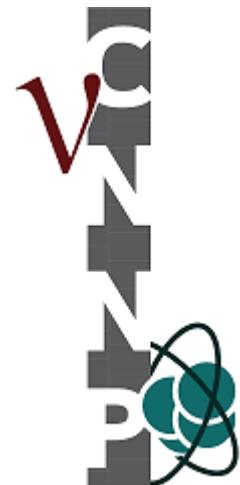




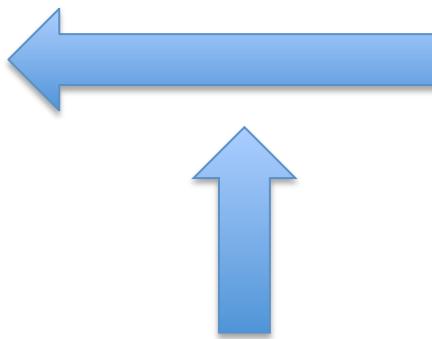
# **Study Of EoS Dependence of SNe via Relic Supernova Neutrino**

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Toshitaka Kajino (Univ. of Tokyo/NAOJ),  
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# Basic Idea

Relic Supernova  
Neutrino  
(RSN)



Astrophysical  
Scenario

SFR: Star Formation Rate  
IMF: Initial Mass Function

Types of SNe

ONeMg SNe, CCSNe, fSNe  
 $E_\nu^{tot}, T_{\bar{\nu}_e}, T_{\nu_e}, T_{\nu_x}$

# Relic Supernova Neutrino Energy Spectrum

: # flux per unit energy

Totani et al (1996)  
 Lunardini (2009)  
 Lunardini&Tomborra  
 (2012)

For Flux

$$\frac{dN_\nu}{dE_\nu} = \frac{c}{H_0} \int_0^{z_{max}} R_{SN}(z) \frac{dN_\nu(E'_\nu)}{dE'_\nu} \times \frac{dz}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}$$

$z=5$

Supernova  
Rate at  $z$

Parameterized by  
 $E_\nu^{tot}, T_{\bar{\nu}_e}, T_{\nu_e}, T_{\nu_x}$

Fermi-Dirac Distribution

SNe-type

Expanding Universe

$\Lambda$ CDM

$$\Omega_m = 0.3$$

$$\Omega_\Lambda = 0.7$$

# Relic Supernova Neutrino Energy Spectrum

: # flux per unit energy

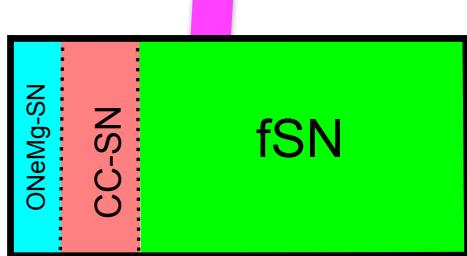
For Flux

$$\frac{dN_\nu}{dE_\nu} = \frac{c}{H_0} \int_0^{z_{max}} R_{SN}(z) \frac{dN_\nu(E'_\nu)}{dE'_\nu} \times \frac{dz}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}$$

Supernova  
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Fermi-Dirac Distribution



SNe-type

Expanding Universe

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$$\Omega_m = 0.3$$

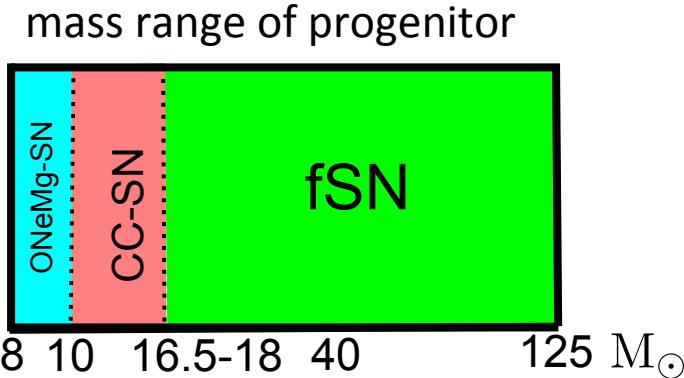
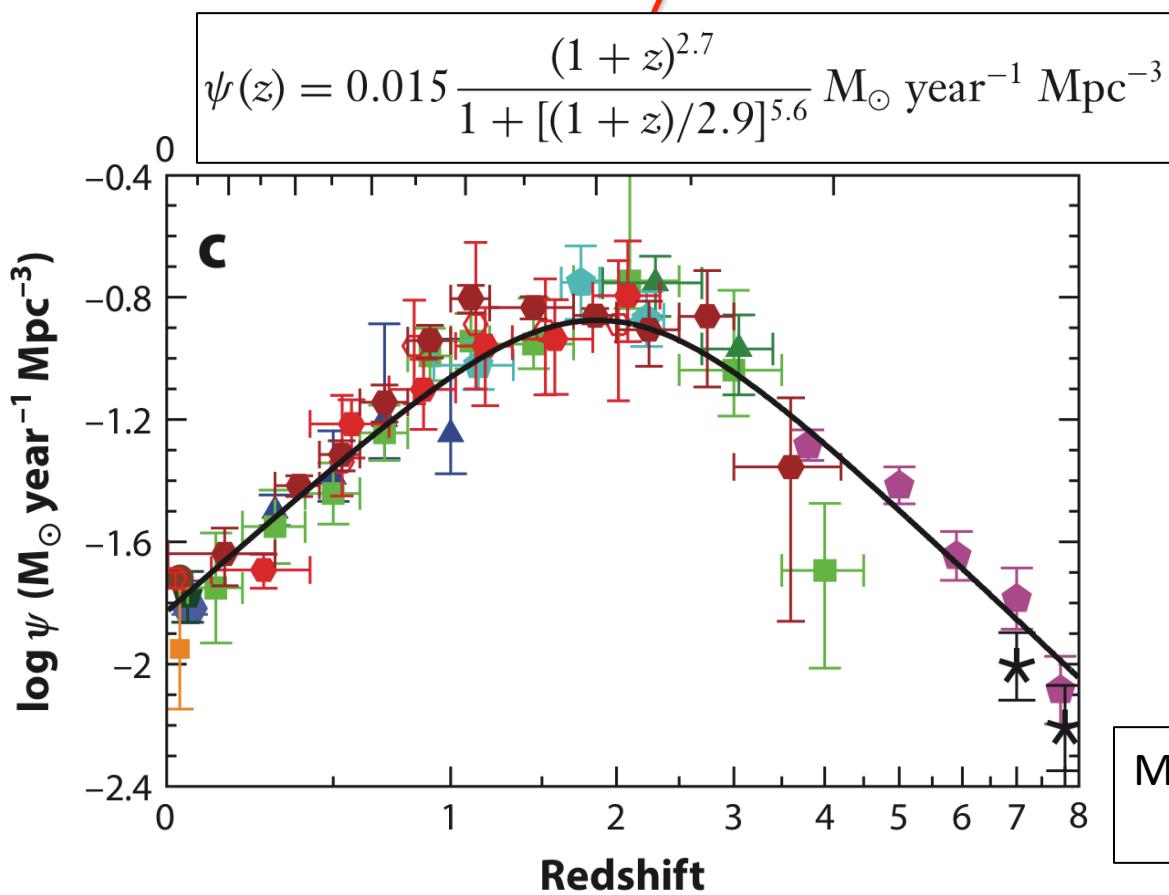
$$\Omega_\Lambda = 0.7$$

Red Supergiant problem  
 Hidaka, Kajino & Mathews, ApJ, (2016)

$$R_{SN}(z) = \Psi_*(z) \times \frac{\int_{M_{SN}}^M dM \phi_0(M)}{\int_{M_{min}}^{M_{max}} dM M \phi_0(M)}$$

R<sub>SN</sub>(z)
Star Formation Rate (obs.)
IMF (Initial Mass Function)

for each type of SNe



Madau and Dickinson  
(2014)

# Relic Supernova Neutrino Energy Spectrum

: # flux per unit energy

For Flux

$$\frac{dN_\nu}{dE_\nu} = \frac{c}{H_0} \int_0^{z_{max}} R_{SN}(z) \frac{dN_\nu(E'_\nu)}{dE'_\nu} \times \frac{dz}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}$$

