Joint BSM@ν Workshop Overview

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Outline

- BSM@ν the Genesis & Strategy
- BSM@ν focus for Snowmass
- Workshop Goals
- Snowmass Report Timeline

BSM@ν, the genesis

- BSM@ν picked up steam after the 2013 U.S. Snowmass exercise
- The P5 science drivers clearly lists strategic opportunities

Science Drivers

- We distilled the eleven groups of physics questions f… Snowmass* into five compelling lines of inquiry th… promise for discovery over the next 10 to 20 ye…
- The Science Drivers:
  - Use the Higgs boson as a new tool for …
  - Pursue the physics associated with …
  - Identify the new physics of dark …
  - Understand cosmic accelera… …gy and inflation
  - Explore the unknown: ne… …ractions, and physical principles
- The Drivers are delib… …oritized because they are intertwined, probe… …ply than is currently understood.
- A selected set … …perimental approaches that reinforce e… …quired. Projects are prioritized.
- The vis… …sing each of the Drivers using a selected set … – their approximate timescales and how they fi… given in the report.

Take full advantage of the world's highest intensity neutrino beam. This approach would be an excellent example of global cooperation and planning.

* See Appendix D and http://www.slac.stanford.edu/econf/C1307292/

BSM@ν, the genesis

- BSM@ν picked up steam after the 2013 U.S. Snowmass exercise
- The P5 science drivers clearly lists strategic opportunities
- Must leverage the neutrino facility capabilities for precision oscillation measurements to the next step
- Need to further increase community interests on BSM opportunities and complement those in the EF regime
- Leadership needed in expanding physics opportunities
- Theory and experiment groups have been working together closely and playing the necessary leadership roles!
- A paper on ROP covers some of these opportunities (Argüelles *et al*., ROP 83, 124201, 2020)

BSM@ν Strategy, Thus far

Overarching strategic goal : To ensure the BSM physics at neutrino experiments a solidly established area of study

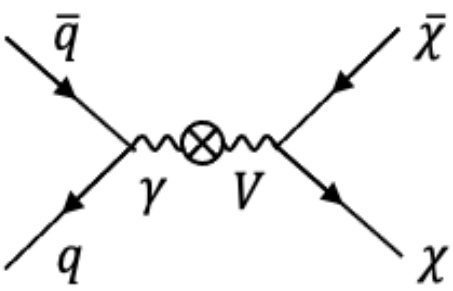
- Strategy
  1. Ensure BSM@ν physics to be an official topic at all subsequent future Snowmass studies
  2. Increase awareness and interests on BSM@ν physics within and outside the community
  3. Ensure BSM@ν topics to take a prominent presence in all official documents ➔ P5 strategic plan, Science book, CDR, PDR, TDR, Review reports and presentations, etc
  4. Form a strong collaborative group of experimentalists and theorists to continue developing and exploring new ideas and publish the work

