Dark Matter Hunters

#DarkMatterDay
https://www.darkmatterday.com

Dr. Teppei Katori
Dark Day at King's College London

Today is the International #DarkMatterDay! It is a celebration of all projects desperately looking for Dark Matter and cannot find it!

Find more about Dark Matter, https://www.darkmatterday.com/

What do we know about Dark Matter

Dark Matter is 85% of all mass in the Universe

Dark Matter is unlikely to be ordinary matter or paritcles.
Dark Matter can be **new particle**

Dark Matter particles can be very heavy or very light particles

Dark Matter particles may interact with ordinary particles, but interaction should be very rare

From cosmology, we know on average 2 GeV of Dark Matter in every $1m^3$ of the universe

Anatomy Lecture Theatre

Don't worry! The last dissection was more than 20 years ago so this room is not that haunted

Roughly 400m^3 in this room → 800 GeV of Dark Matter
→ ~1 very heavy Dark Matter (mass is 800 GeV)
or
→ so many light Dark Matter

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Anatomy Lecture Theatre

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The heaviest elementary particle is the top quark ~ 175 GeV

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Anatomy Lecture Theatre

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Dark Matter particles interact very rarely with ordinary particles, but the probability of interaction is not zero.

→ Let's hunt Dark Matter!

Astrophysical signal of Dark Matter

If Dark Matter is heavy particle, they may be accumulated around heavy objects like galaxy core

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Such neutrinos may be detected by Neutrino Telescope, like the IceCube Neutrino Observatory

IceCube Neutrino Observatory (South Pole)

Astrophysical signal of Dark Matter

Why neutrinos?

Charged particles are easy to detect.
But their trajectories are bent by magnetic field.

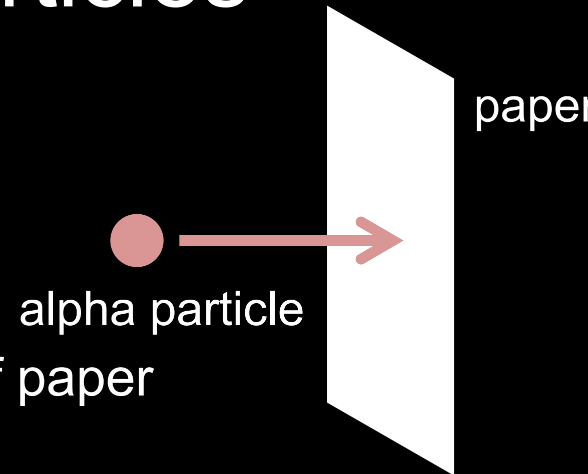
Gamma rays come to the Earth straight, like neutrinos.
But high-energy gamma rays cannot penetrate dense materials, like galaxy core or rocks.

Neutrinos have no electric charge (no bending), also they penetrate everything

Neutrino Telescope has the widest and deepest view of the universe for the highest energy particles.

IceCube Neutrino Observatory (South Pole)

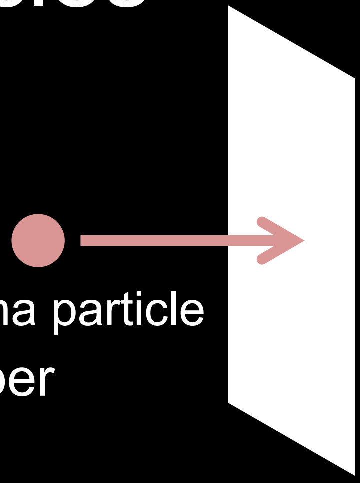
Neutrinos, Ghost particles



Extremely difficult to detect neutrinos

Example: how to stop particles?
- Alpha particle (nuclei of Helium) → sheet of paper
- Beta particle (electron) → sheet of copper
- Gamma particle (photon) → chunk of lead

Neutrinos, Ghost particles



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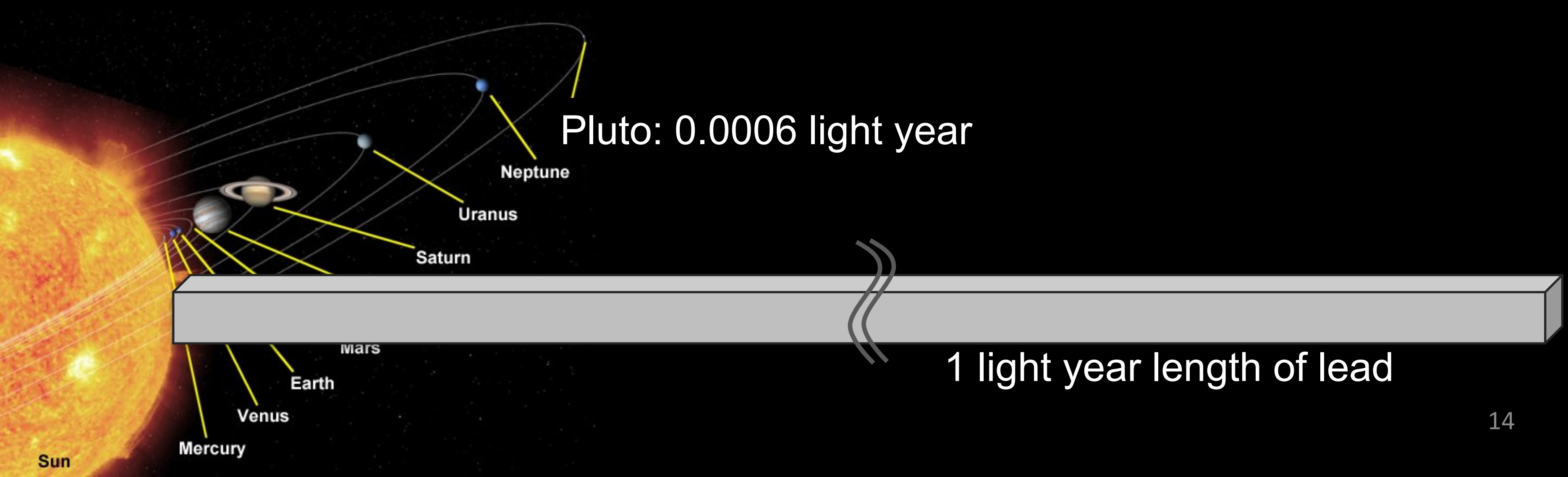

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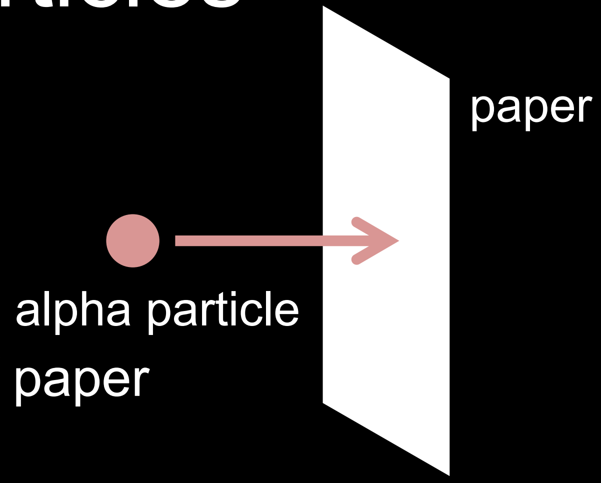

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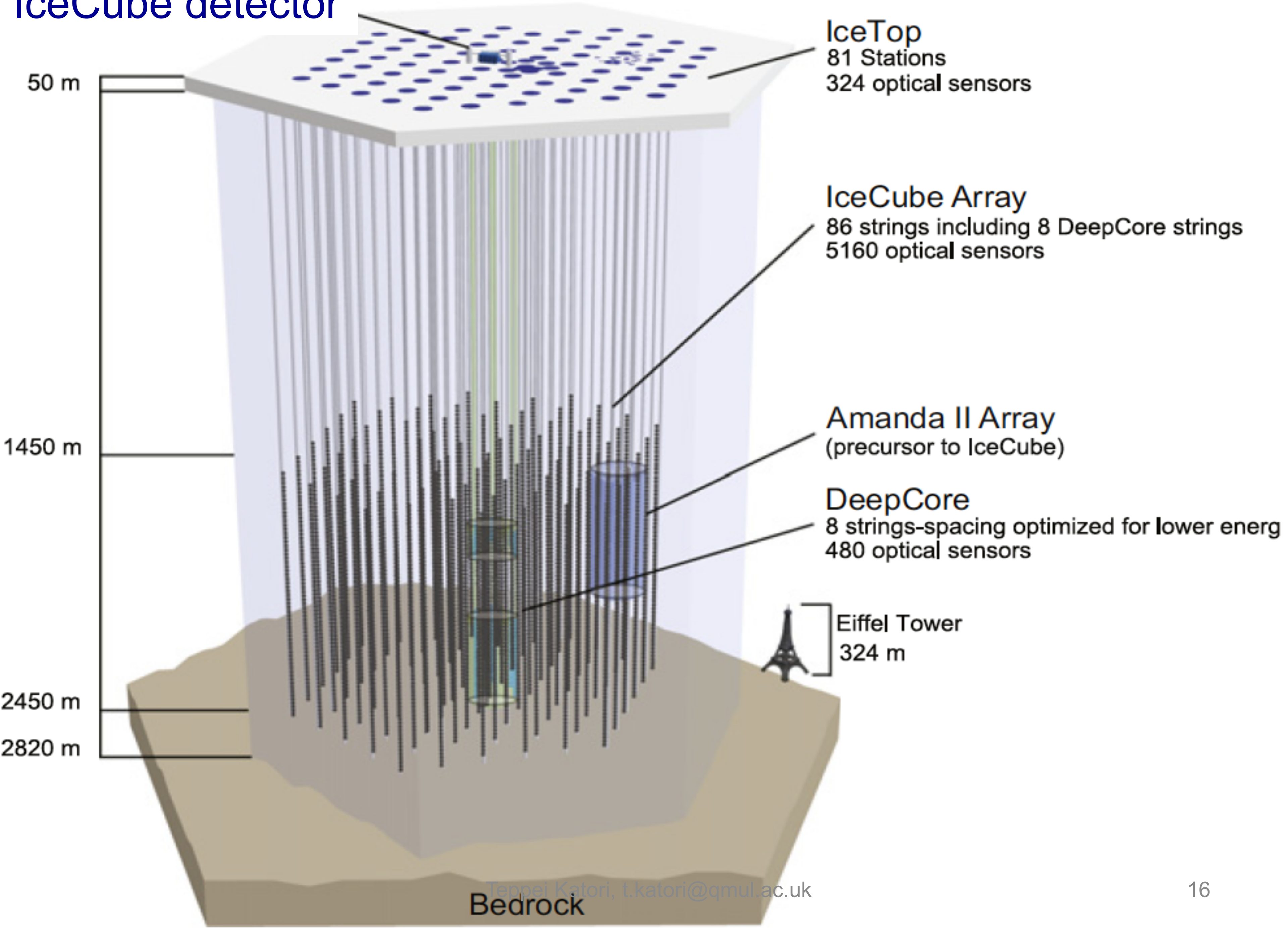
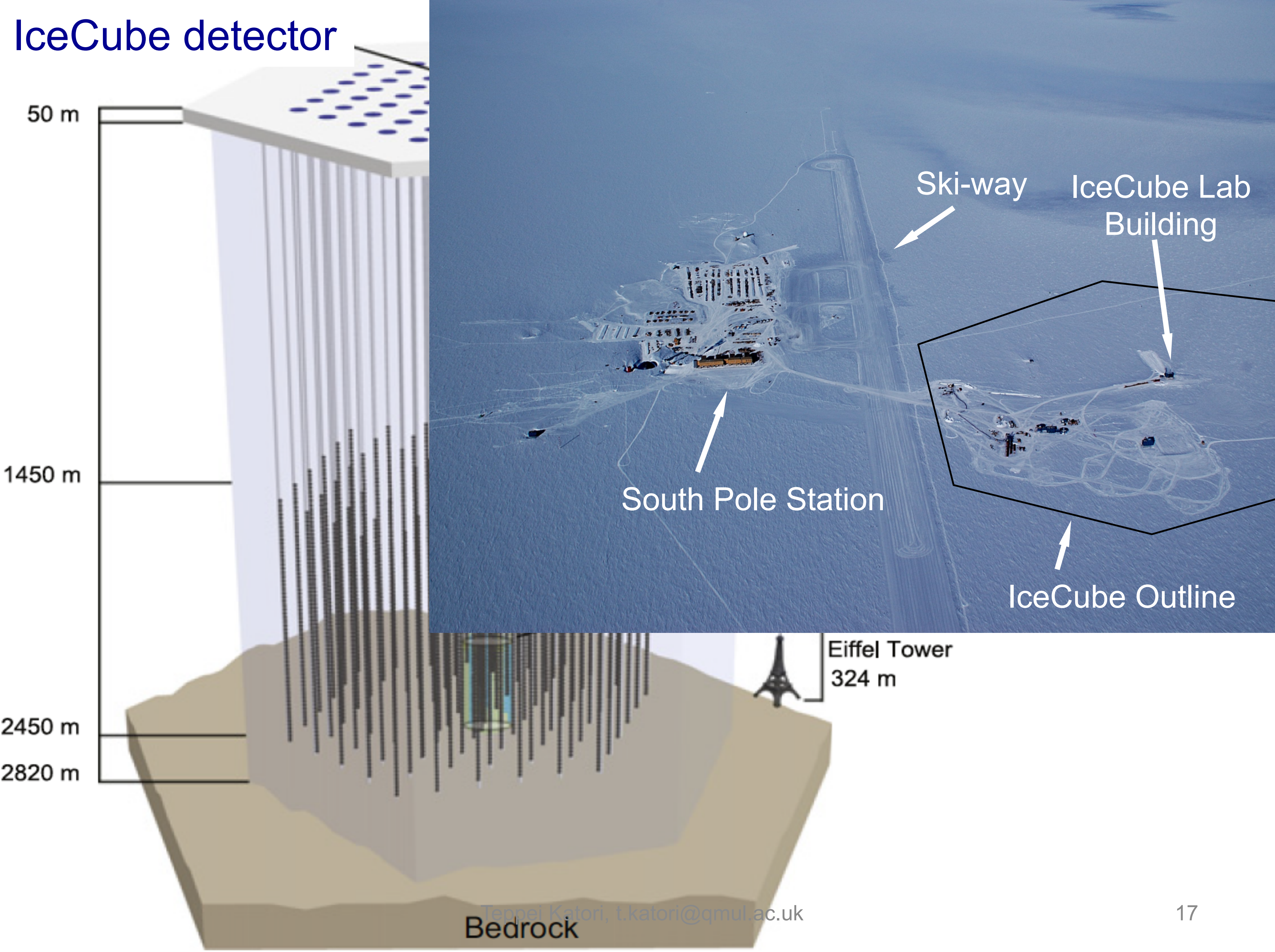
Of course you cannot prepare so many lead bricks!

