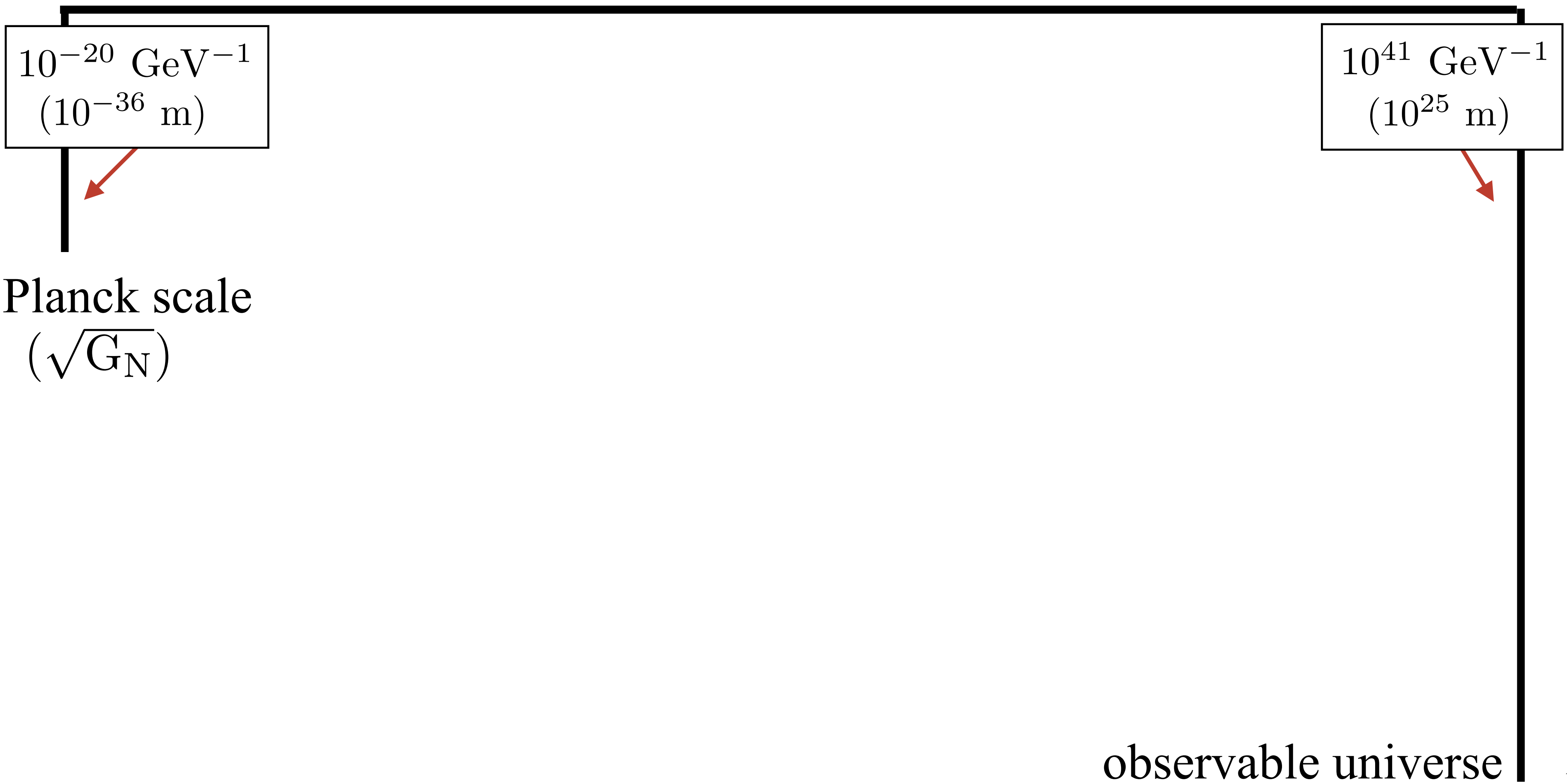
Length Scales



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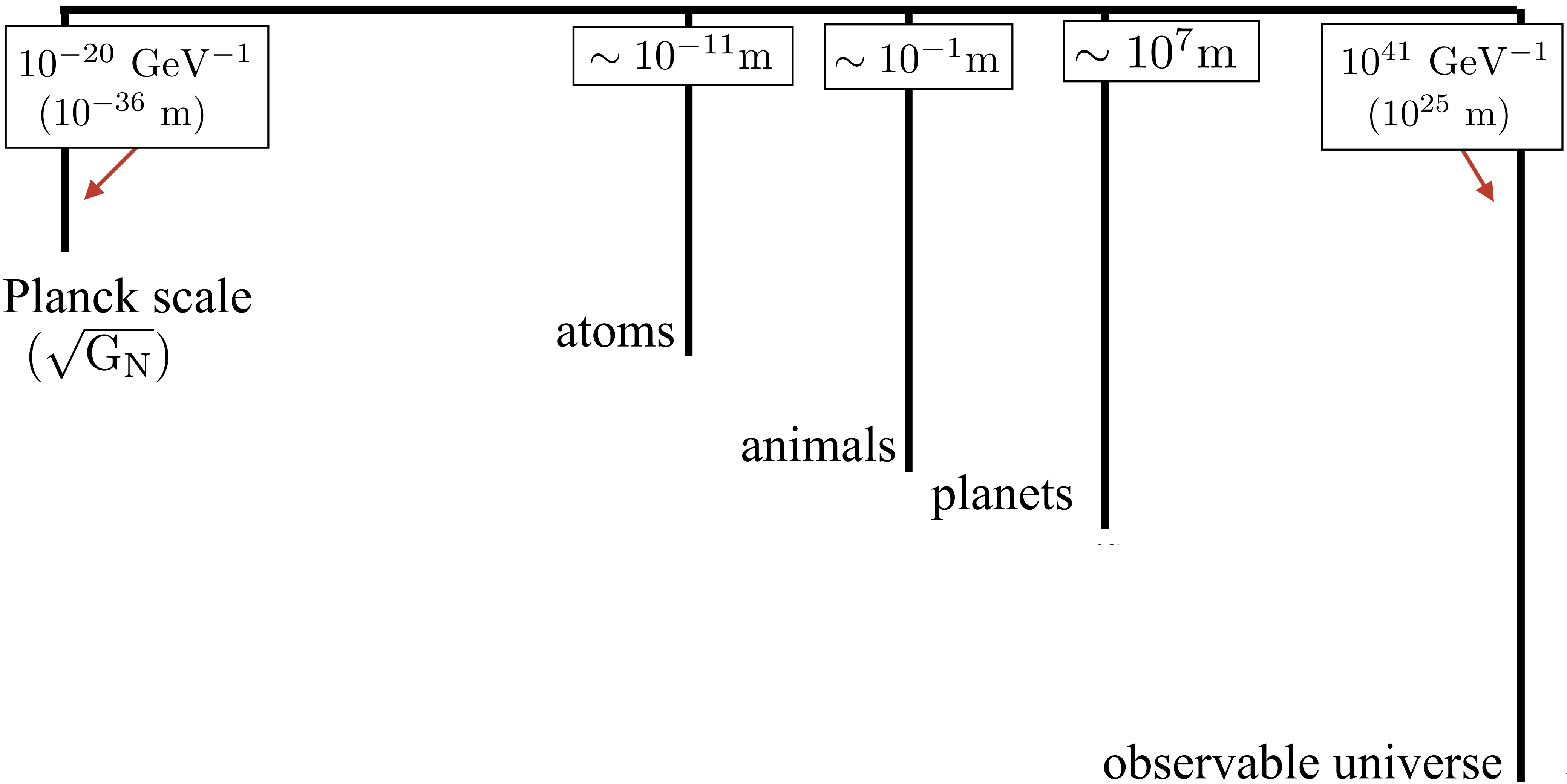

