DIFFRACTION PHYSICS WITH ALICE AT THE LHC

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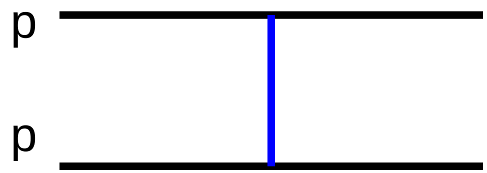
OUTLINE

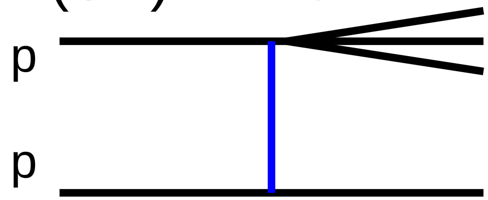
- Motivation: why study diffraction?
- ALICE experiment: setup and advantages
- Single and double diffraction measurements
- Central diffraction
- Plans for the future

CROSS-SECTION AT LHC ENERGIES

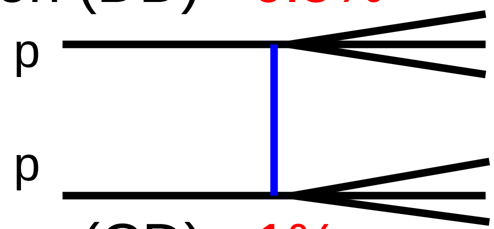
- Total cross-section:
  - Elastic scattering ~26%



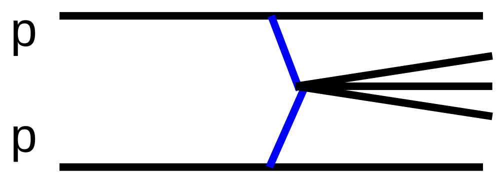
- Single diffraction (SD) ~12.5%



- Double diffraction (DD) ~6.5%

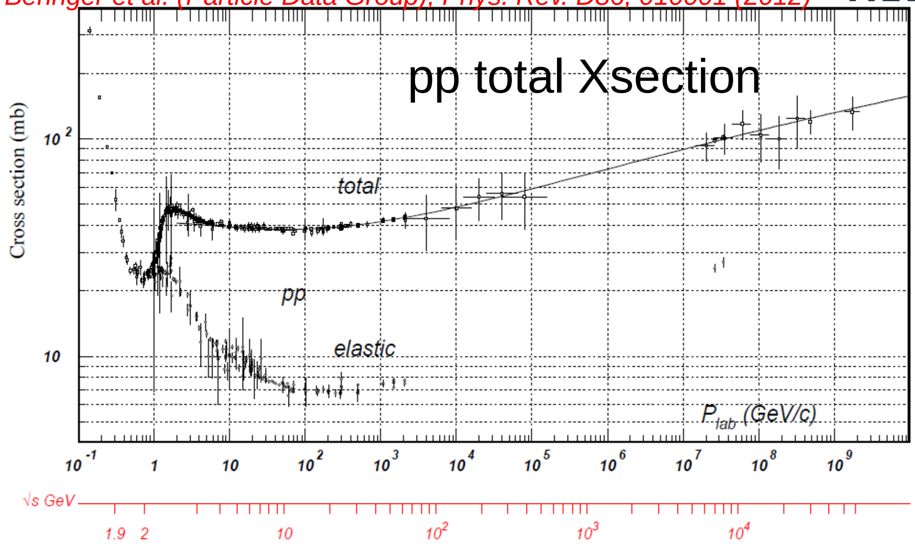


- Central diffraction (CD) <1%



- Non-diffractive (rest of the cross-section)

J. Beringer et al. (Particle Data Group), Phys. Rev. D86, 010001 (2012)



Serpukhov effect: increase of total Xsection

In Regge pole approximation: $\sigma_{tot}(s) \sim \left(\frac{s}{s_0}\right)^{\alpha(0)-1}$

α(0) > 1 supercritical Pomeron is needed (V.Gribov)

| = vacuum quantum numbers exchange

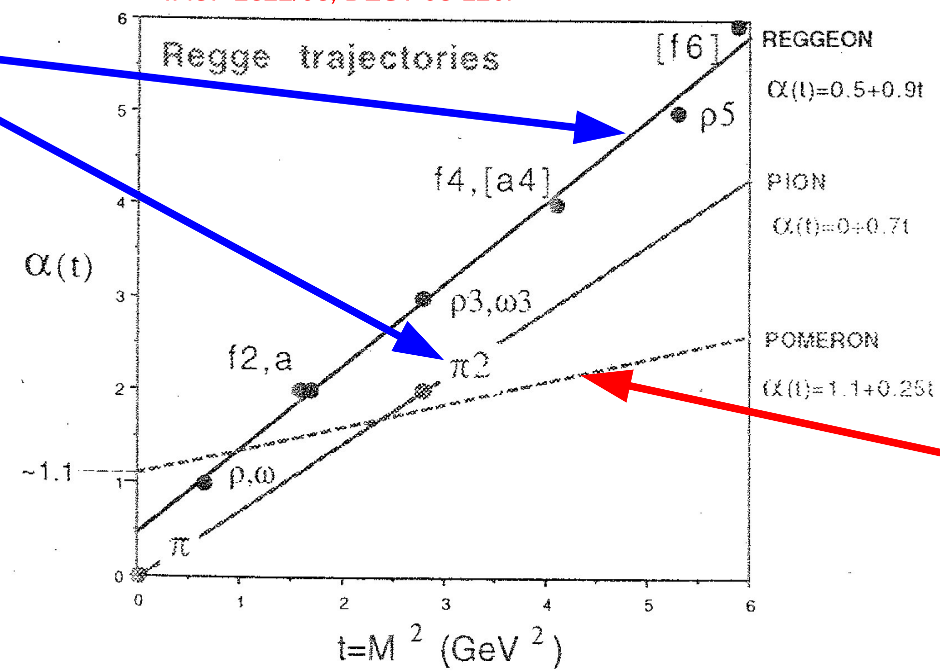
Numbers from: J.P.Revol HESZ workshop 2013

THE POMERON

- Pomeron: colour singlet object with vacuum quantum numbers.
- The Pomeron was introduced as a Regge trajectory responsible for the growth of the total cross-section with collision energy.
- Events in which a pomeron is exchanged: diffraction.
- Thereby the study of diffraction helps in understanding nature of the Pomeron and its connection the soft QCD processes and vice versa.

E. Levin. An Introduction to Pomerons. TAUP 2522/98, DESY 98-120.

Regge trajectories of ordinary particles



Donnachie–Landshoff Pomeron trajectory

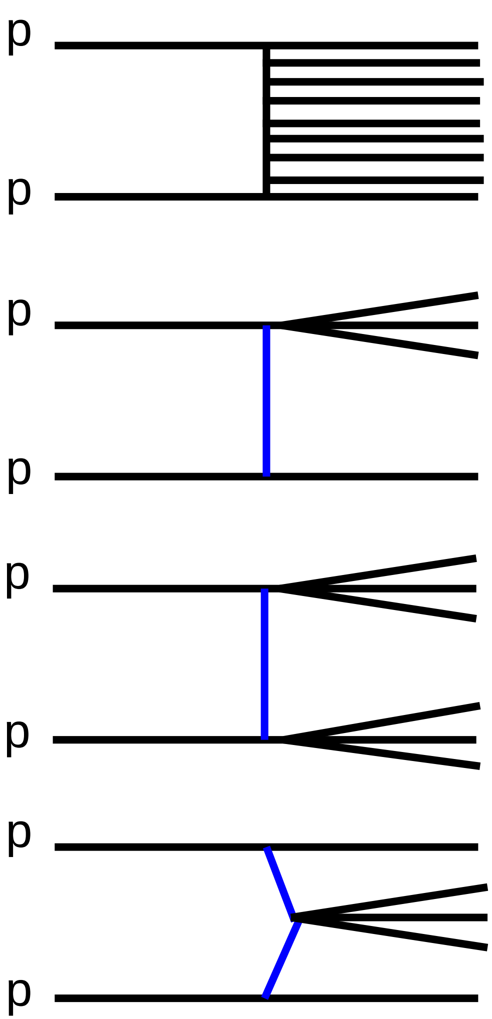
DIFFRACTION FOR EXPERIMENTALISTS

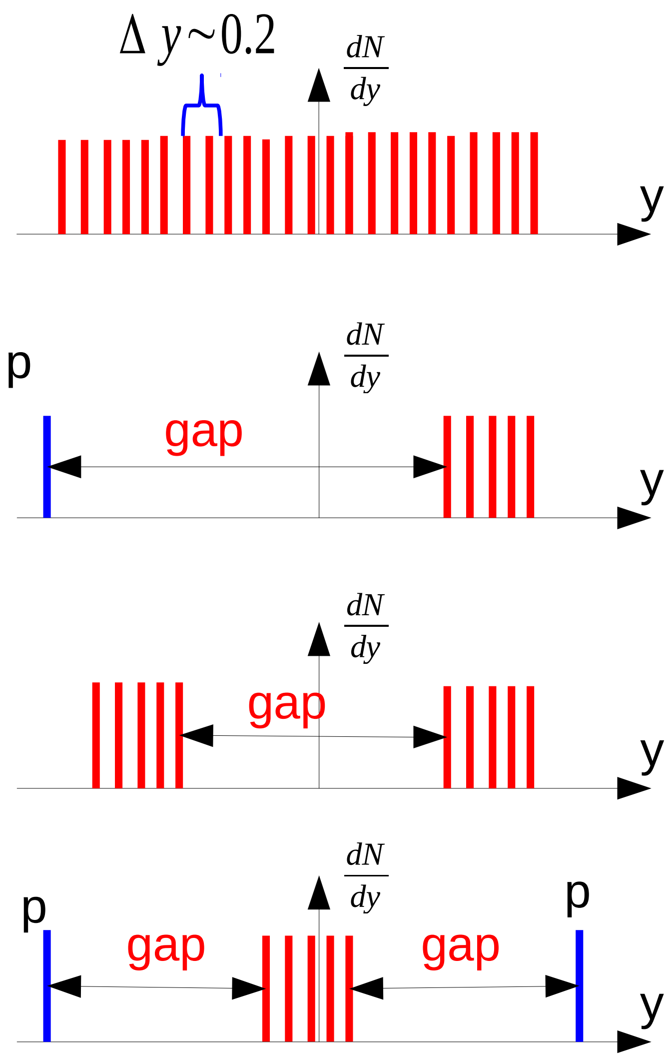
- Classification of diffractive and non-diffractive processes using (pseudo)rapidity gaps:

