Title: Particle/Astro Observations 4

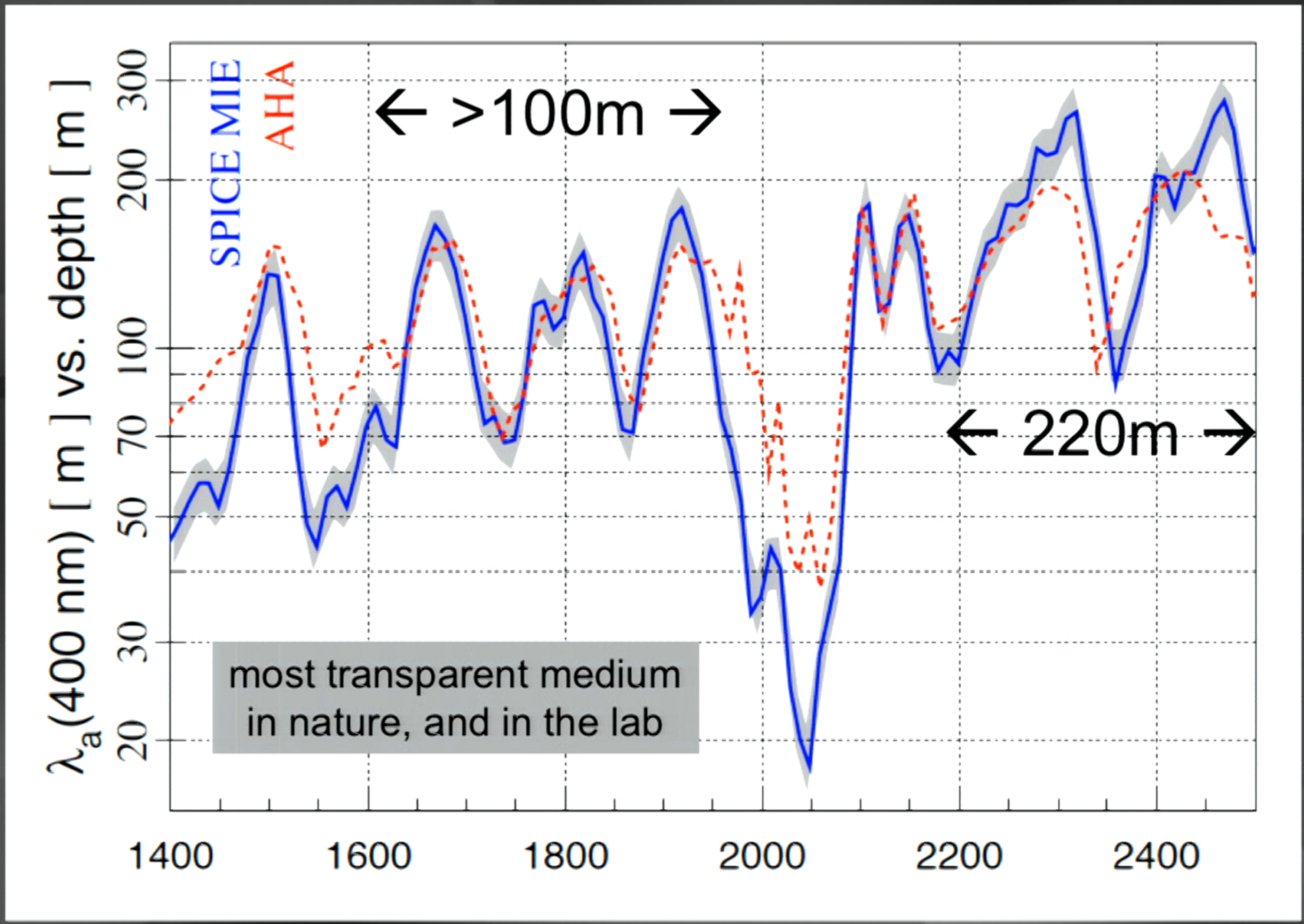
Date: Jul 10, 2018 04:30 PM

URL: http://pirsa.org/18070024

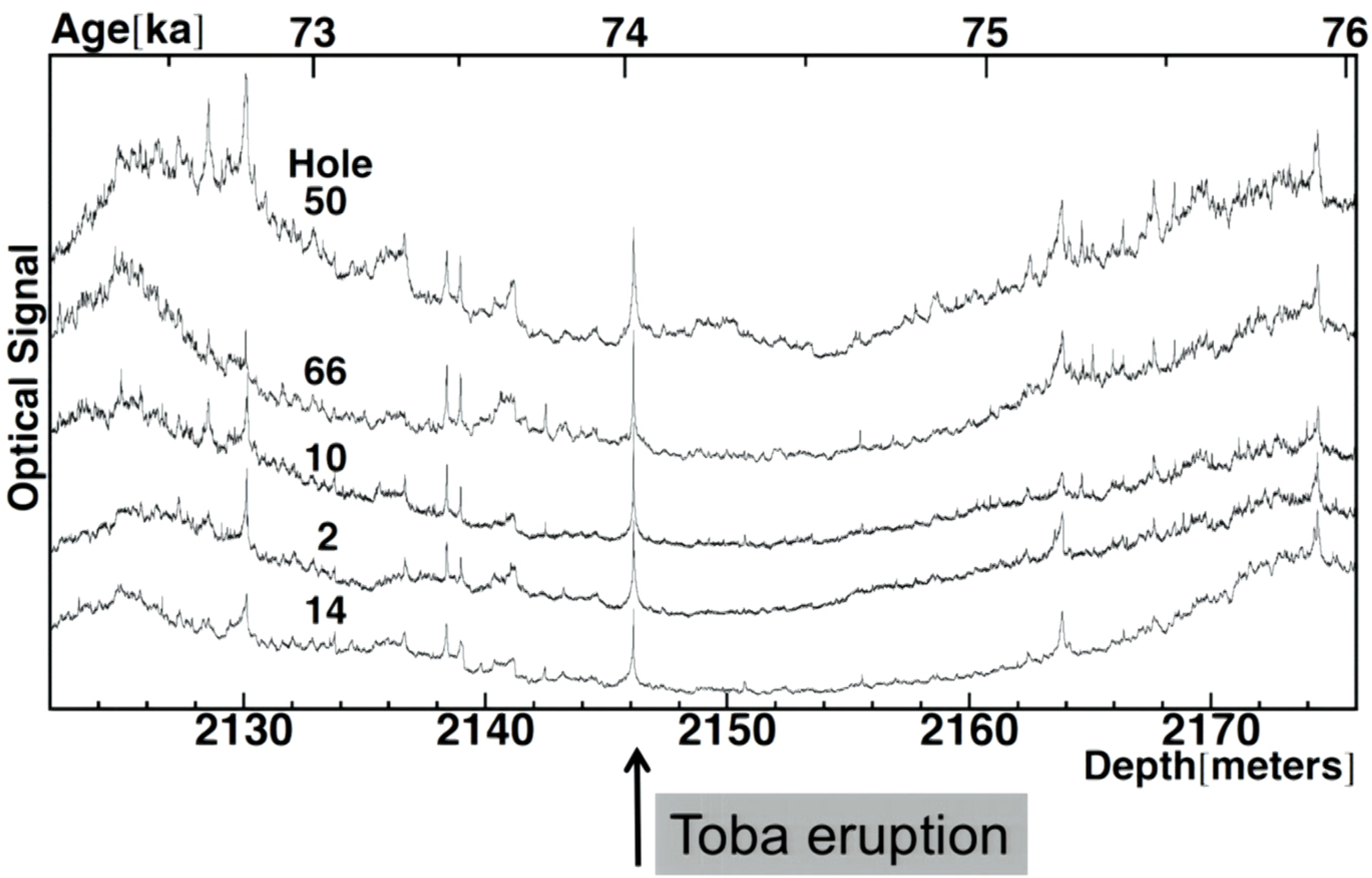
Abstract:

- a next-generation IceCube with a volume of 10 km^3 and an angular resolution of ~ 0.1 degree will see multiple neutrinos from single sources and identify the sources
- need 1,000 events versus 100 now in a few years
- discovery instrument → astronomical telescope

