Pion and kaon pair production in double gap events in ALICE Run 3

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UNIVERSITÄT HEIDELBERG
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ALICE

BMBF Forschungsschwerpunkt
ALICE Experiment 202
ALICE

The ALICE upgrade 2019-2022

Data rate with the upgraded ALICE

Pion and kaon pairs in double gap events in proton-proton collisions

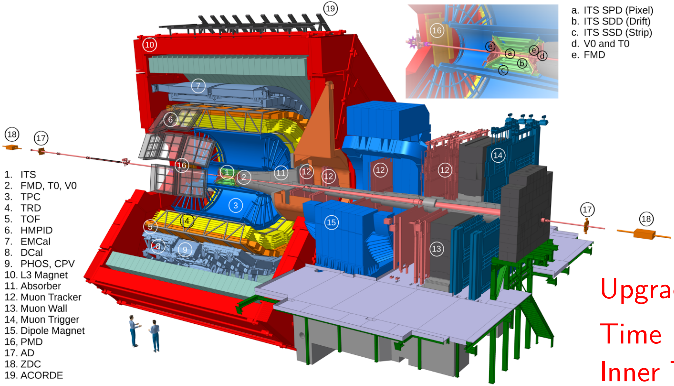
Godfrey-Isgur model of $q\bar{q}$ bound states

Complex Regge trajectory

The isoscalar trajectory in the strange sector

Conclusions

The ALICE upgrade in long shutdown LS2 2019-2022



Midrapidity tracks in central barrel:

ITS,TPC,TRD,TOF: $-0.9 < \eta < 0.9$

Fast Interaction Trigger outside central barrel:

Detector coverage $\Delta\eta \sim 4$ for $\eta > 0$, $\Delta\eta \sim 3$ for $\eta < 0$

Upgrade of:

Time Projection Chamber (TPC)

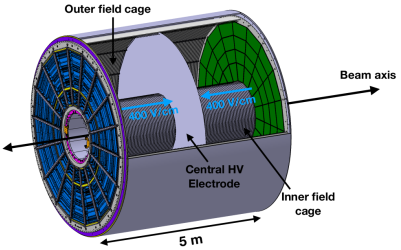
Inner Tracking System (ITS)

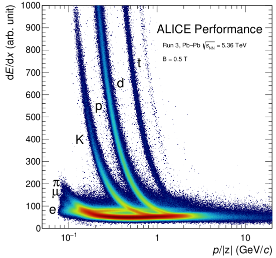
Fast Interaction Trigger (FIT)

Computing system On-Offline (O^2)

The TPC

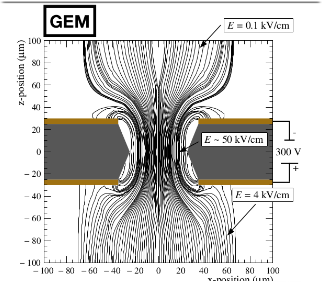
- Total length 5m,
  radial dimension 83.5 cm $< r <$ 254.5 cm
- Gas mixture Ne-CO_2-N_2 (90-10-5)
- Central electrode and field cage,
  uniform E-field 400 V/cm along beam-axis
- Charged particles traversing TPC volume ionise the gas atoms
- Ionisation electrons drift to endplates,
  segmented readout, $\sim$ 550000 pads
- 3-d measurement of ionisation clusters,
  x and y-coordinate from pad position,
  z-coordinate from drift time

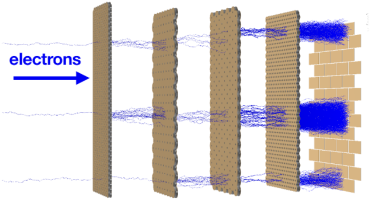




The TPC upgrade

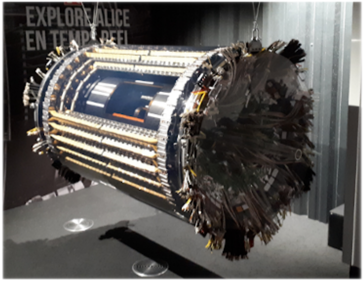
- Positive-ion backflow from amplification region a major issue in operation of a TPC
- Positive-ion backflow usually controlled by gating grid; in Runs 1,2 rate limit $\sim$ 3 kHz
- Electron multiplication in Run 3 by staging of 4 Gas Electron Multiplier (GEM) foils
- Ion backflow $\leq$ 0.7% with 4 staged GEMs
- Pb-Pb data taking rate increased from 1 kHz in Runs 1,2 to 50 kHz in Run 3
- 3-d cluster position information is input for global track reconstruction
- still significant space charge distortions, calibrated continuously