- Non-diffractive

$$\frac{dN}{dy}(\sqrt{s}=7\,TeV)\sim 6 \Rightarrow \Delta y \sim 0.2$$

- Single diffraction
- Double diffraction
- Central diffraction





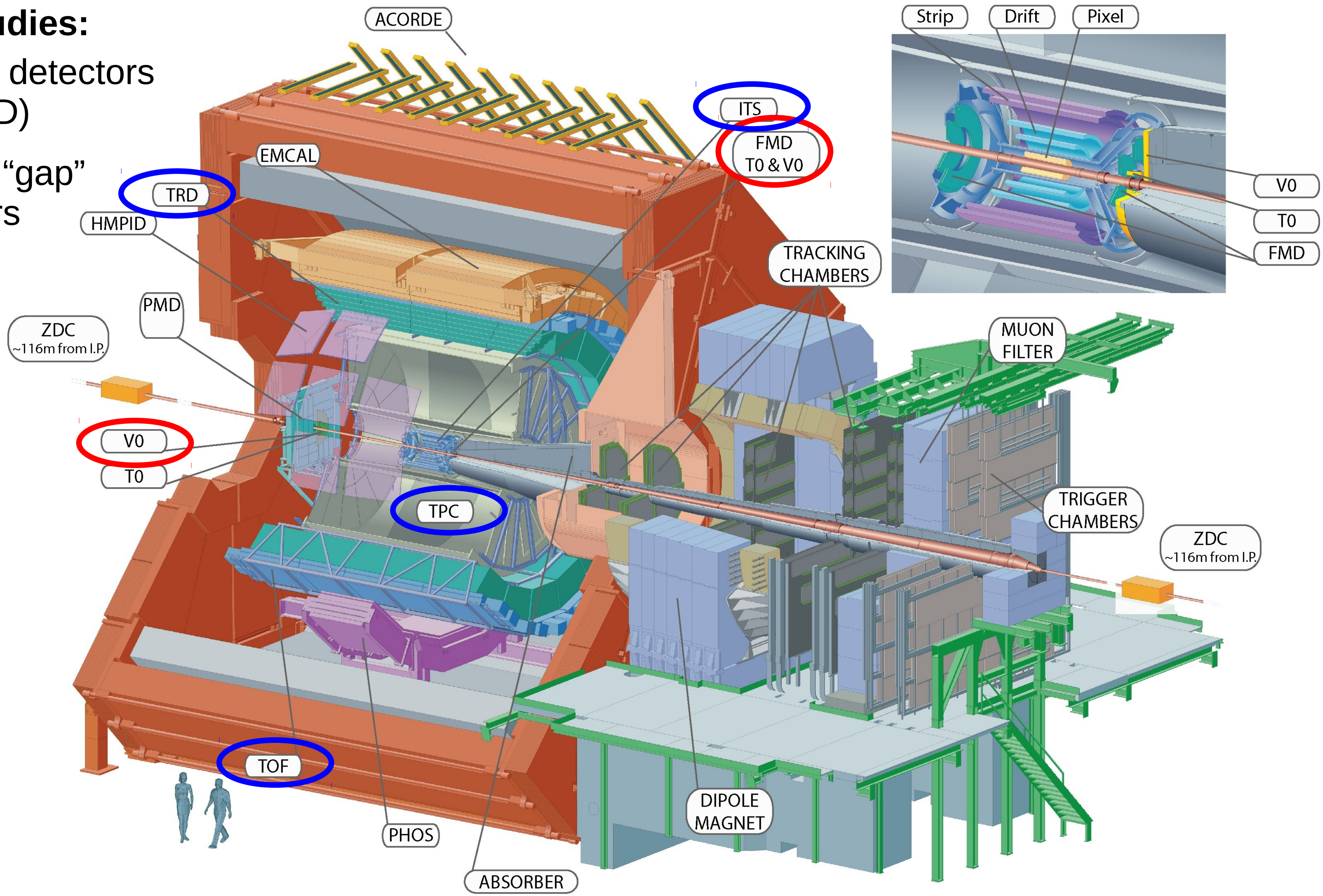
DIFFRACTION FOR EXPERIMENTALISTS (2)

- **Advantages of (pseudo)rapidity gap classification**:
  - Can be used when outgoing protons are not detected;
  - Possibility to introduce asymmetric triggers with enriched diffractive events;
- **Difficulties of (pseudo)rapidity gap classification**:
  - Misclassification of different processes (multiplicity fluctuations, gap survival probability);
  - Model-dependence of the results (detector does not see the full inelastic cross-section);
  - Limitation on maximal diffractive masses;
  - A big variety of existing models – how to choose a good one?
  - No reliable model for central diffraction at low masses (< 1 GeV/c^2).

THE ALICE DETECTOR

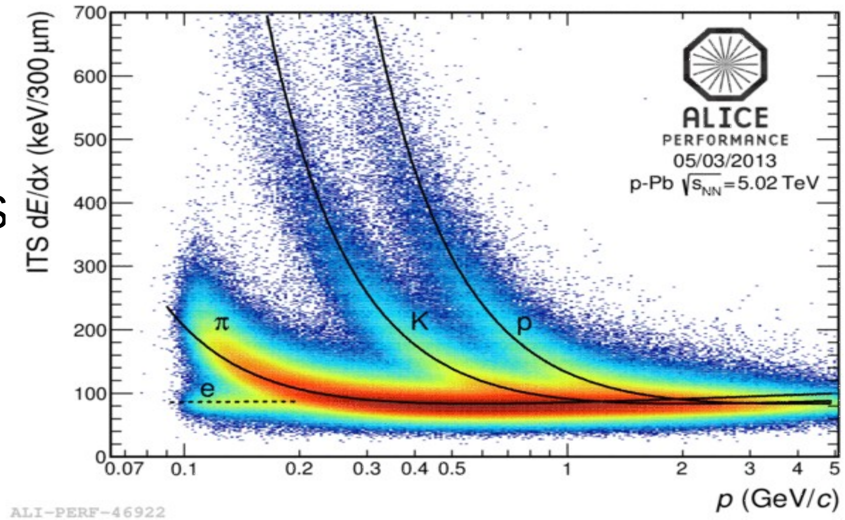
Detectors which can be used in diffractive studies:

- tracking detectors (with PID)
- forward "gap" detectors

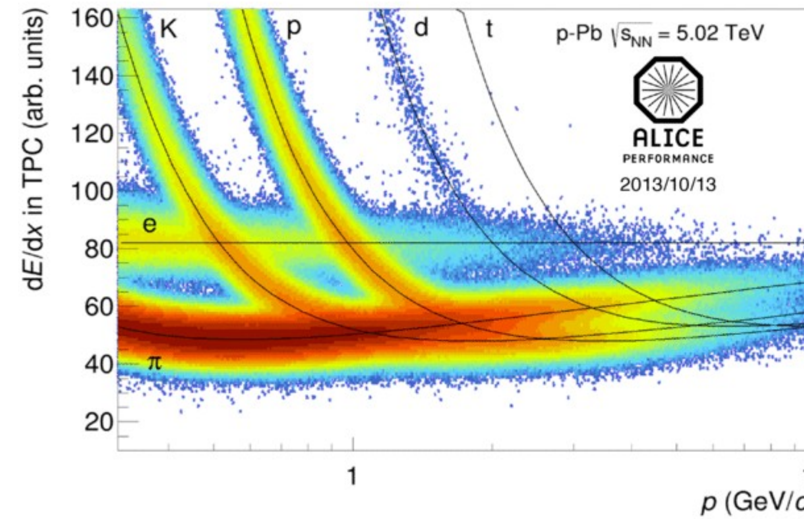


PID CAPABILITIES OF ALICE

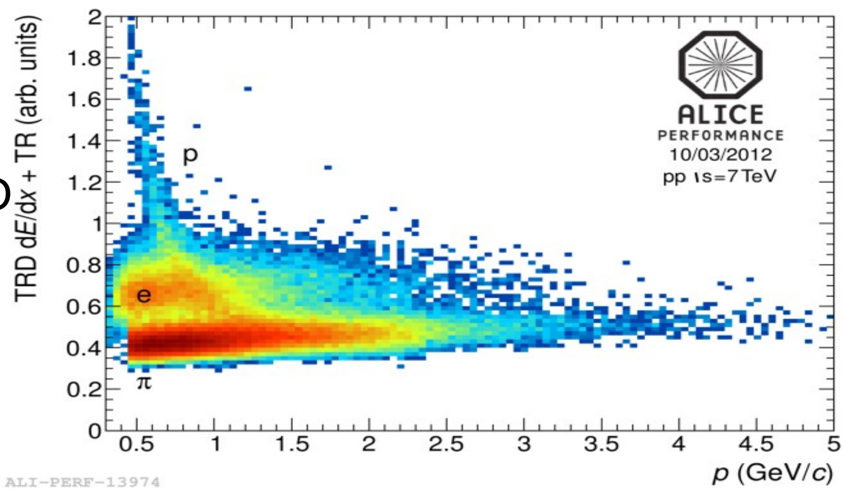
ITS



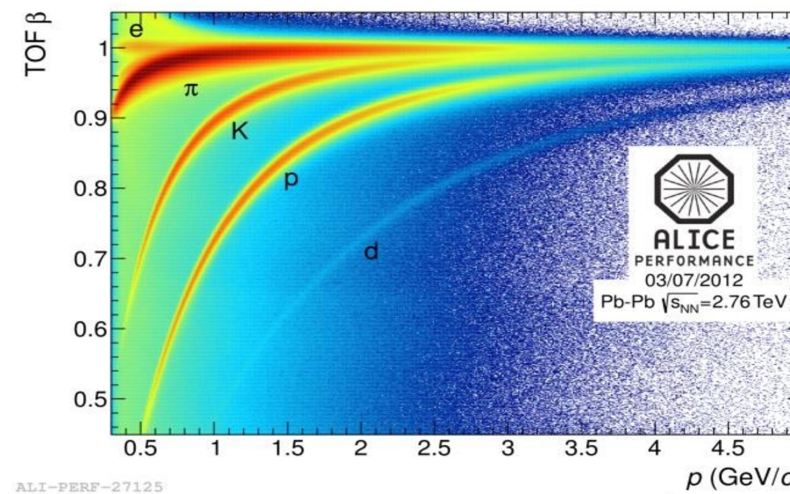
TPC



TRD

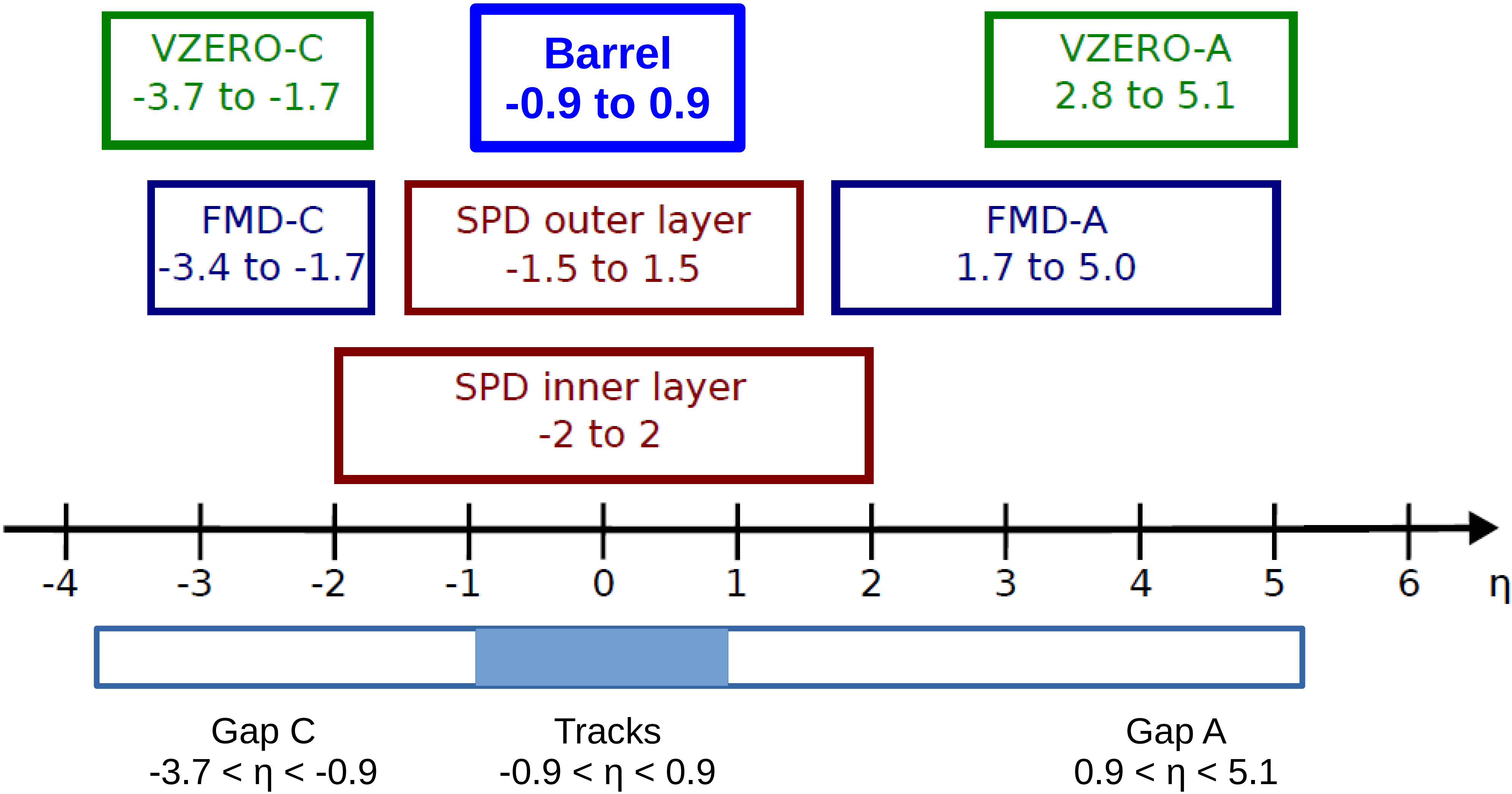


TOF



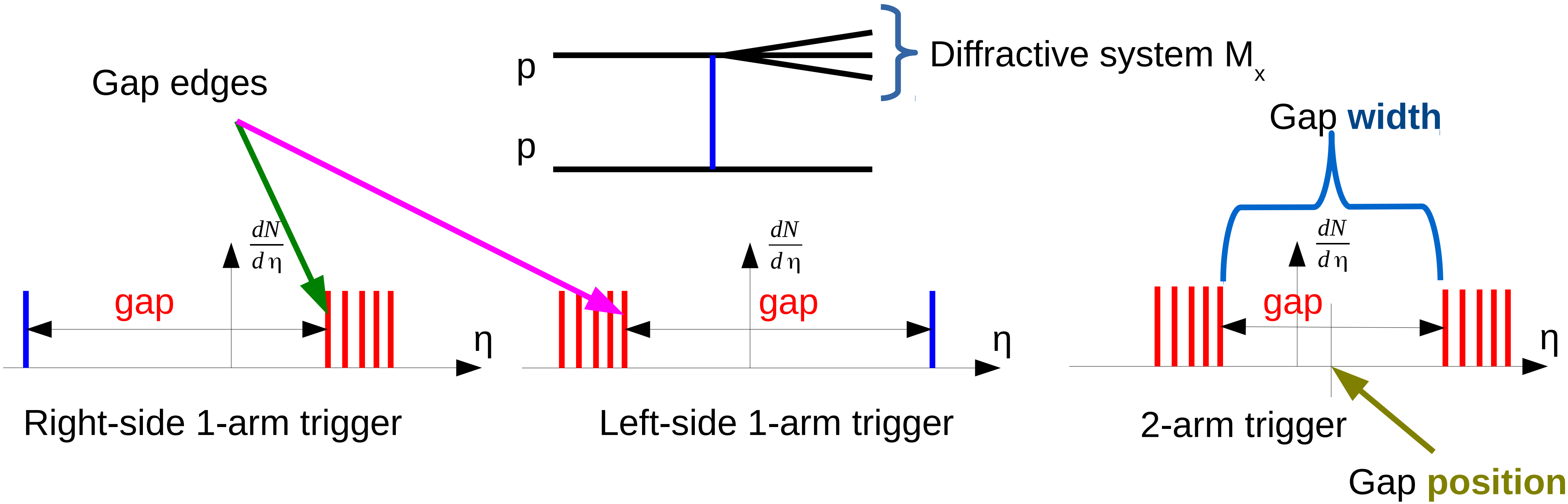
Excellent PID for low momentum particles: opportunity to study central production in various channels (ππ, KK, ...)

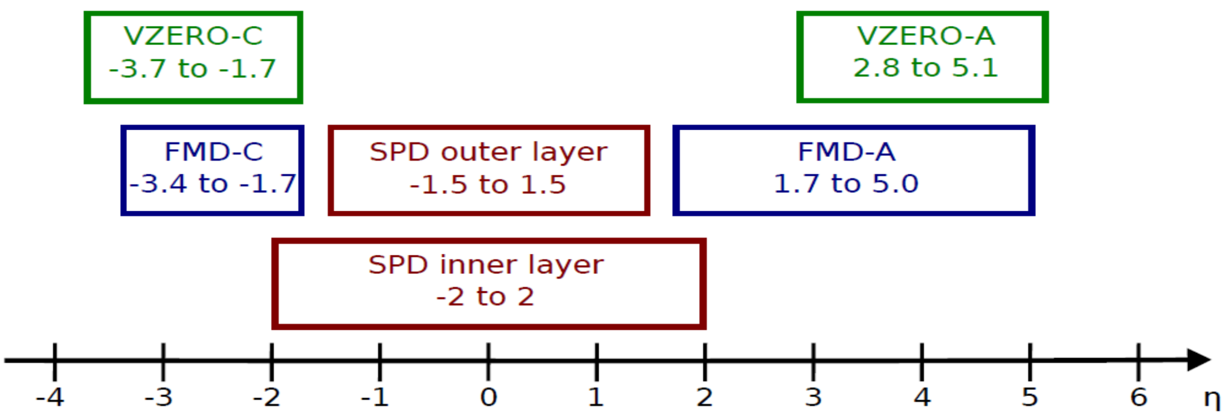
ALICE PSEUDORAPIDITY COVERAGE



Total pseudorapidity coverage is almost 9 units!

