

Some Theory Lessons from the $O(1\text{TeV})$ LHC Runs

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Disclaimer

- Impossible to cover everything
- *Focus* on important outstanding questions which could be settled by early LHC measurements at 900 and 2360 GeV
- Note that, for most of them, this is our *only* chance to settle these questions

Monte Carlos and Precision

- To get high precision, must have good MC

Constraining MC

- A wealth of data available at lower energies
 - Used for tuning
 - The low-energy LHC runs give 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?

Charged Multiplicity

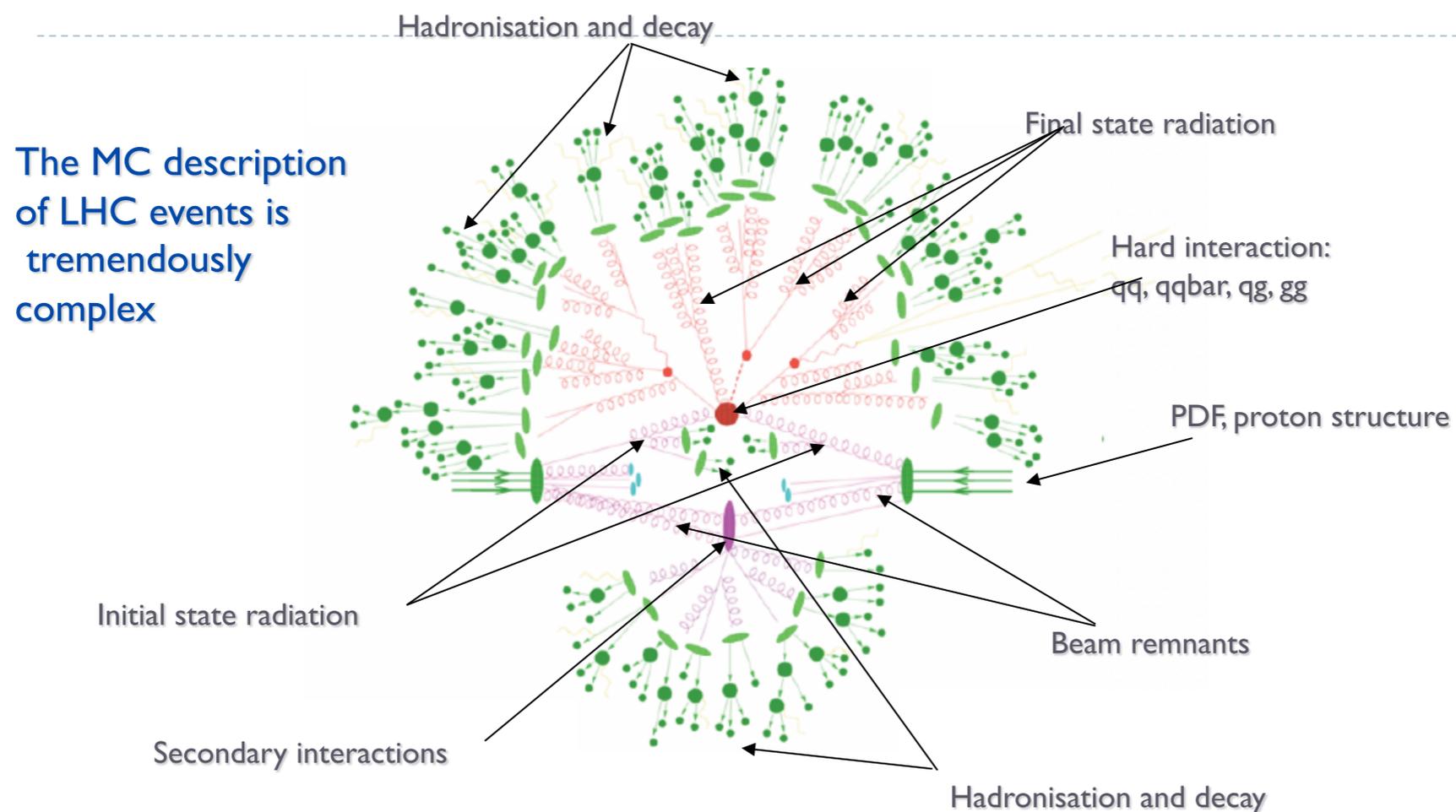
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 - But fundamental does not imply easy

Charged Multiplicity

- One of the most fundamental quantities to measure
 - But fundamental does not imply easy
 - Complications: Corrections for Trigger Bias, Diffraction, Zero Bin, Long-Lived particles, Extrapolations from fiducial region to full phase space, ...

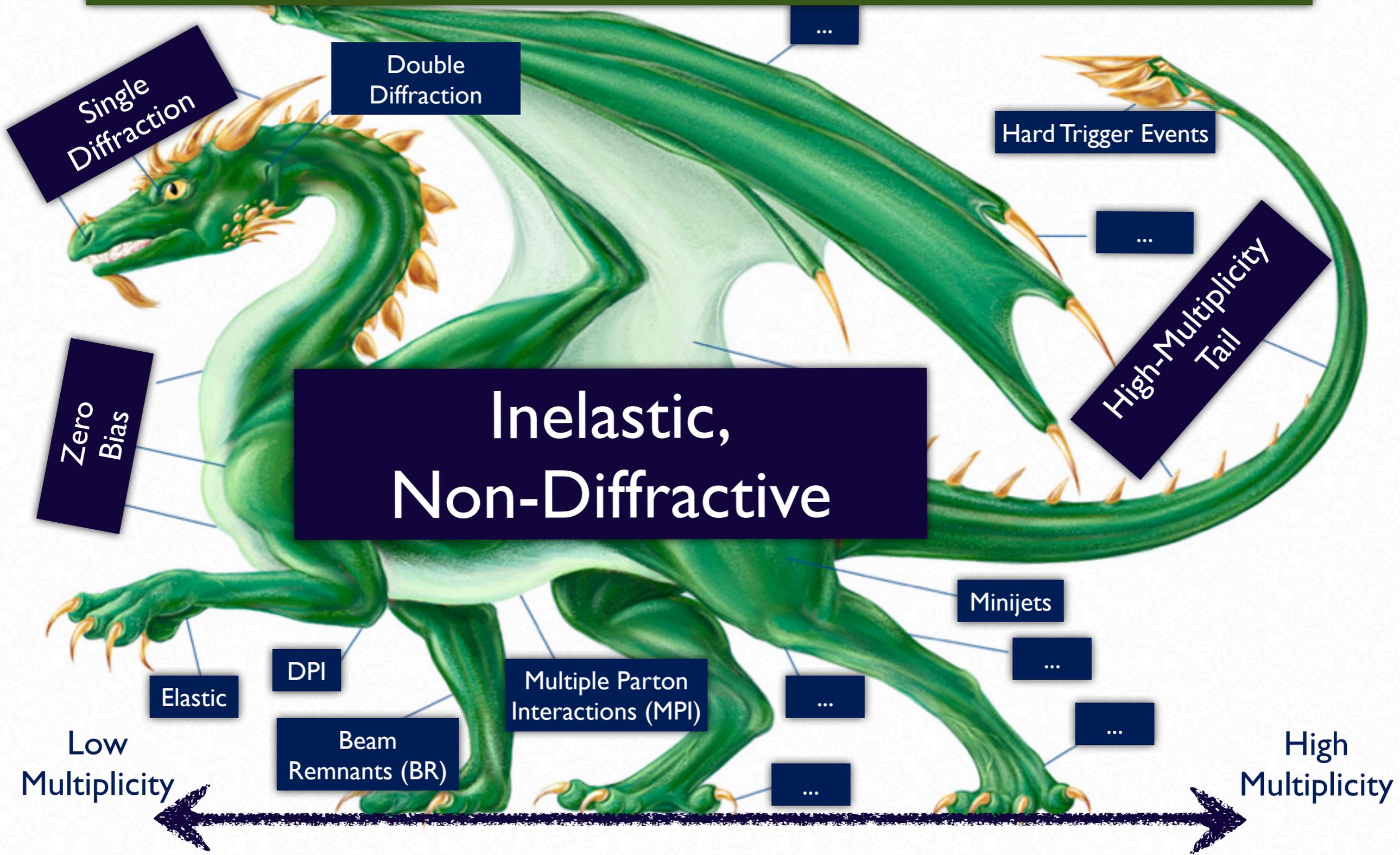
Dissecting Minimum-Bias

Physics requirements: basics



This is a schematization to be able to cut down the problem in pieces and model them in a different way. The “pieces” are correlated !

Dissecting Minimum-Bias



Measured Results

- **How to Compare to Older Measurements?**
 - Bubble chambers etc extrapolated to full phase space
 - More model-dependent at Tevatron and LHC experiments

