

Towards a common particle-emitting source in HM pp at 13 TeV for mesons and baryons with ALICE



Maximilian Korwieser (TUM) on behalf of the ALICE Collaboration
MESON 2023 Kraków 22.-27. June 2023
24/06/23 Parallel Session A5 15:25 - 15:45

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- Study final-state interactions of exotic pairs
- Needs **precise** understanding of the source

- Access final state interactions
 - Complementary to scatterings experiments
 - Access interaction between short-lived particles

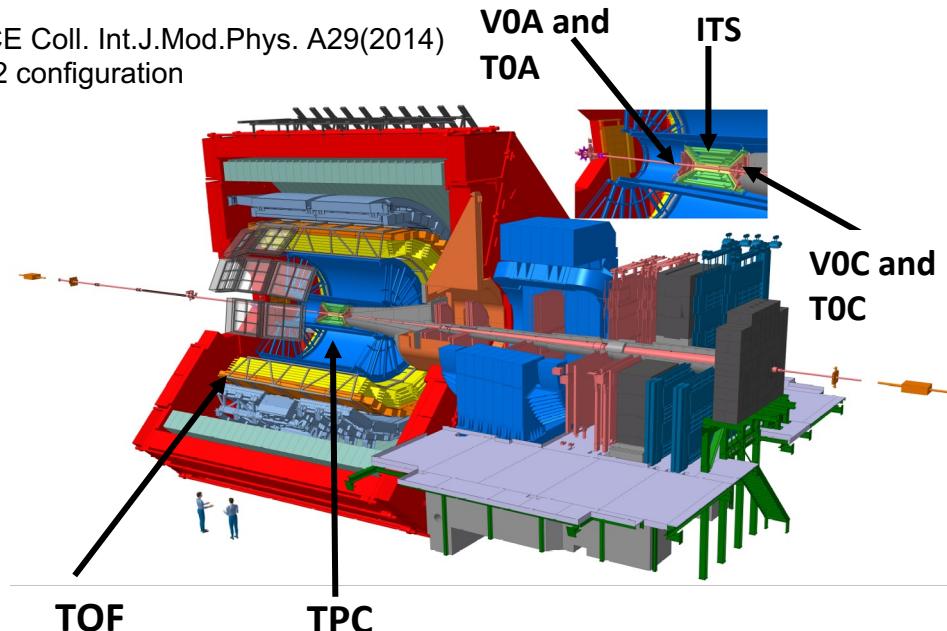
→ Valentina Mantovani Sarti (C5):
“Accessing the strong interaction between Λ baryons and kaons with femtoscopy at LHC”

→ Wioleta Rzesa (C5):
“A study of K^-d and K^+d interactions via femtoscopy technique”

- Enables theory comparisons
 - Tests of LQCD
 - χ EFT

→ Albert Feijoo (C5):
“Correlation Function constraints on $S=2$ meson–baryon interaction from UChPT.”

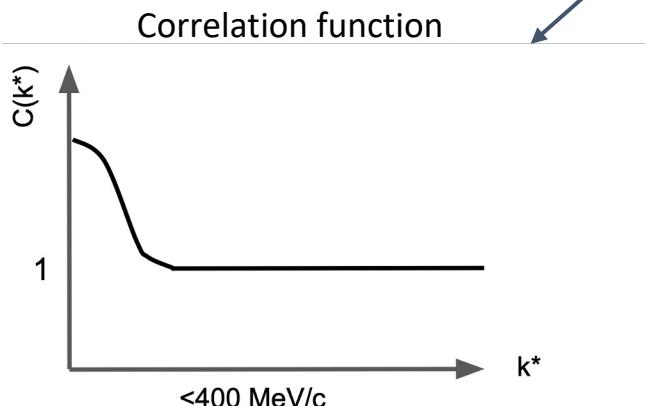
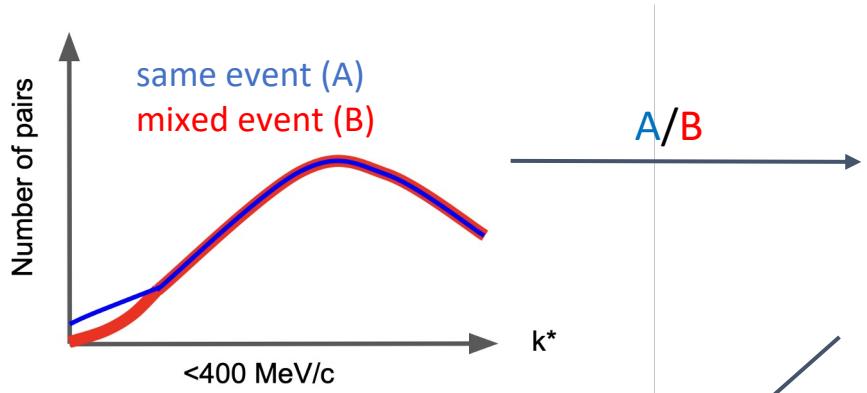
ALICE Coll. Int.J.Mod.Phys. A29(2014)
Run2 configuration



- Direct detection of charged particles (π , K, p) by TPC and TOF
- Purity of about 99 % for π , K, p due to excellent PID capabilities

- HM pp collisions @ 13 TeV
 - Particles produced with relative distances of $O(1 \text{ fm})$
 - 1 Billion events in Run2
- Analyses so far...
ALICE Collaboration
PRC 99 (2019) 2, 024001
PLB 797 (2019), 134822
PRL 123 (2019), 112002
PLB 805 (2020), 135419
PLB 811 (2020), 135849
Nature 588 (2020) 232-238
PRL 127 (2021), 172301
PLB 833 (2022), 137272
PLB 829 (2022), 137060
PRD 106 (2022) 5, 052010
PLB (2022), 137223

M. Lisa et. al. Ann.Rev.Nucl.Part.Sci.55:357-402, 2005

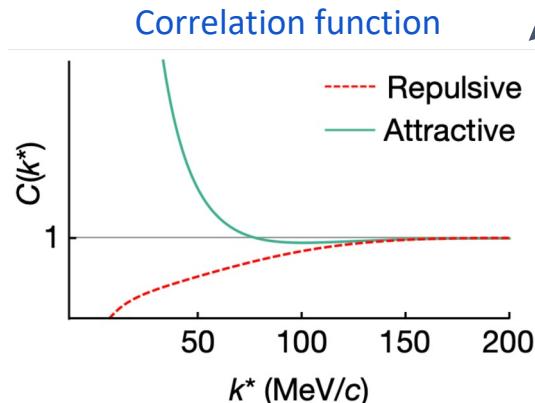
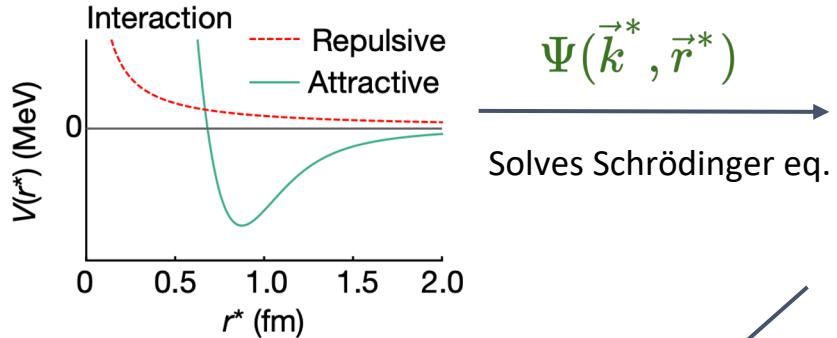


Experiment

$$C(k^*) = \frac{P(\vec{p}_1, \vec{p}_2)}{P(\vec{p}_1)P(\vec{p}_2)} = \mathcal{N} \frac{A(k^*)}{B(k^*)}$$

- Obtain pairs form
 - correlated sample (A): pairs from the *same* event
 - uncorrelated sample (B): pairs from *different* events
- Understand data
 - purity, feed-down
 - background?
 - ...

[M. Lisa et. al. Ann.Rev.Nucl.Part.Sci.55:357-402, 2005](#)



Theory

$$C(k^*) = \int S(r^*) |\Psi(\vec{k}^*, \vec{r}^*)|^2 d^3 r^*$$

- Model $S(r^*)$
 - Gaussian, Exponential, ...
 - Resonances?
- Calculate $\psi(r^*, k^*)$
 - QS, Coulomb, χ EFT, ...
- Evaluation:
CATS framework [1]

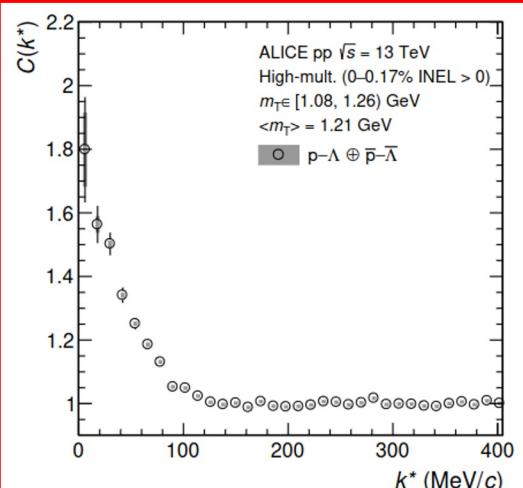
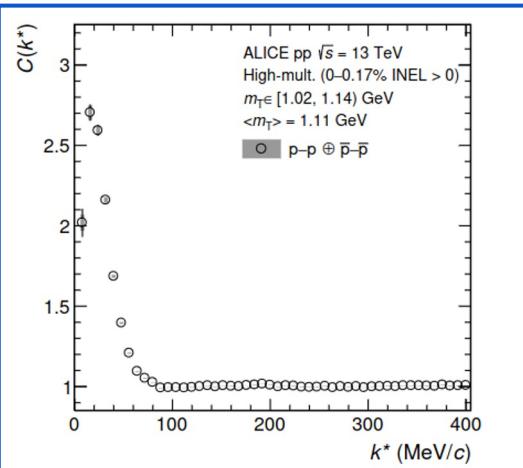
[1] D. Mihaylov et al. EPJC78(2018) 394

- Common source for all produced baryons in small collision systems?
- Use p-p (well known interaction) to constrain the femtoscopic source
- Validate findings with p- Λ

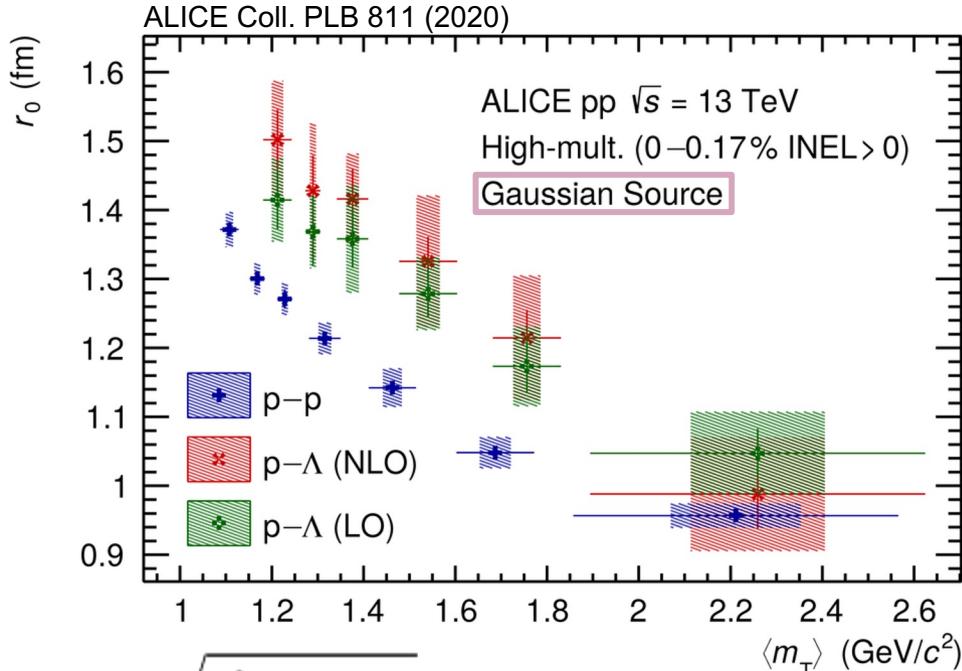
$$m_T = \sqrt{k_T^2 + m_{\text{avg}}^2}$$

$$k_T = \frac{1}{2} |\vec{p}_{T,1} + \vec{p}_{T,2}|$$

ALICE public note PUB-1378 (2023)



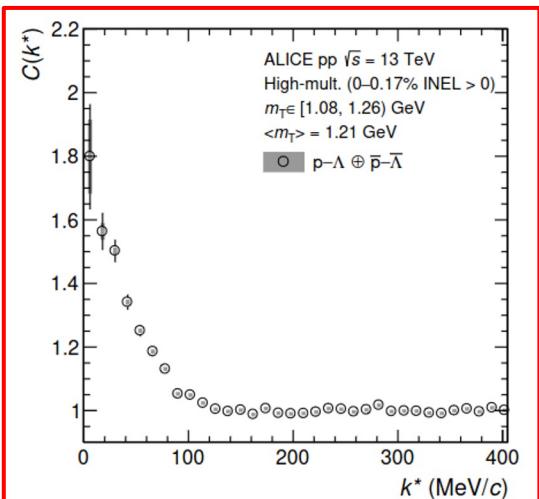
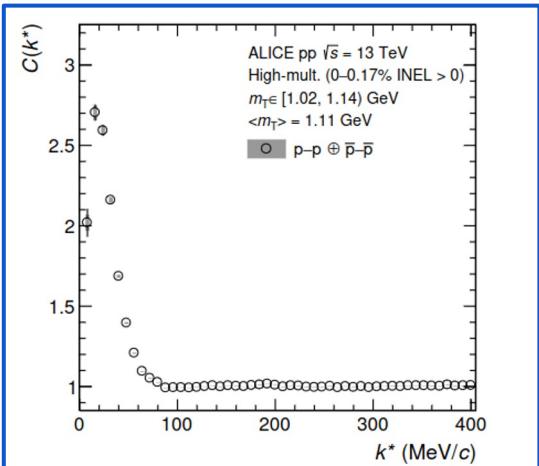
Baryon source in HM pp 13 TeV

