Probing Trillion Degree Matter

DOE CSGF Program Review 2016

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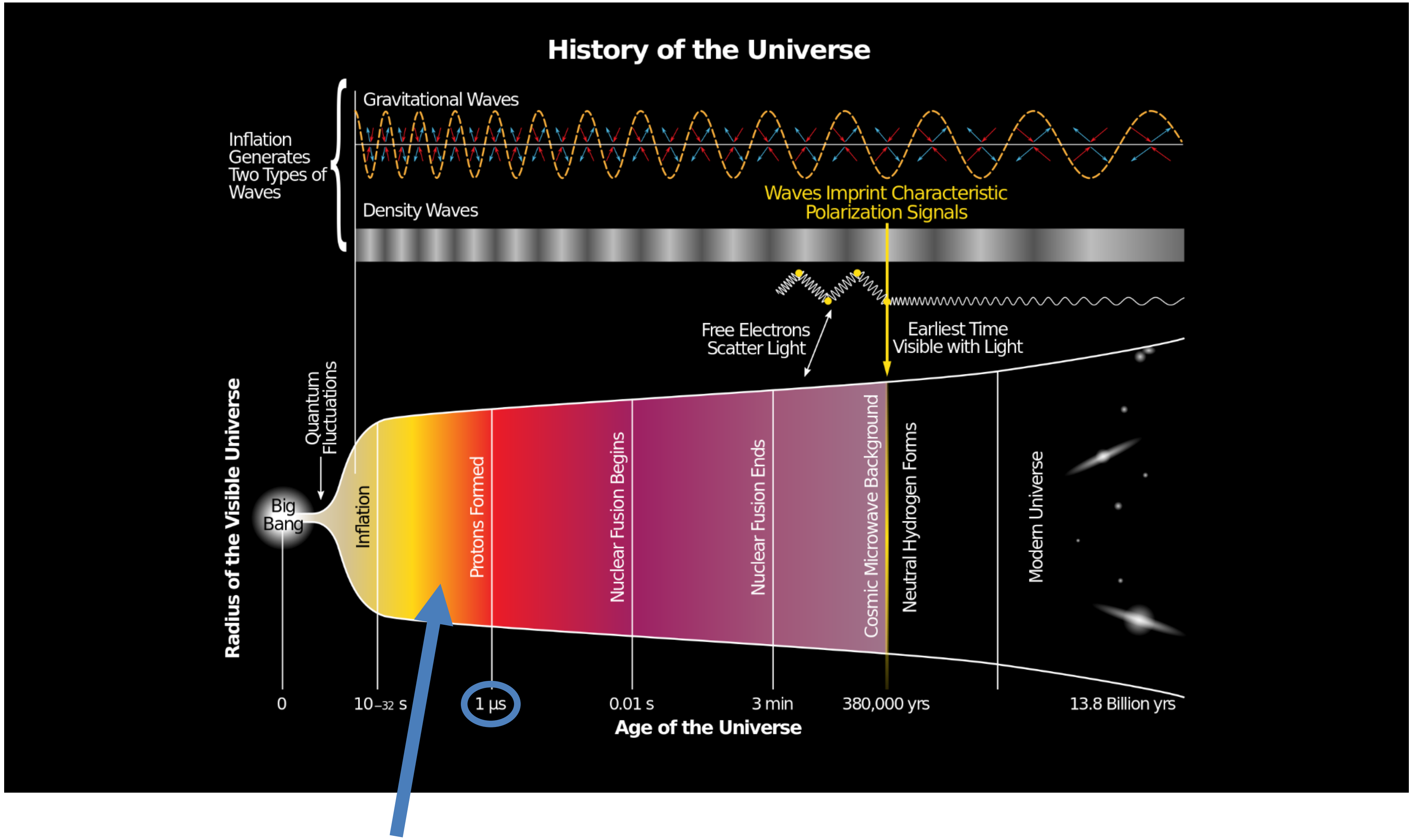
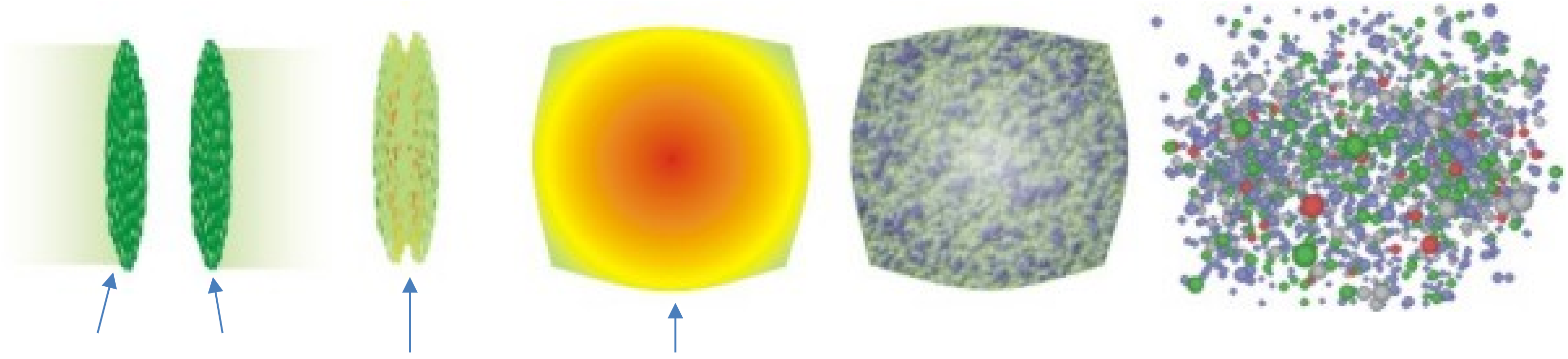
In the beginning…



