Min-Bias Models
The Modeling of ND, SD, DD

Peter Skands (CERN PH-TH)

UE/MB Meeting, CERN, March 1, 2010

Disclaimer

- *Not* giving this talk to explain diffraction models, but to give input from modeling community
- ***Focus*** **on important** outstanding questions *addressed by early LHC data*
- **The answers are** crucial to *improving* our physics models

Monte Carlos and Precision

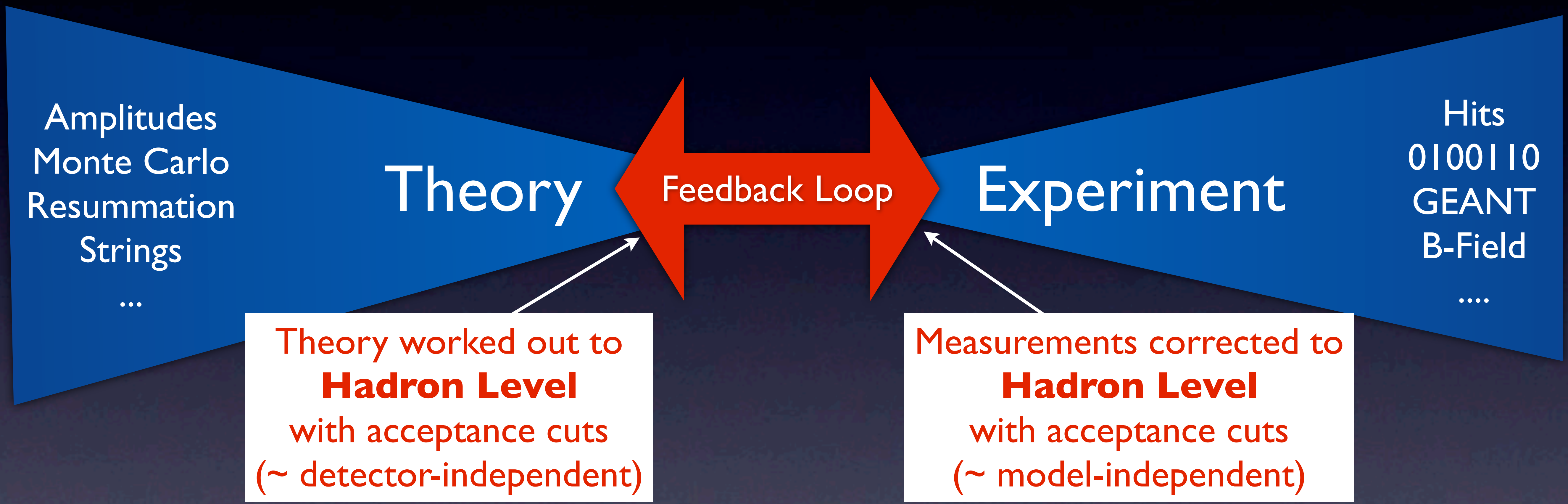
- **A Good Physics** Model gives you
  - **Reliable calibrations** for both signal and background (e.g., jet energy scales)
  - **Reliable corrections** (e.g., track finding efficiencies)
  - **Background estimates** with as small uncertainty as possible (fct of both theoretical accuracy and available experimental constraints)
  - **Reliable discriminators** with maximal sensitivity to New Physics

Count what is Countable

Measure what is Measurable

(and keep working on the beam)

G. Galilei



If not worked out to hadron level: data must be unfolded with *someone else's* hadron-level theory

Unfolding beyond hadron level dilutes precision of raw data (Worst case: data unfolded to ill-defined 'MC Truth' or 'parton level')

Constraining Models

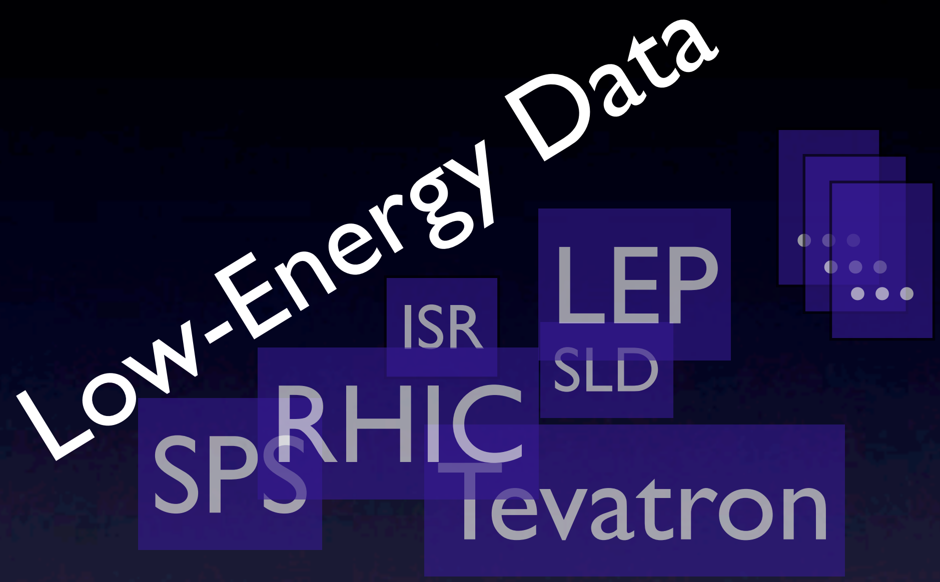
- A wealth of data available at lower energies
- Used for constraining ('tuning') theoretical models (E.g., Monte Carlo Event Generators)

Constraining Models

- 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 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?

Constraining Models



- 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 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

- One of the most fundamental quantities to measure
  - But fundamental does not imply easy

Charged Multiplicity

- One of the most fundamental quantities to measure
  - But fundamental does not imply easy
  - **Experimental Complications: Corrections** for Trigger Bias, Diffraction, Zero Bin, Long-Lived particles, Extrapolations from raw measurement to: hadron-level (with acceptance cuts) and/or to: hadron-level (full phase space), ...

Charged Multiplicity

- One of the most fundamental quantities to measure
  - **Theoretical Complications:**
    - N_{ch} is very **IR sensitive** ...A model that fits N_{ch} but fails on p_T is getting the overall energy flow wrong > agreement on N_{ch} alone may be deceptive

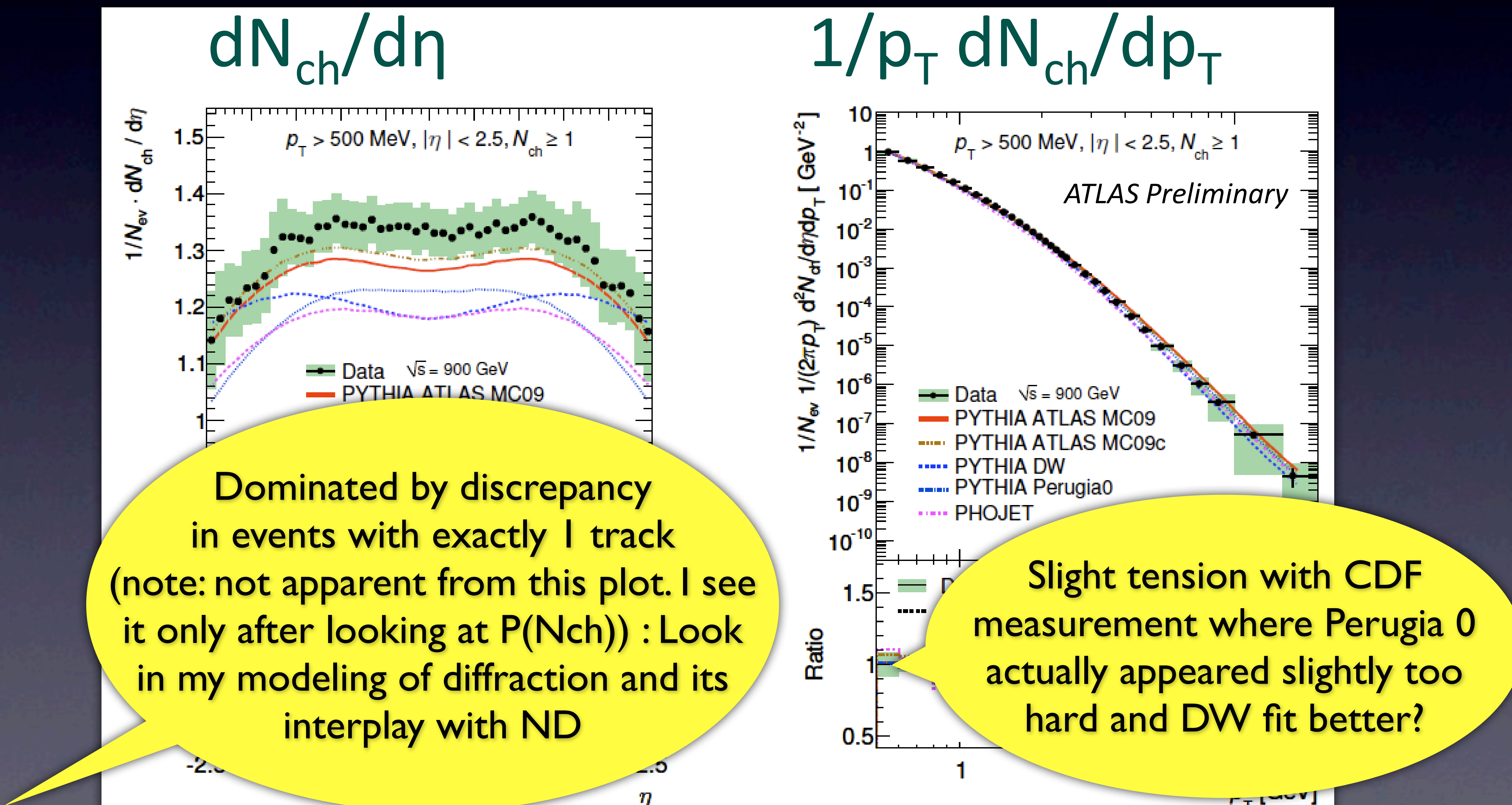
Charged Multiplicity

- One of the most fundamental quantities to measure
  - **Theoretical Complications:**
    - N_{ch} is very **IR sensitive** ...A model that fits N_{ch} but fails on p_T is getting the overall energy flow wrong > agreement on N_{ch} alone may be deceptive

- Need to test several distributions, in several phase space regions, to get complete picture
  - Who breaks down and where : can see patterns and ask why
  - *(Note: a 10% agreement with an IR sensitive number is usually pretty good...)*

The Overall Picture

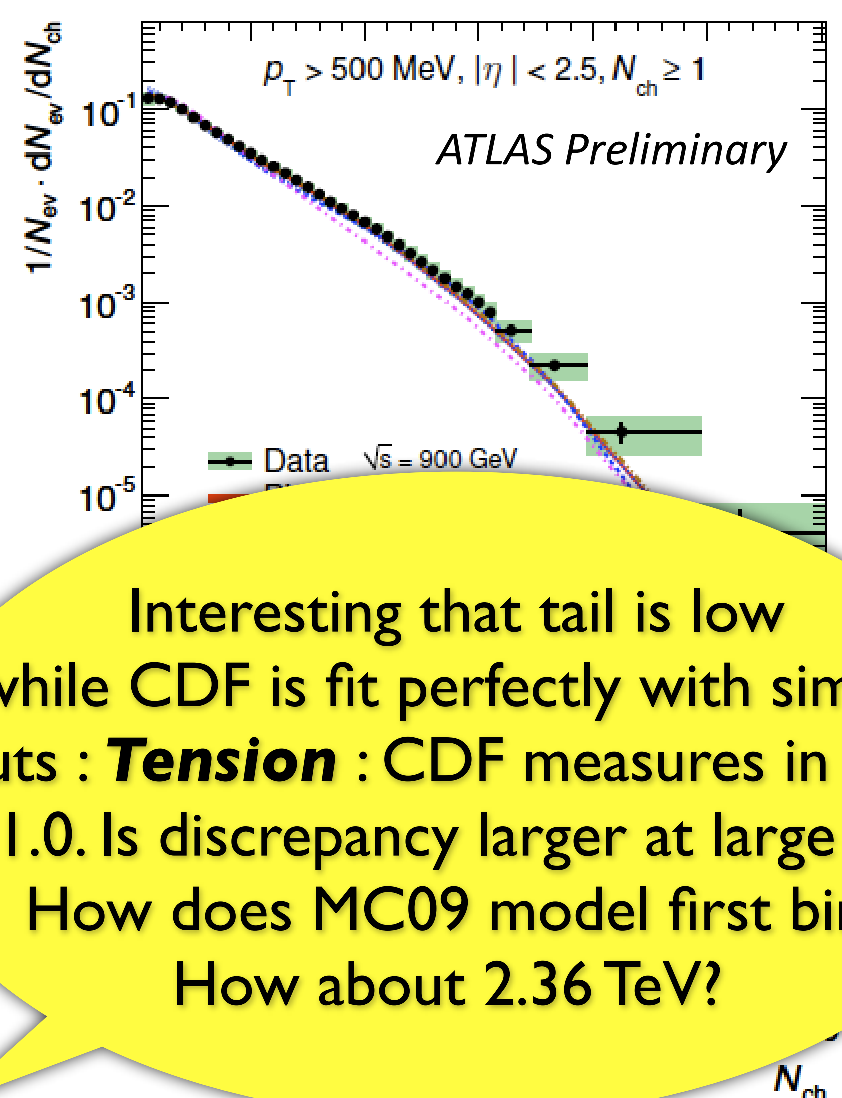
- How does a model builder look at this?



The Overall Picture

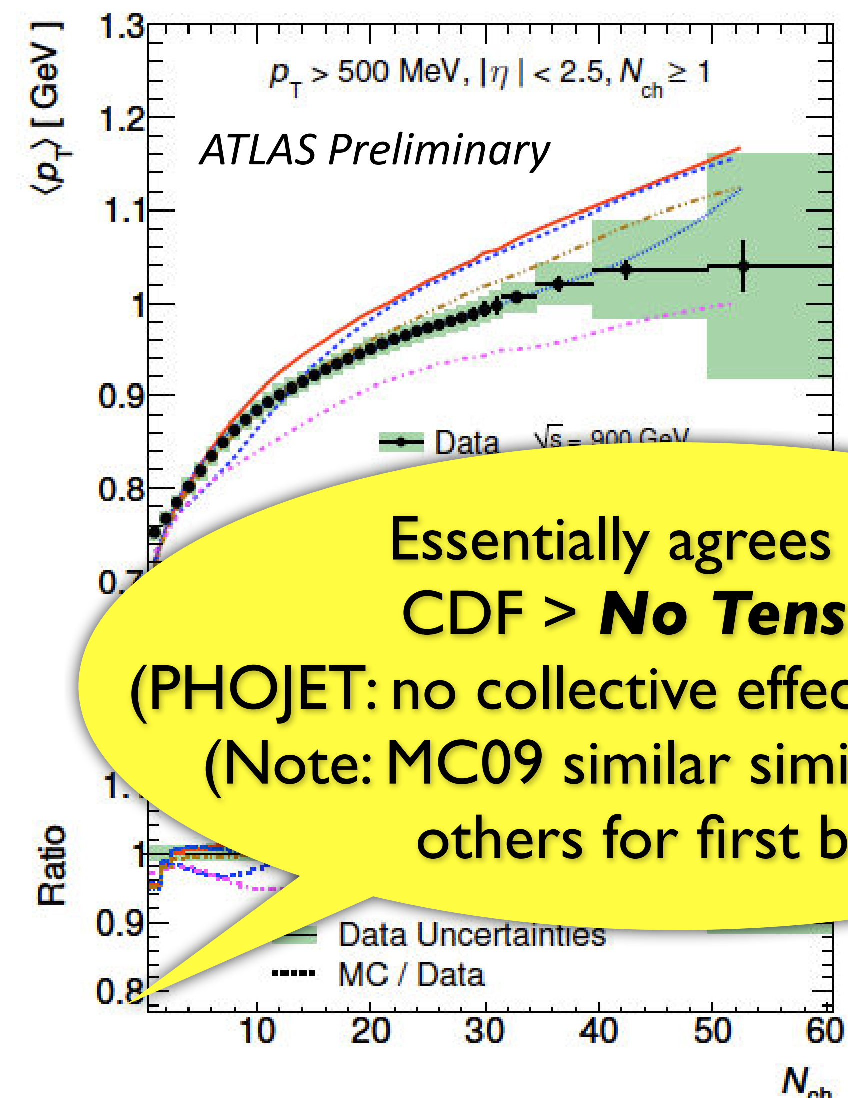
- How does a model builder look at this?

dN_{ev}/dN_{ch}



Interesting that tail is low while CDF is fit perfectly with similar cuts : ***Tension*** : CDF measures in |eta| <1.0. Is discrepancy larger at large eta? How does MC09 model first bin? How about 2.36 TeV?

$<p_T>$ vs N_{ch}

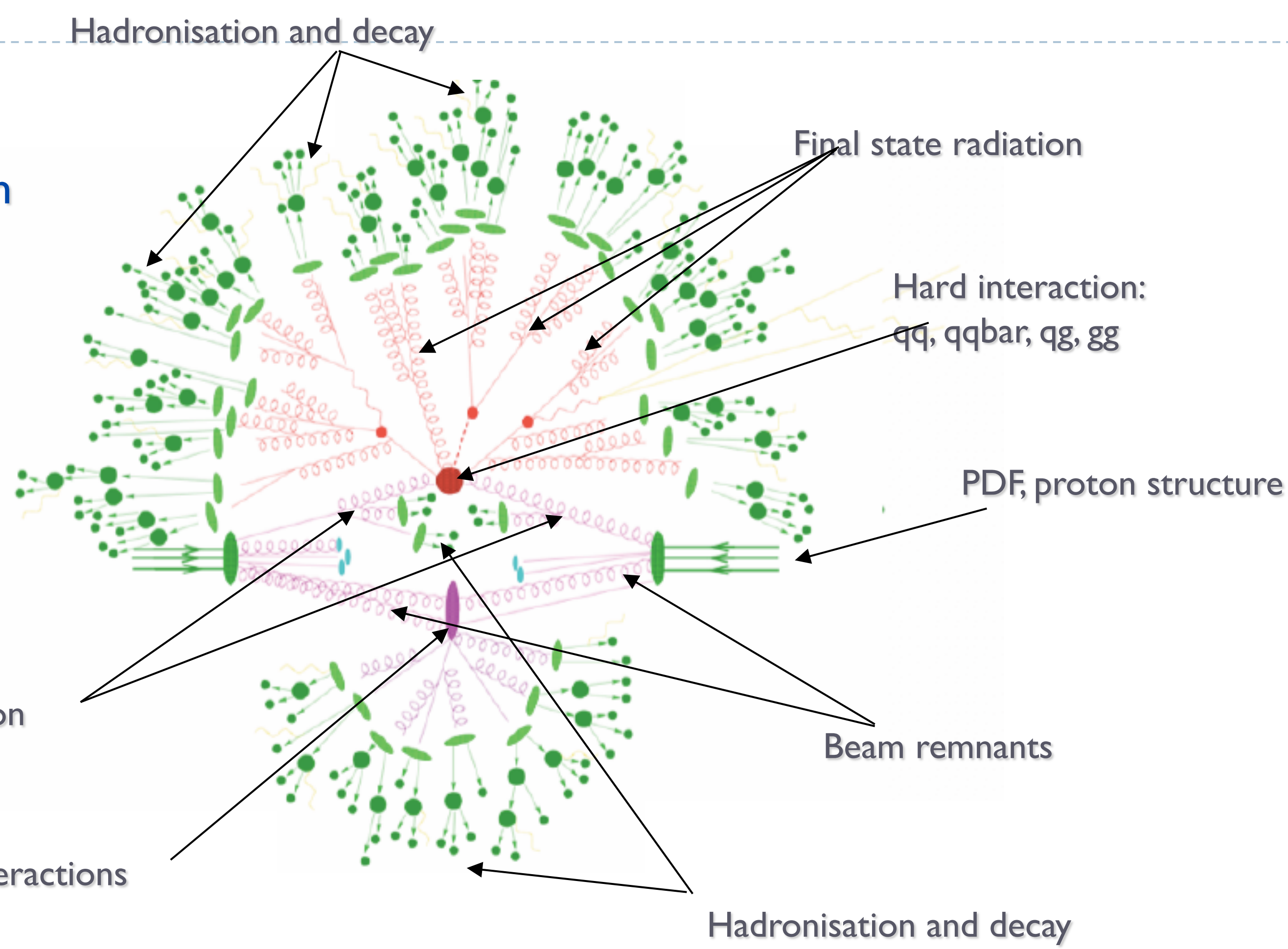


Essentially agrees with CDF > ***No Tension***. (PHOJET: no collective effects > too soft?) (Note: MC09 similar similar <pT> as others for first bin)

Dissecting Minimum-Bias

Physics requirements: basics

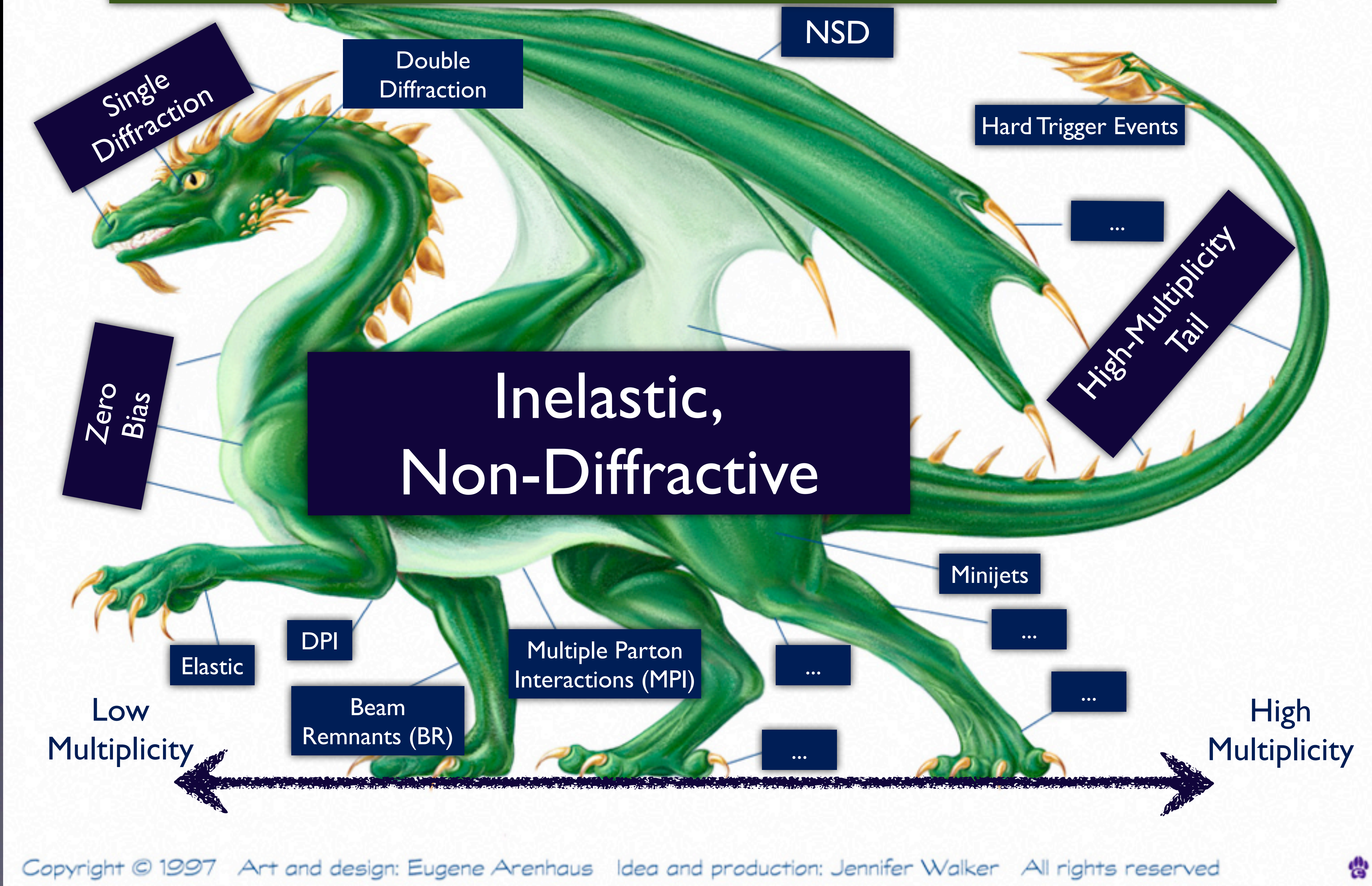
The MC description of LHC events is tremendously complex



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 !

