The QCD phase diagram. An overview and the MexNICA research lines.

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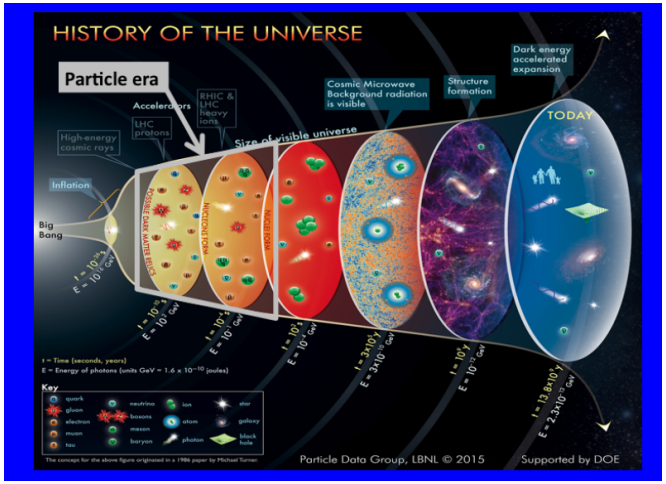
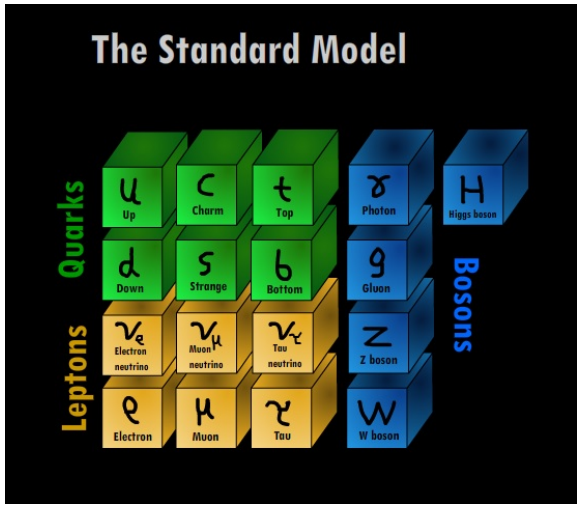
July 3th, 2020. 2nd Computer Workshop of the MexNICA Collaboration

A standard universe.



An schematic evolution of the universe, once the *Big Bang* happened.



The most fundamental blocks of visible matter know so far.

New physics: Many body systems made of fundamental blocks of matter.

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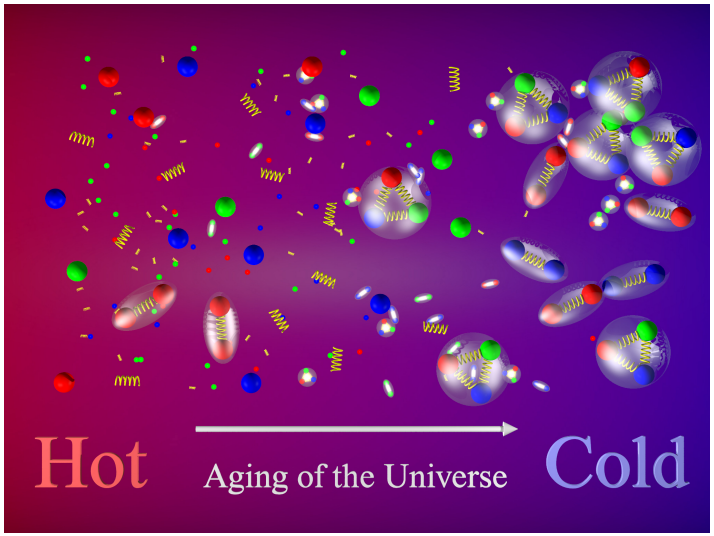
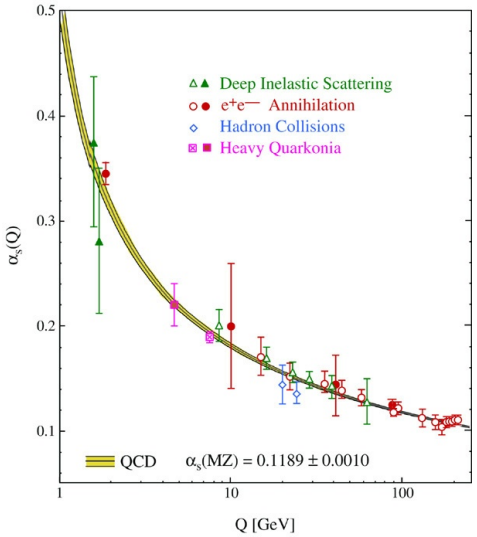
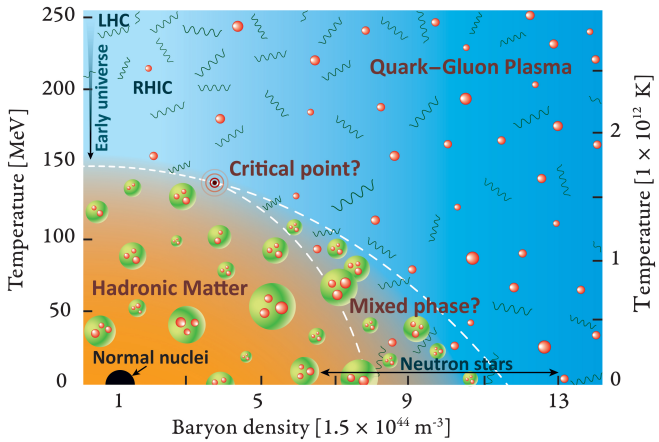
Strongly interacting matter



