

Cosmology meets functional QCD:  
First-order cosmic QCD transition  
induced by large lepton flavour asymmetries

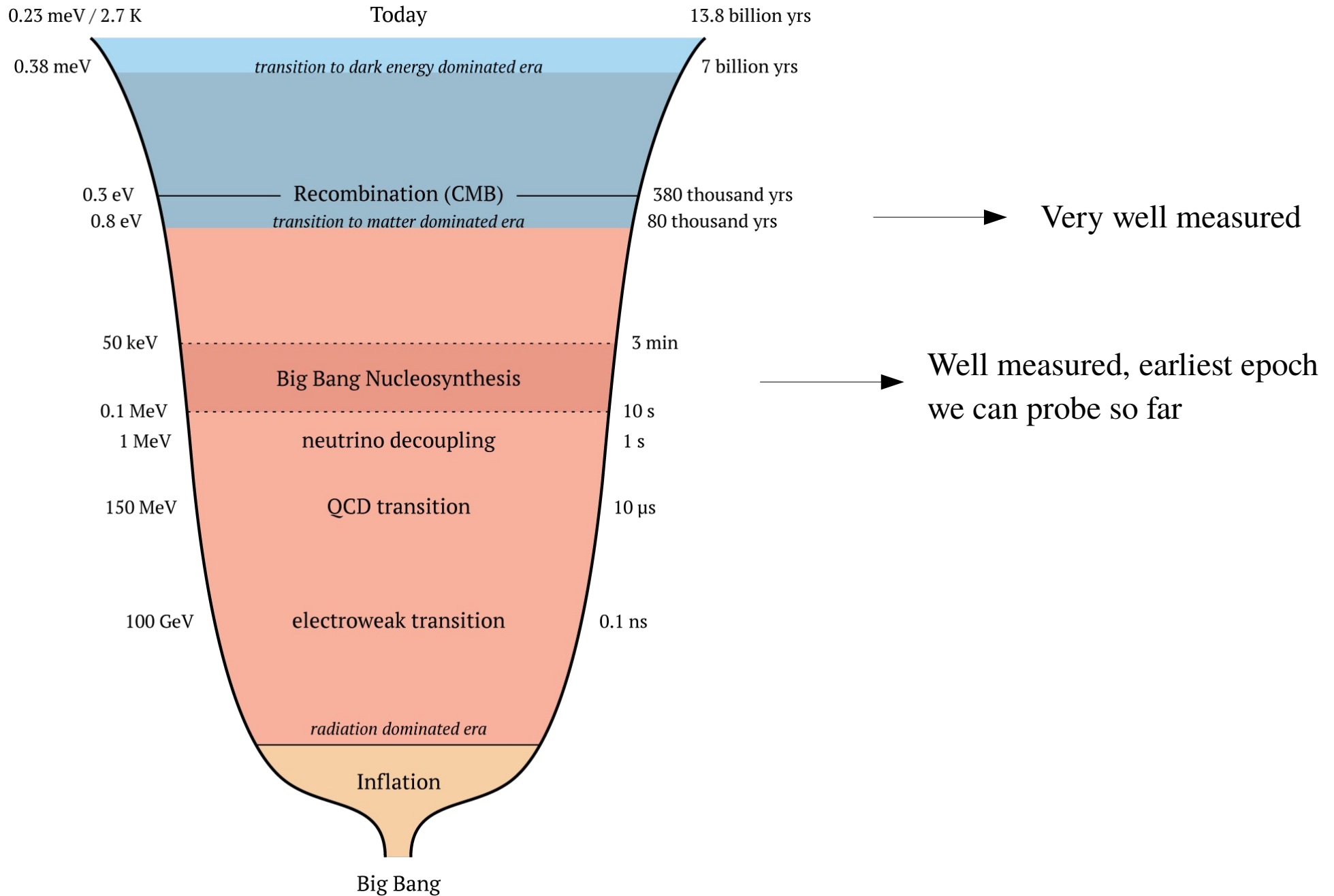
Isabel M. Oldengott\*

