HIGGS Factory
Overview of technology options

J.P Delahaye / SLAC (CERN)

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Accelerators for a HIGGS Factory workshop @ FNAL (Nov 14-16, 2012)

https://indico.fnal.gov/conferenceDisplay.py?confId=5775

Linear

Circular e^+e^-

DISCLAIMER

Data from Report of the ICFA HF2012 Workshop

(FERMILAB-CONF-13-037-PAC)

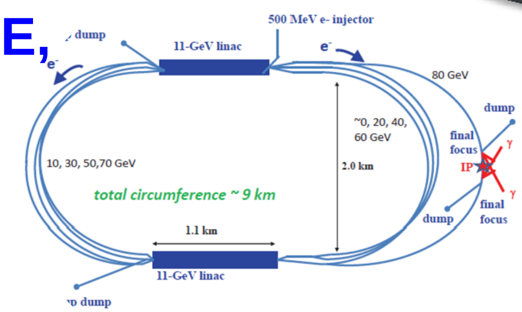
(A.Blondel, A.Chao, W.Chou, J.Gao, D.Schulte, K.Yokoya)

ILC
CLI
SLC
Adv
Co

Higgs
Factories

IHEP, ...
...

SAPPHIRE,
CLICHÉ,
SLC like
...



γ-γ Colliders

Muon Colliders

A Zoo of Candidates for a Higgs Factory

W.Chou @
HIGGS Fact. Wkp
(FNAL,Nov2012)

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- **Circular e+e- collider:**
  - LEP3
  - TLEP
  - SuperTRISTAN
  - Fermilab site-filler
  - China Higgs Factory (CHF)
  - SLAC/LBNL big ring
- **Linear e+e- collider:**
  - ILC
  - CLIC
  - X-band klystron based
  - Plasma (beam or laser driven)
- **$\gamma\gamma$ collider:**
  - ILC-based
  - CLIC-based
  - Recirculating linac-based (SAPPHiRE)
  - SLC-type
- **Muon collider**
  - Low luminosity
  - High luminosity

Two strategies:

- Projects focused on Physics in HIGGS energy range:
  - $\gamma\gamma$ collider
  - E+/E- colliding rings
- HIGGS factory as first stage of a facility upgradable to (multi)-TeV energy range
  - Linear Colliders
  - Muon Colliders
  - Colliders rings (with protons)

Higgs Factory Accelerator Pros and Cons

S.Henderson @ HIGGS Fact. Wkp (FNAL,Nov2012)

	Linear Collider	Circular Collider	Muon Collider	γ–γ Collider
Technical Maturity	☺	☺☺	☹	☹
Size	☹	☹	☺	☺*
Cost	☹	😐	😐	☺*
Power Consumption	😐	☹	😐	😐
Energy Resolution	☹	☹	☺	☹
MDI	😐	😐	☹	☹
TeV Upgradability (Energy)	☺	☹☹	☺☺	☺
TeV Upgradability (Cost, Size, Power)	😐	☹☹	☺	😐

Lepton colliders HIGGS Factory main parameters

Parameter	Unit	ILC	CLIC	PWFA	Muon Collider
Energy (cm)	GeV	250	250	250	126
Luminosity (per IP)	$10^{34}cm^{-2}s^{-1}$	0.75	1.37	1.60	0.01
Peak (1%)Lum(/IP)	$10^{34}cm^{-2}s^{-1}$	0.65	1.19	0.94	0.01
Yearly HIGGS (/IP)	1000	23	34	30	50
# IP	-	1	1	1	1
Length or circumference	km	21	13.2	2.5	1.5 (0.3)
Power (wall plug)	MW	128	235	133	200
Polarisation (e+/e-)	%	80/30	80/0	?/?	15/15
Lin. Acc. grad. (peak/eff)	MV/m	31.5/25	100/80	$10^4/10^3$	-
# particles/bunch	10^{10}	2	0.34	1	500
# bunches/pulse	-	1312	842	1	1
Bunch interval	ns	554	0.5	-	-
Average/peak current	nA/A	21/0.006	22.9/1.09	48.6/-	-
Pulse repetition rate	Hz	5	50	30000	30
Beam power/beam	MW	2.63	2.87	6.08	1.52
Norm Emitt (X/Y)	$10^{-6}/10^{-9}$rad-m	10/35	0.66/25	10/35	200/200000
Sx, Sy, Sz at IP	nm,nm,μm	729/7.7/300	150/3.2/72	671/3.8/20	$1.2\ 10^5/1.2\ 10^5/4.10^4$
Crossing angle	mrad	14	18.6	14?	0
Av # photons	-	1.17	0.7	0.57	?
δb beam-beam	%	0.95	1.5	2.75	?
Upsilon	-	0.02	0.05	0.084	?

Circular colliders HIGGS Factory main parameters

Parameter	Unit	LEP3	TLEP	STristan	FNAL	IHEP80	SLACLBL
Energy (cm)	GeV	240	240	240	240	240	240
Luminosity (per IP)	$10^{34}cm^{-2}s^{-1}$	1	4.9	1	0.52	3.85	1
Yearly HIGGS (per IP)	1000	20	100	20	13	77	20
# IP	-	2	4	1	1	2	1
Length or circumf.	km	26.7	81	40	16	70	26.7
Power (wall)	MW	300	320	260	300	320	300
Polarisation (e+/e-)	%	0	0	0	0	0	0
# particles/bunch	10^{10}	100	50	67	80	60	8
# bunches/beam	-	4	80	8	2	52	50
Beam intensity	mA	7.2	24.3	6.5	5	21.3	7.2
Synchrotron loss/turn	GeV	7.0	2.1	3.5	10.5	2.35	7.0
Synchro. power/beam	MW	50	50	22.5?	50	50	50
RF voltage	GV	12	6	8.3	12	12	12
Norm Emitt (X/Y)	$10^{-3}/10^{-6}$radm	5.87/23	2.21/12	9.4/9.4	5.32/27	3.36/16.7	1.01/5.05
Sx, Sy, Sz at IP	μm,nm,mm	71/320/3.1	43/220/1.7	89/63/1.2	67/476/2.9	53/266/1	15/2.6/1.5
Crossing angle	mrad	0	0	0	0	0	
Tune shift (x/y)	-/-	0.09/0.08	0.1/0.1	0.03/0.08	0.070.095	0.08/0.08	0.04/0.07
Beam lifetime	sec	1080	1920	?	1080	600	?
Average # photons	-	0.6	0.5	3.2	0.36	0.48	0.24
δb beam-beam	%	0.03	0.035	0.02	0.022	0.057	0.0088
Upsilon	-	0.00231	0.00348	0.00320	0.00212	0.0057	0.00186

