Fermilab

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Possible Elements of the US Plan Towards a Muon Collider

Vladimir Shiltsev (Fermilab)

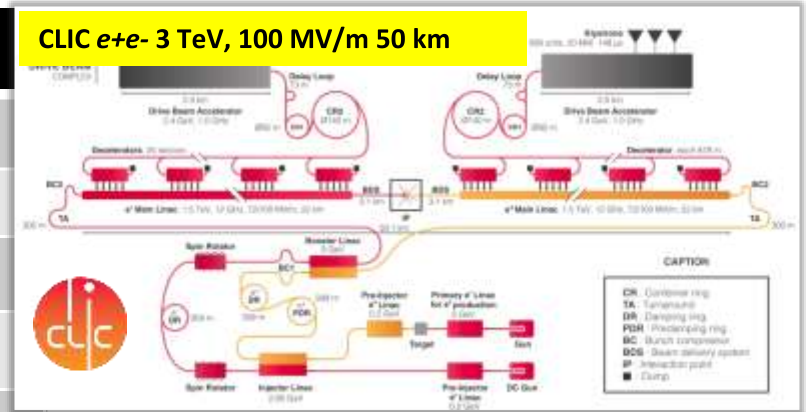
MC Workshop/Snowmass MC Forum, January 26, 2022

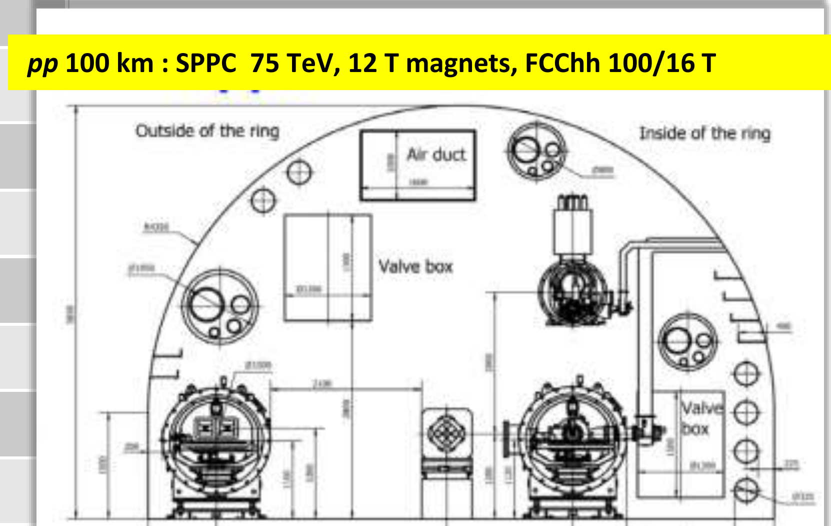
30'000 ft *(~30 years)* View:

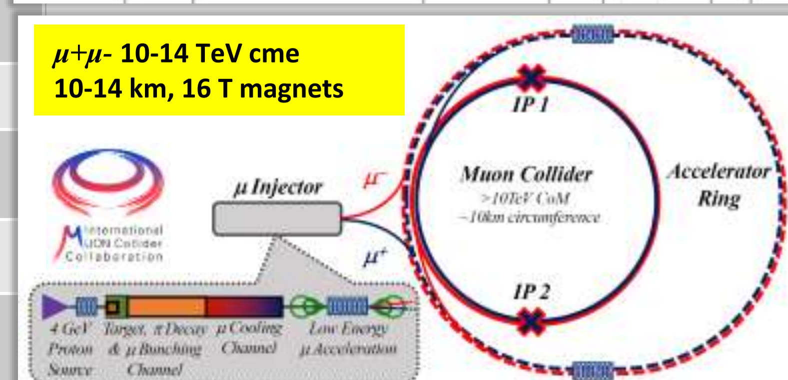
- (we believe that) MC is the most viable option for HEP future:
  - ~ x7 energy reach vs *pp*
  - *μ*'s do not radiate when bent → acceler'n in rings:
    - *Smaller(est) footprint*
    - *Low(est) cost*
    - *(best) power efficiency*
- (we believe that) 3-10 TeV MC can be designed in ~10-15 yrs and built in 20-25 yrs from now
- (the rest of) the HEP community not so sure yet