Supernova  
Rate at z

Parameterized by  
 $E_\nu^{tot}, T_{\bar{\nu}_e}, T_{\nu_e}, T_{\nu_x}$

Fermi-Dirac Distribution

SNe-type

$z=5$

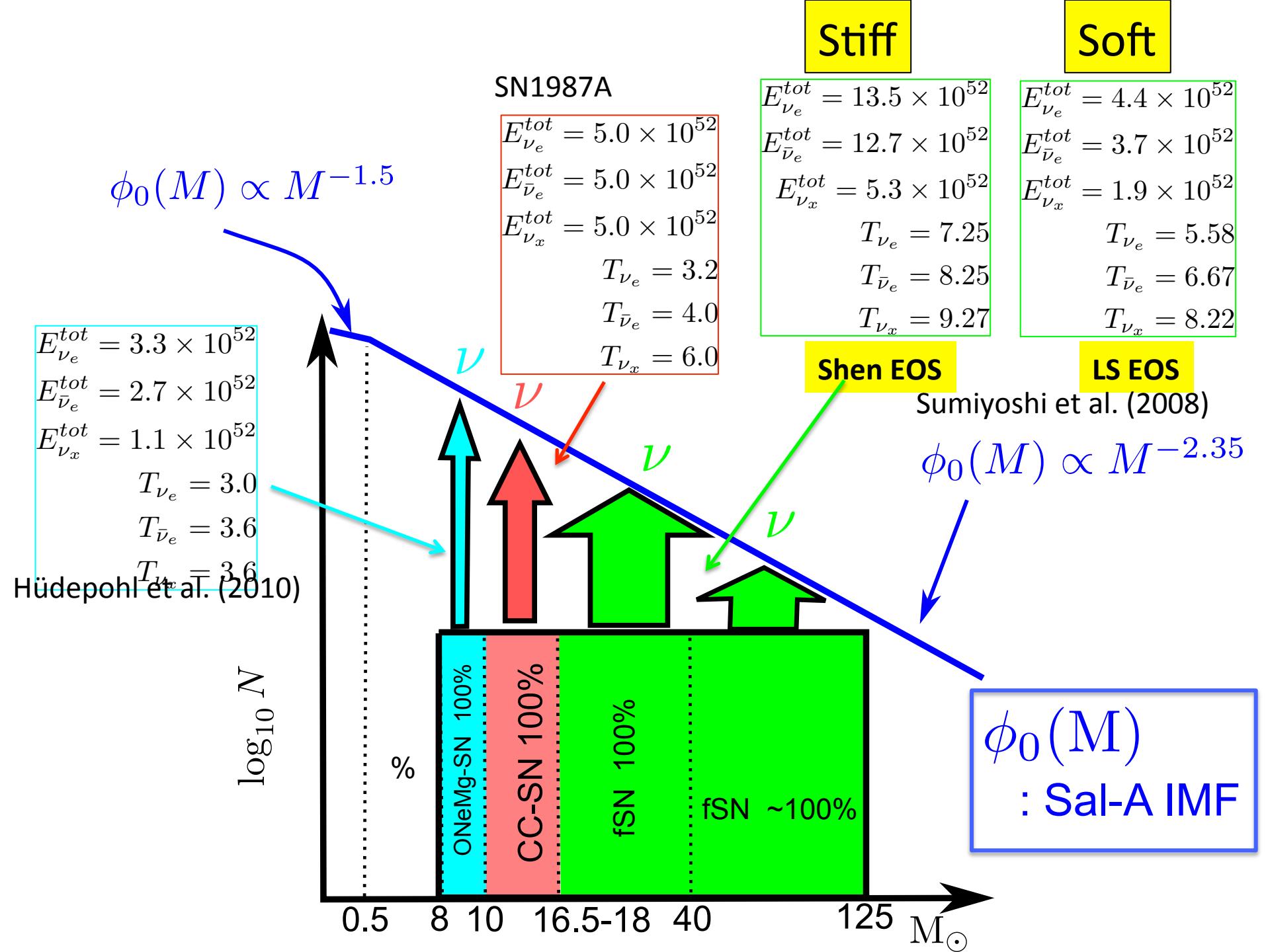
Redshifted  $E'_\nu = (1+z)E_\nu$

Expanding Universe

$\Lambda$ CDM

$$\Omega_m = 0.3$$

$$\Omega_\Lambda = 0.7$$



# Event Rate

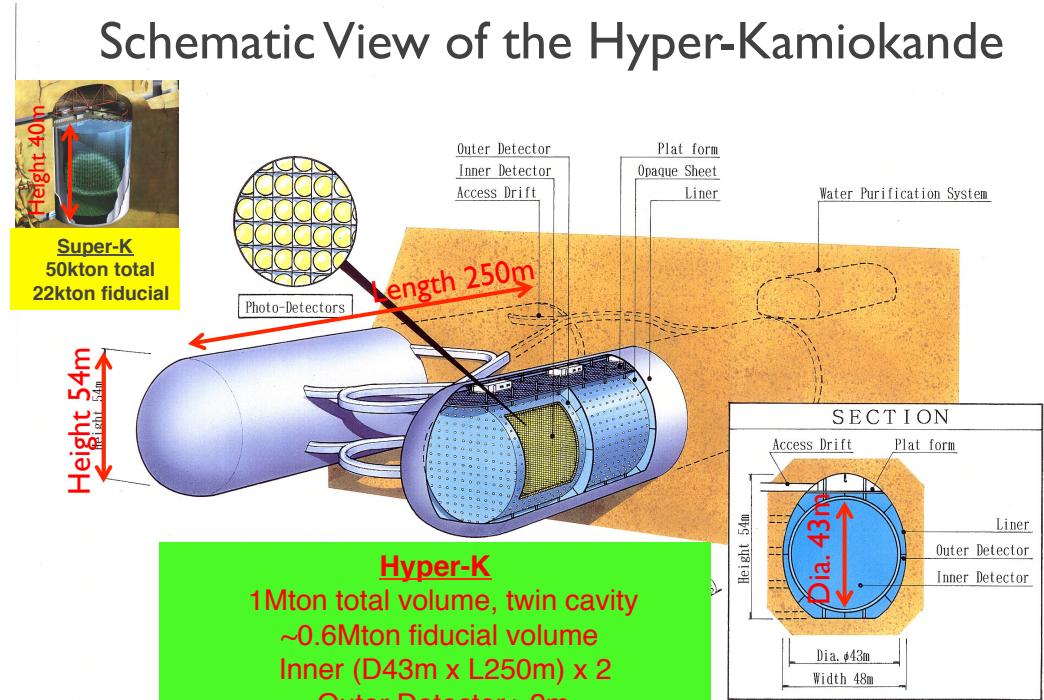
$$\frac{dN_{\text{event}}}{dE_{e^+}} = N_{\text{target}} \frac{1}{c} \frac{dN_\nu}{dE_\nu} \sigma(E_\nu) \frac{dE_\nu}{dE_{e^+}}$$

$$\left\{ \begin{array}{l} E_\nu = E_{e^+} + 1.3 \text{ MeV} \\ \bar{\nu}_e + p \rightarrow e^+ + n \end{array} \right.$$

Strumia & Vissani (2003)

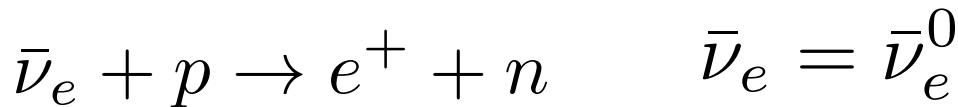
ex) 10 years run  
of Hyper-Kamiokande  
( Water Čerenkov Detector )

