Beams, Accelerator R&D and Future Facilities:

Accelerator Frontier Vision

Community Summer Study – Seattle, July 21, 2022

Stephen Gourlay, Tor Raubenheimer, and Vladimir Shiltsev

(*Snowmass'21* AF Conveners)

Content (Plan)

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:

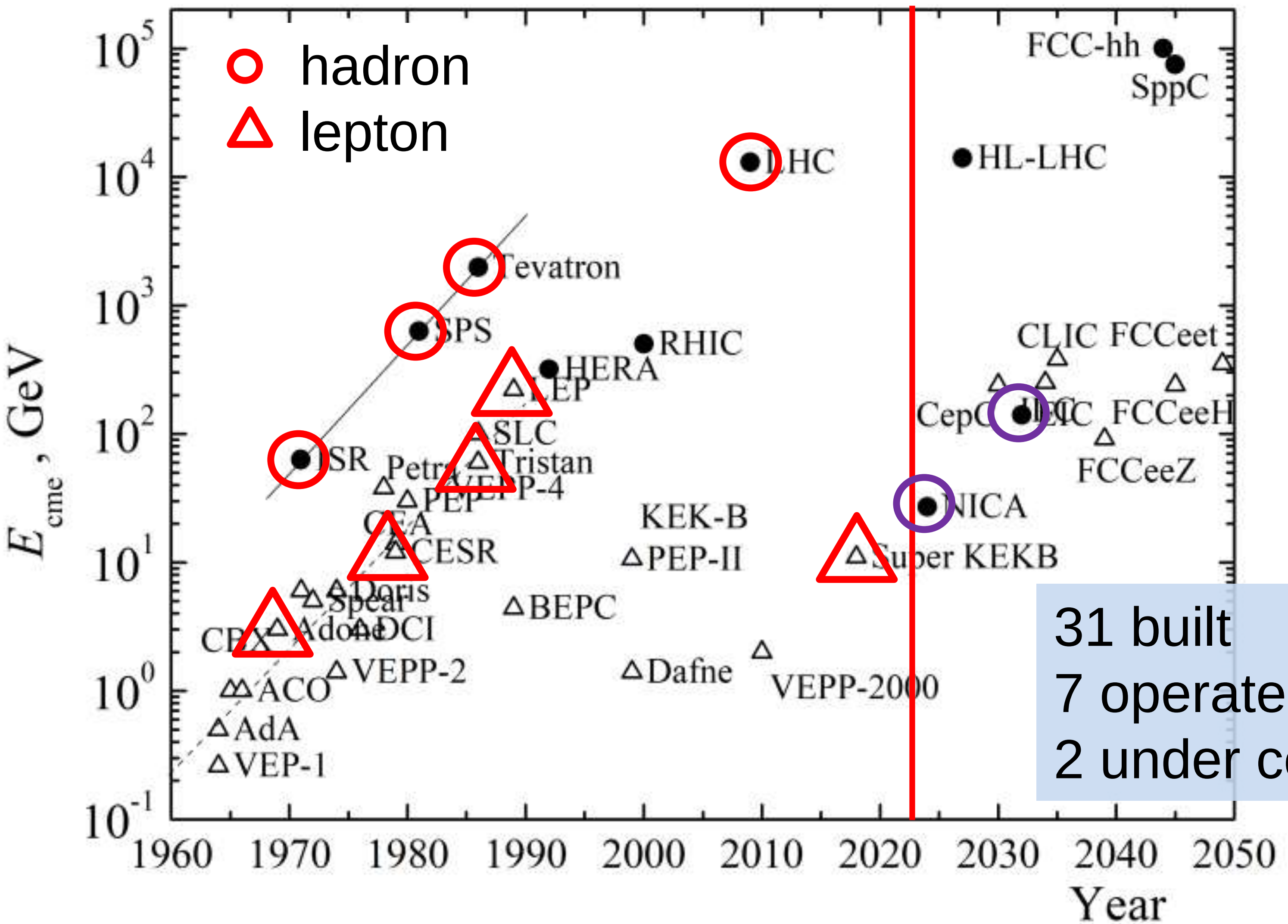
- with 4500 experts+15000 staff
- serving ~80,000 users (Cond. Matter, HEP, bio, NP, etc)

~ ¼ in the US

Pushing the envelope:

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

Colliders: Livingston Plot

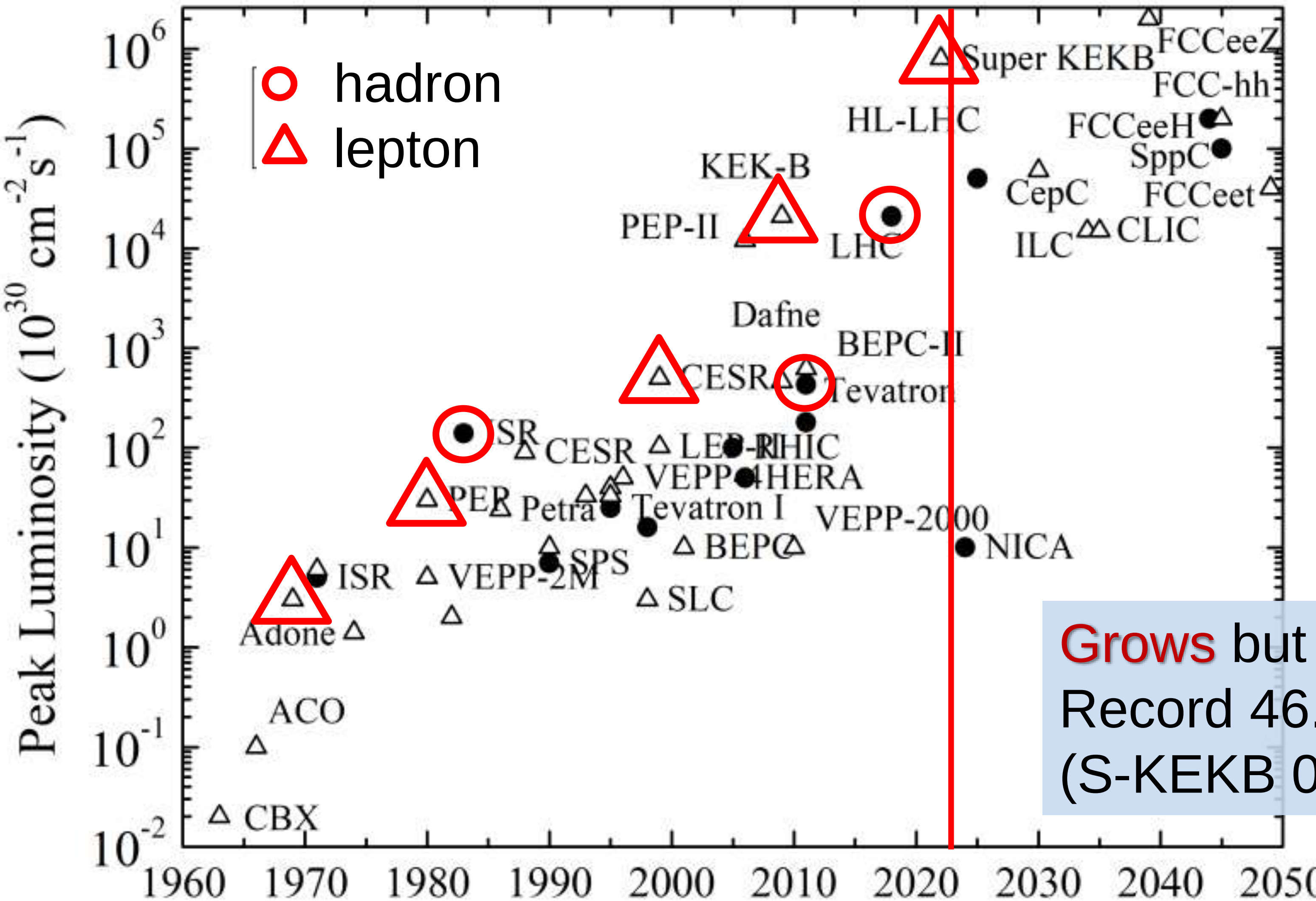


31 built
7 operate now
2 under construction

NICA
EIC

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

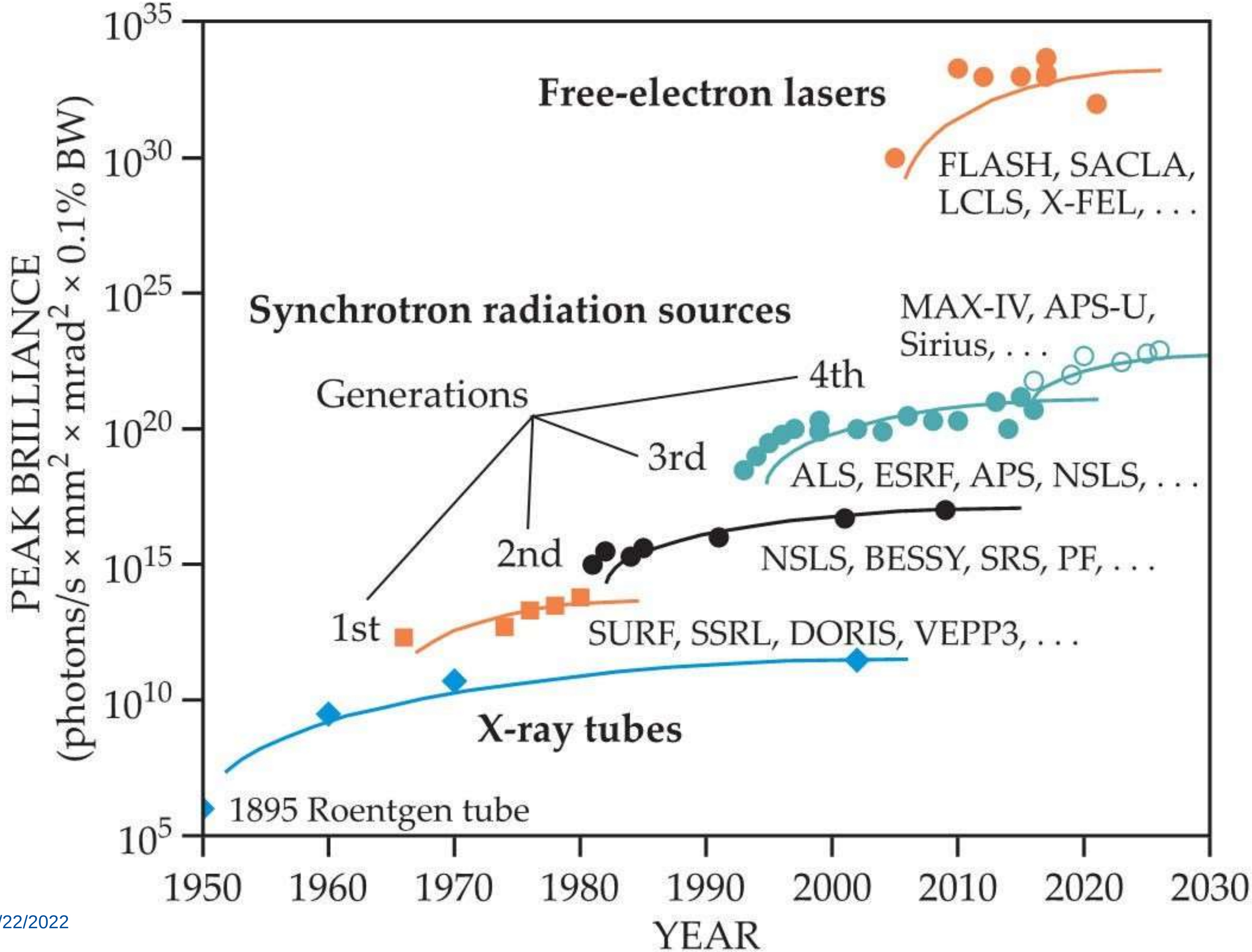
Collider Luminosities



Grows but not as E^2
Record 46.5 nb^{-1}s^{-1}
(S-KEKB 06/08/22)

