Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Realization, Timeline, Challenges and Ultimate Limits of Future Colliders

Vladimir Shiltsev (Fermilab)

eeFACT'22 – 65th ICFA BD Workshop (INFN Frascati, Sep 12-15, 2022)

12 September 2022

Content (Plan)

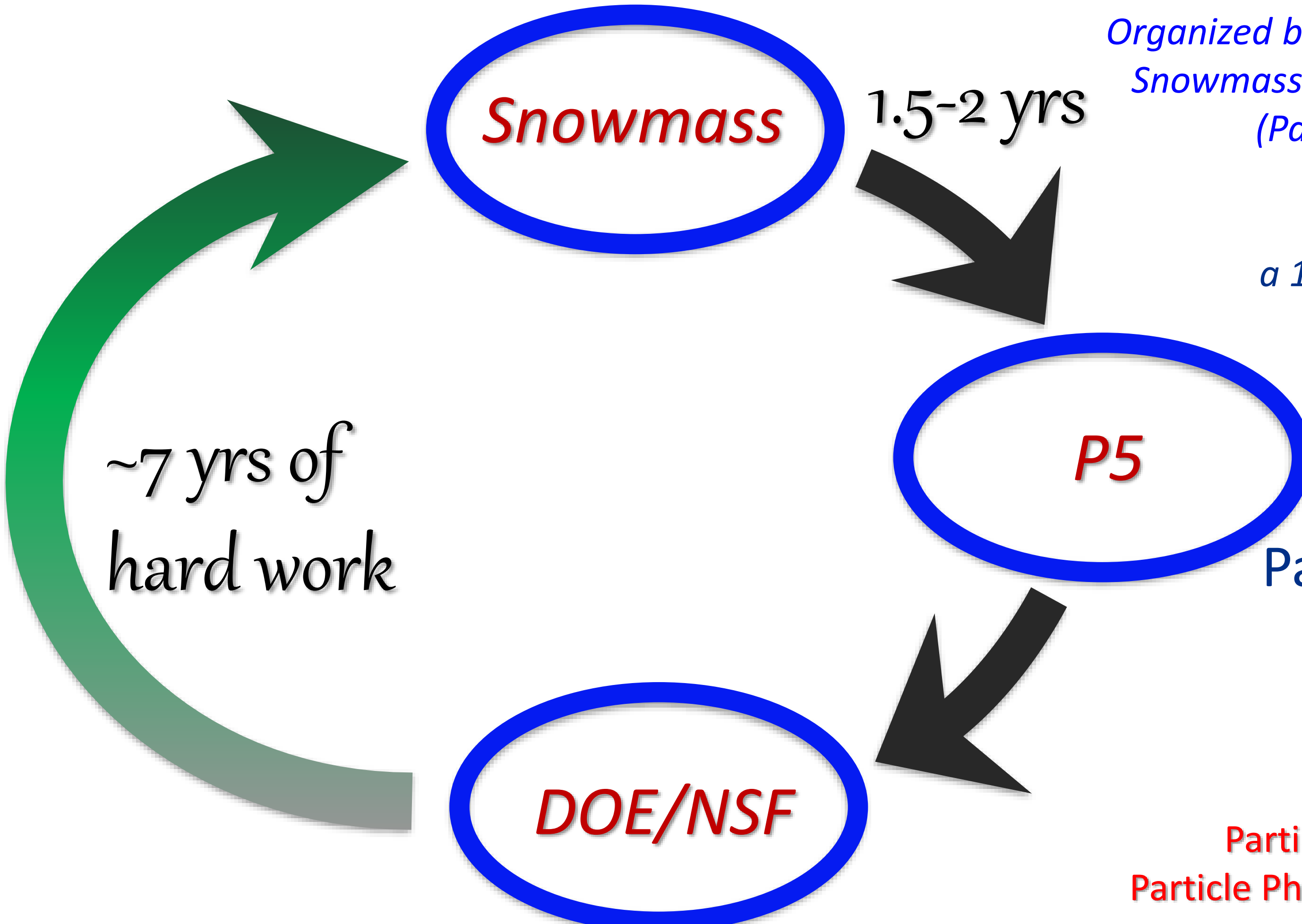
I. Snowmass'21 Accel. Frontier (4 slides)

II. Implementation Task Force (7 slides)

III. On Limits of Colliders (17 slides)

Snowmass'21 Discussions (incl. colliders)

"Snowmass is a particle physics community study"



Organized by APS DPF, DPB, et al
Snowmass provides input to P5
(Particle Physics Project
Prioritization Panel)
which develops
a 10-20 yrs strategy for
the US HEP program

~ 1 yr

Particle Physics
Project
Prioritization
Panel

Particle Physics is global
Particle Physics is not isolated

https://www.snowmass21.org/

Snowmass'21 Accelerator Frontier Conveners

Steve Gourlay (LBNL)

Tor Raubenheimer (SLAC)

Vladimir Shiltsev (FNAL)

Topical Group		Topical Group co-Conveners			
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				
	Sub-Group RF	E. Nanni (LBNL)	H.Weise (DESY)	S. Belomestnykh (FNAL)	
	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)	

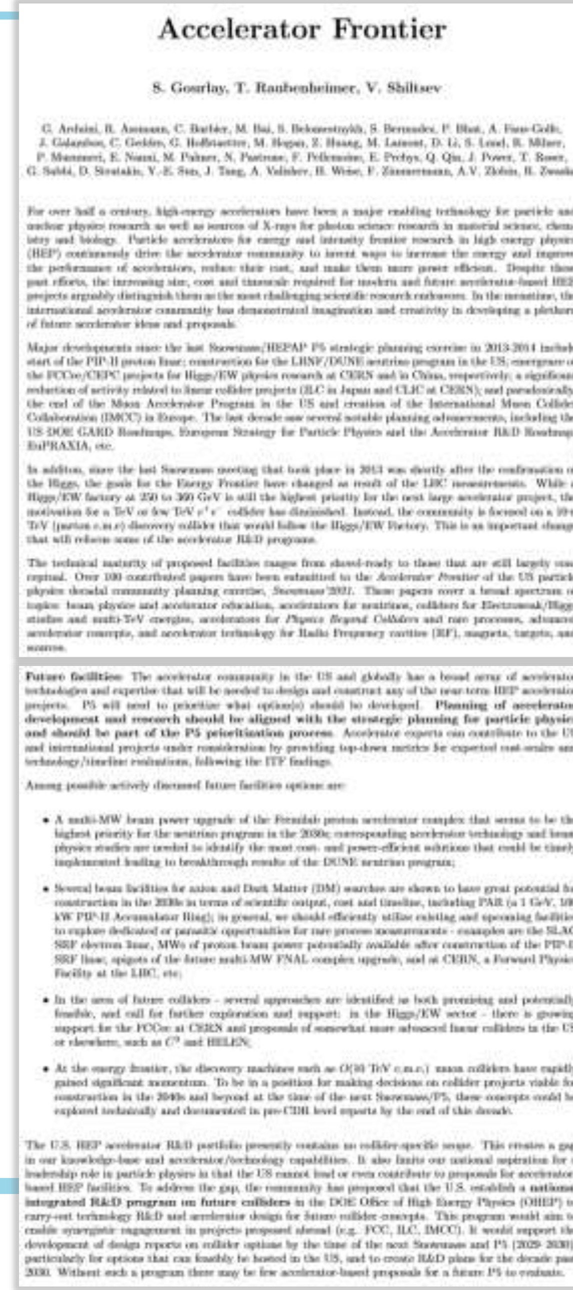
AF Report: Exec. Summary

"Intro":

- Since last P5, this Snowmass'21 process

"Future Facilities":

- *TBD by P5* – accelerator/people need to be part of P5; ITF analysis can greatly help
- *Multi-MW FNAL complex upgrade* will be priority for NF in 2030 (AF ready)
- Many opportunities for Rare Processes (AF ready), incl. *PAR and utilize what we have*
- Several Higgs/EW factories are feasible: *FCCee, C3 and HELEN* to be explored
- *O*(10 TeV/parton) needed for >2040's, *muon colliders* to be explored/ pre-CDR by 2030
- Need an *Integrated Future Colliders R&D program* in OHEP to provide design reports by next Snowmass/P5'2030 and engage internationally (FCC, ILC, IMCC)


Accelerator Frontier

S. Gourlay, T. Raubenheimer, V. Shiltsev

Accelerator R&D: Next Decade

Multi-MW targets:

- 2.4 MW for PIP-III

- 4-8 MW for **muon collide**

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

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Full AF "final draft" report available and via https://snowmass21.org/accelerator/start

Part II

Collider Implementation Task Force

(*Snowmass'21* Accelerator Frontier)

Implementation Task Force

https://arxiv.org/abs/2208.06030

- The Accelerator Frontier **Implementation Task Force (ITF)** is charged with developing metrics and processes to facilitate a comparison between collider projects:
  - Higgs/EW factories (focus of slides below)
  - Lepton colliders with 3 TeV cme
  - Lepton and hh colliders 10+ TeV cme
  - FNAL site-fillers and eh colliders
- ITF addressed (four subgroups):
  - Physics reach (impact), beam parameters
  - Size, complexity, power, environment
  - Technical risk, readiness, and R&D required
  - Cost and schedule


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)

REPORT


Dmitry Denisov


Meenakshi Narain


Liantao Wang (U.Chicago)


Sarah Cousineau (ORNL)


Marlene Turner (LBNL)