absorption length of Cherenkov light

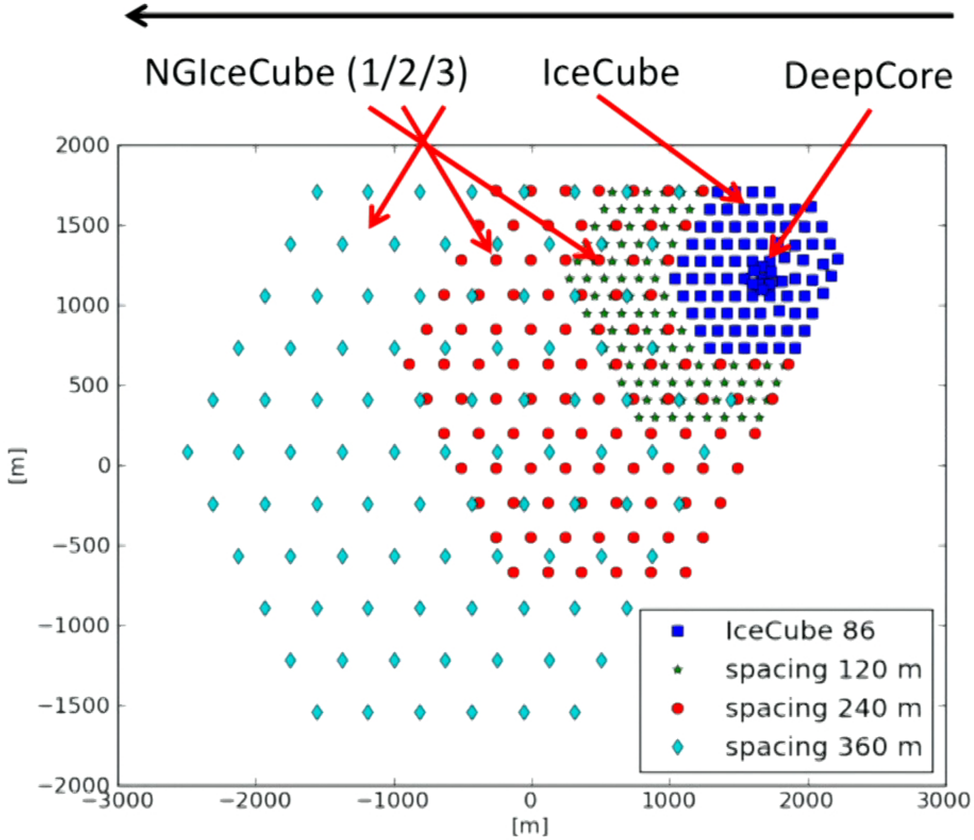


we are limited by computing, not the optics of the ice



measured optical properties → twice the string spacing

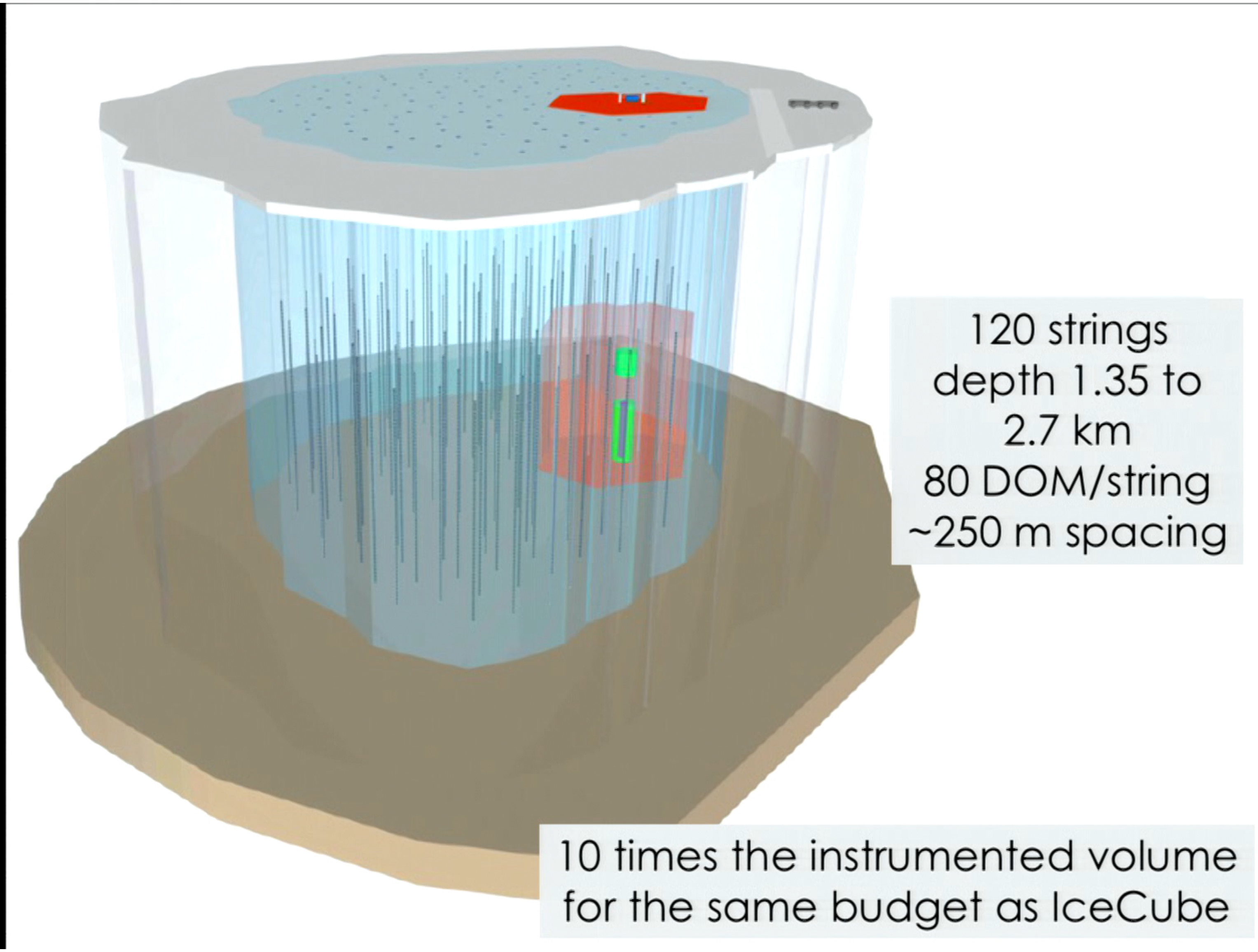
(increase in threshold not important: only eliminates energies where the atmospheric background dominates)

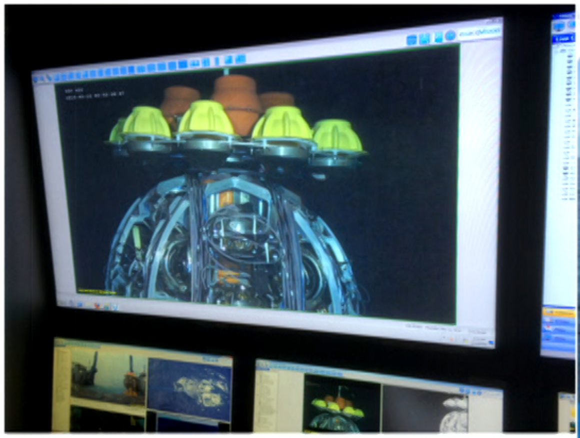


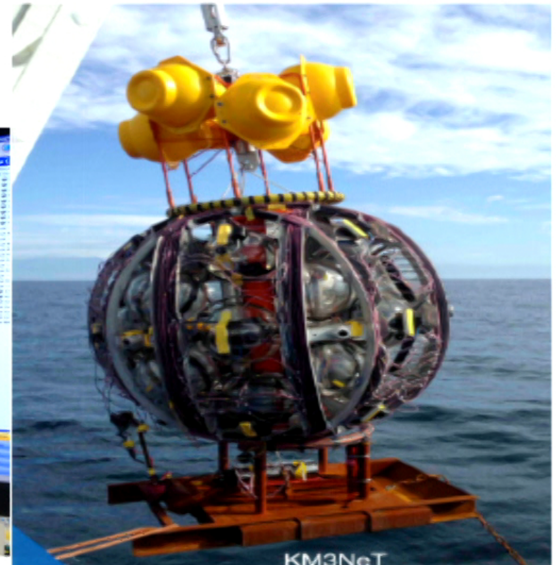
Spacing 1 (120m):
IceCube (1 km^3)
+ 98 strings (1,3 km^3)
= 2,3 km^3

Spacing 2 (240m):
IceCube (1 km^3)
+ 99 strings (5,3 km^3)
= 6,3 km^3

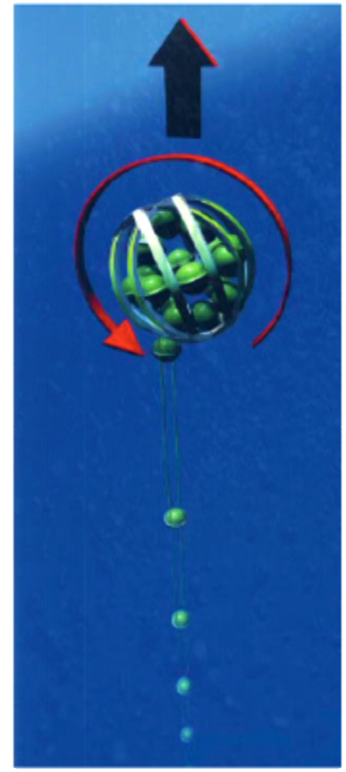
Spacing 3 (360m):
IceCube (1 km^3)
+ 95 strings (11,6 km^3)
= 12,6 km^3


120 strings
depth 1.35 to
2.7 km
80 DOM/string
~250 m spacing
10 times the instrumented volume
for the same budget as IceCube



