

Supernova neutrinos at

Erin O'Sullivan
SNnuD 2023



Proceedings Of The 1982 DPF Summer Study On Elementary Particle Physics And Future Facilities

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Cassiday • Chanowitz • Chau • Cho • Cline • Collins • Cook • Cool
Courant • Dake • Derrick • Diebold • Dauwe • Eichten • Eisler
Elbert • Erichsen • Farhi • Fisk • Friedman • Fuki • Gabathuler
Gaisser • Garelick • Gittelman • Goldberg • Gordon • Gottfried
Grannis • Greenhalgh • Gregory • Hayashi • Heinz • Heller • Herb
Hinchliffe • Hoffman • Holman • Holmes • Holynski • Huson
Igo-Kemenes • Iwai • Jackson • Johnson • Jones • Jurak • Kagan
Kane • Kenney • Killian • Knapp • Kreymer • Lambertson • Lane
Lanou • Lederman • Lee • Leemann • Lepage • Leveille
Lindenbaum • Lipton • Littenberg • Loh • Lorenz • Lord • LoSecco
Lowenstein • Lubatti • Ludlam • Lundy • Macek • MacLachlan
Mann • Mantsch • Marciano • Melissinos • Miyamura • Month
Murtagh • Naculich • Nodulman • Odorico • Ogata • O'Halloran
Olsen • Paige • Palmer • Parnell • Parsa • Pauss • Pellett • Perl
Peoples • Peskin • Pipkin • Platner • Pondrom • Potter • Price
Protopopescu • Ratner • Reece • Rehak • Reibel • Reiner • Richter
Rogers • Ruchti • Saito • Samios • Samuel • Sandberg • Schwitters
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Tannenbaum • Taylor • Teng • Thiessen • Thornton • Tigner
Tominaga • Trueman • Tuts • Tye • Tzanakos • Vogel • Watts
Wenzel • Weygand • White • Wiedemann • Wilkes • Williams
Wilson • Wiss • Wolter • Wosiek • Ye

June 28-July 16, 1982
Snowmass, Colorado



What is Snowmass?

Snowmass 1982: Three week retreat
to plan strategy for particle physics

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June 28-July 16, 1982
Snowmass, Colorado

Proceedings of the 1982 DPF Summer Study on Elementary Particle Physics and Future Facilities (June 28-July 16, 1982, Snowmass, Colorado)

Hardcover – January 1, 1982

by [Rene Donaldson](#) (Editor), [Richard Gustafson](#) (Editor), [Frank Paige](#) (Editor)

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United States
Department of
Energy

Publication date



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June 28-July 16, 1982
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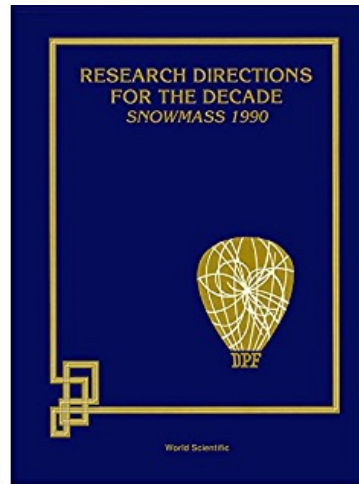
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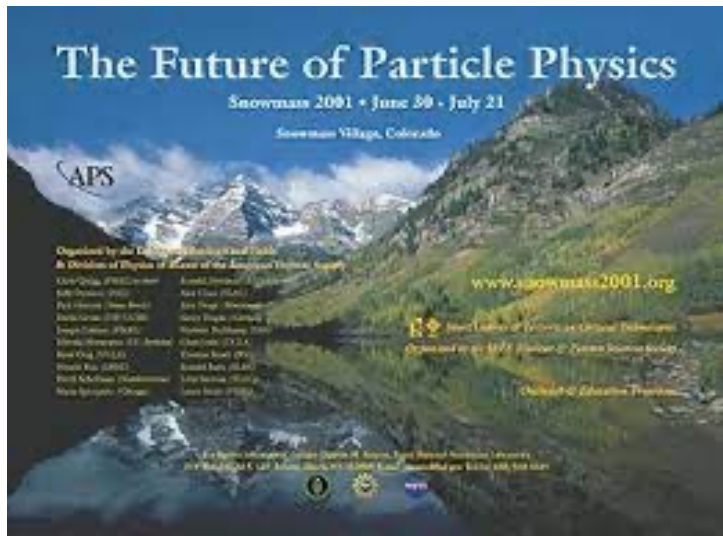
June 28-July 16, 1982
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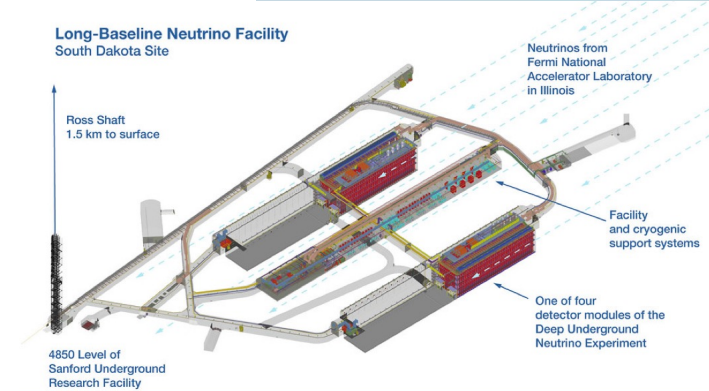
Outcome of first “Snowmass”:
the superconducting supercollider



