*UO QuarkNet - 2020*

# Planning the Future of US High Energy Physics

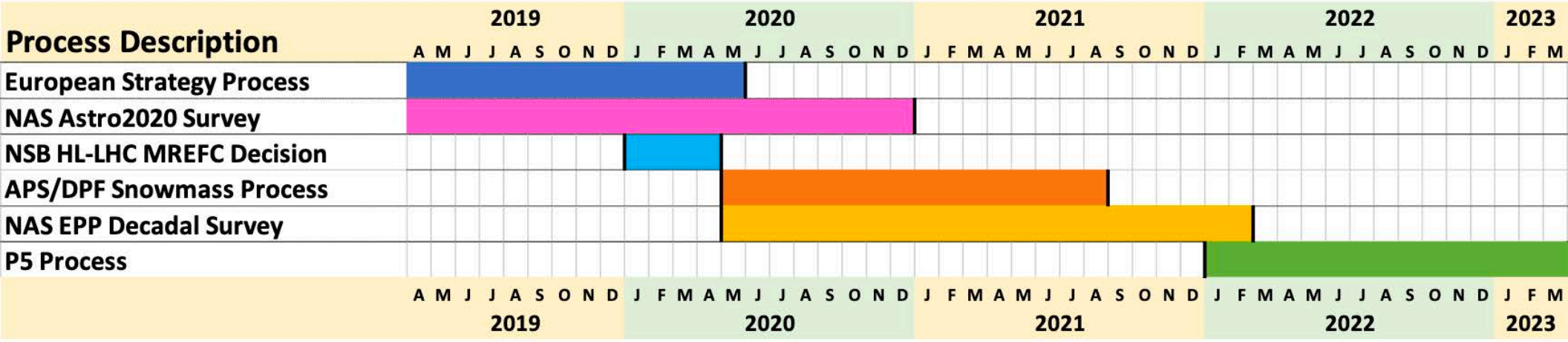
Jim Brau

June 22, 2020

# US High Energy Physics Planning

- There are three important processes that define the US HEP program:
  - "Snowmass" community planning organized by the American Physics Society (APS) Division of Particles and Fields (DPF).
  - National Research Council (NRC) recommendations every ten years or so in Decadal Survey. I served on NRC committee and co-authored 1998 P5 report.
    - NRC charged to provide independent, objective advice to the nation (eg. Congress) on matters related to science and technology.
  - High Energy Physics Advisory Panel (HEPAP) subpanel P5. I served on panel & co-authored 2008 & 2010 reports.

# US High Energy Physics Planning

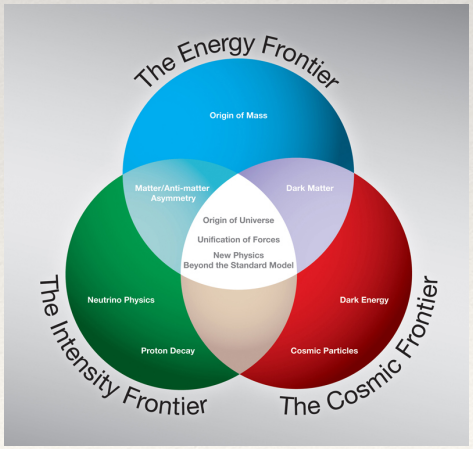



**European Strategy Process** just concluded. Besides support for **HL-LHC,**

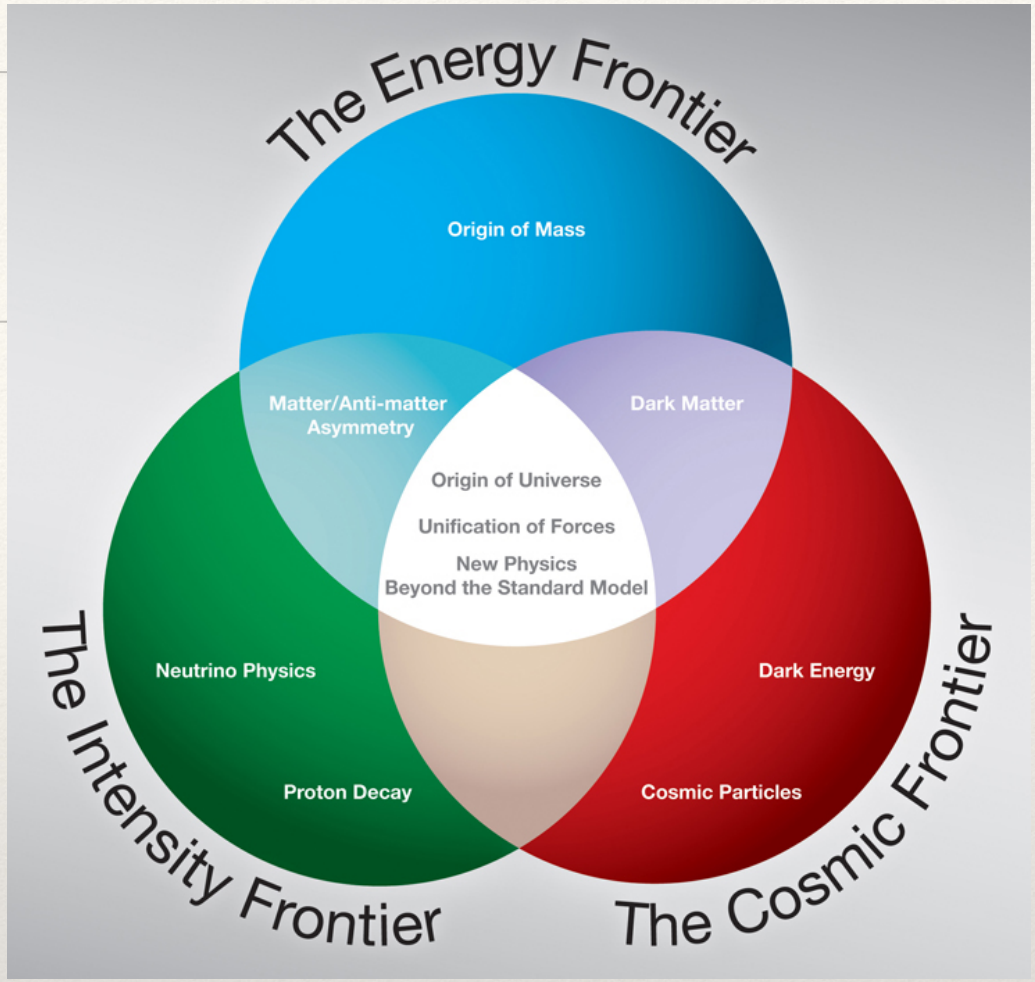
- "An **electron-positron Higgs factory** is the highest-priority **next collider.** For the longer term, the European particle physics community has the ambition to operate a **proton-proton collider at the highest achievable energy**."
- "The timely realisation of the electron-positron **International Linear Collider (ILC)** in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate."

