DUNE-India Meeting at TIFR

6 June 2025

SN Neutrinos at DUNE

Opportunities, Challenges, Ideas

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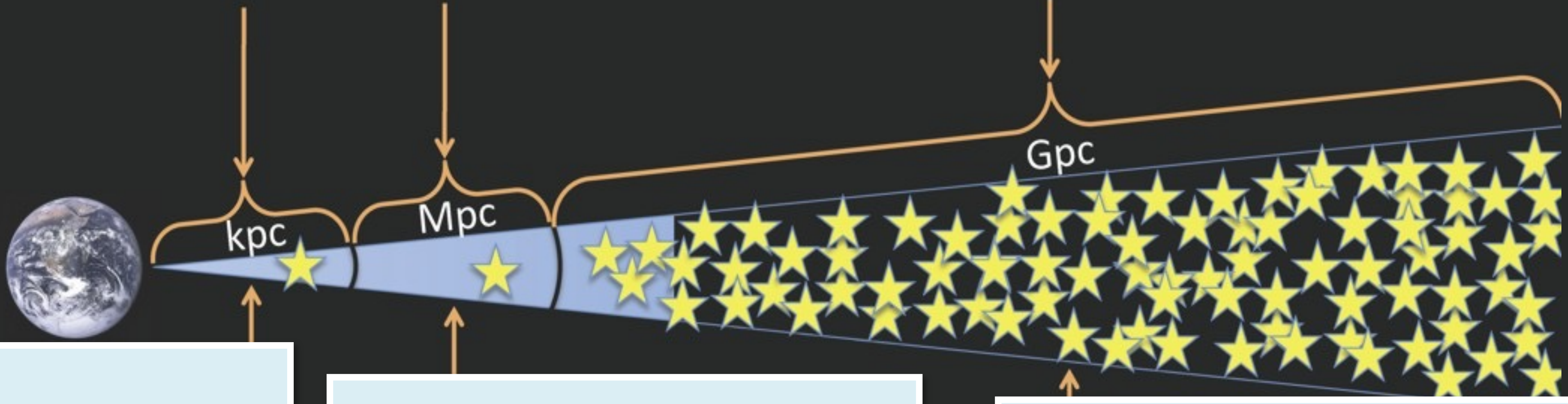
Here, There, Everywhere