Trillion degree matter here

How to create trillion degree matter

- Accelerate lead nuclei to near the speed of light, and smash them together



Pb nuclei Contact Quark-Gluon-Plasma Individual Particles

Short animation of a collision

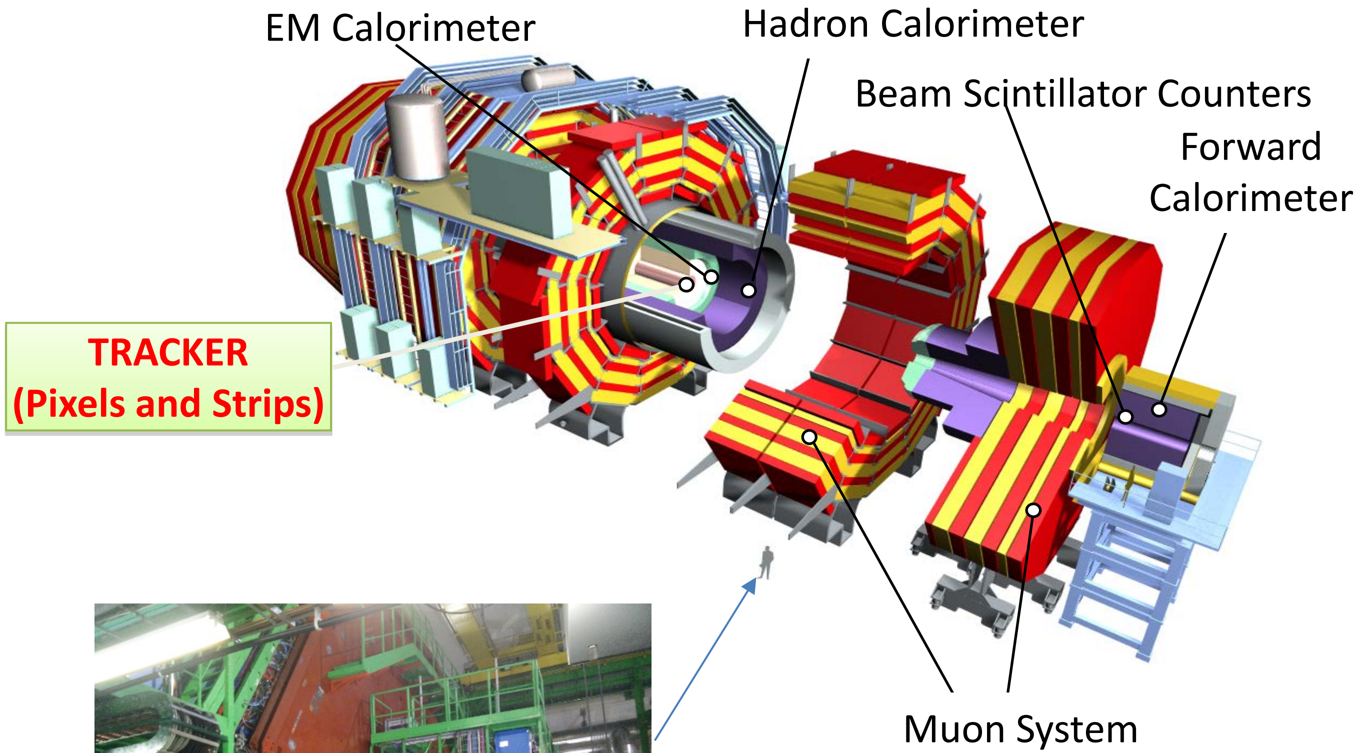
▶

1 fm/c $= 3 \times 10^{-24} s$

On this time scale, 1μs is ages!

