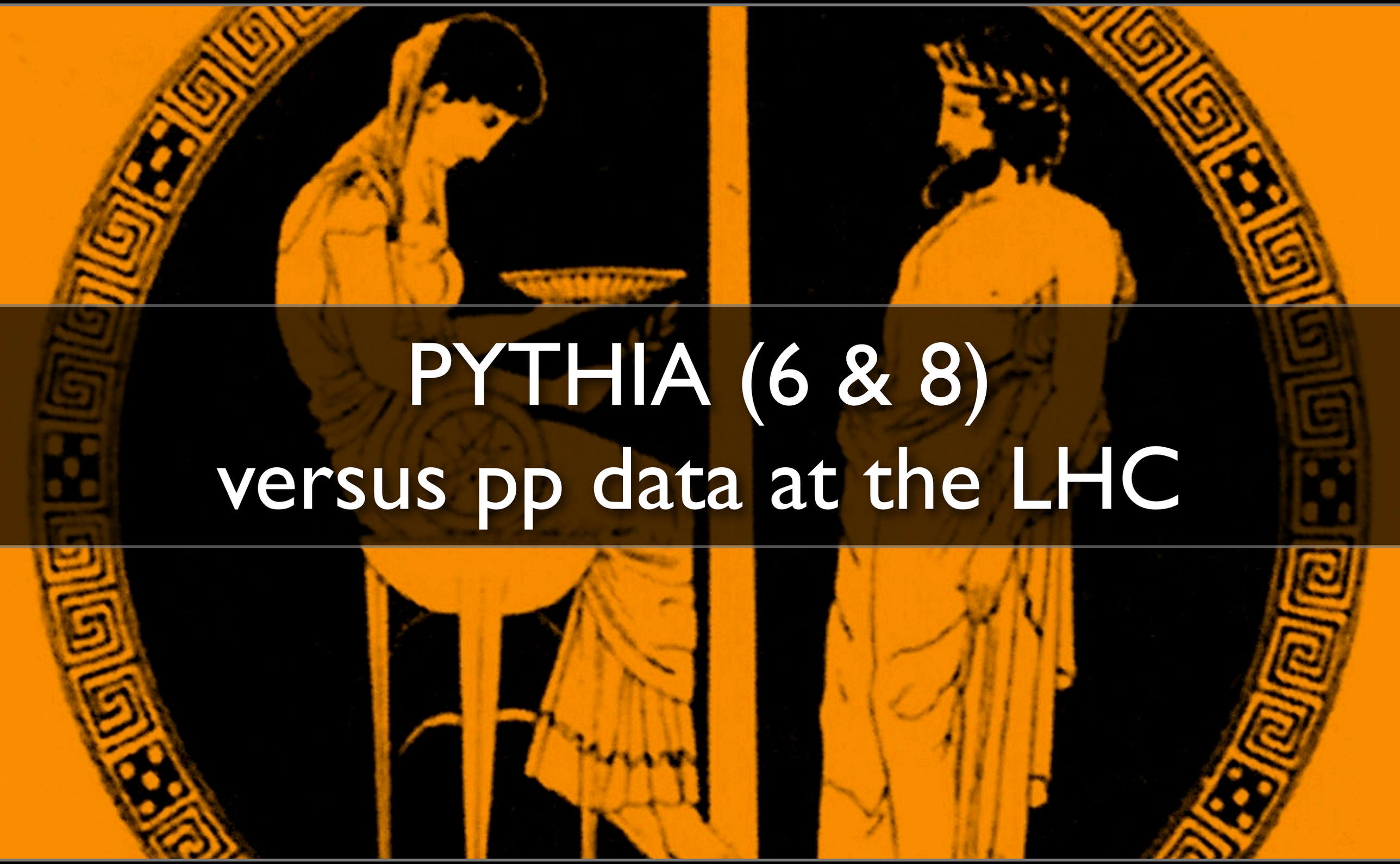


PYTHIA (6 & 8)
versus pp data at the LHC

Peter Skands (CERN)

QCD in PYTHIA

Multiple Parton Interactions (MPI)

Regularise cross section with $p_{\perp 0}$ as free parameter

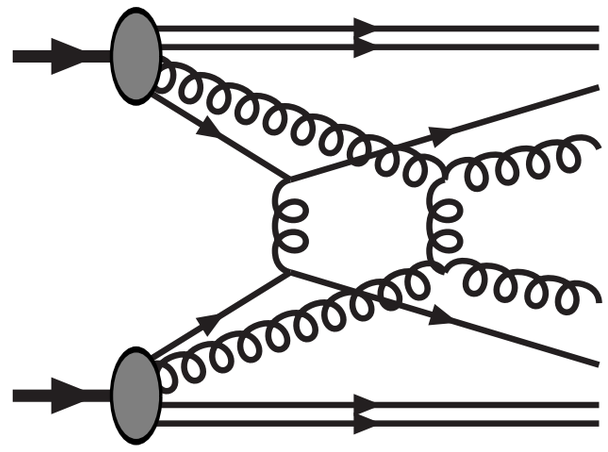
IR Regularization

$$\frac{\mathrm{d}\hat{\sigma}}{\mathrm{d}p_\perp^2} \propto \frac{\alpha_s^2(p_\perp^2)}{p_\perp^4} \to \frac{\alpha_s^2(p_{\perp 0}^2 + p_\perp^2)}{(p_{\perp 0}^2 + p_\perp^2)^2}$$

with energy dependence

Energy Scaling

$$p_{\perp 0}(E_{\mathrm{CM}}) = p_{\perp 0}^{\mathrm{ref}} \times \left(\frac{E_{\mathrm{CM}}}{E_{\mathrm{CM}}^{\mathrm{ref}}}\right)^{\epsilon}$$



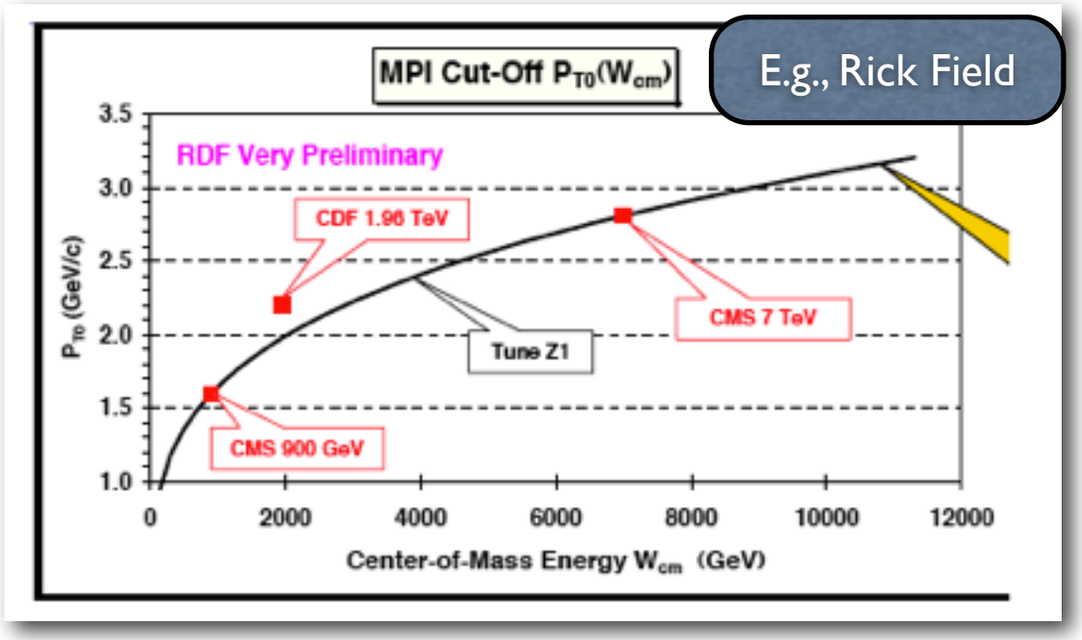
See, e.g., new MCnet Review: *"General-purpose event generators for LHC physics"*, arXiv:1101.2599

From Tevatron to LHC

Tevatron tunes appear to be "low" on LHC data

Problem for "global" tunes.

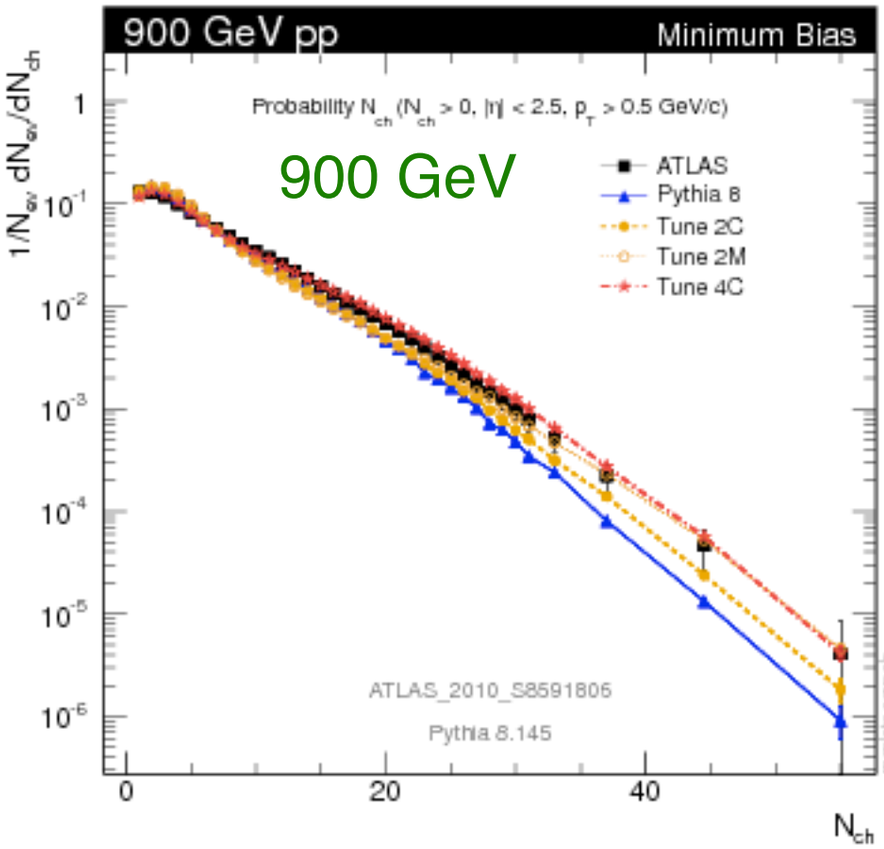
Poor man's short-term solution: dedicated LHC tunes

