

# From Higgs Hunters to Cosmos Hunters

Turn Your Phone Into A Particle Detector

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**NAOC, CAS**

1st Tibet HEP Forum

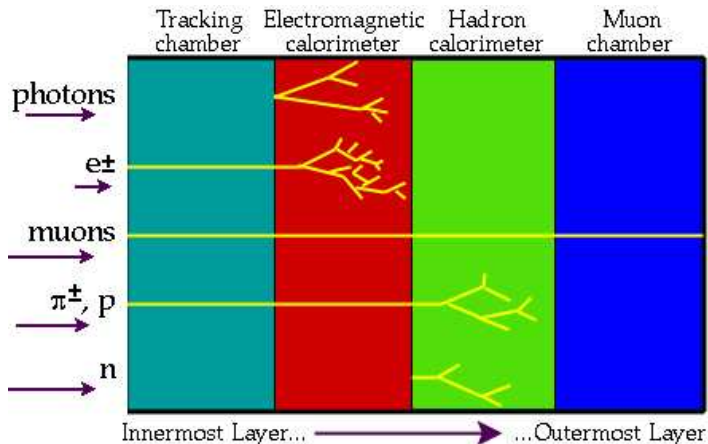
July 15th, 2021

# From Higgs Hunters to Cosmos Hunters

- Turn Your Camera/Phone Into A Particle Detector
- Ultra High Energy Cosmic Rays, Cosmic Neutrinos
- Cosmic Neutrinos from the BIG BANG (Relic Neutrinos)
- "DARE THE MIGHTY THING": Cosmic Neutrino Telescope
- Into the Dark Forest:
  - Dark Matter?
  - Dark Energy??

- Pixel Detectors @ Colliders
- Digital Cameras @ Telescopes
- Smart Phones @ CRAYFIS
- Science Outreach: Desktop DIY

# Particle Detection



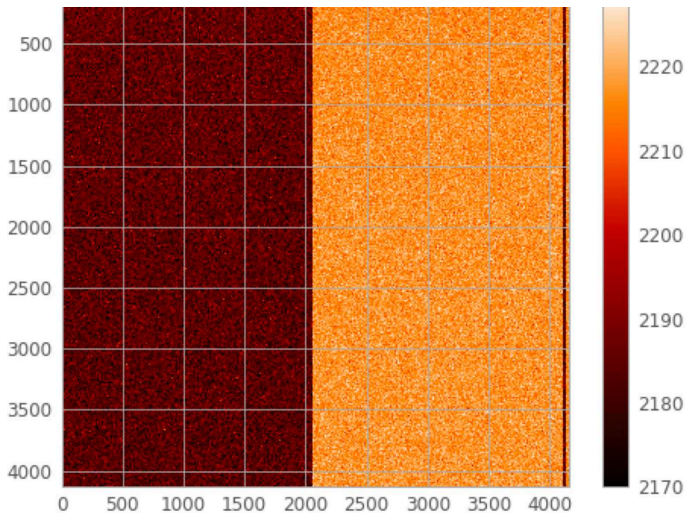
# Take A Photo of Particles Using A Digital Camera

- CCD Arrays @ Telescopes (LAMOST)
- Pixel Sensors on A CCD Camera

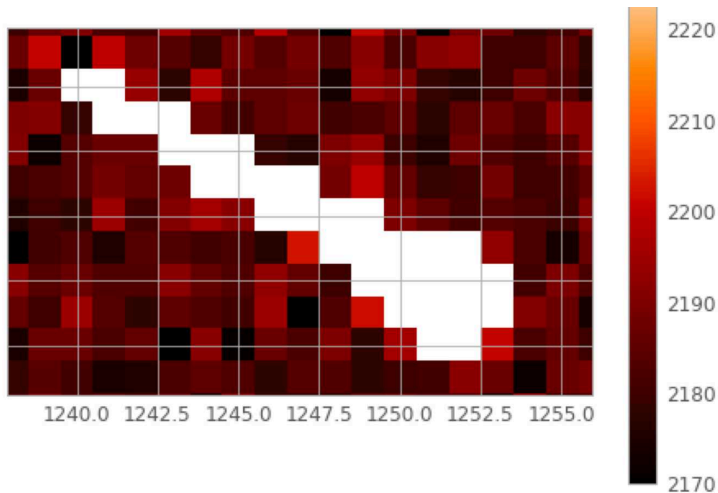
# The LAMOST Charge-Coupled Device (CCD)

- 32 CCDs
  - 16 for Blue band
  - 16 for Red band
  - #1-8 on the seventh floor
  - #9-16 on the sixth floor
- Cooling:
  - Liquid Nitrogen cooling
  - at  $-130^{\circ}$  Celsius
  - 4K by 4K pixels
  - 12 x 12 micron pixel size