Spencer Gessner (SLAC)

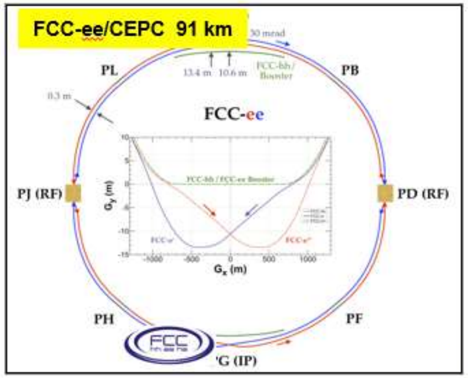
Below I mostly follow T.Roser presentation in Seattle

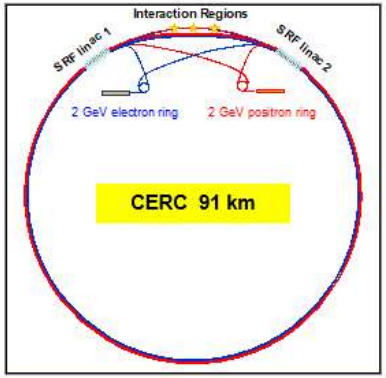
Proposals – Higgs/EW Physics

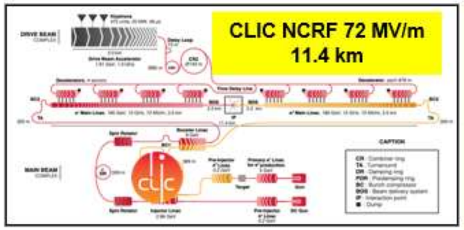
6

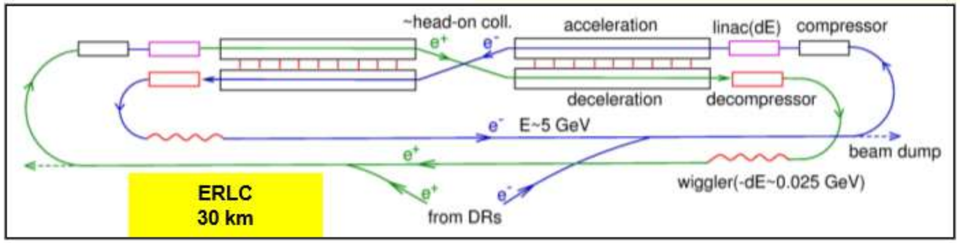
Higgs factory concepts (10)

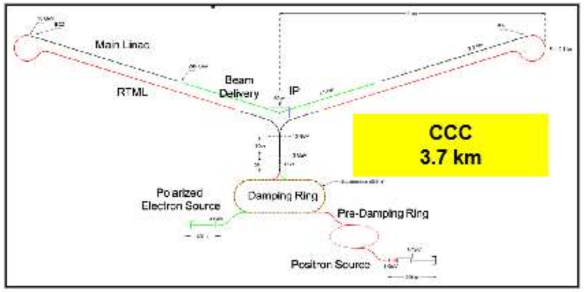
Name	CM energy range
FCC-ee	e+e-, $\sqrt{s} = 0.09 - 0.37$ TeV
CEPC	e+e-, $\sqrt{s} = 0.09 - 0.37$ TeV
ILC (Higgs factory)	e+e-, $\sqrt{s} = 0.09 - 1$ TeV
CLIC (Higgs factory)	e+e-, $\sqrt{s} = 0.09 - 1$ TeV
CCC (Cool Copper Collider)	e+e-, $\sqrt{s} = 0.25 - 0.55$ TeV
CERC (Circular ERL collider)	e+e-, $\sqrt{s} = 0.09 - 0.60$ TeV
ReLiC (Recycling Linear Collider)	e+e-, $\sqrt{s} = 0.25 - 1$ TeV
ERLC (ERL Linear Collider)	e+e-, $\sqrt{s} = 0.25 - 0.50$ TeV
XCC (FEL-based $\gamma\gamma$ collider)	ee ($\gamma\gamma$), $\sqrt{s} = 0.125 - 0.14$ TeV
MC (Higgs factory)	$\mu+\mu-$, $\sqrt{s} = 0.13$ TeV

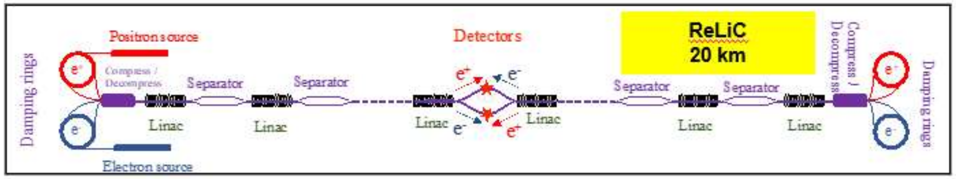




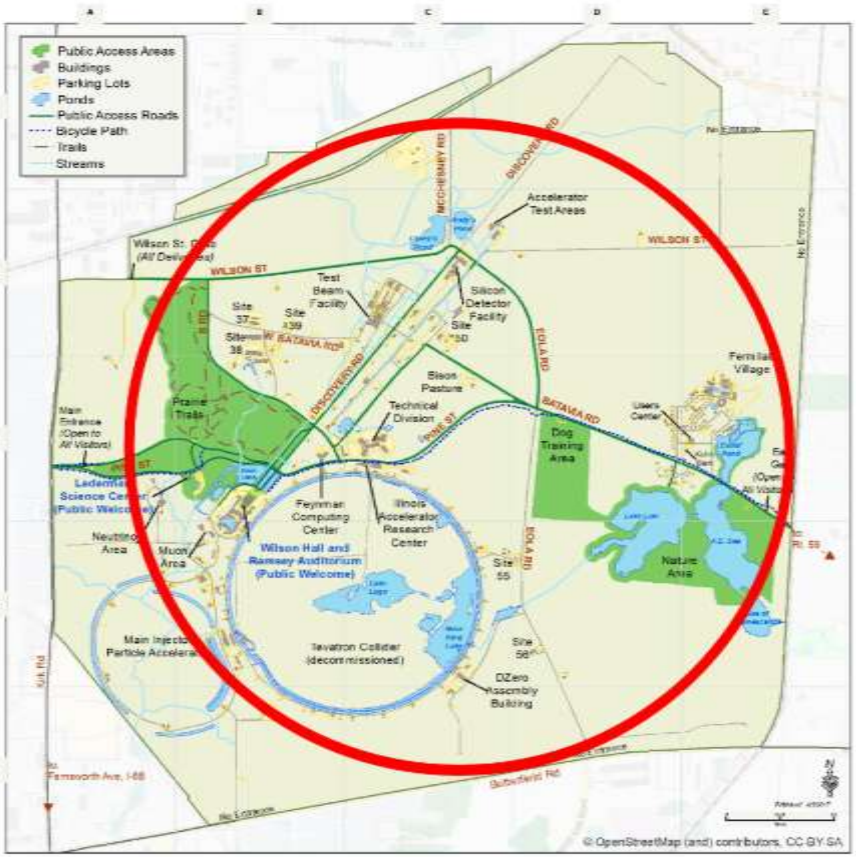






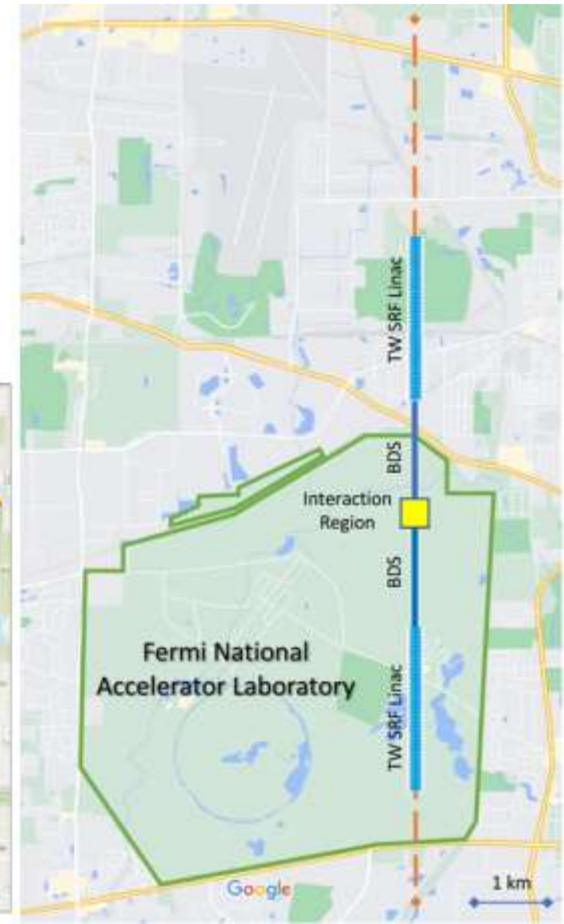


250 GeV cme Fermilab Site-Fillers



CCC

HELEN



16-km collider e+e- ring

https://arxiv.org/abs/2203.08088

cool- or *SC-RF* e+e- linear colliders
7-km for 250 GeV, 12-km 0.5+ TeV

https://arxiv.org/abs/2203.08211
https://arxiv.org/abs/2110.15800

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Higgs factory summary table

- Main parameters of the submitted Higgs factory proposals.
- The cost range is for the single listed energy.
- The superscripts next to the name of the proposal in the first column indicate:
  - (1) Facility is optimized for 2 IPs. Total peak luminosity for multiple IPs is given in parenthesis;
  - (2) Energy calibration possible to 100 keV accuracy for MZ and 300 keV for MW ;
  - (3) Collisions with longitudinally polarized lepton beams have substantially higher effective cross sections for certain processes