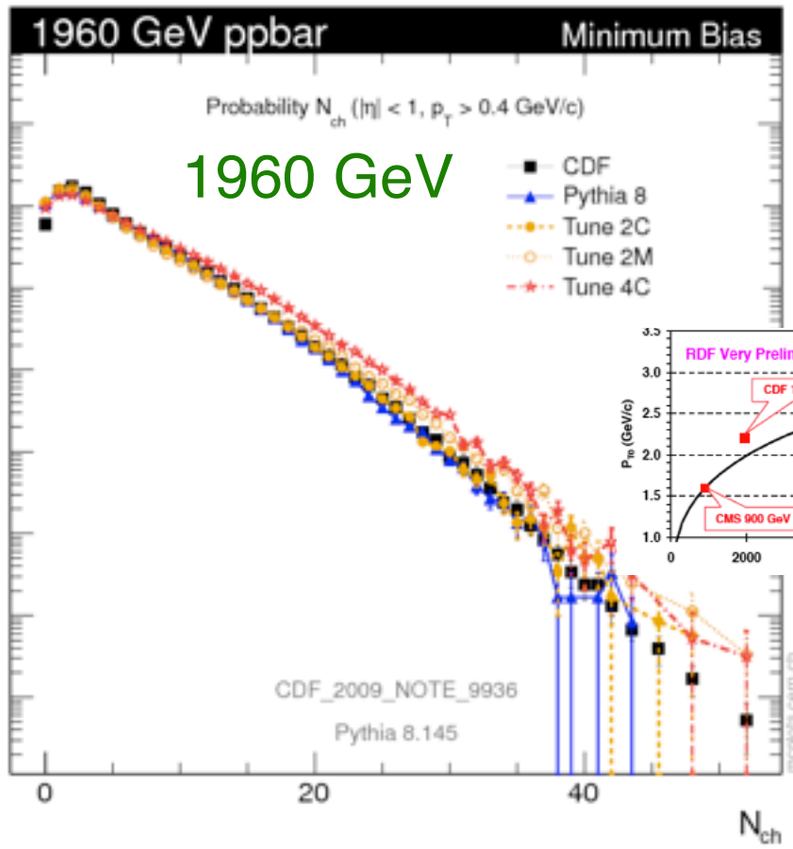


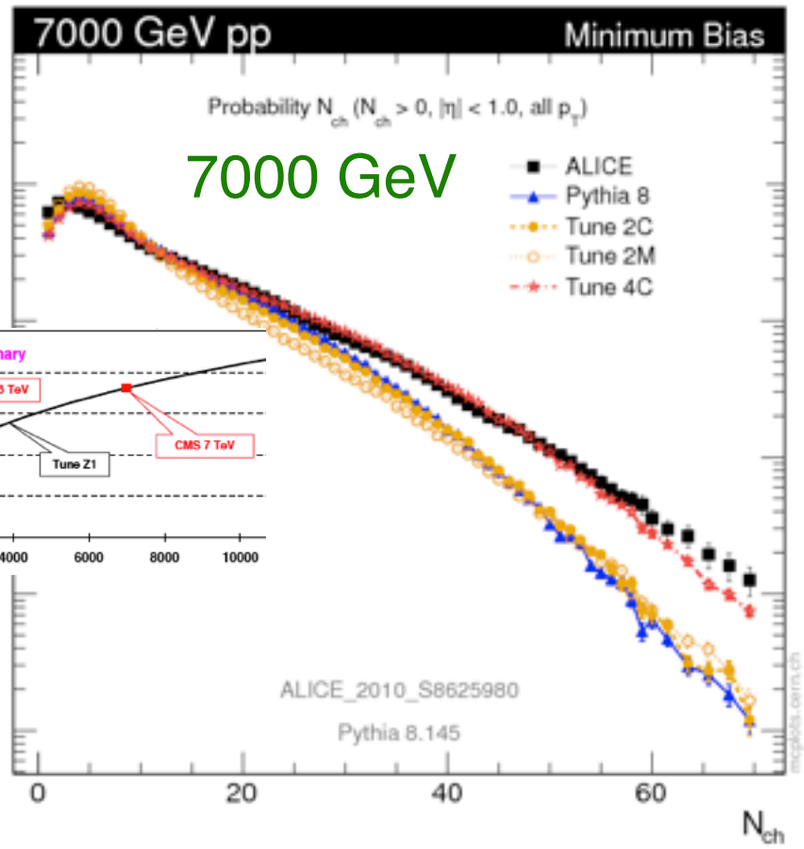
Tunes of PYTHIA 8

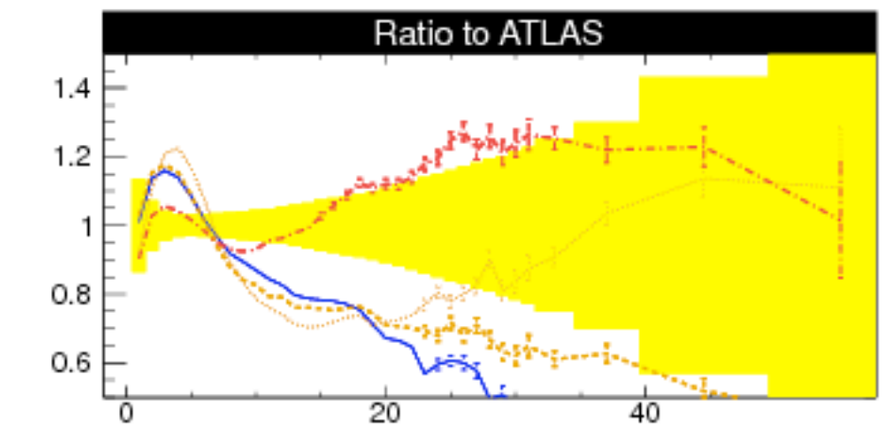
Tuning PYTHIA 8 and 4C, see:
Corke, Sjöstrand, arXiv:1011.1759

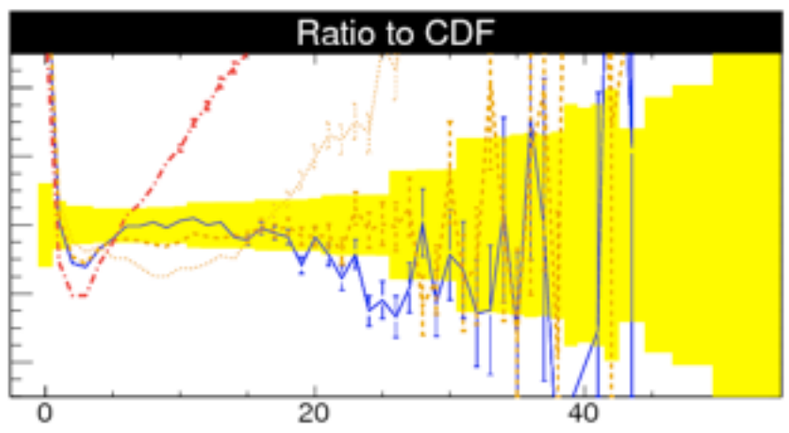
Hadron Collisions: can*not* use PYTHIA 6 tunes (e.g., not "Perugia", Z1, etc). Need PYTHIA 8 ones. Tension between Tevatron and LHC?

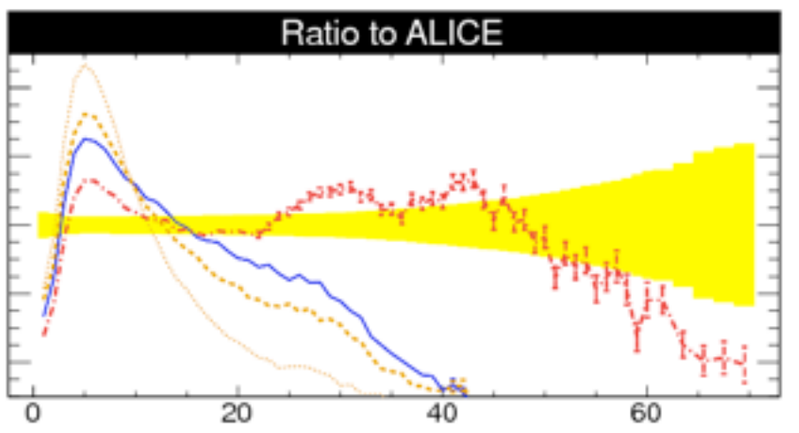












(Plots from mcplots.cern.ch)

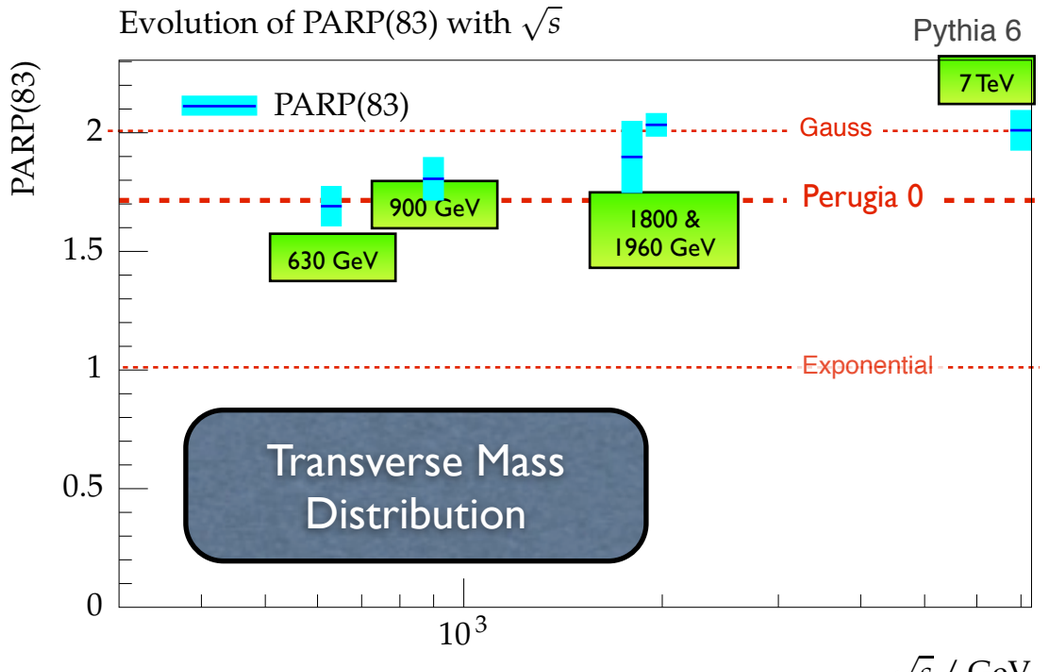
Tuning vs Testing Models

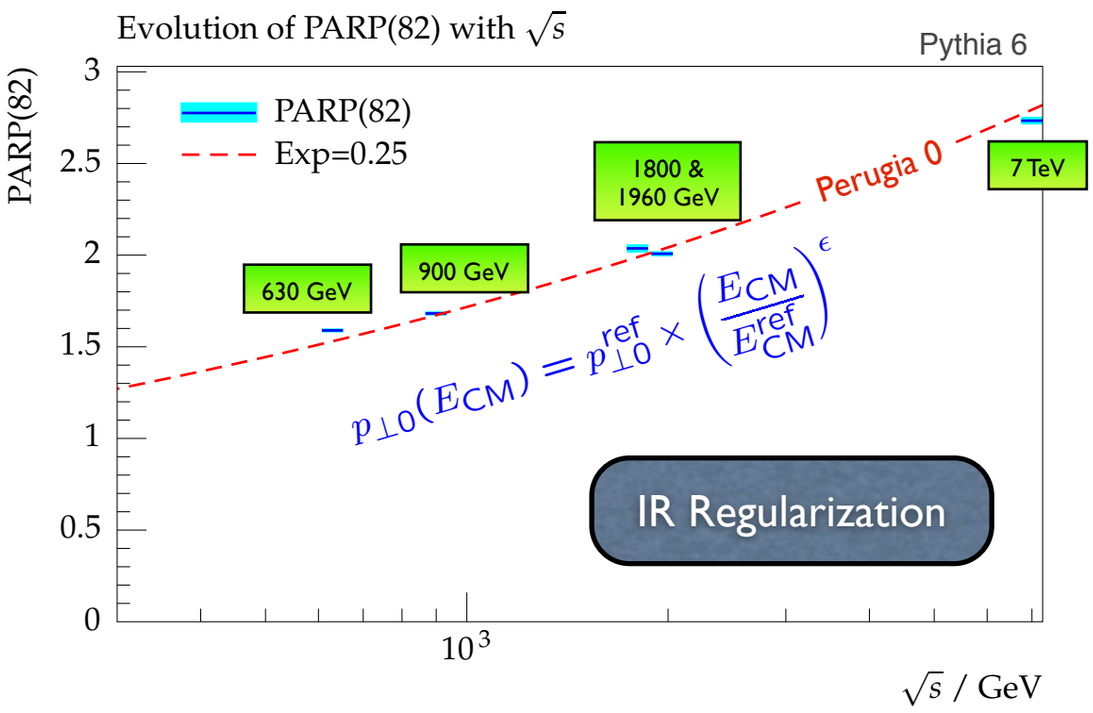
TEST models

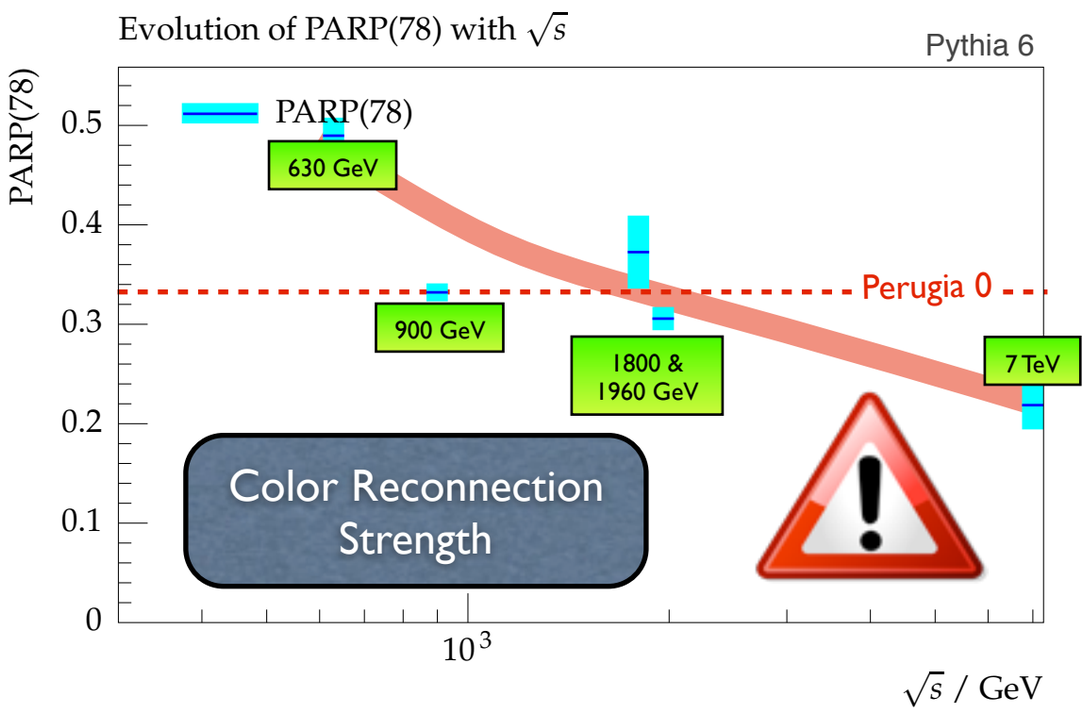
Tune parameters in several complementary regions

Consistent model → same parameters

Model breakdown → non-universal parameters







"Energy Scaling of MB Tunes", H. Schulz + PS, in preparation

Nota Bene

Crucial Task for run at 2.8 TeV

Make systematic studies to map/ resolve Tevatron/LHC tension

Measure regions that interpolate between Tevatron and LHC
E.g., start from same phase-space region as CDF
$|\eta| < 1.0 \quad pT > 0.4$ GeV