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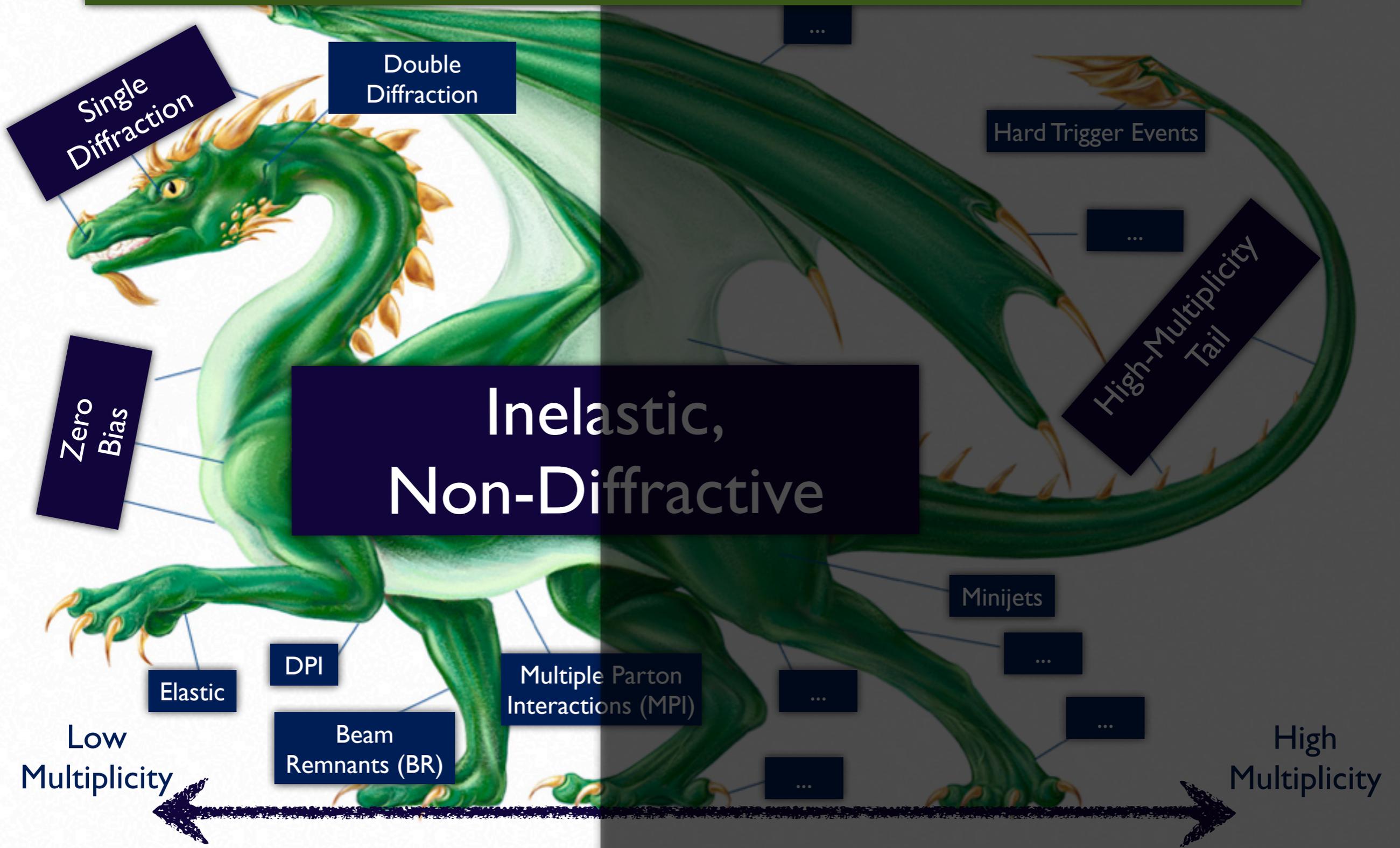
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- **How to Compare to Theory?**

- Inelastic > 'NSD' > Inelastic Non-Diffractive, ... ?
- For all: Define event set in terms of hadron-level cuts
- Today's theorists not interested in filling up unmeasured region with some model (especially if it is some other guy's model) - **Keep main measured result as close to raw acceptance as possible.**
Extrapolate only to do comparisons (inflates uncertainties)

Issues at Low Multiplicity

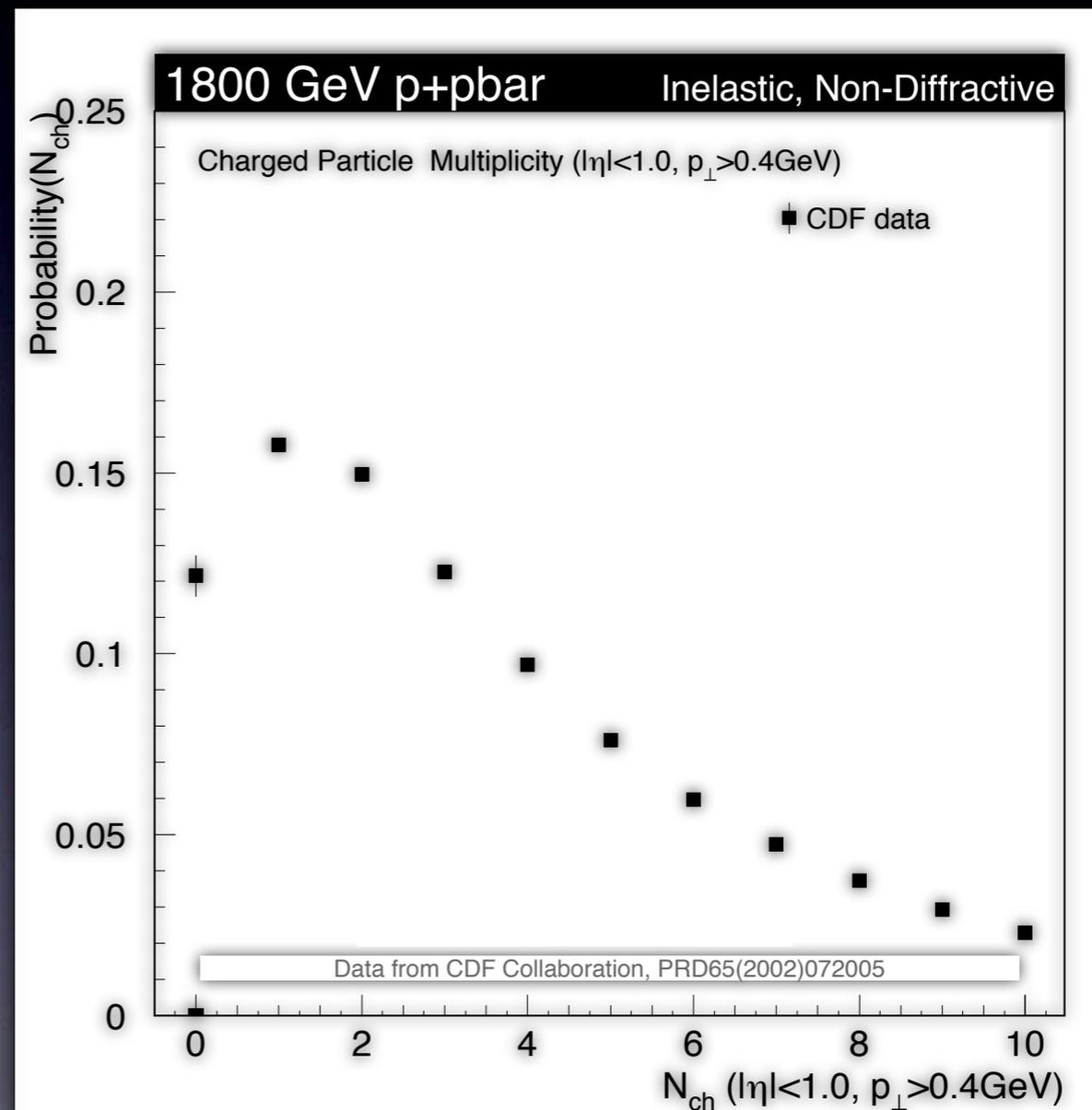


Low Multiplicities: Correcting for Diffraction

- Diffractive processes
 - Large part of total cross section
 - Populate the low-multiplicity bins: lower $\langle N_{ch} \rangle$
 - Characteristic rapidity spectrum with large rapidity gaps: affect $dN_{ch}/d\eta$
 - Impossible to interpret min-bias spectra without knowing precisely how diffraction was treated

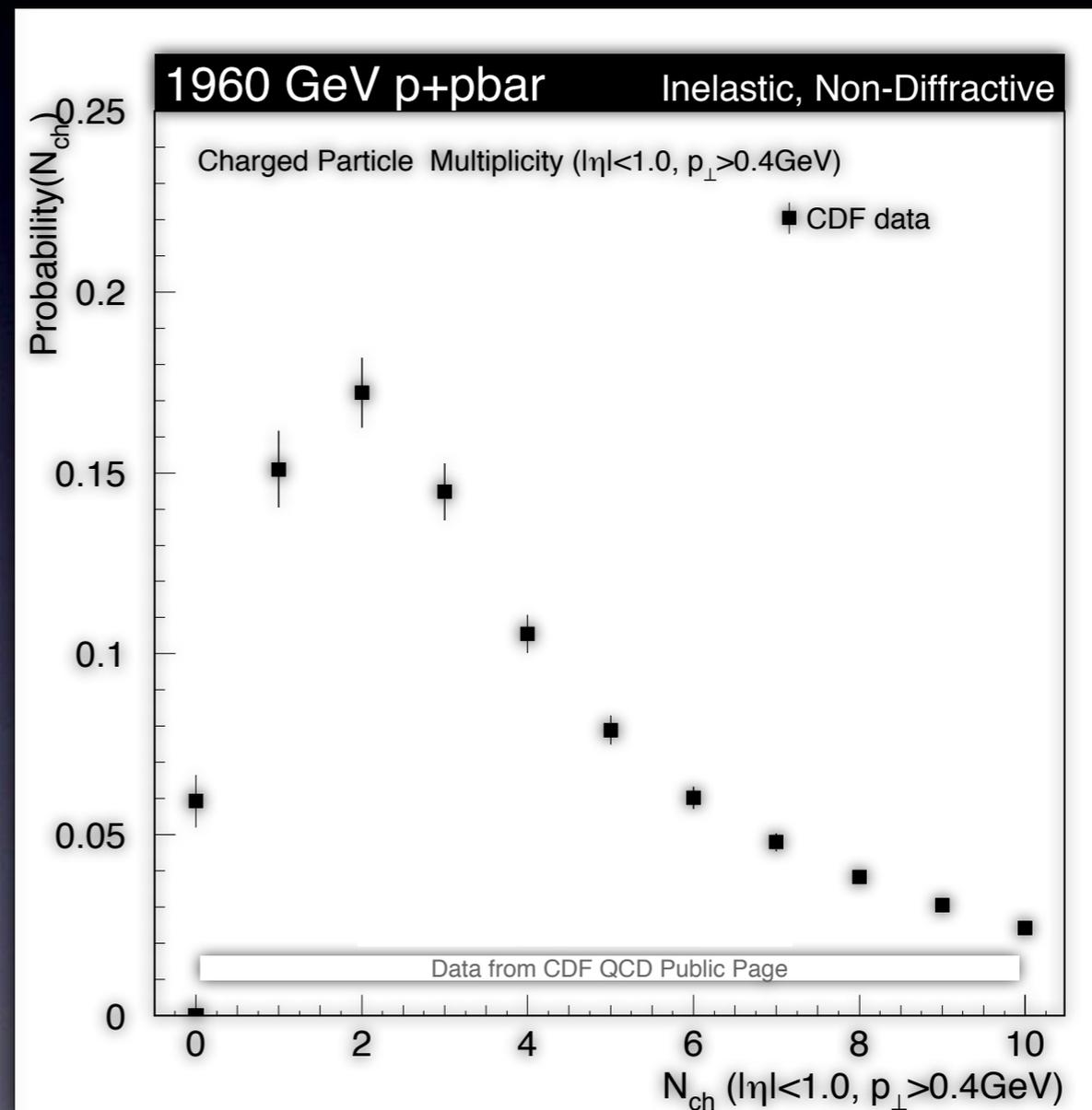
Low Multiplicities: Correcting for Diffraction

