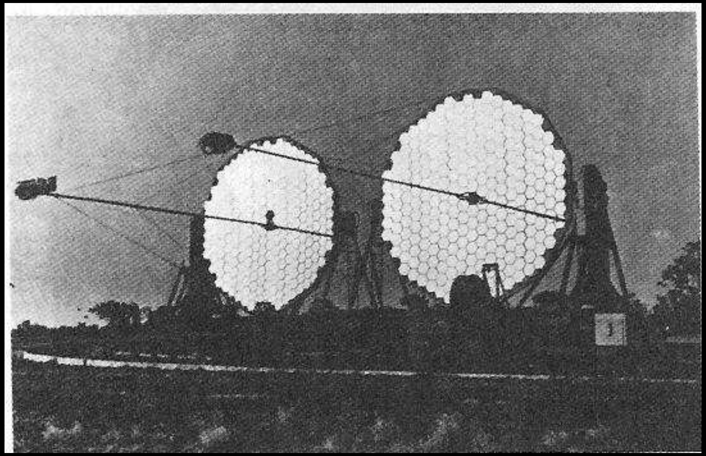
Anti-matter from secondary cosmic-ray interactions



And the role of HBT interferometry

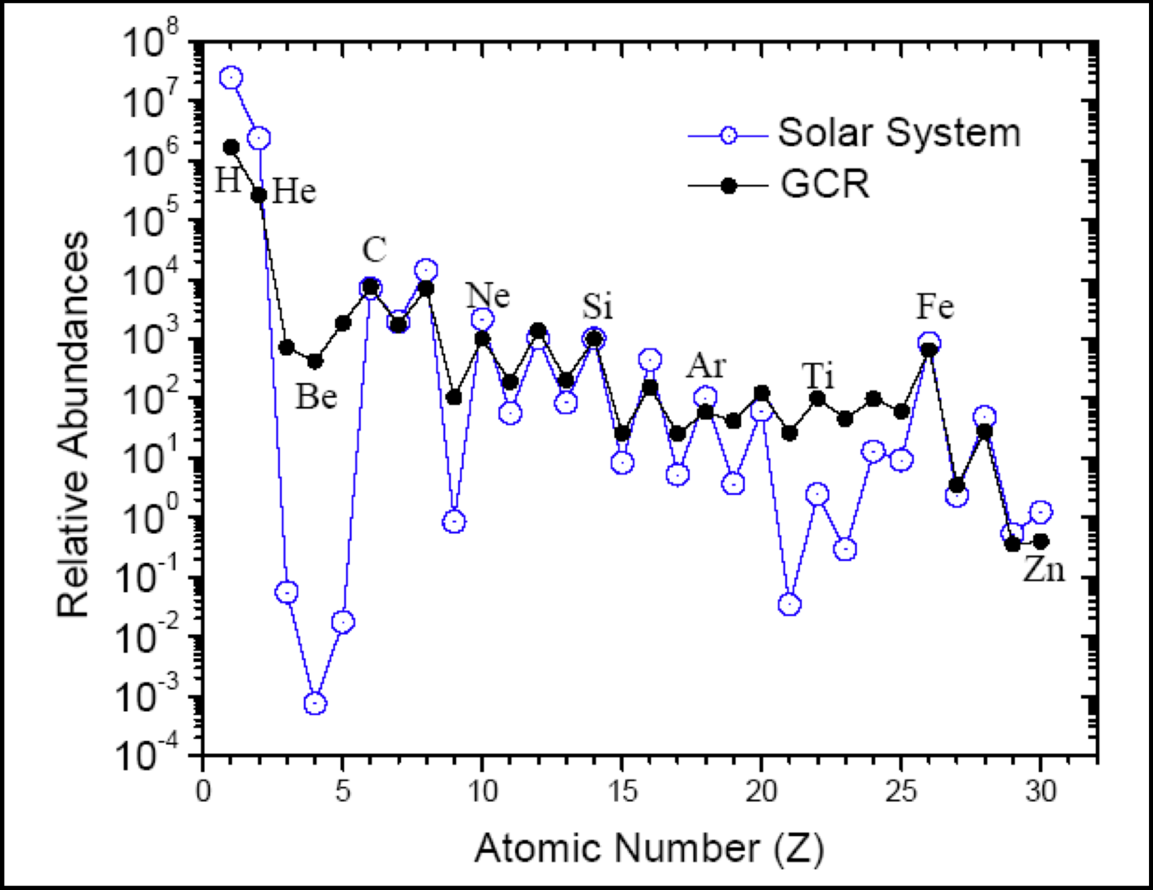
Blum, KCYN, Sato, Takimoto 1704.05431
Also recently, Blum Takimoto 1901.07088

Kenny, Chun Yu Ng (吳震宇)
Weizmann Institute of Science

Cosmic ray relative abundance

- Primary ratios determined by the source +acceleration Physics

- Secondaries produced by spallation in flight



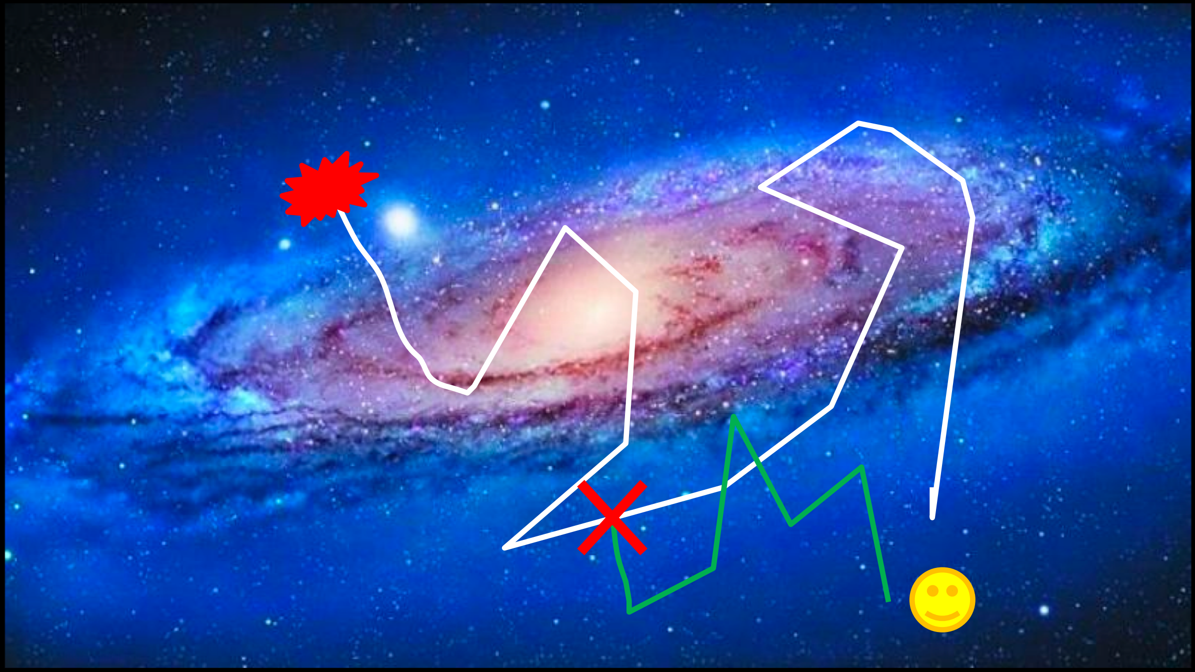
Martin Israel

Secondary production

- Primary ratios determined by the source +acceleration Physics

- Secondaries produced by spallation in flight

- Mean column density (Rigidity)



Cosmic Ray Beam Dump experiment

- Rigidity-dependent propagation
- Observed secondaries ∝ net production rate

$$\frac{n_a(\mathcal{R})}{n_b(\mathcal{R})} = \frac{Q_a(\mathcal{R})}{Q_b(\mathcal{R})}$$

$$Q_a(\mathcal{R}) = \sum_P n_P(\mathcal{R}) \frac{\sigma_{P\to a}(\mathcal{R})}{m} - n_a(\mathcal{R}) \frac{\sigma_a(\mathcal{R})}{m}$$

