Muon Colliders vs other technologies based Colliders

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Disclaimer

Comparison between High Energy Leptons & Protons Colliders

- Muon Colliders (MAP, LEMMA, MC in LHC tunnel, (in FCC tunnel?)
- E^+/E^- Circular colliders (FCC ee)
- E^+/E^- Linear colliders (ILC, CLIC, PWFA, LPA, DLA)
- Protons Colliders (LHC, FCC hh)

Over a wide energy range

- From 125 GeV to Multi-TeV at the level of the elementary constituents

Of major performances, especially:

- Physics potential: Luminosity
  - Including whole particle energy spectrum
  - limited to particles within 1% momentum spread
  - Total = ∑ from all detectors
- Practical technicalities:
  - Cost & Power

Through Figures of Merit (FoM) for fair and objective comparison

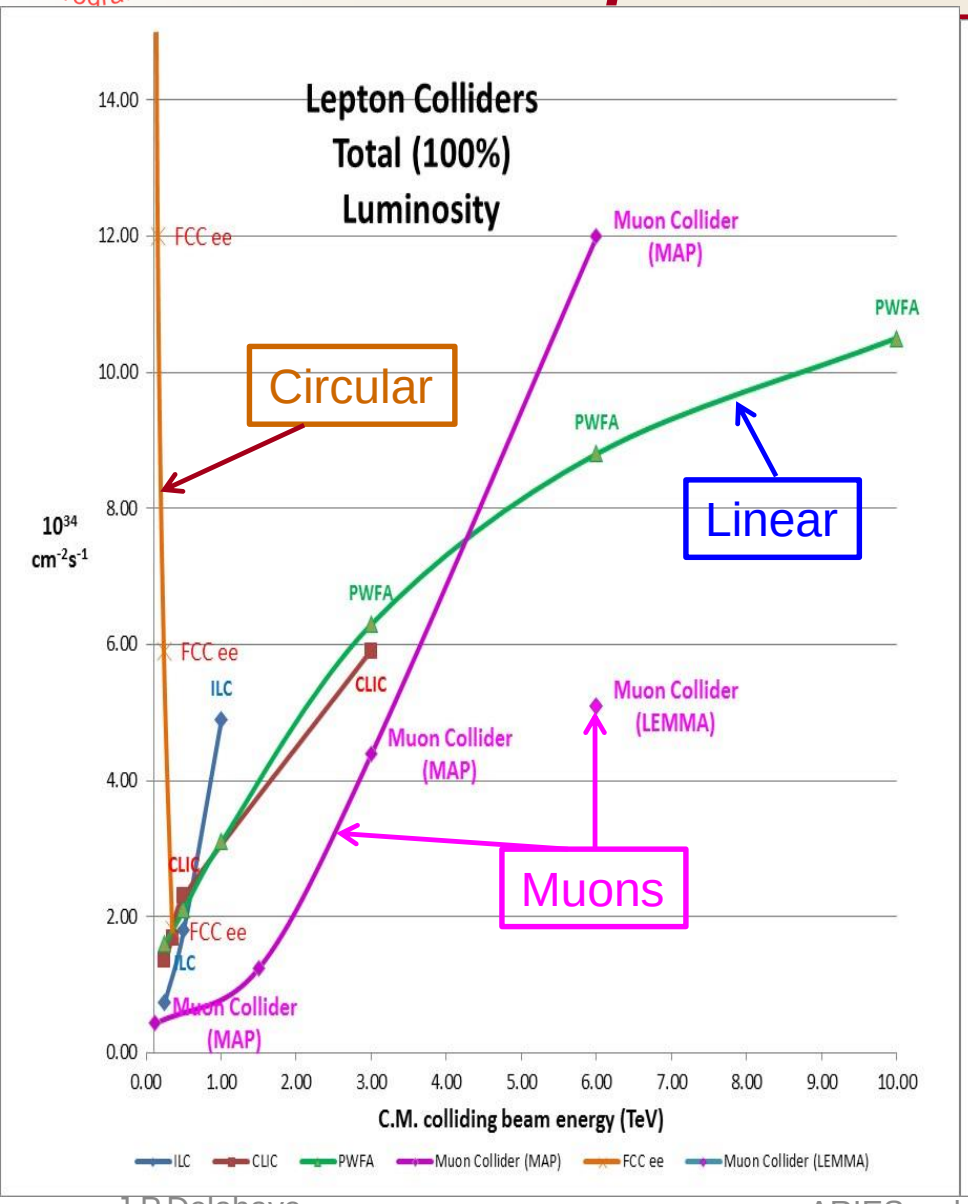
- Based on official data when available, collected in 2015, thus possibly out of date
- Some power estimations slightly corrected for common assumptions
- When no available data (Cost), estimation using a common model even if not accurate

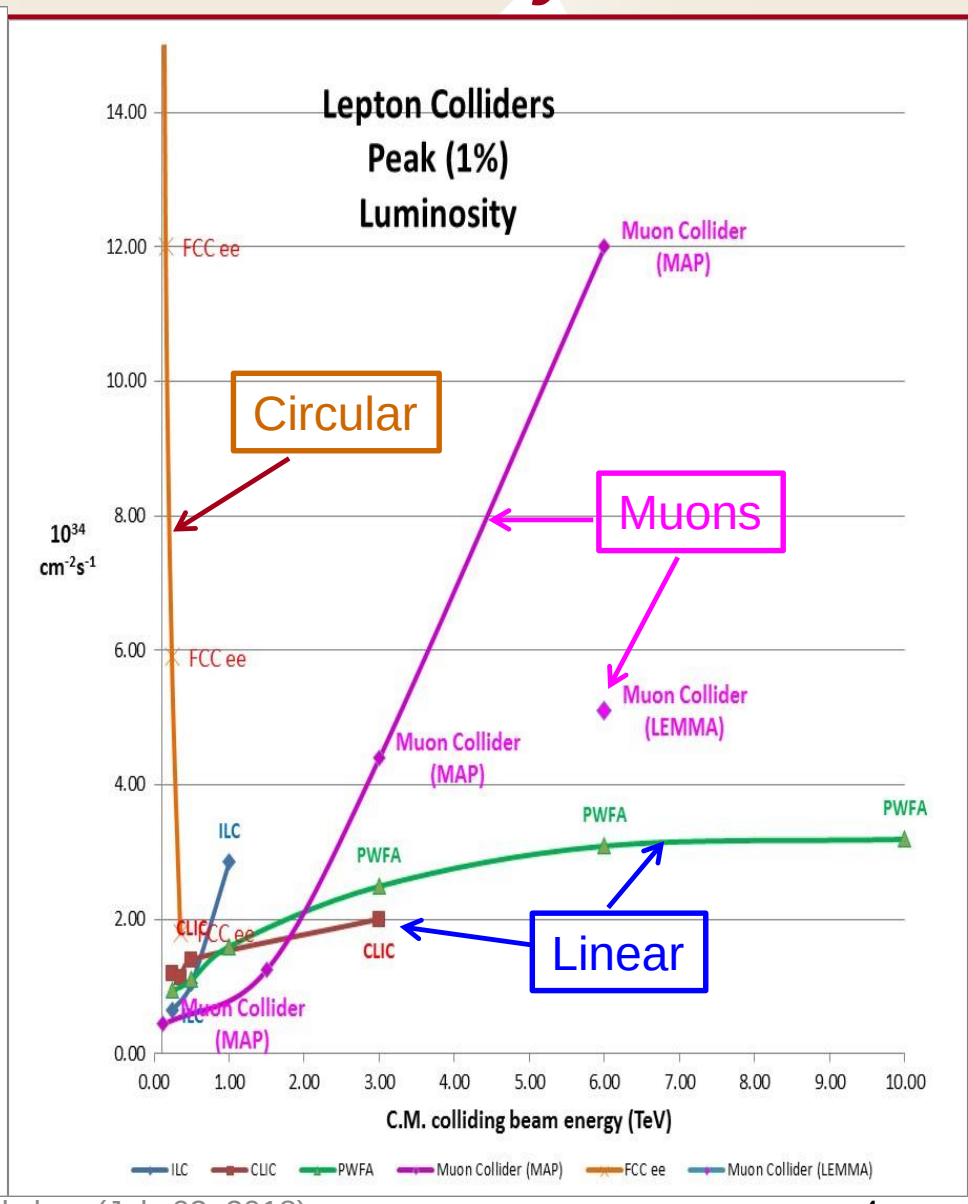
Welcome to point out necessary corrections or updates

Data (updated August 2015)

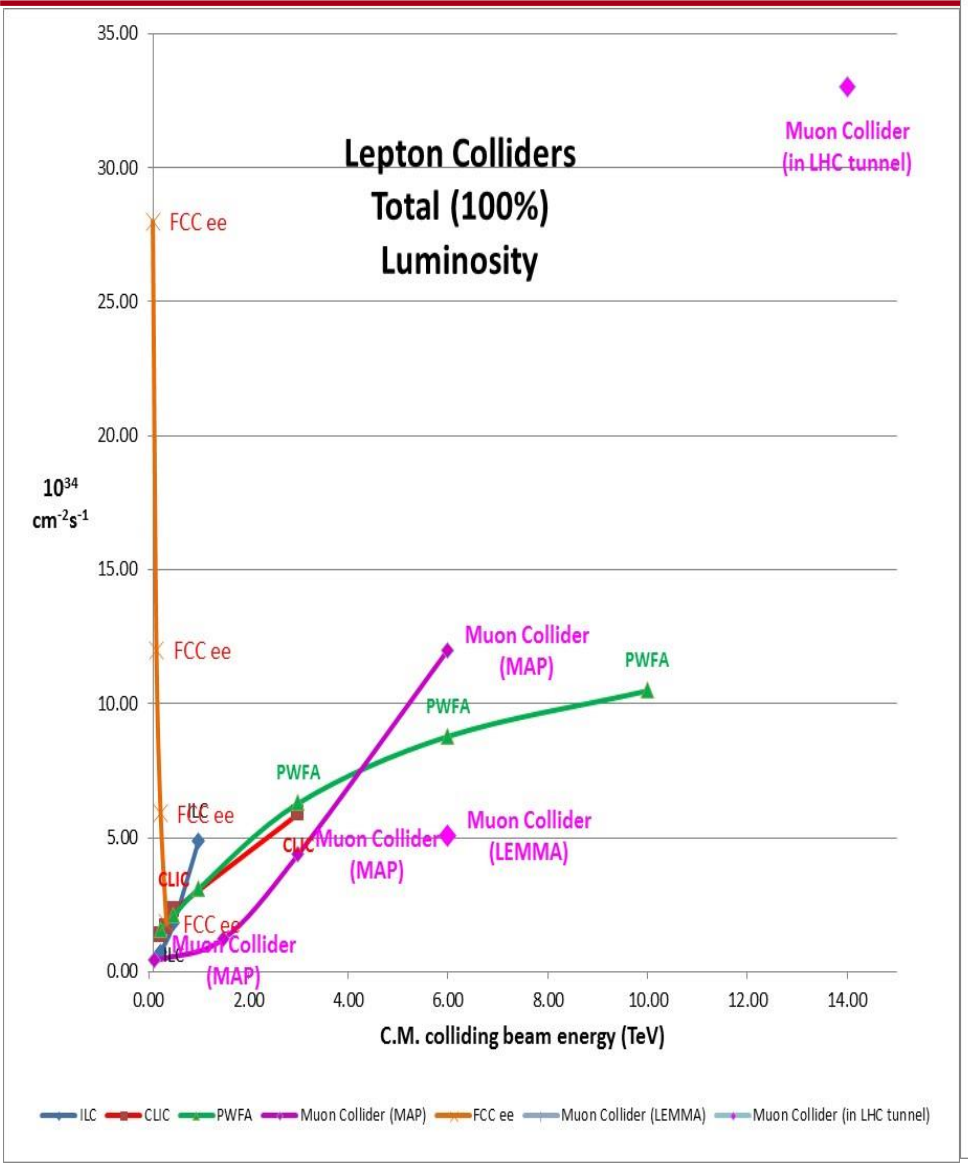
	Facility	Ecm		HIGGS/5y	Ltot	L0.01	Nb IP	Power	size	Cost	
		TeV			10^34	10^34	#	MW	km	Official	Shiltsev
										B$	
Linear Colliders	ILC	0.25		115000	0.75	0.65	1	128	21.0	5.07	1.02E+01
		0.50			1.80	1.05	1	162	31.0	7.80	1.31E+01
		1.00			4.90	2.86	1	301	48.0	12.09	1.79E+01
	CLIC	0.25		170000	1.37	1.19	1	235	13.2	6.13	1.04E+01
		0.35			1.69	1.13	1	250	11.4		1.12E+01
		0.50			2.30	1.40	1	272	13.2	7.81	1.27E+01
		3.00			5.90	2.00	1	589	48.3		2.66E+01
	PWFA beam driven	0.25		150000	1.60	0.94	1	133	2.3		8.25E+00
		0.50			2.10	1.10	1	150	3.0		1.06E+01
		1.00			3.10	1.60	1	186	4.5		1.41E+01
		3.00			6.30	2.50	1	301	8.0		2.26E+01
		6.00			8.80	3.10	1	398	13.0		3.08E+01
		10.00			10.50	3.20	1	478	18.5		3.87E+01
	Laser driven Plasma (LPA)	0.25		1.00	0.64	0.64	1	113	2.3		8.08E+00
		3.00		1.00	6.40	6.40	1	344	5.6		2.25E+01
		10.00			10.00				15.0		
	Dielectrics (DLA)	0.25		185000	1.30	1.30	1	146	3.1		8.53E+00
		3.00			5.40	5.40	1	449	15.6		2.41E+01
Circular Colliders	FCC ee	0.09			28.00	28.00	4				
		0.16			12.00	12.00	4				
		0.24	0.00	1458000	5.90	5.90	4	320	81.0	10.00	1.42E+01
		0.35	0.00		1.80	1.80	4	350	81.0	10.50	1.53E+01
Muon Collider	HIGGS Factory	0.13	Rubbia	220000	1.43	1.43	1	200	1.5	3.75	7.21E+00
	MAP	0.13	MAP	67500	0.44	0.44	1	200	1.5	3.75	7.14E+00
		1.50	MAP		1.25	1.25	2	216	2.5		1.62E+01
		3.00	MAP		4.40	4.40	2	230	4.0		2.16E+01
		6.00	MAP		12.00	12.00	2	270	6.0		2.93E+01
	LEMMA	6.00	LEMMA 6kme+acc		5.10	5.10	2.00	490.00	6.00		3.05E+01
		6.00	LEMMA27kme+acc		5.10	5.10	2.00	399.00	6.00		3.00E+01
	LHC tunnel	14.00	LHC 2 det	135000	33.00	33.00	2	333	26.7		1.07E+01
		14.00	LHC 4 det		33.00	33.00	4	377	26.7		1.07E+01
	FCC upgrade	100.00	FCC μμ		10.00	10.00	4		100.00		
Proton Collider	LHC	2.00			2.00	2.00	2	200	26.7		2.02E+01
	LHC-HL	2.00			5.00	5.00	2	200	26.7		2.02E+01
	FCC-hh	14.29			10.00	10.00	2	400	100.0		4.81E+01

