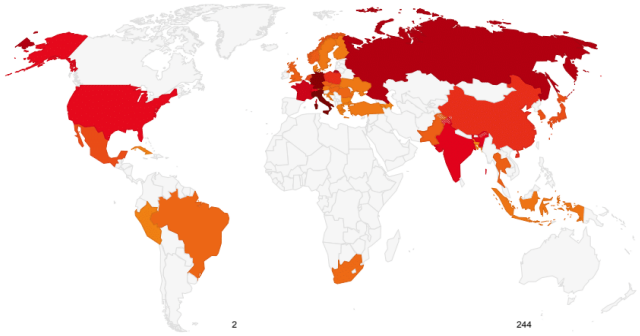
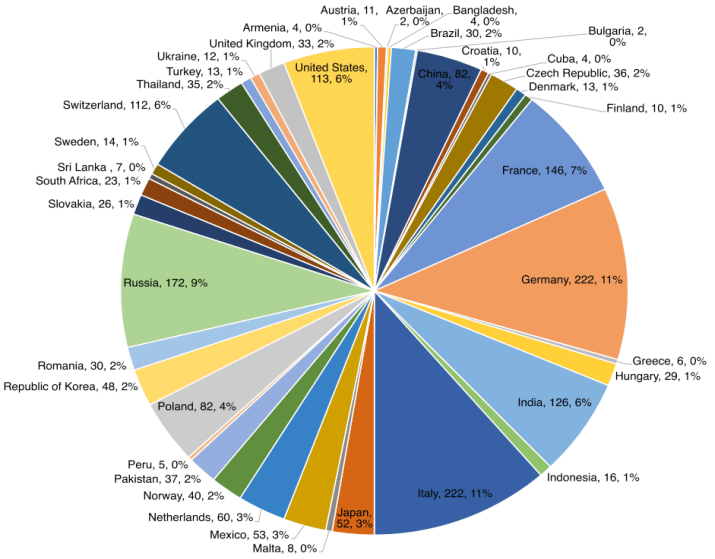
New results obtained in the ALICE experiment with a participation of the JINR team.

B.Batyunya

55th PAC, Dubna, 22.06.2021

The ALICE Collaboration





40 Countries, 176 Institutes (including 19 Associates)

1946 Members, about 1000 signing authors

941 Physicists (including PhD Students)

- 587 PhD Physicists
- 355 PhD Students

52 Senior Engineers

The ALICE JINR analysis group:

-- 7 physicists;

-- 2 PhD students;

-- 1 undergraduate student

-- 1 expert for the root software updating and GRID computing management.

Main activity of the Dubna team in ALICE

- Bothe-Einstein correlations (femtoscopy physics):
  Analysis of two-charged kaons correlations in p-p, p-Pb and Pb-Pb collisions. Updating of the analysis software.

- Ultraperipheral collisions of heavy ions:
  Study of vector meson photoproductions in the Pb-Pb and p-Pb collisions.

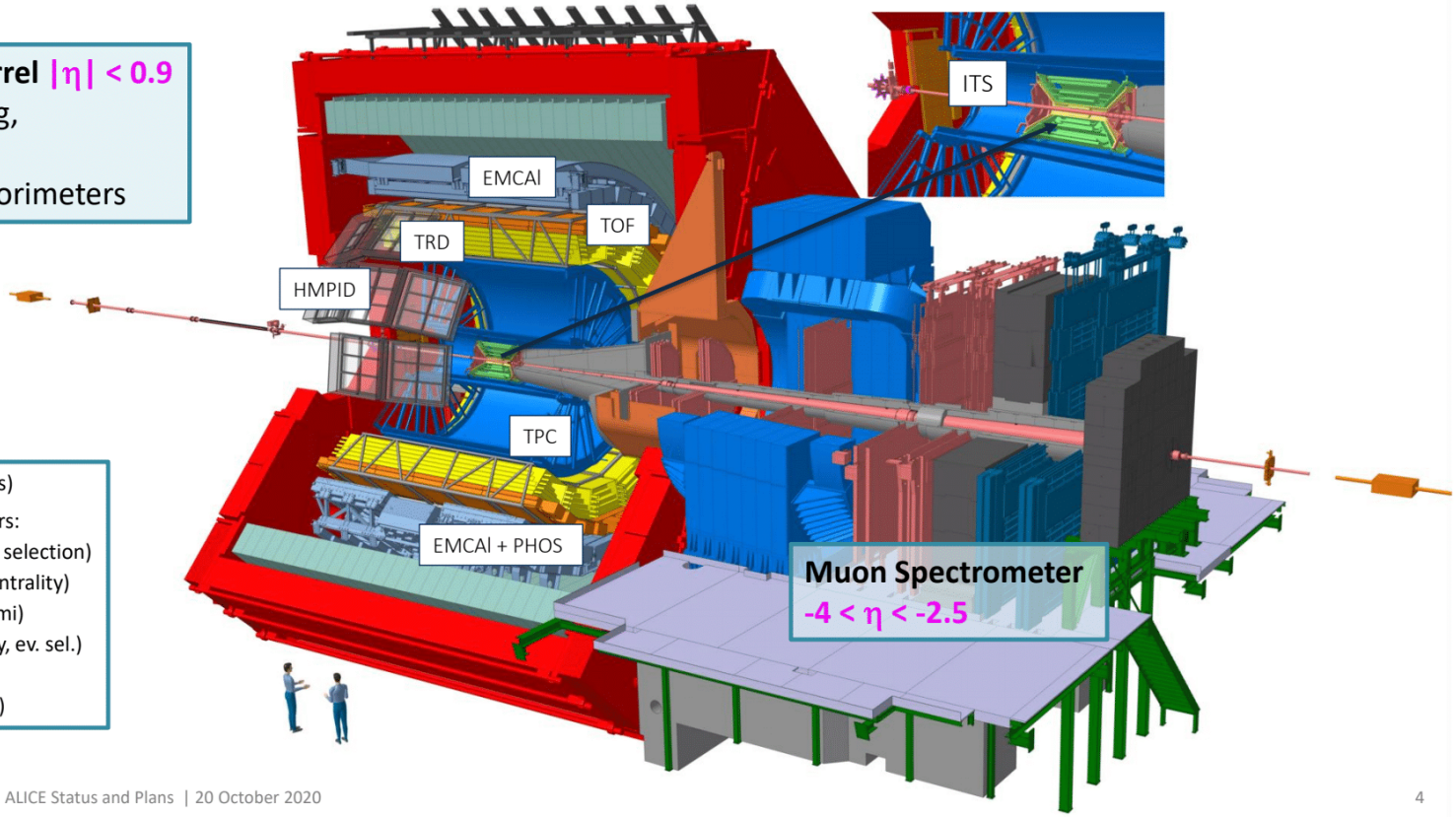
- Thermal model of particle production in pp and A-A collisions.