Particle physics is all about probability. If many neutrinos pass by you, sometimes you are lucky and neutrinos may hit.
→ You have to wait long time to see a rare neutrino interaction with large detector.

IceCube detector



IceCube detector



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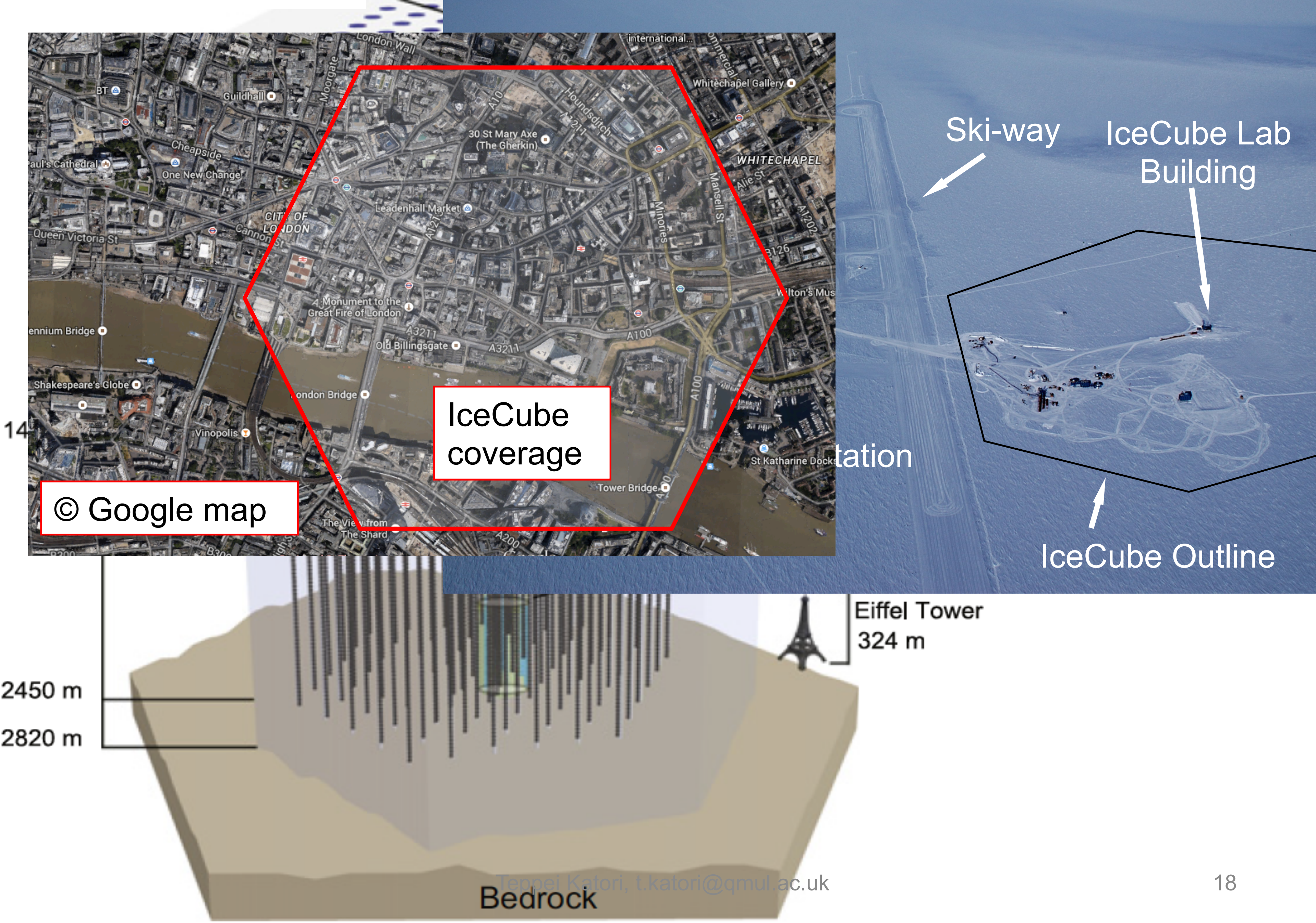

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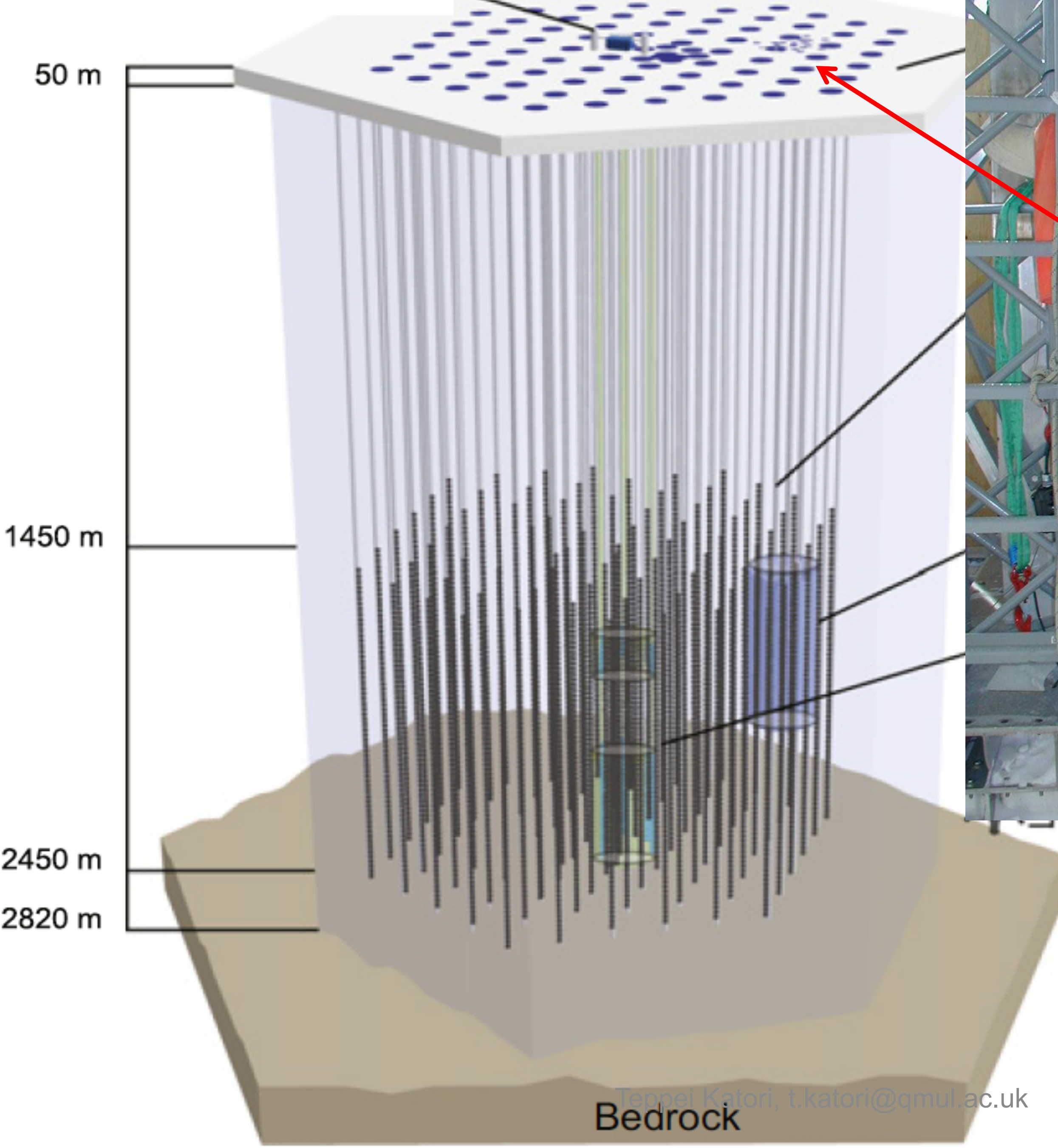
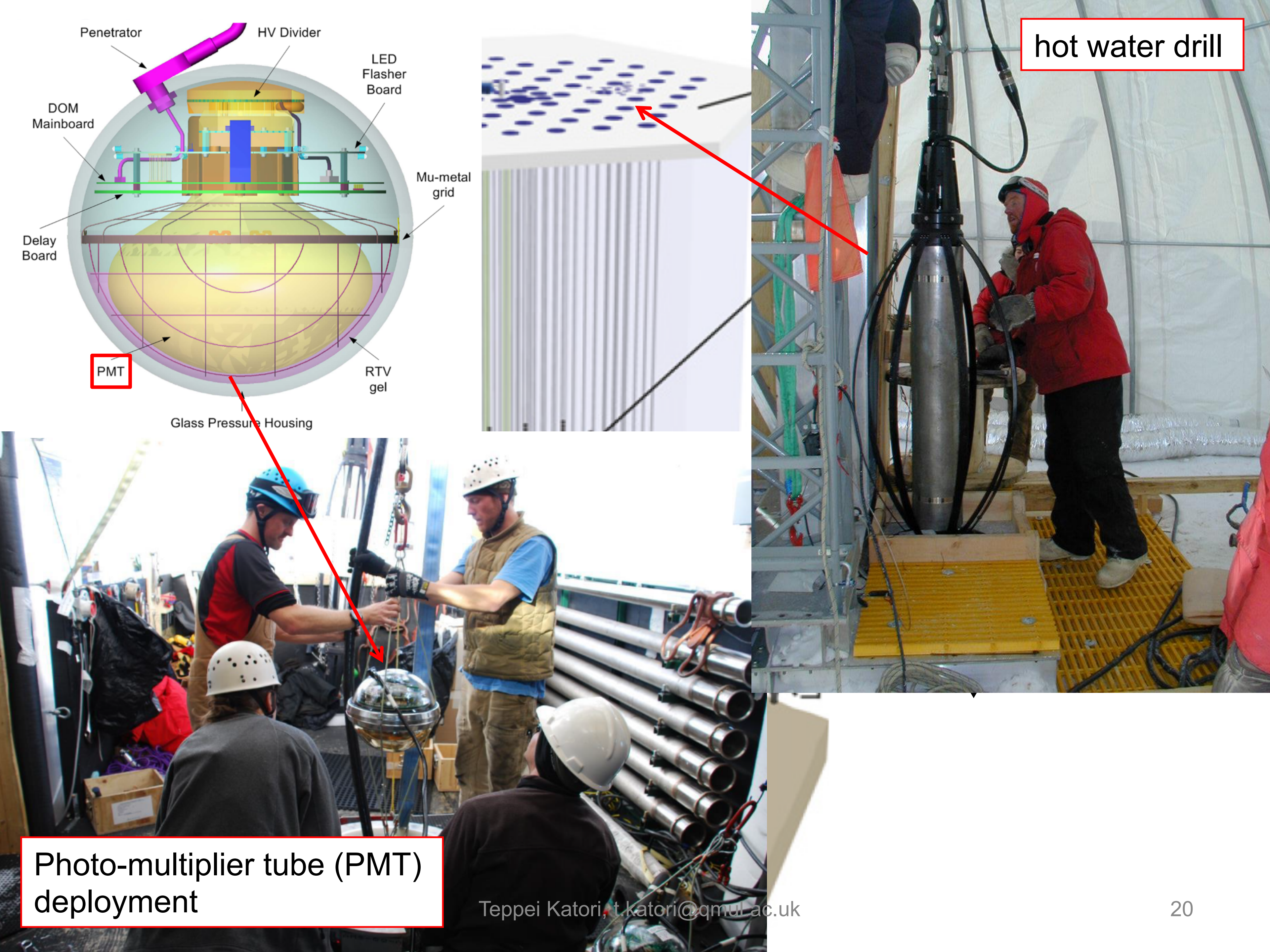
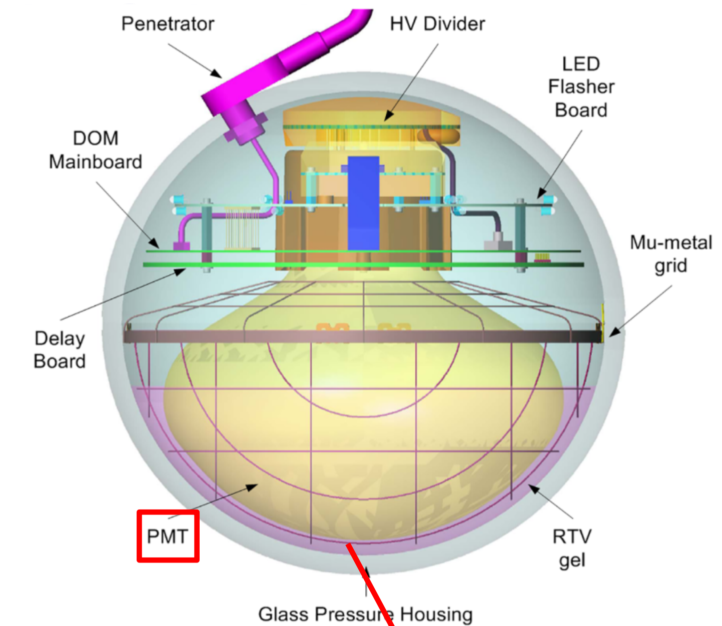
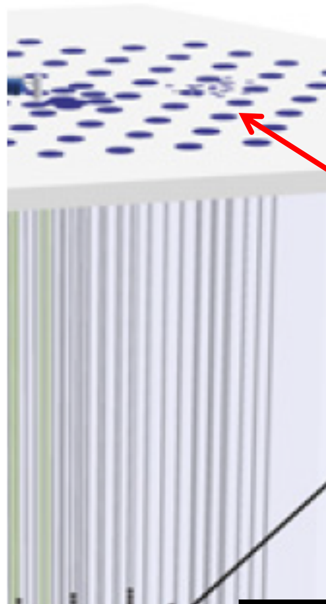
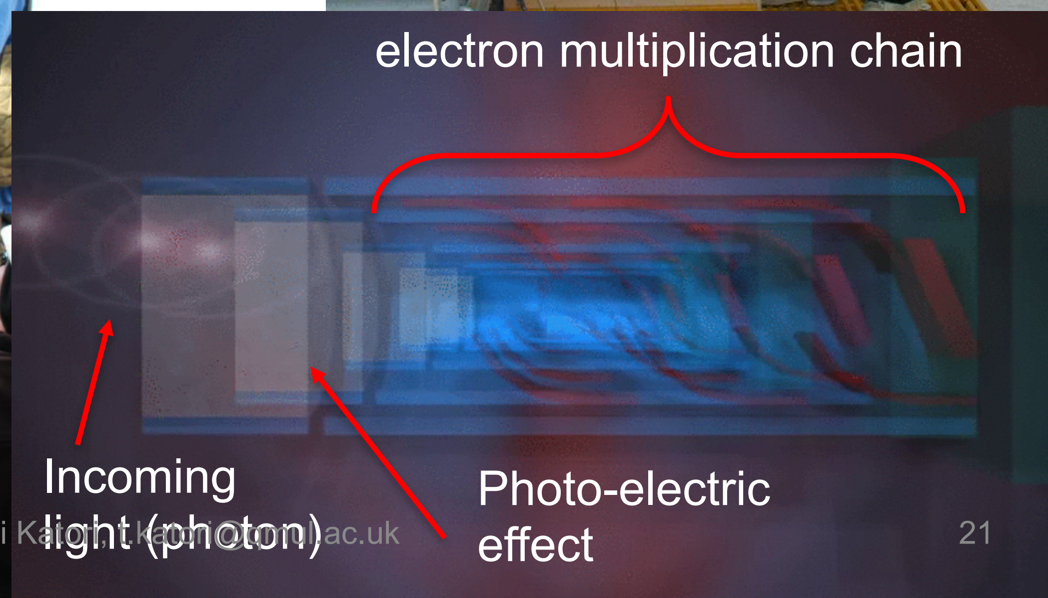



hot water drill
Penetrator
HV Divider
LED
Flasher
Board
DOM
Mainboard
Mu-metal
grid
Delay
Board
PMT
RTV
gel
Glass Pressure Housing
Photo-multiplier tube (PMT)
deployment