SINGLE AND DOUBLE DIFFRACTION MEASUREMENTS



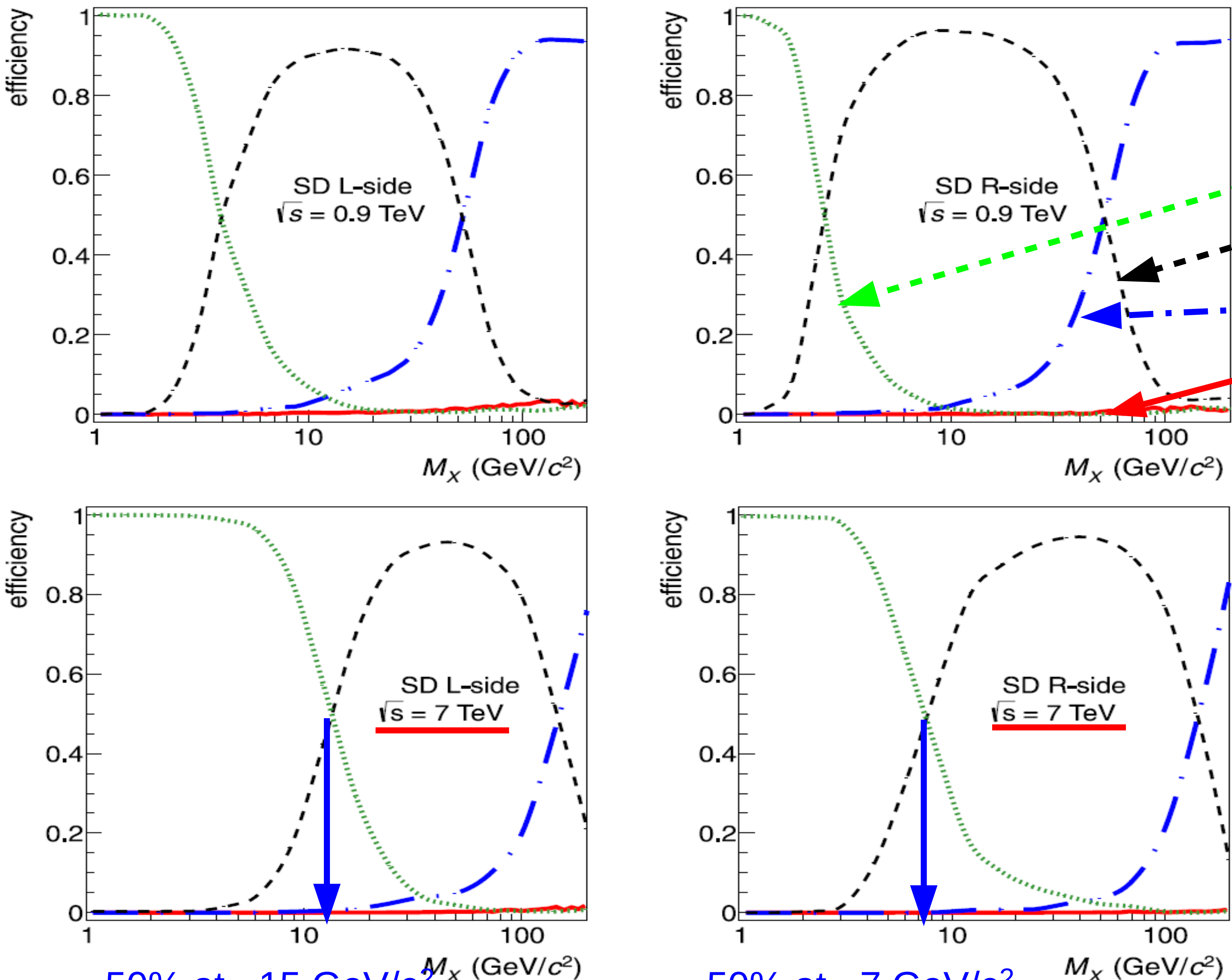


Observables:

- Gap edges (left and right) – 1-arm
- Gap **width** – 2-arm
- Gap **position** – 2-arm

B.Abelev et al (The ALICE Collaboration). Measurement of inelastic, single- and double-diffraction crosssections in proton–proton collisions at the LHC with ALICE. Eur. Phys. J. C (2013) 73:2456

SD EFFICIENCY



No trigger (inefficiency)

1-arm trigger

2-arm trigger

Opposite 1-arm trigger

PYTHIA6 simulations

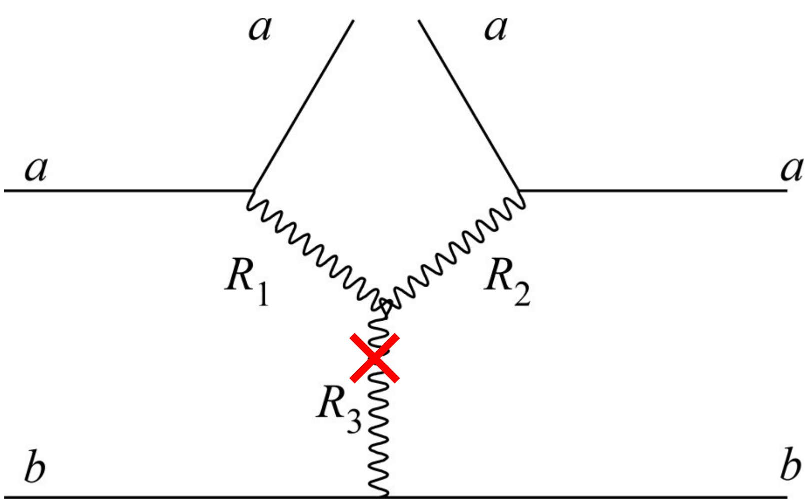
Acceptance is limited by $M_x < 200$ GeV/c^2

50% at ~15 GeV/c^2

50% at ~7 GeV/c^2

DIFFRACTIVE MODEL

- The pseudorapidity gap approach for diffraction studies involves a model with the diffractive mass distribution as a main source of systematic uncertainties.



$$\frac{d\sigma_{SD}}{dM_x^2\,dt} = \left(\frac{s_0}{s}\right)^2 \sum_{i,j,k} G_{ijk}(t) \left(\frac{s}{M_x^2}\right)^{\alpha_i(t)+\alpha_j(t)} \left(\frac{M_x^2}{s_0}\right)^{\alpha_k(0)}$$

Here $R_{1,2,3}$ could be either pomeron or reggeon

P: $\alpha_P(0)=1+\Delta$ R: $\alpha_R(0)=0.5$

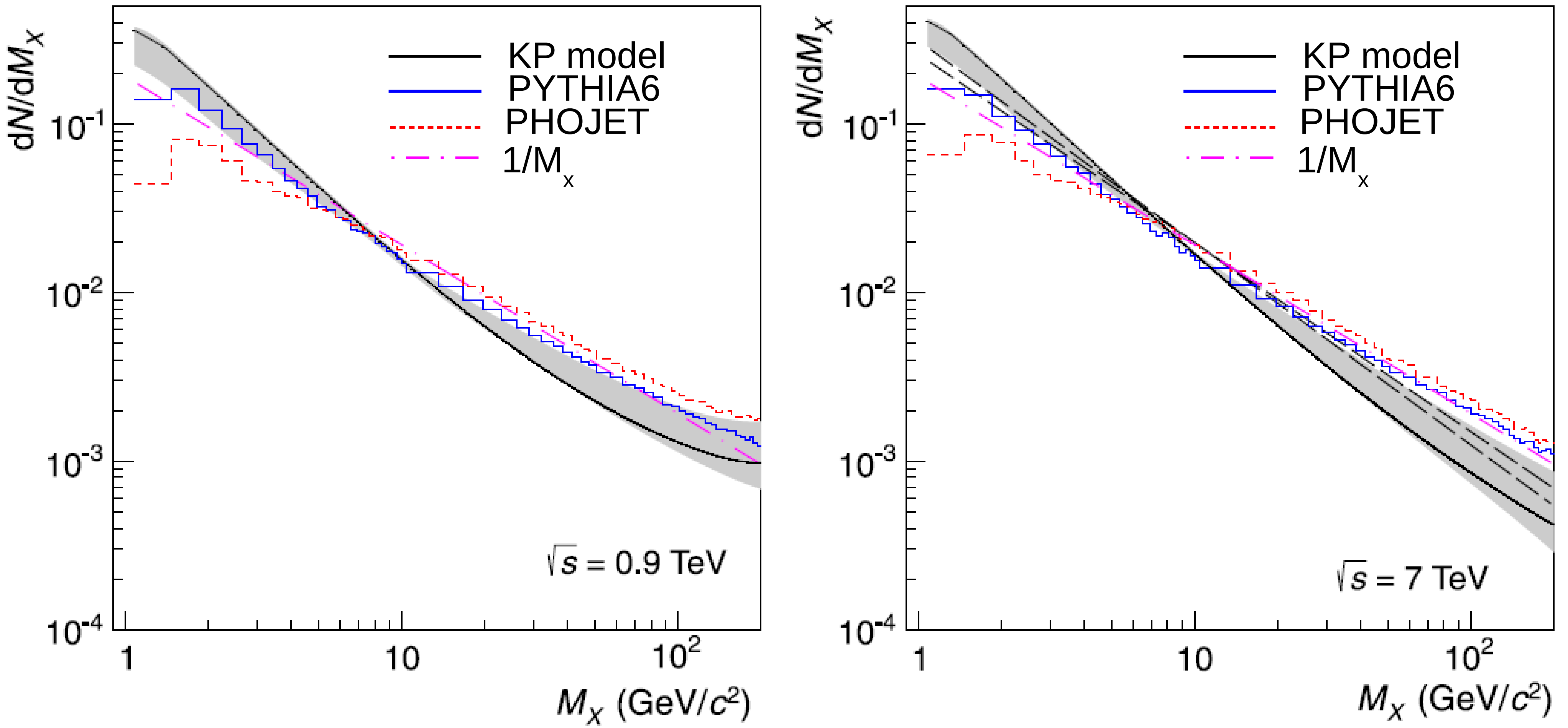
$$(PP)P: \frac{d\sigma}{dM_x} \sim s^{2\Delta}/M_x^{1+2\Delta} \qquad (PP)R: \frac{d\sigma}{dM_x} \sim s^{2\Delta}/M_x^{2+4\Delta}$$

8 different combinations

- ALICE: Kaidalov-Poghosyan model based on Gribov's Regge calculus.

A.B. Kaidalov and M.G. Poghosyan, Proc. Conf. on Elastic and Diffractive Scattering, ("Blois Workshop", CERN, June 2009:ArXiv:0909.5156)

DIFFRACTIVE MASS DISTRIBUTIONS



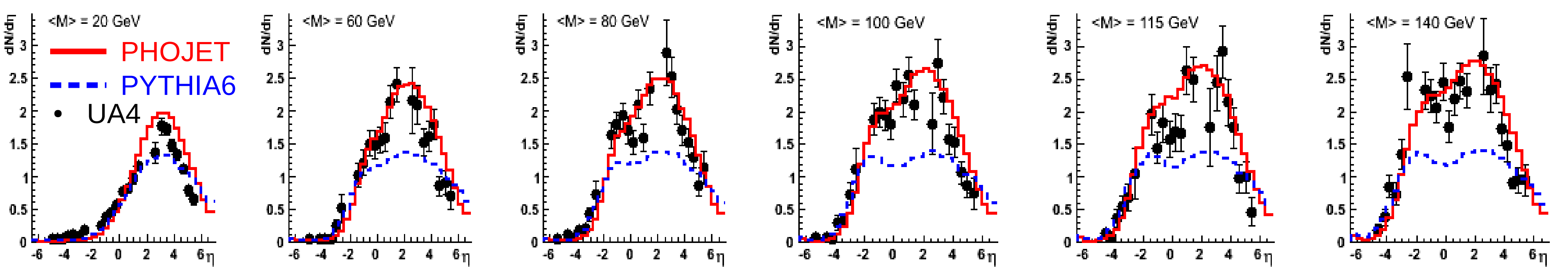
The shaded area around the black line is delimited by variation of the KP model + 50% at the threshold and by Donnachie–Landshoff parametrization. This variation is used for estimating systematic uncertainties.

