La prossima Strategia Europea sulla Fisica delle Particelle

Materiale preso da vari talk, in particolare da A. Nisati e B. Mele

La European Strategy for Particle Physics

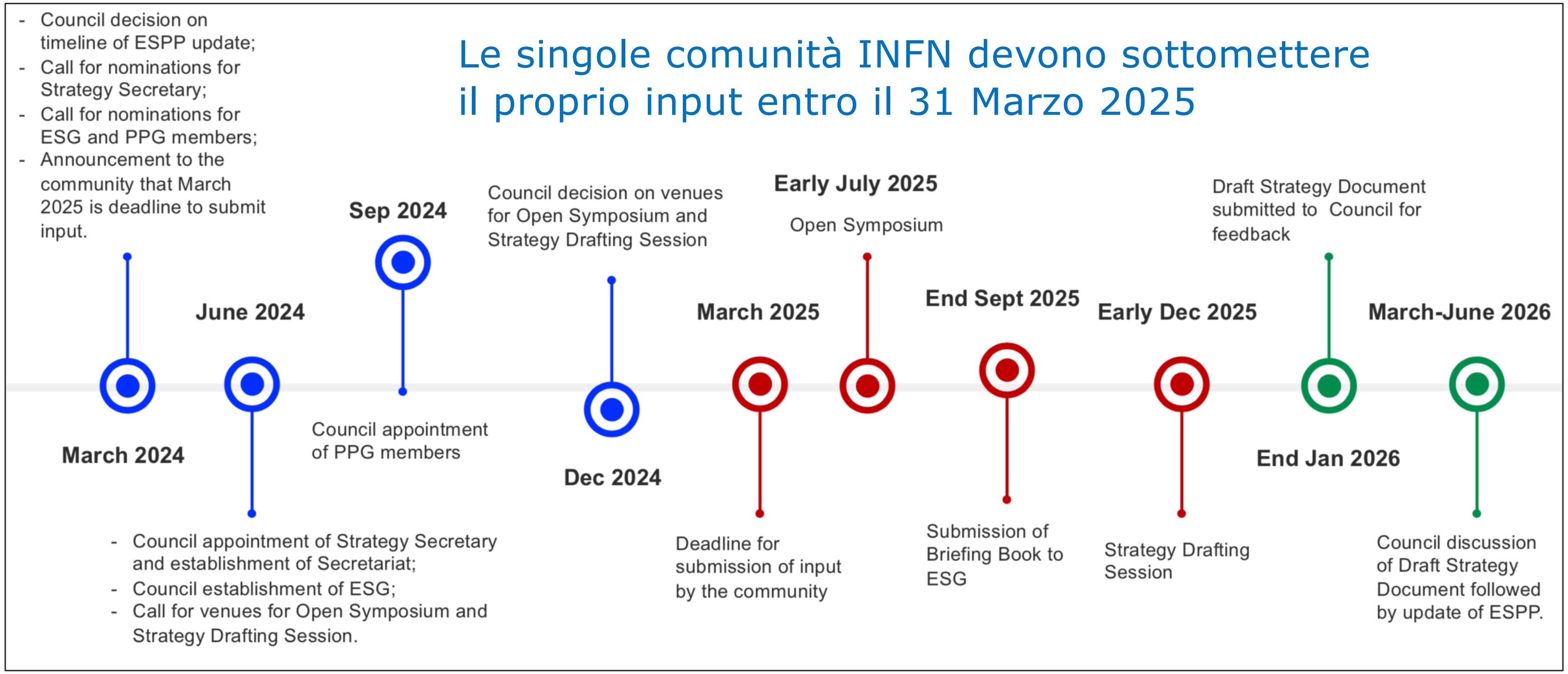
La European Strategy for Particle Physics fornisce un quadro completo per definire le priorità e la direzione della ricerca futura in Fisica delle Particelle in Europa. E` un processo coordinato dal CERN.

- si prefigge di guidare le decisioni scientifiche, tecnologiche e finanziarie in Europa;
- ha un impatto su scala globale per via delle collaborazioni internazionali e per via dell'impatto che sia il CERN sia L'Europa hanno sulla ricerca fondamentale (vedi punti sottostanti)
  - Complementarietà: Il settore della fisica nucleare e delle astroparticle beneficerà dei risultati di HL-LHC e FCC;
  - Sinergia: la fisica del neutrino non è attualmente nei programmi del CERN ma con la Neutrino Platform il CERN contribuisce a sviluppare la tecnologia che serve per l'esperimento DUNE;
  - Convergenze di interessi: nell'attuale Report P5 (US) si cita che le priorità sono DUNE, CMB, EIC, ma si prevede un contributo offshore alle Higgs factories che verranno fatte in Europa;
- E` un processo portato avanti ogni 7-8 anni, basato su ampie consultazioni con la comunità Scientifica, con gli Stackeholder e le Istituzioni rilevanti (di cui l'INFN fa parte) per essere sicuri che rifletta gli avanzamenti nel campo scientifico e tecnologico più aggiornati e che si occupi delle sfide emergenti;
- Predilige un approccio «bottom-up»; gli enti finanziatori svolgono un ruolo principale ma anche i singoli individui possono sottomettere un input alla strategy;

Il processo di aggiornamento e la sua sequenza temporale

2024: year of preparation, establishments of committees, choice of locations for the various meetings
2025: submission of scientific inputs, Open Symposium, drafting of the strategic document
2026 discussion at Council and Strategy update *(in 2027/2028 Council decides…)*

Le singole comunità INFN devono sottomettere il proprio input entro il 31 Marzo 2025



Strategy Secretariat: organising and running the ESPP process

Strategy Secretary (K. Jakobs.)
Paris Sphicas (ECFA Chair)
Hugh Montgomery (SPC Chair)
Dave Newbold (LDG Chair)

European Strategy Group (ESG): Prepares the Strategy Document

Physics Preparatory Group (PPG): collects input from the community, organises the Open Symposium, prepares the Briefing Book

Inputs from the community will be reviewed by **ESG**: careful and rigorous study of the documentation provided, i.e of the Briefing Book drafted by **PPG** with support of the **Strategy Secretariat**

Open Symposium 23-27 June 2025 - Lido di Venezia ! I do hope to see you there …..

INFN Istituto Nazionale di Fisica Nucleare

Struttura logica dell'Input richiesto

Indicare la macchina acceleratrice preferita per la futura ricerca in fisica delle particelle

Cosa fare se
- ILC realizzato tempestivamente
- CEPC costruito nella timescale annunciata;
- US decide di costruire il Muon Collider;
- Risultati inaspettati da HL-LHC

Motivazioni più importanti per la scelta
- Potenziale di fisica
- Prospettive a lungo termine
- Risorse finanziarie e umane,
- implicazioni per altri progetti
- Tempistica
- Carriere e formazione
- Sostenibilità

Cosa fare se non è realizzabile
- a causa dei costi elevate;
- a causa della scala temporale lunga;
- a causa della situazione geopolitica;
- per alter ragionj

Continuare con l'opzione preferita

progetto alternativo a)

progetto alternativo b)

Quali altre aree della fisica il CERN dovrebbe perseguire e con quale priorità relativa?

In che misura il CERN dovrebbe partecipare alla fisica nucleare, alla fisica astroparticellare o ad altri settori della scienza?

