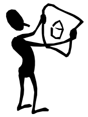
Tatranská Štrba, June 27th - July 1st, 2011

Forward Physics and Soft Diffraction at the LHC (selected topics)

(IPPP, Durham & PNPI, St. Petersburg)



PLAN

1. Introduction (20 years on).
2. Difftaction as seen through the theorist's eyes.
3. Basic quantities to measure.
4. Caveats with the forward instrumentation currently available?
   (towards Full Acceptance Detector at the LHC)
5. Diffraction in the first LHC runs.
6. Selected items from the diffraction@LHC shopping list.
7. Conclusion.

WITH A BIT OF PERSONAL FLAVOUR

Main aims - to show the 'soft diffraction & Forward Physics ' flag
- to identify measurements which could allow discriminative tests of the theoretical models for soft diffraction.

1. Introduction

20 years ago

- A Full Acceptance Detector for the SSC (J.D. Bjorken, SLAC-PUB-5692, 1991)
  - …the physics at the very lowest mass scales, the log-s physics, has suffered from lack of attention at energies higher than attained at the CERN ISR.
  - The physics of diffractive processes (Pomeron physics). i.e. physics of event structure containing “rapidity gaps” (regions of rapidity into which no particles are produced), must not be compromised.
- **FELIX proposal for LHC- 1997 (J.Phys.G(28:R117-R215,2002).**
  (A Full Acceptance Detector at the LHC (FELIX).)
- Proposal to Extend
  ATLAS
  for Luminosity Measurement
  and Forward Physics

June 2000

H. Ahola[1], M. Battaglia[2], O. Bouianov[3,4], M. Bouianov[2,3], G. Forconi[4], E. Heijne[5], J. Heino[4], V. Khoze[6], A. Kiiskinen[4,7], K. Kurvinen[4], L. Lahtinen[4], J.W. Lamsa[8], E. Lippmaa[9], T. Meinander[1], V. Nomokonov[4], A. Numminen[4], R. Orava[2,4], K. Piotrzkowski[10], M. White[4], M. Ryynänen[1], L. Salmi[4,7], J. Subbi[9], K. Tammi,[4], S. Tapprogge[4], T. Taylor[5]

20 years on

The popularity of diffractive physics at the LHC is similar to that of vegetarian sandwiches at the meat dinner.

Why important to study diffraction at the LHC?

Fundamental interest.

The LHC reaches, for the first time, sufficiently HE to distinguish between the different theoretical asymptotic scenarios for HE interactions.

(currently available data are still not decisive)

Practical interest. **Underlying events, triggers, calibration..**

In HE pp collisions about 40% of σ_{tot} comes from diffractive processes, like elastic scatt., SD, DD. Need to study diffraction to understand the structure of σ_{tot} and the nature of the underlying events which accompany the sought-after rare hard subprocesses. (Note the LHC detectors do not have 4π geometry and do not cover the whole rapidity interval. So minimum-bias events account for only part of total $\sigma_{inelastic}$.)

Rate of CEP

Central Exclusive Processes as a means to study New Physics

Evaluation of the survival probabilities of LRG to soft rescattering.
Recall ‘diffractive Higgs’ : pp→p+H+p and other goodies…

HE cosmic rays

New exp. results on dijet,diphoton, charmonium CEP

Needed so as to understand the structure of HE cosmic ray phenomena (e.g. Auger experiment).

LHC energy - above the ‘knee’. Diffraction is important for understanding of air-showers

Development of MC models.

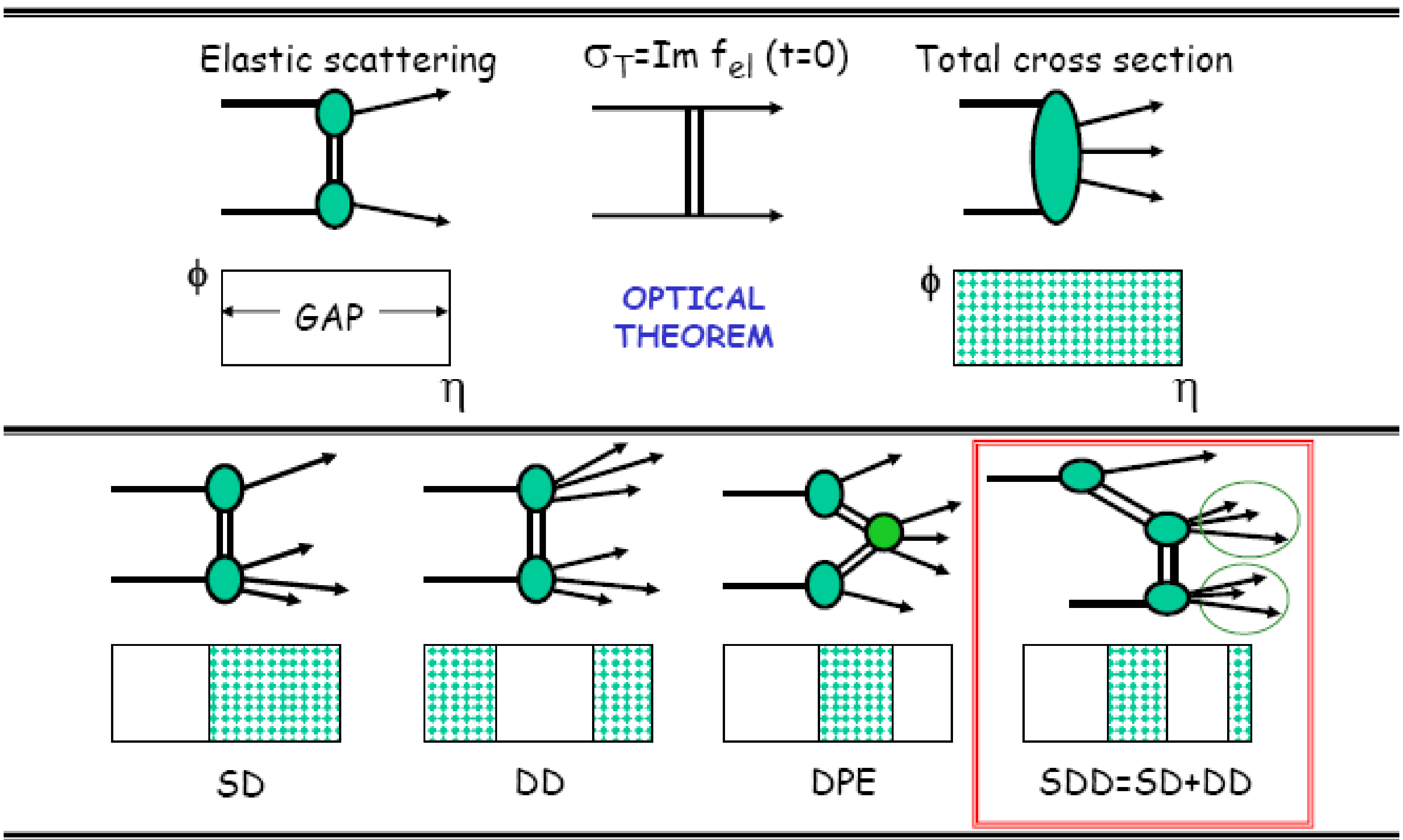
Finally, the hope is that a study of diffraction may allow the construction of a MC which merges “soft” and “hard” HE hadron interactions in a reliable and consistent way.

Diffractive pp Processes

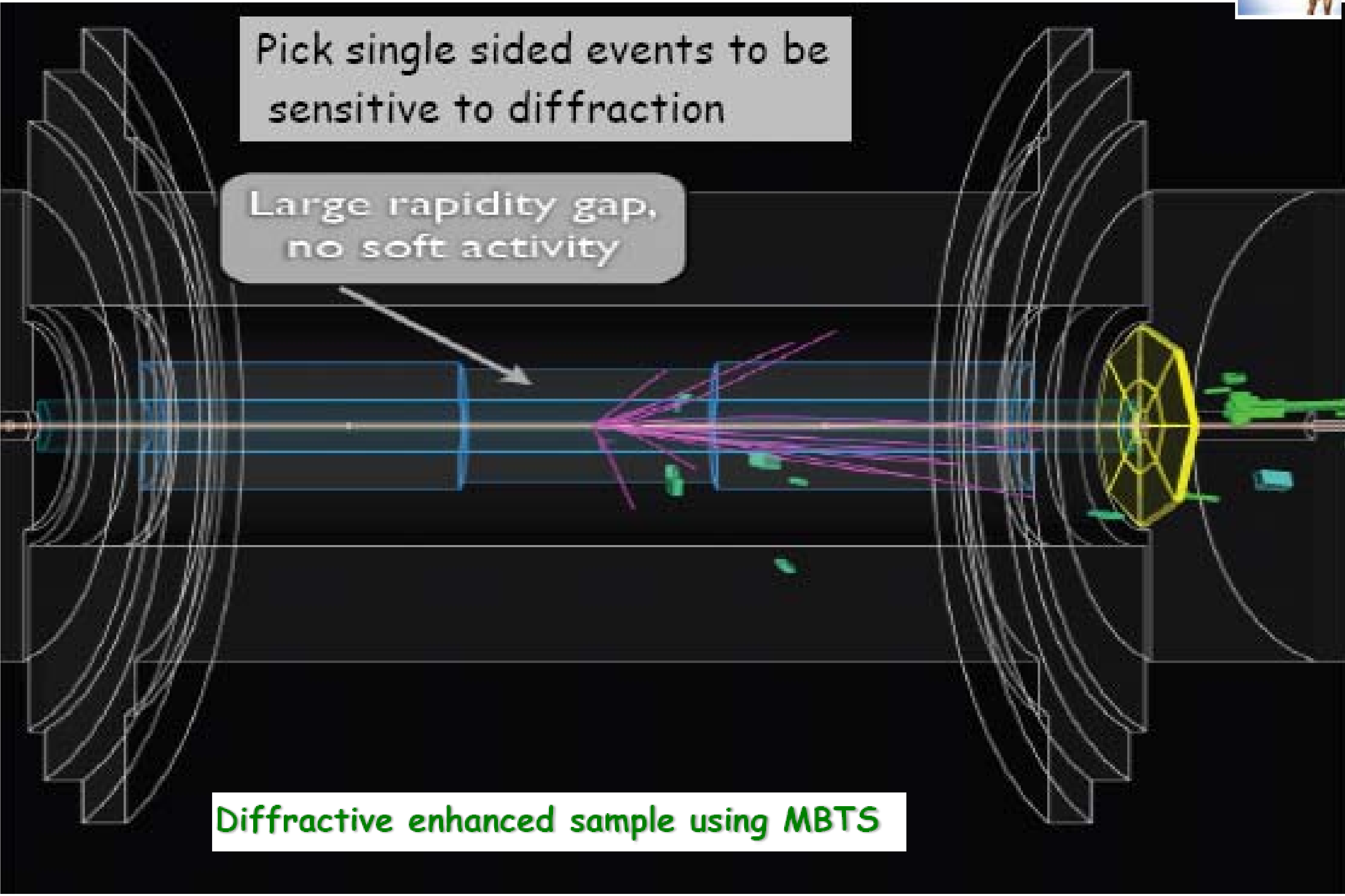
Experimental signature ☞ presence of:

(also EW exchanges)

- ❑ intact leading protons
- ❑ Large Rapidity Gaps

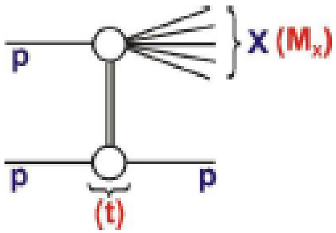


SNAPSHOT OF SINGLE DIFFRACTION

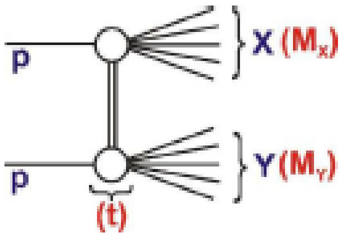


Immediate caveat

slide from Per Grafstrom
(ATLAS)



Single diffraction



Double diffraction

There is no unique way of defining diffraction

Theoretically:

Exchange of the quantum numbers of the vacuum

t-channel Pomeron exchange

Experimentally:

Large rapidity gaps and intact protons (Single Diffraction)

Mapping is not one to one ......

Not clear to what extent one can always disentangle non-diffractive and diffractive processes !

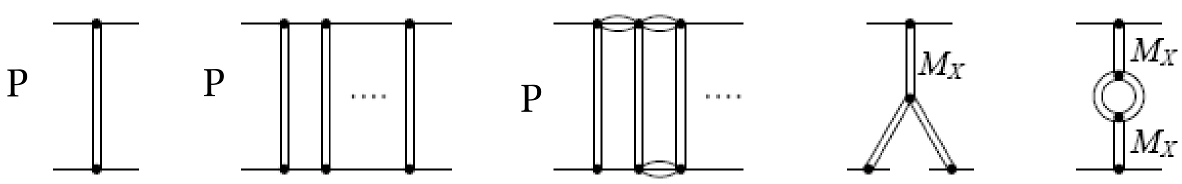
2. Diffraction through the theorist's eyes.

- Current theoretical models for soft hadron interactions are still incomplete, and their parameters are not fixed, in particular, due to lack of HE data on Low-Mass diffraction.

- Recent (RFT-based) models allow reasonable description of the data in the ISR-Tevatron range:
 KMR-09-11,GLMM-09-11,KP-10,11, Ostapchenko-10-11.

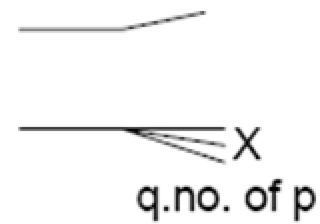
- The differences between the results of other existing models wildly fluctuate.

Reggeon Field Theory, Gribov- 1986

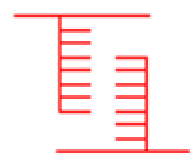


No unique definition of diffraction

1. Diffraction is elastic (or quasi-elastic) scattering caused, via s-channel unitarity, by the absorption of components of the wave functions of the incoming particles
   e.g. pp→pp,
   pp→pX (single proton dissociation, SD),
   pp→XX (both protons dissociate, DD)



Good for quasi-elastic proc.
– but not high-mass dissoc^n



2. A diffractive process is characterized by a large rapidity gap (LRG), which is caused by t-channel Pomeron exch.
   (or, to be more precise, by the exchange corresponding to the rightmost singularity in the complex angular momentum plane with vacuum quantum numbers).

Only good for very LRG events – otherwise Reggeon/fluctuation contaminations

How Large is Large ?

Diffraction is any process caused by Pomeron exchange.