# 2008 Particle Physics Project Prioritization Panel (P5)

- Funding for the US high-energy physics program by Department of Energy (DOE) and National Science Foundation (NSF) responds to recommendations of P5.
- P5 framework was recommended by the HEPAP subpanel in 2001.
- 2008 P5 (I served on this panel) formatted field into three frontiers:
  - Energy Frontier
  - Intensity Frontier
  - Cosmic Frontier



# 2008 P5




The panel recommends a balanced program of research at three frontiers to address fundamental questions about the laws of the universe: the **Energy Frontier**, using both hadron colliders and lepton colliders to discover and illuminate the physics of the terascale; the **Intensity Frontier**, comprising neutrino physics and high-sensitivity experiments on rare processes; and the **Cosmic Frontier**, probing the nature of dark matter and dark energy and other topics in particle astrophysics.

# 2014 Particle Physics Project Prioritization Panel (P5)

- 2014 P5 defined five "Science Drivers"
  - Use of the Higgs boson as a tool for further inquiry
  - Investigation of the physics of neutrino mass
  - Investigation of the physics of dark matter
  - Investigation of the physics of dark energy and cosmic inflation
  - Exploration of new particles, interactions, and physics principles

# 2014 P5

## Construction and Physics Timeline

# 2014 P5

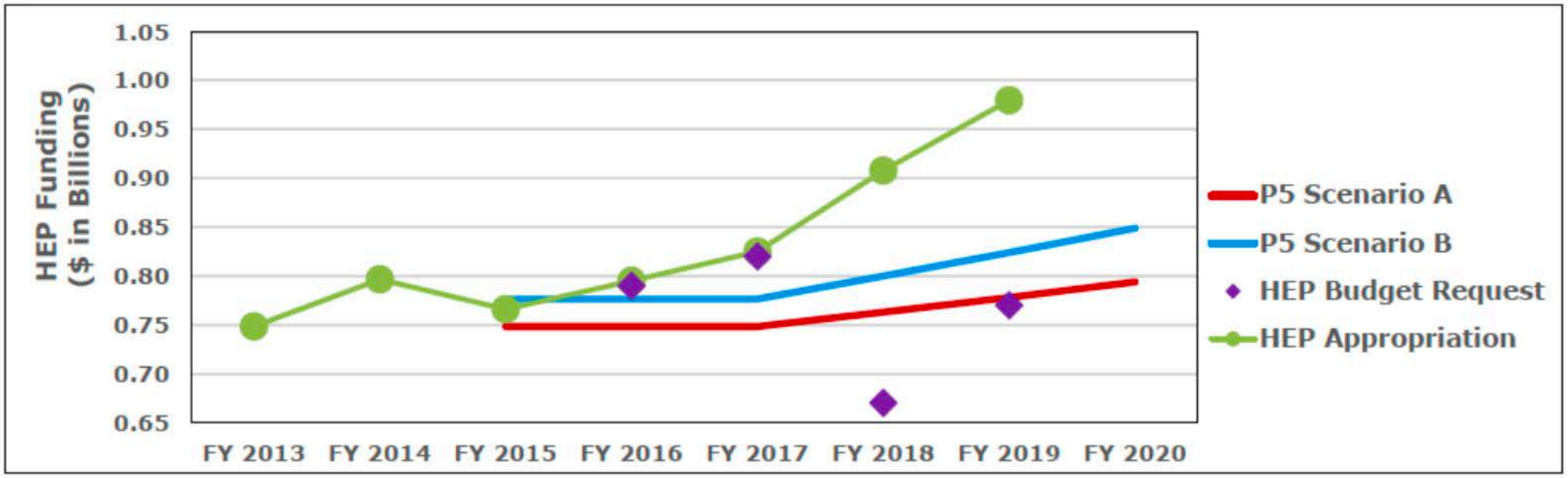
## Summary of Scenarios

**Scenario A** - 3 years constant funding then increases of 2%/year.
**Scenario B** - 3 years constant funding then increases of 3%/year.
**Scenario C** - uncon-strained budget.