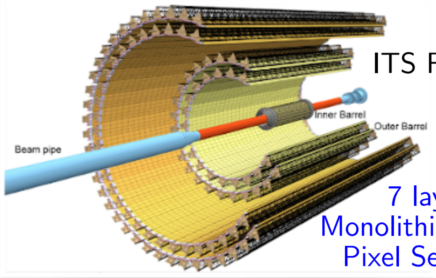


The ITS upgrade

- A new Inner Tracking System: *improved resolution, less material, faster readout*



ITS Run 1,2 → ITS Run 3

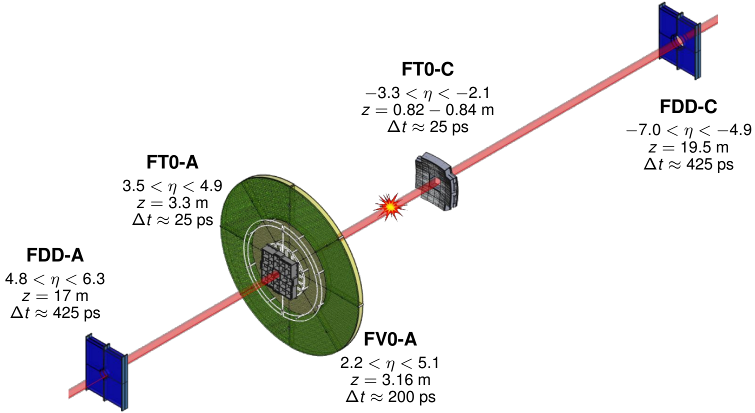


7 layers of Monolithic Active Pixel Sensors

	ITS Run 1,2	ITS Run 3
Distance to IP (mm)	39	22
X_0 (innermost layers) (%)	∼1.14	∼0.35
Pixel pitch (μm^2)	50 x 425	27 x 29
Readout rate (kHz)	1	100
Spatial resolution ($r\varphi$ x z) (μm^2)	11 x 100	5 x 5

The FIT upgrade

- The Fast Interaction Trigger (FIT) detector serves as interaction trigger, online luminometer, and forward multiplicity counter
- Provides precise collision time for time-of-flight based particle identification



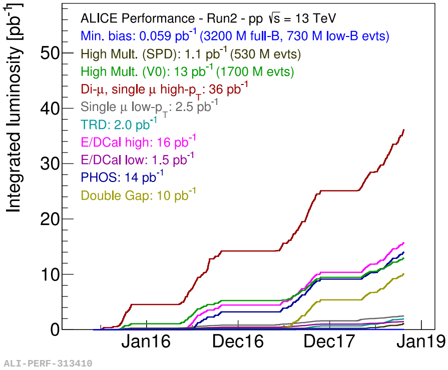
The computing system upgrade

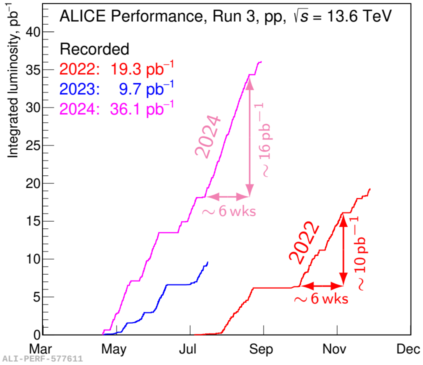
- New common Online-Offline (O^2) computing system