(Old convention was any event with LRG of size $\delta\eta>3$, since Pomeron exchange gives the major contribution)

However LRG in the distribution of secondaries can also arise from

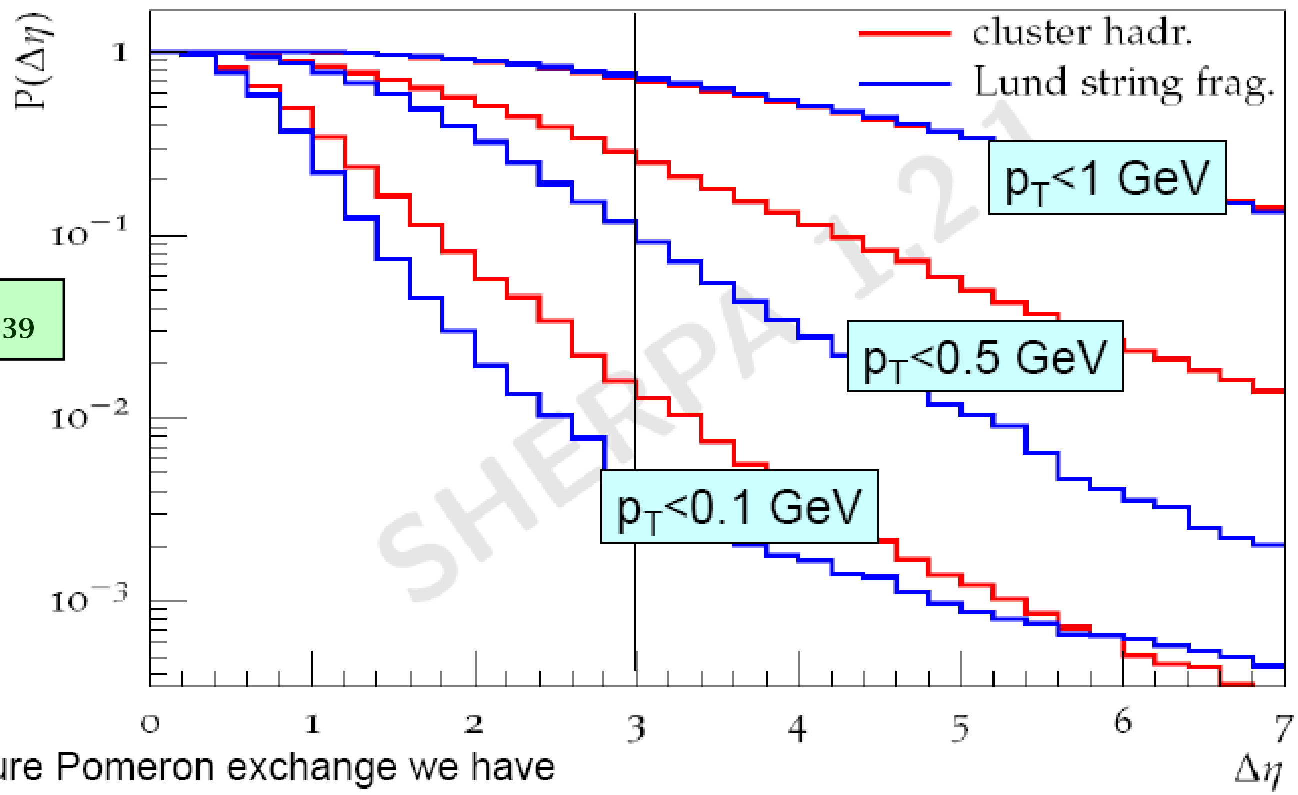
(a) Reggeon exchange
(b) fluctuations during the hadronization process

Indeed, at LHC energies LRG of size $\delta\eta>3$ do not unambiguously select diffractive events.

MIND THE GAP

Prob. of finding gap larger than $\Delta\eta$ in inclusive event at 7 TeV due to fluctuations in hadronization

gap anywhere in $-5 < \eta < 5$, different threshold p_T



KKMRZ, arXiv:1005.4839

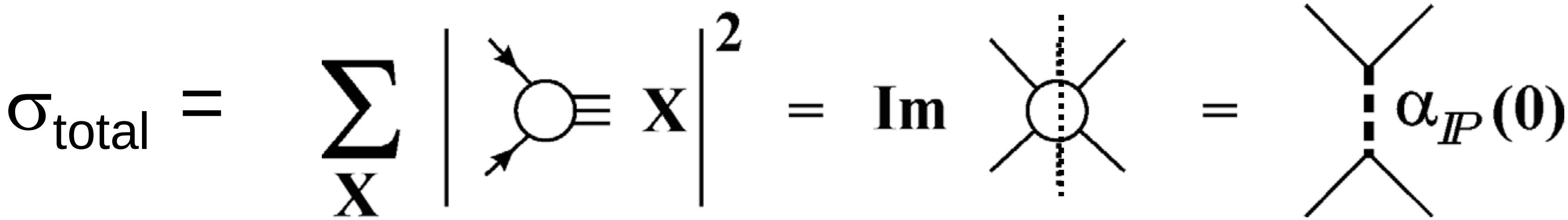
So to study pure Pomeron exchange we have

either to select much larger gaps

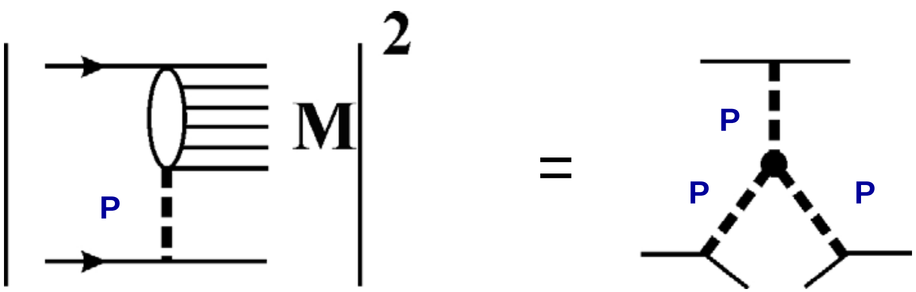
or to study the Δy dependence of the data, fitting so as to subtract the part caused by Reggeon and/or fluctuations.

Optical theorem

A diffractive process is characterized by a large rapidity gap (LRG), which is caused by t-channel Pomeron exch.



High mass diffractive dissociation



PPP-diagram

$$d^2\sigma/dM^2dt|_{t=0} \sim \frac{s^{2\epsilon}}{(M^2)^{1+\epsilon}}\ S^2 \quad \sim 1/M^2$$

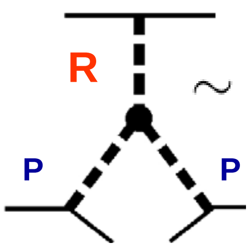
Screening is very important.
(semi) enhanced absorption …

(t-dependence !?)

Low mass diffractive dissociation

introduce diff^{ve} estates ϕ_i, ϕ_k (comb^{ns} of p,p*,..) which only undergo "elastic" scattering (Good-Walker)

dual to



$$\sim \frac{s^{2\epsilon}}{(M^2)^{1.5+2\epsilon}}\ S^2 \ \sim 1/M^3$$

PPR-diagram

Calculation of S^2

average over diff. estates i,k

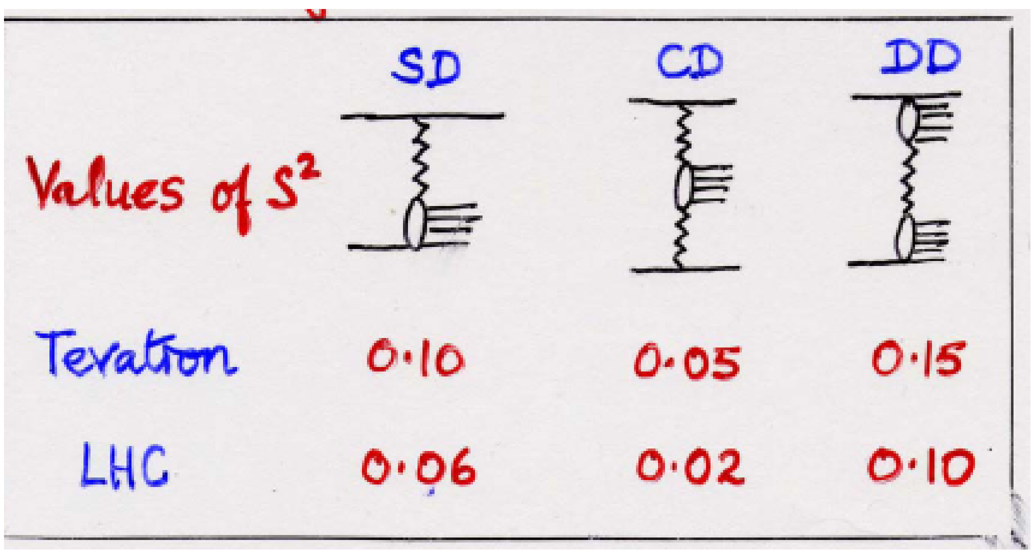
over b

prob. of proton to be in diffractive estate i

hard m.e. $i\,k \rightarrow H$

$$\overline{S^2} = \frac{\sum_{i,k} \int d^2b \, |a_{pi}|^2 \; |a_{p'k}|^2 \; |\mathcal{M}_{ik}|^2 \; \exp(-\Omega_{ik}(s,b))}{\sum_{i,k} \int d^2b \, |a_{pi}|^2 \; |a_{p'k}|^2 \; |\mathcal{M}_{ik}|^2}$$

survival factor w.r.t. soft i-k interaction. Recall that $e^{-\Omega}$ is the prob. of no inelastic scatt. (which would otherwise fill the gap)



Values of S^2	SD	CD	DD
Tevatron	0·10	0·05	0·15
LHC	0·06	0·02	0·10

There still is a freedom in the asymptotic behaviour

Different scenarios at $s \to \infty$

1. Weak coupling of the Pomerons $\sigma_{\rm tot} \longrightarrow {\rm constant}$
2. Strong coupling of the Pomerons; $\sigma_{\rm tot} \propto (\ln s)^{\eta}$ with $0 < \eta \leq 2$,

(V.N. Gribov,A.A.Migdal, -1969).

3. Asymptotically decreasing cross sections.

(P.Grassberger, K.Sundermeyer-1978; K.Boreskov-2001)

- All depends on the behaviour of the triple -(multi)-Pomeron vertices.
- Current data are usually described by scenario 2 with $\eta = 2$ (Froissart-Martin limit), but the weak coupling scenario is not excluded (LKMR-10)
- To reach asymptotics we formally would need UH energies, when in the slope of elastic amplitude $\alpha'_{\rm P}\ln(s) \gg B_0$
- Measurements of $\frac{d\sigma_{\rm SD}}{dt dM^2}(pp \to pX)$ at the LHC could allow to 'probe' the asymptotics (LKMR-2010).

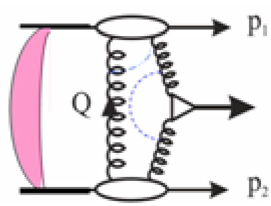
How long is the way to asymptotics?

3. Basic quantities to measure

- $\sigma_{\rm el}, \ \sigma_{\rm tot}, \ \frac{d\sigma_{\rm el}}{dt}, \ \sigma_{SD}, \sigma_{DD}, \sigma_{DPE}$ (most usual suspects)

- $\frac{d\sigma_{\rm SD}}{dt\,dM^2}(pp \to pX)$, $d\sigma_{DPE} / d\xi_1 d\xi_2$

- CEP reactions $pp \to p + X(J/\psi, \chi_c, \Upsilon, \chi_b, jj) + p$



- Detailed comparison of particle distributions and correlations (e.g. BEC) in pp, p**P** and **PP** –reactions (sensitivity to the (small) size of the Pomeron).

$$dN_{DPE} / d\eta dp_t^2$$

- The cross-sections are (normally) large, and we do not need high luminosity. Special (high β^*) optics is required.
- Pile-up at high instantaneous luminosity.

What about current theoretical uncertainties ?

$\sqrt{s} = 14$ TeV.

	σ^{tot}	σ^{el}	σ^{SD}	σ^{DD}	σ^{SD}_{LM}	σ^{SD}_{HM}	σ^{DD}_{LM}	σ^{DD}_{HM}
Set (A)	128	37.5	12.1	4.61	8.48	3.62 (3.54)	1.15	2.06
Set (B)	126	37.3	12.4	5.18	8.22	4.24 (4.14)	1.08	2.50
Set (C)	114	33.0	11.0	4.83	5.58	5.22 (5.12)	0.47	3.15
KMR-08	91.7	21.5	19.0		4.9	14.1		
GLMM-08	92.1	20.9	11.8	6.08	10.5	1.28		
KP-10	108	29.5	14.3					

For illustration purposes only

(A,B,C) S. Ostapchenko, Phys.Rev.D81:114028,2010.
KMR-08: KMR, EPJ C54,199(2008); ibid C60,249 (2009).
GLMM-08: GLMM,EPJ C57,689 (2008).
KP-10 A.B. Kaidalov, M.Poghosyan

Large variation of σ^{SD}_{LM} in the range 5- 10.5 mb

Model expectations for total inelastic cross-section

- Strong dependence of the longitudinal development of air showers on σ_{inel}
- Various MC generators are used by the CR community (some with full resummation of multi-Pomeron graphs)

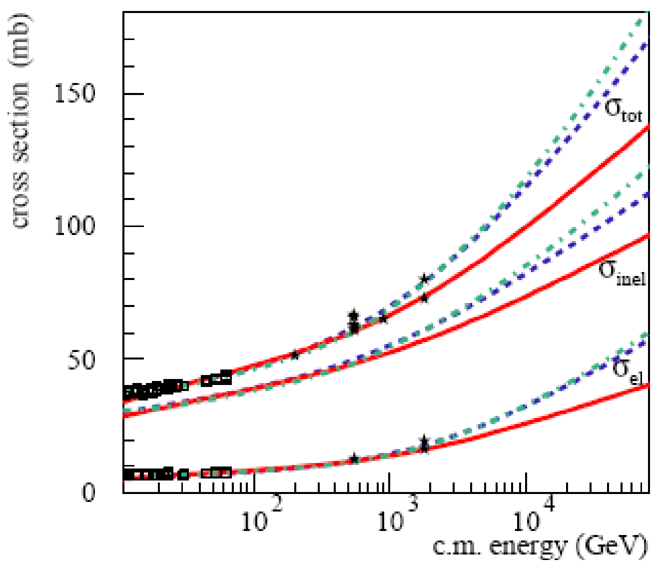


Figure 1: Model predictions for total, elastic, and inelastic proton-proton cross sections: QGSJET-II-4 - solid, QGSJET-II-3 - dashed, and SIBYLL - dot-dashed. The compilation of data is from Ref. [17].

$\sqrt{s} = 7$ TeV

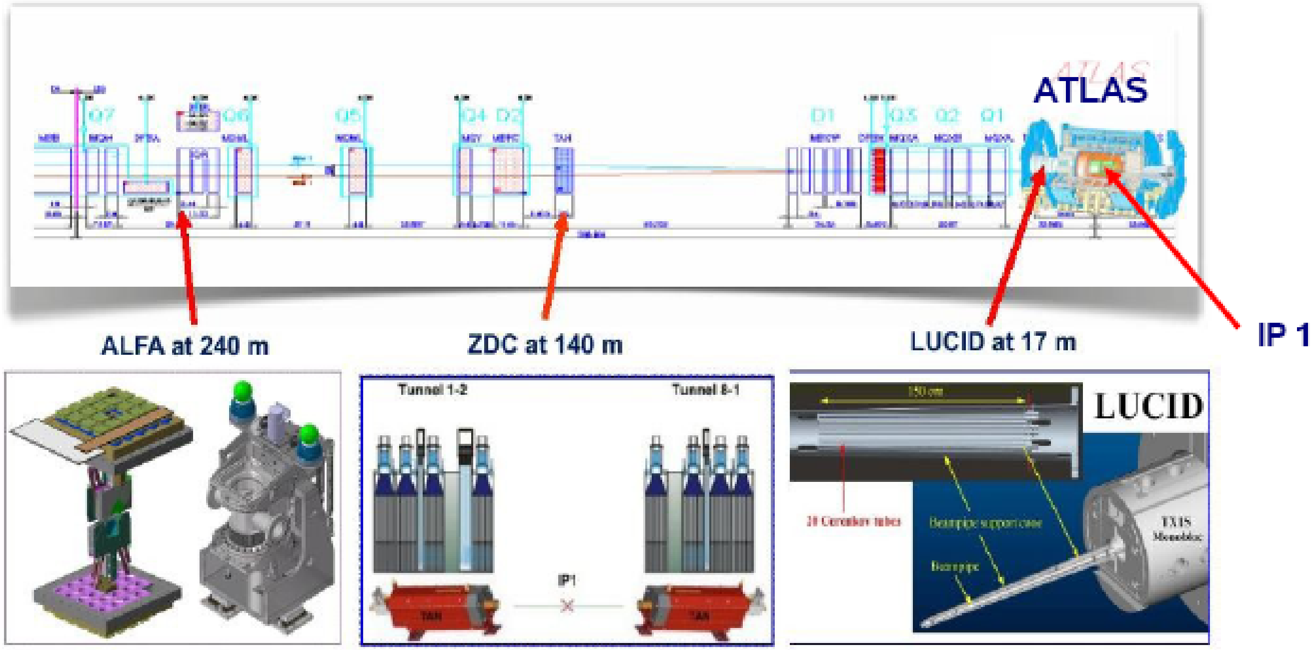
S.Ostapchenko, ArXiv:1103.5684)

(in mb)	σ_{inel}	$\sigma^{\text{LM}}_{\text{SD}} + \sigma^{\text{LM}}_{\text{DD}}$
QGSJET II-04	69.7	7.1
QGSJET II-03	77.5	3.3
SIBYLL	79.6	0
PYTHIA	71.5	0
KMR-11	**65.2/67.1**	**6/7.4**
GLM	**68**	
MPS-11	73.4	
KP-10	**71.6**	
Achili et al	**60-75**	

For illustration purposes only

4.Can we accurately measure diffractive characteristics with the current forward instrumentation ?

