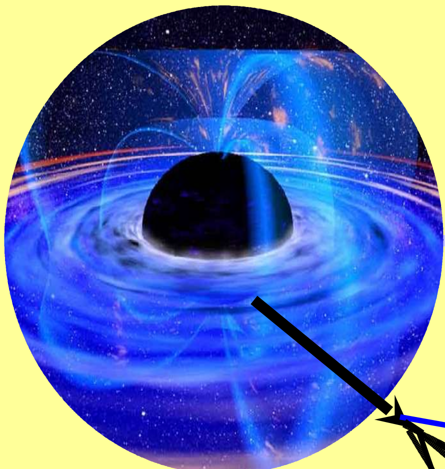
acoustic detection of **ultra high energy neutrinos**

predicting the sensitivity of km^3 hydrophone arrays to fluxes of uheνs

introduction - uhe production scenarios I

bottom up: active galactic nucleus

e.g. V.Berezinsky, A.Z.Gazizov, S.I.Grigorieva hep-ph/0204357



uhe particle emission from **agn black hole** jets **(proton accelerator)**

gamma rays **absorbed** by inter stellar/galactic matter and re-radiated at longer λ

surrounded by enveloping **ambient radiation (beam dump) → neutrinos**

charged particles deflected by **magnetic** fields

~massless νs retain **energy** + **directionality** as they traverse the cosmos

→detector

introduction - uhe production scenarios II
cosmogenic neutrinos

- cosmic ray **protons** can interact with **ambient radiation** to produce associated flux of **neutrinos** (previous slide)
- above a certain **threshold**, cosmic ray **protons** will interact with **cosmic microwave background** photons **("gzk" effect)**

$$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow n + \pi$$

$$n \rightarrow p + e^{-} + \overline{\nu}_{e}$$

$$\pi \rightarrow \mu + \nu_{\mu}$$

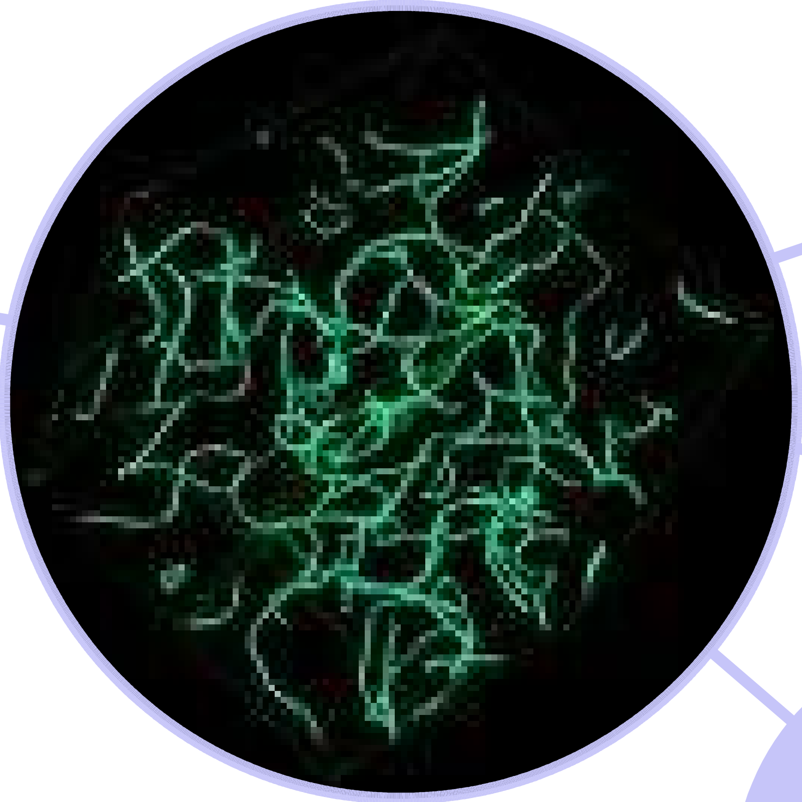
$$\mu \rightarrow e^{+} + \nu_{e} + \overline{\nu}_{\mu}$$

