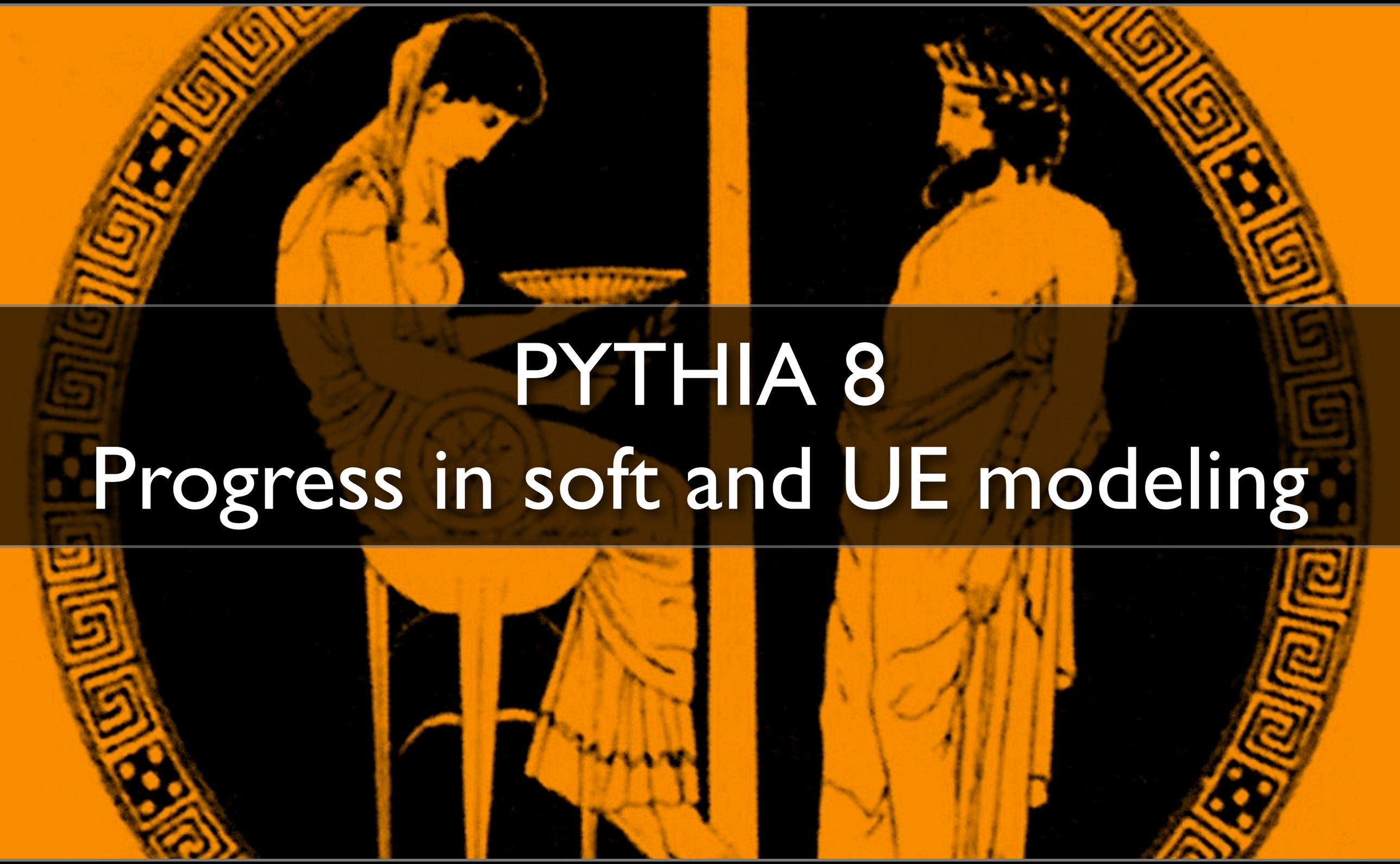


PYTHIA 8

Progress in soft and UE modeling

Peter Skands (CERN)

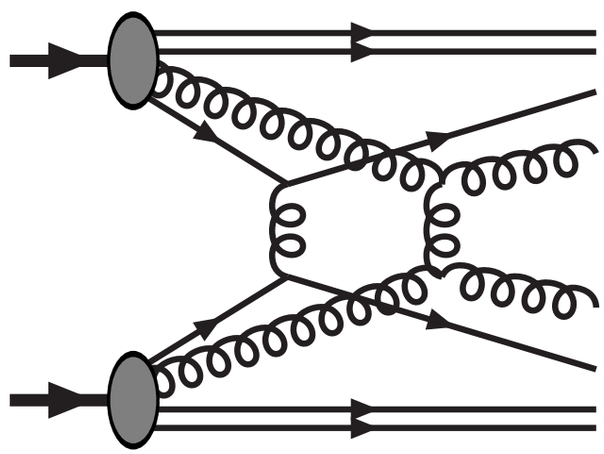
Multiple Parton Interactions

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

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

with energy dependence

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



Matter profile in impact-parameter space gives time-integrated overlap which determines level of activity: simple Gaussian or more peaked variants

ISR and MPI compete for beam momentum → PDF rescaling + flavour effects (valence, qq pair companions, . . .) + correlated primordial $k_\perp$ and colour in beam remnant

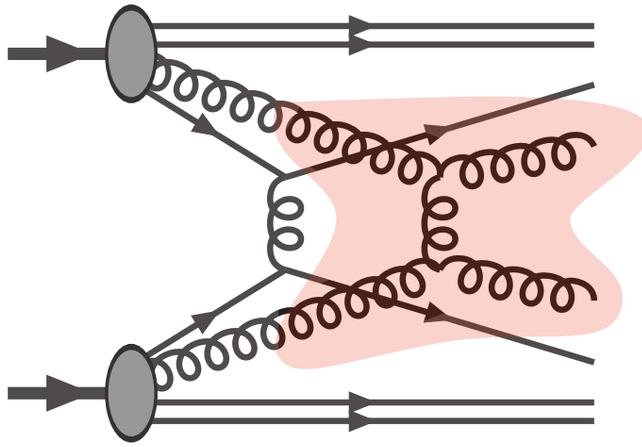
Many partons produced close in space–time

⇒ *colour rearrangement; reduction of total string length ⇒ steeper* $\langle p_\perp \rangle (n_{ch})$

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

A Second Hard Interaction

Multiple interactions key aspect
of PYTHIA since $>$ 20 years.
Central to obtain agreement with data:
Tune A, Professor, Perugia, . . .



Before 8.1: could not <u>select</u> character of 2nd interaction

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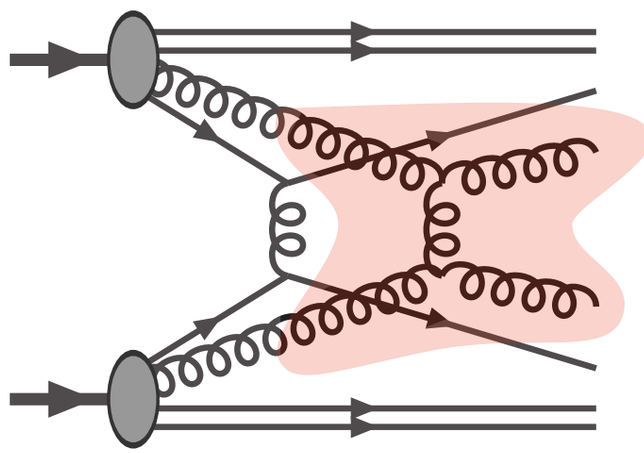

Before 8.1: could not <u>select</u> character of 2nd interaction

Now free choice of first process (including LHA/LHEF) *and* second process combined from list:

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

Can be expanded among existing processes as need arises.

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

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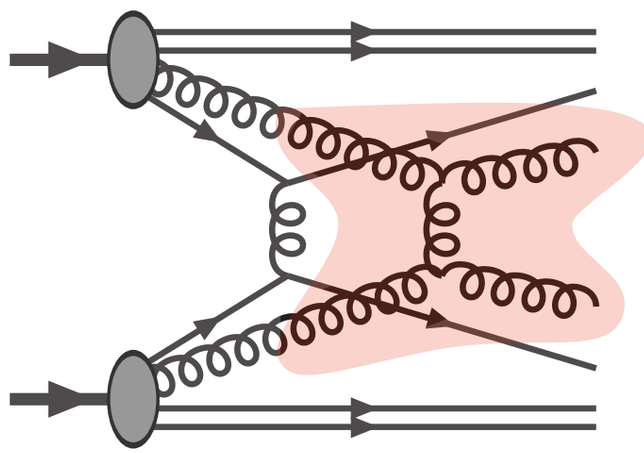

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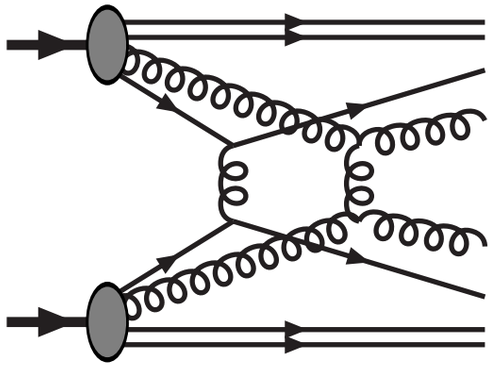
See the PYTHIA 8 online documentation, under "A Second Hard Process"

Can be expanded among existing processes as need arises.

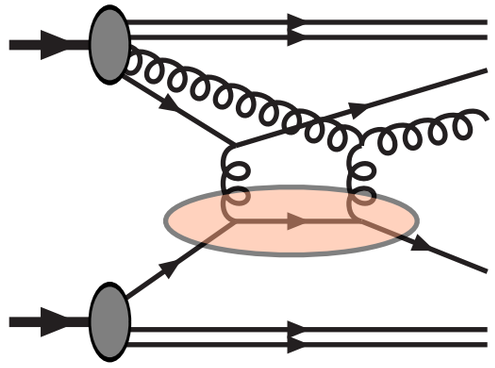
By default same phase space cuts as for "first" hard process ⇒ second can be harder than first.
However, possible to set $\widehat{m}$ and $\widehat{p_\perp}$ range separately.

