Study of Central Exclusive Production in proton-proton collisions with ALICE at LHC

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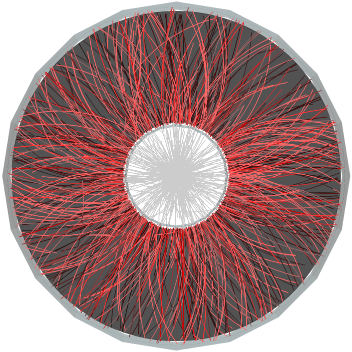
on behalf of the ALICE collaboration

Central Exclusive Production with ALICE

Heavy Ion event - A+A



Central Exclusive Production with ALICE

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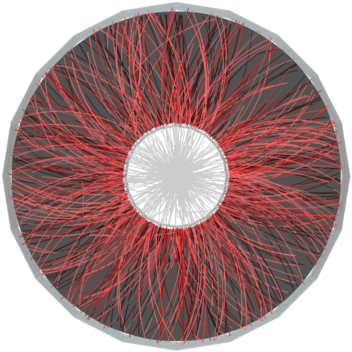
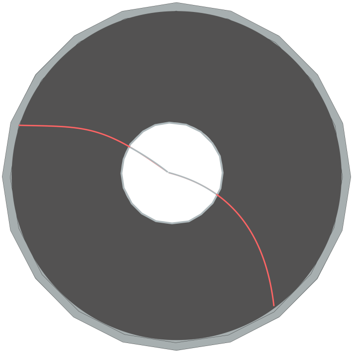


CEP event - p+p



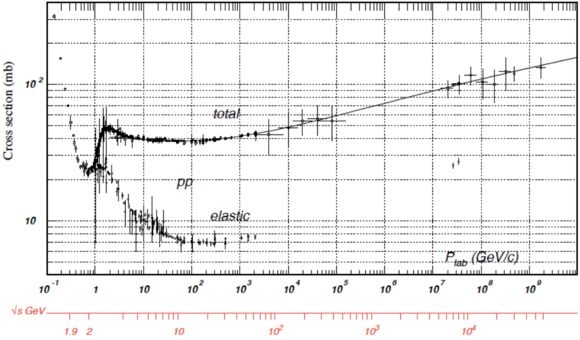
Outline

- High energy proton-proton collisions - Pomeron
- High energy particle diffraction
- CEP - a type of diffractive event
- ALICE to study CEP

pp collisions at LHC energies

At LHC energies

- $\sigma_{tot} = \sigma_{el} + \sigma_{in}$
  20% 80%
- rising with $\sqrt{s}$

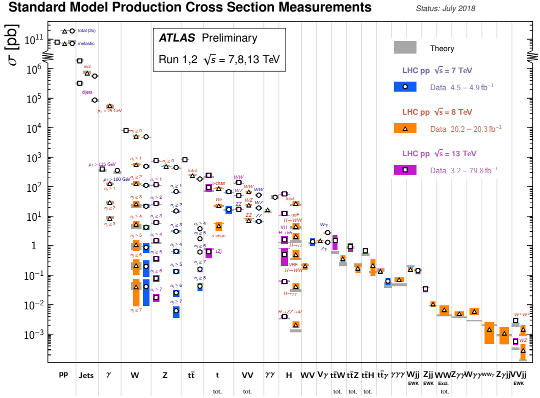


[PDG, http://pdg.lbl.gov/]

pp collisions at LHC energies

At LHC energies

- $\sigma_{tot} = \sigma_{el} + \sigma_{in}$
  20% 80%
- rising with $\sqrt{s}$
- soft/hard processes
  small/large momentum $|t|$ exchange
- soft processes
  - dominating $\sigma_{tot}(LHC)$
  - small $|t|$ exchange
  - large length scale R
  - pQCD not adequate