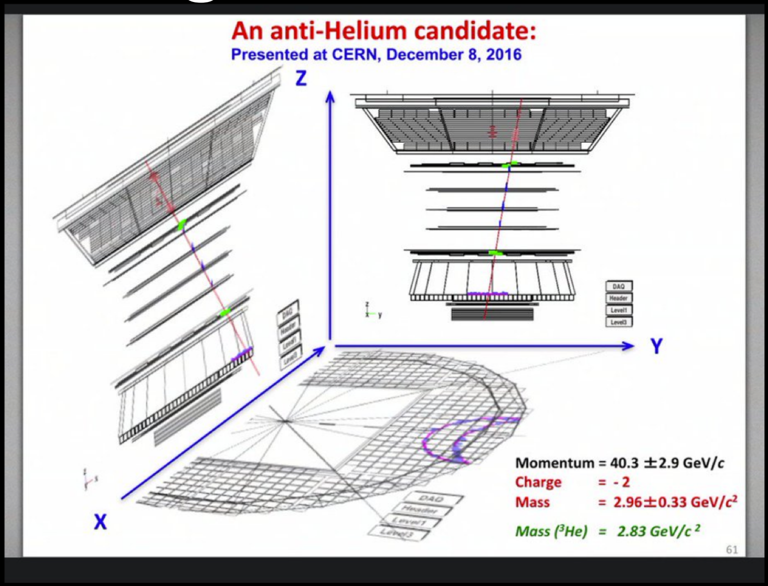
- Grammage

$$X_{\mathrm{esc}}(\mathcal{R}) = \frac{n_{\mathrm{B}}(\mathcal{R})}{Q_{\mathrm{B}}(\mathcal{R})}$$

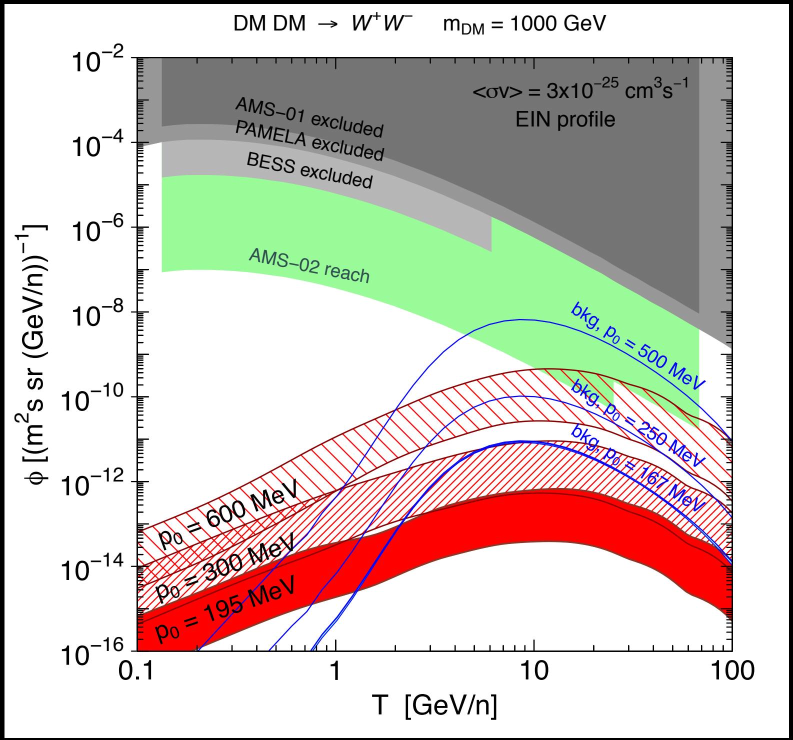
$$X_{\mathrm{esc}} = \frac{(\mathrm{B/C})}{\sum_{\mathrm{P=C,N,O,\ldots}} (\mathrm{P/C}) \frac{\sigma_{\mathrm{P\to B}}}{m} - (\mathrm{B/C}) \frac{\sigma_{\mathrm{B}}}{m}}$$

Secondary CR antimatter

- We just need the production cross section now
- Astrophysical effects are absorbed in the empirical grammage factor*



- Secondary?
- Dark matter?
- ???



Cirelli et al 2014

Anti-deuteron and Anti-Helium

- The coalescence picture

$$E_A \frac{dN_A}{d^3 p_A} = B_A \, R(x) \left(E_p \frac{dN_p}{d^3 p_p} \right)^A$$

Coalescence yield
To be determined by data

$$\frac{A}{m_p^{A-1}} \left(\frac{4\pi}{3} p_c^3 \right)^{A-1} = B_A$$

- p_c: the coalescence momentum***

Coalescence Yield (p_c)

- Chardonnet, Orloff, Salati 1997
  - 58 MeV for both B2 and B3, from $pp \to \bar{d}$ data
  - Drag down by low-CME high-p_t Serpukhov data

- Duperray et al 2005
  - 79 MeV for B2, joint pp and pA fit (underfits pp)
  - 79 MeV for B3, poor fits to the sparce pA data

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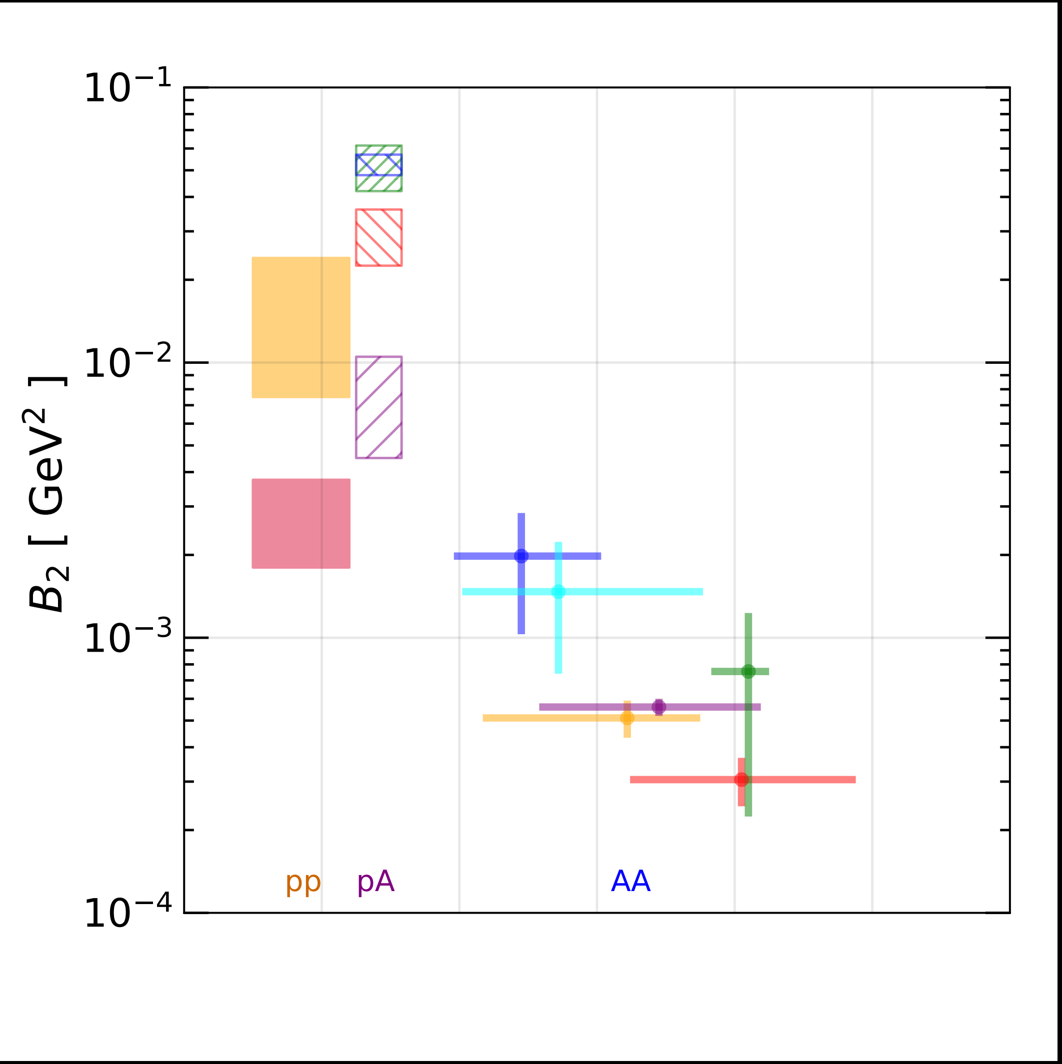
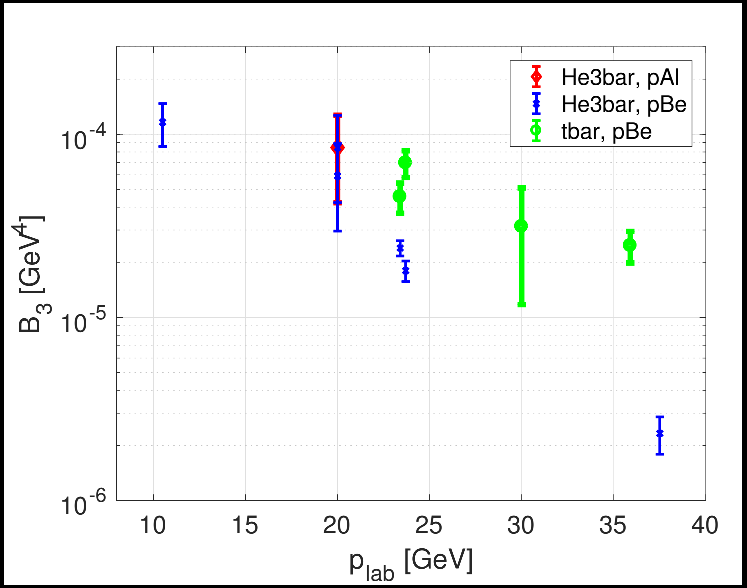
Coalescence data (B2)