$1.0 \times 10^6 \text{ ton}$

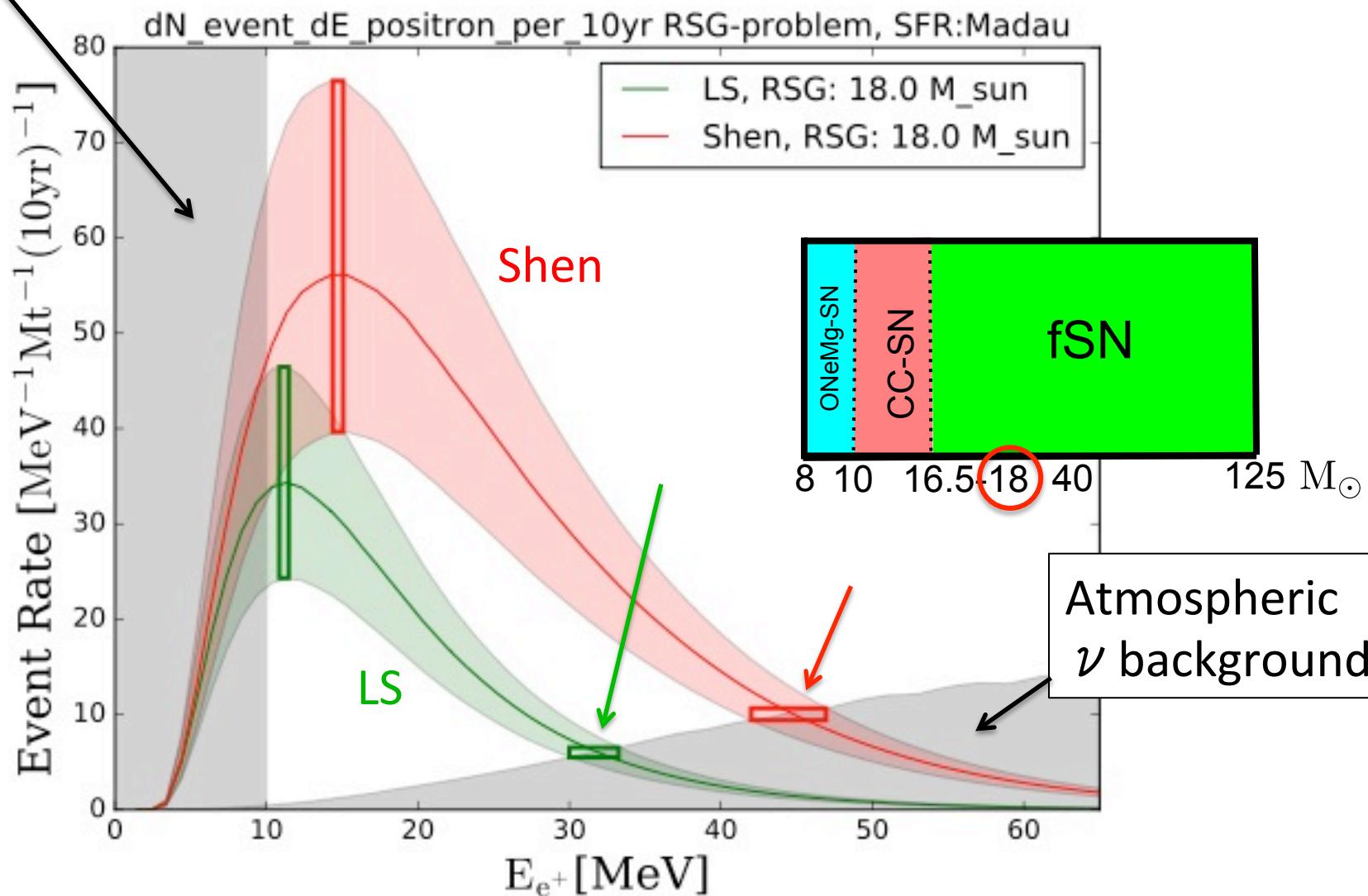


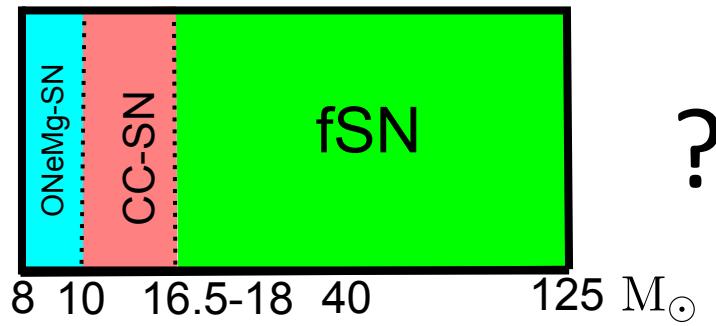
# Event Rate

without neutrino oscillation



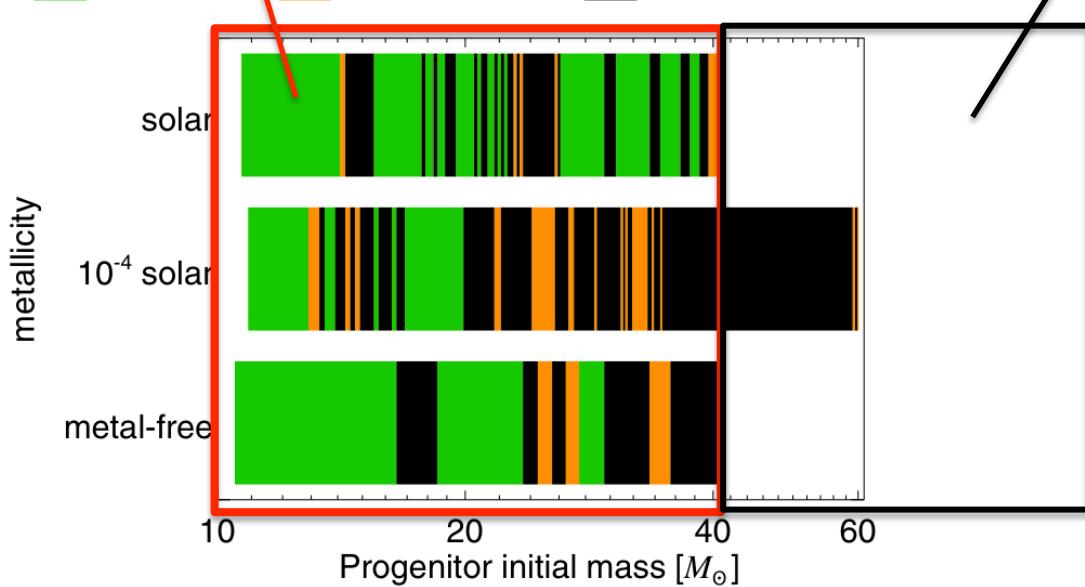
Reactor  
 $\nu$  background



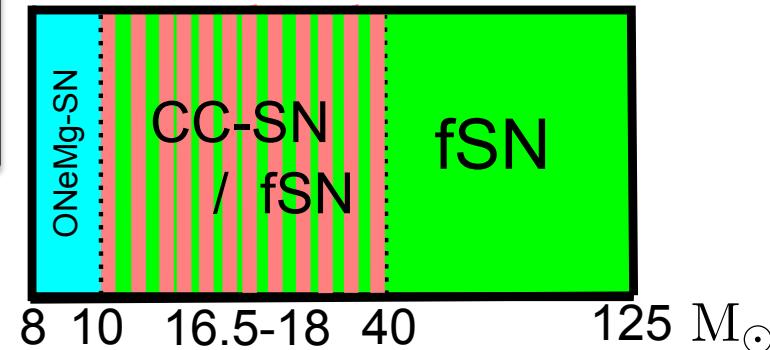


**CCSN:75%, fSN : 25%**

█ neutron star  
 █ significant fallback  
 █ failed explosion, BH



**fSNe : 100%**

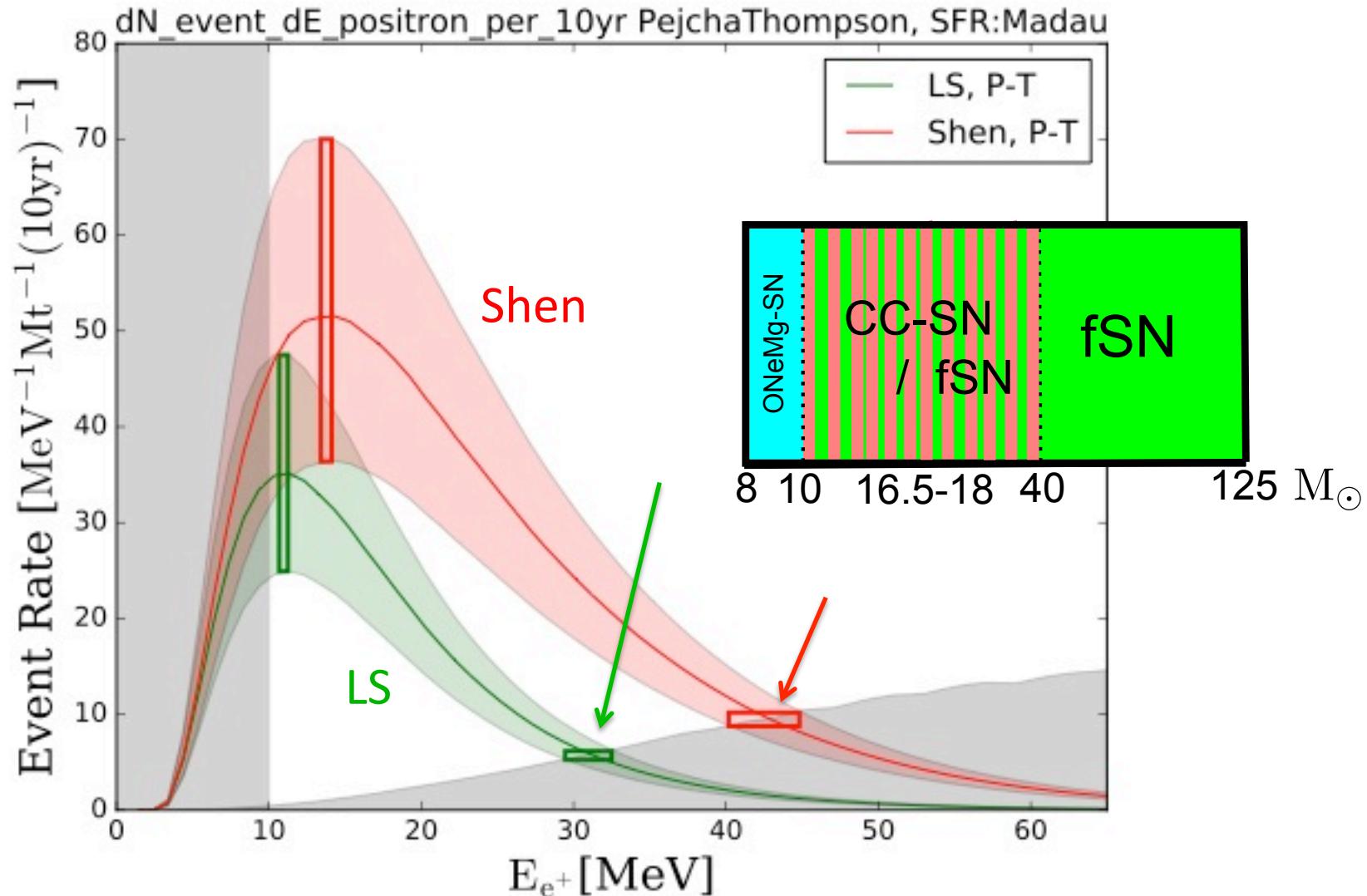


# Event Rate

without neutrino oscillation



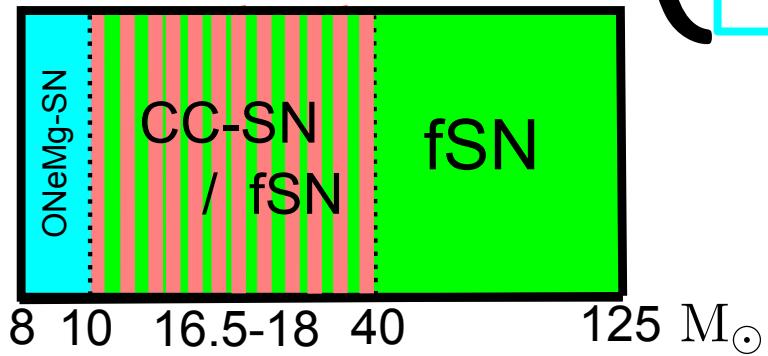
$$\bar{\nu}_e = \bar{\nu}_e^0$$



# Basic Idea

# Astrophysical Scenario

Relic Supernova  
Neutrino  
(RSN)