https://atlas.web.cern.ch/

High energy proton-proton collisions

Soft processes

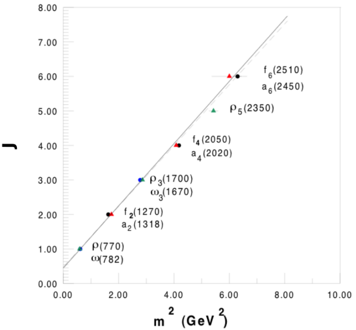
- pQCD is not adequate
- Regge theory (long–range) - Tullio Regge, 1960s
  - describes hadronic reactions at high energies
  - exchange of family of particles: *regge trajectories, Reggeon,* $\mathbb{R}$
    . generalizes exchange of single particle

High energy proton-proton collisions

Regge trajectories

Mesons

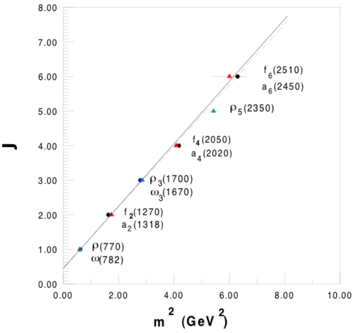
$n\,^{2s+1}\ell_J$	J^{PC}	$I=1$ $u\bar{d}$, $\bar{u}d$, $\frac{1}{\sqrt{2}}(d\bar{d}-u\bar{u})$	$I=\frac{1}{2}$ $u\bar{s}$, $d\bar{s}$; $\bar{d}s$, $-\bar{u}s$	$I=0$ f'	$I=0$ f
$1\,^1S_0$	0^{-+}	π	K	η	$\eta'(958)$
$1\,^3S_1$	1^{--}	$\rho(770)$	$K^*(892)$	$\phi(1020)$	$\omega(782)$
$1\,^1P_1$	1^{+-}	$b_1(1235)$	K_{1B}†	$h_1(1380)$	$h_1(1170)$
$1\,^3P_0$	0^{++}	$a_0(1450)$	$K_0^*(1430)$	$f_0(1710)$	$f_0(1370)$
$1\,^3P_1$	1^{++}	$a_1(1260)$	K_{1A}†	$f_1(1420)$	$f_1(1285)$
$1\,^3P_2$	2^{++}	$a_2(1320)$	$K_2^*(1430)$	$f_2'(1525)$	$f_2(1270)$
$1\,^1D_2$	2^{-+}	$\pi_2(1670)$	$K_2(1770)$†	$\eta_2(1870)$	$\eta_2(1645)$
$1\,^3D_1$	1^{--}	$\rho(1700)$	$K^*(1680)$		$\omega(1650)$
$1\,^3D_2$	2^{--}		$K_2(1820)$		
$1\,^3D_3$	3^{--}	$\rho_3(1690)$	$K_3^*(1780)$	$\phi_3(1850)$	$\omega_3(1670)$
$1\,^3F_4$	4^{++}	$a_4(2040)$	$K_4^*(2045)$		$f_4(2050)$
$1\,^3G_5$	5^{--}	$\rho_5(2350)$	$K_5^*(2380)$		
$1\,^3H_6$	6^{++}	$a_6(2450)$			$f_6(2510)$
$2\,^1S_0$	0^{-+}	$\pi(1300)$	$K(1460)$	$\eta(1475)$	$\eta(1295)$
$2\,^3S_1$	1^{--}	$\rho(1450)$	$K^*(1410)$	$\phi(1680)$	$\omega(1420)$



High energy proton-proton collisions

Regge trajectories

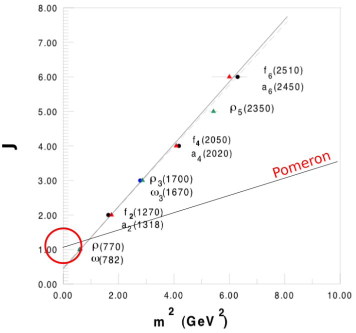
- $J = \alpha(t) = \alpha + \alpha'(t)$
- $\sigma_{tot}(s) \propto s^{(\alpha-1)}$
  with $\alpha < 1$, $\sigma_{tot}(s)$ is falling



