Forward physics and diffraction at the LHC

M.L. Mangano
CERN TH

based on the input collected from the presentations and discussions at the LPC/LPCC Oct 31 mtg

Special Joint LPC/LPCC meeting on the LHC forward physics programme (Run-2 and beyond)

31 Oct 2016, 14:00 → 18:00 Europe/Zurich

https://indico.cern.ch/event/575250/

4-3-006 - TH Conference Room (CERN)

Christoph Schwick (CERN), Jamie Boyd (CERN), Michelangelo Mangano (CERN)

14:00	Introduction to the landscape of forward and diffractive physics at the LHC: an overview of the studies documented in the report by the LHC Fwd Phys WG	Christophe Royon (The University of Kansas (US)), Nicolo Cartiglia (INFN) Full Report lhcc2016.pdf
14:30	Input from ATLAS	Ulla Blumenschein (University of London (GB)) AtlasForward.pdf
14:55	Input from CMS	Arthur Moraes (CBPF - Brazilian Center for Physics Research (BR)) Forward physics with CMS_ planning for 2017-18 data-taking.pdf
15:20	input from TOTEM	Mario Deile (CERN), Mario Deile (CERN) lpcc20161031.pdf
15:45	Input from ALICE	Christoph Mayer (Polish Academy of Sciences (PL)) 2016.10.31_LPCC_ALICE_forward_physics.pdf
16:00	Input from LHCb	Daniel Johnson (CERN) 16-10Oct-31_DanJohnson.pdf
16:15	The LHC perspective, including a first assessment of the implications of these requests, also based on the experience accumulated so far	Helmut Burkhardt (CERN) LPCc_Forward_2016_10_31.pdf

The LHC forward physics and diffraction Working Group

J.Phys. G43 (2016) 110201

DOI: 10.1088/0954-3899/43/11/110201
e-Print: **arXiv:1611.05079**

Short 10-page summary, as input to this mtg, is attached to today's agenda

(thanks to C.Royon for putting it together)

CERN-PH-LPCC-2015-001
SLAC-PUB-16364
DESY 15-167

September 3 2015

LHC Forward Physics

Editors: N. Cartiglia, C. Royon
The LHC Forward Physics Working Group

K. Akiba[21], M. Akbiyik[1], M. Albrow[2], M. Arneodo[3,4], V. Avati[5,6], J. Baechler[6], O. Villalobos Baillie[87], P. Bartalini[7], J. Bartels[8], S. Baur[1], C. Baus[1], W. Beaumont[9], U. Behrens[10], D. Berge[11], M. Berretti[6,12], E. Bossini[12], R. Boussarie[13], S. Brodsky[14], M. Broz[15], M. Bruschi[16], P. Bussey[17], W. Byczynski[81], J. C. Cabanillas Noris[18], E. Calvo Villar[19], A. Campbell[10], F. Caporale[22], W. Carvalho[21], G. Chachamis[22], E. Chapon[23], C. Cheshkov[24], J. Chwastowski[25], R. Ciesielski[26], D. Chinellato[83], A. Cisek[25], V. Coco[6], P. Collins[6], J. G. Contreras[15], B. Cox[27], D. de Jesus Damiao[21], P. Davis[28], M. Deile[6], D. D'Enterria[6], D. Druzhkin[29,6], B. Ducloué[30,31], R. Dumps[6], R. Dzhelyadin[82] P. Dziurdzia[6], M. Eliachevitch[1], P. Fassnacht [6] F. Ferro[32], S. Fichet[33], D. Figueiredo[21], B. Field[34], D. Finogeev[35], R. Fiore[29,36], J. Forshaw[27], A. Gago Medina[19], M. Gallinaro[37], A. Granik[82], G. von Gersdorff[33], S. Giani[6], K. Golec-Biernat[25,38], V. P. Goncalves[39], P. Göttlicher[10], K. Goulianos[26], J.-Y. Grosslord[24], L. A. Harland-Lang[40], H. Van Haevermaet[9], M. Hentschinski[41], R. Engel [1], G. Herrera Corral[42], J. Hollar[37], L. Huertas[21], D. Johnson[6], I. Katkov[1], O. Kepka[43], M. Khakzad[44], L. Kheyn[45], V. Khachatryan[46], V. A. Khoze[47], S. Klein[48], M. van Klundert[9], F. Krauss[47], A. Kurepin[35], N. Kurepin[35], K. Kutak[49], E. Kuznetsova[1], G. Latino[12], P. Lebiedowicz[25], B. Lenzi[6], E. Lewandowska[25], S. Liu[28], A. Luszczak[25,38], M. Luszczak[25], J. D. Madrigal[50], M. Mangano[6], Z. Marcone[34], C. Marquet[51], A. D. Martin[47], T. Martin[52], M. I. Martinez Hernandez[53], C. Martins[21], C. Mayer[25], R. Mc Nulty[54], P. Van Mechelen[7], R. Macula[25], E. Melo da Costa[21], T. Mertzimekis[55], C. Mesropian[26], M. Mieskolainen[31], N. Minafra[6,56], I. L. Monzon[18], L. Mundim [21], B. Murdaca[20,36], M. Murray[57], H. Niewiadowski[58], J. Nystrand[59], E. G. de Oliveira[60], R. Orava[31], S. Ostapchenko[61], K. Osterberg[31], A. Panagiotou[55], A. Papa[20], R. Pasechnik[62], T. Peitzmann[63], L. A. Perez Moreno[53], T. Pierog[1], J. Pinfold[28], M. Poghosyan[64], M. E. Pol[65], W. Prado[21], V. Popov[66], M. Rangel[67], A. Reshetin[35], J.-P. Revol[68], M. Rijssenbeek[34], M. Rodriguez [5]3, B. Roland[10], C. Royon[25,43,57], M. Ruspa[3,4], M. Ryskin[47,69], A. Sabio Vera[22], G. Safronov[66], T. Sako[70], H. Schindler[6], D. Salek[11], K. Safarik [6], M. Saimpert[71], A. Santoro[21], R. Schicker[73], J. Seger[64], S. Sen[73], A. Shabanov[35], W. Schafer[25], G. Gil Da Silveira[39], P. Skands[74], R. Soluk[28], A. van Spilbeeck[9], R. Staszewski[25], S. Stevenson[75], W.J. Stirling[86], M. Strikman[76], A. Szczurek[25,38] L. Szymanowski[77], J.D. Tapia Takaki,[57] M. Tasevsky[43], K. Taesoo[78], C. Thomas[75], S. R. Torres[18], A. Tricomi[79], M. Trzebinski[25], D. Tsybychev[34], N. Turini[12], R. Ulrich[1], E. Usenko[35], J. Varela[37], M. Lo Vetere[80], A. Villatoro Tello[53], A. Vilela Pereira[21], D. Volyanskyy [84], S. Wallon[13,85], G. Wilkinson[75], H. Wöhrmann[1]. K. C. Zapp[6], Y. Zoccarato[24].