3.6 TeraBytes/s raw data
→ up to 170 GBytes/s to disk

50k CPUs
2700 GPUs
130 PetaBytes disk

Data statistics in Run 2 and Run 3

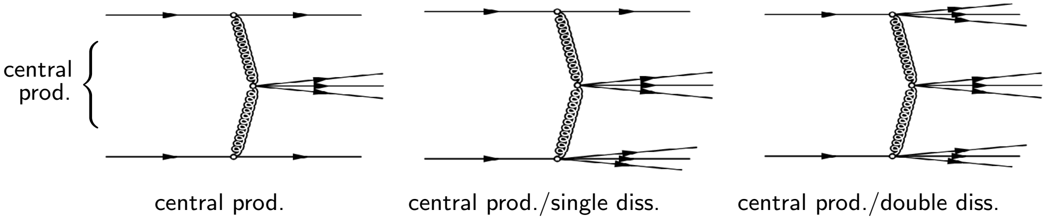




Double gap data sample of 10 pb^{-1} in Run 2

Central barrel min bias data sample Run 3:
$\sim$ 10 pb^{-1} per 6 weeks of data taking in 2022
$\sim$ 16 pb^{-1} per 6 weeks of data taking in 2024

Central diffractive production at the LHC

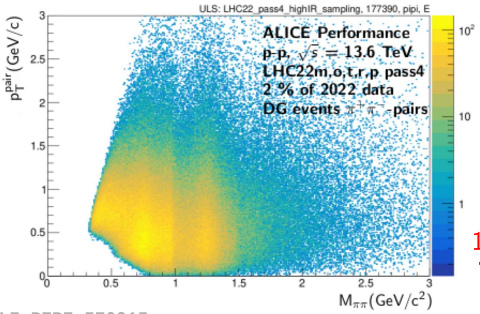


- Pomerons $\mathbb{P}$, Reggeons $\mathbb{R}$, photon and $W^{\pm}$,Z-exchange contribute to these topologies
- Hadronic and electroweak channels contribute differently in pp, pA and AA

Experimental identification of these topologies by defining rapidity gap on both sides of midrapidity void of activity $\rightarrow$ no signal in FIT detector $\rightarrow$ double gap event
Pomeron fusion events present a gluon rich environment, a bonanza for searches of states beyond the constituent quark model, such as hybrids and glueballs
$\rightarrow$ Understand first the well-known resonances listed by Particle Data Group

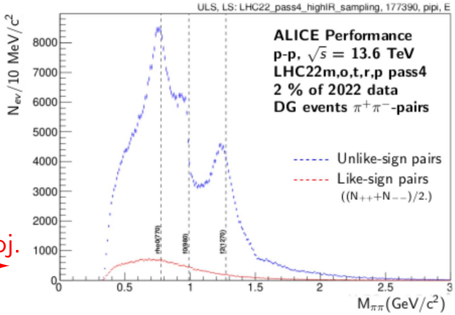
Pion pairs in double gap events

- particle ident. by dE/dx from TPC, identify pion pairs $\pi^+\pi^-, \pi^+\pi^+, \pi^-\pi^-$



$\pi^+\pi^-$-pairs

1-d proj.

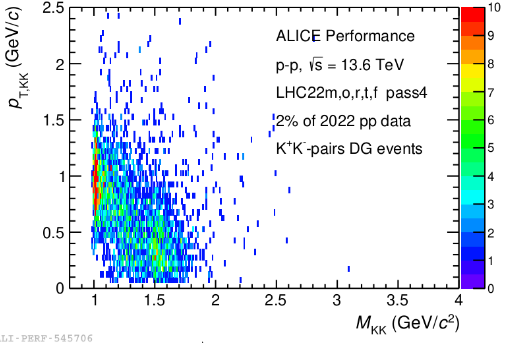


$\pi^+\pi^-, \pi^+\pi^+, \pi^-\pi^-$-pairs

- resonance structures seen in the pion sector: $\rho(770)$, $f_0(980)$, $f_2(1270)$

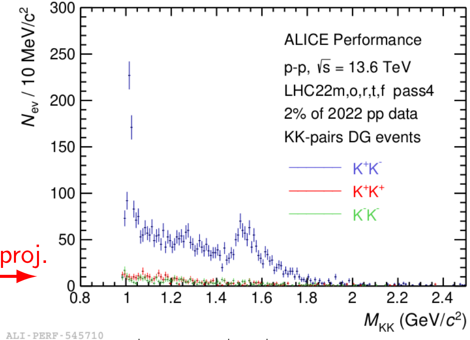
Kaon pairs in double gap events

- particle ident. by dE/dx from TPC, identify kaon pairs K^+K^-, K^+K^+, K^-K^-



K^+K^--pairs

1-d proj.



