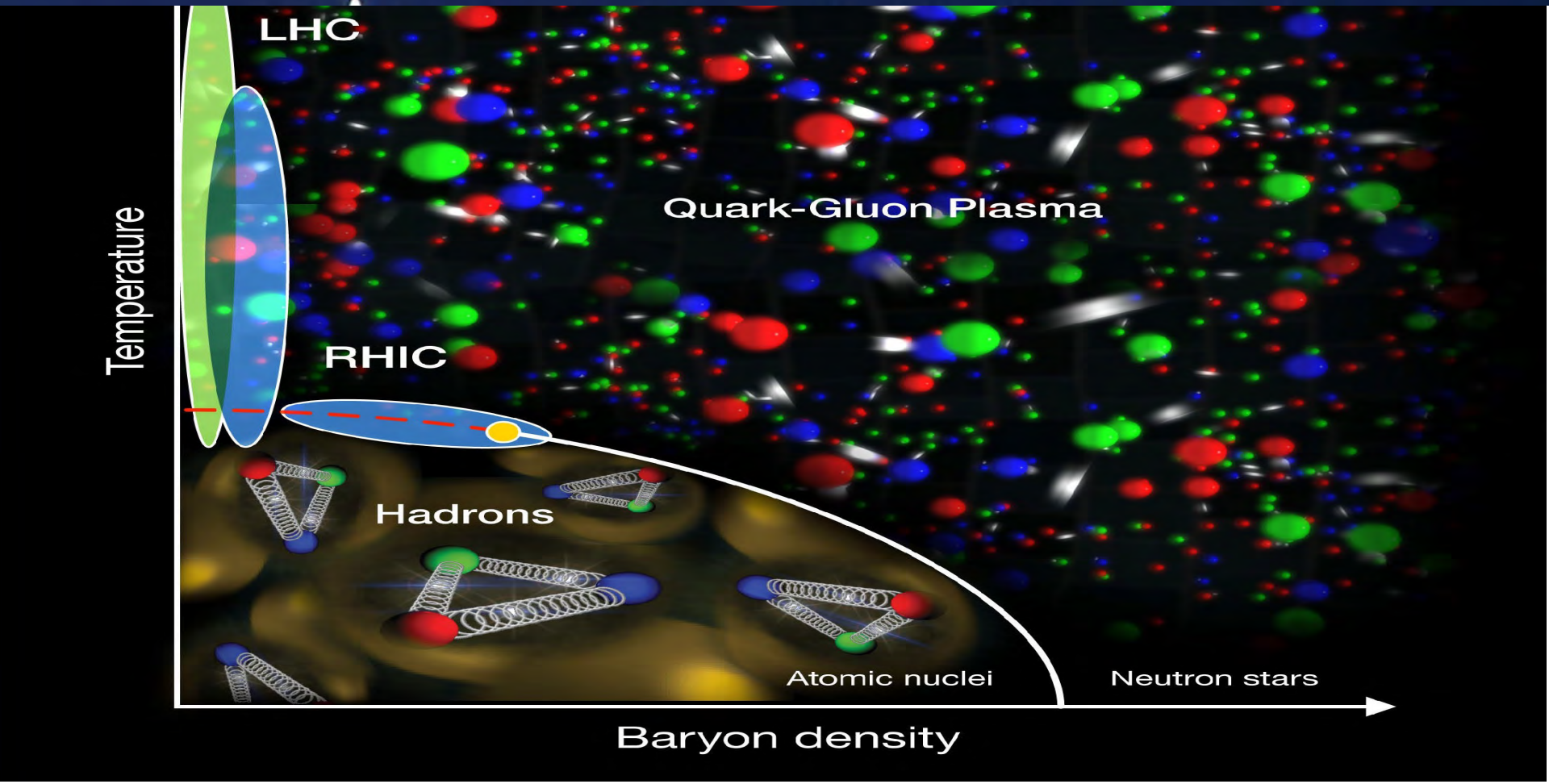
XIV. INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE PROPERTIES
NSP2021, 2-4 June 2021, Selçuk University, Konya-Turkey



Diffraction Cross-Section Measurements at the LHC

Prof. Dr. Ayben Karasu Uysal
KTO Karatay University
NSP-21
4 June 2021

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  - Diffractive Reactions
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Introduction and Motivation

Cross Sections

- The cross sections of inelastic and diffractive processes in proton–proton (pp) collisions are among the basic observables.
  - used to characterize the global properties of interactions.
  - thus are always a subject of interest at a new centre-of-mass energy.

- The behaviour of hadronic cross sections at high energies is usually described in the framework of Regge theory and its various QCD-inspired interpretations.
  - Diffraction: In HEP any process involving Pomeron exchange.

- As these collisions are dominated by relatively small-momentum transfer processes, such measurements contribute to the theoretical understanding of QCD in the non-perturbative regime.

Introduction and Motivation

Cross Sections

- Usually the total pp cross section is decomposed as:

$$\sigma_{Tot} = \sigma_{elastic} + \sigma_{Non-Diffractive} + \sigma_{SD} + \sigma_{DD} + \sigma_{CD}$$

- Diffractive processes represent more than 25% of the cross-section for inelastic proton–proton collisions at the LHC.

- Diffractive and photon induced physics is a research area with a remarkable discovery potential at the LHC.

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- Diffractive and photon induced physics is a research area with a remarkable discovery potential at the LHC.

- As part of the pp interaction analysis program, the ALICE Collaboration is studying diffractive production:
  - Investigation of energy dependence of single and double diffraction cross-sections.
  - Study of central production.
  - Program of upgrades to improve sensitivity to diffractive processes.

Introduction and Motivation

Cross Sections

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- The new sub-detector for diffractive physics would enhance the performance of ALICE to address some relevant topics on this matter.

- It consists of four stations of scintillator pads that would tag the diffractive gap more efficiently.

diffraction cross sections

- Study of central production
- Programme of upgrades to improve sensitivity to diffractive processes.

Introduction and Motivation

Diffractive Reactions

- In a diffractive reaction, no color is exchanged between the particles colliding at high energies.

- Diffraction is elastic (or quasi elastic) scattering caused by the absorption of components of the wave function of the incoming particles.

