

CURRENT AND FUTURE PROSPECT OF HEAVY ION PHYSICS

IN-KWON YOO (PUSAN NAT'L UNIVERSITY)

An elephant is like a big snake

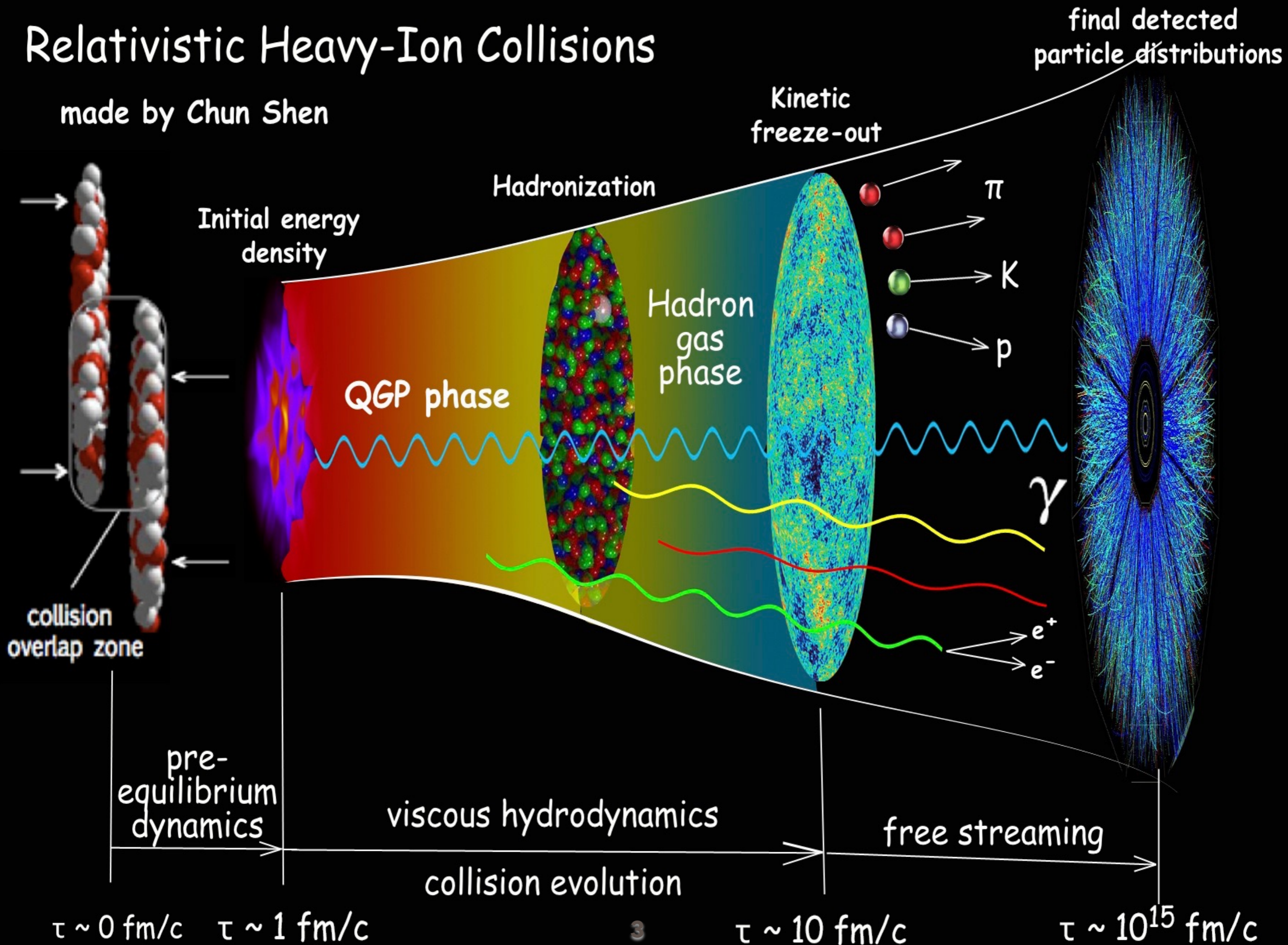
What are you saying! It is like a sheath of leather!!

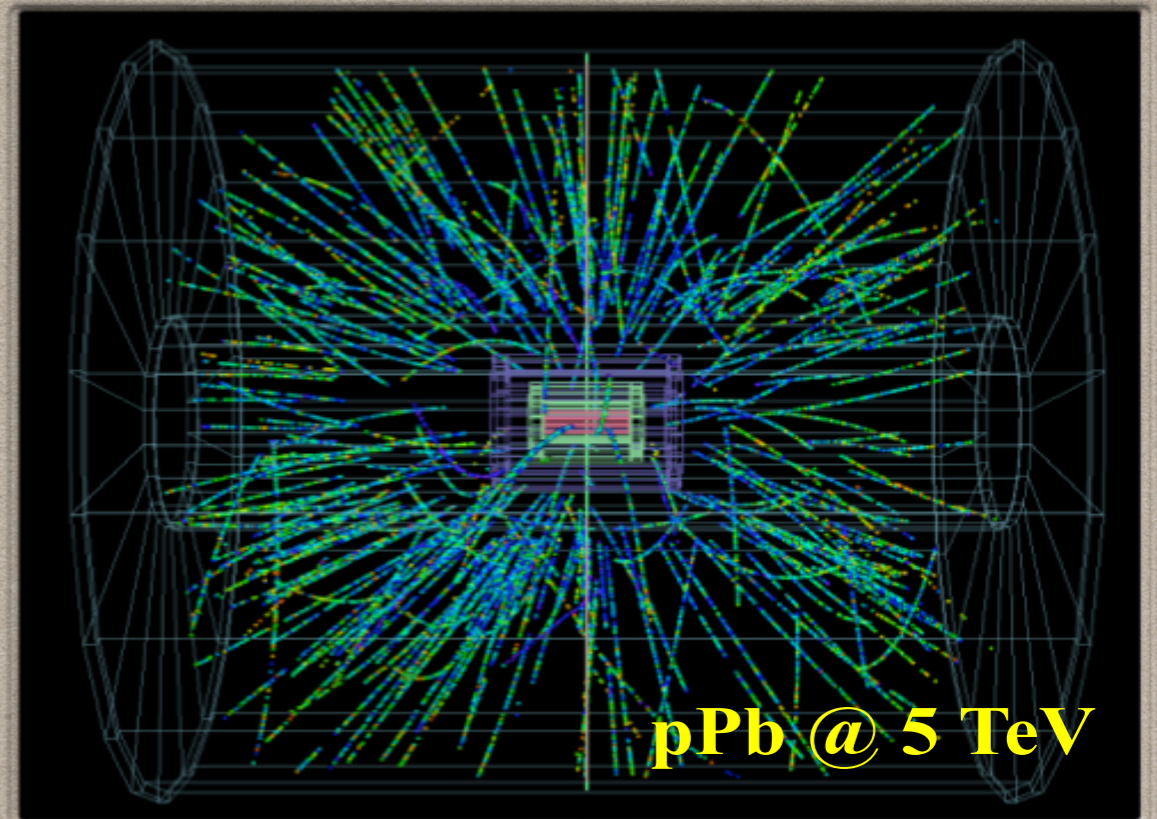
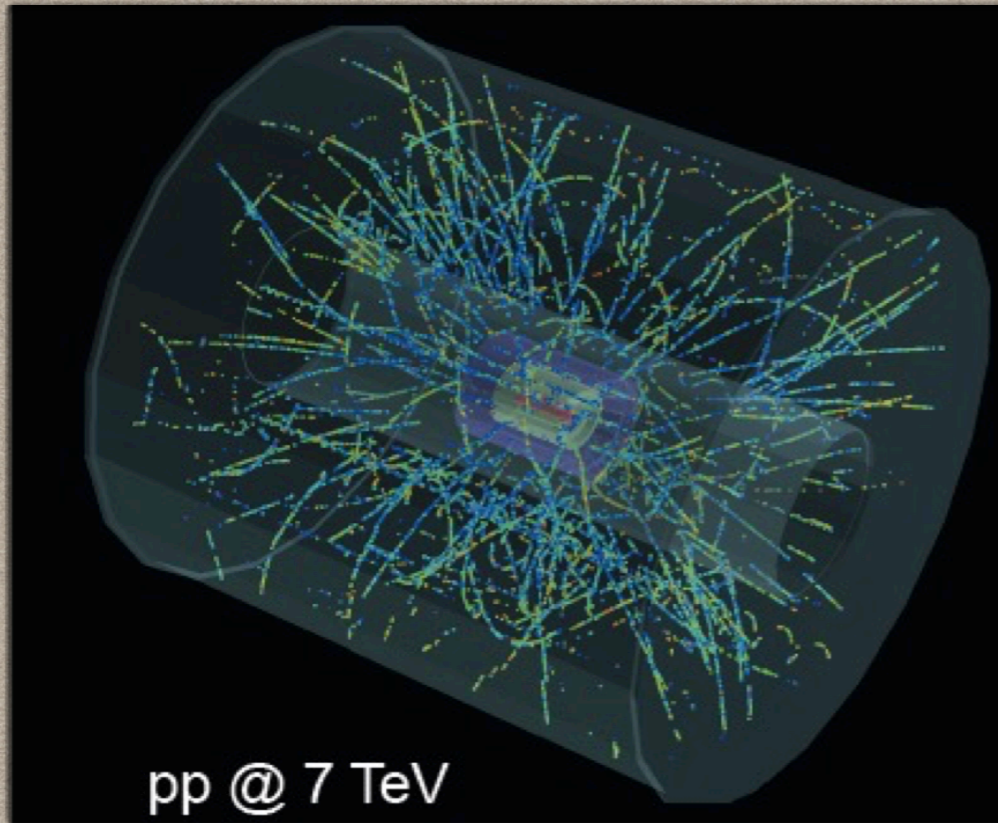
Your all wrong!!! It's actualy like a little furry mouse.

Actually, No! It's a tree stump!

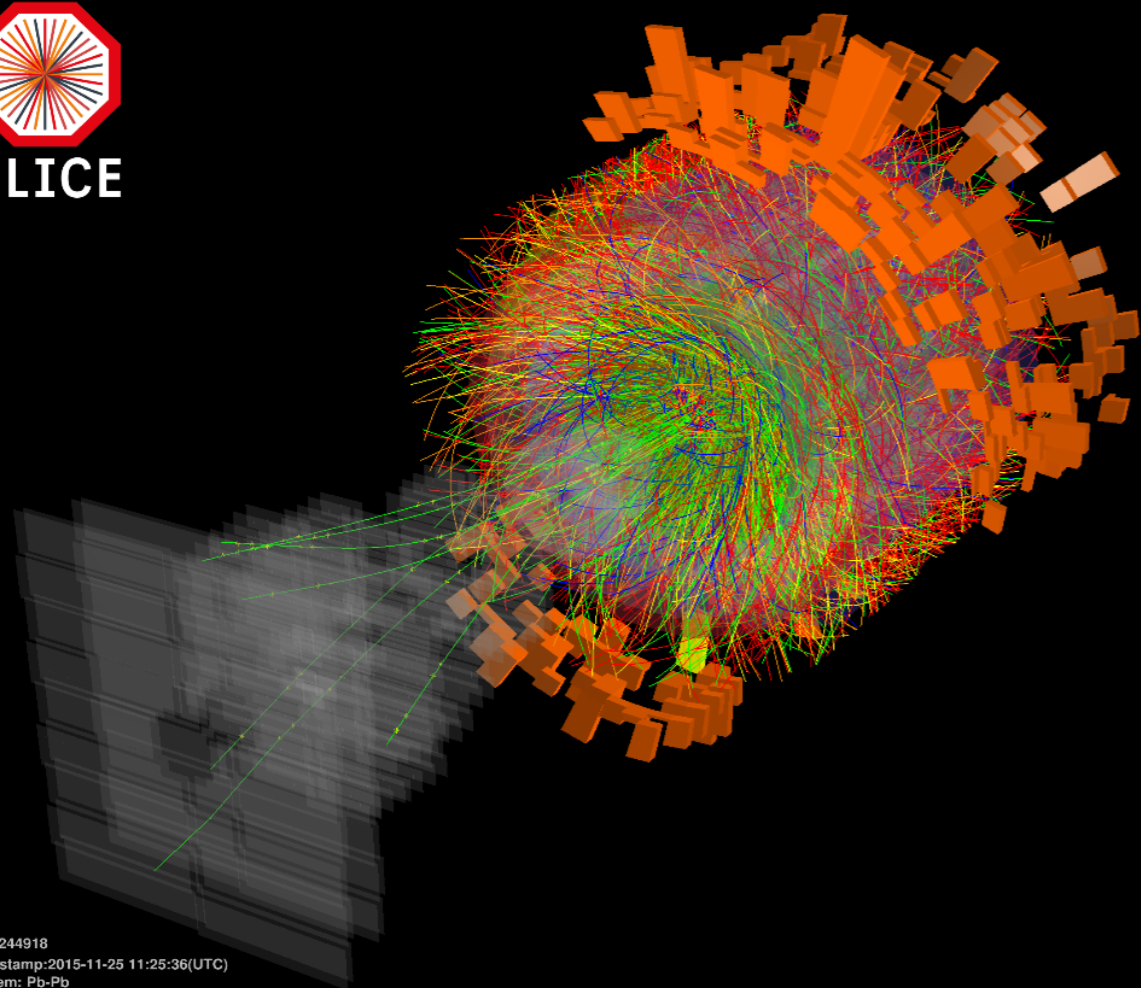
Relativistic Heavy-Ion Collisions

made by Chun Shen





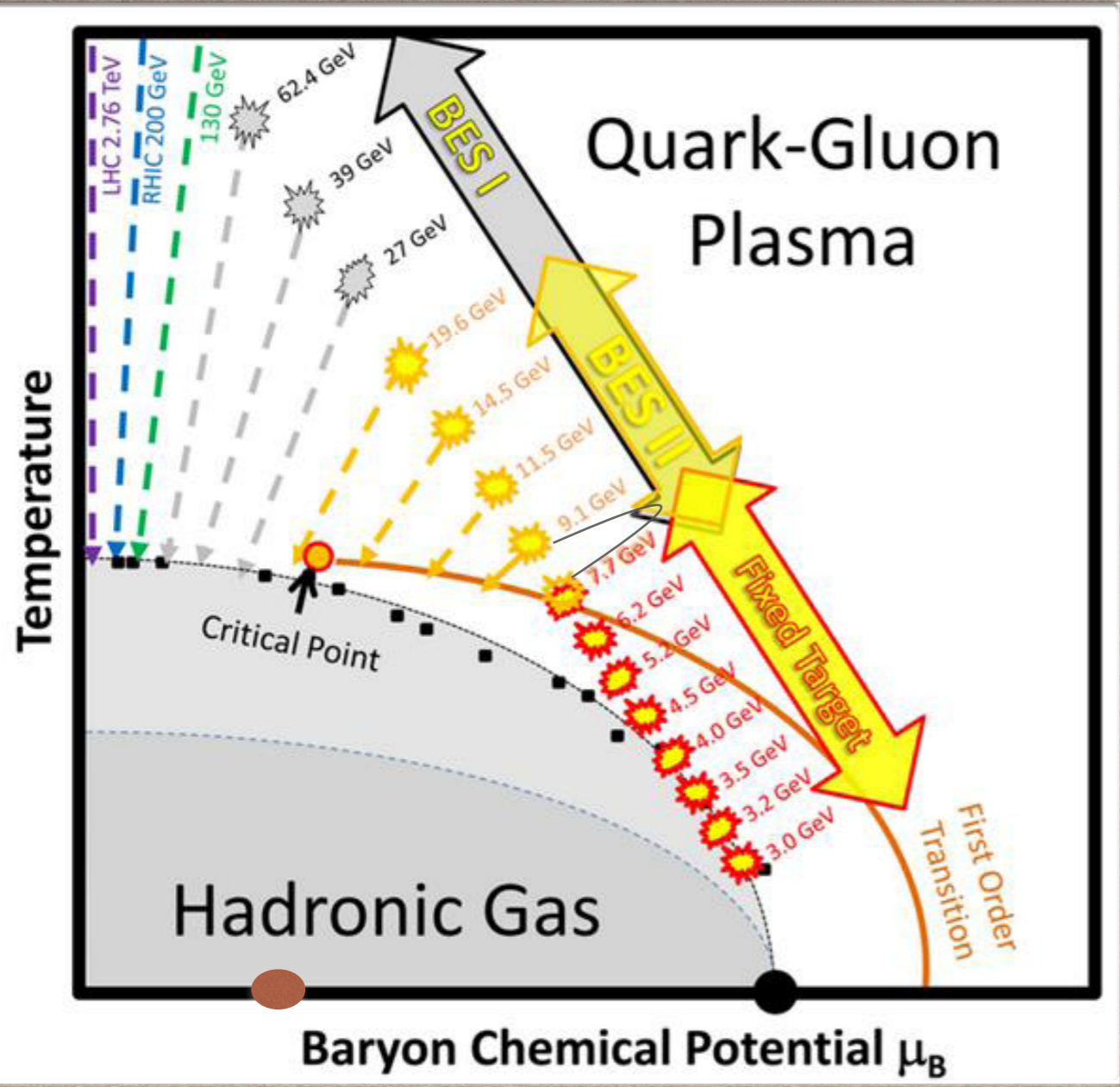
ALICE



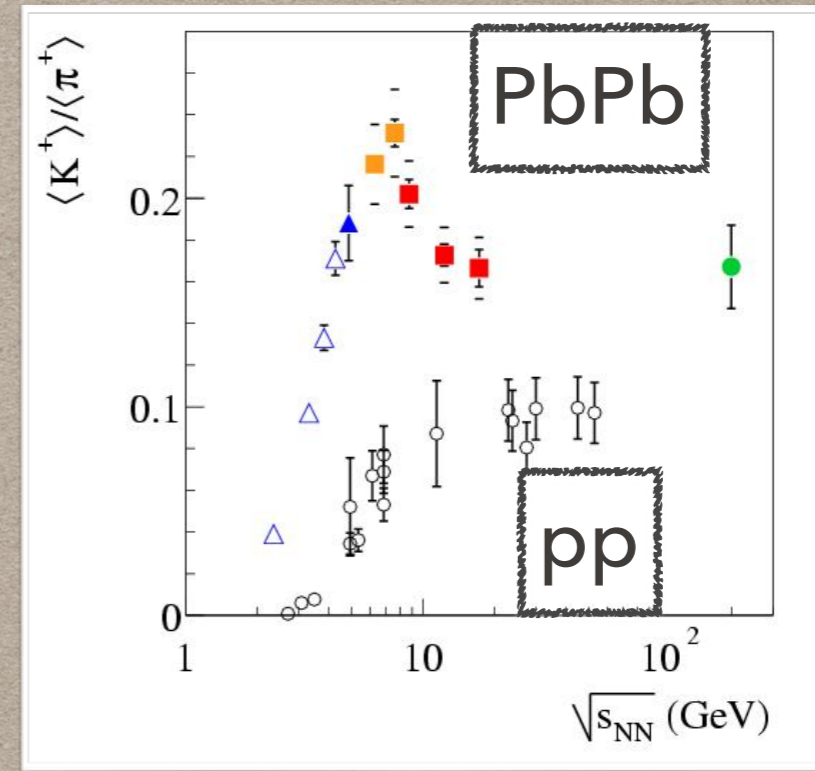
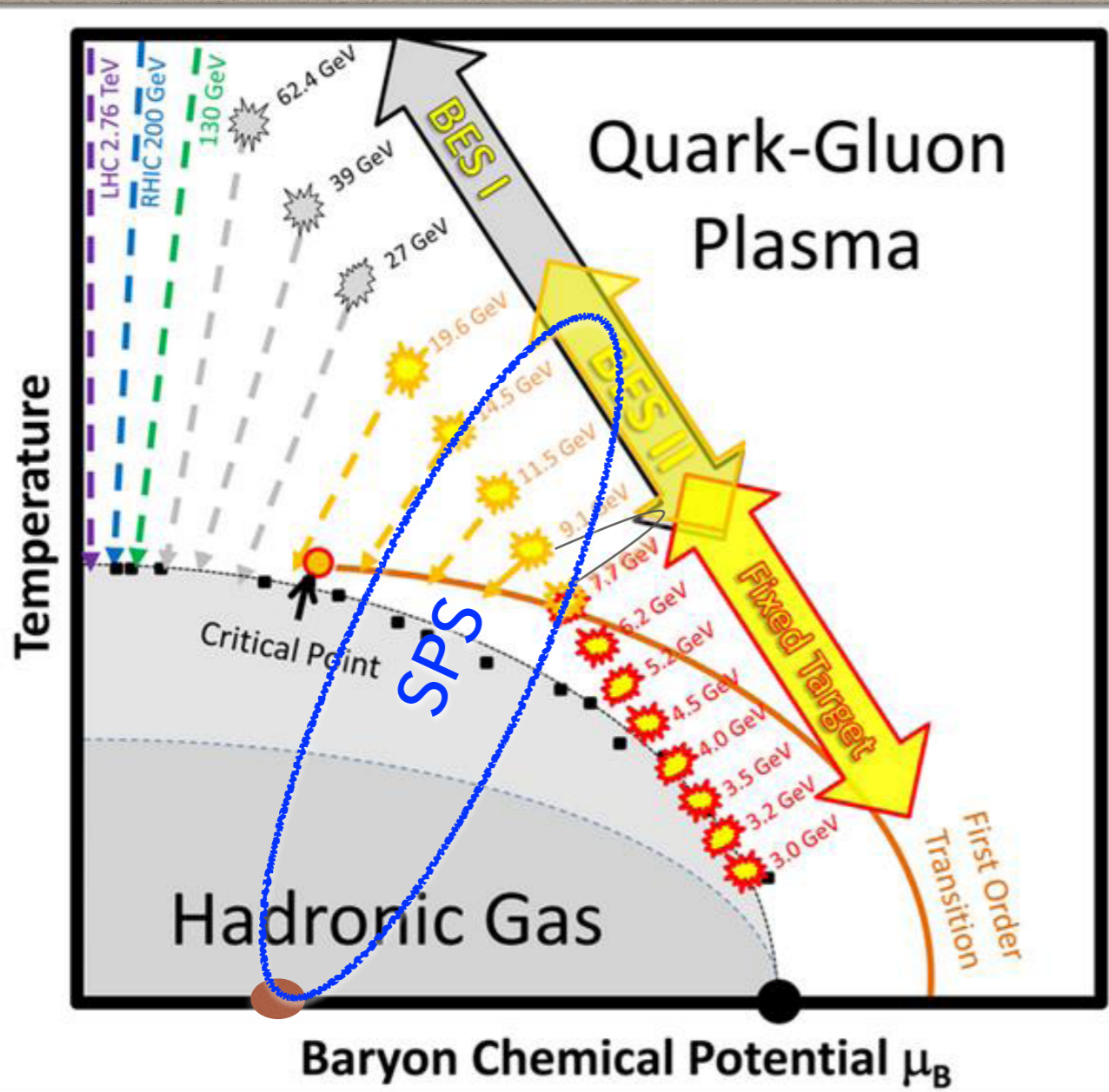
Run:244918
Timestamp:2015-11-25 11:25:36(UTC)
System: Pb-Pb
Energy: 5.02 TeV

PbPb \neq 208 \otimes 208 pp

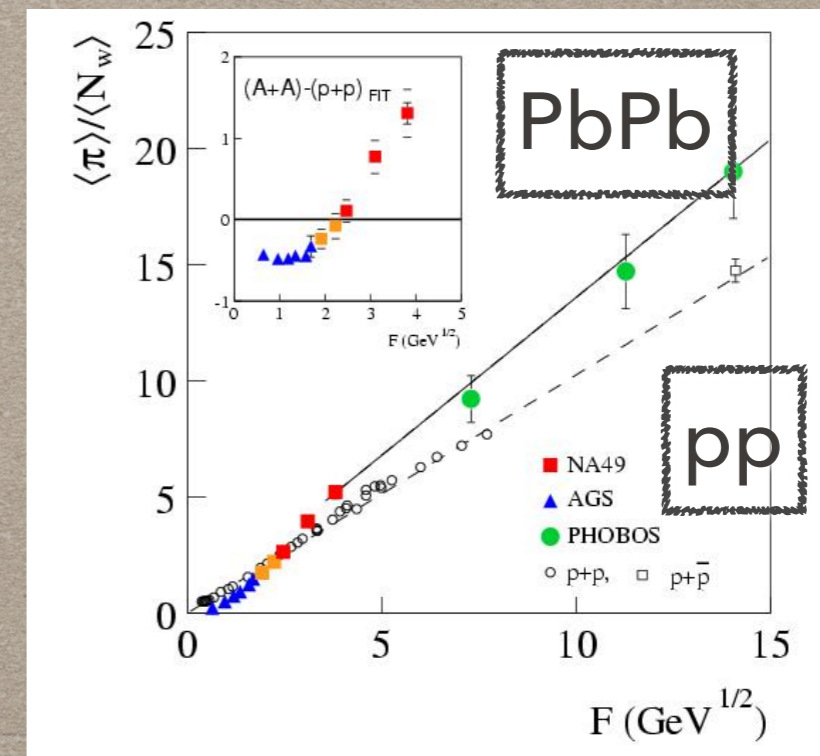
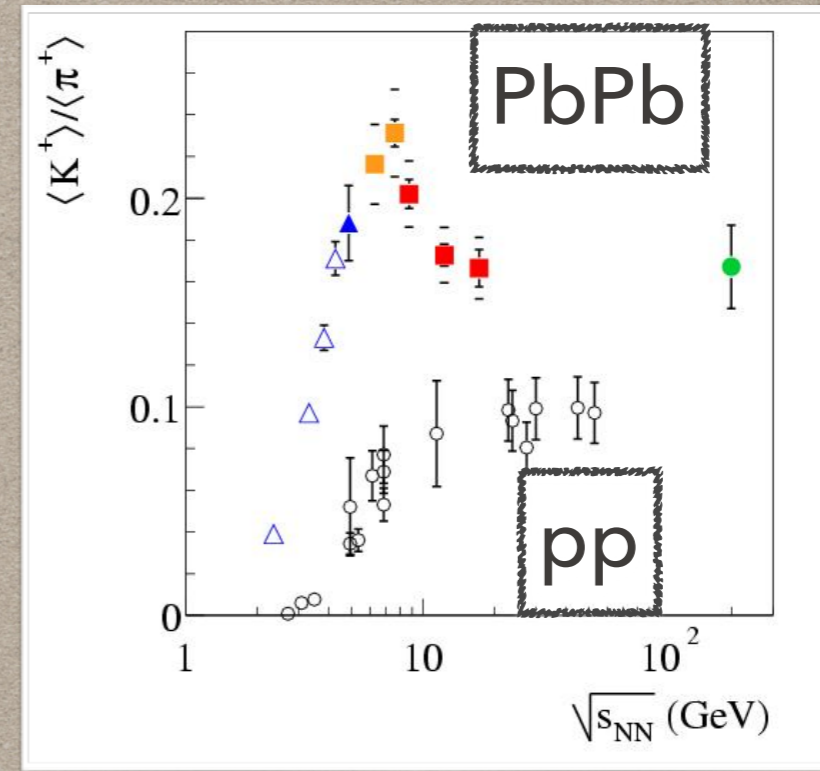
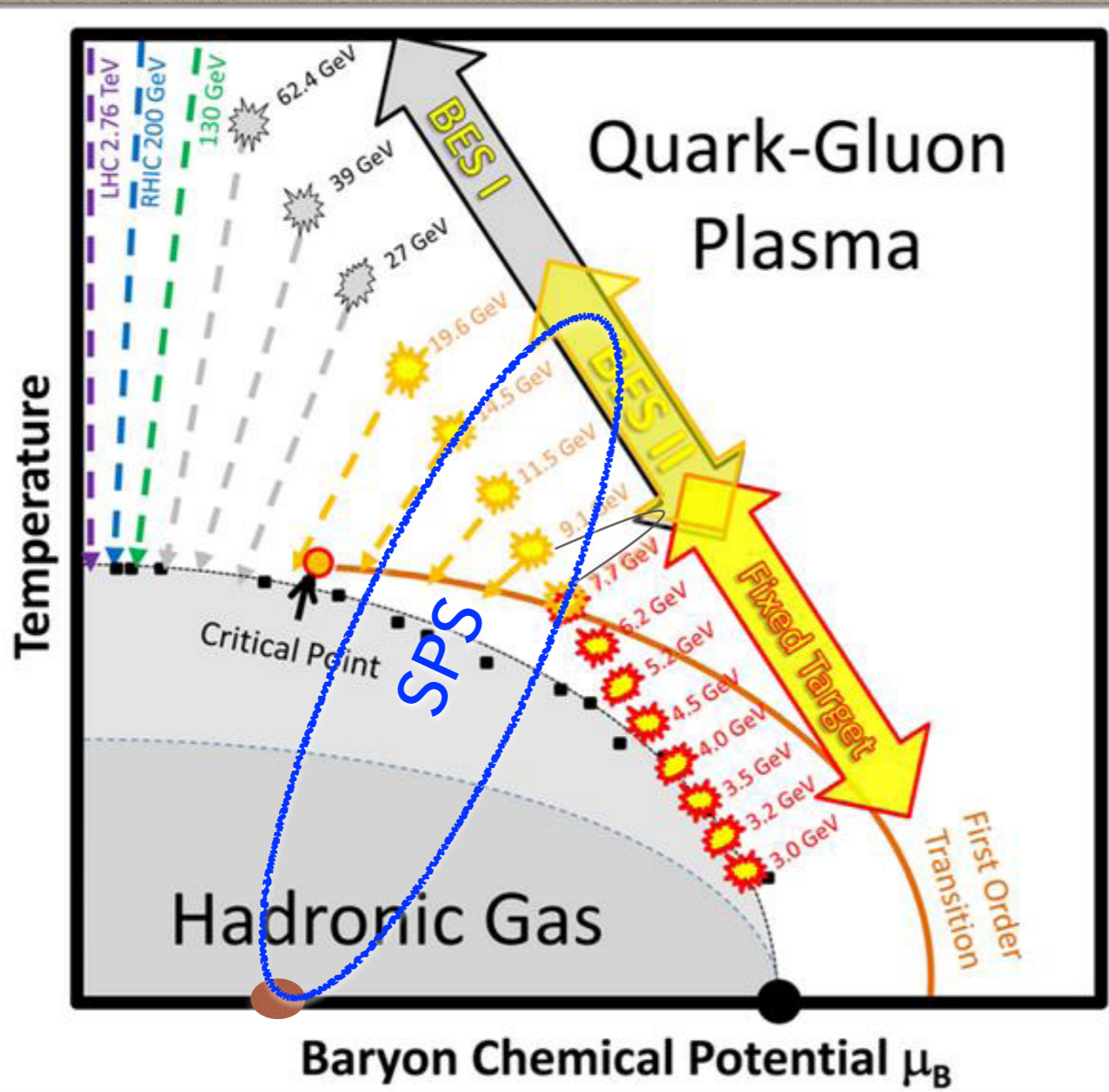
EXPLORING QCD PHASE I (SPS)



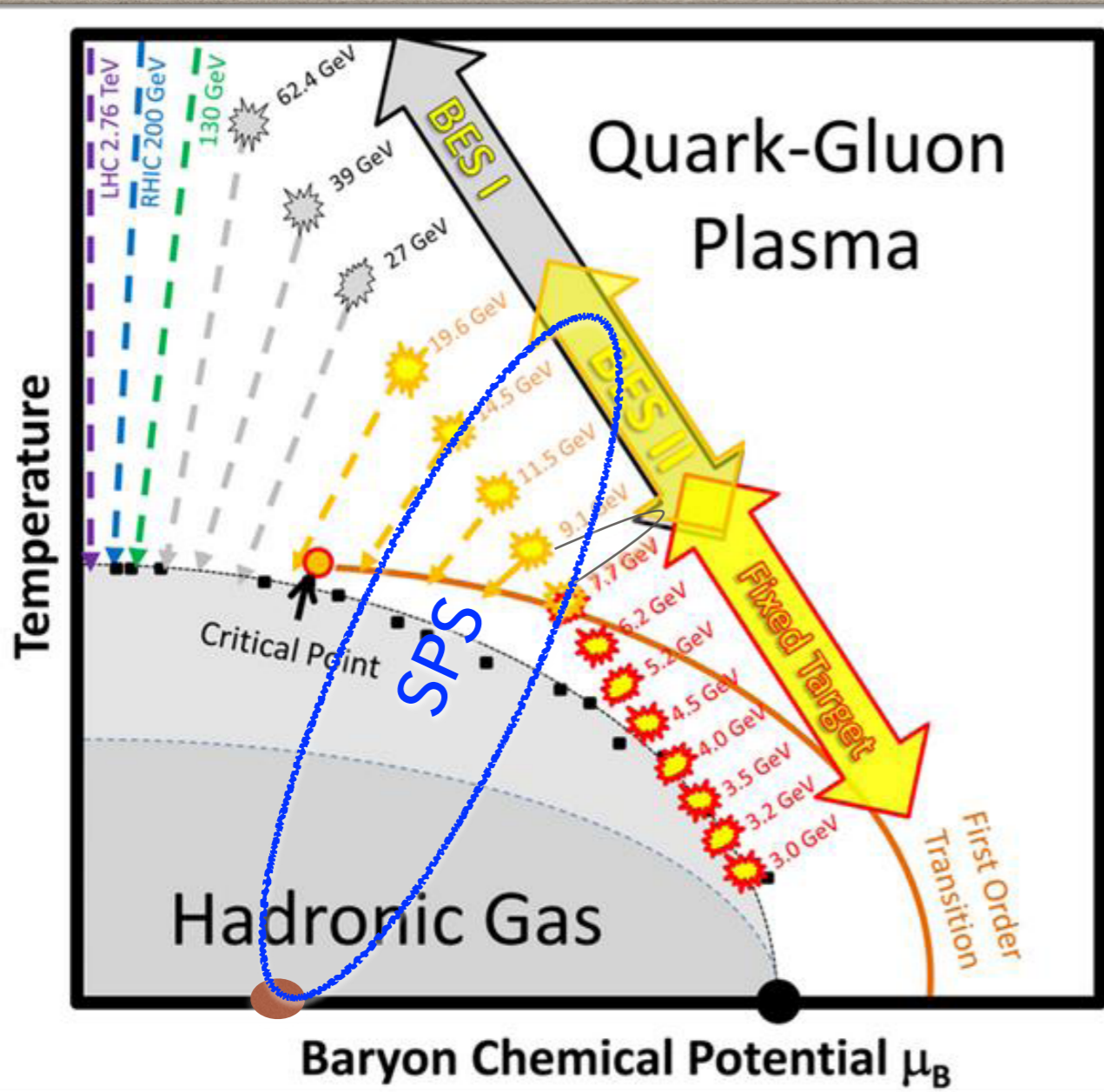
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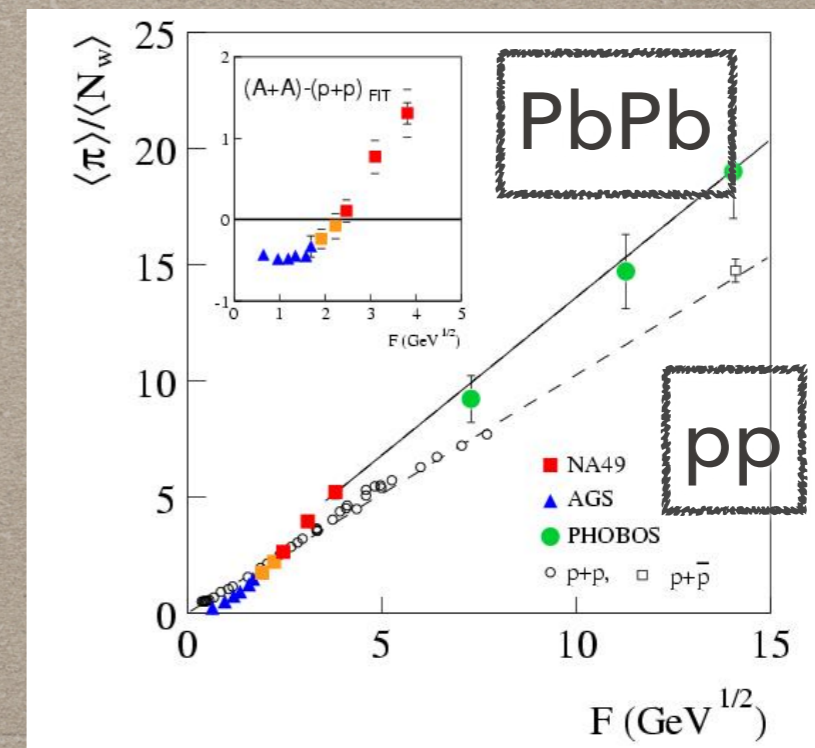
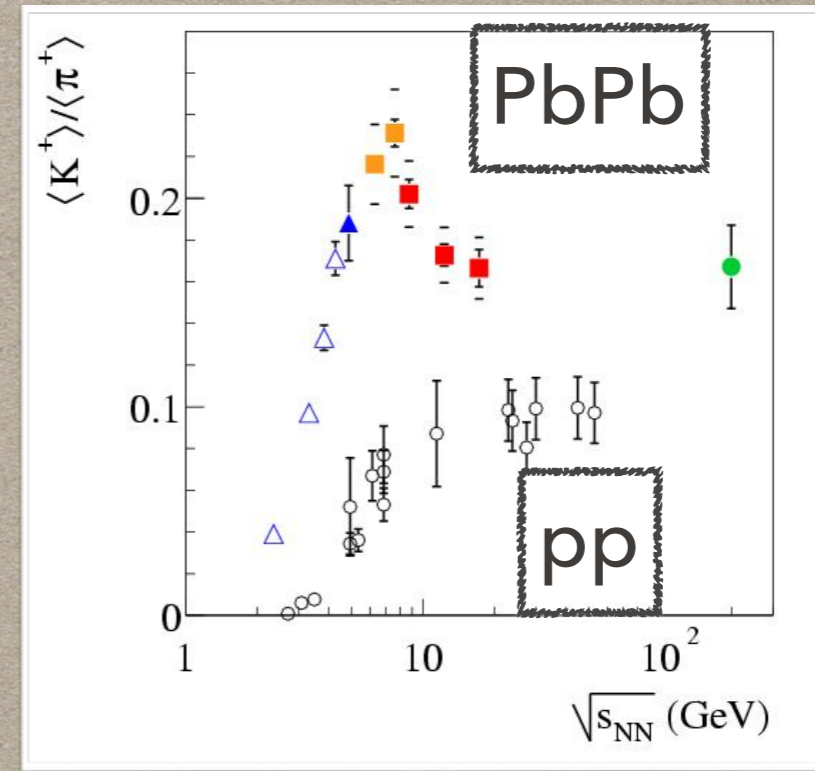
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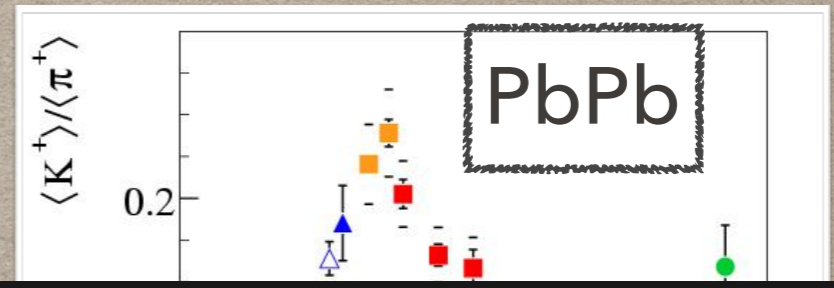
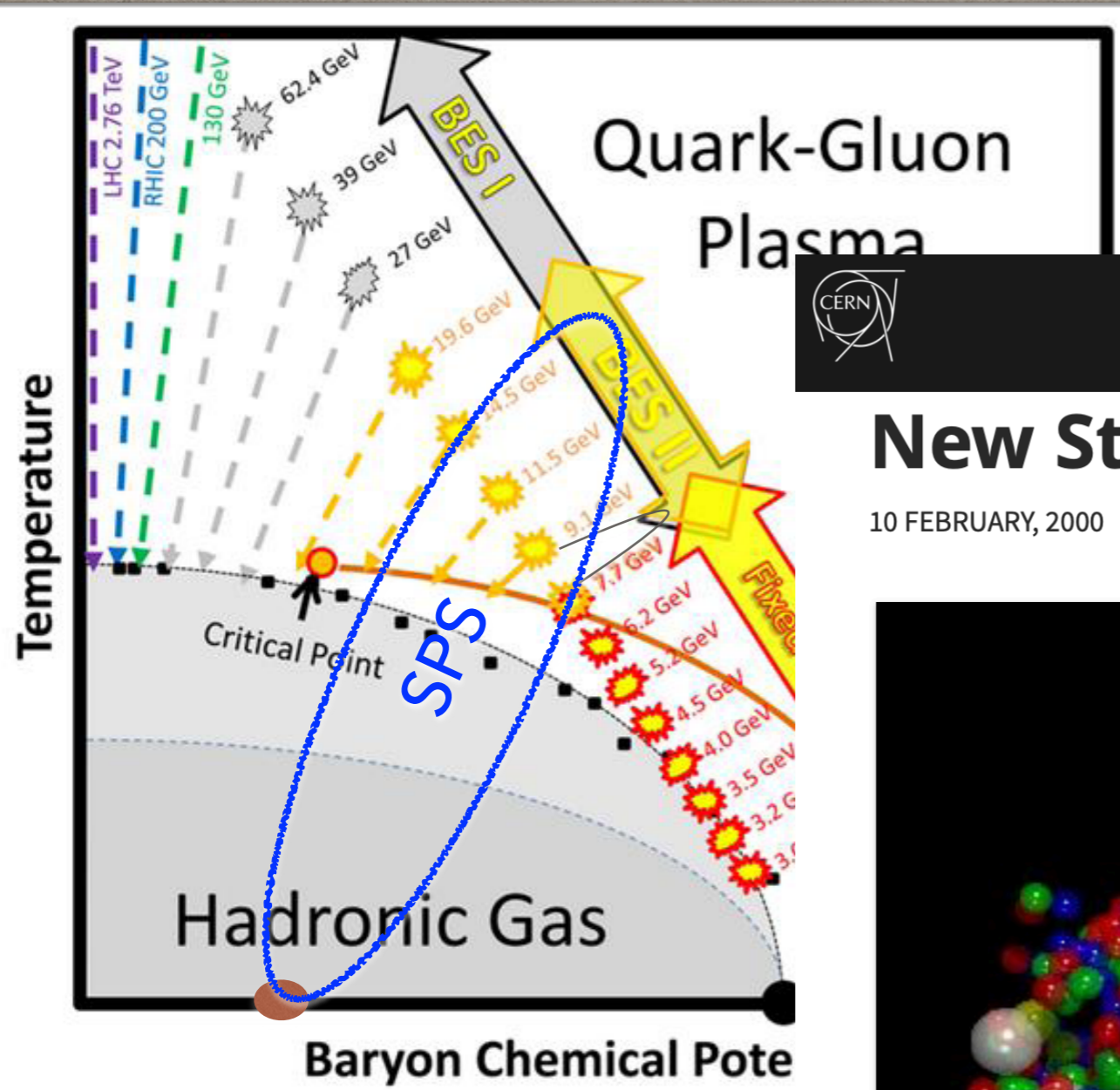


Onset of Deconfinement?



