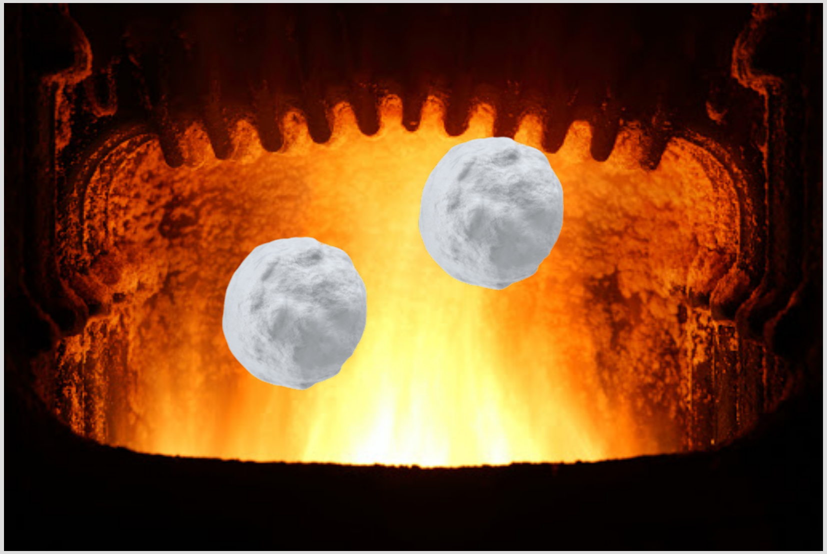
RHIC Beam Energy Scan, Spring 2023

Topical discussion: Light nuclei and hyper-nuclei production

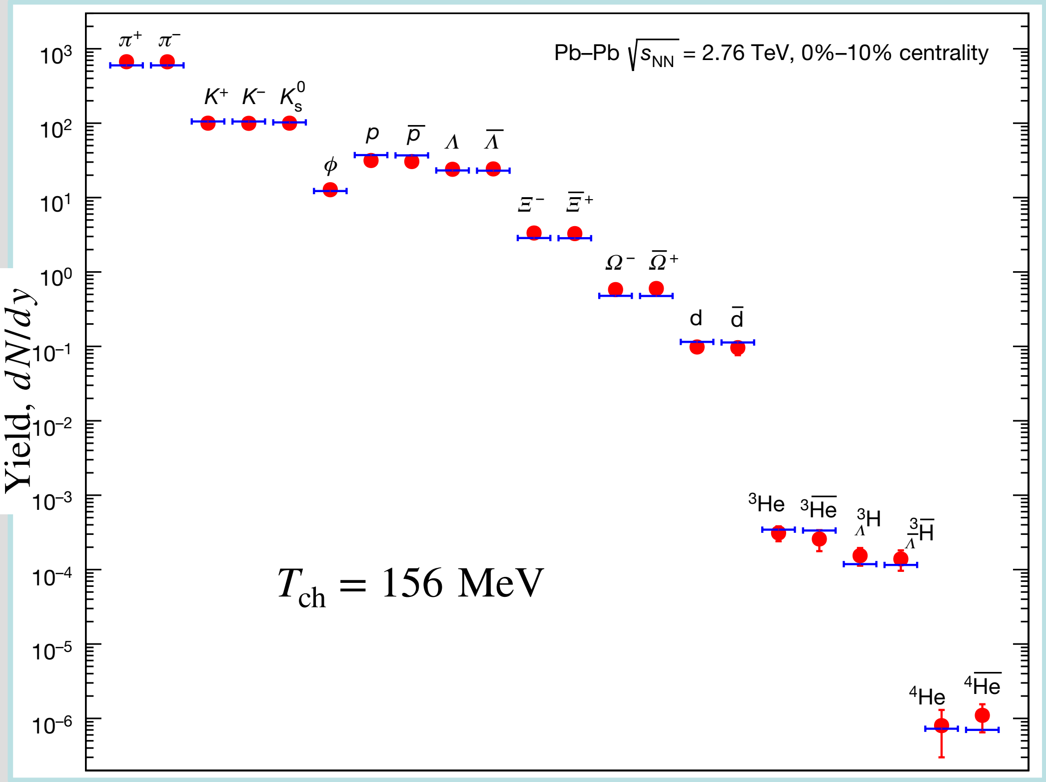
(Hyper-)nuclei production and the coalescence—correlations relation

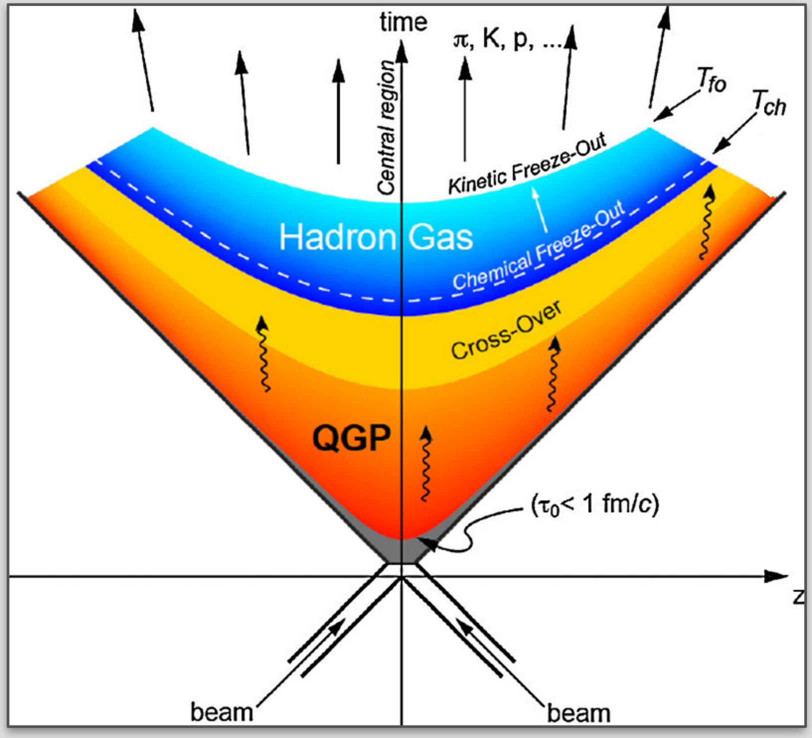
Kfir Blum (Weizmann Institute)



A puzzle in heavy-ion collisions:

Why does the thermal model work *for nuclei?*





Andronic et al 2017

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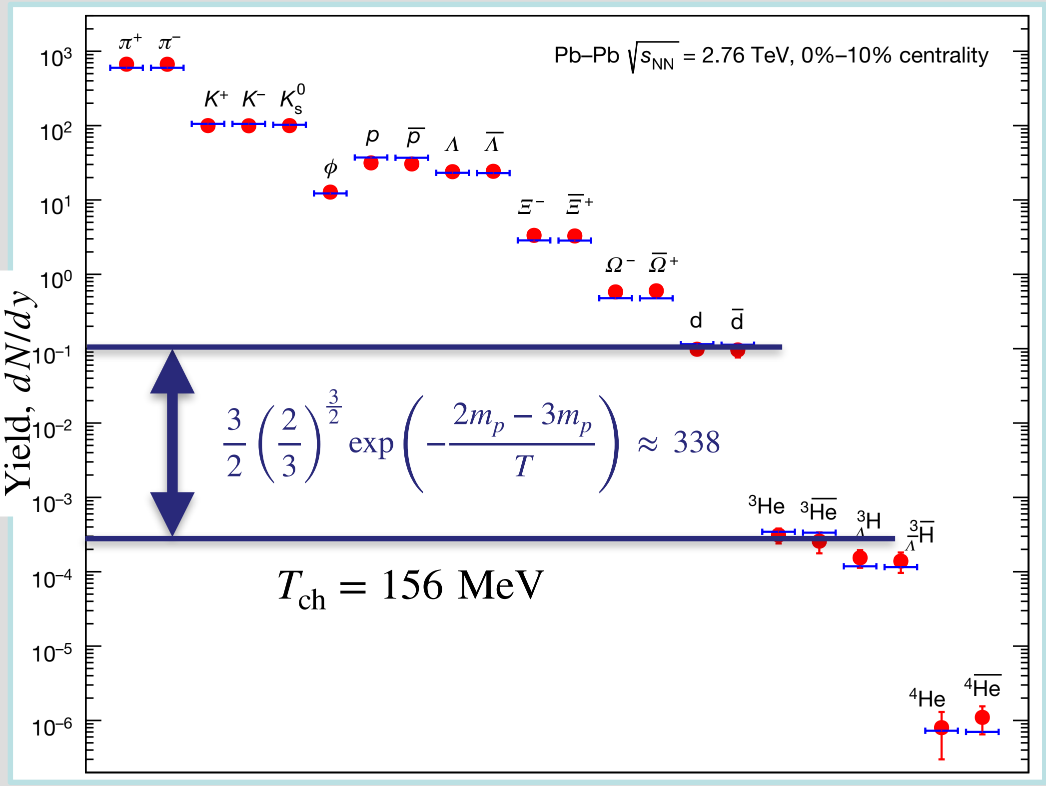
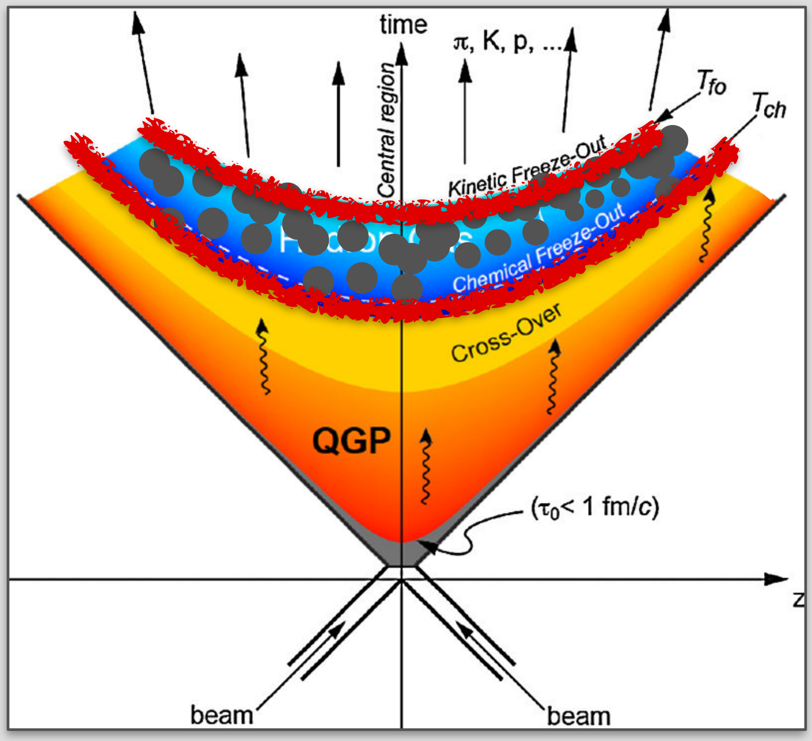
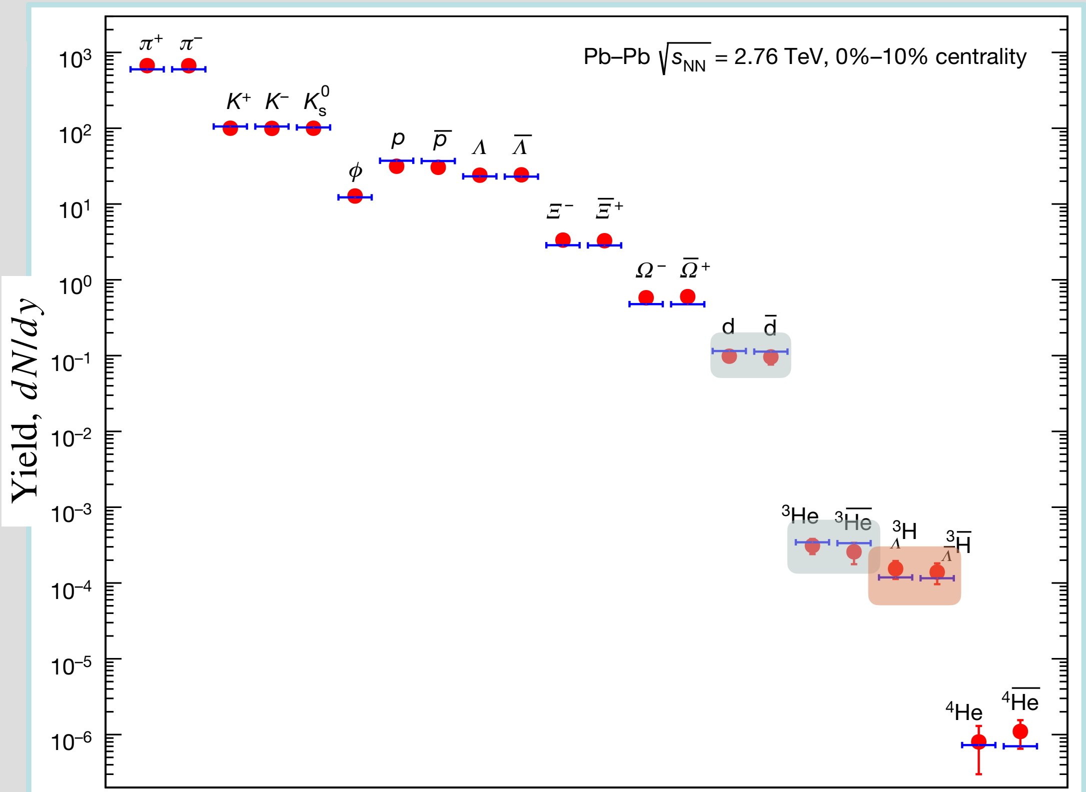