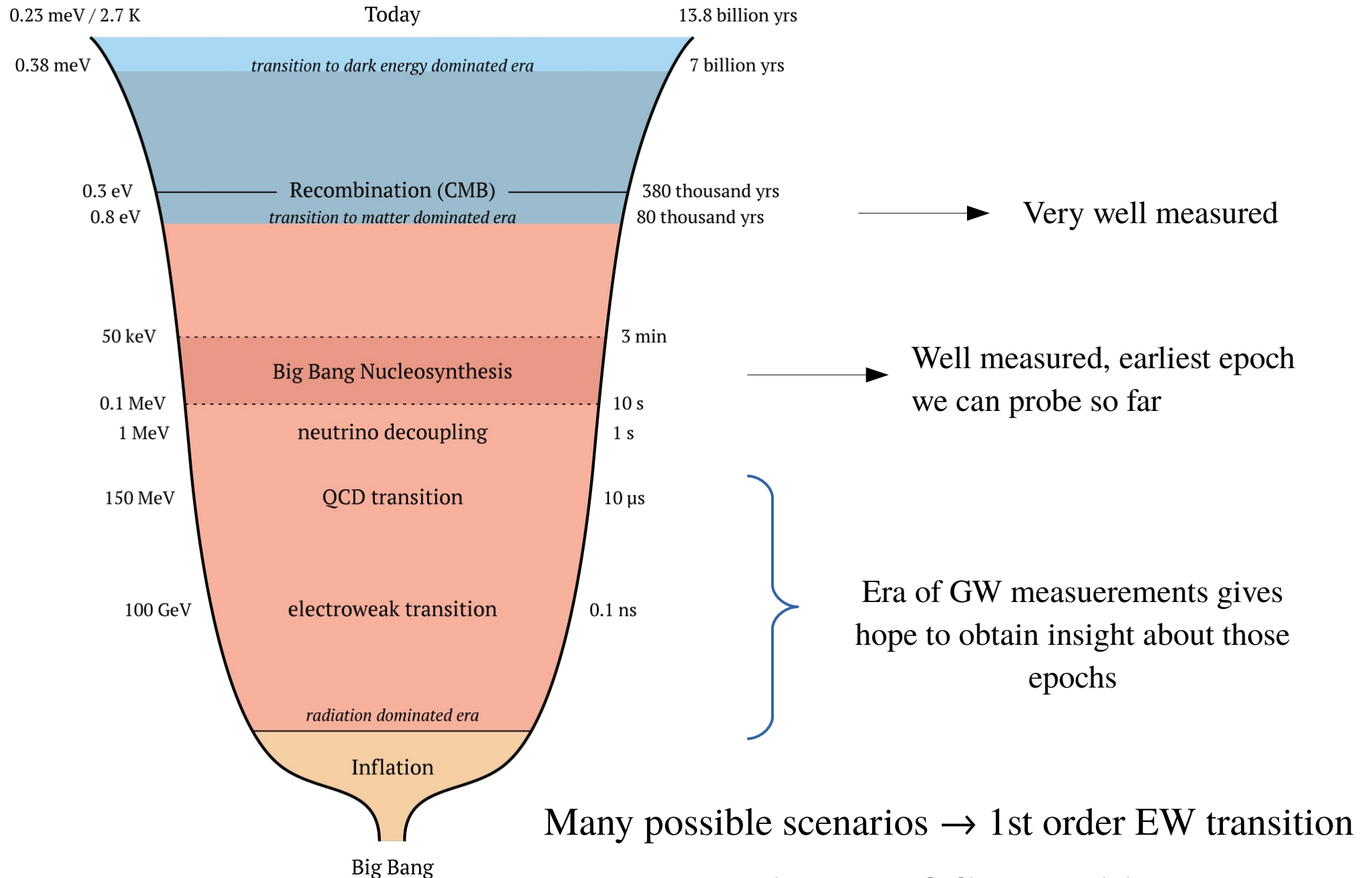
Fei Gao<sup>+</sup>

\* CP3 (UCLouvain), Louvain-la-Neuve

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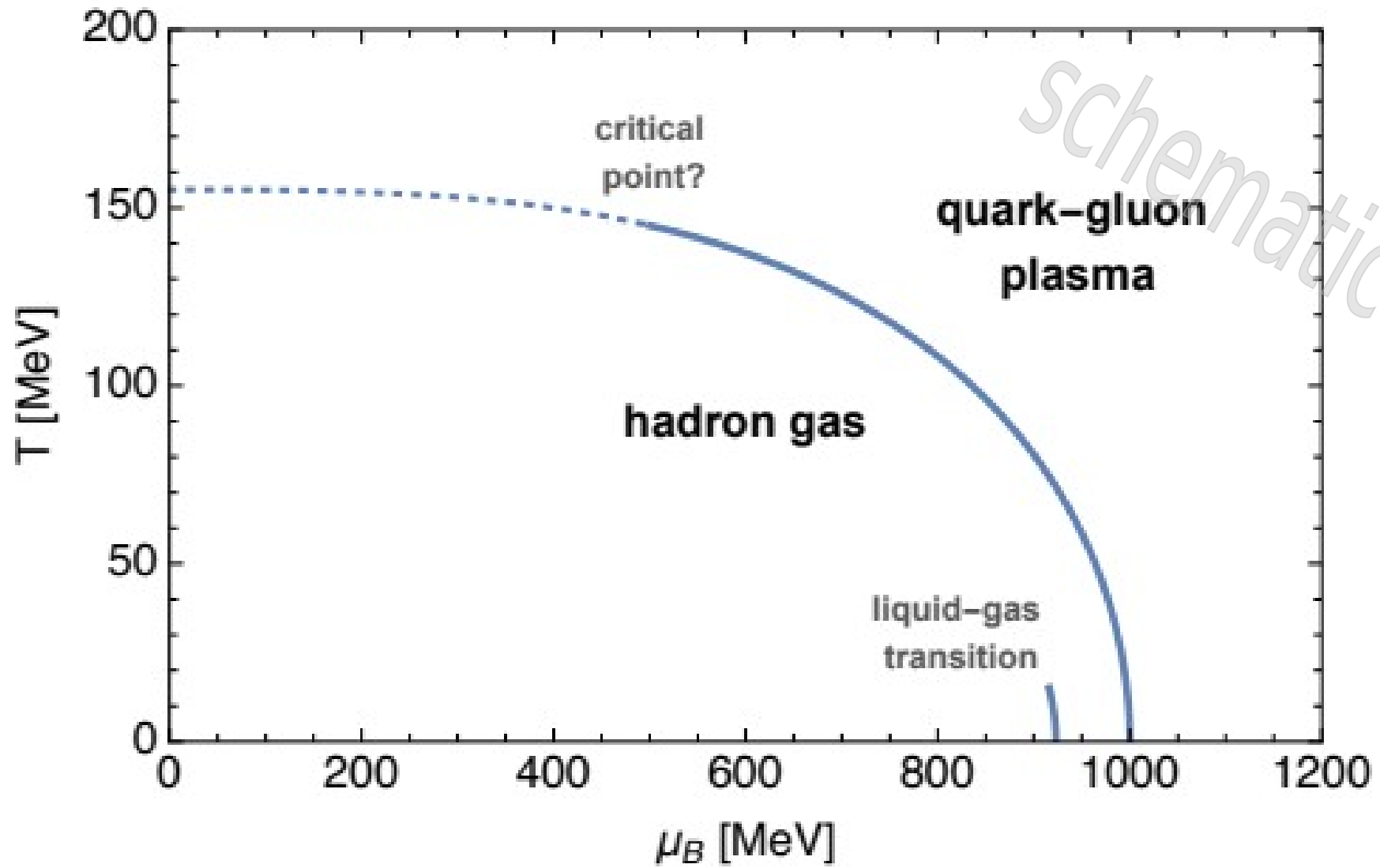
*arXiv: 2106.11991*