European Particle Physics Strategy Update 2024 – 2026

HOME ABOUT PROCESS SUBMITTED INPUT ORGANISATION RESOURCES

Welcome

The European Strategy for Particle Physics is the cornerstone of Europe's strategy-setting process for the long-term future of the field. Mandated by the CERN Council, the Strategy takes into account results from the LHC and other facilities in the world, the international physics landscape and developments in related fields with the aim to maximise scientific returns.

In March 2024, the CERN Council launched the process for the third update of the Strategy. The European Strategy Group (ESG) and the Strategy Secretariat for this update were established in June 2024 to organise the full process. The remit of the European Strategy Group was also approved in June 2024.

The Strategy update process is expected to converge by January 2026, when an draft Strategy document will be submitted to the Council. The community at large will be involved during the full process and is asked to provide input at several stages.

RELATED WEBSITES

- The European Strategy for Particle Physics
- CERN Council
- European Committee for Future Accelerators (ECFA)
- European Strategy Forum on Research Infrastructures (ESFRI)

contact: eppsu.2024@cern.ch

La home page della prossima Strategy si trova a questo link:
https://europeanstrategyupdate.web.cern.ch/welcome

Come procede l'INFN

- Workshop INFN 6 e 7 Maggio sulla strategia
  - è consistente con quanto presentato e discusso da Segretariato ESPP e ECFA al meeting di LNF.
  - dobbiamo fare del lavoro ulteriore per elaborare le opzioni sui progetti alternativi

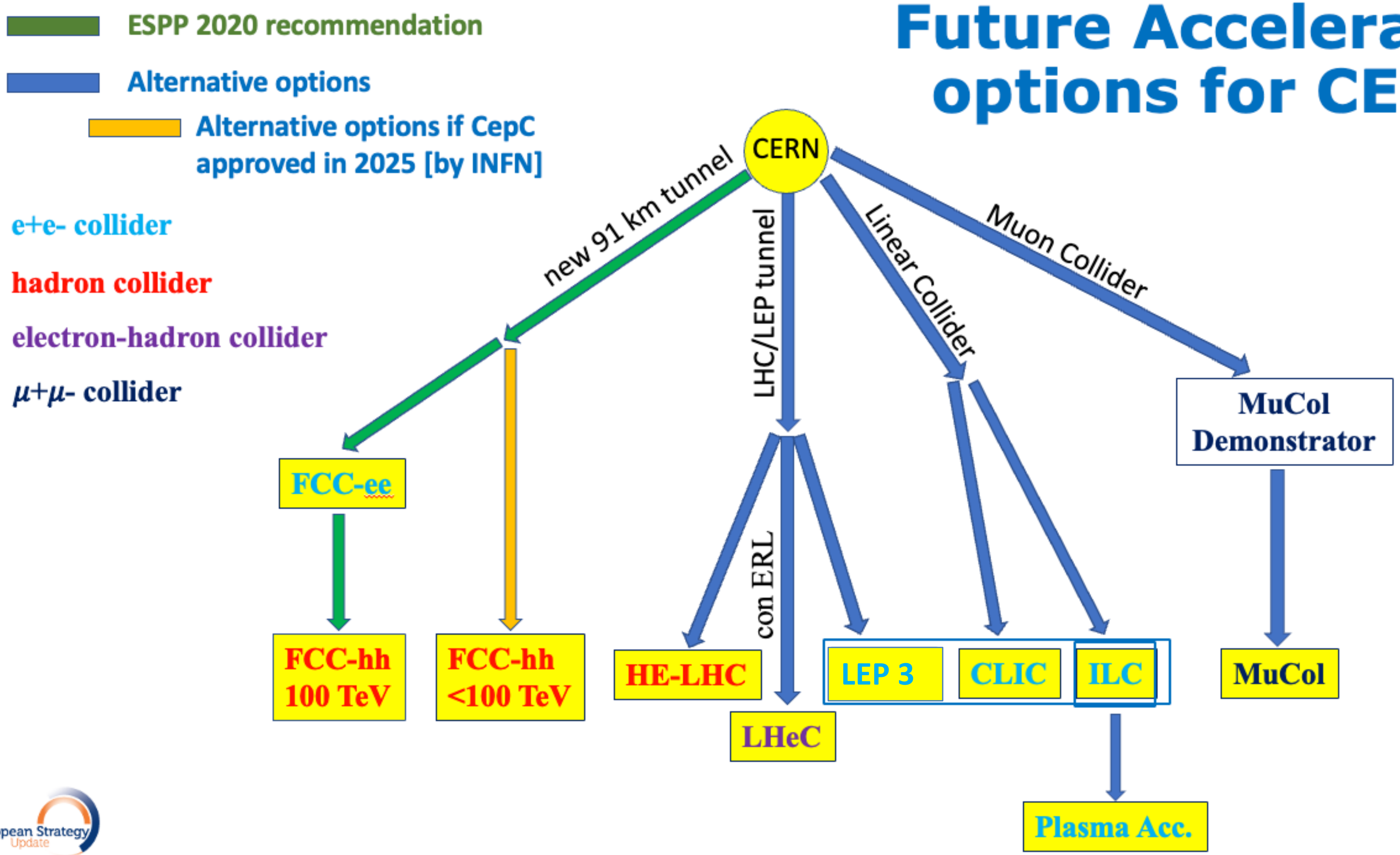
- La preparazione dei documenti che si pensa di utilizzare come Input alla prossima ESPP è in linea con quanto richiesto o suggerito. Verranno preparati da uno Steering Group (Borca, Nisati, Malvezzi, Ciuchini, Tenchini) + un gruppo di lavoro (GdL) composto dai presidenti delle CSN, i Direttori dei Laboratori, il coordinatore del MAC e un rappresentante del calcolo.