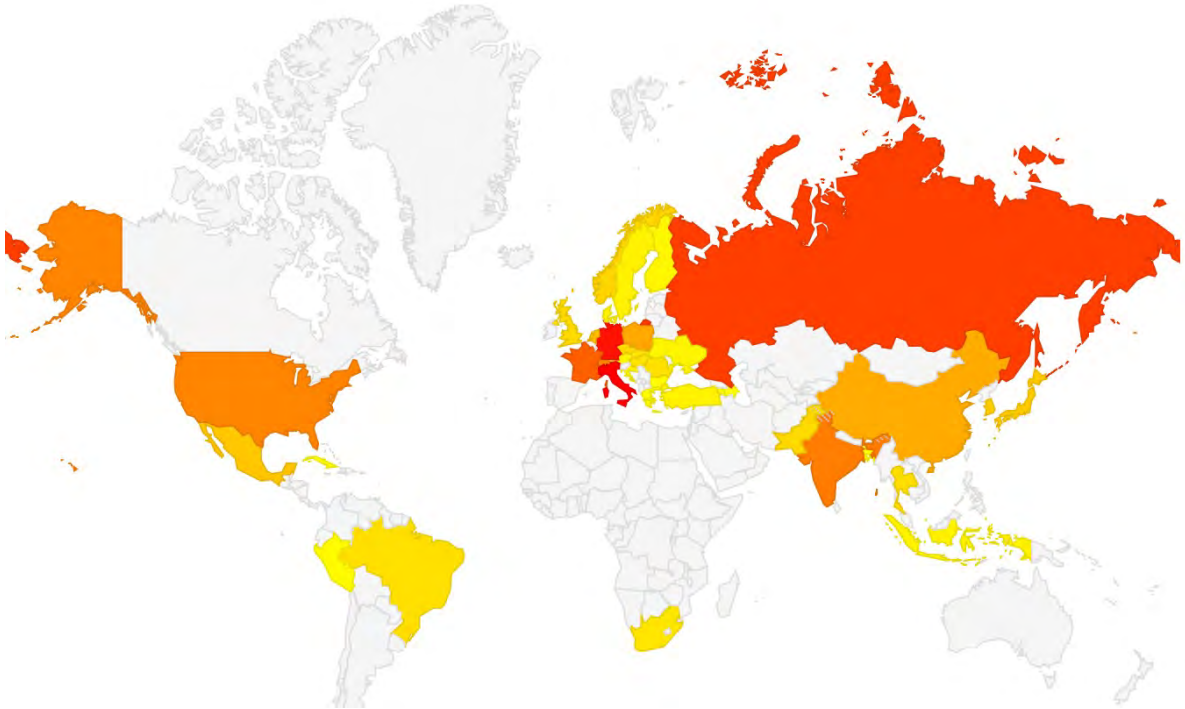
- p-p -> p-p, p-p -> pX (single proton dissociation, Single Diffractive), p-p -> XY (both protons dissociate, Double Diffractive), or Central Diffractive, p-p->p+X+p

- A diffractive process is characterized by a rapidity gap. Experimentally, there is no defined way to distinguish rapidity gaps caused by Pomeron exchange from those caused by other colour-neutral exchanges, so the separation is model dependent.

A Large Ion Collider Experiment

ALICE Collaboration

39 countries, 174 institutes, 1946 members



- Each institute has **specific responsibilities** as formalized in a Memorandum of Understanding.
- **Financial support** comes from the funding agencies of individual participating states.

KTO Karatay University is the **the first and the only** full member Turkish institute of CERN – ALICE Experiment.

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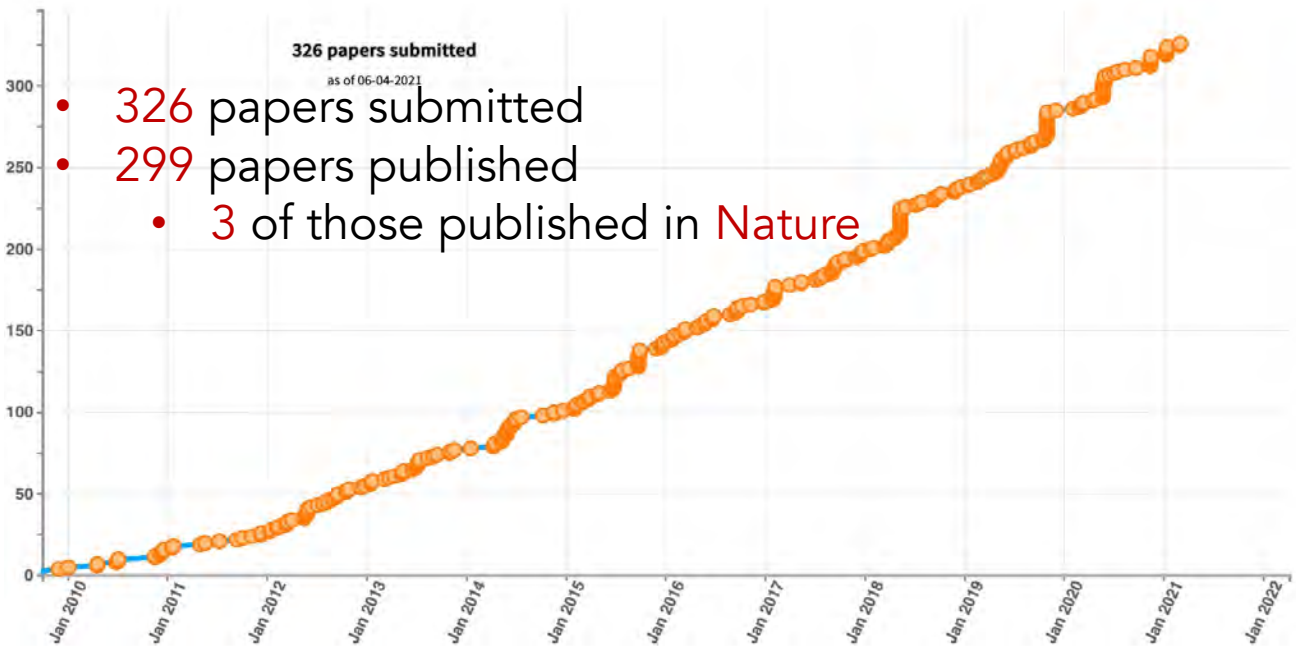