A Large Particle Accelerator

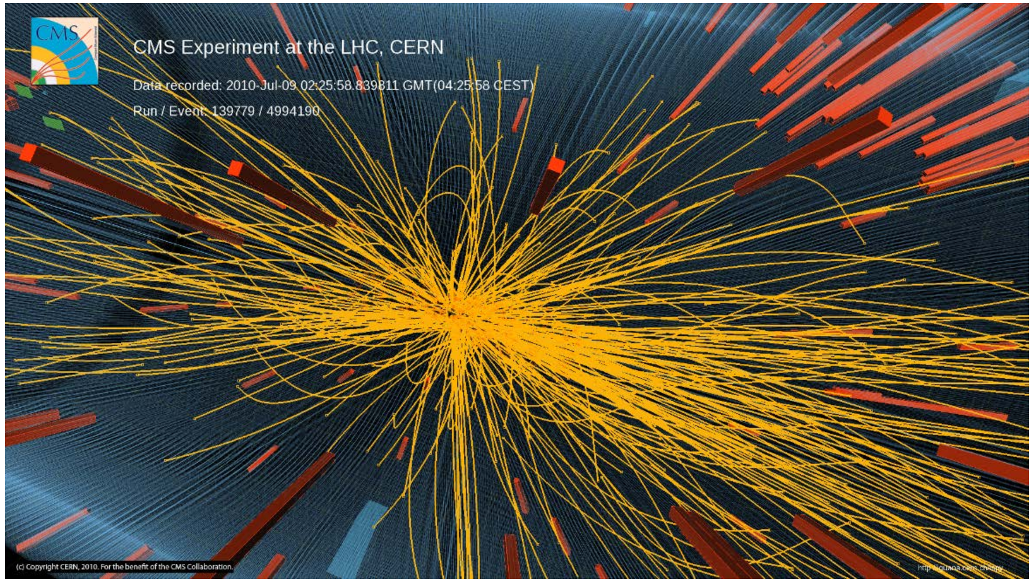
A Compact Particle Detector - CMS



- Surround collision point with different particle detectors
  - – 4 Tesla solenoid
  - – Tracker – connect the dots, (75 million dots…)
    - $p^{\pm}$, $e^{\pm}$…
  - – Calorimeters – measure charged (EM) and neutral energy
    - n, γ

