Quark Gluon Plasma at LHCb

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LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Rencontres des Jeunes Physicien(ne)s 2019

Quarks? Gluons?

- What is matter made of?

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10^{-1}m

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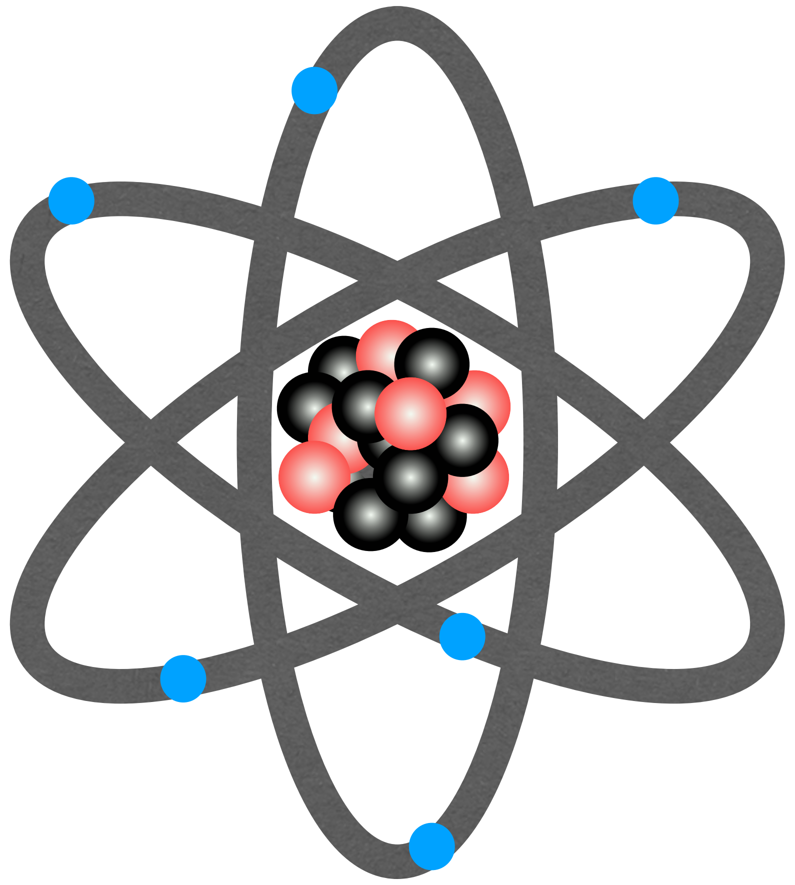

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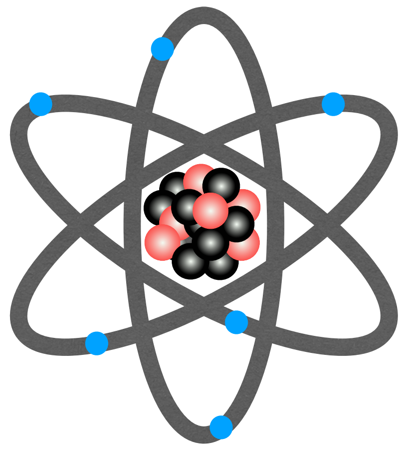

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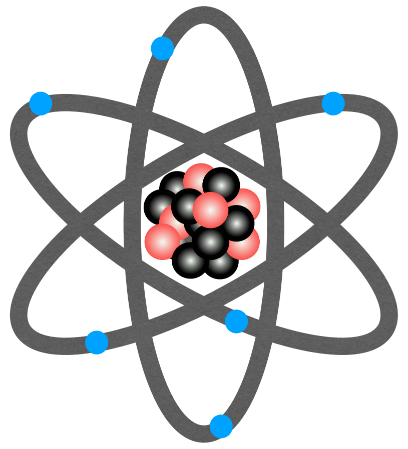

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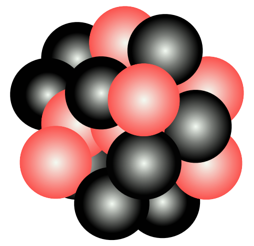

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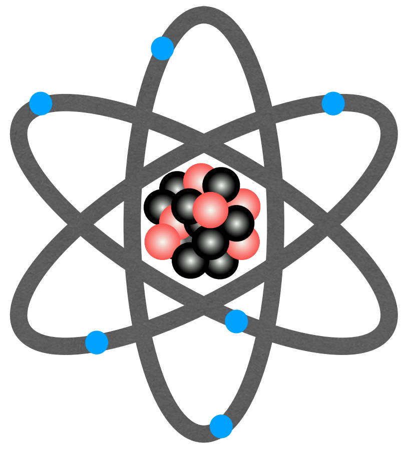

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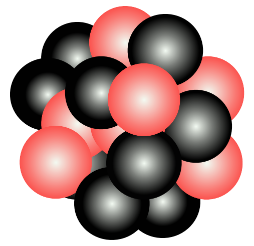

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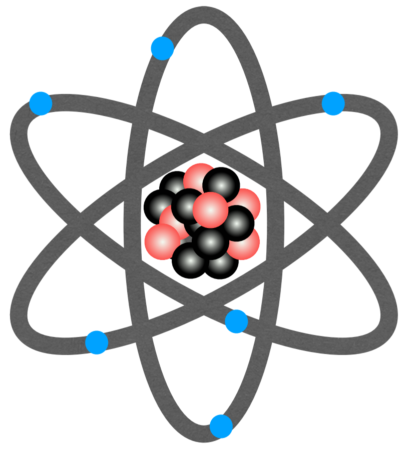

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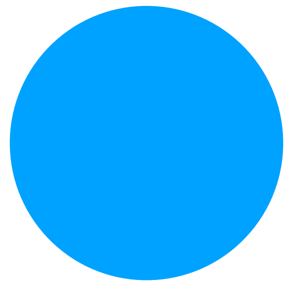

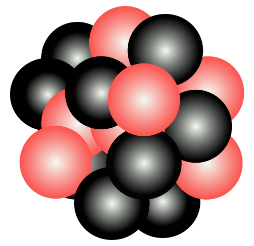

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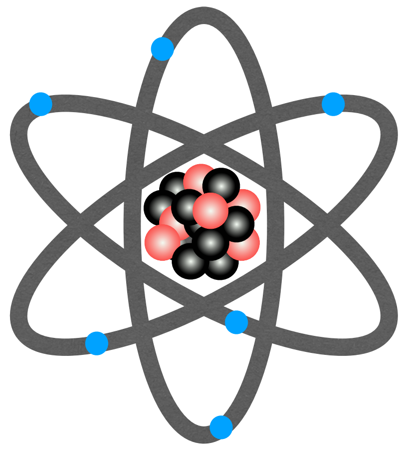

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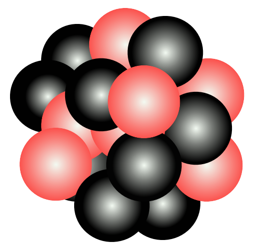

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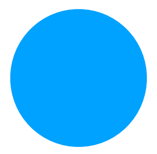

10^{-18}m

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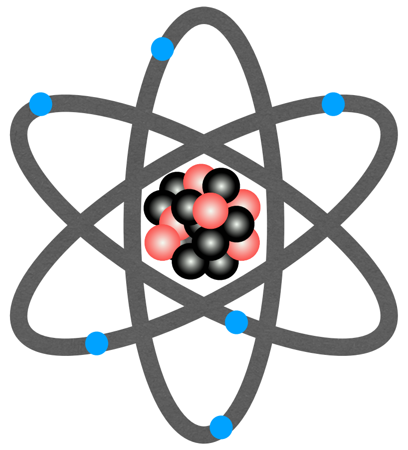

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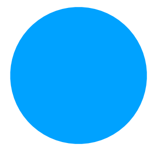

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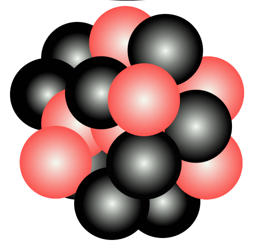

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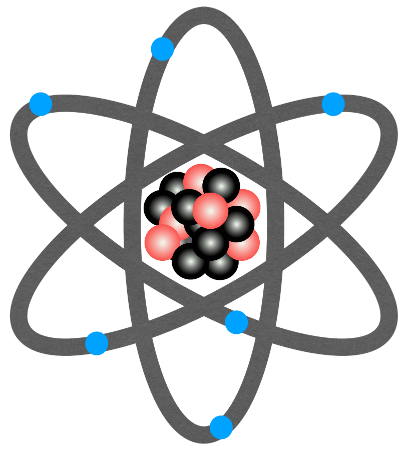

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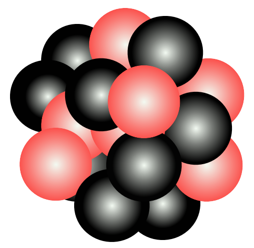

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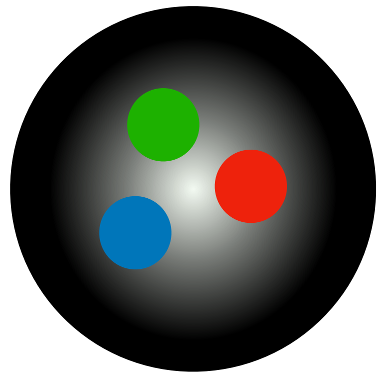

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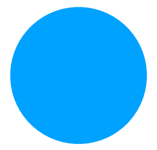

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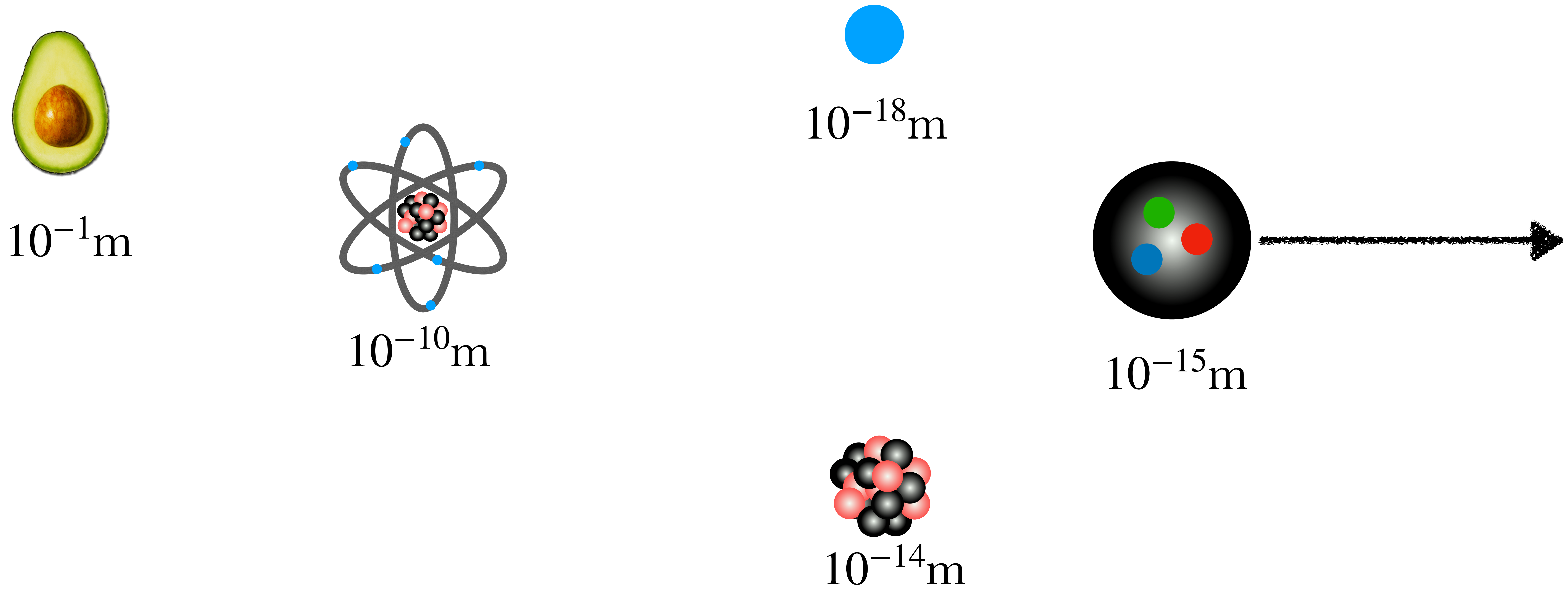

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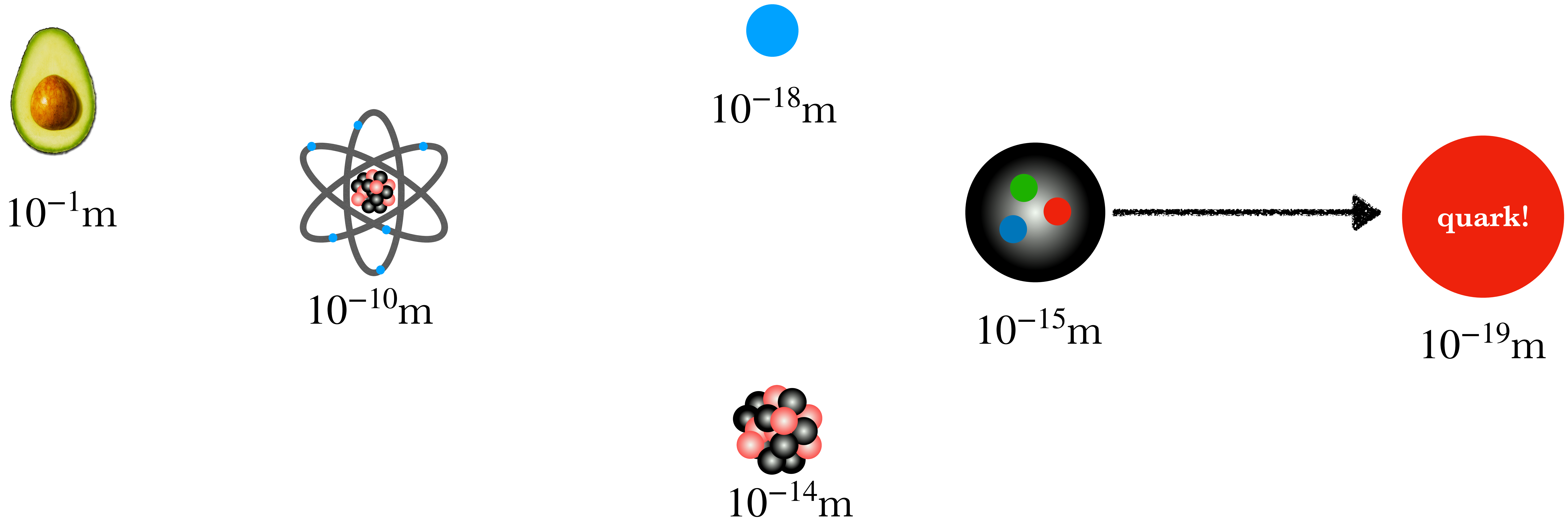