- 326 papers submitted
- 299 papers published
  - 3 of those published in Nature

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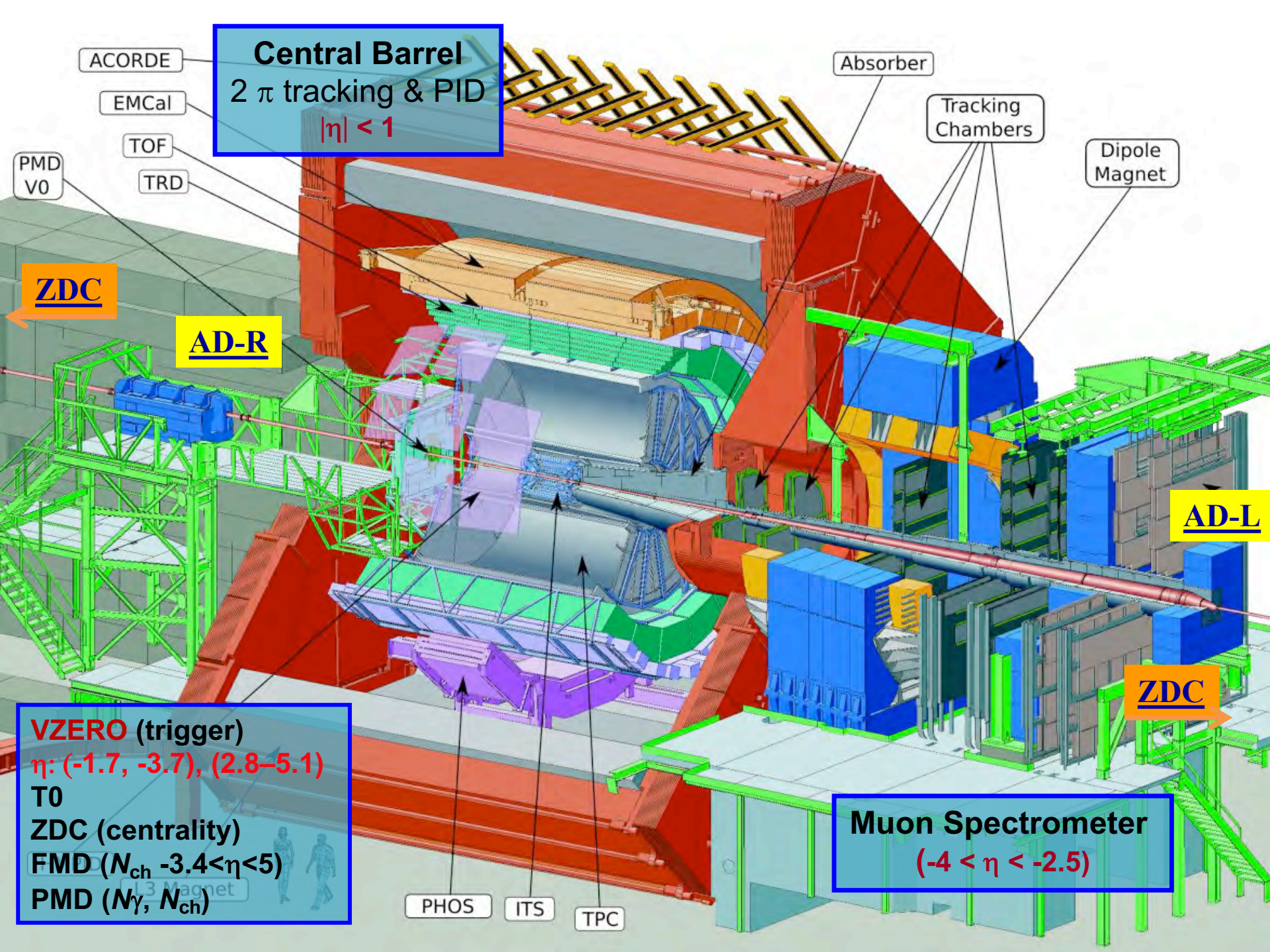
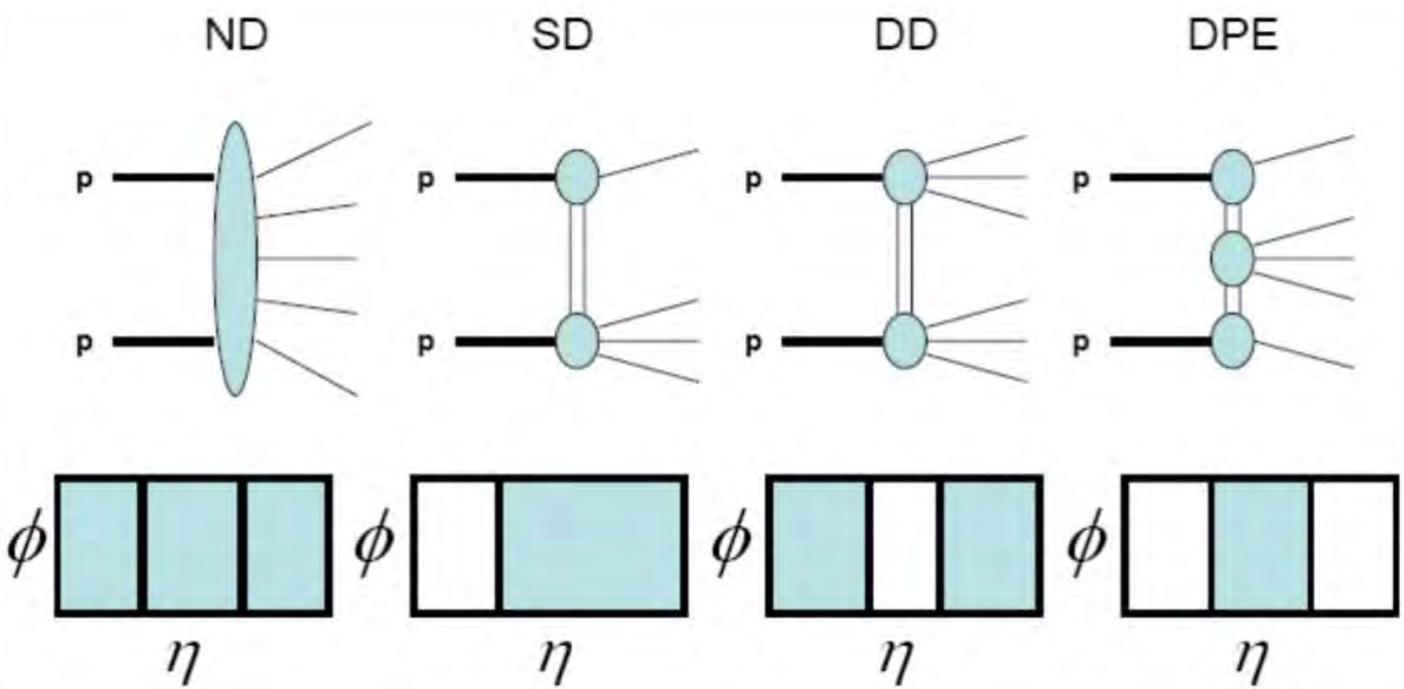

Central Barrel
2 π tracking & PID
|η| < 1
ACORDE
EMCal
TOF
TRD
PMD
V0
Absorber
Tracking Chambers
Dipole Magnet
ZDC
AD-R
AD-L
ZDC
VZERO (trigger)
η: (-1.7, -3.7), (2.8–5.1)
T0
ZDC (centrality)
FMD (N_{ch} -3.4<η<5)
PMD (N_γ, N_{ch})
PHOS
ITS
TPC
Muon Spectrometer
(-4 < η < -2.5)