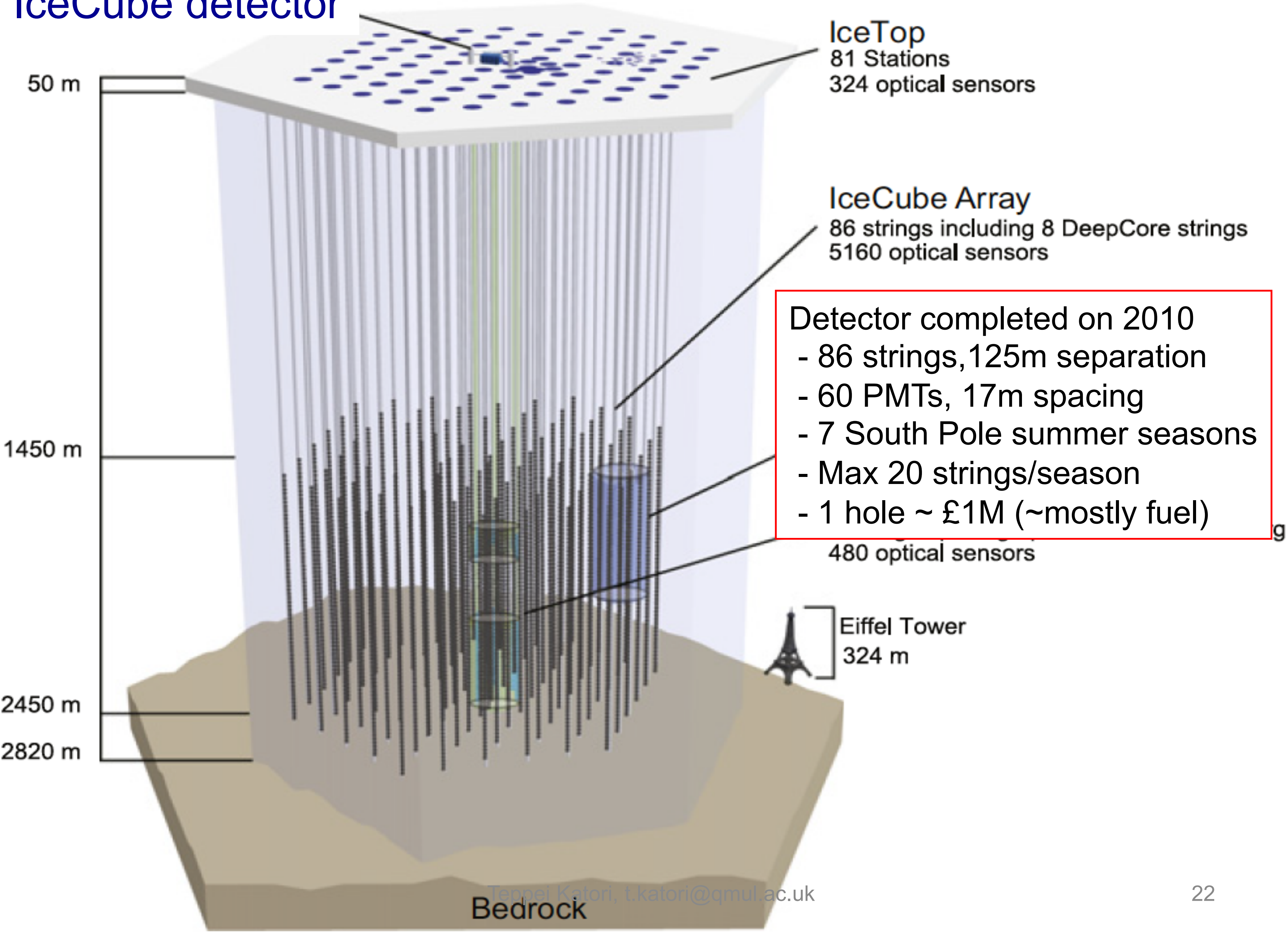




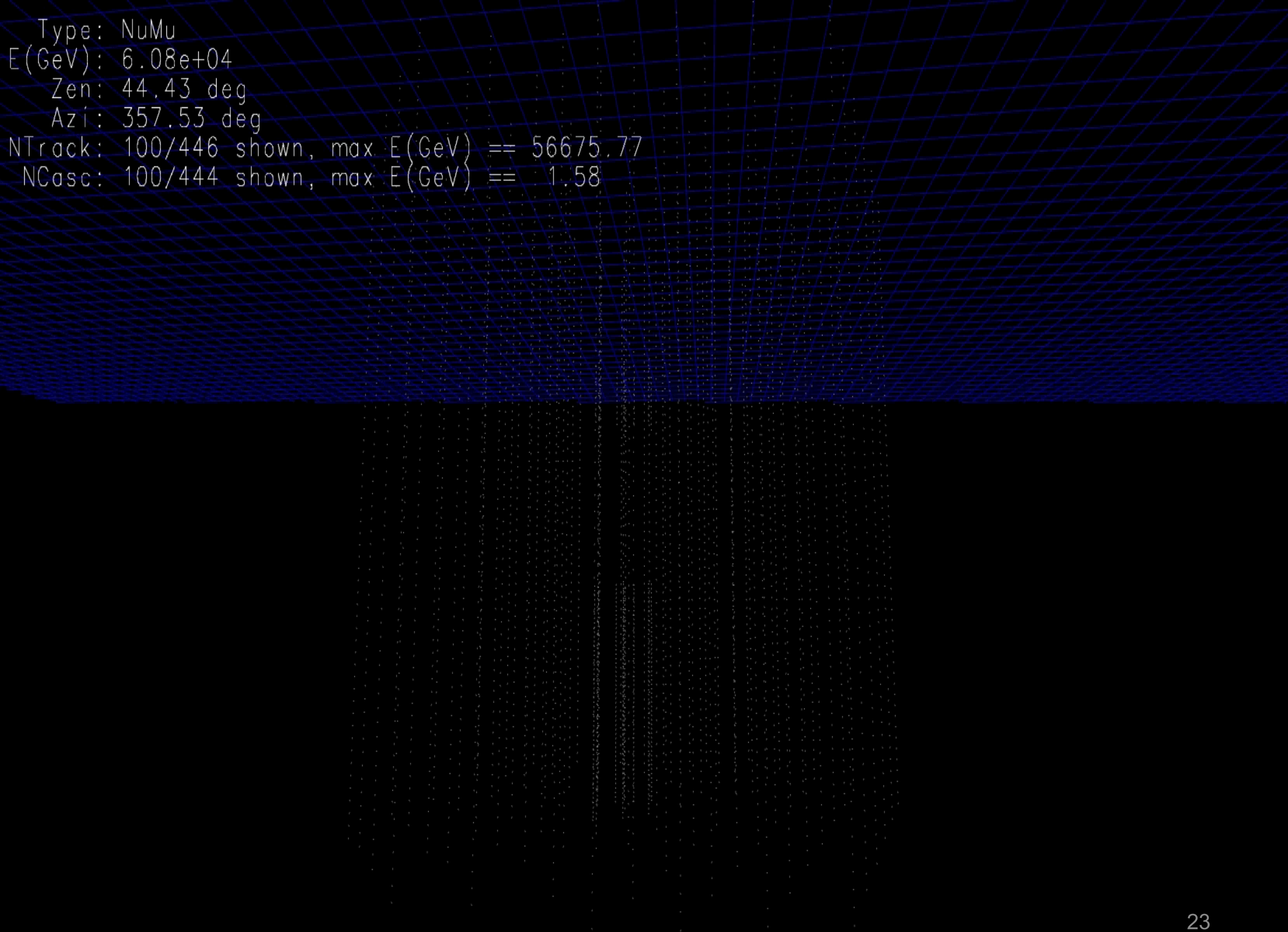
Einstein's Nobel prize is about the study on **photo-electric effect**



IceCube detector

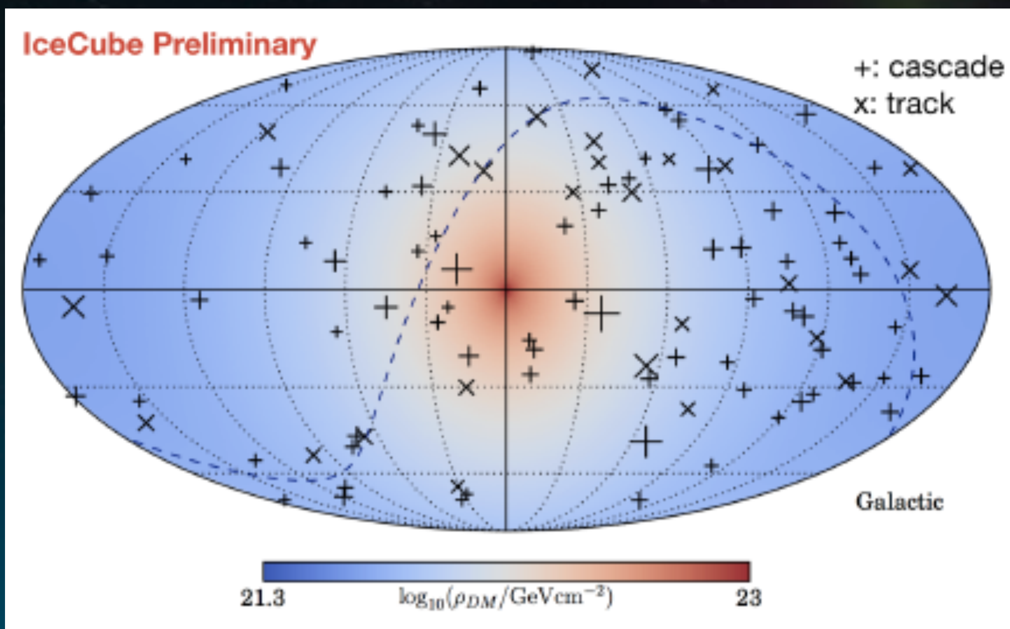


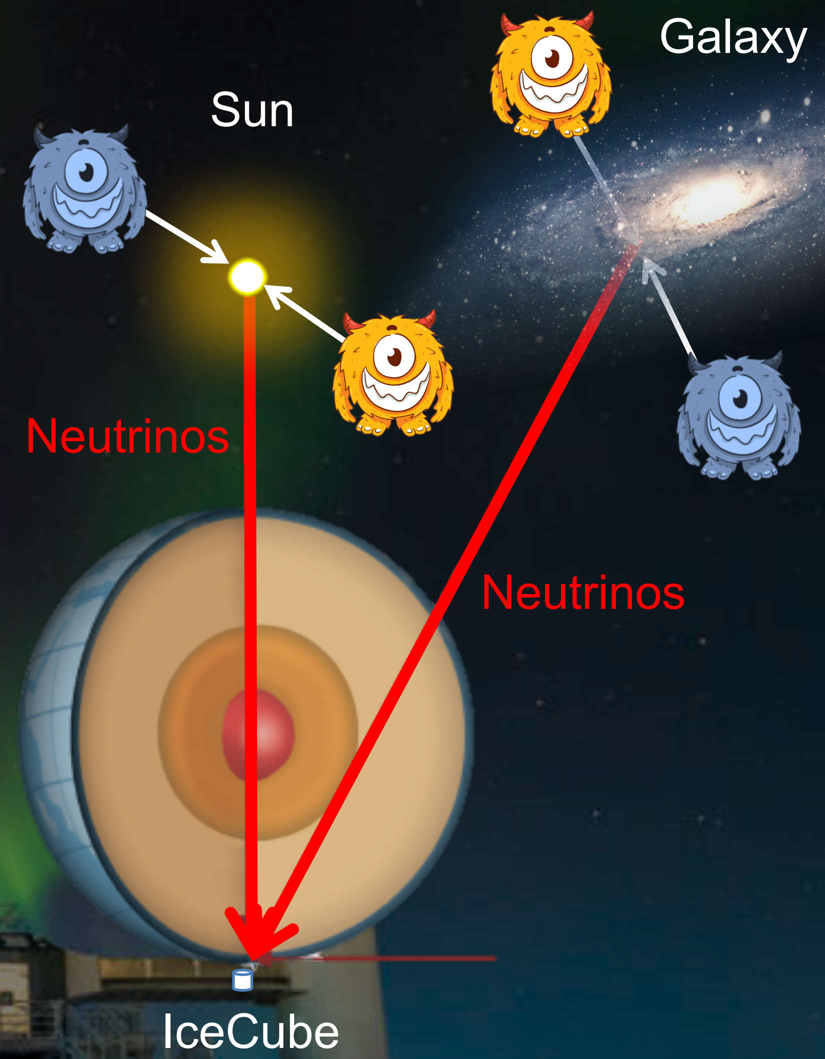
Detector completed on 2010
- 86 strings,125m separation
- 60 PMTs, 17m spacing
- 7 South Pole summer seasons
- Max 20 strings/season
- 1 hole ~ £1M (~mostly fuel)


Type: NuMu
E(GeV): 6.08e+04
Zen: 44.43 deg
Azi: 357.53 deg
NTrack: 100/446 shown, max E(GeV) == 56675.77
NCasc: 100/444 shown, max E(GeV) == 1.58

Astrophysical signal of Dark Matter

So far, IceCube doesn't observe excess of neutrinos from the Earth, Sun, and Galaxy centres.