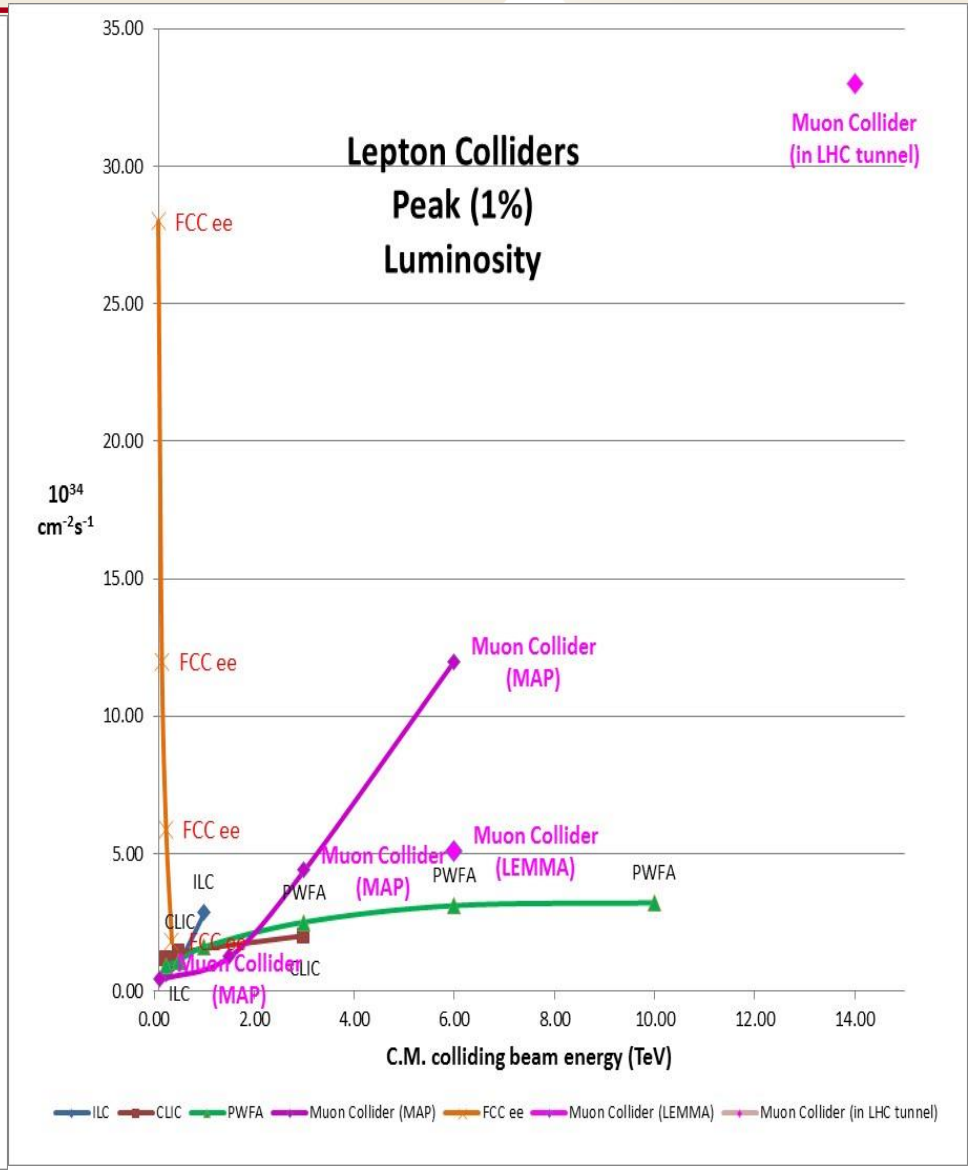
Lepton Colliders Luminosity



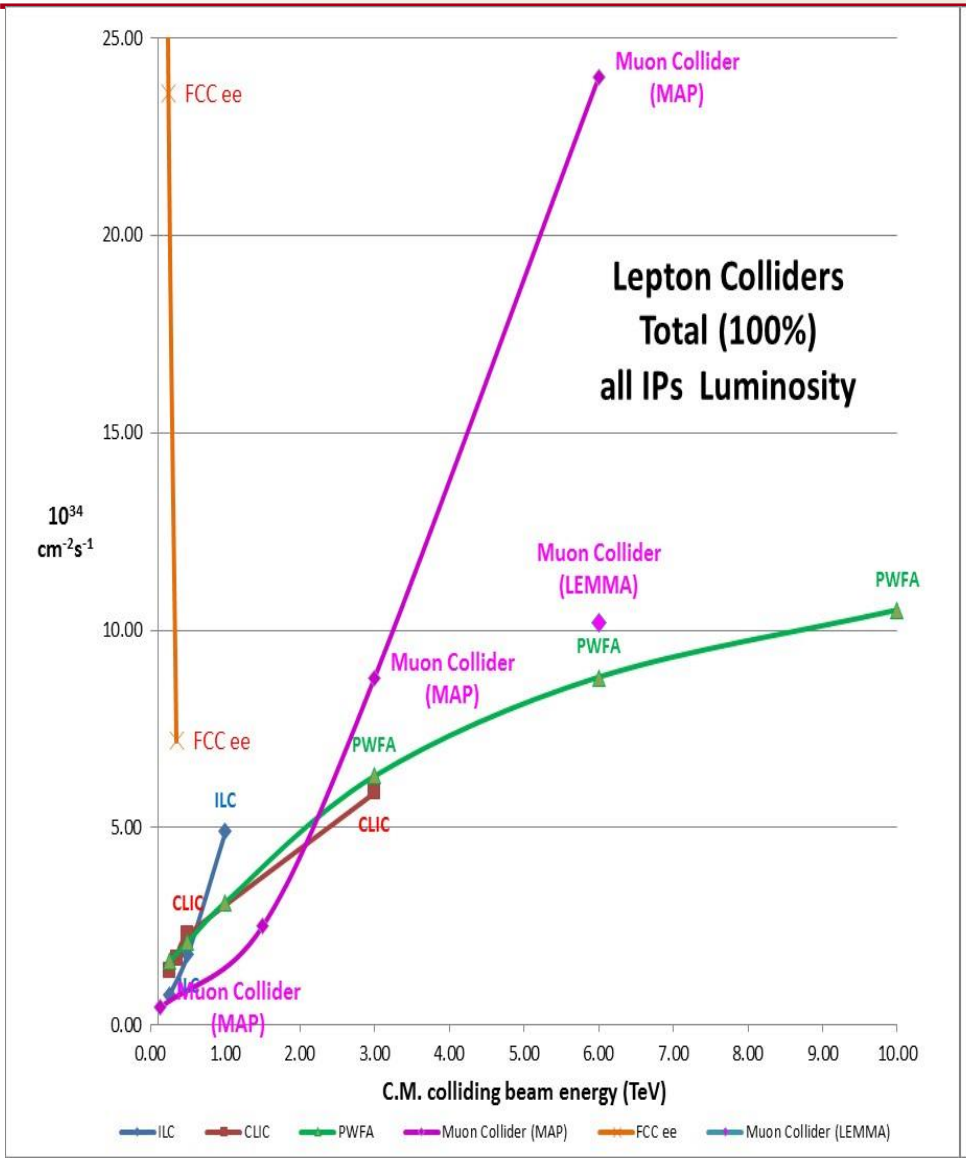


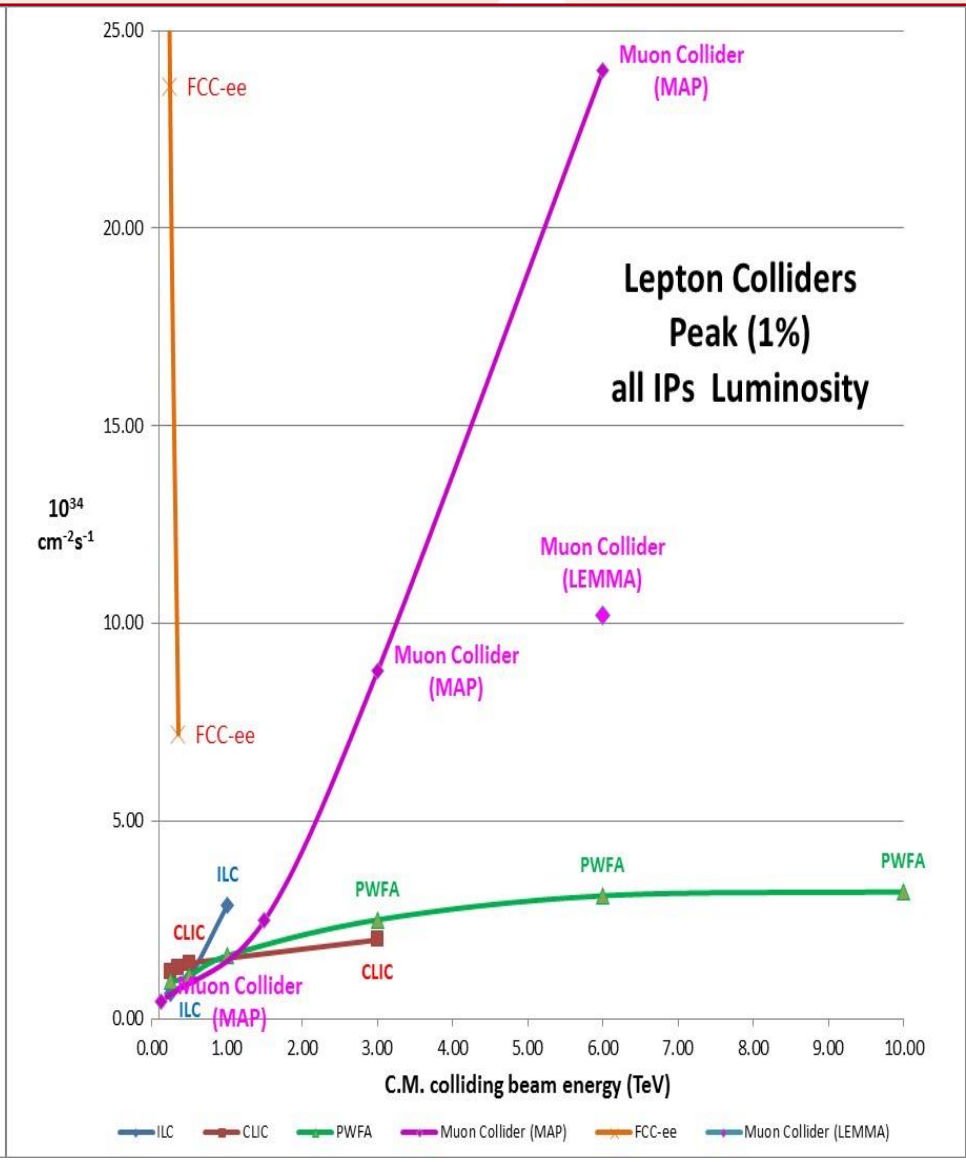
Lepton Colliders Luminosity



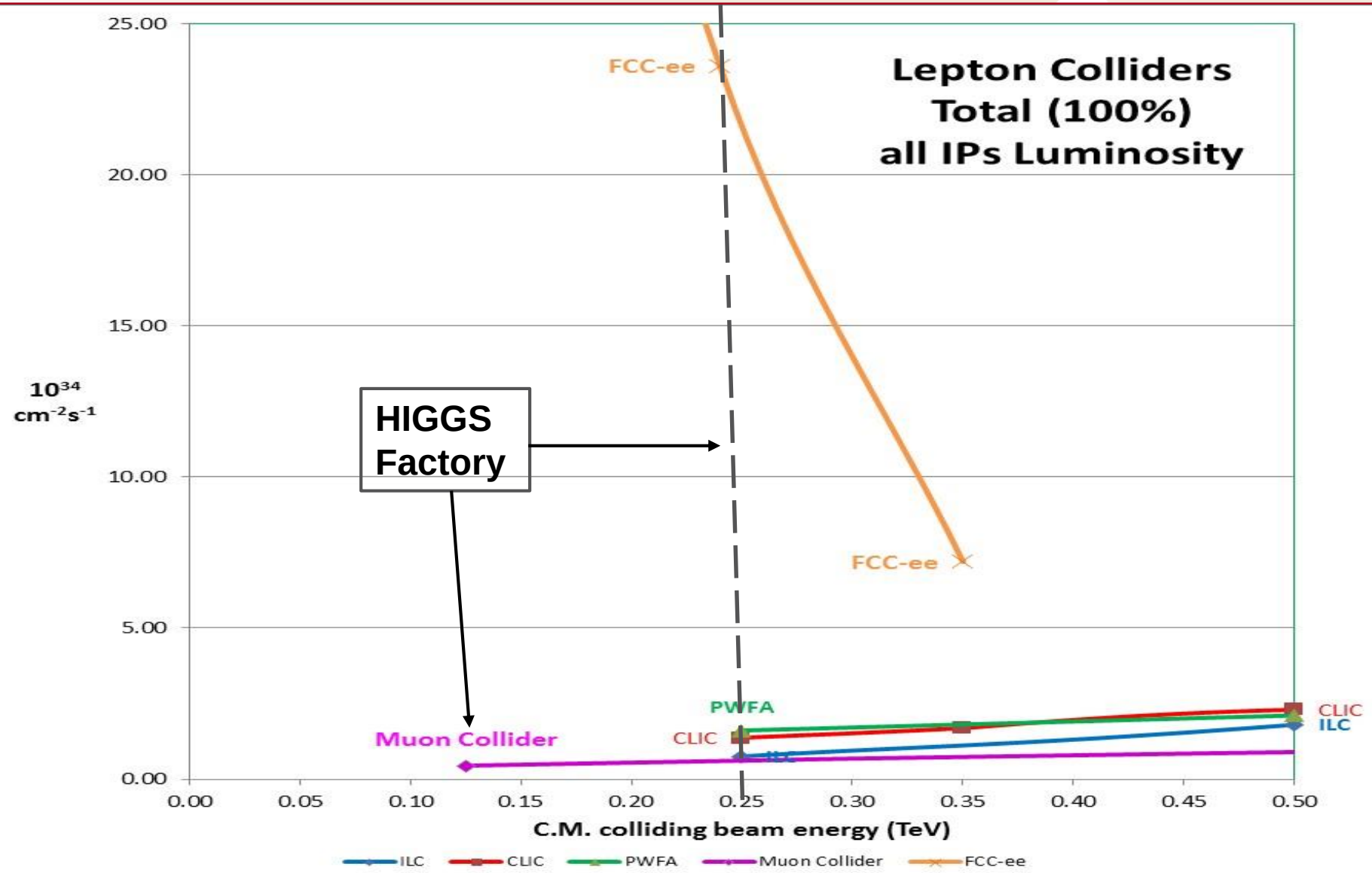


Lepton Colliders Σ IP Luminosity

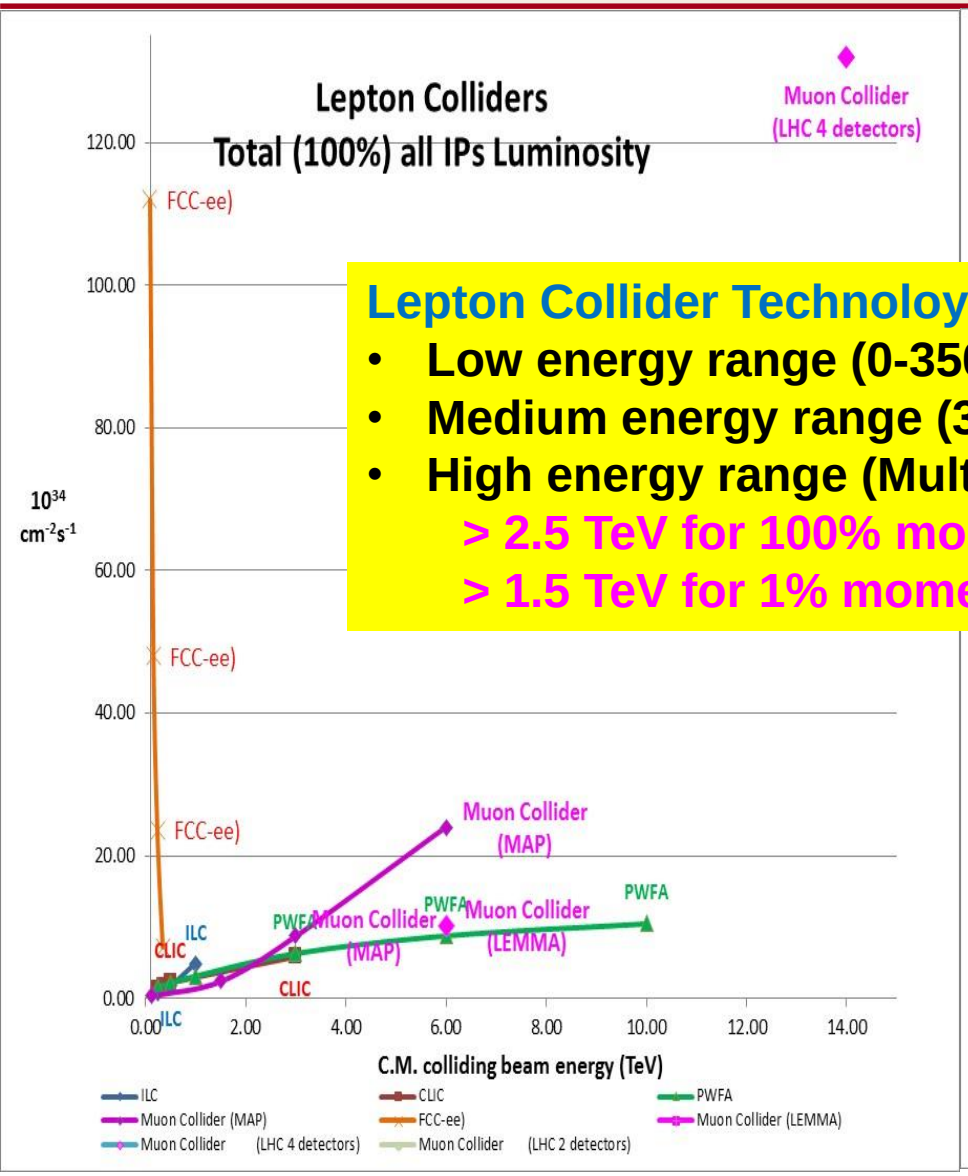


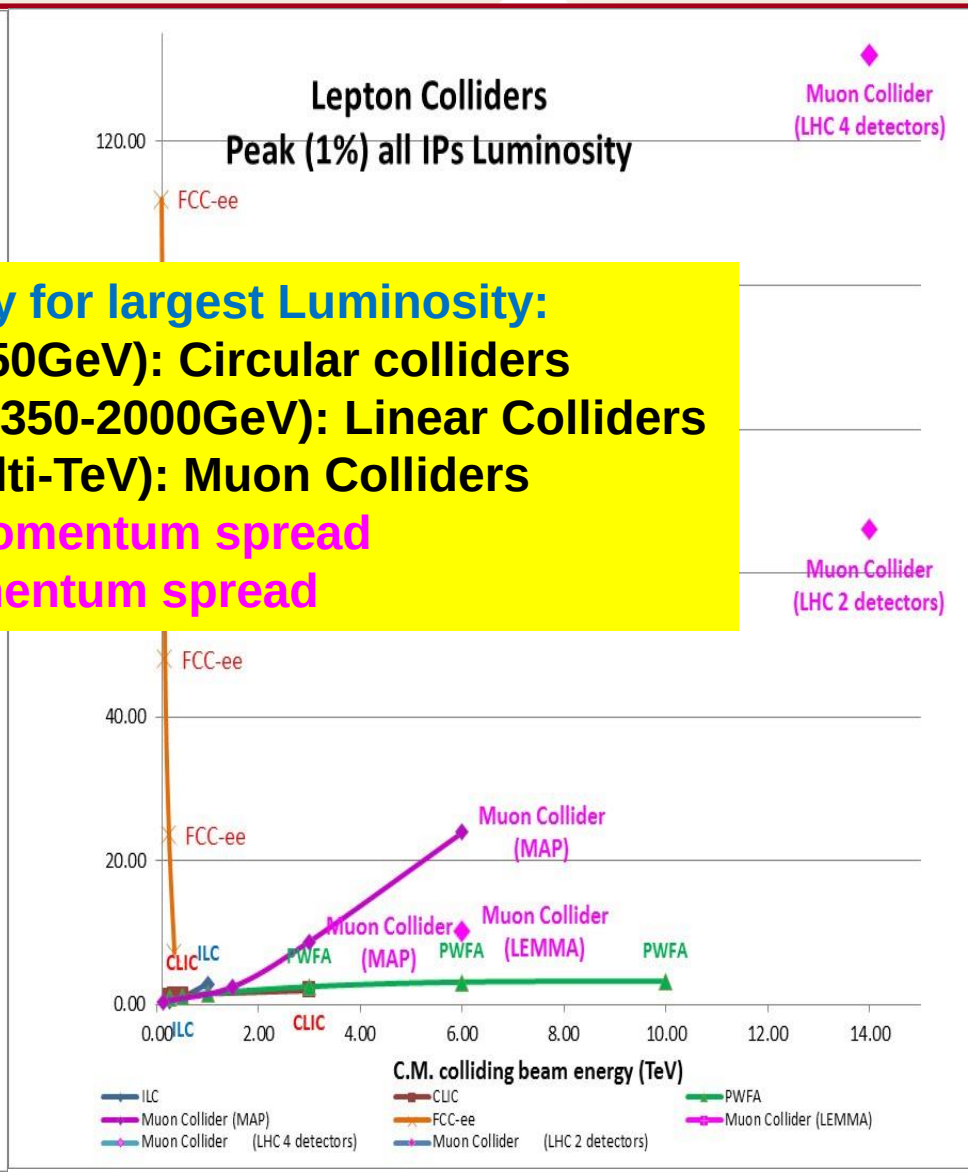


Lepton Colliders
Σ IP Luminosity in HIGGS energy range



Lepton Colliders All IP Luminosities