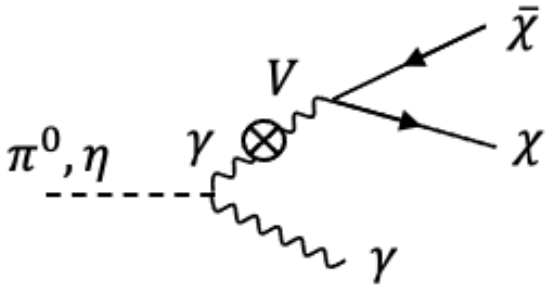
Some BSM@ν Topics

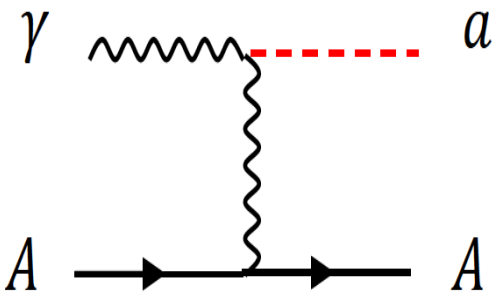
- High beam power, large detector mass + highly capable, precision near and far detectors with low E threshold make BSM physics viable
  - Signal to background ratio grows by the sqrt of the beam power
  - Near Detector Searches ➔ Take advantage of high beam power
    - Low mass Dark Matter (LDM)
    - Axion-like Particles (ALP)
    - Heavy Neutral Leptons (HNL)
    - Milli-charge Particles (mCP)
    - Neutrino Trident
  - Far Detector Searches ➔ Take advantage of ND, large V_A FD and long baseline
    - Sterile neutrino searches
    - Non-standard Interactions, Non-Unitarity, CPT violation
    - Large Extra Dimensions (LED)
    - Boosted Dark Matter (BDM)/ Inelastic Boosted Dark Matter (iBDM)
- Promote strong collaboration of theorists and experimentalists
- Some of these topics from DUNE covered in EPJ C.81, 322 (2021)

BSM@ν Physics Signatures at ND

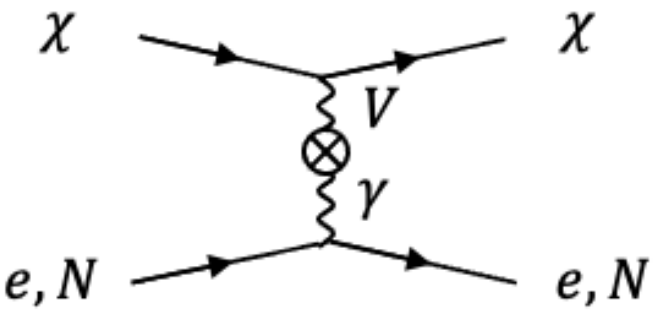
- High intensity proton beams produce large number of photons from brem, DY or neutral mesons decays ➔ Make it possible to contemplate couplings of new U(1) gauge to the SM γ

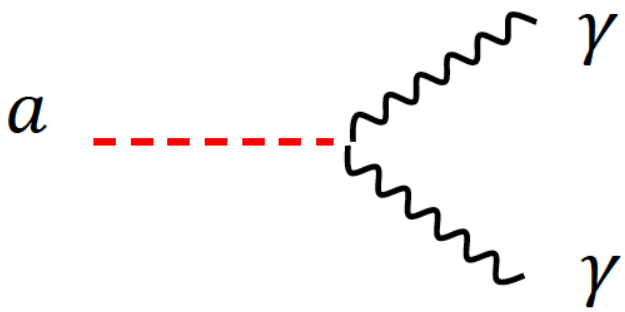






- Detection through an electron, μ, N(n) recoil or 1, 2 γ final states





BSM Signature Categories

- Direct Observation Signatures
  - Requires high beam flux
  - Sufficiently large mass for interaction signatures
  - Sufficiently large volume for decay signatures
- Inferred Observation Signatures from both beam and cosmogenic sources
  - Leverage oscillatory behaviors
  - Large target mass FD for interactions
- What do we need to know?
  - Signal flux
  - Neutrino flux

