FEMTOSCOPY AND HADROCHEMISTRY

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* in the spirit of a femtoscopy workshop

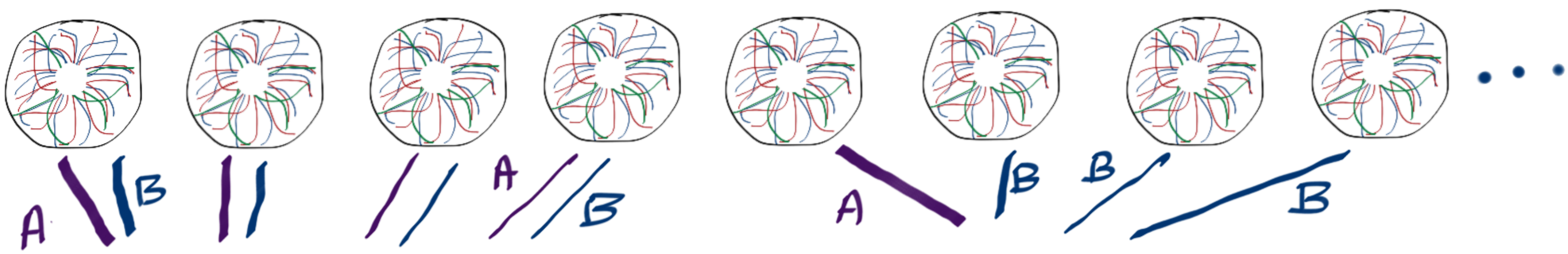
OUTLINE

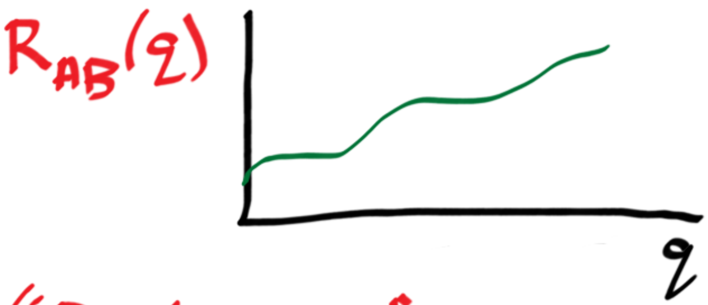
- TWO VIEWS OF A 2-PARTICLE CORRELATION
- STAR $\pi - \Xi$ PUZZLE
- FEMTOSCOPY - NUCLEO/HADROCHEMISTRY "DUALITY"
  - IN SIMPLEST MODEL

    "DOUBLE COUNTING" ?
- MANY QUESTIONS
- NO CONCLUSION SLIDE*

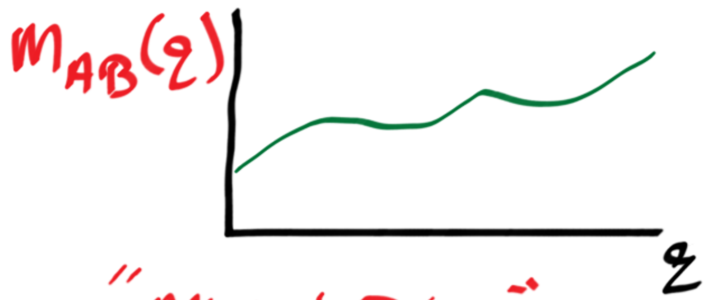
* in the spirit of a femtoscopy workshop

"MIXED EVENT" APPROACH:





"Real pairs"



"Mixed Pairs"

q = difference measure: k^*, M_{inv}, Q ....

RESONANCE $D^* \longrightarrow A + B$ (e.g. $\Delta^+ \longrightarrow p\,\pi^0$)

MANIFESTS AS AN ENHANEMENT IN R_{AB}

D^*
- ATTRACTIVE STRONG FSI b/t A + B?
- "PARTICLE"?

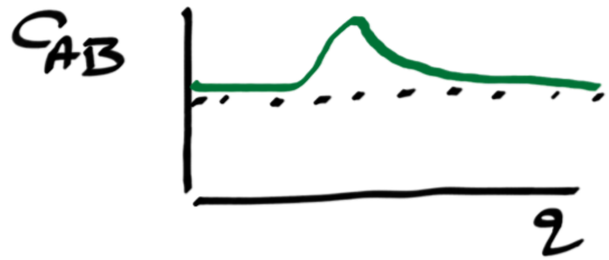
$R_{AB}(q)$ - "real" pairs $M_{AB}(q)$ - "mixed" pairs

FEMTOSCOPY

$$C_{AB}(q) = N \frac{R_{AB}(q)}{M_{AB}(q)} = \int d^3r\, S_{AB}(r')\, |\Phi(q', r')|^2$$

KOONIN - PRATT EQ.

- sensitive to spatial scales ("HBT radii", homo volume...)



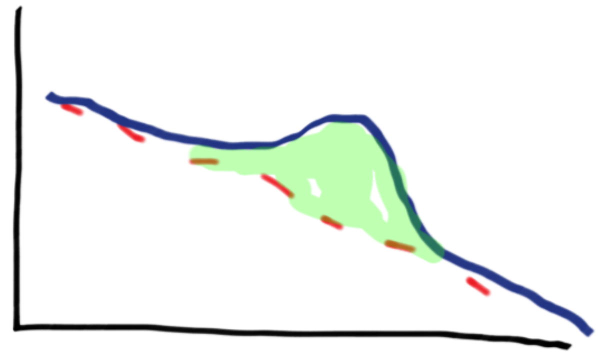
- insensitive to "Temperature, μ_B ...

D^* · ATTRACTIVE STRONG F.S.I. b/t A, B
– included in $\Phi_{AB}(r', q)$

$R_{AB}(q)$ - "real" pairs $M_{AB}(q)$ - "mixed" pairs

HADROCHEMISTRY

• D^* IS A PARTICLE



$$N_{D^*} = \int dM_{inv} \left[R_{AB}(M_{inv}) - \mathcal{N} M_{AB}(M_{inv}) \right]$$

$$N_A = \int d^3p_A \frac{d^3N}{d^3p_A} = V \frac{g_A}{2\pi^2} e^{\mu_A/T} \int_0^\infty p^2 dp \, e^{-E_A(p)/T}$$

• $\mu_A = B_A \mu_B + S_A \mu_S + I_{3A} \mu_I + \ldots$

• $\mu_{D^*} = \mu_A + \mu_B$

• PARTICLE RATIOS

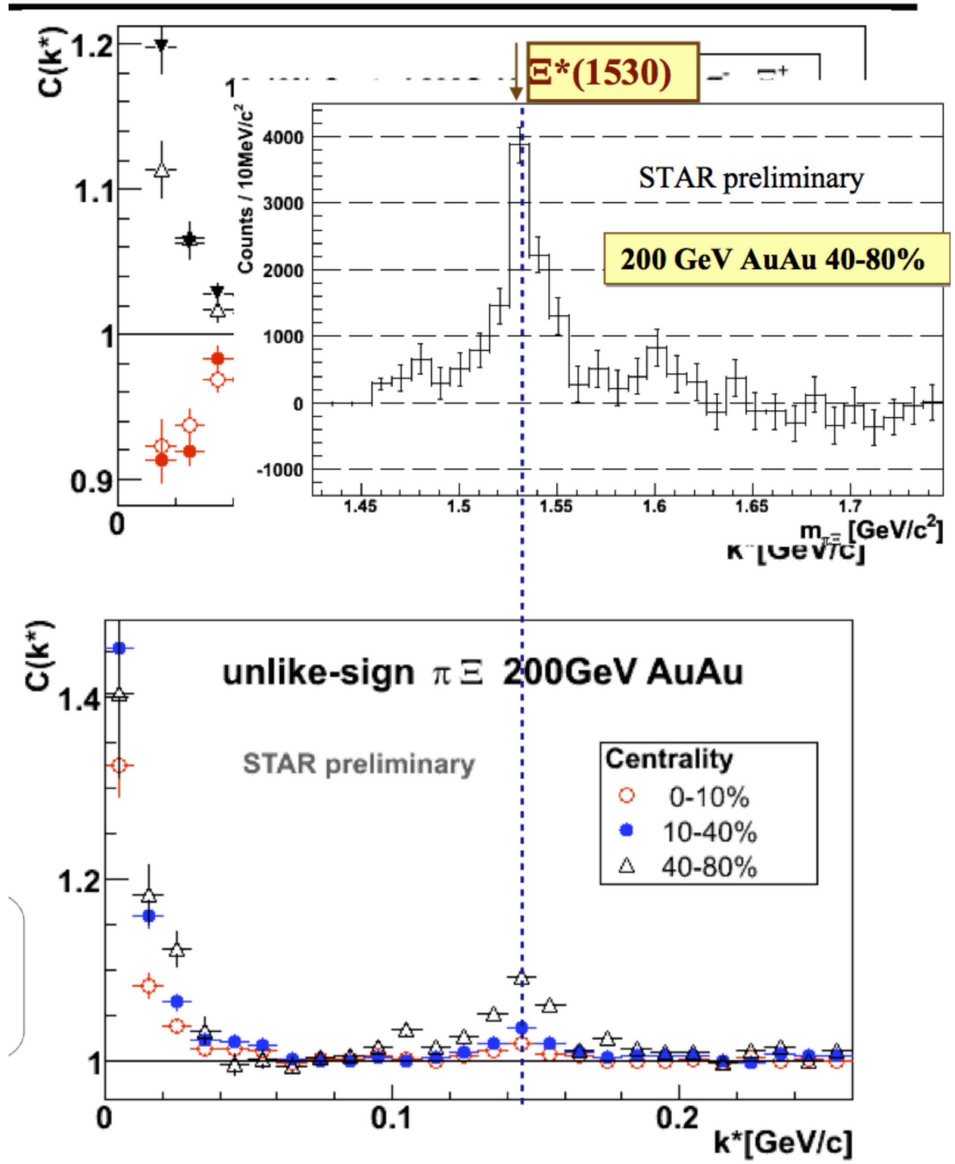
- Sensitive to T, μ_*
- insensitive to V

