Beams, Accelerator R&D and Future Facilities: Accelerator Frontier Vision

Community Summer Study – Seattle, July 21, 2022

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(Snowmass’21 AF Conveners)
I. On Accelerators (8 slides)

II. Progress since 2014 P5 (3 slides):

III. Snowmass’21 AF View of HEP (23 slides):
   – Accelerators for Neutrinos
   – Accelerators for Rare Processes
   – Colliders

IV. Accelerator “Messages/Asks” (10 slides):
   – Ongoing efforts
   – Goals by next Snowmass/P5: Facilities
   – Next Decade: Accelerator R&D Priorities
   – P5 and Accelerator R&D
90 Years of Accelerators

Since Cockroft & Walton, Lawrence, van der Graaf:

- 4 Nobel Prizes + led to 1/3 of all Physics Nobels and more

140 used in research now:

- with 4500 experts + 15000 staff
- serving ~80,000 users (Cond. Matter, HEP, bio, NP, etc)

Pushing the envelope:

- Energy, performance (power, luminosity, brilliance, species), cost, complexity, size, R&D, …
Colliders: Livingston Plot

- 31 built
- 7 operate now
- 2 under construction

[V. Shiltsev and F. Zimmermann, Rev. Mod. Phys. 93, 015006 (2021); V. Shiltsev, Phys. Usp. 55, 965 (2012)]
Collider Luminosities

[V. Shiltsev and F. Zimmermann, Rev. Mod. Phys. 93, 015006 (2021); V. Shiltsev, Phys. Usp. 55, 965 (2012)]

Grows but not as $E^2$
Record 46.5 nb$^{-1}$s$^{-1}$
(S-KEKB 06/08/22)
Revolution in Light Sources /X-ray Sources

The graph illustrates the evolution of peak brilliance in light sources from 1895 to 2030. It categorizes sources into three generations:

1. **1st Generation**: X-ray tubes, including the 1895 Roentgen tube.
2. **2nd Generation**: Synchrotron radiation sources, such as SURF, SSRL, DORIS, VEPP3, etc.
3. **3rd Generation**: Free-electron lasers, including FLASH, SACLAL, LCLS, X-FEL, etc.
4. **4th Generation**: Synchrotron radiation sources, such as MAX-IV, APS-U, Sirius, etc.

The graph also shows projected development up to 2030, with expected sources like NSLS, BESSY, SRS, PF, etc., and advanced laser sources like X-FEL, etc.
Accelerators: Not only HEP

Approx. total cost of accelerator construction projects/decade

HEP (colliders, neutrino, etc)
Non-HEP (NP. BES, etc)

SNS, LCLS, Diamond, etc
FRIB, SLS CSNS, XFEL, SwissFEL, PAL, ESRF-U, NICA SXFEL, FAIR, NSLS-II, Spring-8, Sirius, etc
LCLS-II/HE EIC, APS-U FAIR, ESS, SHINE, NICA ALS-U, SKIF, PETRA-IV, etc
HL-LHC PIP-II, LBNF
S-KEKB, LIU

LHC J-PARC VEPP-2000

SNS-STS, X-sources LCLS-X

PIP-III? collider?
Costs of Accelerators

- Future circular hadron colliders (proposed)
- Multi-TeV lepton colliders (proposed)
- Smaller facilities for medical, industrial, security, and R&D applications
- Small-scale light sources
- Large accelerator facilities for R&D, industrial, and security applications
- Upgrades of existing light sources, proton beams, nuclear physics facilities, and FELs
- Large medical accelerator facilities

- $10+ B$ (Very Large Hadron Collider at CERN)
- $3-10 B$
- $1-3 B$
- $0.3-1 B$
- $0.1-0.3 B$
- $10-30 M$
- $30-100 M$

- X-ray FELs
- Large nuclear physics and multi-MW proton-beam facilities
- Frontier electron-ion collider (proposed)

- Third- and fourth-generation light sources
- LHC upgrade
- Smaller nuclear physics and <1 MW proton-beam facilities, small electron-ion colliders