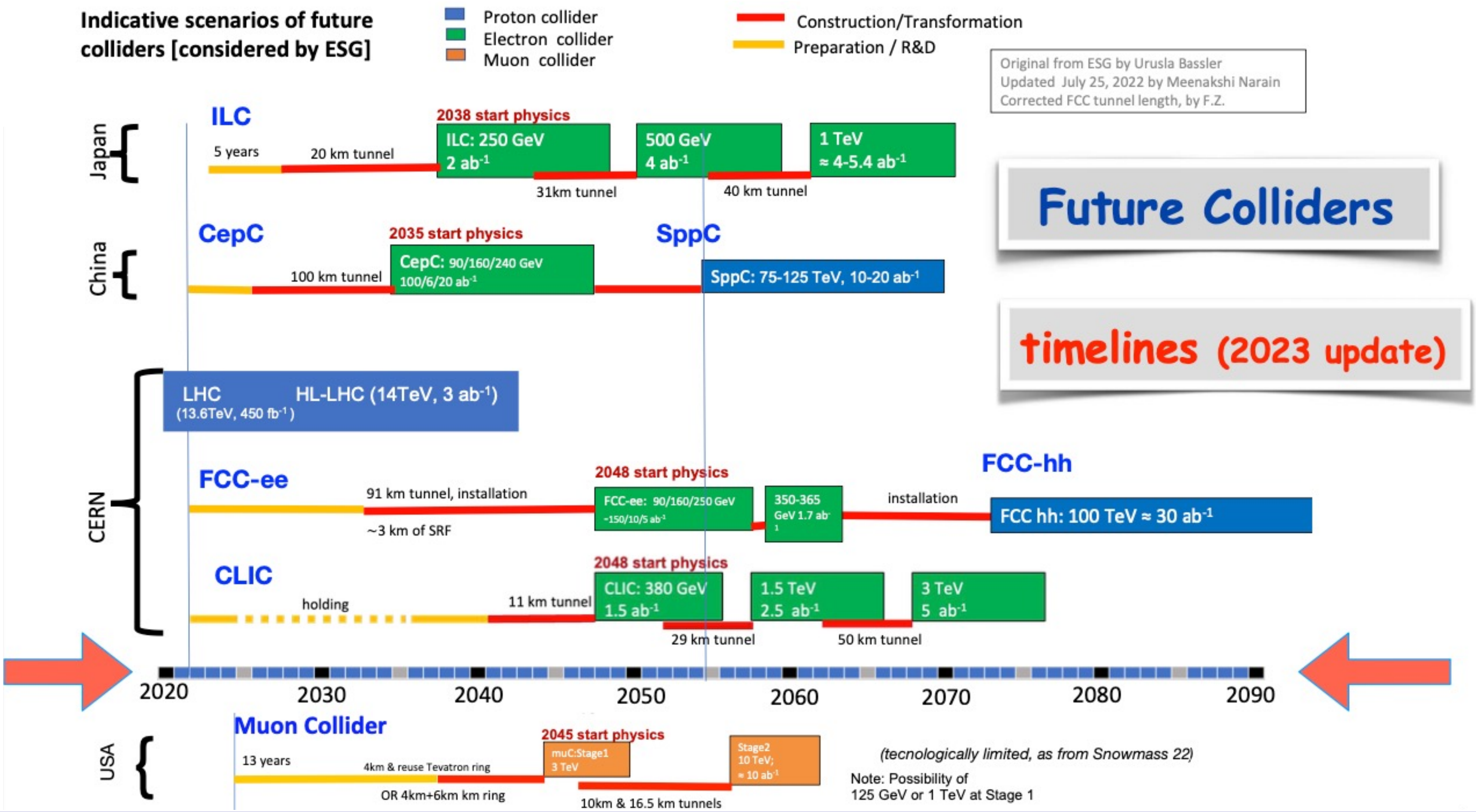
- Ulteriori affinamenti del documento di *Input* principale terranno conto delle discussioni che hanno e avranno luogo presso i Laboratori Nazionali, le Sezioni e le Commissioni Scientifiche;

- Sottometteremo entro il 31 Marzo 2025 i nostri documenti di Input. Il documento principale lo vorremmo sottomette insieme a tutti gli altri. Il Management INFN valuterà se sarà necessario un aggiornamento da parte nostra, da sottomettere dopo il Briefing Book e prima della Drafting Session.

- Riunioni svolte e previste dello Steering con il GdL, previsto anche un evento pubblico finale il 4 Febbraio 2025 a Milano – da confermare!
  - possibili riunioni anche dopo il Simposio e prima della riunione dell' ESG

Future Accelerator options for CERN




Indicative scenarios of future colliders [considered by ESG]
Proton collider
Electron collider
Muon collider
Construction/Transformation
Preparation / R&D
Original from ESG by Urusla Bassler
Updated July 25, 2022 by Meenakshi Narain
Corrected FCC tunnel length, by F.Z.
Future Colliders
timelines (2023 update)
Japan
ILC
5 years
20 km tunnel
2038 start physics
ILC: 250 GeV 2 ab-1
31km tunnel
500 GeV 4 ab-1
40 km tunnel
1 TeV ≈ 4-5.4 ab-1
China
CepC
100 km tunnel
2035 start physics
CepC: 90/160/240 GeV 100/6/20 ab-1
SppC
SppC: 75-125 TeV, 10-20 ab-1
CERN
LHC (13.6TeV, 450 fb-1)
HL-LHC (14TeV, 3 ab-1)
FCC-ee
91 km tunnel, installation
~3 km of SRF
2048 start physics
FCC-ee: 90/160/250 GeV ~150/10/5 ab-1
350-365 GeV 1.7 ab-1
installation
FCC-hh
FCC hh: 100 TeV ≈ 30 ab-1
CLIC
holding
11 km tunnel
2048 start physics
CLIC: 380 GeV 1.5 ab-1
29 km tunnel
1.5 TeV 2.5 ab-1
50 km tunnel
3 TeV 5 ab-1
2020
2030
2040
2050
2060
2070
2080
2090
USA
Muon Collider
13 years
4km & reuse Tevatron ring
OR 4km+6km km ring
2045 start physics
muC:Stage1 3 TeV
10km & 16.5 km tunnels
Stage2 10 TeV; ≈ 10 ab-1
(tecnologically limited, as from Snowmass 22)
Note: Possibility of 125 GeV or 1 TeV at Stage 1

Caso di fisica aperto

Da **LHC** + [**HL-LHC**] → **lo Standard Model funziona!**

- l'enorme quantità di dati dell'LHC si adatta alle previsioni del SM con un livello di precisione sorprendente;
- nessun accenno di nuova fisica;
- i limiti su nuovi stati pesante previsti da molti modelli sono stati ampiamente estesi;
- le versioni più semplici dei modelli BSM sembrano tunate sui dati;

ma ....

- esistono fenomeni "esterni"

(Quantum?) Gravity + evidenze empiriche
- Dark Matter
- Baryon Asimmetry
- Neutrino Masses

- mancanza di consistenza interna
  - dovuta principalmente al settore EWSB/Higgs

Come risolvere?

Quattro settori principali per la ricerca ai collider

1. esplorare le caratteristiche del settore di Higgs che possano confermare o smentire le previsioni dello Standard Model (rilevanza primaria poiché il settore di Higgs è critico!);
2. cercare nuovi stati pesanti accoppiati a SM (agiscono come cut-off per il modello, possibilmente risolvono il problema della naturalezza e spiegano qualche altro fenomeno, e.s dark matter);
3. cercare nuovi stati "DARK", ossia disaccoppiati a tree-level, sia in produzione sia come decadimenti di stati pesanti (H, top...); producono segnature elusive e long-lived.
4. esplorare effetti indiretti $\Lambda \gg O(1TeV)$ attraverso studi di alta precisione di sezioni d'urto / distribuzioni SM e ricerche di processi rari (parametrizzazione EFT)

Ogni singolo metodo è di importanza fondamentale per fare progressi!

I collider e^+e^- offrono grandi opportunità in tutti i settori:

chiarezza nell'ambiente sperimentale, accuratezza e possibilità di fare misure model independent

C'è un consenso generale sul fatto che un e^+e^- Higgs Factory è il prossimo collider che deve essere costruito!