The ATLAS forward detectors



	Pseudorapidity	Position (from IP)
LUCID	$5.6 < \|\eta\| < 5.9$	± 17 m
ZDC	$\|\eta\| > 8.3$	± 140 m
ALFA	$10.6 < \|\eta\| < 13.5$	± 240 m

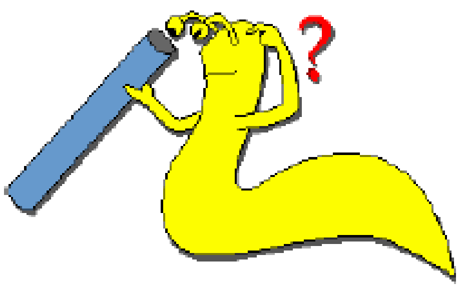
More caveat

ATLAS central detector sensitive to high mass diffraction.
($|\eta| < 4.9 \Rightarrow M_x > 7$ GeV)

Is there a theoretically solid way to extrapolate from high mass diffraction to low mass diffraction ?

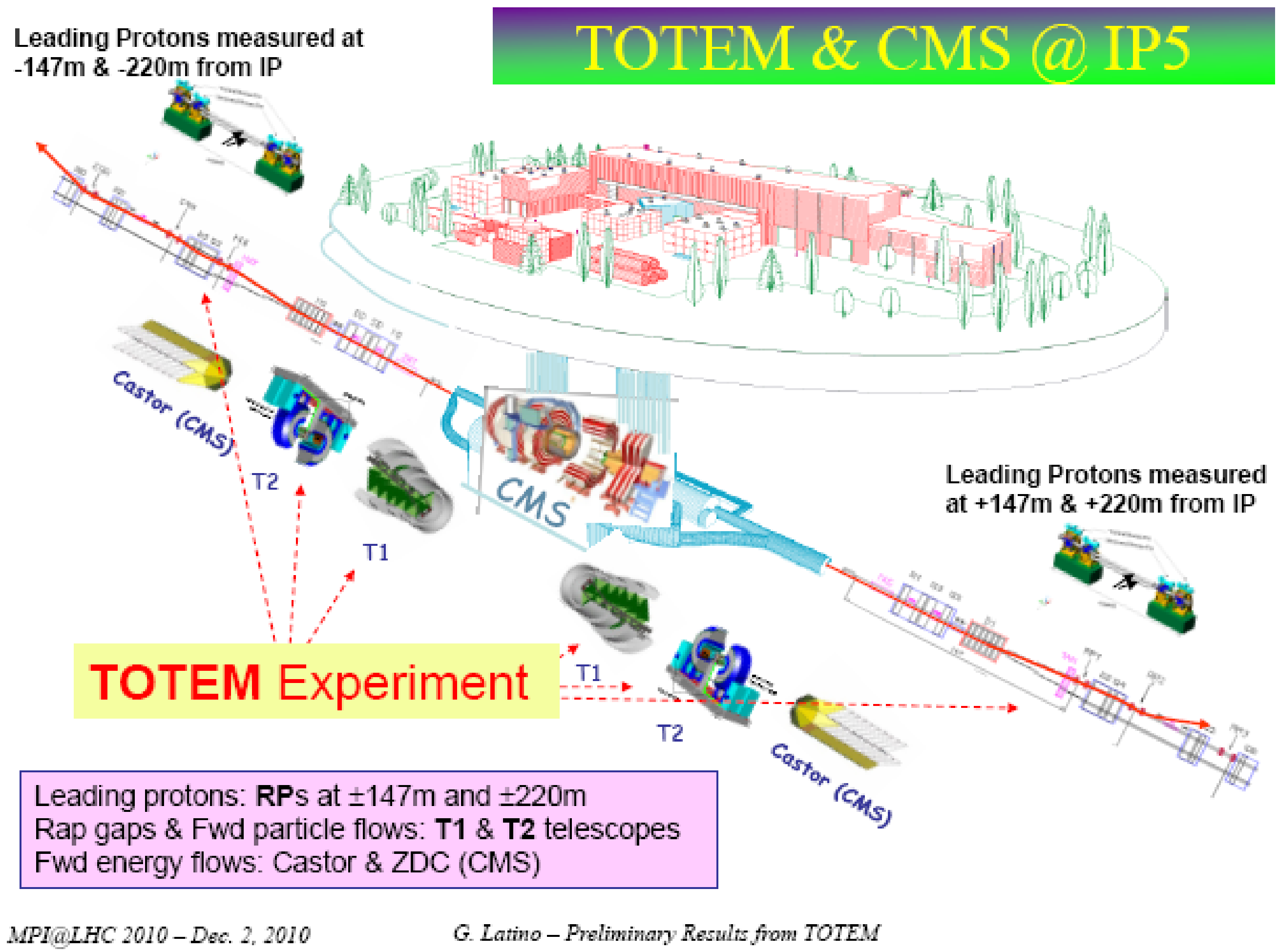
How many "mb " disappear in the beam pipe.... ?

Is there consensus in the theoretical community...... ?



May be there is a demon in the beam pipe ?

slide from Per Grafstrom
(ATLAS)



TOTEM-2011

- **TOTEM detector setup completed !!**
- **First data with T1 very promising**
- **Eagerly waiting higher β* to make σ_{tot}**

Hope

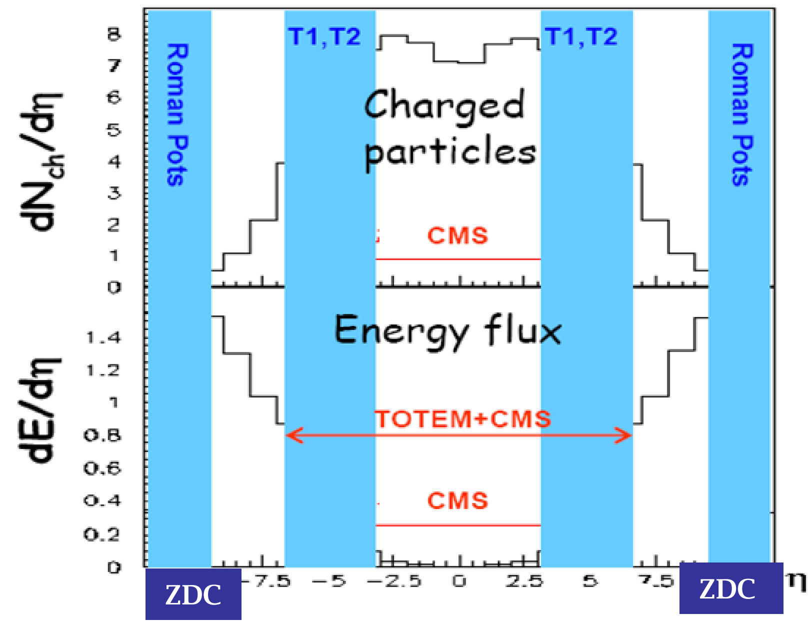
CMS + TOTEM ⇒ largest acceptance detector ever built at a hadron collider

BUT

- CMS is currently blind between =6.4(CASTOR) and beam rapidity y_p except ZDC (neutrals).

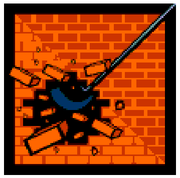
- T1+T2 detectors do not cover low-mass diffraction.

Even with common DAQ, we miss a few mb in inelastic cross section.



IS THERE A WAY OUT ?

Yes, an addition of Forward Shower Counters around beam pipes at CMS!



(8 FSC per side see showers from particles with $|\eta| = 7\text{-}9$)

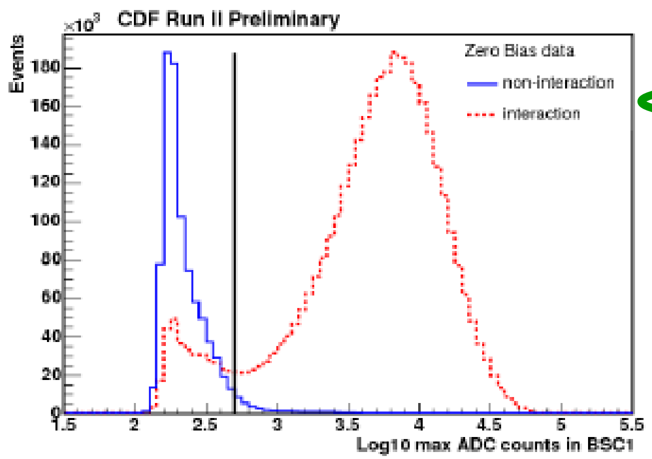
BSC very important as rap gap detectors.
All LHC experiments should have them!

FORWARD PHYSICS WITH RAPIDITY GAPS AT THE LHC

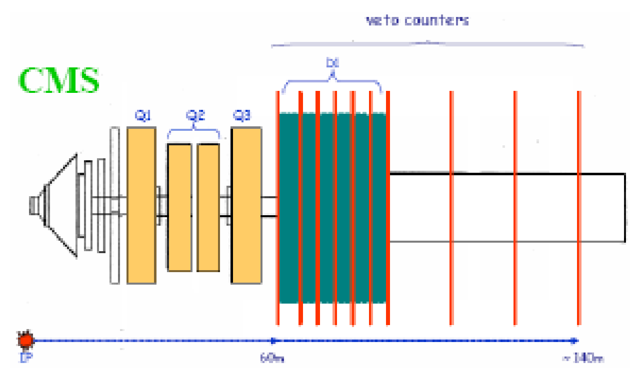
arXiv:0811.0120

Michael Albrow[1], Albert De Roeck[2], Valery Khoze[3], Jerry Lämsä[4,5], E. Norbeck[6],
Y. Onel[6], Risto Orava[5], and M.G. Ryskin[7]
Sunday, November 09, 2008

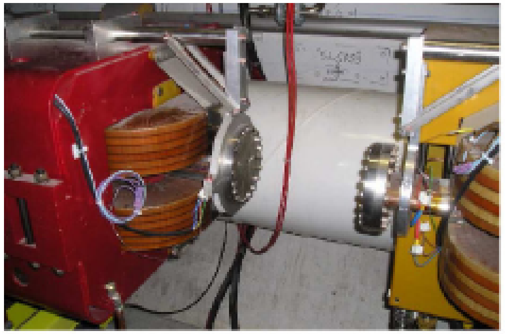
JINST-09

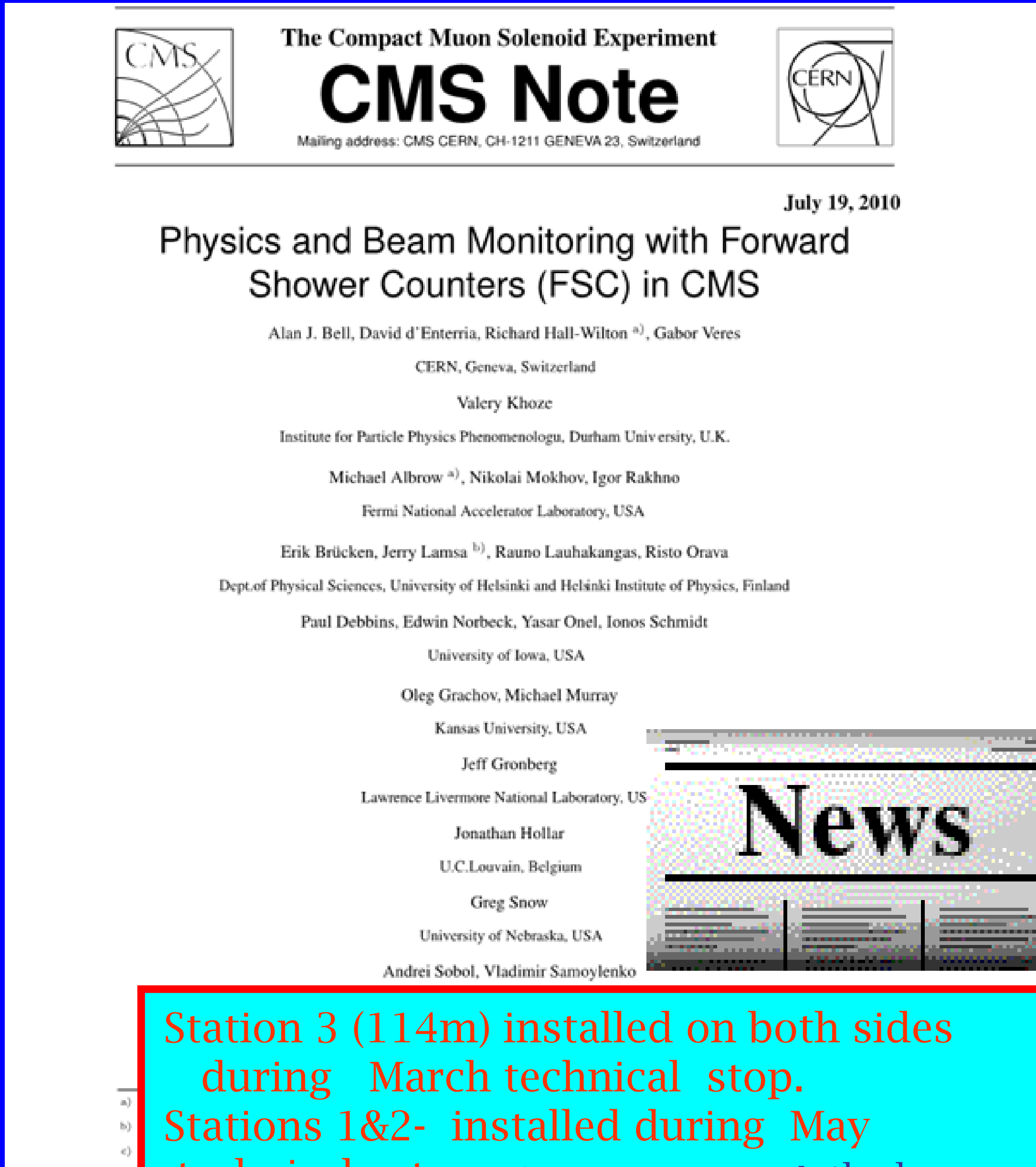


Warm accessible vacuum pipe (circular – elliptical)
Do not see primary particles, but showers in pipe ++
Simple scintillator paddles: **Gap detectors in no P-U events**



Take 0-bias events (Essential!)
{1} = prob no interaction
{2} = prob >= 1 interaction
Take hottest PMT of 8 BSC1
Plot log max ADC for {1} and {2}
Separates empty / not empty
Repeat for all detectors





The Compact Muon Solenoid Experiment

CMS Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

July 19, 2010

Physics and Beam Monitoring with Forward Shower Counters (FSC) in CMS

Alan J. Bell, David d'Enterria, Richard Hall-Wilton [a], Gabor Veres
CERN, Geneva, Switzerland
Valery Khoze
Institute for Particle Physics Phenomenologu, Durham University, U.K.
Michael Albrow [a], Nikolai Mokhov, Igor Rakhno
Fermi National Accelerator Laboratory, USA
Erik Brücken, Jerry Lamsa [b], Rauno Lauhakangas, Risto Orava
Dept.of Physical Sciences, University of Helsinki and Helsinki Institute of Physics, Finland
Paul Debbins, Edwin Norbeck, Yasar Onel, Ionos Schmidt
University of Iowa, USA
Oleg Grachov, Michael Murray
Kansas University, USA
Jeff Gronberg
Lawrence Livermore National Laboratory, US
Jonathan Hollar
U.C.Louvain, Belgium
Greg Snow
University of Nebraska, USA
Andrei Sobol, Vladimir Samoylenko

a)
b)
c)

CMS NOTE-2010/015

Approved by CMS MB for Jan-Feb 2011 installation.