V. Shiltsev, Physics Today 73 (4), 32 (2020)
Cost is set by the scale (energy, length, power) and technology

- **Accelerator technology**
  (magnets NC and SC, RF and SCRF)
  \[ \sim 50 \pm 10\% \]

- **Civil construction technology**
  \[ \sim 35 \pm 15\% \]

- **Power delivery, transformation and distribution technology**
  \[ \sim 15 \pm 10\% \]
Accelerators Timeline $X+Y+Z$

Bigger size and cost $\rightarrow$ longer:

- **Pre-project R&D** $X$ years
  - Depends on novelty

- **Construction project** $Y$ years
  - Limited annual peak M$/year
  - “Oide law”: need $\sim$1 expert to spend (intelligently) 1 M$/year
  - NB: <4500 experts worldwide

- **Commissioning** $Z$ years
  - Depends on complexity
  - Past large colliders:
    - 5 yrs $^+4$ (SLC, DAFNE, BEPCII)
    - 3 yrs $^-$ (PEP-II, Tevatron-I, LEP-II)
Part II

Progress since 2014 P5
• **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)
Some Examples – Facilities/Programs

(under construction) AUP LHC
\[ \text{Nb}_3\text{Sn IR quads for HL-LHC} \]
CD-3 project
be ready LS3
FNAL
BNL
LBNL

(ongoing) muon beams for g-2 and mu2e 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 Program
1\( \text{st} \) 1.3GHz full CM with beam
Fermilab
FAST facility
ILC type beam
31.5MeV/m
255 MeV/CM
= \( G \cdot Q \) specs
Some Examples – Accelerator R&D

Record 14.5T Dipole (at FNAL, part of the US MDP)

Nb3Sn conductor
Stress control

MAP/MICE: Ionization cooling of muons (140 MeV/c, RAL, UK)

MICE
~10% in one pass

FACET-II User facility (SLAC)

BELLA: LWFA records (LBNL)

Unique beam
10 GeV
1 nC
1x1x1 μm

IOTA Ring/Optical Stochastic cooling e- (100 MeV, FNAL)

soon – experiments with p’s

8 GeV/0.2m
staging p.o.p
0.1+0.1 GeV

07/22/2022

THz bandwidth
Snowmass’21 Accelerator Frontier View

AF Topical Groups provided input to community/P5 to evaluate options on future facilities:

I. Accelerators for Neutrinos
II. Accelerators for Rare Processes
III. Colliders
I: Accelerators for ν’s: 2020s – PIP-II constr./commiss.

What’s in plan for 2030s?

0.8 GeV PIP-II Linac Status (webcam July 2022)

PIP-II Injector Test
HWR CM
SSR1 CM Prototype

Cryoplant Building
Multi-MW $\nu$ Beams for DUNE

**LBNF/DUNE Project – Phase I:**
- By 2032: **1.2 MW** proton beam (120 GeV, MI) on target + near $\nu$-detector + 20 kton LAr $\nu$-detector in Lead, SD
- Expected rate of “physics” outcome – up to $\sim 3\sigma$ in $\delta_{\text{CP}}$, in the **first 6 years** (also $\Delta m^2_{32}$, $\sin^2\theta_{23}$, $\sin^2\theta_{13}$)
- To get to $\sim 5\sigma$ will take too long, plus – competitor experiment *Hyper-K* in Japan (30 GeV J-PARC $p$ beam)

**Proposed LBNF/DUNE Phase II:**
- By 2038: **2.4 MW** proton beam + new near $\nu$-detector + extra 20 kton LAr $\nu$-detector
- Expected to get to $\sim 5\sigma$ in $\delta_{\text{CP}}$ in the **following 6 years**

https://arxiv.org/abs/2203.06100
2.4 MW Upgrade Challenge

Booster prevents x2 PIP-II power: injection energy and transition-crossing limits