STAR COLLAB ~ 2005

P. CHALOUPKA (Prague)

Ξ-π femtosopy

- Coulomb
- Ξ* → Ξ + π for opposite sign



STAR COLLAB ~ 2005

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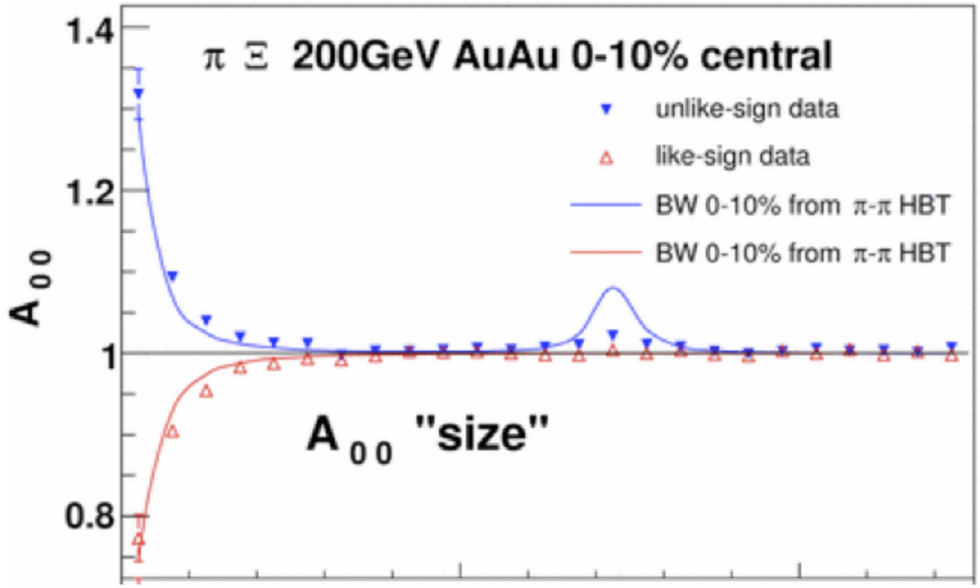


$\Xi - \pi$ femtosopy

- Coulomb
- $\Xi^* \rightarrow \Xi + \pi$ for opposite sign

Calculation w/ Koonin-Pratt + STAR BW source:

Space-time source

✓ Coulomb

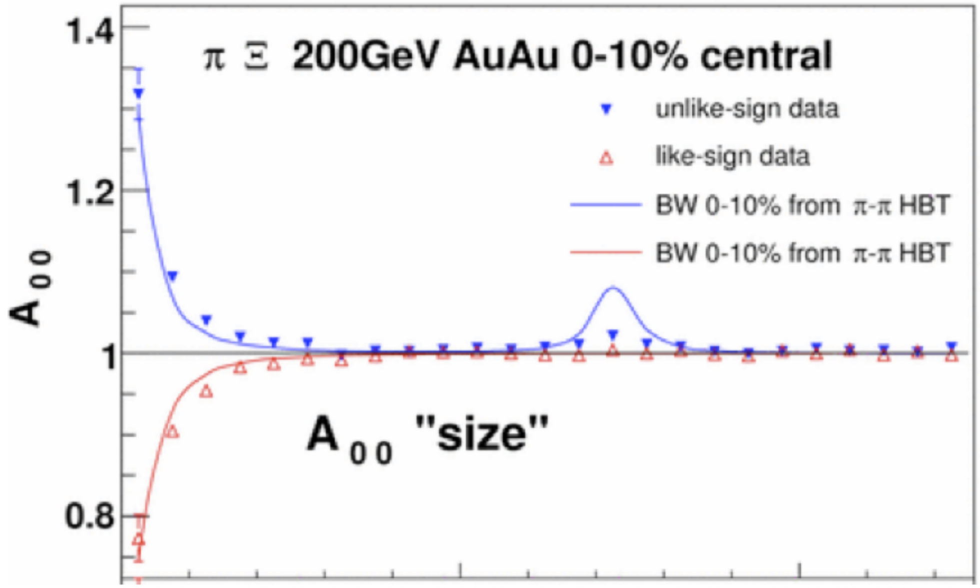
✗ Strong F.S.I. (Ξ^*)

STAR COLLAB ~ 2005

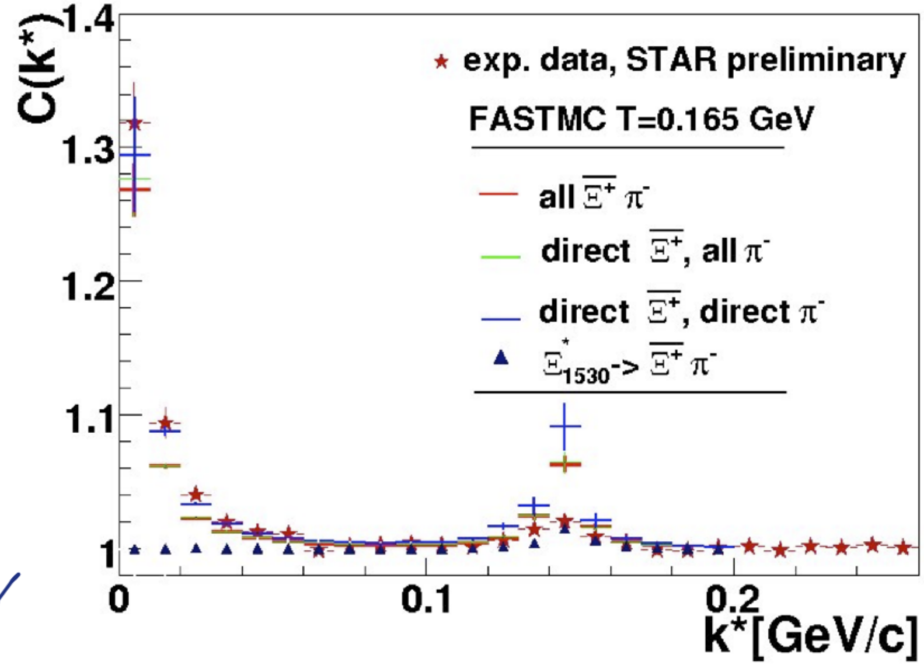
P. CHALOUPKA (Prague)

Ξ - π femtosopy

- Coulomb
- $\Xi^* \rightarrow \Xi + \pi$ for opposite sign



- Treatment as strong FSI with KOONIN-PRATT OVER-PREDICTS enhancement



- Neglecting Ξ-π F.S.I., "directly-produced" Ξ^* decay UNDER-PREDICTS enhancement

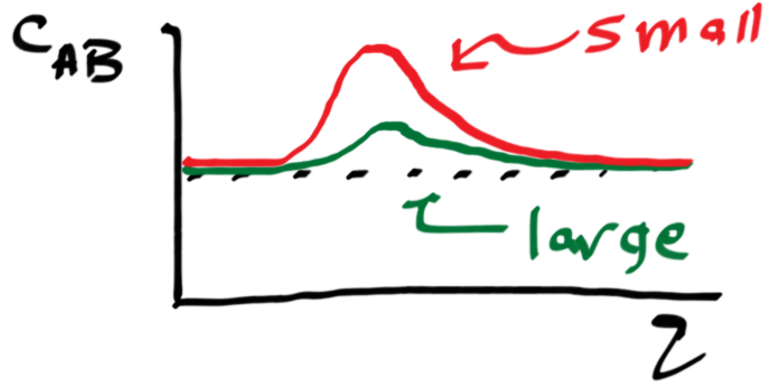
$\rightarrow$ try a little of each? ......