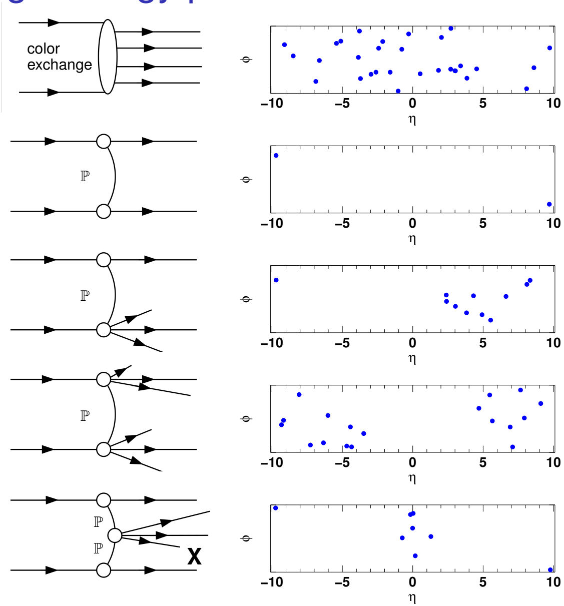
High energy proton-proton collisions

Regge trajectories

- $J = \alpha(t) = \alpha + \alpha'(t)$
- $\sigma_{tot}(s) \propto s^{(\alpha-1)}$
  with $\alpha < 1$, $\sigma_{tot}(s)$ is falling
- Pomeron trajectory - V. Gribov, 1960s
  $\alpha(t) = 1.0808 + 0.25 \cdot t$
  with $\alpha > 1$, $\sigma_{tot}(s)$ is rising
- no known particles - glueballs?
- *pomeron* $\mathbb{P}$ has quantum numbers of vacuum:
  $I^{PC} = 0^{++}$



High energy particle diffraction



non-diffractive

elastic scattering

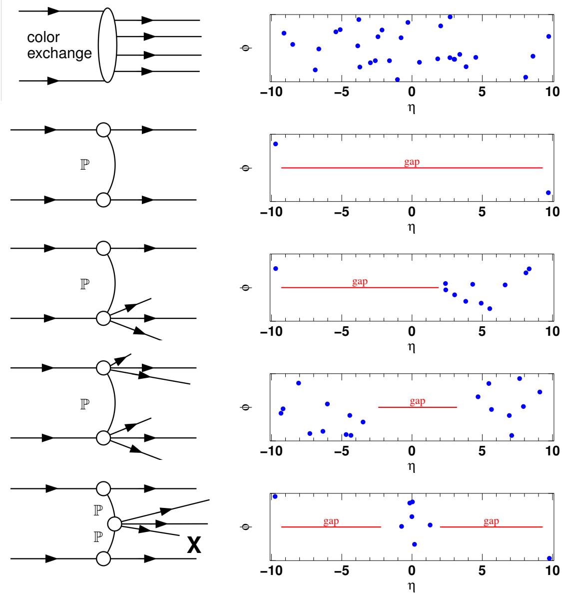
single-diffractive (SD)

double-diffractive (DD)

Central Exclusive Production (CEP)

$m(X) = \zeta_1 \cdot \zeta_2 \cdot \sqrt{s}$

High energy particle diffraction



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Central Exclusive Production (CEP)
$m(X) = \zeta_1 \cdot \zeta_2 \cdot \sqrt{s}$

High energy particle diffraction

pp collisions

- Diffraction

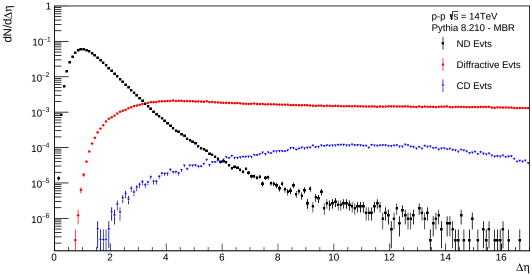
  a reaction at high energies, in which no quantum numbers are exchanged between the colliding particles

