MAX-PLANCK-GESELLSCHAFT

Werner-Heisenberg-Institut

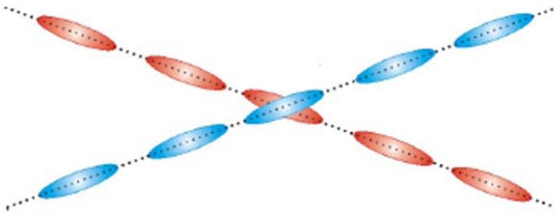
$\Delta x \Delta p_x \geq \hbar$

Precision targets for luminometry at the LHC from theoretical perspective

V.A. Khoze (IPPP, Durham)

Durham University

(Manchester, St. Petersburg, Helsinki & Rockefeller)



LHC Lumi Days

chaired by Helmut Burkhardt (CERN) , Massimiliano Ferro-Luzzi (CERN) , Michelangelo Mangano (CERN)

from Thursday 13 January 2011 at **08:00** to Friday 14 January 2011 at **18:00** (Europe/Zurich)

at CERN (503-1-001 - Council Chamber)

Description The aim of this workshop will be to review the results of the first luminosity calibration measurements at the LHC and to stimulate a discussion on future measurements. A total accuracy of around 5% seems achievable with the current instrumentation, on relatively short term. The need for and the challenges associated with a more precise determination will be debated. The importance of knowing the cross section scale to a given precision will be reviewed. Direct luminosity calibration methods will be compared to indirect methods, including recent experience at other cyclical colliders. Physics motivations, systematic uncertainties, proposals for optimal running conditions for future luminosity calibration experiments, etc., will be openly discussed.

2011 ~ 3.4% (ATLAS)
~ 4% (CMS)

11%→5% →1-2% ?

Thursday 13 January 2011

09:00 - 12:55 Physics aspects

** What precision should the experiments aim at?*
** What is the benefit for physics?*
** Relevance of lum measurements at different energies*
** Comparison between the reach of direct and indirect lum determinatio[n]*

Convener: Michelangelo Mangano (CERN)

09:00 **Welcome and introduction** *05'*
Speaker: Massimiliano Ferro-Luzzi (CERN)

09:05 **Motivations and precision targets for luminosity** *20'*
Speaker: Michelangelo Mangano (CERN)
Material: Slides

09:30 **Indirect luminosity measurements: theoretical assessment** *30'*
Speaker: Valery Khoze (Science Laboratories)
Material: Slides

10:05 **TOTEM: prospects for total cross section measurements** *20'*
Speaker: MARIO DEILE (CERN, PH-TOT)
Material: Slides

10:30 **LHCb: indirect luminosity measurement** *20'*
Speaker: Jonathan Anderson (Universitaet Zuerich)
Material: Slides

10:55 Coffee break *15'*

11:10 **Status and prospects of ALFA** *15'*
Speaker: Karlheinz Hiller (Deutsches Elektronen Synchrotron (DESY)-Unknown-Unknown)
Material: Slides

11:30 **ATLAS: W and Z boson cross sections and prospects for other precision cross section measurements** *20'*
Speaker: Matthias Schott (CERN)
Material: Slides

11:55 **CMS: W and Z boson cross sections and prospects for other precision cross section measurements** *20'*
Speakers: Jeremy Werner (Princeton University) , Jeremy Werner (Princeton University)
Material: Slides

12:20 **CMS forward detectors for indirect luminosity measurements** *15'*
Speakers: Stephen Schnetzer (CERN) , Steve Schnetzer (Rutgers University)
Material: Slides

14:00 - 18:30 First results of direct luminosity calibration and future prospects

** review results of 2009-2010 luminosity calibration experiments*
** comparison to machine parameters (b*, emittances, ..)*
** ATLAS/CMS cross comparison*
** review systematic uncertainties: current list and future prospects*
** propose optimal conditions for future luminosity calibration experiments*
** requirements for a possible intermediate b* run in 2011?*

Convener: Massimiliano Ferro-Luzzi (CERN)

14:00 **BCTs and BPTX analysis results** *15'*
Speaker: Thilo Pauly (CERN)
Material: Slides

14:20 **ALICE 2010 luminosity determination** *30'*
Speaker: Ken Oyama (University of Heidelberg)
Material: Slides

15:00 **LHCb 2010 luminosity determination** *30'*
Speaker: Vladislav Balagura (ITEP Institute for Theoretical and Experimental Physics (ITEP)-U
Material: Slides

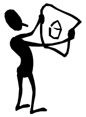
15:40 **LHCb beam-gas imaging results** *15'*
Speakers: Plamen Hopchev, Plamen Hristov Hopchev (LAPP-Laboratoire d'Annecy-le-Vieux de Physique des Particules (L)
Material: Slides

16:00 Coffee/tea break *20'*

16:20 **CMS 2010 luminosity determination** *30'*
Speaker: Marco Zanetti (MIT)
Material: Slides

17:00 **ATLAS 2010 luminosity determination** *30'*
Speaker: Mika Huhtinen (CERN)
Material: Slides

17:40 **ATLAS/CMS comparison** *15'*
Speaker: Beate Heinemann (LBNL and UC Berkeley)

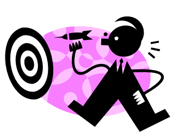


PLAN

1. Introduction (10 years on).
2. Two photon production of muon pairs
3. Optical theorem: forward elastic +total inelastic rates.
4. Towards Full Acceptance Detector at the LHC.
5. Other methods & Related subjects
   (light shining through the hole)
6. Overall conclusions

WITH A BIT OF PERSONAL FLAVOUR

Main aims - to identify the issues which may require further theoretical efforts
-to estimate the size of theoretical uncertainties in the 'low Q^2' approaches.



1. Introduction

$$L = \frac{N}{\sigma}$$

Luminosity measurements-why?

PRIOR to the LHC START-UP

- Cross sections for "Standard" processes
  - t-tbar production (test for the Higgs production)
  - W/Z production
  - …….
- New physics manifesting in deviation of $\sigma \times BR$ relative the Standard Model predictions
- Important precision measurements
  - Higgs production $\sigma \times BR$
  - $\tan\beta$ measurement for MSSM Higgs
  - …….

Any deviations in the **rates** from the SM expectations

Ten Years Back

L³

Eur. Phys. J. C 19, 313–322 (2001)
Digital Object Identifier (DOI) 10.1007/s100520100616

THE EUROPEAN PHYSICAL JOURNAL C

Luminosity measuring processes at the LHC

V.A. Khoze[1], A.D. Martin[1], R. Orava[2], M.G. Ryskin[1,3]

[1] Department of Physics and Institute for Particle Physics Phenomenology, University of Durham, Durham, DH1 3LE, UK
[2] Department of Physics, University of Helsinki, and Helsinki Institute of Physics, Finland
[3] Petersburg Nuclear Physics Institute, Gatchina, St. Petersburg, 188300, Russia

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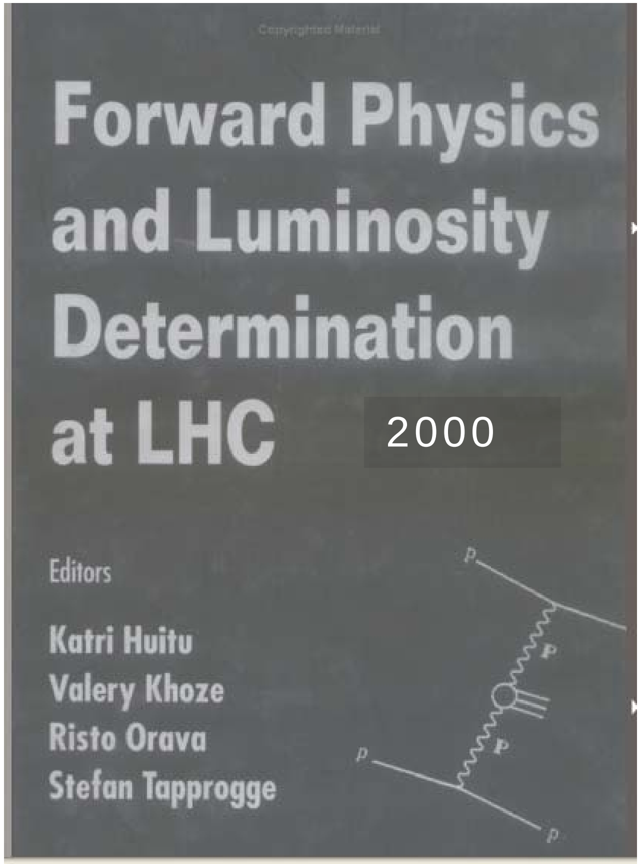
Published online: 15 March 2001 – © Springer-Verlag 2001

Abstract. We study the theoretical accuracy of various methods that have been proposed to measure the luminosity of the LHC pp collider, as well as for Run II of the Tevatron $p\bar{p}$ collider. In particular we consider methods based on (i) the total and forward elastic data, (ii) lepton-pair production and (iii) W and Z production.

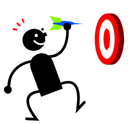


Absolute and relative luminosity measurements

1. Measure the absolute luminosity with a theoretically reliable accurate method at the most optimal conditions.
2. Calibrate luminosity monitor(s) with this measurement, which then can be used at different conditions.

Luminosity monitoring- relative measurements

Use dedicated luminosity monitors either provided by the experiment or by the machine

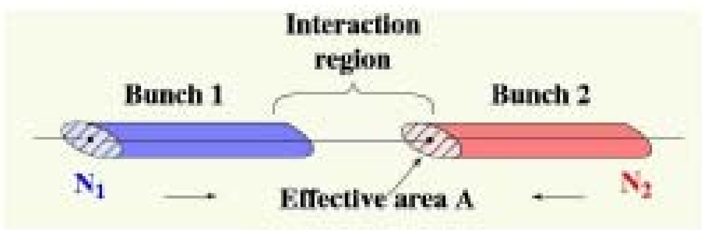


Target: to illustrate how well calculable could be standard 'low-Q^2' processes proposed for luminosity calibration (in the real world environment).

The 2 ways of luminosity measurement

Direct from machine parameters

$$L = \frac{f \cdot N_1 \cdot N_2}{A}$$



f-revolution frequency

Input:
- beam currents
- crossing area (e.g. from transverse beam scans)

Already 3.4%

Precision:
~ 10% at LHC startup,
~ 5 % with best systematics

Beam profiling via beam-gas interact^{n}. -LHCb

Indirect from rates via $L = N / \sigma$

$$L = \frac{(N_{sig} - N_{bg})}{(\varepsilon \cdot acc \cdot \sigma)}$$

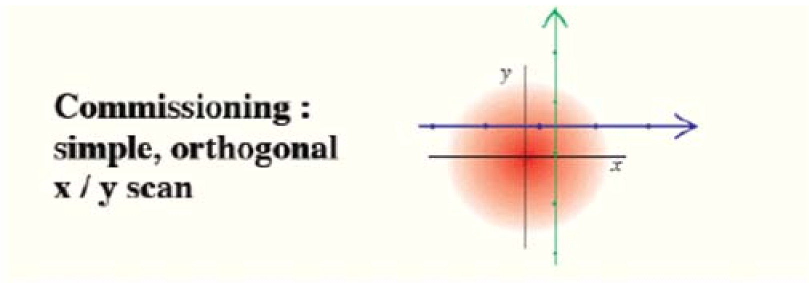
Input:
- cross sections e.g. W/Z from PDFs, or σ_{tot} via optical theorem (lepton pairs)
- efficiency, acceptance and backgrounds

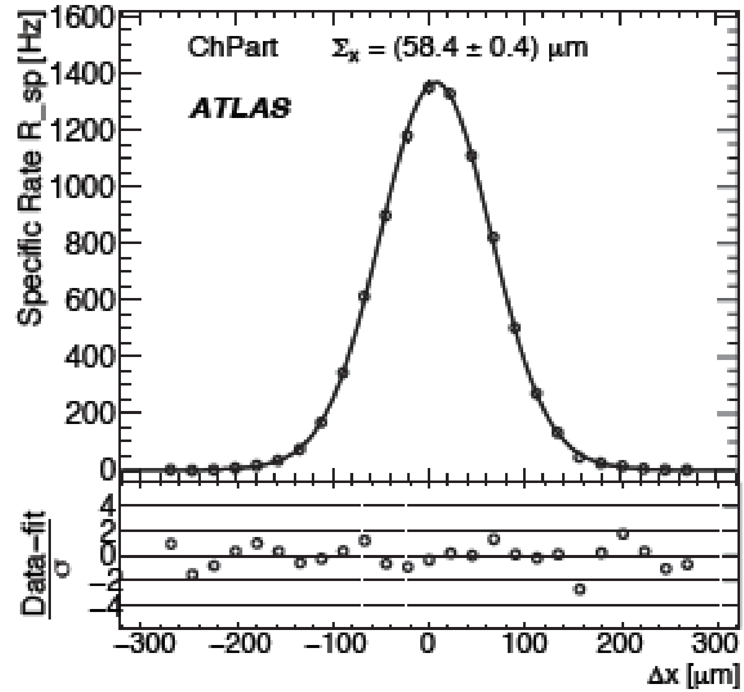
ALFA concept to determine the luminosity from small angle proton scattering:

1) total + elastic rates + optical theorem limited due to ATLAS η range
2) elastic rate + σ_{tot}, e.g. TOTEM
3) elastic rate in the Coulomb-Nuclear Interference region

Determination of the overlap integral (pioneered by Van der Meer @ISR)

ISR-record 1%

- 



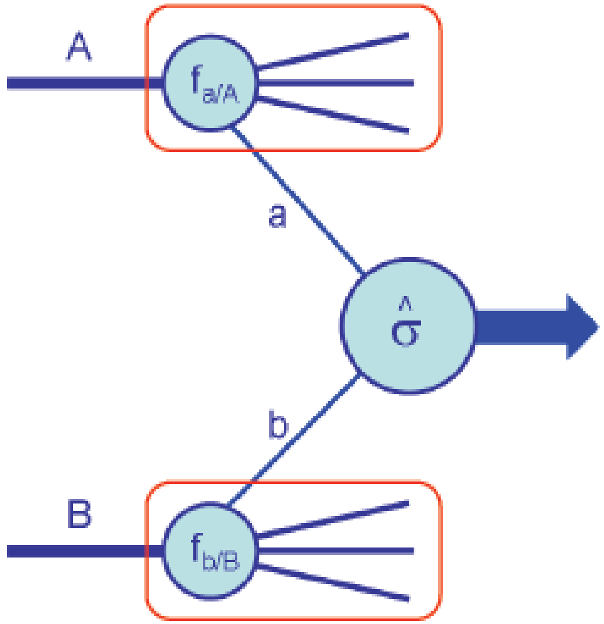
- Default $\mathcal{L}$ comes from LUCID event counting
  - Several other methods
  - **Stability** of measurement over 2010 **better than 0.5%**
- Systematic uncertainty of 3.4%
  - Dominated by uncertainty on bunch charge (beam current) knowledge (3.1%)

arXiv:1101.2185v1
ATLAS-CONF-2011-011

‘HIGH-Q^2 ‘ -probe

Slides from Graeme Watt

Event rate = Cross section (σ) × Luminosity (L)



Phenomenology

Theory

Experiment

- Theoretical calculations: Feynman diagrams have initial quarks and gluons.
- **Problem:** the LHC collides protons. Need to know density of quarks and gluons (partons) inside the proton.

Parton **D**istribution **F**unctions (**PDFs**)

$$\sigma = f_{a/A} \otimes f_{b/B} \otimes \hat{\sigma}_{ab}$$

No predictions for signal or background cross sections without knowledge of PDFs!

QCD factorisation

QCD = Quantum ChromoDynamics

(describes interactions between quarks and gluons)

- $f_{a/A}(x, Q^2)$ gives *number density* of partons a in hadron A with momentum fraction x at a hard scale $Q^2 \gg \Lambda^2_{\rm QCD}$.

$$\sigma_{AB} = \sum_{a,b=q,g} \int_0^1 \mathrm{d}x_a \int_0^1 \mathrm{d}x_b\, f_{a/A}(x_a, Q^2)\, f_{b/B}(x_b, Q^2)\, \hat{\sigma}_{ab}$$

(personal doubts)

Perturbative expansion: $\hat{\sigma}_{ab} = \hat{\sigma}^{\rm LO}_{ab} + \alpha_S\, \hat{\sigma}^{\rm NLO}_{ab} + \alpha_S^2\, \hat{\sigma}^{\rm NNLO}_{ab} + \ldots$

PDF evolution: (DGLAP equation)

$$\frac{\partial f_{a/A}}{\partial \ln Q^2} = \frac{\alpha_S}{2\pi} \sum_{a'=q,g} \left[P^{\rm LO}_{aa'} + \alpha_S P^{\rm NLO}_{aa'} + \ldots\right] \otimes f_{a'/A}$$

α_S evolution:

$$\frac{\partial \alpha_S}{\partial \ln Q^2} = -\beta^{\rm LO}\alpha_S^2 - \beta^{\rm NLO}\alpha_S^3 - \ldots$$

- Need to extract input values $f_{a/A}(x, Q_0^2)$ and $\alpha_S(M_Z^2)$ from data.

NLO is standard.

NNLO $P_{aa'}$ (2004) and 2→1.

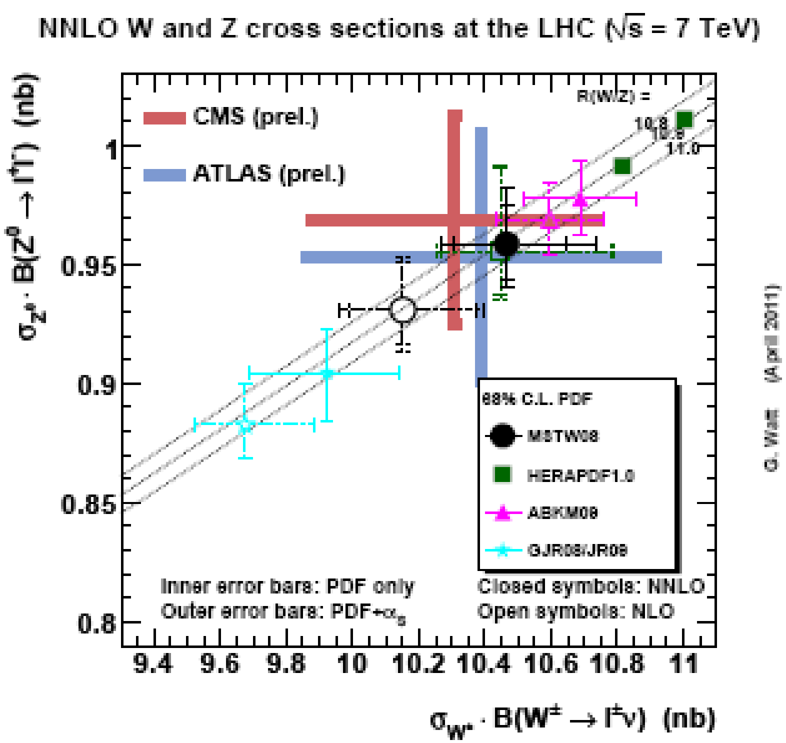
Lattice QCD?

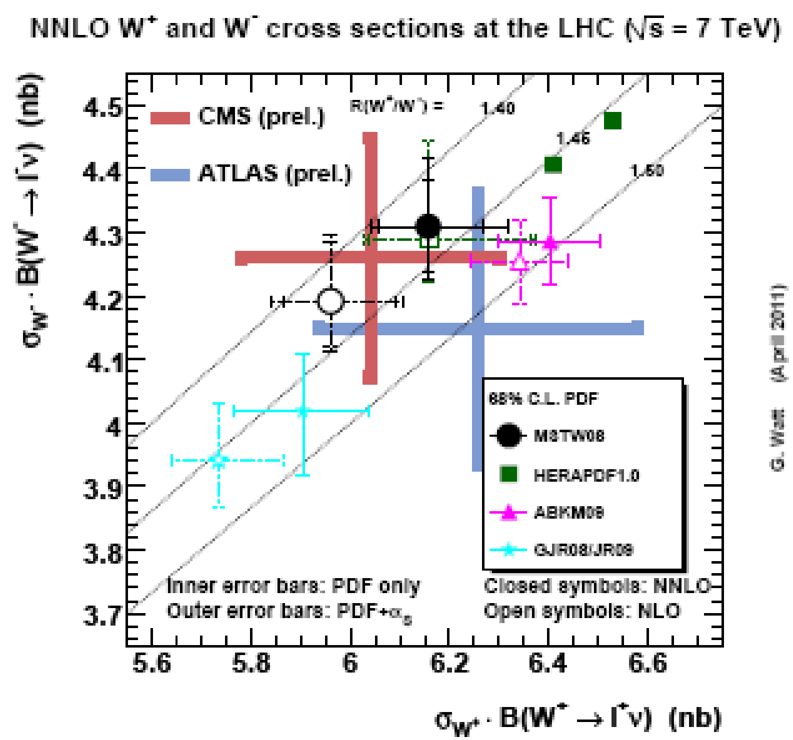
well developed machinery

NNLO $W^{\pm}$ vs. Z^0 and W^+ vs. W^- total cross sections

G.Watt, April 2011

- Consolidate two cross section measurements (and their ratio).





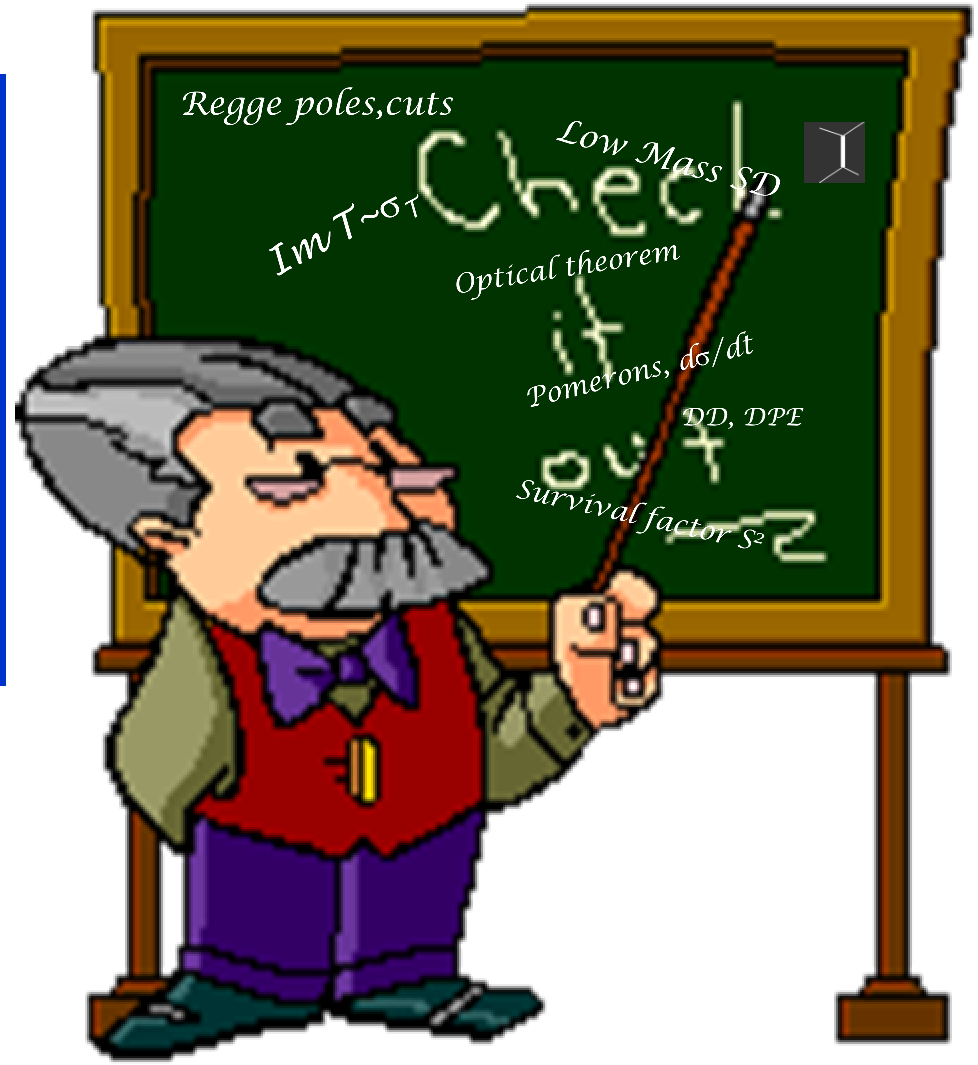
- Know correlation of both data and theory (from eigenvector PDFs).
  - Luminosity uncertainty 3–4%, comparable with PDF spread.

'LOW-Q^2 ' -APPROACHES

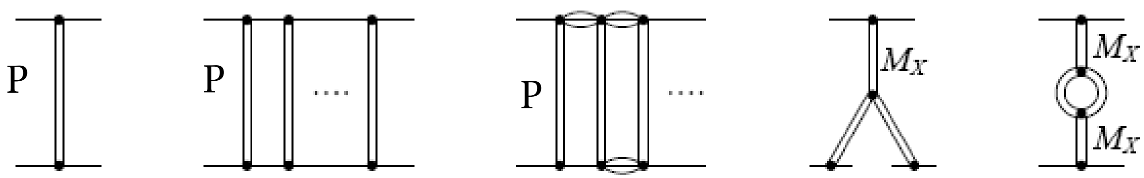
- Current theoretical models for soft hadron interactions are still incomplete, and their parameters are not fixed, in particular, due to lack of HE data on **Low-Mass Diffraction**.

