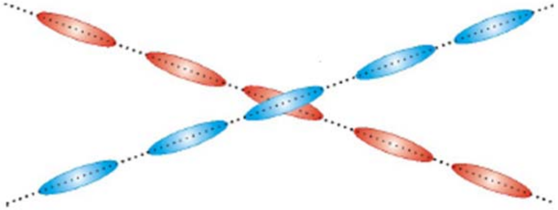
Precision targets for luminometry at the LHC from theoretical perspective

V.A. Khoze (IPPP, Durham)



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.

Already ~ 4%

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 determinations*

Convener: Michelangelo Mangano (CERN)

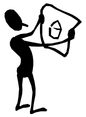
- 09:00 **Welcome and introduction** *05'*
  Speaker: Massimiliano Ferro-Luzzi (CERN)
- 09:05 **Motivations and precision targets for luminosity** *20'*
  Speaker: Michelangelo Mangano (CERN)
  Material: Slides
- 09:30 **Indirect luminosity measurements: theoretical assessment** *30'*
  Speaker: Valery 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 **F**ull **A**cceptance **D**etector 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?

- Cross sections for "Standard " processes
  - t-tbar production
  - W/Z production
  - …….
- New physics manifesting in deviation of σ x BR relative the Standard Model predictions
- Important precision measurements
  - Higgs production σ x BR
  - tanβ measurement for MSSM Higgs
  - …….

PRIOR to the LHC START-UP

Any deviations in the rates from the SM expectations

Ten Years Back

L^3

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

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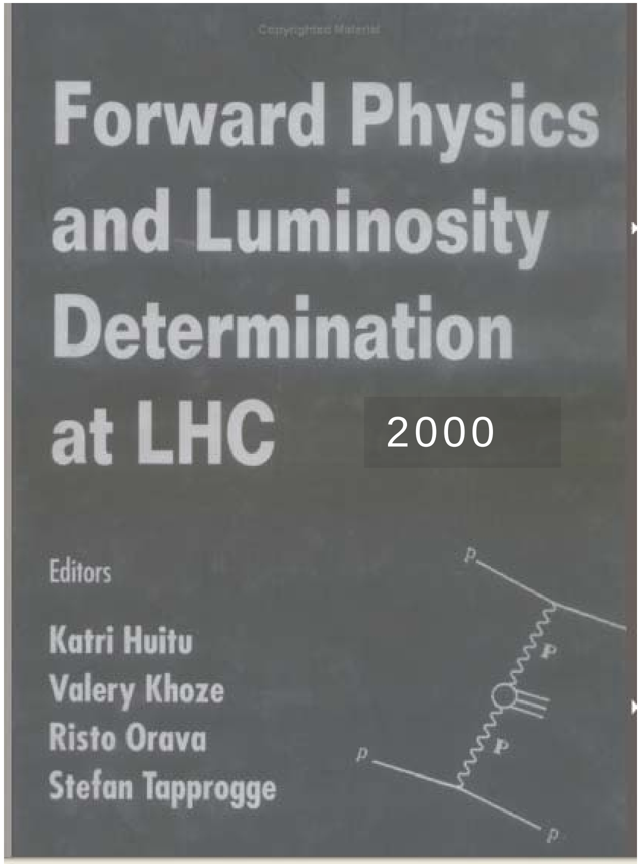
Received: 18 October 2000 / Revised version: 9 February 2001 /
Published online: 15 March 2001 – © Springer-Verlag 2001

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.

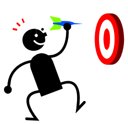


Absolute and relative luminosity measurements

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

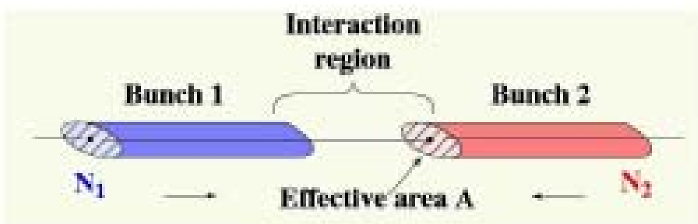


Target: to illustrate how well calculable could be standard 'low-Q^2' processes proposed for luminosity calibration (in the real world environment).

The 2 ways of luminosity measurement

Direct from machine parameters

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



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

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

Beam profiling via beam-gas inter. -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, (lepton pairs)
  or σ_{tot} via optical theorem
- 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

Which precision do we want?

Example III (W and Z production, and determination of PDFs)

will be measured to sub-% level

$$\int dx_1\, dx_2 \sum_{i,j} f_i(x_1)\, f_j(x_2)\, \boxed{\hat{\sigma}_{(ij\to Z)}}\, \boxed{M_Z, g_{EW}} \ldots) = \frac{\boxed{N_{events}(Z)}}{\text{Luminosity}}$$

known to 2%, most accurately known elementary cross section at the LHC

known to sub-%o level

$$\sigma(f_i\, f_j) \sim 2\% \oplus \sigma(\text{lum})$$

The real precision cannot be estimated naively like this, because of the convolution integral, external constraints on the range of PDFs, etc. See later for concrete examples

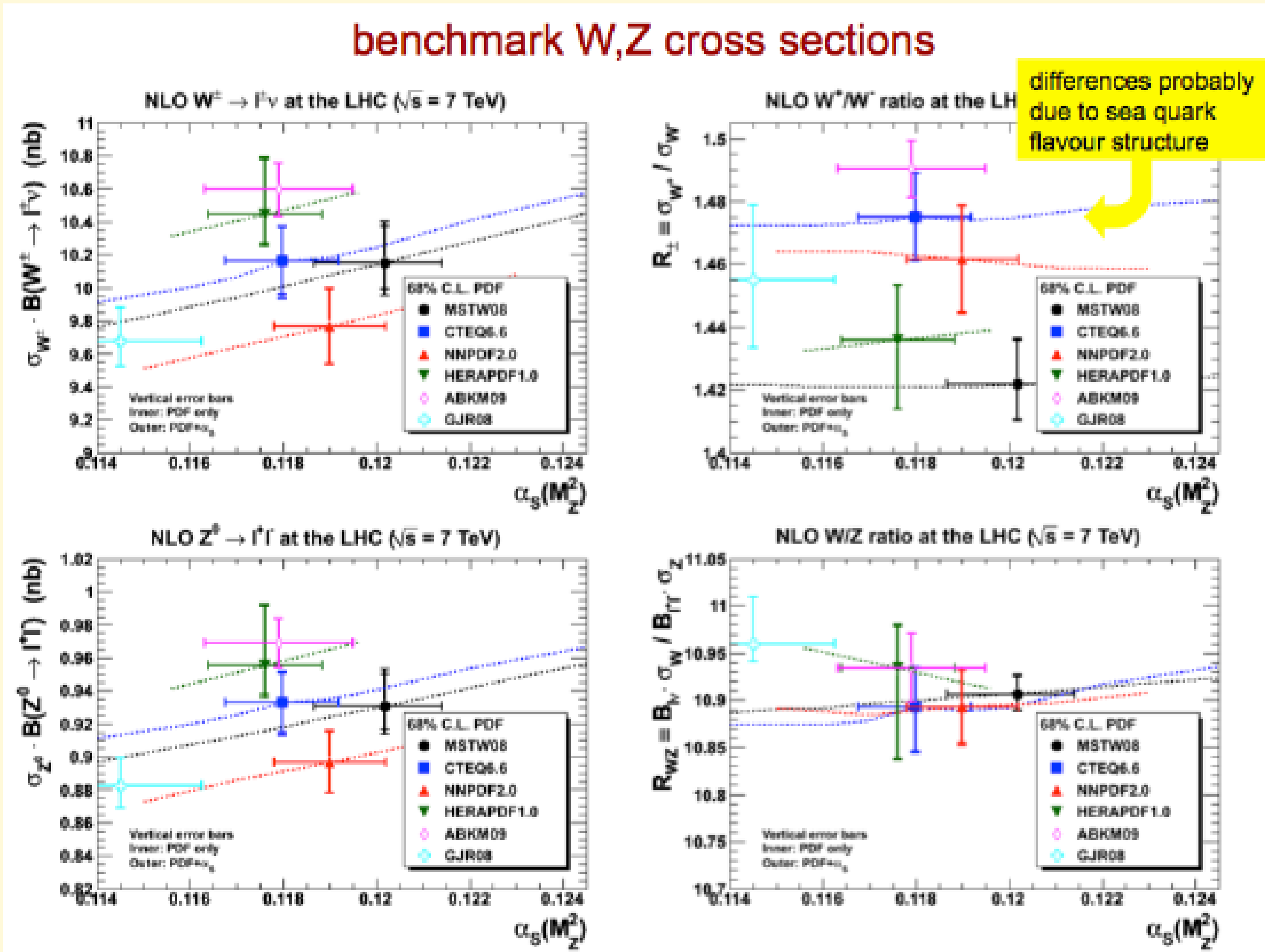
This is the process that defines, as of today, the ultimate target of the absolute luminosity measurements:

± 2%

slides from Mangano's talk

(Personal doubts)

From G.Watt, and W.J. Stirling talk at Trento Workshop "LHC at the LHC"



Current level of PDF systematics on W and Z cross section predictions: ~ ±5%

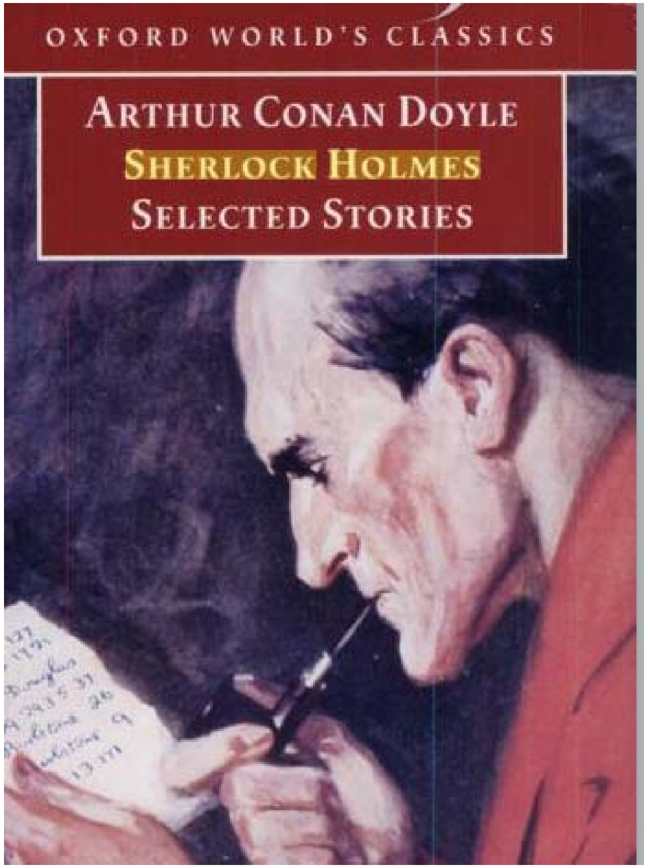
⇒ a luminosity measurement better than 5% would allow to make progress

'LOW-Q^2 ' -APPROACHES

Reggeon Field Theory, Gribov- 1986

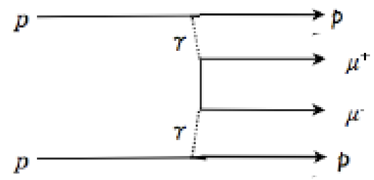
A large variety of theoretical models for soft hadron interactions..
Difference in the predictions for LHC x-sections up to a factor of 2.
(Most) probable models should
- be theoretically self-consistent
- allow good description of the available data in the ISR-Tevatron range (+LHC).