1.2 → 2.4 MW
LBNF Neutrinos to DUNE

https://arxiv.org/abs/2203.08276
2.4 MW: Rapid-Cycling Synchrotron (RCS) Option

|                                | 8 GeV Booster | 8 GeV RCS  
|--------------------------------|---------------|------------
| Injection energy, GeV          | 0.8           | 1-3        
| Transition crossing            | yes           | no         
| Circumference, m               | 480           | ~600       
| Rep rate, Hz                   | 20            | 10-20      
| Supports power 120/8 GeV       | 1.2 / 0       | 2.4 / 0.1+ 

Main Injector (MI)

Optional Storage Ring

RCS

Optional Storage Ring ~ 1 GeV

PIII Linac

Optional 1-3 GeV Linac Upgrade

H- Injection easier at lower energy

https://arxiv.org/abs/2203.08707
Path to 2.4 MW: 8 GeV Linac Option

Main Injector (MI)

8 GeV storage ring (s)

Optional Storage Ring

PIP-II Linac

8 GeV Linac

H- Injection is challenge at 8 GeV

https://arxiv.org/abs/2203.05052
2.4 MW Upgrade: Challenges

- Competition with Hyper-K / J-PARC
- Short timeline, design Q:
  - Other spigots (μ2e-II, DM and RPF, MuCollider)
- Cost challenge
- The rest of the complex
  - Main Injector RF upgrade
  - 2.4 MW target R&D
- Performance risk (beam losses):
  - Instabilities
  - Injection, collimation
  - Space-charge effects
  - IOTA-ring ρ R&D
## II: >20 Proposed Experiments For Rare Processes
(most via Snowmass Whitepapers)

Searches for DM, axions, EDMs, CLFV experiments, muons, light mesons, beam dump experiments...calls for corresponding beam facilities @FNAL, SLAC, Jlab, SNS

<table>
<thead>
<tr>
<th>Experiment Type</th>
<th>Experiment Name</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>Precision tests</td>
<td>Proton Storage Ring EDM and Axion Searches</td>
<td>Proton</td>
<td>0.7 GeV (beam momentum)</td>
<td>~1 kW</td>
<td>Fill the ring every 100s</td>
</tr>
<tr>
<td>Precision tests</td>
<td>Protons with Muon</td>
<td>Protons (producing muon in surface scintillator)</td>
<td>0.9 GeV</td>
<td>1 kW/300 MHz</td>
<td>CW</td>
</tr>
<tr>
<td>Precision tests</td>
<td>Neutrino Electromagnetic Form Factors from Lepton Scattering</td>
<td>Neutrino</td>
<td>E\text{GeV} \to 2 \text{GeV}</td>
<td>1 kW/10 microamps for electron, 1000 - 10000 microamps for muon</td>
<td>Continuous or pulsed structure (ideally with a duty factor of 1% or larger) should be sufficient</td>
</tr>
<tr>
<td>Precision tests</td>
<td>Rare Decay of Light/Nucl Events (REDTOP)</td>
<td>Proton</td>
<td>0.62 GeV (Run II; 0.62 - 0.8 GeV (Run I, 0.8 GeV)</td>
<td>0.03 - 0.06 (Run I, 0.01, 0.02, 0.03, 0.04, 0.05)</td>
<td>CW or slow extraction for Run I</td>
</tr>
<tr>
<td>Precision tests</td>
<td>Ultra-Cold Neutron Source for Fundamental Physics Experiments, Including Neutron-Neutron Oscillations</td>
<td>Proton</td>
<td>0.8 - 2 GeV</td>
<td>~100 microamps</td>
<td>Quasi-continuous</td>
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<td>CLFV</td>
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<td>Proton</td>
<td>~1 GeV</td>
<td>~100 microamps</td>
<td>Continuously beam on the timescale of the muon lifetime, i.e., proton pulses separated by a microsecond or less. The more continuous the better</td>
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### Electron beams:
- ~GeV to multi-GeV