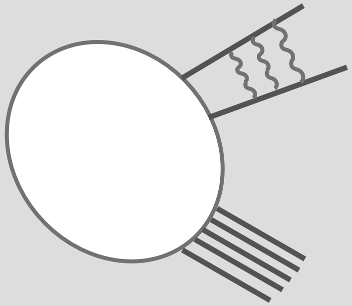


Andronic et al 2017

``Snowballs ~~in~~ from Hell"

Mrowczynski





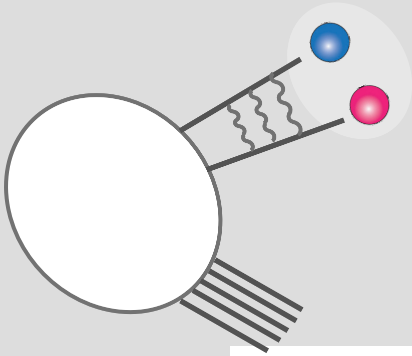
Scheibl & Heinz 1999

KB, Ng, Takimoto, Sato 2017
KB, Takimoto 2019
Bellini, KB, Kalweit, Puccio 2020

Nuclei form by **coalescence** after kinetic freeze out.

For large systems, nuclei approximately inherit the thermal features of nucleon constituents.

Coalescence — correlations relation: tools to test this hypothesis.



Coalescence from correlation functions

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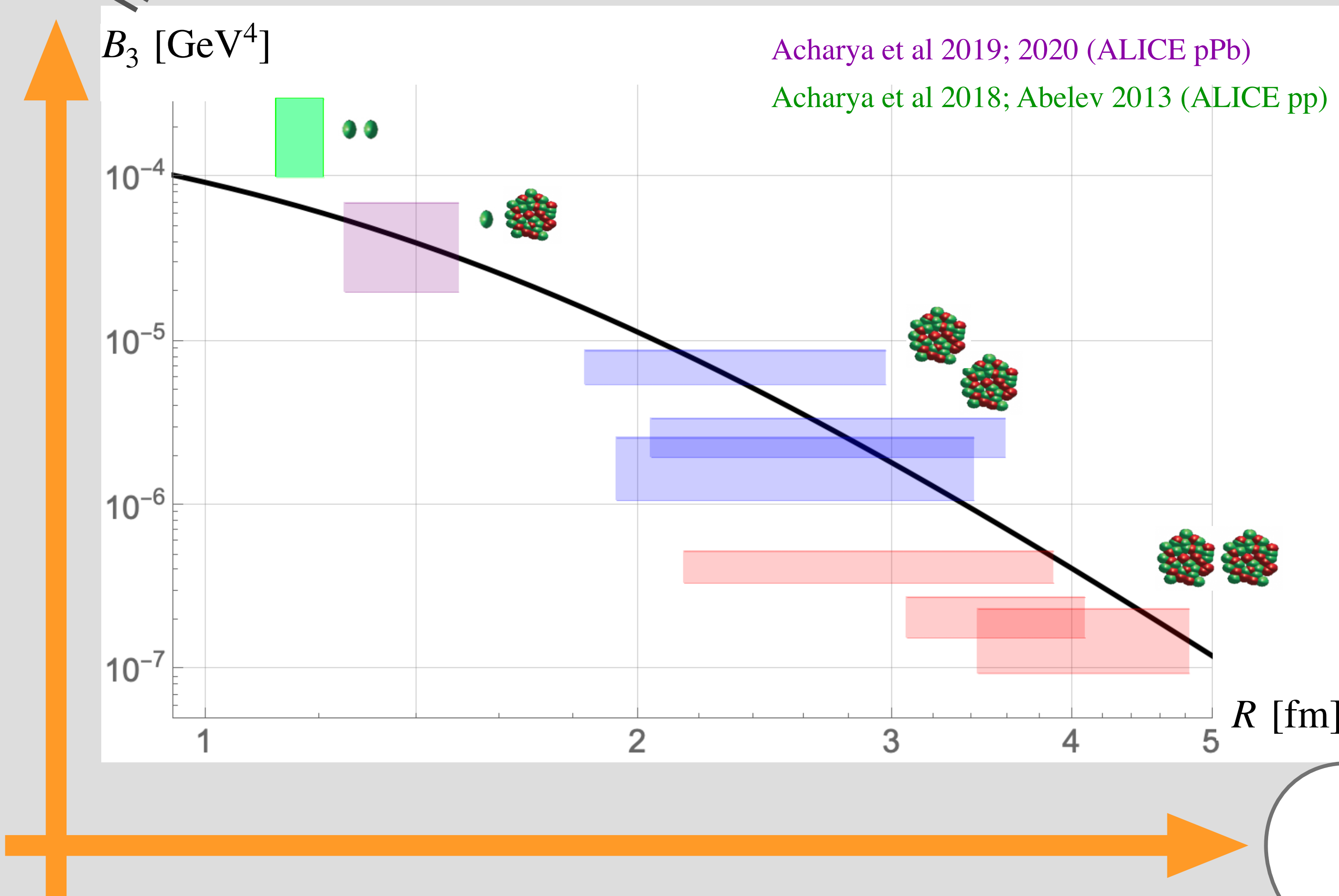
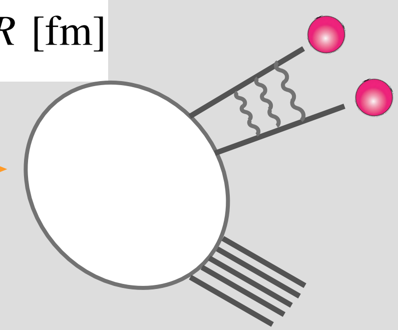
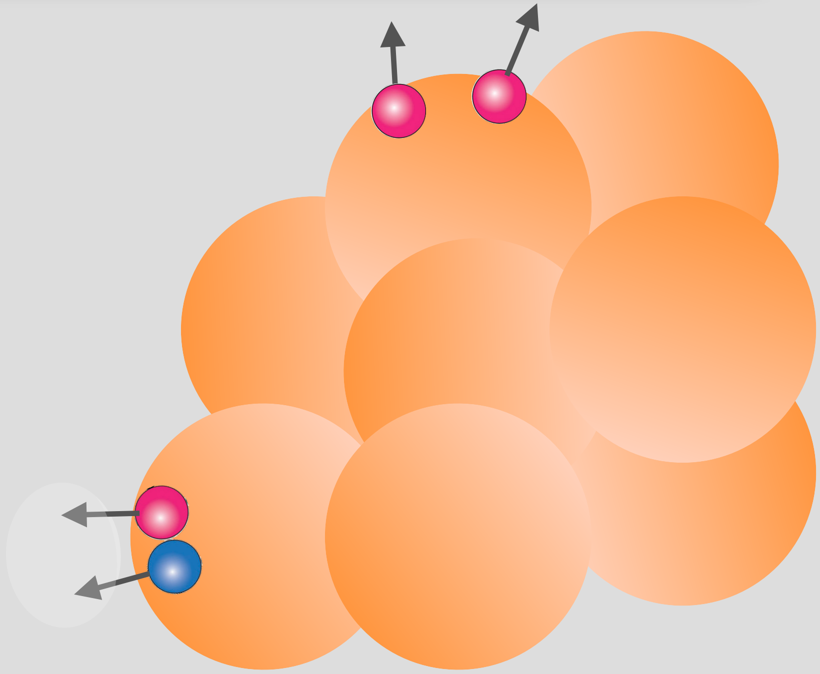
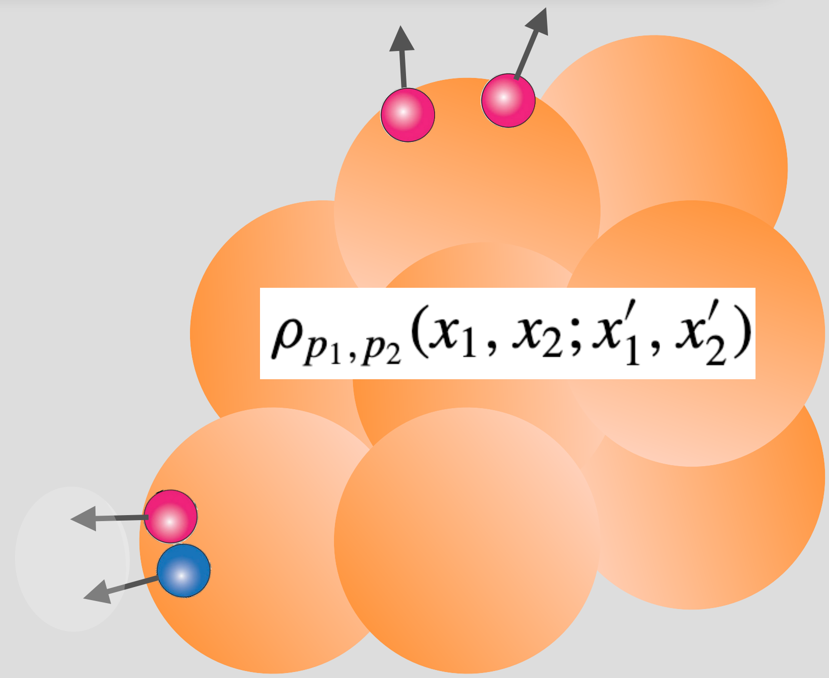


