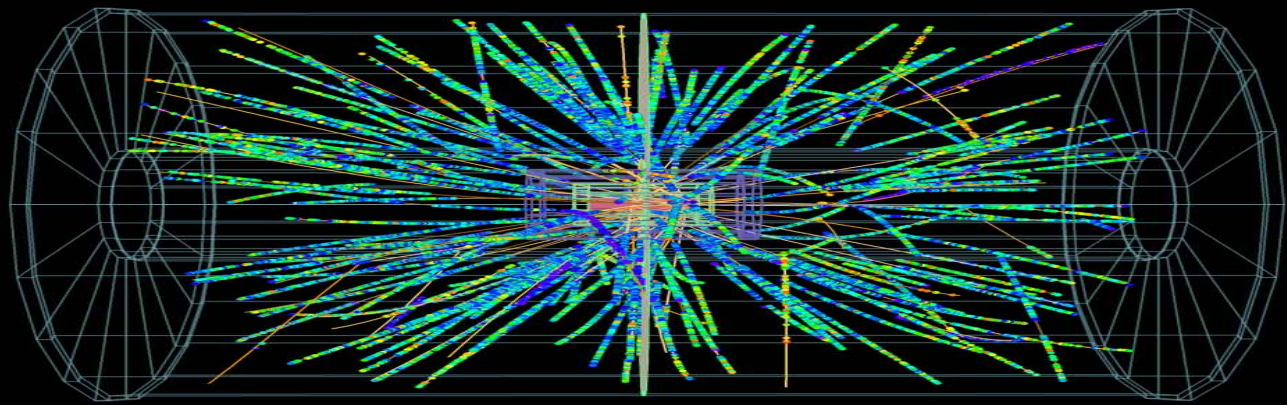


Charged hadron spectra of p+Pb collisions

Kushagra Chandak

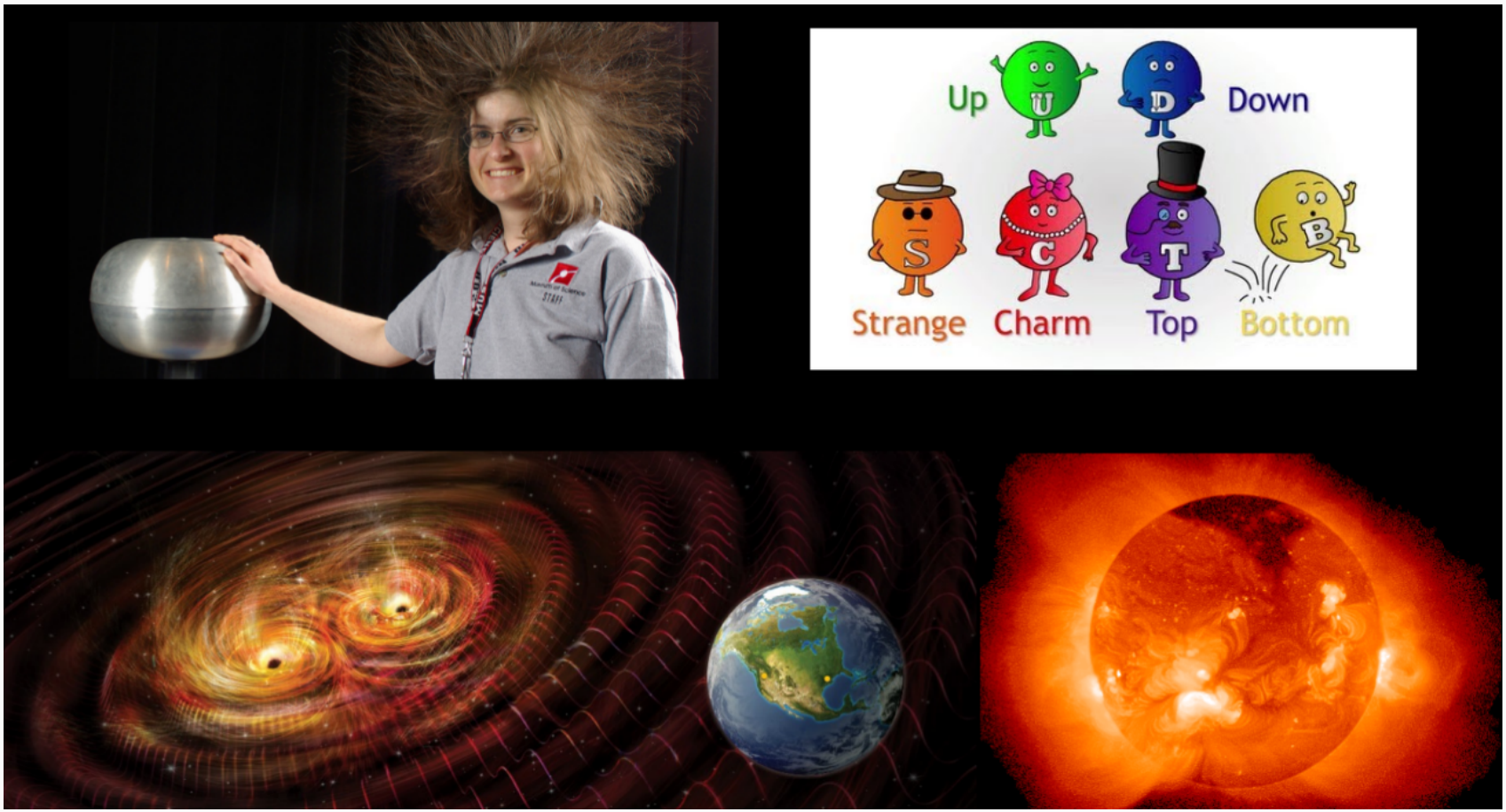
November 15, 2020

Contents

Motivation: Why study heavy ion collisions?

What's the *hottest* thing you can imagine?

Fundamental Interactions



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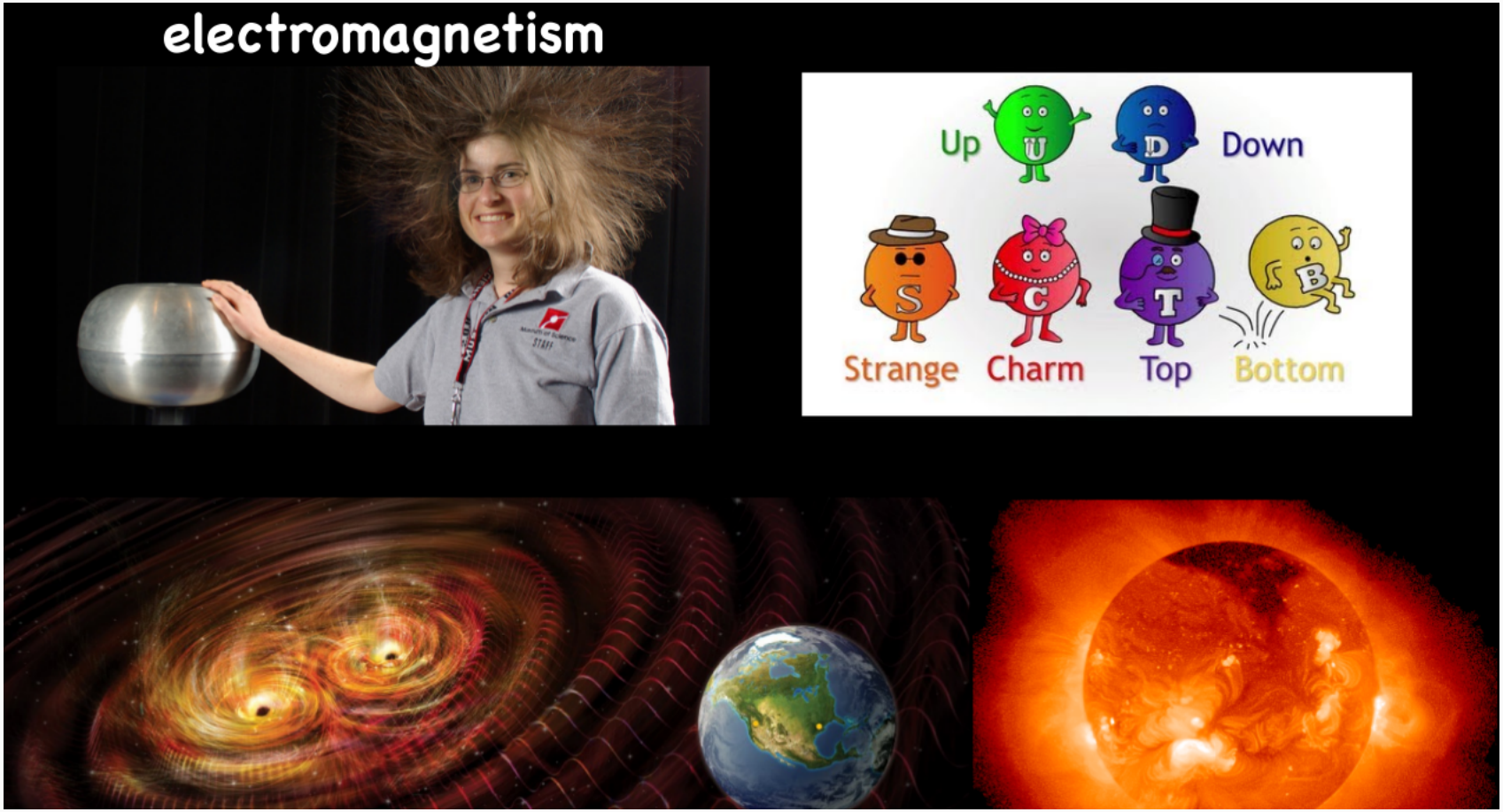