Sandor Katz, Eotvos University



Siegfried Bethke, arXiv:hep-ex/0606035



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From the microscopic world to understand the whole universe.

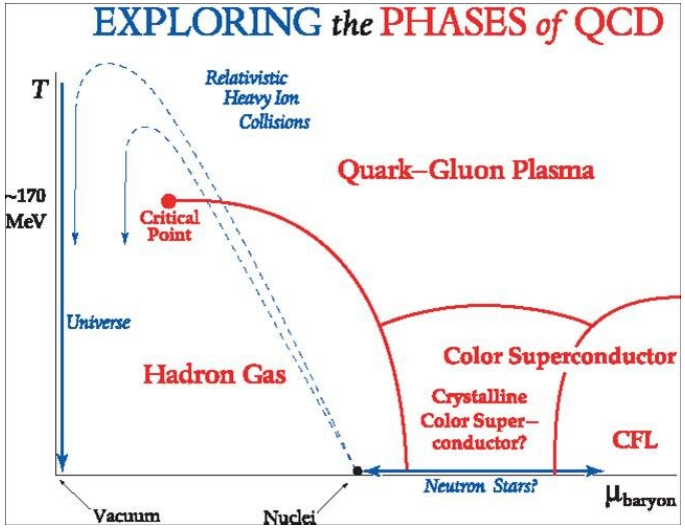
The QCD phase diagram.

Work done and what else for the future.

Backup

Strongly interacting matter II

- Quantum ChromoDynamics (quarks and gluons).
- Hadrons.
- Many body systems.
- Extreme conditions.



Cartoon of a QCD phase diagram. Ref [1]

- Chiral Simmetry.
- Phase Transition.

[1] P. Jacobs, D. Kharzeev, B. Muller, J. Nagle, K. Rajagopal and S. Vigdor, arXiv:0705.1930 [nucl-ex].

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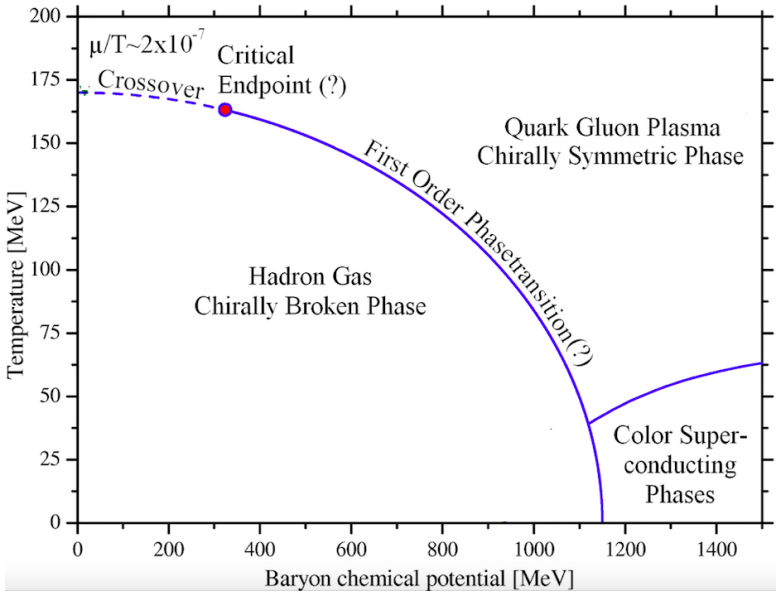
The QCD phase diagram