| | Scenarios | | | Science Drivers | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Project/Activity | Scenario A | Scenario B | Scenario C | Higgs | Neutrinos | Dark Matter | Cosm. Accel. | The Unknown | Technique (Frontier) |
| **Large Projects** | | | | | | | | | |
| Muon program: Mu2e, Muon g-2 | Y, Mu2e small reprofile needed | Y | Y | | | | | ✓ | I |
| HL-LHC | Y | Y | Y | ✓ | | ✓ | | ✓ | E |
| LBNF + PIP-II | Y, LBNF components delayed relative to Scenario B. | Y | Y, enhanced | | ✓ | | | ✓ | I,C |
| ILC | R&D only | R&D, possibly small hardware contri-butions. See text. | Y | ✓ | | ✓ | | ✓ | E |
| NuSTORM | N | N | N | | ✓ | | | | I |
| RADAR | N | N | N | | ✓ | | | | I |
| **Medium Projects** | | | | | | | | | |
| LSST | Y | Y | Y | | ✓ | | ✓ | | C |
| DM G2 | Y | Y | Y | | | ✓ | | | C |
| Small Projects Portfolio | Y | Y | Y | | ✓ | ✓ | ✓ | ✓ | All |
| Accelerator R&D and Test Facilities | Y, reduced | Y, some reductions with redirection to PIP-II development | Y, enhanced | ✓ | ✓ | ✓ | | ✓ | E,I |
| CMB-S4 | Y | Y | Y | | ✓ | | ✓ | | C |
| DM G3 | Y, reduced | Y | Y | | | ✓ | | | C |
| PINGU | Further development of concept encouraged | | | | ✓ | ✓ | | | C |
| ORKA | N | N | N | | | | | ✓ | I |
| MAP | N | N | N | ✓ | ✓ | ✓ | | ✓ | E,I |
| CHIPS | N | N | N | | ✓ | | | | I |
| LAr1 | N | N | N | | ✓ | | | | I |

# Congressional funding

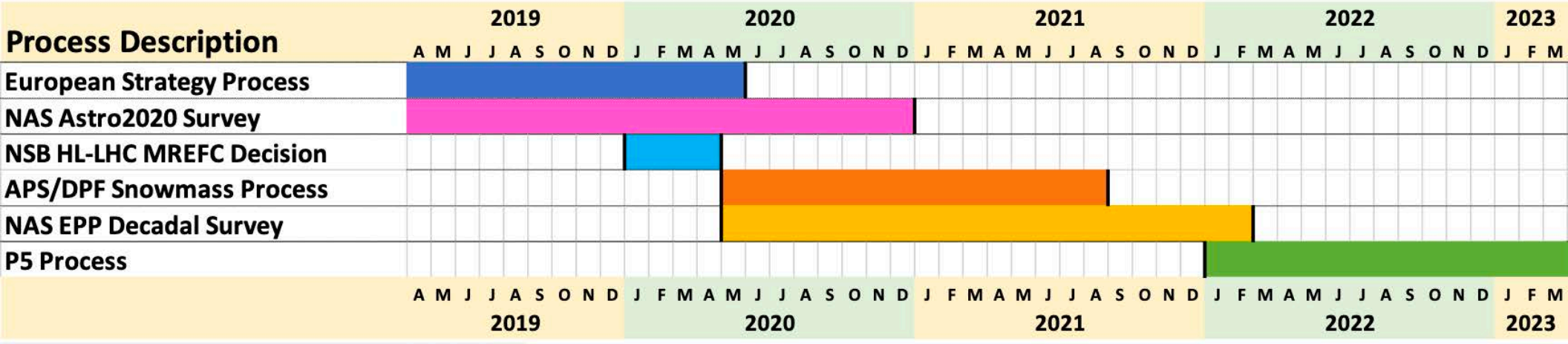
- Congress has responded favorably to the P5 plan and DOE Office of Science's execution of the plan and its effectiveness in meeting milestones and goals.



# US High Energy Physics Planning

- 2014 P5 followed 2013 Snowmass community planning.

**NEXT SET OF PROCESSES**




- Next P5 is planned for 2022-23
- Snowmass 2021 (starts now) will inform the next P5.

# Snowmass 2021

- **Since 1982, the high-energy community in the US has periodically gathered to examine and articulate the current state of the discipline and to chart its future.**
- Snowmass, Colorado, has been traditional site of workshop.
- The last process was concluded in the "Snowmass on the Mississippi" workshop at the University of Minnesota in 2013.
  - More than 600 in person participants.
  - Overall, more than 1000 contributed
- This year we started a process that will conclude in Seattle at UW next summer.