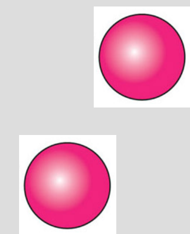




R. Lednicky et al, 1982, 2002, 2009



$$\gamma_1\gamma_2 \frac{dN_{2,s}}{d^3\mathbf{p}_1 d^3\mathbf{p}_2} = \frac{2s+1}{(2\pi)^6} \int d^4x_1 \int d^4x_2 \int d^4x_1' \times \int d^4x_2' \, \Psi^*_{s,p_1,p_2}(x_1', x_2') \, \Psi_{s,p_1,p_2}(x_1, x_2) \times \rho_{p_1,p_2}(x_1, x_2; x_1', x_2'), \quad (1)$$



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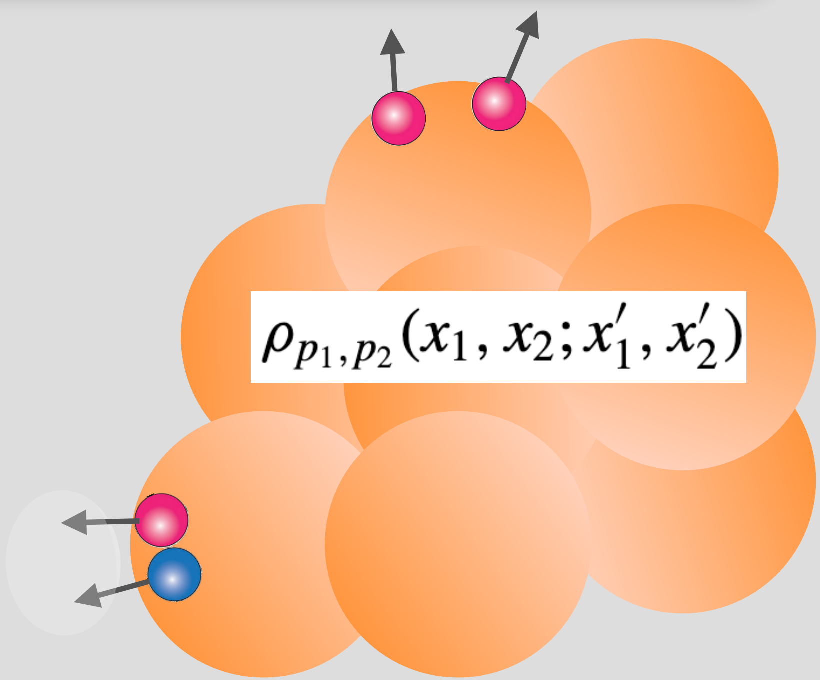

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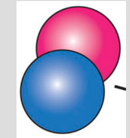

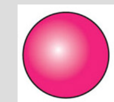

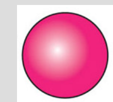

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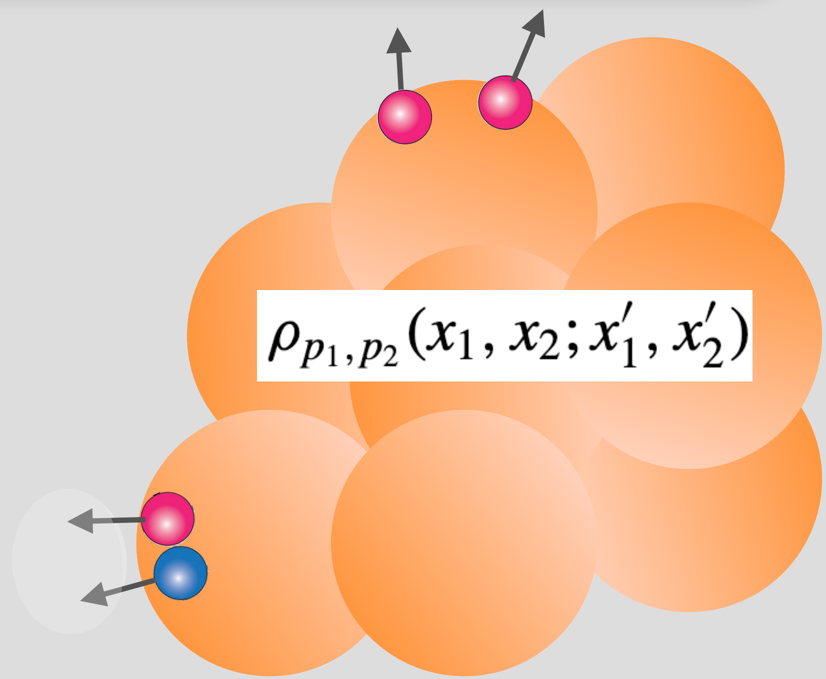

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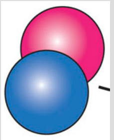

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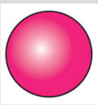
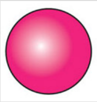
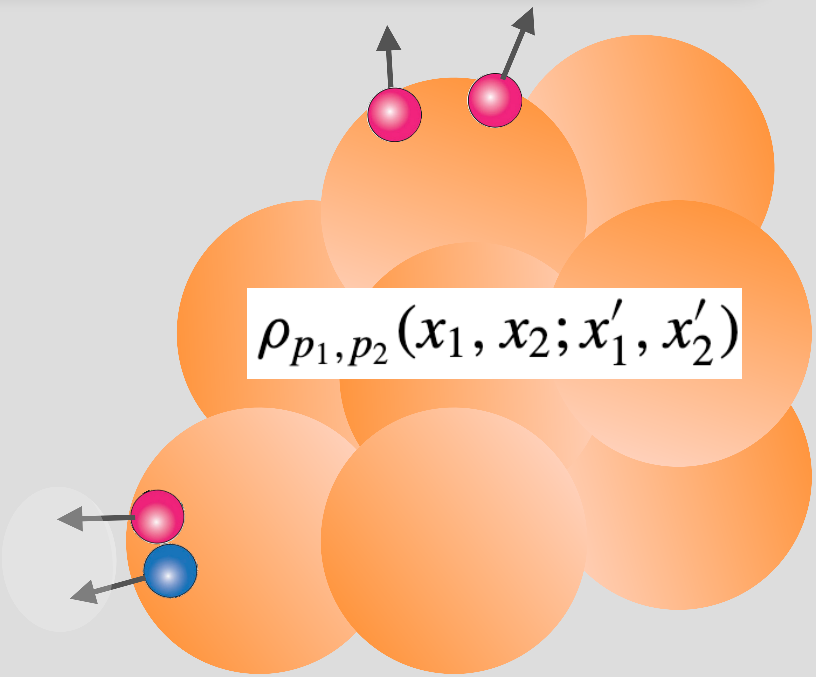




$$C(p, q) = \frac{\sum_s \gamma_1\gamma_2 \frac{dN_{2,s}}{d^3\mathbf{p}_1 d^3\mathbf{p}_2}}{\gamma_1\gamma_2 \frac{dN_2^0}{d^3\mathbf{p}_1 d^3\mathbf{p}_2}}$$



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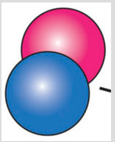

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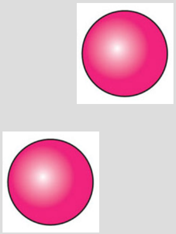
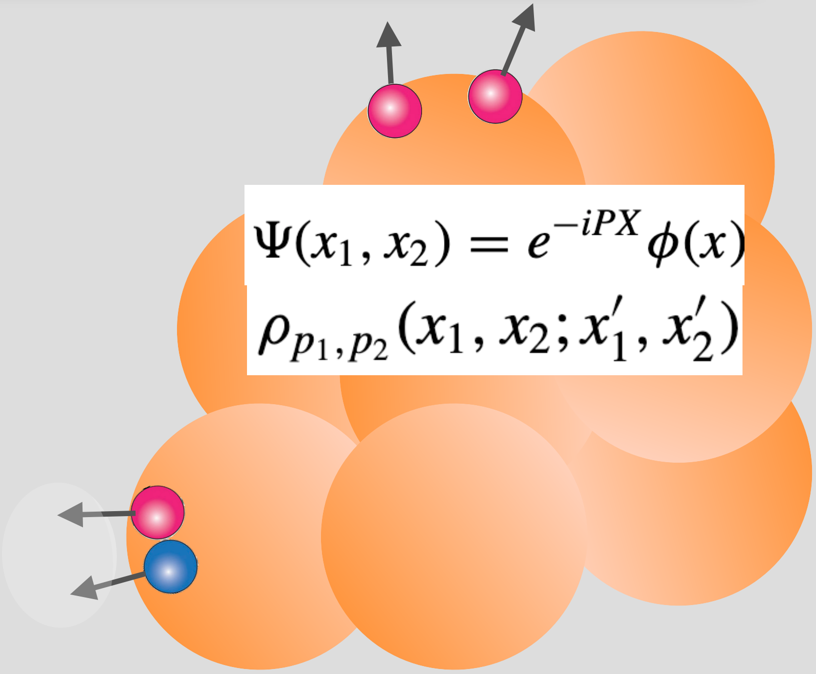


$$C_s(p, q) \approx \int d^3\mathbf{r} \, |\phi_{s,q}(\mathbf{r})|^2 \mathcal{S}_2(\mathbf{r})$$