K^+K^-, K^+K^+, K^-K^--pairs

- resonance structures seen in the kaon sector: $\phi(1020)$, $f_2(1270)$, $f_2'(1525)$

A model of $q\bar{q}$ bound states

- *"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)

$$V(\mathrm{p},\mathrm{r}) = H^{conf} + H^{so} + H^{hyp} + H_A \quad (1)$$

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

isoscalar meson sector: - states with predominant light quark (u,d) composition
- states with predominant strange quark (s) composition

Known isoscalar states with hidden strangeness:

PDG	J^{PC}	mass (PDG)	width (PDG)
ϕ	1^{--}	1019 MeV	4 MeV
f_2'	2^{++}	1518 MeV	86 MeV
ϕ_3	3^{--}	1854 MeV	87 MeV

Predictions Godfrey-Isgur model

- Isoscalar mesons in Godfrey-Isgur model for light-quark and strangeness sector

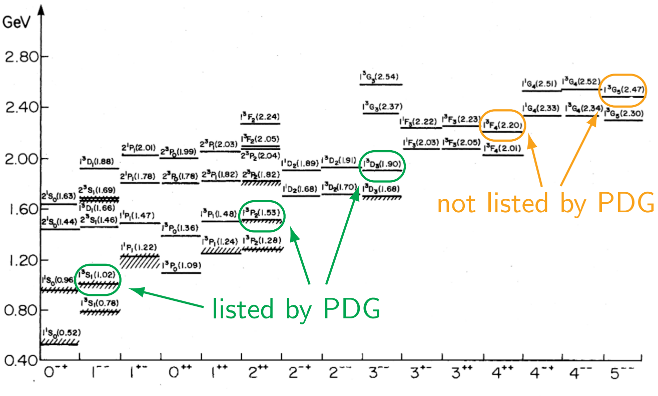


FIG. 5. The isoscalar mesons (mainly $u\bar{u}$, $d\bar{d}$, $s\bar{s}$). The legend is as for Fig. 3. Significant spectroscopic mixings in this sector are given in Table III. The comparison of the 0^{-+} isoscalars with experiment requires special consideration: see Sec. V A. For the E meson see Ref. 9.

spectr. notat. $n\,^{2S+1}L_J$
- n radial quant. num.
- S spin
- L orb. ang. mom.
- J total ang. mom.

PDG	J^{PC} (G-I)	$n^{2S+1}L_J$ (G-I)	mass (G-I)
ϕ	1^{--}	1^3S_1	1020 MeV
f_2'	2^{++}	1^3P_2	1530 MeV
ϕ_3	3^{--}	1^3D_3	1900 MeV
f_4'	4^{++}	1^3F_4	2200 MeV
ϕ_5	5^{--}	1^3G_5	2470 MeV

Nonlinear, complex meson trajectories

- Complex Regge trajectory based on Dual Amplitude with Mandelstam Analyticity (DAMA)
- Real and imaginary part of trajectory are connected by dispersion relation

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

- Imaginary part is related to the decay width

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

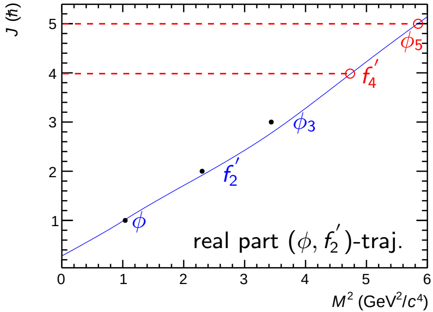
- Imaginary part chosen as sum of single threshold terms