Collisions

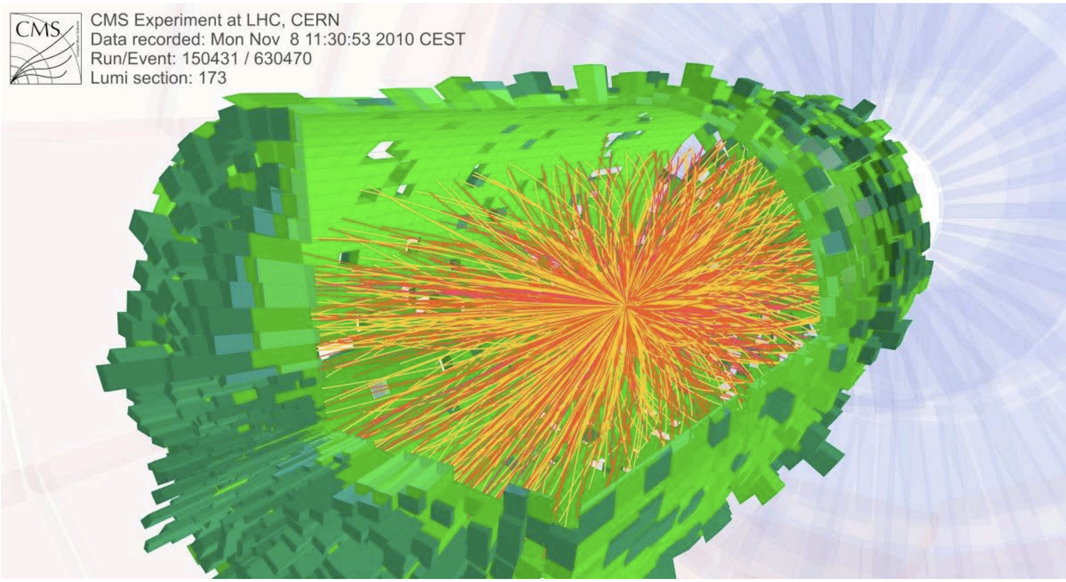
A single 7 TeV p-p collision , ~ 20 MHz



1+1 = 200?

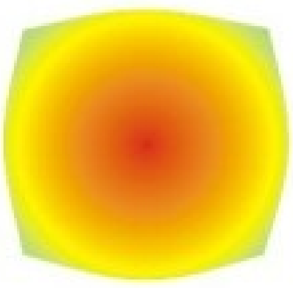
$E = mc^2$

A single 2.76 TeV Pb-Pb collision , up to 20 KHz



200+200 = 30000

An instant of Quark Gluon Plasma (QGP)



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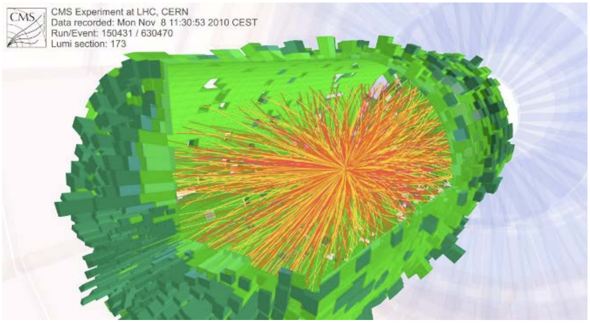
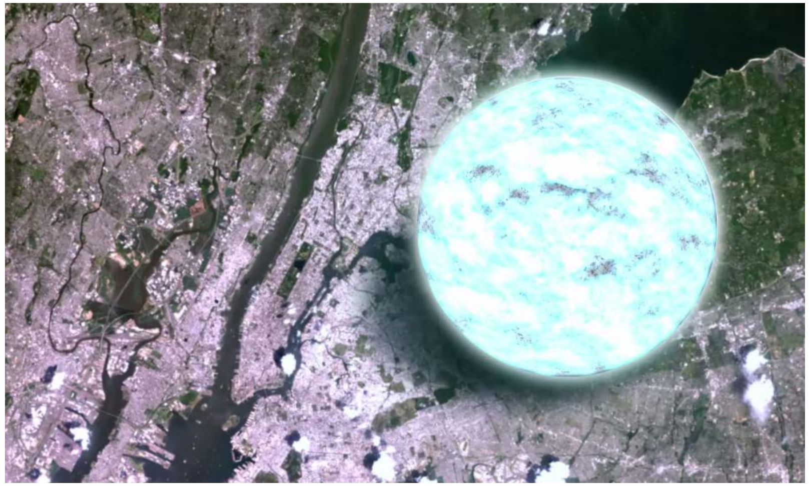


