Towards an operational definition of diffraction

H. Jung, P. Skands
(+ further input from M. Albrow, A. de Roeck)

Low-Multiplicity Min-Bias Diffraction

- Diffractive processes
  - Large part of total cross section
  - 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

Ways Out

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

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Employed by most previous experiments.

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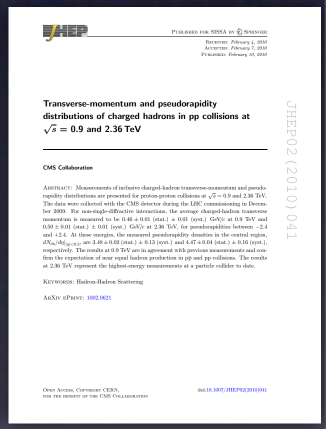
Also used in the first two LHC papers
ALICE Collaboration, Eur. Phys. J. C65 (2010) 111
CMS Collaboration, JHEP 02 (2010) 041


The European Physical Journal C

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


JHEP

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

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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. Bogdanov, 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,

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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.) ± 0.01 (syst.) GeV/c at 0.9 TeV and 0.50 ± 0.01 (stat.) ± 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.) ± 0.13 (syst.) and 4.47 ± 0.04 (stat.) ± 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

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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

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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
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MC “Truth” : Double Diffractive

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6	pi-	-0.65347	0.35445	10.76828	10.79481	0.13957
7	pi+	[illegible]	[illegible]	[illegible]	[illegible]	0.13957
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13	pi+	-0.37412	0.04117	0.68340	0.79257	0.13957
14	pi-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	pi+	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	pi-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	pi-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	pi+	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
sum(p). ma		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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
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sum	momentum	0.00000	0.00000	0.00000	900.00000	900.00000

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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 makes little sense to correct back to it