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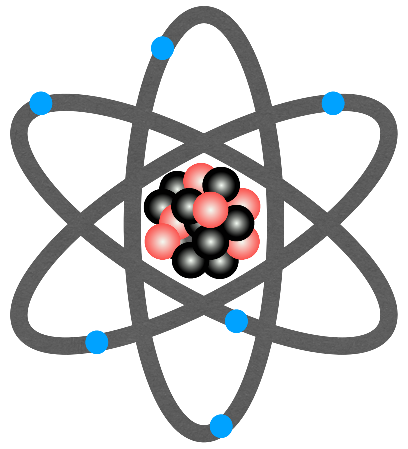

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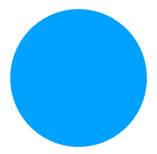

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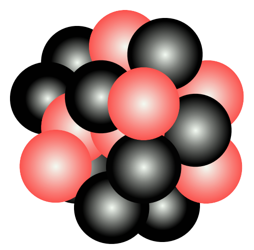

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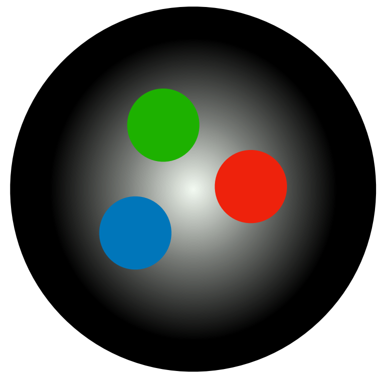

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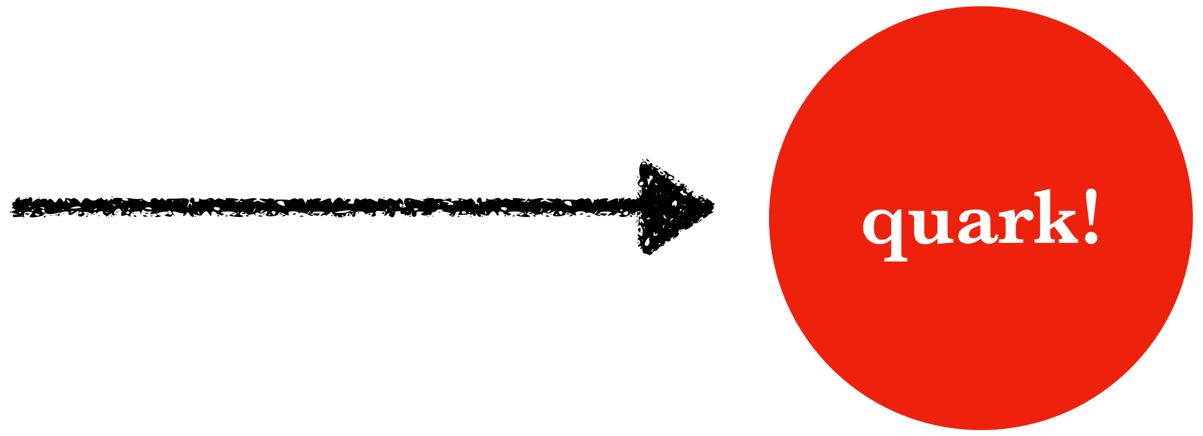


10^{-19}m

But that is not the whole story!

Quarks? Gluons?

❖ In order to keep Quarks stuck together, we need more:

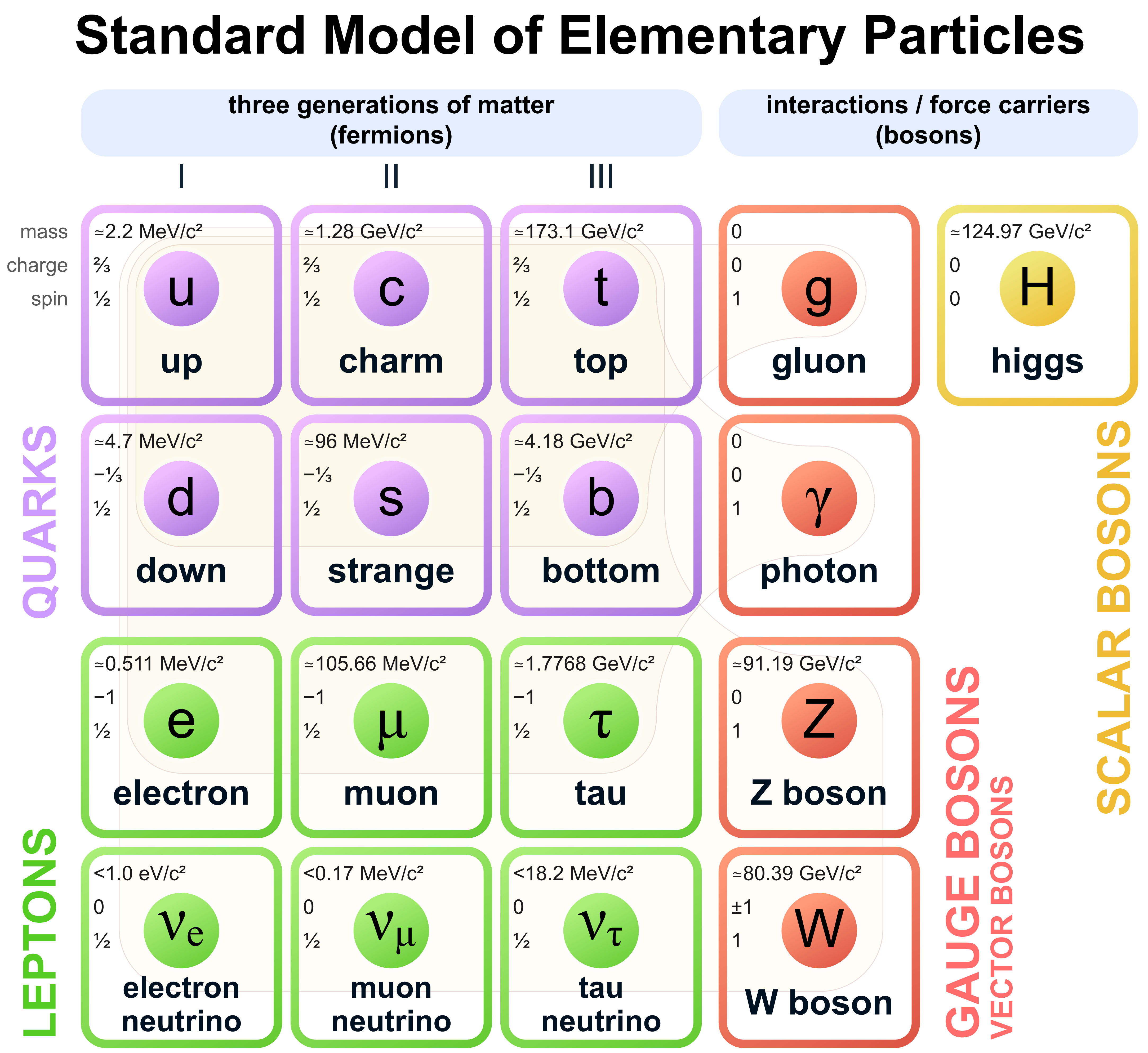
⇒ GLUONS!

together with quarks, they carry colour charge.

❖ Gluons are the carriers of the Strong Force.

❖ Comes with a caveat:

- Any final state must be “white” or colourless.
- We cannot observe quarks alone, they must be in “packages”.



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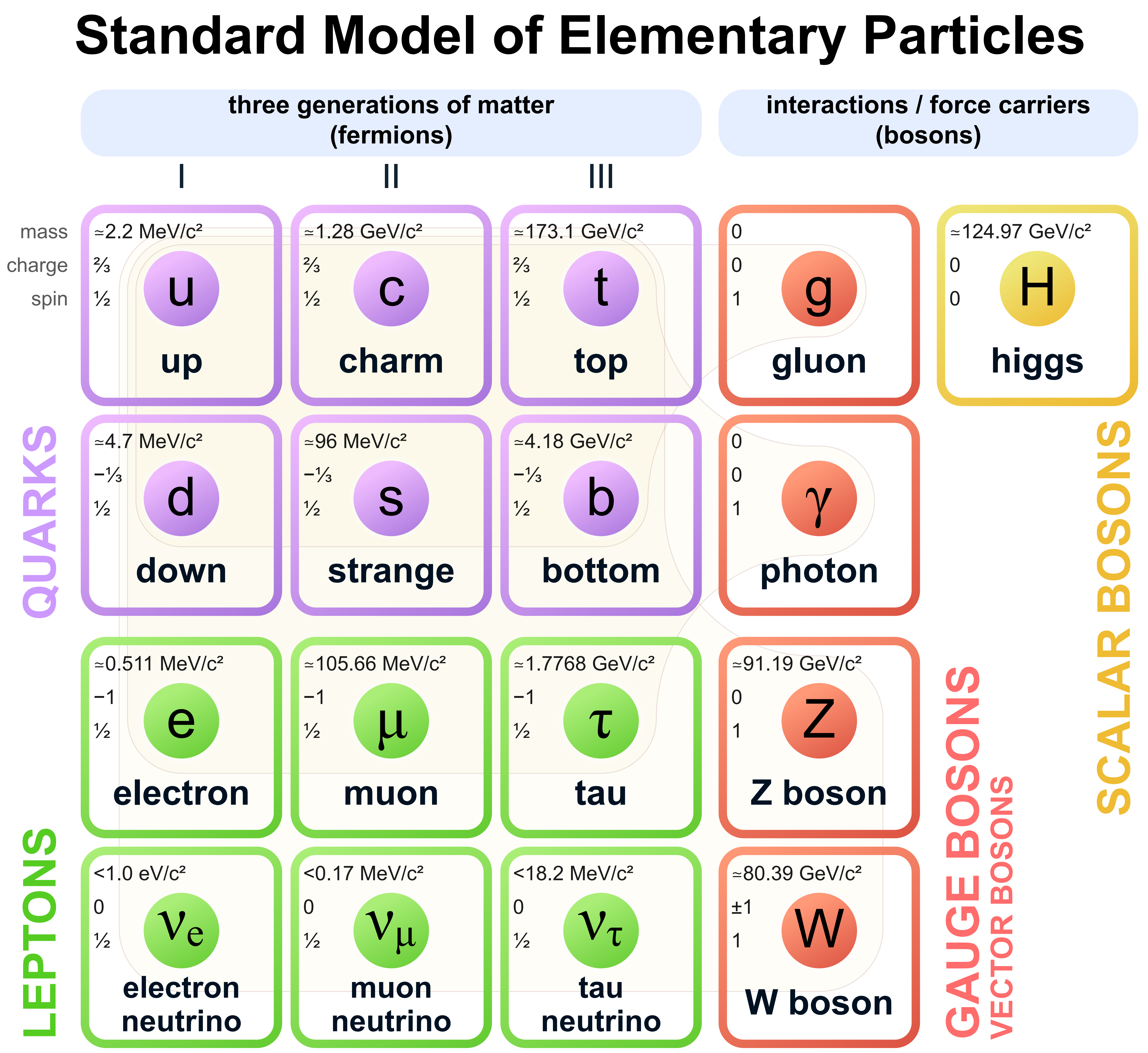
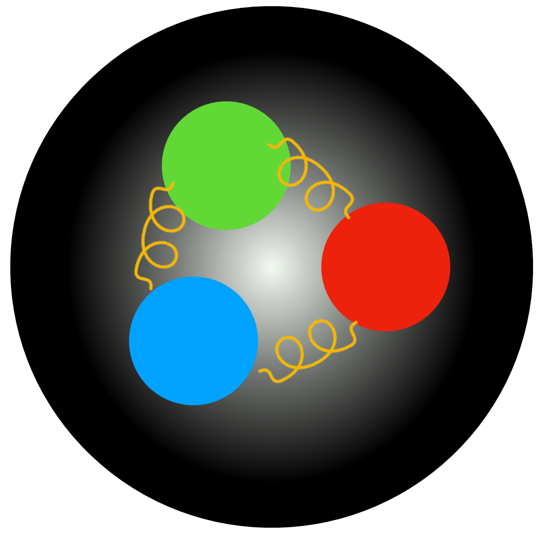
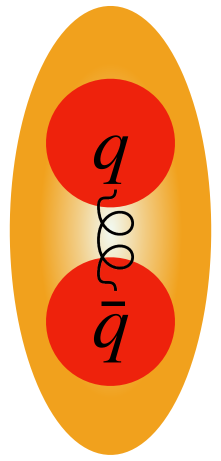
Confinement



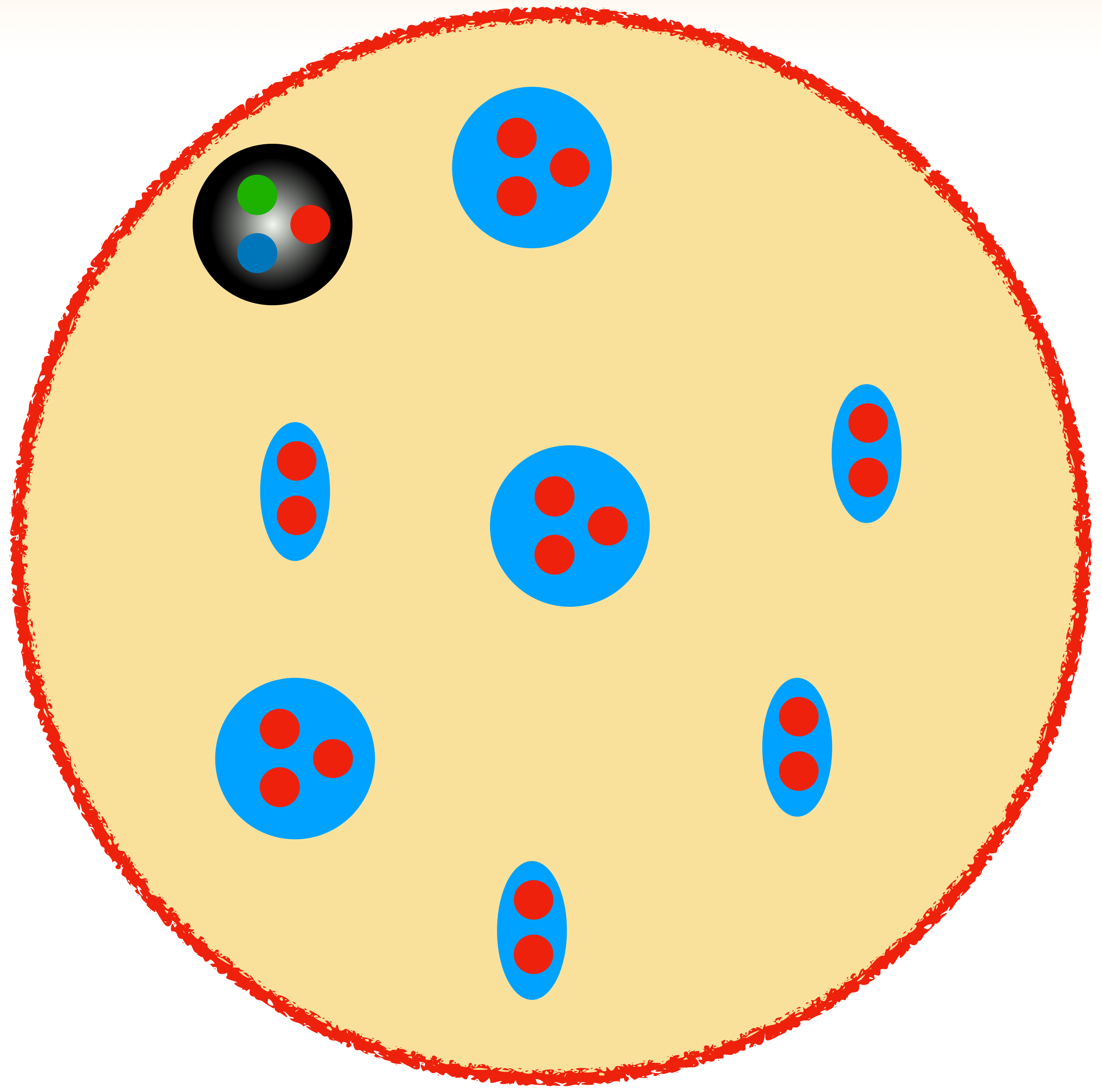
Confined to deconfined





- Quarks and gluons are doomed to always be in “white” or colourless packages → Hadrons.