# CCD Raw Data

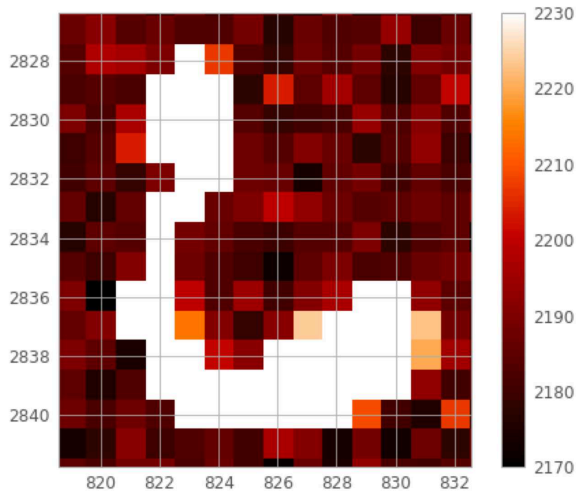


# CCD Raw Data: Muon Candidate

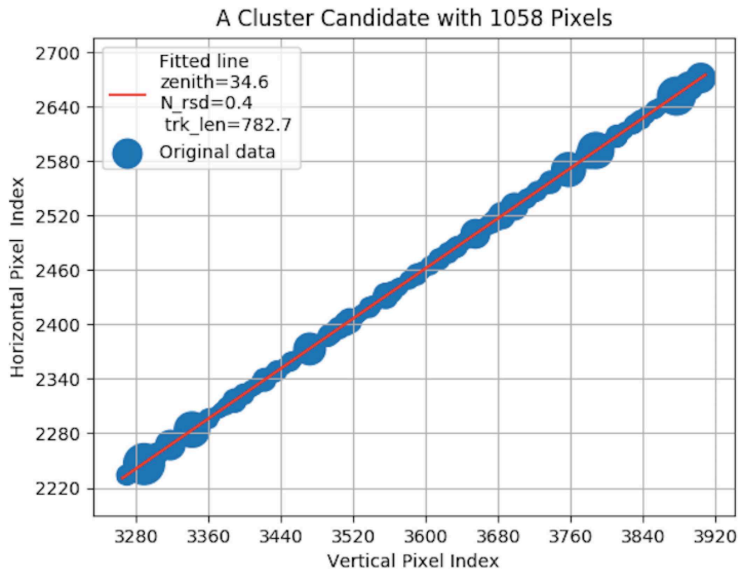




# CCD Raw Data: EGamma Candidate



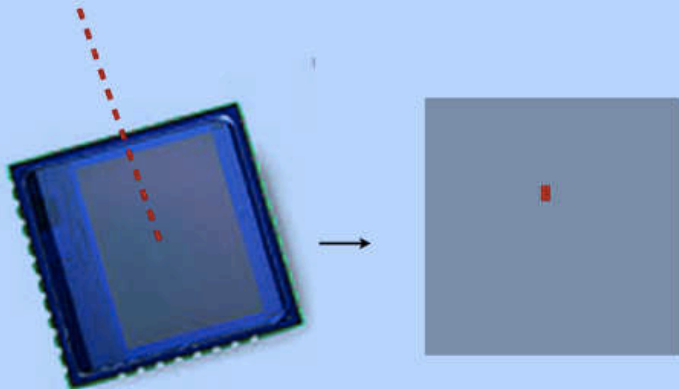
# Cosmic Rays Recorded on CCD Camera at LAMOST



# CRAYFIS: Turns Your Smartphone Phone Into A Particle Detector

- CRAYFIS: Cosmic RAYs Found In Smartphones
- Web: [crayfis.io](http://crayfis.io)
- Use Phone's built-in Camera
  - can detect visible light
  - can also detect high energy particles:
    - photons: X rays, gamma rays
    - electrons, muons
- Use Phone's built-in GPS
  - for position information