- GRID computing and software activities.

- Participation in the maintenance and operation tasks.

The ALICE detector (Run 2)

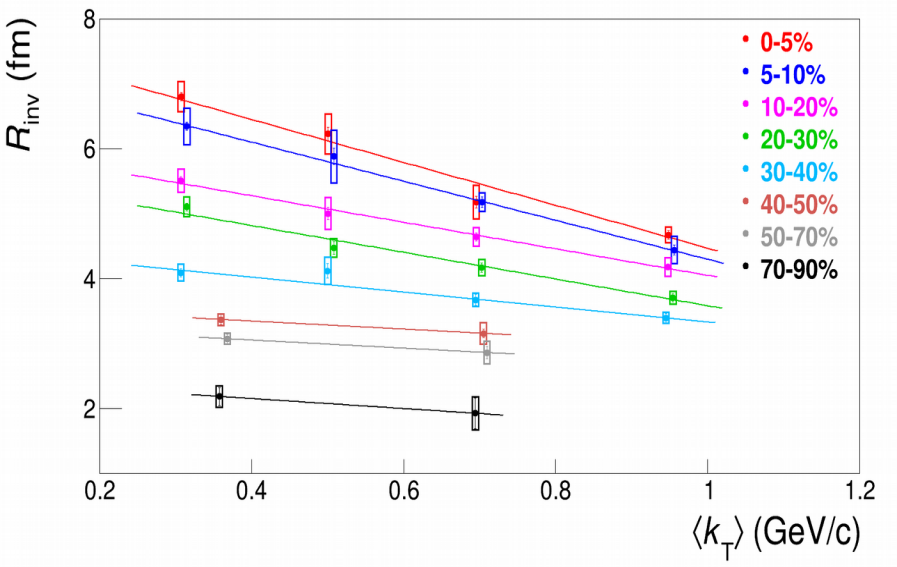
Central Barrel $|\eta| < 0.9$
- Tracking,
- PID
- EM-Calorimeters

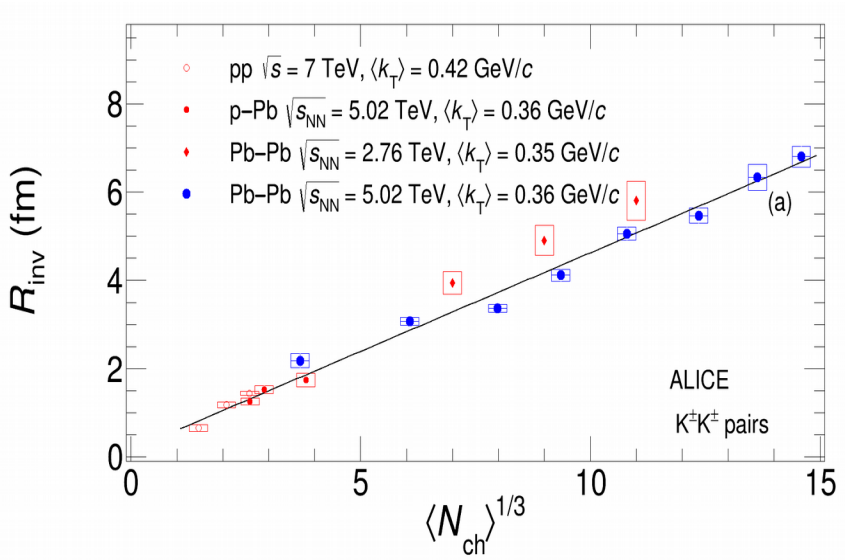


ACORDE (cosmics)

Forward detectors:
- AD (difraction selection)
- V0 (trigger, centrality)
- V0 (timing, lumi)
- ZDC (centrality, ev. sel.)
- FMD (N_{ch})
- PMD ($N\gamma$, *Nch*)

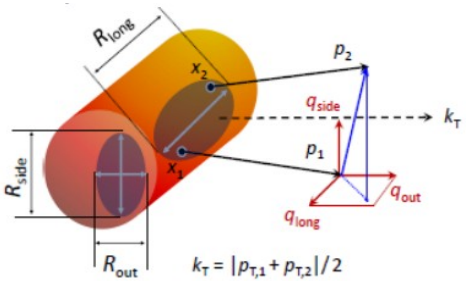
New results were obtained in 1-D femtoscopic correlation analysis for identical $K^{\pm}K^{\pm}$ pair production in Pb-Pb collisions at 5.02 TeV. The source radii (R_{inv}) were extracted from the fit of Correlation Functions by the Bowler-Sinyukov formula $C(q) = N[(1-\lambda) +\lambda K(q)(1+\exp(-R_{inv}^2 q^2))]$, $q=p_1-p_2$, λ – correlation strength, K(q) – Coulomb factor.





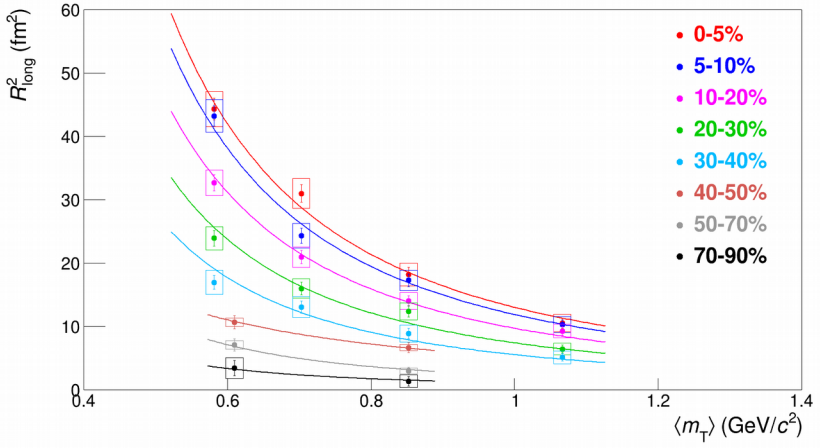
- **The known R_{inv} decrease with increase of transverse pair momentum (k_T) is seen in the left panel, but the slope of this dependence becomes very small in the most peripheral collisions with a weak influence of nuclear effects.**
- **Comparison of pp, p-Pb and Pb-Pb collisions shows (right panel) that R_{inv} values are very near at the same mean numbers of charged particles in the different collision types.**