- **"guaranteed" flux of cosmogenic neutrinos**

introduction - uhe production scenarios III

top down emission

http://www.pact.cpes.sussex.ac.uk/~markh/strings.html

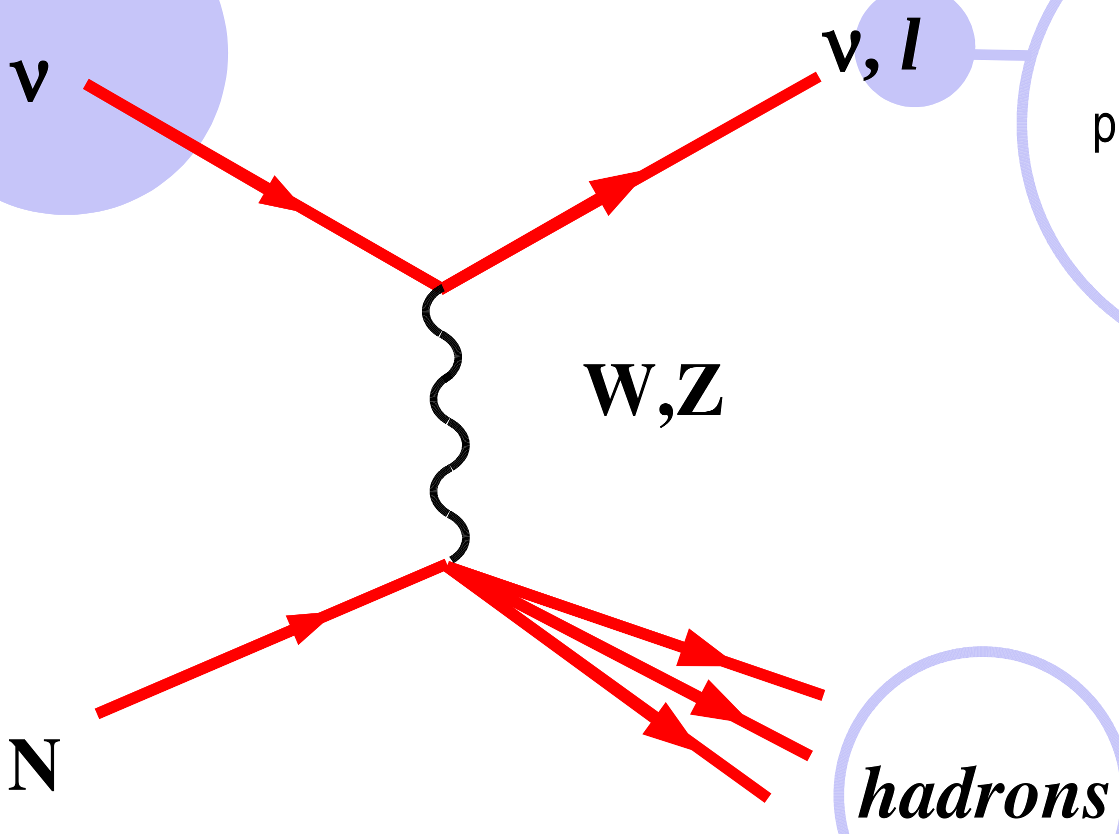


exotic physics (Z bursts, quantum gravity - modified cross-sections...)

radiation from **topological defects** (cosmic strings, phase transitions monopoles...)

uhe particle emission from decay of **massive super heavy relic particles**

the neutrino interaction CC/ NC
inelastic scattering

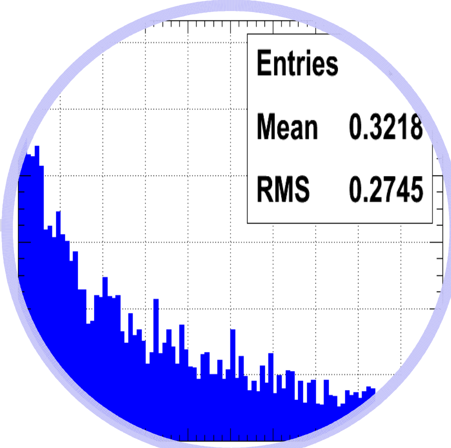


this **charged lepton** can produce **optical cerenkov** radiation

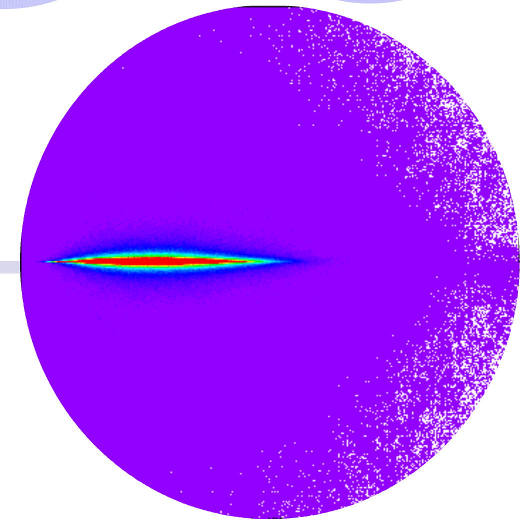
this **cascade** can produce **radio cerenkov emission** and locally **heats** the interaction medium **(ice/salt/water)** causing an **acoustic shock**

simulating the neutrino interaction I
the hadronic energy fraction

~27% of $\mathbf{E}_\nu$ taken by **cascade**



the evolution of the **cascade** in a **detector** is simulated by **geant4** and **corsika**

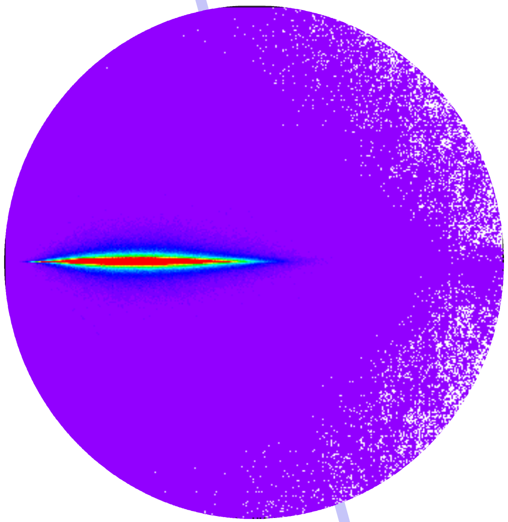


we can generate the hadronic energy fraction (**bjorken-y**) with event generators like **pythia** or **anis**

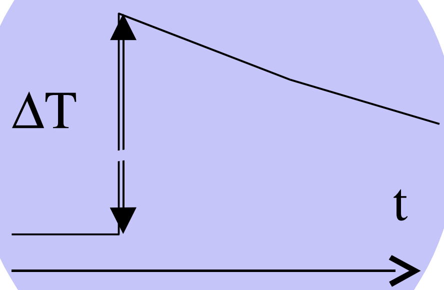
hadrons

this **cascade** can produce **radio cerenkov emission** and locally **heats** the interaction medium **(ice/salt/water)** causing an **acoustic shock**