Proposal Name	CM energy nom. (range) [TeV]	Lum./IP @ nom. CME [10^{34} cm^{-2}s^{-1}]	Years of pre-project R&D	Years to first physics	Construction cost range [2021 B$]	Est. operating electric power [MW]
FCC-ee[1,2]	0.24 (0.09-0.37)	7.7 (28.9)	0-2	13-18	12-18	290
CEPC[1,2]	0.24 (0.09-0.37)	8.3 (16.6)	0-2	13-18	12-18	340
ILC[3] - Higgs factory	0.25 (0.09-1)	2.7	0-2	<12	7-12	140
CLIC[3] - Higgs factory	0.38 (0.09-1)	2.3	0-2	13-18	7-12	110
CCC[3] (Cool Copper Collider)	0.25 (0.25-0.55)	1.3	3-5	13-18	7-12	150
CERC[3] (Circular ERL Collider)	0.24 (0.09-0.6)	78	5-10	19-24	12-30	90
ReLiC[1,3] (Recycling Linear Collider)	0.24 (0.25-1)	165 (330)	5-10	>25	7-18	315
ERLC[3] (ERL linear collider)	0.24 (0.25-0.5)	90	5-10	>25	12-18	250
XCC (FEL-based $\gamma\gamma$ collider)	0.125 (0.125-0.14)	0.1	5-10	19-24	4-7	90
Muon Collider Higgs Factory[3]	0.13	0.01	>10	19-24	4-7	200

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Proposal Name	CM energy nom. (range) [TeV]	Lum./IP @ nom. CME [10^{34} cm^{-2}s^{-1}]	Years of pre-project R&D	Years to first physics	Construction cost range [2021 B$]	Est. operating electric power [MW]
High Energy LeptoN (HELEN) e^+e^- colider	0.25 (0.09-1)	1.4	5-10	13-18	7-12	~110
e^+e^- Circular Higgs Factory at FNAL	0.24 (0.09-0.24)	1.2	3-5	13-18	7-12	~200

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ITF Report – T.Roser, et al, arXiv:2208.06030

Cost Estimates for Higgs Factories

- The ITF cost model for the EW/Higgs factory proposals.
- Horizontal scale is approximately logarithmic for the project total cost in 2021 B$ without contingency and escalation.
- Black horizontal bars with smeared ends indicate the cost estimate range for each machine.

ITF Report – T.Roser, et al, arXiv:2208.06030

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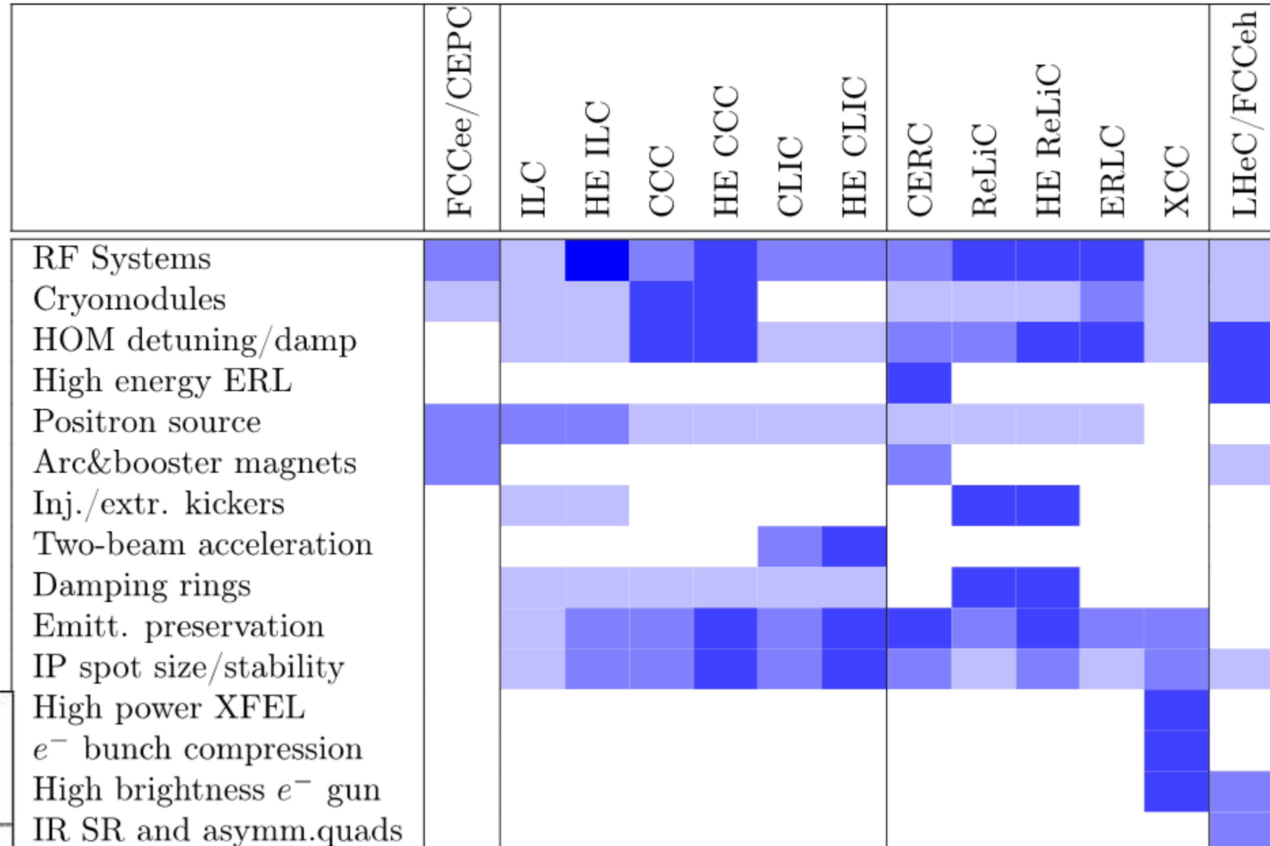
ITF Technical Risk Registry

- Technical risk registry of accelerator components and systems for **future e^+e^- and ep colliders**: lighter colors indicate progressively higher TRLs (less risk), white is for either not significant or not applicable.



Proposal Name (c.m.e. in TeV)	Collider Design Status	Overall Risk Tier
FCCee-0.24	II	1
CEPC-0.24	II	1
ILC-0.25	I	1
CCC-0.25	III	2
CLIC-0.38	II	1
CERC-0.24	III	2
ReLiC-0.24	V	2
ERLC-0.24	V	2
XCC-0.125	IV	2
MC-0.13	III	3

ITF Table 14: "Design Status": I - TDR complete, II - CDR complete, III - substantial documentation; IV - limited documentation and parameter table; V - parameter table. Overall risk tier category ranging from Tier 1 (lower overall technical risk) to Tier 4 (multiple technologies that require further R&D).

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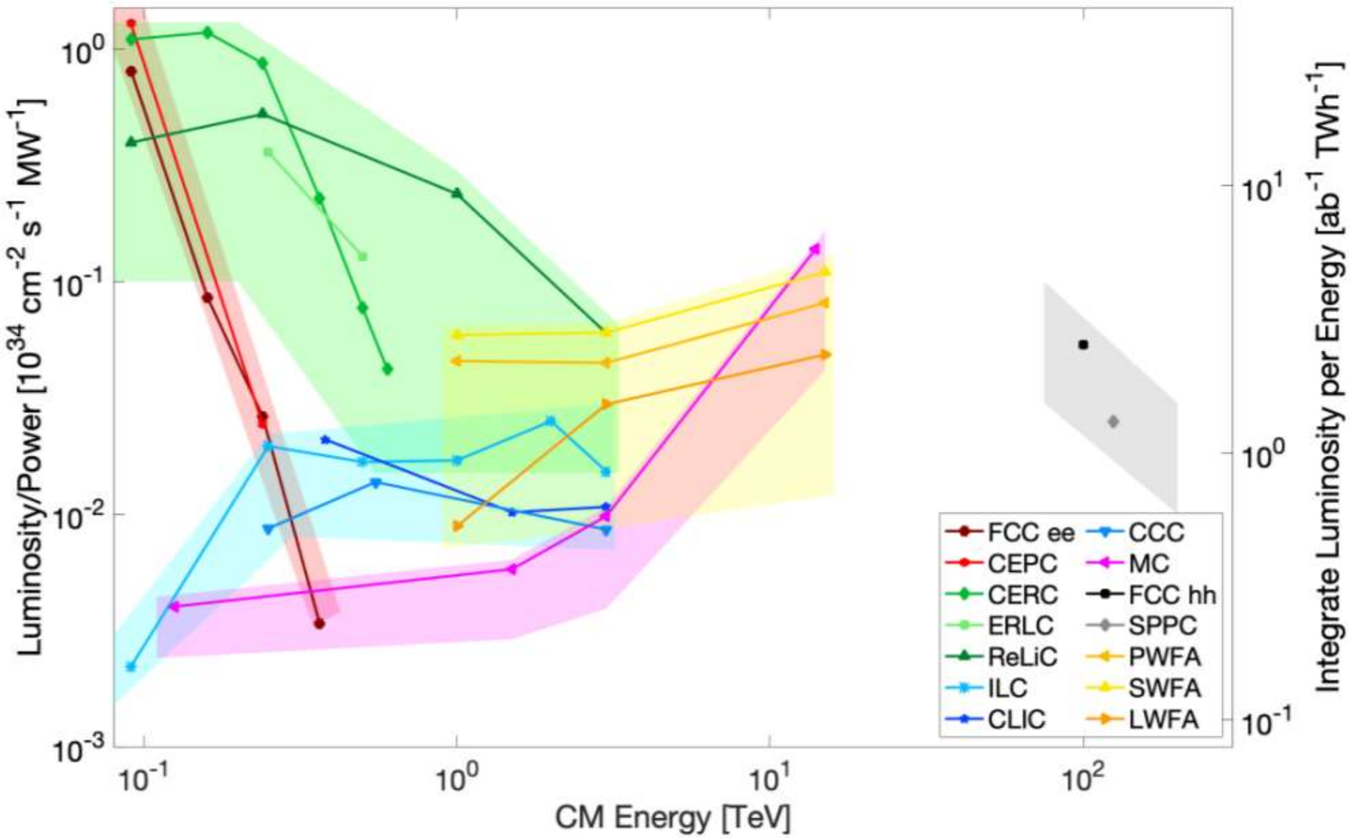
ITF Report – T.Roser, et al, arXiv:2208.06030