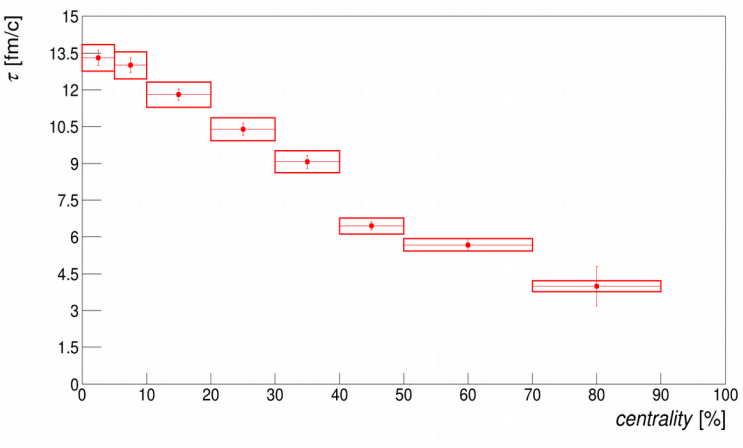
New results were obtained in 3-D femtoscopic correlation analysis for identical $K^{\pm}K^{\pm}$ pair production in Pb-Pb collisions at 5.02 TeV. The three radii (top right figure) were extracted from the fit of Correlation functions by the Bowler-Sinyukov formula



(long || beam).

$$C(\mathbf{q}) = N(1-\lambda) + N\lambda K(q)\left[1 + \exp\left(-R_{\text{out}}^2 q_{\text{out}}^2 - R_{\text{side}}^2 q_{\text{side}}^2 - R_{\text{long}}^2 q_{\text{long}}^2\right)\right]$$

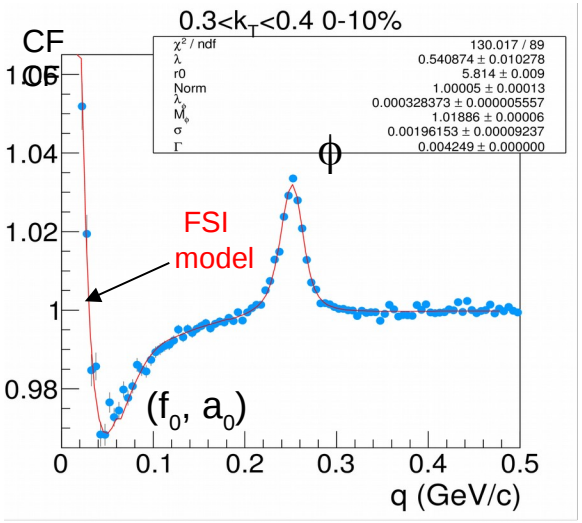


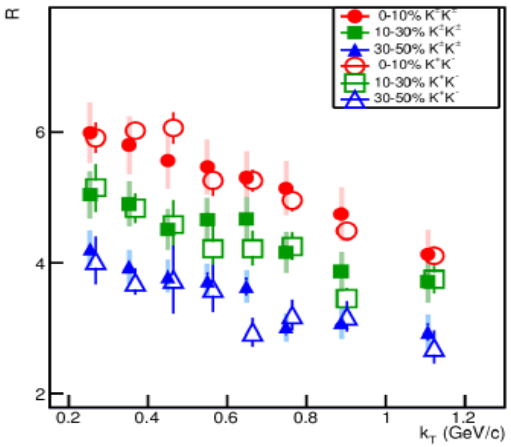


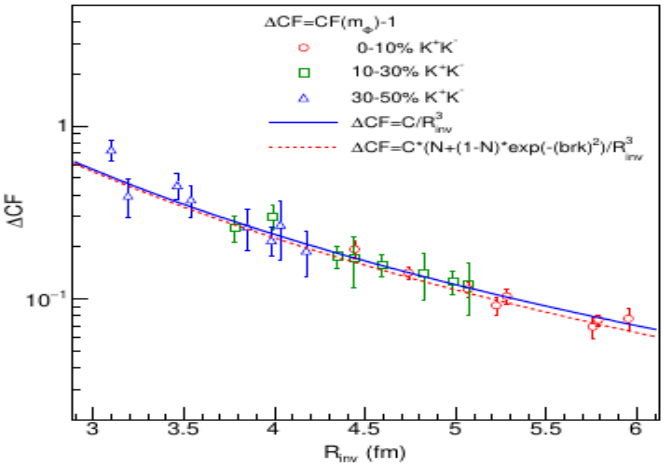
One can see again (the left panel) the very small slopes of the R_{long} dependence from mean $m_T = (m^2 + p_T^2)^{1/2}$ in the most peripheral collisions. Also **the first result** of the kaon emission time decrease for the more peripheral events (the right lower panel) was obtained using the theoretical prediction in the hydrokinetic approach.

The all results for 1-D and 3-D femtosscopy were presented in the ALICE Meeting (9.06.2021) by Gleb Romanenko and were included in his magister diploma of MSU (the supervisor is Ludmila Malinina, SINP MSU, JINR).

Final results were obtained for femtoscopic correlation analysis of nonidentical K^+K^- pairs in Pb-Pb collisions at 2.76 TeV (per nucleon pair).
The kaon emitting source radii were found by a comparison of Correlation Function (CF, left panel) with prediction of Final State Interaction (FSI) model (R.Lednicky and V.Lyuboshitz) I.







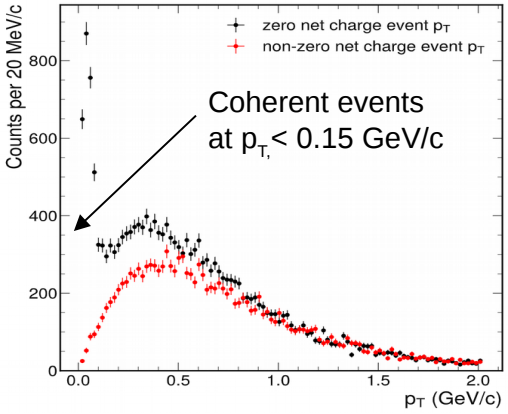
- Masses and widths of f_0, a_0 and ϕ mesons obtained from the fit (the left panel) close the ones from the PDG.

- The kaon emitting source radii (R_{inv}) versus transverse pair momentum (the middle panel) correspond the ones obtained in the analysis of identical charged kaons.

