Snowmass’21

Accelerator Frontier:

Summary of Discussions on Future HEP Facilities in the US

ICHEP’2022 – Bologna, Italy, July 8, 2022

Vladimir Shiltsev,
Stephen Gourlay, Tor Raubenheimer

(Snowmass’21 AF Conveners)
What is Snowmass:

“Snowmass is a particle physics community study”

Snowmass provides input to P5 (Particle Physics Project Prioritization Panel) which develops a 10-20 yrs strategy for the US HEP program.

Snowmass is global
Particle Physics is not isolated

~ 1 yr

DOE/NSF

~ 7 yrs of hard work

1.5-2 yrs

P5

https://www.snowmass21.org/
• **Major accelerator-related recommendations:**
  - Contribute to LHC and HL-LHC
  - Engage in the ILC in Japan, contribute if it goes
  - Build >1 MW proton source PIP-II for ν LBNF/DUNE
  - Provide beams for g-2 and mu2e experiments
  - Reassess Muon Accelerator Program and MICE

• **A follow-up 2015 Accelerator R&D subpanel recommended several thrusts:**
  - Beam Physics (incl. IOTA and PIP-III)
  - Sources and Targets (incl. multi-MW)
  - RF (high-Q, high-G, low cost)
  - Magnets and materials (16 T, low cost)
  - Advanced acceleration (towards wakefield colliders)
Few Examples – Facilities/Programs

(under construction) AUP LHC
\( \text{Nb}_3\text{Sn IR quads for HI-LHC} \)

CD-3 project
be ready LS3
FNAL
BNL
LBNL

(ongoing) muon beams for 
\( g-2 \) and \( \mu^2e \) experiments

(FNAL)
8 GeV \( p \)’s \( \rightarrow \) target \( \rightarrow \) \( \mu \)’s
Run-I (2021) 
major muon 
\( g-2 \) discovery

(construction started) PIP-II
800 MeV proton SRF linac @FNAL

Goal: 1.2MW for LBNF/DUNE
Beam to Booster in 2029
30% Int’l contrib.

(completed) ILC@Fermilab
1\(^{st}\) 1.3GHz full CM with beam

FAST facility
ILC type beam
31.5 MeV/m
255 MeV/CM
\( G, Q_0 \) specs

07/08/2022

Fully assembled magnet
Few Examples – Accelerator R&D

Record 14.5T Dipole (at FNAL, part of the US MDP)
- Nb3Sn conductor
- Stress control

FACET-II User facility (SLAC)
- BELLA: PWFA records (LBNL)
  - Unique beam
  - 10 GeV
  - 1 nC
  - 1x1x1 μm
- 8 GeV/0.2m staging p.o.p
- 5+0.1 GeV

MAP/MICE: Ionization cooling of muons (140 MeV/c, RAL, UK)
- MICE
  - ~10% in one pass

IOTA Ring/Optical Stochastic cooling e- (100 MeV, FNAL)
  - soon – experiments with p’s
- THz bandwidth
1. What is needed to advance the physics?
2. What is currently available (state of the art) around the world?
3. What new accelerator facilities could be available on the next decade (or next next decade)?
4. What R&D would enable these future opportunities?
5. What are the time and cost scales of the R&D and associated test facilities as well as the time and cost scale of the facilities?
# Accelerator Frontier Conveners

![Accelerator Frontier Conveners](image)