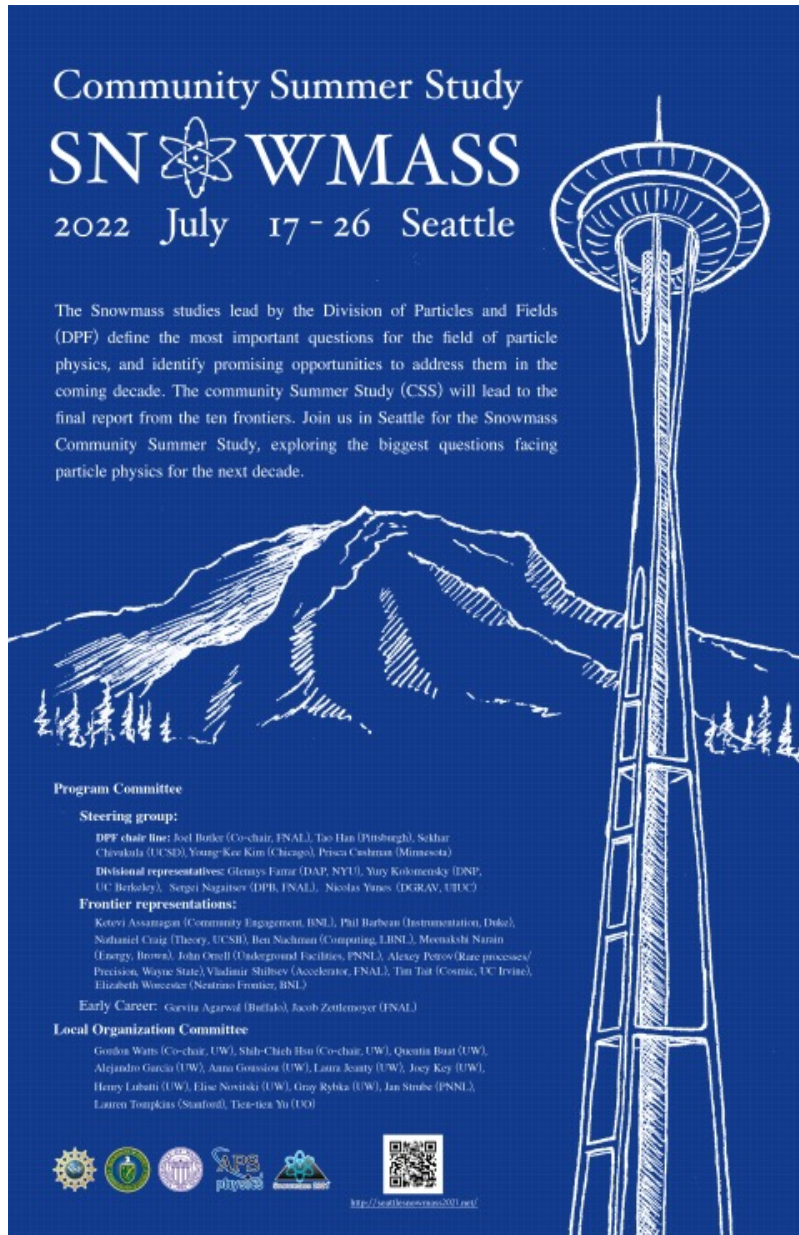
Many more
planning meetings
at Snowmass every
5-10 years



Final Snowmass
Snowmass in 2001



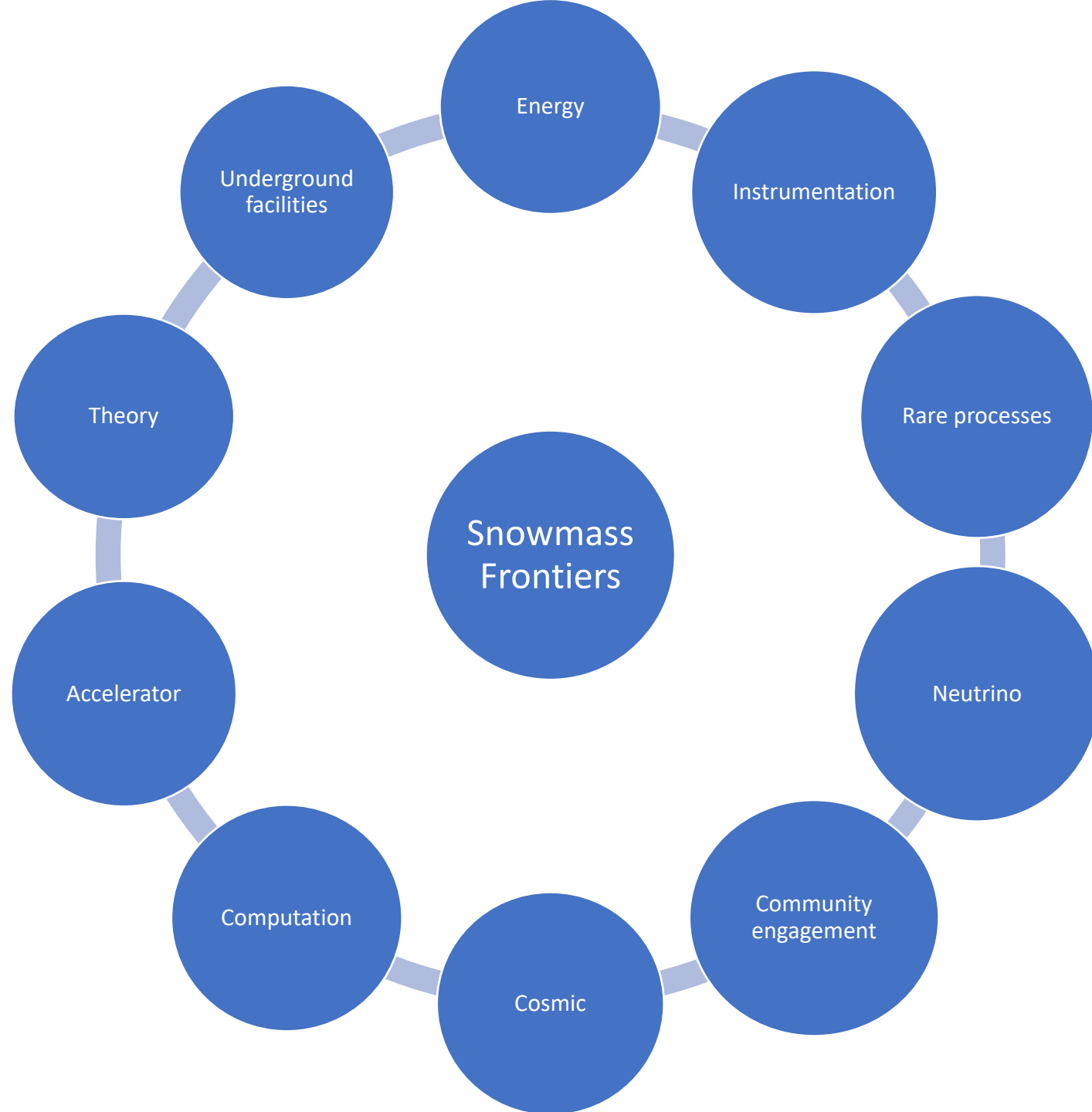
2013, Not at Snowmass and new
format: meetings through the year
and a shorter in-person meeting



