The Underlying Event from Tevatron to LHC

P. Skands (CERN)

Standard Model Benchmarks at the Tevatron and LHC, Fermilab, Nov 19-20, 2010

Min-Bias and UE

Minimum-Bias High-Statistics reference laboratory

Study fragmentation: Compare to ee!

Study hadron collisions: Scaling | Soft-QCD | High Multiplicity | Diffraction | ...

No hard scale → *all* observables depend significantly on IR physics
10-20% precision is *very good*

Min-Bias and UE

Minimum-Bias

High-Statistics reference laboratory

Study fragmentation: Compare to ee!

Study hadron collisions: Scaling | Soft-QCD | High Multiplicity | Diffraction | ...

No hard scale → *all* observables depend significantly on IR physics
10-20% precision is *very good*

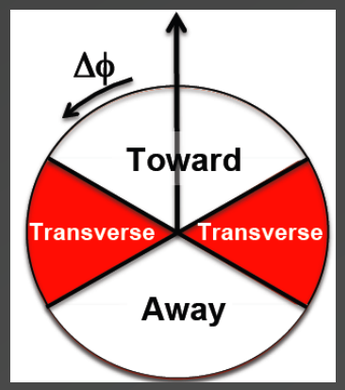
Underlying Event

Pedestal effect → larger than min-bias

Multiple parton interactions → multiple (mini)jets

Large fluctuations

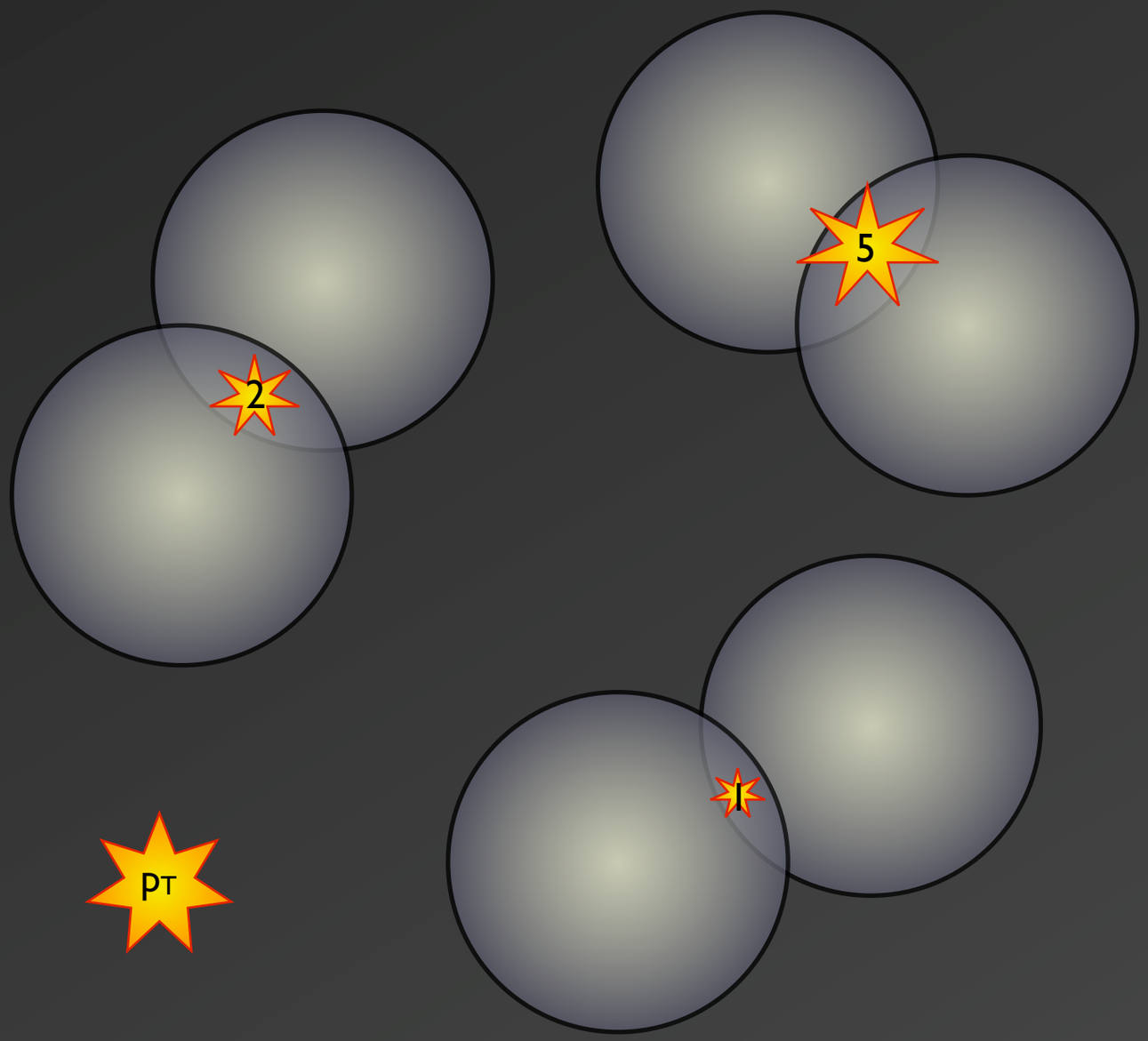
Hard scale present, but look at observables that don't (explicitly) involve it
10-20% precision is *very good*



The Pedestal Effect

and Multiple Parton-Parton Interactions

MINIMUM BIAS



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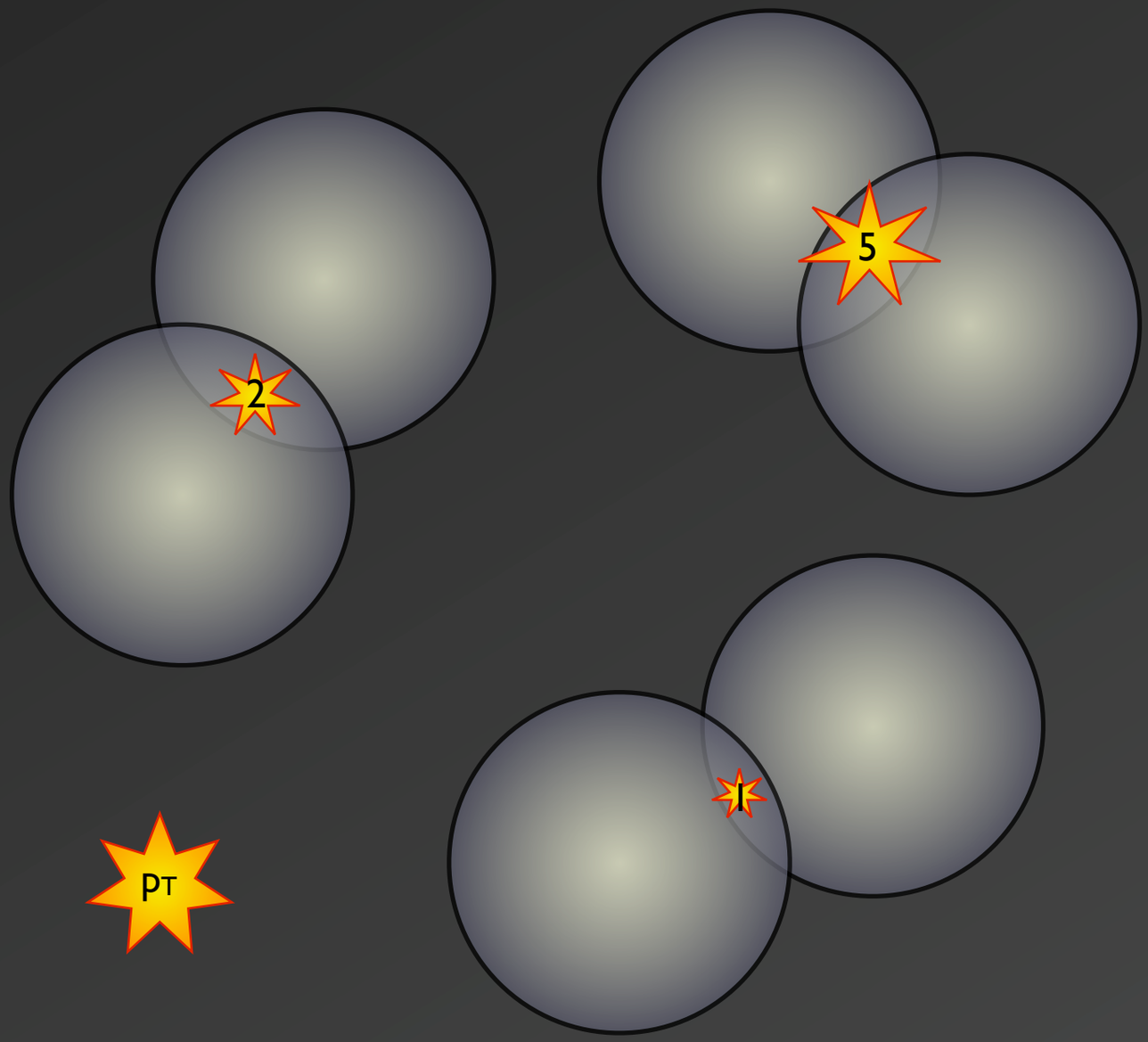
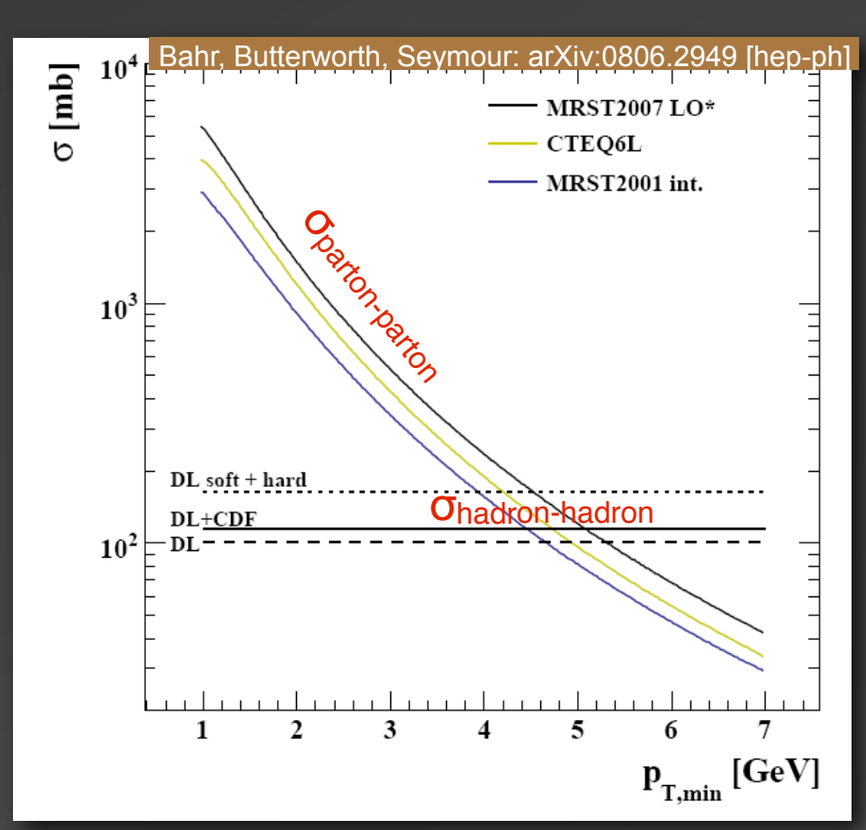


