Classification of diffraction at the LHC

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Diffractive measurements at the LHC: Elastic & Inelastic Soft Diffraction

- Elastic pp scattering - indirect
- Low mass Single Diffraction
- Low mass Central Exclusive Diffraction
- Event classification: Diff vs. Non-Diff
HOW TO CLASSIFY INELASTIC LHC EVENTS AS DIFFRACTIVE or NON-DIFFRACTIVE IN AN EXPERIMENT?

\[ \sigma_{\text{TOT}} \equiv \sigma_{\text{EL}} + \sigma_{\text{SD}} + \sigma_{\text{DD}} + \sigma_{\text{CD}} + \sigma_{\text{ND}} \]

The event classes are not uniquely defined.
IDEAL EXPERIMENT FOR DIFFRACTION

• Measure rapidity gaps $\Delta \eta \geq 3$ for a maximal $\eta$- and $p_T$-span

  and/or

• Measure leading protons for a maximal $(\xi, t, \varphi)$ range

  and

• Measure forward systems for full $\varphi$:
  • acceptance down to $M^* \sim 1$ GeV !!
  • charged multiplicities (particle id’s!?)
  • transverse energies/momenta

  also

• Measure timing (for pile-up discrimination)

LUMINOSITY MEASUREMENT AND MONITORING.
At HERA - bremsstrahlung (from electrons).

At LHC – bremsstrahlung - from protons!

Luminosity and $\sigma_{el}/\sigma_{tot}$ ?
BREMSSTRAHLUNG FROM PROTONS

- SMALL $t \Rightarrow$ theoretical uncertainties minimal
  $\Rightarrow$ direct relation between the photon spectra and $(\sigma_{el}/\sigma_{tot})^2$

- Bremsstrahlung cross section is large: $\sim 0.18 \times 10^{-3}$ of $\sigma_{el}$

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ROAD MAP

• Use luminosity from the W/Z standard candle measurements or from the beam scan (Van der Meer) ⇒ model-independent way to measure $\sigma_{el}$

• 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 $3.5 \times 3.5$ TeV and/or $5 \times 5$ TeV.
FORWARD DETECTORS: THE ROMAN POTS AND ZDC

Zero Degree Calorimeter has fine granularity. Bremsstrahlung photons close to 0 degrees – can be used for alignment (RP’s, ZDC), luminosity monitoring.
T1, T2 SPECTROMETERS, CASTOR

T1 and T2 detect particle flows

CASTOR detects energy flows

T1, T2 and CASTOR help in rejecting the backgrounds from SD and ND events.
SD BACKGROUND vs. BREMSSTRAHLUNG PHOTONS

**NO VETO**

- \( pp \rightarrow pp\gamma \)
- No SD background

**T1/T2 VETO**

- \( pp \rightarrow pp\gamma \)
- No SD background
PROPOSED FORWARD SHOWER COUNTERS

veto counters

60m ~ 140m
Q1 Q2 Q3
D1
IP
Rapidity Gap Veto – Detector Lay-Out
magnification x vs. y: 70
80cm

60 to 140 meters

FSCs DETECT INTERACTIONS IN THE BEAM PIPE

HISTORY:
BSC @ CDF!

magnification x vs. y: 70

Forward Physics with Rapidity Gaps at the LHC.
By USCMS Collaboration (Michael Albrow et al.),
Published in JINST 4:P10001,2009.
e-Print: arXiv:0811.0120 [hep-ex]

Central Diffraction at the LHCb.
10pp.
Published in JINST 4:P11019,2009.

February 2002

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EFFICIENCY OF DETECTING SD EVENTS

WITH FSC, DETECT SD EVENTS DOWN TO $M_{\text{diff}} \geq 1.1 \text{ GeV}$
With the addition of FSCs get a clean measurement of elastic bremsstrahlung.
ND BACKGROUND vs. BREMSSTRAHLUNG PHOTONS

**Graph 1:**
- Y-axis: \( \gamma s / \text{Elastic Event} \)
- X-axis: \( R^2 \) [cm]
- ND background

**Graph 2:**
- Y-axis: \( 30 \times 10^{-6} \)
- X-axis: \( R^2 \) [cm]
- Single Photon - ZDC
- \( pp \rightarrow pp\gamma \) is indicated by an arrow.
Low Mass Single Diffraction
Mass of the diffractive system

Calculate using the rap gap:
\[ \ln M_x^2 = \Delta \eta \]

Access to small \( M_x \) iff forward detectors to cover \( |\eta| > 5 \).
Single Diffraction at $M_X < 10$ GeV

For calculating $\sigma_{tot}^{pp}$ need to measure the inelastic rate.

$\sigma_{SD}(M_X < 10$ GeV) = several mb's?