(slide from F. Cossutti (CMS), 7th MCnet Annual Meeting, January 2010)

Dissecting Minimum-Bias



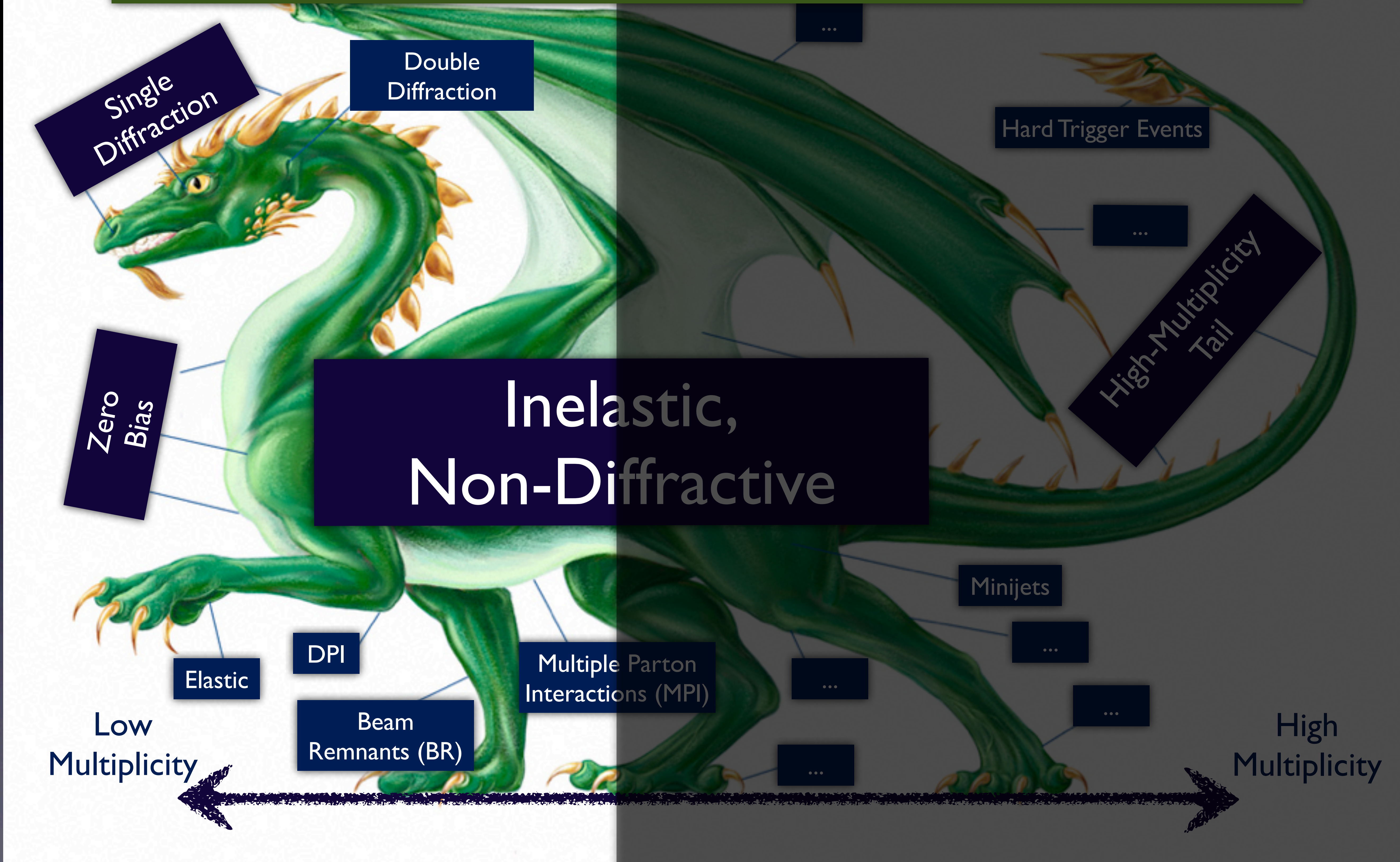
Measured Results

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

Measured Results

- How to Compare to Older Measurements?
  - Bubble chambers etc extrapolated to full phase space
  - More model-dependent at Tevatron and LHC experiments
- How to Compare to Theory?
  - Inelastic > 'NSD' > Inelastic Non-Diffractive, ... ?
    - For all: Define event set in terms of hadron-level cuts (model-*inspired, yes,* but not model-*dependent*)
  - Model constraints not helped by filling up unmeasured region with some model/fit (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

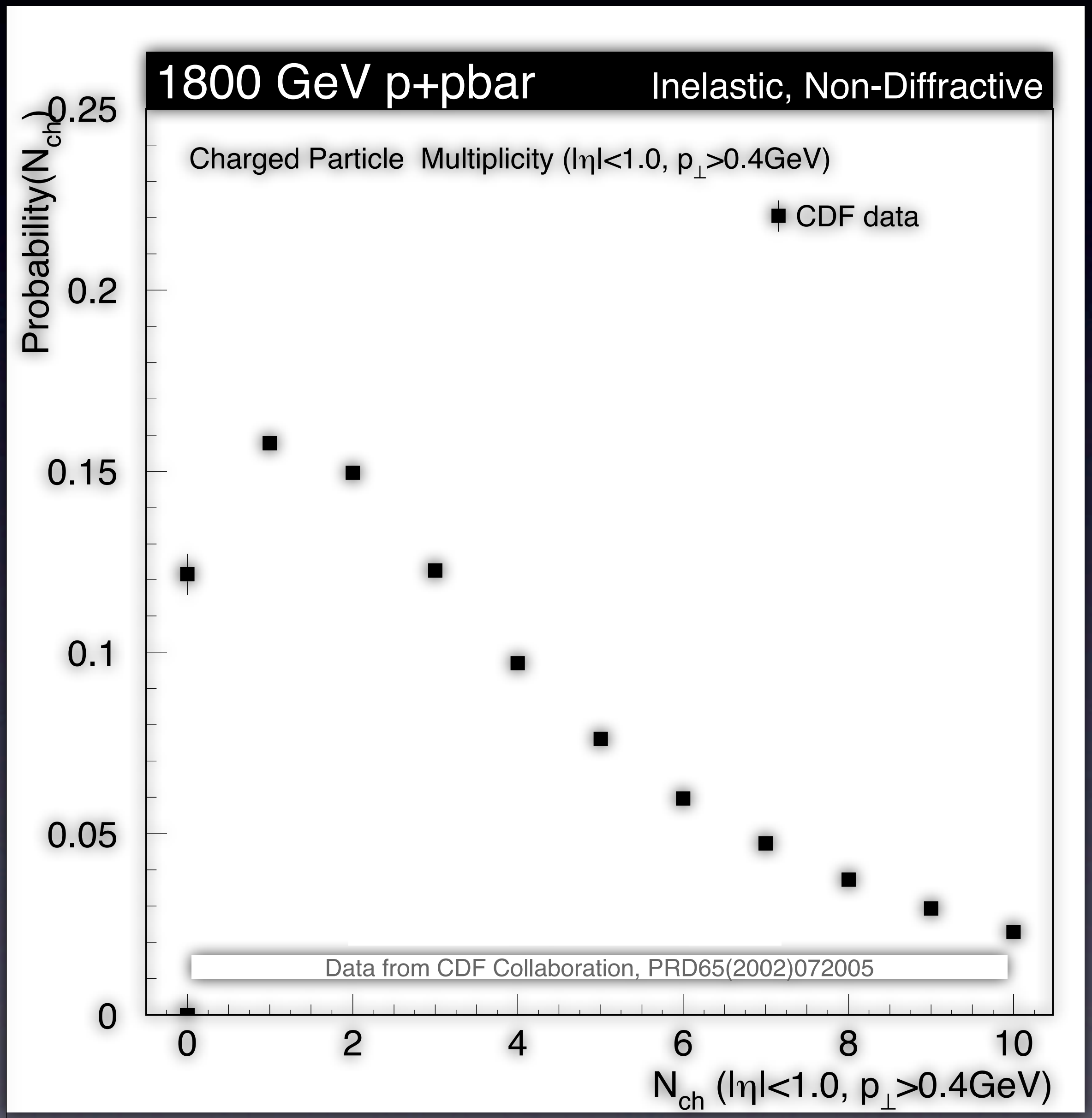


Low Multiplicities: Correcting for Diffraction

- Diffractive processes
  - Large part of total cross section ↗ cf. Beate's talk
  - Populate the low-multiplicity bins: lower $<N_{ch}>$
  - Characteristic rapidity spectrum with large rapidity gaps: affect dN_{ch}/deta
  - Impossible to interpret min-bias spectra without knowing precisely how diffraction was treated

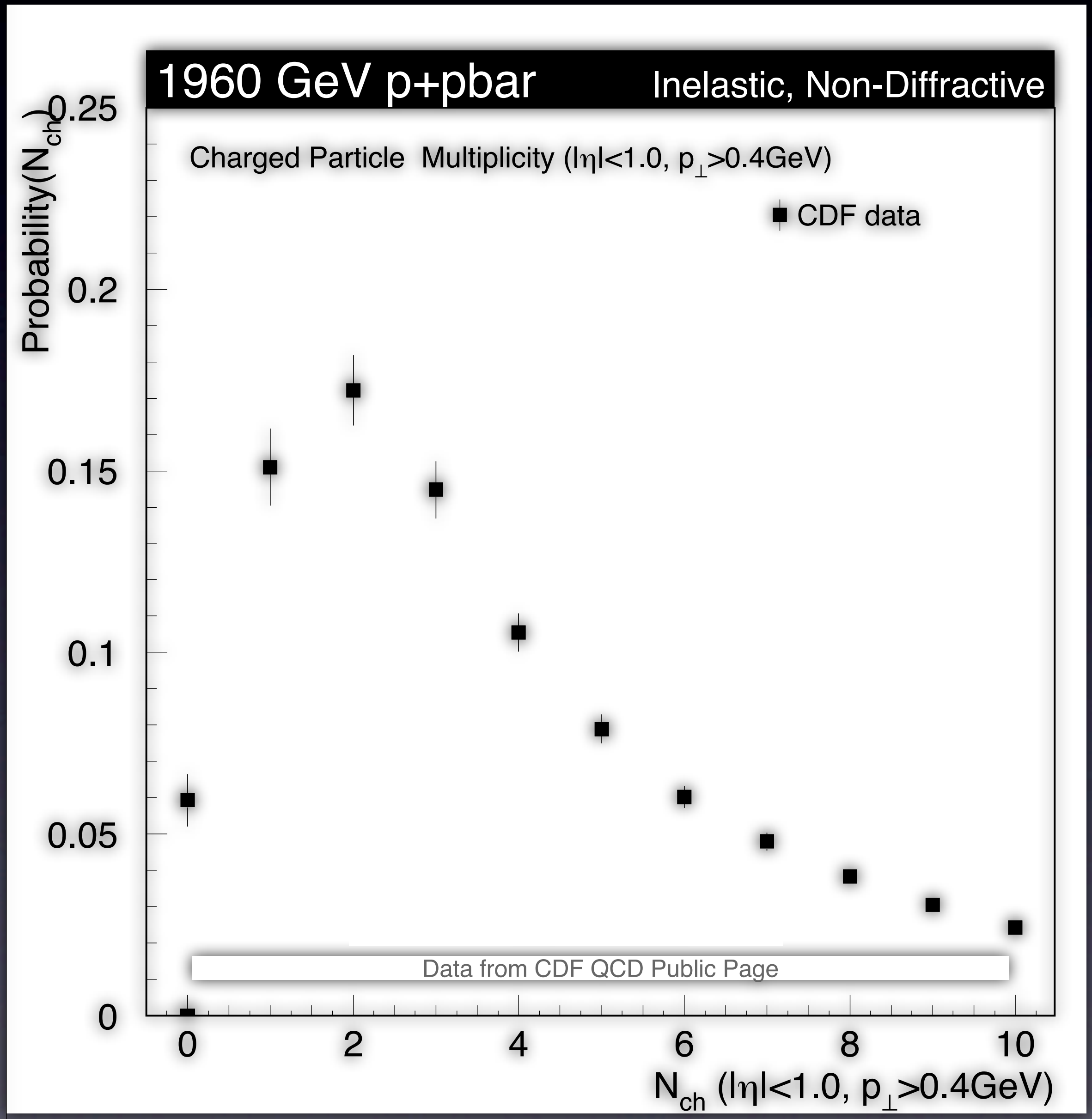
Low Multiplicities: Correcting for Diffraction

- CDF Run-I Data
  - Corrected to pT>0.4 GeV instead of full PS: less model dependence
  - First few bins corrected for diffraction (also affects average Nch and dN/deta)



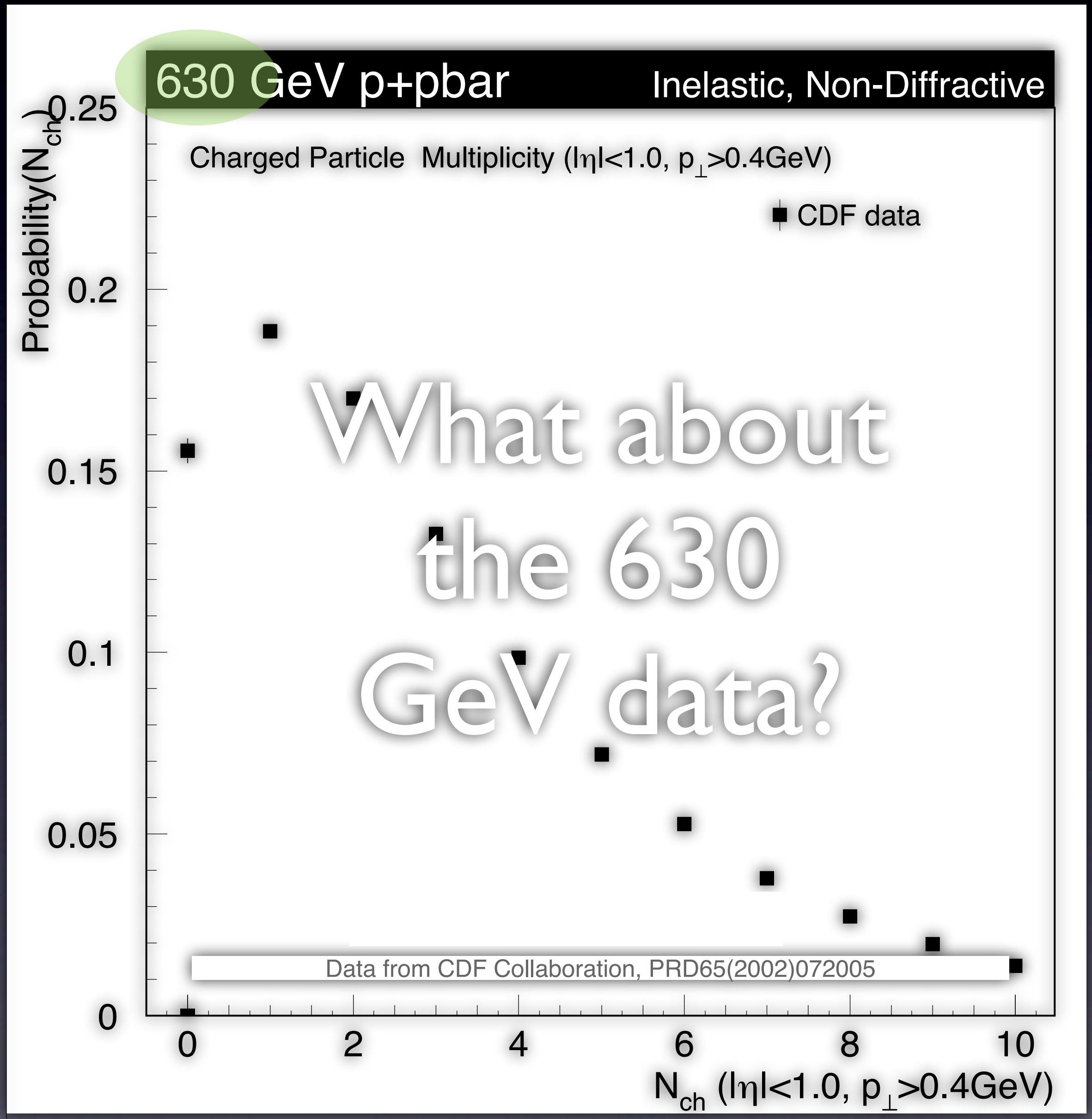
Low Multiplicities: Correcting for Diffraction

- CDF Run-II Data
  - Corrected to pT>0.4 GeV instead of full PS: less model dependence
  - First few bins corrected for diffraction (also affects average Nch and dN/deta)



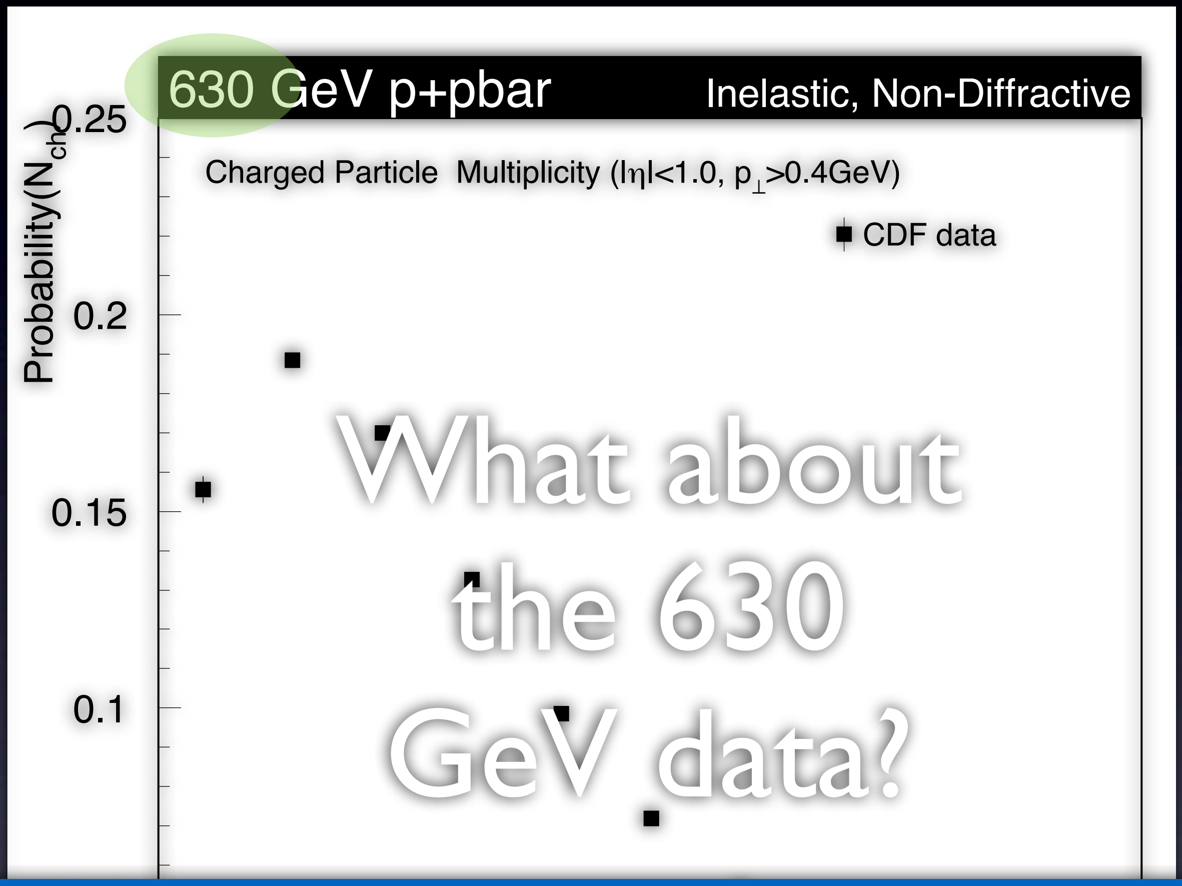
Low Multiplicities: Correcting for Diffraction