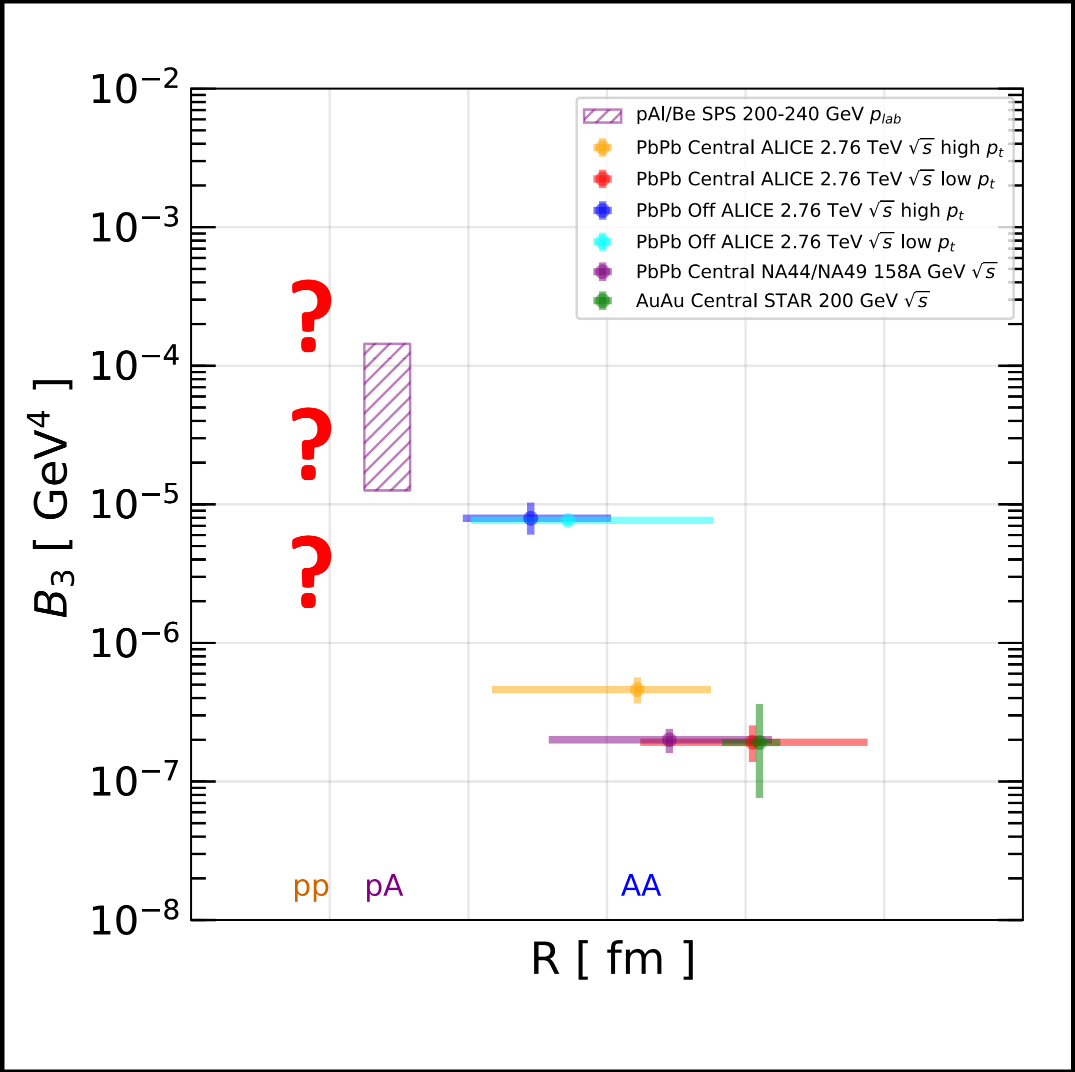
- Large variation
  - Between classes
  - Within classes
- For CR secondaries
  - pp most important



Coalescence data (B3)