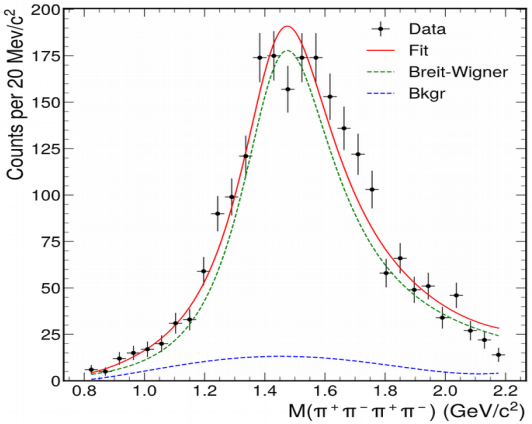
- Also the results in such an analysis was obtained for the estimation of the FSI fraction using a dependence of ϕ meson maximum (ΔCF) from the R_{inv} (right panel). From the comparison of the fit results obtained for the ϕ direct production and in the step of the FSI this fraction of 20-30% has been estimated.

- The all results were presented by Konstantin Mikhaylov (ITEP, JINR) and a paper draft was approved in the ALICE Physics Forum (21.04.2021) for the publication in Phys.Rev. C.

New (preliminary) results were obtained for the ρ^0 high mass state, J/ψ and ψ(2s) coherent photoproduction in Ultra-Peripheral Pb-Pb Collisions (UPC) at 5.02 TeV (per nucleon pairs) with net four charged particle production.

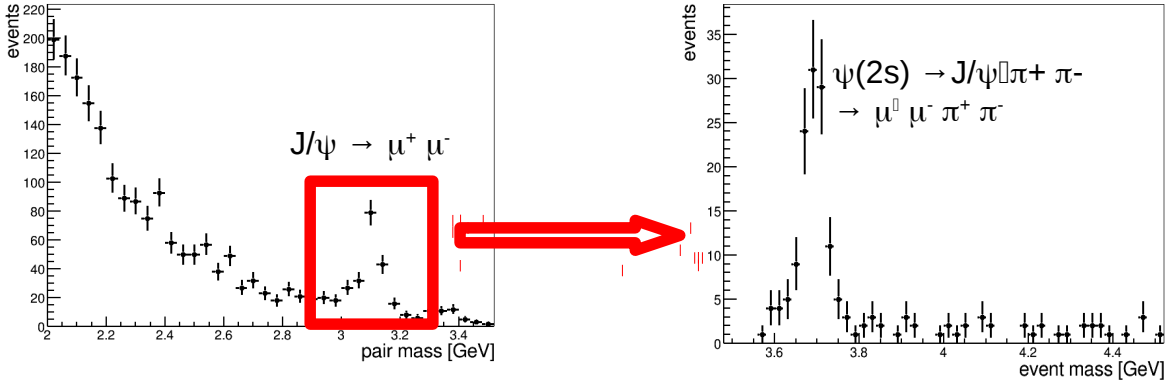


Transverse momentum of four pions



Fit result for the mass spectrum of four pions.

The mass and width values for ($\pi^+\pi^-\pi^+\pi^-$) state obtained from the fit (right top panel) were equaled to 1489± 11 MeV/c^2 and 405 ± 43 MeV/c^2 respectively. These values are consistent with the ones for ρ^0(1450) in the PDG (m = 1465 ± 25, Mev/c^2, Γ = 400 ± 60 MeV/c^2).



The four particle invariant masses were calculated for the events with any pair invariant masses in the range of J/ψ (left lower panel). The result is consistent with the mass of ψ(2s) state throw the decays to J/$\psi\pi^+\pi^-$ → $\mu^+\mu^-\pi^+\pi^-$ (right lower panel).

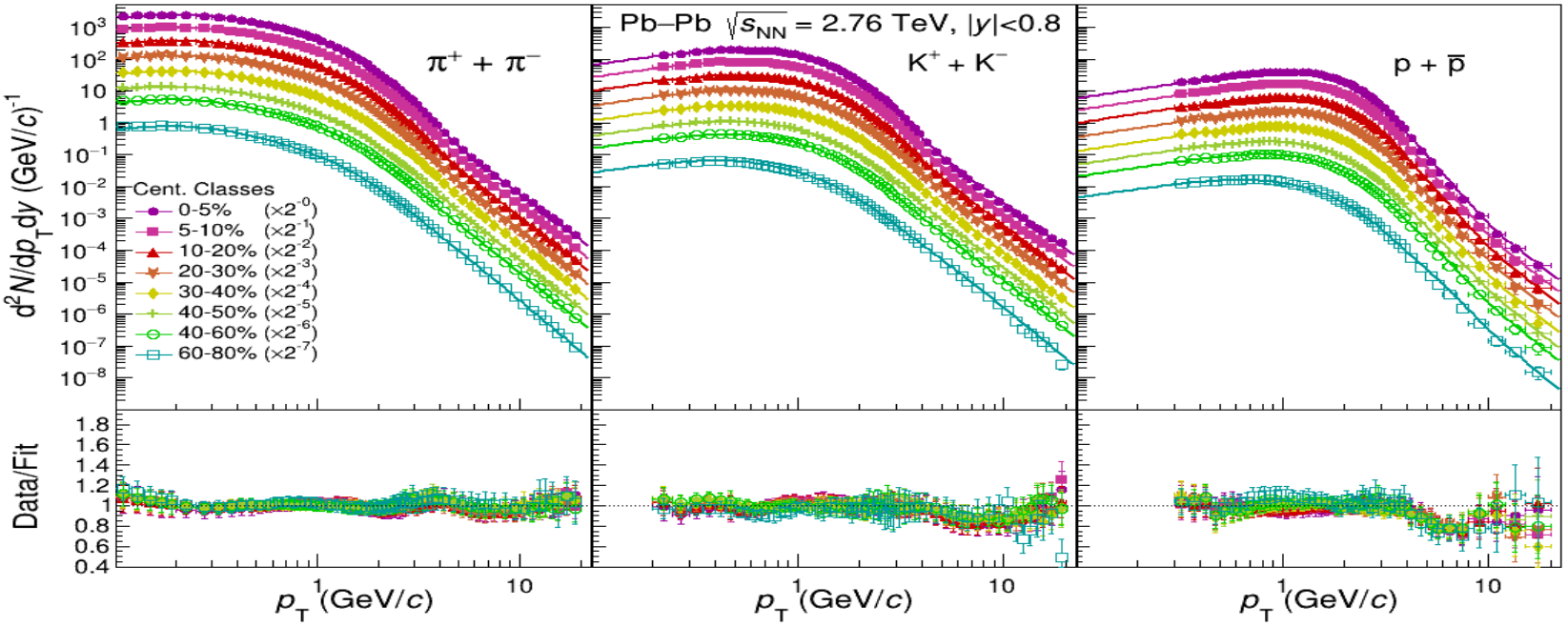
The results were presented in the ALICE Meetings by Boris Rumyantsev, PhD student (08.06.20210) and Valery Pozdnyakov (15.06.2021)..