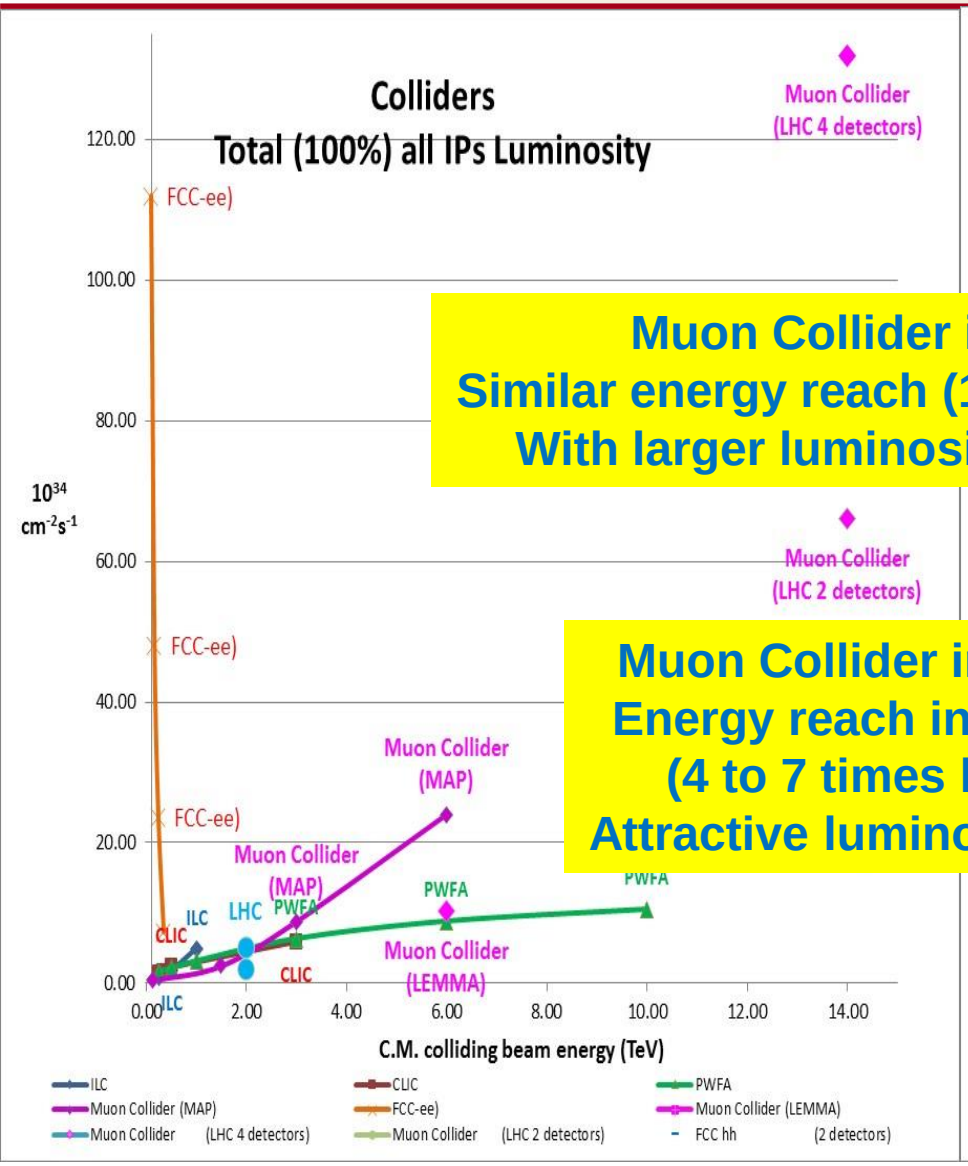


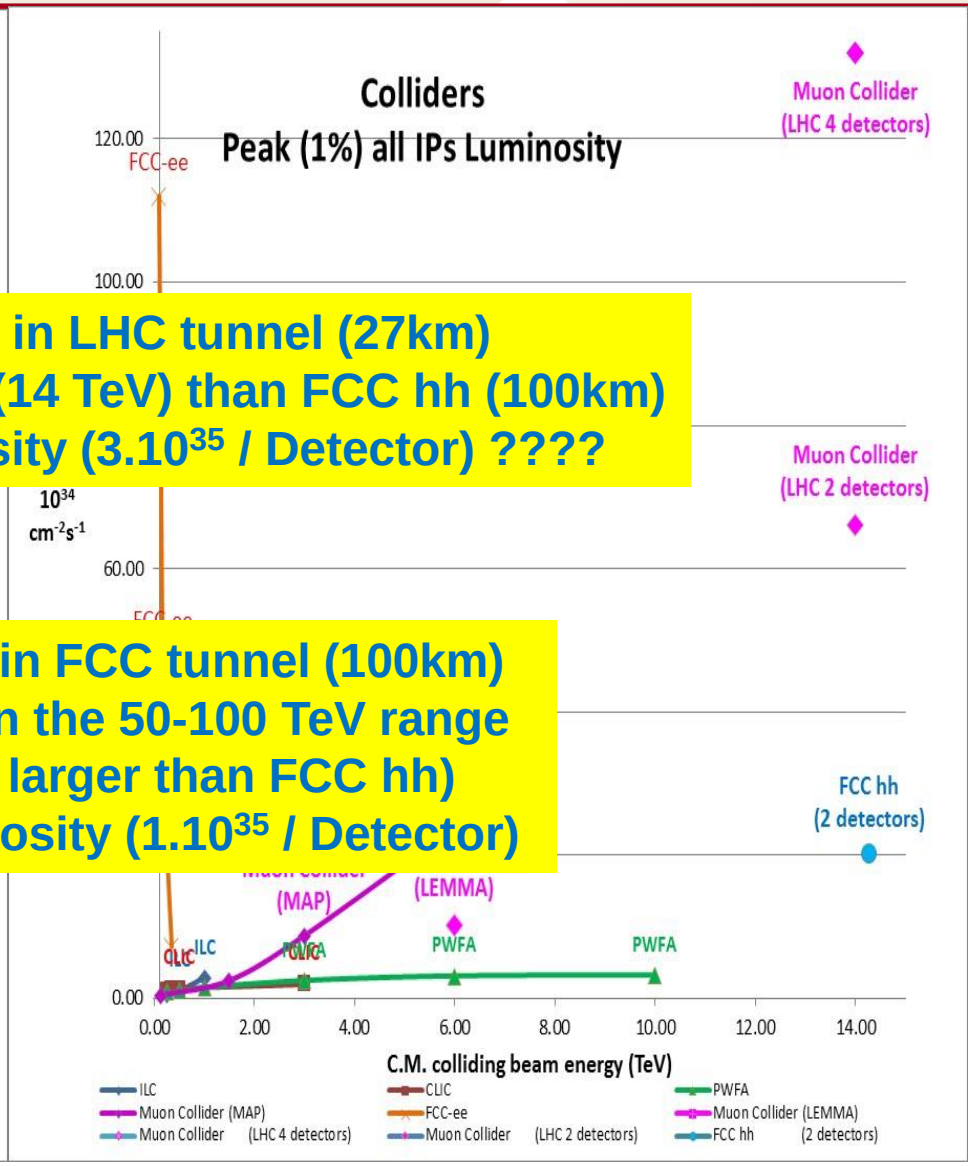


Lepton Collider Technoloy for largest Luminosity:

- **Low energy range (0-350GeV): Circular colliders**
- **Medium energy range (350-2000GeV): Linear Colliders**
- **High energy range (Multi-TeV): Muon Colliders**
  - **> 2.5 TeV for 100% momentum spread**
  - **> 1.5 TeV for 1% momentum spread**