Power and efficiency

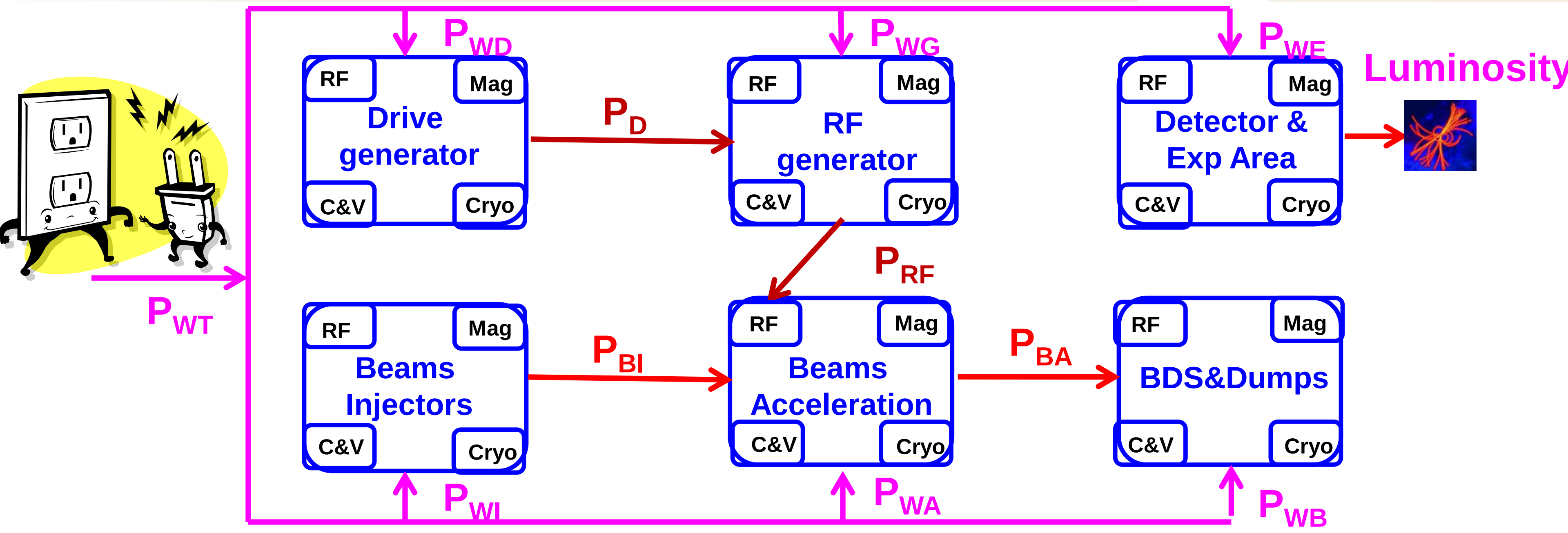


Figure of merit: η_L = Luminosity/P_{WT}

$P_{WT} = \sum P_{WX}$

Wall plug to beam transfer efficiency: $\eta_T = P_{BA}/P_{WT}$

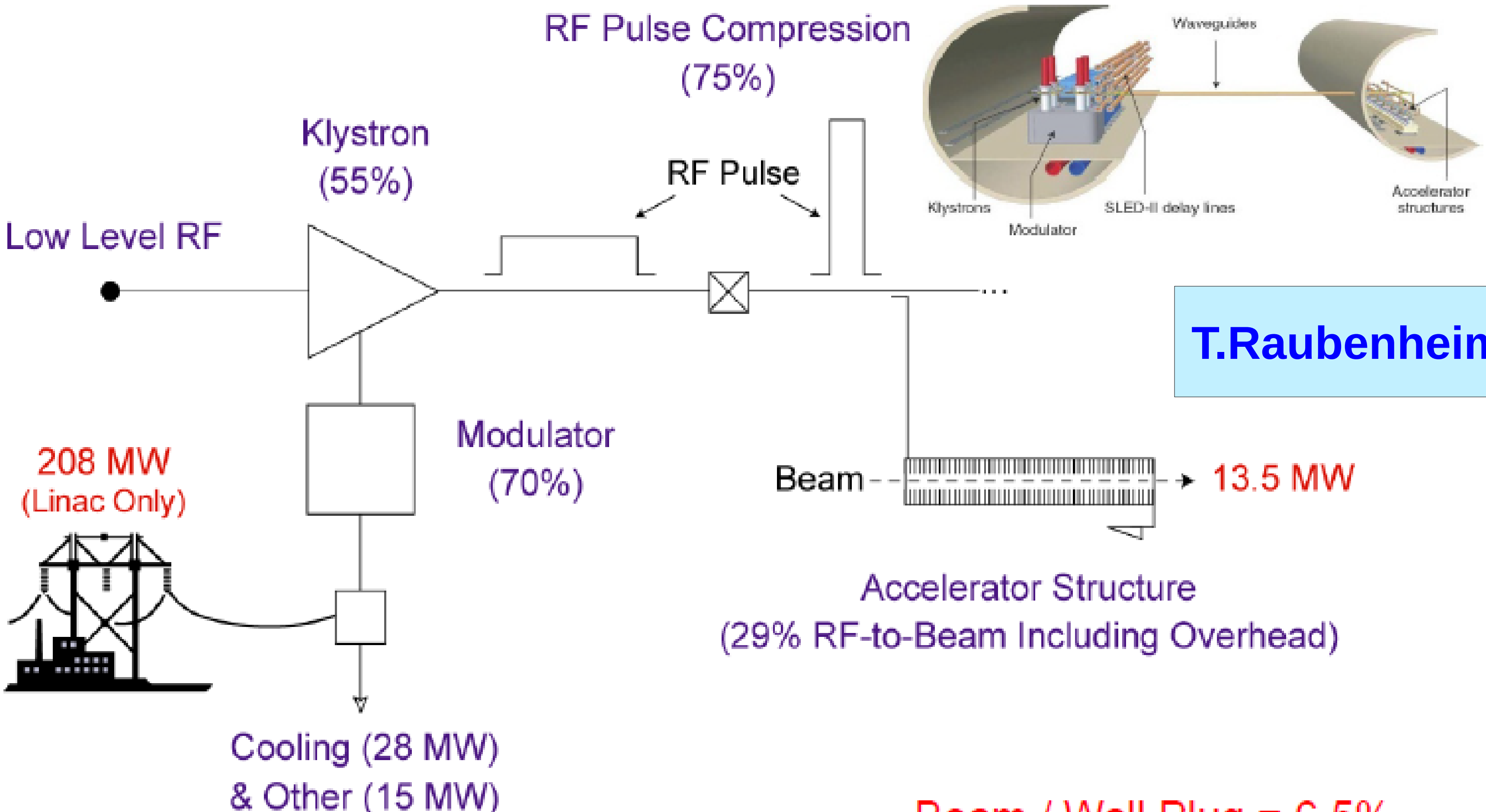
Acceleration efficiency: $\eta_A = (P_{BA}-P_{BI})/(P_{WA}+P_{WD}+P_{WG})$

RF to beam transfer efficiency: $\eta_B = P_{BA}/P_{RF}$

RF generation efficiency: $\eta_{RF} = \eta_D * \eta_G = P_{RF}/(P_D+P_{WG}) * P_D/P_{WD} = P_{RF}/(P_{WD}+P_{WG})$

Simplified Layout of NLC/GLC RF System

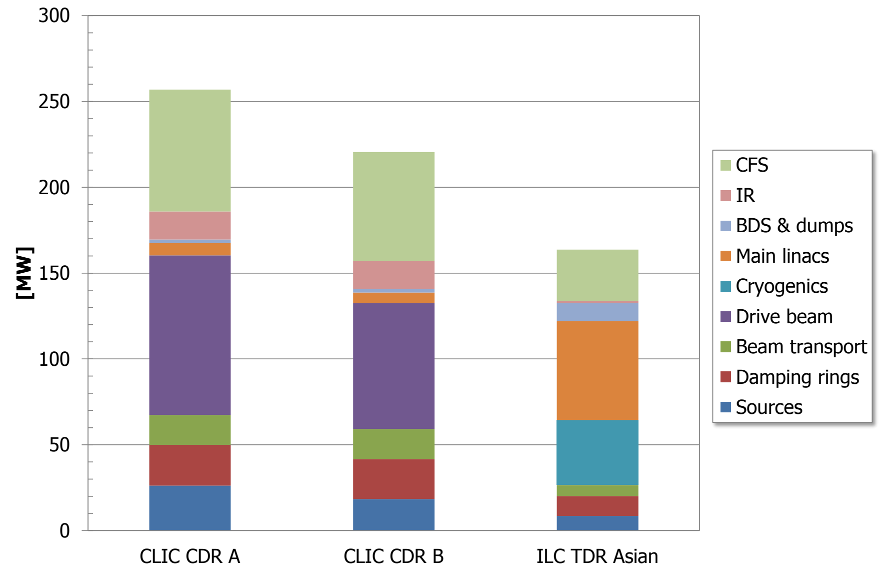
(Efficiencies & Powers in Parentheses)

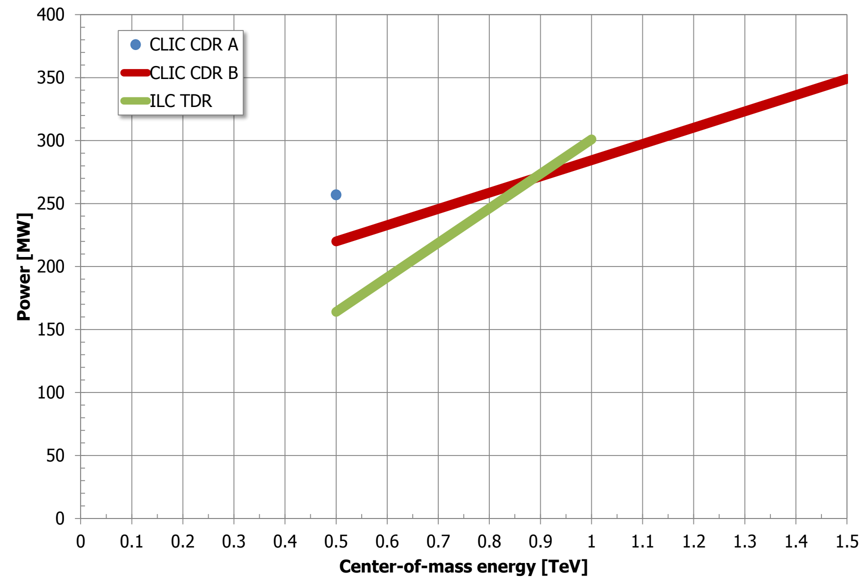


T.Raubenheimer

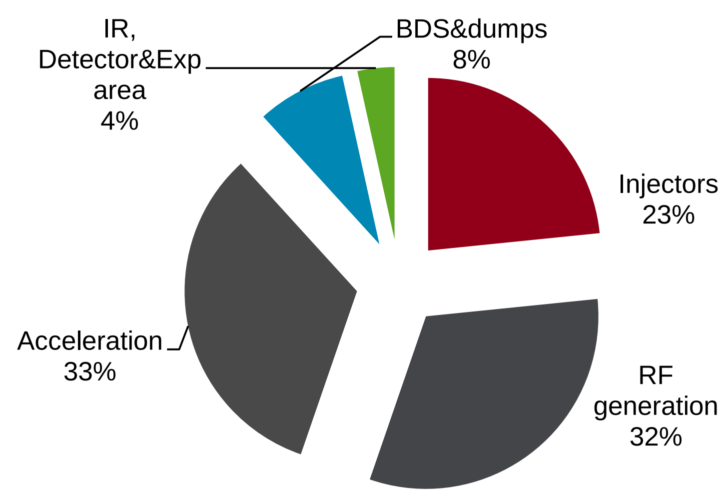
Beam / Wall Plug = 6.5%

Power distribution in ILC & CLIC (as good examples of detailed studies)





ILC 500 GeV (TDR)		Magnets	RF	Cryo	Inst&cont	Cooling&vent	Total (MW)	Part total (%)
Injectors	PWI	9.9	16.1	2.84	0.5	8.97	38.31	23.4
Drive generation	PWD						0	0.0
RF generation	PWG		52.23				52.23	31.9
Acceleration	PWA	0.91		32	4.66	16.4	53.97	33.0
BDS&dumps	PWB	10.43		0.41		2.75	13.59	8.3
IR, Detector&Exp area	PWE	1.16		2.65		1.86	5.67	3.5
Total (MW)	PWT	22.4	68.33	37.90	5.16	29.98	163.77	100.0
Part in total (%)		13.7	41.7	23.1	3.2	18.3	100.0	
Luminosity (1%)	L	1.04E+34		Figure of merit: Luminosity/MW			6.37E+31	
Beam power	PBA	10.6		Overall efficiency			6.5	
RF power	PRF	23.30		Acceleration efficiency			10.0	
Total Wall plug power	PWT	164		RF to beam transfer efficency			45.5	
				RF generation efficiency			44.6	