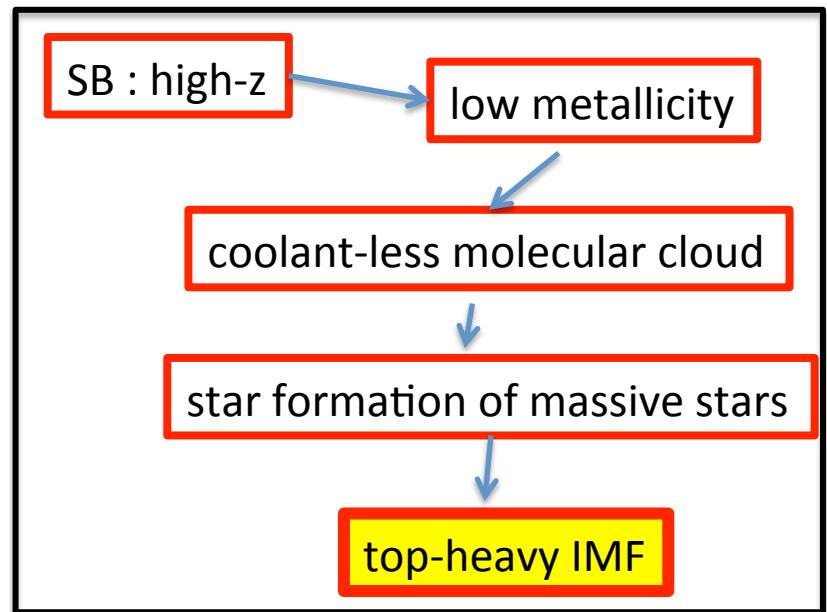
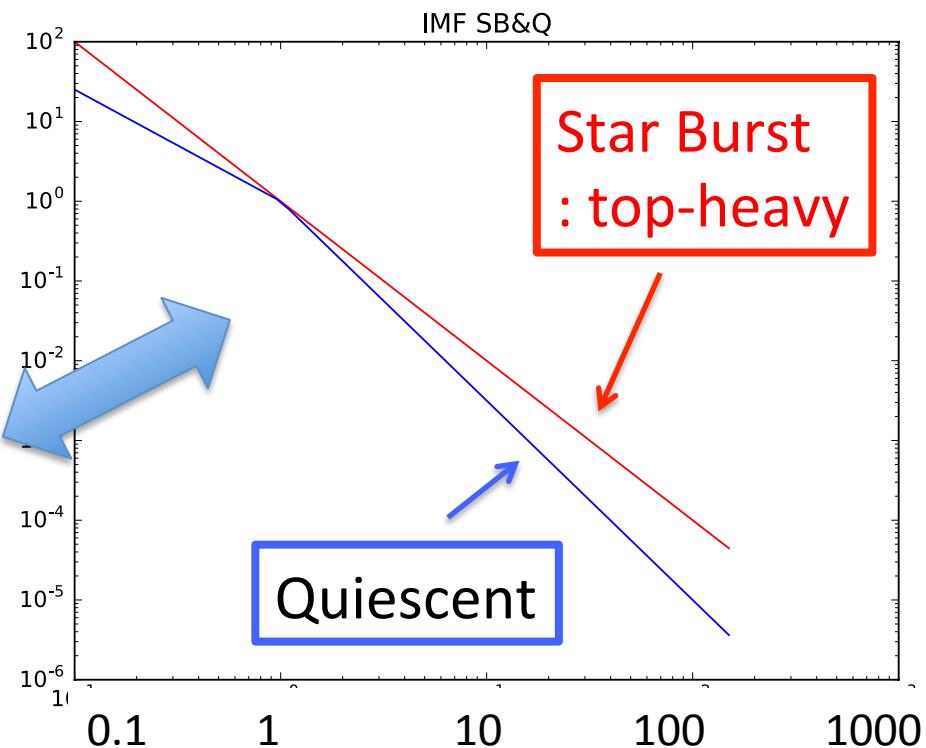
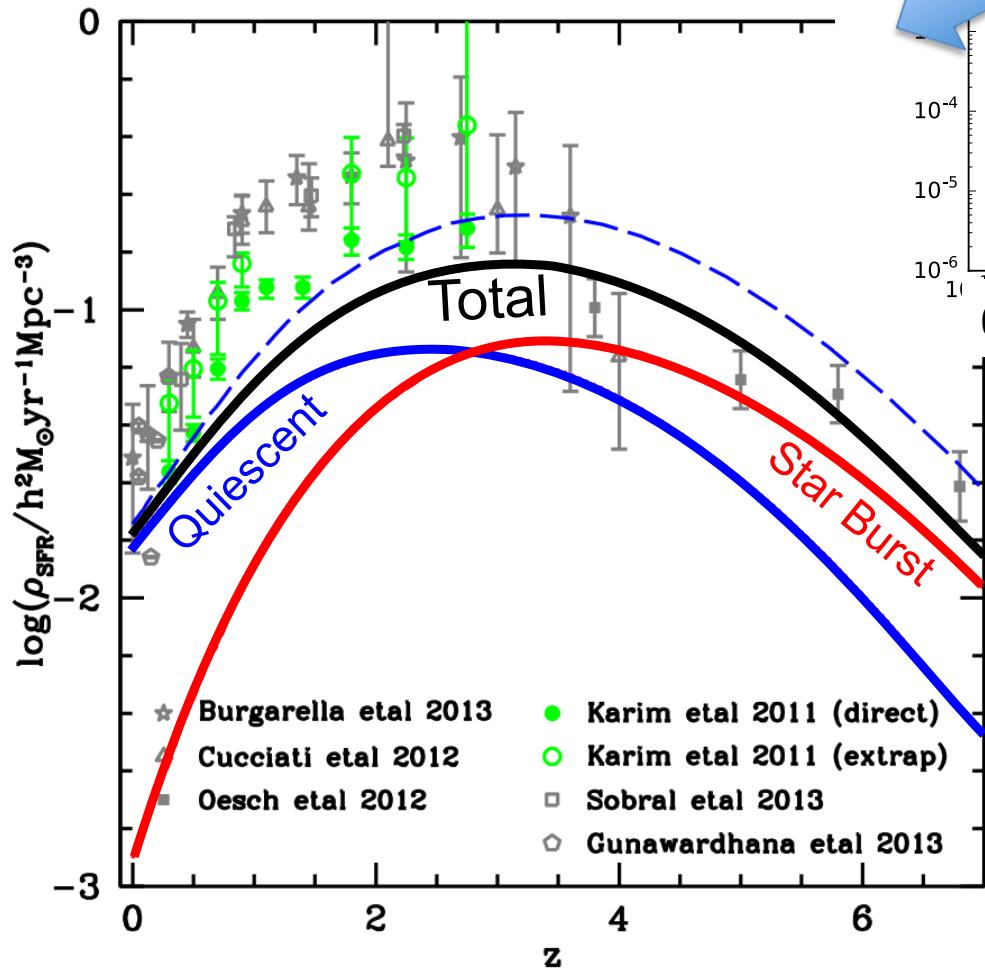
Star Formation Phase:  
Star Burst / Quiescent

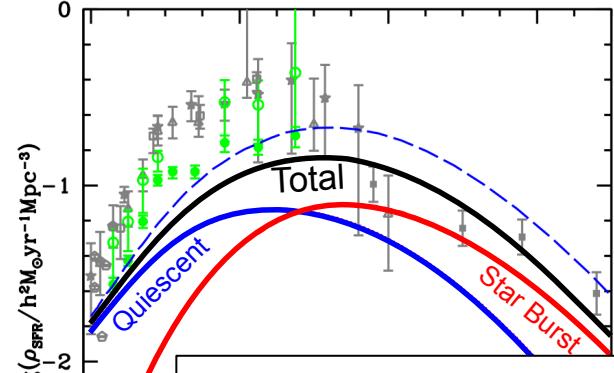
Varying IMF:  
Phase dependent  
 $z$ -dependent  
( Metallicity  
dependent)

# Star Formation Phase: Star Burst / Quiescent

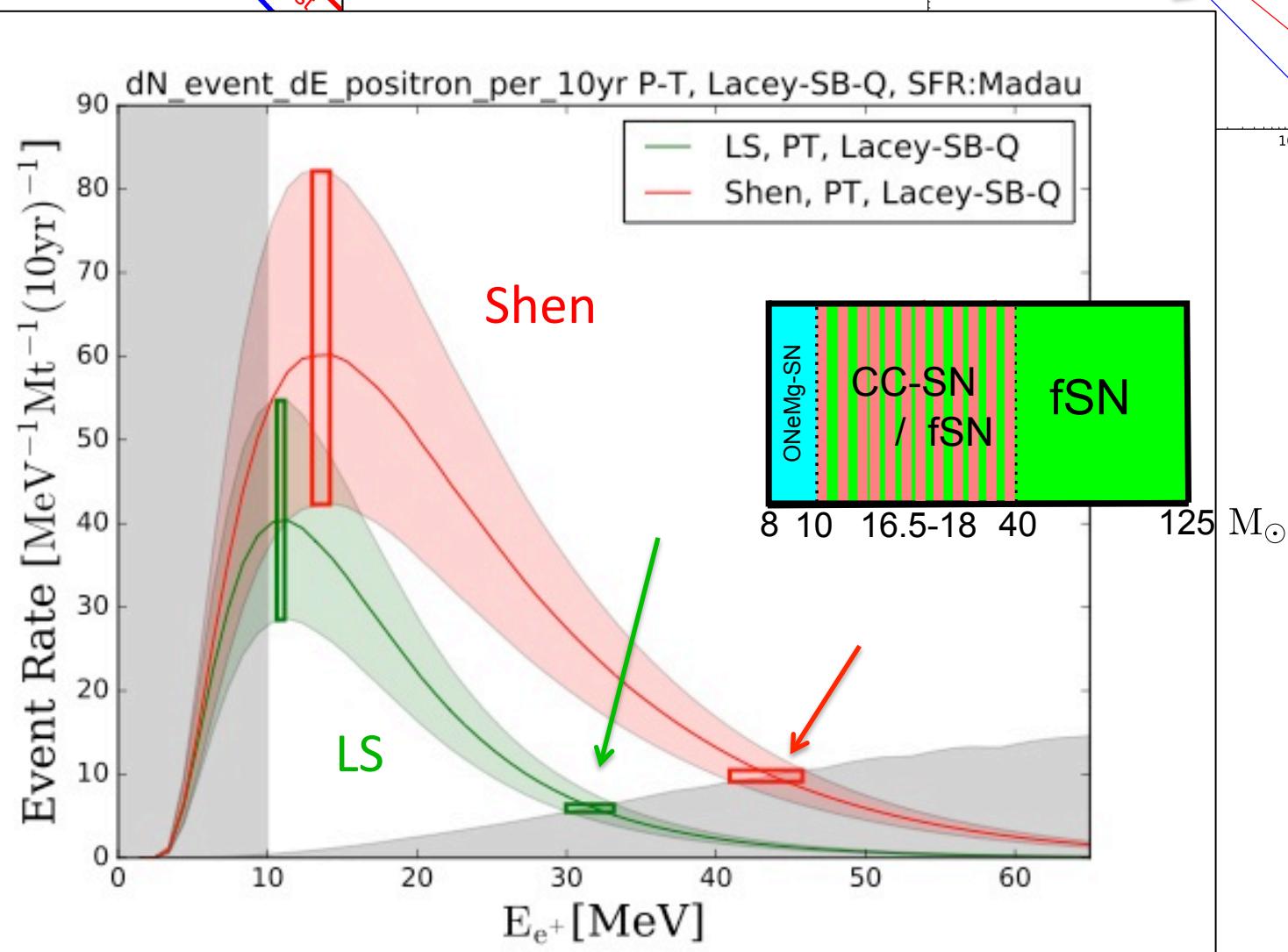
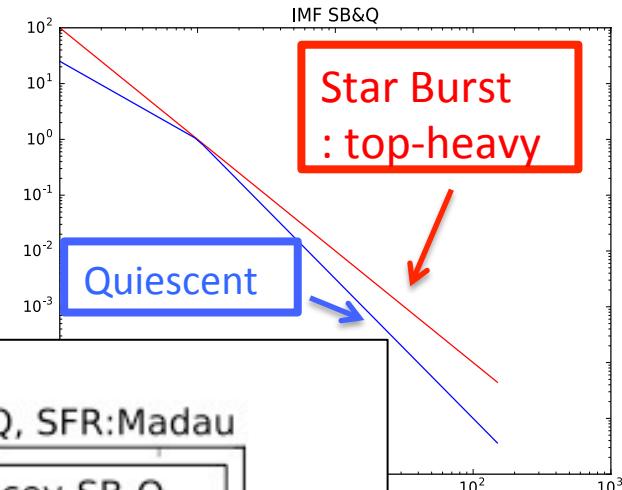
N-body Cosmological Simulation