'Well, it is a possible supposition.'
'You think so, too ?'
'I did not say a probable one'



$\mu\mu$

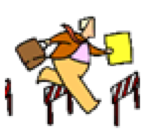
2. Exclusive QED Lepton Pair Production



- 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.

Myth:

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



Reality

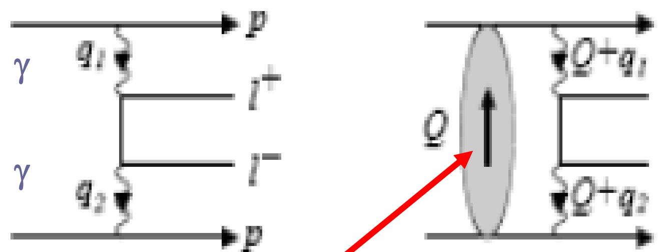
- Strong interaction effects (we collide protons after all).
- **Backgrounds**:
mis-ID, various contributions due to the incomplete exclusivity (lack of full detector coverage), pileup…

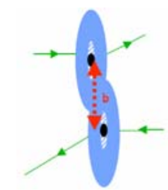
$\mu\mu$

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 $p_t(\mu\mu) \sim 10\text{–}50\ \mathrm{MeV}$ absorpt. correction $2\delta < 0.3\%$.
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...)

$\mu\mu$

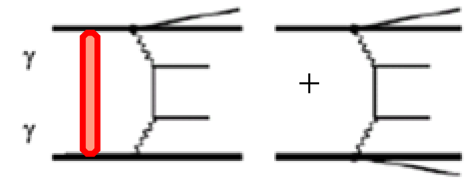
Main Backgrounds

- **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).

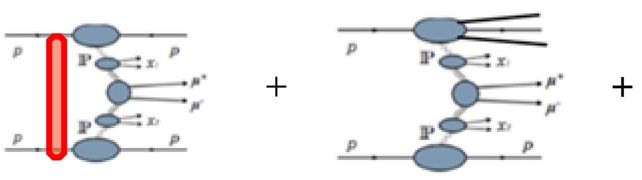
  For P_t >> $P_t(\mu\mu)$ the strong interaction effects are less than 1%.



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

  Usually evaluated using POMWIG (or DPEMC) MC.

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



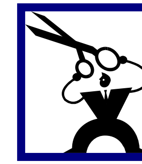
  Without proton dissociation $S^2_{PP} \simeq 0.1$, but , in reality, some particles accompanying dimuons could go undetected, thus some increase of the effective survival factor.
  Strong dependence on experimental conditions.

- 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) μμ

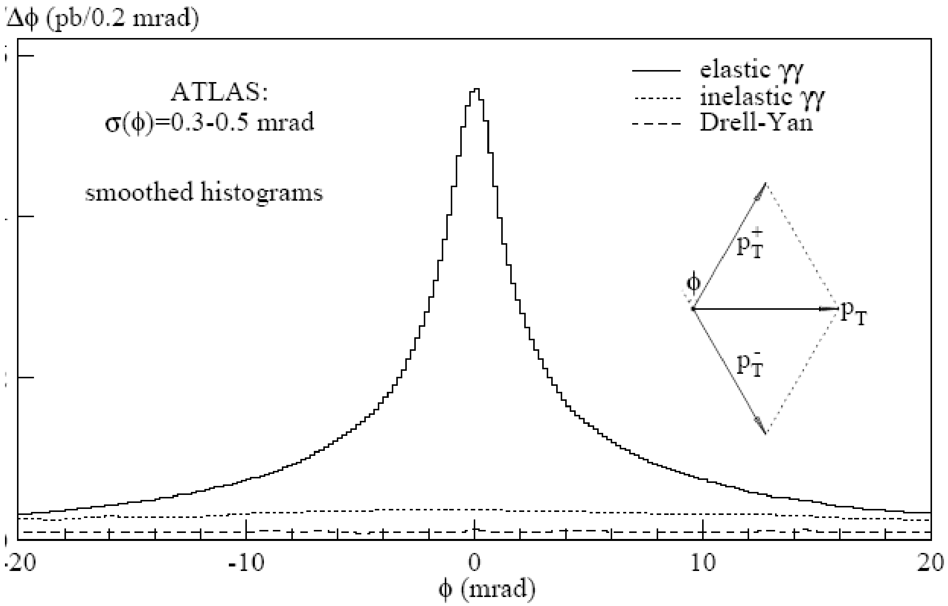
Old recipe: cut, cut and fit.



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

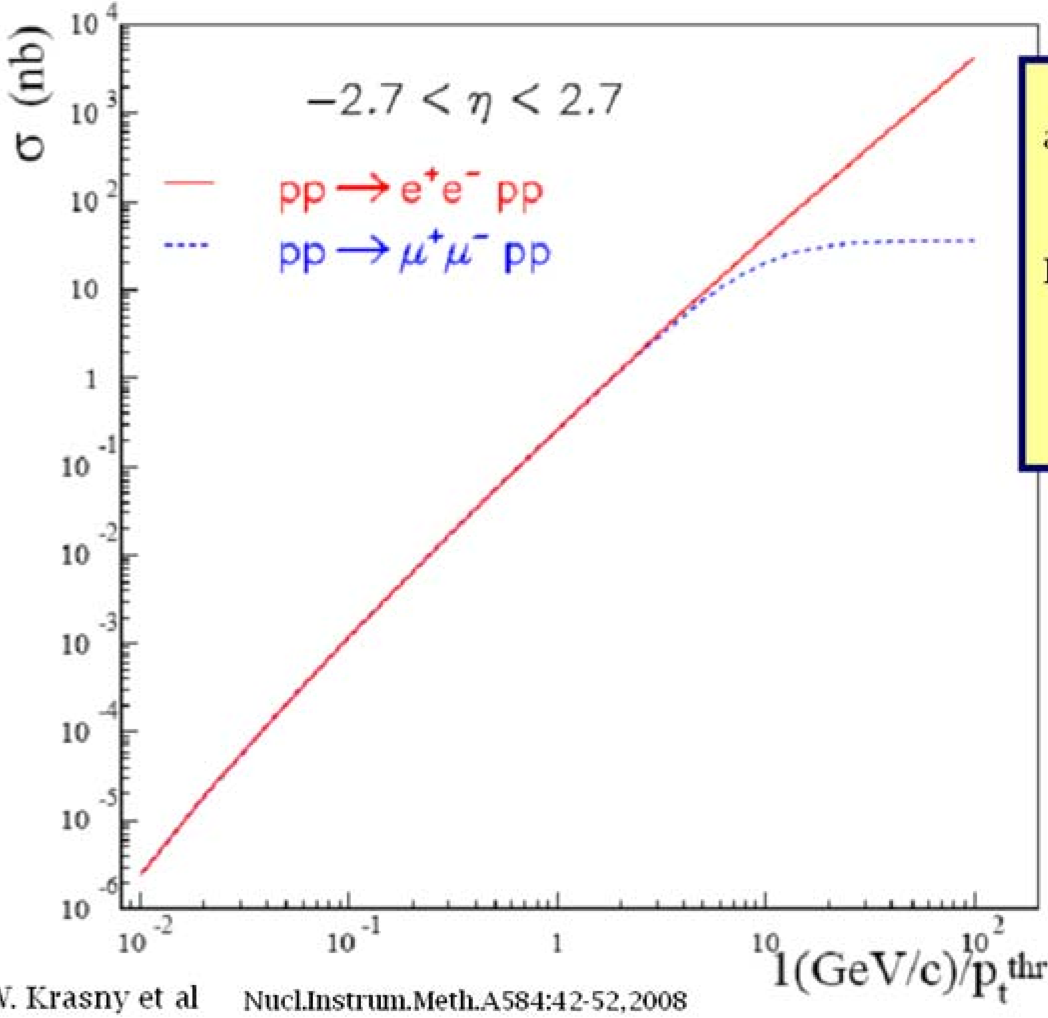
- Efficient suppression of proton dissociation and DPE background.
Reduction of the absorptive correction.

- 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

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.

$\mu\mu$

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)

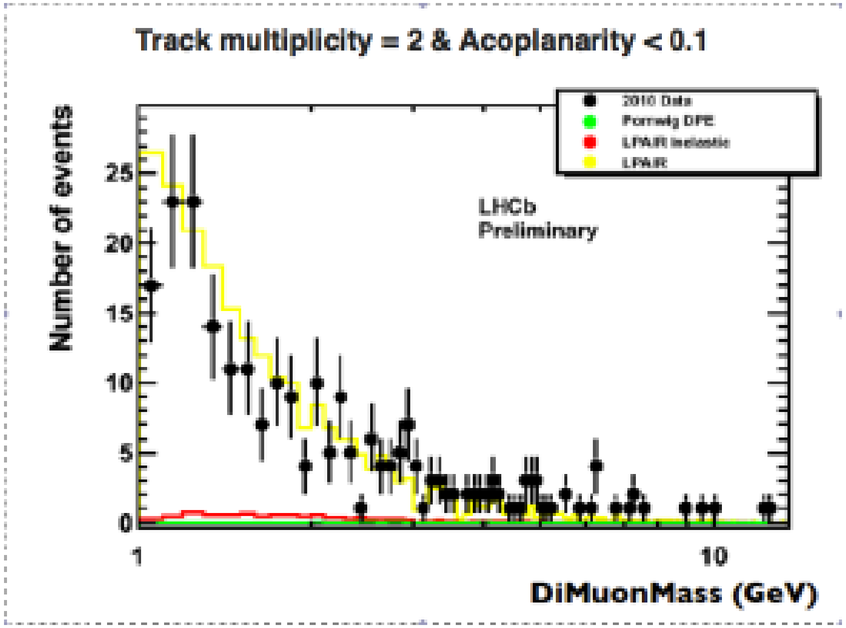
- LHCb has good potential to provide a precise luminosity calibration.

Goal- (1-2%)

Which precision do we want?