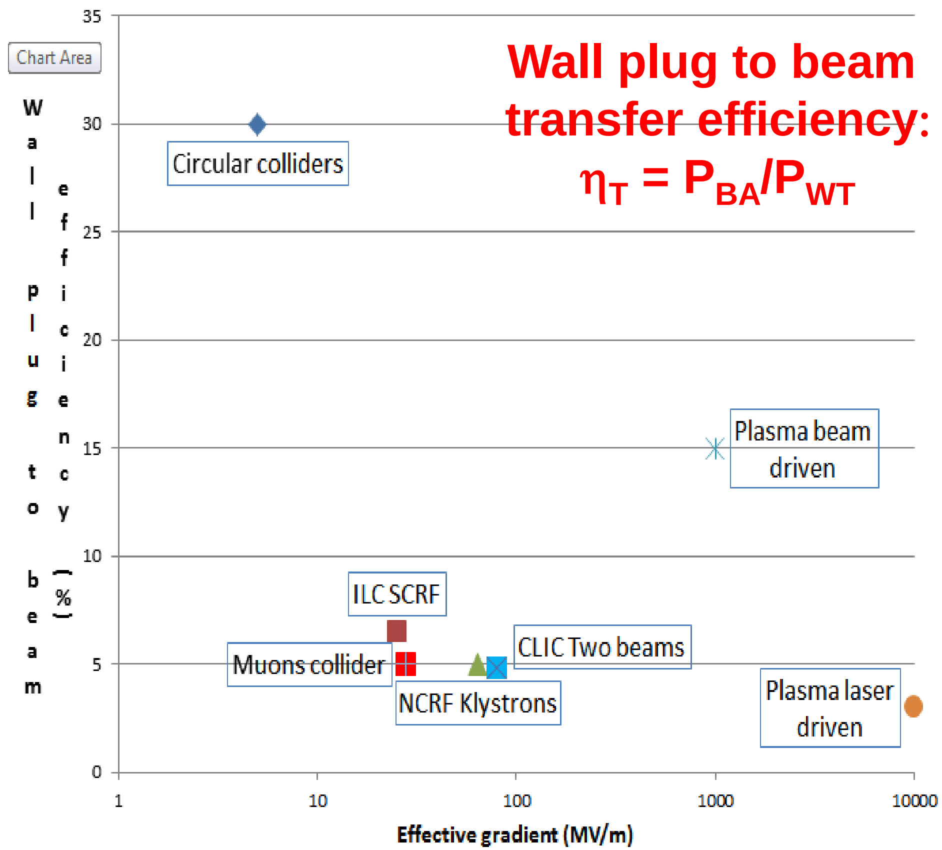


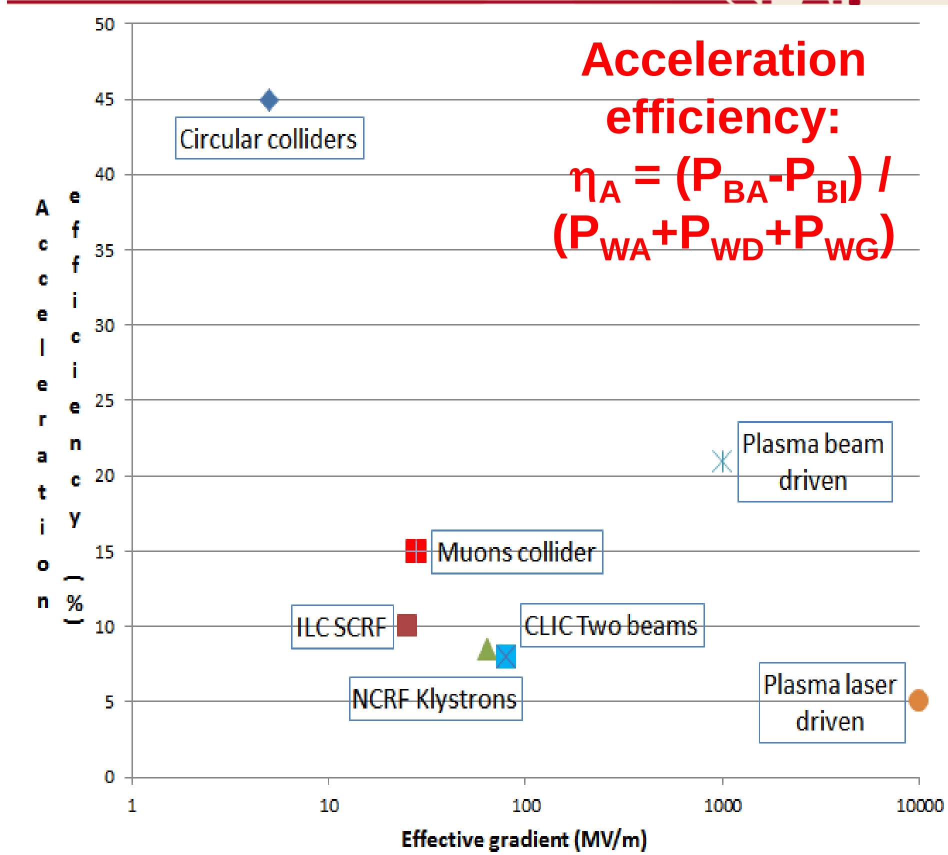
Power related systems

Option	Technology	Injectors	Drive	RF generat	Acceleration
Circular Collider	Normal or Super conducting	E+/E-gen., damping, pre-accel.&comp	Power supply	Klystrons& distribution	NC or SC RF
Linear Collider	Super Conducting	E+/E-gen., damping, pre -accel.&comp	Modulators	Klystrons& distribution	SC structures & cryogenics
	Normal Conducting	E+/E-gen., damping, pre -accel.&comp	Modulators	Klystrons & pulse compression & distribution	RF structures
	Two-Beam	E+/E-gen., damping, pre -accel.&comp	Drive beam generation	Drive to RF Extraction & Transfert	RF structures
	Plasma Laser driven	E+/E-gen., damping, pre -accel.&comp	Laser generation	Laser –plasma interaction	Plasma
	Plasma Beam driven	E+/E-gen., damping, pre -accel.&comp	Drive beam generation	Beam –plasma interaction	Plasma
Muon Collider		E+/E-gen., damping, pre -accel.&comp	Modulators	Klystrons & pulse compression & distribution	RF structures

	Circular	ILC	Klystrons	CLIC	Plasma driven		Muons
		SC-RF	NC-RF	TwoBeams	Beam	Laser	
Overall efficiency	30	6.5	5	4.8	15	3	5
Acceleration efficiency	45	10	8.5	8	21	5	15
RF to beam transfer efficiency	95	45	30	27	66	66	40
Drive to RF transfer efficiency	55	45	42	38	76	76	55
Drive generation efficiency			70		44	10	80

Efficiency versus accelerating gradient





	Circular	ILC	Klystrons	CLIC	Plasma driven		Muons
		SC-RF	NC-RF	TwoBeams	Beam	Laser	
Overall efficiency	30	6.5	5	4.8	15	3	5
Acceleration efficiency	45	10	8.5	8	21	5	15
RF to beam transfer efficiency	95	45	30	27	66	66	40
Drive to RF transfer efficiency	55	45	42	38	76	76	55
Drive generation efficiency			70		44	10	80

Total luminosity per IP of the various HIGGS Factory proposals and their variation with collision energy