This is how correlations are always analyzed.



$$\Psi(x_1, x_2) = e^{-iPX}\phi(x)$$

$$\rho_{p_1,p_2}(x_1, x_2; x_1', x_2')$$

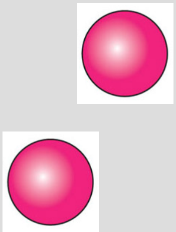
$$\gamma_1\gamma_2 \frac{dN_{2,s}}{d^3\mathbf{p}_1 d^3\mathbf{p}_2} = \frac{2s+1}{(2\pi)^6}\int d^4r \times \int \frac{d^4k}{(2\pi)^4}\,\tilde{\mathcal{D}}_{s,q}(k,r)\,\tilde{S}_{p_1,p_2}(k,r)$$

$$\tilde{\mathcal{D}}(k,r) = \int d^4\zeta\, e^{ik\zeta}\,\phi\left(r+\frac{\zeta}{2}\right)\phi^*\left(r-\frac{\zeta}{2}\right)$$

$$\tilde{S}_{p_1,p_2}(k,r) = \int d^4x \int d^4l_1\, e^{-il_1(c_1P+k)} \int d^4l_2\, e^{-il_2(c_2P-k)} \times \rho_{p_1,p_2}\left(x+c_2r+\frac{l_1}{2}, x-c_1r+\frac{l_2}{2}; x + c_2r-\frac{l_1}{2}, x-c_1r-\frac{l_2}{2}\right).$$

$$\phi(x) = \phi(\mathbf{x})\left[1+O\left(\frac{t}{m\mathbf{x}^2}\right)\right]$$

$$\mathcal{S}_2(\mathbf{r}) = \frac{\int dr^0\,\tilde{S}_{p_1,p_2}(0,r)}{\int d^4r\,\tilde{S}^0_{p_1,p_2}(0,r)}$$



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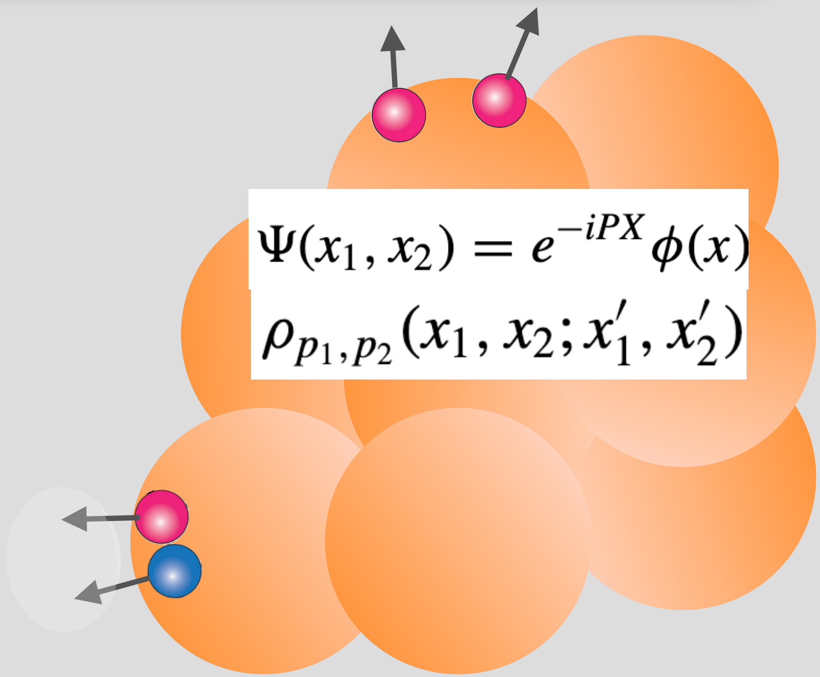

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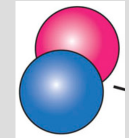

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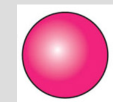

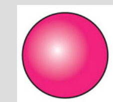

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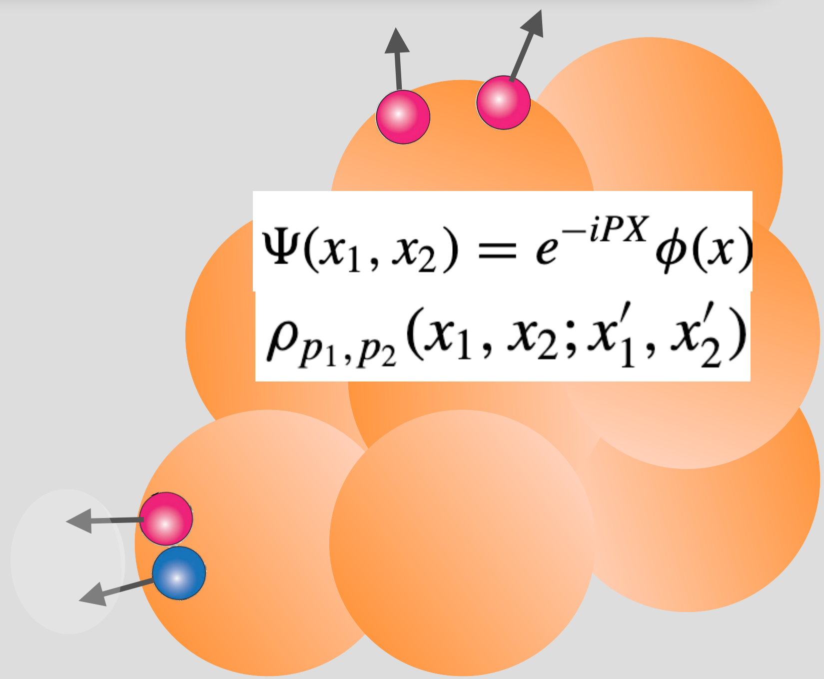
$$\mathcal{B}_2(p) = \frac{P^0 \frac{dN_\mathrm{d}}{d^3\mathbf{P}}}{p_1^0 p_2^0 \frac{dN_2^0}{d^3\mathbf{p}_1 d^3\mathbf{p}_2}} \approx \frac{2}{m} \frac{\gamma \frac{dN_\mathrm{d}}{d^3\mathbf{P}}}{\gamma_1\gamma_2 \frac{dN_2^0}{d^3\mathbf{p}_1 d^3\mathbf{p}_2}}$$



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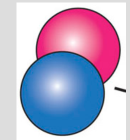

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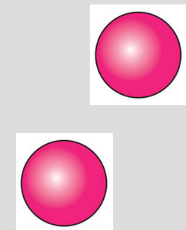

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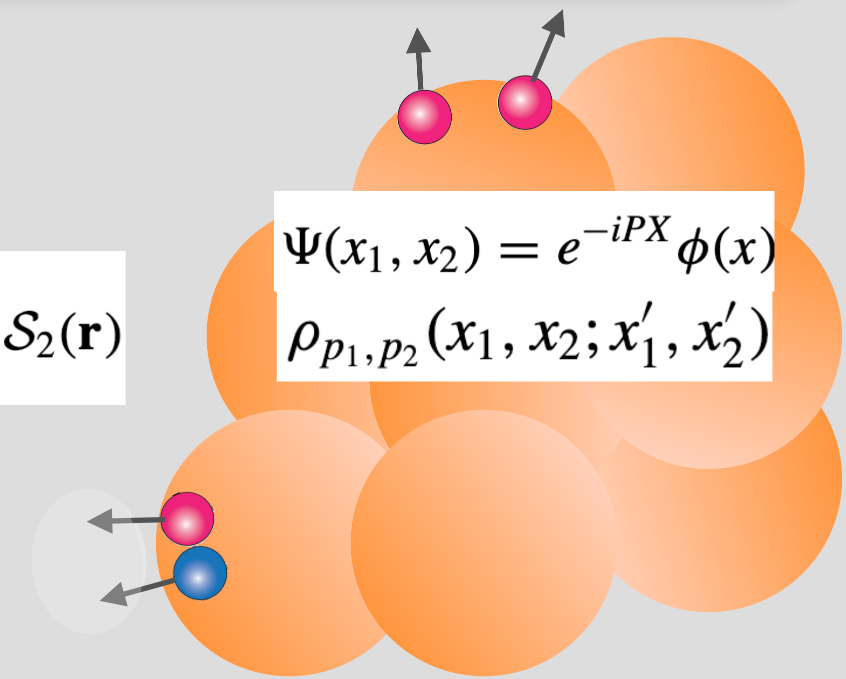

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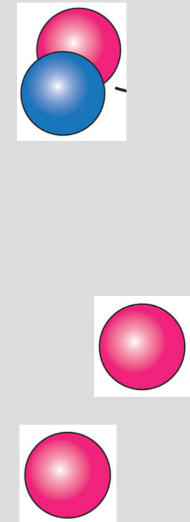

KB, Takimoto 2019 (Heinz, Mrowczynski…)

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Same object.