Precisione necessaria per le misure sull'HIGGS

Impatto dei modelli BSM sui coupling dell'Higgs all'ordine piu` alto

- Pochi percento nei modelli che prevedono stati pesanti non accessibili alle energie LHC

	$\Delta g(hVV)$	$\Delta g(ht\bar{t})$	$\Delta g(hb\bar{b})$
Composite Higgs	10%	tens of %	tens of %
Minimal Supersymmetry	< 1%	3%	tens of %
Mixed-in Singlet	6%	6%	6%

- Il tipo di deviazione varia a secondo del modello

	Model	$b\bar{b}$	$c\bar{c}$	gg	WW	$\tau\tau$	ZZ	$\gamma\gamma$	$\mu\mu$
1	MSSM [38]	+4.8	-0.8	- 0.8	-0.2	+0.4	-0.5	+0.1	+0.3
2	Type II 2HD [39]	+10.1	-0.2	-0.2	0.0	+9.8	0.0	+0.1	+9.8
3	Type X 2HD [39]	-0.2	-0.2	-0.2	0.0	+7.8	0.0	0.0	+7.8
4	Type Y 2HD [39]	+10.1	-0.2	-0.2	0.0	-0.2	0.0	0.1	-0.2
5	Composite Higgs [40]	-6.4	-6.4	-6.4	-2.1	-6.4	-2.1	-2.1	-6.4
6	Little Higgs w. T-parity [41]	0.0	0.0	-6.1	-2.5	0.0	-2.5	-1.5	0.0
7	Little Higgs w. T-parity [42]	-7.8	-4.6	-3.5	-1.5	-7.8	-1.5	-1.0	-7.8
8	Higgs-Radion [43]	-1.5	- 1.5	+10.	-1.5	-1.5	-1.5	-1.0	-1.5
9	Higgs Singlet [44]	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5

arXiv:1710.07621

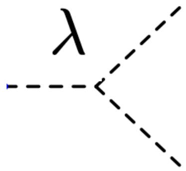
Impatto sul coupling trilineare

Il coupling trilineare è il più esposto ai modelli di fisica BSM.

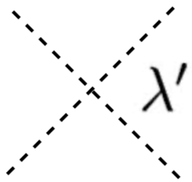
ha impatto sulla bariogenesi, sulla stabilità del vuoto e sulla EWPT cosmologica;

- La misura ha bisogno di:

coppie di HH



oppure HHH



accessibile a HL-LHC ?

sezioni d'urto minuscule, necessaria alta luminosità

massima deviazione di λ compatibile con nessuna fisica BSM

da qualche % a 20%

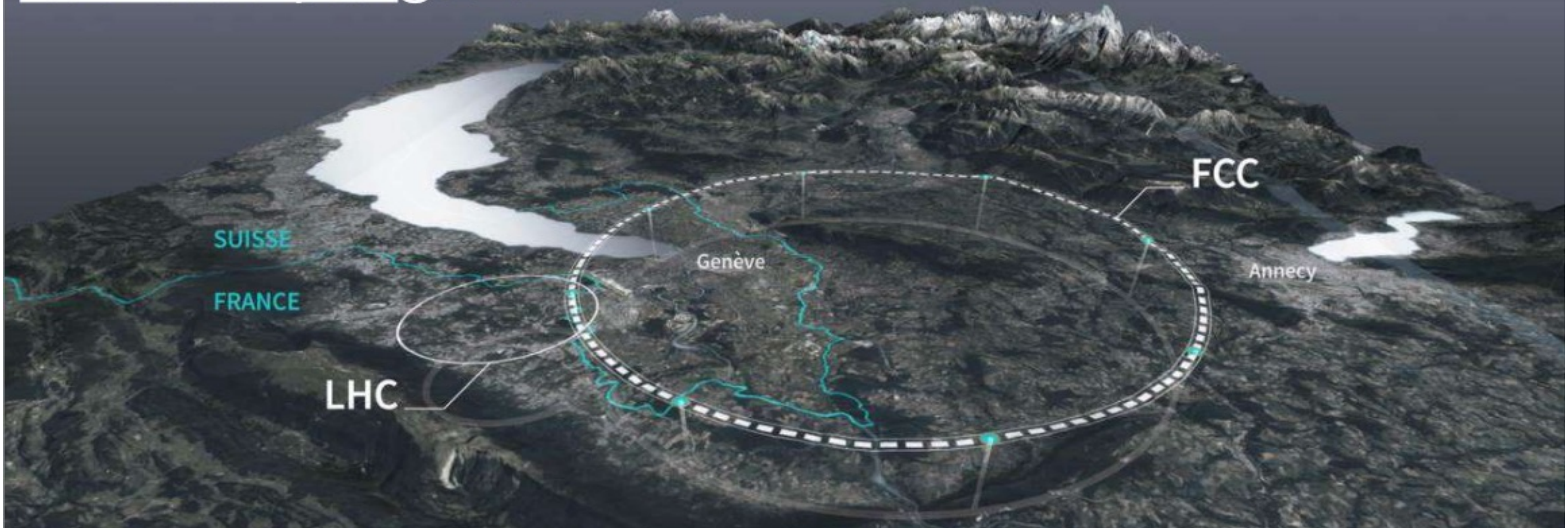
target per la teoria e le misure

Model	$\Delta g_{hhh}/g_{hhh}^{SM}$
Mixed-in Singlet	$-18\,\%$
Composite Higgs	tens of %
Minimal Supersymmetry	$-2\,\%^{a}$ $-15\,\%^{b}$
NMSSM	$-25\,\%$

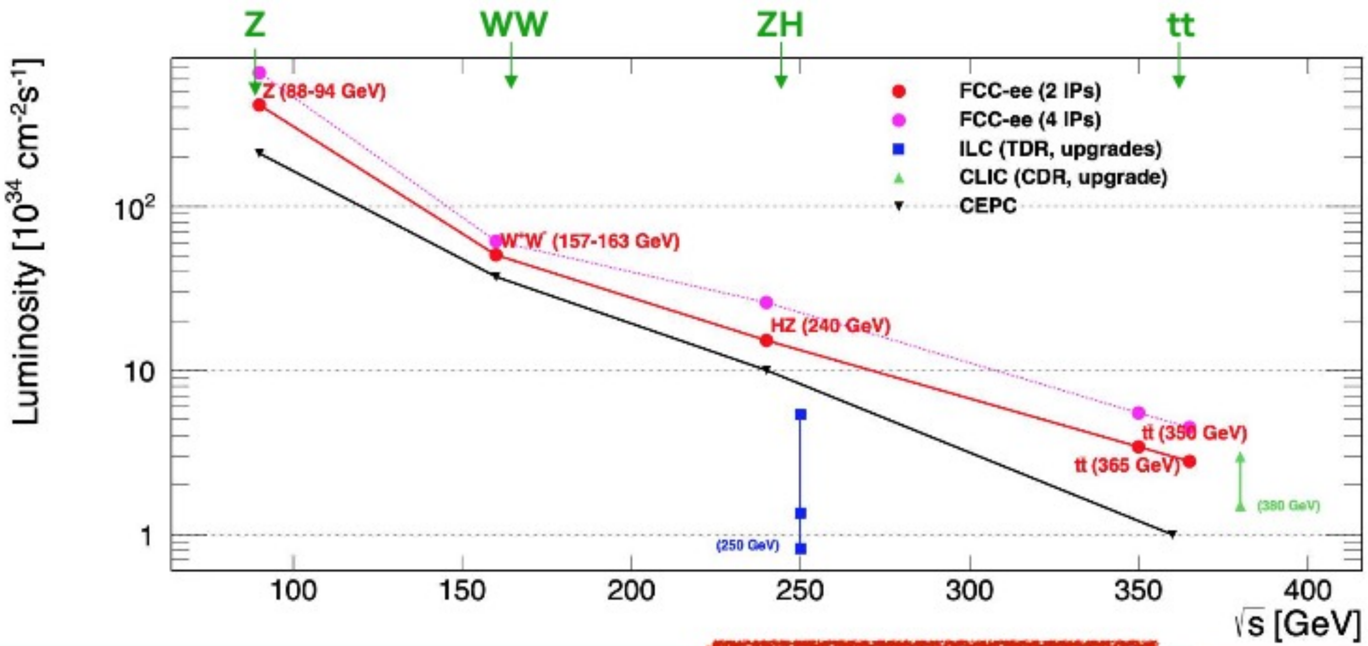
1395.6397

FCC research infrastructure for the 21st century

A new 91 km tunnel to host multiple colliders
100 – 300 m under ground, 8 surface sites
FCC-ee: electron-positron @ 91, 160, 240, 365 GeV
FCC-hh: proton-proton @ 100 TeV, and heavy-ions (Pb) @39 TeV
FCC-eh: electron-proton@ 3.5 TeV