Luminosity per Power

Circular *ee*	ERL based *ee*	Linear *ee*	Muon coll	Wakefield	Hadron *pp*

- Figure-of-merit Peak Luminosity (per IP) per Input Power and Integrated Luminosity per TWh.
- Integrated luminosity assumes 10^7 seconds per year.
- The luminosity is per IP.
- Data points are provided to the ITF by proponents of the respective machines.
- The bands around the data points reflect approximate power consumption uncertainty for the different collider concepts.



Once again: luminosity and power consumption values have not been reviewed by ITF - we used proponents' numbers.

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ITF Report – T.Roser, et al, arXiv:2208.06030

Part III

Limits of Colliders

(as discussed at the *Snowmass'21 Accelerator Frontier Topical Group 1* Workshop "Physics Limits of Ultimate Beams", Jan. 2022;

mostly following

V.Shiltsev, Proc. IPAC'21, WEPAB017)

How ultimate colliders might look like?

- **BASED ON EXISTING TECHNOLOGIES ?**
  - **Circular ee**
  - **Linear *ee*/$\gamma\gamma$**
  - **Circular *pp***
  - **Circular $\mu\mu$**
- **BASED ON EMERGING TECHNOLOGIES ?**
  - **ERL *ee*/$\gamma\gamma$**
  - **Plasma *ee*/$\gamma\gamma$**
  - **Linear $\mu\mu$ / Plasma $\mu\mu$**
- **EXOTIC SCHEMES ?**
  - **Crystal linear $\mu\mu/\tau\tau$**
  - **Crystal linear $\tau\tau$**
  - **Crystal circular *pp***

ITF's Look Beyond Higgs Factories

	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
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-10-IMCC	10-14	20	>10	>25	12-18	$O(300)$
FCChh-100	100	30	>10	>25	30-50	~560
Collider-in-Sea	500	50	>10	>25	>80	»1000

ITF Report – T.Roser, et al, arXiv:2208.06030

Factors and Limits

- Main factors to consider feasibility of future colliders used to be
  - Feasibility of ***E***nergy
  - Feasibility of ***L***uminosity
  - Feasibility of ***C***ost
- The *European Strategy* (2019) and *Snowmass'21* discussions revealed additional limits:
  - ***Time*** to construct and commission
  - ***Societal limits***: # of experts, size of facility, radiation, etc
  - ***Environmental impacts***: power consumption, carbon footprints, scarcity of resources (*He*, *Nb*, *W*, etc), excavated materials, etc

Here we will only briefly touch some important points

Limits on Energy

- Synchrotron radiation defines linear vs circular if $U_{SR} < E$

$$U_{SR} = C_\gamma \frac{E^4}{\rho} = 88.46 \frac{r_0}{r_e}\left(\frac{m_e}{m_0}\right)^3 \frac{E^4[GeV]}{\rho[m]}$$

- for e-/e+: $E_{cm} \leq 500\ GeV \left(\frac{\rho}{10km}\right)^{\frac{1}{3}}$
- for muons: $E_{cm} \leq 600\ TeV \left(\frac{\rho}{10km}\right)^{\frac{1}{3}}$
- for protons: $E_{cm} \leq 10\ PeV \left(\frac{\rho}{10km}\right)^{\frac{1}{3}}$

- Production and survival: unstable particles such as muons

$$\frac{dN}{dt} = -\frac{N}{\gamma\tau_0};\ \gamma = \gamma_i + z\frac{d\gamma}{dz}$$

where τ_0 is the lifetime, $\tau_0 \sim 2.2\mu s$ for muons… requires fast acceleration

for muons $G \gg 3\ \mathrm{MeV\ m^{-1}}$

for τ-leptons $G \gg 0.3\ \mathrm{TeV\ m^{-1}}$

- Staging efficiency (losses) per stage for M stages ≥ $\eta = 1 - 1/M$

- Technology within limited space /area:

Circumference 100 km , B<16 T , *E*<50 TeV

Circumference 40,000 km, B=1 T, *E*<1.3 PeV

Length 50 km , G<0.1 GV/m, *E*<5 TeV

Length 10 km, G<1 TV/m, *E*<10 PeV

Limits on *Luminosity* (some)

- General Equation

$$L = f_0 n_b N^2 / 4\pi\sigma^2$$

  - *sheer beam power*

$$P_b = f_0 n_b N \gamma m c^2$$

$$L = P_b^2 / (4\pi\gamma n_b \varepsilon \beta^* m^2 c^4) \propto P_b^2 / E$$

  - *e/p SR rad. power*

$$L \propto (\xi/\beta^*)(P_{SR}/2\pi R)(R^2/\gamma^3))$$

  - *μ→ν radiation dose*

$$D \propto (dN/dt) E^3 / \Phi$$

flux dilution factor

$$L \propto B \frac{D\Phi}{E^2} \frac{N}{4\pi\epsilon_n \beta^*}$$

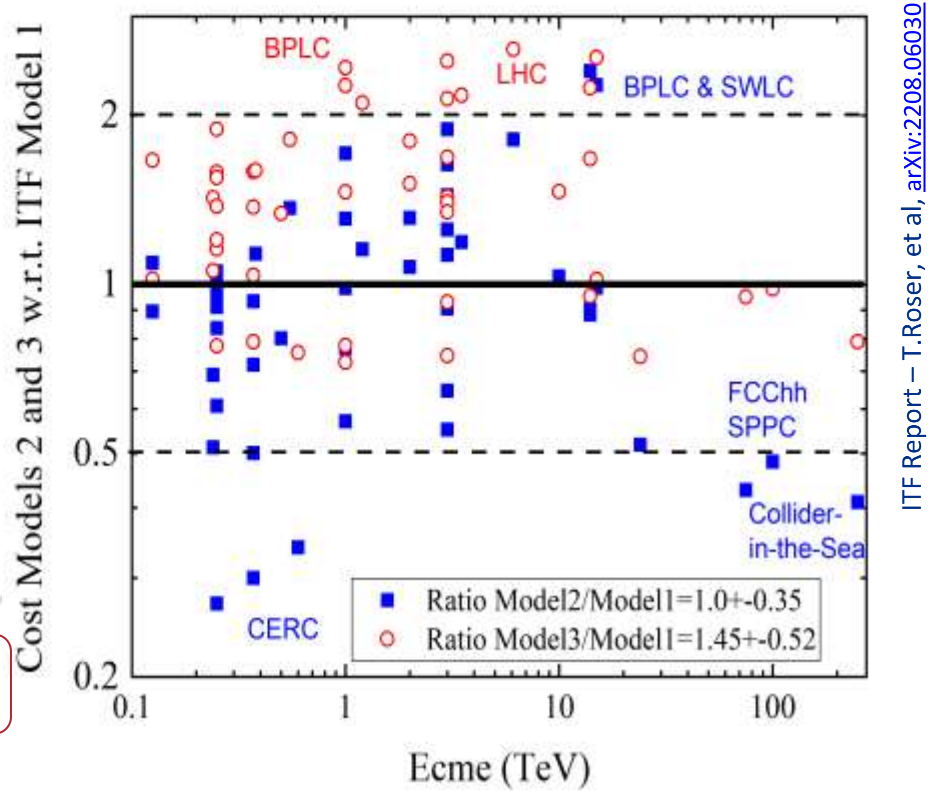
  - *LC power, BS, jitter*

$$L \propto (P/E)(N_\gamma/\sigma_y)$$

αβγ vs ITF 30-parameter cost model

Higher energy → usually bigger size, more power and higher costs:

- Where is the societal limit on the cost of colliders?
- Cost ranges estimates – detailed vs parametric models



ITF Report - Figure 7: Ratio of the estimates of the three-parameters ***αβγ*** Model (#2) and Model 3 to the 30-parameter cost Model 1 for future collider projects vs E_{CM}.