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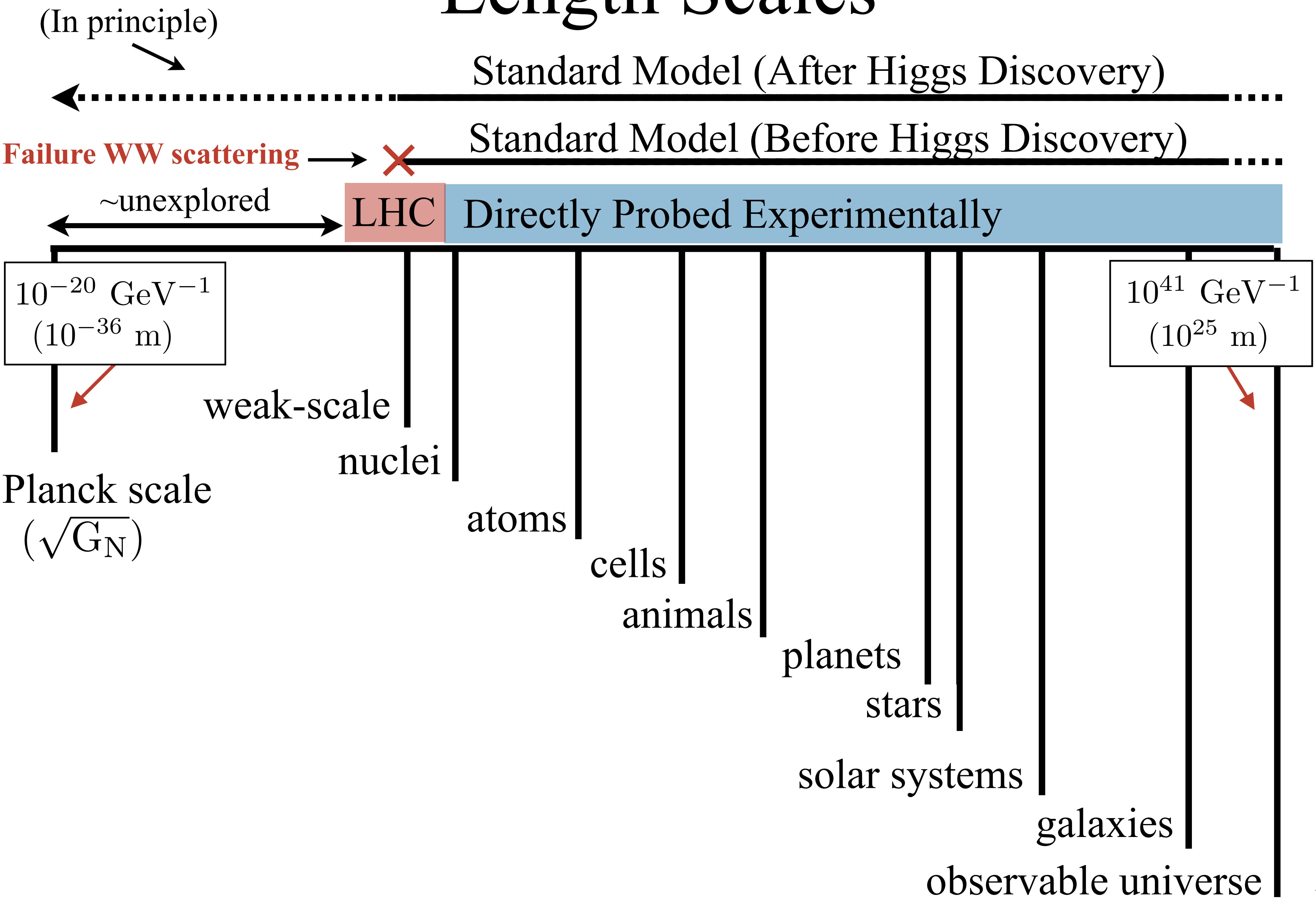