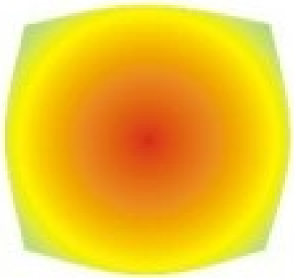
- Initial volume of QGP ~ volume of Pb nucleus, O(10 fm^3)
- Initial energy = final energy, which we can measure
  - Calculate density ~30 GeV/fm^3 →
  - Simulations give temperature ~4 Trillion Kelvin (1M hotter than sun core)



Much denser than a neutron star

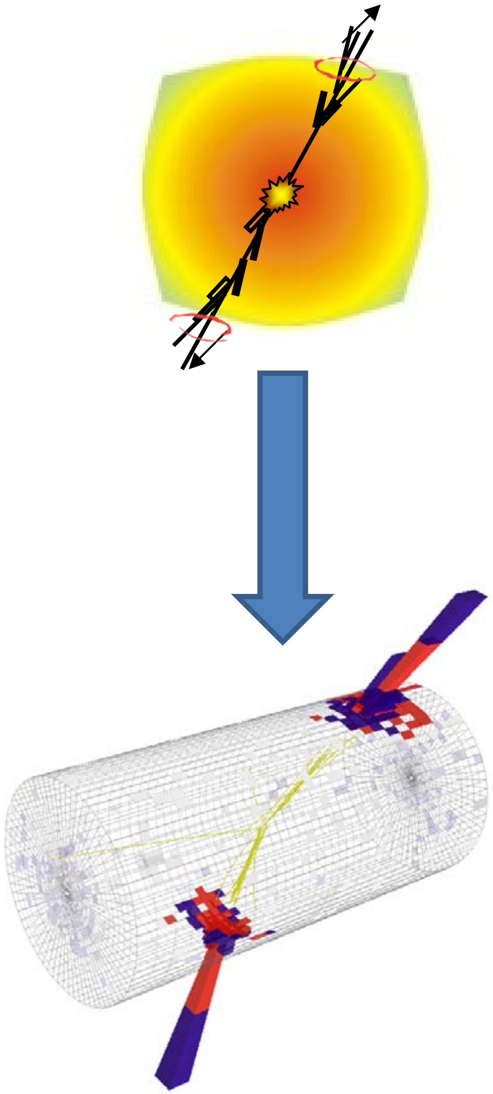
How to study this form of matter

- Can study correlations between final state particles in detector
  - Discovered hydrodynamic properties of the expanding quark gluon plasma, initial state anisotropies, challenged our fundamental understanding of relativistic hydro in progressively smaller systems
- But can we probe this plasma that lives 10^{-23}s and is the size of a lead nucleus?



