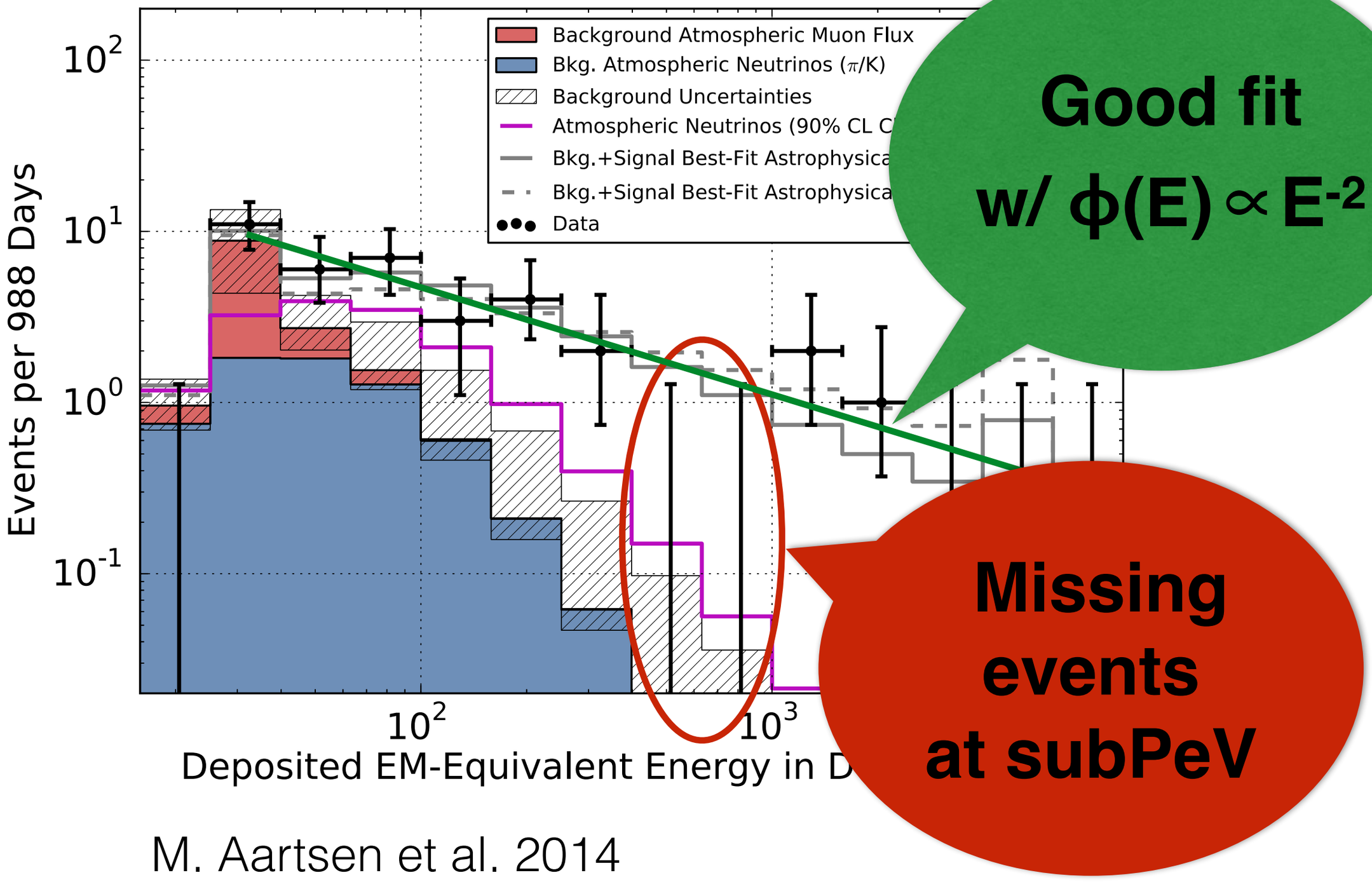
Resonant Neutrino Self-Interaction with $U(1)_{L\mu-L\tau}$ Model

AYUKI KAMADA (UC Riverside)
in collaboration with Hai-bo Yu (UCR)

@第28回宇宙ニュートリノ研究会

“Dip” in IceCube



M. Aartsen et al. 2014

Possible Interpretation

Sources w/ $\phi(E) \propto E^{-2}$

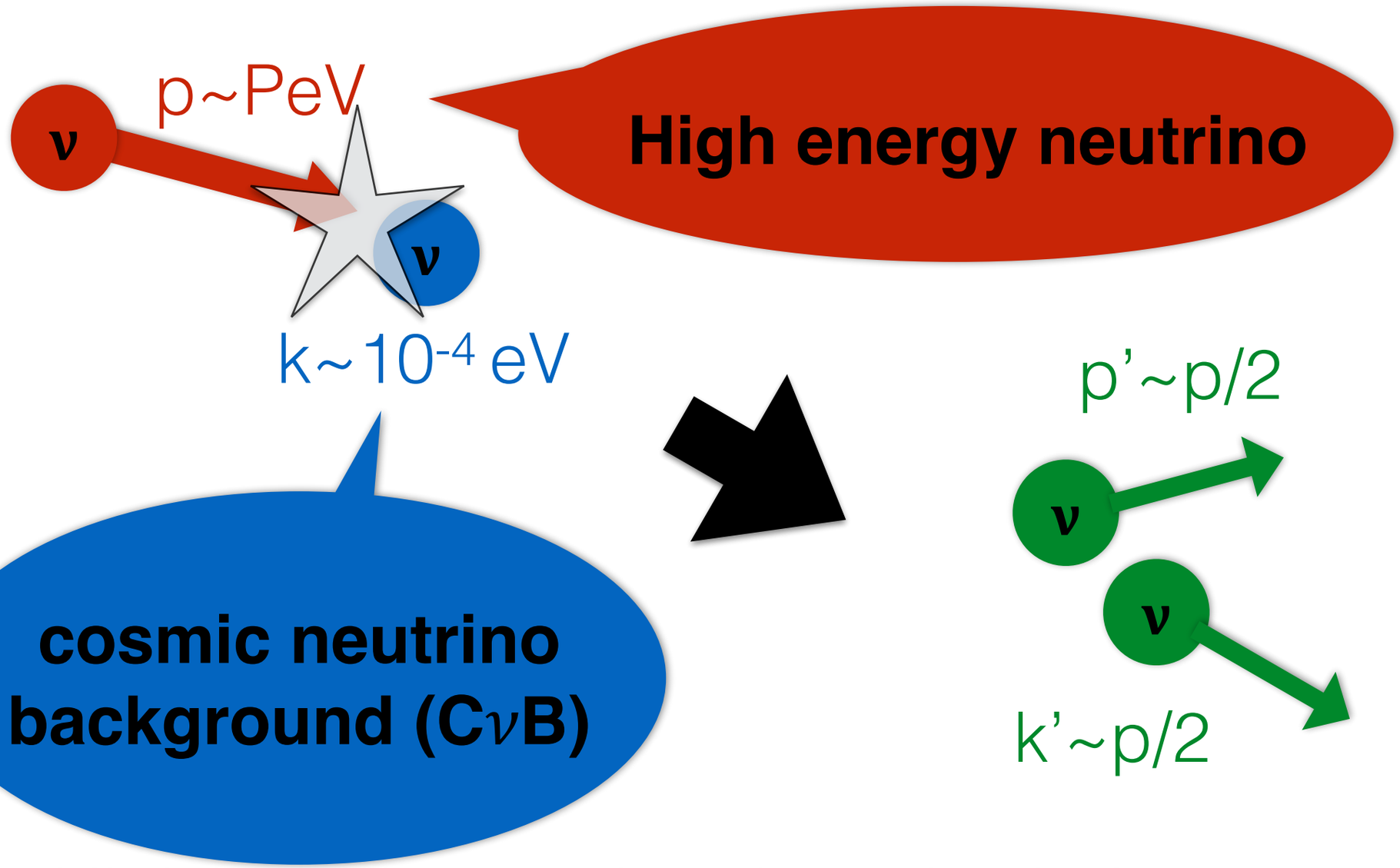
- Astrophysical (GRB, SNR)
- Cosmogenic (pp, pγ…)
- New Physics (DM decay, annihilation)

Origins w/ dip

- Statistical fluctuation
  -a few events expected (2σ consistent)
- New Physics (neutrino interactions)

This talk

How does neutrino self-interaction work?