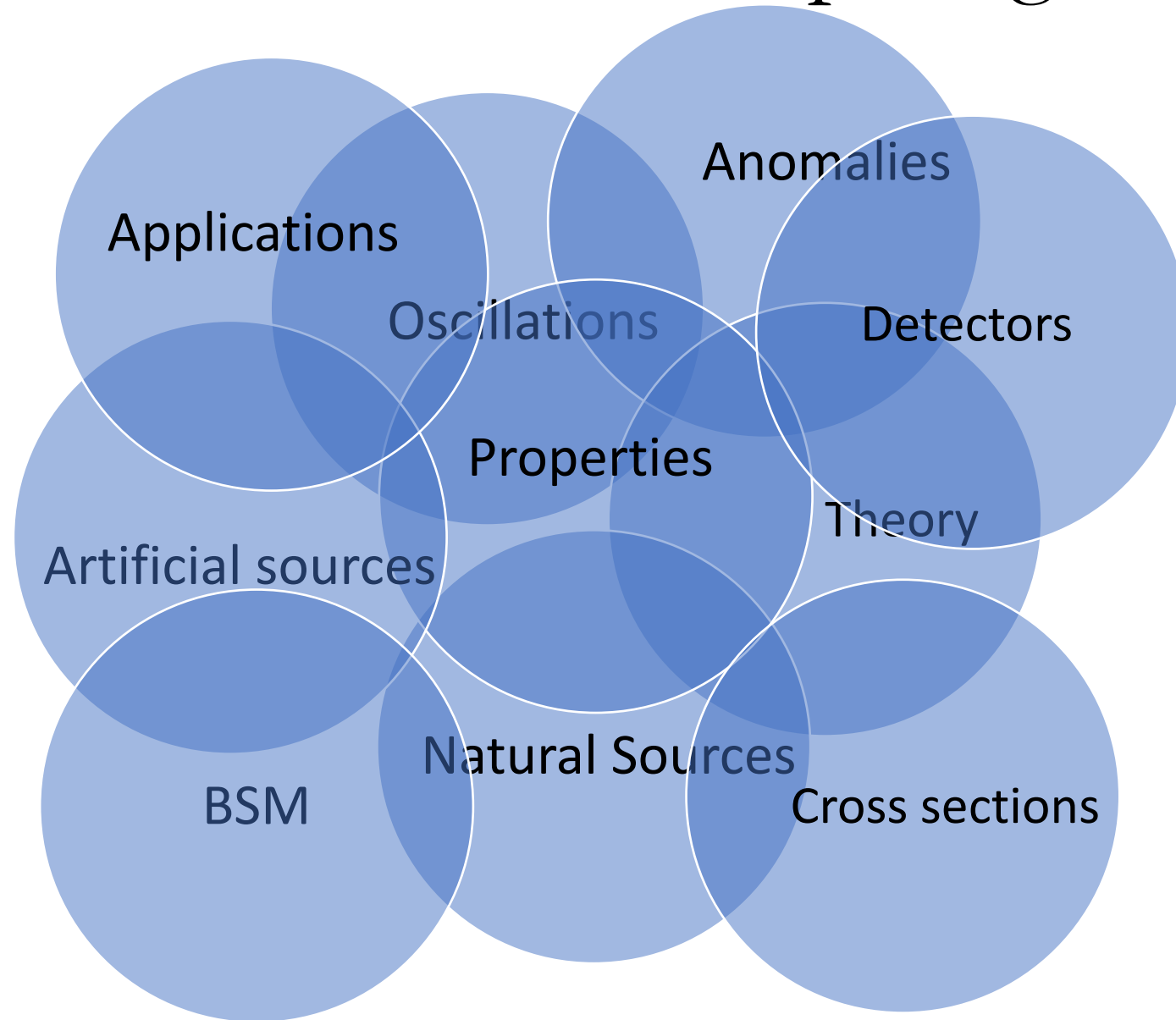
2021: Aimed for similar format to 2013.
 Small meetings leading up to 10 day meeting
 in Seattle

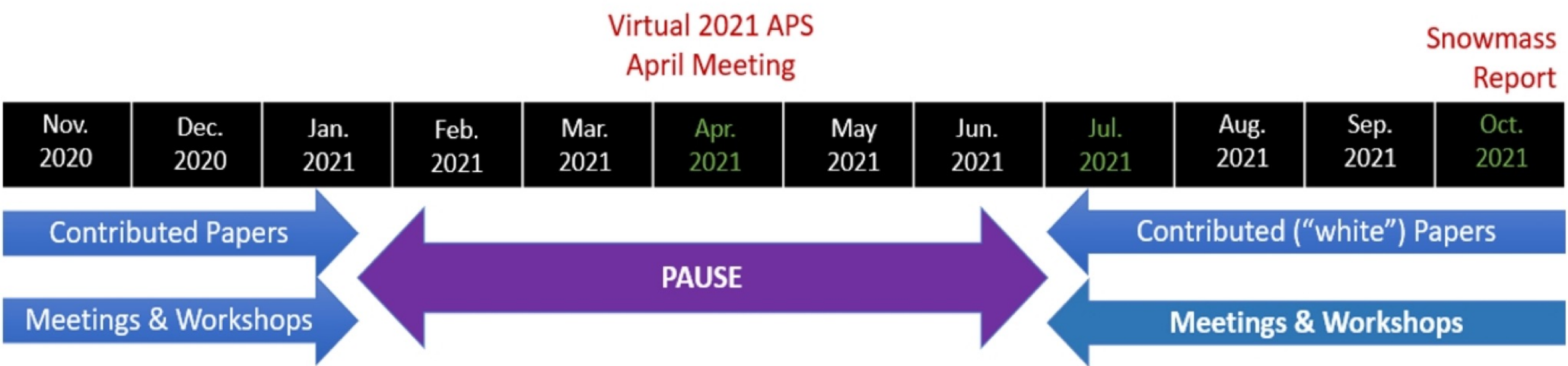
What is (modern) Snowmass:

- Community-driven planning for future of particle physics
- Mainly particle physics in the US, but in a global context
- Also feeds into funding processes (P5, DOE, NSF), but is not only that



Neutrino Frontier Topical groups





Community Summer Study (CSS)
July 2022 (UW Seattle)

Snowmass
Report



White paper submission ?

Preliminary TG reports

Preliminary Frontier reports

Frontier Executive summaries ?

Final TG/Frontier reports ?

Snowmass Book (SG) & on-line arXiv docs

Letters of interest

- Two pagers (+ references), describing ideas
- Total number of Lols: > 1500
- Lols to the neutrino frontier: 206
- Lols that mention supernova neutrinos: 96

Snowmass 2021 Letter of Interest:

Supernova neutrinos and particle-physics opportunities

Primary topical groups:

NF08/TF11 (Theory of Neutrino Physics)

NF04 (Neutrinos From Natural Sources)

Other topical groups: TF08, TF09, CF3, CF7

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Snowmass2021 - Letter of Interest