Rescattering

Often assume that MPI =



. . . but should also include



Same order in α_S, $\sim$ same propagators, but

- one PDF weight less $\Rightarrow$ smaller σ
- one jet less $\Rightarrow$ QCD radiation background $2 \to 3$ larger than $2 \to 4$

$\Rightarrow$ will be tough to find direct evidence.

Rescattering grows with number of "previous" scatterings:

	Tevatron		LHC	
	Min Bias	QCD Jets	Min Bias	QCD Jets
Normal scattering	2.81	5.09	5.19	12.19
Single rescatterings	0.41	1.32	1.03	4.10
Double rescatterings	0.01	0.04	0.03	0.15

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)

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A Model for Phenomenological Studies

Corke, Sjöstrand, arXiv:1101.5953

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

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

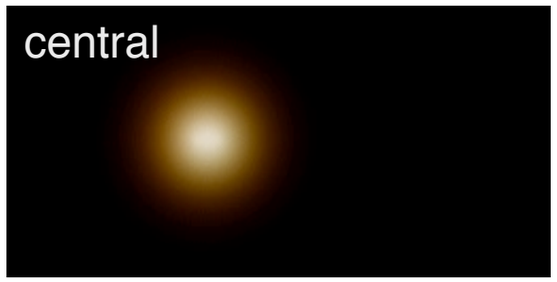
Constrain by requiring a_1 responsible for growth of cross section

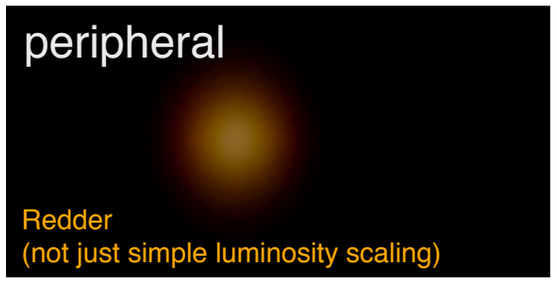
X-Dependent Proton Size

Initial study + tuning in arXiv:1101.5953

At least as good MB/UE fits as old model (based on "Tune 4C")

Details will be different!





E.g.,

"Homogenous" model: can have (rare) high-*x* scattering at large *b*:

⇒ *There should be a tail of dijets/DY/… with essentially "no" UE*

E.g., ATLAS "RMS" distributions, and/or take UE/MB density ratios

"X-Dependent" model: high-*x* scatterings only at small *b*:

⇒ *Enhanced pedestal effect? (increased selection bias)*

(needs to be interpreted with care, due to effects of (re)tuning …)

Model available from next PYTHIA 8 version, ready for playing with …

Diffraction in PYTHIA 6

Diffractive Cross Section Formulæ:

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

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

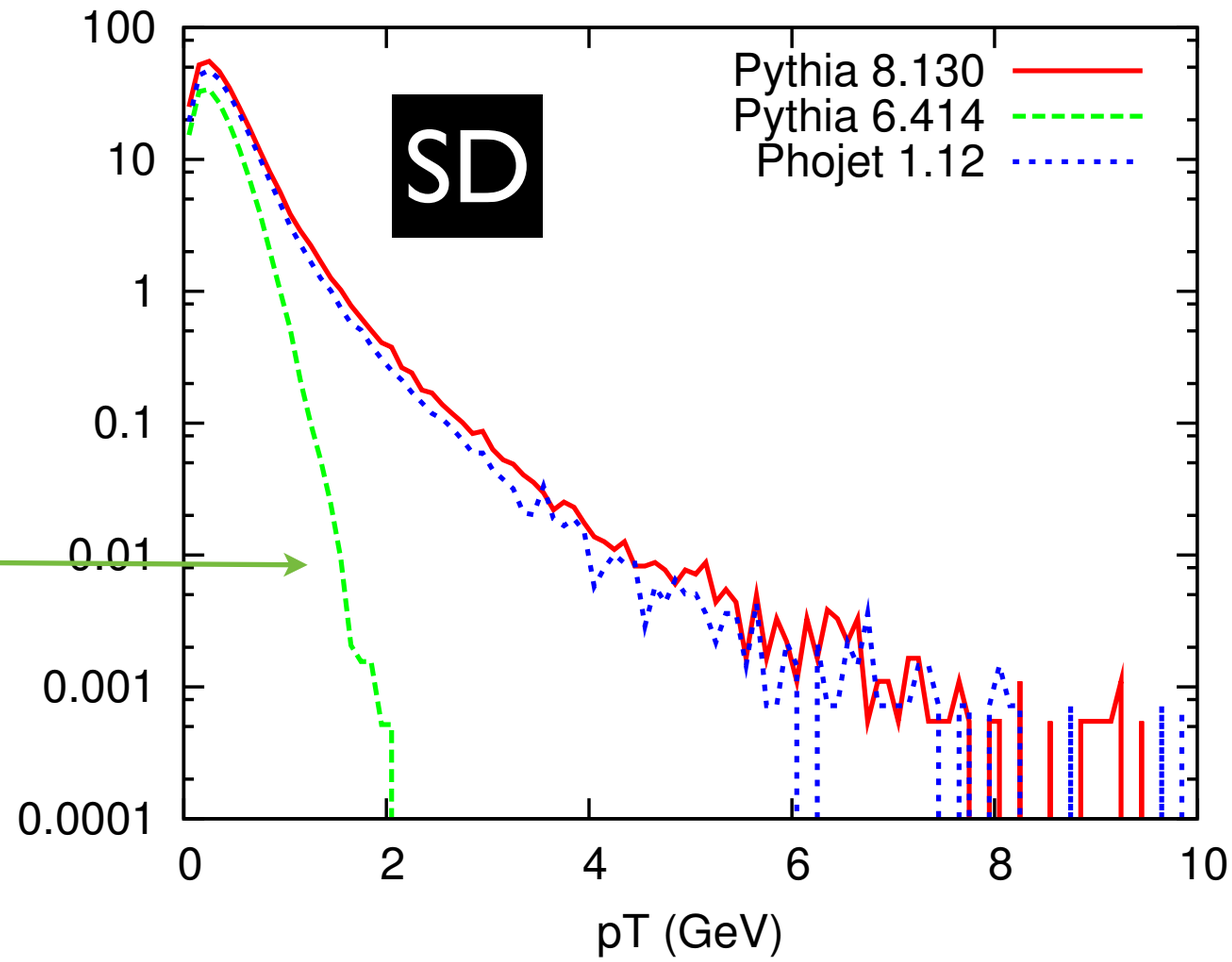
Spectra:

2 m_{pi}< M_D < 1 GeV: 2-body decay

M_D > 1 GeV : string fragmentation

Partonic Substructure in Pomeron:

Only in POMPYT addon (P. Bruni, A. Edin, G. Ingelman) ► high-p_T "jetty" diffraction absent



Very soft spectra without POMPYT

PYTHIA 6: Supported, but not actively developed

Diffraction in PYTHIA 8

Diffractive Cross Section Formulæ:

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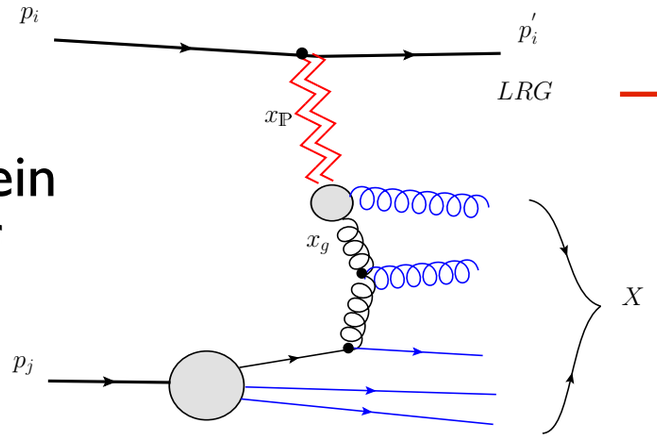
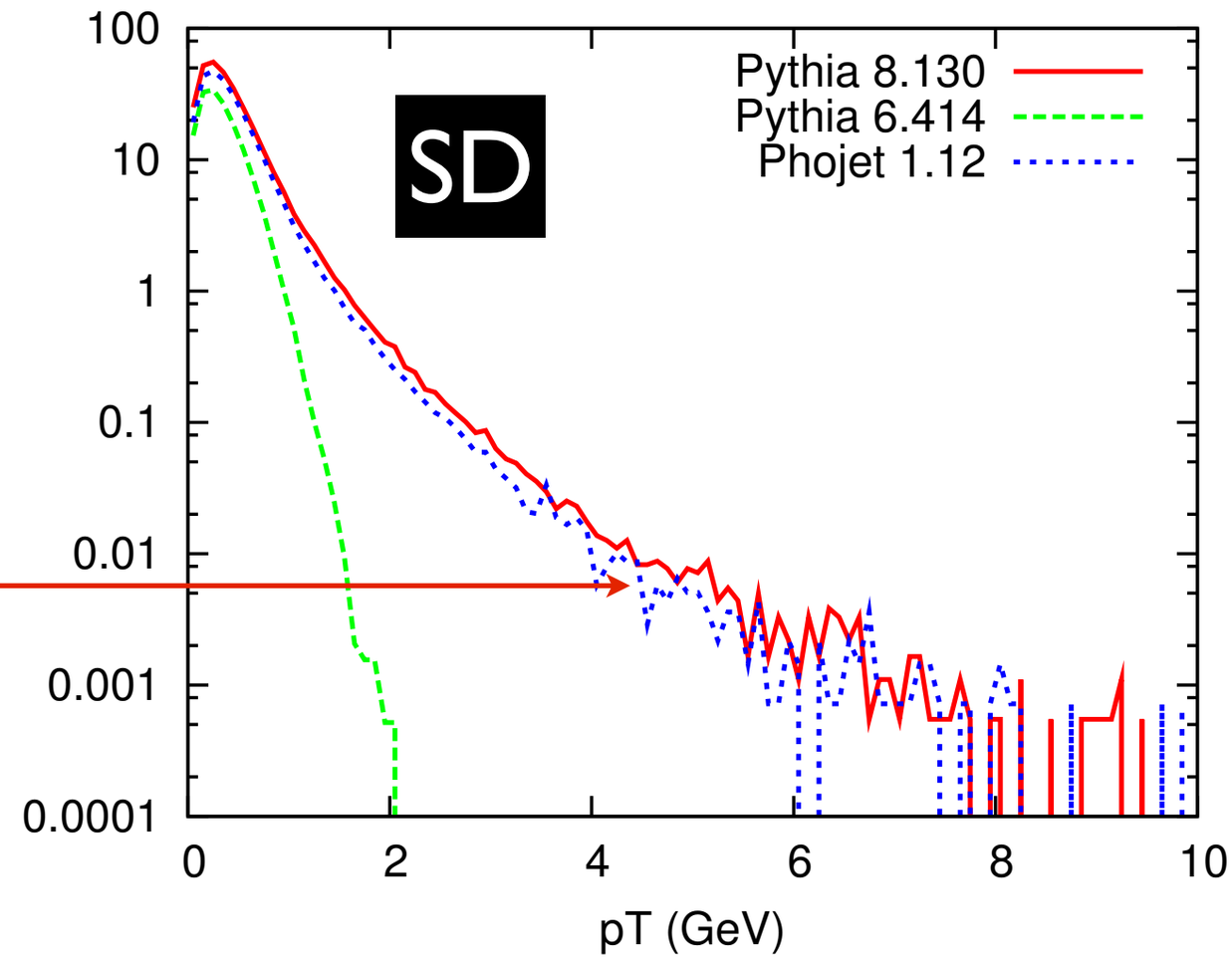
Partonic Substructure in Pomeron:

Follows the Ingelman-Schlein approach of Pompyt





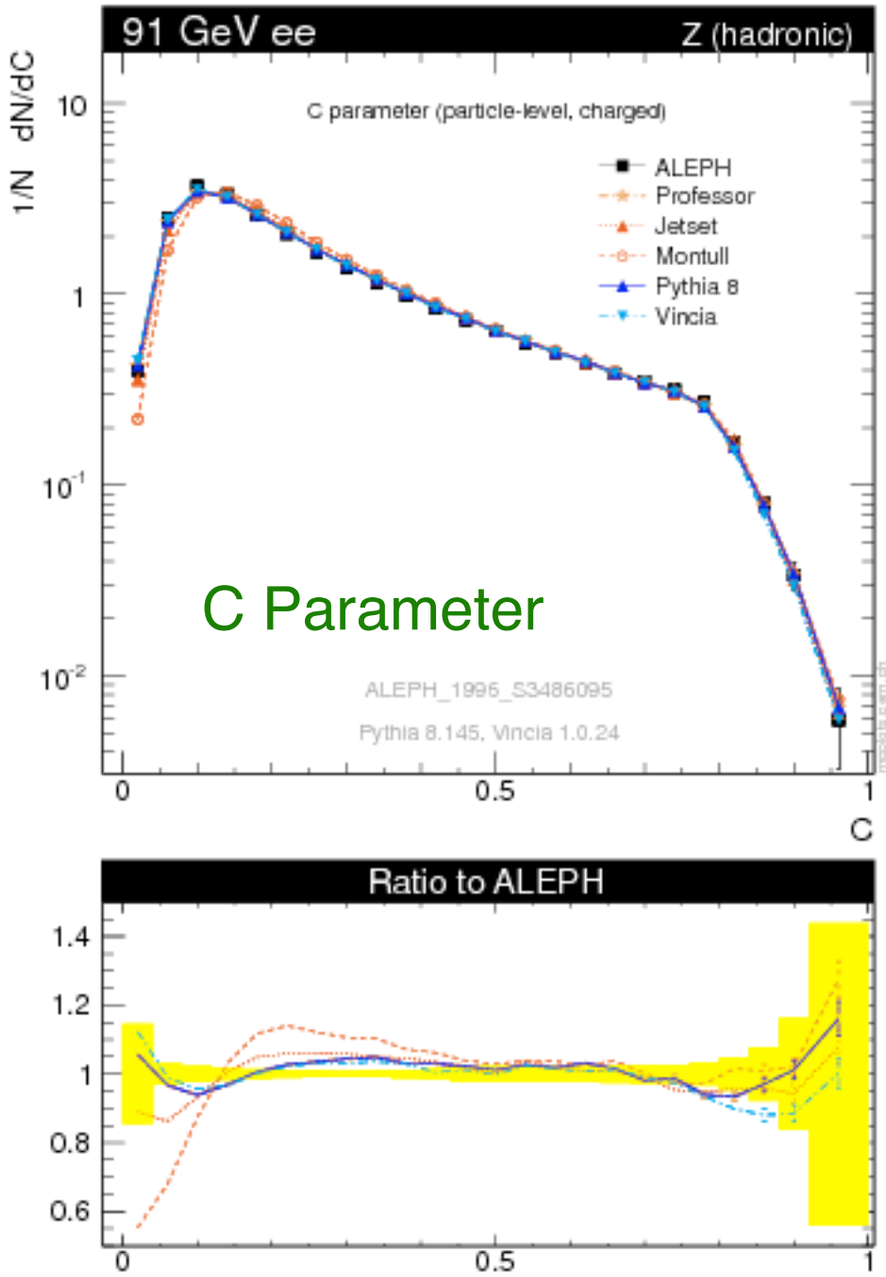
- $M_X \leq 10\,\mathrm{GeV}$: original longitudinal string description used
- $M_X > 10\,\mathrm{GeV}$: new perturbative description used (incl full MPI+showers for **P**p system)

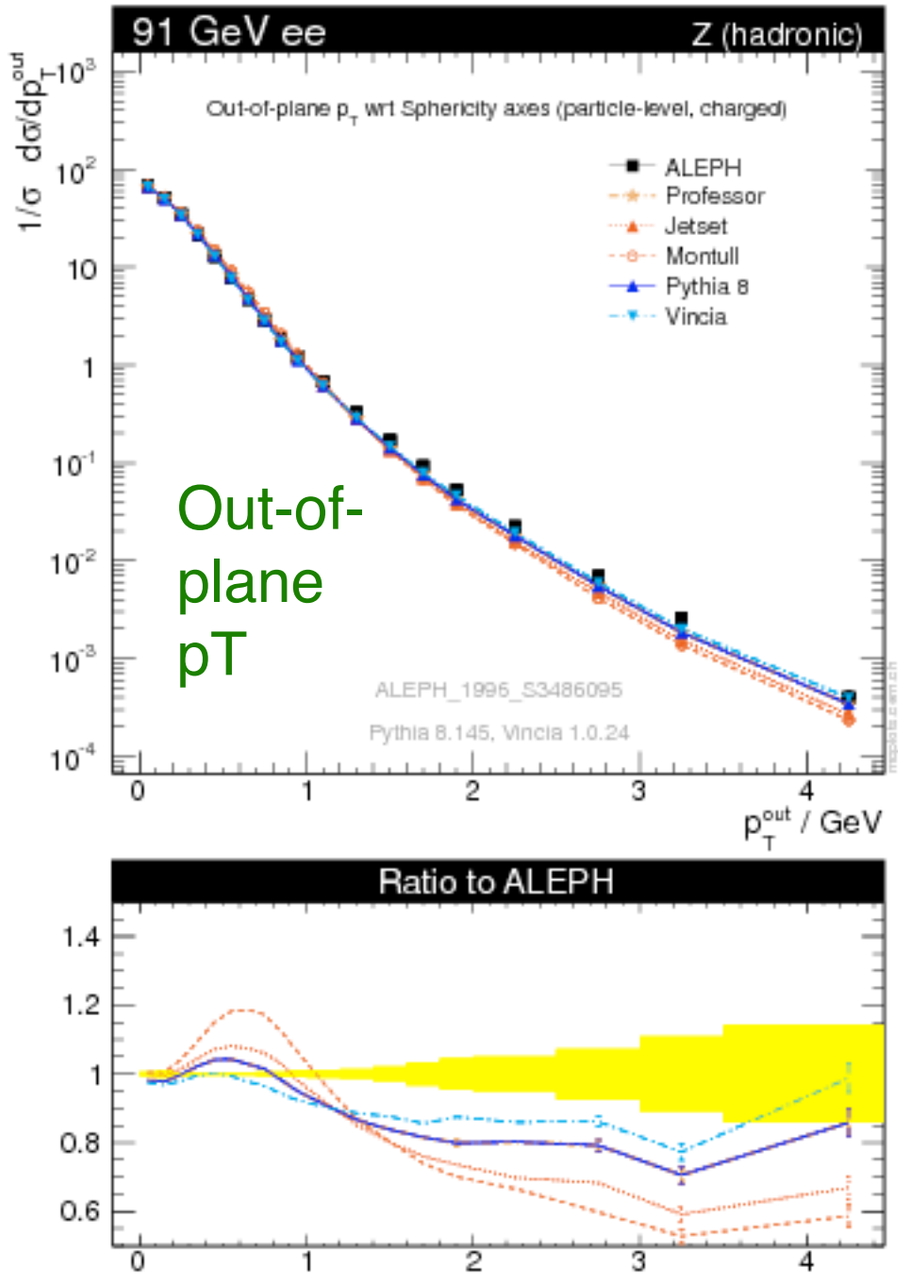
Choice between 5 Pomeron PDFs. Free parameter $\sigma_{\mathbb{P}\mathrm{p}}$ needed to fix $\langle n_{\mathrm{interactions}}\rangle = \sigma_{\mathrm{jet}}/\sigma_{\mathbb{P}\mathrm{p}}$.

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

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?