FCC-ee: luminosità e numero di eventi a differenti stage



					√s errors
ZH maximum	√s ~ 240 GeV	3 years	10^6 $e^+e^- \to ZH$	Never done	2 MeV
$\bar{t}t$ threshold	√s ~ 350 GeV	5 years	10^6 $e^+e^- \to t\bar{t}$	Never done	5 MeV
Z peak	√s ~ 91 GeV	4 years	5×10^{12} $e^+e^- \to Z$	LEP x 10^5	< 100 keV
WW threshold+	√s ≥ 161 GeV	2 years	$> 10^8$ $e^+e^- \to W^+W^-$	LEP x 10^3	< 300 keV
s-channel H	√s = 125 GeV	? Years	~5000 $e^+e^- \to H$	Never done	< 200 keV

Event statistics (with 2 IPs, x1.7 for 4 IPs)

exact sequence and duration for stages to be elaborated !

in each detector:
10^5 Z/sec, 10^4 W/hour,
1500 Higgs/day, 1500 top/day

FCC verso Cepc

Energy ($\sqrt{s}$)	$\mathcal{L}_{\text{int}}$ (Run time)		$\mathcal{L}_{\text{FCC-ee}}/\mathcal{L}_{\text{CEPC}}$
	FCC-ee (4 IPs)	CEPC (2 IPs)	
91 GeV (Z-pole)	300 ab^{-1} (4 years)	100 ab^{-1} (2 years)	3
161 GeV ($2\,m_W$)	20 ab^{-1} (2 years)	6 ab^{-1} (1 year)	3.3
240 GeV	10 ab^{-1} (3 years)	20 ab^{-1} (10 years)	0.5
350 GeV	0.4 ab^{-1} (1 year)	0.2 ab^{-1}	2
365 GeV ($2\,m_t$)	3 ab^{-1} (4 years)	1 ab^{-1} (5 years)	3

plus two well know collision setups at hugely higher statistics !!

*** "intensity frontier" : $e^+e^- \rightarrow$ Z, WW [→ super LEP]**

*** EW & QCD** →

- m_Z, Γ_Z, N_ν
- R_l, A_{FB}
- m_W, Γ_W
- $\alpha_S(m_Z)$ with per-mil accuracy
- Quark and gluon fragmentation
- Clean non-perturbative QCD studies

*** direct searches of "light new physics"** →

- Axion-like particles, dark photons, Heavy Neutral Leptons
- long lifetimes - LLPs

*** Flavor Factory (Z → 10^{12} bb/cc; $1.7\times10^{11}\tau\tau$)**

*** B physics** →

- Flavour EWPOs (R_b, $A_{FB}^{b,c}$)
- CKM matrix,
- CP violation in neutral B mesons
- Flavour anomalies in, e.g., $b \rightarrow s\tau\tau$

tau physics →

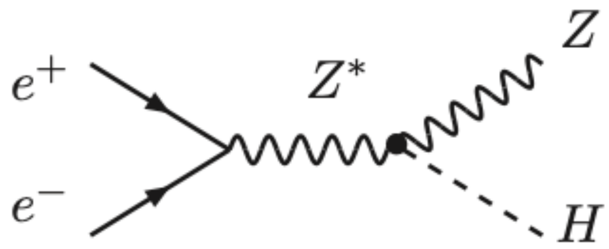
- τ-based EWPOs
- lept. univ. violation tests

→ Belle II x 15

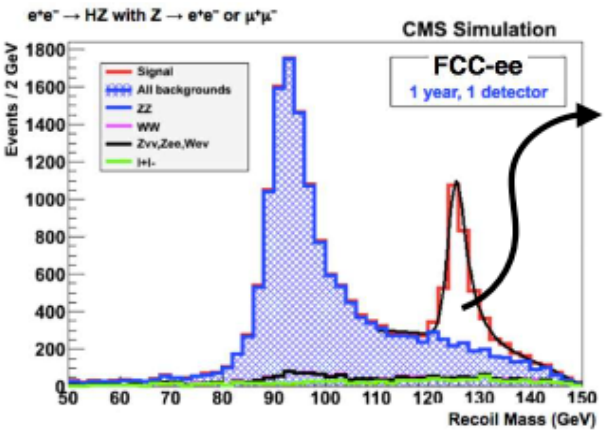
$ee \rightarrow HZ$ allows model-independent g_{HXX} measurem.s

- selected by just identifying Z decay products
  → absolute σ_{tot} ($\sim g_{HZZ}^2$) measurement → model independent g_{HZZ}

> by identifying Higgs final states X
> → absolute measurement of BR_X
> → g_{HXX}



- direct access to invisible H decays, $H \rightarrow cc$, $H \rightarrow ss$ (?), $H \rightarrow gg$



N(ZH) ∝ σ(ZH) ∝ g_{HZZ}^2

Coupling	HL-LHC	FCC-ee (240–365 GeV) 2 IPs / 4 IPs
κ_W [%]	1.5*	0.43 / 0.33
κ_Z [%]	1.3*	0.17 / 0.14
κ_g [%]	2*	0.90 / 0.77
κ_γ [%]	1.6*	1.3 / 1.2
$\kappa_{Z\gamma}$ [%]	10*	10 / 10
κ_c [%]	–	1.3 / 1.1
κ_t [%]	3.2*	3.1 / 3.1
κ_b [%]	2.5*	0.64 / 0.56
κ_μ [%]	4.4*	3.9 / 3.7
κ_τ [%]	1.6*	0.66 / 0.55
BR_{inv} (<%, 95% CL)	1.9*	0.20 / 0.15
BR_{unt} (<%, 95% CL)	4*	1.0 / 0.88

