

# MC Tools: Matching & Tuning

P. Skands (CERN-TH)

# Merging Parton Showers and Matrix Elements

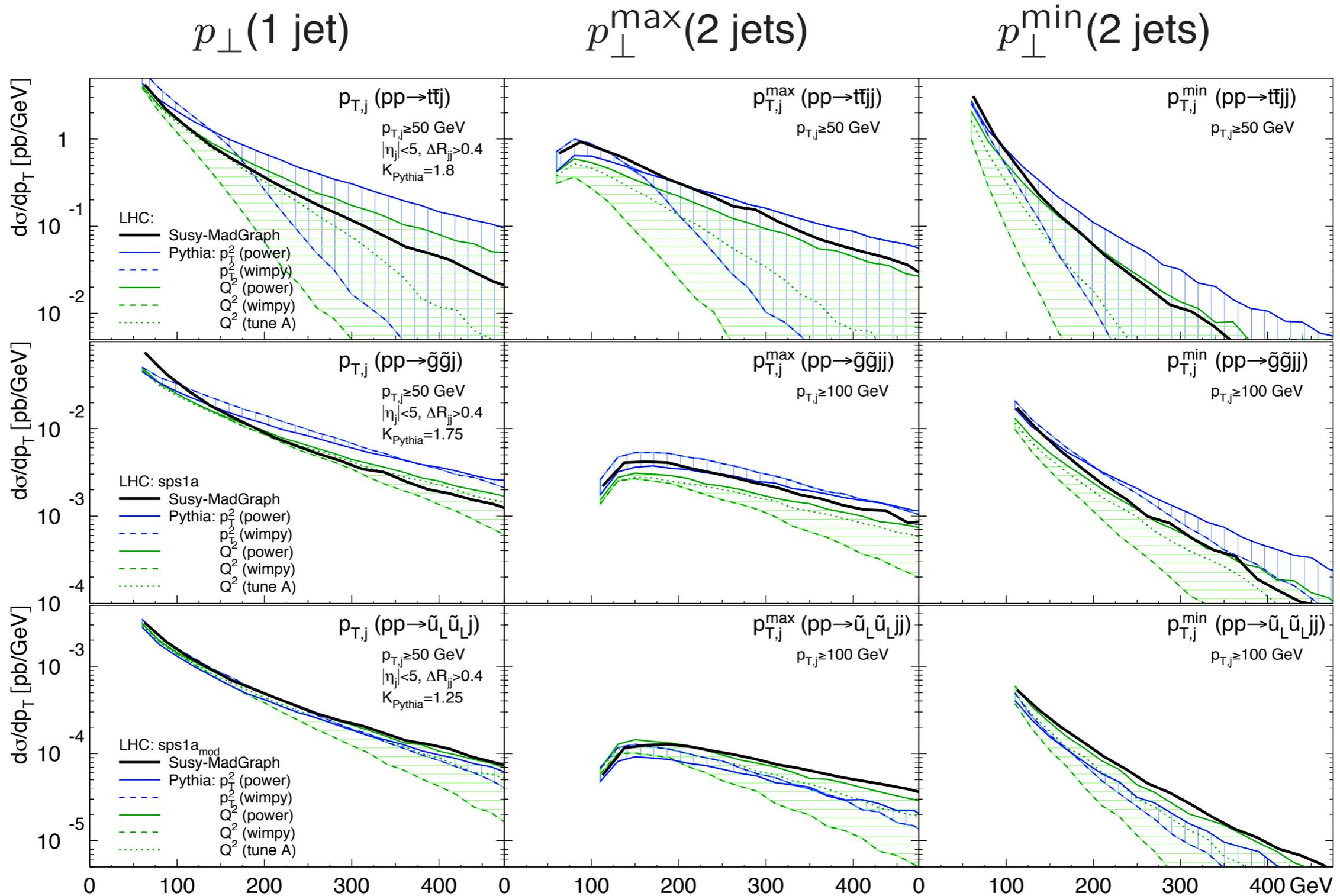
## Matching

Note: tough subject

Not required to understand everything

Don't loose yourselves in the details,

Just try to understand the overall reasoning



power:  $Q_{\max}^2 = s$ ;    wimpy:  $Q_{\max}^2 = m_{\perp}^2$ ;    tune A:  $Q_{\max}^2 = 4m_{\perp}^2$   
 $m_t = 175 \text{ GeV}$ ,     $m_{\tilde{g}} = 608 \text{ GeV}$ ,     $m_{\tilde{u}_L} = 567 \text{ GeV}$

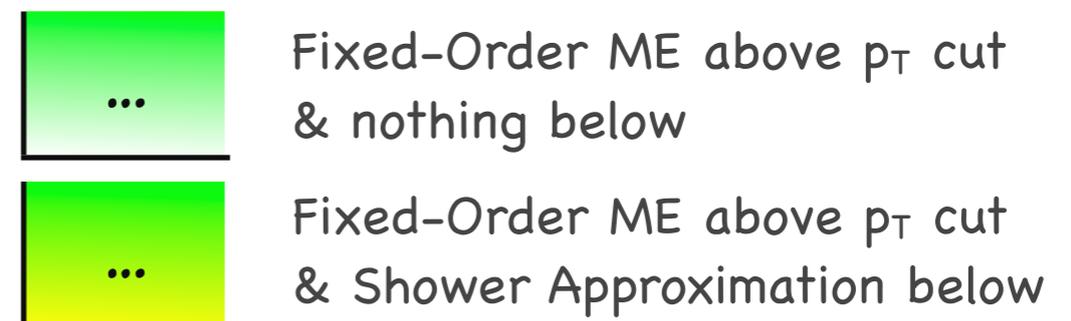
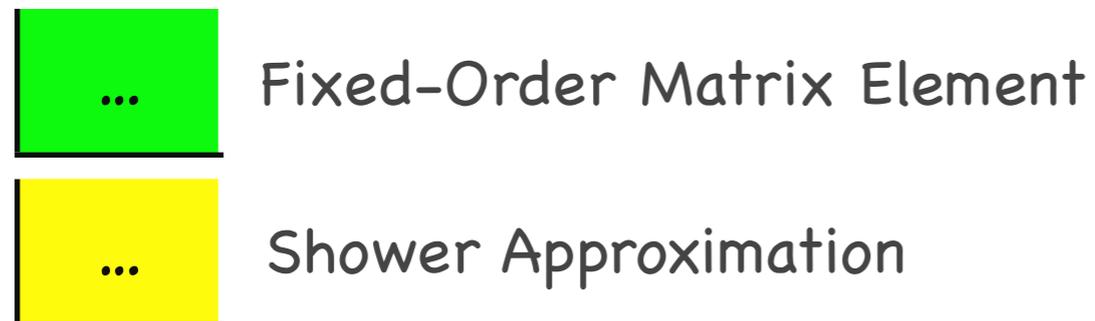
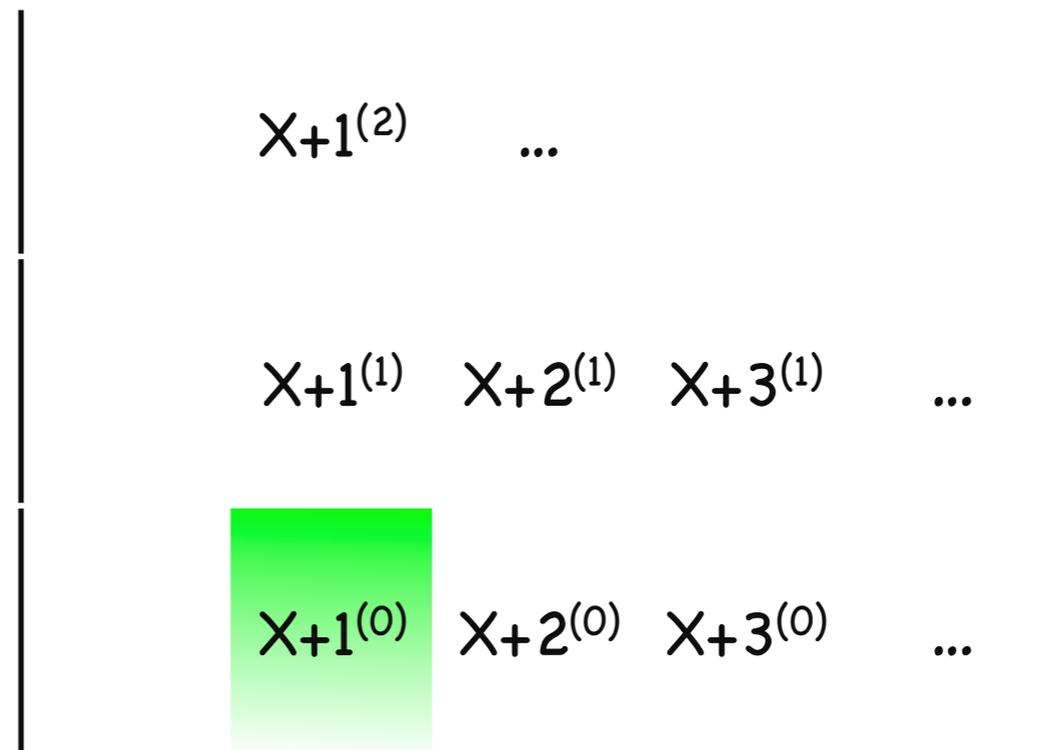
(T. Plehn, D. Rainwater, P. Skands)

# A Naive Proposal

Born  $\times$  Shower



$X_{+1}$  @ LO



# A Naive Proposal

Born  $\times$  Shower

$X^{(2)}$	$X_{+1}^{(2)}$	...		
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...

...	Fixed-Order Matrix Element
...	Shower Approximation

$X_{+1}$  @ LO  $\times$  Shower

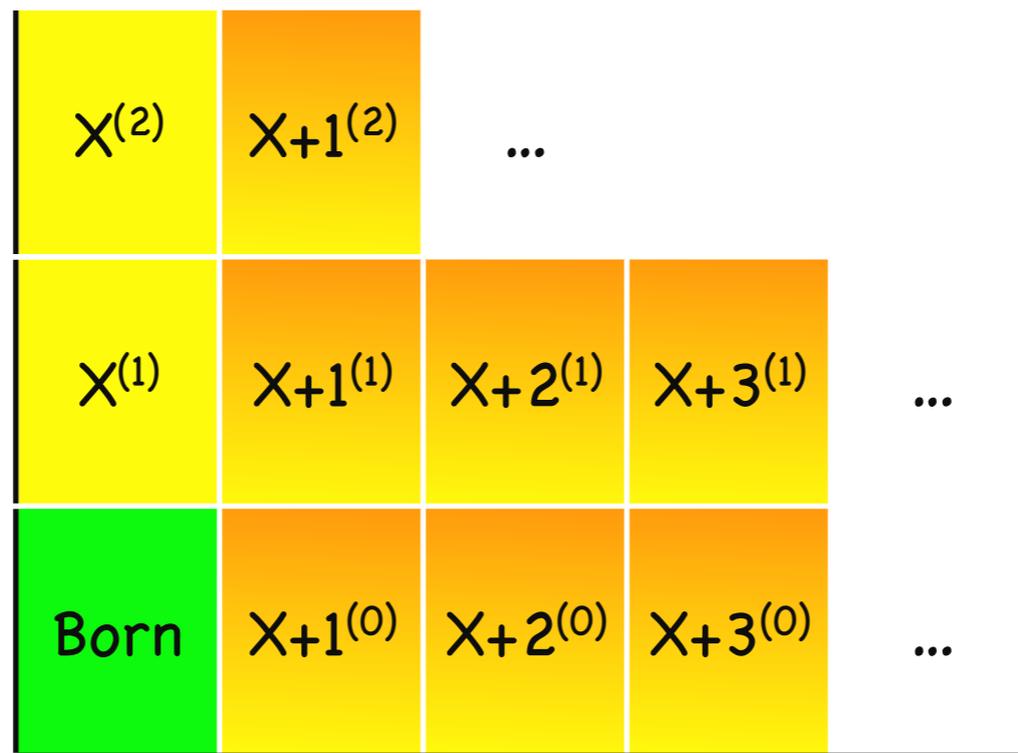
$X_{+1}^{(2)}$	...		
$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...
$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...

...	Fixed-Order ME above $p_T$ cut & nothing below
...	Fixed-Order ME above $p_T$ cut & Shower Approximation below

# A ~~Naive~~ <sup>wrong</sup> Proposal

$$\text{Born} \times \text{Shower} + (X+1) \times \text{shower}$$

Double Counting of terms present in both expansions



Worse than useless



Fixed-Order Matrix Element



Fixed-Order ME above  $p_T$  cut & nothing below



Shower Approximation



Fixed-Order ME above  $p_T$  cut & Shower Approximation below

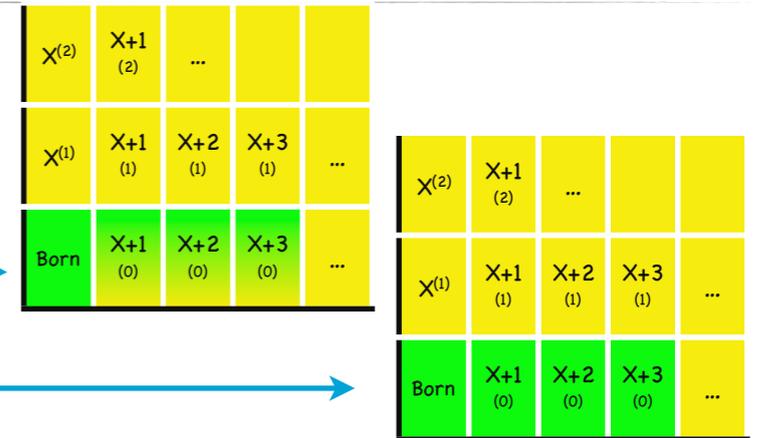


# Cures

## Tree-Level Matrix Elements

PHASE-SPACE SLICING (a.k.a. CKKW, MLM, ...)

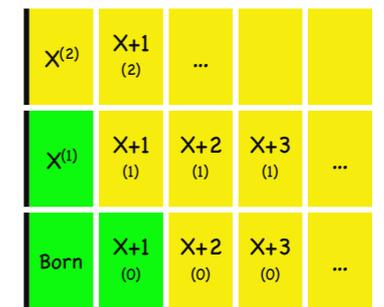
UNITARITY (a.k.a. merging, PYTHIA, VINCIA, ...)