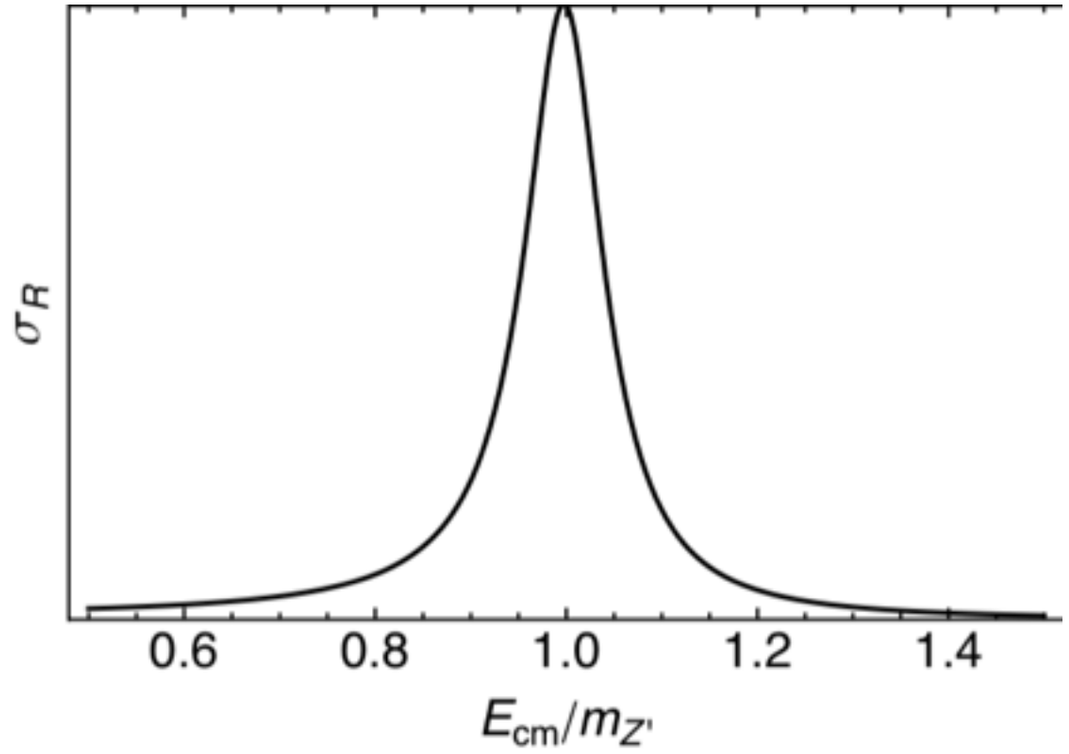
High energy neutrino deposits their energy in cosmic neutrino background

Exclusive for subPeV

Only **subPeV** neutrinos interact effectively

achieved by
Breit-Wigner Resonance

$\nu\nu$ -> Z' -> $\nu\nu$



$$m_{Z'}^2 = 2p(\sqrt{k^2 + m_\nu^2} - k\cos\theta)$$

cosθ: injection angle

Typically $m_\nu \sim 0.1$ eV
>> k~10^{-4} eV

$$m_{Z'} = \sqrt{2m_\nu p} \sim 10 \text{ MeV}$$

10 MeV mediator implied!!

Well-motivated model

$U(1)_{L\mu-L\tau}$

Gauging (muon number - tau number)
$\nu_\mu(+1)$, $\nu_\tau(-1)$… anti-particles(opposite sign)
couple with Z'-boson ($m_{Z'}$~10MeV!!)

Advantages

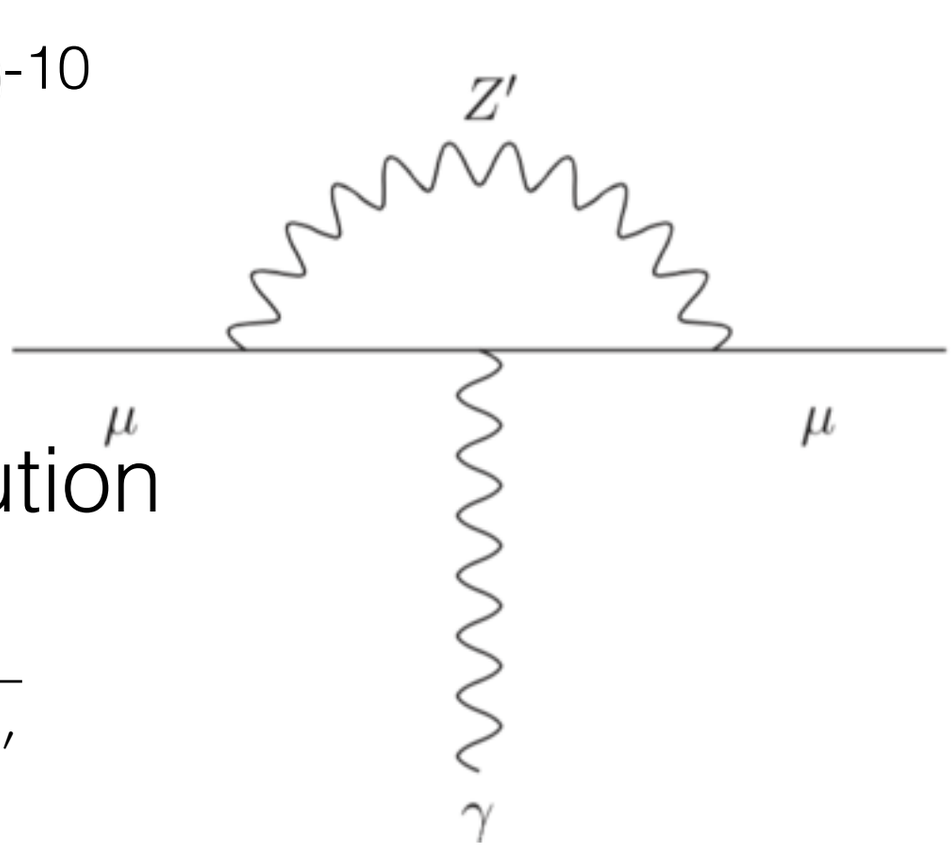
- Anomaly-free (well-defined theory)
- natural explanation of maximal mixing
  for atmospheric neutrino $\theta_{23}\sim\pi/4$
- No experimental difficulty
  (e.g. beam-dump experiment)
  unlike $U(1)_{Le-L\mu}$, $U(1)_{Le-L\tau}$

Muon g-2

Measured muon anomalous magnetic moment (g-2) deviates from standard model prediction

$\Delta a_\mu(\text{exp}) = a_\mu(\text{exp}) - a_\mu(\text{SM})$ $\quad a_\mu = (g-2)/2 \sim 0.001$

$= (42.6 \pm 16.5) \times 10^{-10}$



Z'-boson exchange contribution

$$\Delta a_\mu^{Z'} = \frac{g'^2}{8\pi^2} \int_0^1 dx \frac{2m_\mu^2 x^2 (1-x)}{x^2 m_\mu^2 + (1-x) m_{Z'}^2}$$

Gauge coupling of g'~10^{-4} can fill the gap!!

Optical depth

$$\widetilde{\tau}_s(z) = 18\zeta(3) T_{\nu,0}^3 (1+z)^3 \frac{1}{H(z) m_{Z'}^2} \frac{\Gamma_{Z'}}{m_{Z'}}$$