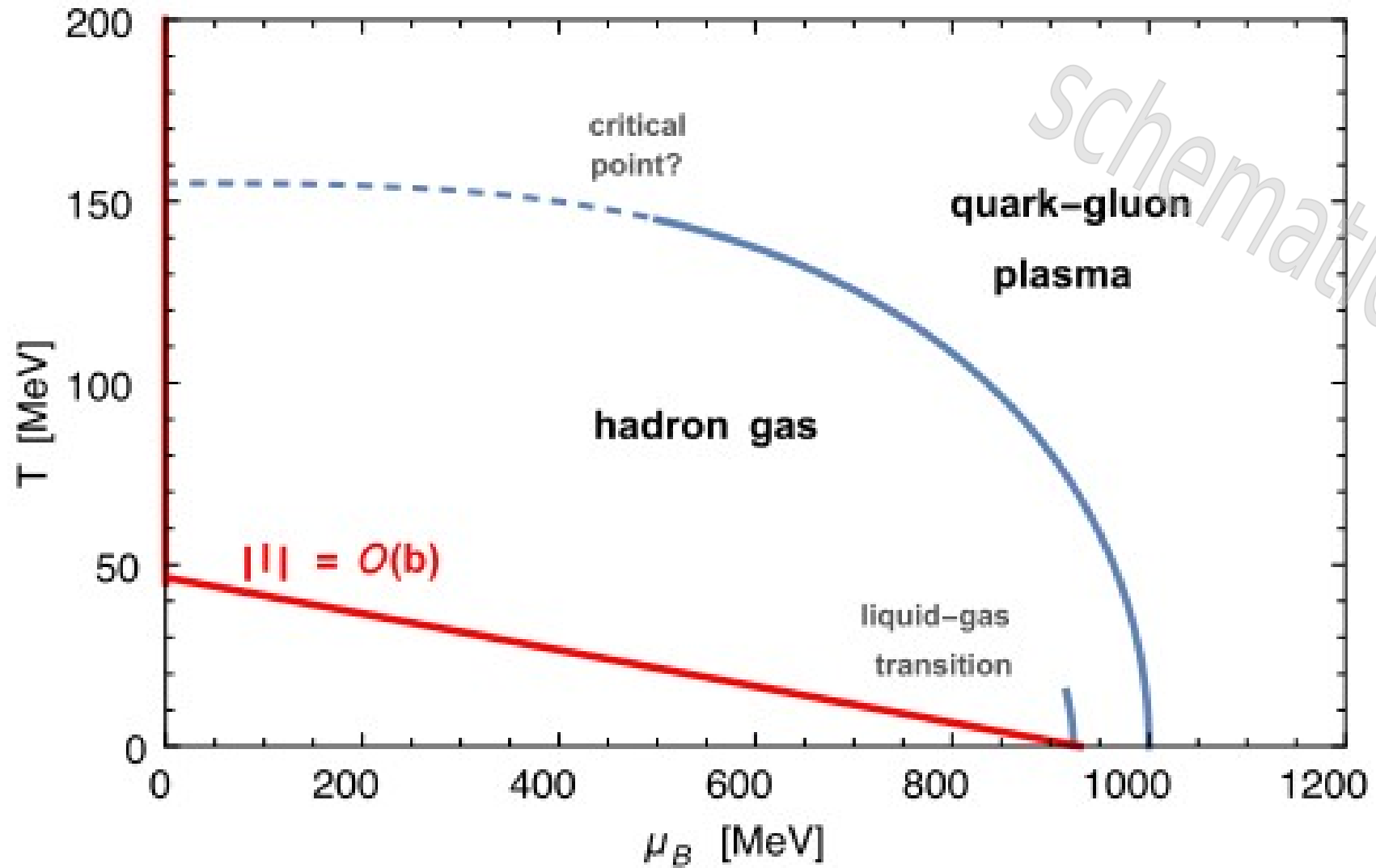


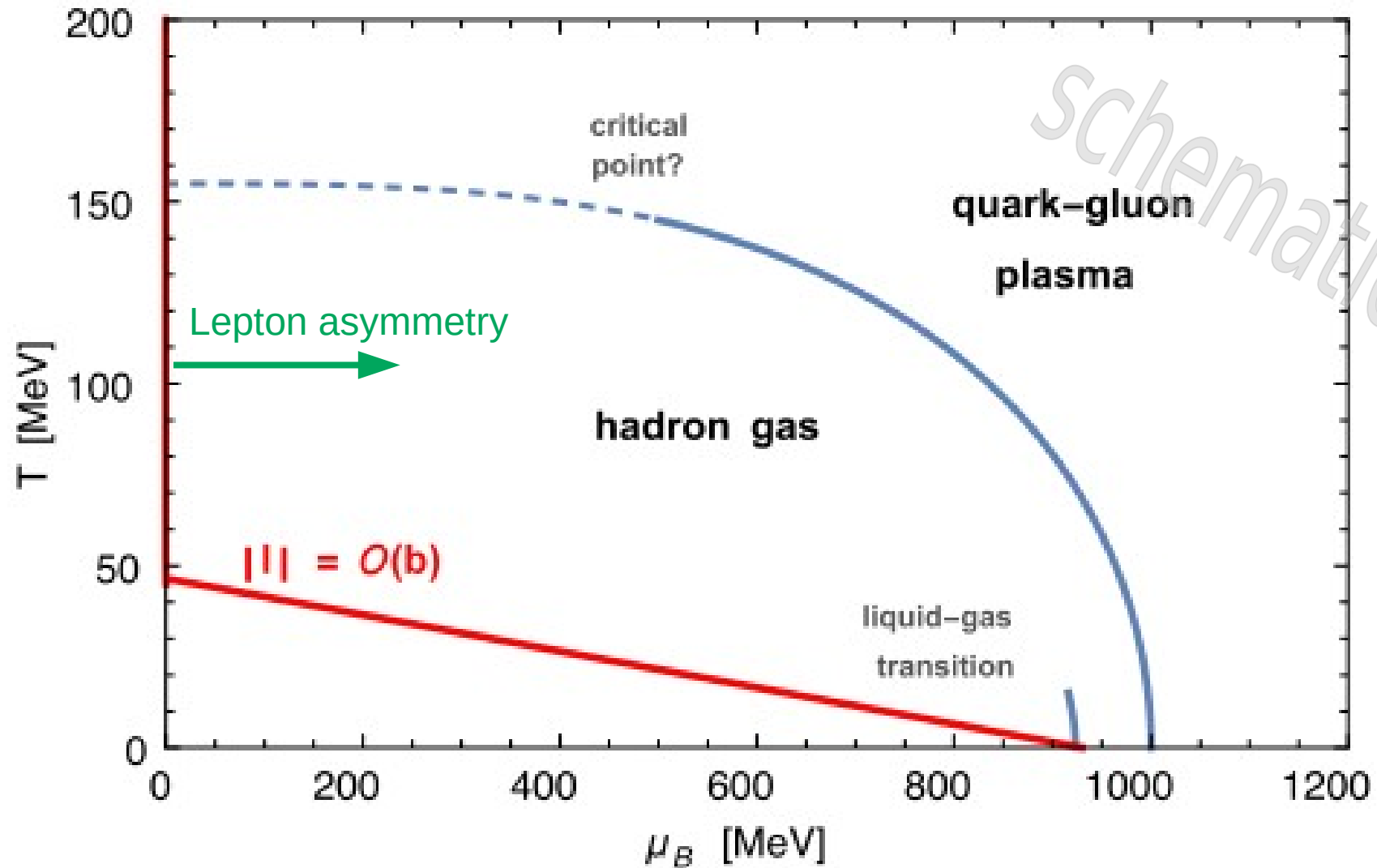


Many possible scenarios → 1st order EW transition

**This work: QCD transition**







*M. Stuke, D. Schwarz (2009), arXiv:0906.3434*

*M. Wygas, IMO, D. Bödeker, D. Schwarz (2018), arXiv:1807.10815*

*M. Middeldorf-Wygas, IMO, D. Bödeker, D. Schwarz (2020), arXiv:2009.00036*

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Tiny, but why so big?

→ Baryogenesis, Leptogenesis

**Leptogenesis:** 1.) Mechanism for creation of lepton asymmetry

2.) Sphaleron processes transfer lepton asymmetry to baryon asymmetry

→ standard assumption:

**lepton asymmetry  $\approx$  baryon asymmetry (i. e. tiny)**



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Possible caveats?

- sphaleron processes experimentally not confirmed
- suppress sphaleron processes? (*S. Eijima, M. Shaposhnikov 2017; G. Barenboim, W. Park 2017;...*)
- create large lepton asymmetry at later times, when sphaleron processes are inefficient (*Drewes et al. 2021; Canetti et al. 2012; Affleck-Dine mechanism; Barbieri & Dolgov 1991; ...*)