- Operational definition

  events with large, non exponentially suppressed (pseudo) rapidity gaps $\Delta\eta$ in the final state

- Pseudo-rapidity

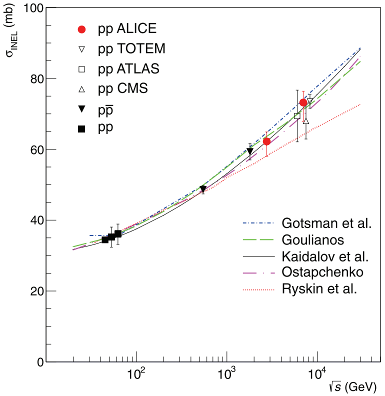
  $\eta = \frac{1}{2} \ln \left(\frac{p+p_L}{p-p_L} \right)$

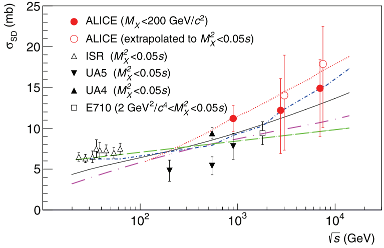


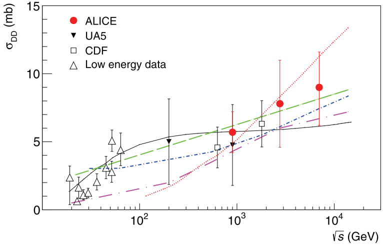
S. Ratzenböck, SMI (2017)

High energy particle diffraction

ALICE coll., EPJC **78** (2013) 2456.







$$\sigma\ @\ \sqrt{s} = 7$$

INEL : SD : DD : CEP $\approx$ 60 : 10 : 5 : 1 mb

CEP - a type of diffractive event

- Central Exclusive Production of X

  $p_a + p_b \rightarrow p_c \oplus X \oplus p_d$

- Double Pomeron Exchange (DPE)