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

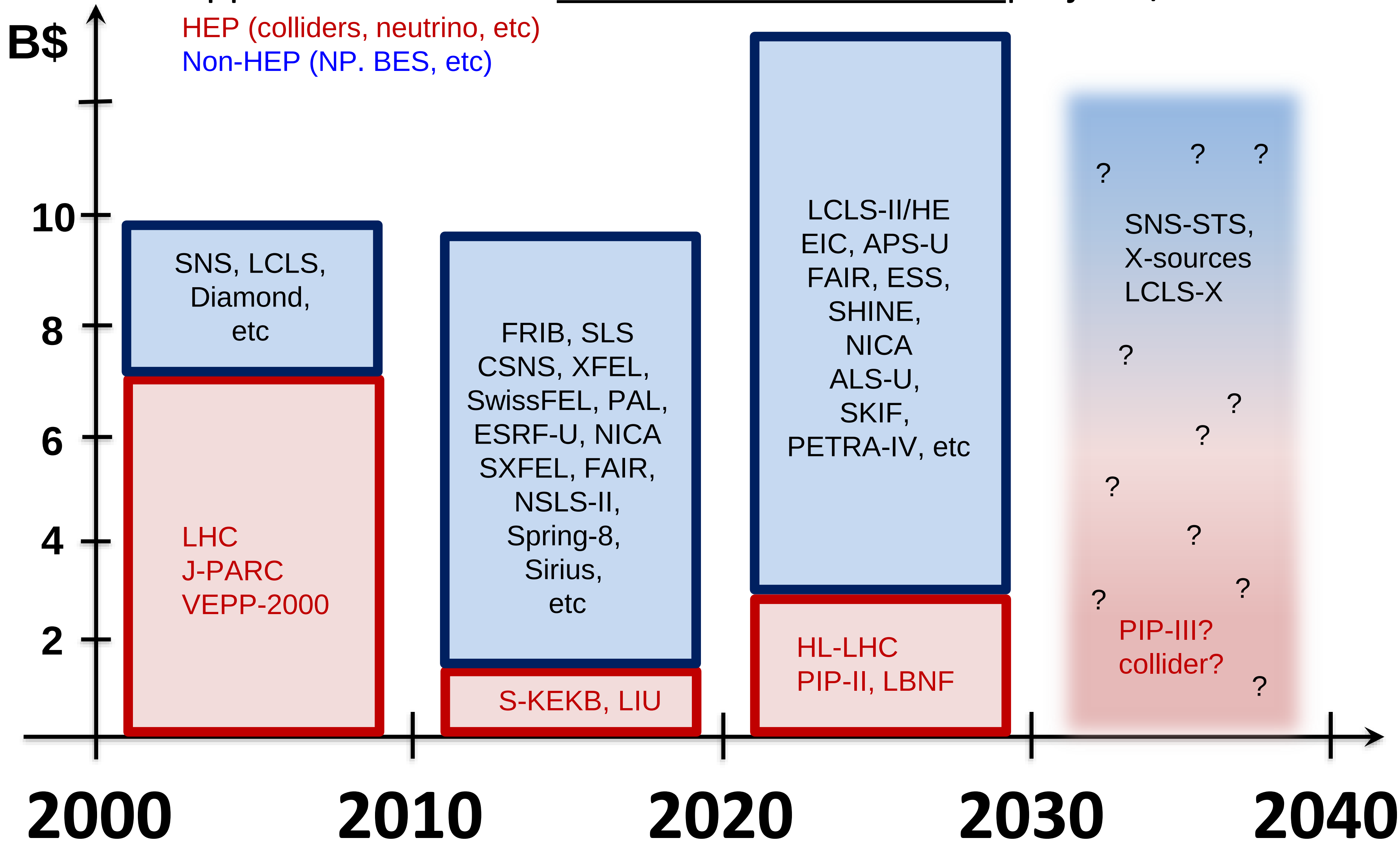
Revolution in Light Sources /X-ray Sources



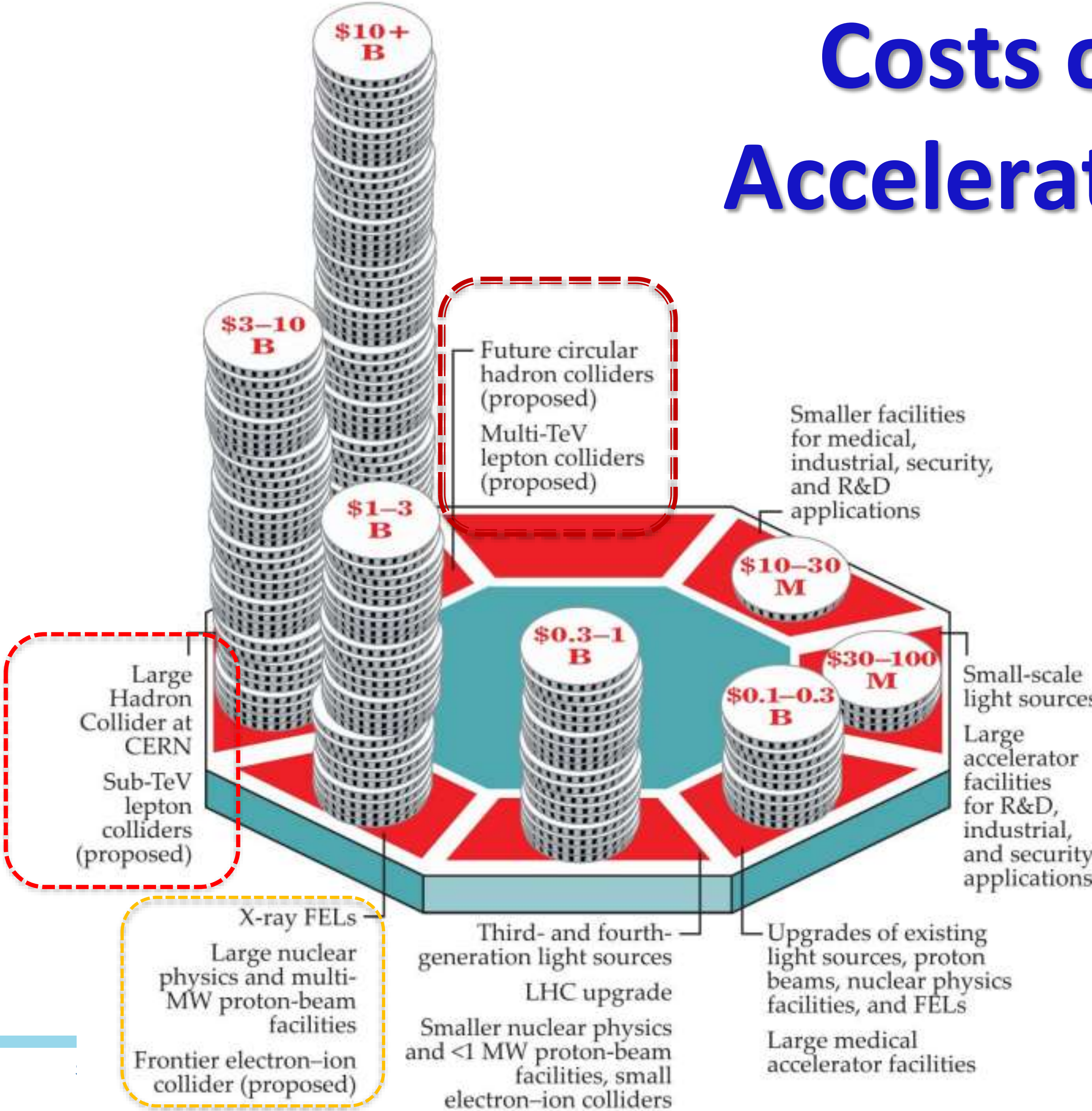
V.Shiltsev, Physics Today **73** (4), 32 (2020)

Accelerators: Not only HEP

approx. total cost of accelerator construction projects/decade



Costs of Accelerators



V.Shiltsev, Physics Today **73** (4), 32 (2020)

Cost is set by the scale (*energy, length, power*) and technology

~50±10 %

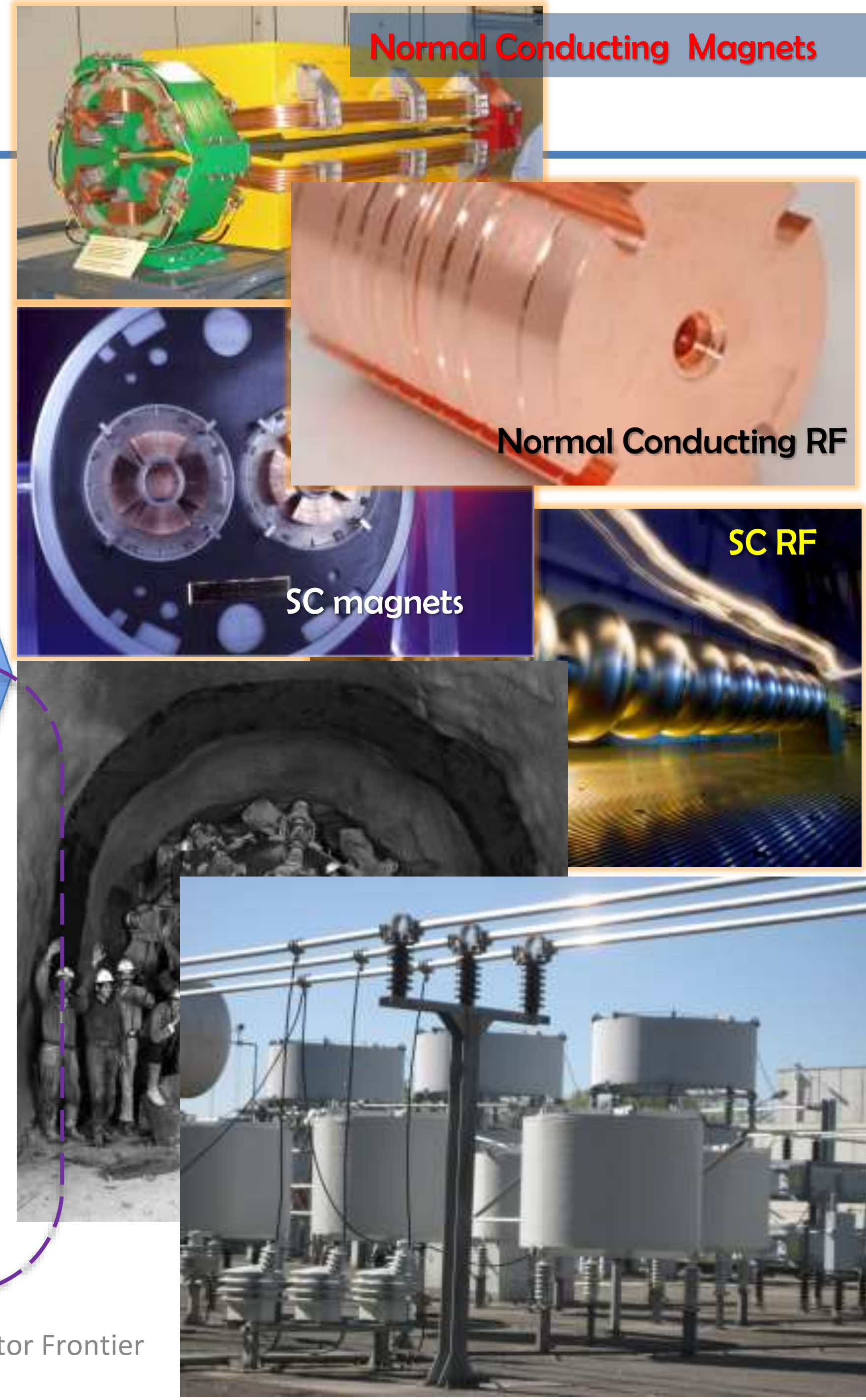
- *Accelerator technology* (magnets NC and SC, RF and SCRF)