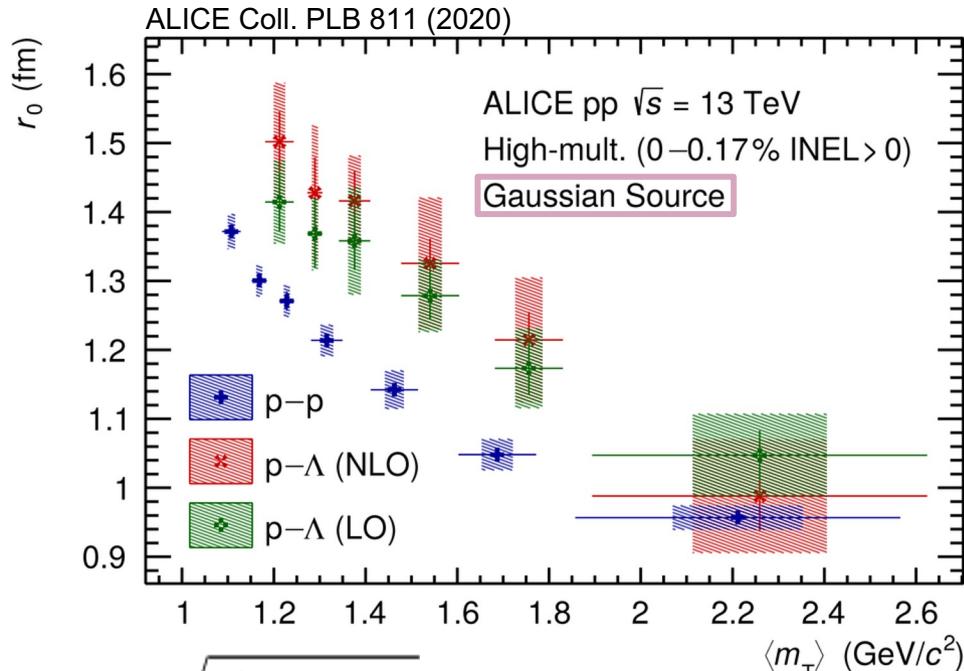


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ALICE public note PUB-1378 (2023)

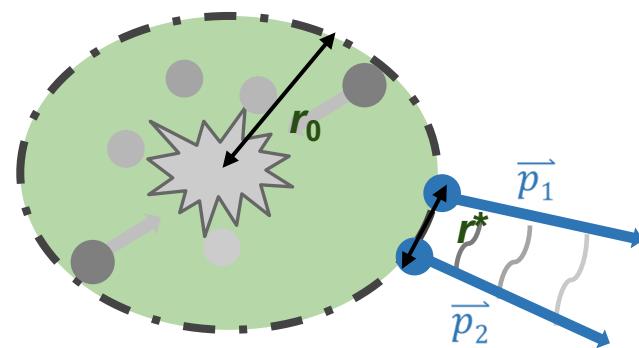


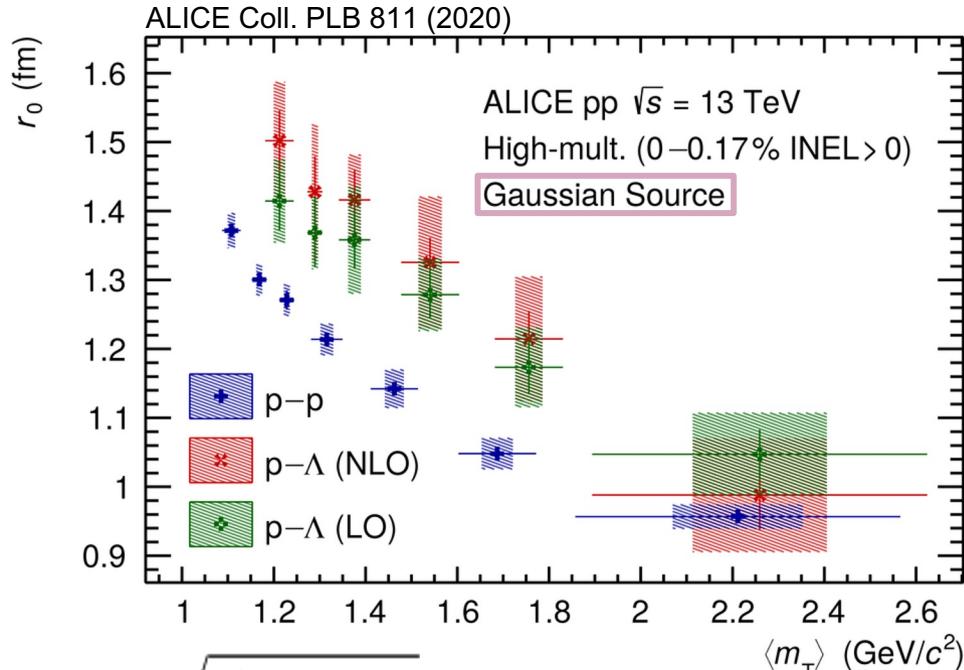


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- Scaling is expected for common radial flow velocity and hadronization time scale





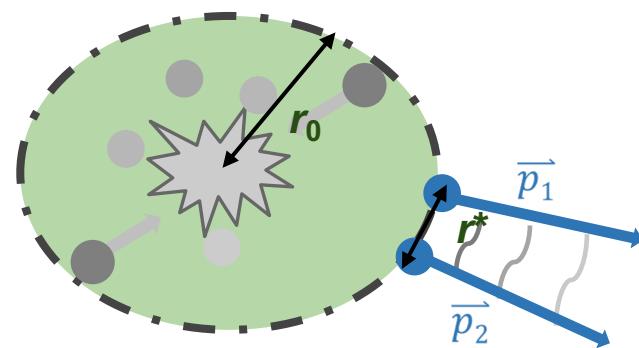
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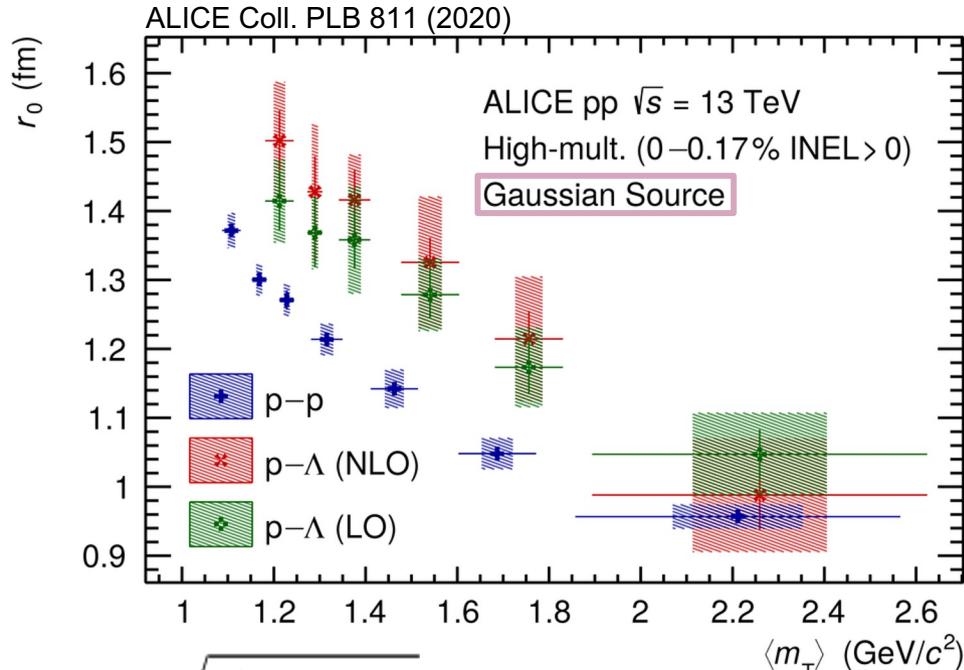
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- [1] Y. Sinyukov et al. NPA 946 (2016)
[2] A. Widemann et al. PRC 865 56 (1997)

- Scaling is expected for common radial flow velocity and hadronization time scale
- Effects influencing the scaling include **non-gaussian** contributions to the source

- Feed down from resonances [1,2]



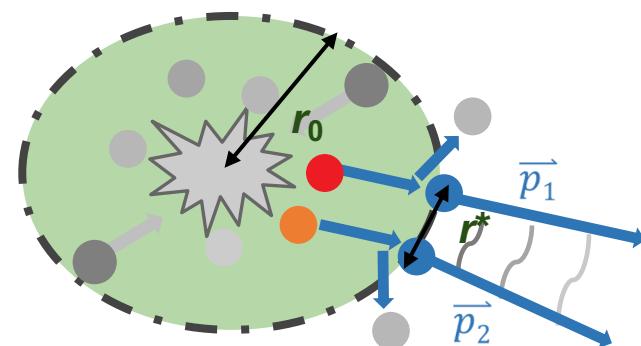


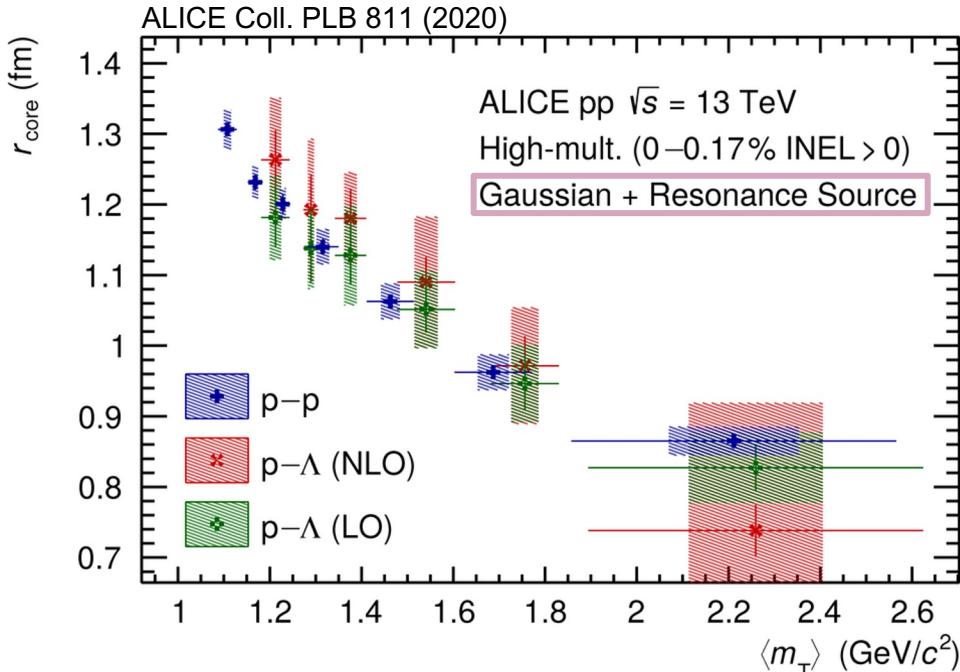
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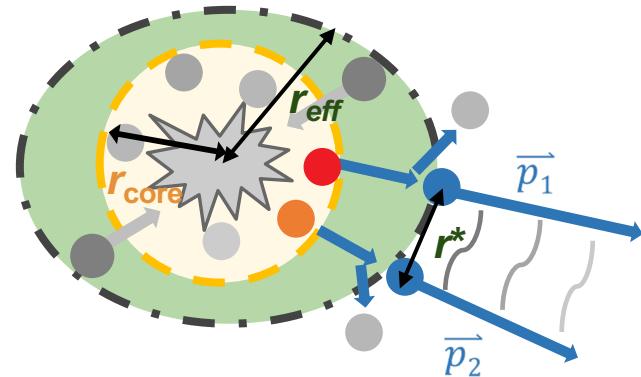
[1] Y. Sinyukov et al. NPA 946 (2016)
[2] A. Widemann et al. PRC 865 56 (1997)



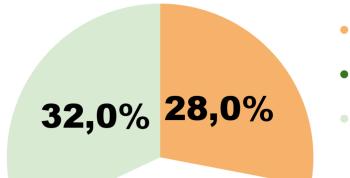


Access smaller m_T by studying π - π and meson-baryon correlations with K⁺-p

- Common scaling is restored by accounting for **non-gaussian** contributions
 - Motivates the assumption of a universal particle source for baryons
- How well does the source resonance model (RSM) perform for mesons?
Is the scaling different?

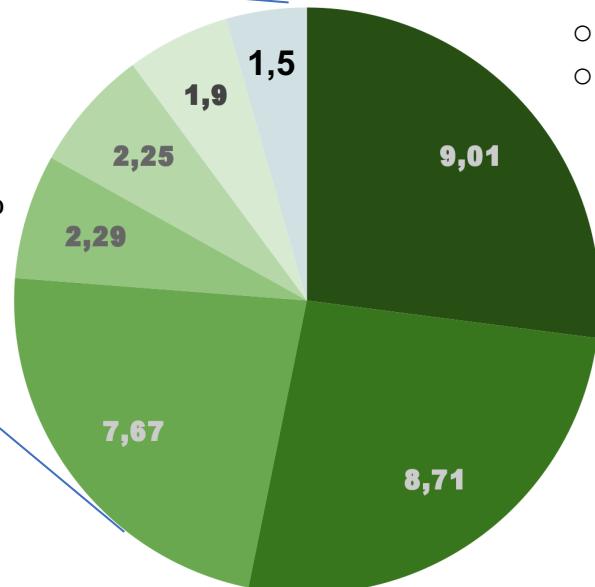


Pion composition (TF)



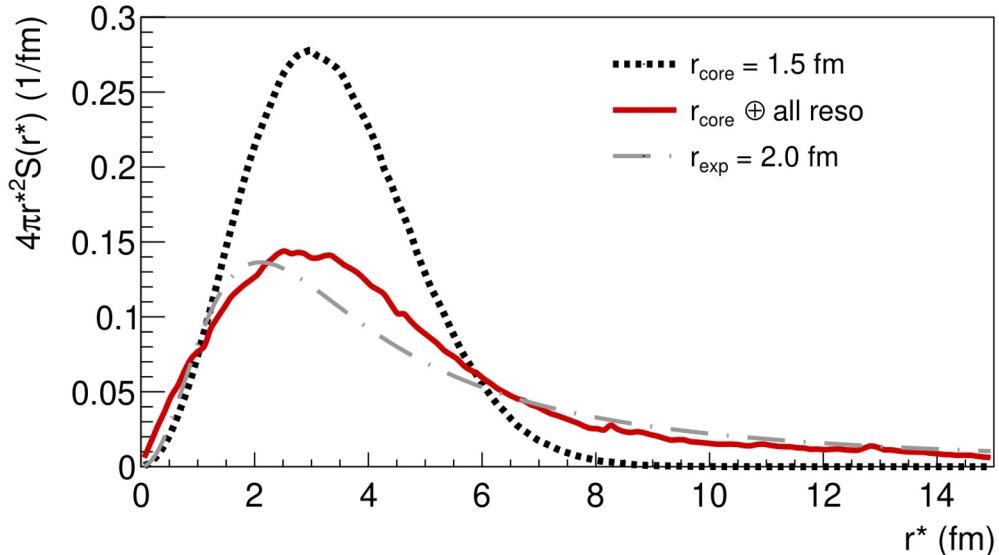
- Primordial
- Resonances $f > 1\%$
- Resonances $f < 1\%$

