Fermilab

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

Global Planning for Colliders:
EPPSU, Snowmass, China, Russia…

Vladimir Shiltsev, Fermilab

IAS/HKUST Program on HEP (virtual), Jan 13, 2022

Colliders Landscape

58 years since 1st collisions

- Spring 1964 AdA and VEP-1

31 operated since

- (see RMP review)

7 in operation now

- see next slides

2 under construction

- NICA and EIC

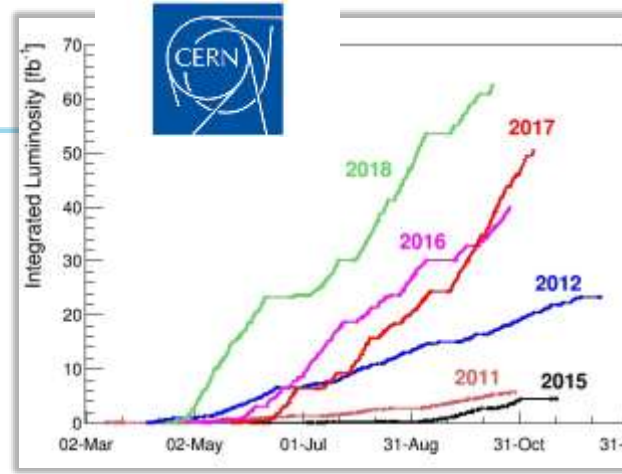
At least 2 more types needed

- Higgs/Electroweak factories
- Frontier *E* >> LHC

V. Shiltsev and F. Zimmermann: Modern and future colliders

	Species	E_b, GeV	C, m	$\mathcal{L}_{peak}^{max}$	Years
AdA	e^+e^-	0.25	4.1	10^{25}	1964
VEP-1	e^-e^-	0.16	2.7	5×10^{27}	1964-68
CBX	e^-e^-	0.5	11.8	2×10^{28}	1965-68
VEPP-2	e^+e^-	0.67	11.5	4×10^{28}	1966-70
ACO	e^+e^-	0.54	22	10^{29}	1967-72
ADONE	e^+e^-	1.5	105	6×10^{29}	1969-93
CEA	e^+e^-	3.0	226	0.8×10^{28}	1971-73
ISR	pp	31.4	943	1.4×10^{32}	1971-80
SPEAR	e^+e^-	4.2	234	1.2×10^{31}	1972-90
DORIS	e^+e^-	5.6	289	3.3×10^{31}	1973-93
VEPP-2M	e^+e^-	0.7	18	5×10^{30}	1974-2000
VEPP-3	e^+e^-	1.55	74	2×10^{27}	1974-75
DCI	e^+e^-	1.8	94.6	2×10^{30}	1977-84
PETRA	e^+e^-	23.4	2304	2.4×10^{31}	1978-86
CESR	e^+e^-	6	768	1.3×10^{33}	1979-2008
PEP	e^+e^-	15	2200	6×10^{31}	1980-90
S$p\bar{p}$S	$p\bar{p}$	455	6911	6×10^{30}	1981-90
TRISTAN	e^+e^-	32	3018	4×10^{31}	1987-95
Tevatron	$p\bar{p}$	980	6283	4.3×10^{32}	1987-2011
SLC	e^+e^-	50	2920	2.5×10^{30}	1989-98
LEP	e^+e^-	104.6	26659	10^{32}	1989-2000
HERA	ep	30+920	6336	7.5×10^{31}	1992-2007
PEP-II	e^+e^-	3.1+9	2200	1.2×10^{34}	1999-2008
KEKB	e^+e^-	3.5+8.0	3016	2.1×10^{34}	1999-2010
VEPP-4M	e^+e^-	6	366	2×10^{31}	1979-
BEPC-I/II	e^+e^-	2.3	238	10^{33}	1989-
DAΦNE	e^+e^-	0.51	98	4.5×10^{32}	1997-
RHIC	p, i	255	3834	2.5×10^{32}	2000-
LHC	p, i	6500	26659	2.1×10^{34}	2009-
VEPP2000	e^+e^-	1.0	24	4×10^{31}	2010-
S-KEKB	e^+e^-	7+4	3016	8×10^{35} *	2018-

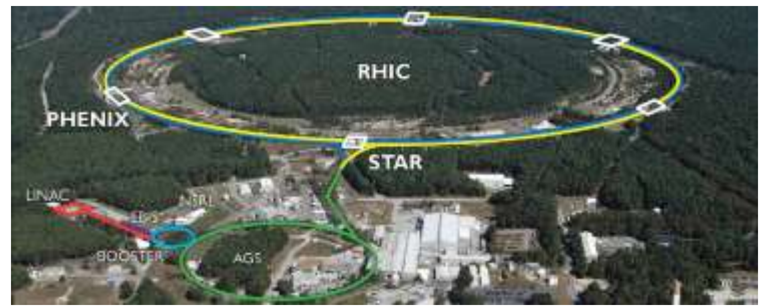
Highest *E* Colliders



most at 13TeV cme

Highlights – LHC : *pp* 13→14 TeV cme

- 190 fb-1/IP by now, x2 design *pp* luminosity
- **ALICE:** ~1nb^{-1} in 5TeV$_{cme}$ *PbPb*, 0.3ub^{-1}XeXe
- *High-Lumi upgrade* by 2028: double beam current, smaller β^* (new Nb_3Sn IR magnets), "crabbing", leveling @14 TeV → 250 fb^{-1}/yr
- Followed by ~decade of ops to 3-4 ab^{-1}



Highlights - RHIC *pp/ep/ions 510* GeV *cme*

- **RHIC:** >0.5 fb-1 in 510 GeV cme polarized *pp* (*P*=55%)
- **RHIC:** >10 nb-1 4-100 GeV/u ions (Au, Zr, …)