- No pp data (yet)
- 79 MeV
  - $\sim 2\times10^{-5}\,\mathrm{GeV}^4$



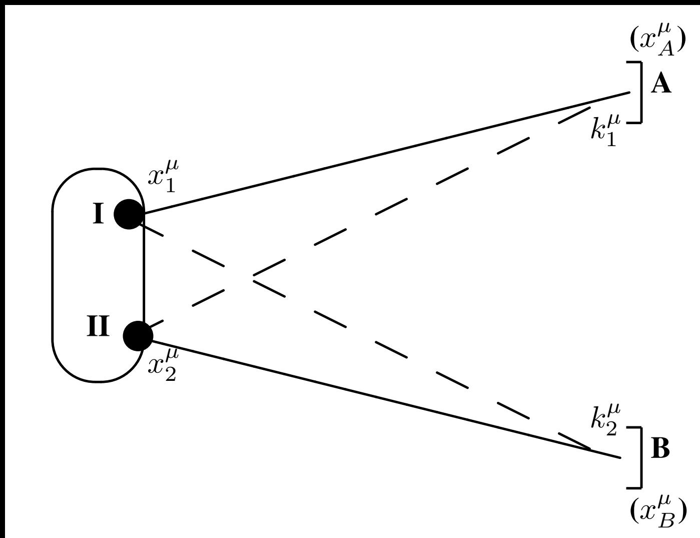


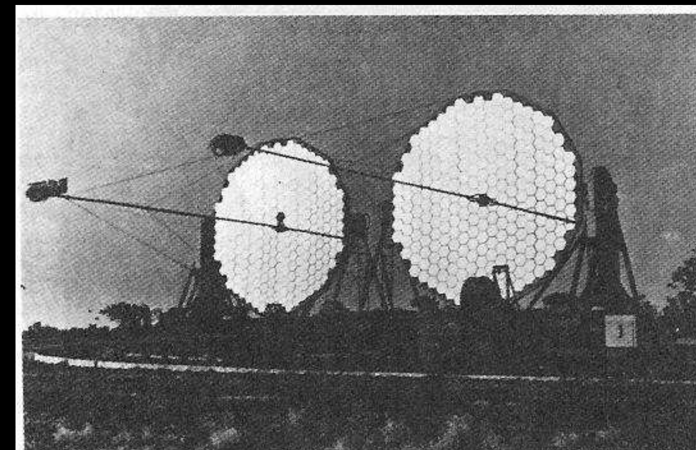
Coalescence-HBT relation

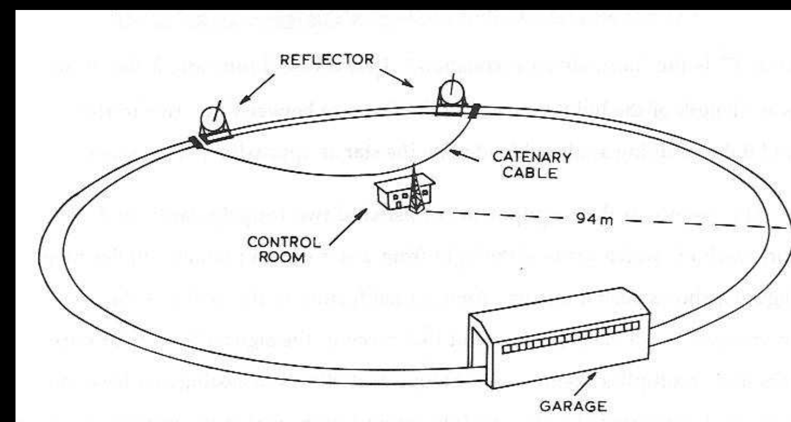
- Scheibl and Heinz 1999 (also Mrowczynski 1987 +++)
  - Coalescence probability is related to the source size R
  - R measured by the HBT interferometry

- Hanbury Brown and Twiss interferometry

Hanbury Brown and Twiss interferometry

- 





$$C(k_1,k_2) = \frac{P_2(k_1,k_2)}{P_1(k_1)P_1(k_2)} = 1 \pm \cos[(k_1 - k_2).(x_1 - x_2)]$$

$$\sim kd\theta$$

Generalize

$$C(k_1,k_2) = \frac{P_2(k_1,k_2)}{P_1(k_1)P_1(k_2)} = 1 \pm \lambda\, |\tilde{\rho}(q)|^2$$

Padula 2004

Hanbury Brown and Twiss interferometry

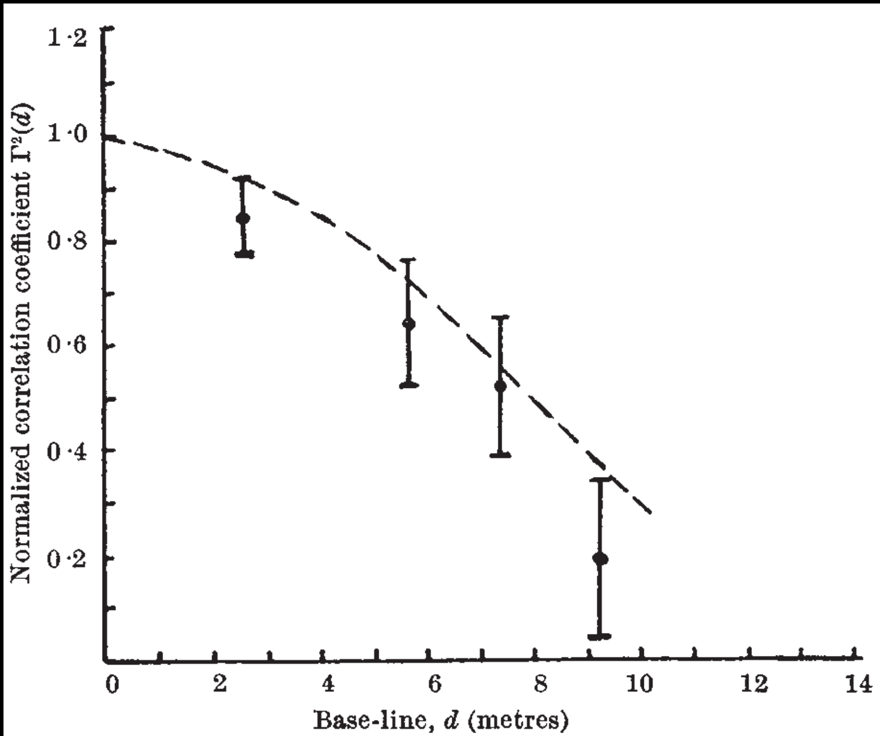
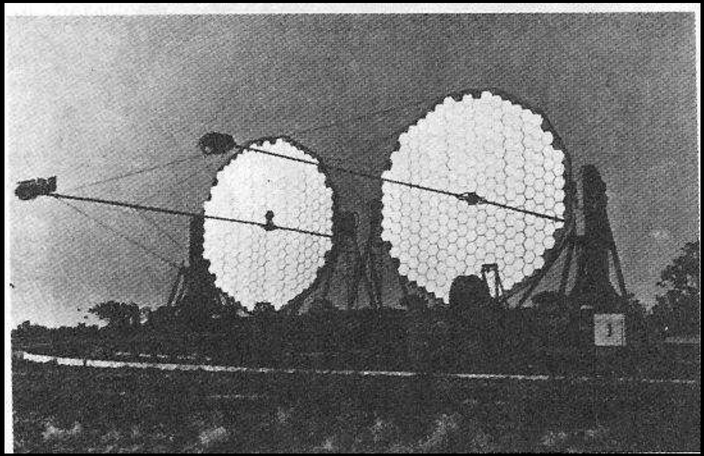
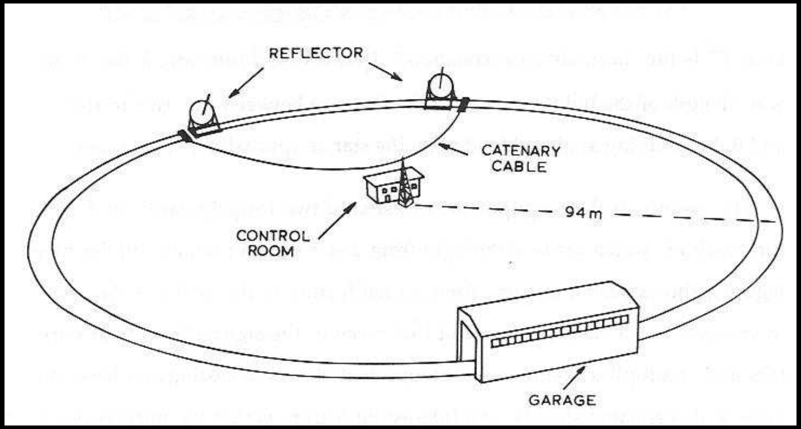


Fig. 2. Comparison between the values of the normalized correlation coefficient $\Gamma^2(d)$ observed from Sirius and the theoretical values for a star of angular diameter 0·0063″. The errors shown are the probable errors of the observations