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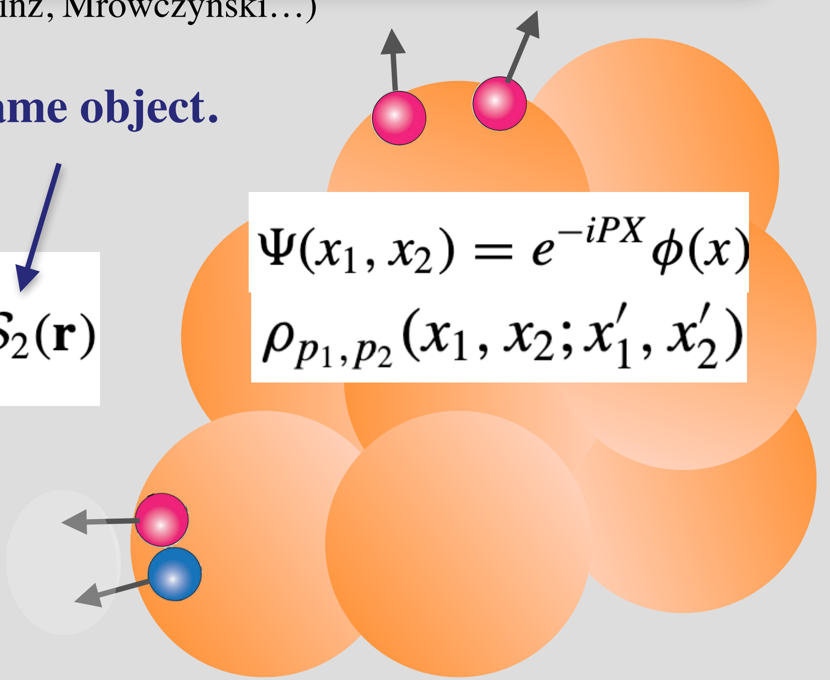

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— Would be great to see nuclei yields and correlation size **on the same plot.** With the same cuts, rapidity, pt, multiplicity,…

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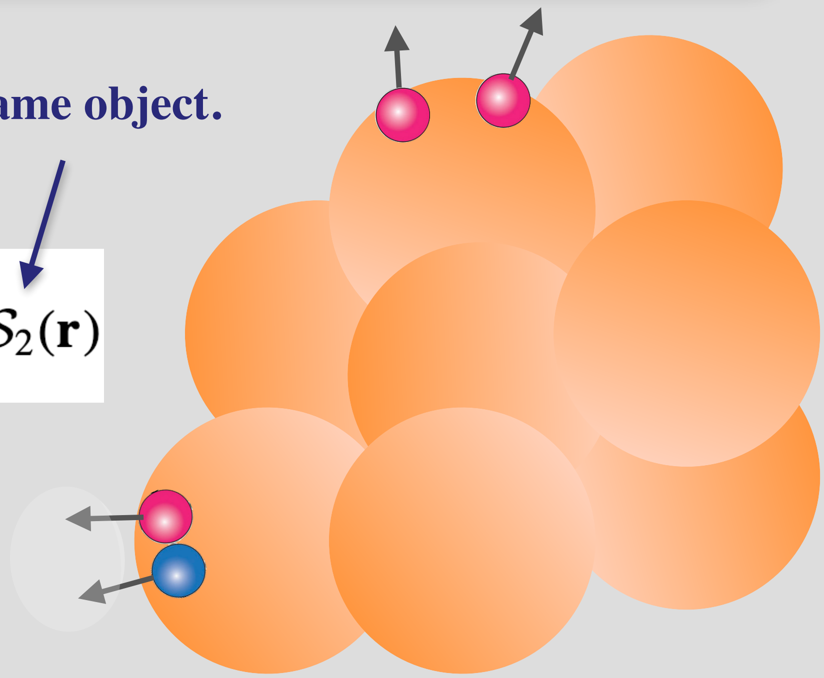

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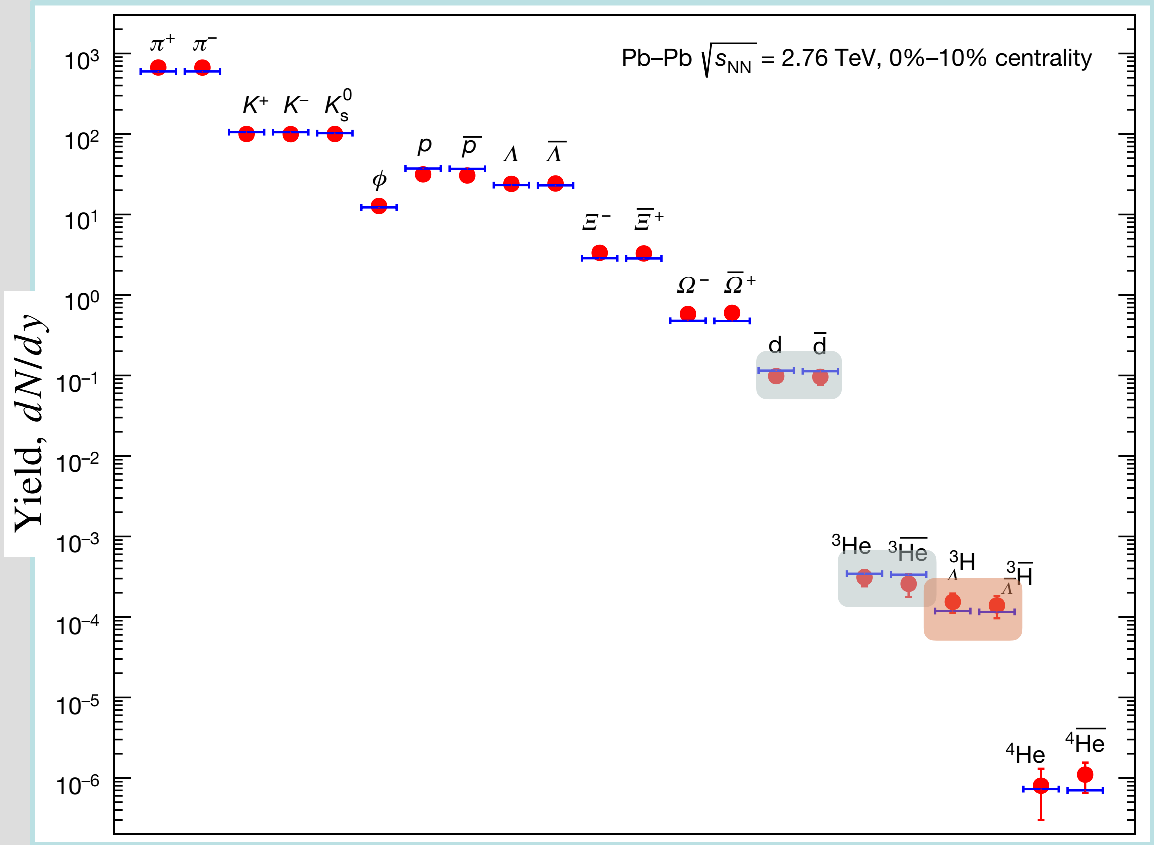

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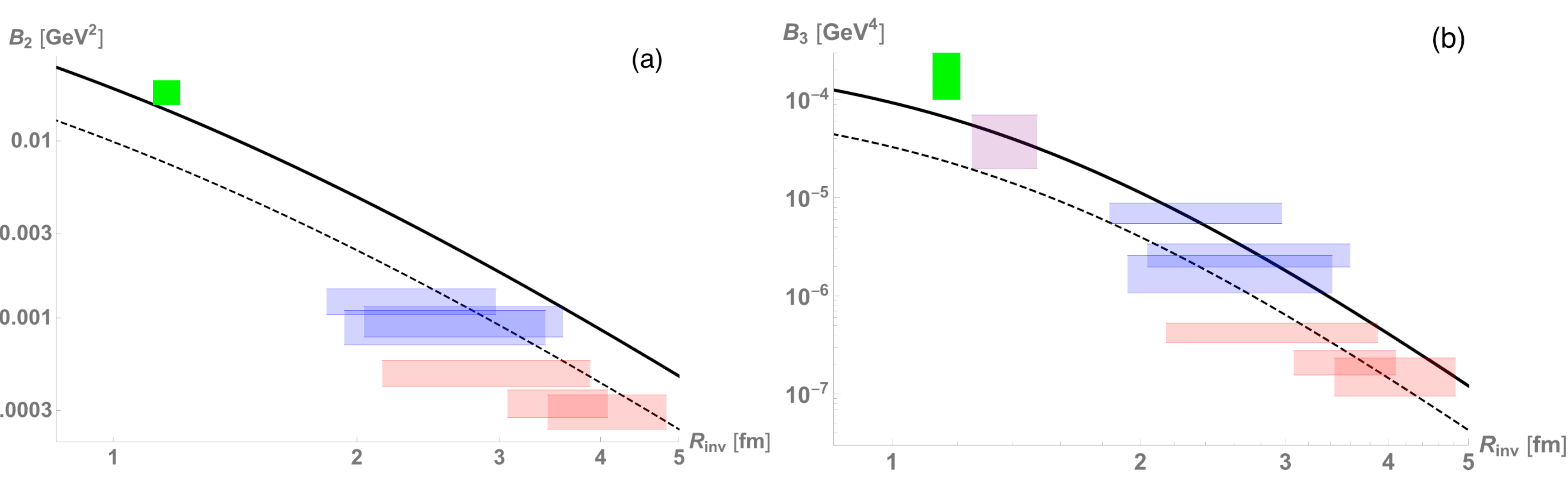