CνB number density

Streaming Length

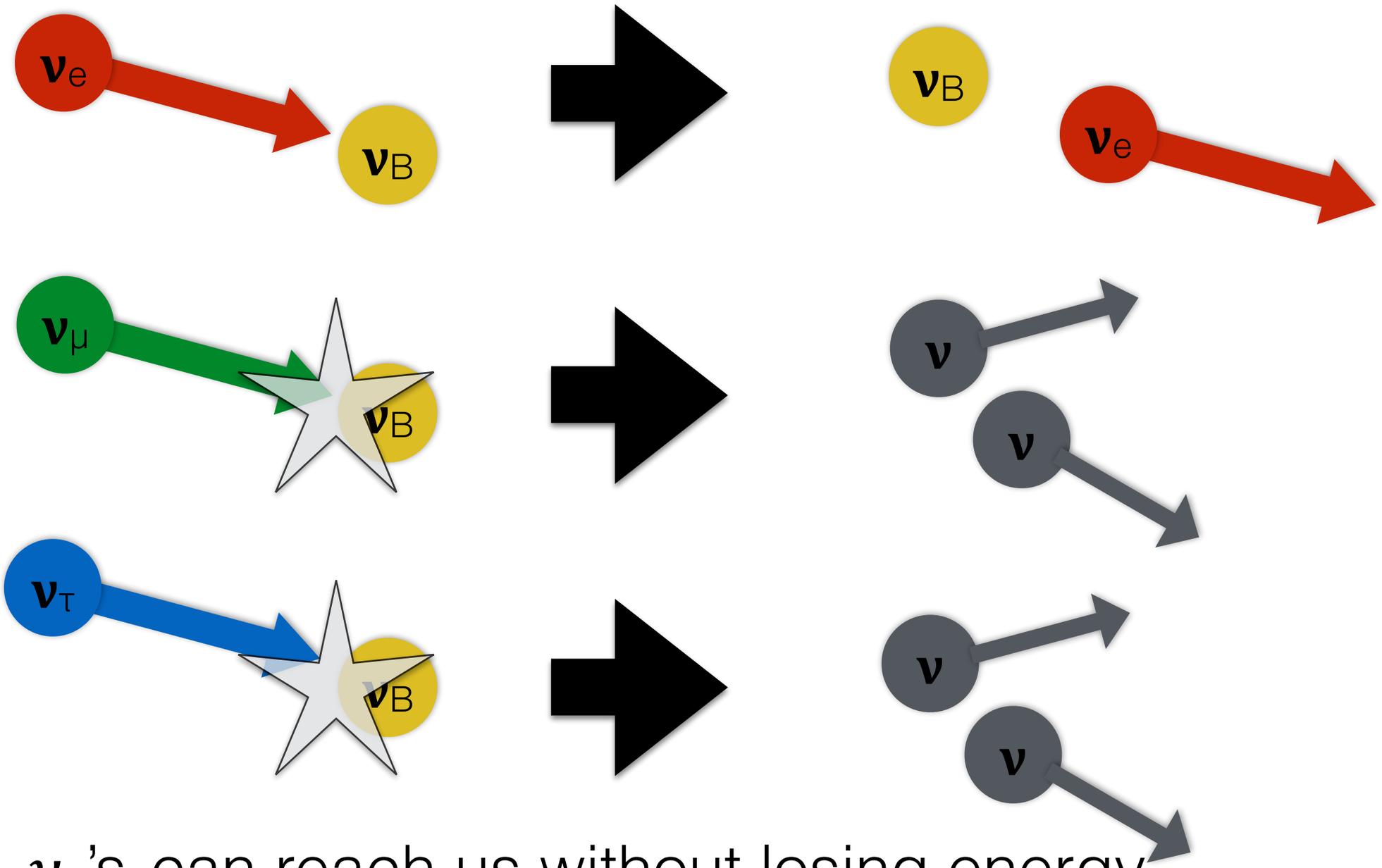
Cross section

$$\simeq 1 \left(\frac{g'}{2.5 \times 10^{-5}} \right)^2$$

T. Araki et al. 2014

Gauge coupling of g'~10^{-4} is also sufficient to explain dip in IceCube!!

Is this brilliant story true?



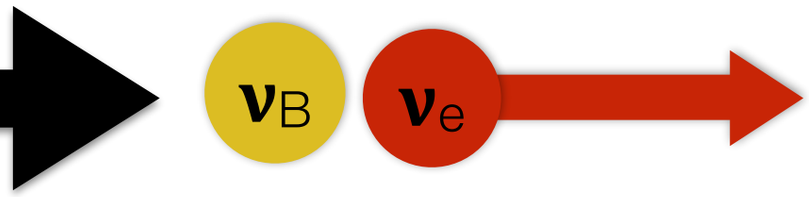
ν_e's can reach us without losing energy

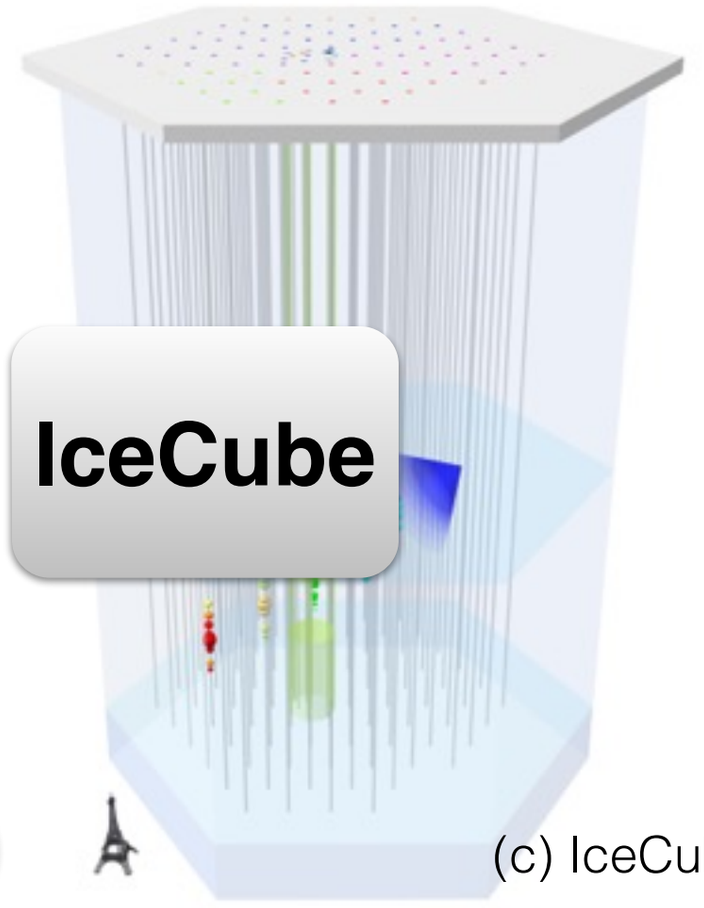
flavored (<->flavor-blind)