$\sigma_{\text{parton-parton}} > \sigma_{\text{hadron-hadron}}$



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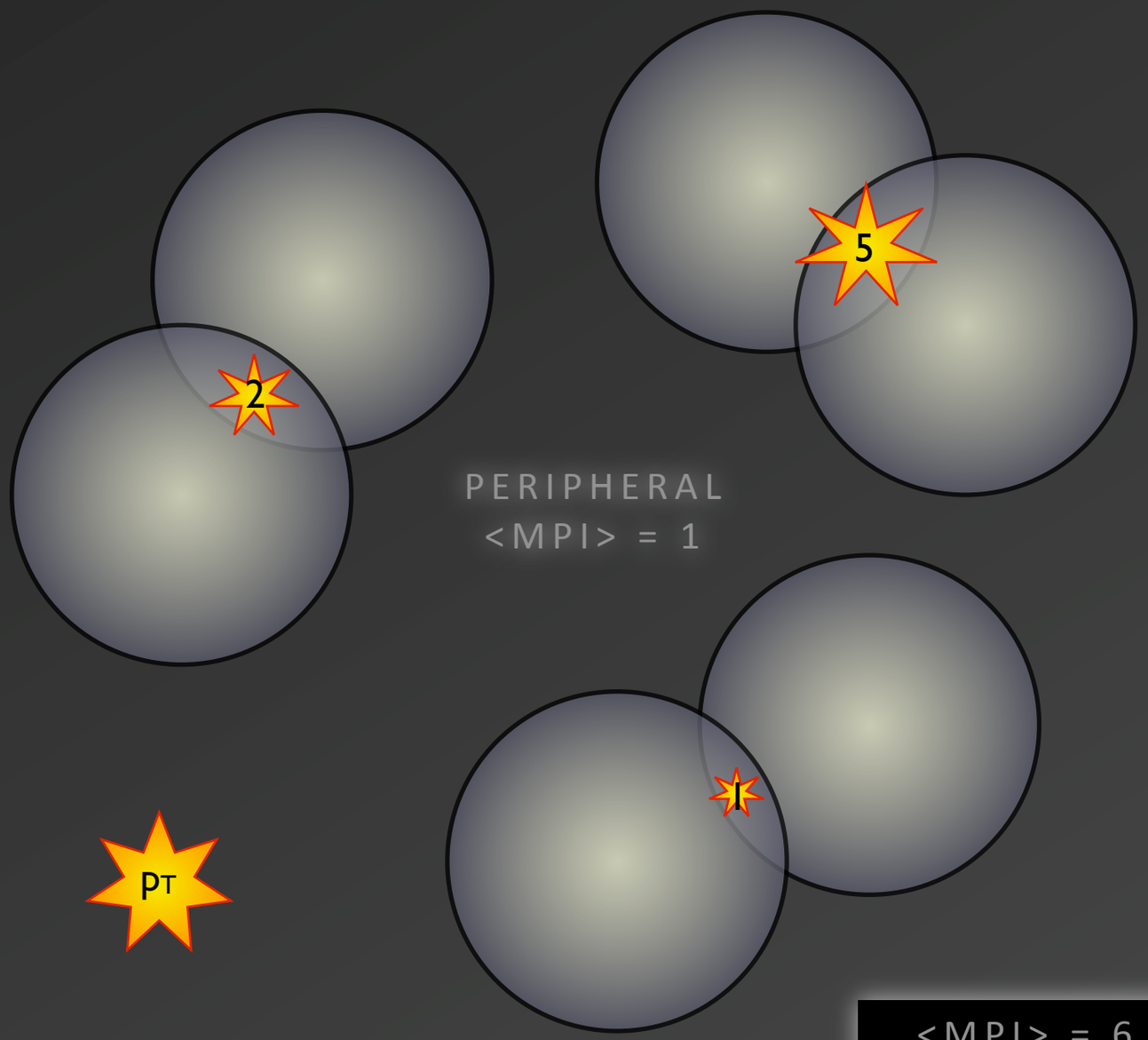
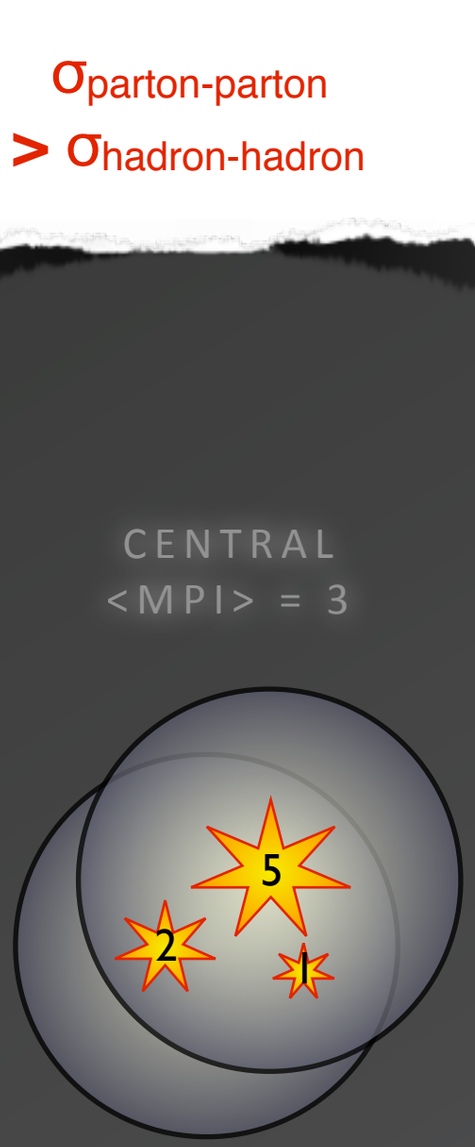