- CDF Run-I Data
 - Corrected to $p_T > 0.4$ GeV instead of full PS: less model dependence
 - First few bins corrected for diffraction (also affects average N_{ch} and $dN/d\eta$)



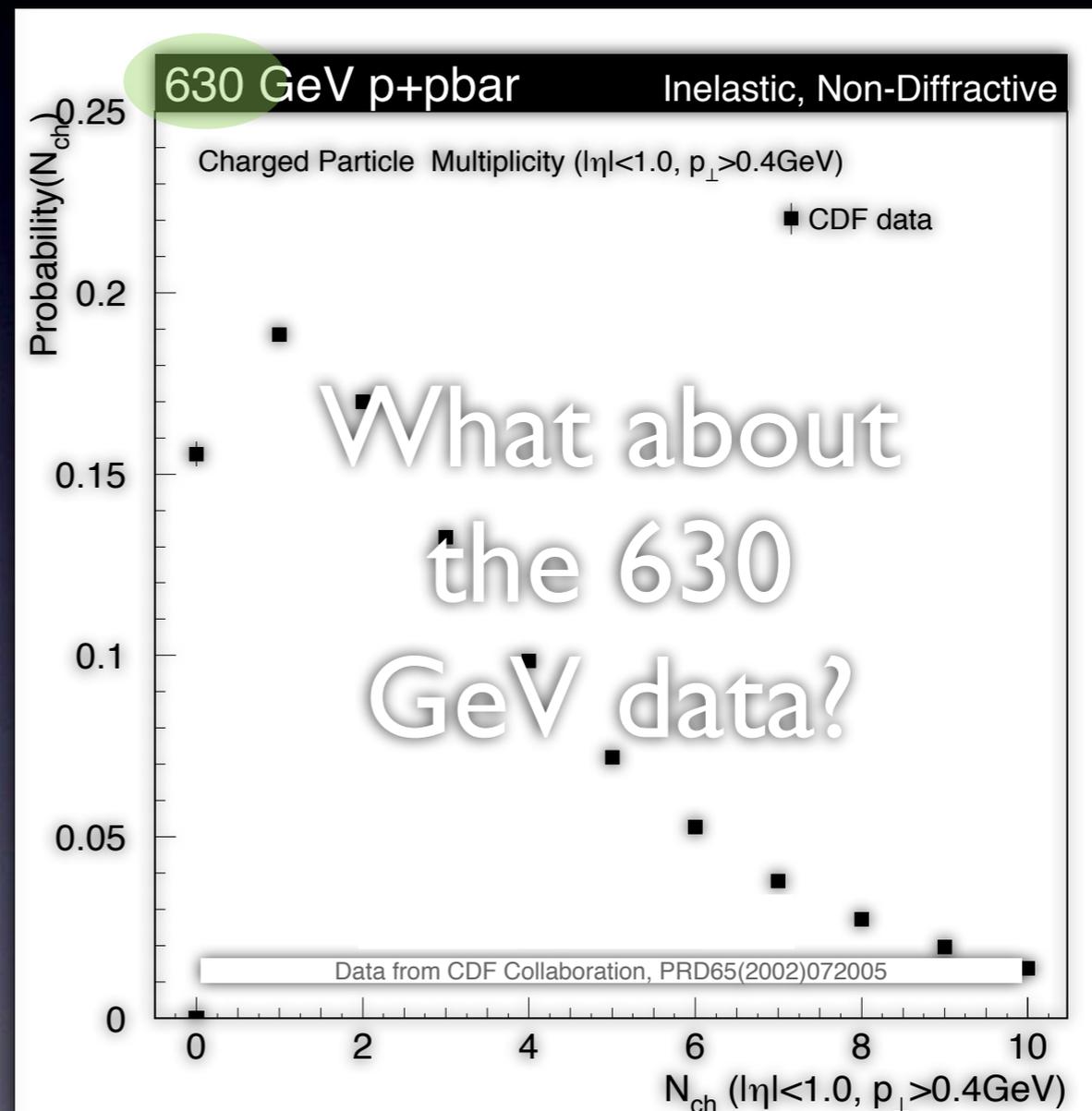
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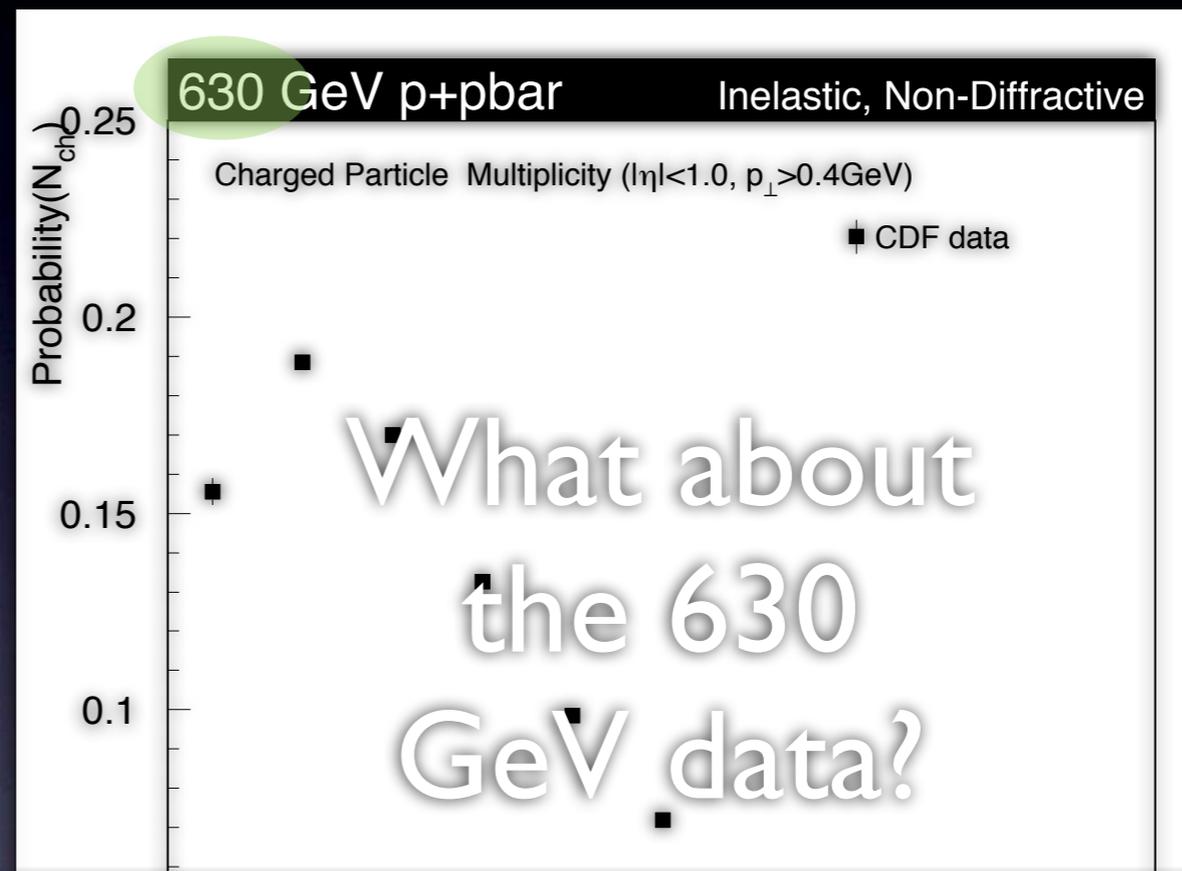
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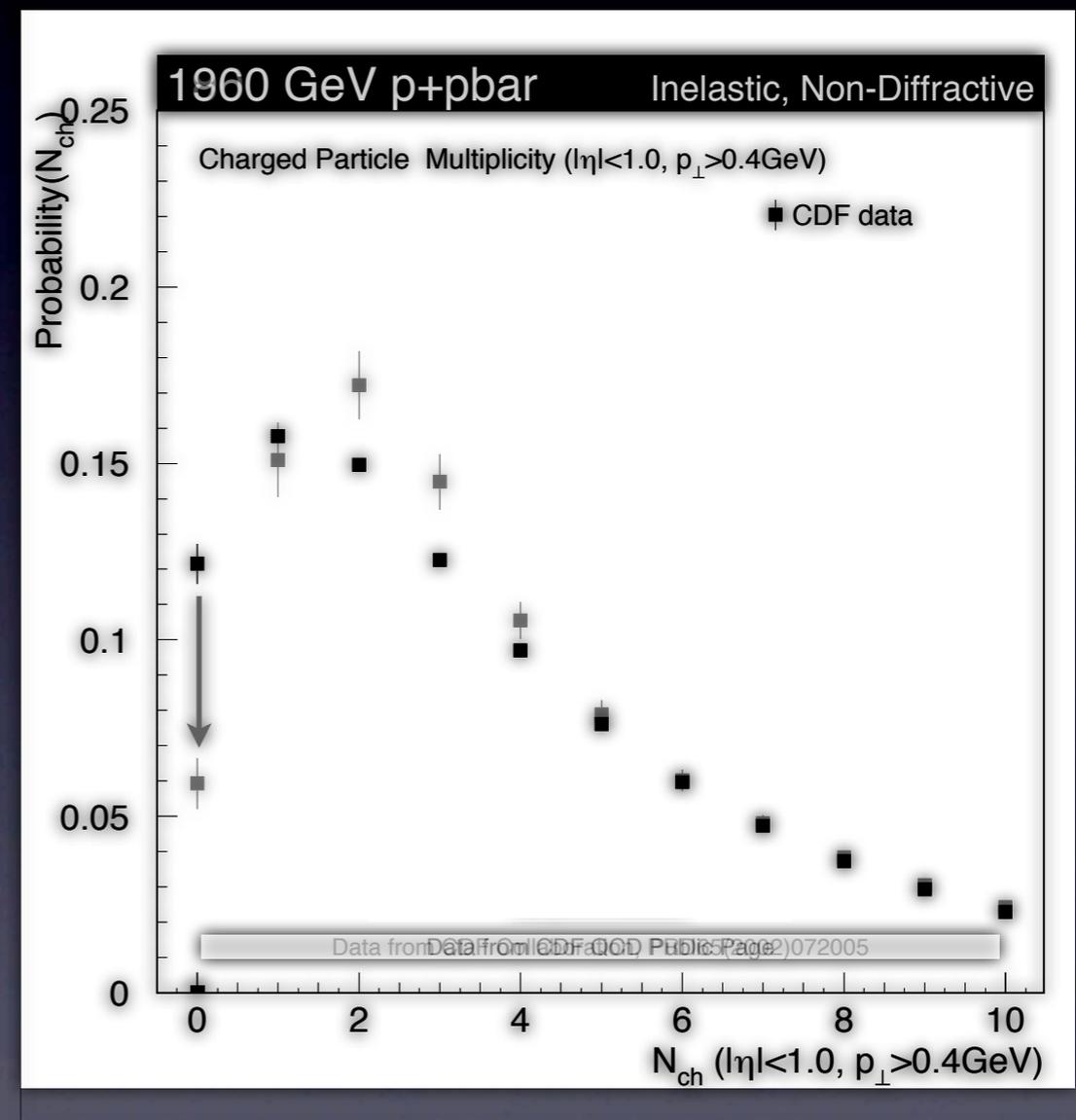
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LHC Measurements at 900 and 2360 GeV, with a well-defined, agreed-upon, definition of diffraction can kill this issue

