Multiple pion pair production in a Regge based model

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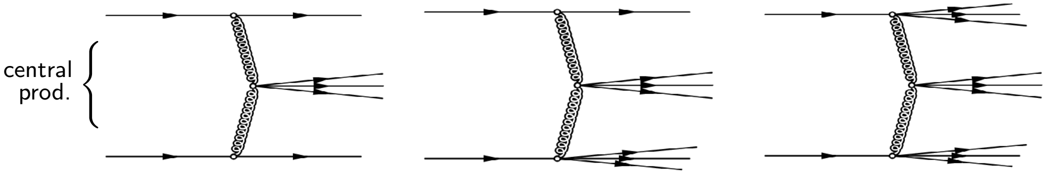
(in coll. with Laszlo Jenkovszky)

Diffraction and Low-x, Sept 29, 2022

Central diffractive production at the LHC



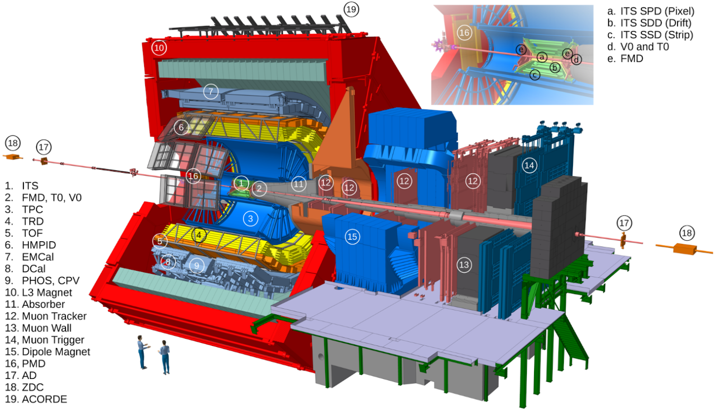
central prod.   central prod./single diss.   central prod./double diss.

- Pomerons $\mathbb{P}$ and Reggeons $\mathbb{R}$ contribute to these topologies
- Rapidity gaps can also be due to photon and $W^{\pm}$,Z-exchange
- Pomerons and photons contribute differently in pp, pA and AA

Experimental identification of these topologies by

1. Tag the foward protons or fragments by Roman pots (no Roman Pots in ALICE)
2. Define rapidity range on both sides of midrapidity void of activity (rapidity gap)
   $\rightarrow$ used by ALICE in Run 1, 2 and 3

The ALICE Detector



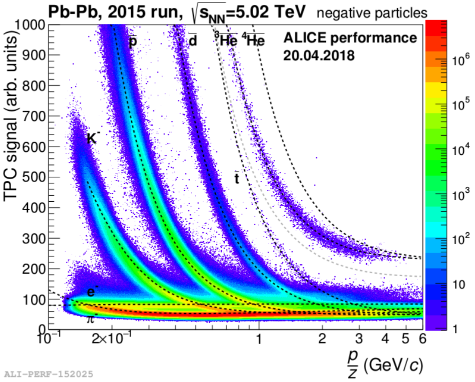
midrapidity tracks in central barrel: ITS,TPC,TOF: $-0.9 < \eta < 0.9$

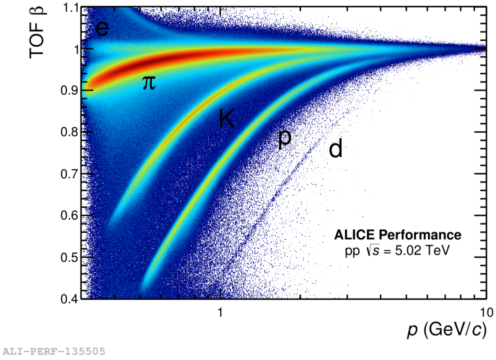
rapidity gap C-side: AD C: (-7.0, -4.9), V0C: (-3.7, -1.7), FMD: (-3.4, -1.7)

rapidity gap A-side: AD A: (4.8, 6.3), V0A: (2.8, 5.1), FMD: (1.7, 5.1)