DATA SAMPLES AND MC GENERATORS

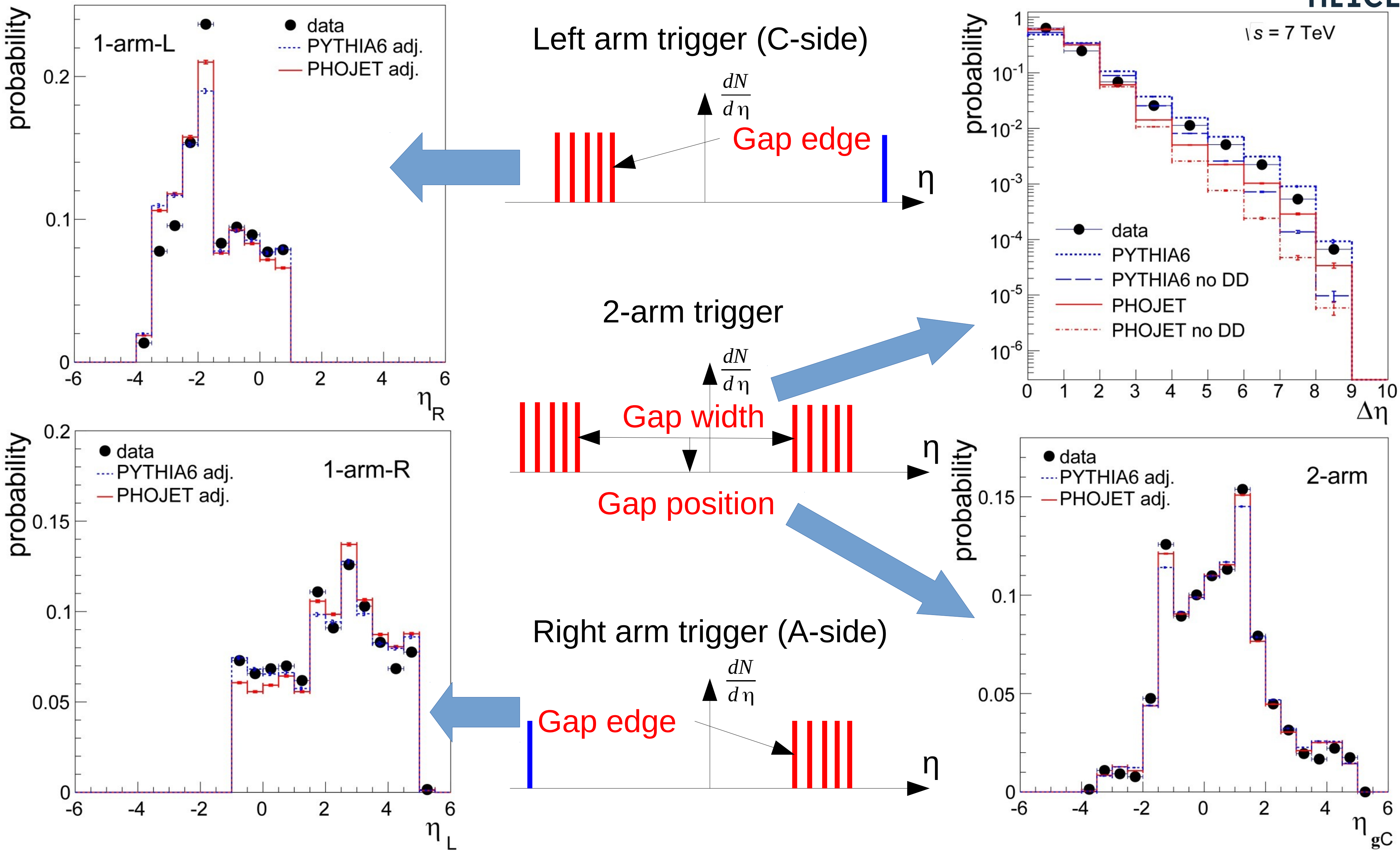
- pp data (Minimum Bias trigger) have been collected at three energies:
  - $\sqrt{s}$ = 0.9 TeV — 7×10^6 events
  - $\sqrt{s}$ = 2.76 TeV — 23×10^6 events
  - $\sqrt{s}$ = 7 TeV — 75×10^6 events
- Two MC generators have been employed:
  - PYTHIA6.421 (“Perugia-0” tune)
  - PHOJET1.12

  } *Modified to follow Kaidalov-Poghosyan diffractive mass distribution*

- The main difference between the two generators is the used model of diffractive cluster fragmentation.
- The "inner" edge of the pseudorapidity distribution is relevant for this study and it is reasonably well described by both PYTHIA6 and PHOJET.

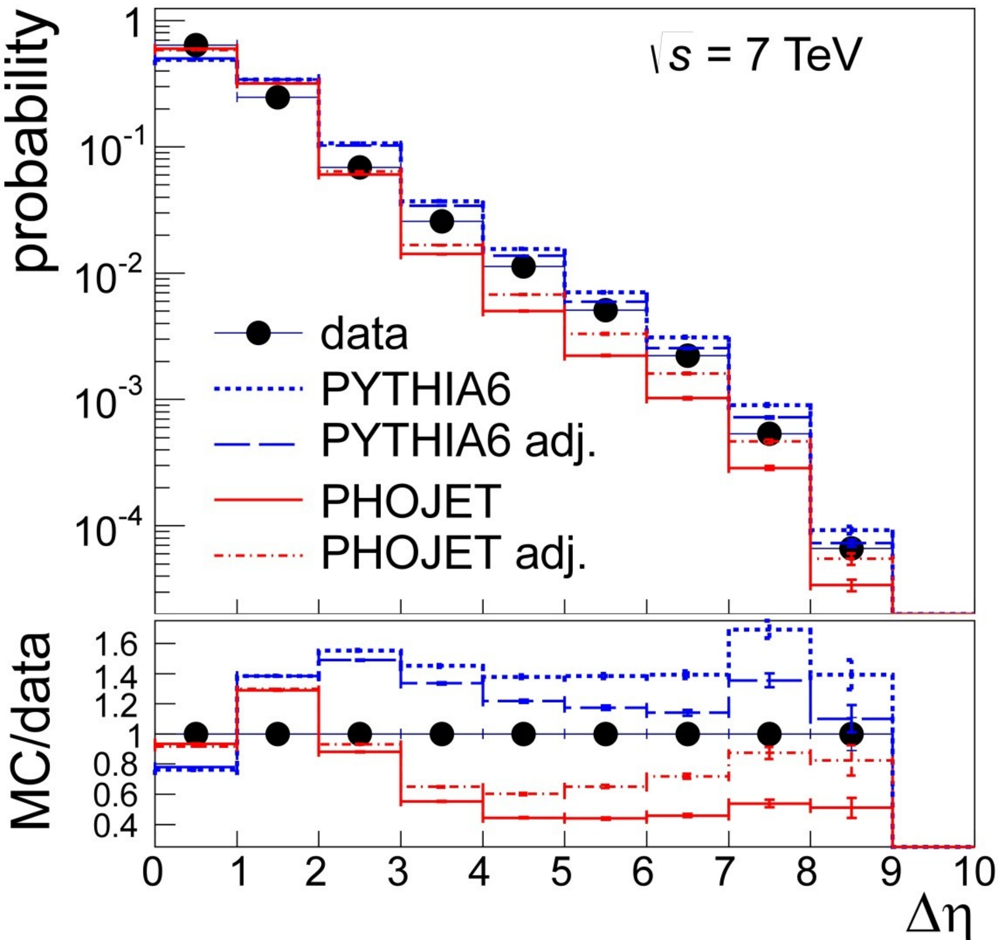


ALICE DATA VS MC SIMULATIONS



Eur. Phys. J. C (2013) 73:2456

MC TUNING



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Strategy:

- **ADJUST** SD and DD fractions in PYTHIA6 and PHOJET to bracket the gap width distribution (for $\Delta\eta>3$) in 2-arm events and to reproduce 1-arm/2-arm trigger ratios.
- **EVALUATE** trigger efficiencies for SD and non-single diffractive (NSD) events to extract SD contribution to inelastic cross-section.
- **COMPUTE** DD contribution to inelastic cross-section from adjusted MC generators.

SD FRACTION

$\sqrt{s}$ (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	$0.10^{+0.02}_{-0.03}$	

Uncorrected ratios (Ratio column) — Extracted fractions ($\sigma_{SD}/\sigma_{INEL}$ columns)

After correction the L/R ratios become symmetric, as we expect from the symmetry of the process.
All error are systematic, statistical errors are negligible.

B.Abelev et al (The ALICE Collaboration). Measurement of inelastic, single- and double-diffraction crosssections in proton–proton collisions at the LHC with ALICE. Eur. Phys. J. C (2013) 73:2456

DD FRACTION

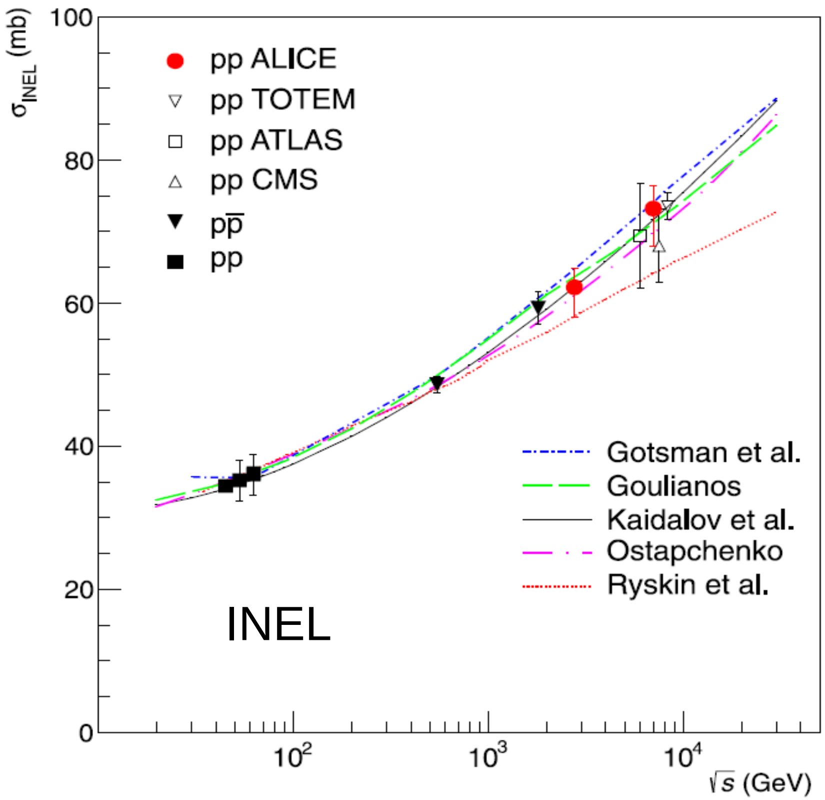
$\sqrt{s}$ (TeV)	$\sigma_{DD}/\sigma_{INEL}$
0.9	0.11 ± 0.03
2.76	0.12 ± 0.05
7	$0.12^{+0.05}_{-0.04}$