# Snowmass 2021 Frontiers

- **Energy Frontier**
- Frontiers in Neutrino Physics
- Frontiers in Rare Processes & Precision Measurements
- **Cosmic Frontier**
- Theory Frontier
- Underground Facilities and Infrastructure Frontier
- Accelerator Frontier
- Instrumentation Frontier
- Computational Frontier
- Community Involvement

# Snowmass 2021 Energy Frontier

- **EF0l: EW Physics: Higgs Boson properties and couplings**
- **EF02: EW Physics: Higgs Boson as a portal to new physics**
- **EF03: EW Physics: Heavy flavor and top quark physics**
- **EF04: EW Physics: EW Precision Physics and constraining new physics**
- EF05: QCD and strong interactions : Precision QCD
- EF06: QCD and strong interactions : Hadronic structure and forward QCD
- EF07: QCD and strong interactions : Heavy Ions
- EF08: BSM: Model specific explorations
- EF09: BSM: More general explorations
- EFl0: BSM: Dark Matter at colliders

# Snowmass 2021 - EF01
# EW Physics: Higgs Boson properties and couplings

- Higgs mass
- Higgs width
- Production modes
- Higgs couplings
- Anomalous Higgs couplings
- Rare decays, including H→ μμ, H→cc
- H→ invisible
- Double Higgs production

# Snowmass 2021 - EF02
# EW Physics: Higgs Boson as a portal to new physics

- Some of the Big Questions
  - Is there something more to EWSB?
  - Is there a solution for the naturalness problem?
  - Higgs and EW phase transition
  - Higgs and Flavor
  - Higgs portal...

# Snowmass 2021 - EF03
# EW Physics: Heavy flavor and top quark physics

- Top quark physics and heavy flavor production through EW processes
- Precision measurements of top-quark related processes
- High-precision predictions for top-quark observables
- Heavy flavor (b, c) production at hadron colliders in association with an electroweak boson
- Heavy flavor production at lepton colliders

WHY TOP?

- Top is the heaviest fundamental particle with the strongest Higgs coupling
- Could provide first glimpse of BSM physics
- Decays before hadronization - spin info transferred to decay products

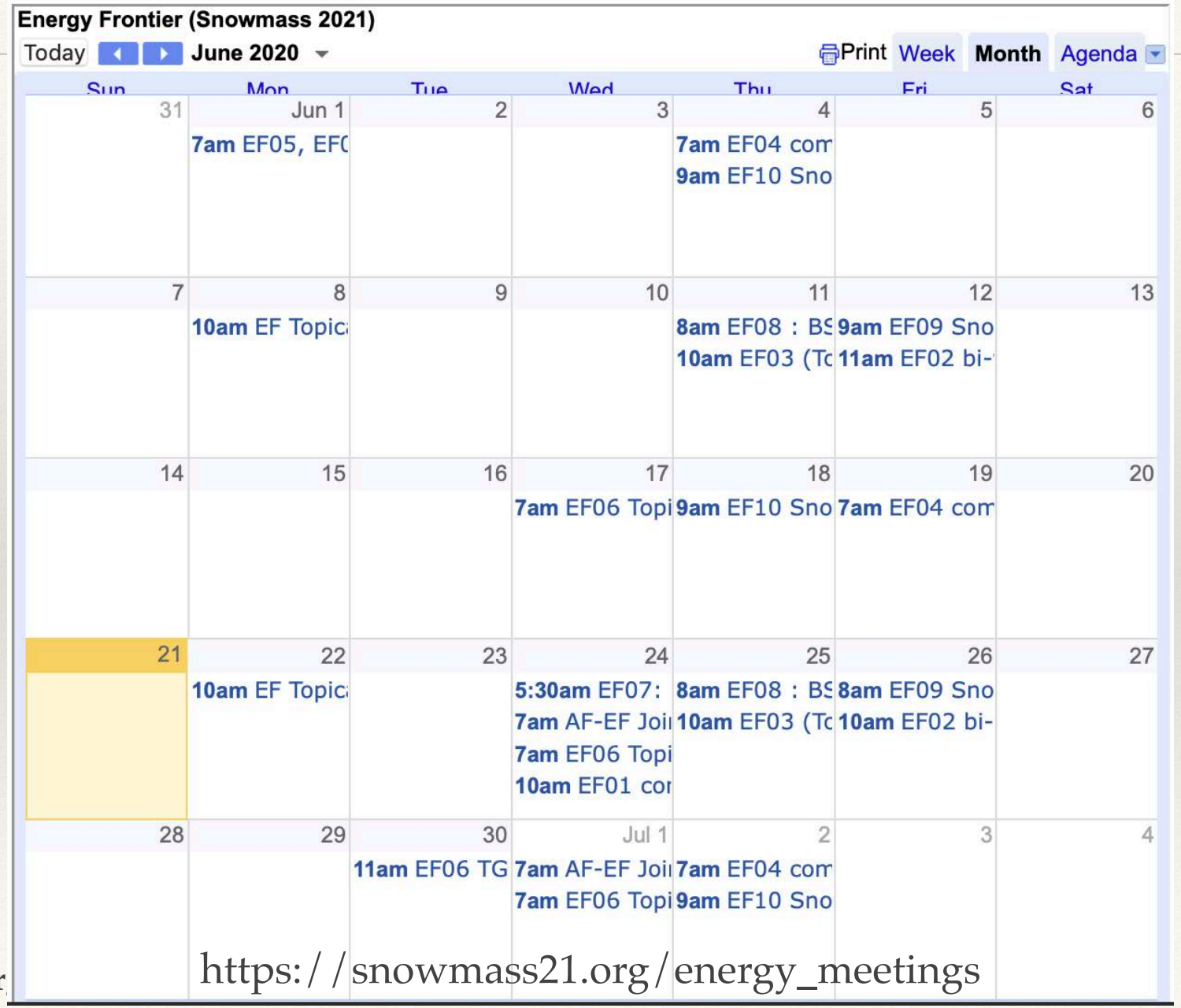
# Snowmass 2021 - EF04
# EW Physics: EW Precision Physics and constraining new physics