+



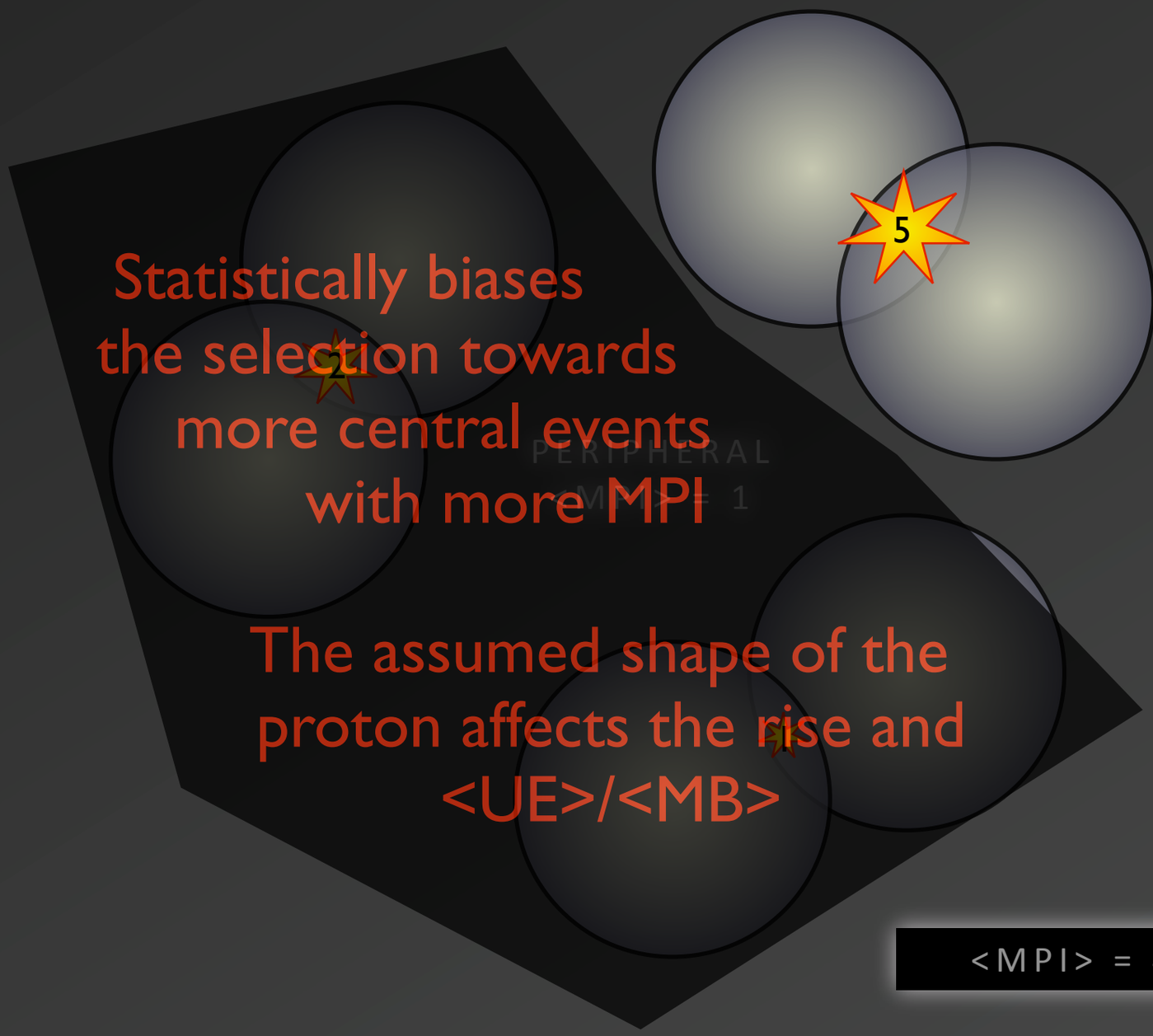
$\sigma_{parton\text{-}parton} > \sigma_{hadron\text{-}hadron}$

<MPI> = 6 / 4 = 1.5

The Pedestal Effect

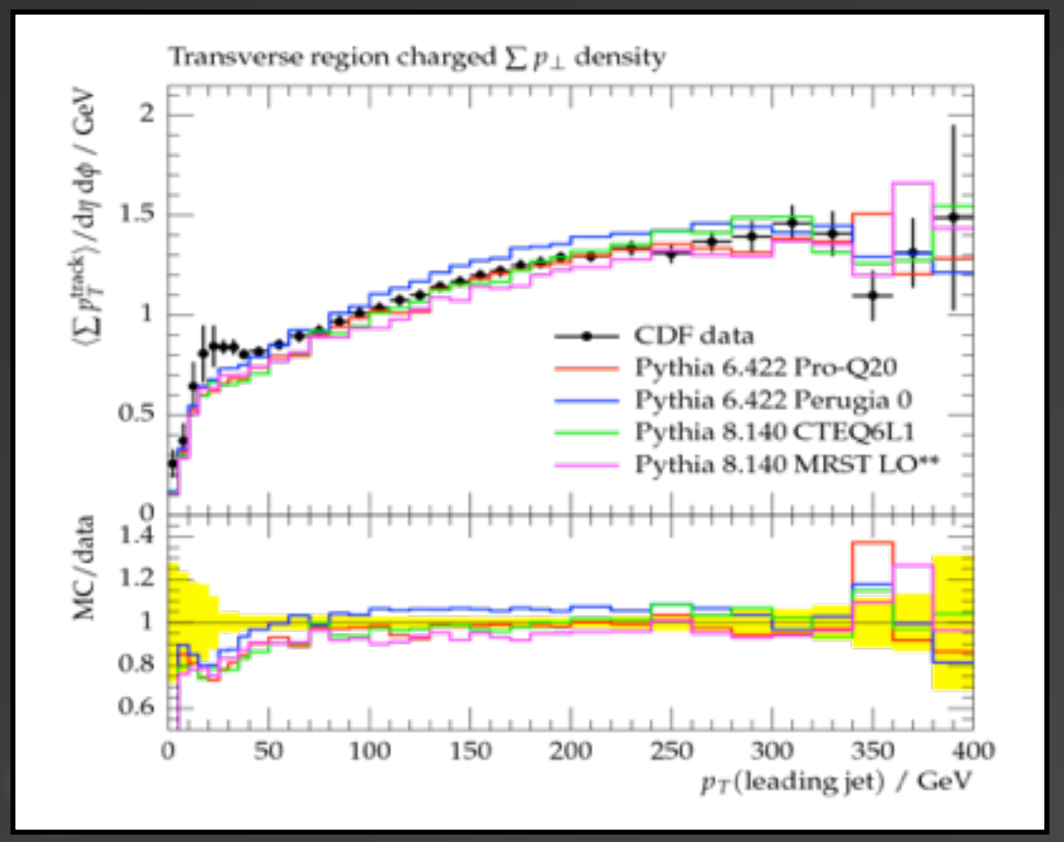
and Multiple Parton-Parton Interactions

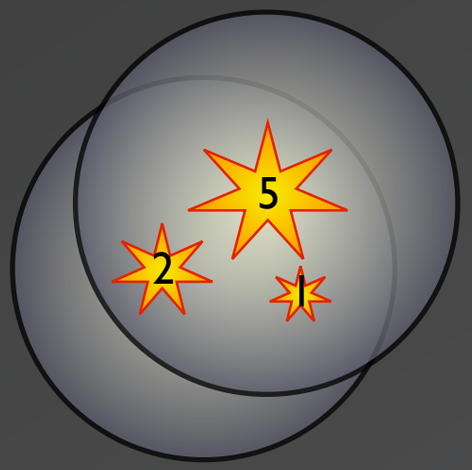
JET > 5 GeV



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

The Pedestal Effect

and Multiple Parton-Parton Interactions

JET > 5 GeV

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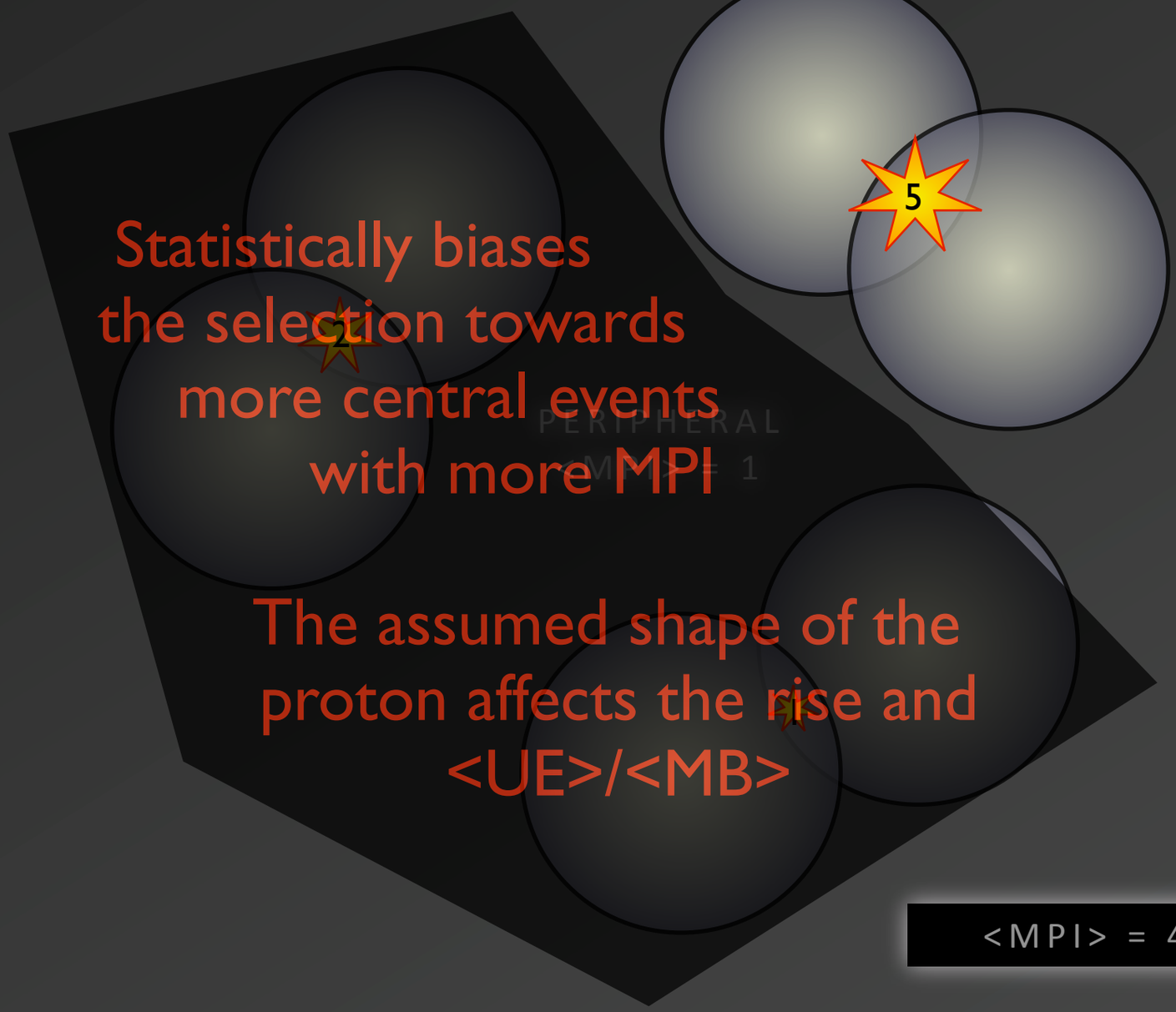
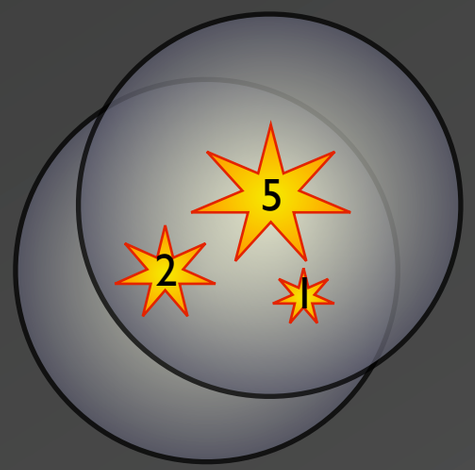


Can we tell the difference?