The Zero Bin

- The most problematic is the **zero bin**: *the event was triggered, but no fiducial tracks*
- *E.g, was it a diffractive event with no tracks, or an inelastic non-diffractive event, with no tracks? Or ... ?*



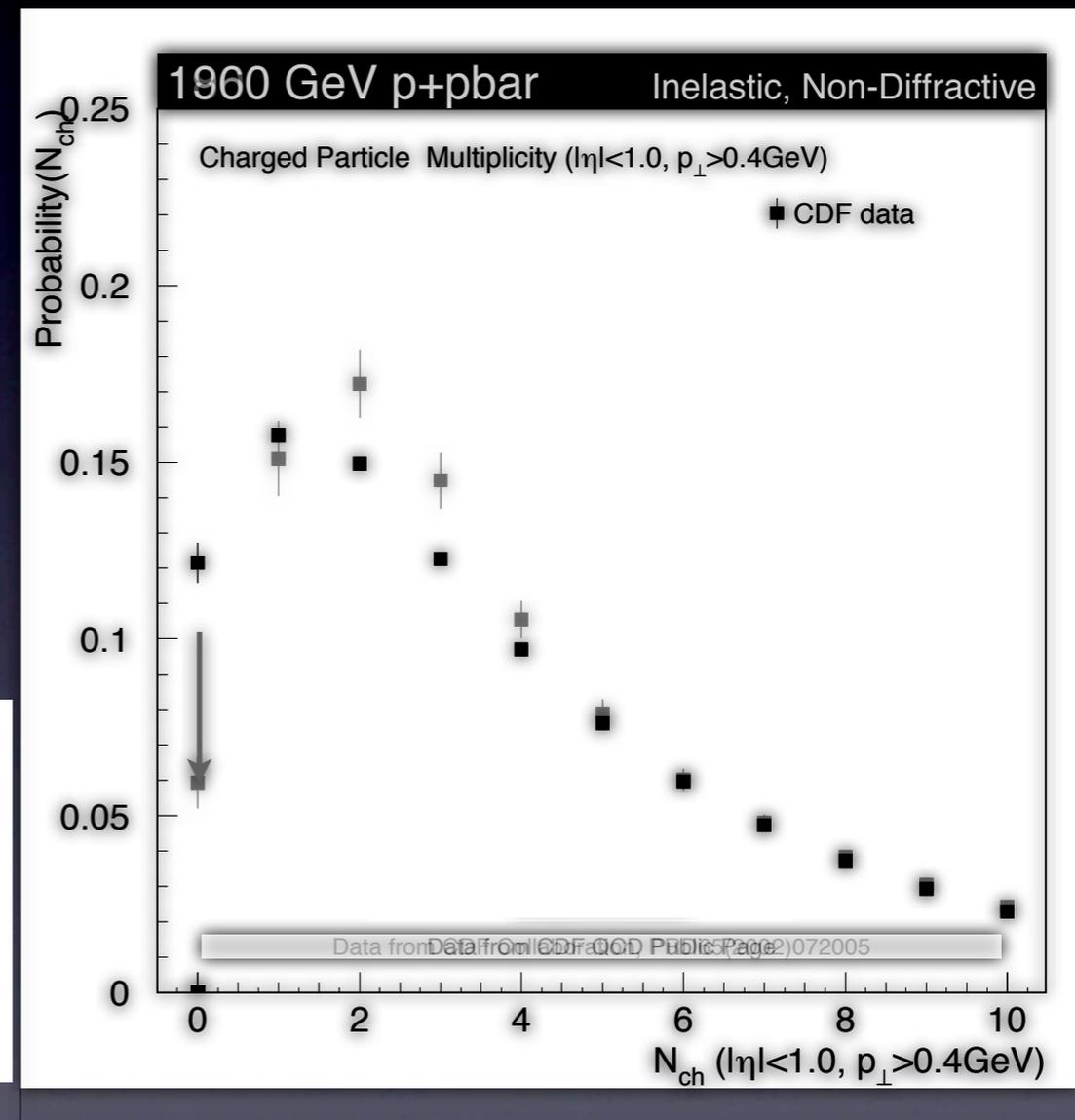
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Predictions for Mean Densities of Charged Tracks

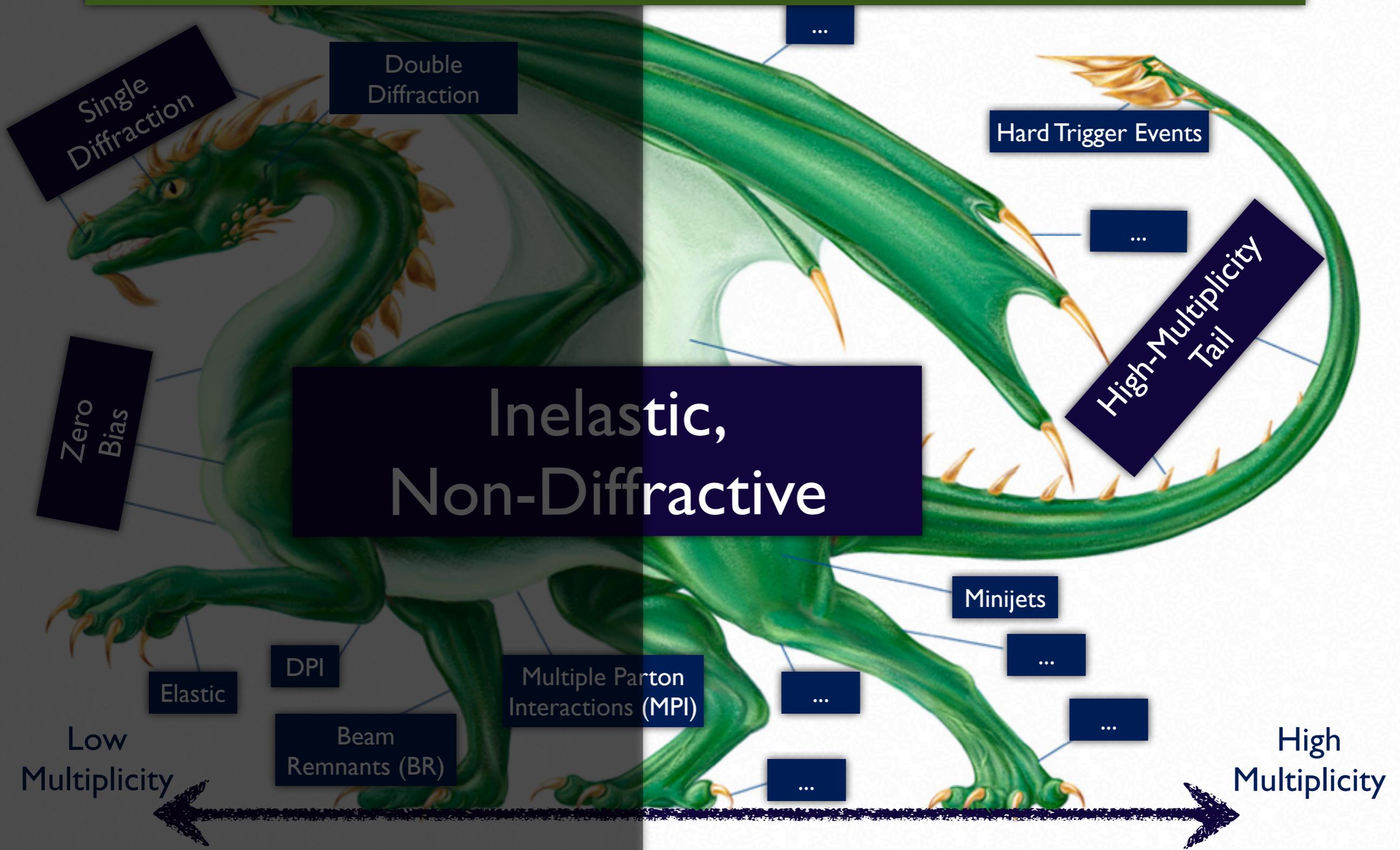
	$\frac{\langle N_{ch} \rangle _{N_{ch} \geq 0}}{\Delta\eta\Delta\phi}$	$\frac{\langle N_{ch} \rangle _{N_{ch} \geq 1}}{\Delta\eta\Delta\phi}$	$\frac{\langle N_{ch} \rangle _{N_{ch} \geq 2}}{\Delta\eta\Delta\phi}$	$\frac{\langle N_{ch} \rangle _{N_{ch} \geq 3}}{\Delta\eta\Delta\phi}$
LHC 10 TeV	0.40 ± 0.05	0.41 ± 0.05	0.43 ± 0.05	0.46 ± 0.06
LHC 14 TeV	0.44 ± 0.05	0.45 ± 0.06	0.47 ± 0.06	0.51 ± 0.06