ALICE particle identification capability

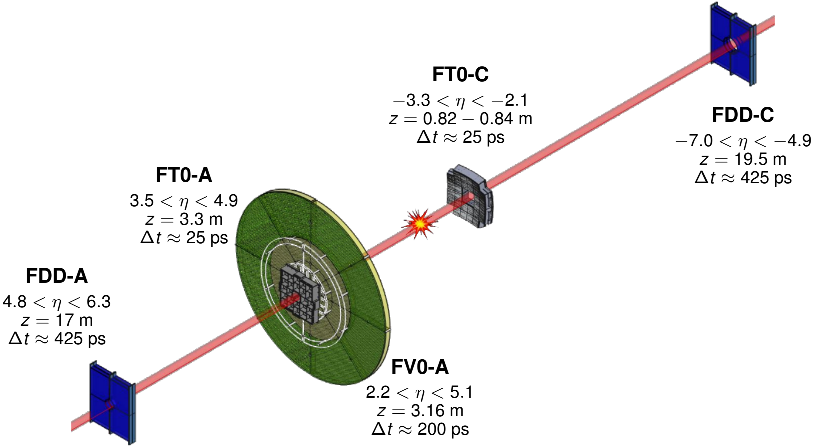
- Particle identification by specific energy loss dE/dx in TPC (left), and by TOF detector (right)





ALICE rapidity gap detectors Run 3

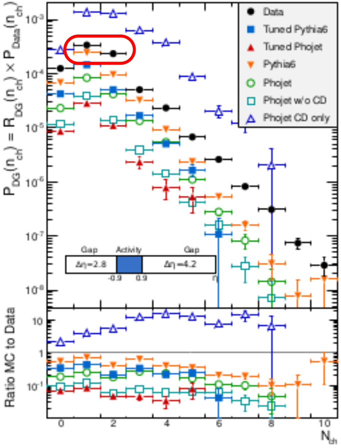
- new rapidity gap detectors in Run 3 with similar rapidity coverage



Multiplicity distribution in double gap events in ALICE

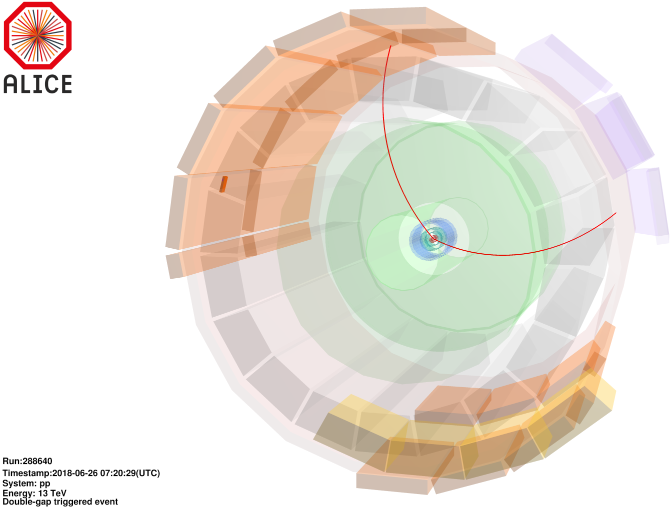
- master thesis Felix Reidt, University Heidelberg: *"Analysis of Double-Gap Events in Proton-Proton Collisions at $\sqrt{s}$ = 7 TeV with ALICE at the LHC"*
- look at events with fixed charged particle multiplicity in central barrel
- evaluate the fraction of double gap events in this event class
- compare to Pythia6 and Phojet