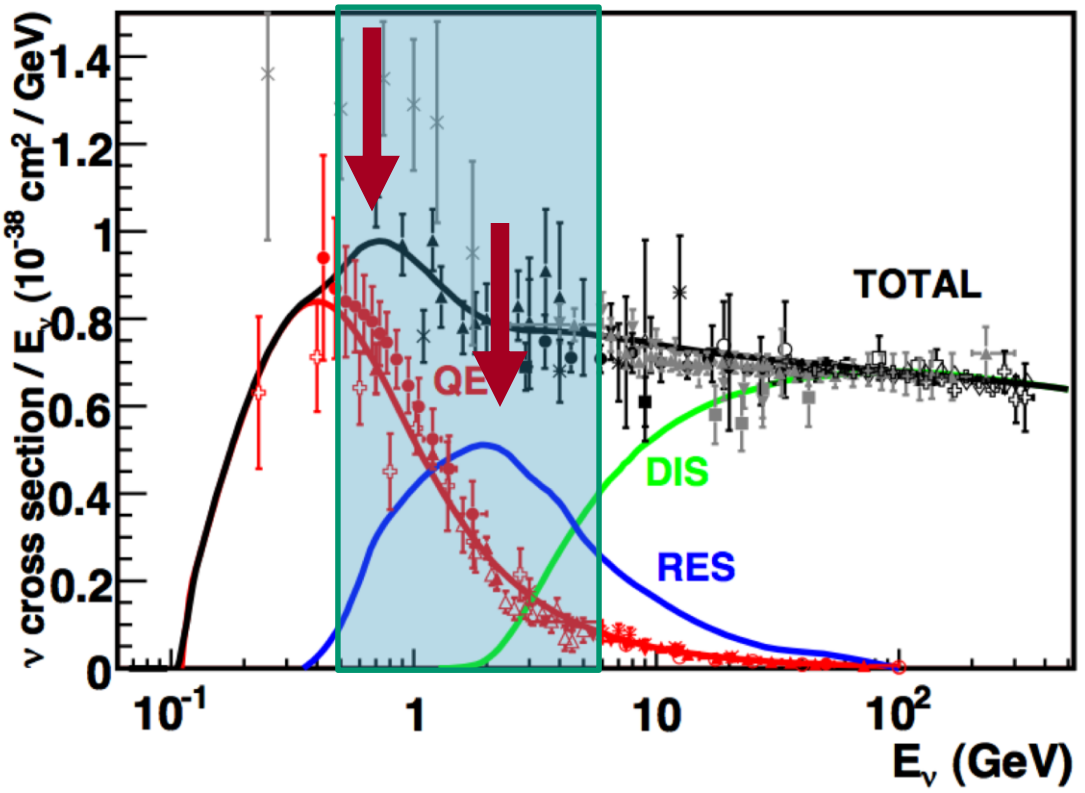
Some BSM Signatures & BCK

BSM signal final states include charged leptons (e+/-, μ+/-), photons and nucleus (nucleon) recoil ➔ ν-N interactions the primary background

Process	Signatures	Background
ALP	Scattering: γ+e/ γ+N (n) Decay in flight : $\gamma\gamma$	ν coherent, NC w/ π^0, ν_e CC w/ π^0, etc
LDM	$\chi e^- \rightarrow \chi e^-$, $\chi N \rightarrow N'n$	NC w/ π^0, ν_e CC, QE, RES
mCP	Multiple e^- scatterings	ν_e CC w/ π^0
Dark Photon	$A \rightarrow e^-e^+$, $\mu^-\mu^+$	ν CC + mis-ID π, Accidental overlap of CC
HNL	$N \rightarrow \nu e^-e^+$, $\nu\mu^-\mu^+$, $\nu e\mu$, $\nu\pi^0$, $e\pi$, $\mu\pi$	ν CC + mis-ID π, ν_e CC w/ π^0
ν trident	$\nu \rightarrow \nu e^-e^+$, $\nu\mu^-\mu^+$, $\nu e\mu$	$\nu_\mu N \rightarrow \nu_\mu \pi N$□ (ν CC)
BDM/ iBDM	$\chi N \rightarrow e^- N$	ν coherent, NC w/ π^0, ν_e CC