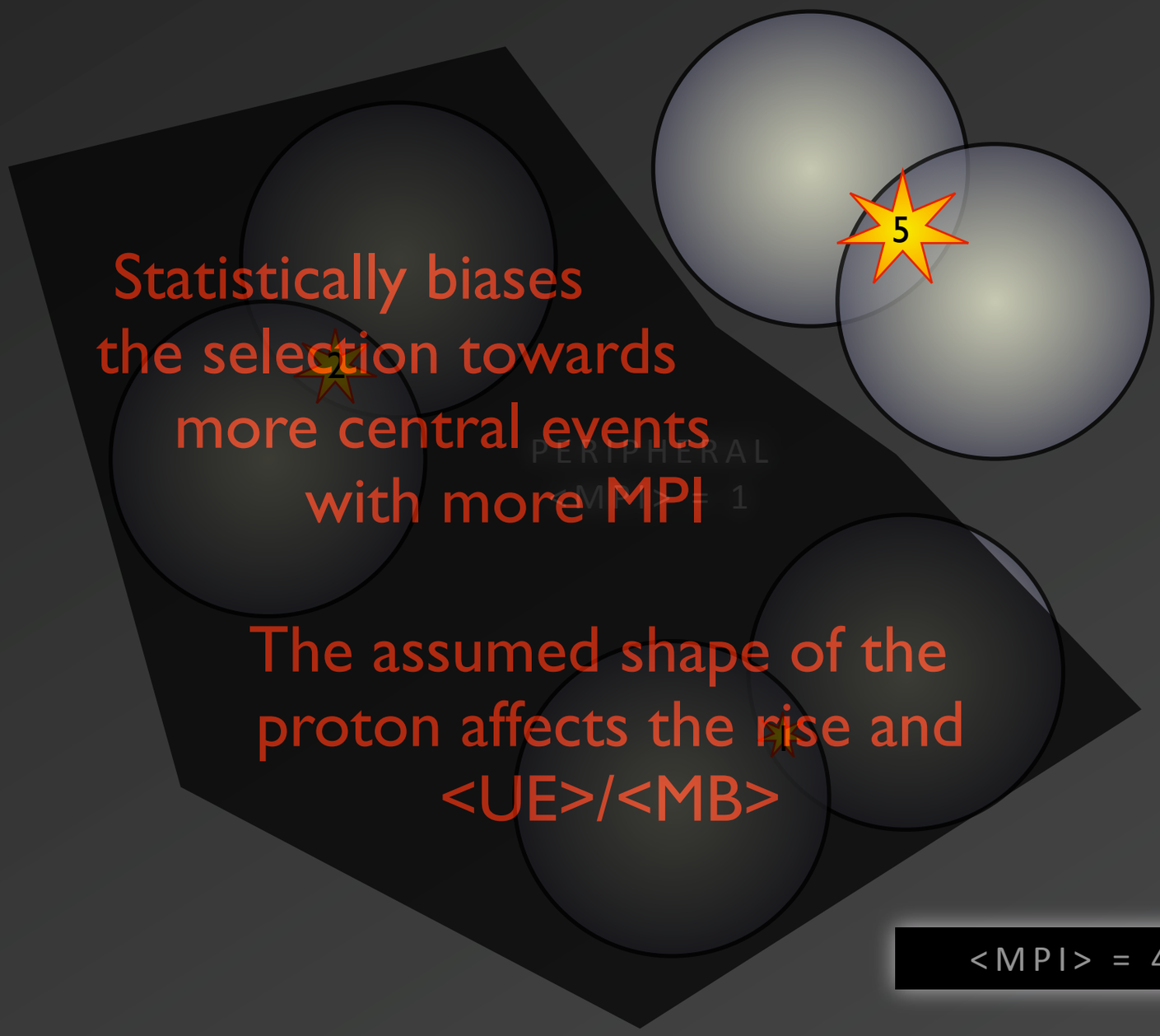
CENTRAL
<MPI> = 3



<MPI> = 4 / 2 = 2

Dissecting the Pedestal

JET > 5 GeV



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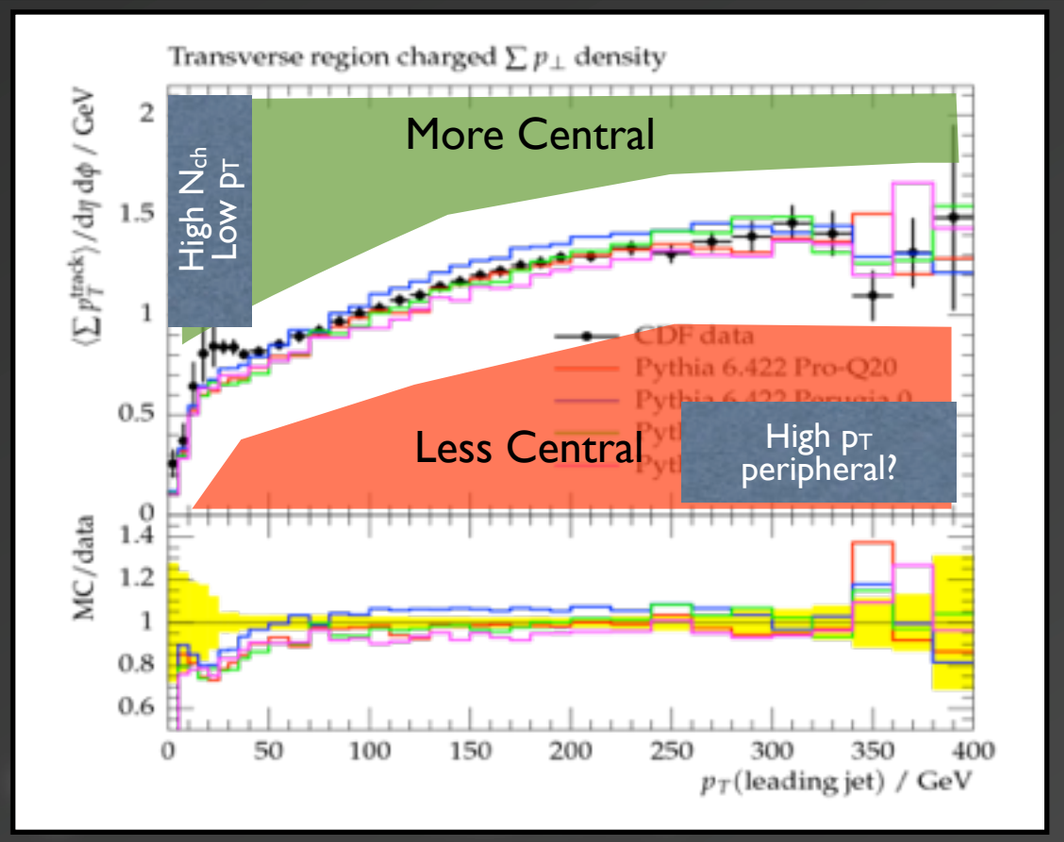
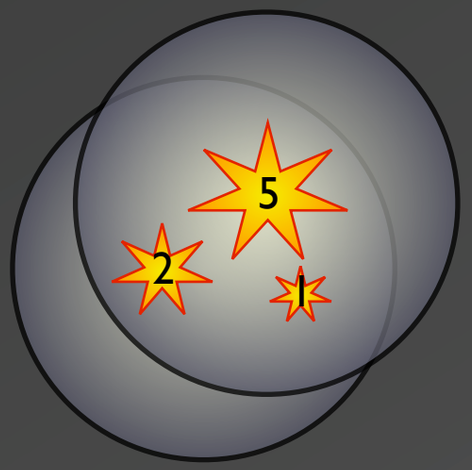
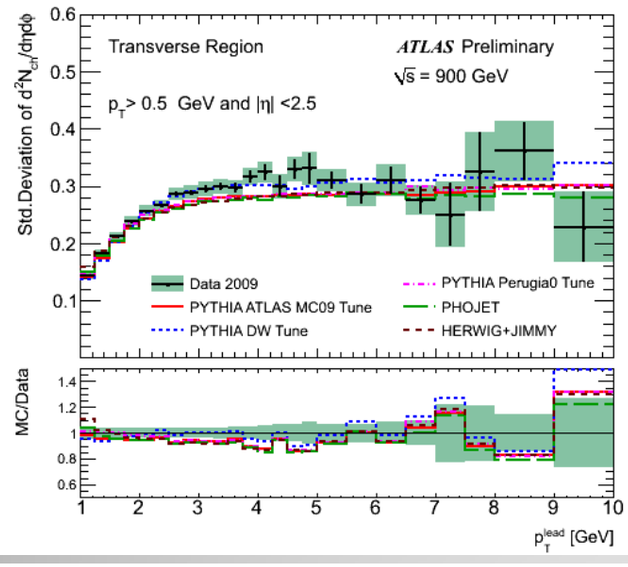