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

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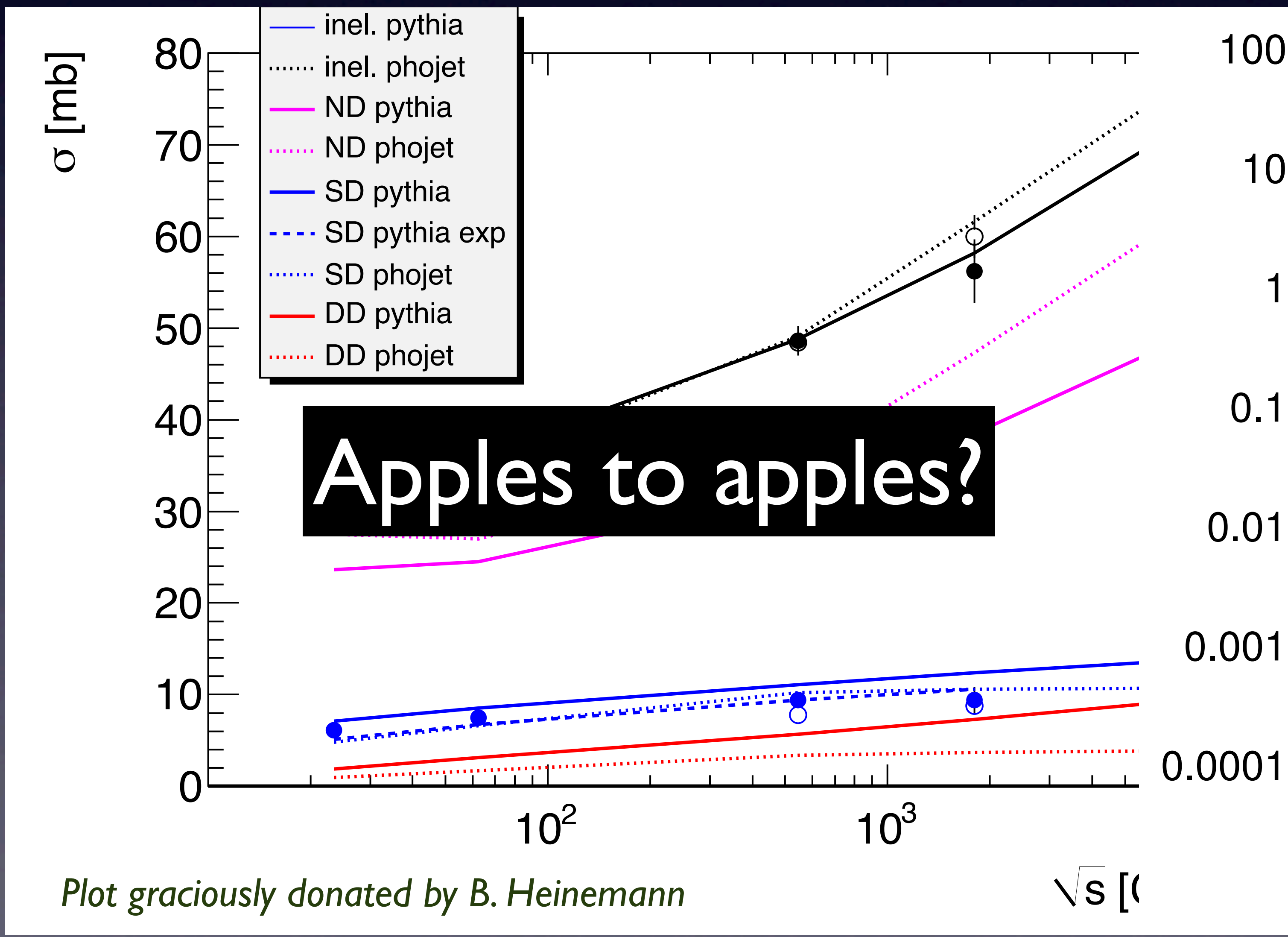
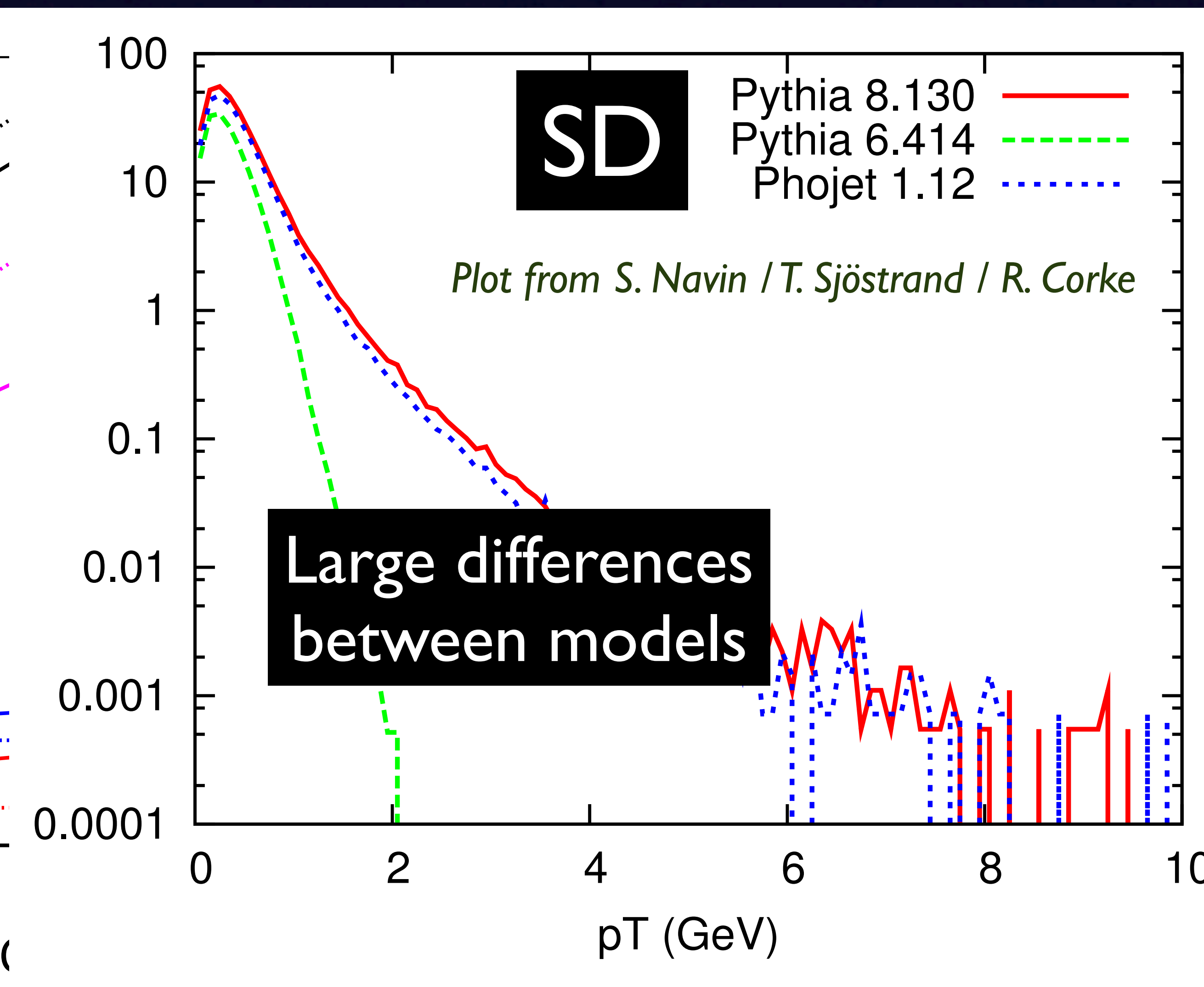
A) Trust the theorists. Correct to specific set of fundamental processes ➜ NSD, INEL, ...