Benchmark with EW processes

$\mu\mu$



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

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

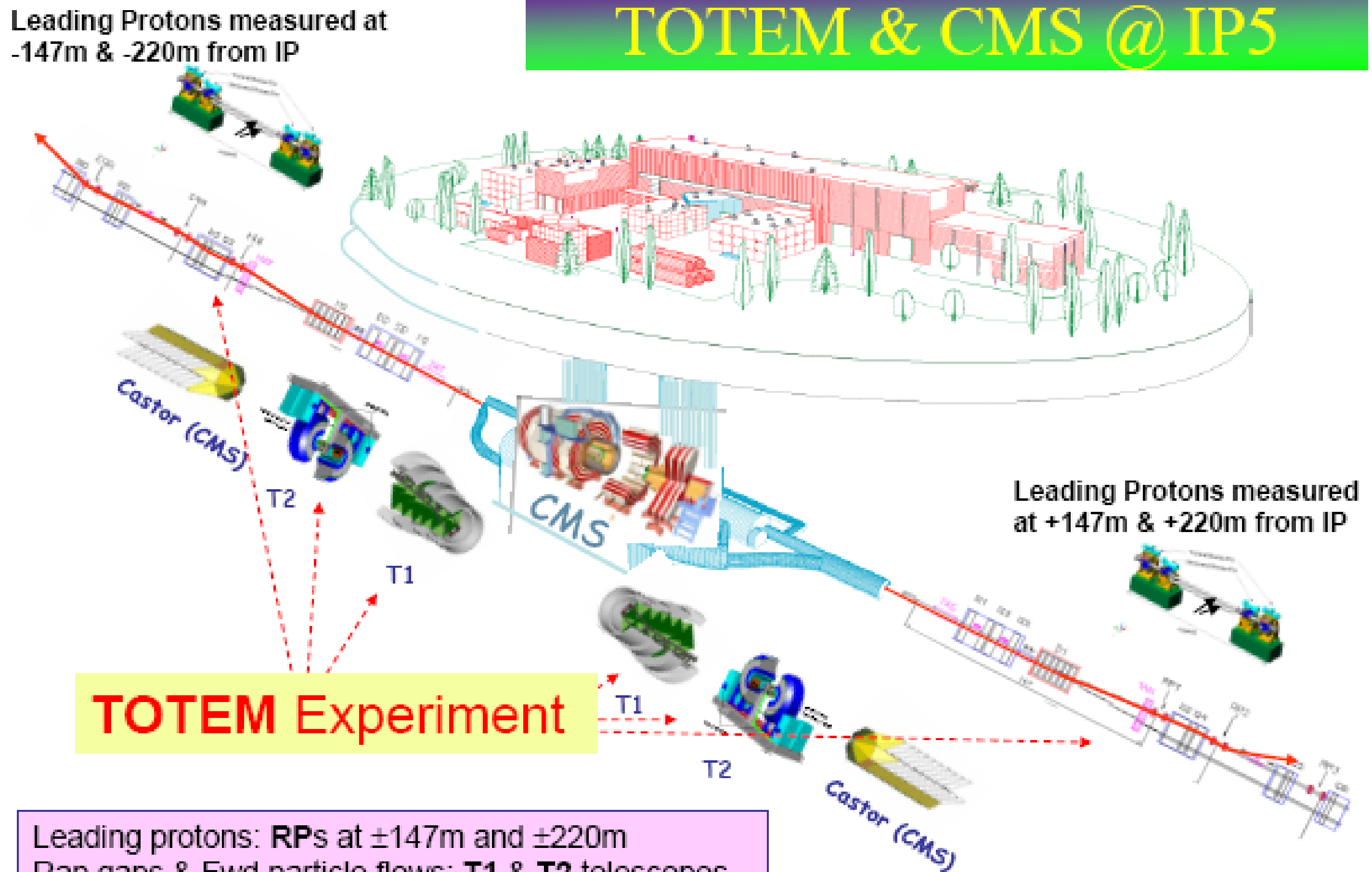
- Elastic rate N_{el}
- Differential elastic rate $\frac{dN_{el}}{dt}$ for small $-t$
- Inelastic rate N_{inel}

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 & CMS @ IP5

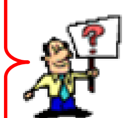


Leading protons: **RP**s at ±147m and ±220m
Rap gaps & Fwd particle flows: **T1** & **T2** telescopes
Fwd energy flows: Castor & ZDC (CMS)

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.

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

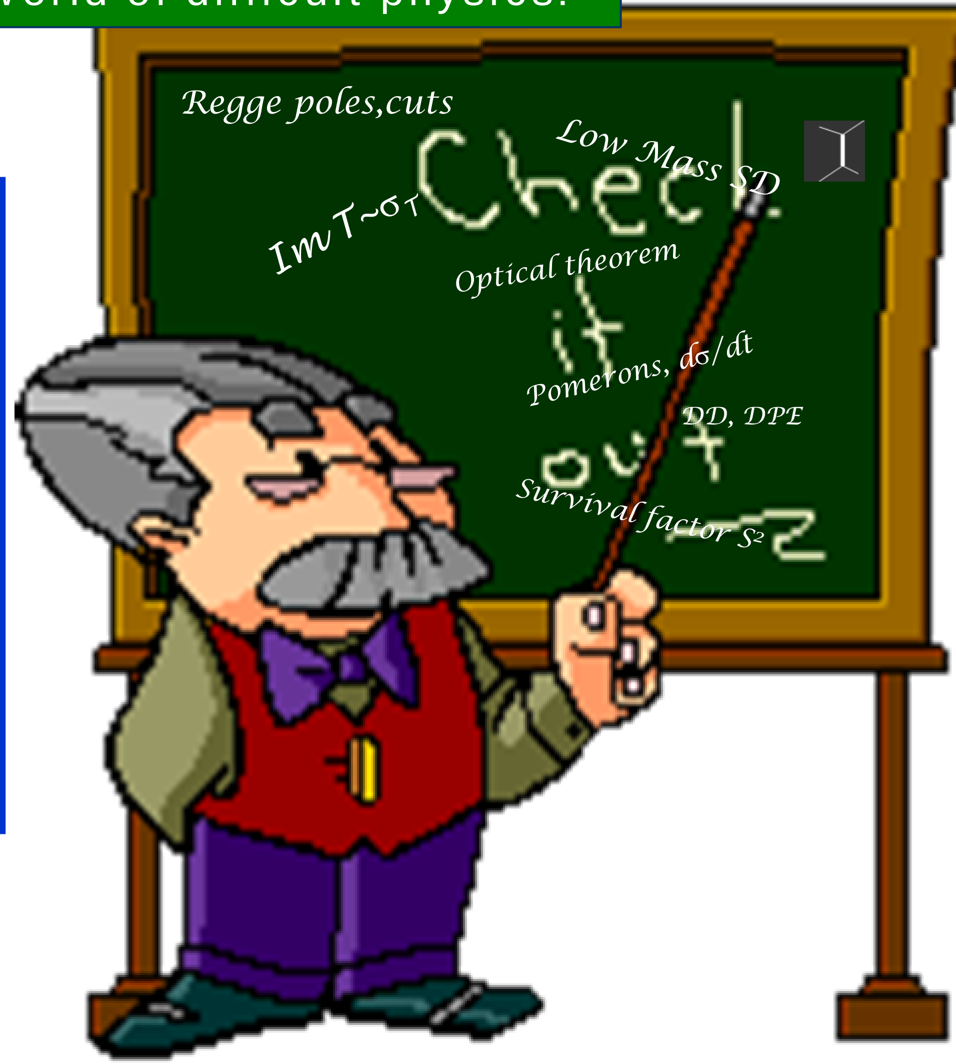
Longer term:
Measurement at the 1% level with very-high-β^* optics (~1 km);
might give access to the ρ parameter if the energy is still low ($\sqrt{s}$ ~ 8 TeV);
needs optics development work.

Welcome to the world of difficult physics!

- 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.

- For illustration purposes only three recent (ideologically close) MP- models are used, which allow good description of the data in the ISR-Tevatron range: KMR-09-10,GLMM-09 and Ostapchenko-10.

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



Reggeon Field Theory, Gribov- 1986

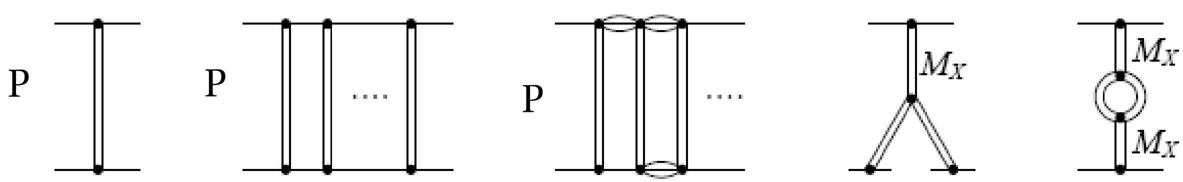


ILLUSTRATION I: INELASTIC EVENT RATE N_{inel}

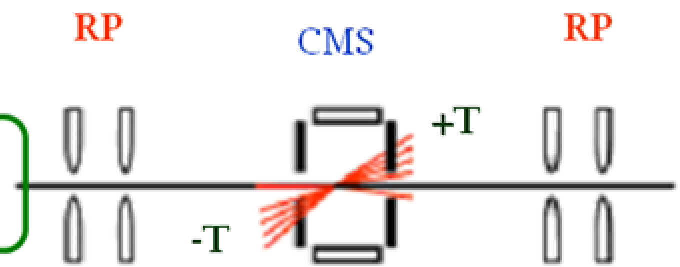
THEORETICAL UNCERTAINTIES in the T1+T2 RUNNING SCENARIO
T1+T2=T, $3.1 < |\eta| < 6.5.$

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

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

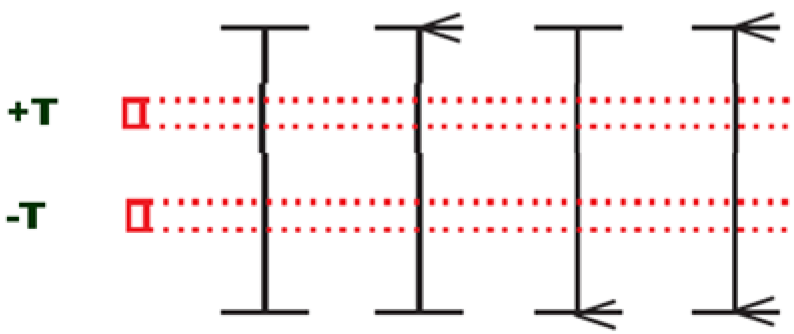
- N_{inel} measured by inelastic detectors T1 and T2
- to suppress background:
  - primary vertex reconstruction with T1 and T2

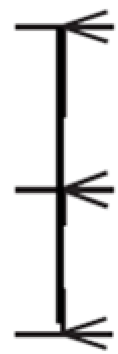
'Double Diffractive' Trigger:



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

What is missed then?





multi-gap (DPE)- (very) small

Optical theorem

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.

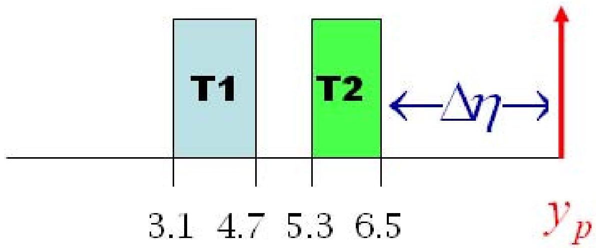
	σ_{tot}	σ_{inel}	+T	(+T or –T)	(+T & –T)
SO-2010	108	78.5	69.1	72.0	66.0
KMR-2009	91.5	70.0	50.7	59.0	42.4

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

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

Low mass Single Diffraction region: $M_X < 2.5$ -3.5 GeV → un-instrumented (4-5 GeV conserv.)

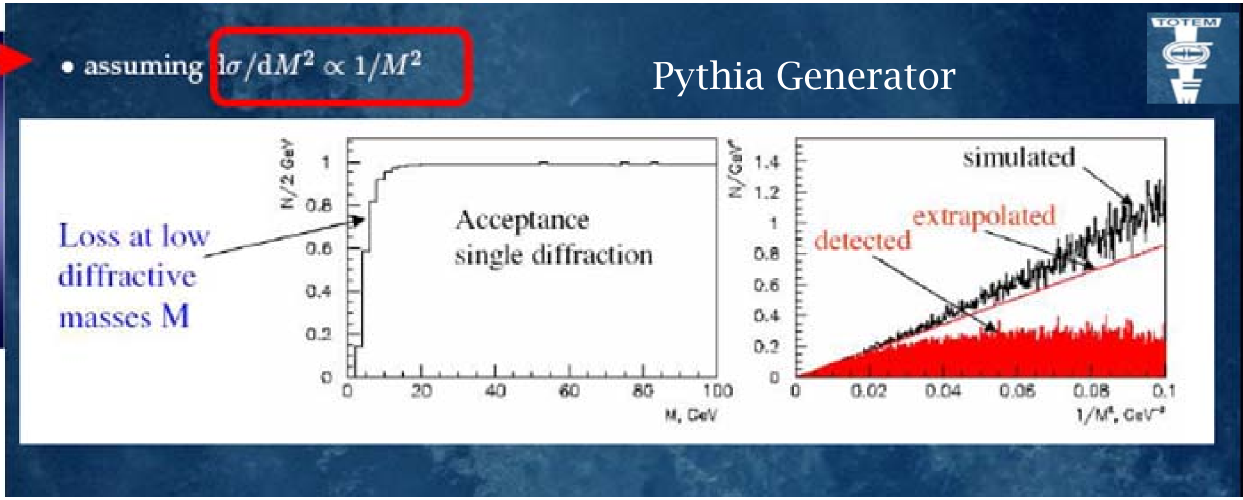


$$\eta = -\ln \tan \frac{\vartheta}{2}$$

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

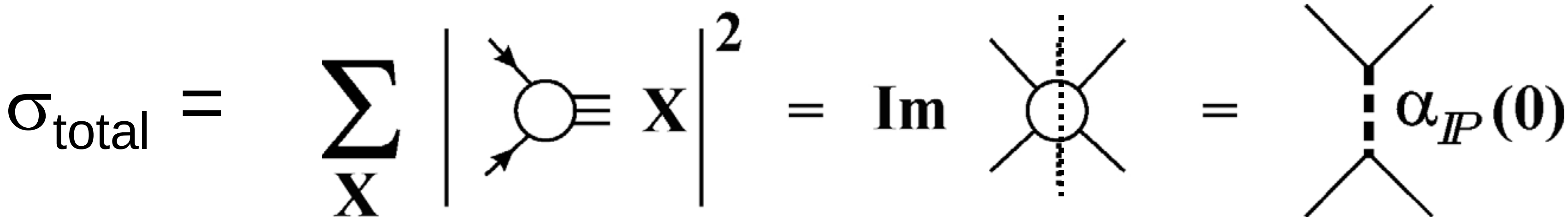
Can we extrapolate from HM SD ?