L.Jenkovzsky, O. Kuprash, J. Lämsä, V. Magas, RO, work in progress
N*(1440) is covered by the FSCs...
Low Mass Central Exclusive Diffraction
CENTRAL DIFFRACTION AT THE LHCb

LHCb/ALICE IDEAL FOR DETECTING AND ANALYSING LOW MASS CENTRAL DIFFRACTIVE PRODUCTION OF EXCLUSIVE $\pi^+\pi^-/K^+K^-$ STATES IN:

$$pp \rightarrow p + M + p$$

glueballs, hybrids, heavy quarkonia: $\chi_c$, $\chi_b$

$\pi^+\pi^-/K^+K^-$ STATES AS SPIN-PARITY ANALYZERs.

HOW TO FACILITATE THIS?

THE PROPOSED LHCb FSC LAY-OUT

ADD FSCs AT 20 – 100 METERS ON BOTH SIDES OF IP8 – THE FSCs DETECT SHOWERS FROM THE VERY FORWARD PARTICLES.

Figure 1. The layout of LHCb detectors at the LHC Interaction Point (IP8). The proposed Forward Shower Counters (FSCs) are shown as vertical lines (1 to 8). The locations of the dipole (D) and quadrupole (Q) magnet elements are shown as green (dark) and yellow (light) boxes.
THE PROPOSED ALICE FSC LAY-OUT
PURITIES FOR EXCLUSIVE STATES

\[ \Delta M \approx 20 \text{ MeV} \]
Figure 2. The detector acceptance as a function of the central diffractive mass for $\pi^+\pi^-$, $K^+K^-$, $2\pi^+2\pi^-$ and $K^+K^+\pi^+\pi^-$ decay channels.
**SINGLE DIFFRACTION BACKGROUND**

**Figure 3.** The probability per event for a given number of charged particles to be emitted within the spectrometer detector acceptance region is given by the upper curve (filled circles), the lower curve (filled squares) gives the acceptance with deployment of the FSCs.
Figure 6. The efficiency to detect single diffractive events (SD) by the Forward Shower Counters (FSCs) as a function of the diffractive mass.
Figure 7. The efficiency to detect non-diffractive events (ND) by the Forward Shower Counters (FSCs) as a function of the charged multiplicity in the detector.
How to classify pp interactions/diffraction in a consistent way at the LHC?

Use Multivariate Techniques for Accessing Diffractive Interactions at the LHC.

Probability of finding a rap gap (in inclusive QCD events) depends on the $p_T$ cut-off

Fig. 4. Probability for finding a rapidity gap (definition 'all') larger than $\Delta \eta$ in an inclusive QCD event for different threshold $p_{t,\text{min}}$. From top to bottom the thresholds are $p_{t,\text{cut}} = 1.0$, 0.5, 0.1 GeV. Note that the lines for cluster and string hadronisation lie on top of each other for $p_{t,\text{cut}} = 1.0$ GeV. No trigger condition was required, $\sqrt{s} = 7$ TeV.

KKMRZ:
How to identify diffraction at the LHC?

- Events that have **rapidity gaps** beyond $\Delta \eta > 3$ units.
  - experimentally depends on detector **thresholds**, $p_{T,\text{min}}$
  - **rapidity correlations** $\sim \exp(-\lambda \Delta \eta)$, $\lambda \sim 1$, hadronization models?
  - rapidity gaps are **not unique** to diffraction

- Diffraction is a **coherent** phenomenon, each component present with a non-zero probability amplitude in a pp interaction

⇒ Assign each pp event a probability to belong to **every one** of the event classes: SDr/SDl, DD, CD, ND

⇒ **Use all the relevant input** information to characterize the space-time evolution of an event.

"Diffraction enhanced" events/ SD vs. "Non-SD" events (Atlas/CMS)
- Talk by Andy Pilkington
INPUT INFORMATION FOR MULTIVARIATE EVENT CLASSIFICATION

- *particle flows* by TOTEM $T_1_{R/L}$, $T_2_{R/L}$ spectrometers and CMS $FSC_{R/L}$ counters at $\pm 60$ to $\pm 140$ m from IP5 [5],

- *transverse energy detection* by the CMS Barrel and End Cap Calorimetry, $HF_{R/L}$, and $CASTOR_{R/L}$ calorimeters

- *neutral particle detection* by the CMS $ZDC_{R/L}$ calorimeters.

A PROBABILISTIC APPROACH: EACH EVENT BELONGS TO EVERY ONE OF THE EVENT CLASSES WITH A WEIGHT $\neq 0$. THE GOOD-WALKER APPROACH FOLLOWED EXPERIMENTALLY.
ENERGIES

MULTIPLICITIES

23 INPUTS FOR EVENT CLASSIFICATION
Figure: *Left:* Charged particle multiplicity distribution for double diffractive (DD) events. *Right:* Distributions after subtraction of MC truth. Comparison of soft classification (soft kNN) and hard classification (hard kNN & neural network).

see: Mikael Kuusela’s presentation on Wednesday!
CONCLUSIONS


- Low mass Single Diffraction: Important for assessing the uncertainties in $\sigma_{\text{tot}}$

- Low mass Central Exclusive Diffraction: Meson spectroscopy, quarkonia, glueballs..ALICE, LHCb

- Identifying Diffractive Scattering in a consistent way.