N >> 1 : Burst
N ~ 1 : Mini-Burst
N << 1 : DSNB



Rare & Complex but Rich

Need multi-messenger and/or bigger detectors

Hard but Promising

Rate ~ 0.01/yr
Rate ~ 1/yr
Rate ~ 10^8/yr

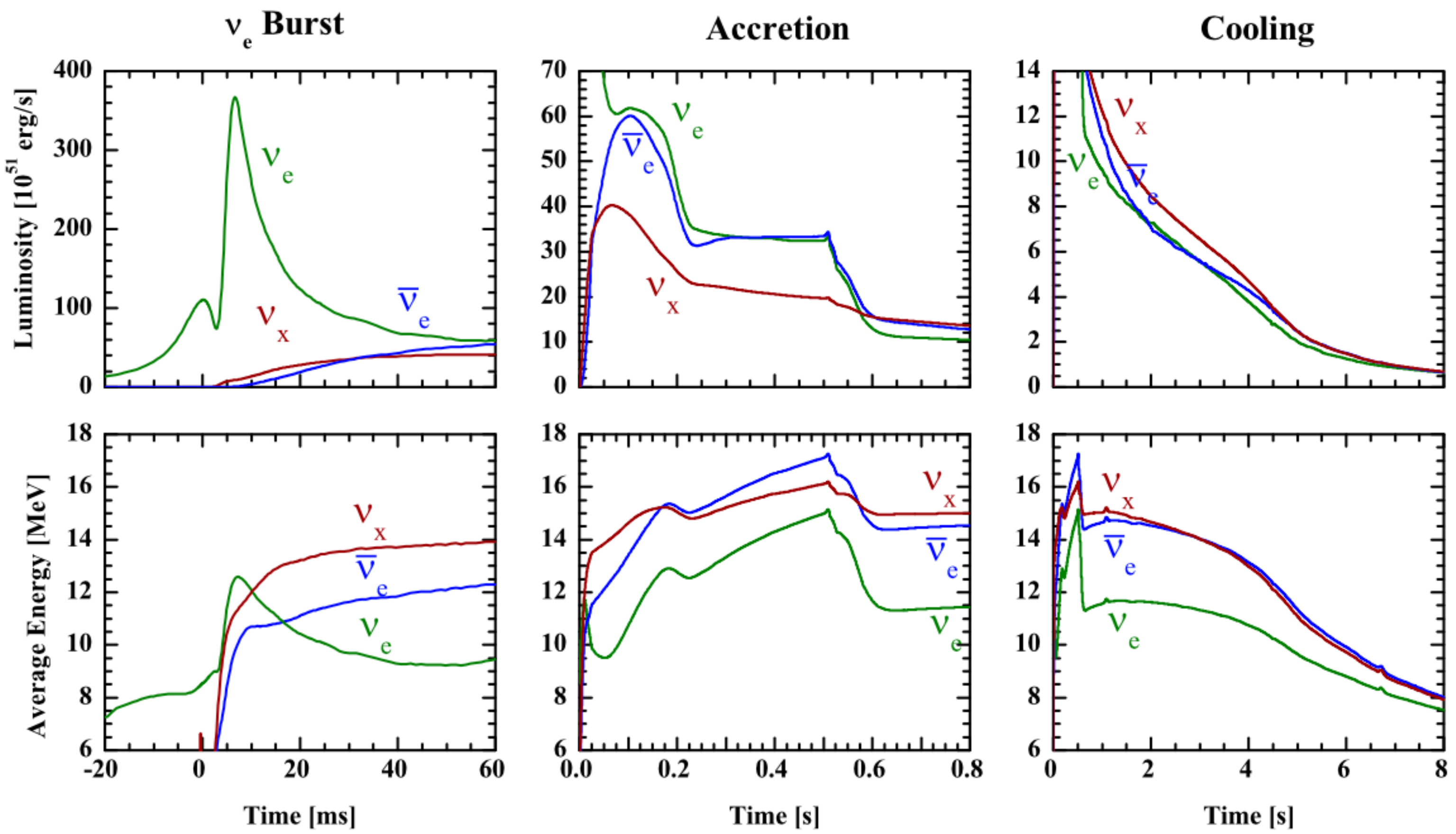
high statistics, all flavors

object identity, burst variety

cosmic rate, average emission

Slide adapted from John Beacom

Neutrinos from a SN



1d simulation of a 27 M_{sun} star by Garching group
See review by Janka, Melson, and Summa (2016)

Modelling is driven by SN simulations, though most features are theoretically well- justified

SN1987A is the only data.