**Steve Gourlay** (LBNL)  
**Tor Raubenheimer** (SLAC)  
**Vladimir Shiltsev** (FNAL)

<table>
<thead>
<tr>
<th>Topical Group</th>
<th>Topical Group co-Conveners</th>
</tr>
</thead>
</table>
| **AF01** Beam Phys & Accel. Education | Z. Huang (Stanford)  
                           M. Bai (SLAC)  
                           S. Lund (MSU) |
| **AF02** Accelerators for Neutrinos   | J. Galambos (ORNL)  
                          B. Zwaska (FNAL)  
                          G. Arduini (CERN) |
| **AF03** Accelerators for EW/Higgs    | F. Zimmermann (CERN)  
                          Q. Qin (ESRF)  
                          G. Hoffstaetter (Cornell)  
                          A. Faus-Golfe (IN2P3) |
| **AF04** Multi-TeV Colliders          | M. Palmer (BNL)  
                          A. Valishev (FNAL)  
                          N. Pastrone (INFN)  
                          J. Tang (IHEP) |
| **AF05** Accelerators for PBC and Rare Processes | E. Prebys (UC Davis)  
                          M. Lamont (CERN)  
                          Richard Milner (MIT) |
| **AF06** Advanced Accelerator Concepts | C. Geddes (LBNL)  
                           M. Hogan (SLAC)  
                           P. Musumeci (UCLA)  
                           R. Assmann (DESY) |
| **AF07** Accelerator Technology R&D   | E. Nanni (LBNL)  
                           H. Weise (DESY)  
                           S. Belomestnykh (FNAL) |
| **Sub-Group RF**            | G. Sabb (LBNL)  
                           S. Zlobin (FNAL)  
                           S. Izquierdo Bermudez (CERN) |
| **Sub-Group Magnets**        | C. Barbier (ORNL)  
                           Y. Sun (ANL)  
                           Frederique Pellemeine (FNAL) |
Snowmass Activities: pre-Seattle

**Proponents’ Inputs**

<table>
<thead>
<tr>
<th>Letters-Of-Interest</th>
<th>White Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>257</td>
<td>114</td>
</tr>
</tbody>
</table>

- **AF1:** Beam Physics, Education & General
  - Letters-Of-Interest: 61
  - White Papers: 24
- **AF2:** Accelerators for Neutrinos
  - Letters-Of-Interest: 18
  - White Papers: 9
- **AF3:** Accelerators for EW/Higgs
  - Letters-Of-Interest: 32
  - White Papers: 11
- **AF4:** Multi-TeV Colliders
  - Letters-Of-Interest: 56
  - White Papers: 10
- **AF5:** Accelerators for PBC and Rare Proc.
  - Letters-Of-Interest: 37
  - White Papers: 7
- **AF6:** Advanced Accelerator Concepts
  - Letters-Of-Interest: 71
  - White Papers: 10
- **AF7:** Accelerator Technology R&D
  - Letters-Of-Interest: 137
  - White Papers: 43

PLUS:

- > 30 Topical Workshops
- 8 Cross-Frontier **Agoras**
  - All types of colliders: ee, linear/circular, mumu, pp, advanced
  - Experiments and accelerators for rare processes physics
- Special cross-Frontier Groups (e.g., AF-EF-TF)
  - eeCollider Forum, Muon Collider Forum, Implementation Task Force
Now – *Draft Report Only*, will be finalized in Seattle

AF Topical Group, ITF and Fora Summaries – mostly available

Below, only few topics will be briefly covered:

- Accelerators for Neutrinos
- Accelerators for Rare Processes/DM Searches
- Future Colliders
- Key Accelerator R&D

For each - key “messages” (vision):

- Proposed directions (“what”)
- Timeline (“when”) – e.g., by 2030, after 2030
- Challenges (“what’s needed”)
1. Multi-MW \(\nu\) Beams for DUNE

**LBNF/DUNE Project – Phase I:**

- By 2032: **1.2 MW** proton beam (120 GeV) on target + near \(\nu\)-detector + 20 kton LAr \(\nu\)-detector in Lead, SD
- Expected rate of “physics” outcome – upto \(\sim 3\sigma\) in \(\delta_{CP}\), in the **first 6 years** (also \(\Delta m^2_{32}, \sin^2 \theta_{23}, \sin^2 2\theta_{13}\))
- To get to \(\sim 5\sigma\) will get too long, plus – competitor experiment Hyper-K in Japan

**Proposed Plan - LBNF/DUNE Phase II:**

- By 2038: **\sim 2.4 MW** proton beam (120 GeV) on target + new near \(\nu\)-detector + extra 20 kton Lar \(\nu\)-detector
- Expected to get to \(\sim 5\sigma\) in \(\delta_{CP}\) in the **following 6 years**
- Accelerator options proposed/under active study now:
  - (understand max performance and limits with PIP-II linac)
  - New 8 GeV RCS [two options] with/w.o. new 1-3 GeV linac upgrade
  - New 8 GeV linac with or without new 8 GeV accumulator ring
  - In any case – need upgrade of MI RF power and new m-MW targets
  - See S.Nagaitsev talk earlier today
  - Fermilab has formed a special design group
2. >20 Proposed Experiments For Rare Processes

(most via Snowmass Whitepapers)

DM searches, Axion searches, CLFV experiments, muons, light mesons, beam dump experiments… need explore feasibility of corresponding beam facilities