Neutrino oscillation I

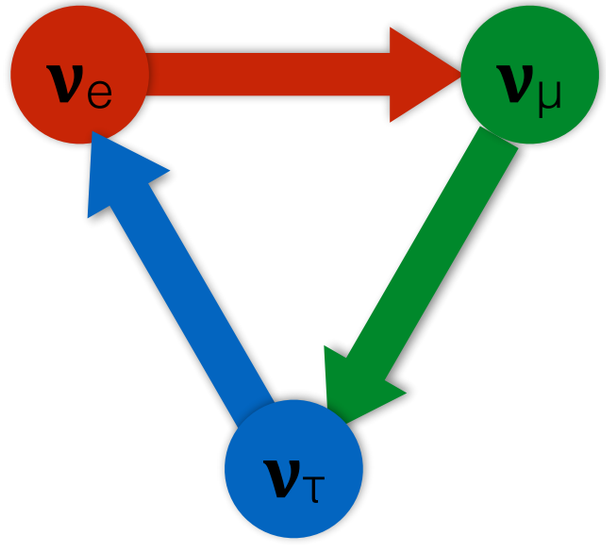
Starting with

w/o oscillation



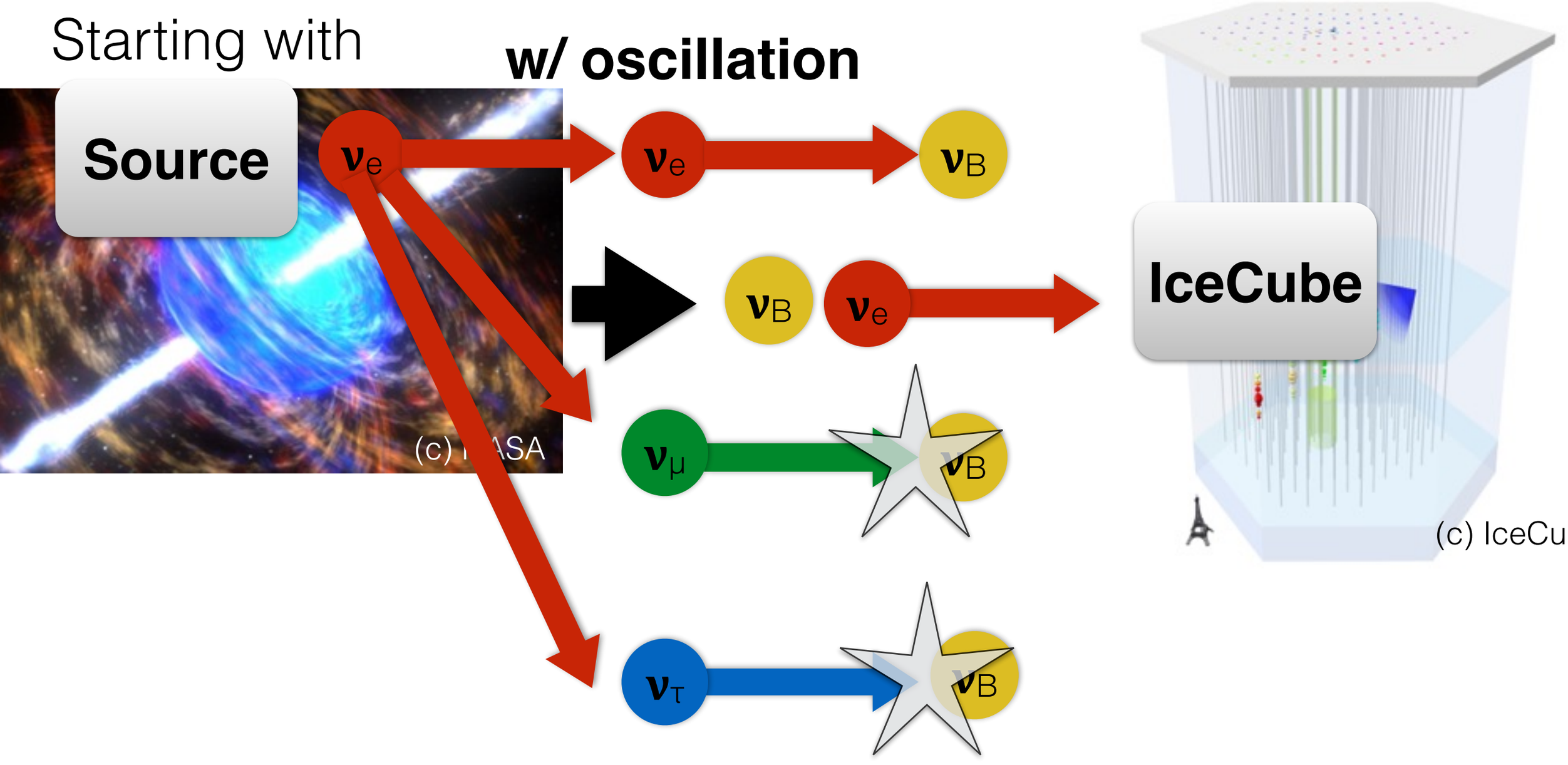


Neutrinos change their flavors during oscillations



Neutrino oscillation II

Starting with



Even starting with ν_e's, only **a part of** ν's can reach us

Neutrino oscillation IV

Probability matrix

Starting with ν_e ν_μ ν_τ End up with ν_e ν_μ ν_τ

$$\mathscr{P} \simeq \begin{bmatrix} 0.30 & 0.13 & 0.12 \\ 0.13 & 0.06 & 0.05 \\ 0.12 & 0.05 & 0.04 \end{bmatrix}$$

$$+e^{-\widetilde{\tau}_s(z_s)/2} \begin{bmatrix} 0.07 & -0.05 & -0.03 \\ -0.05 & 0.03 & 0.02 \\ -0.03 & 0.02 & 0.01 \end{bmatrix}$$

$$+e^{-\widetilde{\tau}_s(z_s)} \begin{bmatrix} 0.18 & 0.15 & 0.12 \\ 0.15 & 0.29 & 0.31 \\ 0.12 & 0.31 & 0.35 \end{bmatrix}$$

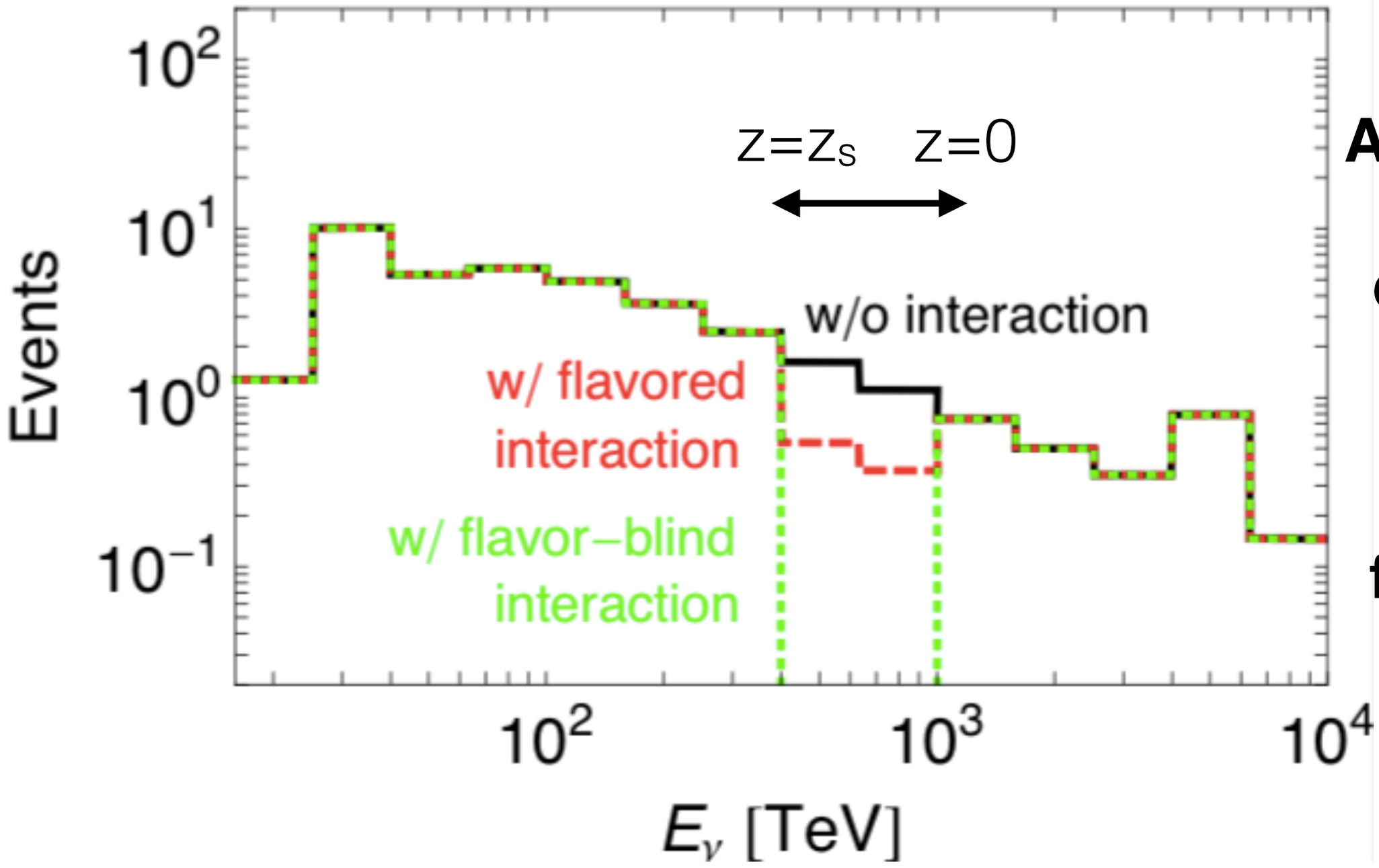
Predictions and Prospects

pp interaction

$(\phi_{\nu_e}, \phi_{\nu_\mu}, \phi_{\nu_\tau}) \simeq (1, 2, 0)$

@ IceCube (1/3 survived)

$(0.56, 0.25, 0.22)$



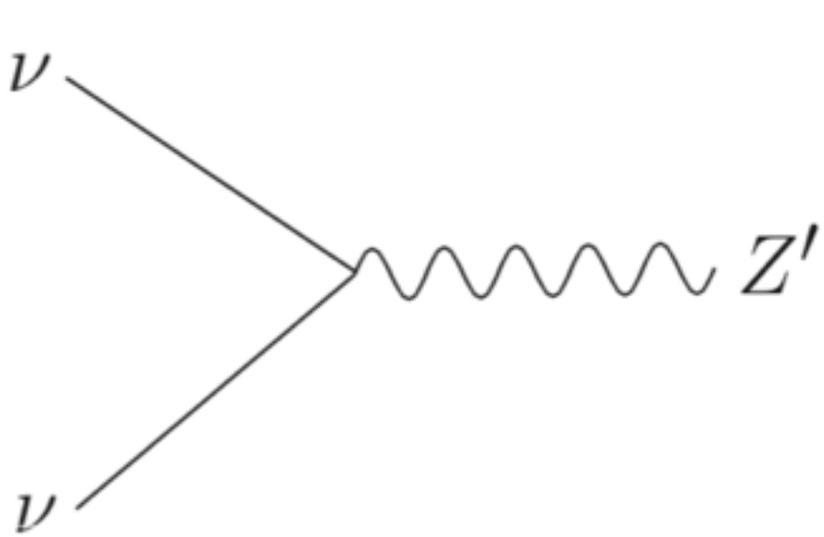
Accumulated date can distinguish flavored model from flavor-blind model