acoustic signal production
real and simulated

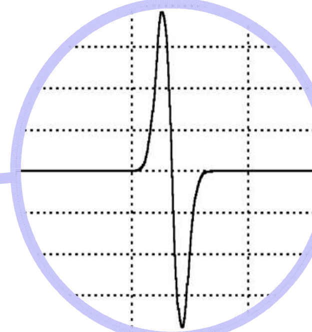


intergrate cascade energy to yield **thermal energy density**



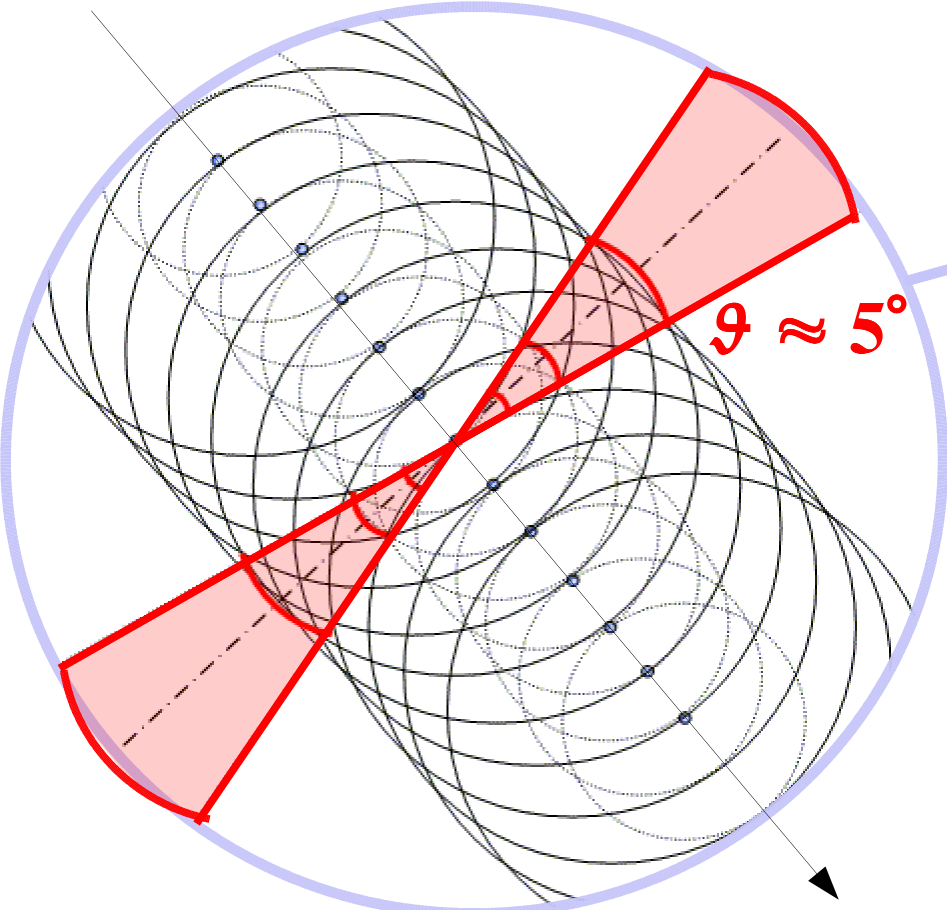
leads to quasi-instantaneous **temperature increase**

the **pressure** is related to the double time derivative of the **temperature rise** and leads to a characteristic **bipolar pulse** of ~**100μs** width

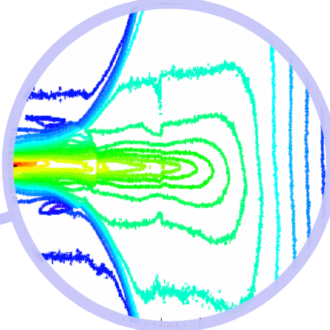


pulse is **integral** of contributions from each **heating element** along cascade

angular behaviour of signal
formation of acoustic pancake

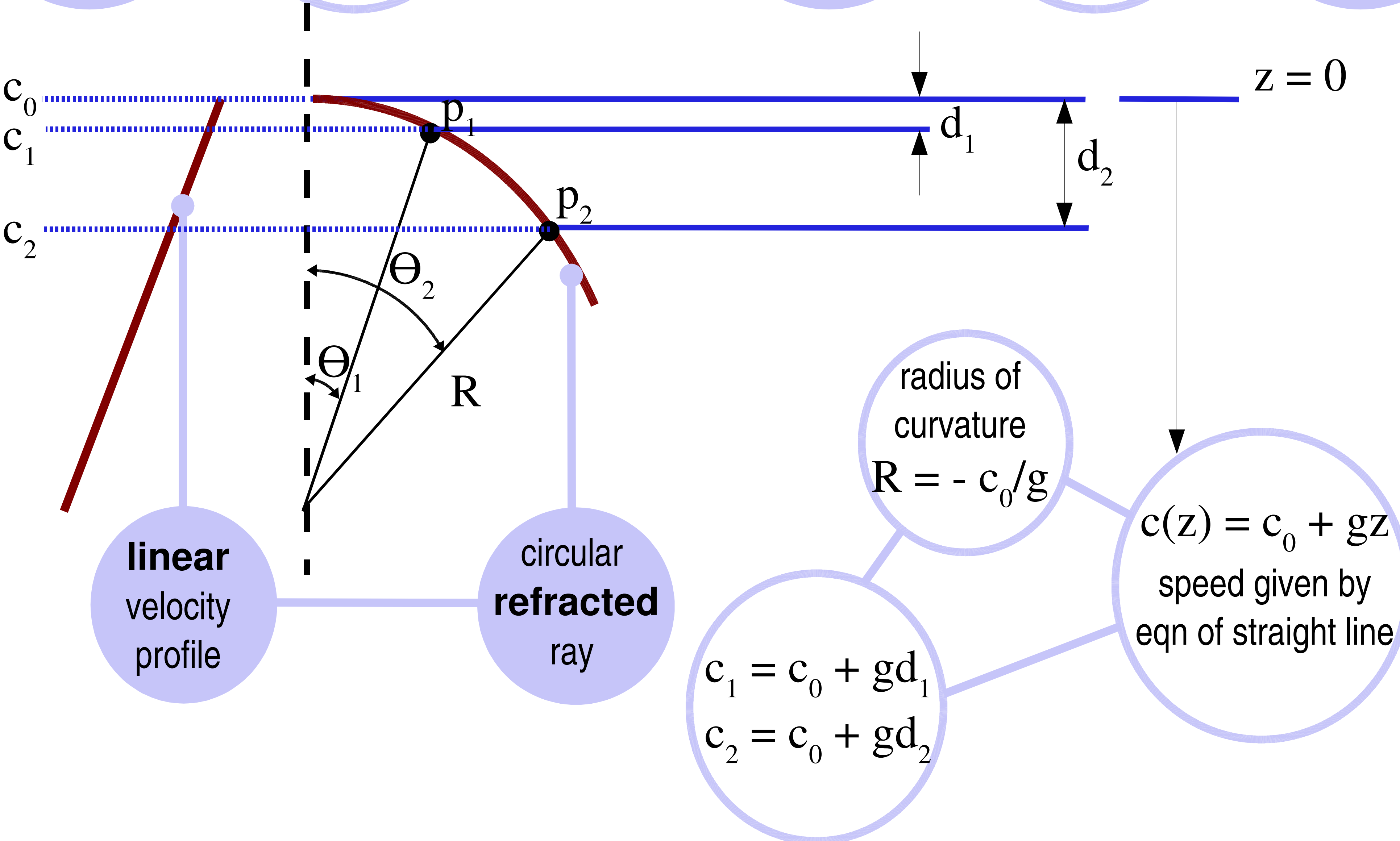


Radiation is emitted **coherently** along the cascade axis – leading to a **confinement** of the signal to a **narrow pancake** due to a superposition of wavelets.