- Ultimate goal is global fit of SM parameters, and evaluation of SMEFT constraints
  - Overall coherence of EFT interpretations
- Global fit of electroweak parameters and SMEFT

Global fits to SM: $m_W$, $m_Z$, $\Gamma_W$, $\Gamma_Z$, $A_{LR}^f$ (f=e/μ/τ/b/c), $A_{FB}$, $\alpha_{EW}$, $\sigma_{had}$, …
- Inputs from Higgs (mass), top (mass), QCD ($\alpha_s$)

  - Theoretical calculations and uncertainties (NNLO and beyond)

# Snowmass 2021 EF Telecons




https://snowmass21.org/energy_meetings

# Snowmass 2021 Energy Frontier

- EF0l: EW Physics: Higgs Boson properties and couplings
- EF02: EW Physics: Higgs Boson as a portal to new physics
- EF03: EW Physics: Heavy flavor and top quark physics
- EF04: EW Physics: EW Precision Physics and constraining new physics
- EF05: QCD and strong interactions : Precision QCD
- EF06: QCD and strong interactions : Hadronic structure and forward QCD
- EF07: QCD and strong interactions : Heavy Ions
- EF08: BSM: Model specific explorations
- EF09: BSM: More general explorations
- EFl0: BSM: Dark Matter at colliders

# Snowmass 2021 Cosmic Frontier

- CF1. Dark Matter: Particle-like
- CF2. Dark Matter: Wave-like
- CF3. Dark Matter: Cosmic Probes
- CF4. Dark Energy and Cosmic Acceleration: The Modern Universe
- CF5. Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
- CF6. Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
- **CF7. Cosmic Probes of Fundamental Physics**

# Snowmass 2021 - CF7

**Cosmic Probes of Fundamental Physics**

- Fundamental physics topics that are not necessarily Dark Energy and Cosmic Acceleration, nor Dark Matter.
  - measurements of neutrinos properties from cosmology,
  - tests of GR with gravitational waves,
  - cosmic ray physics.
- A number of LIGO collaborators are participating in this working group

# Snowmass 2021 - CF7

## Cosmic Probes of Fundamental Physics

- tests of GR with gravitational waves

LIGO/Virgo's collection of binary black hole mergers provide best data for these GR tests.

arXiv:1903.04467

| Event | Properties | | | |
|---|---|---|---|---|
| | $D_L$ [Mpc] | $M_{tot}$ [$M_\odot$] | $M_f$ [$M_\odot$] | $a_f$ |
| **GW150914**[a] | $440^{+150}_{-170}$ | $66.1^{+3.8}_{-3.3}$ | $63.1^{+3.4}_{-3.0}$ | $0.69^{+0.05}_{-0.04}$ |
| GW151012[a] | $1080^{+550}_{-490}$ | $37.2^{+10.6}_{-3.9}$ | $35.6^{+10.8}_{-3.8}$ | $0.67^{+0.13}_{-0.11}$ |
| **GW151226**[a,b] | $450^{+180}_{-190}$ | $21.5^{+6.2}_{-1.5}$ | $20.5^{+6.4}_{-1.5}$ | $0.74^{+0.07}_{-0.05}$ |
| **GW170104** | $990^{+440}_{-430}$ | $51.0^{+5.3}_{-4.1}$ | $48.9^{+5.1}_{-4.0}$ | $0.66^{+0.08}_{-0.11}$ |
| **GW170608** | $320^{+120}_{-110}$ | $18.6^{+3.2}_{-0.7}$ | $17.8^{+3.4}_{-0.7}$ | $0.69^{+0.04}_{-0.04}$ |
| GW170729[c] | $2840^{+1400}_{-1360}$ | $84.4^{+15.8}_{-11.1}$ | $79.5^{+14.7}_{-10.2}$ | $0.81^{+0.07}_{-0.13}$ |
| **GW170809** | $1030^{+320}_{-390}$ | $59.0^{+5.4}_{-4.1}$ | $56.3^{+5.2}_{-3.8}$ | $0.70^{+0.08}_{-0.09}$ |
| **GW170814** | $600^{+150}_{-220}$ | $55.9^{+3.4}_{-2.6}$ | $53.2^{+3.2}_{-2.4}$ | $0.72^{+0.07}_{-0.05}$ |
| GW170818 | $1060^{+420}_{-380}$ | $62.2^{+5.2}_{-4.1}$ | $59.4^{+4.9}_{-3.8}$ | $0.67^{+0.07}_{-0.08}$ |
| **GW170823** | $1940^{+970}_{-900}$ | $68.7^{+10.8}_{-8.1}$ | $65.4^{+10.1}_{-7.4}$ | $0.72^{+0.09}_{-0.12}$ |