Diffraction

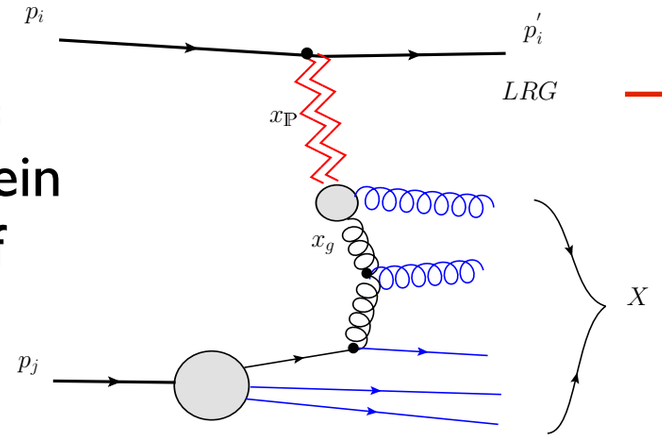
Diffractive Cross Section Formulæ:

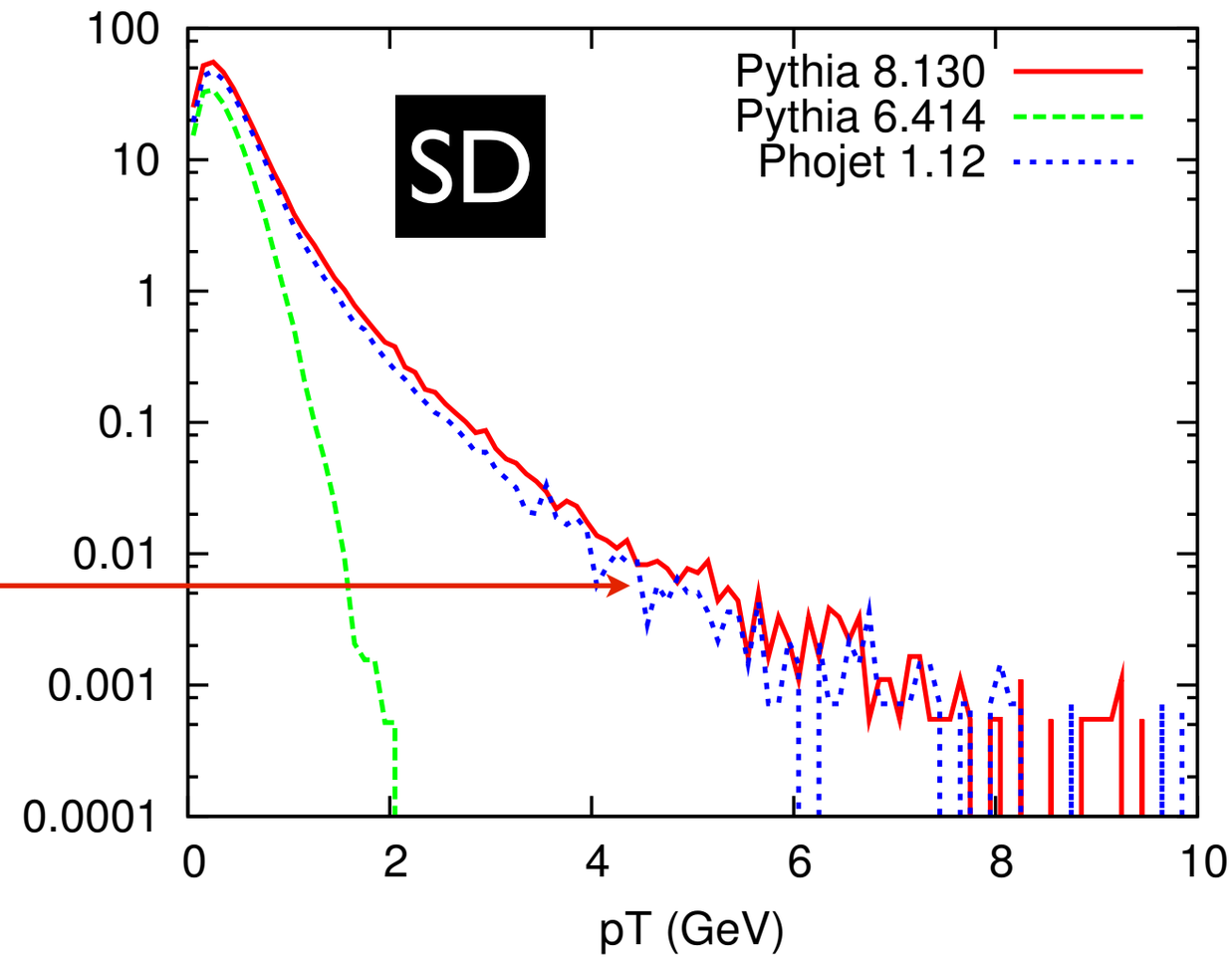
$$\frac{\mathrm{d}\sigma_{\mathrm{sd}(AX)}(s)}{\mathrm{d}t\,\mathrm{d}M^2} = \frac{g_{3\mathbb{P}}}{16\pi}\,\beta^2_{A\mathbb{P}}\,\beta_{B\mathbb{P}}\,\frac{1}{M^2}\,\exp(B_{\mathrm{sd}(AX)}t)\,F_{\mathrm{sd}}\ ,$$

$$\frac{\mathrm{d}\sigma_{\mathrm{dd}}(s)}{\mathrm{d}t\,\mathrm{d}M_1^2\,\mathrm{d}M_2^2} = \frac{g^2_{3\mathbb{P}}}{16\pi}\,\beta_{A\mathbb{P}}\,\beta_{B\mathbb{P}}\,\frac{1}{M_1^2}\,\frac{1}{M_2^2}\,\exp(B_{\mathrm{dd}}t)\,F_{\mathrm{dd}}\ .$$

Partonic Substructure in Pomeron:

Follows the Ingelman-Schlein approach of Pompyt





- $M_X \leq 10\,\mathrm{GeV}$: original longitudinal string description used
- $M_X > 10\,\mathrm{GeV}$: new perturbative description used (incl full MPI+showers for **P**p system)

PYTHIA 8

Choice between 5 Pomeron PDFs. Free parameter $\sigma_{\mathbb{P}\mathrm{p}}$ needed to fix $\langle n_{\mathrm{interactions}}\rangle = \sigma_{\mathrm{jet}}/\sigma_{\mathbb{P}\mathrm{p}}$.

Framework needs testing and tuning, e.g. of $\sigma_{\mathbb{P}\mathrm{p}}$. Navin, arXiv:1005.3894

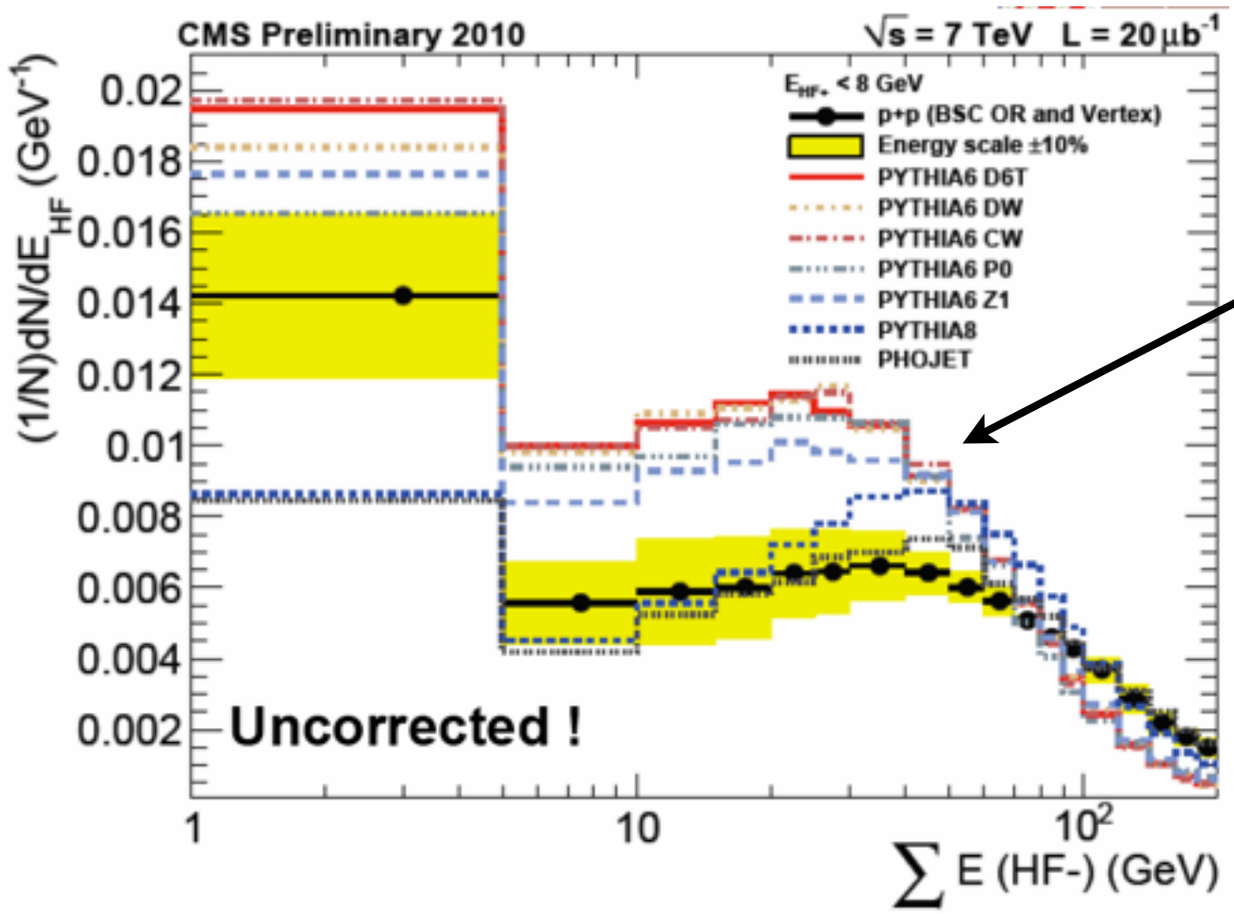
Diffraction

Framework needs testing and tuning

E.g., interplay between non-diffractive and diffractive components

+ LEP tuning used directly for diffractive modeling

Hadronization preceded by shower at LEP, but not in diffraction → dedicated diffraction tuning of fragmentation pars?



