New results obtained in the ALICE experiment with participation of the JINR group

(The Project was approved for 2017-2019 years.)

E. Rogochaya

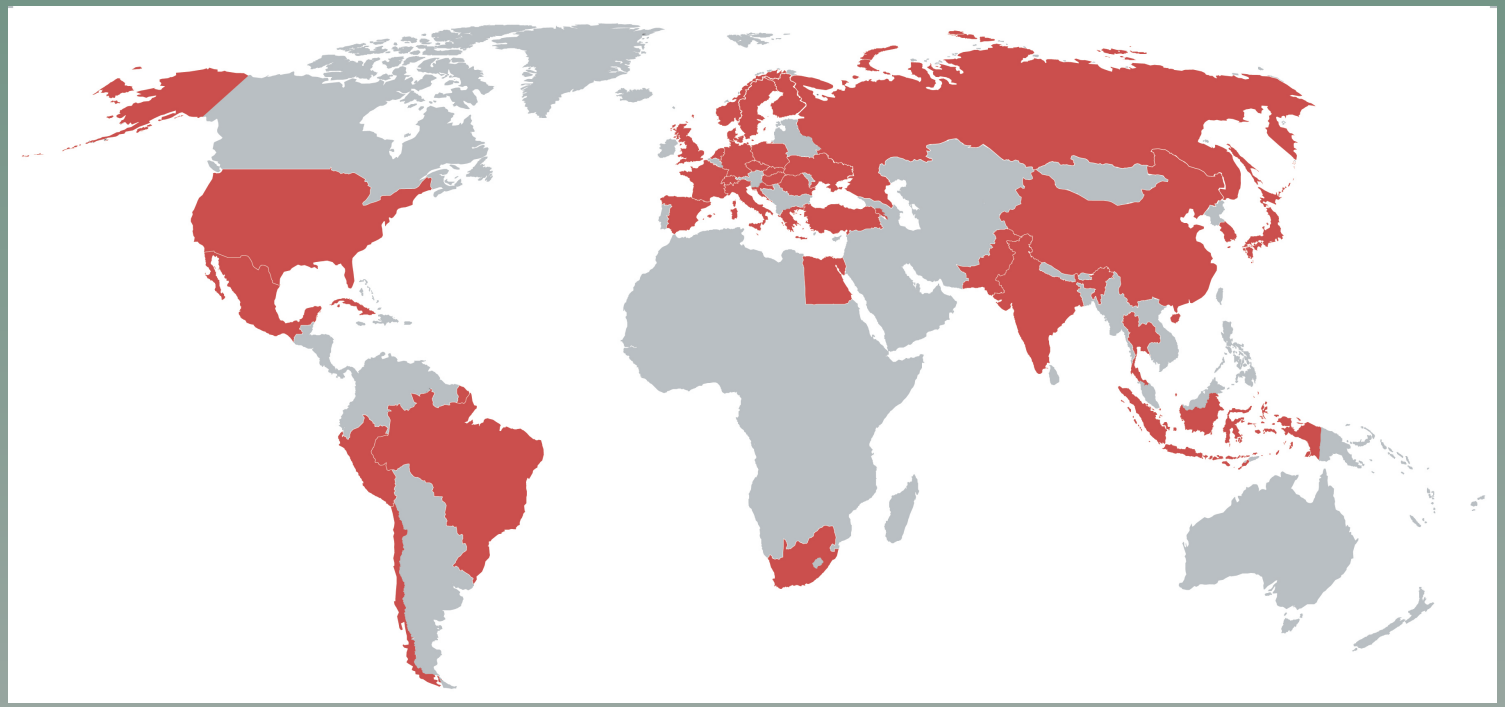
JINR, Dubna

January 16, 2017

Outline

- JINR group in ALICE
- Femtoscopic kaon analysis
  - 1D K^+K^- correlation analysis in Pb-Pb@2.76 TeV
  - 1D $K^{\pm}K^{\pm}$ correlation analysis in p-Pb@5.02 TeV
- Quarkonia physics
- Ultra-peripheral collisions of heavy ions
- GRID status
- R&D upgrade of ALICE PHOS read-out system
- Conclusions and plans for future

ALICE Collaboration



42 countries, 174 institutes, 1800 members

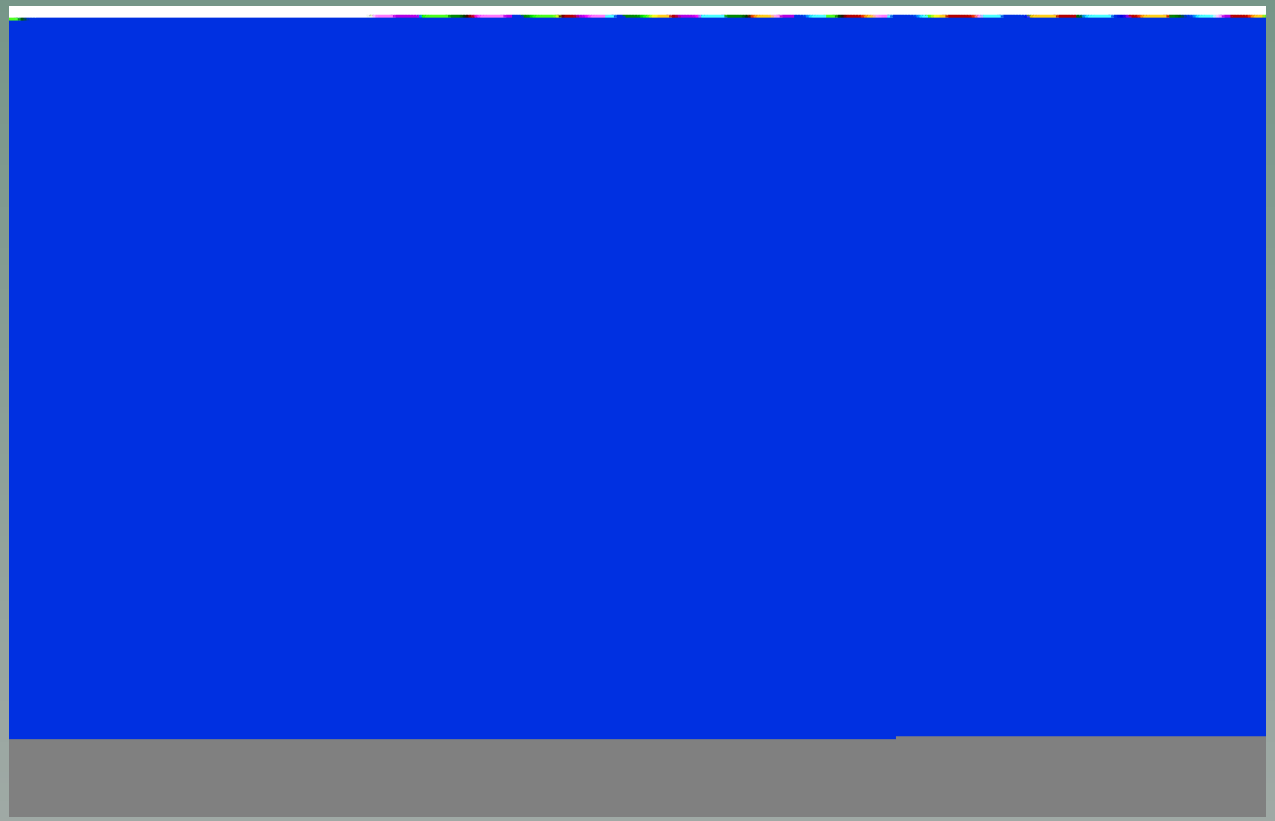
ALICE-JINR group:

- 10 physicists including 2 PhD students
- 1 undergraduate student
- 1 expert for the root software updating and GRID computing management
- 2 physicists from P.J. Safarik University (UPJS) in Kosice, Slovakia (by the Joint Research Protocol)

Interests and activity of ALICE-JINR group

- Bose-Einstein correlations (femtoscopy physics)
  - Analysis of two charged kaon correlations in pp, p-Pb and Pb-Pb collisions and update of the analysis software.
- Quarkonia physics
  - Creation and update of the Cocktail generator (model) of J/ψ and Υ production in pp, p-Pb and Pb-Pb collisions.
  - Monte Carlo simulation using this generator to estimate the registration efficiency of these mesons in the dimuon decay mode ($J/\psi \to \mu^+\mu^-$, $\Upsilon \to \mu^+\mu^-$).
- Ultra-peripheral collisions of heavy ions:
  - Study of J/ψ and ρ_0 photoproduction in Pb-Pb collisions.
- Physics of resonances
  - Suggestion (under consideration) to study of the spin-alignment (tensor polarization) of ϕ meson production in Pb-Pb collisions (in collaboration with the group of P.J. Safaric University, Kosice, Slovakia).
- GRID computing and software activities
- R&D upgrade of the ALICE PHOS electronic system
- Participation in the ALICE Shifts (90 shifts in 2016)

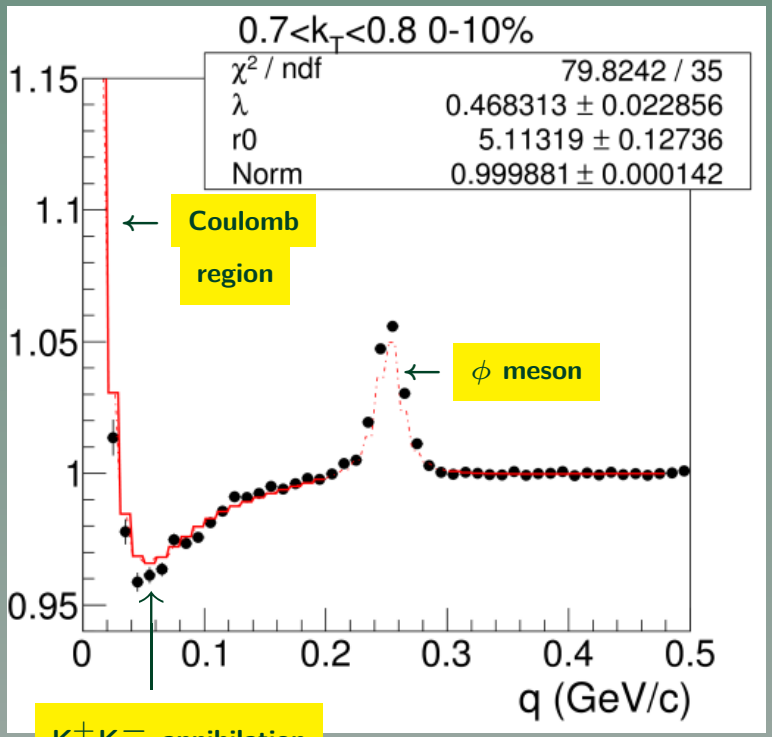
ALICE setup



- Tracking and vertex:
  - Time Projection Chamber - **TPC**
  - Inner Tracking System - **ITS**
- Particle identification:
  - **TPC**
  - Time-of-Flight -**TOF**
- Centrality determination:
  - **V0**
- Muon Forward Spectrometer - **MUON ARM** (absorber, dipole magnet, tracking chambers, muon filter, trigger chambers)

Femtoscopic analysis: 1D K^+K^- correlations in Pb-Pb@2.76 TeV

Work in progress!

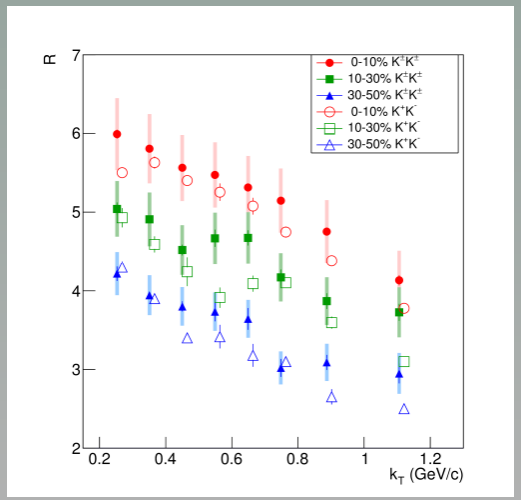


Correlation function:

$$C(q_{\mathrm{inv}}) = \mathrm{Norm} \cdot (1 + \lambda \cdot \mathrm{FSI}(q_{\mathrm{inv}}))\, P(q_{\mathrm{inv}}),$$

where

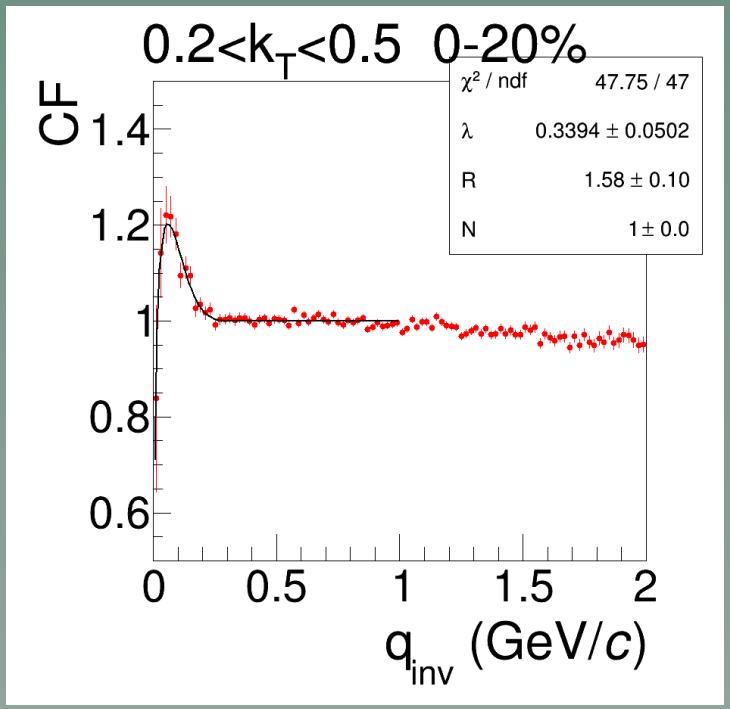
- FSI=$\mathrm{CF}_{\mathrm{FSI}}$-1 and $\mathrm{CF}_{\mathrm{FSI}}$ (shown on the left) is numerically calculated using the Lednicky CF formula [R. Lednicky, V.L. Lyuboshits, Sov. J. Nucl. Phys. 35 (1982) 770]
- including resonance formation due to FSI [R. Lednicky, Phys. Part. Nucl. Lett. 8 (2011) 965]
- a_0 and f_0 resonances parameters are taken from the ***combined Martin*** [A.D. Martin et al., Nucl. Phys. B 121 (1977) 514] + ***Achasov*** [N.N. Achasov, A.V. Kiselev, Phys. Rev. D 68 (2003) 014006] ***model***



- $R_{\mathrm{K^+K^-}}$ are lower than $R_{\mathrm{K^\pm K^\pm}}$ but within errors
- Presented at GDRE2016 (Nantes, France) by K.R. Mikhaylov (JINR/Moscow ITEP)

Femtoscopic analysis: 1D $K^{\pm}K^{\pm}$ correlations in p-Pb@5.02 TeV

Work in progress!