Q-Pix: Kiloton-scale pixelated liquid noble TPCs

Physics Opportunities in ANNIE

Multi-ton scale bubble chambers

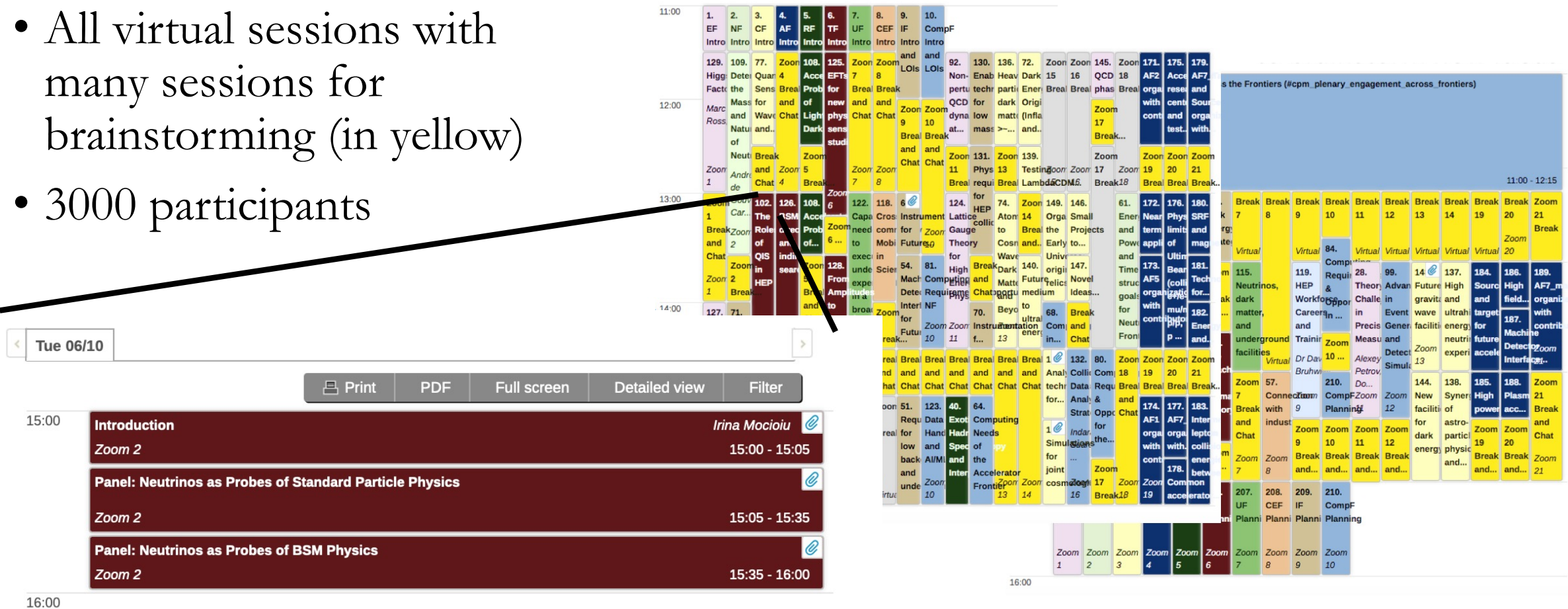
Wavelength-shifting Reflector Foils in Liquid Argon
Neutrino Detectors

*[Supernova Burst and Other Low-Energy
Neutrino Physics in DUNE]*

**Snowmass2021 — Letter of Interest: a kiloton-scale gadolinium-doped water detection
concept for Neutrino Experiment One at the Advanced Instrumentation Testbed in
Northern England**

Community planning exercise: Oct 5-8, 2020

- All virtual sessions with many sessions for brainstorming (in yellow)
- 3000 participants



The neutrino frontier whitepapers (87 papers each roughly 20 pages long)

[arXiv:2203.05525](https://arxiv.org/abs/2203.05525)

Passive low energy nuclear recoil detection with color centers –

PALEOCCENE

[aXiv:2202.12839](https://arxiv.org/abs/2202.12839)

THEIA: Summary of physics program

Snowmass White Paper Submission

[arXiv:2203.07377](https://arxiv.org/abs/2203.07377)

Synergy between cosmological and laboratory searches in neutrino physics

Community Summer Study

SN⁺WMASS

2022 July 17 - 26 Seattle

The Snowmass studies lead by the Division of Particles and Fields (DPF) define the most important questions for the field of particle physics, and identify promising opportunities to address them in the coming decade. The community Summer Study (CSS) will lead to the final report from the ten frontiers. Join us in Seattle for the Snowmass Community Summer Study, exploring the biggest questions facing particle physics for the next decade.

Program Committee

Steering group:

DPF chair line: Joel Burke (Co-chair, FNAL), Tao Han (Pittsburgh), Sekhar Chivukula (UCSD), Young-Kee Kim (Chicago), Priya Choudhary (Minnesota)

Divisional representatives: Glenys Farrar (DAP, NYU), Yuri Kobayashi (DNP, UC Berkeley), Sergei Nagaitsev (DPF, FNAL), Nicolas Yunes (DGRN, UIUC)

Frontier representations:

Kateri Assamagan (Community Engagement, BNL), Phil Barbeau (Instrumentation, Duke), Nathaniel Craig (Theory, UCSB), Ben Nachman (Computing, LBNL), Meenakshi Narain (Energy, Brown), John Orell (Underground Facilities, PNNL), Alexey Petrov (Rare processes/Precision, Wayne State), Vladimir Shilbsev (Accelerator, FNAL), Tim Tait (Cosmic, UC Irvine), Elizabeth Worcester (Neutrino Frontier, BNL)

Early Career: Garvita Agarwal (Buffalo), Jacob Zetzelmeyer (FNAL)

Local Organization Committee

Gordon Watts (Co-chair, UW), Shih-Chieh Hsu (Co-chair, UW), Quentin Burt (UW), Alejandro Garcia (UW), Anna Goussiou (UW), Laura Jeanty (UW), Joey Key (UW), Henry Lubatti (UW), Elise Novitski (UW), Gray Rybka (UW), Jan Strube (PNNL), Lauren Tompkins (Stanford), Tien-tien Yu (UC)



<http://seattle.snowmass2022.org/>

1400 participants (750 in person)