Lacey et al. MNRAS 462, 3854L



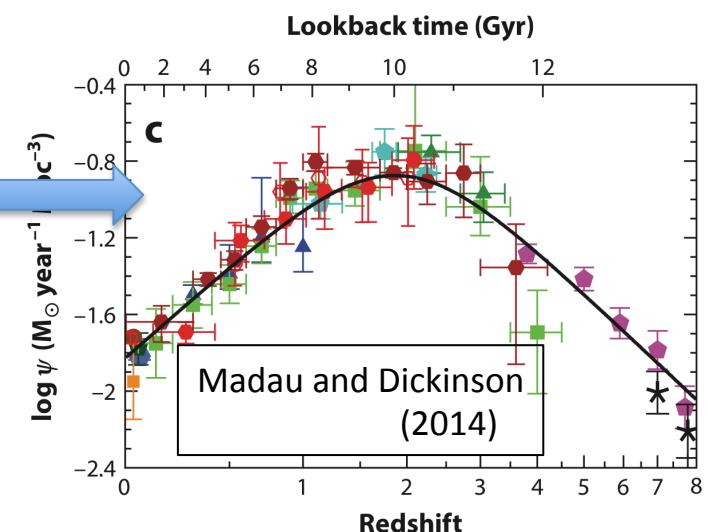
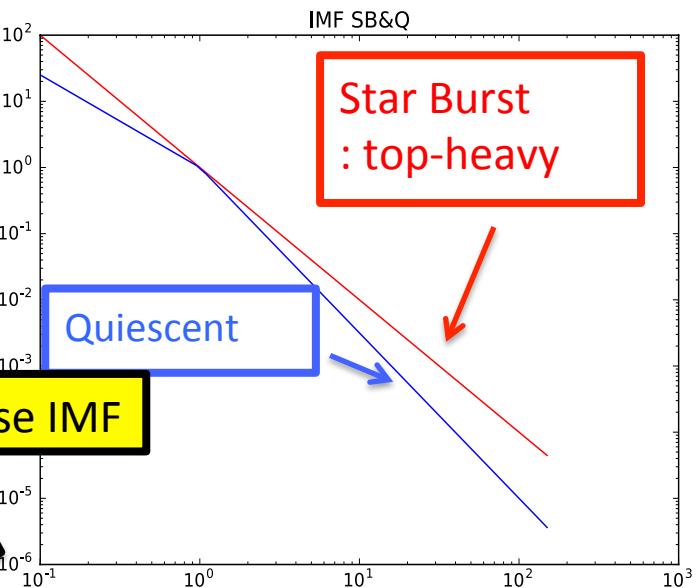
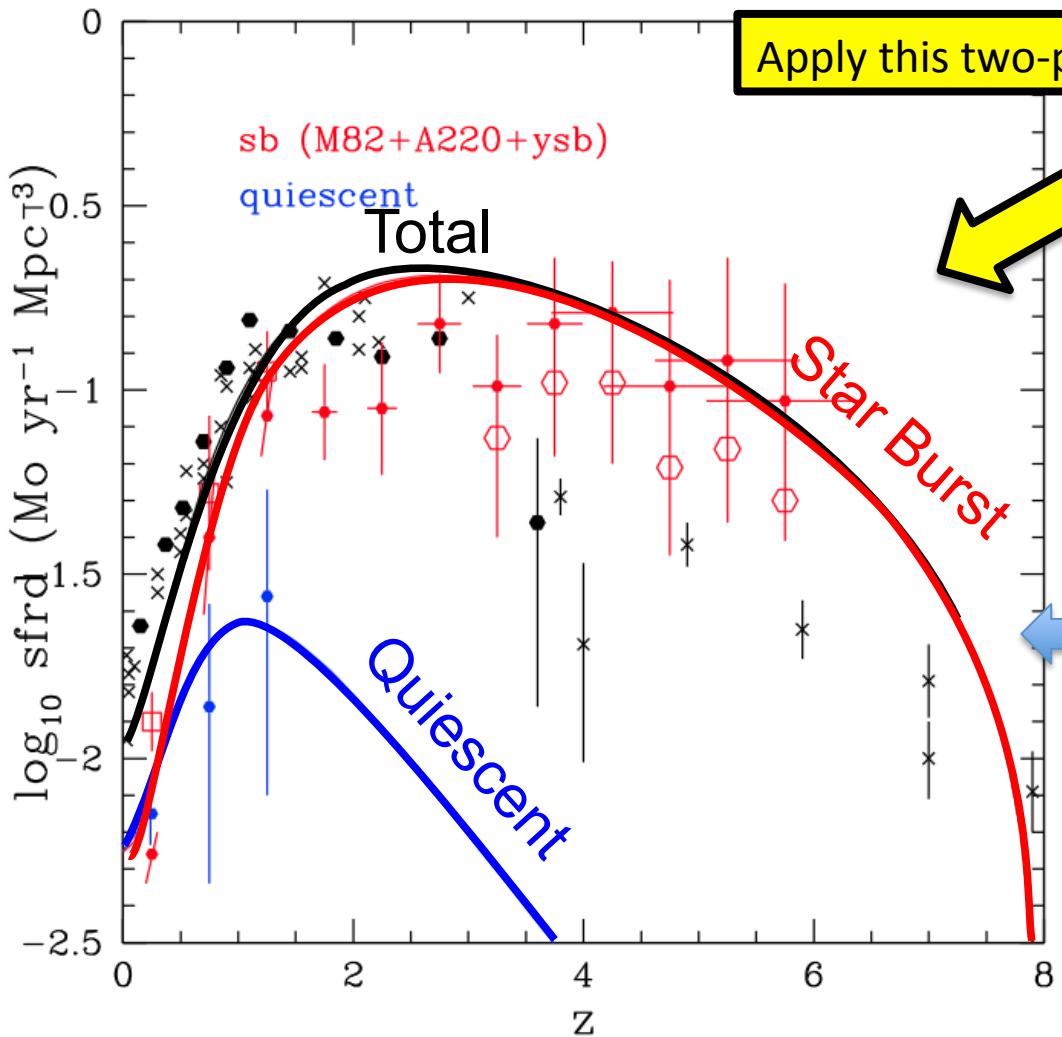


# Event Rate

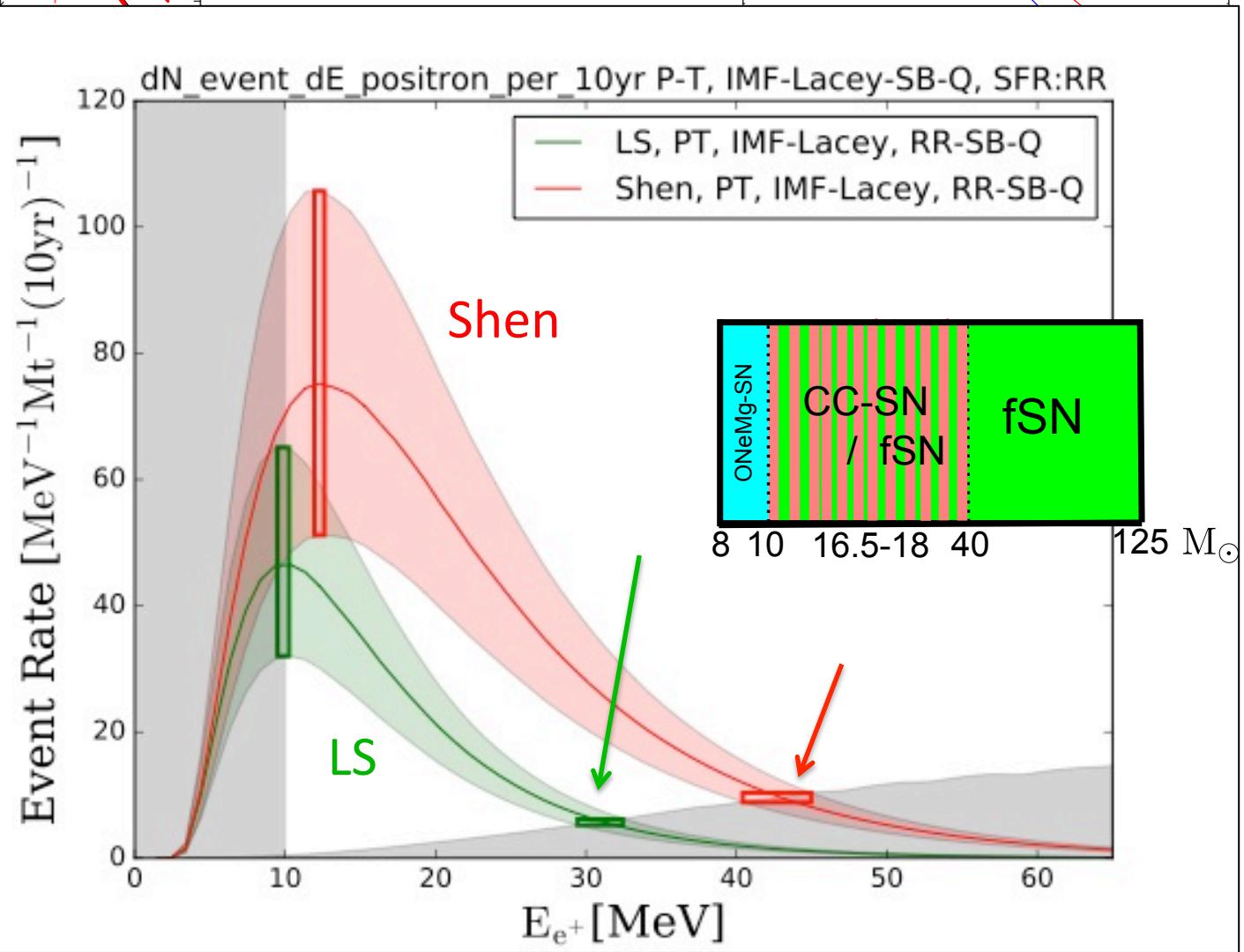
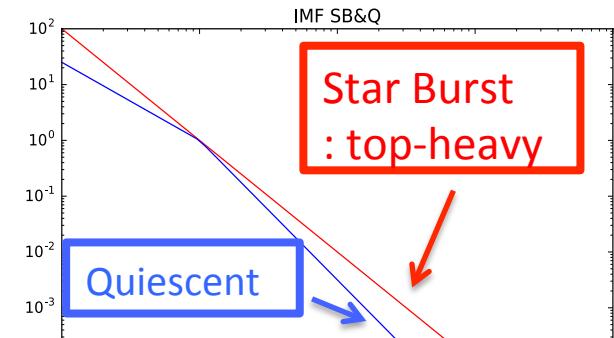
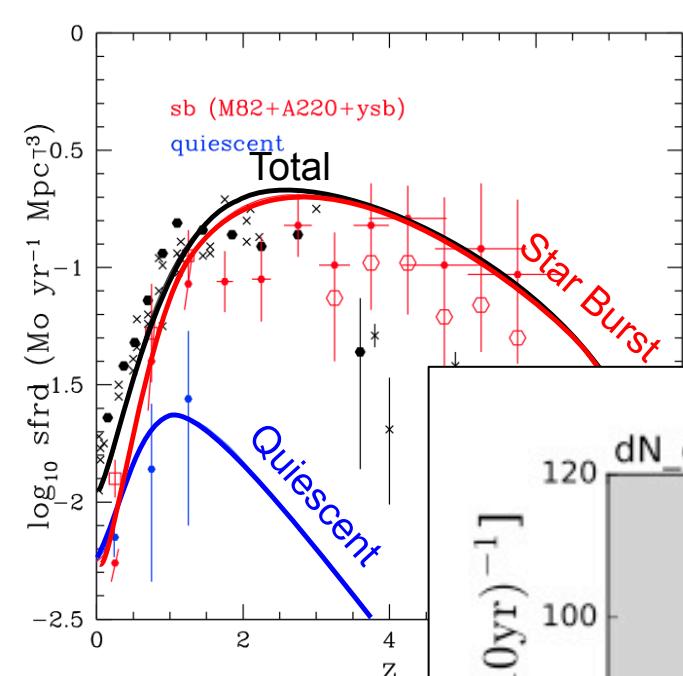
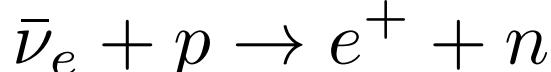