- 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.

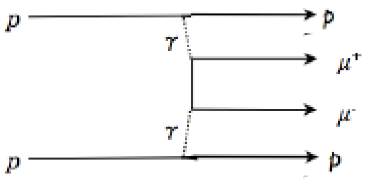


Reggeon Field Theory, Gribov- 1986



$\mu\mu$

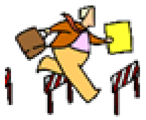
2. Exclusive QED Lepton Pair Production



- First proposed for luminometry by. V. Budnev et al, Nucl. Phys. **B63** (1973) 519.
- First studies of feasibility for the dimuons at the LHC: A.Shamov and V.Telnov-1998 (ATLAS TDR-99).
- Strong-interaction effects- KMOR, Eur.Phys.J.C19:313-322,2001
- First observation of exclusive l^+l^- by CDF: Phys.Rev.Lett.98:112001,2007
- Ongoing studies of exclusive dimuons: CMS and LHCb (ATLAS in the pipeline)

Myth:

- **Pure QED process** –thus, theoretically well understood (higher-order QED effects- reliably calculable).



Reality

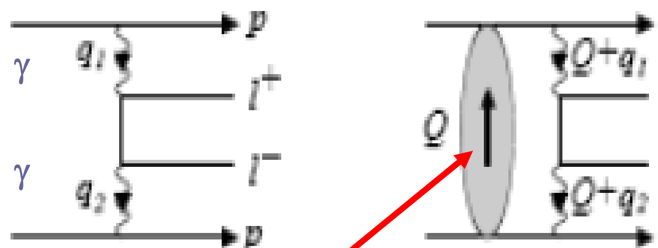
- Strong interaction effects (we collide protons after all).
- **Backgrounds**:
mis-ID, various contributions due to the incomplete exclusivity (lack of full detector coverage), pileup…

$\mu\mu$

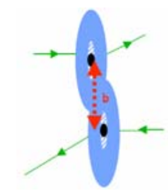
Strong interaction between colliding protons (rescattering or absorptive corrections).

Even in the fully exclusive case:

schematically



Notorious survival factor.



(large impact parameters)

Usually, for photon-photon central production $S^2_{\gamma\gamma}(LHC) \simeq 0.9$

However, in the case of $pp \to p + \ell^+\ell^- + p$ absorption effects could be very small.

In particular, for low $p_t(\mu\mu) \sim 10\text{–}50$ MeV absorpt. correction $1\text{-}S^2 = 2\delta < 0.3\%$.
Will be additionally suppressed by the muon acoplanarity cuts.

$$\delta \approx \frac{\sigma_{\rm inel}}{8\pi}\, p_t^2\, C$$

with C~0.1, KMOR, Eur.Phys.J.C19:313 (2001).

($\ell^+\ell^-$-pair production : K. Pietrzkowsi et al., A. Shamov and V. Telnov, M. Krasny et al…)

$\mu\mu$

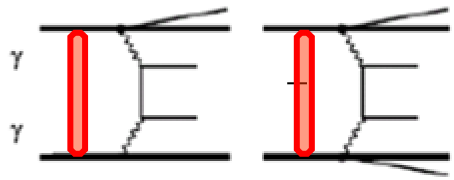
Main Backgrounds

- **Proton dissociation. accompanied by diphoton fusion**

  $P_t(\mu\mu)$ distribution is much wider (slope ~ 0.5-1.5 GeV²)

  Usually generated with LPAIR (ZEUS version).

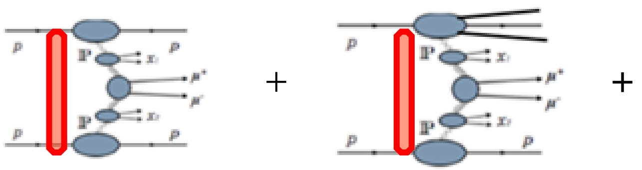
  For P_t >> $P_t(\mu\mu)$ the strong interaction effects are less than 1%.



- **Dimuons from Double Pomeron Exchange (DPE)**

  Usually evaluated using POMWIG (or DPEMC) MC.

  Caveat ☞ survival factor S^2_{PP} (should be calculated theoretically).



Without proton dissociation $S^2_{PP} \simeq 0.1$, but , in reality, some particles accompanying dimuons could go undetected, thus some increase of the effective survival factor.

Strong dependence on experimental conditions.

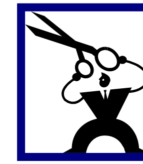
- K/pion mis-ID , muons from b,c- pair decays (the experts say these are manageable).
- $J/\psi, \psi'$ - decays could be removed by proper mass cuts.
- CMS: inel. bgds could be further suppressed by veto on HF,ZDC,Castor, (T1/T2) and FSC.

  Even in the presence of (moderate) pileup. (M.Albrow et al)

  (dielectrons@Alice with FSC -looks promising)

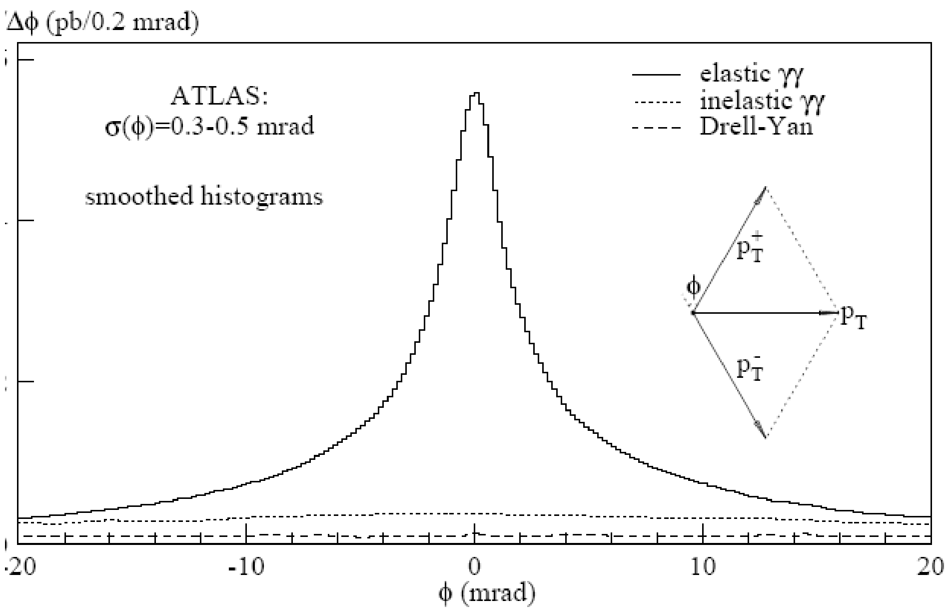
$\mu\mu$

Old recipe: cut, cut and fit.



Tight cuts on $P_t(\mu\mu)$, muon acoplanarity $\Delta\phi$ and fitting of the distributions..
.

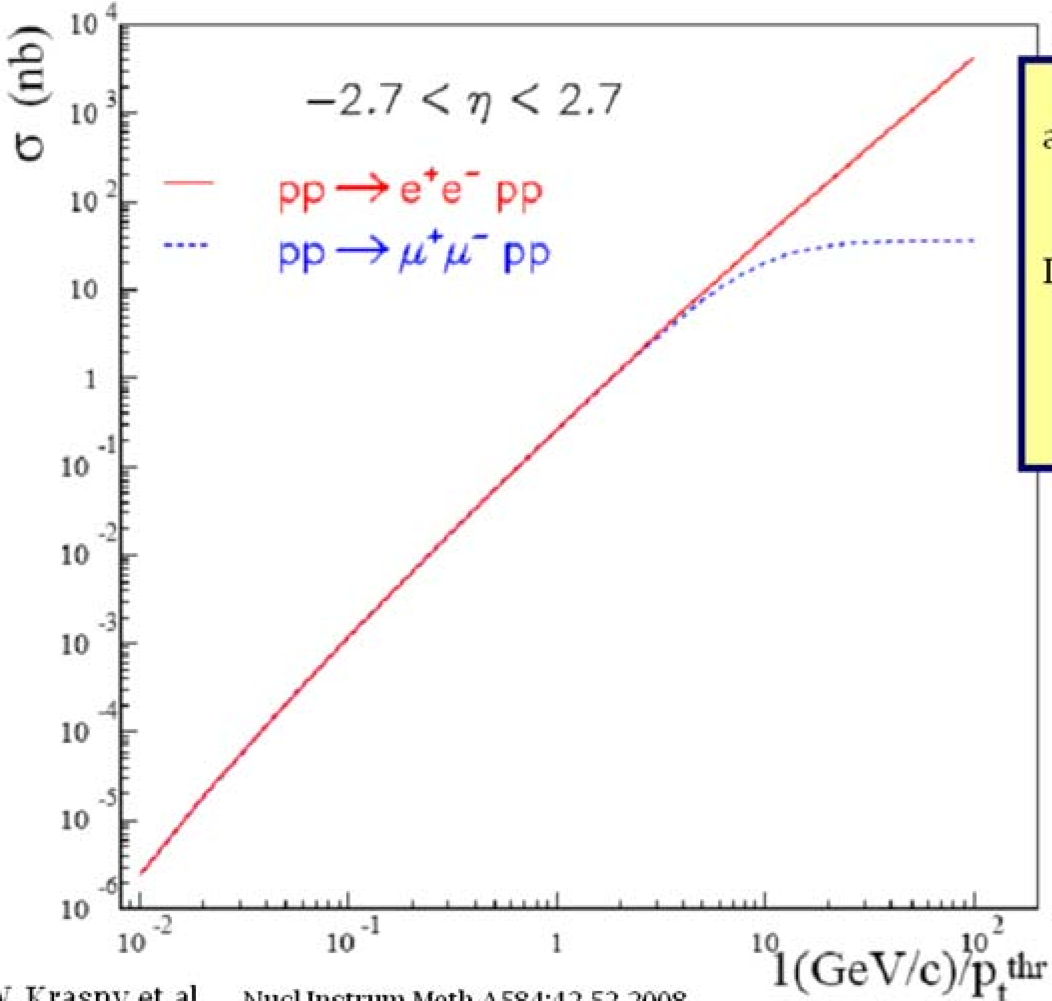
P_t of muons are equal within 2.5 σ of the measurement uncertainty



A. Shamov and V. Telnov, Nucl.Instrum.Meth.A494:51-56,2002

- Efficient suppression of proton dissociation and DPE background.
  Reduction of the absorptive correction.
- With good vertex fit
  Suppression of hadron decays and pileup.
- However a price to pay- event rate ! 
- An addition of Forward Shower Counters will allow to reduce inelastic backgrounds.

Lowering lepton detection threshold p_t^{thr} is crucial for statistical accuracy



ATLAS studies:
at p_T >6 GeV , |η|<2.2, M<60 GeV
+isolation requir. ➔ σ ~1.33 pb.

LHCb at M>2.5 GeV ➔ σ ~90 pb.

$P_t(\mu\mu)$ <50 MeV,

(HERA-LHC Worksp. 2008)

M.W. Krasny et al Nucl.Instrum.Meth.A584:42-52,2008

$\mu\mu$

Problems ?

The rate: $d\sigma_{QED} / dp_t^2 \sim \alpha^4 * 1 / p_t^4$

$$\sigma_{QED}(pp \to p + \mu\mu + p) \simeq 8\,pb * 2\Delta M / M (6GeV / M)^2$$

with P_t >6 GeV (e.g. ATLAS to maintain trigger eff.) the x-section is on the 1 pb level.

Pile-up: Running at $10^{34}/cm^2/sec$ ⇒ "vertex cut" and "no other charged track cut" will eliminate many good events (Per Grafstrom).

D.Moran, DIS-2010

- Advantages of LHCb: lower muon P_t (studies for P_t > 1 GeV and $P_t(\mu\mu)$ <50 MeV) and low-pile-up data

SUMMARY I

- Exclusive dimuon cross section is very reliably calculable, and this approach is potentially very promising.
- However there should be well optimized tradeoff between the experimental cuts and event rates.