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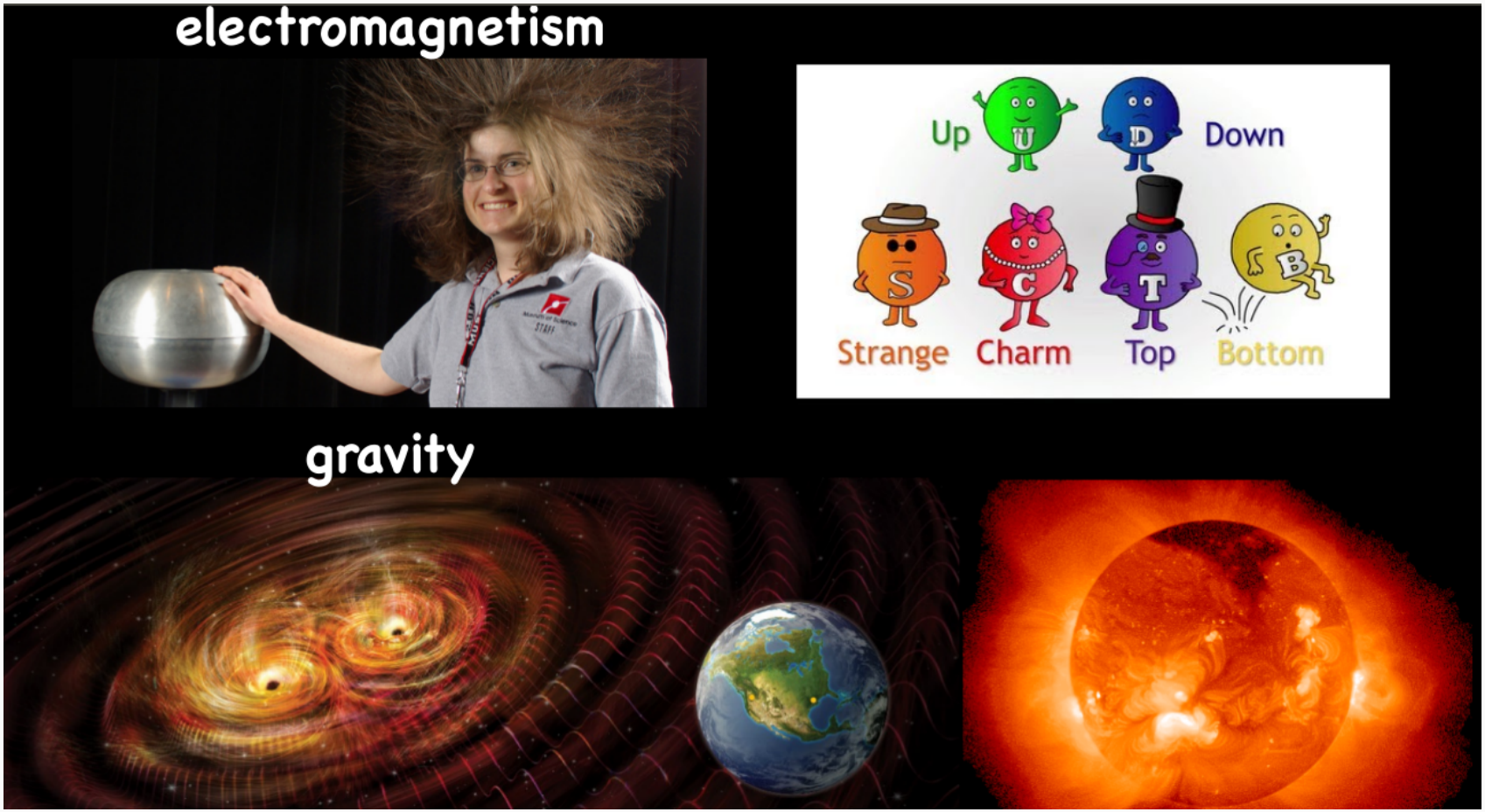

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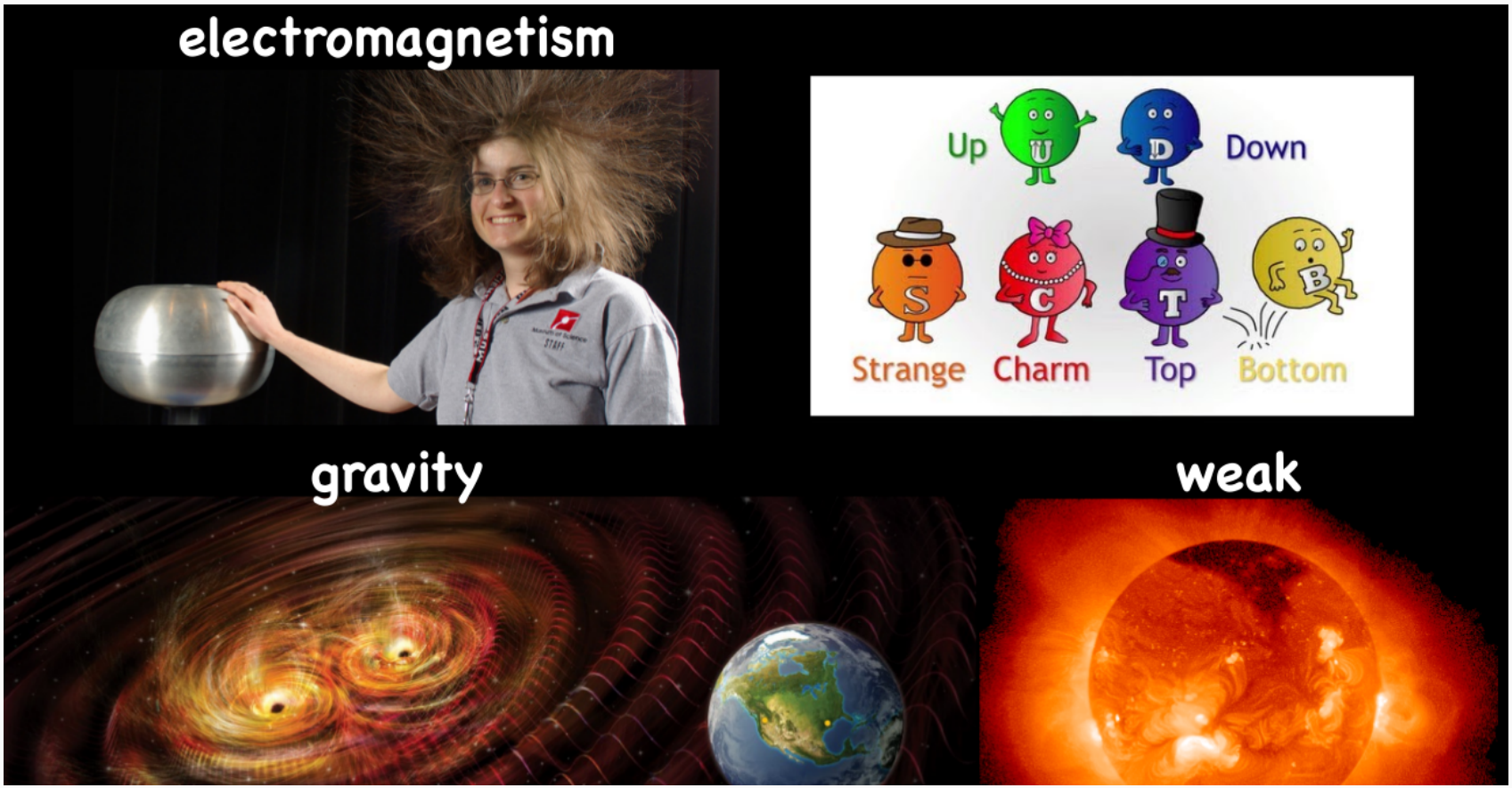

