DENSE, MAGNETIZED, AND STRANGENESS-NEUTRAL QCD FROM IMAGINARY CHEMICAL POTENTIAL

LATTICE CONFERENCE 2024, LIVERPOOL

DEAN VALOIS

IN COLLABORATION WITH

S. BORSÁNYI, J. GUENTHER, M. A. PETRI (WUPPERTAL)

B. B. BRANDT, G. ENDRŐDI (BIELEFELD)

MOTIVATION

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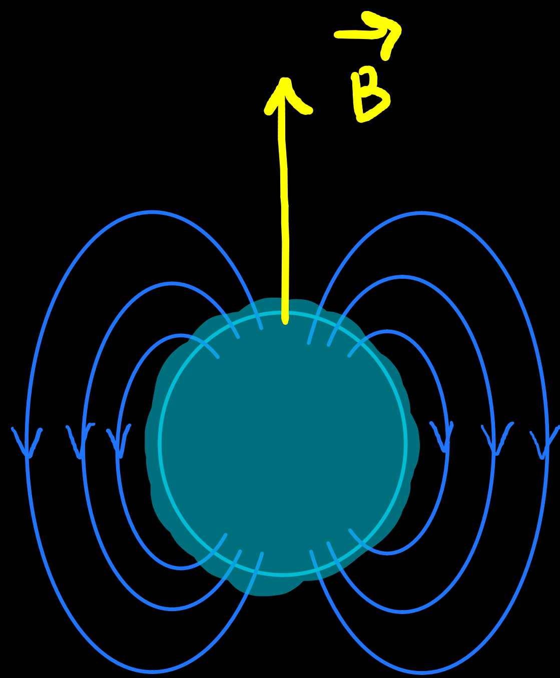

NEUTRON STARS

$\sqrt{eB} \sim 1\,\mathrm{MeV}$

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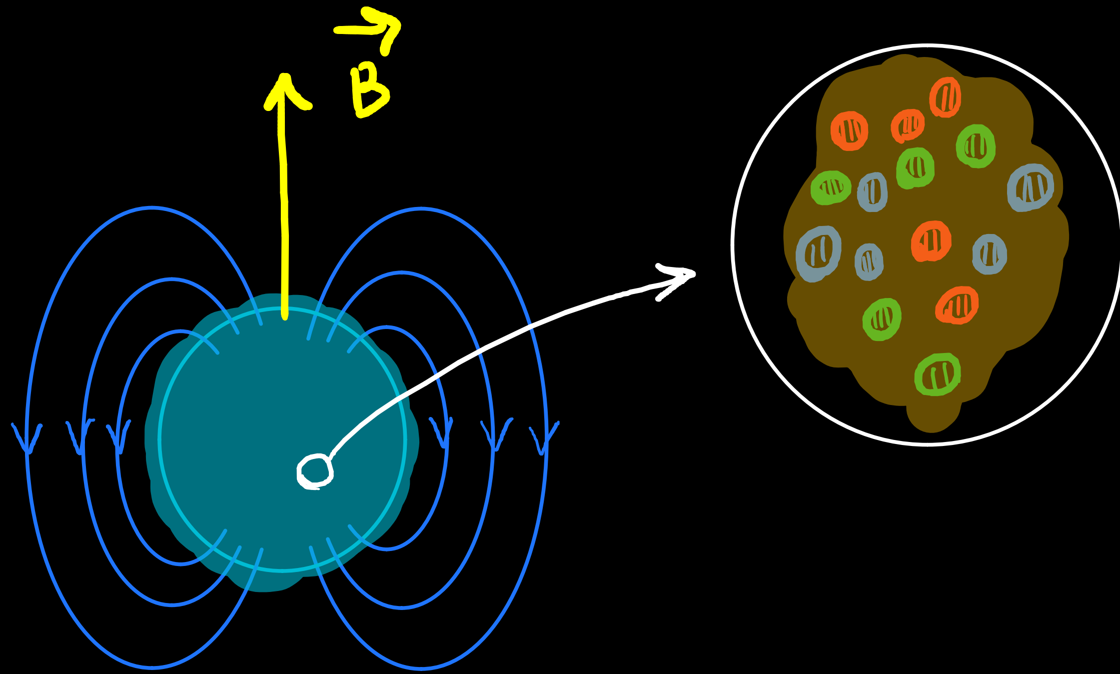

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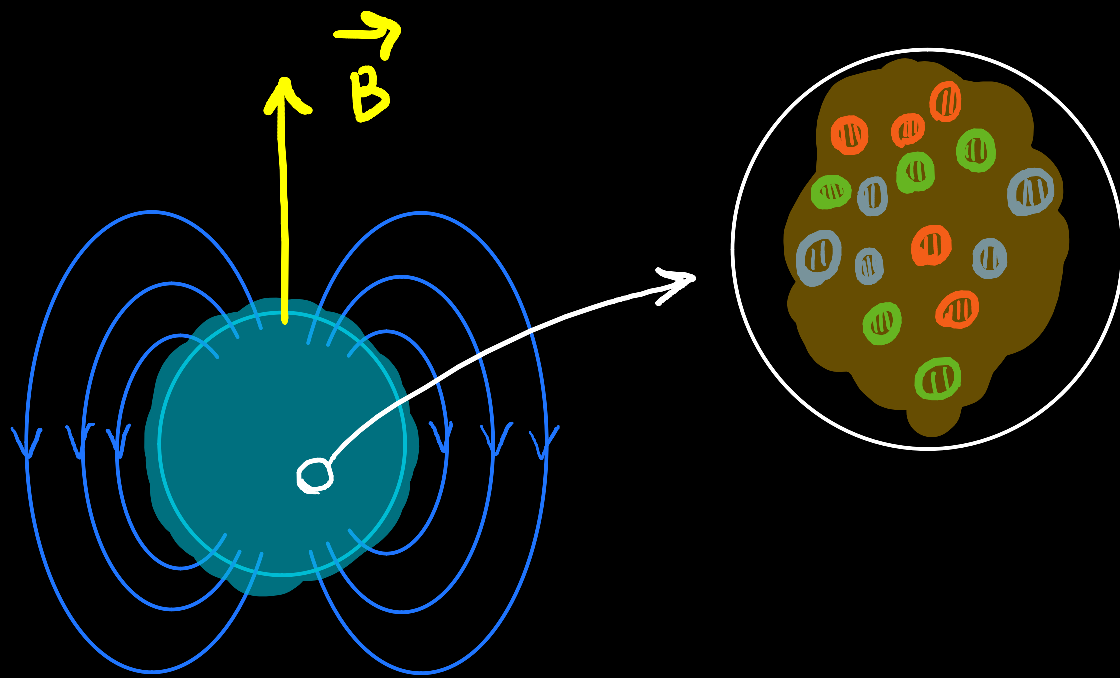
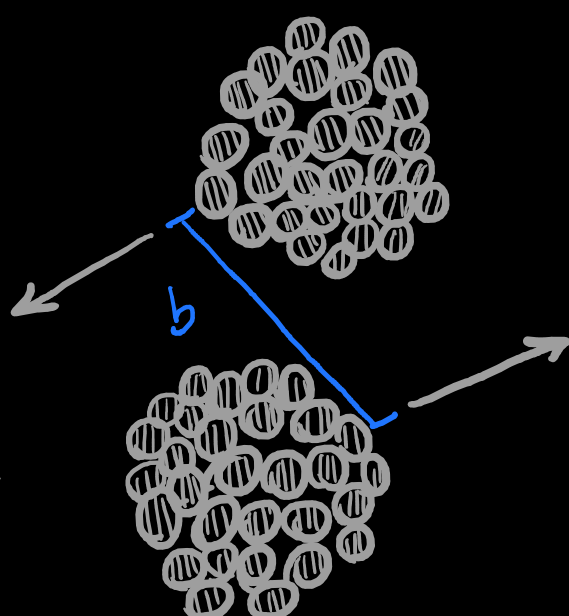


HEAVY-ION COLLISIONS

$\sqrt{eB} \sim 0.1 - 0.5\,\mathrm{GeV}$



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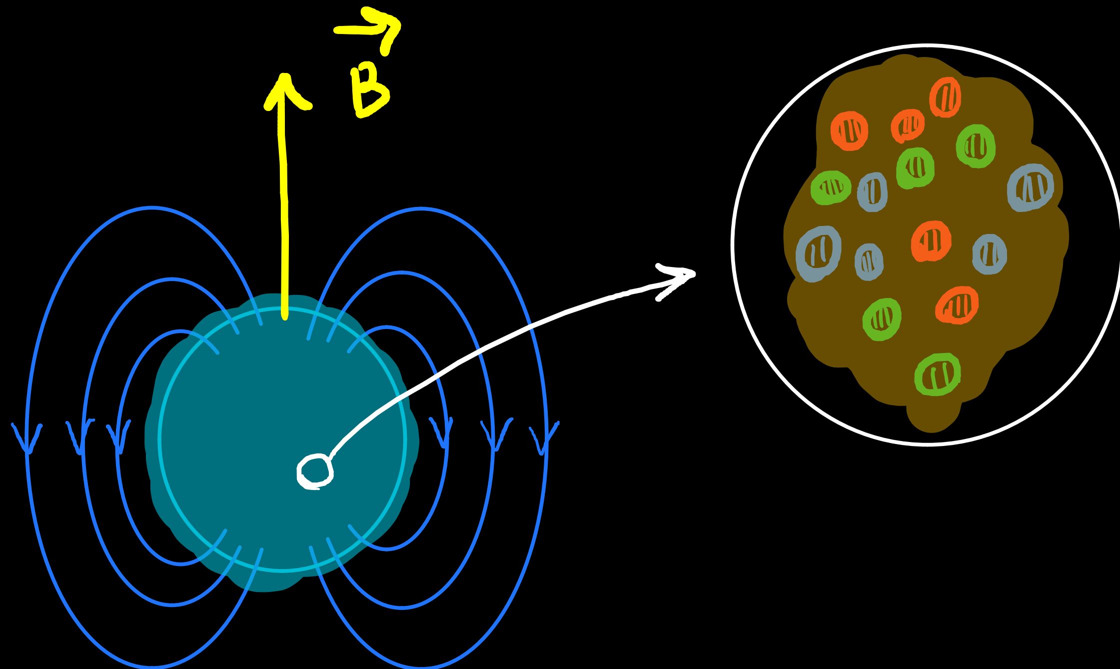

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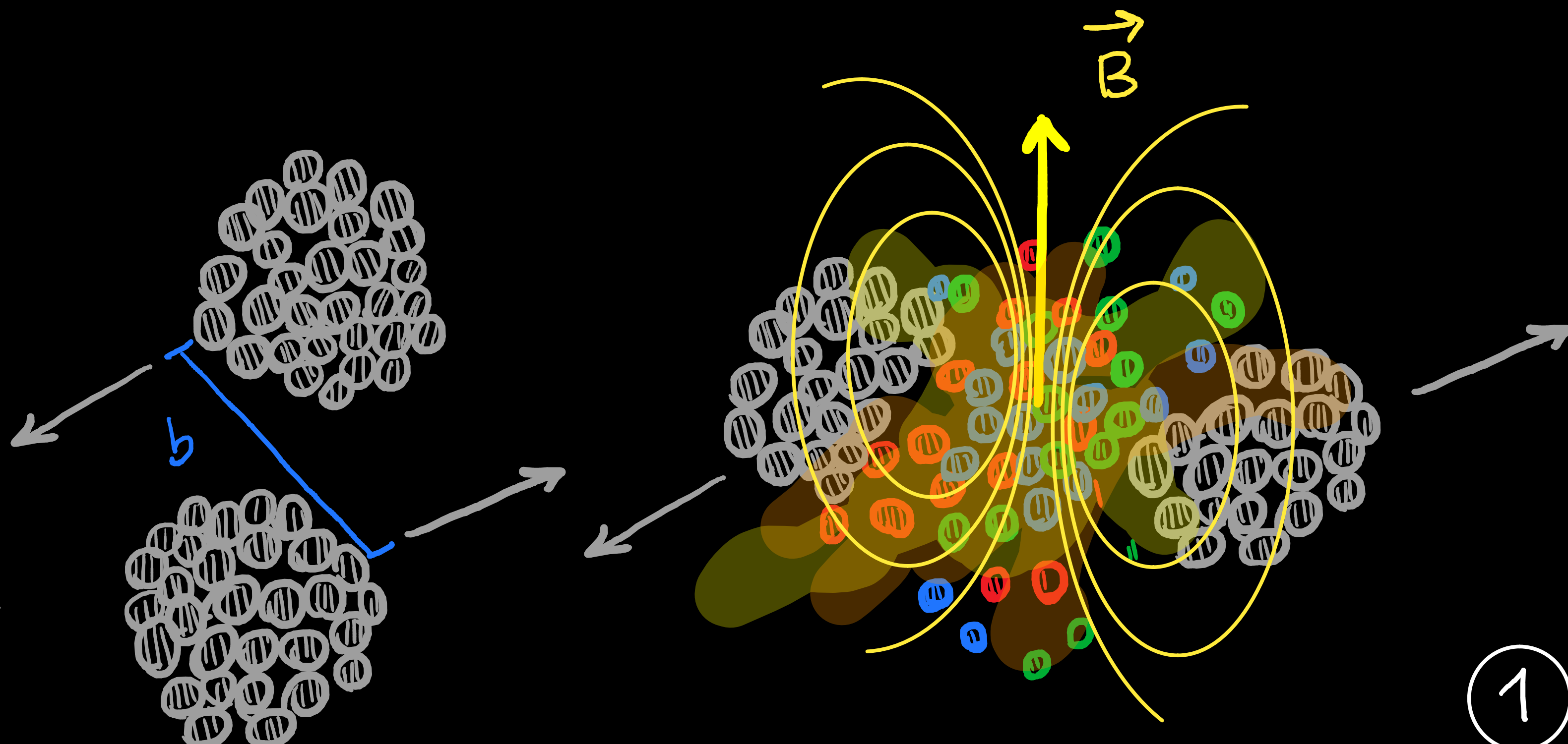

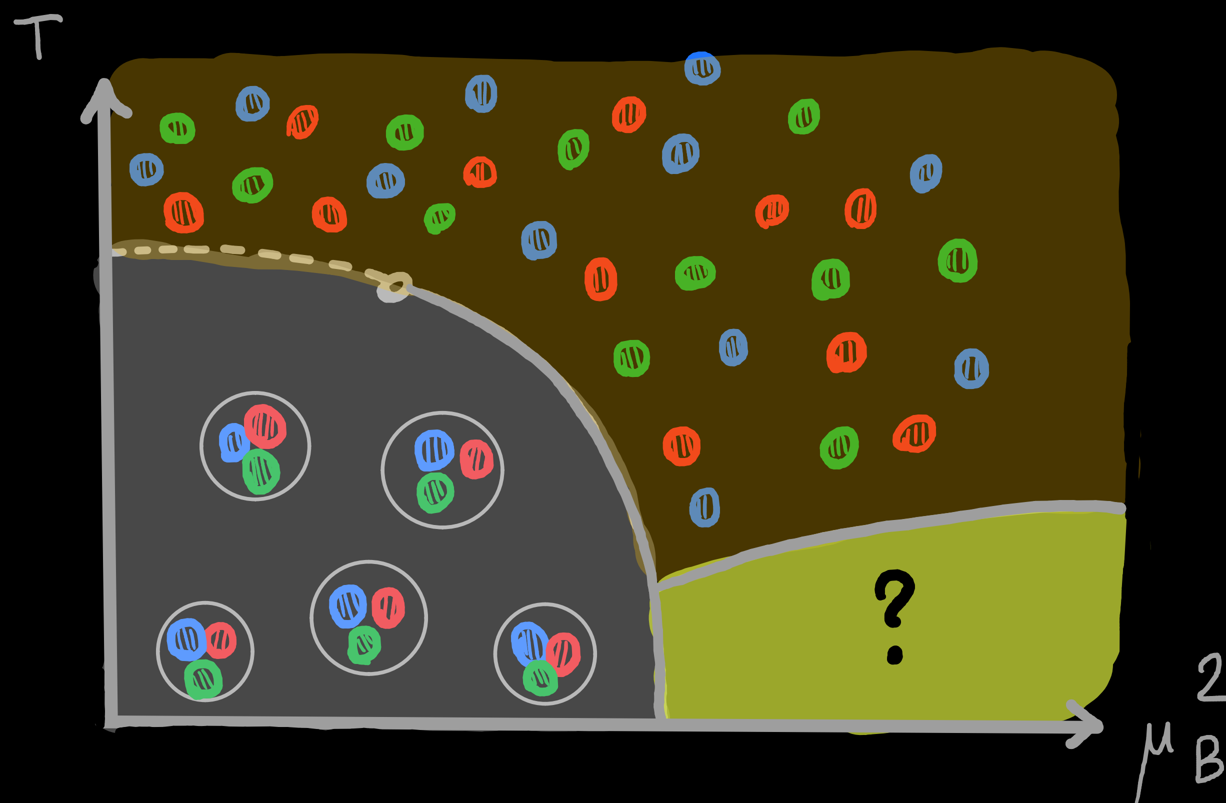
T
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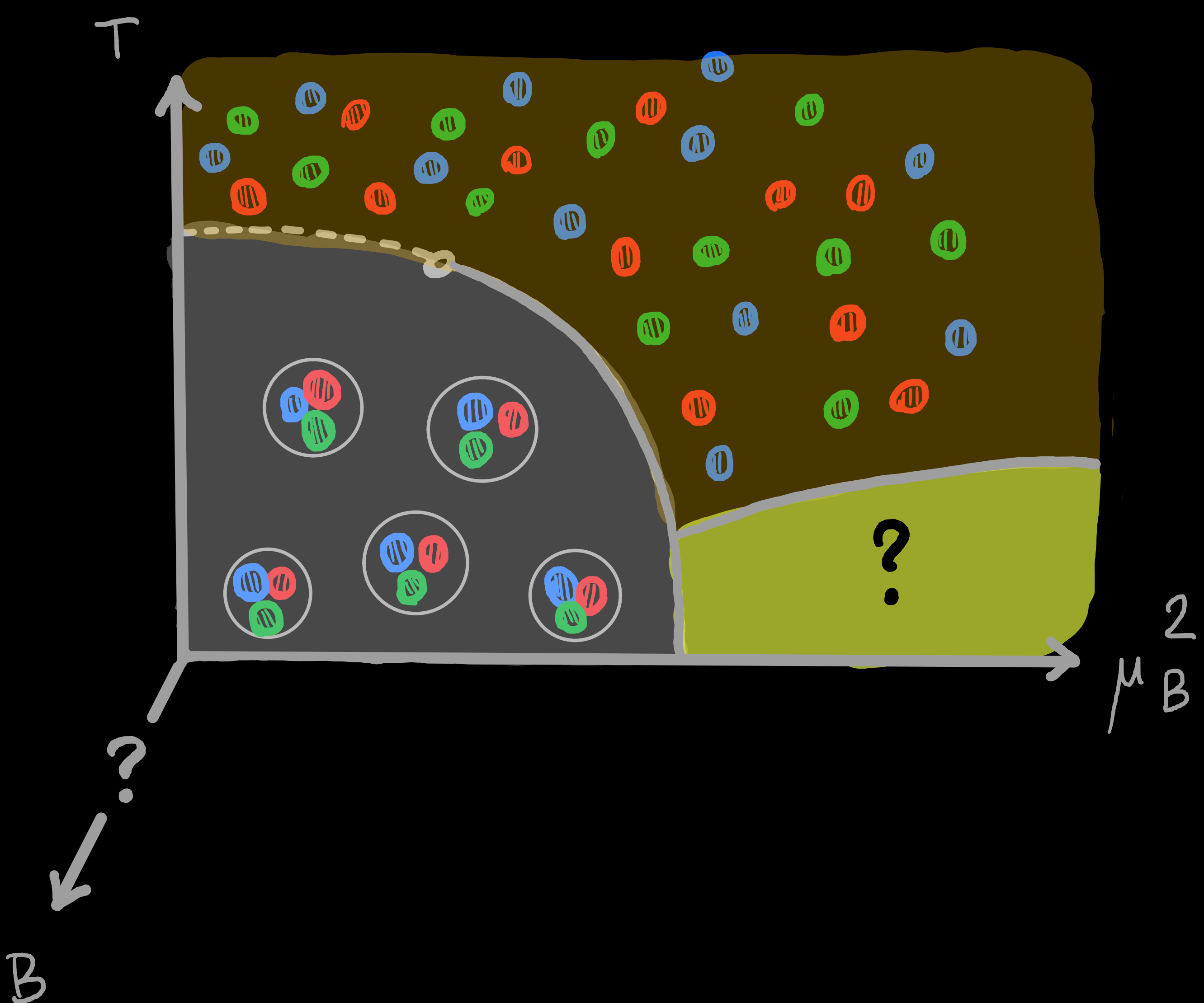
μ_B^2