Bellini, KB, Kalweit, Puccio 2020

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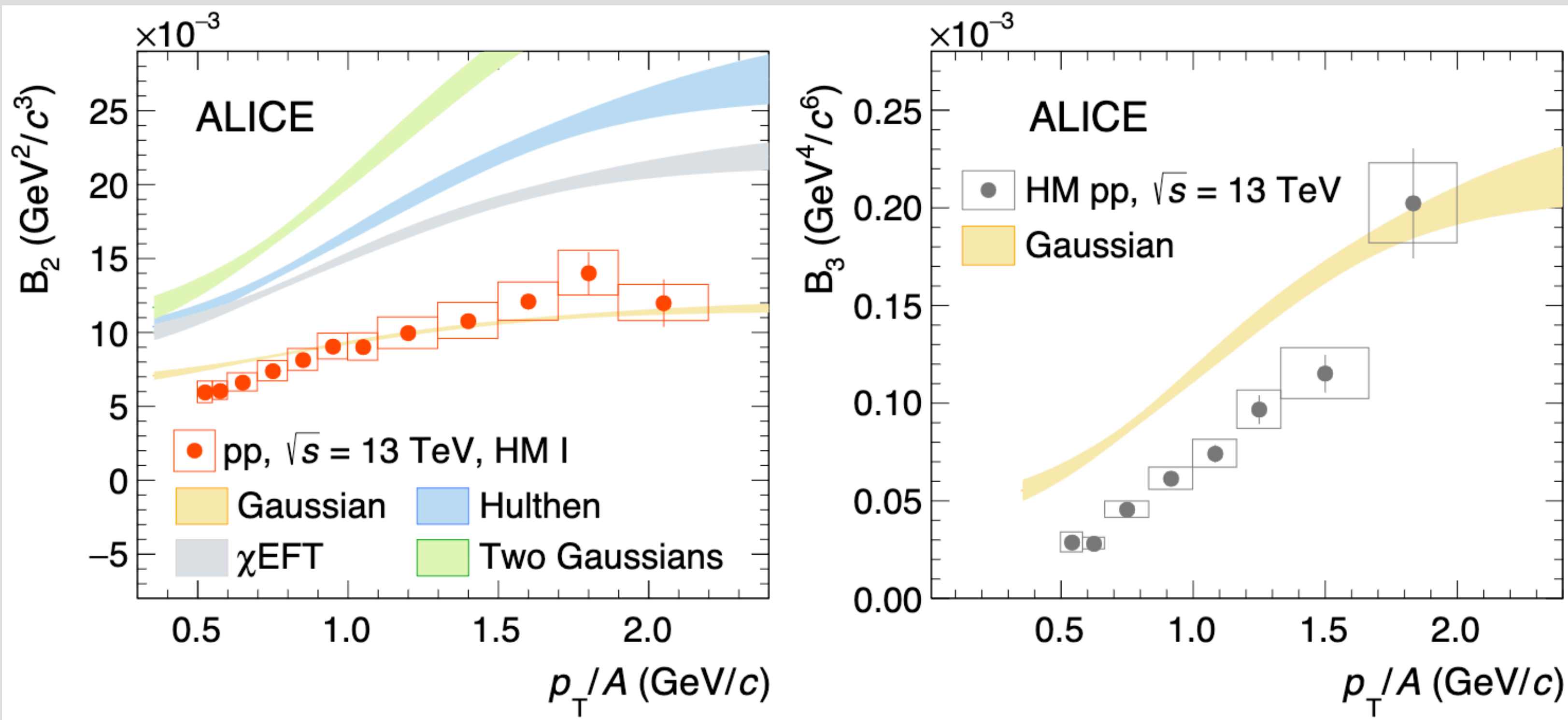
ALICE is making progress in this. Would love to see program @RHIC.

2004.08018 (HBT), 2109.13026 (yields)



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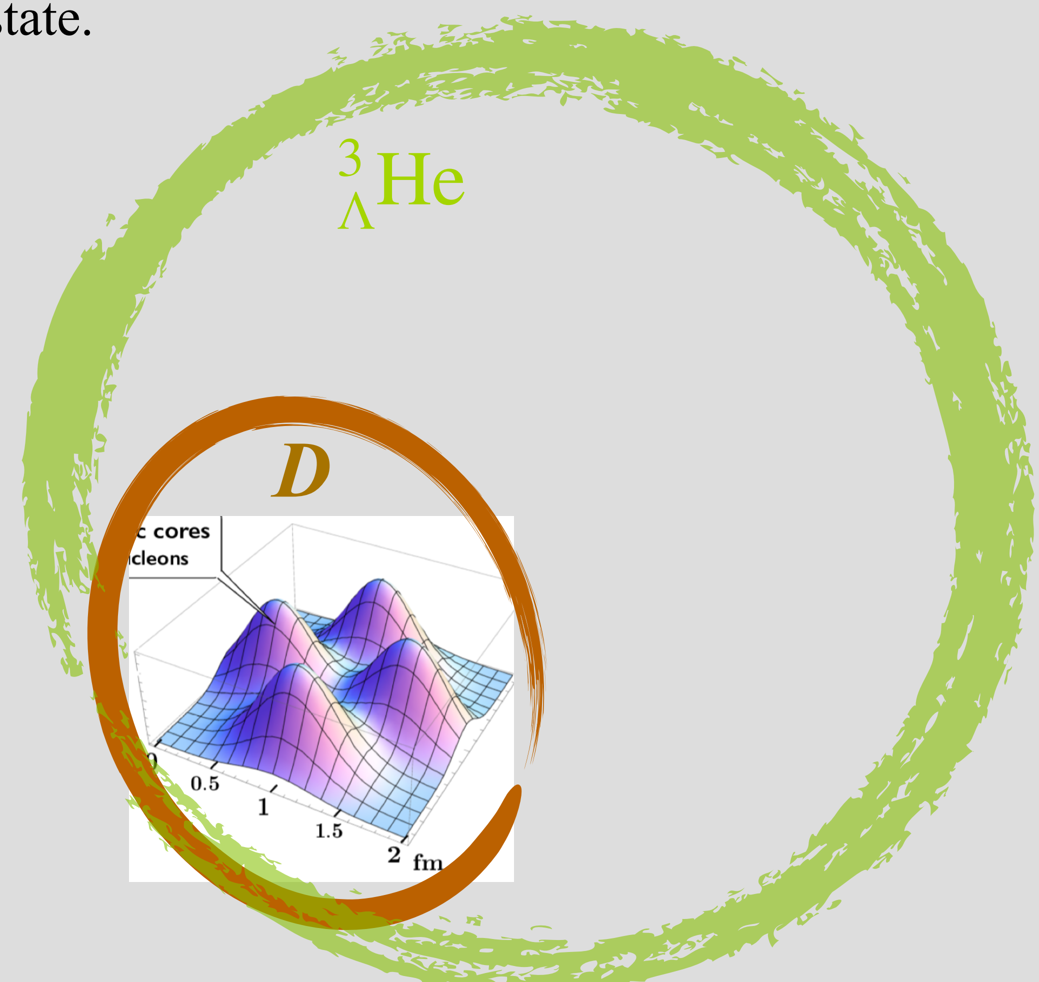

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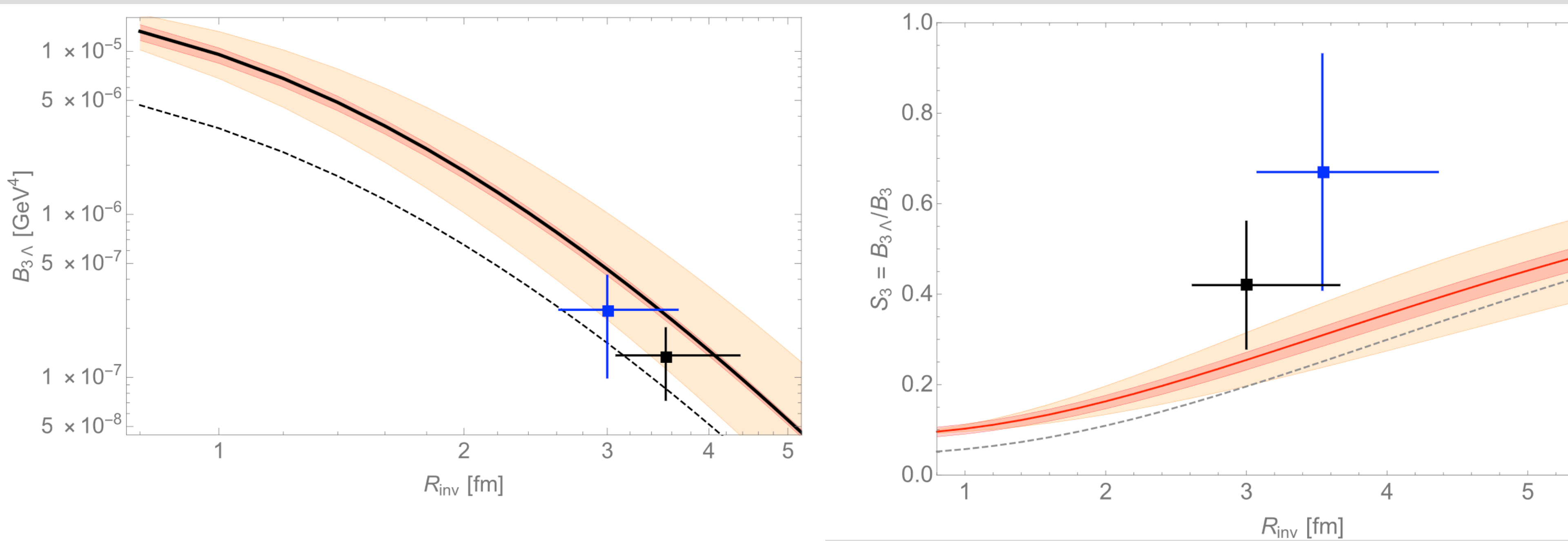

Bellini, KB, Kalweit, Puccio 2020

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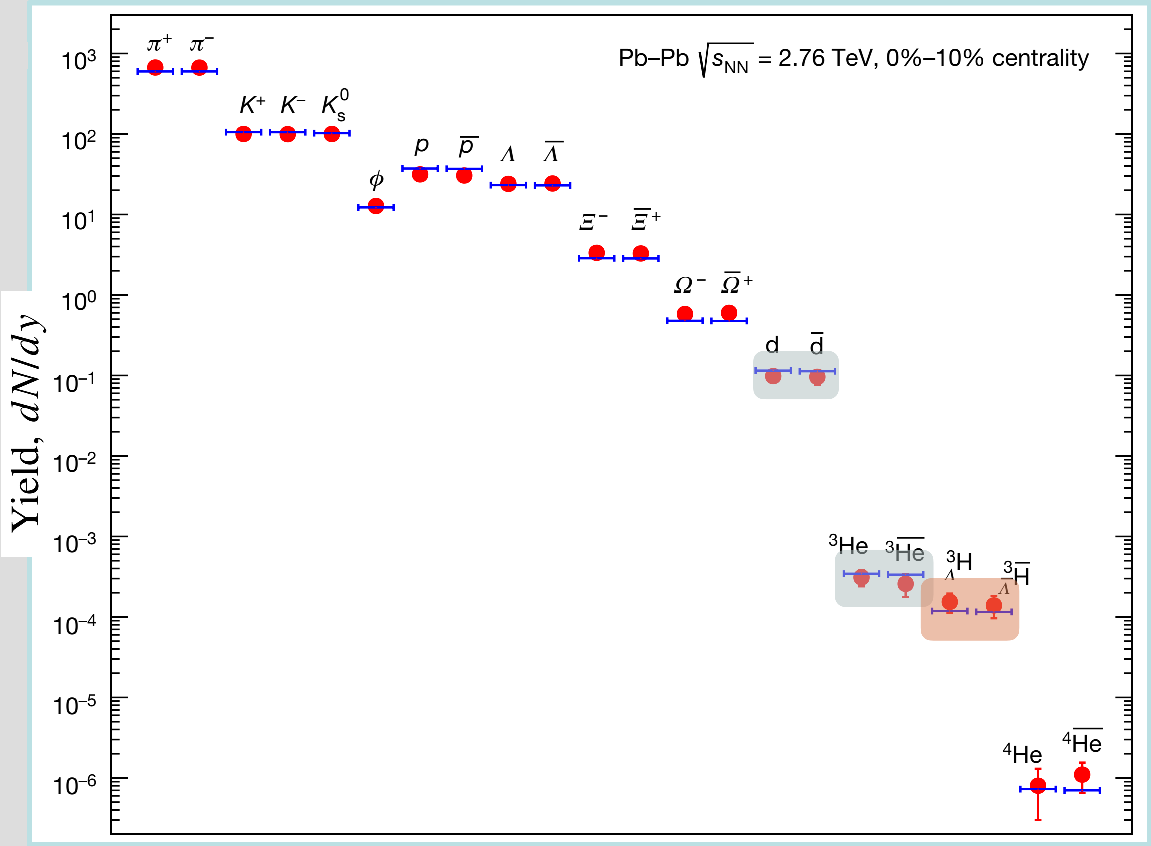