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

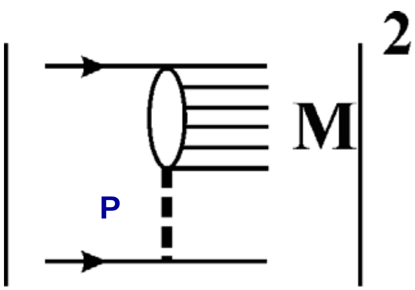


(UA4-experience ☞ factor of 2 for M<4 GeV)

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



High mass diffractive dissociation



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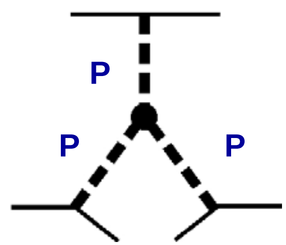


PPP-diagram

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

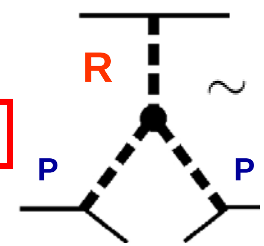
Screening is very important.
(semi) enhanced absorption **…**

(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

Optical theorem

ILLUSTRATION II: SCALE OF UNCERTAINTIES

$\sqrt{s} = 14$ TeV.

(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).

	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	5.76	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		

Cross sections (in mb) versus collider energy (in TeV)

energy	σ_{tot}	σ_{el}	σ^{lowM}_{SD}	σ^{highM}_{SD}	σ^{tot}_{SD}
1.8	72.8/72.5	16.3/16.8	4.4/5.2	8.3/11.1	12.7/16.3
14	98.3/94.6	25.1/24.2	6.1/7.5	14.0/15.9	20.1/23.4
100	127.1/117.4	35.2/31.8	8.0/9.9	20.6/20.0	28.6/29.9

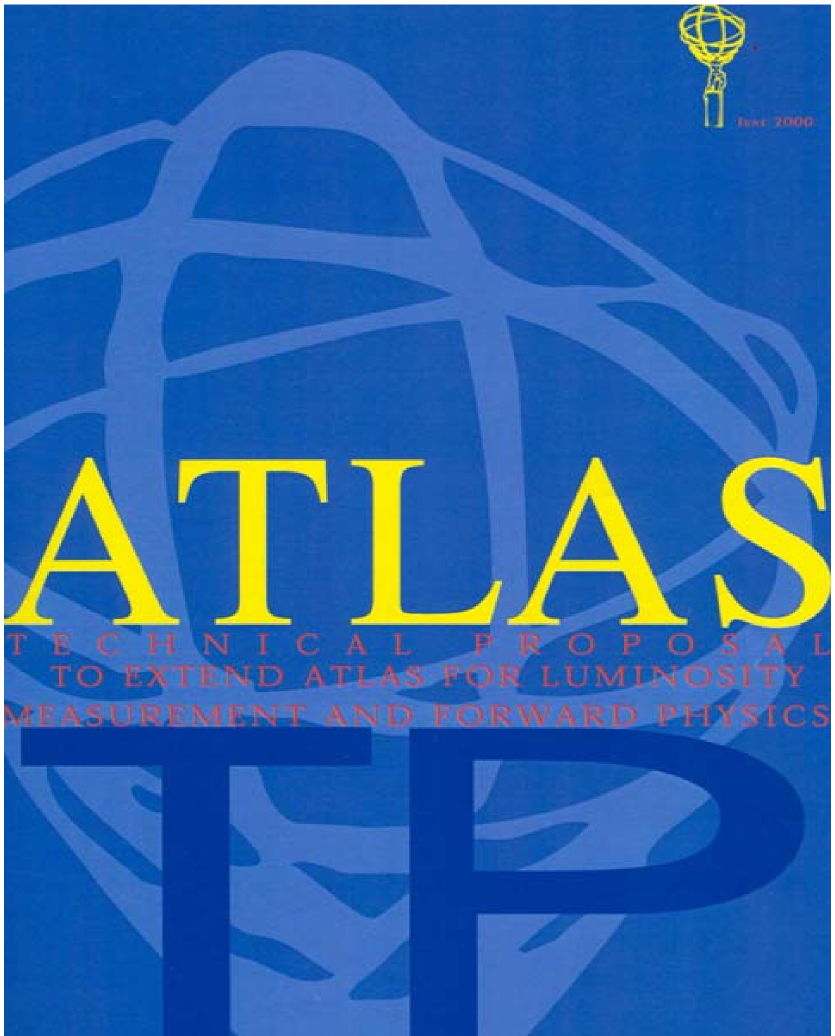
KMR-2010, preliminary results

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

FAD@LHC A BIT OF HISTORY

Full Acceptance Detector – J. Bjorken (1991)

FELIX LOI (1997)



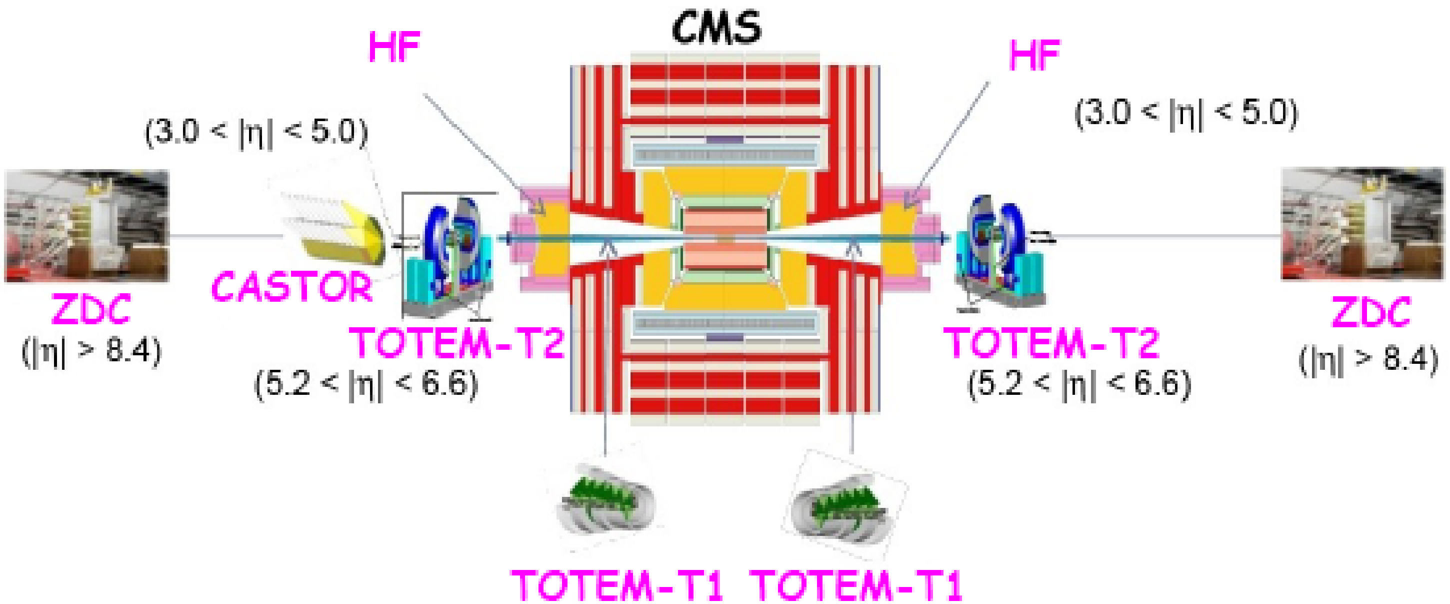
June 2000

Proposal to Extend
ATLAS
for Luminosity Measurement
and Forward Physics

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]

1 Technical Research Center of Finland, VTT Automation, Espoo, Finland
2 Physics Department, University of Helsinki, Finland
3 Espoo-Vantaa Institute of Technology, Finland
4 Helsinki Institute of Physics, Helsinki, Finland
5 CERN, Geneva, Switzerland
6 University of Durham, U.K.
7 Academy of Finland, Helsinki, Finland
8 Iowa State University, Ames, U.S.A.
9 KBFI, Tallinn, Estonia
10 Department of High Energy Physics, H.Niewodniczanski Institute of Nuclear Physics, Krakow, Poland

CMS Forward Detectors



- CMS integrated detector: HF, CASTOR, ZDC
  → Cerenkov sampling calorimeters
- TOTEM + FP420: additional forward detectors around IP5 !

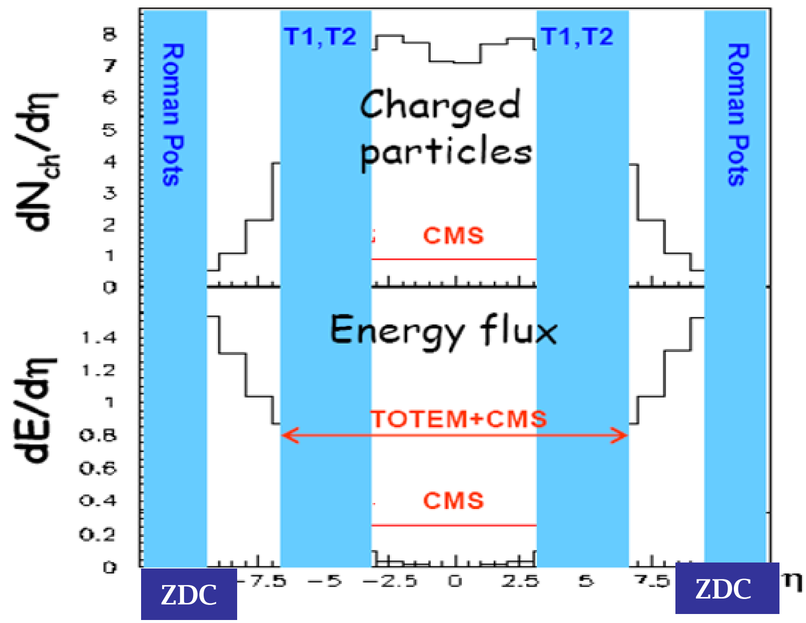
unprecedented calorimetric coverage !