  $\mathbb{P}_1 + \mathbb{P}_2 \rightarrow X$

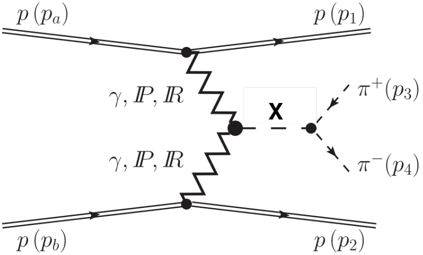
- $I^G J^{PC}(X) = 0^+(even)^{++}$

  $\rightarrow$ *quantum number filter*

- glue–rich process

- $m(X)$ depends on momentum exchange Δp

  $m(X) \approx 1 - 5\ GeV/c^2 \rightarrow \frac{\Delta p}{p} \approx 10^{-4}$



CEP - a type of diffractive event

Mesons below 2.0 GeV/c^2

particle	IG(JPC)
η	0+(0-+)
f_0(500) or σ was f_0(600)	0+(0++)
ρ(770)	1+(1–)
K_0^*(800)or κ	1/2(0+)
ω(782)	0-(1–)
K^*(892)	1/2(1-)
η'(958)	0+(0-+)
f_0(980)	0+(0++)
a_0(980)	1-(0++)
ϕ(1020)	0-(1–)
h_1(1170)	0-(1+-)
K_1(1270)	1/2(1+)
b_1(1235)	1+(1+-)
a_1(1260)	1-(1++)
f_2(1270)	0+(2++)
f_1(1285)	0+(1++)
η(1295)	0+(0-+)
π(1300)	1-(0-+)
a_2(1320)	1-(2++)
f_0(1370)	0+(0++)
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K_1(1400)	1/2(1+)
η(1405)	0+(0-+)
K^*(1410)	1/2(1-)
f_1(1420)	0+(1++)
ω(1420)	0-(1–)
K_0^*(1430)	1/2(0+)
K_2^*(1430)	1/2(2+)
a_0(1450)	1-(0++)
K(1460)	1/2(0-)
ρ(1450)	1+(1–)
η(1475)	0+(0-+)
f_0(1500)	0+(0++)
f'_2(1525)	0+(2++)
$K_2$2(1580)	1/2(2-)
π_1(1600)	1-(1-+)
η_2(1645)	0+(2-+)
ω(1650)	0-(1–)
K_1(1650)	1/2(1+)
ω_3(1670)	0-(3–)
π_2(1670)	1-(2-+)
ϕ(1680)	0-(1–)
K^*(1680)	1/2(1-)
ρ_3(1690)	1+(3–)
ρ(1700)	1+(1–)
f_0(1710)	0+(0++)
π(1800)	1-(0-+)
ϕ_3(1850)	0-(3–)
π_2(1880)	1-(2-+)

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Quantum number filter

particle	$I^G(J^{PC})$
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$f_0(980)$	$0^+(0^{++})$
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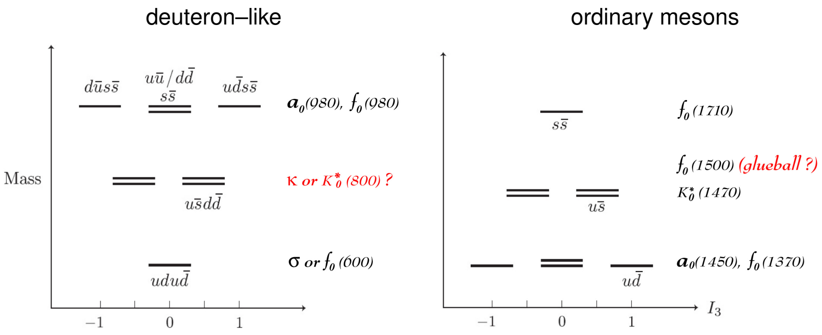
$f_0(1370)$	$0^+(0^{++})$
$f_0(1500)$	$0^+(0^{++})$
$f'_2(1525)$	$0^+(2^{++})$
$f_0(1710)$	$0^+(0^{++})$
$f_2(1950)$	$0^+(2^{++})$

Glue ball ? $J^{PC} = 2^{++}$

CEP - a type of diffractive event



Nagashima, JPSJ News and Comments **4** (2007) 05.

0^{++} nonets with q = u, d, s

- *a*: isospin triplet (I=1)
- K^*: isospin doublet (I=1/2)
- *f*: isospin singlet (I=0)

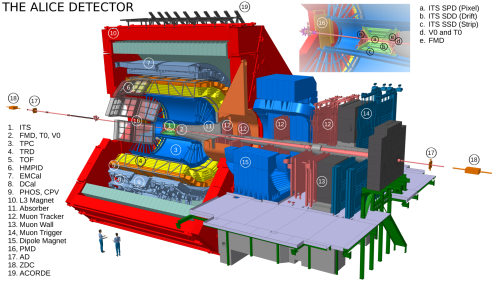
ALICE to study CEP

CEP strategy with ALICE

1. Select CEP events by double-gap strategy
2. Investigate centrally produced particles by invariant mass analysis of their stable decay products - 2 (4) π (K, p), net charge = 0

ALICE to study CEP

1. CEP selection with ALICE
   - ITS: 6 layers of silicon detectors
   - V0: scintillator hodoscopes
   - FMD: silicon strips
   - AD: scintillator pads
   - ZDC: neutron and proton calorimeters