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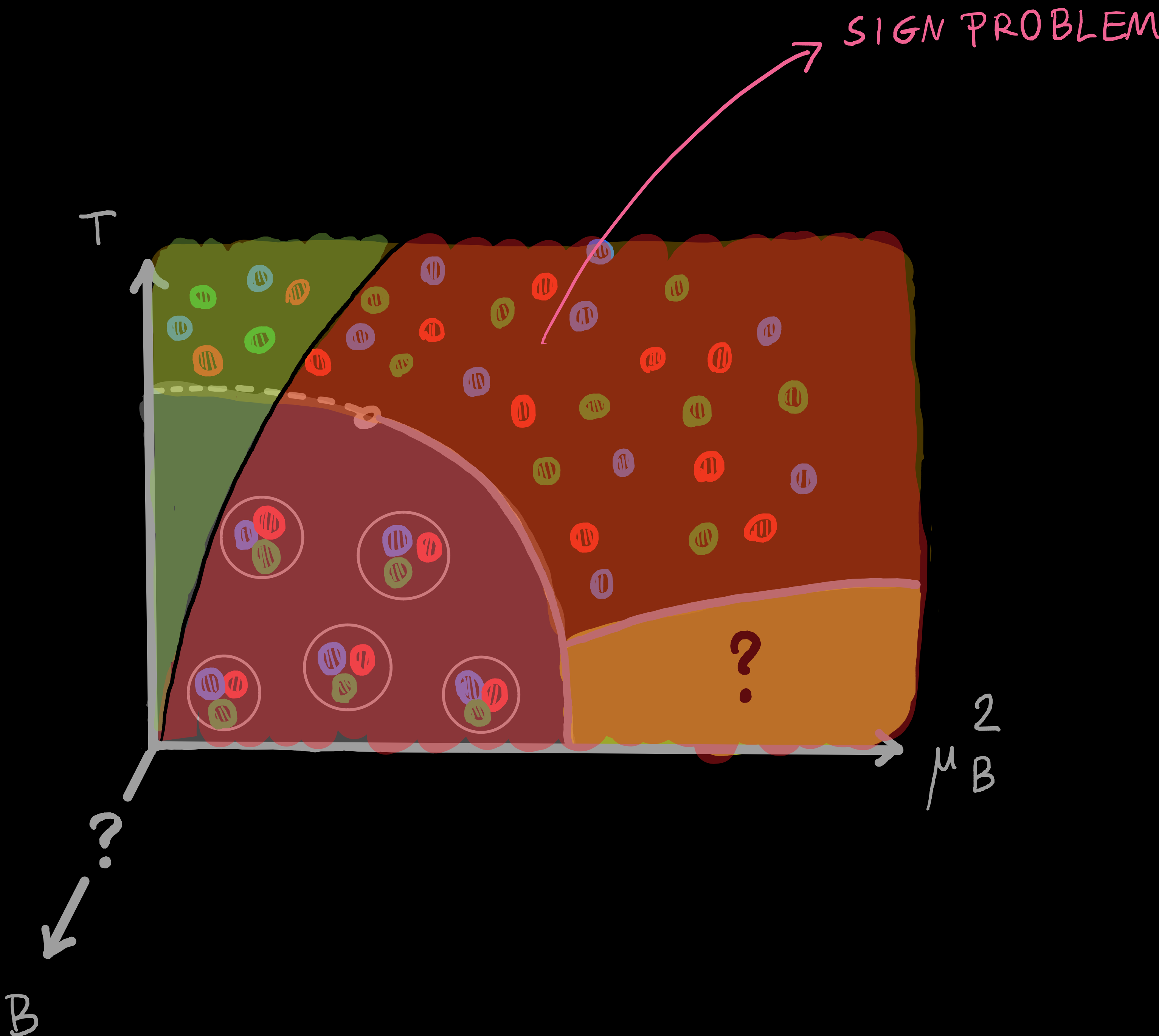
SIGN PROBLEM
T
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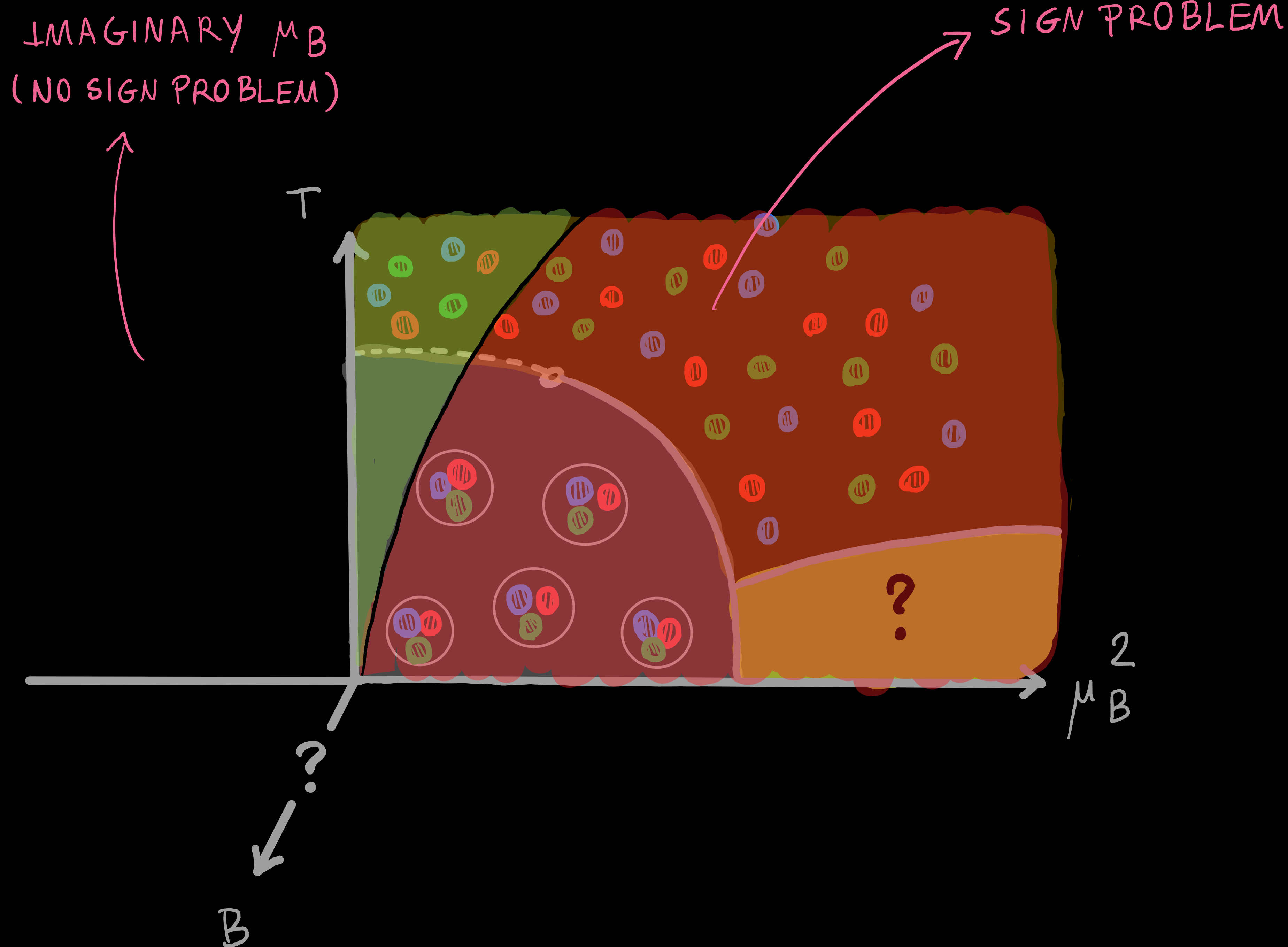

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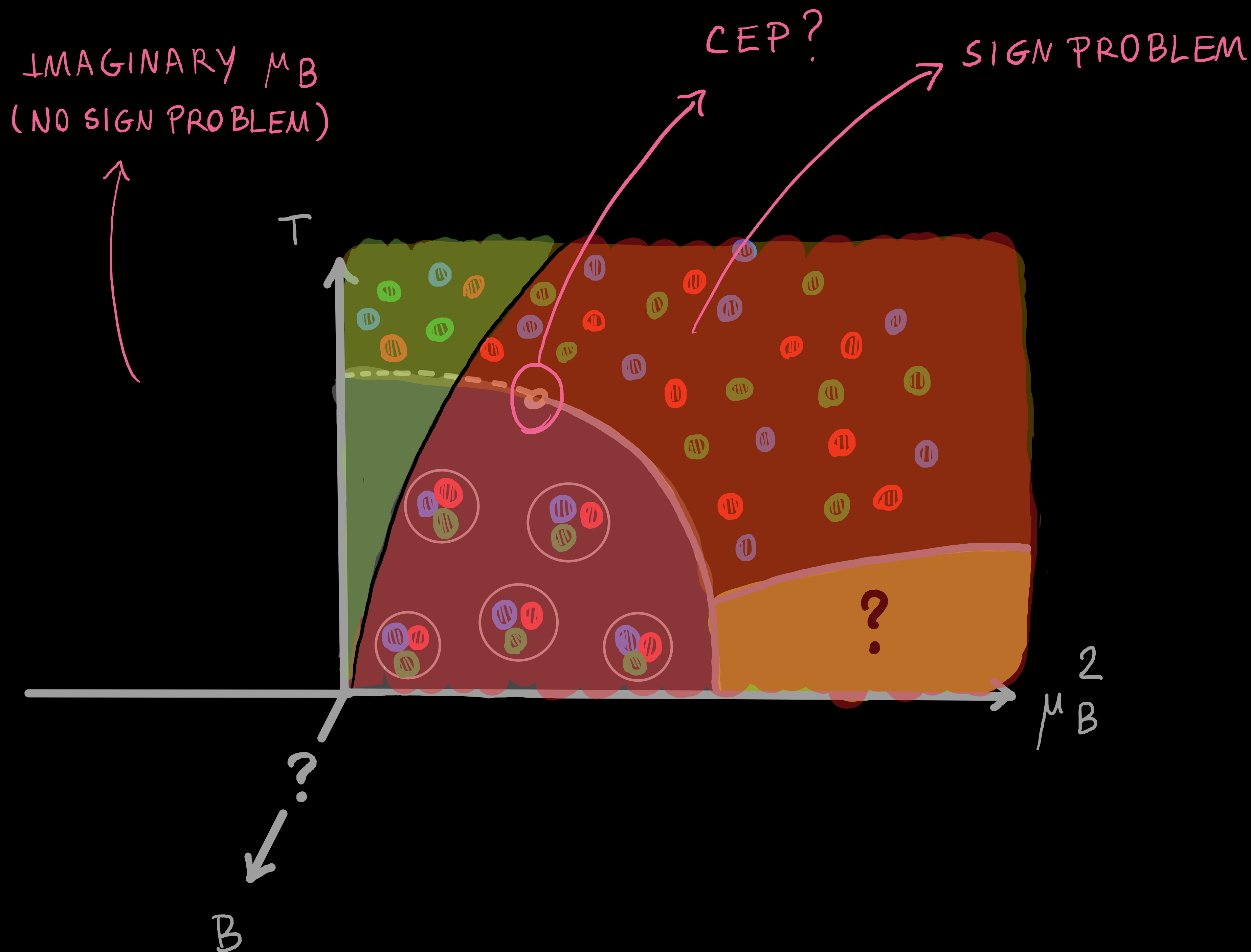
IMAGINARY μB
(NO SIGN PROBLEM)
CEP?
SIGN PROBLEM
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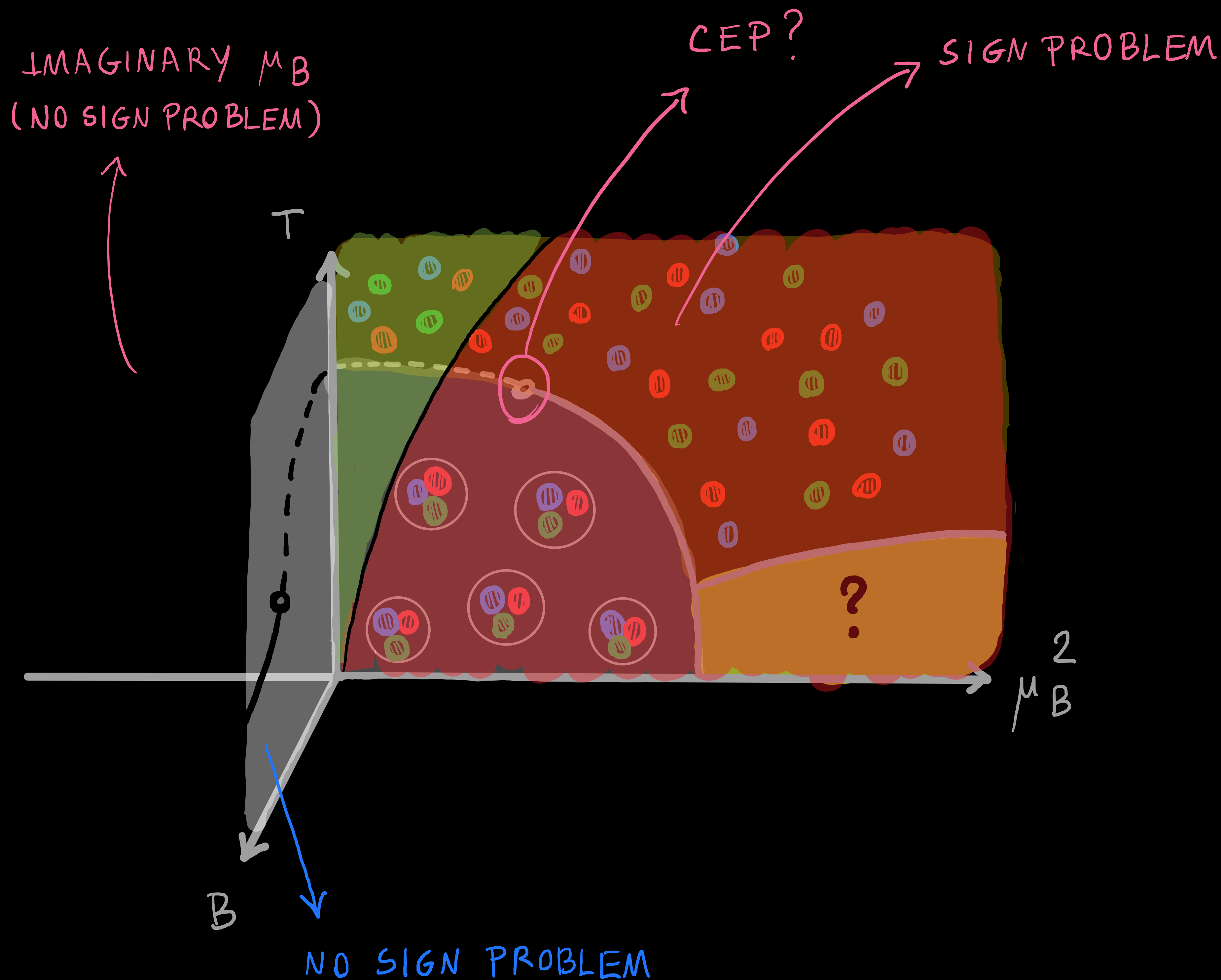
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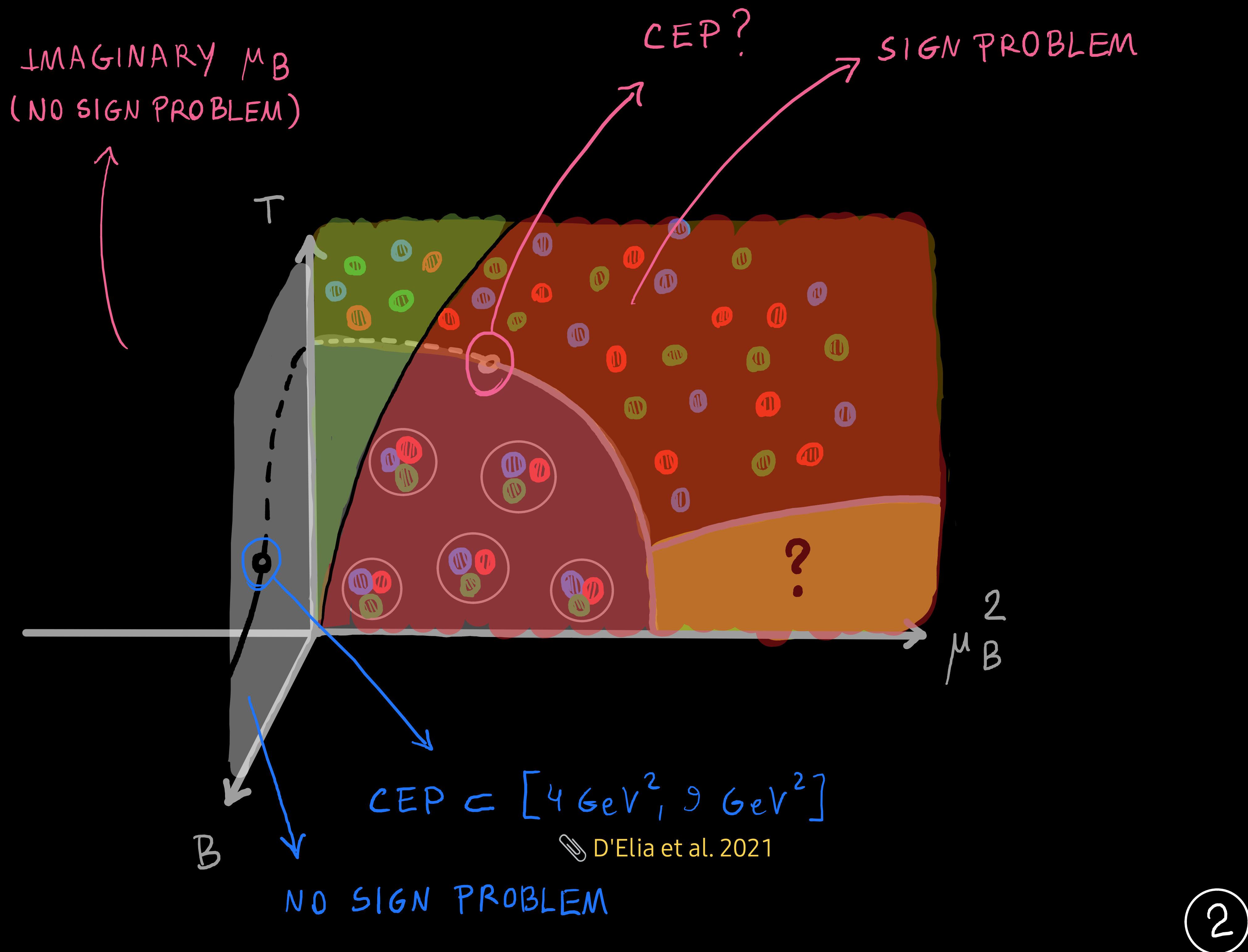
IMAGINARY μ_B
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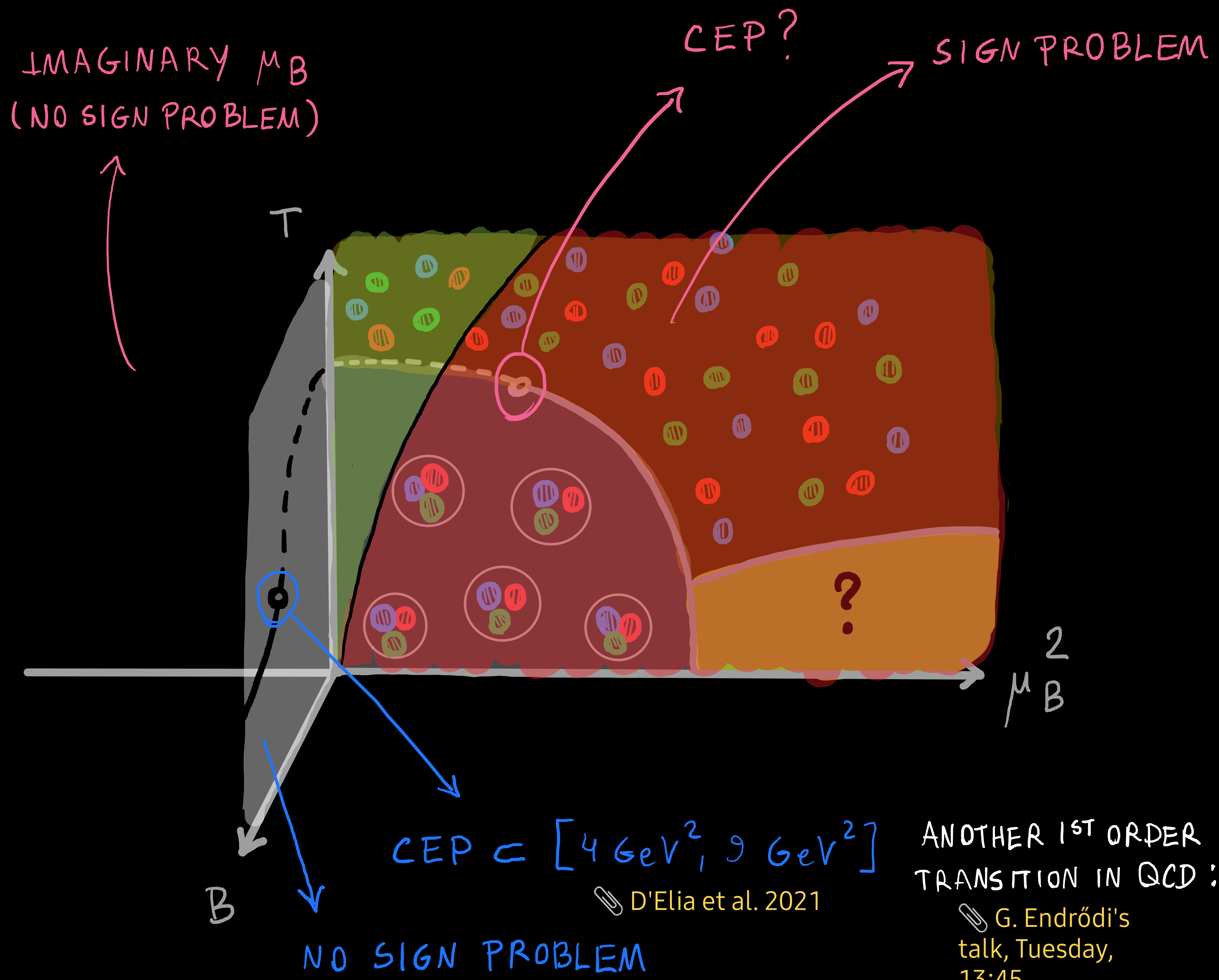
CEP ⊂ [4 GeV², 9 GeV²]
D'Elia et al. 2021
NO SIGN PROBLEM
2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G. Endrődi's
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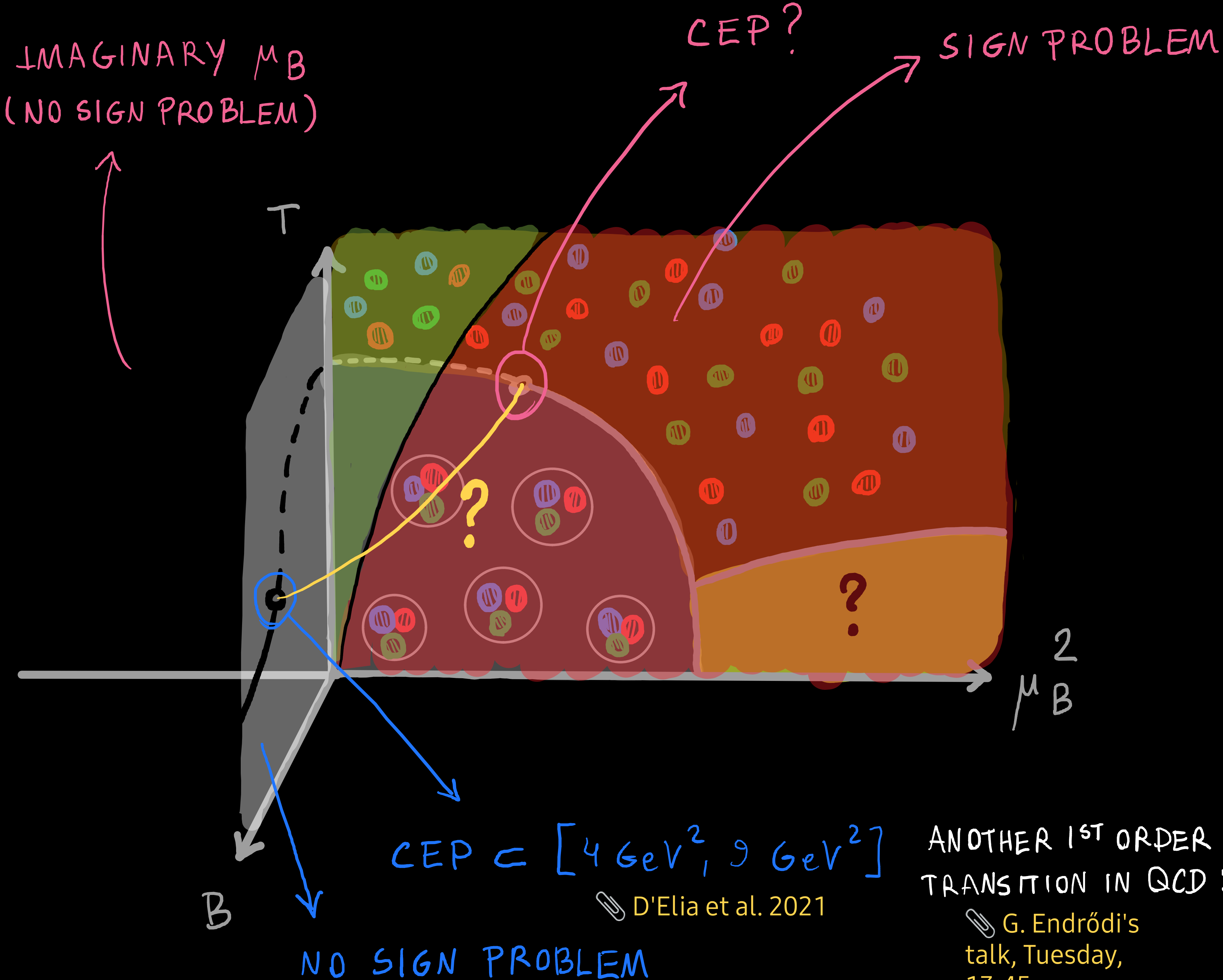
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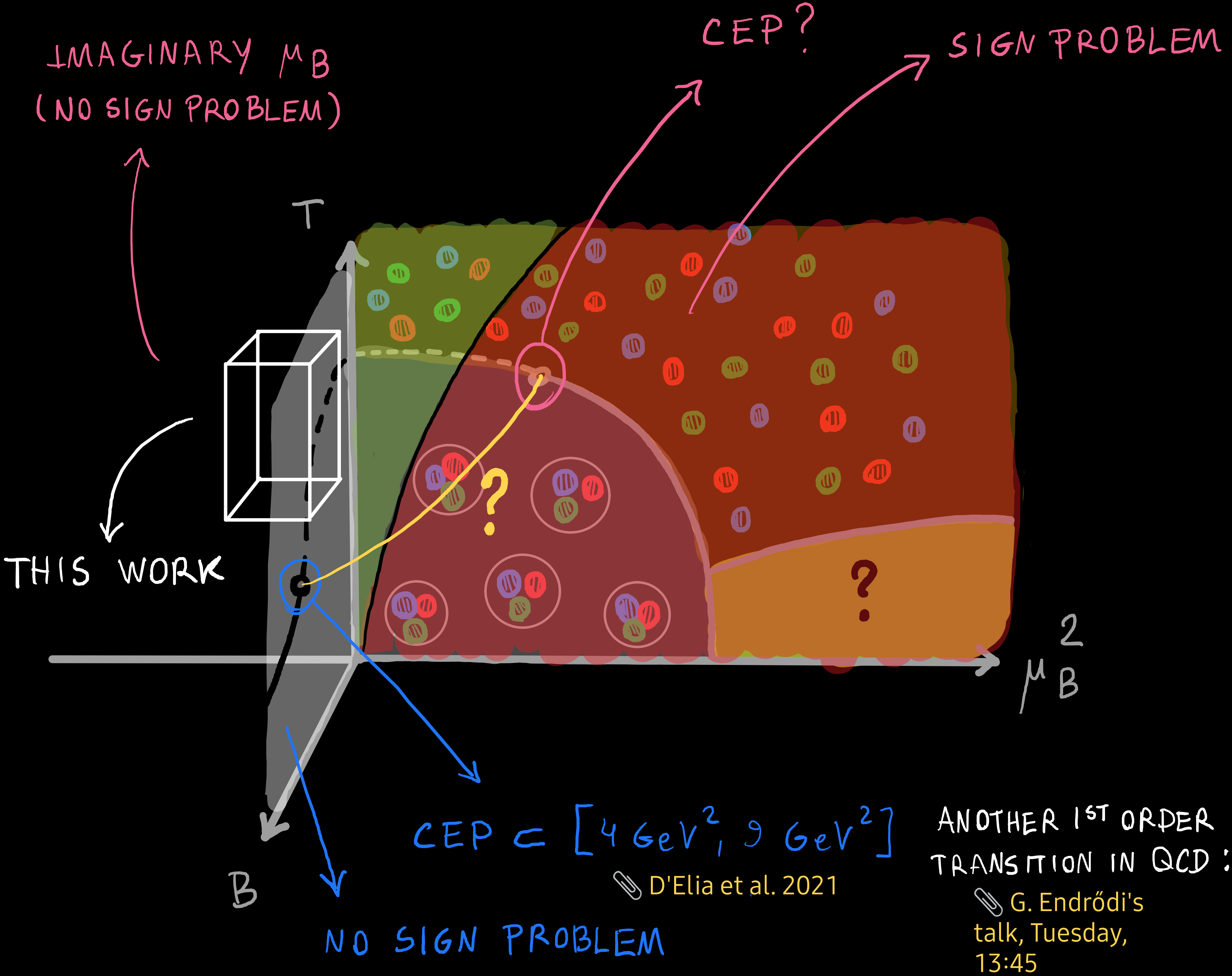