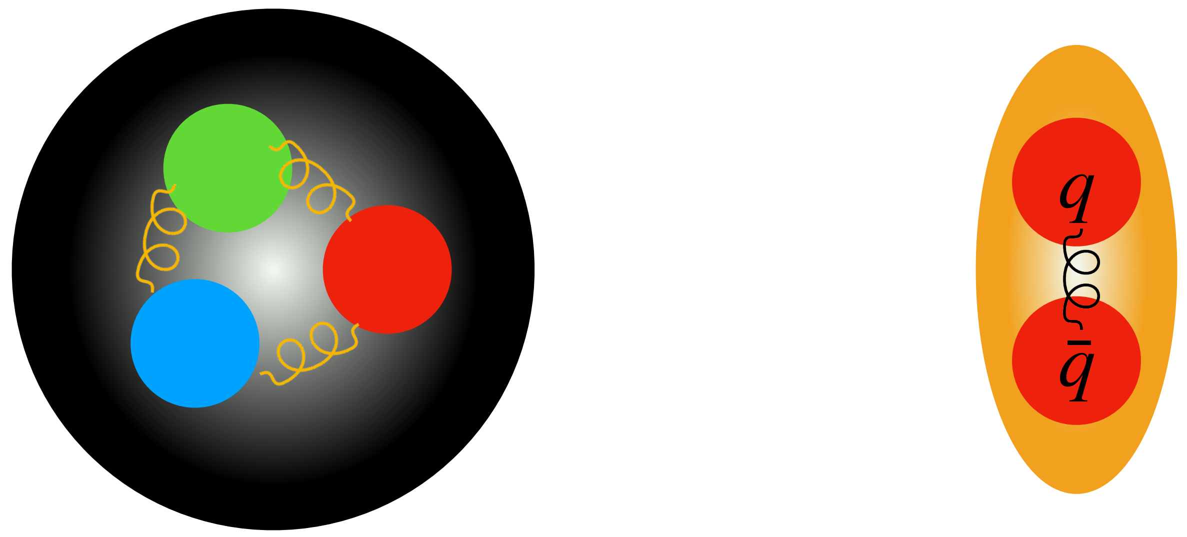
- If you try to pull one apart, by injecting energy you will eventually produce another pair that makes it “white”.



- In very high density and temperature conditions, quarks and gluons can move freely.

- This is a deconfined state of matter.
  The Quark Gluon Plasma (QGP)

Confined to deconfined



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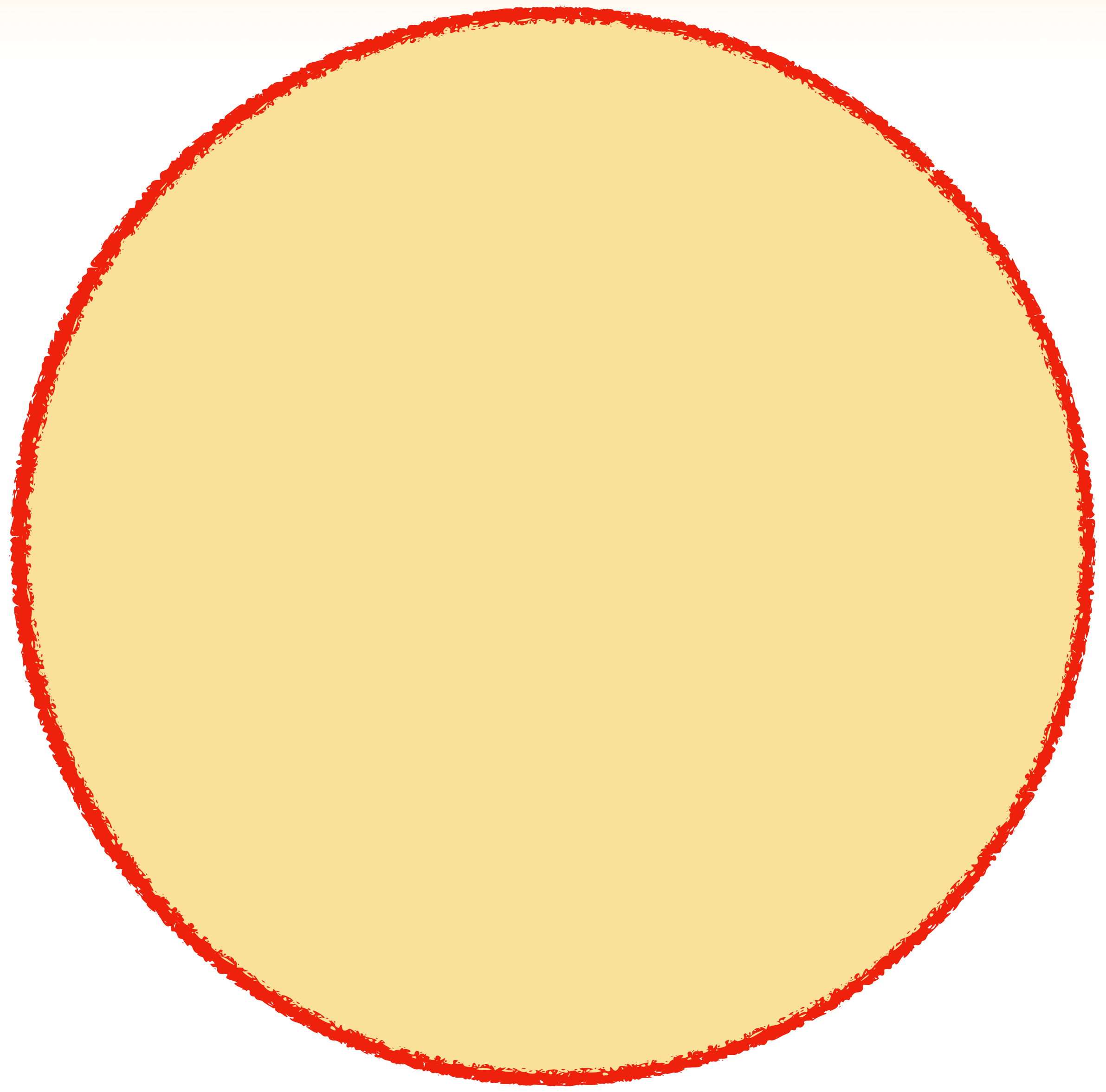

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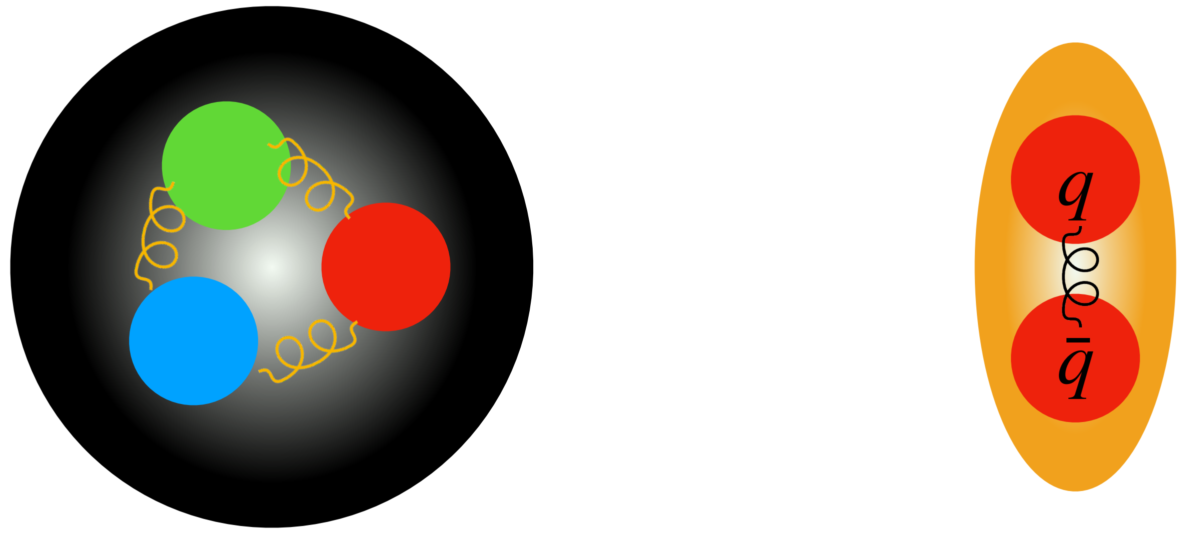