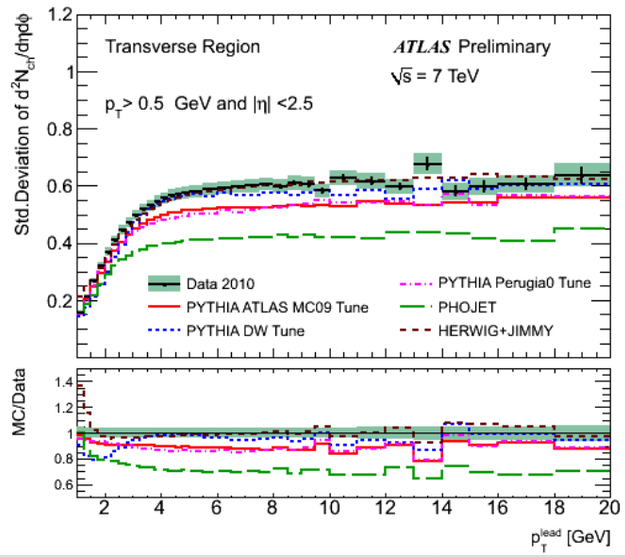


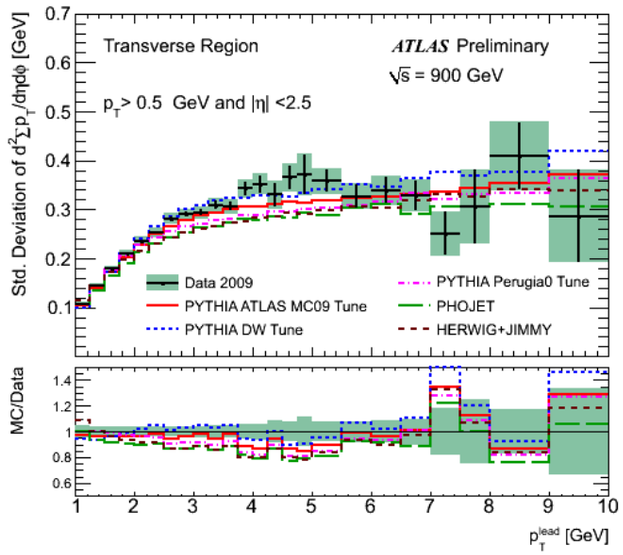
<MPI> = 4 / 2 = 2

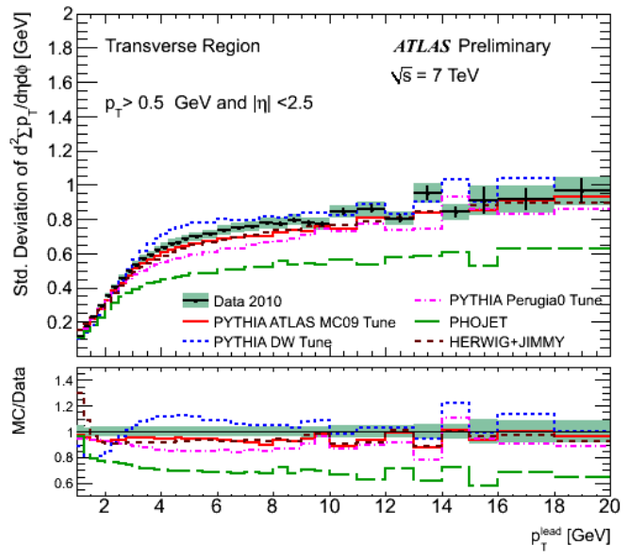
Possible to do at Tevatron?

Transverse Region Variances









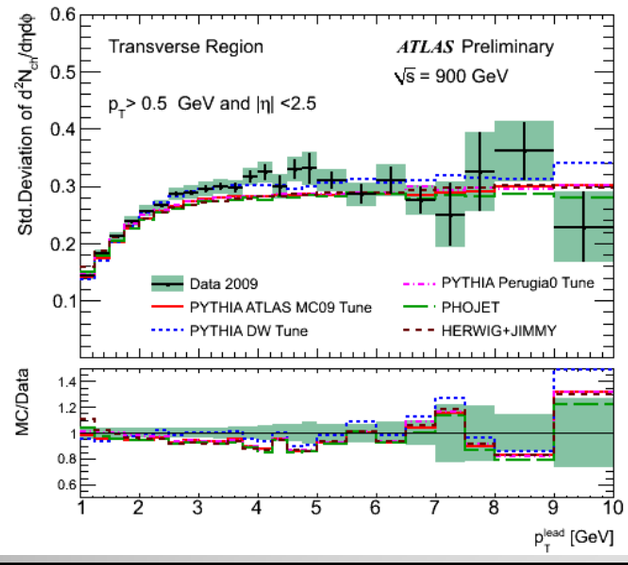
S.D. lower than mean, but more than square root of mean.

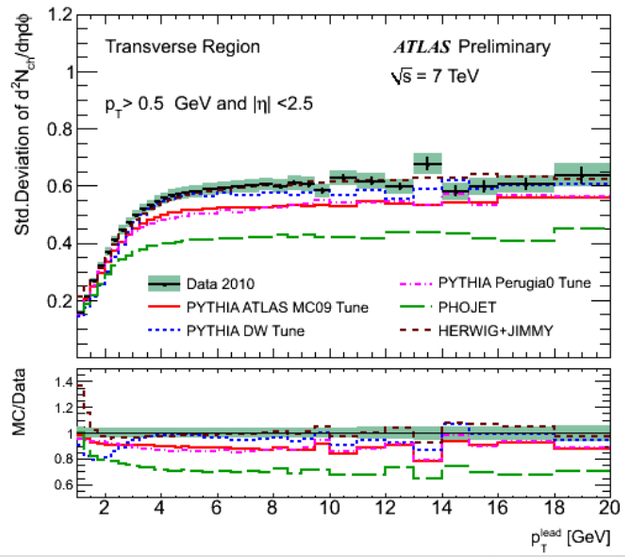
Suggests tracks not independently produced (not Poisson distribution).

S.D. provides a additional constraint on generator tunes

Possible to do at Tevatron?

Transverse Region Variances





S.D. lower than mean, but more than square root of mean.

Suggests tracks not independently

Analyzing the Pedestal?

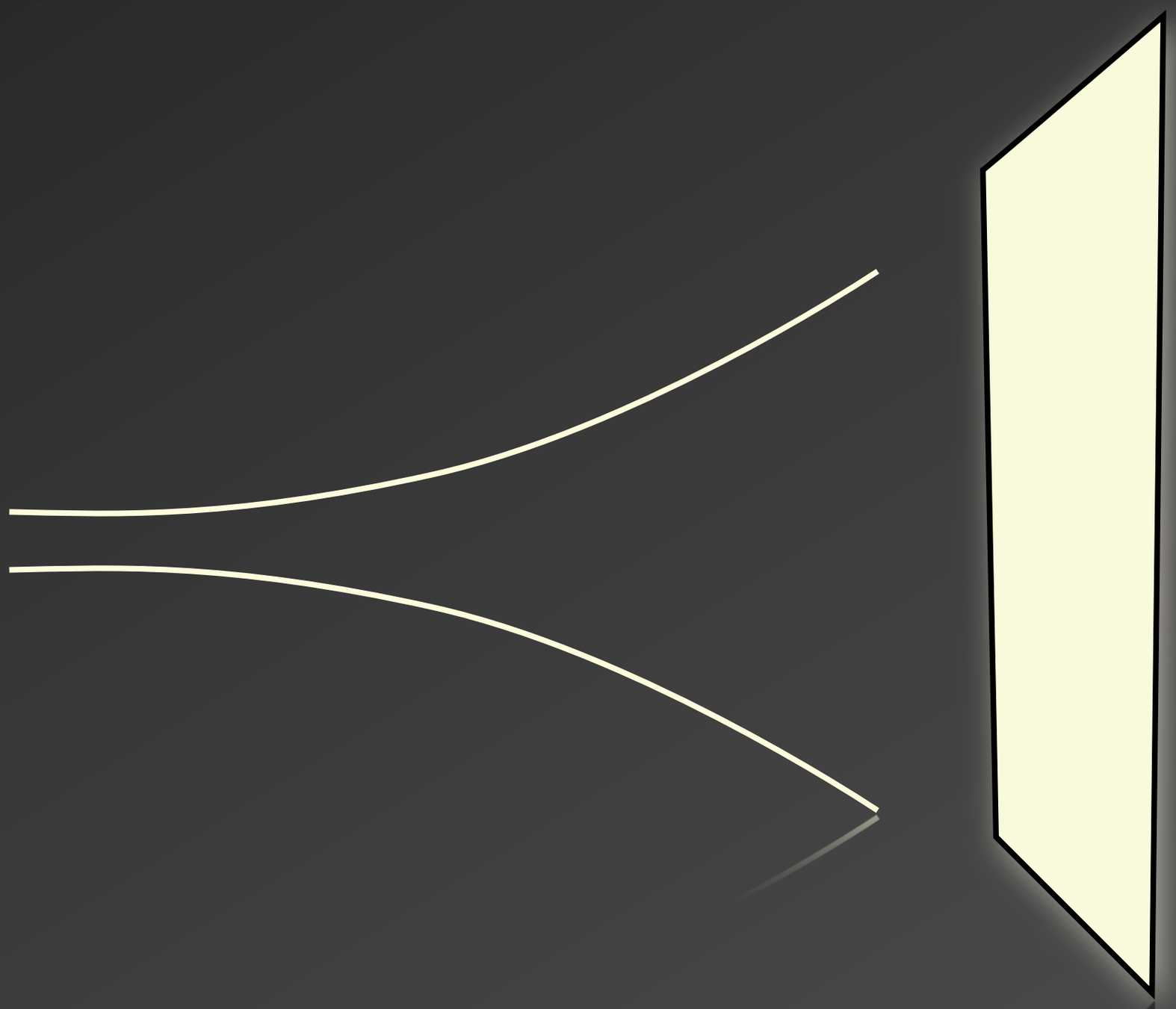
Initial rise & <UE>/<MB> → "average" proton shape