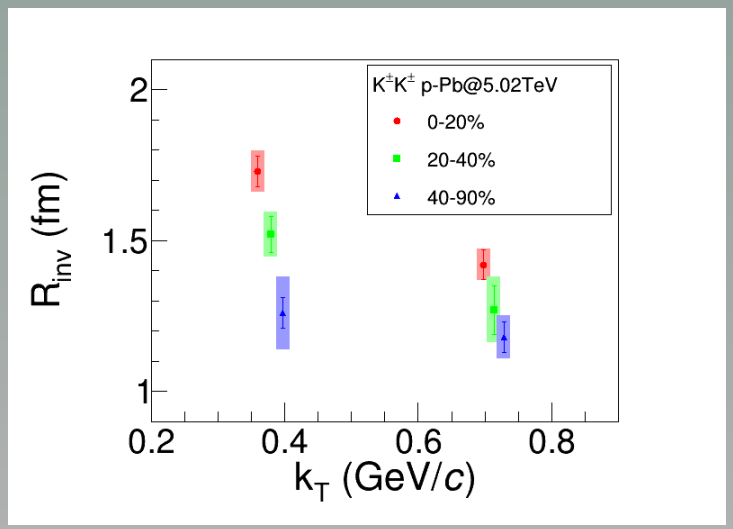
Correlation function is fitted by the Bowler-Sinyukov formula:

$$C(q_{\mathrm{inv}}) = \left((1-\lambda) + \lambda K(q_{\mathrm{inv}})\left(1 + e^{-R_{\mathrm{inv}}^2 q_{\mathrm{inv}}^2}\right)\right) P(q_{\mathrm{inv}}),$$

where K - Coulomb interaction, P - baseline.

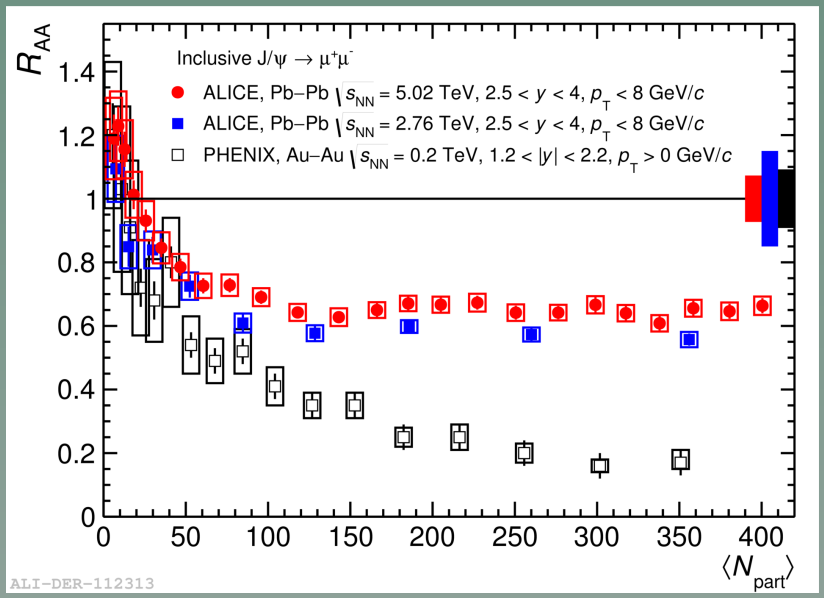
Typical correlation function of identical $K^{\pm}K^{\pm}$ pairs (here shown for central events and low transverse momentum k_{T}).

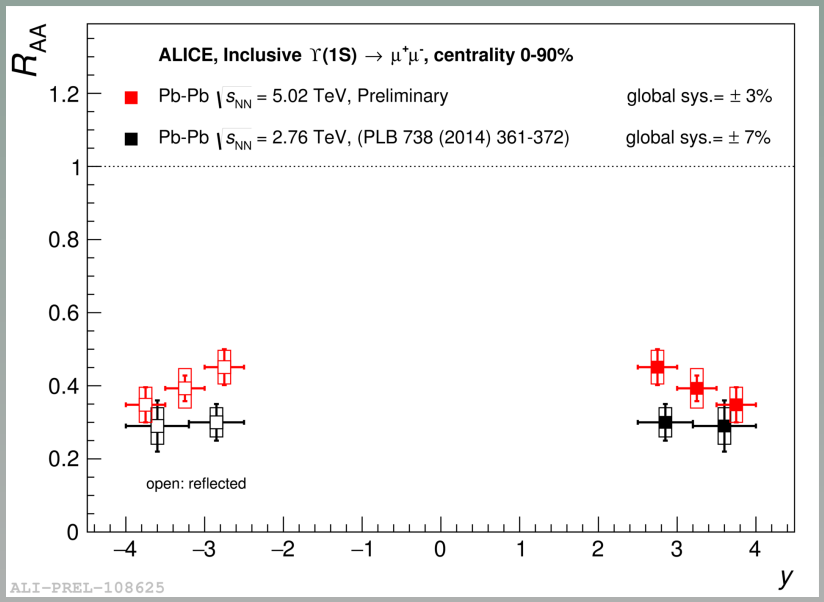
- Invariant radii R_{inv} of $K^{\pm}K^{\pm}$ pairs shown with statistical (vertical lines) and systematic (boxes) errors
- Presented at CERN femtoscopy meetings by E.P. Rogochaya (JINR)



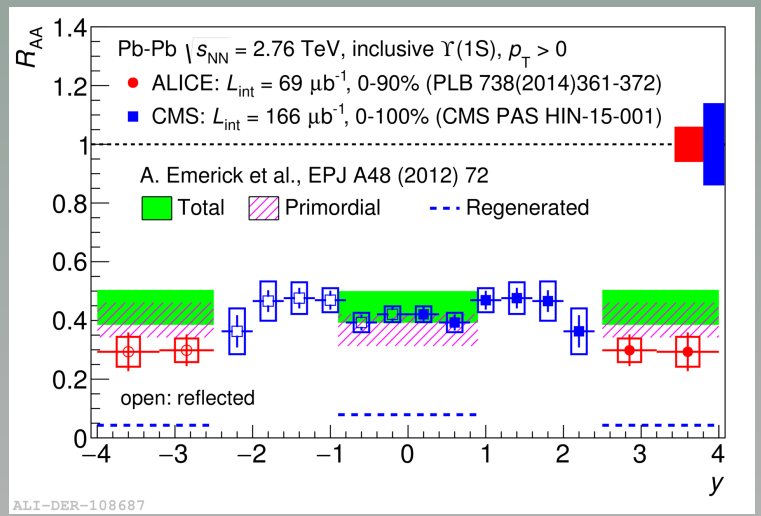
Quarkonia

Nuclear modification factor: $R_{AA} = \frac{Y^{\mathrm{Pb-Pb}}}{<T_{\mathrm{AA}}> \times \sigma^{\mathrm{pp}}}$, where $Y^{\mathrm{Pb-Pb}}$ - corrected J/ψ (Υ) yield in Pb-Pb, T_{AA} - nuclear overlap function.