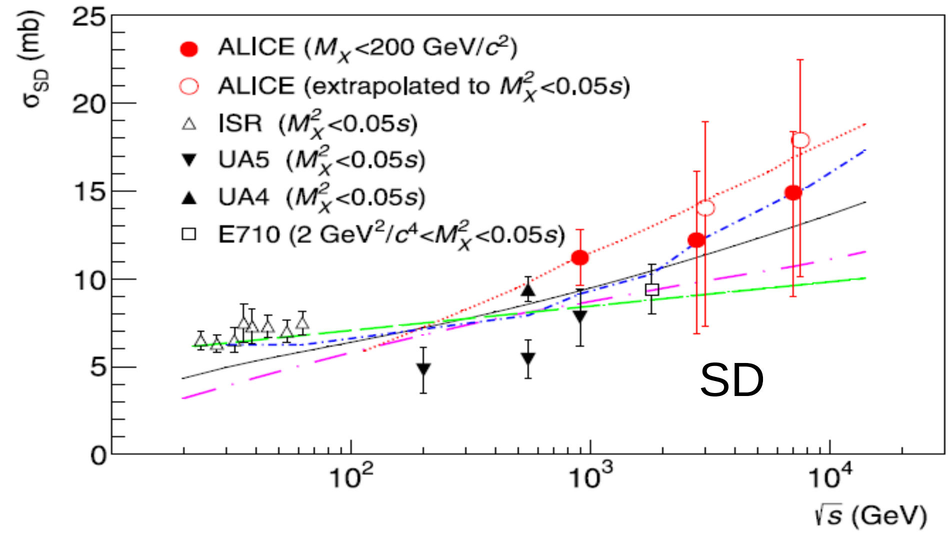
All errors are systematic, statistical errors are negligible.

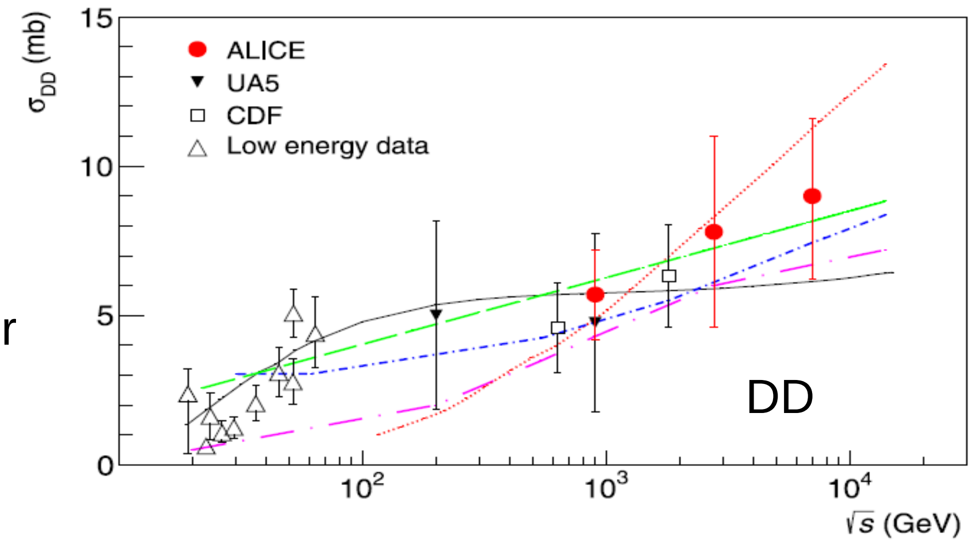
DD is defined as all NSD events with $\Delta\eta>3$, irrespective of generator classification, and calculated from adjusted PYTHIA6 and PHOJET.

B.Abelev et al (The ALICE Collaboration). Measurement of inelastic, single- and double-diffraction crosssections in proton–proton collisions at the LHC with ALICE. Eur. Phys. J. C (2013) 73:2456

OBTAINED CROSS-SECTIONS







- σ_{INEL} was measured by ALICE (v.d.Meer scan) at $\sqrt{s}$ = 2.76TeV and 7TeV.
- σ_{INEL} was taken from UA5 experiment and re-analysis of extrapolation to low diffractive masses at $\sqrt{s}$ = 0.9 TeV.

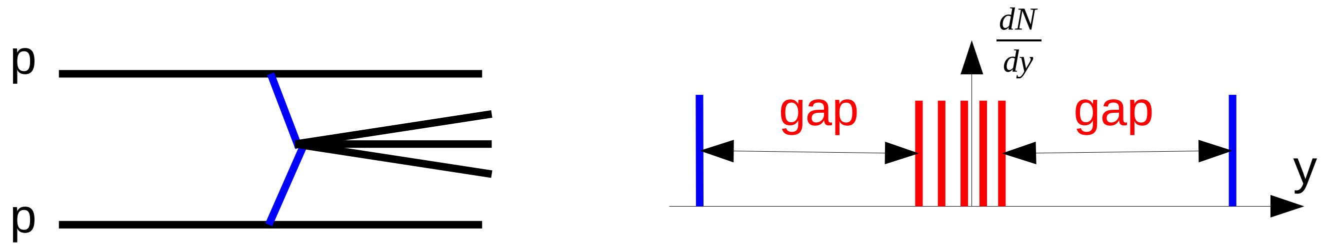
Eur. Phys. J. C (2013) 73:2456

Gotsman et al. Phys. Rev. D85 (2012), arXiv:1208:0898
Goulianos Phys. Rev. D80 (2009) 111901
Kaidalov et al., arXiv:0909.5156, EPJ C67 397 (2010)
Ostapchenko, arXiv:1010.1869, PR D81 114028 (2010)
Ryskin et al., EPJ C60 249 (2009), C71 1617 (2011)

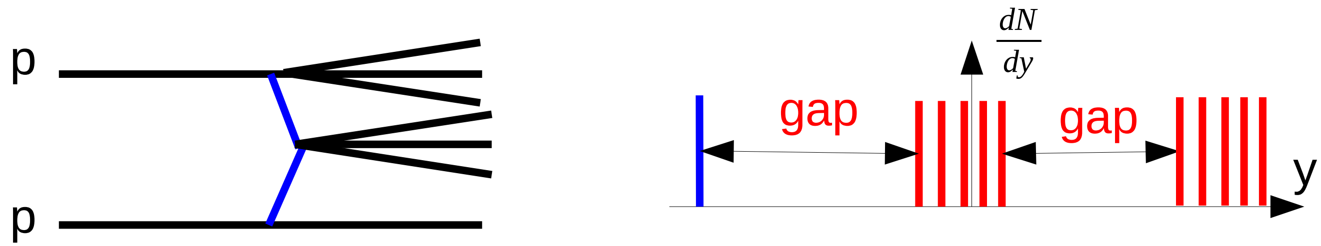
CENTRAL PRODUCTION (CP)

- The gap technique can be used to study gap-X-gap processes.
- We cannot know if scattered protons remain intact or break-up.
- There are three different possibilities to observe gap-X-gap processes.

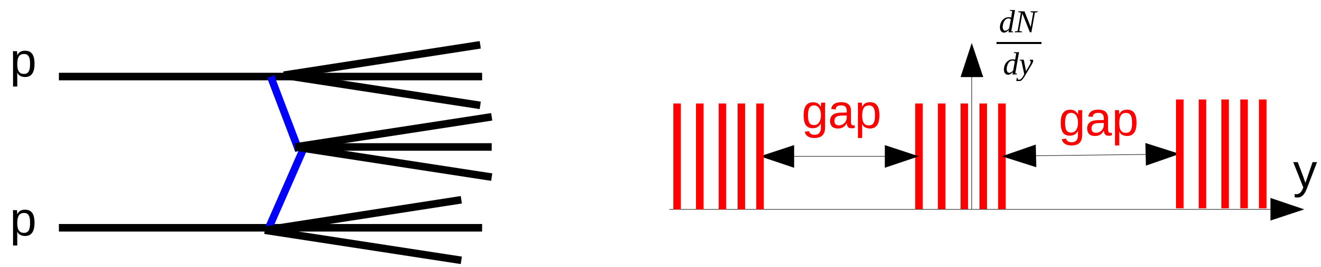
  - Exclusive CD



  - CD + SD



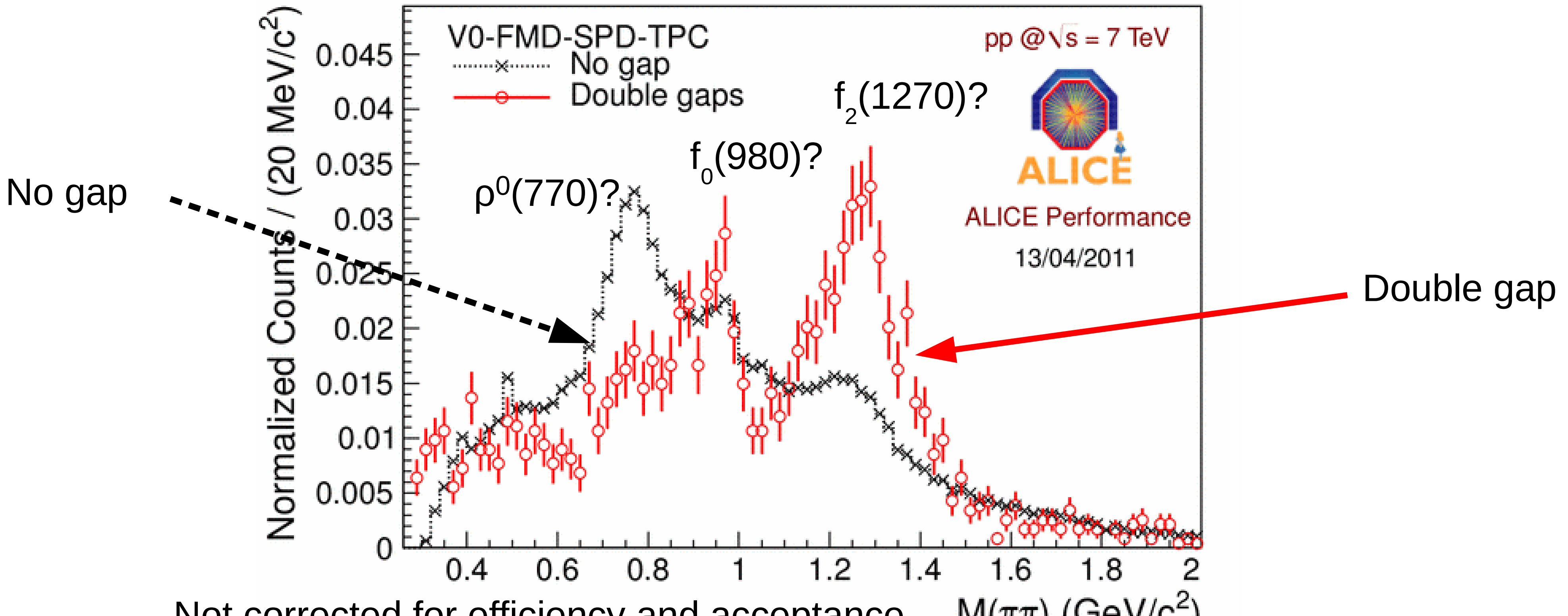
  - CD + DD



Without detection of outgoing protons all three processes are indistinguishable.