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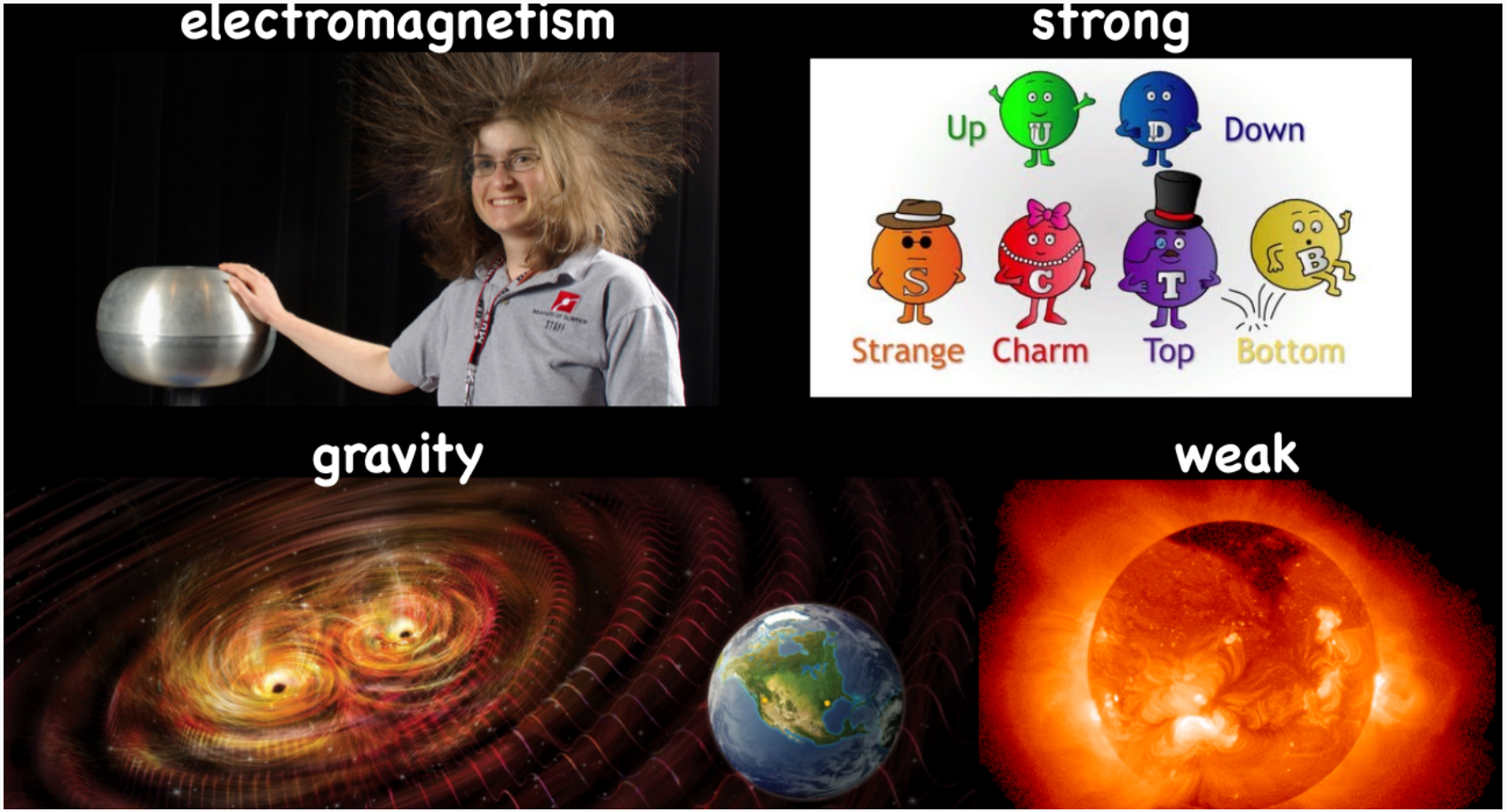


Fundamental Interactions

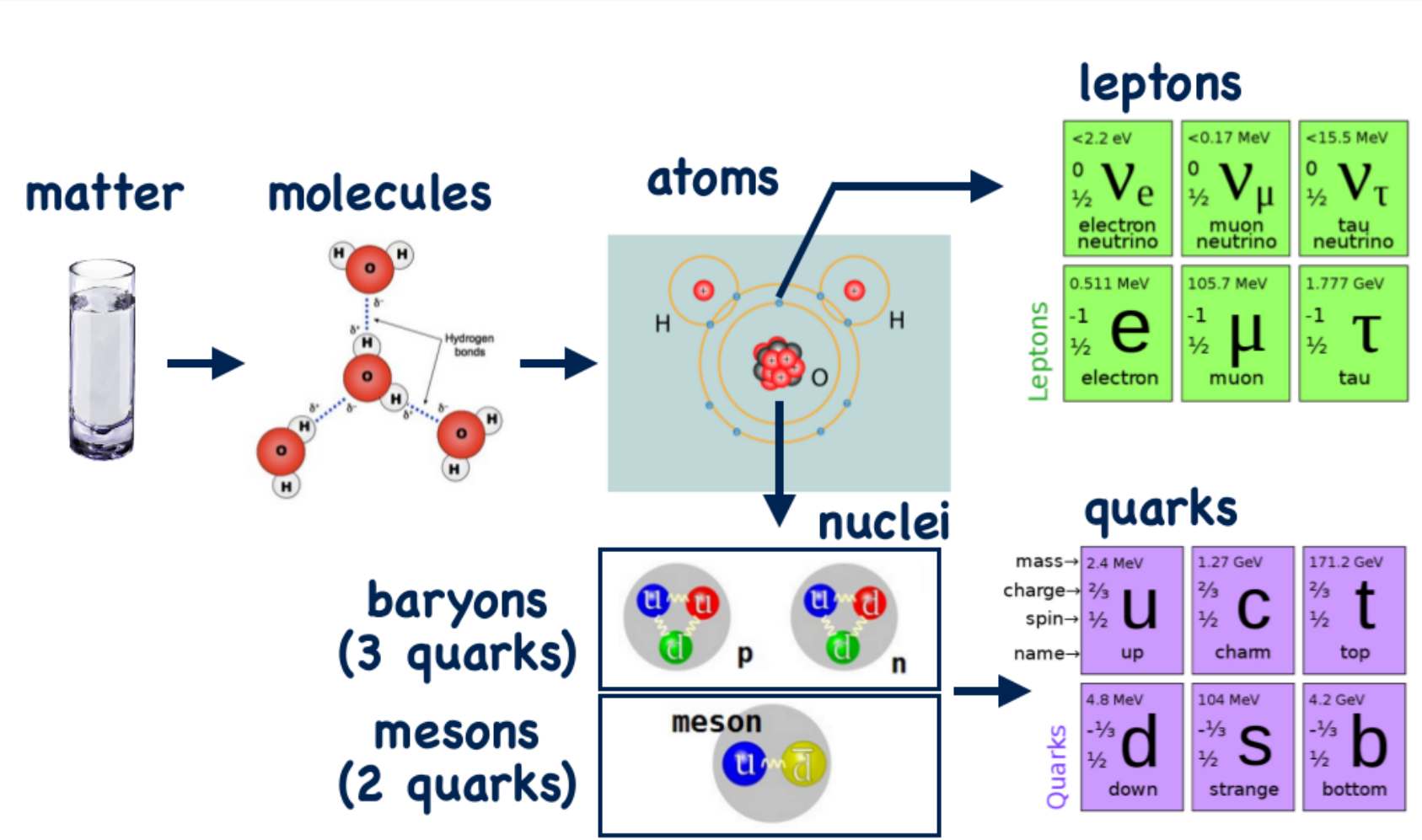
Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60
	long range	*range<<*	*long range*	*range<<*