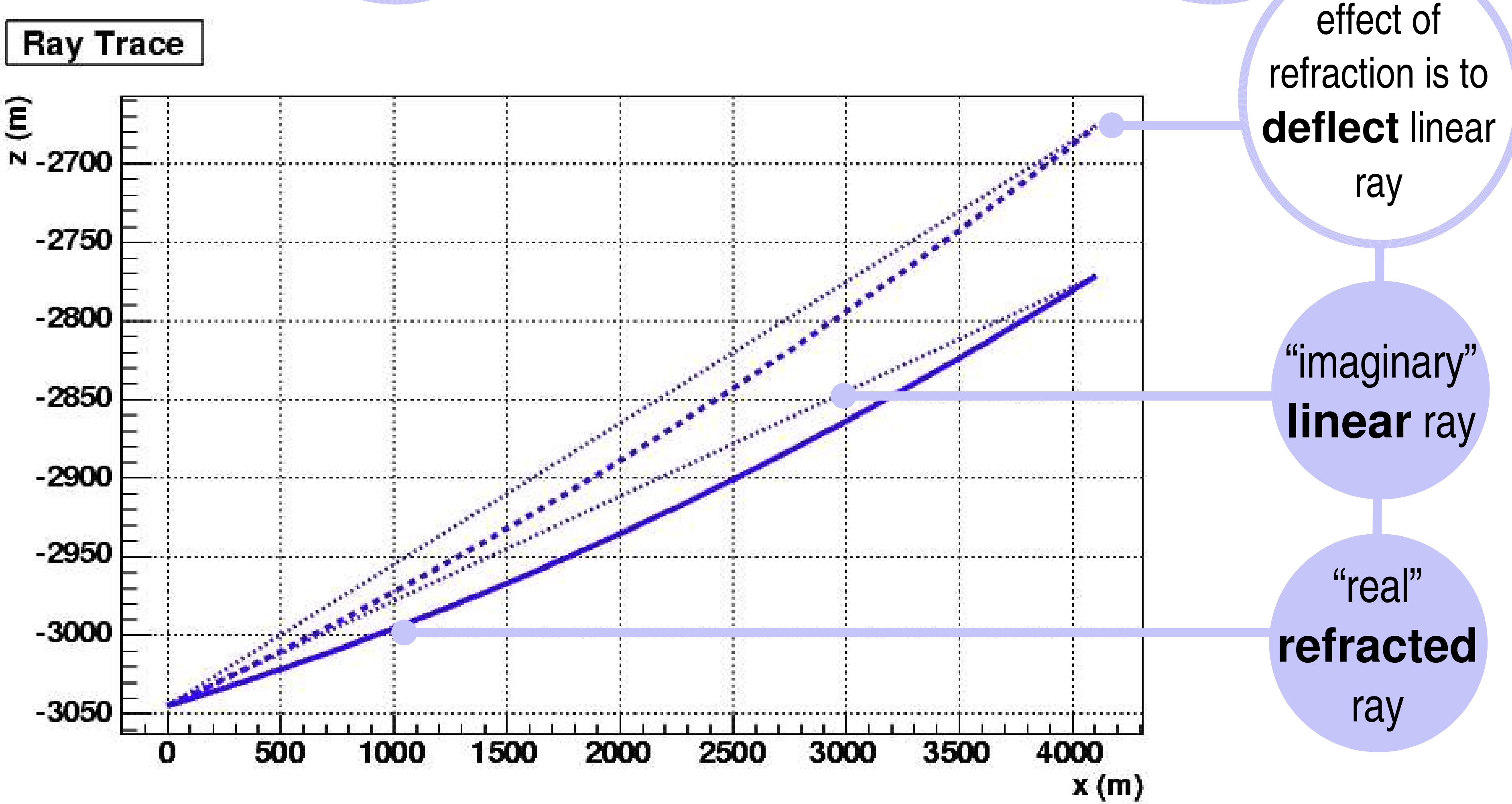


This is **analogous** to the **diffraction** of **light** through a **narrow slit**

propagation of the signal
schematic of refraction



propagation of the signal
ray tracing

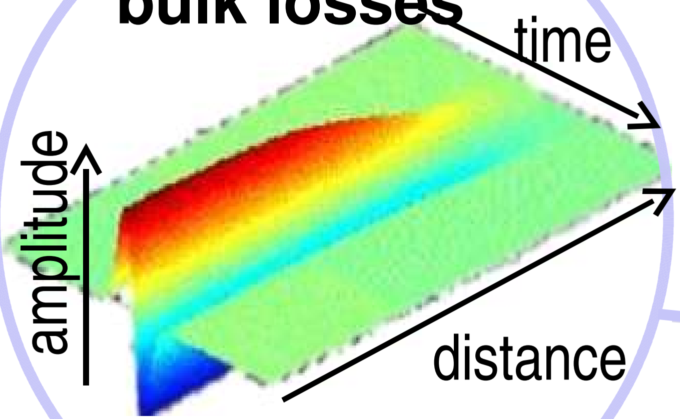


the travel time for an acoustic pulse is calculated along the path of the refracted ray...

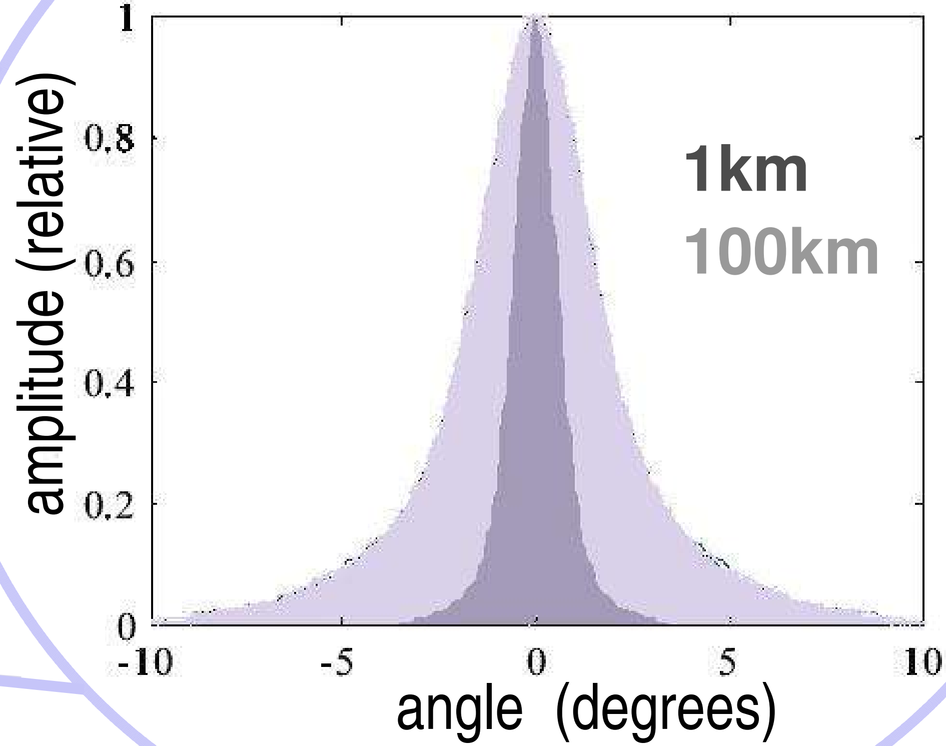
simulated bulk losses and angular spread