FOR A FIXED N_A, N_B, A LARGE N_{D^*} MEANS...

FEMTOSCOPIST:

SMALL SOURCE!

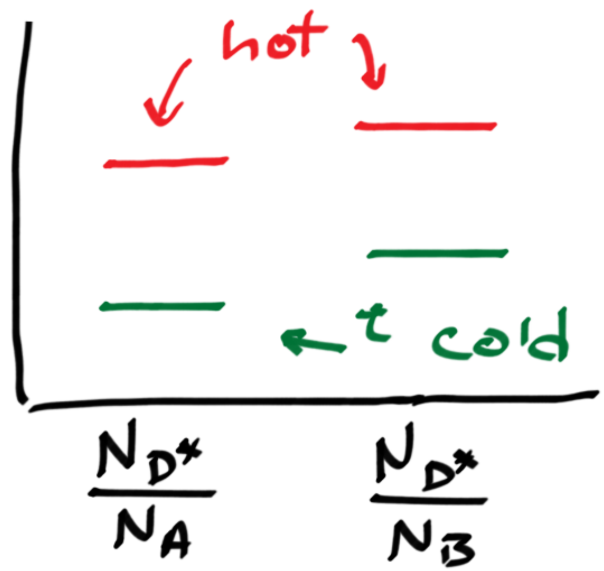
(Hot or cold)



HADROCHEMIST:

HOT SOURCE!

(large or small)

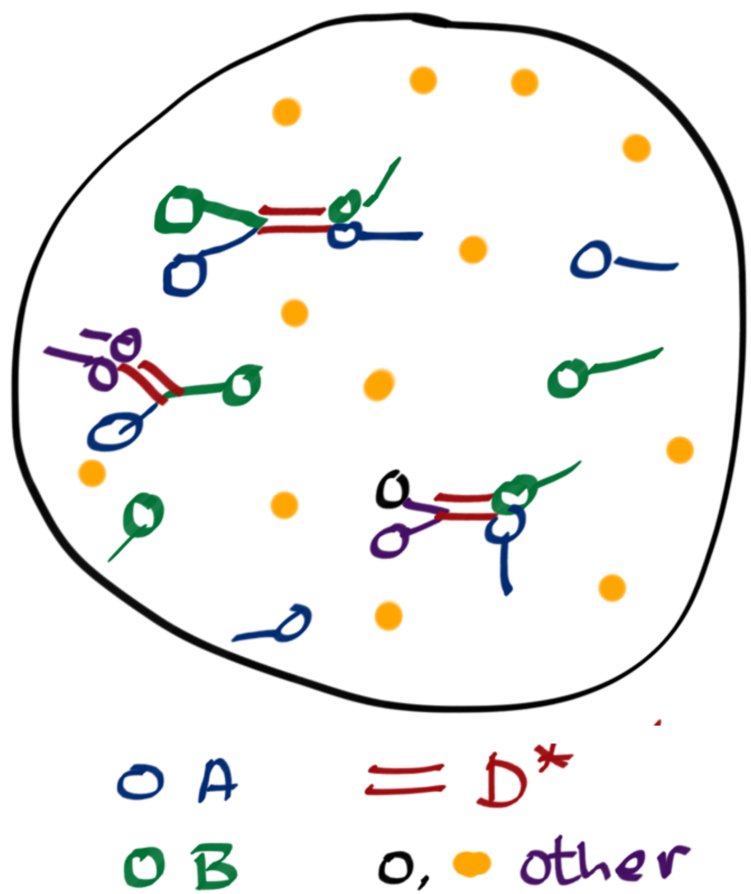


...clearly, we need to be more specific...

FIRST: SIMPLEST THERMAL MODEL ASSUMPTIONS

- SOURCE IN THERMOCHEMICAL EQUILIB $A+B \rightleftarrows D^*$
- Volume V, TEMP T, C.P. μ_*
- UNIFORM DENSITY
- NO FLOW
- INSTANT FREEZEOUT

CONSIDER D^* A PARTICLE



FEMTOSCOPIC

$$C_{AB}(M_{D^*}) = \frac{\dfrac{d^6N_{AB}}{d^3p_A\, d^3p_B}}{\dfrac{d^3N_A}{d^3p_A}\cdot\dfrac{d^3N_B}{d^3p_B}} = \frac{R_{AB}(M_{D^*})}{M_{AB}(M_{D^*})} = \frac{D^*\,\text{contrib} + M_{AB}(M_{D^*})}{M_{AB}(M_{D^*})}$$

FEMTOSCOPIC

$$C_{AB}(M_{D^*}) = \frac{\dfrac{d^6N_{AB}}{d^3p_A\, d^3p_B}}{\dfrac{d^3N_A}{d^3p_A}\cdot\dfrac{d^3N_B}{d^3p_B}} = \frac{R_{AB}(M_{D^*})}{M_{AB}(M_{D^*})} = \frac{D^*\,\text{contrib} + M_{AB}(M_{D^*})}{M_{AB}(M_{D^*})}$$

$$= \frac{V e^{\mu_{D^*}/T} \frac{g_{D^*}}{2\pi^2} \int_0^\infty p^2 e^{-E_{D^*}(p)/T} f(p_{D^*} \rightarrow \vec{p}_A, \vec{p}_B)}{\left(V e^{\mu_A/T} \frac{g_A}{2\pi^2} e^{-E_A(p_A)/T}\right)\left(V e^{\mu_B/T} \frac{g_A}{2\pi^2} e^{-E_B(p_B)/T}\right)} + 1$$

FEMTOSCOPIC

$$C_{AB}(M_{D^*}) = \frac{\dfrac{d^6N_{AB}}{d^3p_A\, d^3p_B}}{\dfrac{d^3N_A}{d^3p_A}\cdot\dfrac{d^3N_B}{d^3p_B}} = \frac{R_{AB}(M_{D^*})}{M_{AB}(M_{D^*})} = \frac{D^*\,\text{contrib} + M_{AB}(M_{D^*})}{M_{AB}(M_{D^*})}$$

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$$(\mu_{D^*} = \mu_A + \mu_B)$$

FEMTOSCOPIC

$$C_{AB}(M_{D^*}) = \frac{\dfrac{d^6N_{AB}}{d^3p_A\, d^3p_B}}{\dfrac{d^3N_A}{d^3p_A}\cdot\dfrac{d^3N_B}{d^3p_B}} = \frac{R_{AB}(M_{D^*})}{M_{AB}(M_{D^*})} = \frac{D^*\,\text{contrib} + M_{AB}(M_{D^*})}{M_{AB}(M_{D^*})}$$

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$(\mu_{D^*} = \mu_A + \mu_B)$

$(E_{D^*} = E_A + E_B)$

μ, T dependence gone ✓

FEMTOSCOPIC

$$C_{AB}(M_{D^*}) = \frac{\dfrac{d^6N_{AB}}{d^3p_A\, d^3p_B}}{\dfrac{d^3N_A}{d^3p_A}\cdot\dfrac{d^3N_B}{d^3p_B}} = \frac{R_{AB}(M_{D^*})}{M_{AB}(M_{D^*})} = \frac{D^*\,\text{contrib} + M_{AB}(M_{D^*})}{M_{AB}(M_{D^*})}$$

$$= \frac{1}{V}\,\frac{2\pi^2 g_{D^*}}{g_A\, g_B}\int_0^\infty p_{D^*}^2\, dp_{D^*}\, f(\vec{p}_{D^*} \longrightarrow \vec{p}_A\, \vec{p}_B) + 1$$