- Resonances $f > 1\%$
- ρ^0
 - ρ^+
 - $\omega(782)$
 - $K^*(892)^+$
 - $K^*(892)^0$
 - $b_1(1235)^+$
 - $a_2(1320)^+$



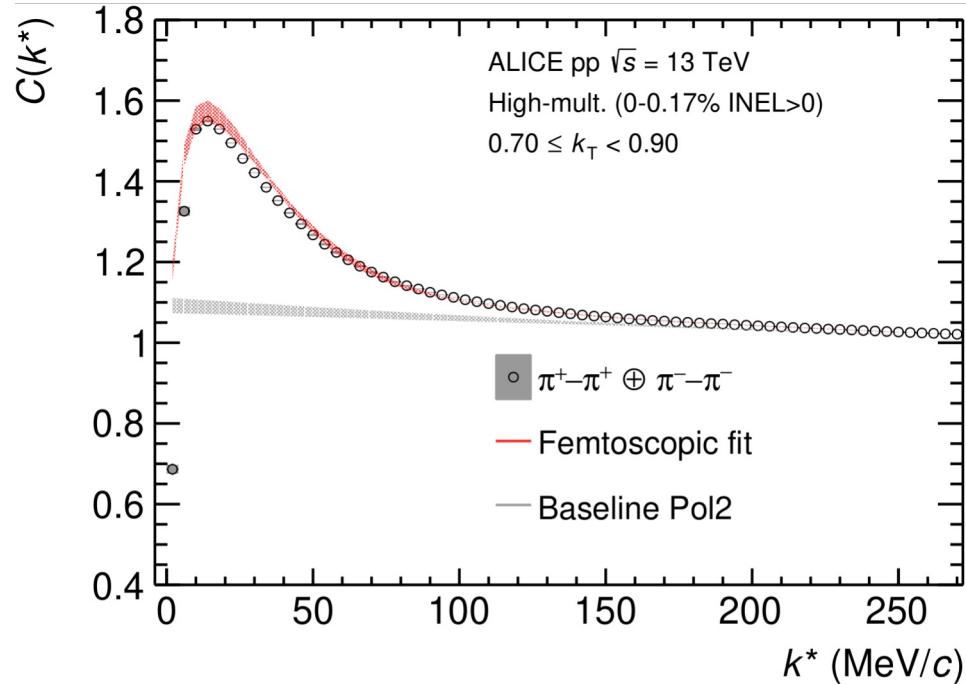
- Calculation carried out with Thermal-FIST [1,2]
 - Use statistical hadronization model [3]
 - **28 %** primordial, **72 %** resonances
- Summary parameters for RSM
 - $m_{\text{eff}} = 1124 \text{ GeV}/c^2$
 - $c\tau_{\text{eff}} = 1.5 \text{ fm}$

- [1] V. Vovchenko et al. PRC 100834 (2019)
[2] V. Vovchenko et al. CPC 100 (2019)
[3] F. Becattini Z. Phys. C 76 (1997)

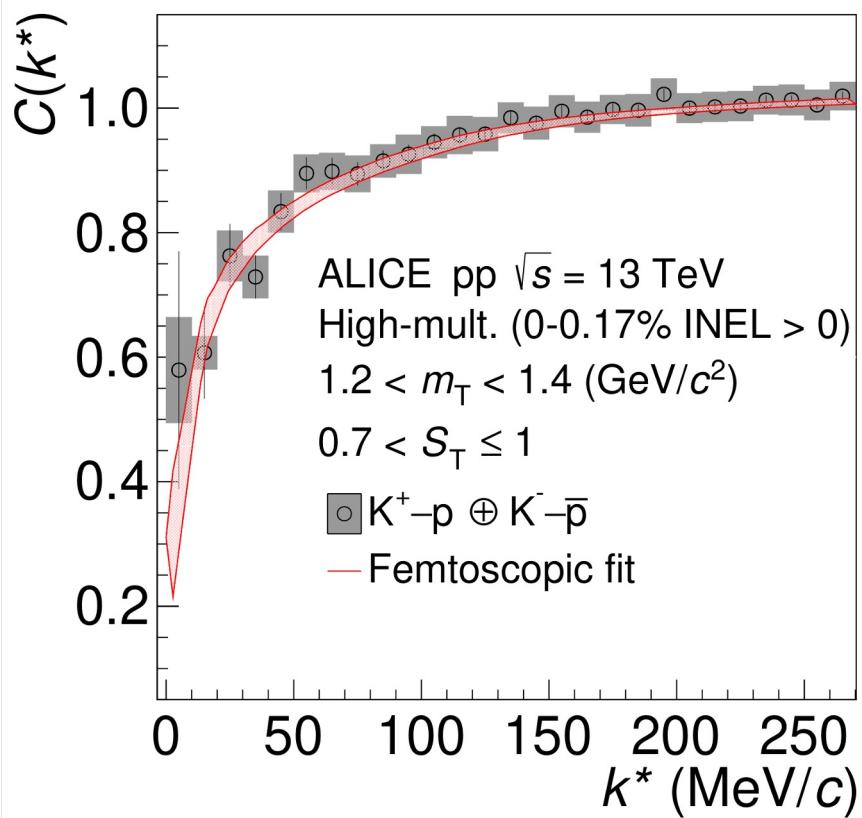


[1] D. Mihaylov et al. EPJC 78 (2018)

- Example calculation using CATS [1]
- Comparison of exponential source with RSM
 - Exponential mimics RSM
 - Obtained radii differ
 - RSM provides quantitative insight of resonance contributions
- Resonances explain previous findings of exponential type source for $\pi-\pi$



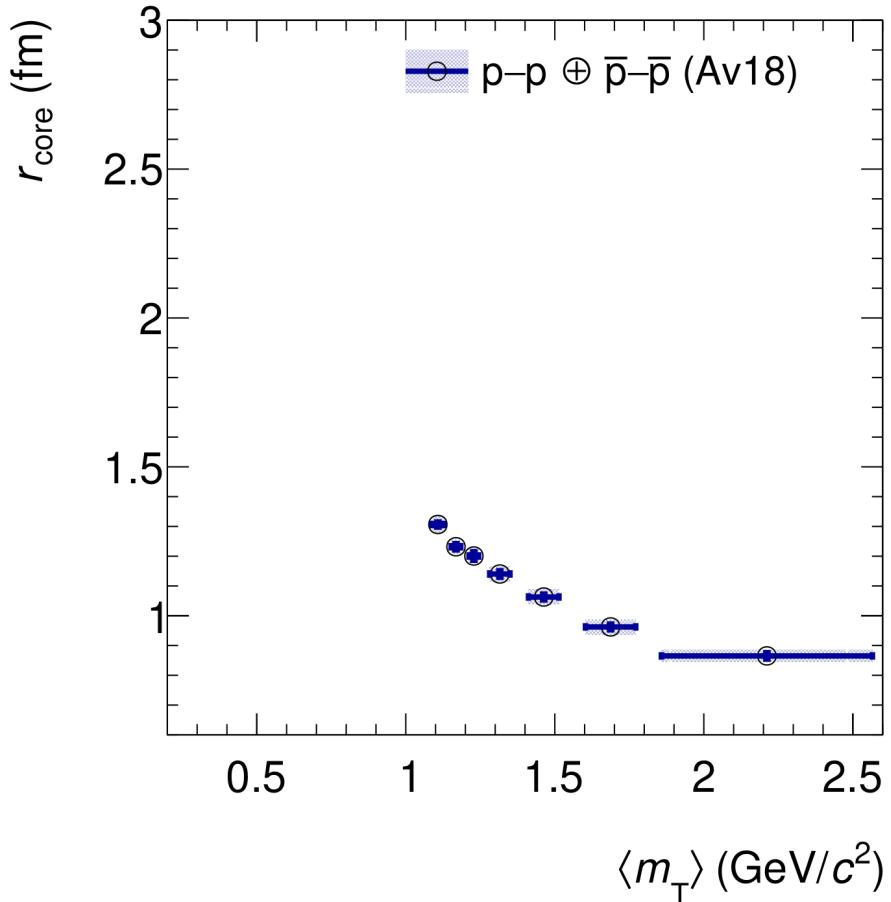
- Obtained in several m_T bins
- Fit with $C^{\pi\pi}(k^*)$ with Pol1 **or** Pol2
 - Polynomial term to account for residual background
 - Interaction is modeled by Coulomb interaction and Quantum Statistics
 - Extract r_{core} for each m_T bin



- Obtained in several m_T bins
- Fit with $C^{Kp}(k^*)$ with Pol0 **or** Pol1
 - Polynomial term to account for residual background
 - Interaction is modeled by Coulomb interaction and χ EFT [1]
 - Extract r_{core} for each m_T bin

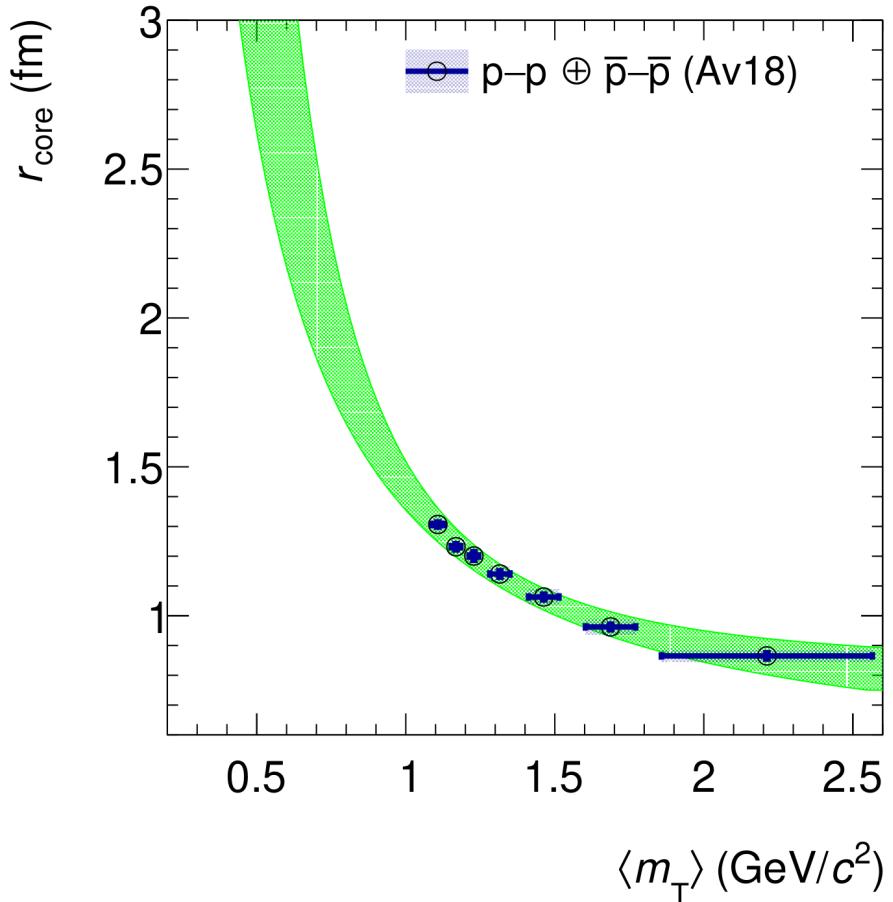
[1] K. Aoki et al. PTEP 1 (2019)