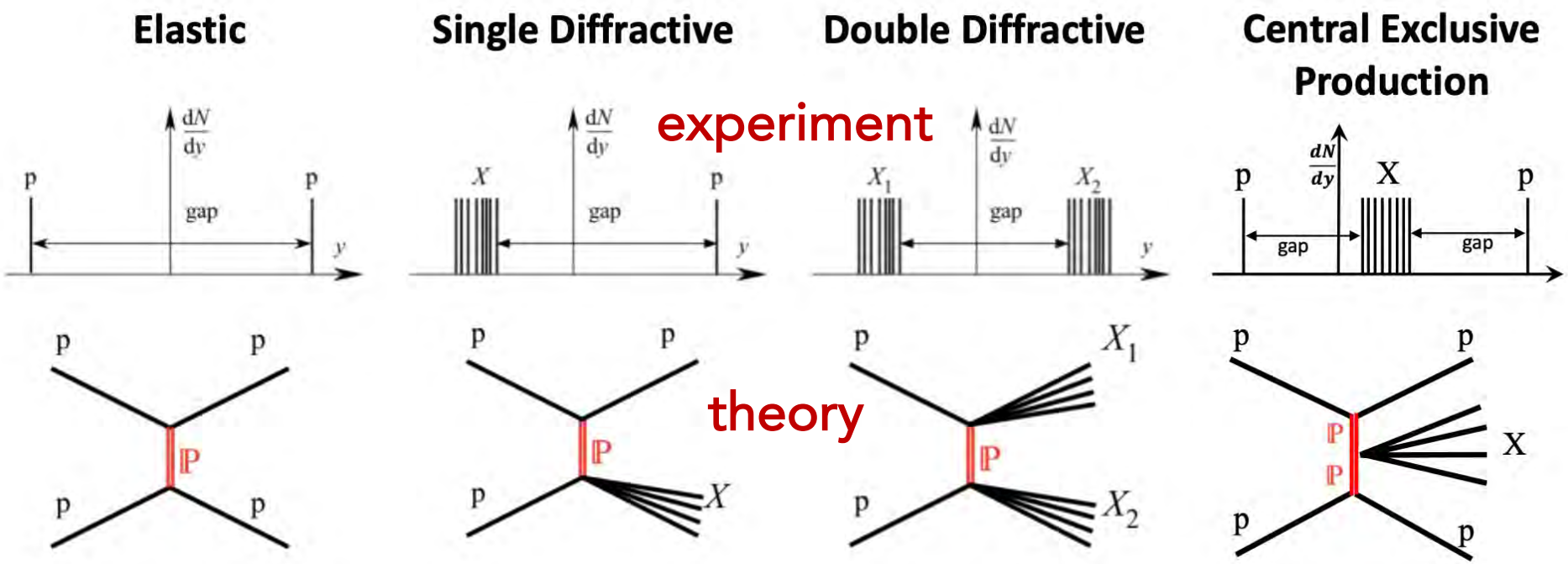
Diffractive Physics in ALICE

- Diffractive reactions can be defined in terms of rapidity gaps.
- Particles emitted in diffractive reactions are mainly found at rapidities close to that of the parent proton.
- It is possible to differentiate between single, double or central diffraction processes depending on the actual location of the rapidity gaps.



Measuring SD and DD with ALICE

Strategy: Measure gap distribution over 8 units in **η** using the central barrel and forward detectors.

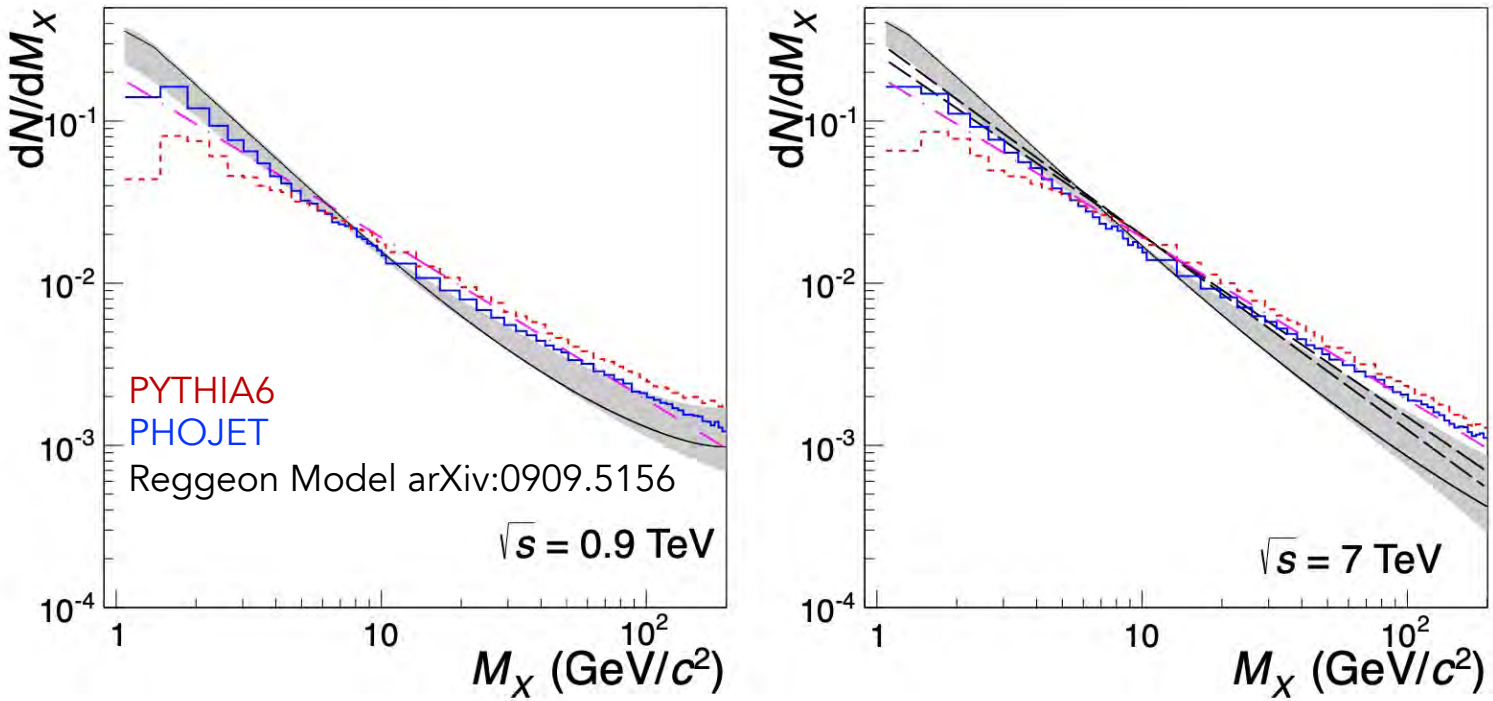


- In Regge theory at high energies, diffraction proceeds via the exchange of Pomerons.
- Pomeron is a colour singlet object with the quantum numbers of the vacuum, which dominates the elastic scattering amplitude at high energies.

Diffractive Physics in ALICE

Simulation of Diffraction: The distribution of diffractive systems are simulated with the PYTHIA6 (Perugia-0) and PHOJET.

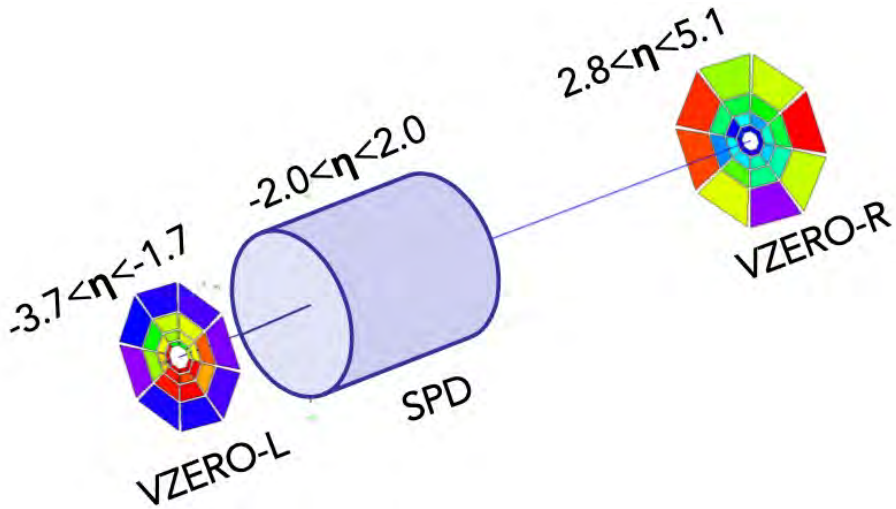
Diffractive Mass Distributions



- The modification of PYTHIA6 and PHOJET consists in reproducing the Reggeon model M_X distribution

Event Samples

- Data at three energies : $\sqrt{s}$ = 0.9, 2.76 and 7 TeV
- Low luminosity, low pile-up:
  average number of collisions per bunch crossing = 0.1
- Trigger used: Minimum Bias – OR i.e.
  at least one hit in SPD or VZERO
- VZERO signal should be in time with particles produced in the collisions