Hanbury Brown and Twiss 1956

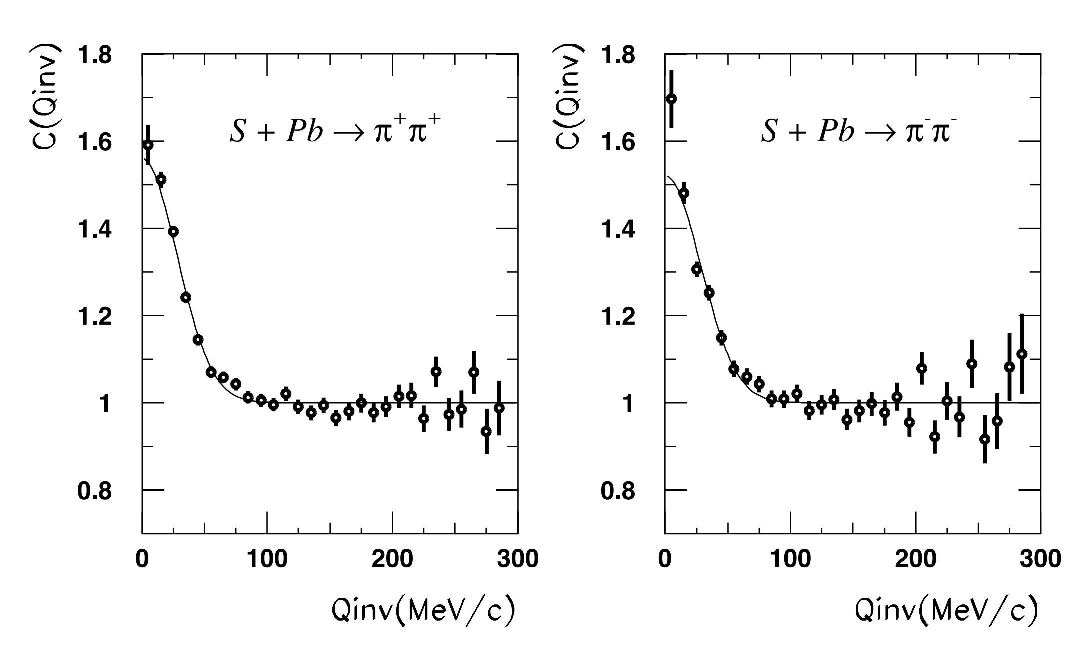
Padula 2004

HBT in nuclear physics

- Goldhaber, Goldhaber, Lee, Pais 1960
  - Independently
  - $p\bar{p} \to S \to \pi\pi$

$$C(Q^2) \quad = \quad 1 + e^{-Q^2 r^2}$$

Baym 1997
N44 1993



- Space-time structure of nuclear collisions

Coalescence-HBT relation

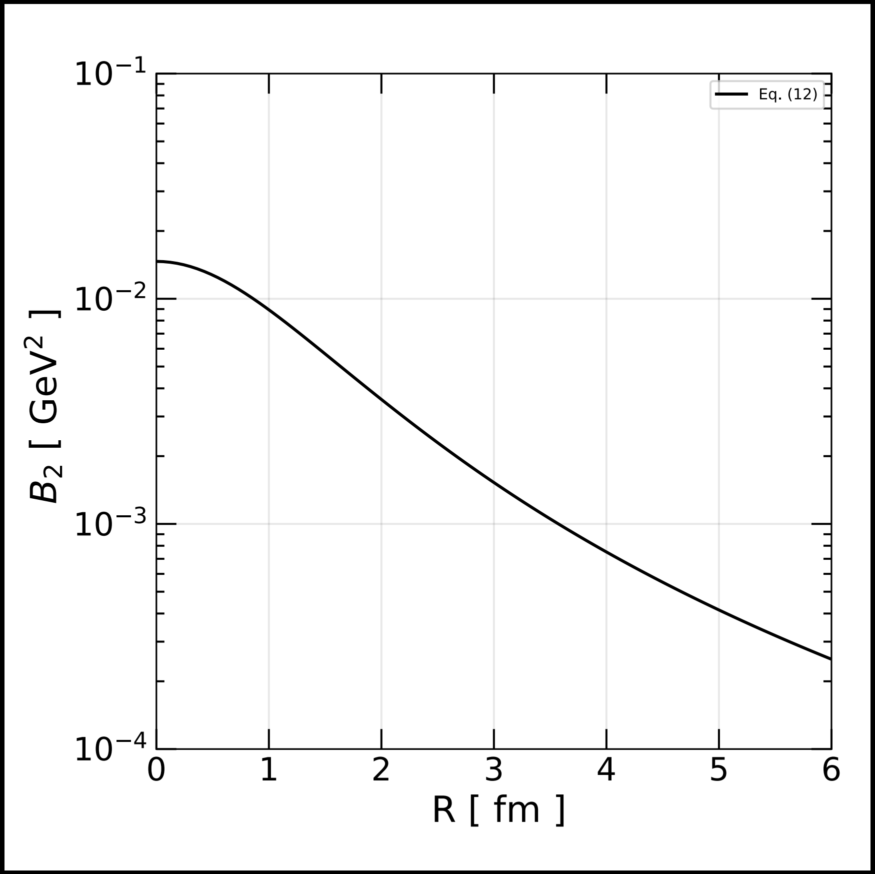
- Scheibl and Heinz 1999 (also Mrowczynski 1987 +++)
  - Coalescence probability is related to the source size R
  - R measured by the HBT interferometry

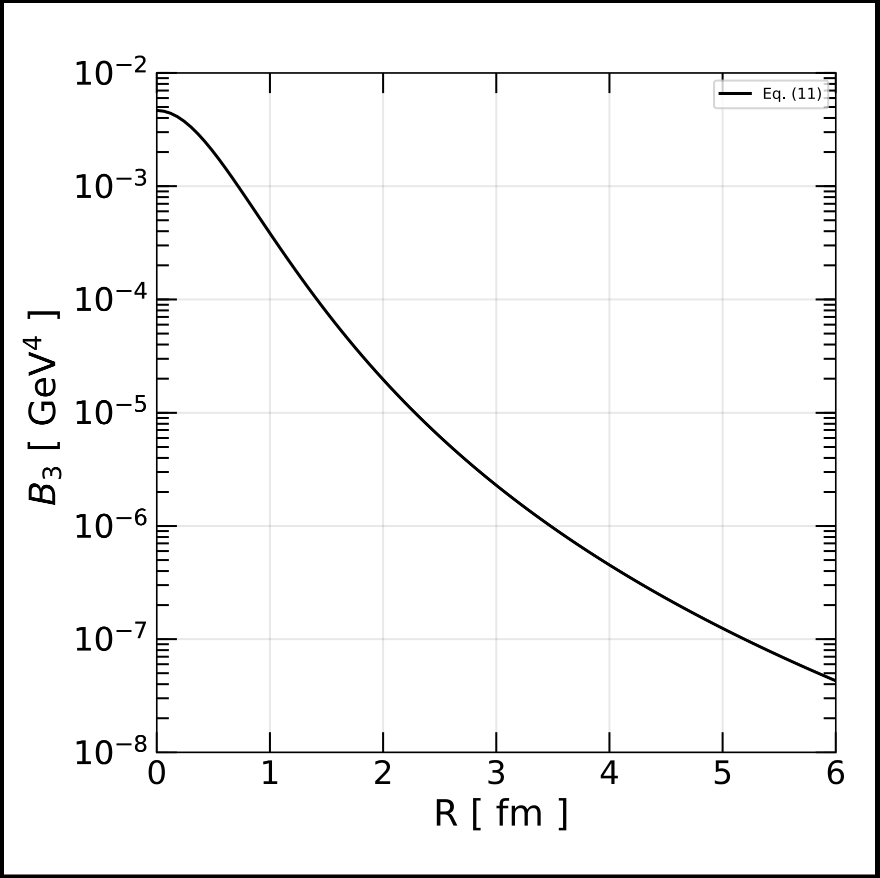
$$B_3 = \frac{(2\pi)^3}{4\sqrt{3}} \langle C_3 \rangle \left(m_t R_1 R_2 R_3\right)^{-2}$$

$$\langle C_3 \rangle \approx \Pi_{i=1,2,3} \left(1 + \frac{b_3^2}{4R_i^2}\right)^{-1}$$

Coalescence-HBT relation

- No free parameters!