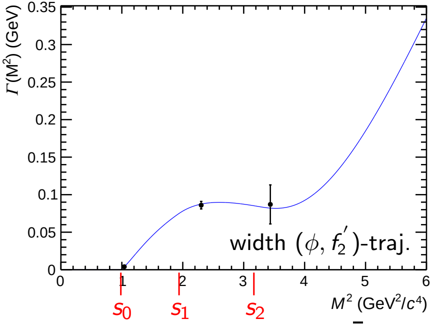
$$\Im m\, \alpha(s) = \sum_n c_n (s - s_n)^{1/2} \left(\frac{s - s_n}{s}\right)^{|\Re e\, \alpha(s_n)|} \theta(s - s_n). \quad (4)$$

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

Reggeizing isoscalar states with hidden strangeness

- DAMA fit to the isoscalar strangeness states ϕ, f_2', ϕ_3 defines the (ϕ, f_2')-trajectory





$\phi_3 \to K^* \bar{K}^*, \; s_2 = 3.18 \text{ GeV}^2$

$f_2' \to KK^*, s_1 = 1.92 \text{ GeV}^2$

$\phi \to K\bar{K}, s_0 = 0.97 \text{ GeV}^2$

- DAMA fit of (ϕ, f_2')-trajectory predicts
  - f_4' state, mass 2182 MeV and width 156 MeV
  - ϕ_5 state, mass 2417 MeV and width 310 MeV

Conclusions and outlook

- ALICE is taking data at unprecedented rate in Run 3 after a major upgrade in LS2
- First analysis of strangeness in double gap events in pp collisions shows clear evidence for strangeonia states $\phi(1020)$ and $f_2^{'}(1525)$
- Improved particle identification by combining TPC dE/dx with TOF information
- 50 times larger data sample from data taking 2022/2023 available for analysis
- The search for the $f_4^{'}(2182)$ and $\phi_5(2417)$ state
- Nature of the known $\phi(1680)$: radial excitation of the $\phi(1020)$?
  The $2^3S_1(1.69)$ state in Godfrey-Isgur model?
  Leading pole of a subleading isoscalar Regge trajectory in the strange sector?
- Extend strangeness analysis to $(u, d)\bar{s}$ kaonia and $(\bar{u}, \bar{d})s$ antikaonia states by analysing πK pairs

BACKUP

Width function of (ϕ, f_2')-trajectory

- Trajectory is a complex quantity, real and imaginary part are related by dispersion relation

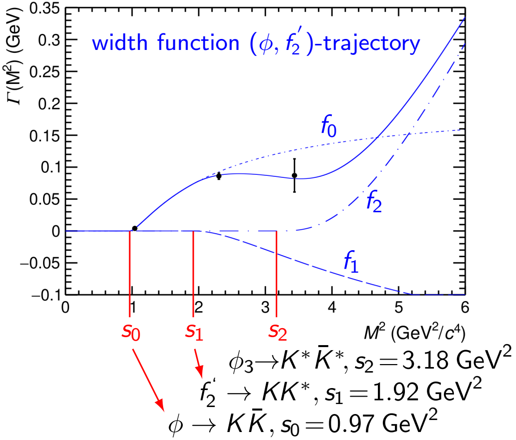
$$\Im m\, \alpha(s) = \sum_n c_n (s-s_n)^{1/2} \left(\frac{s-s_n}{s}\right)^{|\Re e\, \alpha(s_n)|} \theta(s-s_n)$$

$$\Im m\, \alpha(s) = \sum_n c_n\, f_n(s), \;\; s = M^2$$

with $f_n(s) = (s-s_n)^{1/2} \left(\frac{s-s_n}{s}\right)^{|\Re e\, \alpha(s_n)|} \theta(s-s_n)$

for (ϕ, f_2')-trajectory:

- three physics thresholds s_0, s_1 and s_2
- three fit functions f_0, f_1 and f_2
- χ^2 fit for coefficients c_0, c_1 and c_2