The three branches of the programme

σ ~ mb

- cross sections: total, elastic, inelastic
- elastic scattering: Coulomb-nuclear interference and small-t behaviour, diffractive structure at large t
- event structure at ~0 degrees (LHCf — done for run2, may come back in run 3 for pA runs with light A)

=> dedicated optics, μ~0, time-limited and one-off runs

σ ~ μb - nb

- Central exclusive production in the few GeV-100 GeV mass range (elastic, inelastic) cross sections
- Spectroscopy (glueballs, charmonium)
- Missing-energy searches
- dijets/hvqs/DY production, pomeron structure and PDFs
- …

=> varied needs in terms of μ, ∫L and optics

The three branches of the programme

$\sigma \sim$ pb - fb

- Central exclusive production above few 100 GeV
- Hard dijets
- $\gamma\gamma \rightarrow VV$ ($V=W,Z,\gamma$) and anomalous couplings
- Heavy resonances in $\gamma\gamma$ fusion
- …

=> high-μ, high-lumi optics, adapted to maximize acceptance at low mass, but without compromising ∫L

With the final deployment and commissioning of the new detector components (AFP and CT-PPS) through 2016-17, it's becoming integral part of standard data taking

=> no need of special discussion today

Total cross sections

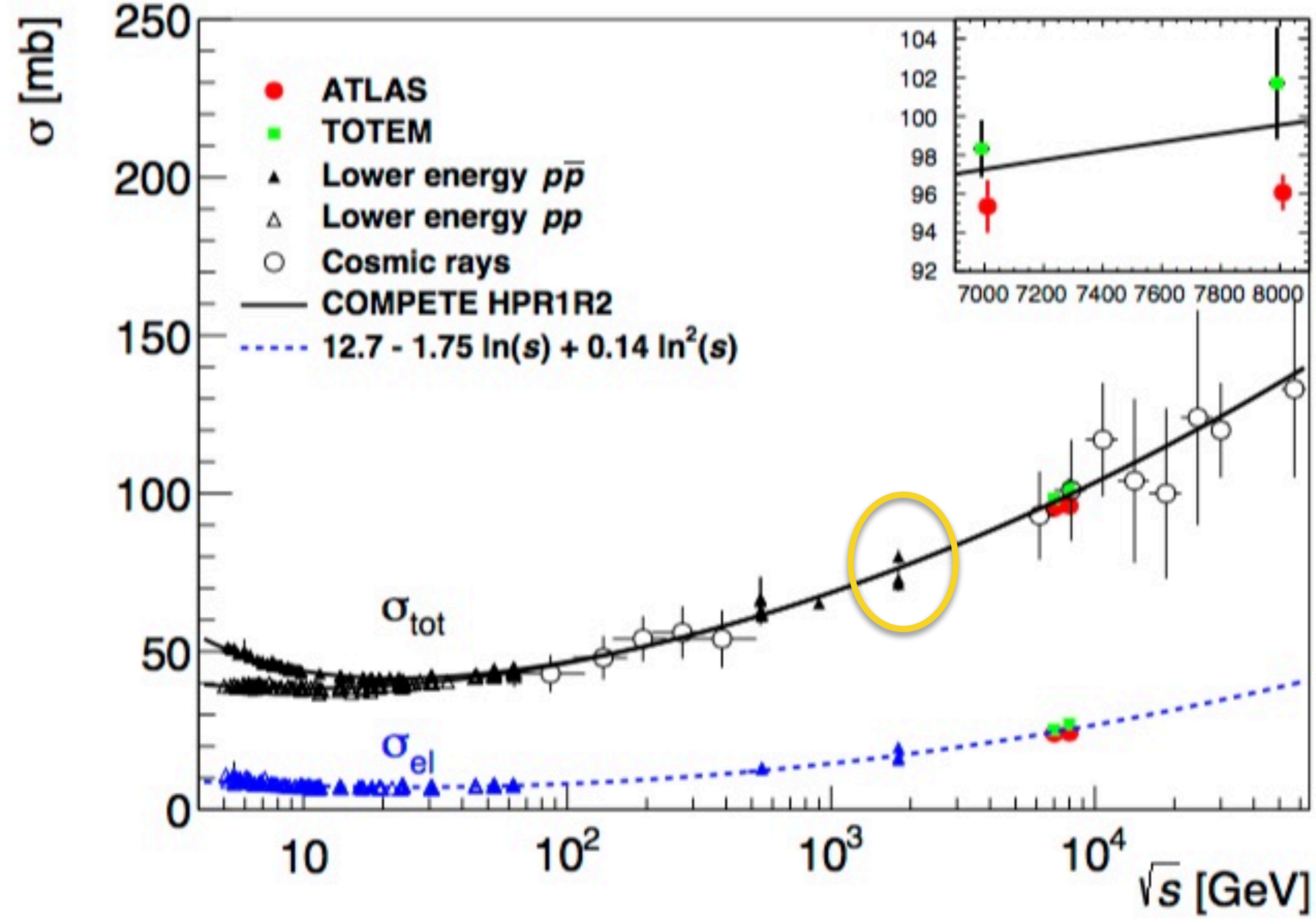
$$\sigma_{\mathrm{tot}} = \frac{1}{\mathscr{L}}(N_{\mathrm{el}} + N_{\mathrm{inel}})$$