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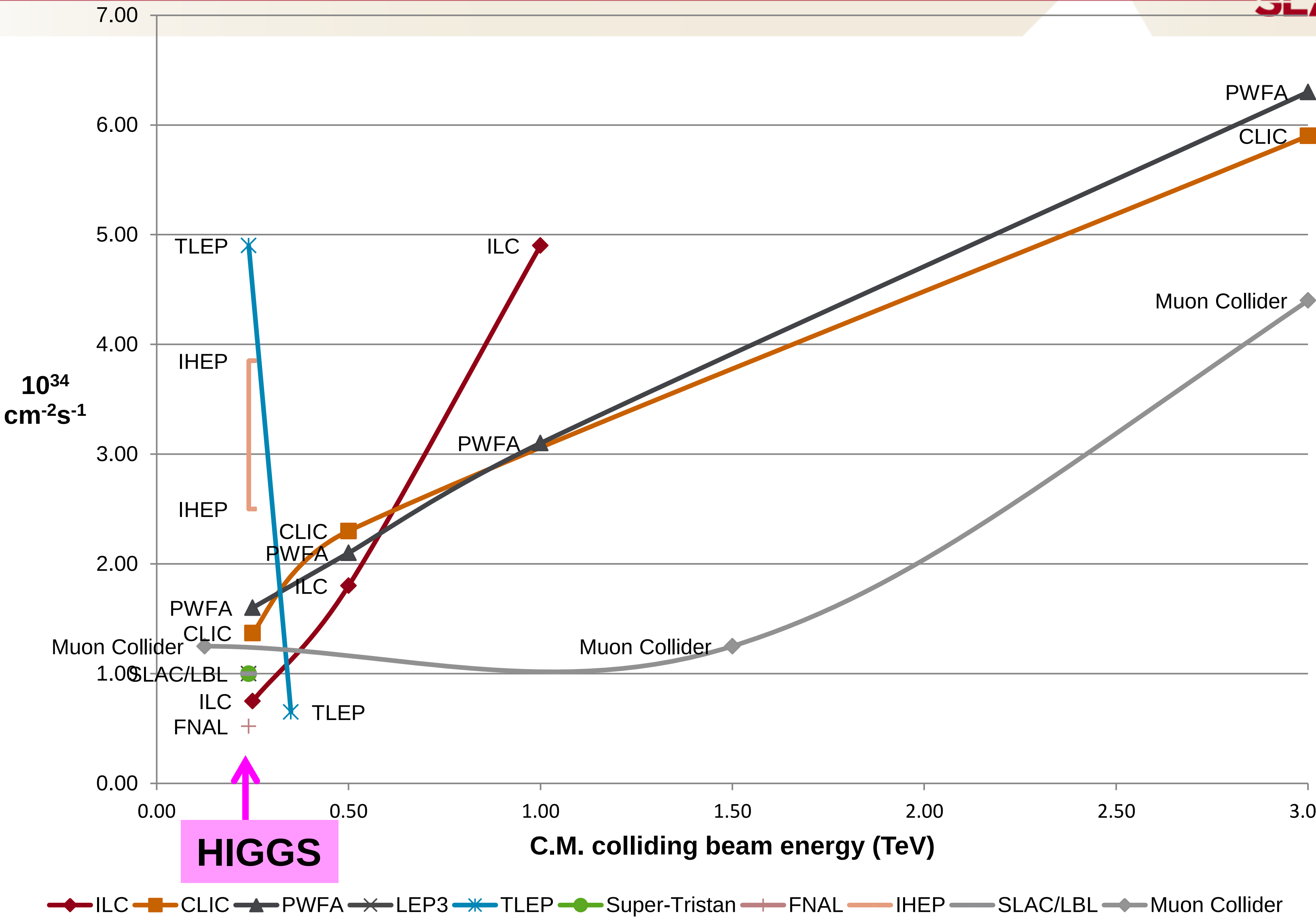
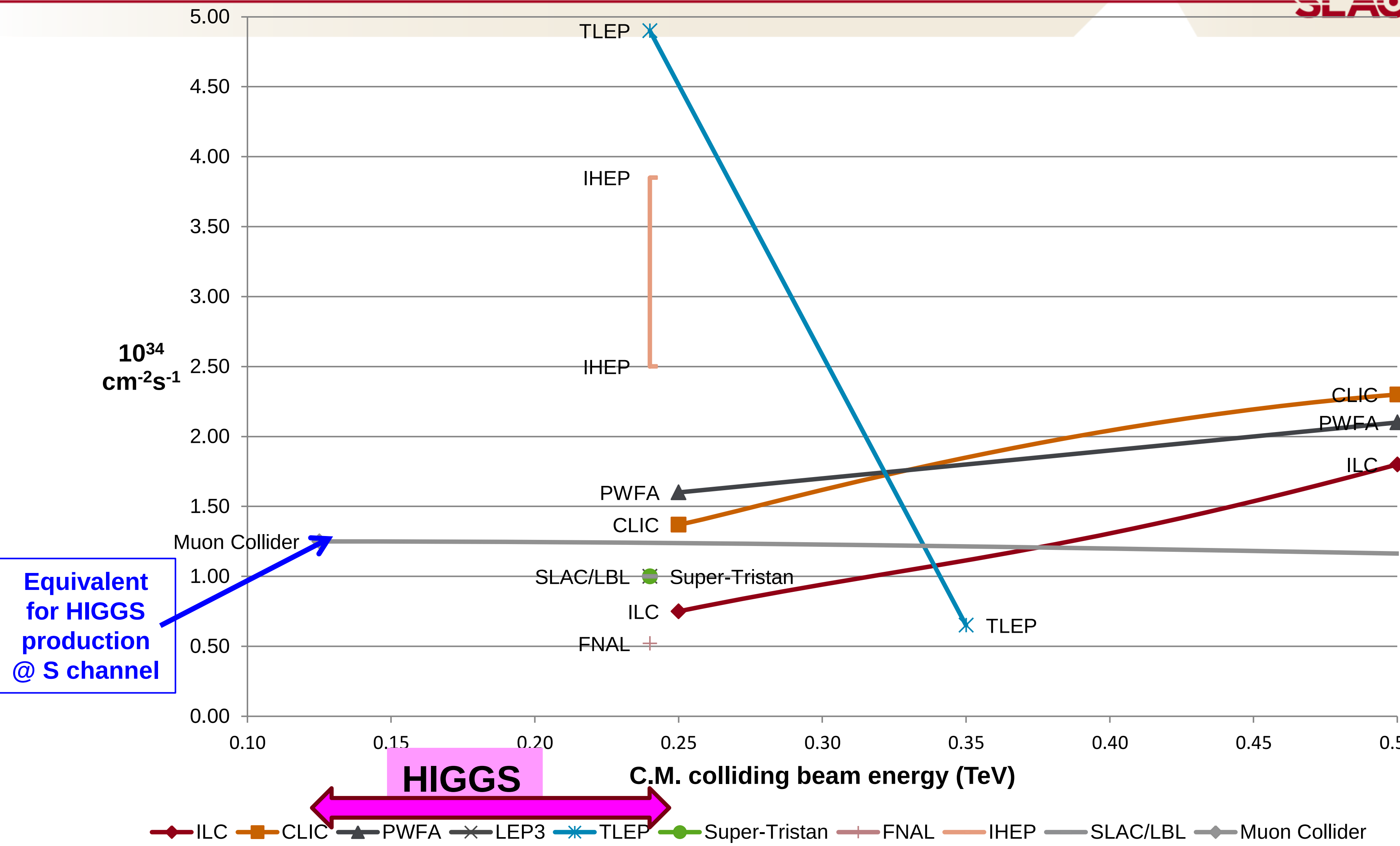


Total luminosity per IP in the energy region of HIGGS interest