PS, Perugia Proceedings, arXiv:0905.3418 [hep-ph]



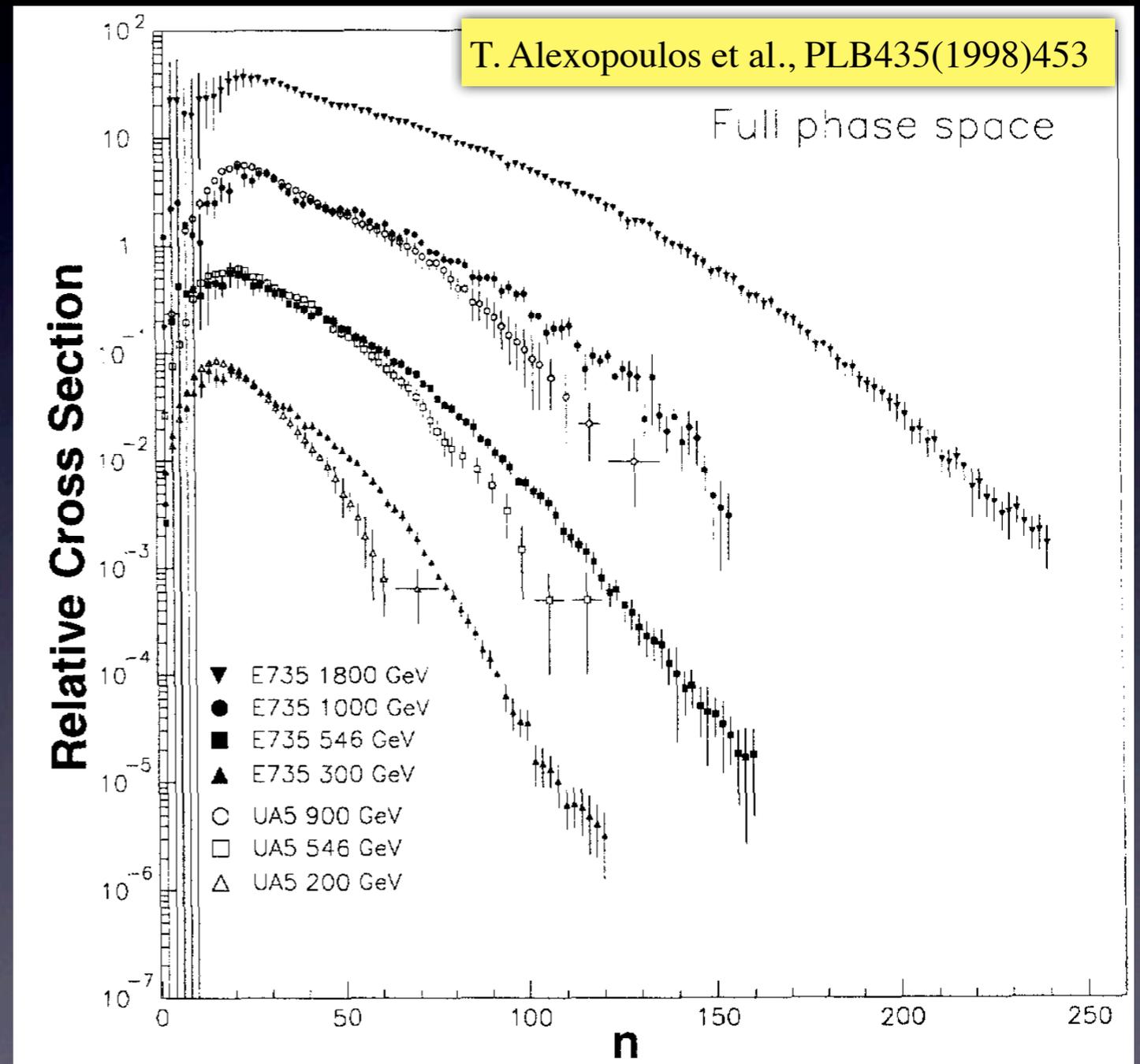
Redefine the event sample to include at least one fiducial track?

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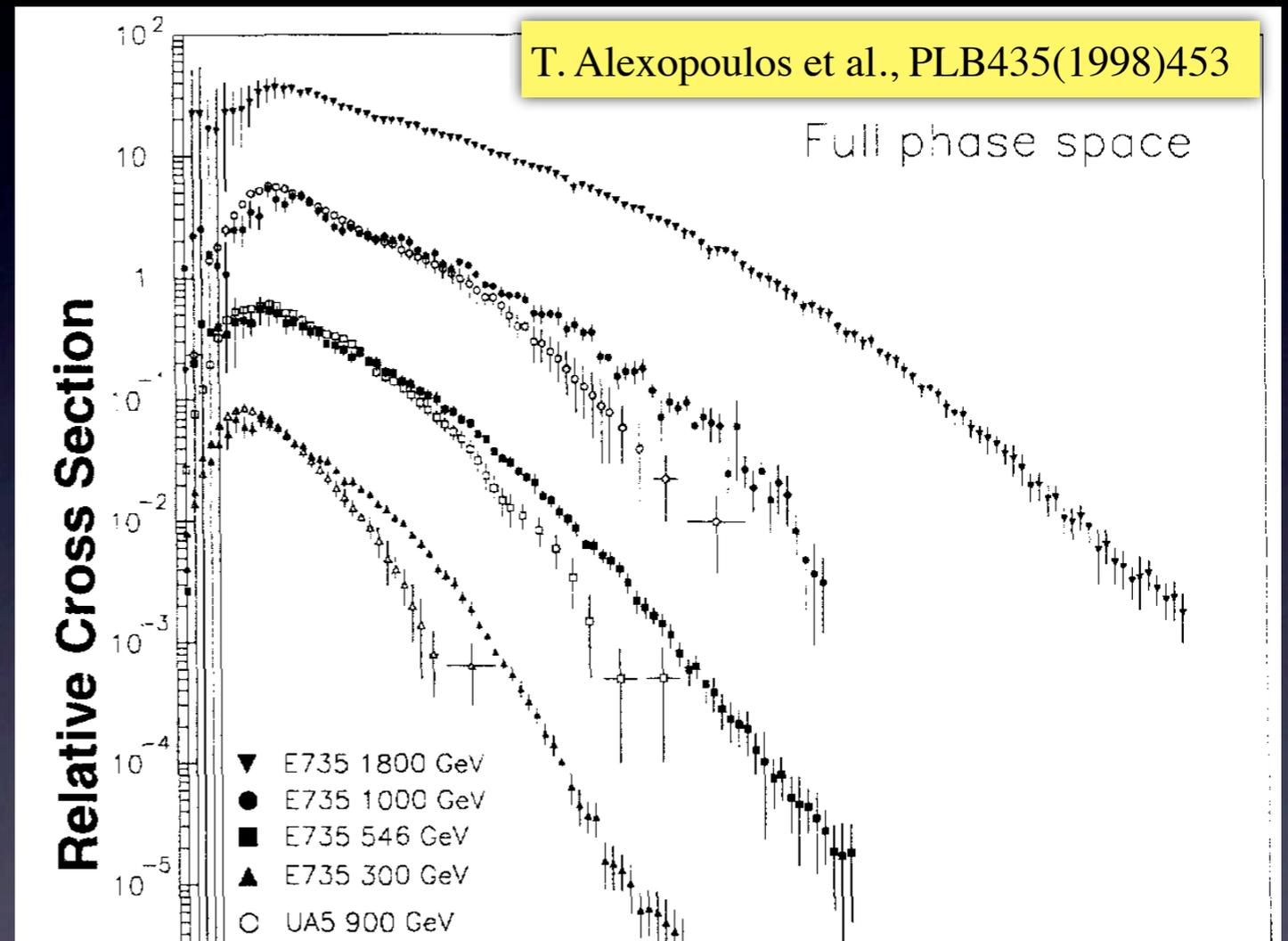
High Multiplicities: An Unresolved Question

- UA5 at 200, 546, and 900 GeV
- E735 at 300, 546, 1000, and 1800 GeV
- Mutually **Inconsistent over Entire Range**