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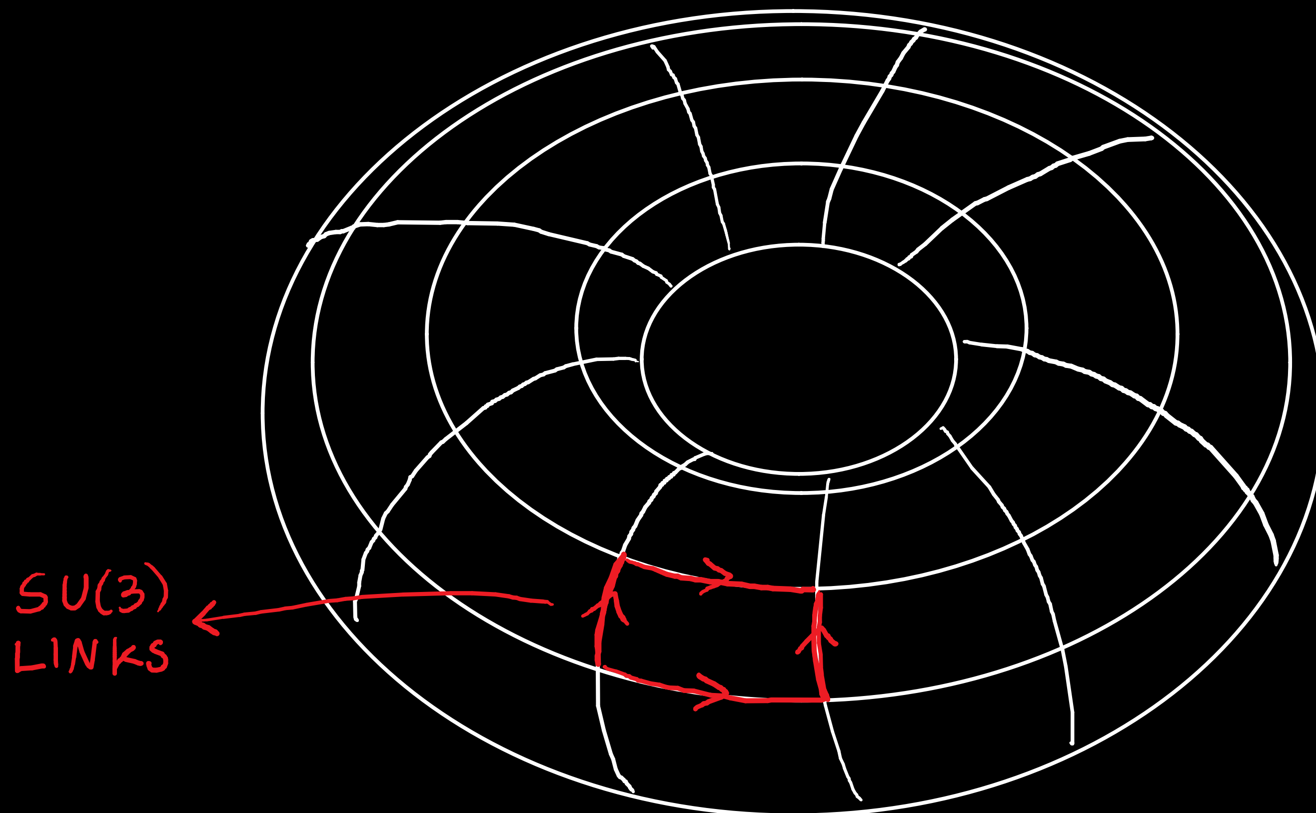
OUTLINE

1. UNIFORM $\vec{B}$ ON THE LATTICE
2. SIMULATION SETUP & EoS
3. LATTICE RESULTS
4. SUMMARY & CONCLUSIONS

UNIFORM $\vec{B}$ ON THE LATTICE

$\vec{B} \parallel \hat{z}$

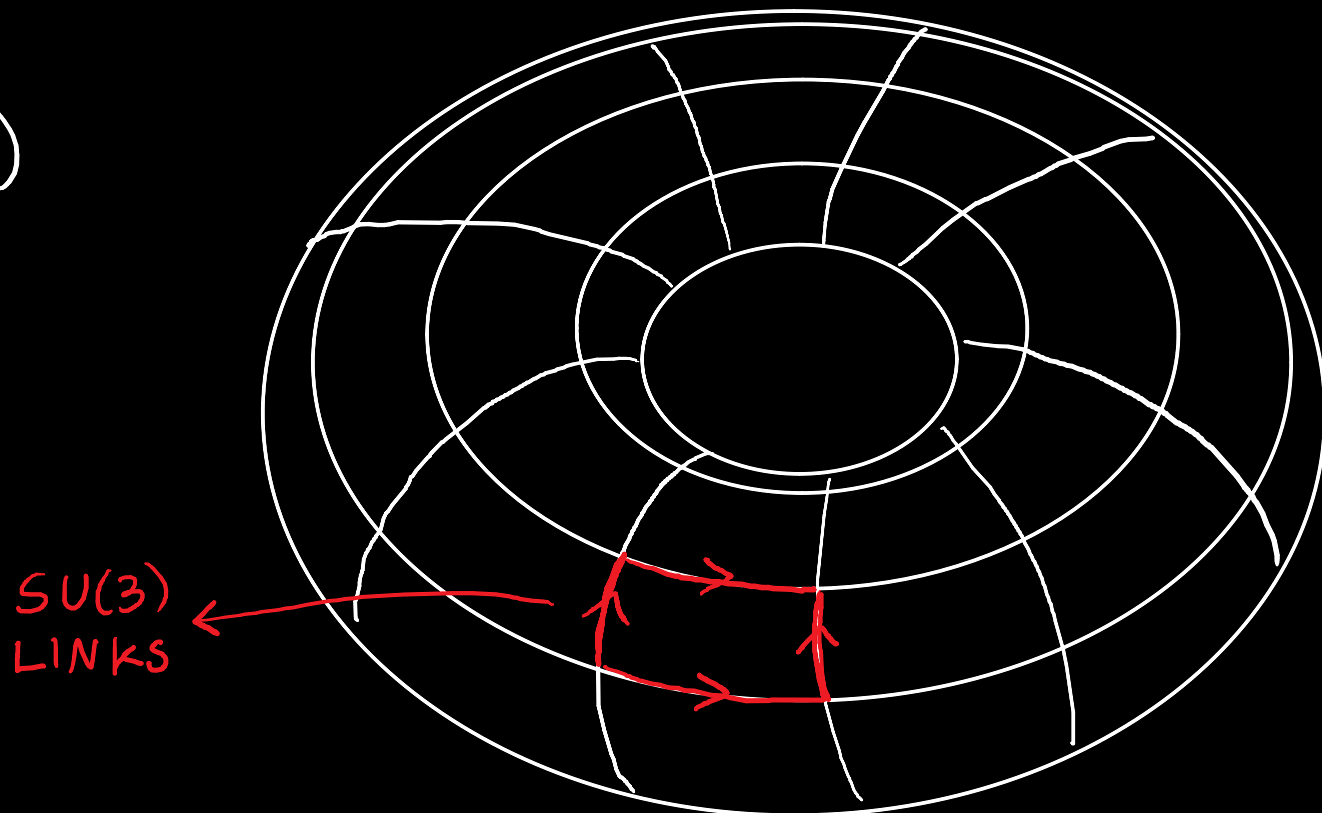
UNIFORM $\vec{B}$ ON THE LATTICE $\quad \vec{B} \parallel \hat{z}$