this figure is thesis work



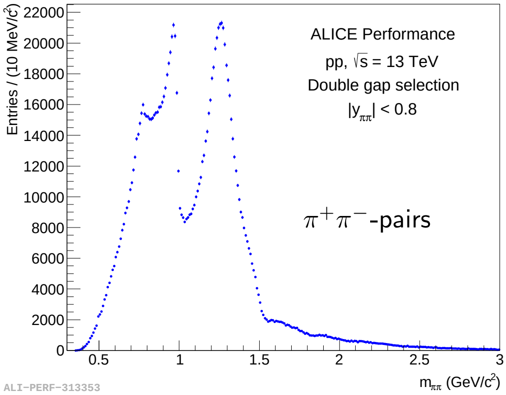
(a) multiplicity distribution from data

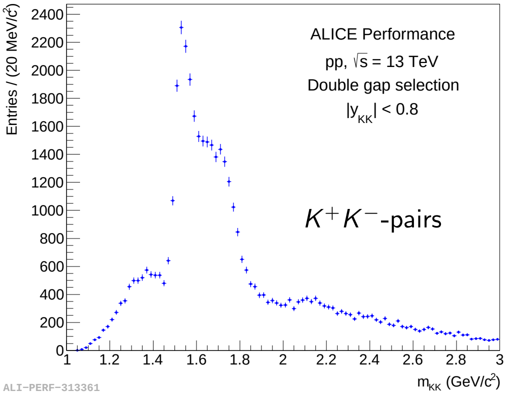
Double gap triggered event in ALICE



Two track double gap events

- analyze invariant mass of pion pairs $\pi^+\pi^-$ and kaon pairs K^+K^-



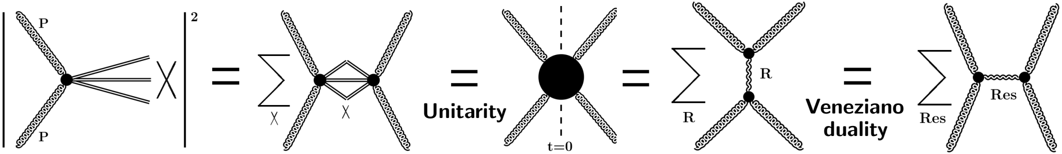


- clear resonance structures seen in pion and kaon sector

Dual resonance model of Pomeron-Pomeron scattering

- many overlapping resonances at low masses M<3 GeV/c^2, transition to continuum
- Dual Amplitude with Mandelstam Analyticity (DAMA)

  (A.I. Bugrij et al., Fortschr. Phys. 21, (1973) 427.)



Connection, through unitarity (generalized optical theorem) and Veneziano-duality, between the Pomeron-Pomeron cross section and the sum of direct-channel resonances.

- DAMA requires the use of nonlinear, complex Regge trajectories
- resonance widths are provided by imaginary part of DAMA
- direct-channel pole decomposition relevant for central production

$$A(M_X^2, t) = a \sum_{i=f,P} \sum_J \frac{[f_i(t)]^{J+2}}{J - \alpha_i(M_X^2)}. \tag{1}$$

Nonlinear, complex meson trajectories

- real and imaginary part of trajectory are connected by dispersion relation

$$\Re e\, \alpha(s) = \alpha(0) + \frac{s}{\pi} PV \int_0^\infty ds^{'} \frac{\Im m\, \alpha(s^{'})}{s^{'}(s^{'} - s)}. \tag{2}$$

- imaginary part is related to the decay width

$$\Gamma(M_R) = \frac{\Im m\, \alpha(M_R^2)}{\alpha^{'}\, M_R}. \tag{3}$$

- imaginary part chosen as sum of single threshold terms

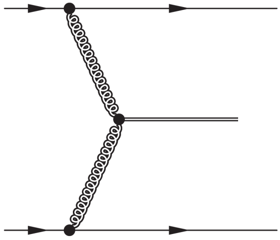
$$\Im m\, \alpha(s) = \sum_n c_n (s - s_n)^{1/2} \left(\frac{s - s_n}{s}\right)^{|\Re e\, \alpha(s_n)|} \theta(s - s_n). \tag{4}$$