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- ITS: 6 layers of silicon detectors
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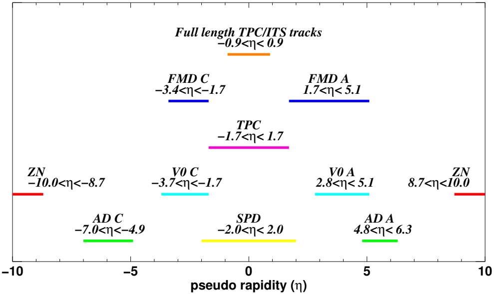
- AD: scintillator pads
- ZDC: neutron and proton calorimeters

ADC - ADA: $\Delta\eta \approx 13$

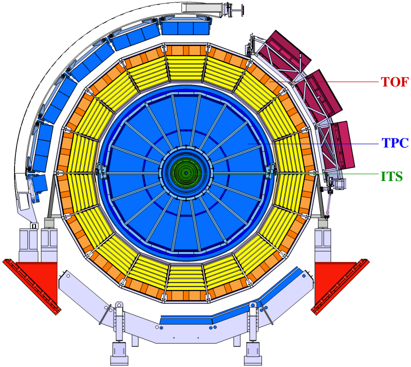


CEP = (*ntrks* in ITS/TPC) & !V0 & !FMD & !AD

$\Delta\eta \approx [6.1, 5.4]$

ALICE to study CEP

2. Tracking and PID with ALICE
   - ITS, TPC, TOF
   - tracking @$p_t > 0.1$ GeV/c with high efficiency
   - PID for charged particles with good separation power



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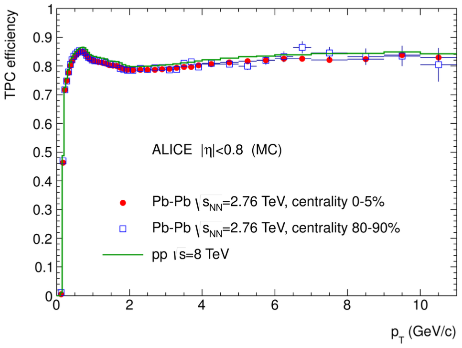

ALICE coll., IJMPA **29** (2014) 1430044.

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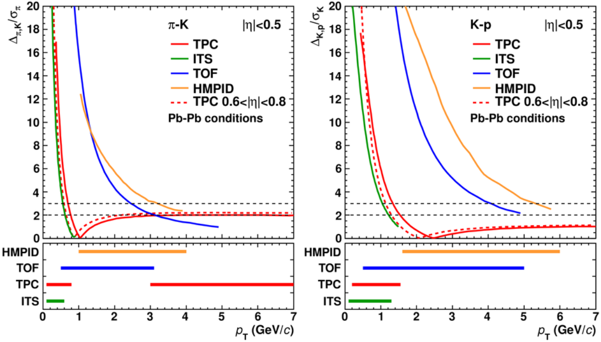


ALICE coll., IJMPA **29** (2014) 1430044.

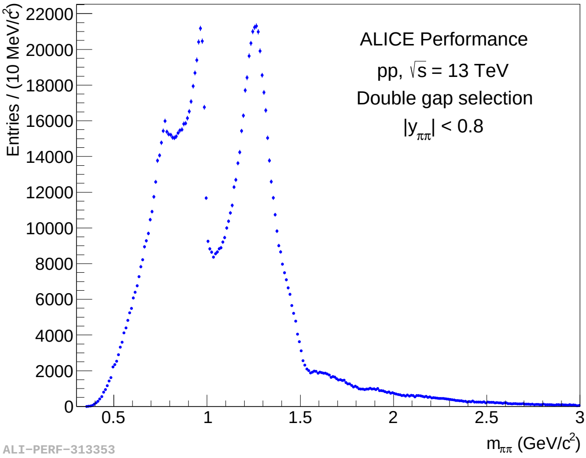
ALICE to study CEP

Data sets

Period	Trigger	Approx. number of 2π DG events
7 TeV		
2010	MBOR SPD || V0	0.6 M
13 TeV		
$\geq$2016	CCUP13 $\geq$2 online tracklets & !V0	1 M
$\geq$2017	CCUP25 $\geq$2 online tracklets & !V0 & $\geq$2 TOF hits	5 M