### Proton beams:
- ~2 GeV CW-capable beam
- ~2 GeV pulsed beam from storage ring ~1 MW
- ~8 GeV pulsed beam ~1 MW
- 120 GeV Slow extraction or LBNF beam

In many cases, existing or planned facilities can be and should be fully utilized!
Features:
- Parasitic use of the SLAC electron SRF linac $E=4$-8 GeV
- Low intensity, almost CW beamline, 1-500 e-/us
- Beam dump and LDMX experiment
- Construction started
Proposed PIP-II Accumulator Ring (PAR)

Features:
- Fixed $E=0.8$-$1.0$ GeV proton storage ring
- $C=480$ m in the form of a *folded figure 8*
- Power 100 kW for Dark Sector program, 100Hz
- There is also compact version $C=120$ m

https://arxiv.org/abs/2203.07339

07/22/2022
Important:

– There are too many concepts to cover them here in any detail

– Brief technical descriptions in RMP and PDG:
  V. Shiltsev, F. Zimmermann, RMP 93, 015006 (2021);

– Detail evaluations and discussions in the Accelerator Topical Group Reports AF3, AF4, AF6 and AF7, and the ITF report:
  available at https://snowmass21.org/accelerator/
From the *Energy Frontier* Draft Report

- **Five year period starting in 2025**
  - Prioritize HL-LHC physics program
  - Establish a targeted e+e- Higgs Factory detector R&D for US participation in a global collider
  - Develop an initial design for a first stage TeV-scale MuC in the US (pre-CDR)
  - Support critical detector R&D towards EF multi-TeV colliders

- **Five year period starting in 2030**
  - Continue strong support for HL-LHC program
  - Support construction of an e+e- Higgs Factory
  - Demonstrate principal risk mitigation and deliver CDR for a first-stage TeV-scale MuC

- **After 2035**
  - Evaluate continuing HL-LHC physics program to the conclusion of archival measurements
  - Begin and support the physics program of the Higgs Factories
  - Demonstrate readiness to construct and deliver TDR for a first-stage TeV-scale MuC
  - Ramp up funding support for detector R&D for EF multi-TeV colliders

*Note: common themes and differences with European strategy*
Other Important Inputs

**e+e- Collider Forum w. EF&TF**

**Higgs Factories:**
FCCee and CEPC more *Lumi* but $$
ILC$ and CCC faster and less costly
US to contribute to any *committed HF*

**O(10 TeV) colliders:** wakefield
R&D focused on collider specs

**μ+μ- Collider Forum w. EF&TF**

**10+ TeV cme MC - ideal:**
No showstoppers, best $ab^{-1}/TWh, $
Need engineering and targeted R&D
Develop pre-CDR by 2030
Establish US MuC organization
Join Int’l collaboration (IMCC/CERN)

**US Nat’l Collider R&D Initiative**

**Gap in R&D on colliders →**
Establish targeted OHEP program
Integrated approach to cover:
Int’l efforts (ILC, FCC, IMCC,…) and
toward US options feasible in the US
(CCC, HELEN, 10+ TeV MC, etc)

**Implementation Task Force**

**Evaluated 32 collider proposals:**
Cost and schedule
Technical readiness, needed R&D
Power requirements, complexity
Physics reach (impact), parameters
(call for R&D on energy efficiency)
Higgs Factory Proposals: mature ones

Advantages

Challenges

❖ FCCee (CEPC):
  ❖ Supported by Europe/CERN, high L
  ❖ Longest, $$, power consumption

❖ CLIC:
  ❖ Lowest power needs, shortest
  ❖ 2-beams (or klystrons?), tolerances

❖ ILC:
  ❖ Ready to go, polarization
  ❖ Long, e+ source, Japan no-decision
**LC-Higgs Factories on FNAL Site**

Must fit ~7 km including BDS

Required gradients of at least **70MV/m**

Compact → lower cost (wrt ILC/CLIC)