1990s

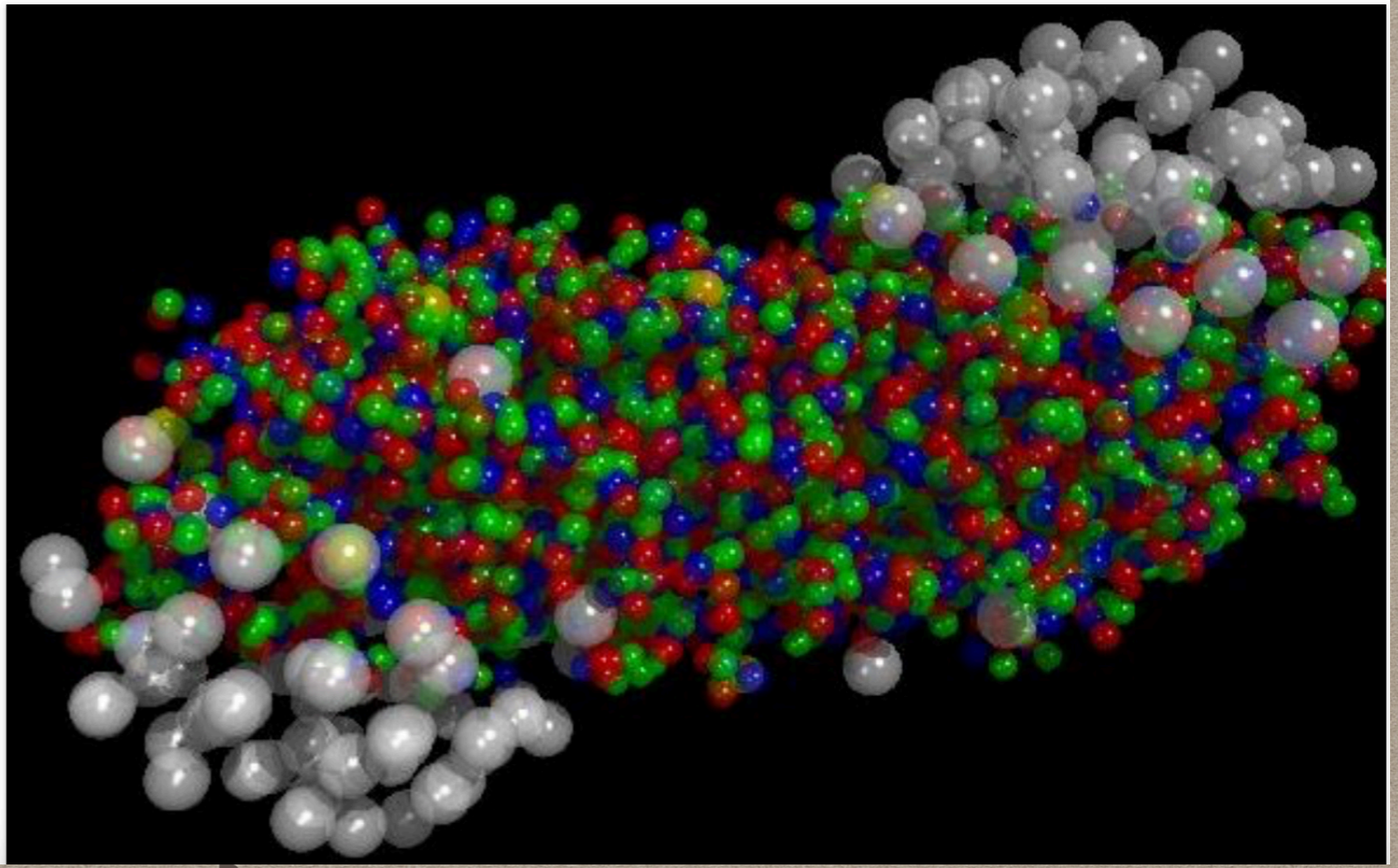
EXPLORING QCD PHASE I (SPS)



CERN [ABOUT](#) [NEWS](#)

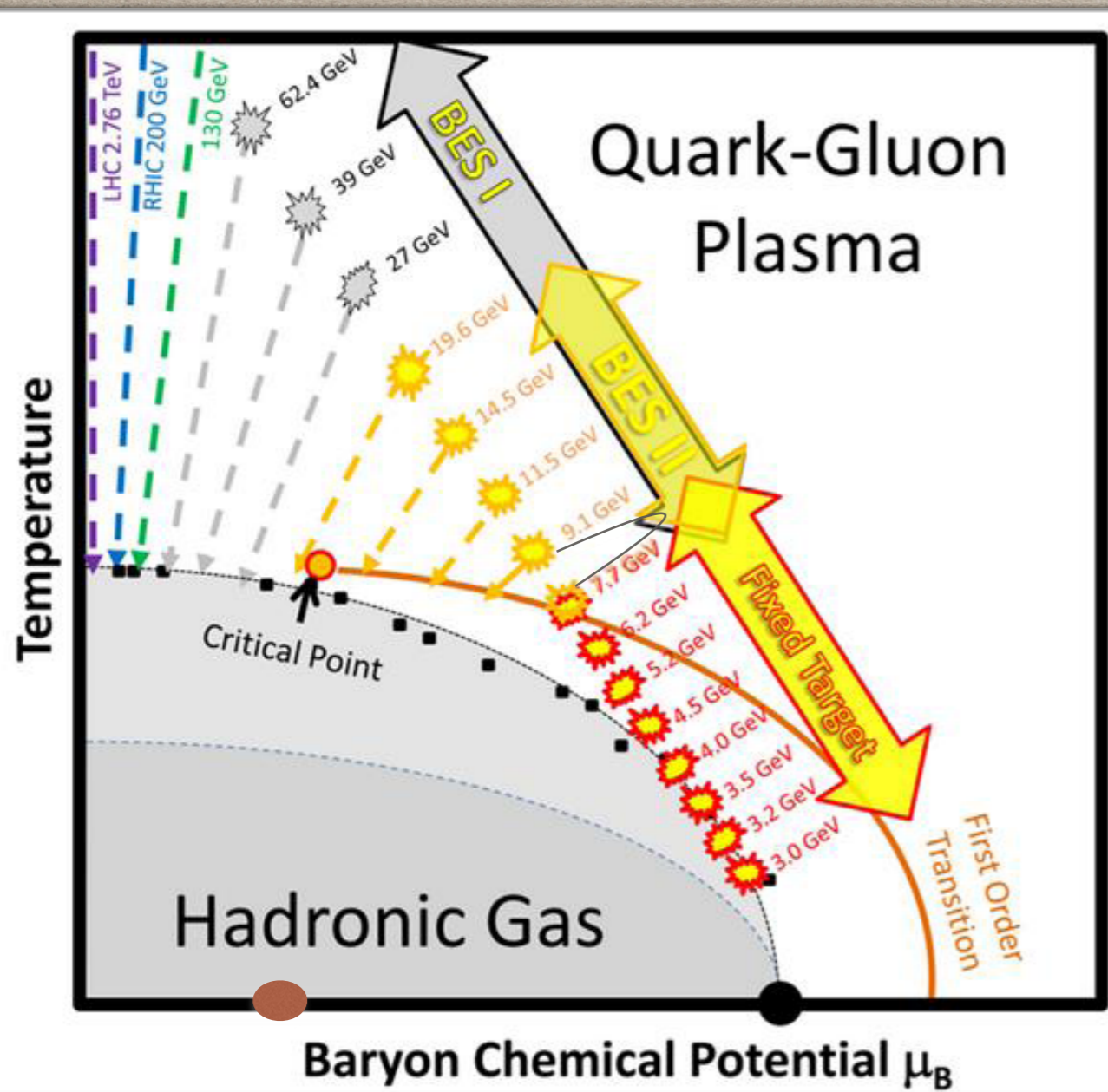
New State of Matter created at CERN

10 FEBRUARY, 2000

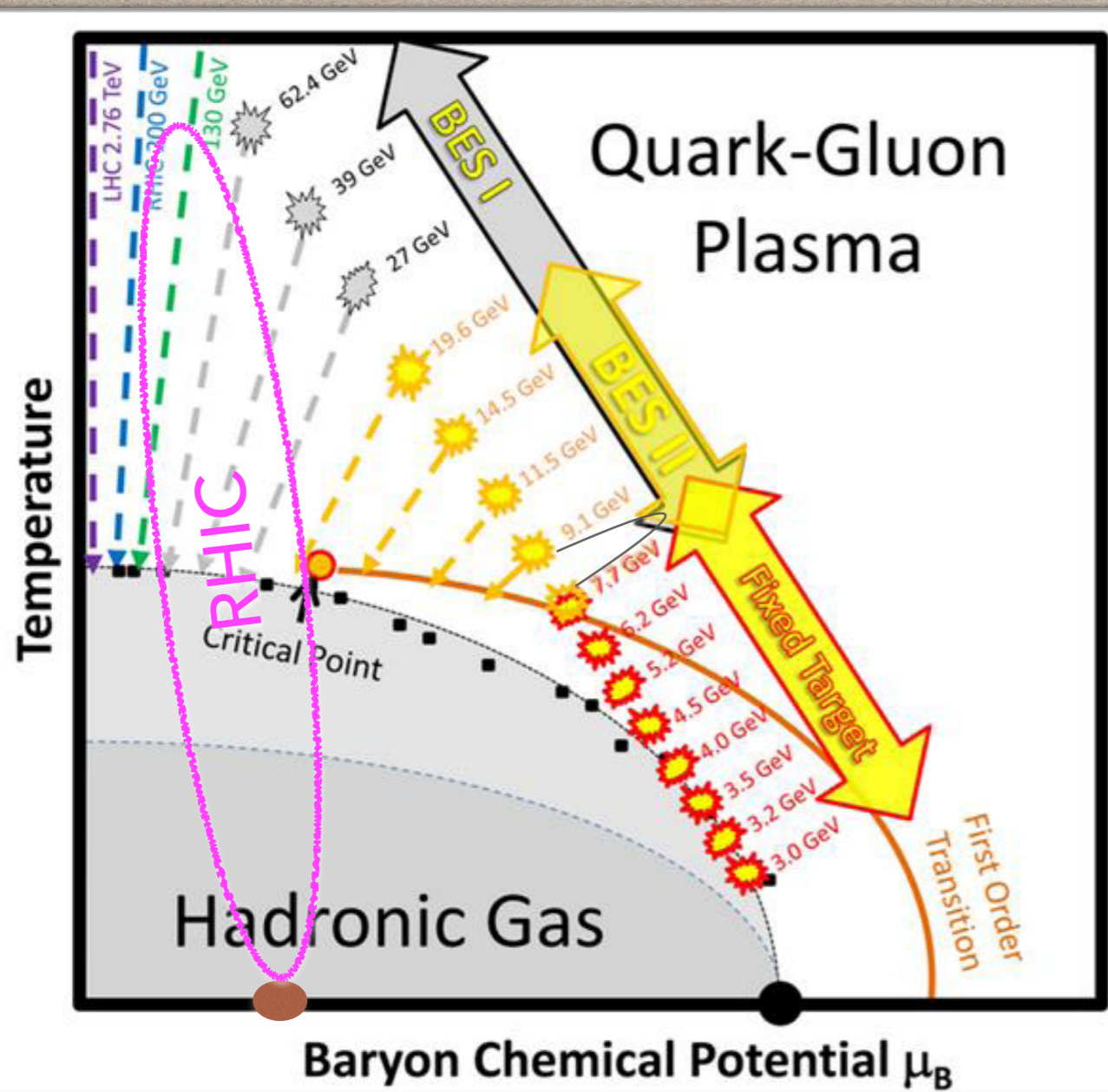


Onset of Deconfinement

EXPLORING QCD PHASE II (RHIC)

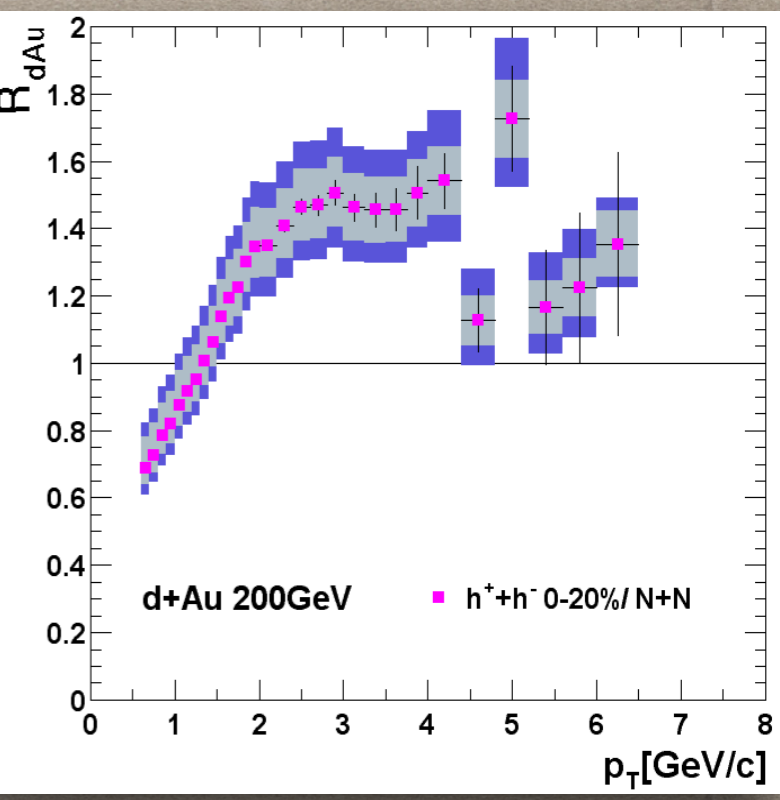
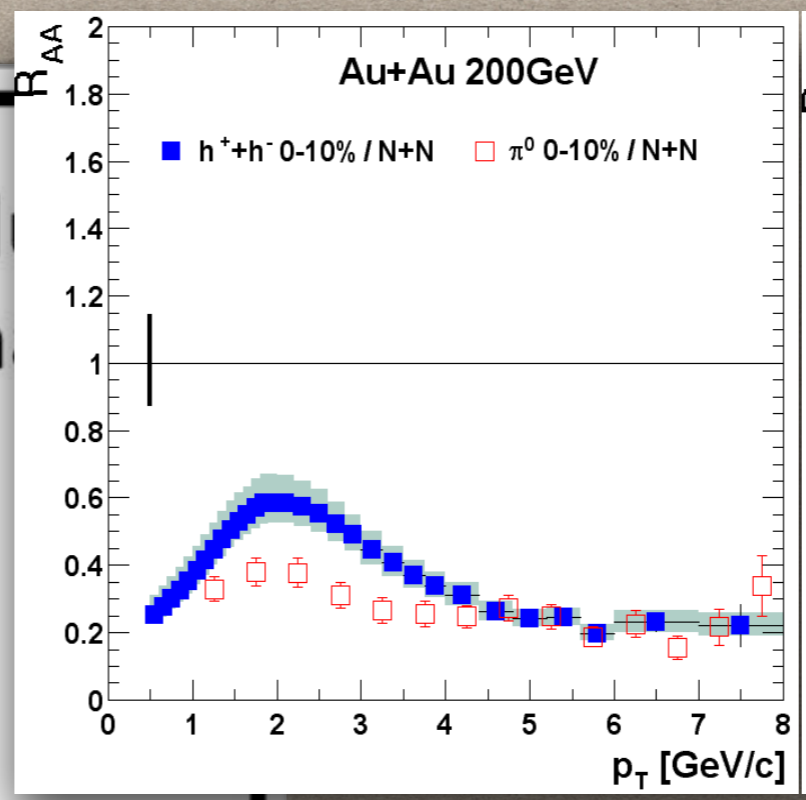
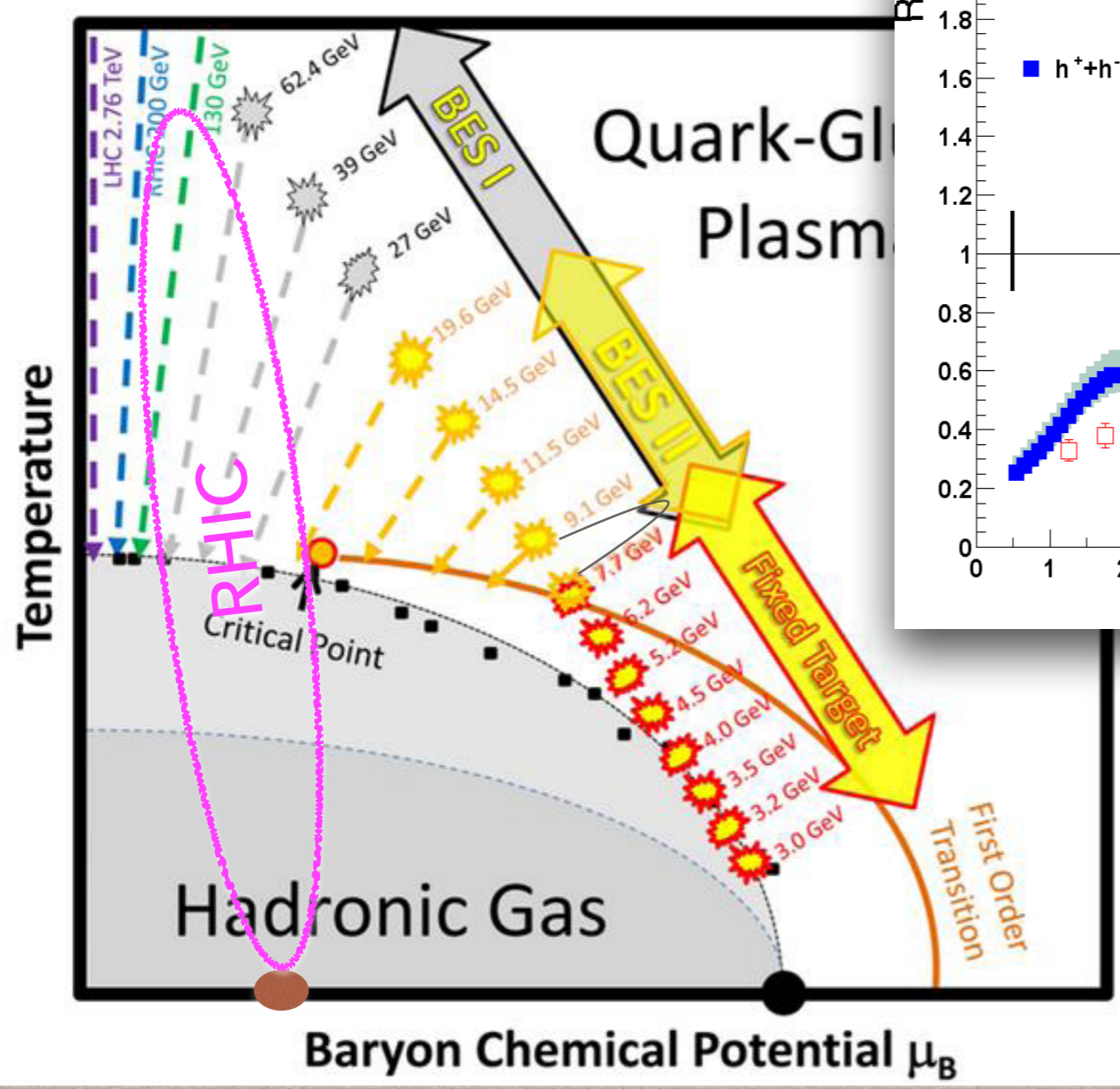


EXPLORING QCD PHASE II (RHIC)



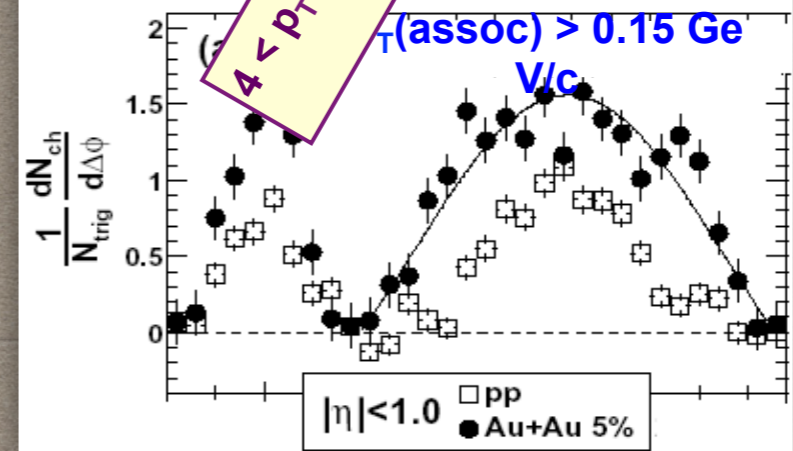
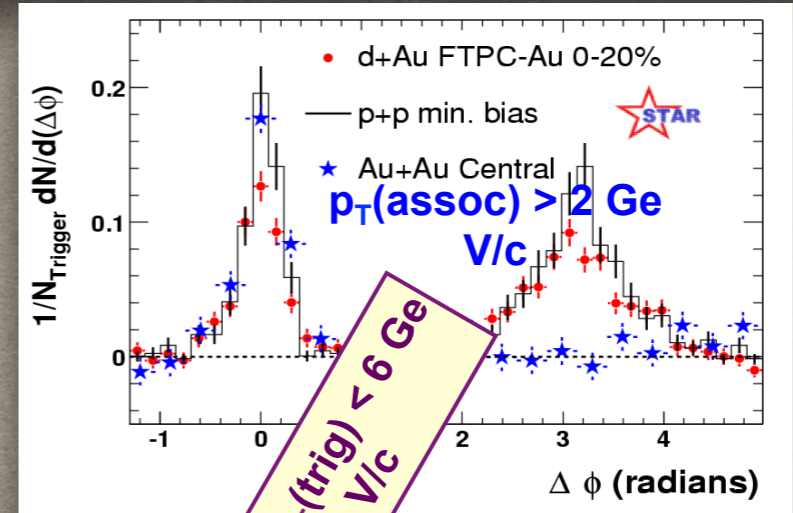
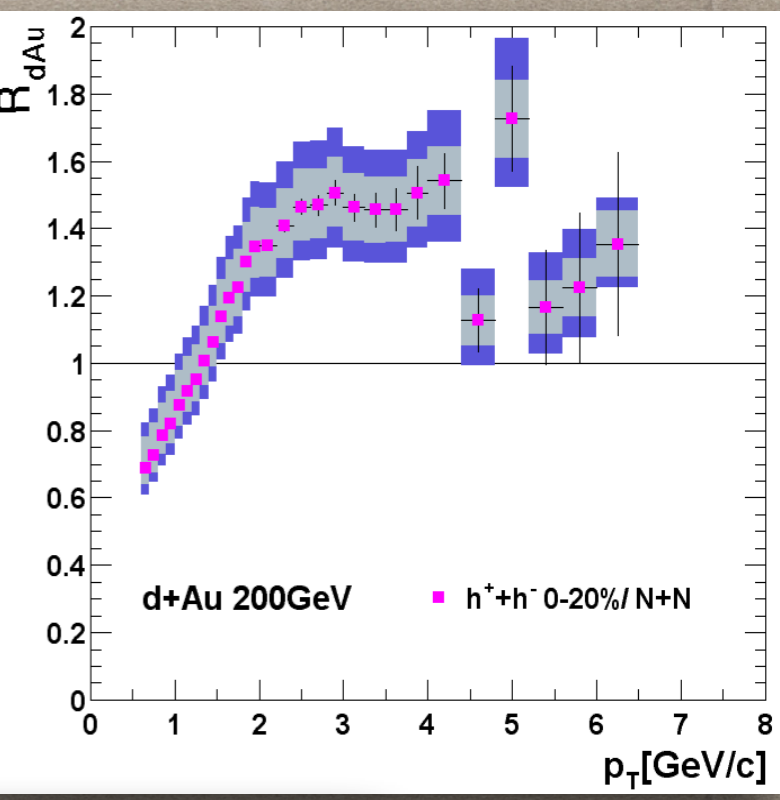
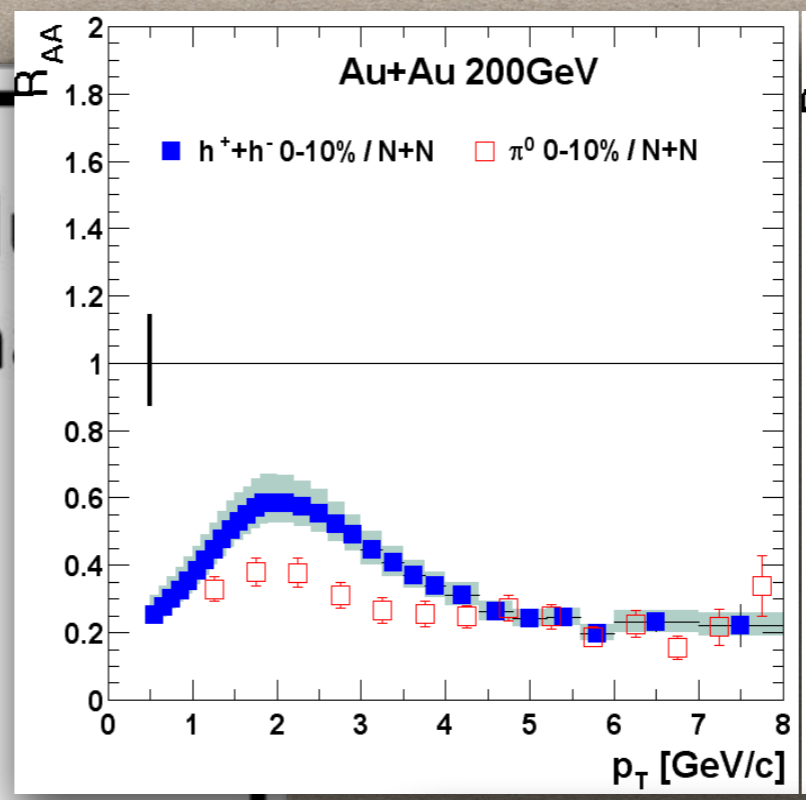
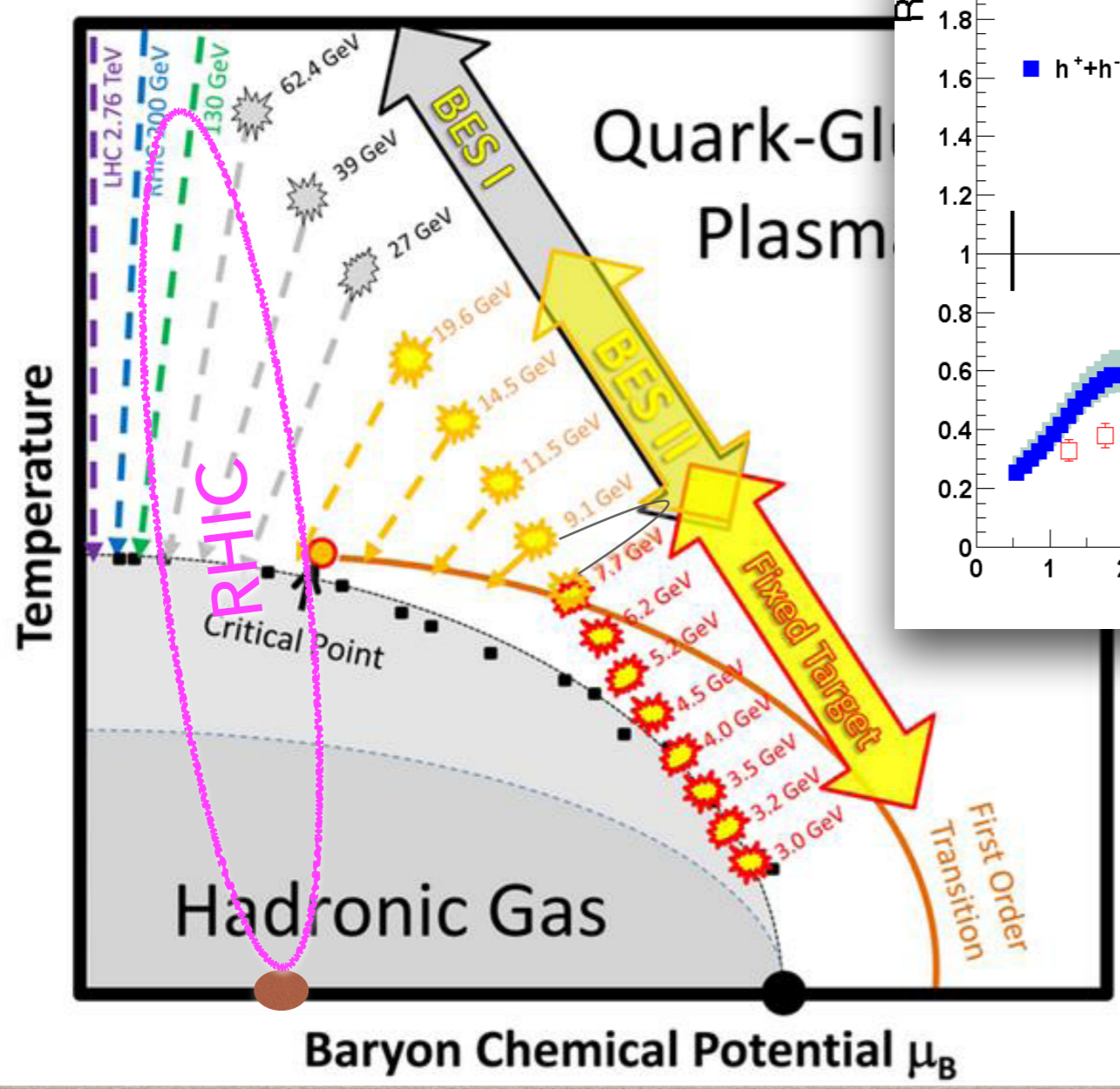
2000s

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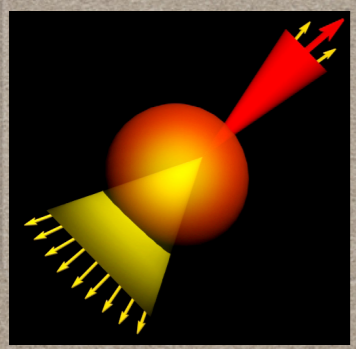
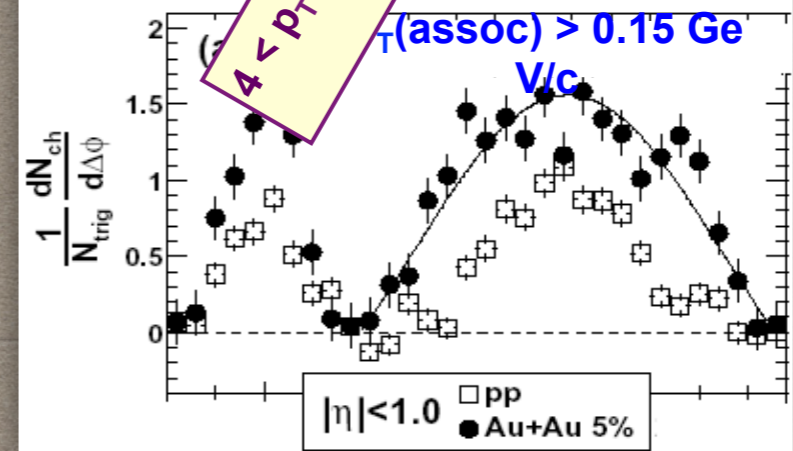
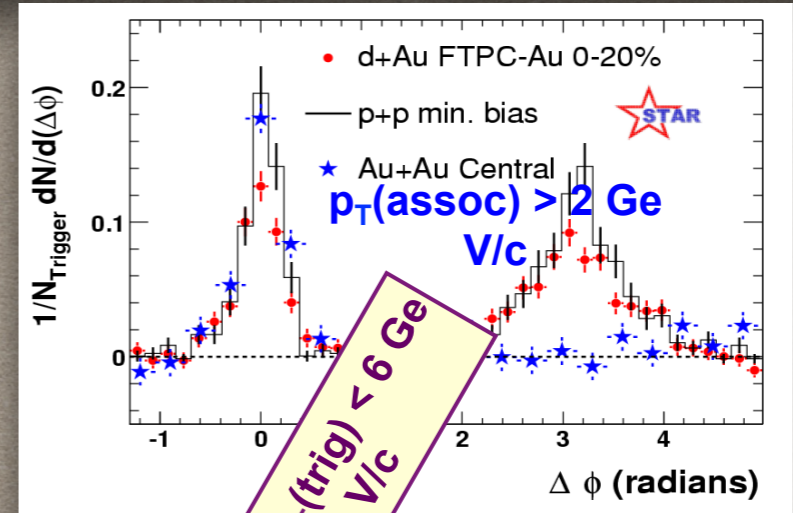
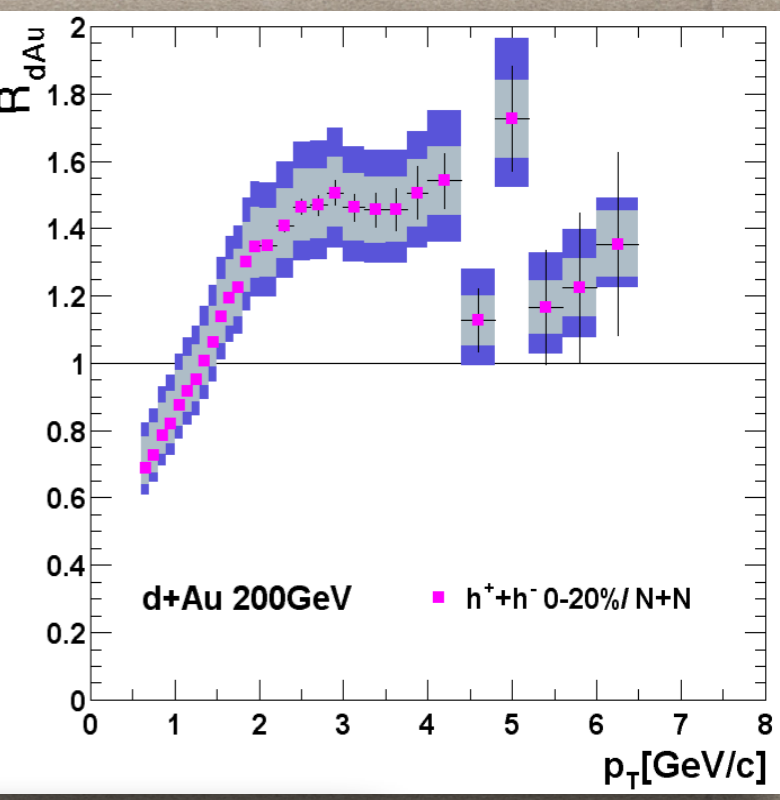
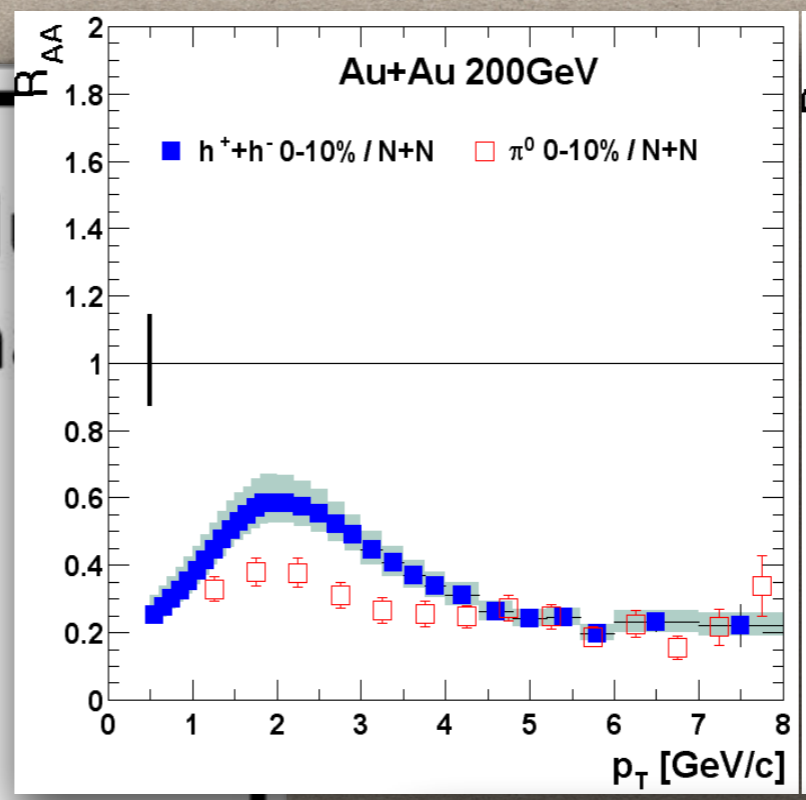
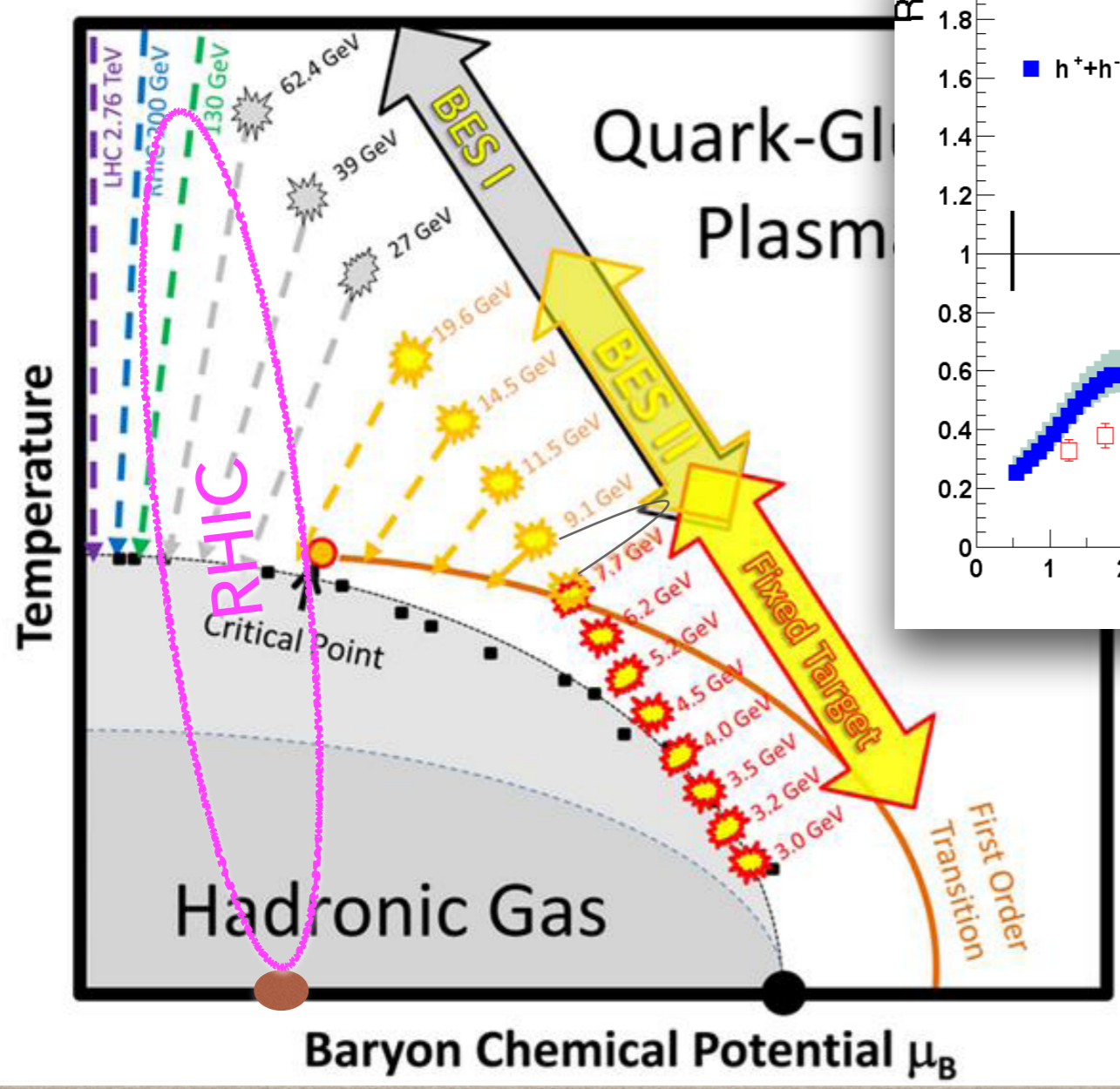
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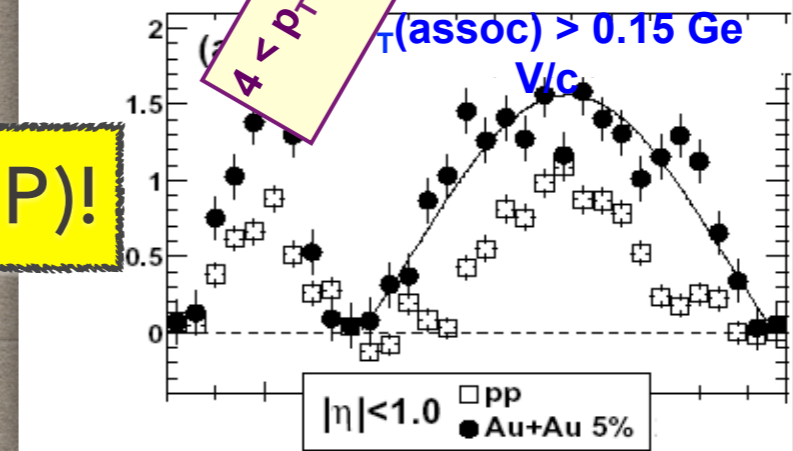
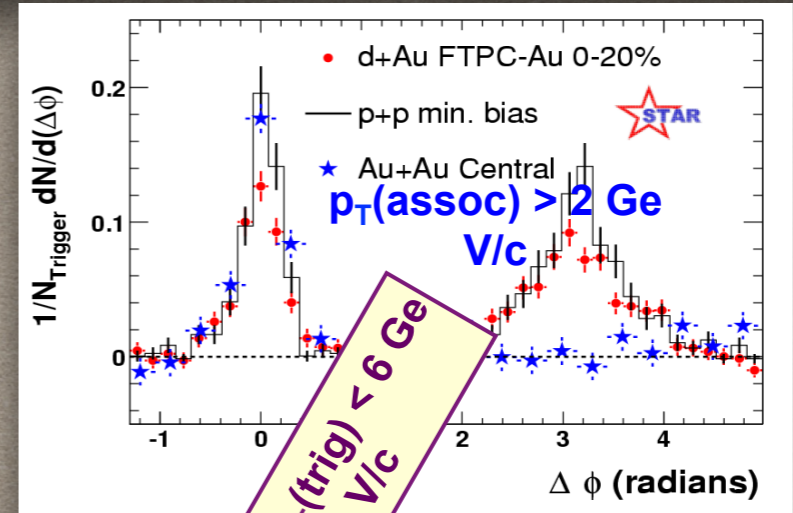
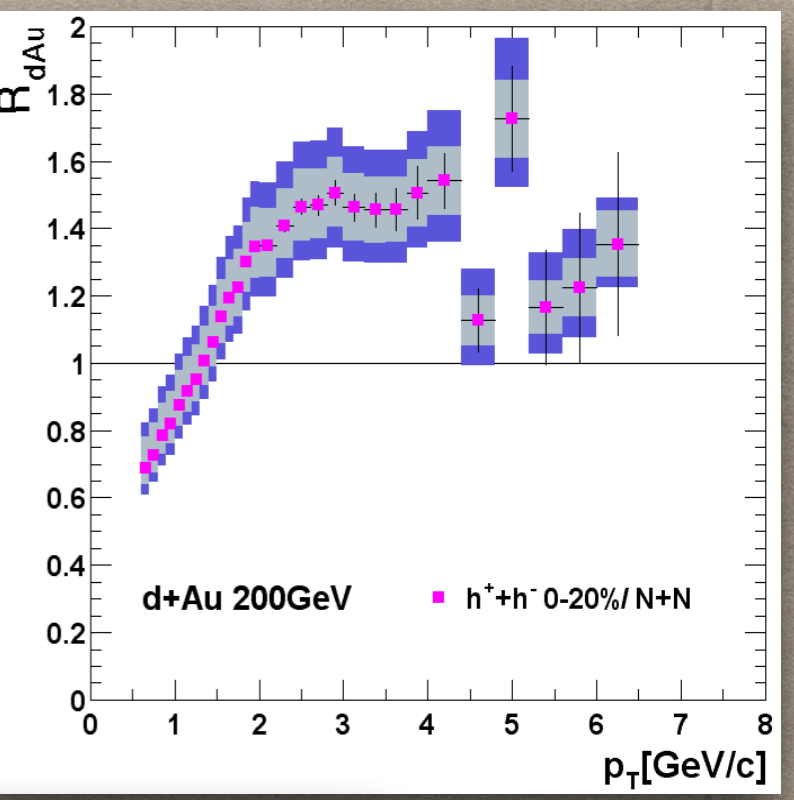
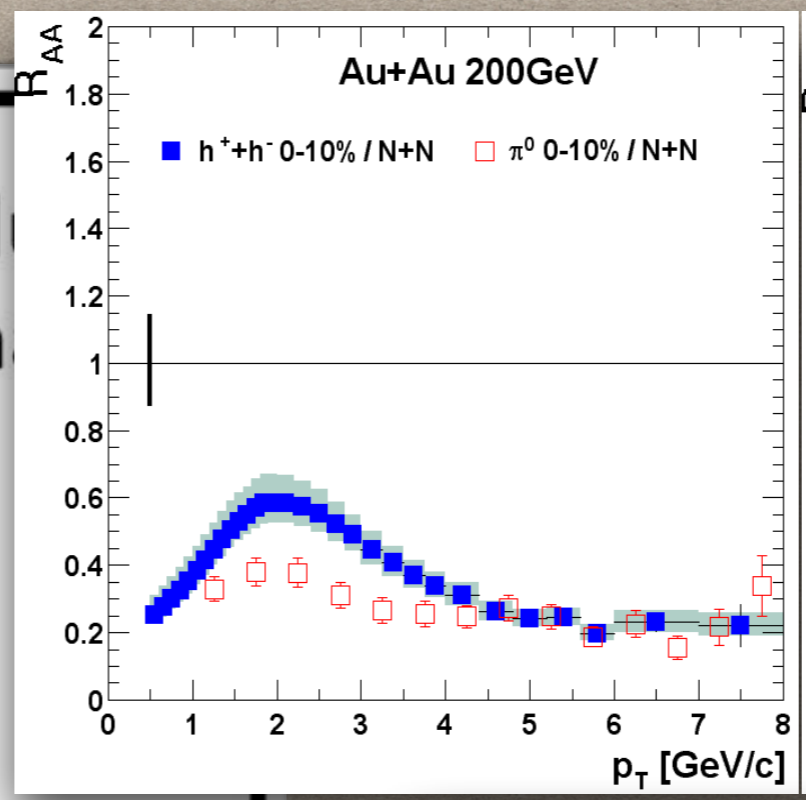
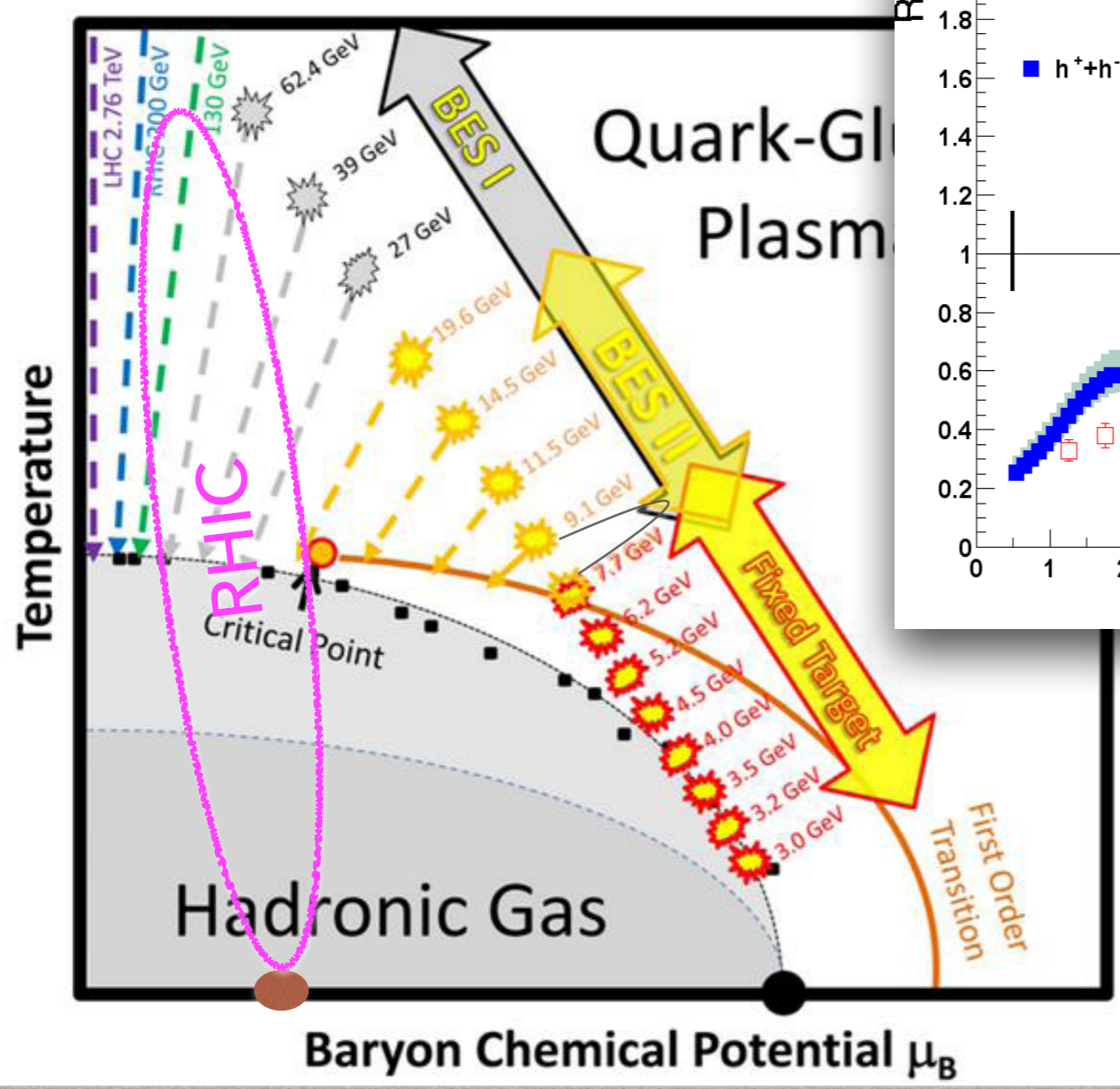
2000s