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

BUT

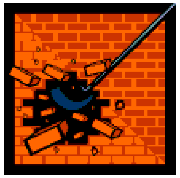
- CMS is currently blind between =6.4(CASTOR) and beam rapidity y_p except ZDC (neutrals).
- T1+T2 detectors do not cover low-mass diffraction.

Even with common DAQ, we miss a few mb in inelastic cross section (without RPs).



IS THERE A WAY OUT ?

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



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

INFN Trieste, Italy

[a] contact person

[b] Also at Iowa State University

[c] Some authors are not members of CMS, but have contributed to this note.

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)

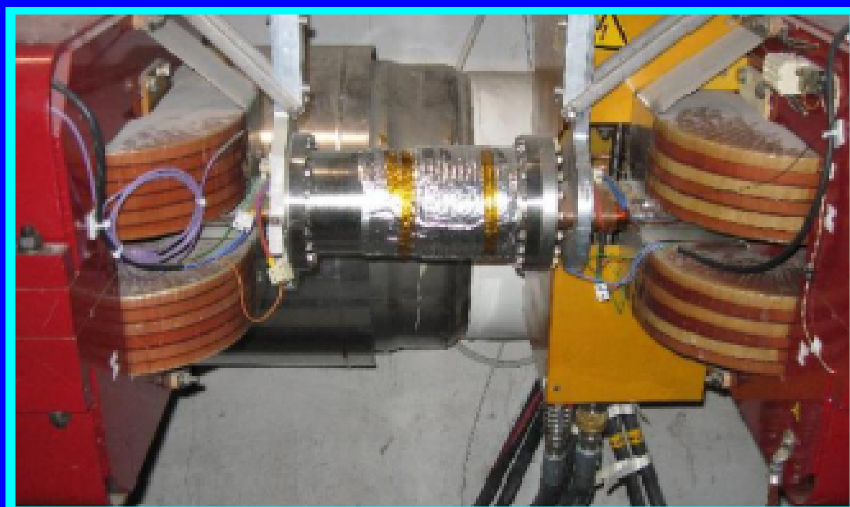
News

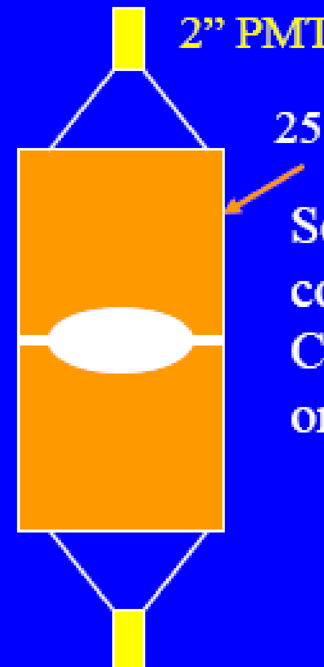
Installation and commissioning:
March Technical Stop (28-31.03.11).
8x2 counters.

The FSC

Very simple, low tech: 8 PMTs on each side in 4 pairs.

Between 2 MBX magnets





25 cm x 25 cm scint.

Schematic of counter pair. Cut-out depends on location

Four locations: z (m) = 59.2, 79.1, 88.5 and ~ 125 m (to be optimized)

Rapidity range: $7 < |\eta| < 11$

Detect showers produced by particles in beam pipe

SUMMARY

We propose to install a set of scintillation counters around both outgoing beam pipes at CMS, ~ 60m – 100 m

Physics, especially diffractive in no-PileUp interactions

(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

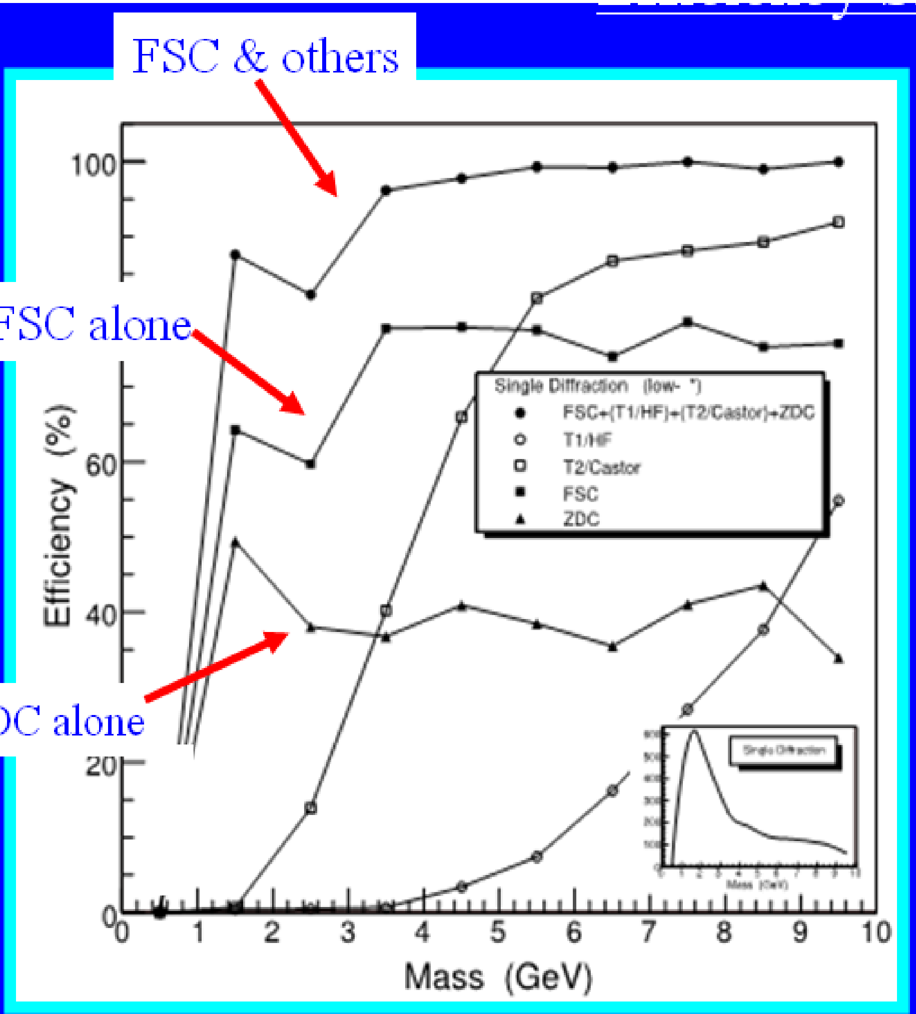
MORE PHYSICS

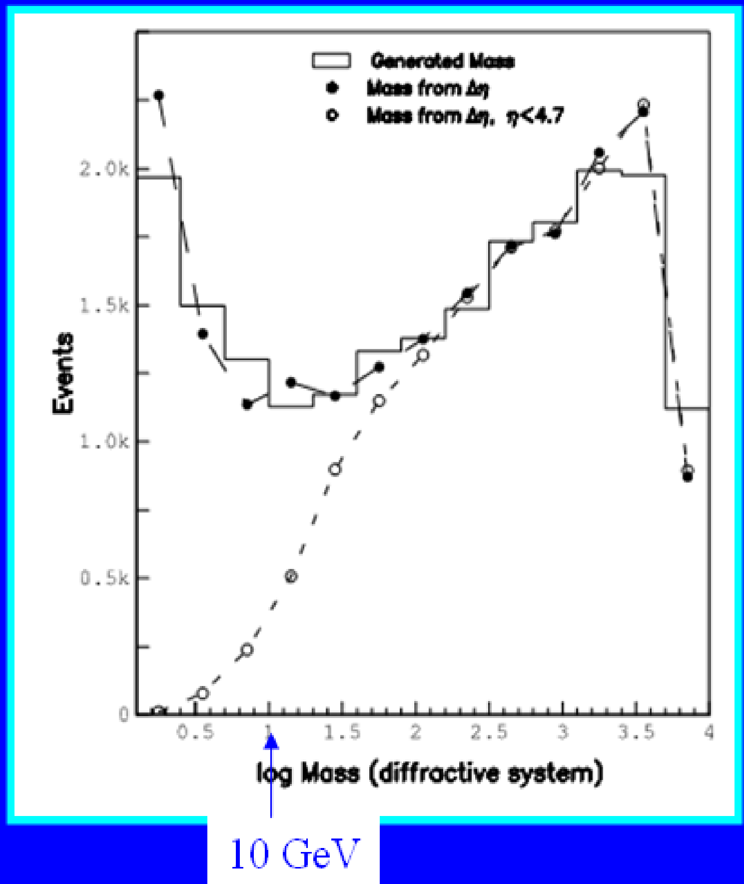
LOW COST

ZERO RISK*

*Subject to support approval by LHC

Efficiency and Diffr. Mass





>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:

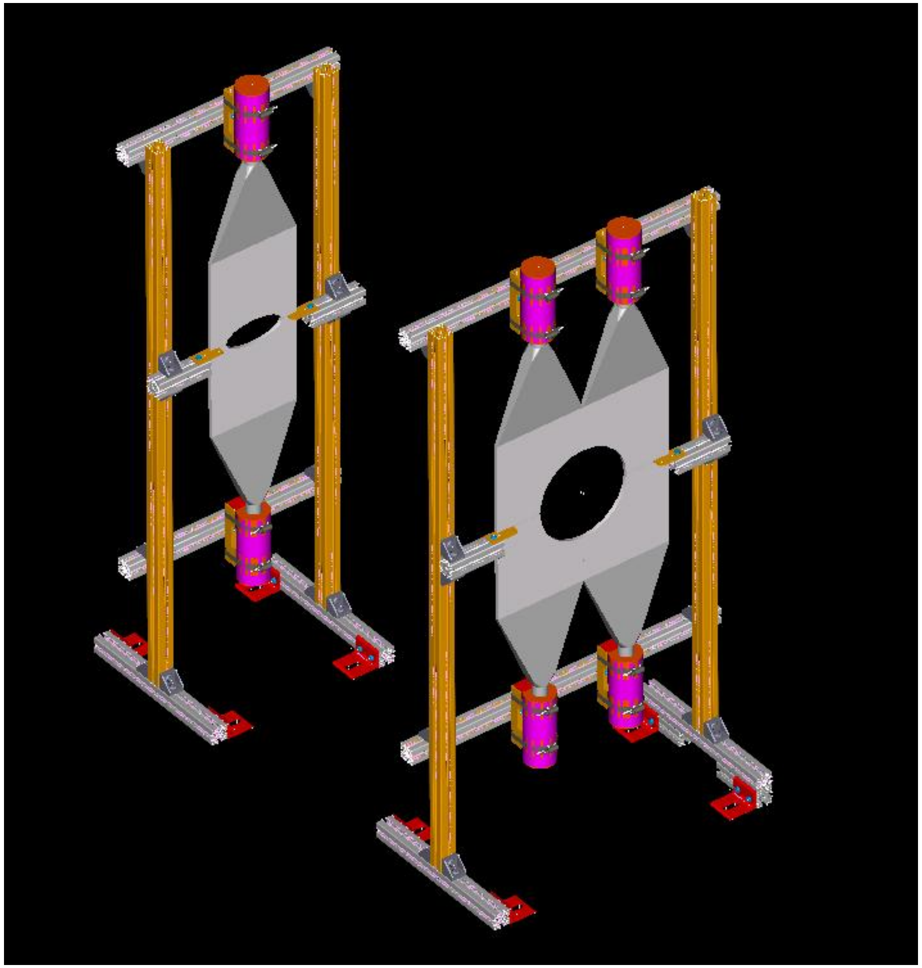
(a) full η coverage

(b) η < 4.7 (no FSC)

Below 10 GeV/c² FSC contain most particles

The FSC- these are for real !