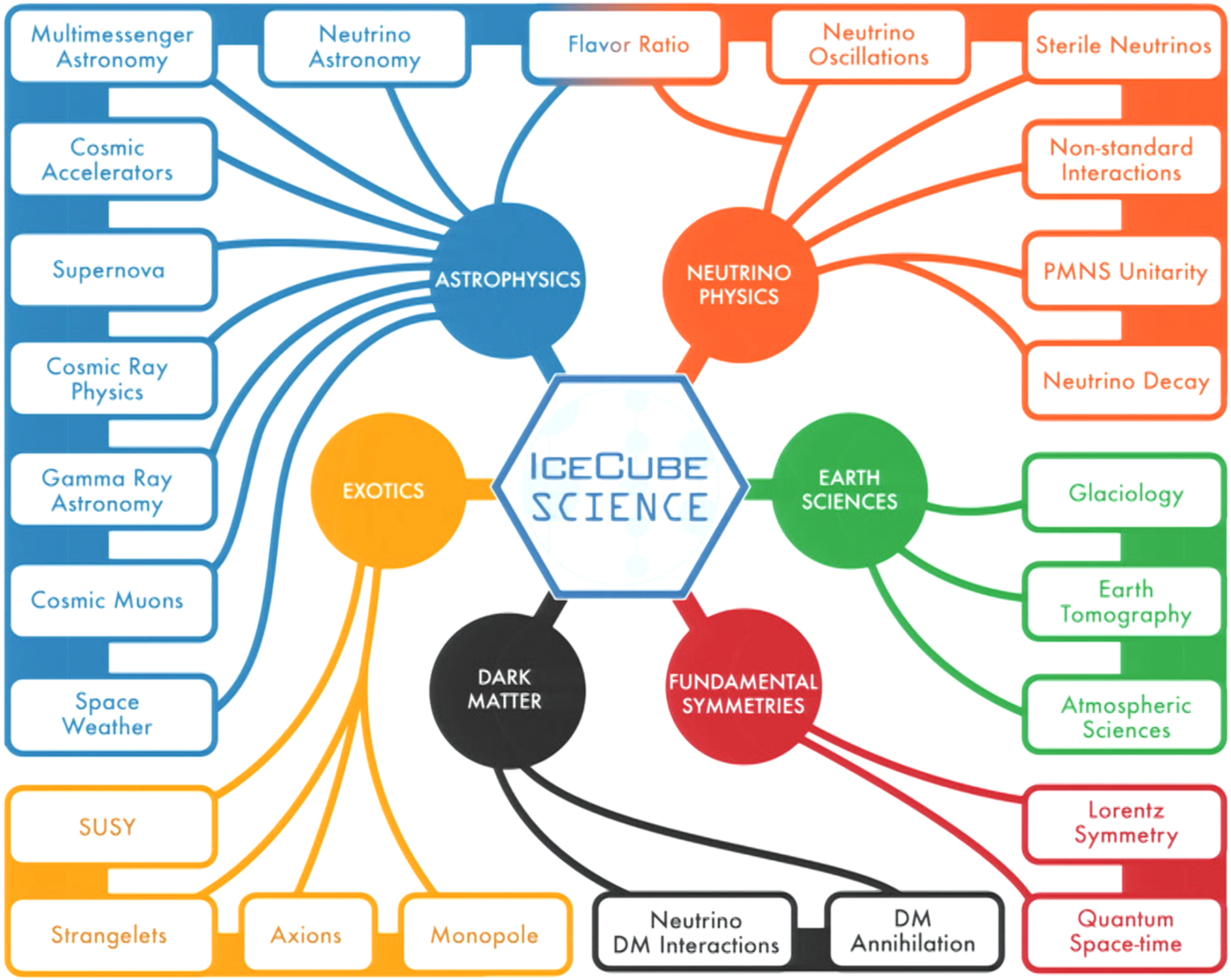


rapid deployment
autonomous unfurling
recoverable



KM3NeT LoI http://arxiv.org/pdf/1601.07459v2.pdf

99

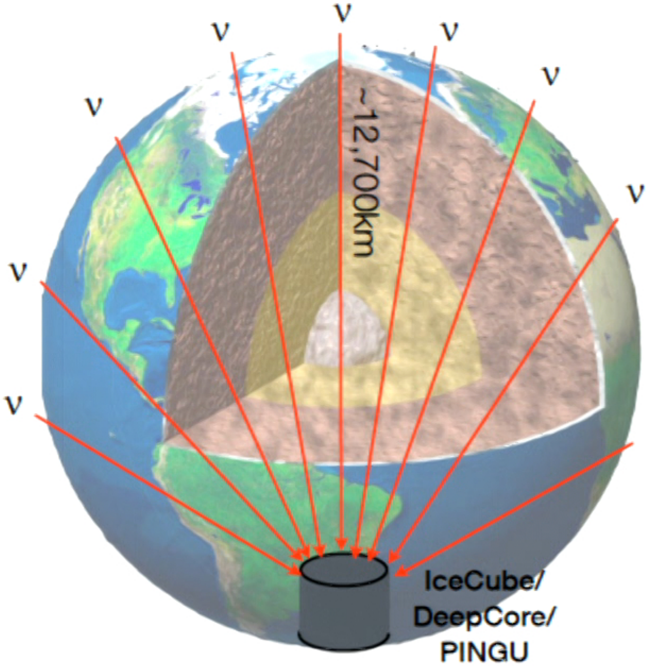


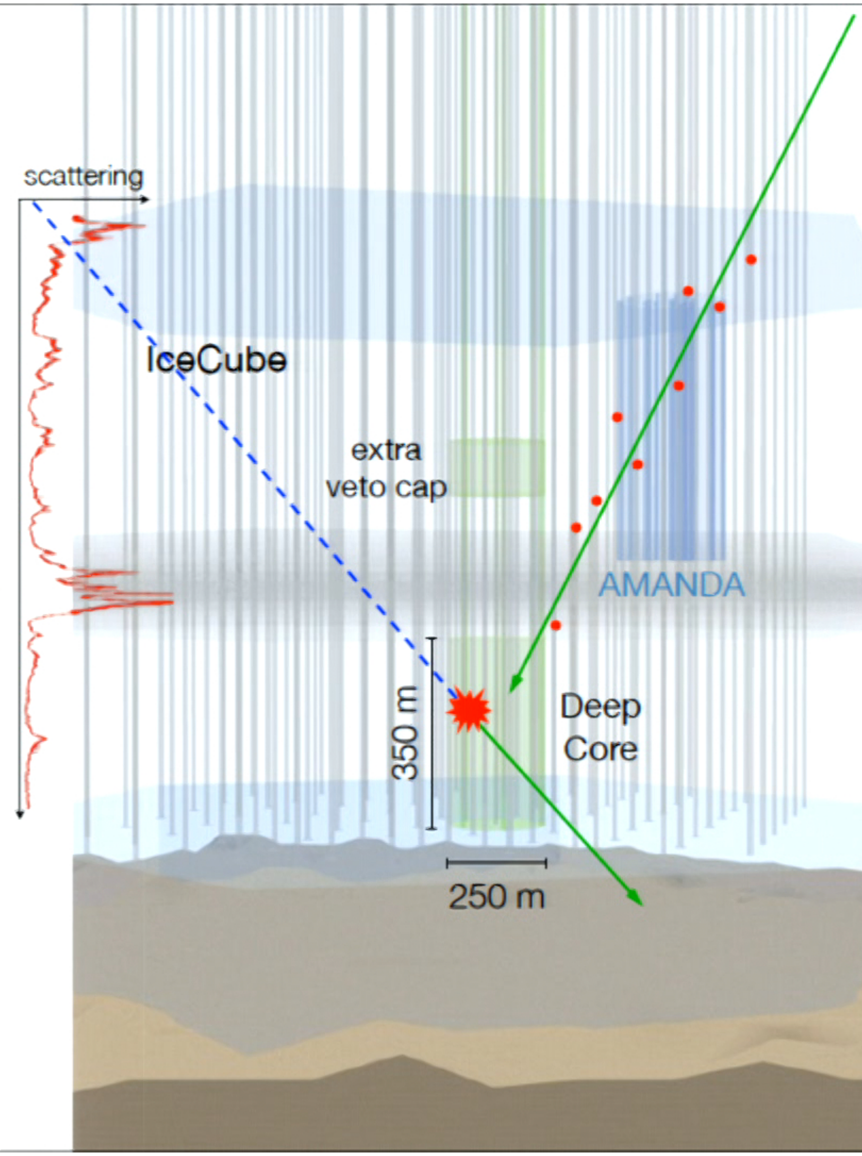
ICECUBE SCIENCE
ASTROPHYSICS
Multimessenger Astronomy
Neutrino Astronomy
Cosmic Accelerators
Supernova
Cosmic Ray Physics
Gamma Ray Astronomy
Cosmic Muons
Space Weather
Flavor Ratio
NEUTRINO PHYSICS
Neutrino Oscillations
Sterile Neutrinos
Non-standard Interactions
PMNS Unitarity
Neutrino Decay
EXOTICS
SUSY
Strangelets
Axions
Monopole
EARTH SCIENCES
Glaciology
Earth Tomography
Atmospheric Sciences
DARK MATTER
Neutrino DM Interactions
DM Annihilation
FUNDAMENTAL SYMMETRIES
Lorentz Symmetry
Quantum Space-time

did not talk about:

- measurement of atmospheric oscillation parameters
- supernova detection
- searches for dark matter, monopoles,…
- search for eV-mass sterile neutrinos
- cosmic ray physics, muon maps,…
- PINGU/ORCA
- ….