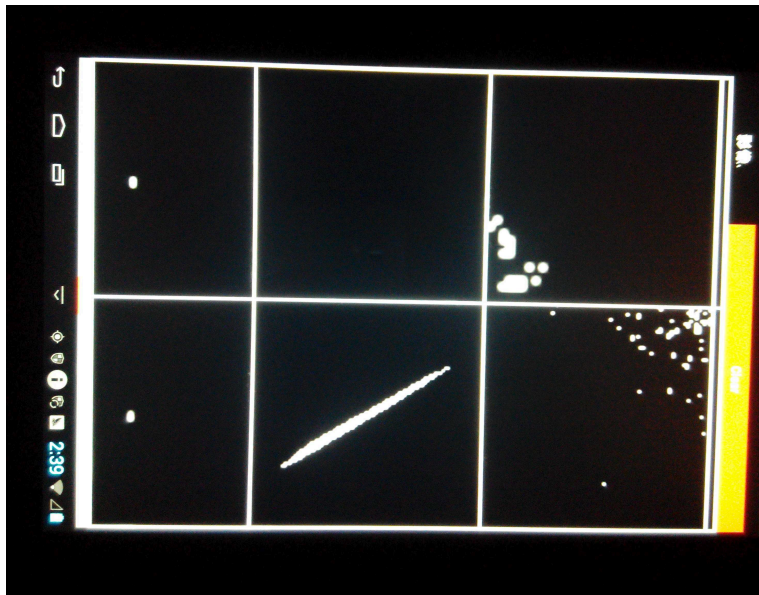
# Particle detector



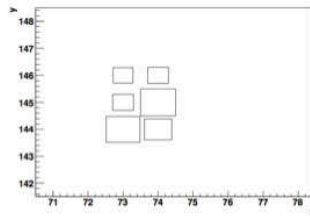
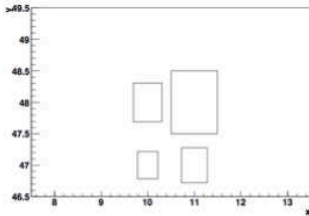
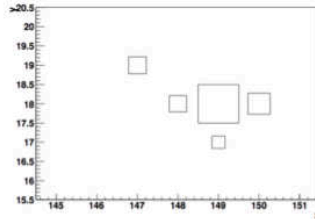
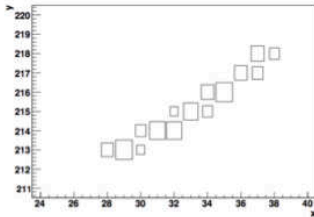
Particle incident  
on CMOS chip

Hot pixel  
in image

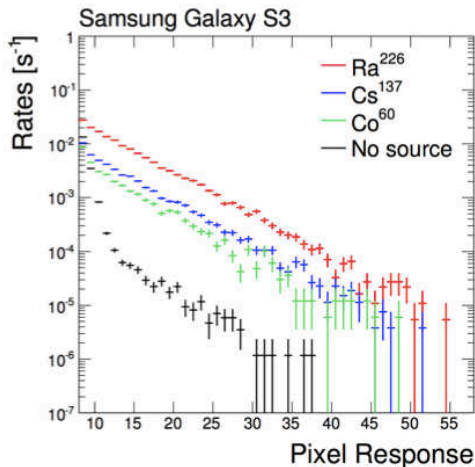
# Some Photos of Cosmic Rays from My HuaWei Pad



# Individual hits



# Sources



Sources held  
at fixed distance  
from phones.

Other devices give  
qualitatively similar  
spectra

# Cosmic RAYs Found In Smartphones Collaboration



Whiteson  
Shimmin  
Strong  
Brodie  
Goddard  
Porter  
Sandy



Cranmer



Ustyuzhanin  
+2 masters st.



Mulhearn  
Burns  
Buonacarsi

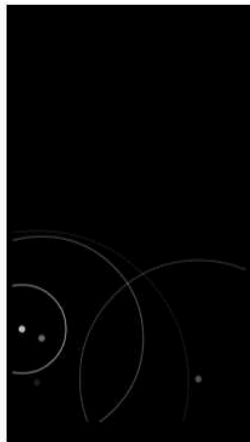
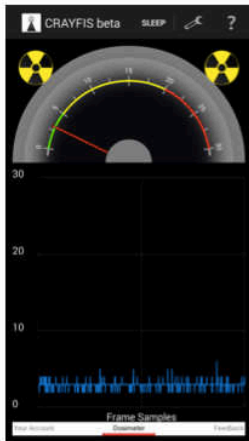
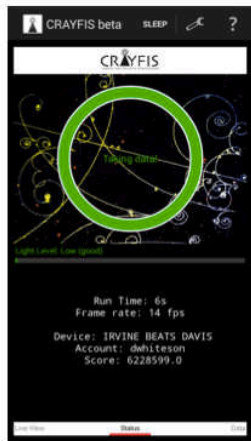


Deng



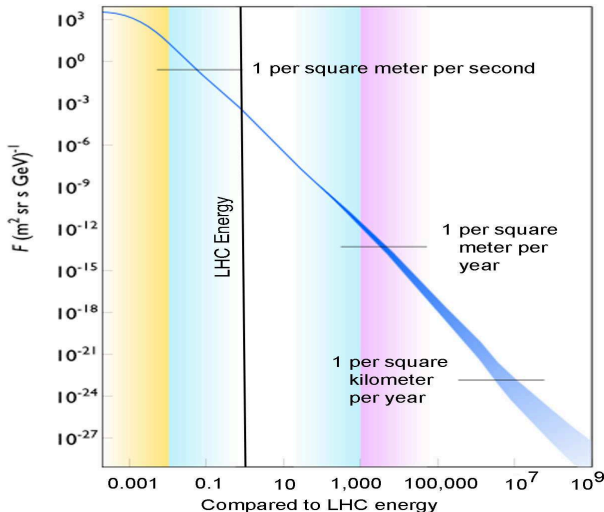


# Android App



- Tevatron @ 2 TeV
- LHC @ 14 TeV
- Next Generation Colliders: O(100) TeV

# Listen to Nature's Messengers: Cosmic Rays



● Our Universe is a high energy accelerator, and it is FREE!