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Experiment type</th>
<th>Primary beam particle</th>
<th>Beam Energy [GeV]</th>
<th>Beam power [kW]</th>
<th>Beam time structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton Storage Ring: EDM and Axion Searches</td>
<td>Precision tests, Dark Matter</td>
<td>proton</td>
<td>0.7 GeV, beam momentum</td>
<td>1e4/11 polarized protons per fill</td>
<td>Fill the ring every 1000s</td>
</tr>
<tr>
<td>Protons with Muons</td>
<td>Precision tests</td>
<td>proton (producing surface muons)</td>
<td>0.8 GeV</td>
<td>1k/300m ROF per second</td>
<td>CW</td>
</tr>
<tr>
<td>Nucleon Electromagnetic Form Factors from Lepton Scattering</td>
<td>Neutrino</td>
<td>electron or proton (producing muons)</td>
<td>0.85 GeV to 2 GeV</td>
<td>1 kW to 10 microamps for electrons, 10% to 10% per second for muons</td>
<td>A continuous or pulsed structure (usually with a duty factor of 1% or larger) should be sufficient</td>
</tr>
<tr>
<td>Rare Decays of Light Mesons (REDM)</td>
<td>Precision tests</td>
<td>protons</td>
<td>1.8-2.2 GeV (Run 1), 0.8-0.9 GeV (Run 2)</td>
<td>0.05-0.5 (Run 1), 0.2 (Run 2)</td>
<td>CW: slow extraction for Run 1</td>
</tr>
<tr>
<td>Ultra-cold Neutron Source for Fundamental Physics Experiments, Including Neutron-Anti-Neutron Oscillations</td>
<td>Precision tests</td>
<td>proton</td>
<td>0.9-2</td>
<td>1000</td>
<td>quasi-continous</td>
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<tr>
<td>CLFV with Muon Decays</td>
<td>CLFV</td>
<td>proton</td>
<td>Not critical D to a few GeV</td>
<td>100 or more</td>
<td>1000</td>
</tr>
<tr>
<td>Mu2e II</td>
<td>CLFV</td>
<td>proton</td>
<td>1 to 3</td>
<td>100</td>
<td>Pulse with width of GeV or better separated by 200 to 3000 ns, flexible time structure and timerate pulse-to-pulse variation</td>
</tr>
<tr>
<td>Fixed Target Searches for new physics with O(1 GeV) Proton Beam Dump</td>
<td>Dark Sector, Neutrino</td>
<td>proton</td>
<td>0.8 to 1.5 GeV</td>
<td>100 or more</td>
<td>Pulse with width of GeV or better separated by 200 to 3000 ns, flexible time structure and timerate pulse-to-pulse variation</td>
</tr>
<tr>
<td>RHICbL: Charged Lepton Flavor Violation</td>
<td>CLFV</td>
<td>proton</td>
<td>1-3 GeV</td>
<td>up to 2MW</td>
<td></td>
</tr>
<tr>
<td>Electron Missing Momentum (EDMX)</td>
<td>Dark Sector</td>
<td>electron</td>
<td>3-20 GeV</td>
<td>1 electron per HP hit and 52 MHz</td>
<td>CWvia:</td>
</tr>
<tr>
<td>Electron Beam Dumps</td>
<td>Dark Sector</td>
<td>electron</td>
<td>Few GeV</td>
<td></td>
<td></td>
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<tr>
<td>Proton Irradiation Facility</td>
<td>BNO</td>
<td>proton</td>
<td></td>
<td>10^15 electrons on target over the experiment of runtime</td>
<td>Pulsed beam (duty factor not specified)</td>
</tr>
<tr>
<td>Muh</td>
<td>Neutrino</td>
<td>proton</td>
<td>5</td>
<td>52</td>
<td>3kHz</td>
</tr>
<tr>
<td>Fixed Target Searches for new physics with O(10 GeV) Proton Beam Dump</td>
<td>Dark Sector, Neutrino</td>
<td>proton</td>
<td>0</td>
<td>up to 115</td>
<td>Beam splits less than a microsecond with separation between splits greater than 50 microseconds</td>
</tr>
<tr>
<td>Muon Collider (R&amp;D and Neutrino Factory)</td>
<td>BNO</td>
<td>proton</td>
<td>3 GeV/4 muons</td>
<td>0.14/4 muons in total for the whole run</td>
<td>CW</td>
</tr>
<tr>
<td>Muon Missing Momentum</td>
<td>Dark Sector</td>
<td>proton (producing muons)</td>
<td>5-30 GeV</td>
<td>10^14 muons per beam pulse</td>
<td>Pulsed beam (duty factor not specified)</td>
</tr>
<tr>
<td>High Energy/Proton Fixed Target</td>
<td>Dark Sector, Neutrino</td>
<td>proton</td>
<td>0 GeV</td>
<td>1e4 POT/30s therefore ~20nA</td>
<td>CW via resonant extraction, &quot;If we could upgrade the duty factor that would also even better&quot;</td>
</tr>
<tr>
<td>Test Beam Facility</td>
<td>BNO</td>
<td>proton</td>
<td>100</td>
<td>10 to 100 kHz on the testing apparatus</td>
<td>Pulsed beam (duty factor not specified)</td>
</tr>
<tr>
<td>Tau Neutrino</td>
<td>Neutrino</td>
<td>proton</td>
<td>0</td>
<td>0.3 or higher</td>
<td>All time structure</td>
</tr>
</tbody>
</table>