10 days of intense discussion sessions



SNOWMASS NEUTRINO FRONTIER: NF04 TOPICAL GROUP REPORT

NEUTRINOS FROM NATURAL SOURCES

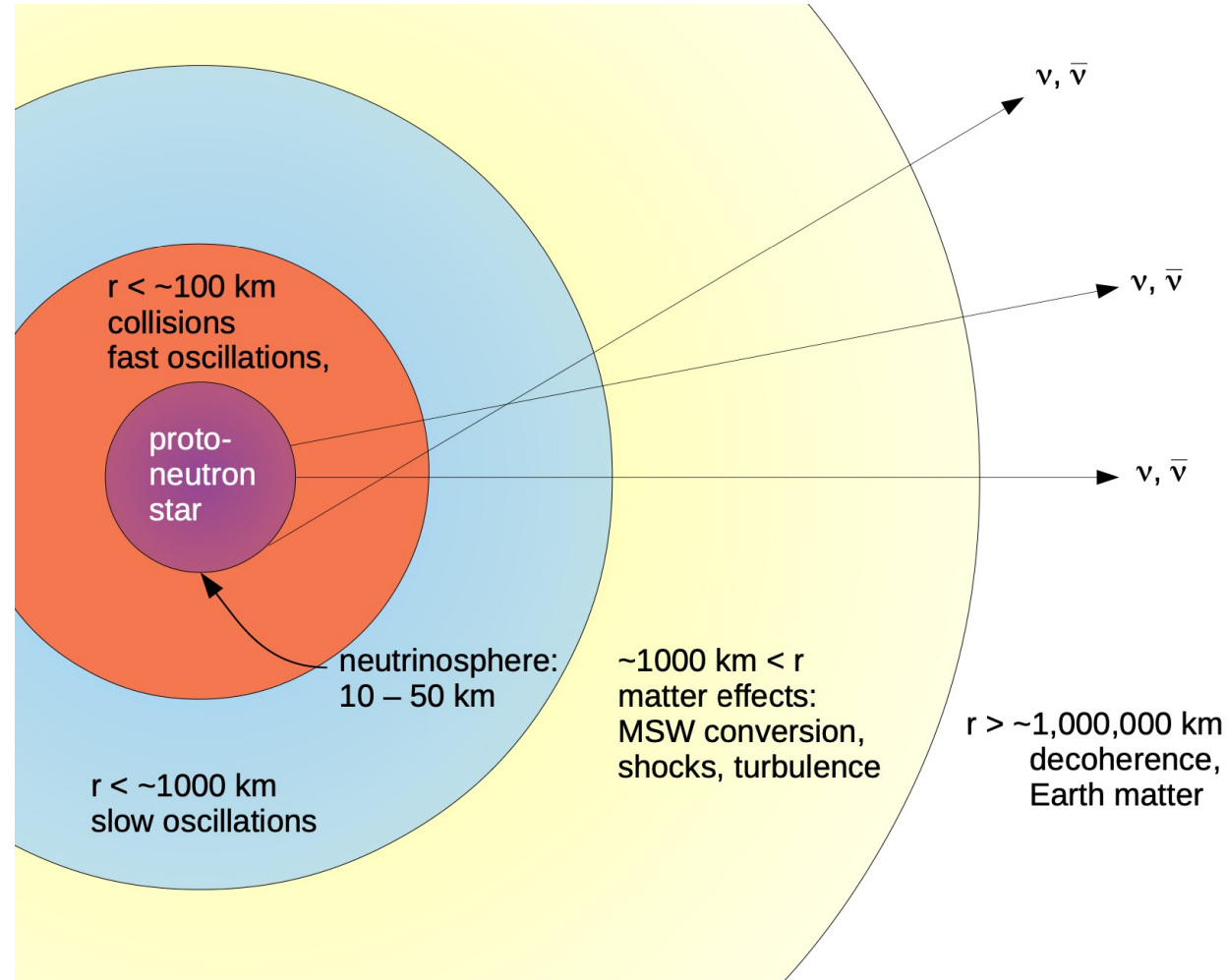
SUBMITTED TO THE PROCEEDINGS OF THE US COMMUNITY STUDY
ON THE FUTURE OF PARTICLE PHYSICS (SNOWMASS 2021)

Y. KOSHIO¹, G.D. OREBI GANN², E. O’SULLIVAN³, AND I. TAMBORRA⁴

5 Supernova Burst Neutrinos and Diffuse Supernova Neutrino Background

- 5.1 Motivation and current understanding
 - 5.1.1 Neutrino flavor mixing
 - 5.1.2 Neutrinos as probes of the supernova physics
 - 5.1.3 Supernova pointing and early warning through neutrinos
 - 5.1.4 Neutrinos as probes of physics beyond the Standard Model
 - 5.1.5 Current experimental landscape
- 5.2 Future Prospects
 - 5.2.1 Prospects for theoretical developments
 - 5.2.2 Prospects for measurements beyond electron anti-neutrino
 - 5.2.3 Expanding the detection horizon for core-collapse supernovae
 - 5.2.4 Early warning for multi-messenger physics
 - 5.2.5 Measuring the diffuse supernova neutrino background

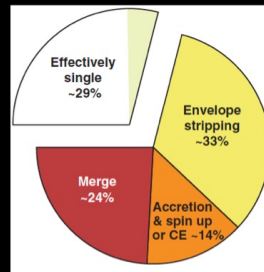
Theoretical developments for the next decade: flavour conversions and improved landscape of long-time models



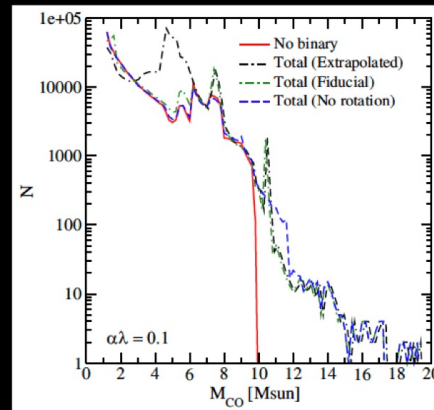
Theoretical developments for the next decade: improved DSNB models

Select other effects

Binaries: are common and can enhance progenitor numbers

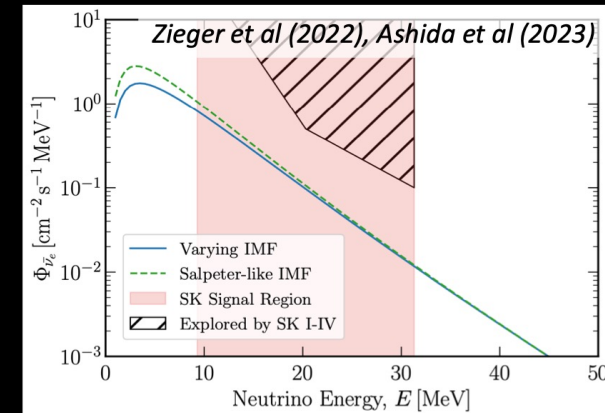


Sana et al (2012)



Horiuchi et al (2021)

Non-Universal IMF: may be environmentally dependent



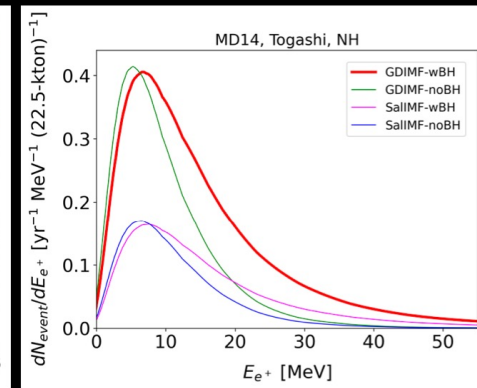
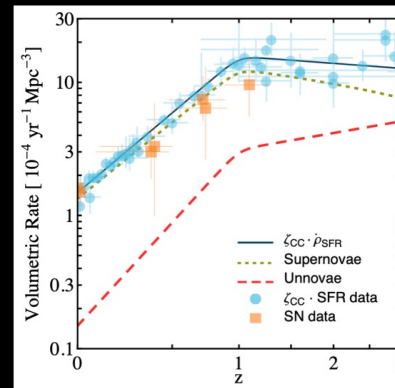
Variable BH fraction: may be more common at high redshifts