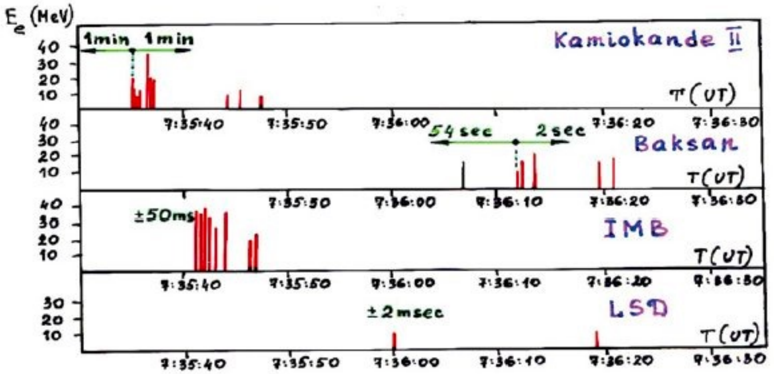
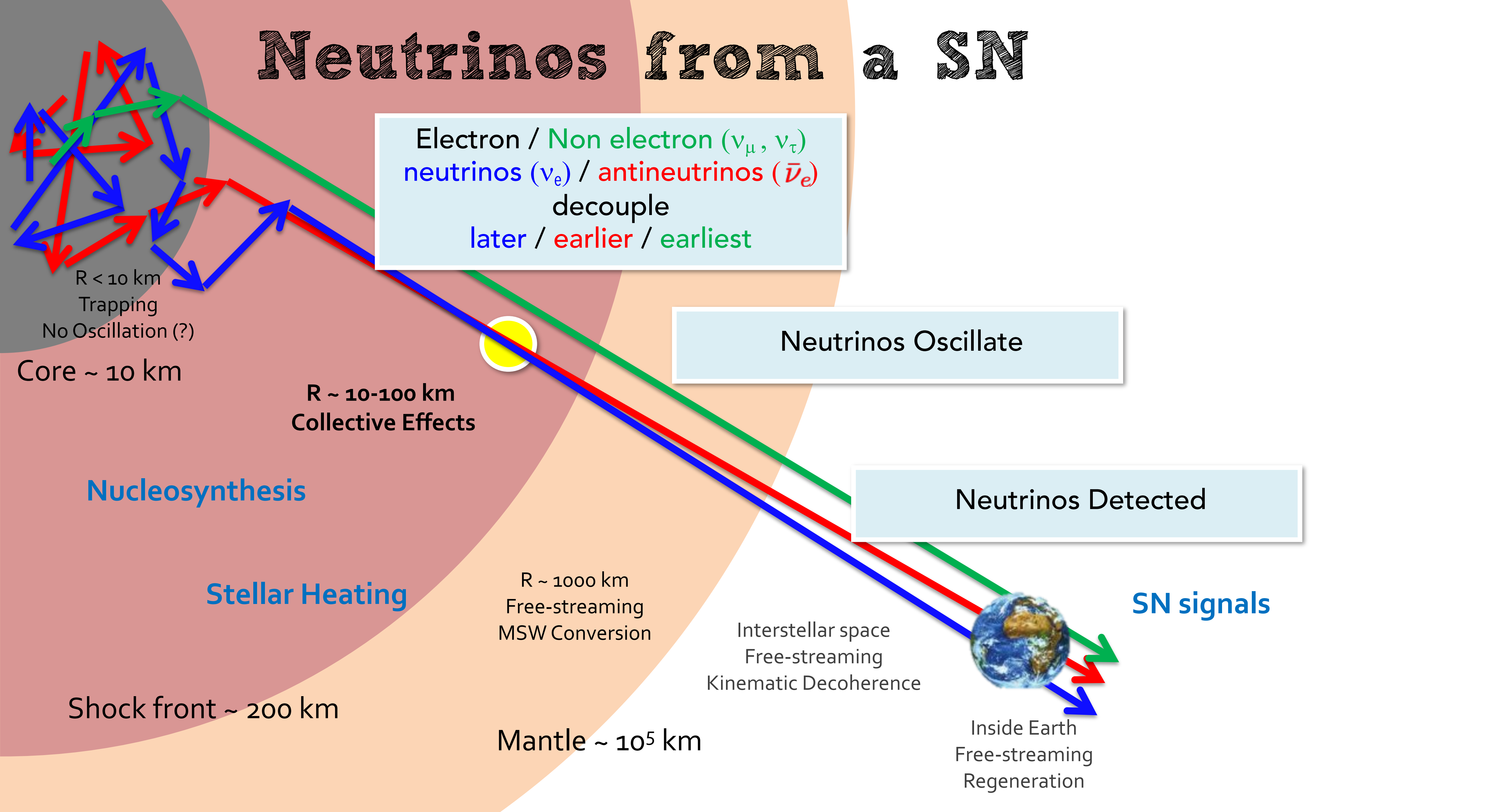


Image credit: Suzuki (2003)