## NLO Matrix Elements

SUBTRACTION (a.k.a. MC@NLO)

UNITARITY + SUBTRACTION (a.k.a. POWHEG, VINCIA)



## + WORK IN PROGRESS ...

NLO + multileg tree-level matrix elements

NLO multileg matching

Matching at NNLO



$X^{(2)}$	$X+1_{(2)}$	...		
$X^{(1)}$	$X+1_{(1)}$	$X+2_{(1)}$	$X+3_{(1)}$	...
Born	$X+1_{(0)}$	$X+2_{(0)}$	$X+3_{(0)}$	...

# Phase-Space Slicing

## Matching to Tree-Level

### Matrix Elements

A.K.A. CKKW, CKKW-L, MLM

# Phase Space Slicing

(with "matching scale")

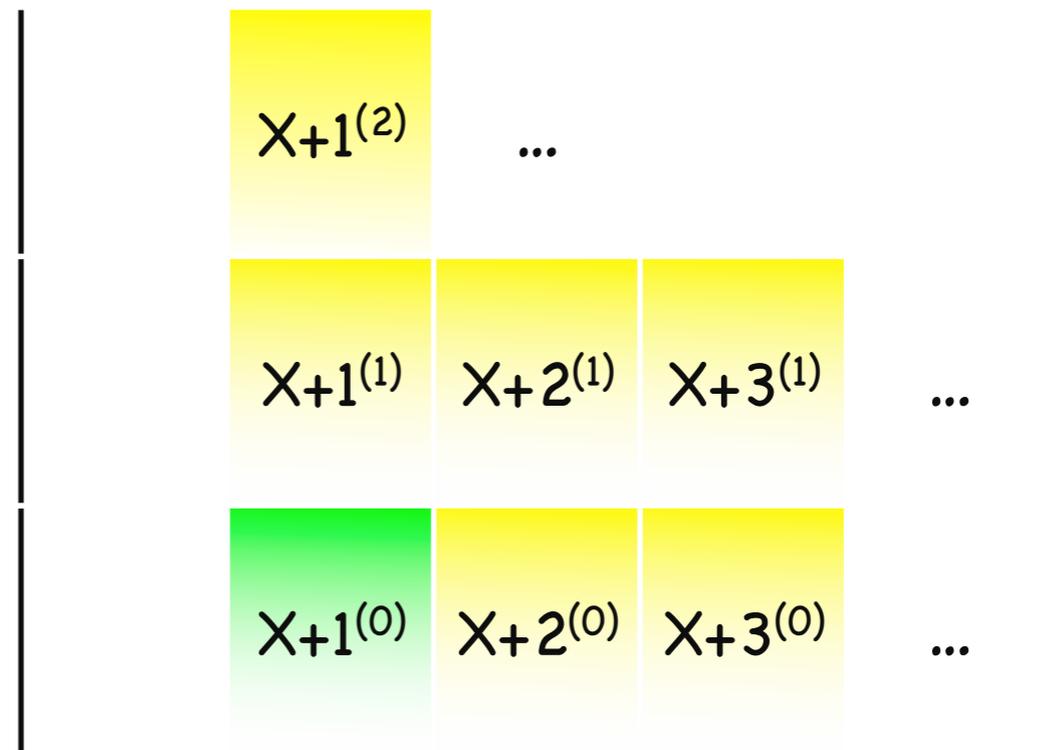
Born  $\times$  Shower

+ shower veto above  $p_T$



$X_{+1}$  @ LO  $\times$  Shower

with 1 jet above  $p_T$



... Fixed-Order Matrix Element

... Shower Approximation

... Fixed-Order ME above  $p_T$  cut & nothing below

... Fixed-Order ME above  $p_T$  cut & Shower Approximation below

# Phase Space Slicing

(with "matching scale")

Born  $\times$  Shower

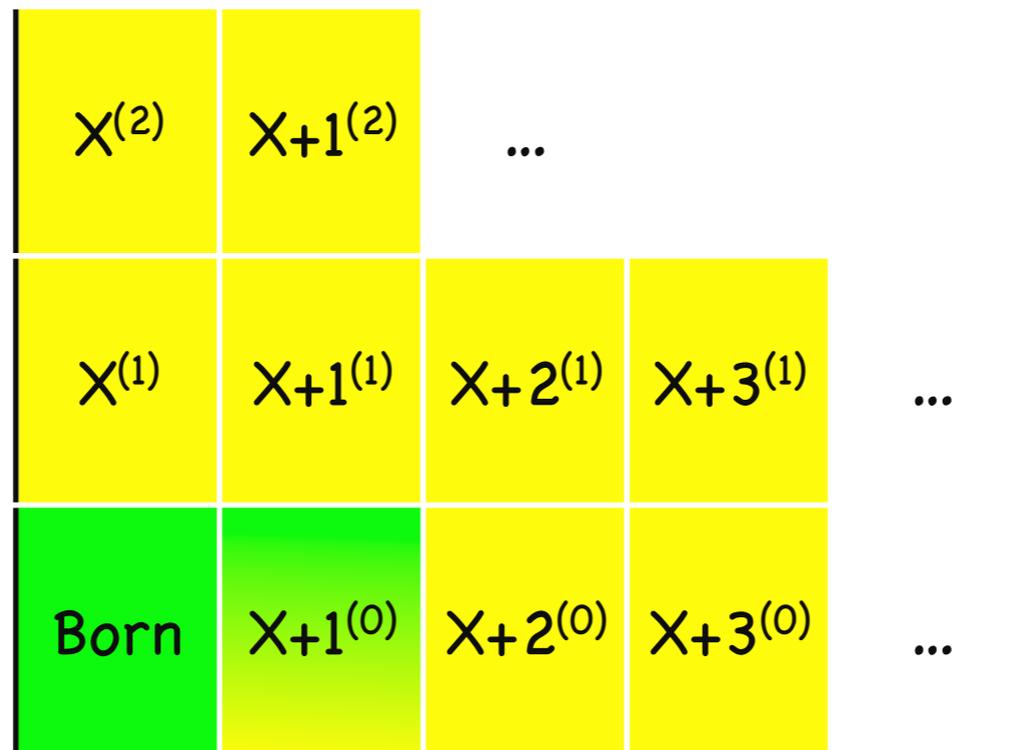
+

$X+1$  @ LO  $\times$  Shower

+ shower veto above  $p_T$

with 1 jet above  $p_T$

$X+1$  now correct in both soft and hard limits



Attention!  
Must use the SAME  $p_T$  cut in both samples

But still ... :  
 $\alpha_s$  and "splitting functions" usually discontinuous



Fixed-Order Matrix Element



Shower Approximation



Fixed-Order ME above  $p_T$  cut & nothing below



Fixed-Order ME above  $p_T$  cut & Shower Approximation below

# Multi-Leg Slicing

(a.k.a. CKKW or MLM matching)

CKKW: Catani, Krauss, Kuhn, Webber, JHEP 0111:063,2001.

MLM: Michelangelo L Mangano

Keep going

Veto all shower emissions above “matching scale”  
(except for the highest-multiplicity matrix element)

LO: when all jets hard  
LL: for soft emissions

$X^{(2)}$	$X_{+1}^{(2)}$	...		
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...

→ Multileg Tree-level matching

# Vetoed Parton Showers

(used in Phase Space Slicing, a.k.a. CKKW or MLM matching)

## Common (at ME level):

1. Generate one ME sample for each of  $\sigma_n(p_{T\text{cut}})$  (using large, fixed  $\alpha_{s0}$ )
2. Use a jet algorithm (e.g.,  $k_T$ ) to determine an approximate shower history for each ME event
3. Construct the would-be shower  $\alpha_s$  factor and reweight

$$w_n = \text{Prod}[\alpha_s(k_{Ti})] / \alpha_{s0}^n$$

→ “Renormalization-improved” ME weights

## CKKW and CKKW-L

1. Apply Sudakov  $\Delta(t_{\text{start}}, t_{\text{end}})$  for each reconstructed internal line (NLL for CKKW, trial-shower for CKKW-L)
2. Accept/Reject:  $w_n \propto \text{Prod}[\Delta_i]$
3. Do parton shower, vetoing any emissions above cutoff

## MLM

1. Do normal parton showers
2. Cluster showered event (cone)
3. Match ME partons to jets
4. If {all partons matched &&  $n_{\text{partons}} == n_{\text{jets}}$ } Accept : Reject;

$X^{(2)}$	$X+1_{(2)}$	...		
$X^{(1)}$	$X+1_{(1)}$	$X+2_{(1)}$	$X+3_{(1)}$	...
Born	$X+1_{(0)}$	$X+2_{(0)}$	$X+3_{(0)}$	...

# Subtraction

## Matching to Born+NLO

### Matrix Elements

A.K.A. MC@NLO, POWHEG, VINCIA<sub>[incl X+n @ LO]</sub>

# MC@NLO

## Subtraction

Born × Shower

$X^{(2)}$	$X_{+1}^{(2)}$	...			
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...	
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...	

NLO

$X^{(2)}$	$X_{+1}^{(2)}$	...			
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...	
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...	

... Fixed-Order Matrix Element

... Shower Approximation

# MC@NLO

## Subtraction

### Born × Shower

$X^{(2)}$	$X_{+1}^{(2)}$	...		
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...

...	Fixed-Order Matrix Element
...	Shower Approximation

### NLO - Shower

$X^{(2)}$	$X_{+1}^{(2)}$	...		
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...

Expand shower approximation to NLO analytically, then subtract:

...	Fixed-Order ME minus Shower Approximation (NOTE: can be < 0!)
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# MC@NLO

## Subtraction

Add

Born + shower-subtracted  $O(\alpha_s)$  matrix elements

NLO: for X inclusive  
LO for X+1  
LL: for everything else

$X^{(2)}$	$X_{+1}^{(2)}$	...		
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...

Note 1: NOT NLO for X+1

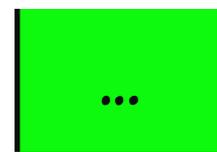
Note 2: Multijet tree-level matching still superior for X+2

→ NLO + parton shower  
(however, the "correction events" can have  $w < 0$ )

# Negative Weights

## Born × Shower

$X^{(2)}$	$X_{+1}^{(2)}$	...		
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...



Fixed-Order Matrix Element



Shower Approximation

## NLO - Shower

$X^{(2)}$	$X_{+1}^{(2)}$	...		
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...

Expand shower approximation to NLO analytically, then subtract:



Fixed-Order ME minus Shower Approximation (NOTE: can be < 0!)

# PYTHIA / POWHEG / VINCIA (Unitarity + Subtraction)

## Born $\times$ First-Order Corrected Shower

$X^{(2)}$	$X_{+1}^{(2)}$	...		
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...

$X^{(2)}$	$X_{+1}^{(2)}$	...		
$X^{(1)}$	$X_{+1}^{(1)}$	$X_{+2}^{(1)}$	$X_{+3}^{(1)}$	...
Born	$X_{+1}^{(0)}$	$X_{+2}^{(0)}$	$X_{+3}^{(0)}$	...

 Fixed-Order Matrix Element  
 Shower Approximation

Use exact (process-dependent) splitting function for first splitting(s)

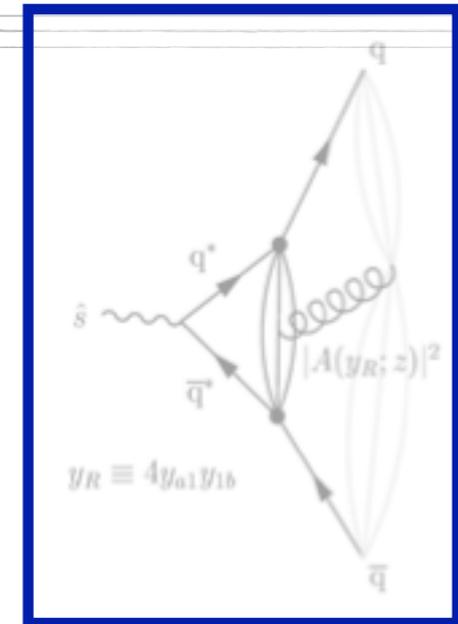
 Fixed-Order ME minus Shower Approximation

# NLO Matching in 1 Slide

## ► First Order Shower expansion

$$\text{PS} \quad \int d\Phi_2 \quad \text{Born} \quad \int_{Q_{\text{had}}^2}^s \frac{d\Phi_3}{d\Phi_2} \quad \text{LL} \quad \delta(\mathcal{O} - \mathcal{O}(\{p\}_3))$$

Unitarity of shower  $\rightarrow$  3-parton real = 2-parton "virtual"



## ► 3-parton real correction ( $A_3 = |M_3|^2/|M_2|^2 + \text{finite terms}; \alpha, \beta$ )

$$\begin{aligned} \chi_{+1^{(0)}} &= \chi_{+1^{(0)}} - \left( \frac{\chi_{+1^{(0)}}}{\text{Born}} + \frac{4\pi\alpha_s \hat{C}_F}{s} \left( \alpha + \beta \frac{s_{ar} + s_{rb}}{s} \right) \right) \text{Born} \\ &= -\frac{4\pi\alpha_s \hat{C}_F}{s} \left( \alpha + \beta \frac{s_{ar} + s_{rb}}{s} \right) |M_2^{(0)}|^2 \quad \Rightarrow \quad \text{Finite terms cancel in 3-parton } \mathcal{O} \end{aligned}$$