● Figure: [http://en.wikipedia.org/wiki/Cosmic\\_ray](http://en.wikipedia.org/wiki/Cosmic_ray)

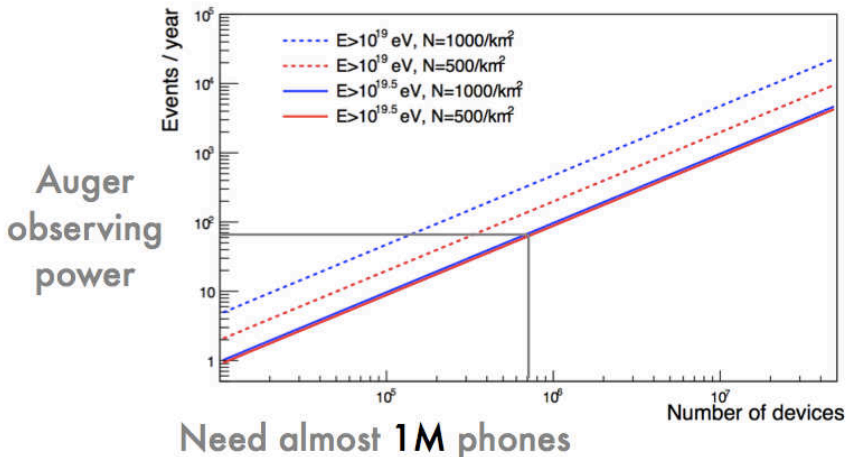
# Listen to Nature's Messengers: Cosmic Rays

- Cosmic Rays:
  - Energetic charged particles
    - originating in outer space
  - Most primary CR:
    - protons, atomic nuclei, or electrons
  - Can have extremely high energy:
    - $10^{18}$  eV and above
  - Energy spectrum of primary CRs known to extend beyond  $10^{20}$  eV
  - Compare to the world's largest particle collider LHC:
    - Designed goal:  $14 \text{ TeV} = 14 * 10^{12} \text{ eV}$
- When Cosmic Rays enter earth atmosphere:
  - collider with oxygen or nitrogen
  - produce a cascade of light secondary particles:
    - photons, electrons, muons, neutrinos...

# Cosmic RAYS Found In Smartphones

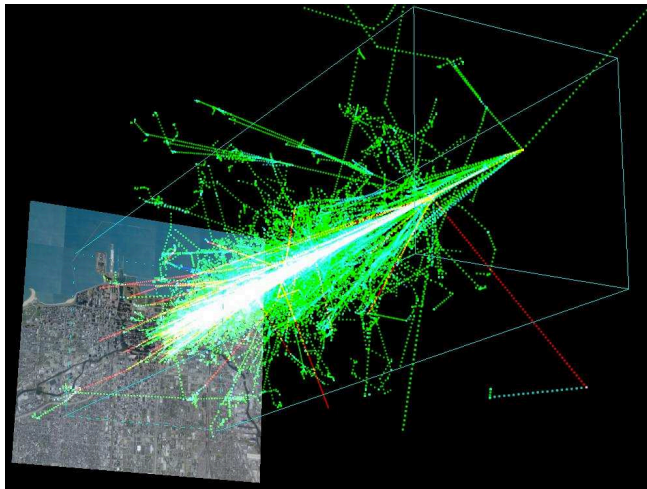
- Event Rate for Ultra High Energy Cosmic Rays:
  - @  $10^{20}$  eV:
    - 1 per square kilometers per century
- Can't wait for a century:
  - need as many detectors to collect data as possible

# How many do we need?



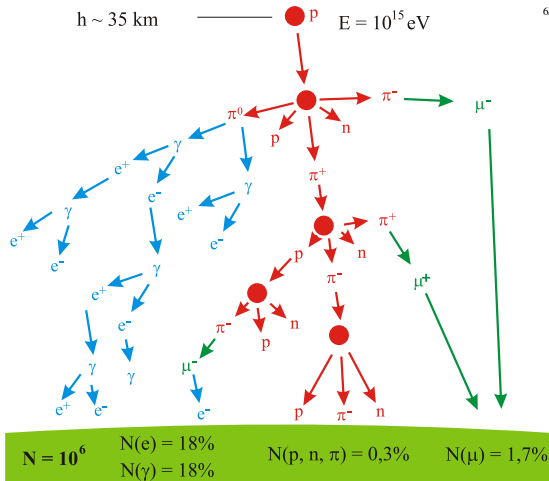
# Cosmic Rays: Extensive Air Shower

● [https://en.wikipedia.org/wiki/Air\\_shower\\_%28physics%29](https://en.wikipedia.org/wiki/Air_shower_%28physics%29)