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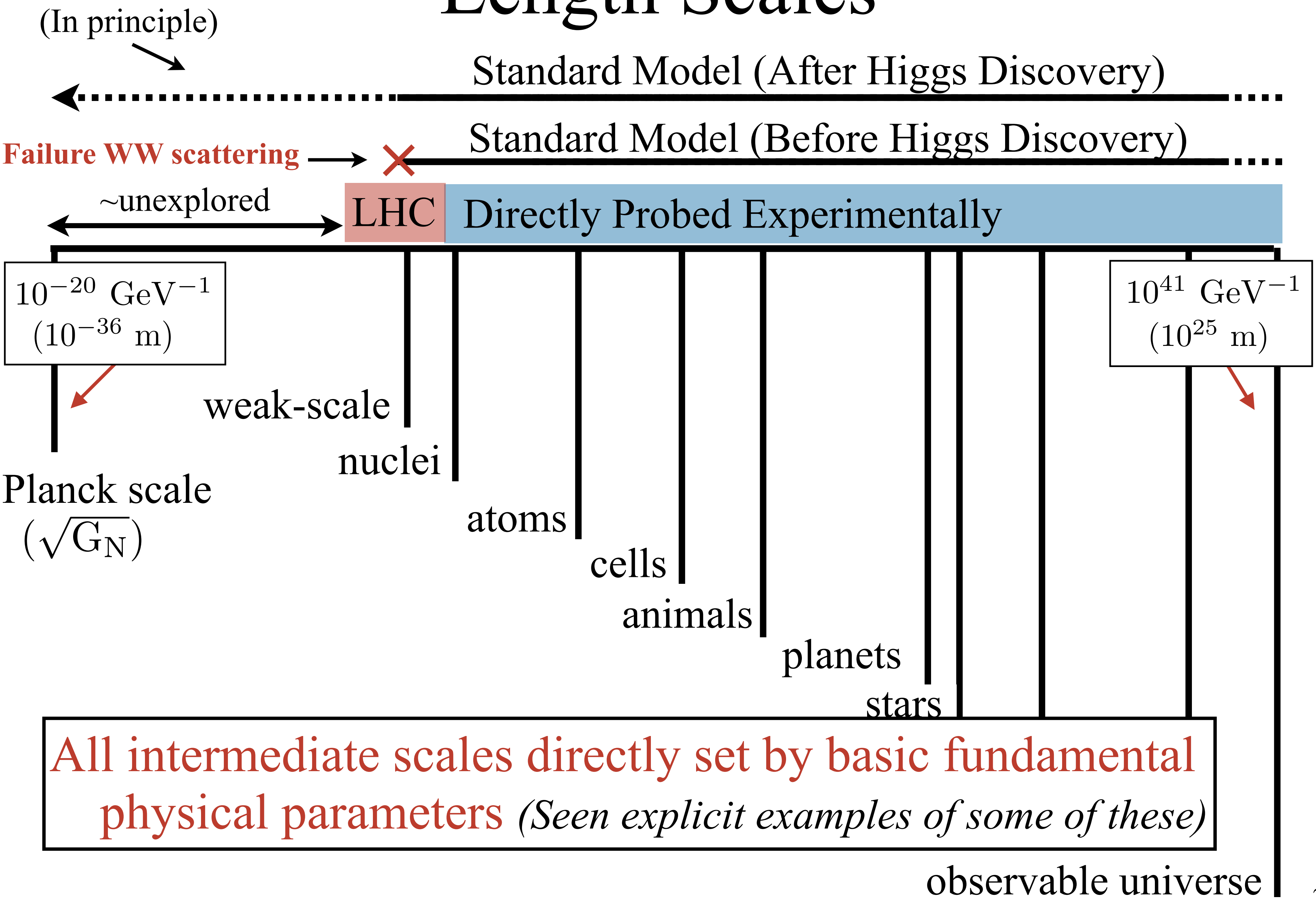
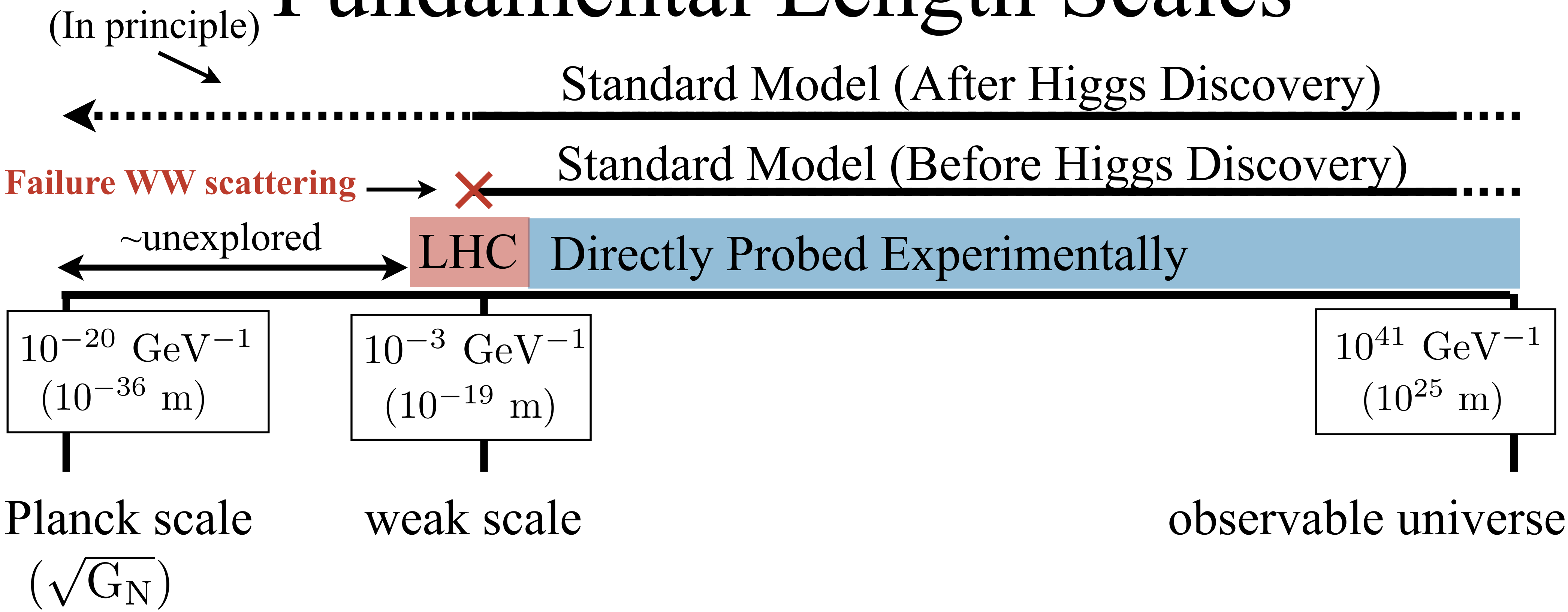