UNIFORM $\vec{B}$ ON THE LATTICE $\quad \vec{B} \parallel \hat{z}$

- COMPLEX U(1) FACTORS:

$$u_\mu = e^{iaqA_\mu(B)}$$



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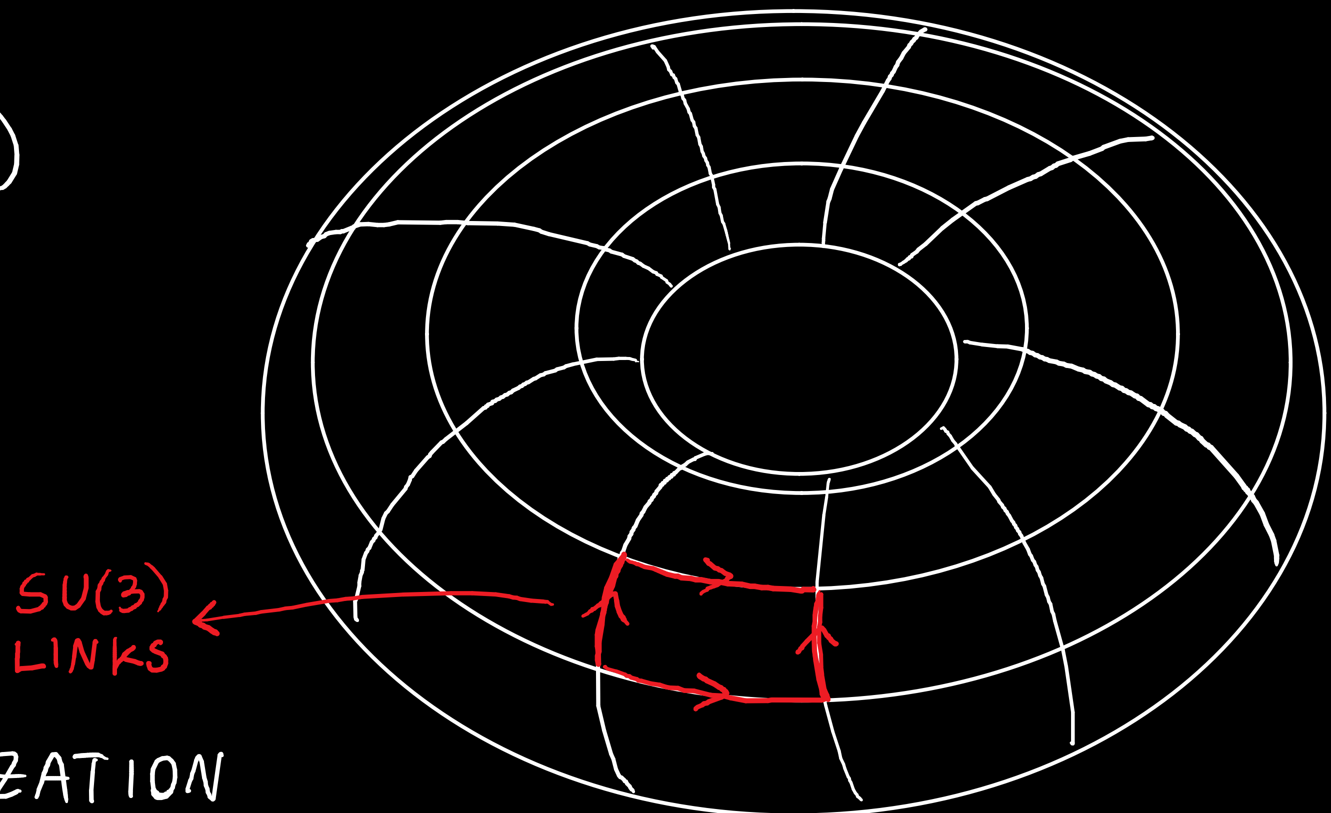

- FLUX QUANTIZATION

$$eB = \frac{6\pi N_b}{L_x L_y}, \quad N_b \in \mathbb{Z}$$

ALSO FOR NON-UNIFORM MAGNETIC FIELDS: Brandt et al. 2023

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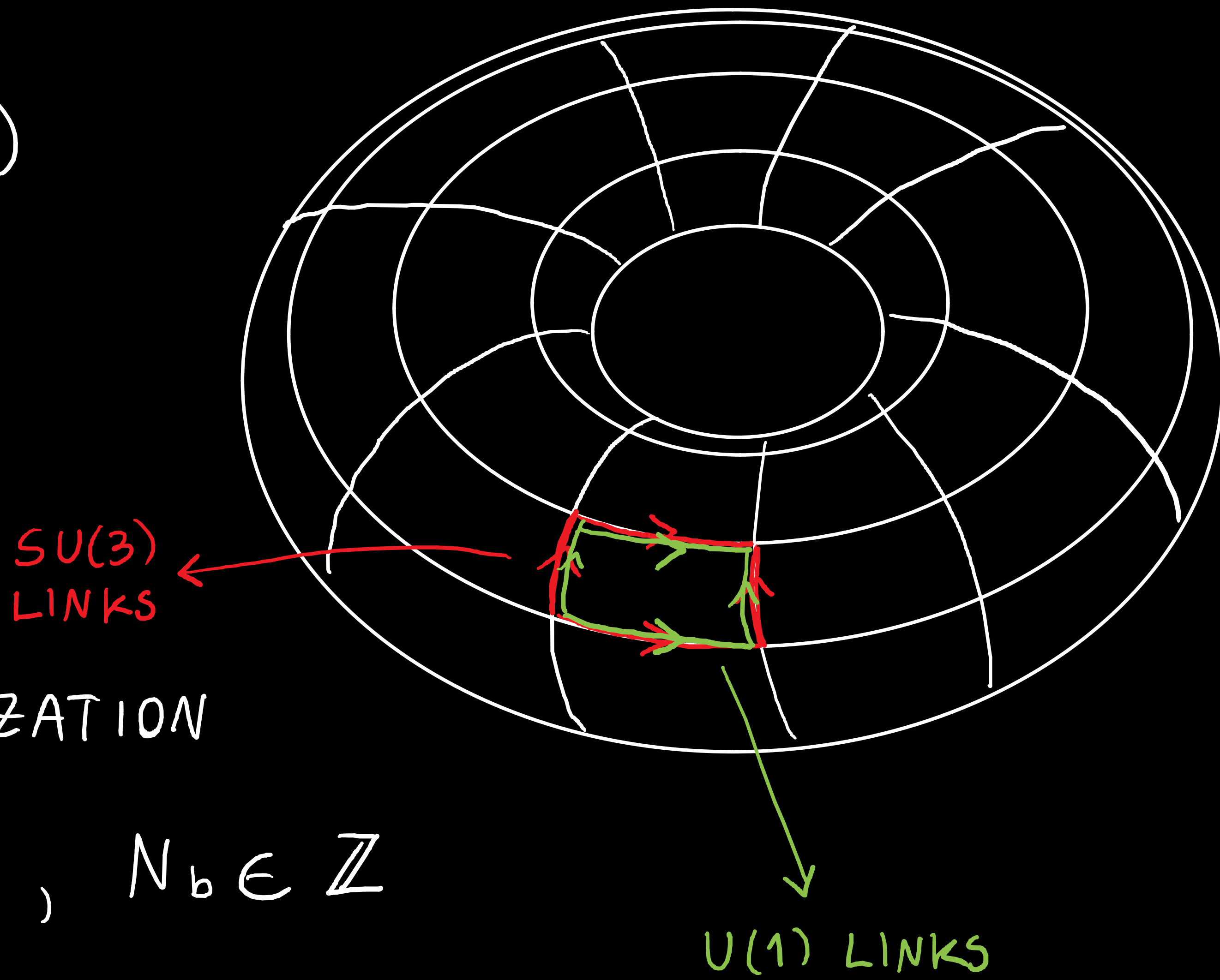

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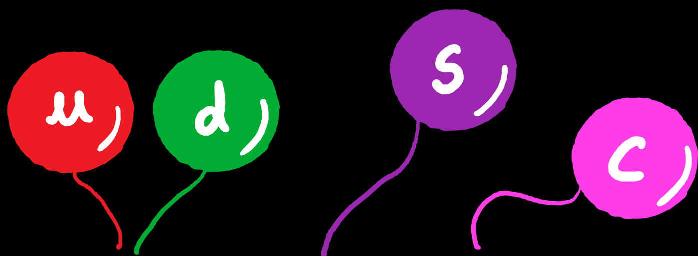
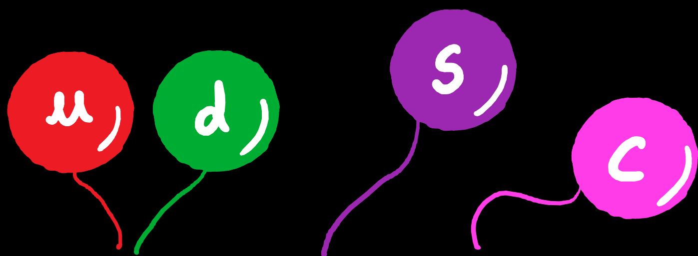


- 2 + 1 + 1 STAGGERED FERMIONS W/ PHYSICAL MASSES
  & 4 STOUT SMEARING STEPS

SIMULATION SETUP



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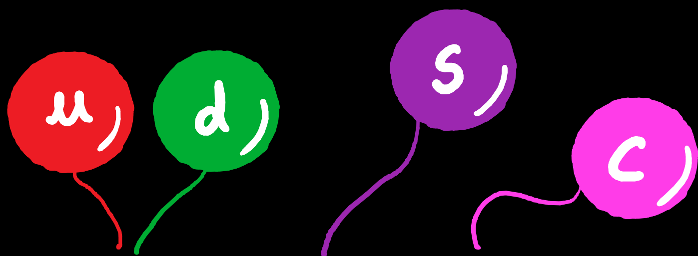

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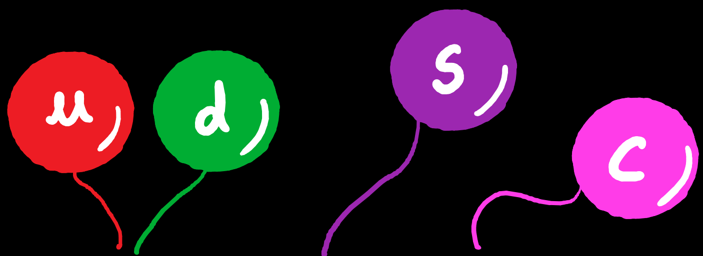

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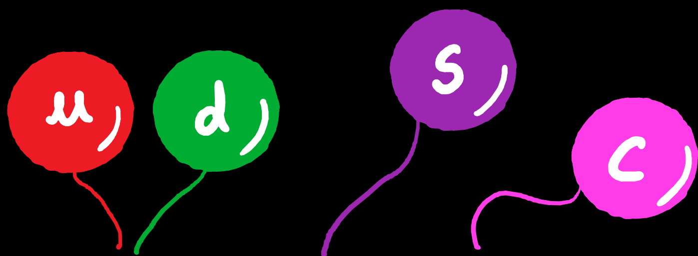

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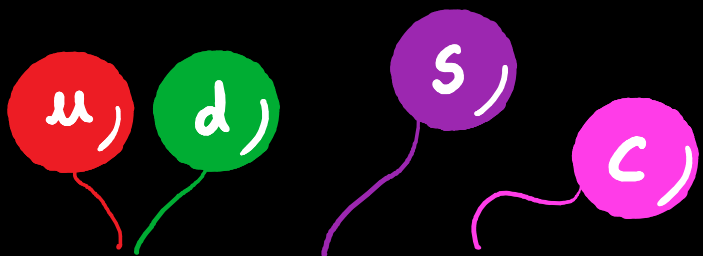

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STRANGENESS-NEUTRALITY & ISOSPIN ASYMMETRY

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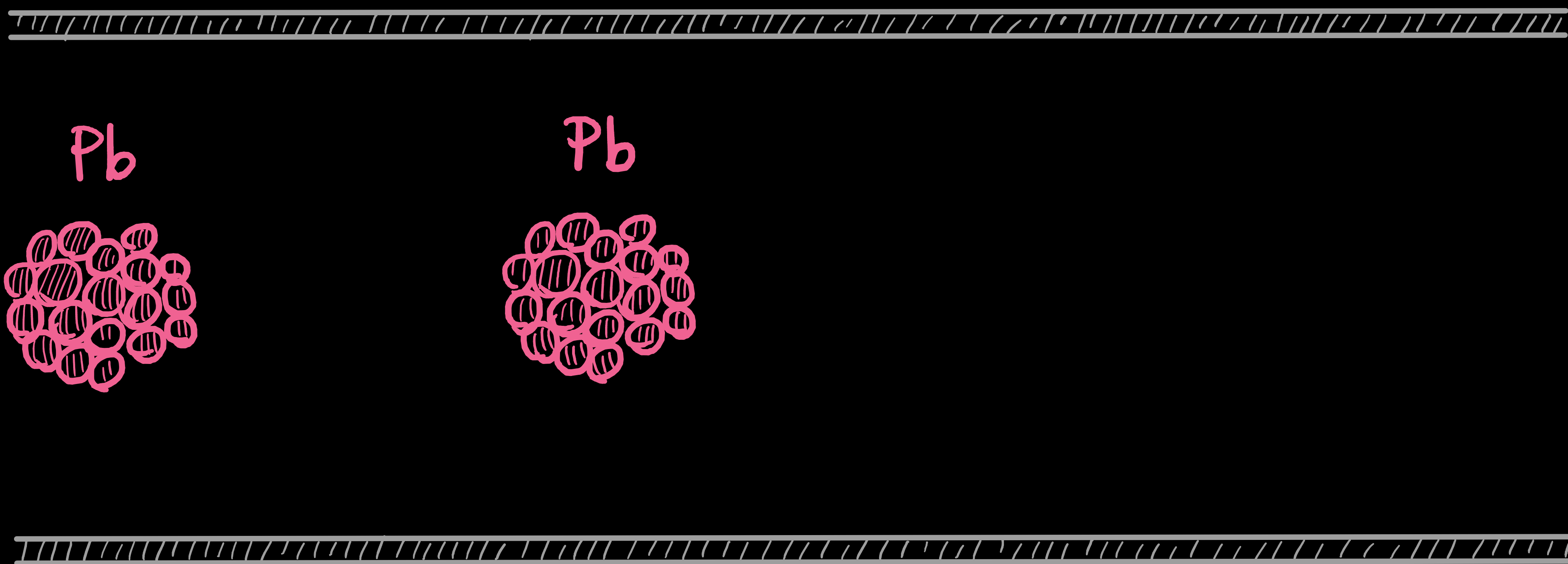

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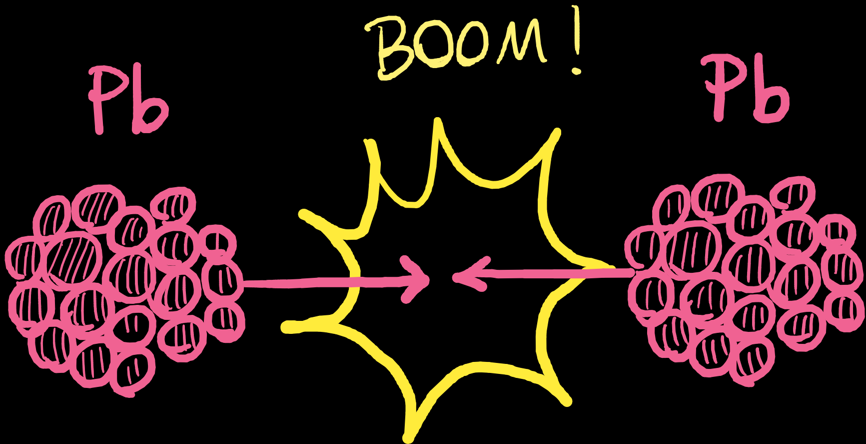

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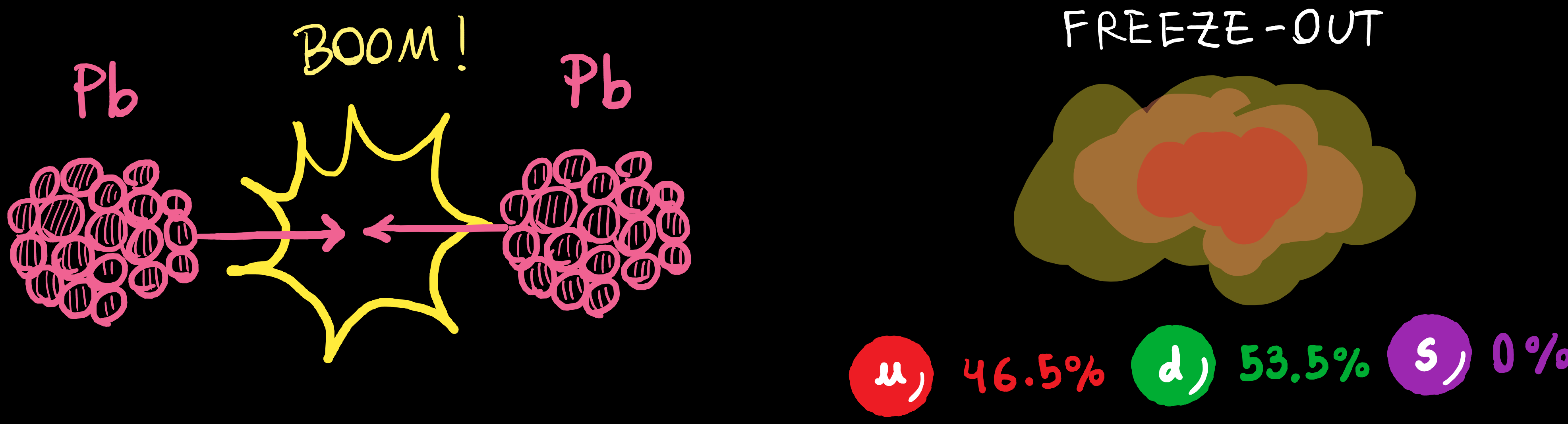

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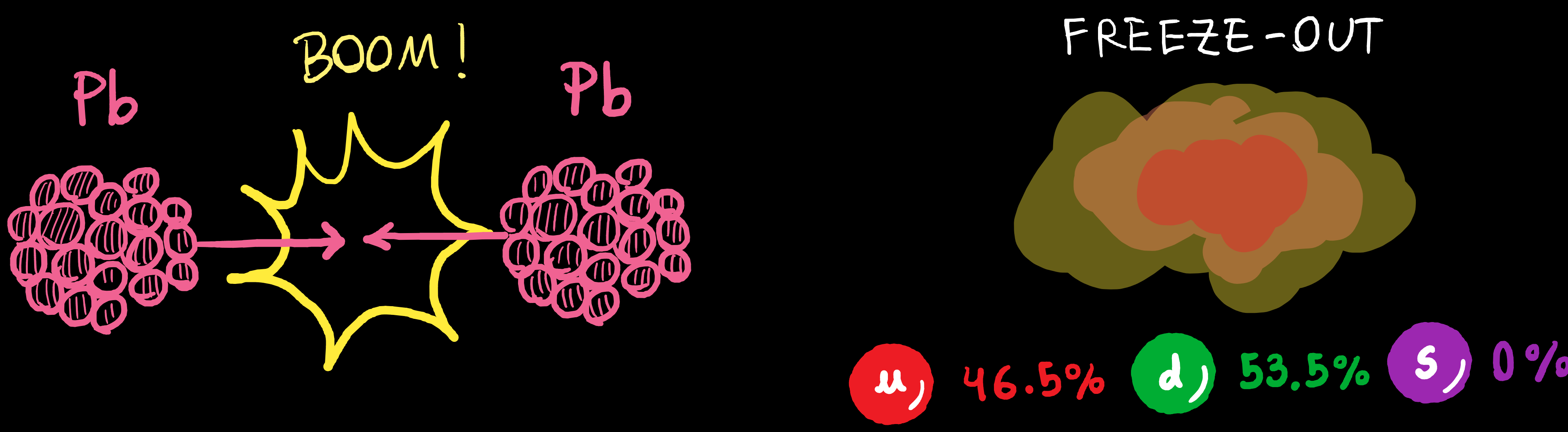
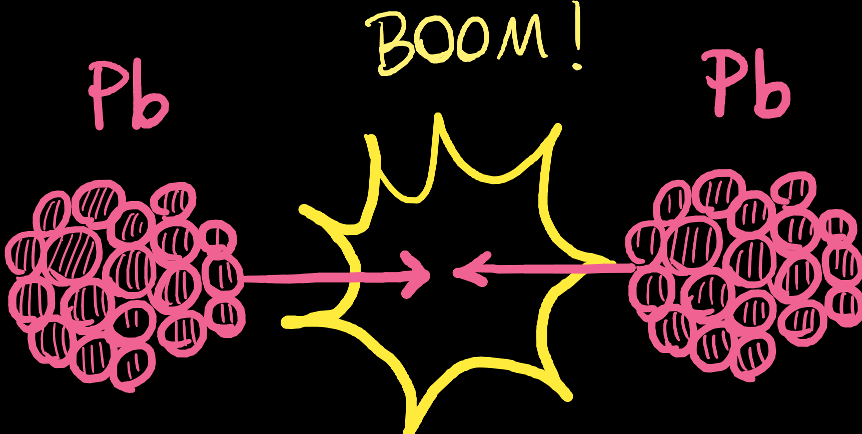
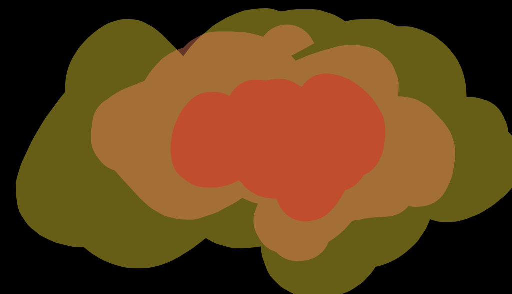