Low Energy ν Interactions

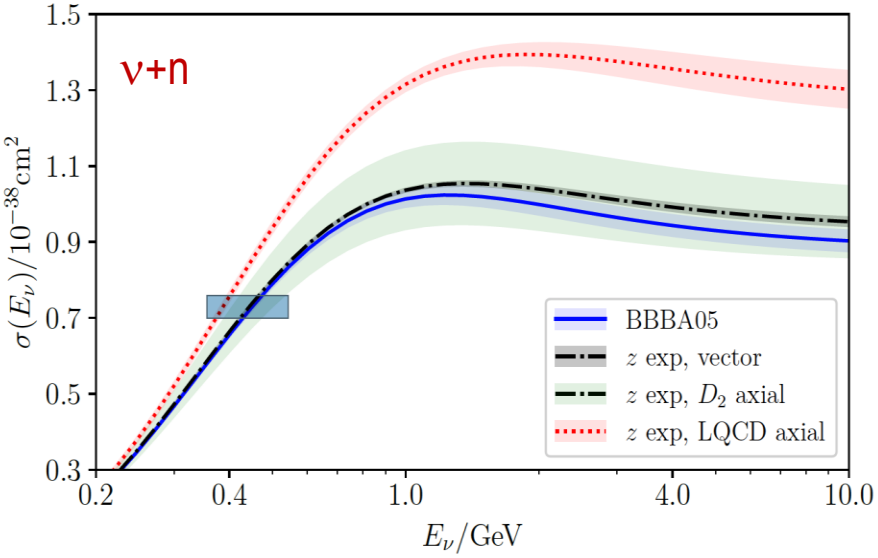
- QE and RES dominate ν-N interactions in DUNE E_ν range where the two oscillation maxima reside
- QE & RES critical to understanding background to BSM
- Large uncertainties for ν-N x-sec calculations in the critical region
  - Precision calculations w/ improved nuclear models and event generations essential for oscillation physics
  - Planned measurement, such as at e4ν collaboration could provide critical missing info
  - Need to clearly identify the list of measurements that can help improving calculations and prioritize them to target low hanging fruits first

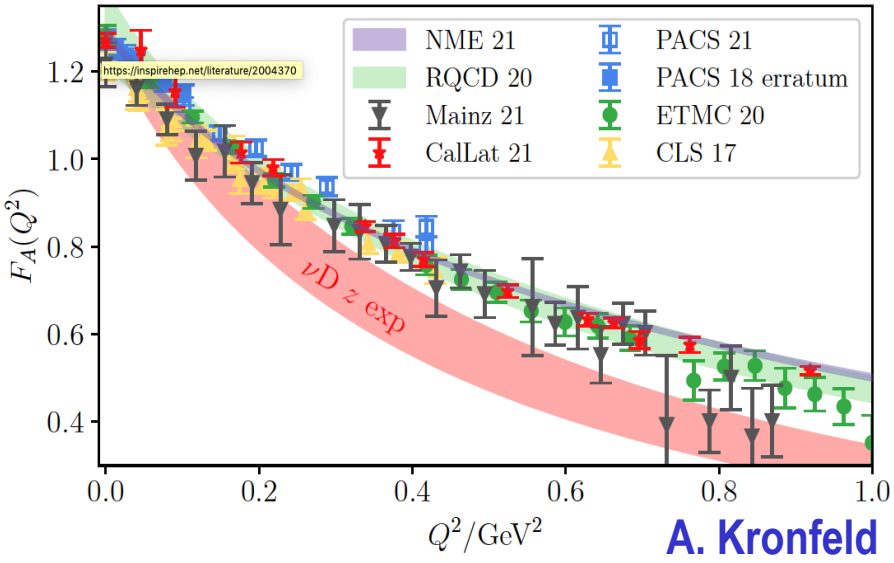


Tails, tails, tails

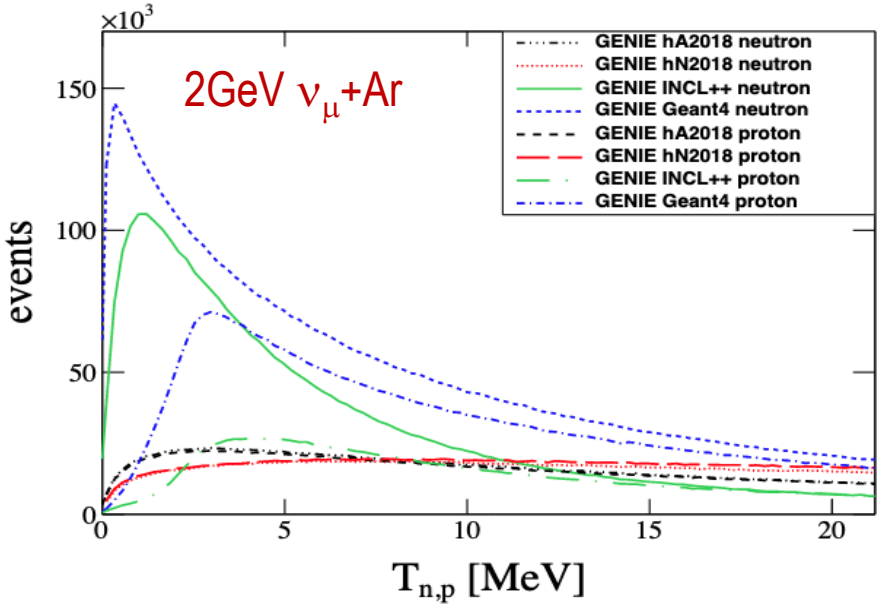
- BSM effects extremely rare and are in the tail ends of the SM processes ➔ can easily be masked by SM fluctuations
- Many theoretical predictions and generators for ν–N interactions have been in existence and continue making remarkable improvements ➔ but they still have sizeable uncertainties within each and between themselves