Critical End Point

Crossover/ Second order phase transition



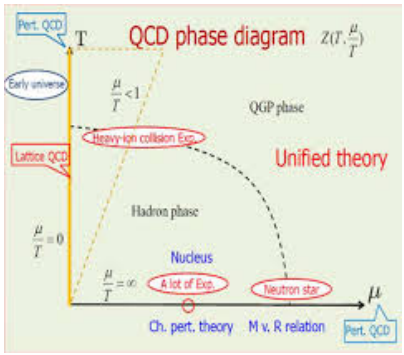
First order phase transition

T. Boeckel *et al.*, arXiv:1105.0832 [astro-ph.CO]

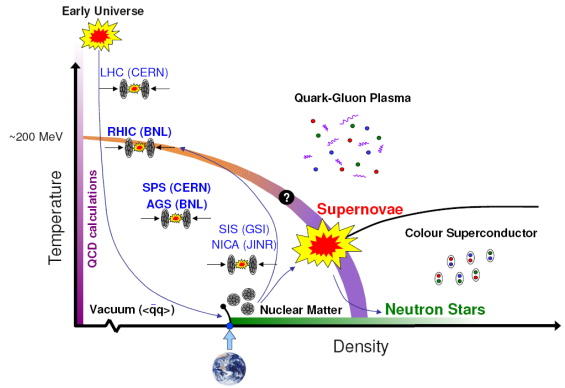
Deconfinement and/or Chiral symmetry restoration.

Phase transition $\Leftrightarrow$ Symmetry restored/broken.

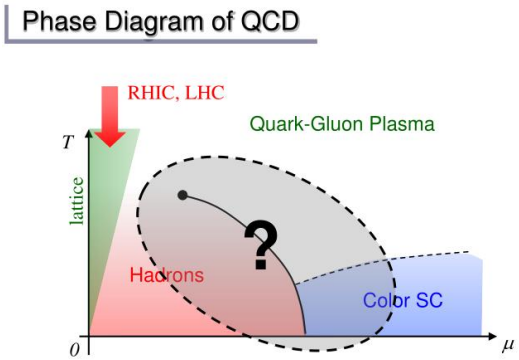
QCD phase diagram. In nature and laboratory



Por M. Yahiro.



Por N. U. F. Bastian, D. Blaschke, T. Fischer and G. Röpke, Universe **4**, no. 6, 67 (2018).



Por M. Kitazawa, Baryons 2010.