- J/ψ yields are less suppressed in ALICE than in PHENIX
- Visible increase of the R_{AA} is seen with the energy rise from 2.76 TeV [J. Adam et al. [ALICE Collaboration], JHEP 1605 (2016) 179] to 5.02 TeV according to the prediction of the models with the J/ψ regeneration mechanism [X. Zhao et al., Nucl. Phys. A 859 (2011) 114; K. Zhou et al., Phys. Rev. C 89 (2014) 05491] in the quark-gluon plasma
- $\Upsilon(1S)$ yields at forward rapidity in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$=5.02 TeV are suppressed in comparison to the ones at 2.76 TeV (left) and CMS results (bottom)

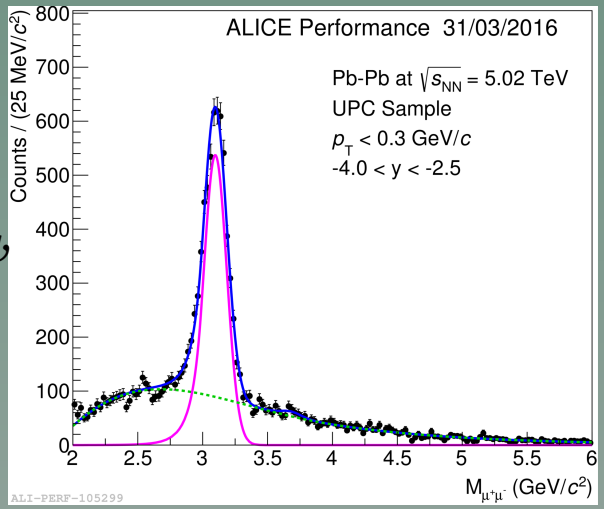


Ultra-peripheral collisions of Pb-Pb@5.02 TeV: J/ψ and ρ^0 photoproduction

γ of one ion electromagnetic field fluctuates into bound $q\bar{q}$ pair (vector meson) $\rightarrow$ meson scatters elastically on another ion by Pomeron exchange:

coherent - on a nucleus as a whole, **incoherent** - on a nucleon.

J/ψ

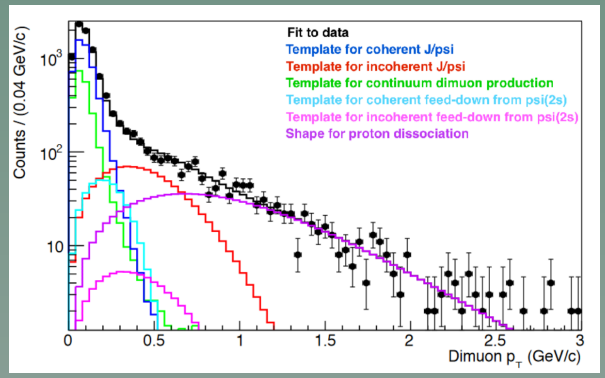


Invariant mass of coherent dimuons:

CB parameterization

background

total



Coherent J/ψ

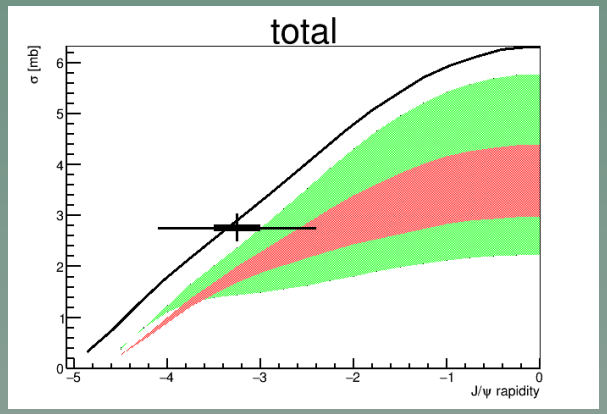
Incoherent J/ψ

Coherent $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$

Incoherent $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$

Continuum $\gamma\gamma \rightarrow \mu\mu$

Incoherent J/ψ with proton dissociation [H1 Collaboration, Eur. Phys. J. C 73 (2013) no.6, 2466]



Total cross section:

statistical error

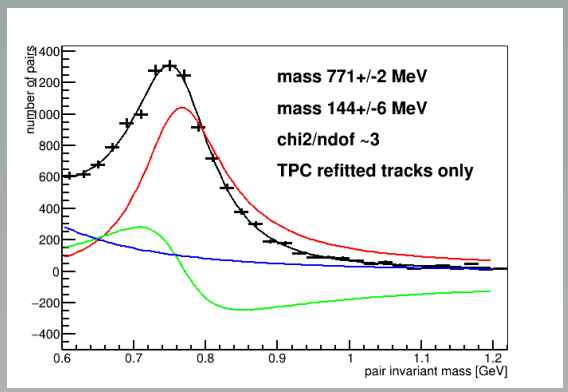
| systematic error

STARlight [S.R. Klein et al., Comput. Phys. Commun. 212 (2017) 258]

EPS09 LO [K.J. Eskola et al., JHEP 0904 (2009) 065]

GKZ [V. Guzey et al., Phys. Rev. 93 (2016) no.5, 055206]