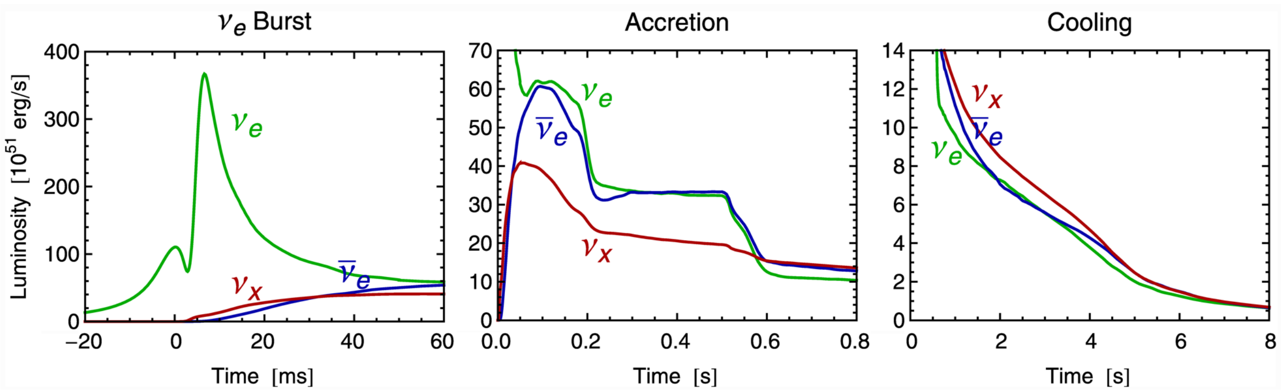

Neutrinos from a SN
Electron / Non electron (ν_μ, ν_τ)
neutrinos (ν_e) / antineutrinos ($\bar{\nu}_e$)
decouple
later / earlier / earliest
R < 10 km
Trapping
No Oscillation (?)
Core ~ 10 km
R ~ 10-100 km
Collective Effects
Nucleosynthesis
Stellar Heating
Shock front ~ 200 km
R ~ 1000 km
Free-streaming
MSW Conversion
Mantle ~ 10^5 km
Neutrinos Oscillate
Neutrinos Detected
Interstellar space
Free-streaming
Kinematic Decoherence
SN signals
Inside Earth
Free-streaming
Regeneration

SN Neutrino Program

Running / Future

Detector	Type	Mass (kt)	Location	Events	Flavors
Super-Kamiokande	H_2O	32	Japan	7,000	$\bar{\nu}_e$
LVD	C_nH_{2n}	1	Italy	300	$\bar{\nu}_e$
KamLAND	C_nH_{2n}	1	Japan	300	$\bar{\nu}_e$
Borexino	C_nH_{2n}	0.3	Italy	100	$\bar{\nu}_e$
IceCube	Long string	(600)	South Pole	(10^6)	$\bar{\nu}_e$
Baksan	C_nH_{2n}	0.33	Russia	50	$\bar{\nu}_e$
MiniBooNE*	C_nH_{2n}	0.7	USA	200	$\bar{\nu}_e$
HALO	Pb	0.08	Canada	30	ν_e, ν_x
Daya Bay	C_nH_{2n}	0.33	China	100	$\bar{\nu}_e$
NOνA*	C_nH_{2n}	15	USA	4,000	$\bar{\nu}_e$
SNO+	C_nH_{2n}	0.8	Canada	300	$\bar{\nu}_e$
MicroBooNE*	Ar	0.17	USA	17	ν_e
DUNE	Ar	34	USA	3,000	ν_e
Hyper-Kamiokande	H_2O	560	Japan	110,000	$\bar{\nu}_e$
JUNO	C_nH_{2n}	20	China	6000	$\bar{\nu}_e$
RENO-50	C_nH_{2n}	18	Korea	5400	$\bar{\nu}_e$
LENA	C_nH_{2n}	50	Europe	15,000	$\bar{\nu}_e$
PINGU	Long string	(600)	South Pole	(10^6)	$\bar{\nu}_e$