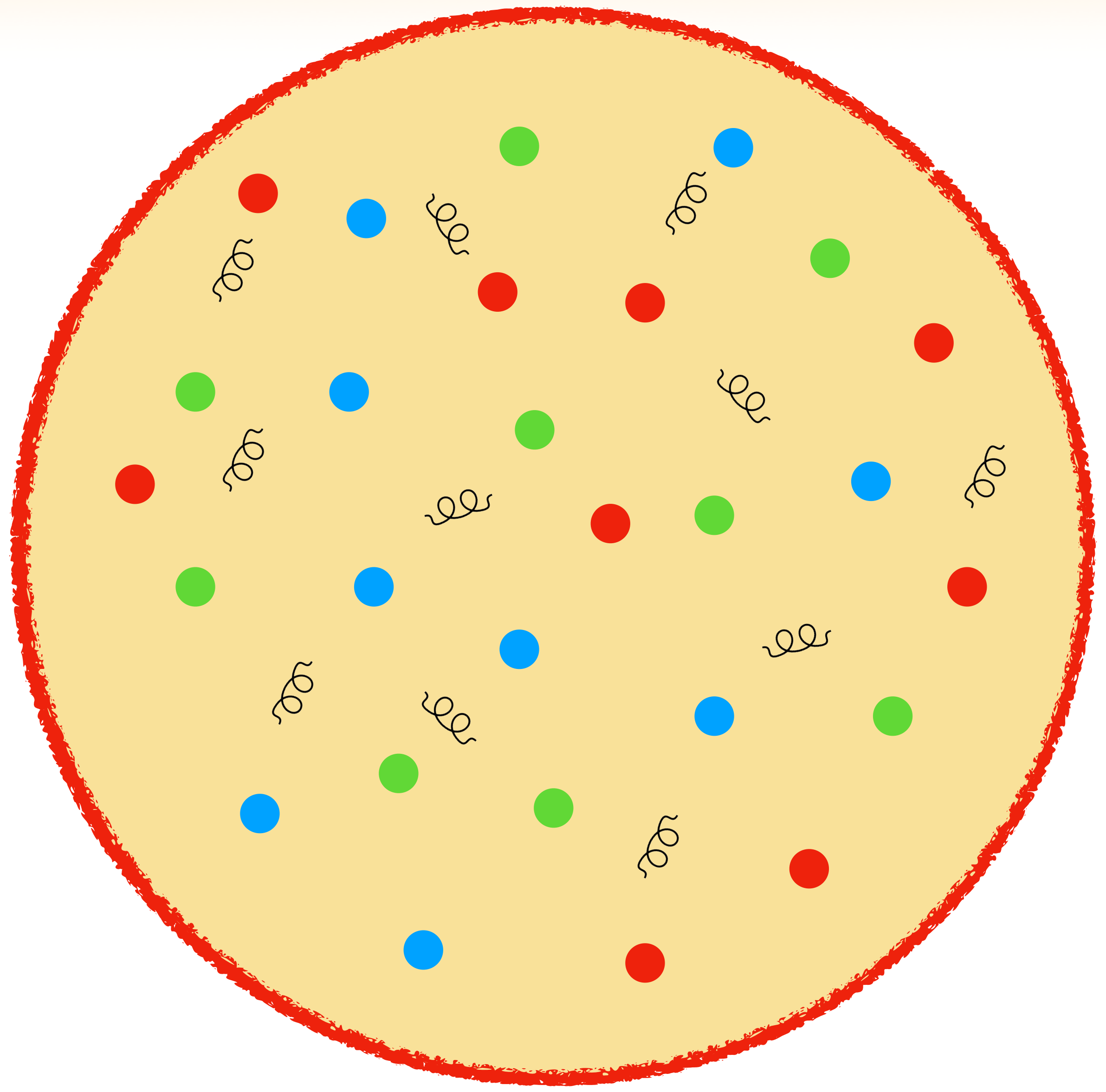

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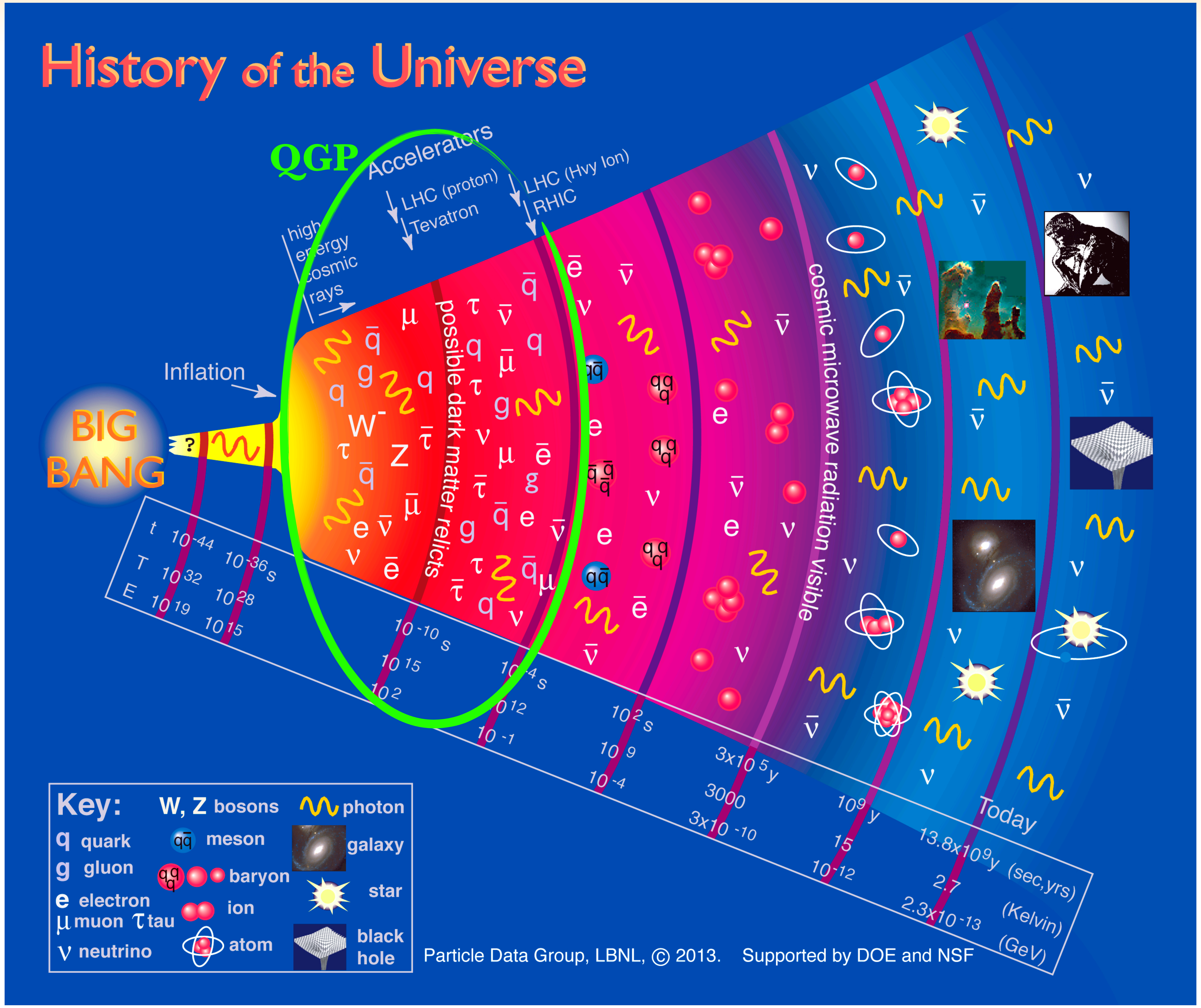
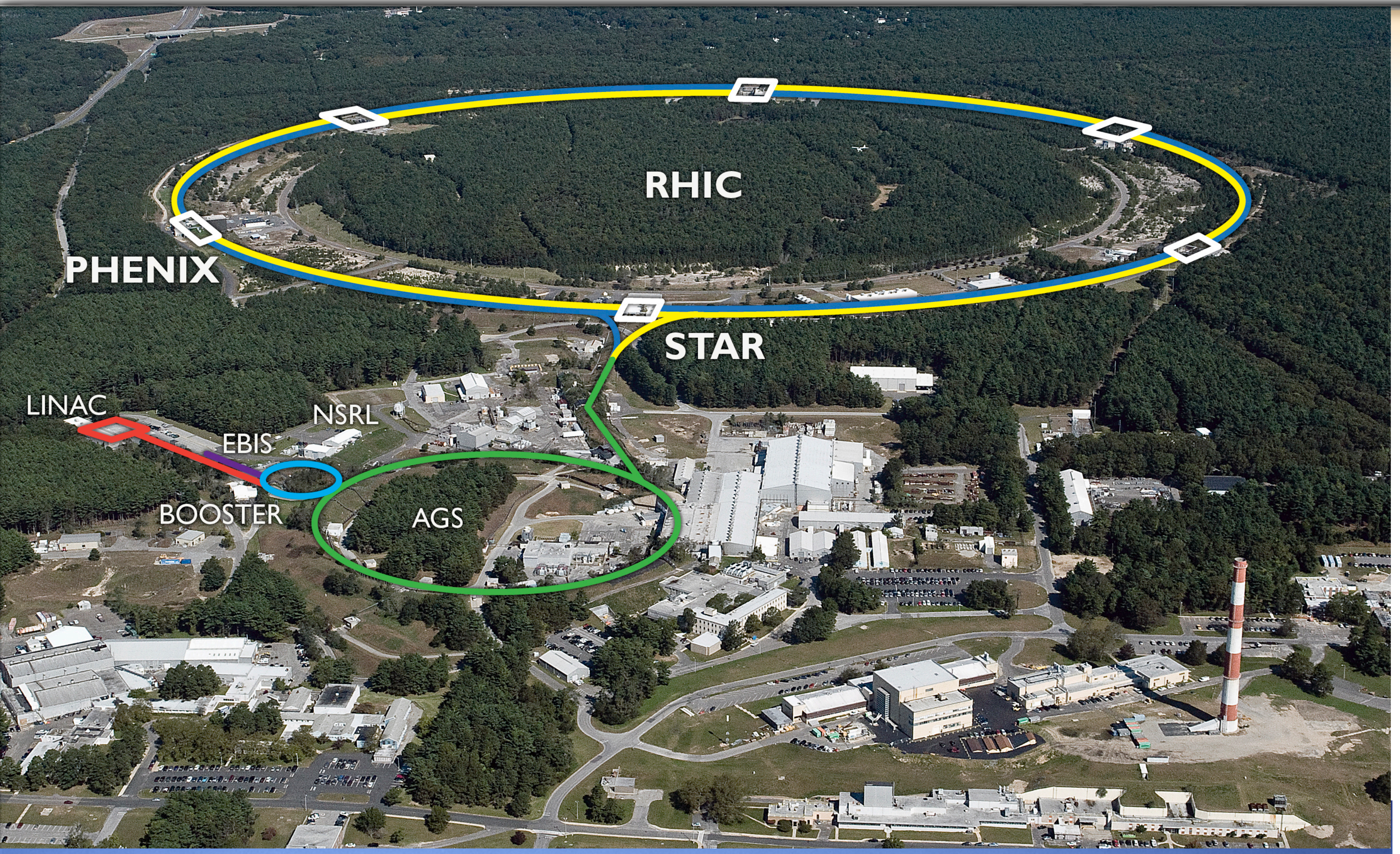
QGP in the Universe



- ❖ QGP is believed to have been the state of the universe up to a few milliseconds after the Big-Bang.
- ❖ Nowadays we can reproduce this state of matter in very small quantities in high energy Heavy Ion collisions.

Heavy Ion colliders



❖ At Brookhaven National Lab (US):

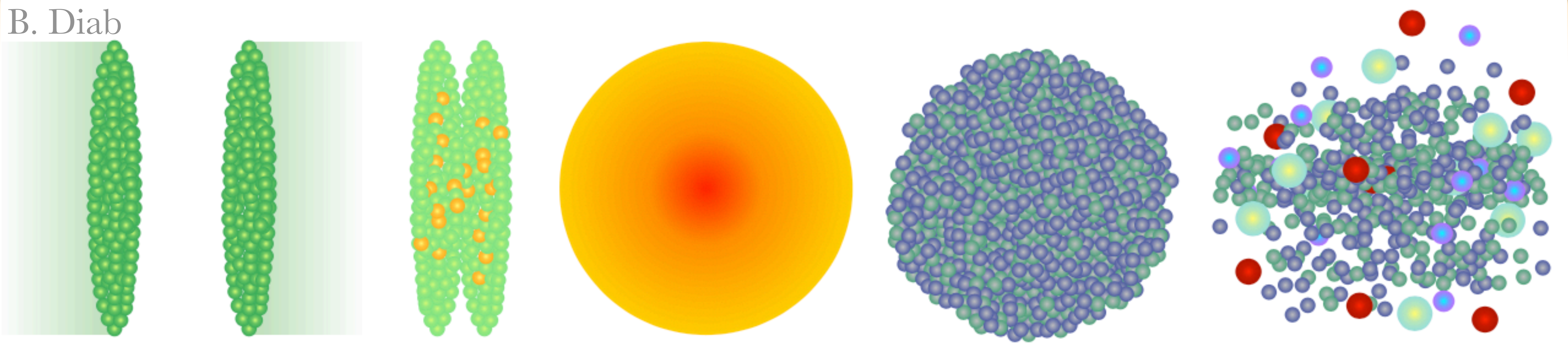
- Relativistic Heavy Ion Collider (RHIC) $\rightarrow \sqrt{s_{NN}} \sim 200$ GeV.

❖ At CERN (Switzerland/France):

- Super Proton Synchrotron (SPS) $\rightarrow \sqrt{s_{NN}} \sim 20$ GeV.
- Large Hadron Collider (LHC)* $\rightarrow \sqrt{s_{NN}} \sim 5$ TeV.

* at LHCb in addition we can have $\rightarrow \sqrt{s_{NN}} \sim 69 - 110$ GeV.

How does this look like?



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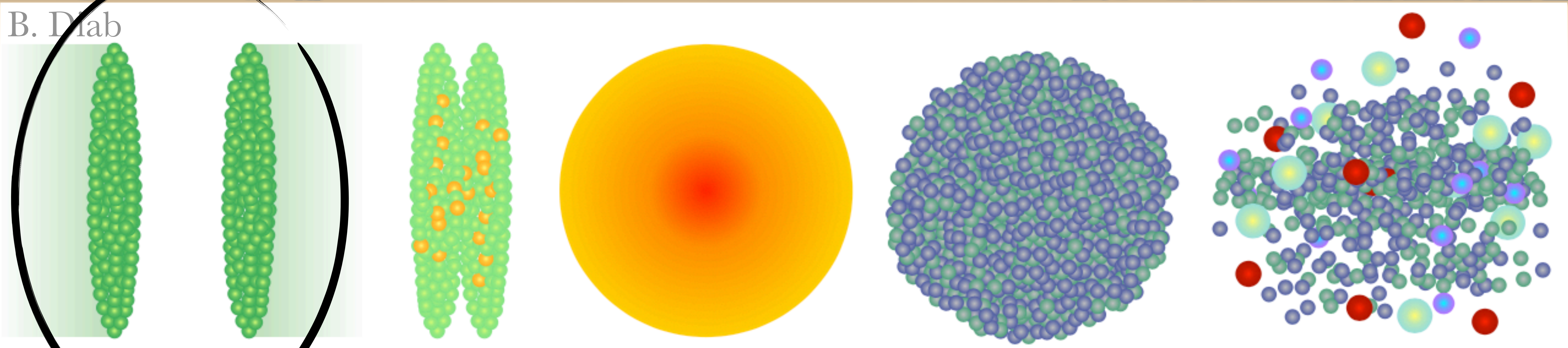
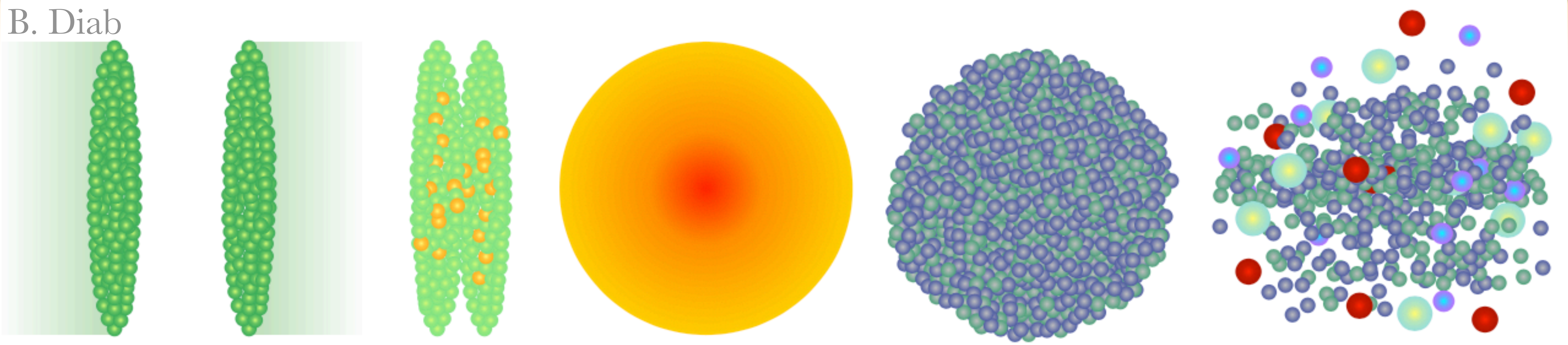


Before colliding

How does this look like?



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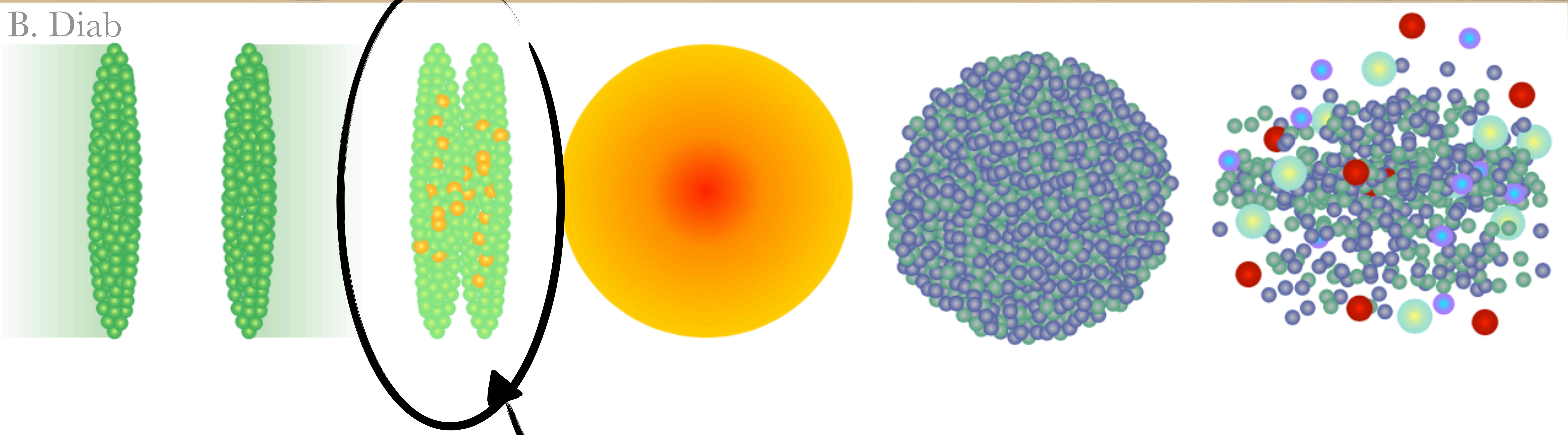
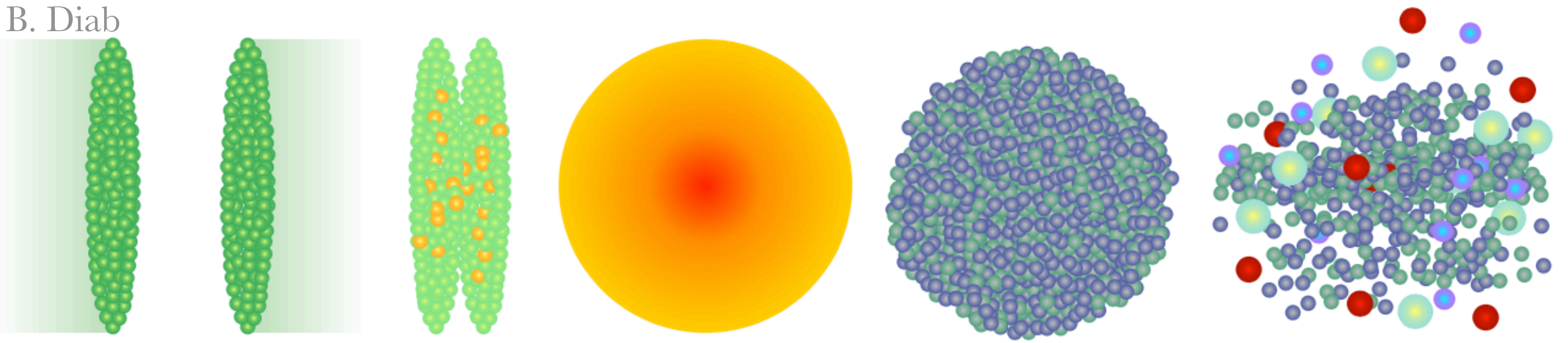


As the collision begins

How does this look like?