"Limited approval" :
Go ahead without detracting from necessary shutdown work.

Most value is 2011 running
& when <n/x> < ~ 5
(Do not expect to use > 2012)

Station 3 (114m) installed on both sides during March technical stop.
Stations 1&2- installed during May technical. stop. Commissioning with the beam.

Physics, especially diffractive in no-PileUp interactions

(from Mike Albrow)

(a) As veto in Level 1 diff. triggers to reduce useless pile-up events.
(b) To detect rapidity gaps in diffractive events (p or no-p).
(c) Measure low mass diffraction and double pomeron exchange.
(d) Measure σ_{INEL} (if luminosity known, e.g. by Van der Meer)
(e) Help establish exclusivity in central exclusive channels

Beam monitoring etc, parallel uses:

(f) To monitor beam halo on incoming and outgoing beams.
(g) To test forward flux simulations (MARS etc.)
(h) Additional Luminosity monitor.
(i) Info on radiation environment for future (?) proton spectrometers

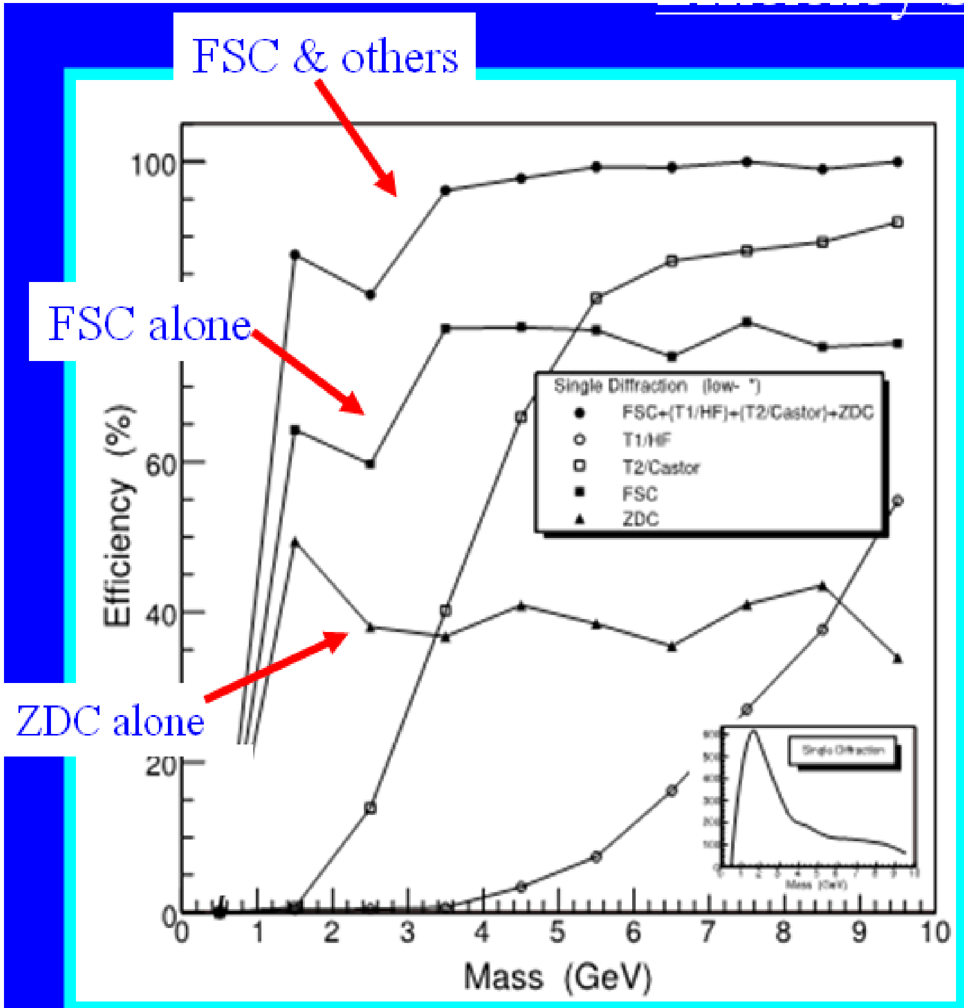
MORE PHYSICS

LOW COST

ZERO RISK*

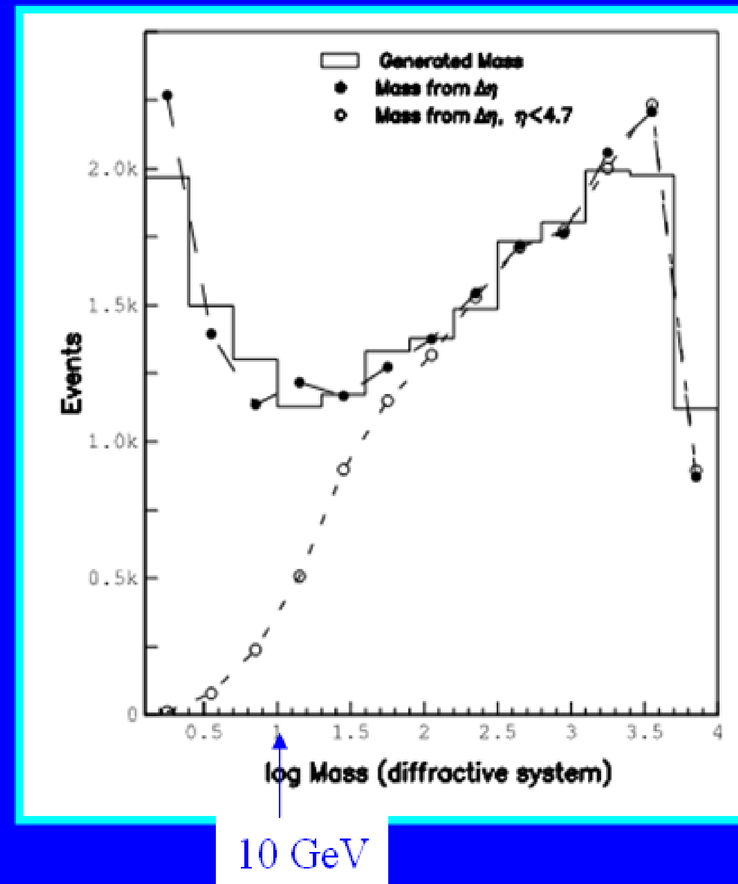
*Subject to support approval by LHC

Priority now - gap+X+gap triggers.
SD measurement requires all counters + low lumi run



>4 hits in FSC or > 1 track in HF or CASTOR or ZDC(min)

M. Albrow et al, JINST 4:P10001,2009.



Generated diffractive mass (PYTHIA/PHOJET) as log(M_X), M_X in GeV/c2, cf to calculated from rapidity gap edge:

(a) full η coverage

(b) η < 4.7 (no FSC)

Below 10 GeV/c² FSC contain most particles

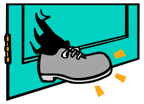
The FSC- these are for real !

- The installation and commissioning phase of FSC during the March Technical Stop.
- Main concern- lumi per bunch crossing might be too high.

What about the precise measurement of SD?

Don't hold your breath, Valery.
This certainly needs all the counters and some low lumi run, or at least bunches. (Mike Albrow)

(FSC→ at least a good foot in the door)



Can we measure $\frac{d\sigma_{el}}{dt}$, σ_{el} and σ_{tot} with a good accuracy ?

- $\frac{d\sigma_{el}}{dt} = \frac{\pi}{sp^2}|F_{el}(t)|^2$
- optical theorem: $\sigma_{tot} = \frac{4\pi}{p\sqrt{s}} \text{Im}\, F_{el}(s, t = 0)$

With known lumi (3.5% VdM)

- $L\sigma_{tot} = N_{el} + N_{inel}$
- Need to separate the Coulomb and hadron scattering

(Lumi independent)

$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \frac{\left.\frac{dN_{el}}{dt}\right|_{t=0}}{N_{el} + N_{inel}}; \qquad L = \frac{1+\rho^2}{16\pi} \frac{(N_{el} + N_{inel})^2}{\left.\frac{dN_{el}}{dt}\right|_{t=0}}$$

Model	ρ
Islam et al.	0.123
Petrov et al. 2P	0.0968
Petrov et al. 3P	0.111
BSW	0.121
Block-Halzen	0.114
COMPETE	0.1316

- measure $\frac{dN_{el}}{dt}$ and extrapolate it to $t = 0 \rightarrow$ needs RP acceptance at small small beam divergence $\rightarrow$ high β^* (parallel to point focusing)

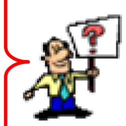
- ALFA- measurement of elastic scattering in the Coulomb interference region

- Will require special LHC runs at high β^* and low $\mathcal{L}_{inst}$: 90m (2011), 2km (2013+)

Combined uncertainty in σ_{tot}

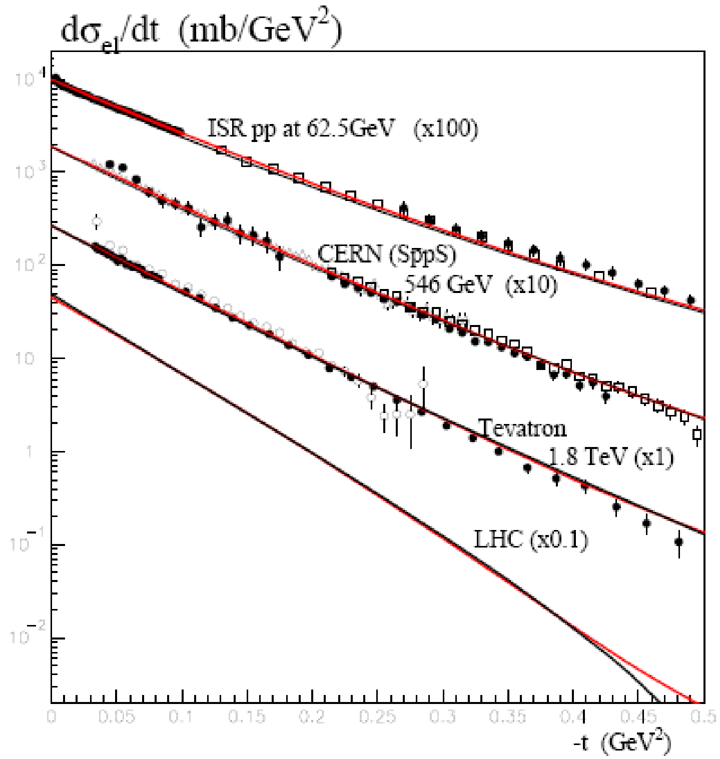
$$\sigma_{tot} = \frac{16\pi}{1+\rho^2} \frac{\left.\frac{dN_{el}}{dt}\right|_{t=0}}{N_{el} + N_{inel}}; \qquad L = \frac{1+\rho^2}{16\pi} \frac{(N_{el} + N_{inel})^2}{\left.\frac{dN_{el}}{dt}\right|_{t=0}}$$

	β^*	90 m	1535 m
$\left.\frac{dN_{el}}{dt}\right\|_{t=0}$ (str. interaction)	Extrapolation of elastic cross-section to $t = 0$ (Smearing effect due to beam divergence, statistical errors, uncertainty of effective length L_{eff}, RP alignment, model dependent deviation)	±4%	±0.2%
N_{el}	Total elastic rate (strongly correlated with extrapolation)	±2%	±0.1%
N_{inel}	Total inelastic rate (error dominated by single diffractive losses)	±1%	±0.8%
ρ	Error contribution from $(1+\rho^2)$ (using full COMPETE error band $\frac{\delta\rho}{\rho} = 33\%$)	±1.2%	
	Total uncertainty in σ_{tot}	±5%	±1 − 2%
	Total uncertainty in L	±7%	±2%



t-dependence of elastic cross section is under control, including pion loop effects, safe extrapolation to the low - t region (KMOR-2000). Recent Multi-Pom studies + compilation by Totem.

KMR-11, arXiv:1102.2844



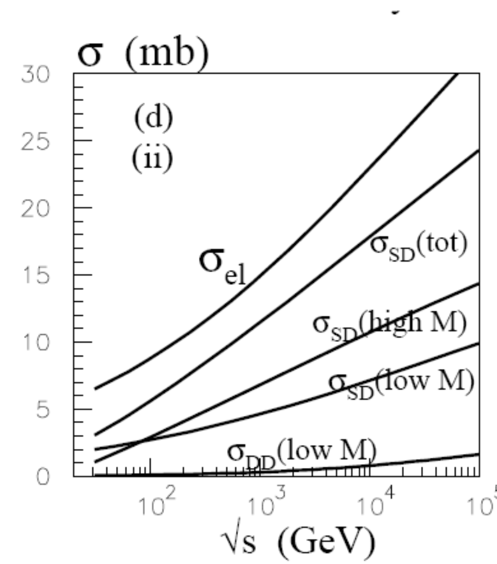


Figure 7: The t dependence of the elastic pp cross section, and the prediction for 14 TeV. The bolder and fainter (red) curves correspond to choices (i) and (ii) of the diffractive eigenstates respectively.

energy	$\sigma_{\rm tot}$	$\sigma_{\rm el}$	$\sigma_{\rm SD}^{{\rm low}M}$	$\sigma_{\rm SD}^{{\rm high}M}$	$\sigma_{\rm SD}^{\rm tot}$	$\sigma_{\rm DD}^{{\rm low}M}$
1.8	72.8/72.5	16.3/16.8	4.4/5.2	7.0/7.8	11.4/13.0	0.3/0.4
7	89.0/86.8	21.9/21.6	5.5/6.7	9.9/10.2	15.4/16.9	0.5/0.7
14	98.3/94.6	25.1/24.2	6.1/7.5	11.5/11.3	17.6/18.8	0.6/0.9
100	127.1/117.4	35.2/31.8	8.0/9.9	16.7/14.4	24.7/24.3	0.9/1.6

ALFA = Absolute Luminosity For ATLAS

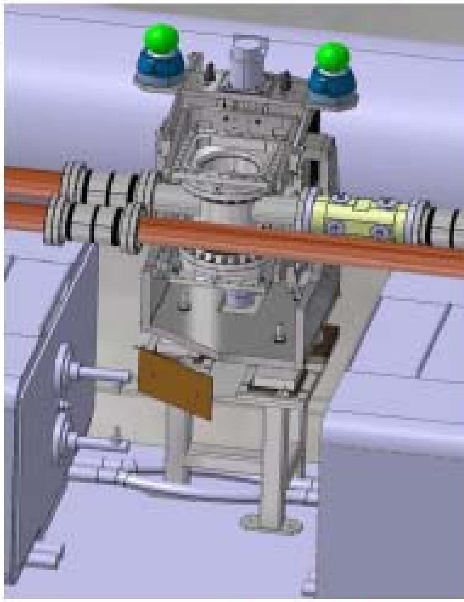
Elastic scattering at very small angles

- Measure elastic scattering at such small t-values that the cross section becomes sensitive to the Coulomb amplitude
- Effectively a normalization of the luminosity to the exactly calculable Coulomb amplitude
- No total rate measurement and thus no additional detectors near IP necessary
- UA4 used this method to determine the luminosity to 2-3 %

ALFA can also measure the absolute luminosity using optical theorem method if/when σ_{tot} is known