Eg Yuksel & Kistler (2014)

Various BSM physics

Eg de Gouvea et al (2019)

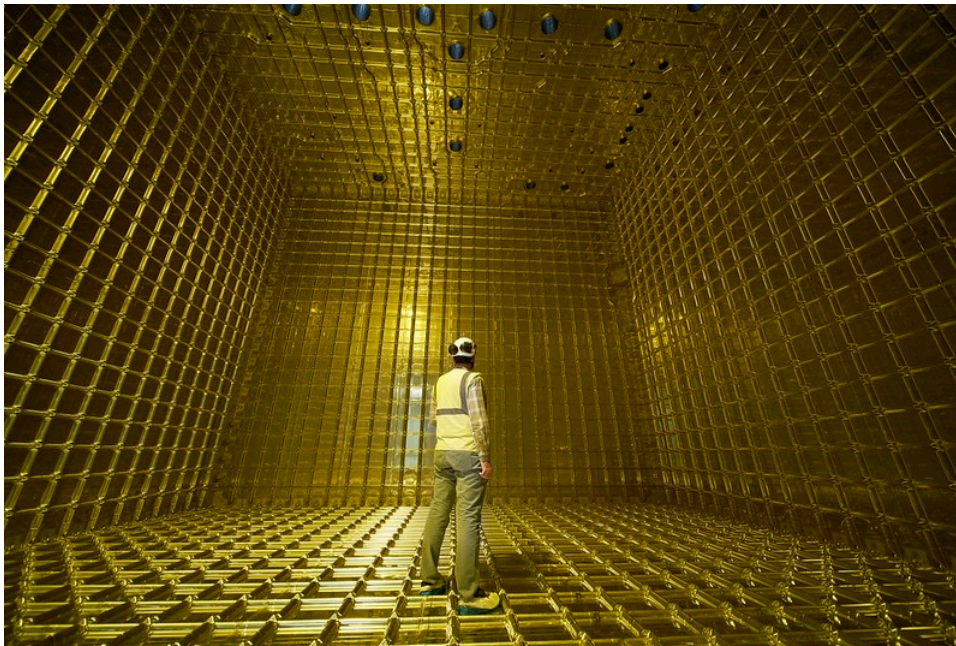
Shunsaku Horiuchi



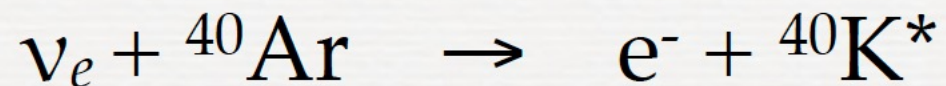
25

Experimental developments for the next decade: moving beyond electron anti-neutrinos

Juno, Achim Stahl



Dune: electron neutrino measurement

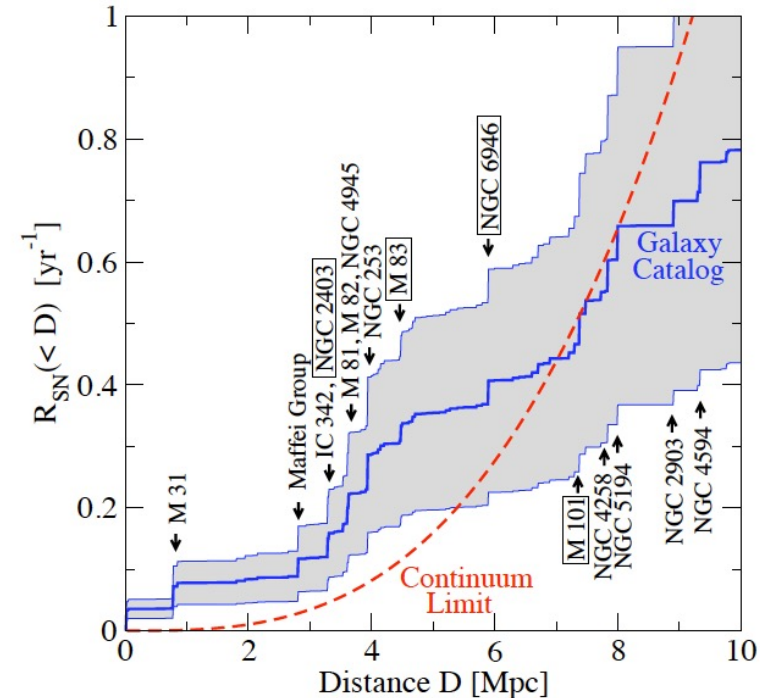
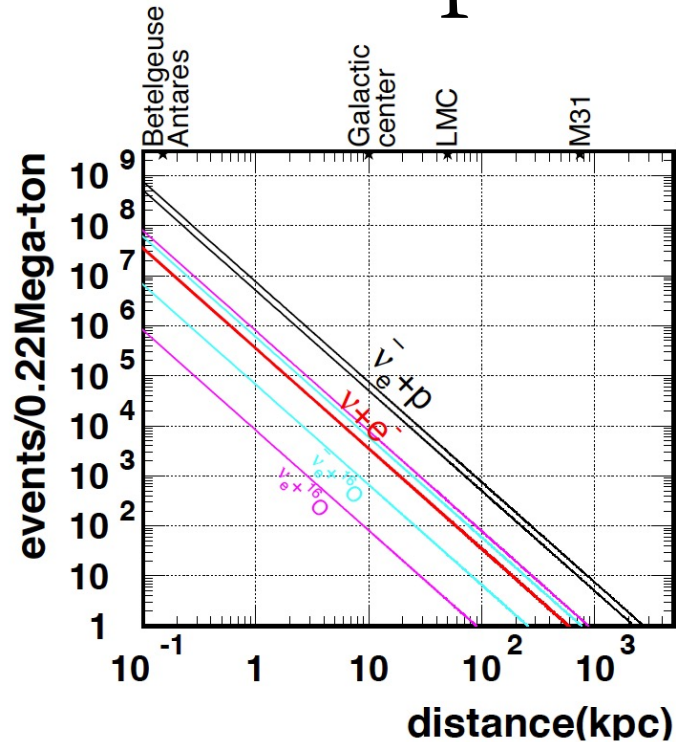


Coherent scattering:
RESNOvA, dark matter
detectors, scintillator

CCSN @ 10 kpc	
Inverse Beta-Decay $\bar{\nu}_e + p \rightarrow e^+ + n$	5000 ev.
p-Elastic Scattering $\nu + p \rightarrow \nu + p$	2000 ev.
e-Elastic Scattering $\nu + e^- \rightarrow \nu + e^-$	300 ev.
Neutral Current $\nu + {}^{12/13}\text{C} \rightarrow \nu + {}^{12/13}\text{C}^*$	300 ev.
Charged Current $\nu_e + {}^{12}\text{C} \rightarrow e^- + {}^{12}\text{N}$	100 ev.
Charged Current $\bar{\nu}_e + {}^{12}\text{C} \rightarrow e^+ + {}^{12}\text{B}$	100 ev.