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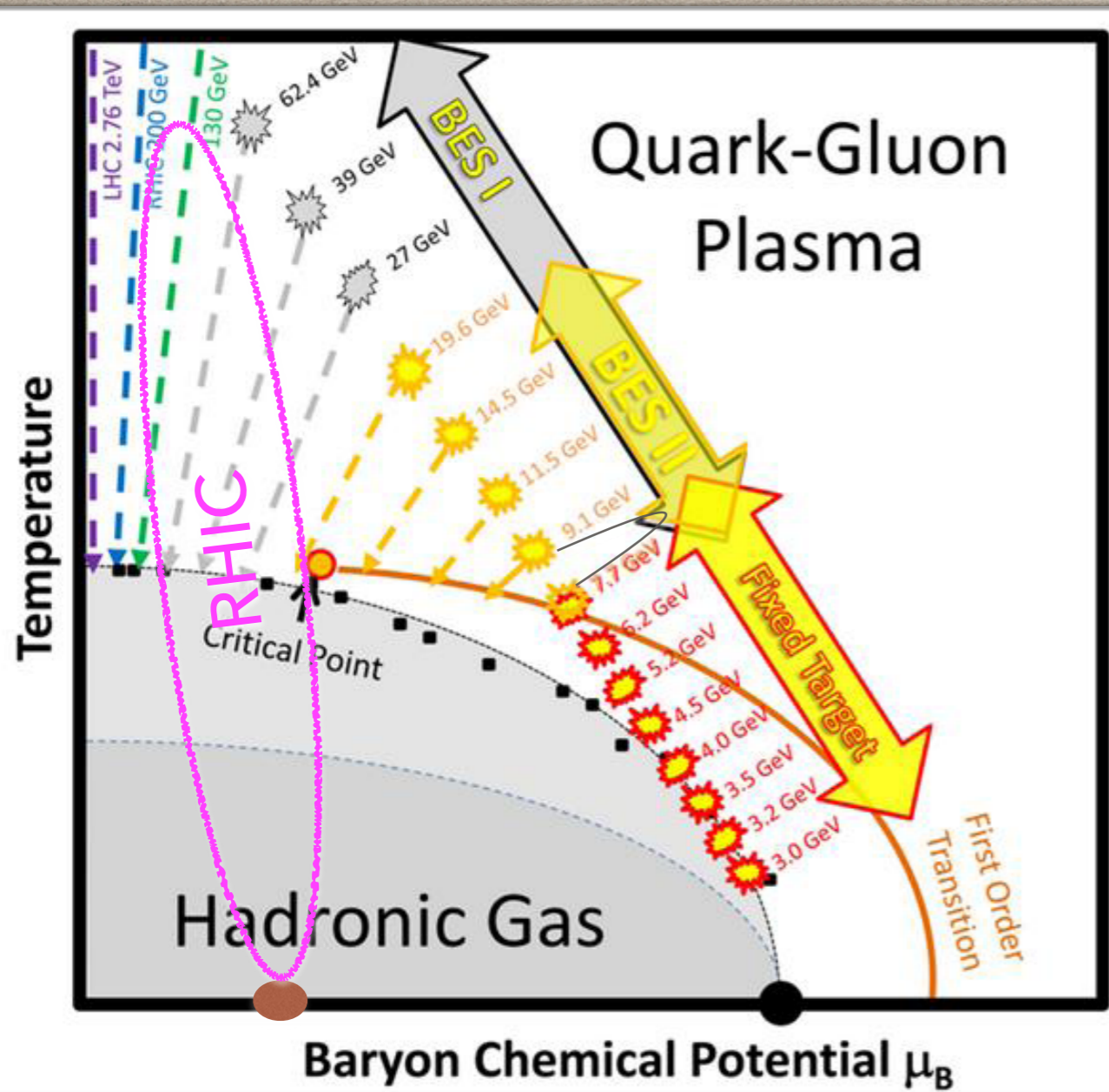
2000s

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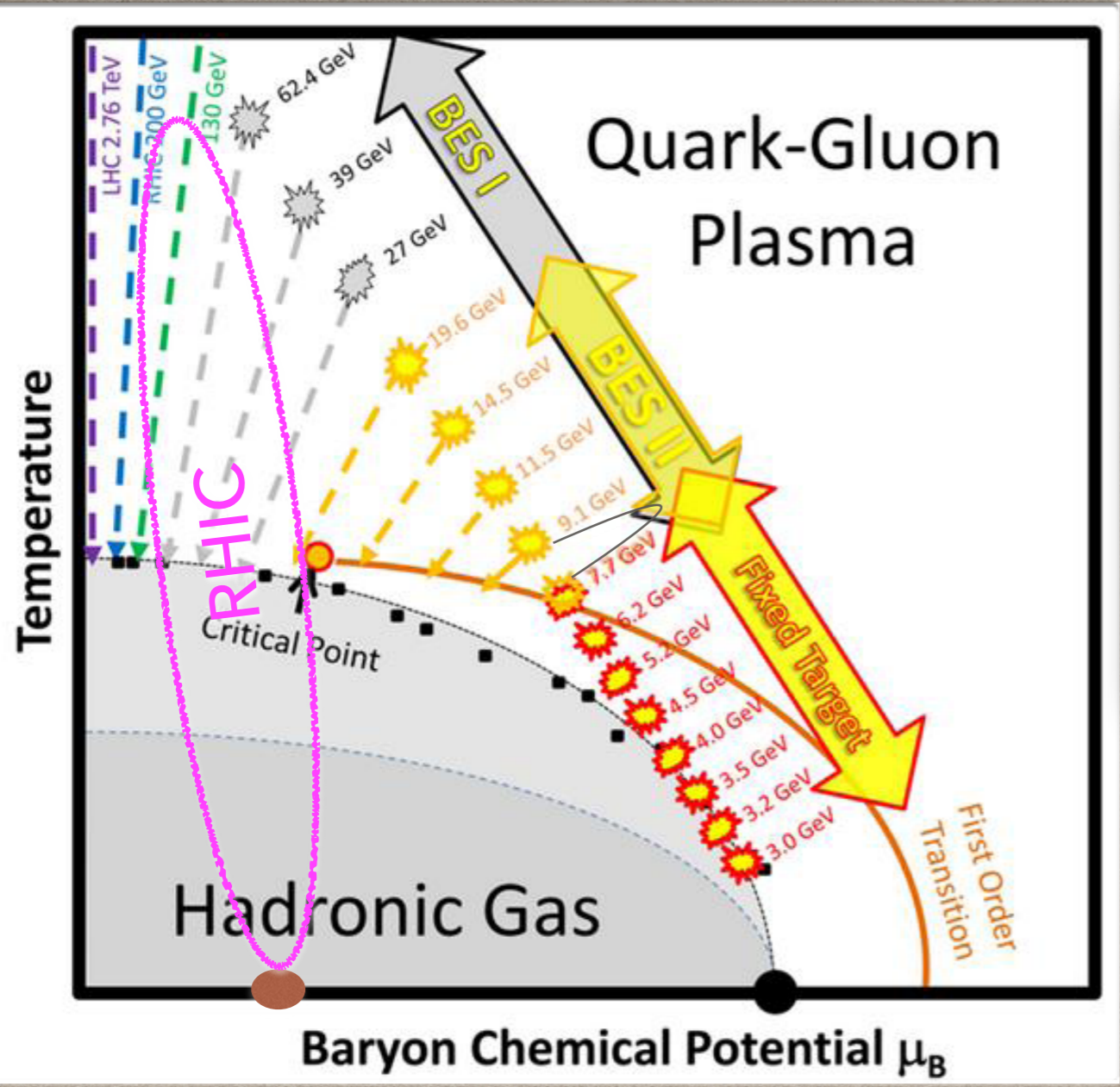


Strongly interacting Matter (QGP)!

EXPLORING QCD PHASE II (RHIC)



EXPLORING QCD PHASE II (RHIC)



The RHIC Revolution

Elliptic Flow v_2 generated by primordial source anisotropy

Sensitive to scaled shear viscosity η/s

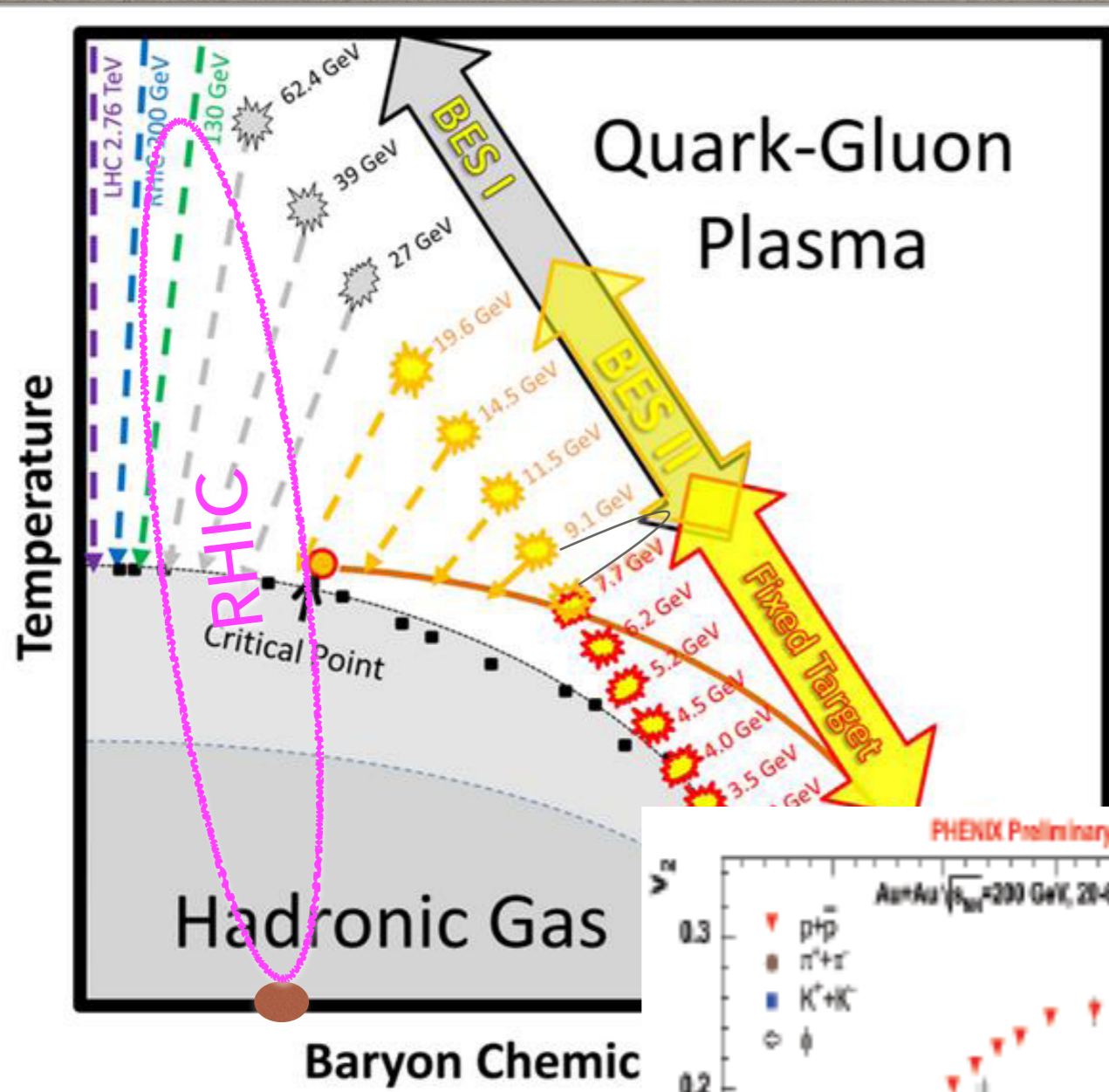
Viscous relativistic hydrodynamics

BUT: η/s is very small

QGP is a nearly ideal fluid

The diagram illustrates the reaction plane in a 3D coordinate system. A red sphere with arrows pointing outwards is positioned between two blue hemispheres on a grey plane. A coordinate system with x, y, z and x, b axes is shown.

EXPLORING QCD PHASE II (RHIC)



The RHIC Revolution

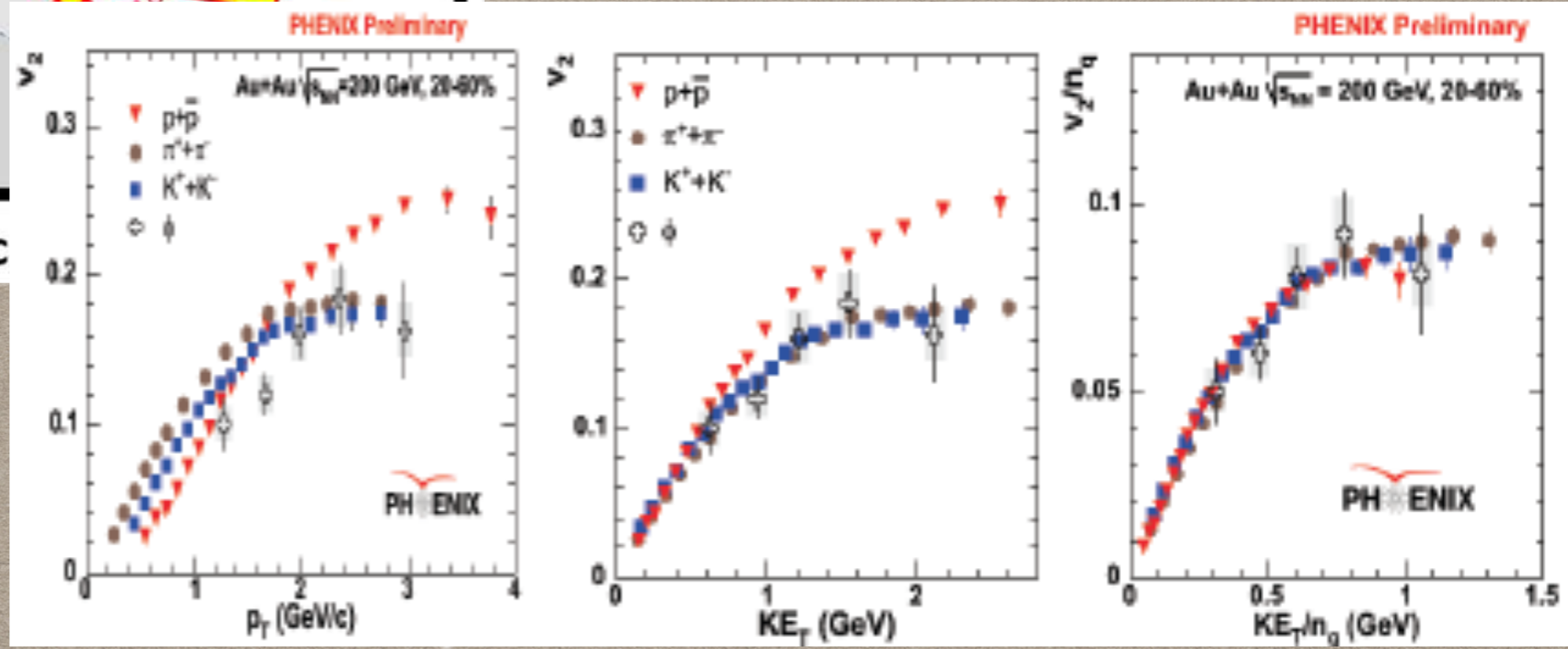
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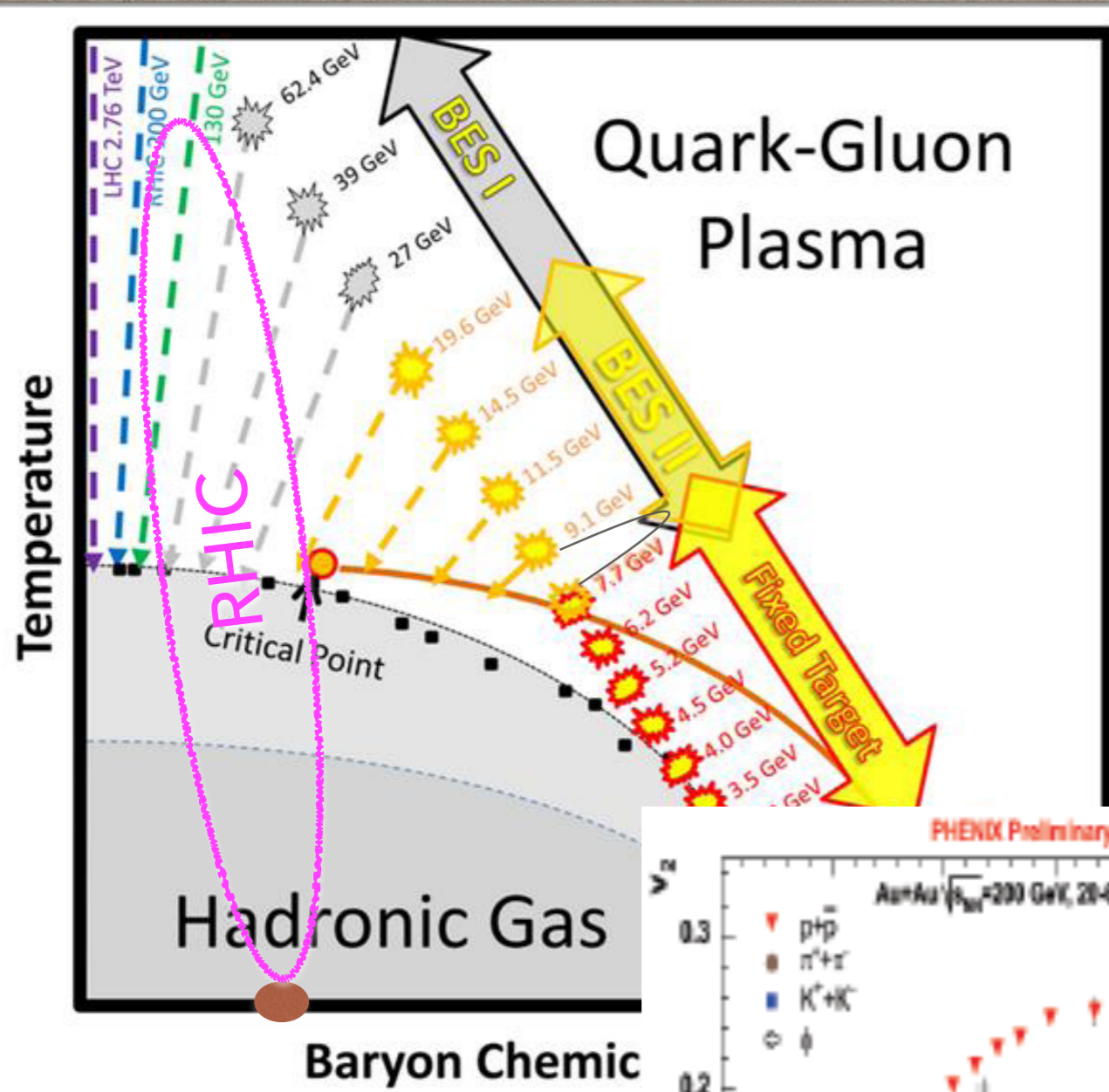
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2000s

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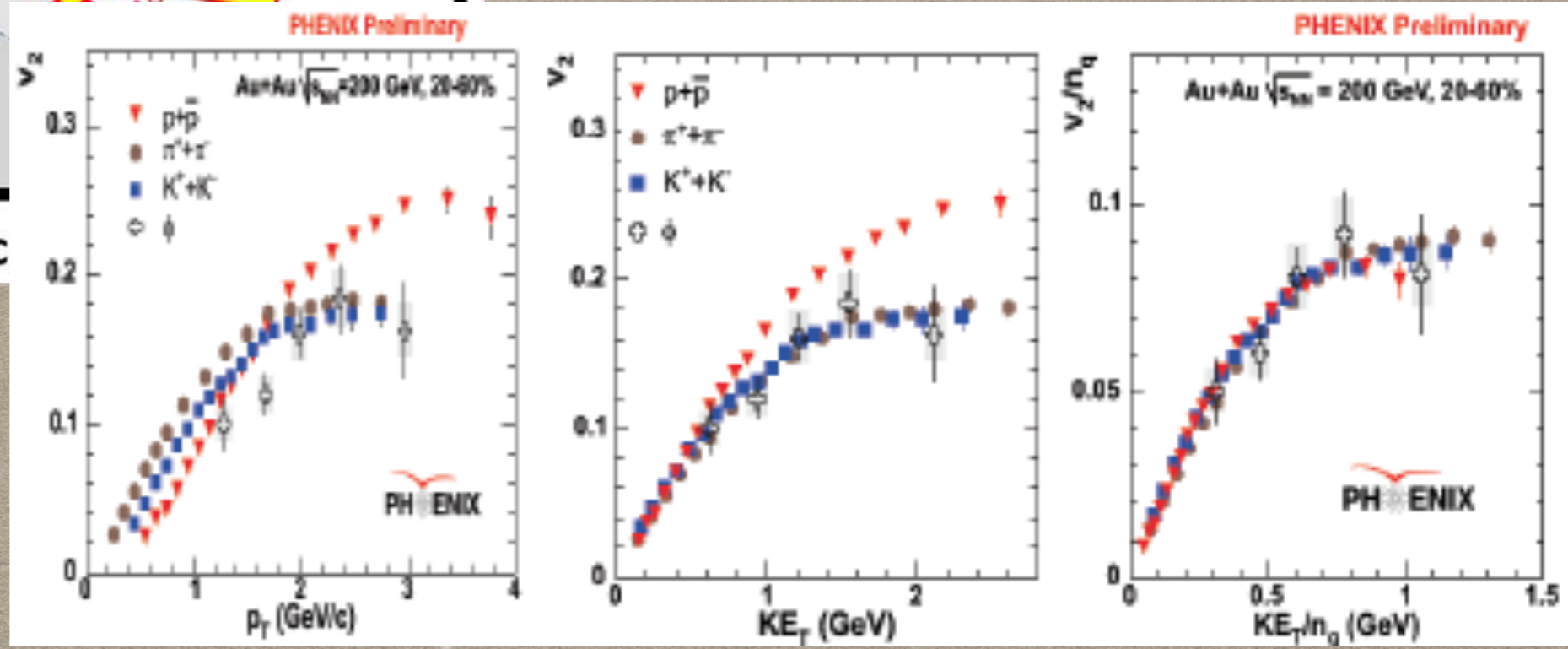
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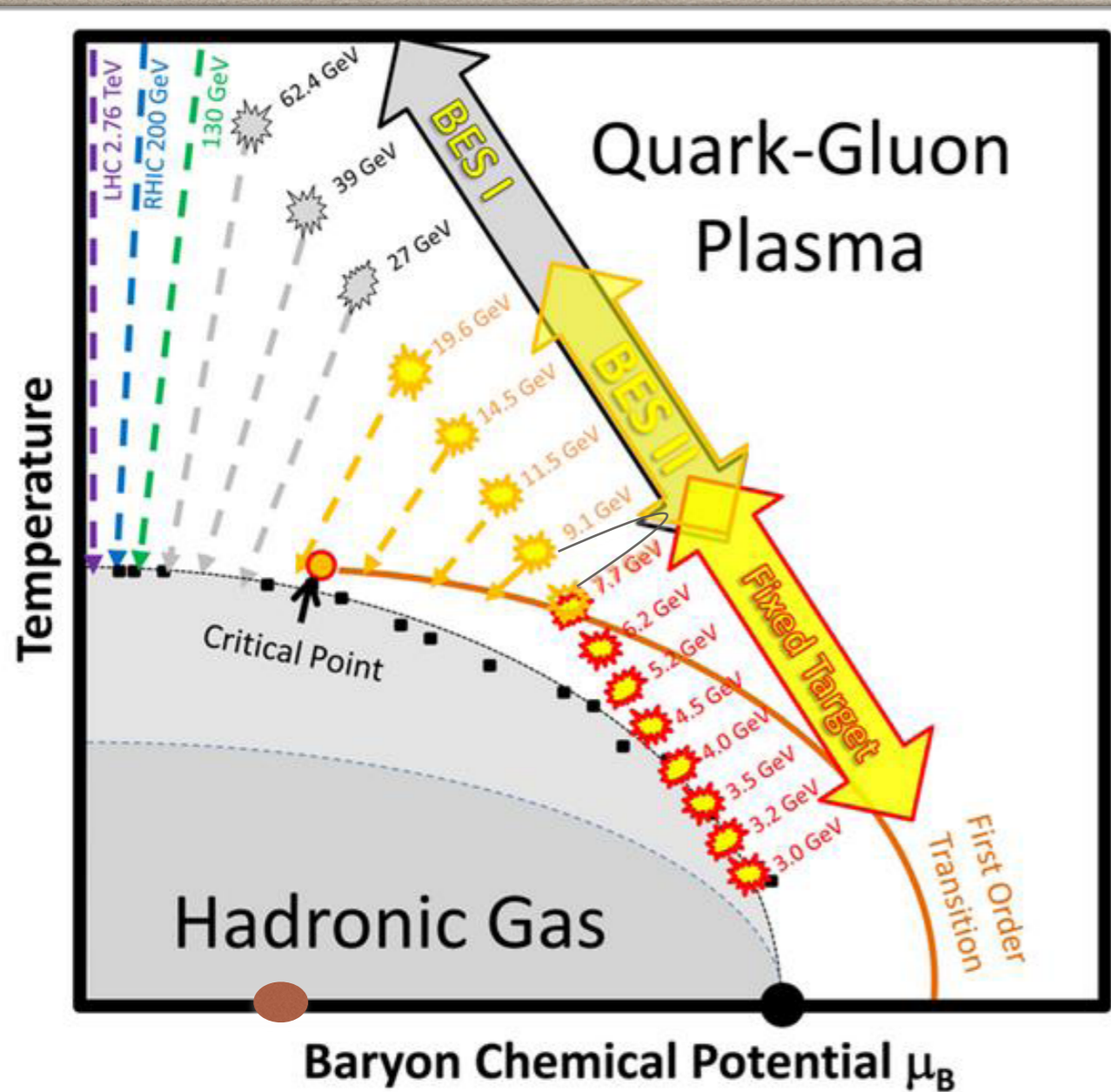
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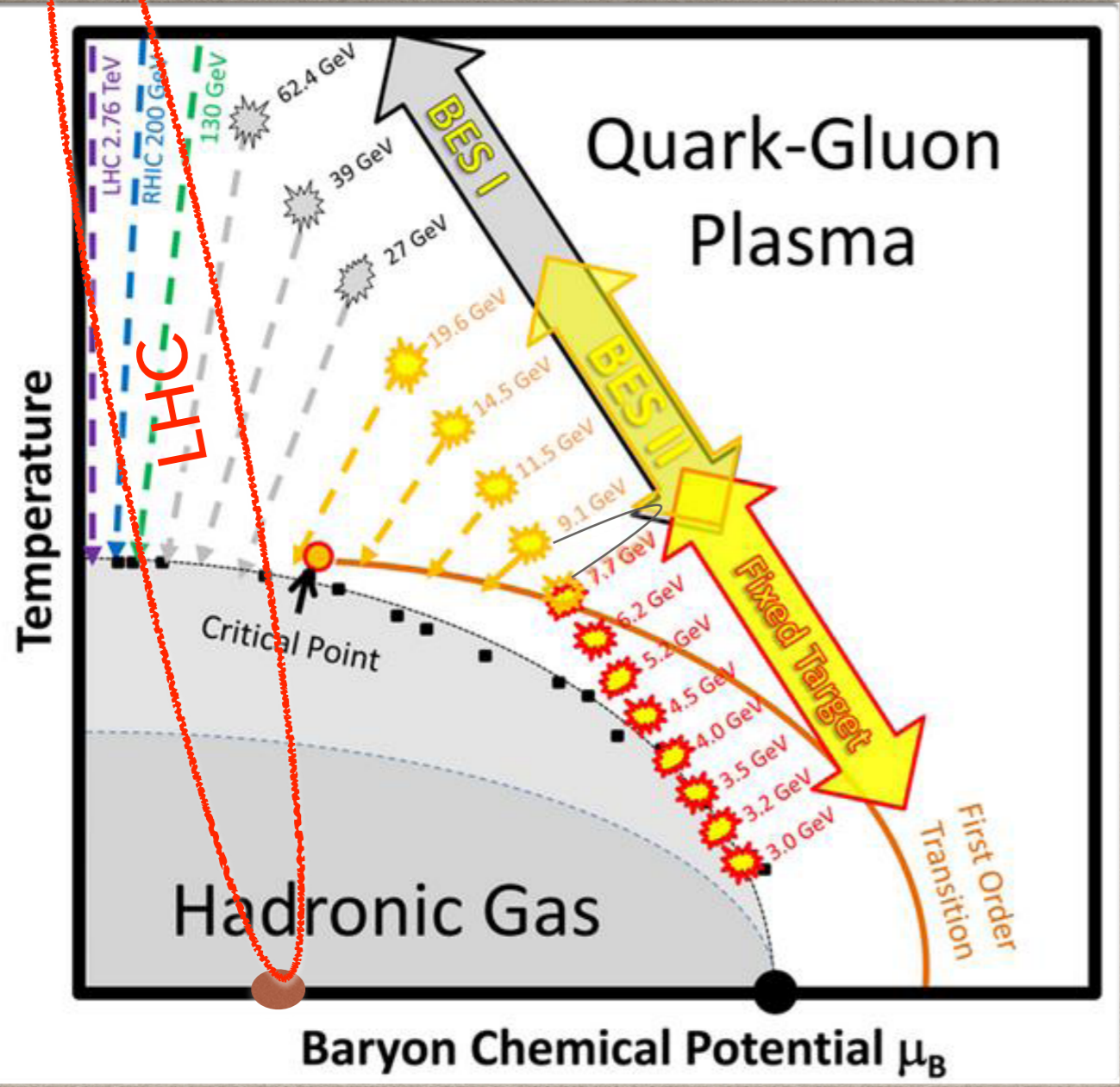
even ideal fluid!



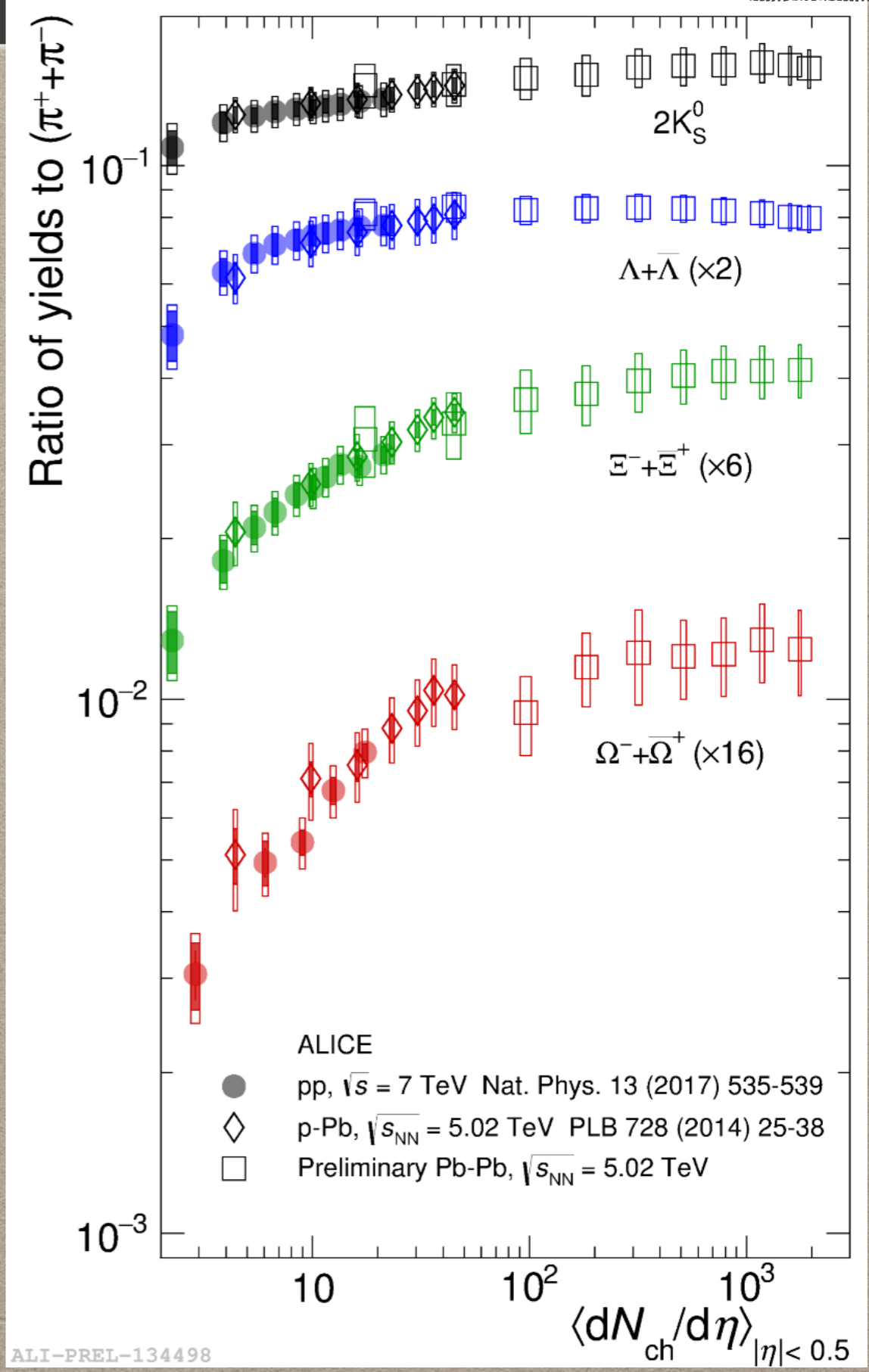
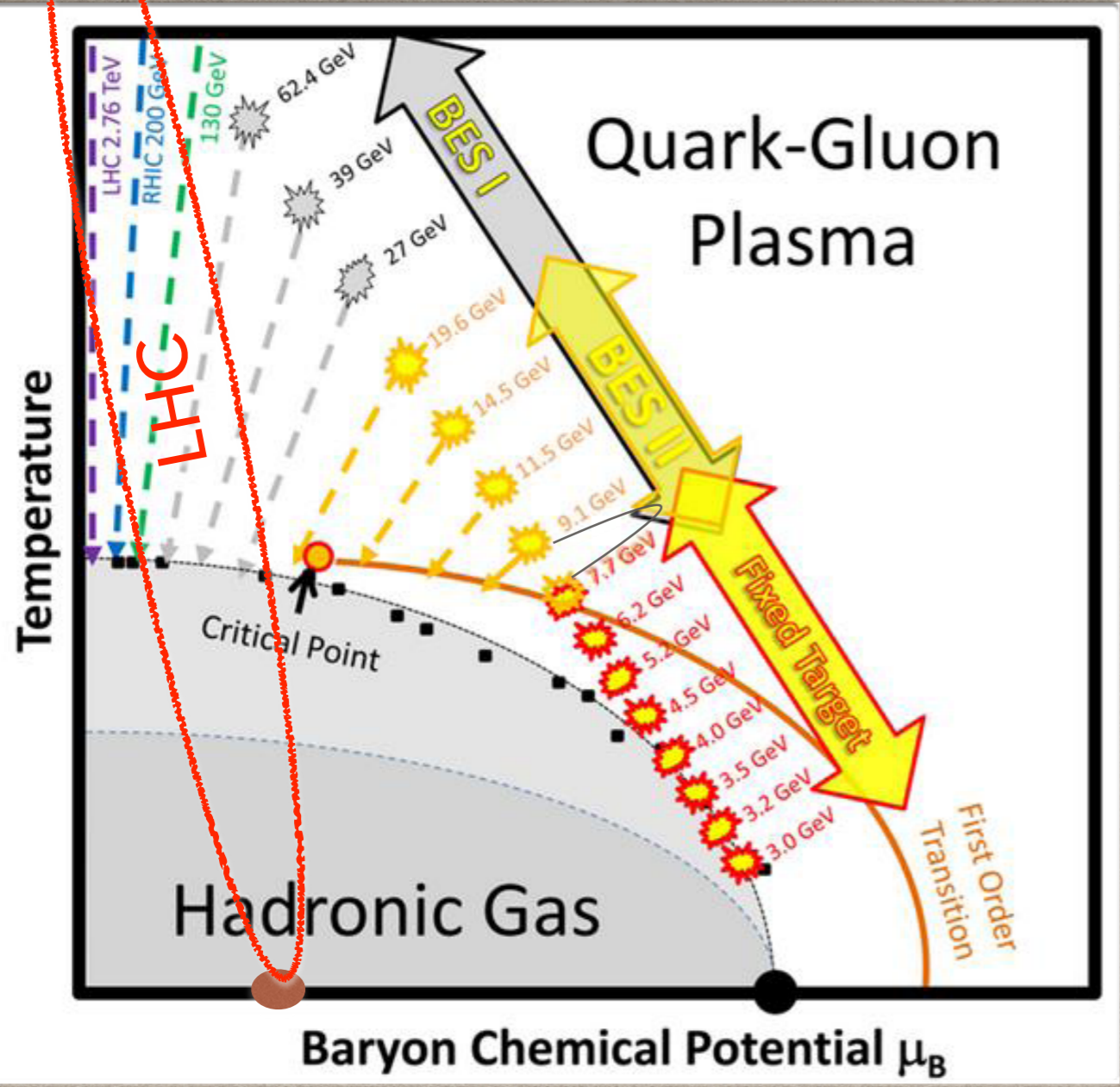
EXPLORING QCD PHASE III (LHC)