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CMB and BBN:  $l \leq \mathcal{O}(0.01)$  *I. Oldengott, D. Schwarz 2017; Pitrou et al. 2018*

I) could be larger than baryon asymmetry by many orders of magnitude



II) only total asymmetry constrained,

individual lepton flavour asymmetries almost unconstrained

**Agnostic point of view: lepton asymmetries = free parameters for cosmology**

## How to compute the cosmic trajectory:

Some new-physics's scale where  
lepton asymmetry gets produced

**Conservation laws** (at  $10 \text{ MeV} < T < T_{BSM}$ ) :

1.) Baryon number:  $b_S = \sum_i B_i n_i$

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3.) Lepton number:  $l_\alpha S = n_\alpha + n_{\nu_\alpha}$ ,  $\alpha = e, \mu, \tau$

+ relations for chemical pot.:

$$\mu_{L_\alpha} = \mu_{\nu_\alpha},$$

$$\mu_u = \mu_c, \quad \mu_e - \mu_{\nu_e} = \mu_\mu - \mu_{\nu_\mu}, \quad \text{etc.} \quad \mu_B = \mu_u + 2\mu_d,$$

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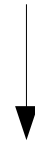
$\mu_{L_\alpha} = \mu_{\nu_\alpha}$ ,

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3 input parameters,  
5 equations,  
5 variables