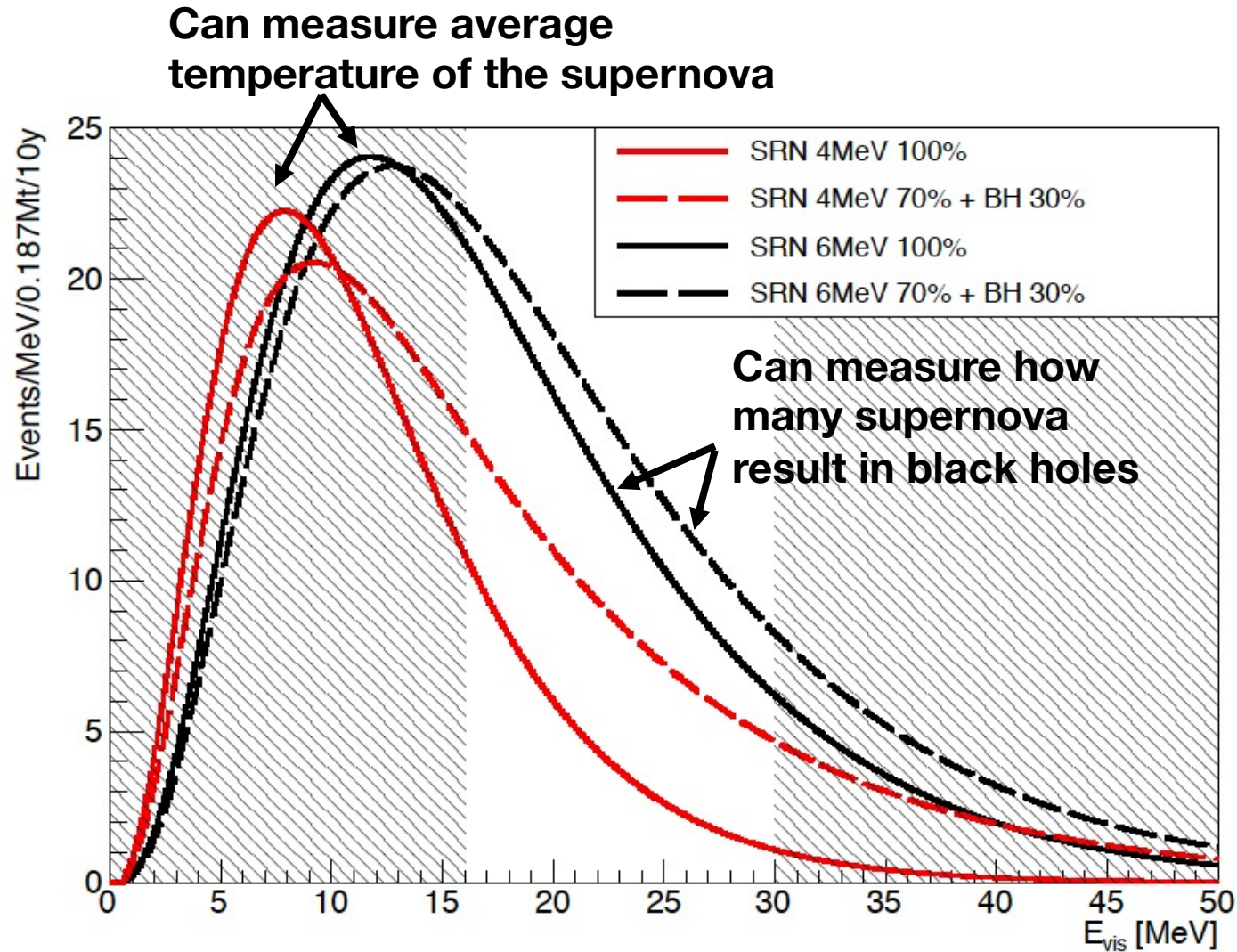
Experimental developments for the next decade: expanding the detection horizon

Ando, Beacom, Yüksel 05



Hyper-K will probe to greater distances,
where the SN rate is $\sim 1/\text{decade}$ instead of $\sim 2\text{-}3/\text{century}$

Experimental developments for the next decade: DSNB



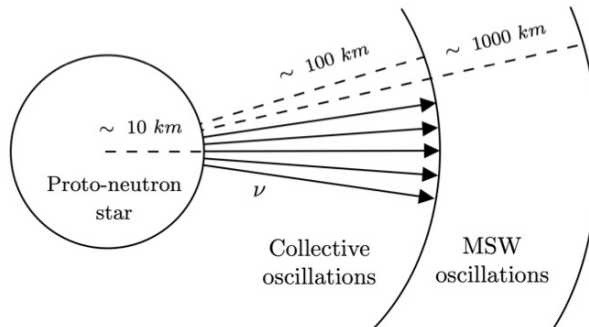
QUANTUM COMPUTING SIMULATION FOR COLLECTIVE NEUTRINO OSCILLATIONS [1]

Valentina Amitrano, Alessandro Roggero, Francesco Turro, Piero Luchi and Francesco Pederiva

Physics department University of Trento, INFN-TIFPA Trento Institute of Fundamental Physics and Applications

MOTIVATIONS

- **Core-collapse supernovae** of massive stars $M \gtrsim 8M_\odot$ emit a huge number of neutrinos ($\sim 10^{58}$).
- The physics of matter under extreme conditions is strongly **flavor-dependent** (nucleosynthesis, neutron-proton ratio, spectrum splits...).
- Interesting quantum many-body problem governed by the weak interaction.
- Describing the full dynamic is very complicated due to the **collective neutrino oscillations** that make the equation non linear.