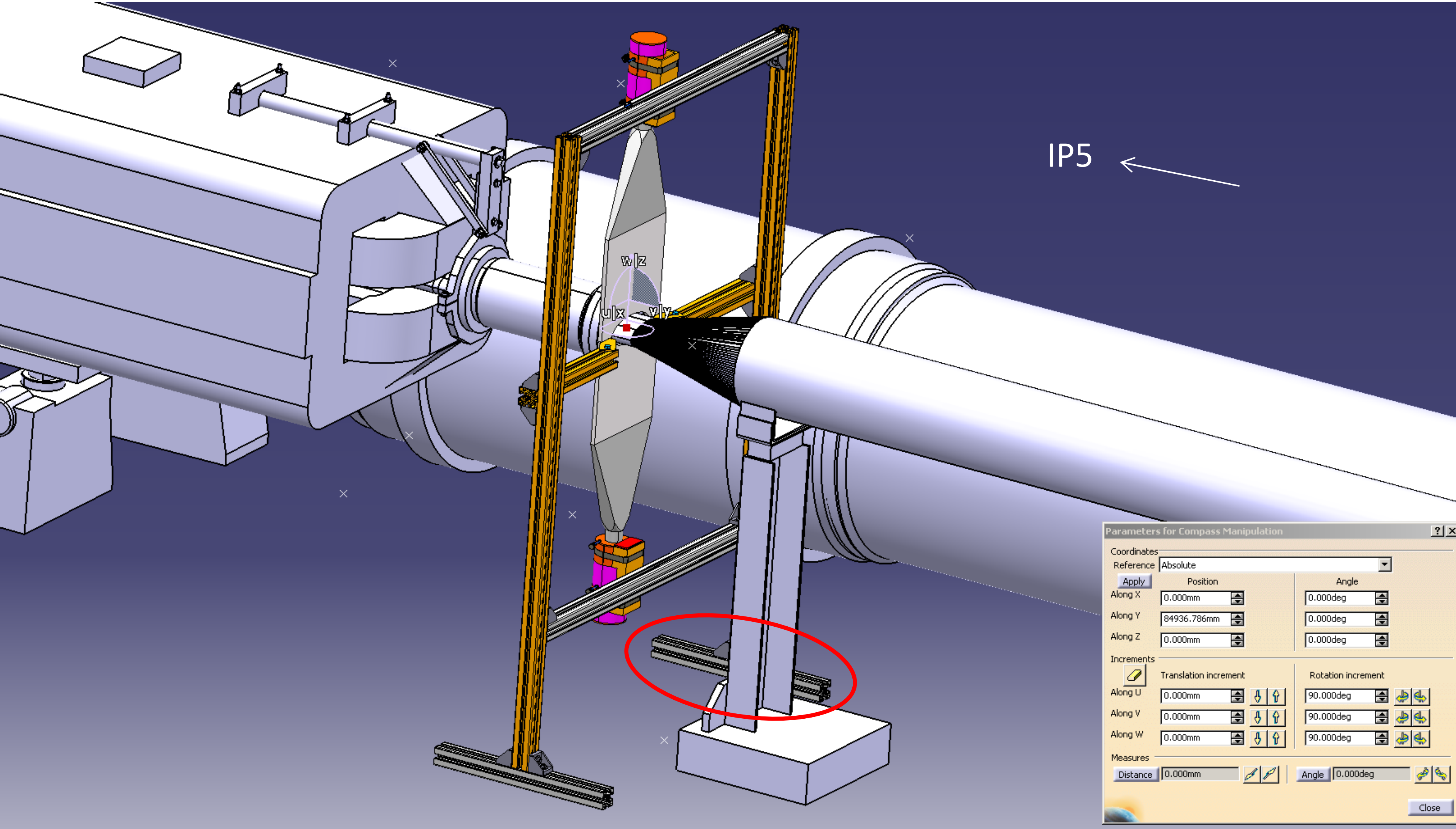
- The installation and commissioning phase of FSC during the March Technical Stop.
- Main concern- lumi per bunch crossing might be too high.



FSC stands after March 1st 2011

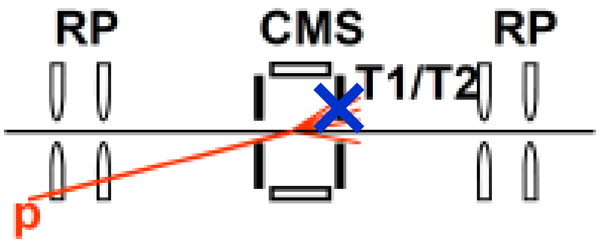
Station #2 – C4R5

Isssue: one foot in the 'caniveau'



If without FSC....

A possibility to probe low-mass SD : proton one side + T/1+T2- silent (+ ZDC)



(resonance decays..)

Without ZDC : missed channels: $p + p \rightarrow p + (n + \pi's)$, $pp \rightarrow p + (p + \pi^0 's), p + (p + \pi^+ + \pi^- (+\pi^0 's)....)$

With ZDC –at least 40-50% (or more) of low-mass SD could be covered

missed $p + \pi^+ + \pi^- (+\pi^0 's)....$

Still – Low-Mass Double Diffraction is not covered (however, expected < 1-2 mb)

Backgrounds (double counting..) ??

More studies needed.

There are known unknowns.

- When the common TOTEM-CMS data taking will happen?
- When the dedicated runs with special optics (1500 m) will take place ?
- When/if the FSC will be fully operational ?

But there may be also unknown unknowns.

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. Recall $\overline{\xi}_p = (1-\overline{x}_p) = (M_{SD}^{LM})^2 / s \le 2*10^{-7}$, while $\delta\ \xi_b \sim 10^{-4}$.
  Beam optics ?, Neutrons at x<0.95?

- 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

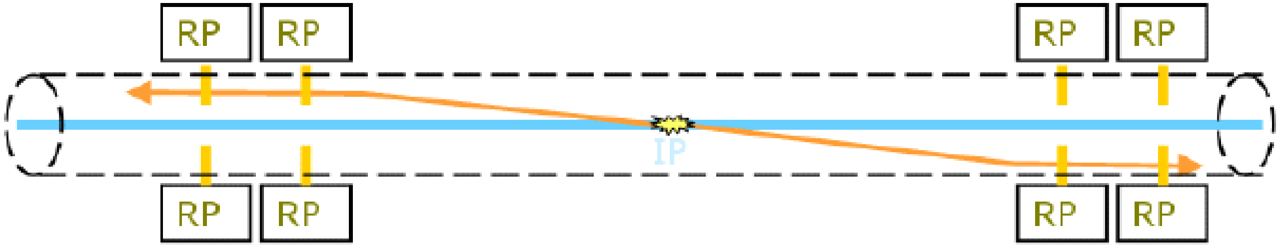
CR physics, the LHC is above the 'knee'.

Coulomb

ALFA = Absolute Luminosity For ATLAS

Elastic scattering at very small angles

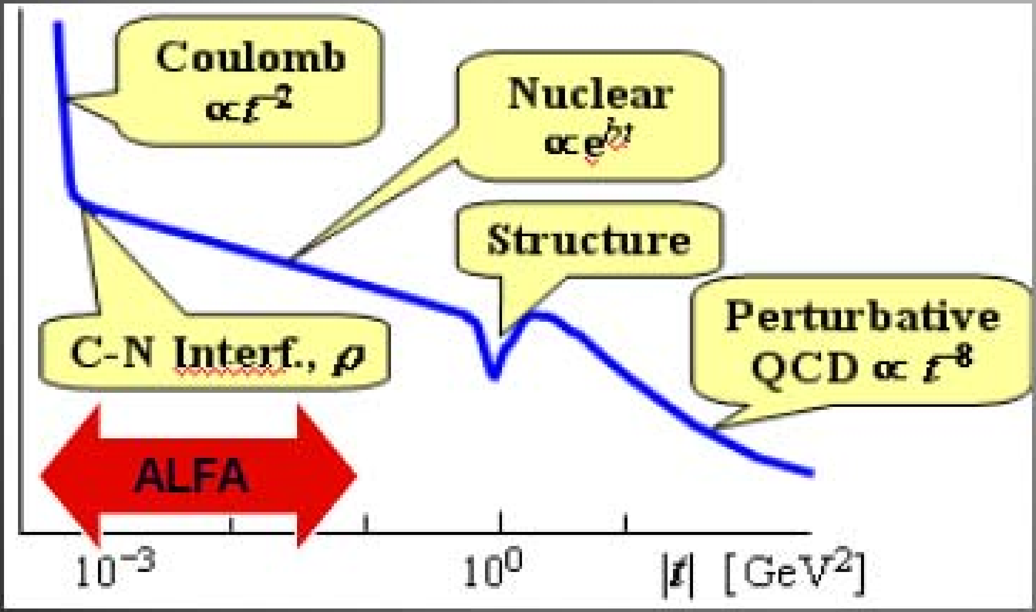
- Measure elastic scattering at such small t-values that the cross section becomes sensitive to the Coulomb amplitude
- Effectively a normalization of the luminosity to the exactly calculable Coulomb amplitude
- No total rate measurement and thus no additional detectors near IP necessary
- UA4 used this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

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

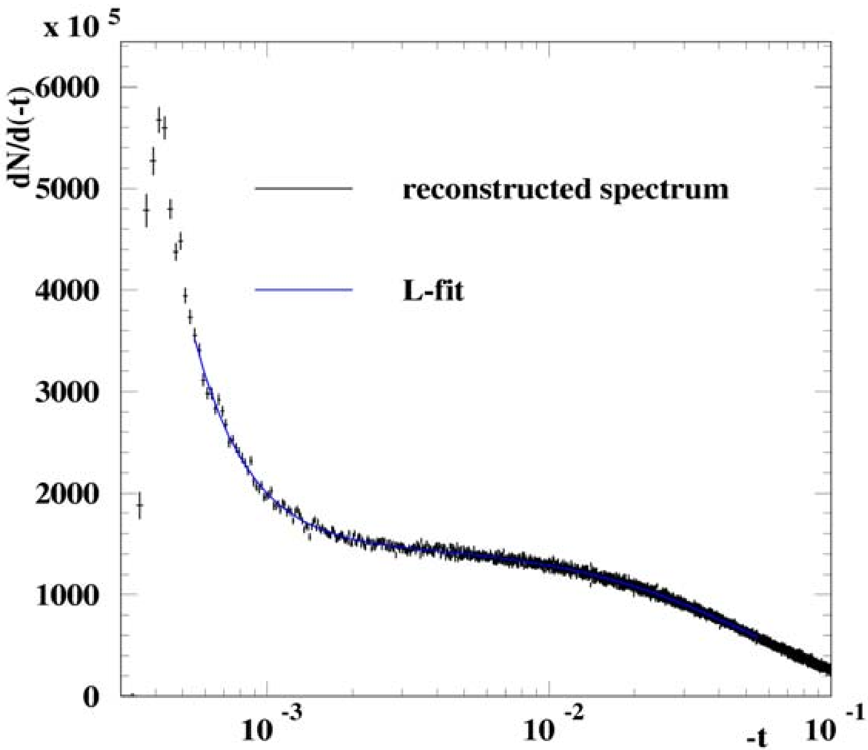
→ Detector positions far from IP

→ Special beam settings

→ Detectors close to beam

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%

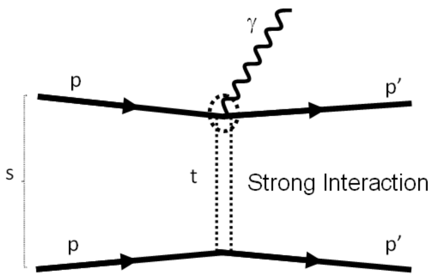
large stat.correlation between L and other parameters

38

➔ Δ L / L ~ 3% seems to be possible

K.Hiller

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 ⇒ theor. uncertainties minimal
- ⇒ 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

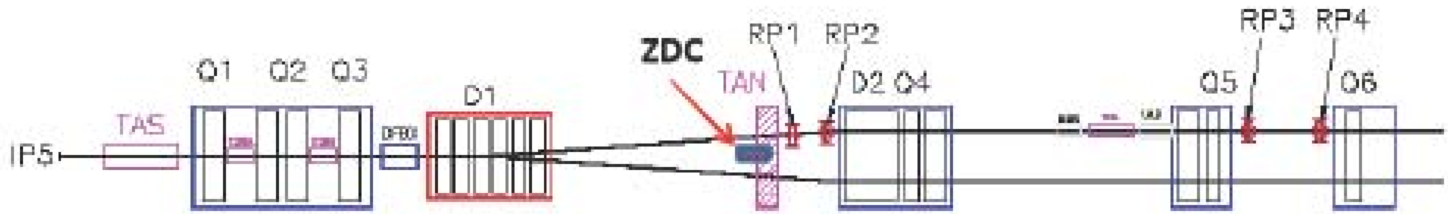
Experience at ee colliders (VEP-I,VEPP-II, ACO, ADONE) and at HERA

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.