one half million atmospheric neutrinos…

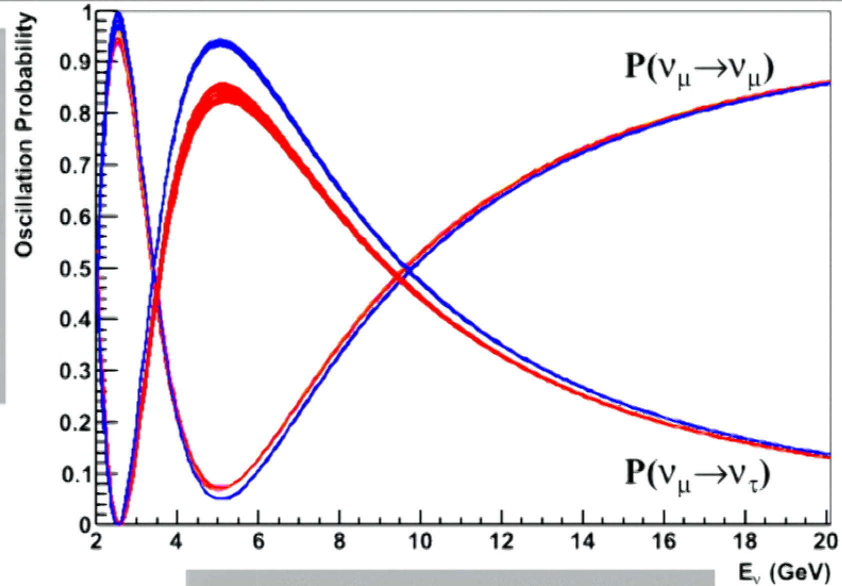




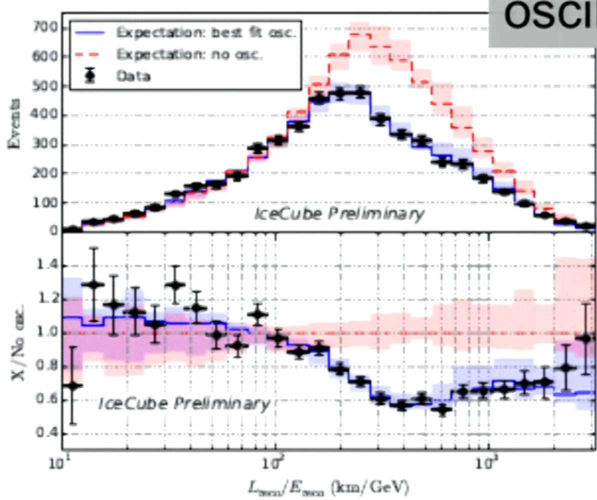
IceCube

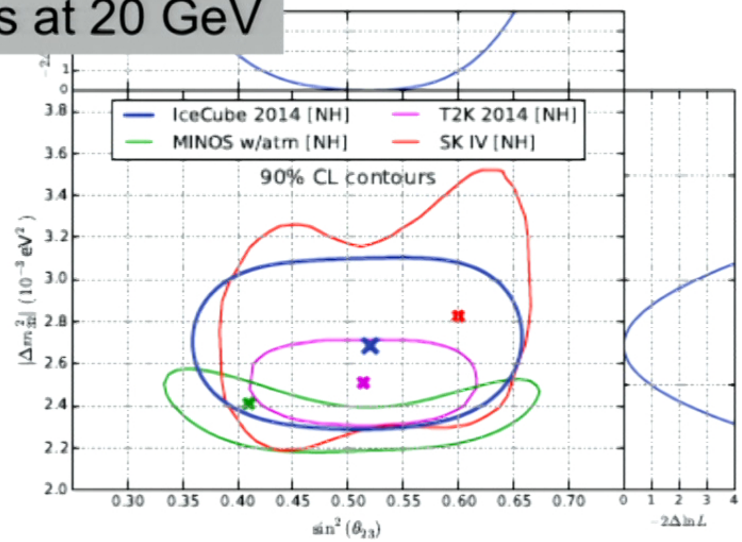
DeepCore

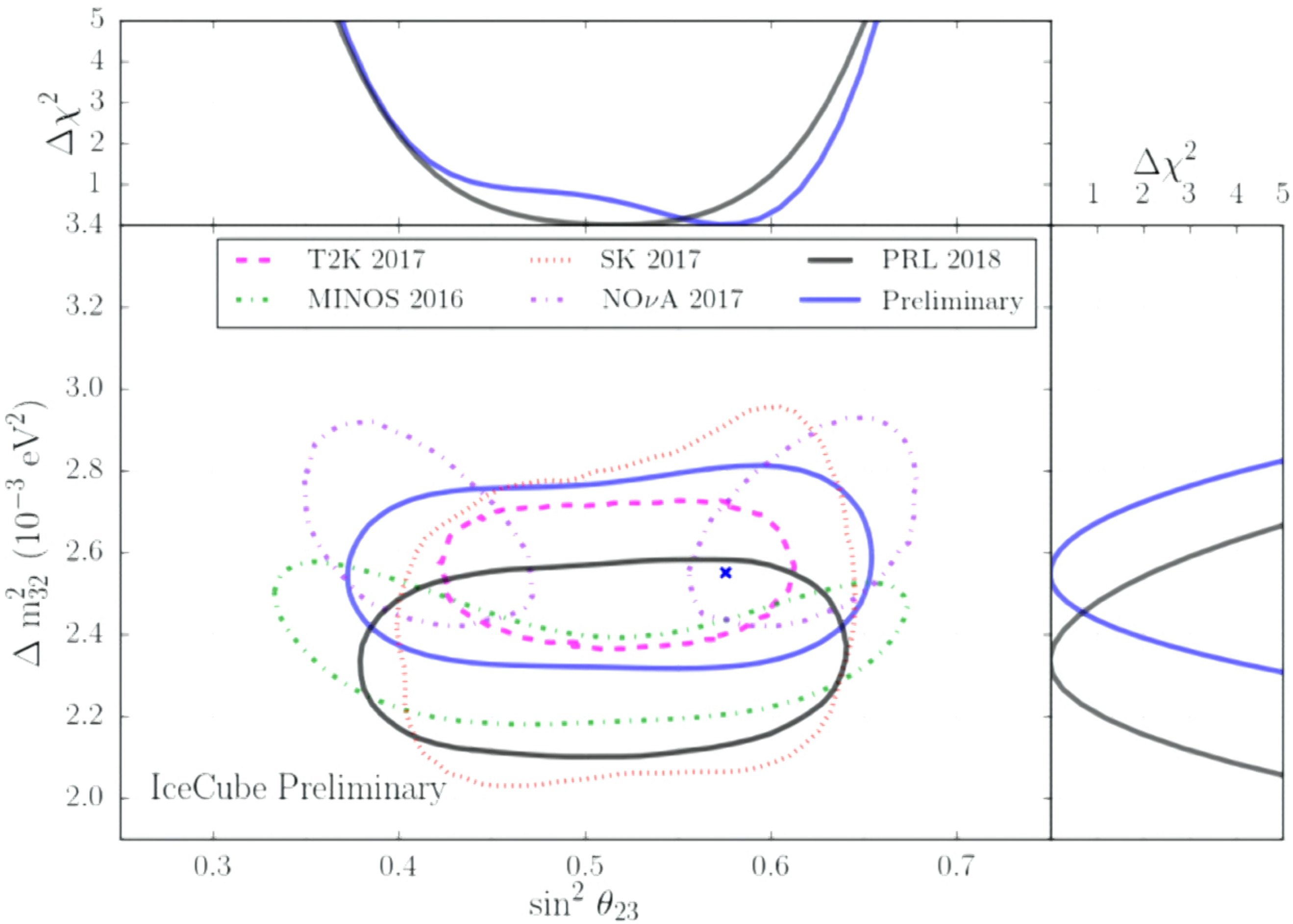
PINGU



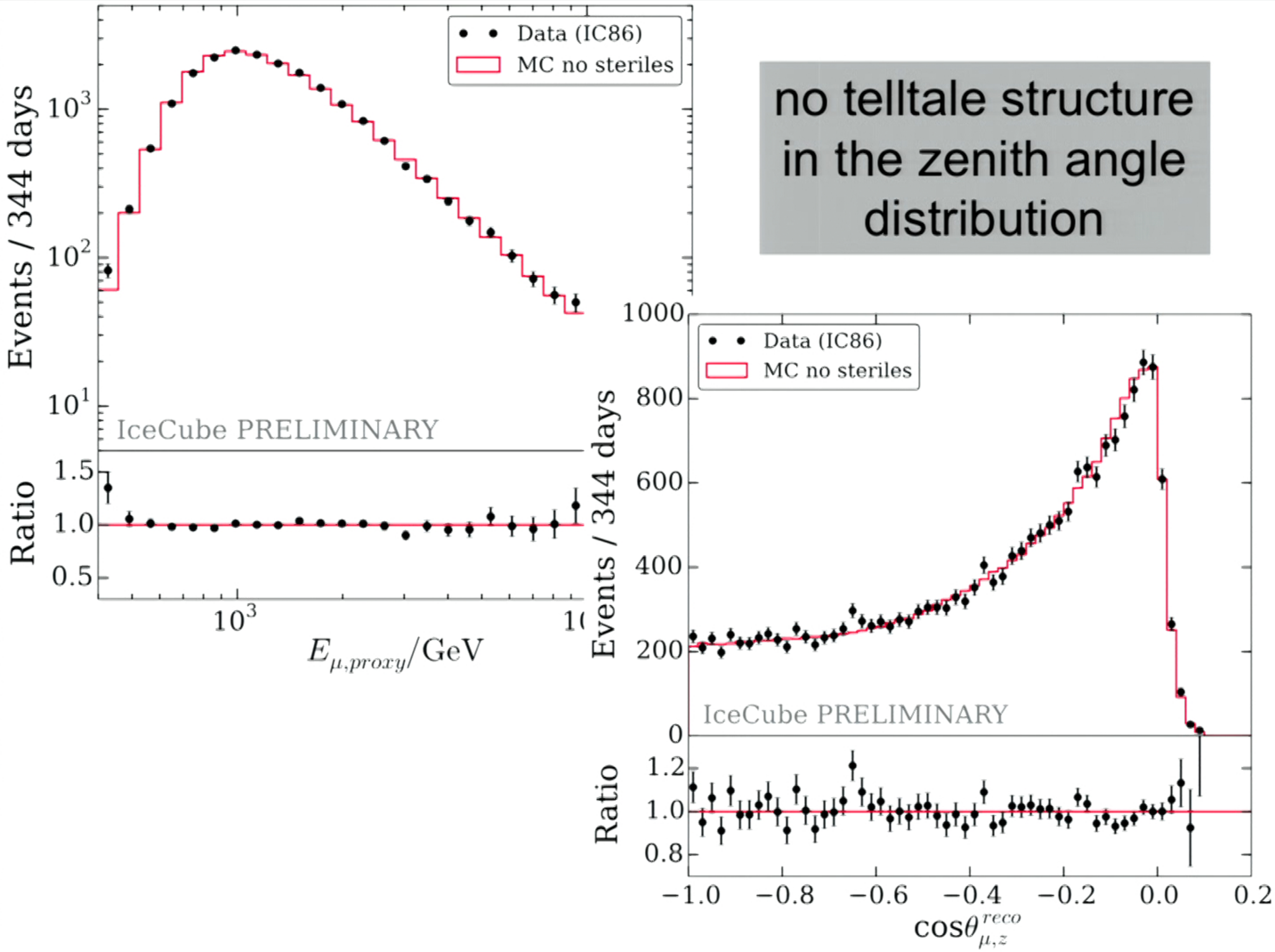
oscillations at 20 GeV



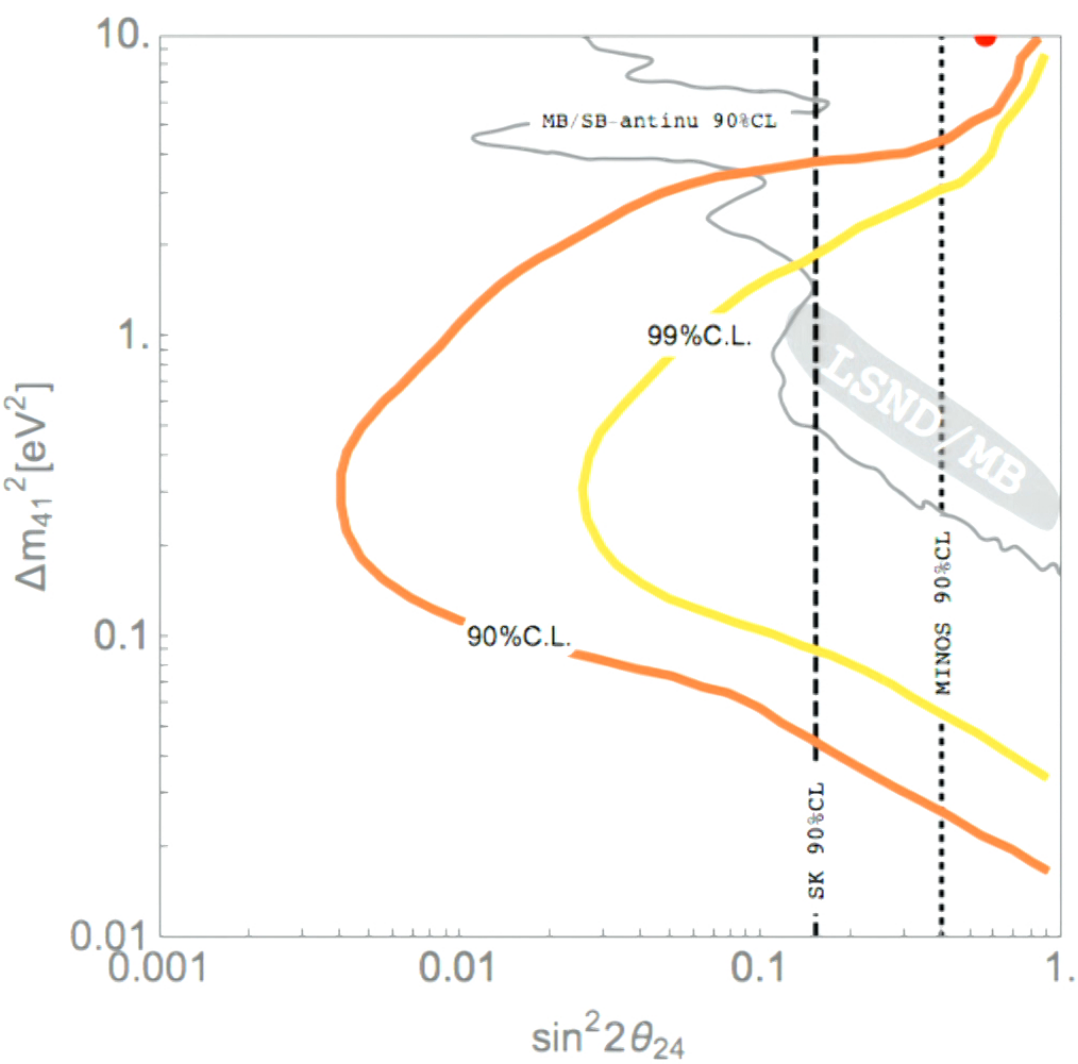


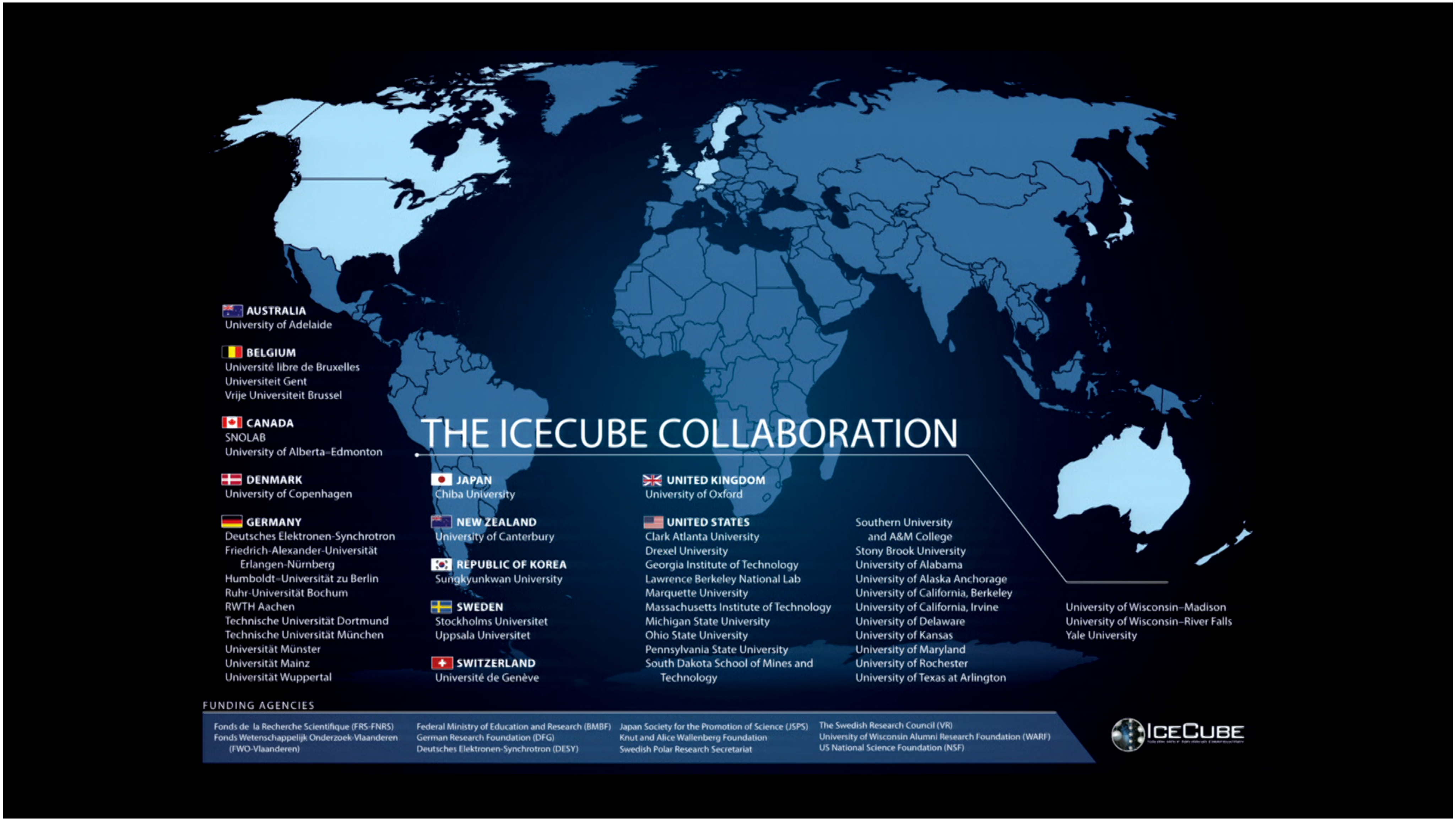


T2K 2017
SK 2017
PRL 2018
MINOS 2016
NOνA 2017
Preliminary
IceCube Preliminary
Δχ²
Δ m²₃₂ (10⁻³ eV²)
sin² θ₂₃



no telltale structure in the zenith angle distribution


10.
1.
0.1
0.01
0.001
0.01
0.1
1.
$\Delta m_{41}{}^2[eV^2]$
$\sin^2 2\theta_{24}$
MB/SB-antinu 90%CL
99%C.L.
90%C.L.
LSND/MB
SK 90%CL
MINOS 90%CL


THE ICECUBE COLLABORATION
AUSTRALIA
University of Adelaide
BELGIUM
Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit Brussel
CANADA
SNOLAB
University of Alberta–Edmonton
DENMARK
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University of Kansas
University of Maryland
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Yale University
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The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)
ICECUBE

- Galactic sources?

- most significant source in pre-defined list (p-value 0.003 pretrial)
- joined HAWC-IceCube analysis in progress using photon templates

Table 1: Results of the pre-defined source list.

Source	Type	α [deg]	δ [deg]	p-Value	TS	n_s	Φ_0 [$\mathrm{TeV\,cm^{-2}\,s^{-1}}$]
PKS 0235+164	BL Lac	39.66	16.62	0.7355	-0.400	0.00	$2.04\cdot10^{-13}$
1ES 0229+200	BL Lac	38.20	20.29	0.4762	-0.059	0.00	$4.47\cdot10^{-13}$
W Comae	BL Lac	185.38	28.23	0.4420	-0.055	0.00	$5.37\cdot10^{-13}$
Mrk 421	BL Lac	166.11	38.21	0.2433	0.029	0.48	$8.68\cdot10^{-13}$
Mrk 501	BL Lac	253.47	39.76	0.6847	-0.172	0.00	$3.51\cdot10^{-13}$
BL Lac	BL Lac	330.68	42.28	0.5104	-0.028	0.00	$5.58\cdot10^{-13}$
H 1426+428	BL Lac	217.14	42.67	0.7890	-0.243	0.00	$1.96\cdot10^{-13}$
3C66A	BL Lac	35.67	43.04	0.3306	-0.001	0.00	$7.50\cdot10^{-13}$
1ES 2344+514	BL Lac	356.77	51.70	0.9264	-0.808	0.00	$1.58\cdot10^{-13}$