r_{core} compared to previous results in HM pp 13 TeV



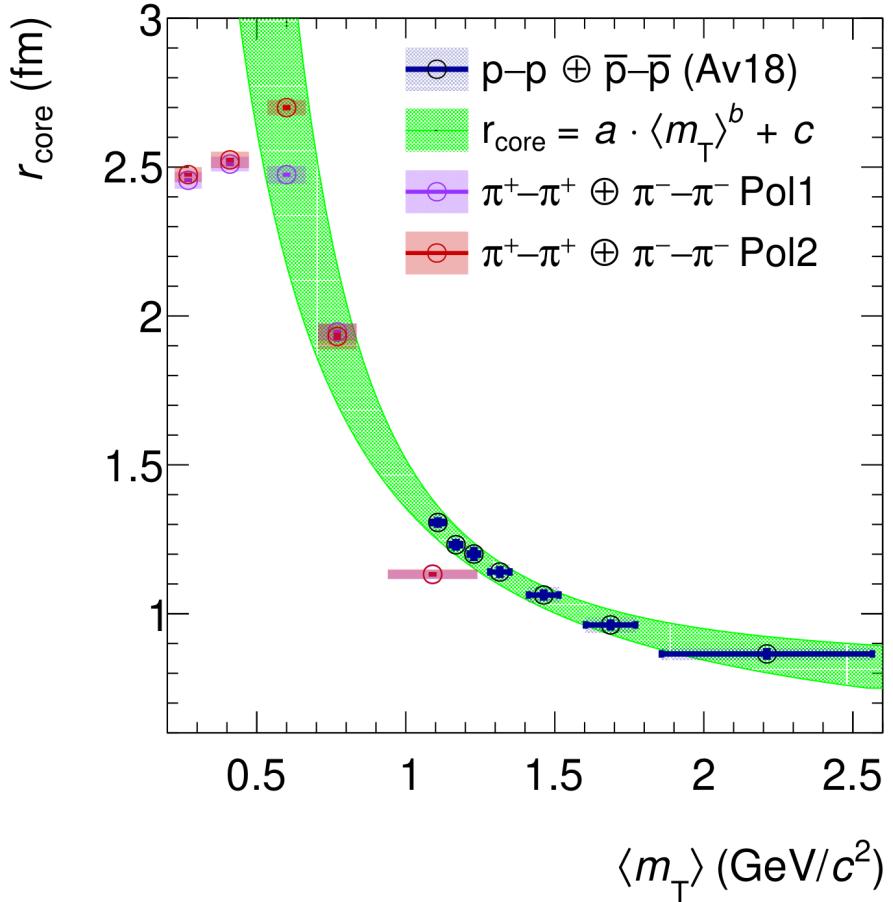
- p-p taken from PLB 811 2020

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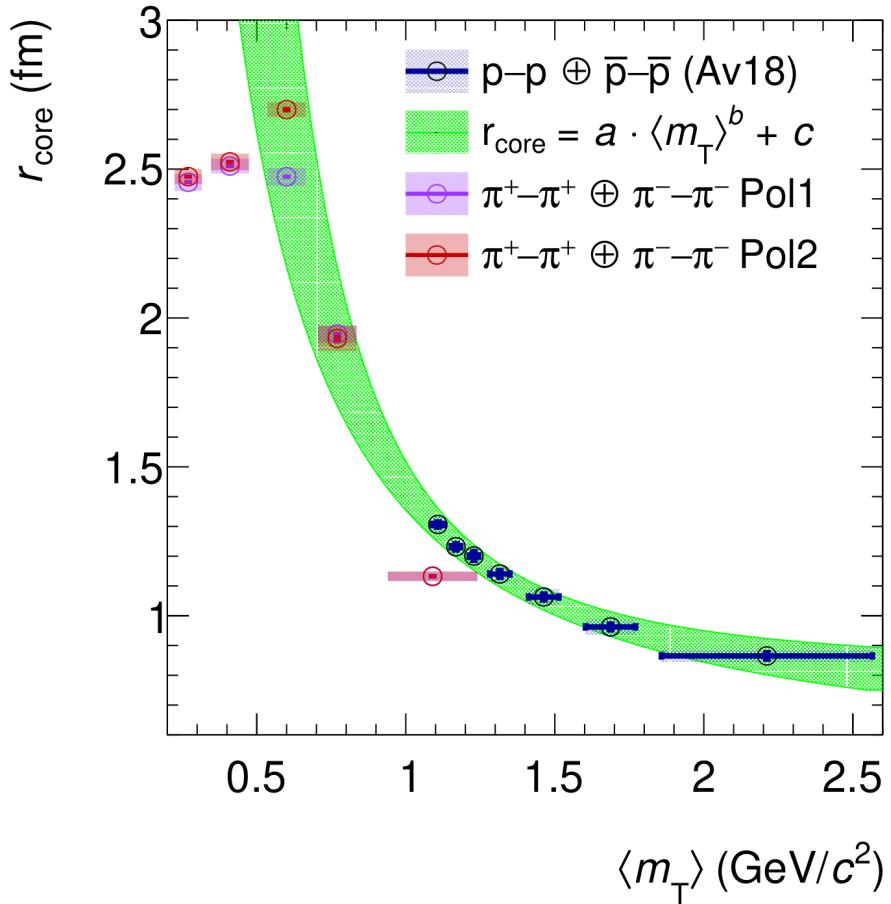
- p-p taken from PLB 811 2020
- Parameterization and extrapolation of the r_{core} dependence

r_{core} compared to previous results in HM pp 13 TeV



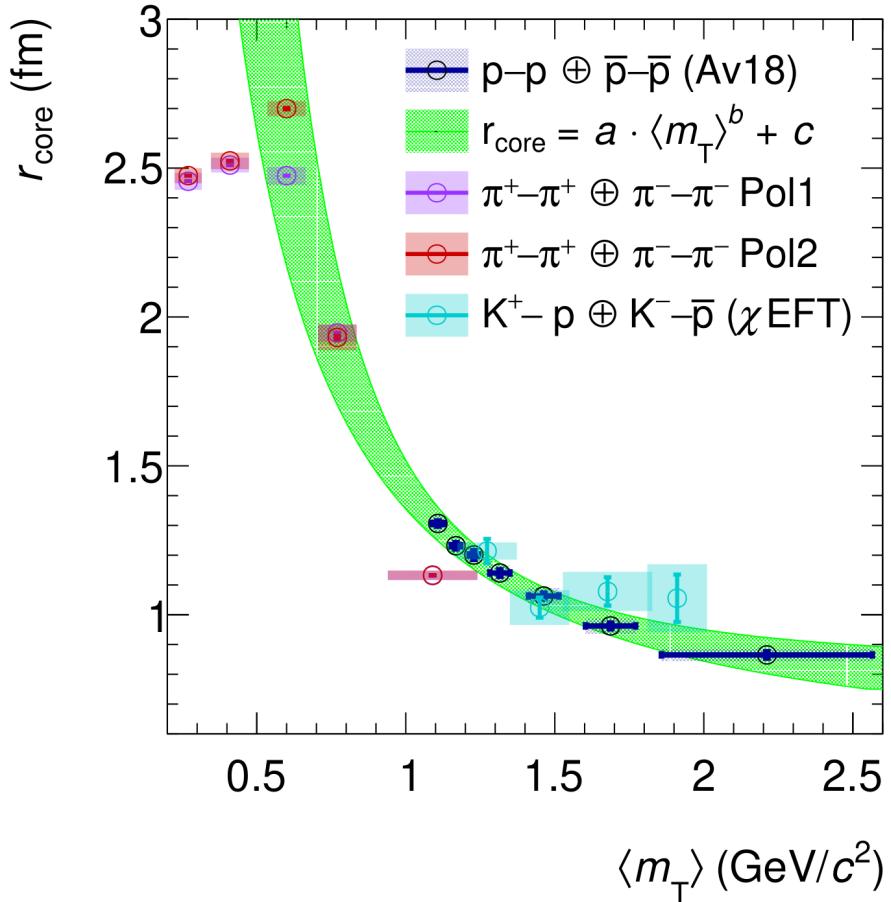
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- $\pi-\pi$ from this analysis

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- p–p taken from PLB 811 2020
- Parameterization and extrapolation of the r_{core} dependence
- $\pi-\pi$ from this analysis
- For m_T above $0.4 \text{ GeV}/c^2$ good agreement with parametrization
→ Saturation for $\pi-\pi$ radii
(not predicted by any model)

r_{core} compared to previous results in HM pp 13 TeV



- p–p taken from PLB 811 2020
- Parameterization and extrapolation of the r_{core} dependence
- $\pi\pi$ from this analysis
- K^+p from this analysis
- For m_T above 0.4 GeV/c^2 good agreement with parametrization
→ Evidence for a common source for all mesons and baryons in HM pp at 13 TeV

Summary

- For the **first time** a quantitative description of the exponential source of pions is presented by **explicitly** considering the influence of short-lived resonances on a Gaussian core (RSM model)
- $K^+ - p$ and same charge $\pi - \pi$ show agreement with the RSM assumption of a **universal** Gaussian core **source** for primordial particles
- Source radii reach **saturation** for $m_T < 0.4 \text{ GeV}/c^2$

Outlook

- Available data to tune particle production coordinates in transport models
- Refine source model in order to account for saturation effects (CECA [1])

[1] D. Mihaylov et al. arXiv 2305.08441(2023)

Summary

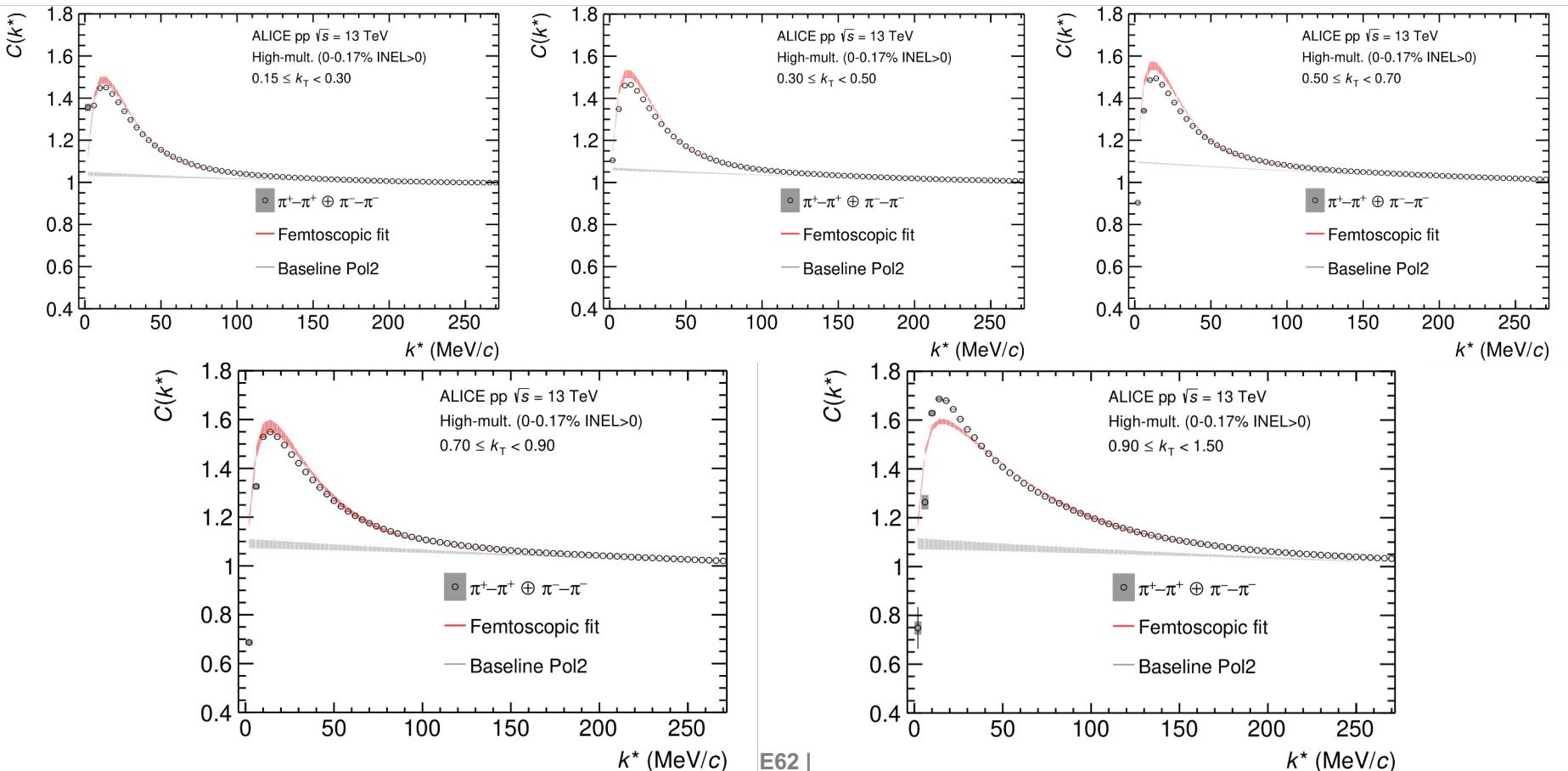
- For the $\pi^+\pi^-$ channel, a Gaussian source was presented. Even more details about the $\pi^+\pi^-$ source were studied: Doubly differential as function of m_T and multiplicity on MB data set!
- K^+p analysis: Same saturation behaviour as in high-multiplicity data set.
- Source radius: Scaling of the radii with multiplicity is observed.

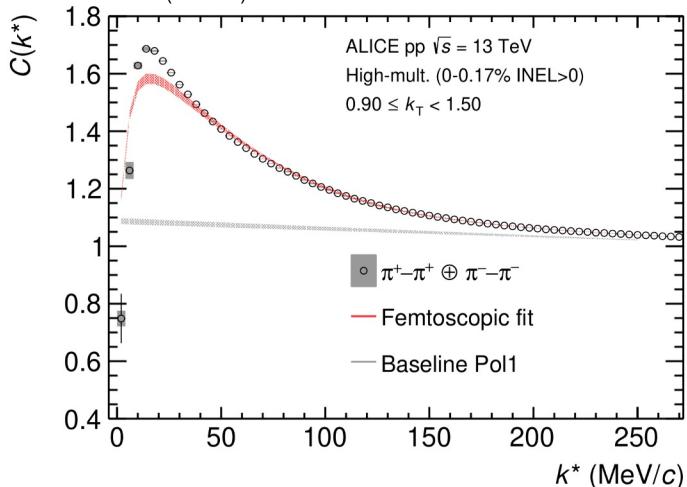
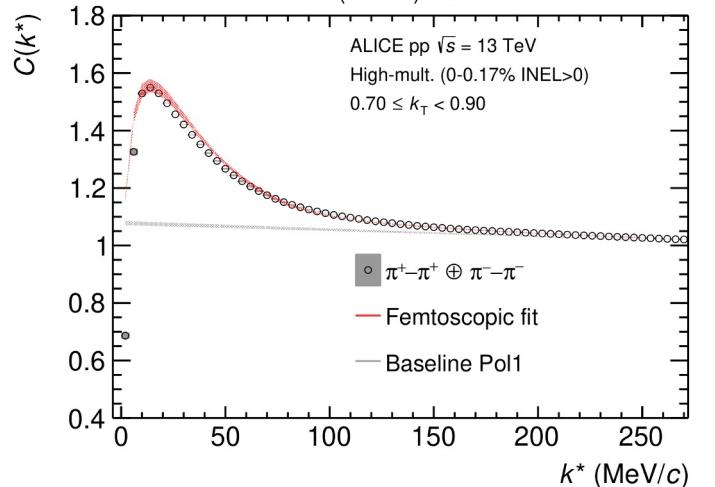
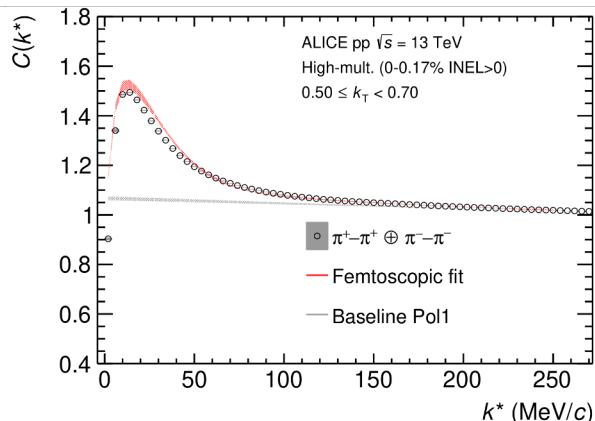
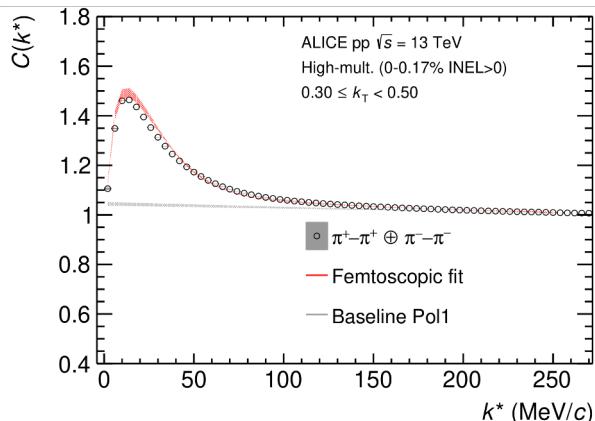
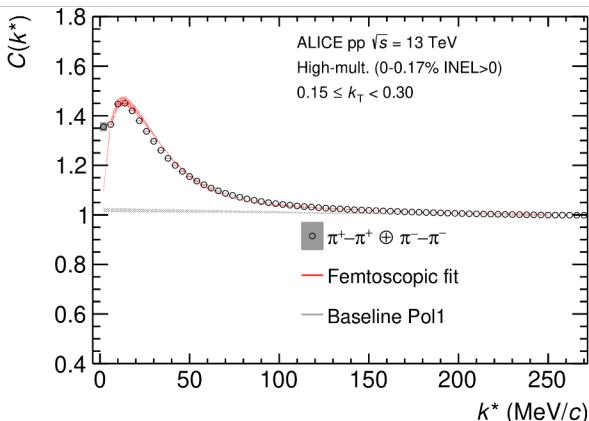
Outlook