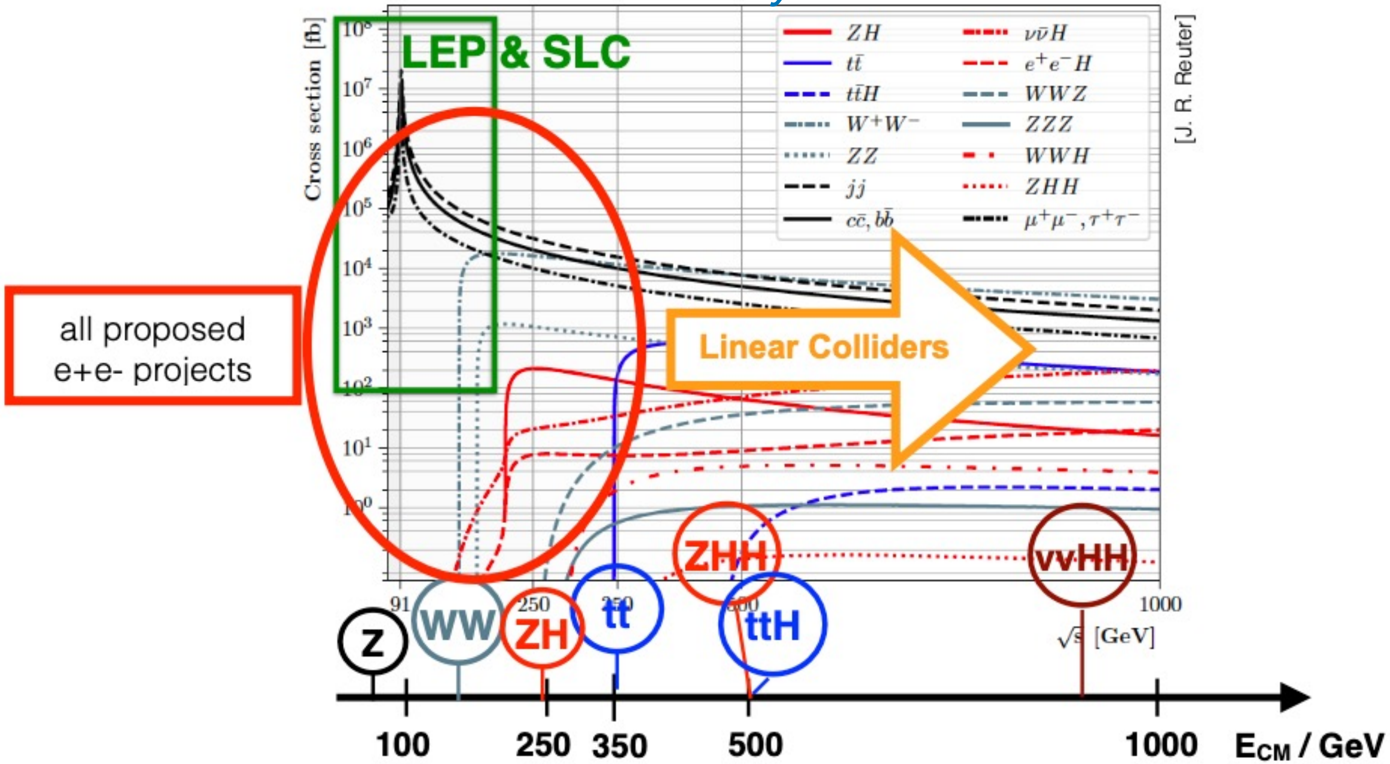
1905.03764 + 4 IP

- sub-% accuracy of couplings to W, Z, b, τ
- % accuracy of couplings to gluon and charm

Energia e luminosità

- I linear collider hanno luminosità più bassa;
- Possono avere I fasci polarizzati;
- Possono raggiungere energie nel CM più elevate;

by J.List at LCWS2024

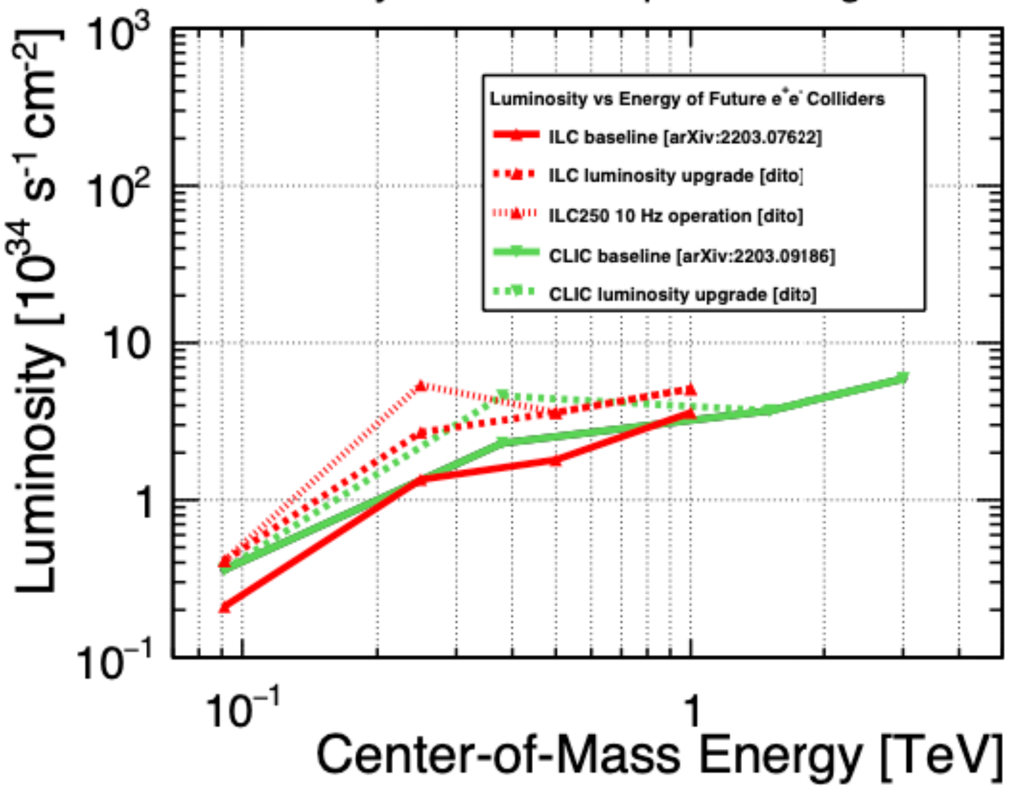


Machine	Pol. (e^-, e^+)	Energy	Luminosity
HL-LHC	Unpolarised	14 TeV	3 ab^{-1}
ILC	$(\mp 80\%, \pm 30\%)$	250 GeV	2 ab^{-1}
		350 GeV	0.2 ab^{-1}
		500 GeV	4 ab^{-1}
	$(\mp 80\%, \pm 20\%)$	1 TeV	8 ab^{-1}
CLIC	$(\pm 80\%, 0\%)$	380 GeV	1 ab^{-1}
		1.5 TeV	2.5 ab^{-1}
		3 TeV	5 ab^{-1}
FCC-*ee*	Unpolarised	Z-pole	150 ab^{-1}
		$2m_W$	10 ab^{-1}
		240 GeV	5 ab^{-1}
		350 GeV	0.2 ab^{-1}
		365 GeV	1.5 ab^{-1}
CEPC	Unpolarised	Z-pole	100 ab^{-1}
		$2m_W$	6 ab^{-1}
		240 GeV	20 ab^{-1}
		350 GeV	0.2 ab^{-1}
		360 GeV	1 ab^{-1}
MuC	Unpolarised	125 GeV	0.02 ab^{-1}
		3 TeV	3 ab^{-1}
		10 TeV	10 ab^{-1}