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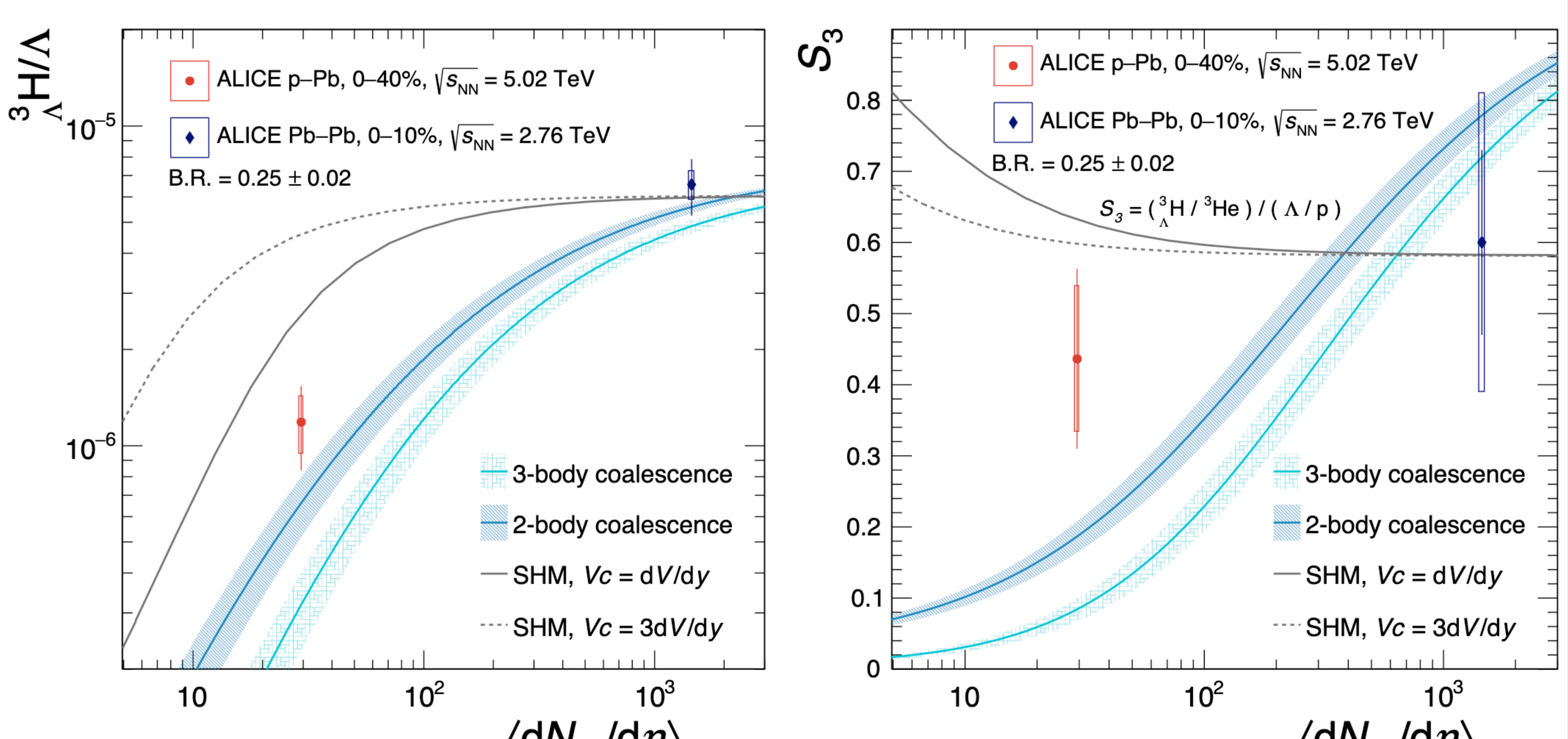

ALICE 2107.10627

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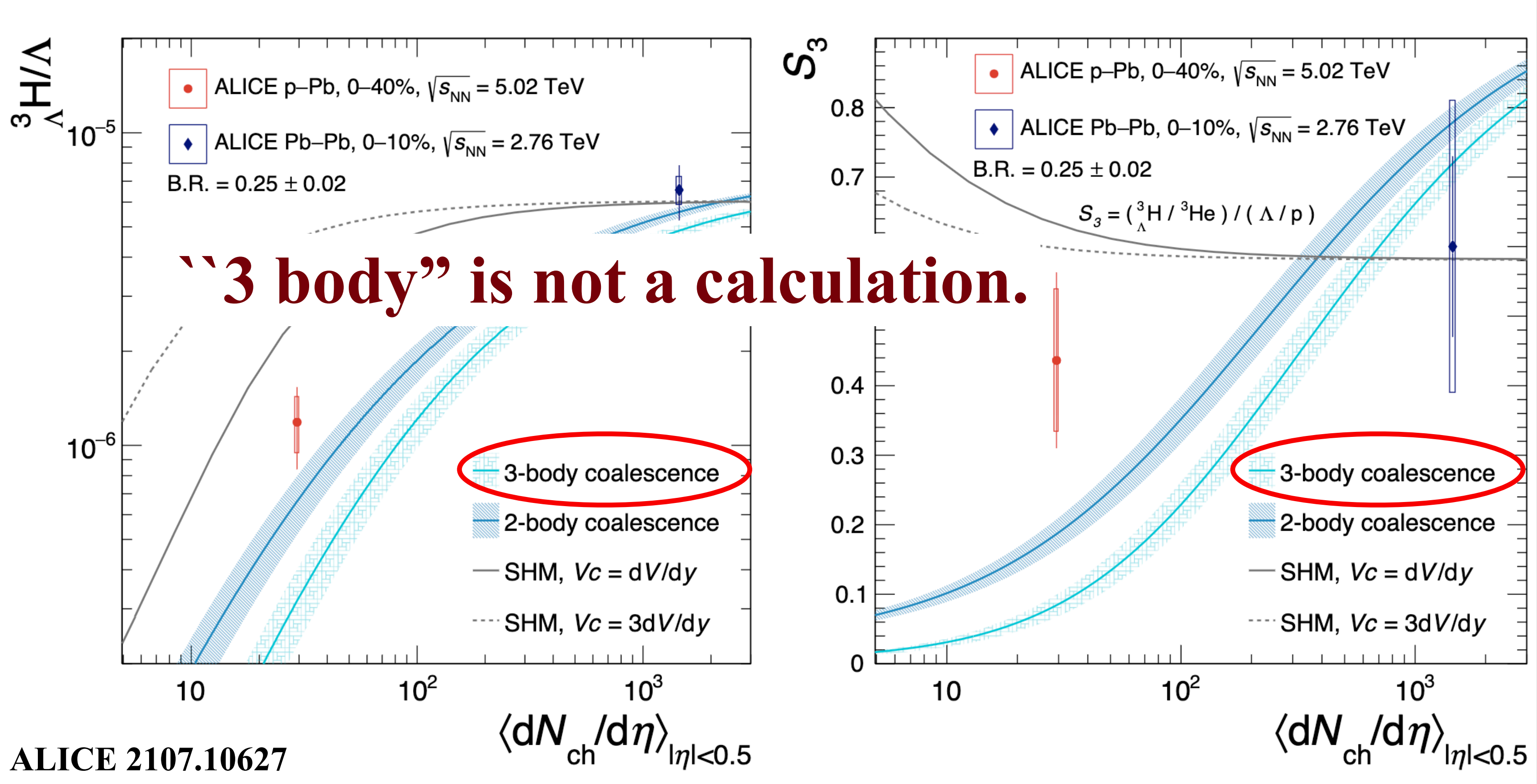

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ALICE 2107.10627

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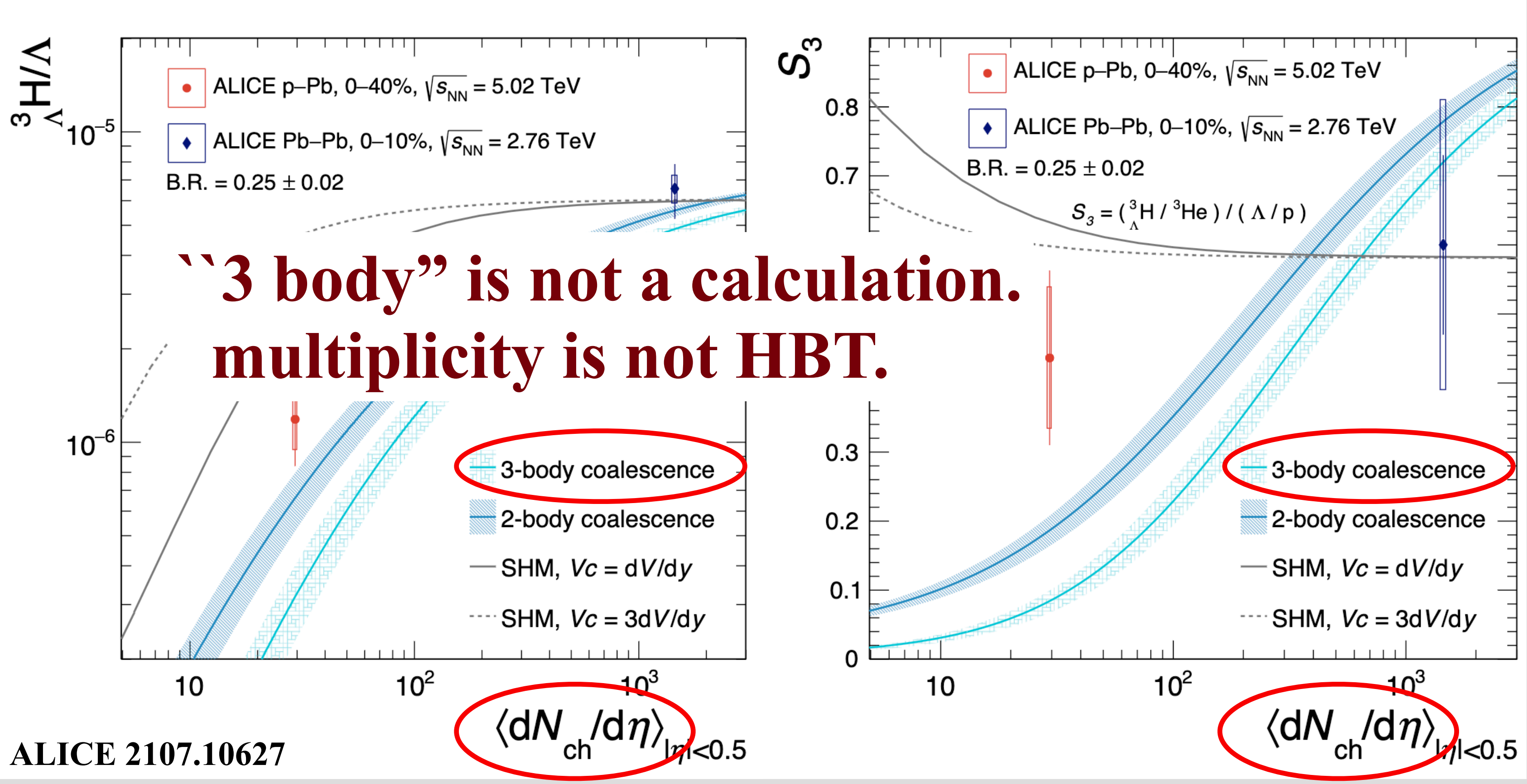