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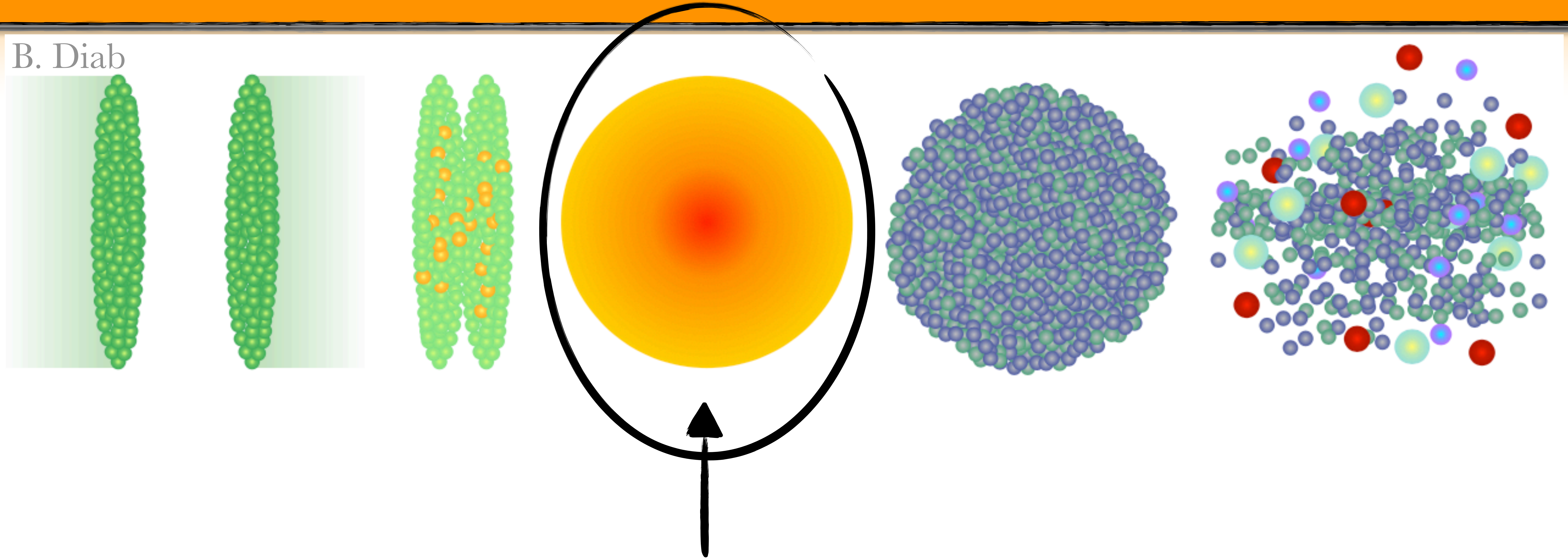
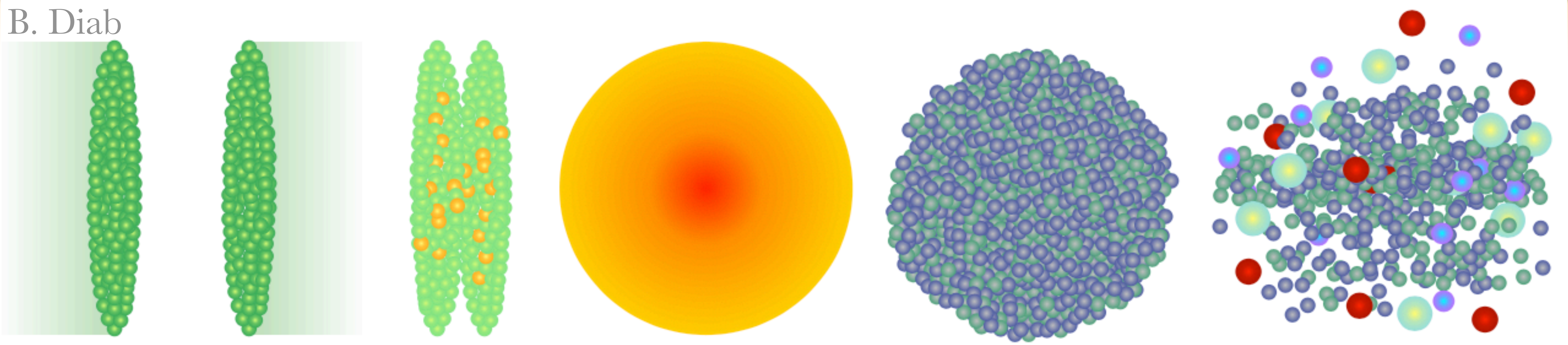


QGP is formed!

How does this look like?



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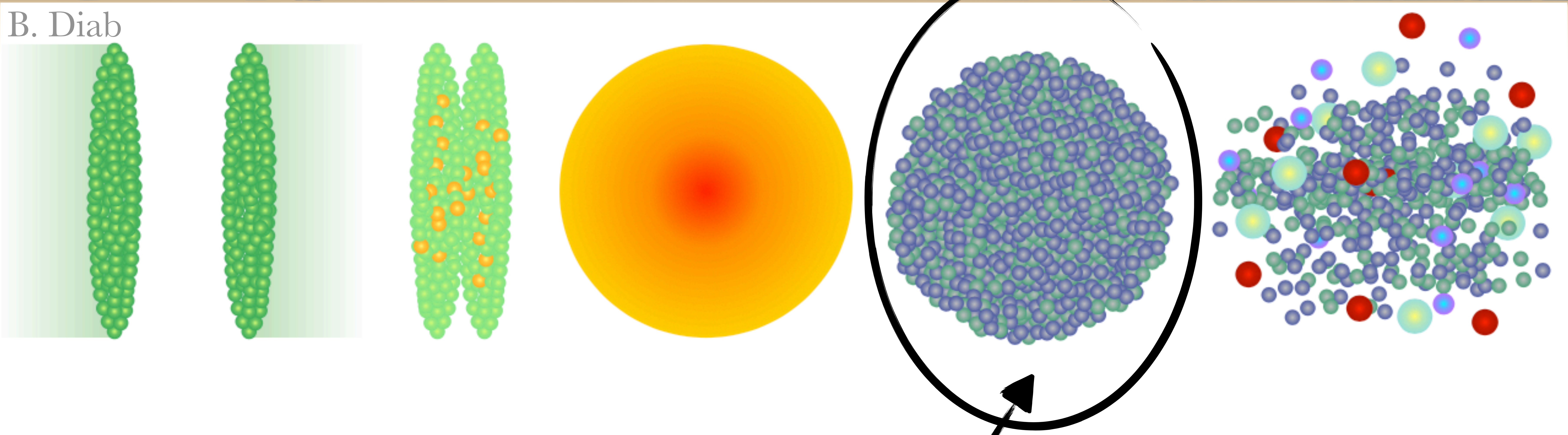
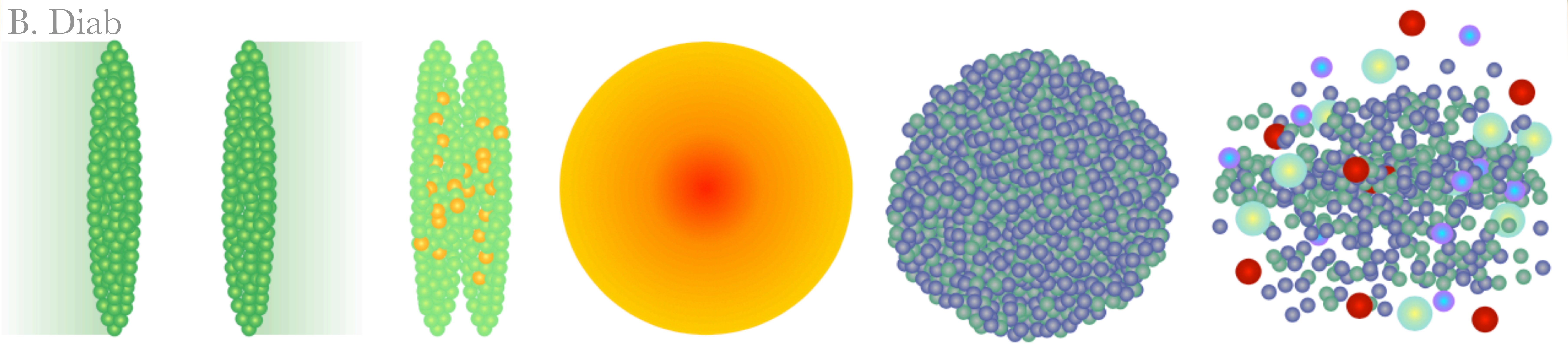


QGP cools down as it expands

How does this look like?



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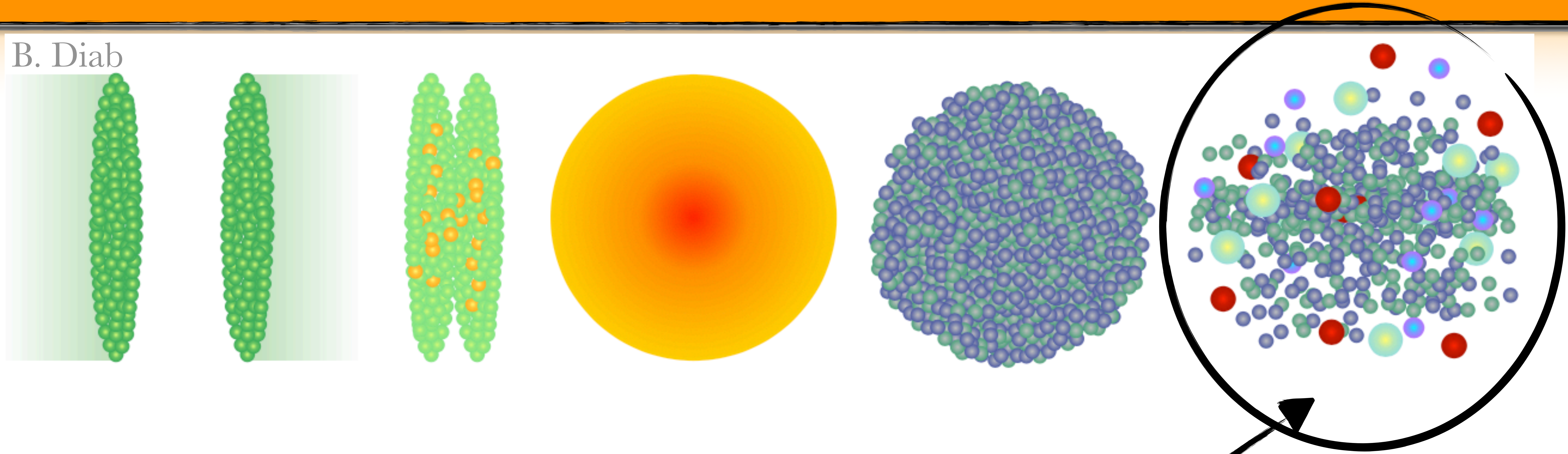
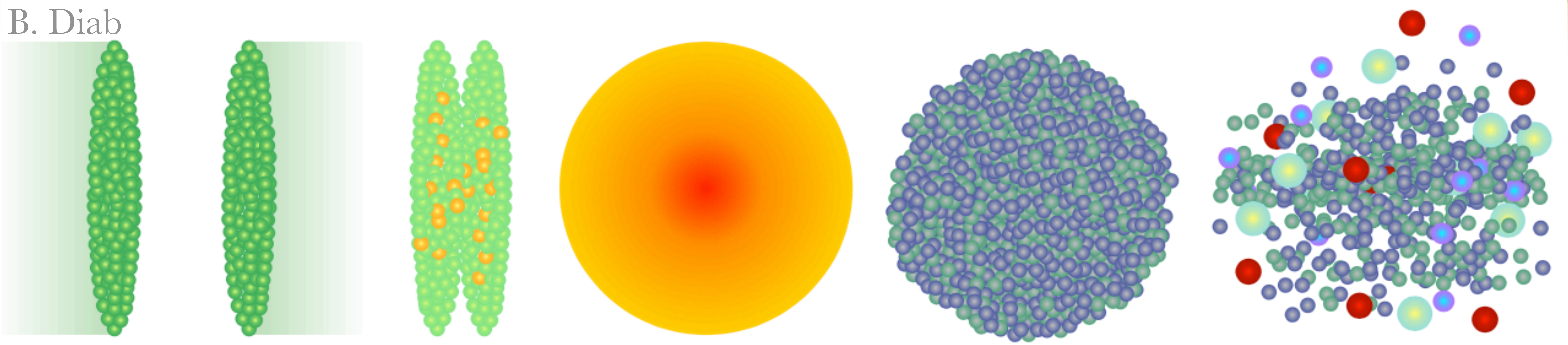


Hadronisation

How does this look like?