# Cosmic Rays: Extensive Air Shower

6/19/15 3:36 PM



[https://en.wikipedia.org/wiki/Air\\_shower\\_%28physics%29](https://en.wikipedia.org/wiki/Air_shower_%28physics%29)



# Outline: Particle Detector In Your Pocket

- CRAYFIS: Cosmic RAYs Found In Smartphones
- Dosimeter
- Ultra High Energy Cosmic Rays and Cosmic Neutrinos
- Cosmic Neutrino Background!
- Connection to The First Second After the Big Bang

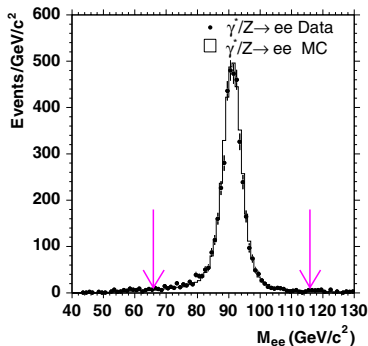
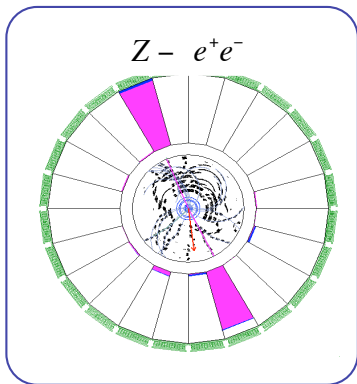
# Cosmic Microwave Background

- CMB:
  - a microwave excess associated with a thermal radiation field with a temperature of about  $-454^{\circ}\text{F}$  (3K)
  - Observed in 1965, the most ancient radiation in the universe and providing evidence for the Big Bang model
- Photons take time to reach Earth from distant parts of Universe
- Whenever we look outward in space, we are also looking back in time
- As the universe cooled and expanded, there was an increase in wavelengths of high-energy photons
  - such as in the gamma-ray and X-ray portion of the Electromagnetic Spectrum
  - and a shifting to lower-energy microwaves

CMB vs Cosmic Neutrino Background (CNB), or so-called relic neutrinos (RN)

- CMB at 2.725 K
- RN at 1.945 K
  - Possibility to reveal the Existence of RN by  $Z^0$  Resonance
  - Relic Neutrino + Ultra High Energy Neutrino  $\rightarrow Z^0$
  - Resonant Cross-section is large
  - Dips in the Spectrum of UHEN at Resonance Energies
  - Let's Map out Our Universe with Neutrinos!

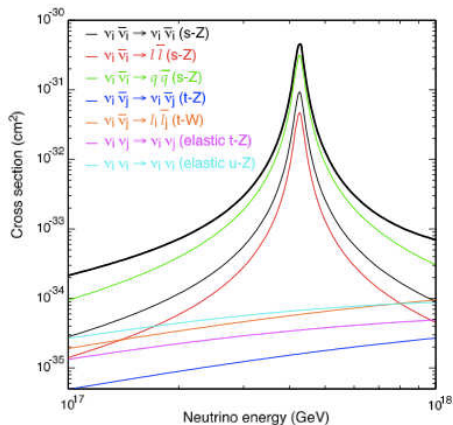
# Z(ee) Boson Event Selection (from My CDF Thesis)



- Two high  $E_T$  electrons
  - $E_T > 20$  GeV

- $66 < M_{ee} < 116$  GeV/c<sup>2</sup>

# Neutrino Cross Section



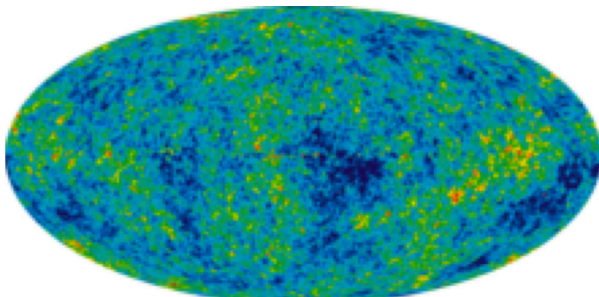
- Total neutrino annihilation cross section
- relic neutrino mass of  $m_\nu = 10^{-5}$  eV and zero redshift

# Perspective: Onto the Golden Age of High Energy Neutrino Astrophysics

- A Possibility to Establish the Existence of Relic Neutrinos from the Big Bang
  - Using Ultra High Energy Neutrino Absorption Spectra
  - Very Long Term Goal...
- See A Bright Future:
  - A Golden Age of Neutrino Astrophysics is Coming!
  - IceCube's Publication on the Observation of PeV ( $10^{15}$  eV) Neutrinos
    - Marks the Beginning of High Energy Neutrino Astrophysics

# GOAL: Neutrino Sky Map

Let's mapping out our Universe with Neutrinos!