Total Luminosity summed-up over all IPs

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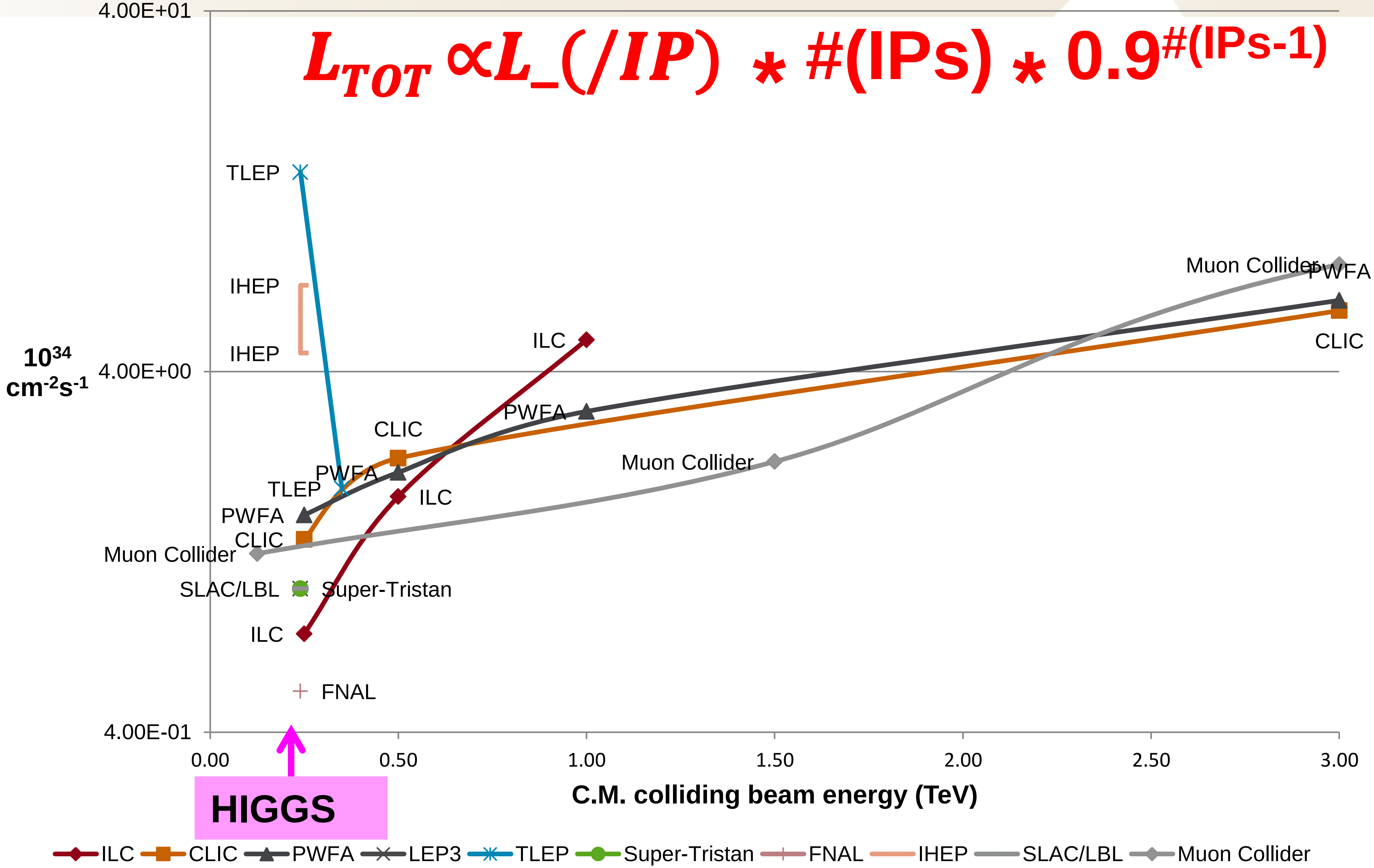
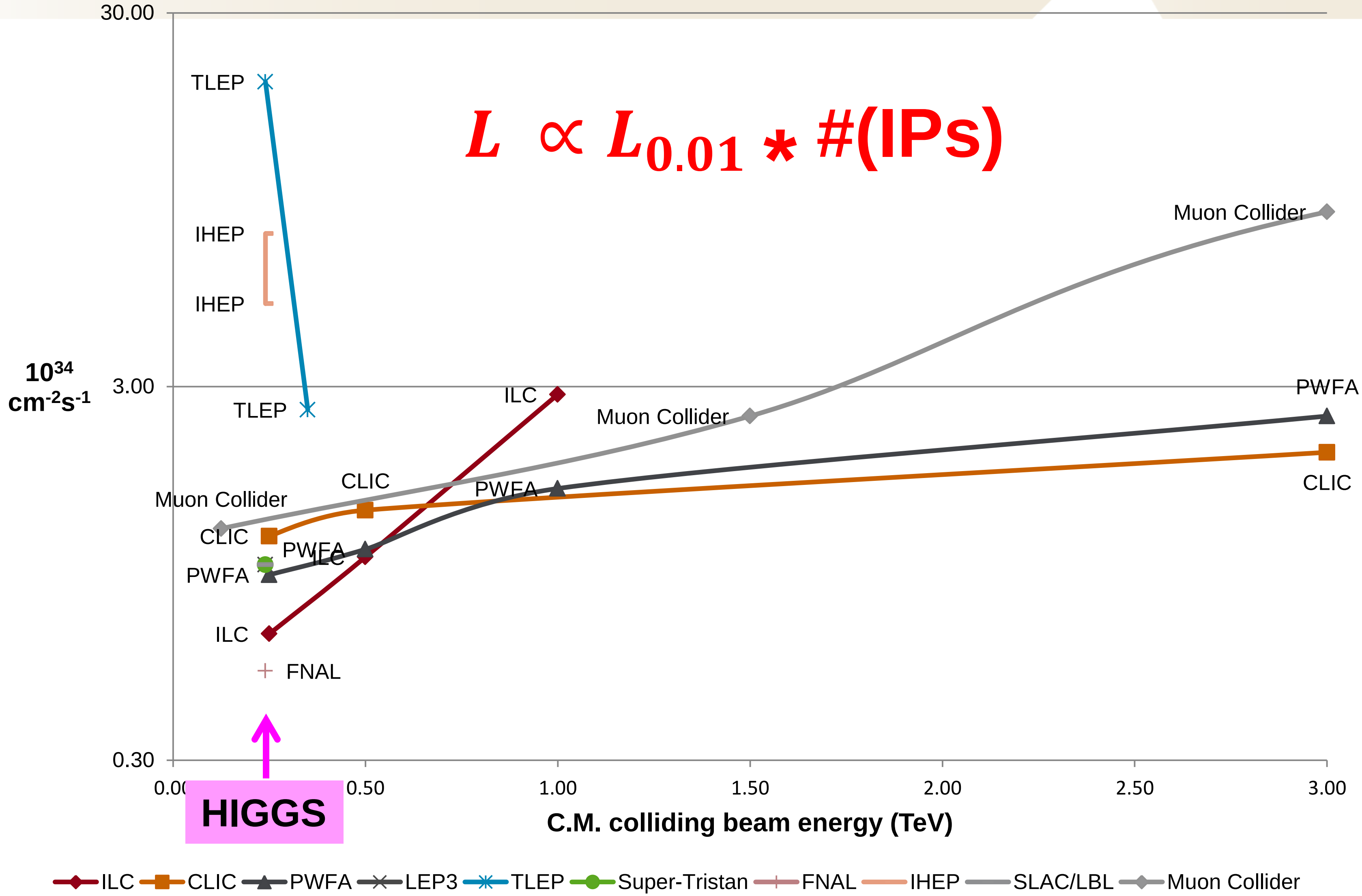
$$L_{TOT} \propto L\_(/IP) * \#(IPs) * 0.9^{\#(IPs-1)}$$