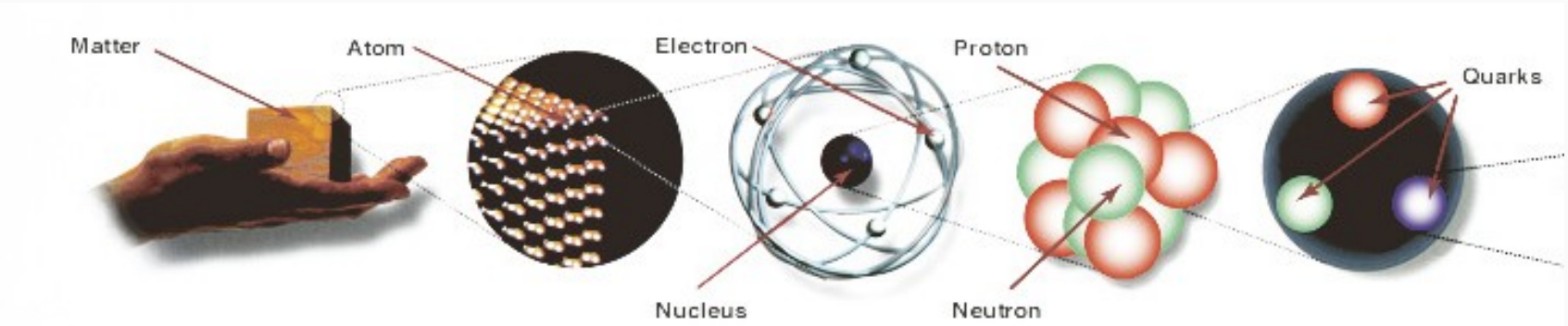
strength →

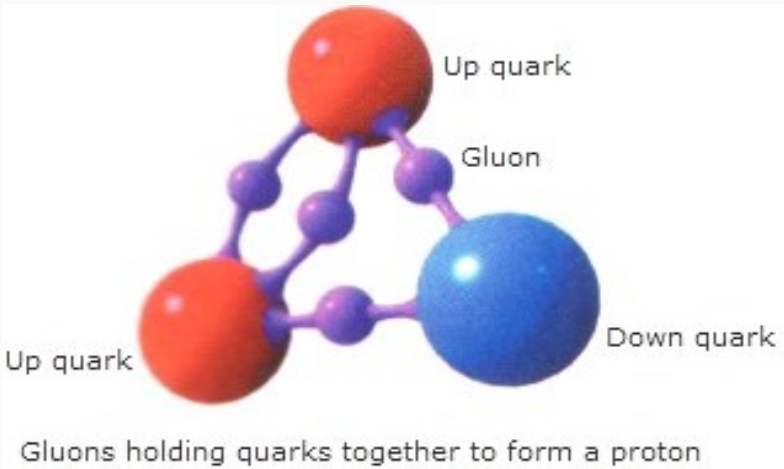
Elementary Particles



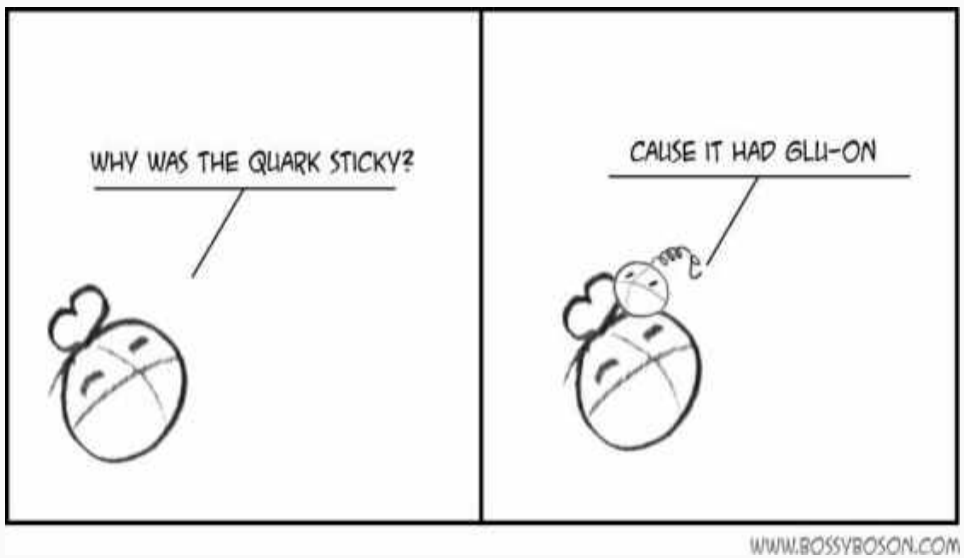
Matter and Quark-Gluon Plasma

QGP: Extremely *hot* and dense state of **matter** where **quarks** and **gluons** are free to move!





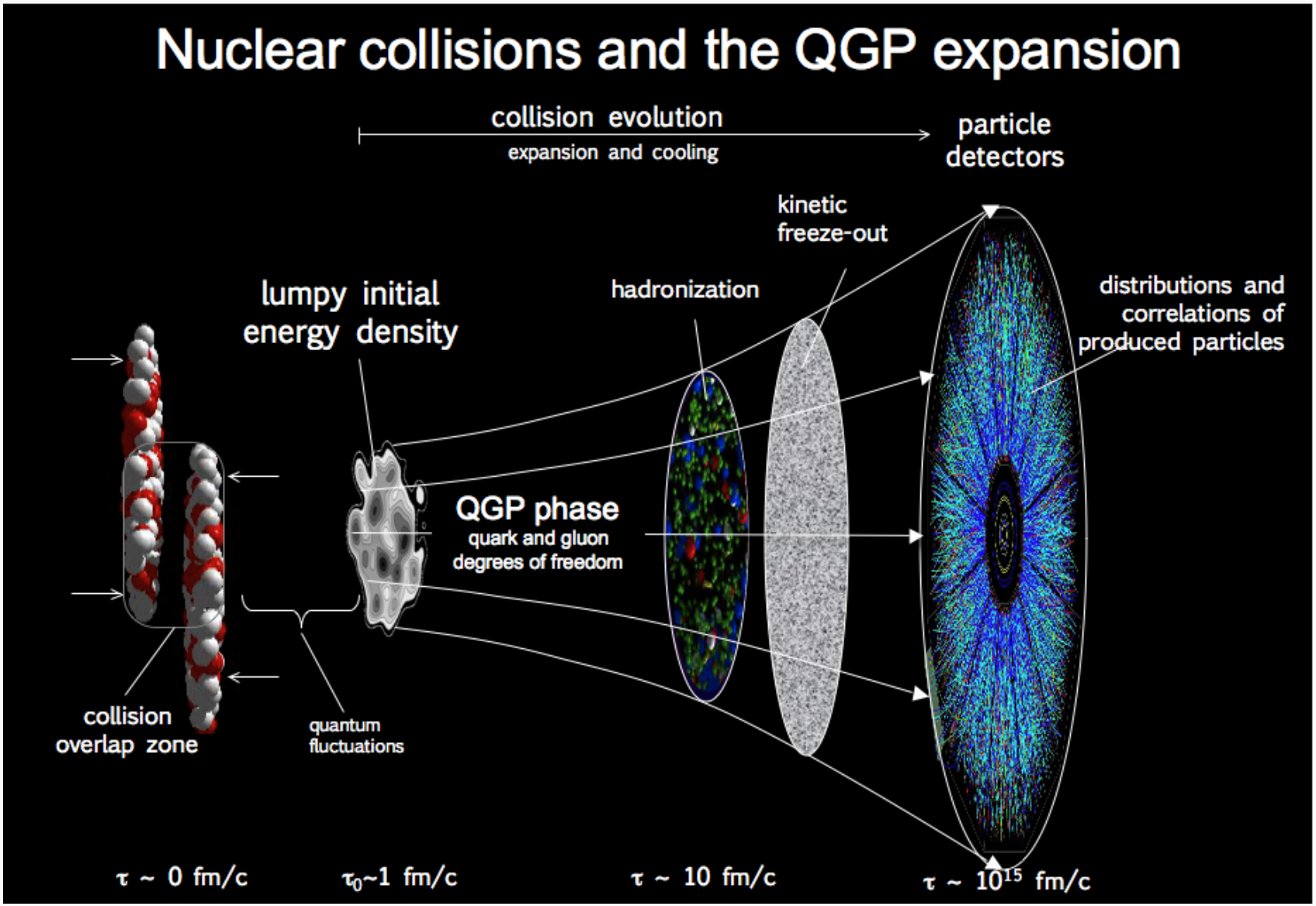
Gluons holding quarks together to form a proton