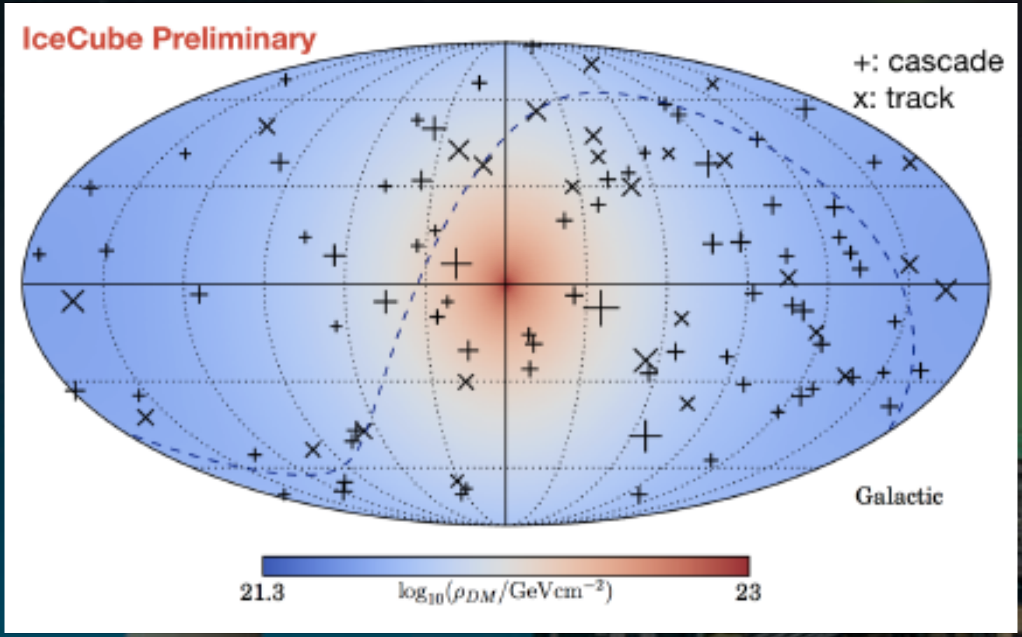


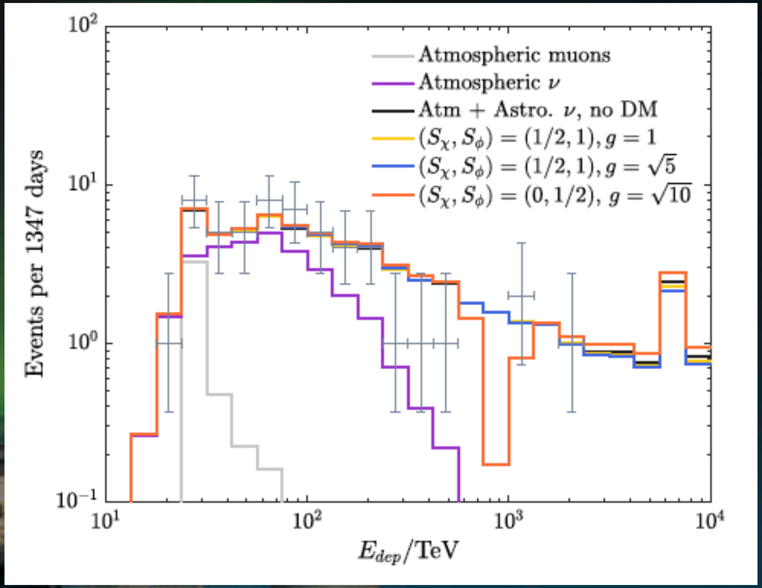
IceCube Neutrino Observatory (South Pole)

Astrophysical signal of Dark Matter

So far, IceCube doesn't observe excess of neutrinos from the Earth, Sun, and Galaxy centres.

Energy spectrum also show no evidence of Dark Matter.





IceCube is still looking for spooky Dark Matter!

Conclusion

Dark Matter may be new particle. If so, they interact very rarely with ordinary matters and particles.

Dark Matter may be annihilate and emit ordinary particles, such as neutrinos. Neutrinos propagate million light years unaffected, and carry signal of Dark Matter.

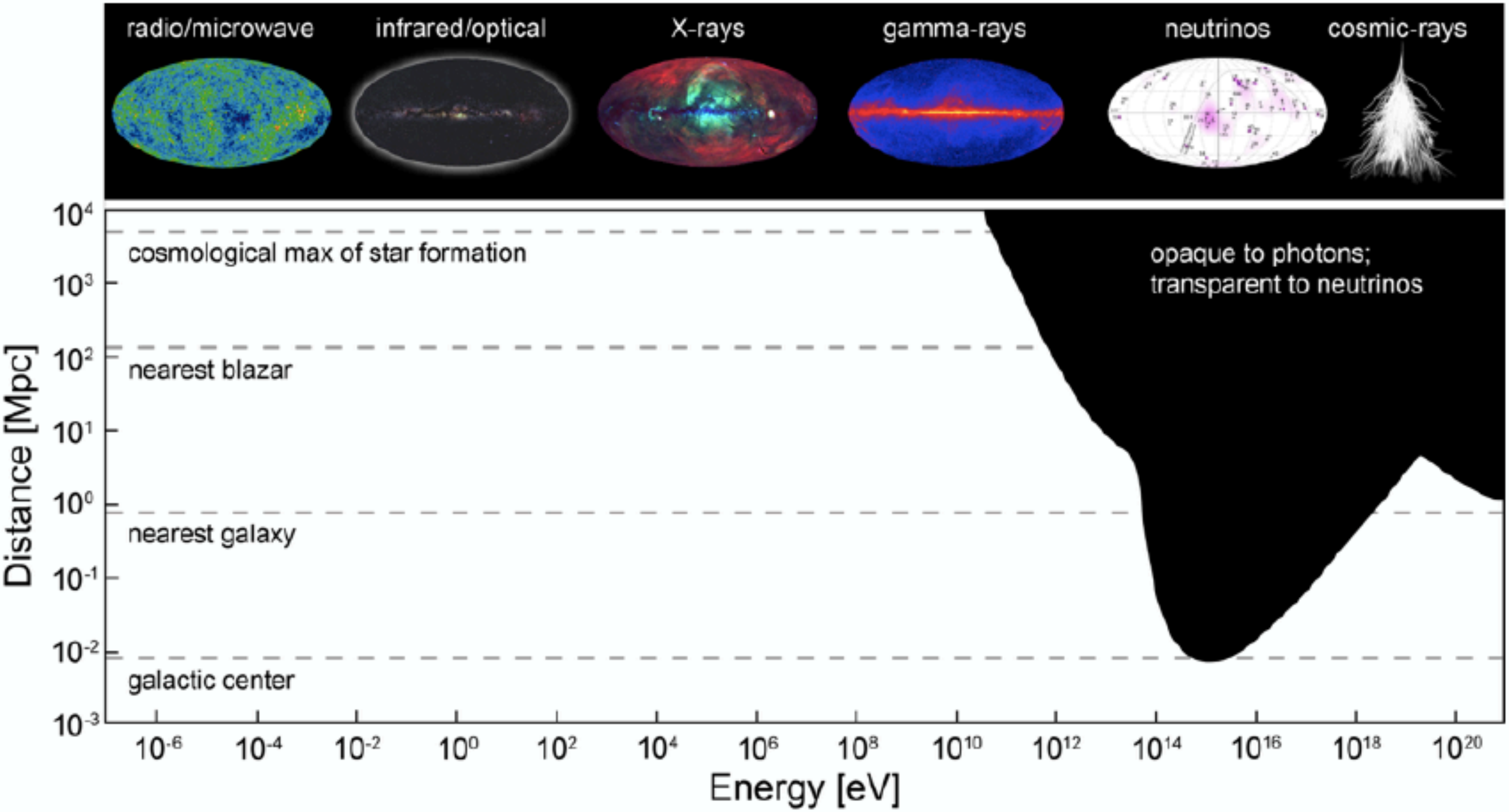
So far, IceCube Neutrino Observatory haven't seen any such neutrino. Search continued.

Thank you for your attention!

… and Happy Halloween!

Any questions?

Neutrinos are only high-energy particles propagate straight from outside of our galaxy

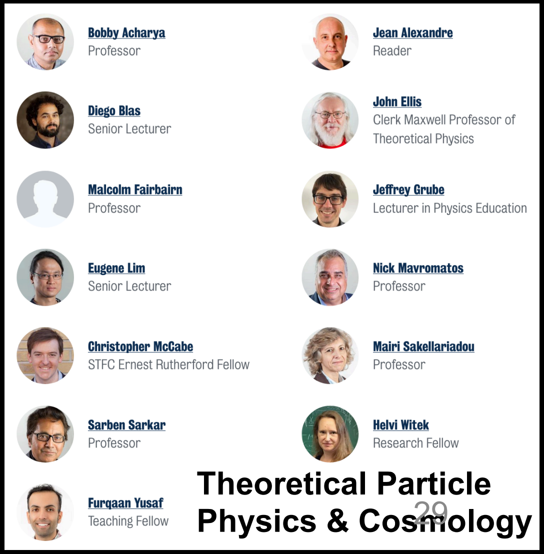


WIMPs (Weakly Interacting Massive Particles)

WIMPs are one type of Dark Matter and theoretically motivated
- Relatively heavy ~40-100 GeV/c^2
- Very slow, slower than the rotation motion of the galaxy
- Very rarely interact with ordinary matter

3 types of experiments to look for WIMPs
- **Indirect detection**
- **Direct detection**
- **Direct production**

Why WIMP is theoretically motivated Dark Matter model? → Ask theorists



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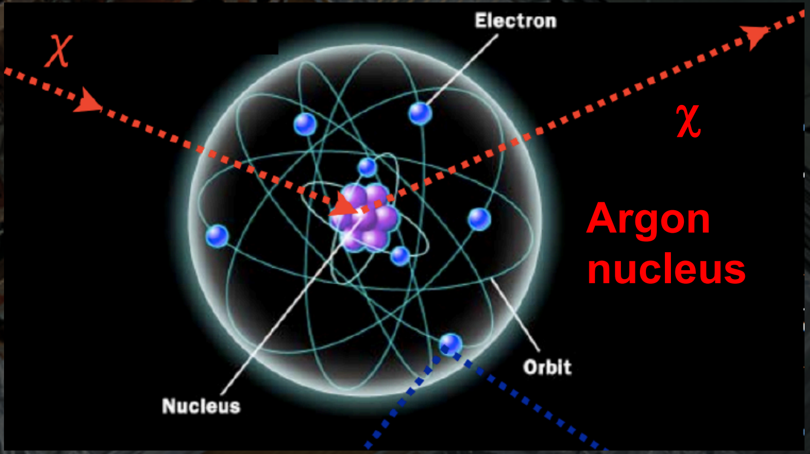
Direct detection experiments

Dark Matters are slower than galactic rotation
→ We are receiving Dark Matter wind on Earth!

Very precise detectors could measure interactions of Dark Matter and atoms.
- Purest materials to avoid radioactive backgrounds
- Highest sensitivity to detect the smallest signals
- Large volume to maximize the chance of interaction



DEAP-3600 dark matter detector

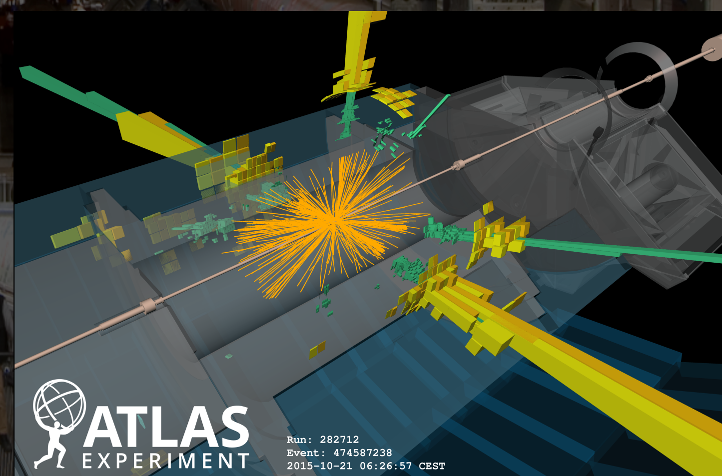
1. Dark Matter Particles

Dark Matter particles cannot be too heavy or too light

Dark Matter particles do not interact with ordinary particles via ordinary forces

Dark Matter particles may interact with ordinary particles, but
- interaction should be very rare
- interaction should be based on **new force**

3 types of experiments;
- **Indirect detection**
- **Direct detection**
- **Direct production**



ATLAS detector at Large Hadron Collider

Accelerator production of Dark Matter

If Dark Matter is light new particle, then it may be possible to produce them by high-power accelerator.

Dark Matter particles may interact with ordinary particles, but interaction should be very rare.

Maybe Dark Matter particles are produced by high-power accelerators, but we do not notice…?

If that is the case, high-precision neutrino detector can detect Dark Matter from the accelerator?

MiniBooNE-DM experiment

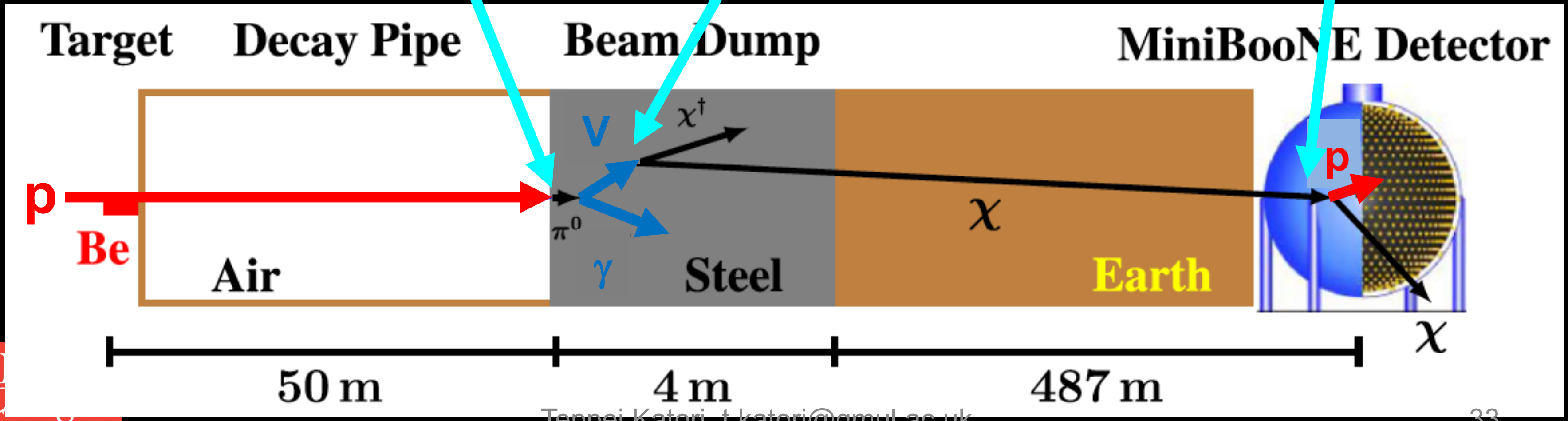
In MiniBooNE experiment, proton beam hits a target, and neutrinos are produced. Then neutrinos are detected by MiniBooNE detector.