Highlights – Super-KEKB: *e+e-* 7+4 GeV

- Startup in 2018, world record *L*=3.8e34 cm^{-2}s^{-1}
- Design luminosity goal x40 of KEK-B
- Now ~4% of the goal, steady progress

NICA: Nuclotron-based Ion Collider fAcility

Main Parameters of The NICA Collider

Circumference, m	503,04		
Bunch number per ring	22		
Mean-square bunch size, m	0.6		
Min. beta-function (β*), m	0.6		
Ion energy, GeV/u	1.0	3.0	4.5
Ion number per bunch, 1e9	0.275	2.4	2.2
Peak luminosity, cm^{-2}·s^{-1}	0.9e25	0.9e27	6.3e27

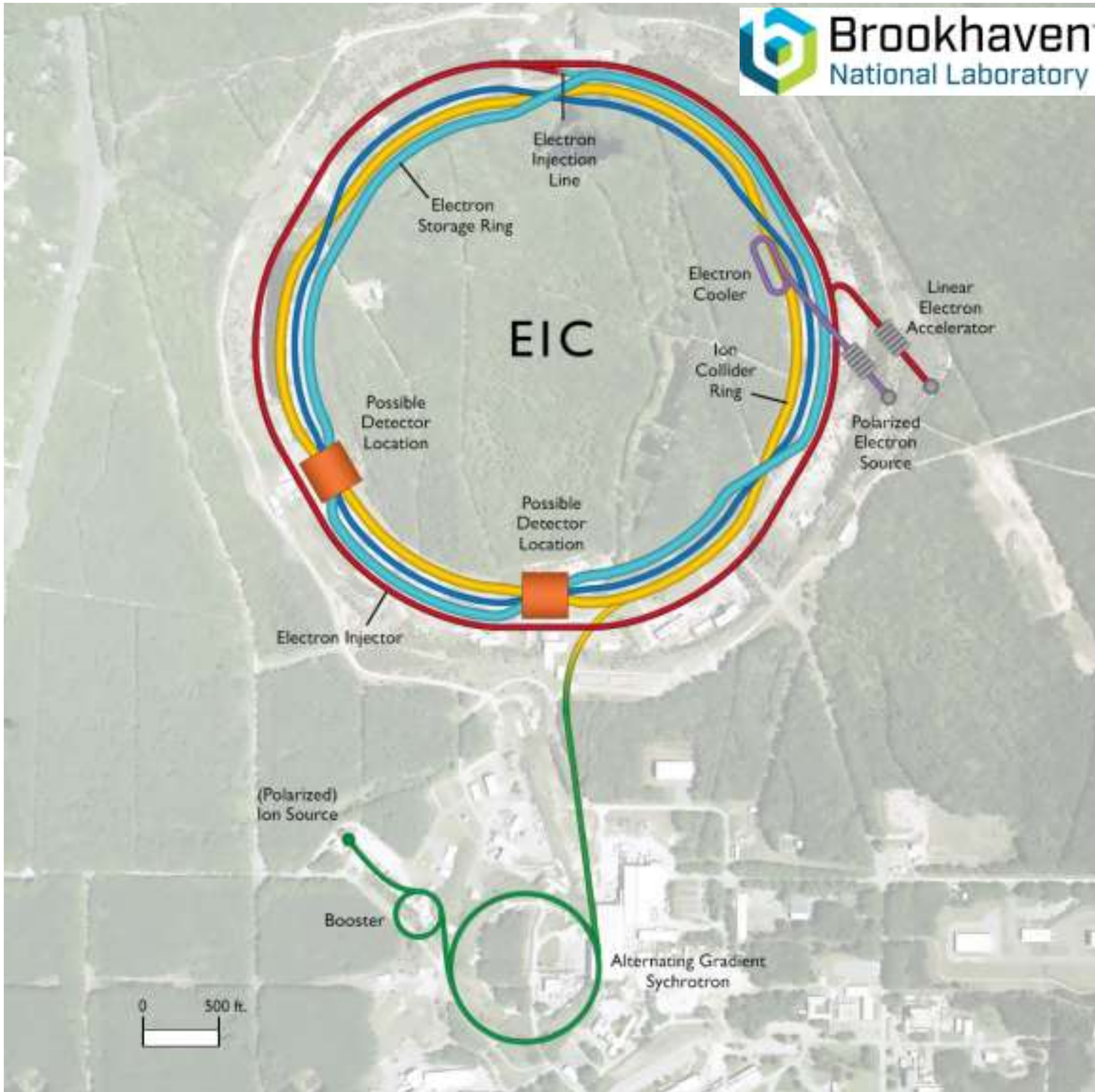
- Protons to ions (Au)

$$\sqrt{s_{NN}} = 4\text{–}11 \text{ GeV}$$

- Polarized *p* and *d*
- Superconducting magnets
- Stochastic and electron cooling for high luminosity 10^{27}

- Construction started in 2013
- More than 80% done
- Booster beam (2021)
- 1st collider magnet in the tunnel (Dec 28, 2021)
- Collisions in 2023-24