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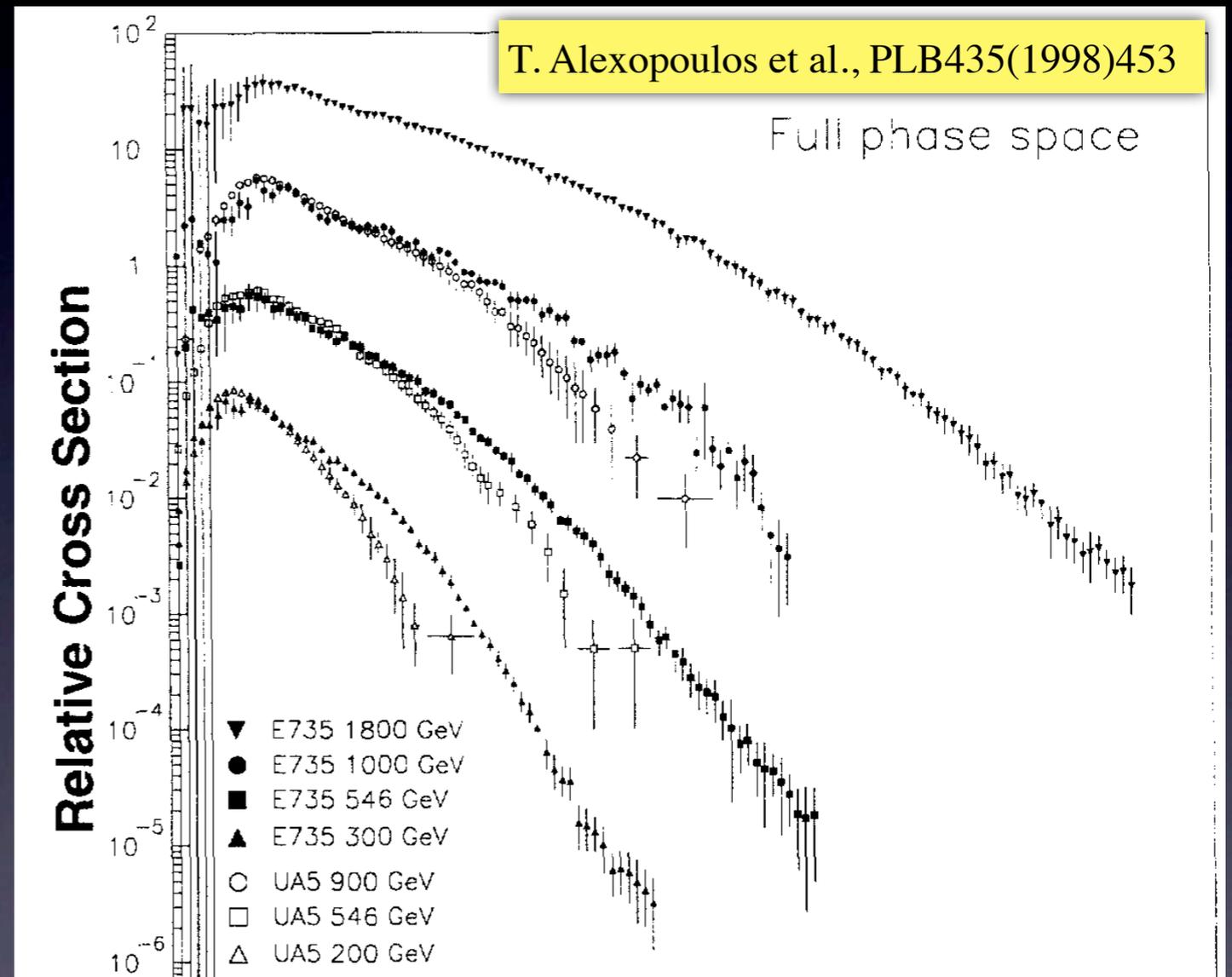
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Without even knowing how many tracks to tune to, how could we hope to constrain non-perturbative models (i.e., Monte Carlos) ?

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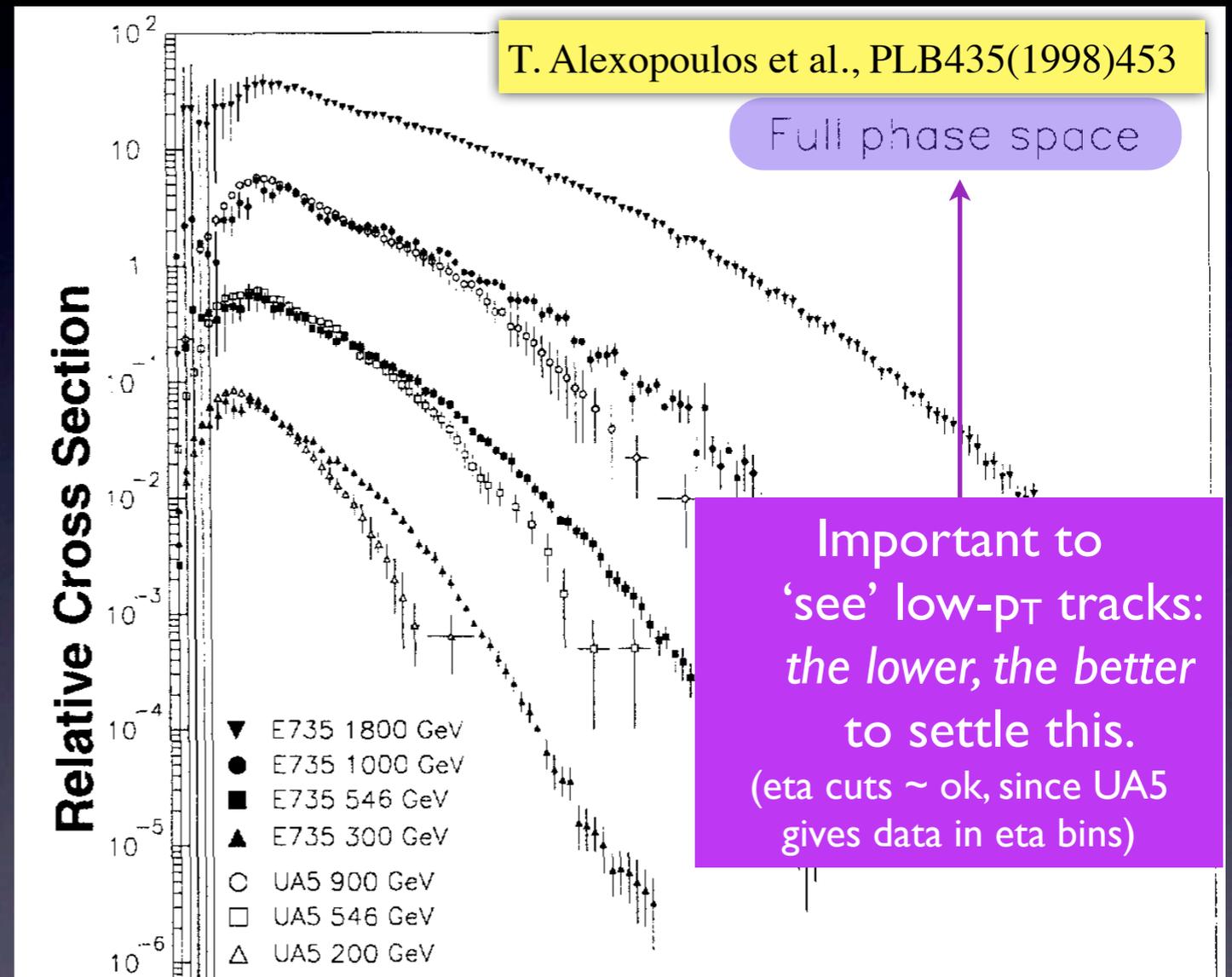
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- Normal MC Tuning Procedure:
 - Fragmentation and Flavour parameters constrained at LEP, then used in pp/ppbar (Jet Universality)

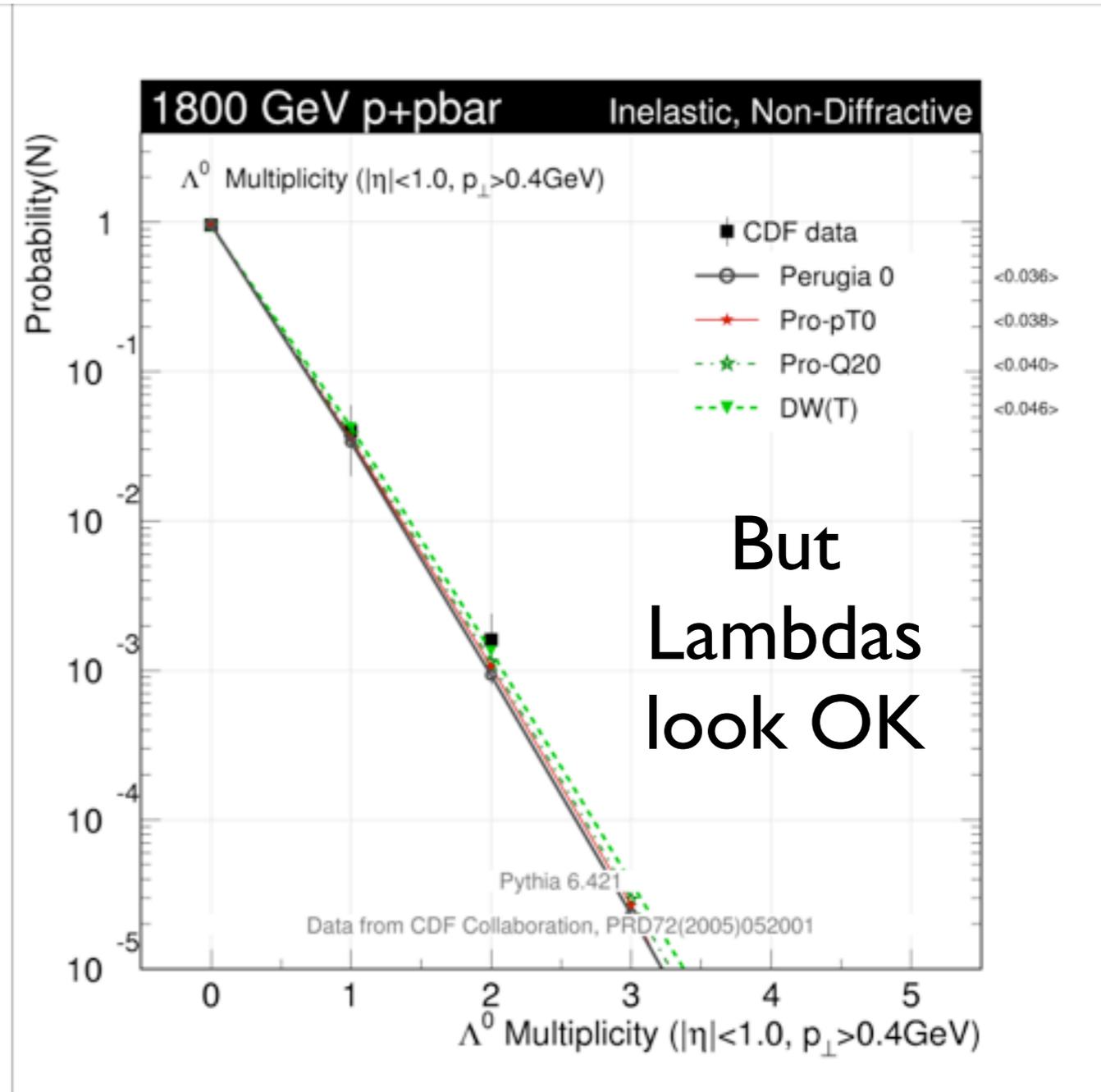
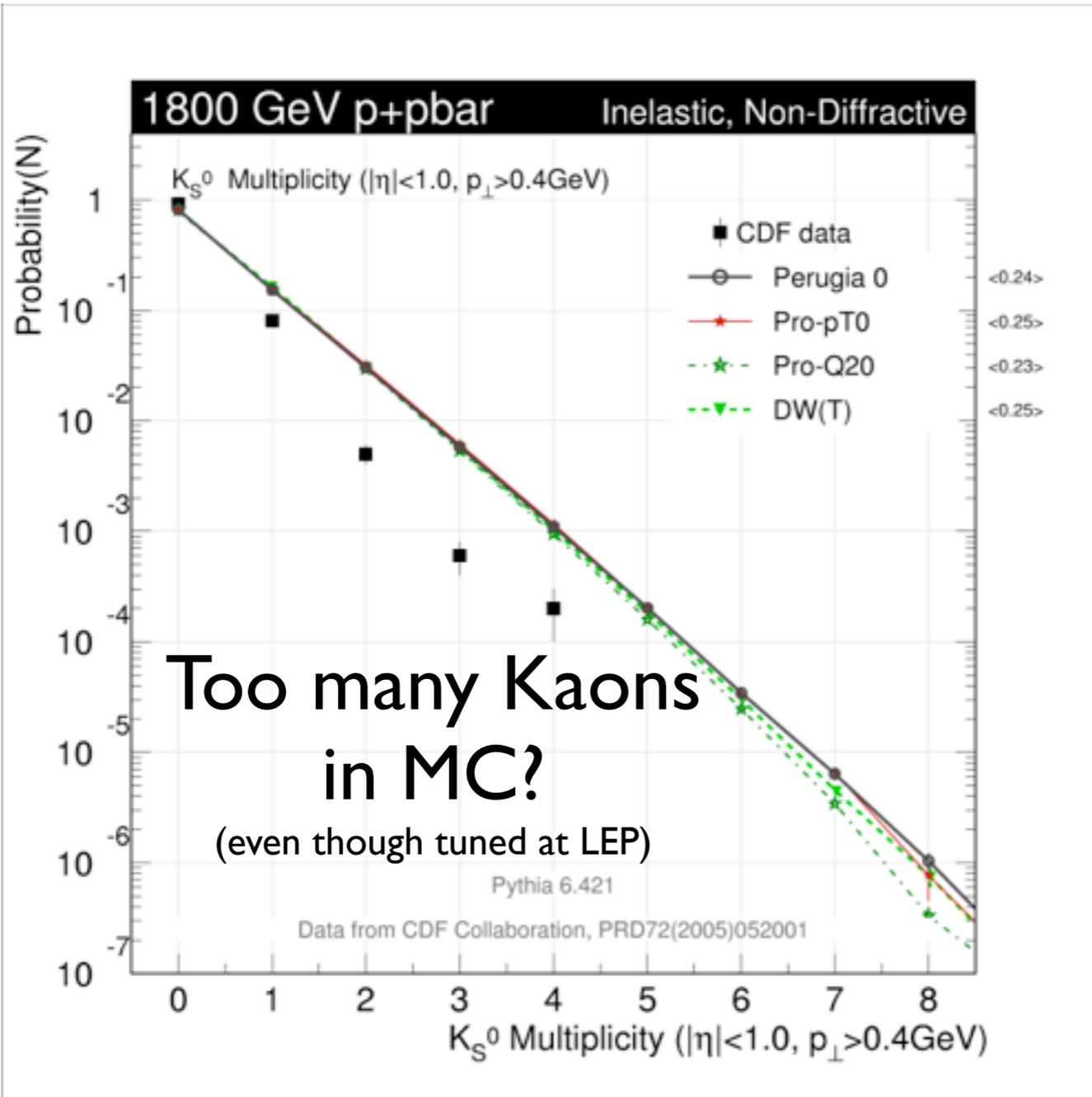
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- Check fragmentation *in situ* at hadron colliders
 - N and p_T spectra (and x spectra normalized to 'jet'/minijet energy?)
Identified particles highly important to dissect fragmentation