Cosmological/Astrophysical Aspects

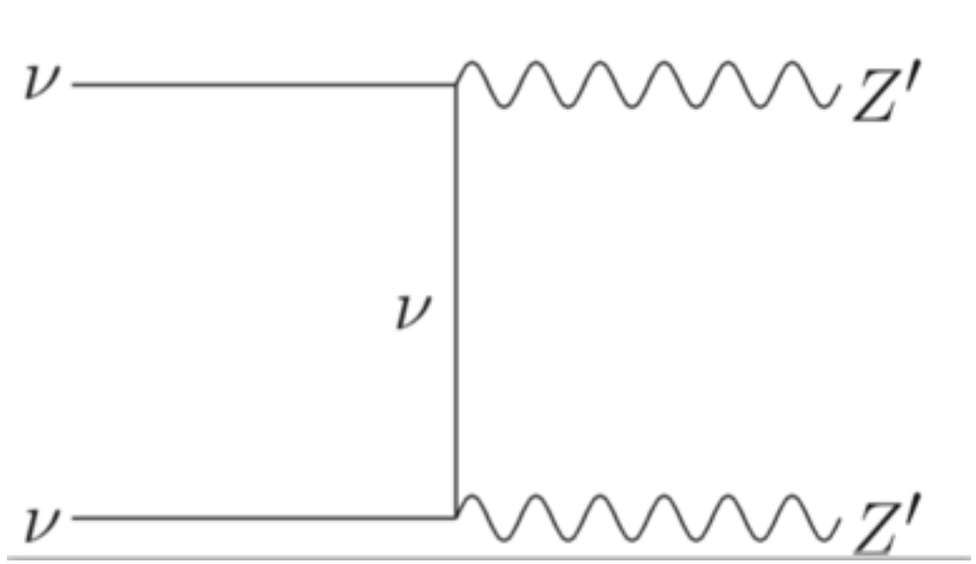
Cosmology of 10 MeV Z'-boson I

Two relevant processes

decay



pair annihilation



inverse decay

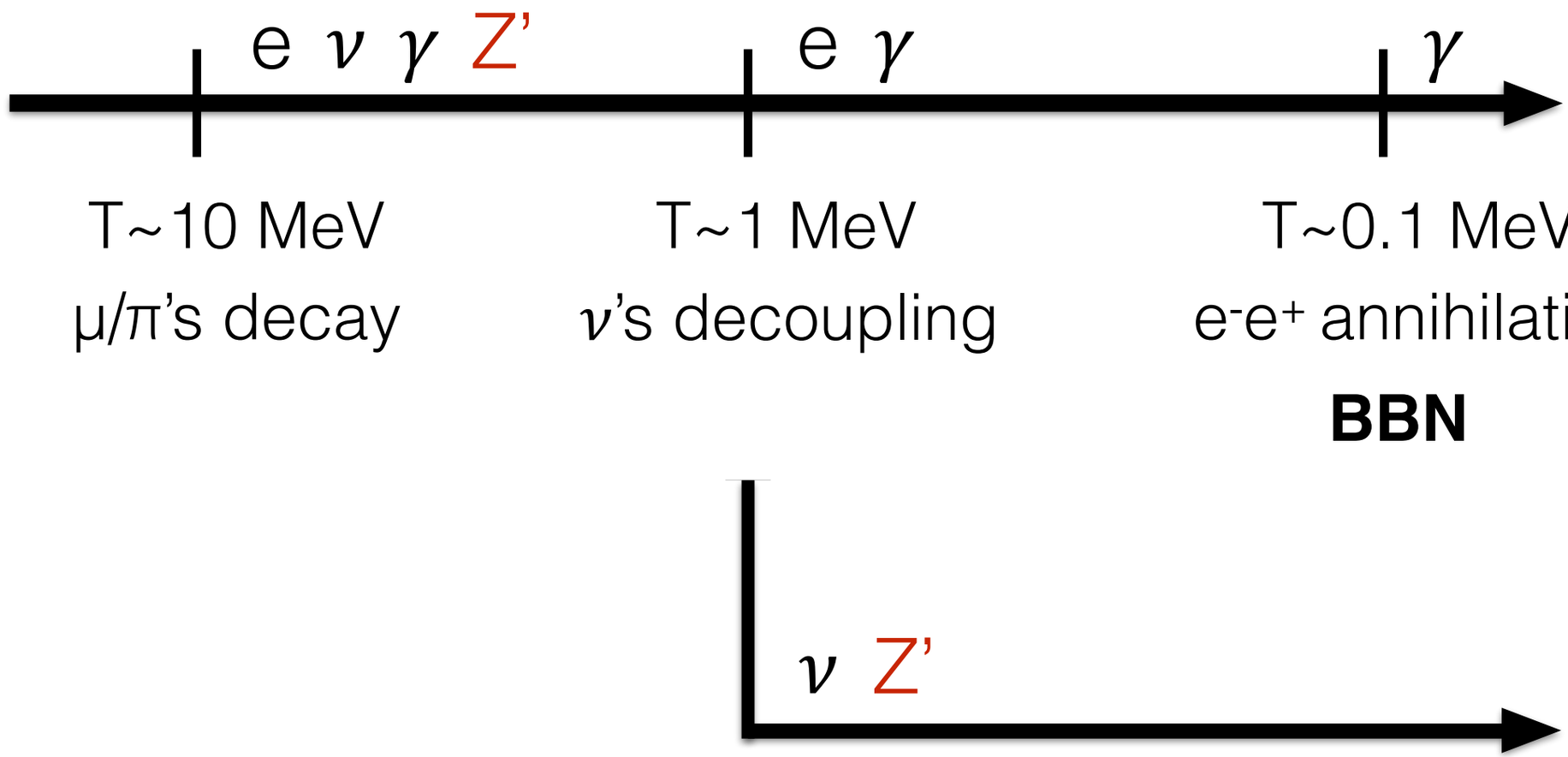
Dominant @ high-T

pair creation

@ low-T

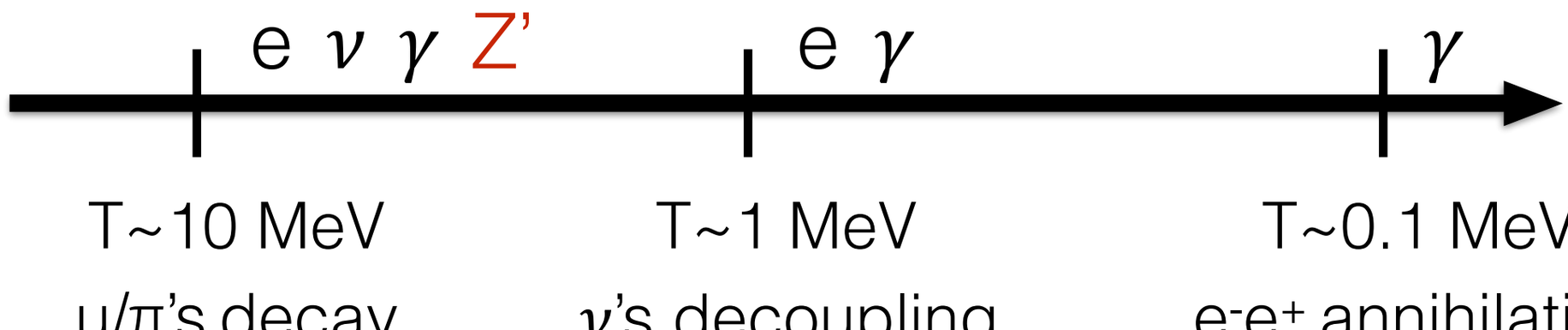
$$T_{\rm crit} \simeq 100\,{\rm GeV} \times \left(\frac{10^{-4}}{g'}\right) \times \left(\frac{m_{Z'}}{10\,{\rm MeV}}\right)$$