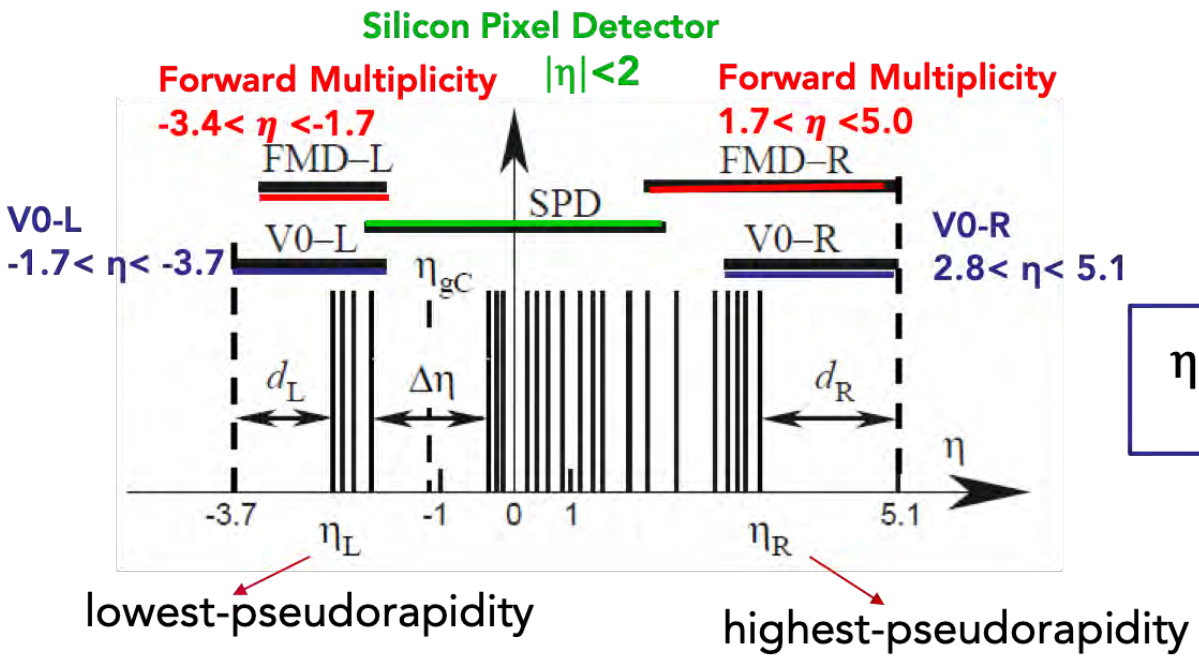
DATA

$\sqrt{s}$ = 0.9	TeV	7 $\times 10^6$events
$\sqrt{s}$ = 7.0	TeV	75$\times 10^6$events
$\sqrt{s}$ = 2.76	TeV	23$\times 10^6$events

- Filled and empty bunch buckets used to measure beam induced background, accidentals due to electronics noise and cosmic showers.

Single and Double Diffractive Events

Pseudorapidity Coverage of FMD, SPD and VZERO Detectors

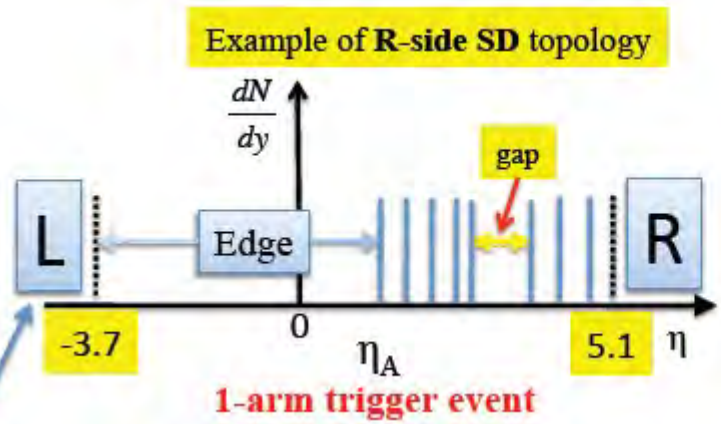


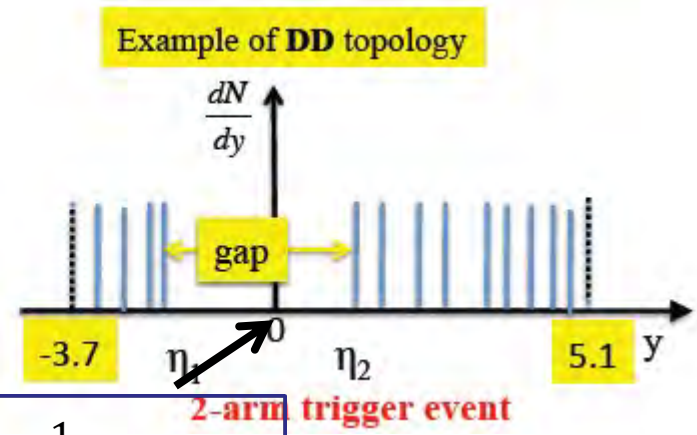
$$\eta_c = \frac{1}{2}(\eta_L + \eta_R)$$

- Events separated into three categories to increase the sensitivity to diffractive processes:
  "1-arm-L", "1-arm- R" and "2-arm".
- 1-arm-L and 1-arm-R have an enriched single-diffraction component.
- 2-arm category can be linked to double diffraction.

Single and Double Diffractive Events

Offline Event Classification: "1 arm-L" "1 arm-R" "2 arm"





muon spectrometer

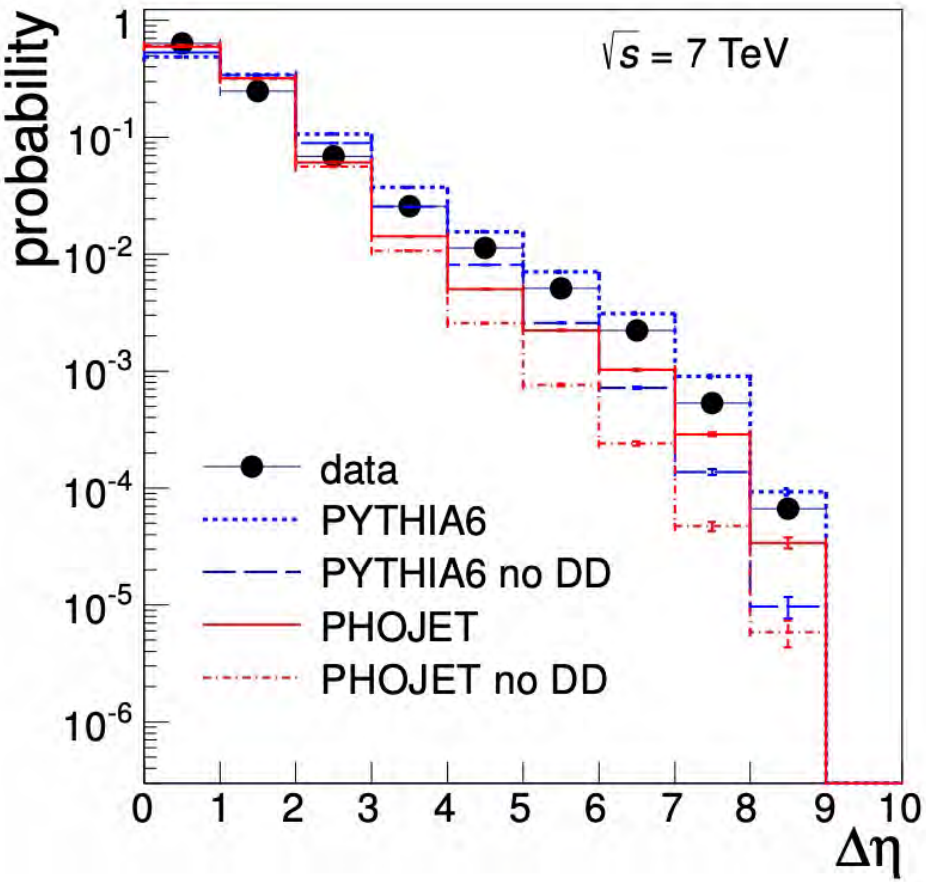
$$\eta_c = \frac{1}{2}(\eta_L + \eta_R)$$