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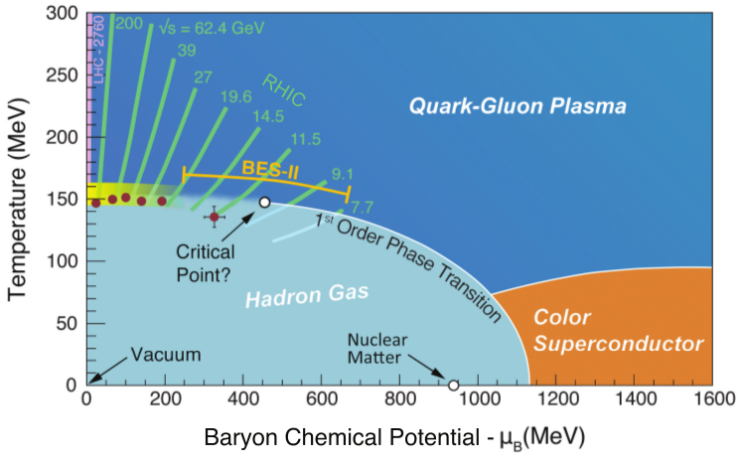
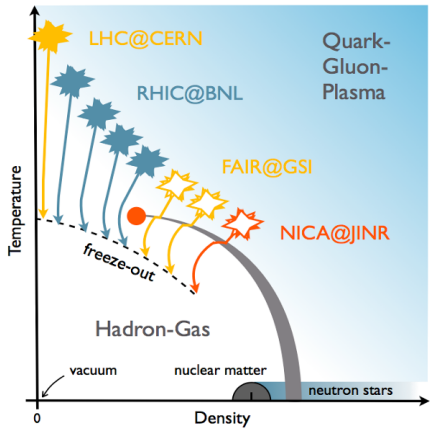
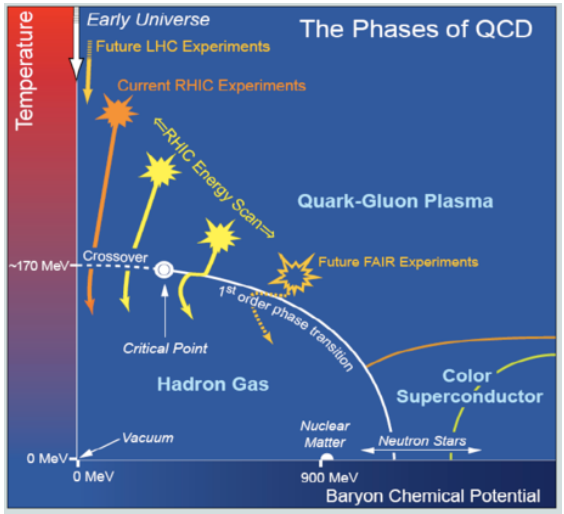
Beginning of a great era



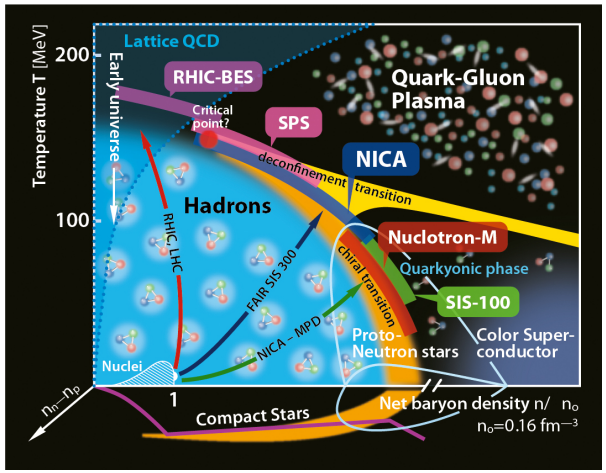
NSAC 2015 Long Range Plan for Nuclear Physics



University of Bielefeld, Physics Department

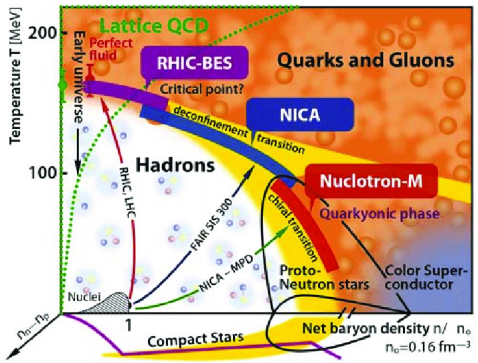


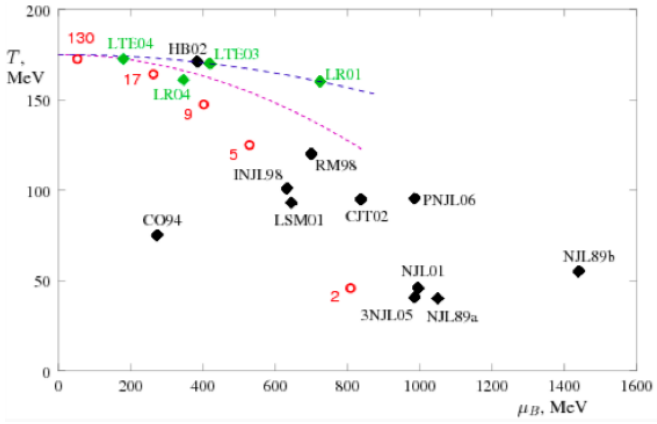
M. J. Tannenbaum, arXiv:1201.5900 [nucl-ex]



CompStar

Critical End Point.