Instead, MiniBooNE-DM experiment changes the beam to hit a wall. This will not produce neutrinos. But if Dark Matter is produced, we can detect it

proton beam hitting a wall

Dark Matter may be produced?

Dark Matter interacts in the detector



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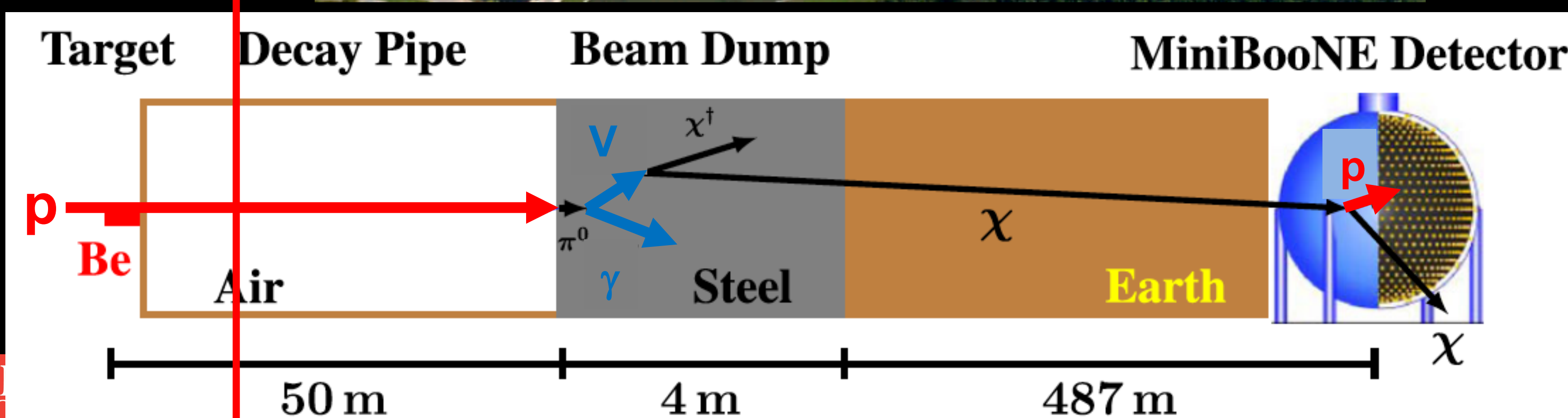
Booster Neutrino Beamline

MiniBooNE-DM experiment is located at Fermilab, USA.



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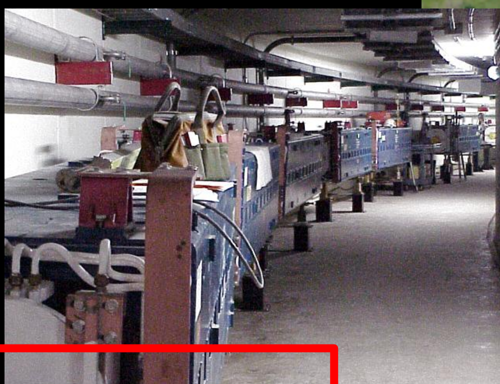
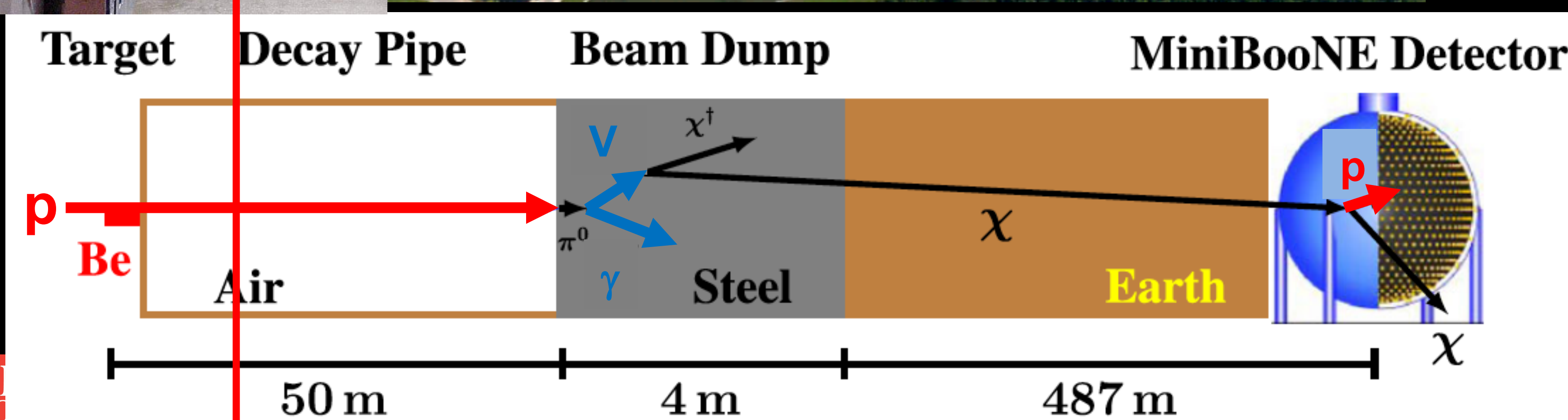
Booster Neutrino Beamline

Booster accelerates protons up to 8 GeV

FNAL Booster





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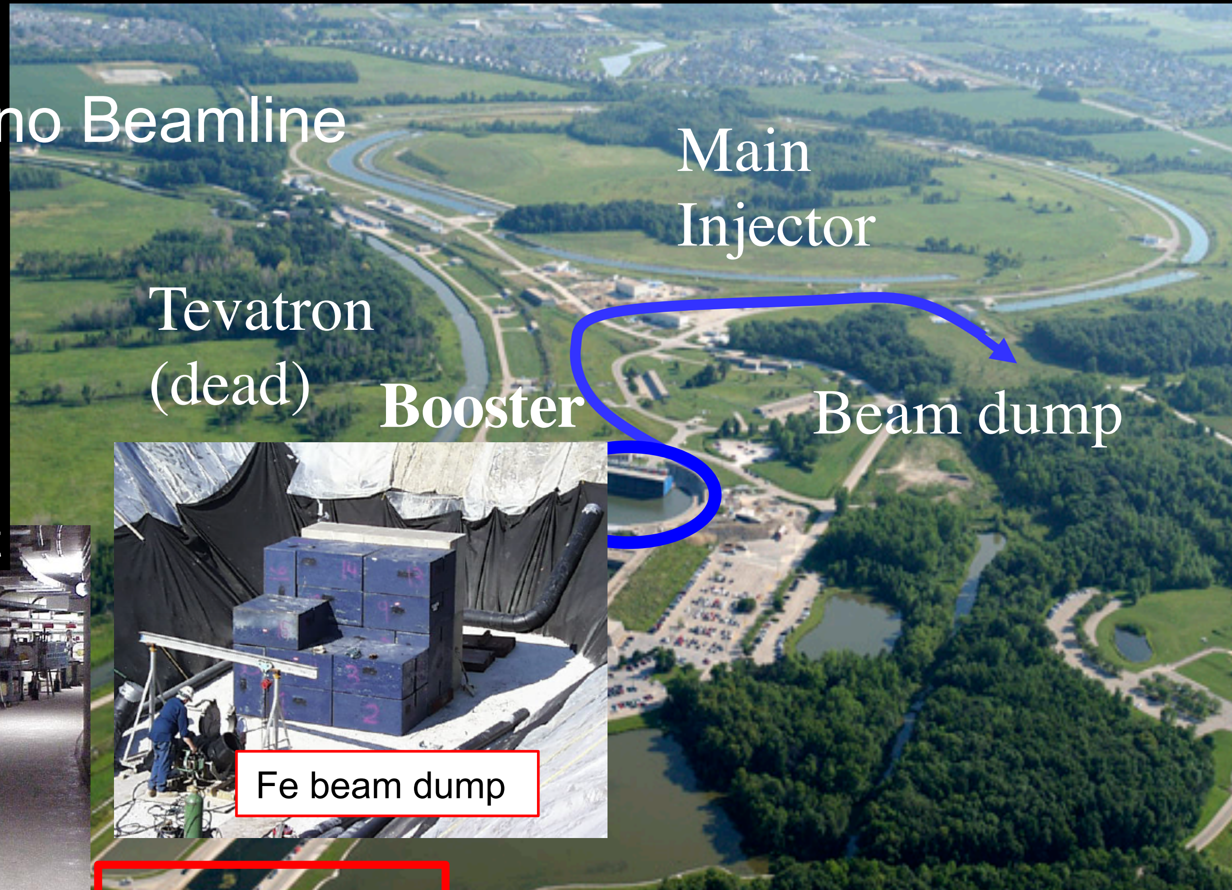
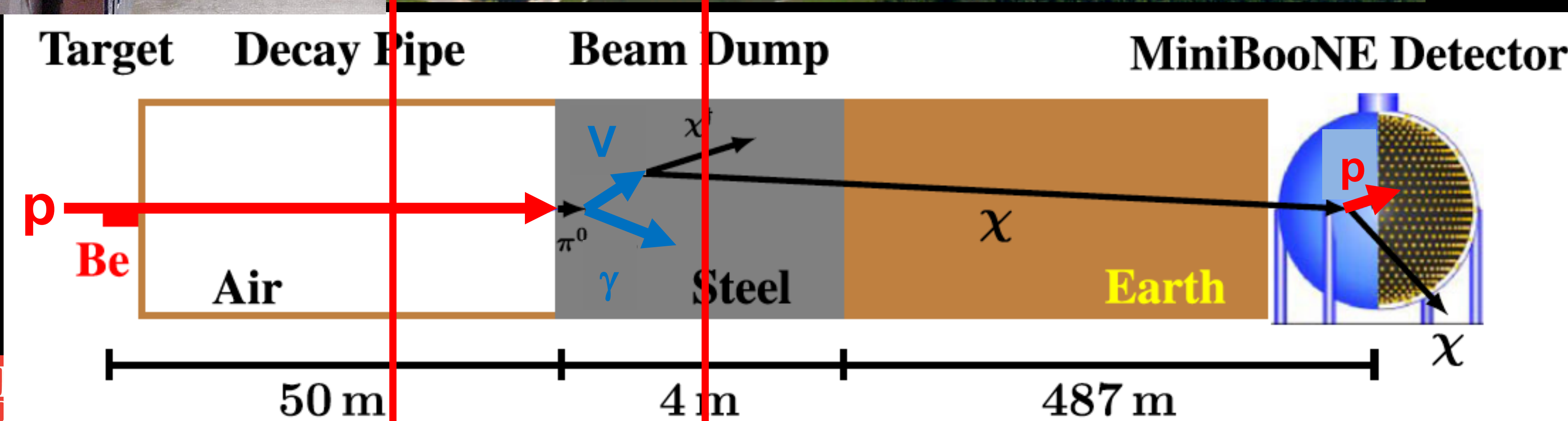
Booster Neutrino Beamline

Protons hit the beam dump, and create many particles.

Photons can be converted to **dark photons** if they exist





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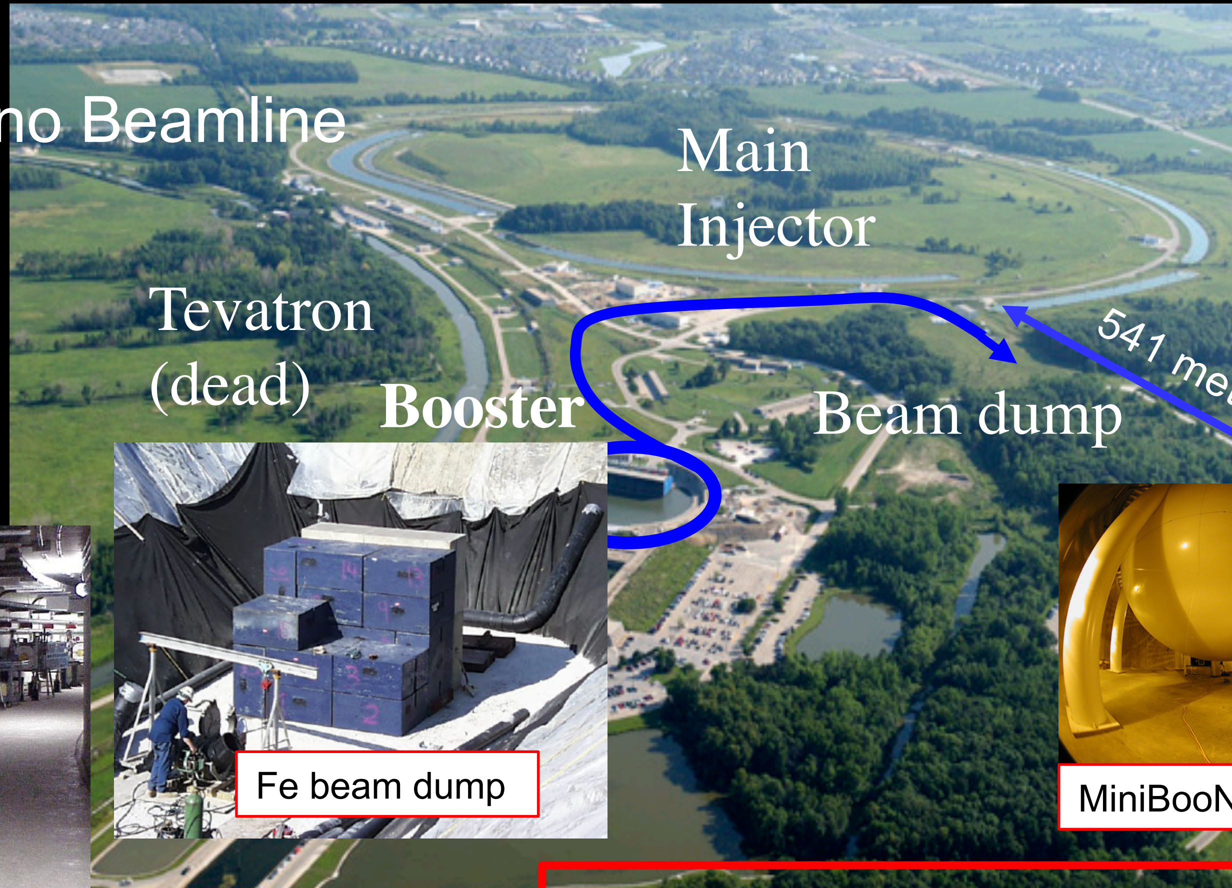
Booster Neutrino Beamline

Dark photons decay to **Dark Matter,** and they may interact with nucleons in the MiniBooNE detector