# Star Formation Phase: Star Burst / Quiescent

Rowan-Robinson et al.  
MNRAS **461**, 1100 (2016)



# Event Rate





$M_* - z$  (Galaxy Mass Function)

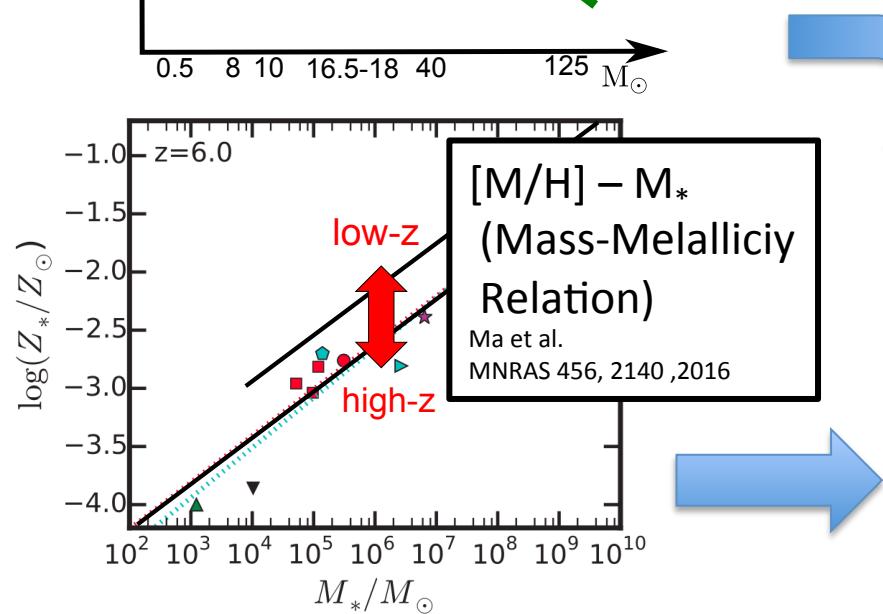
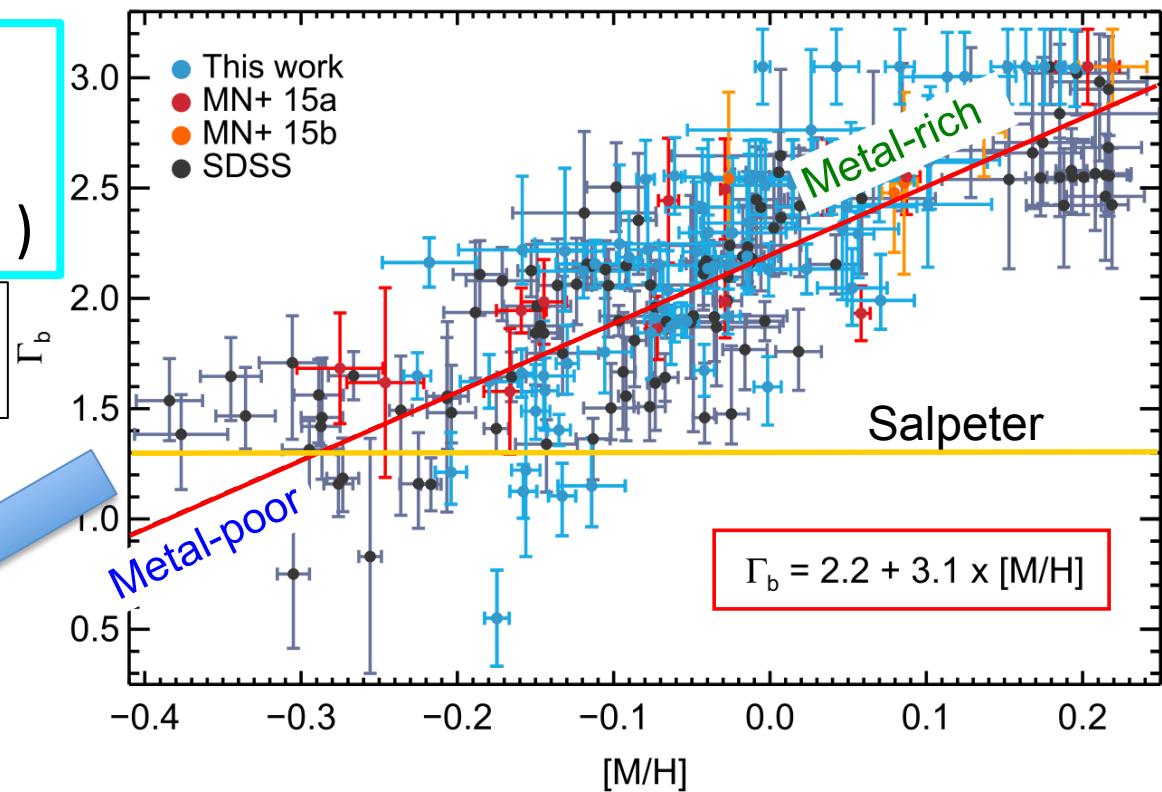
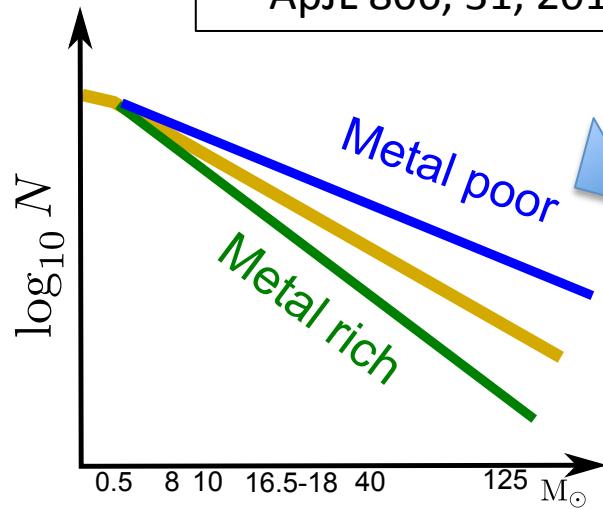


$[M/H] - M_*$   
(Mass-Metallicity Relation)



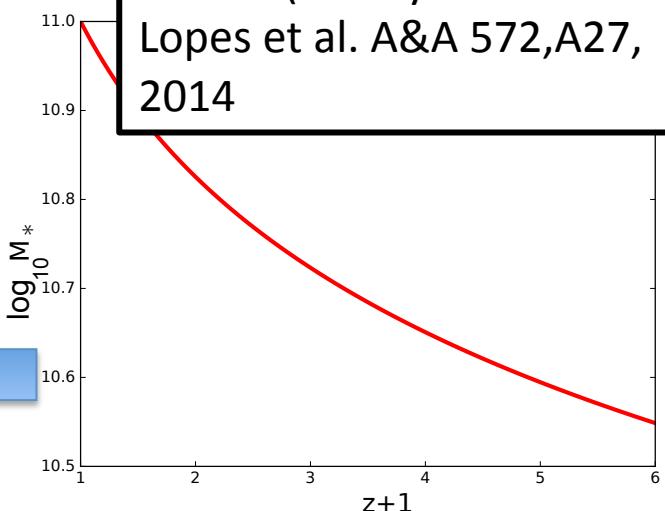
**Varying IMF:**  
**Metallicity dependent**  
 $( \rightarrow z\text{-dependent} )$