$\eta_C < 0$	1-arm-L
$\eta_C > 0$	1-arm-R

if largest	$\Delta\eta > d_L$ and d_R	2-arm
if both	$-1 \leq \eta_L$ and $\eta_R \leq 1$	2-arm

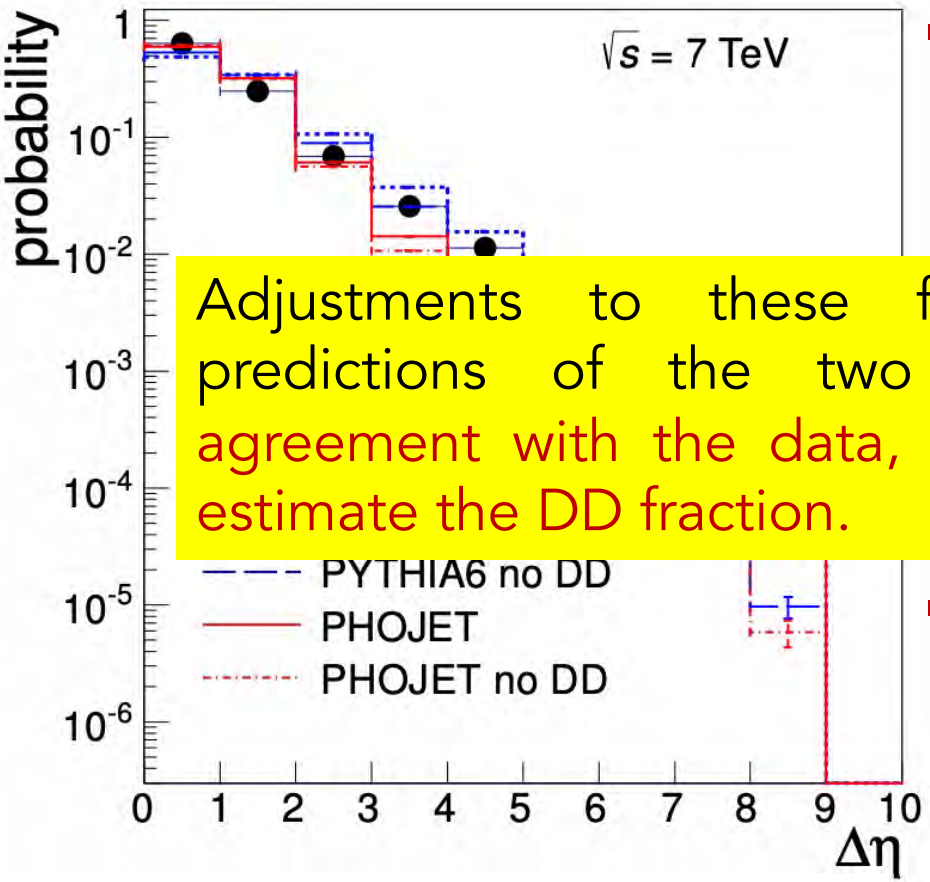
If	$\eta_R < 1$	1-arm-L
If	$\eta_L > -1$	1-arm-R

Results: Pseudorapidity Gaps



- Gap width distribution for 2-arm events is compared to simulations with and without DD, to illustrate the sensitivity to the DD fraction.
- The gap width distribution at large Δη cannot be described by simulations without DD.
- The default DD fraction in PYTHIA6 significantly overestimates the distribution of large pseudorapidity gaps.
- The default DD distribution in PHOJET significantly underestimates it.

Results: Pseudorapidity Gaps



- Gap width distribution for 2-arm events is compared to simulations with and without DD, to illustrate the sensitivity to the DD fraction.

Adjustments to these fractions can bring the predictions of the two generators into better agreement with the data, and lead to a method to estimate the DD fraction.

at large
ed by

- The default DD fraction in PYTHIA6 significantly overestimates the distribution of large pseudorapidity gaps.
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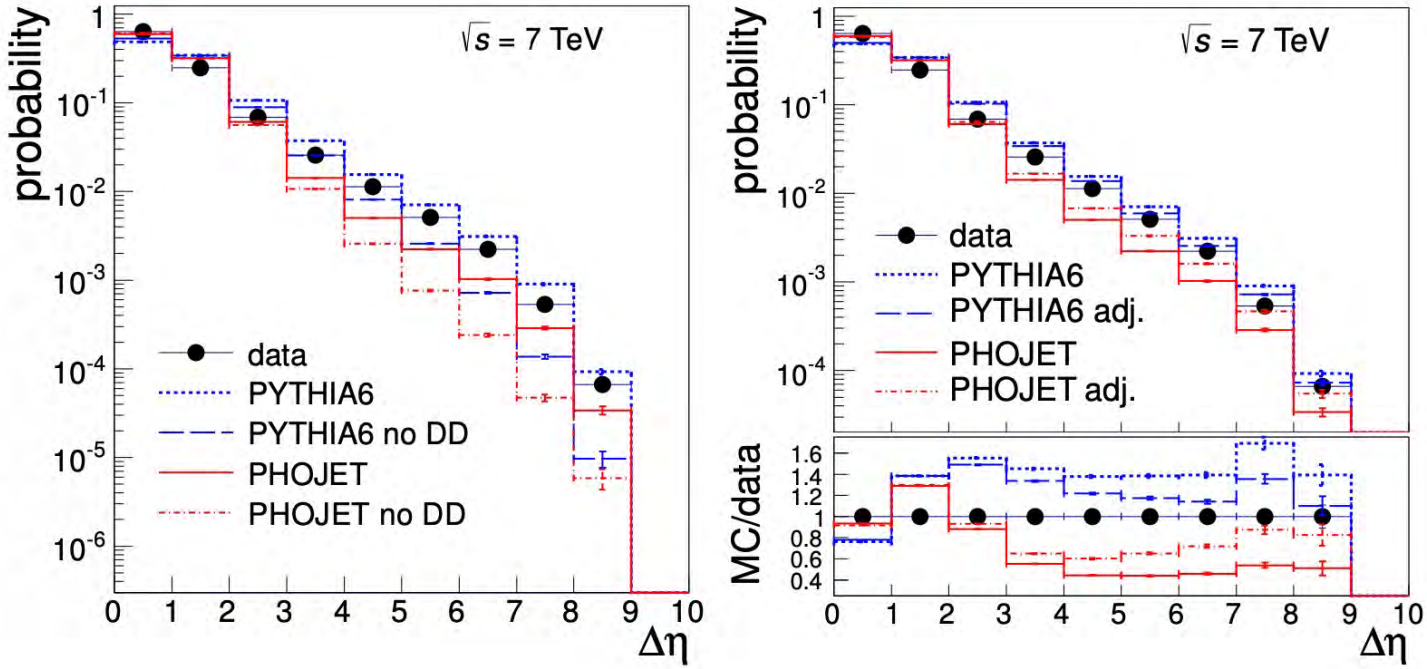
Results: Pseudorapidity Gaps



- The DD fractions in PYTHIA6 and PHOJET were varied in steps so as to approach the measured distribution.
- At the end of the adjustment the PYTHIA6 data still overestimate the data, and the PHOJET data underestimate it.
- But the agreement between data and Monte Carlo is brought to 10% for the bin.