Peak Luminosity (1%) summed-up over all IPs



Wall plug power: a practical limitation?

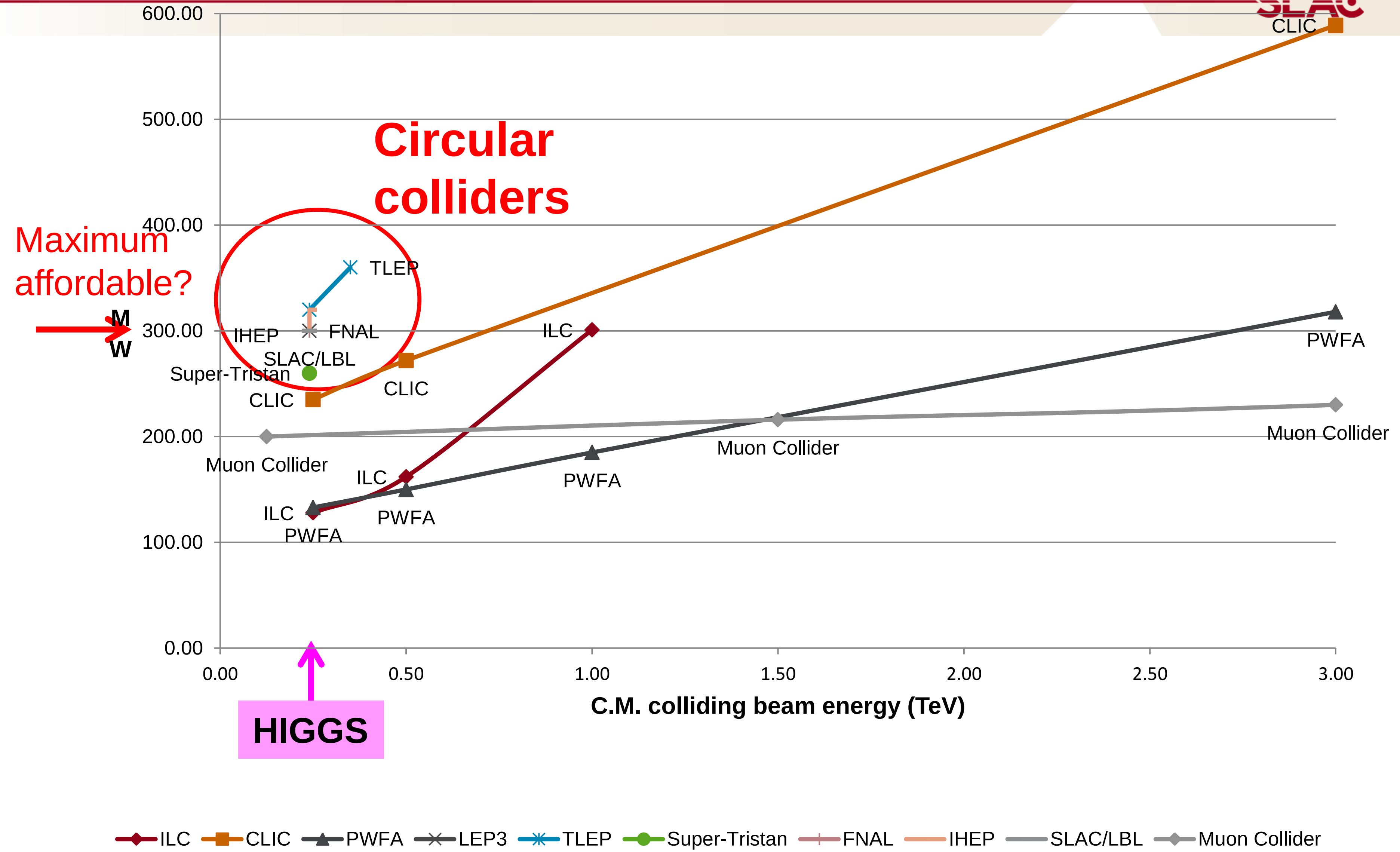
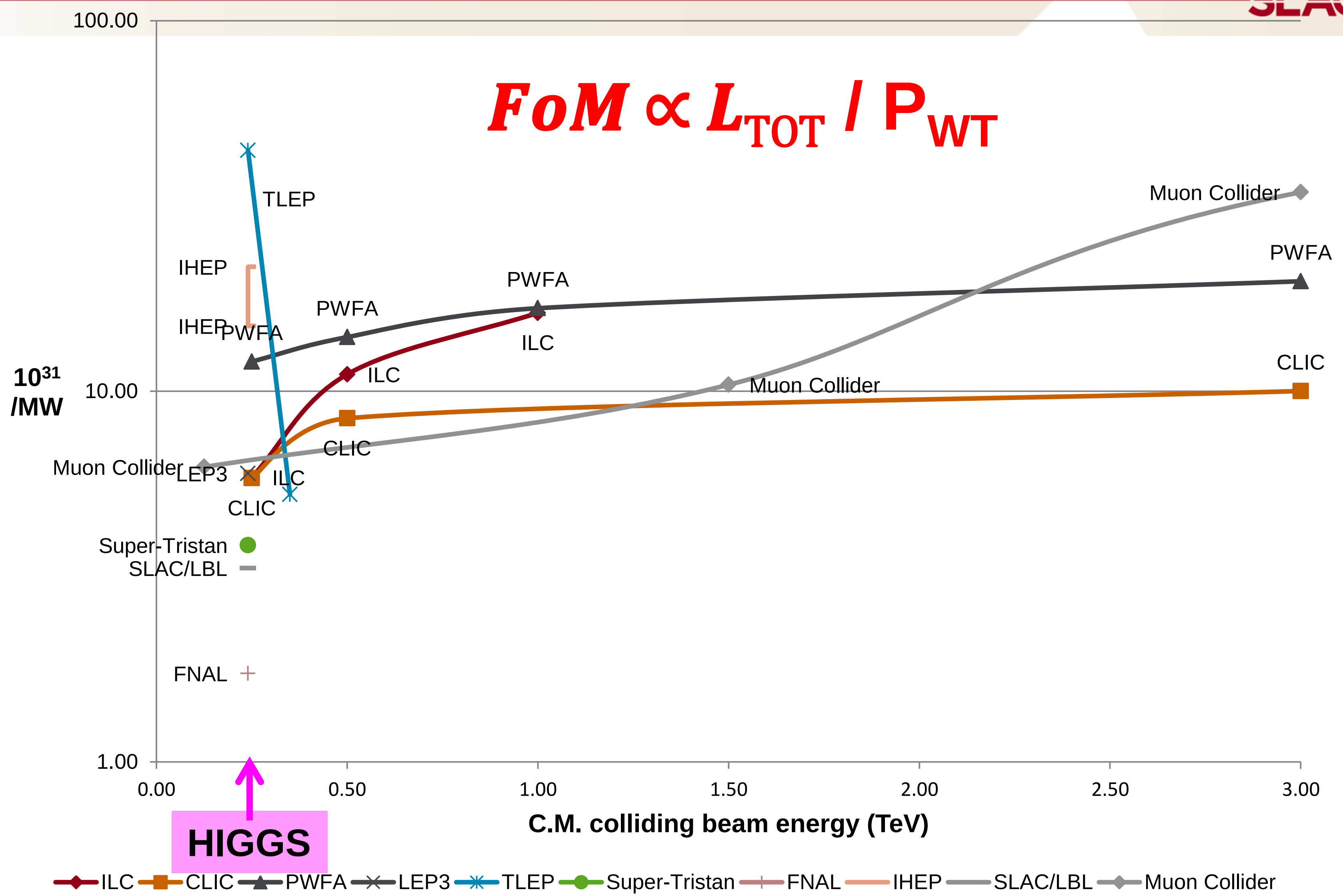
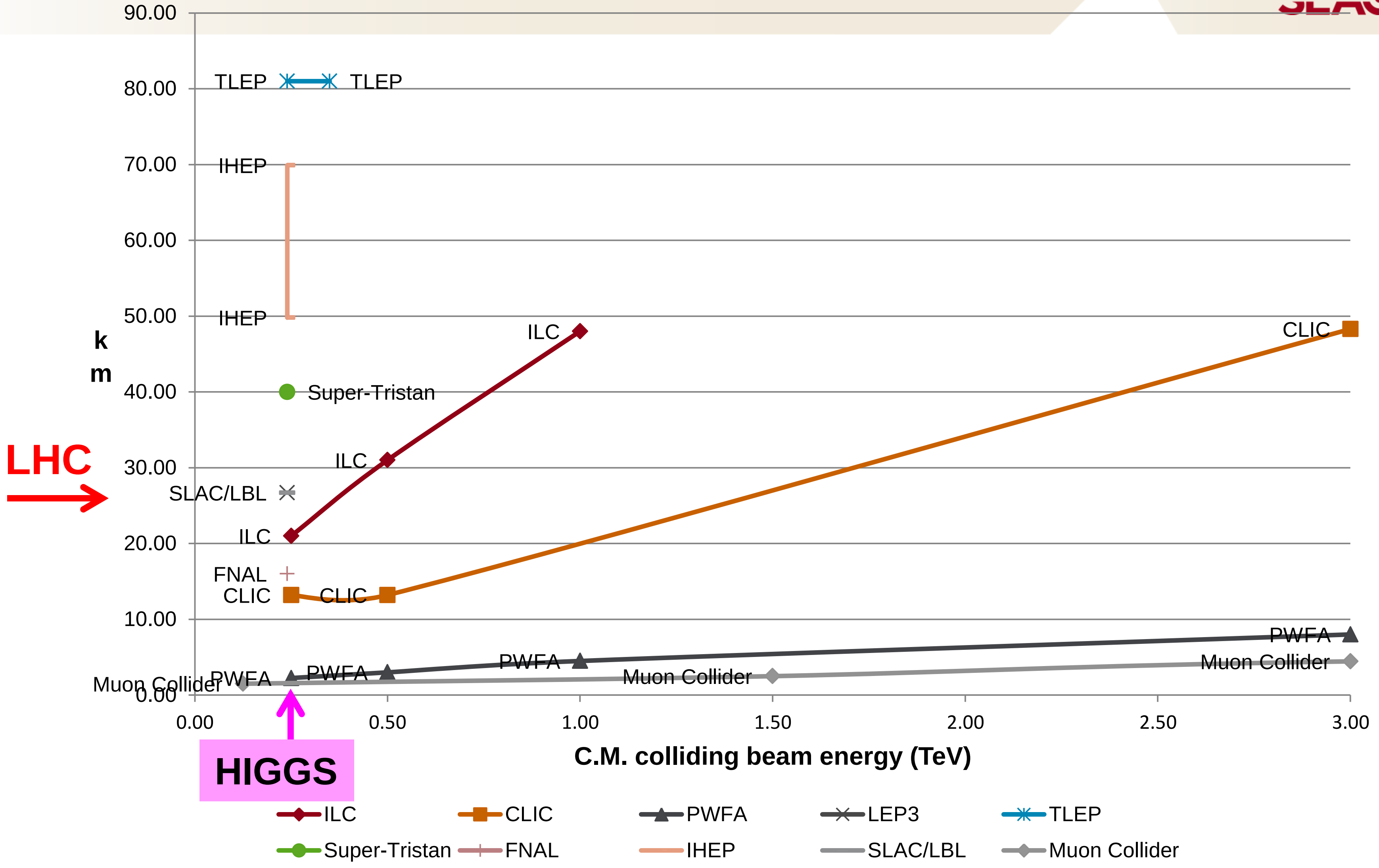


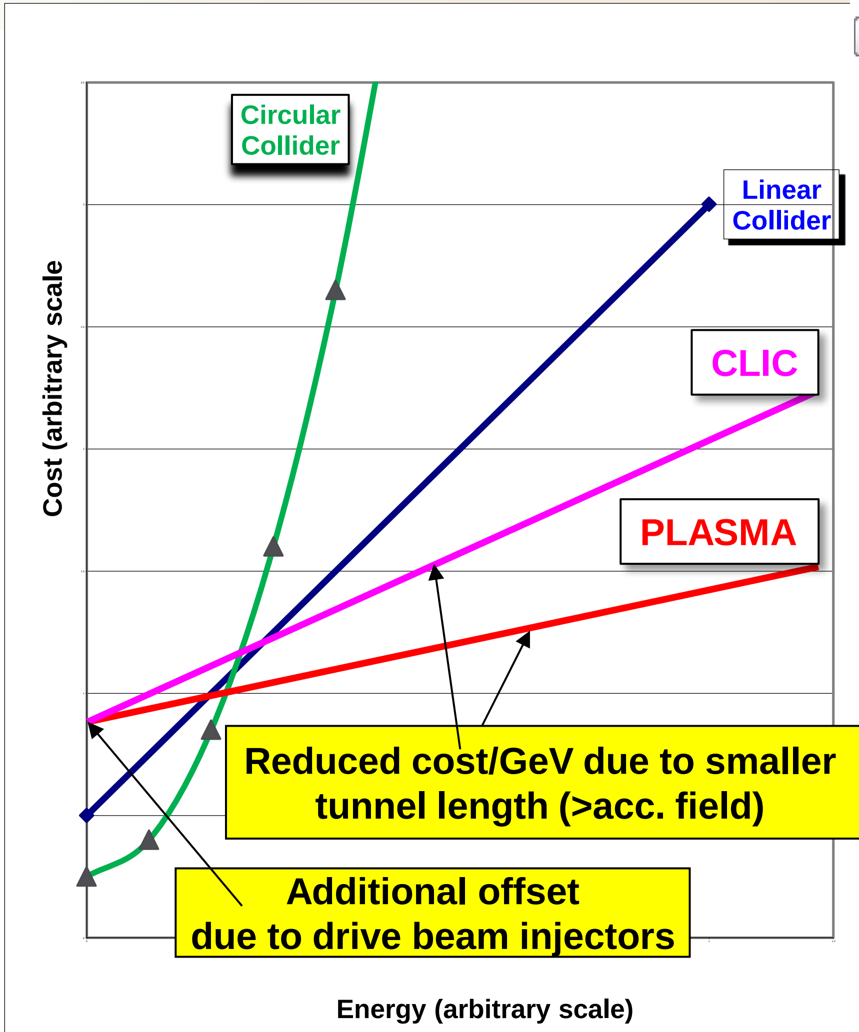
Figure of merit:
Integrated Luminosity/Wall plug power