M. Stephanov, arXiv:hep-lat/0701002.

- Hitherto, we do not have access experimetally in regions with high baryonic density. However, **MPD-NICA experiment** will provide important information that tell us if the CEP exists and where it can be localized.

Reference	Technique	T_{CEP}	μ_{CEP}
arXiv:1602.00062	DSEs	0.85 T_c	1.11 T_c
arXiv:1605.08430	nonlocal PNJL	69.9 MeV	319.1 MeV
arXiv:1611.06669	FRG	5.1 MeV	286.7 MeV
arXiv:1612.06673	LQCD	155 MeV	285 MeV
QM2015 and CPOD2016	LQCD	-	>2 T_{CEP}
PRD90 (2014), 076006	DSEs	129 MeV	372 MeV
JHEP 7, 1-10, 2014	DSEs	127 MeV	405 MeV
PRD90 (2014), 034022	DSEs	115 MeV	504 MeV
QM2017	LQCD	145-155 MeV	>2 T_{CEP}
arXiv:1702.06731	ADS/CFT	112 MeV	612 MeV
arXiv:1705.09124	-	119-162 MeV	252-258 MeV
Sci.Rep. 7 (2017) 45937	NJL	38 MeV	245 MeV

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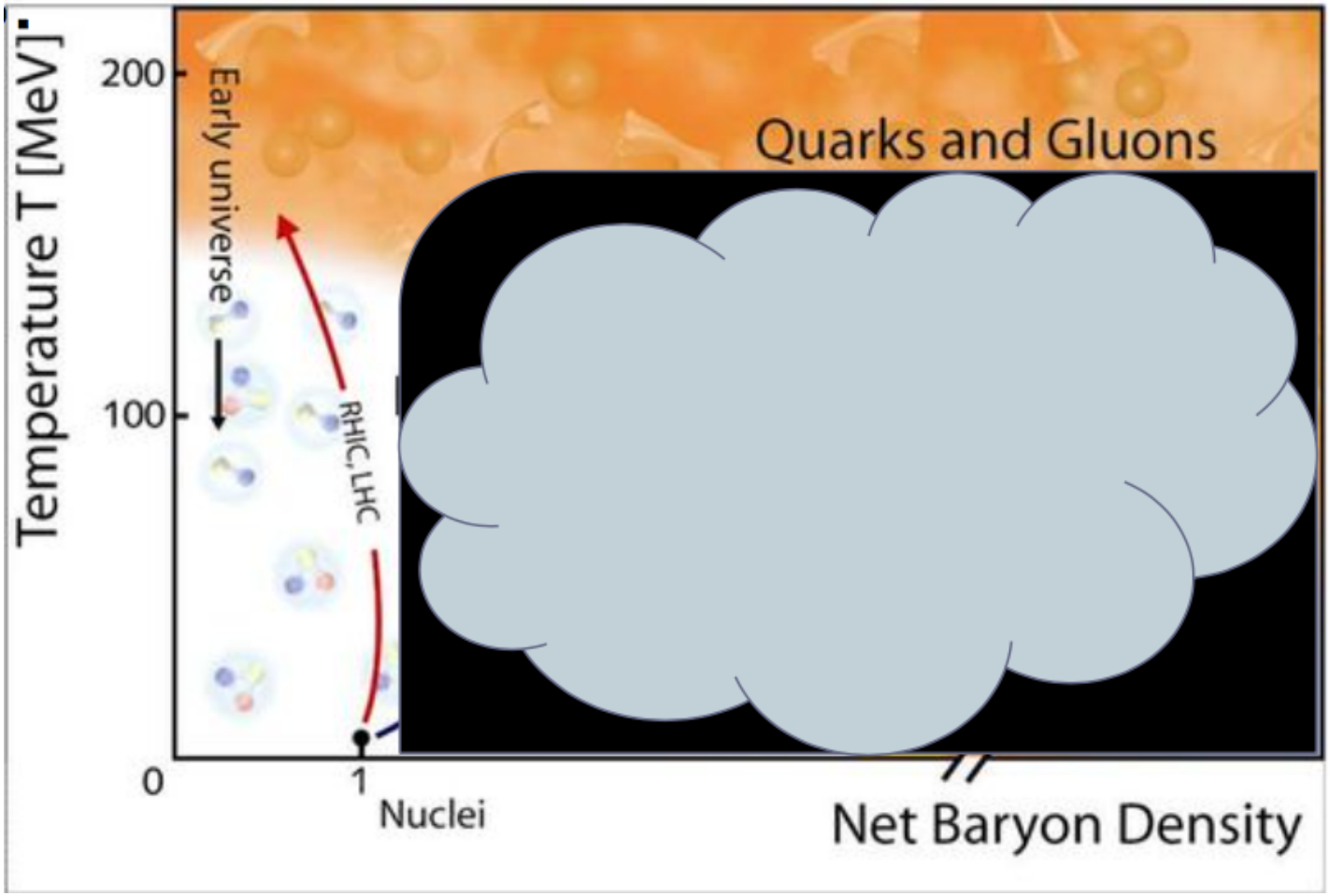
Our current knowledge