- *Civil construction technology*

~35±15 %

- *Power delivery, transformation and distribution technology*

~15±10 %



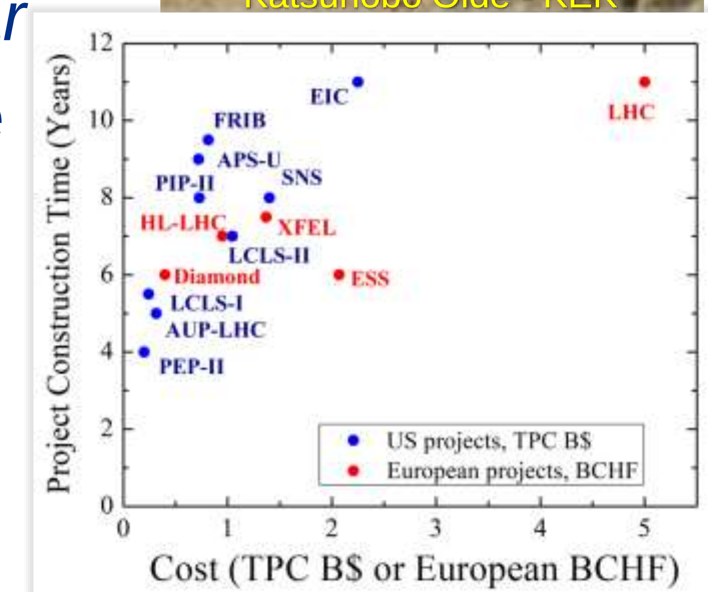
Accelerators Timeline *X+Y+Z*

Bigger size and cost → longer:

- Pre-project R&D *X years*
  - Depends on novelty
- Construction project *Y years*
  - Limited annual peak M$/year
  - “Oide law”: *need ~1 expert to spend (intelligently) 1 M$/year*
  - NB: <4500 experts worldwide
- Commissioning *Z years*
  - Depends on complexity
  - Past large colliders:

5 yrs +4 (SLC, DAFNE, BEPCII)
-3 (PEP-II, Tevatron-I, LEP-II)


Katsunobo Oide - KEK



Part II

Progress since 2014 P5

Previous *Snowmass/P5* (2013/14)

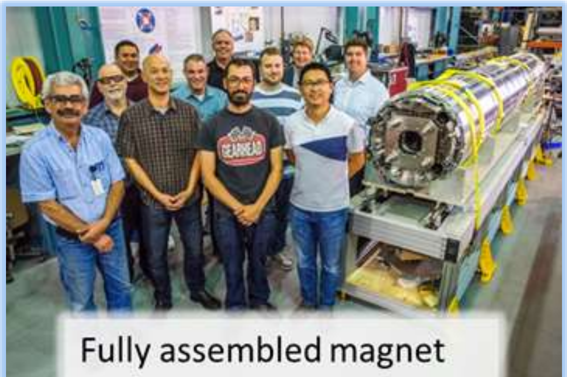
- Major accelerator-related recommendations:
  - Contribute to LHC and HL-LHC — done, in process
  - Engage in the ILC in Japan, contribute if it goes — unclear
  - Build >1 MW proton source PIP-II for *ν* LBNF/DUNE — in process
  - Provide beams for g-2 and mu2e experiments — done, in process
  - Reassess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

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

Some Examples – Facilities/Programs

(under construction) AUP LHC Nb_3Sn IR quads for HL-LHC

CD-3 project
be ready LS3
FNAL
BNL
LBNL


Fully assembled magnet

(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 1st 1.3GHz full CM with beam

Fermilab
FAST facility
ILC type beam
31.5MeV/m
255 MeV/CM
= G, Q_0 specs

(ongoing) muon beams for g-2 and mu2e experiments

FNAL
8 GeV *p*'s → target → μ's
Run-I (2021) major muon *g-2* discovery

Some Examples – Accelerator R&D

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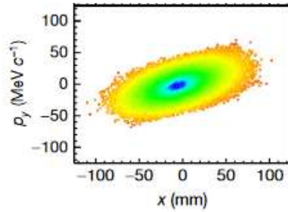
Record 14.5T Dipole (at FNAL, part of the US MDP)

Nb3Sn conductor

Stress control

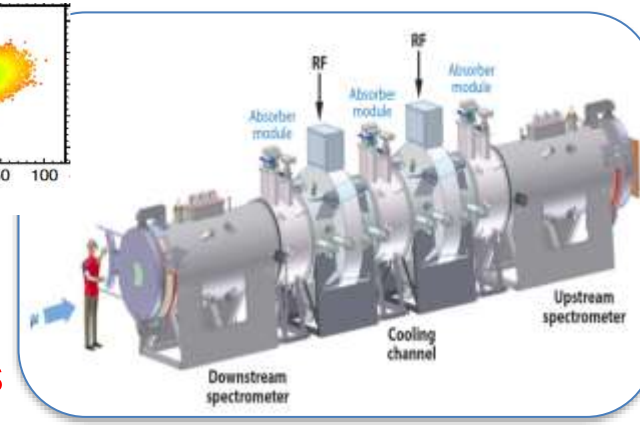
U.S. MAGNET DEVELOPMENT PROGRAM

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



MICE

~10% in one pass



FACET-II User facility (SLAC)

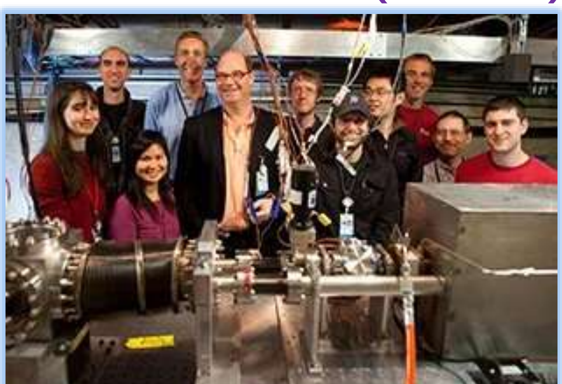
BELLA: LWFA records (LBNL)

Unique beam

10 GeV

1 nC

1x1x1 μm



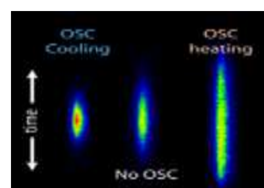
8 GeV/0.2m

staging p.o.p

0.1+0.1 GeV

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

soon – experiments with *p*'s



THz bandwidth

Part III

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.

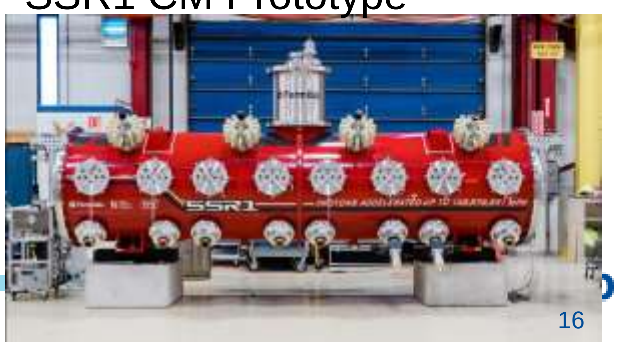
What's in plan for 2030s?

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

PIP-II Injector Test

HWR CM

SSR1 CM Prototype



Multi-MW ν Beams for DUNE

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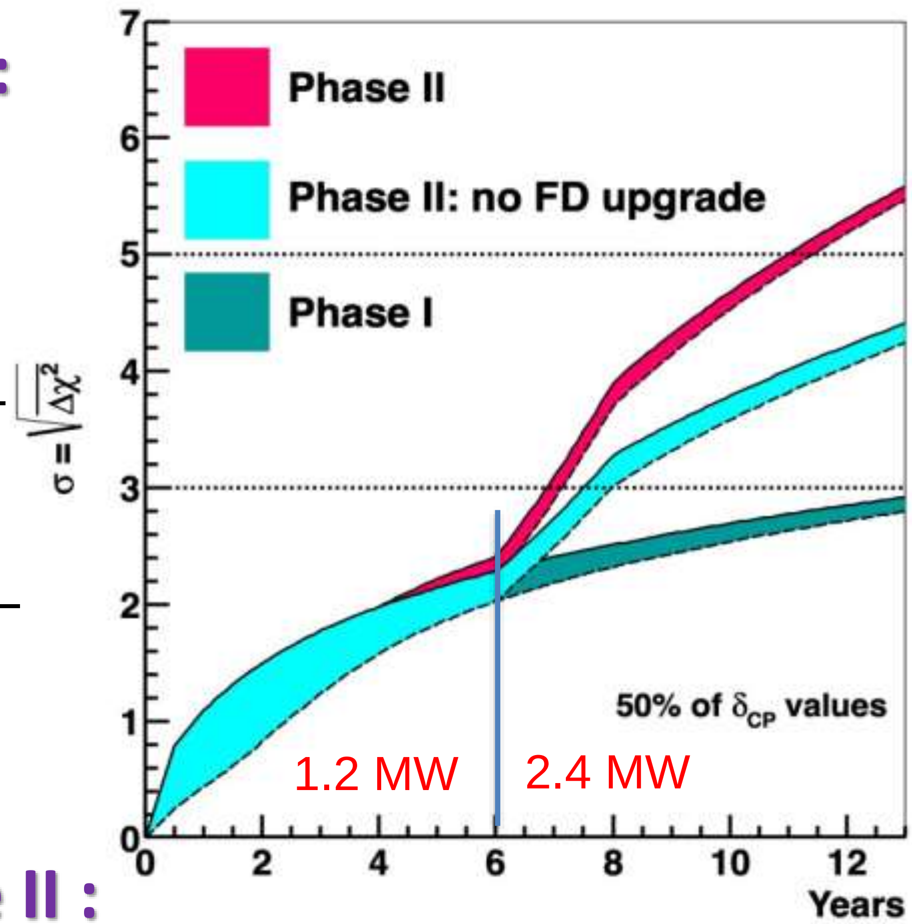
LBNF/DUNE Project – Phase I:

- By 2032: **1.2 MW** proton beam (120 GeV, MI) on target + near ν-detector + 20 kton LAr ν-detector in Lead, SD
- Expected rate of "physics" outcome – up to ~3σ in δ_{CP}, in the first 6 years (also Δm^2_{32}, $\sin^2\theta_{23}$, $\sin^2 2\theta_{13}$)
- To get to ~5σ will take too long, plus – competitor experiment *Hyper-K* in Japan (30 GeV J-PARC *p* beam)

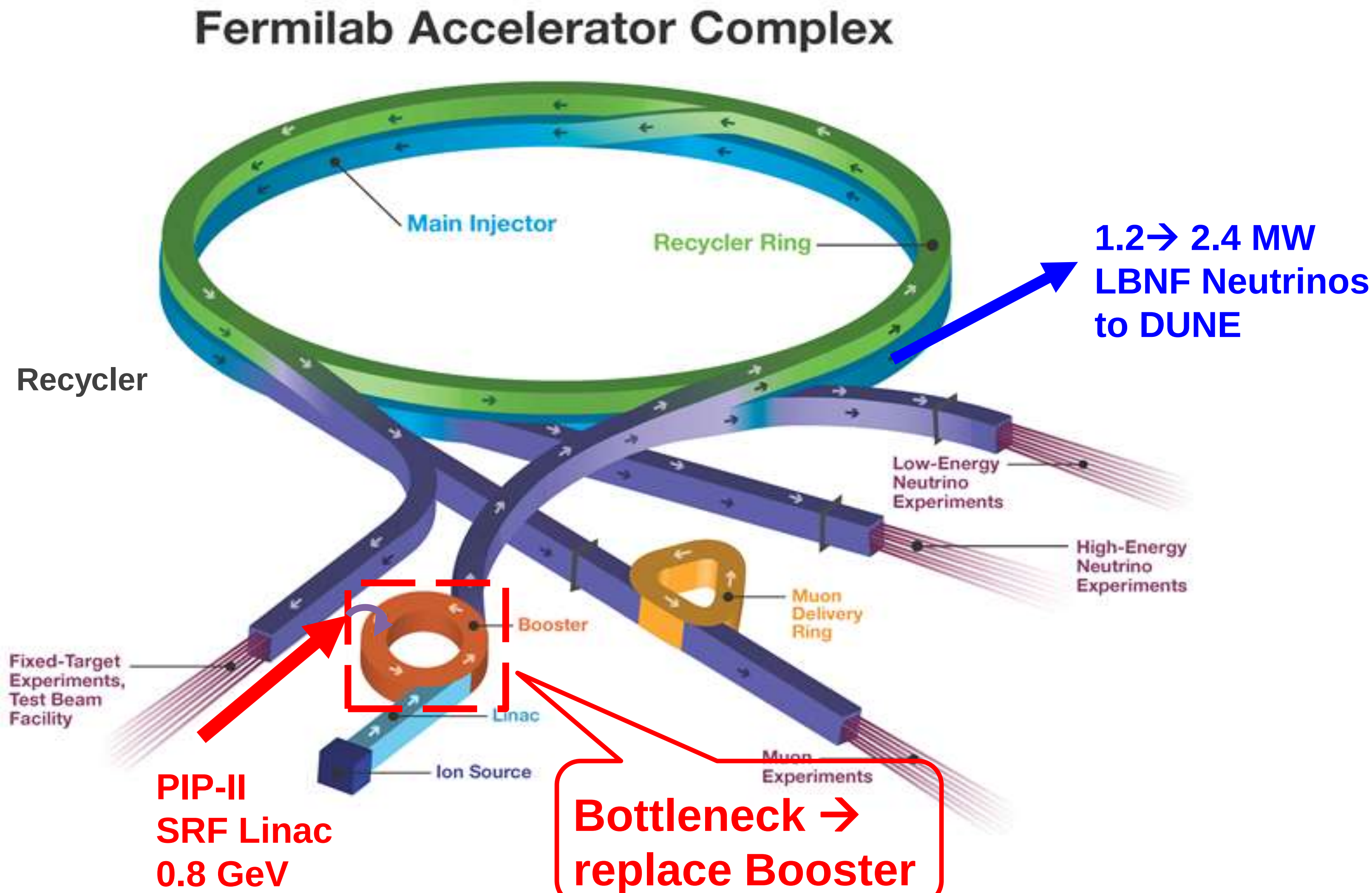


https://arxiv.org/abs/2203.06100

Proposed LBNF/DUNE Phase II :

- By 2038: ~2.4 MW proton beam + new near ν-detector + extra 20 kton Lar ν-detector
- Expected to get to ~5σ in δ_{CP} in the following 6 years

2.4 MW Upgrade Challenge

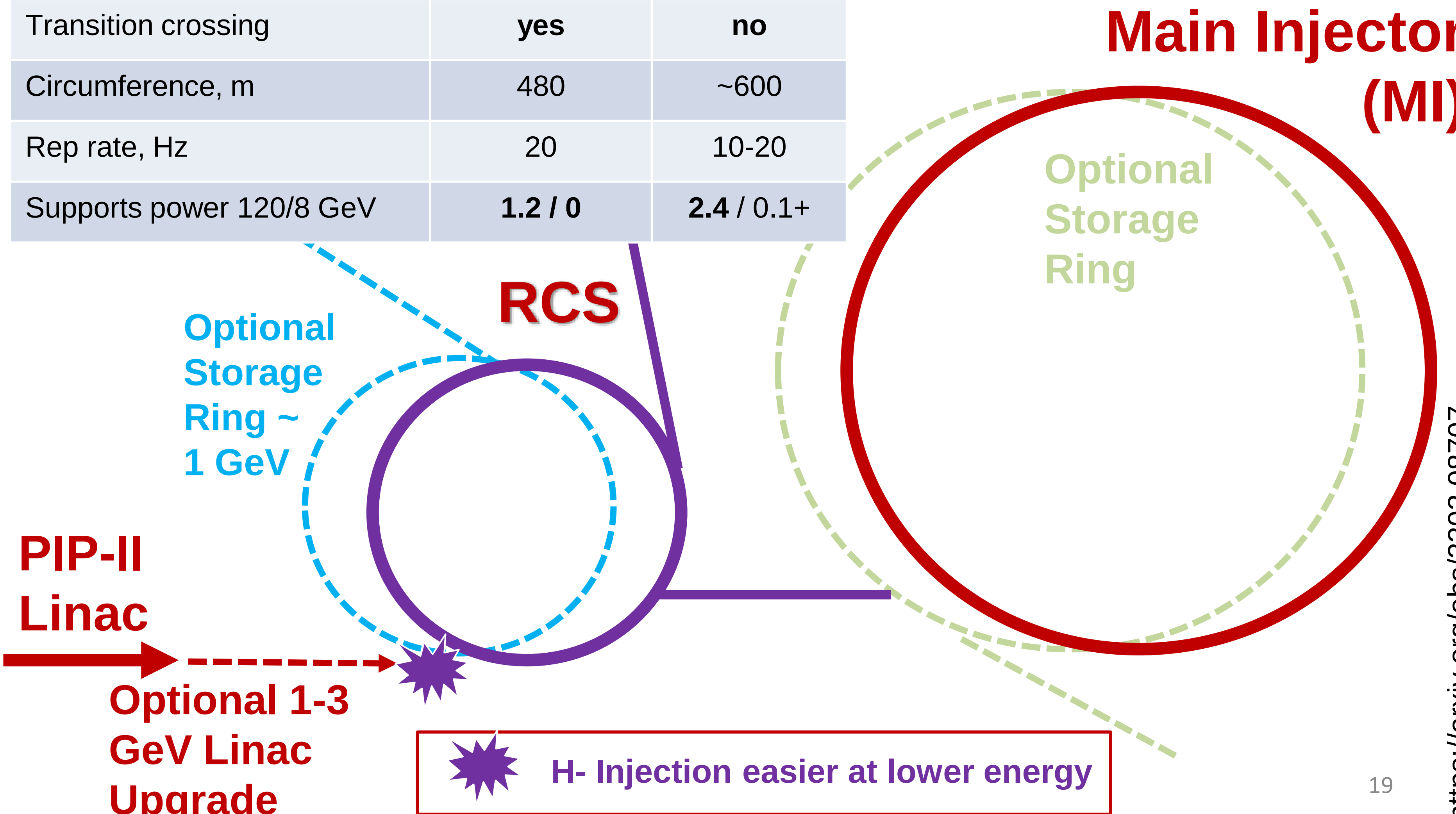


Booster prevents x2 PIP-II power: injection energy and transition-crossing limits

https://arxiv.org/abs/2203.08276

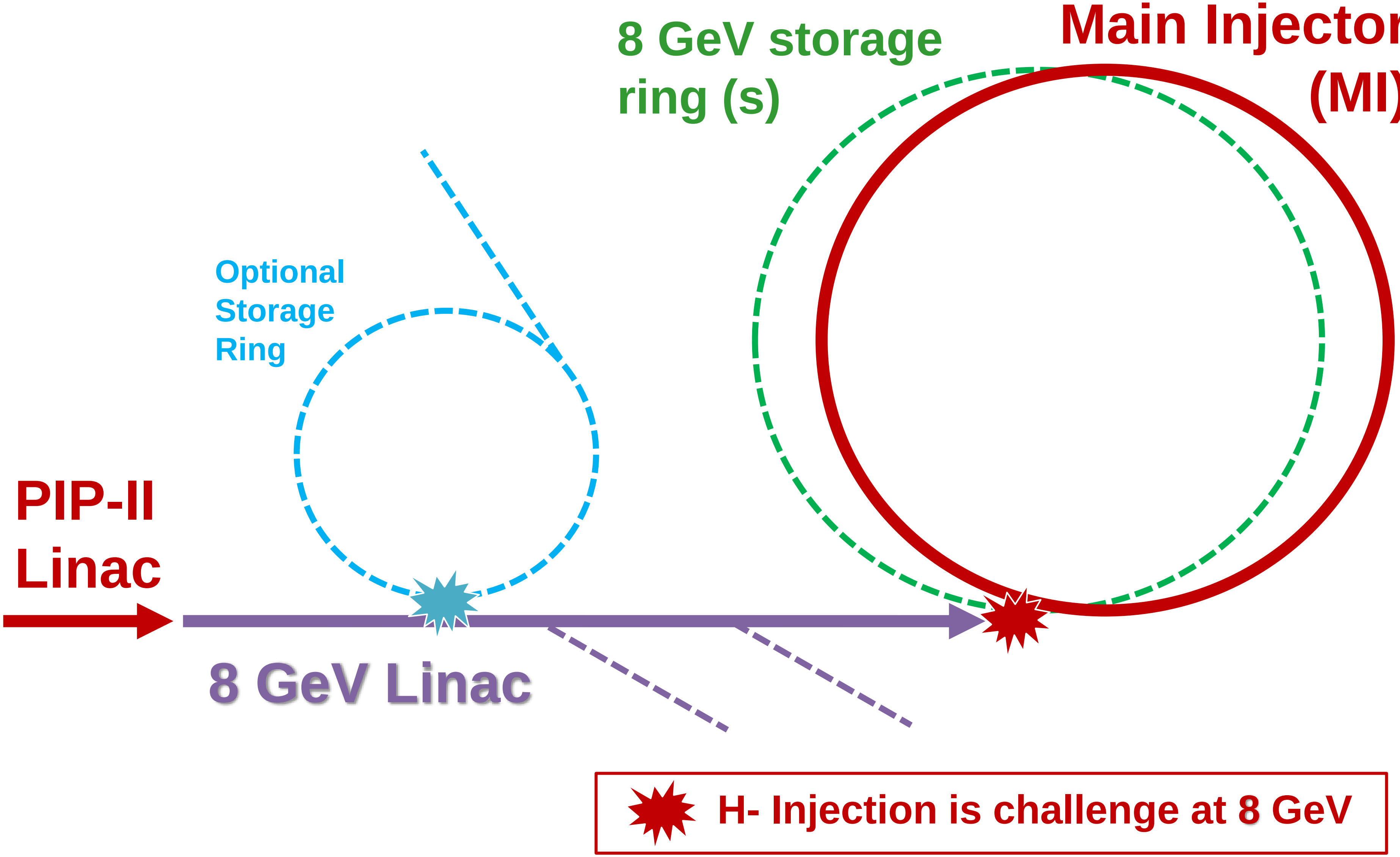
2.4 MW: Rapid-Cycling Synchrotron (RCS) Option