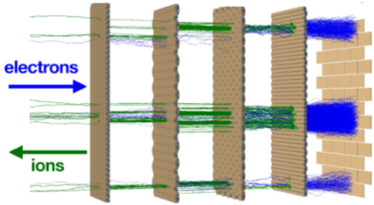


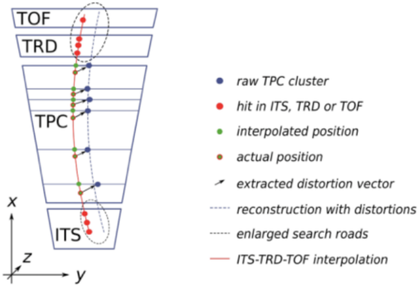
Isoscalar states in light-quark and strangeness sector

- The Godfrey-Isgur model predicts isoscalar states in the light-quark and strangeness sector
- $\underline{1^3S_1}$, $J^{PC} = 1^{--}$:
  One state at 780 MeV, one state at 1020 MeV. The 780 MeV state is identified as $\omega(782)$(light-quark sector), the 1020 MeV as $\phi(1020)$ (strangeness sector).
- $\underline{1^3P_2}$, $J^{PC} = 2^{++}$:
  States at 1280 MeV and 1530 MeV. The 1280 MeV state is identified as $f_2(1270)$ (light-quark sector), Br($\pi\pi$) $\sim$ 85%, Br($K\bar{K}$) $\sim$ 5%, the 1530 MeV as $f_2^{'}(1525)$ (strangeness sector), Br($\pi\pi$) $\sim$ 1%, Br($K\bar{K}$) $\sim$ 88%.
- $\underline{1^3D_3}$, $J^{PC} = 3^{--}$:
  States at 1680 MeV and 1900 MeV. The 1680 MeV state is identified as $\omega_3(1670)$ (light-quark sector), no BR's, the 1900 MeV as $\phi_3(1850)$ (strangeness sector), no BR's.
- $\underline{1^3F_4}$, $J^{PC} = 4^{++}$:
  States at 2010 MeV and 2200 MeV. The 2010 MeV state is identified as $f_4(2050)$ (light-quark sector), Br($\pi\pi$) $\sim$ 17%, Br($K\bar{K}$) $\sim$ 0.7%. PDG lists only one F_4 state.

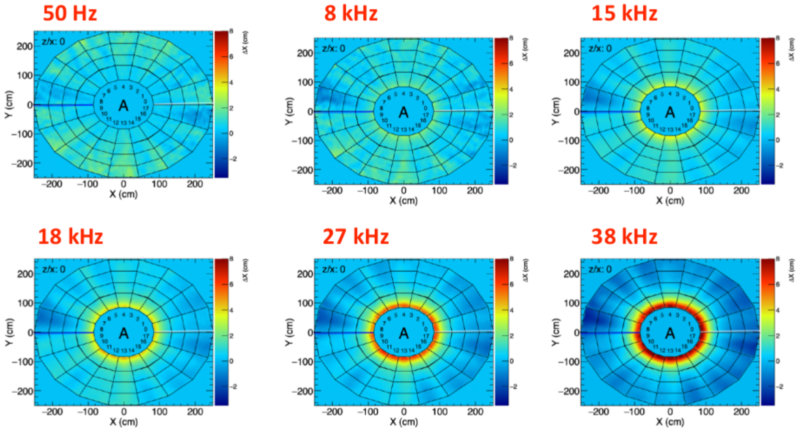
Space Charge Distortions

- Ions from the amplification stage move back into the drift volume
- Ions are slow (~200 ms for full drift)
  - Ions from large number of events pile up (~10k events @ 50 kHz IR)
  - Significant space-charge density (SCD) in drift volume
  - Large average distortions (O(5-10 cm))
  - Intrinsic TPC resolution: ~200 μm
  - $\rho_{SC} \sim I_{prim} \bullet gain \bullet IBF$
- Correction strategy based on reference tracks using ITS extrapolations.
- Corrections every few ms!
- Challenge for Run 3 with continuous readout





Space Charge Distortion Maps



- Average maps. Fluctuations and IR dependence are treated on top.
- Distortions up to ~8 cm in radial direction!
- Corrections applied on the ms timescale to remove fluctuations.