**Option 1:** Cool Copper Collider ($C^3$)

- 5.7GHz
- 77K

**Option 2:** HELEN (Travelling Wave ILC)

- 1.3GHz
- 2 K
Higgs Factory Proposals (3): aggressive alternatives

- **Energy recovery based e+e- colliders (circular or linear):**
  - High luminosity per MW power consumption
  - Not yet mature (orders of magnitude in current, $Q_0$), long, expensive

- **Gamma-gamma linear colliders:**
  - Need only ½ of energy, short, potentially less expensive, no e+
  - need two beyond-state-of-the-art FELS to generate $\gamma$'s in collisions with e-

- **Muon collider Higgs factory:**
  - Need only ½ of energy ($65+65 = 130$ GeV), very compact, less expensive
  - Too long to develop (muon cooling, etc), low Lumi (but high X-section)

Advantages

Challenges
3-10 TeV/Parton CME:

*most discussed*

- **CLIC-3 TeV**:
  - Established CDR, demo facilities
  - Long, $$\$, huge power consumption

- **FCChh-100 TeV**:
  - Re-use FCCee tunnel, high-$L$, LHC exp.
  - 20(?) yrs for 16 T magnets, $$\$, power

- **SPPC-125 TeV**:
  - Re-use CepC tunnel, $ep$ 0.12+62.5 TeV
  - (N) yrs for 20 T magnets, $$\$, power

- **Muon Collider-10(14) TeV**:
  - Potentially lowest cost, best $Lumi/TWh$
  - 6D cooling $R$, $D$ on many subsystems
FNAL Siting – 6-10 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 stages
- Capitalize on existing facilities and expertise:
  - PIP-II and upgrades, Tevatron tunnel
  - Facilities for cooling, target, SRF, and magnet R&D
  - World intellectual leadership in these areas
Energy Frontier Proposals (2): other ideas

❖ “Push to the limit” colliders (circular or linear) – ILC-3 TeV, ERL-based LCs 3 TeV cme, 2100 km long “Collider-in-the-Sea”:
  ❖ “Just scale-up” technology
  ❖ Enormous power consumption, long, expensive

❖ Wakefield acceleration (L/P/S) linear ee/γγ colliders:
  ❖ Most compact, m.b. cost efficient (??) and offer multi-TeV collisions
  ❖ Uncertainties: e+ acceleration, staging, quality, power efficiency, lot of R&D

❖ ep/eh colliders (LHeC-1.2, FCCeh-3.5, epChina-5.5 TeV):
  ❖ Very cost efficient ($), feasible, nice additions to proton machines
  ❖ High current 50 GeV ERL technology needs demonstration (3 orders in P)
**Implementation Task Force**

- 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
### 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>
</tr>
</thead>
<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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<tr>
<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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<tr>
<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>CERC(ERL)</td>
<td>0.24</td>
<td>78</td>
<td>5-10</td>
<td>19-24</td>
<td>12-30</td>
<td>90</td>
</tr>
</tbody>
</table>

**FCCee: 2-4 IPs**  
**all LCs: 1 IP**

**Estimated Total Project Cost**

*No escalation*

*No contingency*

NB: HELEN, C^3 m.b. 85% of ILC but in the same range category

Disclaimer: luminosity and power consumption values have not been reviewed by ITF
From the ITF Report: Tables 1-3, 5

<table>
<thead>
<tr>
<th>All LCs: 1 IP</th>
<th>MC-3/14: 2 IPs</th>
<th>FCChh: 2-4 IPs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CLIC-3</strong></td>
<td>3</td>
<td>5.9</td>
</tr>
<tr>
<td><strong>ILC-3</strong></td>
<td>3</td>
<td>6.1</td>
</tr>
<tr>
<td><strong>MC-3</strong></td>
<td>3</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>MC-FNAL</strong></td>
<td>6-10</td>
<td>20</td>
</tr>
<tr>
<td><strong>MC-10-IMCC</strong></td>
<td>10-14</td>
<td>20</td>
</tr>
<tr>
<td><strong>FCChh-100</strong></td>
<td>100</td>
<td>30</td>
</tr>
</tbody>
</table>