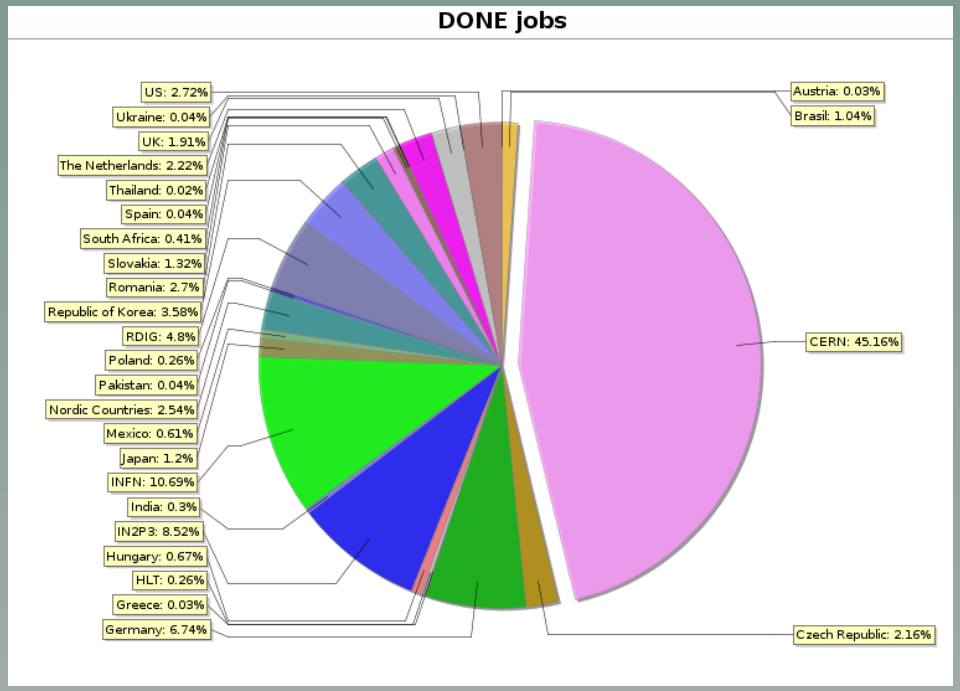
ρ^0

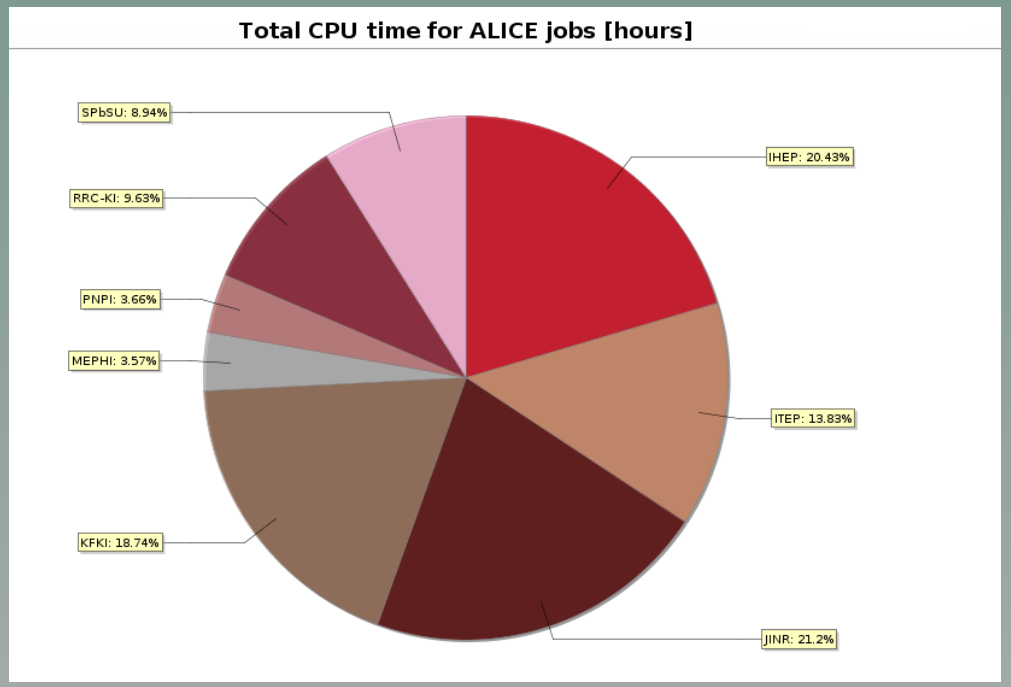


- **Total**:
  - Soding function [P. Soding, Phys. Lett. 19 (1966) 702]:
    Breit-Wigner parameterization + interference of directly and resonantly (ρ^0) produced $\pi^+\pi^-$ pair
  - background
- The first results were obtained and presented at CHARM2016 (Bologna, Italy) by V.N. Pozdnyakov (JINR)

GRID computing and software activities

- ALICE GRID: 47113 cores, 78 centers: T0 - 1 (CERN), T1 - 4, T2 - 73
- JINR ALICE GRID - T2 (T1 - for JINR CMS)
- JINR ALICE GRID is a part of eight Russian ALICE GRID centers (RDIG - Russian Data Intensive Grid)
- JINR GRID Farm (3480 cores CPU, 408 Tb Disk-SE, 139 Tb - EOS)





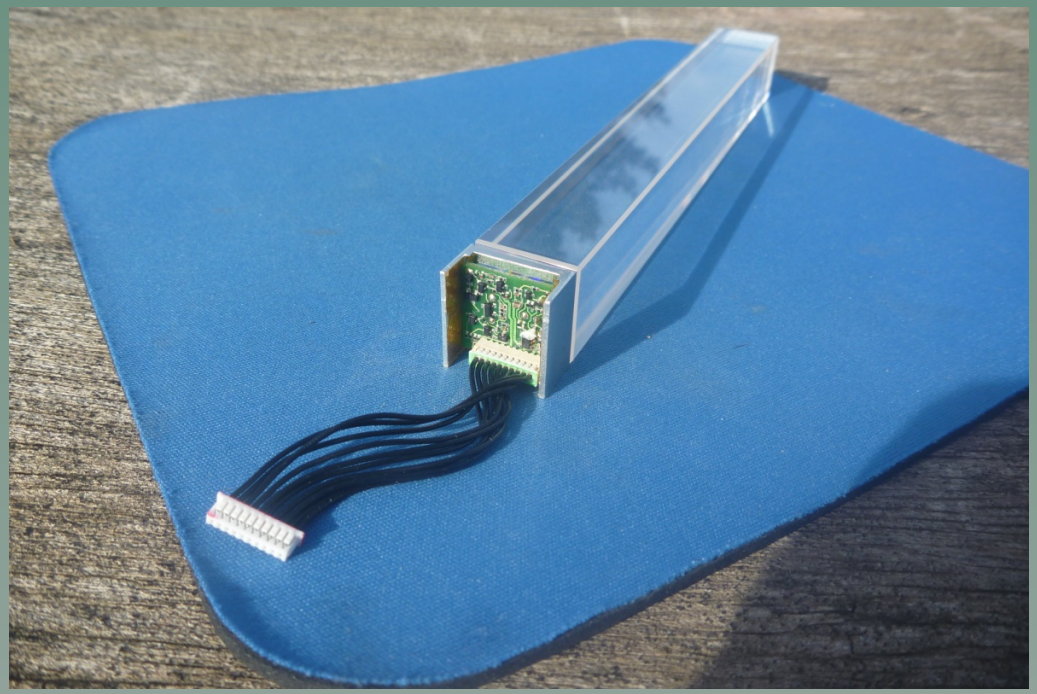
RDIG contribution to the ALICE GRID is 4.8%

JINR contribution to RDIG is 21.2%

Presented at ALICE T1/T2 Workshop (Bergen, Norway) by G. Stiforov (JINR), A. Zarochentsev (SPbGU).

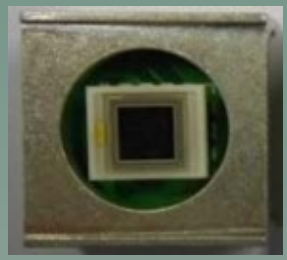
PHOS upgrade R&D: Ways

(in collaboration with NRC "Kurchatov Institute")



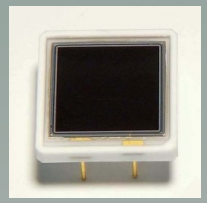
Current PHOS setup:

- Each channel: lead tungstate, $PbWO_4$, crystal of $2.2 \times 2.2\,cm^2$ cross section and 18 cm length + Avalanche photo-detector (**APD**) + preamplifier



- **APD** $5 \times 5\,mm^2$:
- Operating temperature: $-28°C$
- Time-of-flight resolution σ_t =2000-3000 ps at 1 GeV (**useless for particle identification!**)

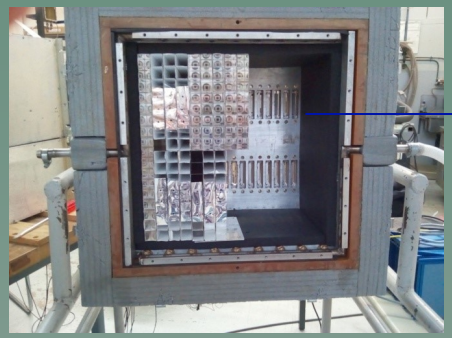
Ways for upgrade:

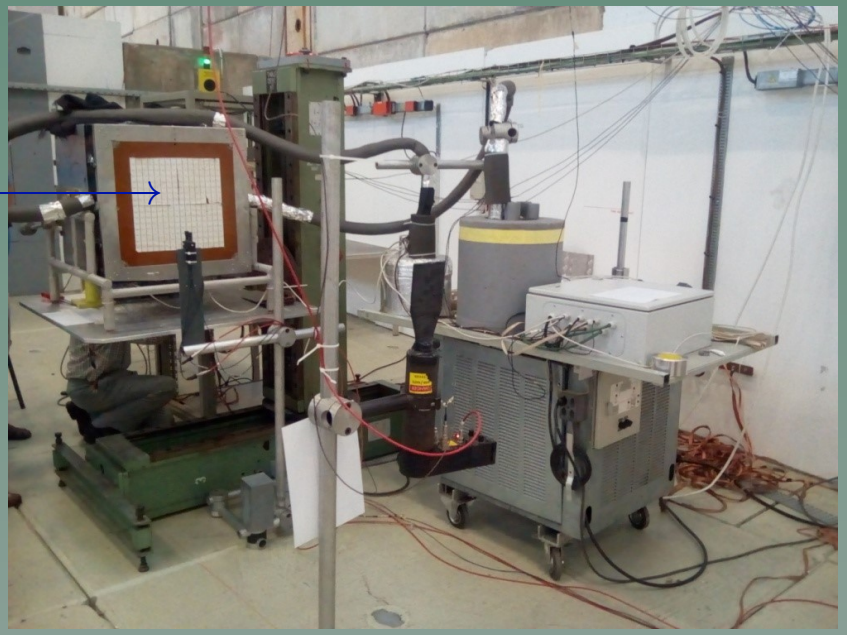


1. New **APD** ($10 \times 10\,mm^2$, 50 μm pixels): σ_t =270 ps at 1 GeV, near the same energy resolution at $+18°C$ as for old **APD** at $-28°C$

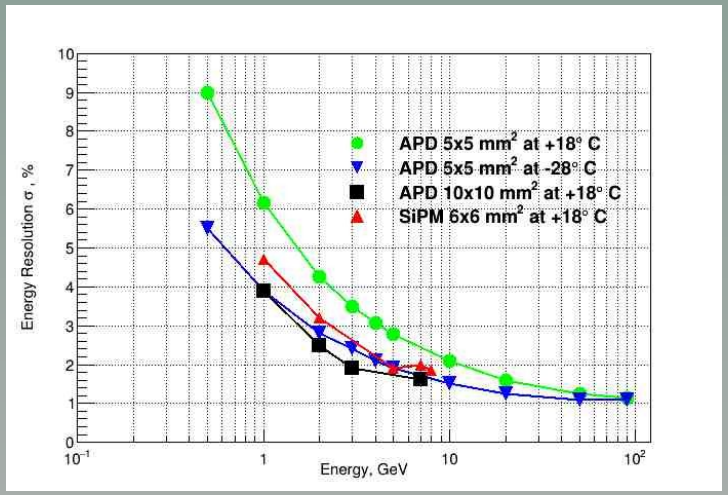
2. Replace **APD** by silicon photo-multiplier **SiPM** ($6 \times 6\,mm^2$, 15 μm pixels): σ_t =150 ps at 1 GeV at $+18°C$; near the same energy resolution as for **APD**; no preamplifiers

PHOS upgrade R&D: Test results

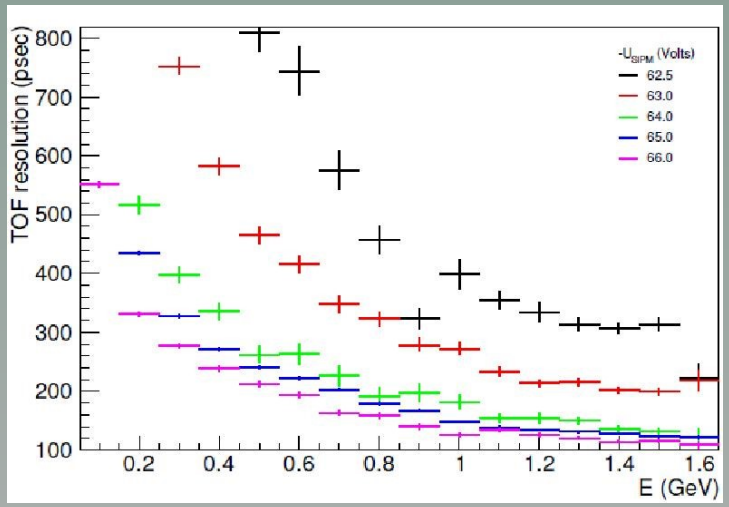




PHOS prototype (256 channels) installed in the electron test beam of the CERN PS (1-8 GeV beam energy) or of the SPS (10-110 GeV).



Energy resolution versus electron energy for all considered types of the photo-detector



Time resolution of the **SiPM** detector versus energy excretion in the crystal for different voltage in the detector at $+18^{\circ}$C

Publications in 2016

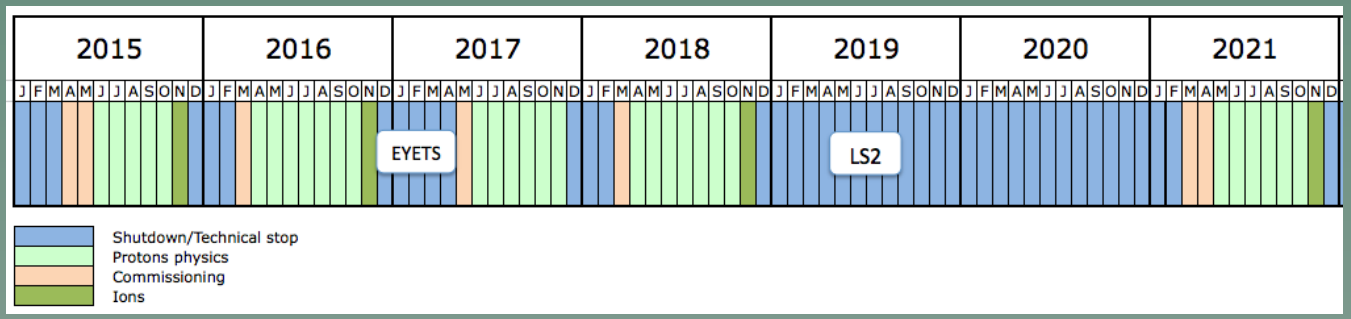
1. "Inclusive quarkonium production at forward rapidity in pp collisions at $\sqrt{s}$=8 TeV", J. Adam et al. [ALICE Collaboration], Eur. Phys. J. C 76 (2016) no.4, 184
2. "Differential studies of inclusive J/ψ and $\psi(2S)$ production at forward rapidity in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$=2.76 TeV", J. Adam et al. [ALICE Collaboration], JHEP 1605 (2016) 179
3. "Centrality dependence of pion freeze-out radii in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$=2.76 TeV", J. Adam et al. [ALICE Collaboration], Phys. Rev. C 93 (2016) no.2, 024905
4. "Inclusive quarkonium production at forward rapidity in pp collisions at $\sqrt{s}$=8 TeV", J. Adam et al. [ALICE Collaboration], Eur. Phys. J. C 76 (2016) no.4, 184
5. "Measurement of an excess in the yield of J/ψ at very low $p_{\rm T}$ in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$=2.76 TeV", J. Adam et al. [ALICE Collaboration], Phys. Rev. Lett. 116 (2016) no.22, 222301
6. "Multipion Bose-Einstein correlations in pp, p-Pb, and Pb-Pb collisions at energies available at the CERN Large Hadron Collider", J. Adam et al. [ALICE Collaboration], Phys. Rev. C 93 (2016) no.5, 054908
7. "Production of $K^*(892)^0$ and $\varphi(1020)$ in p-Pb collisions at $\sqrt{s_{\rm NN}}$=5.02 TeV", J. Adam et al. [ALICE Collaboration], Eur. Phys. J. C 76 (2016) no.5, 245
8. "Centrality dependence of $\psi(2S)$ suppression in p-Pb collisions at $\sqrt{s_{\rm NN}}$=5.02 TeV", J. Adam et al. [ALICE Collaboration], JHEP 1606 (2016) 050
9. "J/ψ suppression at forward rapidity in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$=5.02 TeV", J. Adam et al. [ALICE Collaboration], arXiv:1606.08197[nucl-ex]