attenuation of pressure pulse

the signal is **attenuated** as it propagates through **detector medium**



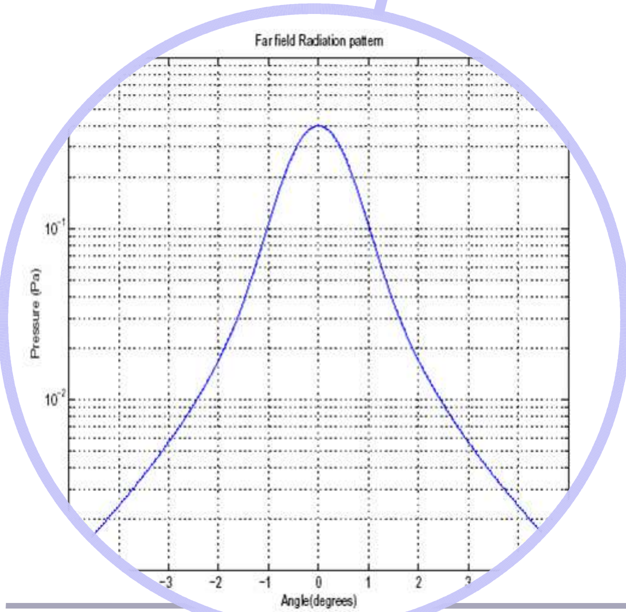
from fraunhoffer diffraction theory



pulse **widens** with distance

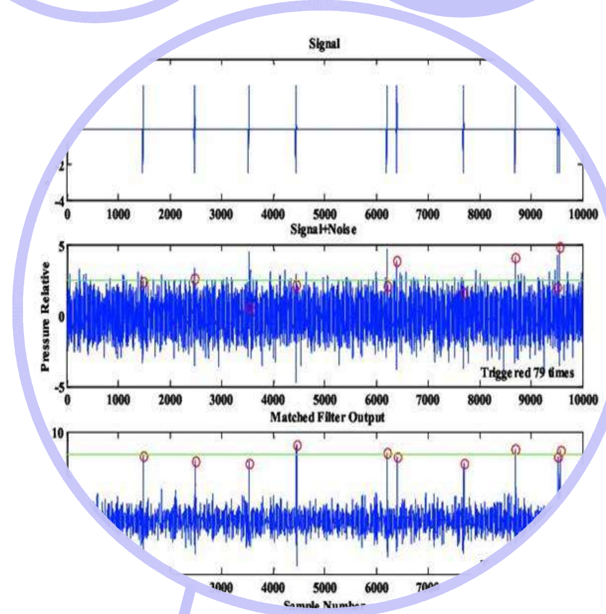
hydrophone cuts
discard the no-hopers then record hits

cut phones >5° out of the plane defined by the **“pancake”**



the **signal** strength has **dropped by 100x** at this distance

cut phones with **signal below** threshold of **0.035Pa**



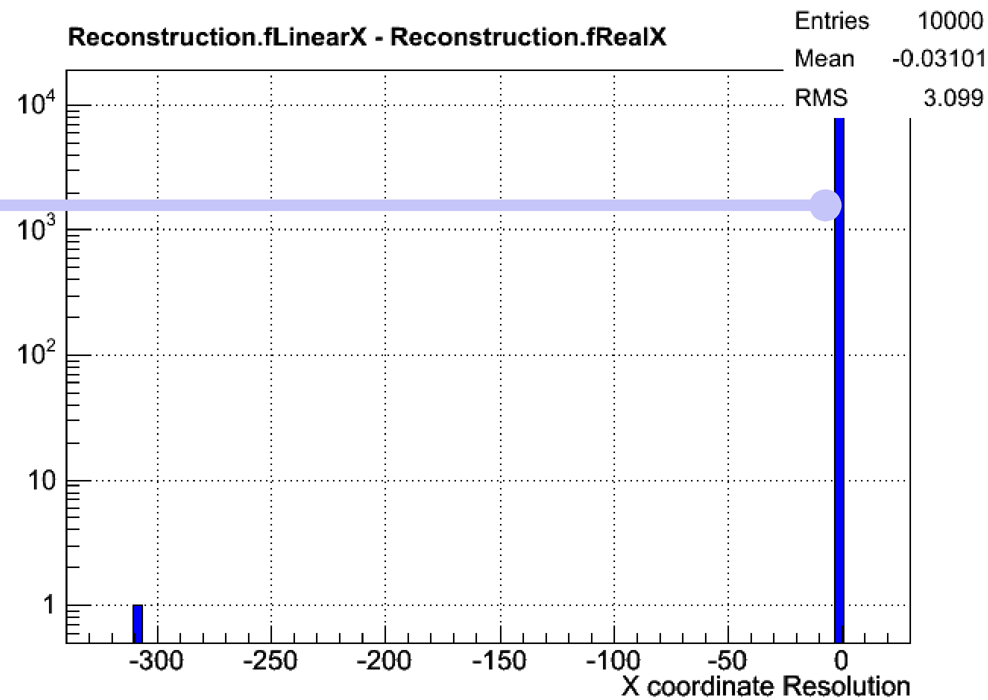
threshold set by **“probability of false alarm”** - 1 event in 5yrs with 5-fold coincidence **due to noise**