- CDF Run-I Data
  - Corrected to pT>0.4 GeV instead of full PS: less model dependence
  - First few bins corrected for diffraction (also affects average Nch and dN/deta)



Low Multiplicities: Correcting for Diffraction

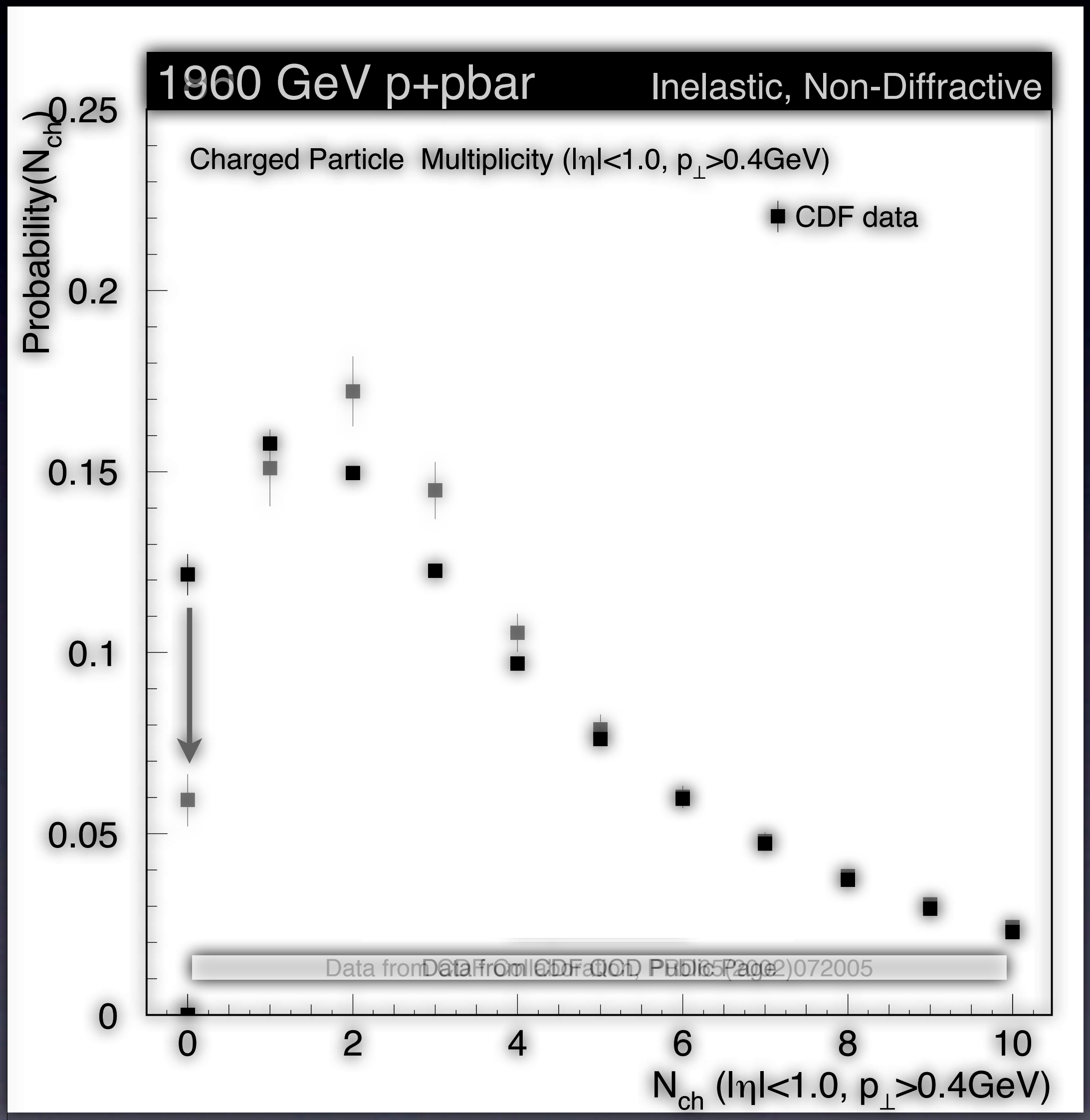
- CDF Run-I Data
  - Corrected to pT>0.4 GeV instead of full PS: less model dependence
  - First few bins



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 ... ?*



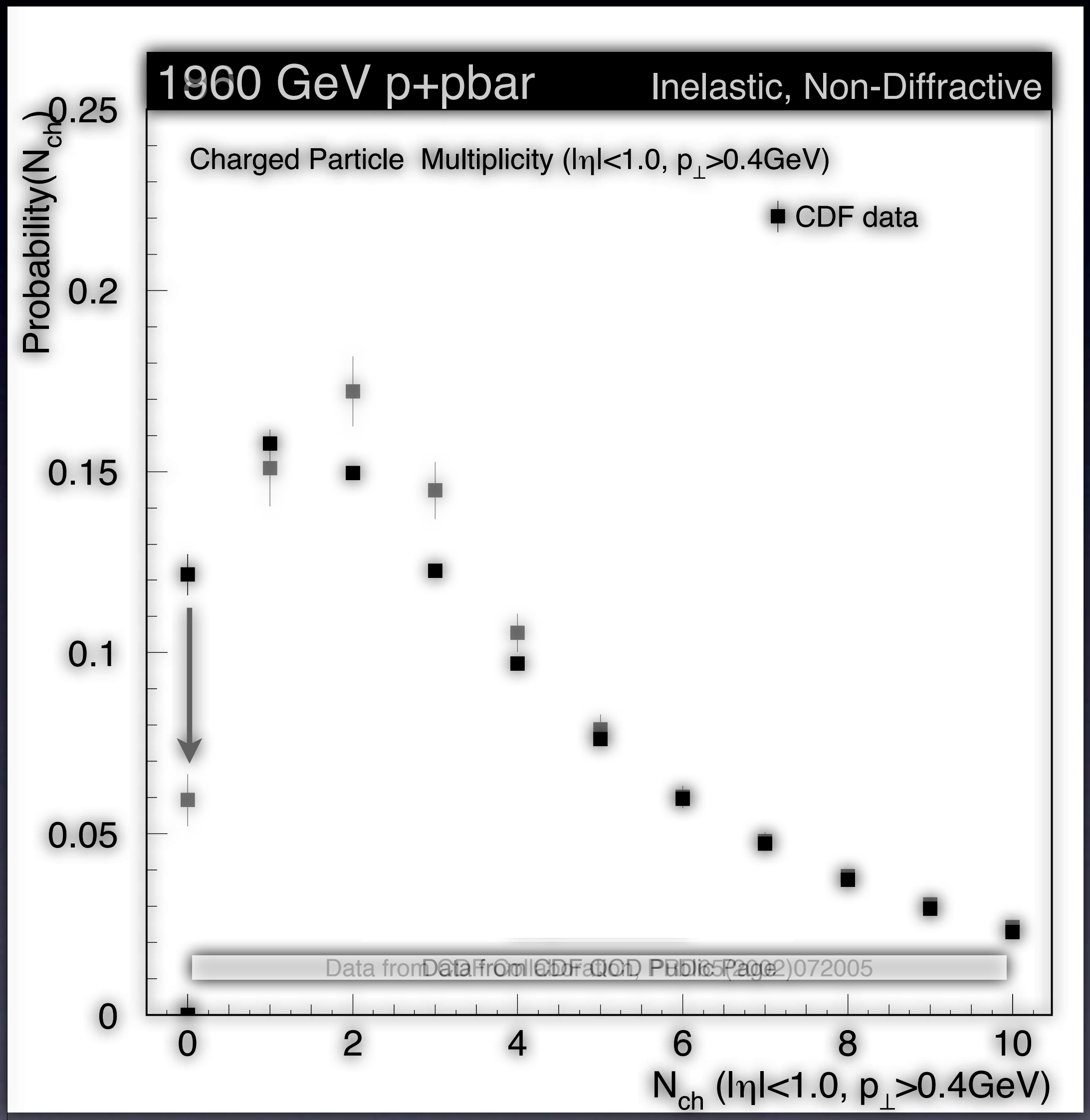
The Zero Bin

- 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 ... ?*

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?

→ATLAS

Ways Out

A) Trust the theorists. Correct to specific set of fundamental processes → NSD, INEL, ...

Ways Out

A) Trust the theorists. Correct to specific set of fundamental processes → NSD, INEL, ...

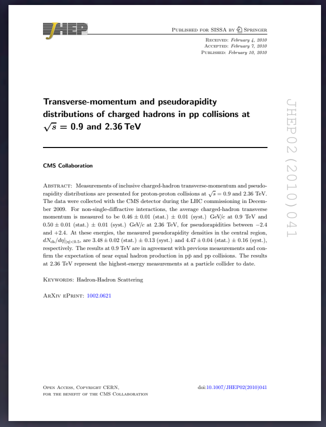
"Traditional" strategy.
Employed by most previous experiments.

Ways Out

A) Trust the theorists. Correct to specific set of fundamental processes → NSD, INEL, ...

"Traditional" strategy.
Employed by most previous experiments.

Also used in the first two LHC papers
ALICE Collaboration, Eur. Phys. J. C65 (2010) 111
CMS Collaboration, JHEP 02 (2010) 041



Ways Out

A) Trust the theorists. Correct to specific set of fundamental processes ➜ NSD, INEL, ...

"Traditional" strategy.
Employed by most previous experiments.

Also used in the first two LHC papers
ALICE Collaboration, Eur. Phys. J. C65 (2010) 111
CMS Collaboration, JHEP 02 (2010) 041

Eur. Phys. J. C (2010) 65: 111–125
DOI 10.1140/epjc/s10052-009-1227-4

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

First proton–proton collisions at the LHC as observed with the ALICE detector: measurement of the charged-particle pseudorapidity density at $\sqrt{s} = 900$ GeV

The ALICE Collaboration

K. Aamodt, N. Abel, U. Abeysekara, A. Abrahantes Quintana, A. Acero, D. Adamová, M.M. Aggarwal, G. Aglieri Rinella, A.G. Agocs, S. Aguilar Salazar, Z. Ahammed, A. Ahmad, N. Ahmad, S.U. Ahn, R. Akimoto, A. Akindinov, D. Aleksandrov, B. Alessandro, R. Alfaro Molina, A. Alici, E. Almaráz Aviña, J. Alme, T. Alt, V. Altini, S. Altinpinar, C. Andrei, A. Andronic, G. Anelli, V. Angelov, C. Anson, T. Antičić, F. Antinori, S. Antinori, K. Antipin, D. Antończyk, P. Antonioli, A. Anzo, L. Aphecetche, H. Appelshäuser, S. Arcelli, R. Arceo, A. Arend, N. Armesto, R. Arnaldi, T. Aronsson, I.C. Arsene, A. Asryan, A. Augustinus, R. Averbeck, T.C. Awes, J. Äystö, M.D. Azmi, S. Bablok, M. Bach, A. Badalà, Y.W. Baek, S. Bagnasco, R. Bailhache, R. Bala, A. Baldisseri, A. Baldit, J. Bán, R. Barbera, G.G. Barnaföldi, L. Barnby, V. Barret, J. Bartke, F. Barile, M. Basile, V. Basmanov, N. Bastid, B. Bathen, G. Batigne, B. Batyunya, C. Baumann, I.G. Bearden, B. Becker, I. Belikov, R. Bellwied, E. Belmont-Moreno, A. Belogianni, L. Benhabib, S. Beole, I. Berceanu, A. Bercuci, E. Berdermann, Y. Berdnikov, L. Betev, A. Bhasin, A.K. Bhati, L. Bianchi, N. Bianchi, C. Bianchin, J. Bielčík, J. Bielčíková, A. Bilandzic, L. Bimbot, E. Biolcati, A. Blanc, F. Blanco, F. Blanco, D. Blau, C. Blume, M. Boccioli, N. Bock, A. Bøgdanov, H. Bøggild, M. Bogolyubsky, J. Bohm, L. Boldizsár, M. Bombara, C. Bombonati, M. Bondila, H. Borel, V. Borshchov, C. Bortolin, S. Bose, L. Bosisio, F. Bossú, M. Botje, S. Böttger, G. Bourdaud, B. Boyer, M. Braun, P. Braun-Munzinger, L. Bravina, M. Bregant, T. Breitner, G. Bruckner, R. Brun, E. Bruna, G.E. Bruno, D. Budnikov, H. Buesching, K. Bugaev, P. Buncic, O. Busch, Z. Buthelezi, D. Caffarri, X. Cai, H. Caines, E. Camacho, P. Camerini, M. Campbell, V. Canoa Roman, G.P. Capitani, G. Cara Romeo, F. Carena, W. Carena, F. Carminati, A. Casanova Díaz, M. Caselle, J. Castillo Castellanos, J.F. Castillo Hernandez, V. Catanescu, E. Cattaruzza, C. Cavicchioli, P. Cerello, V. Chambert, B. Chang, S. Chapeland, A. Charpy, J.L. Charvet, S. Chattopadhyay, S. Chattopadhyay, M. Cherney, C. Cheshkov, B. Cheynis, E. Chiavassa, V. Chibante Barroso, D.D. Chinellato, P. Chochula, K. Choi, M. Chojnacki, P. Christakoglou, C.H. Christensen, P. Christiansen, T. Chujo, F. Chuman, C. Cicalo, L. Cifarelli, F. Cindolo, J. Cleymans, O. Cobanoglu, J.-P. Coffin, S. Coli, A. Colla, G. Conesa Balbastre, Z. Conesa del Valle, E.S. Conner, P. Constantin, G. Contin, J.G. Contreras, Y. Corrales Morales, T.M. Cormier, P. Cortese, I. Cortés Maldonado, M.R. Cosentino, F. Costa, M.E. Cotallo, E. Crescio, P. Crochet, E. Cuautle, L. Cunqueiro, J. Cussonneau, A. Dainese, H.H. Dalsgaard, A. Danu, I. Das, S. Das, A. Dash, S. Dash, G.O.V. de Barros, A. De Caro, G. de Cataldo, J. de Cuveland, A. De Falco, M. de Gaspari, J. de Groot, D. De Gruttola, A.P. de Haas, N. De Marco, R. de Rooij, S. De Pasquale, G. de Vaux, H. Delagrange, G. Dellacasa, A. Deloff, V. Demanov, E. Dénes, A. Deppman, G. D'Erasmo, D. Derkach, A. Devaux, D. Di Bari, C. Di Giglio, S. Di Liberto, A. Di Mauro, P. Di Nezza, M. Dialinas, L. Díaz, R. Díaz, T. Dietel, H. Ding, R. Divià, Ø. Djuvsland, G. do Amaral Valdiviesso, V. Dobretsov, A. Dobrin, T. Dobrowolski, B. Dönigus, I. Domínguez, D.M.M. Don, O. Dordic, A.K. Dubey, J. Dubuisson, L. Ducroux, P. Dupieux, A.K. Dutta Majumdar, M.R. Dutta Majumdar, D. Elia, D. Emschermann, A. Enokizono, B. Espagnon, M. Estienne, D. Evans, S. Evrard, G. Eyyubova, C.W. Fabjan, D. Fabris, J. Faivre, D. Falchieri, A. Fantoni, M. Fasel, R. Fearick, A. Fedunov, D. Fehlker, V. Fekete, D. Felea, B. Fenton-Olsen, G. Feofilov, A. Fernández Téllez, E.G. Ferreiro, A. Ferretti, R. Ferretti, M.A.S. Figueredo, S. Filchagin, R. Fini, F.M. Fionda, E.M. Fiore, M. Floris, Z. Fodor, S. Foertsch, P. Foka, S. Fokin, F. Formenti,

Springer

JHEP

Published for SISSA by Springer

Received: February 4, 2010
Accepted: February 7, 2010
Published: February 10, 2010

Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s} = 0.9$ and 2.36 TeV

CMS Collaboration

Abstract: Measurements of inclusive charged-hadron transverse-momentum and pseudorapidity distributions are presented for proton-proton collisions at $\sqrt{s} = 0.9$ and 2.36 TeV. The data were collected with the CMS detector during the LHC commissioning in December 2009. For non-single-diffractive interactions, the average charged-hadron transverse momentum is measured to be 0.46 ± 0.01 (stat.) $\pm$ 0.01 (syst.) GeV/c at 0.9 TeV and 0.50 ± 0.01 (stat.) $\pm$ 0.01 (syst.) GeV/c at 2.36 TeV, for pseudorapidities between -2.4 and $+2.4$. At these energies, the measured pseudorapidity densities in the central region, $dN_{ch}/d\eta|_{|\eta|<0.5}$, are 3.48 ± 0.02 (stat.) $\pm$ 0.13 (syst.) and 4.47 ± 0.04 (stat.) $\pm$ 0.16 (syst.), respectively. The results at 0.9 TeV are in agreement with previous measurements and confirm the expectation of near equal hadron production in $p\bar{p}$ and pp collisions. The results at 2.36 TeV represent the highest-energy measurements at a particle collider to date.

Keywords: Hadron-Hadron Scattering

ArXiv ePrint: 1002.0621

Open Access, Copyright CERN, for the benefit of the CMS Collaboration

doi:10.1007/JHEP02(2010)041

JHEP02(2010)041

However, it lacks a clear definition at the particle level

Ways Out

A) Trust the theorists. Correct to specific set of fundamental processes → NSD, INEL, ...

I	particle/jet	P(I,1)	P(I,2)	P(I,3)	P(I,4)	P(I,5)
1	p+	0.38955	-0.09031	-444.18188	444.18305	0.93827
2	p+	0.55491	-0.32947	118.14484	118.15033	0.93827
3	pi+	-0.10520	0.04623	21.97324	21.97398	0.13957
4	pi-	-0.36420	0.20220	79.60000	79.60121	0.13957
5	pi+	0.18465	-0.31136	44.33333	44.33503	0.13957
6	pi-	-0.65347	0.35445	10.76828	10.79481	0.13957
7	pi+	-0.31719	-0.18864	4.89293	4.90881	0.13957
8	pi-	0.18684	-0.24438	0.75472	0.82687	0.13957
9	pi+	0.01778	0.47298	1.28424	1.37578	0.13957
10	pi-	0.28540	-0.36795	2.98245	3.02181	0.13957
11	K+	0.01880	0.15742	2.95334	2.99849	0.49360
12	pi-	0.07232	0.23225	6.16625	6.17263	0.13957
13	pi+	-0.37412	0.04117	0.68340	0.79257	0.13957
14	pi-	0.12547	0.33701	2.03239	2.06867	0.13957
15	pi+	0.03865	0.05823	0.98258	0.99490	0.13957
16	pi-	0.16134	0.03535	4.09086	4.09657	0.13957
17	pi-	-0.06906	0.08845	1.96279	1.97095	0.13957
18	pi+	0.11852	-0.32616	3.70555	3.72438	0.13957
sum(p). mass:		0.27097	0.16745	-136.87069	751.99084	739.42987

eta gap = 13.6 units

Ways Out

A) Trust the theorists. Correct to specific set of fundamental processes → NSD, INEL, ...

I	particle/jet	P(I,1)	P(I,2)	P(I,3)	P(I,4)	P(I,5)
1	p+	0.38955	-0.09031	-444.18188	444.18305	0.93827
2	p+	0.55491	-0.32947	118.14484	118.15033	0.93827
3	pi+	-0.10520	0.04623	21.97324	21.97398	0.13957
4	pi-	-0.36420	0.20220	79.60000	79.60121	0.13957
5	pi+	0.18465	-0.31136	44.33333	44.33503	0.13957
6	pi-	-0.65347	0.35445	10.76828	10.79481	0.13957
7	pi+	[illegible]	[illegible]	[illegible]	[illegible]	0.13957
8	pi-	[illegible]	[illegible]	[illegible]	[illegible]	0.13957
9	pi+	[illegible]	[illegible]	[illegible]	[illegible]	0.13957
10	pi-	0.28540	-0.36795	2.98245	3.02181	0.13957
11	K+	0.01880	0.15742	2.95334	2.99849	0.49360
12	pi-	0.07232	0.23225	6.16625	6.17263	0.13957
13	pi+	-0.37412	0.04117	0.68340	0.79257	0.13957
14	pi-	0.12547	0.33701	2.03239	2.06867	0.13957
15	pi+	0.03865	0.05823	0.98258	0.99490	0.13957
16	pi-	0.16134	0.03535	4.09086	4.09657	0.13957
17	pi-	-0.06906	0.08845	1.96279	1.97095	0.13957
18	pi+	0.11852	-0.32616	3.70555	3.72438	0.13957
sum(p). mass:		0.27097	0.16745	-136.87069	751.99084	739.42987

eta gap = 13.6 units

MC "Truth" : Double Diffractive

Ways Out

A) Trust the theorists. Correct to specific set of fundamental processes ➜ NSD, INEL, ...