Conferences in 2016

1. "Operations and plans - RDIG T2s", G. Stiforov (JINR), A. Zarochentsev (SPbGU), ALICE T1/T2 Workshop, Bergen, Norway
2. "Femtoscopy of identical kaons with ALICE at LHC", L. Malinina (JINR/MSU, SINR), XVIII GDRE Workshop, Subatech, Nantes, France
3. "Identical and non-identical kaon correlations in pp and Pb-Pb collisions at the LHC with ALICE", K. Mikhailov (JINR/Moscow ITEP), XVIII GDRE Workshop, Subatech, Nantes, France
4. "Ultra-peripheral J/ψ photoproduction in Pb-Pb interactions at ALICE", V.N. Pozdnyakov (JINR), CHARM2016, INFN, Bologna, Italy
5. "Bose-Einstein correlations of charged and neutral kaons in pp and Pb-Pb collisions at the LHC energies with the ALICE experiment", K. Mikhailov (JINR/Moscow ITEP), International Session-Conference of the Section of Nuclear Physics of PSD RAS, Dubna, Russia

ALICE plans for future

LHC schedule:



Year	System	E (TeV)	Lumi ($cm^{-2}s^{-1}$)	Rate (kHz)	Time
2015	pp	13	5×10^{30}	300	7w
	Pb-Pb	5.02	1×10^{27}	8	3w
	pp-ref	5.02	5×10^{30}	300	4d
2016	pp	13	5×10^{30}	300	28w
	p-Pb	5.02	1×10^{29}	200	4w
	pp-ref	5.02	5×10^{30}	300	7d
2017	pp	13	5×10^{30}	300	24w
2018	pp	13	5×10^{30}	300	28w
	Pb-Pb	5.02	1×10^{27}	8	4w
	pp-ref	5.02	5×10^{30}	300	7d

Minimum bias event numbers stored during the Run 2:

pp at 13 TeV	822M
p-Pb at 5.04 TeV	764M
p-Pb at 8 TeV	126M
Pb-Pb at 5.04 TeV	157M

Conclusion and plans for 2017

Conclusion:

ALICE-JINR group carries out successfully the physics analysis of the experimental data and the R&D upgrade of ALICE PHOS read-out system:

- Analysis results have been reported at international conferences and some finished ones have been published in peer-reviewed journals. Several papers are under preparation.
- RDIG contribution to the ALICE GRID is 4.8%, JINR contribution to RDIG is 21.2%.
- Aim of PHOS upgrade is to provide a good σ_t resolution and improve direct photon identification.

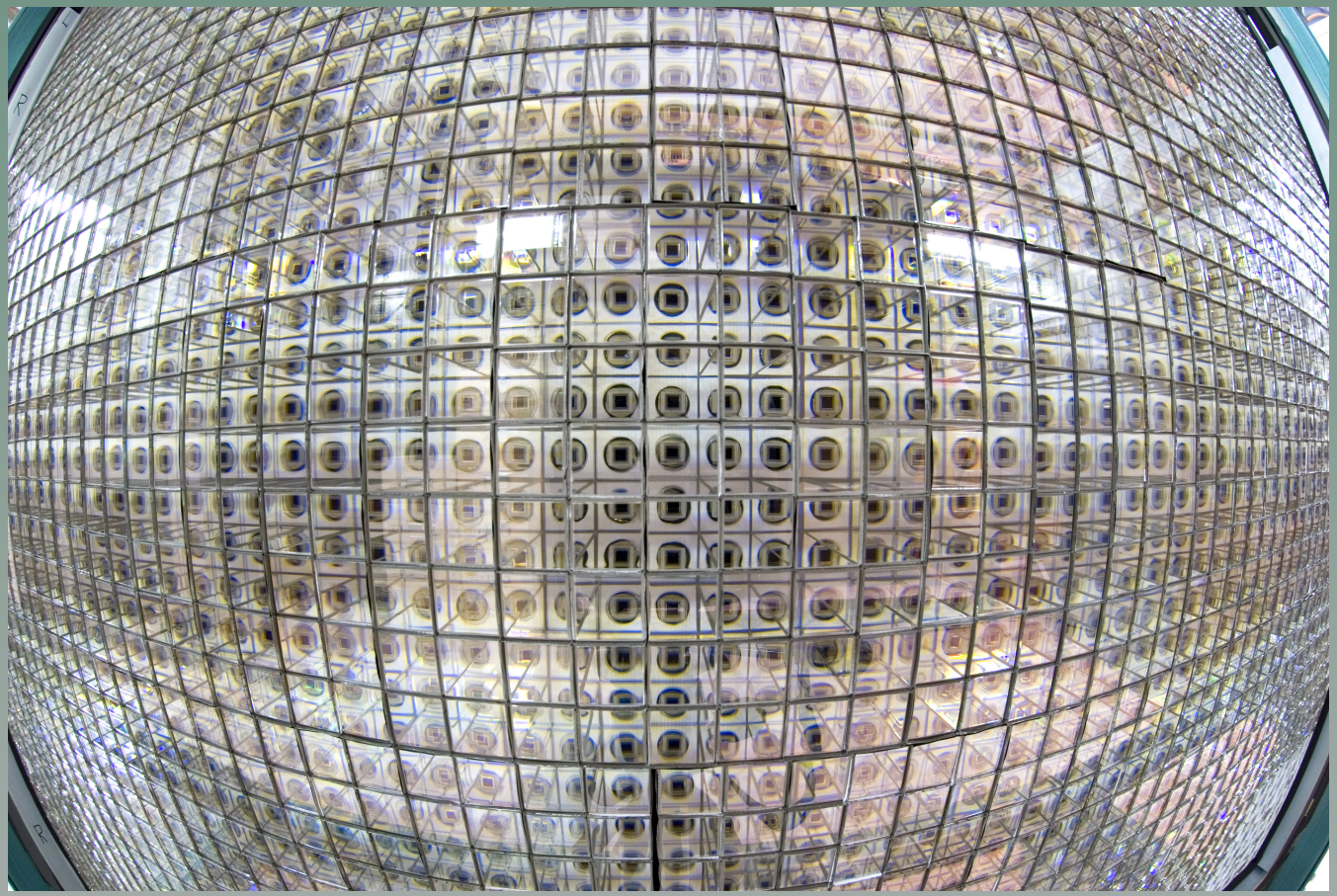
Plans:

- Publication of 3D charged kaon correlation analysis results in Pb-Pb@2.76 TeV (practically finalized).
- Femtoscopic analyses for $K^{\pm}K^{\pm}$ in p-Pb collisions at 5.02 TeV and for $K^{+}K^{-}$ in Pb-Pb collisions at 2.76 TeV.
- Start of the femtoscopic analysis for $K^{\pm}K^{\pm}$ in pp collisions at 13 TeV and in Pb-Pb at 5.02 TeV.
- More detailed resonance analysis, particularly to study the polarization characteristics of ϕ meson (in collaboration with the group from Kosice, Slovakia).
- Development and support of the quarkonia generator.
- Analysis of the J/ψ and ρ^0 photoproduction in ultra-peripheral Pb-Pb collisions at 5.02 TeV.
- Work on the R&D upgrade of the ALICE PHOS read-out system.
- GRID and PROOF support in the JINR computing system.