Focus on specific x range *(pick jet p_T and y, for given collider energy)*

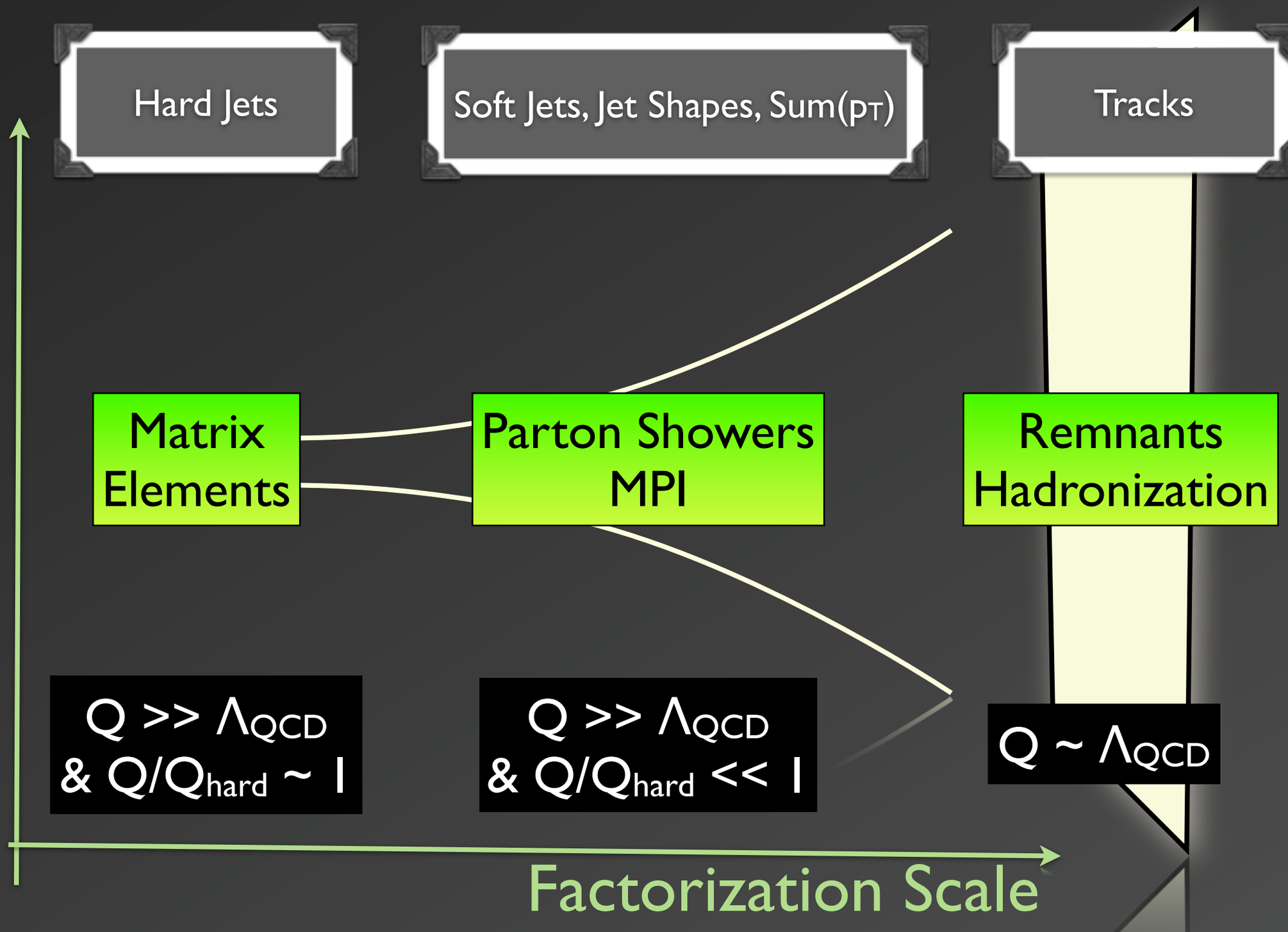
Scan over transverse activity → b dependence for that x ?

And/or look for abundance of minijets in transverse region

A New Look?



A New Look?


Hard Jets
Soft Jets, Jet Shapes, Sum(pT)
Tracks
Matrix Elements
Parton Showers MPI
Remnants Hadronization
Q >> ΛQCD & Q/Qhard ~ 1
Q >> ΛQCD & Q/Qhard << 1
Q ~ ΛQCD
Factorization Scale

A New Look?

Hard Jets

Soft Jets, Jet Shapes, Sum(p_T)

Tracks

MINIMUM BIAS

Matrix Elements

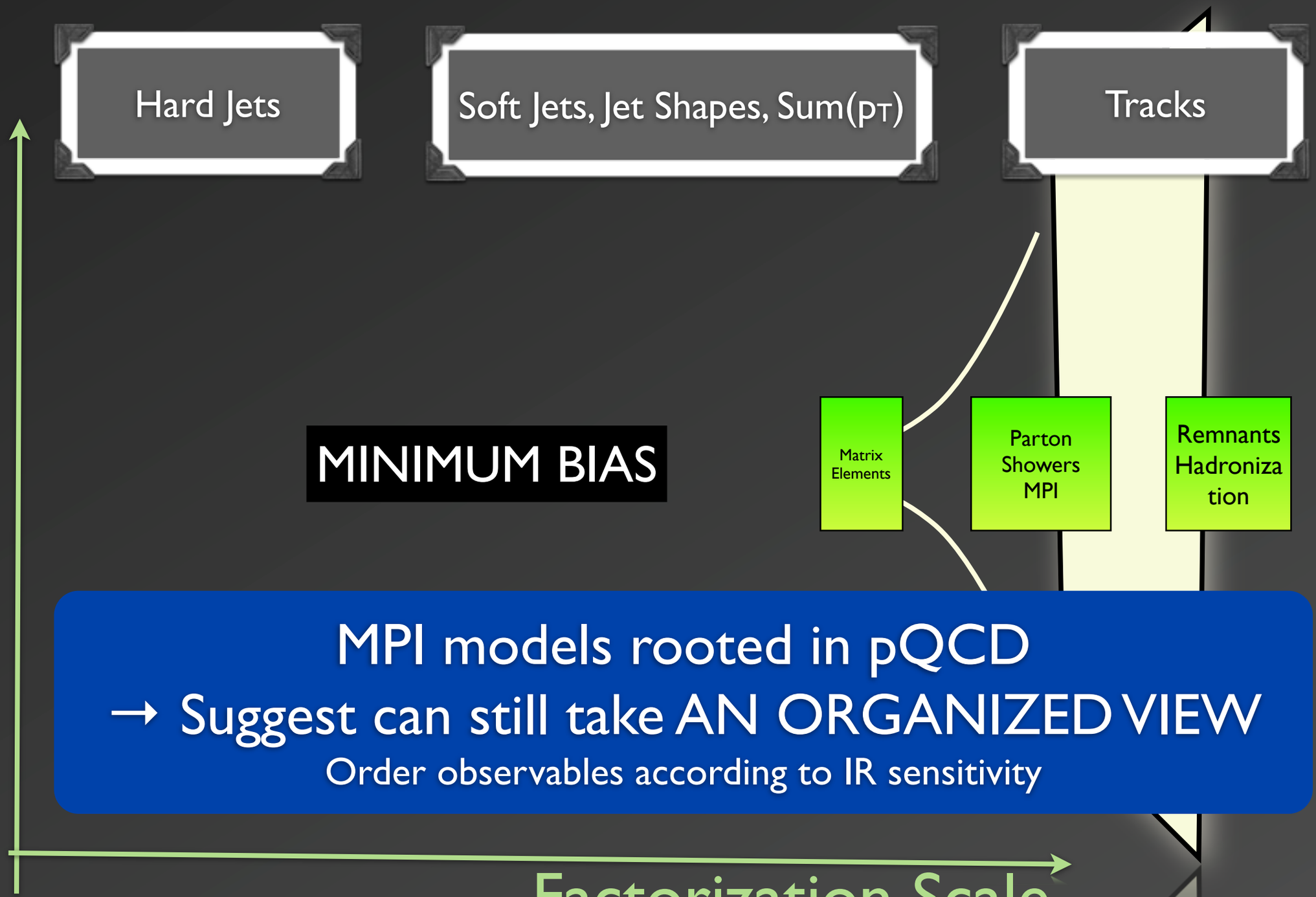
Parton Showers MPI

Remnants Hadronization

$Q \sim \Lambda_{QCD}$

Factorization Scale

A New Look?