I	particle/jet	P(I,1)	P(I,2)	P(I,3)	P(I,4)	P(I,5)
1	p+	0.38955	-0.09031	-444.18188	~~444.18305~~	~~0.93827~~
2	p+	0.55491	-0.32947	118.14484	118.15033	0.93827
3	pi+	-0.10520	0.04623	21.97324	21.97398	0.13957
4	pi-	-0.36420	0.20220	79.60000	79.60121	0.13957
5	pi+	0.18465	-0.31136	44.33333	44.33503	0.13957
6	pi-	-0.65347	0.35445	10.76828	10.79481	0.13957
7	pi+	[illegible]	[illegible]	[illegible]	[illegible]	0.13957
8	pi-	[illegible]	[illegible]	[illegible]	[illegible]	0.13957
9	pi+	[illegible]	[illegible]	[illegible]	[illegible]	0.13957
10	pi-	0.28540	-0.36795	2.98245	3.02181	0.13957
11	K+	0.01880	0.15742	2.95334	2.99849	0.49360
12	pi-	0.07232	0.23225	6.16625	6.17263	0.13957
13	pi+	-0.37412	0.04117	0.68340	0.79257	0.13957
14	pi-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]7
15	pi+	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]7
16	pi-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]7
17	pi-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]7
18	pi+	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]7
sum(p). ma[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]7

eta gap = 13.6 units

MC "Truth" : Double Diffractive

Minimal Conclusion: gap definition not foolproof if we see charged only

I	particle/jet	P(I,1)	P(I,2)	P(I,3)	P(I,4)	P(I,5)
1	p+	0.18101	-0.23124	427.60408	427.60521	0.93827
2	p+	-0.06244	-0.10079	-231.29111	231.29304	0.93827
3	K+	0.33646	0.18878	-33.91055	33.91634	0.49360
4	nbar0	0.54816	-0.06834	-1.20905	1.62781	0.93957
5	pi0	-0.37380	0.02504	0.35486	0.53338	0.13498
6	n0	-0.08115	-0.02823	-0.53314	1.08370	0.93957
7	pi-	-0.23393	0.11296	-5.76403	5.77157	0.13957
8	K-	-0.00627	-0.15812	-44.71705	44.72006	0.49360
9	K+	-0.03848	-0.01139	-64.08264	64.08456	0.49360
10	pi-	-0.02479	0.08067	-2.09126	2.09761	0.13957
11	pi+	-0.41465	-0.13479	-8.29972	8.31234	0.13957
12	pi0	-0.50854	0.11826	-18.60847	18.61629	0.13498
13	pi-	-0.04847	0.20076	-3.15301	3.16285	0.13957
14	pi0	0.76201	-0.09810	-3.33633	3.42631	0.13498
15	K-	-0.08212	0.24522	0.71152	0.90376	0.49360
16	pi+	0.09763	-0.21837	0.15468	0.31721	0.13957
17	pi+	-0.14039	0.17750	0.46433	0.53507	0.13957
18	pi0	0.23292	-0.41112	2.88185	2.92345	0.13498
19	pi+	-0.17876	-0.03157	6.10565	6.10994	0.13957
20	pi-	0.03074	0.07151	0.33071	0.36729	0.13957
21	pi0	0.06314	-0.09334	0.80407	0.82307	0.13498
22	pi0	-0.16321	-0.13453	0.64843	0.69528	0.13498
23	pi0	-0.14686	-0.00214	0.56642	0.60052	0.13498
24	pi-	-0.01222	-0.27842	0.19750	0.36899	0.13957
25	K_L0	-0.45356	0.56332	4.42730	4.51350	0.49767
26	pi+	-0.17413	-0.00385	-0.03275	0.22559	0.13957
27	pi0	0.21046	-0.04576	-1.03674	1.06744	0.13498
28	pi-	0.04562	-0.11103	1.10752	1.12271	0.13957
29	pi+	-0.15254	0.27925	1.58019	1.61794	0.13957
30	pi+	0.00633	0.23779	-20.99897	21.00078	0.13957
31	pi-	0.09527	-0.14227	-9.49998	9.50254	0.13957
32	pi-	0.39307	0.13431	0.53495	0.69152	0.13957
33	pi+	0.29351	-0.13195	0.09074	0.36231	0.13957
sum	momentum	0.00000	0.00000	0.00000	900.00000	900.00000

MC “Truth” : Single Diffractive

I	particle/jet	P(I,1)	P(I,2)	P(I,3)	P(I,4)	P(I,5)
1	p+	0.18101	-0.23124	427.60408	427.60521	0.93827
2	p+	-0.06244	-0.10079	-231.29111	231.29304	0.93827
3	K+	0.33646	0.18878	-33.91055	33.91634	0.49360
4	nbar0	0.54816	-0.06834	-1.20905	1.62781	0.93957
5	pi0	-0.37380	0.02504	0.35486	0.53338	0.13498
6	n0	-0.08115	-0.02823	-0.53314	1.08370	0.93957
7	pi-	-0.23393	0.11296	-5.76403	5.77157	0.13957
8	K-	-0.00627	-0.15812	-44.71705	44.72006	0.49360
9	K+	-0.03848	-0.01139	-64.08264	64.08456	0.49360
10	pi-	-0.02479	0.08067	-2.09126	2.09761	0.13957
11	pi+	-0.41465	-0.13479	-8.29972	8.31234	0.13957
12	pi0	-0.50854	0.11826	-18.60847	18.61629	0.13498
13	pi-	-0.04847	0.20076	-3.15301	3.16285	0.13957
14	pi0	0.76201	-0.09810	-3.33633	3.42631	0.13498
15	K-	-0.08212	0.24522	0.71152	0.90376	0.49360
16	pi+	[illegible]	[illegible]	[illegible]	[illegible]	0.13957
17	pi+	[illegible]	[illegible]	[illegible]	[illegible]	0.13957
18	pi0	0.23292	-0.41112	2.88185	2.92345	0.13498
19	pi+	-0.17876	-0.03157	6.10565	6.10994	0.13957
20	pi-	0.03074	0.07151	0.33071	0.36729	0.13957
21	pi0	0.06314	-0.09334	0.80407	0.82307	0.13498
22	pi0	-0.16321	-0.13453	0.64843	0.69528	0.13498
23	pi0	-0.14686	-0.00214	0.56642	0.60052	0.13498
24	pi-	-0.01222	-0.27842	0.19750	0.36899	0.13957
25	K_L0	-0.45356	0.56332	4.42730	4.51350	0.49767
26	pi+	-0.17413	-0.00385	-0.03275	0.22559	0.13957
27	pi0	0.21046	-0.04576	-1.03674	1.06744	0.13498
28	pi-	0.04562	-0.11103	1.10752	1.12271	0.13957
29	pi+	-0.15254	0.27925	1.58019	1.61794	0.13957
30	pi+	0.00633	0.23779	-20.99897	21.00078	0.13957
31	pi-	0.09527	-0.14227	-9.49998	9.50254	0.13957
32	pi-	0.39307	0.13431	0.53495	0.69152	0.13957
33	pi+	0.29351	-0.13195	0.09074	0.36231	0.13957
sum	momentum	0.00000	0.00000	0.00000	900.00000	900.00000

I	particle/jet	P(I,1)	P(I,2)	P(I,3)	P(I,4)	P(I,5)
1	p+	0.18101	-0.23124	427.60408	427.60521	0.93827
2	p+	-0.06244	-0.10079	-231.29111	231.29304	0.93827

Moral: What some theorist/model defines as SD, DD, etc, *is not itself a physical observable!*

Tails of one are *indistinguishable* from the other (even with a perfect detector with full PID)

If no physical measurement can tell the difference, it does not make sense to correct back to

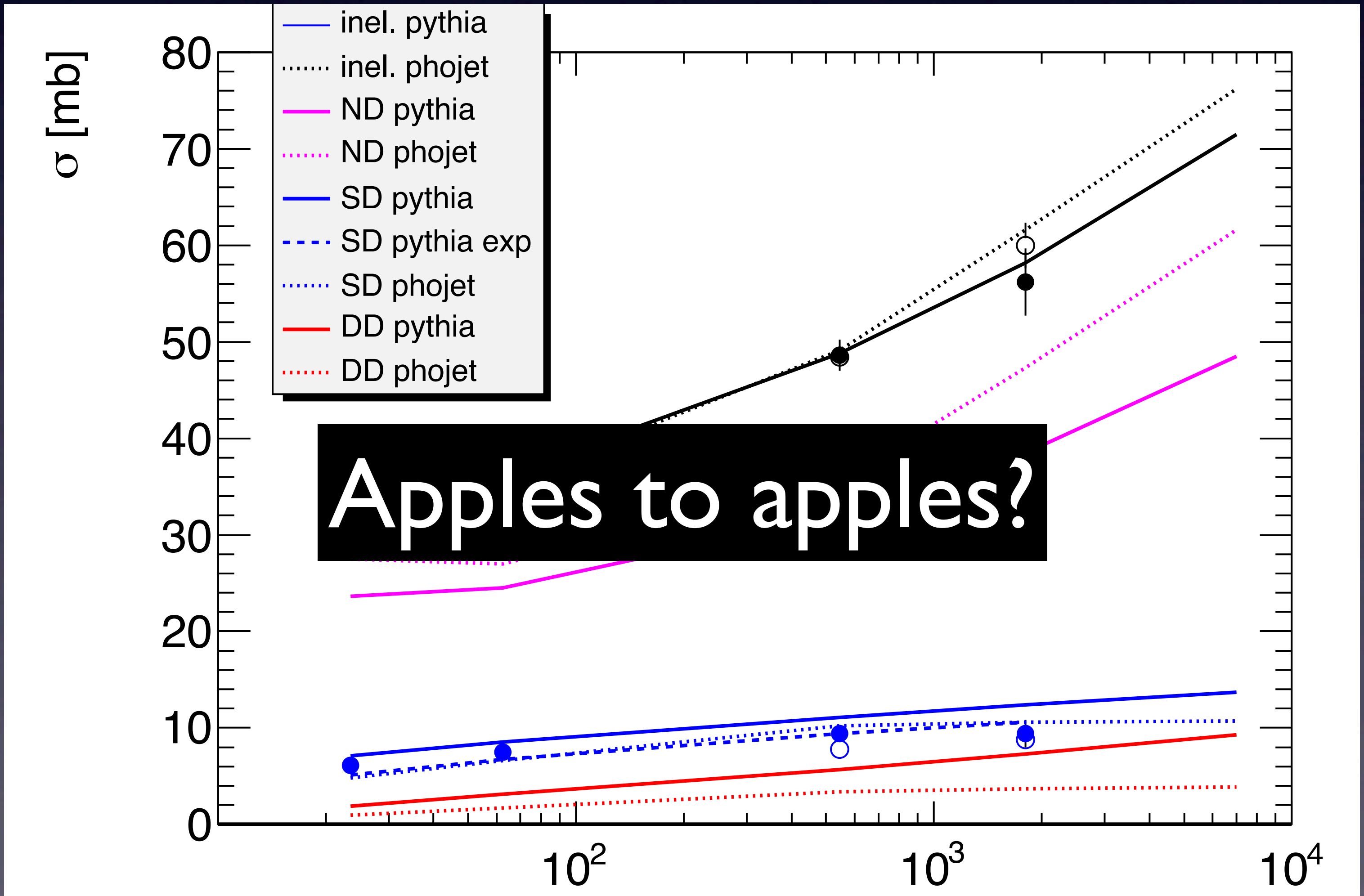
25	K_L0	-0.45356	0.56332	4.42730	4.51350	0.49767

And this is even assuming we had the perfect model on which everyone agrees ...

33	pi+	0.29351	-0.13195	0.09074	0.36231	0.13957
sum	momentum	0.00000	0.00000	0.00000	900.00000	900.00000

Ways Out

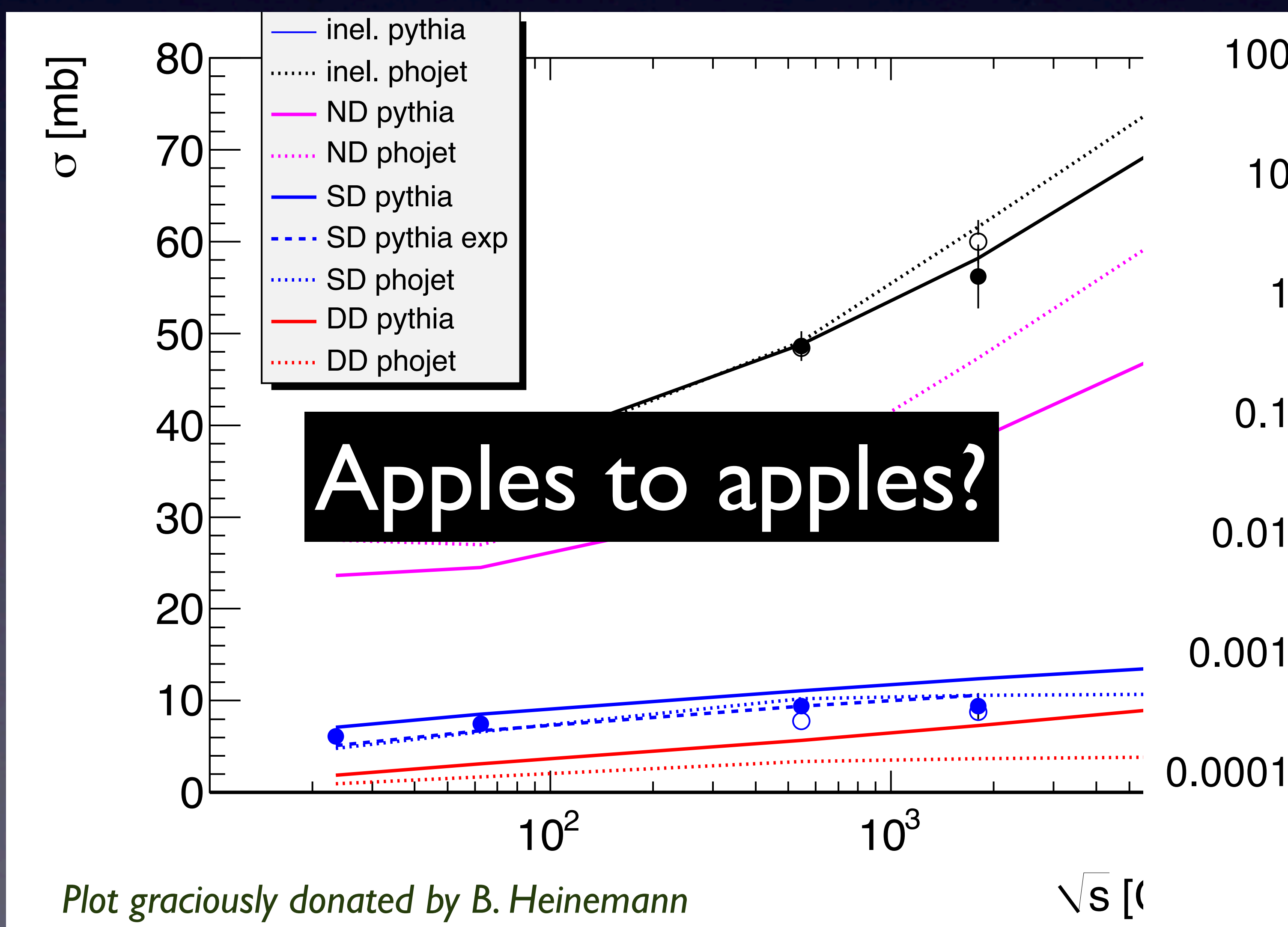
A) Trust the theorists. Correct to specific set of fundamental processes ➜ NSD, INEL, ...

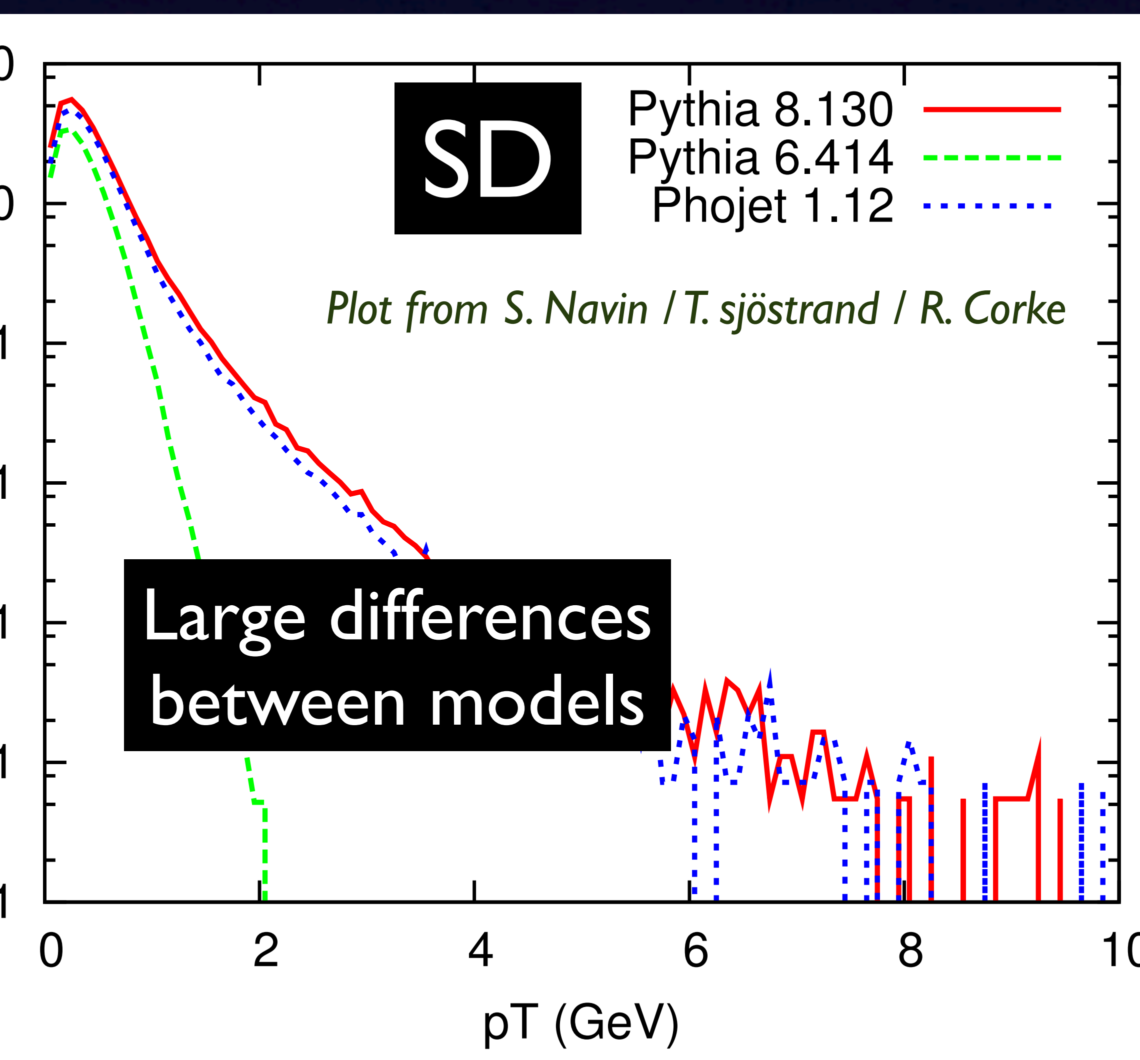


Plot graciously donated by B. Heinemann

Ways Out

A) Trust the theorists. Correct to specific set of fundamental processes → NSD, INEL, ...





Ways Out

A) Trust the theorists. Correct to specific set of fundamental processes → NSD, INEL, ...

Traditional, but not optimal

- Defs of SD, DD, ND, etc, are MODEL-DEPENDENT
- Models DO NOT AGREE
- E.g., "NSD" is not a physical definition, unless defined in terms of hadron-level cuts only
- (+ discussions this morning on measurement definitions)

Note: diffraction is not, itself, "the evil guy" here. A clear hadron-level definition would also bring diffractive studies on a better, more model-independent, footing.

Ways Out

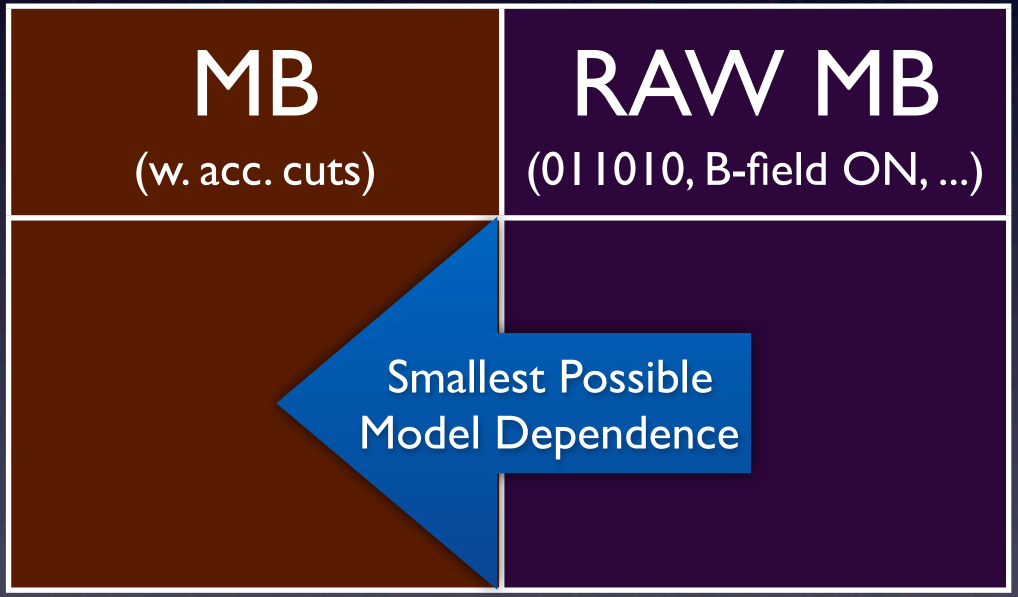
A) Trust the theorists. Correct to specific set of fundamental processes → NSD, INEL, ...