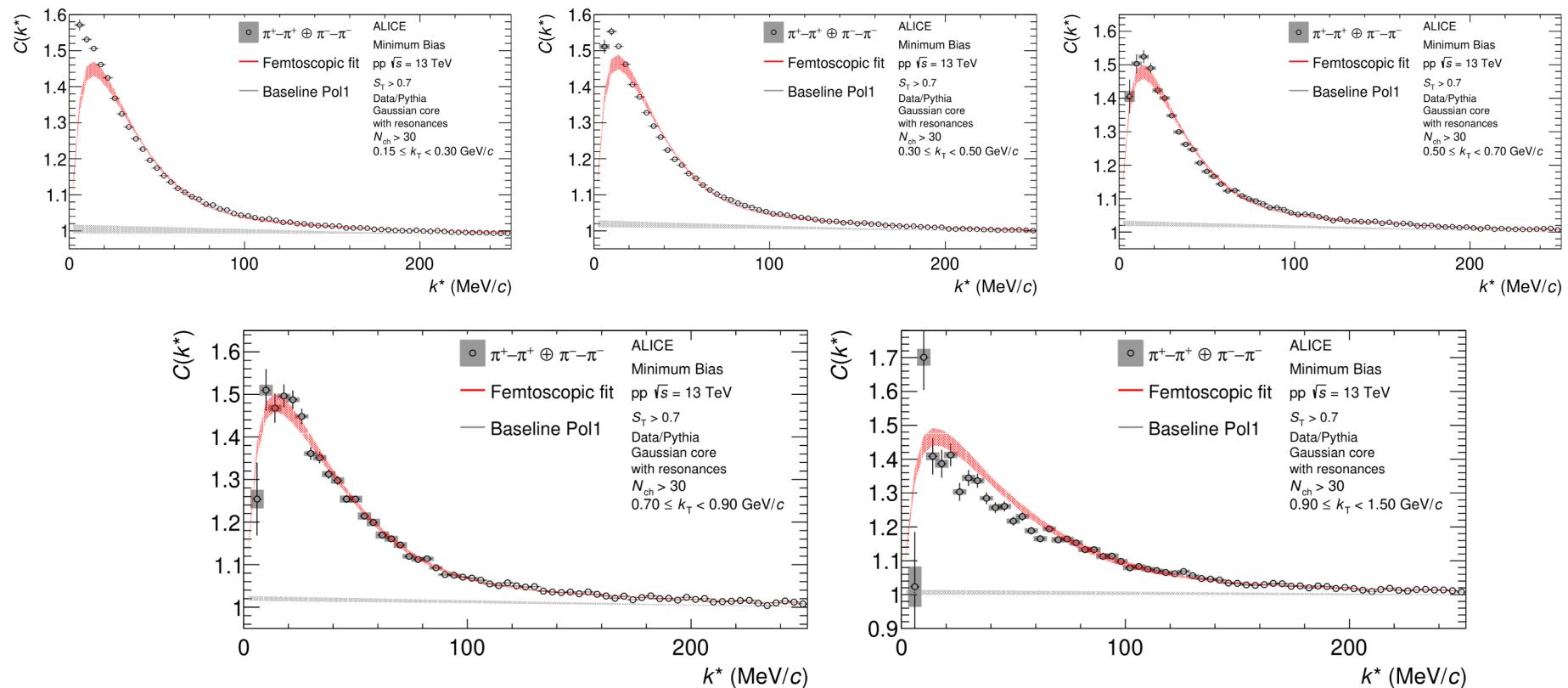
- Available data sets for pions and kaons will be used to refine transport models
- Refine source model in order to account for saturation effects (CECA [1])

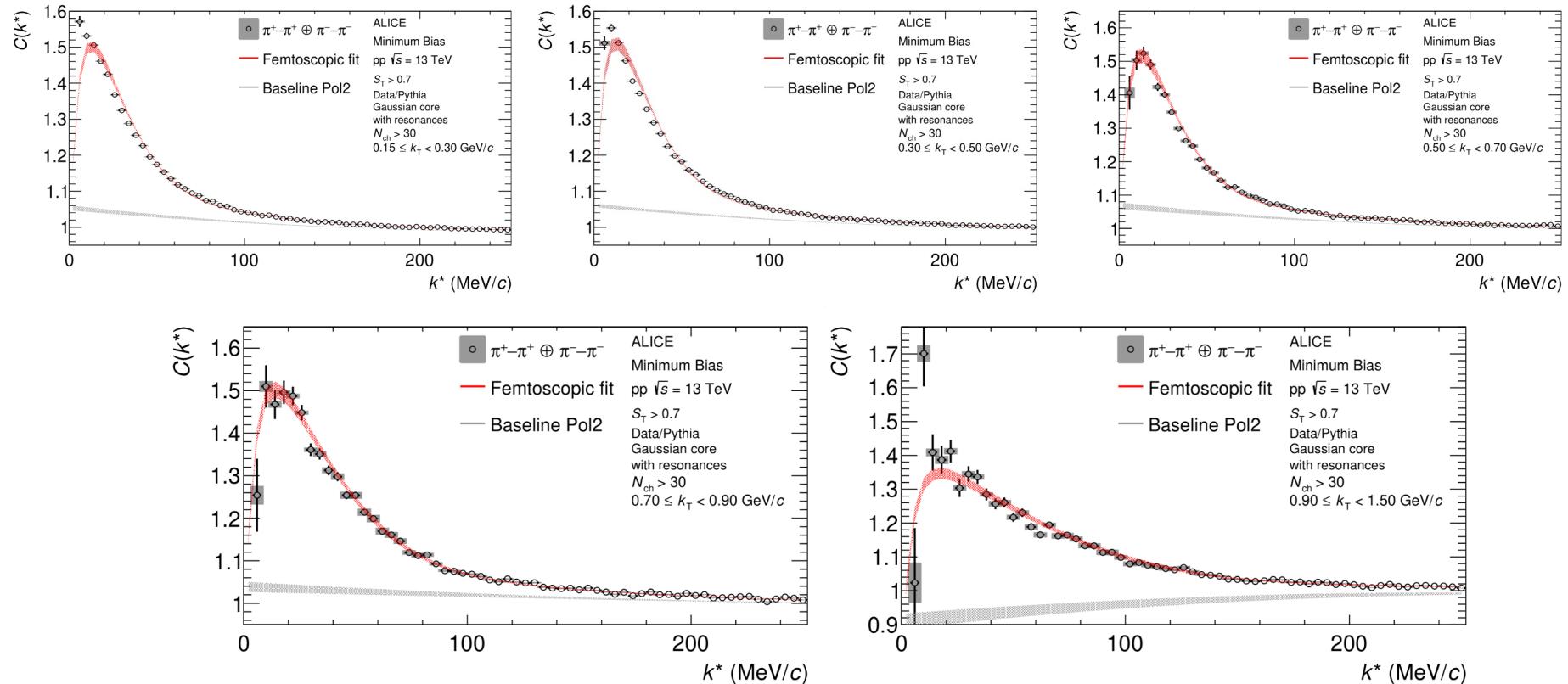
Plots are in the back-up!

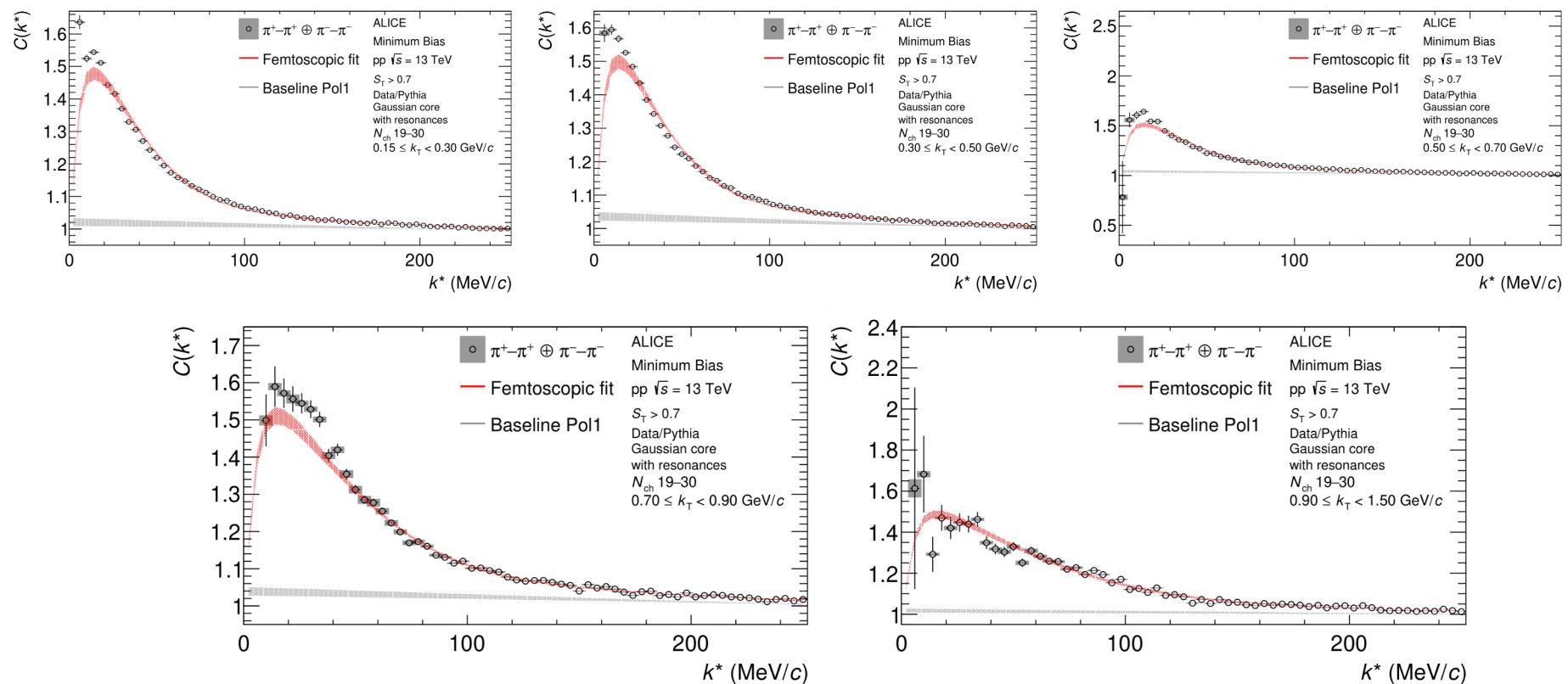
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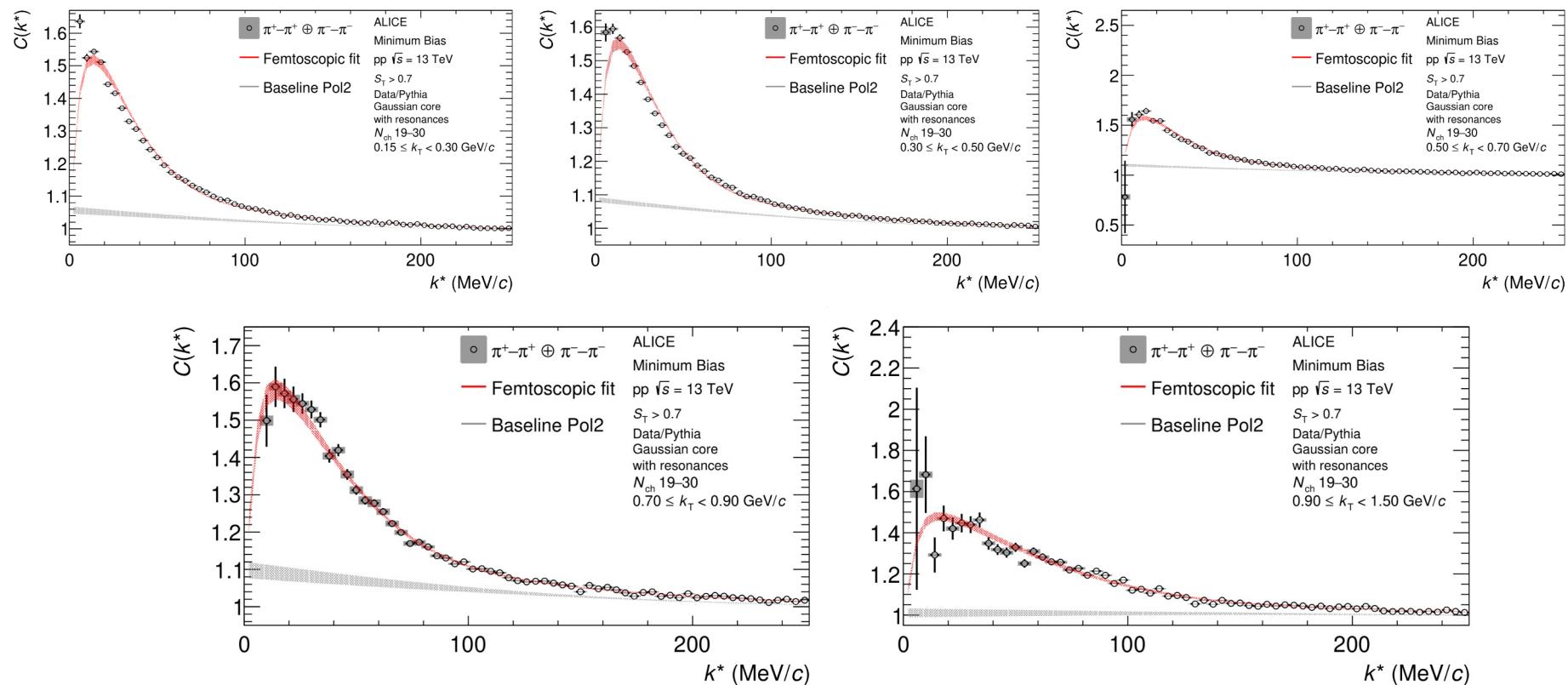