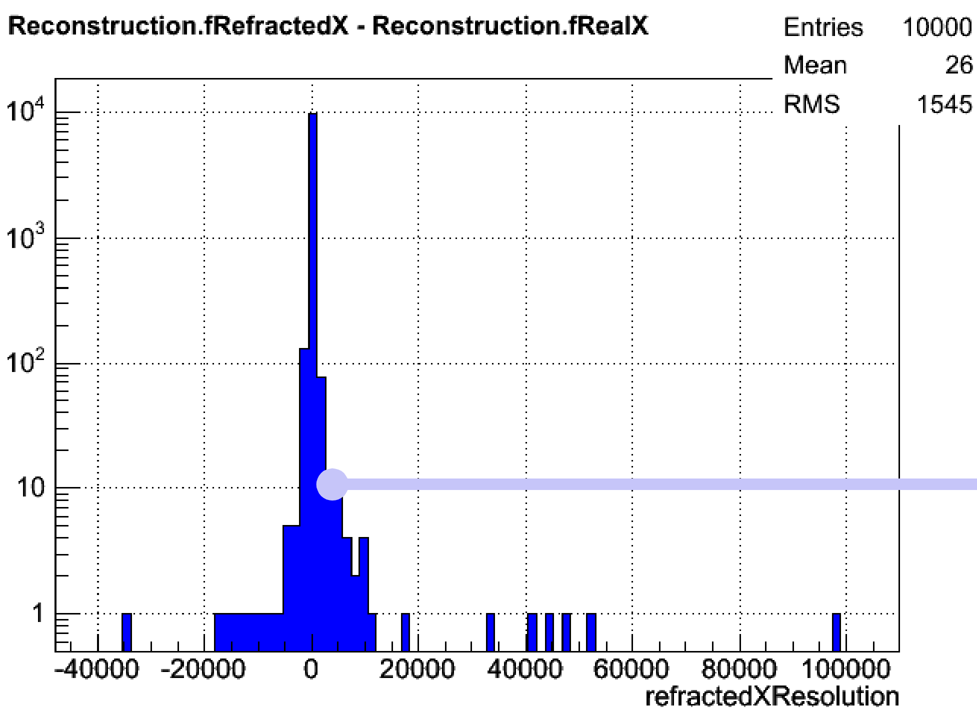
vertex reconstruction from hit times

finding the vertex I

reconstruction (matrix equation) of linear hit times ~ 99.99% reconstruction

resolution essentially a delta function





effect worsens as fiducial volume increses (here only 1km^3)

linear reconstruction of refracted hit times – start to see massive errors (up to 10 km)

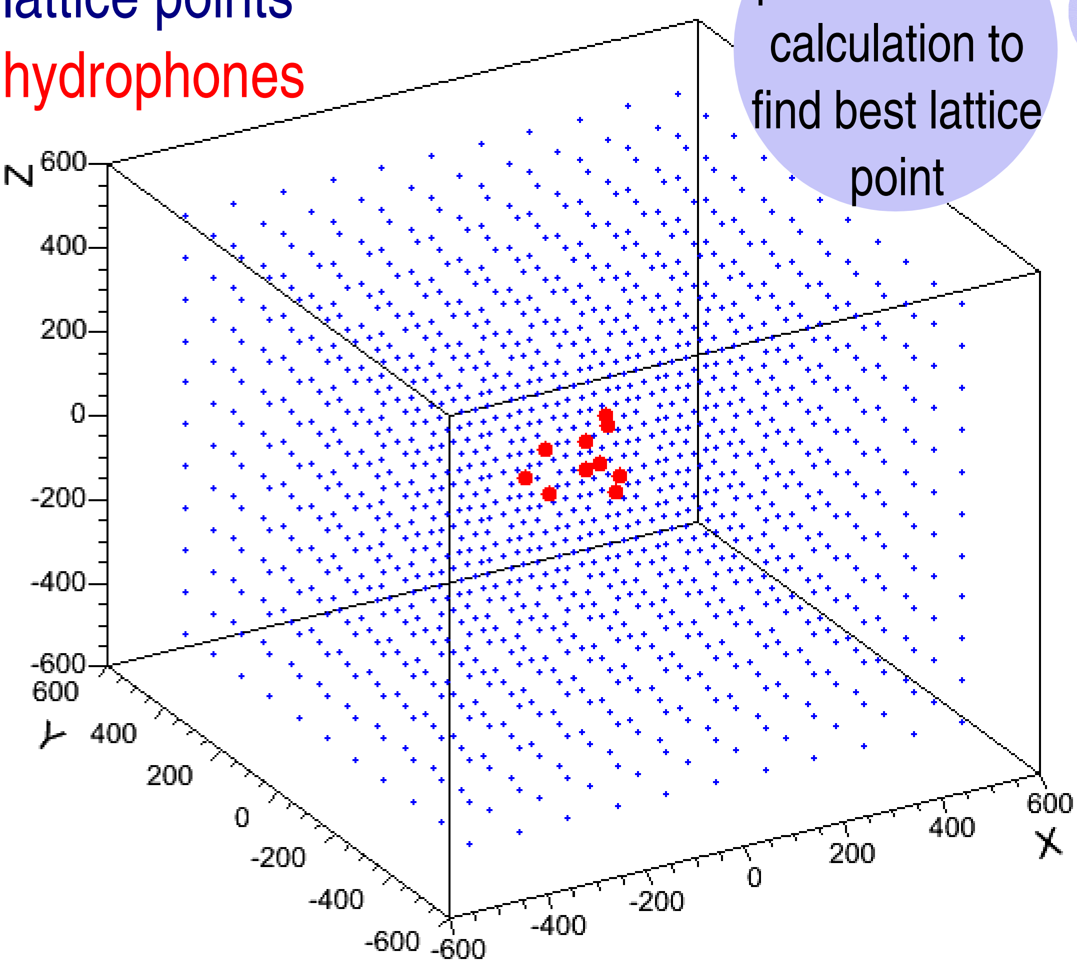
vertex reconstruction from hit times

start with look-up table of signal arrival times

– linear reconstruction algorithms do not work in the presence of refraction!

lattice points

hydrophones



perform vector calculation to find best lattice point

$$\mathbf{v}_a = (t_1^{\,a}, t_2^{\,a}, t_3^{\,a}, \ldots t_{NHydrophones}^{\,a})$$

$$(t_1^{\,b}, t_2^{\,b}, t_3^{\,b}, \ldots t_{NHydrophones}^{\,b}) = \mathbf{v}_b$$

recorded hit times

hit times from lattice point

best lattice point:

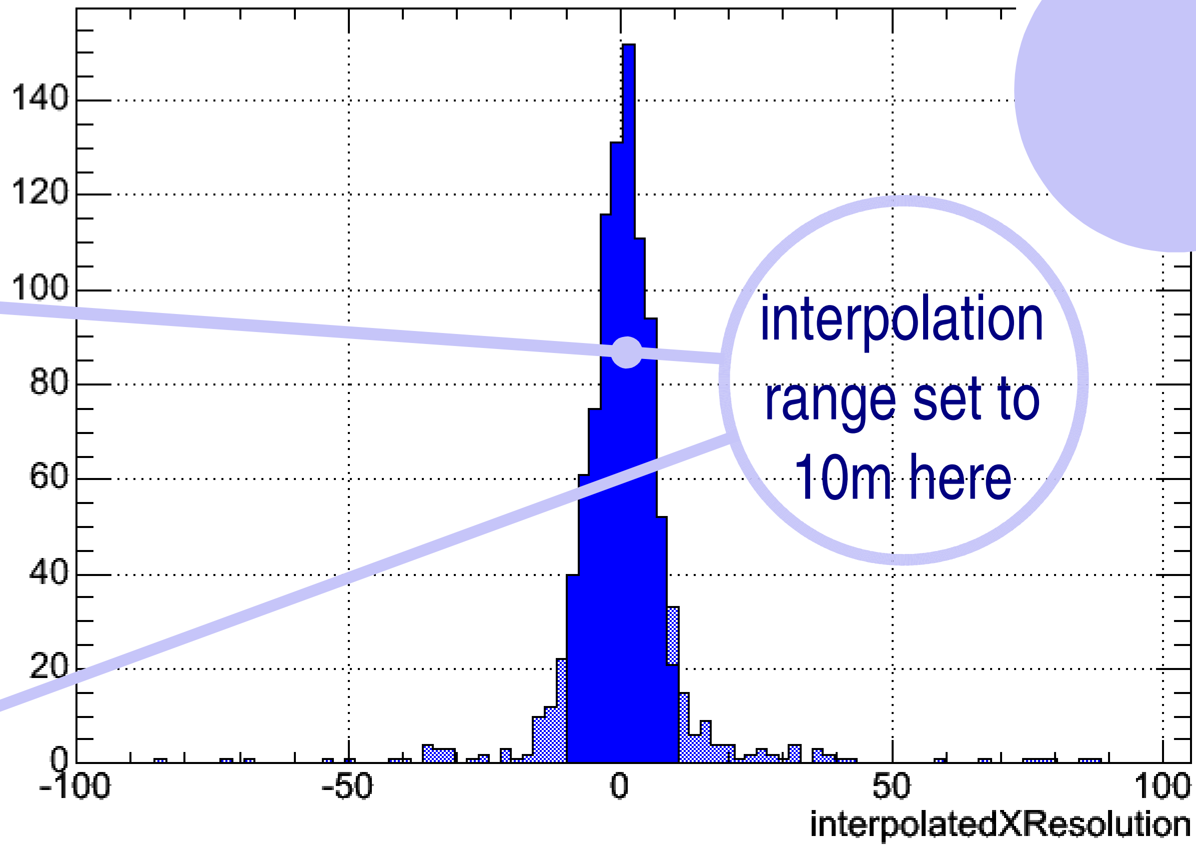
$$|\,\mathbf{v}_a - \mathbf{v}_b\,| \rightarrow 0$$

next, interpolate over a given step size to find the vertex

vertex reconstruction from hit times

finding the vertex II

interpolation of refracted hit times - 85% reconstruction in range (95% within 2x range)



interpolation range set to 10m here

interpolation range is set by user, need to optimise lattice spacing v.s. number of interpolations...

array sensitivity
neutrino flux limits

$1 km^3$, 0.035Pa, 1yr running

$10 km^3$, 0.05Pa, 5yr running

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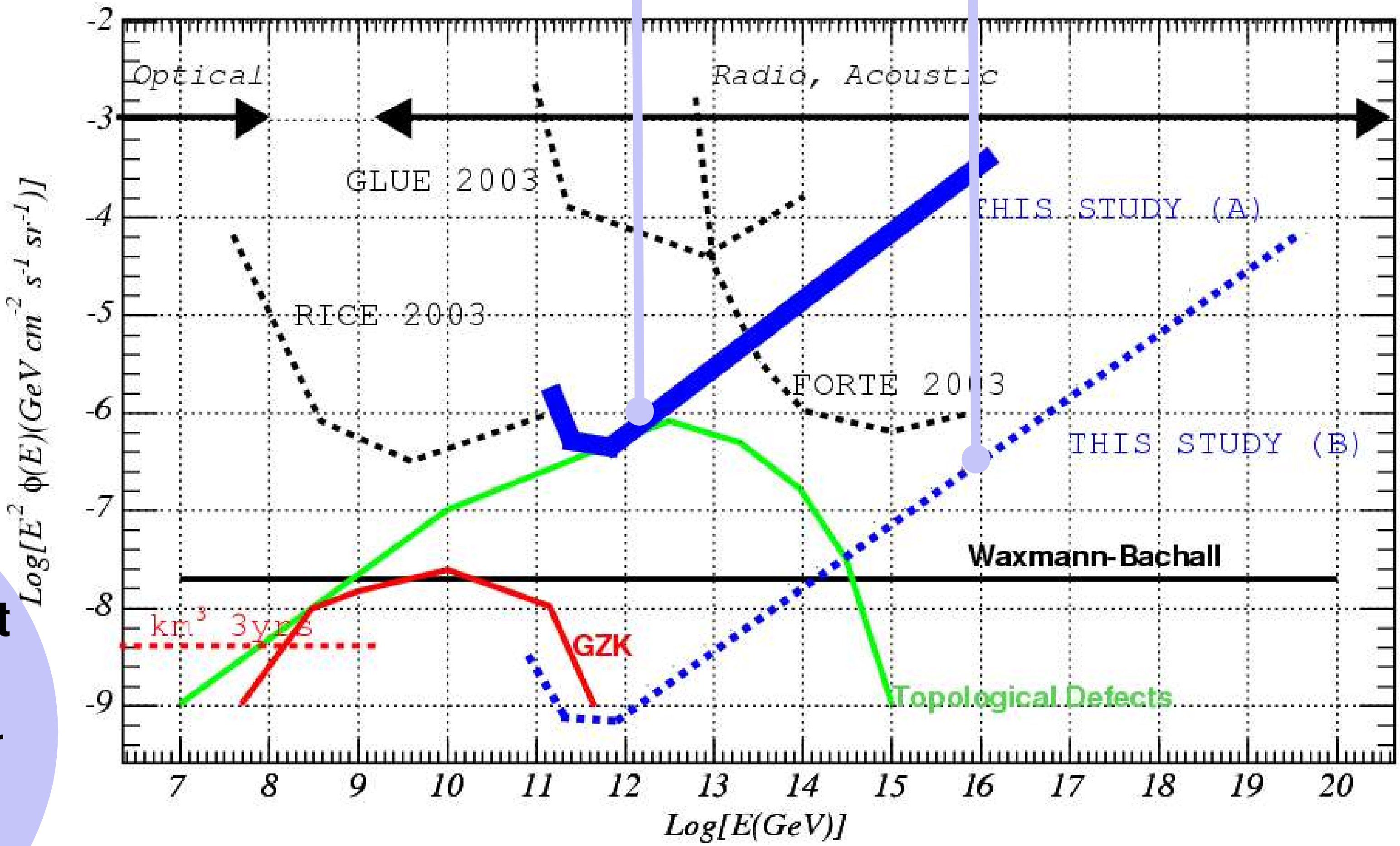
log differential flux: per second, per steradian, per $cm^2 \times E^2$