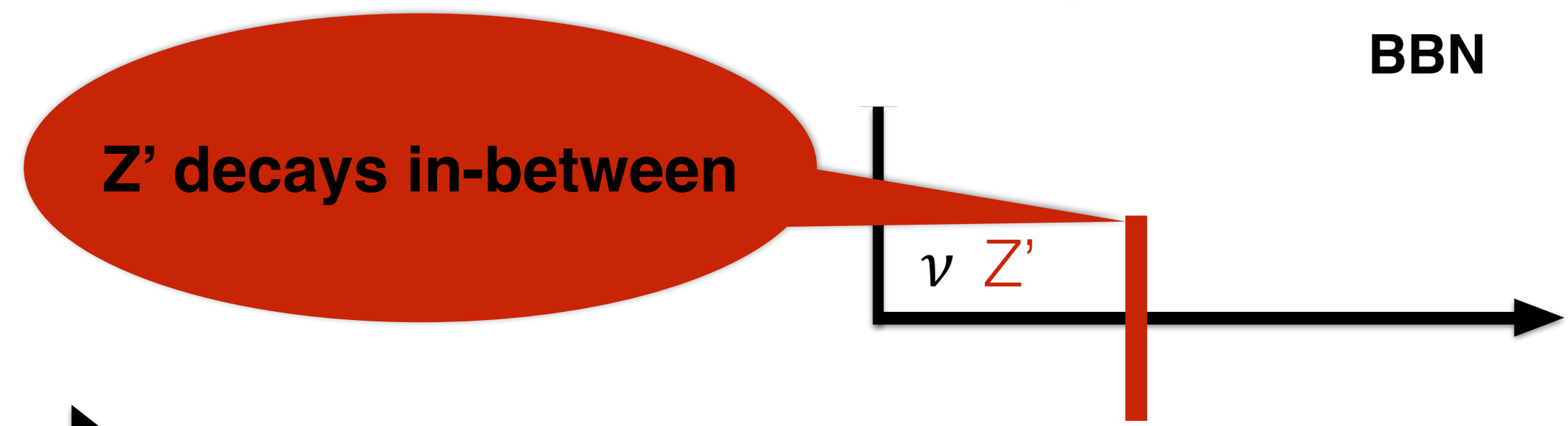
Cosmic history w/ Z’



Important question: When is Z’ decays?