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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

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.

Goal(s)

- Need: operational definition of diffractively enhanced sample(s), in terms of observables
  - Diffracted protons/neutrons not seen
  - LHC detectors miss most of low-mass SD and DD
  - What we can use are *detectable* gaps
    - Gap = no fluctuation above detector noise
- Also think about improvements down the line
  - Including forward detectors
  - Robustness in higher-lumi environments?

Goal(s)

- Need: operational definition of diffractively enhanced sample(s), in terms of observables
  - Diffracted protons/neutrons not seen
  - LHC detectors miss most of low-mass SD and DD
  - What we can use are *detectable* gaps
    - Gap = no fluctuation above detector noise
- Also think about improvements down the line
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Future addition of CMS/TOTEM and ATLAS/LHCf coincidence would open new possible defs?

M. Albrow: E.g, as in CDF, add counters along the beam pipes to detect showers made by the dissociation products => Closer to INEL.

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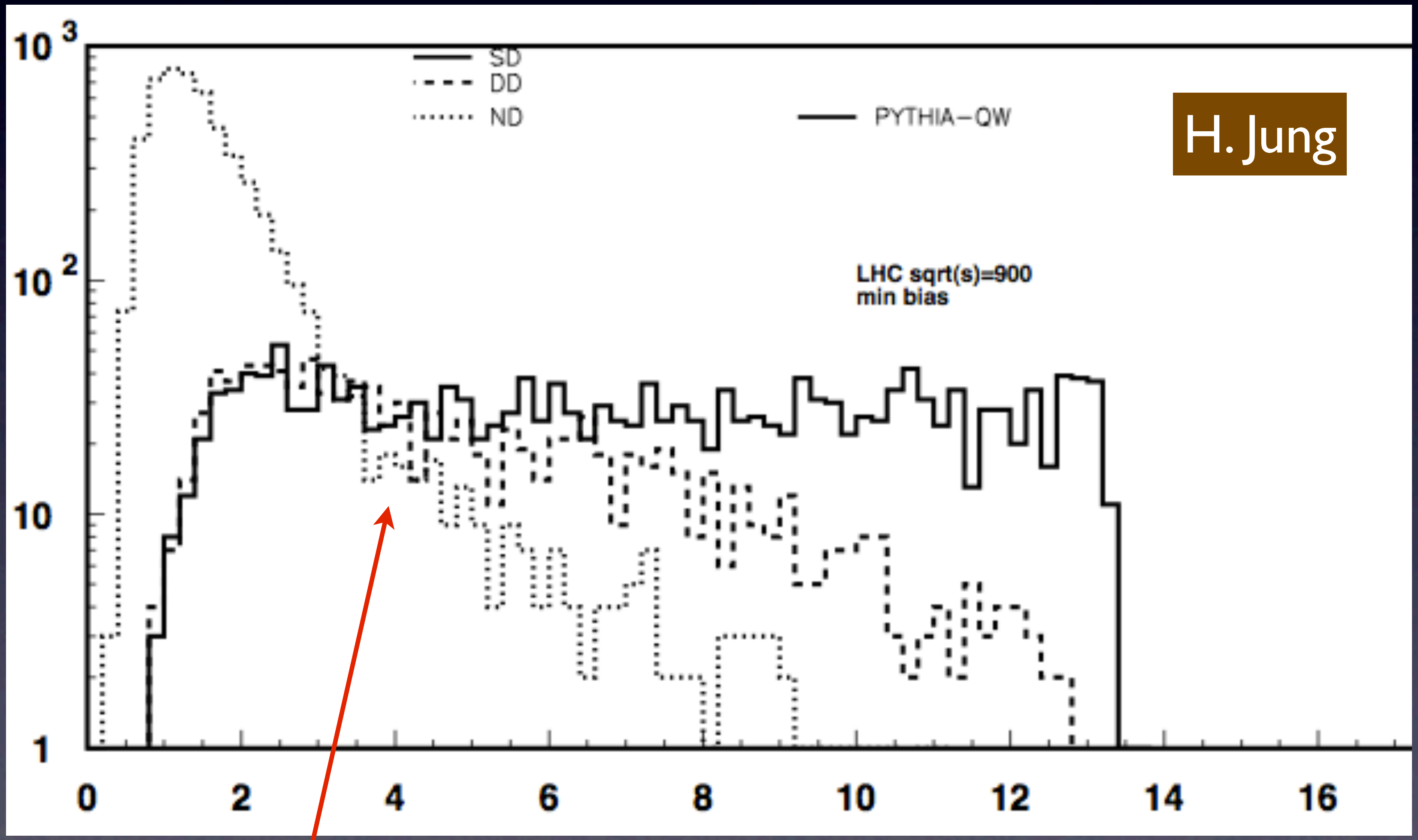
Gap Size