B) Report a measurement with a given set of hadron-level cuts → MB

Employed in the third LHC paper
ATLAS Collaboration, preliminary
(see talk this morning)

Ways Out

B) Report a measurement with a given set of hadron-level cuts → MB

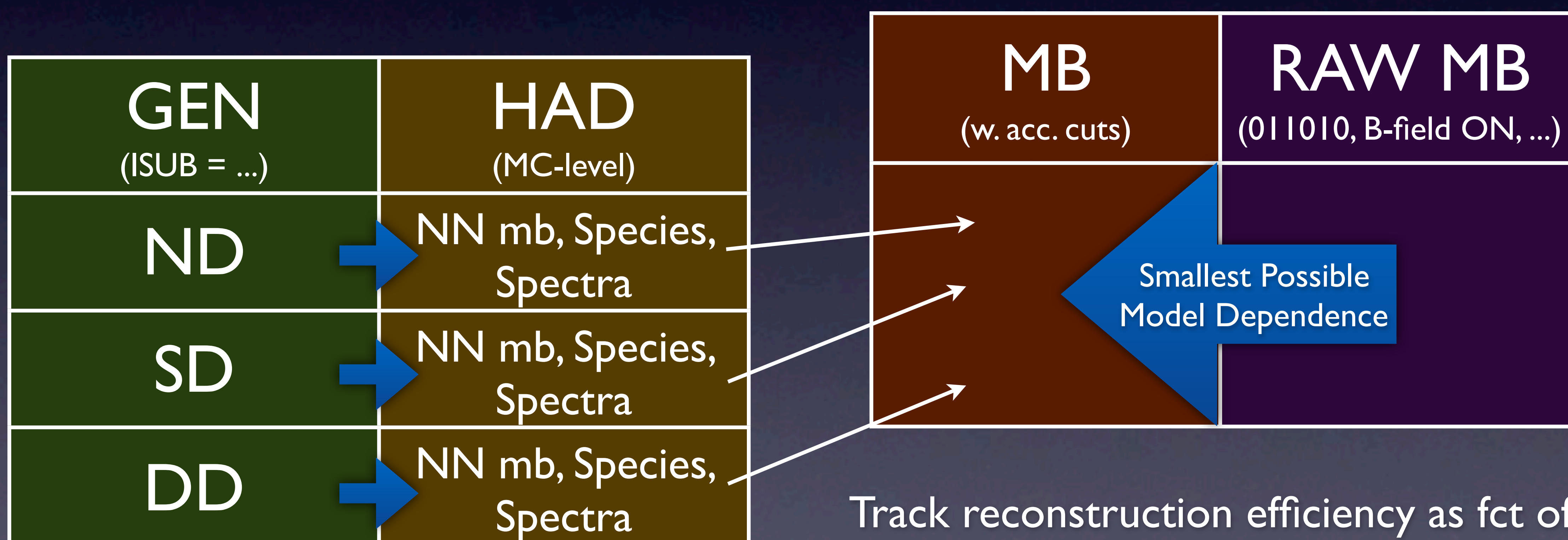


Track reconstruction efficiency as fct of pT, eta corrected to Theta function? (|eta| < Y, pT > X)

Trigger efficiency corrected to Theta function?
(at least M tracks with X pT in phase-space region Y, or similar)

Ways Out

B) Report a measurement with a given set of hadron-level cuts → MB



Theoretical Modeling

Track reconstruction efficiency as fct of pT, eta corrected to Theta function (|eta| < Y, pT > X)

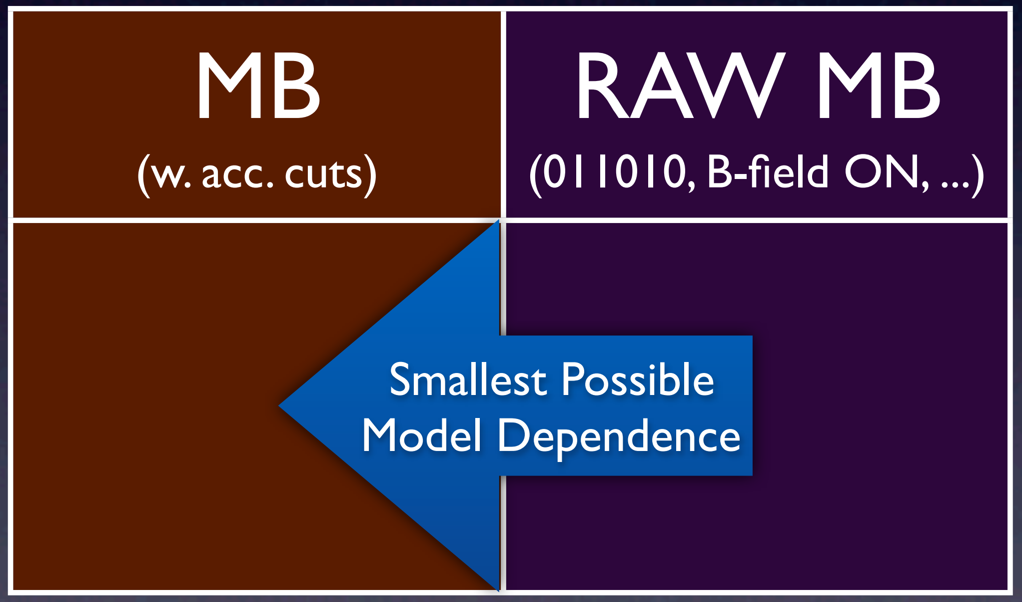
Trigger efficiency corrected to Theta function
(at least M tracks with X pT in phase-space region Y, or similar)

Ways Out

B) Report a measurement with a given set of hadron-level cuts → MB

Drawbacks?

- "MB" is not "ZB"
- "MB" is acc/trig-dependent mixture of SD, DD, ND
- **How to compare** with other measurements or "GEN"-level theory cross sections (e.g., sigmaDiff)?



Track reconstruction efficiency as fct of pT, eta corrected to Theta function (|eta| < Y, pT > X)

Trigger efficiency corrected to Theta function
(at least M tracks with X pT in phase-space region Y, or similar)

Ways Out

B) Report a measurement with a given set of hadron-level cuts → MB

Drawbacks?

- MB *was never* ZB (clear & simple event selection criteria = good enough)
- Mixture of SD, DD, ND in given region = **modeling aspect**
  - The most you can do is optimize selection to *enhance*, e.g.,"ND","SD", ...
- **HAD-level observables** and event-sample definitions give us *not* a ready-made solution but:
  - **A well-defined measurement** and reference for posterity ...
  - **With the smallest** possible uncertainties ...
  - ***A base for*** comparisons to other definitions (other exps / TH defs)

Ways Out

C) More information? Partition MB sample into various “enriched” samples?

Ways Out

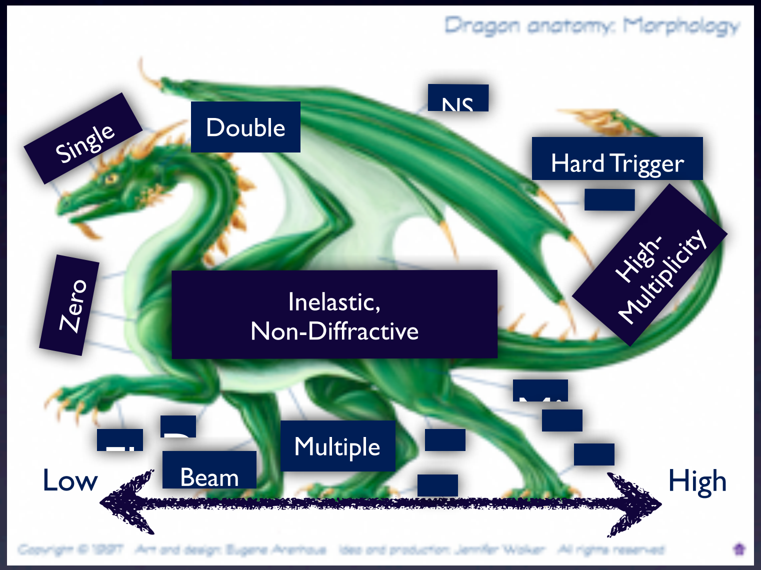
C) More information? Partition MB sample into various “enriched” samples?

- SD-Enriched HAD-level sample (*cannot* be 100% Use models to estimate best purity)
  More sensitive to SD cross section. **Report observed cross section**, then translate to SD-GEN-level cross section using best models of the day. **(Don’t just tell us the latter.)**
- ND-Enriched HAD-level sample (can be almost 100%)
  (... + ... Central-Diffraction-Enhanced, DD-Enhanced, “HARD”, ...)

Ways Out

C) More information? Partition MB sample into various "enriched" samples?

Systematically introduce "biases" ➜ MB



- SD-Enriched HAD-level sample (*cannot* be 100% Use models to estimate best purity)
  More sensitive to SD cross section. **Report observed cross section**, then translate to SD-GEN-level cross section using best models of the day.
  (Don't just tell us the latter.)
- ND-Enriched HAD-level sample (can be almost 100%)
  (... + ... Central-Diffraction-Enhanced, DD-Enhanced, "HARD", ...)

Modeling Diffraction

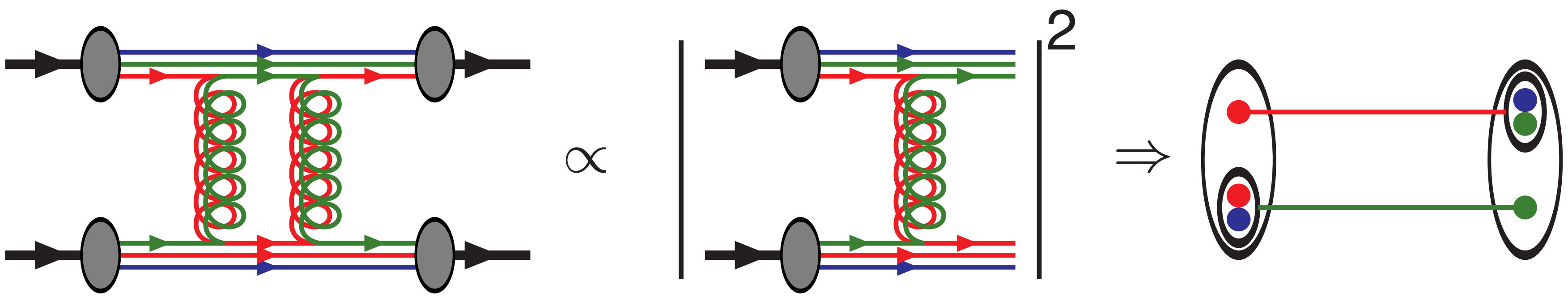
- PYTHIA 6
- POMPYT, POMWIG
- PHOJET (& Relatives)
- PYTHIA 8
- HERWIG++
- SHERPA
- EPOS, RAPGAP, ...

PHOJET (& Relatives)

Slide from T. Sjostrand

(1) Cut Pomeron (1982)

- Pomeron predates QCD; nowadays $\sim$ glueball tower
- Optical theorem relates σ_{total} and σ_{elastic}



- Unified framework of nondiffractive and diffractive interactions
- Purely low-$p_\perp$: only primordial $k_\perp$ fluctuations
- Usually simple Gaussian matter distribution

(2) Extension to large $p_\perp$ (1990)

- distinguish soft and hard Pomerons (cf. Ivan):
  soft = nonperturbative, low-$p_\perp$, as above
  hard = perturbative, "high"-$p_\perp$
- hard based on PYTHIA code, with lower cutoff in $p_\perp$

Status: PHOJET web site to be resurrected soon

PYTHIA 6

Diffractive Cross Section Formulæ:

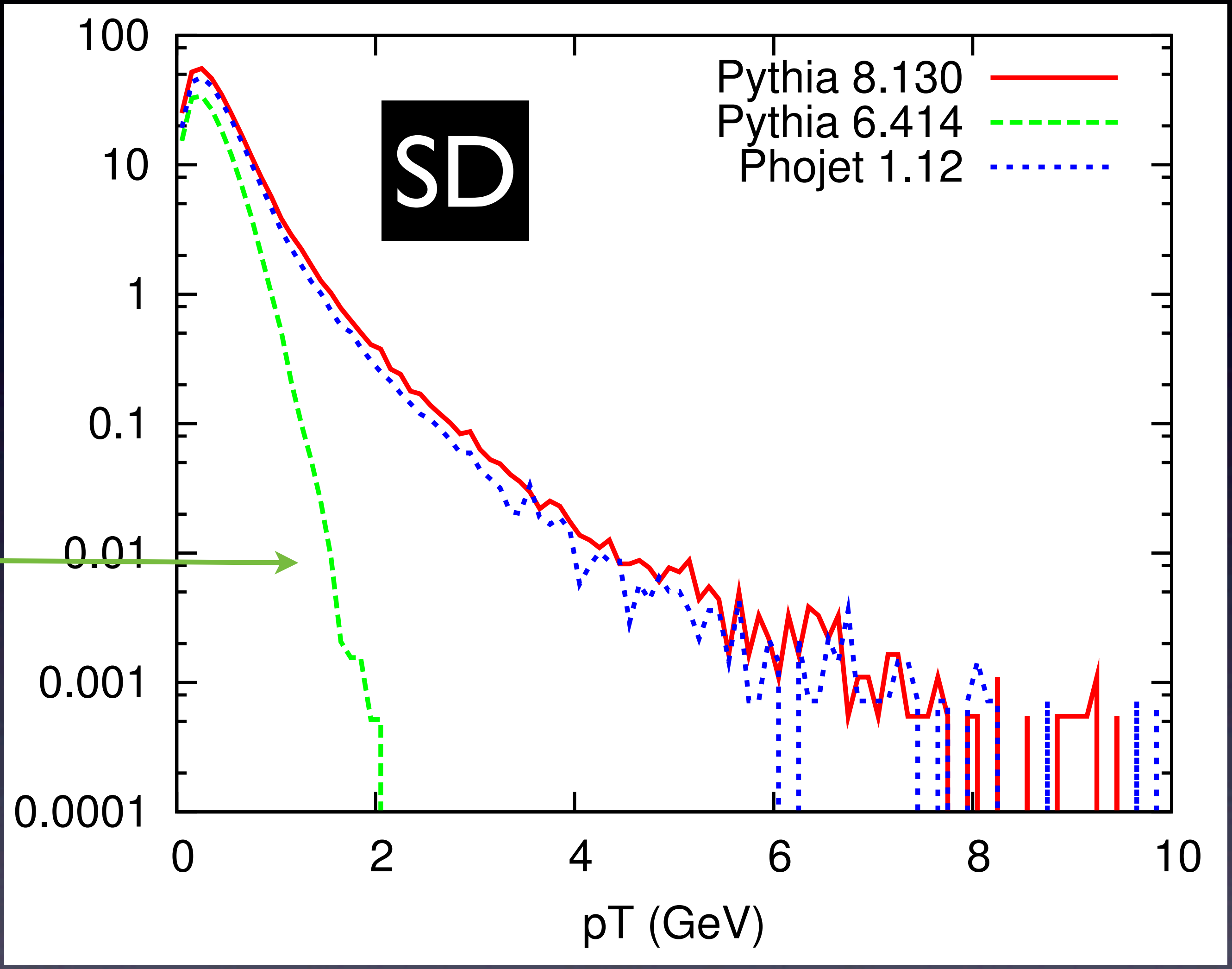
$$\frac{d\sigma_{sd(AX)}(s)}{dt\, dM^2} = \frac{g_{3\mathbb{P}}}{16\pi} \beta^2_{A\mathbb{P}} \beta_{B\mathbb{P}} \frac{1}{M^2} \exp(B_{sd(AX)}t) F_{sd} ,$$

$$\frac{d\sigma_{dd}(s)}{dt\, dM_1^2\, dM_2^2} = \frac{g^2_{3\mathbb{P}}}{16\pi} \beta_{A\mathbb{P}} \beta_{B\mathbb{P}} \frac{1}{M_1^2} \frac{1}{M_2^2} \exp(B_{dd}t) F_{dd} .$$

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

Status: Supported, but not actively developed

PYTHIA 8

S. Navin (MCnet) + T. Sjöstrand

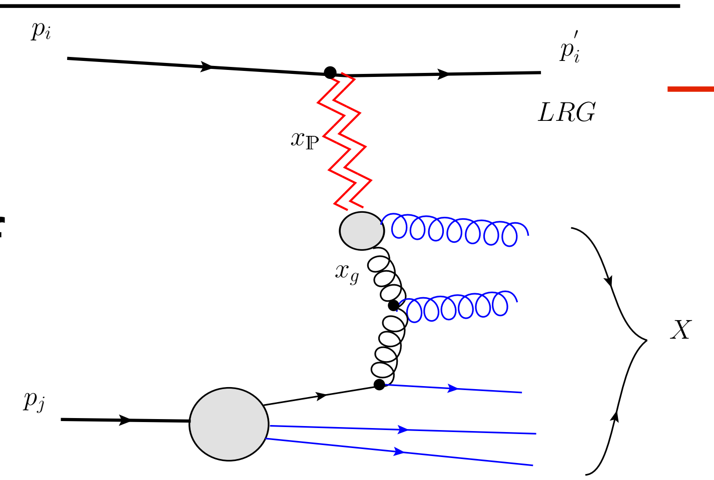
Diffractive Cross Section Formulæ:

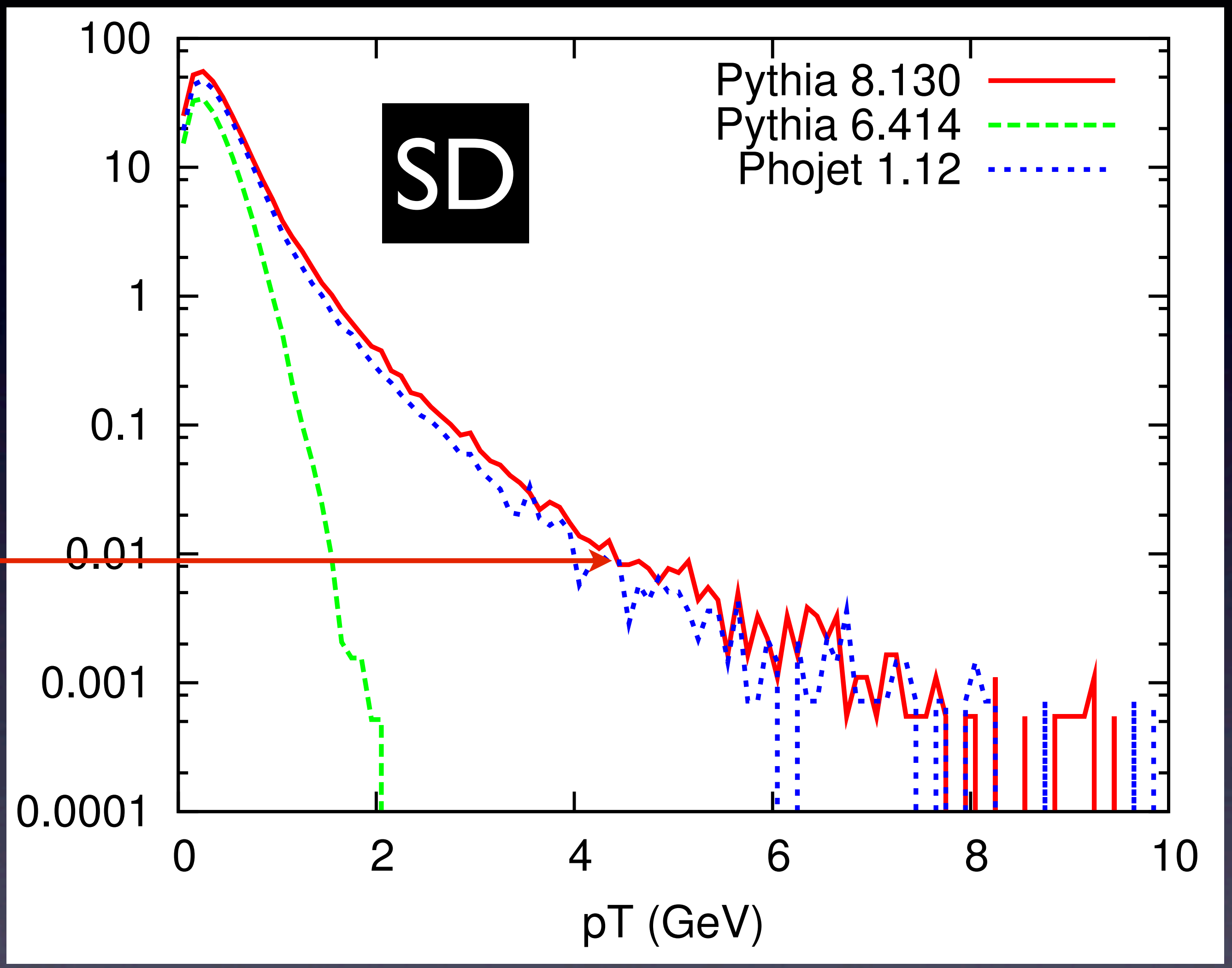
$$\frac{\mathrm{d}\sigma_{\mathrm{sd}(AX)}(s)}{\mathrm{d}t\,\mathrm{d}M^2} = \frac{g_{3\mathbb{P}}}{16\pi}\,\beta_{A\mathbb{P}}^2\,\beta_{B\mathbb{P}}\,\frac{1}{M^2}\,\exp(B_{\mathrm{sd}(AX)}t)\,F_{\mathrm{sd}}\,,$$

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

Partonic Substructure in Pomeron:

Follows the approach of Pompyt





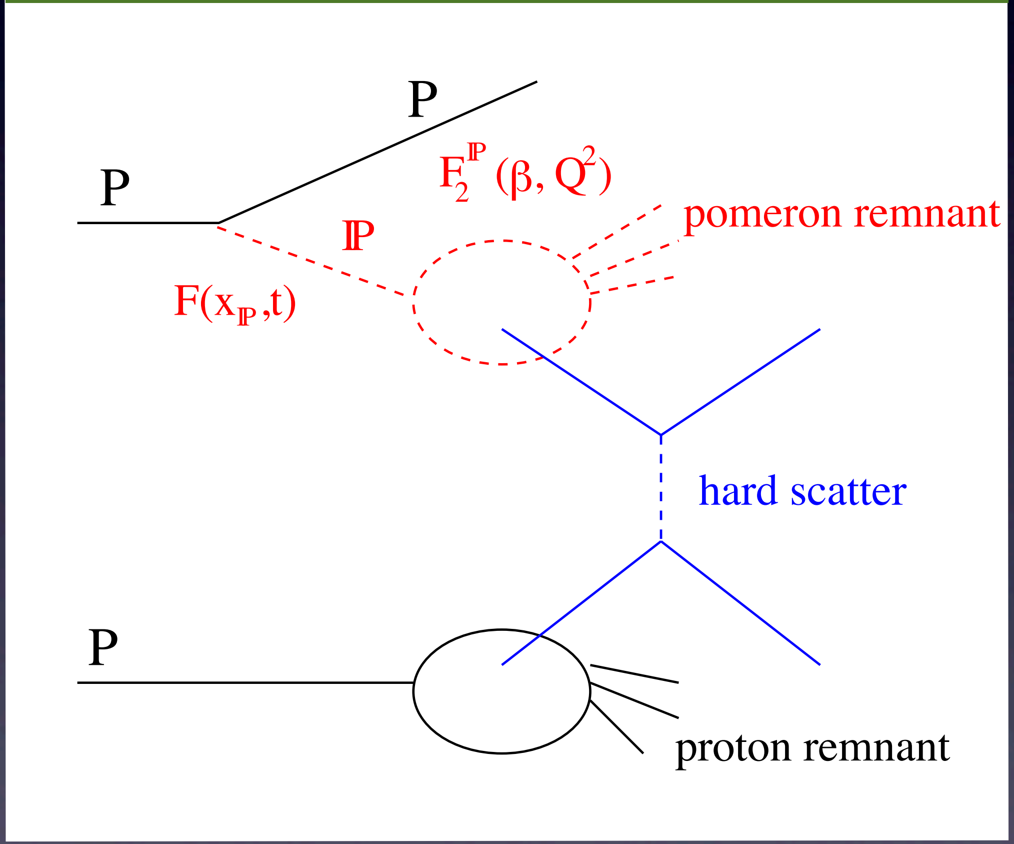
- $M_X \leq 10\,\mathrm{GeV}$: original longitudinal string description used
- $M_X > 10\,\mathrm{GeV}$: new perturbative description used