## ► 2-parton virtual correction (same example)

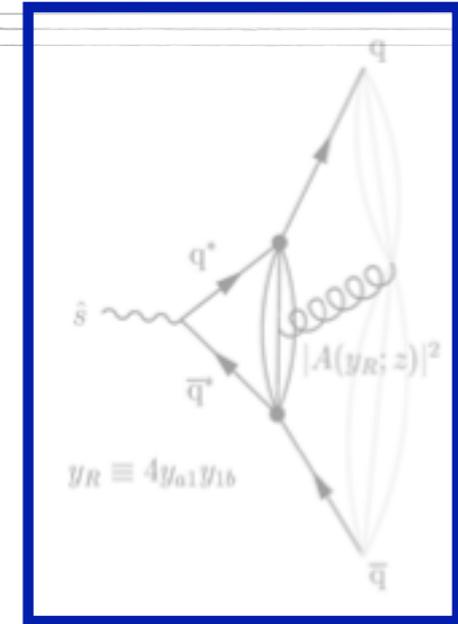
$$\begin{aligned} \chi^{(1)} &= \chi^{(1)} + \text{Born} \int_0^s \frac{d\Phi_3}{d\Phi_2} \quad \text{LL} \quad + \int_0^{Q_{\text{had}}^2} \frac{d\Phi_3}{d\Phi_2} \chi_{+1^{(0)}} \\ &= \frac{\alpha_s \hat{C}_F}{2\pi} \left( 2I_{q\bar{q}}^{(1)}(\epsilon, s) - 4 - 2I_{q\bar{q}}^{(1)}(\epsilon, s) + \frac{19 + \alpha + \frac{2}{3}\beta}{4} \right) \text{Born} \\ &= \frac{\alpha_s}{\pi} \left( 1 + \frac{1}{3} \left( \alpha + \frac{2}{3}\beta \right) \right) \text{Born} \quad \Rightarrow \quad \text{Finite terms cancel in 2-parton } \mathcal{O} \text{ (normalization)} \end{aligned}$$

# NLO Matching in 1 Slide

## ► First Order Shower expansion

$$\text{PS} \quad \int d\Phi_2 |M_2^{(0)}|^2 \int_{Q_{\text{had}}^2}^s \frac{d\Phi_3}{d\Phi_2} A_{q\bar{q}}(\dots) \delta(\mathcal{O} - \mathcal{O}(\{p\}_3))$$

Unitarity of shower  $\rightarrow$  3-parton real = 2-parton "virtual"



## ► 3-parton real correction ( $A_3 = |M_3|^2/|M_2|^2 + \text{finite terms}; \alpha, \beta$ )

$$w_3^{(R)} = |M_3^{(0)}|^2 - \left( A_3^0(\dots) + \frac{4\pi\alpha_s \hat{C}_F}{s} \left( \alpha + \beta \frac{s_{ar} + s_{rb}}{s} \right) \right) |M_2^{(0)}|^2$$

$$= -\frac{4\pi\alpha_s \hat{C}_F}{s} \left( \alpha + \beta \frac{s_{ar} + s_{rb}}{s} \right) |M_2^{(0)}|^2 \quad \Rightarrow \quad \text{Finite terms cancel in 3-parton } \mathcal{O}$$

## ► 2-parton virtual correction (same example)

$$w_2^{(V)} = 2\text{Re} \left[ M_2^{(1)} M_2^{(0)*} \right] + |M_2^{(0)}|^2 \int_0^s \frac{d\Phi_3}{d\Phi_2} A_{q\bar{q}}(\dots) + \int_0^{Q_{\text{had}}^2} \frac{d\Phi_3}{d\Phi_2} w_3^{(R)}$$

$$= \frac{\alpha_s \hat{C}_F}{2\pi} \left( 2I_{q\bar{q}}^{(1)}(\epsilon, s) - 4 - 2I_{q\bar{q}}^{(1)}(\epsilon, s) + \frac{19 + \alpha + \frac{2}{3}\beta}{4} \right) |M_2^{(0)}|^2$$

$$= \frac{\alpha_s}{\pi} \left( 1 + \frac{1}{3} \left( \alpha + \frac{2}{3}\beta \right) \right) |M_2^{(0)}|^2 \quad \Rightarrow \quad \text{Finite terms cancel in 2-parton } \mathcal{O} \text{ (normalization)}$$

# Approaches on the Market

## Hw/Py standalone

1<sup>st</sup> order matching for many processes, especially resonance decays

## AlpGen + Hw/Py

MLM + HW or PY showers

NOTE: If you just write "AlpGen" on a plot, we assume AlpGen standalone! (no showering or matching!) - very different from Alp+Py/Hw

## MadGraph + Hw/Py

MLM-slicing + HW or PY showers

## Sherpa

CKKW-slicing + CS-dipole showers

## Ariadne

CKKW-L-slicing + Lund-dipole showers

## MC@NLO

NLO with subtraction, 10%  $w < 0$   
+ Herwig showers

## POWHEG

NLO with unitarity; 0%  $w < 0$   
+ "truncated" showers + HW or PY

## (Vincia+Py8)

Still only for LEP

NLO + multileg with unitarity  
+ dipole-antenna showers

# Constraints

## and Tuning

# Constraining Models



- A wealth of data available at lower energies
- Used for constraining ('tuning') theoretical models (E.g., Monte Carlo Event Generators)

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- A wealth of data available at lower energies
- Used for constraining ('tuning') theoretical models (E.g., Monte Carlo Event Generators)

- The low-energy LHC runs are giving us a *unique chance* to fill in gaps in our knowledge at lower energies
- Which model would you trust more? One that also describes SPS, RHIC, Tevatron, Low-Energy LHC? Or one that doesn't?

**But wait ... which gaps?**

# Gaps

- QCD pheno evolving rapidly
- The models that were tested 20 years ago are not the models of today
- Capabilities of experiments are different today than 20 years ago (resolution, coverage, systematics,...)
- We define new observables, new quantities of interest, as knowledge evolves (e.g., IR safety)
- Also learned some hard lessons about data preservation and about 'truth' corrections



# 3 Kinds of Tuning



## 1. Fragmentation Tuning

**Non-perturbative:** hadronization modeling & parameters

**Perturbative:** jet radiation, jet broadening, jet structure

## 2. Initial-State Tuning

**Non-perturbative:** PDFs, primordial  $k_T$

**Perturbative:** initial-state radiation, initial-final interference

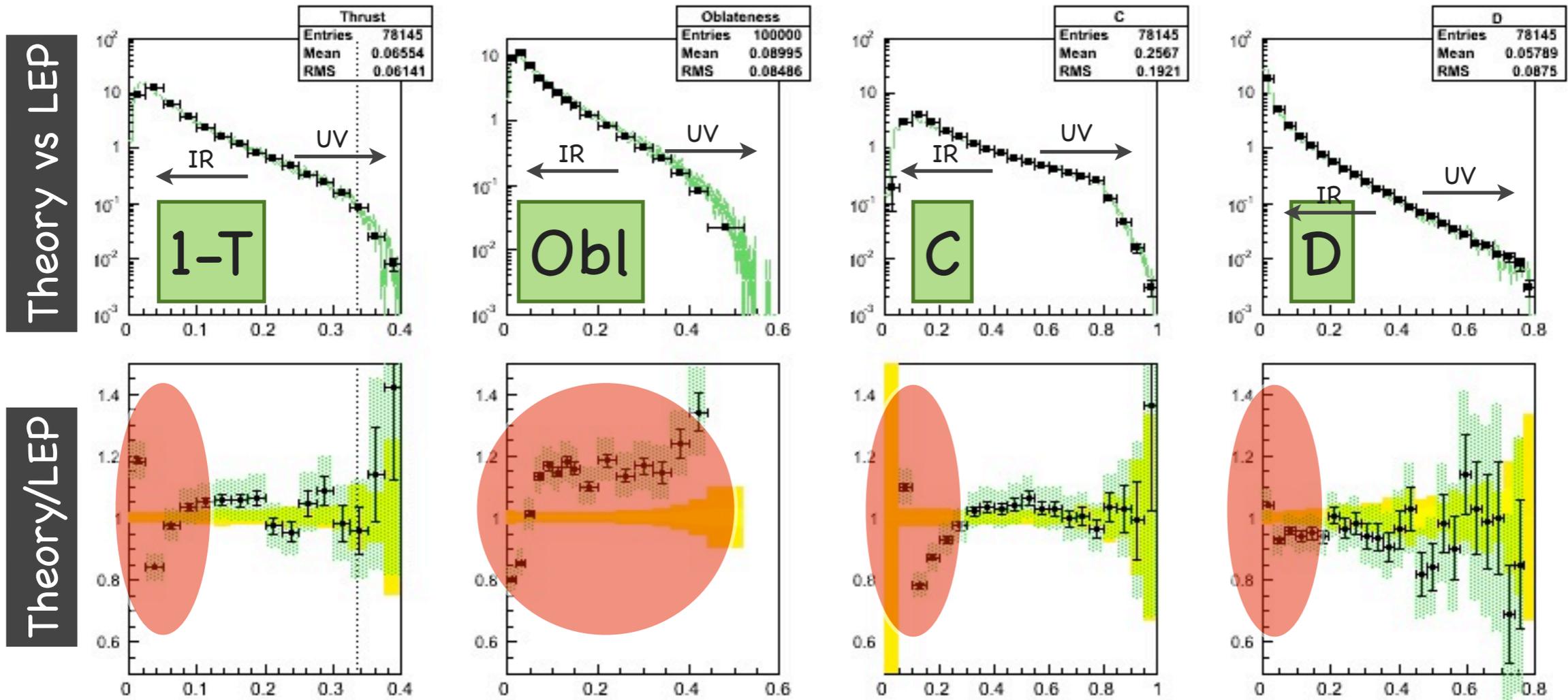
## 3. Underlying-Event & Min-Bias Tuning

**Non-perturbative:** Multi-parton PDFs, Beam Remnant fragmentation, Color (re)connections, collective effects, impact parameter dependence, ...

**Perturbative:** Multi-parton interactions, rescattering

# Pure pQCD - the "parton" level

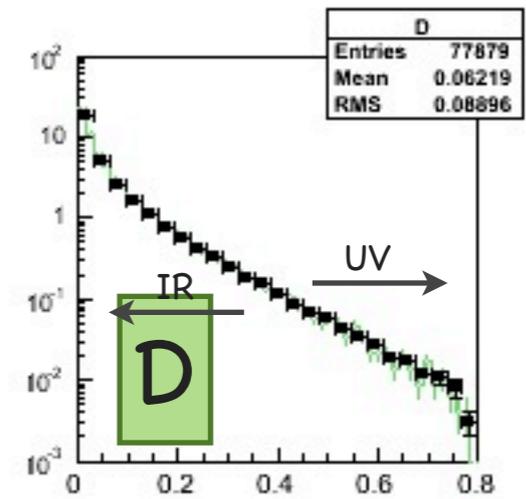
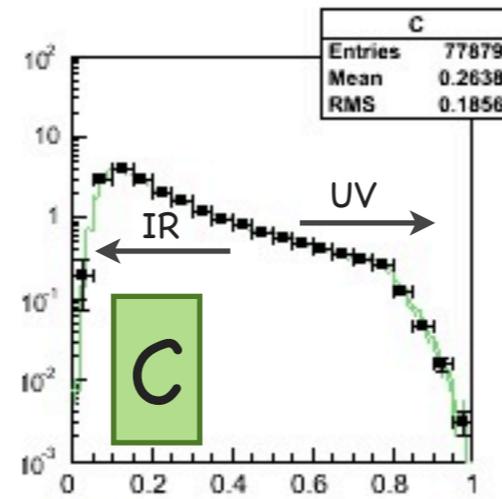
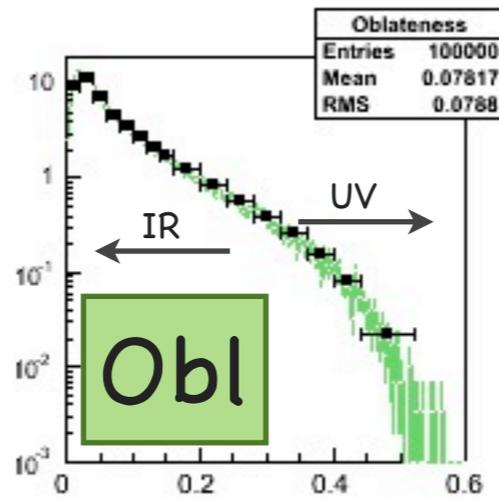
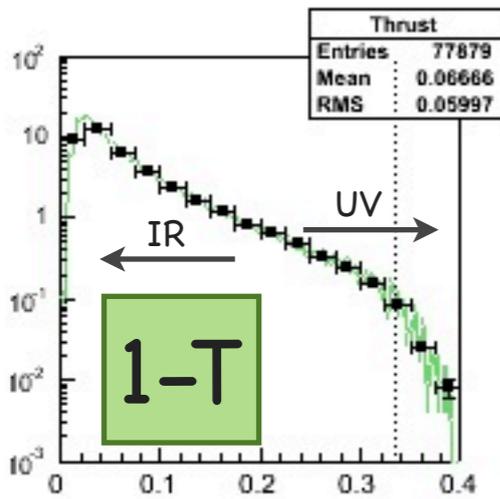
## Default PYTHIA 8 - No Hadronization