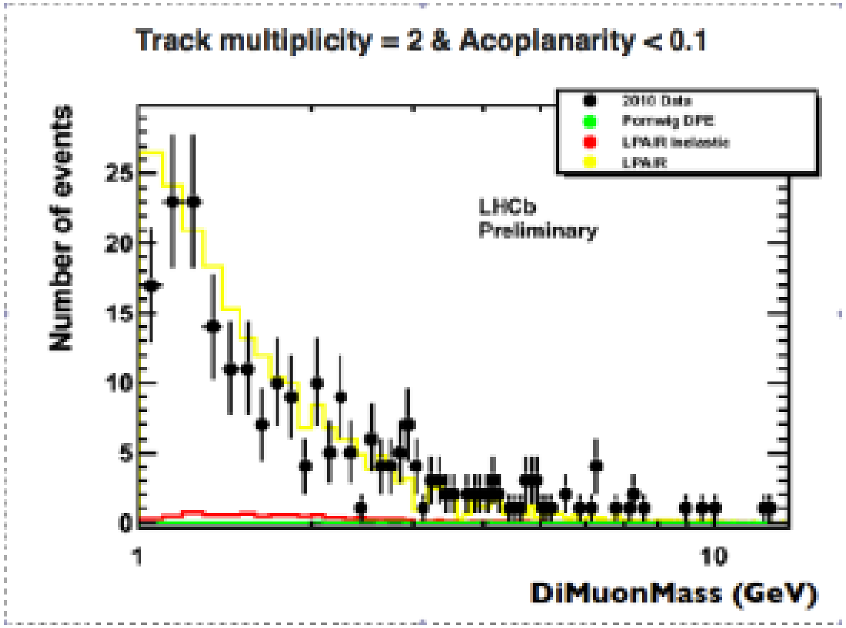
(Alice+ FSC – potential for ee)

- LHCb has good potential to provide a precise luminosity calibration.

Goal- (1-2%)

Which precision do we want?

Benchmark with EW processes

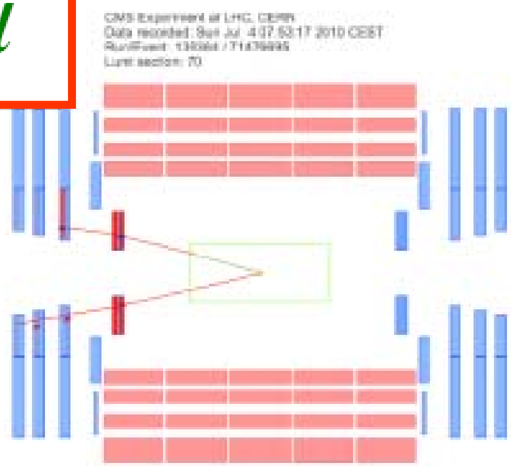


Luminosity measurements with exclusive dimuons from photon fusion

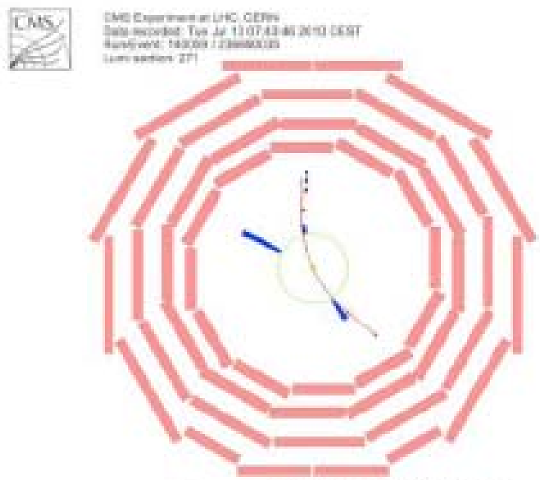
- Cross-sections predicted with < 1% uncertainty
- 250 candidate events selected in 17.5 pb^{-1}
- Purities seem high (more work needed)
- Work on understanding efficiencies has only just begun
- Exclusive JPsi, Psi' and ChiC events have also been isolated and compared to MC

LHC Lumi Days (13/01/11) Jonathan Anderson

$\mu\mu$



$$\text{track: } p_T > 0 \text{ GeV}$$
$$\text{HCAL: } E > 4 \text{ GeV}$$
$$\text{ECAL: } E > 2.5 \text{ GeV}$$



$$m = 3.05 \pm 0.03 \text{ GeV}$$
$$\frac{\Delta\phi}{\pi} = 0.98$$
$$\Delta p_T = 0.05\text{GeV}$$

$$m = 9.44 \pm 0.08 \text{ GeV}$$
$$\frac{\Delta\phi}{\pi} = 0.99$$
$$\Delta p_T = 0.20\text{GeV}$$

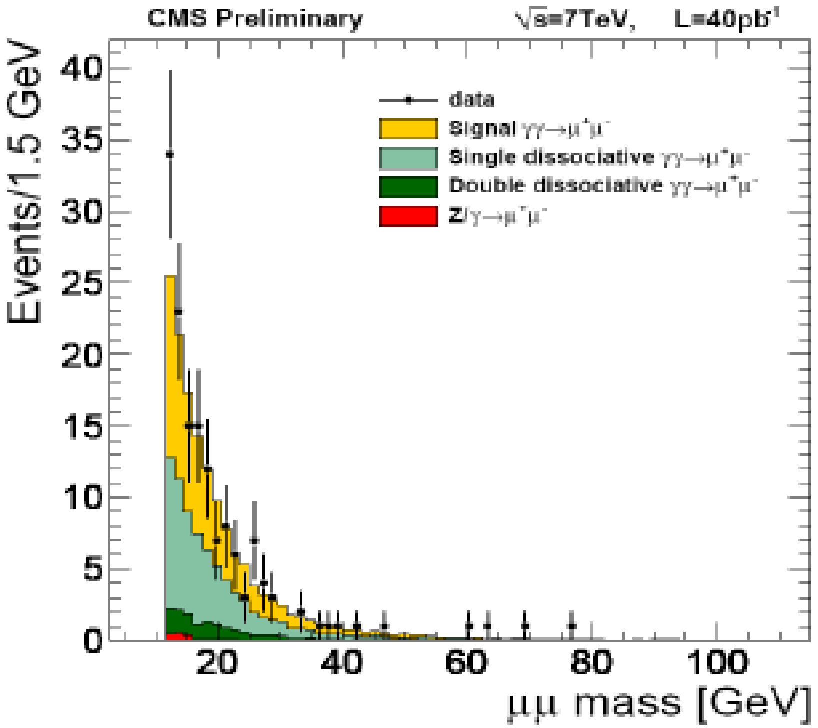
- Ideal case: look for events having 2 muons and "nothing else" in calorimeters or tracker
- Candidates for $\gamma\gamma \rightarrow \mu\mu$, $\gamma p \rightarrow J/\psi p$, $\gamma p \rightarrow \Upsilon p$ observed in early low-luminosity CMS data

CMS-DP-2010-035

- In reality: ideal case is spoiled by extra "pileup" interactions in the same bunch crossing
  - In 2011 data, pileup of 7-10

- Reduce sensitivity to pileup with selection based only on tracking/vertexing and muon kinematics

Dimuon mass distribution



- Dimuon invariant mass, normalized to best-fit value
  - Consistent with prediction of LPAIR signal + proton-dissociation
  - Highest-mass event at ~77GeV

warning: $S^2 < 1$

- Establishes $\gamma\gamma \rightarrow \mu\mu$ as a reference channel for other exclusive measurements with pileup in CMS, possibly interesting as a future luminosity measurement

3. Elastic Scattering and Optical theorem

A well established and potentially powerful method for Luminosity Calibration

- $\frac{d\sigma_{el}}{dt} = \frac{\pi}{sp^2}|F_{el}(t)|^2$
- optical theorem: $\sigma_{tot} = \frac{4\pi}{p\sqrt{s}} \text{Im } F_{el}(s, t=0)$
- $L\sigma_{tot} = N_{el} + N_{inel}$
- Need to separate the Coulomb and hadron scattering

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

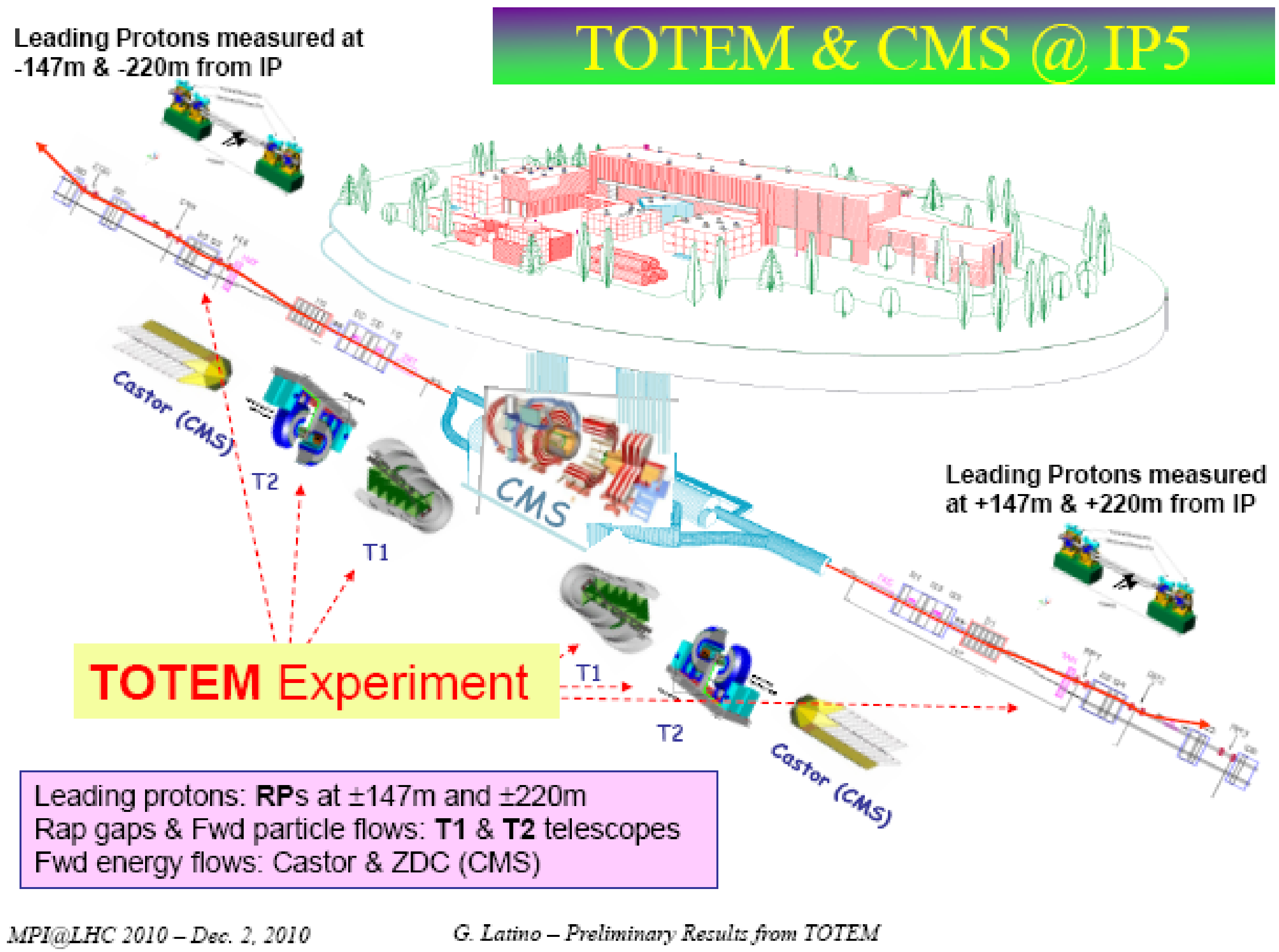
To be measured

- Elastic rate N_{el}
- Differential elastic rate $\frac{dN_{el}}{dt}$ for small $-t$
- Inelastic rate N_{inel}

External input

- $\rho = \frac{\text{Re } F_{el}(s,t=0)}{\text{Im } F_{el}(s,t=0)}$

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



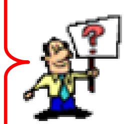
TOTEM-2011

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

Combined uncertainty in σ_{tot} (and L)

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

	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.