Mueller-Tang suggests gap sizes ~ 4 gives good separation between color-less and color-ful exchanges



Rough check with Pythia suggests a similar number

A Baseline Proposal

for discussion ...

3 Nested Samples

Sliding Gap:

All events with a (detectable) gap > 5 units

Central Gap:

gap > 5 units centered at zero

- Can use trackers to check gap efficiency

Extended Gap:

Extend CG towards one side

- Enhances SD relative to DD

Additional Q's: *what noise level? Central diffraction (double gap?)? ...*

Backup Slides

Modeling Diffraction

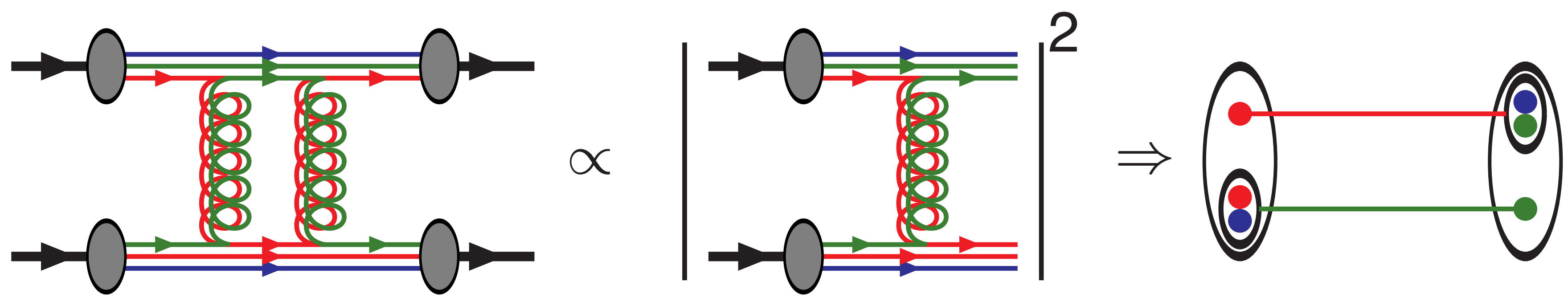
- PYTHIA 6
- POMPYT, POMWIG
- PHOJET (& Relatives)
- PYTHIA 8
- HERWIG++
- SHERPA
- EPOS, RAPGAP, ...