interpret this as a **limit on the neutrino flux based on** your detector **seeing no events** in a given period



thanks for listening

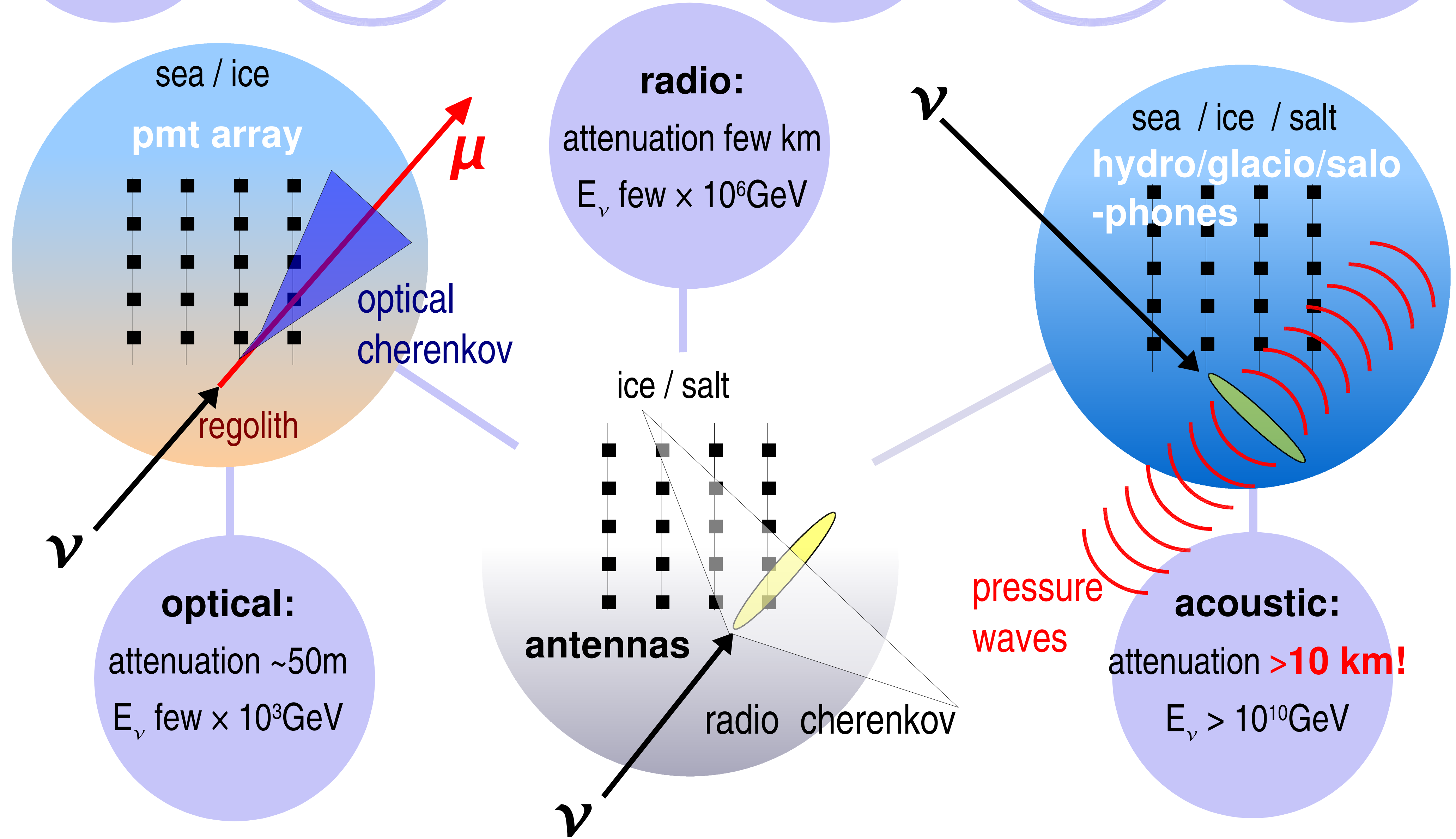
ACoRNE

from tiny acorns...

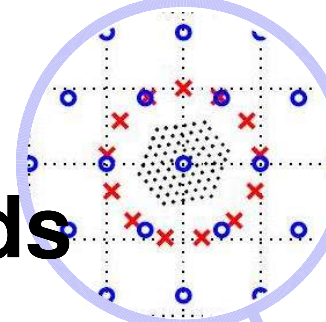
backup slides

backup slides

how to detect high energy neutrinos



the future...
combine all 3 detection methods



~1000 km^3
radio / acoustic instrumentation

~1 km^3
optical instrumentation

IceCube Plus
KM3NeT