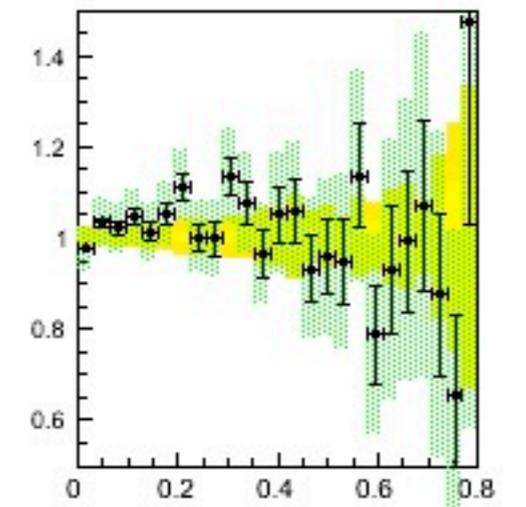
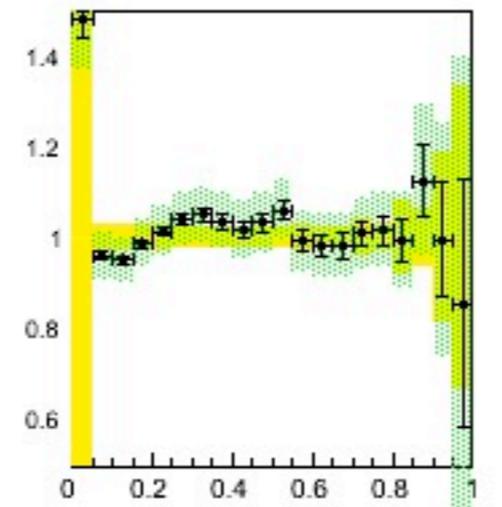
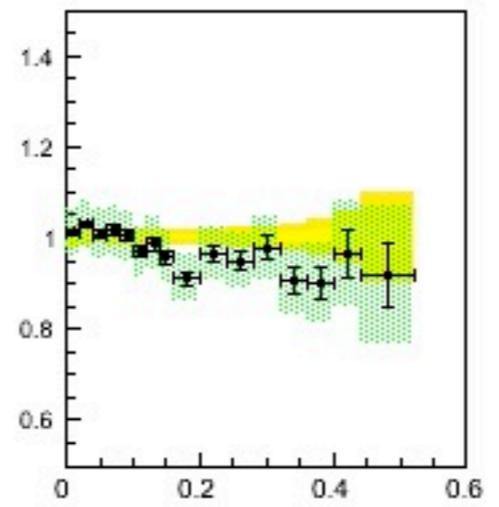
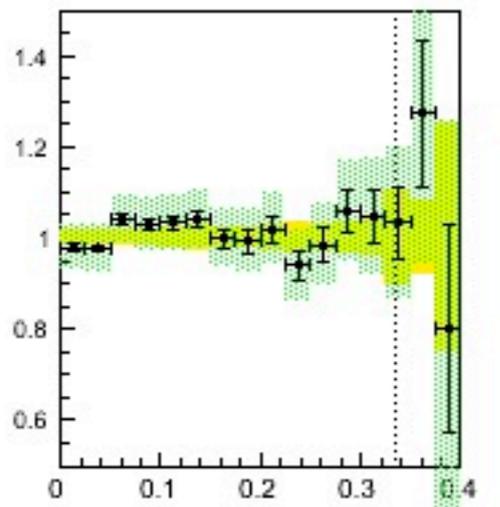
# Hadron Level

## Default PYTHIA 8 + Hadronization

Theory vs LEP



Theory/LEP



# PDG: Wait ... is this Crazy?

strong coupling constant

$\alpha_s(m_Z)$

0.1176(20)

---

## These results

Obtained with  $\alpha_s(M_Z) \approx 0.14 \neq$  World Average =  $0.1176 \pm 0.0020$

## Value of $\alpha_s$

Depends on the order and scheme

MC  $\approx$  Leading Order + LL resummation

Other leading-Order extractions of  $\alpha_s \approx 0.13 - 0.14$

Plus uncertainty from different effective scheme

## Not so crazy

Tune/measure even pQCD parameters with the actual generator.

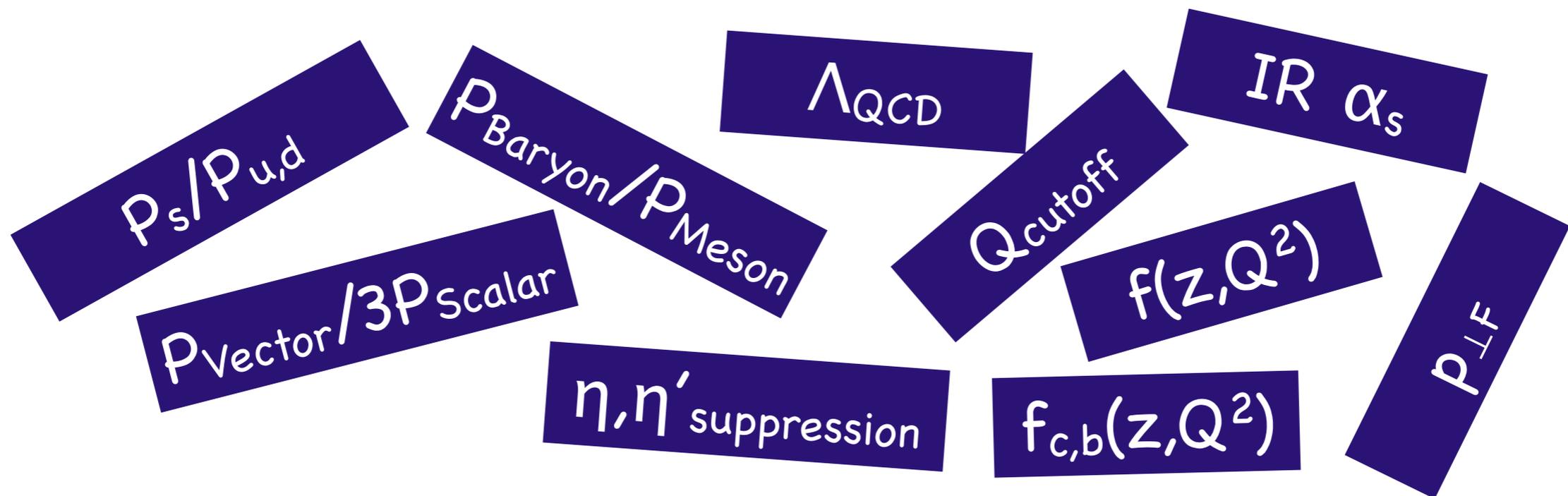
Sanity check = consistency with other determinations at a similar formal order, within the uncertainty at that order (including an (unknown) scheme redefinition to go to 'MC scheme')

# Tuning in the Infrared

## 1. Fragmentation Tuning

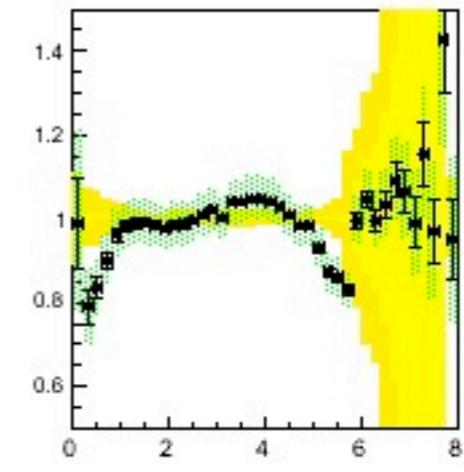
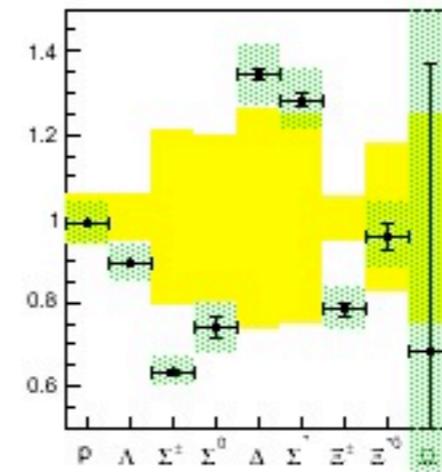
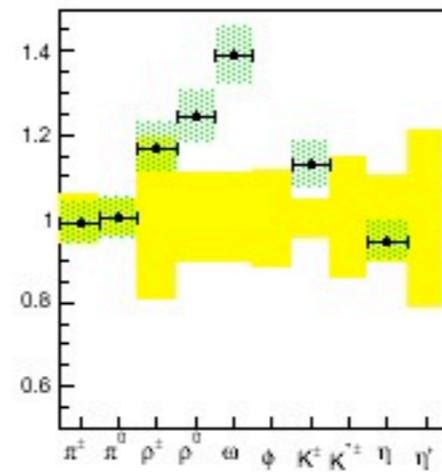
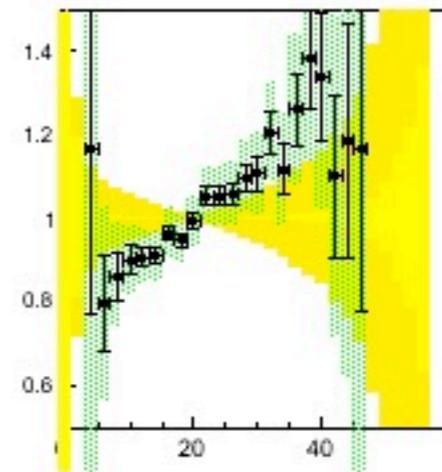
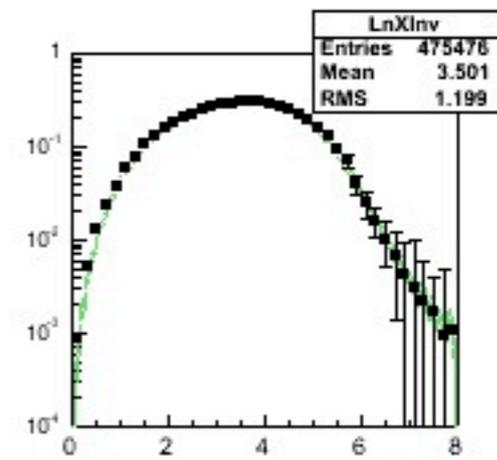
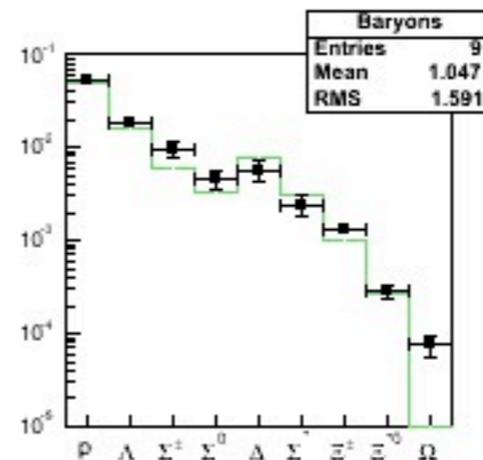
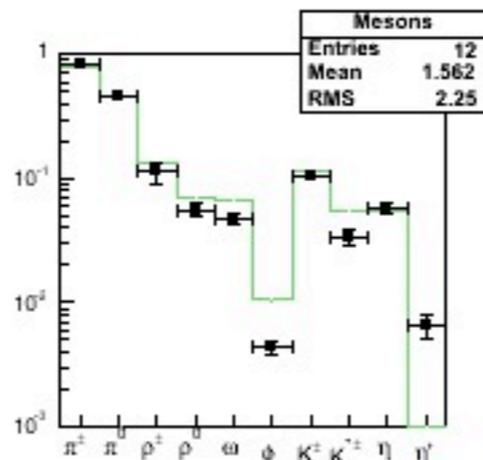
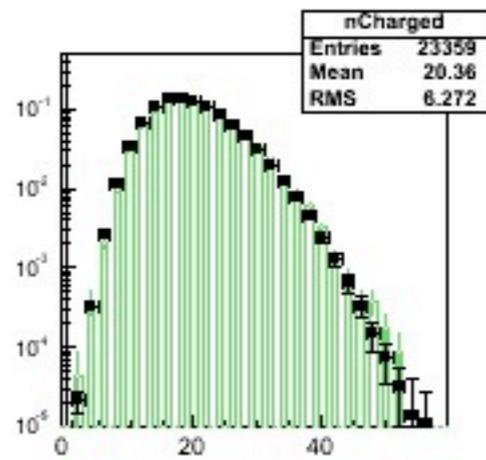
Constrain incalculable model parameters

Good model → good fit. Bad model → bad fit → improve model



# Before

PYTHIA 8.100



$N_{\text{ch}}$

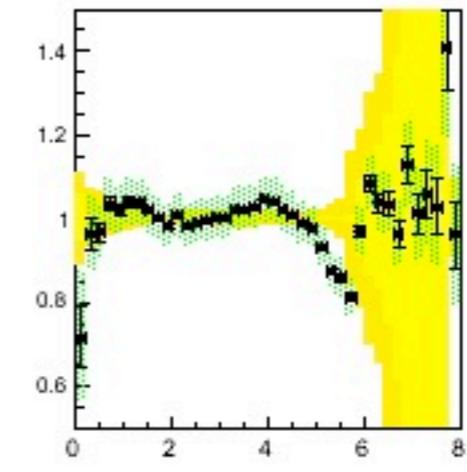
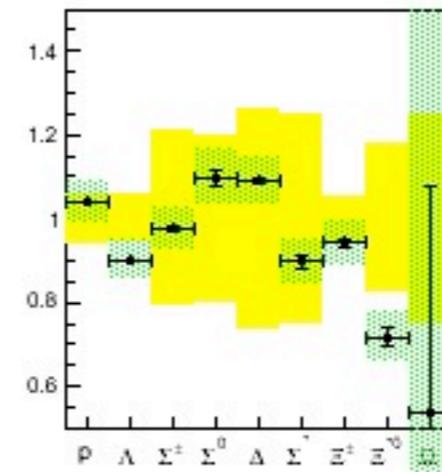
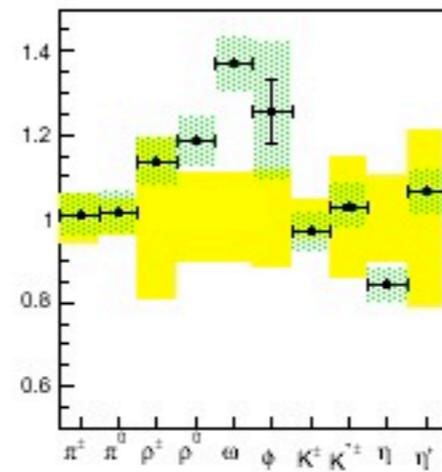
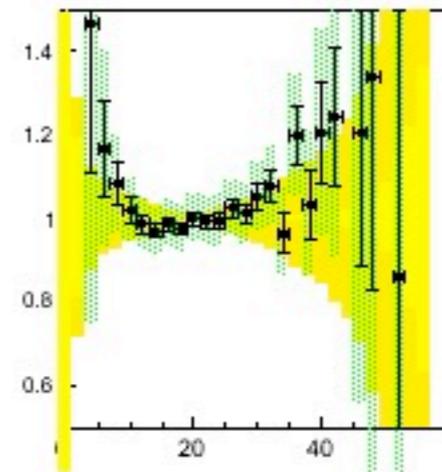
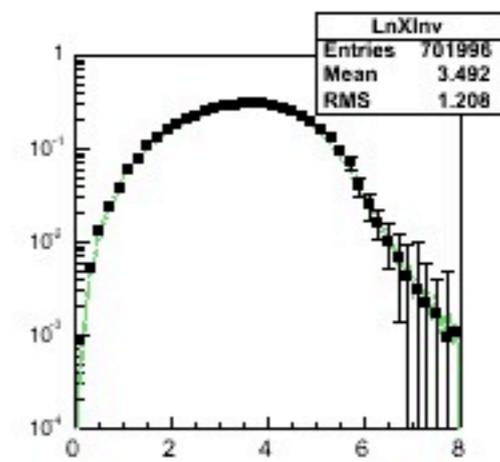
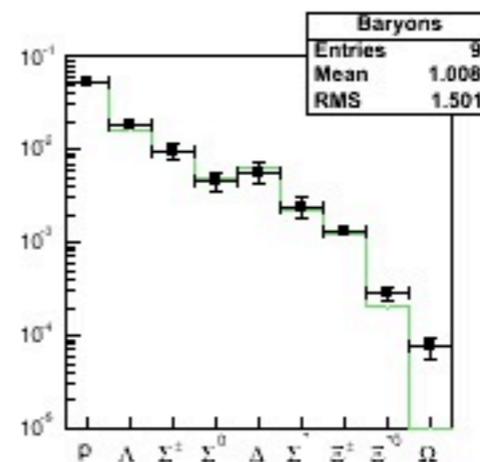
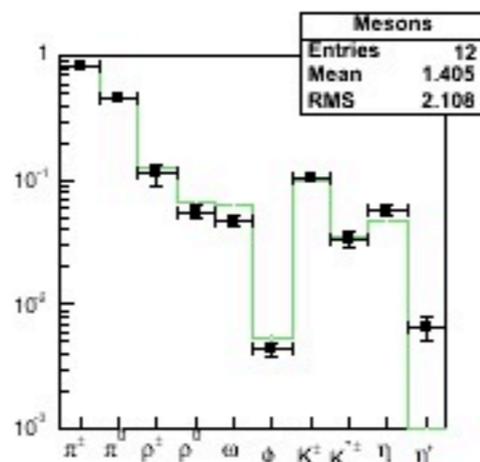
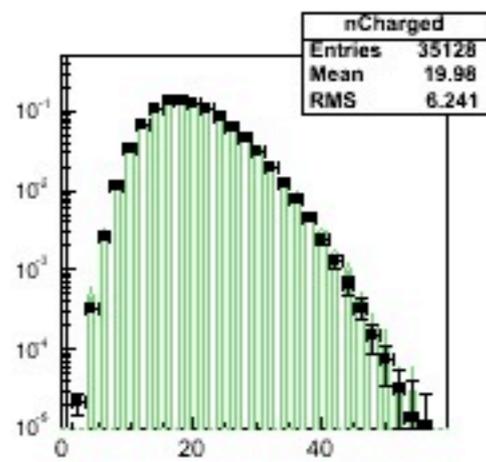
Mesons