$\mu_{L_e}, \mu_{L_\mu}, \mu_{L_\tau}, \mu_B, \mu_Q$



Cosmic trajectory  
= solution for different  
temperatures  $T$



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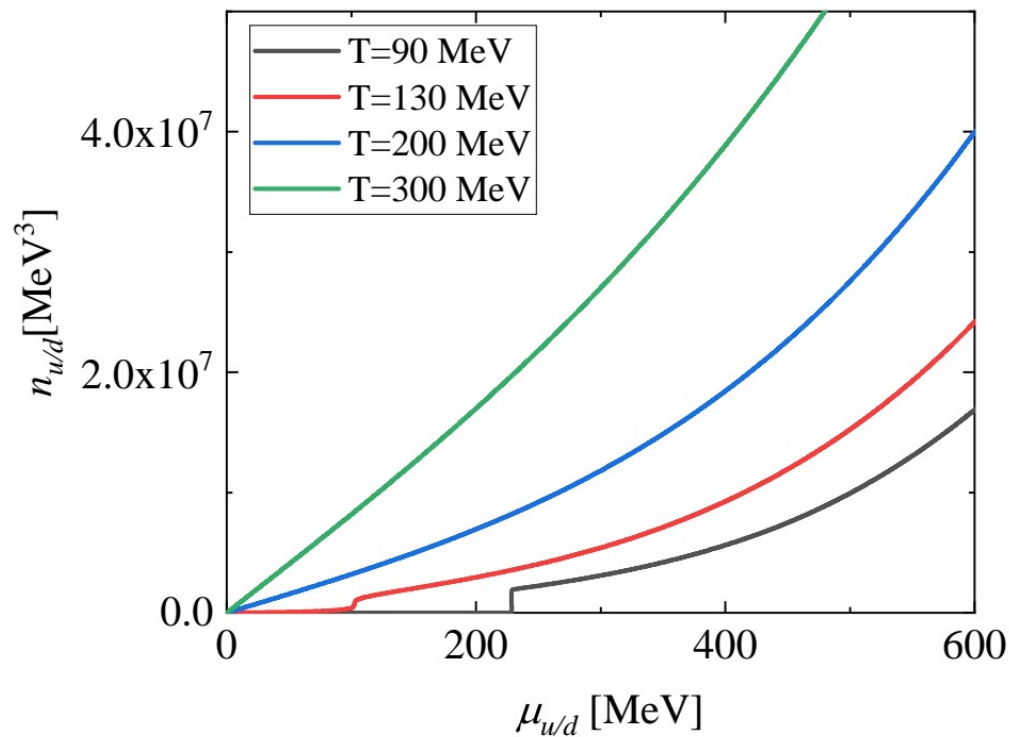
Former works: lattice QCD (*arXiv:1807.10815, arXiv:2009.00036*)

→ *only works for small chemical potential*