- imaginary part of trajectory in Eq.(4) has correct threshold and asymptotic behaviour
- c_n are expansion coefficients, s_n are threshold energies for decay channels

A Regge model for double gap events

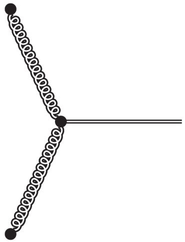
A Regge model for different charged particle multiplicities N_{ch} in Pomeron-Pomeron events

- channel for multiplicities $N_{ch} \geq 2$



$\rightarrow$

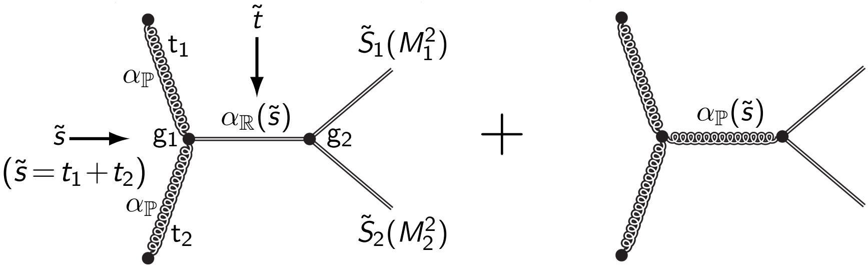
amplitude subdiagram



- cross section from convoluting subdiagram cross section with Pomeron flux of the proton
- Pomeron flux defined by $F^{\mathbb{P}}_{\text{prot}}(t,\xi) = \frac{9\beta_0^2}{4\pi^2}[F_1(t)]^2\xi^{1-2\alpha(t)}$
  (A. Donnachie, P.V. Landshoff, Nucl.Phys. B303 (1988) 634).
  $F_1(t)$ elast. form factor, Pomeron traj. $\alpha(t) = 1. + \varepsilon + \alpha^{'} t$

A Regge model for double gap events

- for multiplicities $N_{ch} \geq 4$, subdiagrams with $\mathbb{PPR}, \mathbb{RRR}$ couplings



- amplitude subdiagram in DAMA model

$$A_{\mathbb{PP}\to\tilde{S}_1\tilde{S}_2}(\tilde{s}, \tilde{t}, M_1^2, M_2^2)) = \frac{1}{\sqrt{M_1^2 M_2^2}} \sum_n \frac{g_1 g_2 e^{b\alpha(\tilde{t})}}{n - \alpha(\tilde{s})} \tag{5}$$

- by optical theorem $\sigma_t(\tilde{s}, M_1^2, M_2^2) = \Im m\, A(\tilde{s}, \tilde{t} = 0, M_1^2, M_2^2)$
- imaginary part of $A(\tilde{s}, \tilde{t}, M_1^2, M_2^2)$ defined by $\alpha_{\mathbb{R}}(\tilde{s}), \alpha_{\mathbb{P}}(\tilde{s})$

Reggeizing $q\bar{q}$ states in the light quark sector

- *"Mesons in a relativized quark model with chromodynamics"*
  S. Godfrey, N. Isgur, Phys.Rev. D 32 (1985) 189.
- calculate $q\bar{q}$ bound states in a relativistic potential V(p, r)

$$V(\mathrm{p},\mathrm{r}) = H^{conf} + H^{so} + H^{hyp} + H_A \tag{6}$$

H^{conf}: confining pot., H^{so}: spin-orbit inter., H^{hyp}: hyperfine inter., H_A: annihilation inter.