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:

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

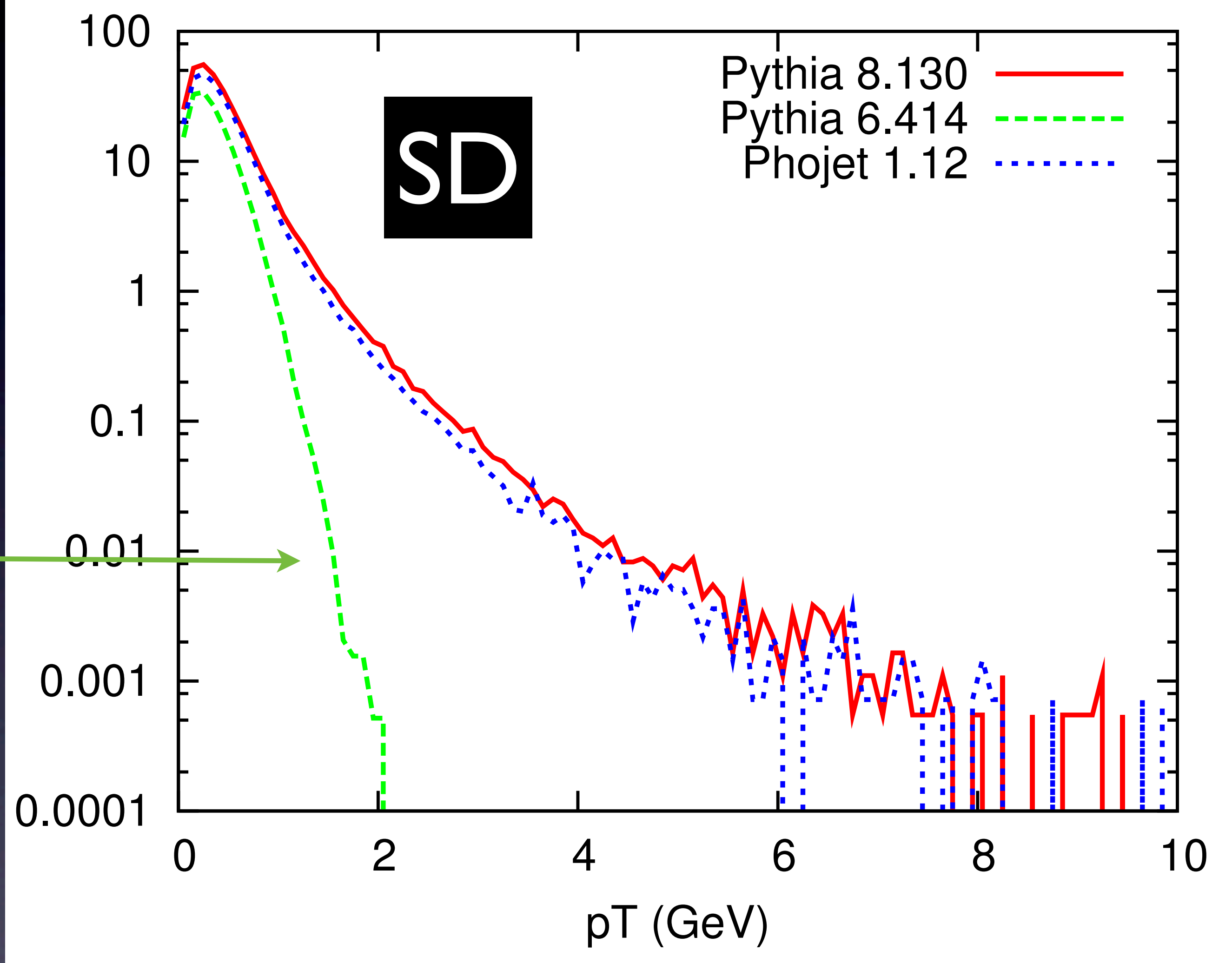
$$\frac{d\sigma_{dd}(s)}{dt\, dM_1^2\, dM_2^2} = \frac{g^2_{3I\!P}}{16\pi}\beta_{AI\!P}\beta_{BI\!P}\frac{1}{M_1^2}\frac{1}{M_2^2}\exp(B_{dd}t)\,F_{dd}\,.$$