## This work: Functional QCD

*F. Gao, J. Chen, Y.-X. Liu, S.-X. Qin, C. D. Roberts, S. M. Schmidt, [arXiv:1507.00875](https://arxiv.org/abs/1507.00875)*

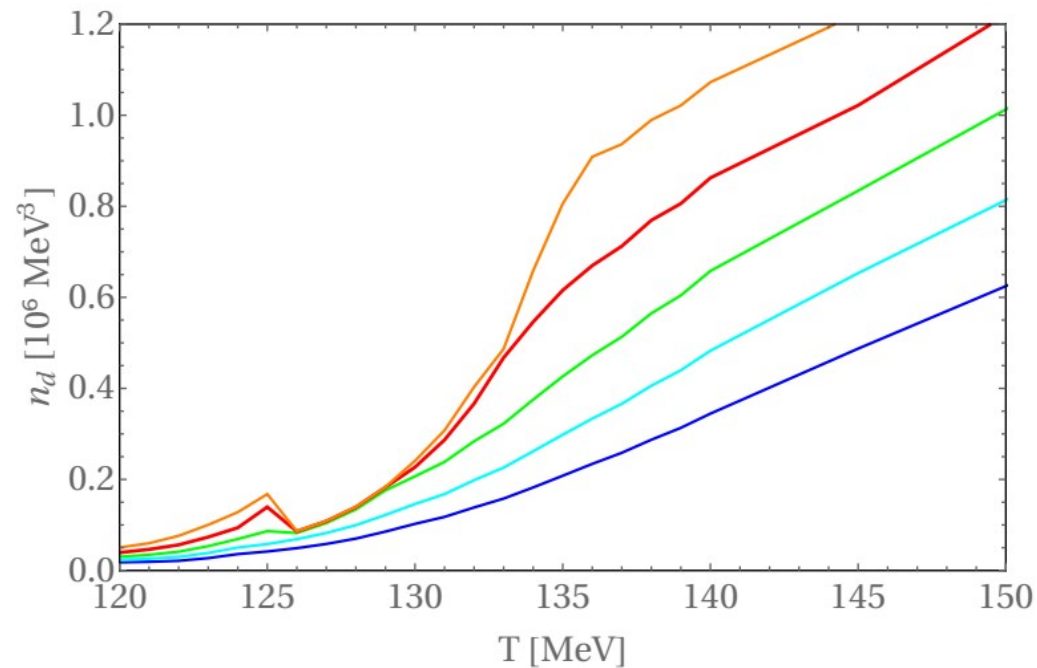
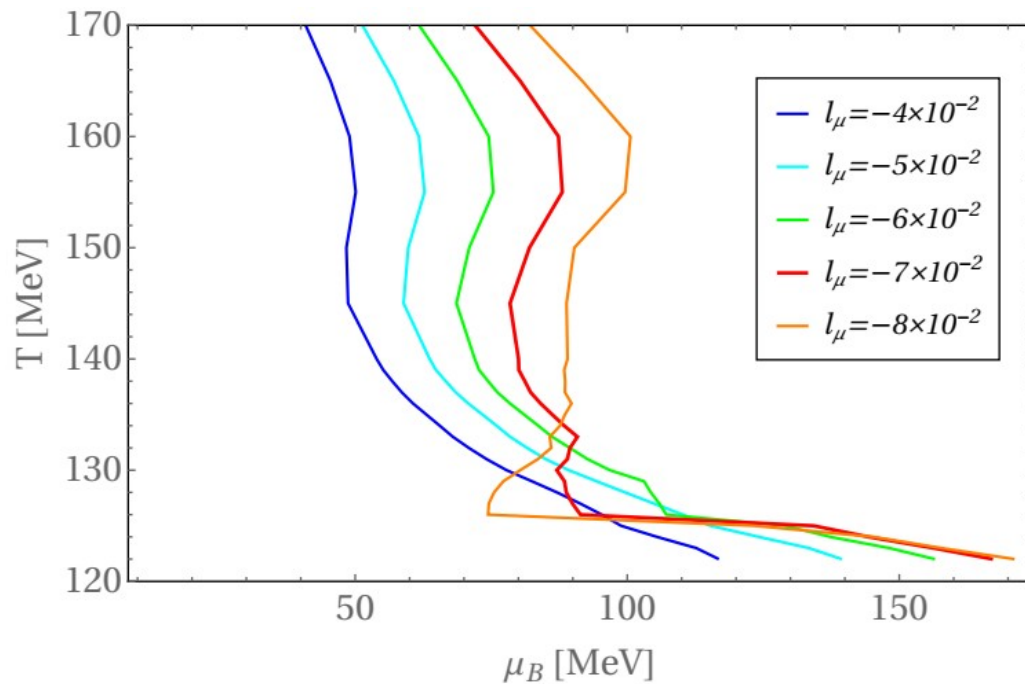
Thermodynamic quantities derived from Dyson-Schwinger equations  
in the rainbow-ladder(RL) truncation:



$$\Rightarrow (T_{\text{CEP}}, \mu_{\text{CEP}})_{u/d} = (125, 111) \text{ MeV}$$

Include thermodynamic quantities into calculation of cosmic trajectory:

**Consider here:**  $l_e=0, l_\mu = -l_\tau$  ← fullfills CMB/BBN requirement  $l=0$



Discontinuity between  $l_\mu = -0.06$  and  $l_\mu = -0.07$

→ **1st order cosmic QCD transition !**

To predict when a first-order transition happens add as an additional constraint to system of equations:

$$\mu_{u/d} \geq \mu_{CEP} \quad \text{at} \quad T = T_{CEP}$$

→ 6 equations, eliminates one degree of freedom

(i)  $l_e = l_\mu = l_\tau = \frac{l}{3}$

(ii)  $l_e = 0, l_\mu = -l_\tau$

(iii)  $l_e = -l_\tau, l_\mu = 0$

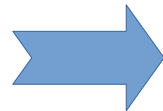
(iv)  $l_e = -l_\mu, l_\tau = 0$

(v)  $l_e = l_\mu, l_\tau = -2l_e$

(vi)  $l_e = l_\tau, l_\mu = -2l_e$

(vii)  $l_e = -2l_\mu, l_\mu = l_\tau$

solutions



	$\mu_u \geq 111 \text{ MeV}$	$\mu_d \geq 111 \text{ MeV}$
(i)	$l \geq 1.10 \times 10^{-1}$	$l \leq -1.03 \times 10^{-1}$
(ii)	$l_\mu \geq 7.43 \times 10^{-2}$	$l_\mu \leq -6.85 \times 10^{-2}$
(iii)	$l_e \geq 7.14 \times 10^{-2}$	$l_e \leq -6.59 \times 10^{-2}$
(iv)	$l_e \geq 1.36 \times 10^{-3}$	no solution
(v)	$l_e \geq 3.46 \times 10^{-2}$	$l_e \leq -3.23 \times 10^{-2}$
(vi)	$l_e \leq -1.20 \times 10^{-1}$	$l_e \geq 1.02 \times 10^{-1}$
(vii)	$l_e \leq -1.14 \times 10^{-1}$	$l_e \geq 9.43 \times 10^{-2}$