17 (!) High Energy Collider Concepts/Proposals

Name	Details
Cryo-Cooled Copper linac	e+e-, $\sqrt{s} = 2$ TeV, L= 4.5 $\times 10^{34}$
High Energy CLIC	e+e-, $\sqrt{s} = 1.5 - 3$ TeV, L= 5.9 $\times 10^{34}$
High Energy ILC	e+e-, $\sqrt{s} = 1 - 3$ TeV
FCC-hh	pp, $\sqrt{s} = 100$ TeV, L= 30 $\times 10^{34}$
SPPC	pp, $\sqrt{s} = 75/150$ TeV, L= 10 $\times 10^{34}$
Collider-in-Sea	pp, $\sqrt{s} = 500$ TeV, L= 50 $\times 10^{34}$
LHeC	ep, $\sqrt{s} = 1.3$ TeV, L= 1 $\times 10^{34}$
FCC-eh	ep, $\sqrt{s} = 3.5$ TeV, L= 1 $\times 10^{34}$
CEPC-SPPpC-eh	ep, $\sqrt{s} = 6$ TeV, L= 4.5 $\times 10^{33}$
VHE-ep	ep, $\sqrt{s} = 9$ TeV
MC – Proton Driver 1	$\mu\mu$, $\sqrt{s} = 1.5$ TeV, L= 1 $\times 10^{34}$
MC – Proton Driver 2	$\mu\mu$, $\sqrt{s} = 3$ TeV, L= 2 $\times 10^{34}$
MC – Proton Driver 3	$\mu\mu$, $\sqrt{s} = 10 - 14$ TeV, L= 20 $\times 10^{34}$
MC – Positron Driver	$\mu\mu$, $\sqrt{s} = 10 - 14$ TeV, L= 20 $\times 10^{34}$
LWFA-LC (e+e- and $\gamma\gamma$)	Laser driven; e+e-, $\sqrt{s} = 1 - 30$ TeV
PWFA-LC (e+e- and $\gamma\gamma$)	Beam driven; e+e-, $\sqrt{s} = 1 - 30$ TeV
SWFA-LC	Structure wakefields; e+e-, $\sqrt{s} = 1 - 30$ TeV







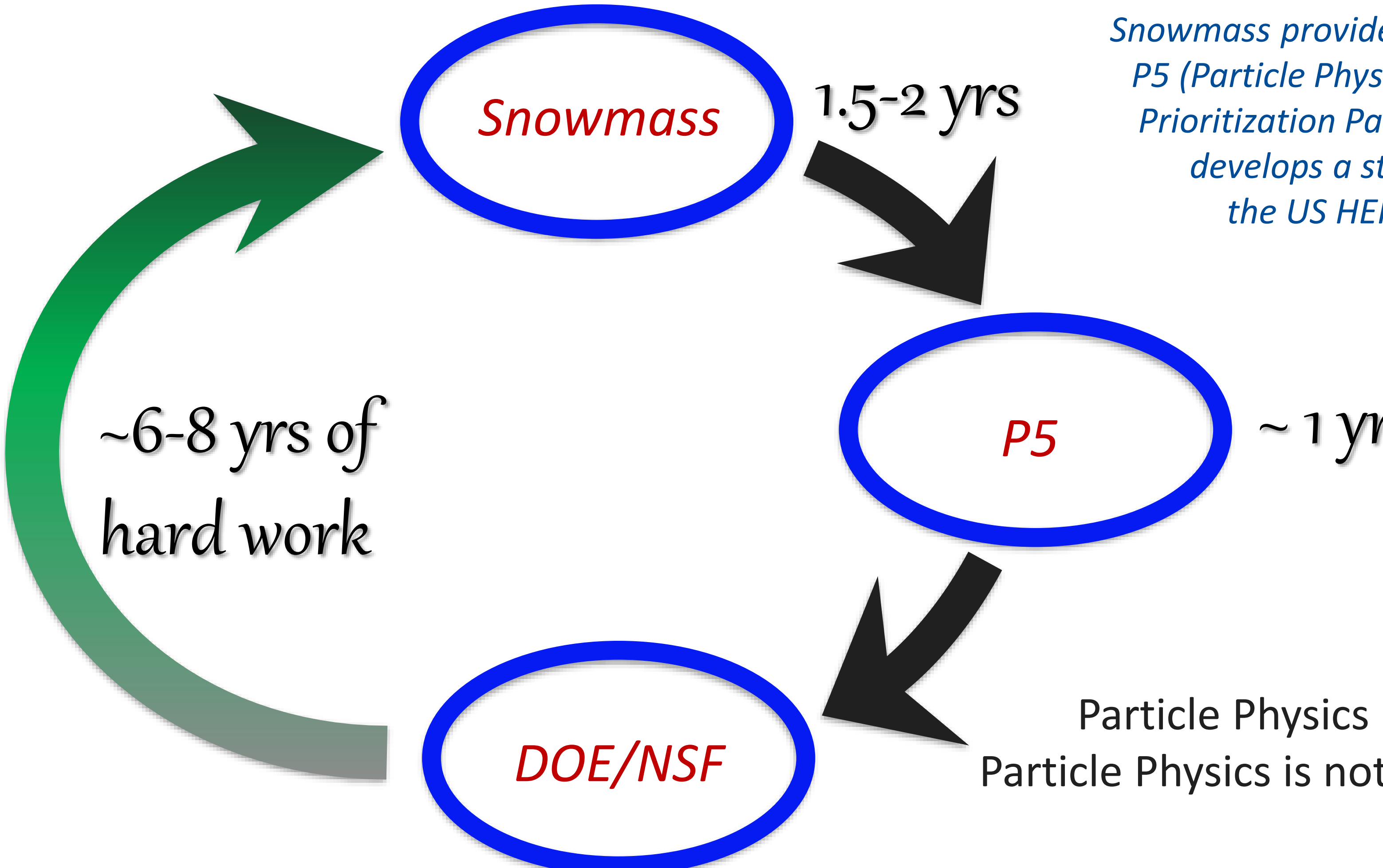
10'000 ft *(~10 years)* View:

- Any plans for the energy frontier facility can be/will be affected by the reality of:
  - LHC operation and LBNF/DUNE/PIPII construction
  - Higgs/EW factory developments:
    - Even apparently lower costs Higgs factories will
      - *Suck big part of "free money" out of ~4B$ world's HEP budget*
      - *Demand significant chunk (~1/5) of ~4500 worldwide accelerator sci & eng workforce*
      - *Delay MC timeline for ~10+ years*
- Given higher priority of Higgs factories, MC may end up be "Future Option B"/C for next decade

10’000 ft *(~10 years)* View:

- Regions are not fully coordinated/integrated yet and might have divergent plans:
  - Japan: ILC (or just a neutrino program)
  - Europe: FCCee and FCChh
  - China: CEPC and may be SPPC
  - US: neutrino program now + call for domestic collider but might be OK with int’l one at CERN or ILC
- Formal strategic plan development processes most established in Europe (EPPSU) and the US (Snowmass-P5)
  - Somewhat different and not-synched timelines

“Snowmass is a particle physics community study”



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

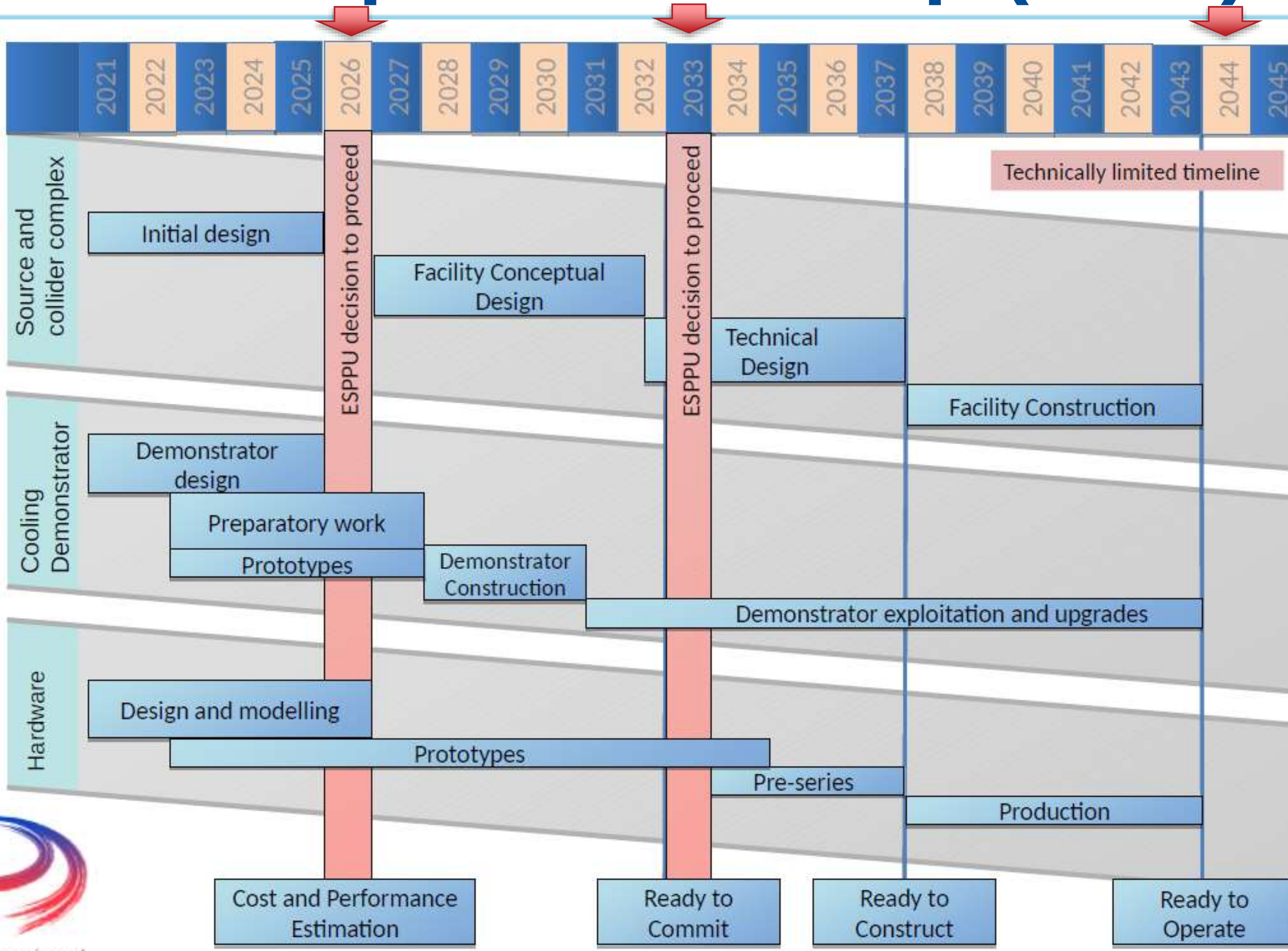
Particle Physics is global
Particle Physics is not isolated