$$\sigma_{\mathrm{tot}}^2 = \frac{16\pi}{1+\rho^2} \frac{1}{\mathscr{L}} \left.\frac{\mathrm{d}N_{\mathrm{el}}}{\mathrm{d}t}\right|_{t=0}$$

$$\sigma_{\mathrm{tot}} = \frac{16\pi}{1+\rho^2} \frac{\mathrm{d}N_{\mathrm{el}}/\mathrm{d}t|_{t=0}}{N_{\mathrm{el}} + N_{\mathrm{inel}}}, \qquad \mathscr{L} = \frac{1+\rho^2}{16\pi} \frac{(N_{\mathrm{el}} + N_{\mathrm{inel}})^2}{\mathrm{d}N_{\mathrm{el}}/\mathrm{d}t|_{t=0}}$$

ATLAS and TOTEM obtained measurements at 7 and 8 TeV, and are working on 13 TeV (β^* = 2.5km run)

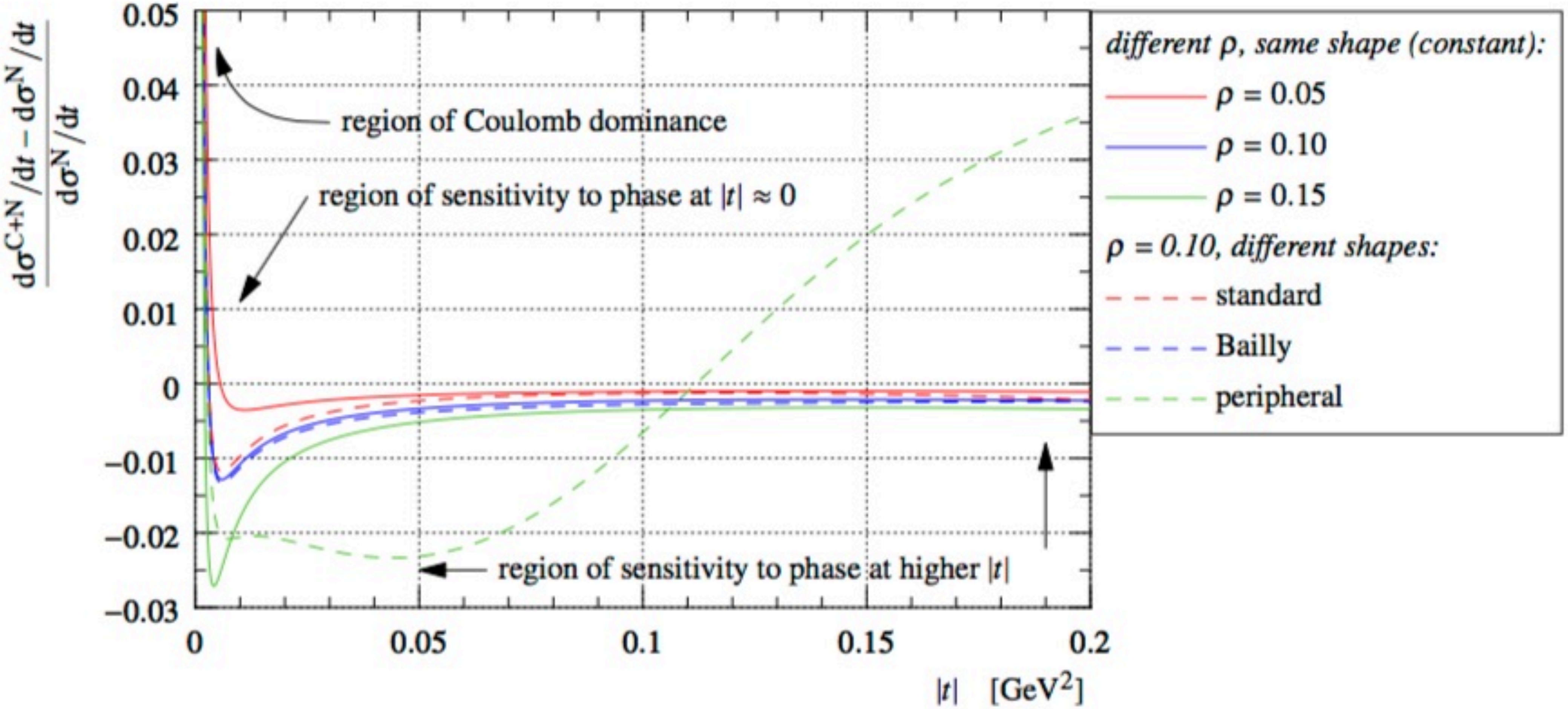
Total cross sections

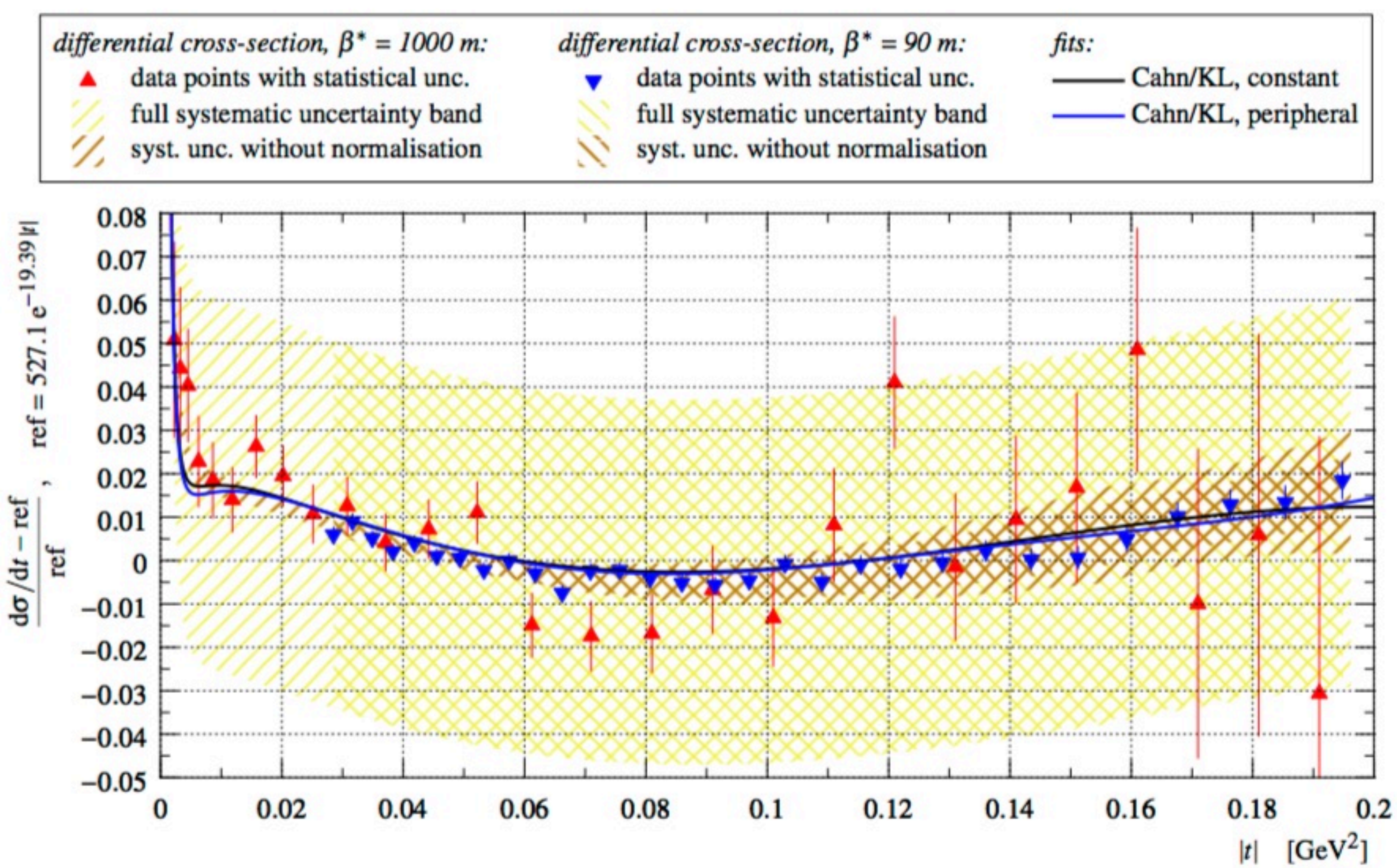


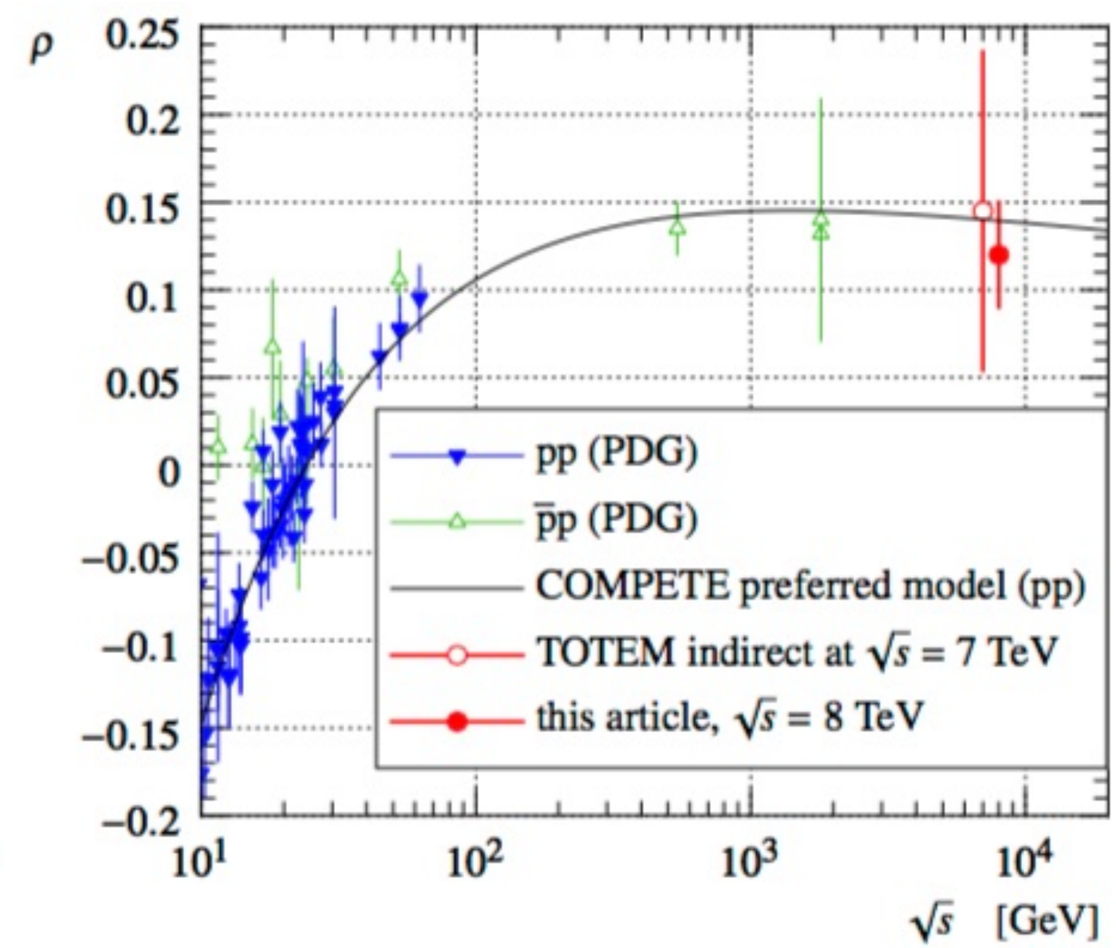
$\sqrt{s}$	Experiment	σ_{tot} [mb]
546 GeV	UA4	61.9 ± 1.5
	CDF	61.26 ± 0.93
1.8 TeV	CDF	80.03 ± 2.24
	E710	72.8 ± 3.1
	E811	71.42 ± 2.41