Status: Supported and actively developed

POMWIG & POMPYT

- Add-ons to F77 HERWIG and PYTHIA to include Pomeron structure
- POMWIG with DPEMC also includes central, e.g., ℙℙ>H

POMPYT: http://www3.tsl.uu.se/thep/MC/pompyt/
POMWIG: B. Cox, J. Forshaw, CPC144(2002)104
DPEMC: M. Boonekamp, T. Kucs CPC167(2005)217

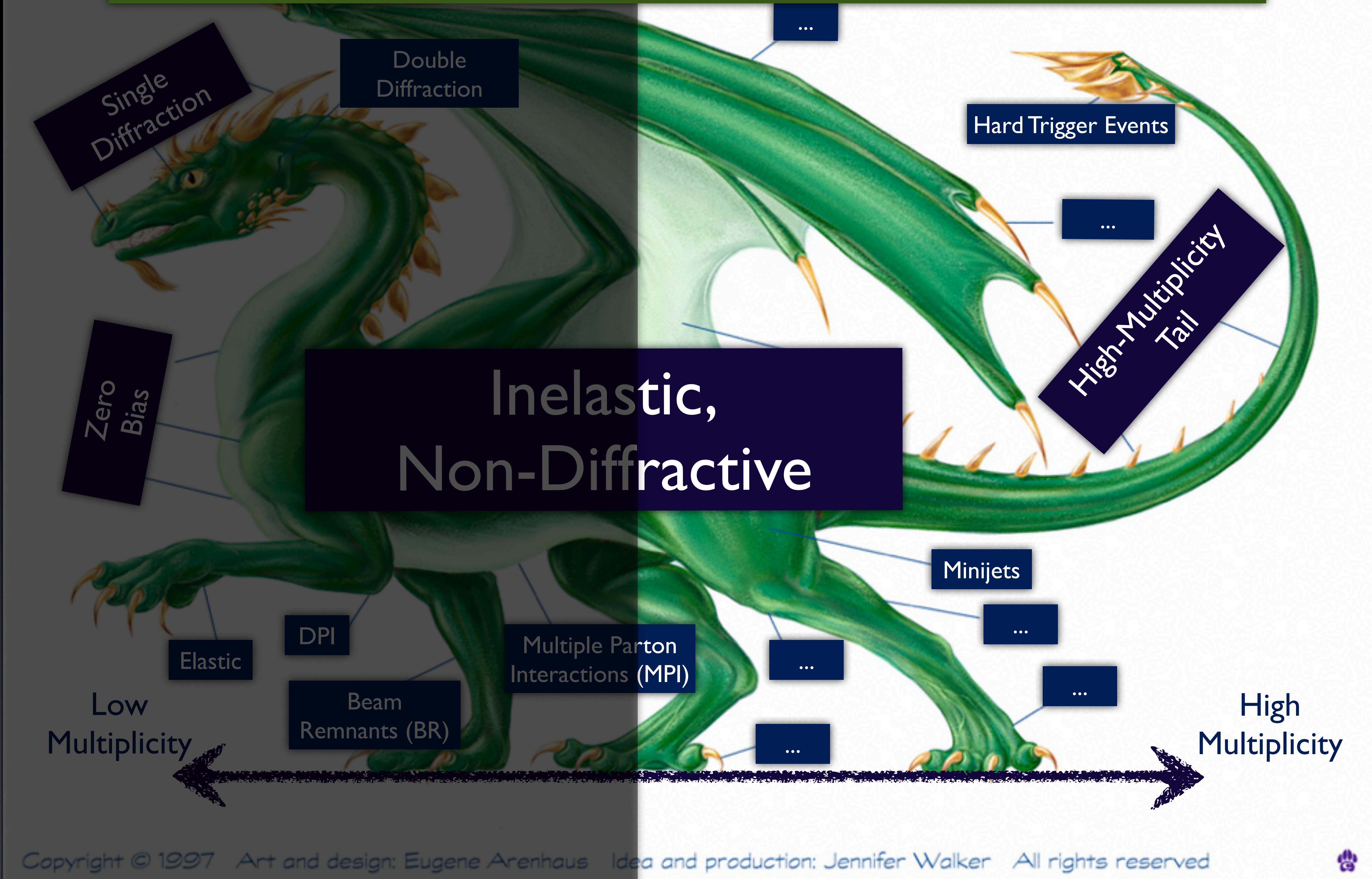


POMWIG Status: Stable, migrating to HERWIG++

Current Status

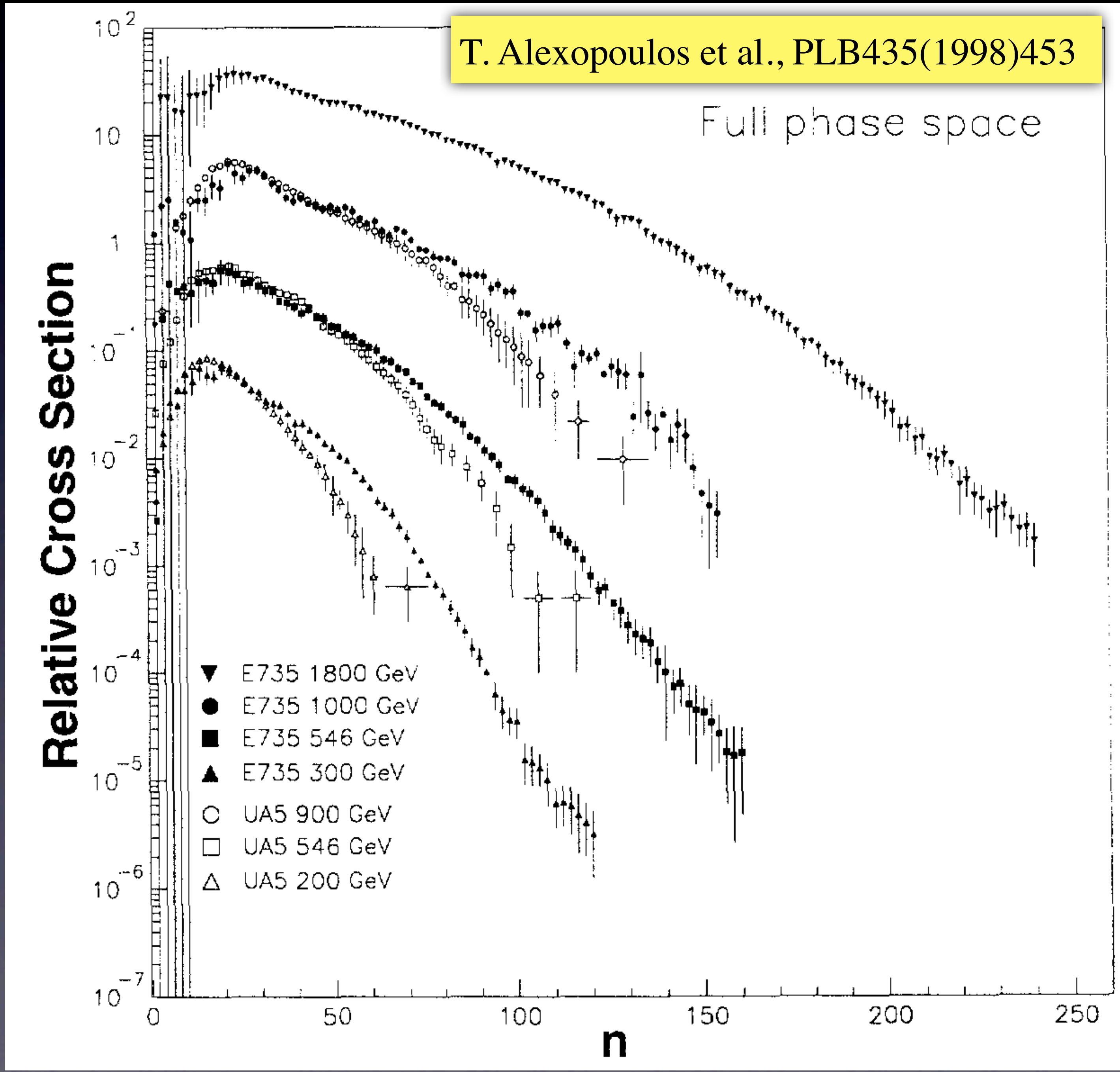
• PYTHIA 6	Obsolete
• POMPYT, POMWIG	Stable
• PHOJET (& Relatives)	Resurrected
• PYTHIA 8 (POMPYT-based)	S. Navin Active
• HERWIG++ (POMWIG++)	P. Ruzicka R&D
• SHERPA (KMR)	K. Zapp R&D
• EPOS, RAPGAP, ...	?

Issues at High Multiplicity



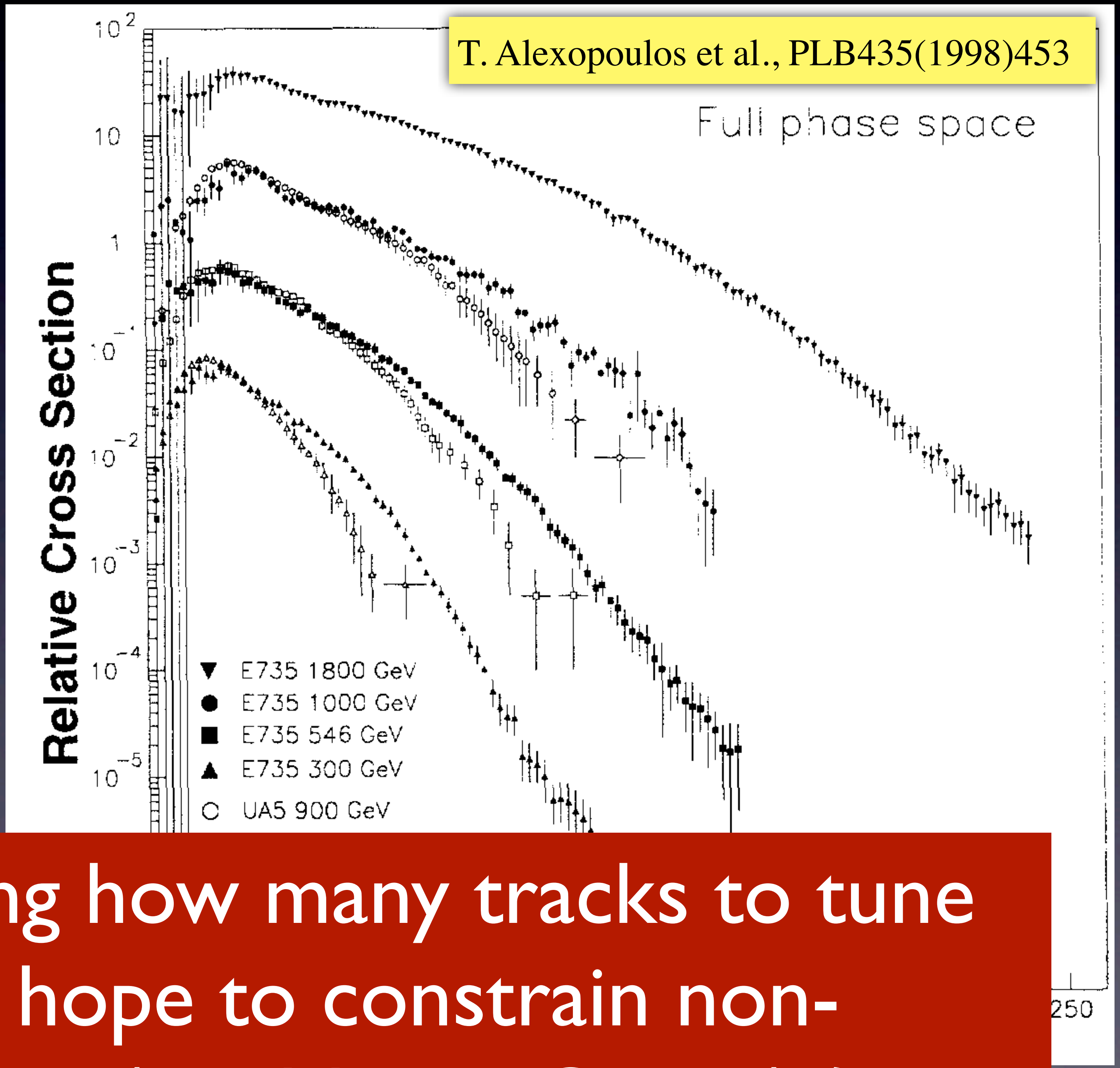
High Multiplicities: An Unresolved Question

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



High Multiplicities: An Unresolved Question

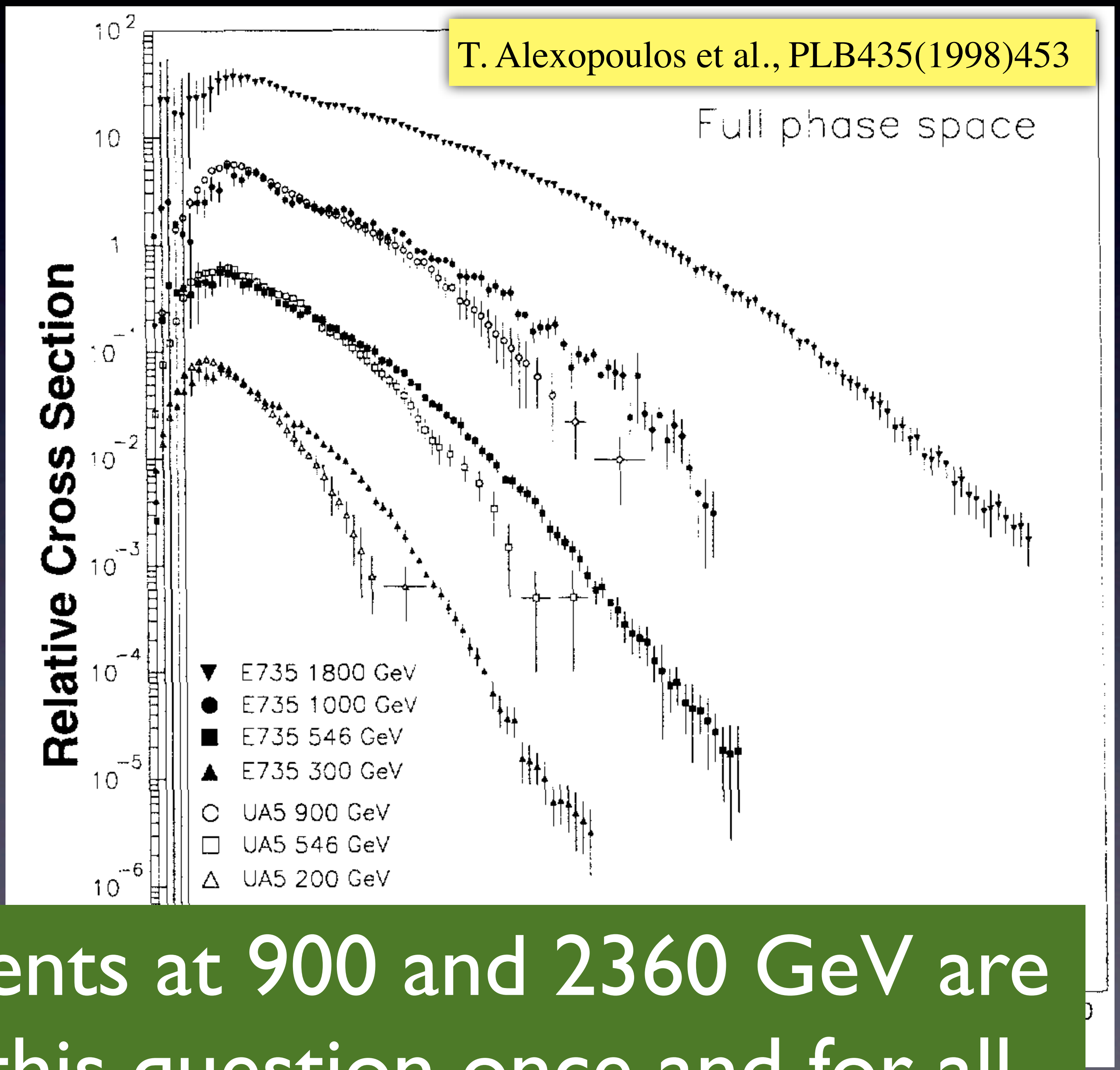
- UA5 at 200, 546, and 900 GeV
- E735 at 300, 546, 1000, and 1800 GeV
- Mutually Inconsistent over *Entire Range*



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

High Multiplicities: An Unresolved Question

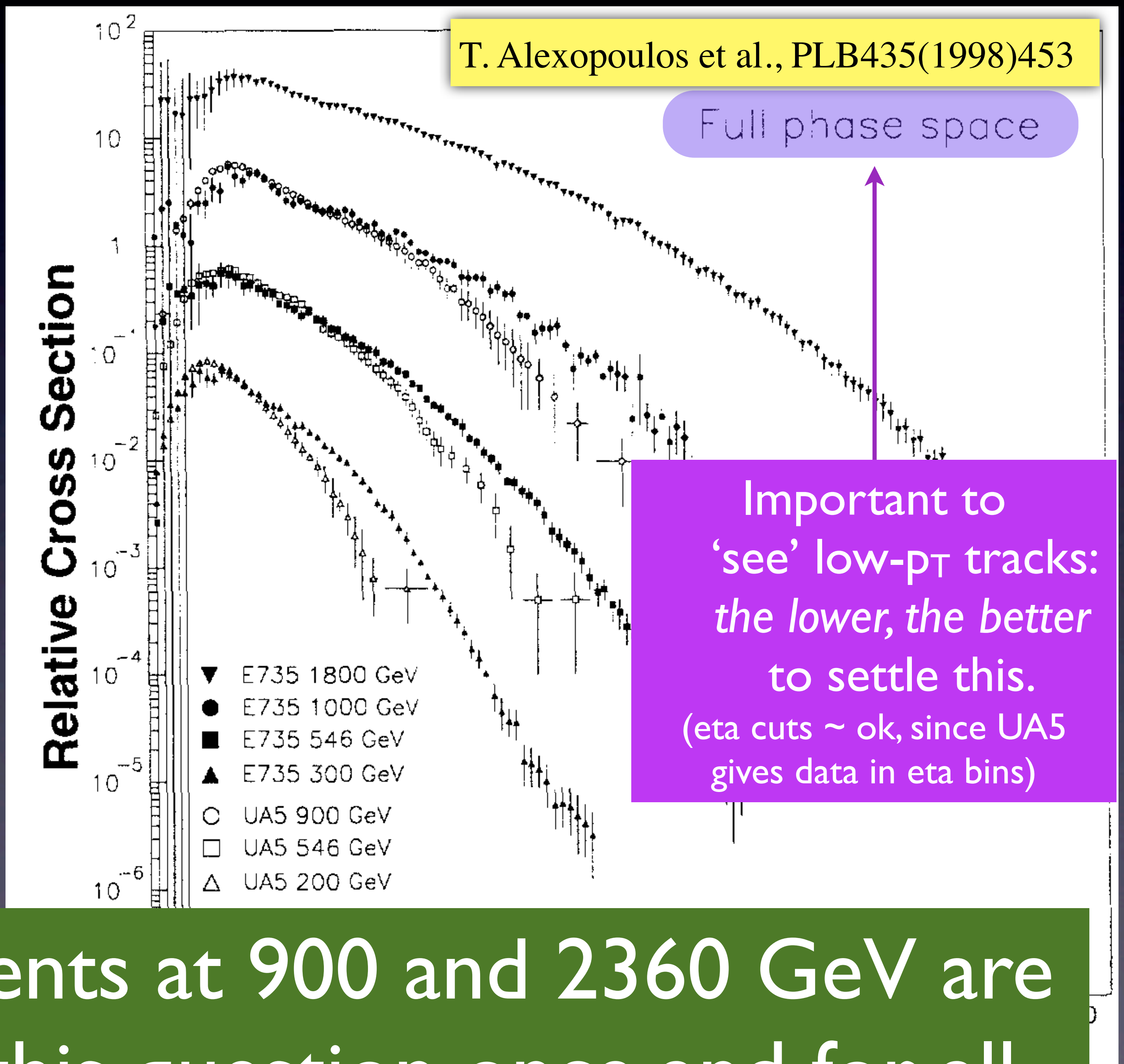
- UA5 at 200, 546, and 900 GeV
- E735 at 300, 546, 1000, and 1800 GeV
- Mutually Inconsistent over *Entire Range*



Again: LHC Measurements at 900 and 2360 GeV are *the only way* to settle this question once and for all