The Kaon Problem



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

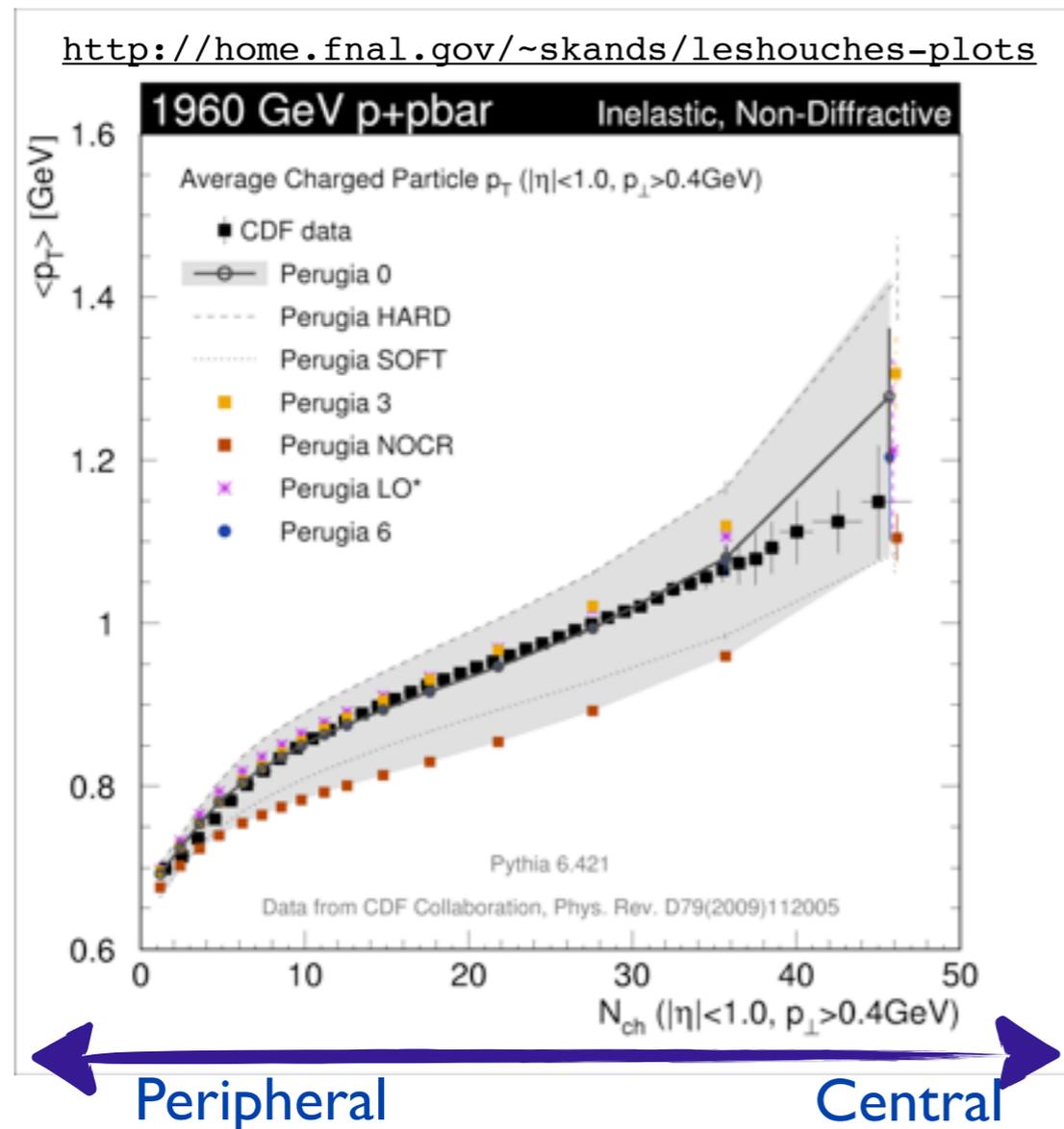
PS, fermilab-conf-07-706-t, in arXiv:0803.0678 [hep-ph]

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Identified particles highly important to dissect fragmentation
 - (How) do the spectra change with (pseudo-)rapidity? (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)

Change with Event Activity

- One (important) example: $\langle p_T \rangle(N_{ch})$



The p_T spectrum becomes harder as we increase N_{ch} .

Important tuning reference (highly non-trivial to describe correctly)

(Color reconnections, string interactions, rescattering, collective flow in pp, ...?)

(Additional Observables)

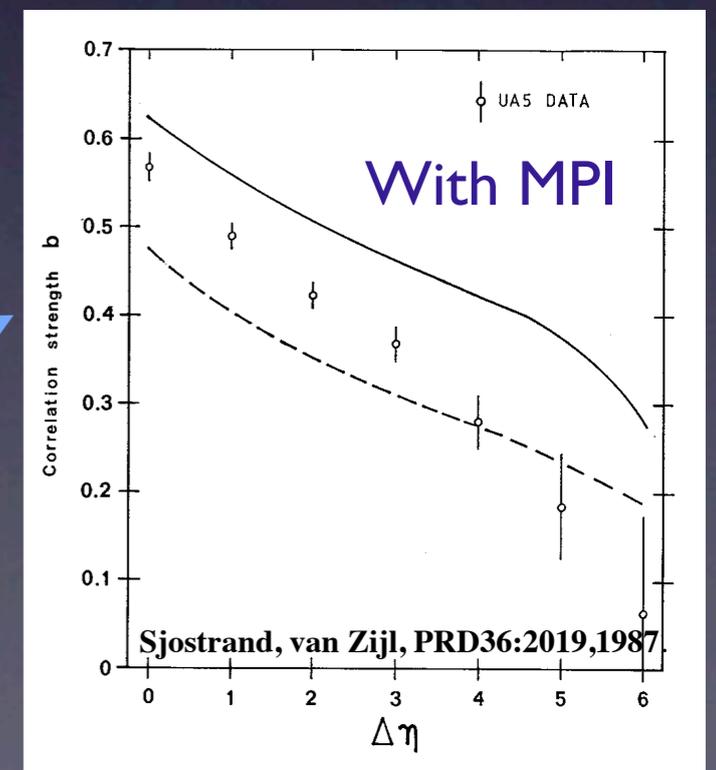
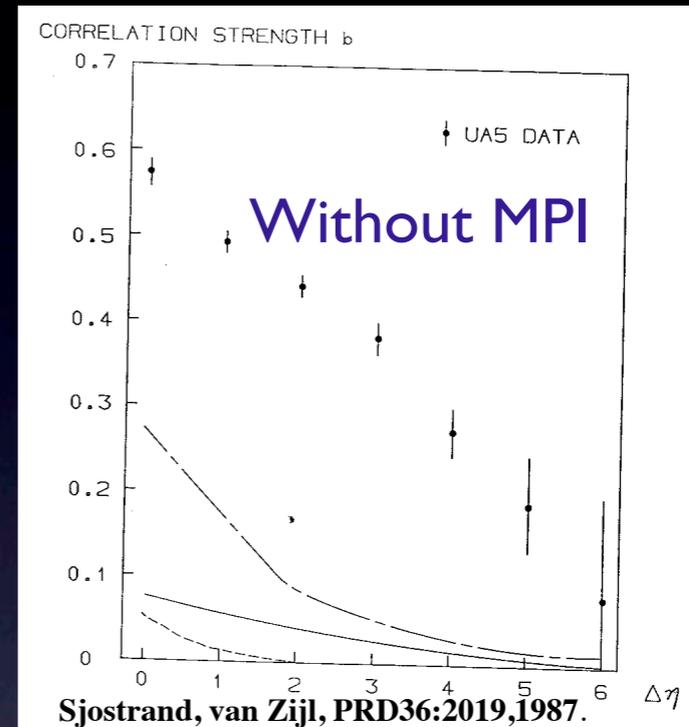
- **Particle-Particle Correlations** probe fragmentation beyond single-particle level. E.g.,:
 - A baryon here, where's the closest antibaryon?
 - + Is the Baryon number of the beam carried into the detector?
 - A Kaon here, where's the closest strange particle?
 - + Multi-Strange particles. Over how big a distance is the strangeness 'neutralized'?
 - Charge correlations. Special case: is the charge of the beam carried into the detector?