Decoupling of Z' III

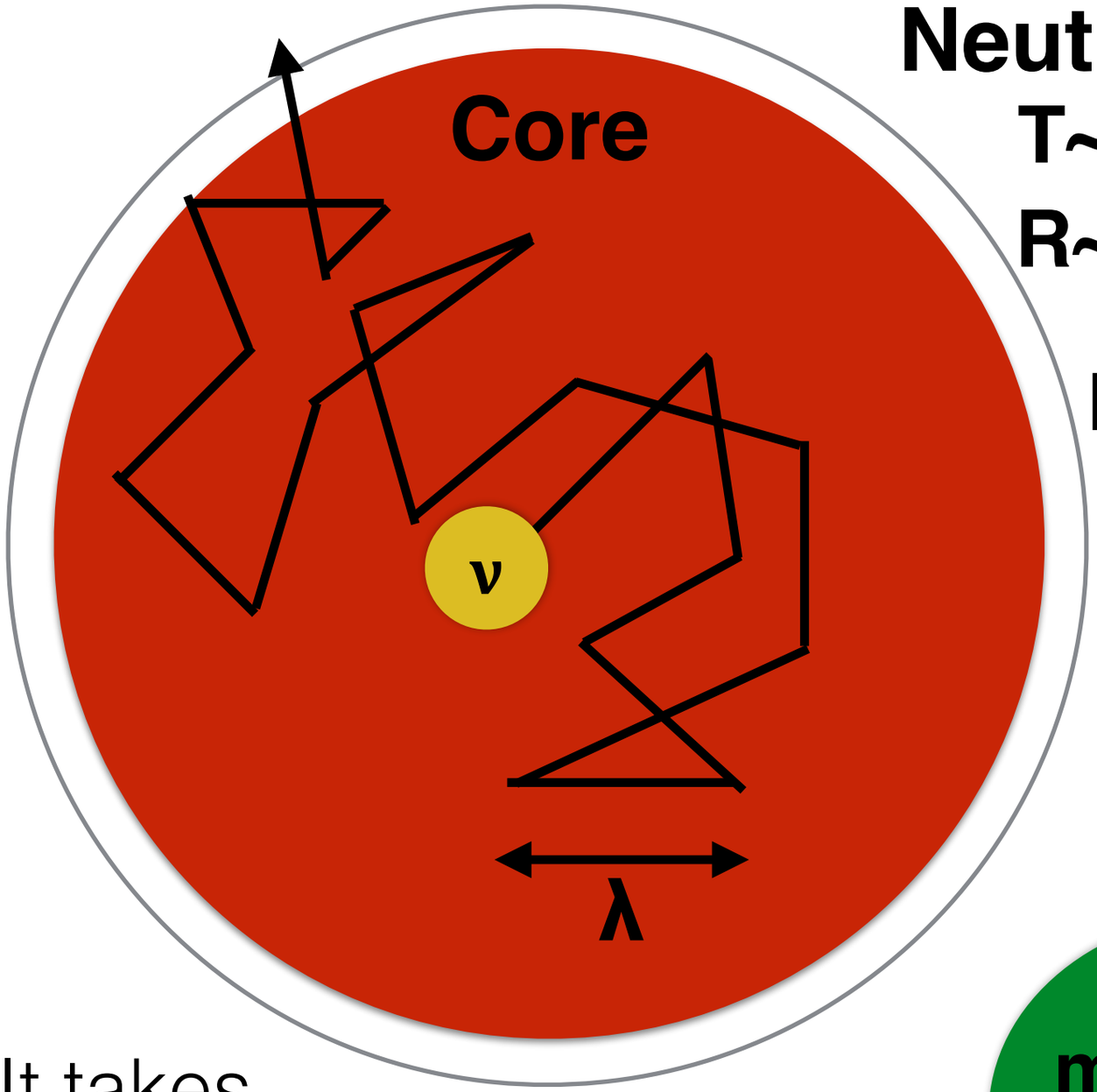




heated ν's change the expansion rate

spoil success of SM in BBN **$m_{Z'} > 6.3$ MeV**

Core Collapse SN



Neutrino sphere

T~8 MeV

R~15 km

Produced ν's can not escape from proto-neutron star

Random walk

$$R = \lambda\sqrt{N}$$

mean free path
λ~4 m

# of collisions
N=t/λ

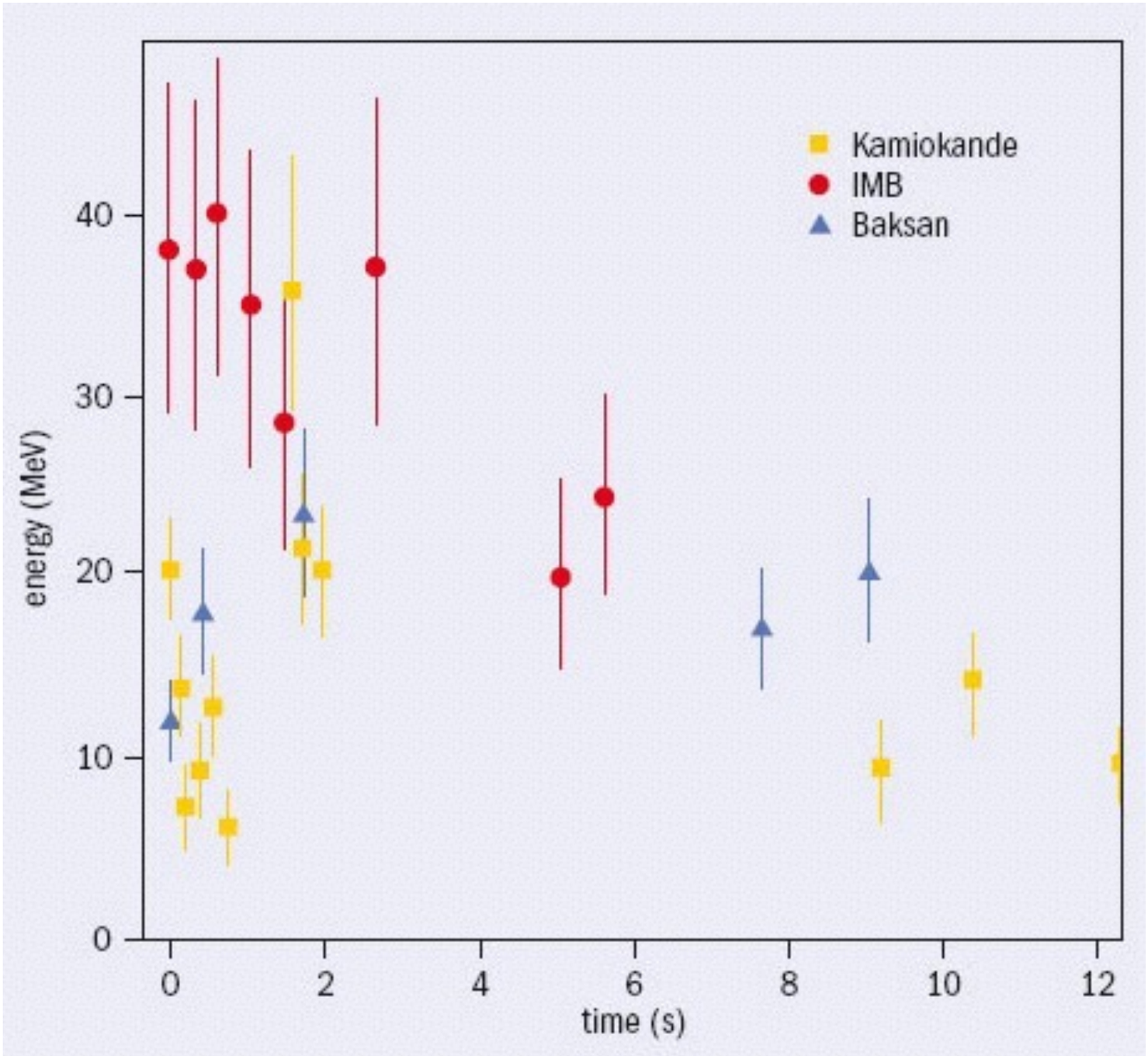
It takes

t~10s

until escape

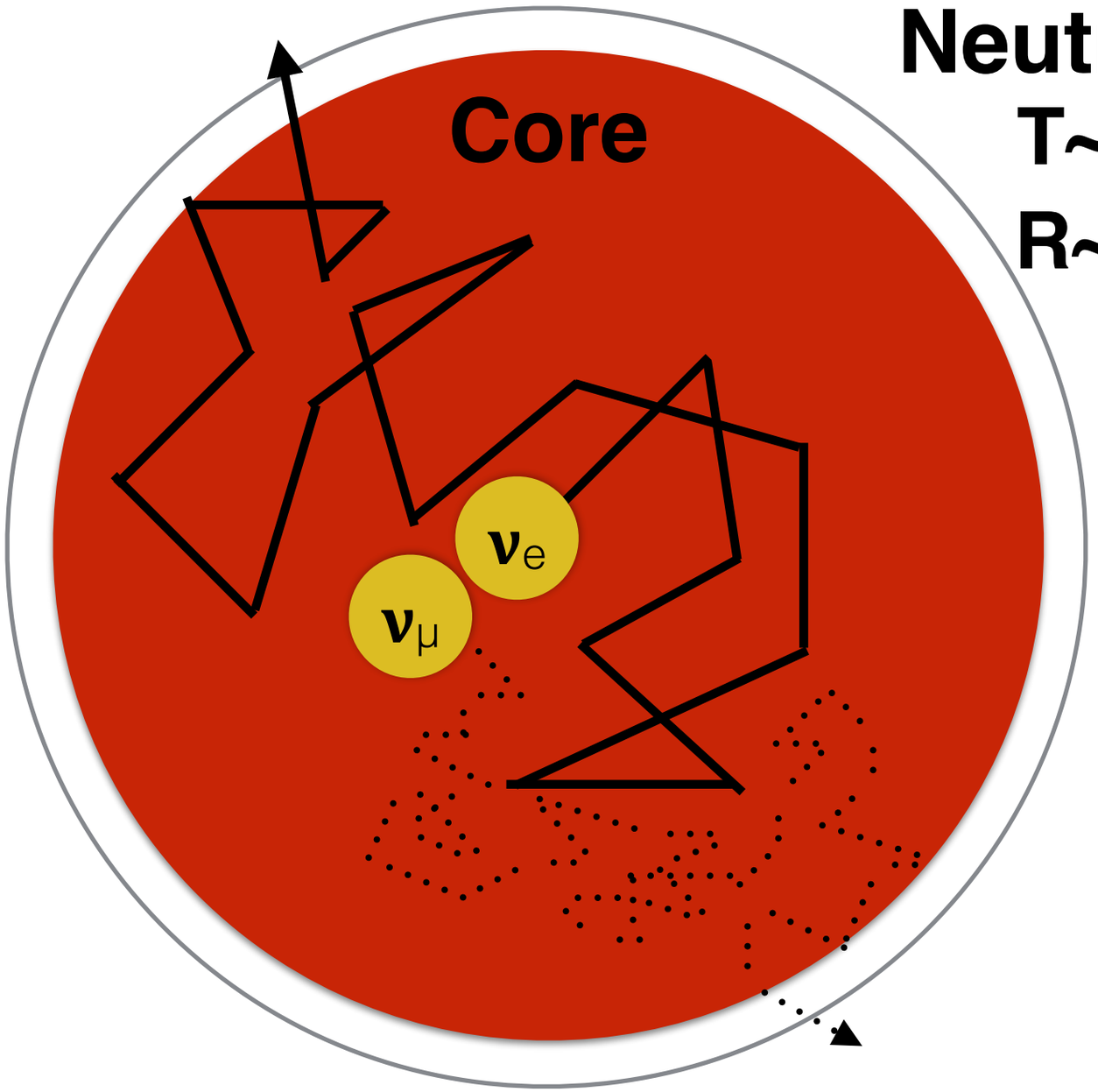
SN1987A

This 10s determines the duration of neutrino cooling



M. Nakahata 2007

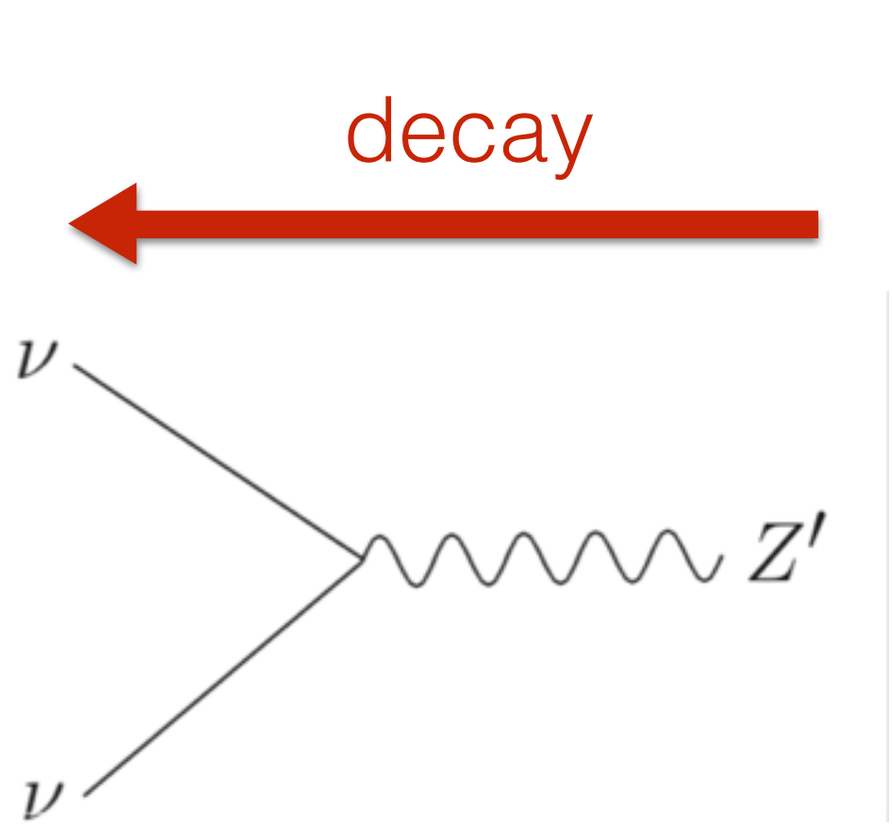
Core Collapse SN w/ Z’