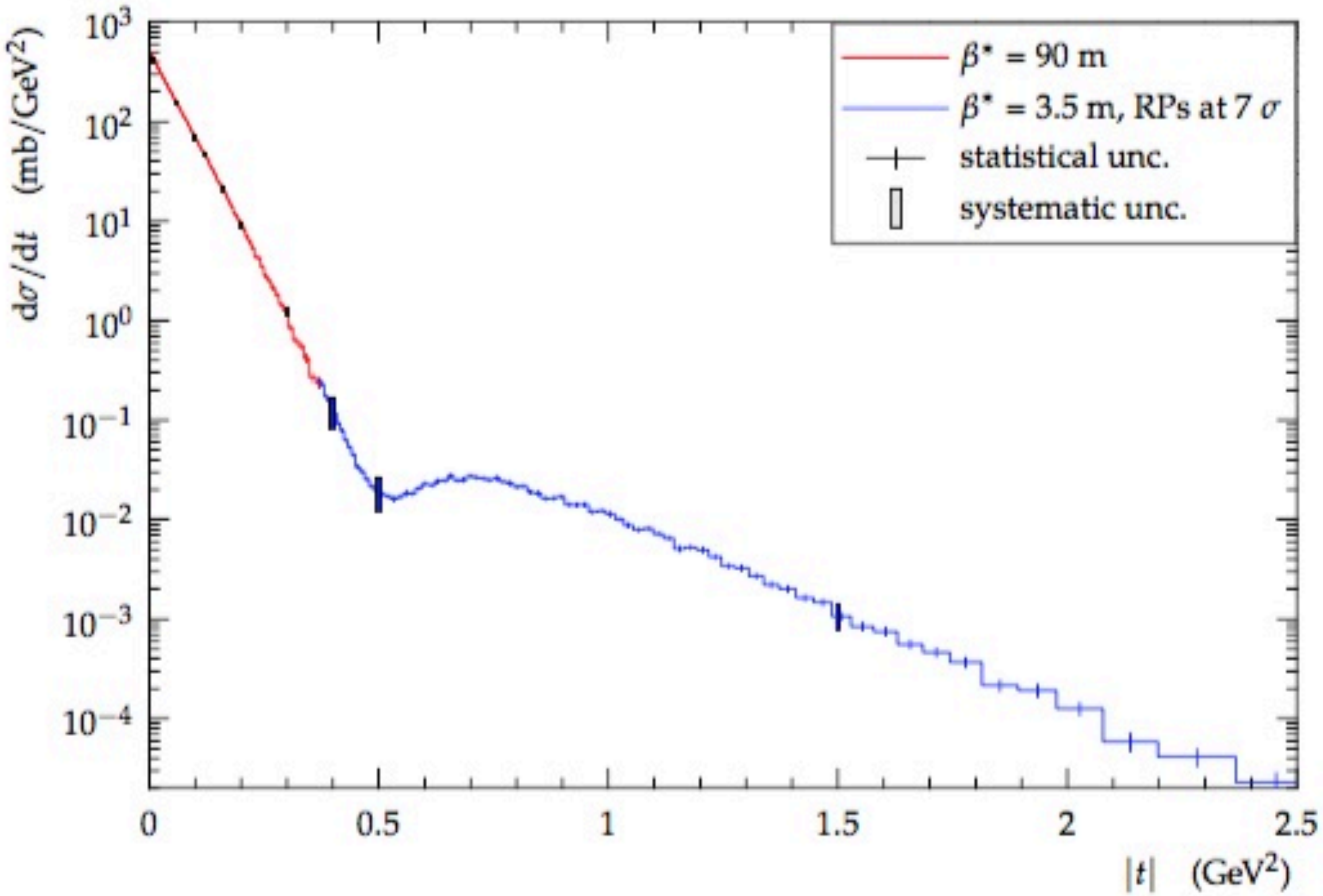
??