Baryons

$\text{Ln}(1/x)$

# After

PYTHIA 8.135



$N_{\text{ch}}$

Mesons

Baryons

$\text{Ln}(1/x)$

# Fragmentation

- Normal MC Tuning Procedure:
  - Fragmentation and Flavour parameters constrained at LEP, then used in pp/ppbar (Jet Universality)
    - But pp/ppbar is a very different environment, at the infrared level!

# Fragmentation

- Normal MC Tuning Procedure:
  - Fragmentation and Flavour parameters constrained at LEP, then used in pp/ppbar (Jet Universality)
- Check fragmentation *in situ* at hadron colliders

---

  - $N$  and  $p_T$  spectra (and  $x$  spectra normalized to 'jet'/minijet energy?)  
**Identified particles** highly important to dissect fragmentation
  - Fully Exclusive → Particle-Particle CORRELATIONS
  - (How) do the spectra change with (pseudo-)rapidity? (forward = synergy with cosmic ray fragmentation, different dominating production/fragmentation mechanisms as fct of rapidity? E.g., compare LHCb with central?)
  - How do they change with event activity? (cf. heavy-ion ~ central vs peripheral collisions, hard trigger event (UE))

# Tuning the Initial State

PS, "The Perugia tunes", arXiv:1005.3457 [hep-ph]

## 2. Initial state

Constrain  $\Lambda$  (or  $\alpha_s$ )  
and "primordial  $k_T$ "

Similar to fitting  
PDF functions

Main reference:

Drell-Yan  $p_T$ , + Jets  
(also DIS)

Complication:

Initial-Final  
interference!

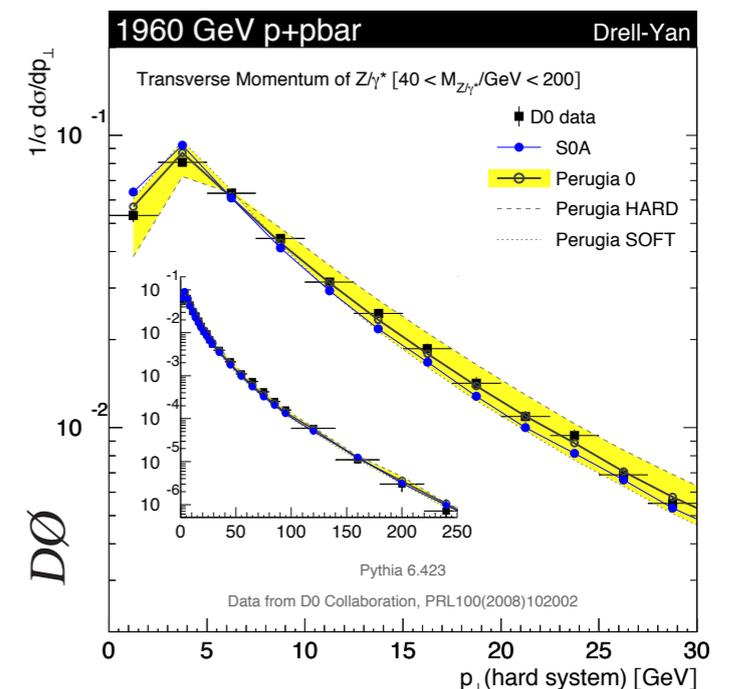
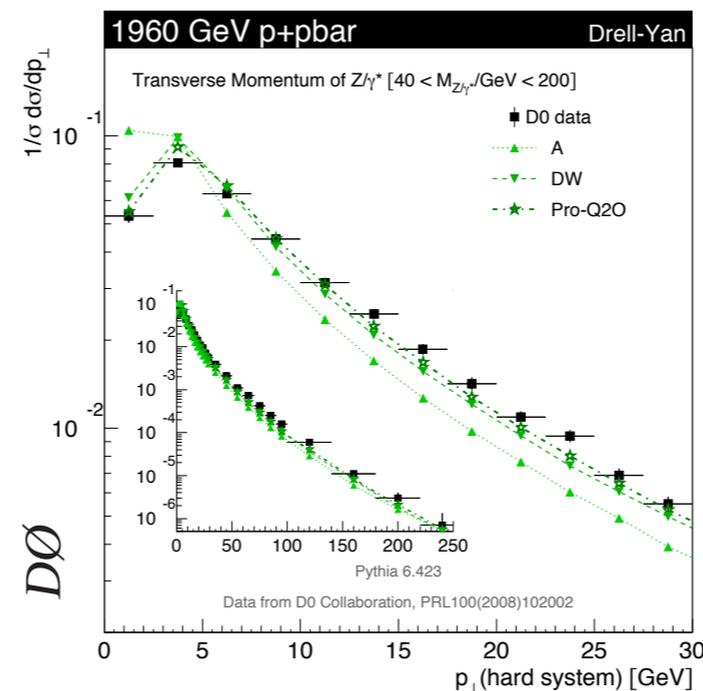
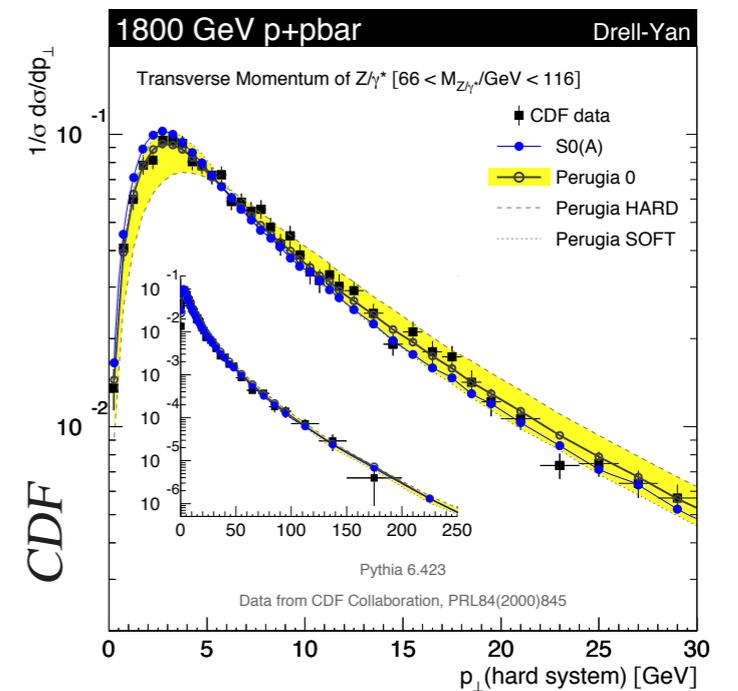
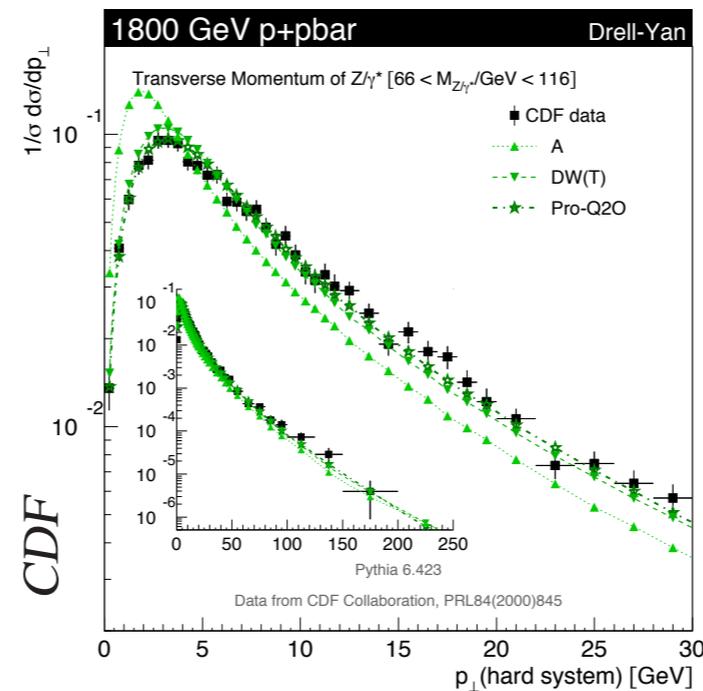


Figure 1: Comparisons to the CDF and DØ measurements of the  $p_{\perp}$  of Drell-Yan pairs [51,52]. Insets show the high  $p_{\perp}$  tails. Left: virtuality ordered showers. Right:  $p_{\perp}$  ordered showers. See [42] for

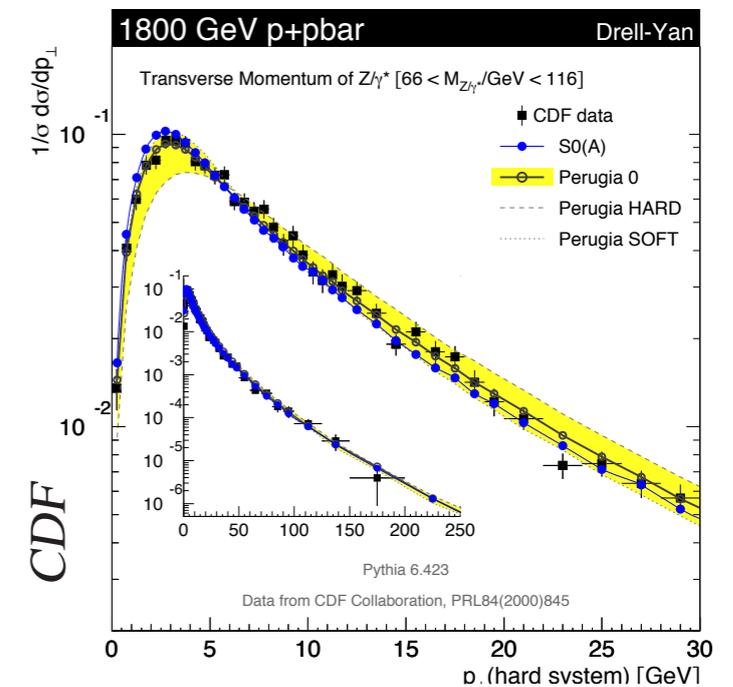
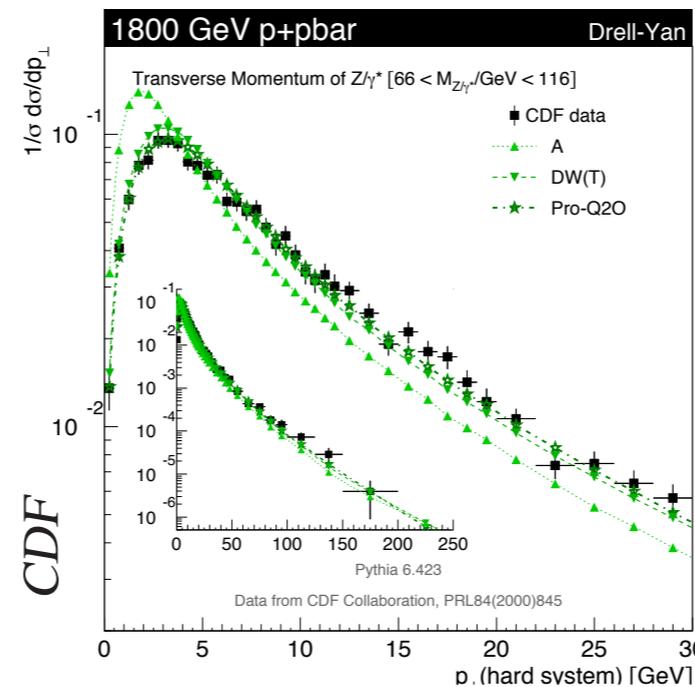
# Tuning the Initial State

PS, "The Perugia tunes", arXiv:1005.3457 [hep-ph]

## 2. Initial state

Constrain  $\Lambda$  (or  $\alpha_s$ )  
and "primordial  $k_T$ "

(Comment): What I learned  
from the Tevatron



**Observe:** tune-A predicts  $\langle p_{\perp Z} \rangle \approx 9.7$  GeV (# taken from Y. Gehrstein's slides)

(Note: the ISR parameters had not been tuned; the ISR renormalization scale had not been touched in Tune A.)