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

YES WE CAN

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

With known lumi (3.5% VdM)

TOTEM

- $L\sigma_{tot} = N_{el} + N_{inel}$
- 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 $|t| \rightarrow$ small beam divergence $\rightarrow$ high β^* (parallel to point focusing)

ILLUSTRATION I: INELASTIC EVENT RATE N_{inel}

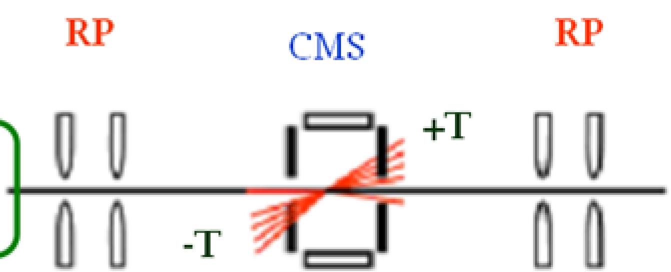
THEORETICAL UNCERTAINTIES in the T1+T2 RUNNING SCENARIO
T1+T2=T, $3.1 < |\eta| < 6.5.$

Maximally (**+T** OR **–T**), expected signal σ_{signal} ~ 0.85-0.95 of σ_{inel}
(depending on the MP- model)

$$\sigma_{inel} = \sigma_{tot} - \sigma_{el}.$$

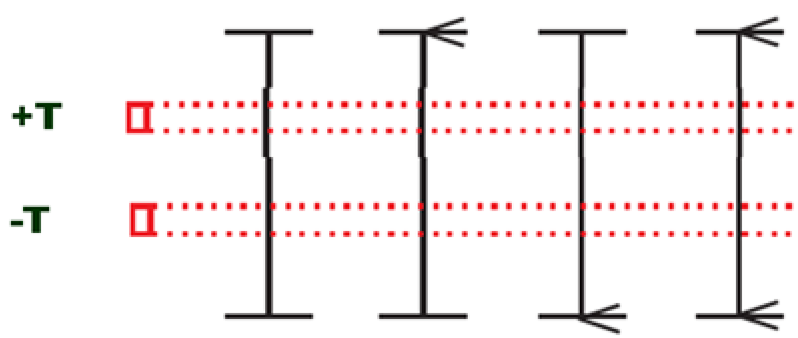
- N_{inel} measured by inelastic detectors T1 and T2
- to suppress background:
  - primary vertex reconstruction with T1 and T2

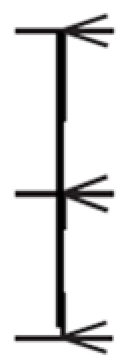
'Double Diffractive' Trigger:



Inelastic (at least 1 'trigger .track' in +T or –T, no RP info)

What is missed then?





multi-gap (DPE)- (very) small

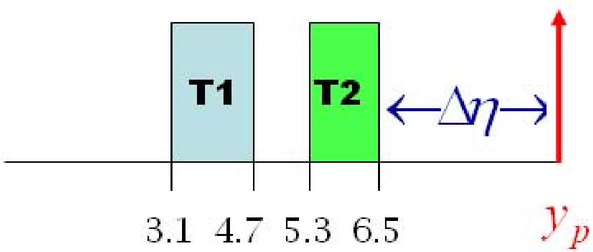
Can we measure σ_{inel} , σ_{SD}, σ_{DD} with high accuracy?

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

Un-instrumented regions: **Totem-CMS** : $M_X \le 2.5 - 3.5 GeV$

Atlas: $M_X \le 7 GeV$

(Castor)

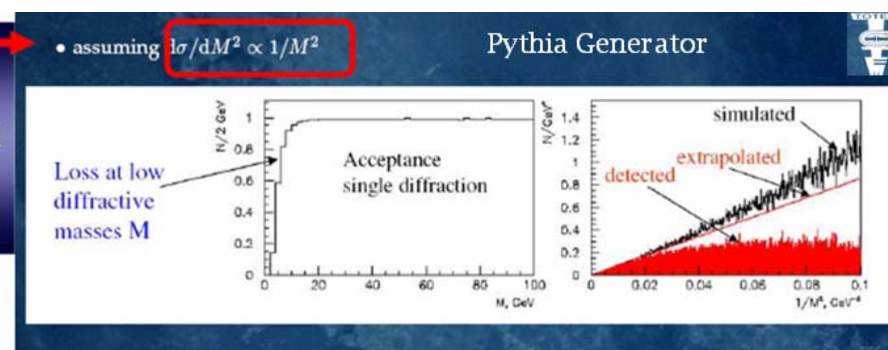


$$\eta = -\ln \tan \frac{\vartheta}{2}$$

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

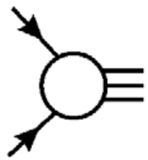
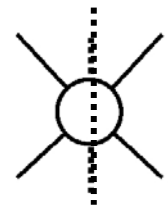
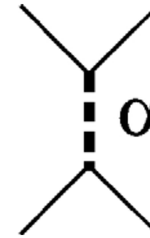
Can we extrapolate from HM SD ?

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

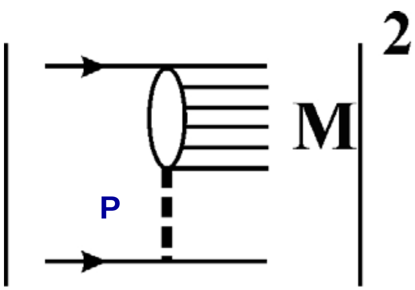


(UA4-experience ☞ factor of 2 for M<4 GeV)

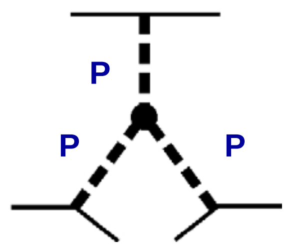
A diffractive process is characterized by a large rapidity gap (LRG), which is caused by t-channel Pomeron exch.

$$\sigma_{total} = \sum_X \Big|$$  $$X\Big|^2 = \mathrm{Im}$$  $$=$$  $$\alpha_{I\!P}(0)$$

High mass diffractive dissociation



=



PPP-diagram

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

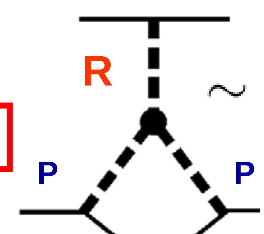
Screening is very important.
(semi) enhanced absorption …

(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** ~**$1/M^3$**

PPR-diagram

To illustrate the size of uncertainties we compare two models.

$\sqrt{s} = 7$ TeV.

	(mb) σ_{tot}	σ_{inel}	+T	(+T OR –T)	(+T & –T)
SO-2010	95.8	71.0	62.8	66.1	59.3
KMR-2009	88.6	68	50.2 (51.8)	58.7 (61.0)	41.8 (42.6)

$\sqrt{s} = 14$ TeV.

	σ_{tot}	σ_{inel}	+ T	(+T or –T)	(+T & –T)
SO-2010	108	78.5	69.1	72.0	66.0
KMR-2009	91.5	70.0	50.7	59.0	42.4

V. A. Khoze, A. D. Martin and M. G. Ryskin, Phys. Lett. B **679**, 56 (2009).
Eur. Phys. J. C60, 249 (2009) KMR-2009

S. Ostapchenko : **arXiv:1010.1869** [hep-ph] SO-2010

Model expectations for total inelastic cross-section

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

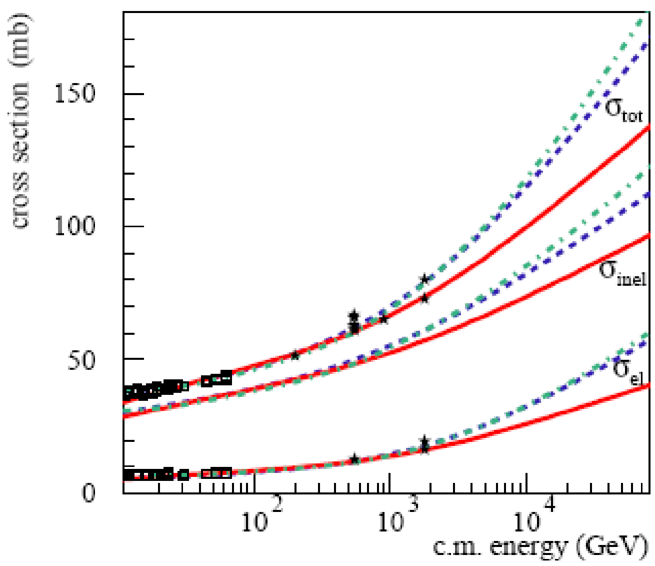


Figure 1: Model predictions for total, elastic, and inelastic proton-proton cross sections: QGSJET-II-4 - solid, QGSJET-II-3 - dashed, and SIBYLL - dot-dashed. The compilation of data is from Ref. [17].

S.Ostapchenko, ArXiv:1103.5684)

$\sqrt{s} = 7$ TeV

(in mb)	$\sigma_{\rm inel}$	$\sigma^{\rm LM}_{\rm SD} + \sigma^{\rm LM}_{\rm DD}$
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**

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	5.15	8.22	4.24 (4.14)	1.08	2.50
Set (C)	114	33.0	11.6	4.83	5.76	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

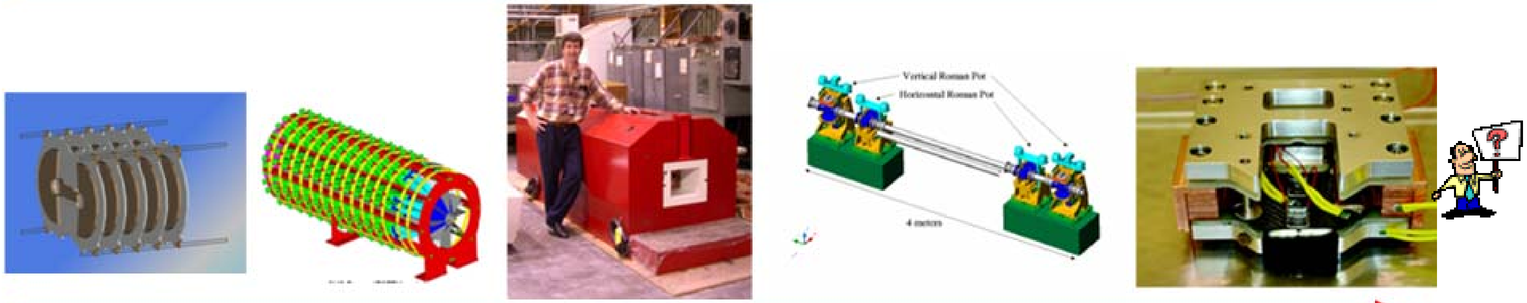
Large variation of σ^{SD}_{LM} in the range 5- 10.5 mb

- 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.

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

TOTEM -T2 | CASTOR | ZDC/FwdCal | TOTEM-RP | HPS

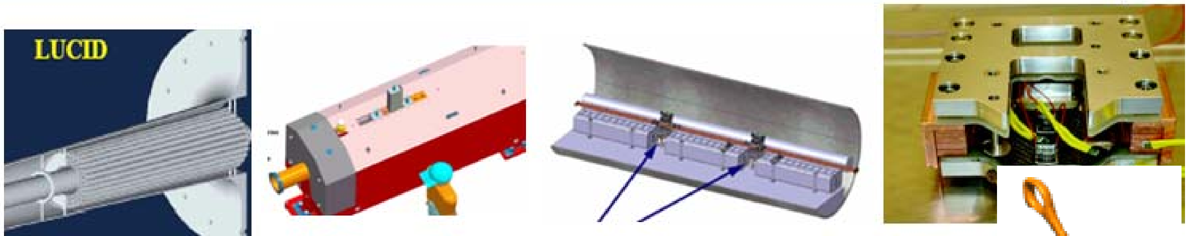
CMS
TOTEM



IP5

14 m | 16 m | 140 m | 147m - 220 m | 420 m

IP1



ATLAS

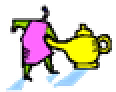
LUCID | ZDC | ALFA/RP220

	Pseudorapidit
LUCID	$5.6 < |\eta| < 5.9$
ZDC	$|\eta| > 8.3$

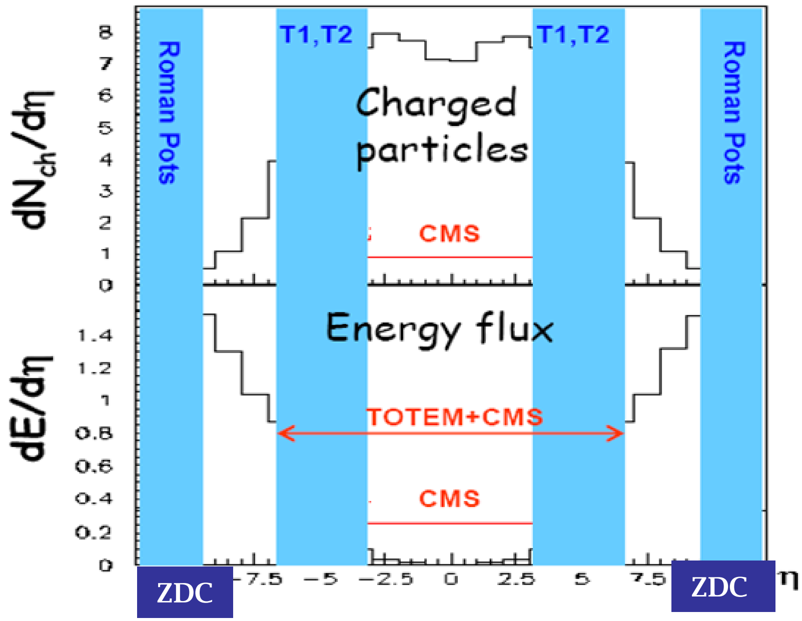
AFP

(STFC cutting rule)

Hope



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



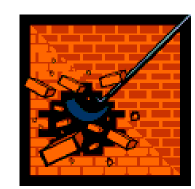
BUT

- 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!