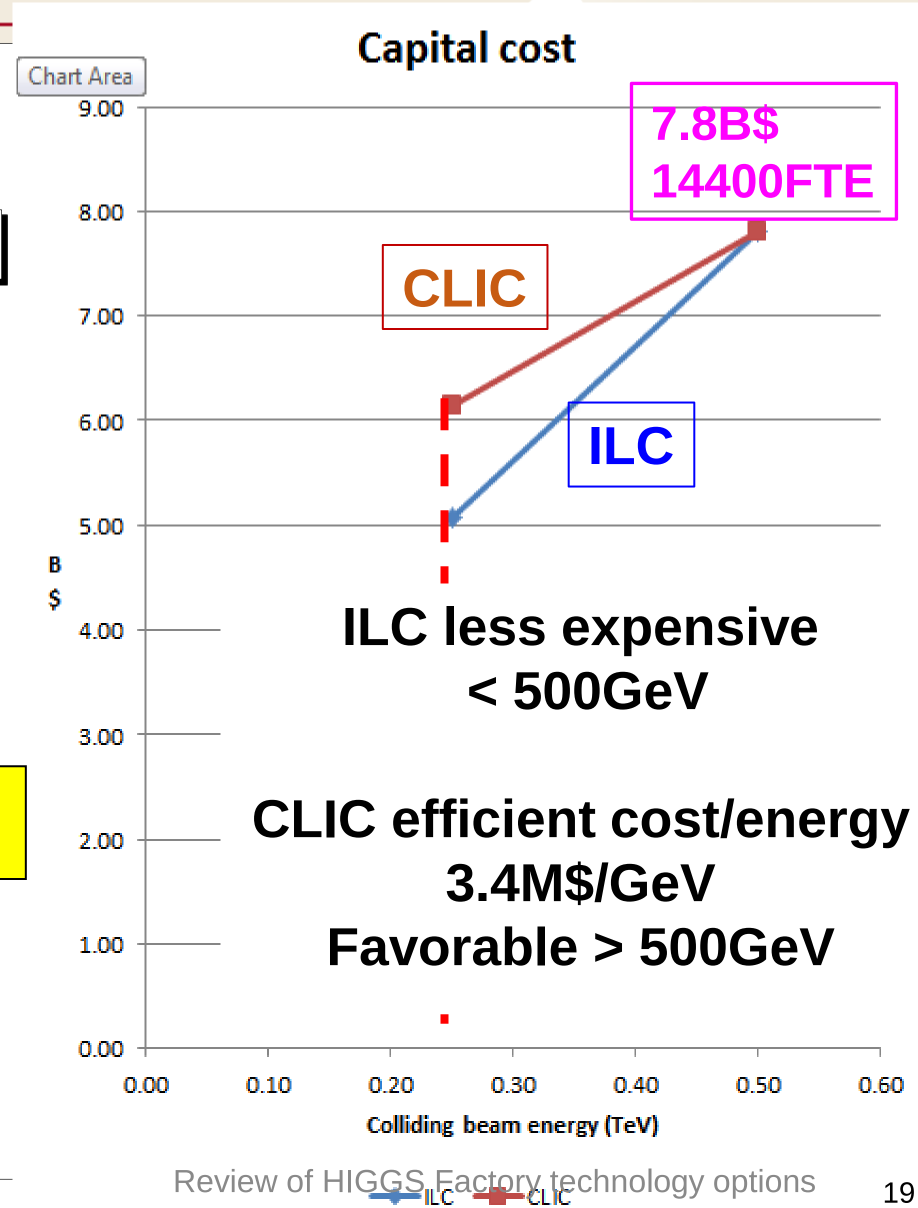


Length or circumference

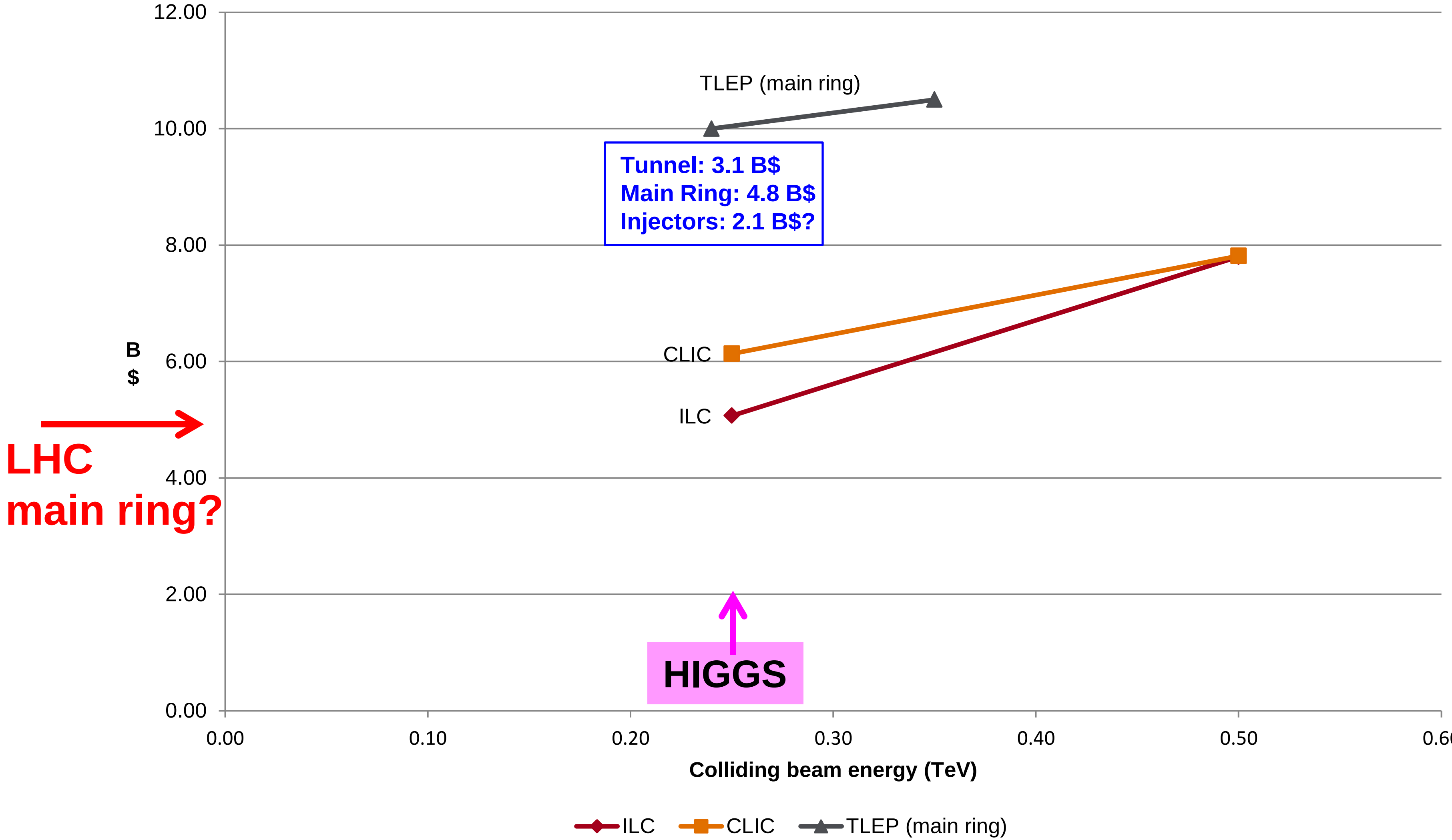


Cost: another practical limitation?

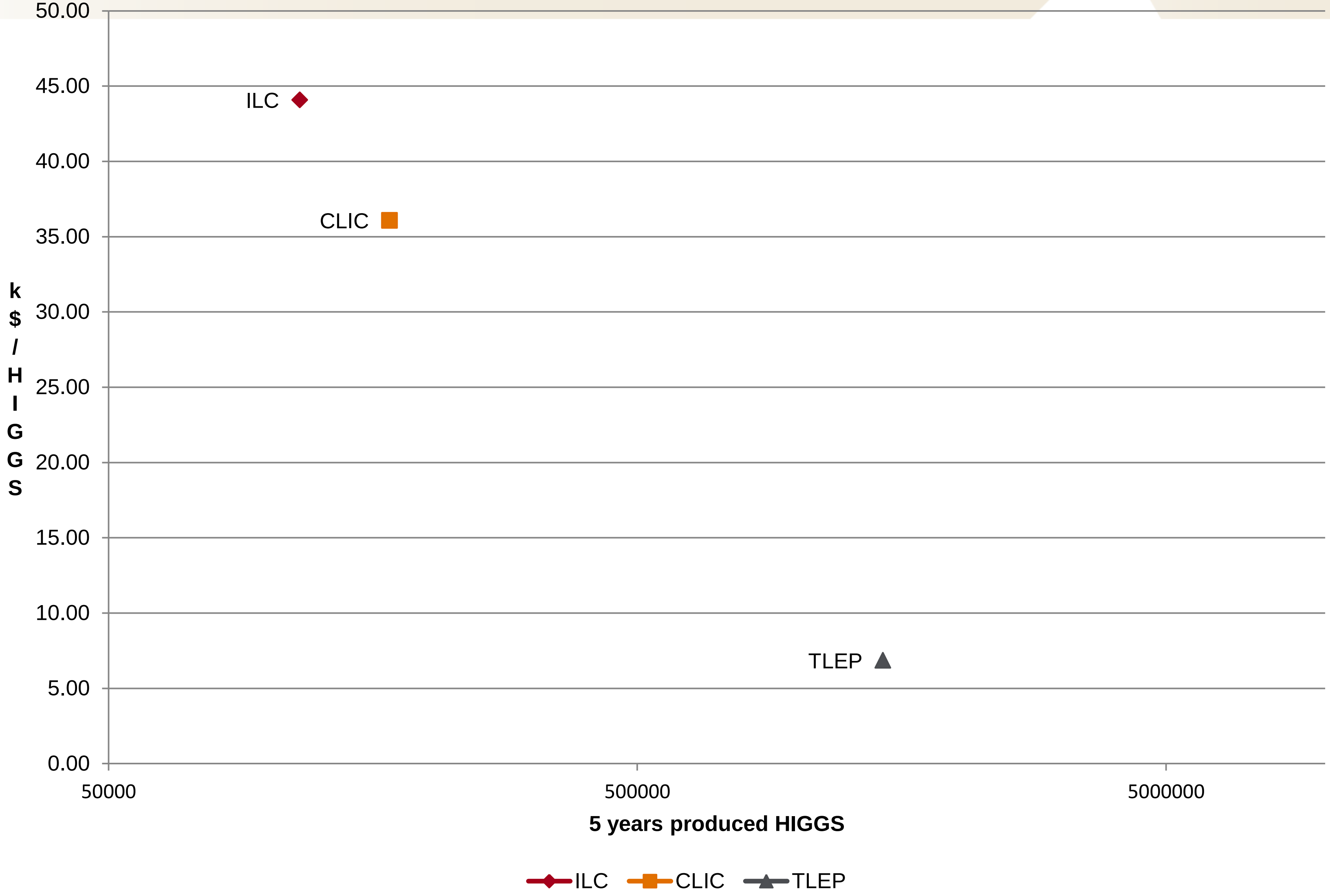




Capital cost



Capital cost per 5 years produced HIGGS



Linear and γ–γ colliders
Technical issues to be addressed by specific R&D

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ILC: TDR available (2013), ready for construction