1. $\langle m_s \rangle = 0$ STRANGENESS-NEUTRALITY

STRANGENESS-NEUTRALITY & ISOSPIN ASYMMETRY



FREEZE-OUT



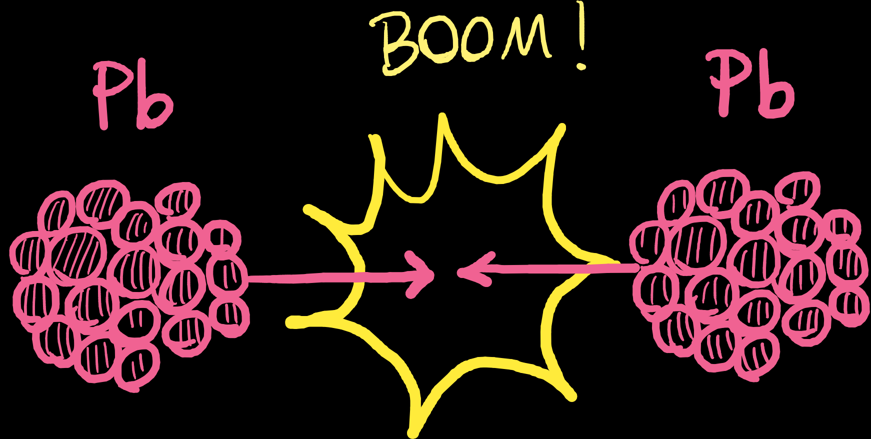
u, 46.5% d, 53.5% s, 0%

1. $\langle m_s \rangle = 0$ STRANGENESS-NEUTRALITY

2. $$\frac{\langle m_Q \rangle}{\langle m_B \rangle} = \frac{\frac{2}{3} \times 0.465 - \frac{1}{3} \times 0.535}{\frac{1}{3} \times 0.465 + \frac{1}{3} \times 0.535} \simeq 0.4$$

ISOSPIN ASYMMETRY

STRANGENESS-NEUTRALITY & ISOSPIN ASYMMETRY



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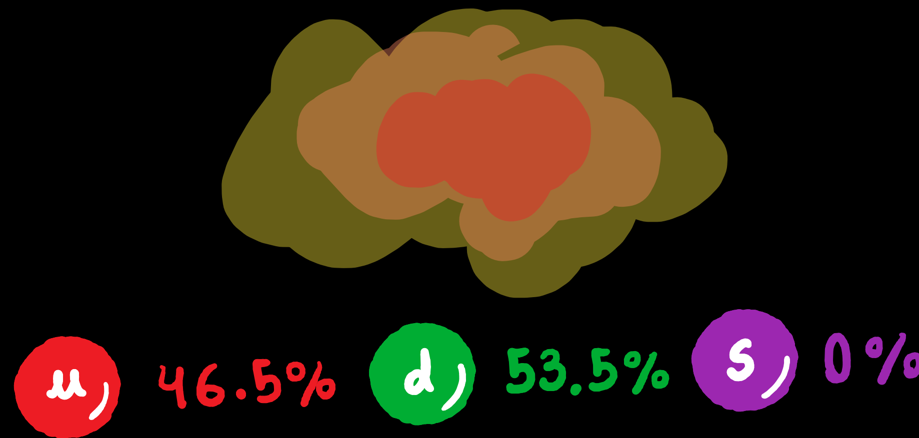

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ISOSPIN SYMMETRY : $\frac{\langle n_Q \rangle}{\langle n_B \rangle} = 0.5$

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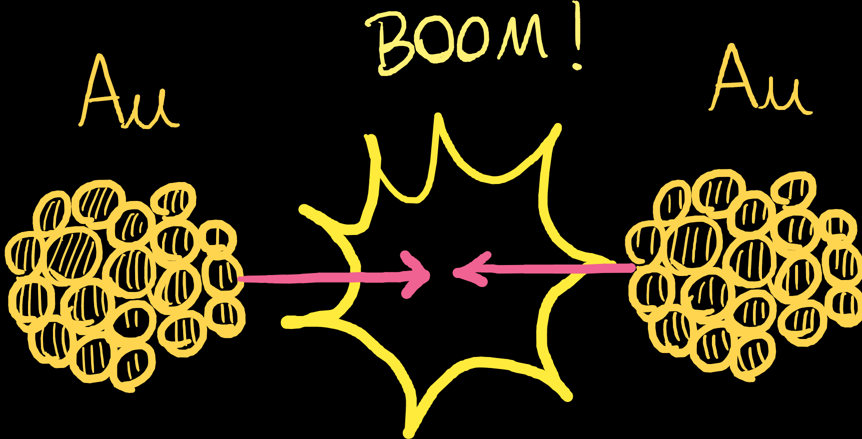

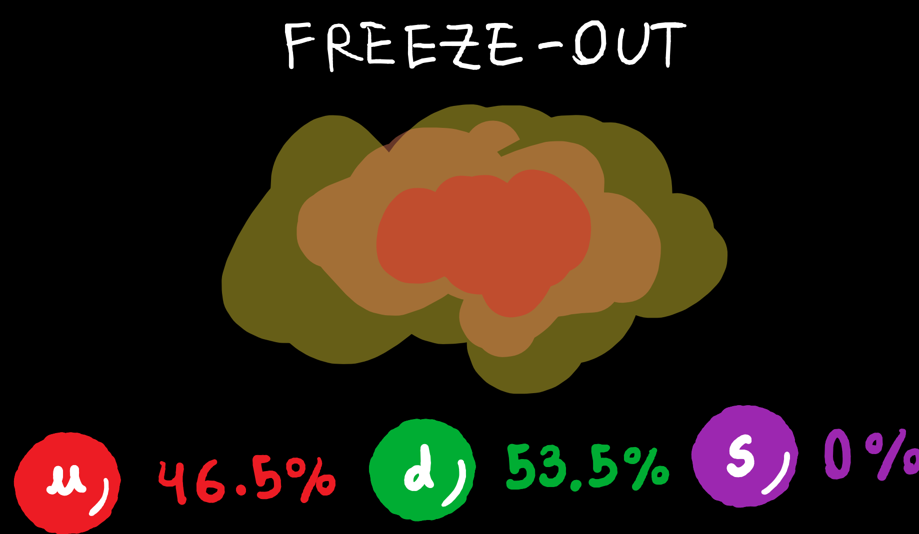

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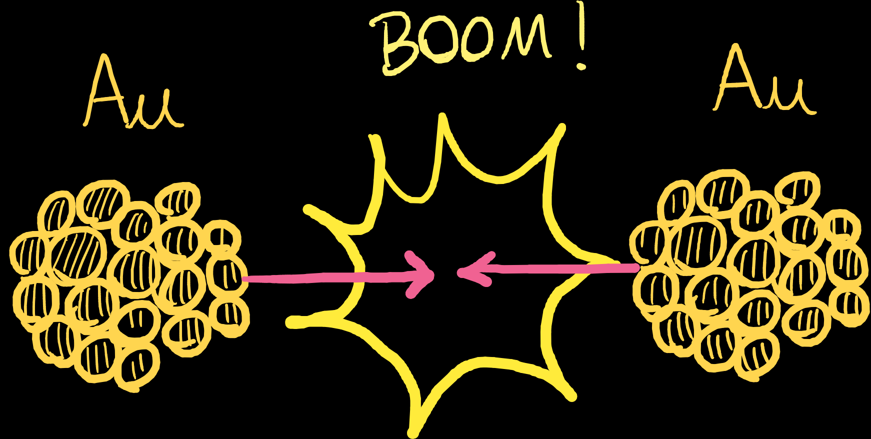

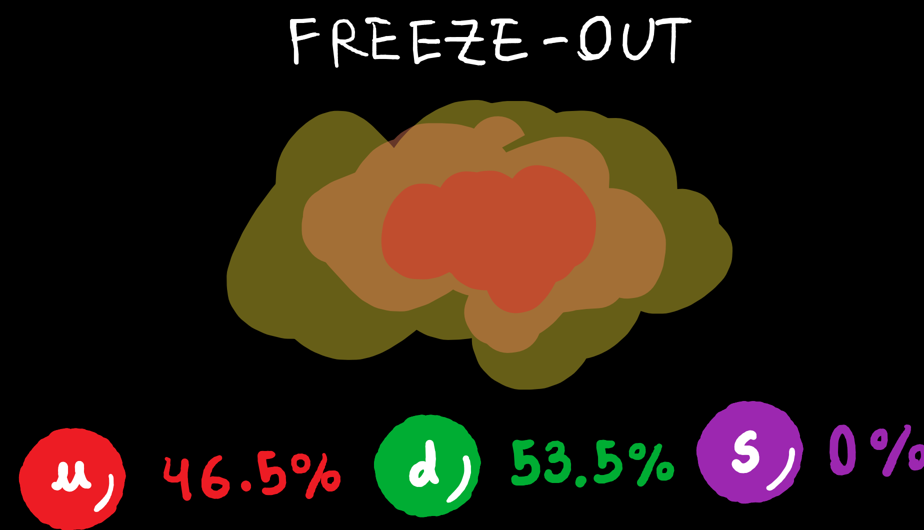

1. $\langle n_S \rangle = 0$ STRANGENESS-NEUTRALITY $\neq (\mu_S = 0)$

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THE EoS AT $\mu_B = 0$

$$\frac{P}{T^4} = \sum_{ijk} \frac{1}{i!j!k!} \chi^{BQS}_{ijk} \hat{\mu}_B^{i} \hat{\mu}_Q^{j} \hat{\mu}_S^{k} , \qquad \hat{\mu}_B \equiv \frac{\mu_B}{T}$$

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TO SATISFY THE CONSTRAINTS

$$\hat{\mu}_Q = q_1 \hat{\mu}_B + \mathcal{O}(\hat{\mu}_B^3) \qquad \hat{\mu}_S = s_1 \hat{\mu}_B + \mathcal{O}(\hat{\mu}_B^3)$$

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q_1 & s_1 : COMPUTED FROM 2^{ND} ORDER SUSCEPTIBILITIES

$$q_1 = \frac{0.4(\chi_{BB}\chi_{SS} - \chi_{BS}^2) - (\chi_{BQ}\chi_{SS} - \chi_{BS}\chi_{QS})}{\chi_{QQ}\chi_{SS} - \chi_{QS}^2 - 0.4(\chi_{BQ}\chi_{SS} - \chi_{BQ}\chi_{QS})}$$

A. Bazavov et al. 2012

SIMPLIFIED NOTATION : $\chi_{BB} = \chi^{BQS}_{200}$, $\chi_{BQ} \equiv \chi^{BQS}_{110}$, ETC.

$$\frac{P}{T^4} = c_0 + \left(\frac{\chi_{BB}}{2} + \frac{\chi_{QQ}}{2} q_1^2 + \frac{\chi_{SS}}{2} s_1^2 + \chi_{BQ} q_1 + \right.$$

$$\left. + \chi_{BS} s_1 + \chi_{QS} q_1 s_1 \right) \hat{\mu}_B^2 + \mathcal{O}(\hat{\mu}_B^4)$$

8

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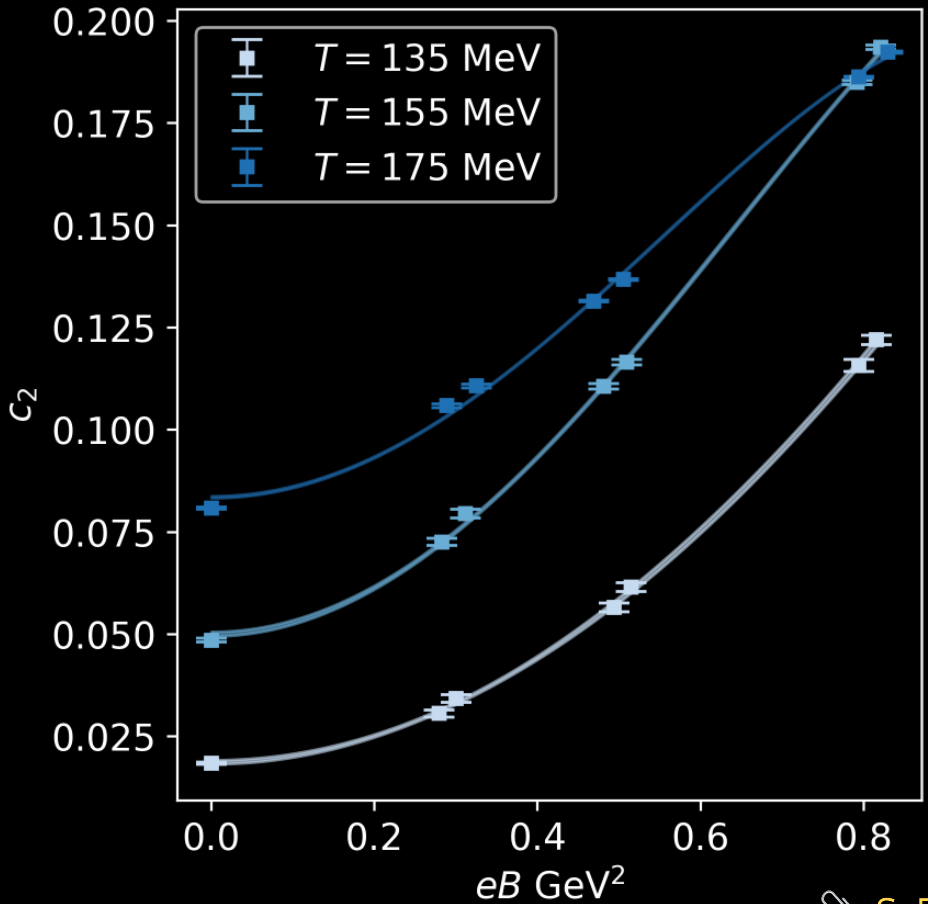
(LO CONTRIBUTION)

$$\frac{P}{T^4} = c_0 + \left(\frac{\chi_{BB}}{2} + \frac{\chi_{QQ}}{2} q_1^2 + \frac{\chi_{SS}}{2} s_1^2 + \chi_{BQ} q_1 + \chi_{BS} s_1 + \chi_{QS} q_1 s_1\right)\hat{\mu}_B^2 + \mathcal{O}(\hat{\mu}_B^4)$$

c_2

(LO CONTRIBUTION)



S. Borsányi et al. 2023

$$\frac{P}{T^4} = c_0 + \left(\frac{\chi_{BB}}{2} + \frac{\chi_{QQ}}{2} q_1^2 + \frac{\chi_{SS}}{2} s_1^2 + \chi_{BQ} q_1 + \chi_{BS} s_1 + \chi_{QS} q_1 s_1 \right) \hat{\mu}_B^2 + \mathcal{O}(\hat{\mu}_B^4)$$

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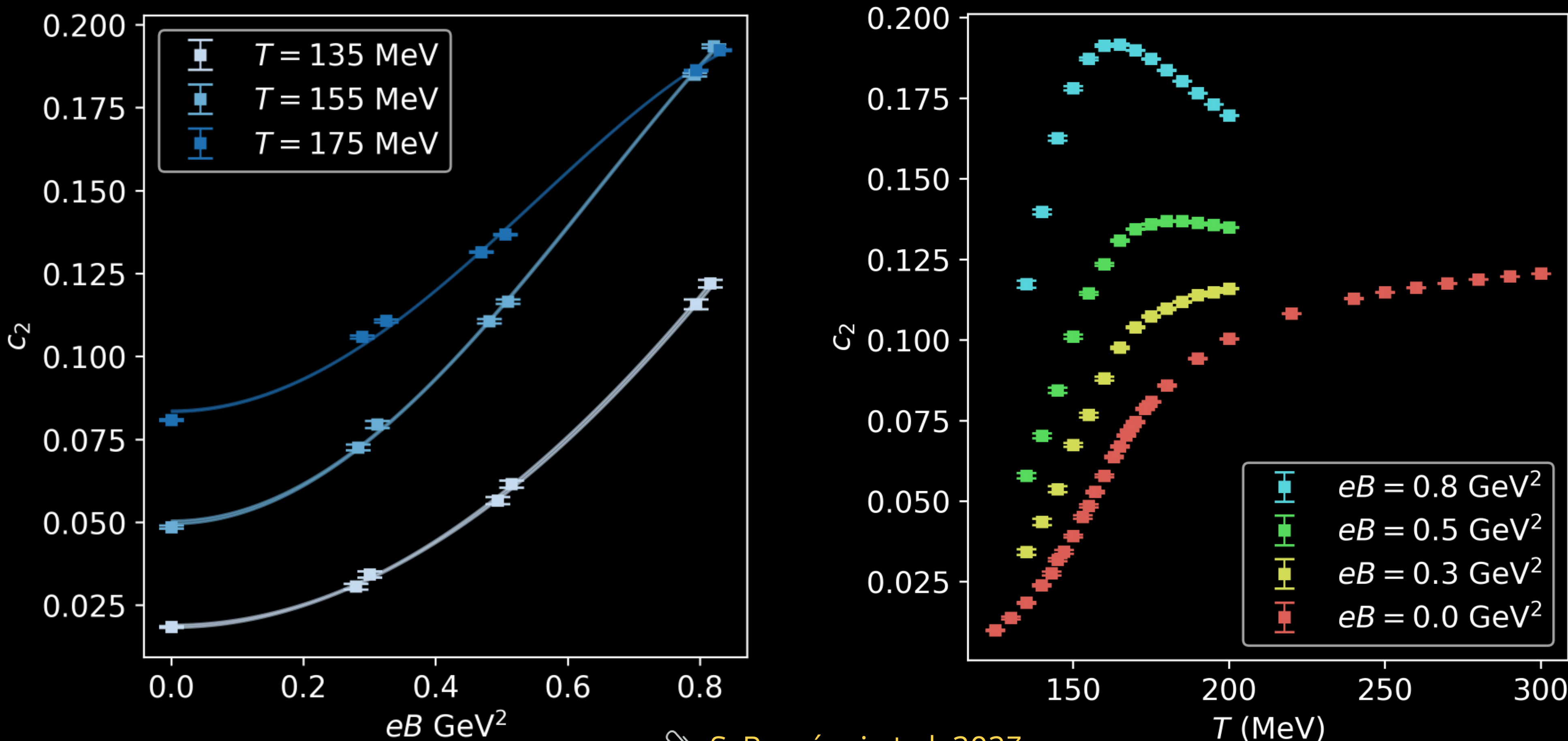