Radiation vs MPI

- What is producing the tracks?
 - Is it **Radiation**? (tends to produce partons close in phase space)
 - Or is it **MPI**? (partons going out in opposite directions)
 - Or is it soft production between the **remnants**?
- Probing long- vs short-distance correlations can tell us!
 - E.g., forward-backward correlation, b

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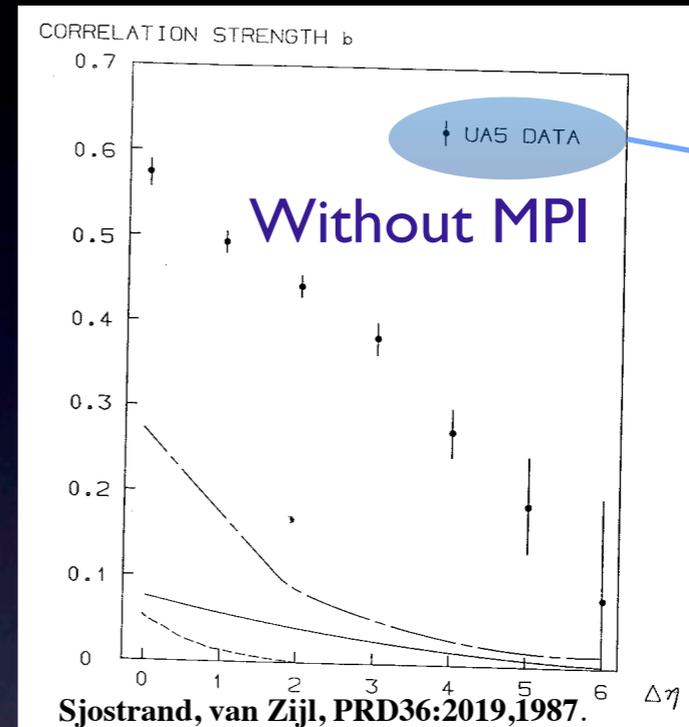
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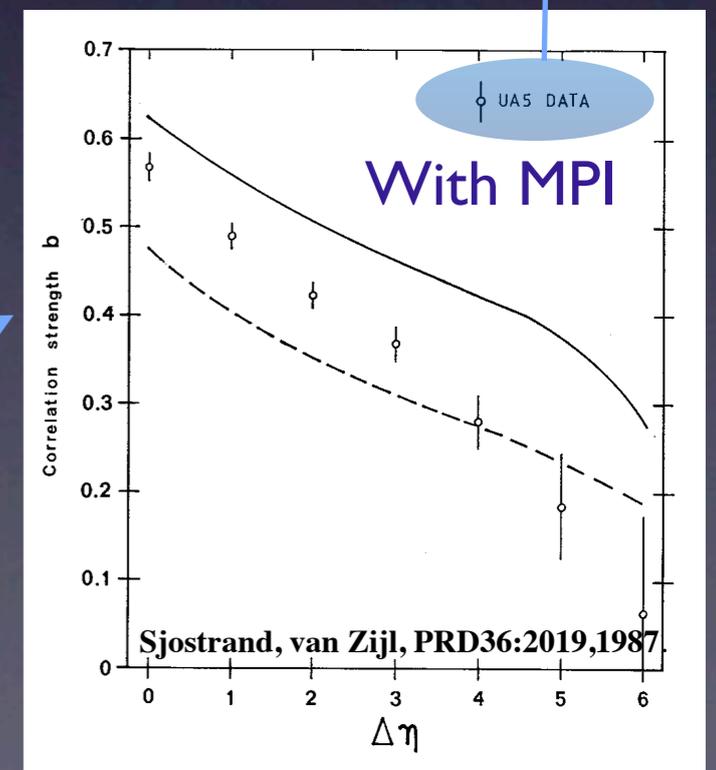
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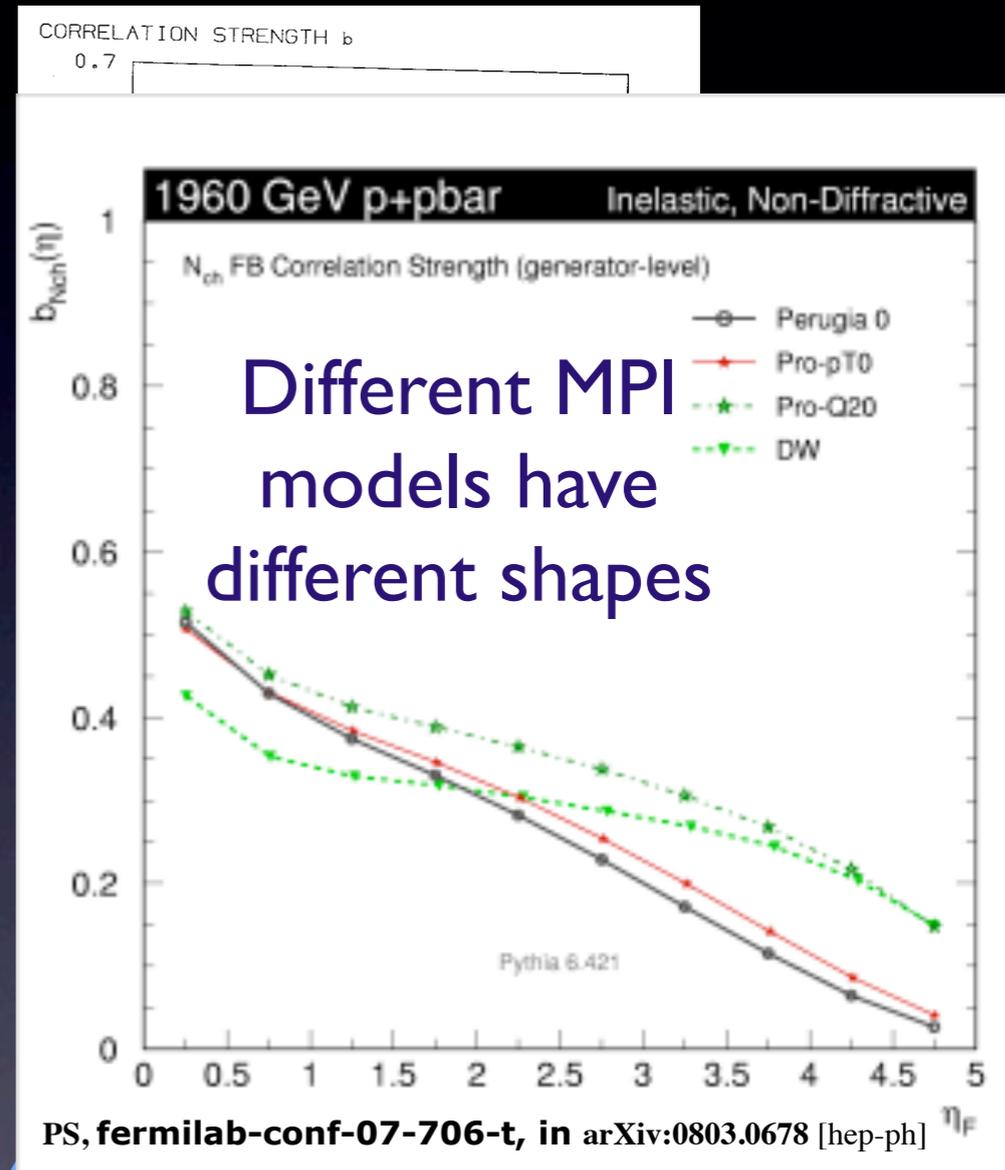
b Not measured at Tevatron



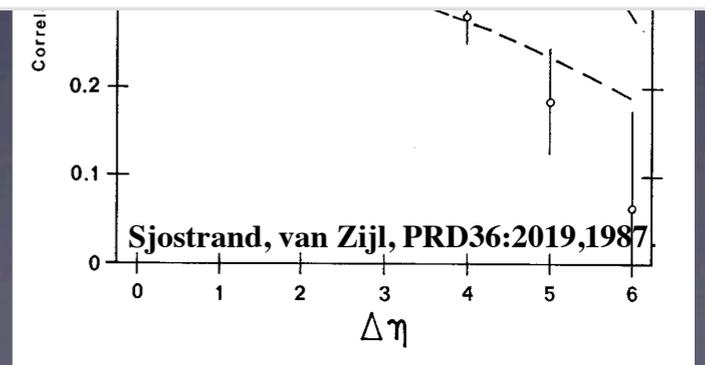
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Summary

- The Low-Energy LHC runs offer a unique possibility to settle important business
- These are questions faced by every person (within or outside experiments) doing MC tuning
- In a broader context, they concern our *knowledge of nature*