Electron Ion Collider (*EIC*)
Brookhaven National Laboratory



- 275 GeV protons, 100 GeV/u (existing RHIC, upgraded)
- 10 GeV electrons (5-18 GeV storage ring, new)

$$\sqrt{s} = 20 \text{ GeV to } 100\,\text{GeV}$$

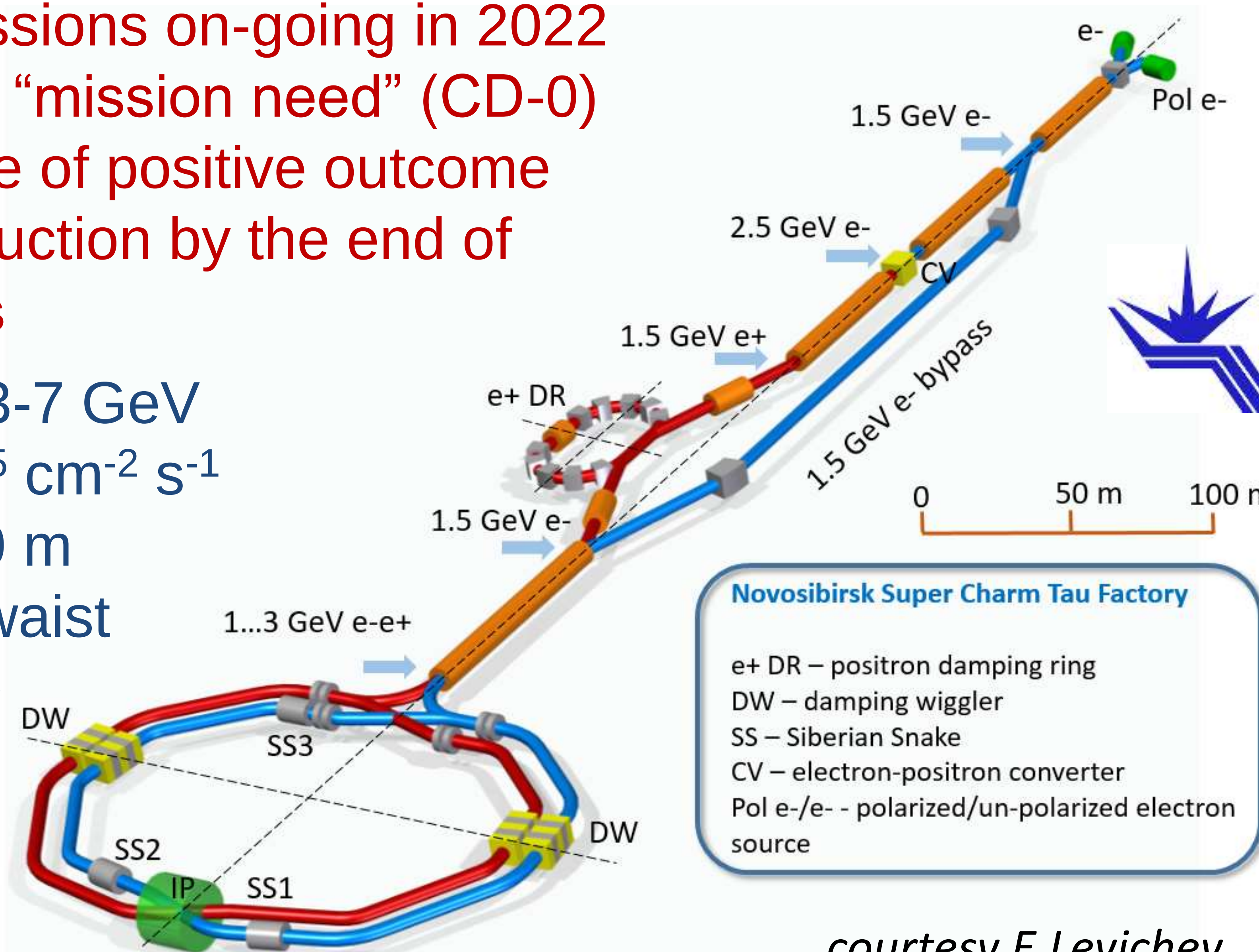
- ~70% polarization
- Luminosity ~x100 HERA (with Strong Hadron Cooling)

- CD-1 in July 2021
- Construction is expected to begin in 2024
- Operations early in the next decade.

Of Note: Super Charm/Tau-Factory (Novosibirsk)

Discussions on-going in 2022 on the “mission need” (CD-0)
In case of positive outcome construction by the end of 2020’s