~2 GeV CW-capable beam

~2 GeV pulsed beam from storage ring ~1MW

~8 GeV pulsed beam ~1MW

120 GeV Slow extraction or LBNF beam
Proposed PIP-II Accumulator Ring (PAR)

Features:
- Fixed $E=0.8\text{-}1.0$ GeV proton storage ring
- $C=480\text{m}$ in the form of a folded figure 8
- Power 100 kW for Dark Sector program, 100Hz
- There is also compact version $C=120\text{ m}$
## Future Collider Proposals: 8 Higgs/EW factories

<table>
<thead>
<tr>
<th>Name</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>CepC</td>
<td>e+e-, $\sqrt{s} = 0.24$ TeV, L= $3.0 \times 10^{34}$</td>
</tr>
<tr>
<td>CLIC (Higgs factory)</td>
<td>e+e-, $\sqrt{s} = 0.38$ TeV, L= $1.5 \times 10^{34}$</td>
</tr>
<tr>
<td>ERL ee collider</td>
<td>e+e-, $\sqrt{s} = 0.24$ TeV, L= $73 \times 10^{34}$</td>
</tr>
<tr>
<td>FCC-ee</td>
<td>e+e-, $\sqrt{s} = 0.24$ TeV, L= $17 \times 10^{34}$</td>
</tr>
<tr>
<td>gamma gamma</td>
<td>X-ray FEL-based $\gamma\gamma$ collider</td>
</tr>
<tr>
<td>ILC (Higgs factory)</td>
<td>e+e-, $\sqrt{s} = 0.25$ TeV, L= $1.4 \times 10^{34}$</td>
</tr>
<tr>
<td>LHeC</td>
<td>ep, $\sqrt{s} = 1.3$ TeV, L= $0.1 \times 10^{34}$</td>
</tr>
<tr>
<td>MC (Higgs factory)</td>
<td>$\mu\mu$, $\sqrt{s} = 0.13$ TeV, L= $0.01 \times 10^{34}$</td>
</tr>
</tbody>
</table>