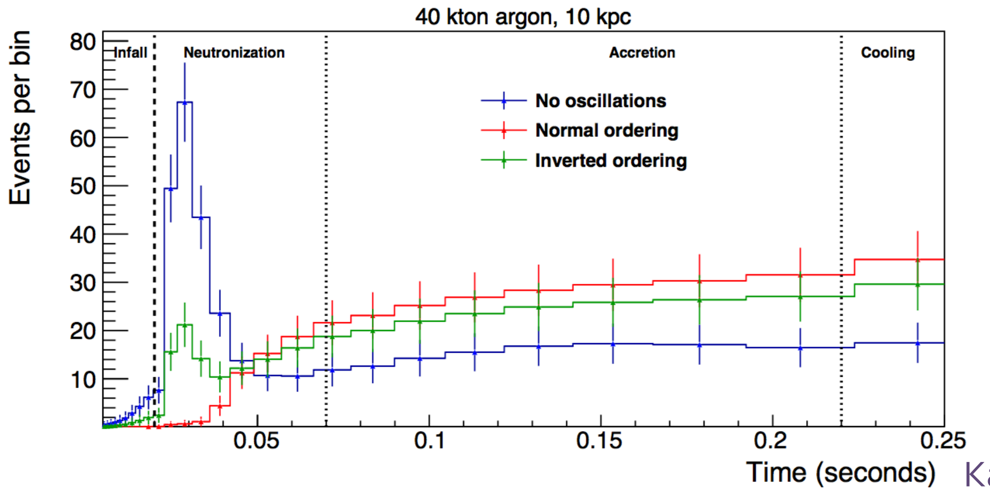
From review by Scholberg (2012)



Burst	Accretion	Cooling
SN standard candle	Collective effects	Nuclear physics
Mass ordering	SN theory	Exotics/Axions
Timing	Mass ordering	Nucleosynthesis
…	Pointing	Shock
	…	…

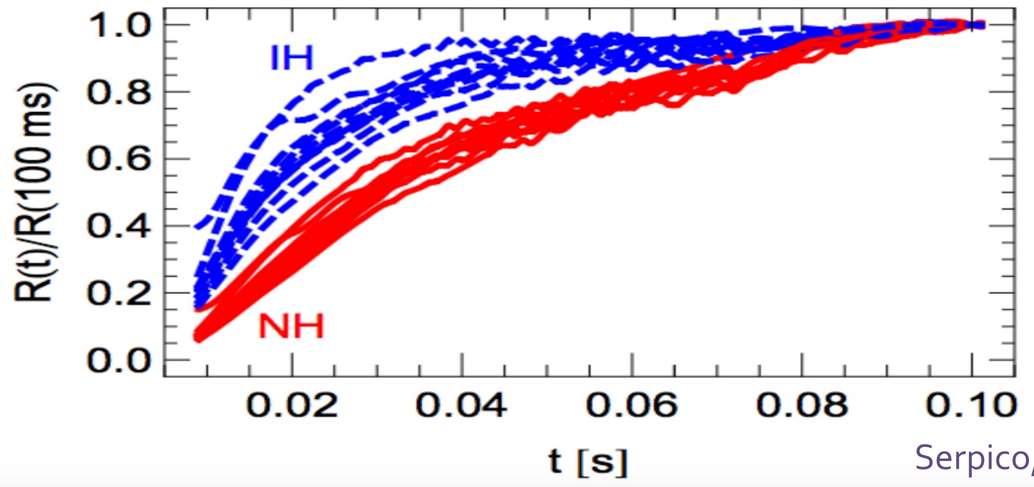
Several detectors capable of detecting SN neutrinos. There is a rich science-case.

Mass Ordering at DUNE



No neutronization peak seen in electron neutrinos for normal mass ordering

Plot from E. Worcester's talk at Neutrino 2018
Wallace, Burrows, Dolence (2015)
Kachelriess, Tomas, Buras, Janka, Marek, Rampp (2004)