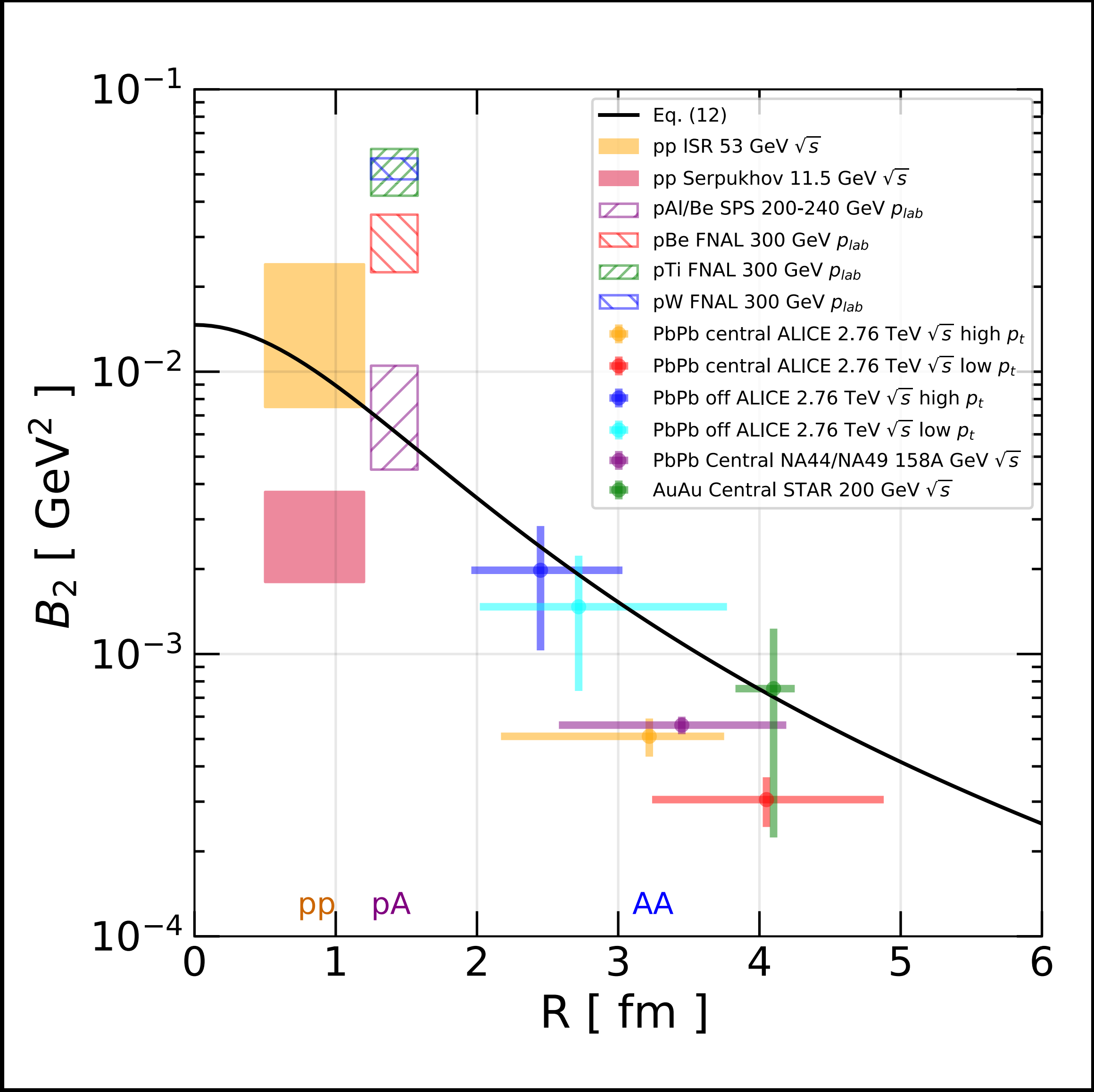




B2

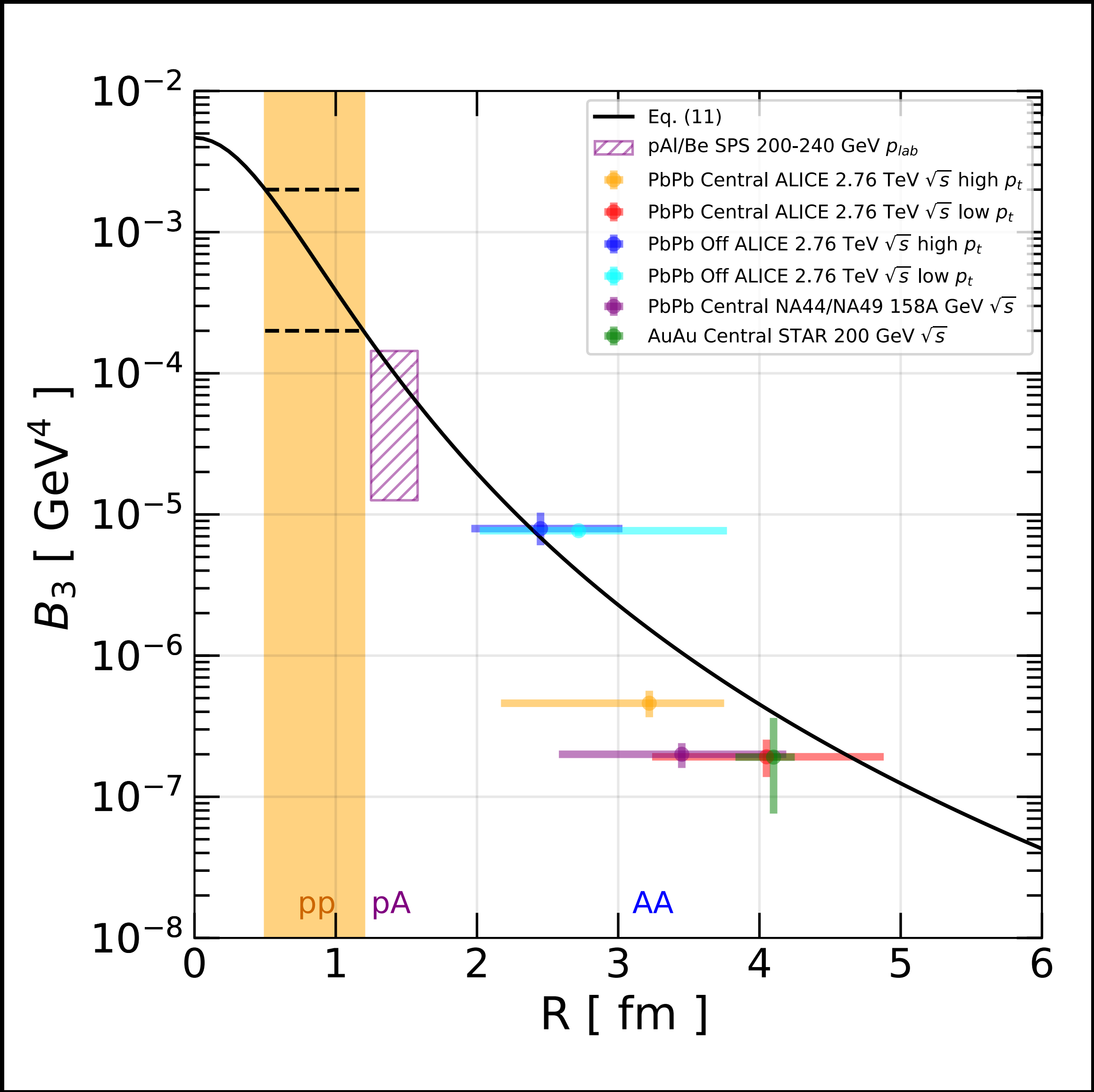
- Works pretty well

- R
  - pp 0.5 – 1.2 fm
  - pA 1.25 – 1.58 fm



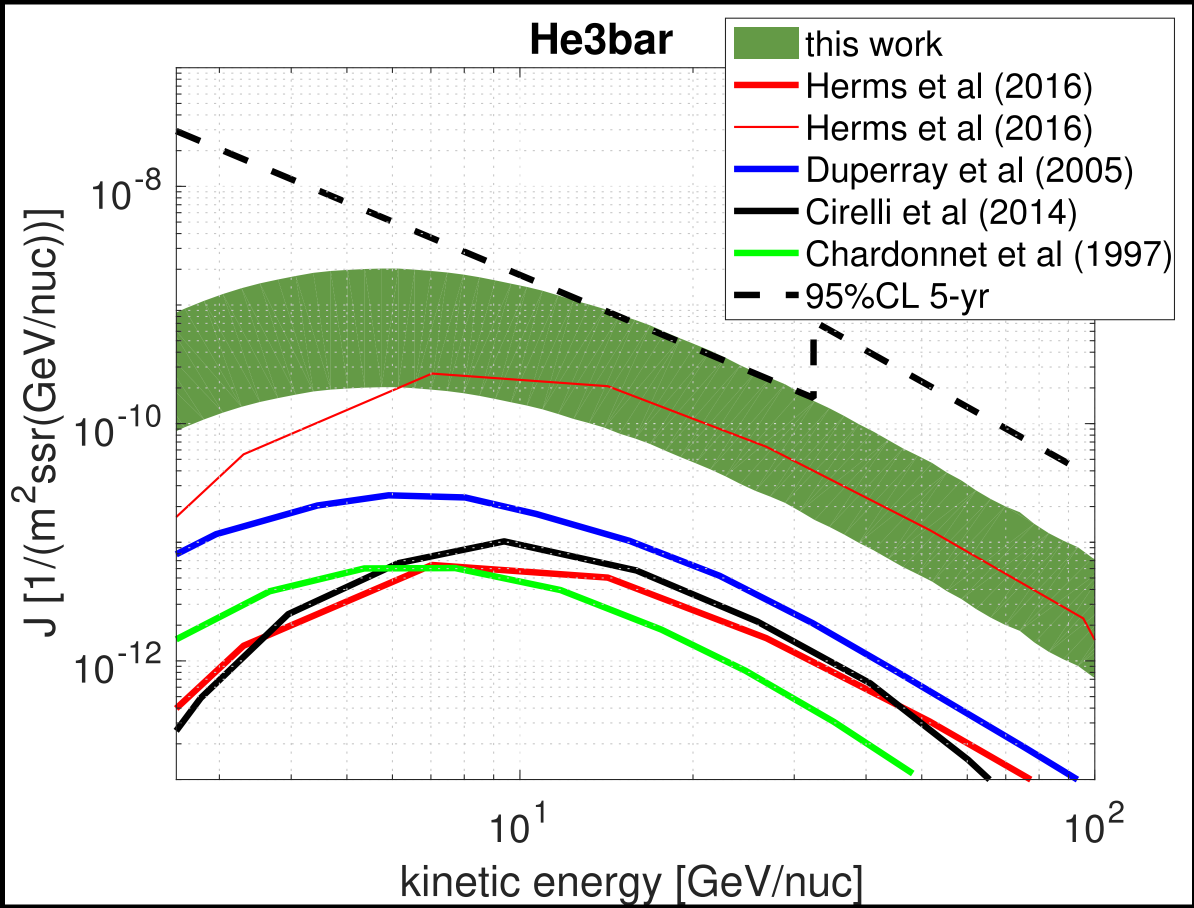
B3

- Also works pretty well
- B3 prediction
  - $2\times10^{-4} - 2\times10^{-3}$
- Dangerous
  - $pA \rightarrow pp$