The final results were obtained for Three-components model of particle production in pp and A-Acollisions at the LHC.

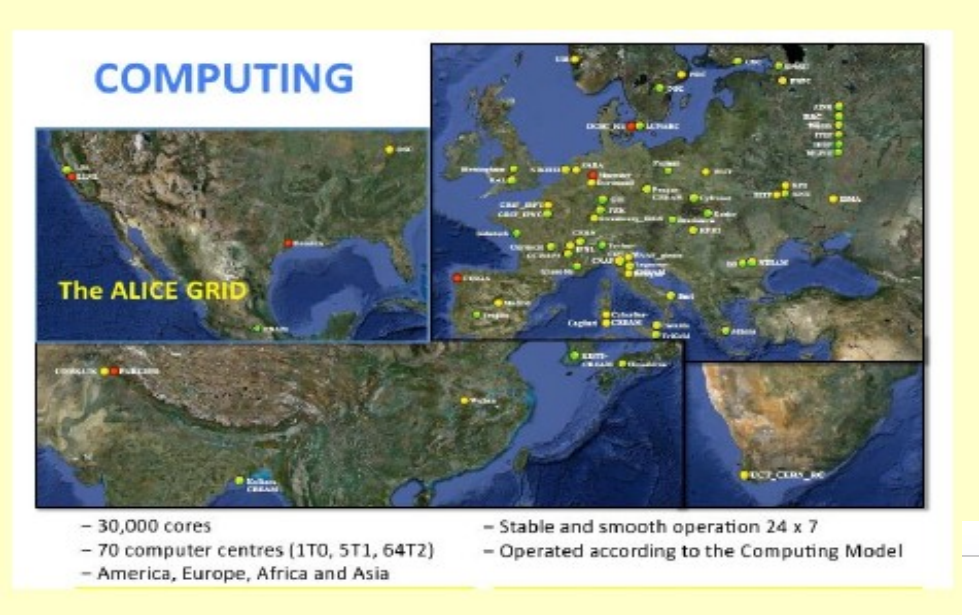
(Modification of the previous model version, S.Grigoryan, Phys Rev. D95 (2017) 056021)

The three components: the Boltzmann-Gibbs thermal distribution for flow effect, the Tsallis distribution for the resonance decays, the power-law form describes the QCD hard processes.

A good coincidence of the experimental and model results are obtained and shown, for example, for transverse momentum particle distributions at different centrality values in Pb-Pb collisions.

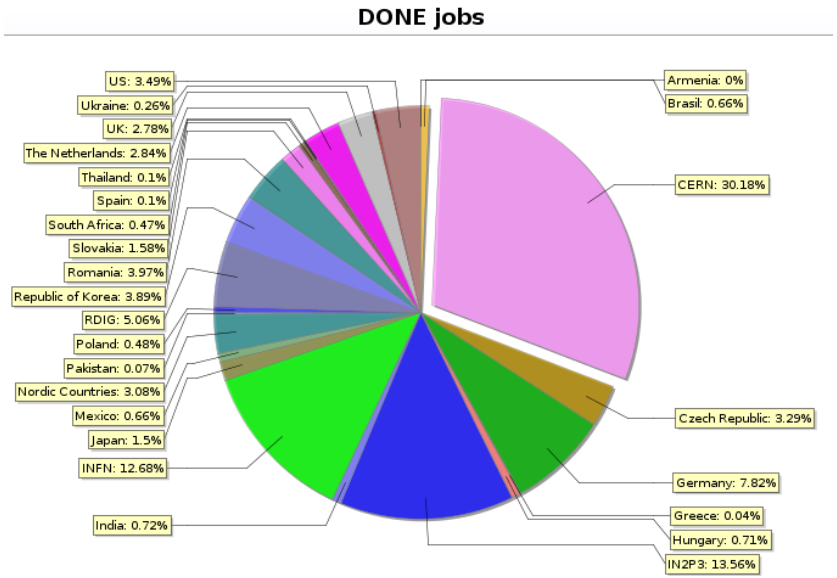


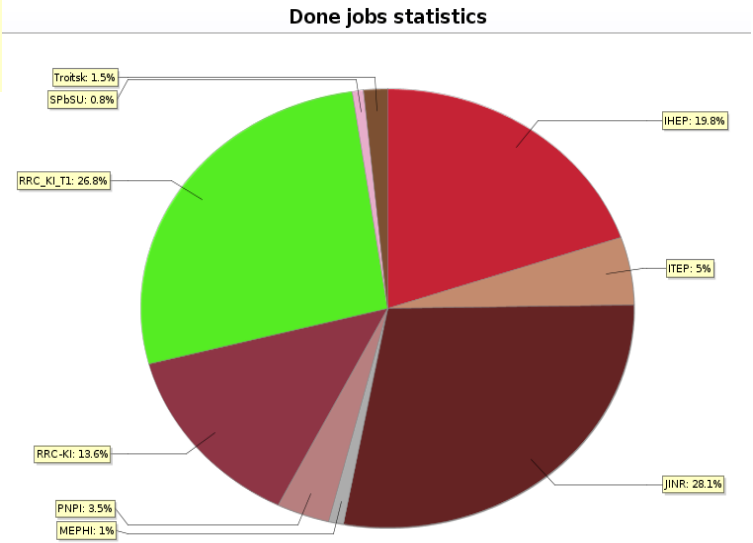
The report in the ALICE meeting and the publication is under preparation by Smbat Grigoryan.



The JINR ALICE GRID is going in the Frame of 9-th Russian ALICE GRID Centers (RDIG – Russian Data Intensive Grid).

The resource of JINR GRID Farm: 9600 cores CPU, 663 Tb Disk-SE.





JINR contribution to the RDIG-GRID is 28% (near 10^7 events per year).

RDIG contribution to the ALICE-GRID is 5.1%

Conference presentations .

1. E.Rogochaya, “Determination of the strong interactions for hyperon-nucleon pairs with ALICE”, The 55th Rencontres de Moriond «QCD & High Energy Interactions» 27th of March - 3rd of April, 2021.

2. V.Pozdnyakov, “Coherent photoproduction of ρ^0 vector mesons in ultra-peripheral Pb-Pb and Xe-Xe collisions with ALICE”, XXVII International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS-2021), Stony Brook University, Aprel 12-16, 2021.

ALICE publications with key contributions from the JINR group.

1. “Investigating the role of strangeness in barion-antibarion annihilation at LHC”, ALICE collaboration (S.Acharya et al.), arXiv:2105.05190, 2021.