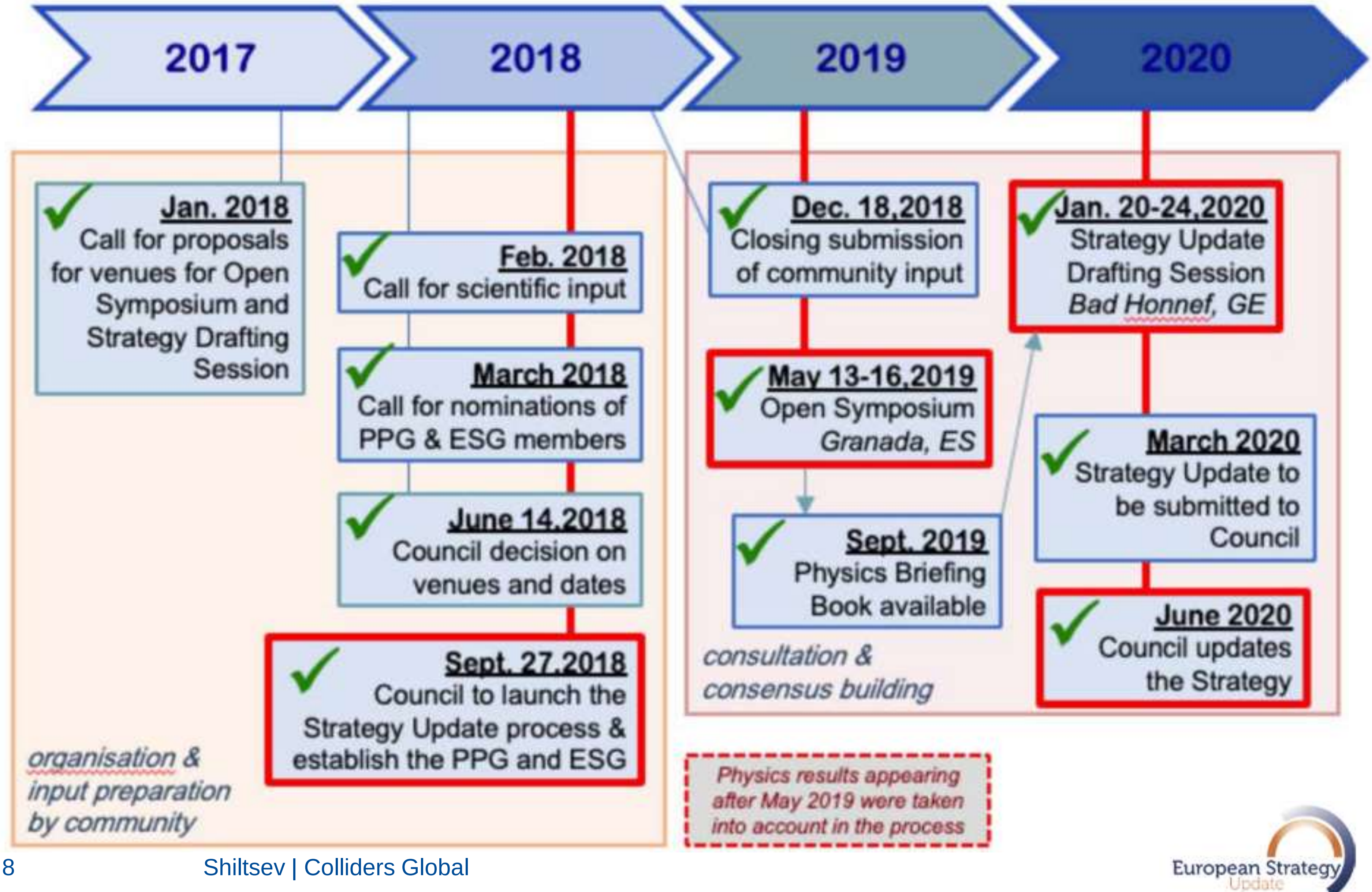
E_{cme}=3-7 GeV
L=10^{35} cm^{-2} s^{-1}
C=870 m
Crab waist
Pol. *e*-



courtesy E.Levichev

Global Planning for Future Colliders

2020 European Particle Physics Strategy Update



Outcome : *20 EPPSU Statements*

2 statements on **Major developments from the 2013 Strategy**
a) Focus on successful completion of HL-LHC upgrade remains a priority
b) Continued support for long-baseline ν experiments in Japan and US and the Neutrino Platform

3 statements on **General considerations for the 2020 update**
a) Preserve the leading role of CERN for success of European PP community
b) Strengthen the European PP ecosystem of research centres
c) Acknowledge the global nature of PP research

2 statements on **High-priority future initiatives**
a) Higgs factory as the highest-priority next collider and investigation of the technical and financial feasibility of a future hadron collider at CERN
b) Vigorous R&D on innovative accelerator technologies – through roadmap

Letters for itemiz… …nts are introduced for identifi… …ization

4 statements on **Other essential scientific activities**
a) Support for high-impact, financially implementable, experimental initiatives world-wide
b) Acknowledge the essential role of theory
c) Support for instrumentation R&D – through roadmap
d) Support for computing and software infrastructure

2 statements on **Synergies with neighbouring fields**
a) Nuclear physics – cooperation with NuPECC
b) Astroparticle – cooperation with APPEC

3 statements on **Organisational issues**
a) Framework for projects in and out of Europe
b) Strengthen relations with European Commission
c) Support active role in supporting Open Science