High Multiplicities: An Unresolved Question

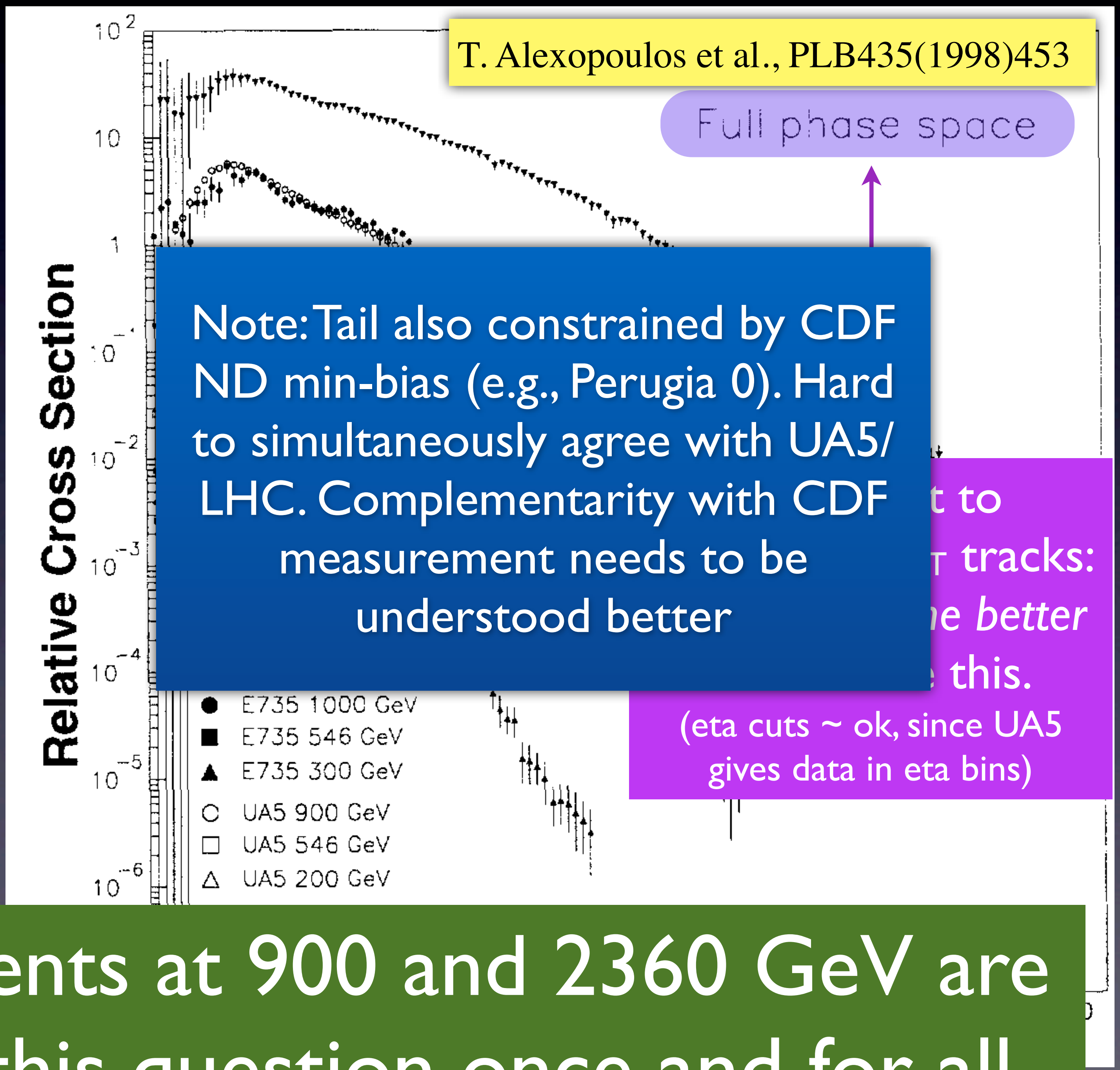
- UA5 at 200, 546, and 900 GeV
- E735 at 300, 546, 1000, and 1800 GeV
- Mutually Inconsistent over *Entire Range*



Again: LHC Measurements at 900 and 2360 GeV are *the only way* to settle this question once and for all

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*



Note: Tail also constrained by CDF ND min-bias (e.g., Perugia 0). Hard to simultaneously agree with UA5/ LHC. Complementarity with CDF measurement needs to be understood better

t to
$_T$ tracks:
ne better
this.
(eta cuts ~ ok, since UA5 gives data in eta bins)

Again: LHC Measurements at 900 and 2360 GeV are *the only way* to settle this question once and for all

Fragmentation

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

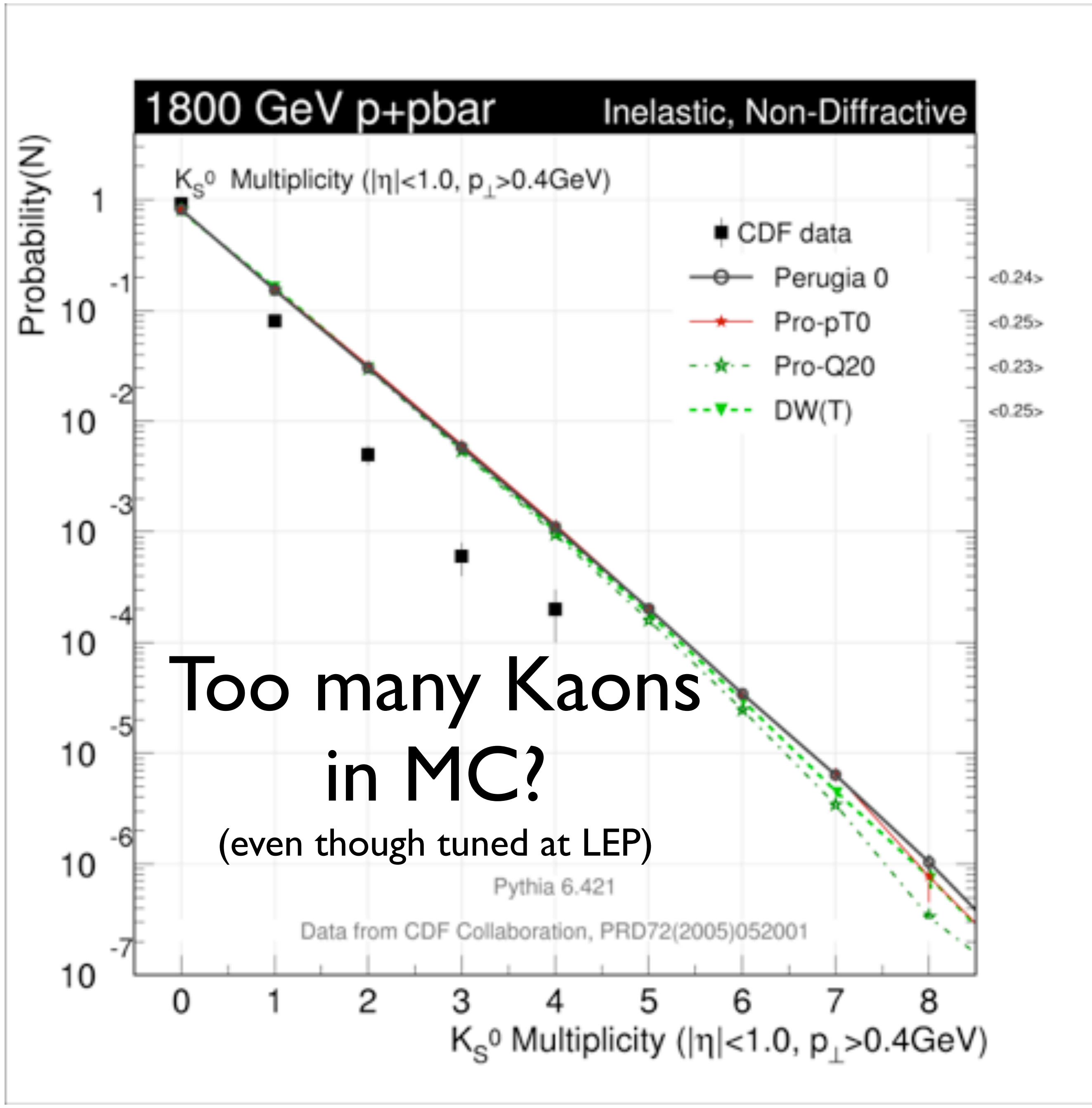
Fragmentation

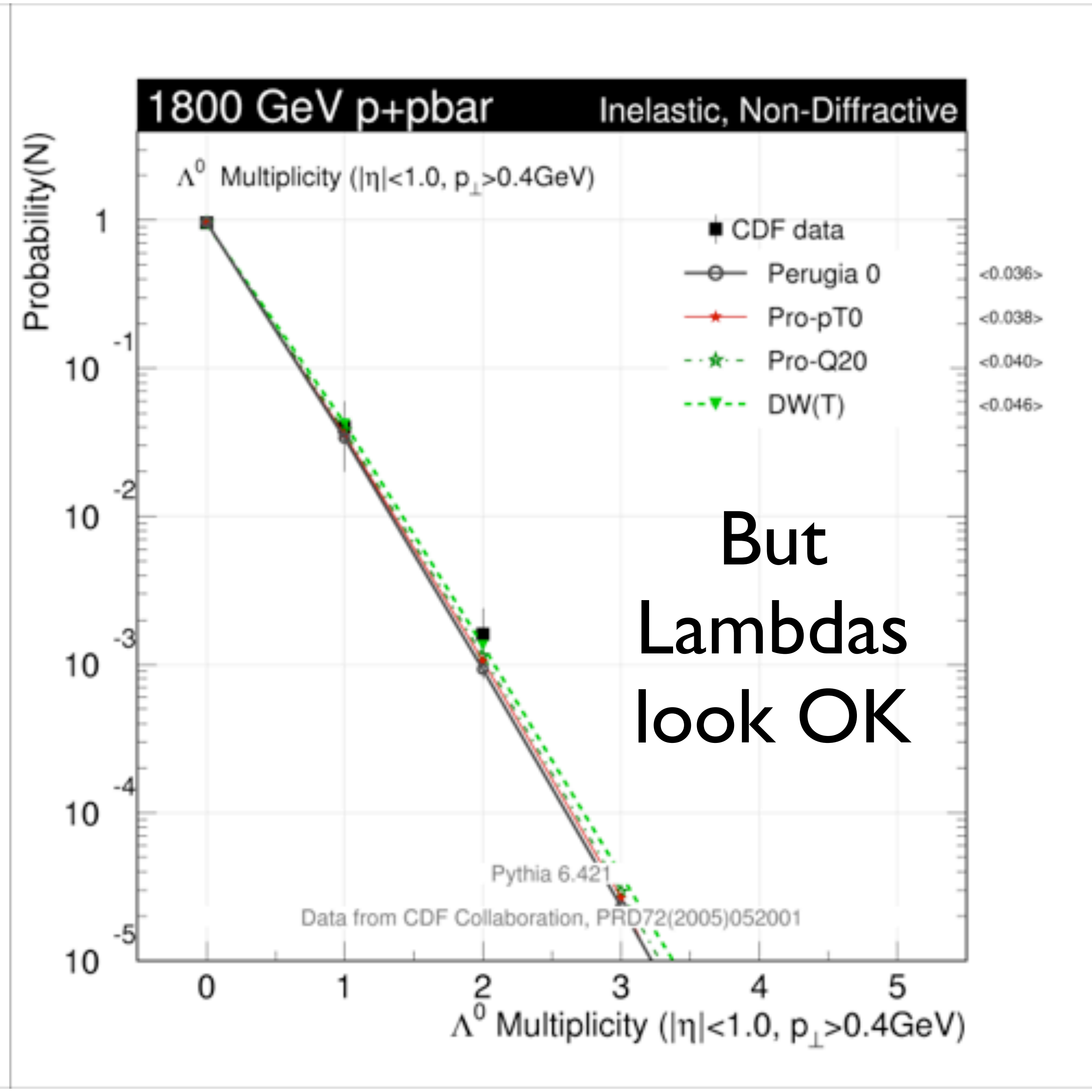
- Normal MC Tuning Procedure:
  - Fragmentation and Flavour parameters constrained at LEP, then used in pp/ppbar (Jet Universality)
    - But pp/ppbar is a very different environment, at the infrared level!

Fragmentation

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

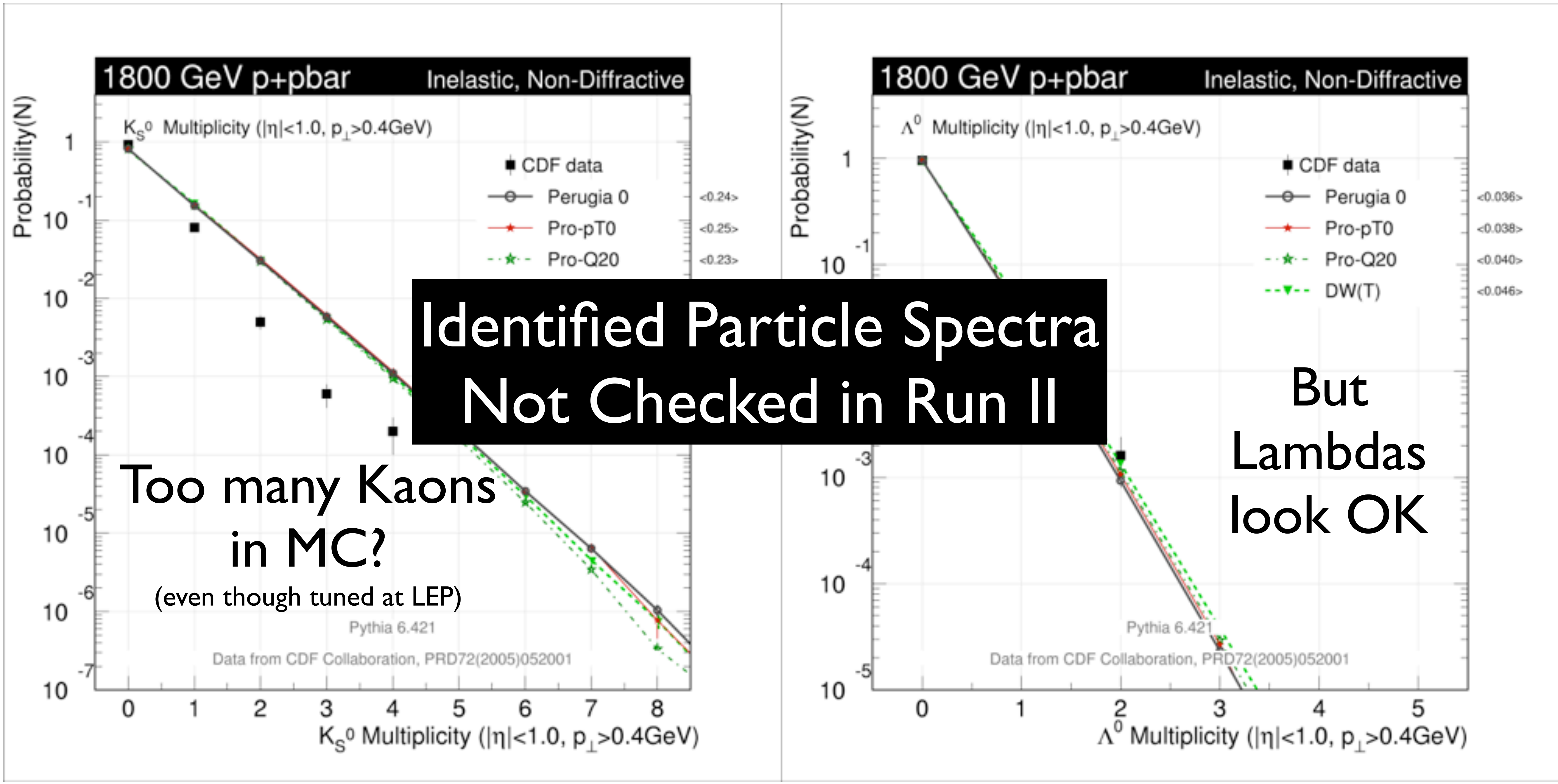




http://home.fnal.gov/~skands/leshouches-plots

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

The Kaon Problem



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

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

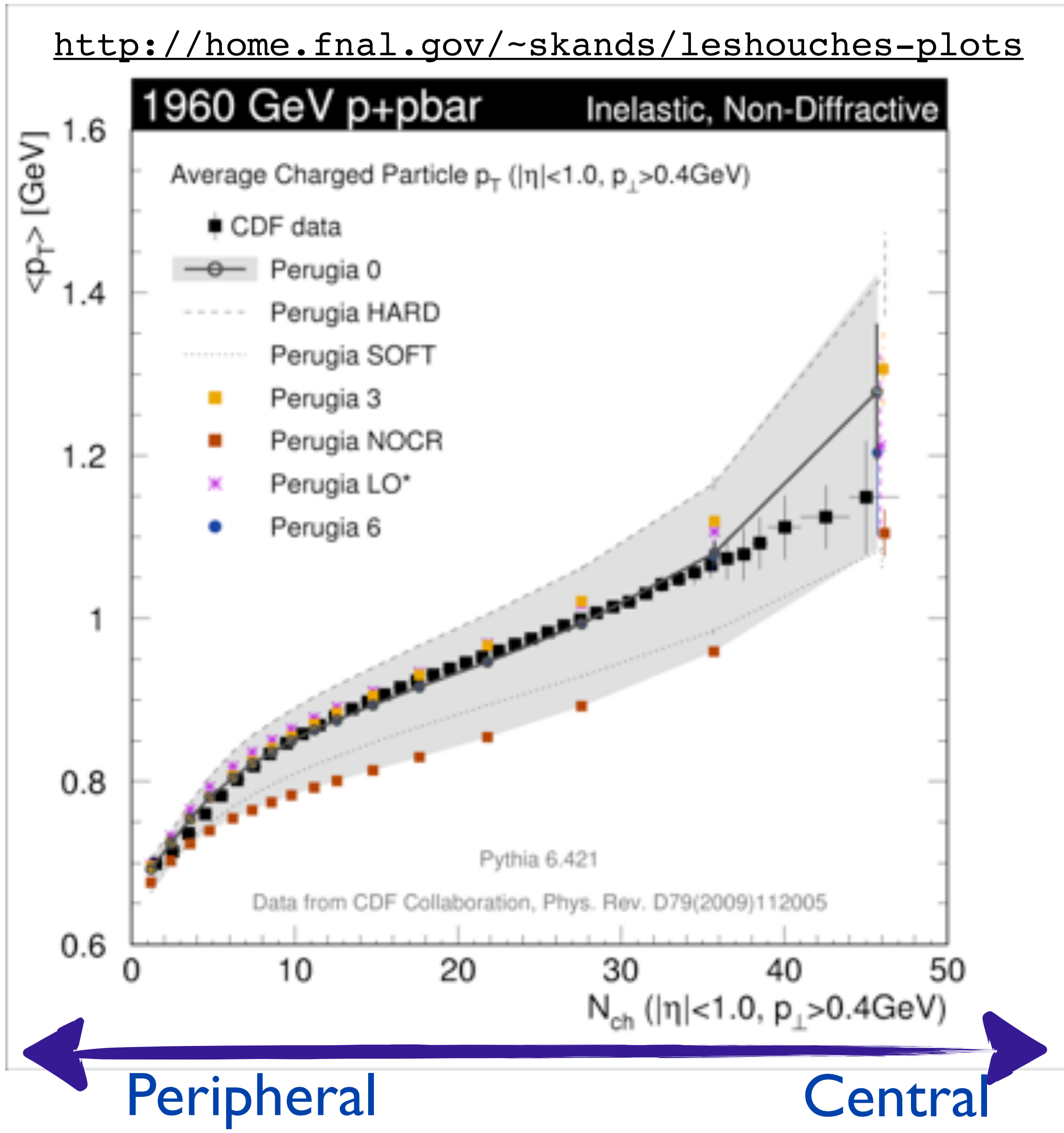
Fragmentation

- 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!

- 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
  - (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: $<p_T>(N_{ch})$



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, ...?)

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!

Hannes' Talk

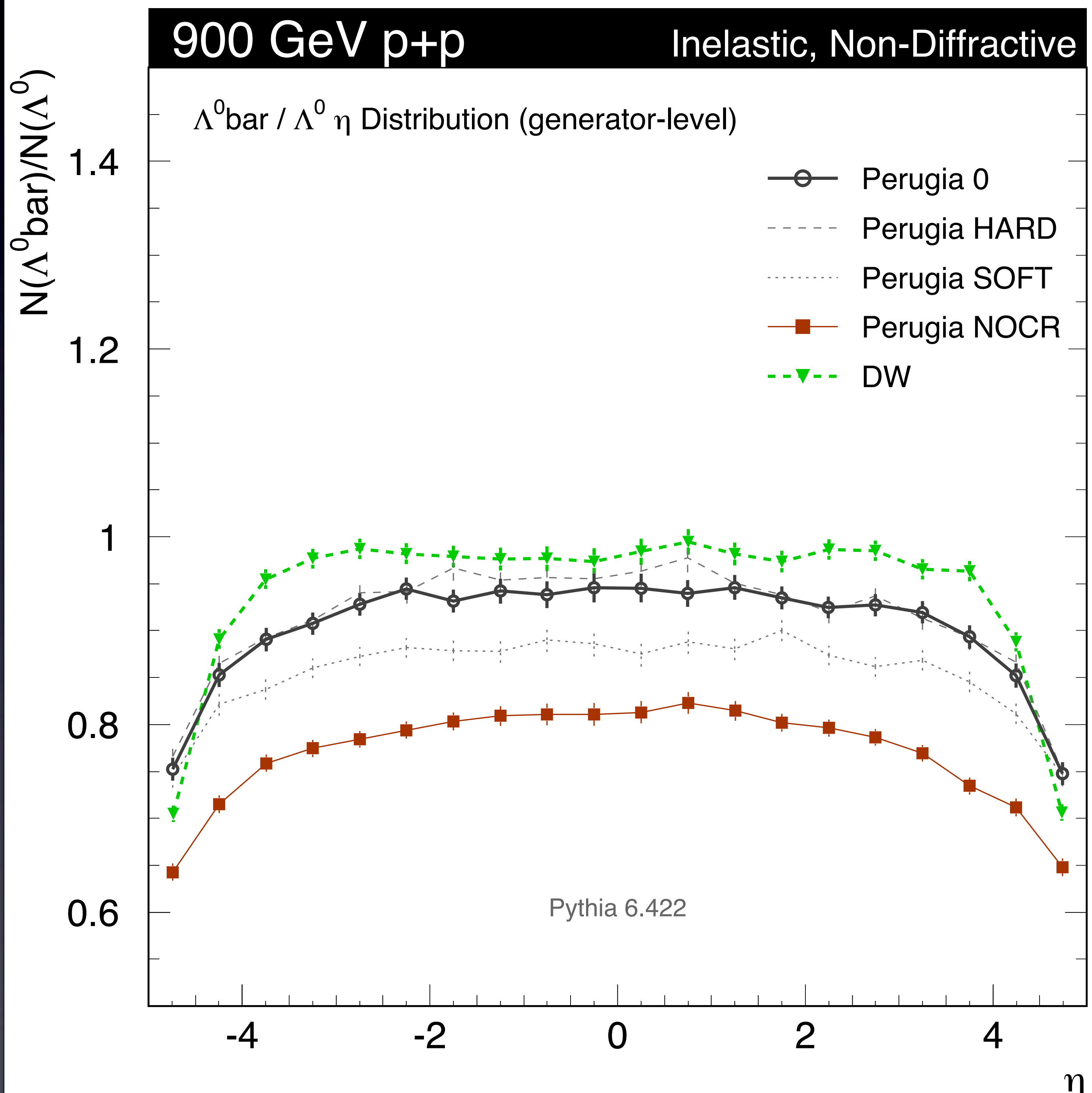
- Check extrapolation to forward region
  - Subir's synergy with Cosmic Ray Fragmentation
  - 'New' Physics: collective effects, multiple scatterings, low-x evolution, BFKL, ..., but central region remains important testing ground

(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?