Martin-Navarro et al.  
ApJL 806, 31, 2015

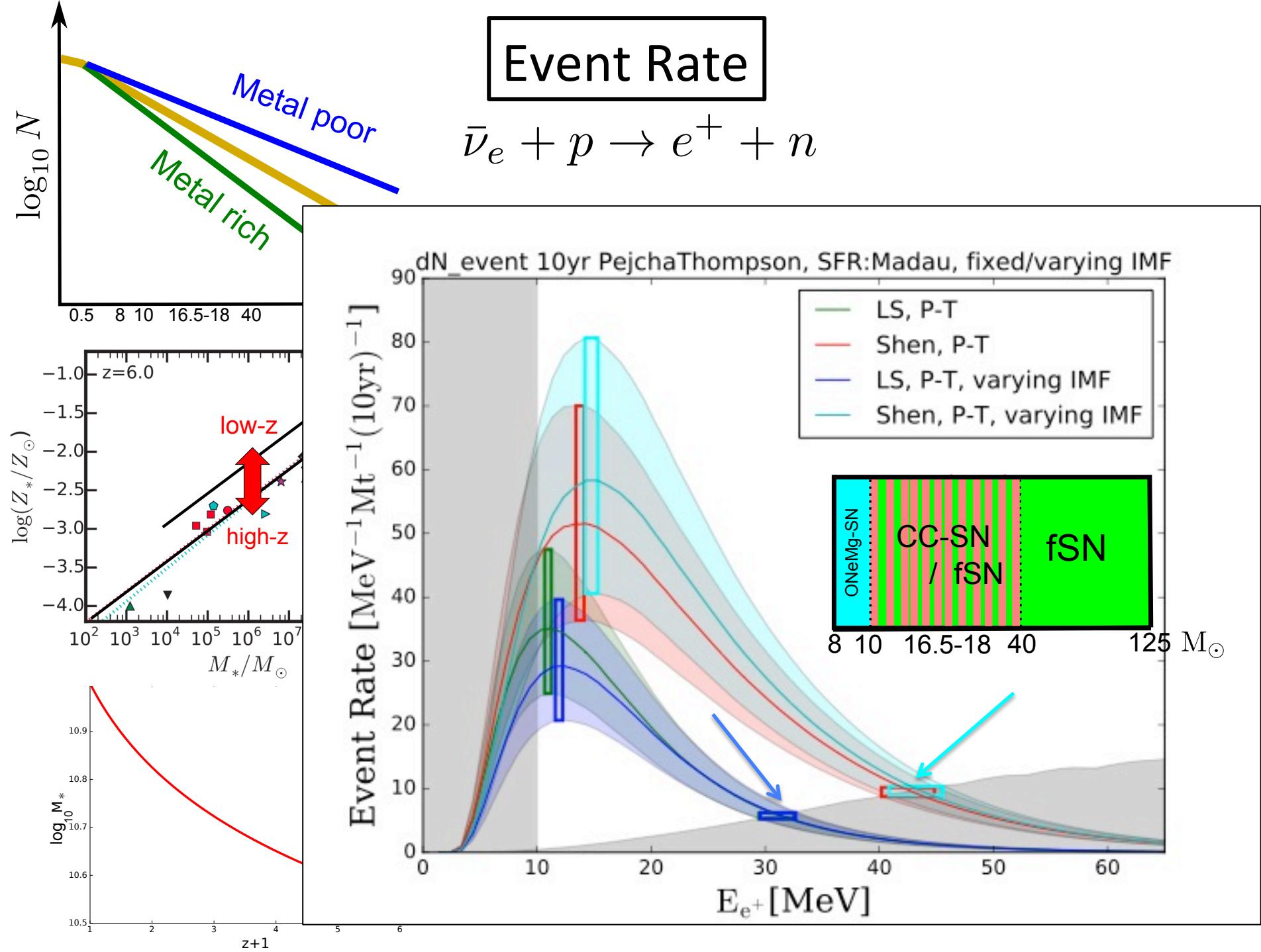


?