	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+



https://arxiv.org/abs/2203.08707

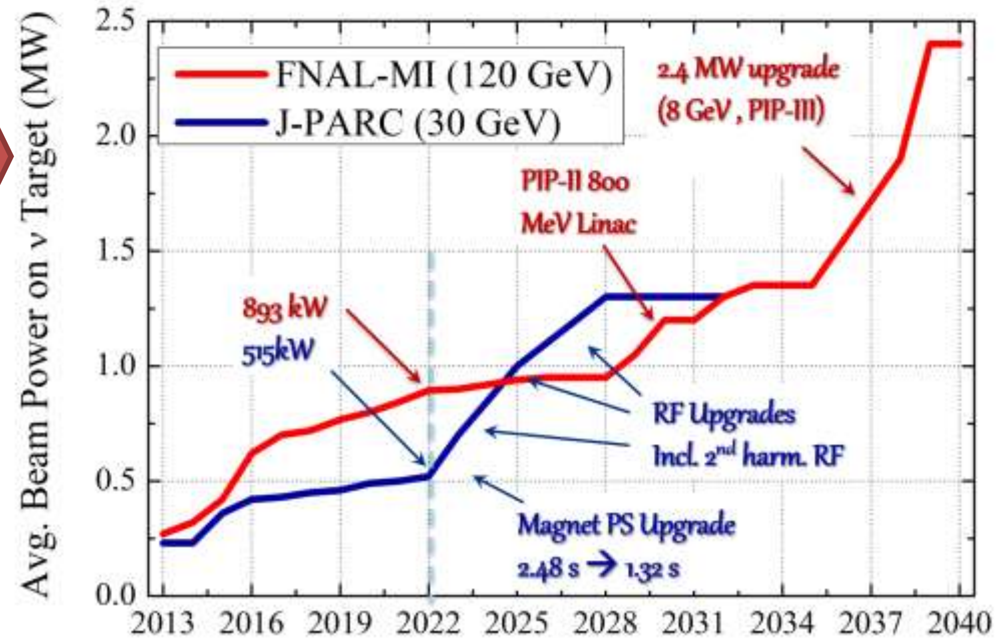
Path to 2.4 MW: 8 GeV Linac Option



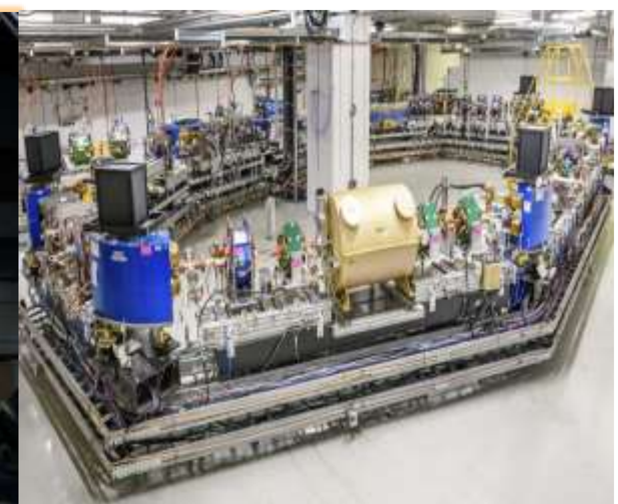
2.4 MW Upgrade: Challenges

Snowmass 2021

- Competition with Hyper-K / J-PARC
- Short timeline, design Q:
  - Other spigots ($\mu 2e$-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 *p* R&D



NUMI horn 0.9MW



Space-charge dominated ring IOTA

II: >20 Proposed Experiments For Rare Processes

(most via Snowmass Whitepapers)

Snowmass 2021

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

Experiment	Experiment type	Primary beam particle	Beam Energy [GeV]	Beam power [kW]	Beam time structure
Proton Storage Ring: EDM and Axion Searches	Precision tests, Dark Matter	proton	0.7 GeV/c beam momentum	1e11 polarized protons per fill	Fill the ring every 1000s
Physics with Muonium	Precision tests	proton (producing surface muons)	0.8 GeV	1e13pm1 POT per second	CW
Nucleon Electromagnetic Form Factors from Lepton Scattering	Neutrino	electron or proton (producing muons)	0.85 GeV to 2 GeV	1 nA to 10 microA for electrons, 10^7 to 10^8 per second for muons	A continuous or pulsed structure (ideally with a duty factor of 1% or larger) should be sufficient
Rare Decays of Light Mesons (REDTOP)	Precision tests	proton	1.8-2.2 GeV (Run I), 0.8-0.92 (Run II), 1.7 (Run III)	0.03-0.05 (Run I), 200 (Runs II and III)	CW, slow extraction for Run I
Ultra-cold Neutron Source for Fundamental Physics Experiments, Including Neutron-Anti-Neutron Oscillations	Precision tests	proton	0.8-2	1,000	quasi-continuous
CLFV with Muon Decays	CLFV	proton	Not critical 0.8 to a few GeV	100 or more	continous beam on the timescale of the muon lifetime i.e. proton pulses separated by a microsecond or less. The more continuous the better
Mu2e II	CLFV	proton	1 to 3	100	pulse width 10s of ns or better separated by 200 to 2000 ns. Flexible time structure and minimal pulse-to-pulse variation
Fixed Target Searches for new physics with O(1 GeV) Proton Beam Dump	Dark Sector, Neutrino	proton	0.8 to 1.5 GeV	100 or more	<O(1 micro s) pulse width for neutrino measurements, <O(30 ns) pulse width for dark matter searches, 10^(-5) or better duty factor
PRISM-like Charged Lepton Flavor Violation	CLFV	proton	1-3 GeV	up to 2 MW	10s pulses at a rep rate of about 1 kHz
Electron Missing Momentum (LDMX)	Dark Sector	electron	~3 GeV to ~20 GeV	O(1 electron per RF bucket at 53 MHz)	CW-ish
Electron Beam Dumps	Dark Sector	electron	few GeV	10^(20) electrons on target over the experiment al runtime	Pulsed beam (duty factor not specified)
Proton Irradiation Facility	R&D	proton	Energy is not very important	1e16 protons in a few hours	Pulsed beam (duty factor not specified)
SBN	Neutrino	proton	8	32	20Hz
Mu2e	CLFV	proton	8	8	<10^(-10) extinction
Fixed Target Searches for new physics with O(10 GeV) Proton Beam Dump	Dark Sector, Neutrino	proton	8	up to 115	Beam spills less than a few microsec with separation between spills greater than 50 microsec
Muon beam dump	Dark Sector	proton (producing muons)	3 GeV muons	3e14 muons in total on target for the whole run	CW
Muon Collider R&D and Neutrino Factory	R&D	proton	5 - 30GeV	1e12 to 1e13 protons per bunch	10 - 50 Hz rep rate and bunch length 1-3 ns
Muon Missing Momentum	Dark Sector	proton (producing muons)	few 10s of GeV	10^(10) muons per experimental runtime	Pulsed beam (duty factor not specified)
High Energy Proton Fixed Target	Dark Sector, Neutrino	proton	O(100 GeV)	1e12 POT/s therefore ~20 kW	CW via resonant extraction. "If we could up the duty factor that woul dbe even better" (?)
Test-Beam Facility	R&D	proton	120, lower energies would also be beneficial	10 to 100 kHz on the testing apparatus	Pulsed beam (duty factor not specified)
Tau Neutrinos	Neutrino	proton	120	1200 or higher	MI time structure

Electron beams:

~ GeV to multi-GeV

Proton beams:

~2 GeV CW-capable beam

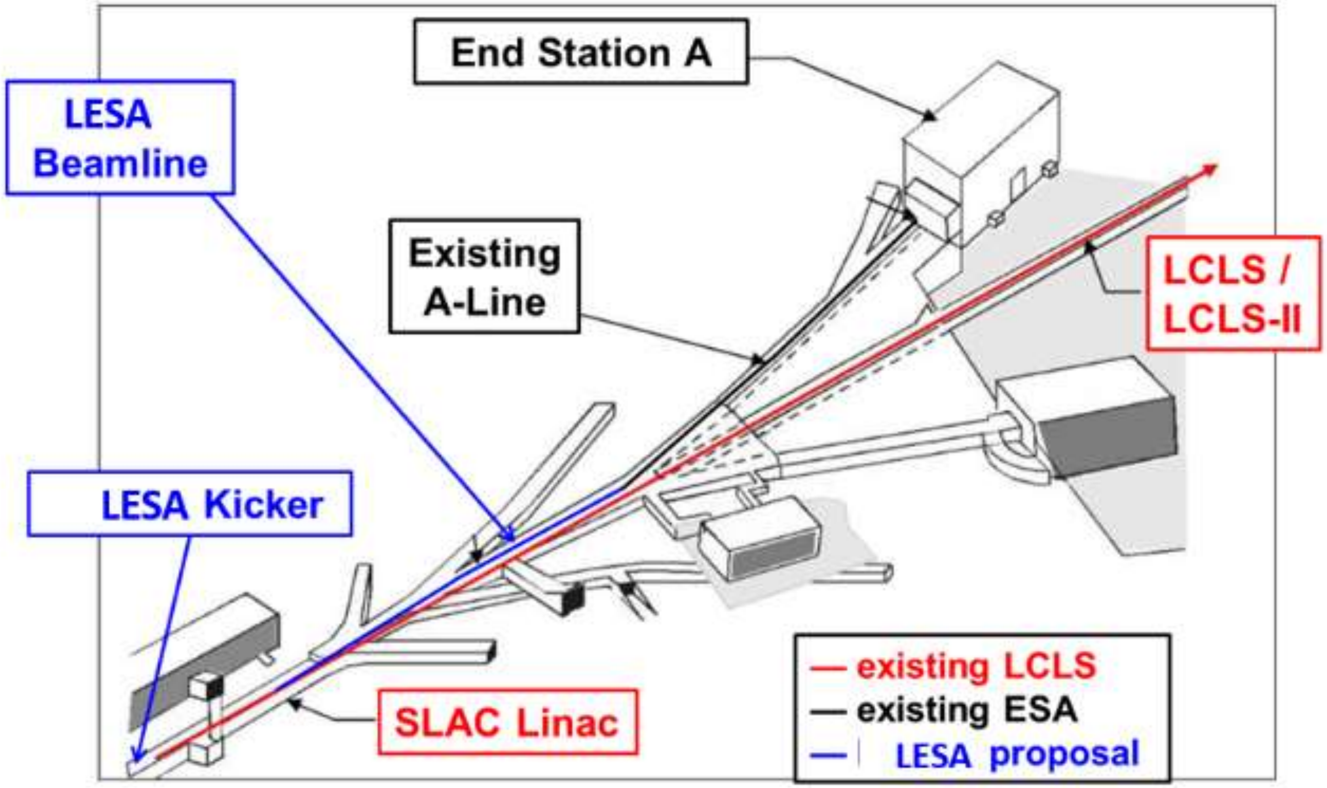
~2 GeV pulsed beam from storage ring ~1MW

~8 GeV pulsed beam ~1MW

120 GeV Slow extraction or LBNF beam

In many cases, existing or planned facilities can be and should be fully utilized!