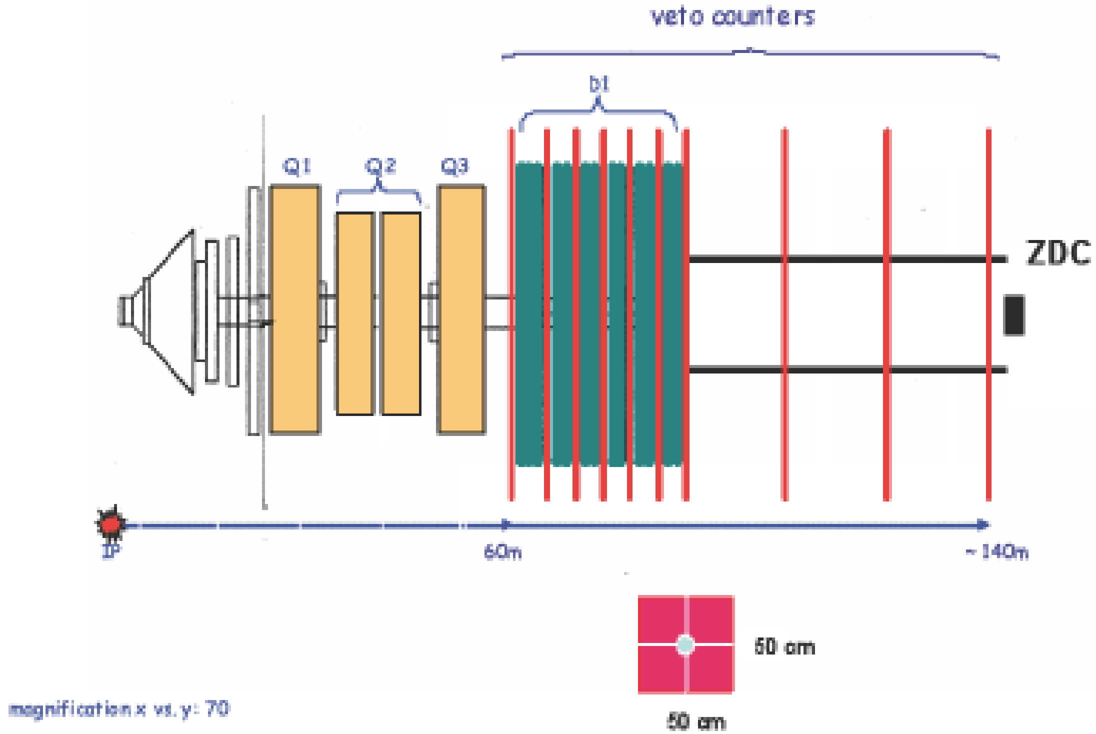
- The soft photons are observed at the Zero Degree Calorimeters (ZDCs) :



- These photons give a distinct physical signal, since the distribution the photons give rise to peaks at zero degrees.

Proposed Forward Shower Counters

- 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

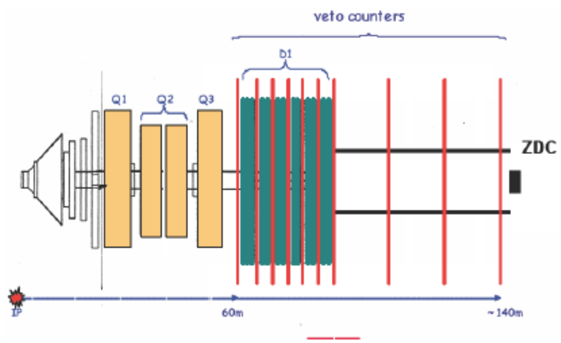


Triggers and Backgound

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

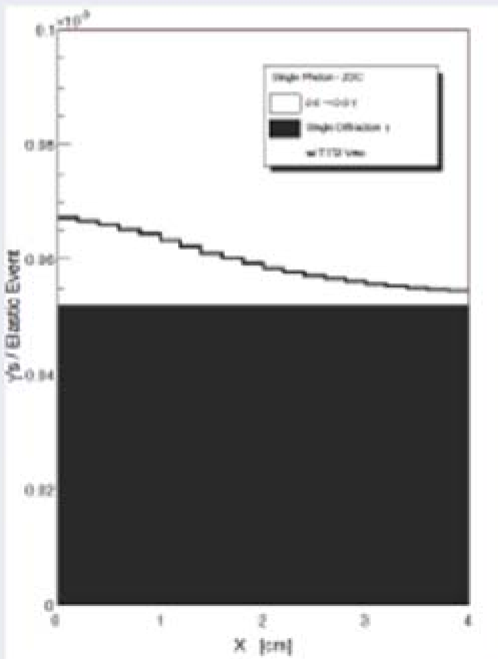


Luminosity, if σ_{el} and B are known

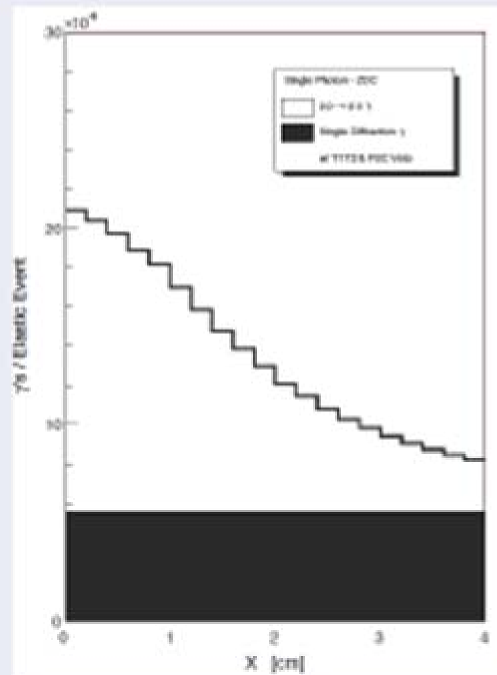
Results from simulations

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

T1T2 Veto



T1T2 & FSC Veto



Why measure total and diffractive cross sections?

2 slides from A. Martin (Diffraction 2010)

Intrinsic interest. The LHC should reach, for the first time, sufficiently HE to distinguish between the different theoretical asymptotic scenarios for HE interactions.

(currently available data not decisive)

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 $\sigma_{inelastic}$.)

Study needed to estimate the survival probabilities of LRG to soft rescattering.
Recall "hard" exclusive diffractive processes (e.g., pp → p + Higgs + p) can be New Physics signals

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

Energy region above the 'knee'. Diffraction is the most important for understanding of air-showers

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.

Recall that the two Tevatron results for σ_{tot} differ by 12%.

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

BACKUP

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)

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, ...

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.

Machine parameters

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

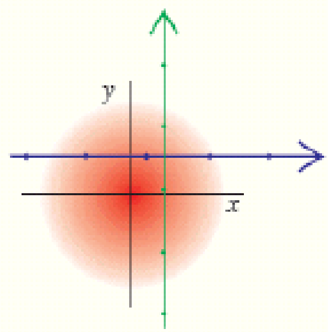
record 1%

Luminosity with separation

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

$\frac{\delta x}{\sigma_x}$	$\frac{\delta y}{\sigma_y}$	$\frac{\mathcal{L}}{\mathcal{L}_0}$
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

Commissioning : simple, orthogonal x / y scan

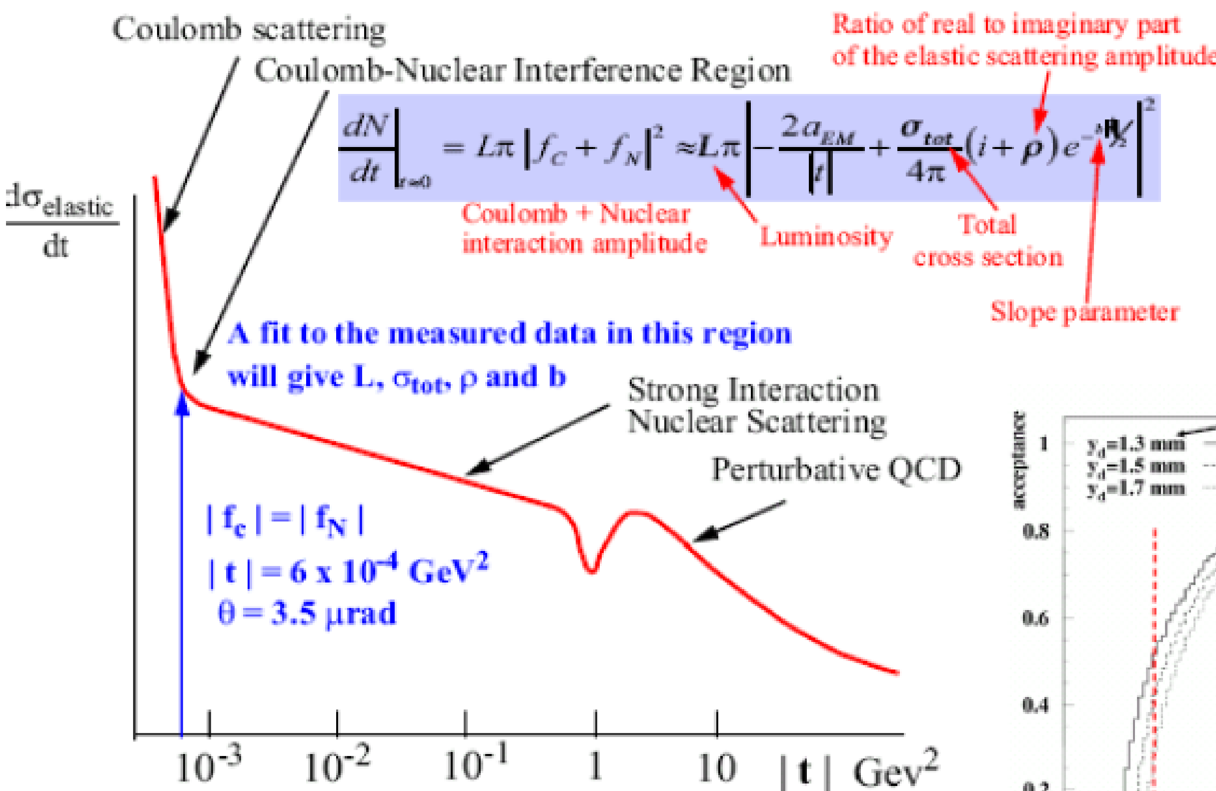


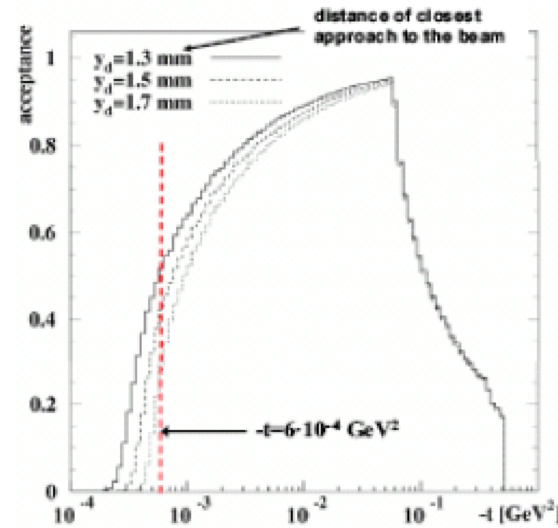
2010- CMS,ATLAS,LHCb, ALICE ~11% accuracy , 5% is on agenda

vdM-scans

Main uncertainty: currents in the LHC magnets

Elastic scattering at very small angles





Commissioning starting after Christmas shut down.

