Strangeness production in double gap events in ALICE

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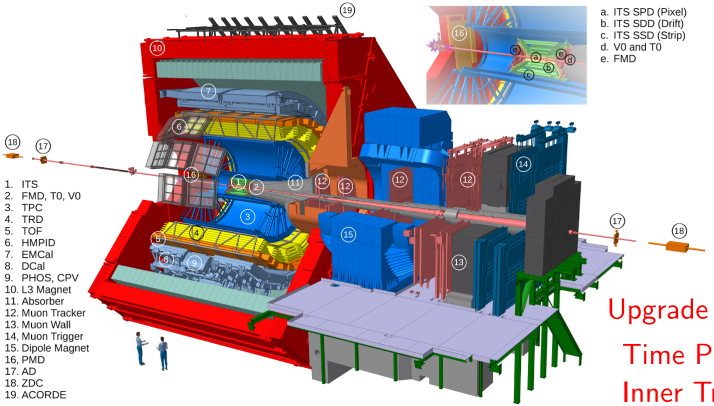
ALICE Experiment 202

The ALICE upgrade in long shutdown LS2 2019-2022



midrapidity tracks in central barrel:

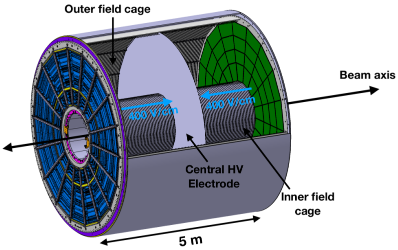
ITS,TPC,TRD,TOF: $-0.9 < \eta < 0.9$

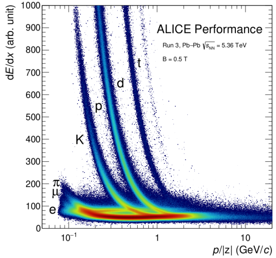
Upgrade of:

- Time Projection Chamber (TPC)
- Inner Tracking System (ITS)
- Fast Interaction Trigger (FIT)
- Computing system On-Offline (O^2)

The TPC

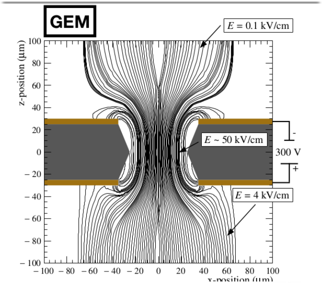
- Total length 5m,
  radial dimension 83.5 cm $< r <$ 254.5 cm
- Gas mixture Ne-CO_2-N_2 (90-10-5)
- Central electrode and field cage,
  uniform E-field 400 V/cm along beam-axis
- Charged particles traversing TPC volume
  ionise the gas atoms
- Ionisation electrons drift to endplates,
  segmented readout,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

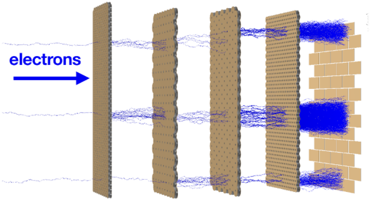




The TPC upgrade

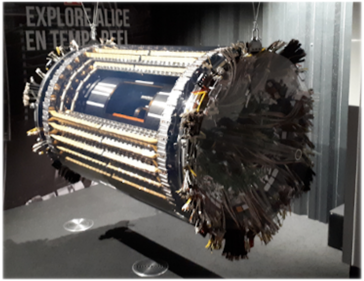
- Positive-ion backflow a major issue in TPC running conditions
- Positive-ion backflow controlled by gating grid in Run 1 and 2, rate limit $\sim$ 3 kHz
- Electron multiplication in Run 3 by staging of 4 Gas Electron Multipliers (GEM)
- Ion backflow $\lesssim 0.7\%$ with configuration of 4 staged GEMs
- Pb-Pb data taking rate increased from 1 kHz in Run 1,2 to 50 kHz in Run 3
- 3-d cluster position information is input for global track reconstruction
- ionisation signal dE/dx is input for PID