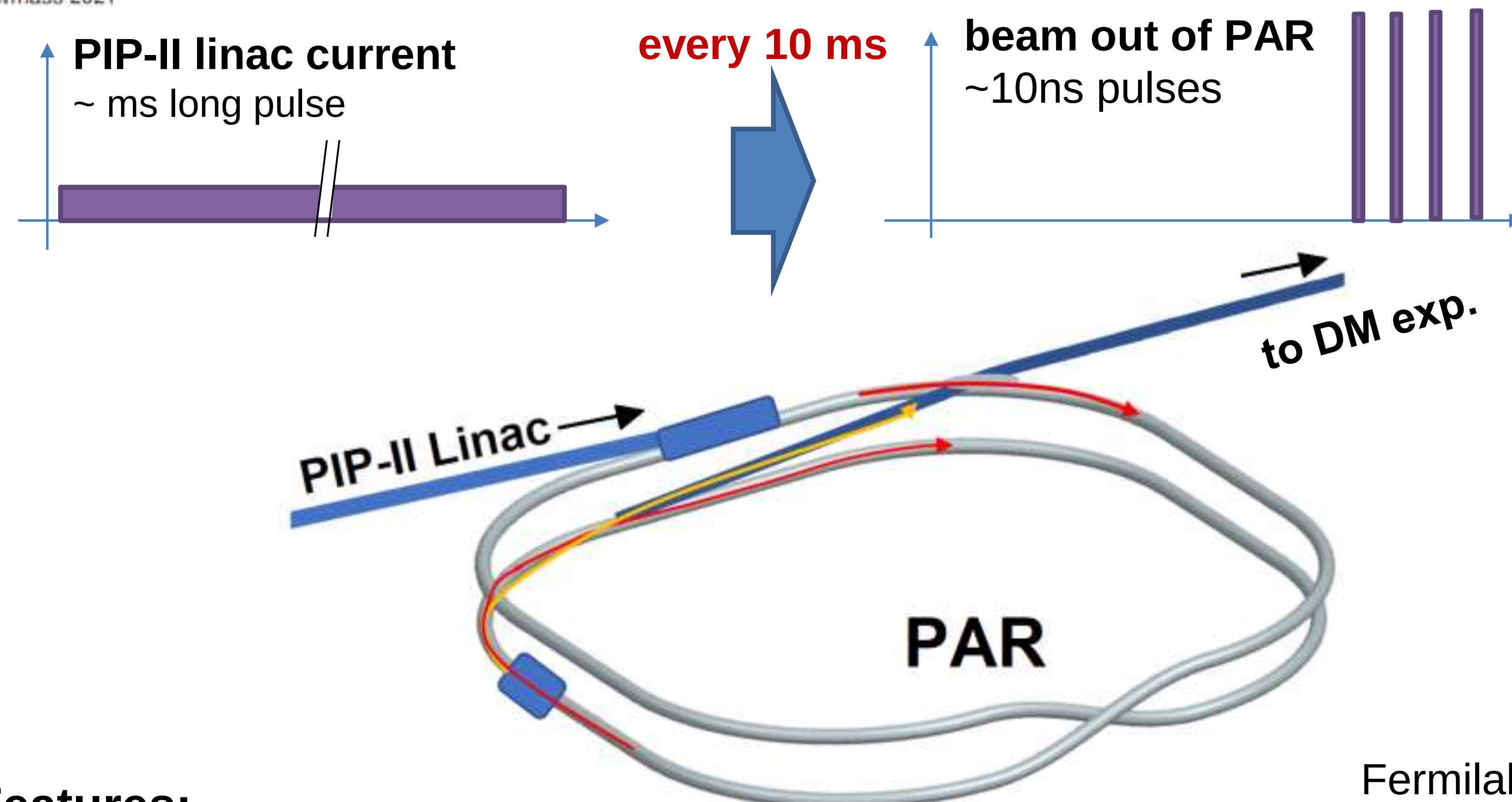
Started LESA Beamline for LDMX @ SLAC



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)



https://arxiv.org/abs/2203.07339

Fermilab

Features:

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

III: Particle Colliders

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);

  https://pdg.lbl.gov/2021/reviews/rpp2021-rev-accel-phys-colliders.pdf
- 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/

#3: Colliders – EF Input

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

$\mu+\mu$- 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

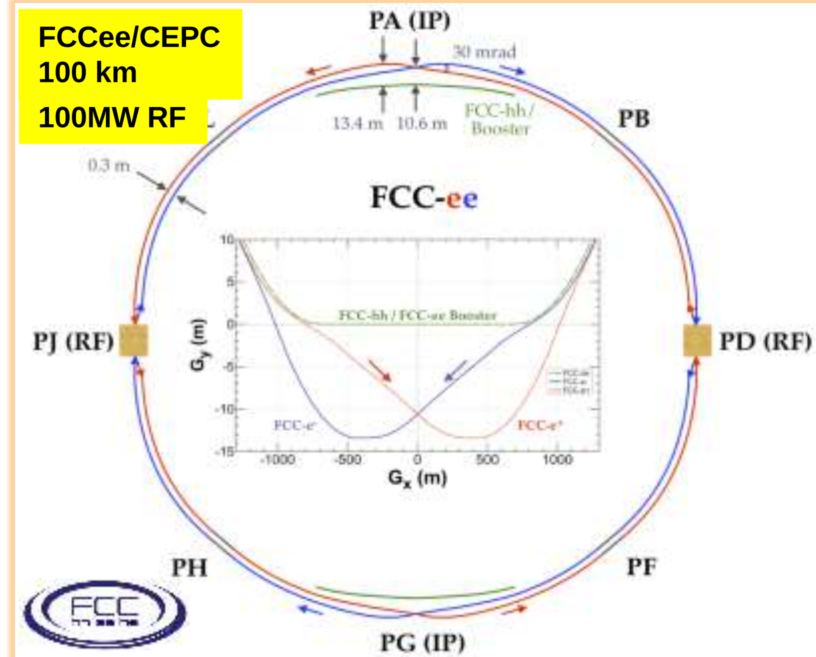
(call for R&D on energy efficiency)

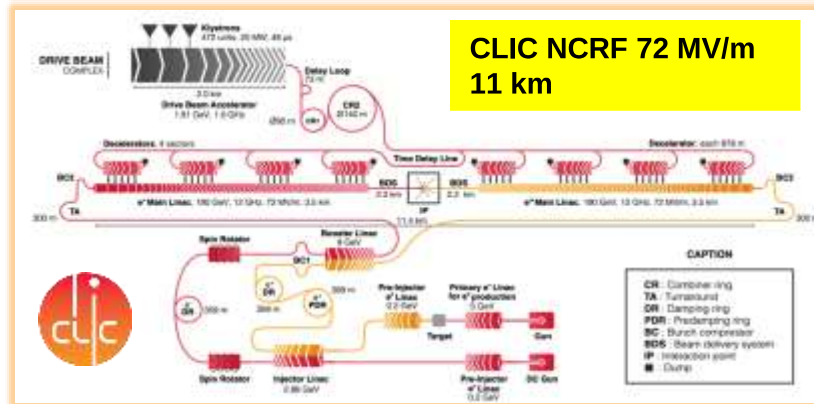
Higgs Factory Proposals: *mature ones*

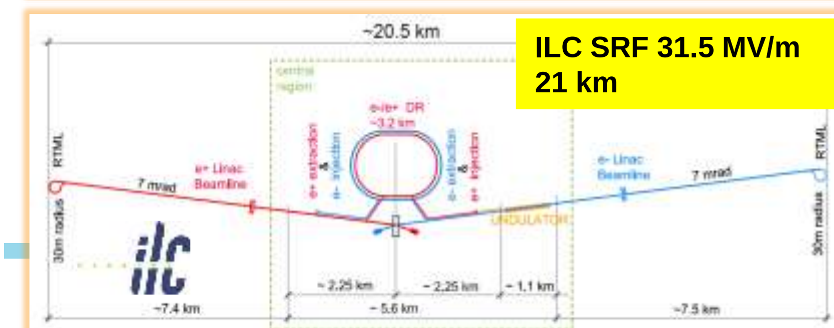
Advantages
Challenges

[not prioritized list]