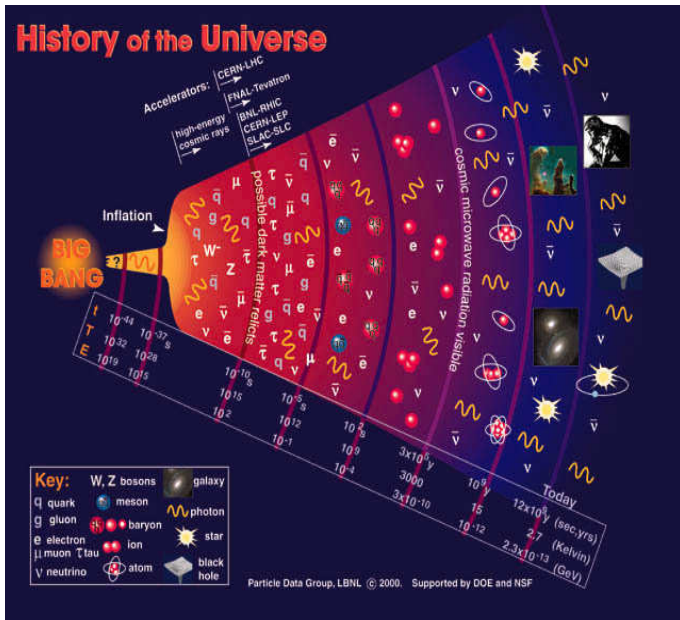
Cosmic Microwave Background Radiation Map

# Outline: Particle Detector In Your Pocket

- CRAYFIS: Cosmic RAYs Found In Smartphones
  - muon
  - photon
  - alpha ...
- Not Just Smartphones:
  - CCD Cameras
    - LAMOST
    - Dark Energy Survey
    - ...
- Ultra High Energy Cosmic Rays and Cosmic Neutrinos
  - Extend Array Sensitive Region
- Cosmic Neutrino Background!
- Connection to The First Second After the Big Bang



# History of the Universe

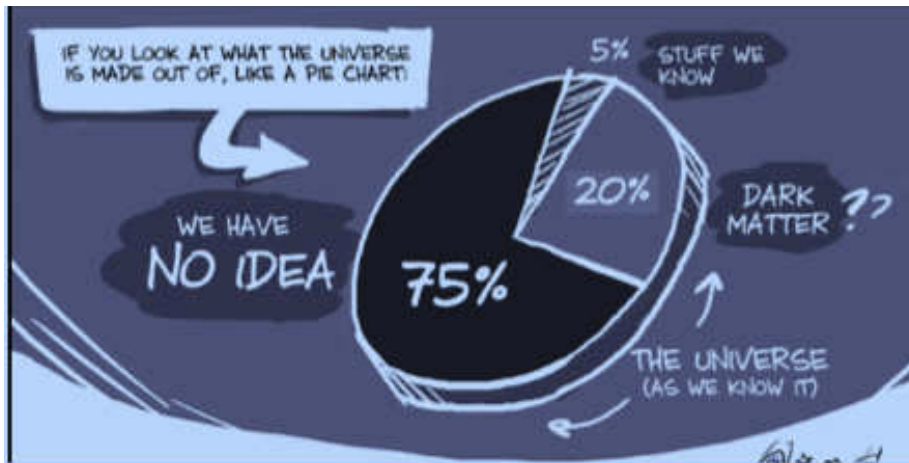


# Connection of LHC and UHECR to the Big Bang

- The Energy at Colliders and of Ultra High Energy Cosmic Rays:
  - Recreate the Condition (Energy) as they were during the Big Bang:
    - at  $t < 0.1$  ns ( $10^{-10}$ s) after the Big Bang:
    - Probe the earliest tick on the cosmic clock
    - Try to understand what happened in that **first second**

time(s)	E (GeV)	T (Kelvin)
$10^{-37}$ s after Big Bang	$10^{15}$	$10^{28}$
$10^{-10}$ s after Big Bang	$10^2$	$10^{15}$
of UHECR/Neutrinos @LHC	$10^{11}$ $10^4$	$10^{24}$ $10^{17}$

We understand  
only a few percent of the Universe so far...