*The **αβγ** cost model (2014):*

$$\mathrm{Cost(TPC)} = \alpha\, L^{1/2} + \beta\, E^{1/2} + \gamma\, P^{1/2}$$

α≈ 2B$/sqrt(L/10 km) for tunnel/civil

β ≈ 10B$/sqrt(E/TeV) for SC/NC RF

β ≈ 2B$ /sqrt(E/TeV) for SC magnets

β ≈ 1B$ /sqrt(E/TeV) for NC magnets

γ≈ 2B$/sqrt(P/100 MW) for site power

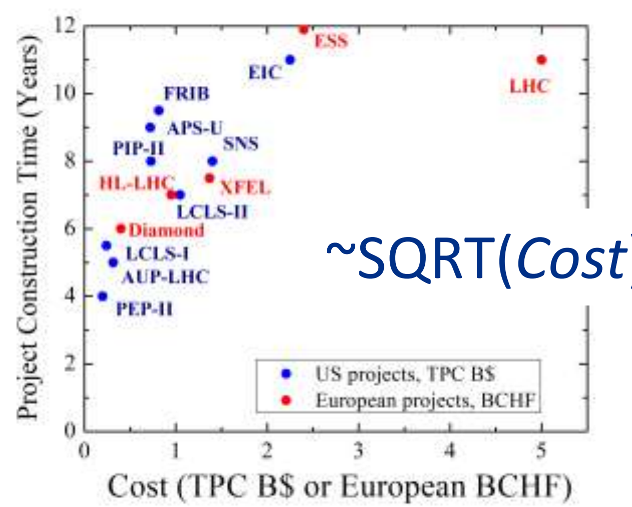
αβγ model – V.Shiltsev, *JINST* 9 T07002 (2014).

Accelerators Timeline *X+Y+Z ≤ ?*

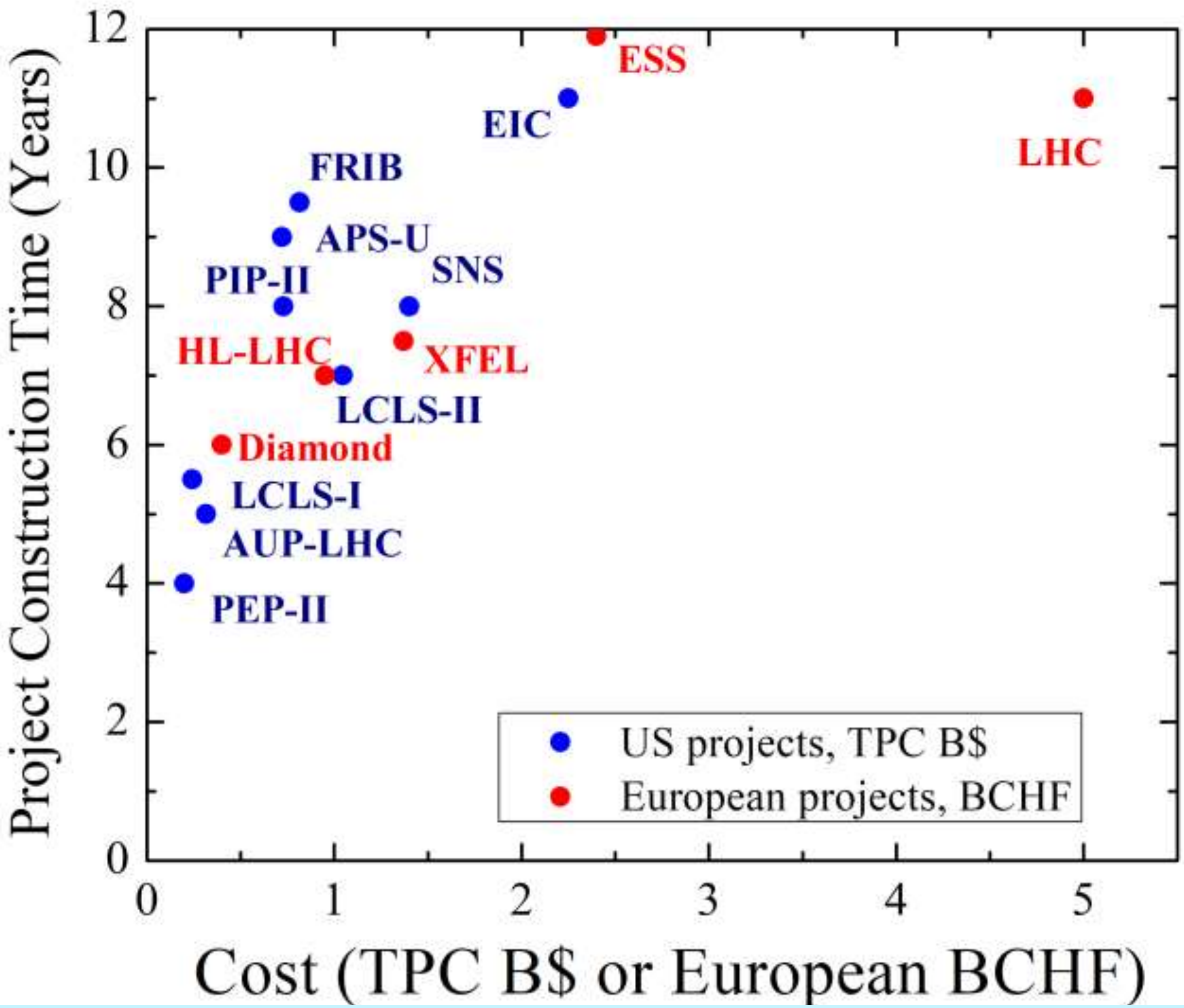
Bigger size and cost → longer:

- Pre-project R&D *X years*
  - Depends on novelty
- Construction project *Y years*
  - Annual peak <0.5B$/year ?
  - "Oide law": *need ~1 expert to spend (intelligently) 1 M$/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)



Construction Time… ~SQRT(*Cost*)?



ITF Report - Figure 11: Construction time for recent large accelerator projects in the US and Europe.

Peak spending rate depends on $$/yr limit and on # of available experts …currently, btw 0.2 to 0.5 B$/yr (total World's HEP ~4B$)

Circular e+e- Colliders

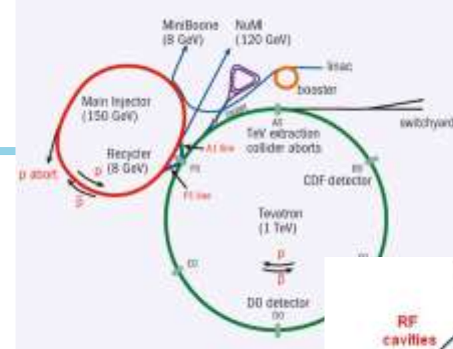
- Let's skip them… dead end… SR power

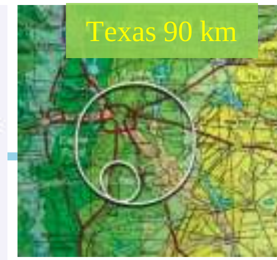
$$L = \frac{3}{16\pi r_e^2 (m_e c^2)} \frac{\xi_y P_T}{\beta_y^*} \rho \gamma^{-3}$$

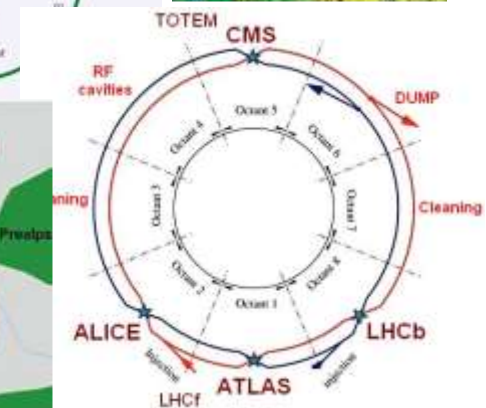
- E.g. >0.5 TeV ring will be
  - Big (>200-300 km?)
  - Low luminosity *O*(10 fb-1/yr)
  - A lot of RF → expensive **>1.5-2 LHCU**

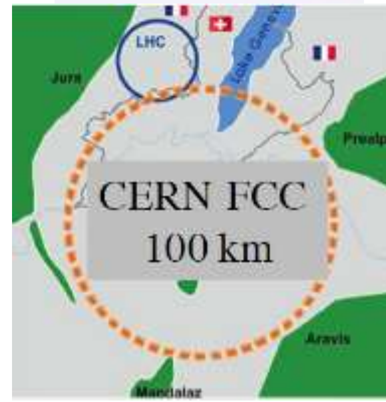
Circular *pp* Colliders

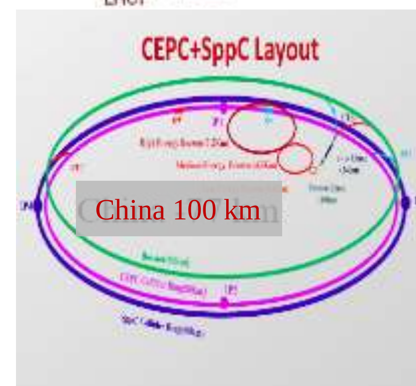
- Can use Tevatron and LHC as reference point
- Parameter sets exist for SSC, FCC-hh, SppC, VLHC, Coll-Sea, Eloisatron, CCMoon
- Major advantages:
  - known technology and physics
  - good power efficiency ab^{-1}/TWh
- Major limitations:
  - Size (magnetic field *B*)
  - Power
  - Beam-beam, burn-off, instabilities
  - Synchrotron radiation
  - Cost