- 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



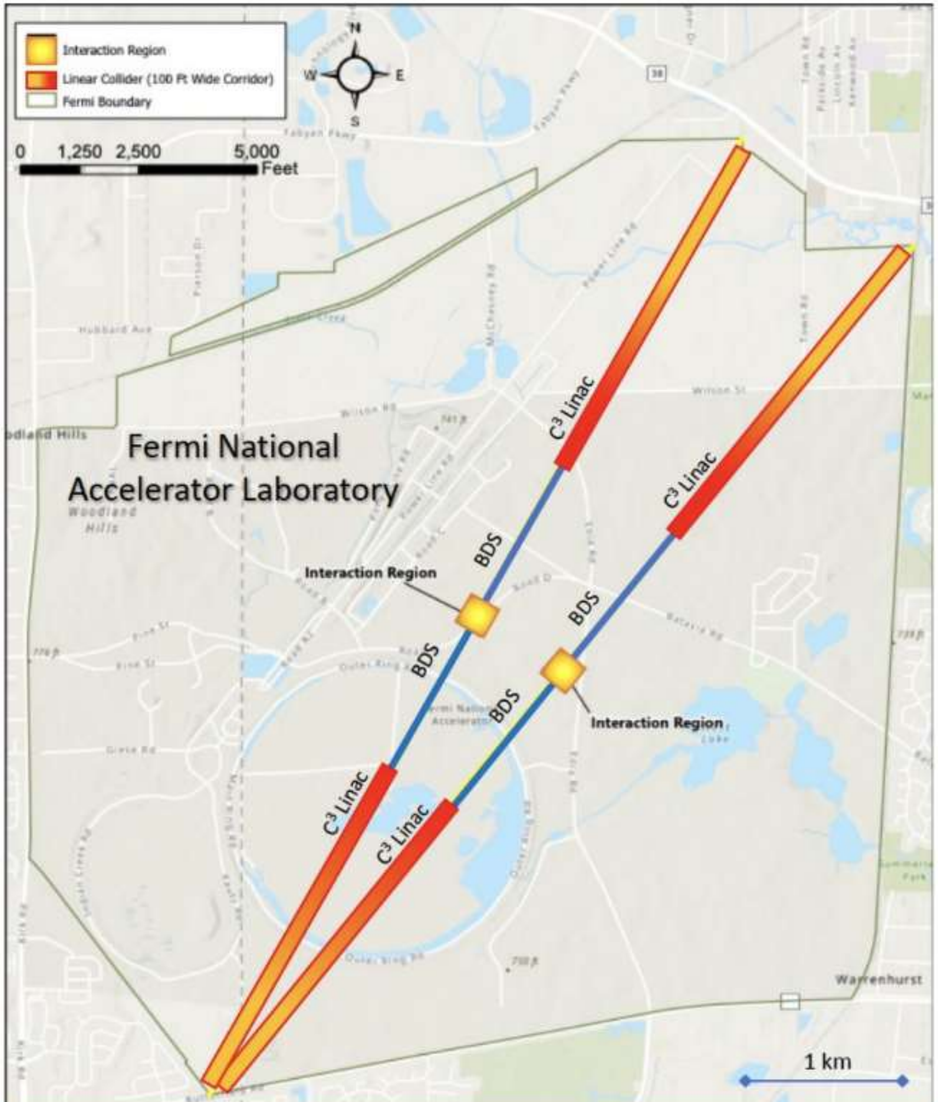




(New!) LC-Higgs Factories on FNAL Site

Snowmass 2021

arxiv:2203.08211 arxiv:2110.15800

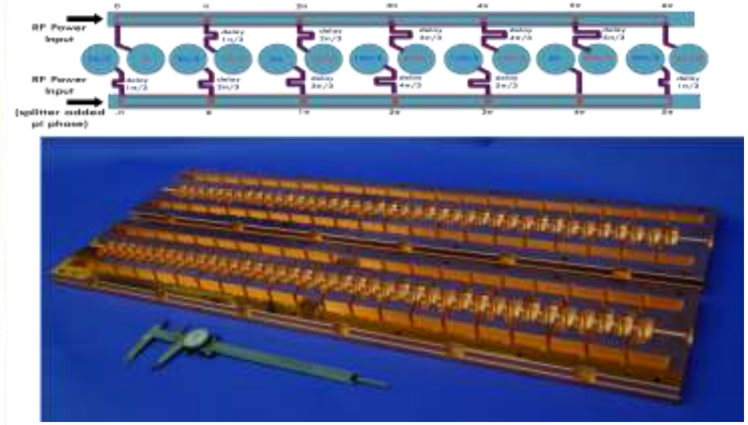


Must fit ~7 km including BDS

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

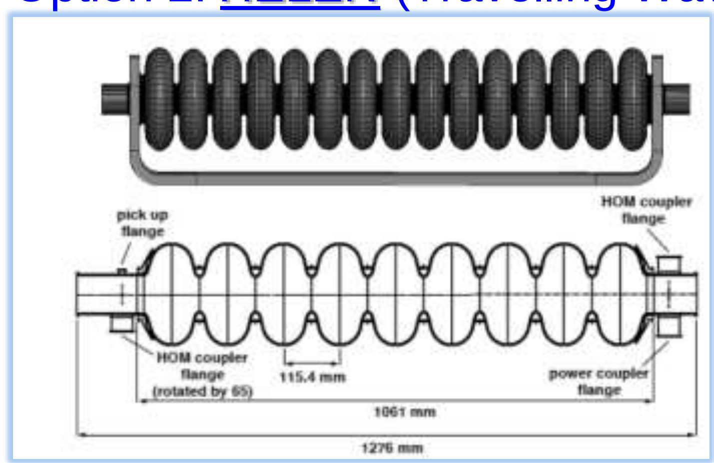
Compact → lower cost (wrt ILC/CLIC)

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*

Advantages
Challenges

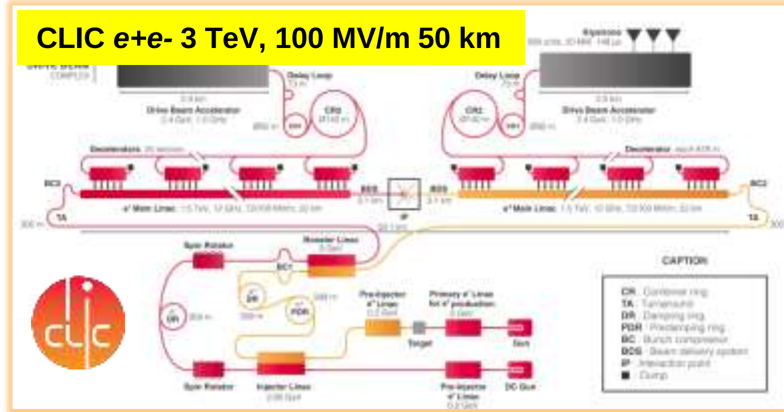
- Energy recovery based e+e- colliders (circular or linear):
  - High luminosity per MW power consumption
  - Not yet mature (orders of magnitude in current, Q_0), long, expensive
- Gamma-gamma linear colliders:
  - Need only ½ of energy, short, potentially less expensive, no *e+*
  - need two beyond-state-of-the-art FELS to generate γ'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)

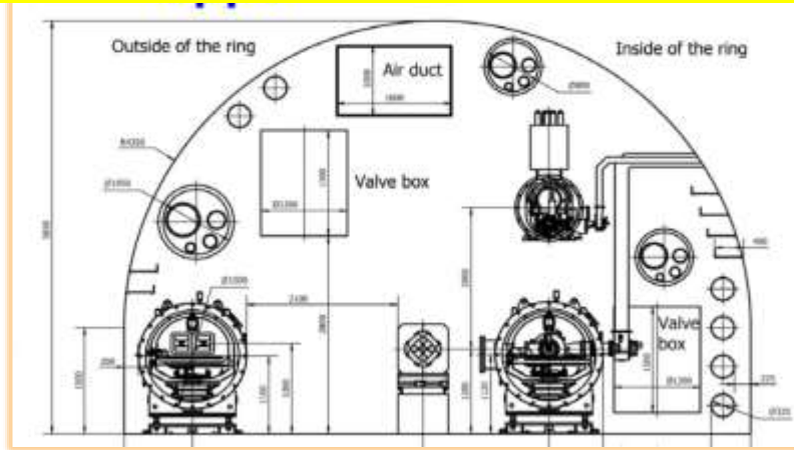
3-10 TeV/Parton CME:

most discussed

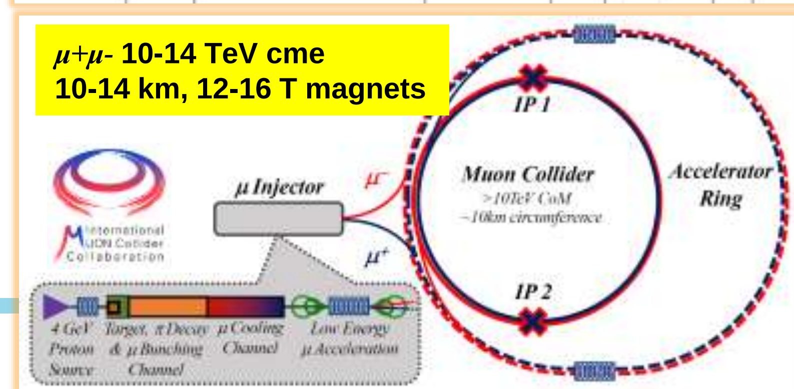
Advantages
Challenges

- 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


CLIC *e+e-* 3 TeV, 100 MV/m 50 km



pp 100 km: FCChh-100TeV, 16T magnets, SPPC-125 20 T



$\mu^+\mu^-$ 10-14 TeV cme
10-14 km, 12-16 T magnets

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

Advantages
Challenges

- *"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/$\gamma\gamma$ 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, *ep*China-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

Snowmass 2021

- 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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Philippe Lebrun (CERN)


Steve Gourlay (LBNL)


Tor Raubenheimer (SLAC)


Katsunobu Oide (KEK)


Jim Strait (FNAL)


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Sarah Cousineau (ORNL)


Marlene Turner (LBNL)


Spencer Gessner (SLAC)

From the ITF Report Draft: Tables 1-3, 5

Snowmass 2021

	CME (TeV)	Lumi per IP (10^34)	Years, pre-project R&D	Years to 1st Physics	Cost Range (2021 B$)	Electric Power (MW)
FCCee-0.24	0.24	8.5	0-2	13-18	12-18	280
ILC-0.25	0.25	2.7	0-2	<12	7-12	140
CLIC-0.38	0.38	2.3	0-2	13-18	7-12	110
HELEN-0.25	0.25	1.4	5-10	13-18	7-12	110
CCC-0.25	0.25	1.3	3-5	13-18	7-12	150
CERC(ERL)	0.24	78	5-10	19-24	12-30	90

FCCee: 2-4 IPs
all LCs: 1 IP

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

Estimated Total Project Cost
No escalation
No contingency
NB: HELEN, C^3 m.b. 85% of ILC but in the same range category

From the ITF Report: Tables 1-3, 5

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

all LCs: 1 IP
MC-3/14: 2 IPs
FCChh: 2-4 IPs

Estimated
Total Project Cost
No escalation
No contingency
NB: broad ranges

	CME (TeV)	Lumi per IP (10^34)	Years, pre-project R&D	Years to 1st Physics	Cost Range (2021 B$)	Electric Power (MW)
CLIC-3	3	5.9	3-5	19-24	18-30	~550
ILC-3	3	6.1	5-10	19-24	18-30	~400
MC-3	3	2.3	>10	19-24	7-12	~230
MC-FNAL	6-10	20	>10	19-24	12-18	O(300)
MC-10-IMCC	10-14	20	>10	>25	12-18	O(300)
FCChh-100	100	30	>10	>25	30-50	~560