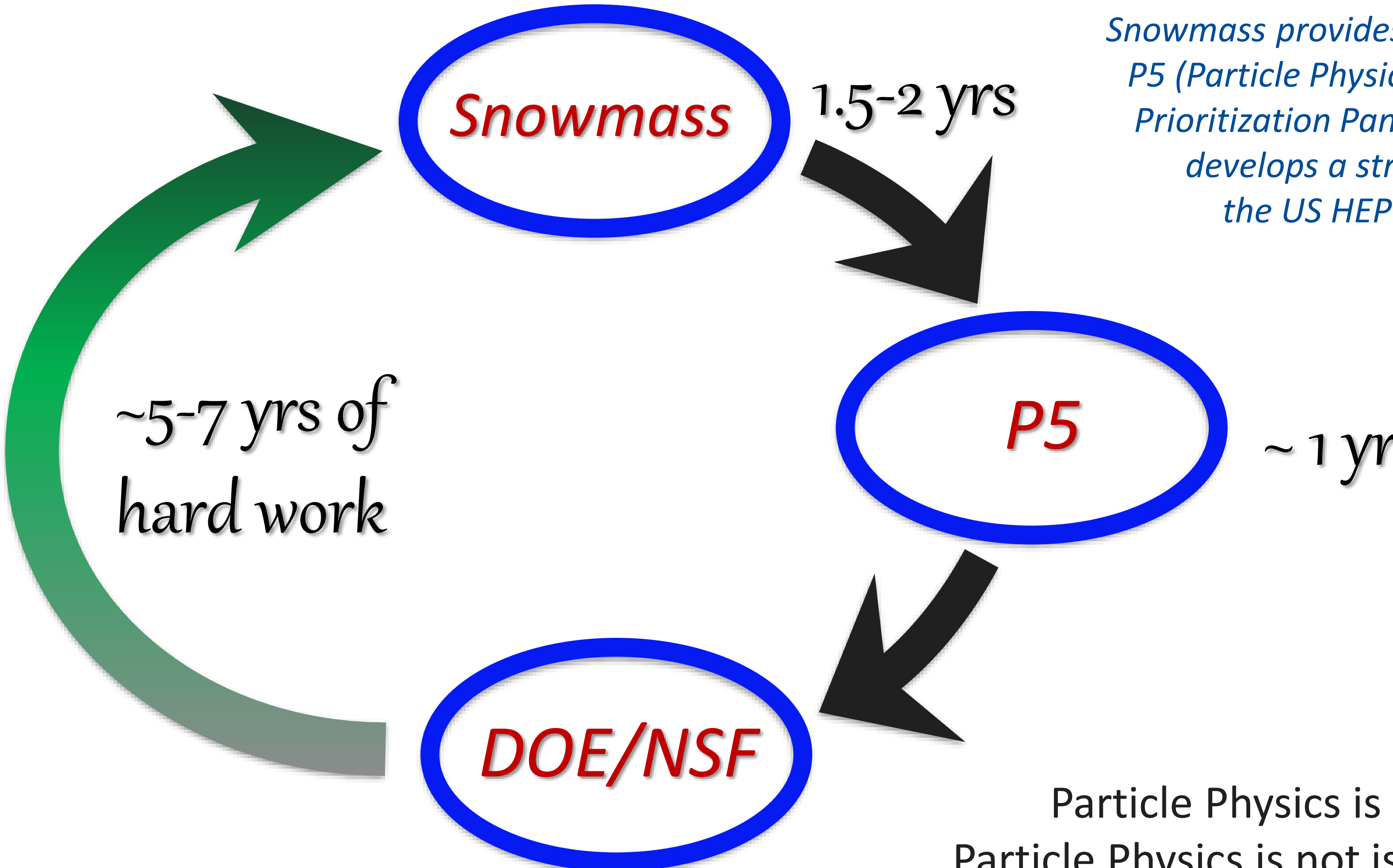
4 statements on **Environmental and societal impact**
a) Mitigate environmental impact of particle physics
b) Invest in next generation of researchers
c) Support knowledge and technology transfer
d) Cultural heritage: public engagement, education and communication

2 statements on **High-priority future initiatives**
a) Higgs factory as the highest-priority next collider and investigation of the technical and financial feasibility of a future hadron collider at CERN
b) Vigorous R&D on innovative accelerator technologies – through roadmap

HEP Planning in the US: *Snowmass*

"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/

Snowmass'21 Timeline

- 2019
  - Announcement, organization of 10 Frontiers
- 2020
  - Organization of Topical Groups
  - Submission of *Letters of Interest (LoIs)*
  - Virtual *Community Planning Meeting* Oct 5-8
- 2021
  - PAUSE due to COVID
  - Restart: work in TGs/Frontiers toward *White Papers*
- 2022
  - White paper submissions, preliminary TG & F reports
  - *Community Summer Study* – July 17-26, 2022
  - Final TG/Frontier reports
  - **Snowmass Book (SG) – October'22**

Energy Frontier
Neutrino Physics Frontier
Rare Processes and Precision
Cosmic Frontier
Theory Frontier
Accelerator Frontier
Instrumentation Frontier
Computational Frontier
Underground Facilities
Community Engagement

Snowmass 2021

Snowmass'21 Accelerator Frontier

Steve Gourlay (LBNL)

Tor Raubenheimer (SLAC)

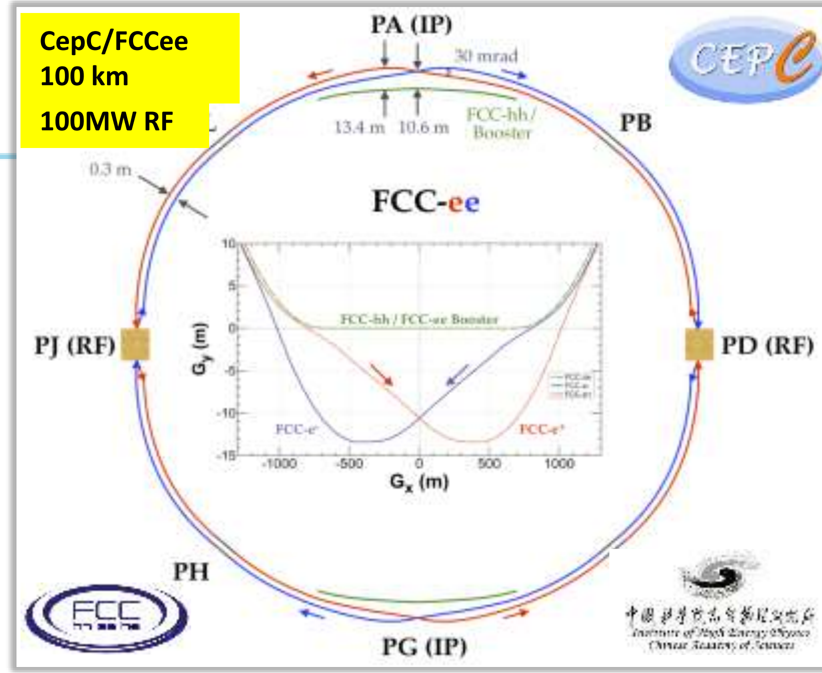
Vladimir Shiltsev (FNAL)