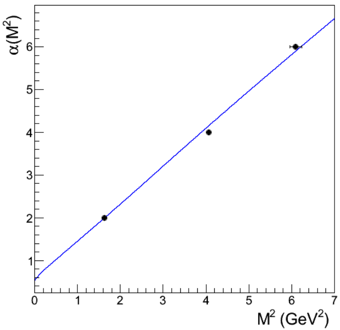
- isoscalar sector: annihilation interaction, considerable mixing with non-$q\bar{q}$ states
- isovector sector: no annihilation interaction, basis states $(-u\bar{d}, (u\bar{u} - d\bar{d})/\sqrt{2}, d\bar{u})$

solve (6) in isovector channel
(mass and width in MeV)
spectroscopic notation $n\,^{2S+1}L_J$:
- n radial quantum number
- S spin
- L orbital angular momentum
- J total angular momentum

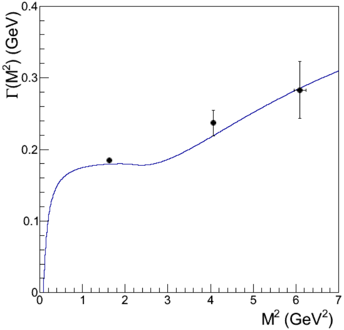
$n\,^{2S+1}L_J$	mass sol.(6)	PDG	mass (PDG)	width (PDG)
1^1S_0	150	π	140	0
1^1P_1	1220	b_1	1230	142
1^1D_2	1680	π_2	1672	258
1^1F_3	2030	——	——	——
1^1G_4	2330	——	——	——

Reggeizing isoscalar states

- Reggeizing the isoscalar states $f_2(1270)$, $f_4(2050)$, $f_6(2510)$



real part f_2 traj.

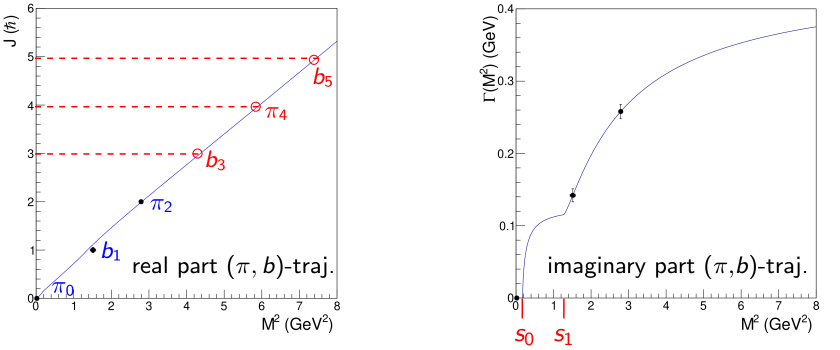


imaginary part f_2 traj.

figures from: R.Fiore, L.Jenkovszky, R.Schicker, Eur.Phys.J. C76 (2016) 38.

Reggeizing isovector states

- DAMA fit to the isovector states π, b_1, π_2 defines the (π,b)-trajectory



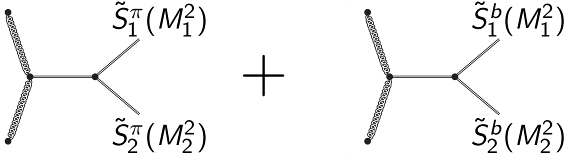
$b_1 \to K\bar{K}\pi$: $s_1 = 1.27$ GeV^2

$\pi_2 \to 3\pi$: $s_0 = 0.176$ GeV^2

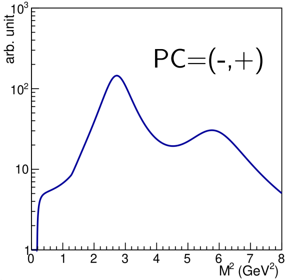
- DAMA fit of (π, b)-trajectory predicts
  - b_3 state, mass 2090 MeV and width 321 MeV
  - π_4 state, mass 2437 MeV and width 352 MeV
  - b_5 state, mass 2738 MeV and width 371 MeV