ITF Take Away

Snowmass 2021

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

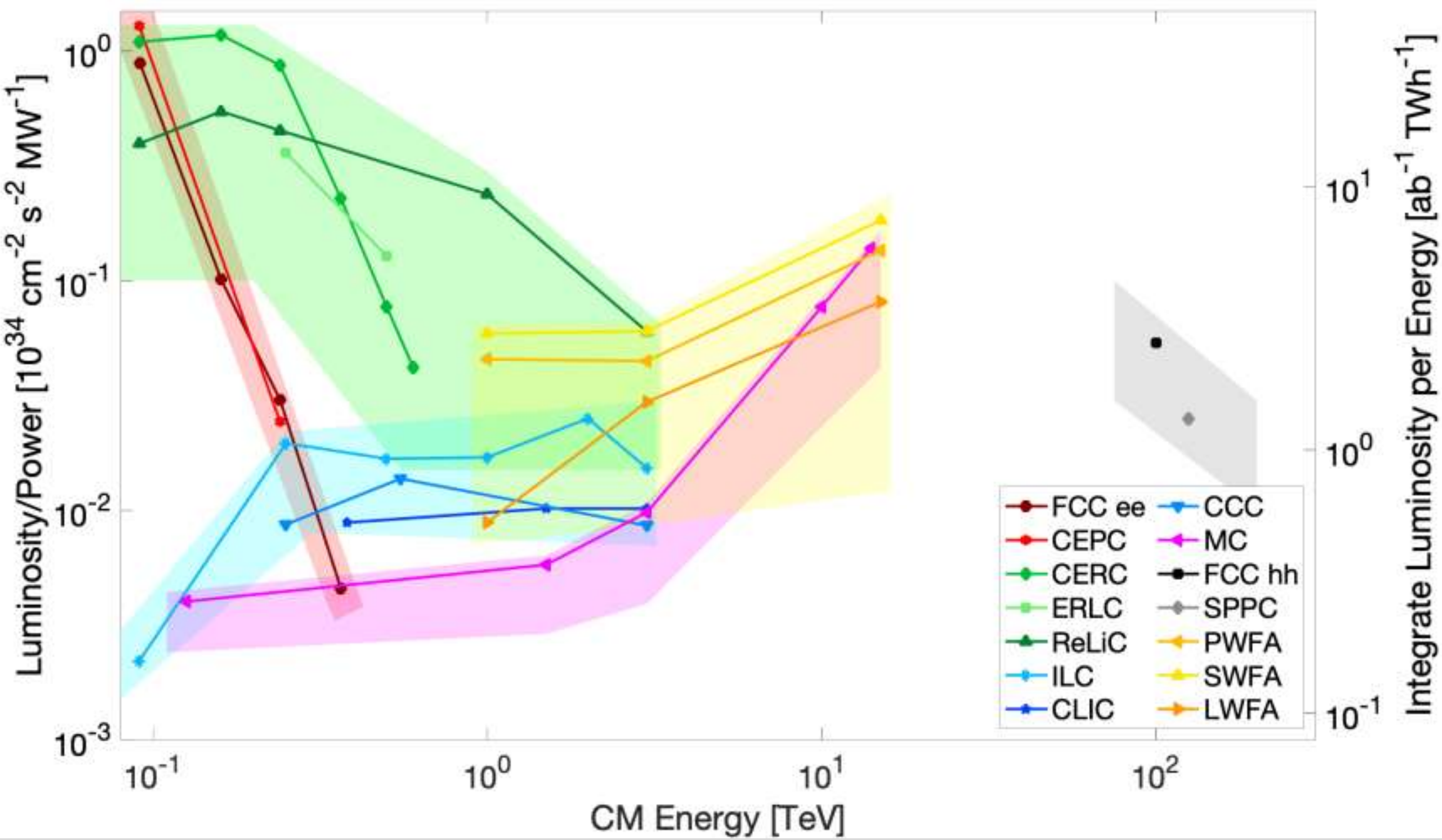
#2 ITF did not review luminosity and power consumption projects

#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*



Part IV

Accelerator "Message & Asks":

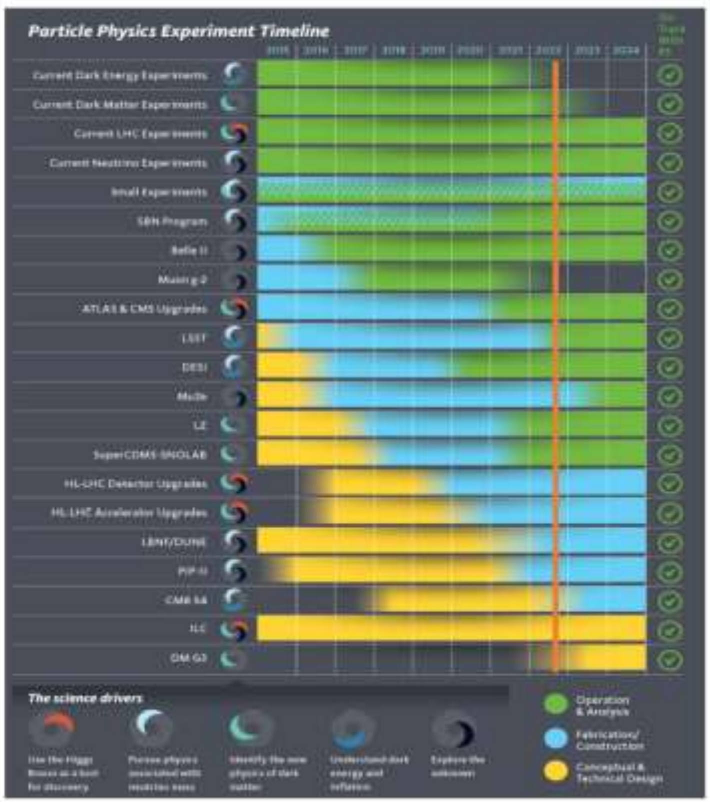
- Ongoing efforts
- Goals by next Snowmass/P5: Facilities
- Accelerator R&D Priorities for Next Decade
- P5 and Accelerator R&D

"We need new ideas coming in"

Message #1 <u>Facilities</u>: 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



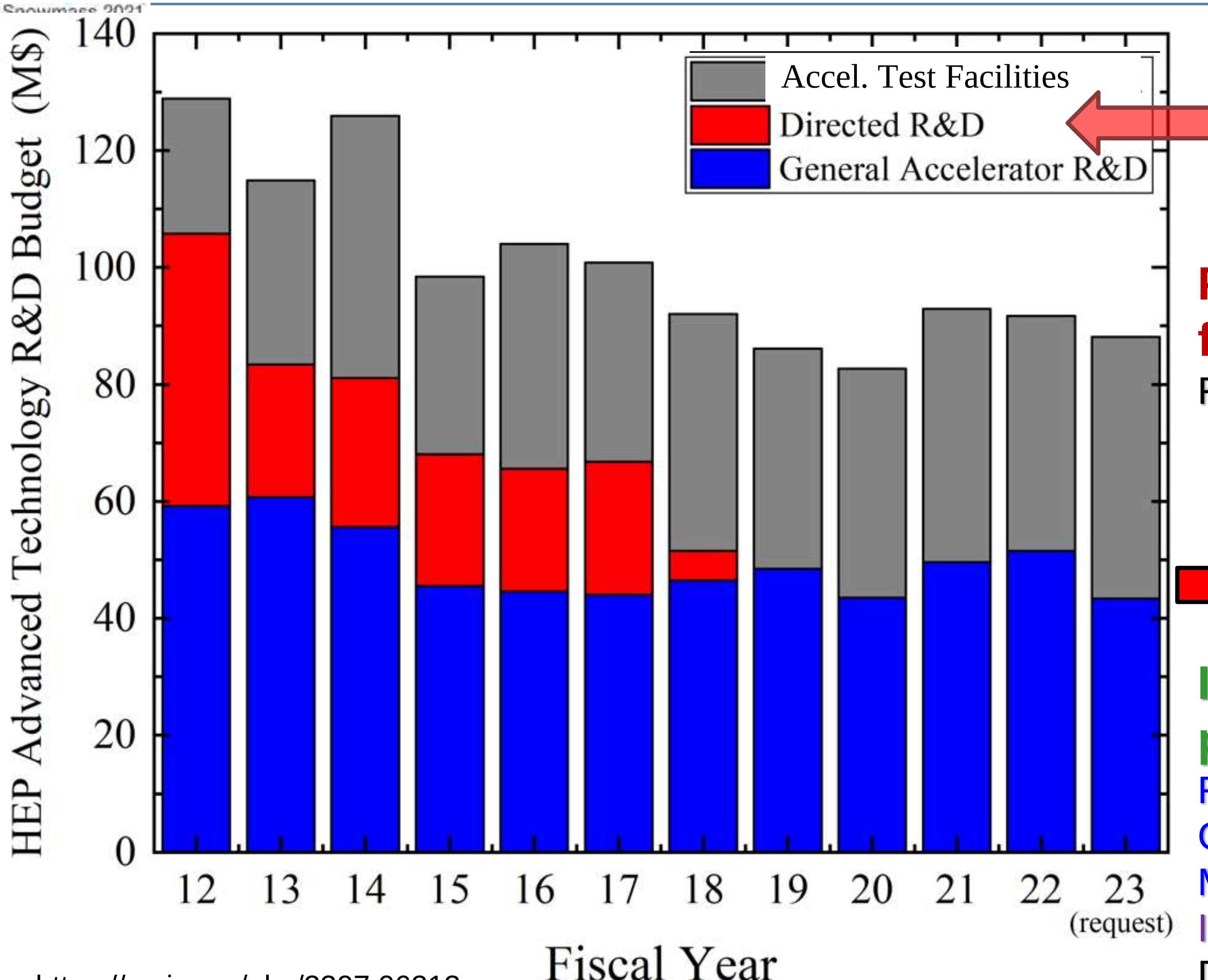
Accelerator Frontier "Message" #2

Snowmass 2021

#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)

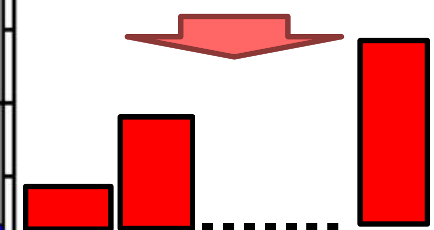
Future Colliders R&D Program - Initiative



https://arxiv.org/abs/2207.06213

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

Accelerator Frontier "Message" #3

Snowmass 2021

#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):

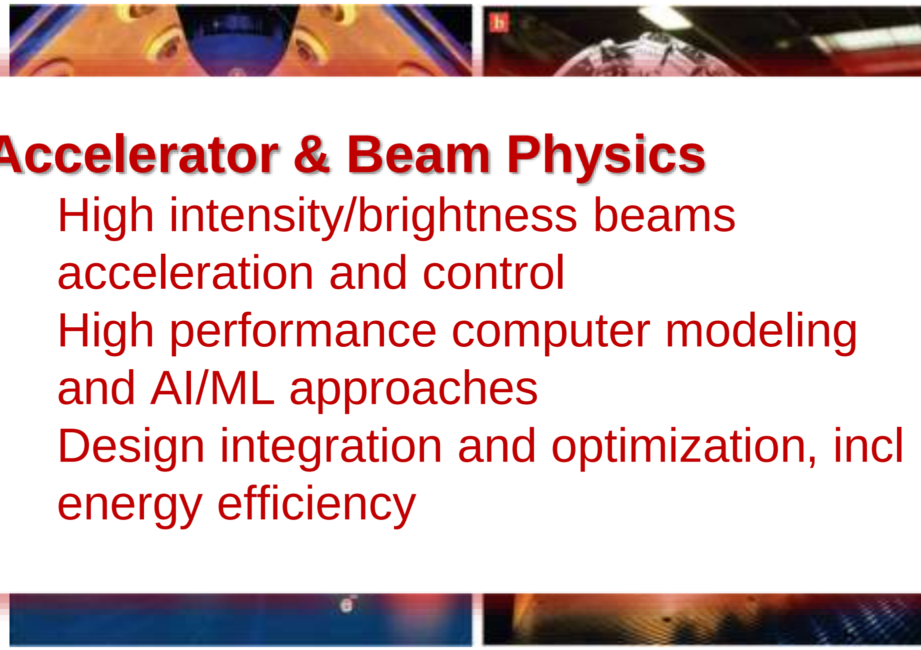
- All these items have broad applicability across future accelerators with ideas from Universities and labs
- R&D is key to facilities for neutrino and rare processes and colliders

Accelerator R&D: Next Decade

Multi-MW targets:
- 2.4 MW for PIP-III
- 4-8 MW for muon collider

Magnets for colliders and RCSs:
- 16T dipoles
- 40T solenoids
- 1000 T/s fast cycling ones

…coordinated with US MDP



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

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

Accelerator Frontier "Message" #4

Snowmass 2021

#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

Accelerator Frontier "Message" #5

Snowmass 2021

#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