CENTRAL PRODUCTION (2)

Mass of 2track double gap events, all tracks assumed to be pions



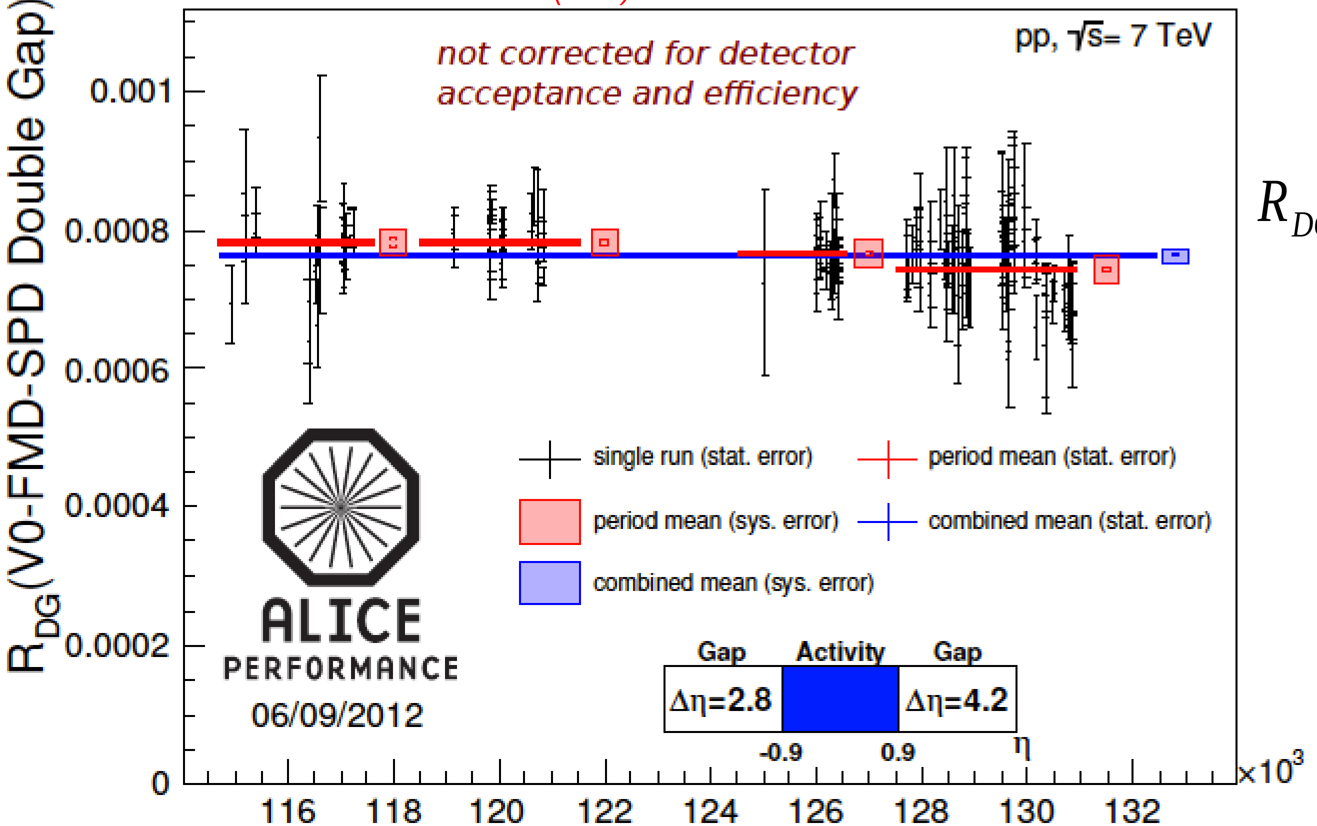
Not corrected for efficiency and acceptance

ALI-PERF-4082

- According to Regge theory, all contributions to CP die out with increasing energy, except pomeron-pomeron fusion.
- Enhancement of 0++,2++,... resonances production and suppression of other resonances production is expected in double-pomeron exchange.

OBSERVED DOUBLE GAP RATE

F.Reidt AIP Conf.Proc. 1523 (2012) 17



systematic error estimated from the spread of the period means, doesn't include detector effects

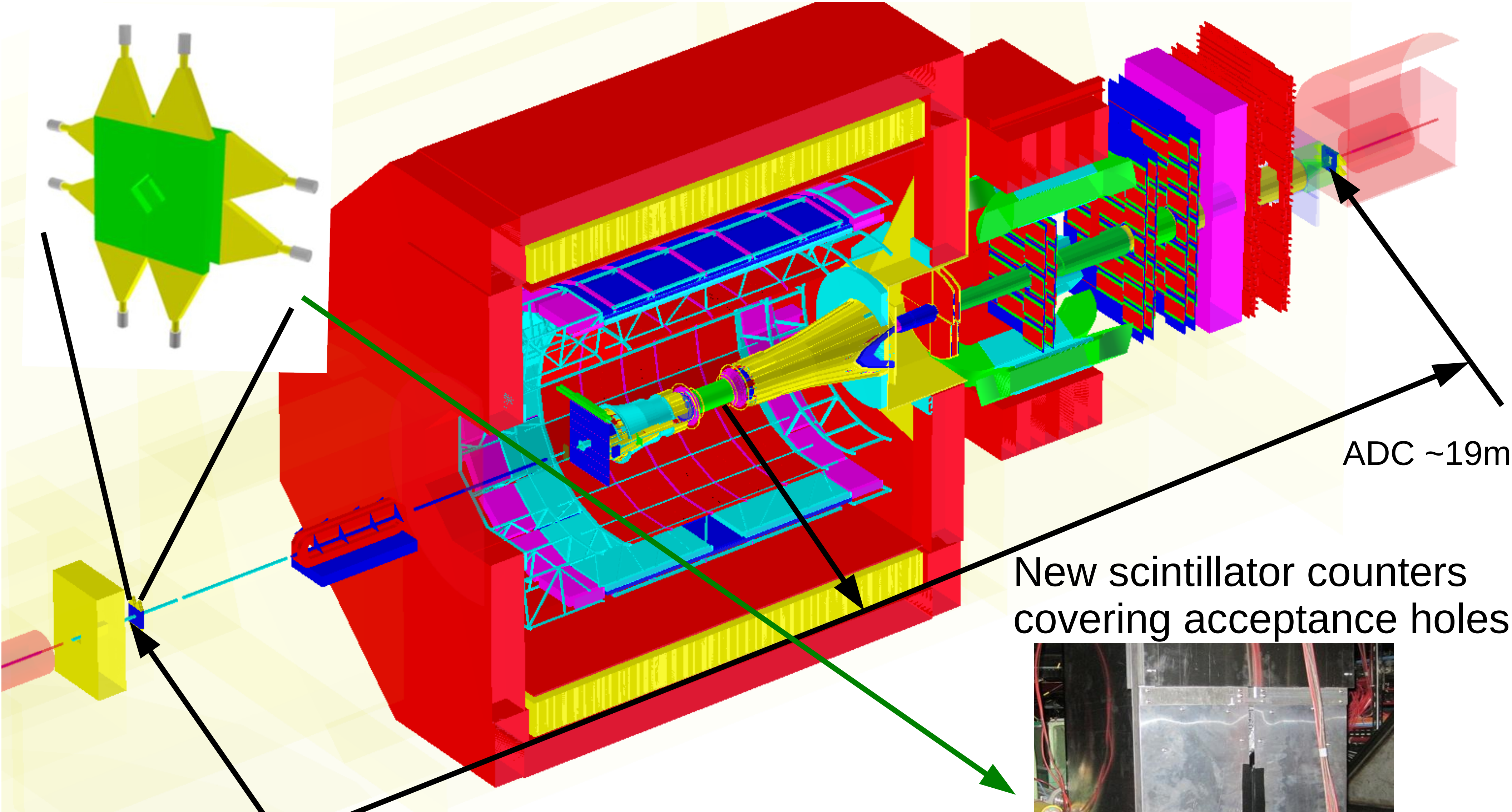
$$R_{DG}=\frac{N_{DG}}{N_{MB_{AND}}}=(7.63\pm0.02\pm0.87)\times10^{-4}$$

Fraction of double gap events is uniform over various data taking periods.

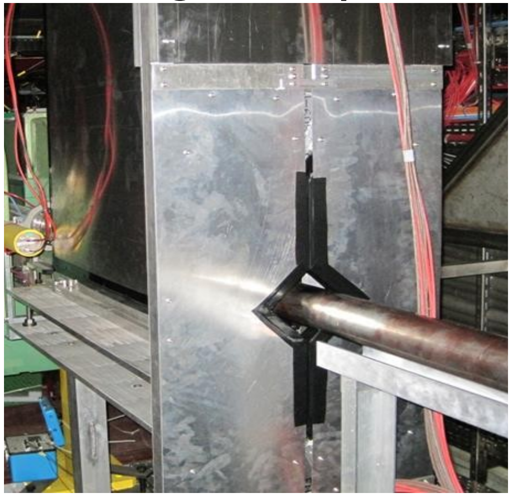
Next step is cross-section for double-gap events:

- reliable model is required to describe low-mass diffraction;
- correction for detector effects.