Tune A undershoots  $\langle p_{\perp Z} \rangle$  by  $\approx 20\%$ . **Not too bad** for LO+LL at  $Q \approx 10$  GeV

→ this model not optimal at subleading level. Conclusion depends on nature of missing terms: renormalization scale for ISR? Kinematics dependence? a few GeV of "intrinsic  $k_T$ "?

Answer not clear yet → Theoretical uncertainty

→ what you learn depends on expectation.

Neither "fudging the MC" nor "whining about it" can replace "thinking about it".

# Min-Bias & Underlying Event

## Main Parameters

### Number of MPI



**Infrared Regularization scale** for the QCD  $2 \rightarrow 2$  (Rutherford) scattering used for multiple parton interactions (often called  $p_{T0}$ )  $\rightarrow$  size of overall activity

### Pedestal Rise



**Proton transverse mass distribution**  $\rightarrow$  difference between central (active) vs peripheral (less active) collisions

### Strings per Interaction



**Color correlations** between multiple-parton-interaction systems  $\rightarrow$  shorter or longer strings  $\rightarrow$  less or more hadrons per interaction

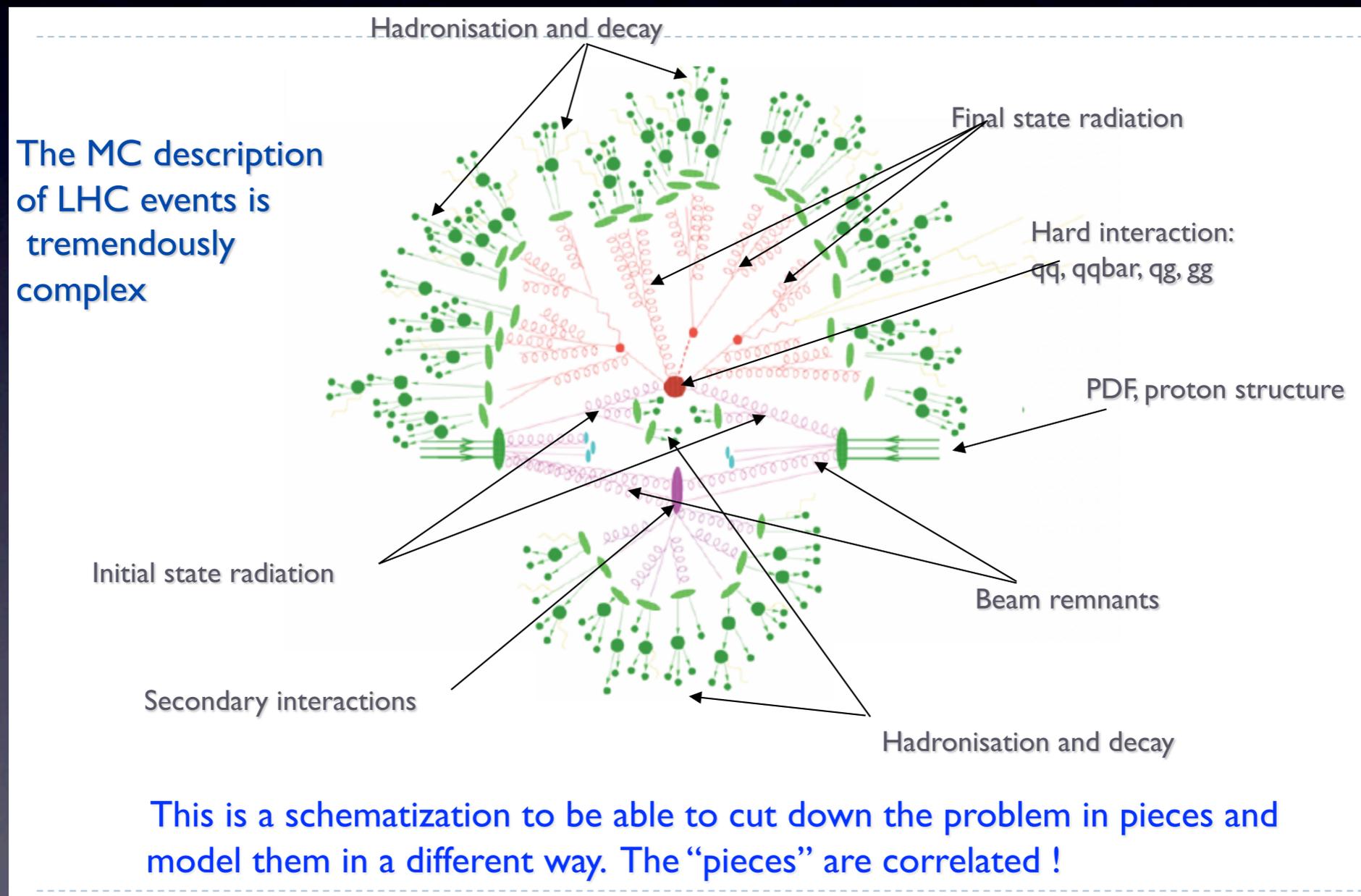
### Diffraction



+ (for Min-Bias): **diffractive mixture** and modeling

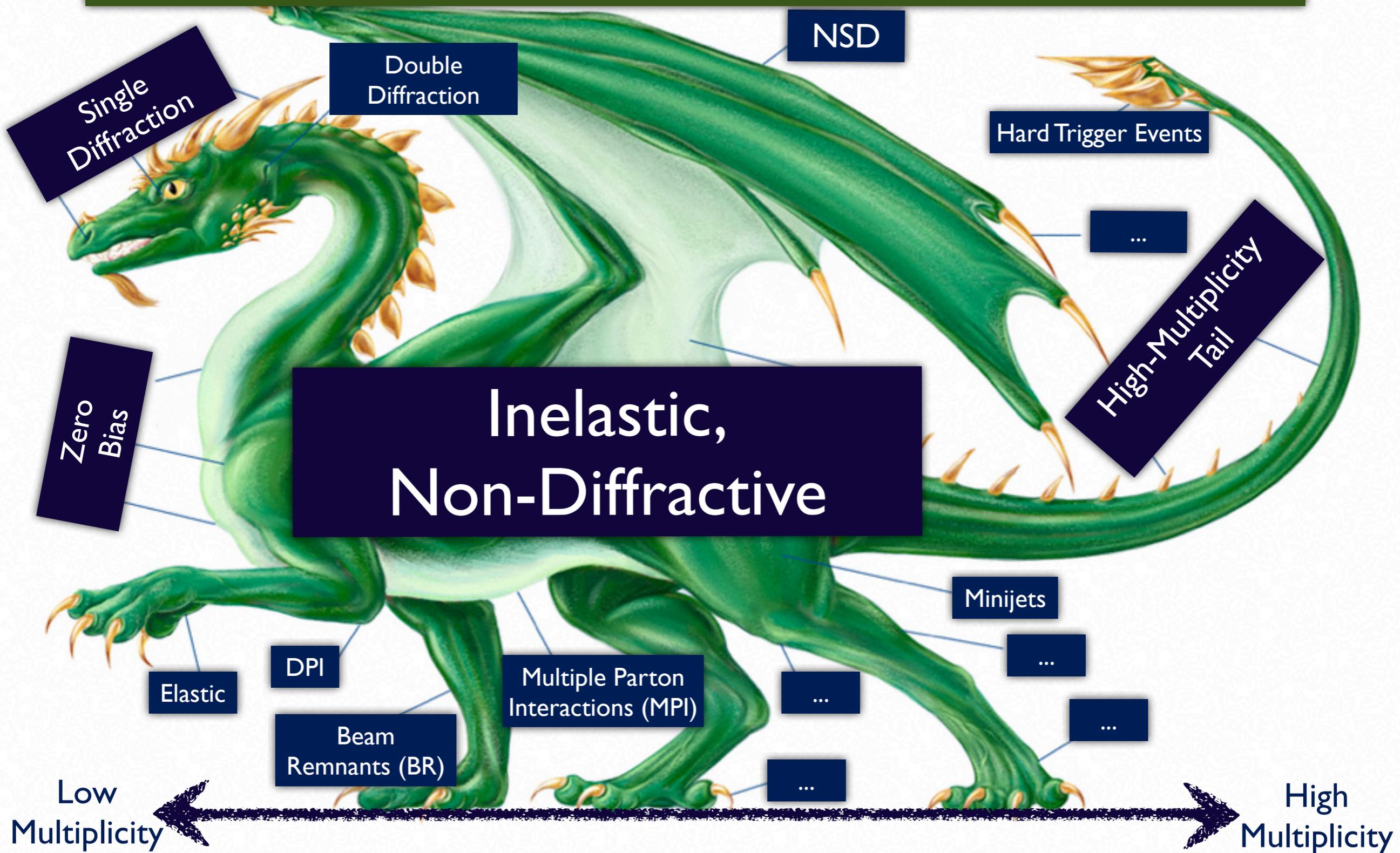
# Dissecting Minimum-Bias

**A lab for** testing theory models and detector performance with high statistics



(illustration by F. Krauss)

# Dissecting Minimum-Bias

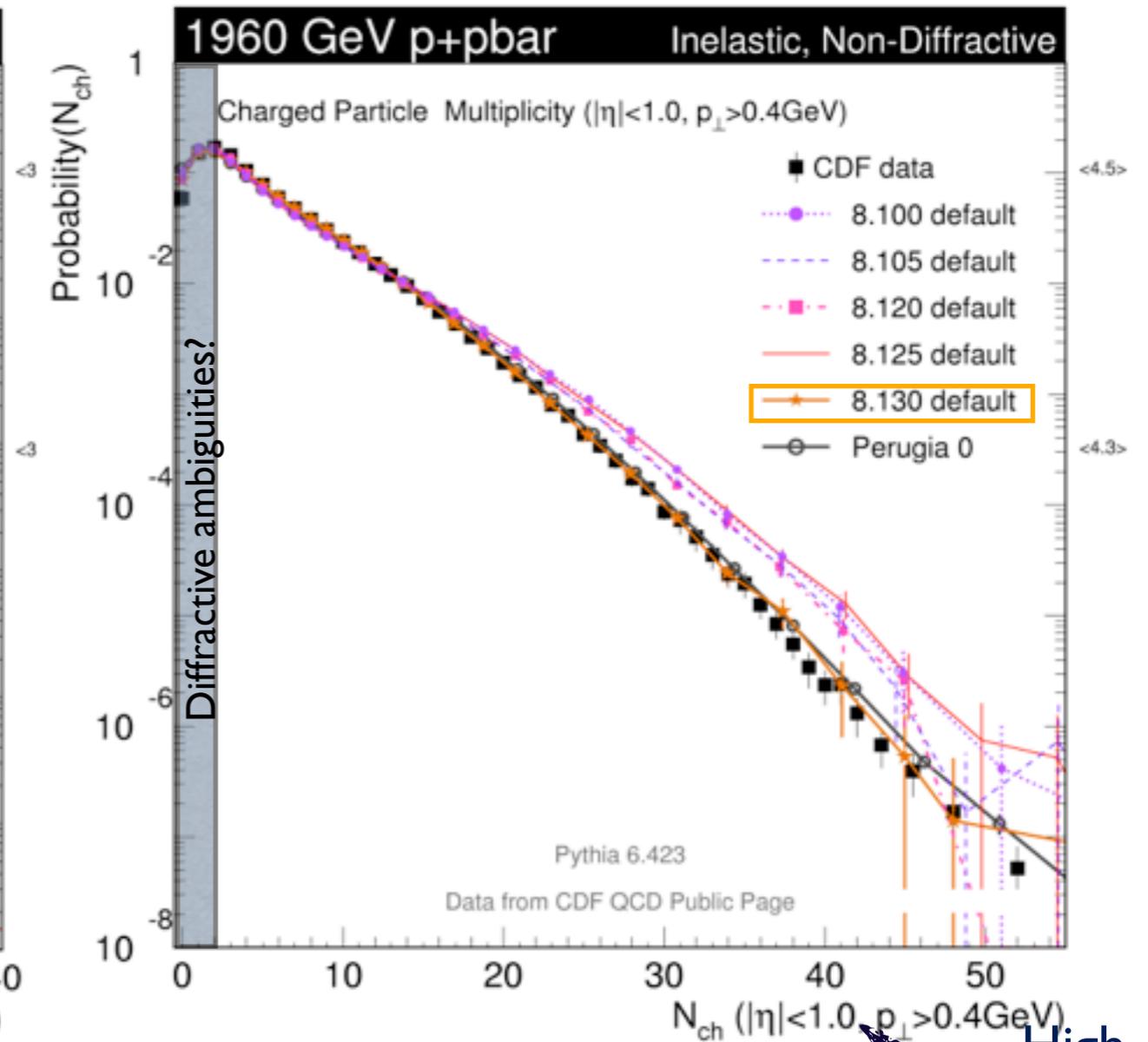
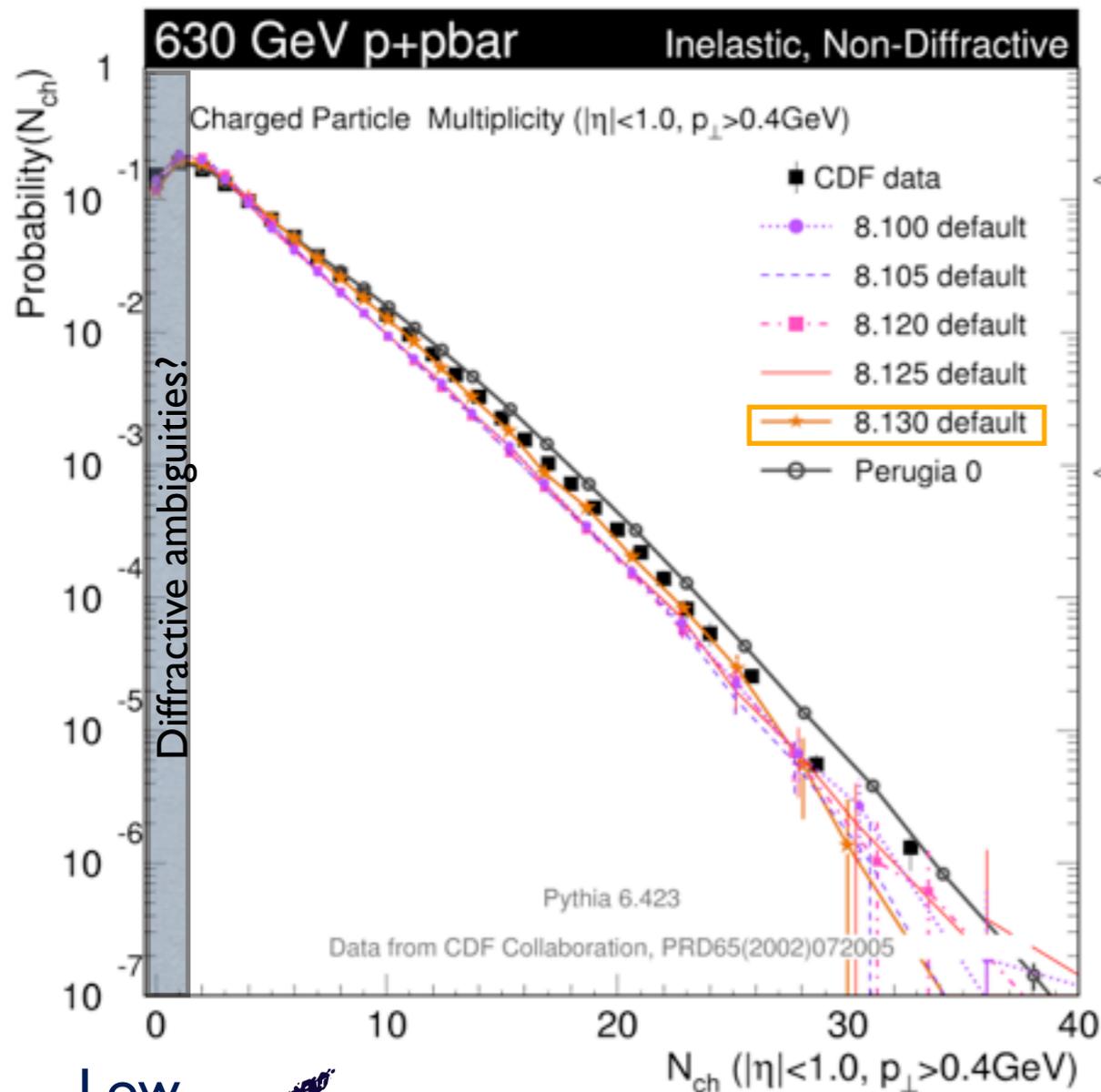