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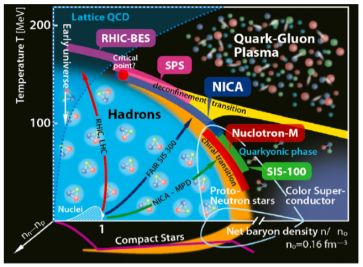
Ideas around the world.



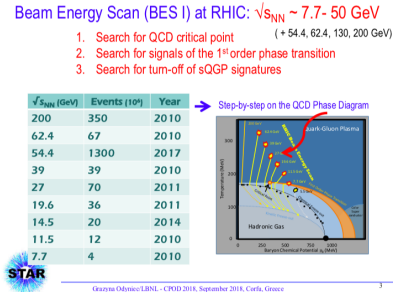
We only have compelling knowledge of the properties of QCD matter at high T and very small baryon density,.

We have strong evidence for the equation of state for very small T and high T from static properties of neutron stars and their collisions.

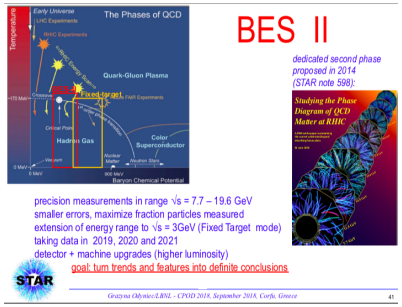
All the rest is at best educated conjecture and at worst idle speculation. Later in the talk I will engage in some speculation

It is not what you don't know that gets you in trouble, it is what you think you know but you don't. *Mark Twain*

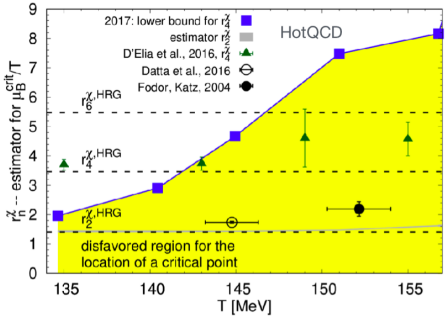
CPOD2018 (Larry McLerran)



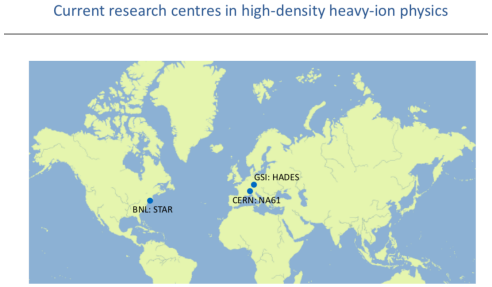
BES-I RHIC, Grazyna Odyniec, CPOD2018.



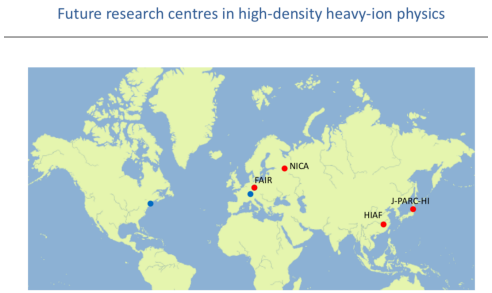
BES-II RHIC, Grazyna Odyniec, CPOD2018.