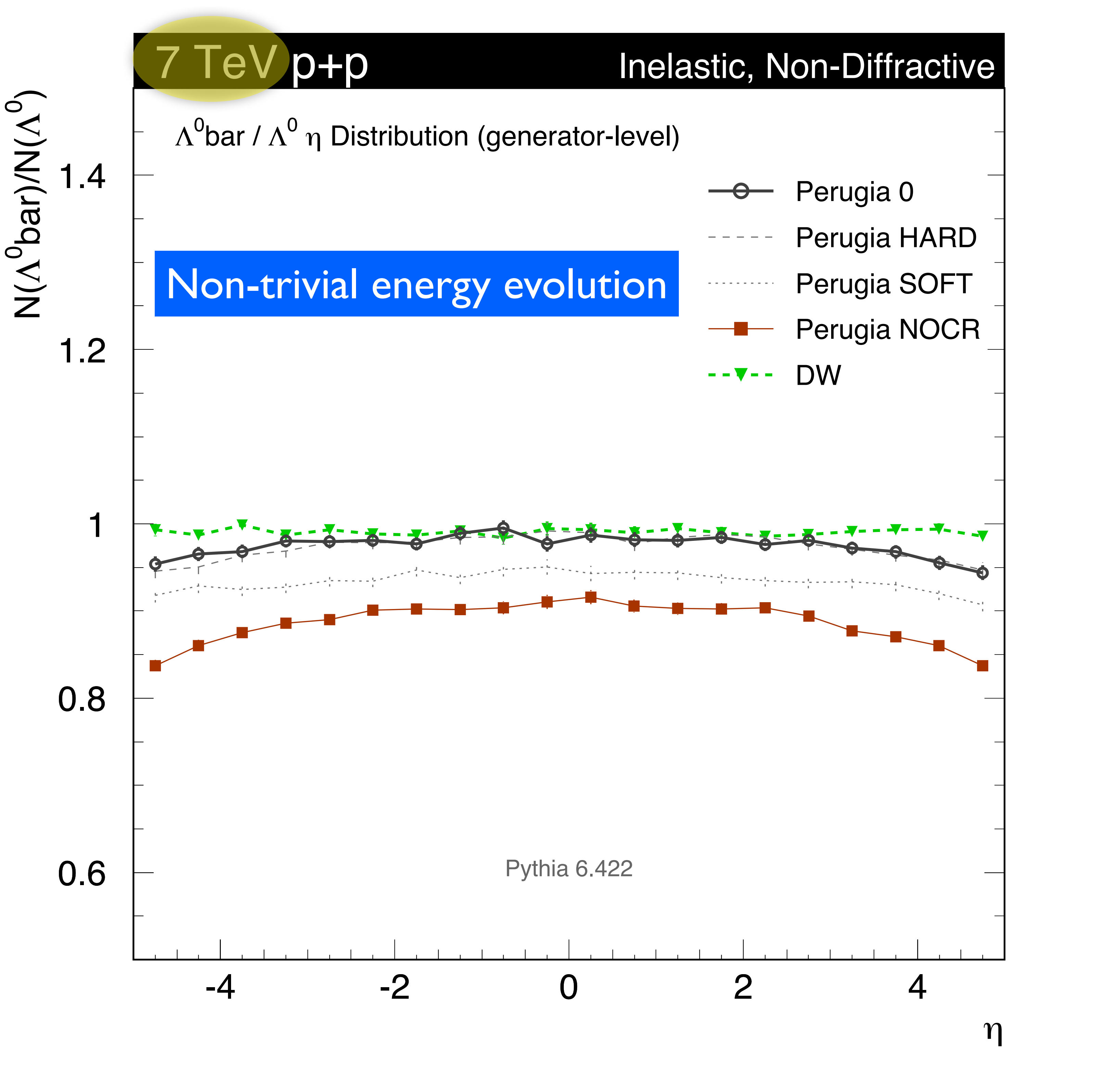
Baryon Transport

- Models disagree wildly.
- Don't listen to them
- (Still, can be used to gauge possible size of effect)



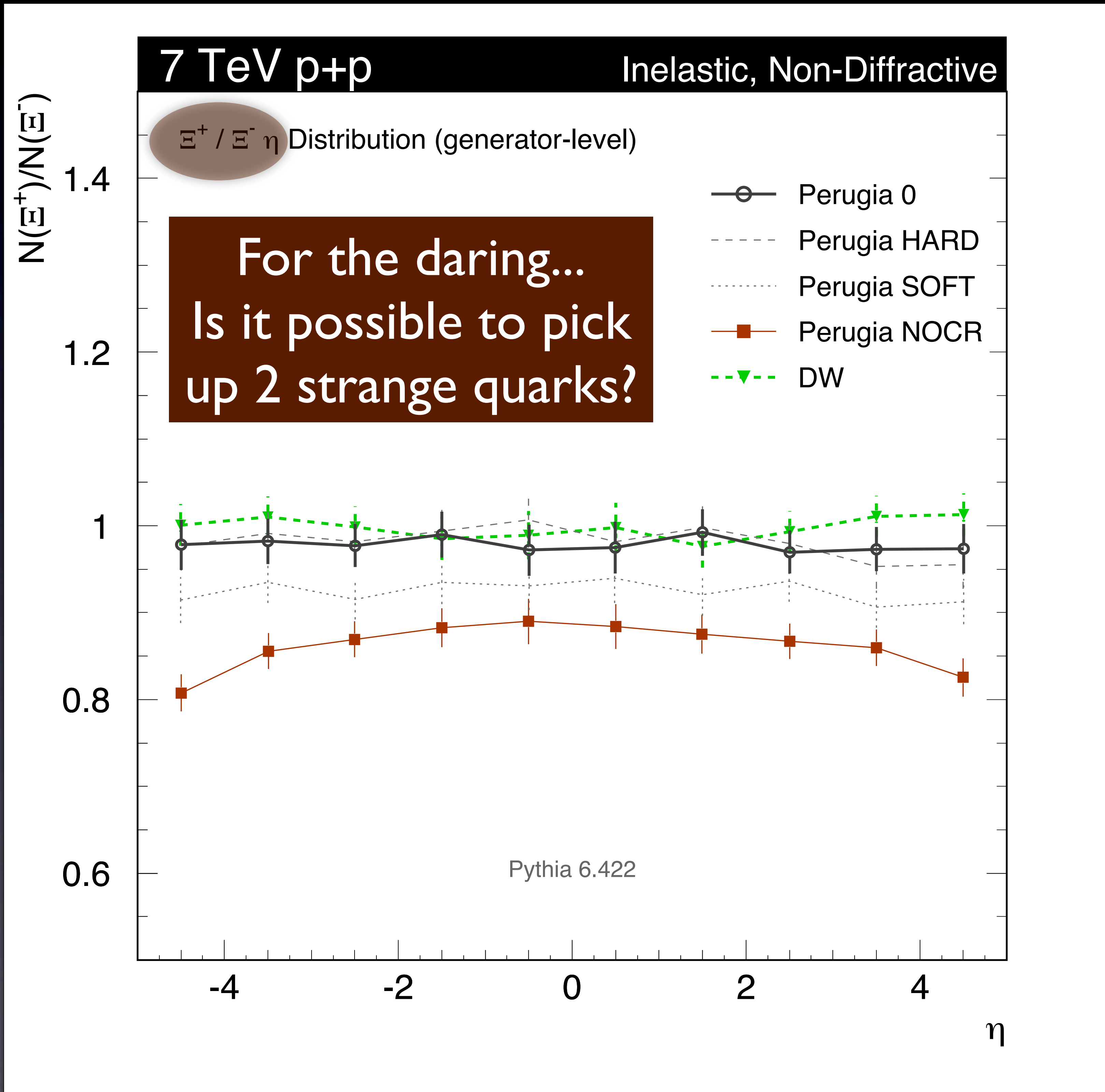
Baryon Transport

- Models disagree wildly.
- Don't listen to them
- (Still, can be used to gauge possible size of effect)



Baryon Transport

- Models disagree wildly.
- Don't listen to them
- (Still, can be used to gauge possible size of effect)

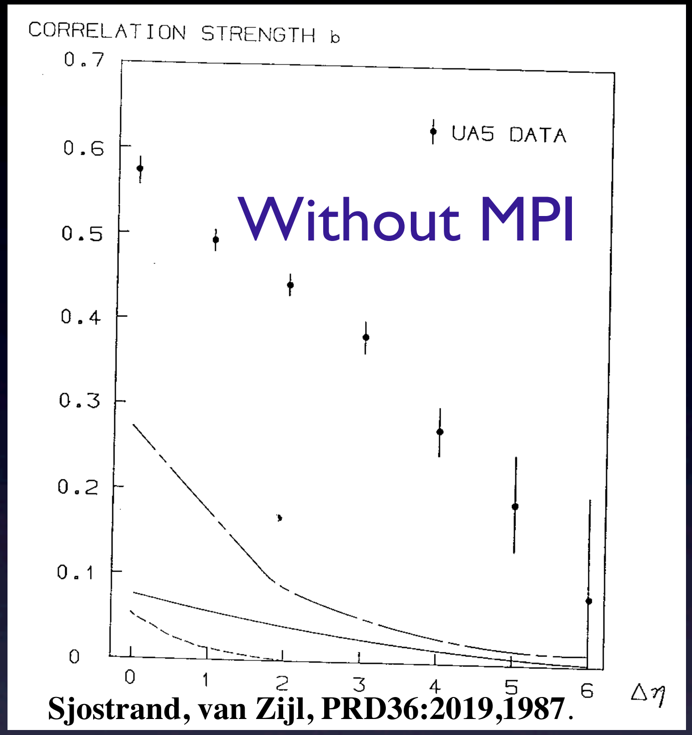


Radiation vs MPI

- 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**?

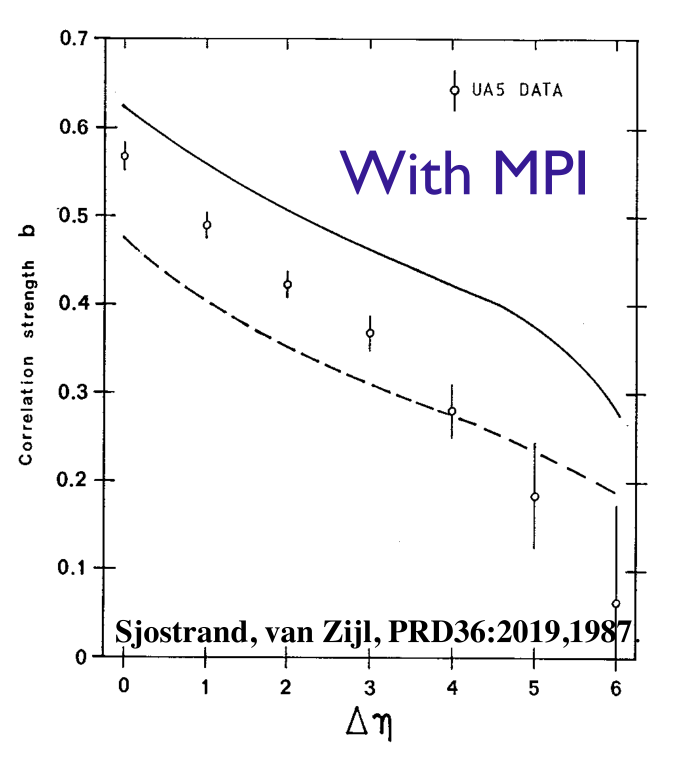
Radiation vs MPI

- 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*



Sjostrand, van Zijl, PRD36:2019,1987.

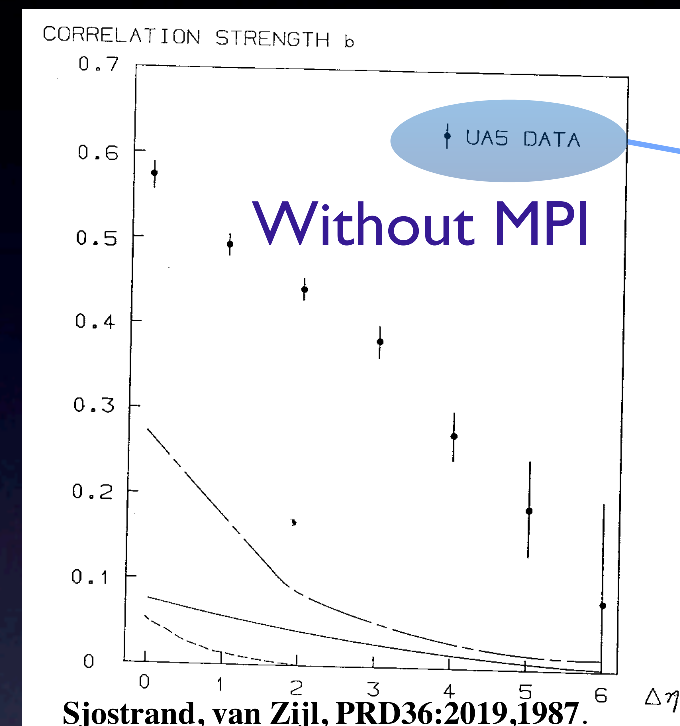
$$b = \frac{\langle n_F n_B \rangle - \langle n_F \rangle^2}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$



Sjostrand, van Zijl, PRD36:2019,1987.

Radiation vs MPI

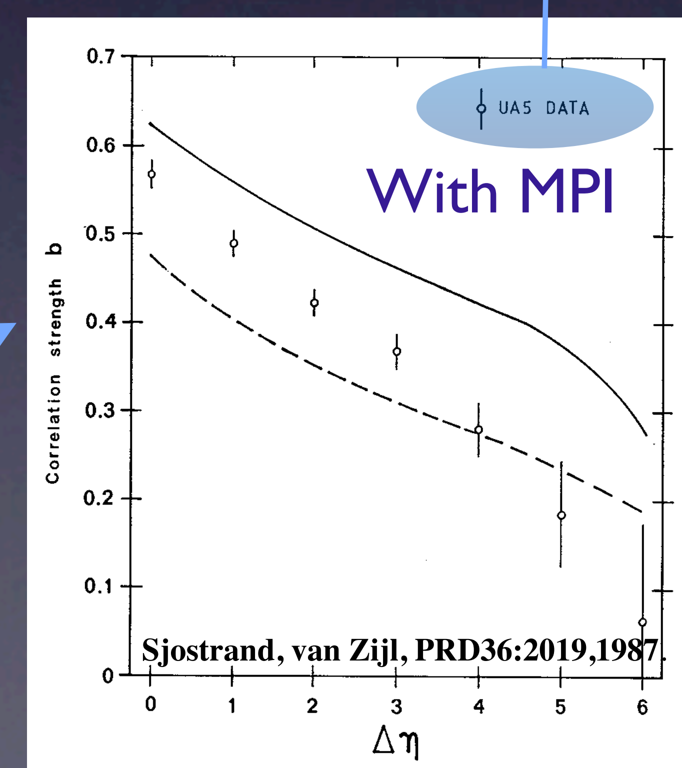
- What is producing the tracks?
  - Is it **Radiation**? (tends to produce partons close in phase space)
  - Or is it **MPI**? (partons going out in opposite directions)
  - Or is it soft production between the **remnants**?
- Probing long- vs short-distance correlations can tell us!
  - E.g., forward-backward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



Sjostrand, van Zijl, PRD36:2019,1987.

b Not measured at Tevatron

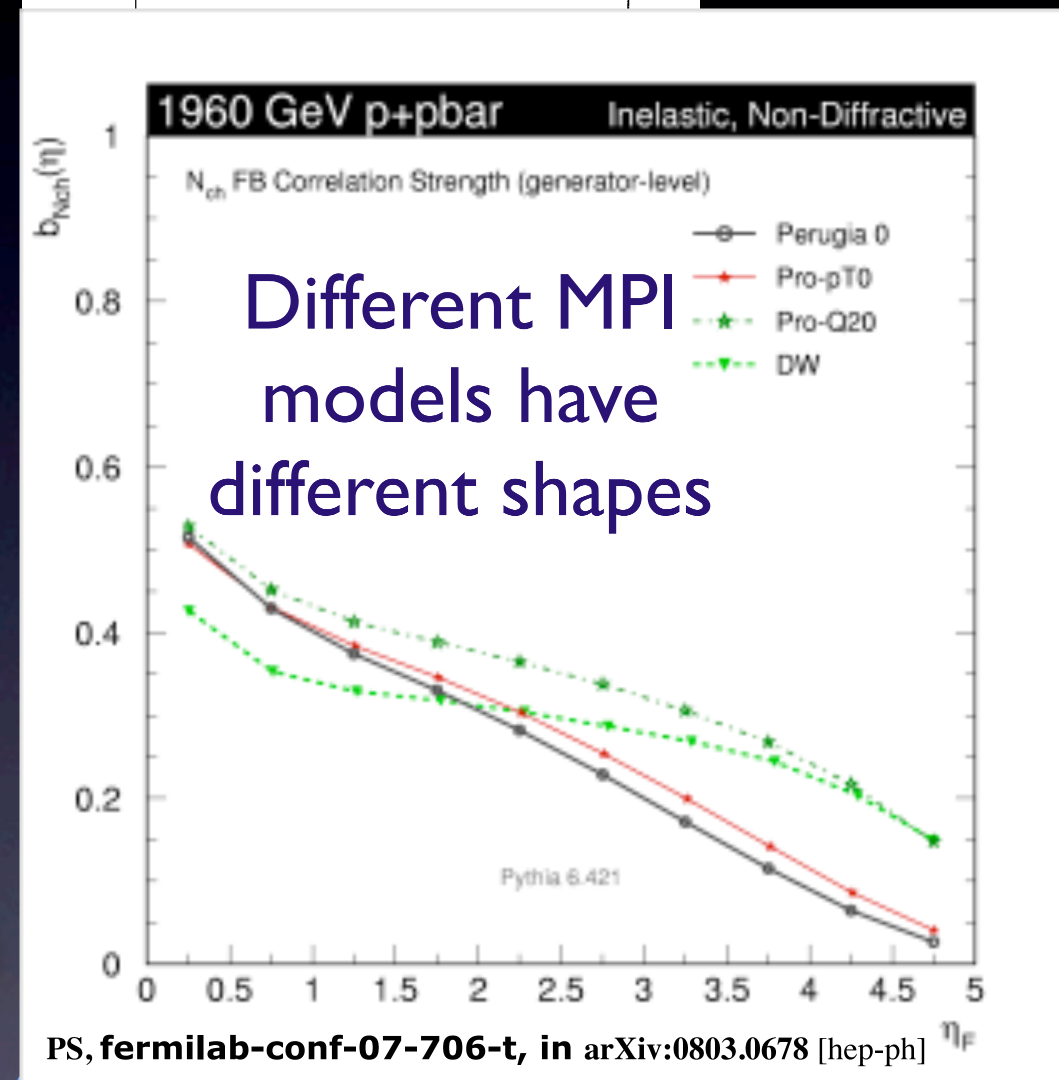
$$b = \frac{\langle n_F n_B \rangle - \langle n_F \rangle^2}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$



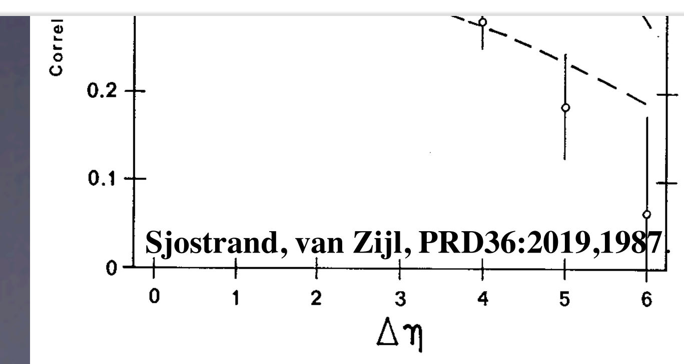
Sjostrand, van Zijl, PRD36:2019,1987.

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*



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

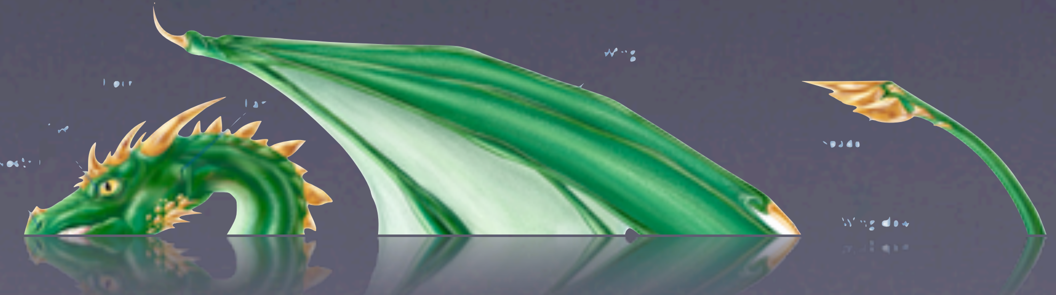


Sjostrand, van Zijl, PRD36:2019,1987

$$b = \frac{\langle n_F n_B \rangle - \langle n_F \rangle^2}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$

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) trying to constrain ('tune') physics models
- In a broader context, they concern our *knowledge* of nature



Dragon anatomy: Morphology

A Systematic Dissection

Perturbative Dynamics :
Infrared **safe** observables
"pQCD"

→ Single-Jet Spectra
Jet-Jet distributions
IR safe Energy Flow variables

Non-perturbative dynamics :
Infrared **sensitive** observables
"MB"

→ Single-Particle Spectra
Particle-Particle distributions
Quantum Number Flow variables

Dragon anatomy: Morphology

A Systematic Dissection

Perturbative Dynamics :
Infrared **safe**
observables

“pQCD”

“UE”

Non-perturbative dynamics :
Infrared **sensitive**
observables

“MB”

Single-Jet Spectra
Jet-Jet distributions
IR safe Energy Flow variables

IR-sensitive vs IR-safe
observables
(e.g., <Nch> vs pTjet)

Single-Particle Spectra
Particle-Particle distributions
Quantum Number Flow variables