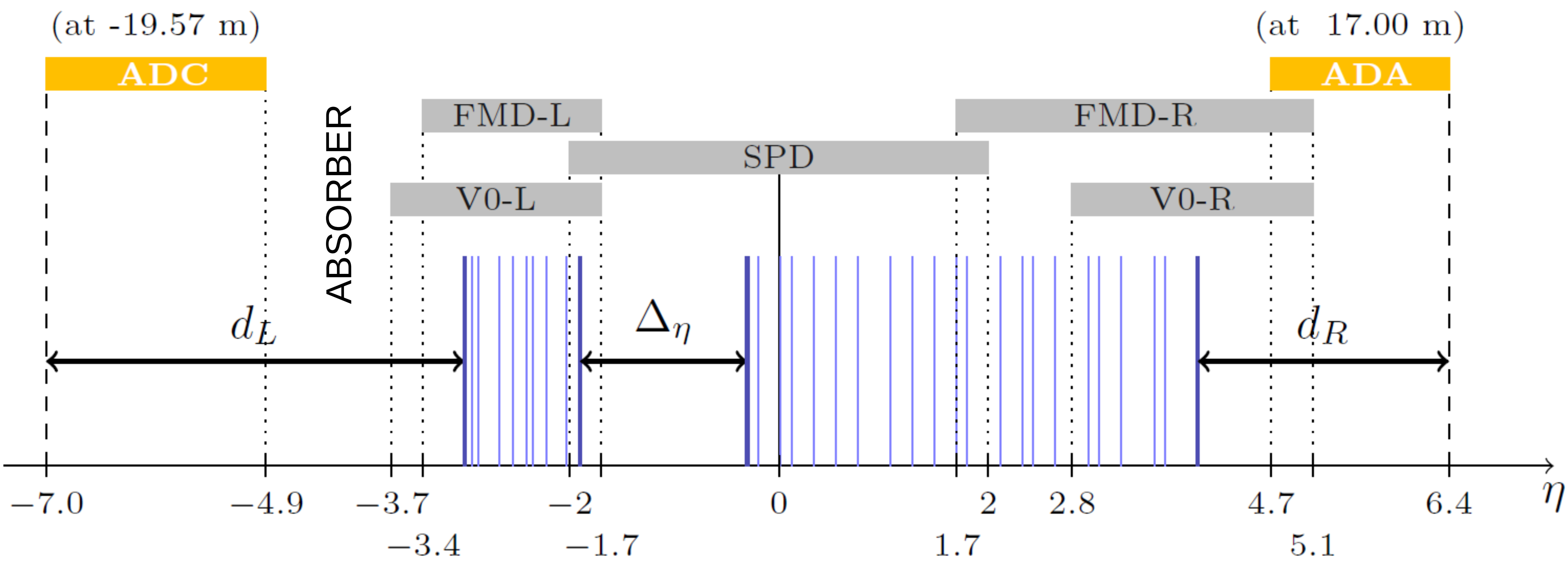
HOW CAN WE DO BETTER?



New scintillator counters covering acceptance holes



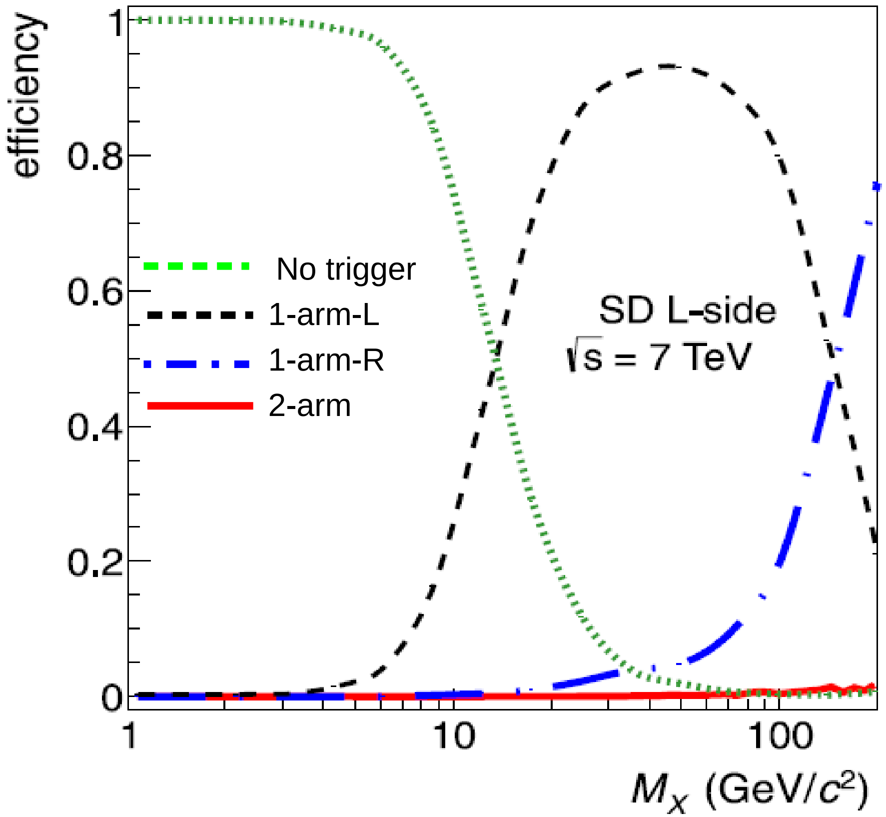
ADA AND ADC COMMISSIONING

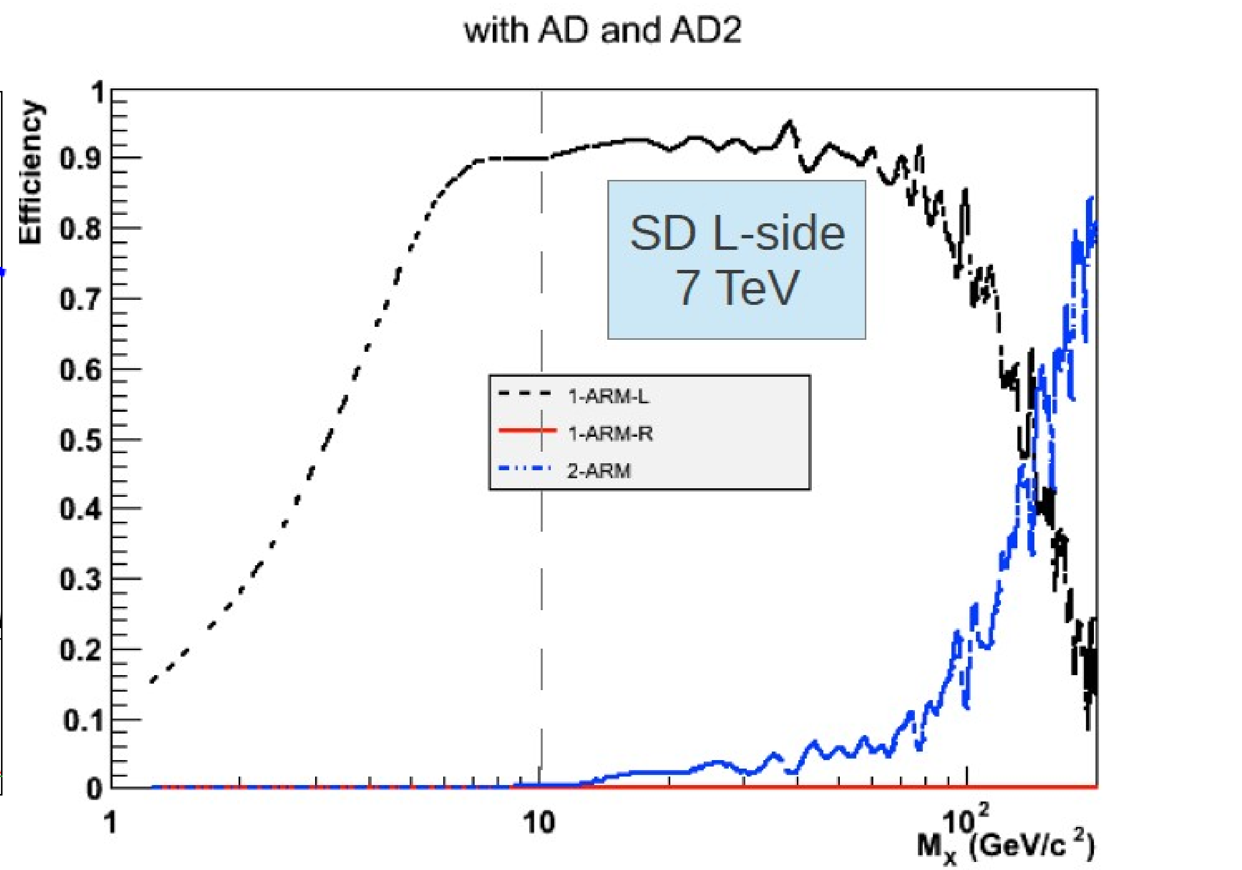


AD stands for **A**LICE **D**iffractive

- New detectors will cover a larger pseudorapidity range and lead to increased acceptance for low single- and double-diffractive masses.
- Sensitivity to low diffractive masses helps to reduce model-dependence of diffractive measurements.
- We plan to start collecting data with these new detectors from the beginning of LHC Run2.

ADA AND ADC COMMISSIONING (2)





Efficiency without ADA and ADC (present)

Efficiency with ADA and ADC (starting from LHC Run2)

SUMMARY

- ALICE has measured the contributions of single- and double-diffractive processes to the inelastic pp cross-section, using a pseudo-rapidity gap technique.
- No strong energy dependence of these fractions is observed.
- The cross-sections of SD processes were obtained for diffractive masses below 200 GeV/c^2. As for the DD measurements, cross-sections were obtained for events with gap width $\Delta\eta > 3$.
- The obtained cross-sections are compared with other measurements at lower energies and to predictions from current models. They are found to be consistent with all of these, within uncertainties.
- Central production: work in progress. New results are expected soon.
- The commissioning of new scintillator counters – ADA and ADC – will increase the acceptance for low diffractive masses.
- We plan to start collecting data with these new detectors from the beginning of LHC Run2.