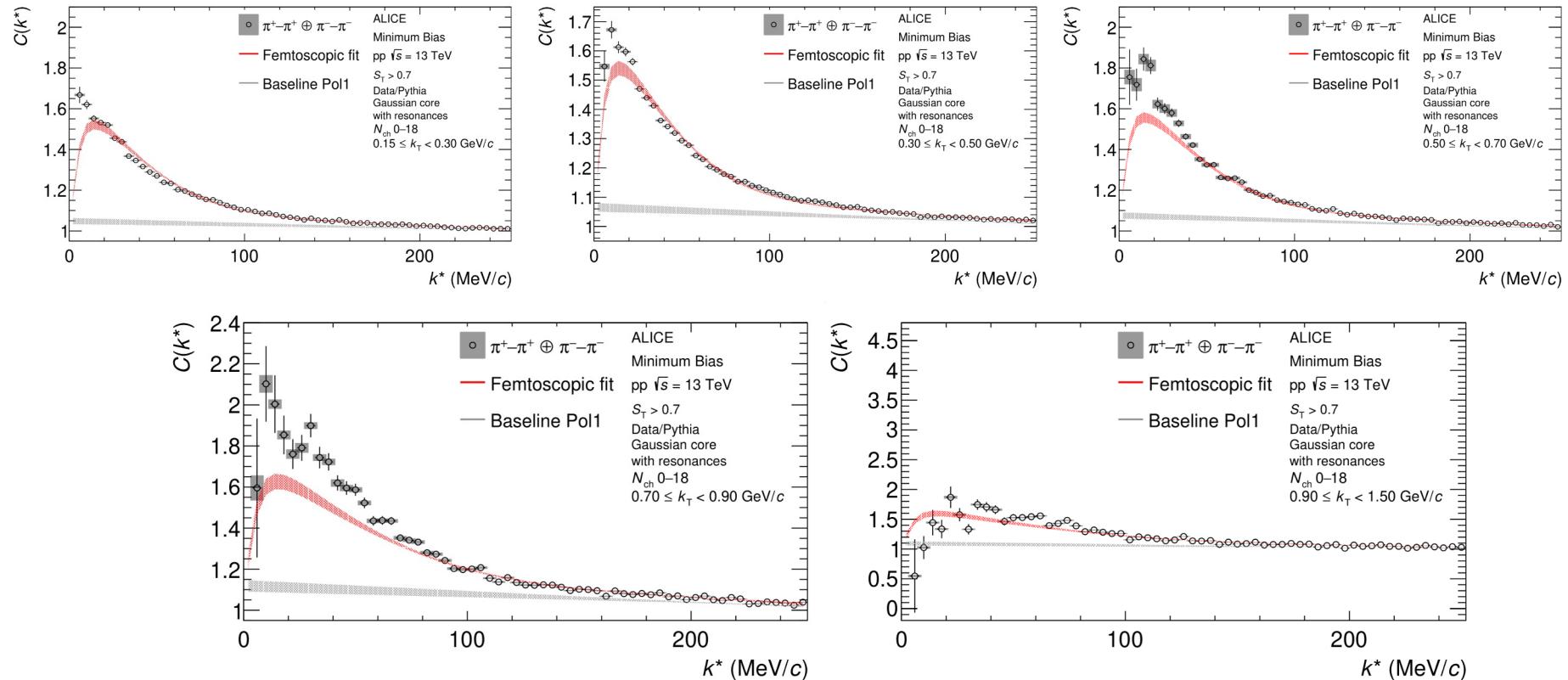


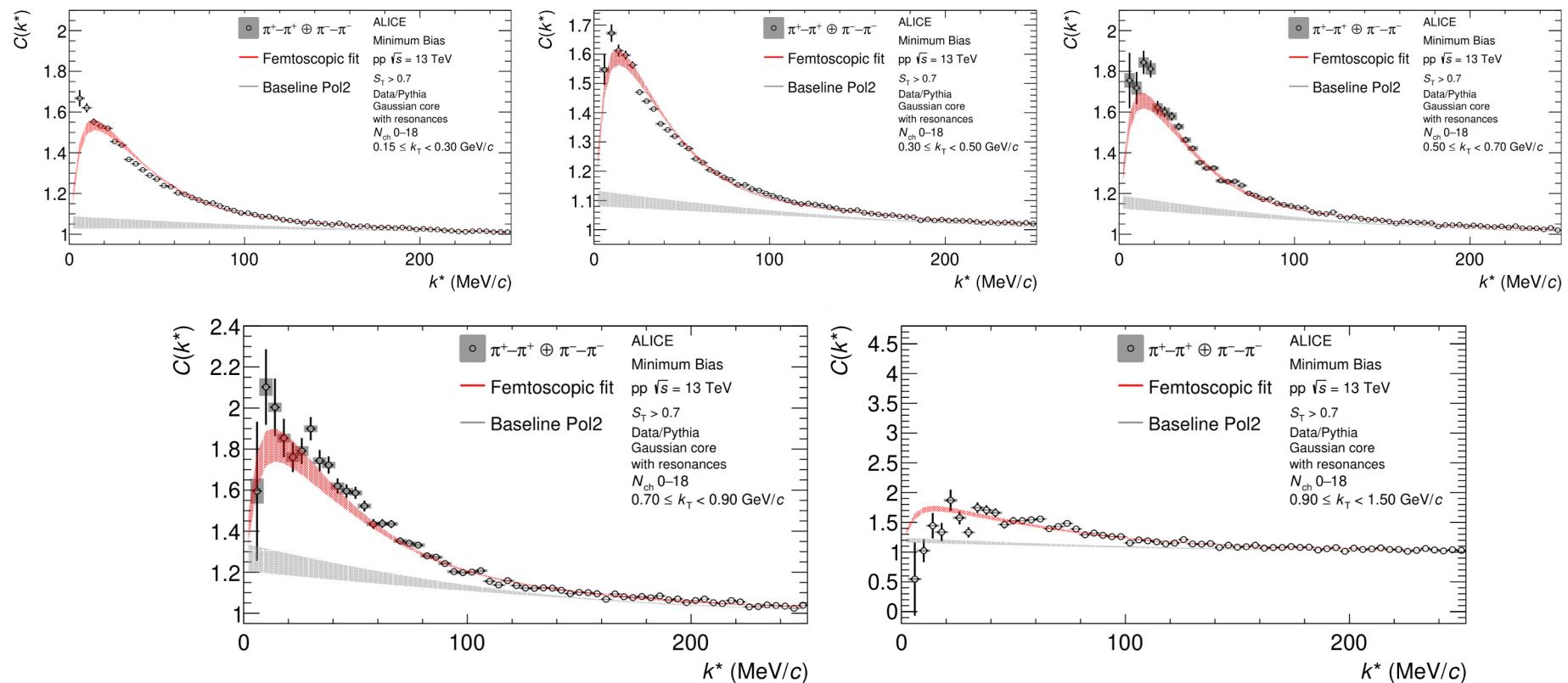


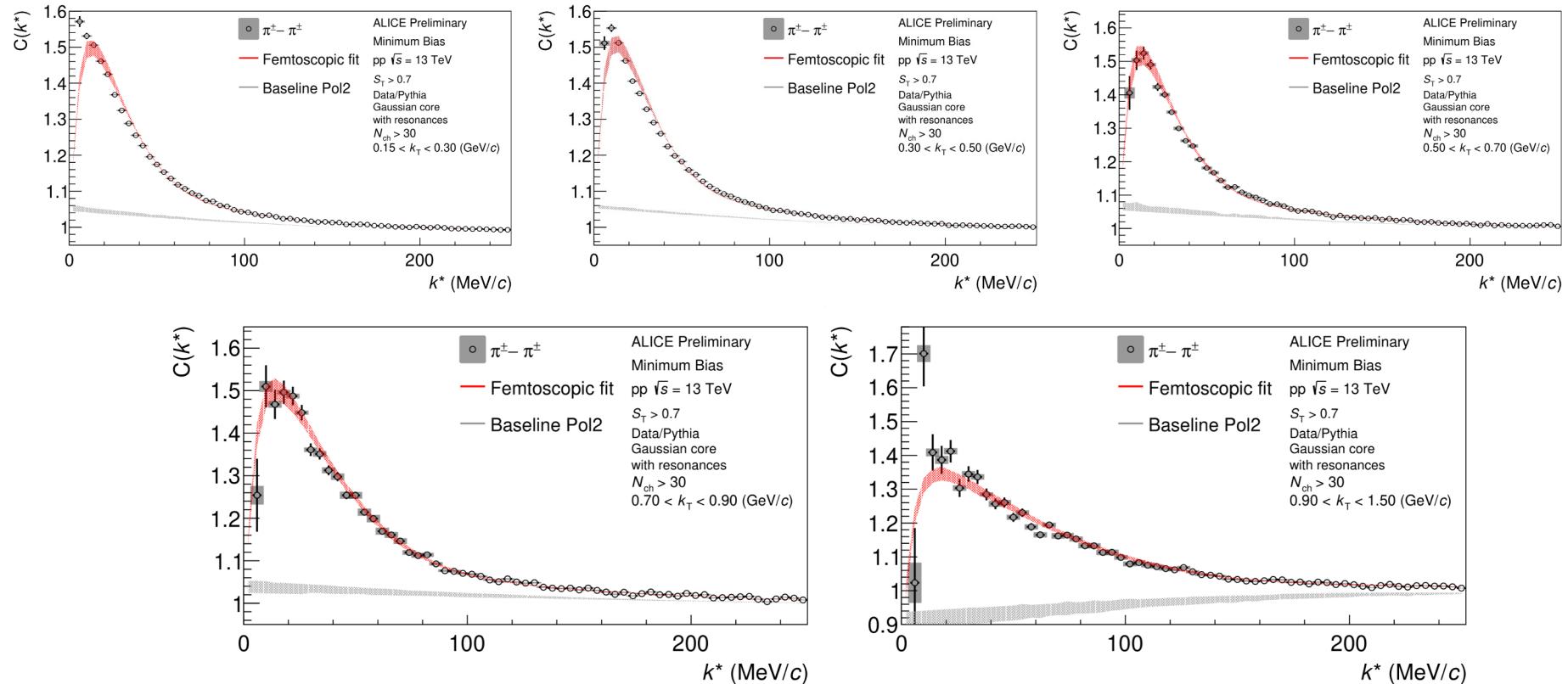


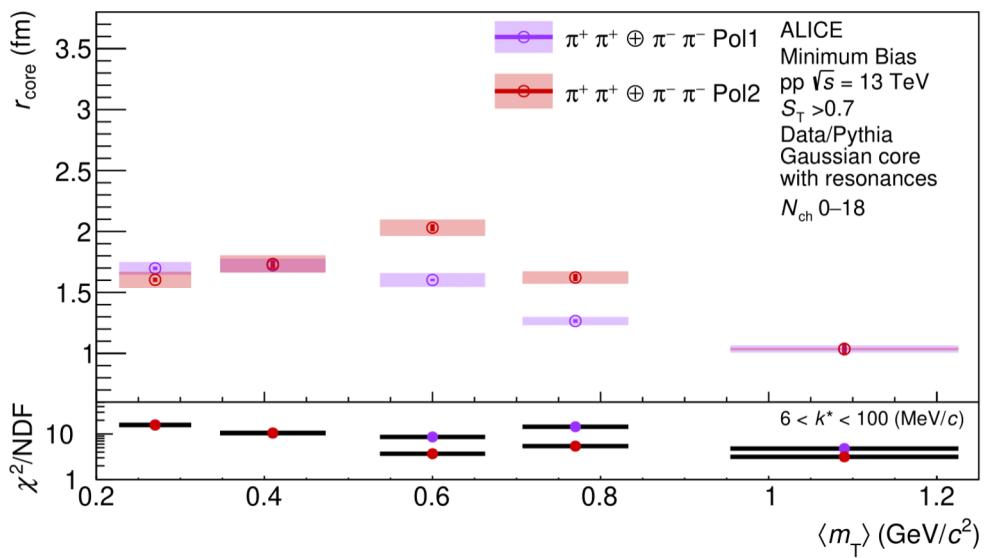




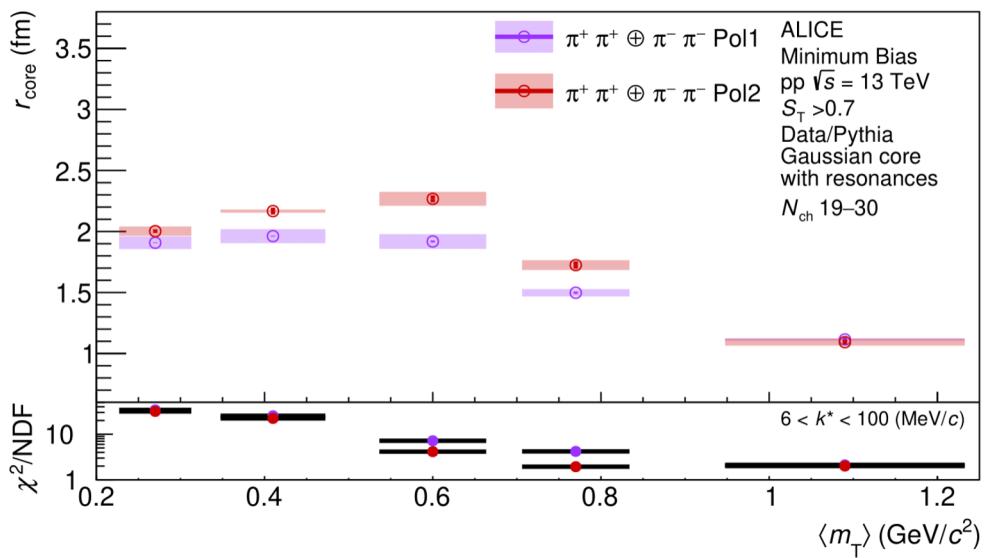




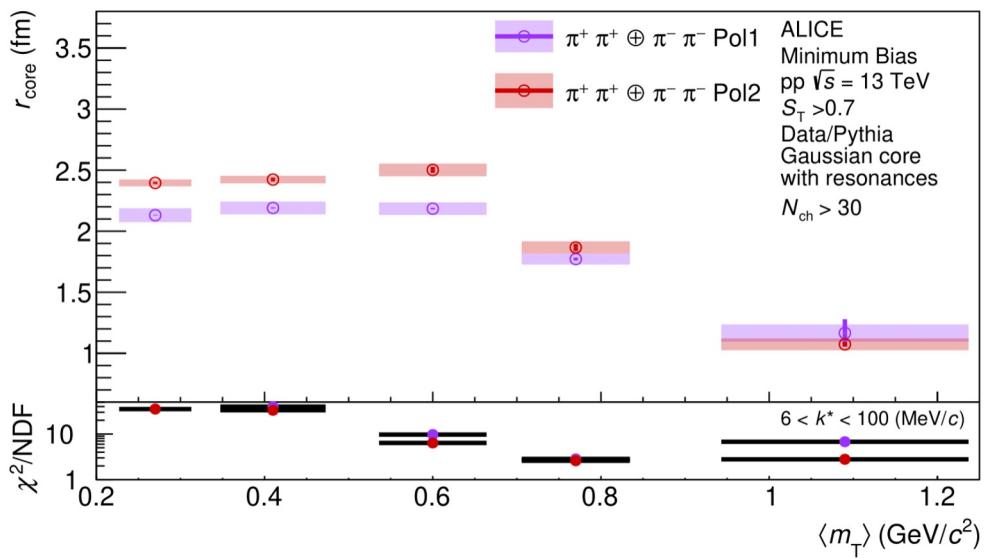




- For $m_T > 0.4$ (GeV/c) scaling with m_T is found for all multiplicity bins
- The extracted r_{core} radii are increasing with multiplicity