TOTEM arXiv:1610.00603

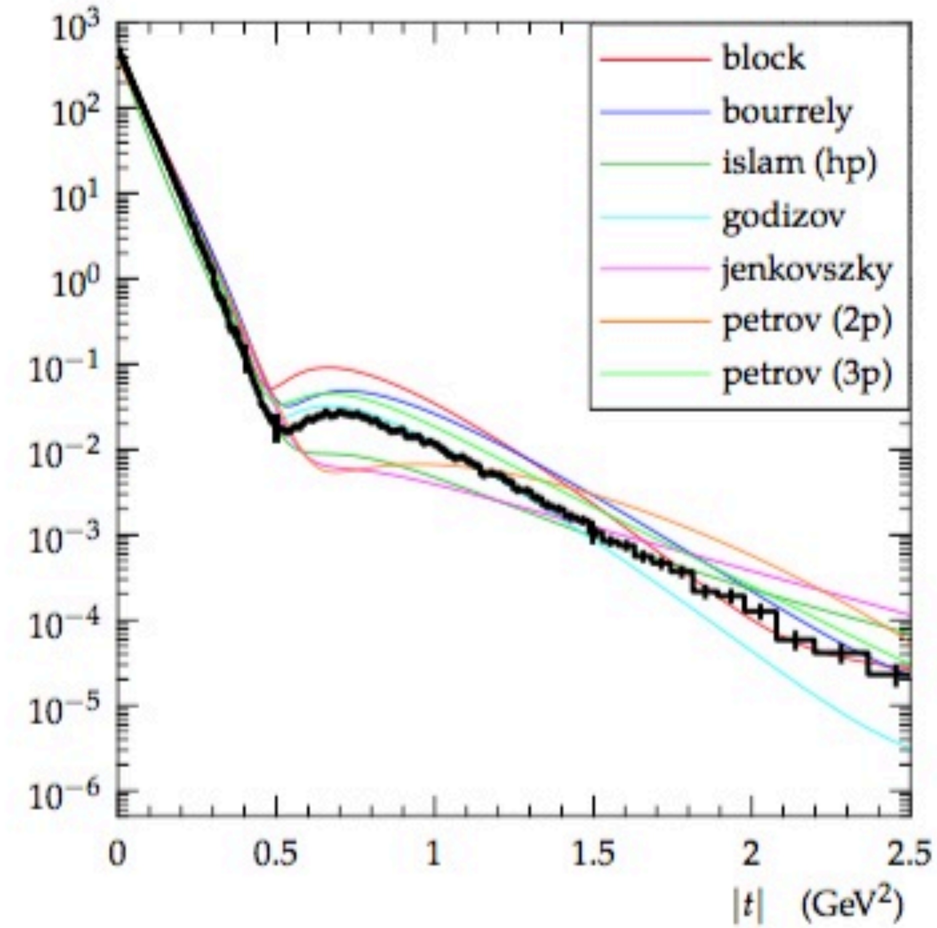








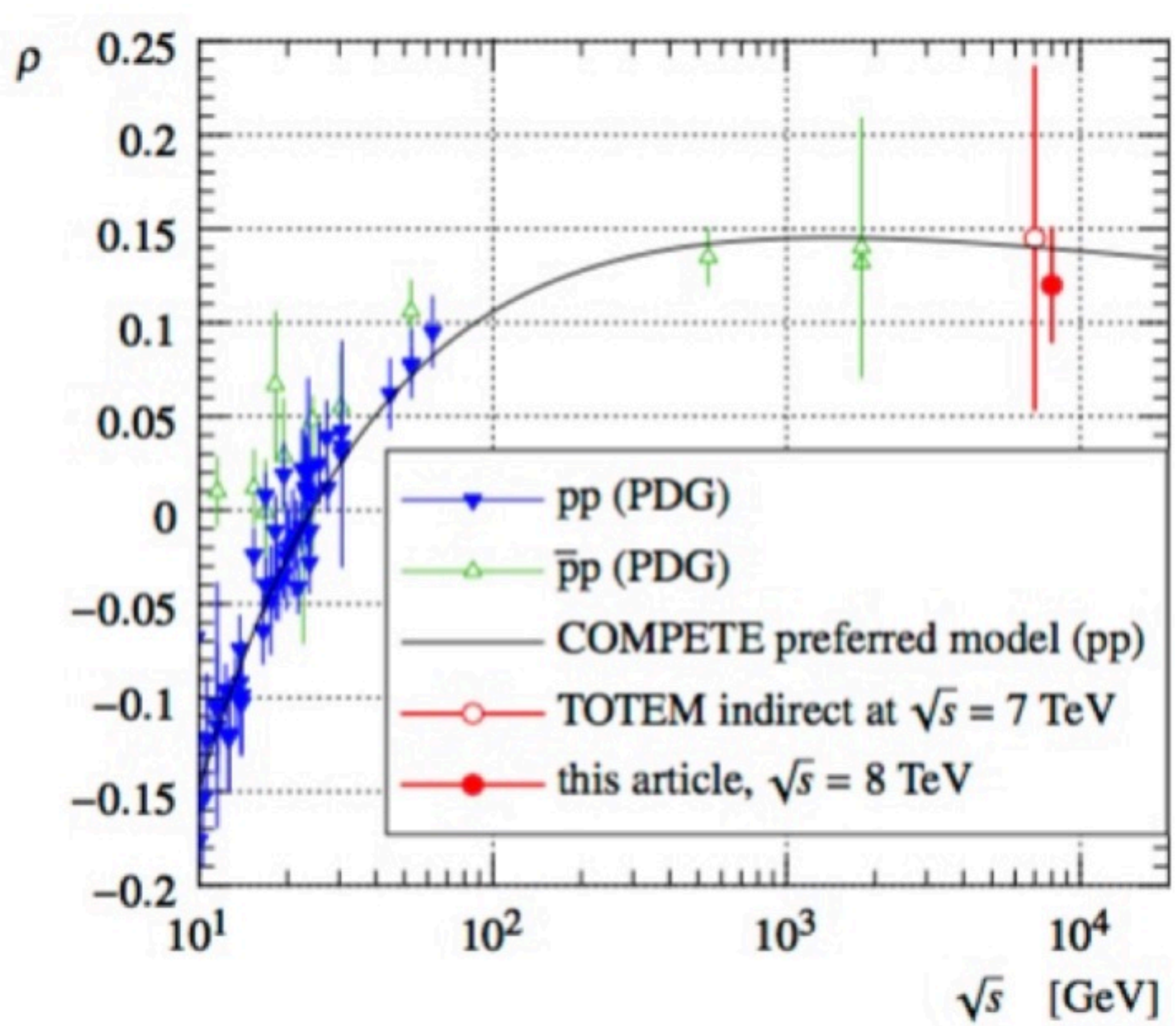
dσ/dt (mb/GeV²)
β* = 90 m
β* = 3.5 m, RPs at 7 σ
statistical unc.
systematic unc.
|t| (GeV²)



block
bourrely
islam (hp)
godizov
jenkovszky
petrov (2p)
petrov (3p)
|t| (GeV²)