Fundamental Length Scales



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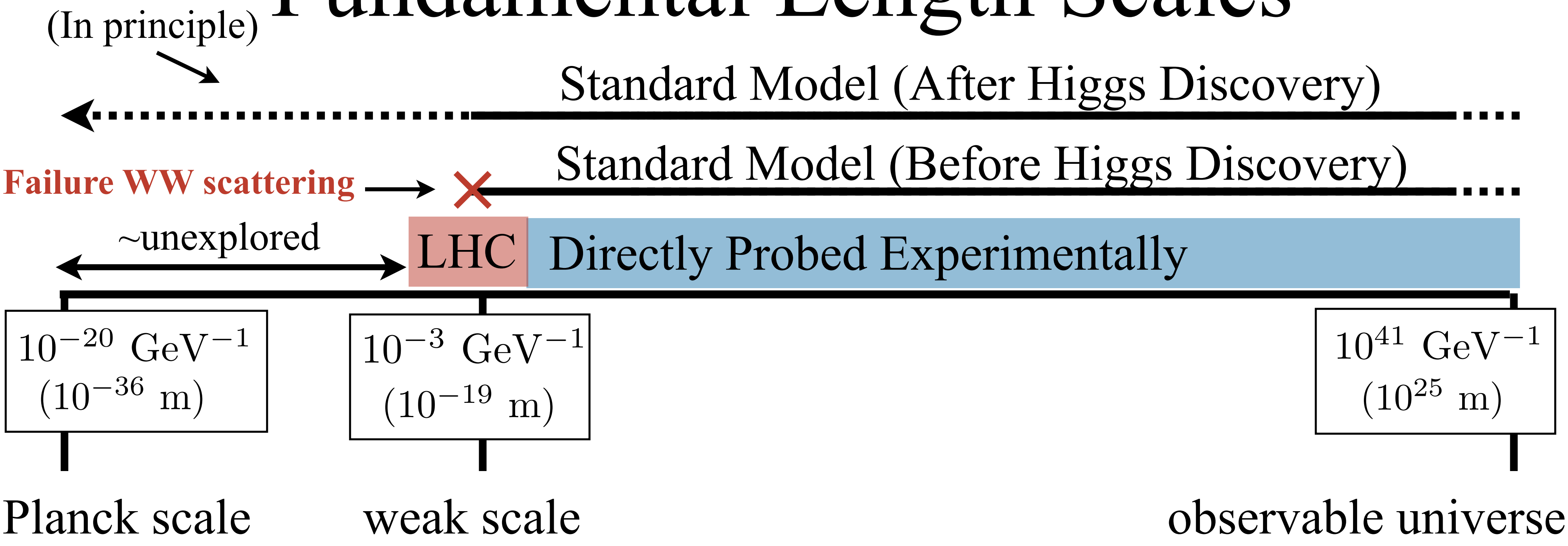
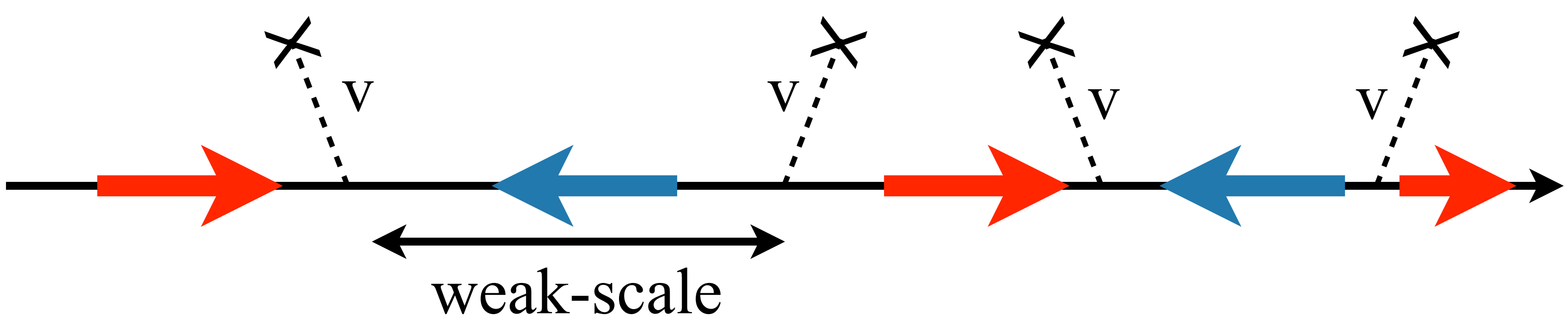
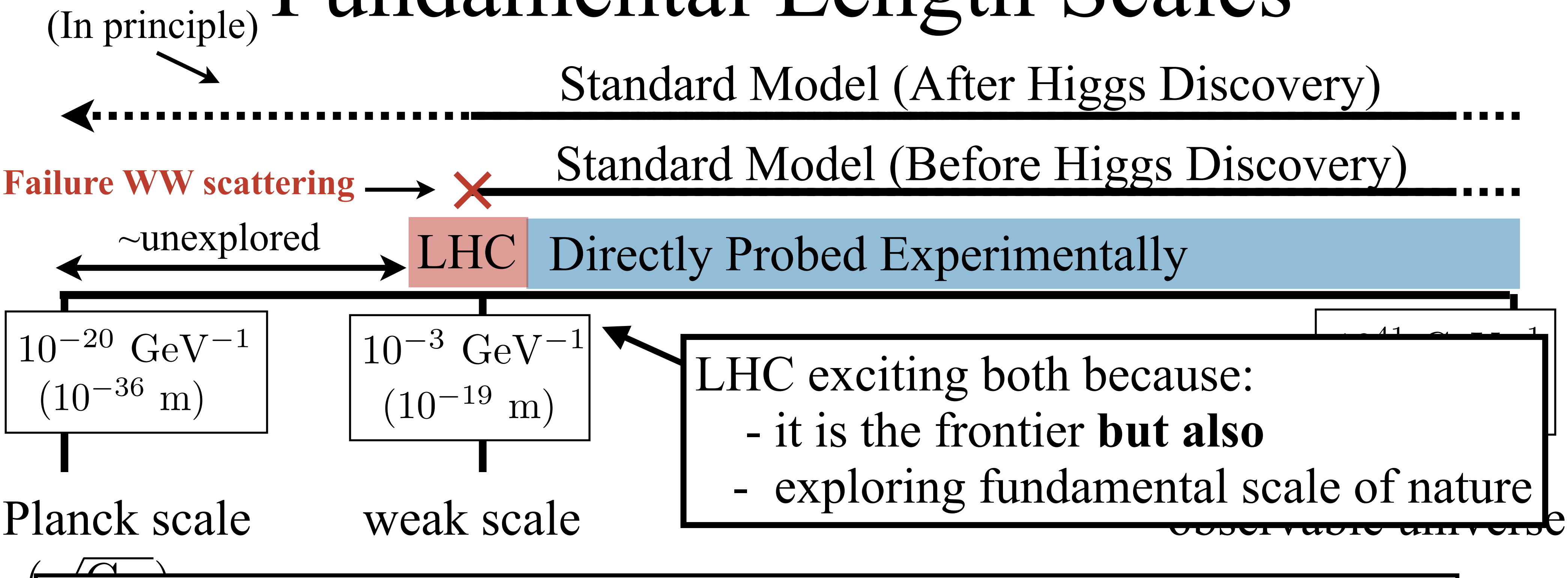