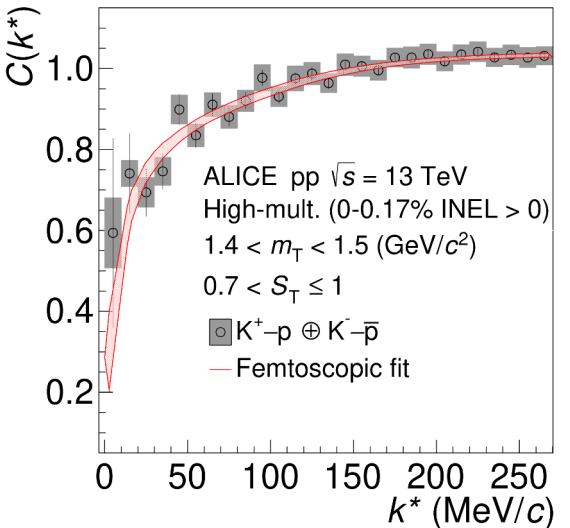
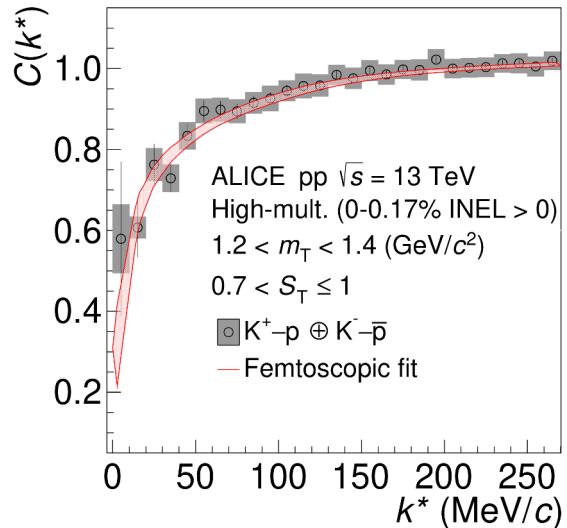


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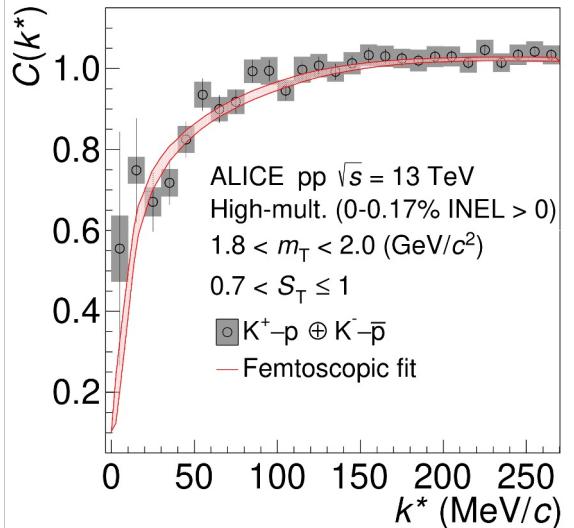
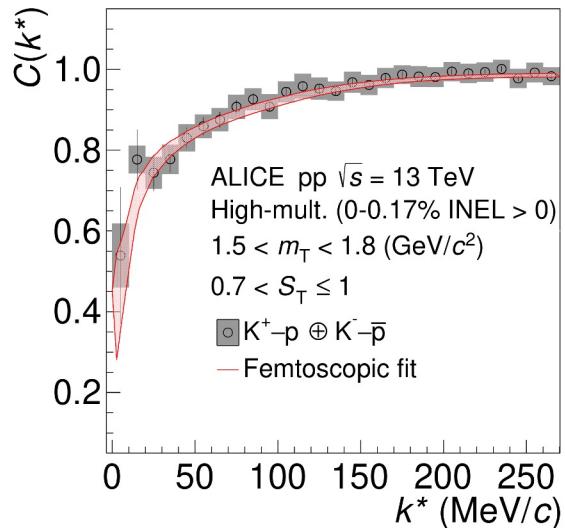
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Fits to the $K^+ - p$ in HM



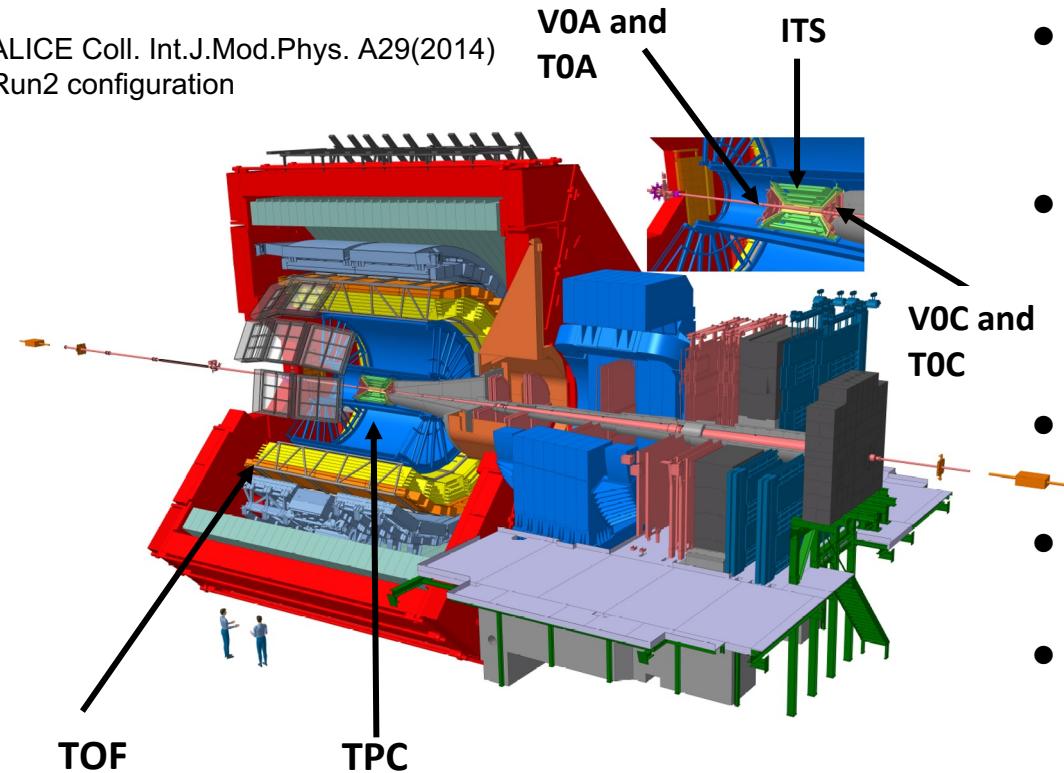
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[K. Aoki et al. PTEP 1 (2019)]
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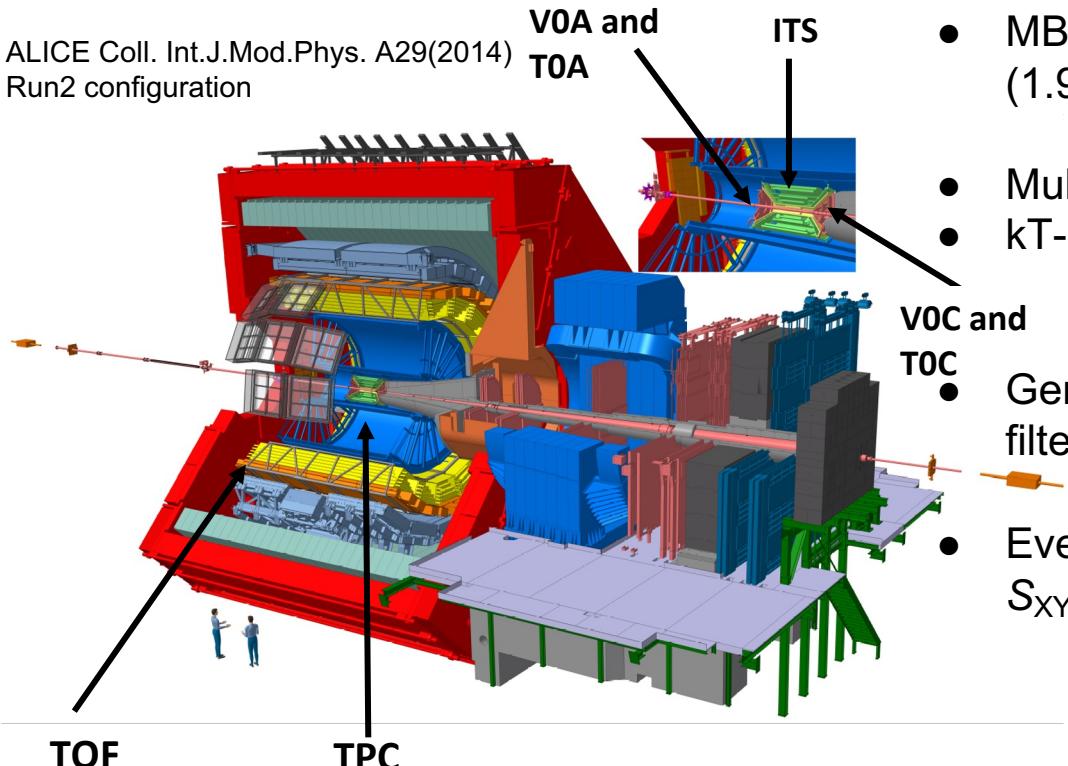
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ALICE Coll. Int.J.Mod.Phys. A29(2014)
Run2 configuration



- Direct detection of charged particles (pions) by TPC and TOF
- Particle identification
 - Mean energy loss in TPC
 - Momentum reconstruction by TOF
- Primary vertex reconstruction by ITS
- Multiplicity estimates by V0
- Reference signal for TOF via T0

ALICE Coll. Int.J.Mod.Phys. A29(2014)
Run2 configuration



- MB pp collisions @ 13 TeV (1.9×10^9 evts.)
- Mult-Binning: [0-18], [19-30], [>30]
- kT-Binning: (0.15-0.3], (0.3-0.5],
(0.5-0.7], (0.7-0.9], (0.9-1.5]
- General purpose Pythia 8 [1] evts. filtered by GEANT4 [2] used as MC
- Event cut on transverse sphericity [3]
 $S_{XY} > 0.7$ suppression of mini-jet background

[1] T. Sjöstrand et al. CPC 191 (2015), [2] S. Agostinelli et al. PRS A 506.3 (2003), [3] ALICE Coll. EPJC 72 (2012)

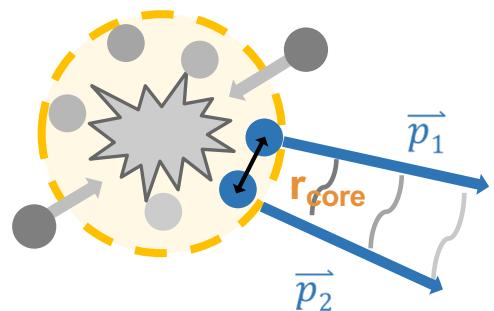
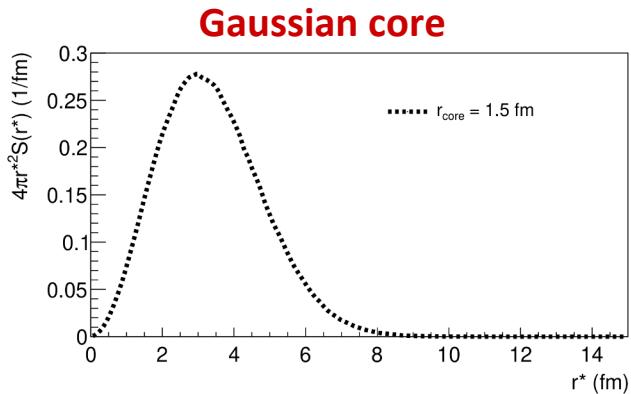
Resonances	$c\tau_{\text{res}}$ (fm)	Fraction (%)
ρ^0	1.3	9.01
ρ^+	1.3	8.71
$\omega(782)$	23.4	7.67
$K^*(892)^+$	3.9	2.29
$\bar{K}^*(892)0$	3.9	2.25
$b1(1235)^+$	1.4	1.90
$a2(1320)^+$	1.8	1.48
η	150631.3	1.45
$a1(1260)^+$	0.5	1.37
$f2(1270)$	1.1	1.36
$a0(980)^+$	2.6	1.36
$h1(1170)$	0.5	1.18