(S.Ostapchenko- 2010)

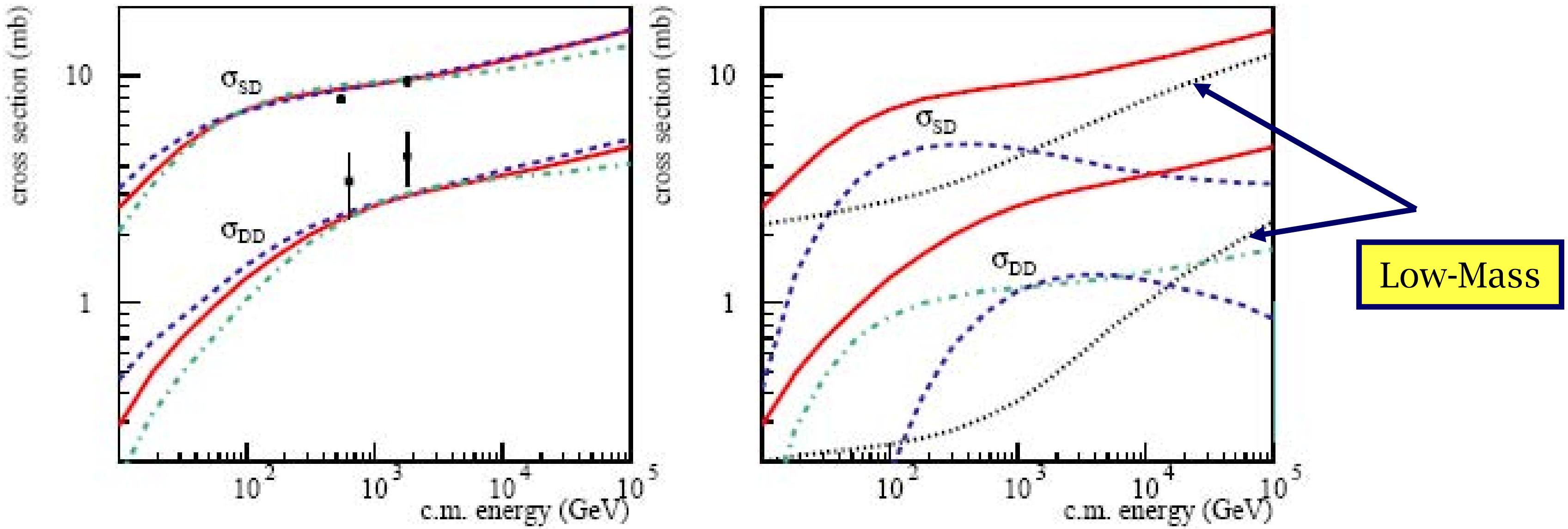
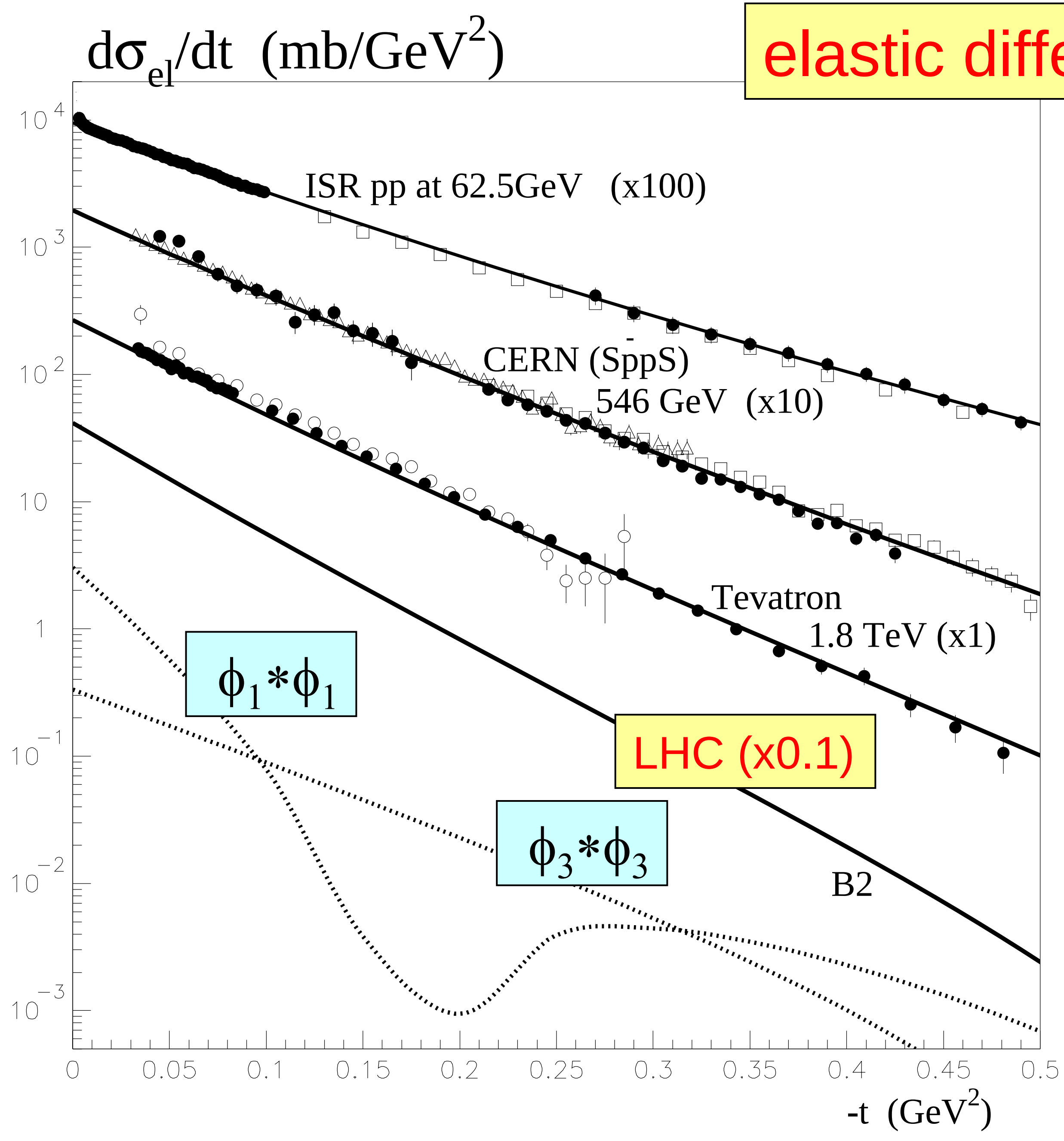


Figure **14**: Left: single and double diffraction proton-proton cross sections ($\sigma^{SD}(M_X^2/s < 0.15)$, $\sigma^{DD}(y_{gap}^{(0)} \geq 3)$), as calculated using the parameter sets (A), (B), and (C) - solid, dashed and dot-dashed lines correspondingly, compared to CDF data [21, 22]. Right: $\sigma^{SD}(M_X^2/s < 0.15)$ and $\sigma^{DD}(y_{gap}^{(0)} \geq 3))$ calculated using the parameter set (A) - solid lines, partial contributions of high and low mass diffraction: $\sigma_{HM}^{SD/DD}$ and $\sigma_{LM}^{SD/DD}$ - dashed and dotted lines correspondingly, σ_{LHM}^{DD} - dot-dashed line.

		σ^{tot}	σ^{el}	σ^{SD}	σ^{DD}	σ^{SD}_{LM}	σ^{SD}_{HM}	σ^{DD}_{LM}	σ^{DD}_{HM}	σ^{DD}_{LHM}	σ^{DPE}
	Set (A)	128	37.5	12.1	4.61	8.48	3.62 (3.54)	1.15	2.06	1.40 (1.37)	0.10 (0.05)
	Set (B)	126	37.3	12.4	5.18	8.22	4.24 (4.14)	1.08	2.50	1.60 (1.56)	0.14 (0.07)
	Set (C)	114	33.0	11.0	4.83	5.76	5.22 (5.12)	0.47	3.15	1.22 (1.19)	0.19 (0.09)
KMR-09	Ref. [7]	91.7	21.5	19.0		4.9	14.1				
GLMM-09	Ref. [9]	92.1	20.9	11.8	6.08	10.5	1.28				

elastic differential dσ/dt

KMR-2009

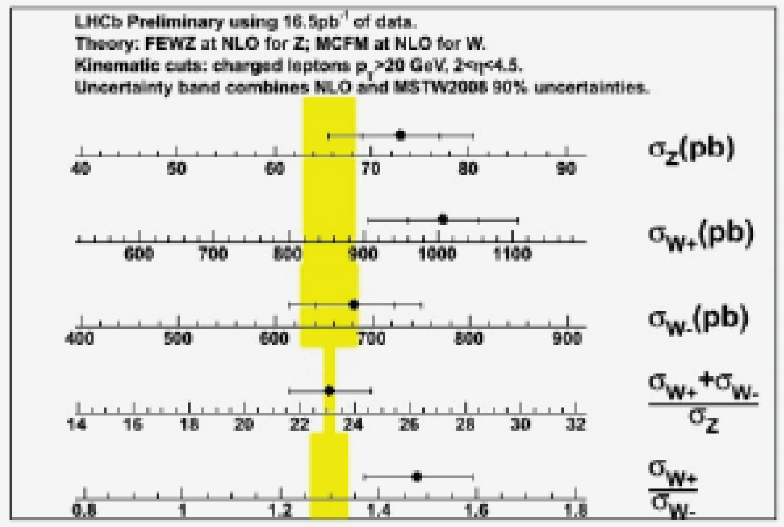


Summary of W & Z measurements

With 16.5 pb-1 we see

- 9500 W's and 833 Z's
- Cross-sections and ratios have been measured and compared to NLO predictions
- This corresponds to ~ half of the 2010 data set.
- Using the Z's alone, a luminosity measurement with an uncertainty of ~ 5 % is possible

LHCb preliminary



ALFA

Time line

1) Commissioning in garage position can happen very soon.

2) Move out of garage position for commissioning with halo particles seems very likely as the next step.

3) β^*=90m needs machine studies, also for parallel running of TOTEM and ALFA
It is a necessary step to very high-β^* and would be very good if it happens 2011.

4) Intermediate β^*=1500m:
Due to hardware intervention realistic only after next long shut-down.

5) Very high β^*=2600m:
As for 4) dedicated machine studies needed. Time scale depend certainly on decision about β^* = 1500m.

Schedule for items 4), 5) depend on experience and results achieved at 1) – 3).
Dedicated machine studies are needed to prepare β^* = 1500 , 2600m runs.