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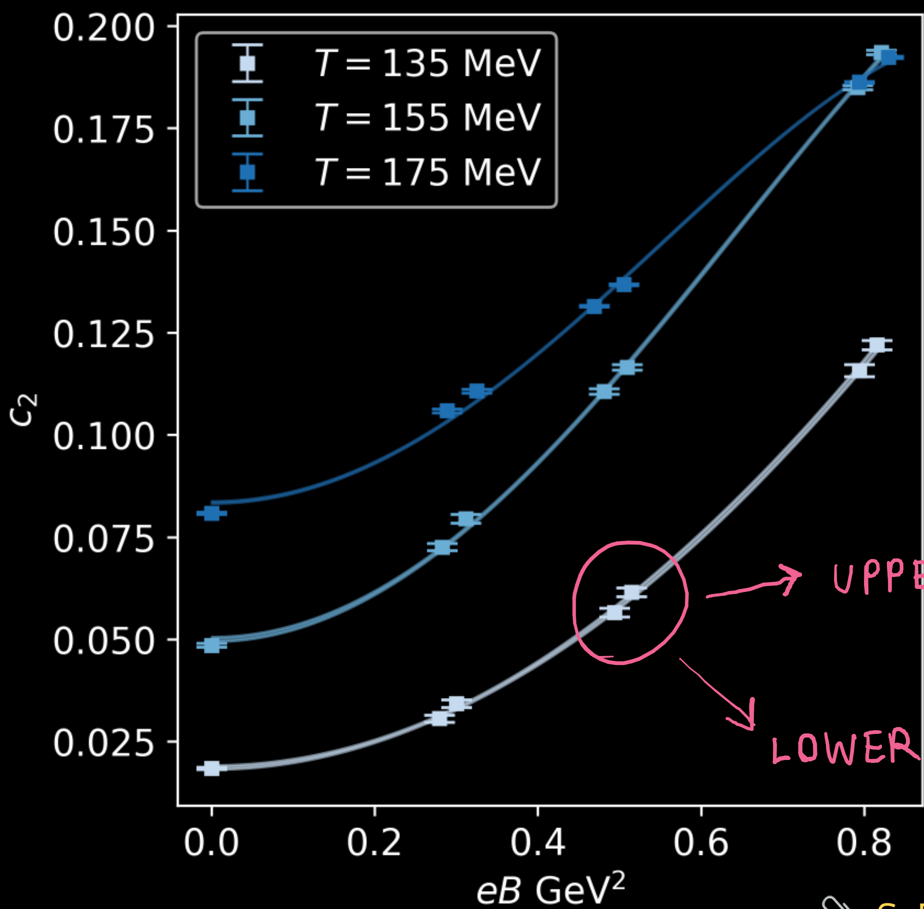
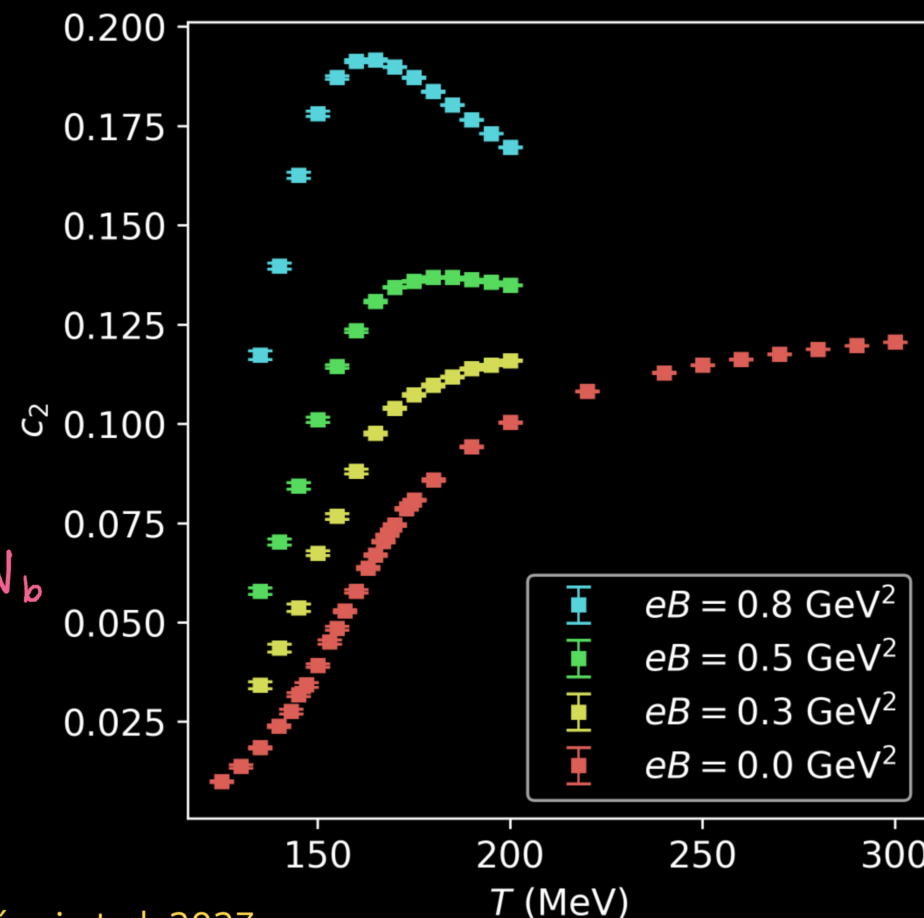


UPPER N_b

LOWER N_b



S. Borsányi et al. 2023

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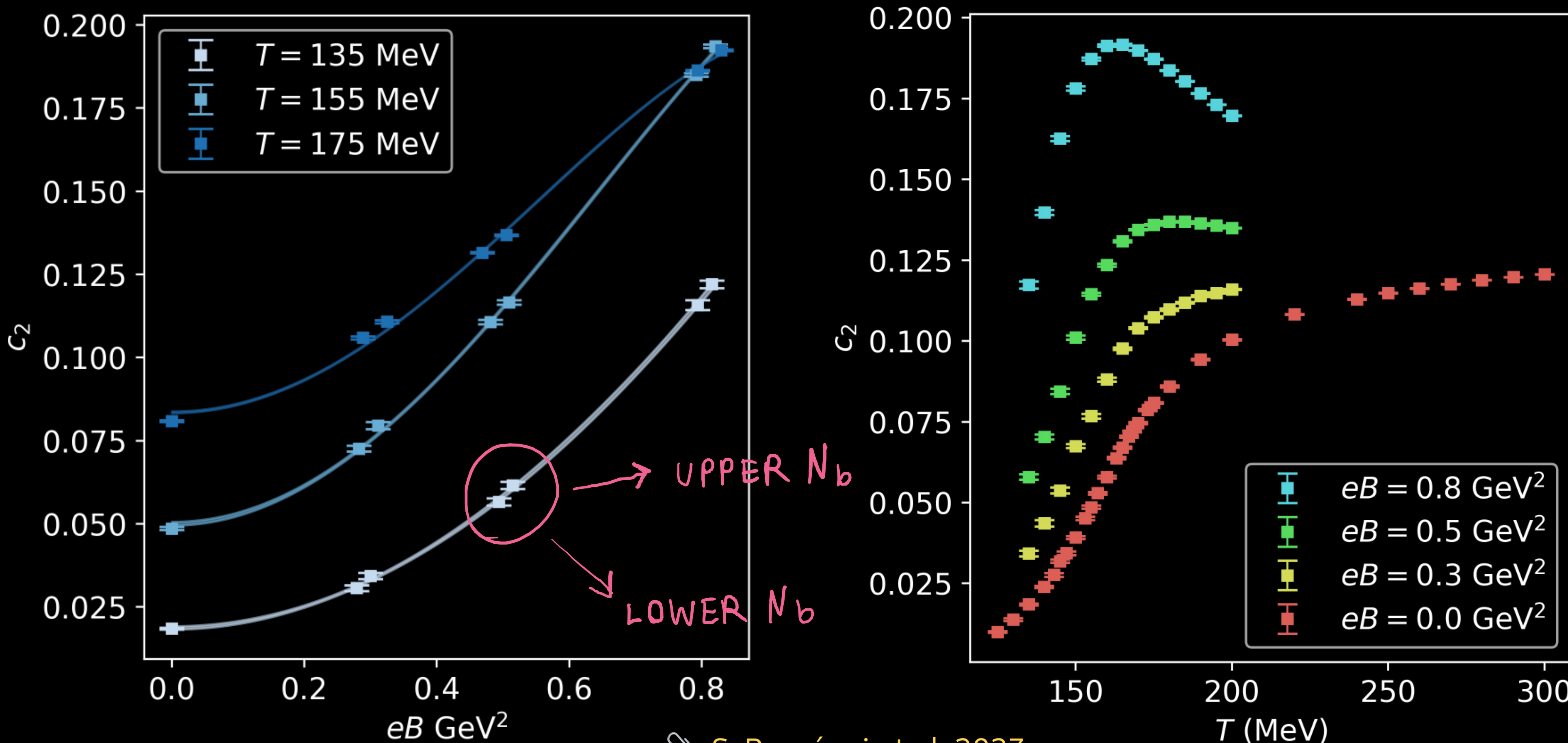

S. Borsányi et al. 2023

q_1 & s_1 : CONSTRAINTS UP TO LO

WHAT ABOUT FINITE $\hat{\mu}_B$?

WE NEED HIGHER ORDERS:

$$\hat{\mu}_Q = q_1 \hat{\mu}_B + q_3 \hat{\mu}_B^3 + \dots$$

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DIFFERENT APPROACHES FOR q_3 & s_3. SEE: Marc-André Petri's poster, Tuesday, 17:15

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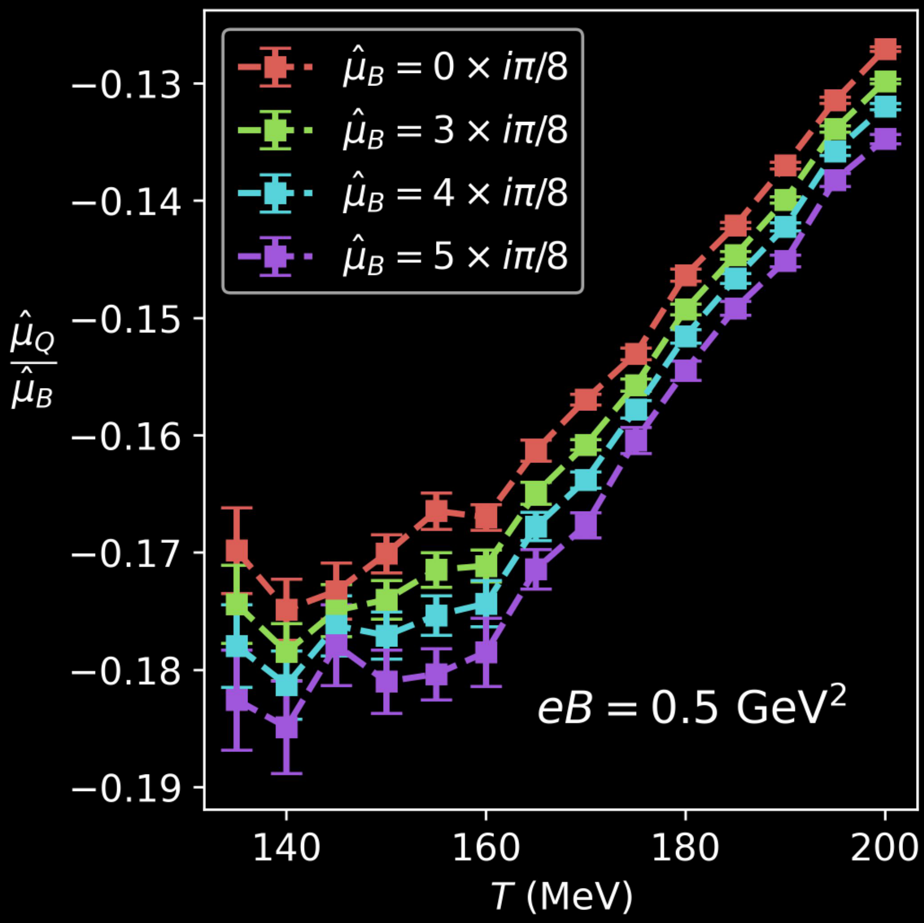

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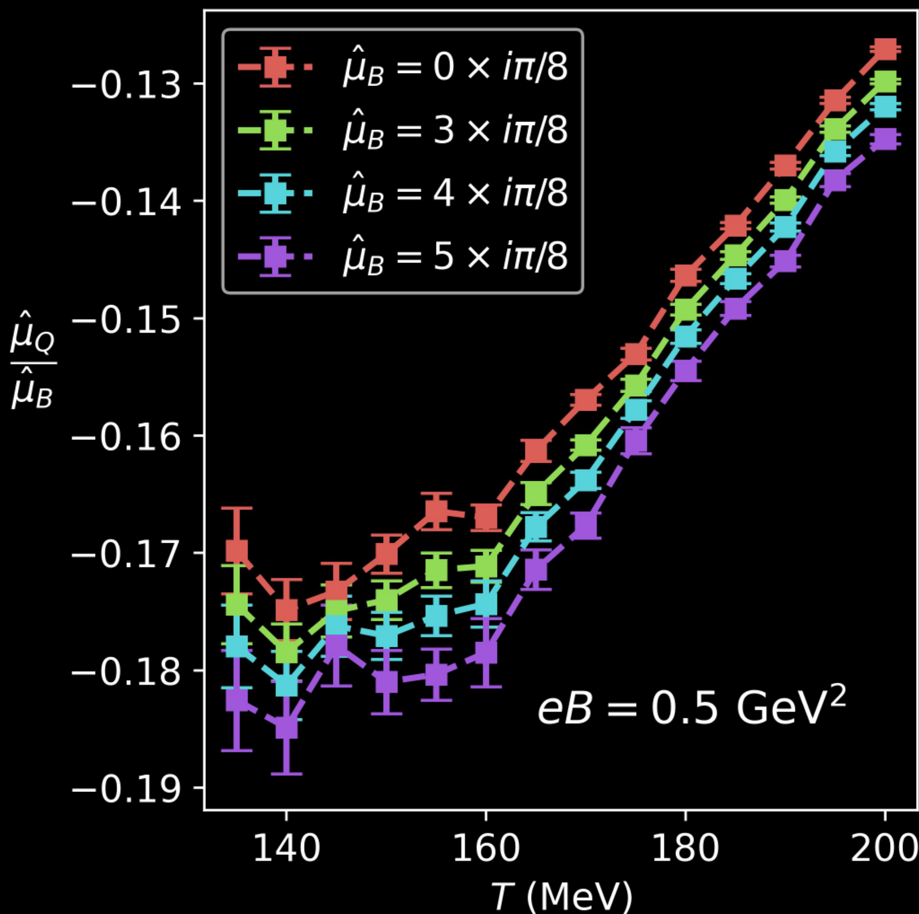

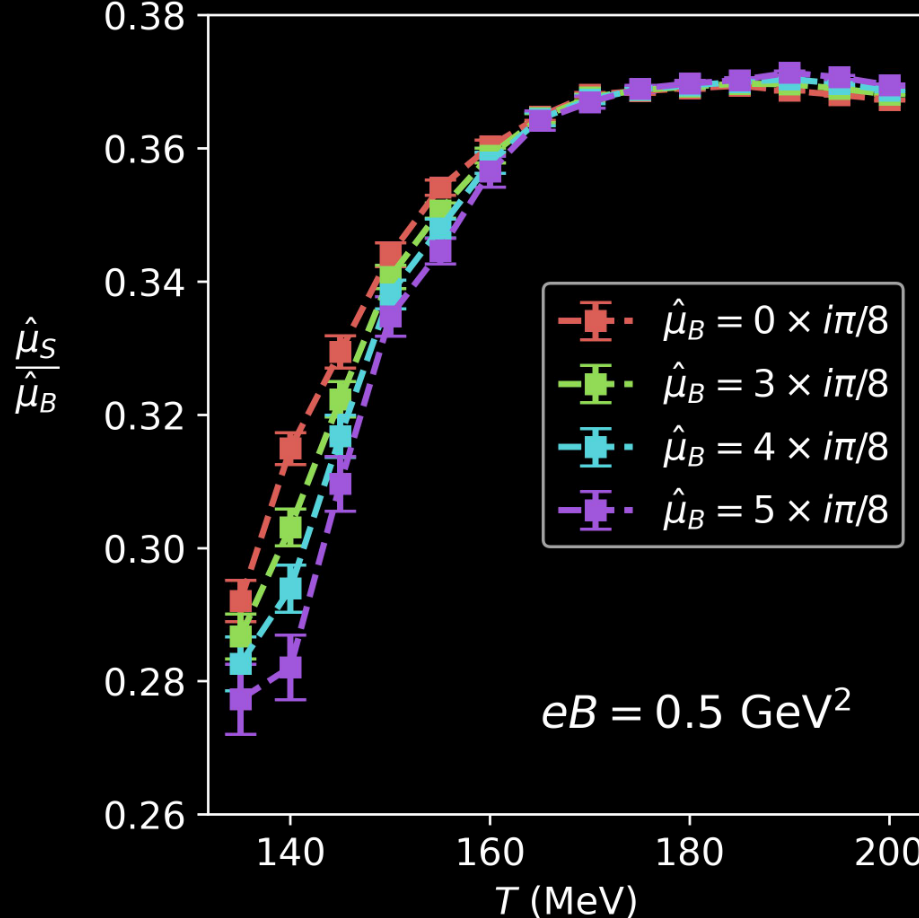

IMPACT OF $\vec{B}$ ON:

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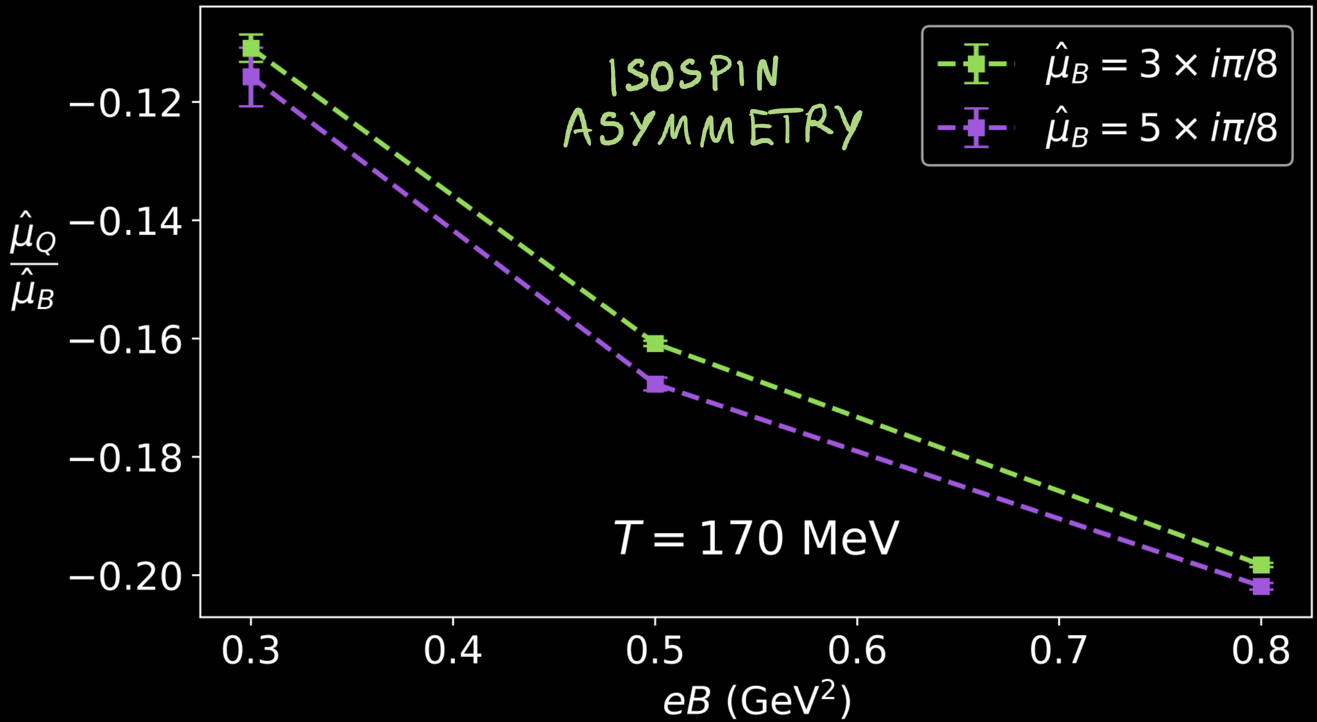