Hard Jets
Soft Jets, Jet Shapes, Sum(pT)
Tracks
MINIMUM BIAS
Matrix Elements
Parton Showers MPI
Remnants Hadronization
MPI models rooted in pQCD
→ Suggest can still take AN ORGANIZED VIEW
Order observables according to IR sensitivity
Factorization Scale

An Organized View

1. Where is the energy going?

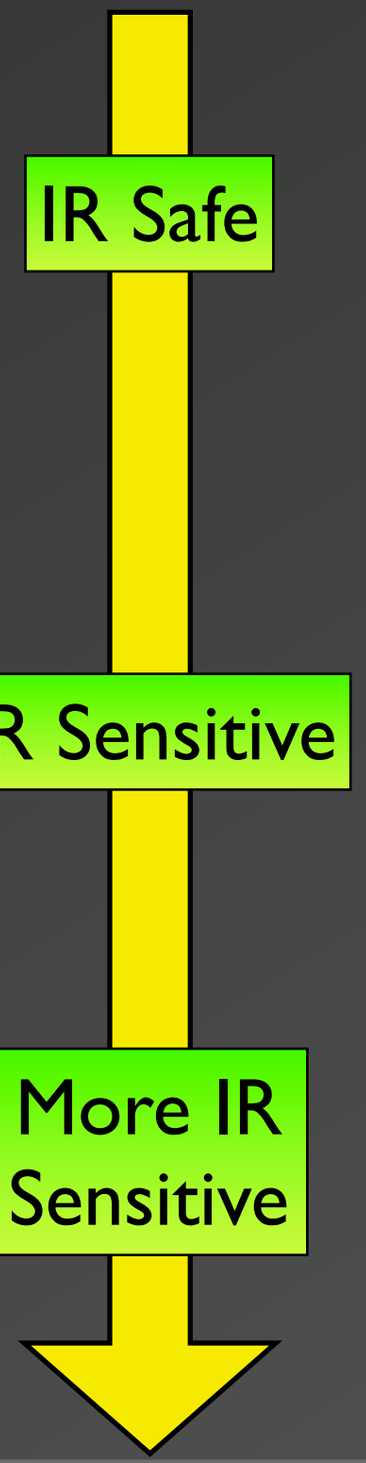
   Sum(pT) densities, event shapes, mini-jet rates, energy flow correlations… ≈ *sensitive to pQCD + pMPI*

2. How many tracks is it divided onto?

   N_{tracks}, dN_{tracks}/dp_T, *Associated track densities, track correlations…* ≈ *sensitive to hadronization + soft MPI*

3. What kind of tracks?

   Strangeness per track, baryons per track, beam baryon asymmetry, … s-baryons per s, multi-s states, s-sbar correlations, …. ≈ *sensitive to details of hadronization*



Organized Tuning

Can we be more general than this-tune-does-this, that-tune-does-that?

Yes

The new automated tuning tools can be used to generate unbiased optimizations for different observable regions

Same parameters → consistent model (not just "best tune")

Critical for this task (take home message):

Need "comparable" observable sets for each region

Example: use different collider energies as our "regions" → test energy scaling
Other complementary data sets could be used to test other model aspects

(example on next pages used PYTHIA 6, but applies to any model)

Energy Scaling

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

Used CDF, UA5, and ATLAS data

$P(N_{ch})$, dN_{ch}/dp_T, $\langle p_T \rangle (N_{ch})$

Not dN/d(eta) to avoid emphasis on low mult

+ for ATLAS: can even focus on $N_{ch} \geq 6$ separately! Possible to do at Tevatron too?

From 630 GeV to 7 TeV

(Unfortunately, did not have a complete obs set from STAR at 200 GeV)

Reduce model to 3 main parameters:

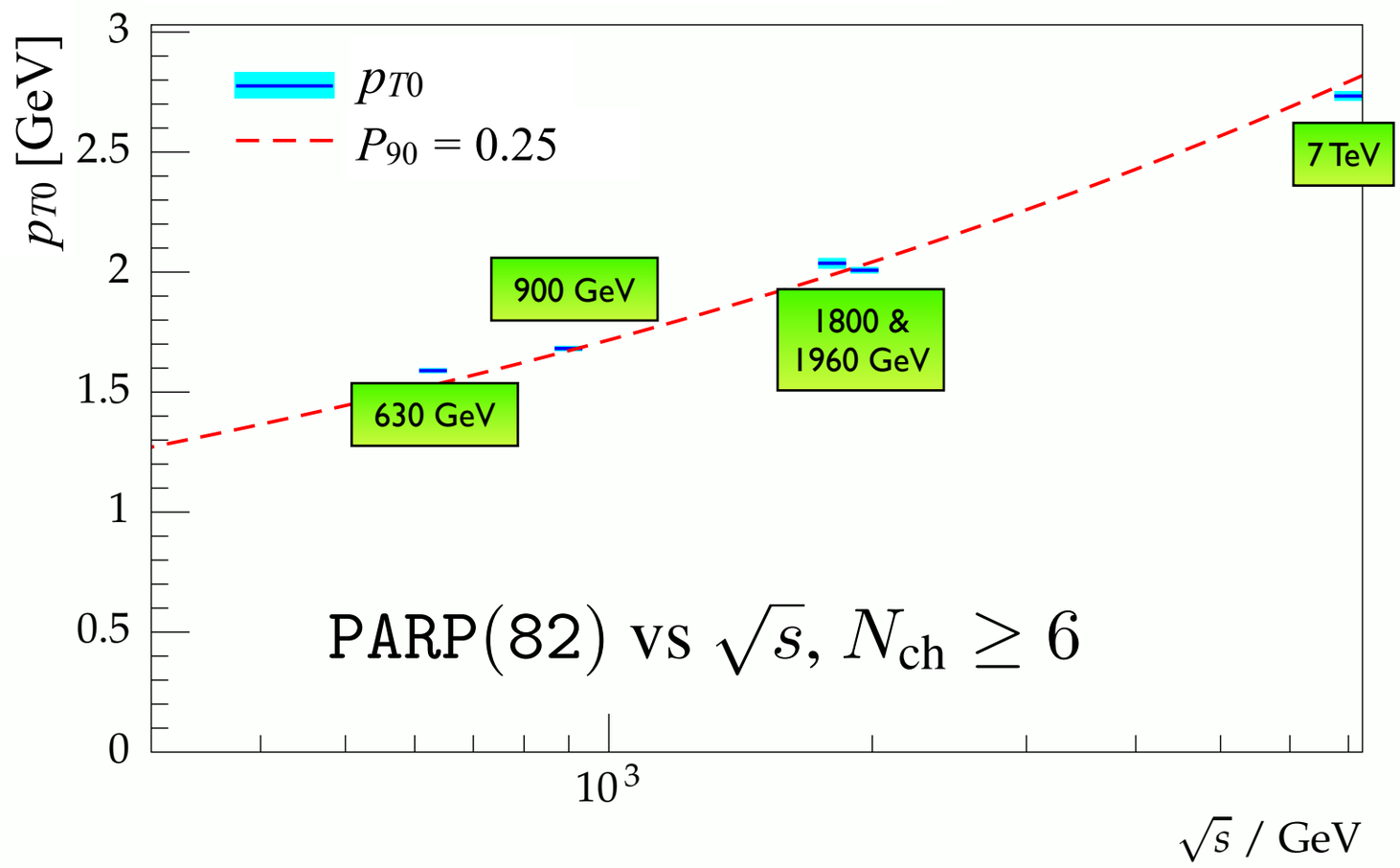
Starting point = Perugia 0

1. Infrared Regularization Scale — $p_{T\min}$ — *PARP(82)*
2. Proton Transverse Mass Distributions — μ — *PARP(83)*
3. Strength of Color Reconnections — CR — *PARP(78)*

Use Professor to do independent optimizations at each energy

Infrared Regularization Scale

Model : $p_{\perp 0}^2(s) = p_{\perp 0}^2(s_{\rm ref}) \left(\frac{s}{s_{\rm ref}}\right)^{P_{90}}$ (power law)



cf., also, e.g., CMS, studies by R. Field

&

Sjöstrand & van Zijl, PRD36(1987)2019

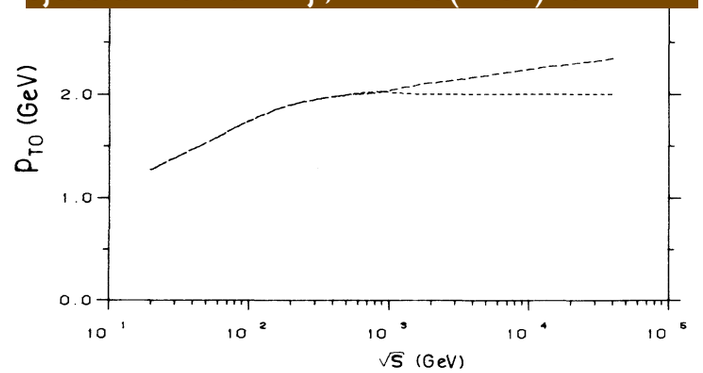


FIG. 8. Values for the cutoff parameter p_{T0} as a function of c.m. energy , as determined from comparisons with the average charged multiplicity. Dashed line, with a logarithmic extrapolation to higher energies, Eq. (38); dotted line, if assumed constant above 900 GeV.