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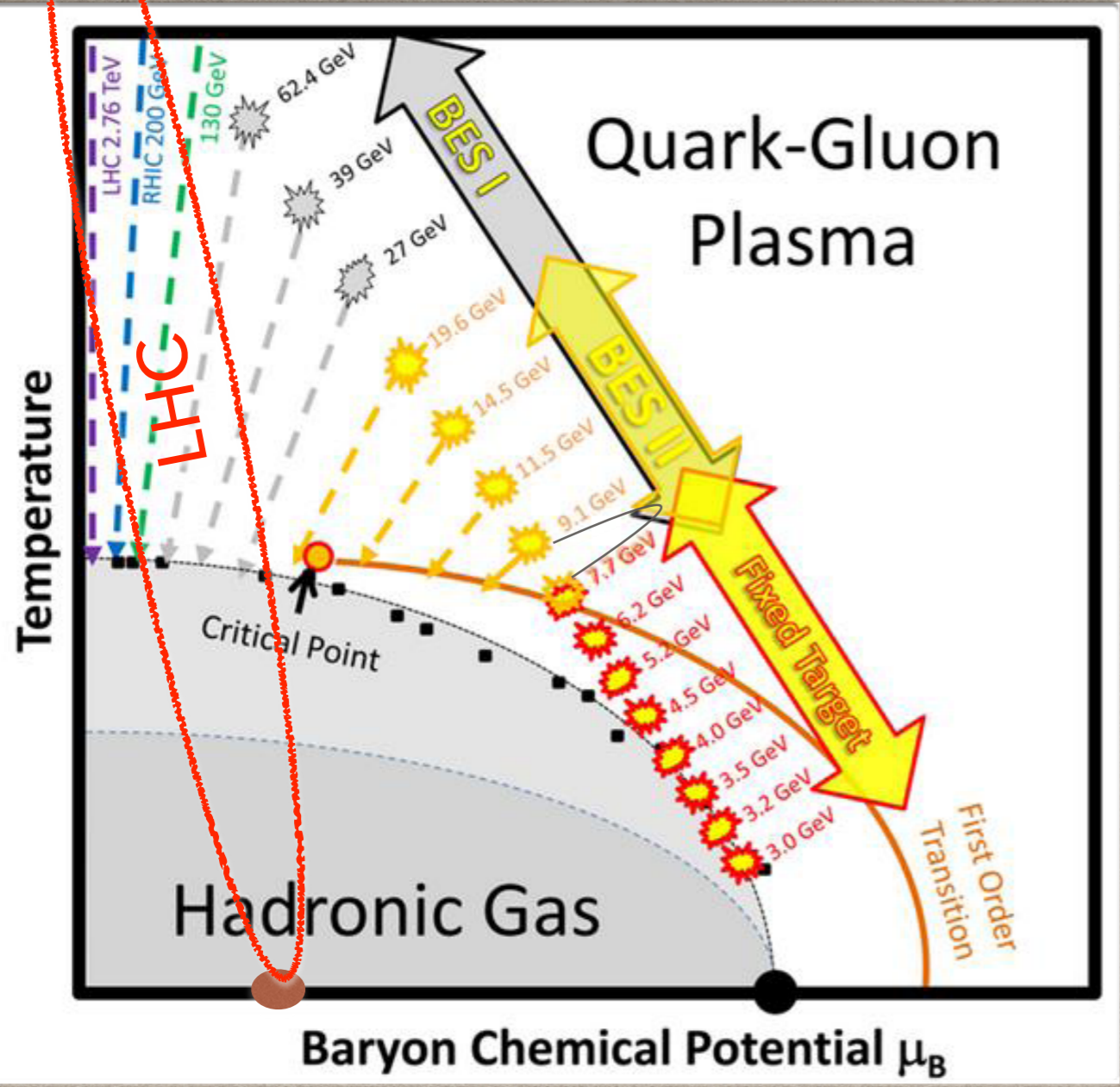


EXPLORING QCD PHASE STRUCTURE

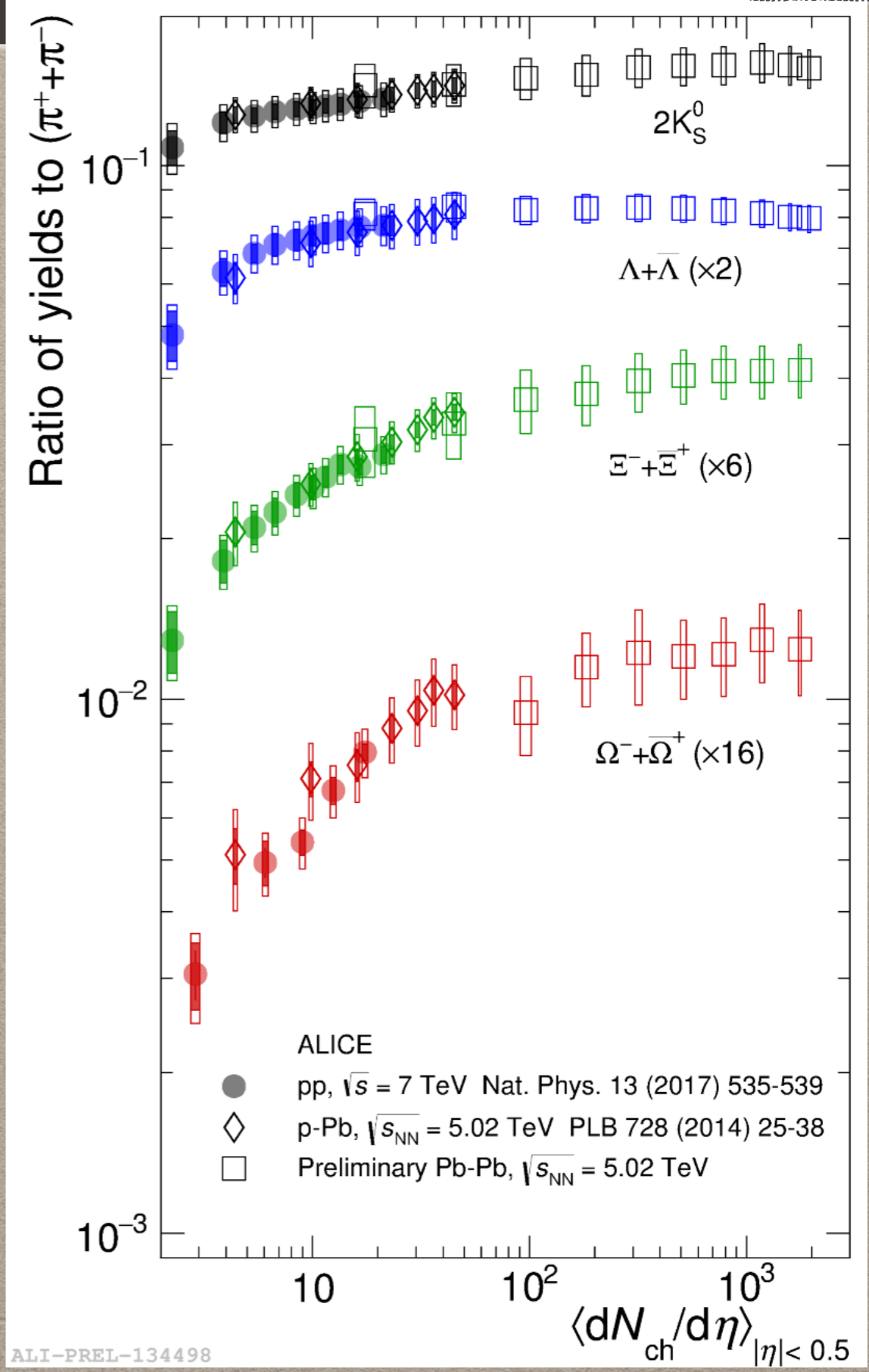


ALI-PREL-134498

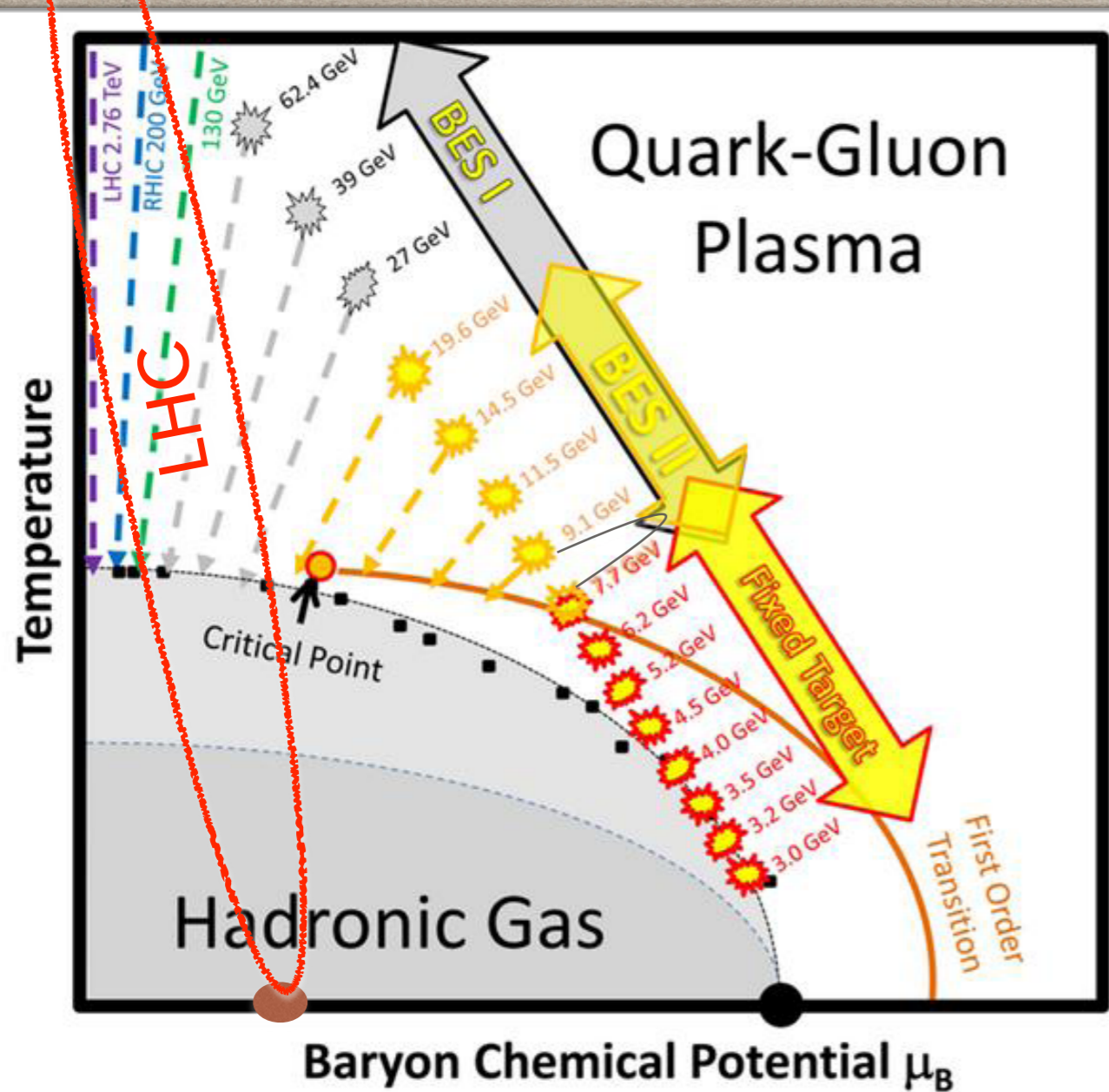
EXPLORING QCD PHASE STRUCTURE



smooth evolution!
from pp to PbPb

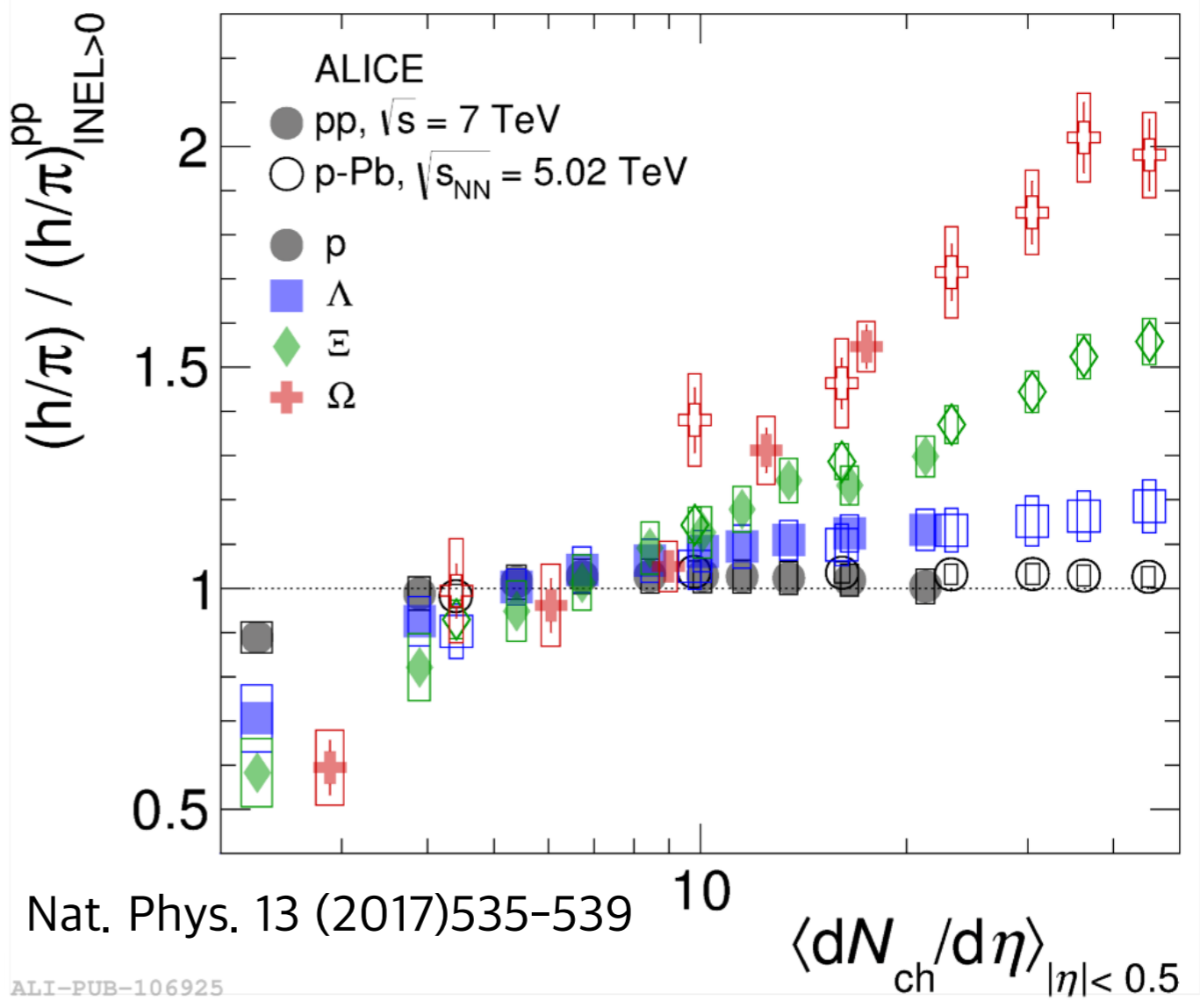
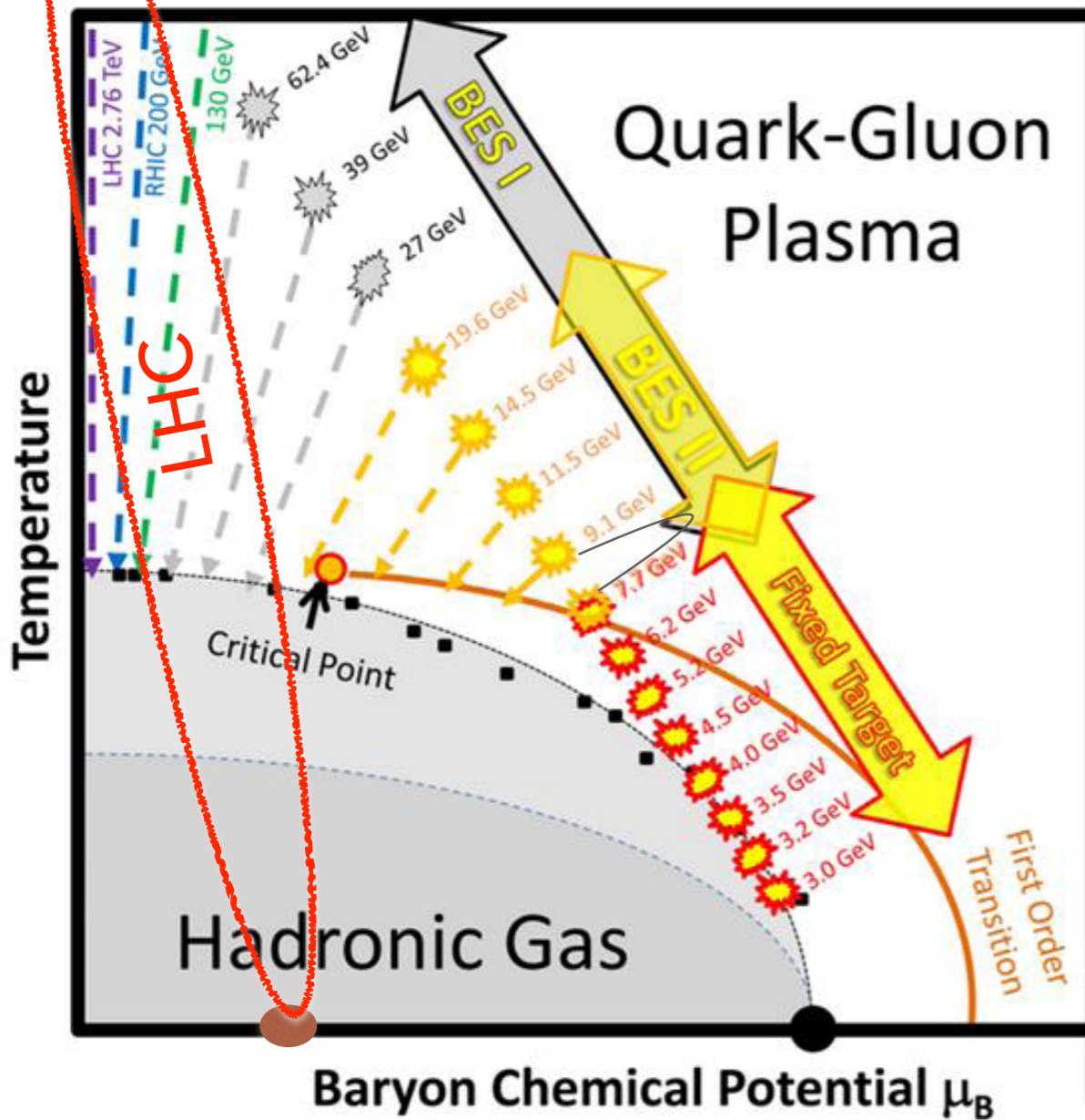


EXPLORING QCD PHASE III (LHC)



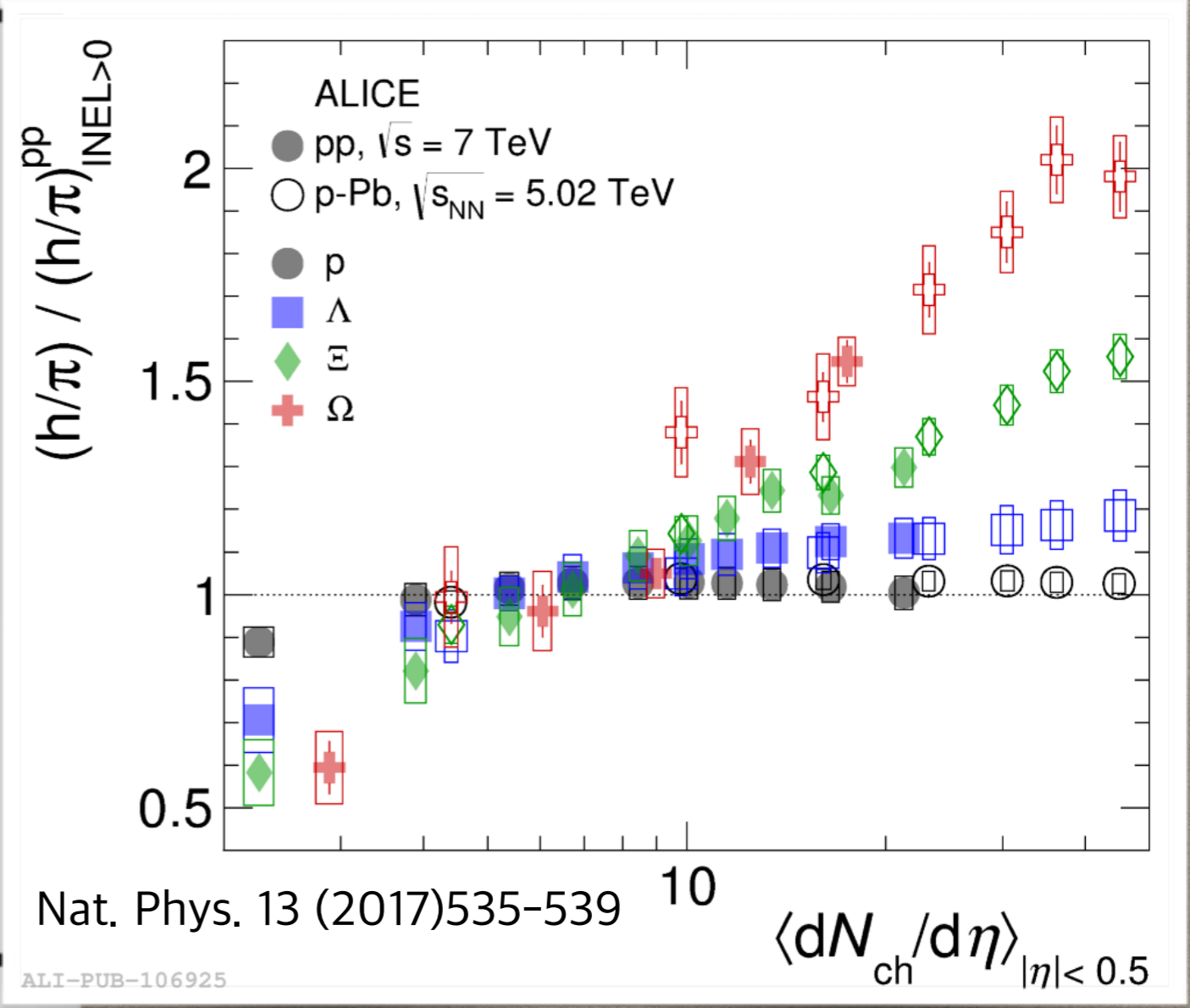
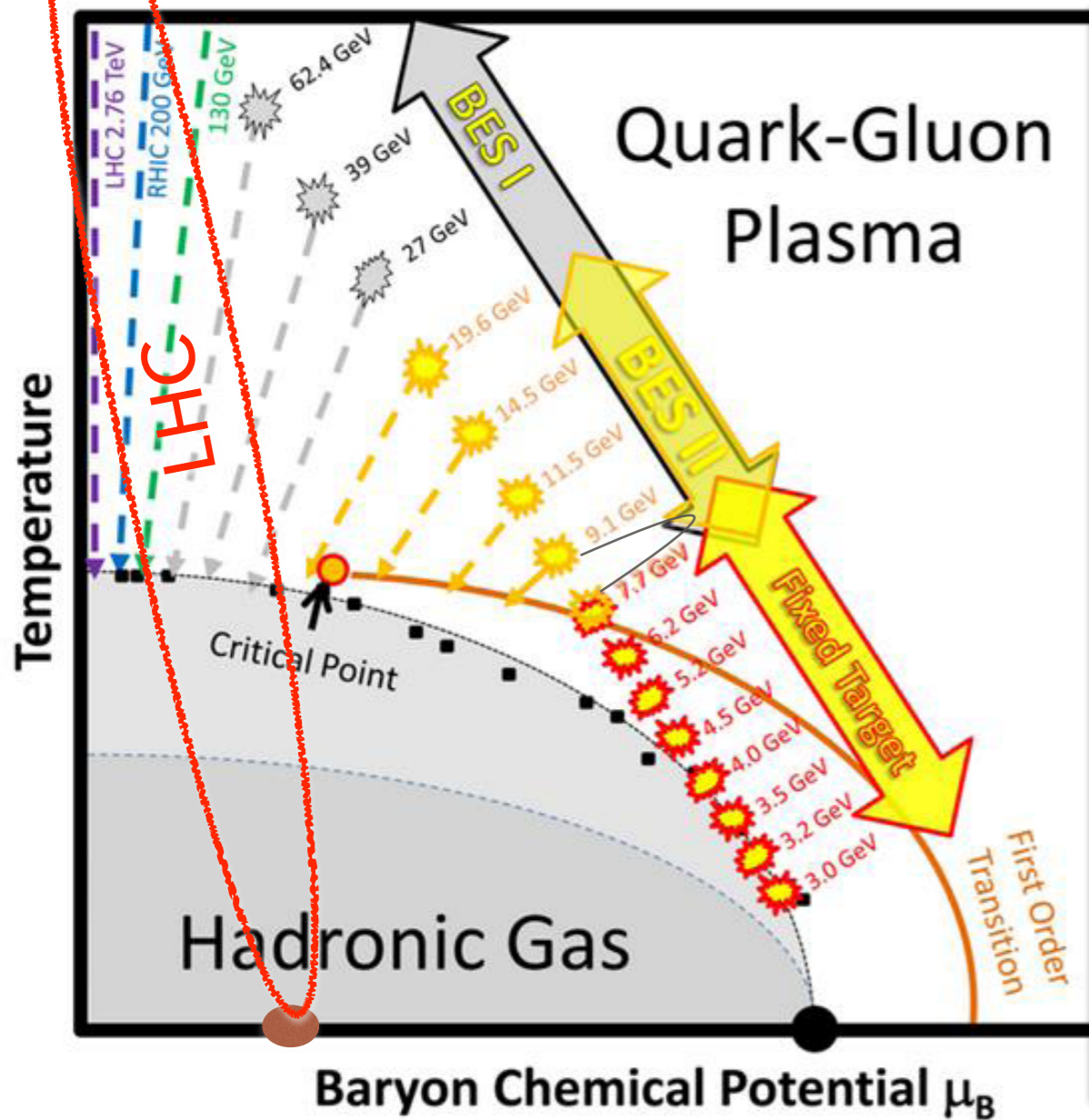
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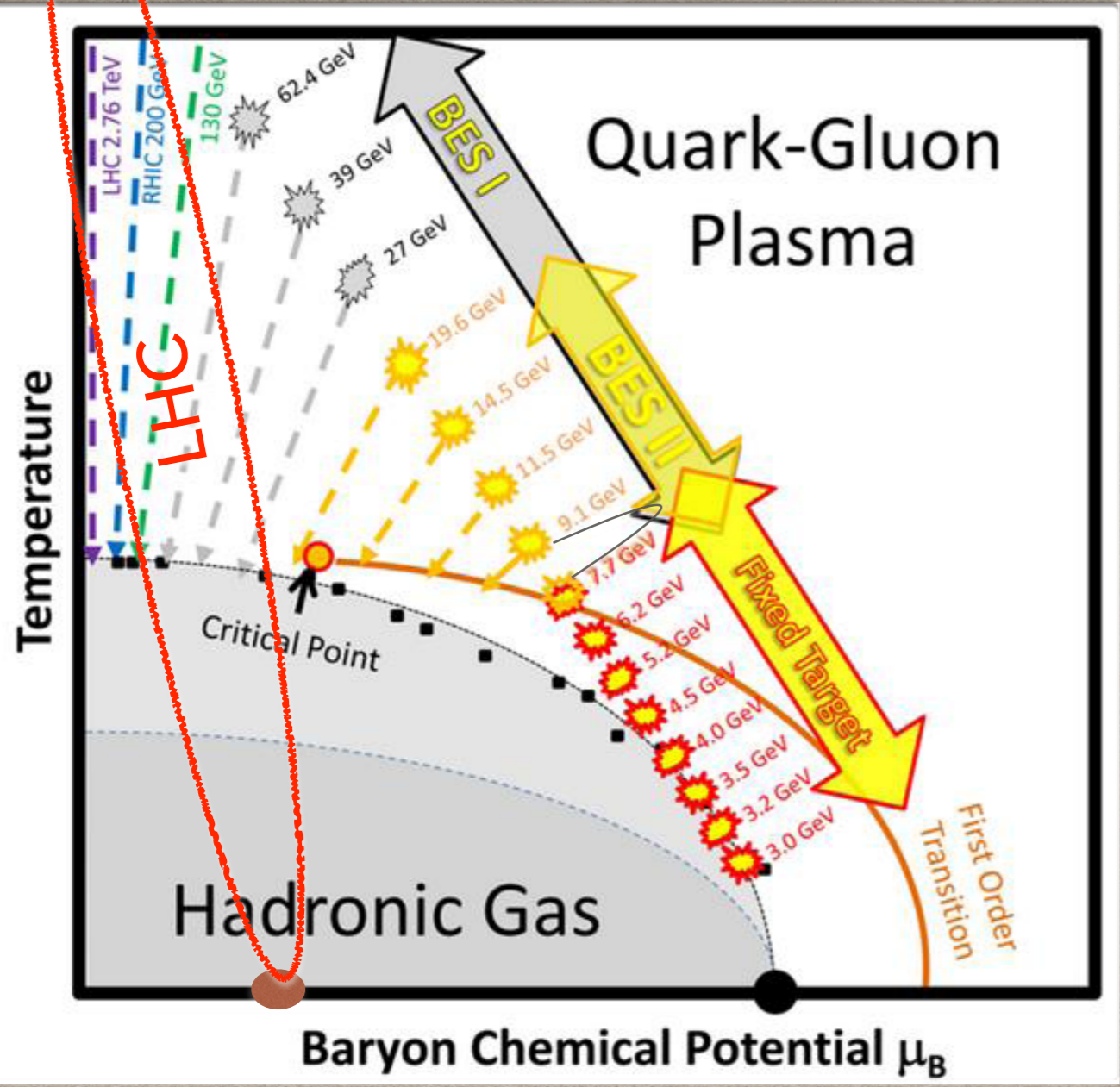
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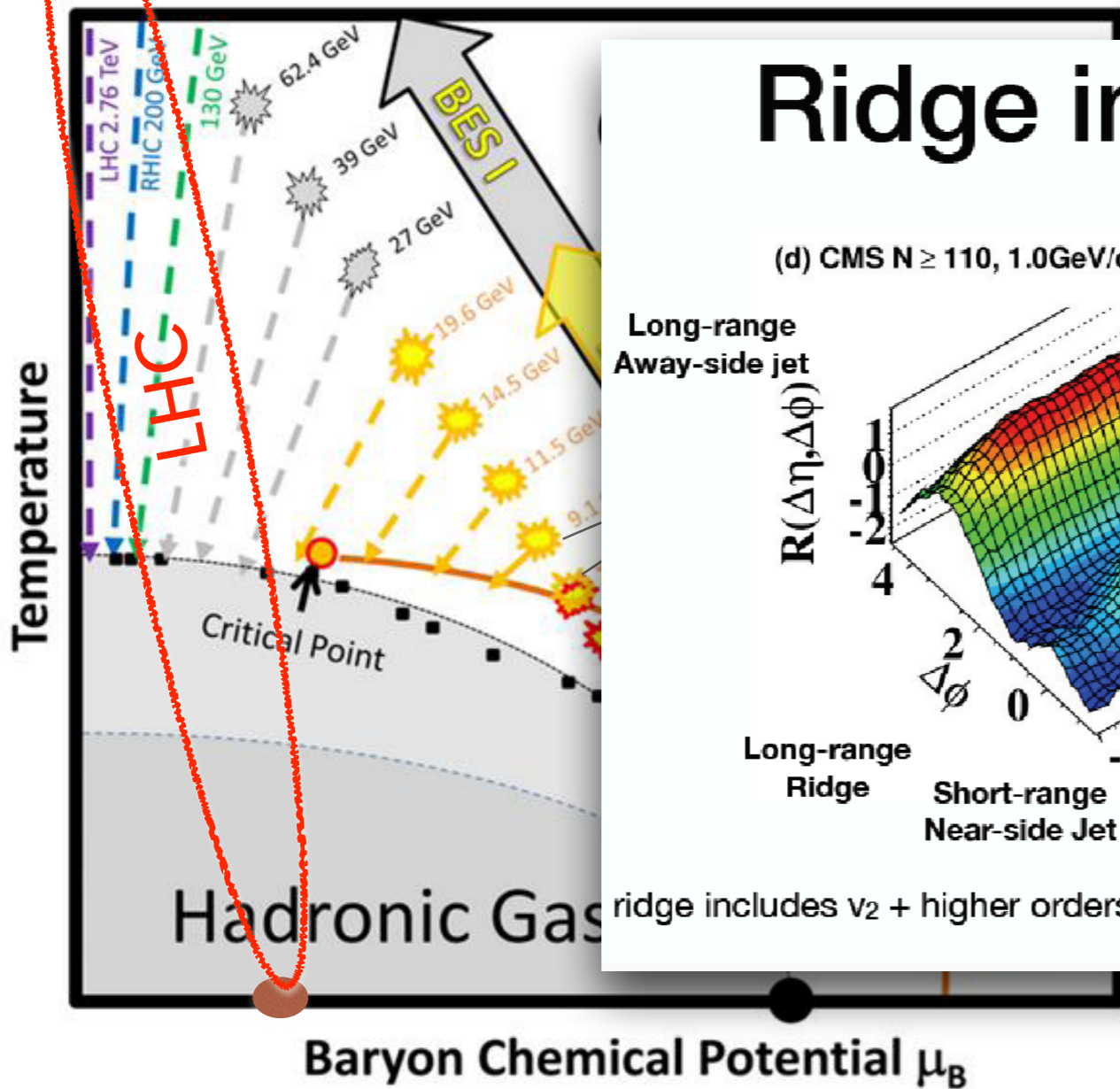
smooth evolution!
from pp to PbPb

Multiplicity = Universal Variable for the collisions
- Energy, System don't matter!
➡ Attention to the small system!

EXPLORING QCD PHASE III (LHC)



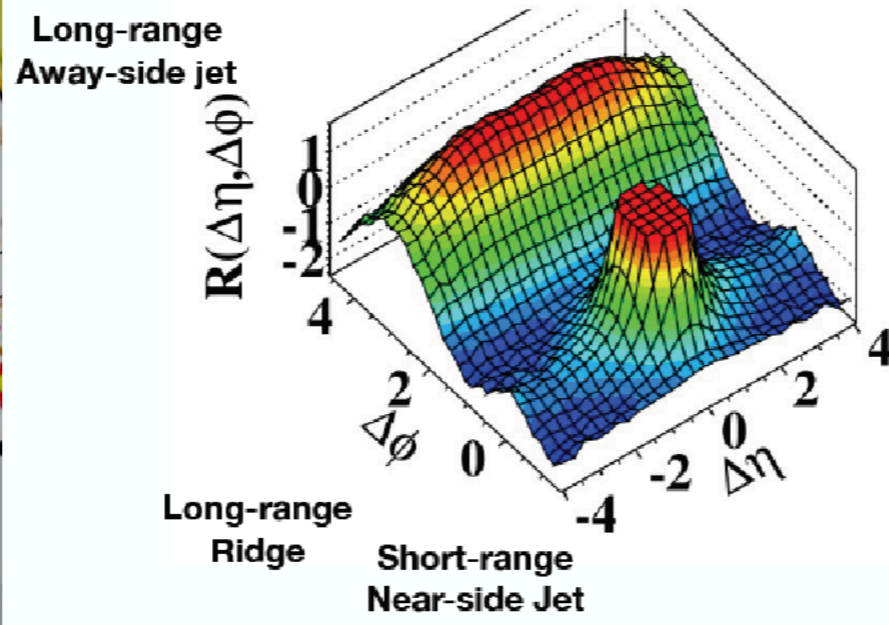
EXPLORING QCD PHASE III (LHC)



Ridge in High Multiplicity pp

CMS, JHEP 09 (2010) 091

(d) CMS $N \geq 110, 1.0 \text{ GeV}/c < p_T < 3.0 \text{ GeV}/c$



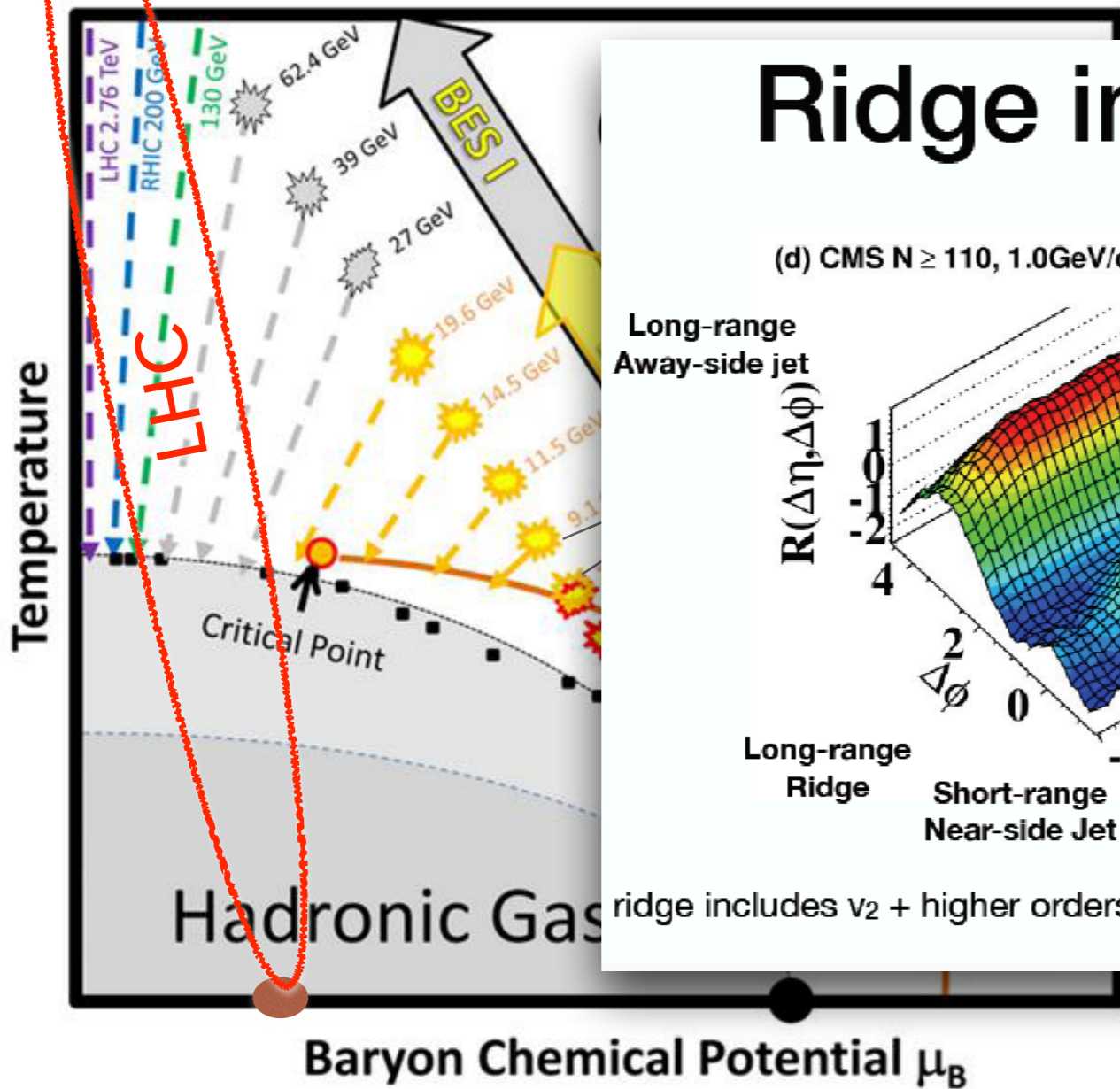
Collectivity in small systems

- ~ year 2005: sQGP signature
- ~ year 2010: sQGP in pp as well?

ridge includes v_2 + higher orders

Li Yi (Shandong University)