  - B2 $\rightarrow p_c \rightarrow$ B3



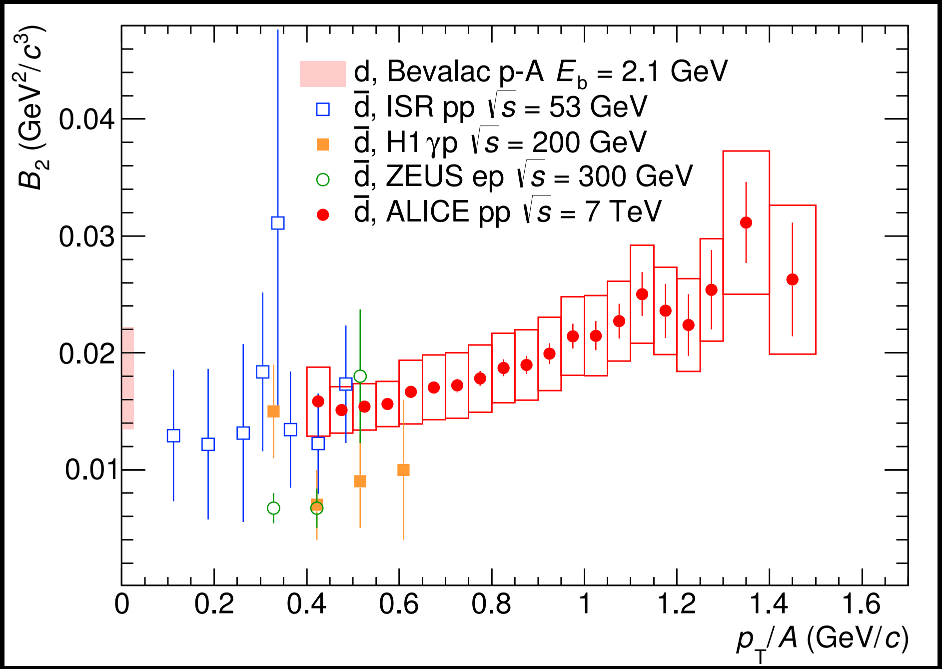
Anti-Helium events?

- Could explain some of the AMS events?
- Need the most optimistic yield value

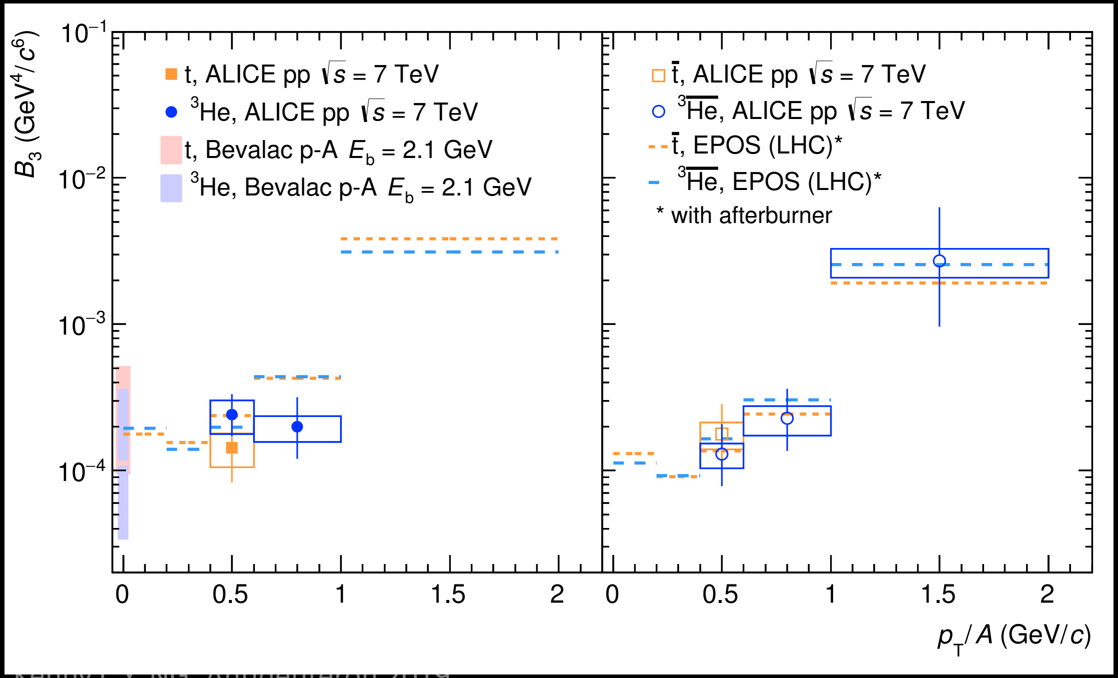


New Alice data

- $R \simeq 1.14$ fm
  - 1.4 GeV m_t
  - $\sqrt{s}$ = 7 TeV
  - (1805.12455)