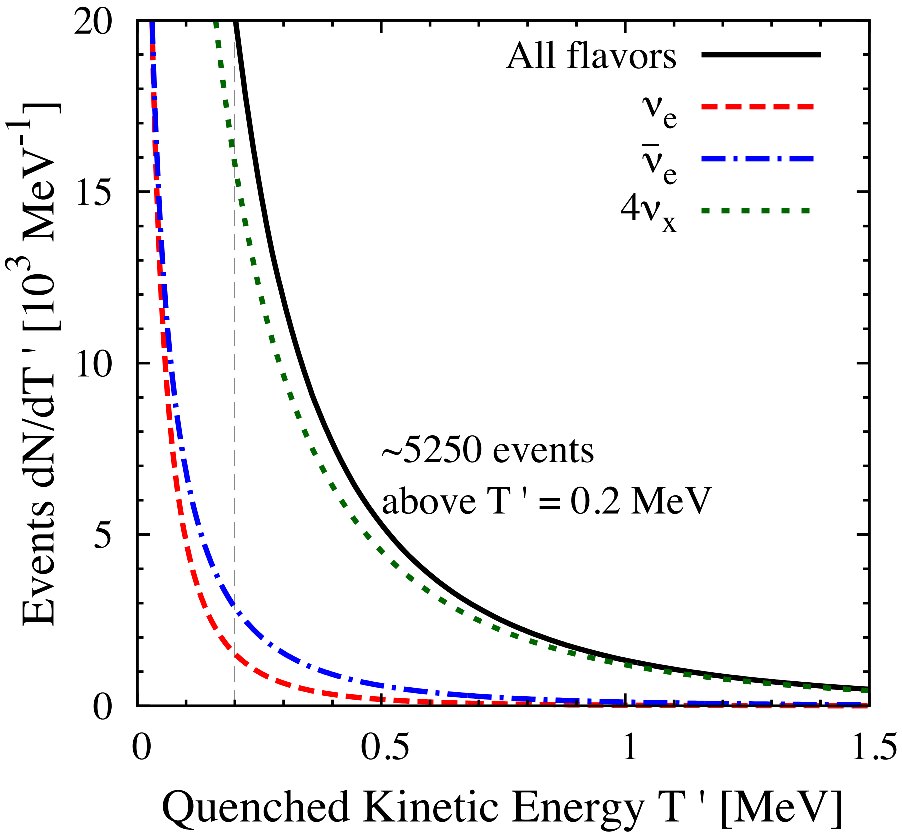
Electron antineutrino signal rises faster for inverted ordering

Note: This can change if fast conversions occurs in the accretion phase

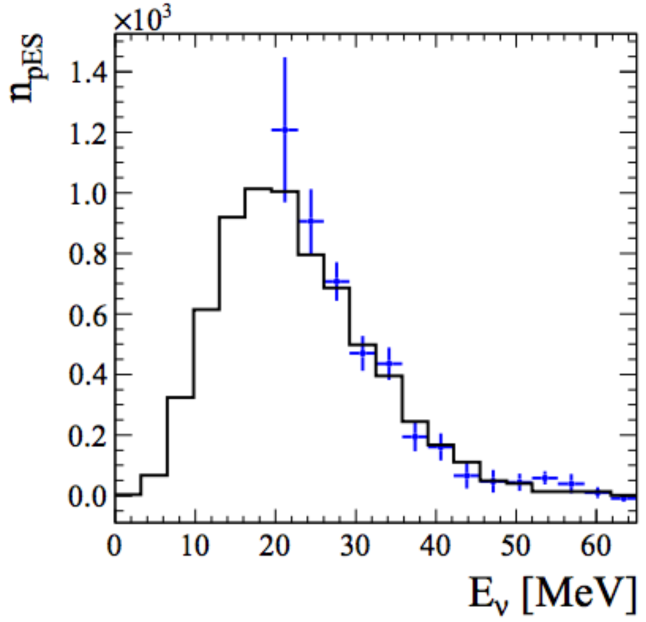
Serpico, Chakraborty, Fischer, Hudepohl, Janka, Mirizzi (2011)

