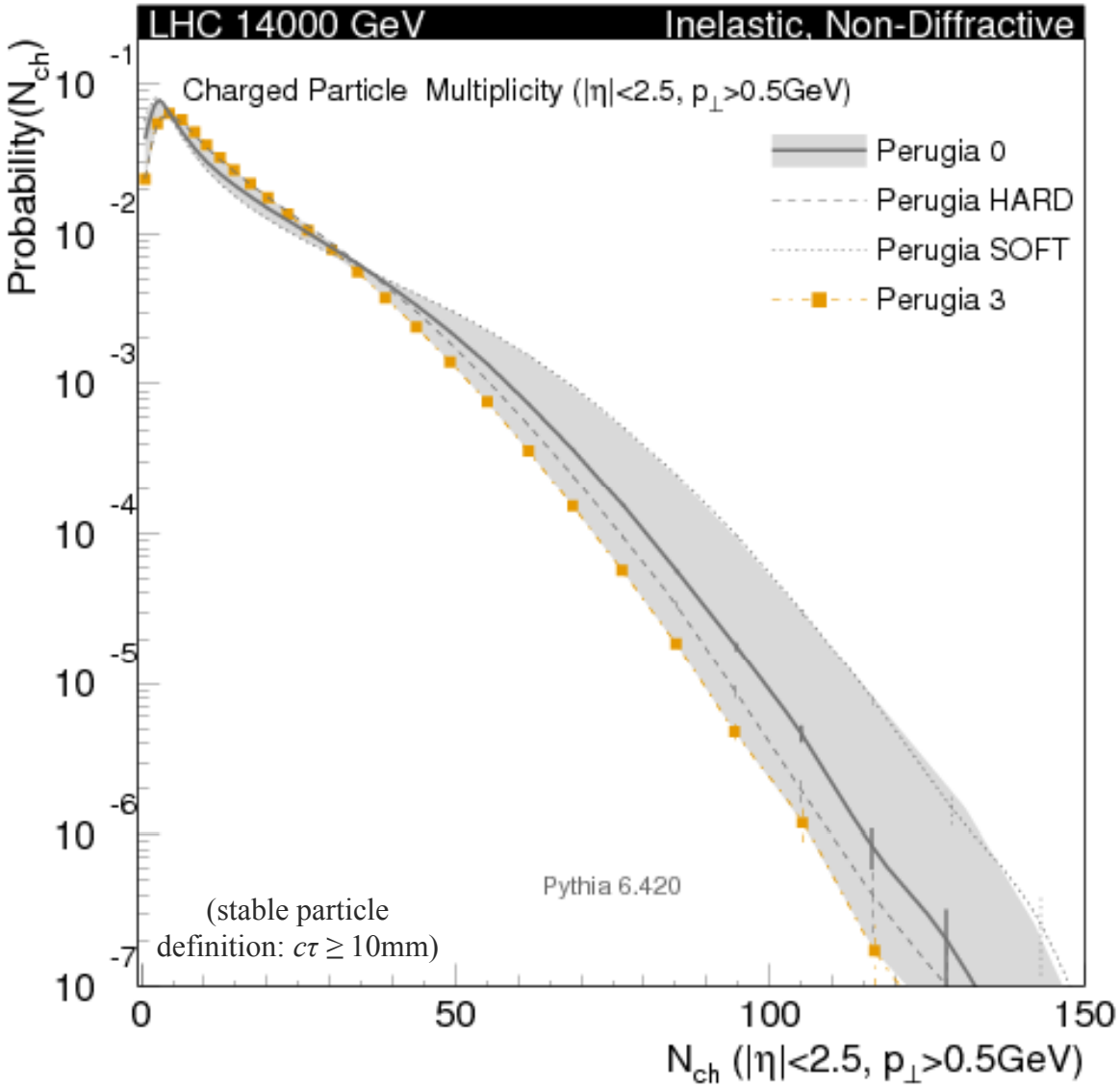
- In addition to the improved LEP parameters, more sophisticated tunes have been done to the Tevatron data
  - Including also data at 630 GeV → energy scaling better constrained





http://home.fnal.gov/~skands/leshouches-plots/

Extrapolations to LHC



➔ Aspen Predictions:

$|\eta| < 2.5$
$p_T > 0.5$ GeV
LHC **10 TeV** (min-bias)
$\langle N_{tracks} \rangle = 12.5 \pm 1.5$
LHC **14 TeV** (min-bias)
$\langle N_{tracks} \rangle = 13.5 \pm 1.5$

$1.8 < \eta < 4.9$
pT > 0.5 GeV
LHC **10 TeV** (min-bias)
$\langle N_{tracks} \rangle = 6.0 \pm 1.0$
LHC **14 TeV** (min-bias)
$\langle N_{tracks} \rangle = 6.5 \pm 1.0$

Conclusions

- Substantial Recent Revisions
  - Updated flavour and fragmentation parameters (LEP)
  - To see effects on you, compare “Tune X” with “Tune X-Pro”
    - For this purpose, “-Pro” versions of all previous tunes included with 6.4.20
    - E.g., compare “DW” with “DW-Pro” (old), or “S0A” with “S0A-Pro” (new)
  - Useful to check your sensitivity to these changes
- Improved hadron collider tunes
  - Including improved constraints on energy scaling to LHC
    - Important to check spectra in-situ to best extent possible (+ please publish!)
  - For serious productions: now recommending “Perugia” or “Professor” tunes (+ systematic variations → first attempt at uncertainty bands)
    - No further substantial updates are foreseen in near future
- Enter Pythia 8
  - Professor Team now working on full-fledged tune of Pythia 8
    - As well as Herwig++, Sherpa