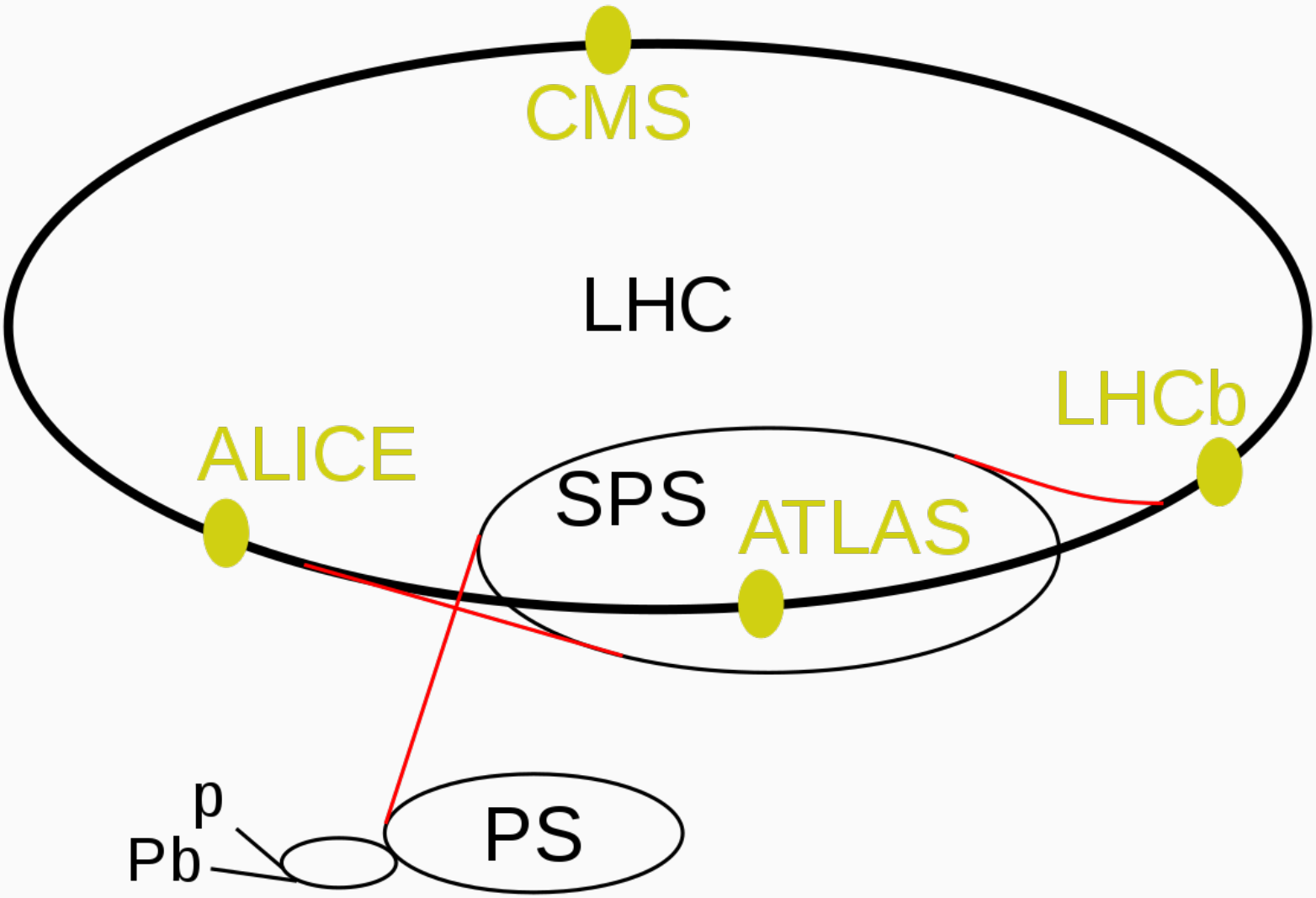
QGP: The Primordial Soup

Setup: How to study Quark-Gluon Plasma?
-From HI collisions

Heavy-Ion Collisions



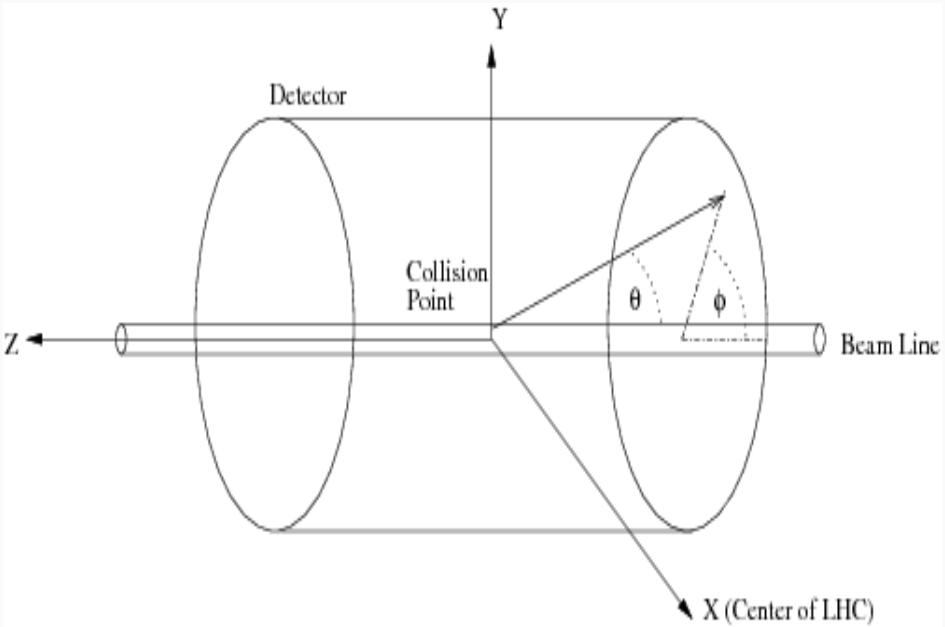
Colliders and Detectors: LHC



Colliders and Detectors: ATLAS

- ATLAS follows right-handed coordinate system.
- Measure positions of particles after collision using θ (from z-axis) and ϕ (from x-axis in transverse plane).
- Transverse Momentum (p_T): a very important quantity to measure.

The ATLAS Detector (cylindrically symmetric)

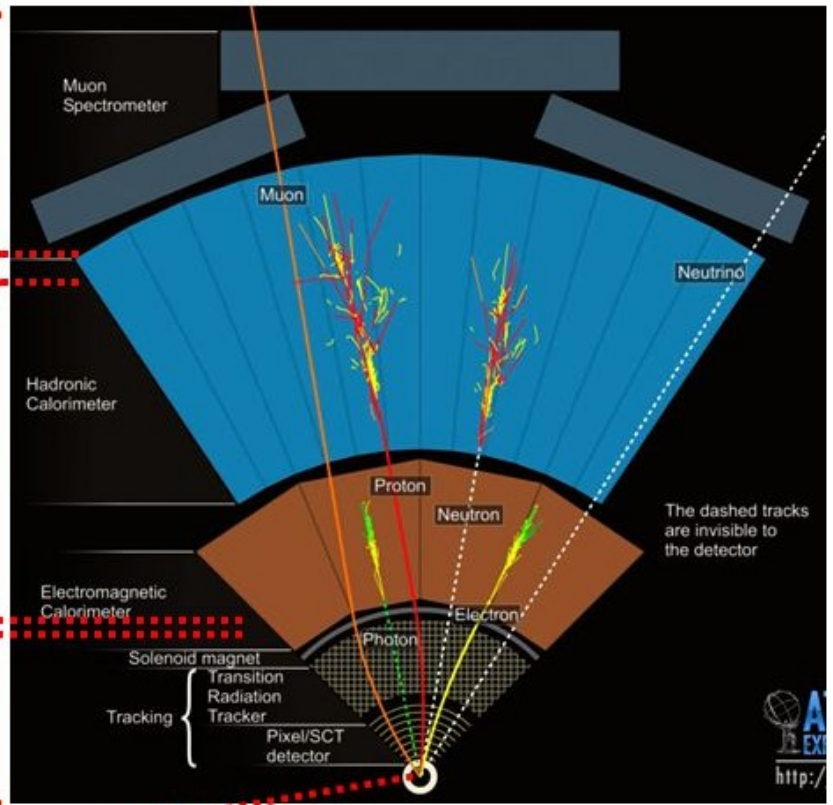


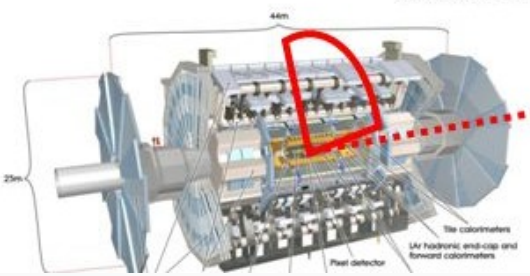
Colliders and Detectors

Measure p of muons
Tracking

Measure E of all particles
Calorimeters convert absorbed energy in light

Measure p of charged particles
Silicon & gas based tracking detectors in B field





Measurable Quantities

- Rapidity: $y = \frac{1}{2} ln(\frac{E+p_z c}{E-p_z c})$

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- For highly relativistic particles $y \approx \eta$

Analysis: Evaluation of charged hadron spectra in p+Pb

Why charged hadron spectra of heavy ion collisions?

- Production of *hadrons* (particles composed of quarks) is modified in HI collisions compared to pp collisions.

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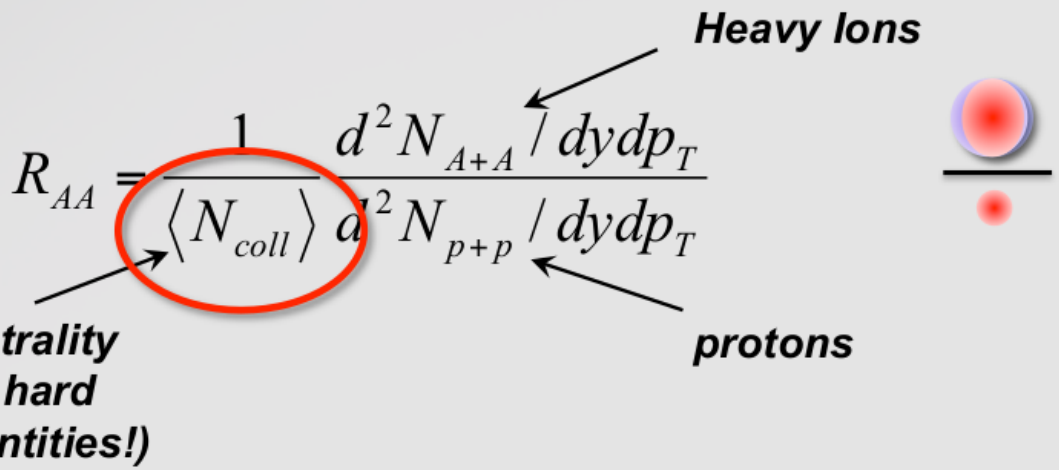
- High p_T tracks are coming from jets.
- How different is heavy-ion system from pp?

Why charged hadron spectra of heavy ion collisions?