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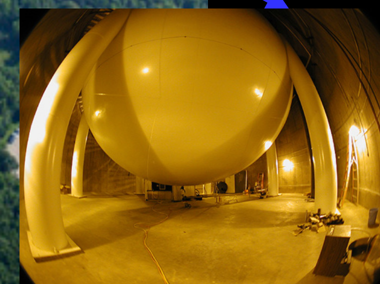
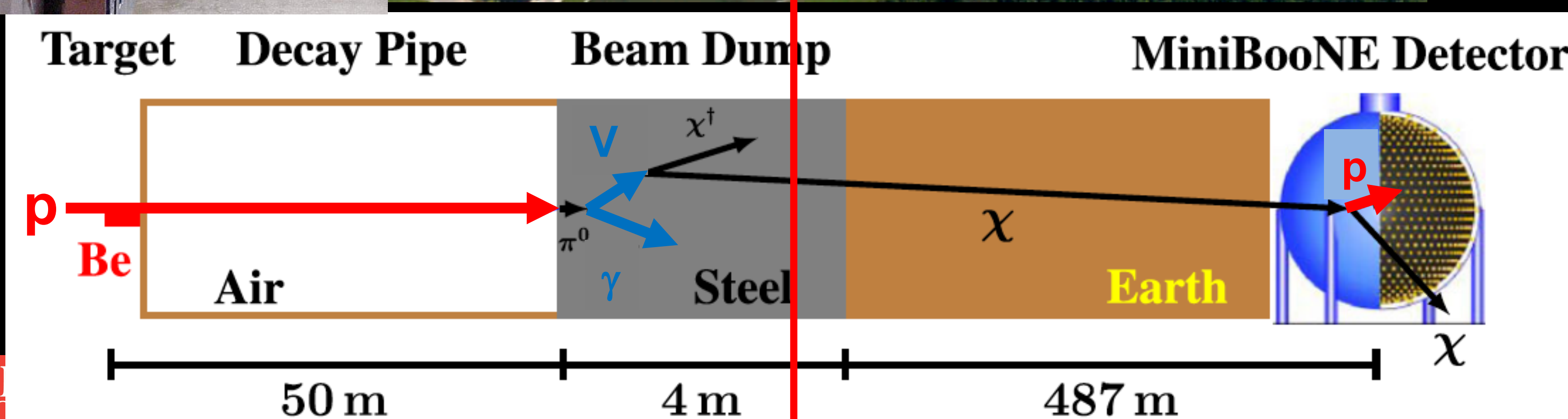


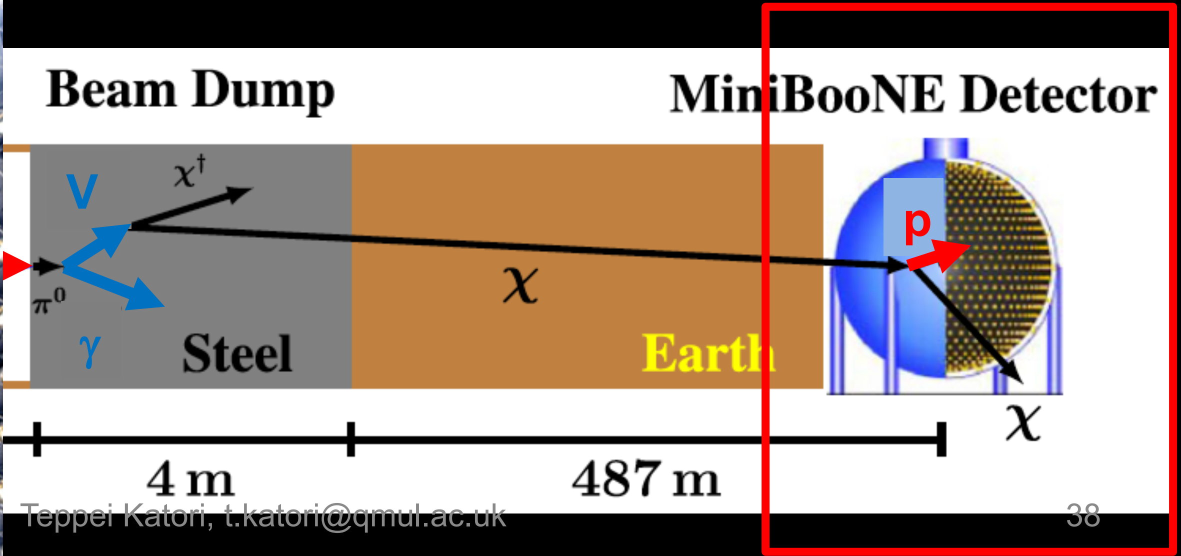
MiniBooNE detector



MiniBooNE detector

541 meters downstream of beam dump

- 12 meter diameter sphere
- Filled with 800 t of pure mineral oil (CH_2)
- **1280 photo-multiplier tubes (PMTs)**



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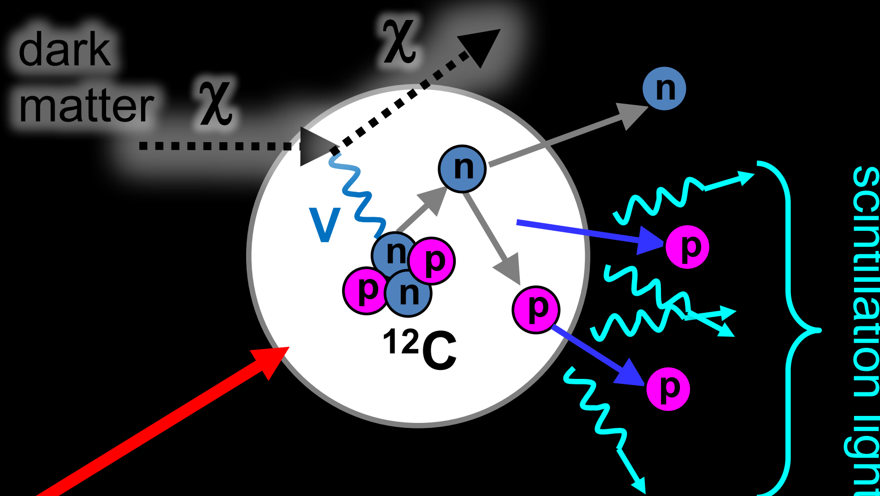
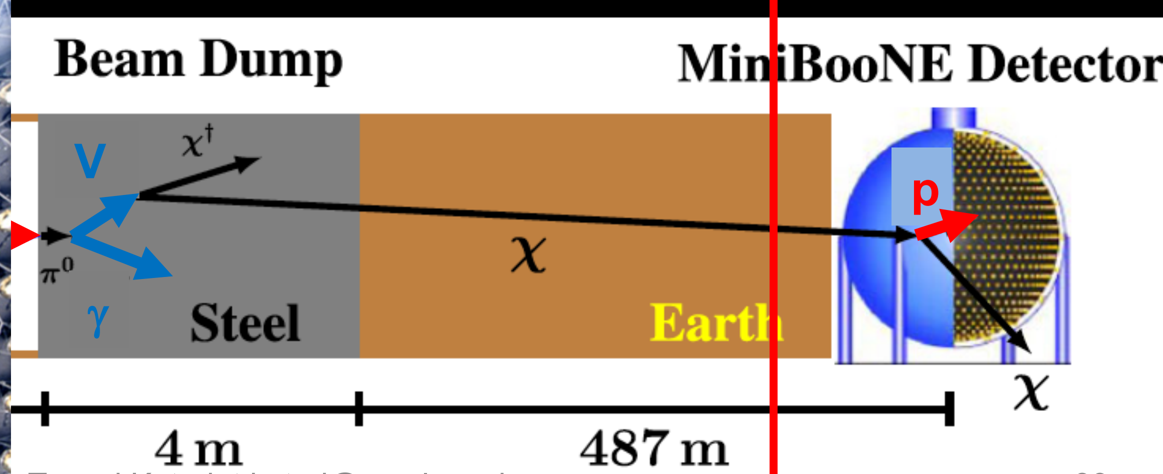
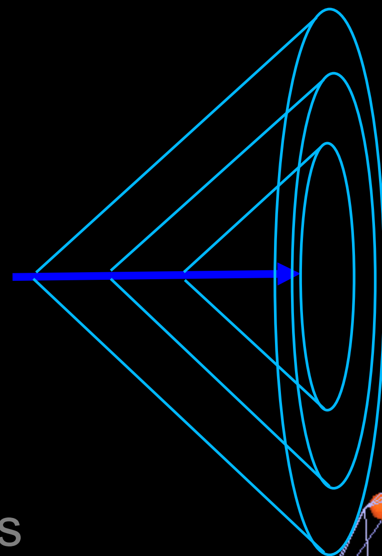




4. Events in the Detector

Muons

- Long strait tracks
  → Sharp clear rings

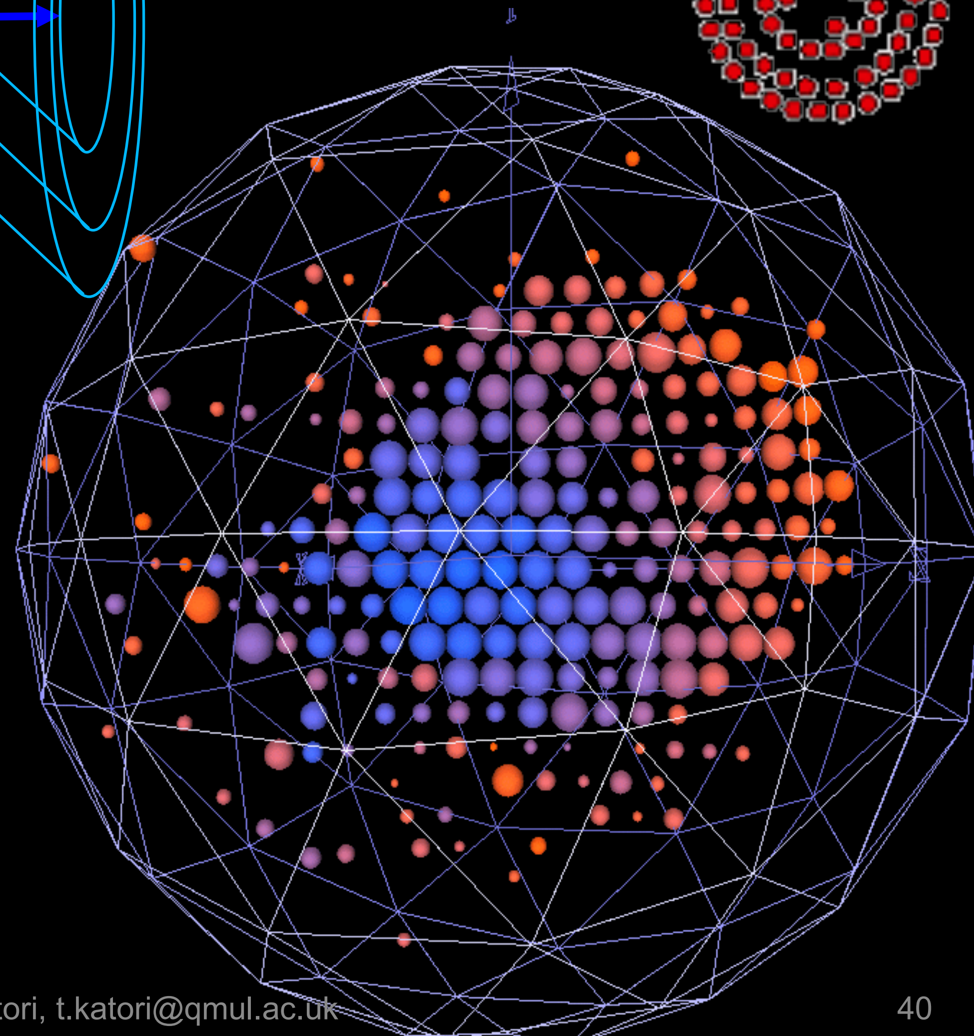


Electrons

- Multiple scattering
- Radiative processes
  → Scattered fuzzy rings

Dark Matter interaction

- No Cherenkov radiation
  → Isotropic scintillation hits



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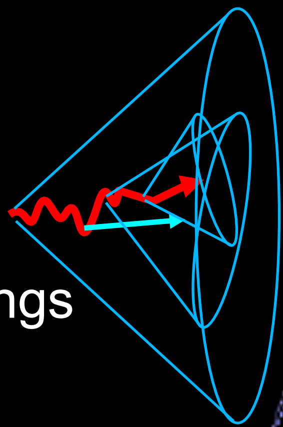

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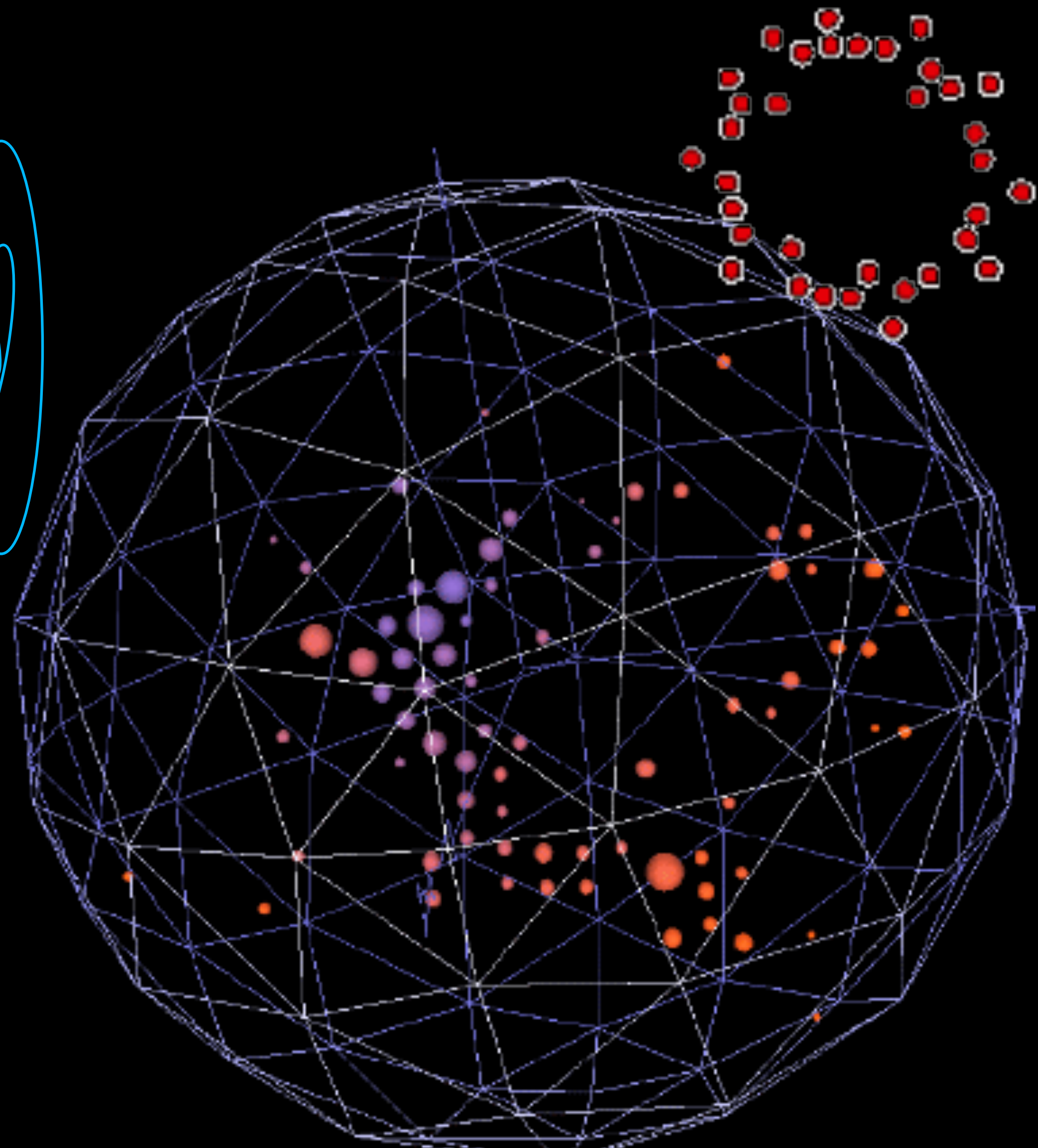