Results: Production Ratios (SD)

Corrected for acceptance, efficiency, beam background, electronic noise and collision pileup

$\sqrt{s}$ (TeV)	ratio definition	ratio	side	$\sigma_{SD}/\sigma_{INEL}$ per side	$\sigma_{SD}/\sigma_{INEL}$ total
0.9	1-arm-L/2-arm	0.0576 ± 0.0002	L-side	0.10 ± 0.02	0.21 ± 0.03
	1-arm-R/2-arm	0.0906 ± 0.0003	R-side	0.11 ± 0.02	
2.76	1-arm-L/2-arm	0.0543 ± 0.0004	L-side	0.09 ± 0.03	$0.20^{+0.07}_{-0.08}$
	1-arm-R/2-arm	0.0791 ± 0.0004	R-side	$0.11^{+0.04}_{-0.05}$	
7	1-arm-L/2-arm	0.0458 ± 0.0001	L-side	$0.10^{+0.02}_{-0.04}$	$0.20^{+0.04}_{-0.07}$
	1-arm-R/2-arm	0.0680 ± 0.0001	R-side	$0.10^{+0.02}_{-0.03}$	

- At high energy the cross section ratio remains constant.
- Results are symmetric despite the different acceptance from ALICE
- Results are consistent with UA5 p-(anti)p

Results: Production Ratios (DD)

Corrected for acceptance, efficiency, beam background, electronic noise and collision pileup

$\sqrt{s}$ (TeV)	$\sigma_{DD}/\sigma_{INEL}$
0.9	0.11 ± 0.03
2.76	0.12 ± 0.05
7	$0.12^{+0.05}_{-0.04}$

with $\Delta\eta > 3$

DD events defined as NSD with large gap

- At high energy the cross section ratio remains constant.
- Results are consistent with UA5 p-(anti)p

Results: Inelastic Cross Section

In order to determine the inelastic cross section, the luminosity has to be measured.

$$\frac{dN}{dt} = A \times \sigma_{\mathrm{INEL}} \times \mathscr{L}.$$

Interaction Rate

Luminosity

- A simultaneous measurement of the LHC luminosity and the interaction rate determines the cross section $A \times \sigma_{\mathrm{INEL}}$.
- Acceptance and efficiency are determined with adjusted simulation.

Results: Inelastic Cross Section

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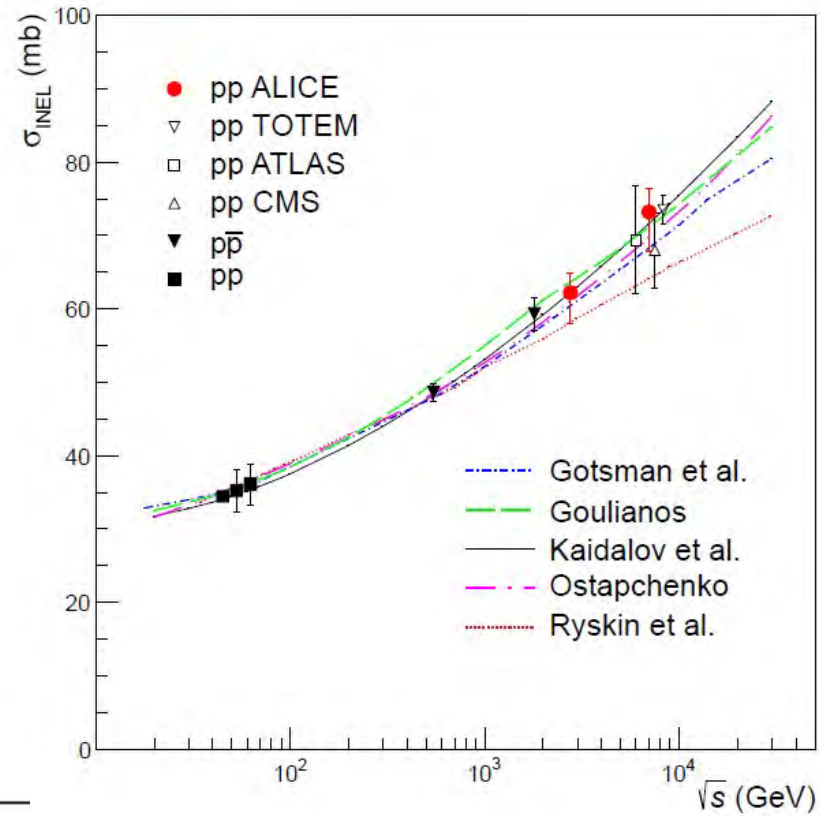
Interaction Rate