THANK YOU FOR YOUR ATTENTION!

Backup: PHOS upgrade R&D

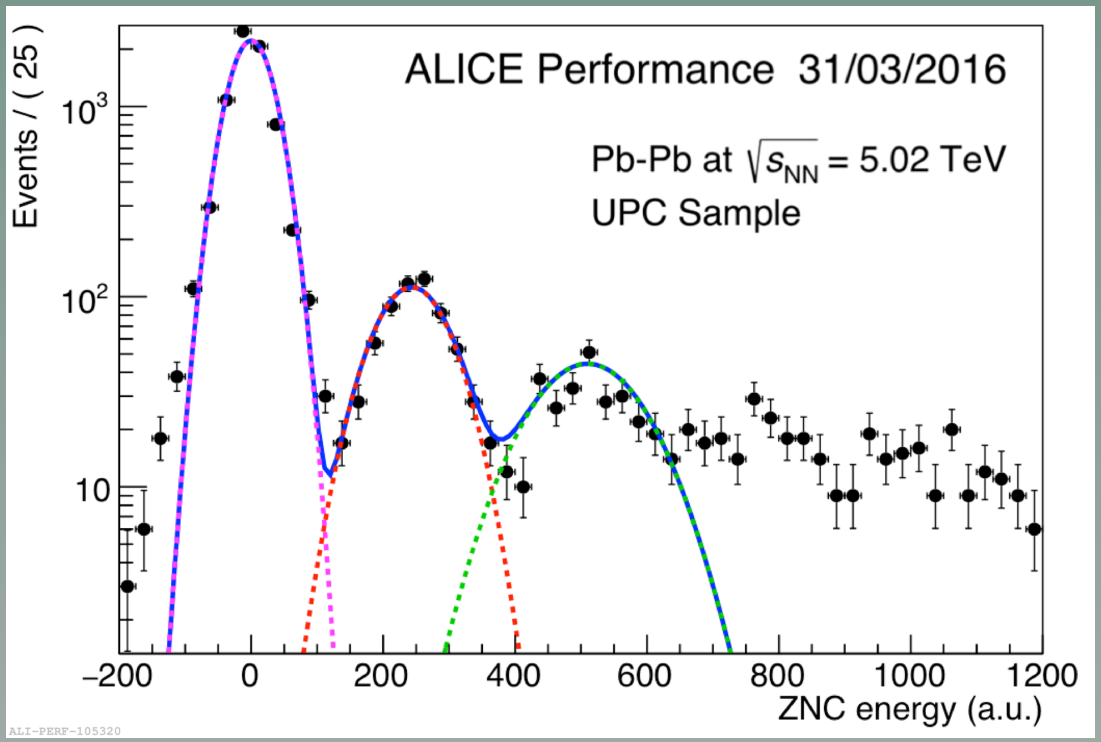
One of the PHOS modules:



The PHOS detector consists of near 3.5 modules installed at a distance of 4.6 m from the interaction point. PHOS covers the acceptance of near 100° in azimuthal angle and $(-0.13, +0.13)$ in pseudorapidity. Each module has 3584 detection channels.

Backup: Ultra-peripheral collisions of heavy ions

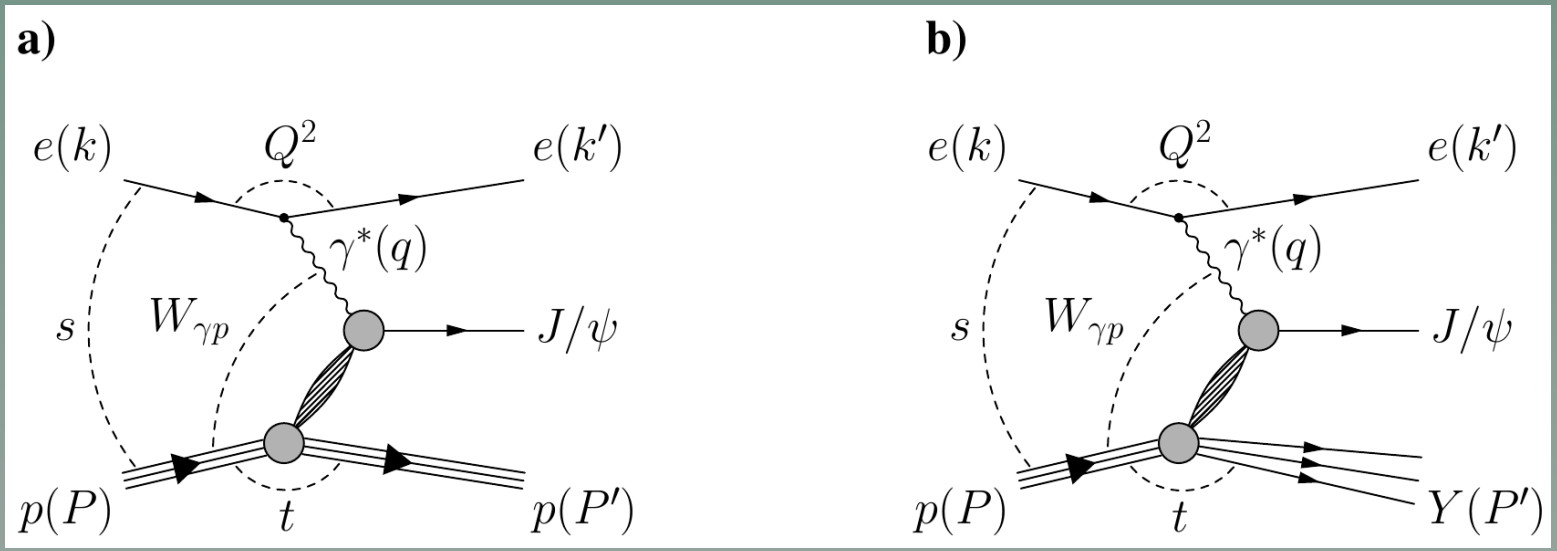
Energy spectrum of the neutron ZDC (C-side) in UPC of Pb-Pb in Run 2:



Events registered in ZDC from left to right (number of detected neutrons): 0n, 1n, 2n.

Backup: Proton-dissociative photoproduction of J/ψ in UPC

H1 Collaboration, Eur. Phys. J. C 73 (2013) no.6, 2466



Diffractive J/ψ meson production in electron-proton collisions:

a) elastic J/ψ production in which the proton stays intact

b) proton-dissociative J/ψ production in which the proton dissociates to a low mass excited state with mass $M_Y > m_p$