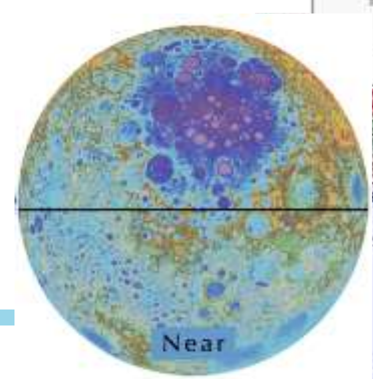


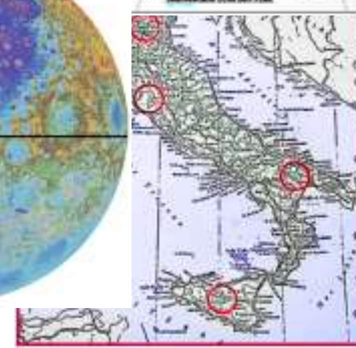


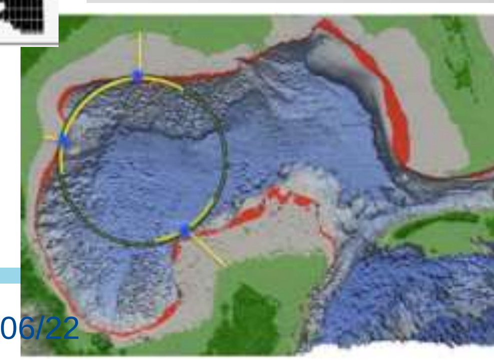




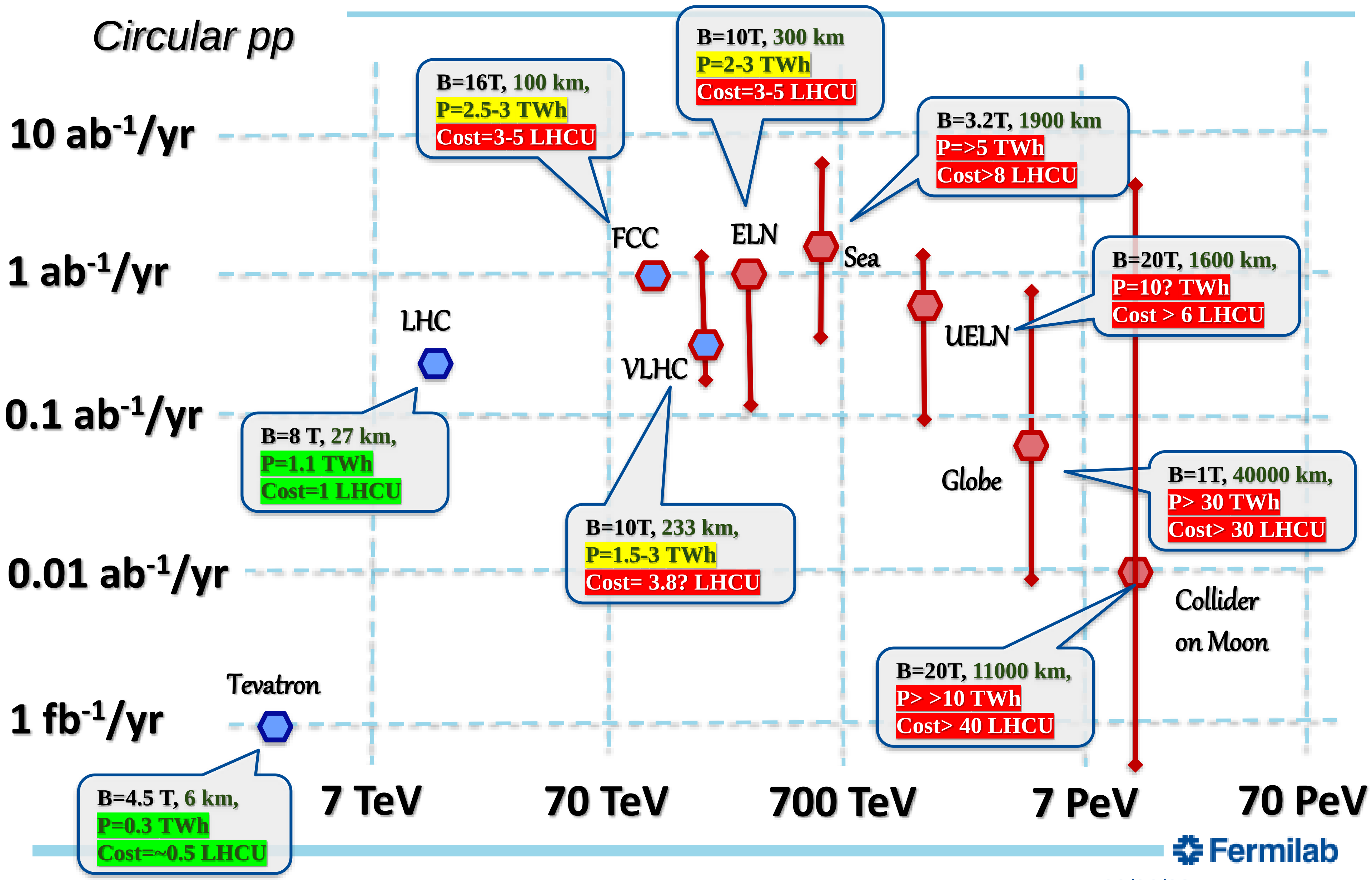




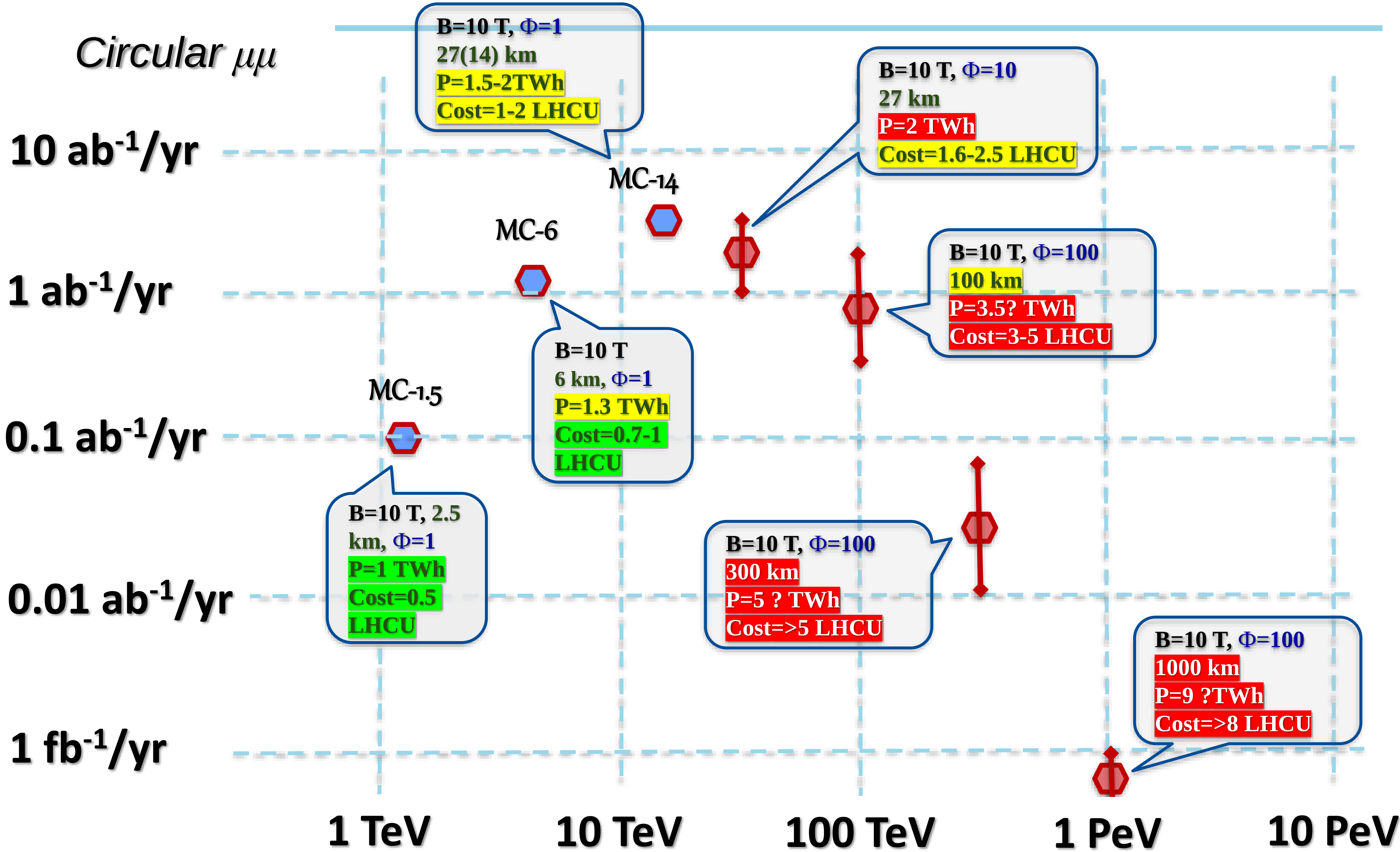




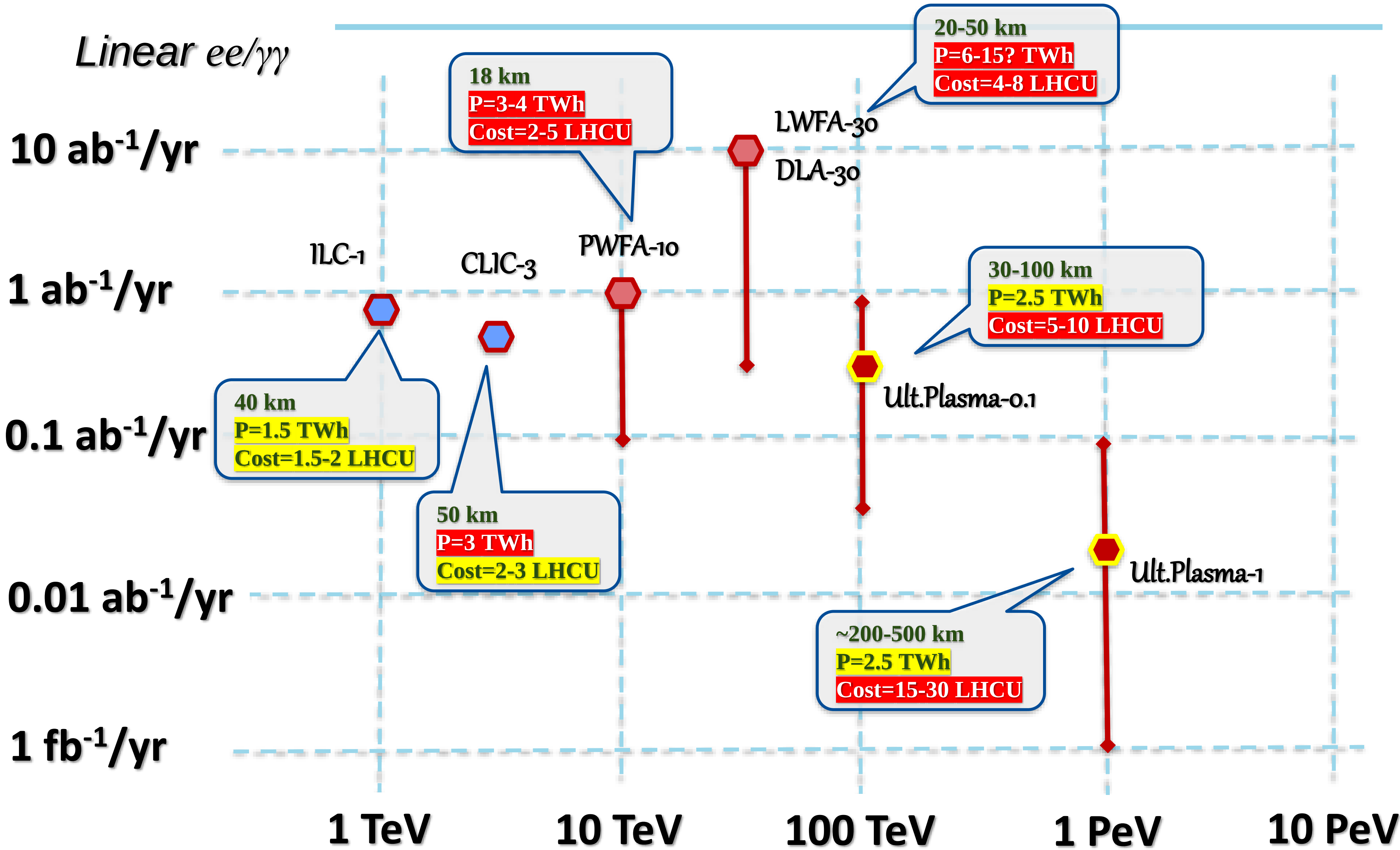
pp Colliders: *Lumi* and *Cost* vs *Energy*



MC: *Lumi* and *Cost* vs *Energy*

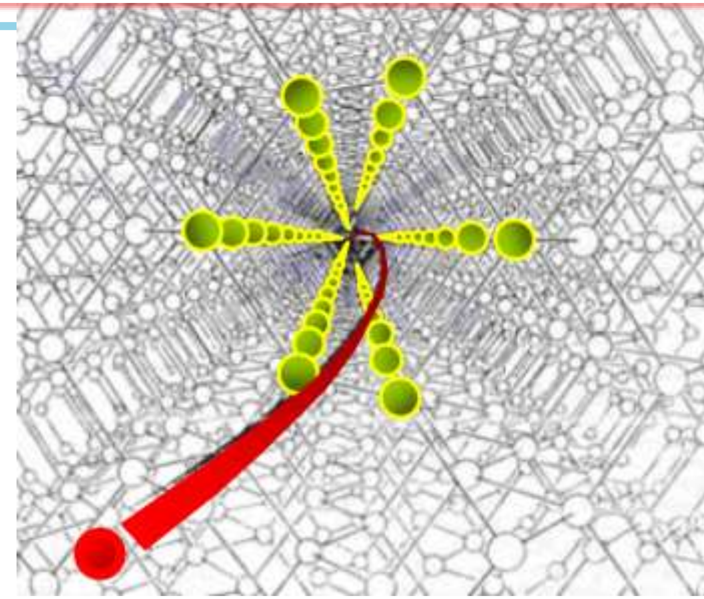


Linear RF and Plasma: *Lumi* and *Cost* vs *Energy*



Exotic Colliders

$$E\,[\mathrm{GV/m}] \approx 100\sqrt{n_0\,[10^{18}\,\mathrm{cm}^{-3}]}$$



- Acceleration in structured media, eg CNTs or crystals (***only muons!!!***)
- Major advantages:
  - solid density → 1-10 TV/m gradients
  - continuous focusing and acceleration (no cells, one long channel, particles get strongly cooled *betatron radiation*)