Scenario per un collisore lineare

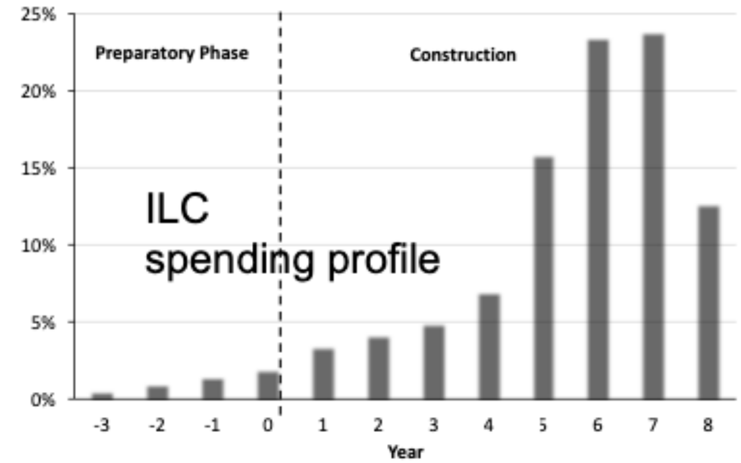
- **250 GeV, ~2ab-1:**
  - precision Higgs mass and total ZH cross-section
  - Higgs -> invisible (Dark Sector portal)
  - basic ffbar and WW program
  - optional: WW threshold scan
- **Z pole, few billion Z's: EWPOs 10-100x better than today**
- **350 GeV, 200 fb-1:**
  - precision top mass from threshold scan
- **500…600 GeV, 4 ab-1:**
  - **Higgs self-coupling in ZHH**
  - **top quark ew couplings**
  - **top Yukawa coupling incl CP structure**
  - improved Higgs, WW and ffbar
  - probe Higgsinos up to ~300 GeV
  - probe Heavy Neutral Leptons up to ~600 GeV
- **800…1000 GeV, 8 ab-1:**
  - Higgs self-coupling in VBF
  - further improvements in tt, ff, WW, ….
  - probe Higgsinos up to ~500 GeV
  - **probe Heavy Neutral Leptons up to ~1000 GeV**
  - searches, searches, searches, …

Based on classic ILC/CLIC luminosity assumptions limited by self-allowed power budget

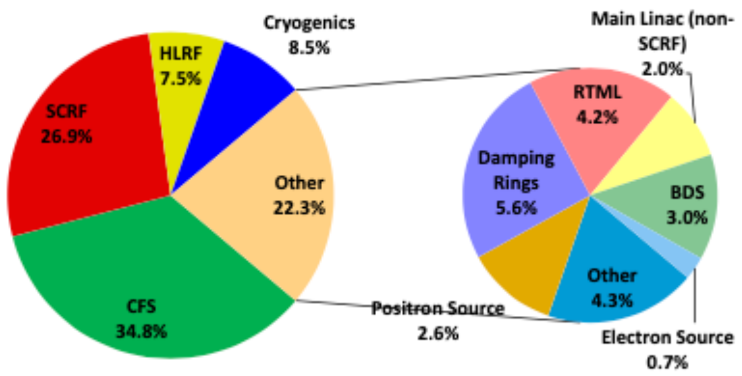


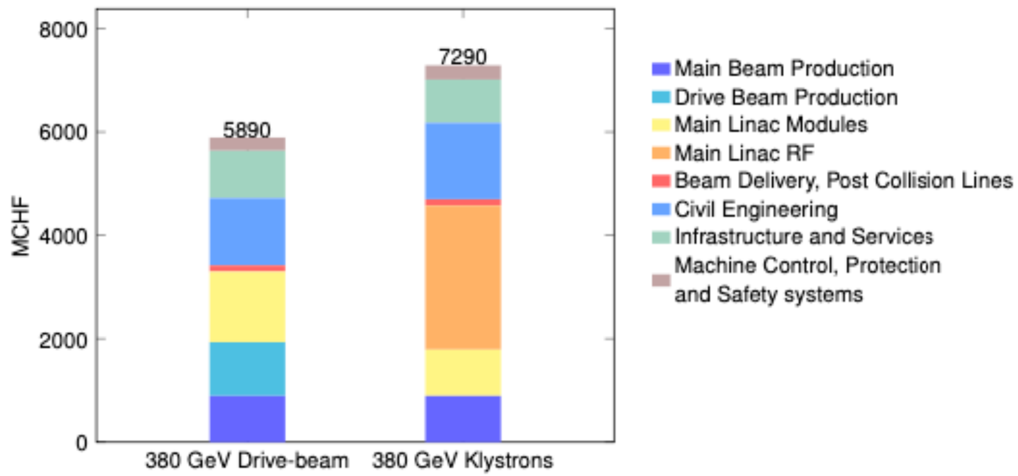
Stima costi dei Linear Collider

- **Cost estimates are being updated - stay tuned….**
- old (!) existing costings (European accounting):
    - CLIC500 (CDR, 2010): **7.4 BCHF**
    - ILC500 (TDR, 2012): **8 BILCU** (ILCU = US$ in 2012)
    - CLIC380 (drive-beam / klystron, EPPSU 2018): **5.9 / 7.3 BCHF**
    - ILC250 (EPPSU 2018): **5 BILCU**
- **CLIC380 has been shown to be financiable from CERN budget over construction time** (CLIC Project Implementation Plan 2018)



Primary cost drivers for the ILC





Let's assume we find a deviation in H couplings…

deviaton from SM : $\delta_i \sim v^2/M^2$ (M scale of New Physics)

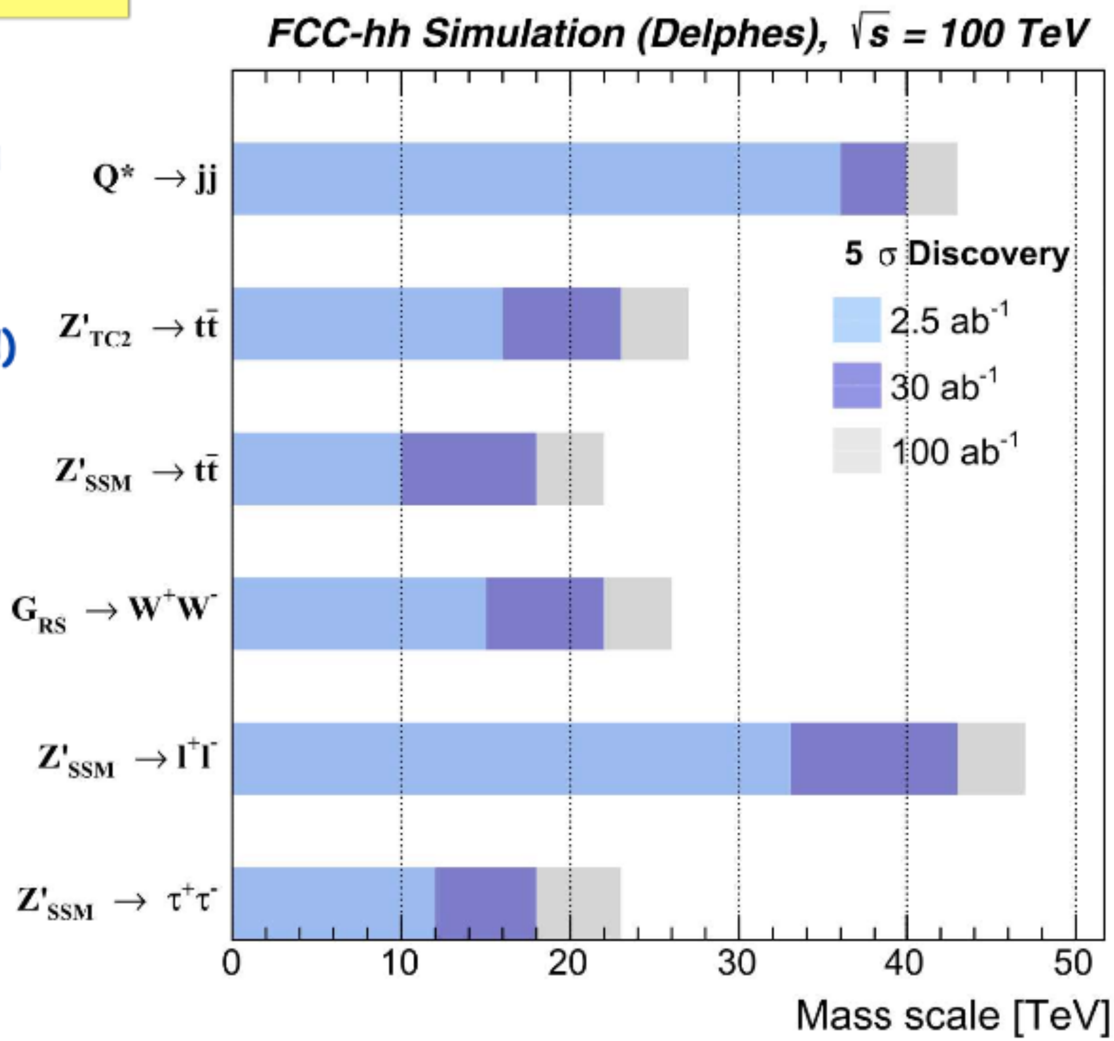
$\delta_i \sim$ [6-0.06] % ➜ M ~ [1-10] TeV