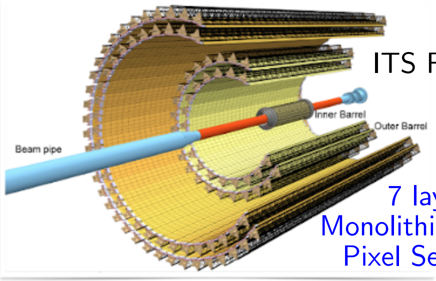


The ITS upgrade

- The upgrade of the ITS detector: *improved resolution, less material, faster readout*



ITS Run 1,2 → ITS Run 3

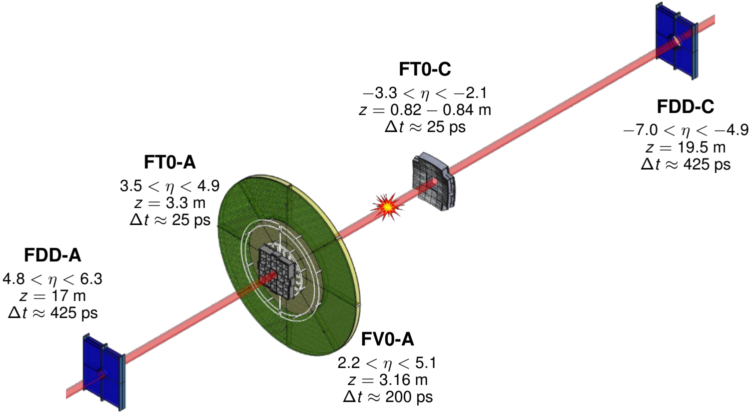


7 layers of Monolithic Active Pixel Sensors

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

ALICE O^2 in a nutshell

Requirements

1. LHC min bias Pb-Pb at 50 kHz
   ~100 x more data than during Run 1
2. Physics topics addressed by ALICE upgrade
   - Rare processes
   - Very small signal over background ratio
   - Needs large statistics of reconstructed events
   - Triggering techniques very inefficient if not impossible
3. 50 kHz > TPC inherent rate (drift time ~100 µs)
   Support for continuous read-out (TPC)
   - Detector read-out triggered or continuous

New computing system

- Read-out the data of all interactions

➔ Compress these data intelligently by online reconstruction

➔ One common online-offline computing system: O^2

- Paradigm shift compared to approach for Run 1 and 2

Unmodified raw data of all interactions shipped from detector to online farm in triggerless continuous mode

HI run 3.3 TByte/s ⇩

Baseline correction and zero suppression
Data volume reduction by zero cluster finder.
No event discarded.
Average compression factor 6.6

500 GByte/s ⇩

Data volume reduction by online tracking.
Only reconstructed data to data storage.
Average compression factor 5.5

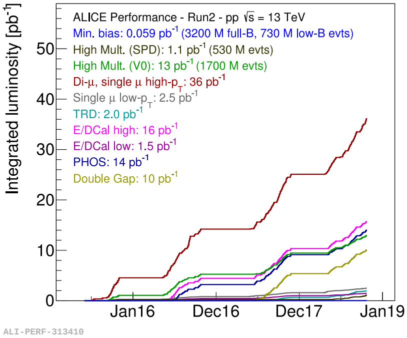
90 GByte/s ⇩

Data Storage: 1 year of compressed data
- Bandwidth: Write 90 GB/s Read 90 GB/s
- Capacity: 60 PB

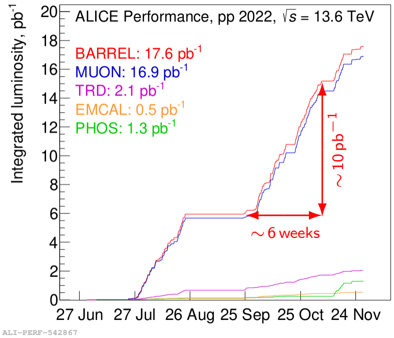
20 GByte/s ⇳ Tier 0, Tiers 1 and Analysis Facilities