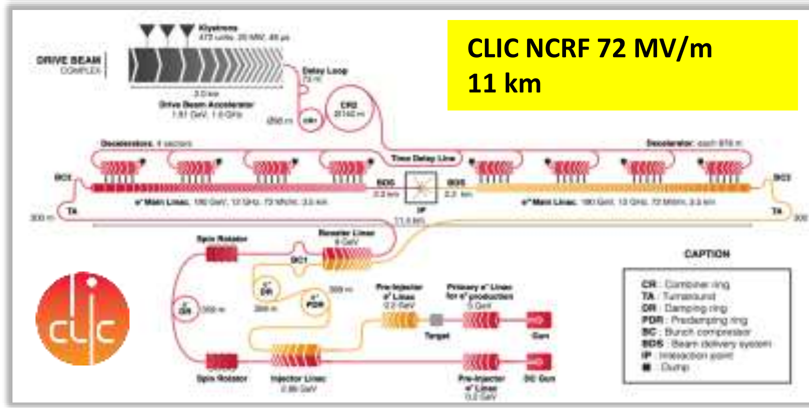
Topical Group		Topical Group co-Conveners			
AF01	Beam Phys & Accel. Education	Z. Huang (Stanford)	M. Bei (SLAC)	S. Lund (MSU)	
AF02	Accelerators for Neutrinos	J. Galambos (ORNL)	B. Zwaska (FNAL)	G. Arduini (CERN)	
AF03	Accelerators for EW/Higgs	F. Zimmermann (CERN)	Q. Qin (ESRF)	G.Hoffstaetter (Cornell) 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				
	Sub-group RF	E. Nanny (SLAC)	S. Posen (FNAL)	H. Weise (DESY)	
	Sub-Group Magnets	G. Sabbi (LBNL)	S. Zlobin (FNAL)	S. Izquierdo Bermudez (CERN)	
	Sub-Group Targets/Sources	C. Barbier (ORNL)	Y. Sun (ANL)	Frederique Pellemoine (FNAL)	
ITF	Implementation Task Force	T.Roser (BNL)			

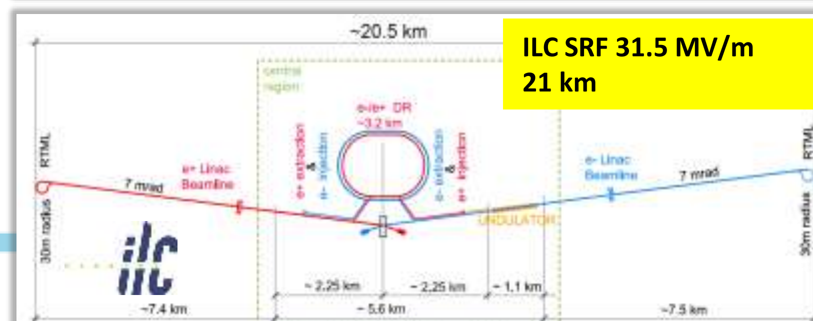
9 out of 29 represent of Asia and Europe; 5 women