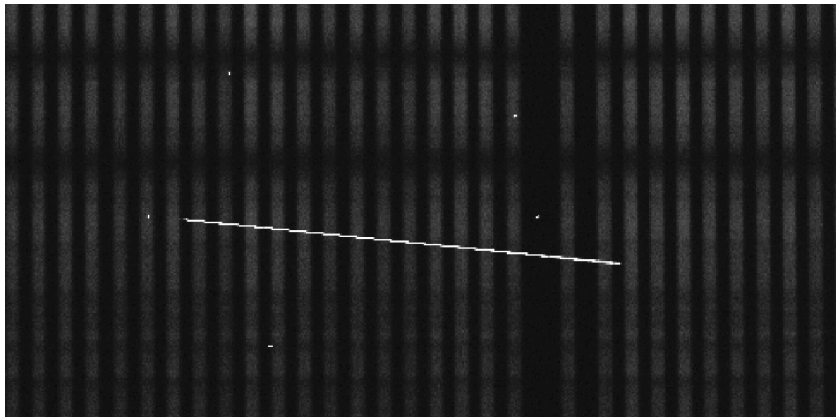


# EXTRAs

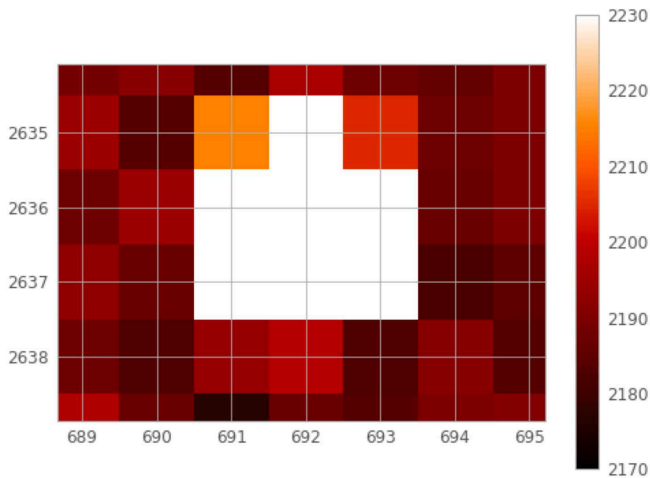
# The LAMOST Charge-Coupled Device (CCD)

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  - 16 for Blue band
  - 16 for Red band
  - #1-8 on the seventh floor
  - #9-16 on the sixth floor
- Cooling:
  - Liquid Nitrogen cooling
  - at  $-130^{\circ}$  Celsius
- e2v 203-82
  - back illuminated CCD
  - 4K by 4K pixels
  - 12 x 12 micron pixel size
  - flatness better than 15 micron with 100% active area
  - support 4 output readout modes?
  - LAMOST uses two of the four amplifiers to generate output images

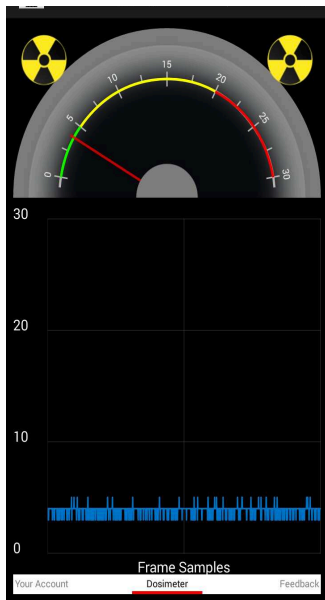
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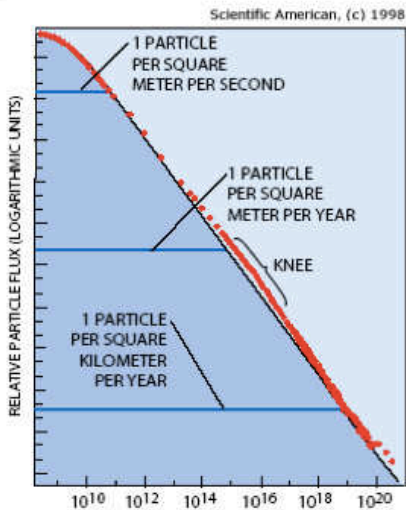


# Turn Your Smartphone Into A Particle Detector





# A loose thread

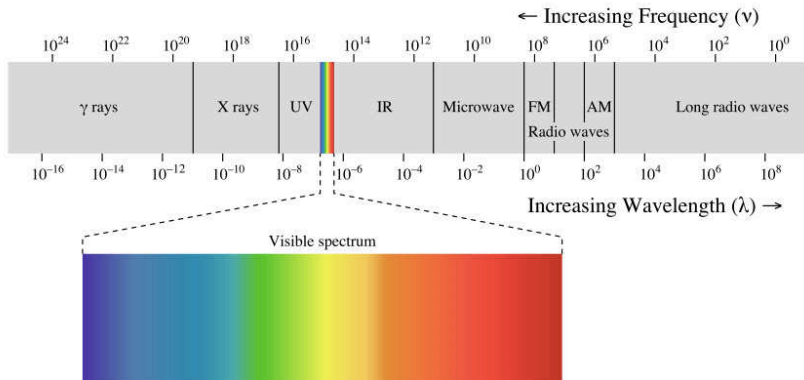


# Nobel Discoveries on Cosmic Rays and Neutrinos

- 1936: Vitor Hess
  - Observed rising radiation at rising altitudes
  - Concluded in 1912
    - a radiation of very great penetrating power
    - enters our atmosphere from above
- 2002: R. Davis and M. Koshiba
  - pioneering contributions to astrophysics
  - in particular for the detection of cosmic neutrinos
- 2015: Takaaki Kajita and Arthur B. McDonald
  - Neutrino Oscillation