# Snowmass 2021 - CF7

**Cosmic Probes of Fundamental Physics**
**- tests of GR with gravitational waves**

- The LIGO/Virgo tests of GR in the highly relativistic, nonlinear regime of strong gravity do not reveal any inconsistency with the predictions of GR.
- Graviton's mass $\leq 4.7 \times 10^{-23}$ eV/$c^2$ (dispersion in signal).
- First constraint on the −1PN coefficient obtained from binary black holes (dipolar radiation?)
  - The early inspiral of compact binaries modeled by the post-Newtonian (PN) approximation to GR.

arXiv:1903.04467

# Snowmass 2021 Cosmic Frontier

## CF3. Dark Matter: Cosmic Probes

**Looking for**
**Dark Matter (axions)**
**w/ Gravitational Waves**

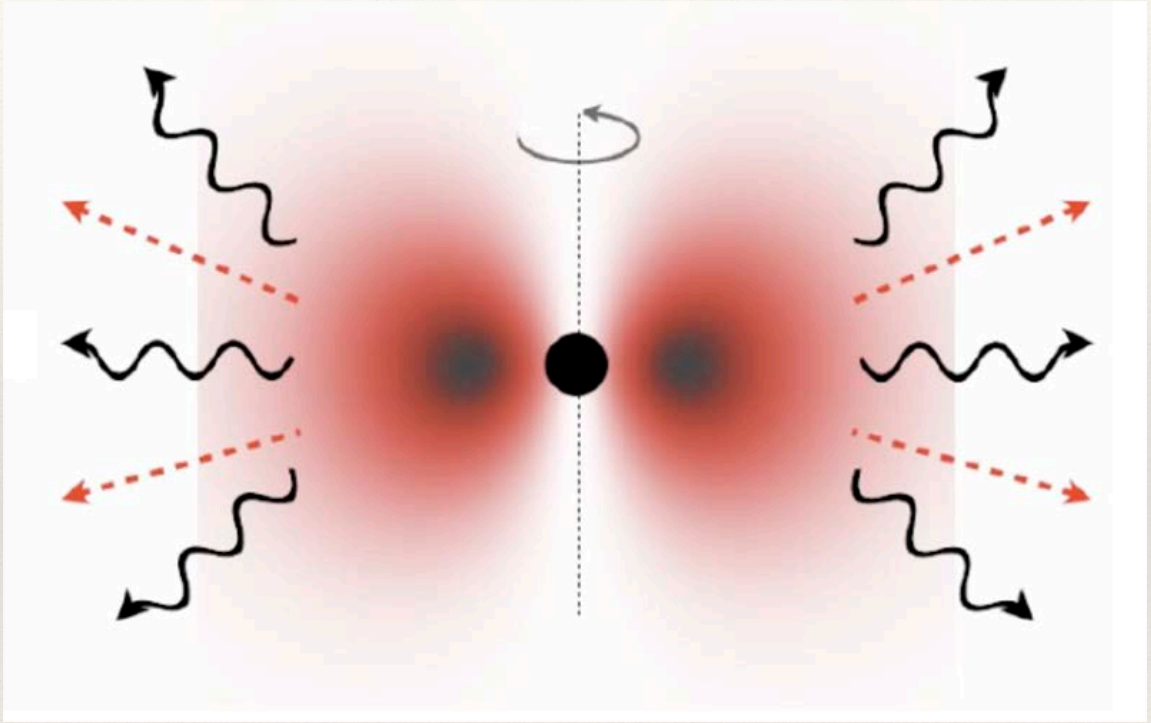
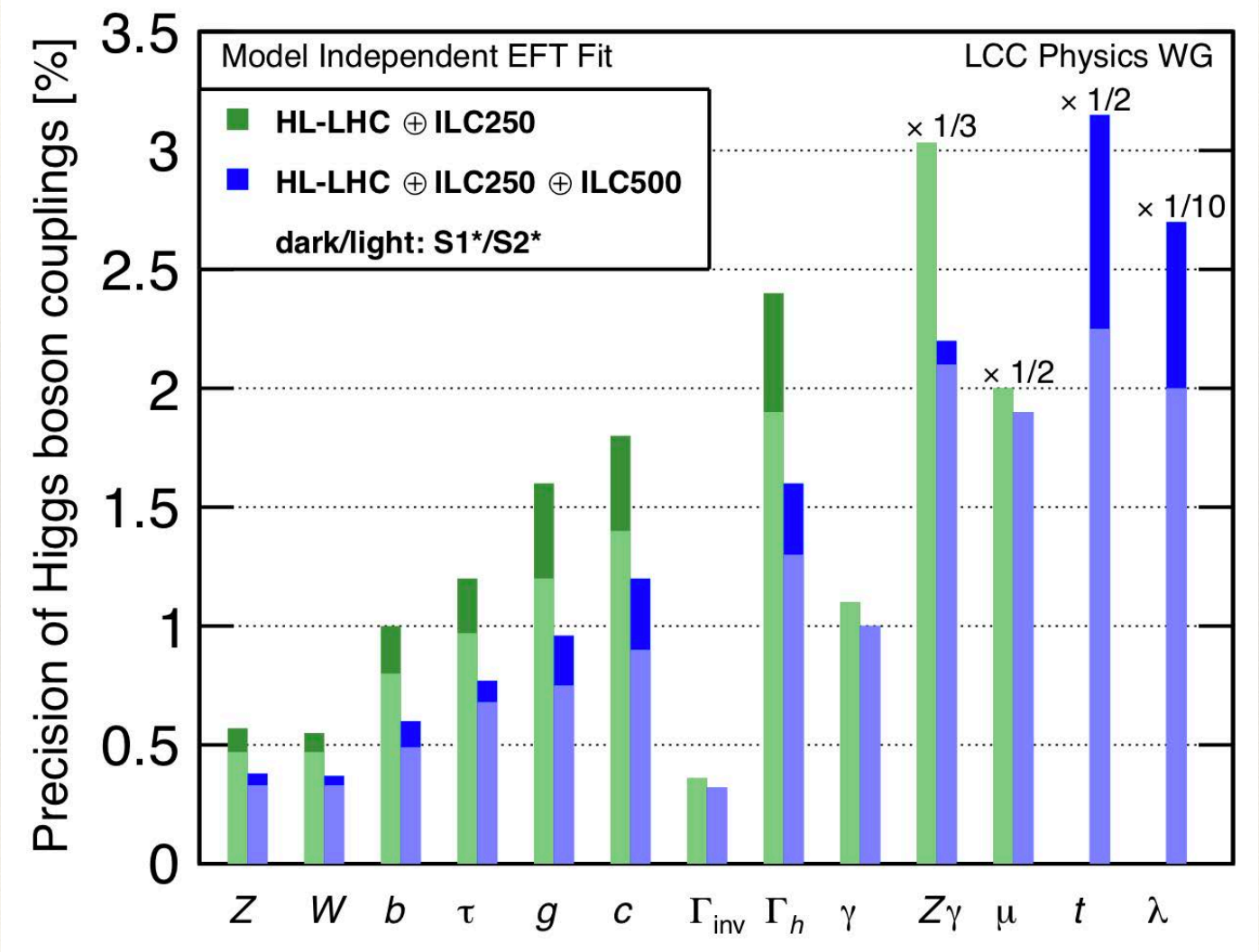