FEMTOSCOPIC

$$C_{AB}(M_{D^*}) = \frac{\dfrac{d^6N_{AB}}{d^3p_A\, d^3p_B}}{\dfrac{d^3N_A}{d^3p_A}\cdot\dfrac{d^3N_B}{d^3p_B}} = \frac{R_{AB}(M_{D^*})}{M_{AB}(M_{D^*})} = \frac{D^*\text{contrib} + M_{AB}(M_{D^*})}{M_{AB}(M_{D^*})}$$

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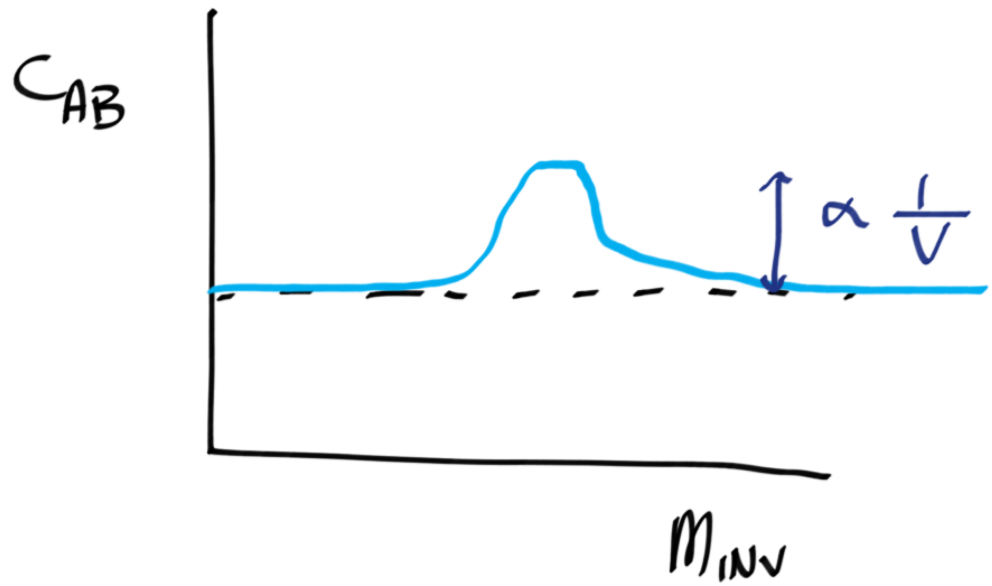


HADROCHEMICAL

non-rel. approx.

$$\frac{N_{D^*}}{N_A} = \frac{V e^{(\mu_{D^*}-m_{D^*})/T} \, \frac{g_{D^*}}{2\pi^2}\sqrt{\frac{\pi}{2}}\,(m_{D^*}T)^{3/2}}{V e^{(\mu_A - m_A)/T} \, \frac{g_A}{2\pi^2}\sqrt{\frac{\pi}{2}}\,(m_A T)^{3/2}}$$

$$= \frac{g_{D^*}}{g_A}\left(\frac{m_{D^*}}{m_A}\right)^{3/2} e^{(\mu_{D^*}-\mu_A-(m_{D^*}-m_A))/T}$$

"Femto-like": $$\frac{N_{D^*}}{N_A N_B} = \frac{g_{D^*}}{g_A g_B}\left(\frac{2\pi\, m_{D^*}}{m_A m_B T}\right)^{3/2}\frac{1}{V}\, e^{-Q/T}$$

- $\sim \frac{1}{V}$
- residual T-dep (b/c integrate over all m^*)

$$Q = m_{D^*} - m_A - m_B$$

LOW-ENERGY EXAMPLES

Coulomb + $^6Li^*$ in d-α

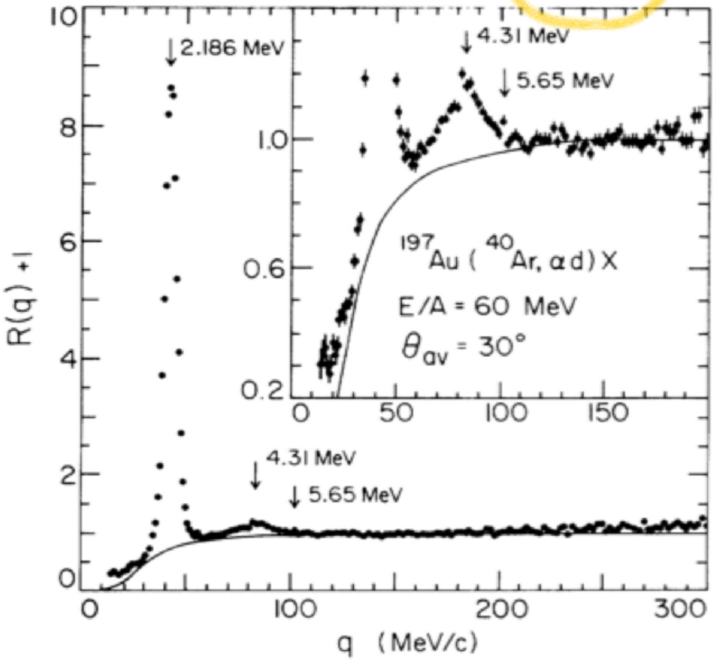
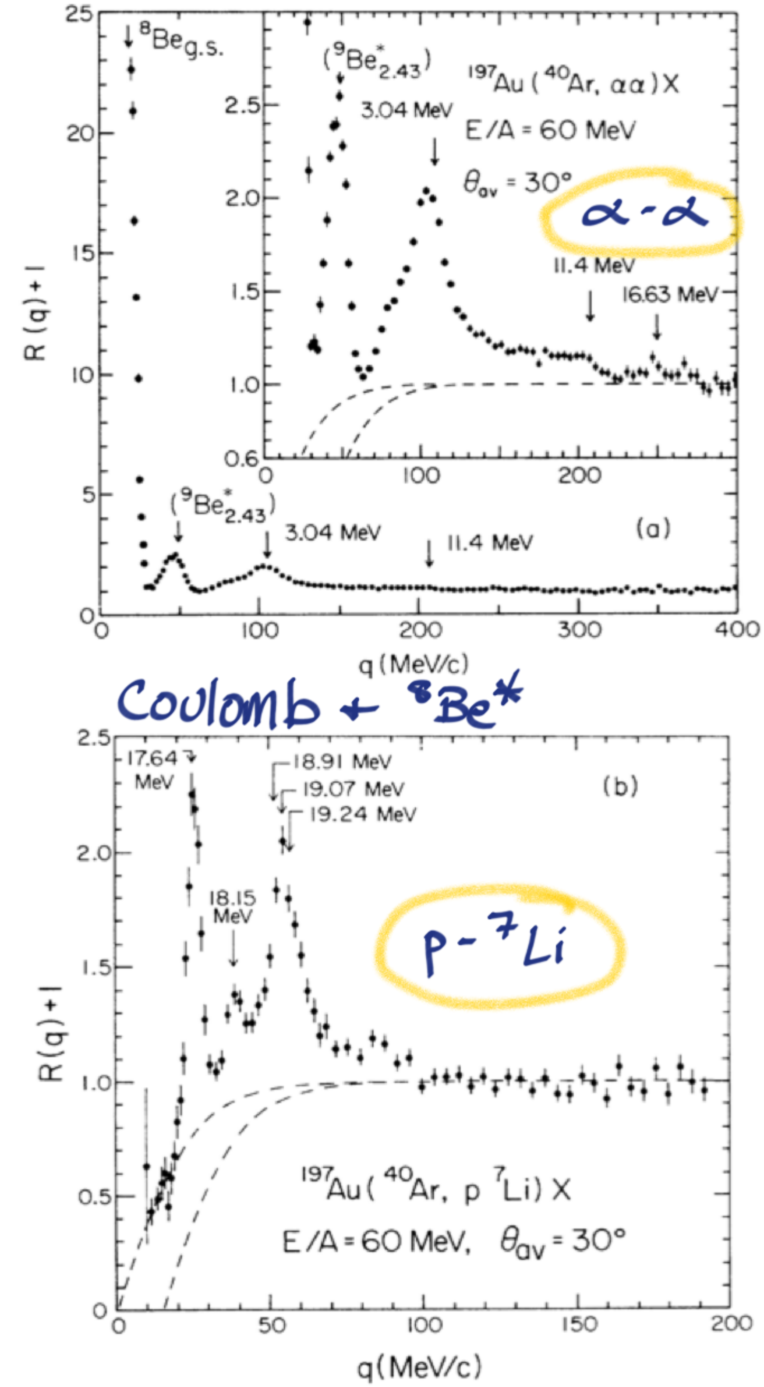


FIG. 8. d-α correlation function. Excited states in ^{6}Li are indicated. The curve represents the background correlation function.