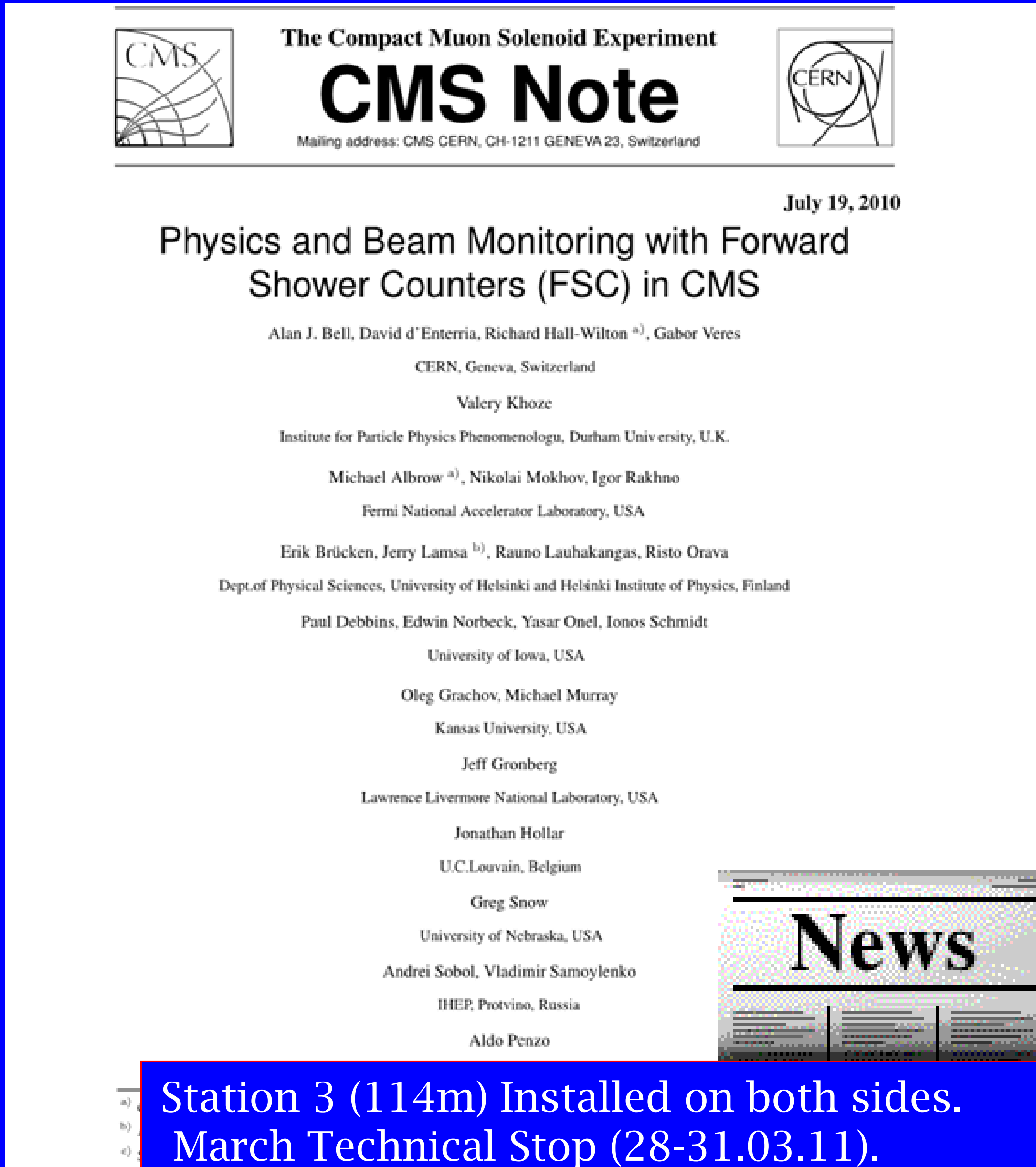
(8 FSC per side see showers from particles with $|\eta| = 7\text{-}9$)

20 years ago

- A Full Acceptance Detector for the SSC (J.D. Bjorken, SLAC-PUB-5692, 1991)
  - In addition 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]



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, USA

Jonathan Hollar

U.C.Louvain, Belgium

Greg Snow

University of Nebraska, USA

Andrei Sobol, Vladimir Samoylenko

IHEP, Protvino, Russia

Aldo Penzo

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.
March Technical Stop (28-31.03.11).
Stations 1&2- to be installed in May (next Techn. Stop)

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

24

Mike's priority now - gap+X+gap triggers.
SD measurement requires all counters + low lumi run

What about total inelastic cross section σ_{INEL}? And total σ_{TOT} if you know σ_{EL} ?

Not done at Tevatron!

Can measure rate of totally empty events, $P(0) = \exp(-\langle n_{inel} \rangle)$
But this misses all the low mass diffraction that give hits
only with $|\eta| >\sim 6$, or $M <\sim 5$ GeV/c^2
This is many mb!

Nobody can measure σ_{INEL} directly, only $\sigma_{TOT} - \sigma_{EL}$ **?**

With FSC, P(0) only faked by events with all particles in cracks
(can study with fake cracks) or inefficient regions (small);
and inefficient because of noise (can study with data).

CMS

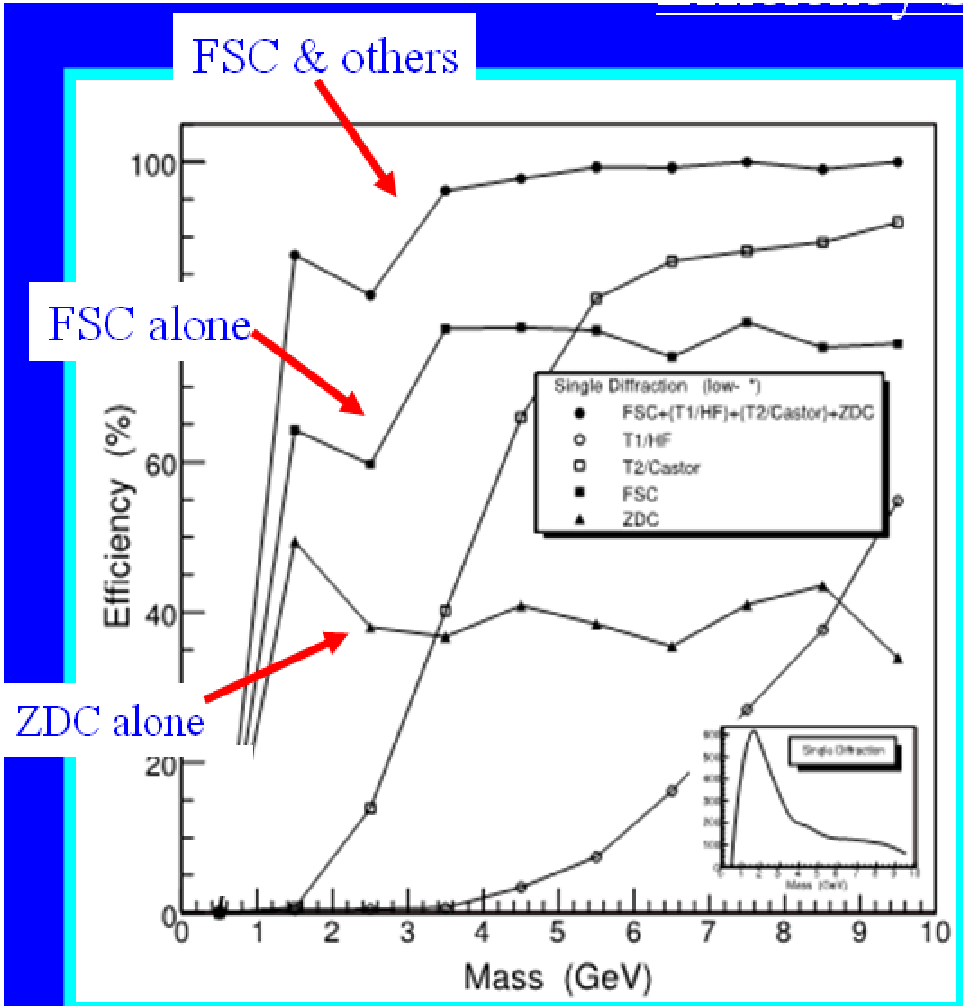
DIS-2011

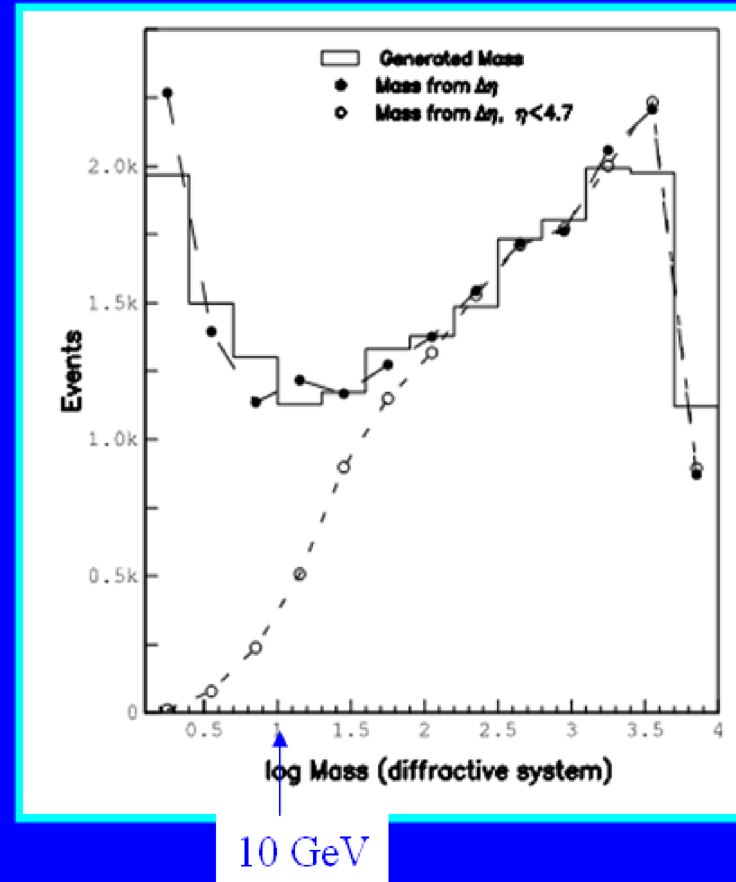
- **We measure the inelastic pp cross section using pile-up (PU) events:**

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

$$P(n_{pileup}) = \frac{(L \cdot \sigma)^{n_{pileup}}}{n_{pileup}!} \cdot e^{-(L \cdot \sigma)}$$

But still LM- diffraction





>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/c^2 FSC contain most particles

The FSCs- 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 precise measurement of SD?

Don't hold your breath, Valery.
This certainly needs all the counters and some low lumi runs (Mike Albrow)

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

N_{inel}

SUMMARY II

Optical theorem

- In the ideal world we would need full coverage detectors to make precise measurement.
- T1+T2 detectors could allow to detect about 0.8-0.9 of inelastic events.
- Because of un-instrumented region of low-mass diffraction we miss about 5-11 mb in σ_{inel}

  We cannot relay on current MC models when attempting to achieve precise extrapolation to the uncovered regions.
- With beam energy increasing the un-instrumented region rises, and, thus, the uncertainties.
- Running scenarios with Roman Pot triggers might be beneficial, but this requires

  comprehensive studies.

- Common data taking by CMS and TOTEM + FSC (especially T1/T2 + ZDC+FCS) will allow to measure (first time after the ISR) the low-mass SD, and thus, hopefully, to reduce the uncertainties in the inelastic rate to 1% level.
- FSC could serve as an additional luminosity monitor.

σ_{tot}, σ_{inel}, σ^{SD} ... ☞ very important physics quantities. Let's measure them at the LHC

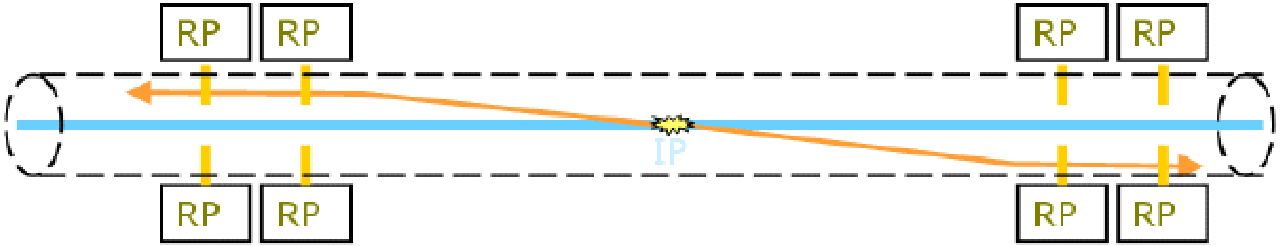
CR physics, the LHC is above the 'knee'.