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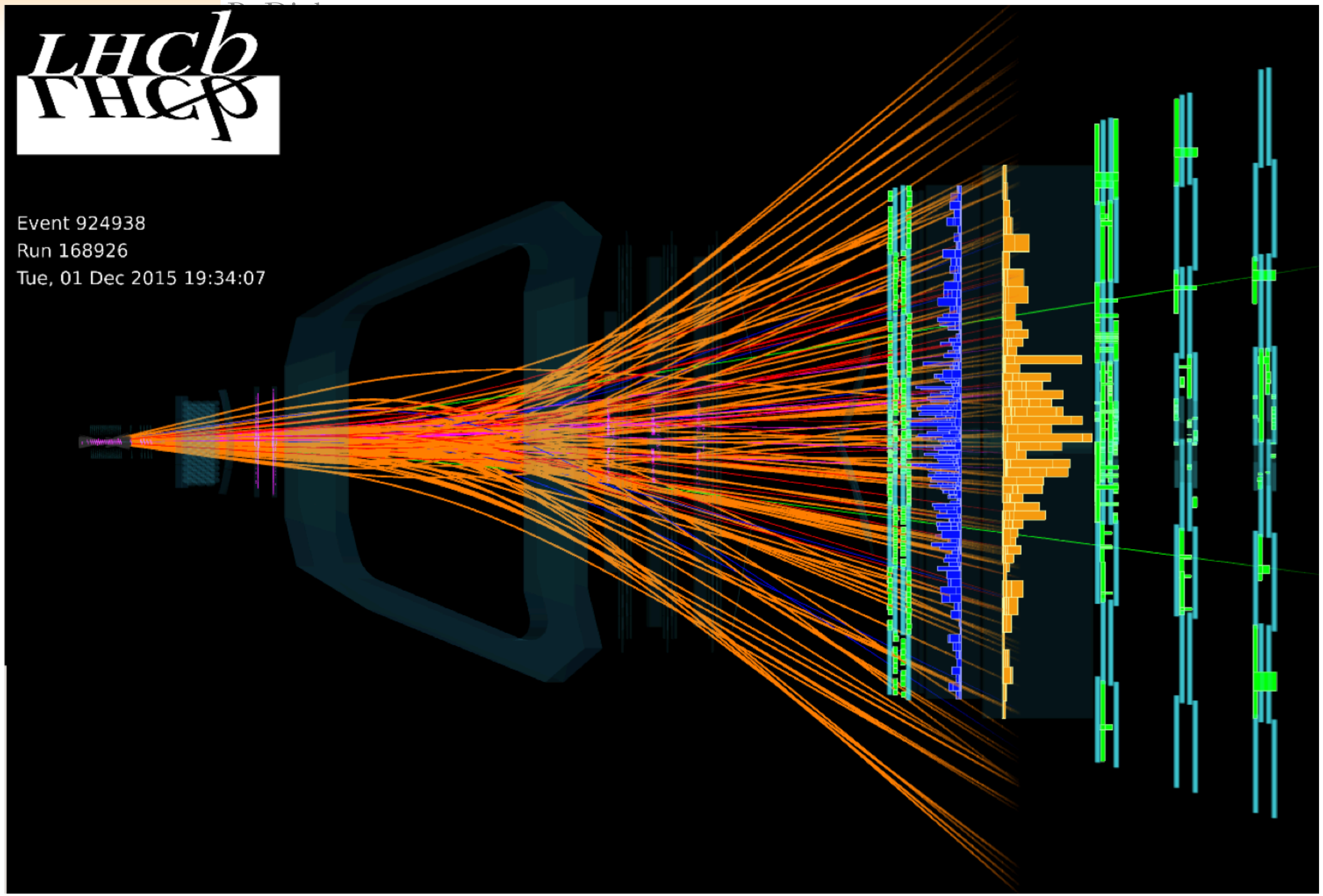
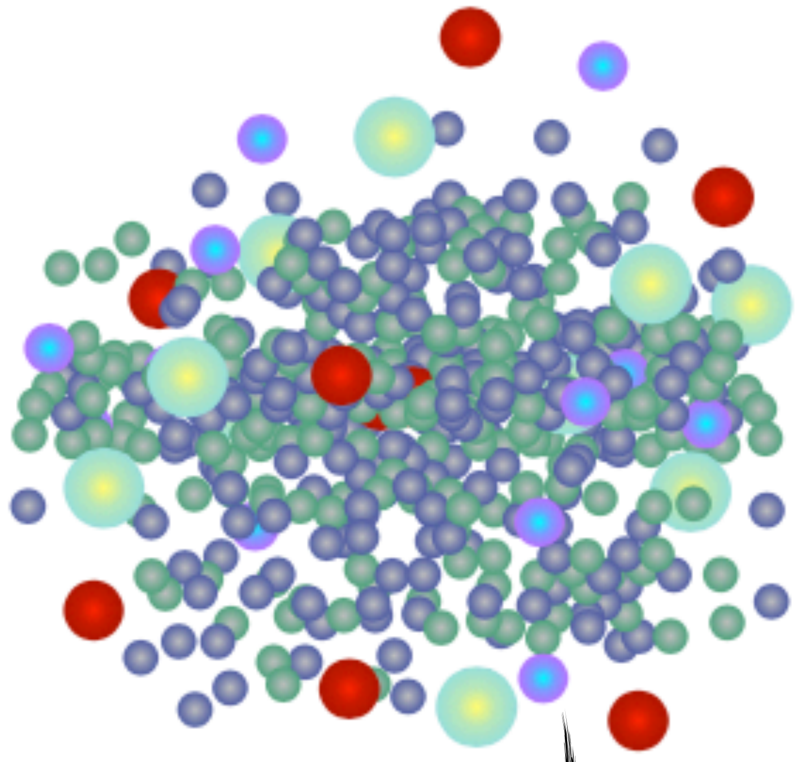


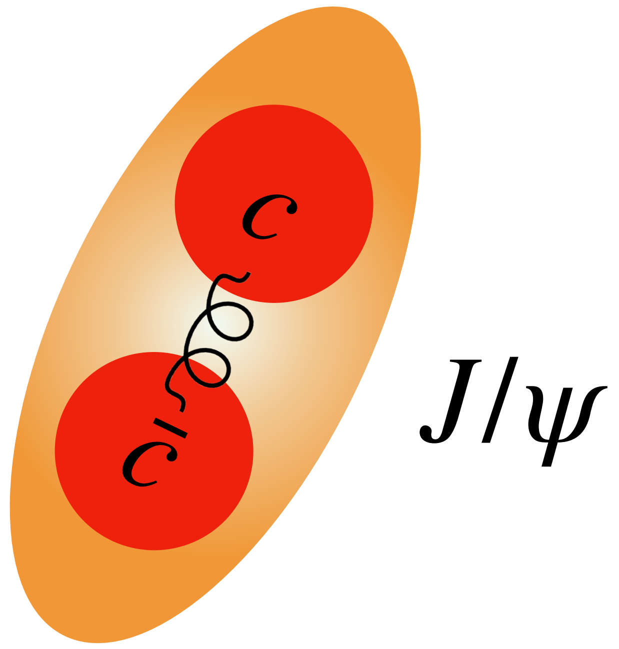


What we can see!

How to probe the QGP

❖ Many different observables are used to extract information about the QGP, the main ones:

- Strange quark enhancement.
- Jet quenching.
- Elliptic flow measurements.
- Charmonia suppression.
  - Bound states between a c and a $\bar{c}$ quark.
  - This bound state would be "melted" into the QGP, and we would see less than expected.



Using Charmonia

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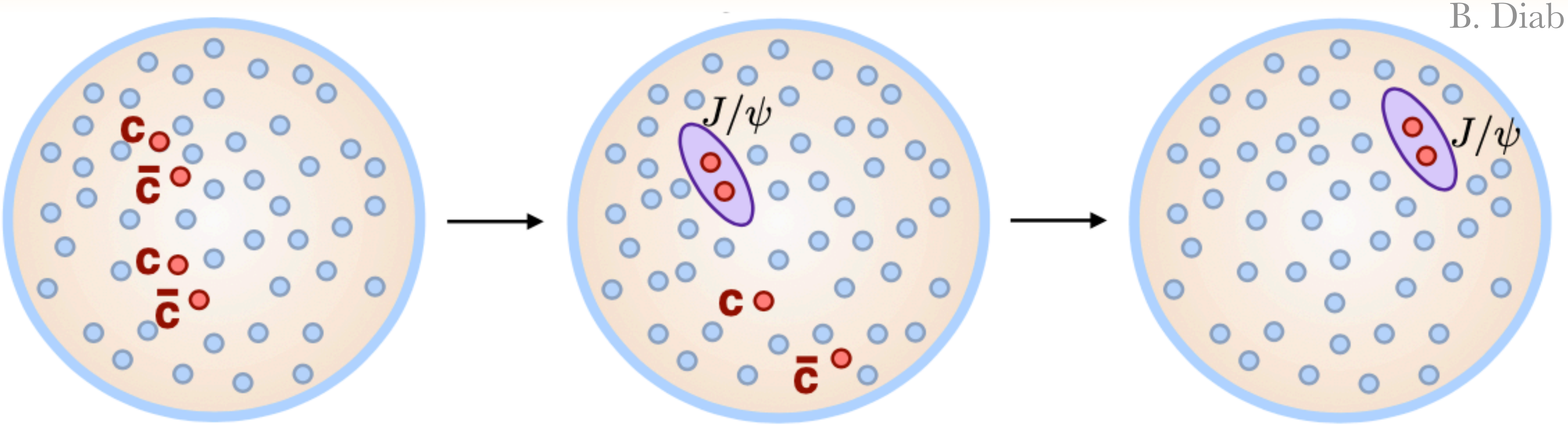


- When a $c\bar{c}$ pair is created, it can hadronise into a J/ψ meson, or lighter mesons with other quark flavours.
- The $c\bar{c}$ mass is high enough that it cannot be created inside the QGP, only in the initial collision.
- $\tau^{c\bar{c}}_{formation} < \tau^{QGP}_{formation} < \tau^{hadronisation} < \tau^{J/\psi}_{decay}$

Using Charmonia

- ❖ There is a constant battle between suppression and regeneration.
  - The higher the collision energy the more $c\bar{c}$ pairs produced.
  - The more $c\bar{c}$ pairs produced, the suppression is more hidden by regeneration.
- ❖ But we need high collision energy to have suppression!

The LHCb detector

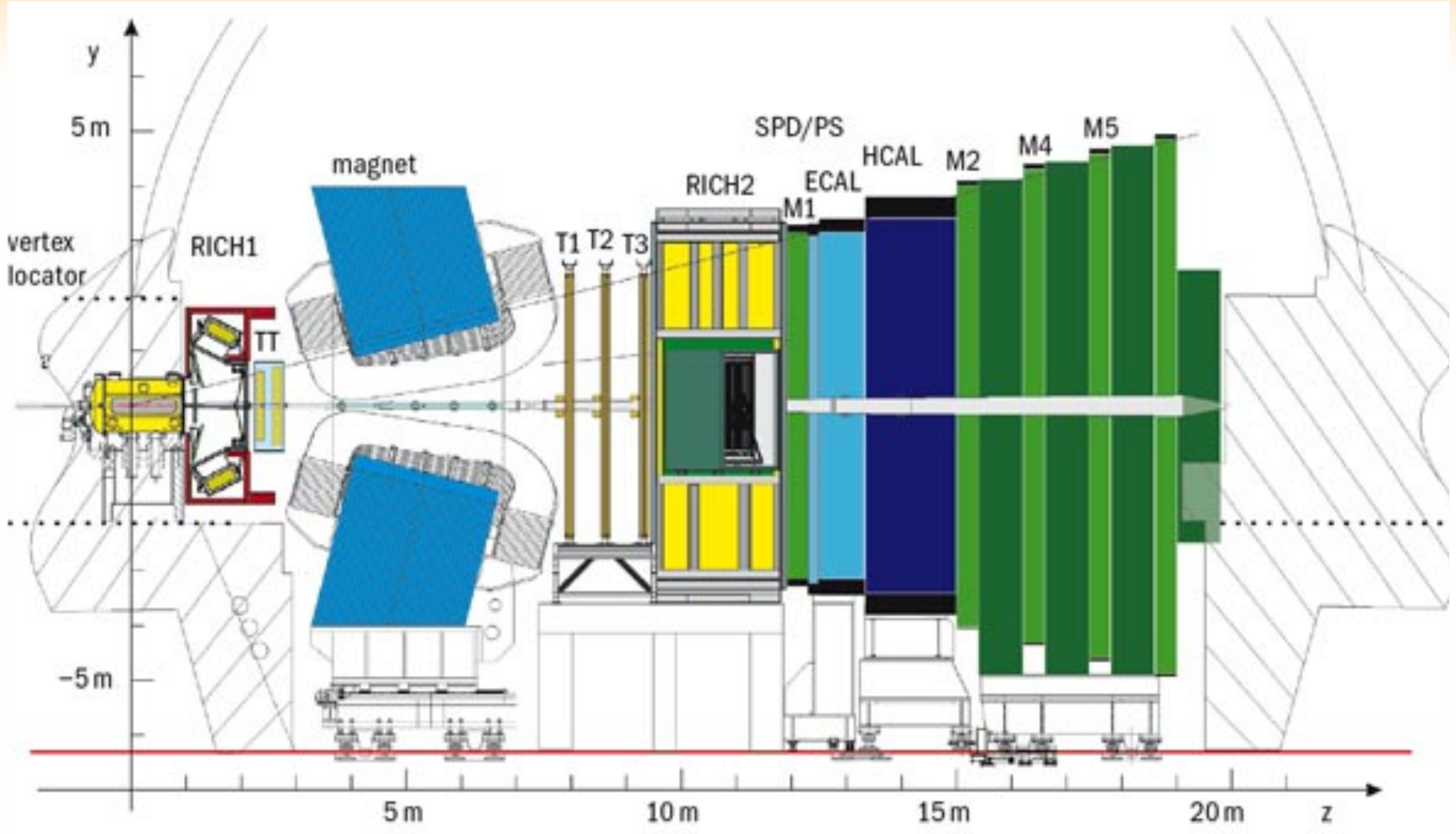
❖Forward single arm spectrometer.