$^{40}Ar + ^{197}Au$ E = 60 A MeV

J. Pochodzalla et al
PRC 35 1695 (1987)

α-α



Coulomb + $^8Be^*$

p-^{7}Li

FIG. 11. (a) α-α and (b) p-^{7}Li correlation functions. Excited states in ^{8}Be are indicated. The dashed lines are extreme bounds for the background correlation function.

TWO-PARTICLE CORRELATION FUNCTIONS IN THE THERMAL MODEL AND NUCLEAR INTEFEROMETRY DESCRIPTIONS

B.K. JENNINGS, D.H. BOAL, J.C. SHILLCOCK

PHYS REV C33, 1303 (1986)

"The equivalence of thermal model and conventional zero-lifetime HBT descriptions is demonstrated"

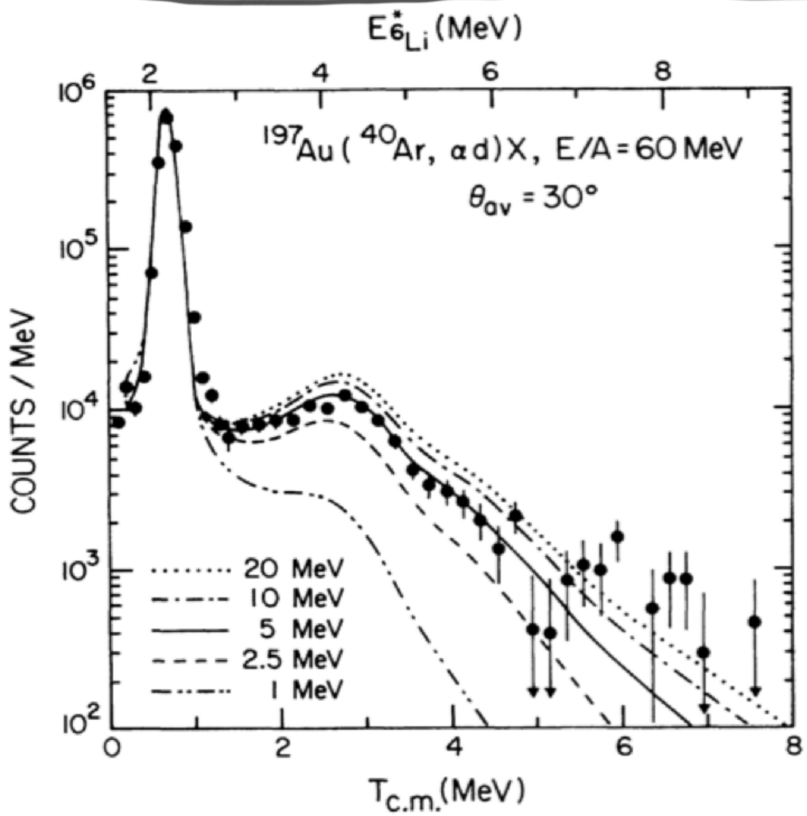


FIG. 20. Energy spectrum resulting from the decay of particle-unstable states in ^{6}Li. The curves correspond to thermal distributions, Eq. (25), with $T=1$, 2.5, 5, 10, and 20 MeV.

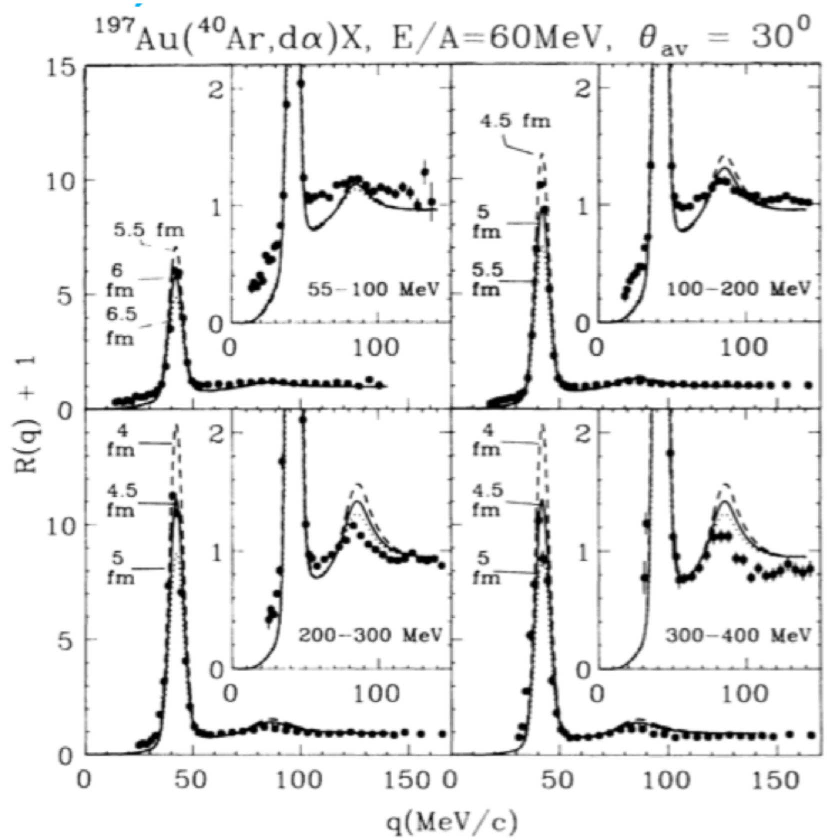


FIG. 16. d-α correlation functions for different constraints on the sum energy, E_1+E_2. The curves show calculations with the final state interaction model, Eq. (18).

d-α data from Pochodzalla (1987)

KOONIN - PRATT

VOLUME 54, NUMBER 5 PHYSICAL REVIEW LETTERS 4 FEBRUARY 1985

Statistical Emission of ^{2}He from Highly Excited Nuclear Systems

p-p femtoscopy

M. Bernstein, ... M.B. Tsang, et al.

FOR REACTIONS FORMING COMPOUND NUCLEUS "^{2}He emission" ✓

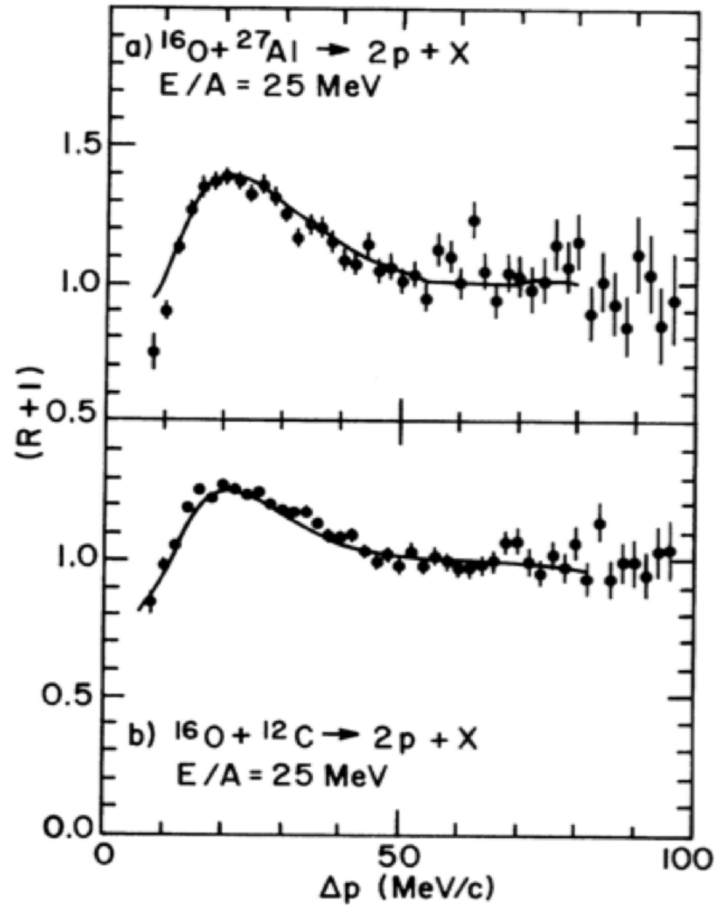


FIG. 2. (a) The experimental correlation function $1+R(\Delta p)$ plotted as a function of the relative momentum for protons produced in reactions on the ^{27}Al target. The theoretical correlation function is drawn as the solid line. (b) Corresponding experimental and theoretical correlation functions for reactions on the ^{12}C target.