- We want to simulate the real time evolution:

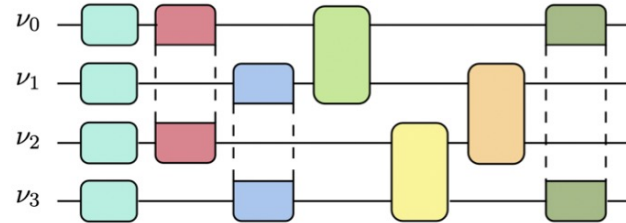
$$|\Psi(t)\rangle = U(t) |\Psi_0\rangle, \quad U(t) = e^{-iHt}. \quad (1)$$

UNITARY IMPLEMENTATION

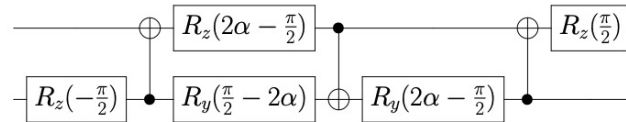
- To perform the quantum simulation we need a **quantum gate decomposition** of the $U(t)$ operator ($2^N \times 2^N$ unitary matrix on the flavor basis):
- Divide 1-body and 2-body parts that commute:

$$U(t) = U_2(t)U_1(t). \quad (5)$$

- Approximate the 2-body part as a product of pair interactions.



- Each 2-qubit gate $u_{ij} = e^{i\alpha(X \otimes X + Y \otimes Y + Z \otimes Z)}$ can be implemented as [3]:



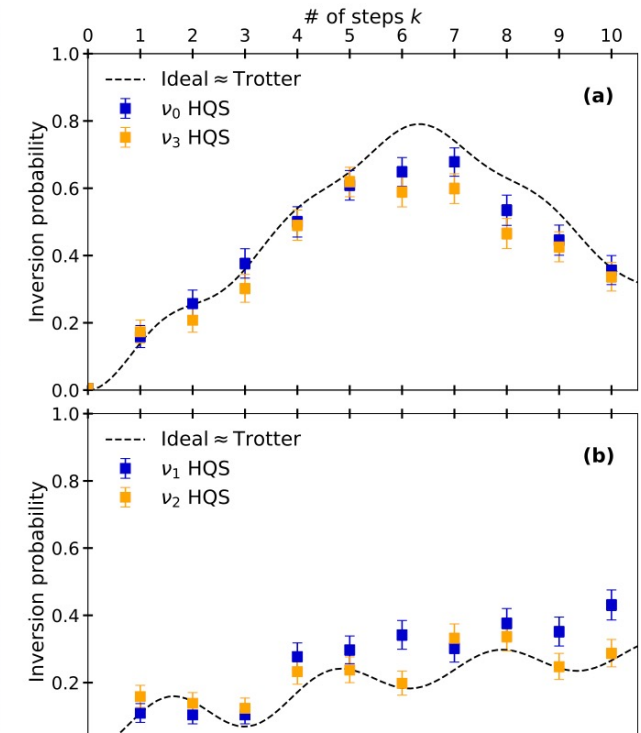
- The order in which the pairs interact changes the error due to the commutators.

MULTIPLE STEPS EVOLUTION

- Evolve the system until T applying $k = T/dt$ Trotter steps:

$$|\Psi(T)\rangle = U_2(dt)^k U_1(dt)^k |\Psi_0\rangle. \quad (6)$$

- Real quantum machine results:



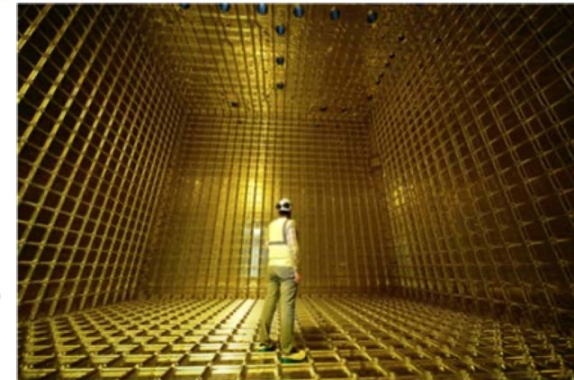
Other themes from the meeting

Neutrino Frontier

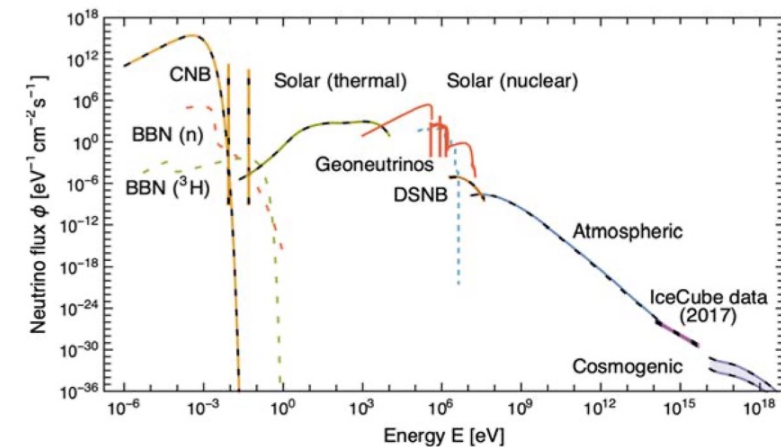
- * We need to **finish DUNE**, and its broad physics program.

Both Phase I and Phase II are required to complete the original DUNE design.

- * We are excited about long-term, broader possibilities that make use of our investment in the facility and could expand the DUNE scope beyond that originally envisioned.
- * A healthy program of projects of different sizes and time scales, with wide-ranging connections is highly desired and very much needed.



Impacts everywhere! But if we have to choose it's the Cosmic Frontier, due to deep connections and intertwined BSM searches in multiple areas.



Neutrinos are tools for astrophysics and cosmology. Astrophysics and cosmology provide insight into NF physics.



2023 P5

P5 (Particle Physics Projects Prioritization Panel) reports to [HEPAP](#) (High-Energy Physics Advisory Panel) that advises [High-Energy Physics](#) of [DOE Office of Science](#) and [Division of Physics](#) of [NSF](#). We will build on the [“Snowmass” community study](#) to hash out priorities for the next 10 years within 20-year context.

Charge

The [charge](#) to P5 was issued by [Dr. Asmeret Asefaw Berhe](#), Director of Office of Science, Department of Energy, and [Dr. Sean L. Jones](#), Assistant Director, Directorate for Mathematical and Physical Sciences, National Science Foundation, to the HEPAP chair JoAnne Hewett on November 2, 2022. The P5 report is expected to be released in October 2023.

Prospects for Snowmass 2030?

Not too early to start thinking of this

- Where will we be going as a community?
- New experimental techniques on the horizon?
- Better integration with other communities (computing, astro)?

P5 Preliminary timeline

- Form panel by early Fall
 - Call for nominations for P5 members in early Aug 2022
 - Panel members wear a community hat
- Hold hybrid in-person/virtual townhalls in Fall 2022
 - Aim for further community input and further information on potential future projects
 - Opportunity for each panel member to start with equal footing covering all frontiers
- Deliberations Winter/Spring 2023
 - Will provide ample opportunity for further community input
- Aim for report late Spring/Early Summer 2023 for HEPAP to approve and submit to DOE/NSF