**Estimated Total Project Cost**

*No escalation*

*No contingency*

NB: broad ranges

Disclaimer: luminosity and power consumption values have not been reviewed by ITF.
ITF Take Away

#1: ITF reviewed concepts to allow comparison but did not prioritize

#2 ITF did not review luminosity and power consumption projects

#3 ITF recommends – and we support them - that R&D to reduce the cost and the energy consumption of future collider projects is given high priority

#4 ITF evaluations could be updated on a regular basis
ITF: Colliders’ Lumi per Power

Circular ee  ERL based ee  Linear ee  Muon coll  Wakefield  Hadron pp
Accelerator “Message & Asks”:

– Ongoing efforts
– Goals by next Snowmass/P5: **Facilities**
– **Accelerator R&D** Priorities for Next Decade
– P5 and Accelerator R&D
“We need new ideas coming in”

Message #1 **Facilities:** We have a broad array of accelerator technologies and expertise to design and construct prioritized HEP accelerator projects (NF, RPF, or EF).

(From Joann Hewett talk Sunday) - see how few new proposals are in the system/under consideration
#2 Colliders: We need an integrated future collider R&D program to engage in the design and to coordinate the development of the next generation collider projects:

- to address in an integrated fashion the technical challenges of promising future collider concepts, that are not covered by the existing General Accelerator R&D (GARD) program.
- to enable synergistic U.S. engagement in ongoing global efforts (e.g., FCC, ILC, IMCC)
- to develop collider concepts and proposals for options feasible to be hosted in the U.S. (e.g., CCC, HELEN, Muon Collider, etc)
Future Colliders R&D Program - Initiative

Completed:
- US ILC
- US LARP (LHC)
- US MAP (Muon)

Proposed for FY24-30:
- Future Colliders

Integrated program:
- FCCee, ILC, C^3, HELEN, Muon Collider, etc

In US and abroad
Design and R&D

https://arxiv.org/abs/2207.06213
#3 R&D: We have an ongoing R&D program aimed at fundamental beam physics and long-term level of accelerator concepts and technologies (RF, magnets, beam physics, advanced concepts, targets & sources, etc):

- All these items have broad applicability across future accelerators with ideas from Universities and labs
- R&D is key to facilities for neutrino and rare processes and colliders
Multi-MW targets:
- 2.4 MW for PIP-III
- 4-8 MW for muon collider

**Accelerator & Beam Physics**
- High intensity/brightness beams acceleration and control
- High performance computer modeling and AI/ML approaches
- Design integration and optimization, incl energy efficiency

Magnets for colliders and RCSs:
- 16T dipoles
- 40T solenoids
- 1000 T/s fast cycling ones
...coordinated with US MDP

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

SC/NC RF:
- 70-120 MV/m C^3
- 70 MV/m TW SRF
- new materials, high Q_0
- efficient RF sources
#4 Workforce: We need to:

– strengthen and expand education/training programs:
  • support for university-based research, incl. grants to involve professors in DOE lab facilities & projects;
  • strengthen US PAS;
  • encourage labs to accept more traineeship students incl. international

– Outreach: enhance recruiting, promote colloquia at universities

– DEI: enhance support to national undergrad recruiting class to bring women and URM talent
#5 Accelerator development should be part of P5: Planning for accelerators should be aligned with the strategic planning for particle physics and should be part of the P5 prioritization process.
Thanks for your attention!

- It was long Snowmass, definitely a success for AF, thanks to:
  - Acc.Frontier Topical Group Conveners
  - Liaisons (EF, IF, NF, TF, CEF, CF)
  - Implementation Task Force
  - eeCollider Forum
  - Muon Collider Forum
  - Fermilab Collider Group
  - Conveners of Collider and RPF Agoras
  - Our (numerous) international partners
- Special thanks:
  - Bigger accelerator community – for enthusiastic participation
  - Gordon and Shih-Chien - for excellent organization of CSS
  - Eric Yuan, the founder of Zoom