1ES 1959+650	BL Lac	300.00	65.15	0.2069	0.124	1.69	$1.17\cdot10^{-12}$
S5 0716+71	BL Lac	110.47	71.34	0.7230	-0.380	0.00	$3.84\cdot10^{-13}$
3C 273	FSRQ	187.28	2.05	0.3807	-0.014	0.00	$4.42\cdot10^{-13}$
PKS 1502+106	FSRQ	226.10	10.52	0.2322	-0.000	0.00	$5.98\cdot10^{-13}$
PKS 0528+134	FSRQ	82.73	13.53	0.2870	-0.002	0.00	$5.74\cdot10^{-13}$
3C454.3	FSRQ	343.50	16.1[illegible]	0.0072	[illegible].503	5.98	$1.26\cdot10^{-12}$
4C 38.41	FSRQ	248.81	38.[illegible]	0.0055	5.[illegible]86	6.62	$1.72\cdot10^{-12}$
MGRO J1908+06	**NI**	**286.99**	**6.2[illegible]**	**0.0032**	**6.[illegible]84**	**3.28**	$\mathbf{1.13\cdot10^{-12}}$
Geminga	PWN	98.48	17.7[illegible]	0.9754	-[illegible].424	0.00	$1.16\cdot10^{-13}$
Crab Nebula	PWN	83.63	22.01	0.1188	[illegible].709	4.32	$8.65\cdot10^{-13}$
MGRO J2019+37	PWN	305.22	36.83	[illegible]	-3.191	0.00	$1.39\cdot10^{-13}$
Cyg OB2	SFR	308.09	41.23	0.3174	-0.002	0.00	$7.53\cdot10^{-13}$
IC443	SNR	94.18	22.53	0.8153	-0.457	0.00	$1.22\cdot10^{-13}$
Cas A	SNR	350.85	58.81	0.2069	0.033	0.88	$1.05\cdot10^{-12}$
TYCHO	SNR	6.36	64.18	0.4471	-0.019	0.00	$8.14\cdot10^{-13}$
M87	SRG	187.71	12.39	0.6711	-0.256	0.00	$2.85\cdot10^{-13}$
3C 123.0	SRG	69.27	29.67	0.9055	-0.747	0.00	$1.30\cdot10^{-13}$
Cyg A	SRG	299.87	40.73	0.0049	6.335	4.30	$1.78\cdot10^{-12}$
NGC 1275	SRG	49.95	41.51	0.2582	0.007	0.25	$8.31\cdot10^{-13}$
M82	SRG	148.97	69.68	0.8887	-0.888	0.00	$1.83\cdot10^{-13}$
SS433	XB/mqso	287.96	4.98	0.8738	-1.085	0.00	$1.01\cdot10^{-13}$
HESS J0632+057	XB/mqso	98.24	5.81	0.8359	-0.917	0.00	$1.01\cdot10^{-13}$
Cyg X-1	XB/mqso	299.59	35.20	0.5422	-0.106	0.00	$4.93\cdot10^{-13}$
Cyg X-3	XB/mqso	308.11	40.96	0.3230	-0.003	0.00	$7.28\cdot10^{-13}$
LSI 303	XB/mqso	40.13	61.23	0.2843	0.001	0.17	$1.01\cdot10^{-12}$

Catalog based on the standard IceCube and ANTARES source list.

The source list has been unchanged for years now.

Here we consider the 34 sources on Northern hemisphere.

For each source the best fit ns, TS, local p-value and the 90% upper flux limit is shown.

The SI is not shown as it is effectively fixed to be about 2.13.