Luminosity

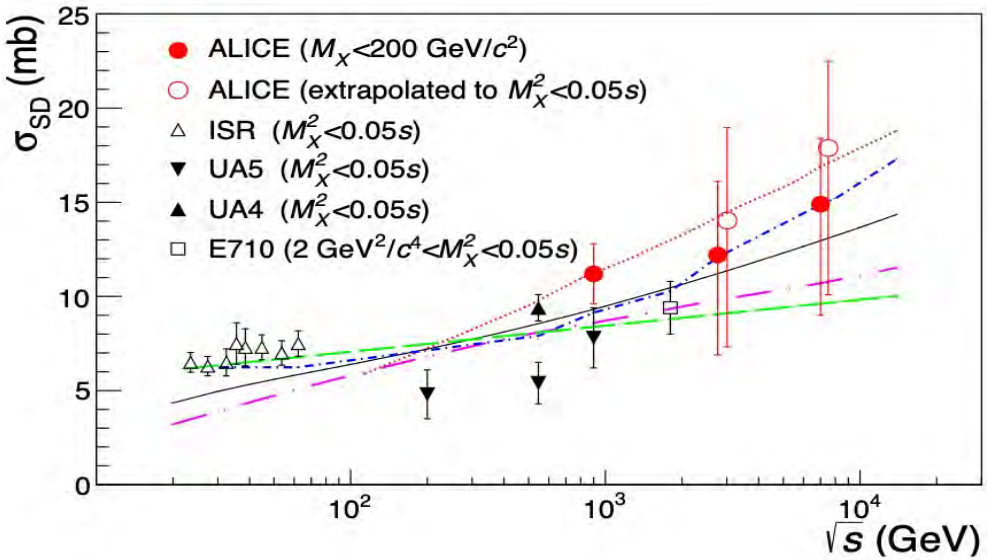


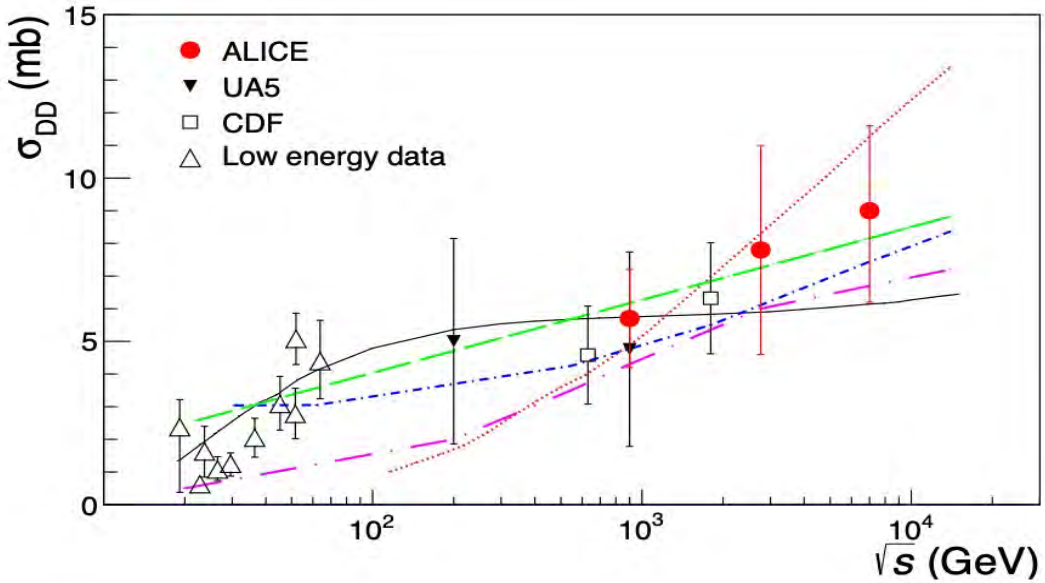
Experiment	σ_{INEL} (mb)
ALICE	$73.2^{+2.0}_{-4.6}(model) \pm 2.6(lumi)$
ATLAS [19]	$69.4 \pm 6.9(model) \pm 2.4(exp)$
CMS [20]	$68.0 \pm 4.0(model) \pm 2.0(syst) \pm 2.4(lumi)$
TOTEM [21]	$73.5^{+1.8}_{-1.3}(syst) \pm 0.6(stat)$

The results from three experiments are consistent within experimental uncertainties.

Results: Diffractive Cross Sections

Combining the measurements of the inelastic cross section with the relative rates of diffractive processes, cross sections for single (M_X < 200 GeV/c^2) and double ($\Delta\eta$ > 3) diffraction were obtained.





Gotsman et al.
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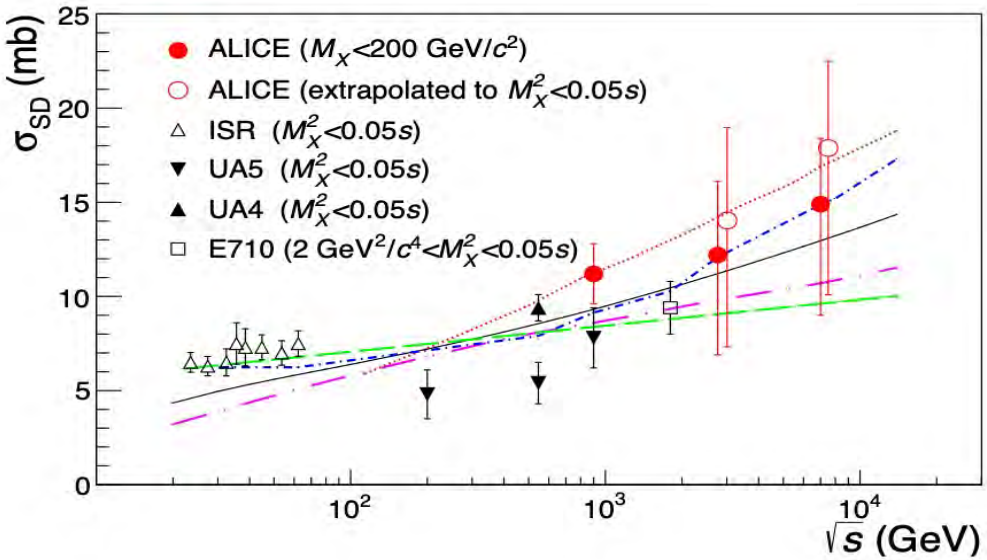

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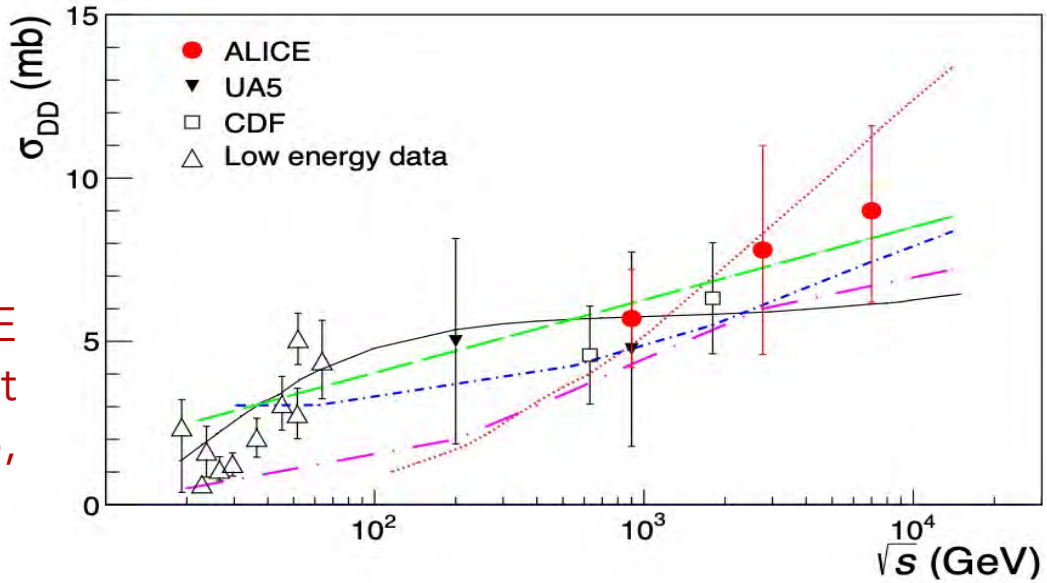

Within large uncertainties ALICE measurements are in agreement with the measurements from UA5, UA4 and CDF.

Summary

- Measurements of cross sections of inelastic and diffractive processes in proton–proton collisions at LHC energies were carried out with the ALICE detector.
- A study of gaps in the pseudorapidity distributions of particles produced in pp collisions at the LHC was used to measure the fraction of diffractive events in inelastic pp collisions at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV.
  - At $\sqrt{s}$ = 0.9 TeV, the ALICE result on diffractive fractions is consistent with the UA5 data for p(anti)p collisions.
- The ALICE inelastic cross section result at $\sqrt{s}$ = 7 TeV is consistent with those from ATLAS, CMS, and TOTEM.
- Combining measured inelastic cross sections with diffraction relative rates, cross sections were obtained for single- and double-diffraction processes.
- Cross section measurements were compared to other measurements at the LHC, to lower energy data, and to predictions from current models, and are found to be consistent with all of these, within present uncertainties.

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