⇳ Asynchronous (few hours) event reconstruction with final calibration

Data statistics in Run 2 and Run 3

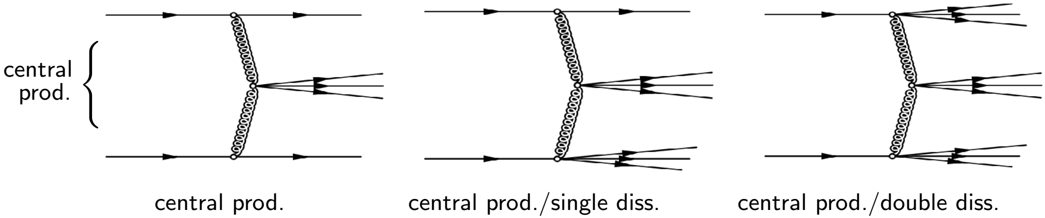


Double gap data sample of 10 pb^{-1} in Run 2



Central barrel data sample of $\sim$10 pb^{-1} per 6 weeks of data taking in 2022 (plus data taken in 2023)

Central diffractive production at the LHC



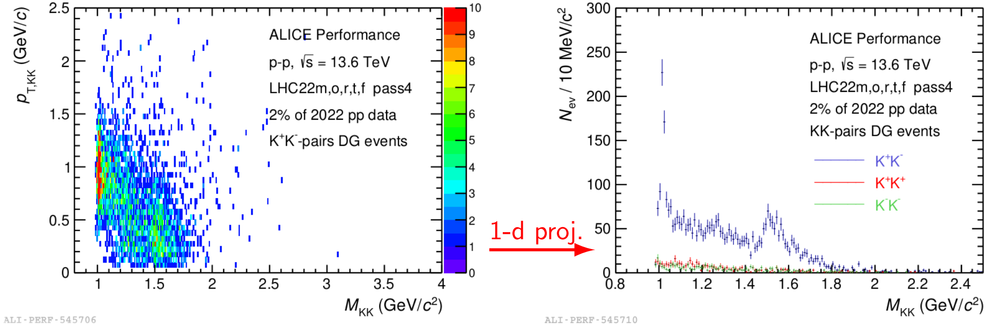
- Pomerons $\mathbb{P}$ and Reggeons $\mathbb{R}$ contribute to these topologies
- Rapidity gaps can also be due to photon and $W^{\pm}$,Z-exchange
- Pomerons and photons contribute differently in pp, pA and AA

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)
   $\rightarrow$ no signal in FIT detector $\rightarrow$ double gap event

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 $\qquad$ K^+K^-, K^+K^+, K^-K^--pairs

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

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

isoscalars with (hidden) strangeness

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.(1)	PDG	J^{PC}	mass (PDG)	width (PDG)
1^3S_1	1020	ϕ	1^{--}	1019	4
1^3P_2	1530	f_2'	2^{++}	1518	86
1^3D_3	1900	ϕ_3	3^{--}	1854	87
1^3F_4	2200	??	??	??	??

mass and width in (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

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

- Imaginary part is related to the decay width

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

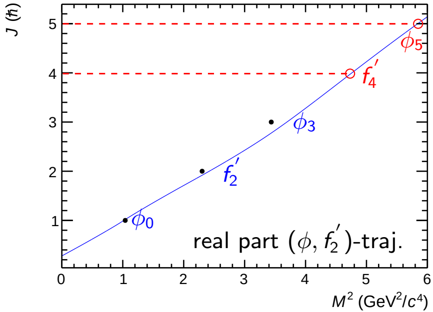
- Imaginary part chosen as sum of single threshold terms

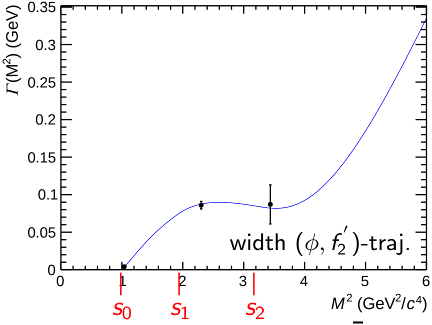
$$\Im m\,\alpha(s) = \sum_n c_n (s-s_n)^{1/2} \left(\frac{s-s_n}{s}\right)^{|\Re e\,\alpha(s_n)|} \theta(s-s_n). \tag{4}$$

- 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





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

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

$\phi \to K\bar{K}, s_0 = 0.97$ 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 in Run 3 after a major upgrade in long shutdown LS2
- First analysis of strangeness in double gap events in pp-collisions shows clear evidence for strangeonia states $\phi(1020)$ and $f_2'(1525)$
- Improve particle identification by combining TPC dE/dx with TOF information
- 50 times larger data sample from data taking 2022 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

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.