Future measurements

- Extend energy range, ideally from injection energy up to the maximum to be reached by the LHC in the future. In particular:
  - match the Tevatron energy (2 TeV), and possibly go to 900 GeV
  - map out the energy dependence of the ρ parameter, with precision at least O(10%) to establish turn-over at ~ 1-2 TeV
  - map out the energy dependence of the nuclear slope parameter(s)



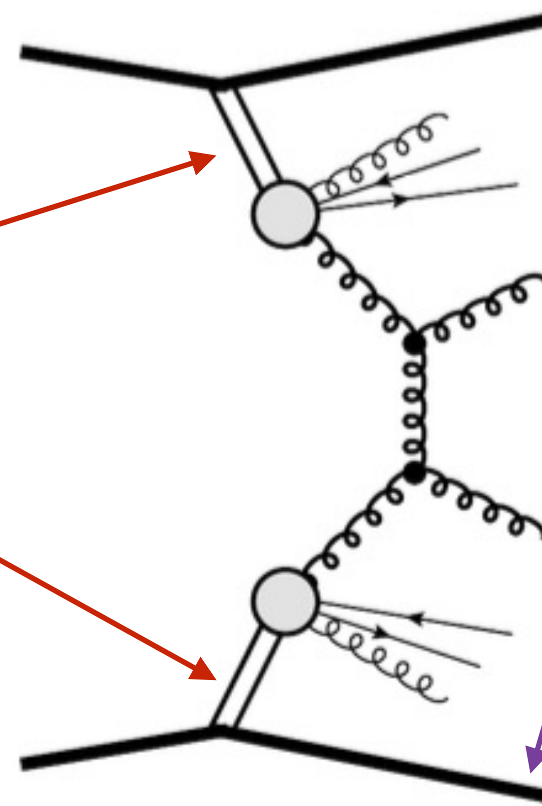
$\rho_{14\ \mathrm{TeV}} - \rho_{2\ \mathrm{TeV}} \sim 0.1 \sim 10\%\ \rho$

Forward physics at intermediate XS's

Keywords: soft/hard diffraction, double diffraction, central exclusive production, rapidity gaps, pomeron structure

Example 1: dijets in double-pomeron exchange

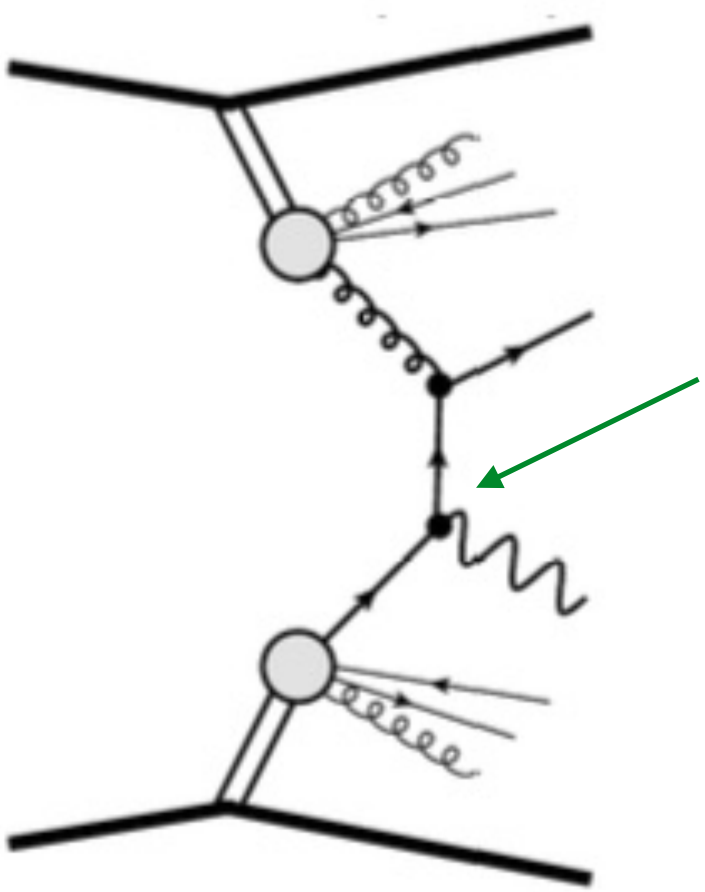
Goal: determine the gluonic structure ("PDF") of the pomeron — *if such a thing exists ….*



- $M_{X,jj}$ vs $y_{X,jj}$ gives the momentum fraction of the gluon w.r.t. pomeron, x^P_{gluon}
- Beam optics defines the range of proton acceptance for a given M_X.
- Higher β* gives access to smaller M_X, but this not crucial for this measurement: at M_X values accessible to β* = 0.4-0.5m, and with L~1-10 pb^{-1} , there is enough lever arm in M_{jj}/M_X to probe a useful range of x^P_{gluon}

Example 2: gamma+jet in double-pomeron exchange

Goal: determine the quark structure ("PDF") of the pomeron

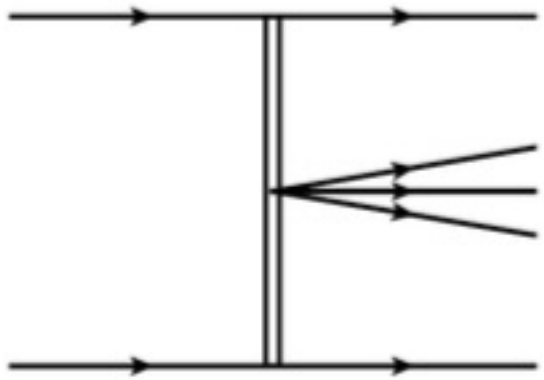


Rate sensitive to relative fraction of up and down quarks. Pomeron interpretation would require u=d=-s ….