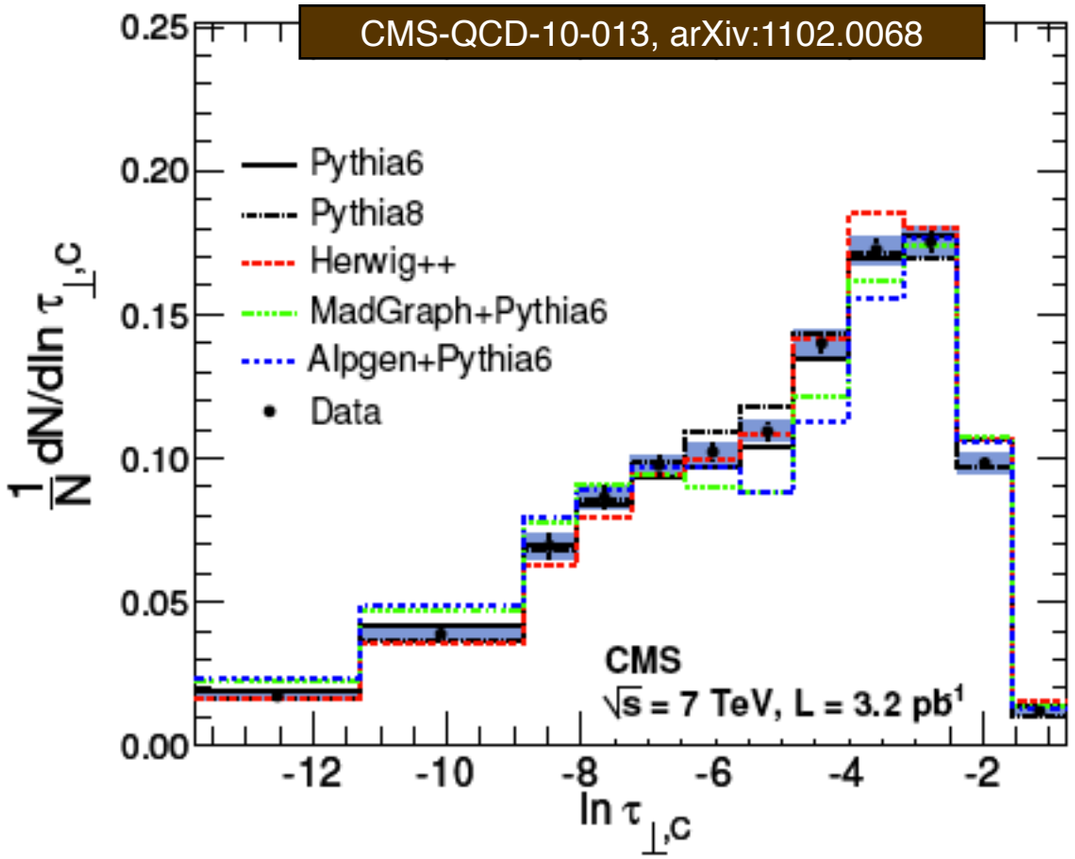
Study this hump

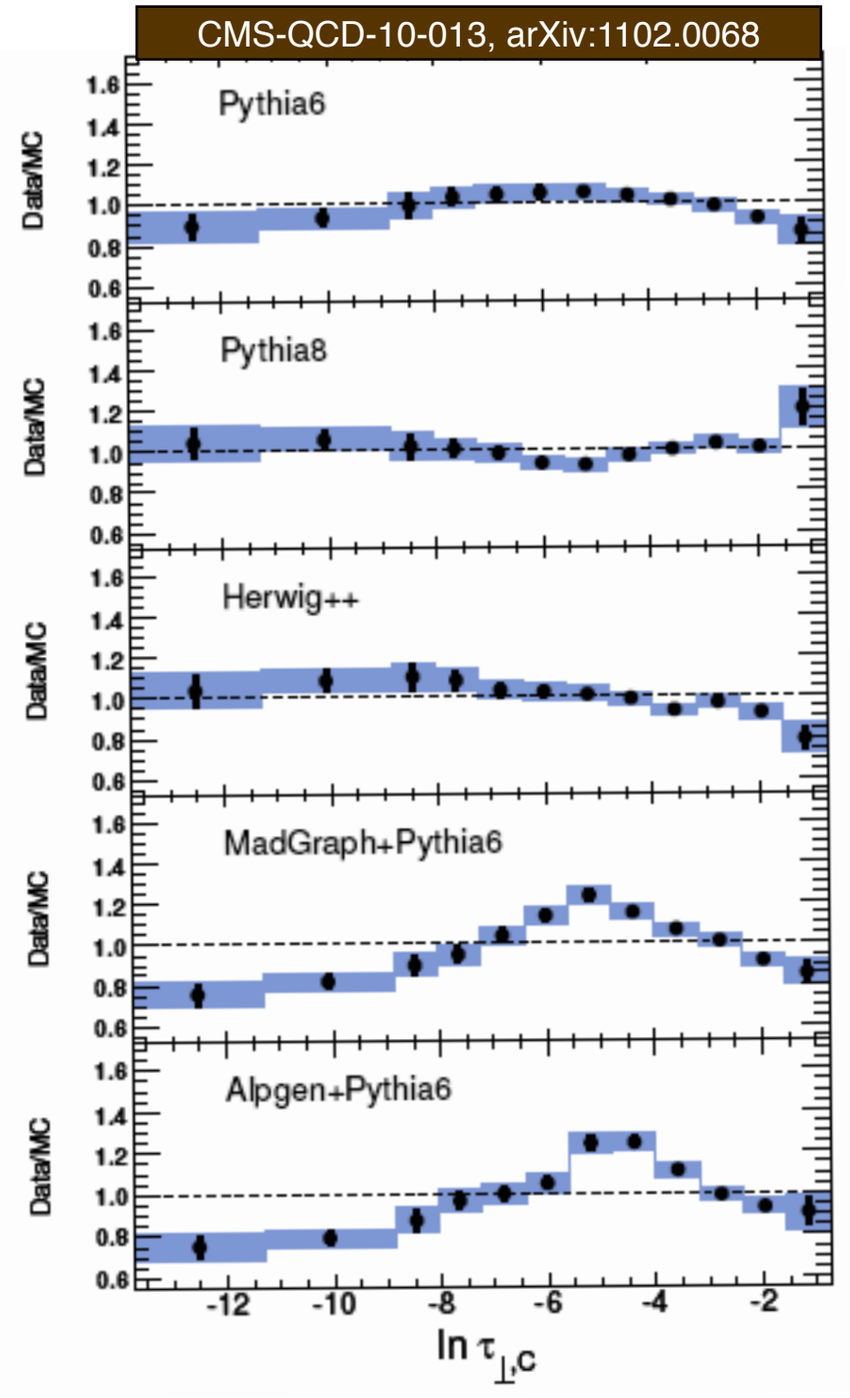
+ Room for new models,
e.g., KMR (SHERPA)
Others?

Event Shapes

PS,K.Wraight, arXiv:1101.5215

CMS: Transverse Thrust





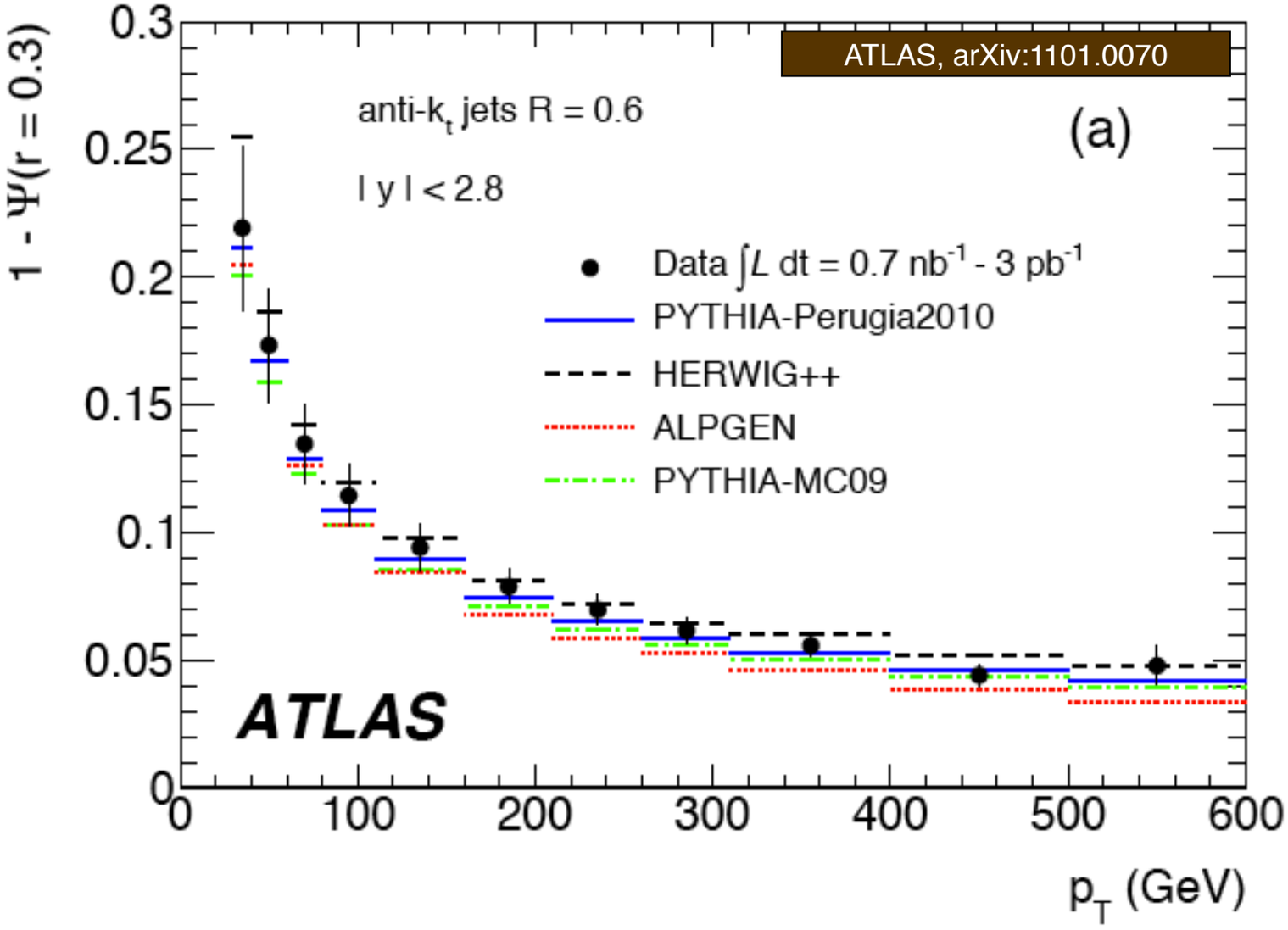
Matched codes exhibit interesting features *away* from the data.

- Inconsistent Matching?
- Inconsistent to tune without matching?
- Highlights need to better understand interplay of tuning and matching

Jet Shapes

Jet shapes ~ shower shapes

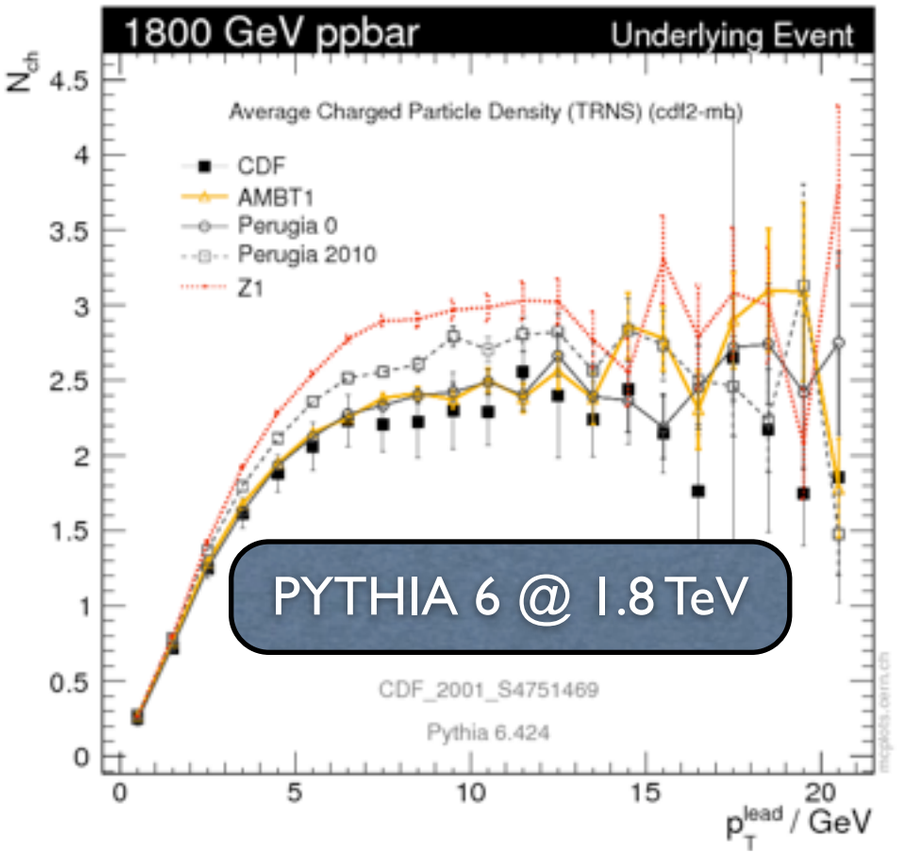
"Perugia 2010" : used (approximate) CDF jet shape measurements



Underlying Event

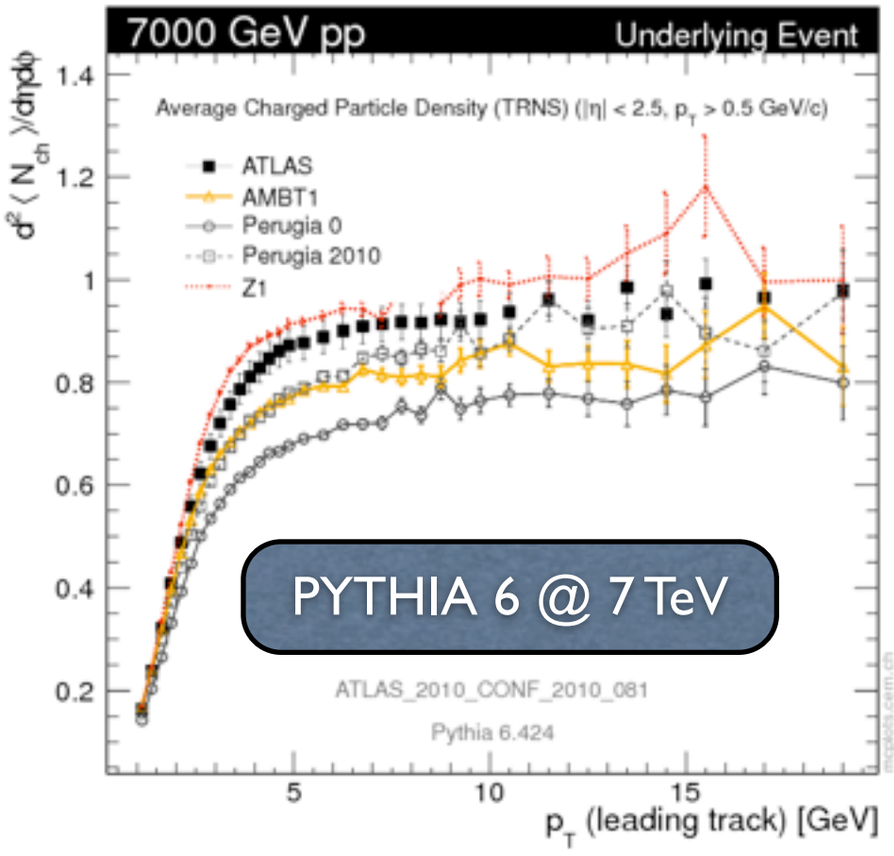
Compromise between Tevatron and LHC?