2. “Kaon-proton srong interaction at low relative momentum via femtoscopy in Pb-Pb collisions at the LHC”, ALICE Collaboration (S.Acharya et al), arXiv:2105.05683, 2021.

3. “First measurement of coherent ρ^0 photoproduction in ultra-peripheral Xe-Xe collisions at $(s_{NN})^{1/2}$ = 5.44 TeV ”, ALICE Collaboration, (S.Acharya et al), arXiv:2101.02581, 2021.

Other scientific activities.

- Elena Rogochaya is the ALICE convener of Femtoscopy Analysis Team up to end of 2022 year.
- Participation of K. Mikhaylov (chair person) and E. Rogochaya in the Internal Review Committees (IRC) for the different ALICE publications.
- JINR Institute review for one of the ALICE publication.
- Participation in the ALICE-ITS-Upgrade shifts.

Conclusions

– The JINR ALICE team carries out successfully the physical analysis of the experimental data for the Femtoscopic Correlations and the Ultra-Peripheral Collisions and for Three component theoretical model.

– All analysis results were reported in the ALICE Meetings and the finished ones were prepared for publications in the Periodical Journals.

– JINR ALICE GRID site continues to provide a stable operation and steady Capacity growth.

JINR plans for the 2021-2022 years.

– Finish the paper for femtoscopic analysys for $K^{+}K^{-}$ pairs in Pb-Pb collisions at 2.76 TeV.

– Go on 1D and 3-D femtoscopic analysis for $K^{ch}K^{ch}$ pairs in Pb-Pb collisions at 5.02 TeV .

– Carry out 1-D femtoscopic analysis for identical charged pion and kaon pairs in the p-p Collisions at 13 TeV with the event sphericity selection.

– Carry out 3-D femtoscopic analysis for $K^{ch}K^{ch}$ in p-Pb collisions at 5.02 TeV.

– Go on the analysis of vector meson photo-productions in the Ultra-Peripheral Pb-Pb collisions at 5.02 TeV.

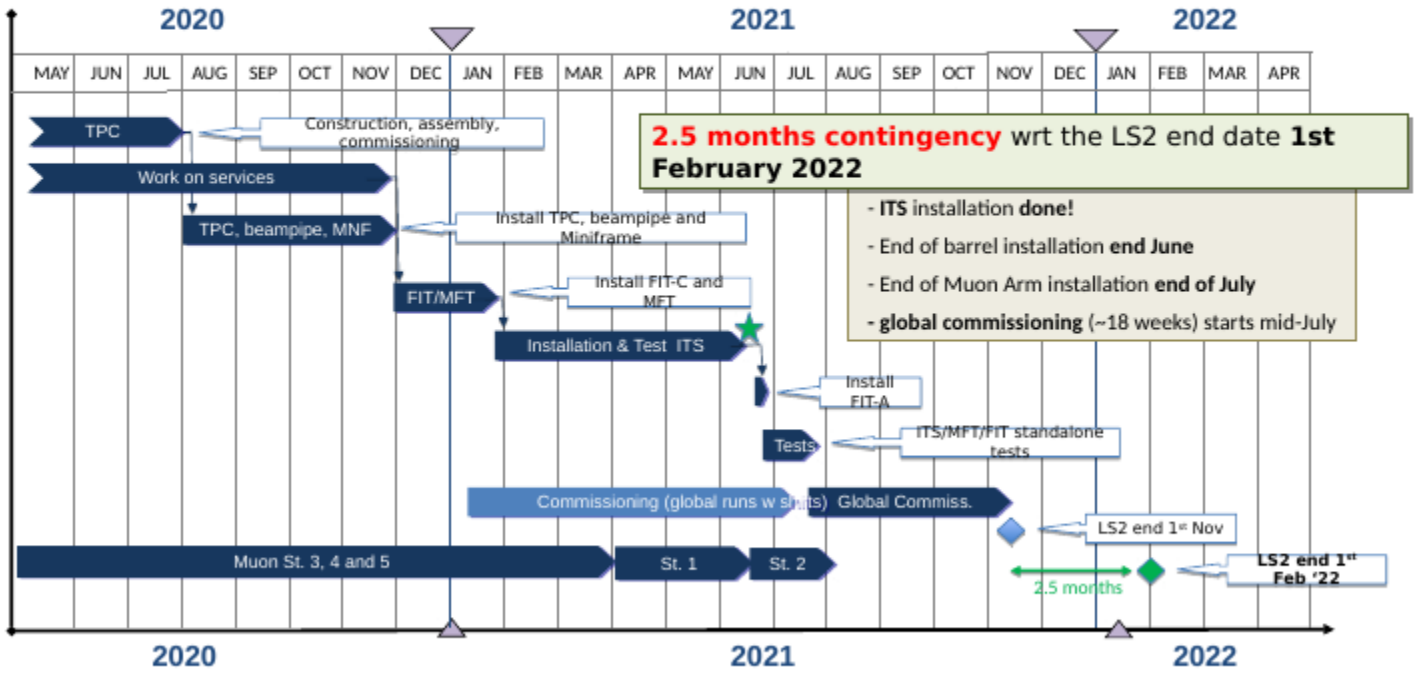
– Preparation of the publication for the Thermal Model of particle production in pp and A-A collisions.

– ALICE GRID support in the JINR computing system.

– Participation in the ALICE shifts and service tasks.