Future Collider Proposals: 8 Higgs/EW factories

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

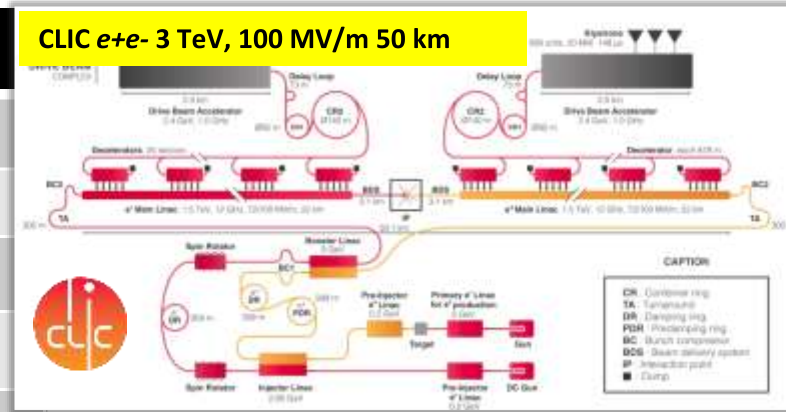


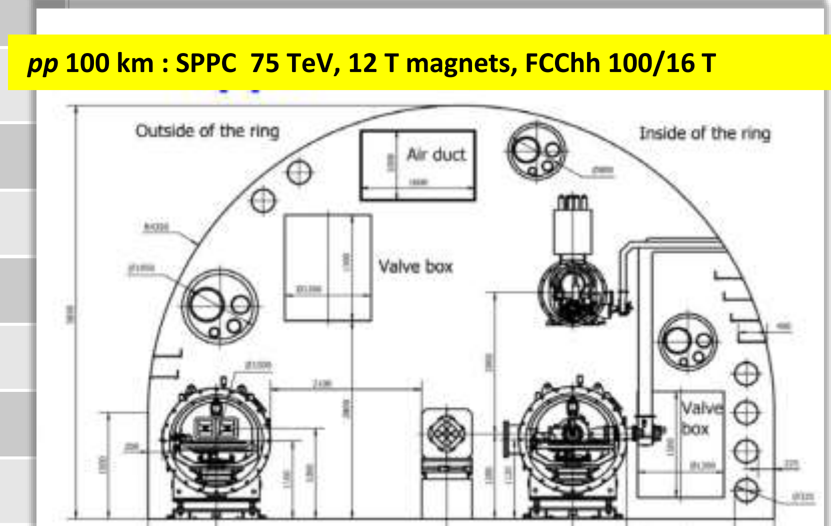


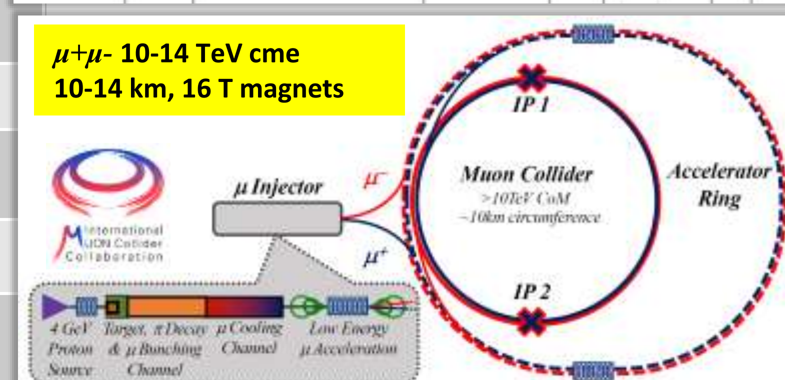


17 (!) High Energy Collider Concepts/Proposals

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

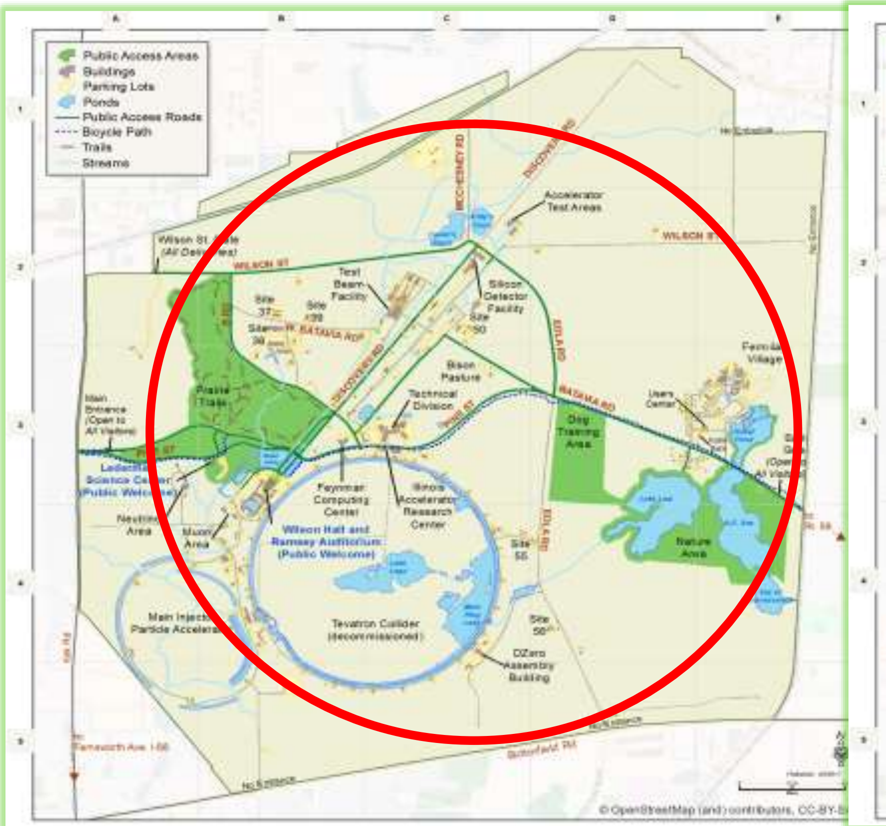






Possible Fermilab Site-Fillers

Circumference ~16 km



Linear ~7 km

Courtesy P.Bhat (FNAL)

1. e+e- Site Filler, √s = 90-240 GeV
2. Muon Collider, √s = 0.126 – 8 (10) TeV
3. pp Site Filler Collider, √s = 24-28 TeV

1. C^3 (Cool Copper Cavity) e+e- Collider, √s = 90 – 500 GeV
2. NC RF (CLIC-Klystron) e+e- Collider, √s = 90 – 500 GeV
3. SRF-Travelling Wave e+e- Linear Collider, √s = 250 GeV

Snowmass 2021

Implementation Task Force

- The Accelerator **Implementation Task Force** is charged with developing metrics and processes to facilitate a comparison between projects.
- 10 int'l experts and 2 Snowmass Young's
- This year worked in four subgroups:
  - ➢ Size, complexity, power, environment
  - ➢ Physics reach (impact), beam parameters
  - ➢ Technical risk, technical readiness, validation
  - ➢ Cost, schedule
- **Plan to finish preliminary analysis and start talking to proponents in Dec-Jan, to be ready to submit report (Snowmass WP) by May 2022**

Steve Gourlay (LBNL)

Philippe Lebrun (CERN)

Thomas Roser (BNL, Chair)

Tor Raubenheimer (SLAC)

Katsunobu Oide (KEK)

Jim Strait (FNAL)

Vladimir Shiltsev (FNAL)

Reinhard Brinkmann (DESY)

John Seeman (SLAC)

Sarah Cousineau (ORNL)

Marlene Turner (LBNL)

Spencer Gessner (SLAC)

ITF Comparison Metrics for Colliders

1. Physics Reach (8 criteria)
2. Beam parameters (7)
3. Size and Complexity of Facility (8)
4. Technical risk (5)
5. Schedule (6)
6. Validation and Preparation (4)
7. Construction Cost (7)
8. Operation and Maintenance (5)
9. Environmental Impact (4)
10. Economic/technological impact
11. Cultural/educational impact

Snowmass 2021

Snowmass'21 *Agora* On Future Colliders

Snowmass 2021

In the context of the Snowmass 2021 Community Planning Exercise, the Accelerator and Energy Frontiers are pleased to announce a series of events, intended for all Snowmass participants, to critically discuss physics and technical aspects of different HEP collider concepts.