"Perugia 2010" : Larger UE at Tevatron → better at LHC



PYTHIA 6
Recommended:
Perugia 2010
(or dedicated LHC tunes AMBT1, Z1)

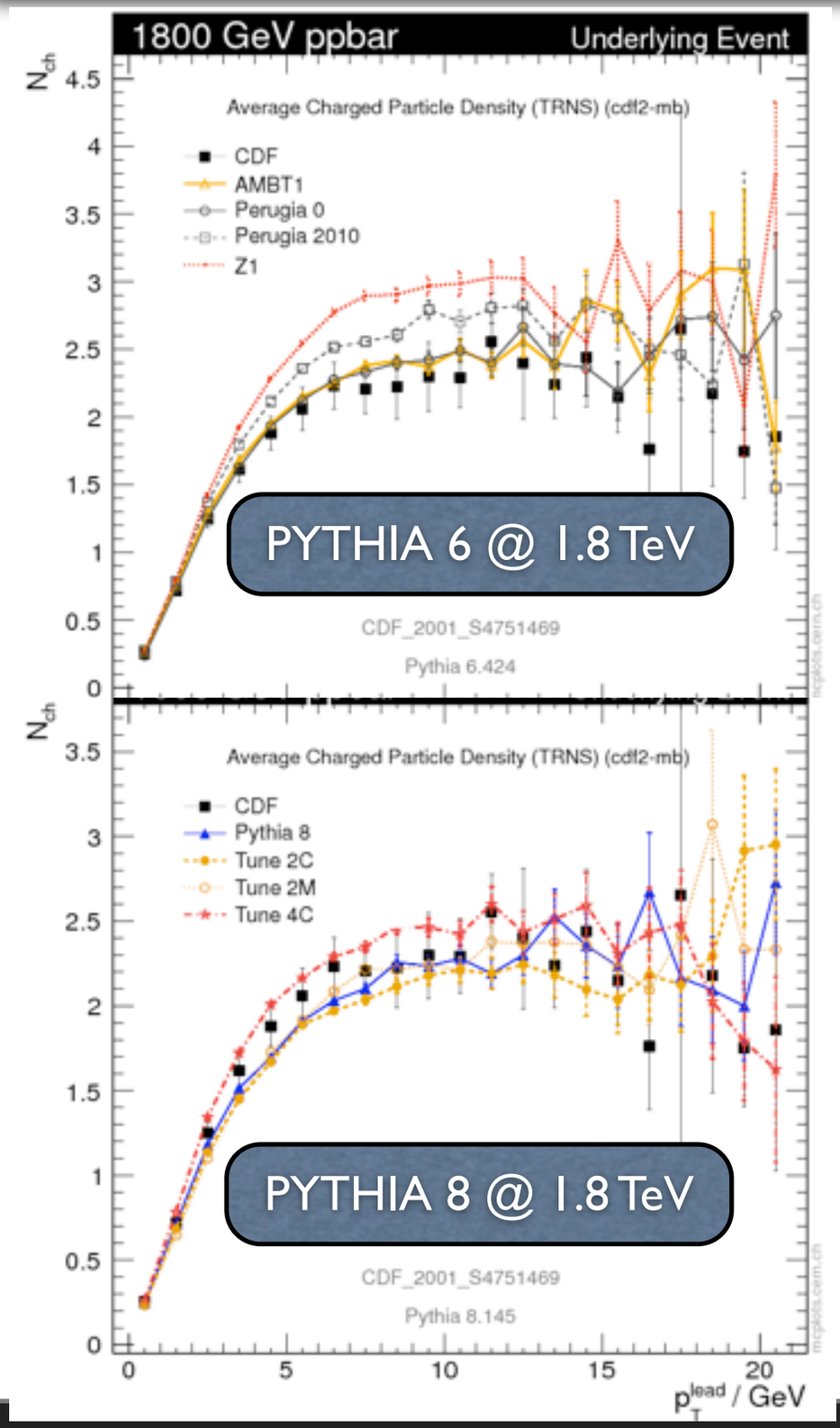
For more on tuning PYTHIA 6, see
PS, arXiv:1005.3457



(next iteration: fusion between Perugia 2010 and AMBT1, Z1?)

(Plots from mcplots.cern.ch)

Underlying Event



PYTHIA 6 @ 1.8 TeV

PYTHIA 8 @ 1.8 TeV

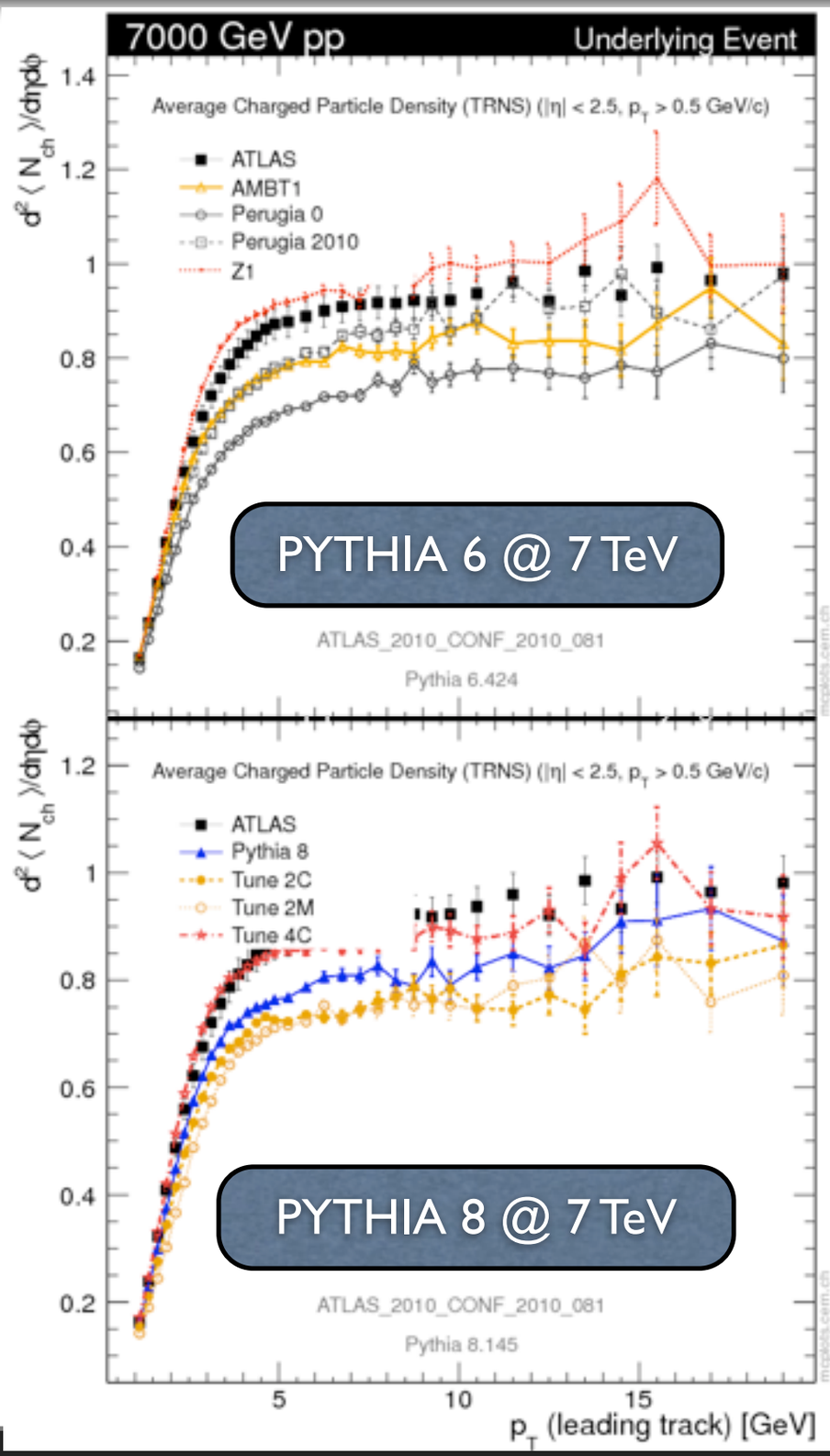
PYTHIA 6
Recommended:
Perugia 2010
(or dedicated LHC tunes AMBT1, Z1)

For more on tuning PYTHIA 6, see
PS, arXiv:1005.3457

PYTHIA 8
Recommended:
Tune 4C
(probably default from next version)

(Also has damped diffraction
following ATLAS-CONF-2010-048)

For more on tuning PYTHIA 8, see
Corke, Sjostrand, arXiv:1011.1759



PYTHIA 6 @ 7 TeV

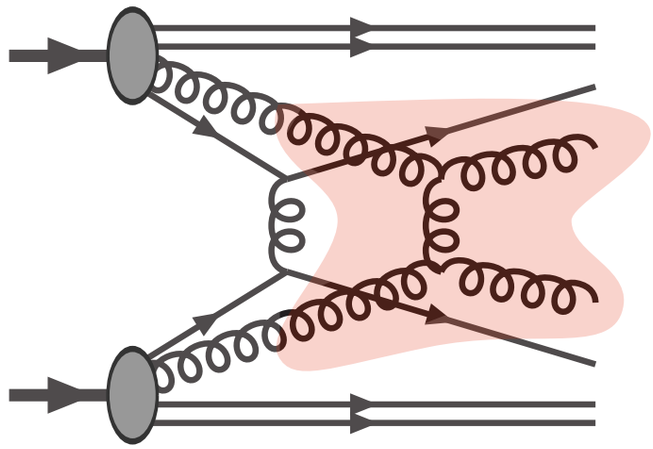
PYTHIA 8 @ 7 TeV

(Plots from mcplots.cern.ch)

New Developments in PYTHIA 8

Can choose 2nd MPI scattering

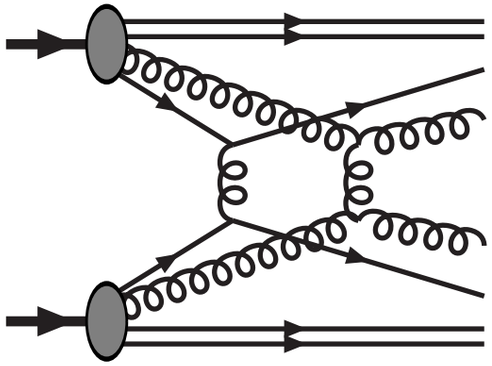
- TwoJets (with TwoBJets as subsample)
- PhotonAndJet, TwoPhotons
- Charmonium, Bottomonium (colour octet framework)
- SingleGmZ, SingleW, GmZAndJet, WAndJet
- TopPair, SingleTop



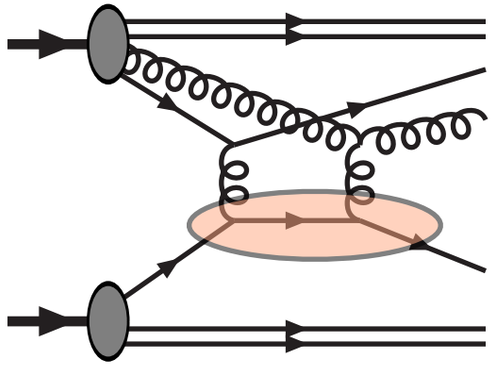
See the PYTHIA 8 online documentation, under "A Second Hard Process"

Rescattering

Often assume that MPI =



. . . but should also include



An explicit model available in PYTHIA 8

Same order in α_S, $\sim$ same propagators, but
- one PDF weight less $\Rightarrow$ smaller σ

Corke, Sjöstrand, JHEP 01(2010)035

X-Dependent Proton Size

Default in PYTHIA (and all other MC*)

*: except DIPSY

Factorization of longitudinal and transverse degrees of freedom

$$f(x,b) = f(x) \times g(b)$$

OK for inclusive measurements, but:

Physics: *Shape = delta function at 0 for $x \to 1$*

Can also be seen in lattice studies at high x

Gribov theory: *high s ↔ low x ⇒ Growth of total cross section ↔ size grows ∝ ln(1/x)*

BFKL "intuition": "random walk" in x from few high-x partons at small b diffuse to larger b at smaller x (More formal: Balitsky/JIMWLK and Color Glass Condensates)

A Model for Phenomenological Studies

Corke, Sjöstrand, arXiv:1101.5953

Basic assumption: Mass distribution = Gaussian. Make width x-dependent

$$\rho(r,x) \propto \frac{1}{a^3(x)} \exp\left(-\frac{r^2}{a^2(x)}\right) \qquad a(x) = a_0\left(1 + a_1 \ln\frac{1}{x}\right)$$

Constrain by requiring a_1 responsible for growth of cross section

Summary

PYTHIA6 is winding down

Supported but not developed

Still main option for current run (sigh)

But not after long shutdown 2013!

Recommended for PYTHIA 6:
Global: "Perugia 2010" (MSTP(5)=327)
+ LHC MB: "AMBT1" (MSTP(5)=340)
+ LHC UE "Z1" (MSTP(5)=341)

PYTHIA8 is the natural successor

Already several improvements over PYTHIA6 on soft physics

(including modern range of PDFs (CTEQ6, LO*, etc) in standalone version)

Though still a few things not yet carried over (such as *ep*, some SUSY, etc)

If you want new features (e.g., x-dependent proton size, rescattering, ψ', MadGraph-5 and VINCIA interfaces, …) then be prepared to use PYTHIA8

Provide Feedback, both what works and what does not

Do your own tunes to data and tell outcome

There is no way back!