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FOR REACTIONS FORMING COMPOUND NUCLEUS

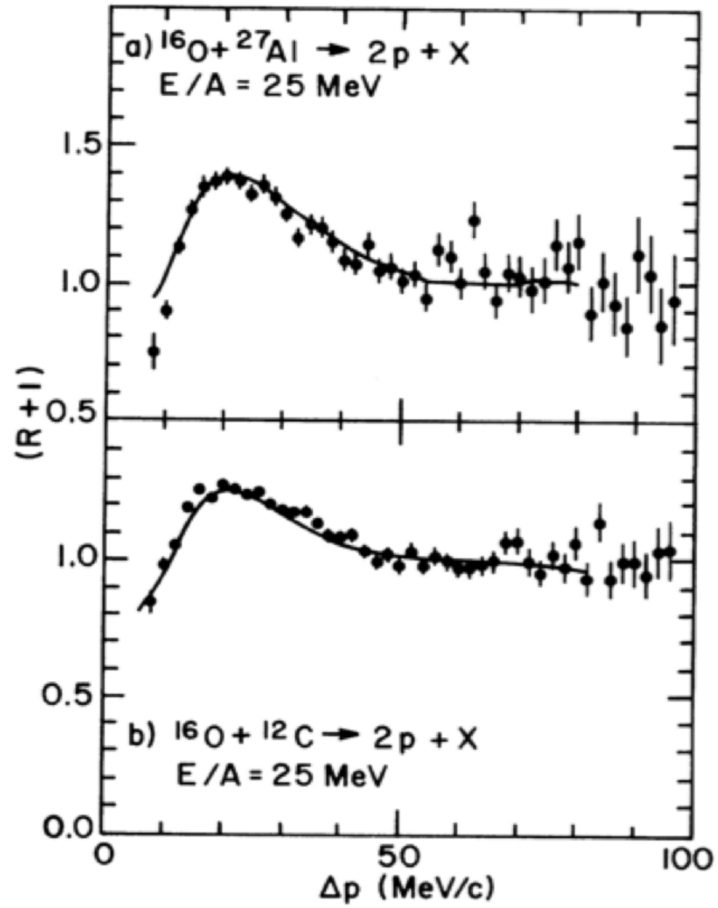
"^{2}He emission" ✓

REACTIONS NOT RESULTING IN EQUILIBRATED SOURCE

(forward ^{16}O + ^{197}Au)

→ thermal treatment does not work

⇒ requires "Koonin formalism"



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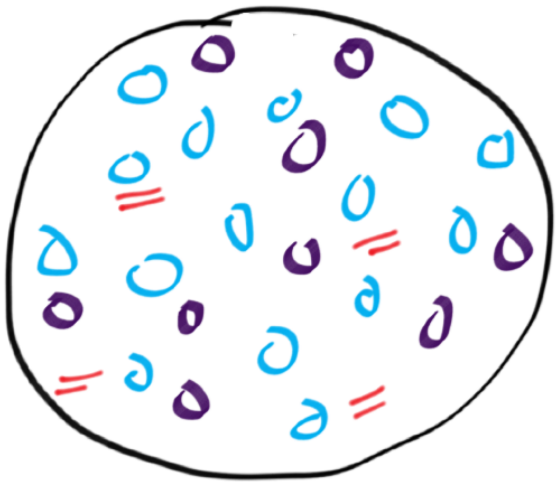
INSTANT DECAY FROM EQUILIBRIUM:

TWO TREATMENTS:

$$\boxed{A + B \rightleftarrows D^*}$$



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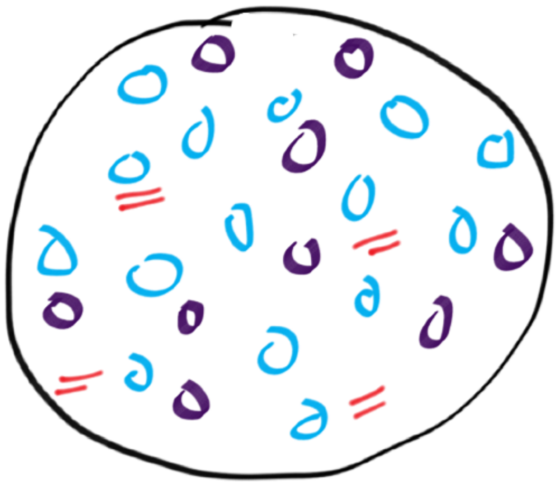

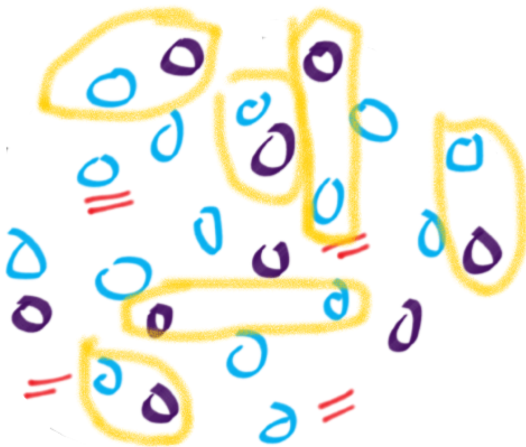

- pairwise $S(r)$
- $C(k^*) = \int d^3r\, S(r) \, |\Psi(k^*, r)|^2$

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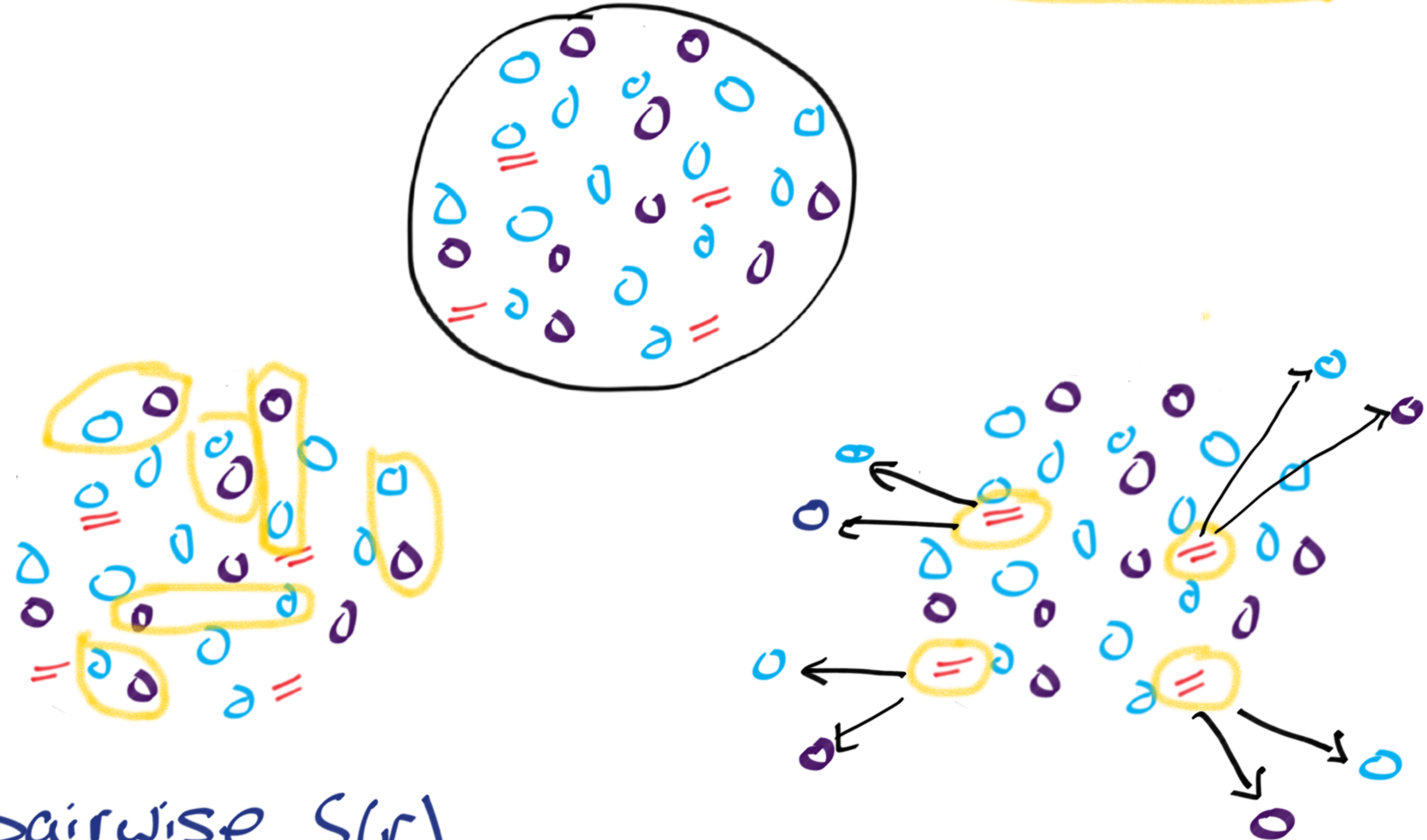