A Large Ion Collider Experiment

ALICE LS2 Schedule



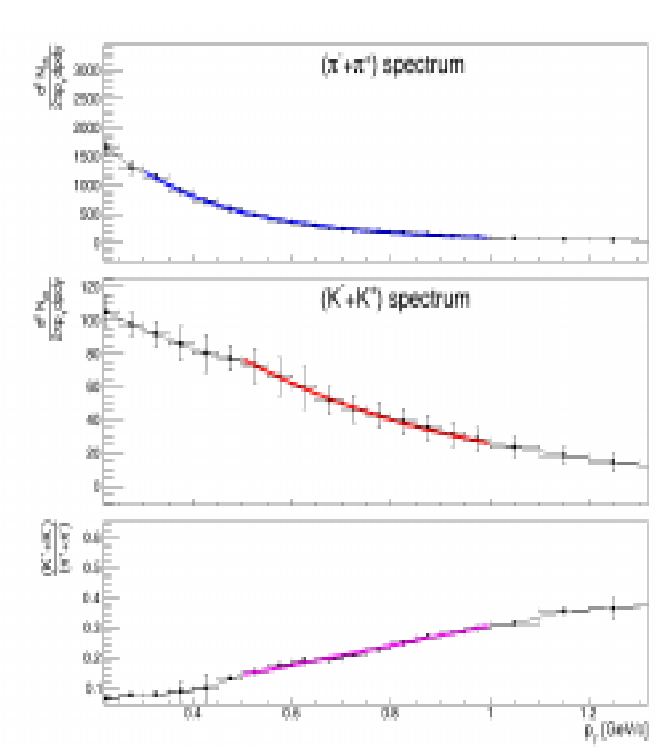
Thank you for your attention

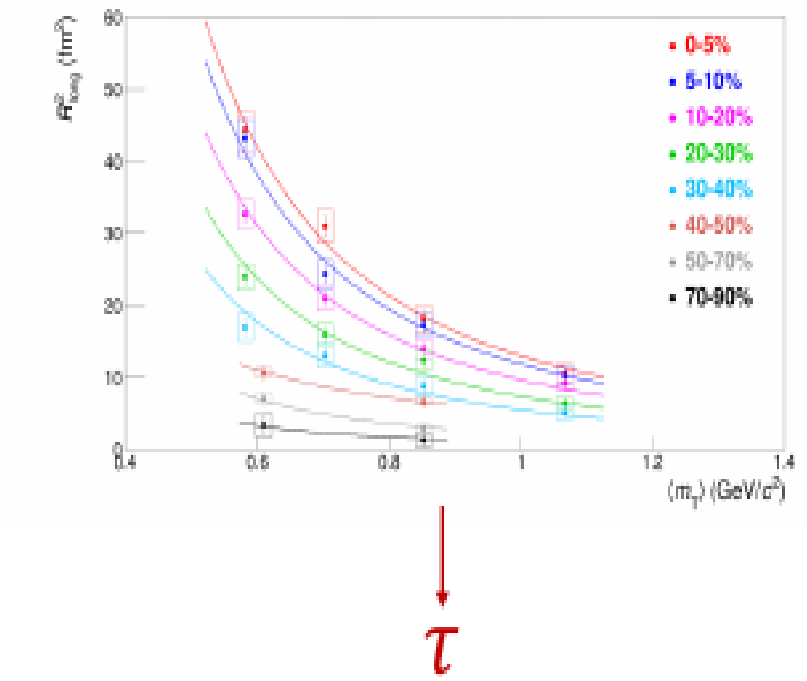
Backup

Results: extracting emission time

$$\frac{d^2N}{2\pi p_T dp_T dy} \propto exp\left[-\left(\frac{m_T}{T}+\alpha\right)\sqrt{1-\bar{v}_T^2}\right] \longrightarrow \text{T} \longrightarrow R^2_{long}(m_T) = \tau^2\lambda^2\left(1+\frac{3}{2}\lambda^2\right)$$

$$\bar{v}_T = \frac{k_T}{m_T + \alpha T} \qquad \lambda^2 = \frac{T}{m_T}\sqrt{1-\bar{v}_T^2}$$





τ

15

K+K- theoretical correlation function (formalism) I

[R.Lednicky,V.Lyuboshitz Sov. J. Nucl. Phys. 35, 770 (1982), R.Lednicky Phys. Part. Nucl.40, pp.307(2009)]

The K+K- correlation function at given **k*** and 3-momentum **P** as

$$C_{sFSI}(\mathbf{k}^*,\mathbf{P}) = \int \mathrm{d}^3\mathbf{r}^* S^{\alpha}(\mathbf{r}^*,\mathbf{P}) \sum_{\alpha'} \left|\psi^{\alpha'\alpha}_{-\mathbf{k}^*}(\mathbf{r}^*)\right|^2$$

where α means K^+K^- and summing over intermediate channels α'=K^+K^-,K^0K^0

Assume a spherically symmetric Gaussian distribution of the particle emitter spatial separation **r*** in the PRF with size R

$$S(\mathbf{r}^*) \sim exp(-\mathbf{r}^{*2}/4R^2)$$

A stationary solution of the scattering problem at large distances has the asymptotic form of a superposition of a plane wave and an outgoing spherical wave:

$$\Psi^{-}_{-\vec{k}^*}(\vec{r}^*) = e^{-i\vec{k}^*\vec{r}^*} + f(\vec{k}^*)\frac{e^{ik^*r^*}}{r^*}$$

The s-wave K+ K− scattering amplitude *f(k*)* is dominated by the near threshold s-wave isoscalar f_0 (980) and isovector a_0 (980) resonances characterized by their masses and respective couplings.

$$f(k^*) = \frac{[f_0(k^*)+f_1(k^*)]}{2}$$

Total amplitude could be written as: , where amplitude for *I=0* and *I=1*:

$$f_0(k^*) = \frac{\gamma_{f_0\to K+K-}}{m^2_{f_0} - s - i(\gamma_{f_0\to K+K-}k^* + \gamma_{f_0\to\pi\pi}k_{\pi\pi})} \quad \text{and} \quad f_1(k^*) = \frac{\gamma_{a_0\to K+K-}}{m^2_{a_0} - s - i(\gamma_{a_0\to K+K-}k^* + \gamma_{a_0\to\pi\eta}k_{\pi\eta})}$$

where $s = 4(m_K^2 + k^{*2})$, m_{a0} , m_{f0} are the masses of the a0 and f0 and $k_{\pi\eta}$, $k_{\pi\pi}$ the momenta in the secondary de

The general form of the strong FSI part (the s-wave scattering only) of the K+K- correlation function is:

$$C(q) = 1 + \lambda\left[\frac{1}{2}\left|\frac{f(q/2)}{R}\right|^2 + \frac{2\Re f(q/2)}{\sqrt{\pi}R}F_1(qR) - \frac{\Im f(q/2)}{R}F_2(qR)\right]$$

$$F_1(z) \equiv \int_0^z dx \frac{e^{x^2-z^2}}{z}, \quad F_2(z) \equiv \frac{1-e^{-z^2}}{z}$$

K+K- theoretical correlation function (formalism) II

The wave function of K+K− with the Coulomb interaction may be written (see Appendix in Sov. J. Nucl. Phys. 35, 770 (1982)) :

$$\Psi_{-\vec{k}^*}(\vec{r}^*) = \sqrt{Ac(\eta)}e^{\delta_c}\left[e^{-i\vec{k}^*\vec{r}^*/2}F(-i\eta,1,i\xi) + f_c(k^*)\frac{\tilde{G}(\rho,\eta)}{|\vec{r}^*|}\right]$$

where A_c is Gamov factor $A_c = 2\pi\eta[exp(2\pi\eta - 1)]^{-1}$, $\eta = 1/(k^* a_c)$, $a_c = 1/(\mu z_1 z_2 e^2)$ Bohr radius

The corresponding effective amplitude (renormalized by Coulomb interaction):

$$f_c(k^*) = \left[\frac{1}{f} - ik^* A_c(\eta) - \frac{2}{a_c}h(\eta)\right]^{-1}$$