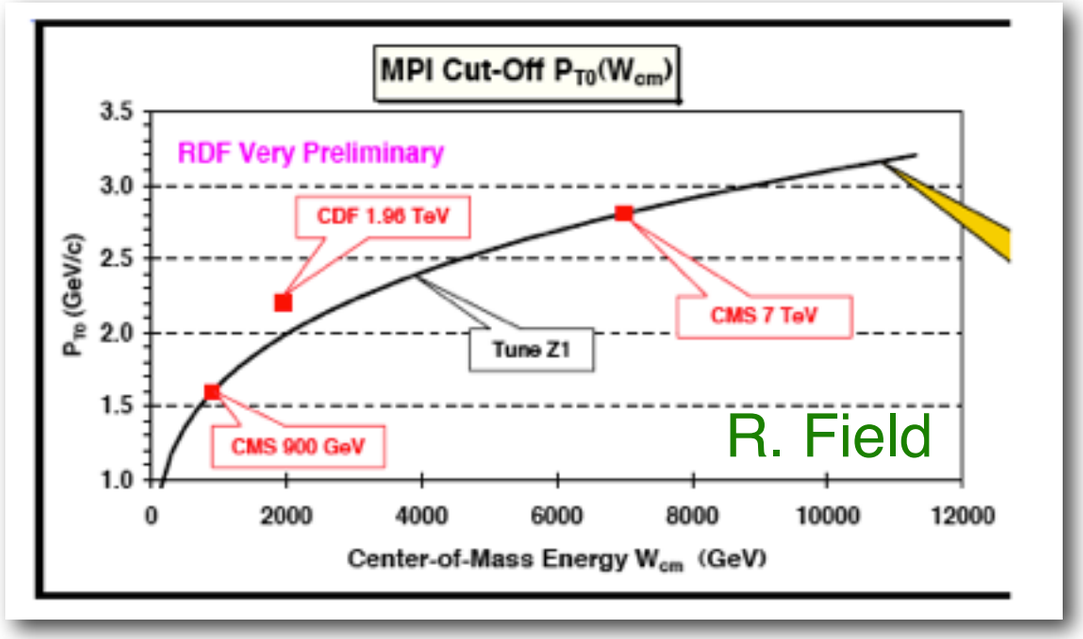




(Plots from mcplots.cern.ch)

Tuning of PYTHIA 8

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



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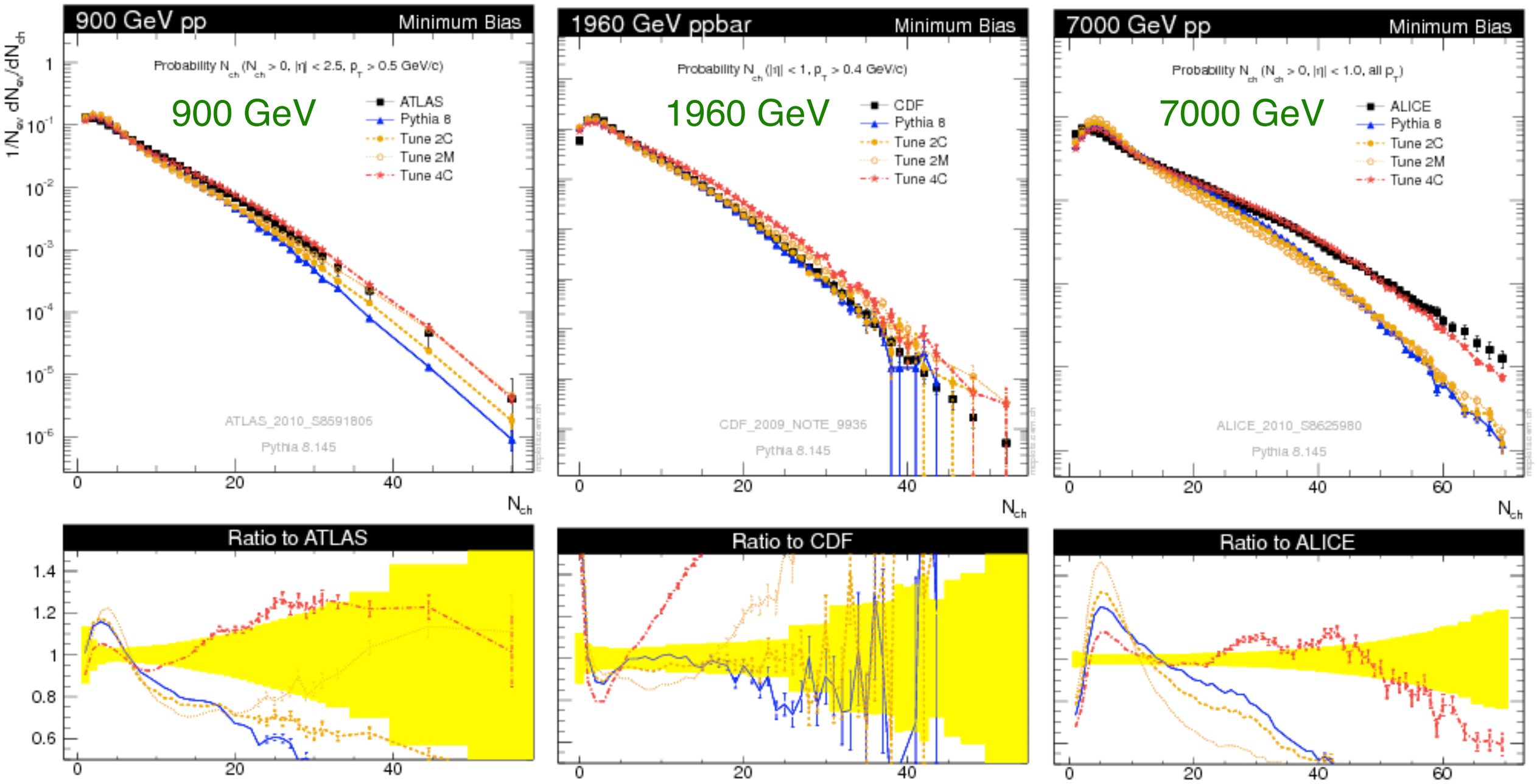
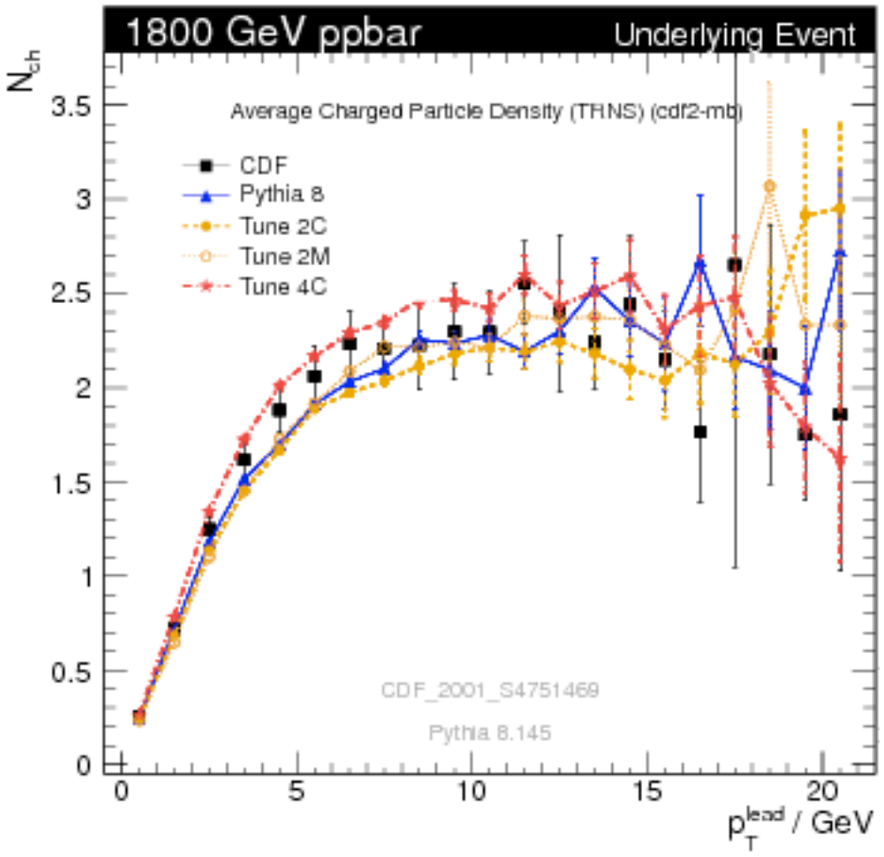
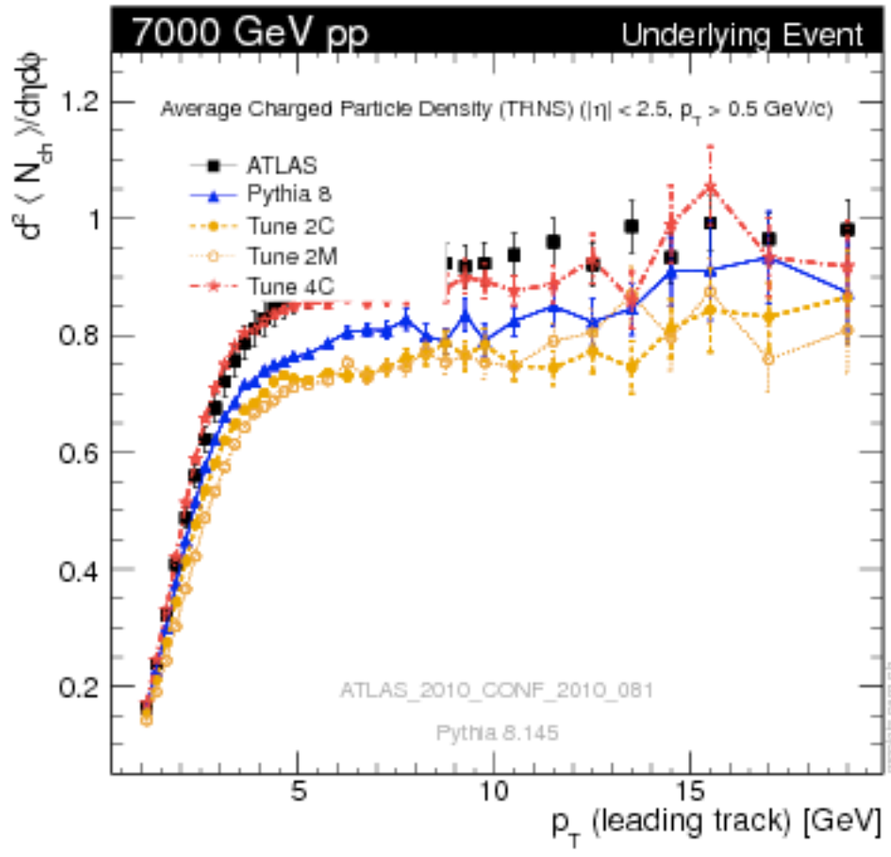