Lepton & Hadron Colliders Luminosities (elementary constituent c.m.energy)





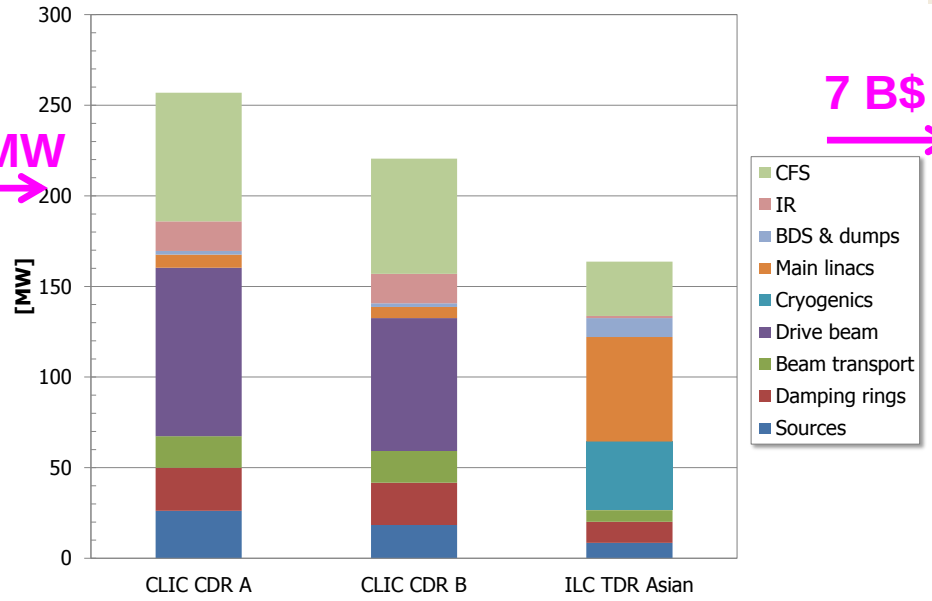
Muon Collider in LHC tunnel (27km)
Similar energy reach (14 TeV) than FCC hh (100km)
With larger luminosity (3.10^{35} / Detector) ????

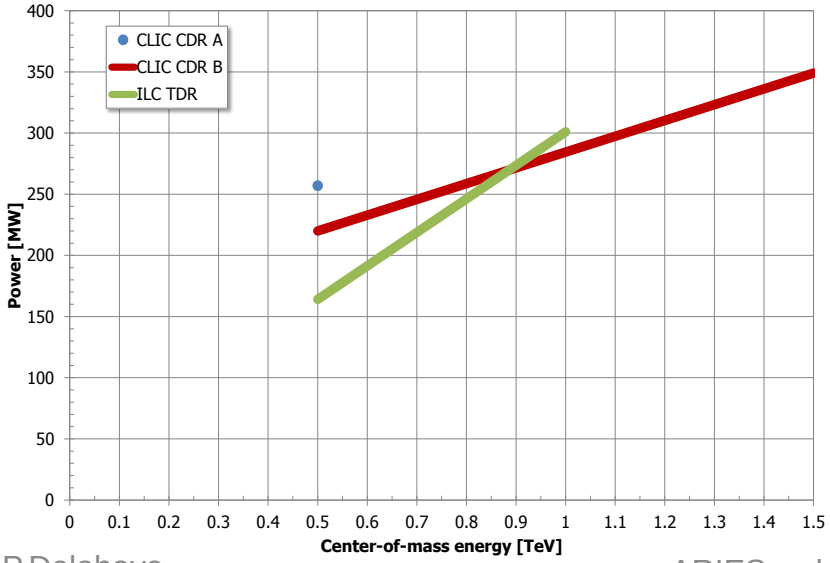
Muon Collider in FCC tunnel (100km)
Energy reach in the 50-100 TeV range
(4 to 7 times larger than FCC hh)
Attractive luminosity (1.10^{35} / Detector)