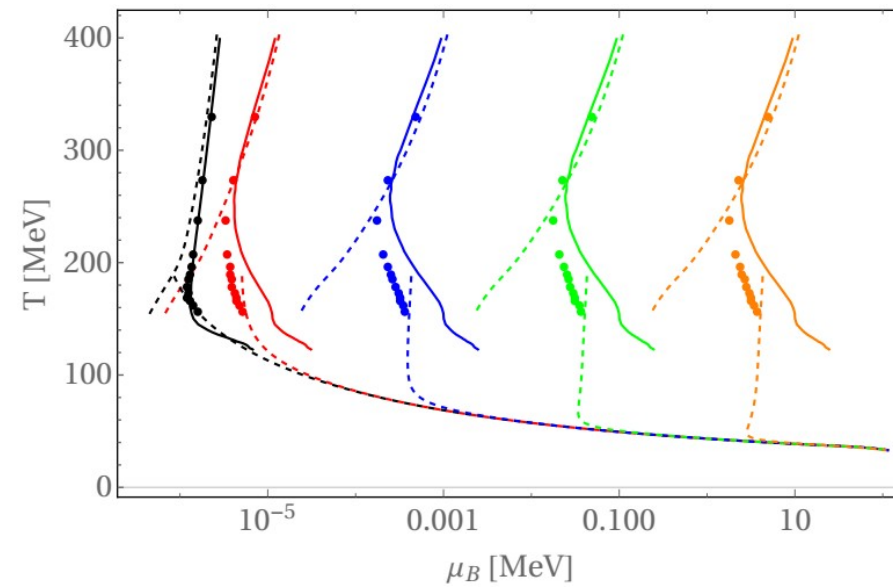
- **Confirms interpretation of 1st order transition.**
- **(i) is already excluded by CMB/BBN constraints, all others are unconstrained observationally.**

described by 1 dof → no further input

**BUT...**

When comparing to results using lattice QCD

→ discrepancy (even at low lepton asymmetry):  
limitations due to truncation scheme...

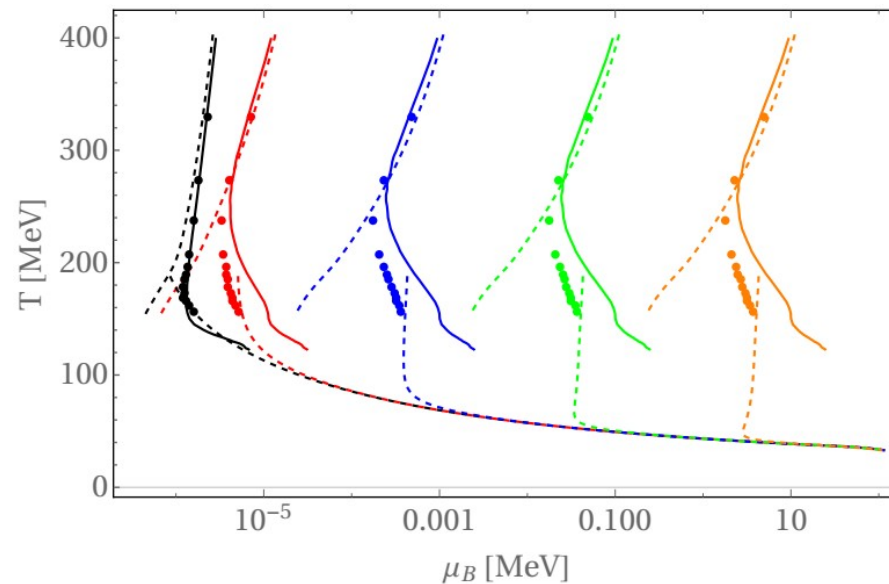




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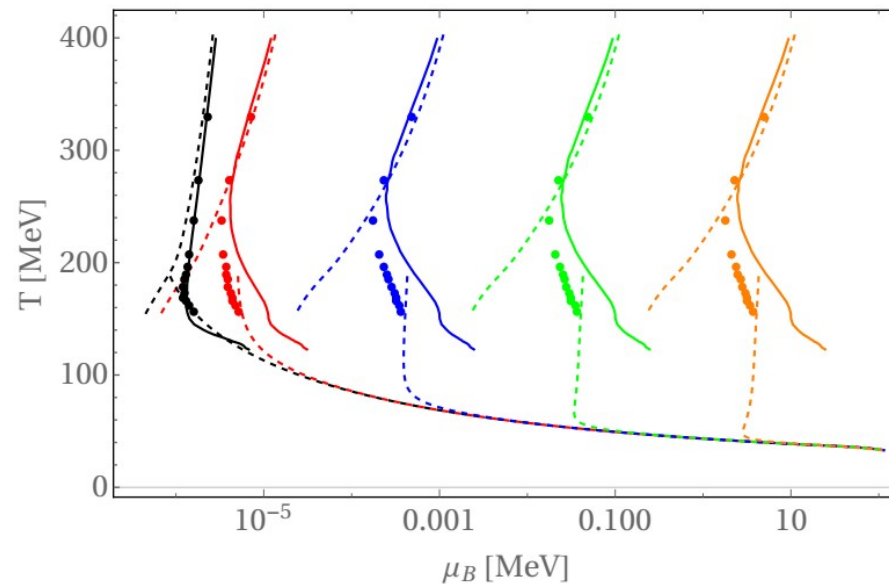


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**Thanks for your attention!**