Neutrino sphere

T~8 MeV

R~15 km



Same story for ν_e,
but not for ν_μ ν_τ

Diffusion time w/ Z’

For g’~10^{-4} (good for Muon g-2, IceCube dip)

Mean free path λ~0.01cm

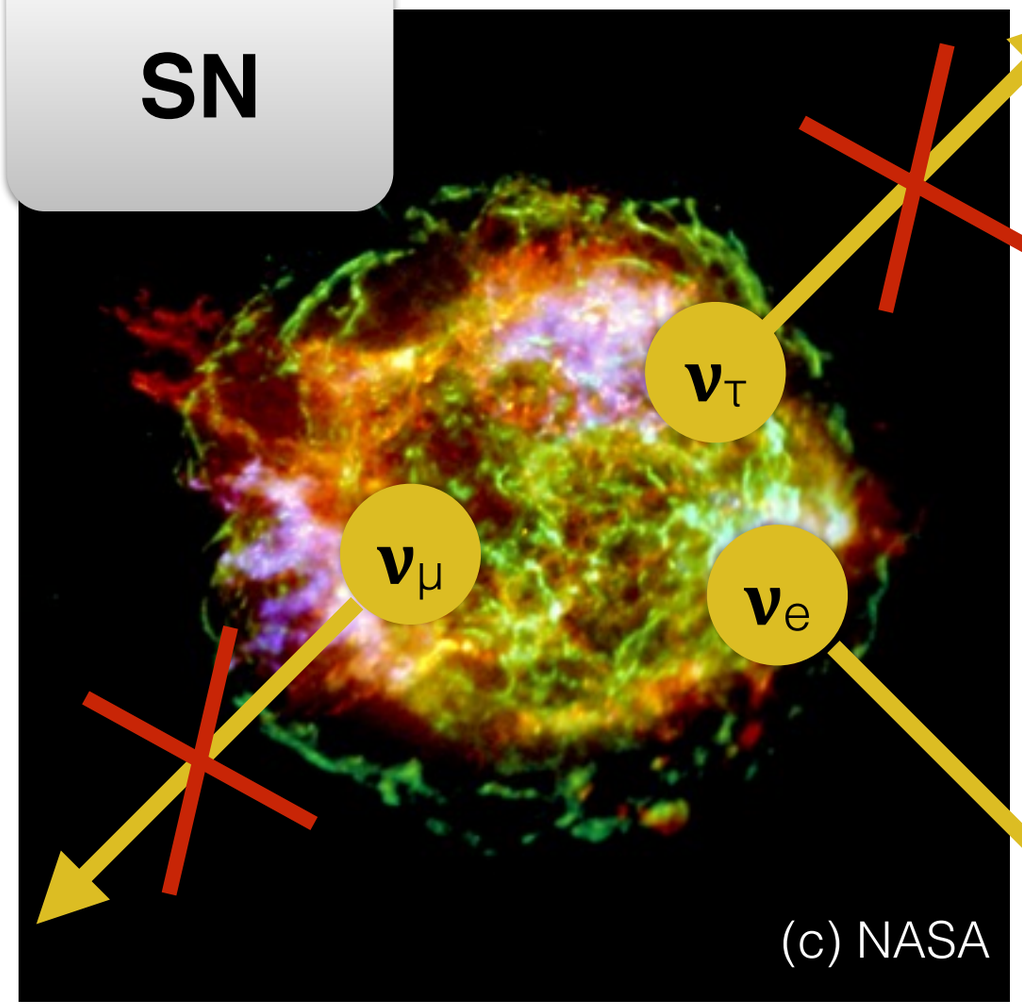
Diffusion time t~10^5s >> 10s (SN1987A)

Only ν_e’s contribute to SN cooling

Notion

- More detailed study needed to conclude…
- Some additional cooling mechanism of core (e.g. axion, hidden photons)

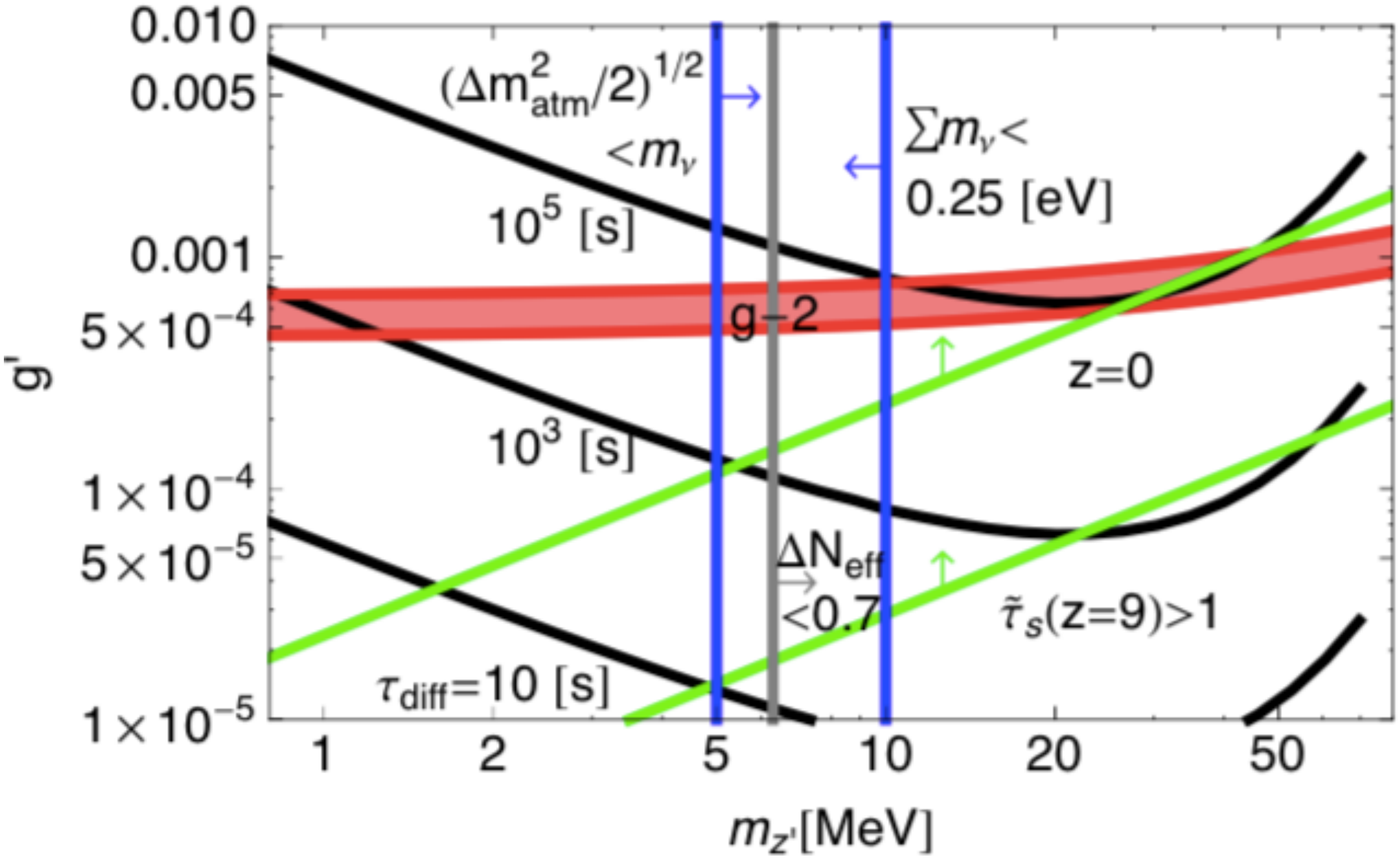
Prediction



Only ν_e's are emitted from SN

Important hint of this scenario

Summary


0.010
0.005
0.001
5×10^{-4}
1×10^{-4}
5×10^{-5}
1×10^{-5}
g'
$(\Delta m^2_{atm}/2)^{1/2}$
$<m_\nu$
10^5 [s]
10^3 [s]
τ_{diff}=10 [s]
g−2
ΔN_{eff}
<0.7
$\sum m_\nu <$
0.25 [eV]
z=0
$\tilde{\tau}_s(z=9)>1$
1
2
5
10
20
50
$m_{Z'}$[MeV]