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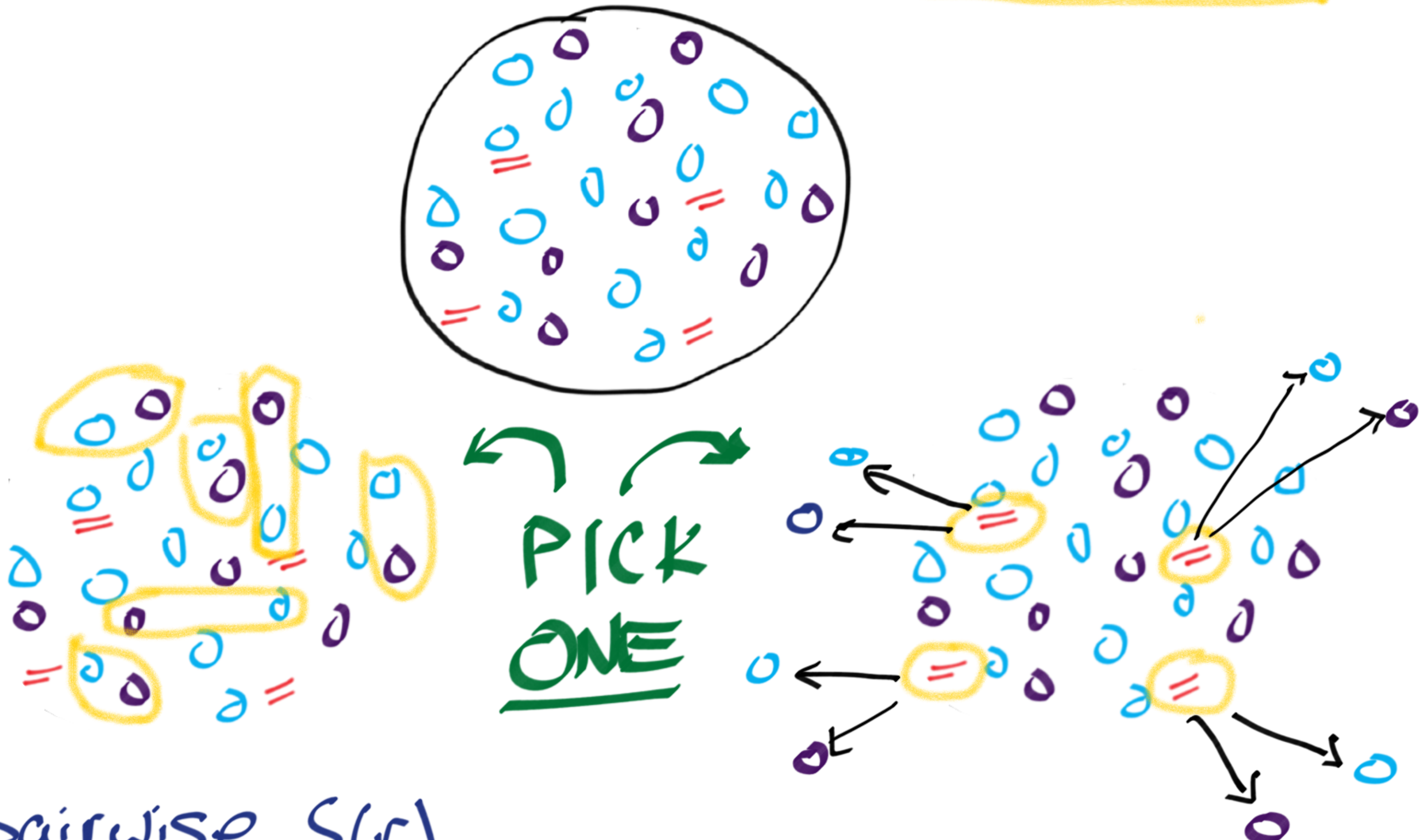
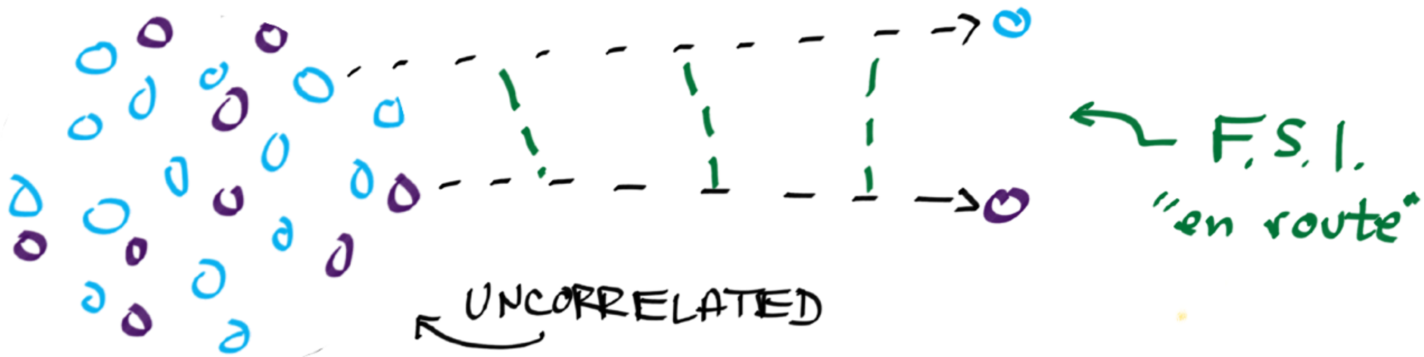


- pairwise $S(r)$
- $C(k^*) = \int d^3r\, S(r) \left|\Psi(k^*, r)\right|^2$

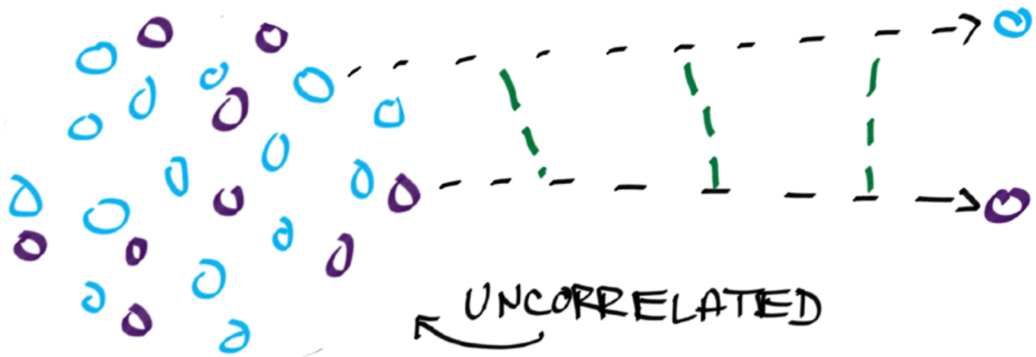
$$D^* \longrightarrow A + B$$

FEMTOSCOPIST'S COMMON PICTURE



$$C(k^*) = \int d^3r \, S_{AB}(r) \, |\psi(k^*, r)|^2$$

FEMTOSCOPIST'S COMMON PICTURE

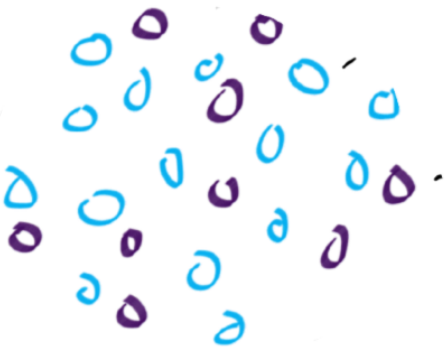


F.S.I.
"en route"