1709.08522



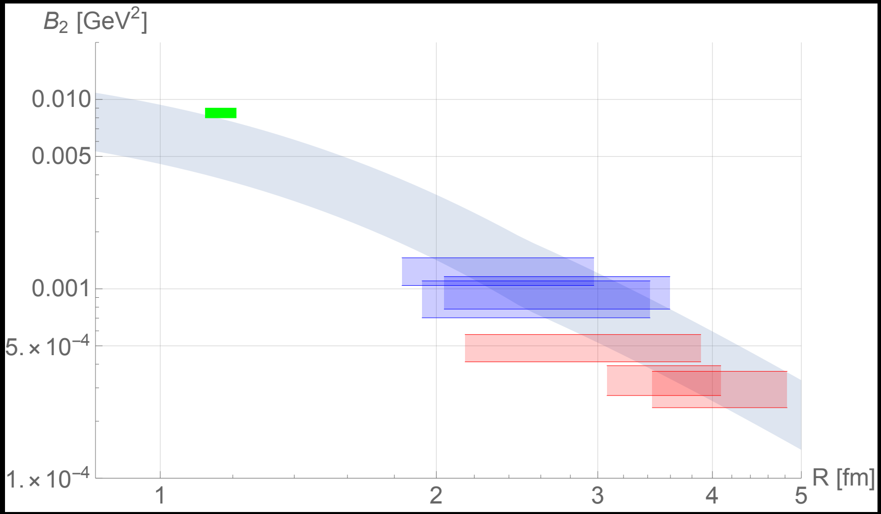
Coalescence-HBT relation

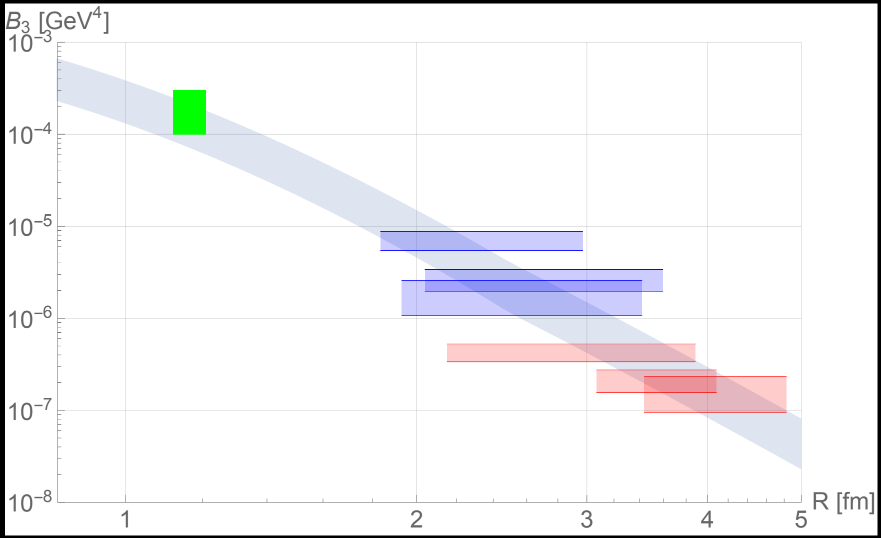
- Blum, Takimoto 1901.07088
  - More general derivation
  - Chaoticity parameter (λ)

$$C(Q^2) = 1 + e^{-Q^2 r^2}$$

- More or less works

- Joint Yield-HBT data analysis should be done
  - Pt
  - centrality





Conclusion

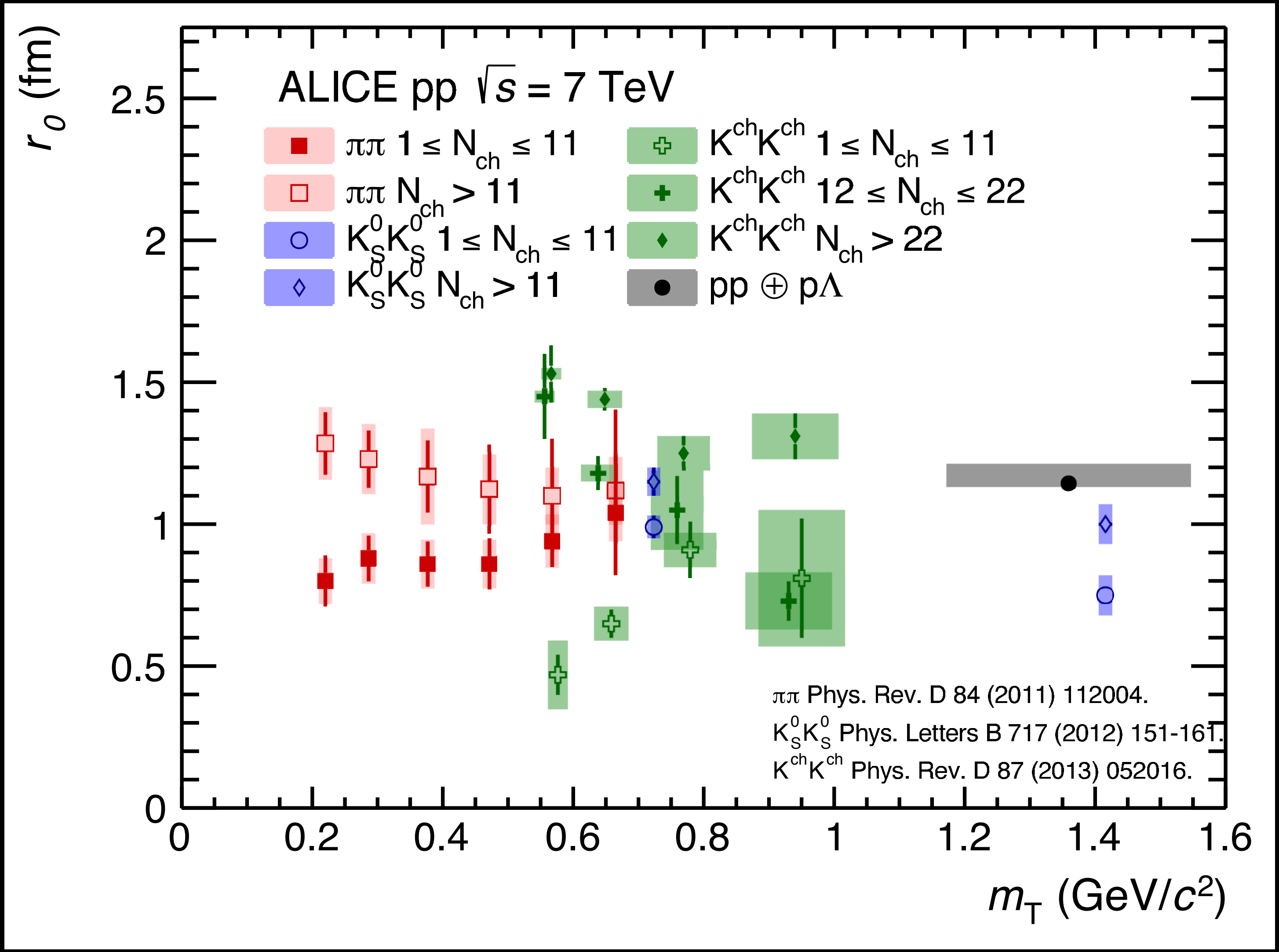
- The Coalescence-HBT relation provides an interpretation to the yield data.

- The predicted anti-helium yield is much higher than previously thought.

- Joint Coalescence-HBT analysis may further reduce the uncertainty (p_t and centrality bins)
  - Help predict the dark matter yield?

- Uncertainty in the secondary CR anti-nuclei could be significantly reduced.

Backup



ALICE pp √s = 7 TeV
ππ 1 ≤ N_ch ≤ 11
ππ N_ch > 11
K0S K0S 1 ≤ N_ch ≤ 11
K0S K0S N_ch > 11
Kch Kch 1 ≤ N_ch ≤ 11
Kch Kch 12 ≤ N_ch ≤ 22
Kch Kch N_ch > 22
pp ⊕ pΛ
ππ Phys. Rev. D 84 (2011) 112004.
K0S K0S Phys. Letters B 717 (2012) 151-161.
Kch Kch Phys. Rev. D 87 (2013) 052016.
r_0 (fm)
m_T (GeV/c²)
0
0.5
1
1.5
2
2.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6