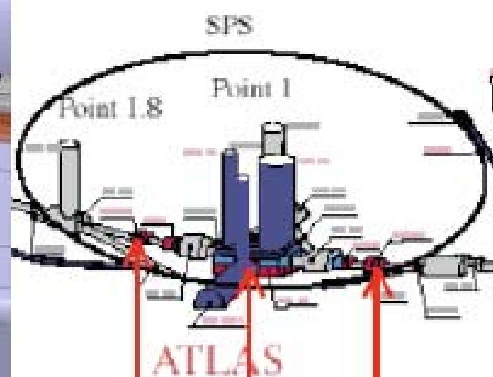
ALFA – Roman Pot stations

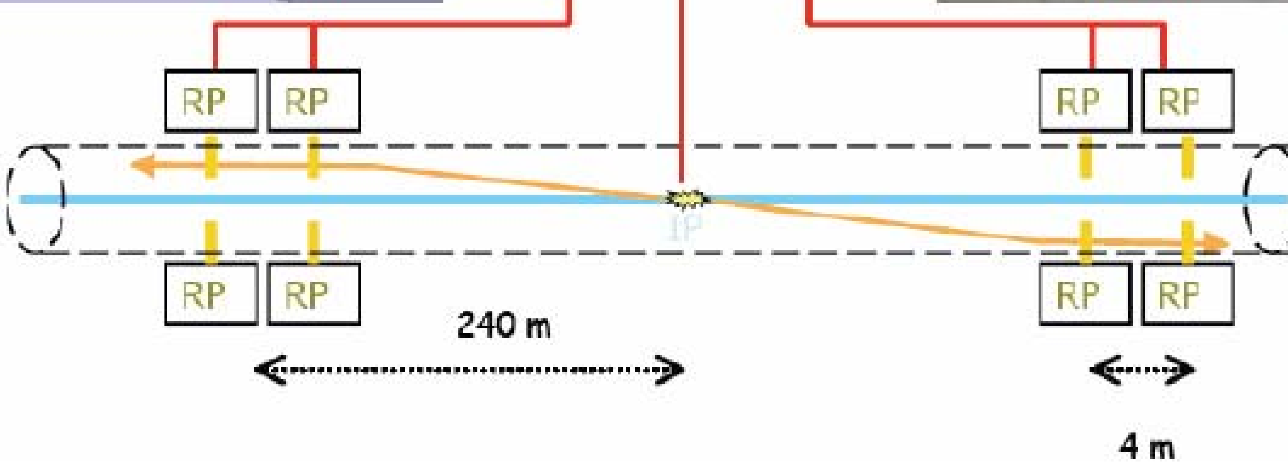
design…



and reality

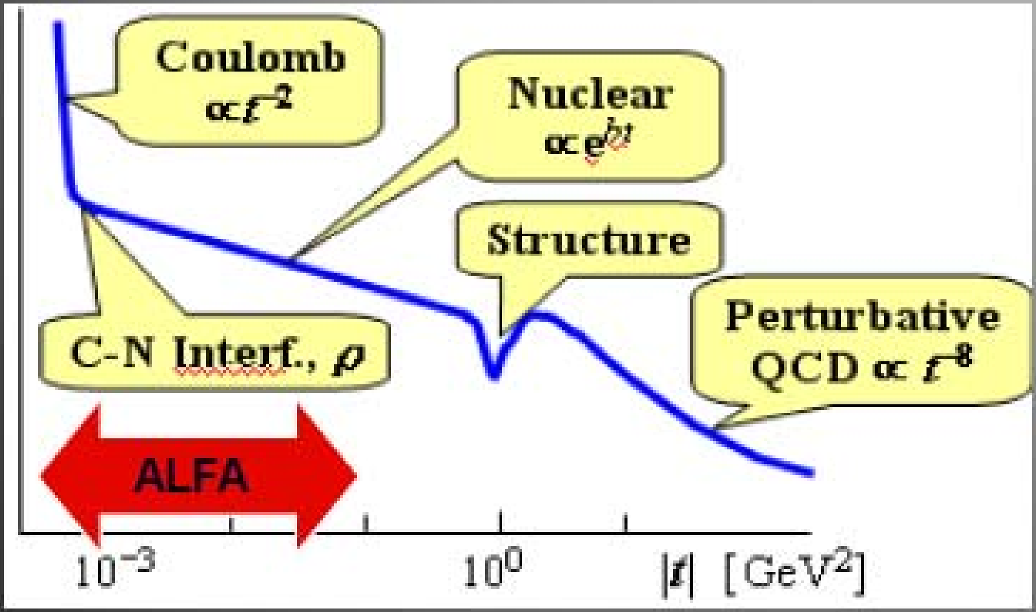
locations:





Concept of the ALFA measurement

Elastic scattering in the Coulomb-Nuclear interference region:



$$\frac{dN}{dt} \approx L\pi \left| -\frac{2\alpha}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)\exp(-b|t|/2) \right|^2$$

L = luminosity , σ_{tot} = total cross section

$\rho = \mathrm{Re}\ f_{el} / \mathrm{Im}\ f_{el}(t=0)$, b = nuclear slope

Measurement program:

1) start from a well-known theoretical rate dependence

2) measure unbiased elastic rate

3) fit luminosity and 3 other free parameters to dN / dt

Main conditions to reach the Coulomb region $|t| < 10^{-3}$ GeV^2

→ Detector positions far from IP

→ Special beam settings

→ Detectors close to beam

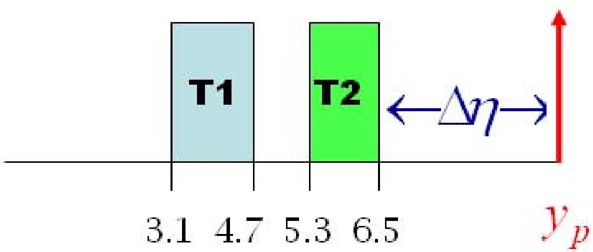
Can we measure σ_{inel} , σ_{SD}, σ_{DD} with high accuracy?

Achilles' Heel of 'inelastic' measurements : low mass SD,DD

Uninstrumented regions: **Totem-CMS :** $M_X \leq 2.5-3.5GeV$

Atlas: $M_X \leq 7GeV$

(Castor)

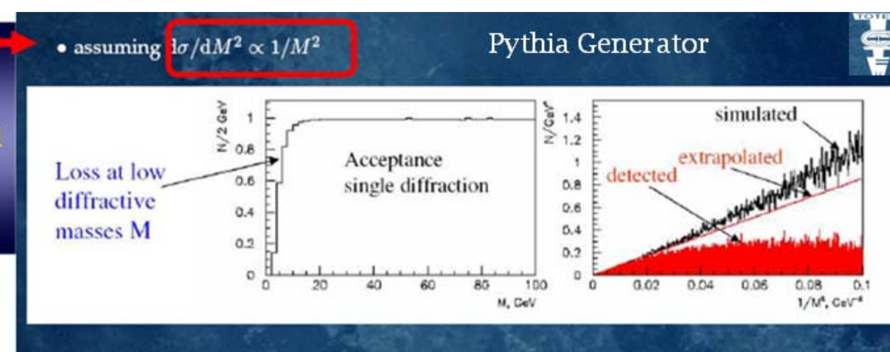


$$\eta = -\ln \tan \frac{\vartheta}{2}$$

$$y_p = \ln(\sqrt{s}/m_p), \Delta\eta \simeq (2.4-3.1)$$

Can we extrapolate from HM SD ?

- Theoretically unjustified
- Currently **NO** theoretically solid way to extrapolate HM to LM single diffraction



(UA4-experience ☞ factor of 2 for M<4 GeV)

There are known unknowns.

- When the common TOTEM-CMS data taking will happen?
- When the dedicated runs with special optics (high β^*) will take place ?
- When the FSC will be fully operational ?

But there may be also unknown unknowns.

It is not clear at the moment if/when CMS can read out T1+T2.
Maybe T1,T2 can be used for veto.

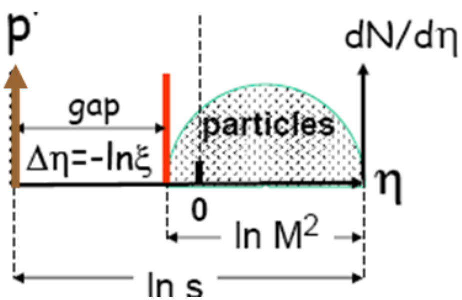
ZDC+HF+Castor +FSC could be sufficient

What the experts think

5. A flavour of diffraction in the first LHC runs.

- First measurement of $\sigma_{\rm inel}$ at 7 TeV.

(arXiv:1104.0326 [hep-ex] , 2 Apr. 2011)



$$\xi = M_X^2/s > 5 \times 10^{-6}$$

$M_X > 15.7$ GeV for $\sqrt{s} = 7$ TeV

$\sigma(\xi > 5 \times 10^{-6})$ [mb]	
ATLAS Data 2010	60.33 ± 2.10(exp.)
Schuler and Sjöstrand	66.4
PHOJET	74.2
Ryskin *et al.*	51.8 / 56.2

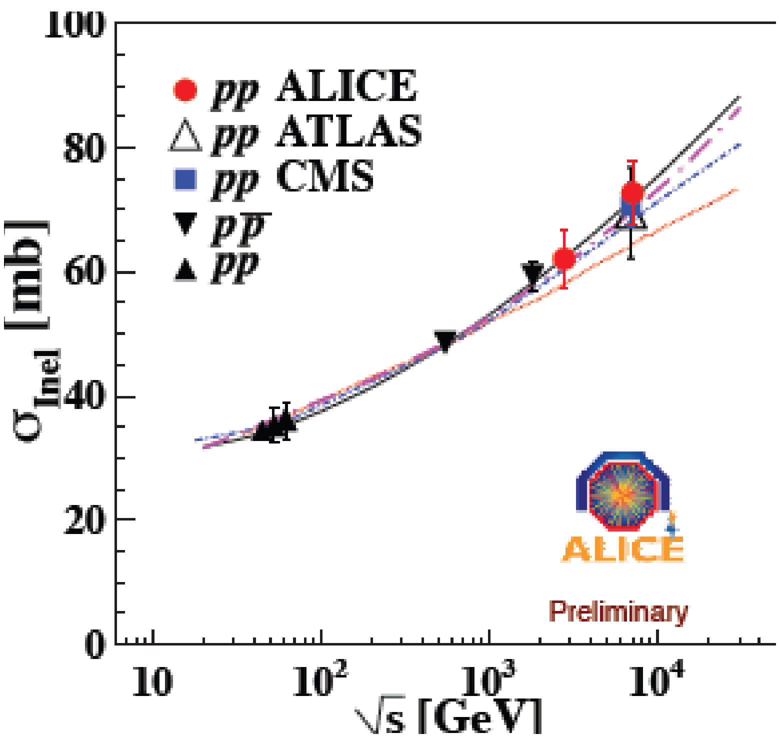
+1.5

$\sigma(\xi > m_p^2/s)$ [mb]	
ATLAS Data 2010	69.4 ± 2.4(exp.) ± 6.9(extr.)
Schuler and Sjöstrand	71.5
PHOJET	77.3
Block and Halzen	69
Ryskin *et al.*	65.2 / 67.1
Gotsman *et al.*	68
Achilli *et al.*	60 – 75

+1.5

(model dependence in the definition of ξ)

$$\Delta\eta = \ln 1/\xi + \ln \langle p_\perp \rangle / m_p$$



Gostman et al., arXiv:1010.5323, EPJ. C74, 1553 (2011)
Kaidalov et al., arXiv:0909.5156, EPJ. C67, 397 (2010)
Ostapchenko, arXiv:1010.1869, PR D83 114018 (2011)
Khoze et al., EPJ. C60 249 (2009), C71 1617 (2011)

ATLAS $\sigma_{inel}(\xi > m_p^2/s) = 69.4 \pm 2.4(\mathrm{exp.}) \pm 6.9(\mathrm{extr.})\ \mathrm{mb}$

CMS $66.8 \le \sigma_t^{inel} \le 74.8\ \mathrm{mb.}$

ALICE $\sigma_{\mathrm{Inel}}(\sqrt{s} = 7\ \mathrm{TeV}) = 72.7 \pm 1.1(\mathrm{model}) \pm 5.1(\mathrm{lumi})\ \mathrm{mb}$

$|\eta| < 2.$ $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1.$

Analysis technique

The probability of having n_{pileup} depends only on the total $\sigma(pp)$ cross section:

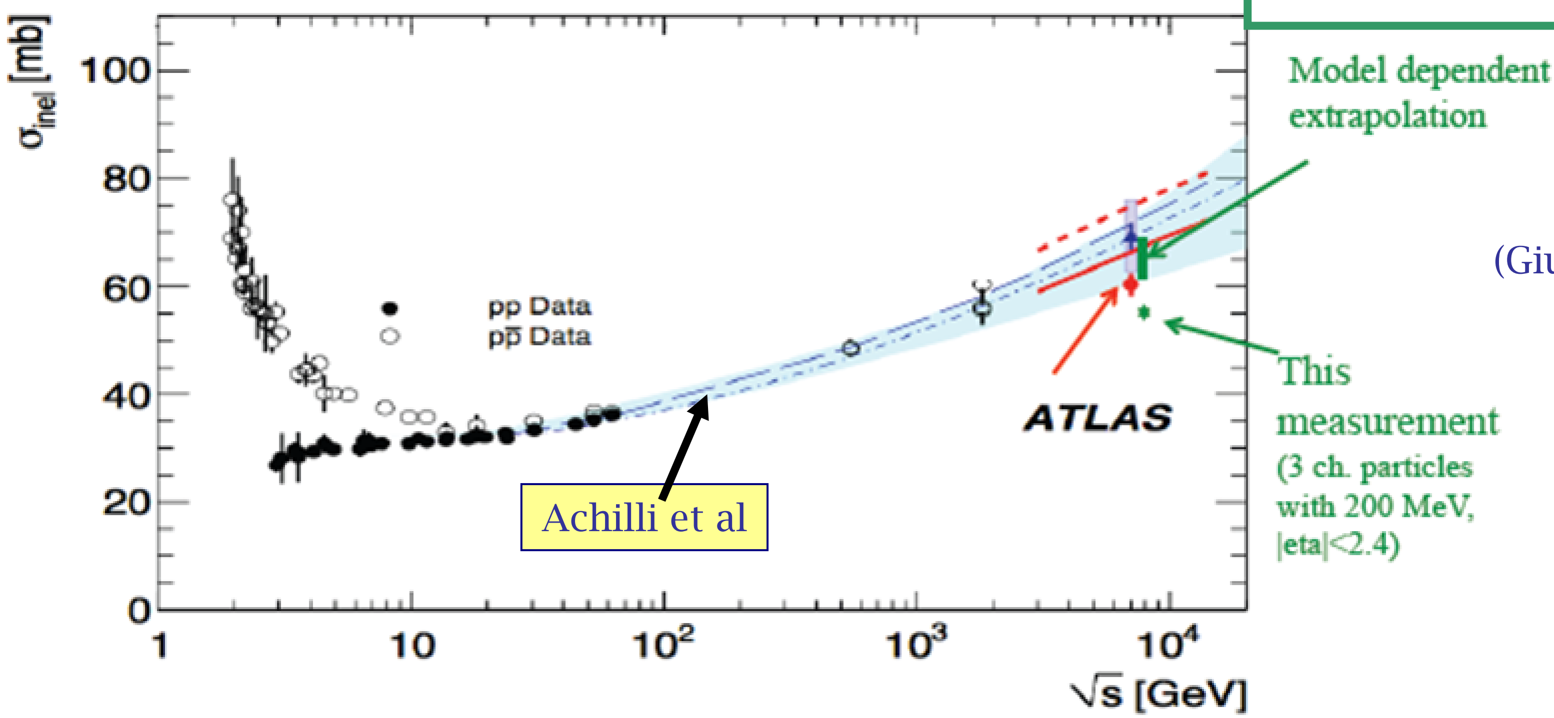
$$P(n_{Pileup}) = \frac{(L*\sigma)^{n\_pileup} * e^{-(L*\sigma)}}{n_{pileup}!}$$

If we count the number of pile-up events as a function of luminosity, we can measure $\sigma(pp)$.

For an accurate measurement we need a large luminosity interval.