https://www.snowmass21.org/

P5 (post Snowmass) and EPPSU

P5 (post Snowmass)	EPPSU
	(2007)
2008	
	2013
2014	
	2020
2023	
	2026-27
2029-30	
	2033-34

MC in European Roadmap (2021)



International MUON Collider Collaboration

'ig. 1.3: A technically limited timeline for the muon collider R&D programme.

IMCC Accelerator R&D Timeline

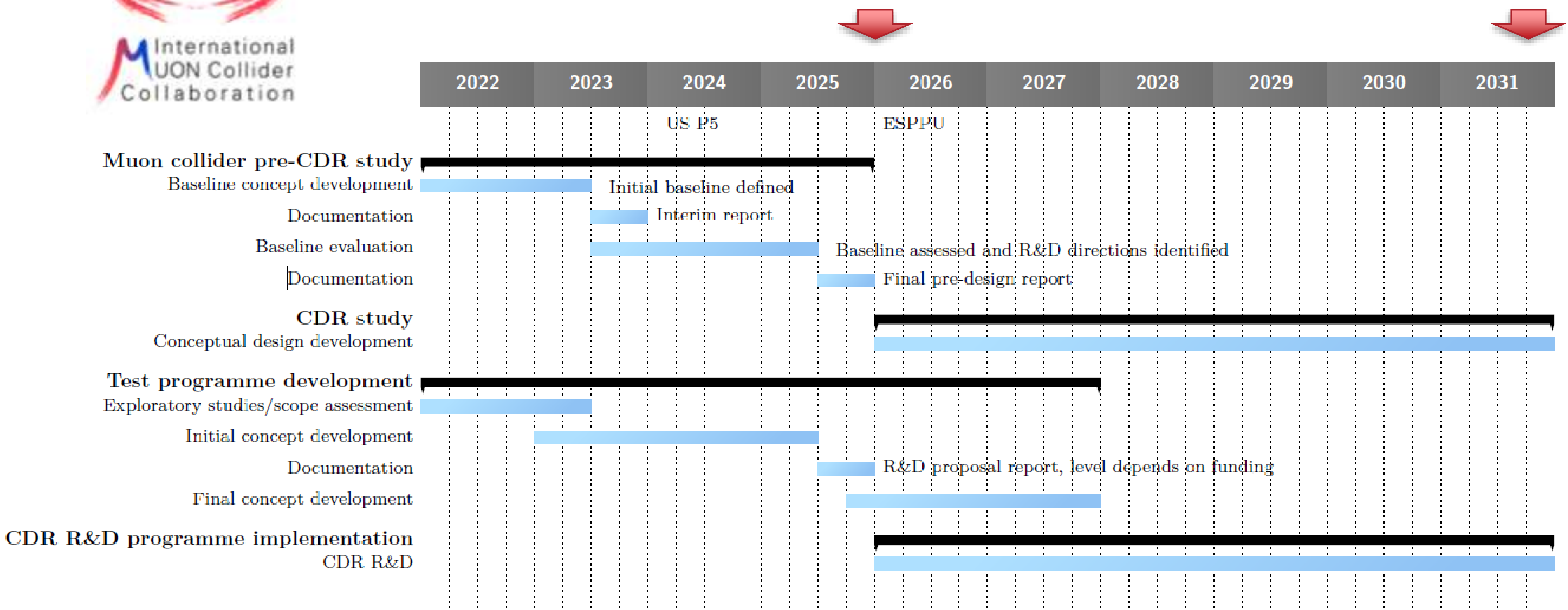


Fig. 1.4: Overall timeline for the R&D programme.

Objectives of a (Possible) US MC Plan

1. Muon Collider (pre-) CDR report available at the time of next Snowmass/P5 (2029-30):
   a. Requires machine design work and expt' R&D
   b. Several options: e.g., 3 and 10 TeV cme, domestic and international siting
   c. In collaboration with IMCC, coordinated designs and experimental R&D programs
   d. Includes theory/analysis and MDI/background work
2. Also by 2030 P5: plan for post-(pre)CDR/TDR phase MC design and development in the US
   - Elements and cost of R&D for 2030-37 specified

P5 (post Snowmass) and EPPSU

Snowmass / P5	P5 (post Snowmass)	EPPSU	European Strategy
	2008	(2007)	
	2014	2013	
		2020	
Snowmass Recm. P5 R: MC R&D	2023		Design and R&D Facility C&TDR MC pre-CDR
Design and R&D work		2026-27	
MC (pre-)CDR	2029-30		CDR work Facility R&D
Post-CDR R&D		2033-34	EPSU decision TDR work

Possible elements of the US MC Plan

1. Btw now and CSS (Snowmass main mtg) :
   a. Prepare strong recommendation/White Paper – joint EF, TF, AF
      1. Justify physics case for e.g., 3 and 10 TeV cme, and 5-6 TeV cme FNAL site filler (Higgs Fact.?)
      2. Converge on the basic elements of accel R&D plan for 2024-2030; assume collaboration with IMCC – avoid duplication of effort in experimental R&D effort
      3. Identify scope of MDI/background studies in 2024-30
   b. Call for/support creation (as P5'2023 recommenda-tion) of an "*Integrated/Inclusive Future Colliders R&D*" program in the DOE OHEP
      1. With MC as one of few sub-programs, together with FCC, FNAL site-fillers and linear colliders (eg C^3)