Coulomb

ALFA = Absolute Luminosity For ATLAS

Elastic scattering at very small angles

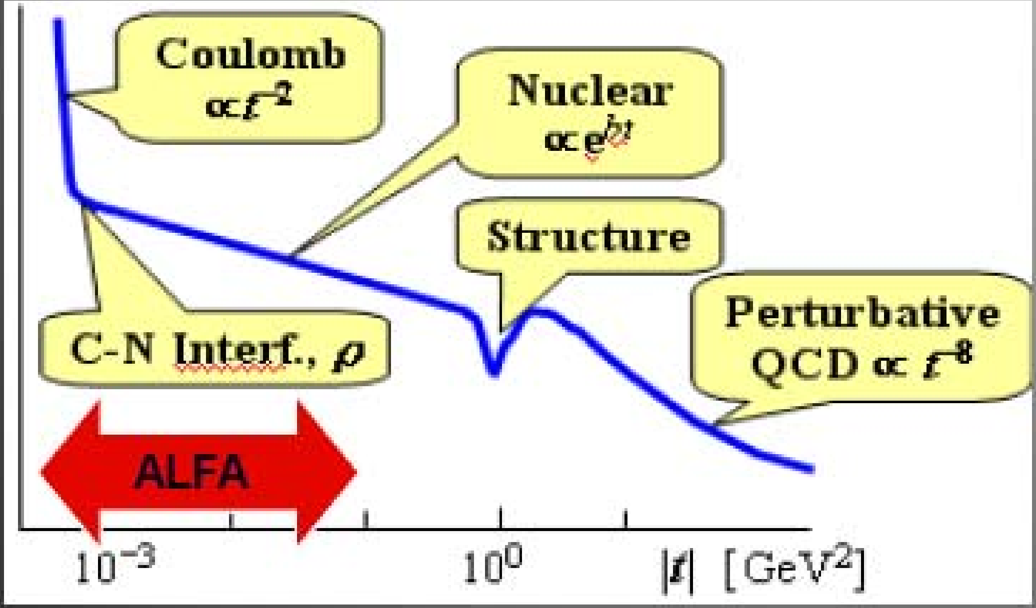
- Measure elastic scattering at such small t-values that the cross section becomes sensitive to the Coulomb amplitude
- Effectively a normalization of the luminosity to the exactly calculable Coulomb amplitude
- No total rate measurement and thus no additional detectors near IP necessary
- UA4 used this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

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 d*N* / dt

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

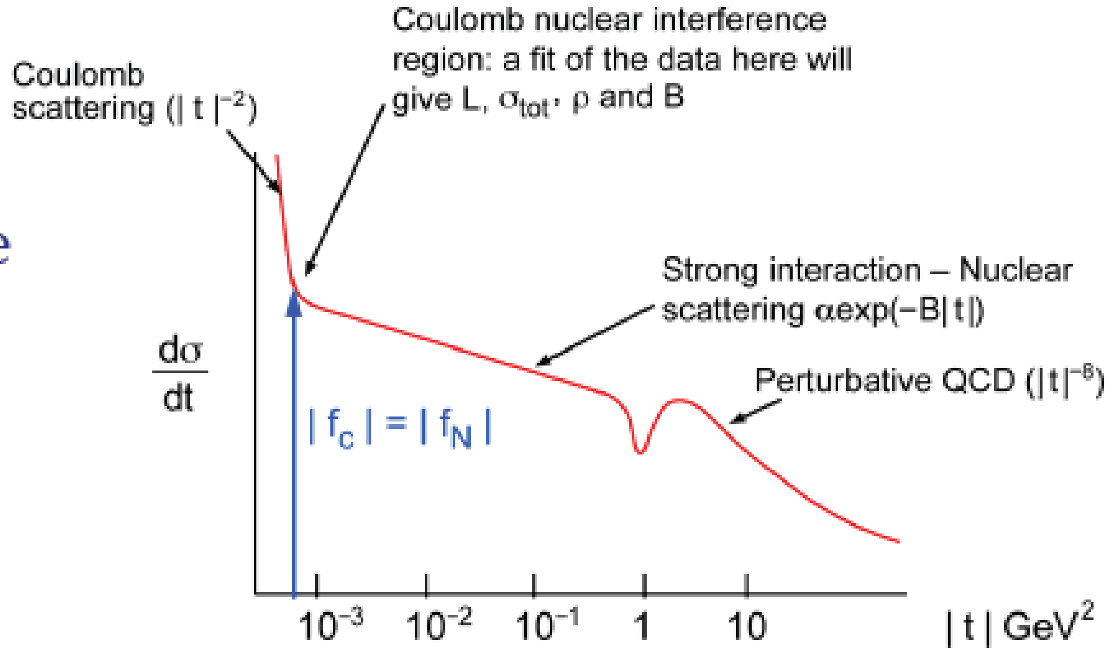
→ Detector positions far from IP

→ Special beam settings

→ Detectors close to beam

For the Future: ALFA

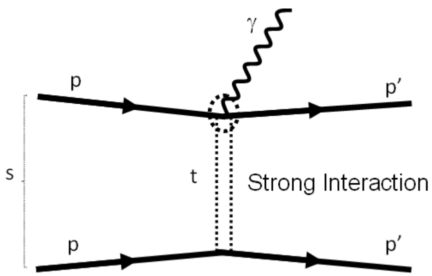
- Principle: use **elastic scattering** in Coulomb interference region to measure for σ_{tot} and $\mathcal{L}$
- Use measured $\mathcal{L}$ value to calibrate luminosity detectors to 2-3%
  - **Complementary** to beam-separation scans with uncorrelated systematic uncertainties



- Technically challenging:
  - need to measure at 3.5 μrad (10σ) from LHC beam:
  - Will require special LHC runs at high β^* and low $\mathcal{L}_{inst}$: 90m (2011), 2km (2013+)

Soft photon radiation accompanying elastic pp- scattering.

R.Orava et al, arXiv:1007.3721 ;
H.Gronquist et al, arXiv:1007.3721



Detect 50 – 500 GeV photons at ~ 0 degrees

$$\Gamma_\gamma = \frac{2\alpha_{em}}{3\pi} \frac{\langle p_t^2 \rangle}{m^2} \frac{dk}{k}.$$

LIGHT SHINNING THROUGH THE HOLE

- small t $\Rightarrow$ theor. uncertainties minimal
- $\Rightarrow$ direct relation between the photon spectra and $\sigma(pp)_{el}/B \sim (\sigma_{el}/\sigma_{tot})^2$
- bremsstrahlung cross section is large: ~ 0.18 x 10^{-3} of σ_{el}
- theor. uncertaint. in $(\sigma_{el}/\sigma_{tot})^2$ are large: 0.05-0.09 or more (0.45- TT-03).
- $N_{\gamma\gamma}/N_\gamma \sim 1/B$; $\frac{d\sigma_{el}^{pp}}{dt} \longrightarrow \sigma_{el}^{pp} B \exp(-B|t|)$

(in principle, a Lumi inependent way to measure eff. elastic slope B)..

Detection advantages, but rate low.

- **Bremsstrahlung photons close to 0 degrees – can be used for alignment (RP's, ZDC), luminosity monitoring.**

BFK-1966

Experience at ee colliders (VEP-I,VEPP-II, ACO, ADONE) and at HERA

Slide from R. Orava- Diffraction 2010

ROAD MAP

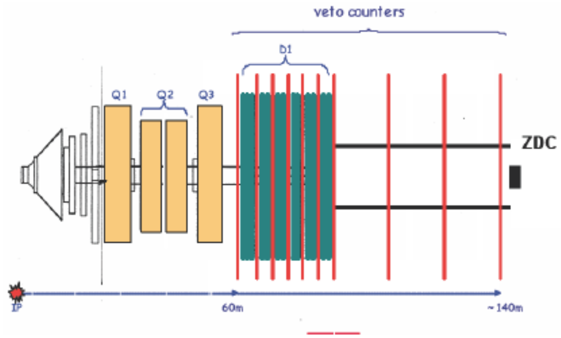
- Use luminosity from the W/Z standard candle measurements or from the beam scan (Van der Meer) $\Rightarrow$ model-independent way to measure $(\sigma_{el} / \sigma_{tot})^2$
- The ZeroDegreeCalorimeter (ZDC) for detecting the bremsstrahlung gammas - the Forward Shower Counters (FSC) to veto backgrounds.
- The set-up of the proposed measurement with k=50-500 GeV and for 3.5 x 3.5 TeV and/or 5 x 5 TeV.

Triggers and Backgound

Slide from H. Gronquist- ISMD-2010

- Main background consists of photons emitted in ineastic diffractive events.
  Non-diffractive events constitute a secondary background.
- For the chosen energy range 50-500 GeV the backgound-to-signal ratio is estimated to be $< 5\%$

- To reduce background further, Forward Shower Counters, FSCs, can be added closely surrounding the beam pipes, at $z \in (60, 120)$m from the interaction point

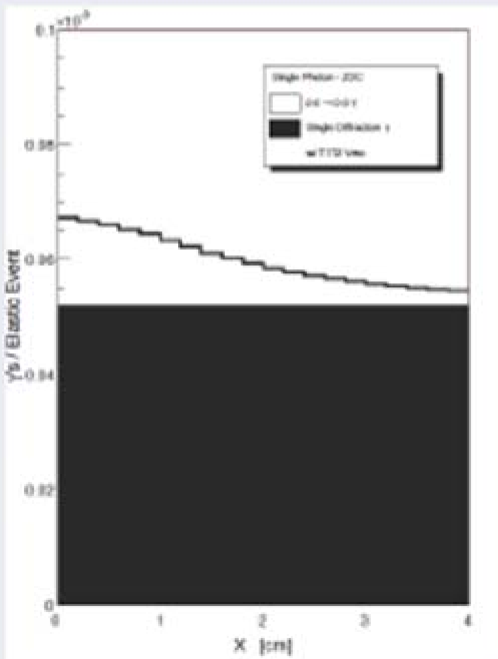


Luminosity, if σ_{el} and B are known

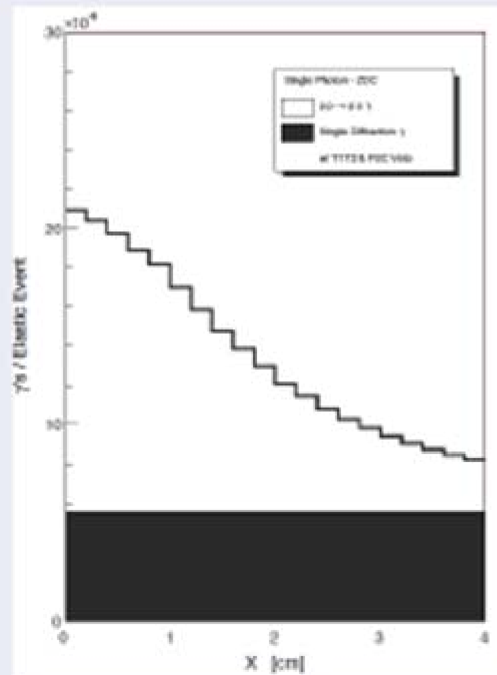
Results from simulations

- According to simulations the probability of detecting a single photon in the ZDC from radiative elastic scattering is :

T1T2 Veto



T1T2 & FSC Veto



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

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

HE cosmic rays

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

A.Erlykin & A.Wolfendale-2010
(LHC data & the origin of the 'knee')

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.

V. Overall conclusions

- We briefly discussed some most popular methods for ‘indirect’ luminosity determination, focussing on potential theoretical uncertainties and the ways how to reduce these.

- On the theory side there seems to be no showstoppers for the dimuon QED production.. Can be performed during the normal collision data taking. However the cross section is small , thus problems with keeping small stat. error on Lumi.

- Optical theorem approach is a potentially very powerful method for Luminosity Calibration. However, for a precise measurement of elastic rate we need special optics, while a very accurate determination of N_{inel} would require a combination of TOTEM with CMS (in particular, ZDC) +FSC. More studies needed.

- σ_{tot} , σ_{inel} ; σ^{SD} are very important physics quantities. **Should be measured at LHC!**

  (TOTEM +CMS, ALFA)

- Further development of theoretical models for HE soft hadron interaction is an important goal as well as creation of “all purpose” Monte Carlo models, tuned to describe various features of elastic and diffractive processes and multi-particle production.

- For first year of operation the LHC precision is surprisingly good. More results to come.


THANK YOU


QUESTIONS?

BACKUP

What means special effort?

Calibration runs

i.e calibrate the relative beam monitors of the experiments during dedicated calibration runs.

- Calibration runs with simplified LHC conditions
  - Reduced intensity
  - Fewer bunches
  - No crossing angle
  - Larger beam size
  - ....

- Simplified conditions that will optimize the condition for an accurate determination of both the beam sizes (overlap integral) and the bunch current.