# Minimum-Bias

630 GeV

Multiplicity Distribution

1960 GeV



Low Multiplicity

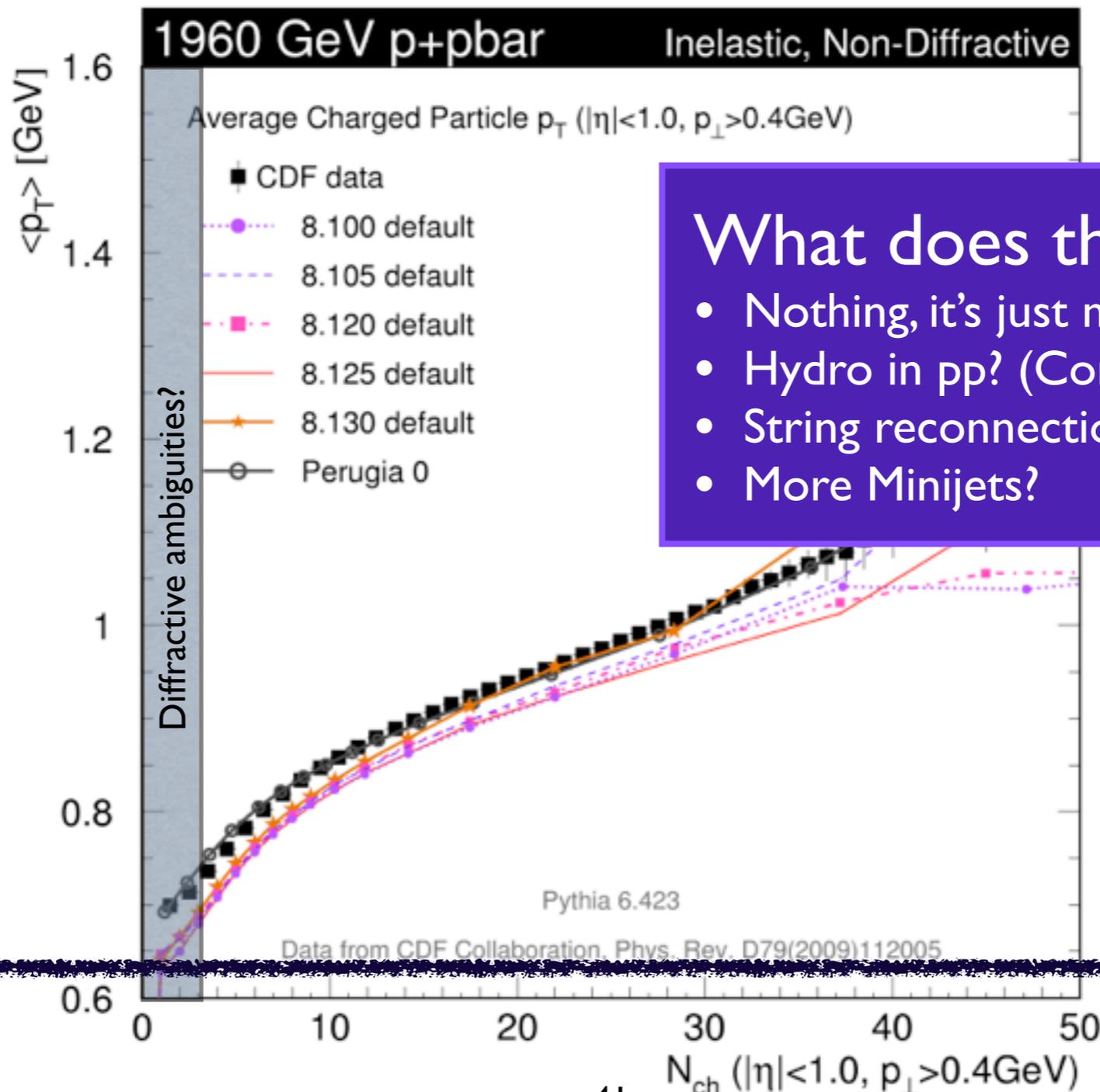


High Multiplicity

→ Constrain energy scaling

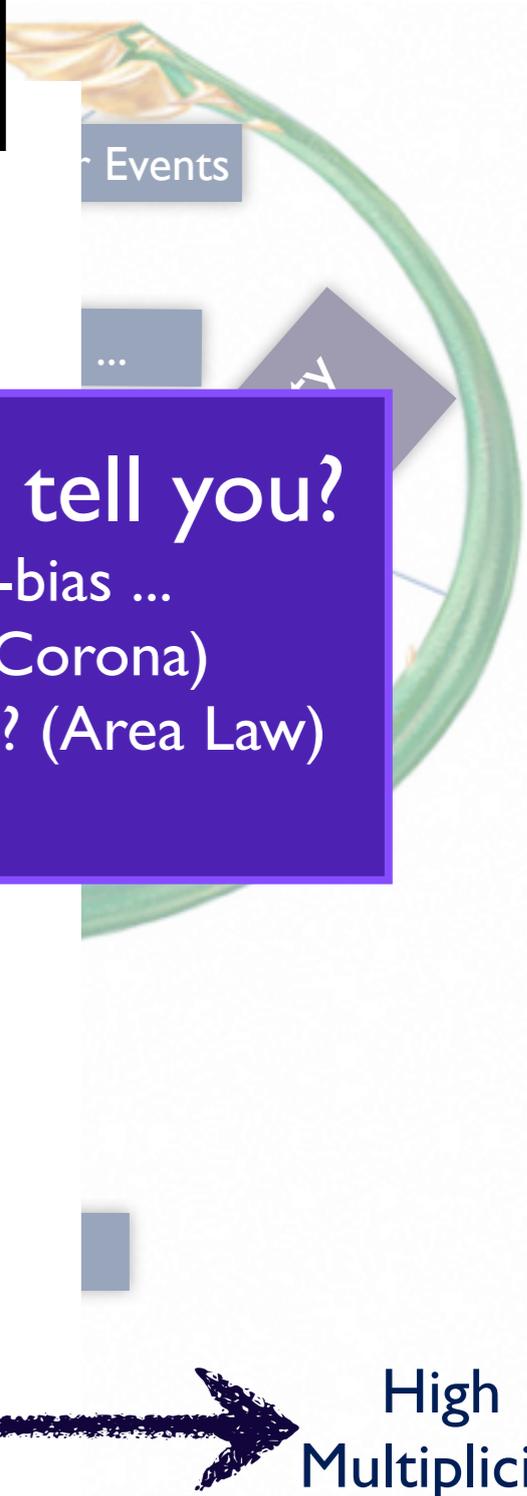
# Minimum-Bias

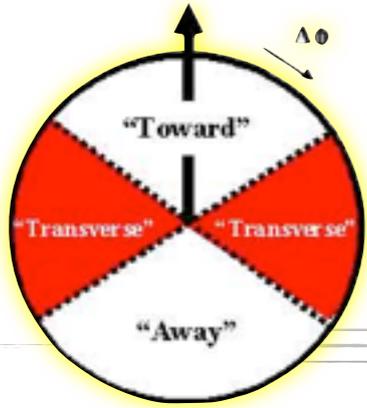
## Average Track $p_T$ vs Multiplicity



What does this tell you?

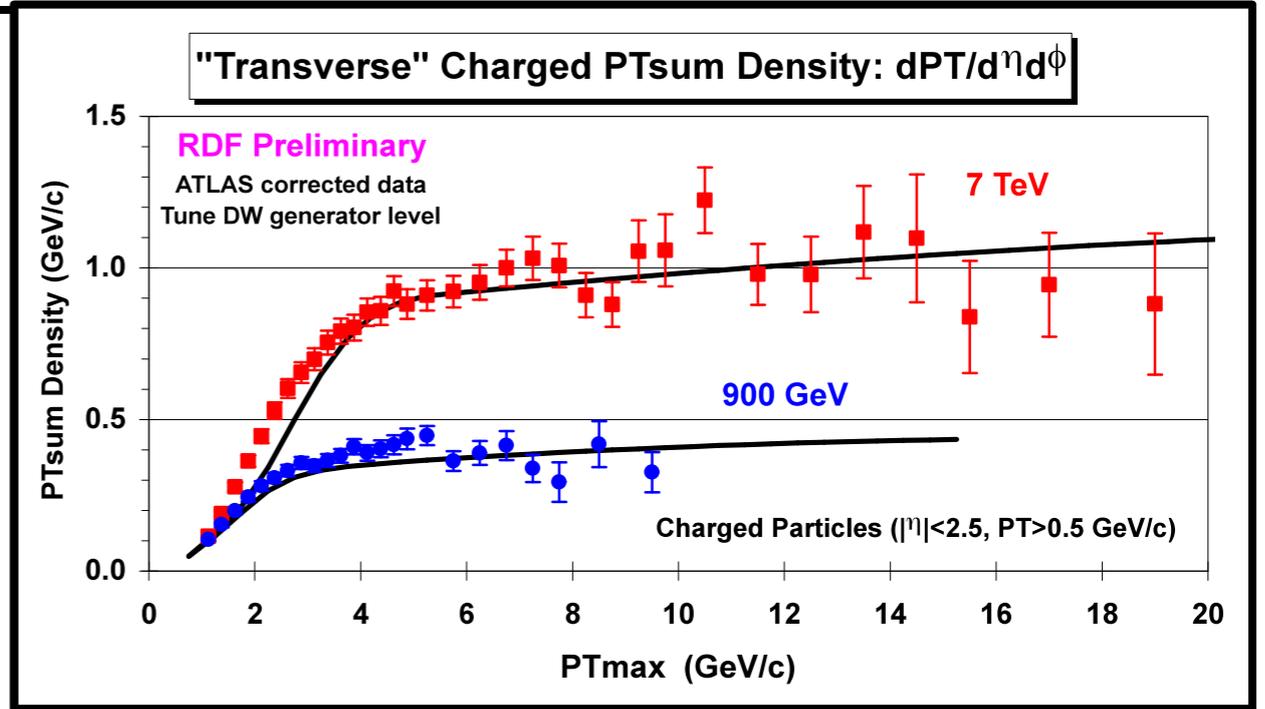
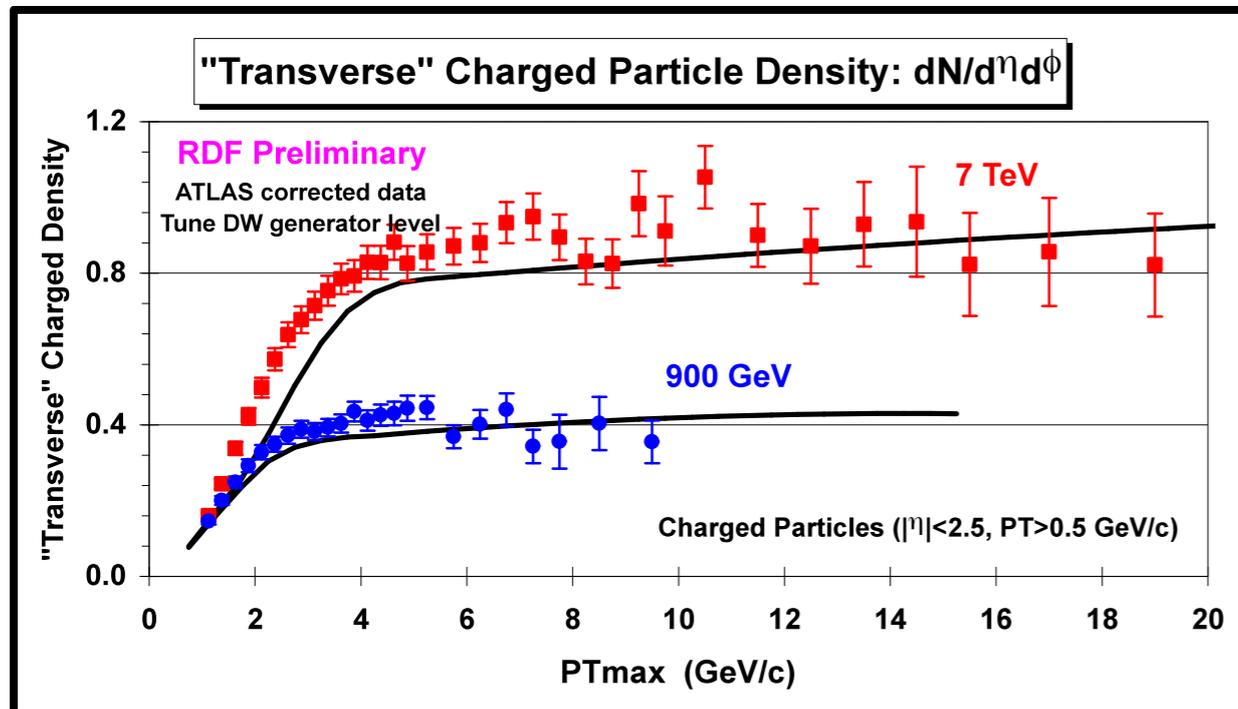
- Nothing, it's just min-bias ...
- Hydro in pp? (Core/Corona)
- String reconnections? (Area Law)
- More Minijets?