LQCD status for the CEP location (S. Mukherjee, CPOD2018)



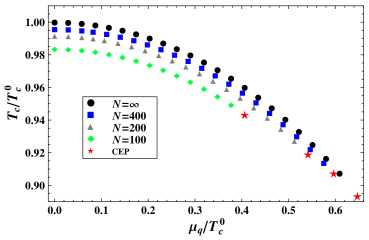
Volker Friese CPOD2018

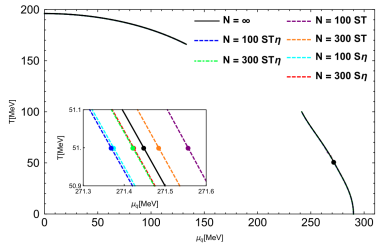


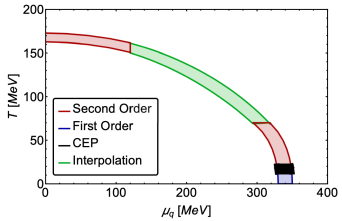
Volker Friese CPOD2018

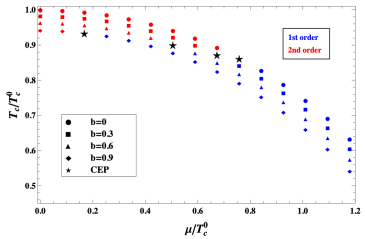
Work done

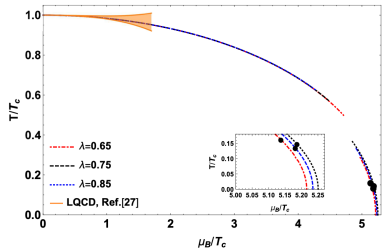
- Effective models (chiral symmetry).
- Analytic expressions (including T and μ finite effects).
- Systems out of equillibrium (non-extensive statistical mechanic $\Rightarrow$ Superstatistic).
- Finite magnetic effects.



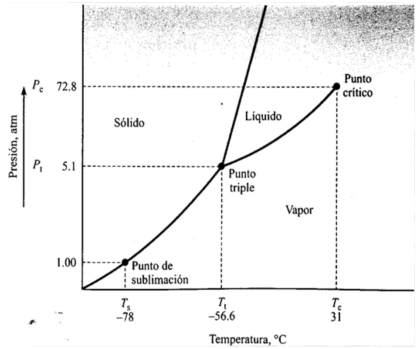


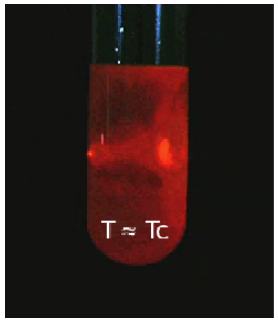


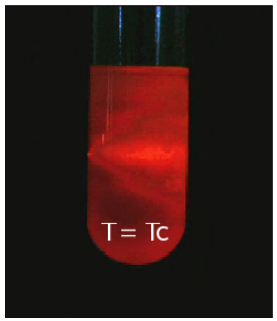




Criticallity

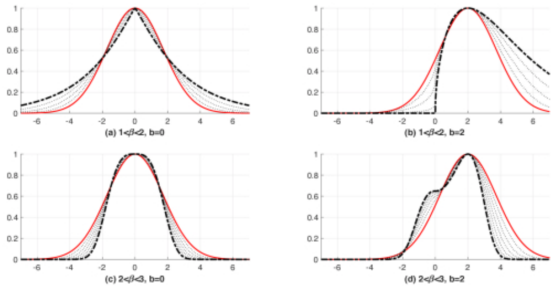






Tamas Csörgö, arXiv:0903.0669 [nucl-th]

Critical opalescence (the correlation length of the liquid diverges)



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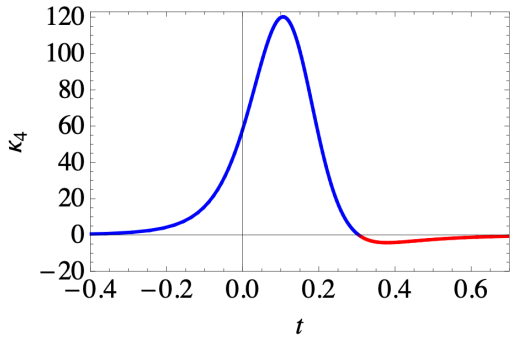
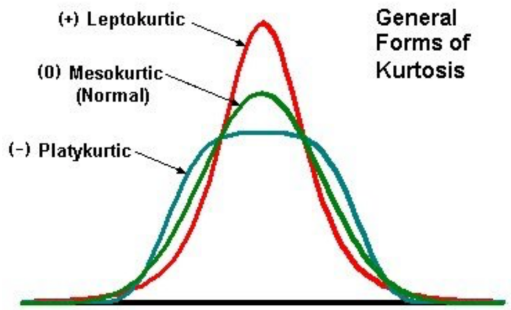
Criticallity in HICs