Invariant mass distributions of CEP events

ALICE 2017/2018 (~8.2 pb^{-1}), 2π uncorrected



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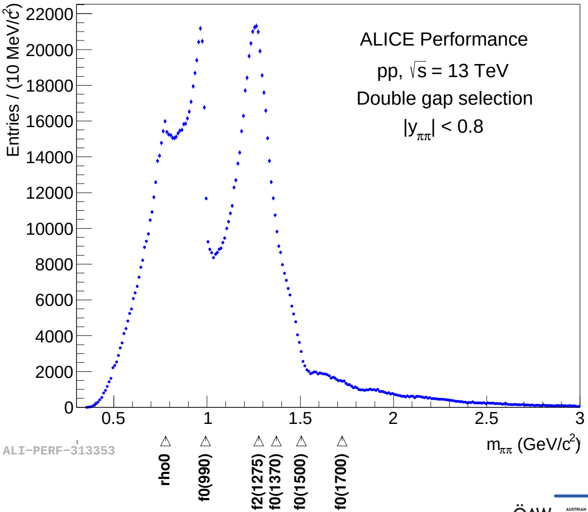
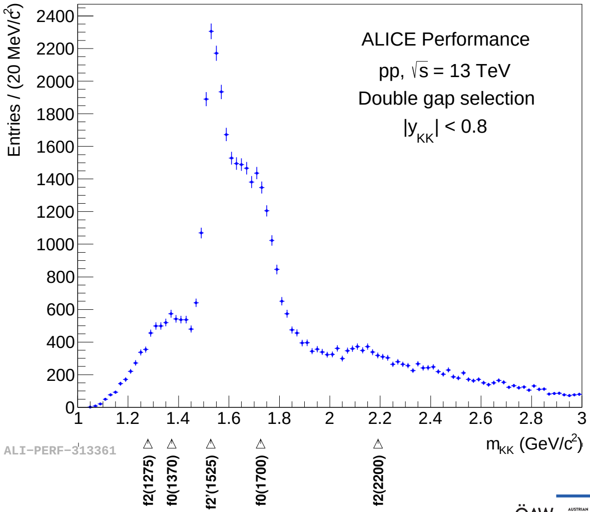


Invariant mass distributions of CEP events

ALICE 2017/2018 (~8.2 pb^{-1}), 2K uncorrected



Invariant mass distributions of CEP events

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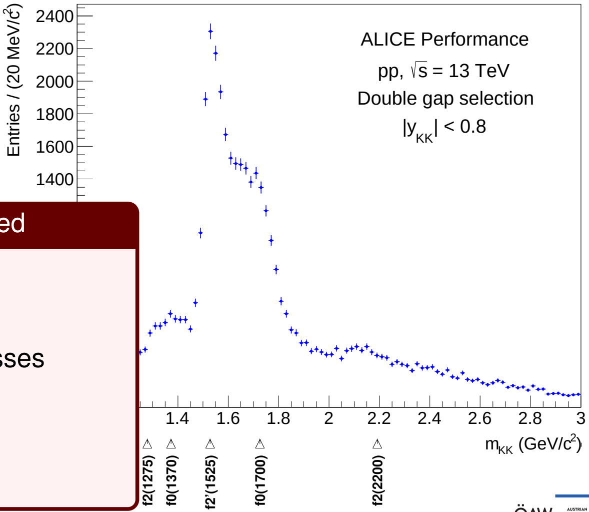

To be disentangled

- resonances
- continuum
- other processes
- background
- acceptance, efficiency

Final remarks

- ALICE exploits gap topology to select diffractive processes
- Profit from large η-coverage, efficient tracking capabilities, and good PID down to low p_t
- CEP is an intriguing environment to study spectrum of low mass mesons
- ALICE 2π and 2K invariant mass spectra of CEP events are rich of features which need to be further investigated
- Additional final states are under investigation