Future Facilities limited by Practicalities

Power

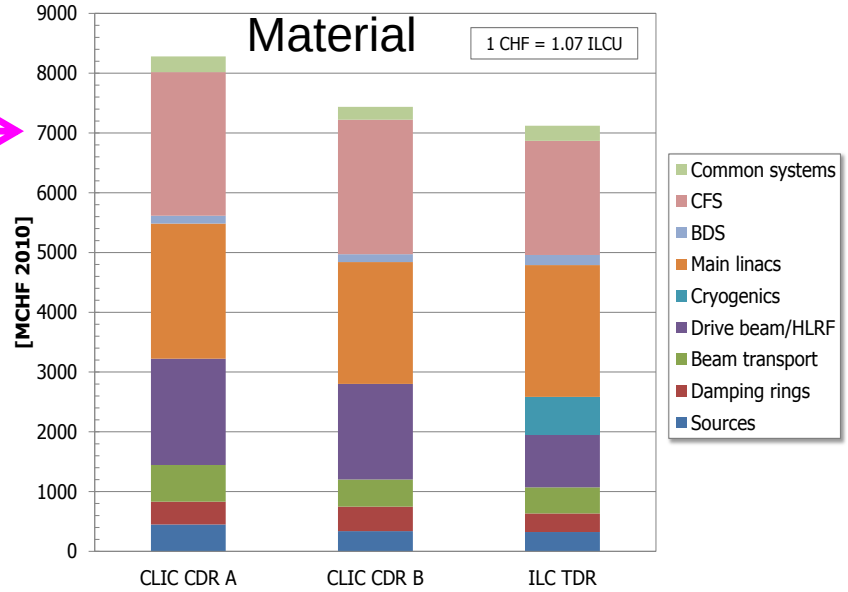
200MW

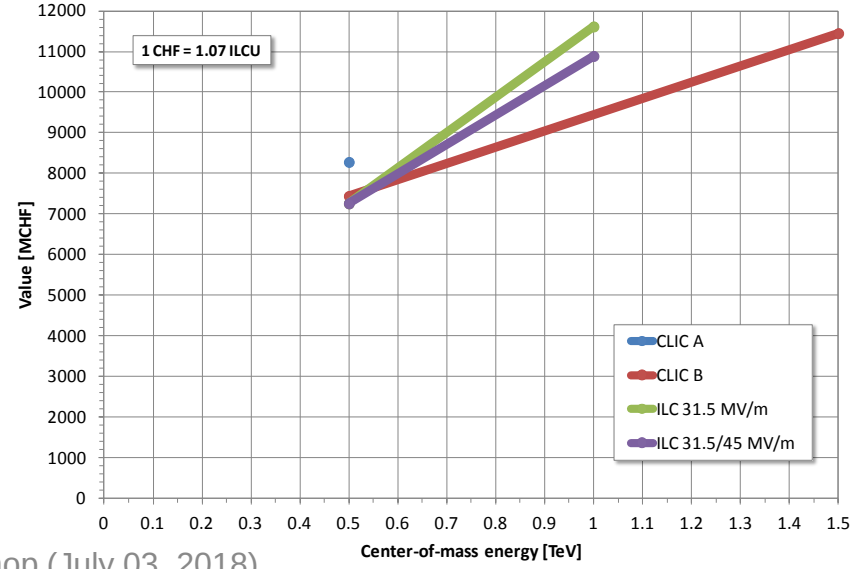




Cost

7 B$





Wall-plug power consumption

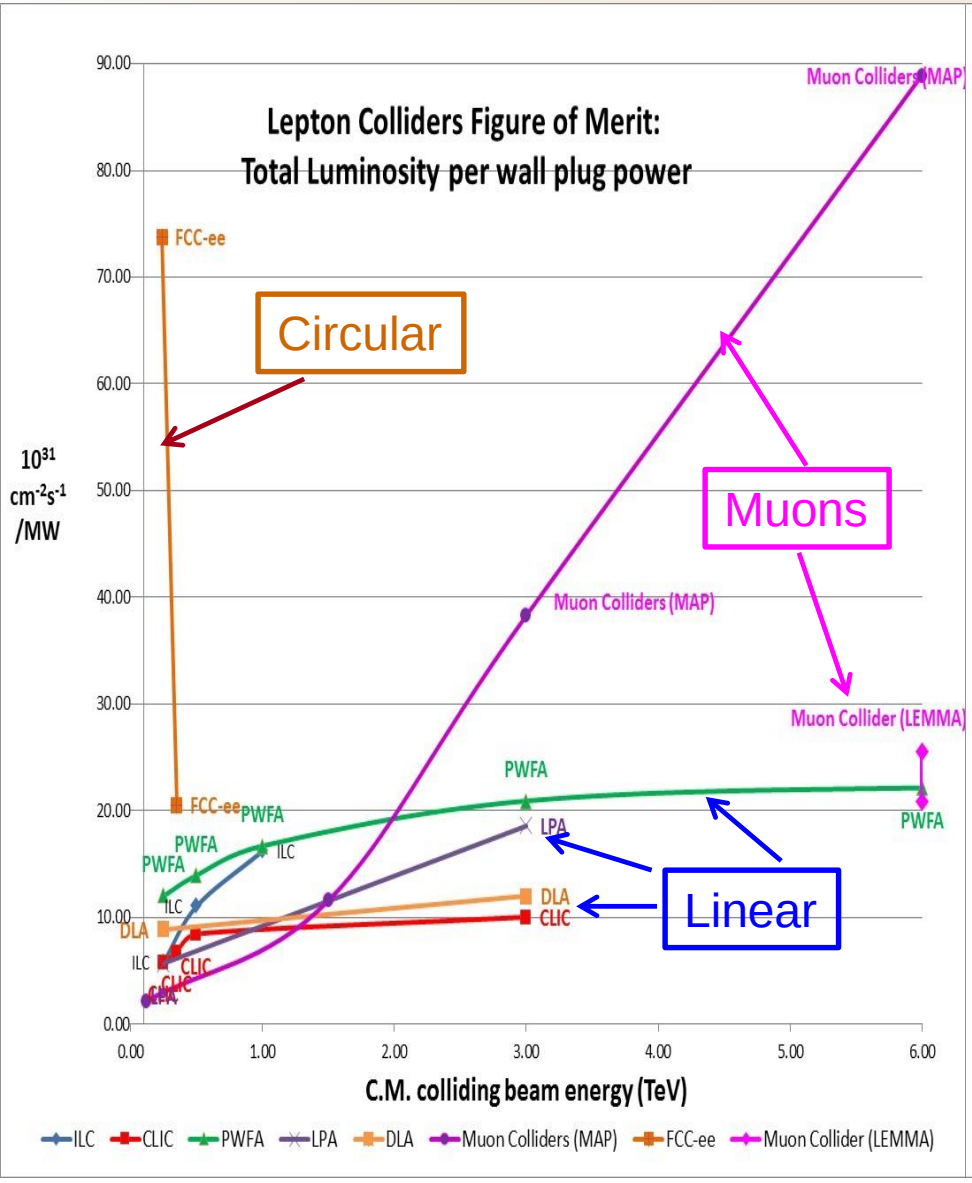
Wall-plug power consumption function of energy and luminosity

- **In linear collider:**
- **P ∝ L*E + offset (Injectors+ conventional facilities)**

Fair comparison through a Figure of merit (FoM):

FoM = Luminosity / Wall Plug consumption (L per MW)

Figure of merit: Luminosity per wall plug power



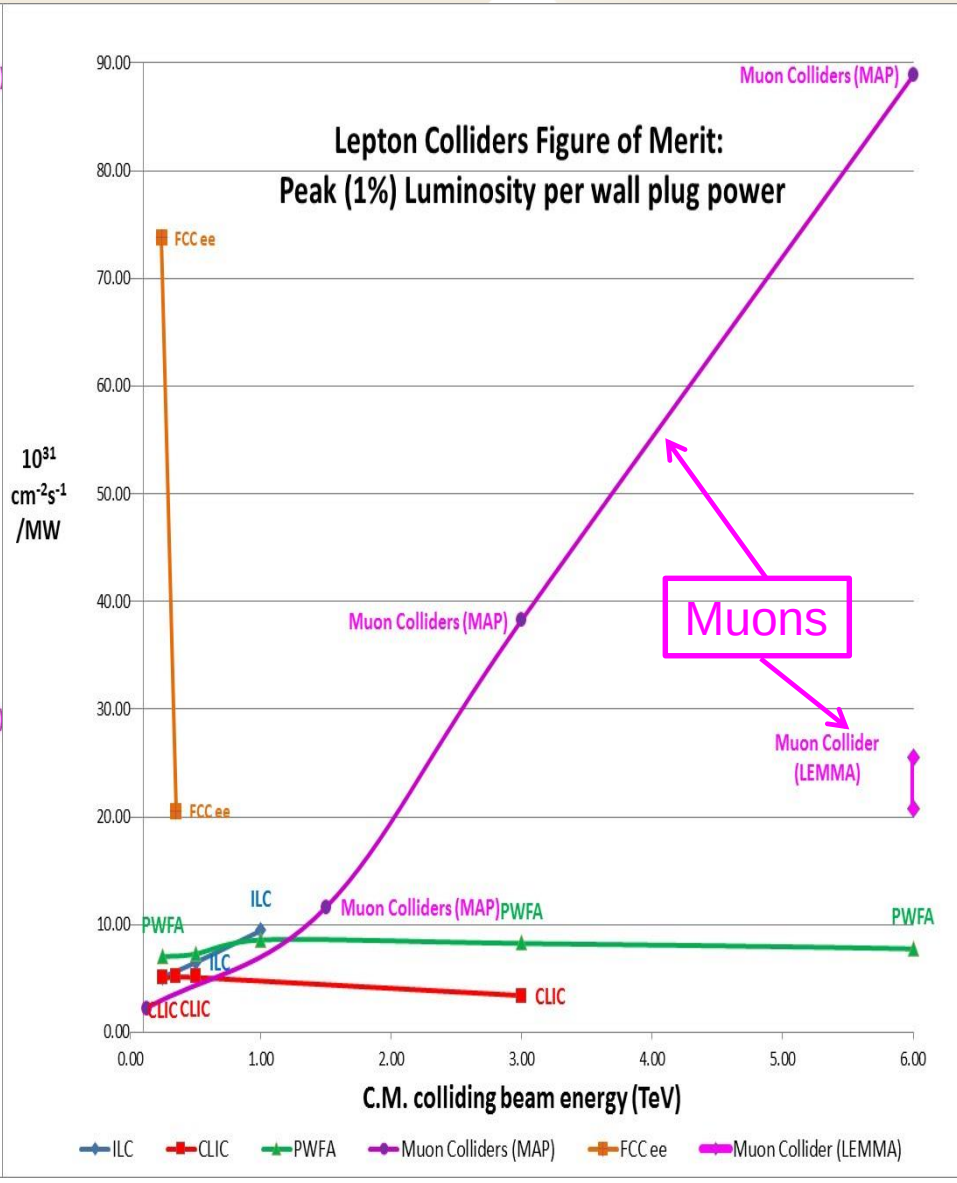
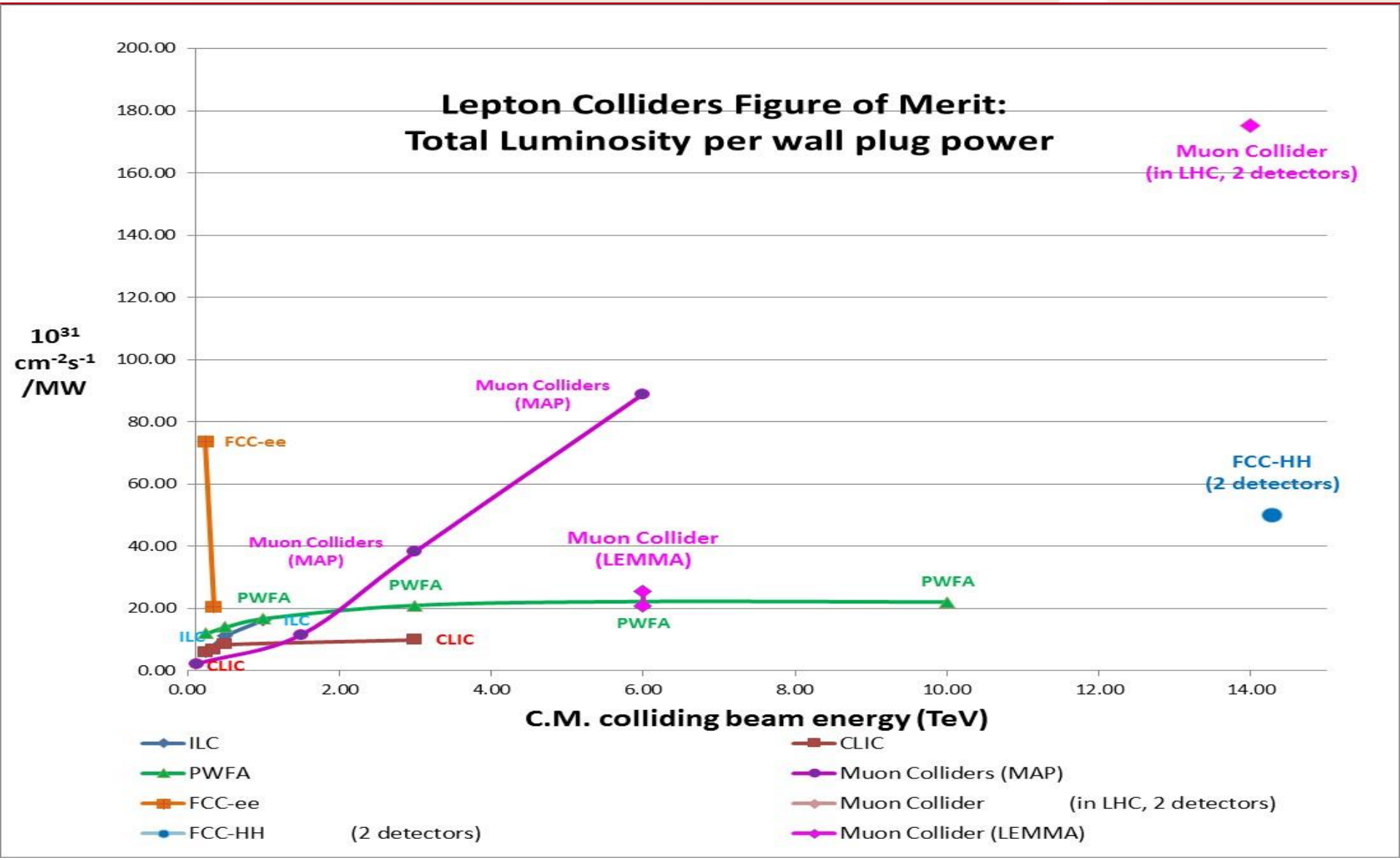