MiniBooNE collaboration,NIM.A599(2009)28

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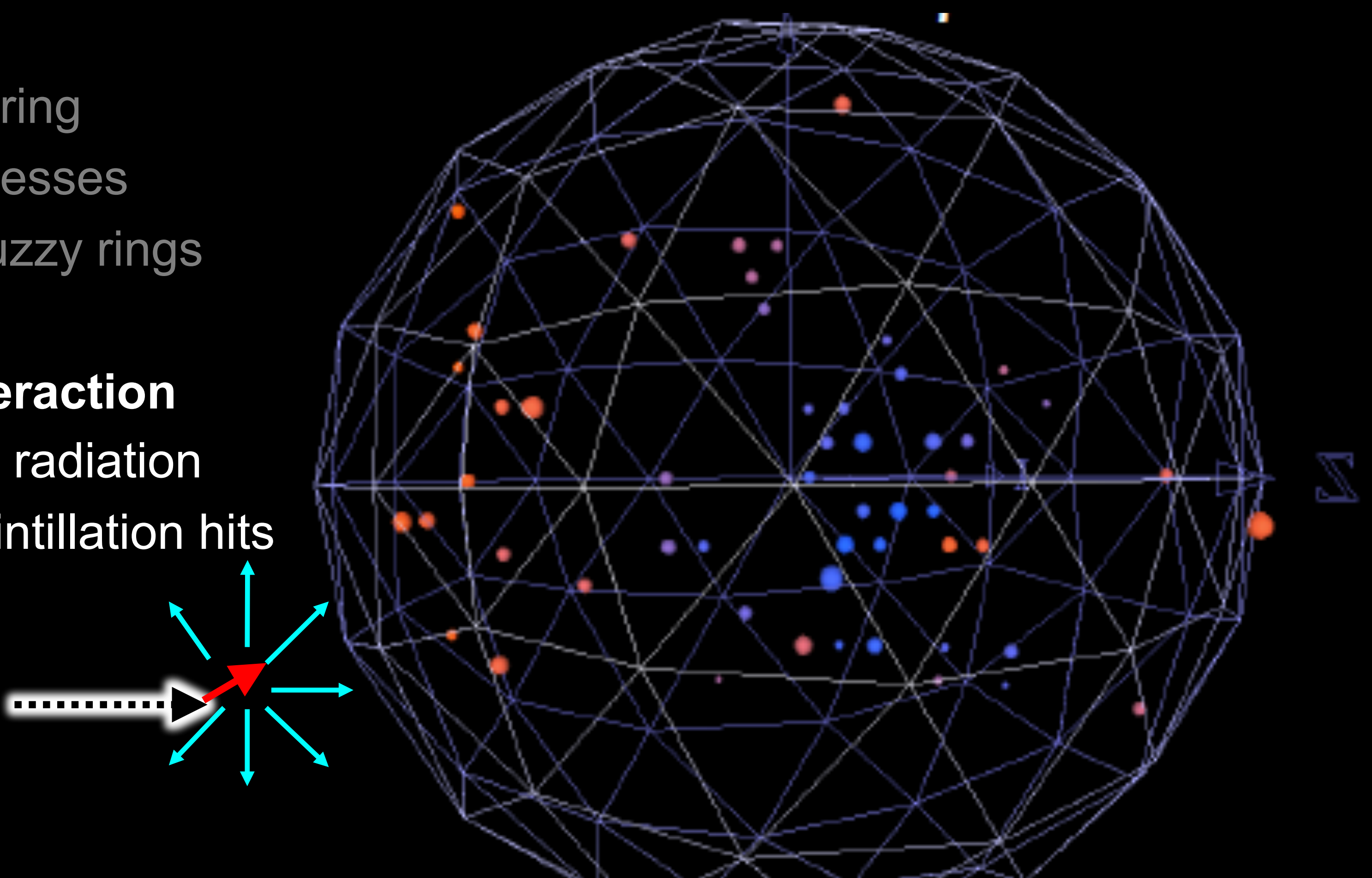
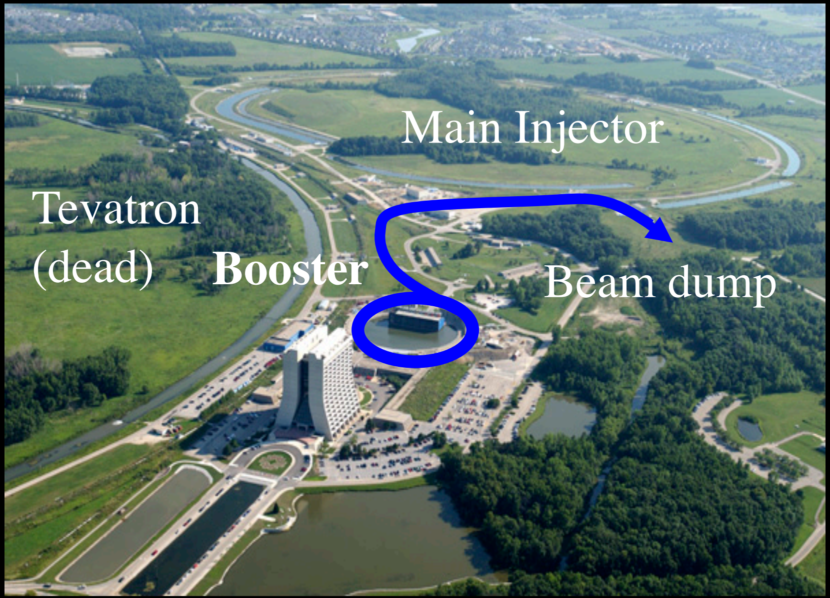
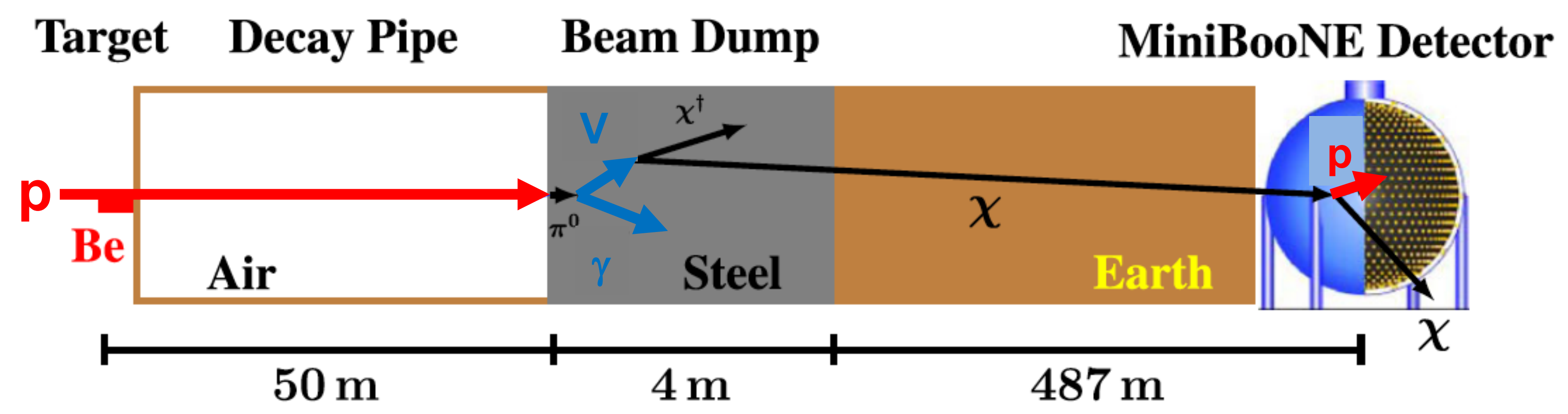


Neutrino neutral current interactions make similar pattern (background)

5. Search of light dark matter particles in MiniBooNE-DM

We send 1.86 x 10^{20} protons to the beam dump during 2014





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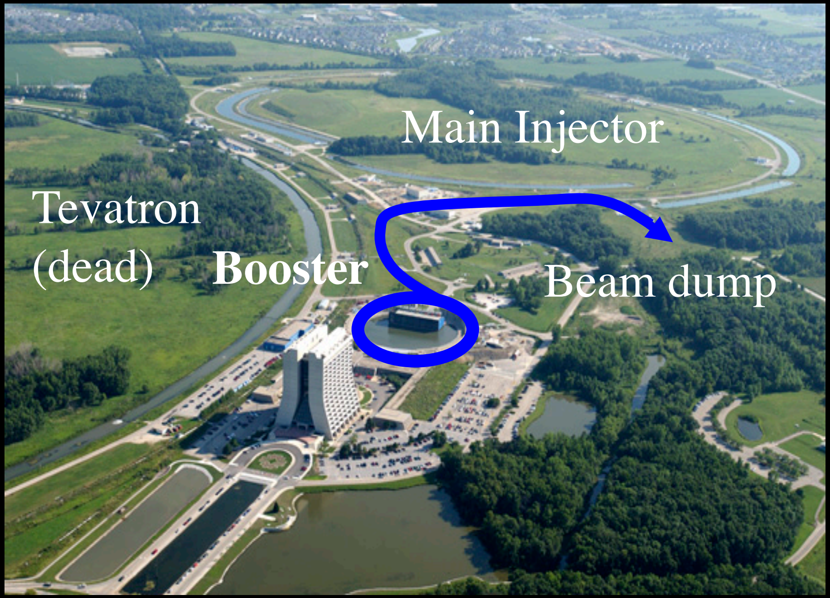
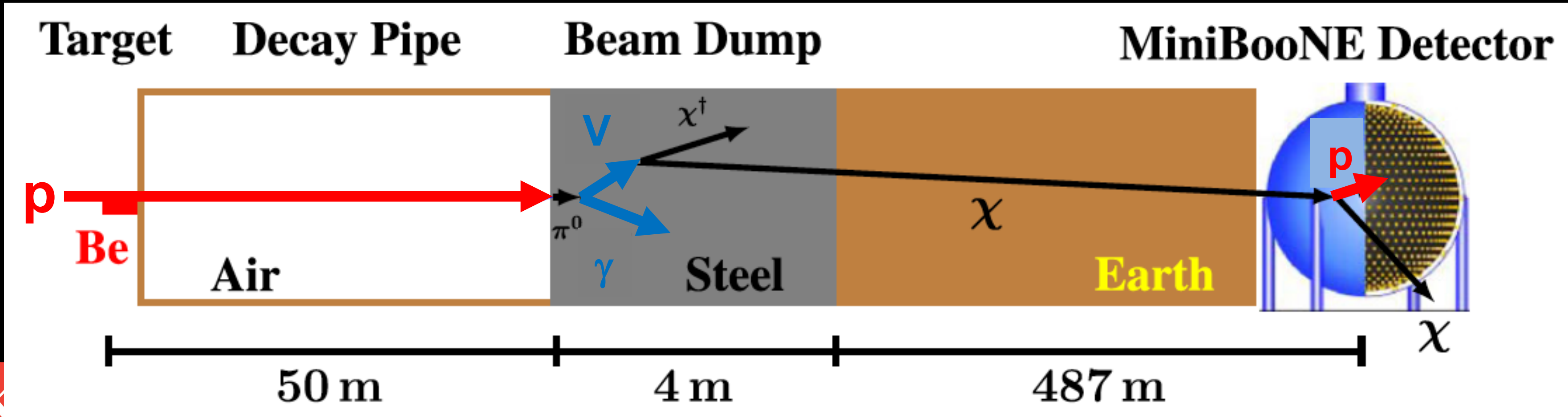
We find **1465±38 interactions** of dark matter candidates (?!)