**CepC/FCCee**
- 100 km
- 100MW RF

**CLIC NCRF**
- 72 MV/m
- 11 km

**ILC SRF**
- 31.5 MV/m
- 21 km

07/08/2022  Shiltsev | Snowmass Accelerators
<table>
<thead>
<tr>
<th>Name</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryo-Cooled Copper linac</td>
<td>$e^+e^-, \sqrt{s} = 2 \text{ TeV}, L = 4.5 \times 10^{34}$</td>
</tr>
<tr>
<td>High Energy CLIC</td>
<td>$e^+e^-, \sqrt{s} = 1.5 - 3 \text{ TeV}, L = 5.9 \times 10^{34}$</td>
</tr>
<tr>
<td>High Energy ILC</td>
<td>$e^+e^-, \sqrt{s} = 1 - 3 \text{ TeV}$</td>
</tr>
<tr>
<td>FCC-hh</td>
<td>$pp, \sqrt{s} = 100 \text{ TeV}, L = 30 \times 10^{34}$</td>
</tr>
<tr>
<td>SPPC</td>
<td>$pp, \sqrt{s} = 75/150 \text{ TeV}, L = 10 \times 10^{34}$</td>
</tr>
<tr>
<td>Collider-in-Sea</td>
<td>$pp, \sqrt{s} = 500 \text{ TeV}, L = 50 \times 10^{34}$</td>
</tr>
<tr>
<td>LHeC</td>
<td>$ep, \sqrt{s} = 1.3 \text{ TeV}, L = 1 \times 10^{34}$</td>
</tr>
<tr>
<td>FCC-eh</td>
<td>$ep, \sqrt{s} = 3.5 \text{ TeV}, L = 1 \times 10^{34}$</td>
</tr>
<tr>
<td>CEPC-SPPpC-eh</td>
<td>$ep, \sqrt{s} = 6 \text{ TeV}, L = 4.5 \times 10^{33}$</td>
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<tr>
<td>VHE-ep</td>
<td>$ep, \sqrt{s} = 9 \text{ TeV}$</td>
</tr>
<tr>
<td>MC – Proton Driver 1</td>
<td>$\mu\mu, \sqrt{s} = 1.5 \text{ TeV}, L = 1 \times 10^{34}$</td>
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<tr>
<td>MC – Proton Driver 2</td>
<td>$\mu\mu, \sqrt{s} = 3 \text{ TeV}, L = 2 \times 10^{34}$</td>
</tr>
<tr>
<td>MC – Proton Driver 3</td>
<td>$\mu\mu, \sqrt{s} = 10 - 14 \text{ TeV}, L = 20 \times 10^{34}$</td>
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<tr>
<td>MC – Positron Driver</td>
<td>$\mu\mu, \sqrt{s} = 10 - 14 \text{ TeV}, L = 20 \times 10^{34}$</td>
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<tr>
<td>LWFA-LC (e+e- and $\gamma\gamma$)</td>
<td>Laser driven; $e^+e^-, \sqrt{s} = 1 - 30 \text{ TeV}$</td>
</tr>
<tr>
<td>PWFA-LC (e+e- and $\gamma\gamma$)</td>
<td>Beam driven; $e^+e^-, \sqrt{s} = 1 - 30 \text{ TeV}$</td>
</tr>
<tr>
<td>SWFA-LC</td>
<td>Structure wakefields; $e^+e^-, \sqrt{s} = 1 - 30 \text{ TeV}$</td>
</tr>
</tbody>
</table>
(New!) LC-Higgs Factories on FNAL Site

Must fit ~7 km incl BDS
Requires gradients of least 72MV/m
Compact → lower cost (wri ILC/CLIC)

Option 1: Cool Copper Collider (C³)
5.7GHz
77K

Option 1: HELEN (Travelling Wave ILC)
1.3GHz
2 K
FNAL Citing – $O(10 \text{ TeV})$ Muon Collider

- First design concept of up to 10 TeV collider developed
- Operation at 125 GeV, 1 and 3 TeV can be envisioned as intermediate states
- Capitalize on existing facilities and expertise:
  - PIP-II and upgrades,

**Muon Colliders Forum:**
- (CERN-led Int’l Muon Collider Collaboration)
- Carry out R&D and deliver pre-CDR ca 2030
The Accelerator Implementation Task Force (ITF) is charged with developing metrics and processes to facilitate a comparison between collider projects.

- 10 int’l experts, 2 Snowmass Young’s, 3 liaisons to Energy & Theory Frontiers
- ITF addressed (four subgroups):
  - Physics reach (impact), beam parameters
  - Size, complexity, power, environment
  - Technical risk, technical readiness, validation and R&D required
  - Cost and schedule

REPORT


Thomas Roser (BNL, Chair)  Philippe Lebrun (CERN)  Steve Gourlay (LBNL)  Tor Raubenheimer (SLAC)  Katsunobu Oide (KEK)  Jim Strait (FNAL)  Vladimir Shiltsev (FNAL)  Reinhard Brinkmann (DESY)  John Seeman (SLAC)
# From the ITF Report Draft: Tables 1-3, 5