Figure of merit: Luminosity per wall plug power



Phenomenological Cost model (V.Shiltsev)

Conventional Technology

$$\text{Cost} = \alpha L^{1/2} + \beta E^{1/2} + \gamma P^{1/2}$$

"Total Project Cost "

"Tunnel Length" Civil Construction

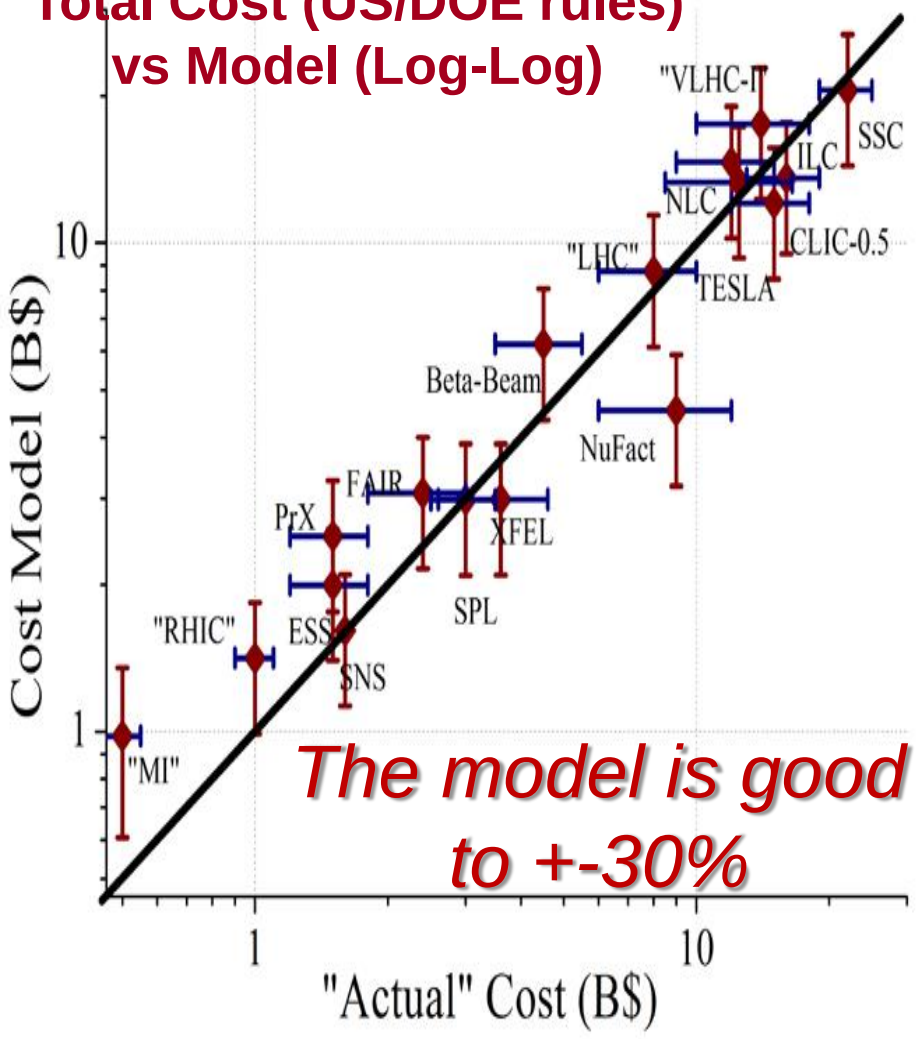
"Energy" – Cost of Accelerator Components

"Site Power" Infrastructure

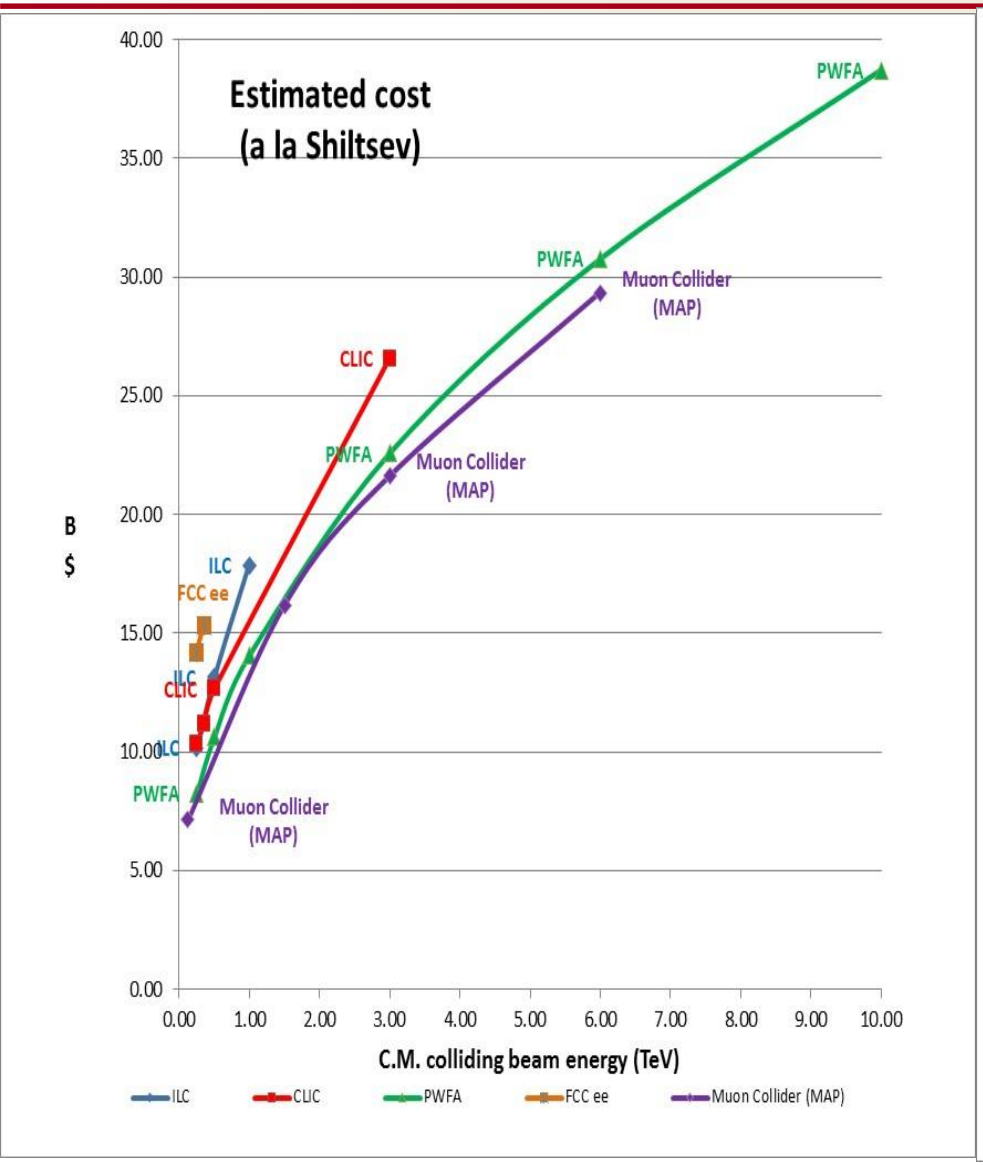
where α,β,γ – technology dependent constants

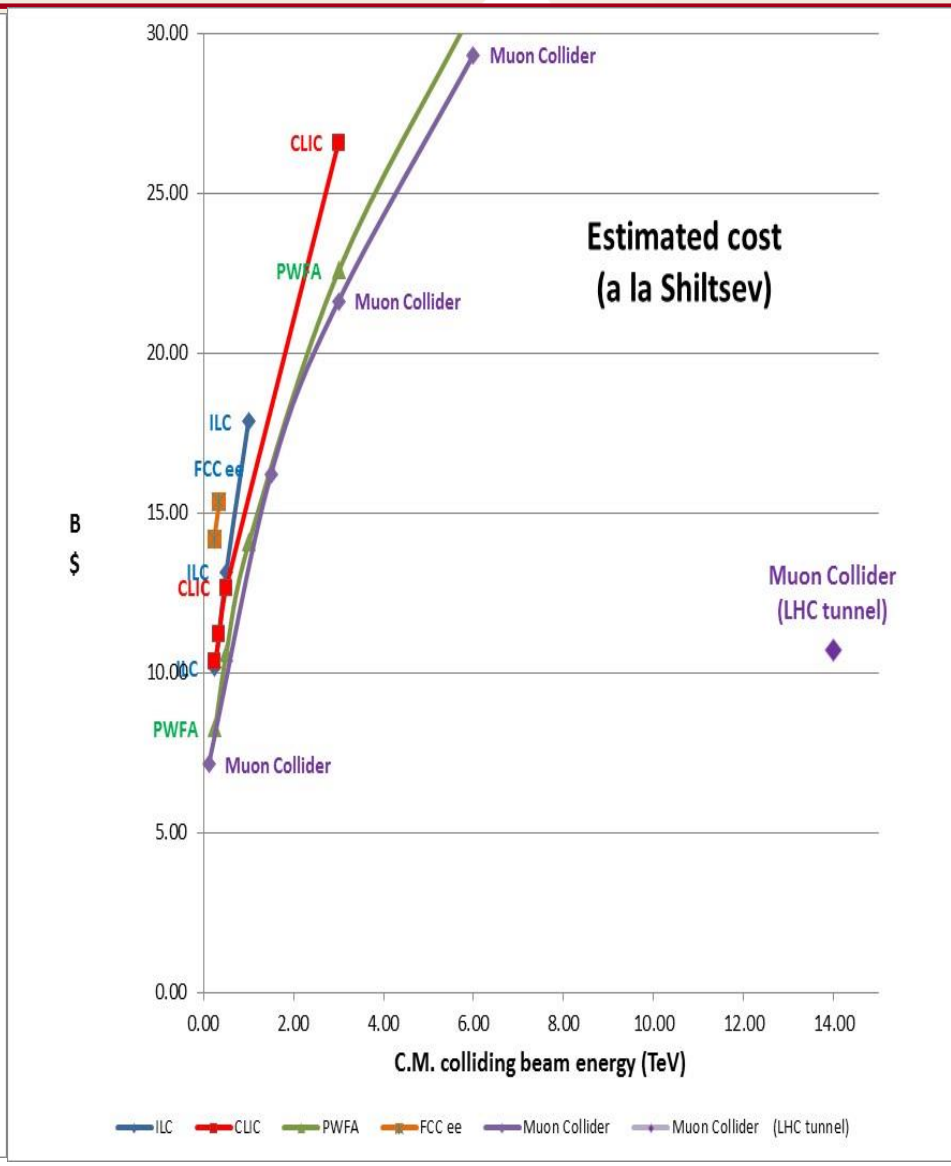
- α≈ 2B$/sqrt(L/10 km)
- β≈ 10B$/sqrt(E/TeV) for RF
- β≈ 2B$/sqrt(E/ TeV) for SC magnets
- β≈ 1B$ /sqrt(E/TeV) for NC magnets
- γ≈ 2B$/sqrt(P/100 MW)