MGRO J1908+06 is source with smallest local p-value

- most significant source in pre-defined list (p-value 0.003 pretrial)
- joined HAWC-IceCube analysis in progress using photon templates

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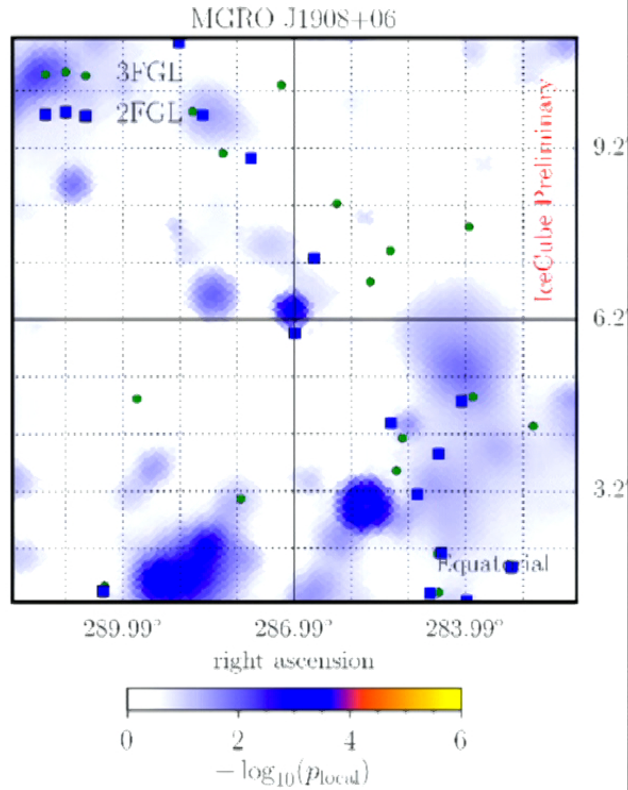
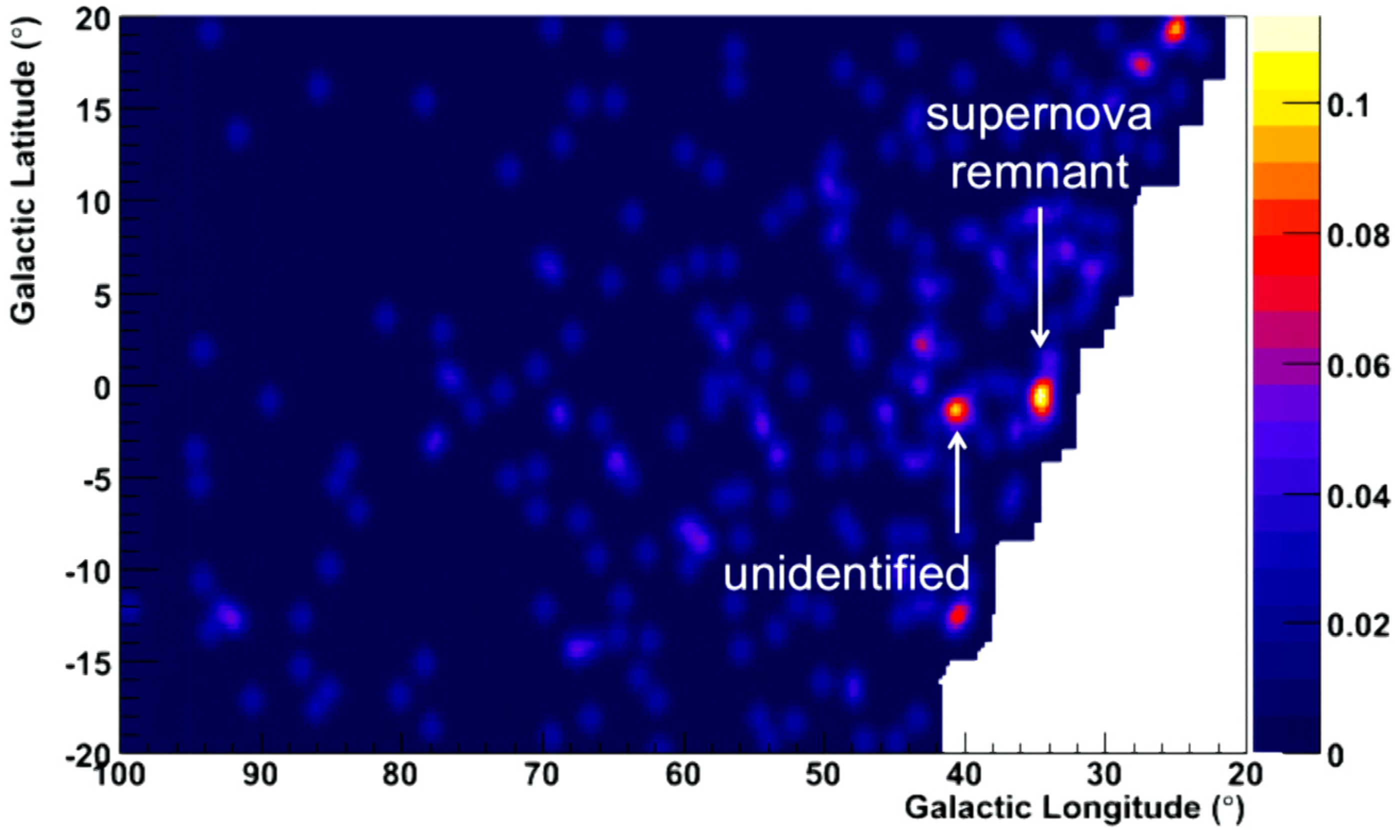
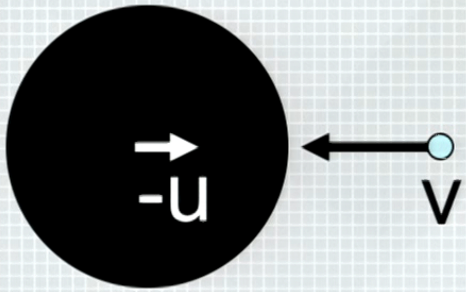


2007 simulated sky map of IceCube in Galactic coordinates after five years of operation of the completed detector. Two Milagro sources are visible with four events for MGRO J1852+01 and three events for MGRO J1908+06 with energy in excess of 40 TeV.



non-relativistic shock



before *our frame* $E_i = \frac{1}{2}mv^2$

before *cloud frame* $E_i^c = \frac{1}{2}m(v+u)^2$

after *cloud frame* $E_f^c = \frac{1}{2}m(-v-u)^2$

after *our frame* $E_f = \frac{1}{2}m(-v-2u)^2$

$$\frac{E_f - E_i}{E_i} = \frac{\frac{1}{2}m(-v-2u)^2 - \frac{1}{2}mv^2}{\frac{1}{2}mv^2}$$

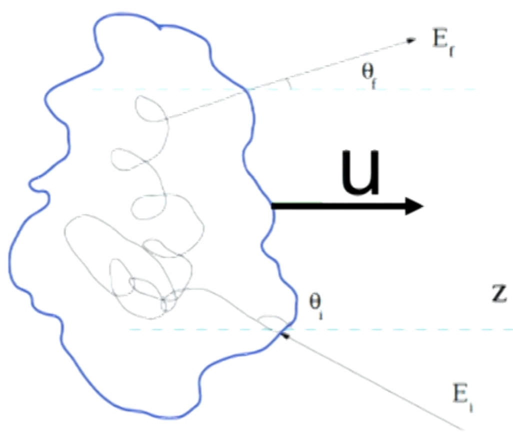
$$= \frac{4uv + 4u^2}{v^2} \approx 4\left(\frac{u}{c} + \frac{u^2}{c^2}\right)$$

before *our frame* E_i, p_i

before *cloud frame* $E_i^c = \gamma\left(E_i + c\beta p_i\right)$ *and* $p_i^c = \gamma\left(p_i + \beta\dfrac{E_i}{c}\right)$

after *cloud frame* $E_f^c = E_i^c$ *and* $p_f^c = -p_i^c$

after *our frame* $E_f = \gamma\left(E_f^c - c\beta p_f^c\right) = \gamma\left(E_i^c + c\beta p_i^c\right)$



$$\text{with } E_i \approx cp_i$$

$$E_f \approx E_i\gamma^2(1+\beta)^2$$

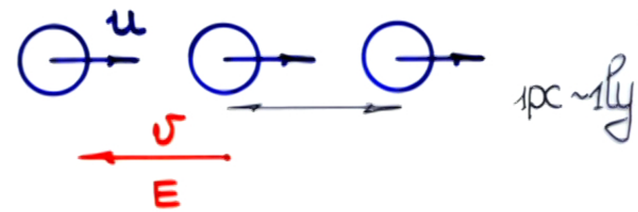
$$\text{with}\,\gamma^2 \approx 1 + \beta^2 + \ldots$$

$$E_f \approx E_i\left(1 + 2\beta + 2\beta^2 + \ldots\right)$$

$$\frac{E_f - E_i}{E_i} \approx 2\left(\beta + \beta^2\right)$$

acceleration time too long

FERMI 49 : particle collides with stellar clouds



$$\frac{\Delta E}{E} \sim \frac{u}{v}\left(\frac{u}{c}+\frac{v}{c}\right) \qquad u \ll v \simeq c$$

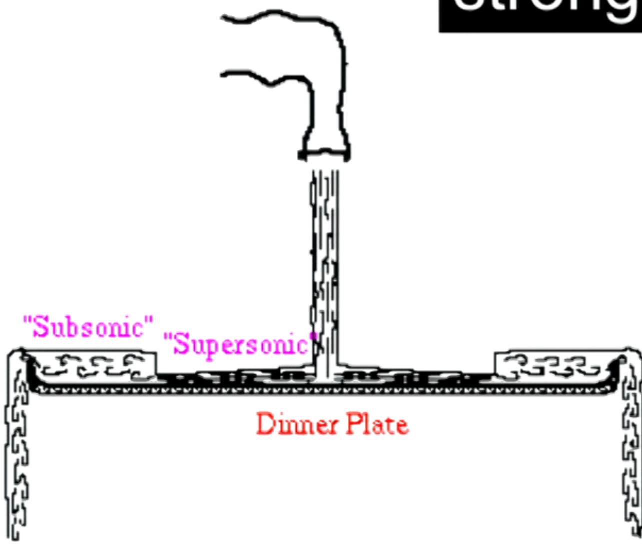
$$\boxed{\frac{\Delta E}{E} \sim \frac{u}{c} + \left(\frac{u}{c}\right)^2}$$