**Table top apparatus**
**aims to collect signals**
**with frequencies**
**as high as 300 kHz,**
**30 times higher than LIGO**

https://meetings.aps.org/Meeting/DAMOP20/Session/C07.3

# Snowmass 2021 and the ILC

Most of the topics in the Energy Frontier are dealing with the physics program of the International Linear Collider (ILC).



# Brief update on the ILC status and transition

- October/Ncvember, 2019 — Linear Collider WorkShop in Sendai
  - Strong statements supporting ILC (Diet, ICFA, etc.)
  - including expression of interest by Melinda Pavek representing US State Department
- Science Council of Japan (SCJ) Master Plan concluded in January.
  - ILC selected as project for hearing, **recognizing scientific merit,** although not on list limited to smaller projects.
  - This **recognition** moves project to next level of consideration.
- ICFA meeting in February.
  - **H. Masuko**, Deputy-Director General, MEXT.
  - **T. Kawamura**, Chairperson of the Federation of Diet Members for the ILC.
  - **Chris Fall,** Director of US DOE Office of Science
- Transition from LCC to Pre-laboratory soon. Being planned.

# LCWS 2019 – Oct/Nov

**Hon . Ryu SHIONOYA, Secretary-General of the Federation of Diet Members for the ILC**

**Reaffirmed Japanese government's interest in hosting the ILC.**

**"US-Japan relation is stronger than ever, and the political and administrative aspects are both working towards the realization of the ILC."**

# LCWS 2019 – Oct/Nov

**Hon . Ryu SHIONOYA, Secretary-General of the Federation of Diet Members for the ILC**

**Melinda Pavek, Director of Science, Innovation and Development, US Embassy, Tokyo**

**Reaffirmed Japanese government's interest in hosting the ILC.**

**"US-Japan relation is stronger than ever, and the political and administrative aspects are both working towards the realization of the ILC."**

*"the U.S. Department of State is ready to assist our partner agencies in developing the next major particle physics facility in Japan—the* ***International Linear Collider.*** *"*

# February ICFA Meeting

- Two leading Japanese figures in the decision process came to SLAC to address ICFA.
  - **H. Masuko**, Deputy-Director General, MEXT.
  - **T. Kawamura**, Chairperson of the Federation of Diet Members for the ILC.
- Both gave encouraging statements.
- **Chris Fall,** Director of US DOE Office of Science, also appeared in person and gave positive ILC statement.
- In response, ICFA released a statement (next slide).
  - https://icfa.fnal.gov/wp-content/uploads/ICFA_Statement_22Feb2020.pdf

# ICFA Statement on the ILC Project

February 22, 2020

ICFA was encouraged by the reports from Mr. H. Masuko, Deputy-Director General, MEXT Research Promotion Bureau and Hon. T. Kawamura, Chairperson of the Federation of Diet Members for the ILC, at the ICFA meeting held at the SLAC National Accelerator Laboratory, Stanford, USA, on the 20th February 2020.