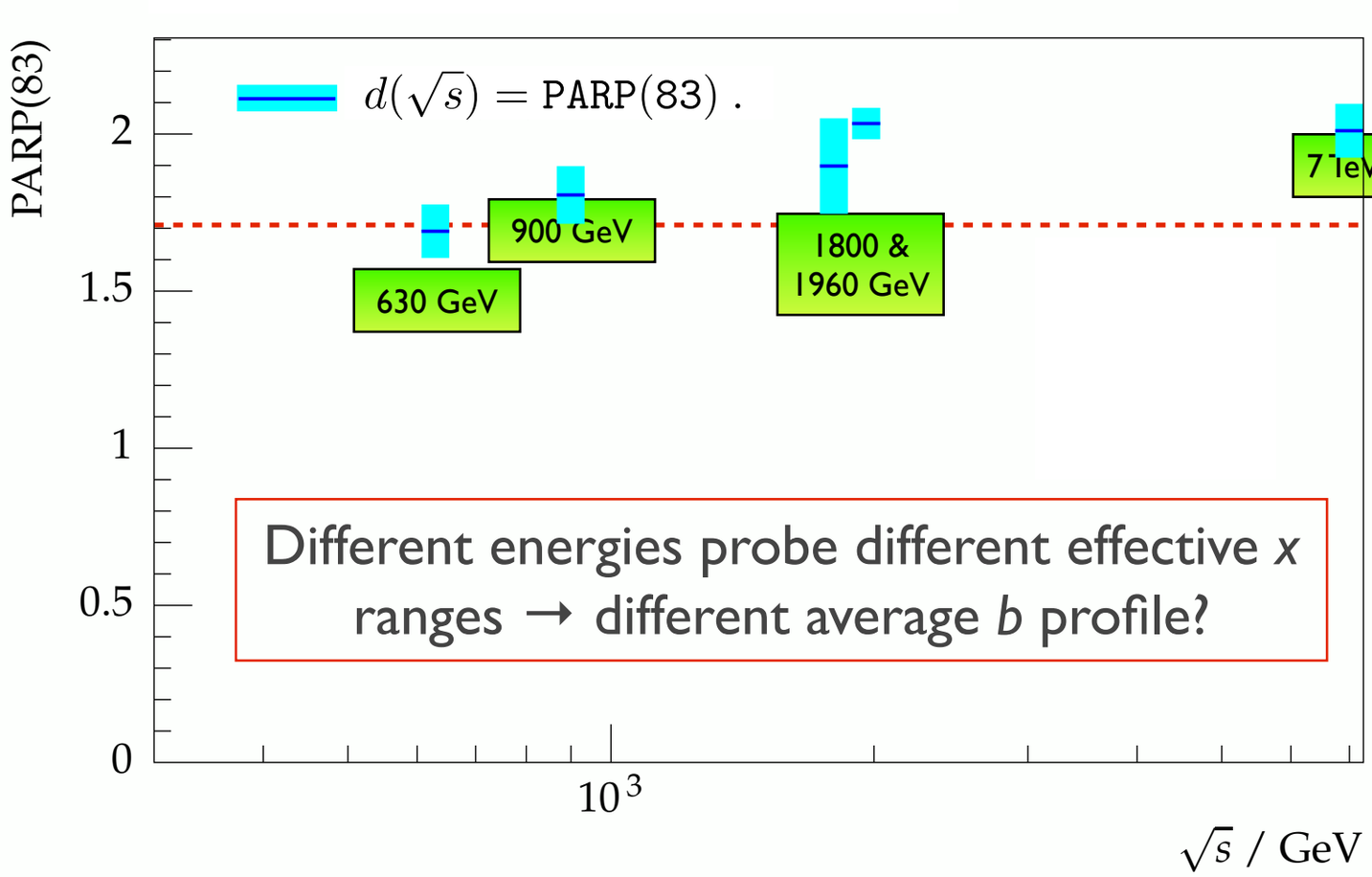
No large deviation from the assumed functional form

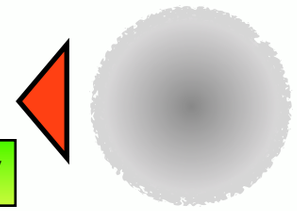
(E.g., Tunes A, DW, Perugia-0 use Exp = PARP(90) = 0.25)

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

Transverse Mass Distribution

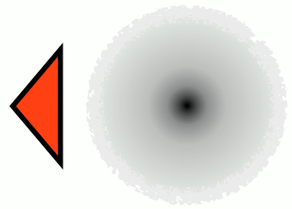
Model : $\mathcal{O}(b) \propto \exp\left(-b^d\right)$ (independent of energy)





d=2 (Gaussian)

Intermediate



d=1 (exponential)

Perugia-0: PARP(83) = 1.7
Too lumpy at high energies?

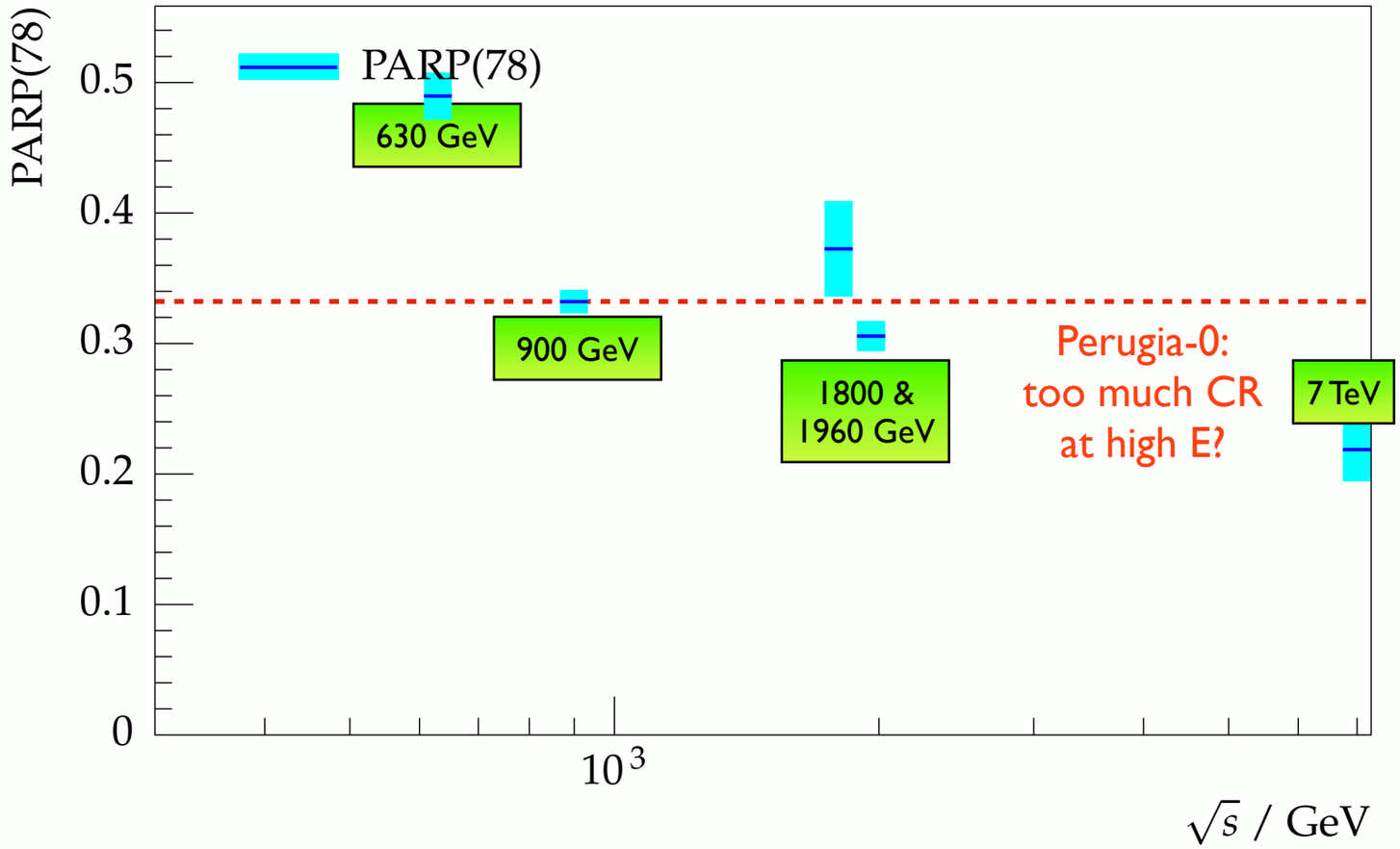
Hint of departure from Gaussian (*d*=2) at lower E_{cm}?

Interesting to get more independent handles on *b* distribution
+ make more use of 200 and 630 GeV data ?

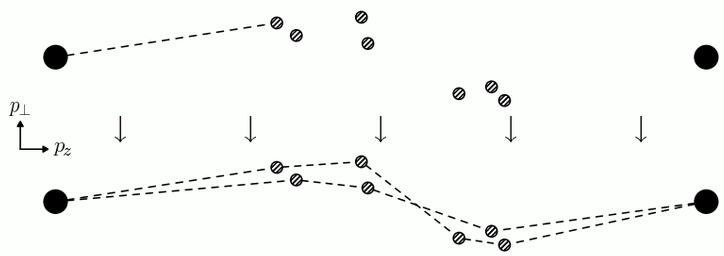
"Energy Scaling of MB Tunes", H. Schulz + PS, in preparation

Color Reconnection Strength

Model : $P_{\text{keep}} = (1 - \zeta P_{78})^{n_{\text{int}}}$ (energy dependence implicit through $\langle n_{\text{int}} \rangle$)



High CR
→ Short/Few Strings



Low CR
→ Long/Many Strings

Assumption of constant strength not supported by data!

Underscores the need for better physical understanding

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

Summary

The pedestal effect

Gives relation MB → UE, driven by proton shape

Tevatron tunes generally low at 7 TeV

But 20% not spectacular; can probably do better, but

Advocate more systematic approach to tuning & testing:

Factorize: *Order observables from IR safe to IR sensitive*

Global View: *test models on many obs, not just one (duh!)*

Tuning Tools: *can be used for more than tuning*

PS: Perugia 7-TeV prediction still untested: $\langle N \rangle_{pT>0.5,|\eta|<2.5,N\geq 4} = 14.45 \pm 1.26$