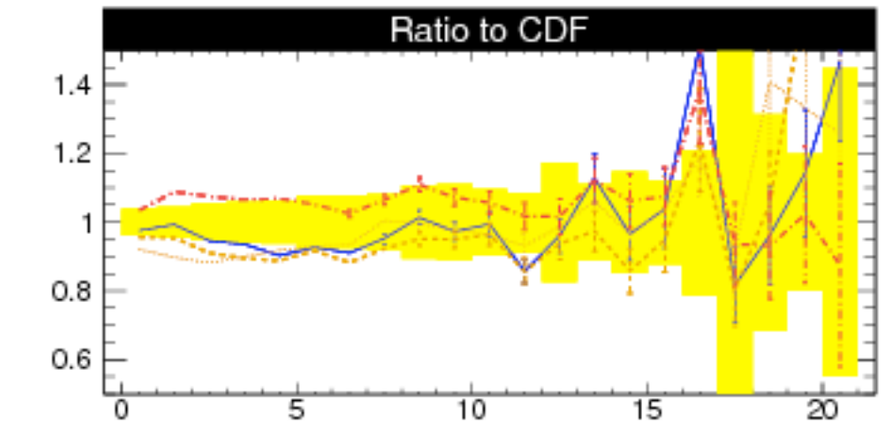
(Plots from mcplots.cern.ch)

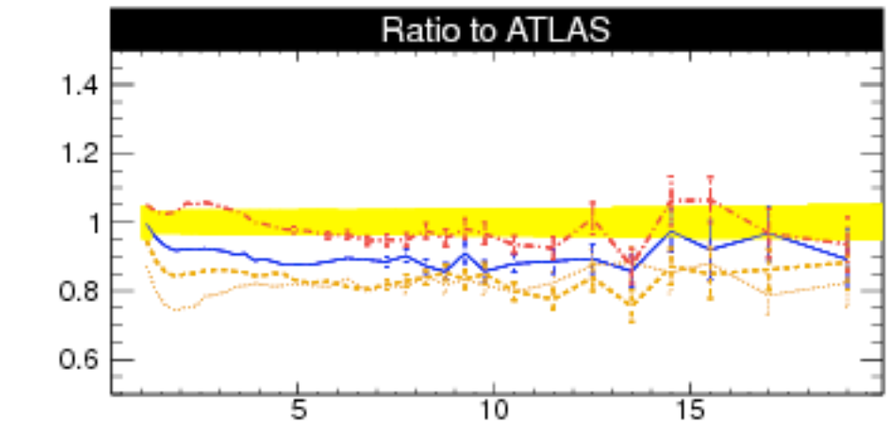
Tuning of PYTHIA 8

Underlying Event? Actually 4C looks fine at both energies









4C

Recommended for LHC studies

(Also has dampened diffractive cross section since ATLAS-CONF-2010-048 showed default too high)

Will probably be default from next version

(though question LHC/ Tevatron is still there and needs resolving)

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

(Plots from mcplots.cern.ch)

Summary

PYTHIA6 is winding down

Supported but not developed

Still main option for current run (sigh)

But not after long shutdown 2013!

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., 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

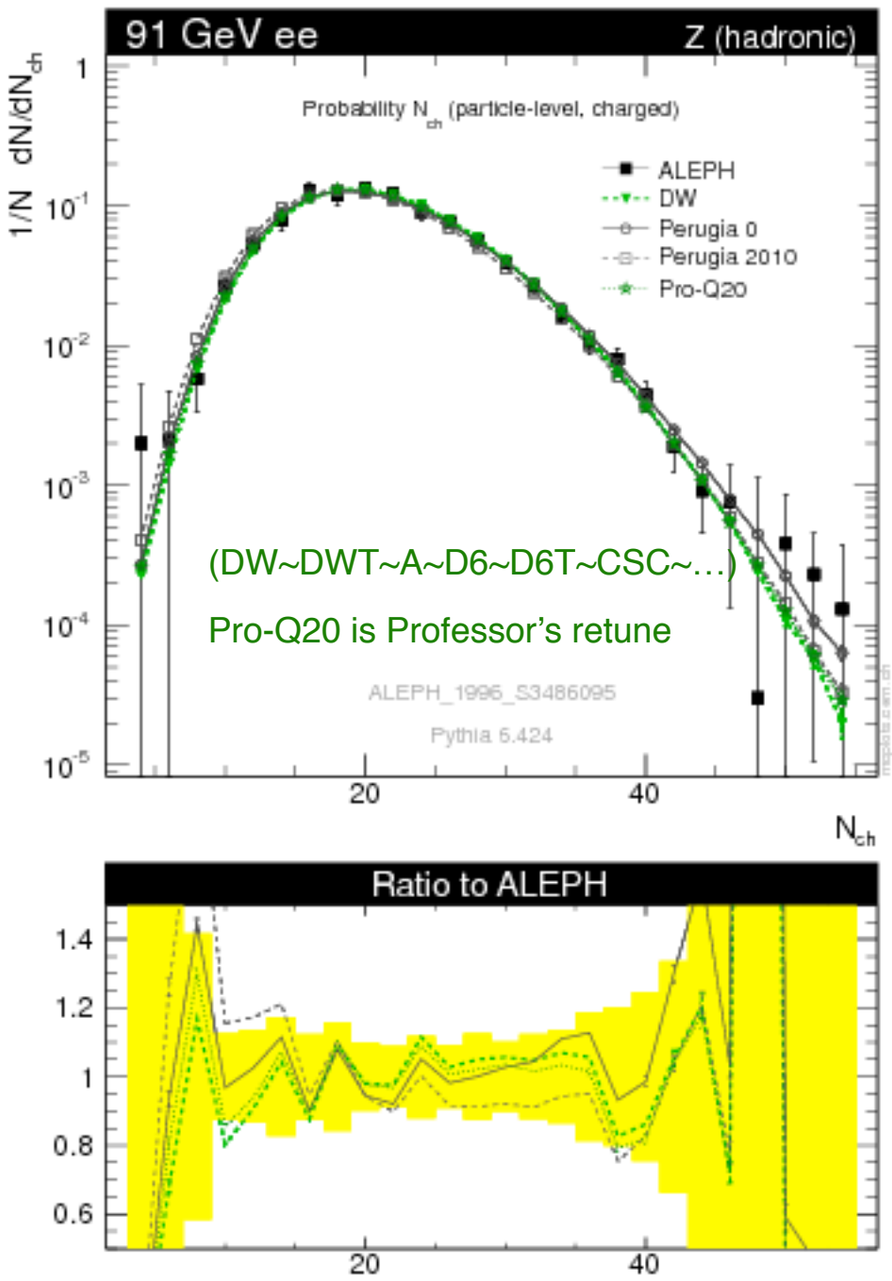
There is no way back!