Based on these reports:

- ICFA reconfirms the international consensus for a Higgs factory and wishes to see the timely construction of the ILC in Japan.
- ICFA acknowledges and welcomes the inter-governmental discussion between Japan, the United States and European nations, to advance international collaborative activities for the ILC.
- ICFA notes the need for a preparatory phase ahead of the establishment of the ILC laboratory and the construction of the ILC in Japan.
- ICFA advocates establishment of an international development team to facilitate transition into the preparatory phase.
    - The development team should be hosted by KEK, with leadership chosen with the help of ICFA.
    - The team would develop a plan for the preparatory phase for the construction of the ILC, including technical, organizational and governance issues. It also would be tasked with understanding the activities and resources required in the preparatory phase. The process of developing the plan should involve the interested laboratories and community.
    - ICFA anticipates that these development activities could be completed in approximately one year, at which point it would be possible to launch the preparatory phase for the ILC, provided Japan expresses intent to do so together with international partners.
- In view of progress towards realisation of the ILC in Japan, ICFA encourages the interested members of the high energy physics community, laboratories, and nations, to support and participate in these preparations aimed at the successful establishment of the ILC.

Menlo Park, CA, USA

# ICFA Statement on the ILC Project

February 22, 2020

ICFA was encouraged by the reports from Mr. H. Masuko, Deputy-Director General, MEXT Research Promotion Bureau and Hon. T. Kawamura, Chairperson of the Federation of Diet Members for the ILC, at the ICFA meeting held at the SLAC National Accelerator Laboratory, Stanford. USA. on the 20th Februarv 2020.

**In view of progress towards realisation of the ILC in Japan, ICFA encourages the interested members of the high energy physics community, laboratories, and nations, to support and participate in these preparations aimed at the successful establishment of the ILC.**

https://icfa.fnal.gov/wp-content/uploads/ICFA_Statement_22Feb2020.pdf

- ICFA anticipates that these development activities could be completed in approximately one year, at which point it would be possible to launch the preparatory phase for the ILC, provided Japan expresses intent to do so together with international partners.

- In view of progress towards realisation of the ILC in Japan, ICFA encourages the interested members of the high energy physics community, laboratories, and nations, to support and participate in these preparations aimed at the successful establishment of the ILC.

Menlo Park, CA, USA

LCC/LCB (today)

Transition (Development Team)

~1 year

Preparatory Phase (Pre-Lab)

~4 year

ILC Lab

# Development Team

- Linear Collider Collaboration, led by Lyn Evans, mandate ends June, 2020.
- ICFA, assisted by LCB, led by Tatsuya Nakada, planning a **transition phase**, led by an **international development team**, hosted by KEK. (**Transition** will last approx. 1-1.5 years.)
- **International development team** plans **pre-Lab preparatory phase** including technical, organizational and governance issues and the activities and resources required in the **pre-Lab preparatory phase.**
- Following about one year planning, if Japan has expressed intent with international partners, **pre-Lab preparatory phase** will be launched.

https://icfa.fnal.gov/wp-content/uploads/ICFA_Statement_22Feb2020.pdf

Transition (Development Team) ~1 year

Preparatory Phase (Pre-Lab) ~4 year

ILC Lab

# Development Team

- "The team would develop a plan for the preparatory phase for the construction of the ILC, including technical, organizational and governance issues. It also would be tasked with understanding the activities and resources required in the preparatory phase. The process of developing the plan should involve the interested laboratories and community."
- **Six or seven member Executive hosted by KEK:**
  - **Three regional representatives**
  - **WG1 chair - Core activities**
  - **WG2 chair - Accelerator**
  - **WG3 chair - Physics & Detectors**
- Following about one year planning, if Japan has expressed intent with international partners, **pre-Lab preparatory phase** will be launched.

https://icfa.fnal.gov/wp-content/uploads/ICFA_Statement_22Feb2020.pdf

# Yomiuri newspaper May 13, 2020

Yomiuri Shimbun (the Japan Times) is Japan's largest newspaper, with the largest circulation in the world:

Reported May 13 that **a letter was sent from the U.S. Deputy Secretary of State to Japan's Foreign Minister** in February.

The letter reportedly conveyed **strong support for advancing the ILC project**, confirming, at a much higher level, the view expressed by the U.S. government in the **speech given at the Sendai LCWS by Melinda Pavek**, US Embassy in Tokyo.

# Current status of ILC

- COVID19 suppresses discussion on a big project like ILC.
- However, the ILC political environment in Japan is now very good, thanks, in particular, to strong US support (last slide).
- A climate change: The first stage of the ILC is 250 GeV but, now studies on energy upgrade even above 1 TeV is encouraged.
- Emergency state recently lifted all over Japan.
  - KEK is restarting normal activities. (SuperKEKB & JPARC )
  - Some ILC promotion activities resuming in Tokyo.
- Strategy discussions at KEK (KEK Roadmap, IPNS Research Planning Committee) and JAHEP (Future HEP Project Committee).
- The International Development Team to follow the LCC/LCB being discussed and planned for installation in a timely fashion.

# Conclusion

- The updated planning for the future of the US high energy physics program is underway.
  - Snowmass 2021.
  - NRC decadal survey by 2022.
  - P5 (HEPAP subpanel) by 2023.
- There are many scientific opportunities that will be identified and prioritized.
- Slides for Snowmass' many presentations available at
  - https://indico.fnal.gov/category/1098/