``3 body" is not a calculation.
multiplicity is not HBT.

ALICE 2107.10627

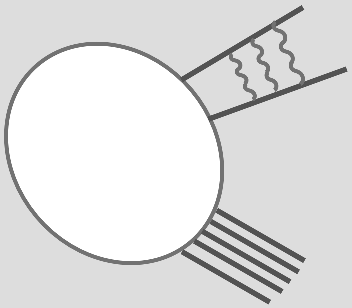
Summary (1)

Coalescence is irreducible
in the same framework in which
people interpret correlations/HBT/femtoscopy.

Scheibl & Heinz 1999

KB, Ng, Takimoto, Sato 2017
KB, Takimoto 2019
Bellini, KB, Kalweit, Puccio 2020

This means that if you accept the standard HBT interpretation,
then you cannot really ask ``does coalescence take place”.
(You can ask ``how much”.)



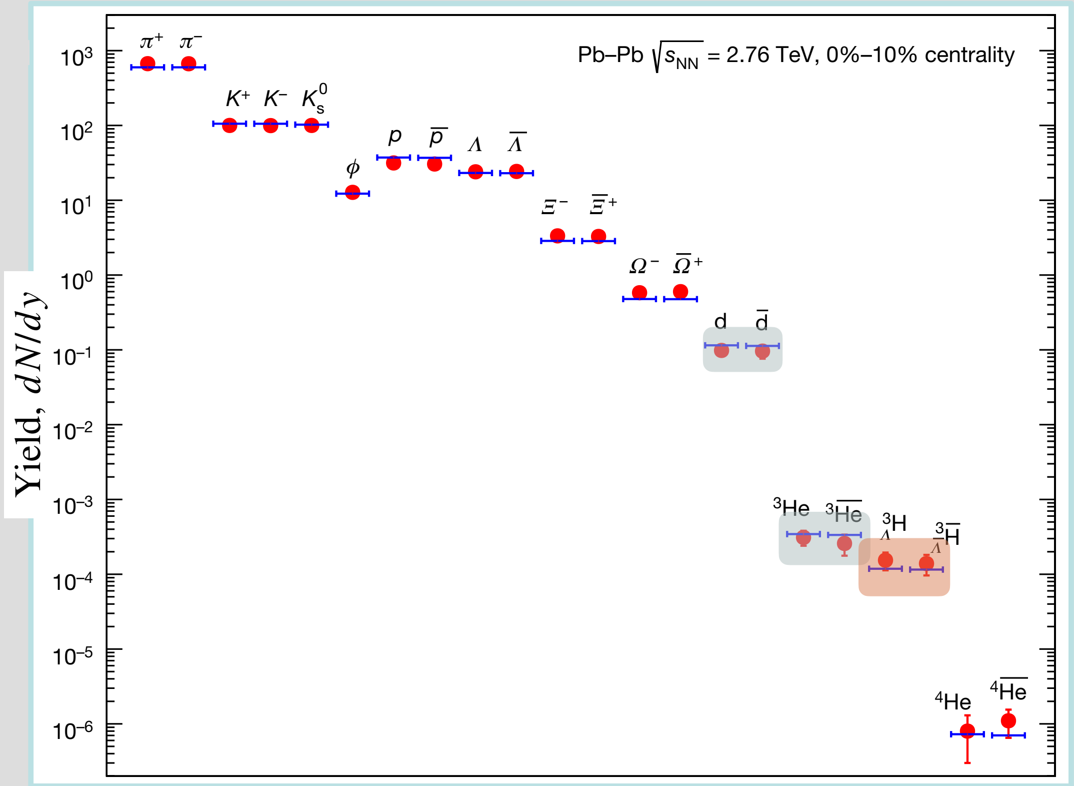
Summary (2)

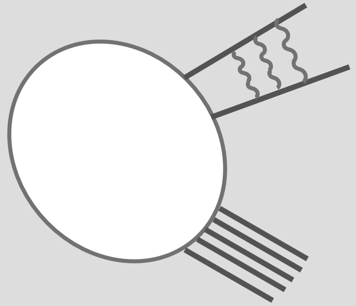
Coalescence does pretty much as well as thermal fit; and it is theory, not a fit.

Calibrated against HBT, coalescence does
not have free model parameters.
I don't know how to do this to better than O(1).
O(1) is not so bad.

Scheibl & Heinz 1999

KB, Ng, Takimoto, Sato 2017
KB, Takimoto 2019
Bellini, KB, Kalweit, Puccio 2020

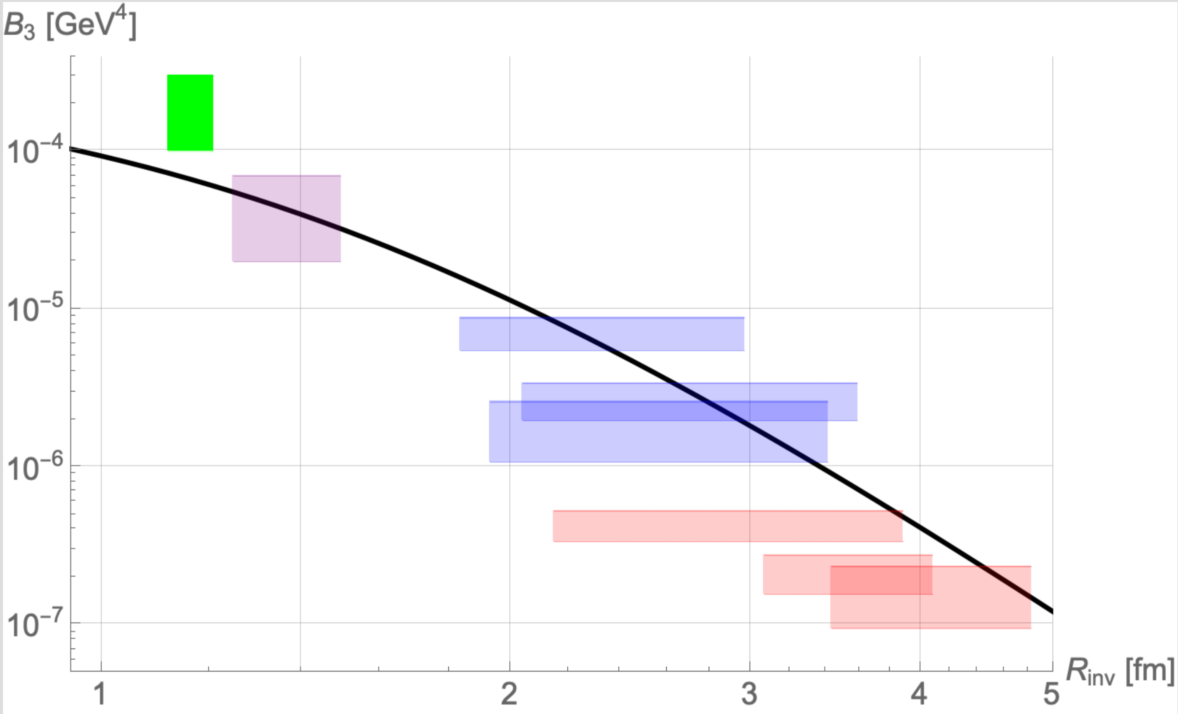




Summary (2.5)

Coalescence does pretty much as well as thermal fit; and it is theory, not a fit.

Coalescence calibrated against HBT:
Quite detailed predictions.
I would be delighted to see this program also at RHIC.



Scheibl & Heinz 1999

KB, Ng, Takimoto, Sato 2017
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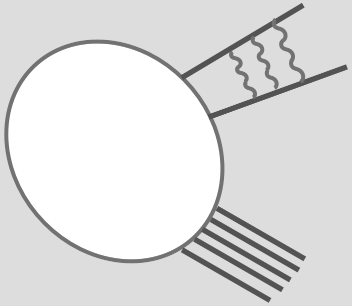


Summary (3)

Coalescence does pretty much as well as thermal fit; and it is theory, not a fit.

Hyper-T is golden because it's fluffy.

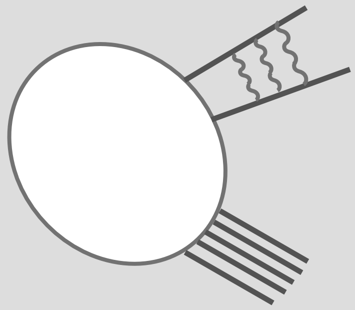
Scheibl & Heinz 1999

Coalescence does OK in PbPb
(Bellini, KB, Kalweit, Puccio 2020)

KB, Ng, Takimoto, Sato 2017
KB, Takimoto 2019
Bellini, KB, Kalweit, Puccio 2020

perhaps not bad in pPb
(ALICE 2107.10627)

what we really want to see is **pp**.



Thank you very much!