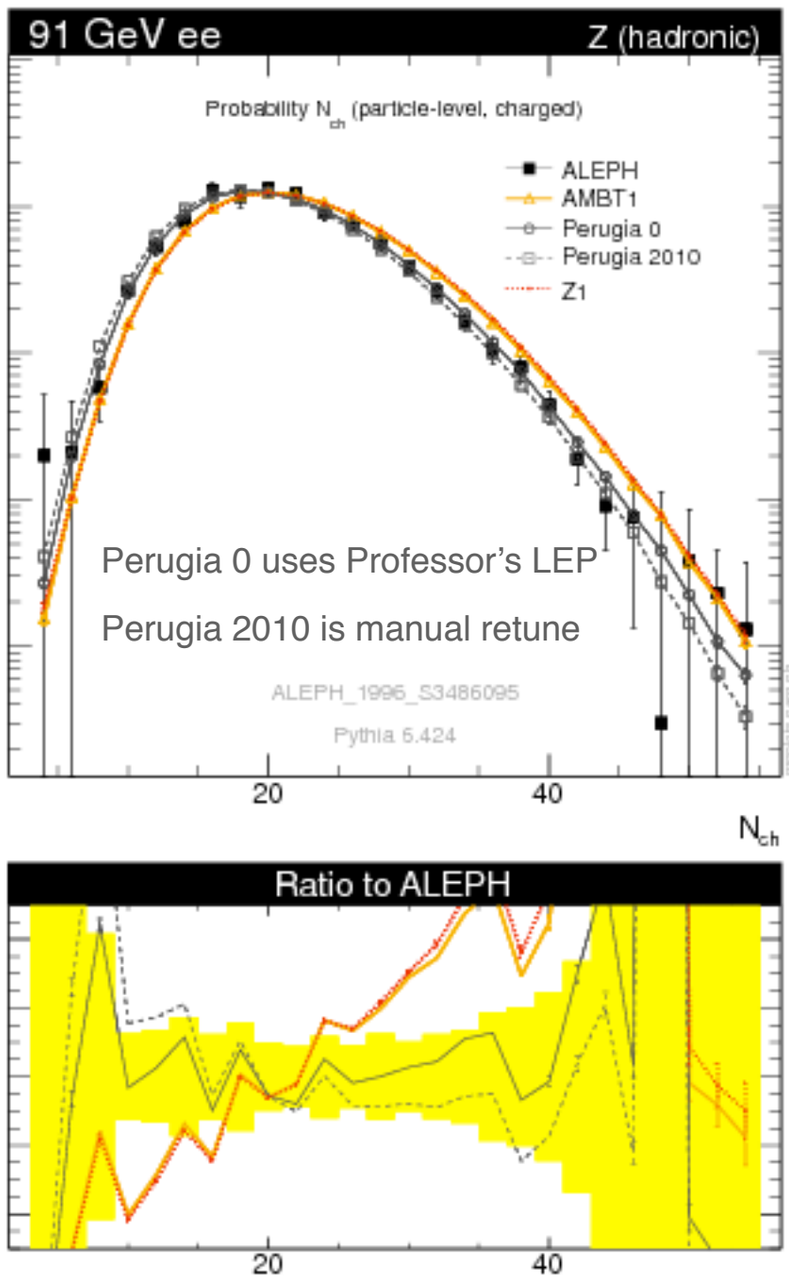
Comments on Strangeness

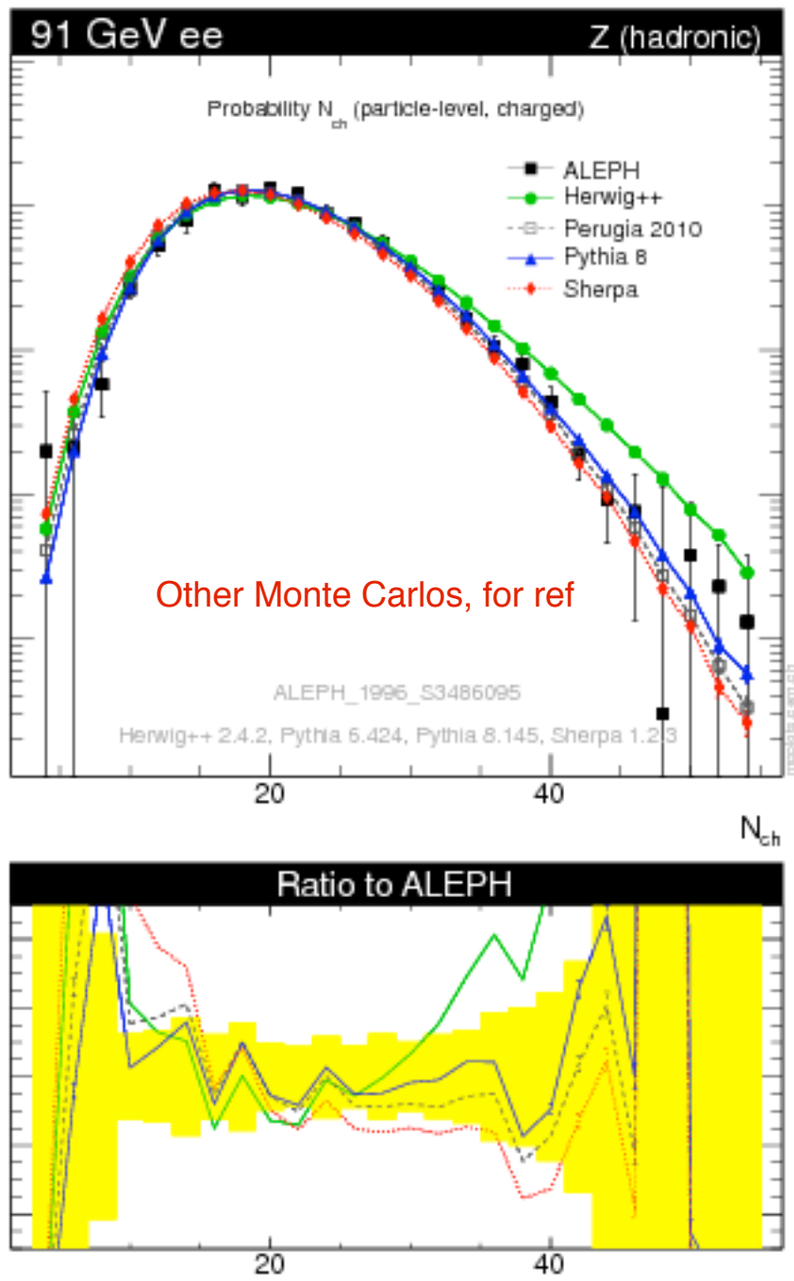
Check 1: Nch at LEP

All tunes get in right ballpark

(AMBT1 & Z1 slightly over)





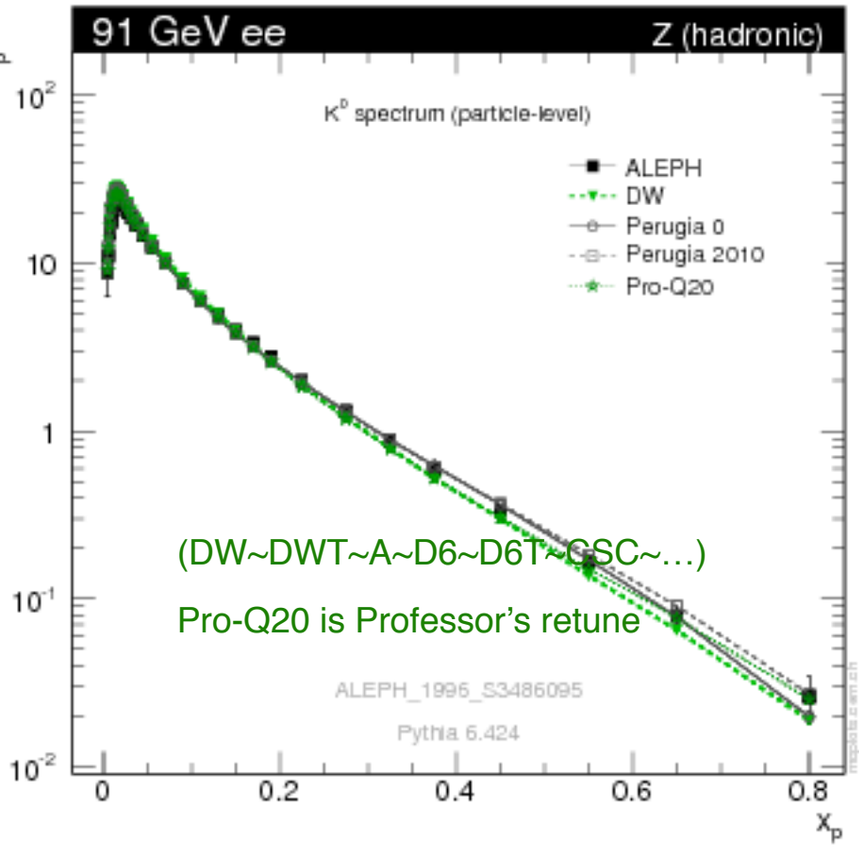


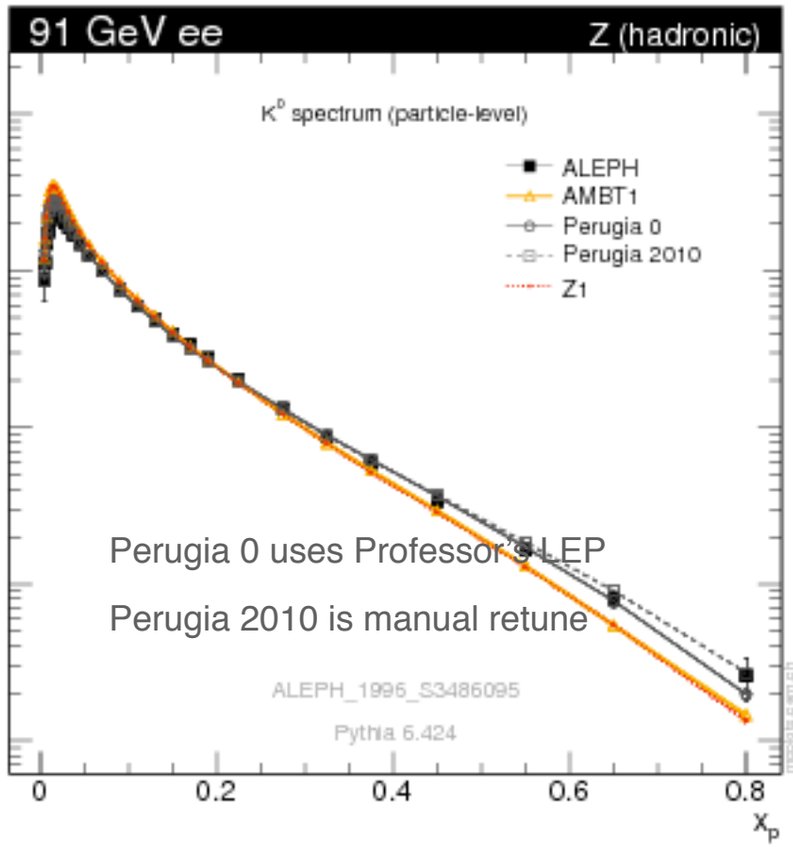
Check 2: Kaons

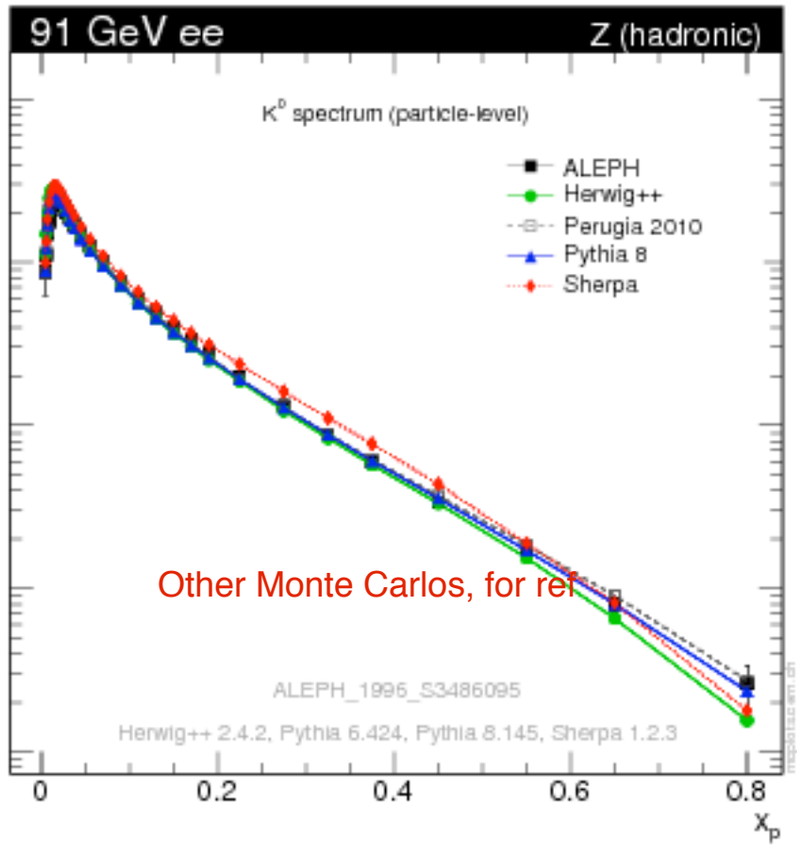
AMBT1 & Z1 quite high, and **spectrum too soft**