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

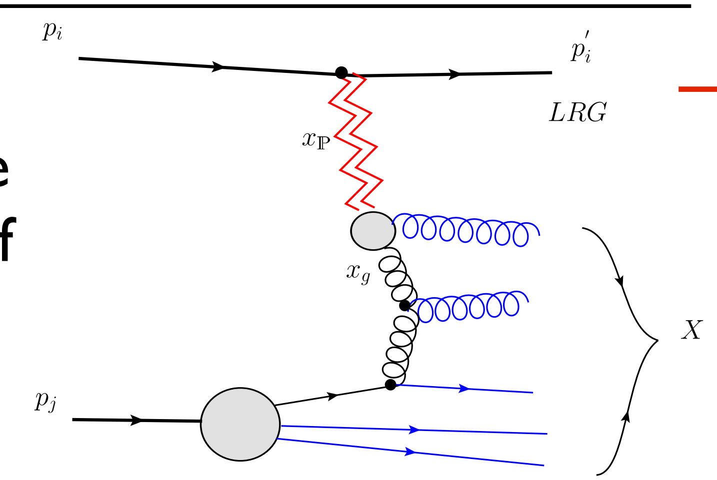
Diffractive Cross Section Formulæ:

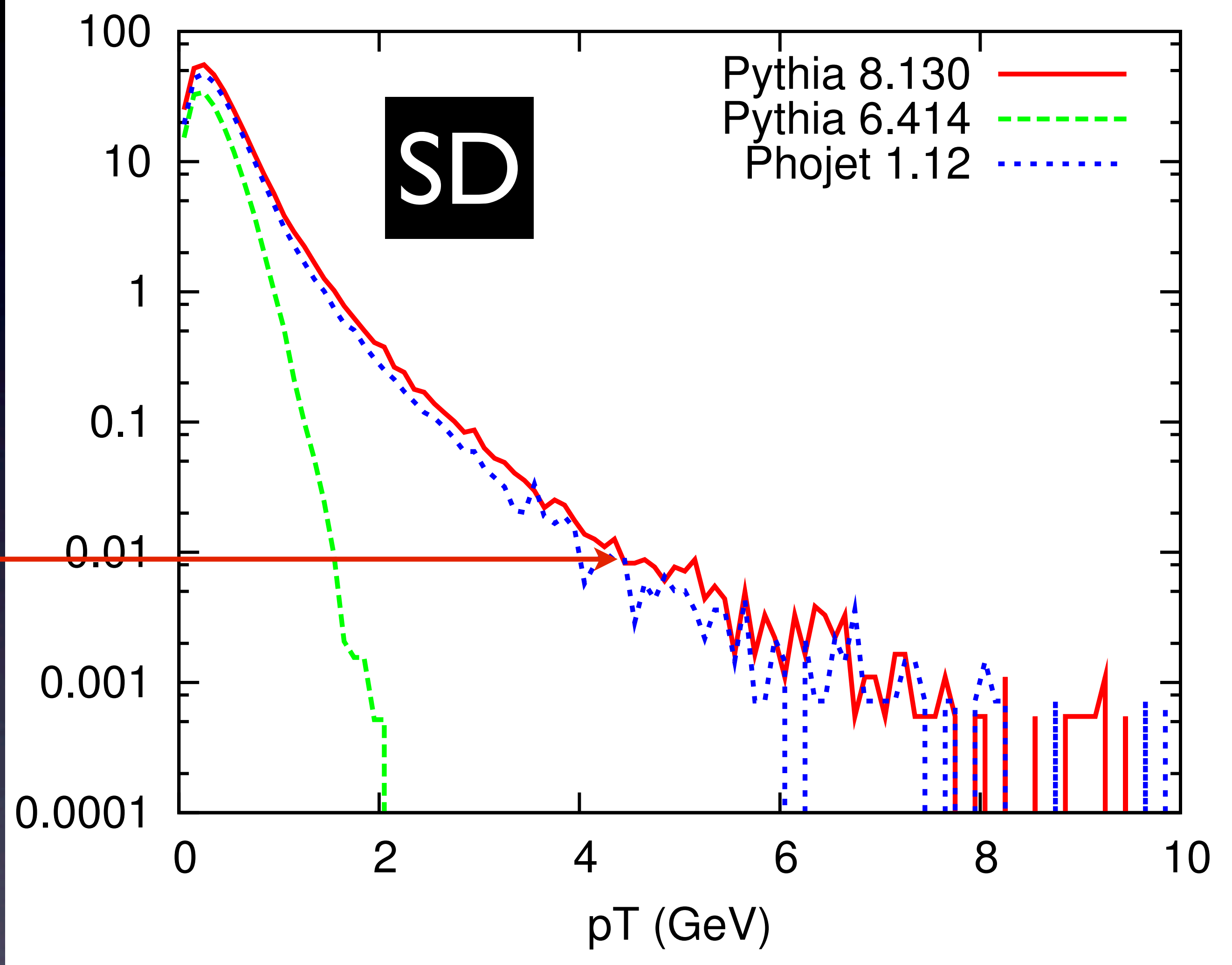
$$\frac{\mathrm{d}\sigma_{\mathrm{sd}(AX)}(s)}{\mathrm{d}t\,\mathrm{d}M^2} = \frac{g_{3\mathrm{I\!P}}}{16\pi}\,\beta^2_{A\mathrm{I\!P}}\,\beta_{B\mathrm{I\!P}}\,\frac{1}{M^2}\,\exp(B_{\mathrm{sd}(AX)}t)\,F_{\mathrm{sd}}\ ,$$