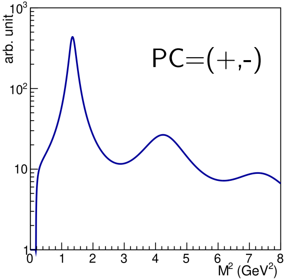
The (π, b)-trajectory

- On the (π, b) -trajectory PC=(-,+) for π_0, π_2, π_4, while PC=(+,-) for b_1, b_3, b_5



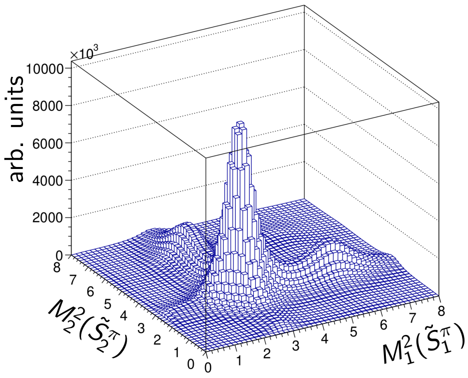
- Mass distribution for PC=(-,+) and (+,-) states on (π, b)-trajectory



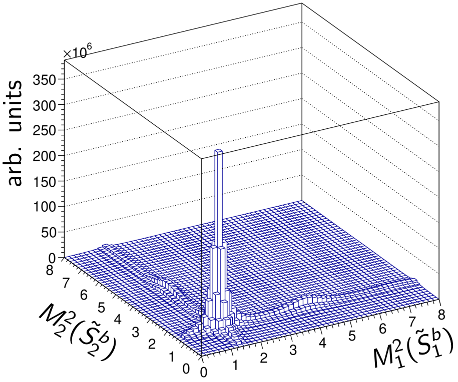


The final state mass distribution

- Two-dimensional mass distribution of final state derived from subdiagram amplitude



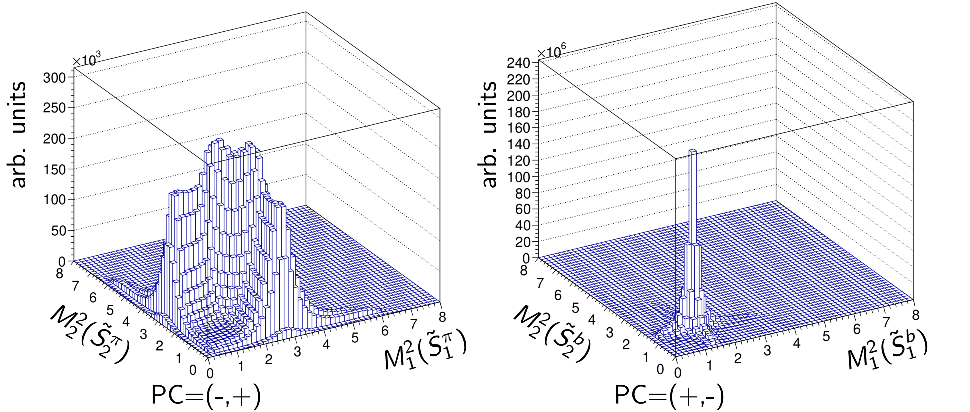
PC=(-,+)



PC=(+,-)

The final state mass distribution

- energy conservation requires $\tilde{s} = t_1 + t_2 = (E_1 + E_2)^2$ in subdiagram, with $E_i^2 = M_i^2 + p_i^2$
- define phase space factor $\sqrt{1 - \frac{(M_1+M_2)^2}{\tilde{s}}}$
- two-dimensional mass distribution with phase space factor for $\sqrt{\tilde{s}} = 3$ GeV



Summary and Outlook

- pion and kaon pairs in double gap events collected by ALICE in Run 1 and Run 2
- multiplicity of charged tracks analysed in ALICE double gap events
- Regge based model for double gap events with multiplicity ≥ 2 being developed
- final state mass distribution from diagram at proton level is under development
- implementation of final state resonance decays is under development

BACKUP