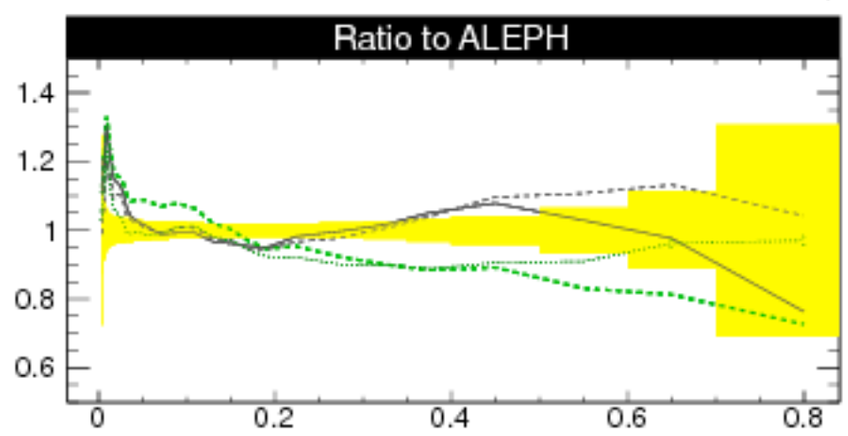
Pro-Q2O, Perugia, and PYTHIA 8 models significantly better

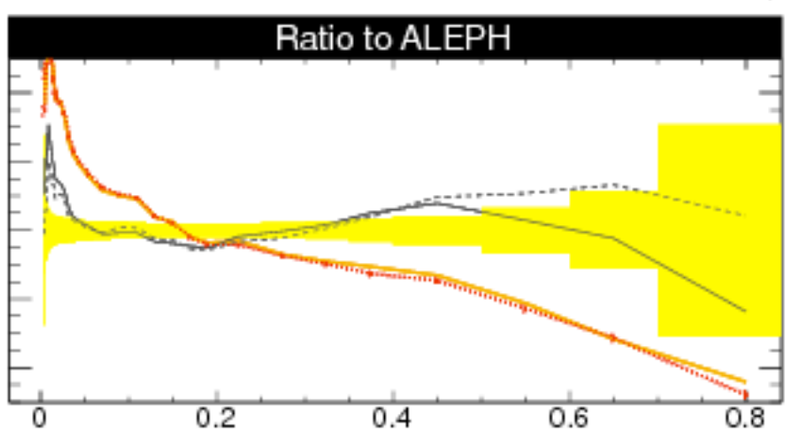
(because they were retuned)

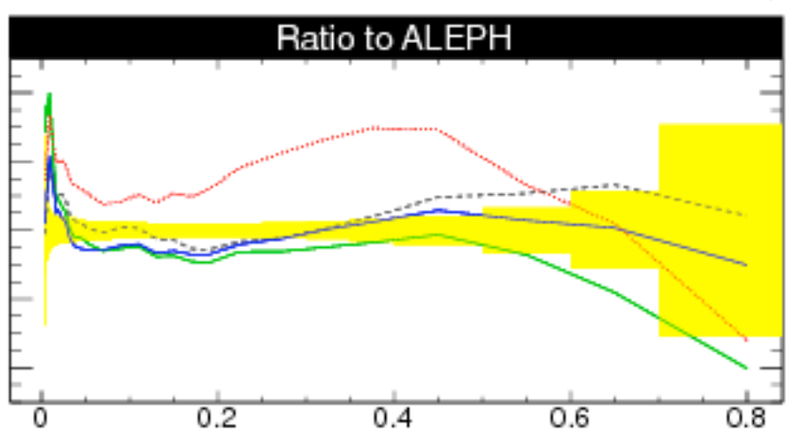








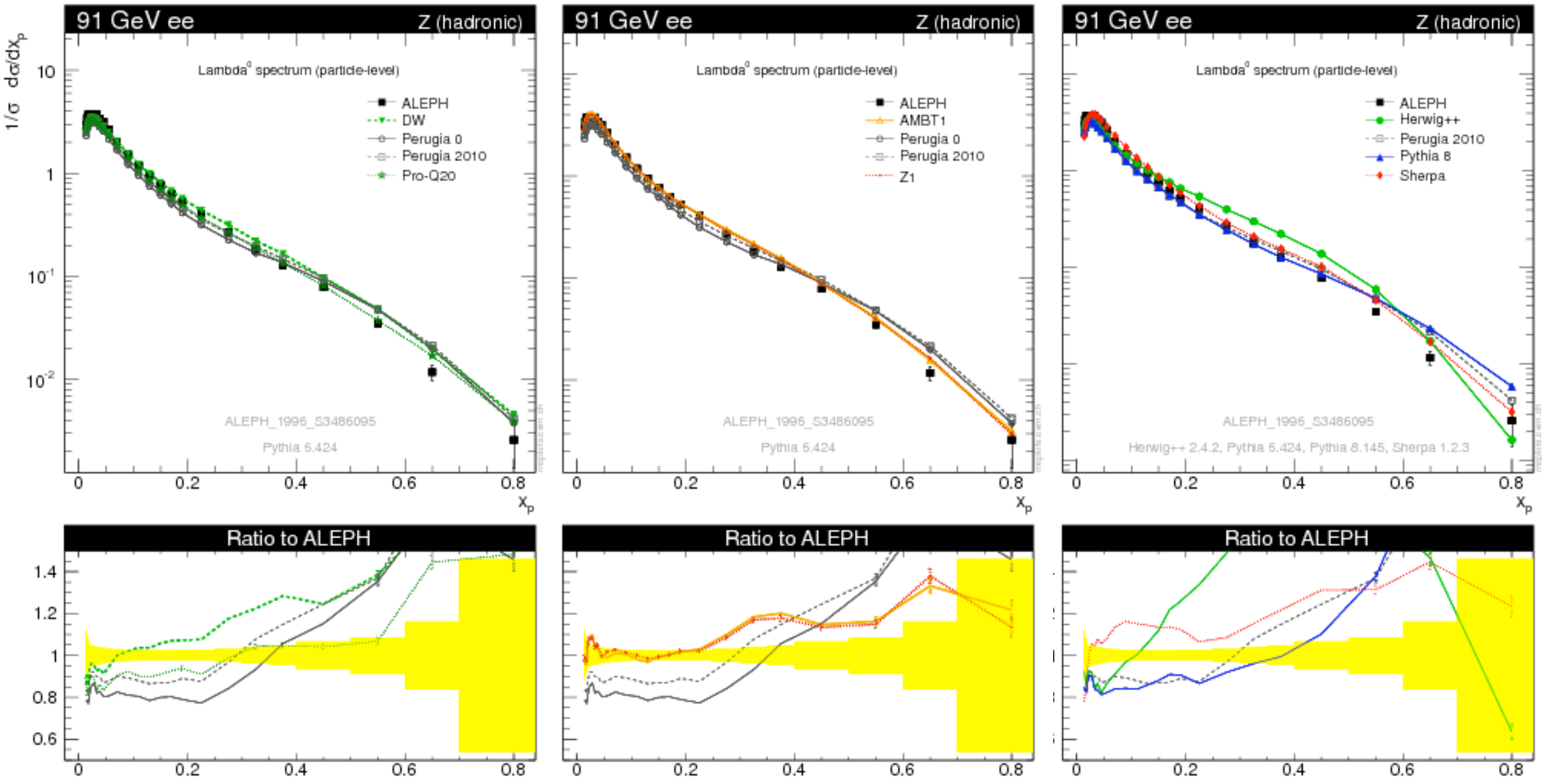




Check 3: Lambda

→ Lambda/K systematically low and **spectrum too HARD!**

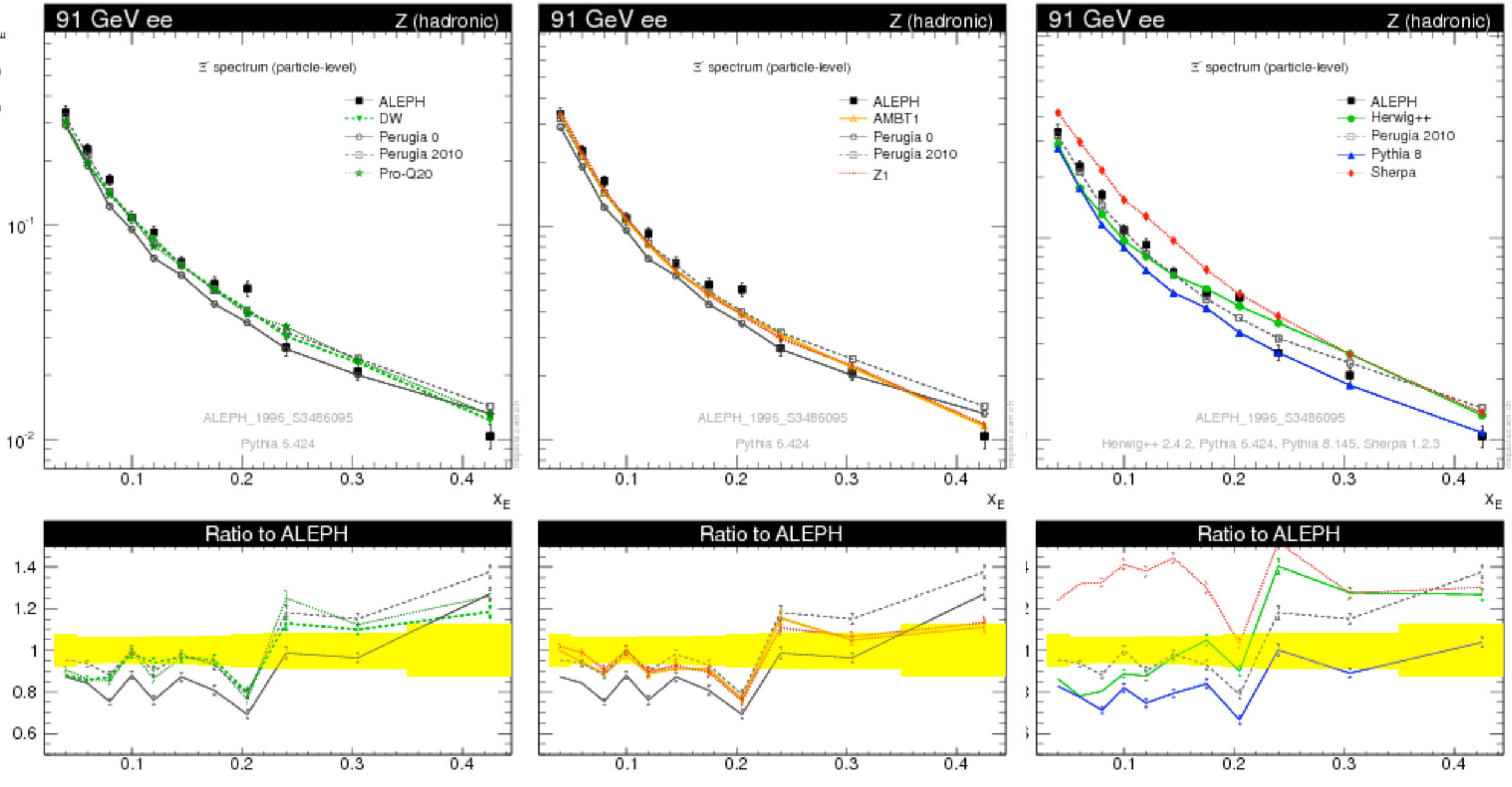
AMBT1 & Z1 may look ok, but since N_K and N_{ch} too high → Λ *fraction is too low*