The p-wave strong interaction through Φ meson resonance [R.Lednicky Part. Nucl. Letters 8(2011)965]:

$$C_\phi(p_1,p_2) = N^{-1}(p_1,p_2)\int d^3\mathbf{r}W_P(\mathbf{r},\mathbf{k})\sum_{\alpha' m'}|\psi_{-\mathrm{k}}^{\alpha' m';\alpha}(\mathbf{r})|^2$$

The emission function with possible position-momentum (***rk***) correlation:

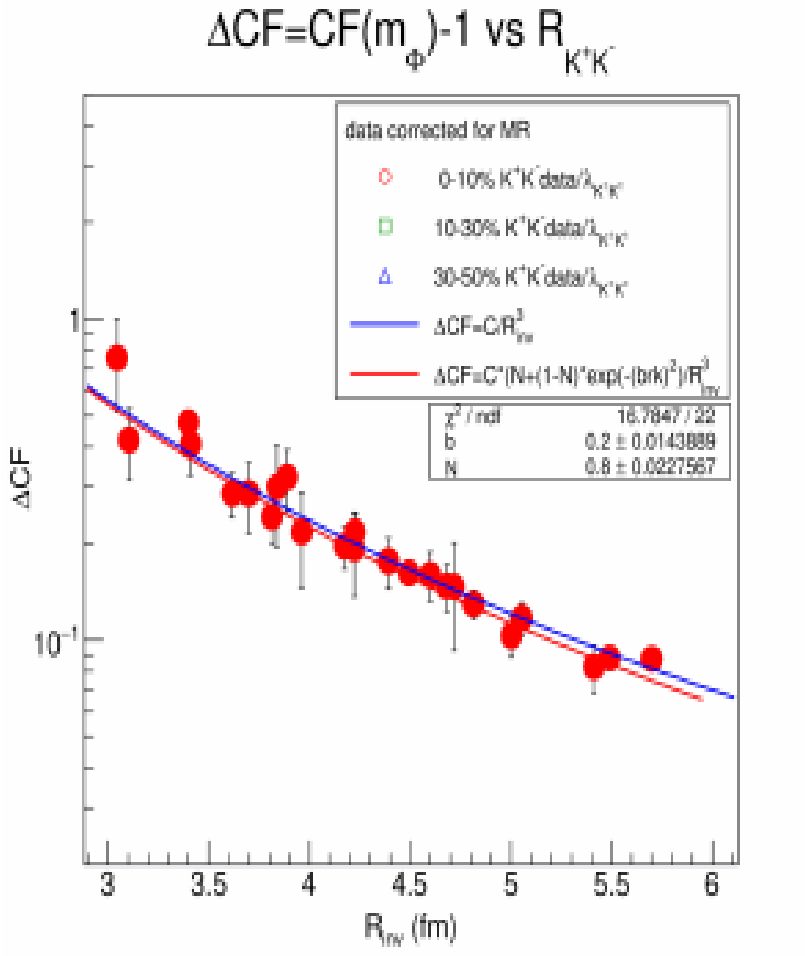
$$W_P(\mathbf{r},\mathbf{k}) = exp\left(-\frac{r^2}{4R^2} + b\mathbf{rk}\right) \qquad N(p_1,p_2) = 8\pi^{3/2}R^3 exp(b^2k^2R^2) \qquad N(p_1,p_2) = \int d^3\mathbf{r}W_P(\mathbf{r},\mathbf{k})$$

The height of CF at Φ meson peak position ΔCF ≈ 1/R³

The total correlation function is defined as a sum : $C_{FSI}(p_1,p_2) = 1 + C_{sFSI}(p_1,p_2) + N_1 C_{\Phi\text{-}direct}(p_1,p_2) + N_2 C_\Phi(p_1,p_2)$,

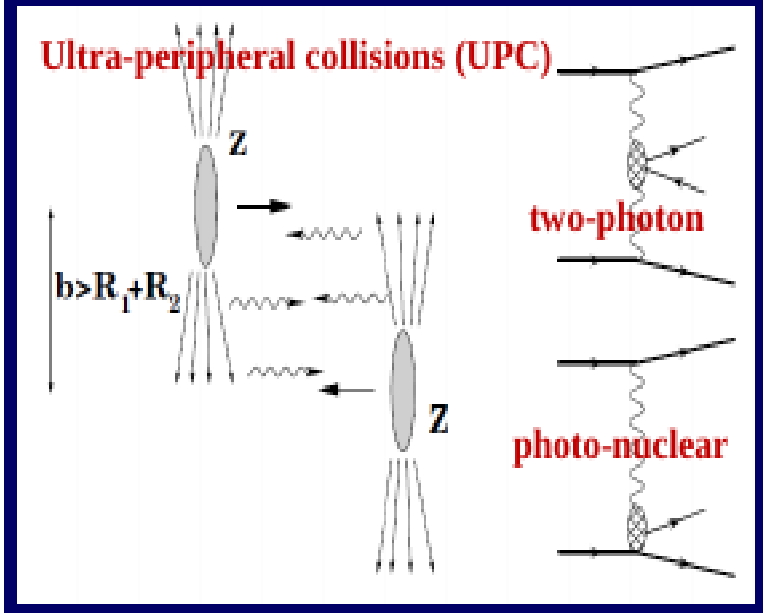
$C_{\Phi\text{-}direct}(p_1,p_2)$ is a non-relativistic Breit-Wigner function.

Direct + FSI



- Let's assume that ϕ direct production corresponds to $1/R^3$ dependence
- And FSI ϕ production corresponds to $C \cdot \exp(-\mathbf{b}^2 k_0^2 R^2)/R^3$
- Then total yield could be written as: $\Delta CF = C[N+(1-N)\exp(-\mathbf{b}^2 k_0^2 R^2)]/R^3$ (1)
- Plot shows the same data(for all centralities and kT's)
- Blue curve shows the data fit by C/R^3
- Red curve shows fit by the formula above for total yield parameters are limited $0.2<b<0.4$ and $N<0.8$ (limit for models: Lednicky and iHKM Sinyukov)
- It can be seen that the fit (Eq.1) does not differ much from C/R^3
- All of the above could indicate the absence of a significant contribution from FSI to the phi meson production

Ultra-peripheral Collisions (UPC) of heavy ions



The LHC in heavy-ion mode → powerful source of quasi-real photons with intensity ~Z^2.

Photon → a vector meson (VM) → scatters off target either coherently off whole nucleus (VM p_T ~30 MeV/c) or incoherently off nucleons (VM p_T~300 MeV/c)