Comparison with "other" 7 TeV results…

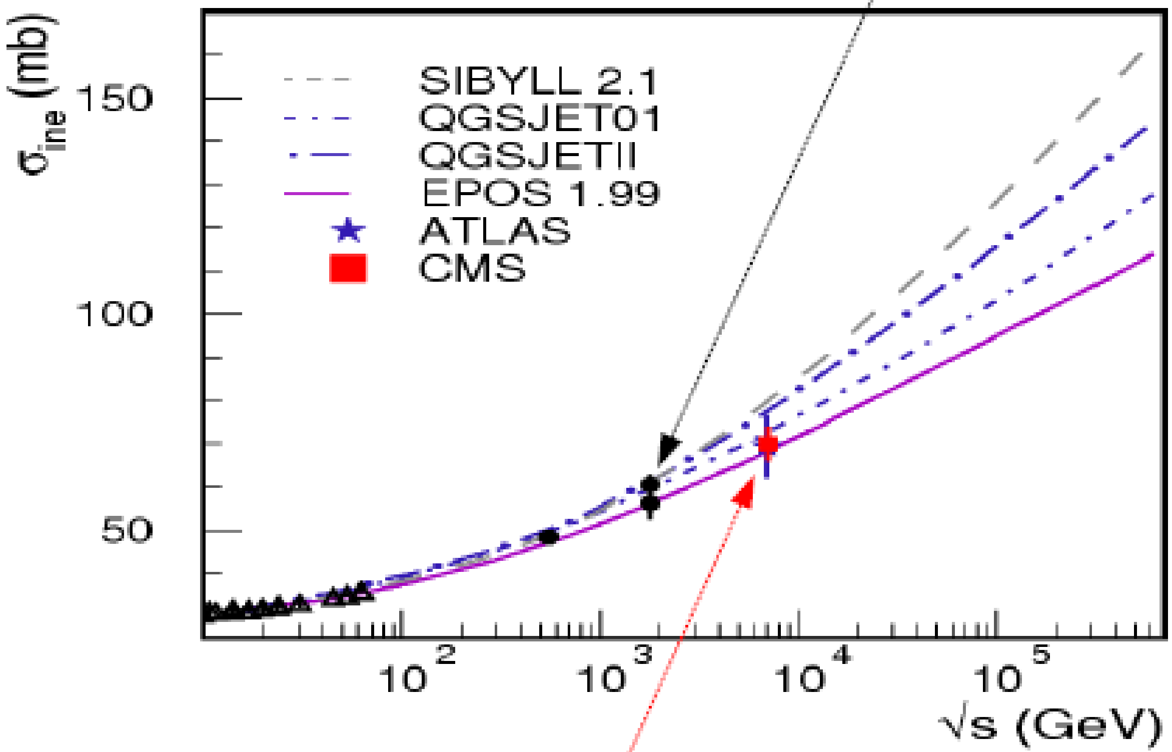
σ_{inel} (pp) = 63 – 70 mb



(Giulia)

LHC inelastic p-p cross sections

- Current model uncertainties driven by E710–CDF 2.6σ disagreement



- σ_{inel} ~ 64(CMS) – 70(ATLAS) mb seem to favour E710 value at 1.8 TeV
- sqrt(s)-evolution better reproduced by EPOS1.99 & QGSJET01

(agreement with KMR-11anal. results)

In ATLAS environment

slides from Per Grafstrom
(ATLAS)

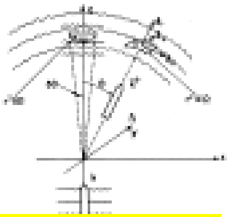
How to measure the « mb » hiding in the forward direction and in the beam pipe?

ATLAS has measured σ_{inel} for $\xi > 5 \cdot 10^{-6}$

How to measure the remaining cross section
i.e. σ_{inel} for $\xi < 5 \cdot 10^{-6}$?

We need three ingredients !
see next slide

1 **Optical theorem**
$\sigma_{tot} \propto \mathrm{Im}\, f_{el}(t=0)$



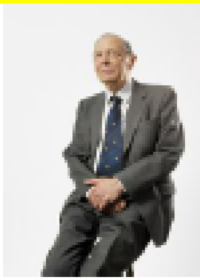
$\Rightarrow$ **The forward direction of elastic scattering is sensitive to all inelastic channels**

(the very existence of scattering requires scattering in the forward direction in order to interfere with the incident wave, and thereby reduce the probability current in this direction)

We also need $\rho = \frac{\mathrm{Re}\, F_{el}(s,t=0)}{\mathrm{Im}\, F_{el}(s,t=0)}$

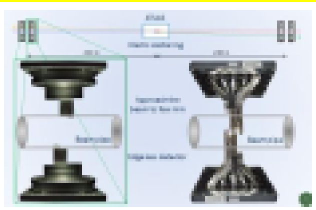
$$\frac{d\sigma_{el}}{dt} = \frac{\pi}{sp^2}|F_{el}(t)|^2$$

2 **VDM scans**



$\Rightarrow$ **Luminosity to ~3 %**

3 **ATLAS Roman Pots: ALFA**



$\Rightarrow$

a) σ_{el} from integrating $d\sigma_{el}/dt$

b) Extrapolation to t=0 i.e optical point

$$\sigma_{inel}\ (\xi < 5 \cdot 10^{-6}) = \sigma_{tot} - \sigma_{el} - \sigma_{inel}\ (\xi > 5 \cdot 10^{-6})$$

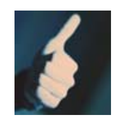
Elastic Scattering: t- Distribution

ELASTIC pp SCATTERING
t-range: 0.36 – 3 GeV^2

The TOTEM experiment is completely installed and running

- All Roman Pots at 147 and 220m installed (24 pots)
- T1 detectors are installed on both sides
- T2 detectors are installed on both sides
- Trigger system based on all detectors is running
- DAQ is running with an event rate capability of 1 kHz
- Special runs with dedicated β^* and bunch structures are prepared

Already allows to restrict/reject theoretical models.



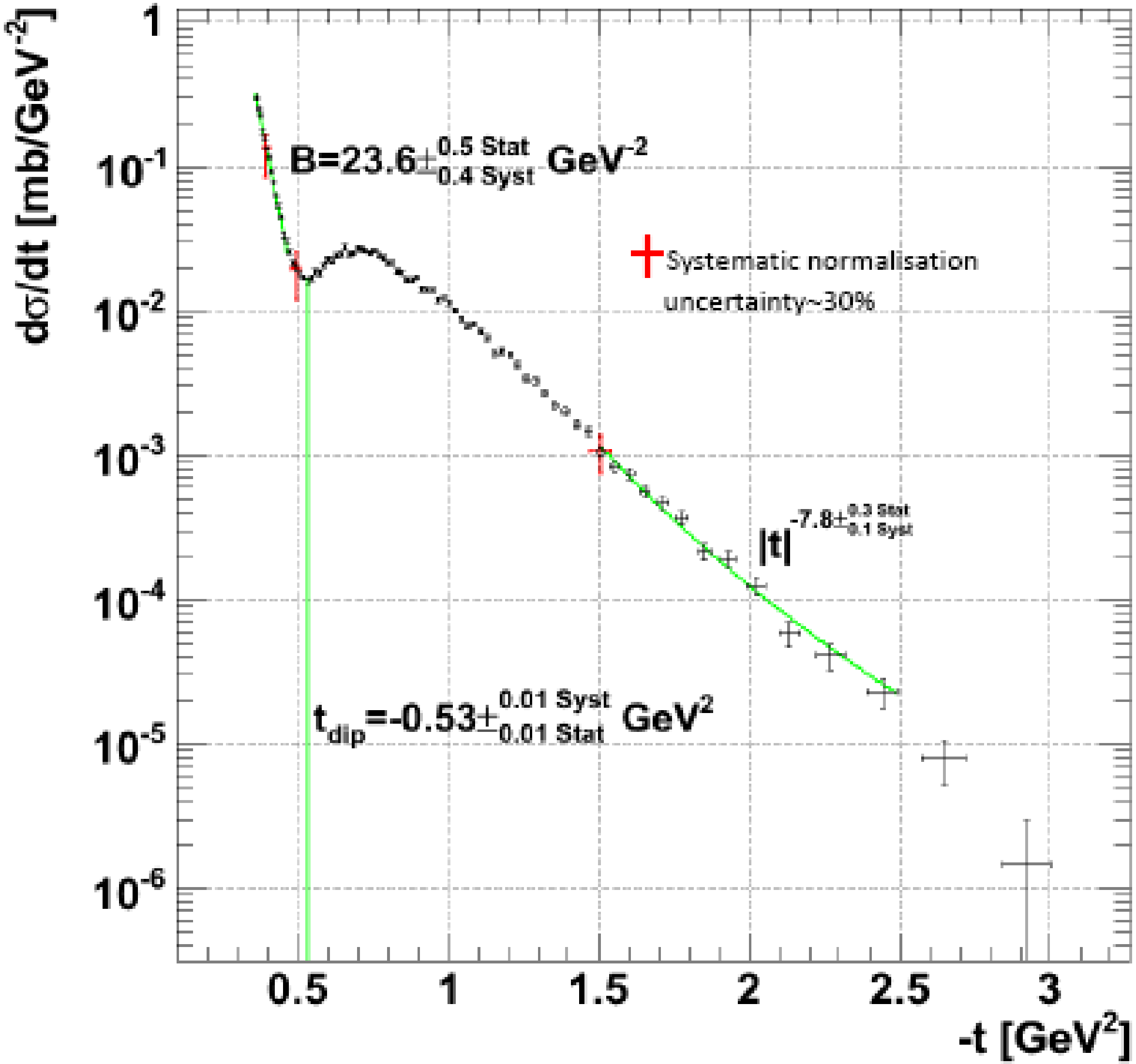
More to come soon!

β^* = 90 m optics

– Physics starting in August / September
- Low-t (10^{-2} GeV^2) elastic scattering
- Total cross-section (extrapolation to t=0 possible)

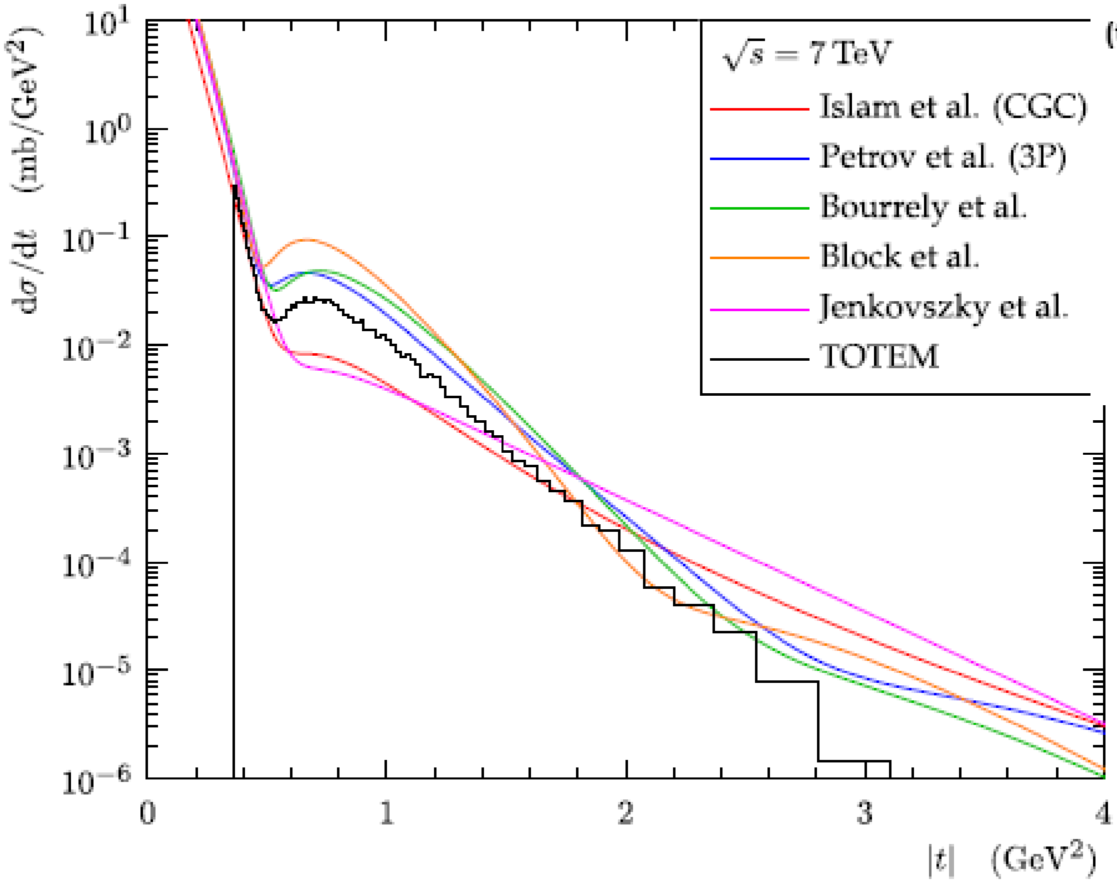
Final unfolded distribution

Hubert Niewiadomski
on behalf of the TOTEM Collaboration
LHCC, 15 June 2011



Hubert Niewiadomski
on behalf of the TOTEM Collaboration
LHCC, 15 June 2011

Comparison to some models



	B (t=-0.4 GeV^2)	t_{DIP}	t^{-n} [1.5–2.5 GeV^2]
Islam et al. (CGC)	20.2	0.60	5.0
Petrov et al. (3P)	**23.3**	**0.51**	**7.0**
Bourrely et al.	**22.0**	**0.54**	**8.4**
Block et al.	25.3	0.48	10.4
Jenkovszky et al.	20.1	0.72	4.2
TOTEM	23.6 ± 0.5	0.53 ± 0.01	7.8 ± 0.3

Better statistics at large t needed

6. Selected items from the diffraction@LHC shopping list.

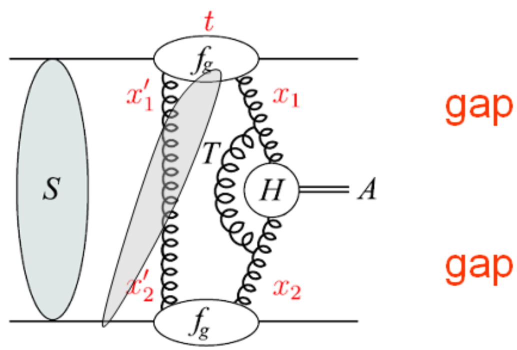
Eur. Phys. J. C 55, 363–375 (2008)
DOI 10.1140/epjc/s10052-008-0611-9

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article – Theoretical Physics

Early LHC measurements to check predictions for central exclusive production

V.A. Khoze[1,2,a], A.D. Martin[1], M.G. Ryskin[1,2]



Divide et Impera

pp → RG +Z+ RG

pp → W +RG

pp →RG +W + RG

} probing quark distributions inside proton $*S^2$

pp →RG +jj+ RG (a la recent CDF studies) probing gluon distributions $*S^2$

pp →RG +Y + RG

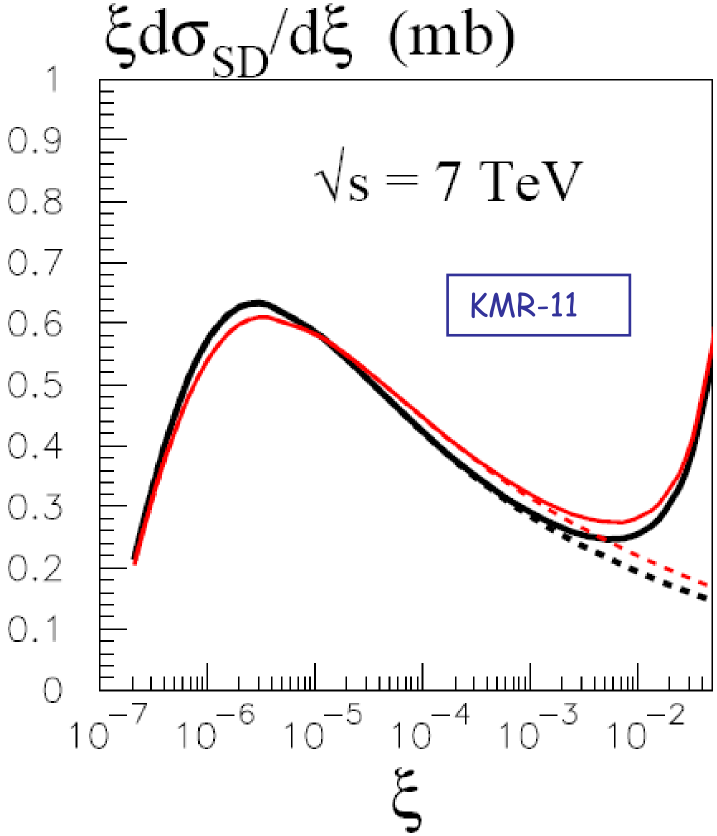
pp →RG +central 'soft junk' + RG

Non-trivial behaviour of $\xi d\sigma_{\rm SD}/d\xi$

$d\sigma/\Delta\eta^F$ ~ 1.0 ±0.2 mb per unit of $\Delta\eta^F$ for $\Delta\eta^F > 3.5$

(ATLAS)

- Could be probed in ongoing ATLAS study of LRG distributions
- High sensitivity to enhanced absorptive effects (KMR-11).
- In the simplified triple-P approach: $\xi d\sigma_{SD}/d\xi \propto 1/\xi^{\Delta}, \Delta = \alpha_P(0) - 1.$



Maximum at $\xi \sim 3\times10^{-5}$ (M~12 GeV).