  - small size promises low cost
- Major limitations:
  - “blue sky”, *O*(10) papers, plans for proof-of-principle experiment *E336* @FACET-II (S.Corde, T.Tajima, et al)
  - how to drive Xtals? lasers, beams?
  - Cost is unknown, power is unknown, luminosity - (how low?)

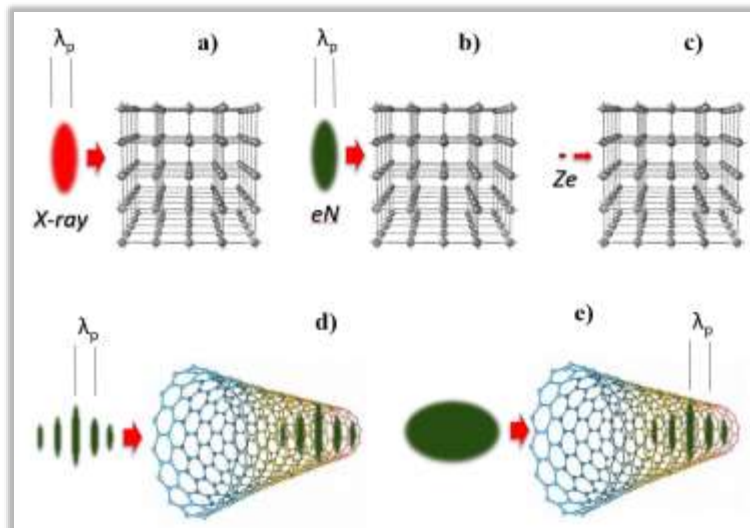


Fig. 2. Possible ways to excite plasma wakefields in crystals or/and nanostructures: (a) by short X-ray laser pulses; (b) by short high density bunches of charged particles; (c) by heavy high-Z ions; (d) by modulated high current beams; (d) by longer bunches experiencing self modulation instability in the media.

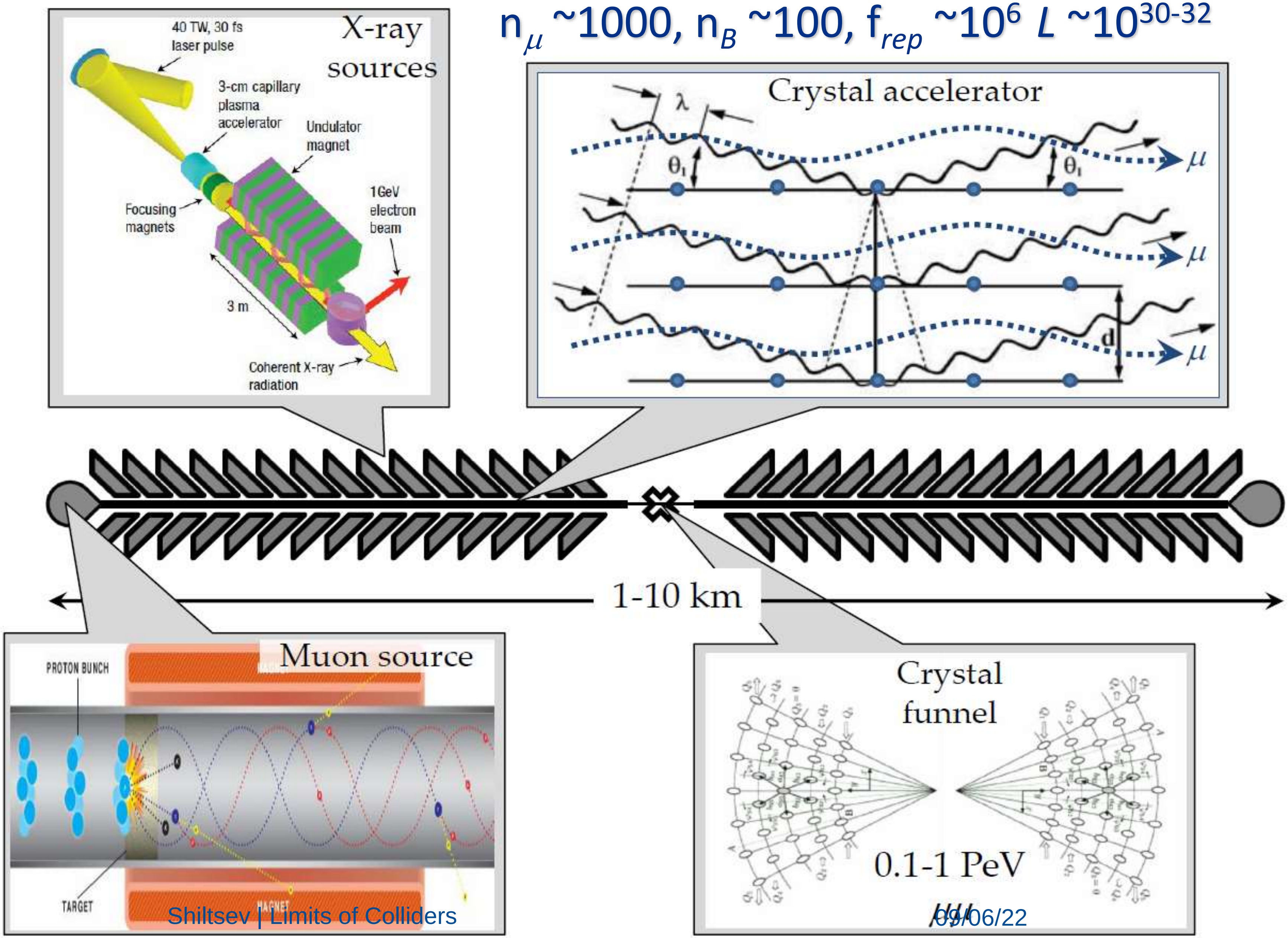
Acceleration in Xtals book (T.Tajima, et al 2020)