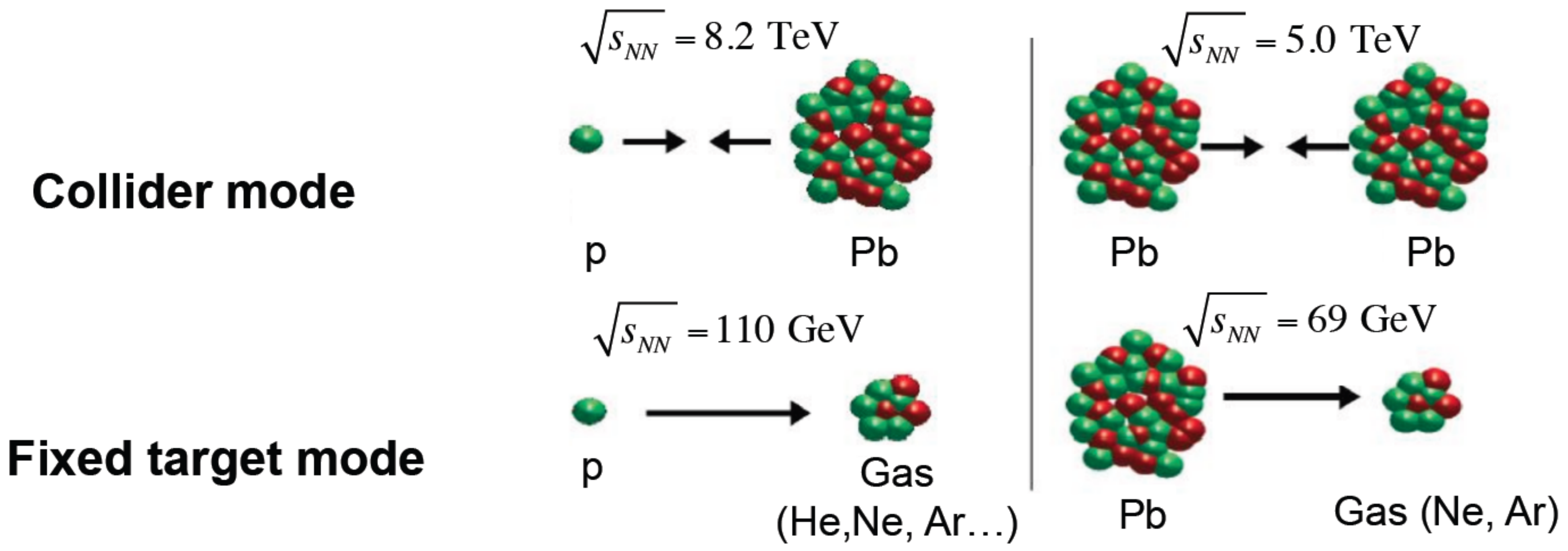
❖Designed to study heavy flavour physics in *pp* collisions.

❖Only LHC experiment fully instrumented between 10 and 250 mrad around the beam axis.

❖LHCb can also operate in *p*-Pb and Pb-Pb collisions.

❖LHCb can be operated as a fixed-target experiment.





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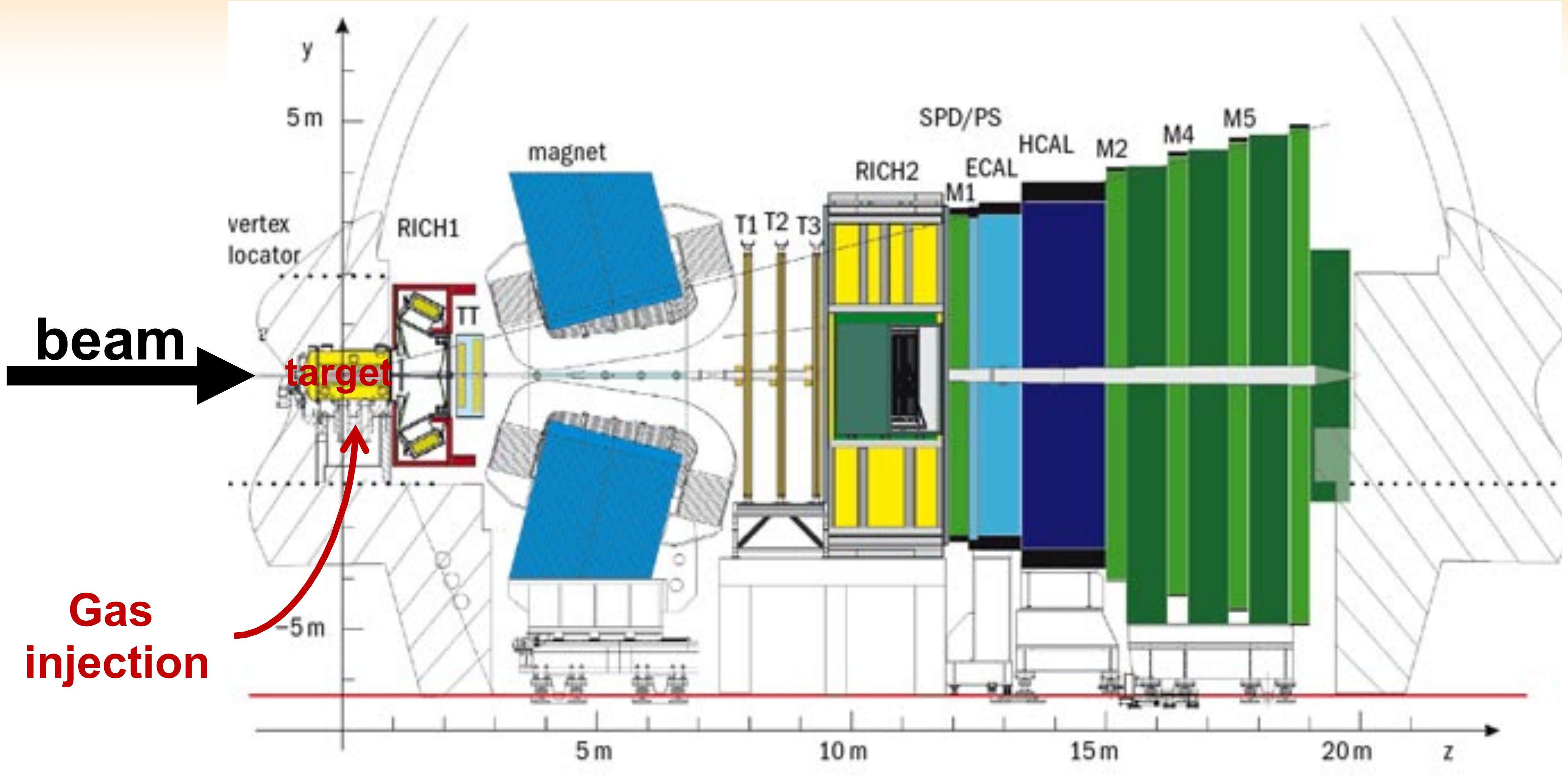
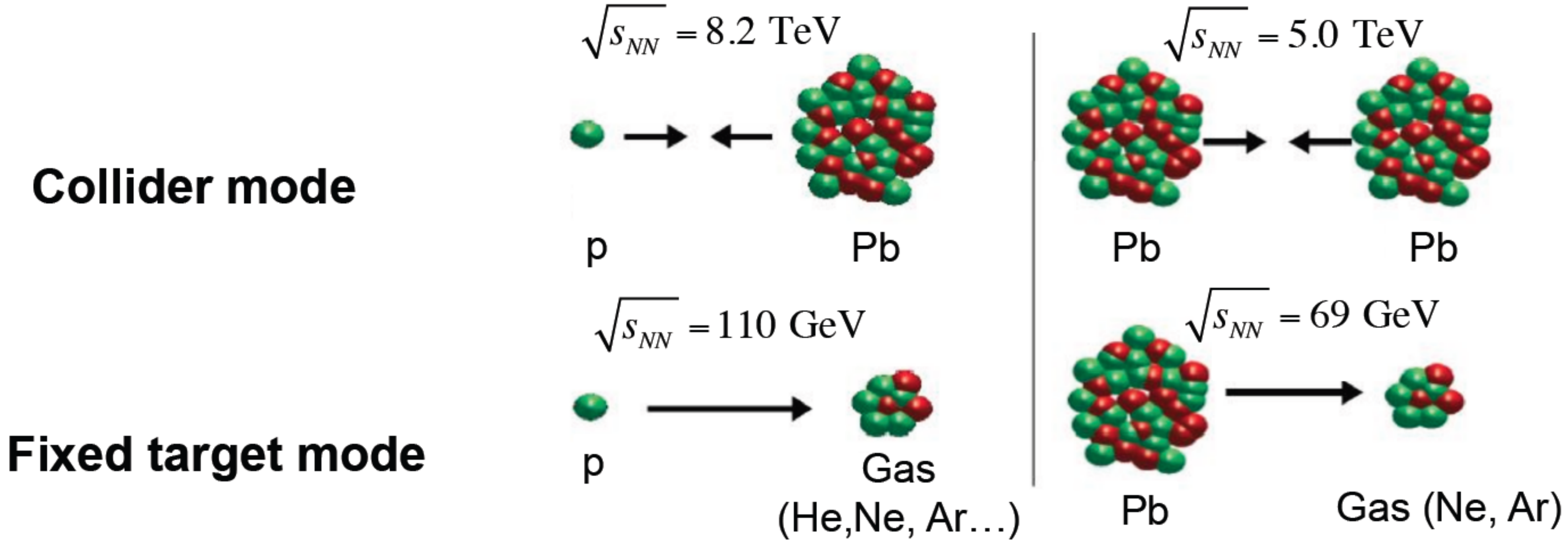




The LHCb detector

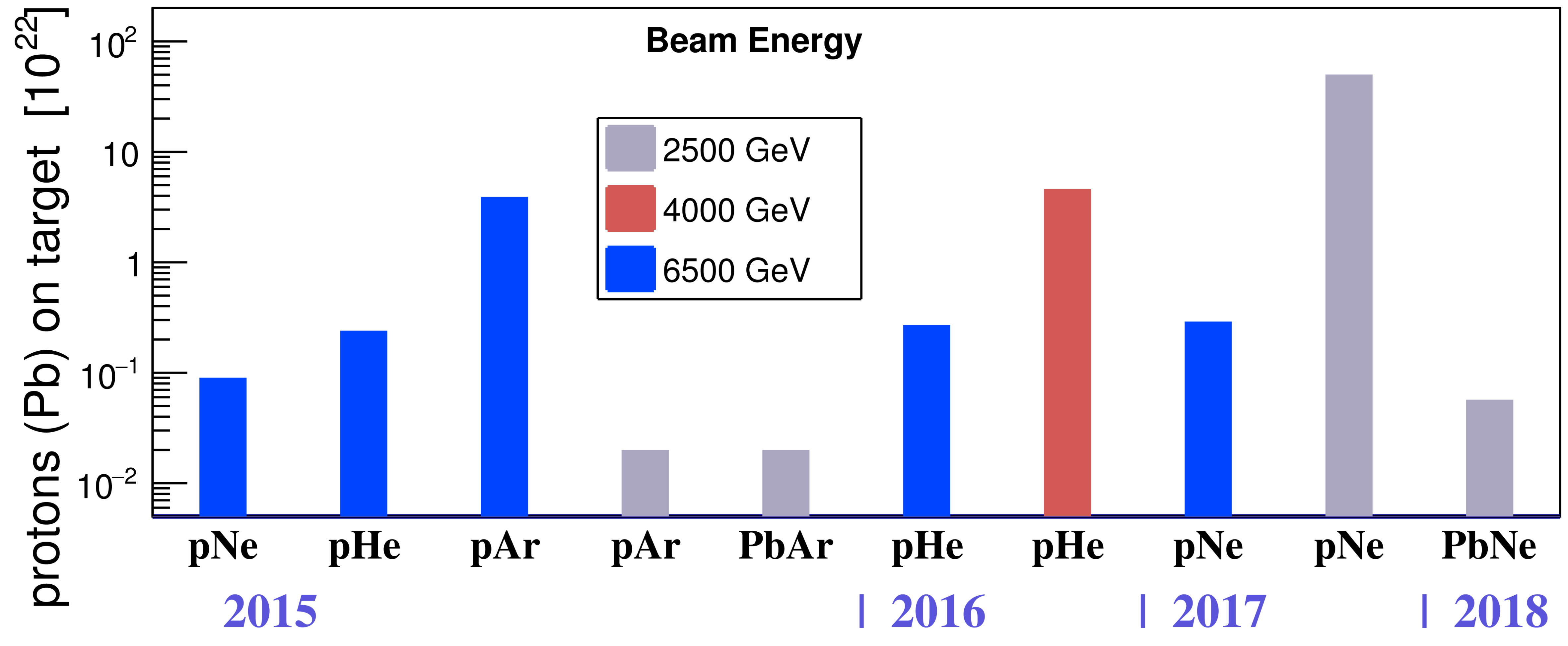
❖Advantages of operating in fixed target.

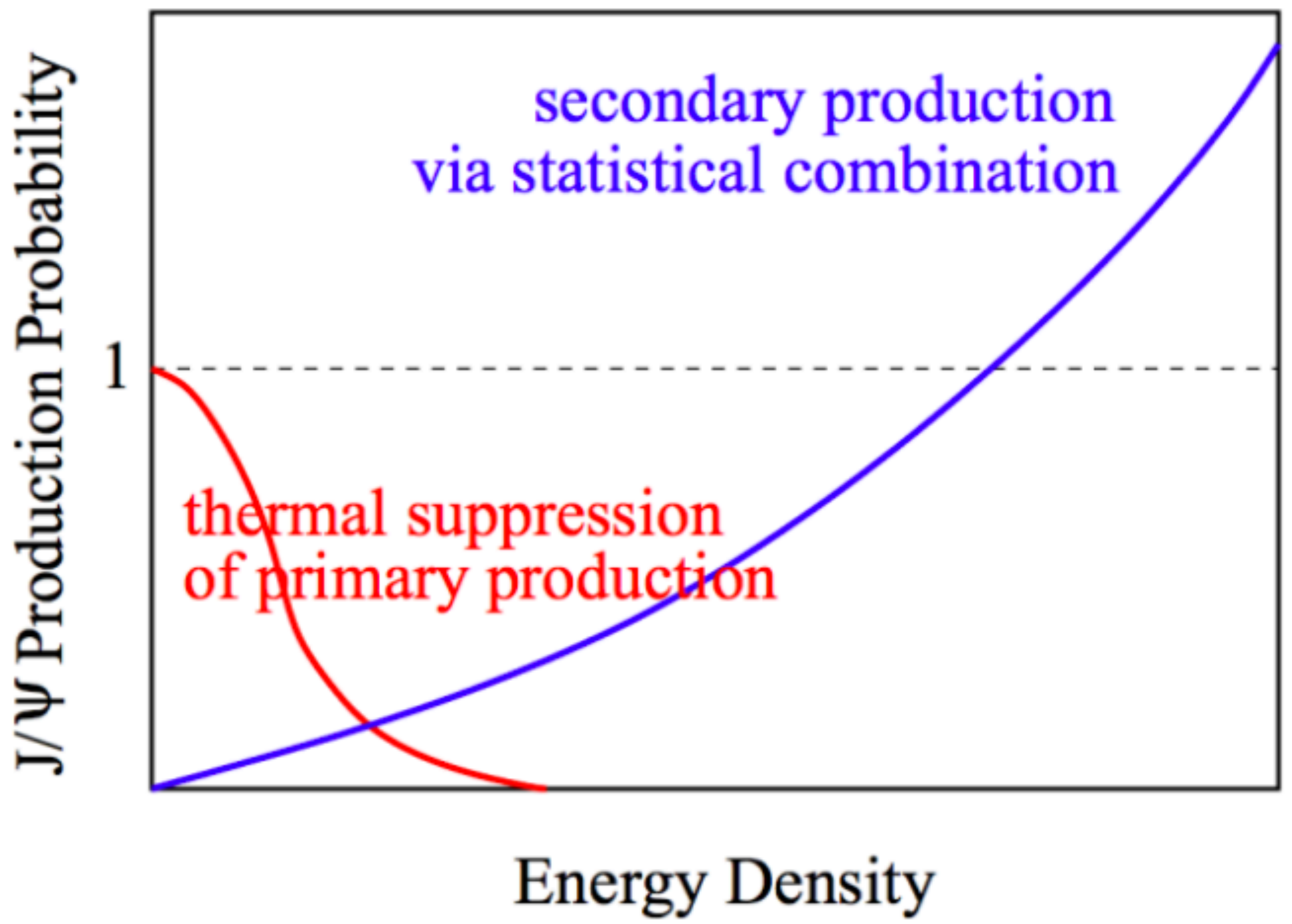
- No regeneration of charmonium.
- Fills the existing energy gap between SPS and RHIC.