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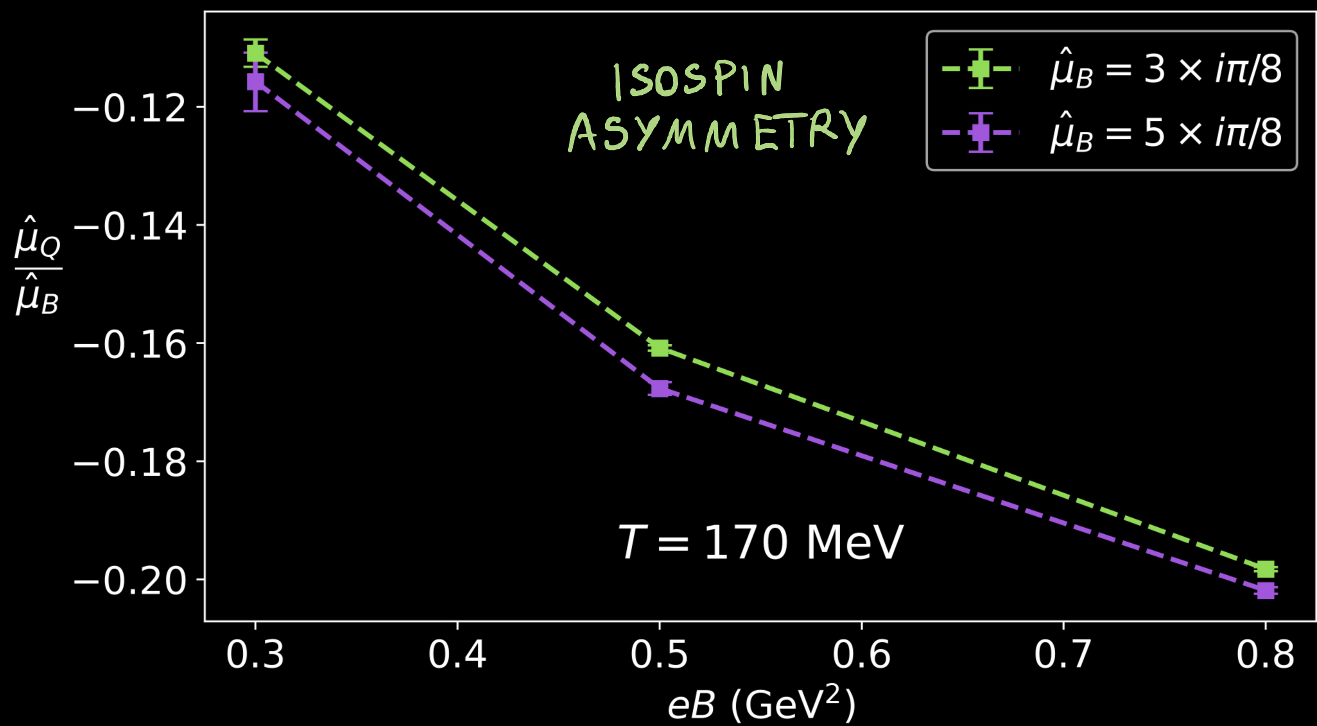
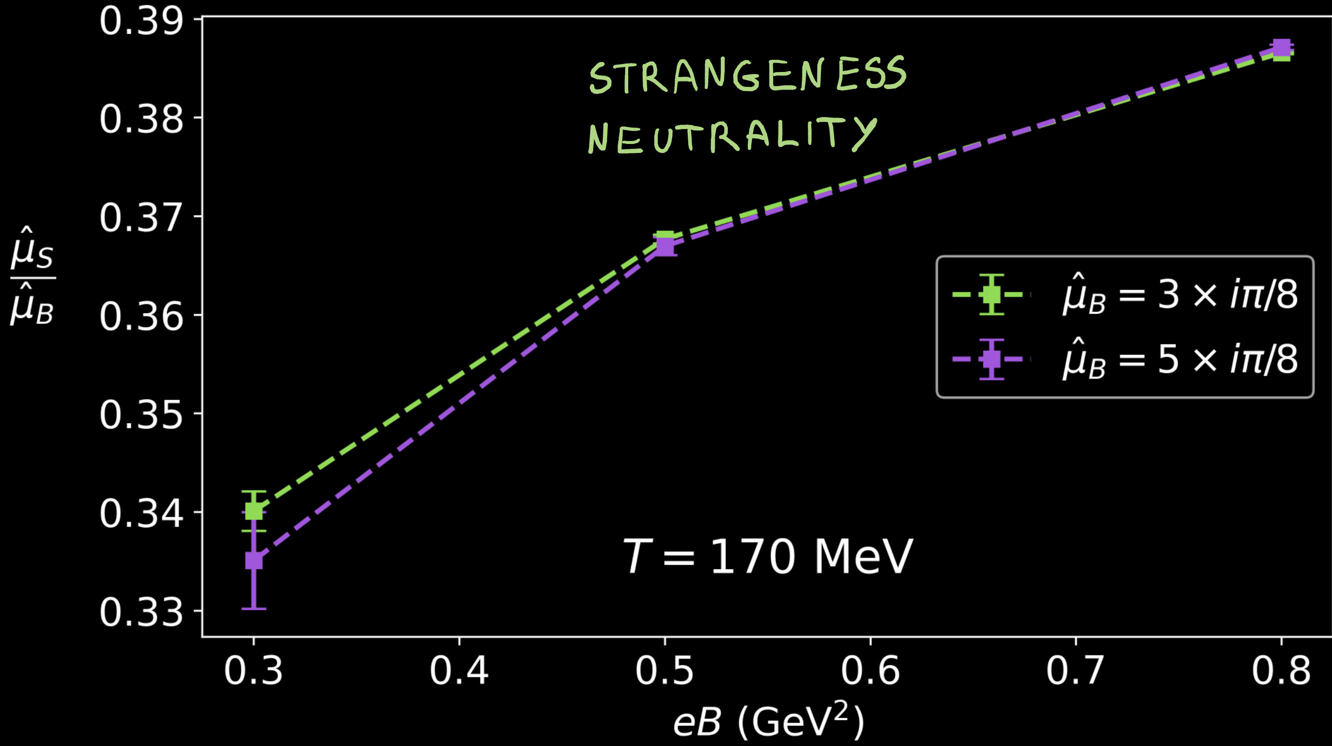
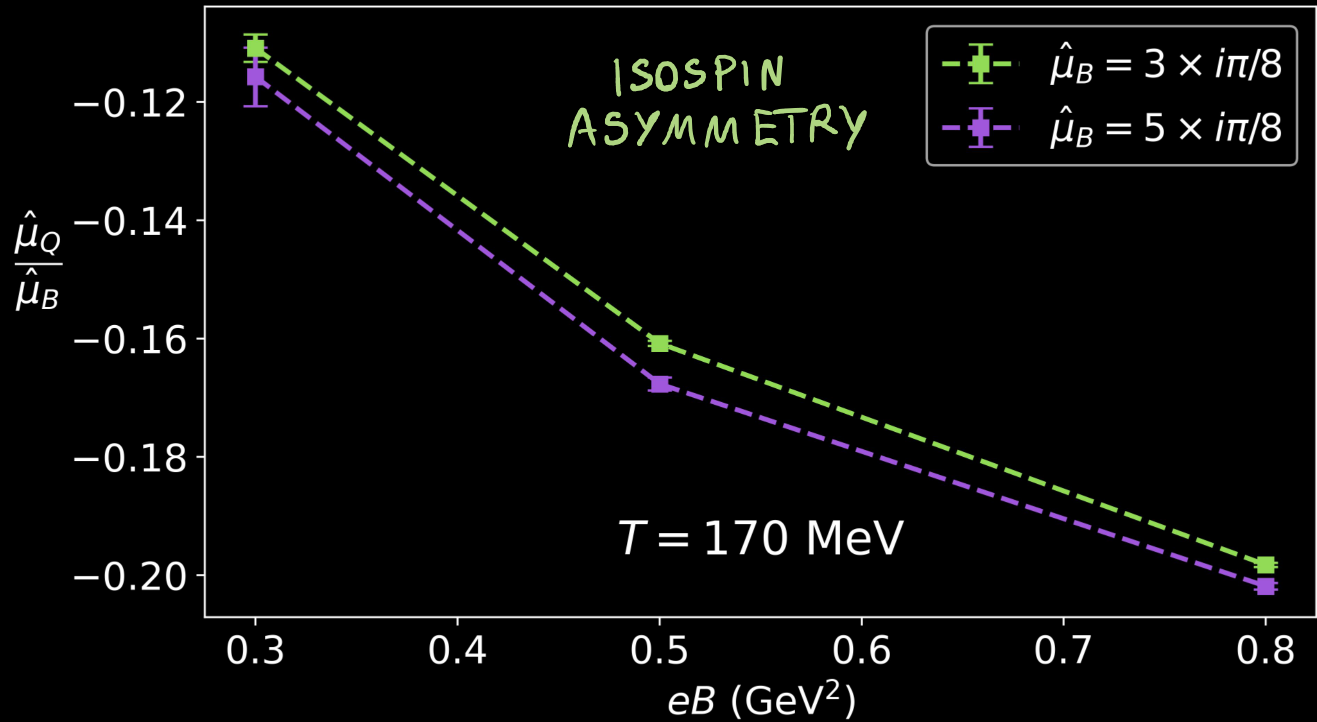


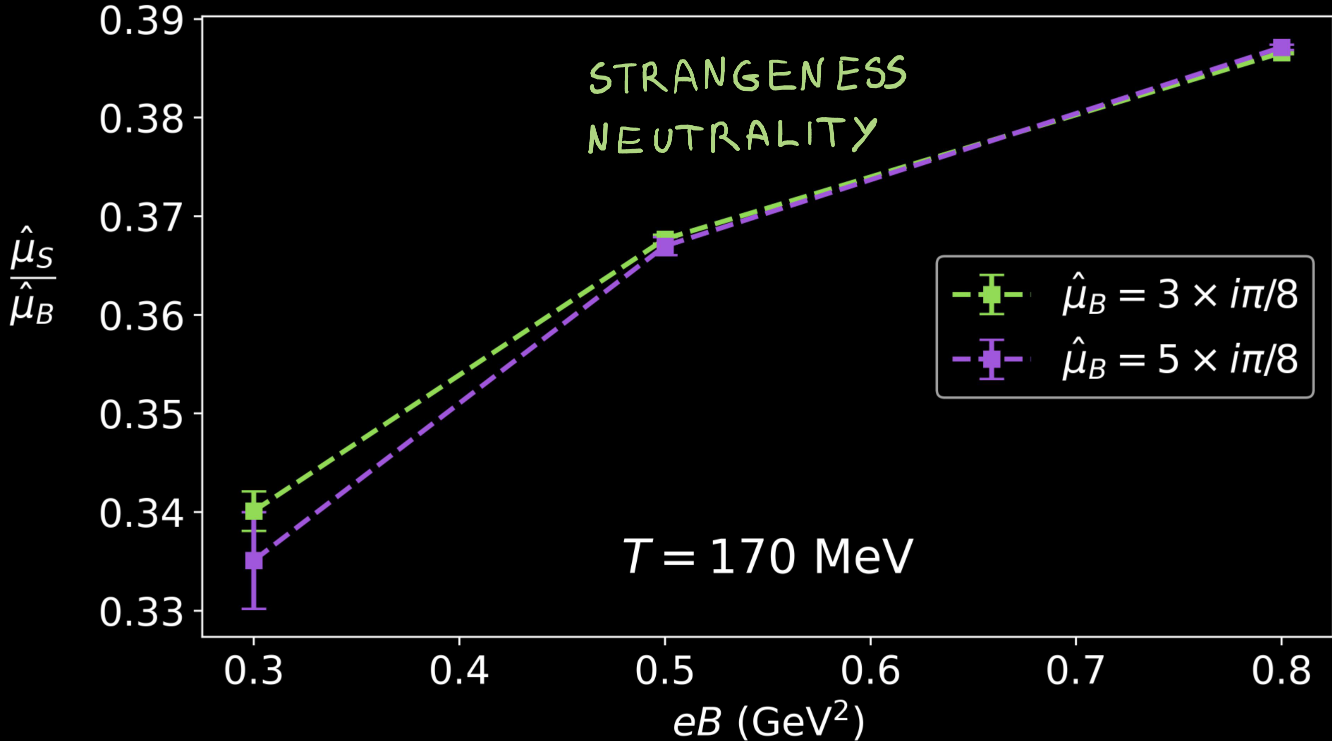


IMPACT OF $\vec{B}$ ON:

ISOSPIN SYMMETRY

$$\frac{\langle n_Q \rangle}{\langle n_B \rangle} = 0.5$$





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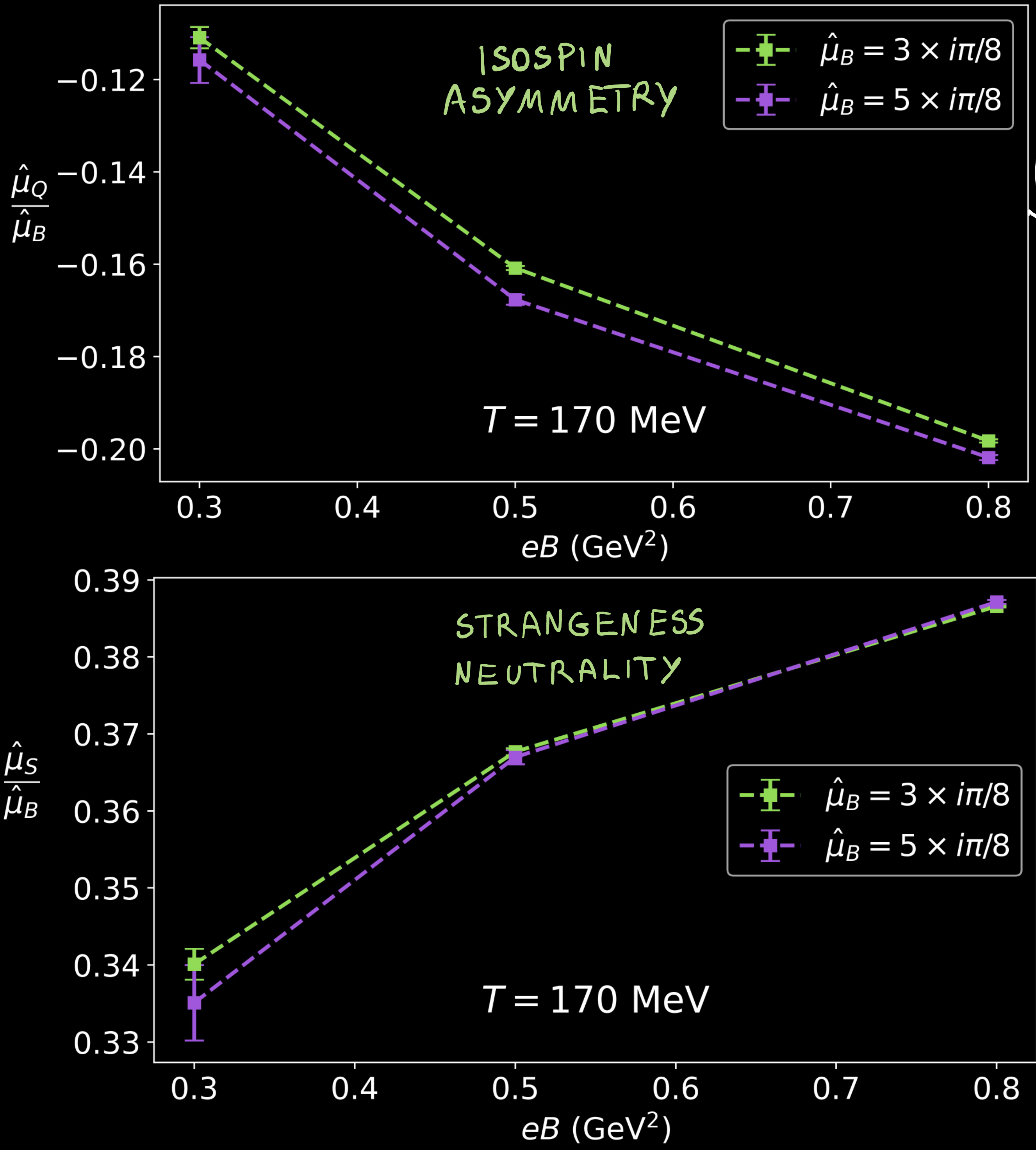

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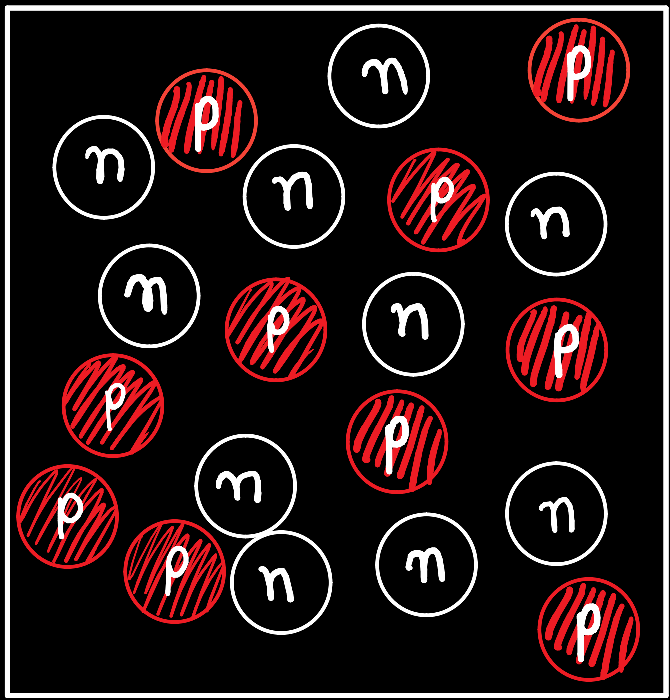
"HRG PICTURE"



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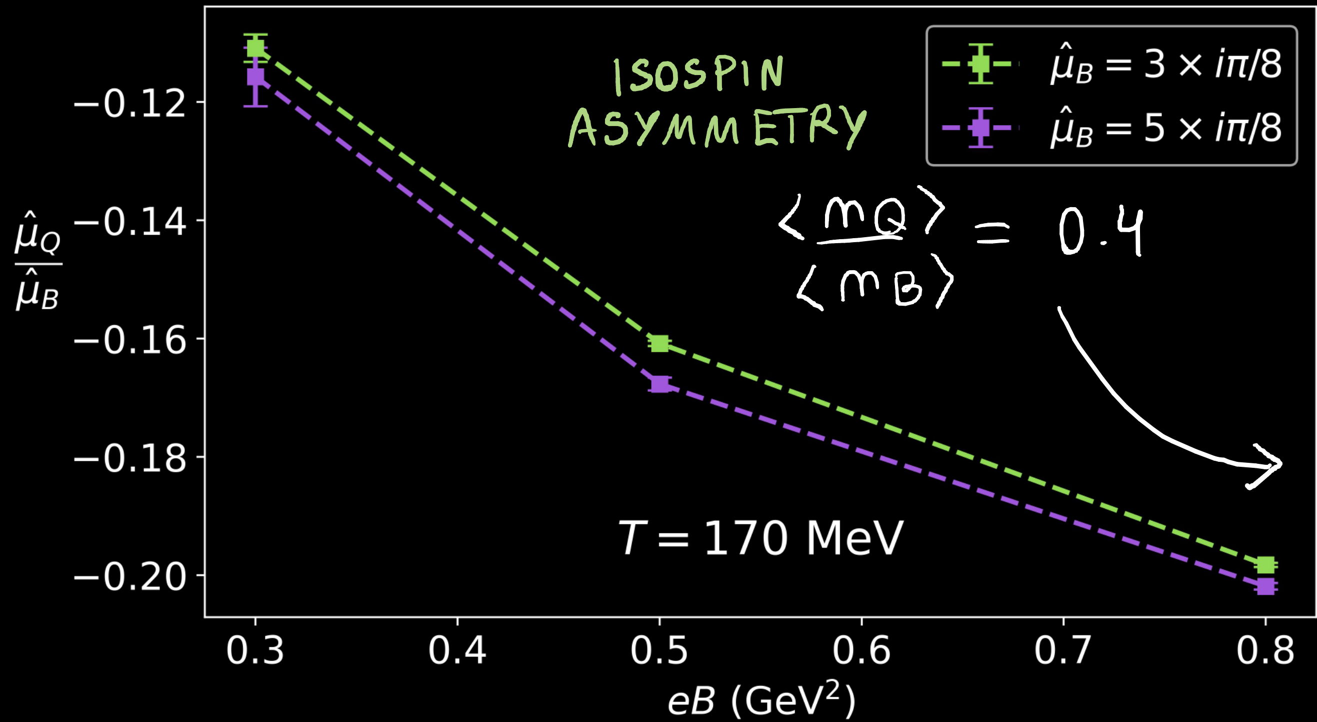