Weak scale: Fundamental scale in physics
- Scale associated with fundamental particle masses
- Typical at which massive particles interact with Higgs field
- The first time start seeing the forces have same underlying structure



Fundamental Length Scales



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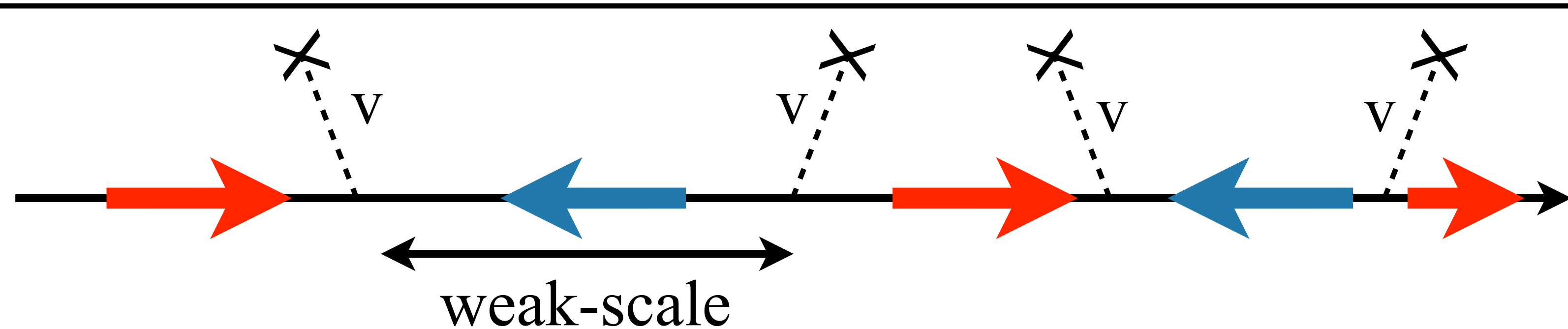

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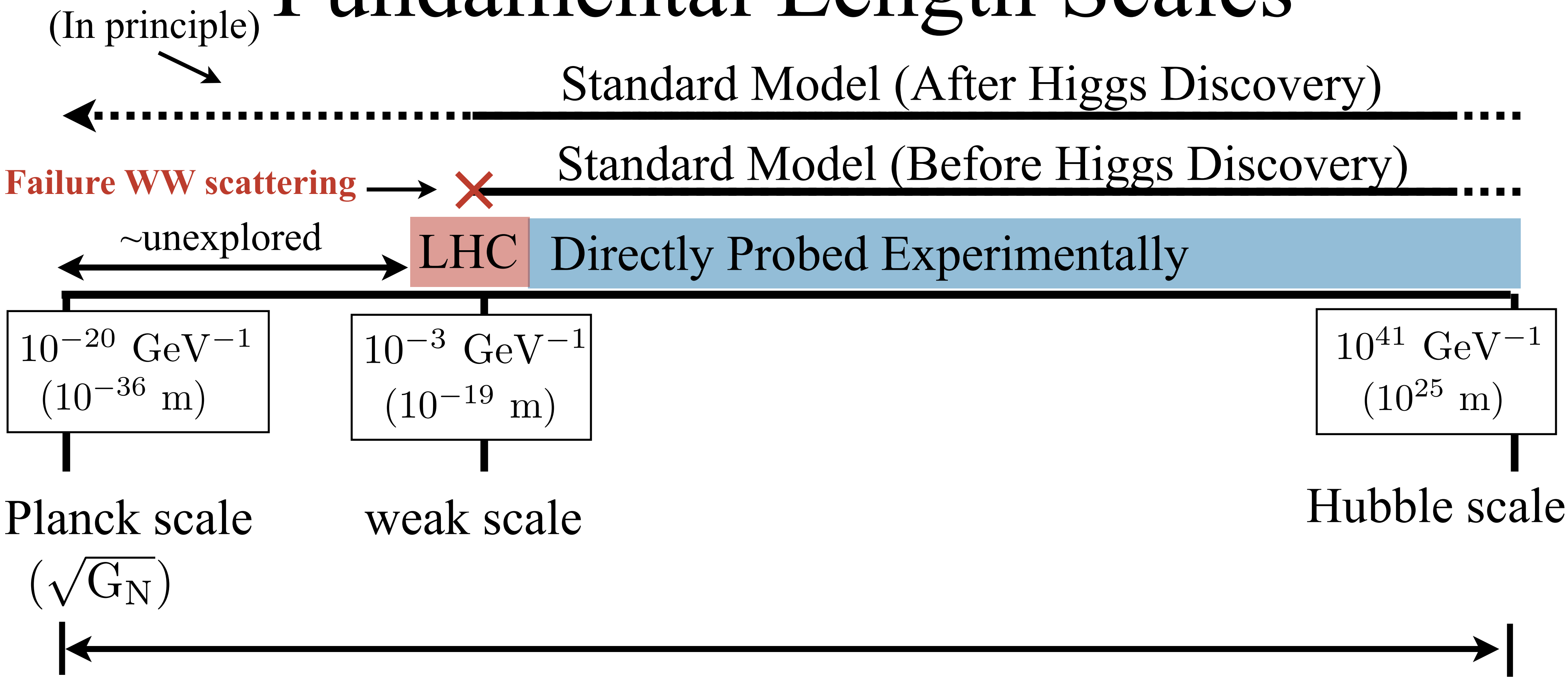