Total Cost (US/DOE rules) vs Model (Log-Log)

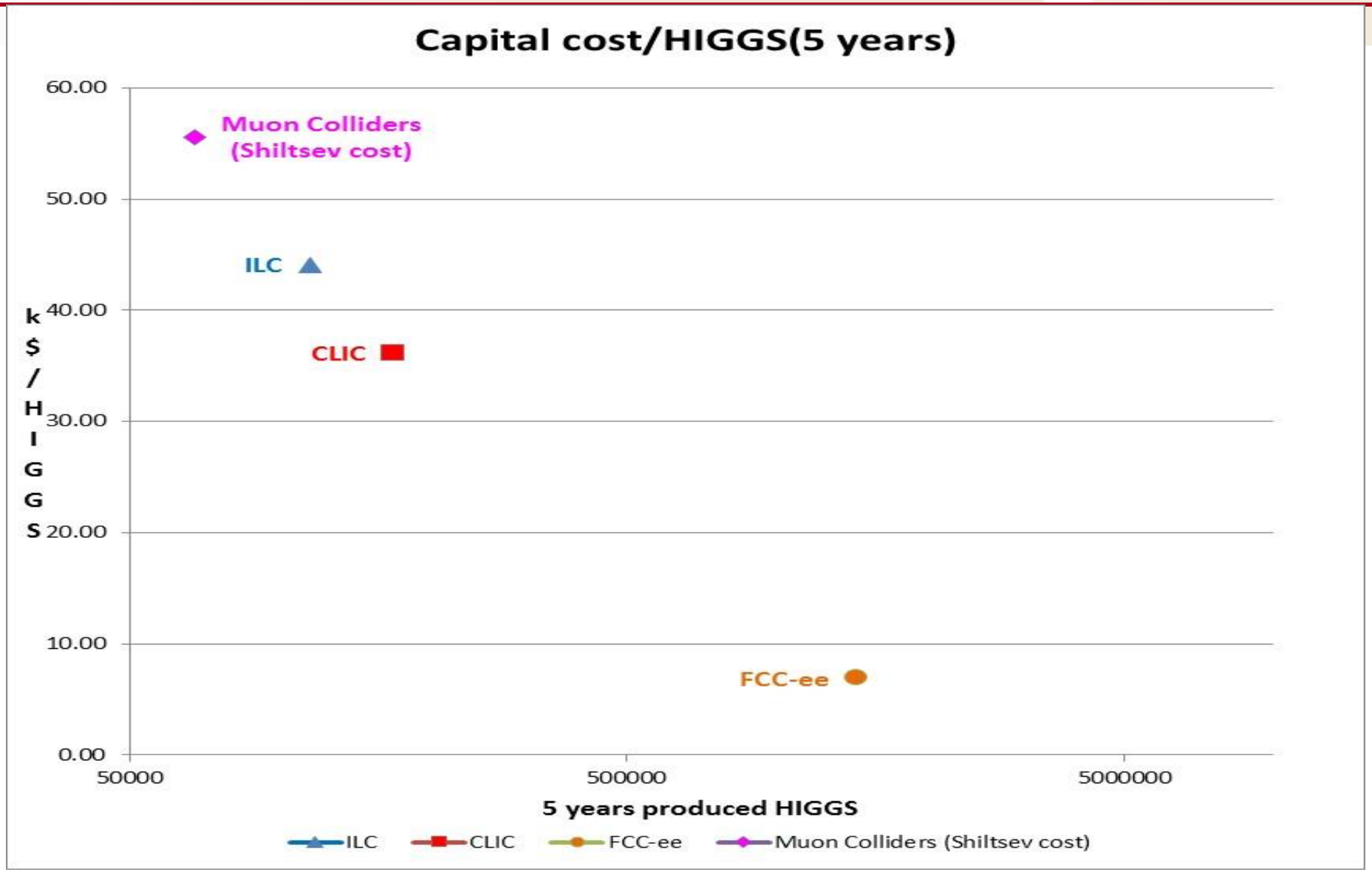


Estimated cost (a la Shiltsev)