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

Partonic Substructure in Pomeron:

Follows the approach of Pompyt





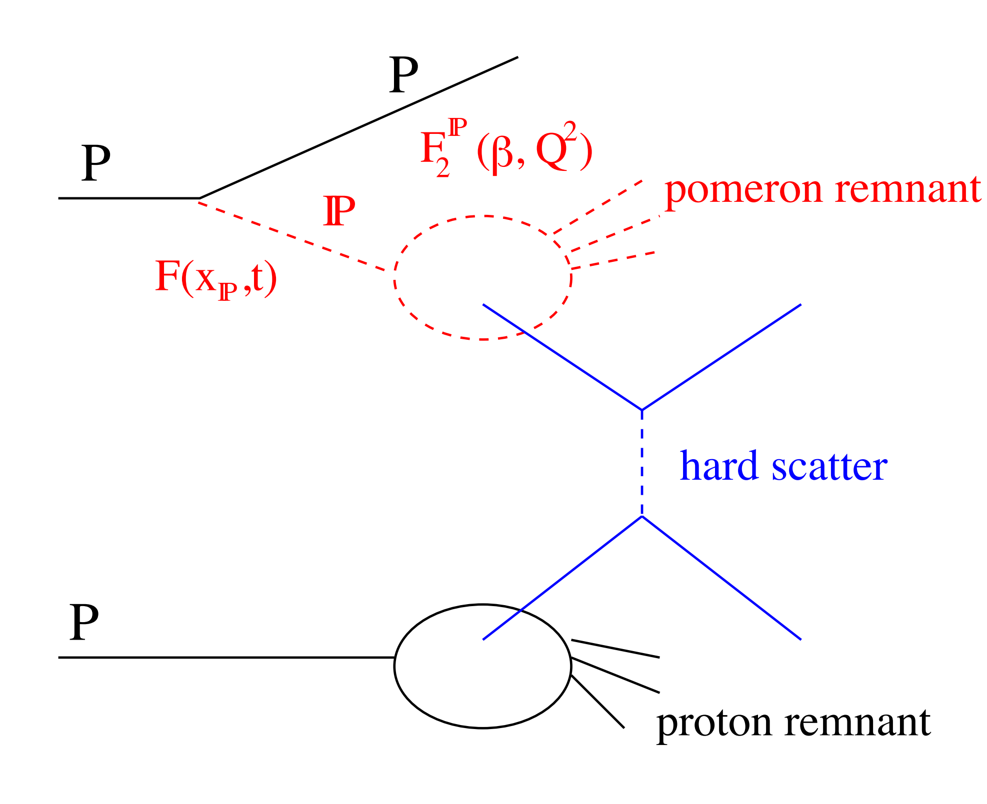
- $M_X \leq 10\,\mathrm{GeV}$: original longitudinal string description used
- $M_X > 10\,\mathrm{GeV}$: new perturbative description used

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., $\mathbb{P}\mathbb{P}$>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	MCnet
• HERWIG++ (POMWIG++)	P. Ruzicka R&D	MCnet
• SHERPA (KMR)	K. Zapp R&D	MCnet
• EPOS, RAPGAP, ...	?	