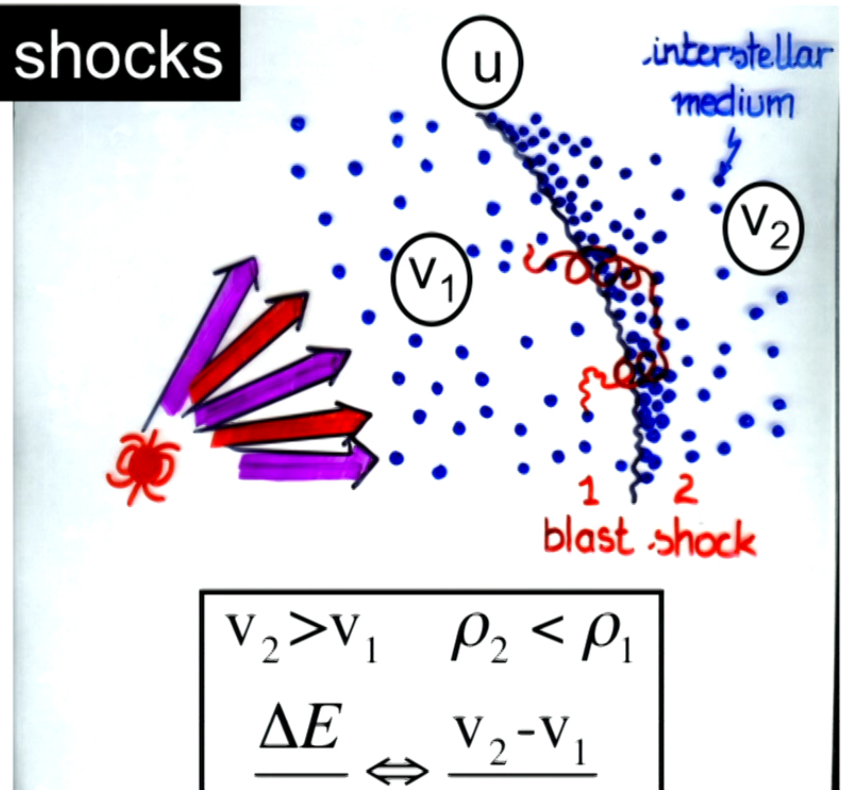
- some clouds ($\frac{v-u}{v+u}$ fraction, Doppler) come from the wrong direction

$$\frac{\Delta E}{E} \sim \frac{u}{v}\underbrace{\left(\frac{u}{c}+\frac{v}{c}\right)}_{\longrightarrow}\left(\frac{u+v}{v}\right) - \frac{u}{v}\underbrace{\left(-\frac{u}{c}+\frac{v}{c}\right)}_{\longleftarrow}\left(\frac{v-u}{v}\right)$$

- u/c term cancels

strong shocks





$$\boxed{\begin{array}{cc} v_2 > v_1 & \rho_2 < \rho_1 \\ \dfrac{\Delta E}{E} \Leftrightarrow \dfrac{v_2 - v_1}{v_2} & \end{array}}$$

shockspeed u > v_{sound}

definition:

- v_2 upstream
- v_1 downstream

mass conservation in shock frame :

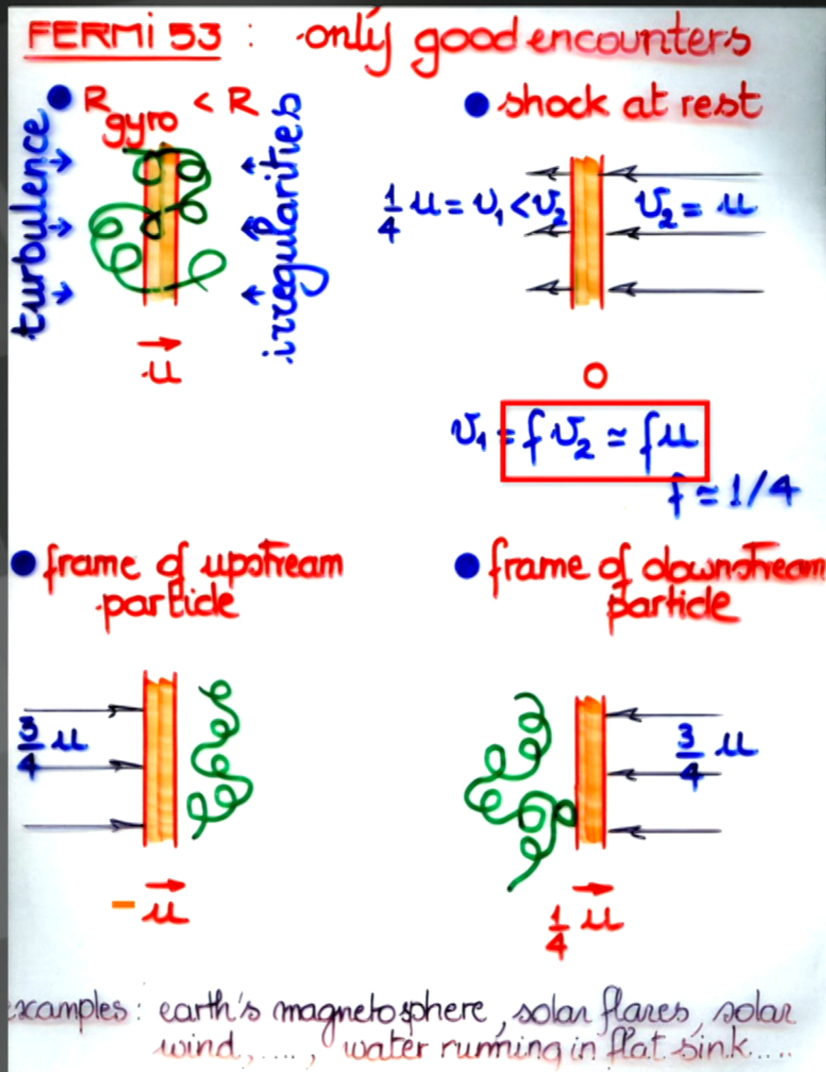
$$\rho_1 v_1 = \rho_2 v_2 \quad \Rightarrow \quad \frac{v_1}{v_2} = \frac{\rho_2}{\rho_1} = \frac{1}{4}$$

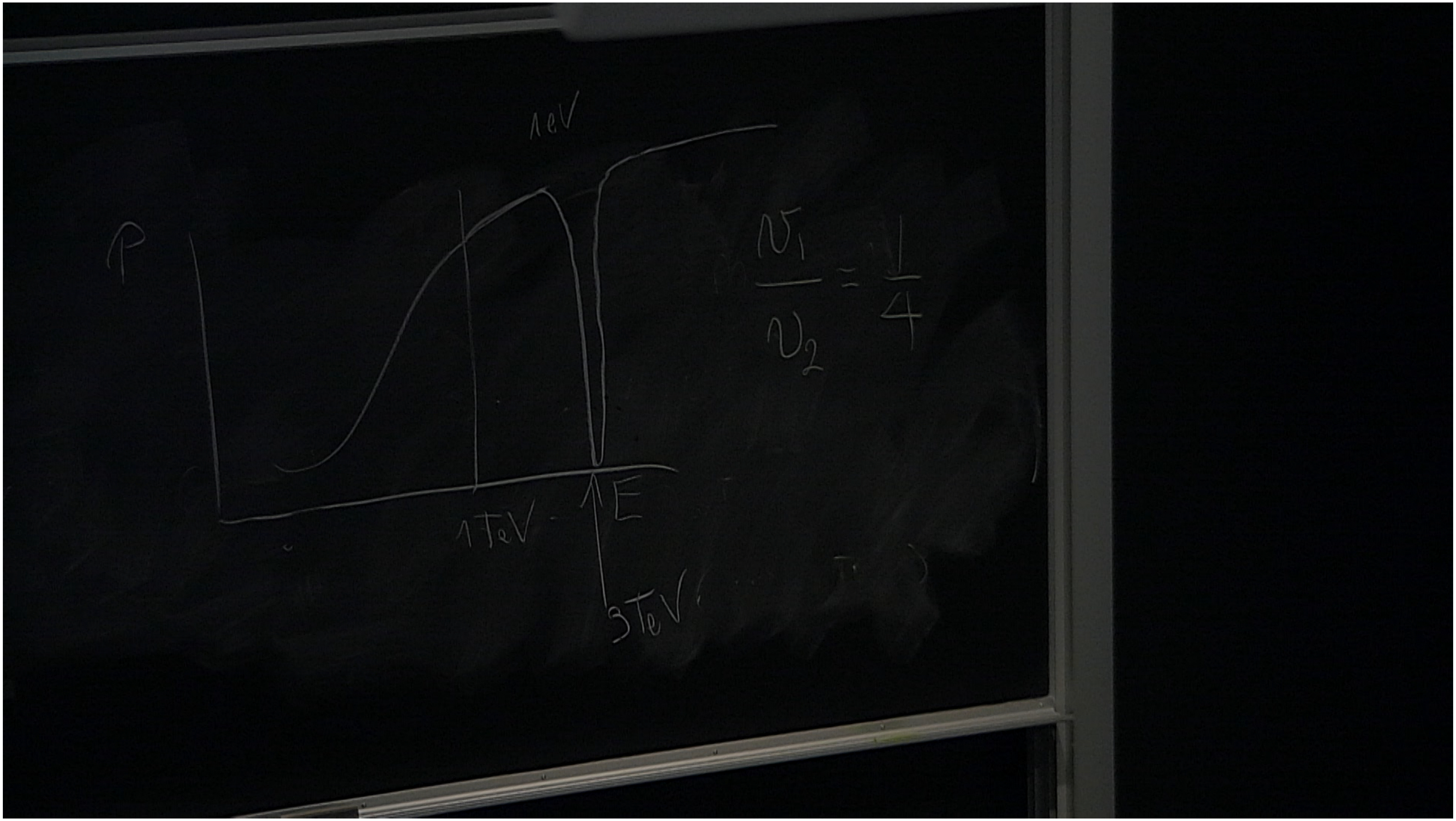
only head-on collisions

mass conservation :