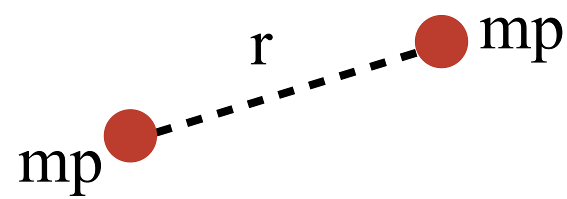
- Large range, but not infinite.
- <u>Claim</u>: Everything we know, ***and can possibly know***, within this range
- Upper bound set by finite upper speed limit (finite age of universe)
- Talk about lower bound, next. Believed to really be hard lower bound
- Deep mysteries/problems with SM directly associated with each fundamental scale

Problem with the Planck Scale

Relative Strength of Gravity

Electromagnetic Interaction

$$F_{EM} = \underbrace{\frac{e^2}{4\pi}}_{\boxed{\text{Pure number: } \alpha}} \frac{1}{r^2}$$

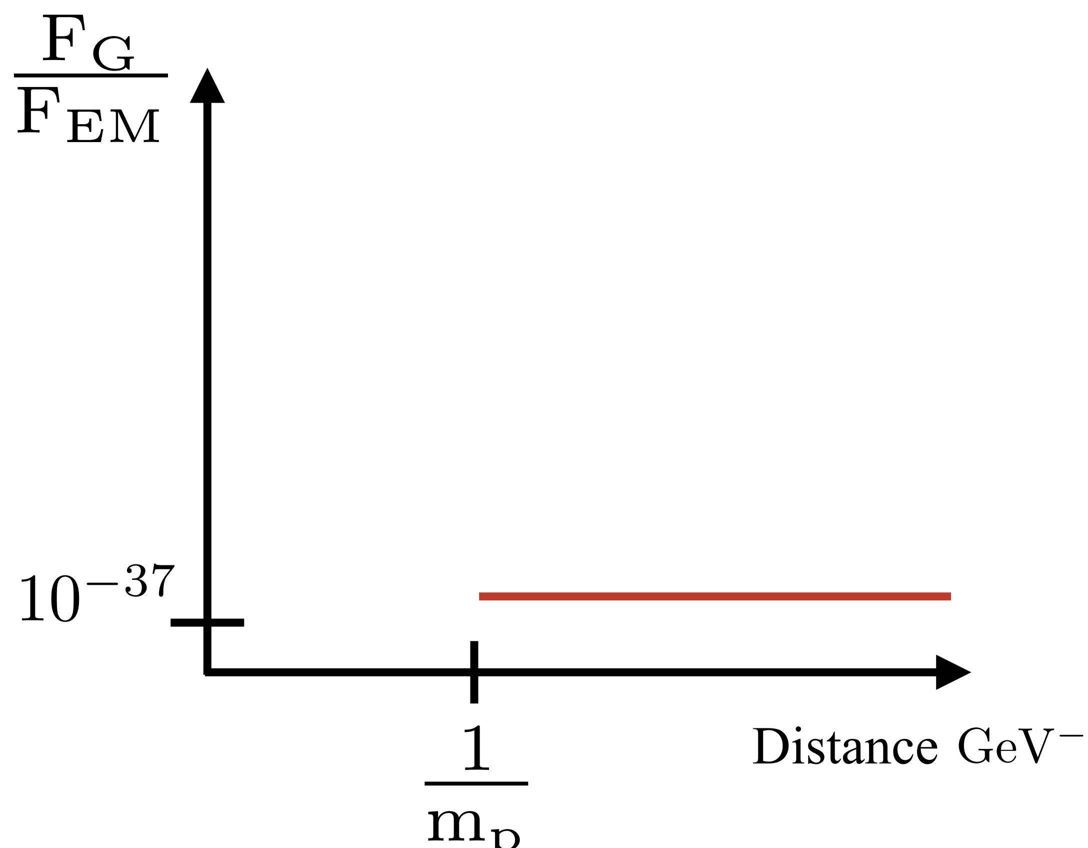


Gravitational Interaction

$$F_G = \underbrace{G_N}_{} \frac{m_p^2}{r^2}$$

Dimensionful number

$$G_N \sim (l_{Pl})^2 \sim (10^{-20}\ \mathrm{GeV}^{-1})^2$$



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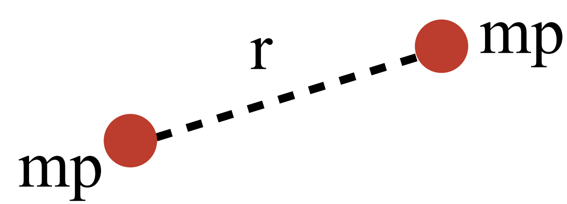

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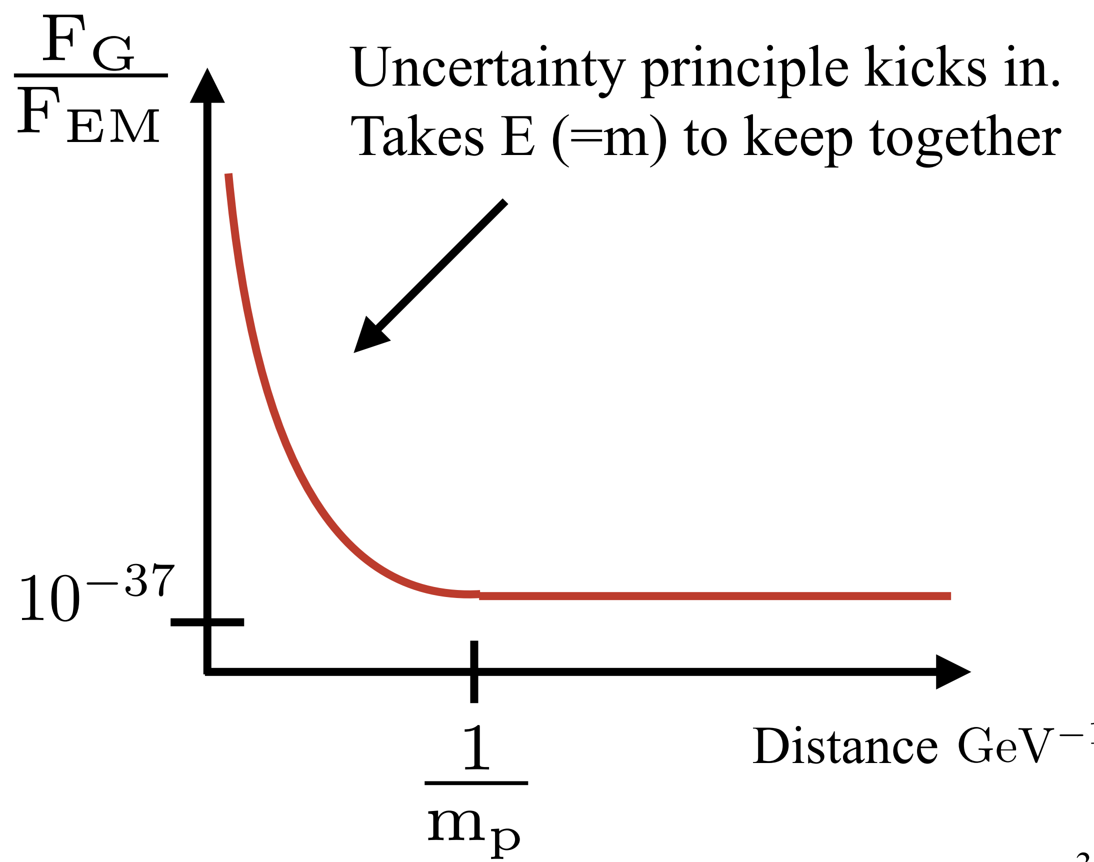
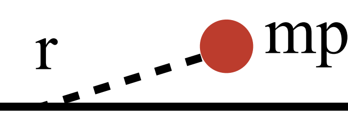