$M_* - z$  (Galaxy Mass Function)  
Lopes et al. A&A 572, A27, 2014



# Event Rate

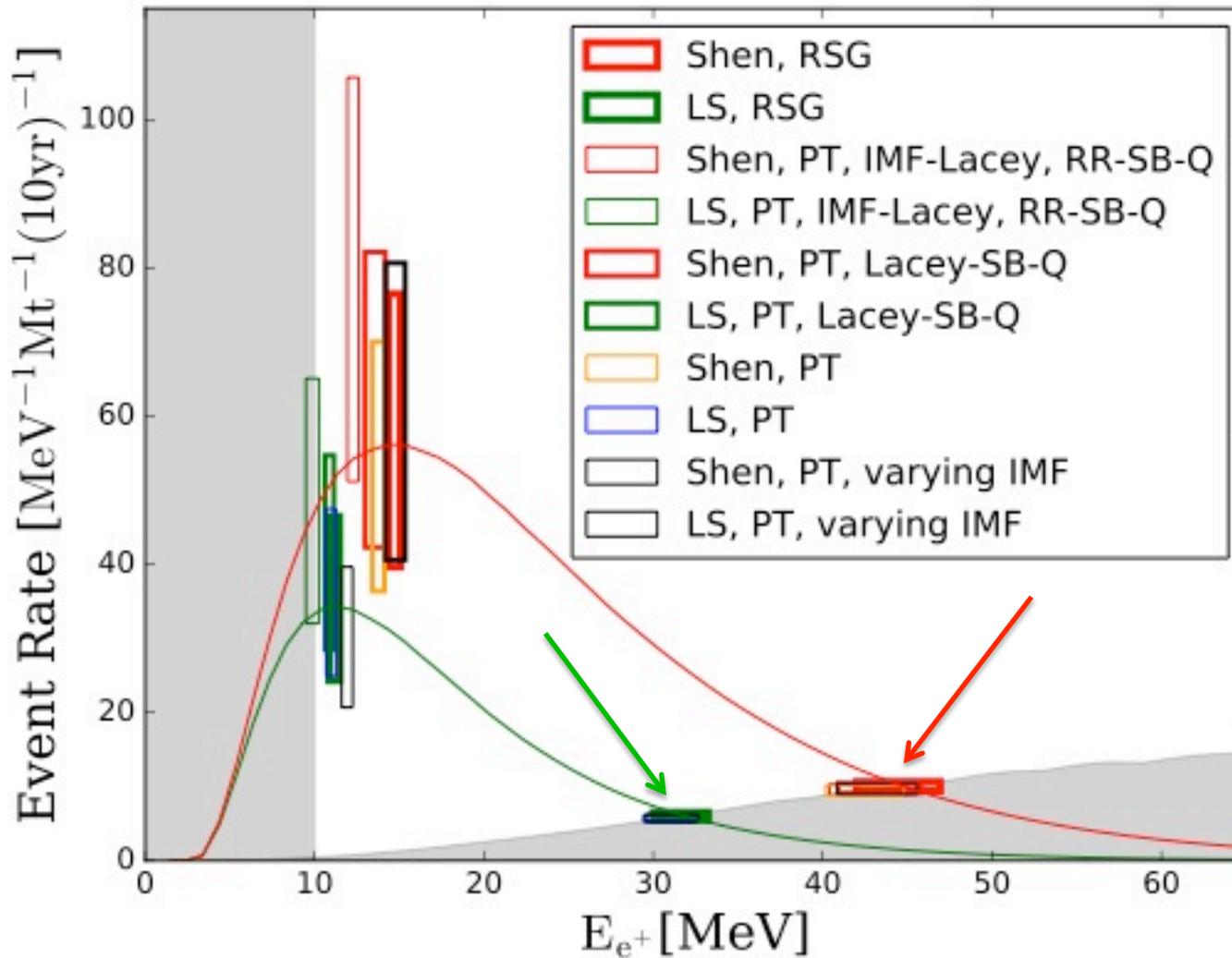


# Event Rate

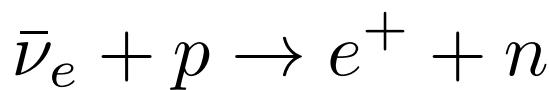
without neutrino oscillation



$$\bar{\nu}_e = \bar{\nu}_e^0$$



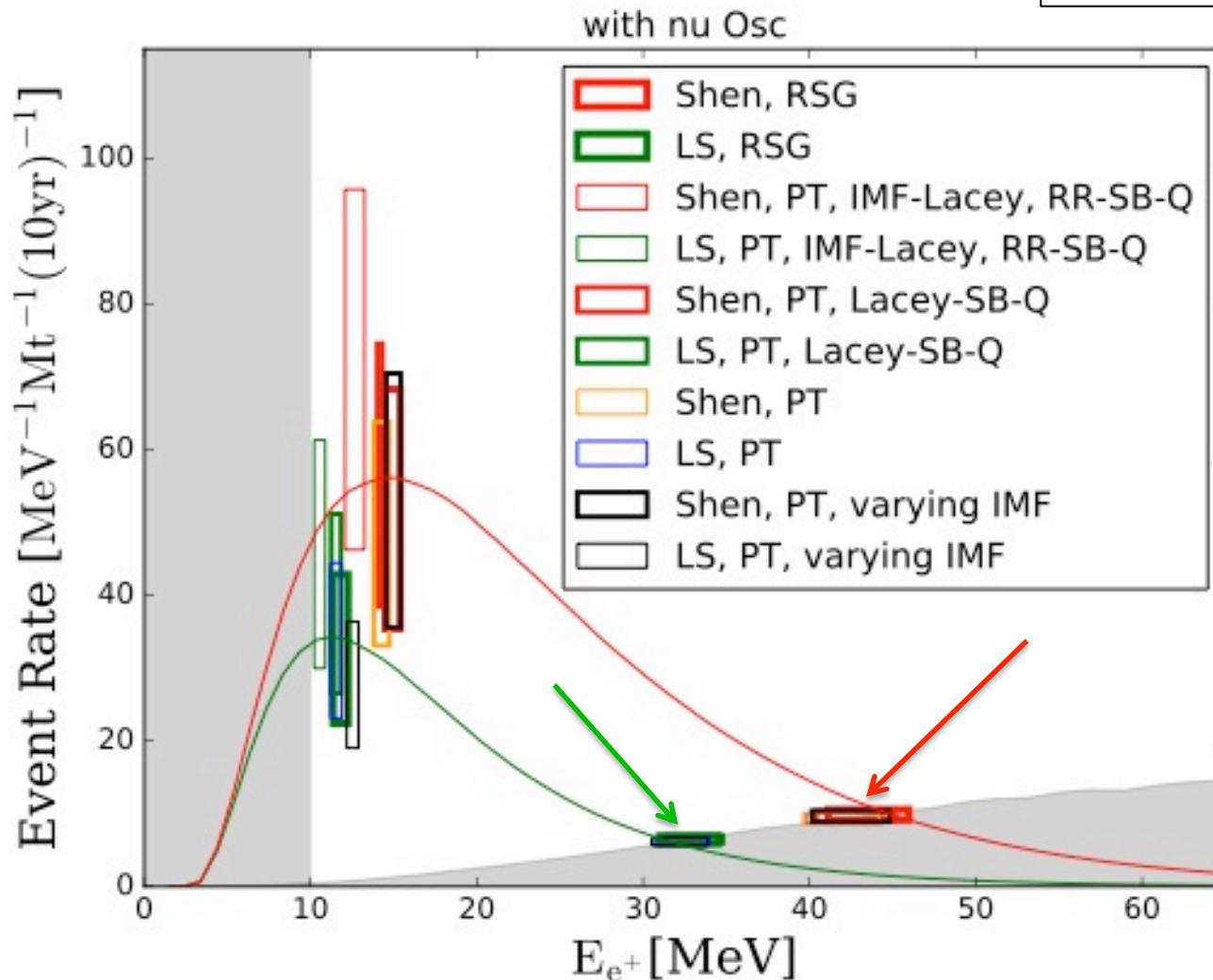
# Event Rate

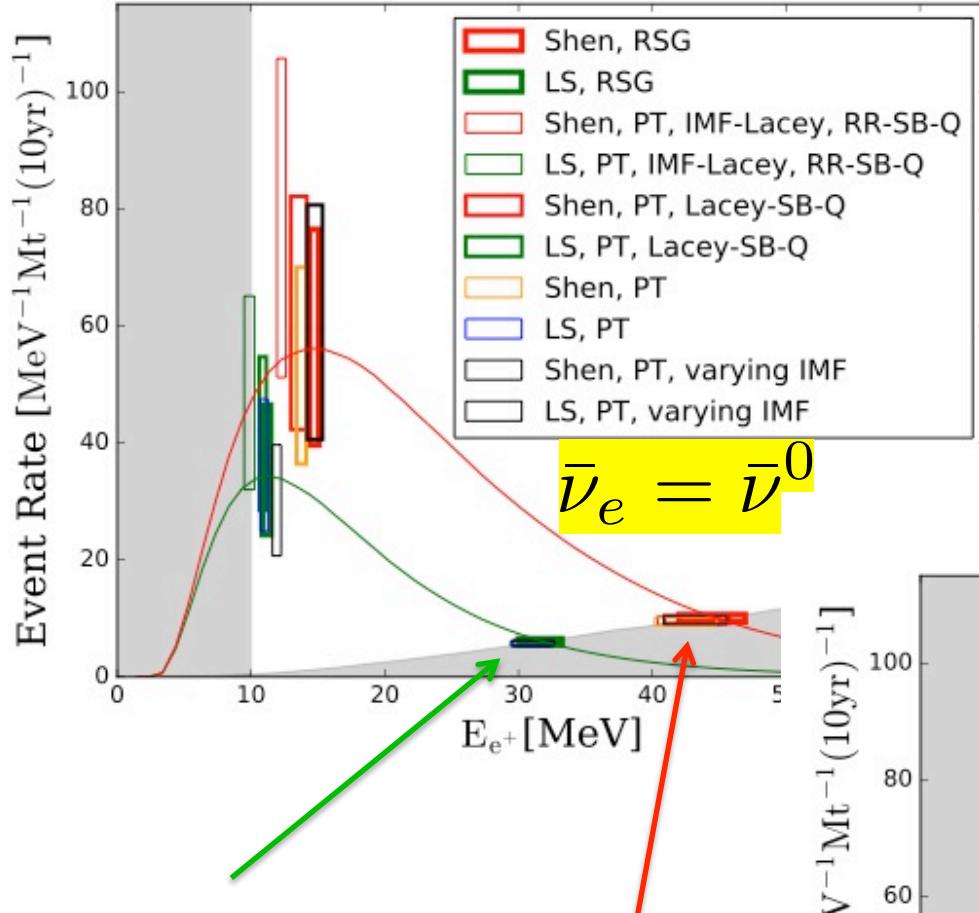


with neutrino oscillation

$$\bar{\nu}_e \leftrightarrow \bar{\nu}_x$$

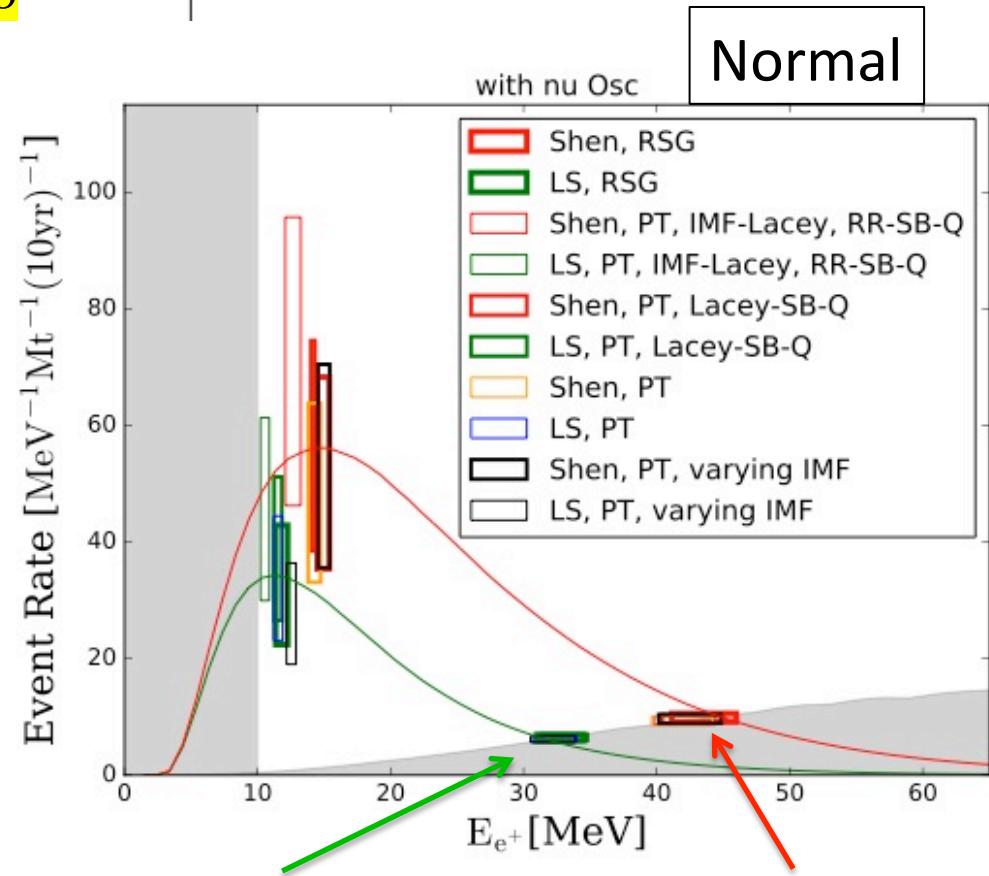
Normal

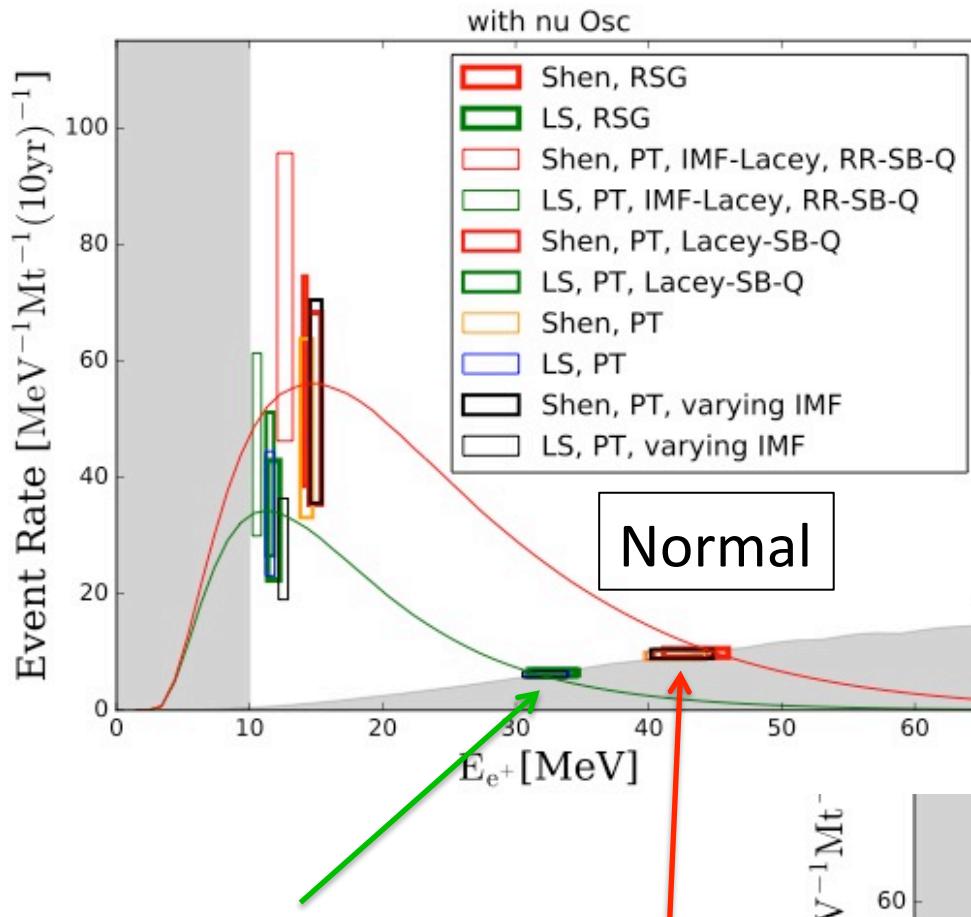




EoS dependency

robust

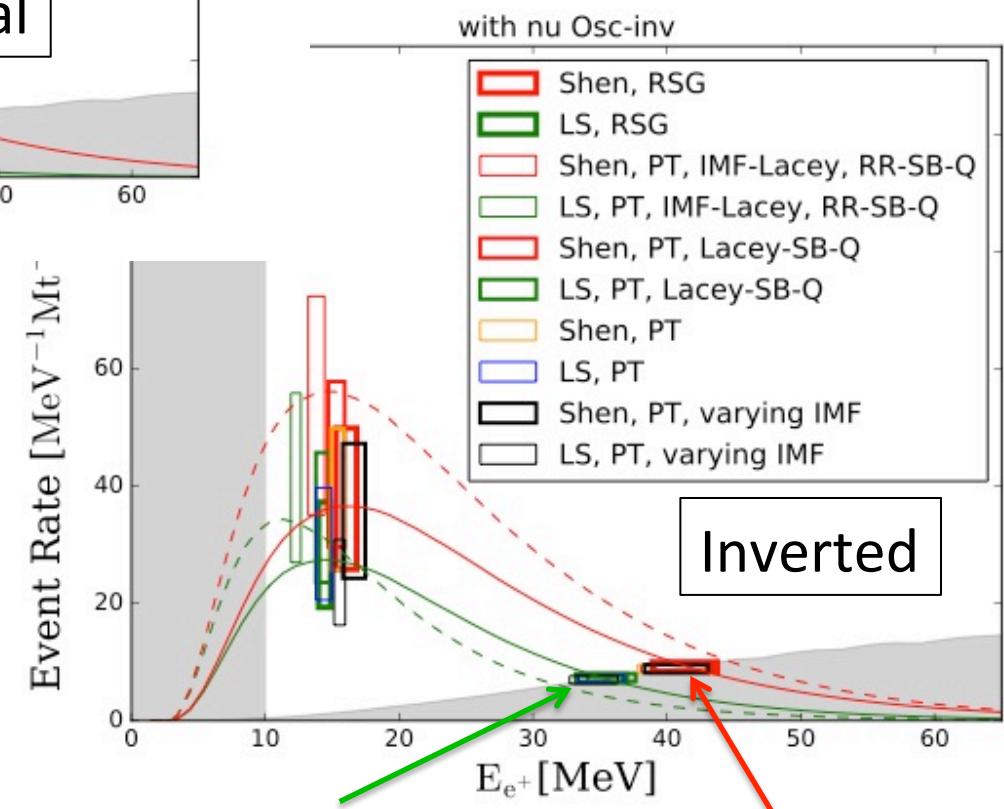




$\bar{\nu}_e \longleftrightarrow \bar{\nu}_x$

EoS dependency

robust( slightly weaker)



# Summary