Additional info from W production (including charge asymmetry)

Generalization to heavy quark production, etc

Example 3: exclusive low-mass production

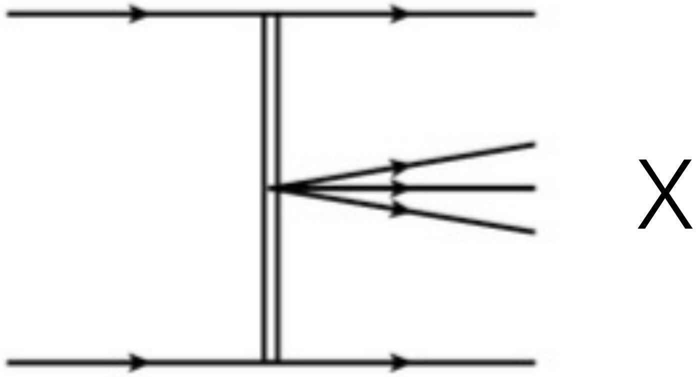


X

glueball, charmonium states, spectroscopy in the 1.5 - 4 GeV mass region

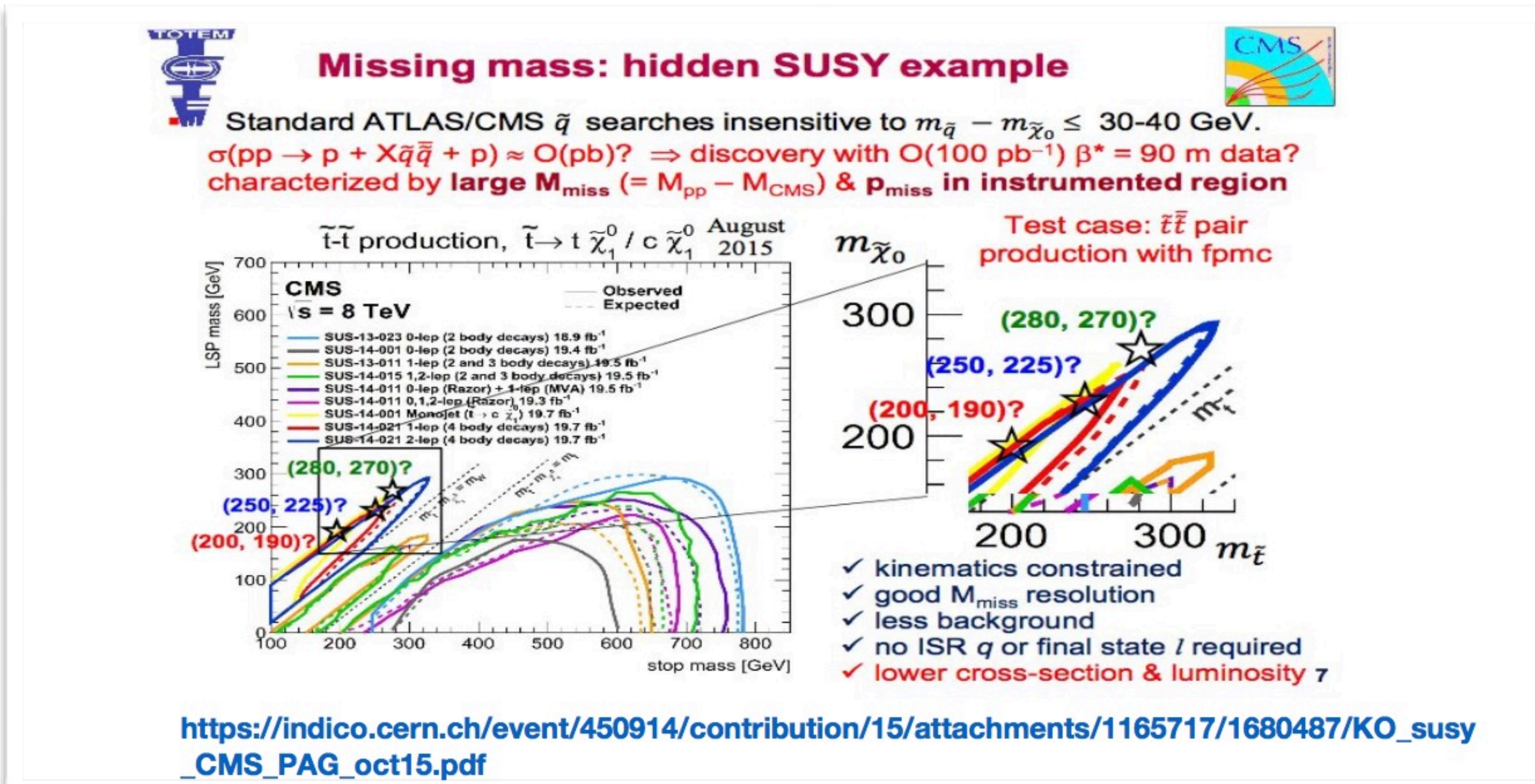
- Demands coincidence of mass reconstruction from X decays products and from proton momentum reconstruction
- Proton acceptance at low M_X crucial => demands high β* (70-90m)
- Detection of relevant resonances (e.g. $f_0(1710)$) expected to require O(1 pb^{-1}). Full study of decay modes, partial wave analysis in mass bins, etc, => O(10 pb^{-1})
- TOTEM vertical timing upgrade designed to allow data-taking at μ~O(1)

Example 4: exclusive missing mass detection



X includes invisible particles, detect mismatch between observed mass and what reconstructed from pp system

$\tilde{t} \to c\, \tilde{\chi}^0_1$



- Acceptance at low masses (O(100 GeV) and below) requires high β* (70-90m)
- Requires at least 50 pb^{-1} to give sensitivity to potential signals
- Its interest may be enhanced by detection during the standard running, or to conclusively exclude corners of phase-space for DM candidates

Conclusions

- Rich programme of forward physics is within reach of the LHC
- This should be seen as integral part of the LHC deliverables
- A good fraction of it can now be done during standard running ops (ATLAS-AFB, CT-PPS, LHCb, ALICE)
- A very important element, however, does require special runs and cannot be avoided:
  - total cross sections at different energies
  - low-mass exclusive production and spectroscopy