Recommended for PYTHIA 8:
"Tune 4C" (Tune:pp = 5)

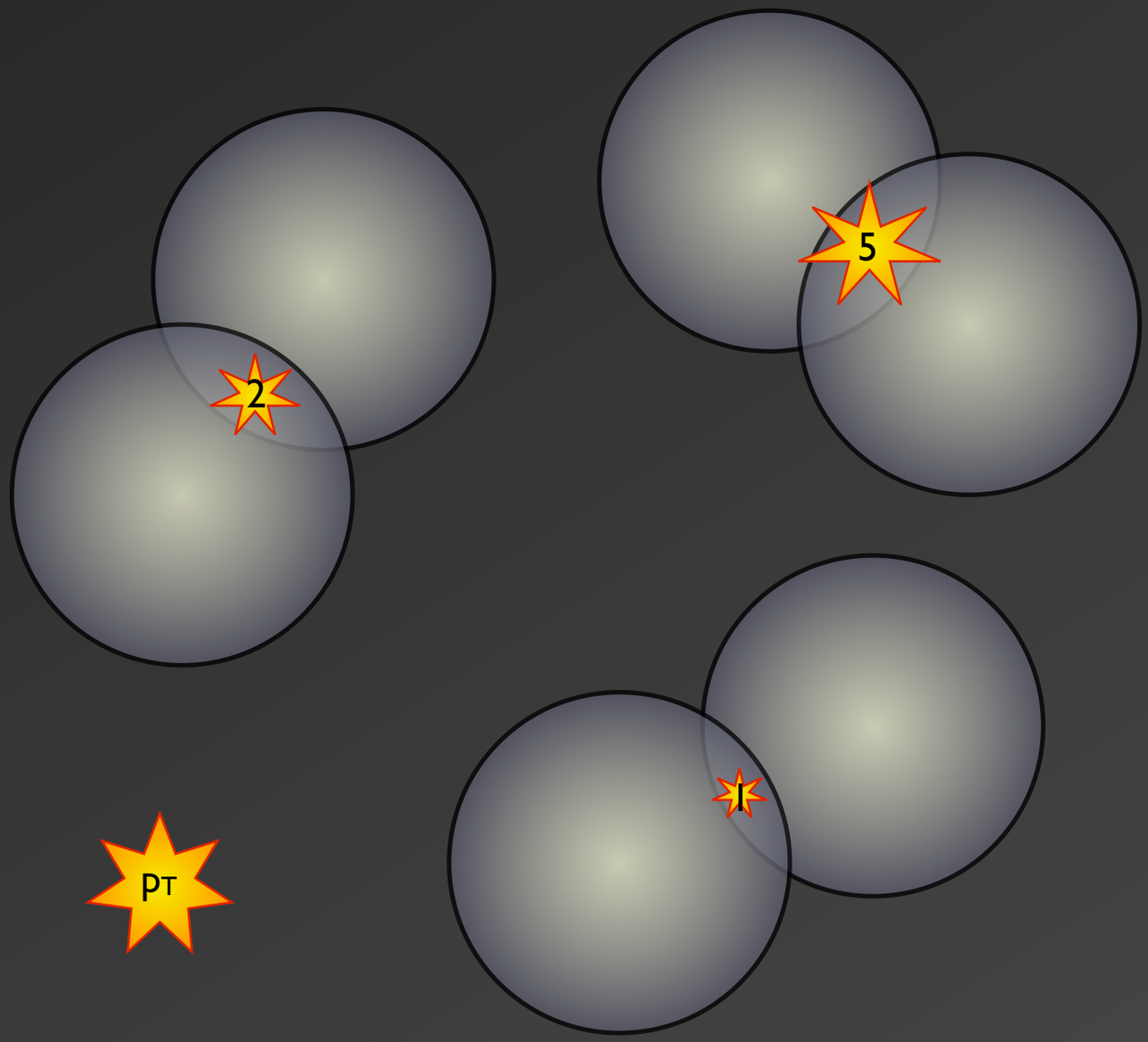
Additional Slides

Diffraction, Identified Particles, Baryon Transport, Tunes

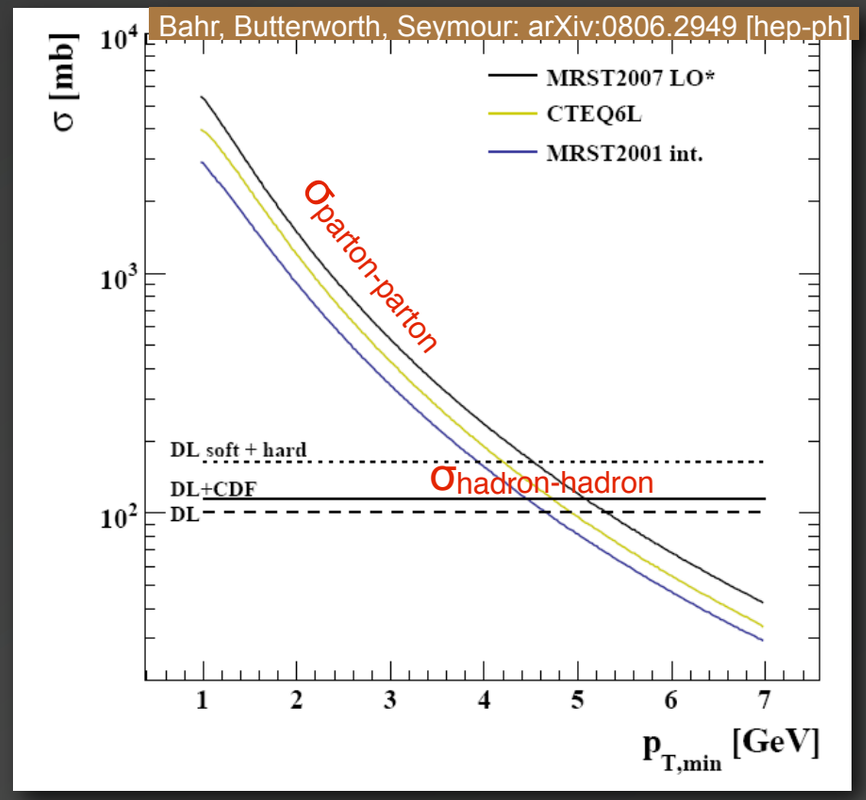
The Pedestal Effect

and Multiple Parton-Parton Interactions

MINIMUM BIAS



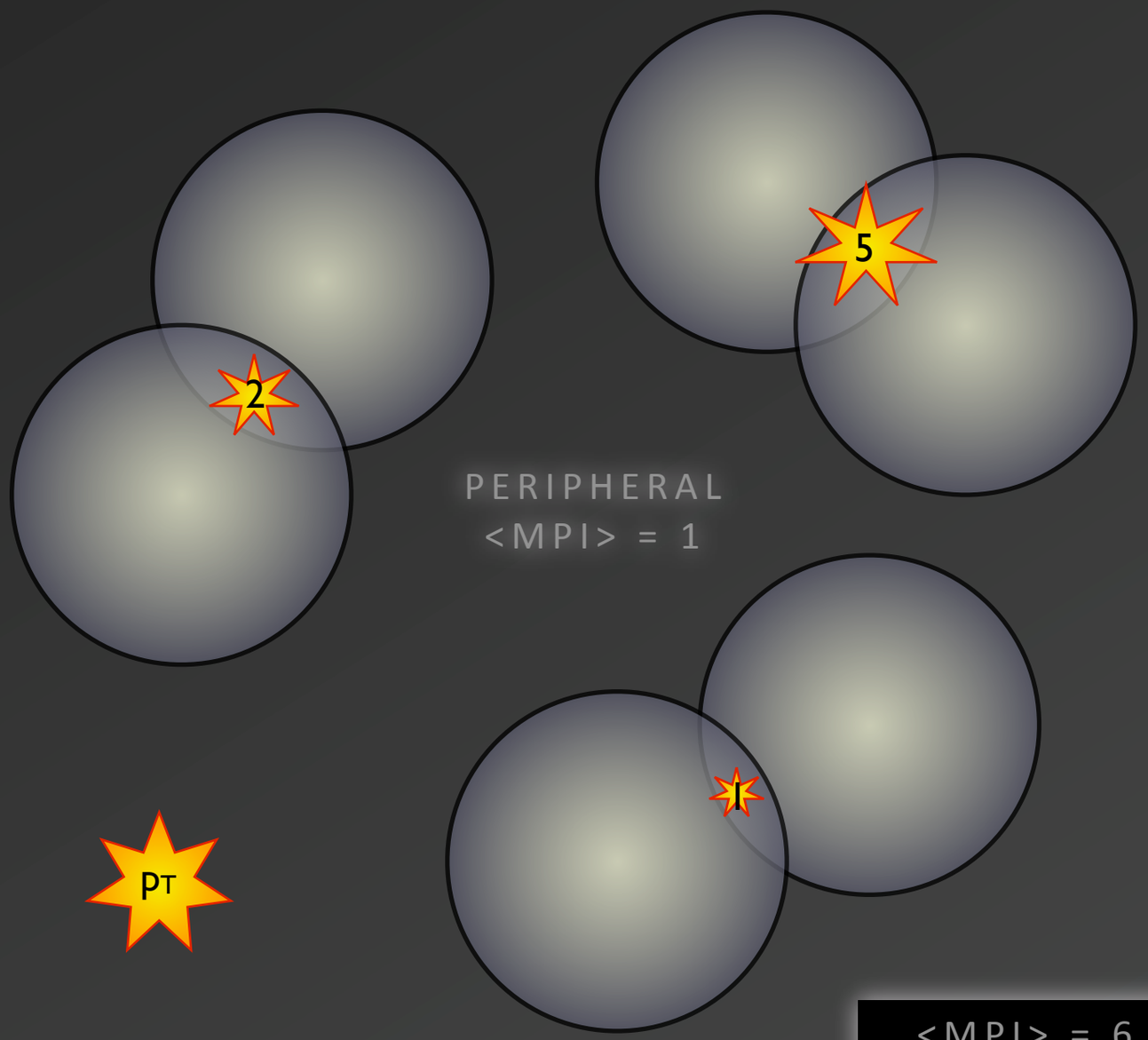
$\sigma_{parton\text{-}parton} > \sigma_{hadron\text{-}hadron}$



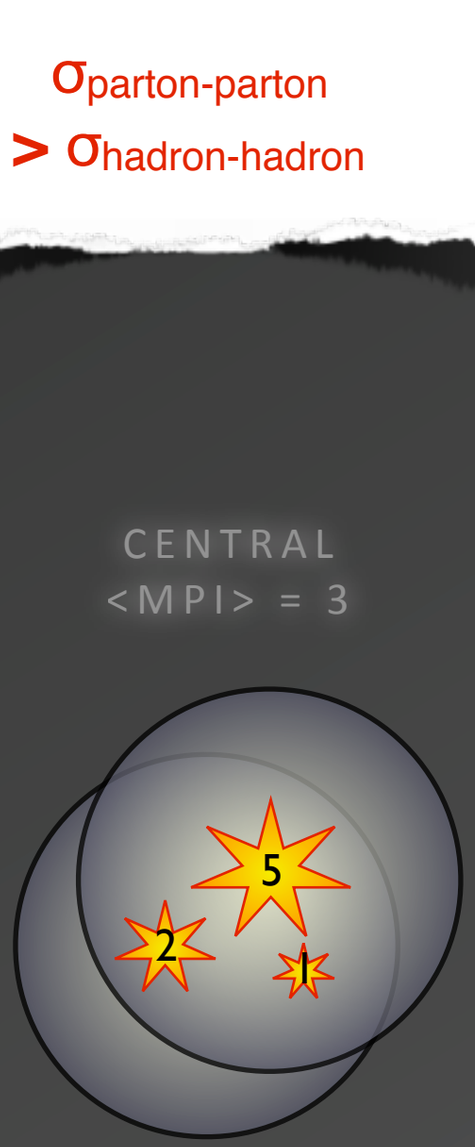
The Pedestal Effect

and Multiple Parton-Parton Interactions

MINIMUM BIAS



+



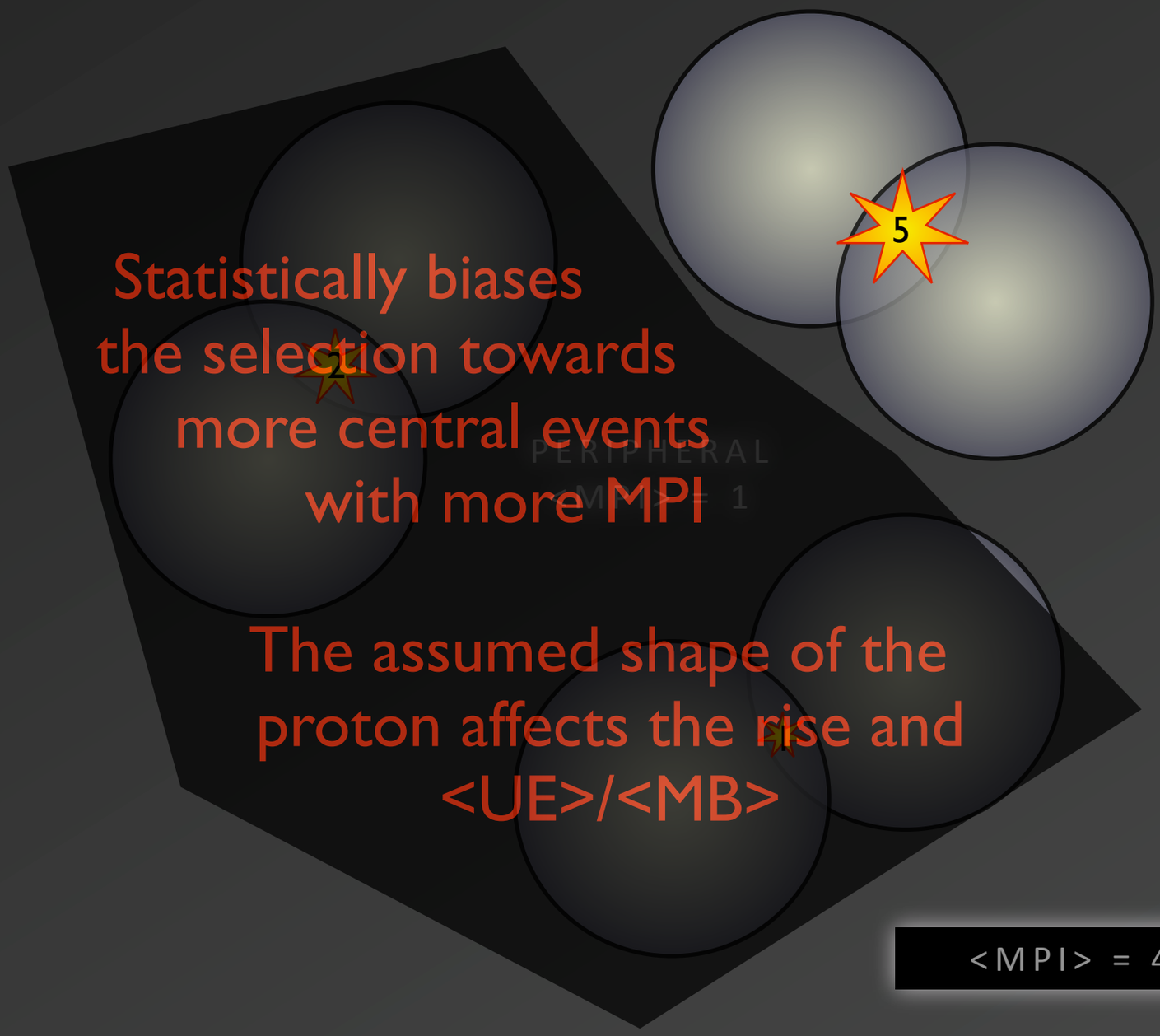
$\sigma_{parton\text{-}parton} > \sigma_{hadron\text{-}hadron}$