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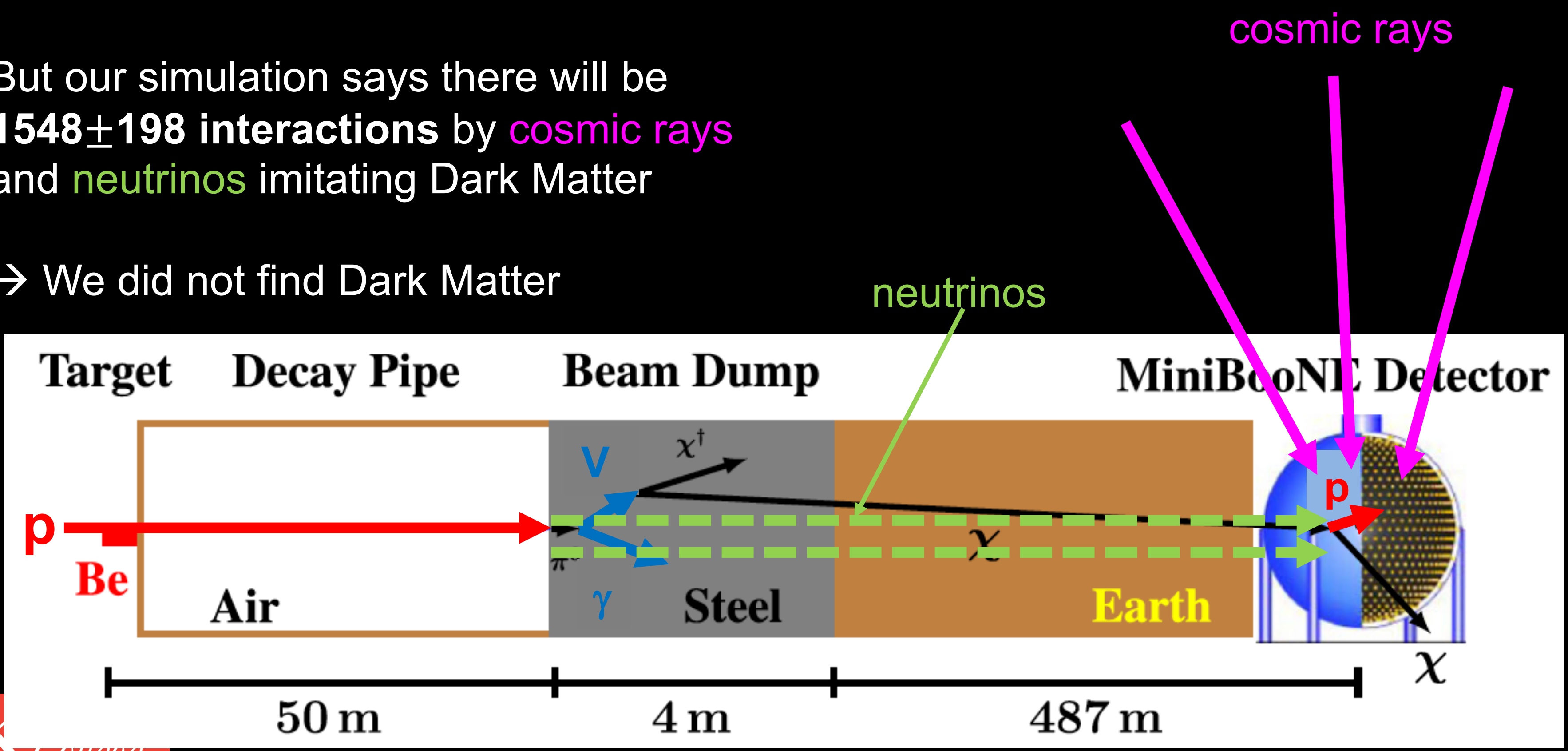
But our simulation says there will be **1548±198 interactions** by cosmic rays and neutrinos imitating Dark Matter

→ We did not find Dark Matter



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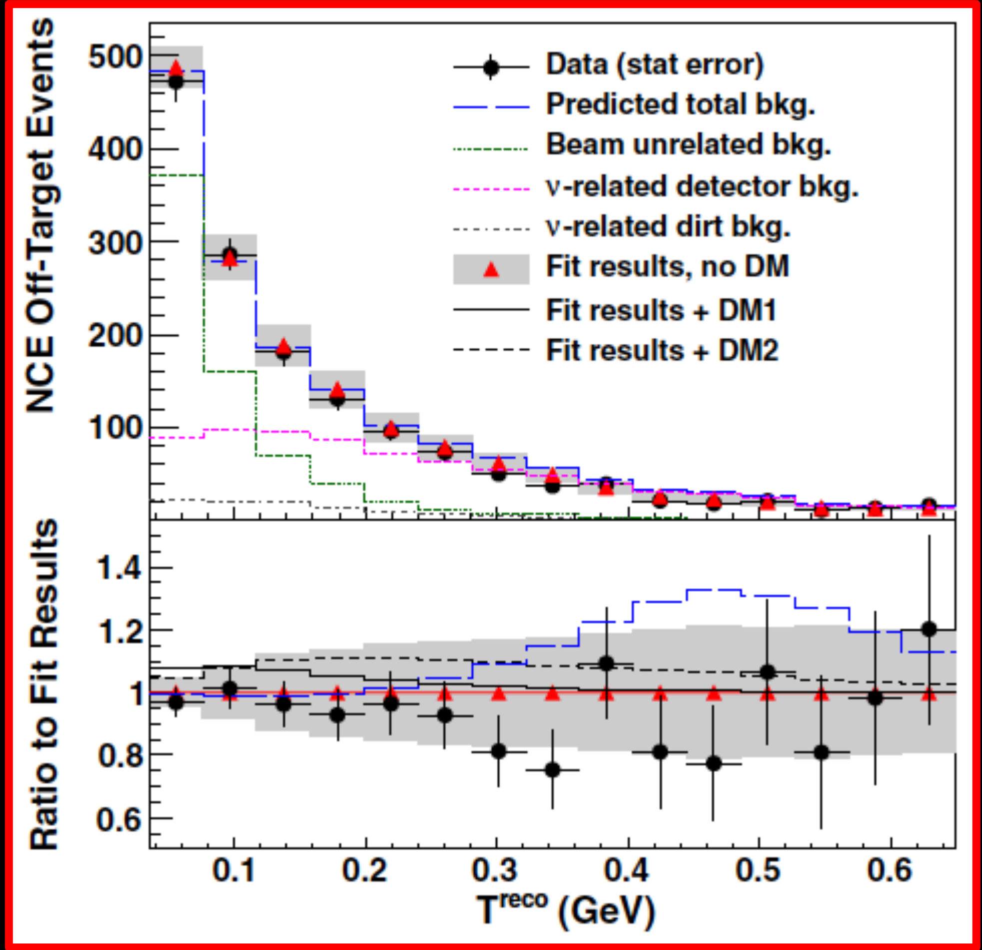

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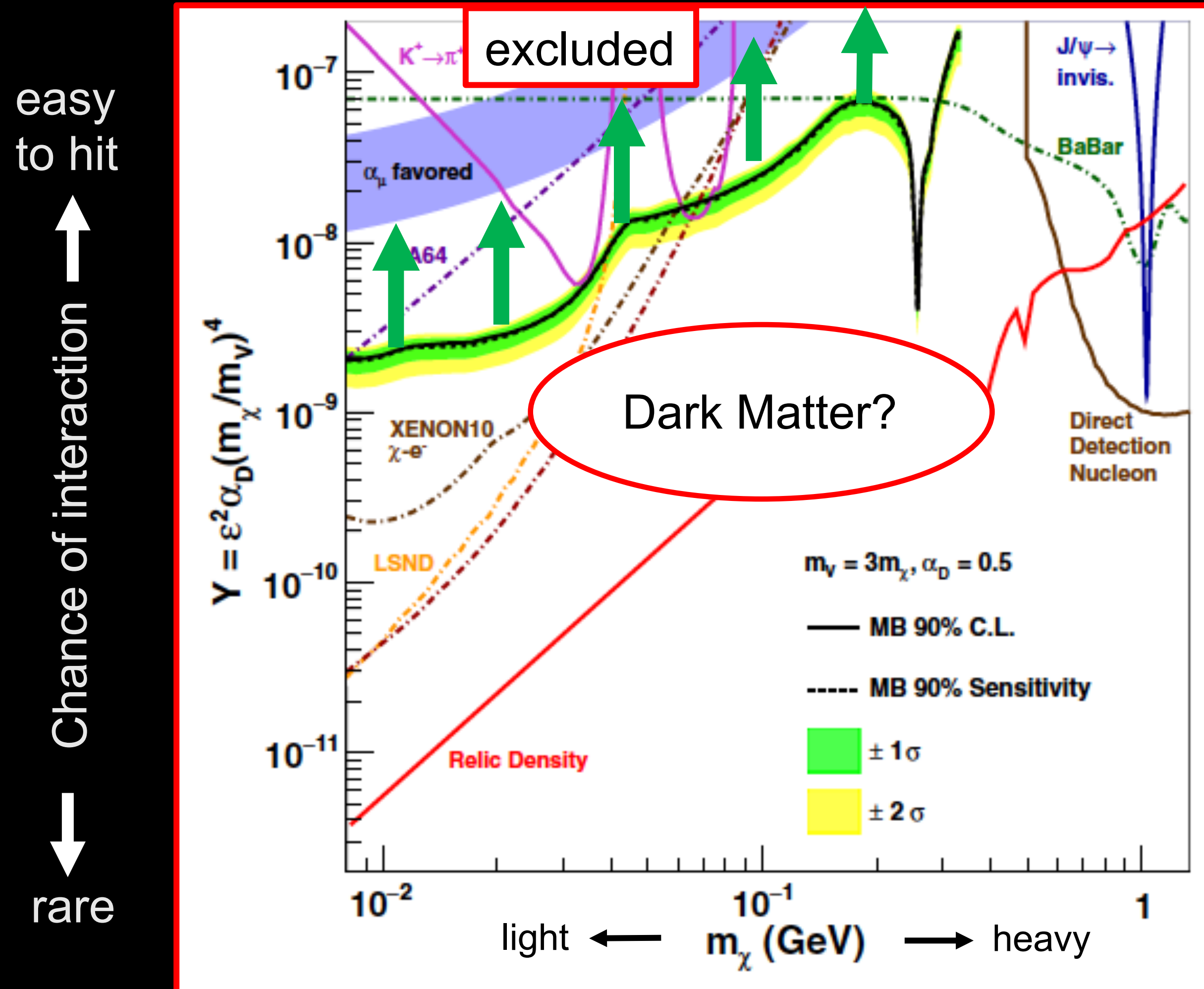
We set the strongest limit for Dark Matter – nucleon interaction in
$0.01\ \mathrm{GeV} < m_\chi < 0.3\ GeV$



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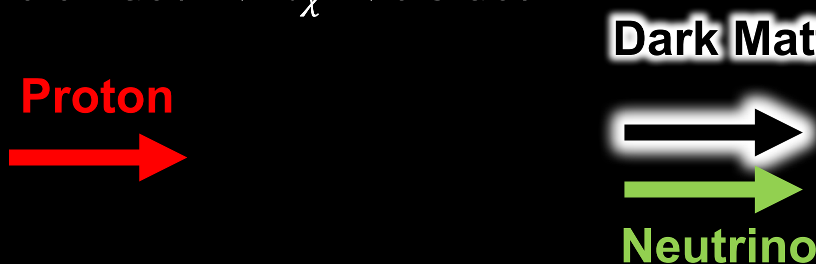
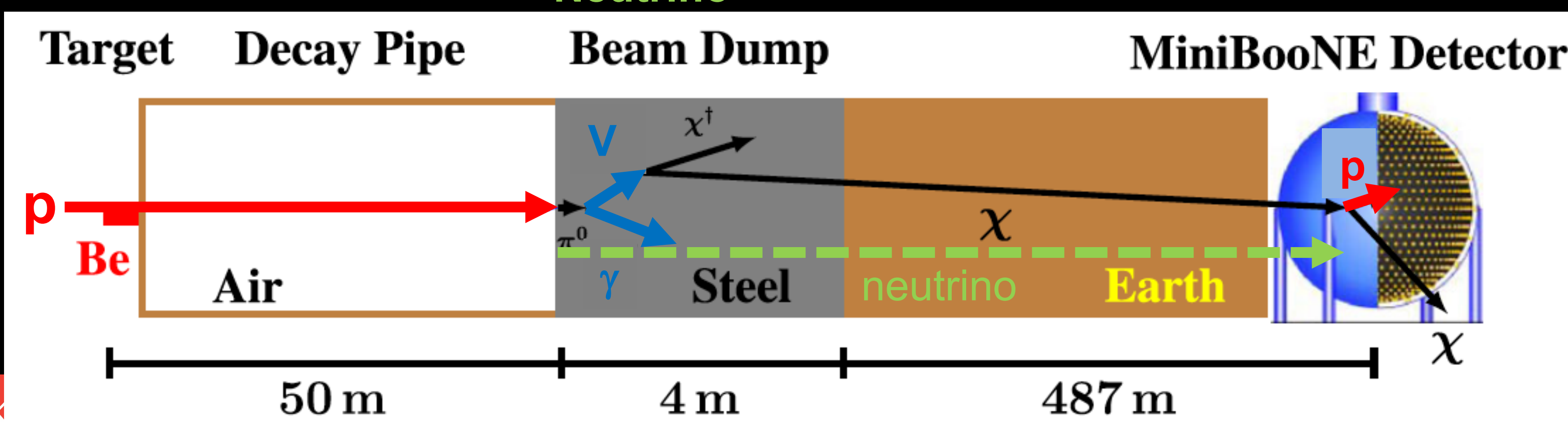
Dark Matter time-of-flight

Dark Matter is slower than neutrinos. Our detector is sensitive to nanosecond delay of Dark Matter





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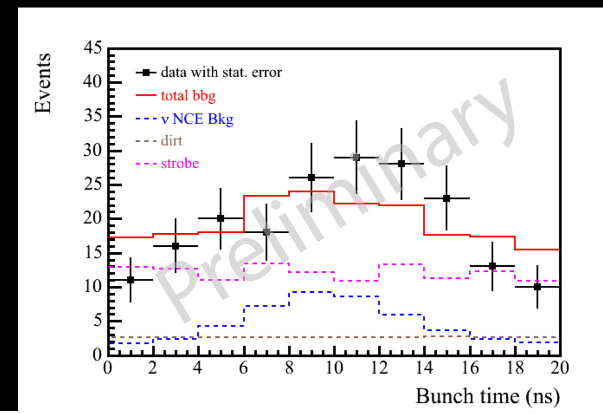
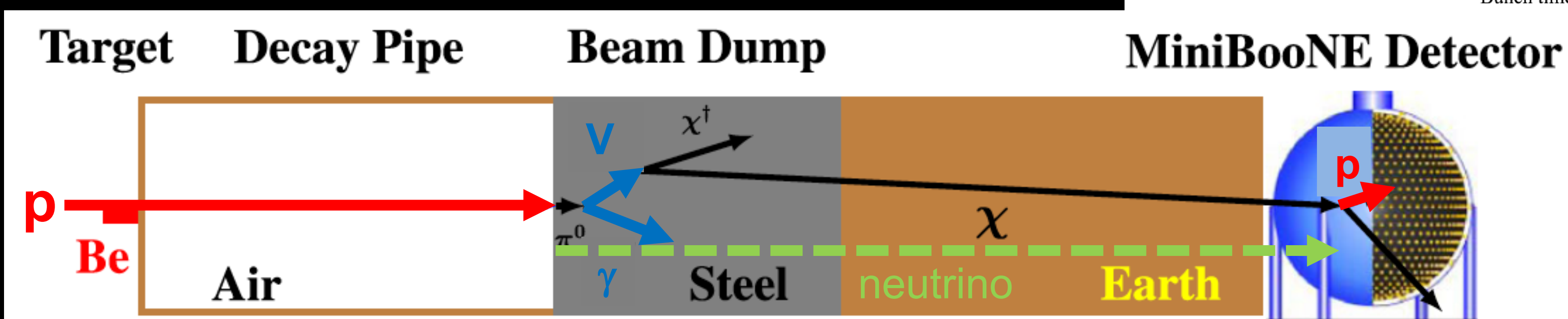
Dark Matter is slower than neutrinos. Our detector is sensitive to nanosecond delay of Dark Matter

Data timing structure must be carefully analyzed





MiniBooNE-DM is still looking for spooky Dark Matter!