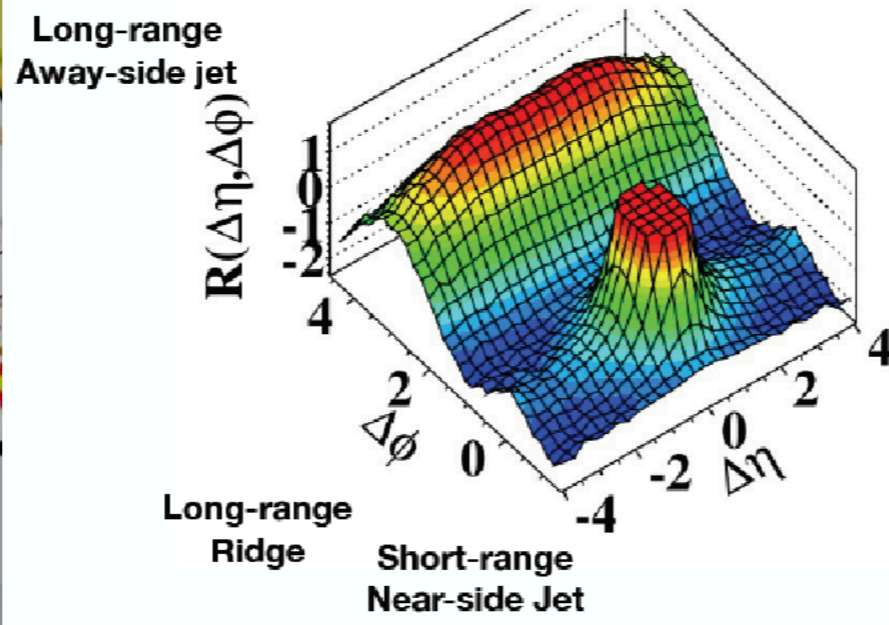
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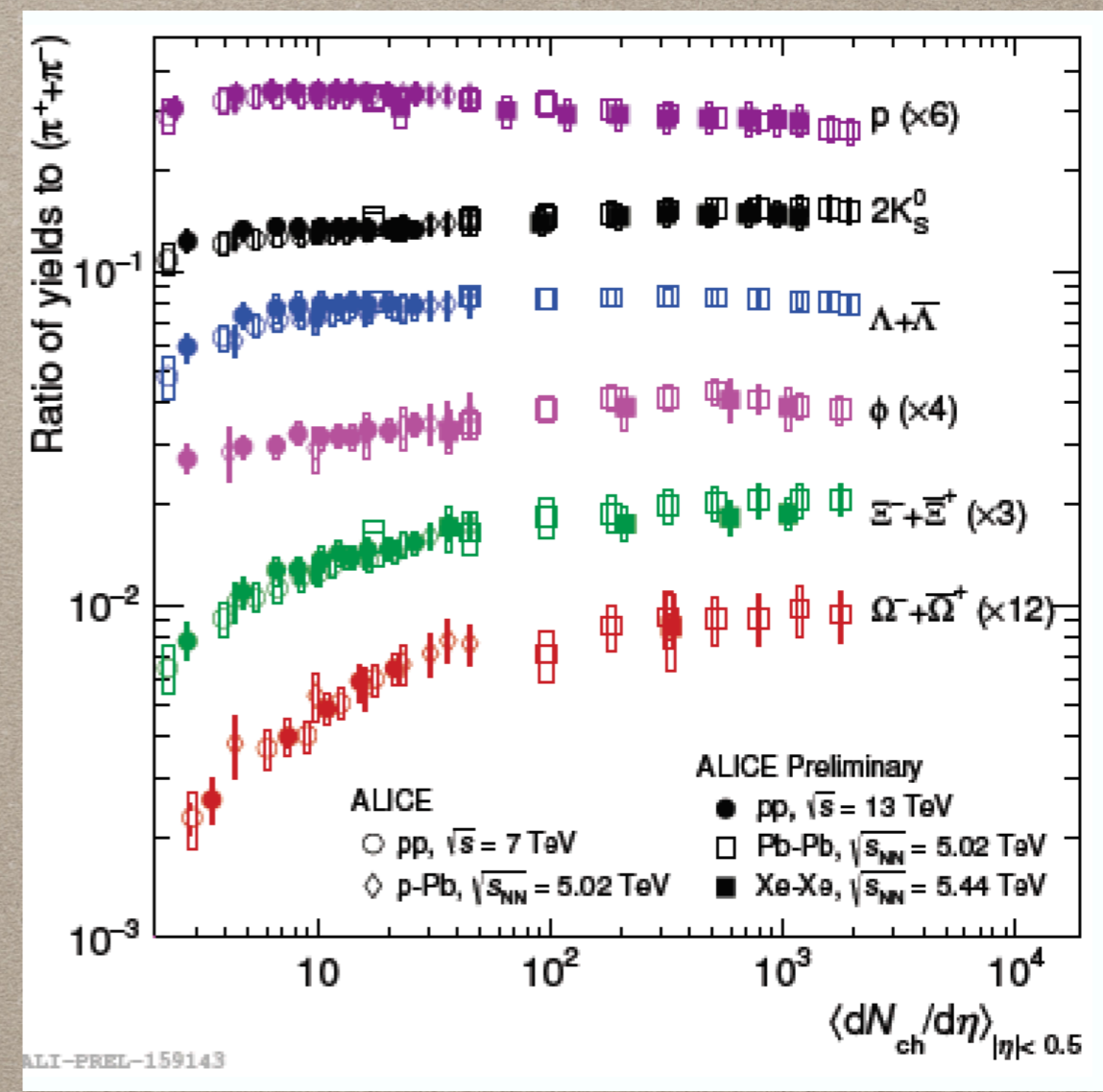
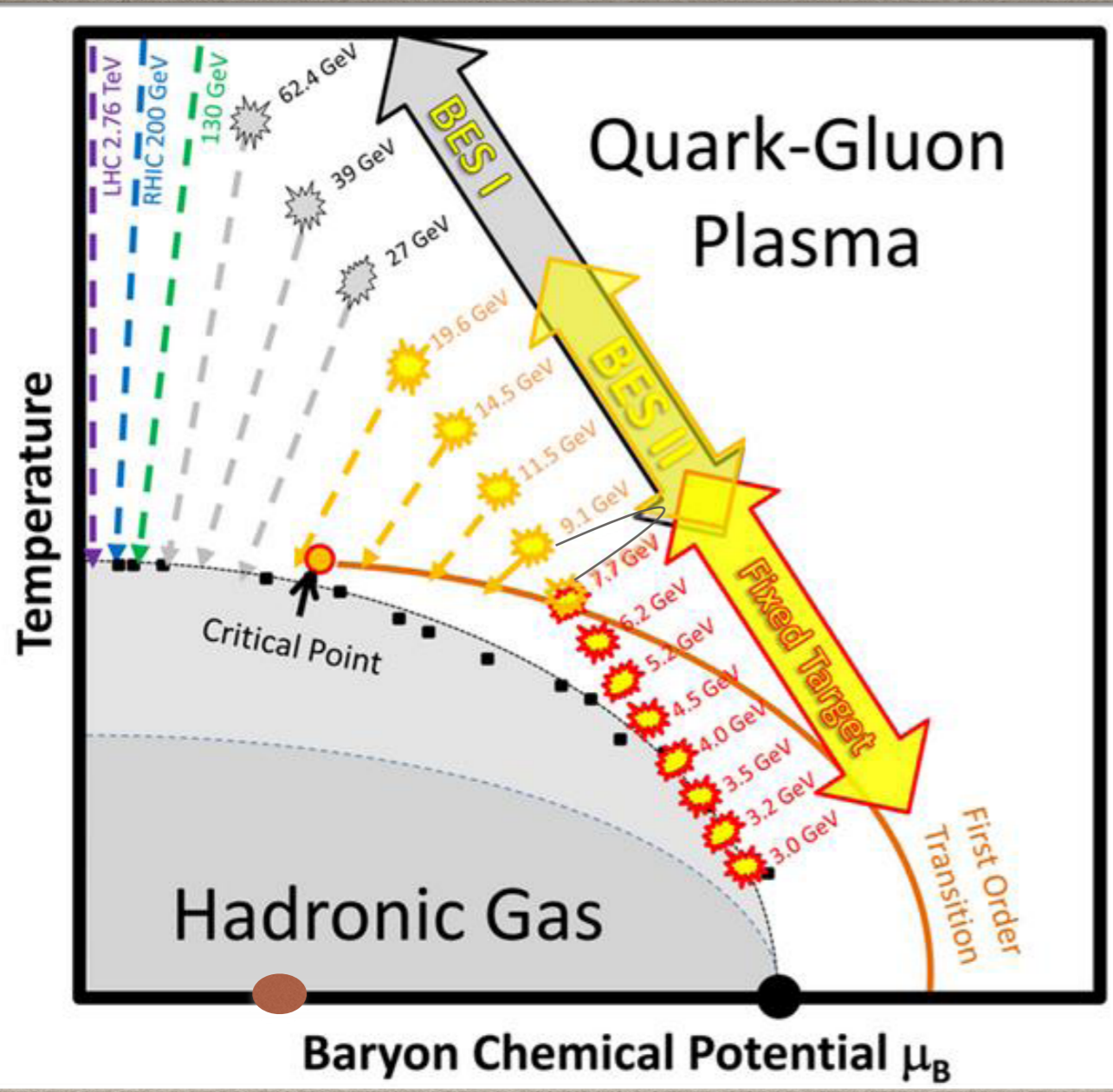
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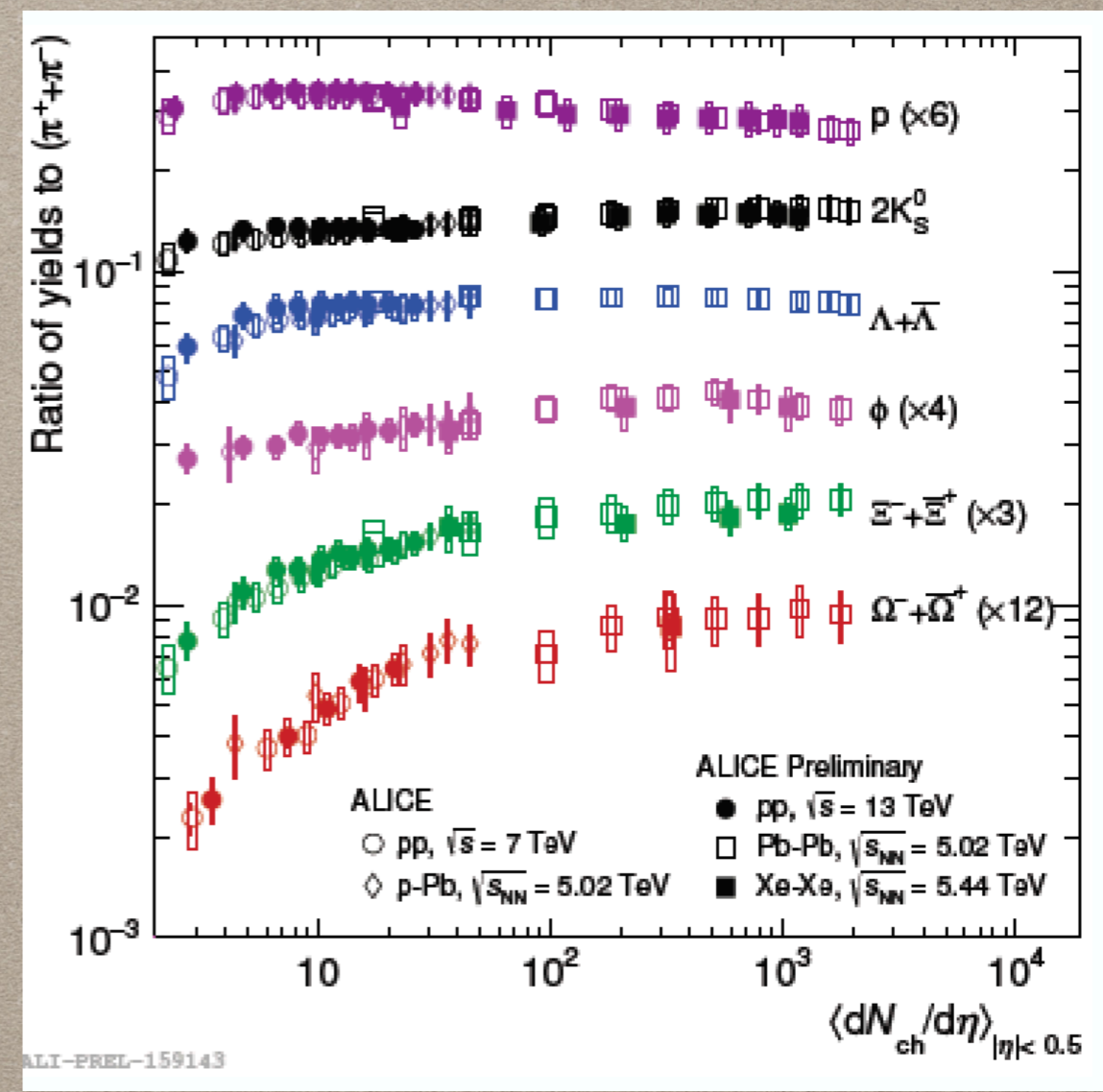
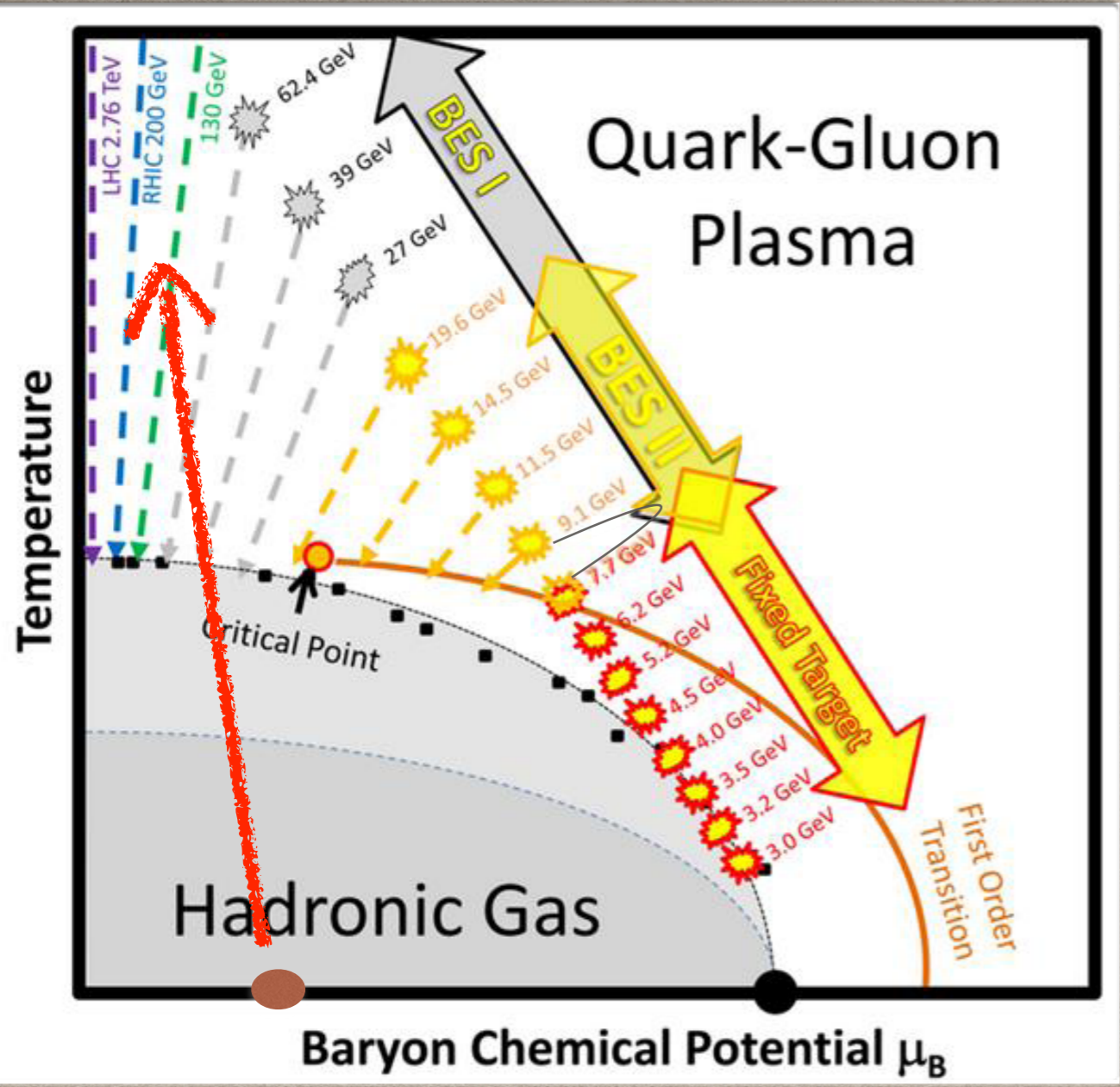
Li Yi (Shandong University)

QGP droplet in high-multiplicity pp events?

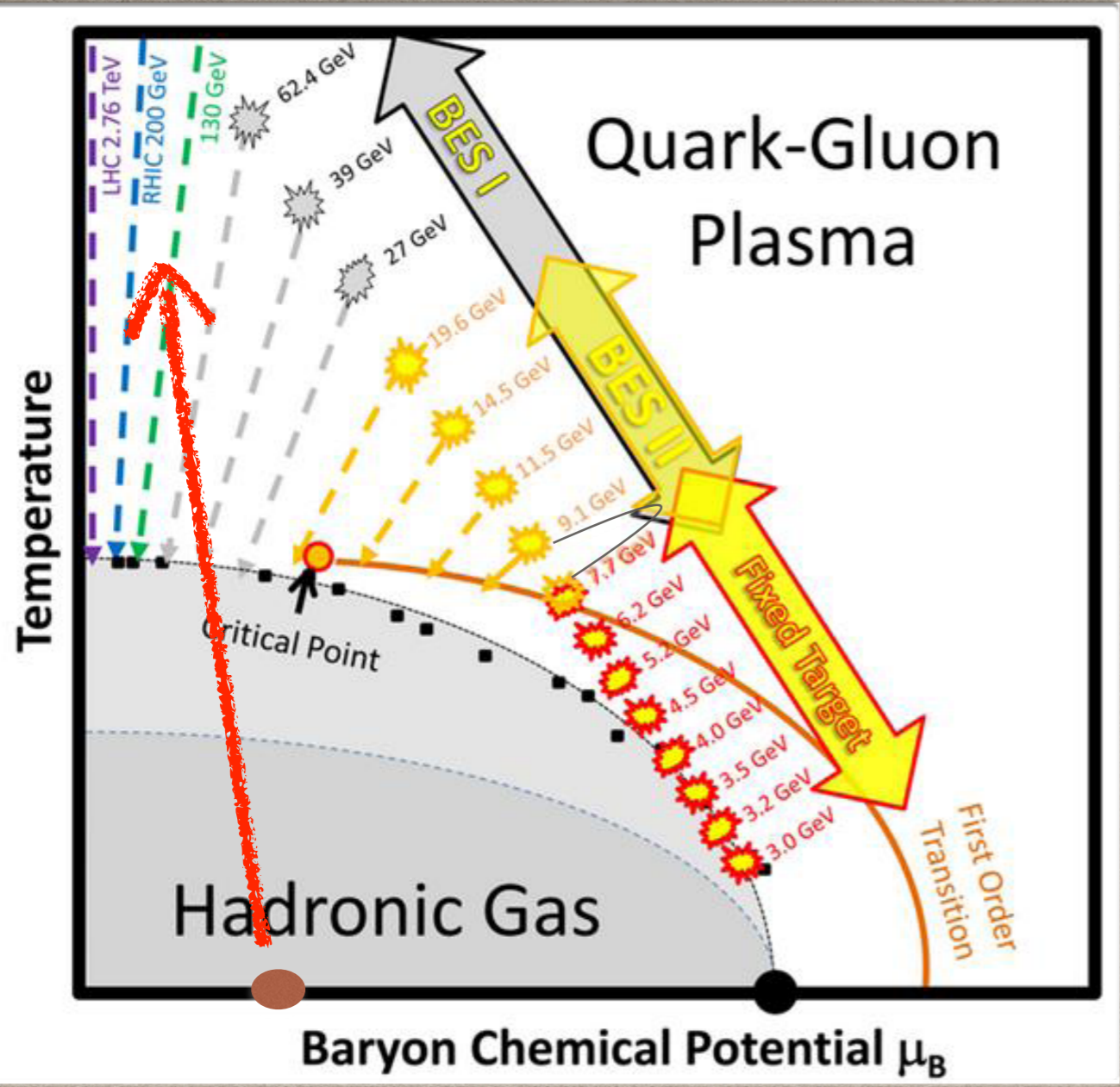
EXPLORING QCD PHASE III (RUN3)



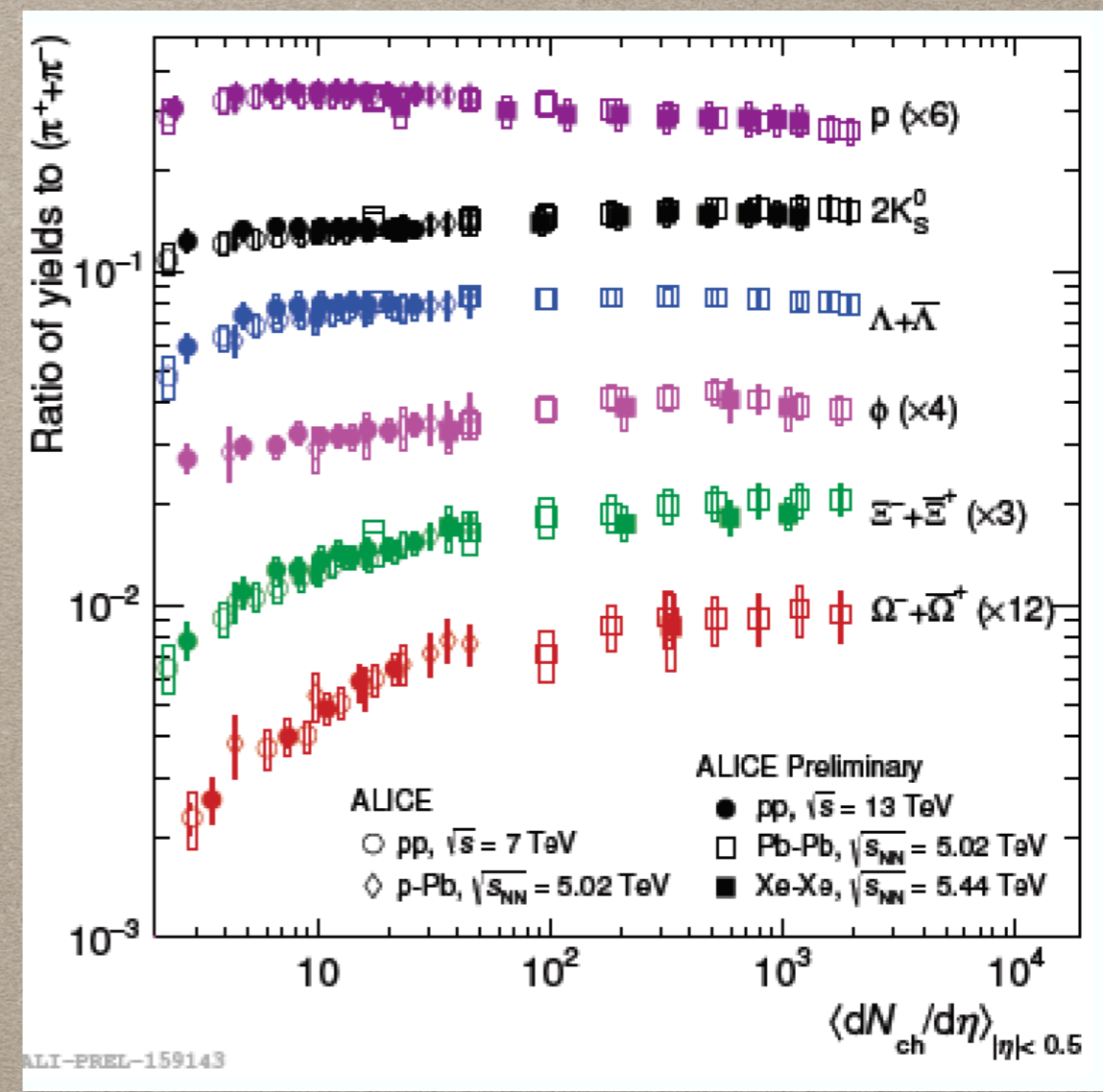
EXPLORING QCD PHASE III (RUN3)



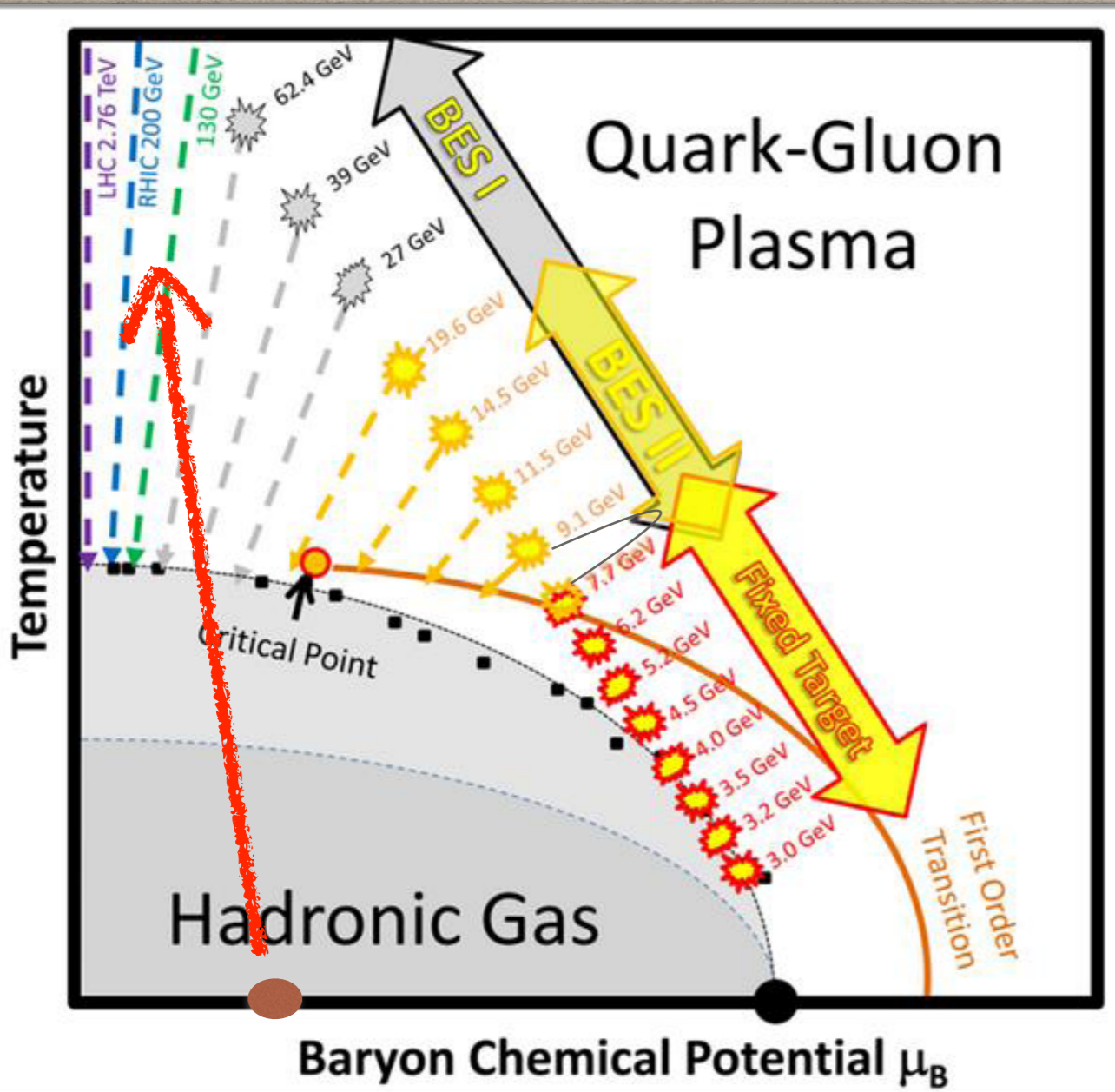
EXPLORING QCD PHASE III (RUN3)



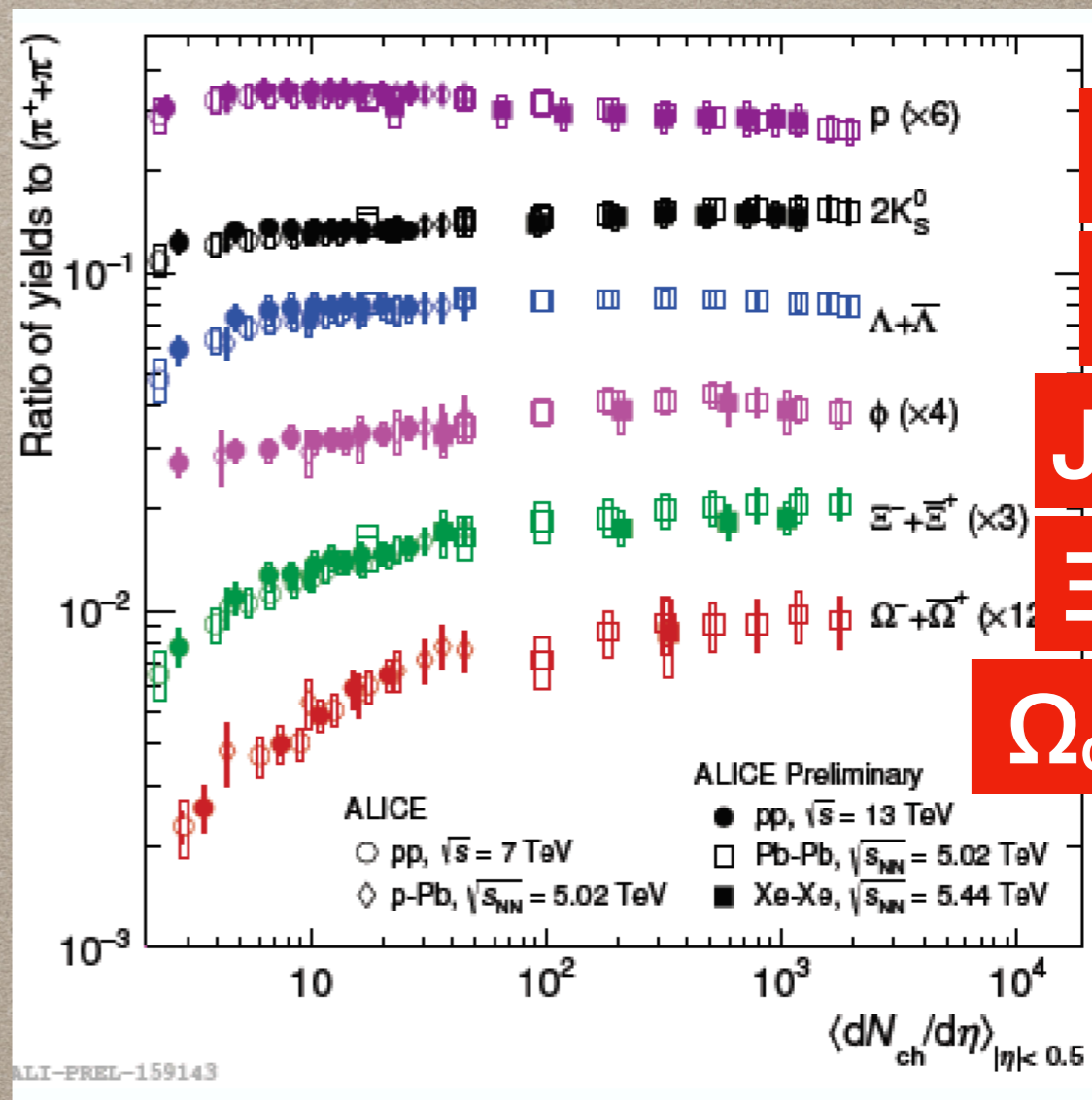
Hot matter study



EXPLORING QCD PHASE III (RUN3)

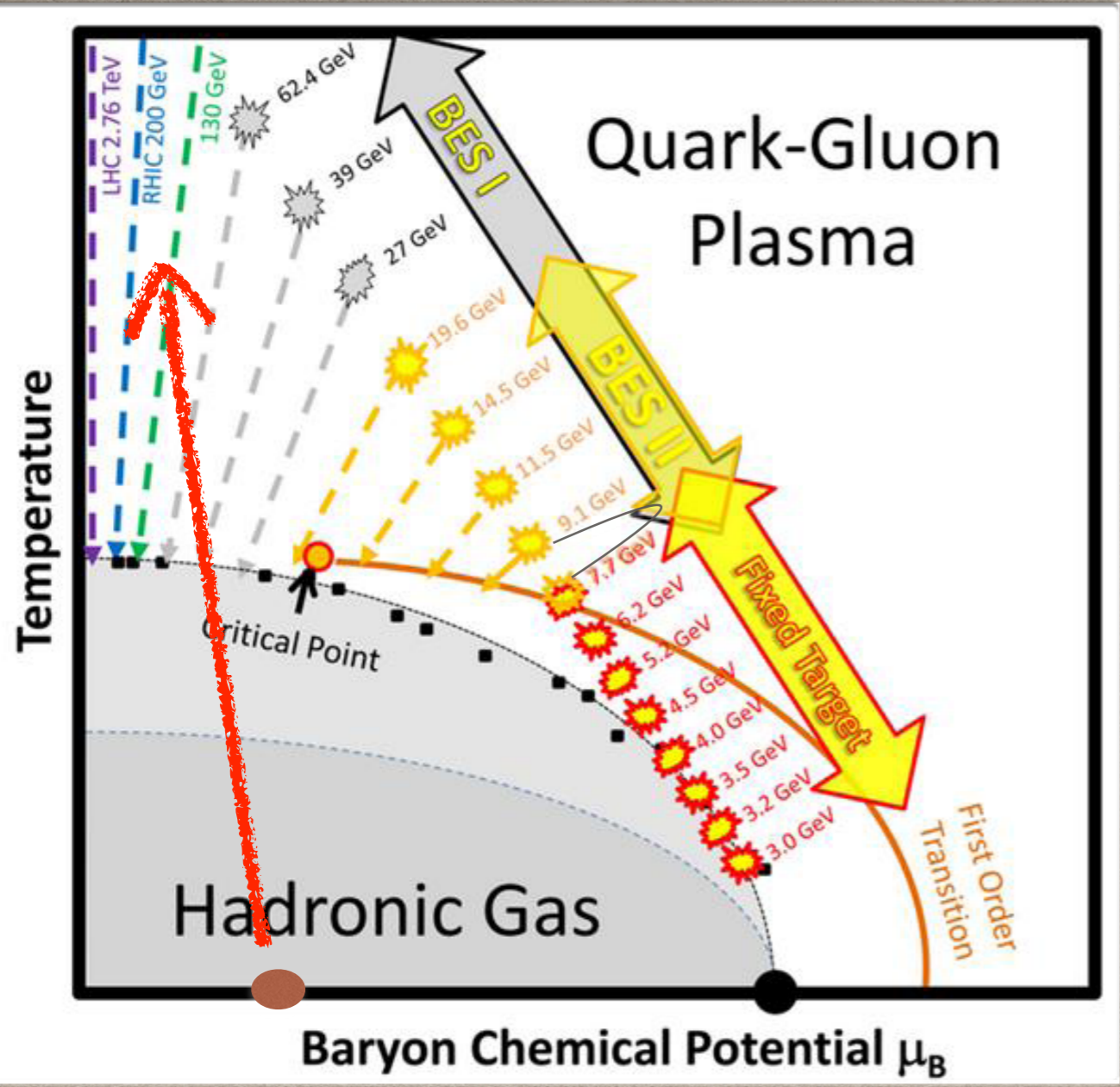


Hot matter study

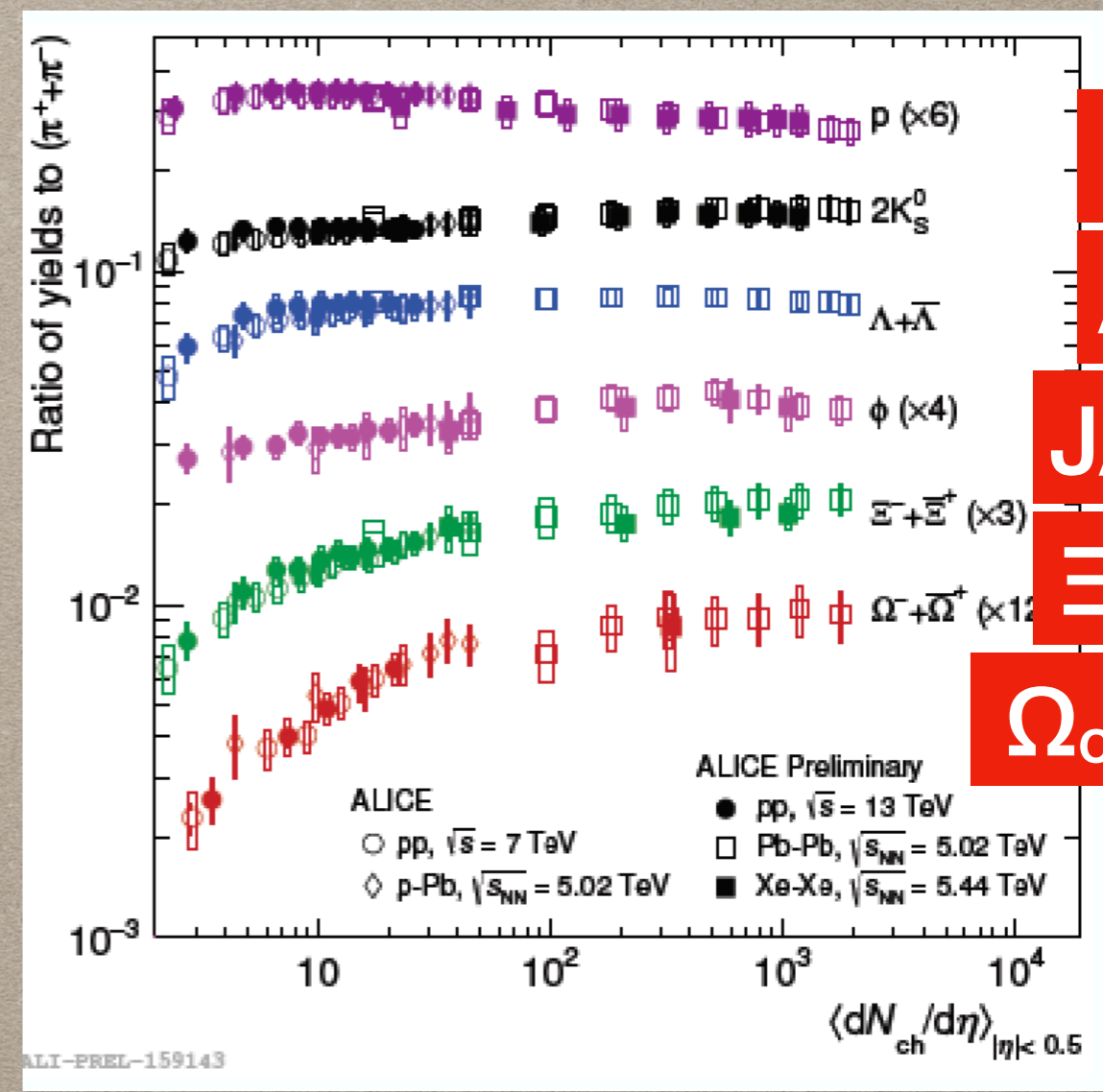


- D
- Λ_c
- J/ψ
- cc
- Ω_{ccc}

EXPLORING QCD PHASE III (RUN3)

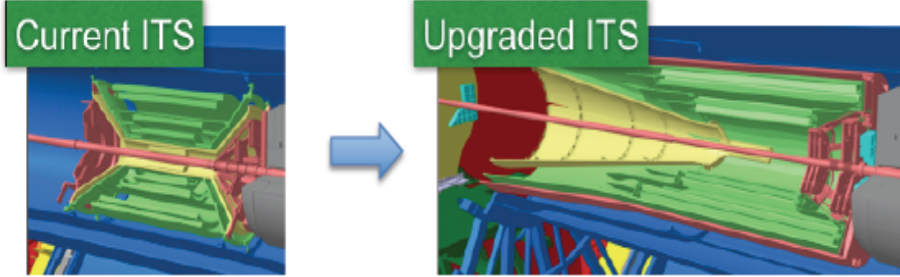


Hot matter study



- D
- Λ_c
- J/ ψ
- Ξ_{cc}
- Ω_{ccc}

LHC RUN3: $2.4 \times 10^{27}/\text{cm}^2\text{s} \sim 10 \text{ nb}^{-1}$ (PbPb)
 ALICE Upgrade is NOW ongoing (LS2)



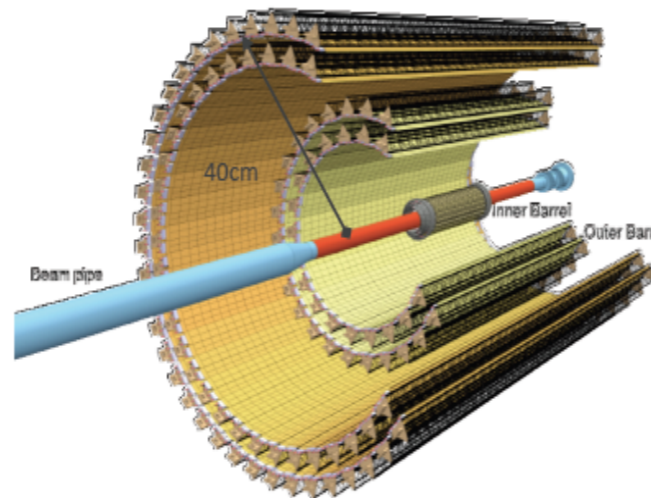
Motivations and goals

- Improved vertex and tracking precision
⇒ closer to IP, smaller pixels, less material
- Faster readout

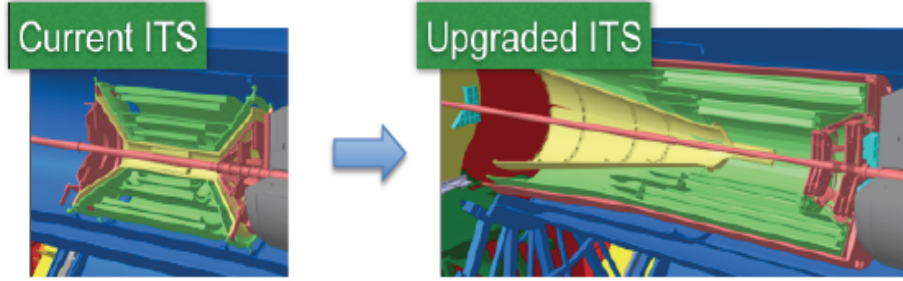
6 layers ($39\text{mm} < r < 440\text{mm}$) $-1 \leq \eta \leq 1$
7 layers ($22\text{mm} < r < 400\text{mm}$) $-1.3 \leq \eta \leq 1.3$

Based on novel MAPS (ALPIDE)

- 10 m^2 active silicon area (12.5 G-pixels)
- Spatial resolution $\sim 5\mu\text{m}$
- Power density $< 40\text{mW} / \text{cm}^2$
- Max particle rate $\sim 100\text{MHz} / \text{cm}^2$ (w/o pile-up)
- Fake hit rate: $< 1\text{Hz} / \text{cm}^2$
- X/X_0 (first three layers): 0.35%



⇒ further improvements exploiting technological innovations



Motivations and goals

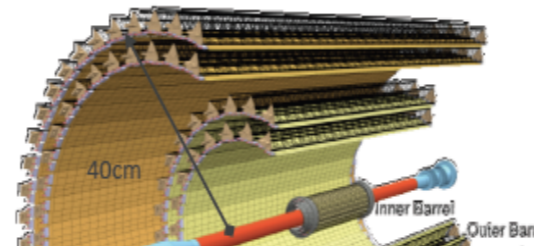
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⇒ further



TPC Continuous Readout with GEMs (Gas Electron Multiplier)

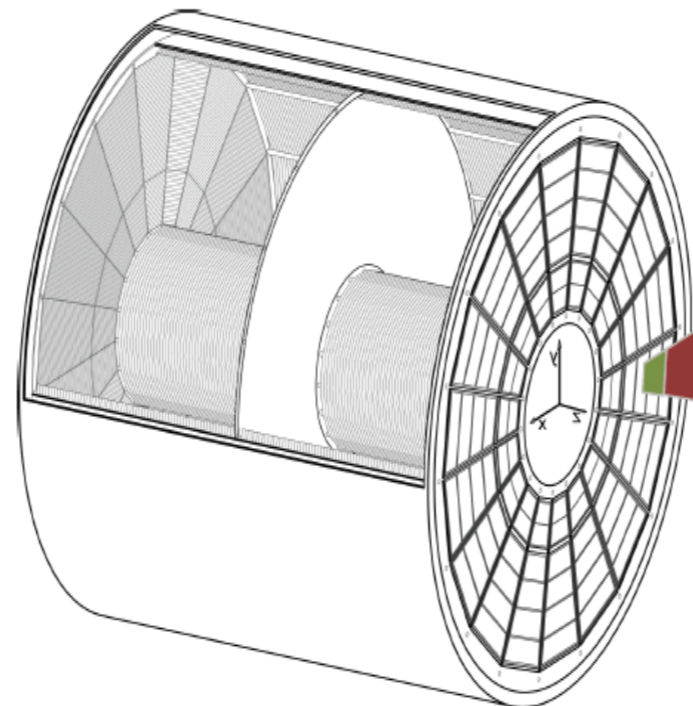
Gate-less TPC for continuous readout

Current MWPC: readout rate limited by ion backflow

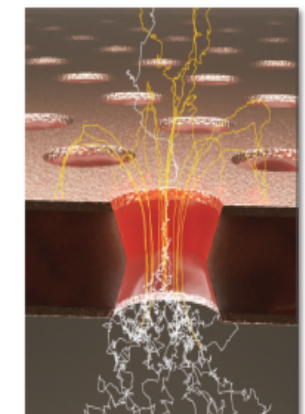
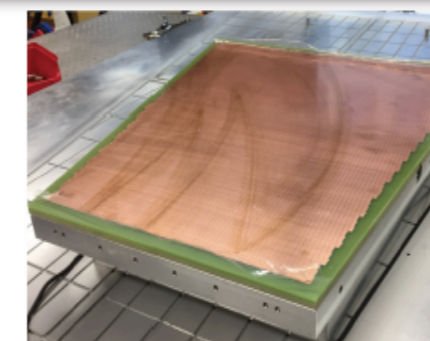
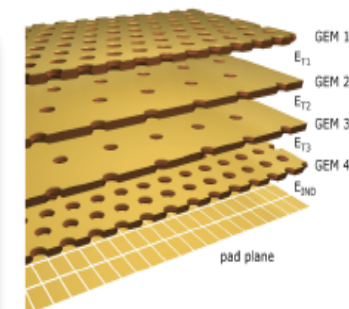
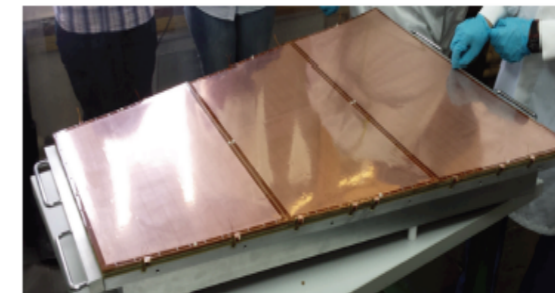
Operate TPC at 50 kHz ⇒ no gating grid