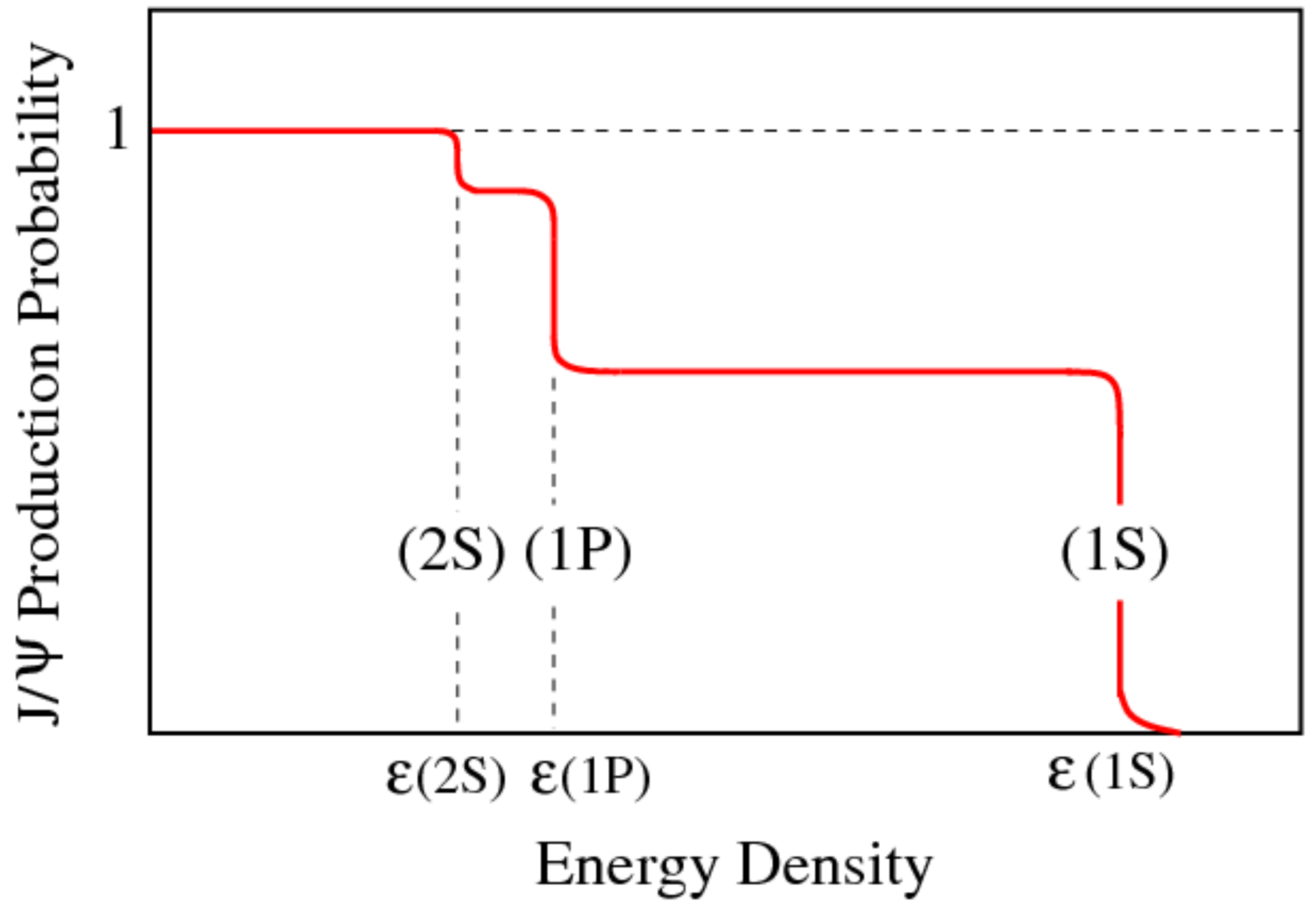
$$\sqrt{s_{NN}}^{SPS} < \sqrt{s_{NN}}^{SMOG} < \sqrt{s_{NN}}^{RHIC} < \sqrt{s_{NN}}^{LHC}$$

$$\sim 20 \text{ GeV} < \sim 70 \text{ GeV} < 200 \text{ GeV} < 5 \text{ TeV}$$

- Probe the Quark Gluon Plasma (QGP) phase transition via colour screening.

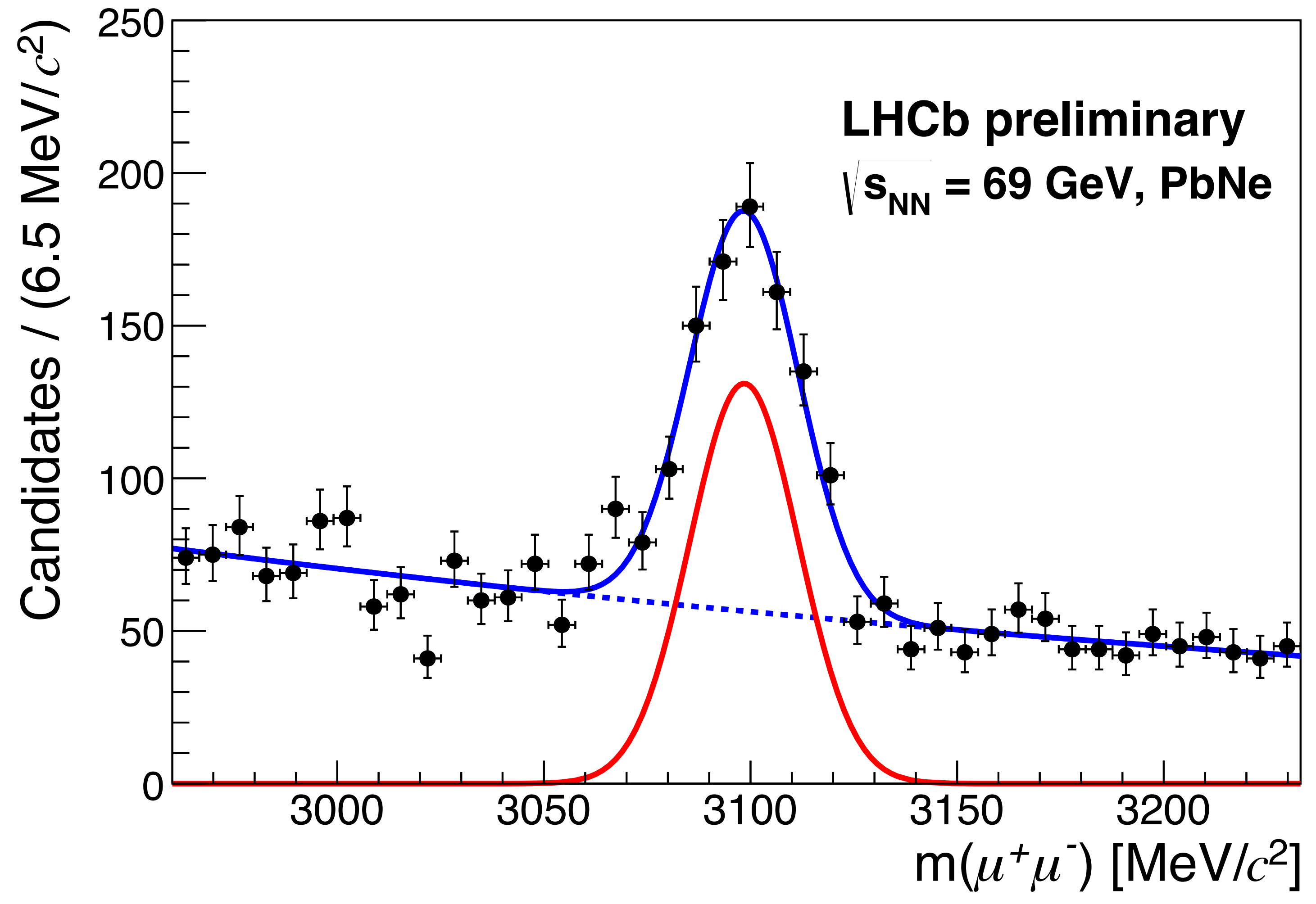


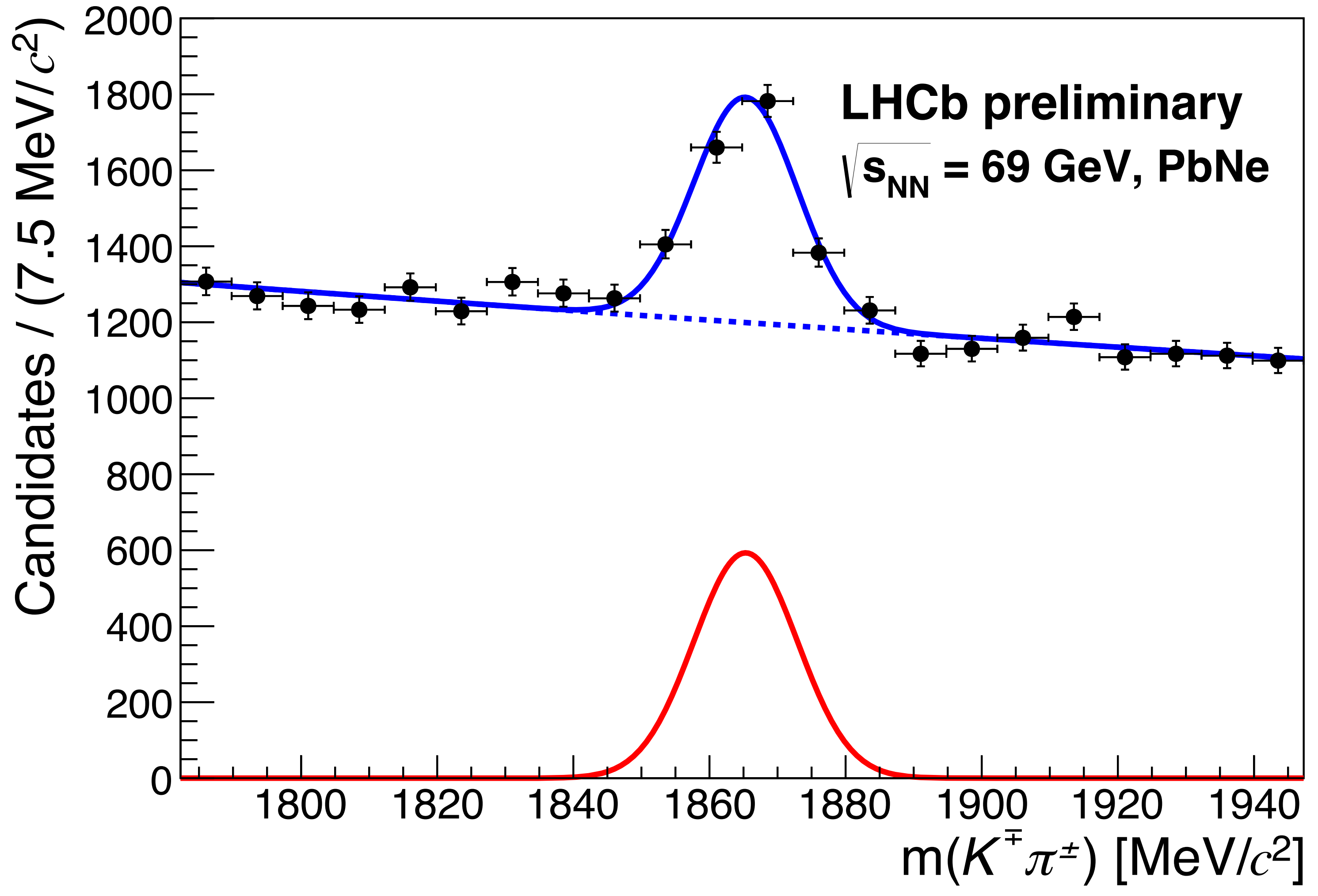




Charmonia production

- How do we want to see the suppression?
  - We reconstruct the $J/\psi \rightarrow \mu\mu$ and the $D^0 \rightarrow K^{\mp}\pi^{\pm}$.
  - We take the ratio $\dfrac{J/\psi}{D^0}$.
  - Compare between the different collision systems.
- This is an ongoing work, and in the future we will have many more collision systems!





The future of LHCb fixed target

LHCb-PUB-2018-015

System	$\sqrt{s_{\rm NN}}$ (GeV)	$<$ pressure$>$ (10^{-5} mbar)	ρ_S (cm^{-2})	$\mathcal{L}$ (cm^{-2}s^{-1})	Rate (MHz)	Time (s)	$\int\mathcal{L}$ (pb^{-1})
pH$_2$	115	4.0	2.0×10^{13}	6×10^{31}	4.6	2.5×10^{6}	150
pD$_2$	115	2.0	1.0×10^{13}	3×10^{31}	4.3	0.3×10^{6}	9
pAr	115	1.2	0.6×10^{13}	1.8×10^{31}	11	2.5×10^{6}	45
pKr	115	0.8	0.4×10^{13}	1.2×10^{31}	12	2.5×10^{6}	30
pXe	115	0.6	0.3×10^{13}	0.9×10^{31}	12	2.5×10^{6}	22
pHe	115	2.0	1.0×10^{13}	3×10^{31}	3.5	3.3×10^{3}	0.1
pNe	115	2.0	1.0×10^{13}	3×10^{31}	12	3.3×10^{3}	0.1
pN$_2$	115	1.0	0.5×10^{13}	1.5×10^{31}	9.0	3.3×10^{3}	0.1
pO$_2$	115	1.0	0.5×10^{13}	1.5×10^{31}	10	3.3×10^{3}	0.1
PbAr	72	8.0	4.0×10^{13}	1×10^{29}	0.3	6×10^{5}	0.060
PbH$_2$	72	8.0	4.0×10^{13}	1×10^{29}	0.2	1×10^{5}	0.010
pAr	72	1.2	0.6×10^{13}	1.8×10^{31}	11	3×10^{5}	5

- ❖ The possible catalog of systems to be studied is broad.
- ❖ Expected data to be recorded in Run 3 of LHC.
- ❖ We expect to reach a deep understanding of nuclear effects.
- ❖ Hopefully we will be able to unambiguously provide evidence of the QGP via colour screening.

Thank You!