Luminosity measurements at LHCb

Direct Measurements

- Direct measurement of beam parameters - shape, current etc.
- Two methods employed
  - Van der Meer scan (ATLAS, CMS, ALICE)
  - Beam profiling via beam gas interactions

Indirect Measurements

- Measure the event rate of some theoretically well known process
- Precision determined by:
  - The uncertainty on the cross-section prediction
  - Experimental uncertainties (efficiencies etc.)
- Two processes identified at LHCb for this purpose
  - W & Z production (ATLAS, CMS)
  - Dimuon production via two photon fusion (CMS)

Determination of the overlap integral (pioneered by Van der Meer @ISR)

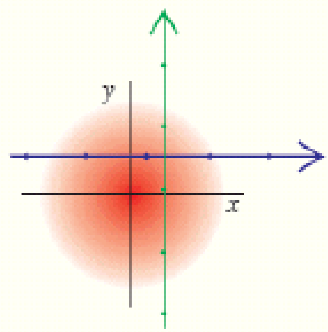
ISR-record 1%

$\frac{\delta x}{\sigma_x}$	$\frac{\delta y}{\sigma_y}$	$\frac{\mathcal{L}}{\mathcal{L}_0}$
0	0	1
1/2	0	0.9394
1/2	1/2	0.8825
1	0	0.7788
1	1	0.6065
2	0	0.3679
2	2	0.1353

Luminosity with separation

$$\frac{\mathcal{L}}{\mathcal{L}_0} = \exp\left[-\left(\frac{\delta x}{2\sigma_x}\right)^2 - \left(\frac{\delta y}{2\sigma_y}\right)^2\right]$$

Commissioning : simple, orthogonal x / y scan



2010- CMS,ATLAS,LHCb, ALICE ~11% accuracy , 3-4% in 2011

vdM-scans

Main uncertainty: currents in the LHC magnets

Luminosity from Machine parameters

- Luminosity depends exclusively on beam parameters:

$$\mathcal{L} = \frac{N^2 f_{rev} n_b}{4\pi\sigma^{*2}}$$

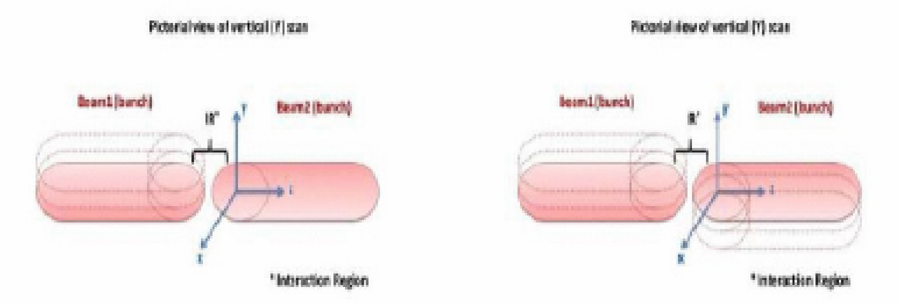
Depends on f_{rev} revolution frequency
n_b number of bunches
N number of particles/bunch
σ^* beam size or rather overlap integral at IP

$$\sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}$$

The luminosity is reduced if there is a crossing angle (300 μrad)

- Luminosity accuracy limited by
  - extrapolation of σ_x, σ_y (or ε, β_x^*, β_y^*) from measurements of beam profiles elsewhere to IP; knowledge of optics, ...
  - Precision in the measurement of the the bunch current
  - beam-beam effects at IP, effect of crossing angle at IP, ...

Van der Mer scan



$$L = \frac{n_b f_r I_1 I_2}{2\pi \Sigma_x \Sigma_y}$$

Source	Uncertainty on σ_{vis} (%)
Beam intensities	10
Lenght scale	2
Imperfect beam centering	2
Transverse emittance changes	3
mu dependence	2
Total	11

Algorithm	Scan number	σ_{vis} (mb)	L_p $(10^{29} cm^{-2} s^{-1})$
LUCID event AND	1	12.15 ± 0.14	6.80 ± 0.08
	2	12.55 ± 0.10	4.85 ± 0.03
	3	12.73 ± 0.10	4.88 ± 0.09
LUCID event AND	1	39.63 ± 0.32	6.85 ± 0.06
	2	40.70 ± 0.13	4.88 ± 0.01
	3	40.77 ± 0.14	4.92 ± 0.02

Summary

TOTEM is ready for a first σ_{tot} and luminosity measurement in 2011 with $\beta^* = 90$m using the Optical Theorem.

Expected precision: ~3% in σ_{tot} , ~4% in L

Wish: start soon with the development of the $\beta^* = 90$m optics to have enough time for learning.

Desired running conditions: low beam intensity, small RP distance to the beam

Longer term:

Measurement at the 1% level with very-high-β^* optics (~1 km);

might give access to the ρ parameter if the energy is still low ($\sqrt{s} \sim 8$ TeV);

needs optics development work.

First CDF results-2007

pp->pμμp

- No backward tracks
- Precisely two forward muons. $m_{\mu\mu}$>2.5 GeV
- No photons

pμμp: 67 +- 19 pb   LPAIR (J. Vermaseren) 42 pb

Sample and muon selection

- Use the full 7TeV 2010 sample collected by CMS ($40pb^{-1}$)
- Restrict to a region of phase-space with well-understood muon systematics, and above the exclusive $\gamma p \rightarrow \Upsilon p \rightarrow \mu\mu p$ region
  - $p_T(\mu) > 4$ GeV, $\eta(\mu) < 2.1$, $m(\mu\mu) > 11.5$ GeV
- Trigger on two muons with $p_T(\mu) > 3$ GeV, tight muon reconstruction and identification as used in CMS *W/Z* cross-section analyses
  - Trigger, muon ID, and tracking efficiencies corrected using control samples of muons from inclusive $J/\psi \rightarrow \mu\mu$ and $Z \rightarrow \mu\mu$ production
- Muon pair kinematics – require muons be back-to-back in ϕ, balanced in p_T
  - $\Delta p_T(\mu\mu) < 1.0$ GeV
  - $1 - |\Delta\phi(\mu\mu)/\pi| < 0.1$
  - Require an opening angle $<0.95\pi$ to suppress cosmic ray muons

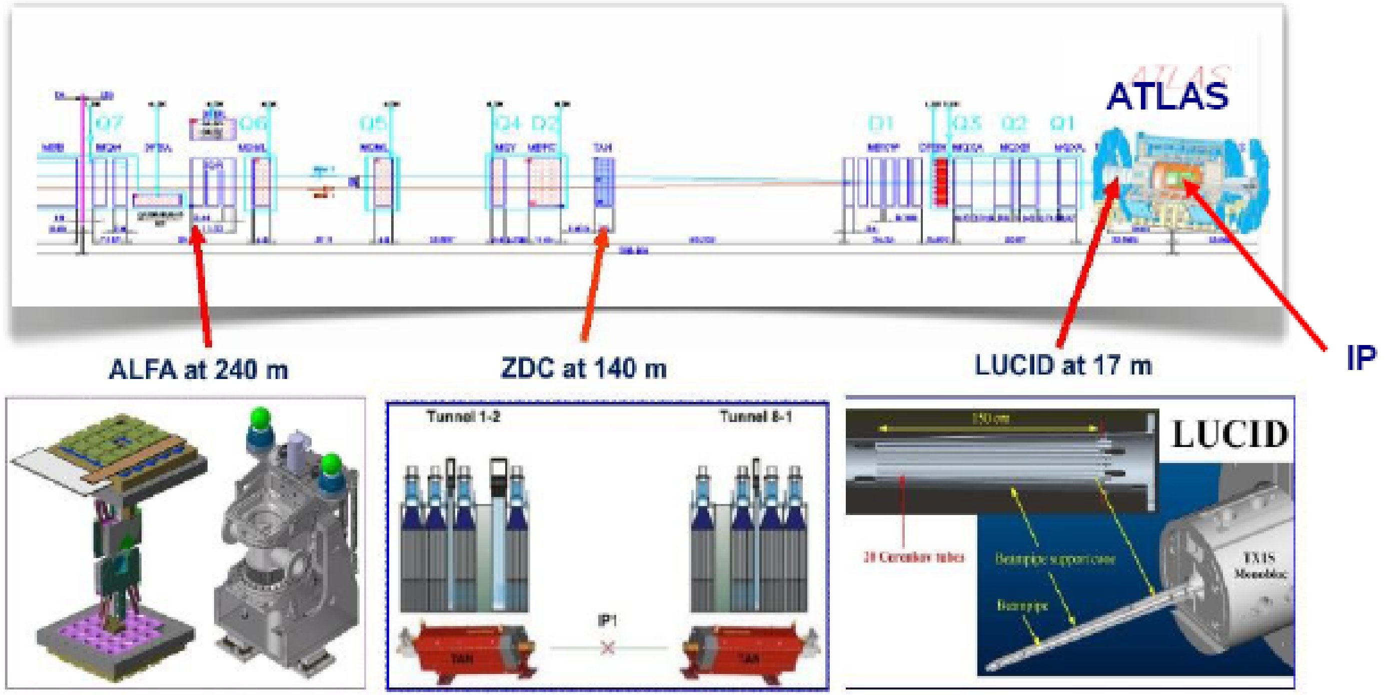
CMS PAS FWD-10-005

Rejection of Proton Dissociative Events

- Don't rely on simulation for cut efficiency and rejection factor
- Use FSC to discriminate between the three contributions: (el-el, el-inel and inel-inel)
- Select "no-pileup" events ("empty" detector except for $\mu\mu$)
- Classify events as FSC empty both sides, one side or neither
- Compare $\Delta\phi_{\mu\mu}$ and $p_T^{\mu\mu}$ distributions for three classes
- Measures relative fraction of el-el, el-inel and inel-inel and tests factorization
- Provides templates for $\Delta\phi_{\mu\mu}$ and $p_T^{\mu\mu}$ distributions

Without FSC, precision luminosity measurement limited by knowledge of cross section for proton dissociation and associated cut kinematics.

The ATLAS forward detectors



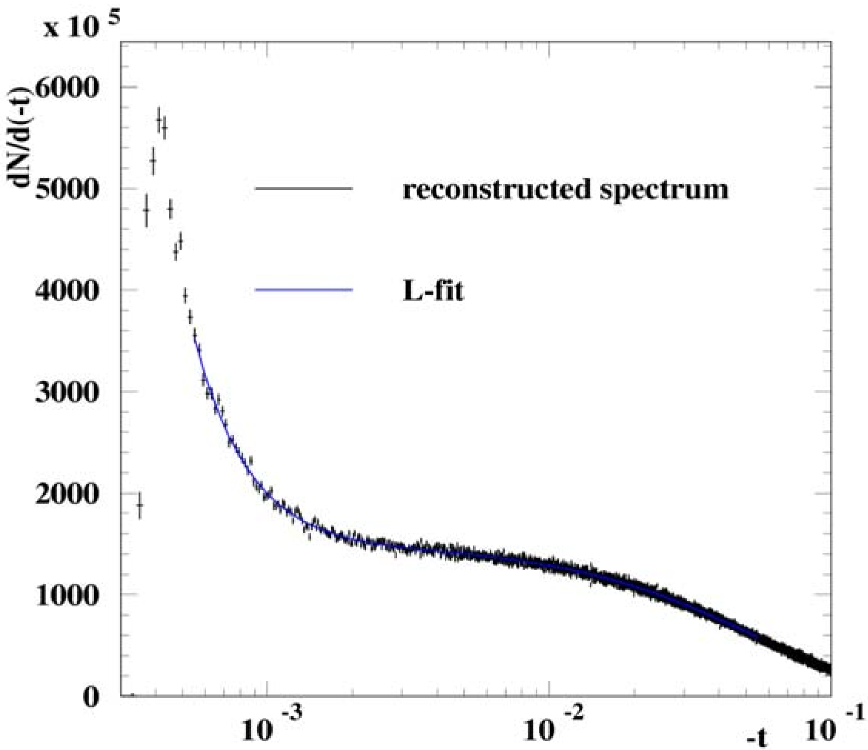
	Pseudorapidity	Position (from IP)
LUCID	$5.6 < \|\eta\| < 5.9$	± 17 m
ZDC	$\|\eta\| > 8.3$	± 140 m
ALFA	$10.6 < \|\eta\| < 13.5$	± 240 m

6

L from a fit to the t-spectrum

$$\frac{dN}{dt} = L\pi\left|F_C + F_N\right|^2$$

$$= L\left(\frac{4\pi\alpha^2(\hbar c)^2}{|t|^2} - \frac{\alpha\rho\sigma_{tot}e^{-B|t|/2}}{|t|} + \frac{\sigma_{tot}^2(1+\rho^2)e^{-B|t|}}{16\pi(\hbar c)^2}\right)$$



Simulating 10 M events,
running 100 hrs
fit range 0.00055-0.055

	input	fit	error	correlation
L	8.10 10^{24}	8.151 10^{24}	1.77 %	
σ_{tot}	101.5 mb	101.14 mb	0.9%	-99%
B	18 Gev^{-2}	17.93 Gev^{-2}	0.3%	57%
ρ	0.15	0.143	4.3%	89%

large stat.correlation between
L and other parameters

38

➔ Δ L / L ~ 3% seems to be possible