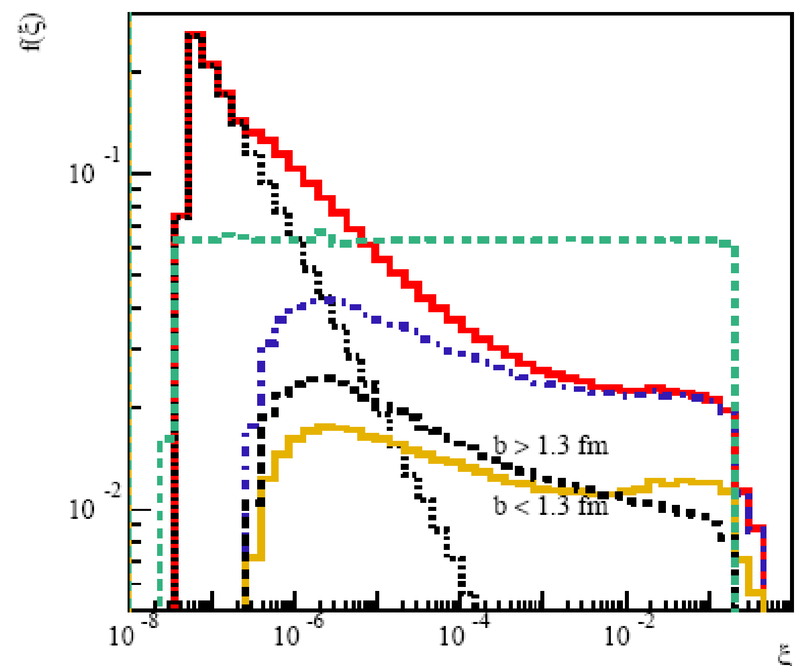
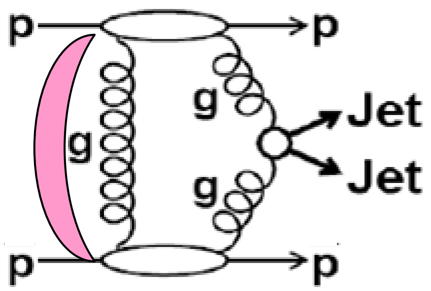


Figure 2: $f_{\rm SD}(\xi) \equiv \frac{\xi}{\sigma_{\rm SD}} \frac{d\sigma_{\rm SD}}{d\xi}$ for single diffractive pp collisions at $\sqrt{s} = 7$ TeV as calculated using QGSJET-II-4 (red solid) and SIBYLL (green dashed).

High Intensity Gluon Factory
(underrated un-biased gluons)

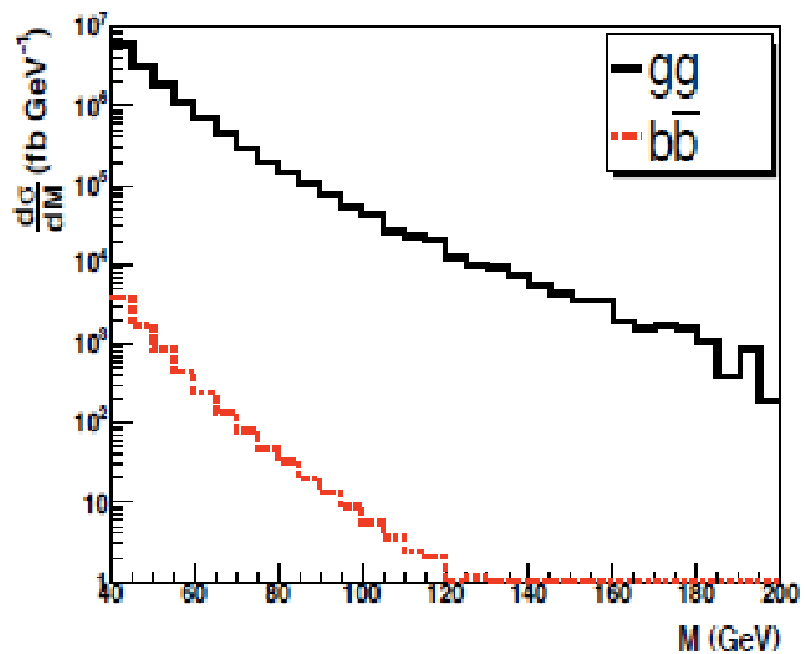
KMR-00, 01



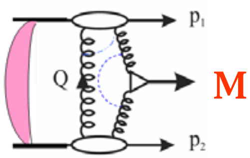
- (~20 M q-jets vs 417 glue-jets at LEP)
- CDF and D0 each have a few exclusive JJ events > 100 GeV
- $J_Z^P = 0^+$ still holds for low mass diffr. dissociation.
- Without forward proton taggers- FSC required (M<2.5 GeV, 98% purity or better)

Prediction of ExHuME:
14 TeV, |η| <~ 3

Scaling down by ~ 5 for
7 TeV, |η| < 2.5 :



Unique possibility for a comprehensive study of the gluon jrt properties in the extremely clean environment (hadron spectra/correlations, particle content, searches for glueballs…)



Central Exclusive Production of Heavy Quarkonia

(P. Lebiedowicz)

- $\chi_{c,b}$ production is of special interest: **(star reactions!)**
  - Heavy quarkonium production can shed light on the physics of bound states (lattice, NRQCD$\cdots$).
  - Potential to produce different J^P states, which exhibit characteristic features (e.g. angular distributions of forward protons).
  - Could shed light on the nature of the various 'exotic' charmonium states observed recently. (X,Y,Z) charmonium-like states.

Spin-Parity Analyzer

(KKMR-2003)

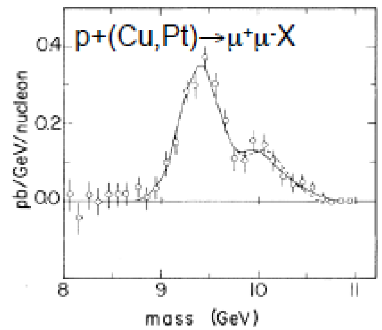
CDF & new LHCb measurements are all in good agreement (factor "few") with the Durham group predictions.

MIND THE GAP

P-wave Bottomonia

Bottomonium history started 30 years ago

(PRL 39, 242 (1977) and PRL 39,1240 (1977))



FNAL, E288

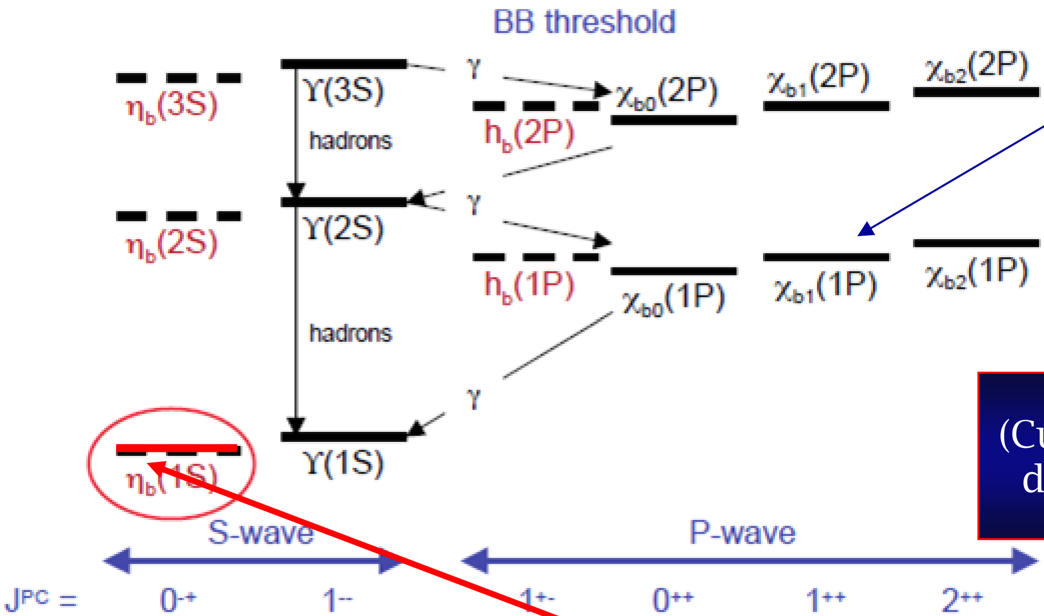
M(Υ)=9.40±0.013

M(Υ')=10.00±0.04

M(Υ'')=10.43±0.12

(spins- still unconfirmed)

30 years later….



Υ(nS) confirmed and $\chi_{bJ}(1,2P)$ states observed

Below BB̄, several states not yet observed: 3 S-wave (η_b), 2 P-wave (h_b), D-wave,etc…

(Currently no complete theoretical description of onium properties.)

(BABAR (2008))

(Still some puzzles)

The heaviest and most compact quark-antiquark bound state in nature

PDG Summary Tables

particle data group

$\chi_{b0}(1P)$ [d]

$I^G(J^{PC}) = 0^+(0^{++})$

J needs confirmation.

Mass $m = 9859.44 \pm 0.42 \pm 0.31$ MeV

$\chi_{b0}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\gamma\, \Upsilon(1S)$	<6 %	90%	391

(Crystal Ball-1986)

$(1.73 \pm 0.35)\%$
CLEO-2011

$\chi_{b1}(1P)$ [d]

$I^G(J^{PC}) = 0^+(1^{++})$

J needs confirmation.

$\gamma\, \Upsilon(1S)$	(35 ± 8) %	423

$\chi_{b2}(1P)$ [d]

$I^G(J^{PC}) = 0^+(2^{++})$

J needs confirmation.

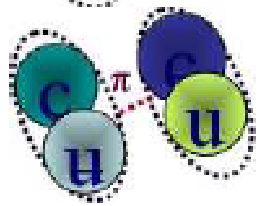
Mass $m = 9912.21 \pm 0.26 \pm 0.31$ MeV

$\chi_{b2}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\gamma\, \Upsilon(1S)$	(22 ± 4) %	442

Zoo of charmonium –like XYZ states

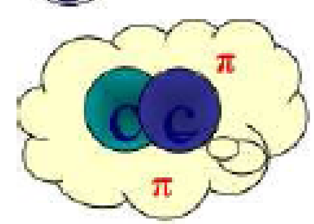
Tetraquark:
four tightly bound quarks

Molecular state:
two loosely bound mesons



Hybrid: states with
excited gluonic degrees of freedom

Hadrocharmonium: charmonium state,
“coated” by excited light-hadron matter



- X(3872) –
- XYZ(3940) & X(3915) –
- Y(4140)/Y(4280) & X(4350)

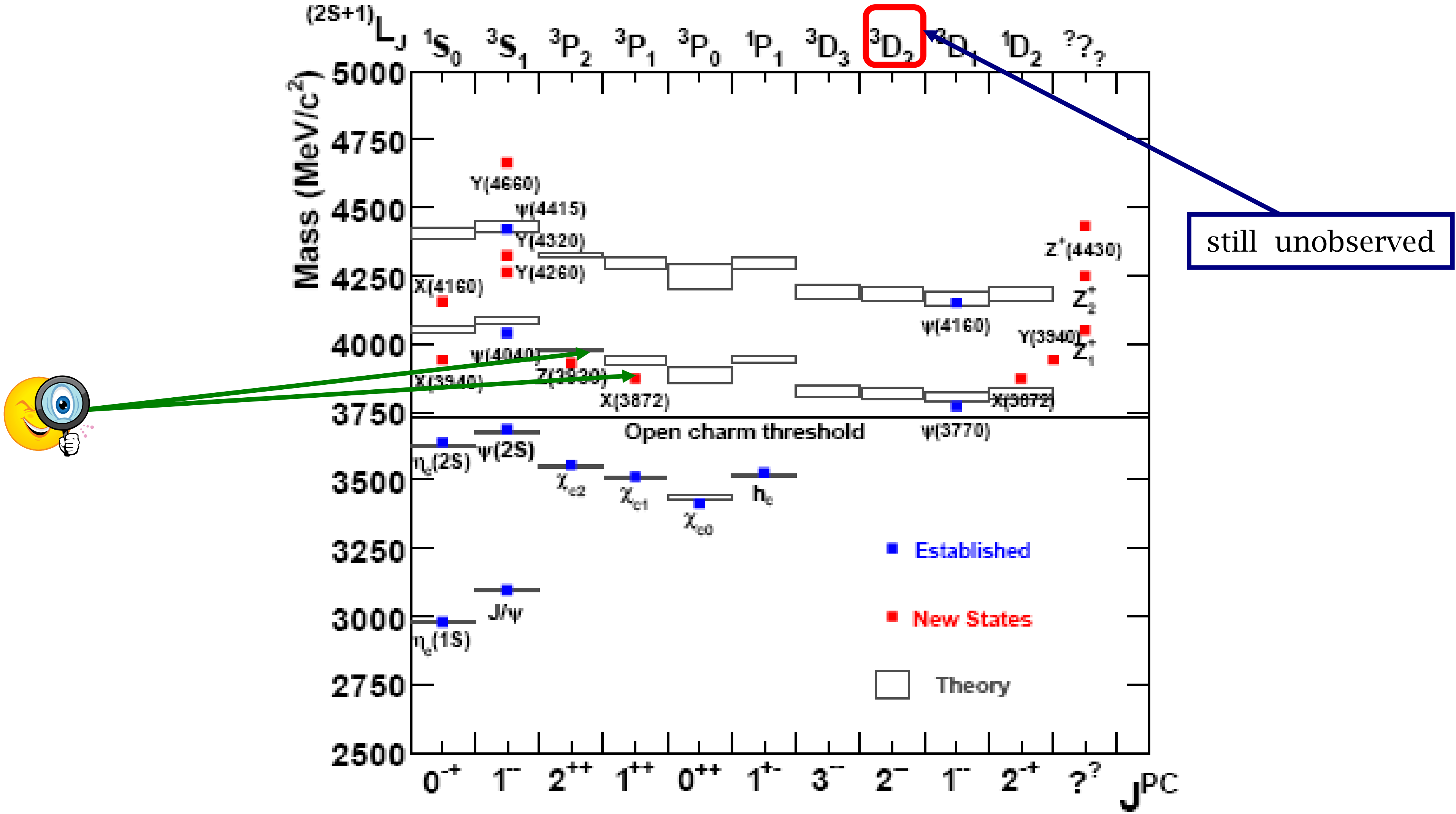
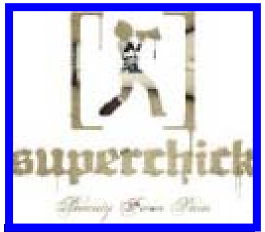


Figure 1: The mass versus the quantum numbers (J^{PC}) for the charmonium-like states. The boxes represent the predictions; blue boxes show the established states, and the red boxes indicate the new states discovered at the B-factories.