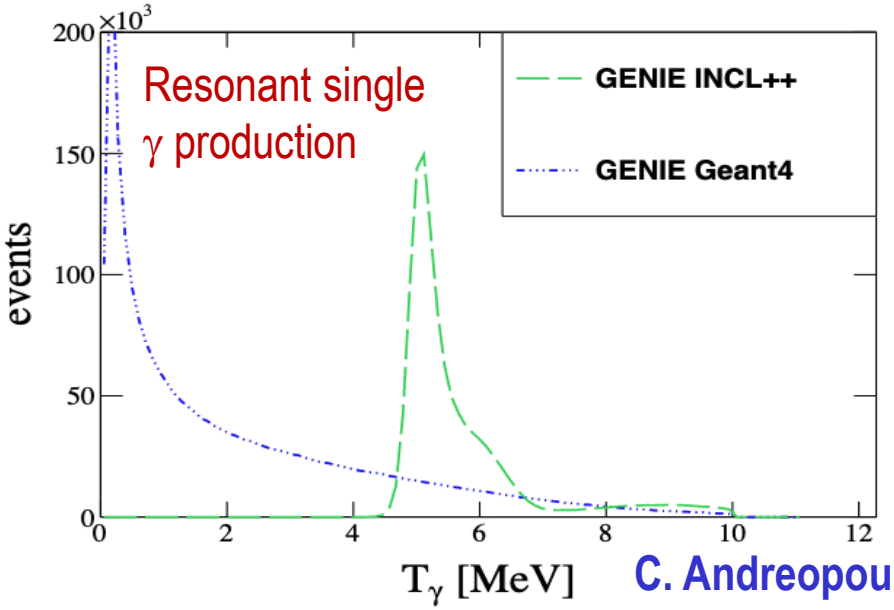
At the CERN ν-N Interactions workshop..





A. Kronfeld





C. Andreopoulos

Tails, tails, tails, and tails

- BSM effects extremely rare and are in the tail ends of the SM processes ➔ can easily be masked by SM fluctuations
- Many different theoretical predictions and generators for ν–N have been in existence and continue improving ➔ but they still have sizeable uncertainties within each and between themselves
  - Significantly reducing the uncertainties critical for B&B osc. physics
  - Essential for estimating backgrounds to BSM searches
- Generators begin to incorporate BSM processes but could take a long time to implement due to insufficient resources ➔ need further strengthening the efforts
  - Strong collaborations between generator teams and experiments a way to boost
  - NP and HEP communities must work together to understand low E processes
  - In addition, we need more concerted efforts and get them done in a timely fashion

Timelines to Consider

- The documents we work on should provide info to help making strategic plan ➔ long term visions must be incorporated
- What would the ν world be like in 2030s?
  - Existing experiments will have increased their exposure
  - Most of the experiments currently in design or in construction will be taking data
    - SBN experiments will have been taking data over 5 years together
    - DUNE (2 FD's) and Hyper-K will have started operating
  - Signal simulations and ν-N modeling would have improved
    - But at what level and what is missing?
- What should the ν world be like in 2040 – 2050?
  - What capabilities should the experiments have to support BSM?
    - Accelerators and detectors