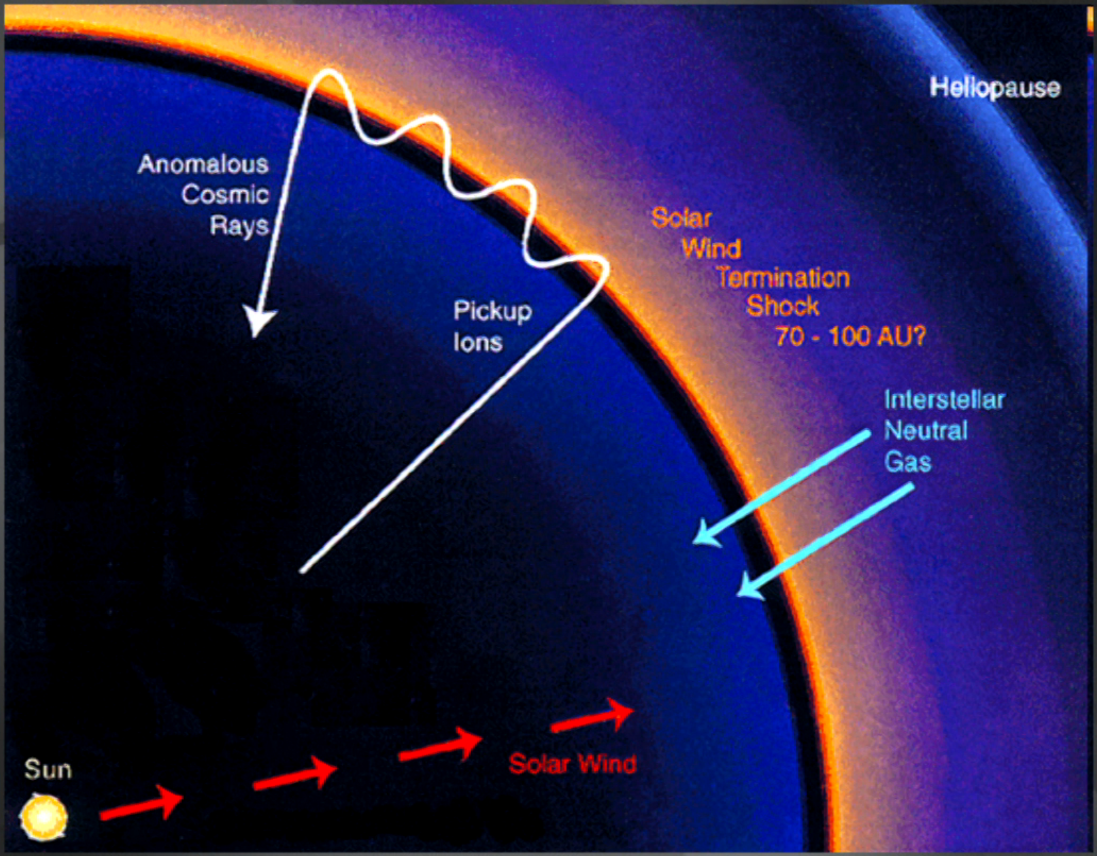
$$\rho_1 v_1 = \rho_2 v_2$$

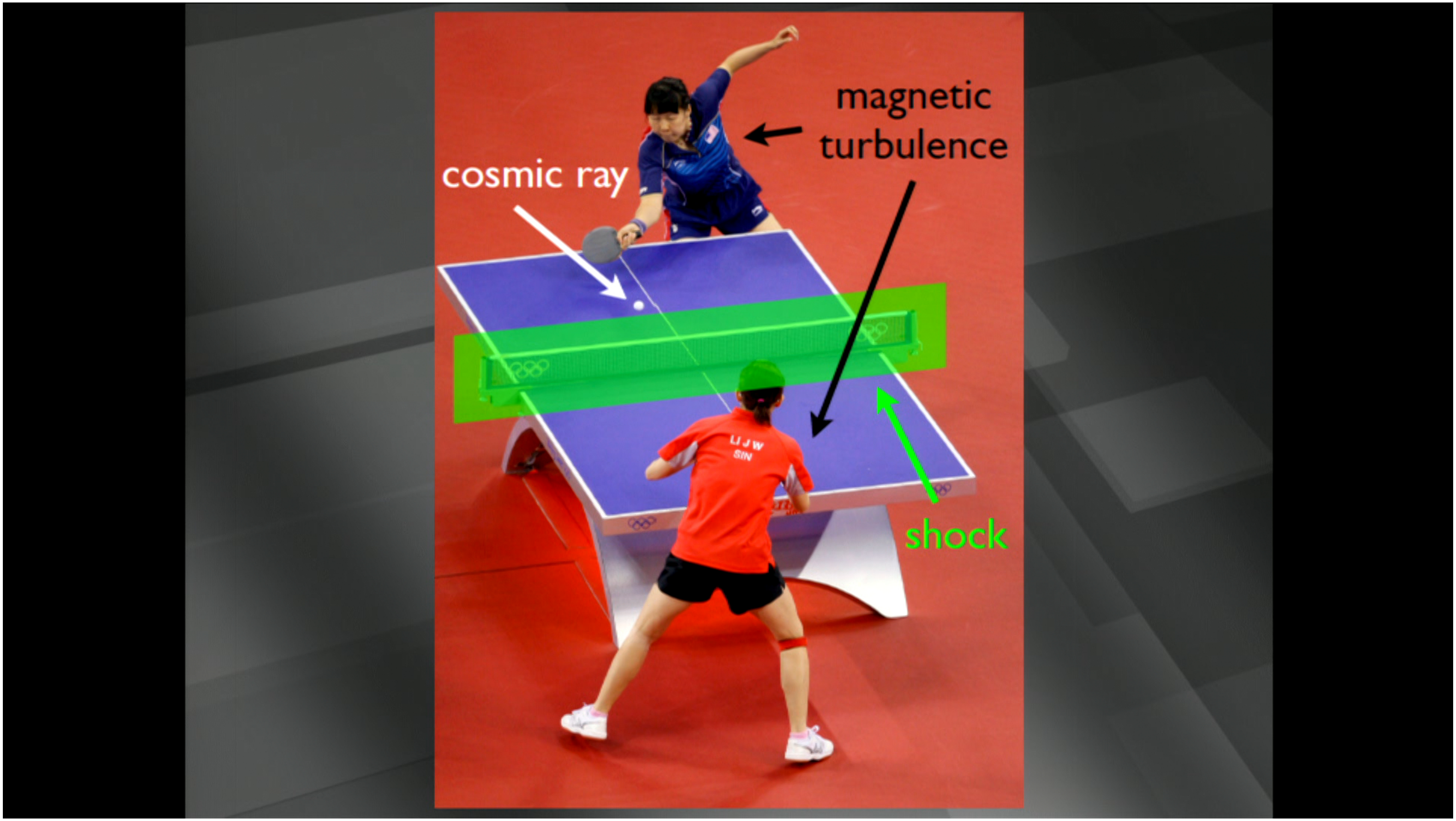
$$\Rightarrow \quad \frac{v_1}{v_2} = \frac{\rho_2}{\rho_1} = \frac{1}{4}$$




1eV
P
$\frac{v_1}{v_2} = \frac{1}{4}$
E
1TeV
3TeV

solar wind termination shock




magnetic
turbulence
cosmic ray
shock

shock spectrum

$$\frac{dN}{dE} \sim \frac{1}{E^2}$$

$$\beta \sim P \sim \frac{u}{c}$$

probability to be swept up by the shock is ~ shock velocity u

$\frac{\Delta E}{E} = \beta^k$ energy gain/encounter

$\frac{\Delta N}{N} = -P^k$ probabilty to cross shock

$\frac{\Delta N}{N} = -\left(\frac{\beta}{P}\right)^k \frac{\Delta E}{E}$ by dividing the two

$\int_{N_0}^{N} \frac{\Delta N}{N} = -\left(\frac{\beta}{P}\right)^k \int_{E_0}^{E} \frac{\Delta E}{E}$ integrate

$$\log \frac{N}{N_0} = -\gamma \log \frac{E}{E_0}$$

$N = N_0 \left(\frac{E}{E_0}\right)^{-\gamma}$ and $\frac{dN}{dE} \sim E^{-1-\left(\frac{\beta}{P}\right)^k} \sim E^{-2}$

... and the answer is E^{-2}

$$\ln\beta = \frac{u}{c} \quad and \quad \ln P = -\frac{u}{c}$$

$$\beta = \frac{E_f}{E_i} = 1 + \frac{\Delta E}{E} = 1 + \underbrace{2}_{\text{roundtrip}} \times \left(\frac{v_{rel}}{c}\right) \times \underbrace{\cos\theta}_{\text{angular integration \#1}} \Rightarrow 1 + \frac{u}{c}$$

$$P = 1 - P_{esc} = 1 - \frac{\rho_{cr} v_{up}}{\underbrace{\rho_{cr}\frac{c}{4}}_{\text{angular integration \#2}}} = 1 - \frac{\rho_{cr}\frac{u}{4}}{\rho_{cr}\frac{c}{4}} = 1 - \frac{u}{c} \quad shock\,restframe$$

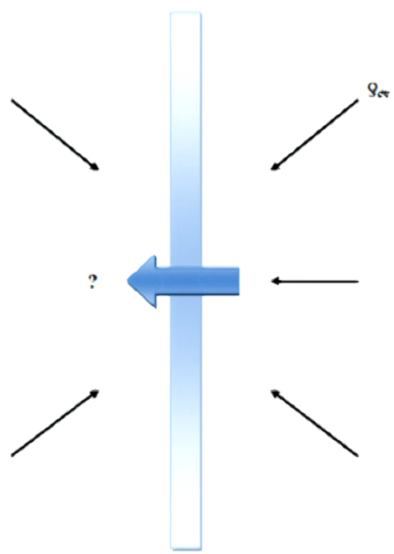
angular integral #1

$$\langle\frac{\Delta E}{E}\rangle = 2\frac{\mathrm{v}_{rel}}{c}\cos\theta \quad where\, \mathrm{v}\, is\, the\, relative\, velocity\ \frac{3}{4}u$$

$$average\, is\, over\, particle\, distribution\, N(\theta) = N\cos\theta$$

$$\langle\frac{\Delta E}{E}\rangle = 2\frac{\mathrm{v}_{rel}}{c}\frac{\int\cos\theta\, N(\theta)\, d\phi\, d\cos\theta}{\int N(\theta)\, d\phi\, d\cos\theta} = 2\frac{\mathrm{v}_{rel}}{c}\frac{\int_0^{\frac{\pi}{2}}\cos^2\theta\, d\cos\theta}{\int_0^{\frac{\pi}{2}}\cos\theta\, d\cos\theta} = \frac{4}{3}\frac{\mathrm{v}_{rel}}{c} = \frac{u}{c}$$

angular integral #2



flux F swept up from isotropic flux ρ_{cr}

$$F = \int_{v>0} f(v)\, v\, d^3v = \pi \int_0^{\inf} f(v)\, v^3 dv$$

$$\langle v \rangle = \frac{1}{n}\int f(v)\, v^3 dv = \frac{4\pi}{n}\int_0^{\inf} f(v)\, v^3 dv$$

combine

$$F = \frac{n\langle v \rangle}{4} \approx \frac{nc}{4}$$

maximum energy

$$\frac{dE}{dt} = f_{cross}\Delta E = \frac{c}{\lambda_{cross}}\beta E = \frac{\beta E}{t_{cross}} \leq \beta E \frac{u}{r_{gyro}}$$

$$from \quad ut_{cross} \approx \lambda_{cross} \geq r_{gyro} \quad or$$

acceleration requires that the mean free path for magnetic scattering is larger than the gyroradius

maximum energy, ctd

$$\frac{dE}{dt} \le \beta E \frac{u}{r_{\mathrm{gyro}}} = \left(\frac{u}{c}\right) E u \left(\frac{E}{ZeB}\right)^{-1} = \frac{u}{c} ZeB\, u$$

$$\boxed{E_{\max} = \frac{u}{c} ZeB(ut)}$$