UNCORRELATED

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

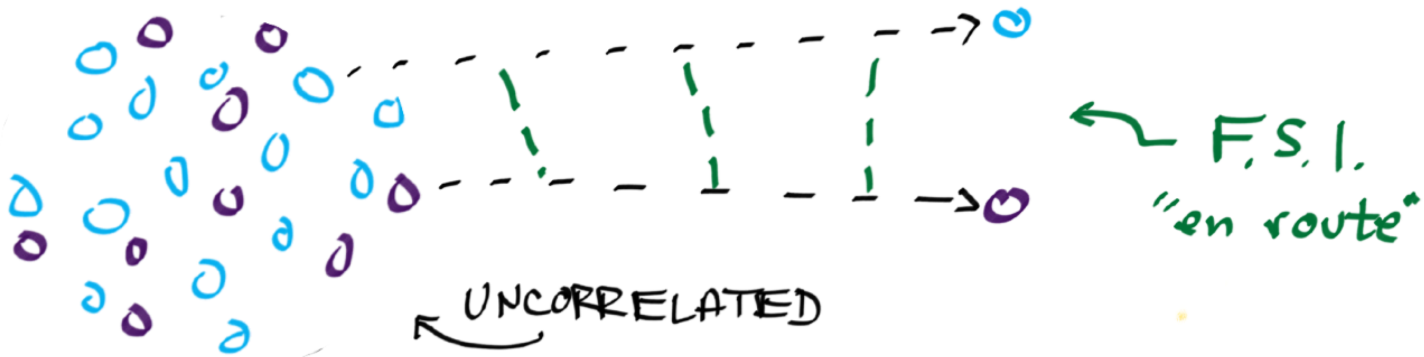
CORRELATED



$|\Psi(r, k^*)|^2$ quantifies modified density of states (including D^*)

$\Rightarrow$ correlation

EQUIVALENT? ONLY FOR EQUILIBRIUM?



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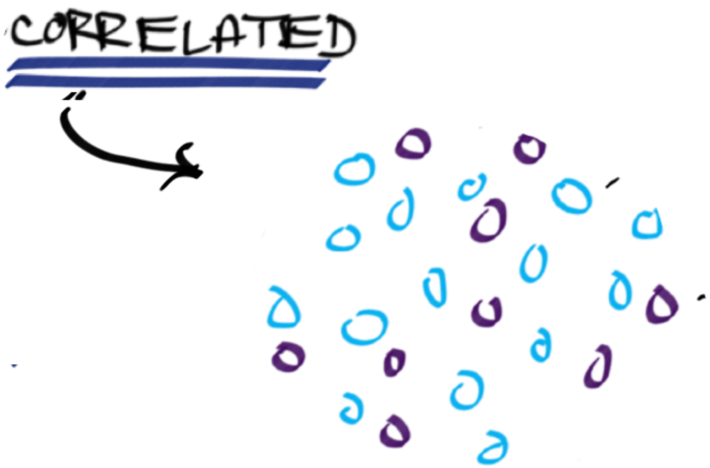

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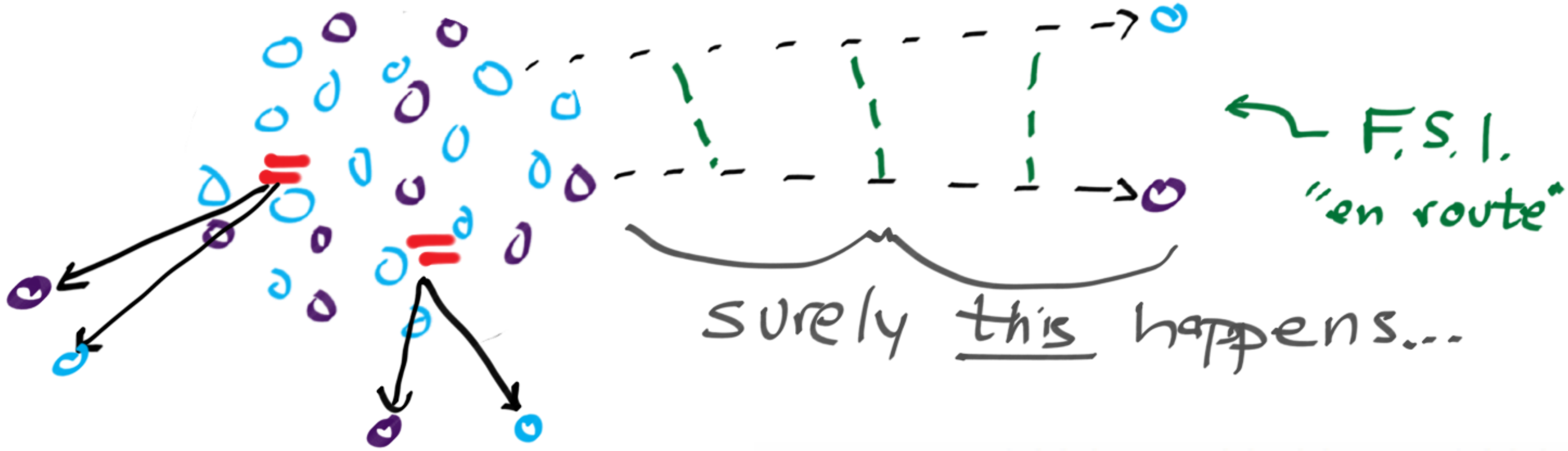
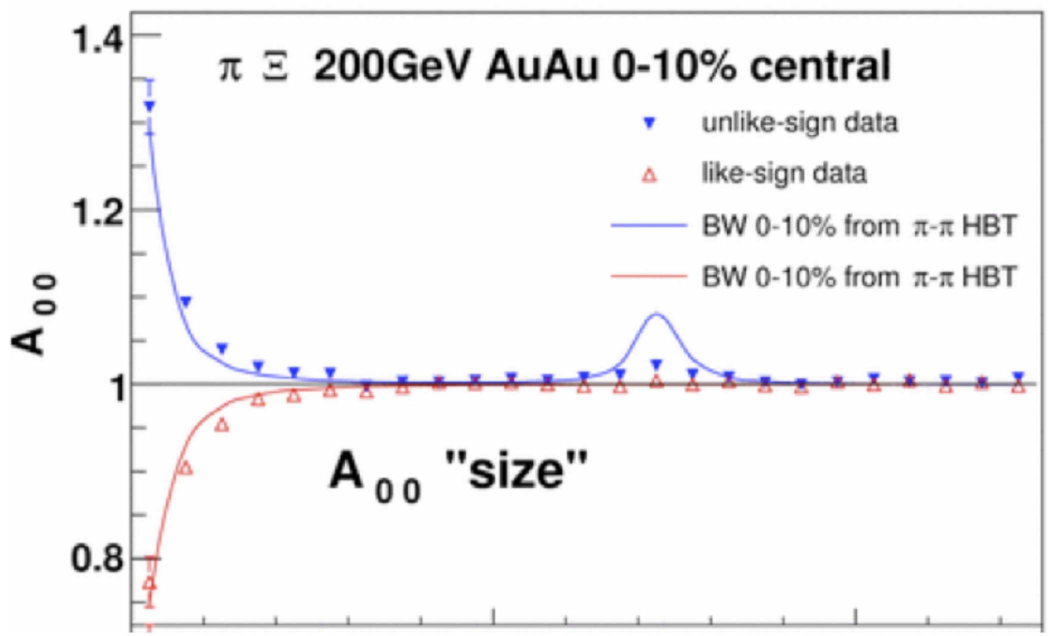
$\Rightarrow$ correlation

IF THERE ARE "EXRA" D^*'s (Ξ^*'s)...





Doesn't that worsen the discrepancy?

THAT'S ALL FOR NOW - THANKS