<MPI> = 6 / 4 = 1.5

The Pedestal Effect

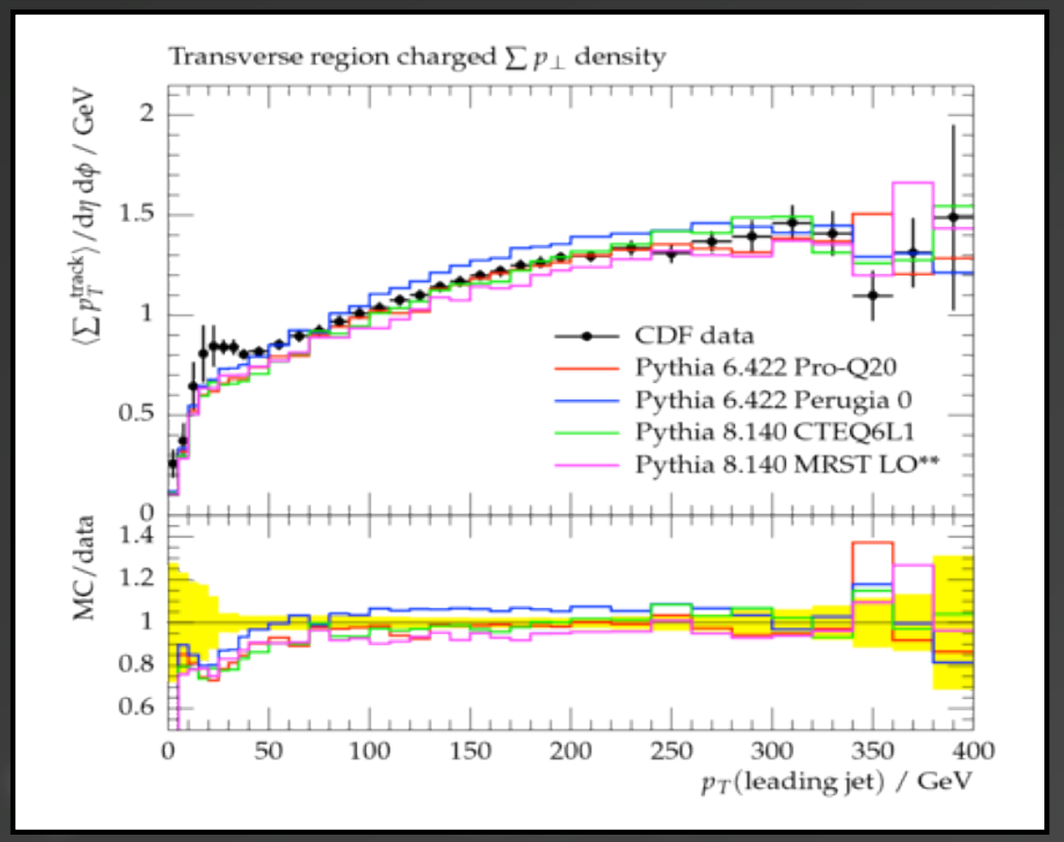
and Multiple Parton-Parton Interactions

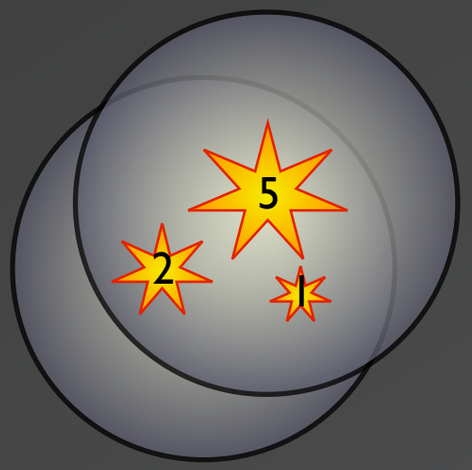
JET > 5 GeV



Statistically biases the selection towards more central events with more MPI

The assumed shape of the proton affects the rise and <UE>/<MB>

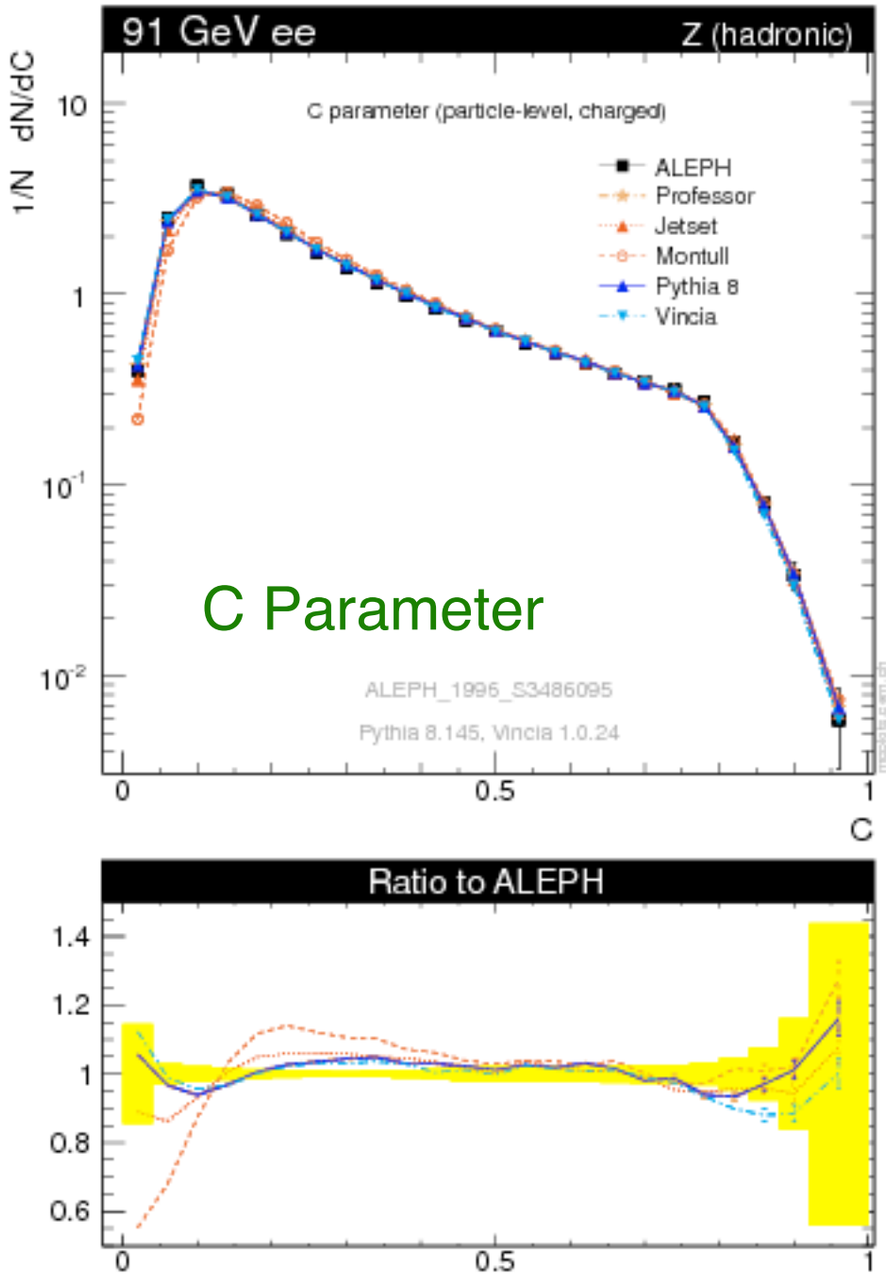


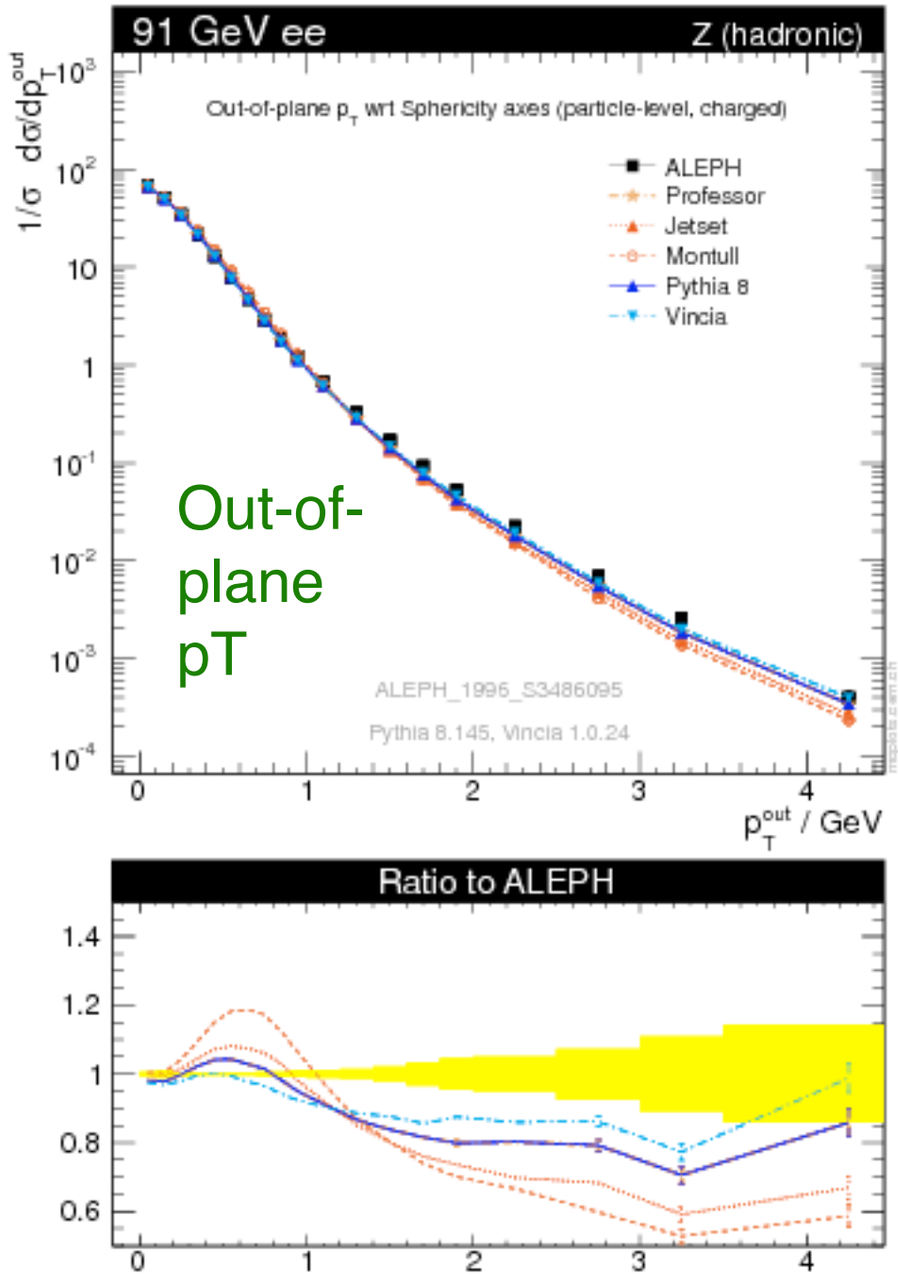


<MPI> = 4 / 2 = 2

Tuning of PYTHIA 8

Tuning to e+e- closely related to p⊥-ordered PYTHIA 6.4. A few iterations already. First tuning by Professor (Hoeth) → FSR ok?