Relative Strength of Gravity

Electromagnetic Interaction



At short distances, (comparable to ℓ_{Pl}) gravitational interaction dominates
- ℓ_{PL} the scale at which gravity is becoming strong

Pure number: α

Gravitational Interaction

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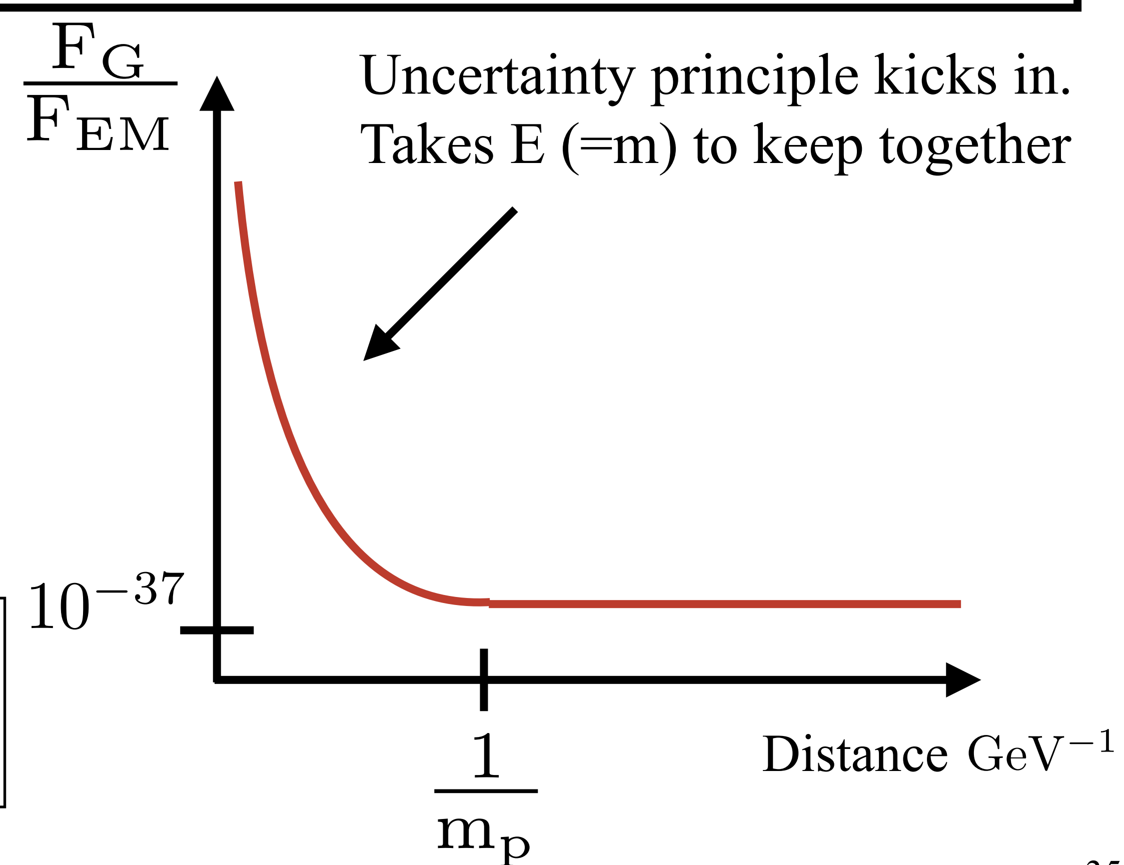
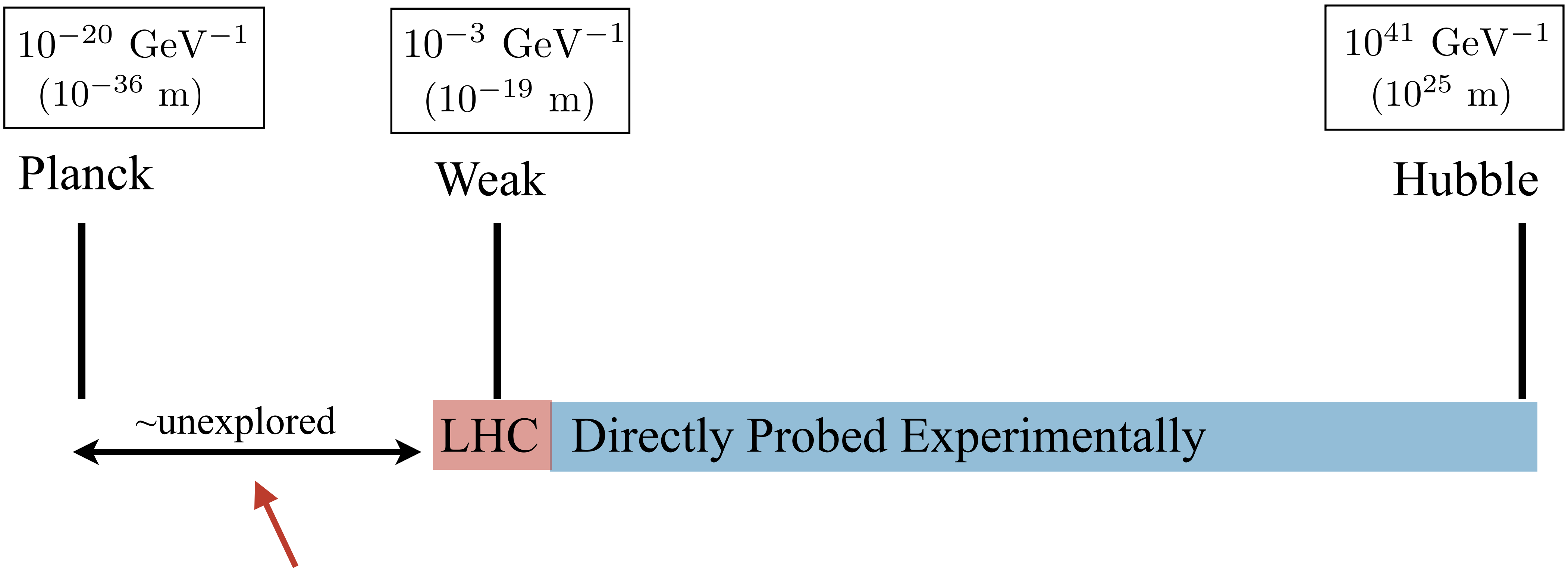