Possible elements of the US MC Plan (2)

For the MC part of the proposed "*Integrated/ Inclusive Future Colliders R&D*" OHEP program :

a. Identify main deliverables by 2030 (pre-CDR, prototypes)
b. Outline synergies with other OHEP R&D programs: GARD magnets, GARD RF, GARD ABP, GARD Targets, detector R&D, etc
c. For the above programs – identify elements to add/focus on in relevance to MC (eg fast cycling booster magnets, etc)
d. Indicate realistic US contributions to the IMCC and expectations to the return (IMCC contributions to US work)
e. Estimate effort and support (FTEs and M$) for all major elements of the US MC R&D program for FY2024-30: account for existing synergetic + new effort/$$ = total

An “educated guess” of the elements of the proposed plan :

1. Theory and MDI work – with EF and TF
2. Machine design: optics and beam physics issues, incl. neutrino hazard and mitigation (GARD ABP synergy)
3. Proton driver accumulator and bunch compressor design – synergy with post-PIPII FNAL complex
4. Muon cooling IMCC magnet, RF & diagnostics design work
5. Muon acceleration RF – simulations and exp test beam loading in ILC-type cavities at FNAL FAST
6. Muon acceleration fast cycling 500-1000 T/s HTS magnet prototypes
7. 12-16 T dipoles design and tests, incl. mechanical tilt – synergetic with the US MDP (and FCC-relevant)
8. 2-4 MW proton target design and development – with GARD targets (and synergistic with neutrino plans)

An “educated guess” of the elements of the proposed plan :

9. MC Target magnet design - synergetic with IMCC
10. Final cooling solenoids design and HTS short magnets tests – synergetic with US MDP
11. Final focus quadrupoles – design extension beyond US LARP/LHC AUP
12. (Later) compile (pre-) CDR, come up with semi-engineering “bottom-to-top” cost estimates *O*(50%) range for a) various options of high energy MC; b) objectives, cost and timeline of the post-CDR US MC R&D program 2030-2036

Back up slides