Signals and Backgrounds

- Currently running experiments looking into their data for BSM explorations ➔ Essential for feedback
- Most studies on BSM physics in future ν experiments thus far primarily at the phenomenological level
- Sufficient demonstration of BSM@ν needs to be accompanied with more realistic studies
  - Signals ➔ Tools must be able to incorporate numerous new signatures with ease, a good verifiability and cross check, and the output be easily fed into the full detector simulations
  - Backgrounds ➔ The ν-N interaction model must be improved to reduce uncertainties in ν interaction background

The next BSM@ν Strategy

Overarching strategic goal : To ensure the BSM@ν a science driver and a primary goal of future ν experiments

- Strategy
  1. Ensure extracting a large number of quantitative BSM physics results from experiments in 2030 time scale
  2. Further increase awareness and interests on BSM@nu physics within and outside the community
  3. Ensure BSM@ν topics to take an essential presence in all official documents ➔ P5 strategic plan, Science book, CDR, PDR, TDR, Review reports and presentations, etc
  4. Further strengthen the collaborative group of experimentalists and theorists to continue developing and exploring new ideas and publish the work

Why are we here?

- To make sure we can do for BSM physics in neutrino experiments at present and in the future!
- Letter from Jim Seigrist describing DOE stance on realizing full scope of DUNE:

"The long-term P5 plan envisions two additional far detectors and a more intense beam than is currently being constructed. Design work performed to date on the DUNE experiment indicates that a more capable near detector will be needed to exploit these enhanced capabilities fully, or even the Phase I capabilities after sufficient statistics have been collected.

HEP would like to put in place a process for discussion and evaluation of these upgrades. We understand that these upgrades are of different scales and timelines. For example, additional far detector mass as well as the Booster replacement will be contemplated as new projects by the next P5 subpanel, (expected to start its work in Fall 2022), and may not proceed until after Phase I is largely complete."

the full complement of the ND

Workshop Goals

- This workshop is the 2nd in the series of the BSM@ν after the 2019 Arlington workshop (d%^&* COVID!)
- Goals of this workshop
  - Discuss activities and progress on Snowmass studies on new physics opportunities at neutrino experiments.
  - Provide a status update of sub-topical groups activities and remaining studies including timelines, if incomplete.
  - **Finalize sub-topical group whitepapers!!!!!**
  - **Generate first draftsof topical frontier group reports** (NF01, NF02, NF03, RF06 & TF11) on new physics opportunities.
  - Define clear timelines for completing the sub-topical group whitepapers and topical group reports.

NF03 Sub-topical Groups and the Leads

- Sub-topical groups formed based on submitted LOI's @ https://www.snowmass21.org/neutrino/bsm/start
- Heavy Neutral Leptons: I. Shoemaker, A. de Roeck
  - Coordinate with NF02
- Coherent Elastic Neutrino-Nucleus Scattering: L. Strigari, P. Barbeau, R. Strauss
- BSM searches within neutrino oscillations: P. Coloma, D. Forero, T. Katori
  - Covers Large Extra Dimension searches, Lorentz and CPT symmetry, Non-unitarity of the neutrino mixing matrix, Non-standard interactions, etc
  - Coordinate with NF01 & NF02
- Baryon number violation: B. Dev, L. Koerner
  - Coordinate with RF04 and any related CPM groups
- Cosmogenic dark matter and exotic particle searches: D. Kim, Y. Tsai
  - Coordinate with CPM97
- Beam-originating dark matter candidate searches: B. Batell, J. Yu
  - Coordinate with CPM108

Snowmass Report Timeline

- Community feedback meetings for report input: Jan-Mar
- Topical Group Report drafts due for community (NF): March 11
- Community feedback period on first TG drafts: Mar. 11-Apr. 10
- NF Workshop @ ORNL : March 16-18
- Preliminary (TG & Frontier) Reports due (NF): May 10
- Preliminary (TG & Frontier) Reports due (Snowmass): May 31
- Community feedback period: June 1 – July 26
- Community Summer Study (Seattle): July 17-26
- Final (TG & Frontier) Reports due (NF): Sept 9
- Final (TG & Frontier) Reports due (Snowmass): Sept 30