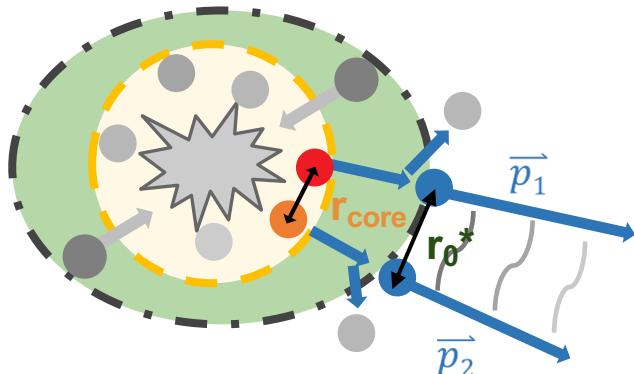
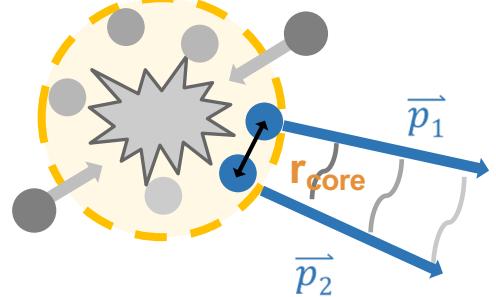
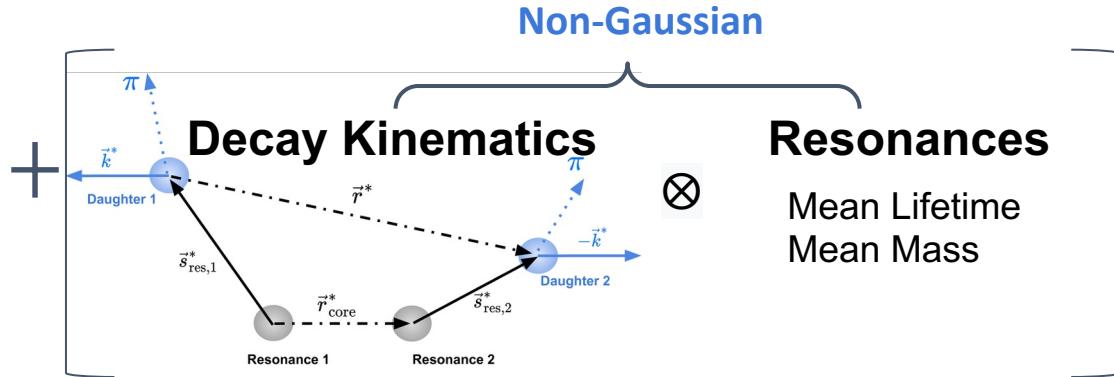
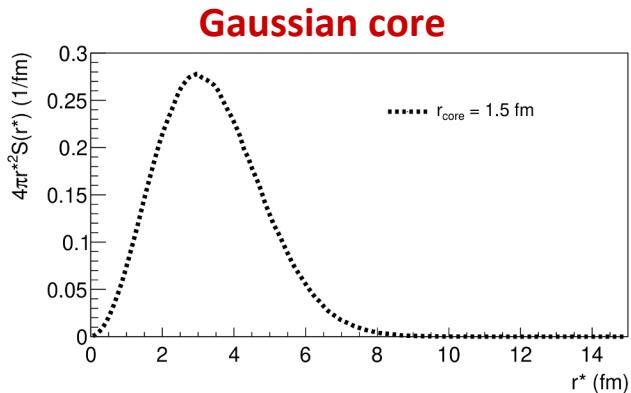
Lifetime $c\tau$ (fm)	Fraction \mathcal{F} (%)	$\langle m_{\text{res}}^{\text{eff}} \rangle$ (GeV/c)
Primordial	28.0	—
$c\tau_{\text{res}} < 1$	14.8	0.308
$1 < c\tau_{\text{res}} < 2$	34.8	0.526
$2 < c\tau_{\text{res}} < 5$	10.2	0.151
$c\tau_{\text{res}} > 5$	12.2	0.146

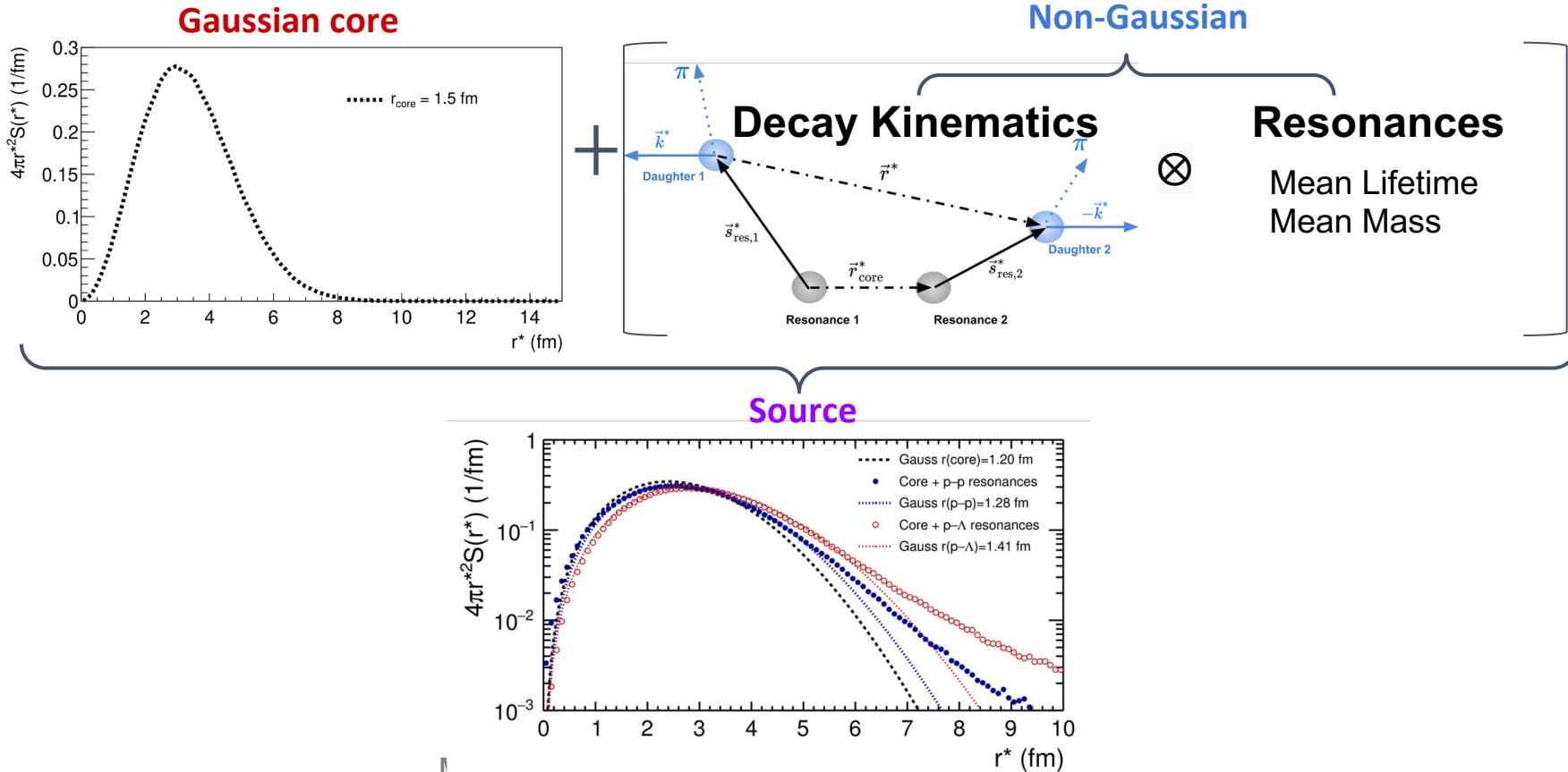
- Employ statistical hadronization model [1]
 - Describe system by statistical ensemble
 - Enforce conservation of quantum numbers
 - Predict yields
- Calculation carried out with Thermal-FIST [2,3]
 - Configure model to pp
 - B.R.s of strong decays fixed to PDG
 - Extract resonances
- Summary parameters for RSM
 - $m_{\text{eff}} = 1124 \text{ GeV}/c^2$
 - $c\tau_{\text{eff}} = 1.5 \text{ fm}$
 - Select resonances cocktail in EPOS [4] for decay kinematics

[1] F. Becattini Z. Phys. C 76 (1997), [2] V. Vovchenko et al. CPC 100 2019,

[3] V. Vovchenko et al. PRC 100834 (2019), [4] K. Werner et al. PRC 92 (2015)







$$C_{\text{model}}(k^*) =$$

???

But **what is measured?**

- Does purity play a role?
- What about feed-down weak decays?
- Do we have background?

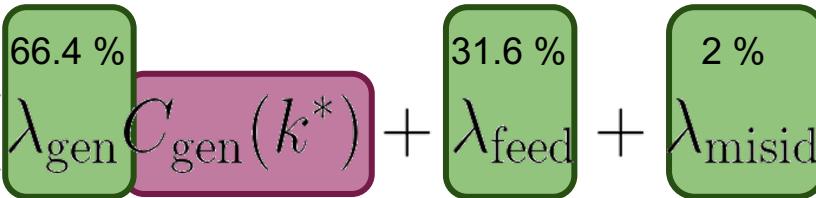
$$C_{\text{model}}(k^*) = 1/C_{\text{MC}}(k^*) \cdot (\lambda_{\text{gen}} C_{\text{gen}}(k^*) + \lambda_{\text{feed}} + \lambda_{\text{misid}})$$

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Model for genuine interaction

- Bose-Einstein quantum statistics
- Coulomb interaction

$$C_{\text{model}}(k^*) = 1/C_{\text{MC}}(k^*) \cdot (\lambda_{\text{gen}} C_{\text{gen}}(k^*) + \lambda_{\text{feed}} + \lambda_{\text{misid}})$$



Model for **genuine interaction**

- Bose-Einstein quantum statistics
- Coulomb interaction

Introduce **λ -parameter**

- Each component has a weight
- $C(k^*) = 1$, for feed-down and misidentified
- Evaluated by MC studies

$$C_{\text{model}}(k^*) = 1/C_{\text{MC}}(k^*) \cdot (\lambda_{\text{gen}} C_{\text{gen}}(k^*) + \lambda_{\text{feed}} + \lambda_{\text{misid}})$$

Correct for non-femto effects

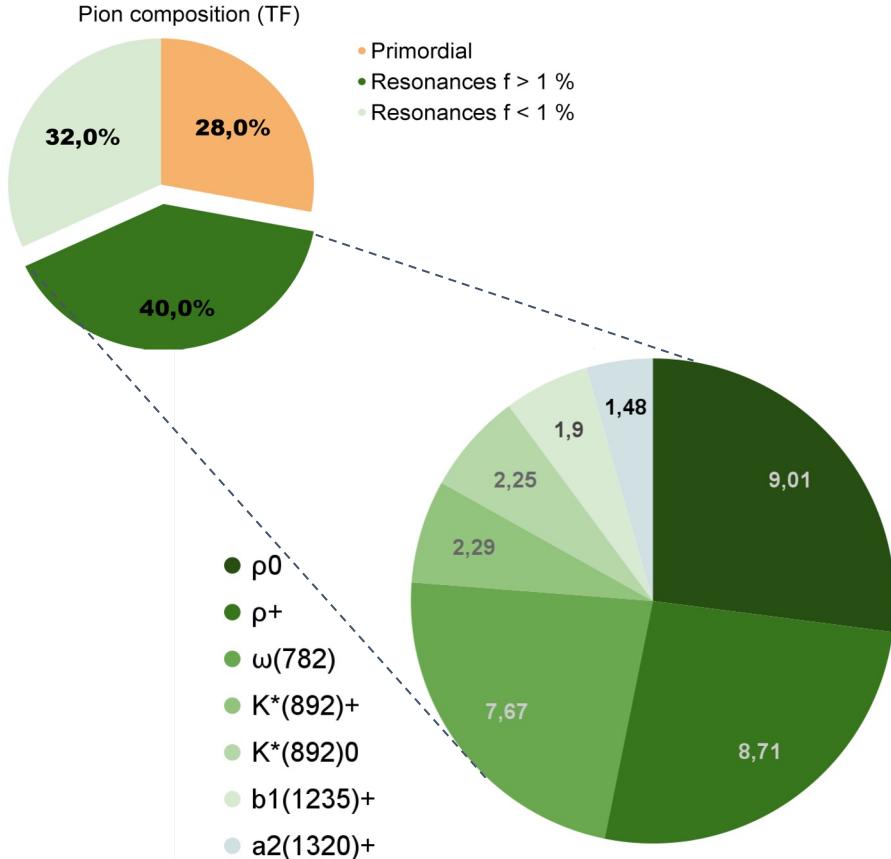
- Divide by $C(k^*)$ obtained from MC
- Collimated production often called ‘mini-jet’

Model for genuine interaction

- Bose-Einstein quantum statistics
- Coulomb interaction

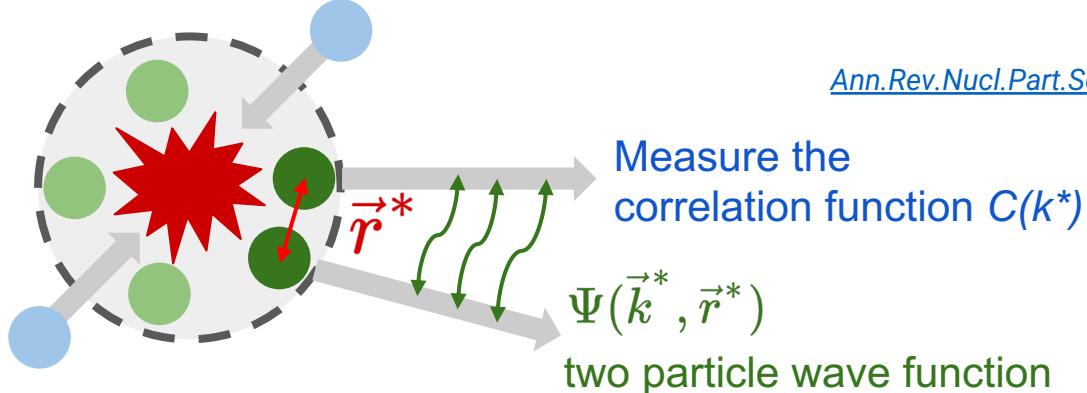
Introduce λ -parameter

- Each component has a weight
- $C(k^*) = 1$, for feed-down and misidentified
- Evaluated by MC studies



- Calculation carried out with Thermal-FIST [1,2]
 - Use statistical hadronization model [3]
 - **28 %** primordial, **72 %** resonances
- Summary parameters for RSM
 - $\langle m_{\text{eff}} \rangle = 1124 \text{ GeV}/c^2$
 - $\langle c\tau_{\text{eff}} \rangle = 1.5 \text{ fm}$
 - Select resonances cocktail in EPOS [4] for decay kinematics

- [1] V. Vovchenko et al. PRC 100834 (2019)
- [2] V. Vovchenko et al. CPC 100 (2019)
- [3] F. Becattini Z. Phys. C 76 (1997)
- [4] K. Werner et al. PRC 92 (2015)



$$C(k^*) = \int S(r^*) \left| \Psi(\vec{k}^*, \vec{r}^*) \right|^2 d^3 r^* \xrightarrow{k^* \rightarrow \infty} 1$$

- Measure $C(k^*)$, ‘fix’ interaction, study $S(r^*)$
- For evaluation of integral and $S(r^*)$ use CATS framework [Eur.Phys.J.C 78 \(2018\) 5, 394](https://doi.org/10.1140/epjc/s10050-018-6034-2)