- Linear e+e- colliders
- **Circular e+e- colliders**
- Muon colliders
- Circular pp and ep
- Advanced colliders

The events will take place once a month from December 2021 till April 2022, on Wednesdays 3-5 p.m. CST. The detailed agenda will be announced soon. We request you to please save the following dates:

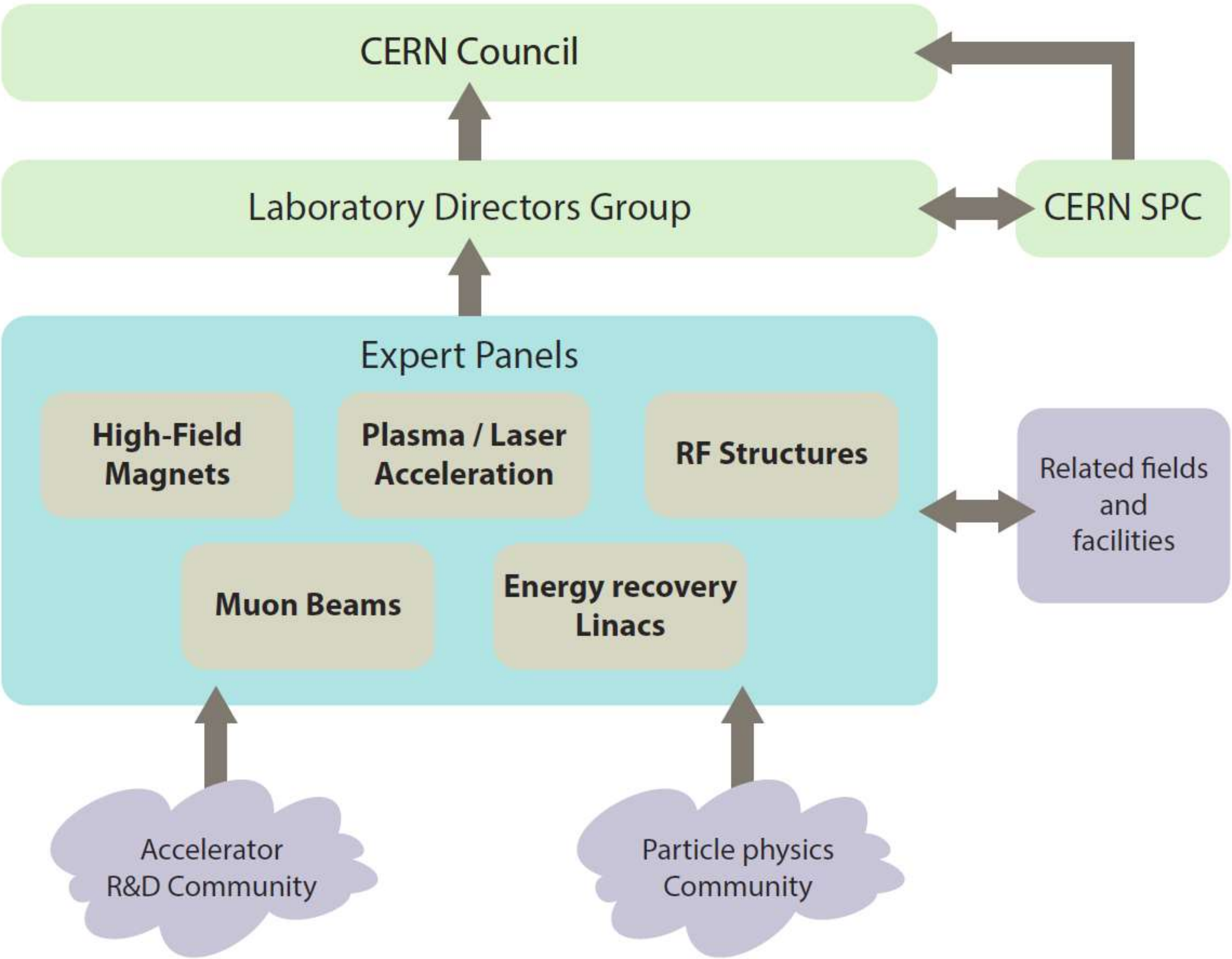
- Dec. 15, 2021
- Jan. 19, 2022
- Feb. 16, 2022
- Mar. 16, 2022
- Apr. 13, 2022

← OPEN TO ALL

Please register at:

https://indico.fnal.gov/event/52534/

Next Steps: in Europe – Accelerator R&D Roadmap



Next Step : in Europe – Accelerator R&D Roadmap

Status:

- All 5 group reports submitted
- Interim report "*European Strategy – Accelerator R&D Roadmap*" compiled and published in 2021
- CERN council met in Dec'21
- Final report (recommend-dations and roadmap) will be published this month
- Roadmap implementation will begin in March 2022

Summary on Worldwide Planning for Colliders

- **Colliders have shown remarkable progress so far:**
  - 31 built since early 1960s, 7 operational now
  - Colliders push the envelope of accelerator technologies – eg recent:
    - Records in RF gradients, *B*-field, *dB/dt* rate, MWs beam targets, etc
  - Instigated breakthroughs in beam physics – eg recent:
    - Several new beam cooling schemes, plasma acceleration to *O*(5GeV), etc
  - Three collider projects are in different stages of construction
    - Hi-Lumi LHC, NICA and EIC, … plus Novosibirsk C/Tau pre-CD0
- **Planning for future is at full speed:**
  - European Strategy Update finished in 2020
  - The US Snowmass'21 process to finish this year
  - HEP community wants two types of colliders:
    - (first) Higgs/Electroweak factories : linear or circular
    - (then) Multi-TeV colliders : either *pp,* or *μμ,* or *ee*
  - European Accelerator R&D roadmap is developed, be published soon
  - Snowmass outcome will provide base fore the 2023 P5 recommendations in 2023

Thanks for your attention!

Useful reference :

Modern and Future Colliders - V. Shiltsev, F. Zimmermann *Rev. Mod. Phys.* 93, 015006 (2021)