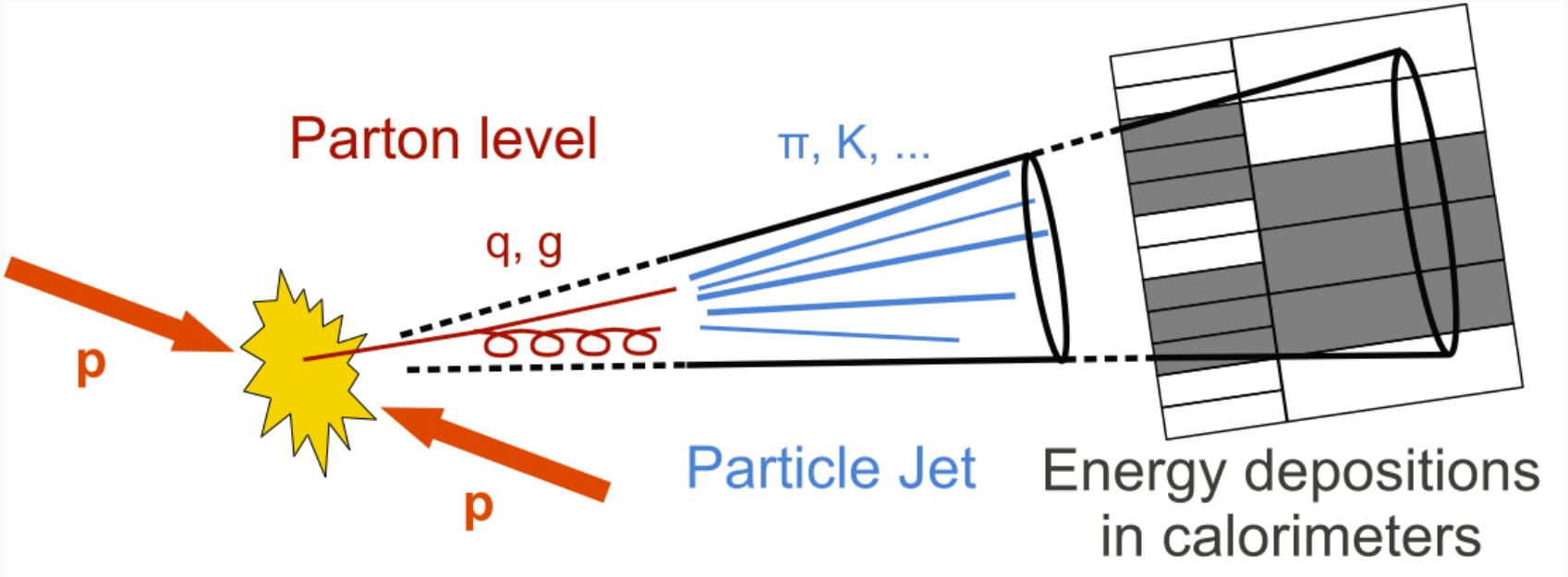
Nuclear modification factor

How different is the Heavy Ion system from proton-proton?



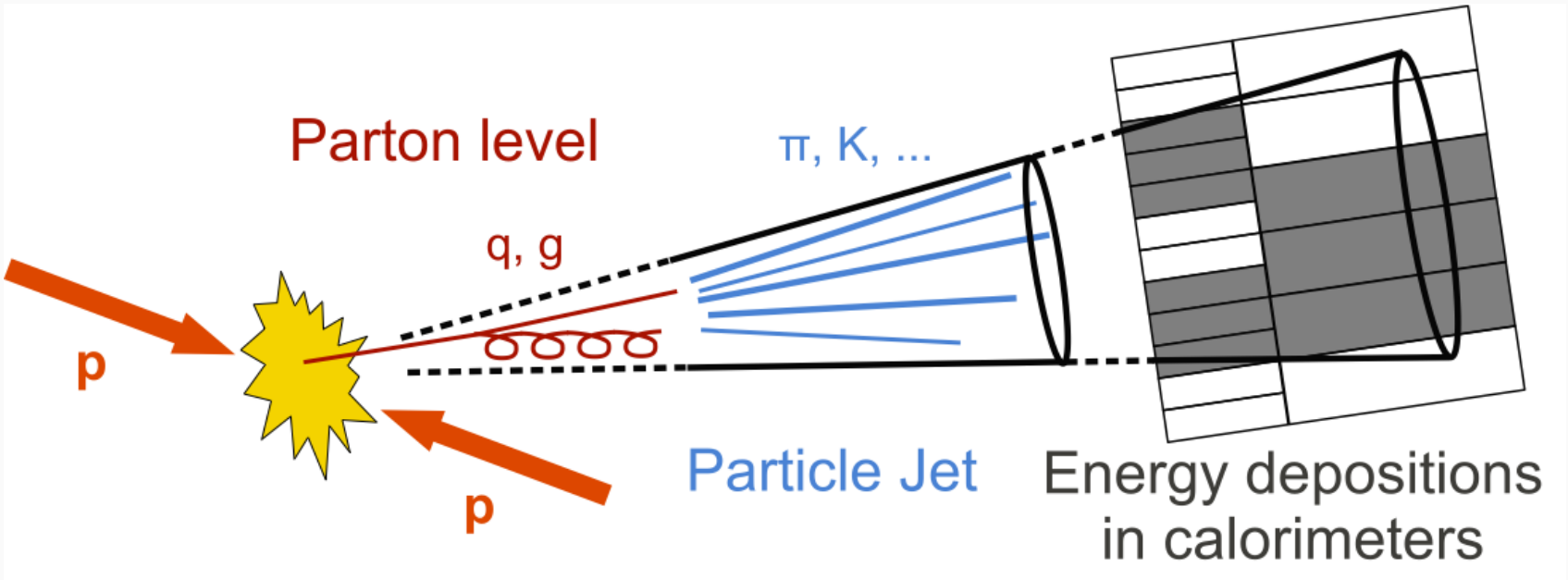
R_{AA} = 1 means HI collision = multiple p+p collisions, 'binary scaling' (of hard quantities)

Analysis: Jets



- **Jet**: A spray of hadrons depositing energy in the calorimeter.

Analysis: Jets



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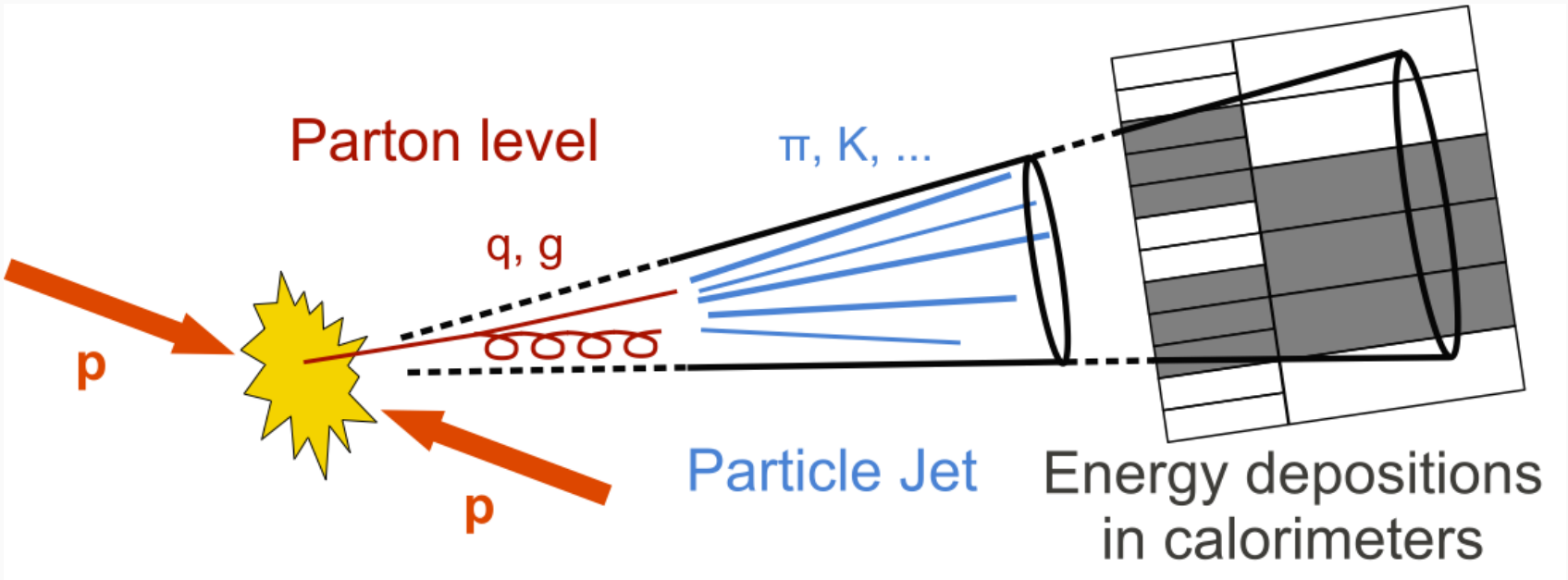

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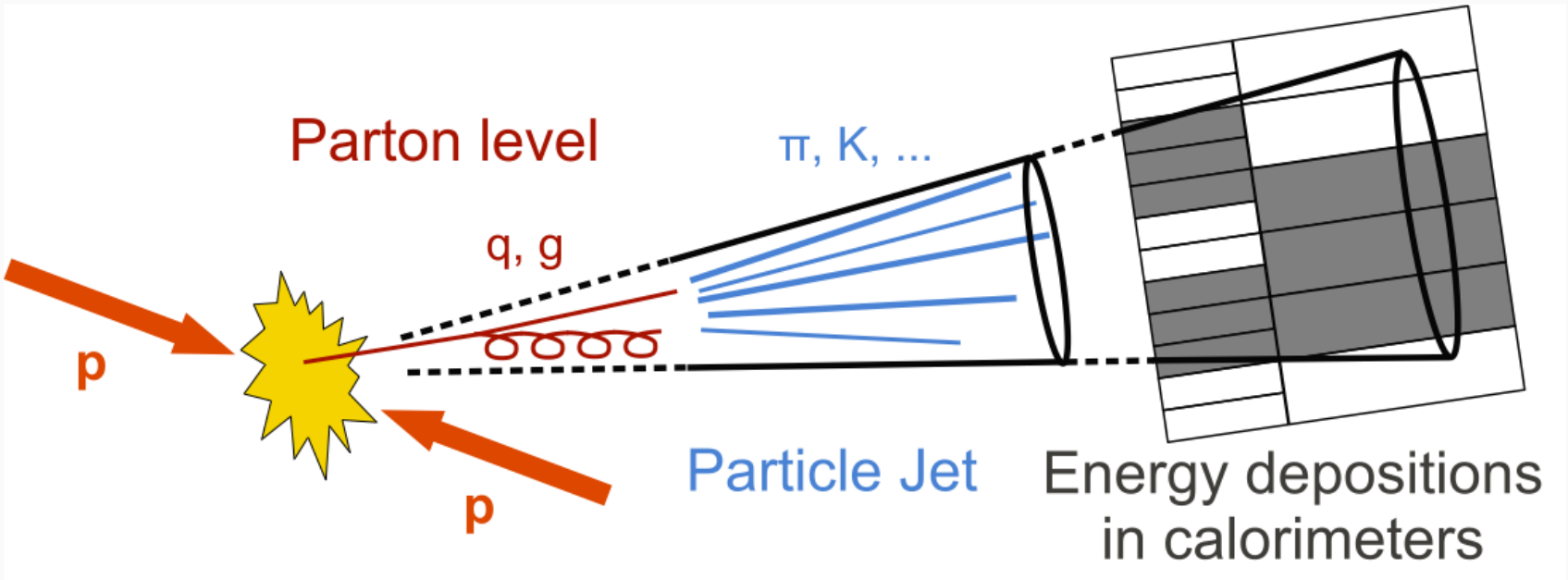