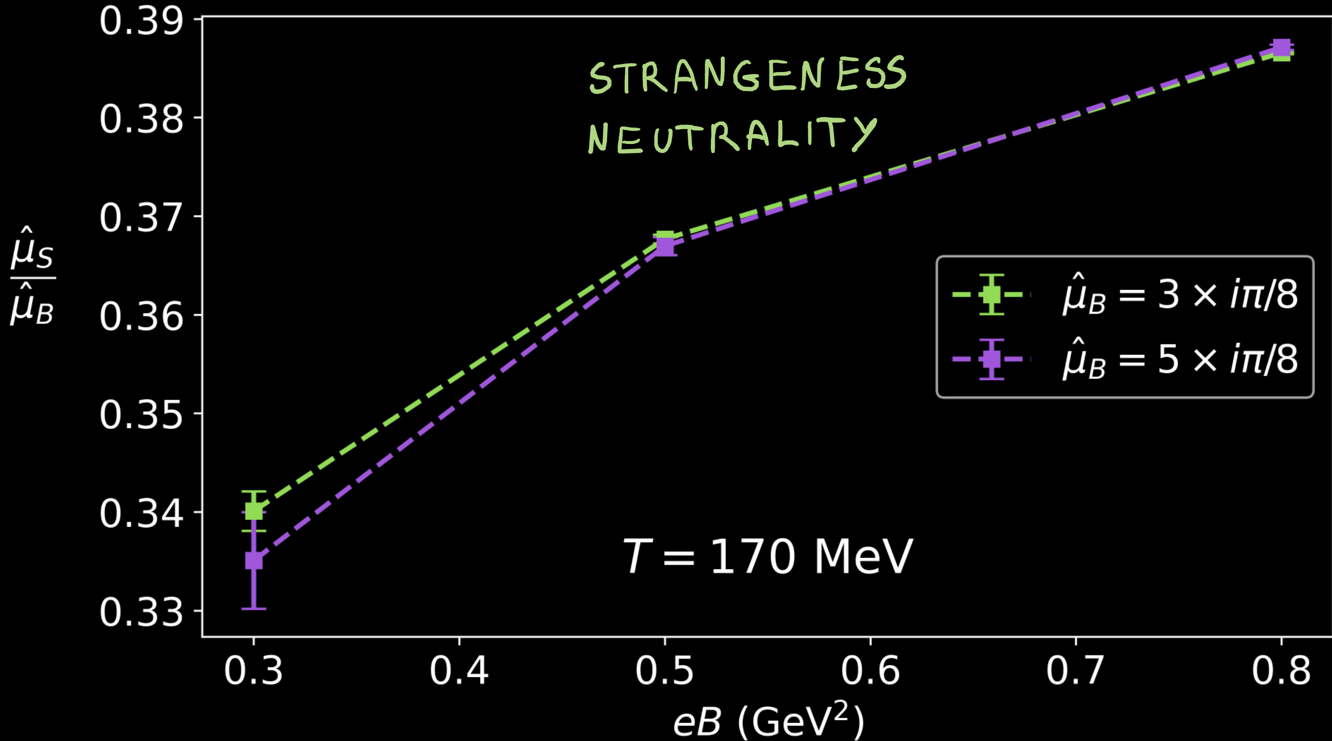

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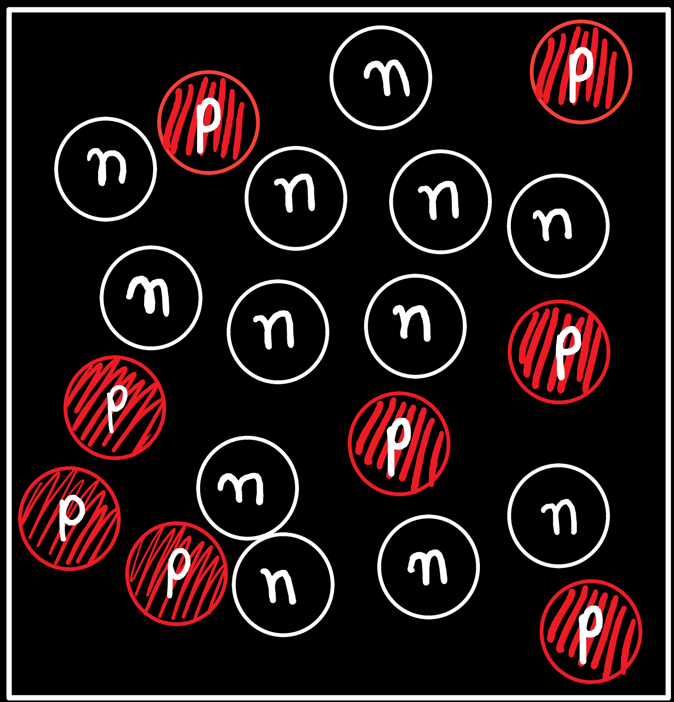

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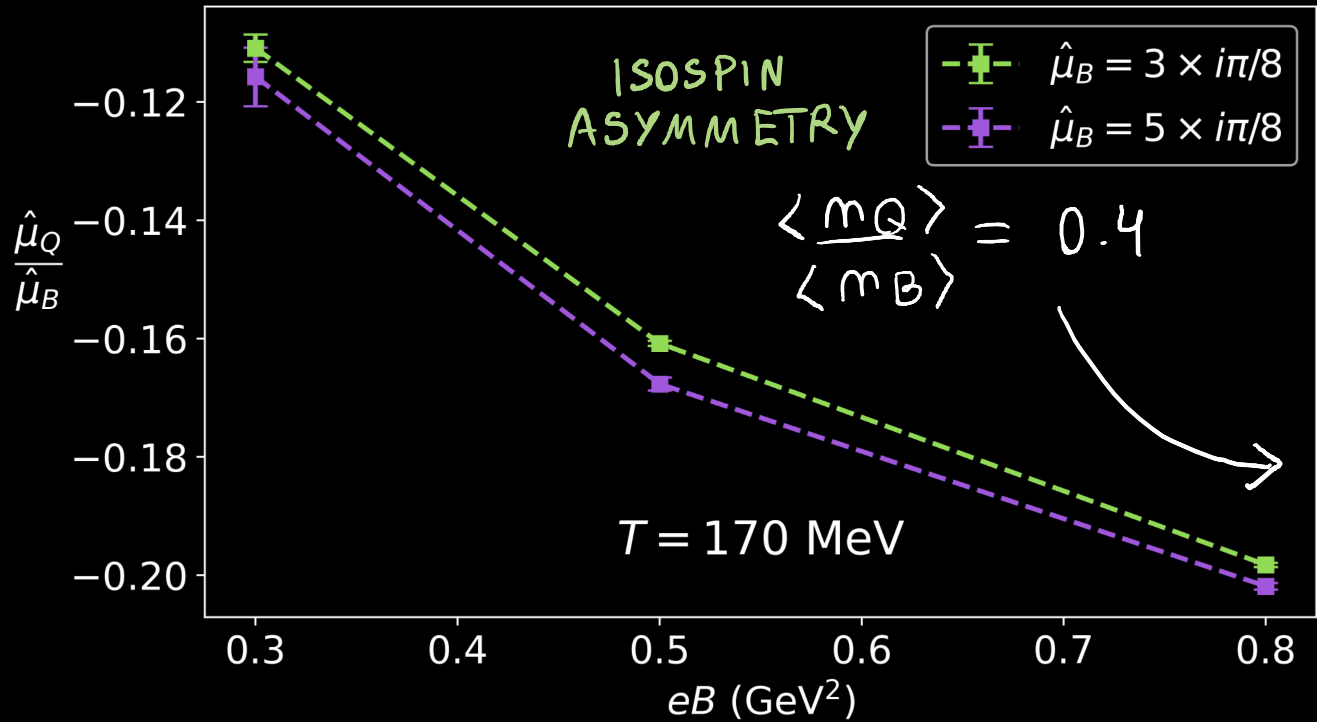

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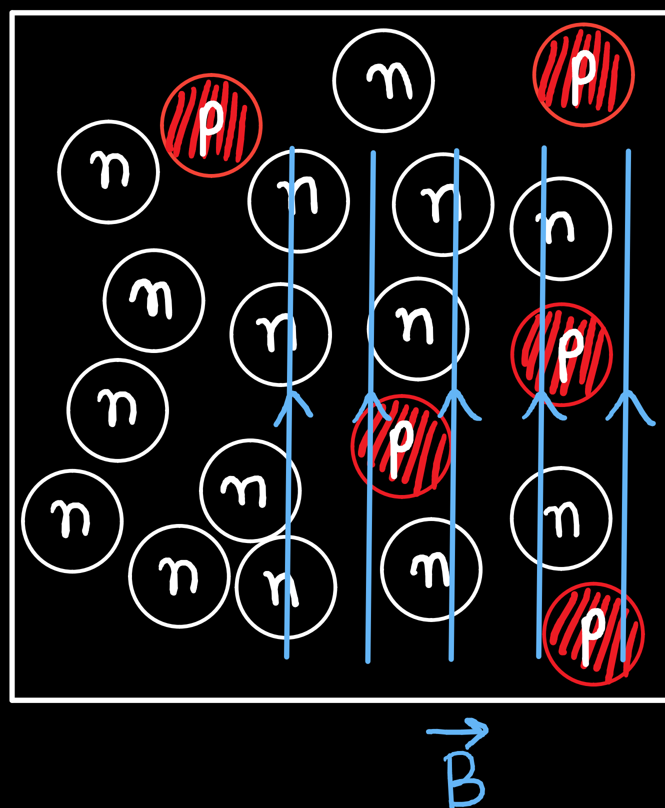

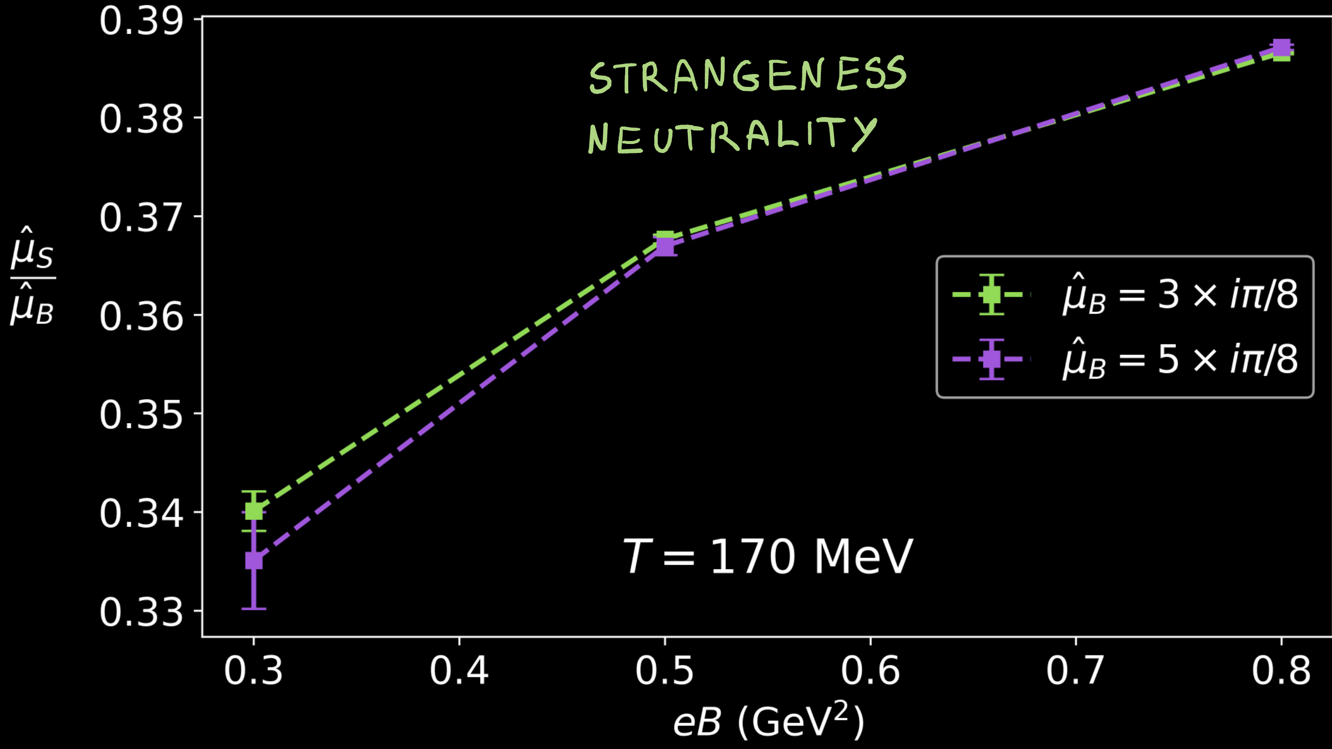

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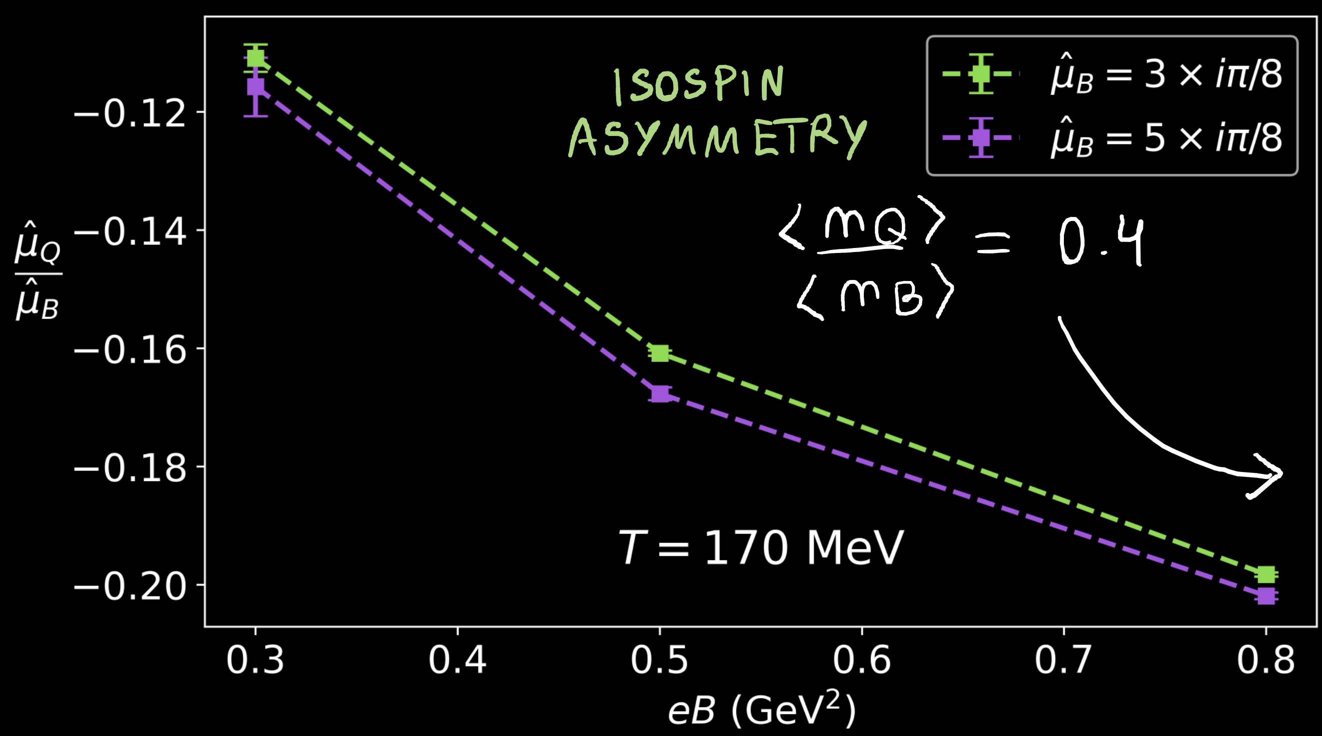

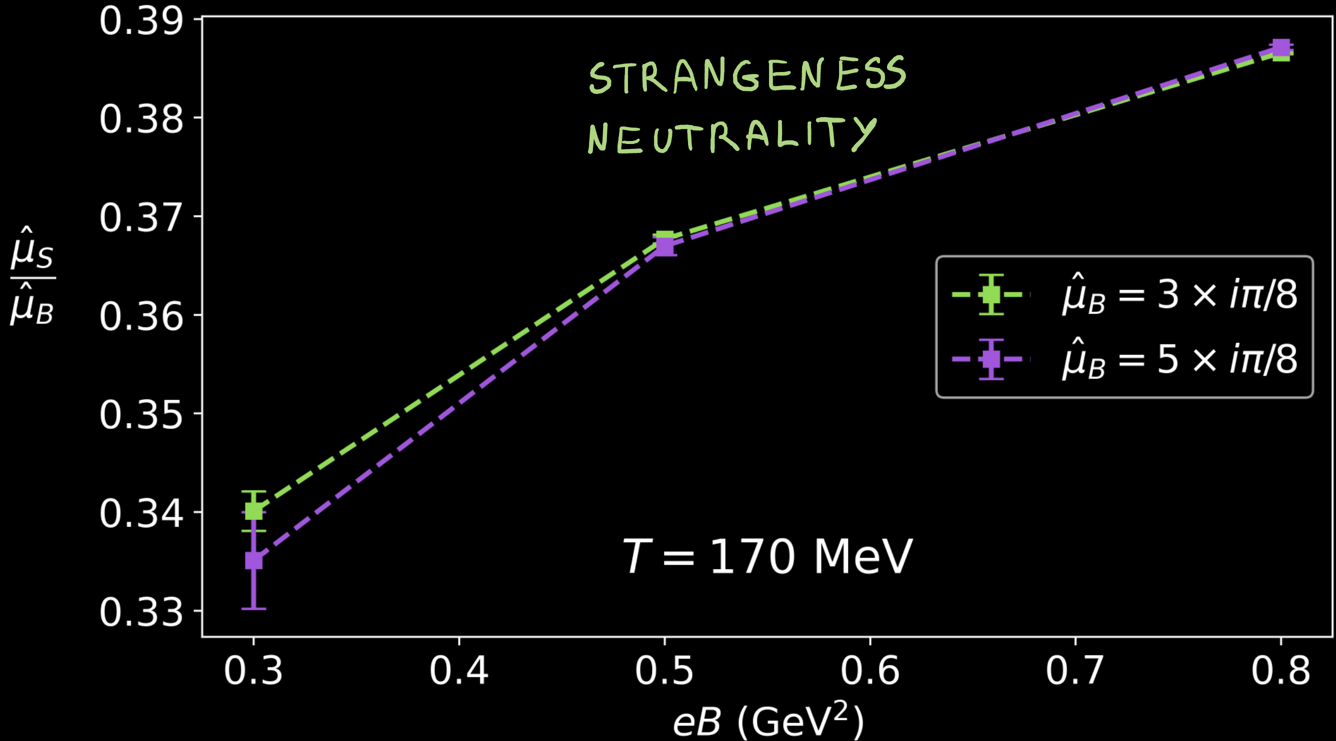

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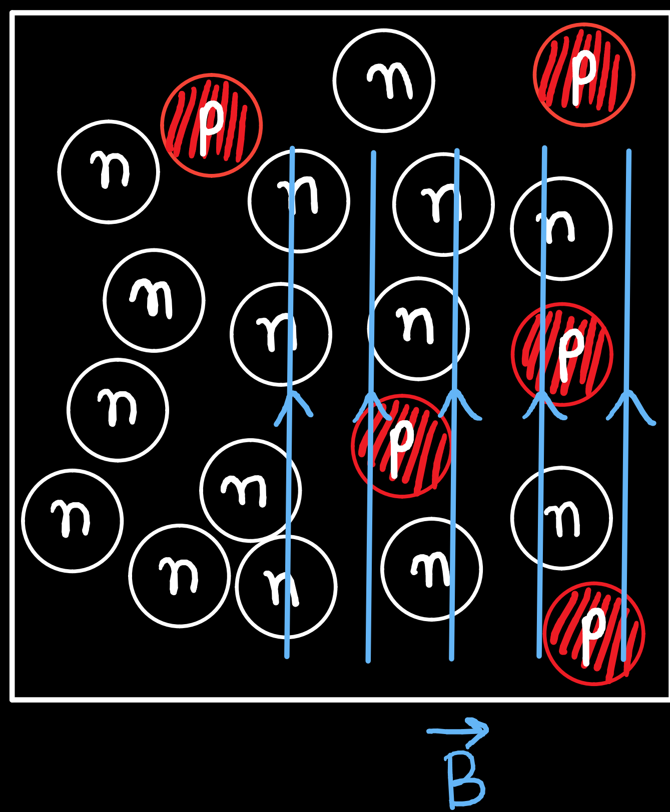

ANALOGOUS FOR μ_S: Λ BARYONS

SUMMARY & CONCLUSIONS

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J. Guenther's talk, Friday, 11:35

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