- fluctuations of:
  - multiplicity of given charged particles (pions or protons).
  - Net baryon charge.
- Kurtosis (4th statistical moment)





A. Bzdak, S. Esumi, V. Koch, J. Liao, M. Stephanov and N. Xu, Phys. Rept. **853** (2020), 1-87.
M. A. Stephanov, J. Phys. G **38** (2011), 124147.

M. A. Stephanov, Phys. Rev. Lett. **107** (2011), 052301

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Thanks!!!

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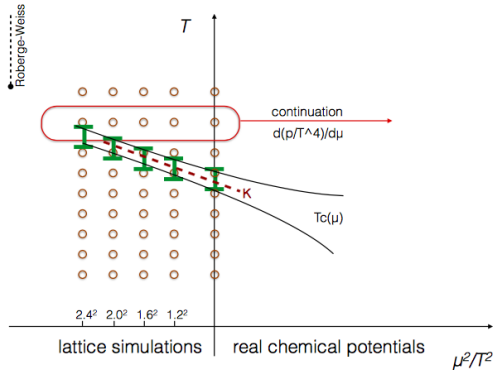
Lattice QCD con $\mu_B \neq 0$

- El problema de signo. S_E a $\mu_B \neq 0$ se vuelve compleja.
- Alternativas. Trabajar con $\mu_B < 0$ o hacer una expansión en serie de Taylor.
- Solo se puede trabajar con valores pequeños de μ_B o al aumentar μ_B el error sistemático crece considerablemente.

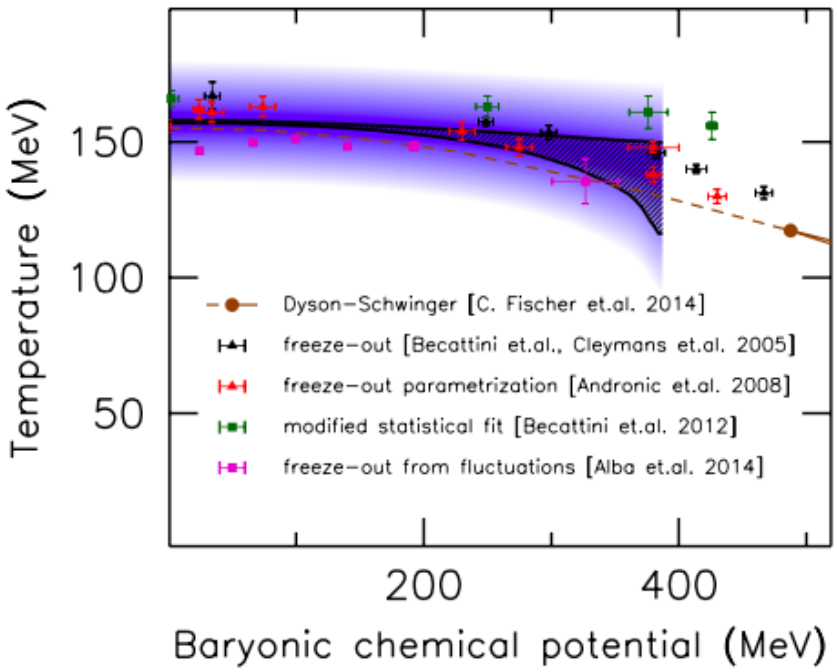
Analytic continuation



Common technique: [de Forcrand, Philipsen, deForcrand:2002hgr], [Bonati et al., Bonati:2015bha], [Cea et al., Cea:2015cya], [D'Elia et al., DElia:2016jqh] ...

Jana Günter, CPOD-2017

Resultados recientes de LQCD.



Jana Günter,Wuppertal-Budapest Collaboration

- Ahora ya pueden extender a valores grandes de μ_B, pero con un incremento sustancial de los errores estadísticos y sistemáticos.

Parámetro de orden