SuperCHIC MC



A MC event generator including[9]:

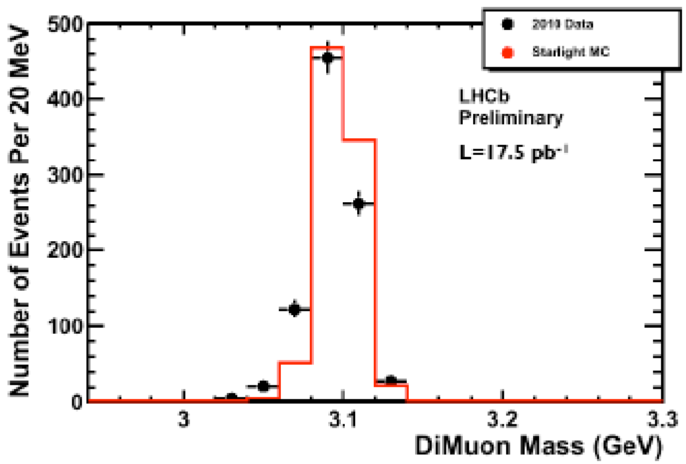
- Simulation of different CEP processes, including all spin correlations:
  - $\chi_{c(0,1,2)}$ CEP via the $\chi_c \to J/\psi\gamma \to \mu^+\mu^-\gamma$ decay chain.
  - $\chi_{b(0,1,2)}$ CEP via the equivalent $\chi_b \to \Upsilon\gamma \to \mu^+\mu^-\gamma$ decay chain.
  - $\chi_{(b,c)J}$ and $\eta_{(b,c)}$ CEP via general two body decay channels
  - Physical proton kinematics + survival effects for quarkonium CEP at RHIC.
  - $\gamma\gamma$ CEP.
  - Exclusive J/ψ and Υ photoproduction.
- Meson pair CEP ($\pi^0\pi^0$, $\eta\eta$, $\eta'\eta'$...) to be included soon.
- More to come (dijets, open quark, Higgs...?).

$\rightarrow$ Via close collaboration with CDF, STAR and LHC groups, in both proposals for new measurements and applications of SuperCHIC, it is becoming an important tool for current and future CEP studies.

[9] The SuperCHIC code and documentation are available at http://projects.hepforge.org/superchic/

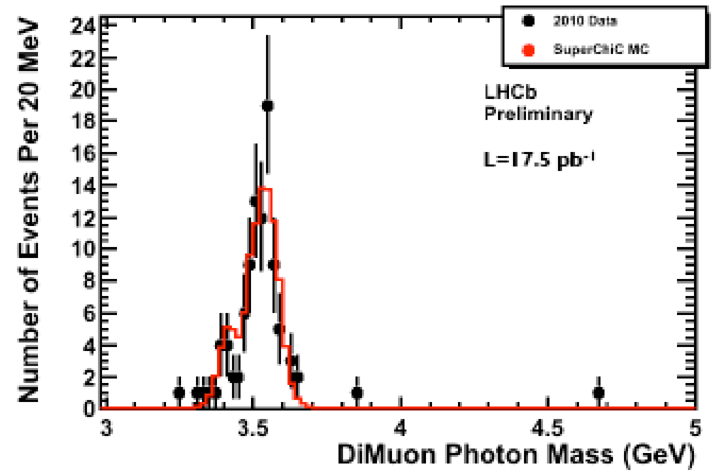
Exclusive charmonium production.

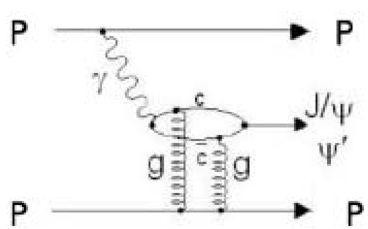
Normalized to number of events



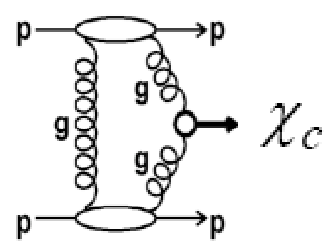
Normalised to number of events

ChiC0: 12%,ChiC1: 36%,ChiC2: 52%





-> $\mu^+\mu^-$

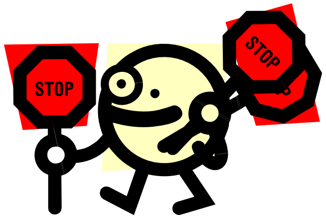


χ_c -> $\mu^+\mu^-$ + γ

SuperChiC: MC for central exclusive production (L.A. Harland-Lang, V.A. Khoze, M.G. Ryskin, W.J. Stirling, arXiv:0909.4748 [hep-ph].).

7. Conclusion

- We firmly believe that a rich LHC diffractive programme will allow to impose strong ‘restriction order’ on the models of diffraction and provide a vital information on the dynamics of soft hadron interaction.



- A very promising start-up of diffractive studies at the LHC. More data & excitement to come soon.

LET THE LHC DATA TALK !


THANK YOU

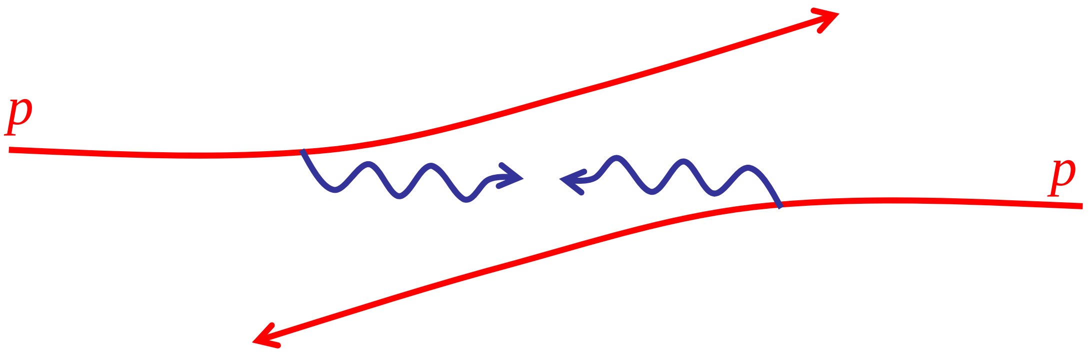

QUESTIONS?

BACKUP

LHC as a High Energy $\gamma\gamma$ Collider

K. Piotrzkowski, Phys. Rev. **D63** (2001) 071502(R)
J.Ohnemus, T.Walsh & P .Zerwas -94;

KMR-02



<u>Highlights</u>:

- **$\gamma\gamma$ CM energy *W* up to/beyond 1 TeV (and under control)**
- **Large photon flux *F* therefore significant $\gamma\gamma$ luminosity**
- **Complementary (and clean) physics to *pp* interactions, eg studies of** *exclusive* **production of heavy particles might be possible ⇒ opens new field of studying very high energy $\gamma\gamma$ (and γp) physics**

Very rich Physics Menu

ALICE pseudorapidity acceptance

→ *additional forward detectors*

(no particle identification)

$1 < \eta < 5$

$-4 < \eta < -1$

→ *definition of gaps* η_+, η_-

p-p luminosity $L = 5 \times 10^{30} cm^{-2}s^{-1}$ **:**

→ **reduced prob. overlapping events**

diffractive L0 trigger (hardware):

Pixel or TOF mult (central barrel)

gap η_+: $3 < \eta < 5 \rightarrow \Delta\eta \sim 0.5$

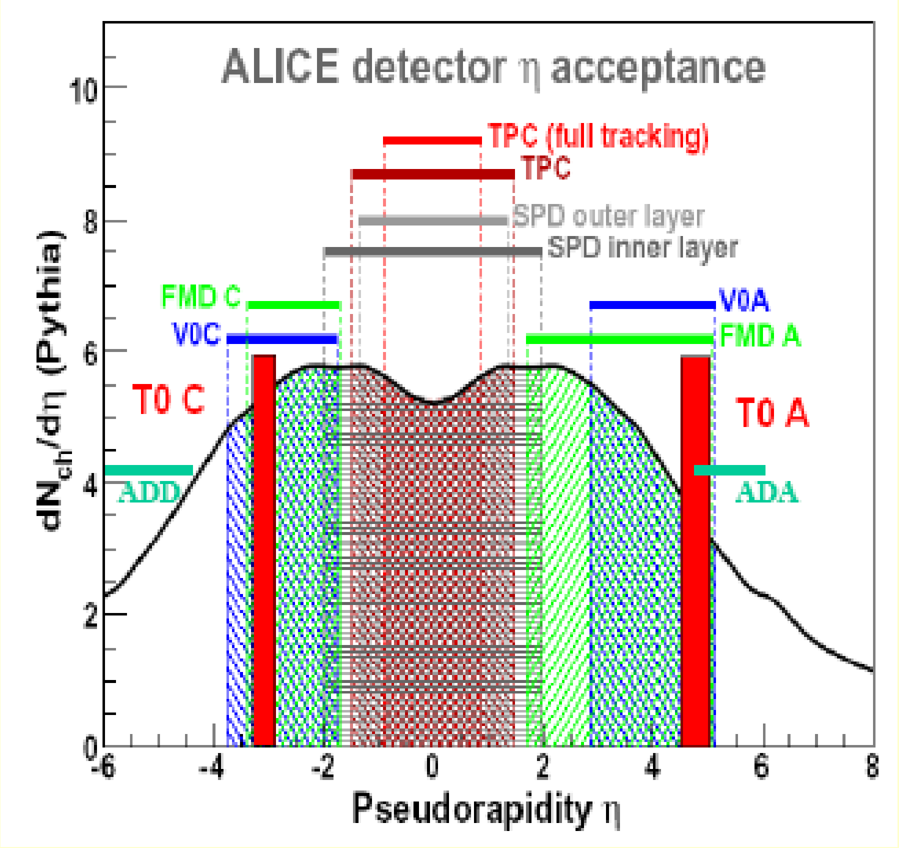
gap η_-: $-2 < \eta < -4 \rightarrow \Delta\eta \sim 0.5$

high level trigger (software):

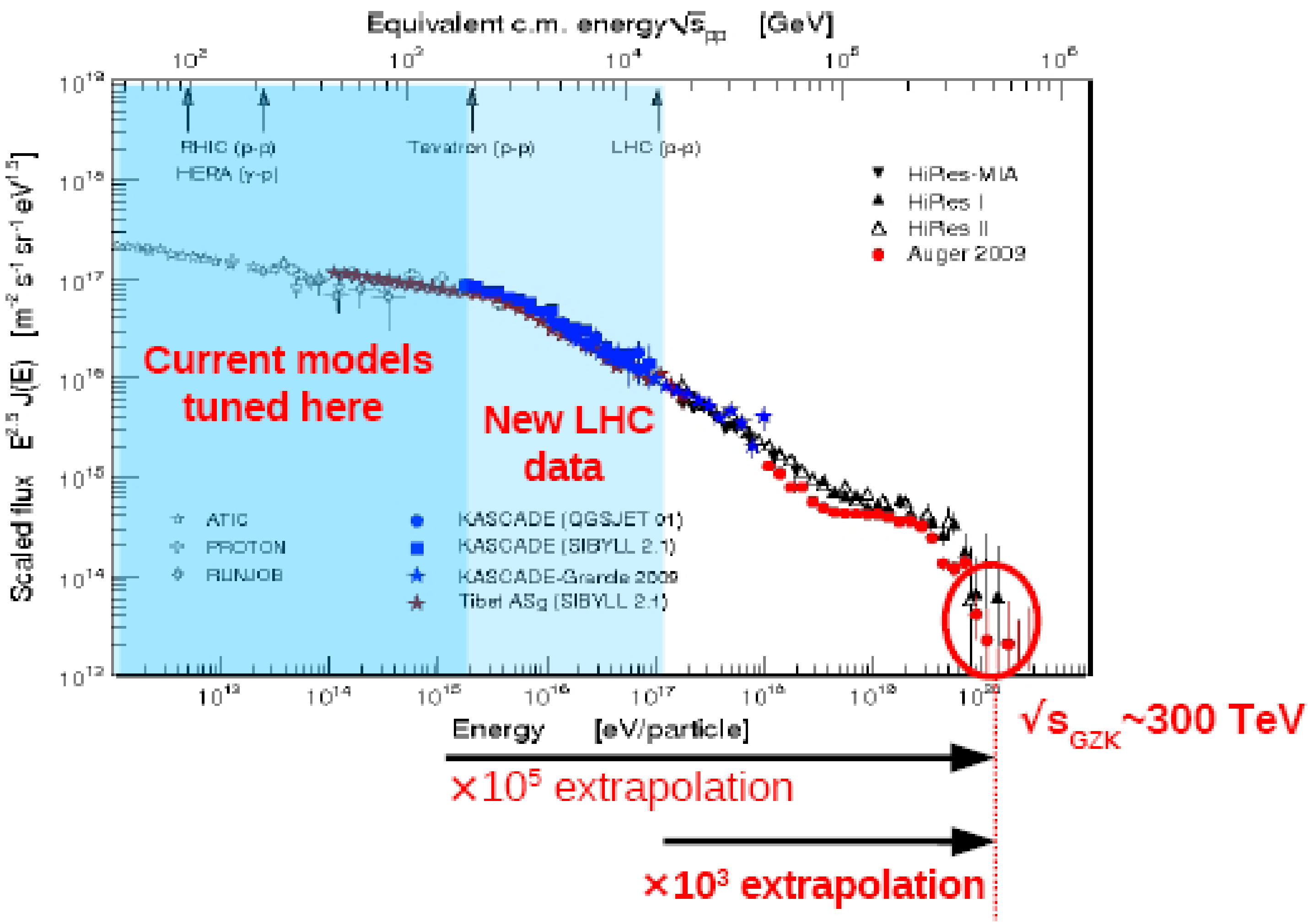
$-3.7 < \eta < 5$

→ *improved including ADA, ADD*

→ *see talk by Daniel Tapia Takaki*



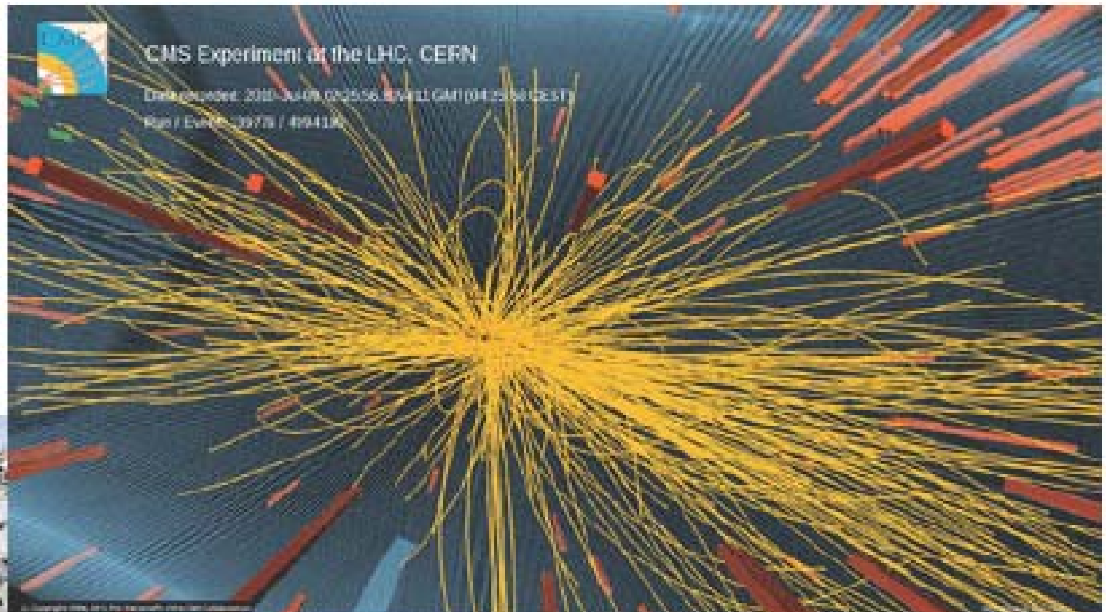
Hadronic MCs tuning with collider data



- The LHC provides a significant lever-arm in providing constrains for hadronic Monte Carlos for UHECR

"Measurement of the pp inelastic cross section using pile-up events with the CMS detector"

How to use annoying pile-up events to your advantage



N. Cartiglia

Single Diffraction: definitions

η - pseudorapidity

$\eta \equiv y|_{m=0} = -\ln\tan(\vartheta/2)$

t - four-momentum transfer squared

ξ - fractional momentum loss

M_X - mass of diffractive system X

$\xi = M_X^2/s$