Neutronization burst can reveal the neutrino mass ordering

Neutral Current is Important



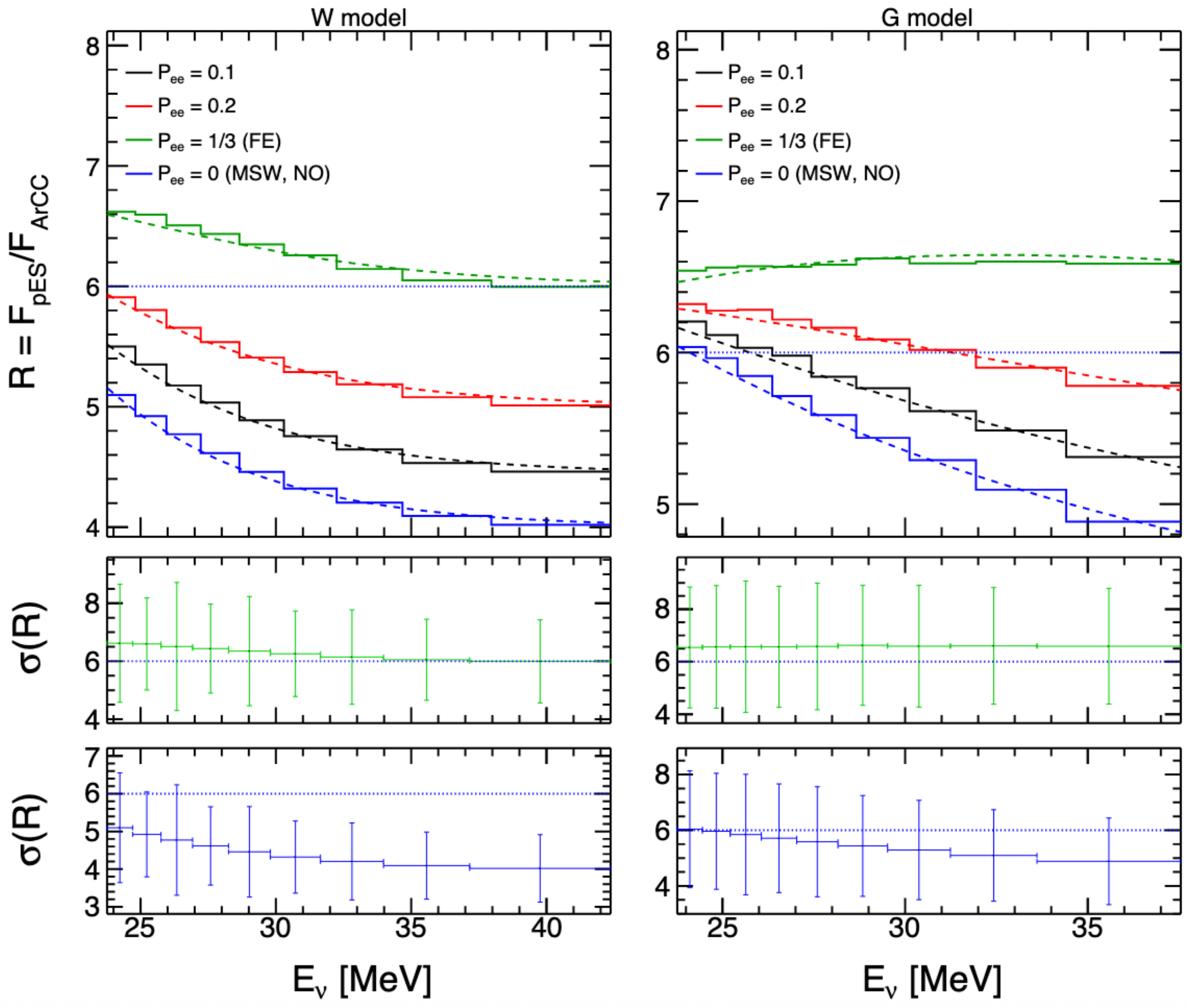
Neutrino – Proton elastic scattering can give the unoscillated fluxes if measured with enough statistics and reconstructed with precision



Beacom, Farr, Vogel (2003)
Dasgupta and Beacom (2011)
See also Chauhan, Dasgupta, Datar (2021) for a new idea using Deuterium

Detailed analysis for JUNO by Li, Li, Wang, Wen, Zhou (2017)

Collective Effects at DUNE



Capozzi, Dasgupta, Mirizzi (2018)

Takeaway

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- SN theory
  - Different phases of SN explosion and different oscillation physics
- Oscillations
  - Adiabatic and Non-adiabatic (at Shock) MSW
  - Slow/Fast Collective Mixing due to "Crossings"
- Detection Prospects
  - Neutrinos of all Flavors, Energies, Times, Directions …
  - Multi-flavor detection helps
- Upshot
  - DUNE is extremely important to detect the electron neutrinos
  - Liq. Scintillator Detectors are useful for non-electron flavors