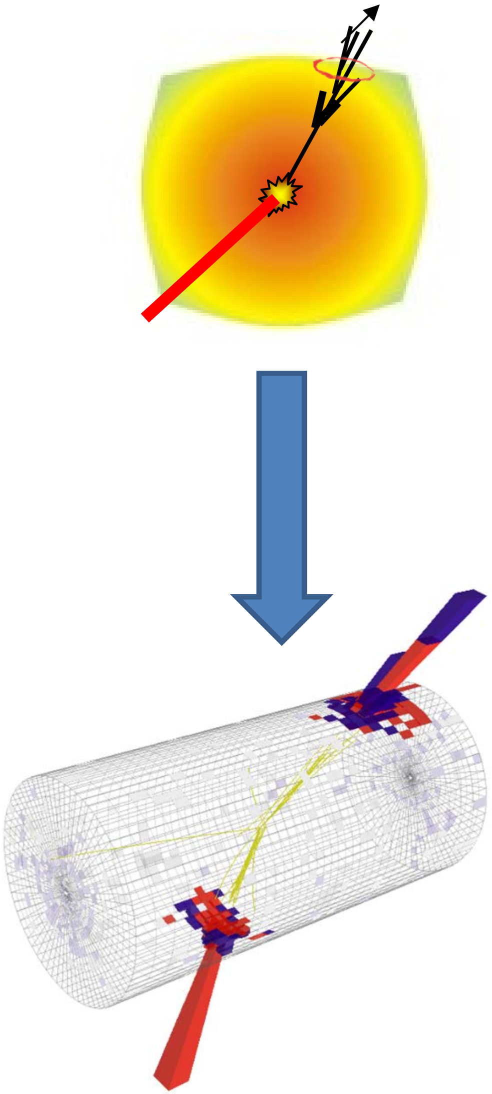
Yes we can

- Sometimes pairs of very high energy back-to-back quarks get created within the quark gluon plasma.
  - These are two probes that both lose energy traversing the QGP
- But quarks don't make it to the detector alone, they convert their high energy into a collimated spray of particles we call jets



An even rarer probe

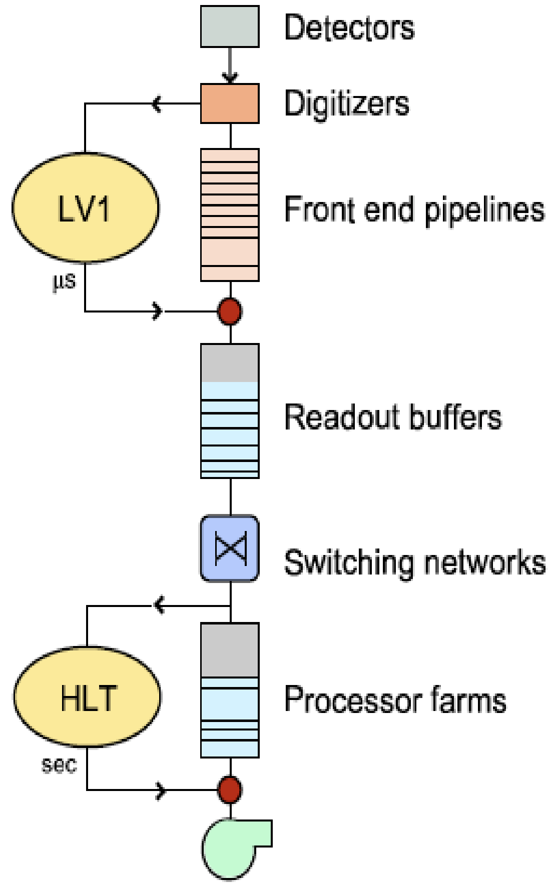
- Very rarely you get back-to-back quark with a photon
- This is the golden probe because the photon doesn't lose energy
  - Now you know the initial energy of your other probe



Computational considerations

- Each collision produces ~10MB
  - Need to read out 10 MB every 50 ns
  - Hard to write ~1TB/s to disk, expensive to store so we “trigger” , selectively throw away collisions, keep few % most interesting
  - Can study rare processes this way!
- ~1 PB of data after a month of running
  - Easy parrelization as each collision is independent of others – can use network of computers if you have efficient many-to-many read/write: LHC computing grid, hadoop

CMS trigger and DAQ



Fresh data at double the energy in 2015

- Last year the Large Hadron Collider turned on at double the energy and higher collision rate
  - Went from having O(1K) collisions with a photon-quark pair to O(150K) of these collisions
  - Now doing precision studies of the energy loss properties of these probes
- We will for the first time have enough data to use these rare-clean probes

Awknowledgements

- I’d like to thank DOE CSGF for giving me the opportunity to gain a deeper understanding of computational tools and methods to be able to work on relativistic hydro simulations at LBNL