Need to minimize IBF ⇒ Replace MWPC with 4-GEMs

100 m² single-mask foils GEM production

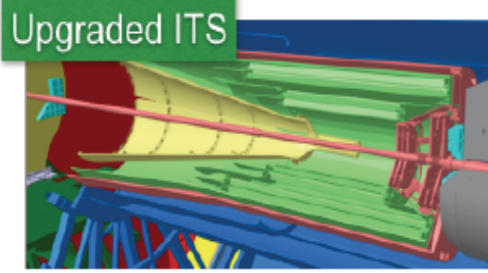
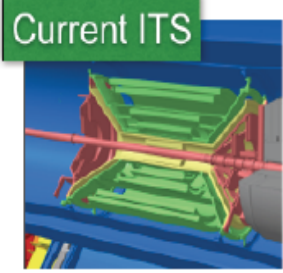


Read Out Chamber



⇒ GEM provides ion backflow suppression to $< 1\%$

⇒ 524 000 pads readout continuously (10bit x 5MSPS) via 6552 links ⇒ 3.4 TByte/sec



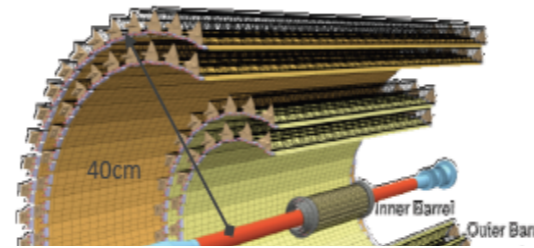
Current ITS: 6 layers ($39\text{mm} < r < 440\text{mm}$) $-1 \leq \eta \leq 1$
 Upgraded ITS: 7 layers ($22\text{mm} < r < 400\text{mm}$) $-1.3 \leq \eta \leq 1.3$

Motivations and goals

- Improved vertex and tracking precision
 ⇒ closer to IP, smaller pixels, less material
- Faster readout

Based on novel MAPS (ALPIDE)

- 10 m² active silicon area (12.5 G-pixels)
- Spatial resolution ~5μm
- Power density < 40mW / cm²
- Max particle rate ~ 100MHz /cm² (w/o pile-up)
- Fake hit rate: < 1Hz/cm²



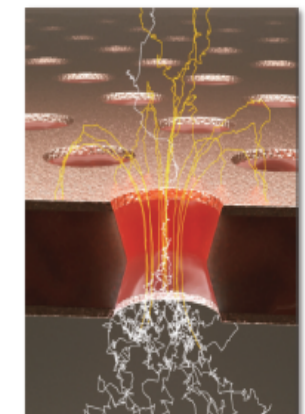
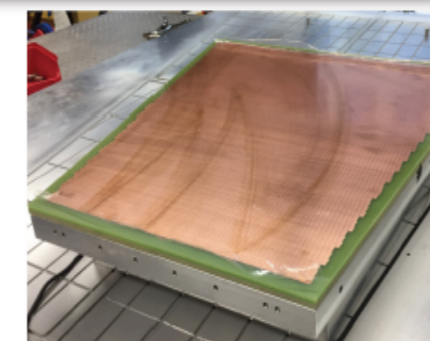
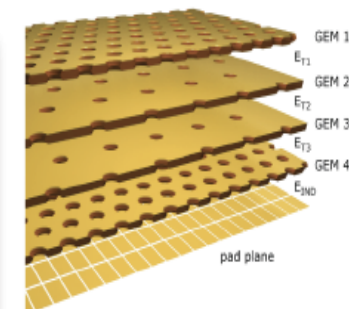
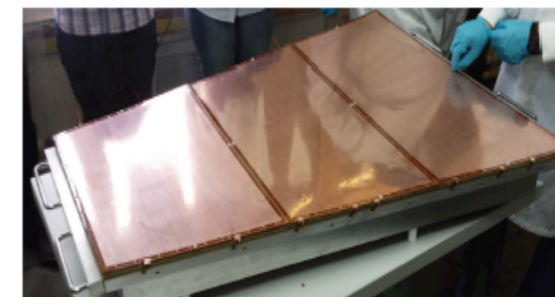
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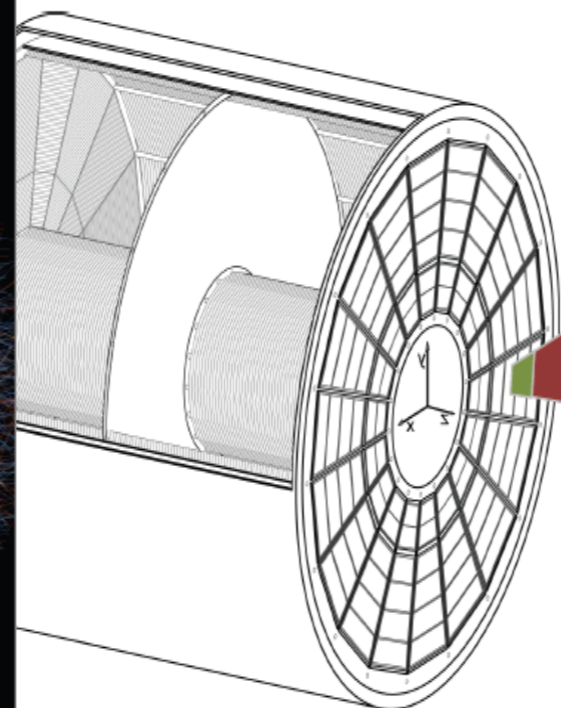
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Read Out Chamber

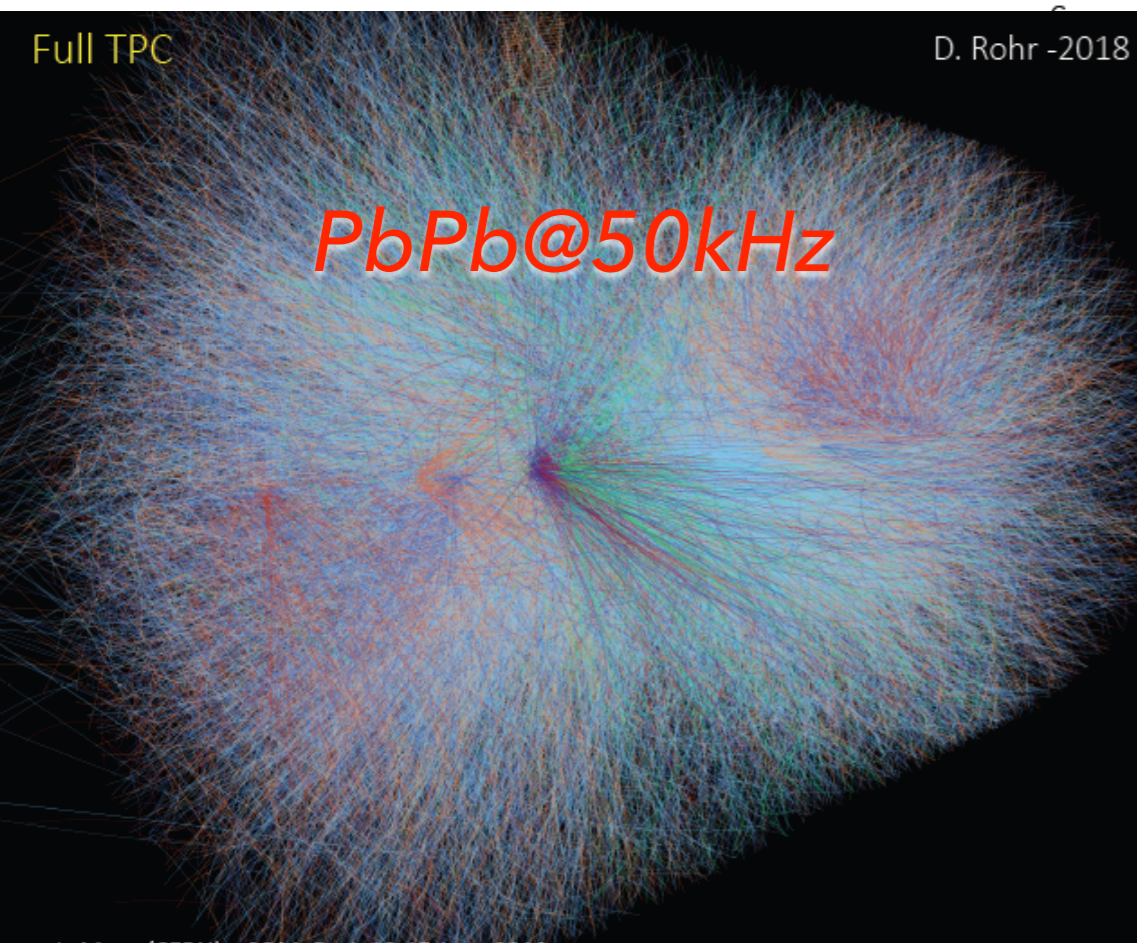


MWPC: readout rate limited by ion backflow



GEM provides ion backflow suppression to < 1%

4 000 pads readout continuously (10bit x 5MSPS) via 6552 links ⇒ 3.4 TByte/sec



Full TPC

D. Rohr -2018

PbPb@50kHz

Vertex Detector (innermost 3 layers)



2030s

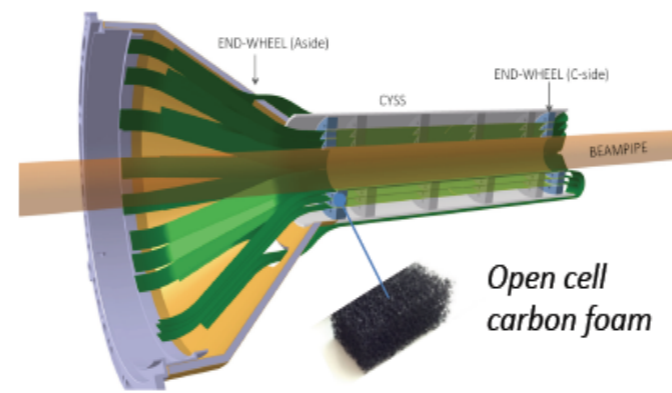
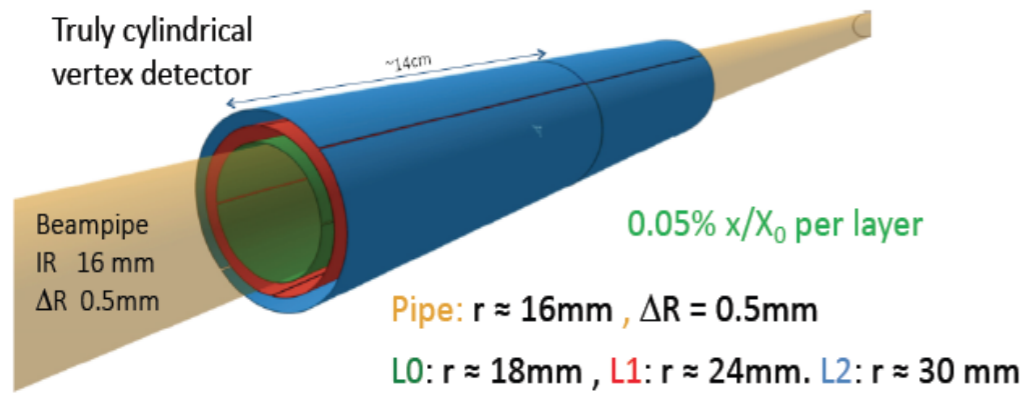
EoI for new ultra-light Inner Barrel in LS3 (CDS, ALICE-PUBLIC-2018-013)

Recent silicon technologies (ultra-thin wafer-scale sensors) allow

- Eliminate active cooling \Rightarrow possible for power $< 20\text{mW}/\text{cm}^2$
- Eliminate electrical substrate \Rightarrow Possible if sensor covers the full stave length
- Sensors arranged with a perfectly cylindrical shape \Rightarrow sensors thinned to $\sim 30\mu\text{m}$ can be curved to a radius of 10-20mm



ideal ITS (LS3)



A new experiment based on a "all-silicon" detector

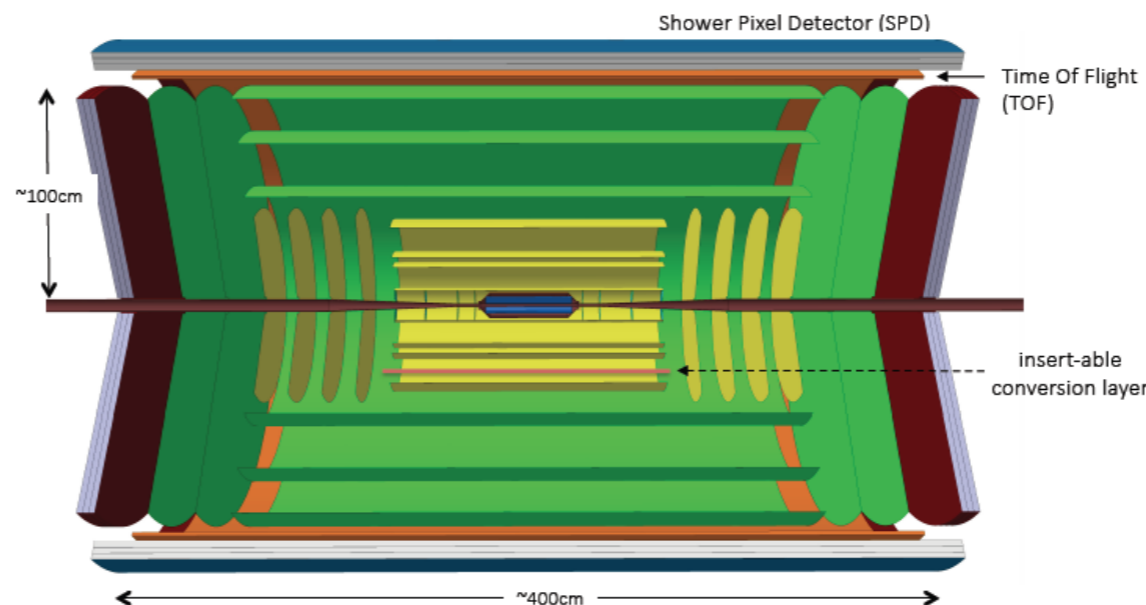


Tracker: ~ 10 tracking barrel layers (blue, yellow and green) based on CMOS sensors

Particle ID:

- TOF with outer silicon layers (orange)
- Shower Pixel Detector (outermost blue layer)

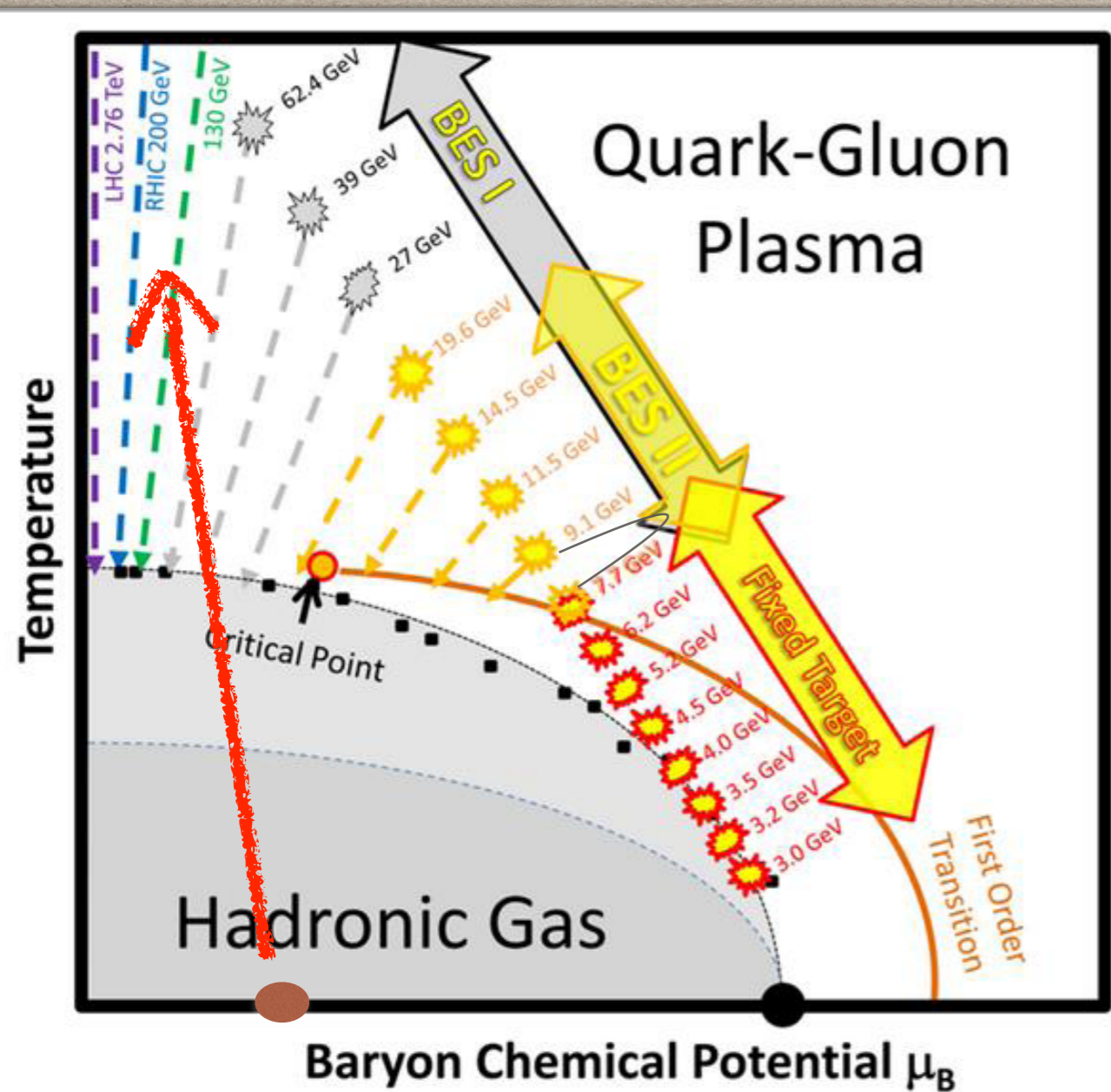
Extended rapidity coverage: up to 8 rapidity units



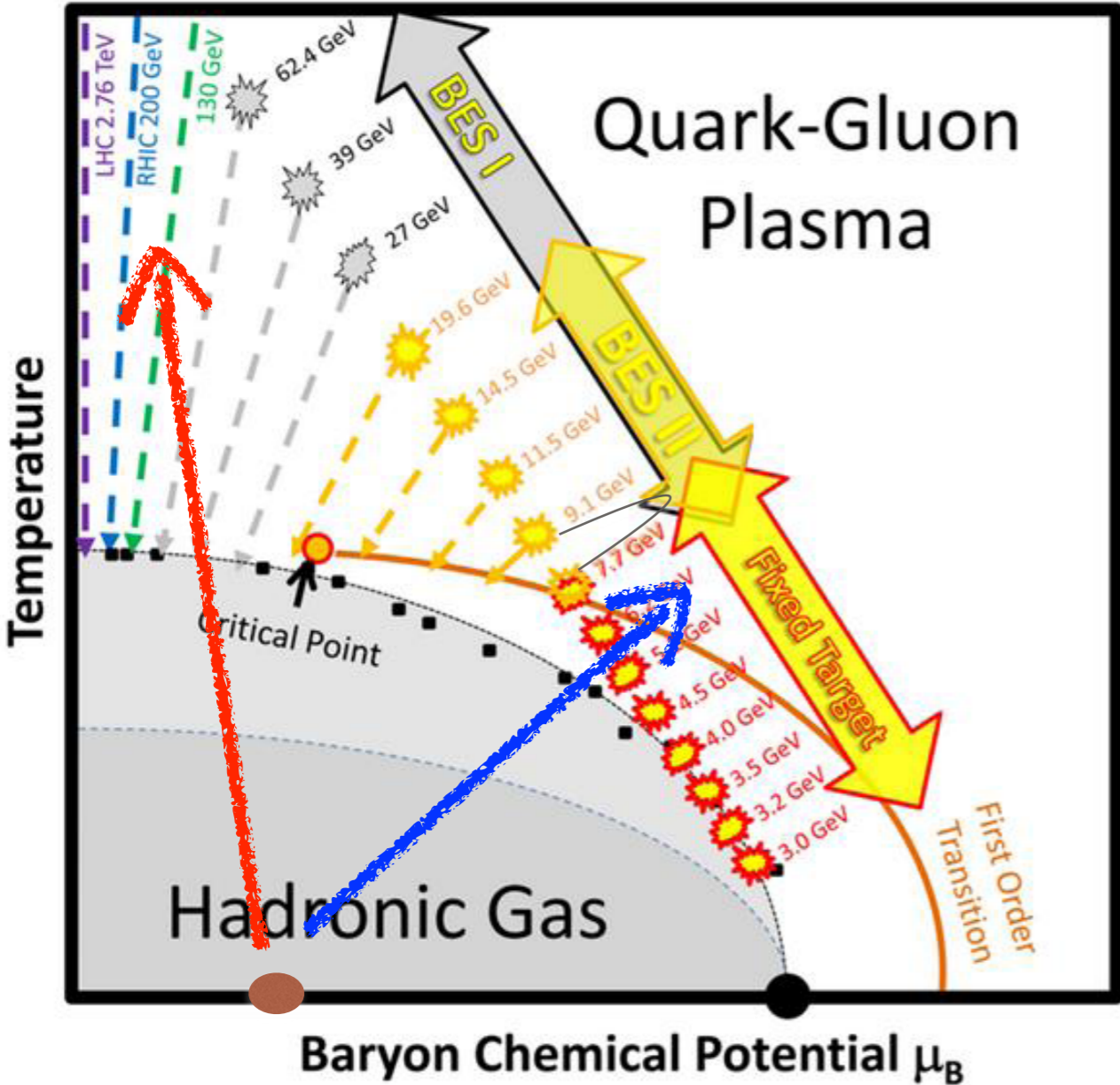
- Magnetic Field
- $B = 0.5$ or 1 T
- Spatial resolution
- Innermost 3 layers: $\sigma < 3\mu\text{m}$
 - Outer layers: $\sigma \sim 5\mu\text{m}$
- Vertex material thickness
- $x/X_0 \sim 0.05\%$ / layer
- Time Measurement
- Outermost layer integrates high precision time measurement ($\sigma_t \sim 20\text{ps}$)

All-Silicon ALICE (LS4)

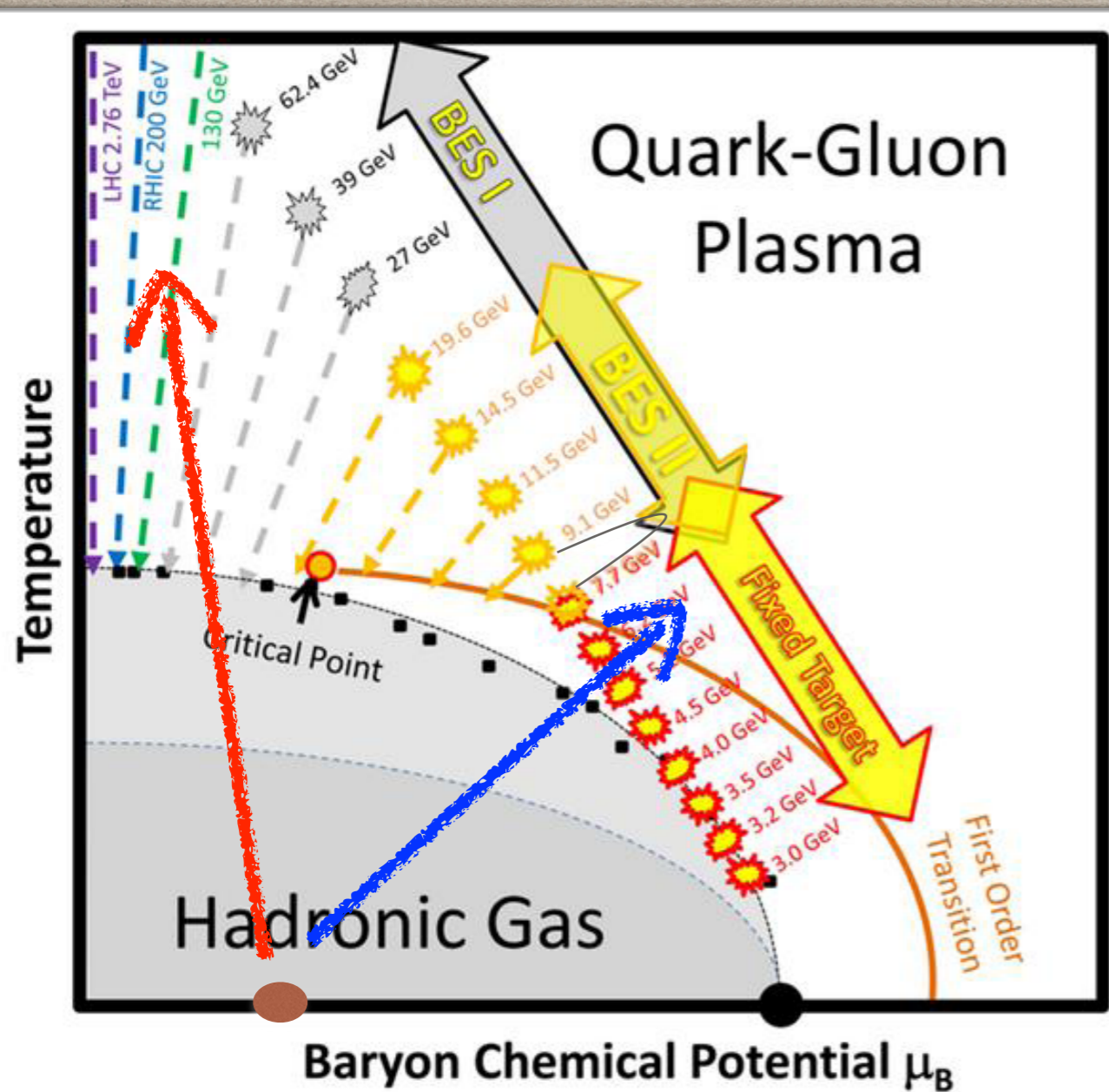
EXPLORING QCD PHASE IV (BES)



EXPLORING QCD PHASE IV (BES)

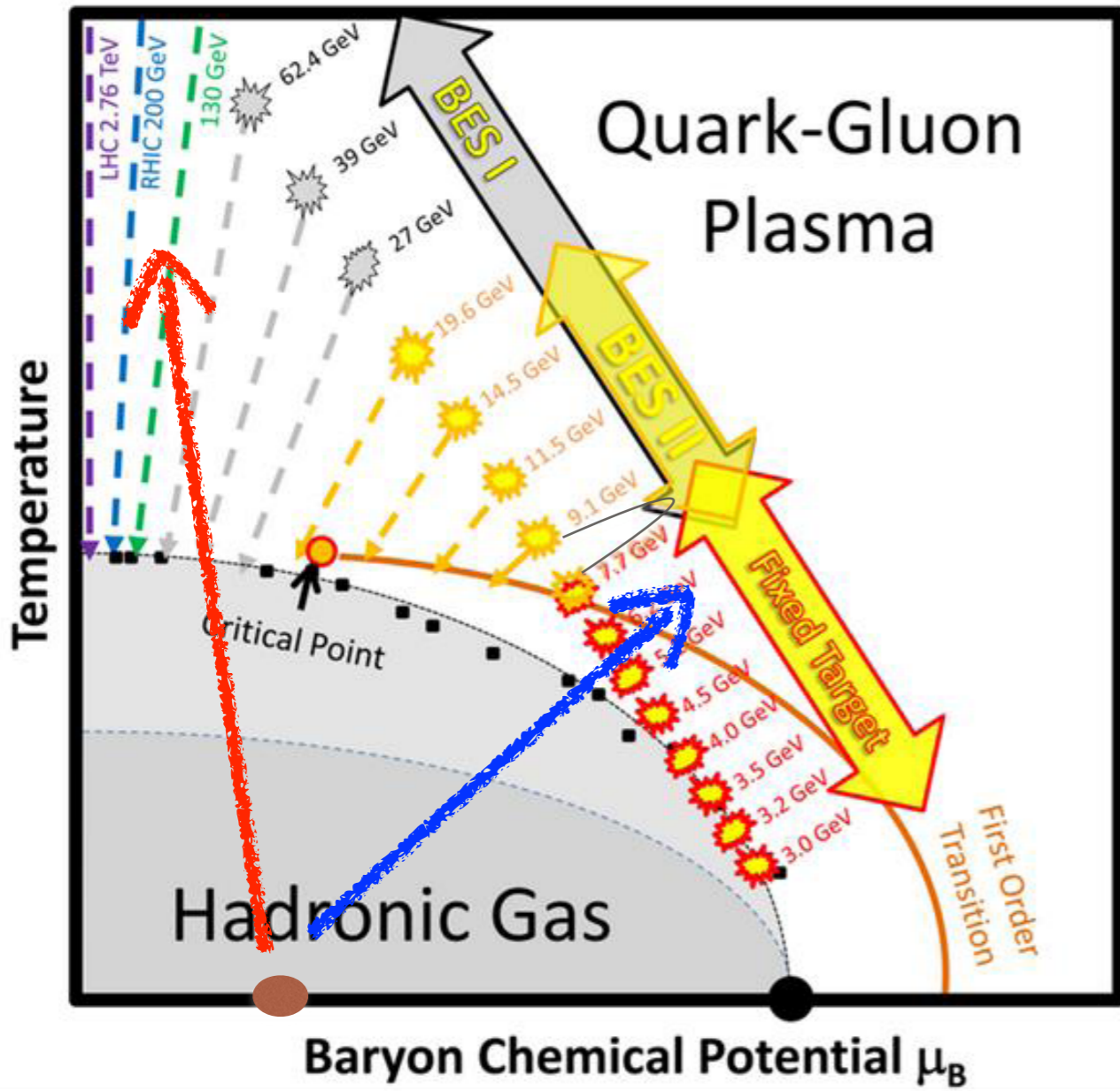


EXPLORING QCD PHASE IV (BES)



Critical Point Search
(1st order phase transition)

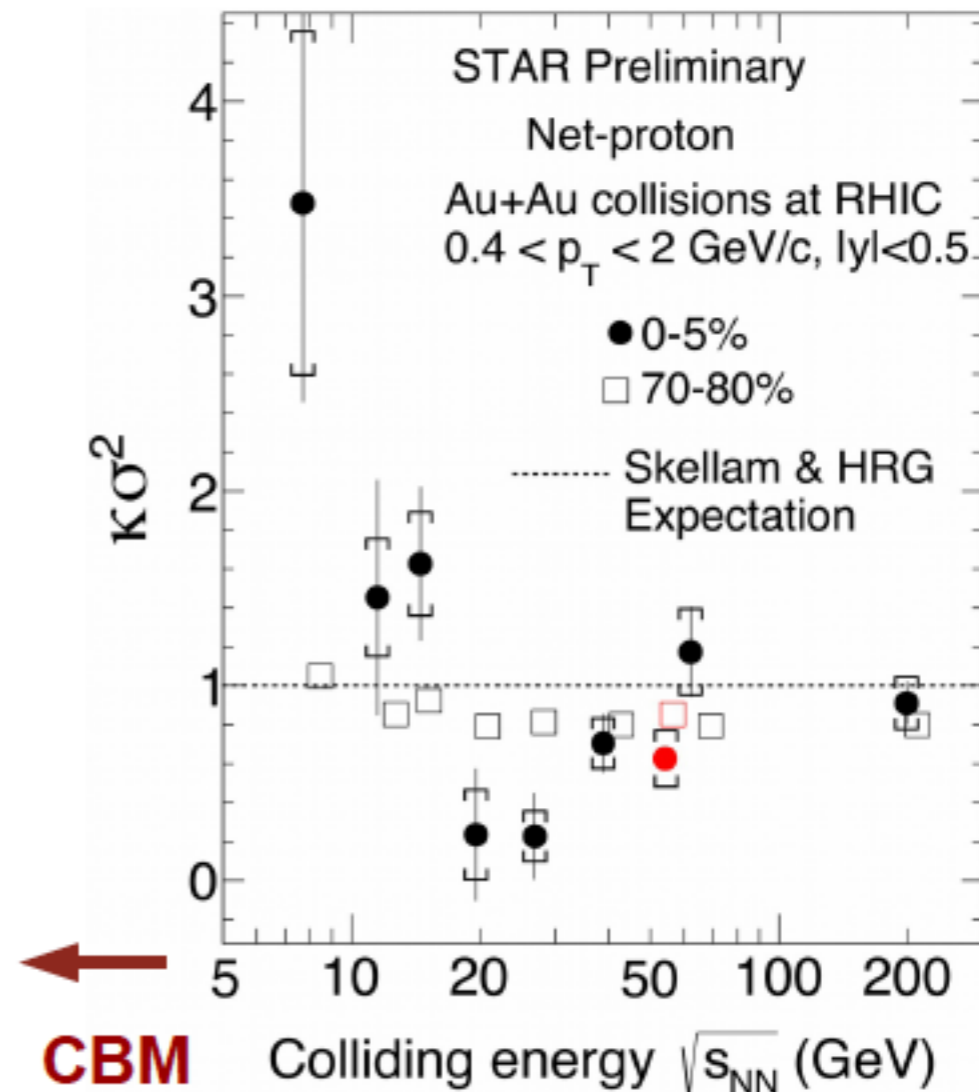
EXPLORING QCD PHASE IV (BES)



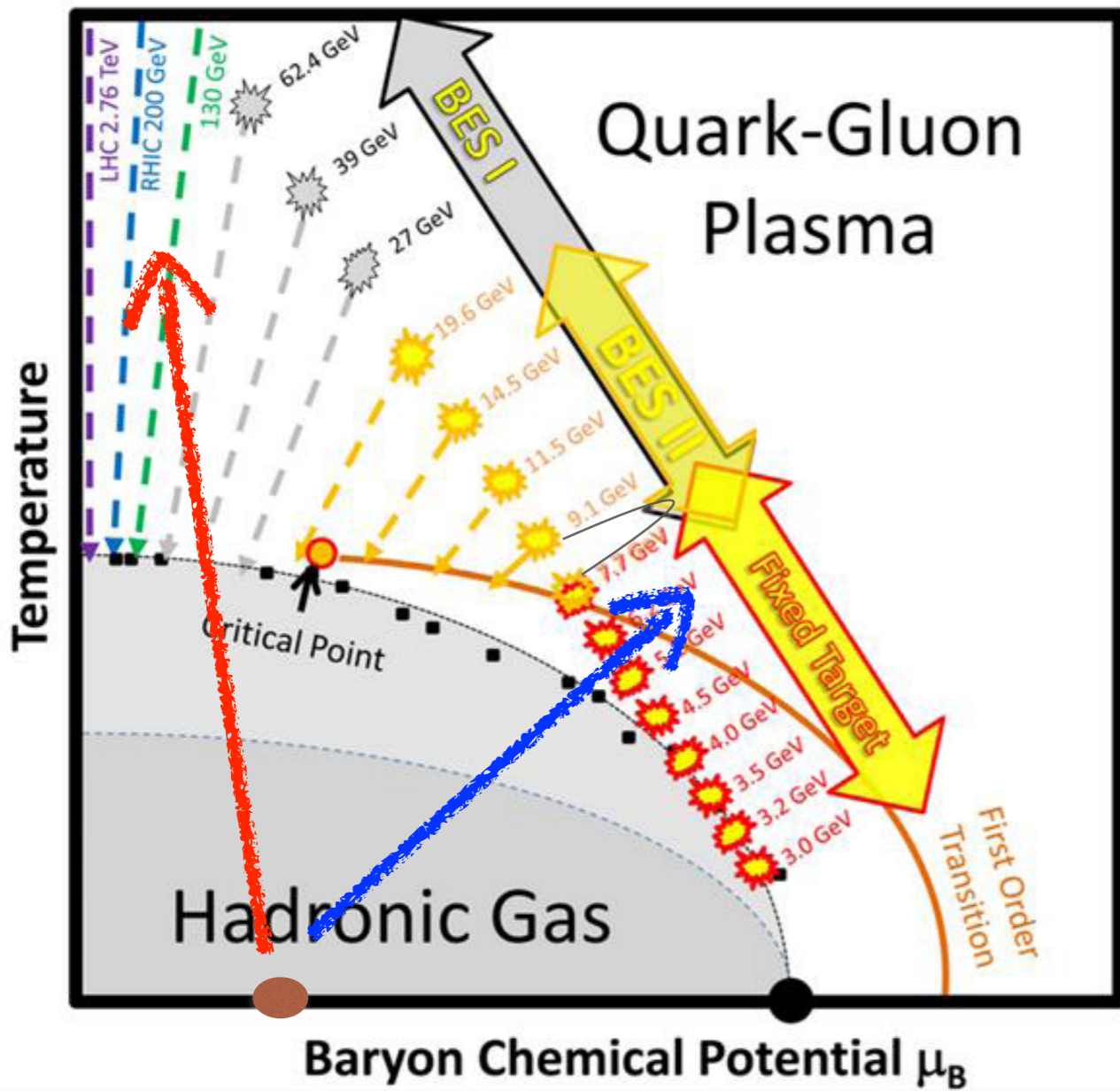
Critical Point Search (1st order phase transition)

Moments:

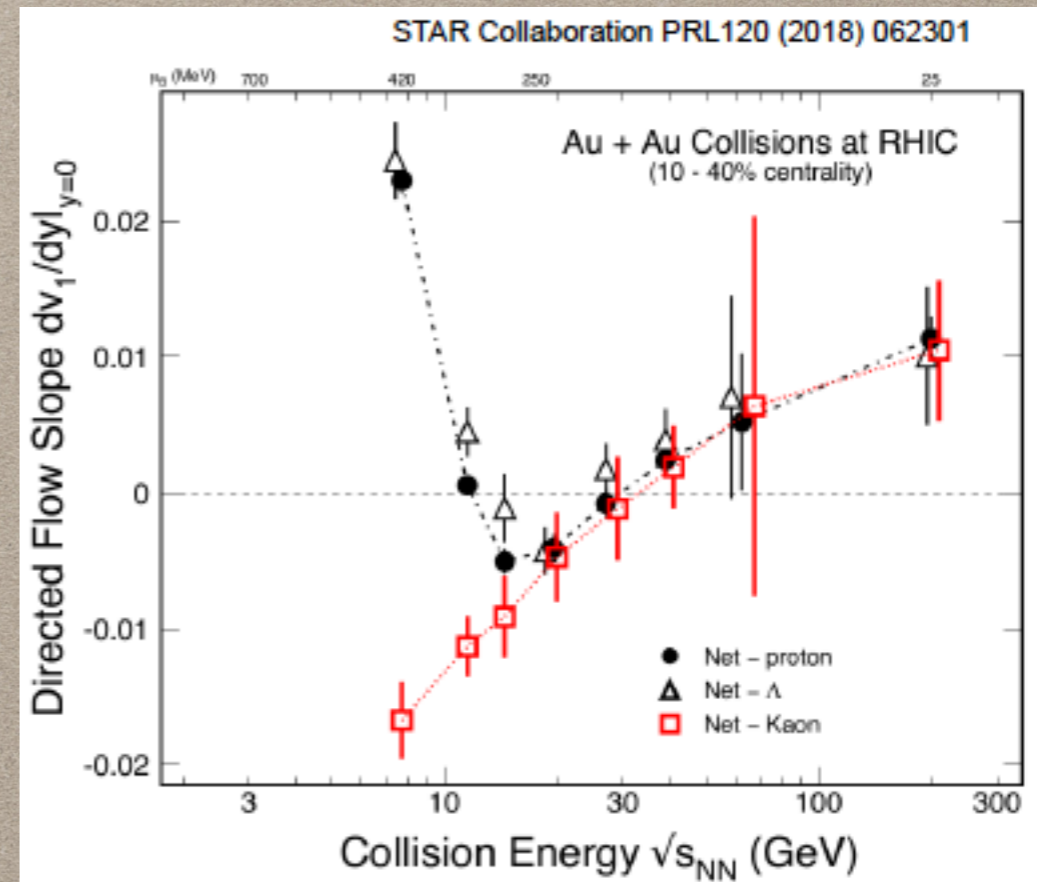
- 1st - mean, 2nd - variance (σ)
- 3rd - skewness (s), 4th - kurtosis (κ)



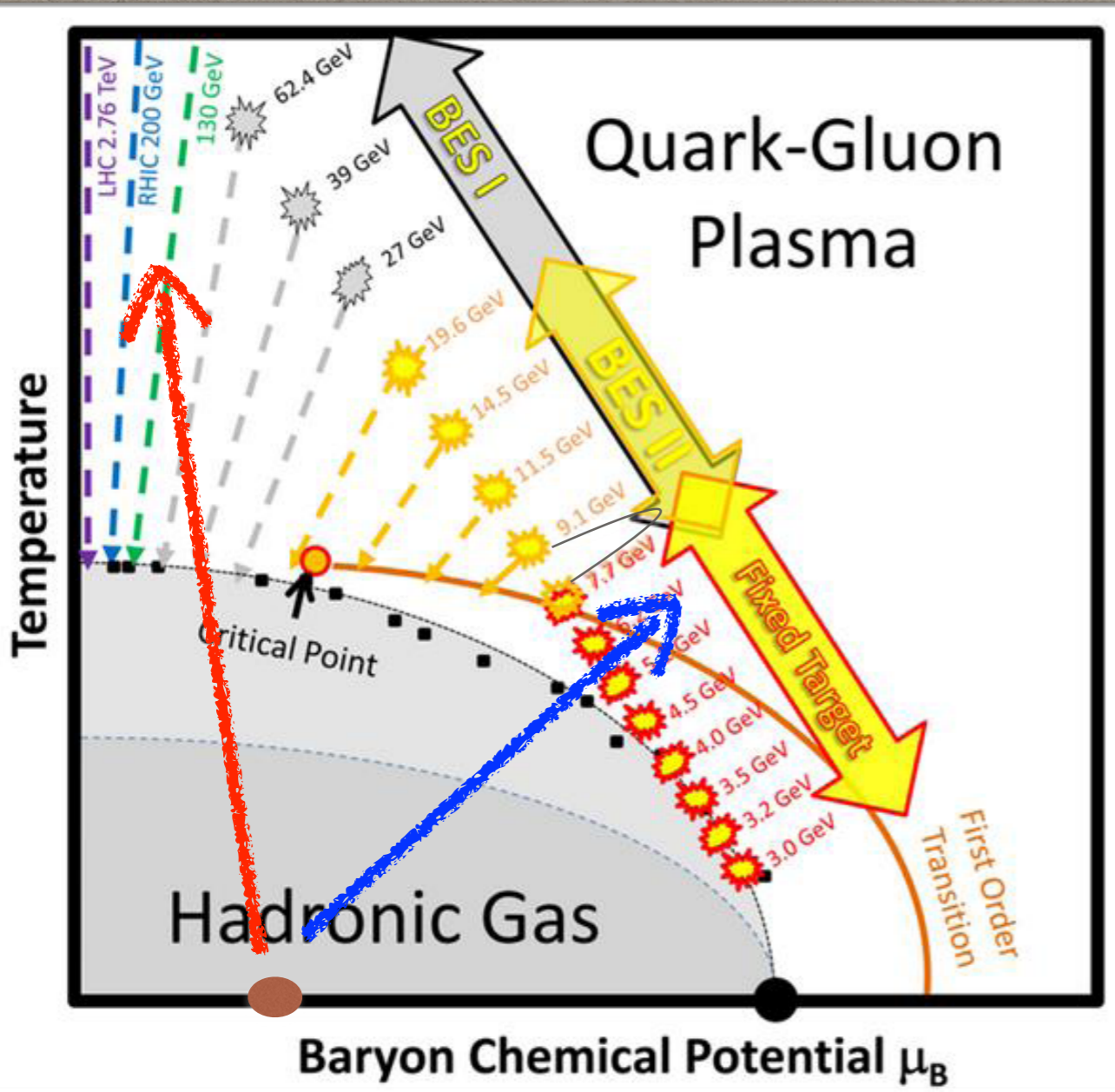
EXPLORING QCD PHASE IV (BES)