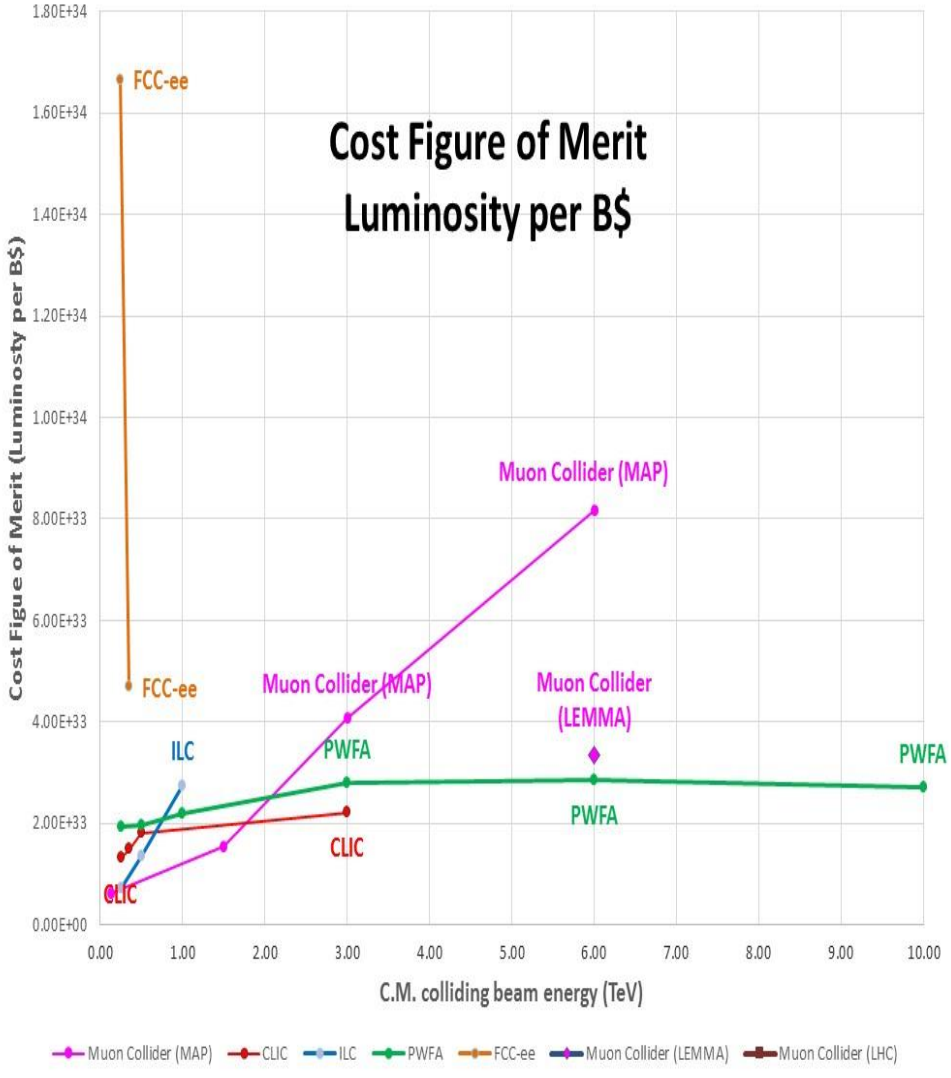


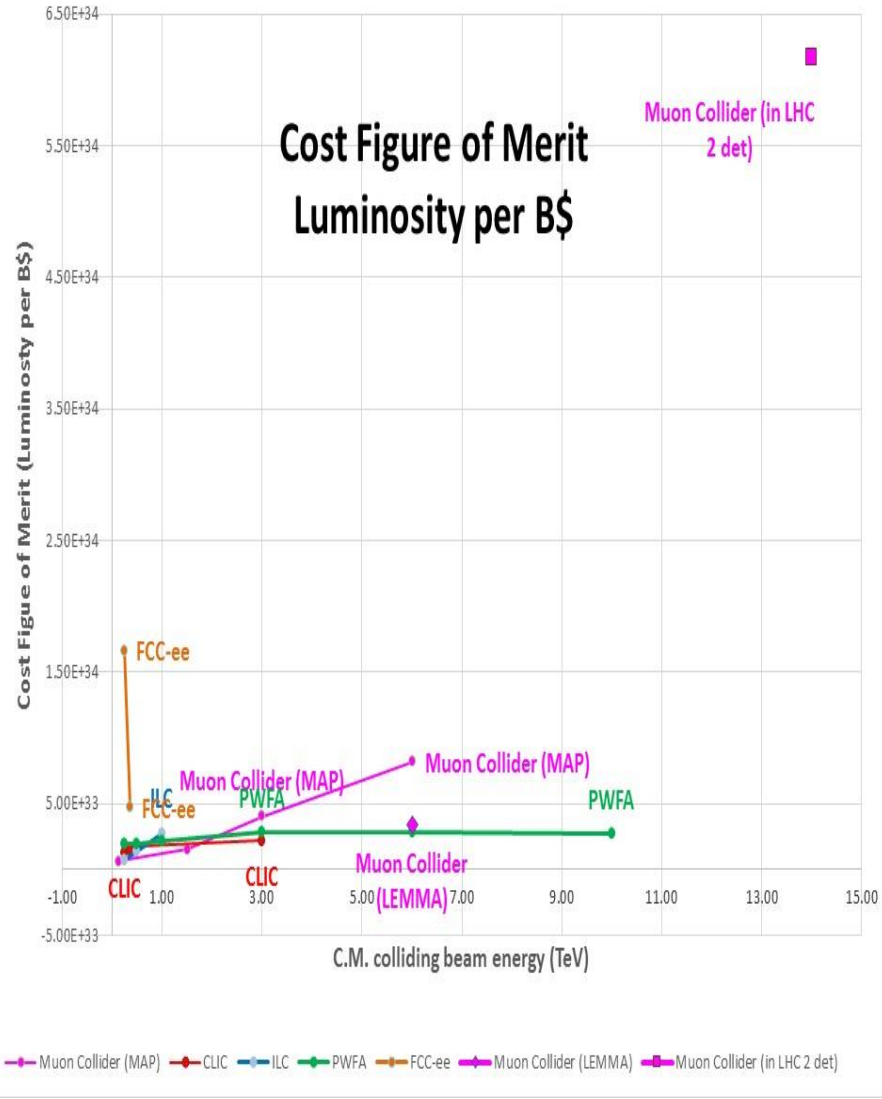


HIGGS cost

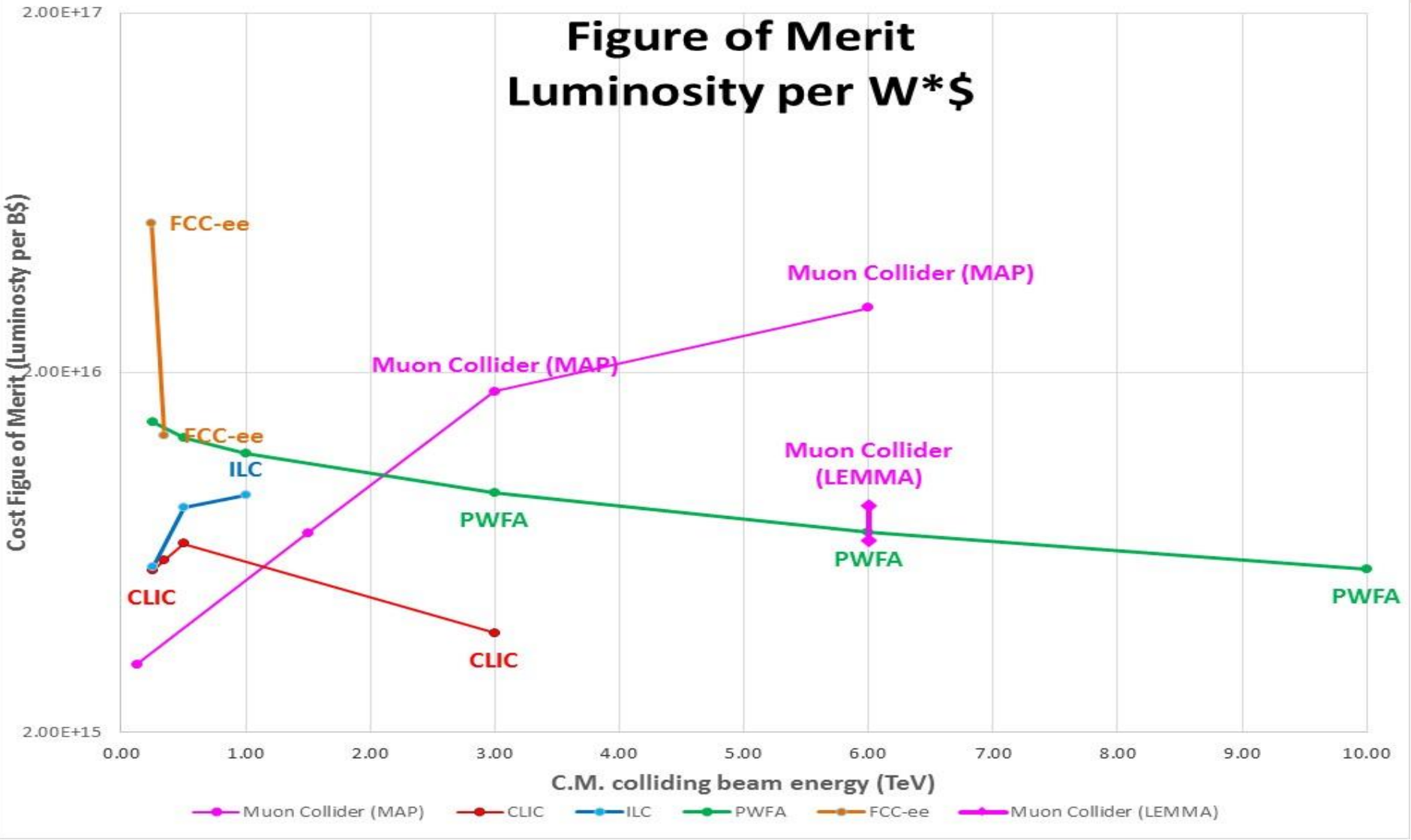

Capital cost/HIGGS(5 years)
60.00
50.00
40.00
30.00
20.00
10.00
0.00
k$/HIGGS
Muon Colliders (Shiltsev cost)
ILC
CLIC
FCC-ee
50000
500000
5000000
5 years produced HIGGS
ILC
CLIC
FCC-ee
Muon Colliders (Shiltsev cost)

Cost Figure of merit Luminosity per Billion$

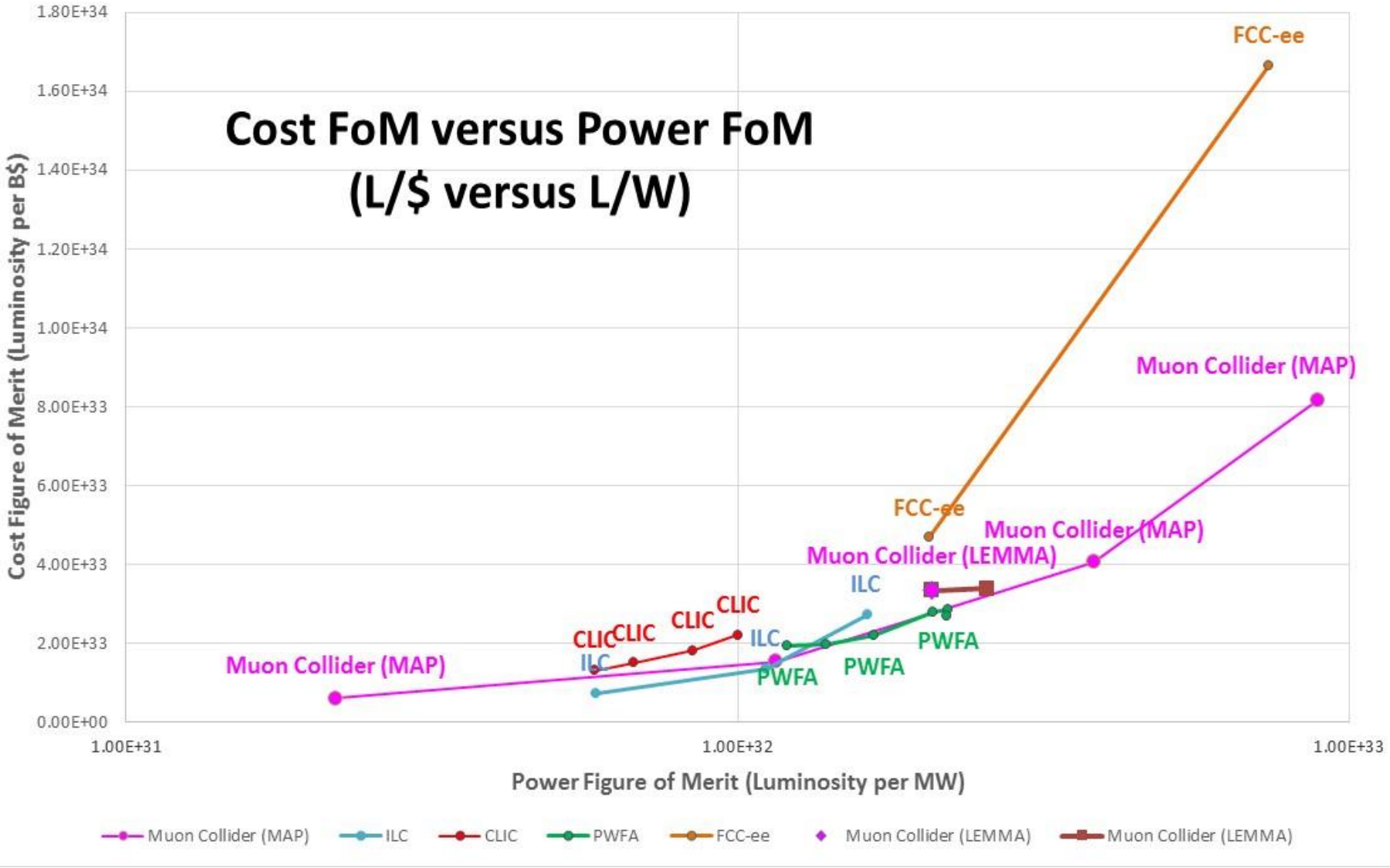




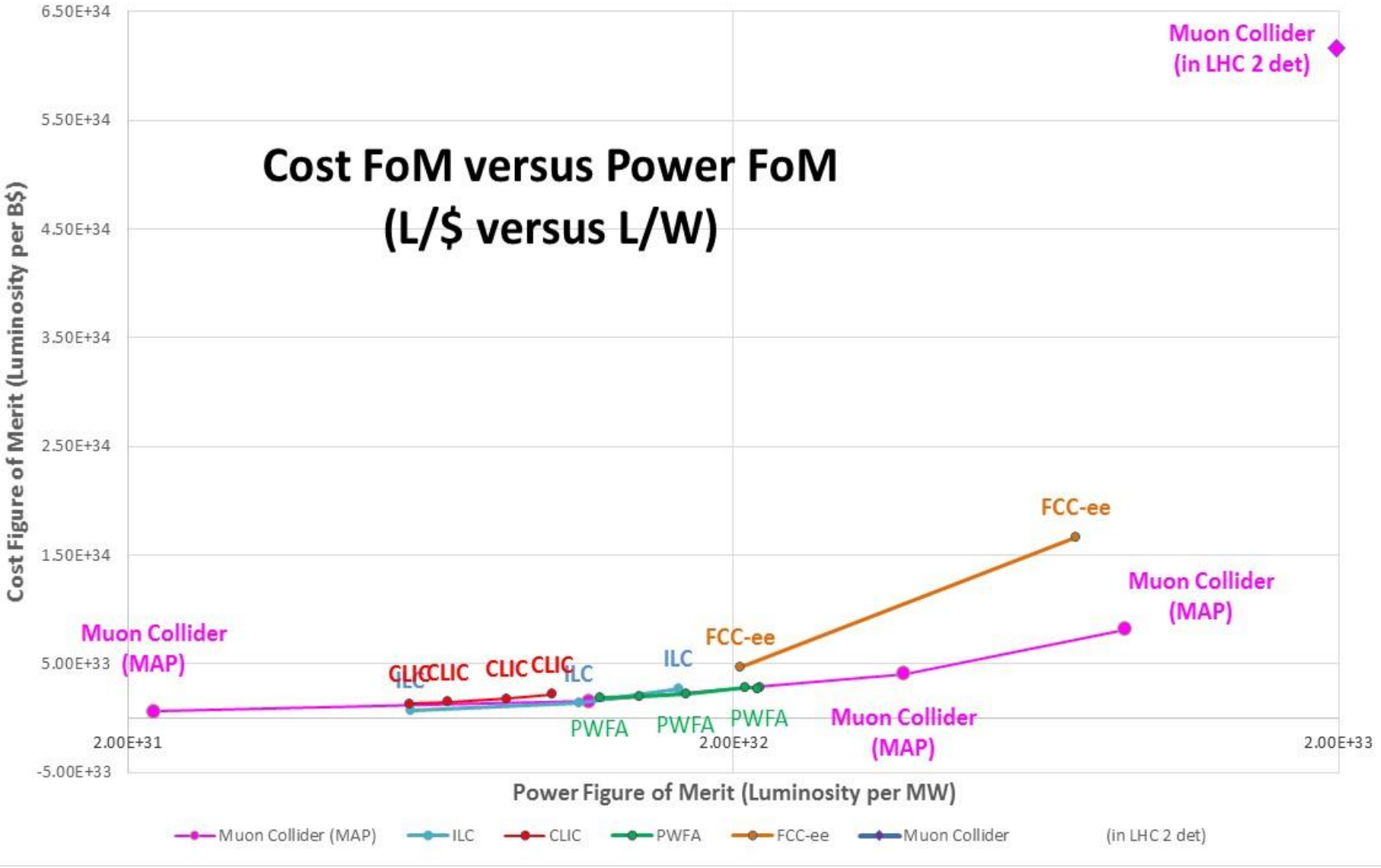
Combined Figure of Merit
FoM =L / (Power x Cost)



Cost Figure of Merit versus Power FoM



Cost Figure of Merit versus Power FoM



Conclusion

In the HIGGS-TOP energy level, e+/e- Circular Colliders best suited but large circumference ring and limited in energy upgrade

In the TeV range, linear colliders most suited technologies with similar performances and various energy reach

Muon Collider (MC) ideal technology to extend lepton colliders in the Multi-TeV range

- **Although challenging and performance limited, MC as HIGGS Factory attractive as a step towards higher colliding beam energies**
- **MAP scheme pretty mature, relies on critical 10^6 6D cooling**
- **LEMMA scheme appealing (no cooling, energy reach) if feasible (e+ rate?)**

Impressive potential of Muon Collider in LHC tunnel (preliminary)

- **Taking advantage of existing CERN facilities (LHC tunnel and injectors) to reduce cost**
- **Excellent Luminosity, Power FoM and Cost FoM but at limit of neutrino radiation**
- **Energy reach similar to 100TeV FCC-hh at level of elementary constituents**
- **«Too nice to be true»??? Preliminary study to be confirmed.**

Plea to launch a feasibility study of a

Muon Collider in the LHC (and FCC?) tunnel