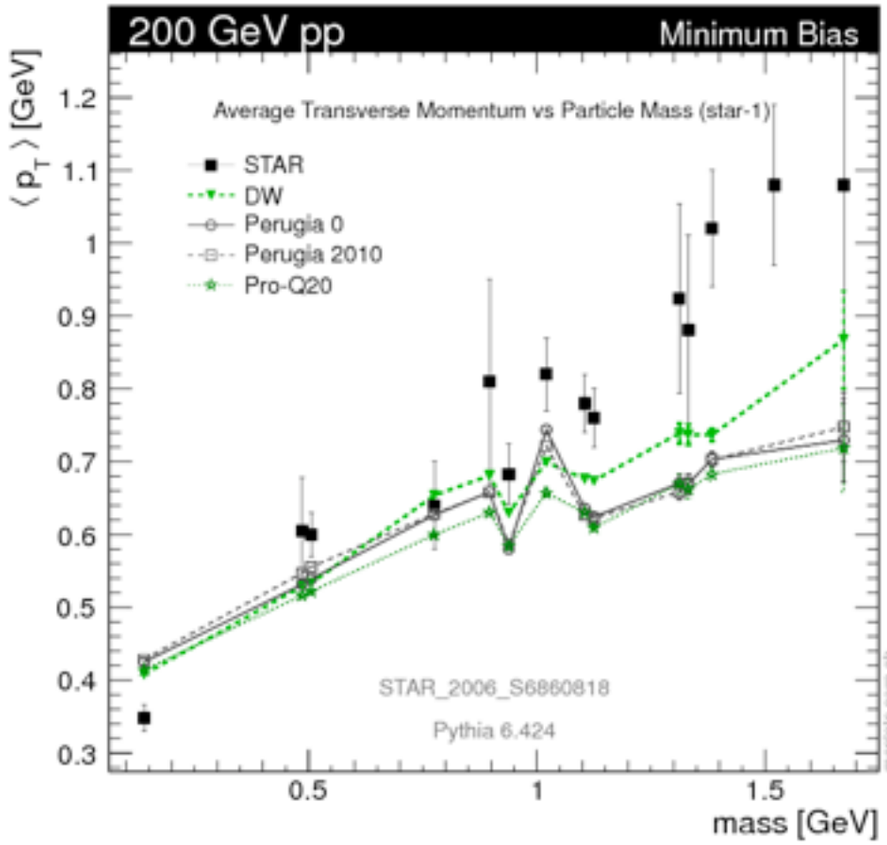


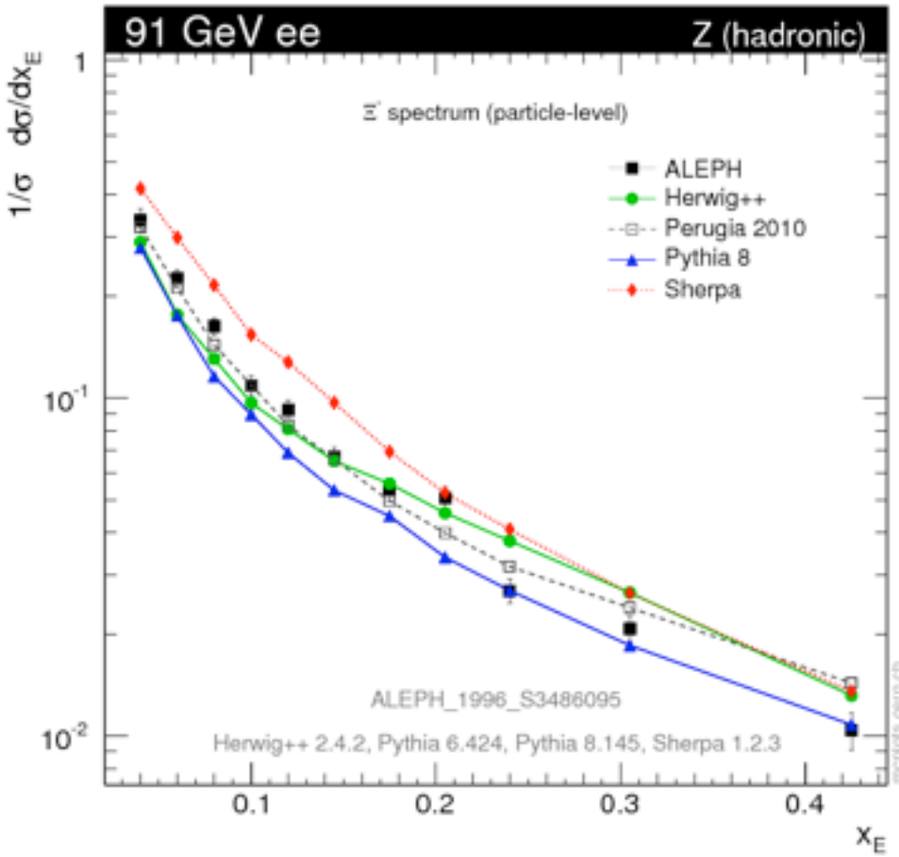


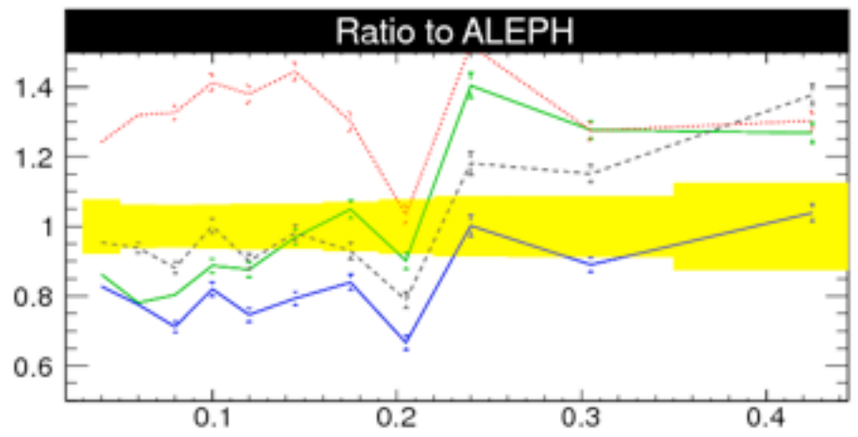
(Plots from mcplots.cern.ch)

(Identified Particles)

Interesting discrepancies in strange sector







+ problems with Λ/K and *s* spectra also at LEP?

Grows worse (?) for multi-strange baryons

Flood of LHC data now coming in!

Interesting to do systematic LHC vs LEP studies

PYTHIA 8 Tune Parameters

Parameter	Tune 2C	Tune 2M	Tune 4C
SigmaProcess:alphaSvalue	0.135	0.1265	0.135
SpaceShower:rapidityOrder	on	on	on
SpaceShower:alphaSvalue	0.137	0.130	0.137
SpaceShower:pT0Ref	2.0	2.0	2.0
MultipleInteractions:alphaSvalue	0.135	0.127	0.135
MultipleInteractions:pT0Ref	2.320	2.455	2.085
MultipleInteractions:ecmPow	0.21	0.26	0.19
MultipleInteractions:bProfile	3	3	3
MultipleInteractions:expPow	1.60	1.15	2.00
BeamRemnants:reconnectRange	3.0	3.0	1.5
SigmaDiffractive:dampen	off	off	on
SigmaDiffractive:maxXB	N/A	N/A	65
SigmaDiffractive:maxAX	N/A	N/A	65
SigmaDiffractive:maxXX	N/A	N/A	65

R. Corke & TS, arXiv:1011.1759 [hep-ph]

Strangeness Tunable Paramters

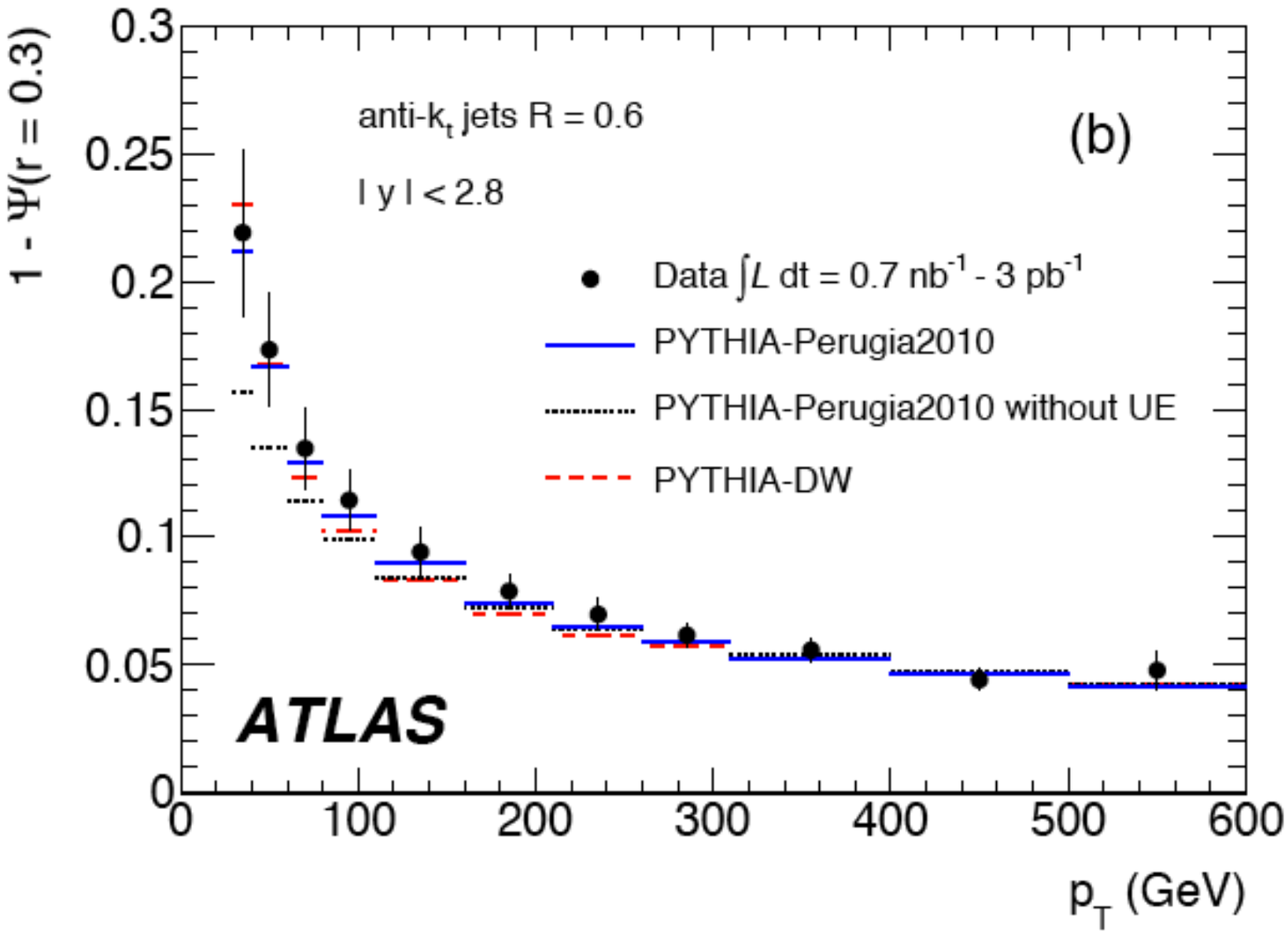
Flavor Sector
(These do not affect pT spectra, apart from via feed-down)

	Main Quantity	**PYTHIA 6**	**PYTHIA 8**
s/u	K/π	PARJ(2)	StringFlav:probStoUD
Baryon/Meson	p/π	PARJ(1)	StringFlav:probQQtoQ
Additional Strange Baryon Suppr.	Λ/p	PARJ(3)	StringFlav:probSQtoQQ
Baryon-3/2 / Baryon-1/2	Δ/p, …	PARJ(4) , PARJ(18)	StringFlav:probQQ1toQQ0 StringFlav:decupletSup
Vector/Scalar (non-strange)	\rho/π	PARJ(11)	StringFlav:mesonUDvector
Vector/Scalar (strange)	K^*/K	PARJ(12)	StringFlav:mesonSvector

Note: both programs have options for c and b, for special baryon production (leading and “popcorn”) and for higher excited mesons. PYTHIA 8 more flexible than PYTHIA 6. Big uncertainties, see documentation.

For pT spectra, main parameters are **shower** folded with: **longitudinal and transverse fragmentation function** (Lund *a* and *b* parameters and p_T broadening (PARJ(41,42,21)), with possibility for larger *a* for Baryons in PYTHIA 8, see “Fragmentation” in online docs).

UE Contribution to Jet Shapes



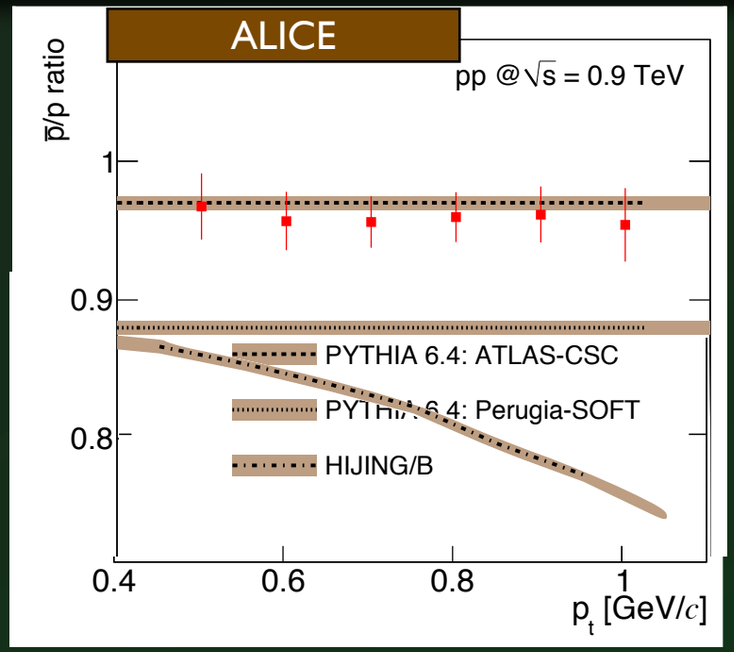
Baryon Transport

LESS than Perugia-SOFT

(at least for protons, in central region)

But MORE than Perugia-0

(at least for Lambdas, in forward region)



cf. J. Fiete's talk