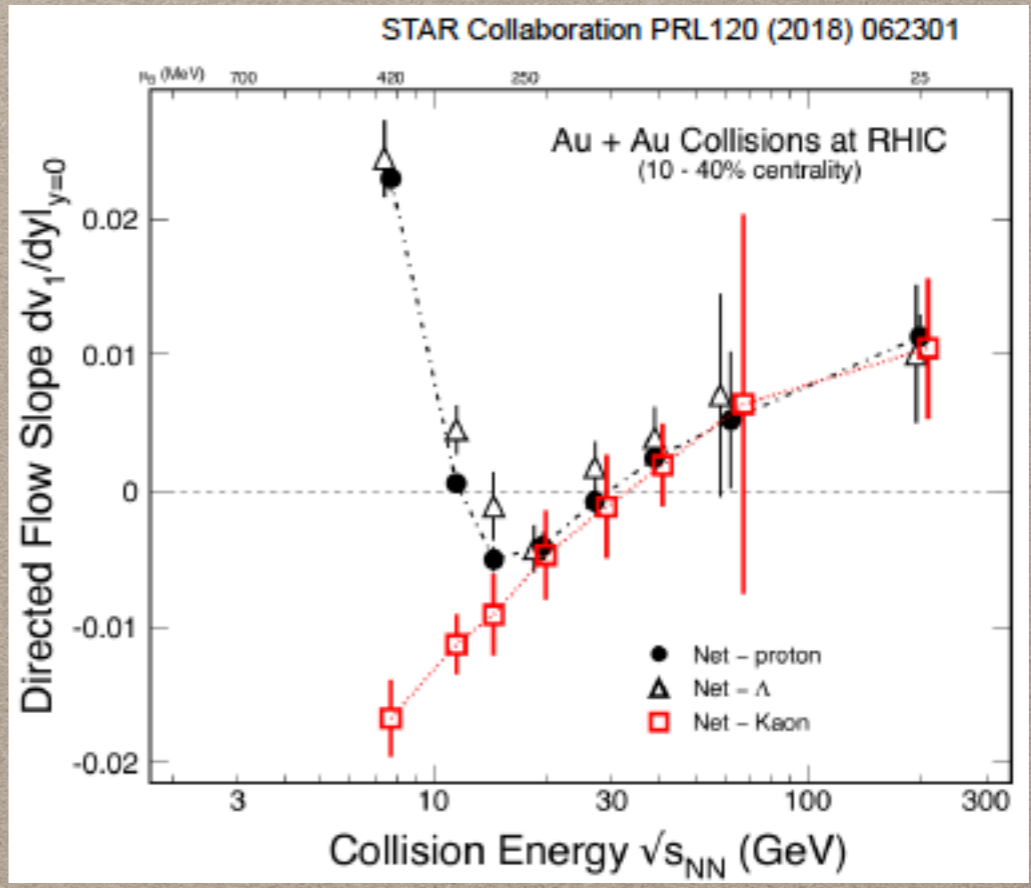
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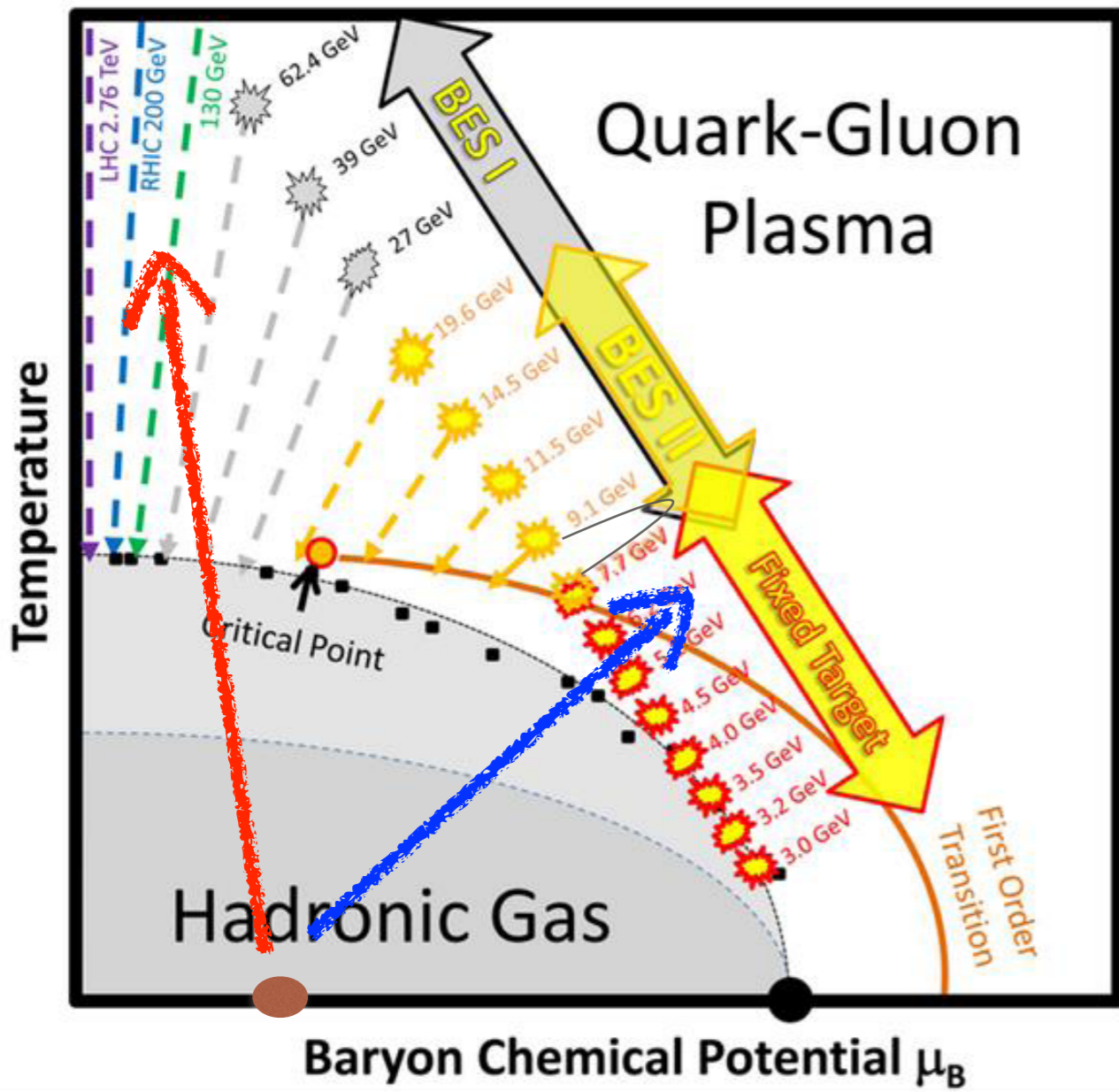


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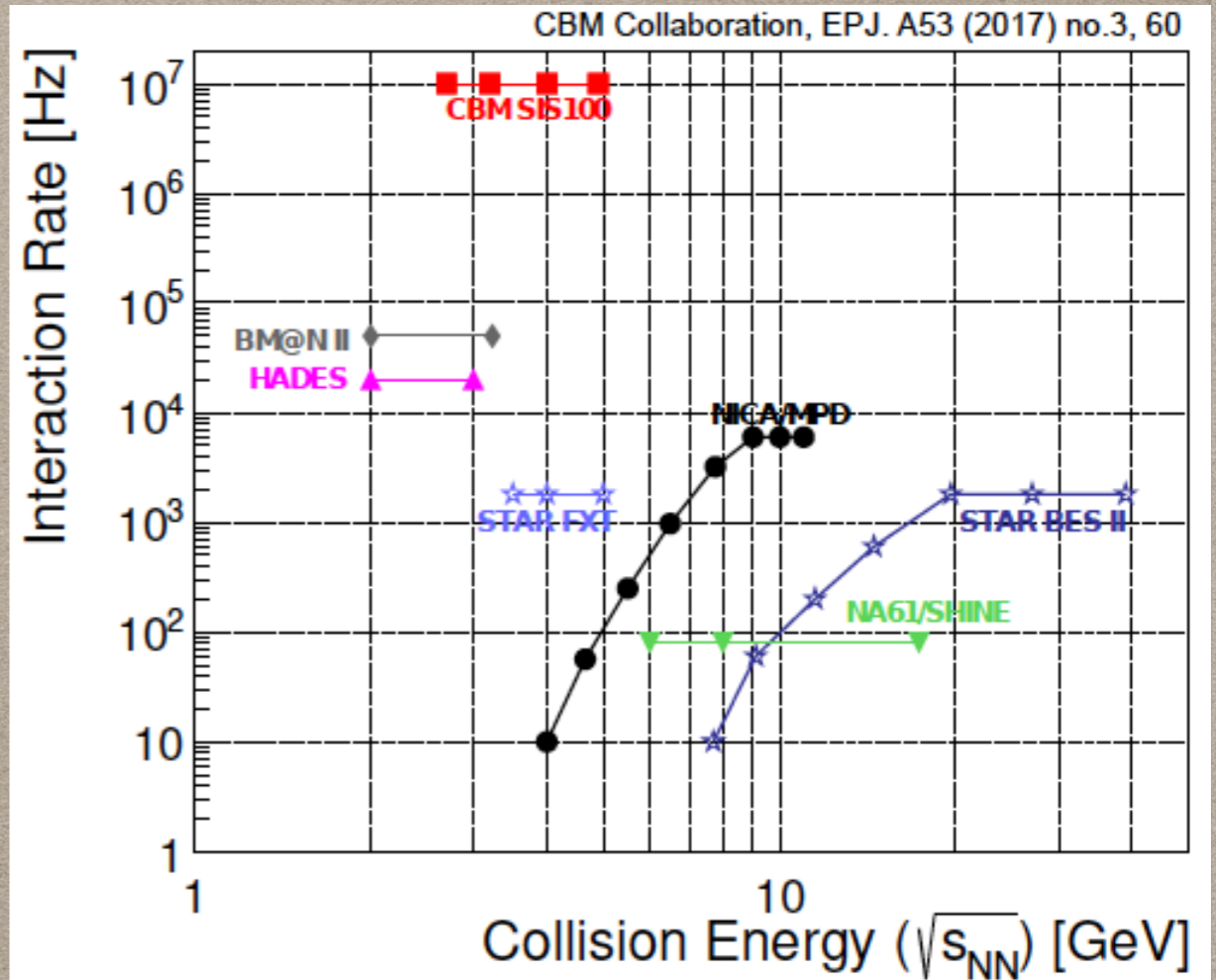


critical region of $\sqrt{s_{NN}} \sim 5 - 30$ GeV

EXPLORING QCD PHASE V (FUTURE)

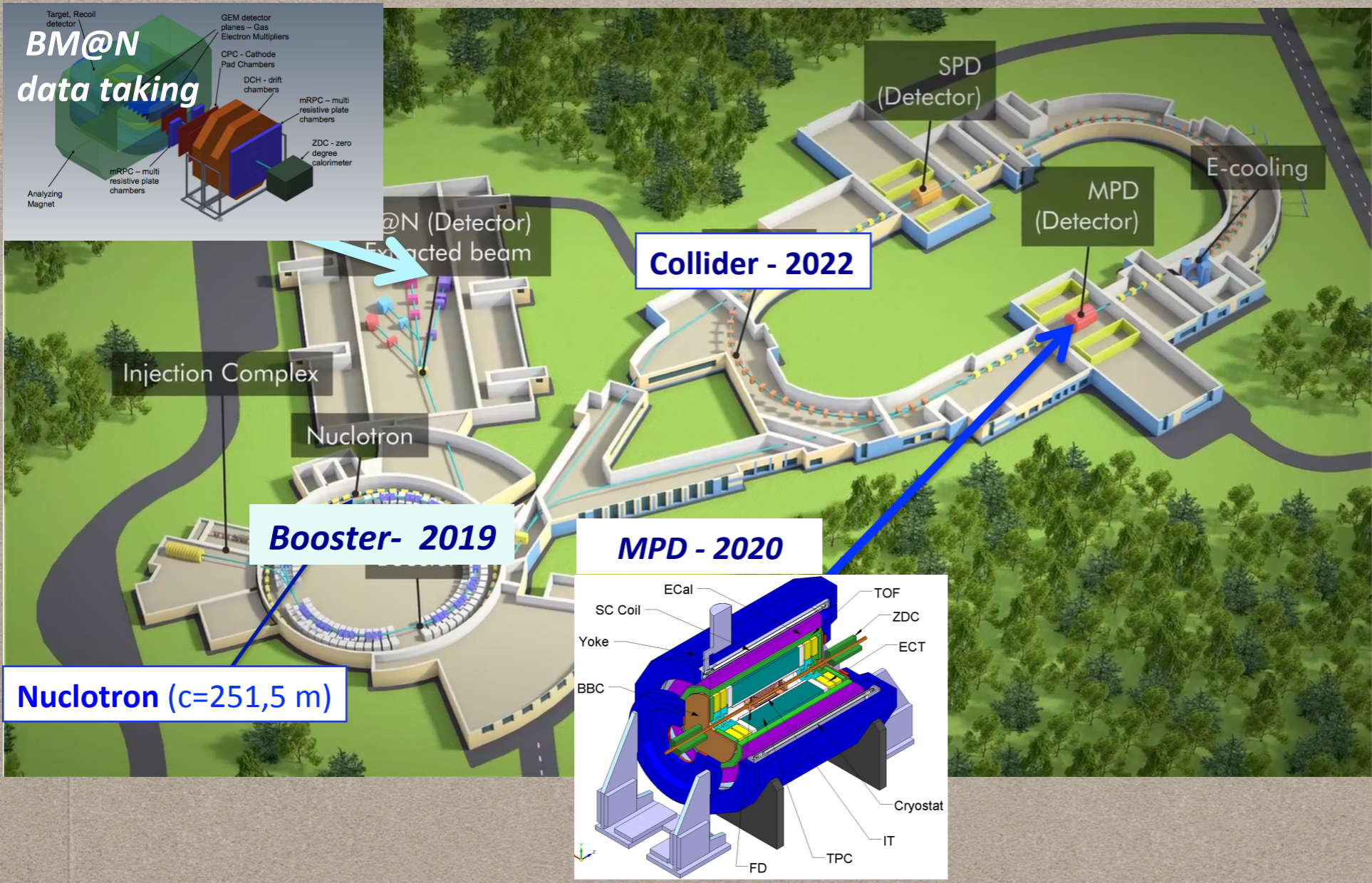


Critical Point Search
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critical region of $\sqrt{s_{NN}} \sim 5 - 30$ GeV

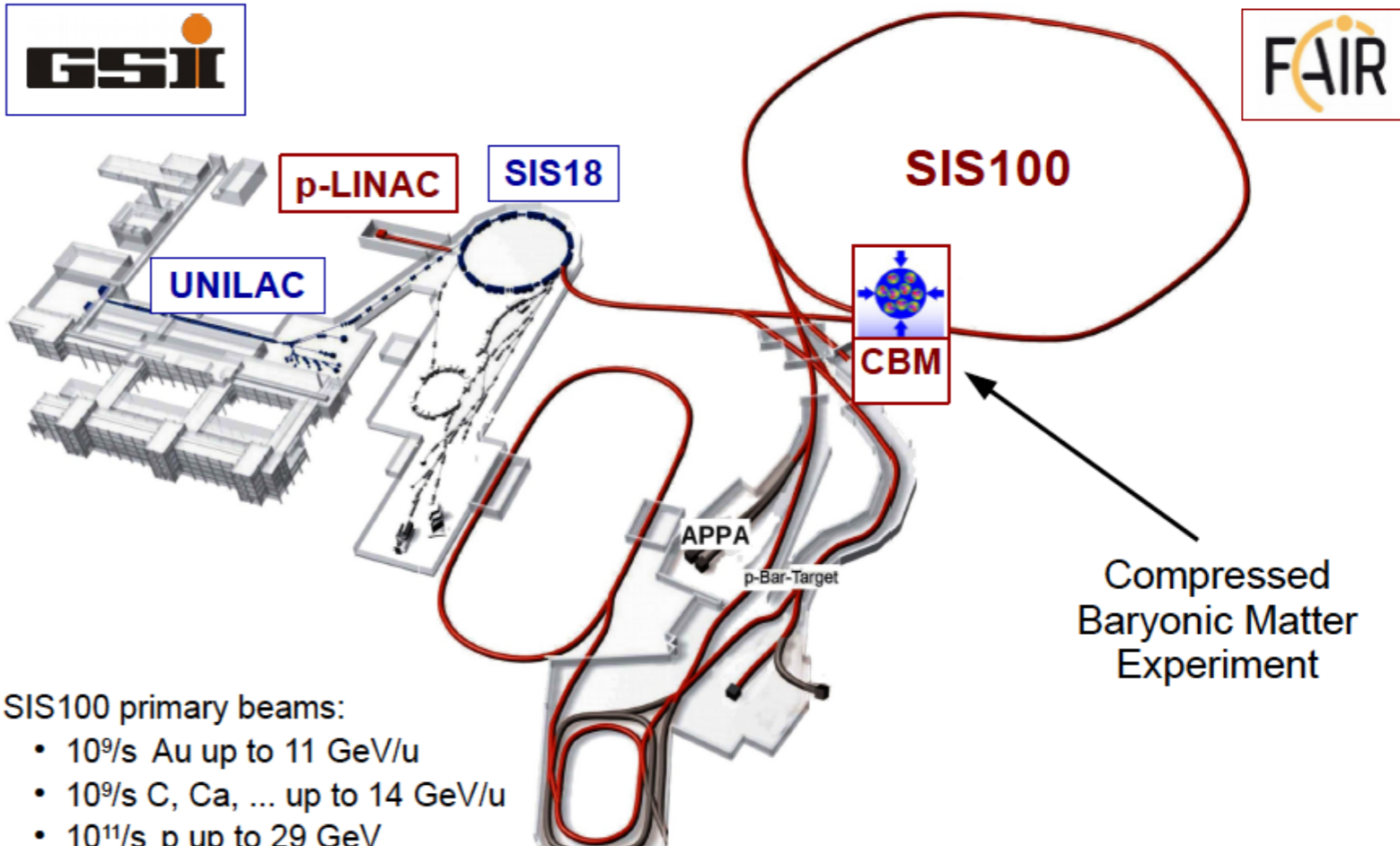
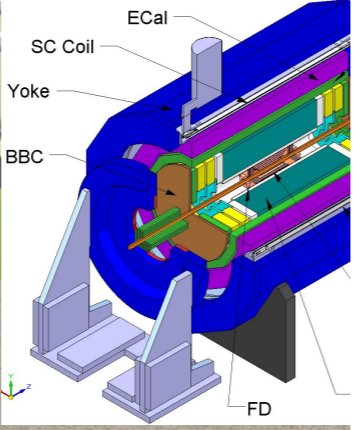
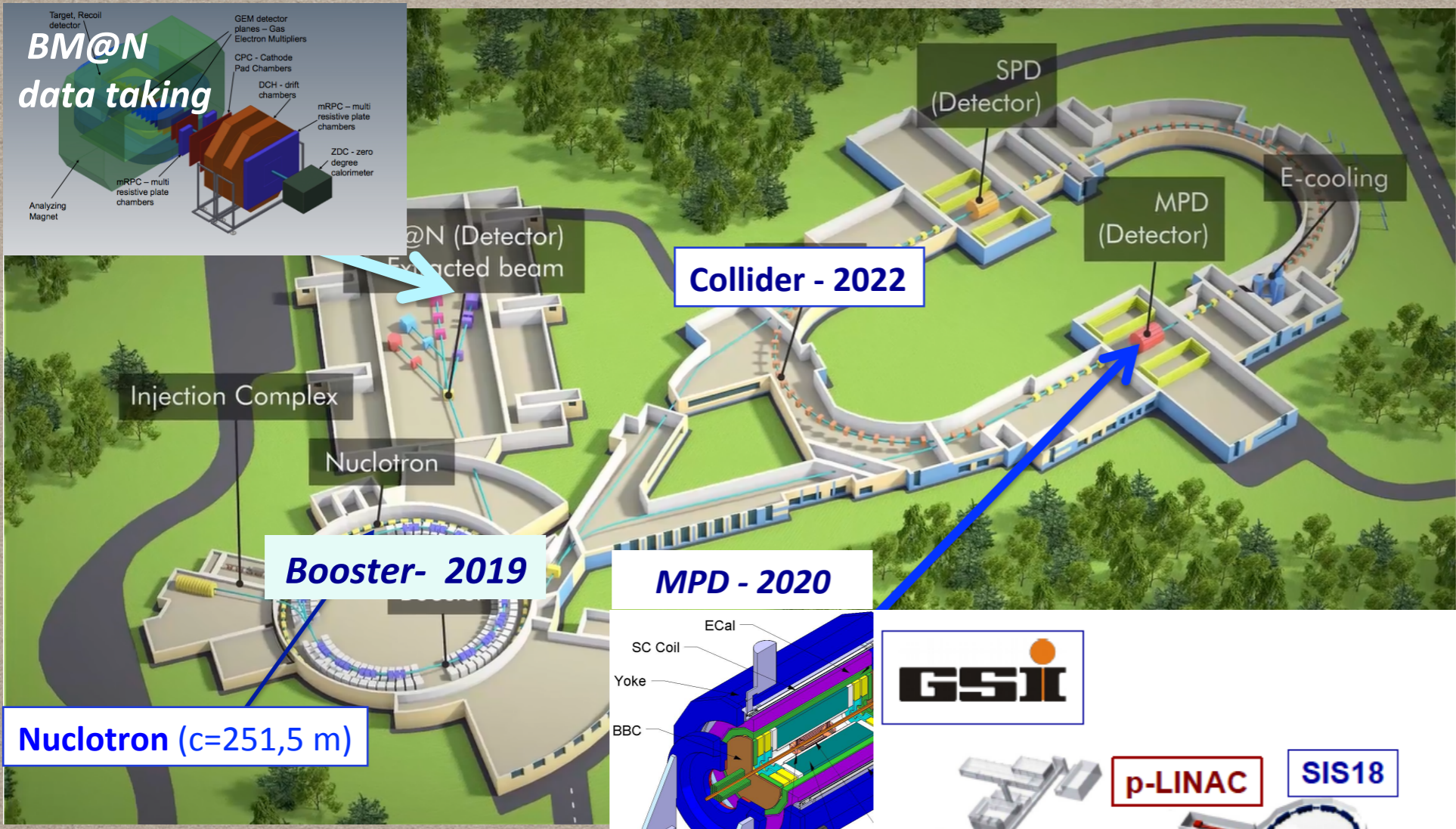
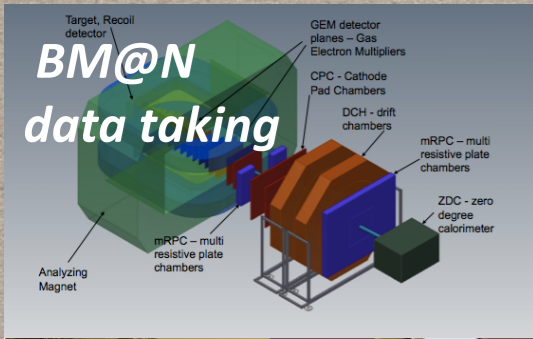
EXPLORING QCD PHASE V (FUTURE)



Critical Point Search
(1st order phase transition)

2030s

EXPLORING QCD PHASE V (FUTURE)

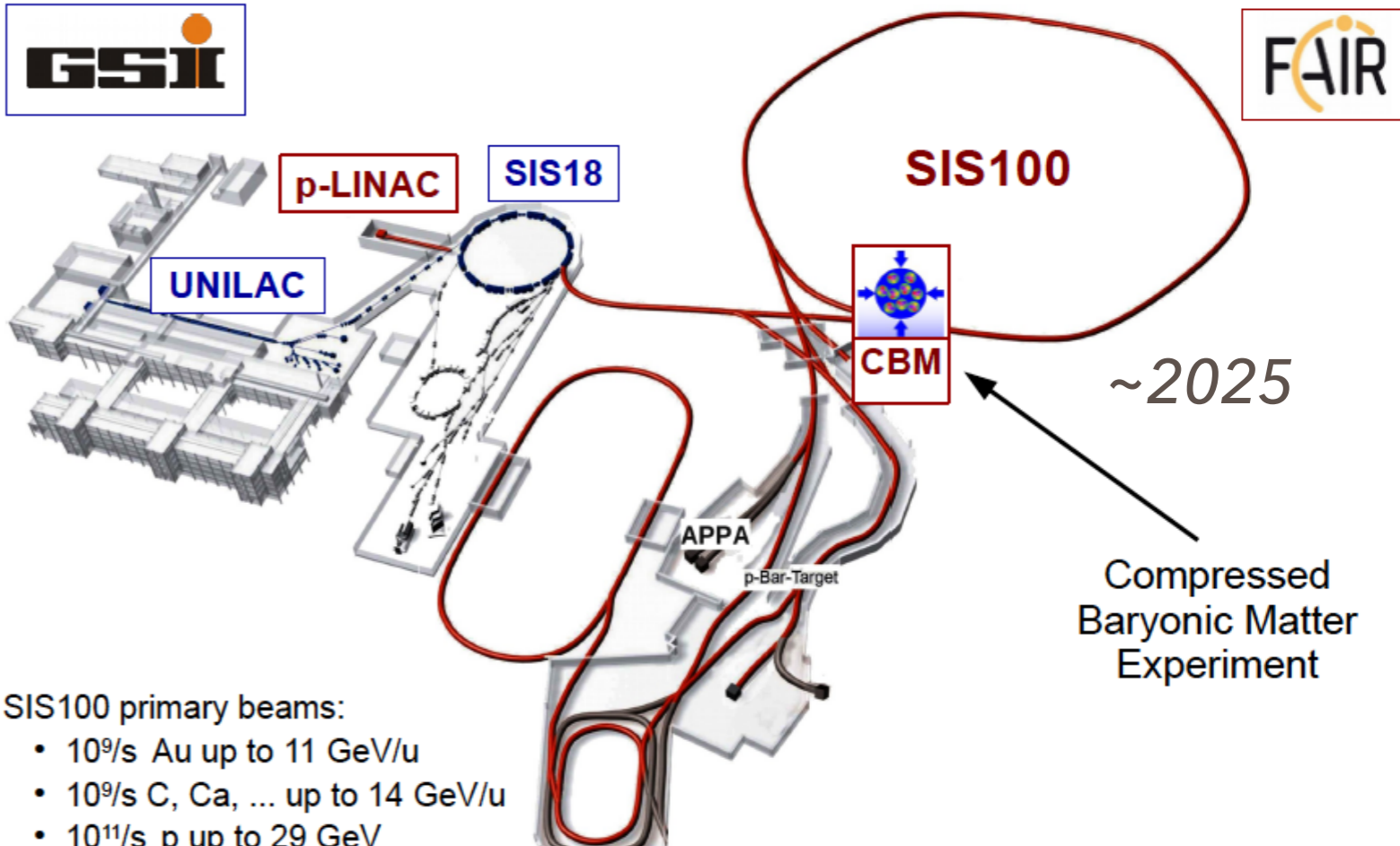
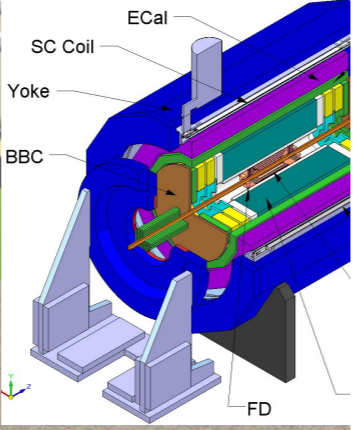
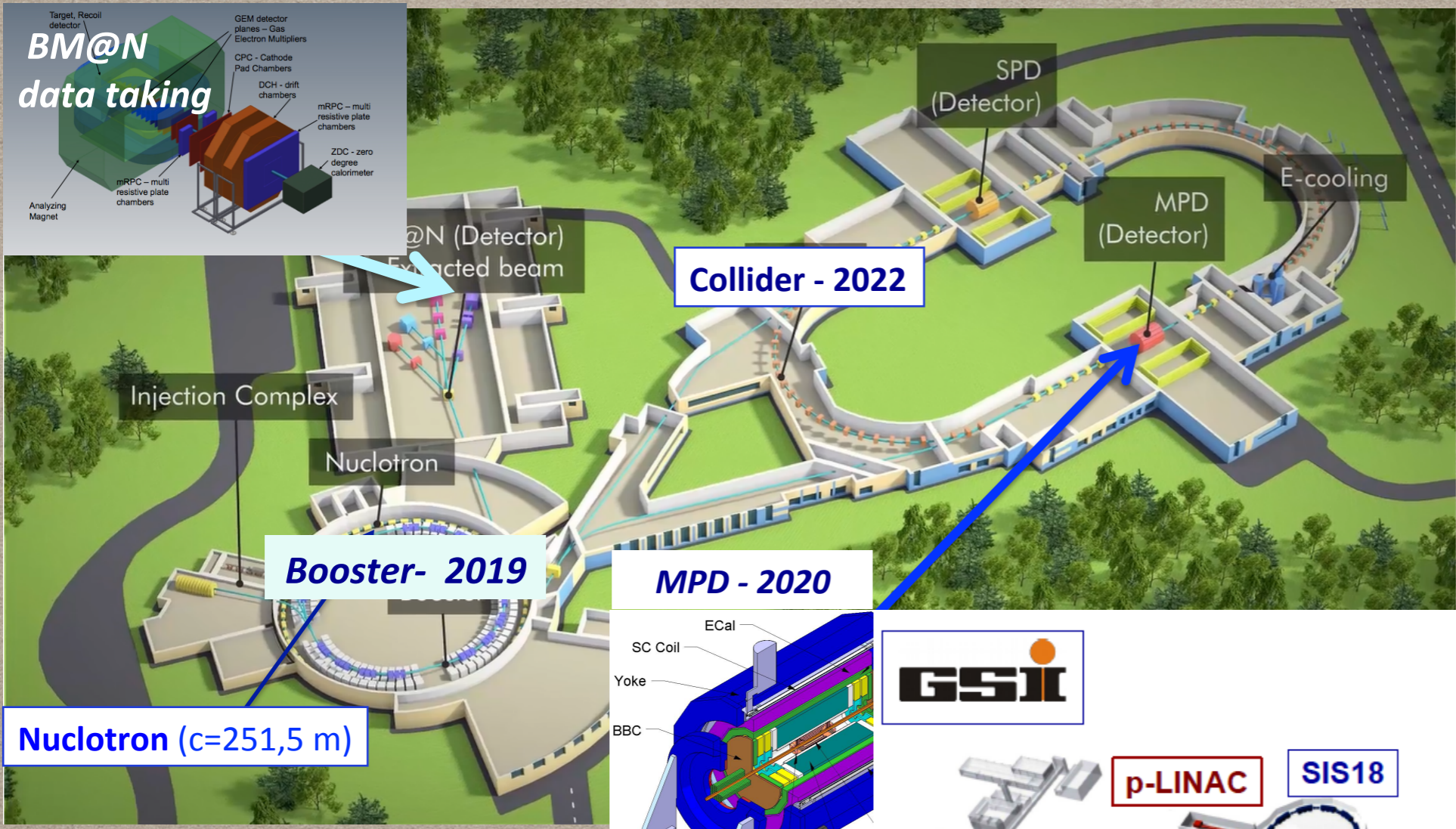
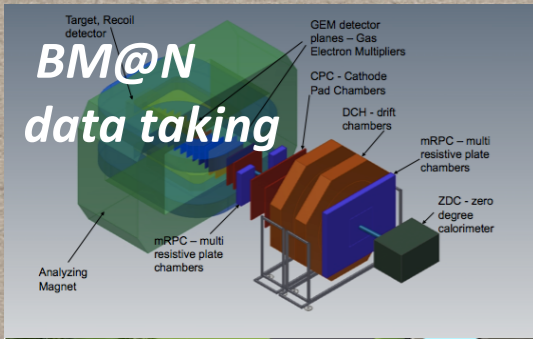


**Critical Point Search
(1st order phase transition)**

- SIS100 primary beams:
- $10^9/s$ Au up to 11 GeV/u
 - $10^9/s$ C, Ca, ... up to 14 GeV/u
 - $10^{11}/s$ p up to 29 GeV

2030s

EXPLORING QCD PHASE V (FUTURE)



**Critical Point Search
(1st order phase transition)**

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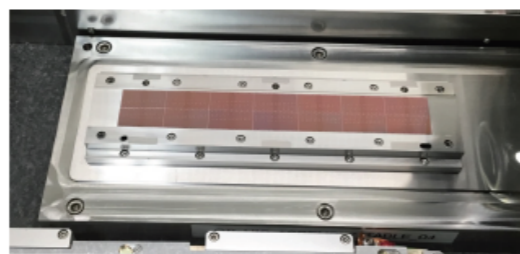
KOREAN CONTRIBUTIONS (ALICE ITS2) (2012 ~ ...)

HIC Production

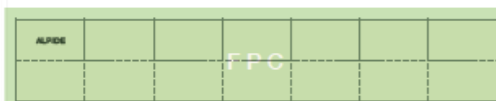
Construction of the elements



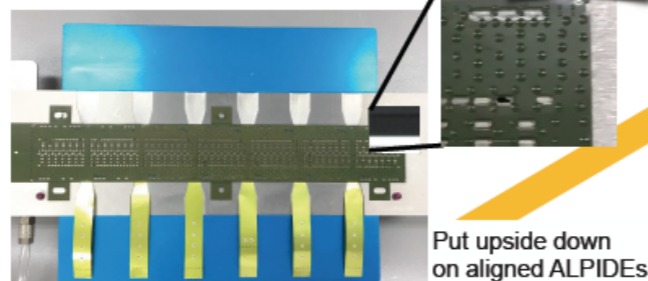
Aligning ALPIDEs
in Position precision <math>< 5\mu\text{m}</math>



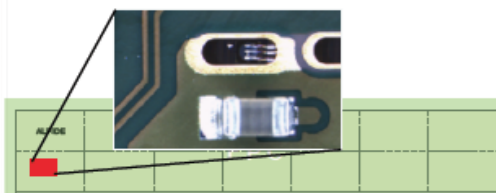
ALPIDE Aligned in ALICIA



Gluing FPC to chips
Mechanical connection



Glued FPC on Gripper



Wire-bonding
Electrical connection

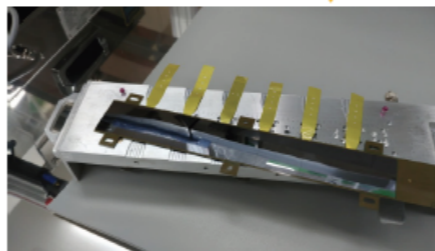
In Pusan/Inha Team, wire-bonding is being done by out-sourcing company MEMSPACK



Pre-Curing in ALICIA (min.) 5 hrs

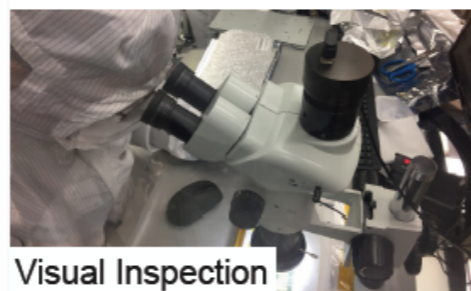
200 OB HIC production + tests completed

Detach HIC from ALICIA

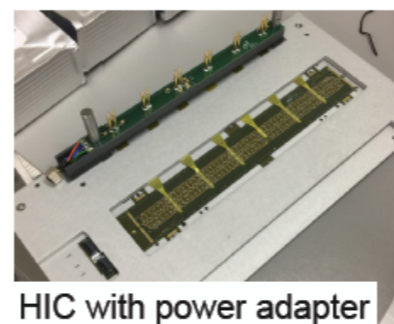


HIC Production

Commissioning procedure

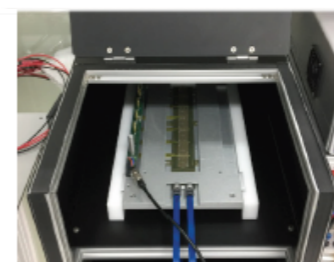


Visual Inspection



HIC with power adapter

- Visual Inspection
 - Confirm bonding quality with microscope
- Impedance Test
 - IV Scan
- Qualification Test
 - Classifying the HIC (Powering, FIFO, Digital Scan, Threshold Scan)
- Endurance Test
 - Long time running test (~ 3.5days)

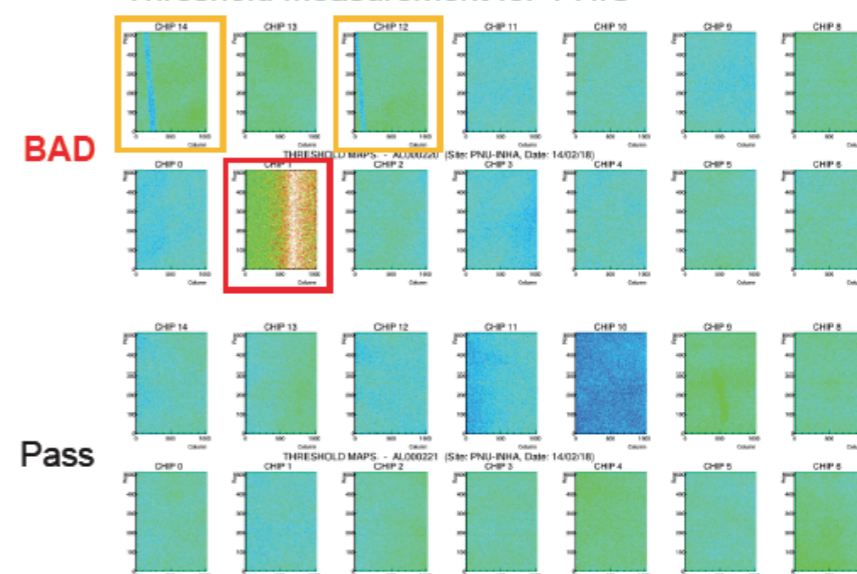


Qualification Test box



Endurance Test Box

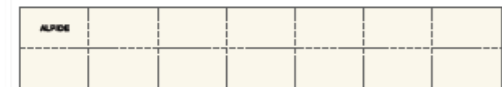
Threshold Measurement for 1 HIC



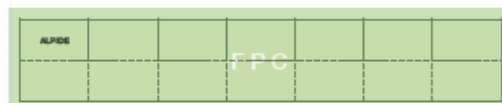
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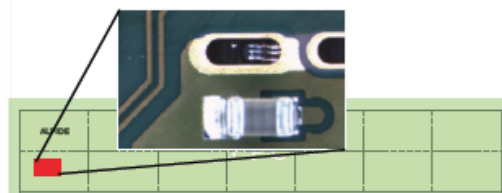
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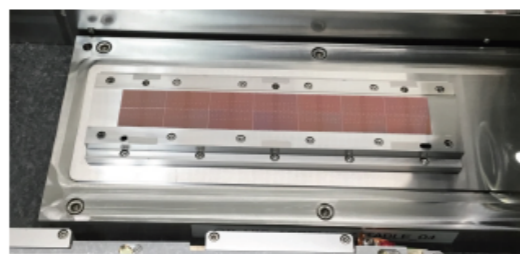
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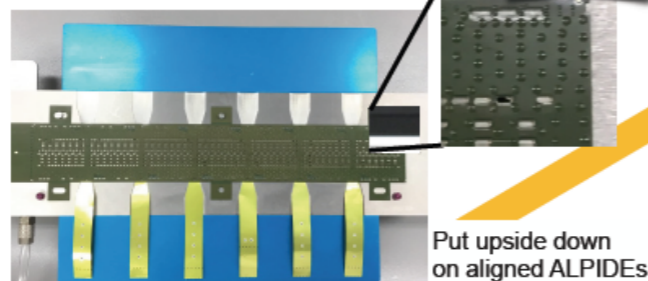
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Wire-bonding
Electrical connection



ALPIDE Aligned in ALICIA



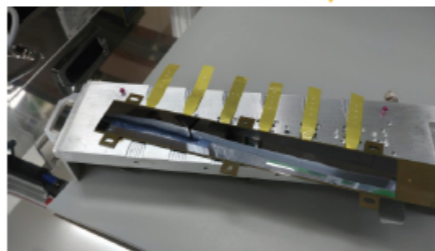
Glued FPC on Gripper

Put upside down on aligned ALPIDEs

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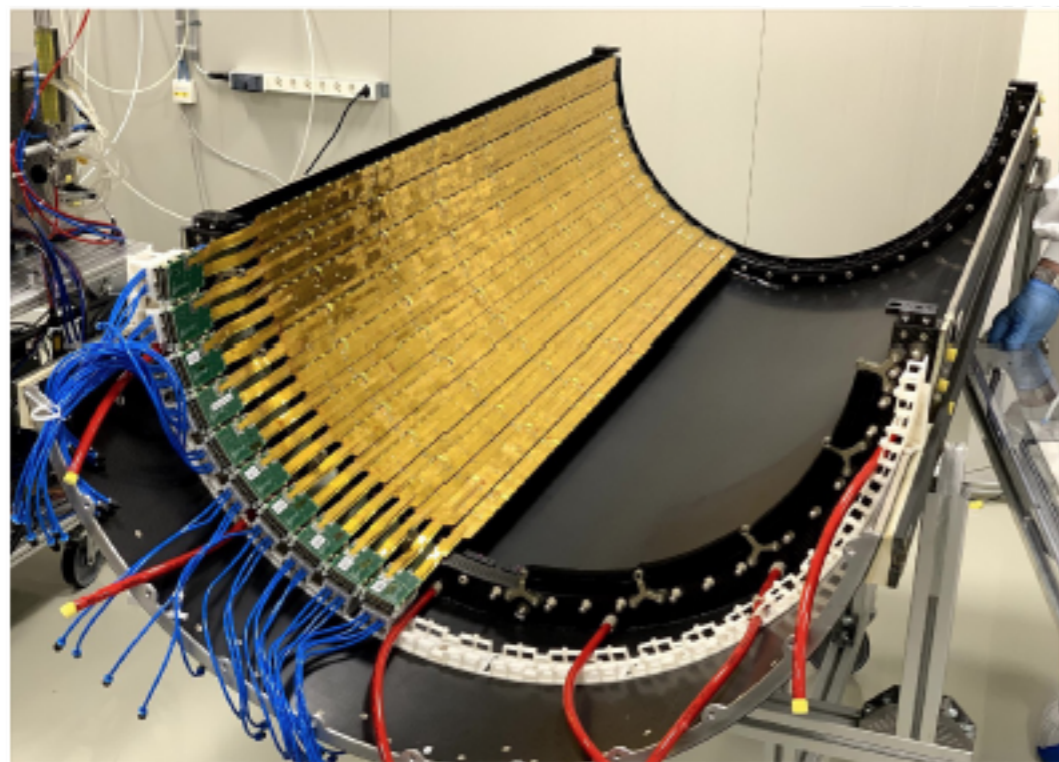
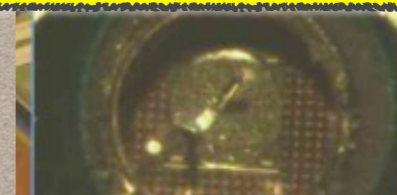