- Generation of ultra small (6nm) beam spot (70nm @ ATF/KEK)
- Target for polarized positrons

CLIC: CDR available (2012)

- If based on Two Beam Acceleration (TBA):
  - Same as ILC above (3nm beam spot)
  - Develop a technical design based on CDR
  - Optimisation of acceleration components and systems
  - Preparation of industrial procurements (series of accelerating structures and integrated Two-Beam modules)
- If based on Klystrons:
  - Cost optimisation and industrialisation of NCRF Xband (NLC/JLC) technology

γ–γ colliders

- Laser power and efficiency
- Optical cavity for gamma Ray generation of several joules with MHz repetition rates
- Gamma ray generation by (tapered) FEL with high efficiency (10%)
- Primary beam as FEL driver in SAPPHIRE
- RF guns with low emittance beam generation

Technical issues to be addressed by specific R&D

E+/E- circular colliders

- Handling of 100 MW synchrotron radiation losses issues
- RF power generation (high efficiency, RF couplers, Coupling impedance)
- Activation by high critical energy of synch. Rad.(1.5MeV)
- High beam current and collective instabilities (MCI)
- Beam-beam effects with large synch tune and small β_y
- Large energy acceptance (2-6%) for acceptable lifetime with strong beamstrahlung
- MDI with strong synchrotron radiation and background

Novel Acceleration Techniques
Technical issues to be addressed by specific R&D

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Muon Colliders:

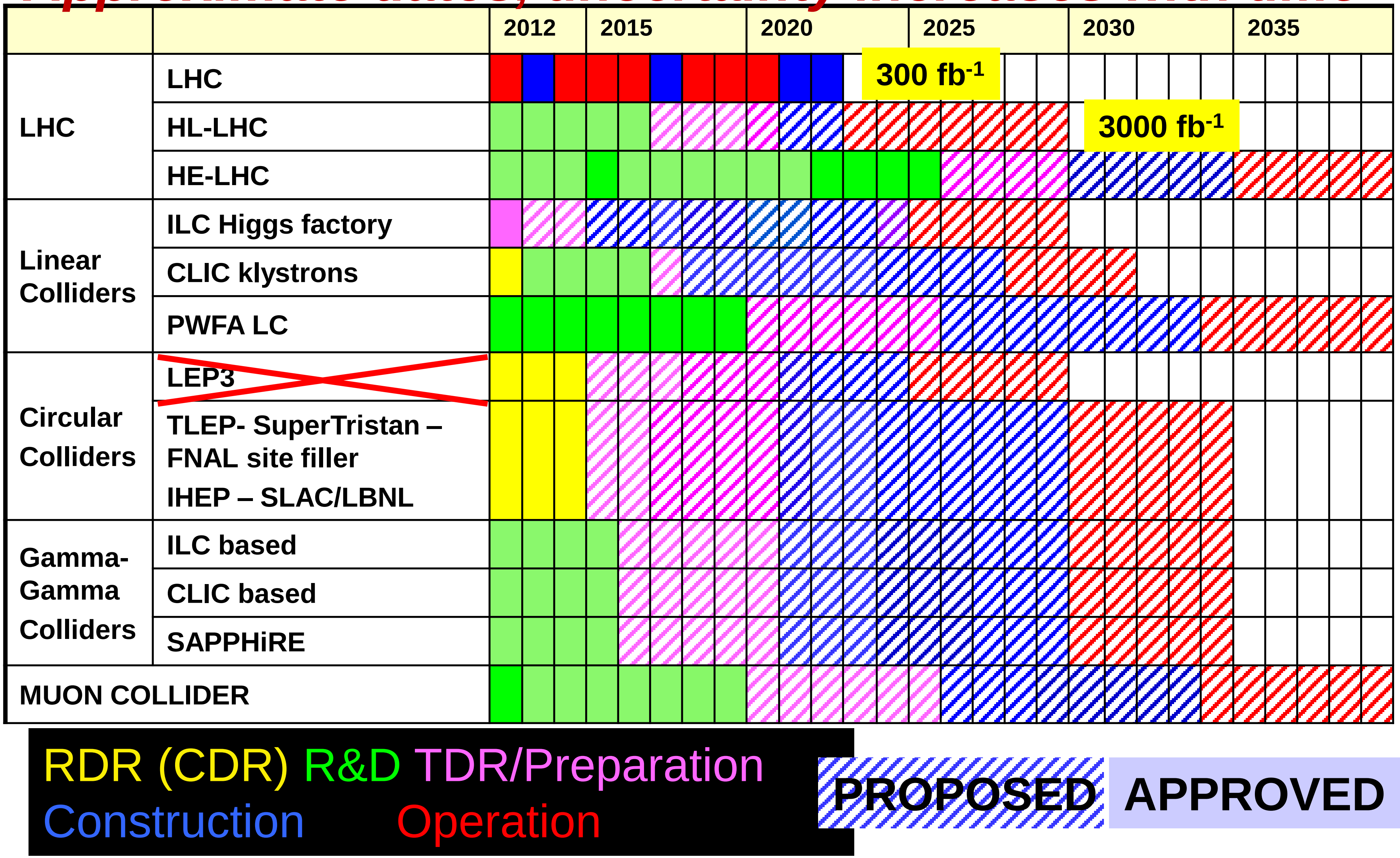
- High power (4MW) proton driver (Project X if at FNAL) and target
- Ionisation cooling (10^6=10^2 transverse and 10^4 longitudinal)
- Accelerating fields in low frequency RF cavities immersed in strong magnetic field
- Large field solenoids (15 to 20T)
- Low beam momentum spread (3.10^{-5}) and stability (10^{-5}) of collider at S resonance
- MDI and detector in high background environment
- Large background and activation due to Muon decays

Plasma based Accelerators (laser or beam driven)

- Drive to bunch acceleration with high gradient and low momentum spread
- Laser power and efficiency (laser driven)
- Laser (or drive beam) to plasma and plasma to main beam power transfer efficiency
- Emittance preservation during acceleration
- Multi-stage acceleration
- Alignment tolerances and instabilities (hose, head erosion)
- Positron acceleration

Timelines of Higgs Factory projects

Approximate dates, uncertainty increases with time



Higgs Factory Accelerator: Pros & Cons

	Linear Collider	Plasma Wakefield	Circular Collider	Muon Collider	$\gamma-\gamma$ Collider
Technical Maturity Proj launch/First beam	☺☺ 2015/2024	☹ 2027/2034	☺ 2018/2024	☹ 2027/2034	😐 2025/2035
Size (km)	☹ 13-20	☺ 2.5	☹ 20-80	☺ 1.5(0.3)	☺ 10
Cost	☹ 6-7	😐 ?	😐☹ ?-10	😐 ?	😐 ?
Power Consumption	☺ 128-235	☺ 133	☹ 300	😐 200	😐 ?
Energy Resolution	☹ 10^{-2}	☹ 10^{-2}	😐 ?	☺☺ 10^{-5}	☹ ?
Polarisation	☺☺ 80/30	☹ ?/?	☹ 0/0	😐 15-15	😐 ?/?
MDI	😐	😐	😐	☹ background	☹ laser
Energy (TeV) Upgradability	☺ 1-2	☺☺ 3	☹☹☺☺ 0.35e-/100 p+	☺☺ 3-6	☺ 1-2

Conclusion (personal)

- Consensus of lepton collider (e+/e- or μ+/ μ-) as precision facility after LHC
  - HIGGS factory logical first stage
- Several alternative technologies but none of them easy & cheap
- Long timeline before HIGGS factory beam available: ILC earliest by 2025
  - What will have been measured by LHC at the time? What left to be measured?
- Facility limited to HIGGS Physics not worth the (multiB$) investment?
  - HIGGS facility only makes sense as near term approach upgradable later to higher colliding beam energies as required by Physics
  - $\gamma\gamma$ colliders as add-on to linear colliders and e+/e- rings (too) limited in energy?
- Circular colliders with high integrated luminosity but power consuming and not upgradable in energy with electrons /positrons
  - Possible discovery facility (with Protons) expending energy frontier with (very large and expensive) circumference
- ILC mature technology and ready to build
  - expensive and limited in energy upgrade
  - Japanese initiative to build ILC not to be missed (if confirmed)
- CLIC only presently feasible technology to extend energy range into Multi-TeV
  - Power consuming
- Novel technologies very attractive (pending feasibility demonstration)
  - PWFA: high gradient and high efficiency: potential of low cost and power consumption
  - Muon Collider: High luminosity by multiturn and multi-IP, No beamstrahlung,
- R&D on novel technologies (Two-Beam, Plasmas, Muons..) strongly supported to extend colliding beam energy range as (possibly) required by Physics in the future at reasonable cost and power

Recommendation

Some issues too important to be left to Physicists and/or project leaders:

International Committee of “wise” and “independent” experts to fairly evaluate all projects on:

- **Power**
- **Cost**
- **Schedule**