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- *Track* with high p_T is part of a jet, which is found by a trigger and the event is recorded.
- *Need to record events but can't record everything!*
- We need triggers!

Triggers and Analysis

- Trigger: A system or a software or both that selects events which potentially contain interesting physics. (”rare” or important events)
- Many types of triggers:
  - MinBias: Selects *basically* all events.
  - Jet Trigger: Selects events with jets.
  - Many other types of triggers...
- The main goal is to combine measurements from all the triggers, in order to make a spectrum to high p_T.

Results

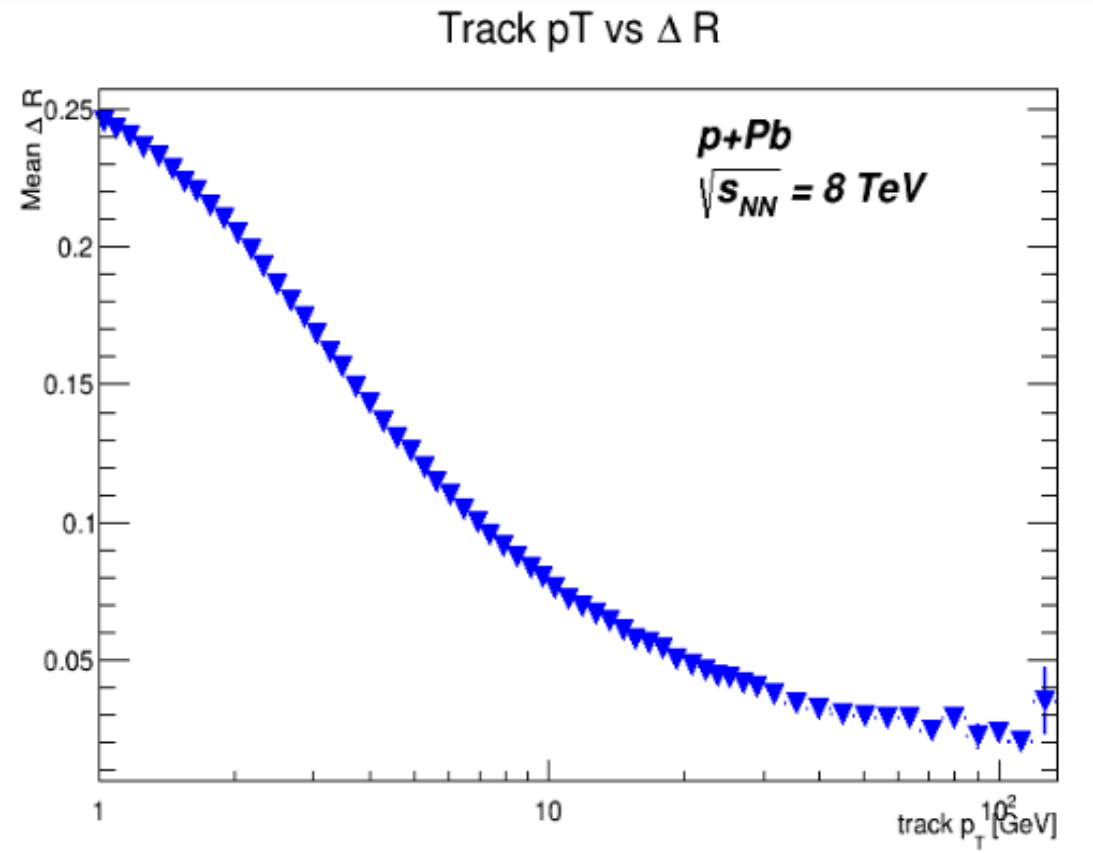
Results: Charged particle yield

- Cross-section: likelihood of two particles interacting under certain conditions.
- Charged particle yields measured in three centrality intervals.
- Statistical errors are indicated with vertical lines and systematic uncertainties are indicated by boxes.

Nuclear modification factor

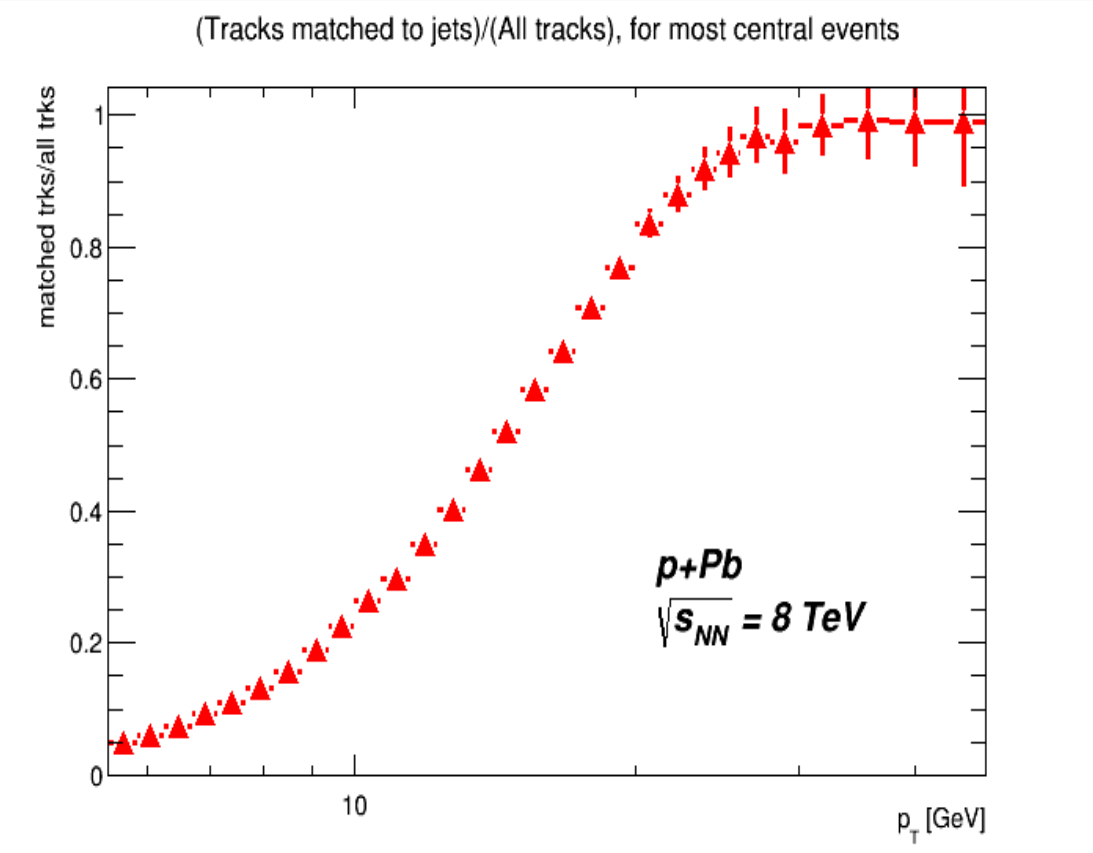
- Nuclear modification factor R_{pPb} deviating from 1.
- Confirms presence of nuclear modification in p+Pb collisions.