Probing Smaller Distance Scales



- Say we decided to probe smaller and smaller distance scales
- Build collider, go to higher and higher energies
- Eventually reach point where gravitational interaction dominates
- Continue to smaller distance … then something new happens…

Create Black Holes !

Some point put so much energy into collisions that you create black hole
Estimate scale when this happens:

$$\mathrm{G_N}\frac{\mathrm{m}^2}{\mathrm{r}} \sim \mathrm{mc}^2$$

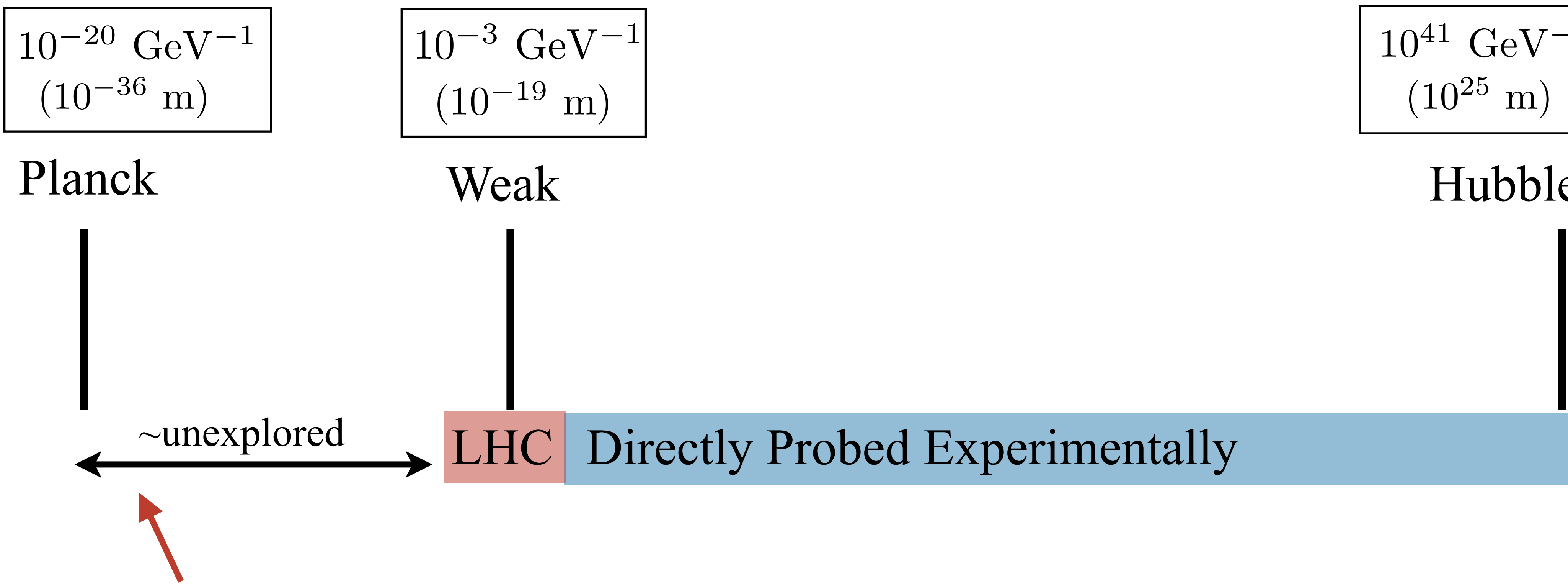
At high energies, mass dominated
by E associated w/uncertainty principle

$$\mathrm{m} \sim \frac{1}{\mathrm{r}}$$

$$\mathrm{G_N}\frac{1}{\mathrm{r}^3} \sim \frac{1}{\mathrm{r}}$$

$$\mathrm{r} \sim \sqrt{\mathrm{G_N}} \sim \mathrm{l_{Pl}}$$

Probing Smaller Distance Scales



- Go to higher-higher energies… Gravity begins to dominate
- At ℓPl make blackhole / Cant tell whats happening in blackhole
- Even higher energies gives bigger blackhole
- Nothing can do (in principle) to get information about smaller scales
  - *Physics telling us that smaller scales dont exist*

(Seen kind of thing before in QM and Relativity)

Probing Smaller Distance Scales

Lower Limit to Spacetime

Notion of space-time breaking down ℓPl /Not clear what replaces it.

<u>Major issue:</u>

- Understanding of these short scales needed for:
  - Early universe: *What happened when universe curvature ℓPl*
  - Details of blackholes
- Physics is about what happens in space-time

Other hints that some dramatic need ("Holographic Principle")

- Black hole information scales like area
- Observables with QM can in principle perfectly predict
- Toy models where see space emerging
- …

(Seen kind of thing before in QM and Relativity)