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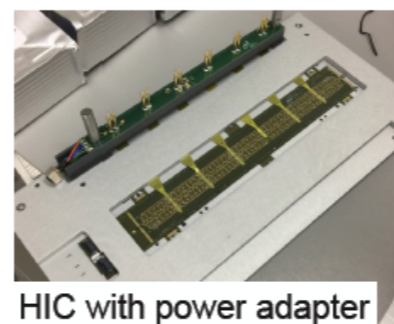
Detach HIC from ALICIA

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Production

ing procedure



HIC with power adapter

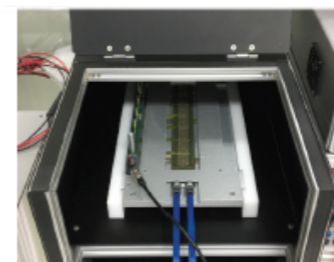
ection

onding quality with microscope

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on Test

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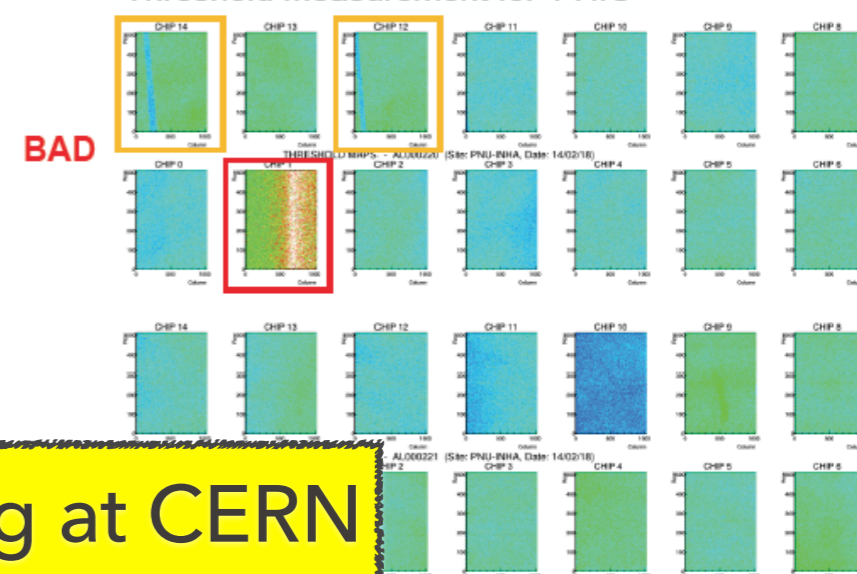


Qualification Test box



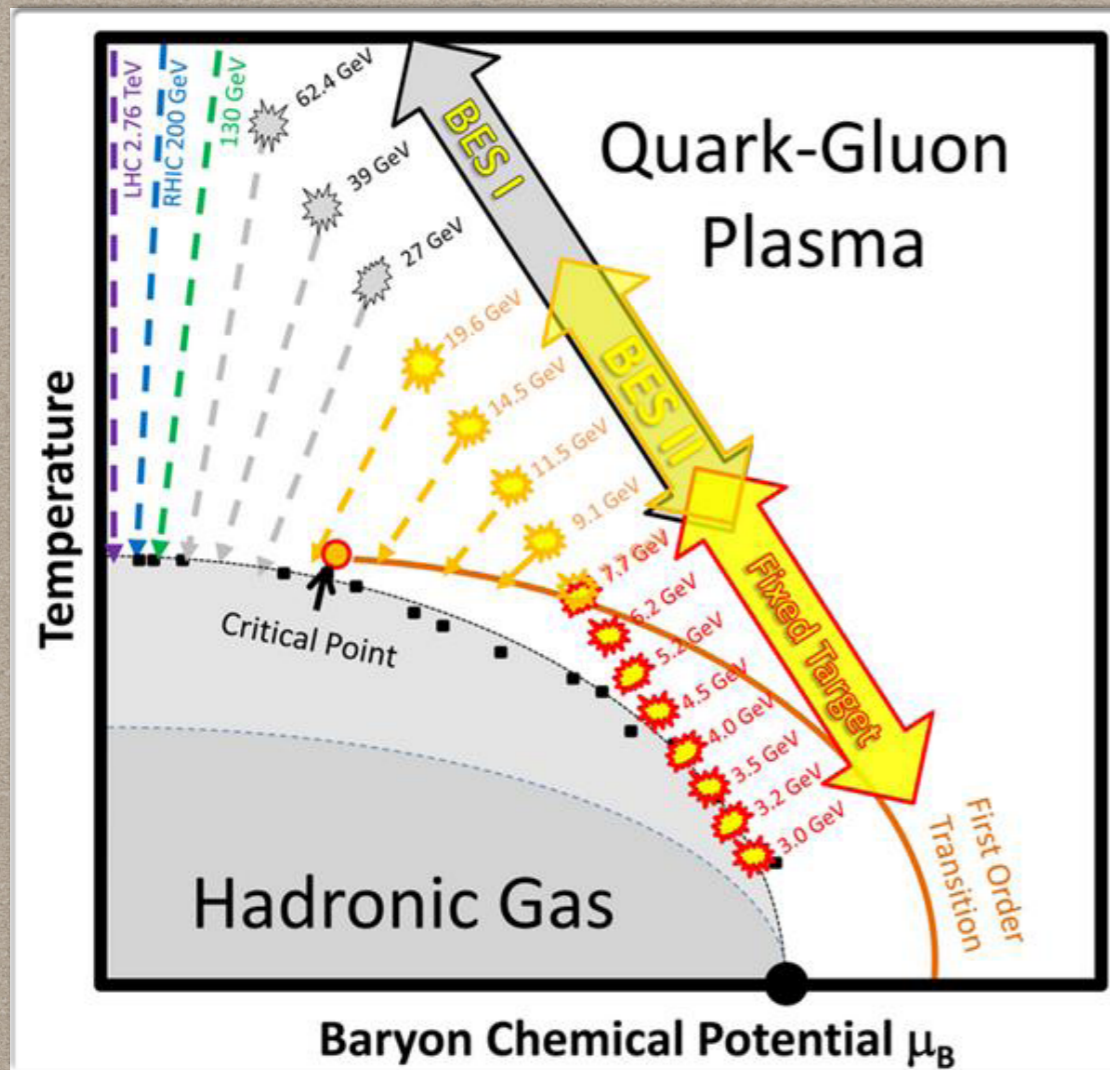
Endurance Test Box

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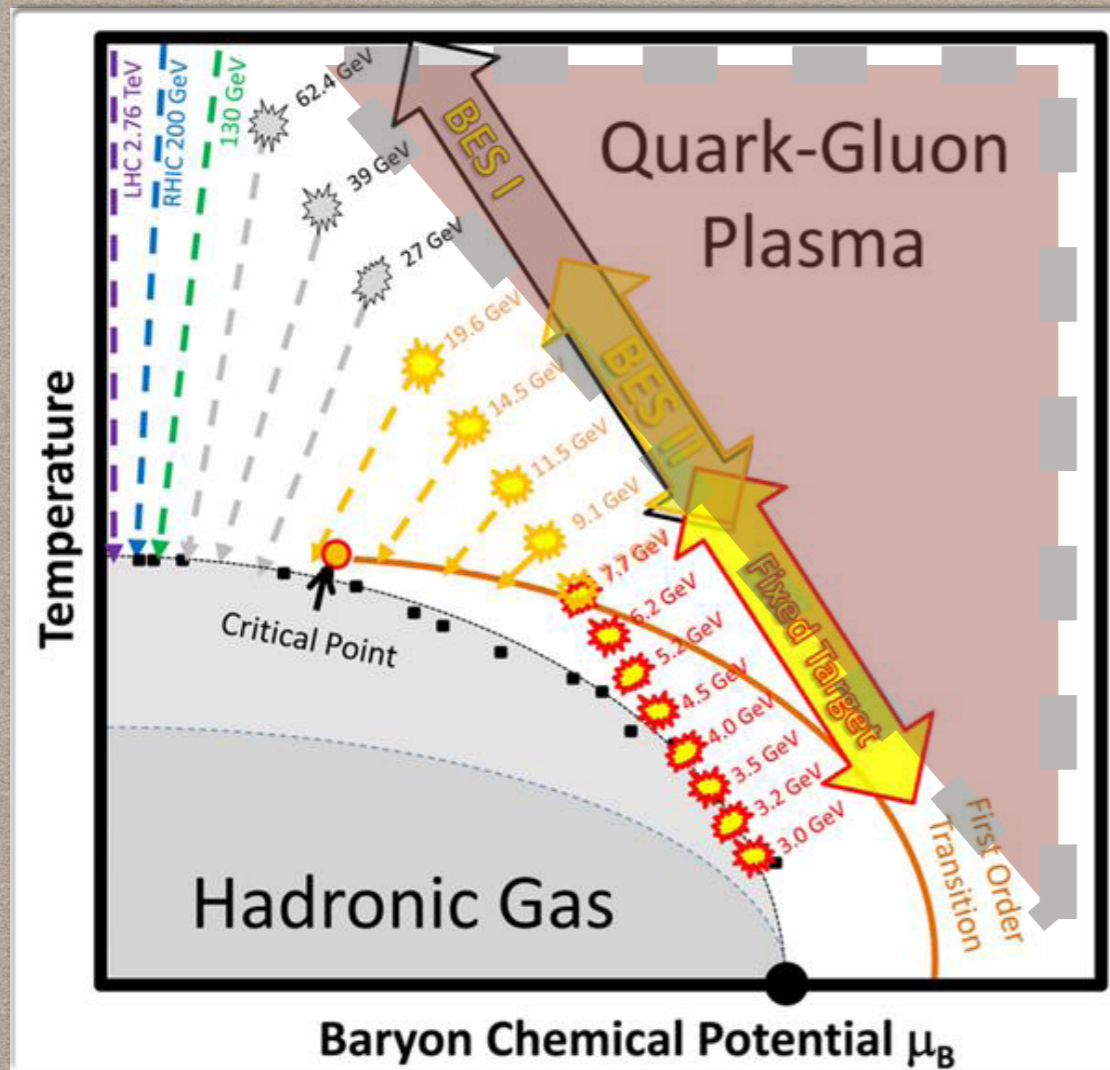


Final assembly & Commissioning is NOW ongoing at CERN

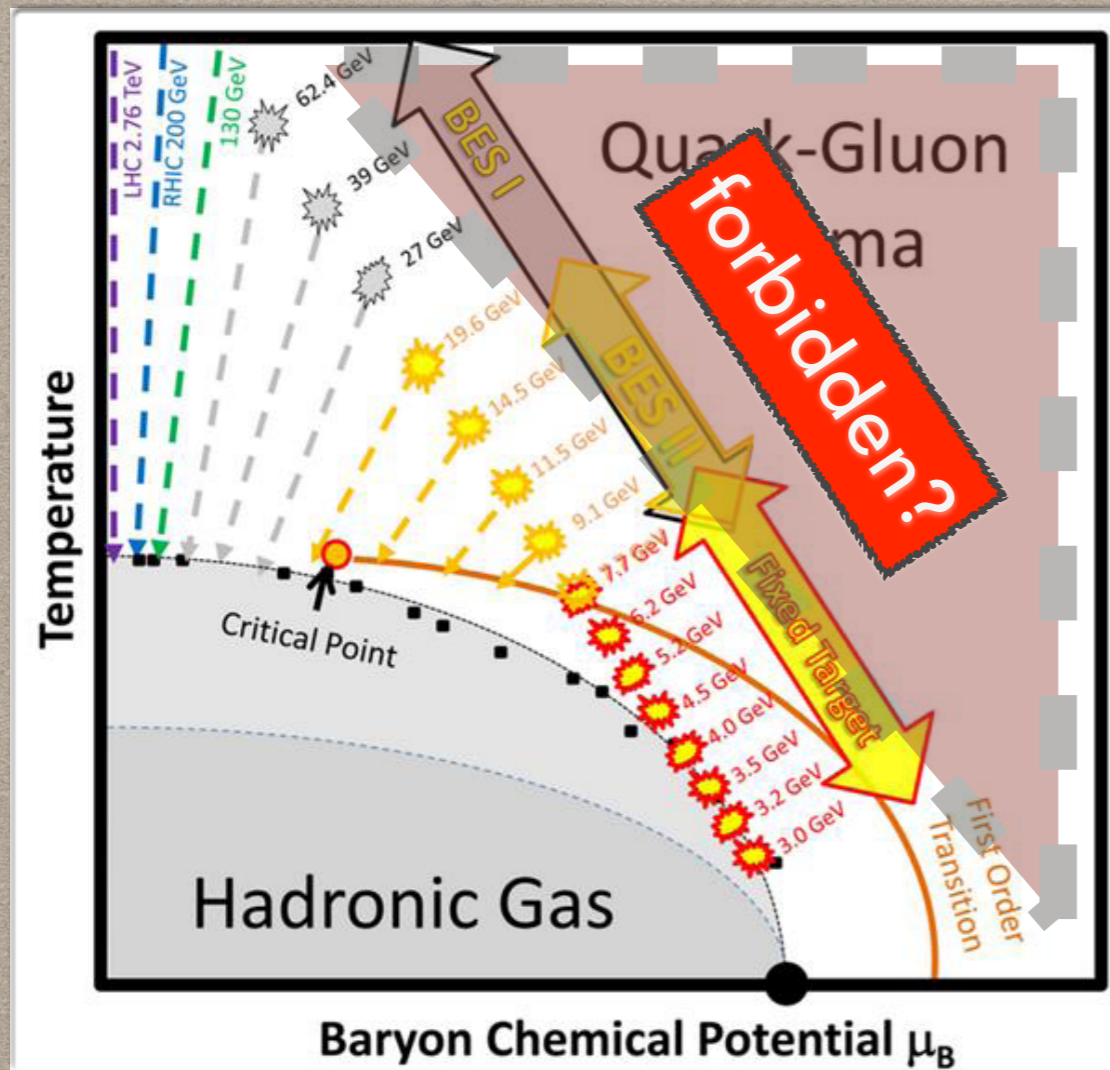
EXPLORING QCD PHASE-X



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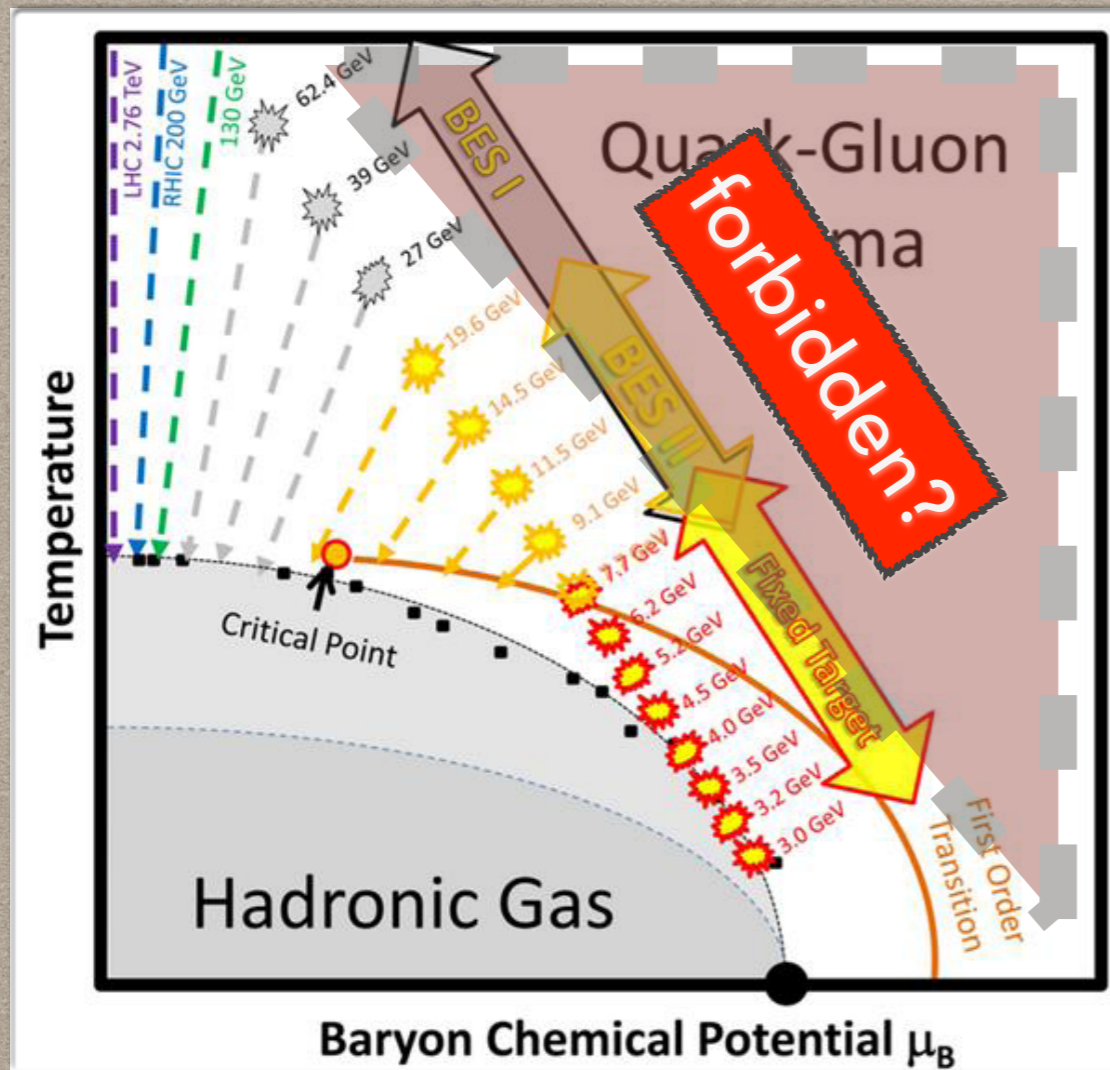


EXPLORING QCD PHASE-X

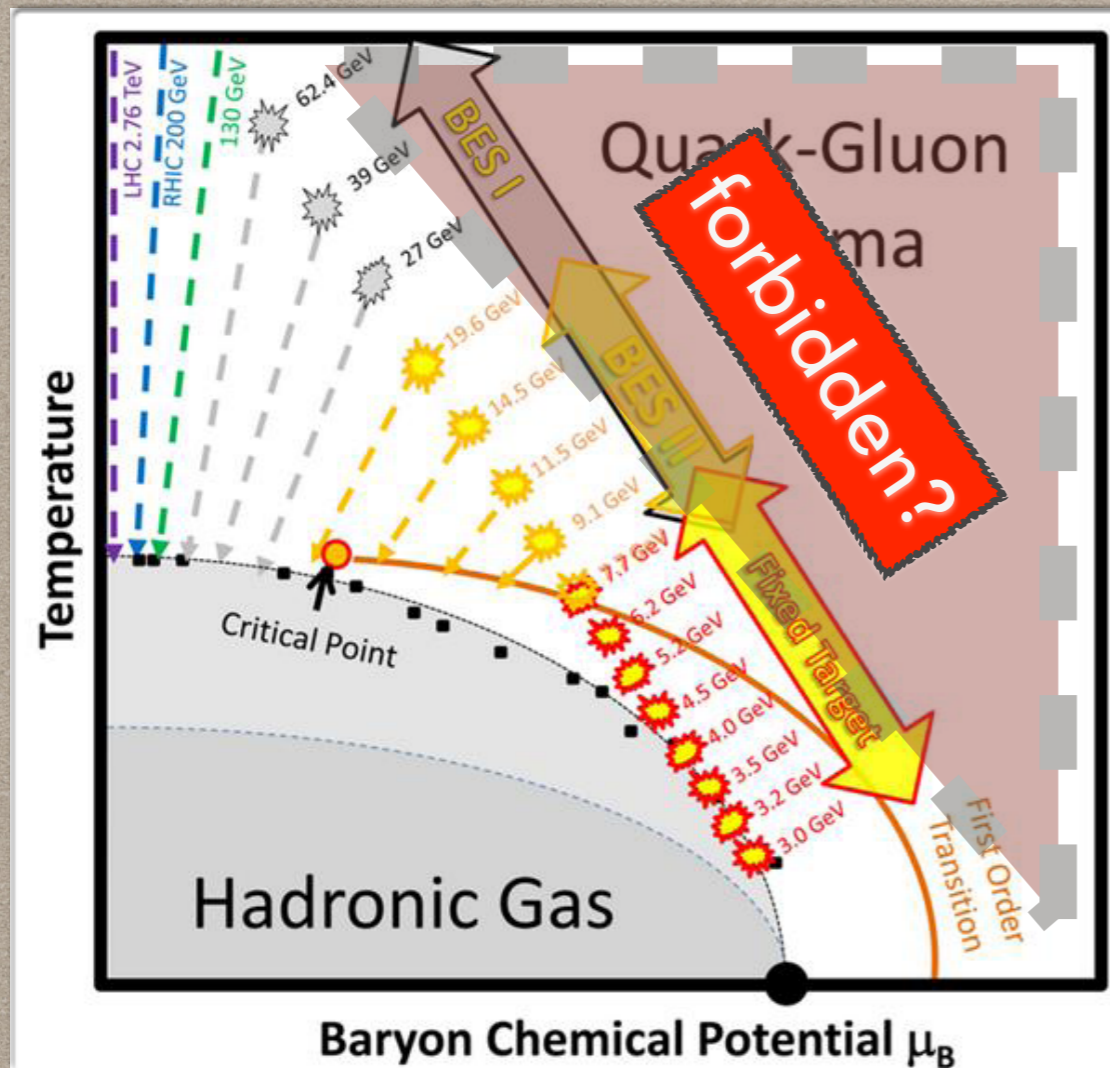


EXPLORING QCD PHASE-X

- Experimental Dilemma

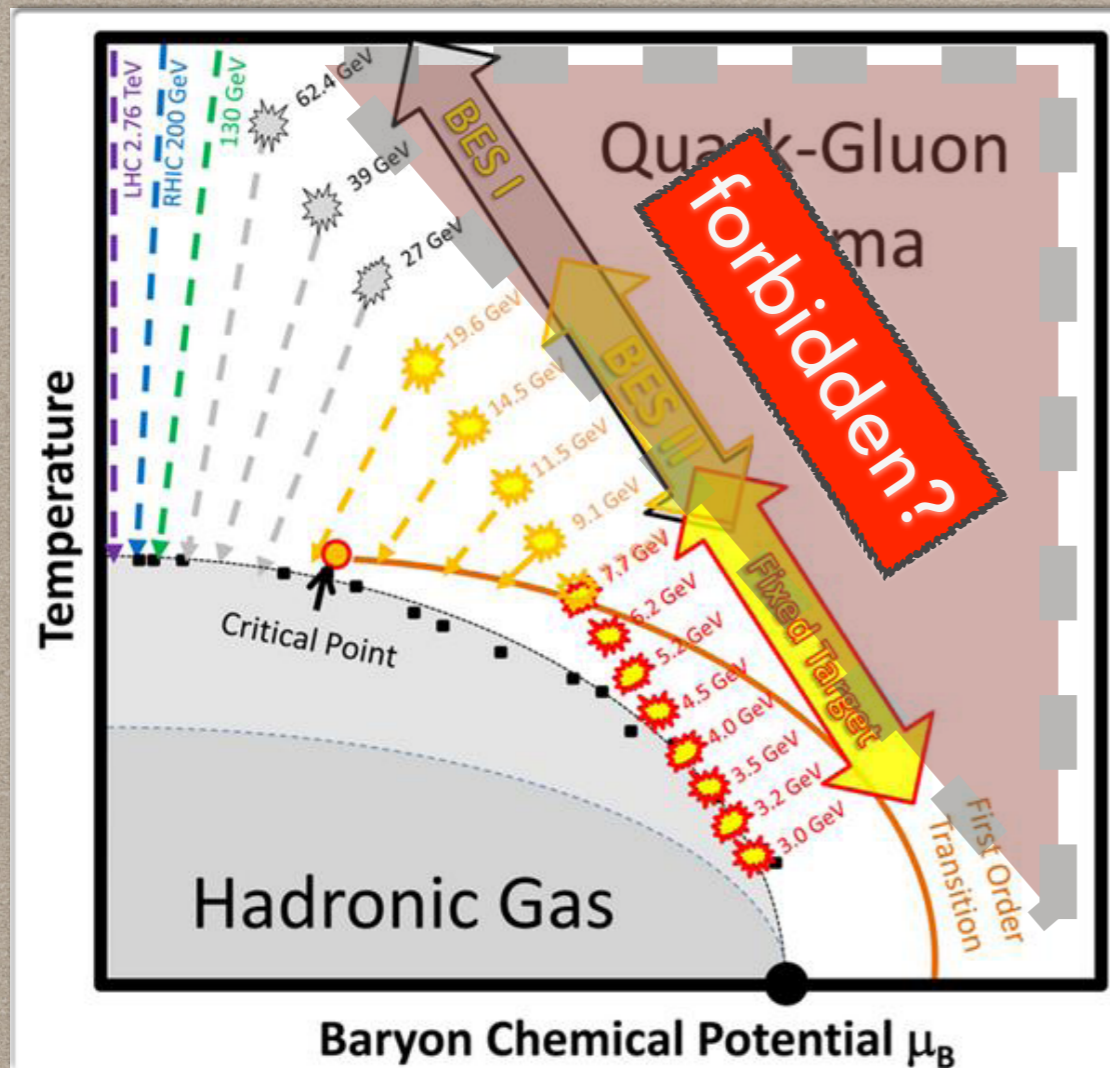


EXPLORING QCD PHASE-X



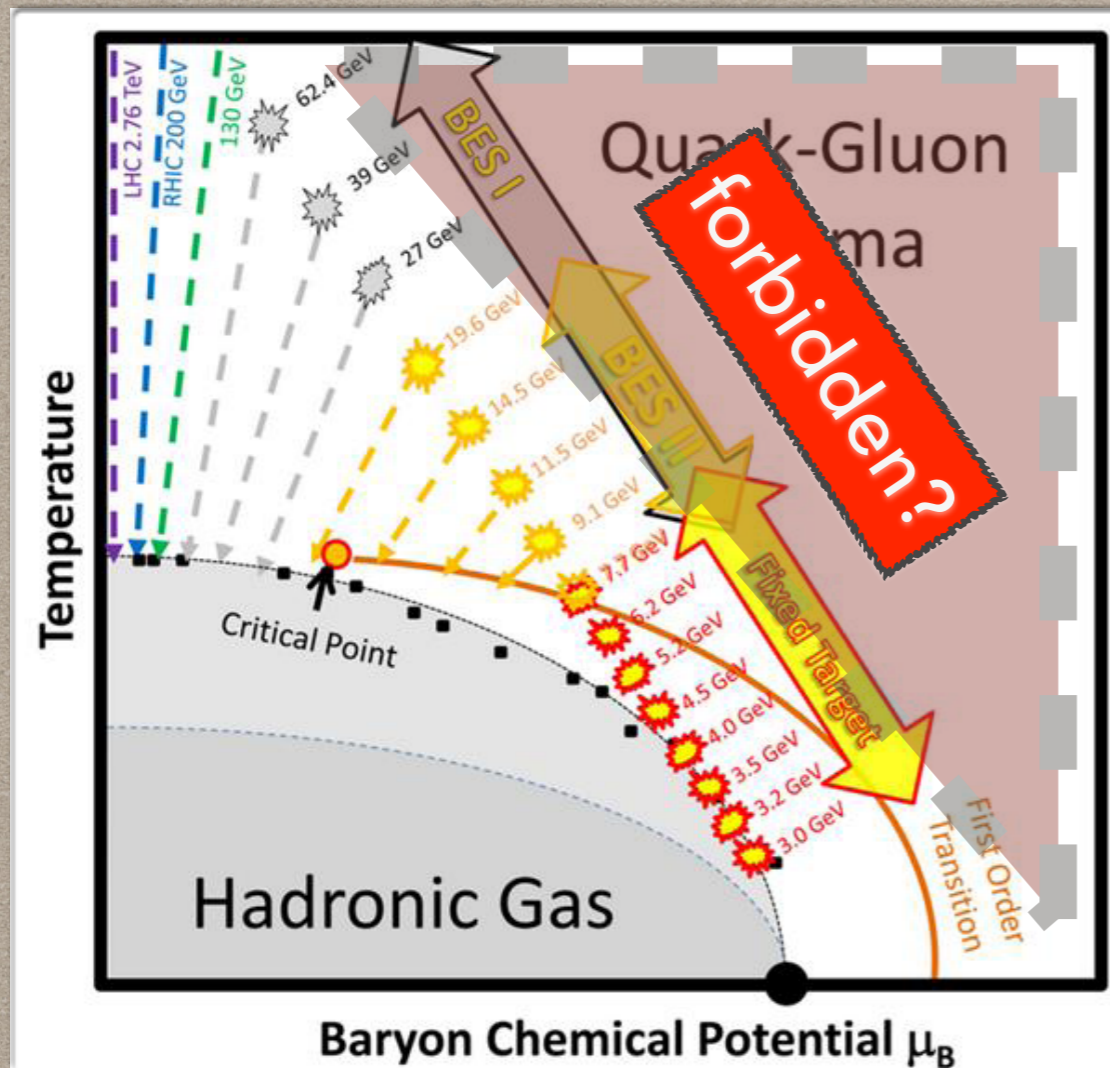
- Experimental Dilemma
- How to touch 'high T & μ' region?

EXPLORING QCD PHASE-X



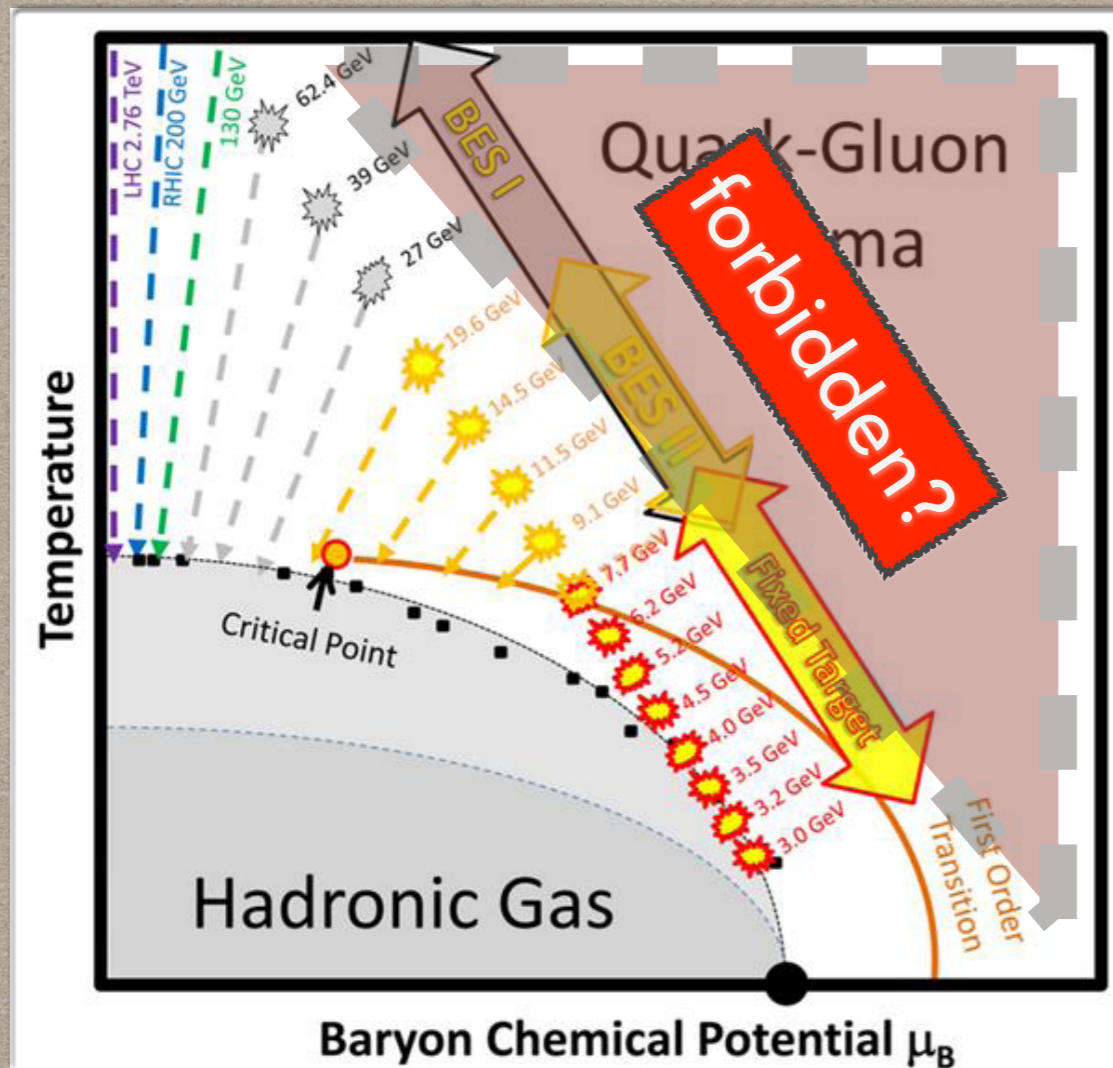
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- Collider + Target?

EXPLORING QCD PHASE-X

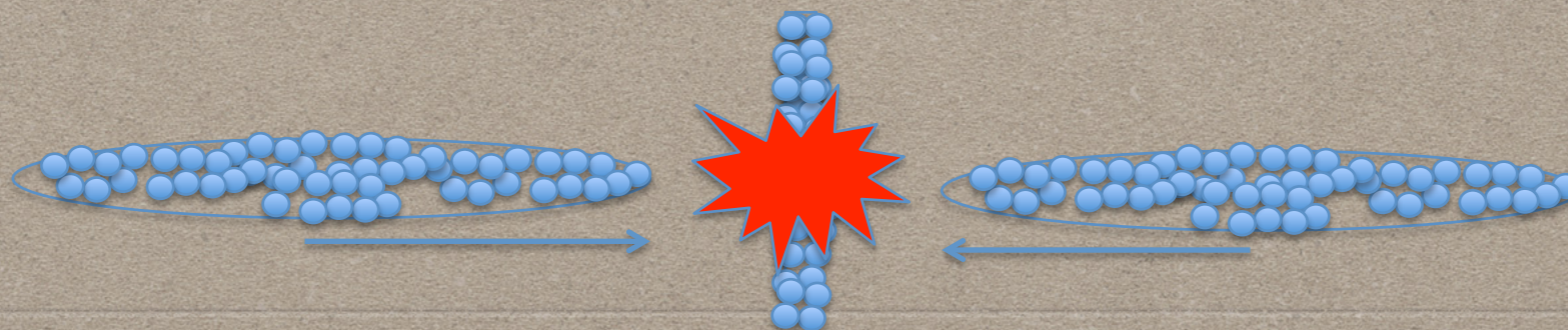


- Experimental Dilemma
- How to touch 'high T & μ' region?
- Collider + Target?
- Tri-Ilision

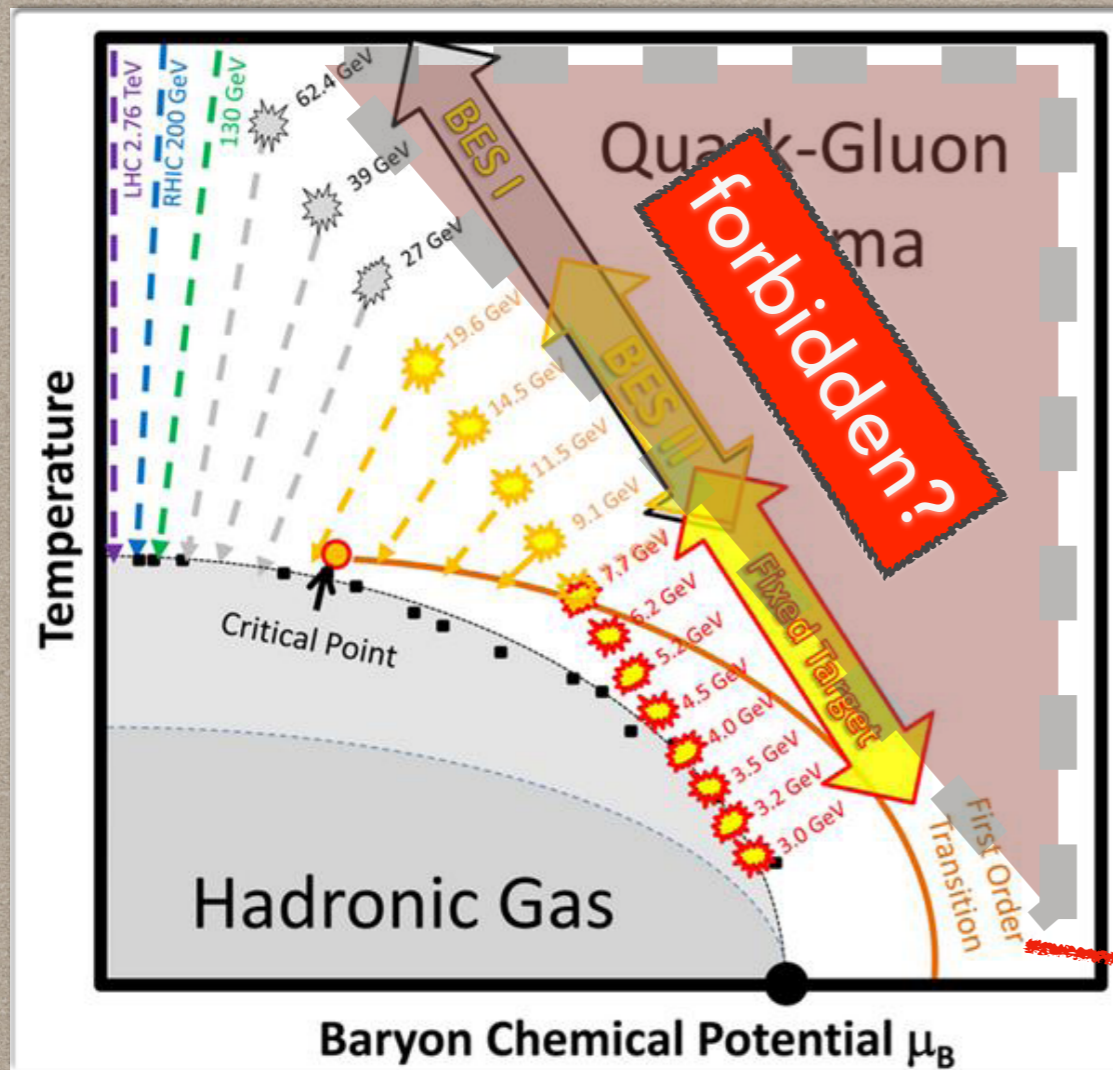
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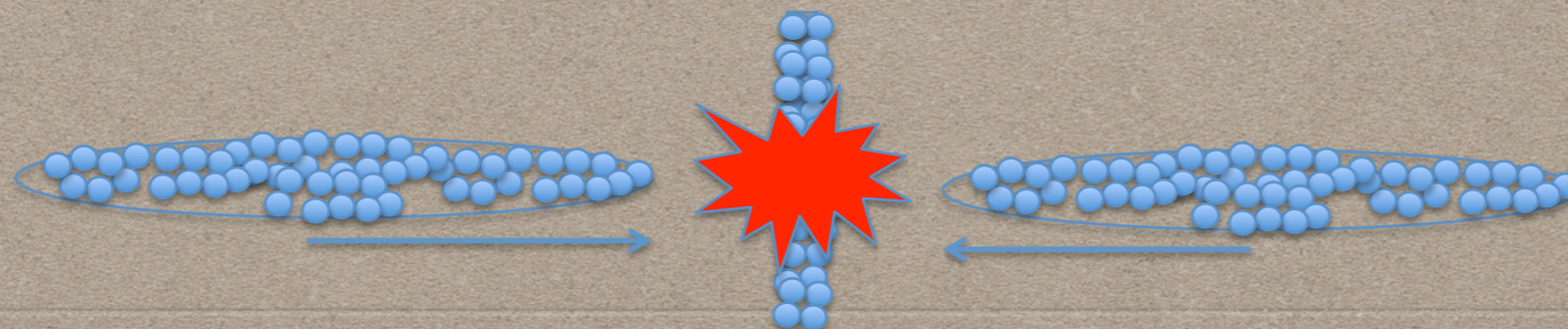
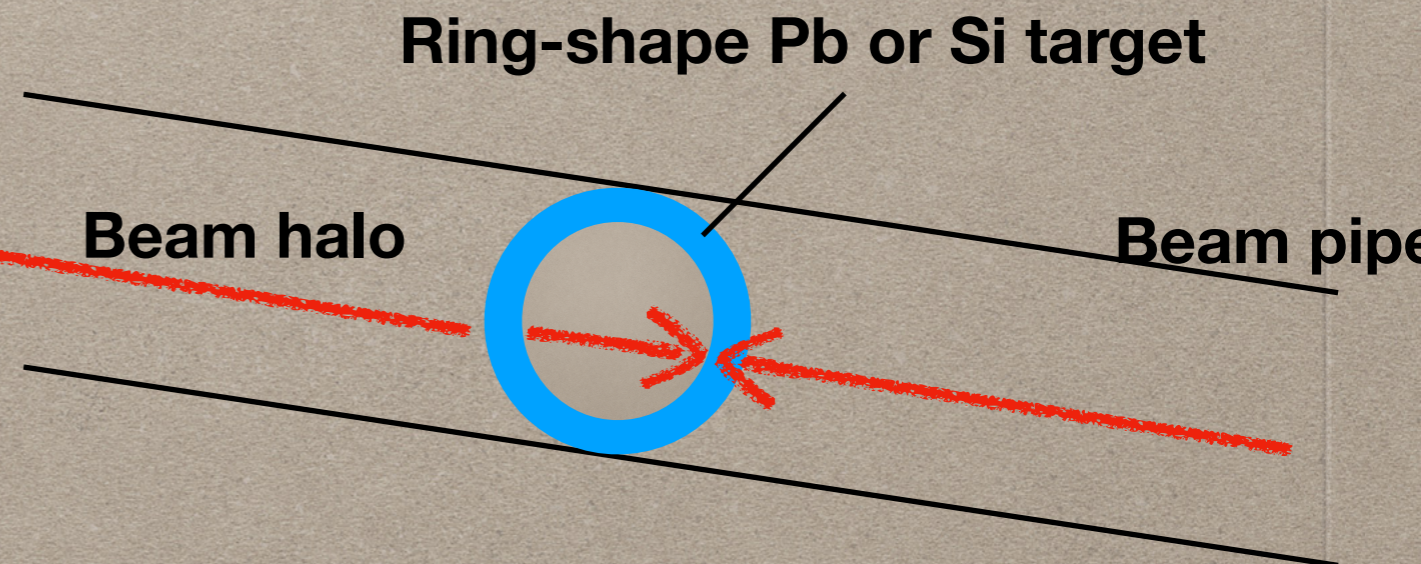
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EXPLORING QCD PHASE-X



- Experimental Dilemma
- How to touch 'high T & μ' region?
- Collider + Target?
- Tri-Illusion



WHERE WE ARE

- KPS Nuclear Division ~ 100 incl. students
 - LENS (Low Energy Nuclear Science): RIKEN, ISOLDE ... RAON
 - HAPHY (Hadron Physics): JLab, JPARC ... RAON
 - HIM (Heavy Ion Meeting): CERN (ALICE, CMS), BNL (STAR, PHENIX,... sPHENIX), FAIR (CBM) ... RAON
 - Application, Neutron etc.
- Accelerators
 - Pohang Light Source (PLS)
 - Korea Multi-purpose Accelerator Complex (Proton@100MeV)
 - RAON

HIGH ENERGY NAT'L LAB. (BLL)

- The **0th step** for possible Korean contributions to the world-community:
Nat'l lab based on RAON
- **Particle - Nuclear - Astro physics + (seed) Accelerator**
- Centering Manpower, Budgets
- Centering Infrastructure (shops, computing etc.)
- International Network Center for fundamental science
- **Issue:**
 - **Accelerator Operation (Governance) Service for users?**
 - **Separation of Applied (Technology) and Fundamental one (Science)**
 - **Any form of endorsement (workshop output?) would be helpful**