Check 4: Cascade

Perugia 0 (and default PYTHIA 8 too low). Pro-Q2O and Perugia 2010 better

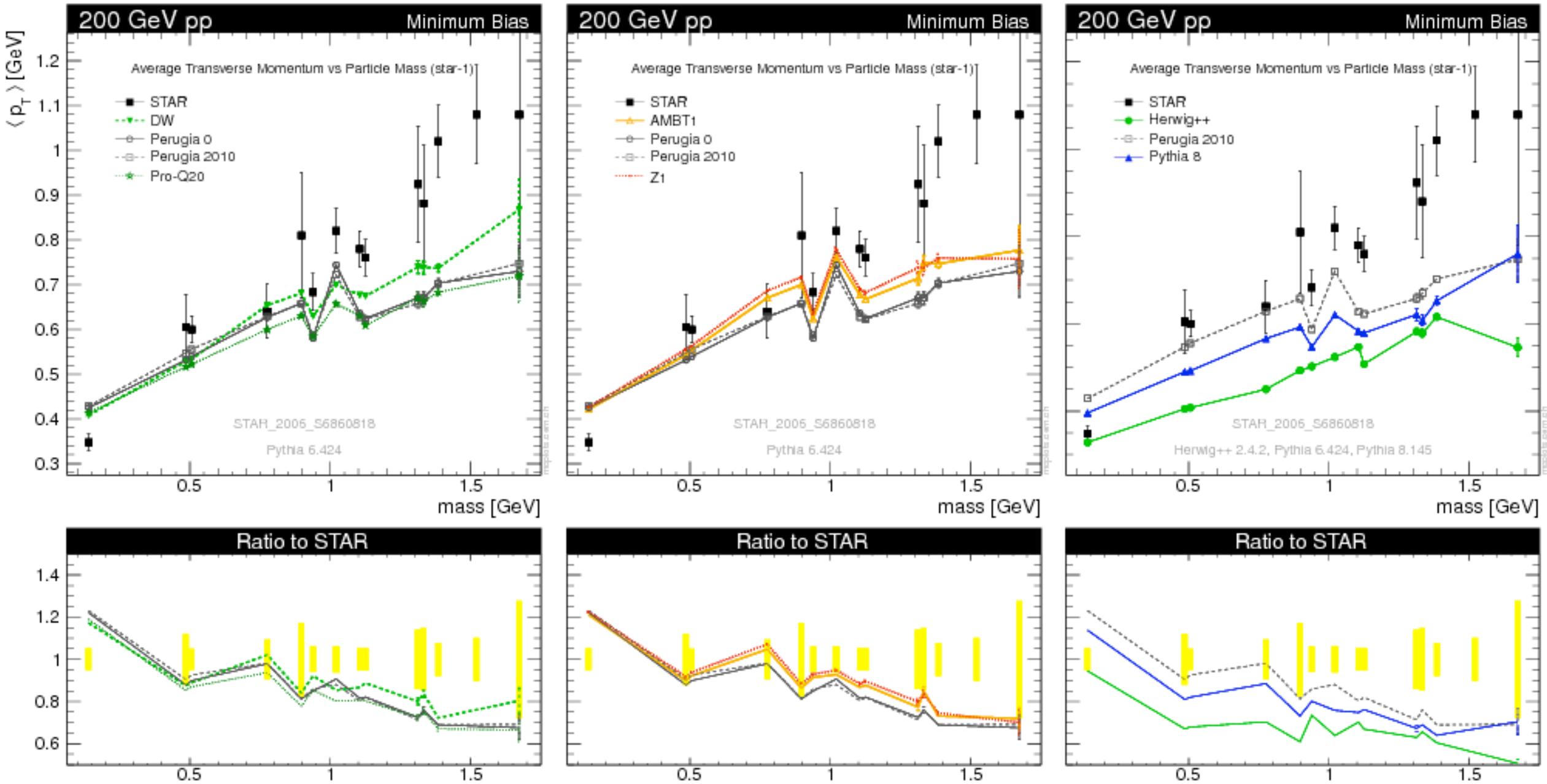
Again: AMBT1 & Z1 hyperon *fractions* too low



So one lesson from LEP:
If anything, the baryon spectra are somewhat too hard

Now compare with hadron collisions

Systematically too soft, the higher the mass



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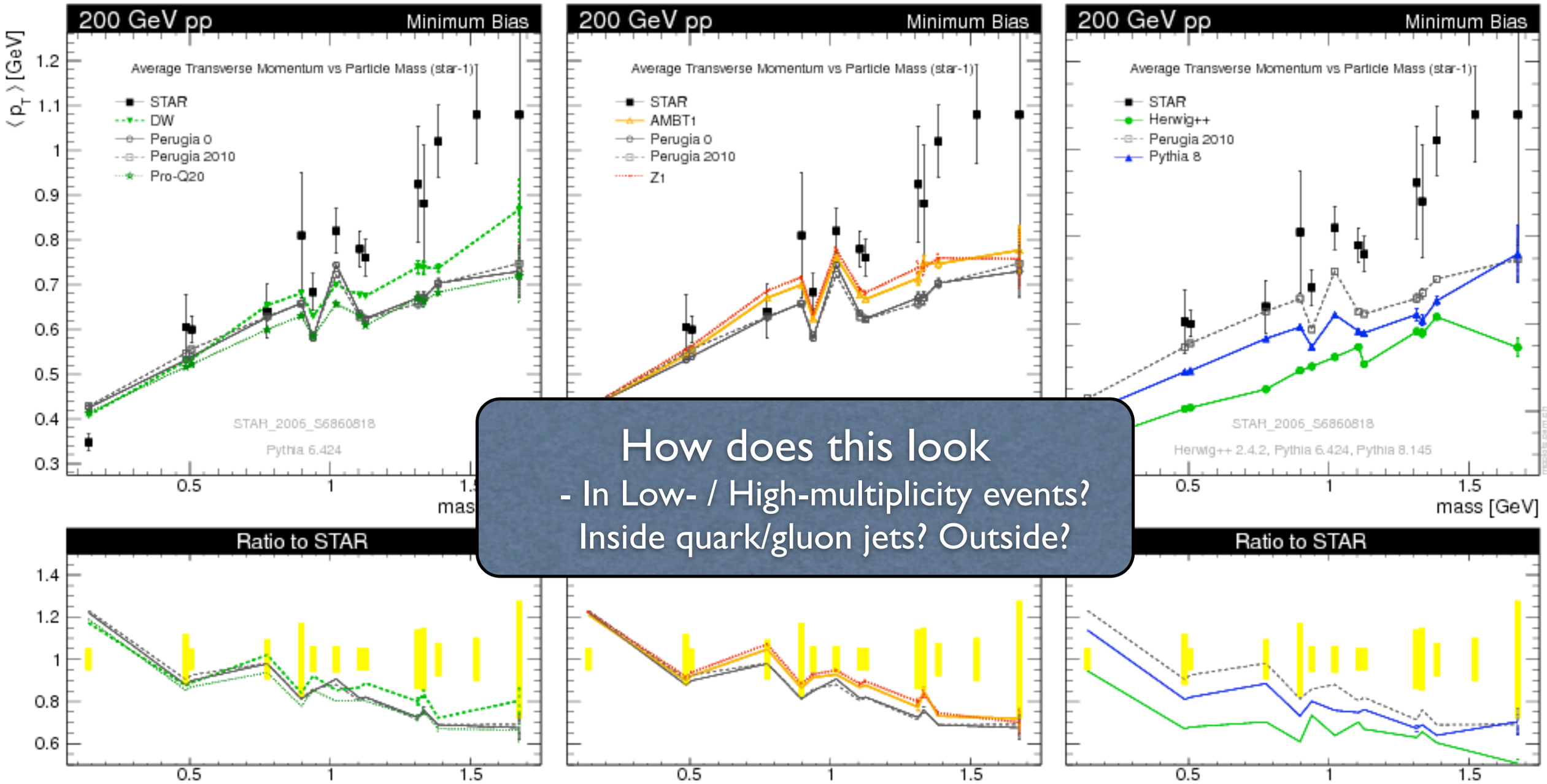

How does this look
- In Low- / High-multiplicity events?
Inside quark/gluon jets? Outside?

Tune Parameters

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]

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).