Results: ΔR



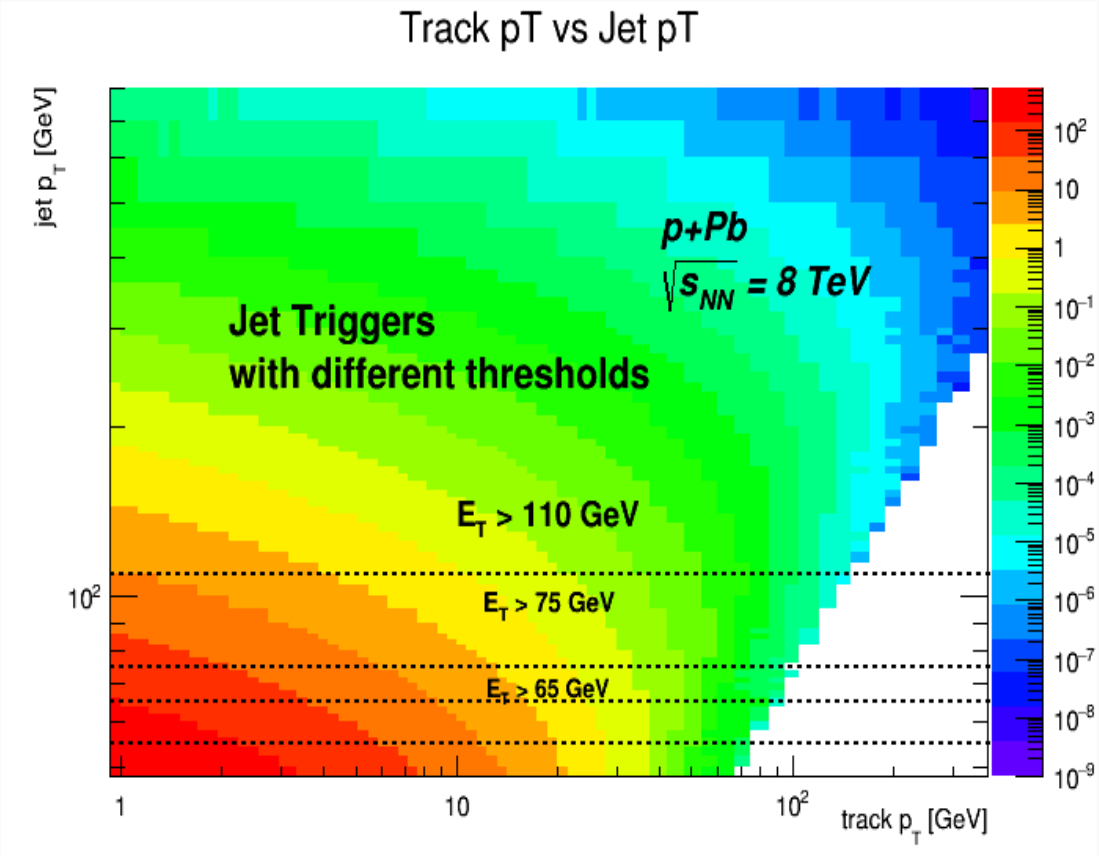
- $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$
- $\eta =$ pseudorapidity = $-ln \tan(\theta/2)$
- Matching: High p_T tracks are sitting near to jet axis, within 0.05.

Results: Ratio



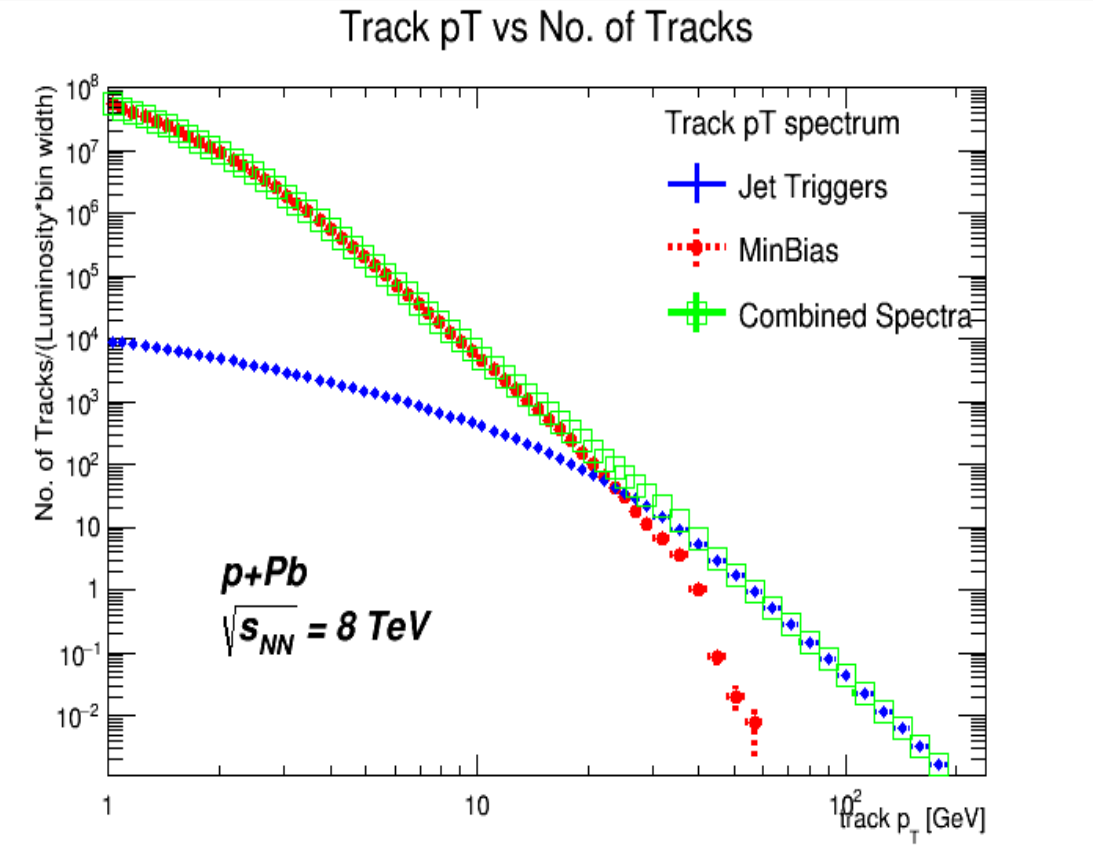
- Matching: Looking at tracks within $\Delta R \leq 0.4$
- MinBias: Doesn't use jets. But ratio at high p_T goes to 1.
- Confirms the initial assumption: More than 99% of the tracks are part of a jet at high p_T.

Results: Correlation between track p_T and jet p_T



- Combination of several triggers with different energy thresholds.
- More tracks and jets at low p_T.
- Record all events with high p_T. (They're *rare*.)
- Energy conservation in high p_T region.
- Histogram properly normalized, so we don't see the triggers in the plot.

Results



- Spectrum for jet triggers, MinBias triggers and combined.
- Combined spectra: *Unbiased*. Seamless transition.
- Ten orders of magnitude measurement!!!
- Use of jet triggers allows to measure spectrum at high p_T.

Conclusion

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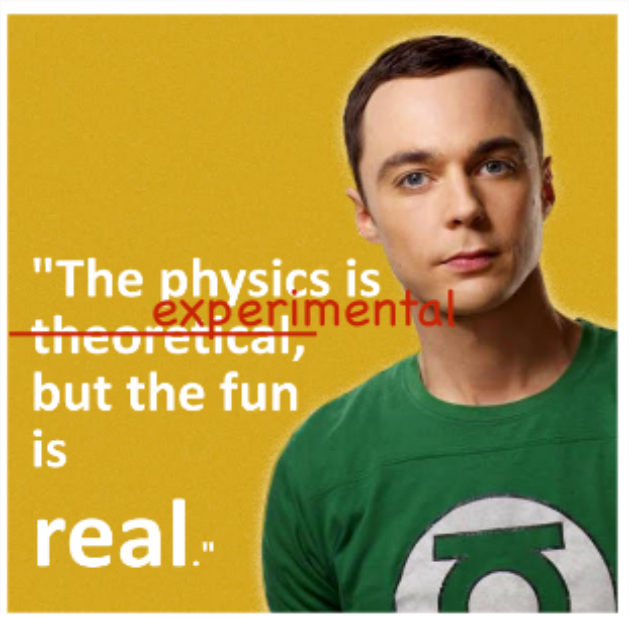
- Initial state effects: is the collision of heavy nuclei only the superposition of many nucleon-nucleon (proton-proton) interactions? (*Hint: No!*)



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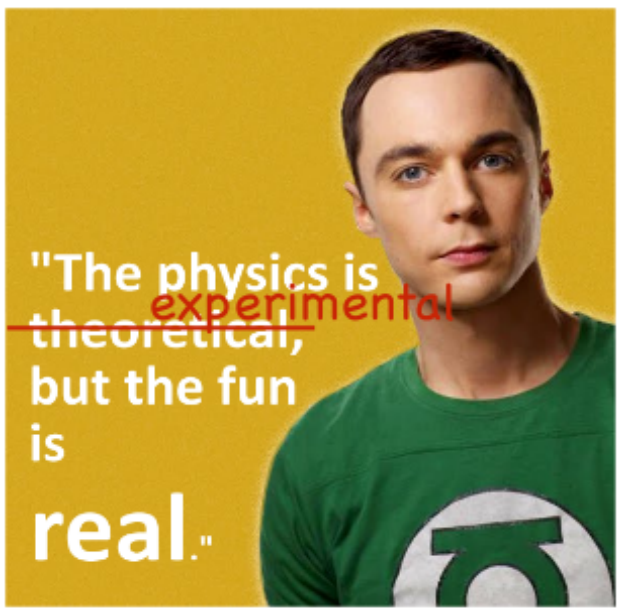
- In pPb there is a clear evidence of the presence of nuclear modification.



Conclusion

- Initial state effects: is the collision of heavy nuclei only the superposition of many nucleon-nucleon (proton-proton) interactions? (*Hint: No!*)
- In pPb there is a clear evidence of the presence of nuclear modification.
- By comparing the hadron spectra in pPb relative to pp, we can study the properties and effects of QGP.