Xtal Collider

n~10^{22} cm^{-3}, **10 TeV/m** → 1 PeV = 1000 TeV

n_{μ} ~1000, n_B ~100, f_{rep} ~10^6 *L* ~$10^{30\text{-}32}$

V.Shiltsev, Phys. Uspekhy 55 965 (2012)



XtalC Luminosity

$$L = f N^2 / A$$

- Considerations :
  - Angstrom size at IP
  - Muons/bunch < Xtal electrons excited
  - Employ many channels
  - Limit beam power O(10MW)
  - Combine *n_channels* to gain ***L*** via ***crystal funnel*** (? Is it possible)

$A \sim 1$ Å$^2 = 10^{-16}$cm^{-2}

$$100\lambda_p \times \lambda_p^2$$

$$N_0 \sim 10^3$$

$$n_{ch} \sim 100$$

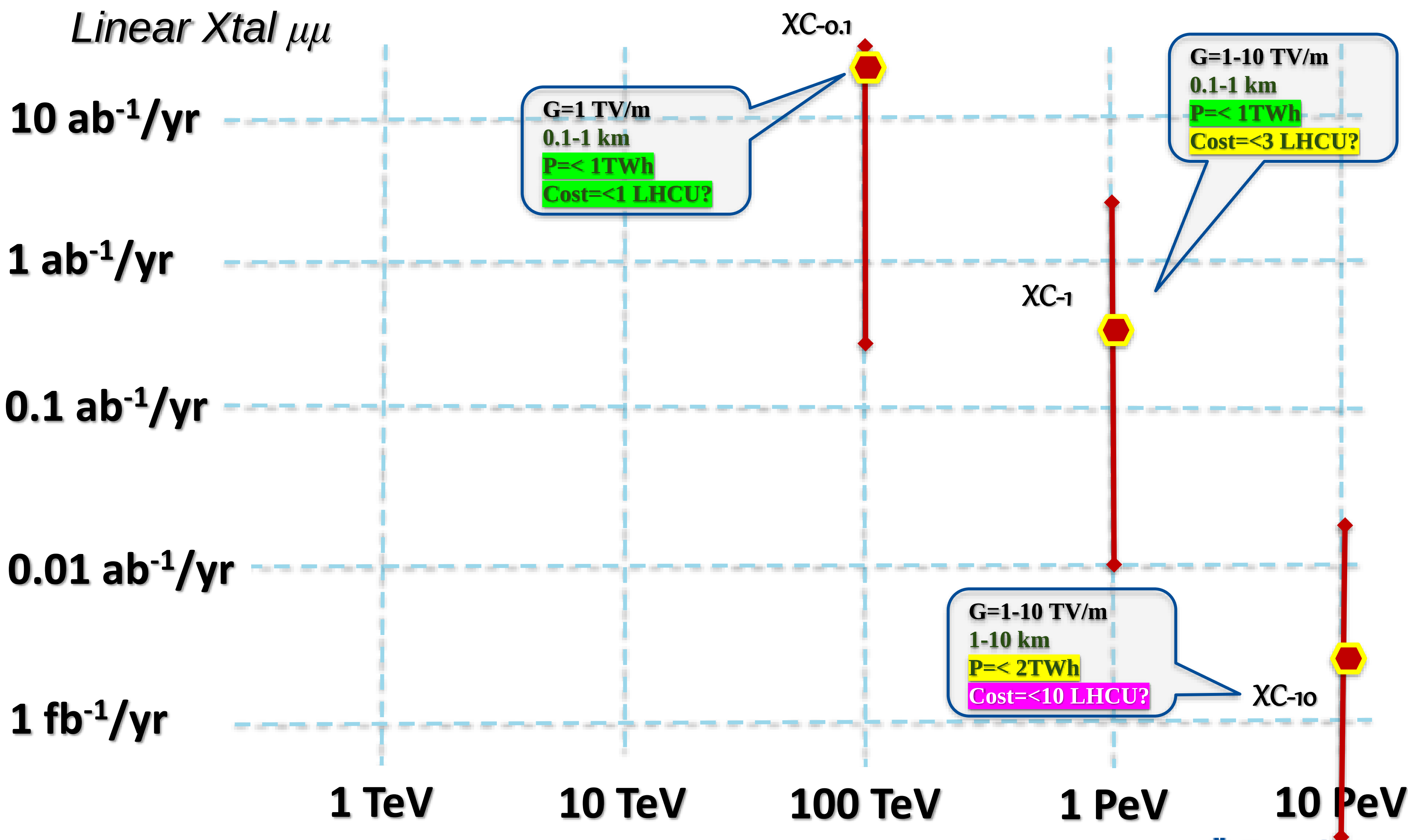
gain a factor of n_{ch}

$$P = f n_{ch} N E$$

$$f = 10^6 \text{ Hz}$$

$$L\,[\text{sm}^{-2}\,\text{s}^{-1}] \approx 4 \times 10^{33\text{–}35} \frac{P^2\,[\text{MW}]}{E^2\,[\text{TeV}]\; f n_{ch}\,[10^8\ \text{Hz}]}$$

Xtal Colliders: *Lumi* and *Cost* vs *Energy*



Main Conclusions:

- **For ultimate high energy colliders:**
  - **Major thrust is *Energy***
  - **Major concern/limit *is Cost***
  - **Main focus is *Luminosity* and *Power***
  - ***There are other important factors (CO_2 footprint, etc)***
- **Cost:**
  - **Critically dependent on core acceleration technology**
  - **Existing injectors and infrastructure greatly help**
- **High *E*nergy means low *L*uminosity :**
  - **Don't expect more than 0.1-1 ab^{-1}/yr at 30TeV - 1 PeV**
  - **Assume *P*ower limited to 1-3 TWh/yr (1-3 x LHC)**

Main Conclusions (2):

- **For considered collider types:**
  - **Circular *pp* – limit is ~100 TeV (14 TeV cme per parton)**
  - **Circular *ee* – limit is ~0.4-0.5 TeV**
  - **Circular $\mu\mu$ – limit is between 30 and 100 TeV**
  - **Linear RF *ee*/$\gamma\gamma$ – limit is between 3 and 10 TeV**

    Plasma *ee*/$\gamma\gamma$
  - **Exotic crystal $\mu\mu$ – promise of 0.1-1 PeV, low *L*uminosity**
- **Muons are particles of the future**

Helpful/cited references (next slide)

(Some Useful) References:

1. ITF Report – T.Roser, et al, arXiv:2208.06030
2. RMP Colliders – V.Shiltsev, F.Zimmermann, *Rev.Mod.Phys.* 93, 015006 (2021); see also arxiv
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5. Nature Physics MC – K.Long, et al, *Nature Physics* (2021), see also arxiv
6. Eloisatron – W.Barletta, in *AIP Conference Proceedings*, vol. 351, no. 1, pp. 56-67(1996).
7. Xtal collider – V.Shiltsev, *Physics Uspekhi*, v.55 (10), p.1033 (2012).
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9. T.Raubenheimer - Phys. Rev. ST Accel. Beams 3, 121002 (2000).
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12. *CPT*-theorem – V.Shiltsev, *Mod. Phys. Lett. A*, vol. 26, No. 11 (2011) pp. 761-772.

Thanks for your attention!

- Special thanks to
  - *My AF co-conveners S.Gourlay and T.Raubenheimer, and AF3 conveners - Angeles, Qing Qin, Frank Z and Georg H.*
  - *Marica and Organizers of the eeFACT'22 Workshop*
- … as final note, tons of material (all reports, etc) available at:

https://snowmass21.org/accelerator/start

Back up slides