# Underlying Event

LHC from 900 to 7000 GeV - ATLAS



Track Density (TRANS)

Sum(pT) Density (TRANS)

Not Infrared Safe

(more) Infrared Safe

Large Non-factorizable Corrections

Large Non-factorizable Corrections

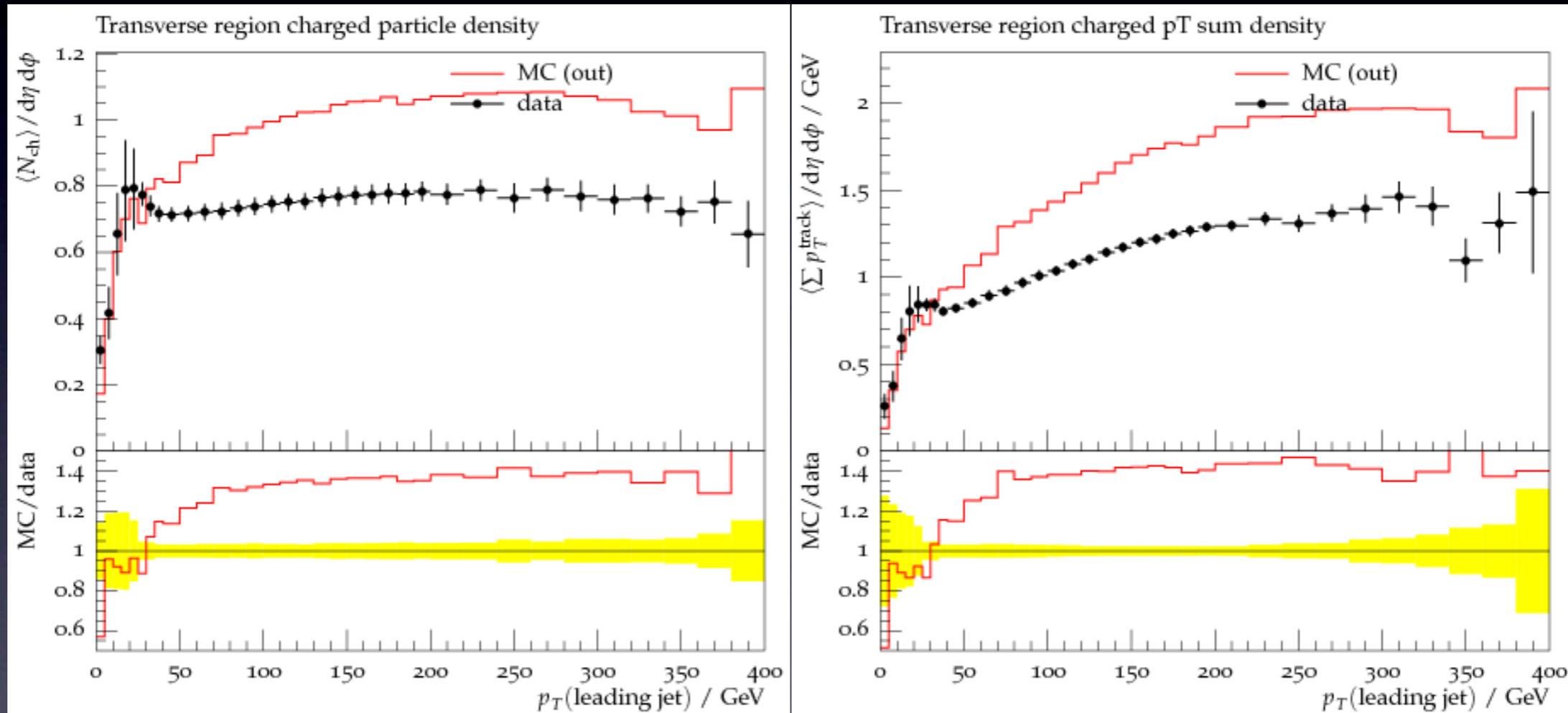
Prediction off by  $\approx 10\%$

Prediction off by  $< 10\%$



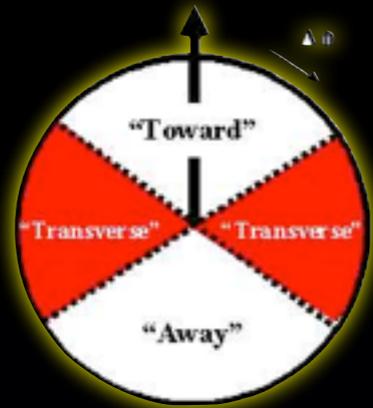
# The Snag!

et+Professor (H. Hoeth) shows it fails miserably for UE  
 (nick Field's transverse flow as function of jet  $p_{\perp}$ ):



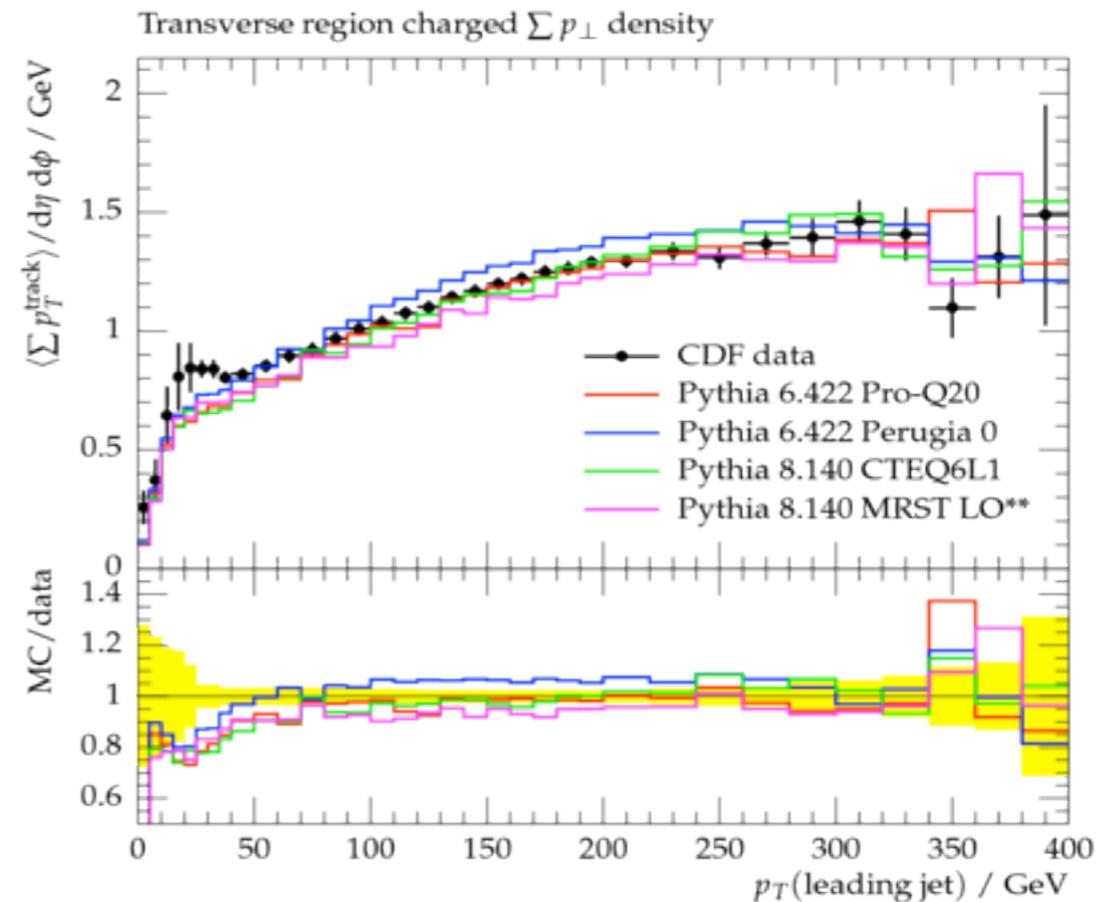
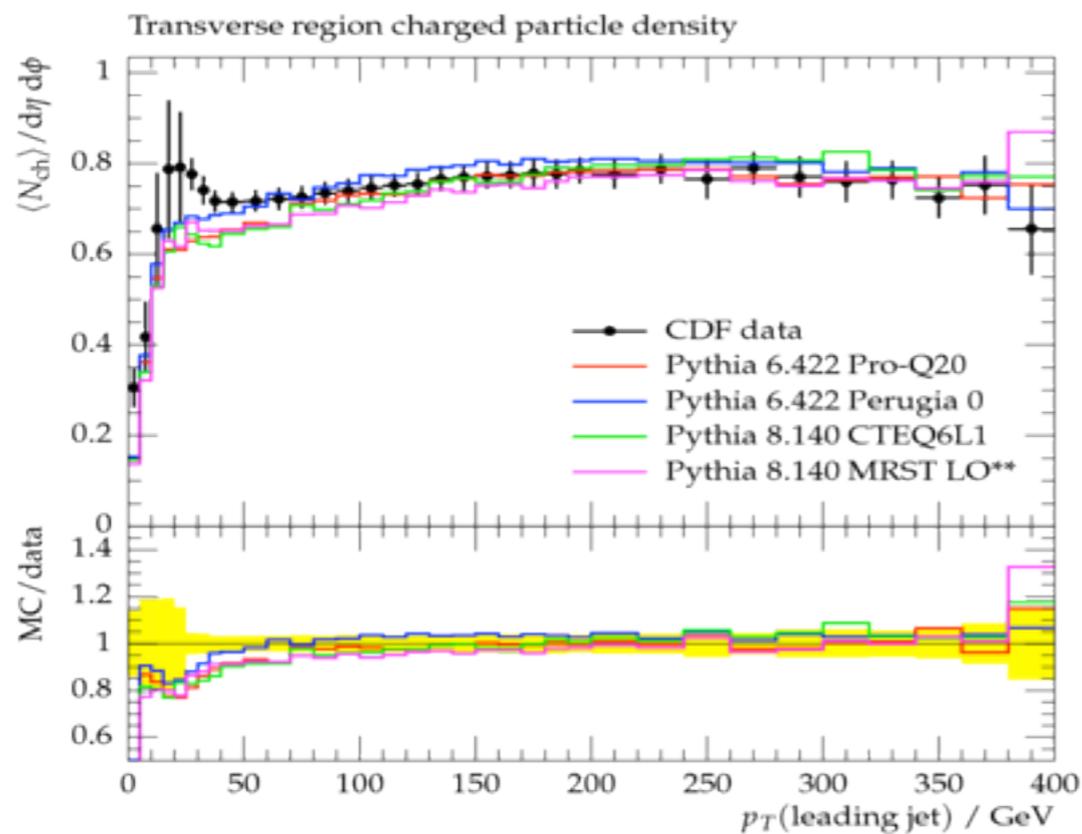
**Where did we go wrong?** ← Note: *not* “we have to fudge it again”

MC Distributions courtesy of the Professor tuning Collaboration  
 Data from the CDF Underlying-Event studies



# 2 Days Ago ...

Pythia 8.140



Plots from R. Corke

A missing initial-final interference effect (coherence)



J. D. Bjorken

# Monte Carlo Tools for Collider Physics

“Another change that I find disturbing is the rising tyranny of Carlo. No, I don’t mean that fellow who runs CERN, but the other one, with first name Monte.

The simultaneous increase in detector complexity and in computation power has made simulation techniques an essential feature of contemporary experimentation. The Monte Carlo simulation has become the major means of visualization of not only detector performance but also of physics phenomena. So far so good.

But it often happens that the physics simulations provided by the the MC generators carry the authority of data itself. They look like data and feel like data, and if one is not careful they are accepted as if they were data. All Monte Carlo codes come with a GIGO (garbage in, garbage out) warning label. But the GIGO warning label is just as easy for a physicist to ignore as that little message on a packet of cigarettes is for a chain smoker to ignore. I see nowadays experimental papers that claim **agreement with QCD** (translation: someone’s simulation labeled QCD) and/or **disagreement with an alternative piece of physics** (translation: an unrealistic simulation), without much evidence of the inputs into those simulations.”

Authors: Can we do better than the GIGO label? Uncertainty Bands  
 Users: Account for parameters + pertinent cross-checks and validations