# Celebrate the International Year of Light

- web: <http://www.light2015.org/Home.html>

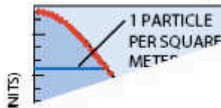


- Figure: [http://en.wikipedia.org/wiki/Electromagnetic\\_radiation](http://en.wikipedia.org/wiki/Electromagnetic_radiation)

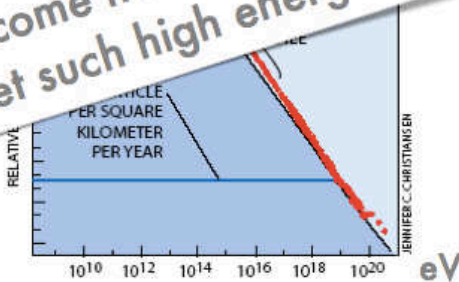
# A loose thread



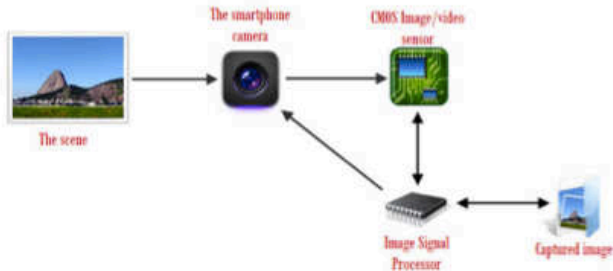
Scientific American, (c) 1997



What are they?  
Where do they come from?  
How do they get such high energies?



# Smartphones

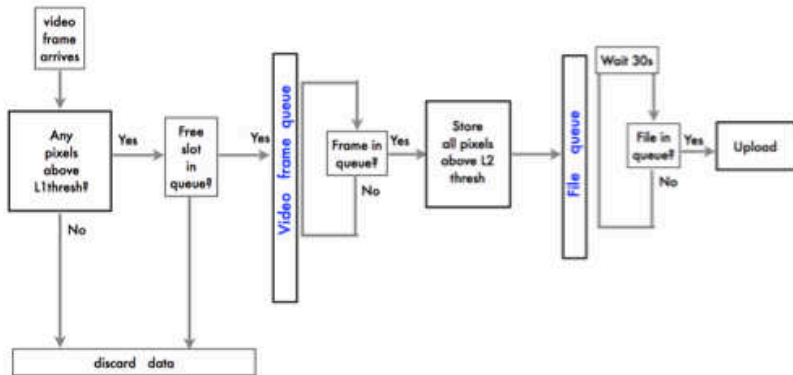


# Software

Video acquire  
thread

Frame process  
thread

Data upload  
thread



# Challenge: big data!



DigitalOcean

50k devices

500kb/sec

250 simul.

connections

**\$1000/month**

1M devices

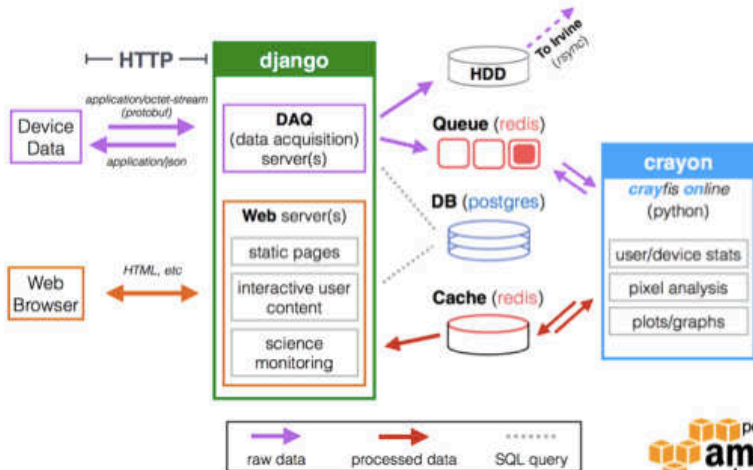
10Mb/sec

5k simul.

connections

**\$20k/month**

# DAQ





# Five Simple Rules

It was the work of generations of searchers who took five simple rules to heart.

- 1.Question authority.
- 2.No idea is true just because someone says so,including me.
- 3.Think for yourself.
- 4.Question yourself.
- 5.Don't believe anything just because you want to.
- – Cosmos: A Space Time Odyssey(2014)

# One Two Three Infinity