<table>
<thead>
<tr>
<th>Project</th>
<th>CME (TeV)</th>
<th>Lumi per IP (10^34)</th>
<th>Years, pre-project R&amp;D</th>
<th>Years to 1st physics</th>
<th>Cost range (2021 B$)</th>
<th>Electric Power (MW)</th>
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<tbody>
<tr>
<td>FCCee-0.24</td>
<td>0.24</td>
<td>8.5</td>
<td>0-2</td>
<td>13-18</td>
<td>12-18</td>
<td>280</td>
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<td>ILC-0.25</td>
<td>0.25</td>
<td>2.7</td>
<td>0-2</td>
<td>&lt;12</td>
<td>7-12</td>
<td>140</td>
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<tr>
<td>CLIC-0.38</td>
<td>0.38</td>
<td>2.3</td>
<td>0-2</td>
<td>13-18</td>
<td>7-12</td>
<td>110</td>
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<td>HELEN-0.25</td>
<td>0.25</td>
<td>1.4</td>
<td>5-10</td>
<td>13-18</td>
<td>7-12</td>
<td>110</td>
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<tr>
<td>CCC-0.25</td>
<td>0.25</td>
<td>1.3</td>
<td>3-5</td>
<td>13-18</td>
<td>7-12</td>
<td>150</td>
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<tr>
<td>MC-Higgs</td>
<td>0.13</td>
<td>0.01</td>
<td>&gt;10</td>
<td>19-24</td>
<td>4-7</td>
<td>~200</td>
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<tr>
<td>CLIC-3</td>
<td>3</td>
<td>5.9</td>
<td>3-5</td>
<td>19-24</td>
<td>18-30</td>
<td>~550</td>
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<tr>
<td>ILC-3</td>
<td>3</td>
<td>6.1</td>
<td>5-10</td>
<td>19-24</td>
<td>18-30</td>
<td>~400</td>
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<tr>
<td>MC-3</td>
<td>3</td>
<td>2.3</td>
<td>&gt;10</td>
<td>19-24</td>
<td>7-12</td>
<td>~230</td>
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<tr>
<td>MC-FNAL</td>
<td>6-10</td>
<td>20</td>
<td>&gt;10</td>
<td>19-24</td>
<td>12-18</td>
<td>O(300)</td>
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<tr>
<td>MC-10</td>
<td>10-14</td>
<td>20</td>
<td>&gt;10</td>
<td>&gt;25</td>
<td>12-18</td>
<td>O(300)</td>
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<tr>
<td>FCChh-100</td>
<td>100</td>
<td>30</td>
<td>&gt;10</td>
<td>&gt;25</td>
<td>30-50</td>
<td>~560</td>
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</table>
Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

June 30, 2022

U.S. National Accelerator R&D Program on Future Colliders

We propose that the U.S. establish a national integrated R&D program on future colliders in the DOE Office of High Energy Physics (OHEP) and charge the program

- to carry-out technology R&D and accelerator design for future collider concepts,
- to enable synergistic engagement in projects proposed abroad (e.g. FCC, ILC, CLIC, IMCC),
- to develop design reports on collider options, by the time of the next Snowmass and P5 (2029–2030), particularly for options that are feasible to be hosted in the U.S.,
- to develop R&D plans for the decade beyond 2030
Multi-MW targets:
- 2.4MW PIP-III
- 4-8 MW for muon collider

Magnets for colliders and RCSs:
- 16T dipoles
- 30T solenoids
- 1000 T/s fast cycling ones
coordinate with US MDP

Advanced:
- collider quality beams
- efficient drivers
- close coordination with Int’l (Euro Roadmap, EUPRAXIA,..)

SC/NC RF:
- 72-120 MV/m C³
- 72 MV/m TW SRF
- new materials, high Q₀
- efficient power sources
• ICHEP’22 presentations on AF/related topics **Thursday, July 7:**
  – A.Faus-Golfe (AF3) on CLIC and ILC
  – N.Pastrone (AF4) on energy frontier colliders
  – S.Nagaitsev on multi-MW proton beams at FNAL
  – D.Druitti and R.Reimann on the muon g-2 ring
  – V.Pronskykh on the mu2e target
  – S.Nagaitsev on the optical stochastic cooling
  – D.Calzolari on MDI of multi-TeV muon collider
• Later in this session:
  – D.Schulte on the energy frontier muon colliders
  – P.Burrows – on ILC and CLIC
• Special thanks to
  – My co-conveners S.Gourlay and T.Raubenheimer
  – T.Roser (ITF chair) and P.Bhat (FNAL collider group leader)
  – Accelerator Frontier Topical Group conveners and liaisons to EF, NF and TF
• In preparation of the **Snowmass in Seattle**, tons of material available at:
  [https://snowmass21.org/accelerator/start](https://snowmass21.org/accelerator/start)

Thanks for your attention!