- in order to figure out what's going on we will need an energy-frontier facility to explore the corresponding M scale in a direct way
- R&D for future high-energy colliders needed (new technologies ?)
  FCC-hh [natural follow-on to FCC-ee]
  higher energy linear collider ? multi-TeV muon collider ?
  plasma acceleration ?

FCC-hh : 30 ab^{-1} at ~100 TeV

Resonance production

- mass reach in BSM searches ~ (4÷6) x $M_{[HL-LHC]}$
- for multiple-heavy-p.le final states n(H,W,Z,t) N_{100}/N_{14} >100 (e.g. ~500 for ttH, ~400 for HH)
- large Higgs rates (>10^{10}H, >10^7 HH)
- unique sensitivity to rear decays
- explores extreme (clean) phase-space with high statistics
- much higher gain at high-P_T and large invariant masses !



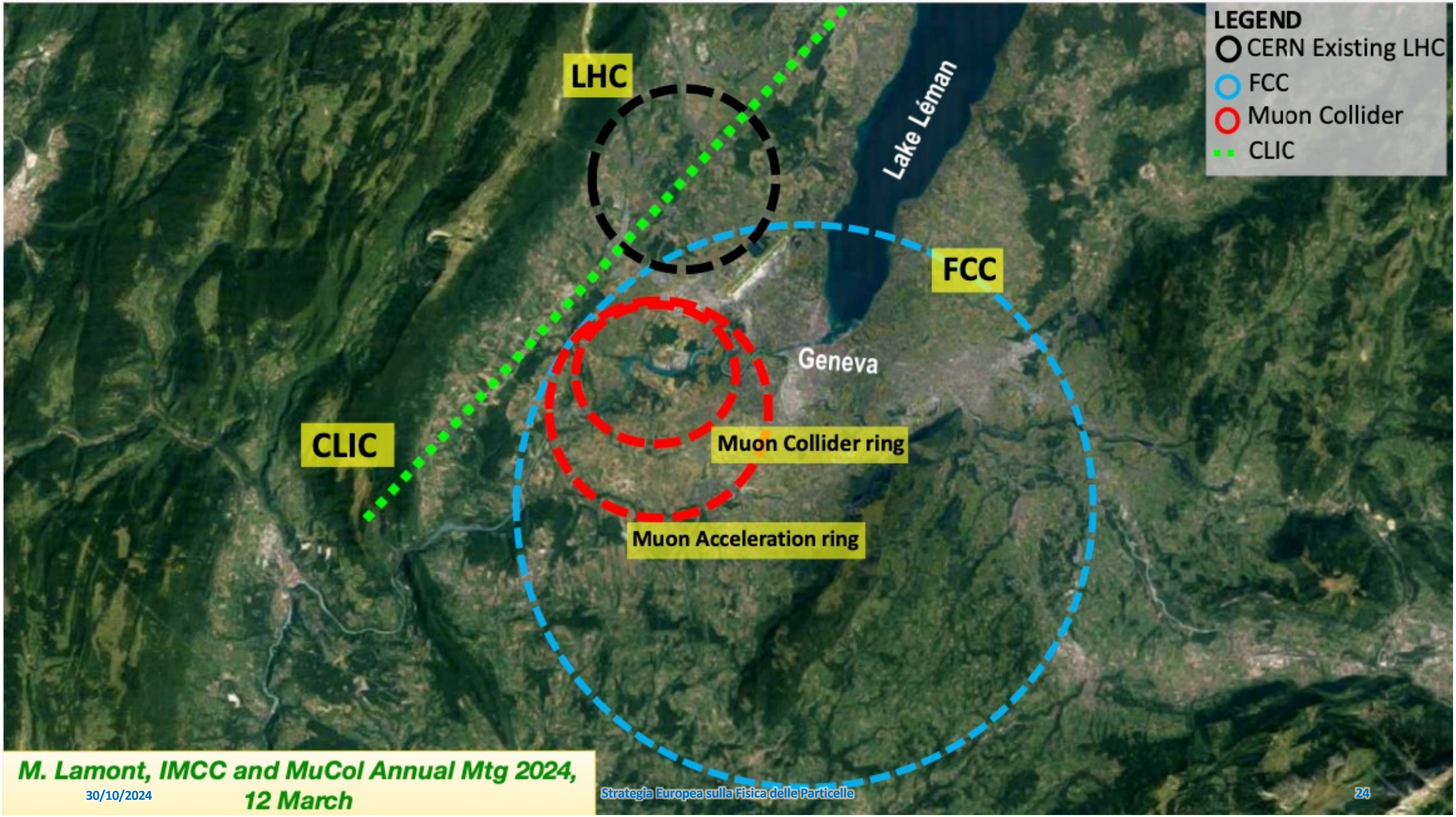
Collider options FCC-hh

FUTURE CIRCULAR COLLIDER

name	F12LL	F12HL	F12PU	F14	F17	F20
√s (TeV)	72	72	72	84	102	120
current (A)	0.5	1.12	1.12	0.5	0.5	0.2
PU	600	3000	1000	600	700	150
SR power (MW) 2 beams	1.3	2.9	2.9	2.4	5.2	4.0
Lumi/yr (ab-1)	1	2	1.3	0.9	0.9	0.4

Limiting factor: 5MW synchrotron power

M. Selvaggi FCC-hh Studies for the next European Strategy: kickoff meeting 3 Sept 2024


LEGEND
CERN Existing LHC
FCC
Muon Collider
CLIC
LHC
Lake Léman
FCC
Geneva
CLIC
Muon Collider ring
Muon Acceleration ring
M. Lamont, IMCC and MuCol Annual Mtg 2024, 12 March

μ^+ → ← μ^-

$\sqrt{S_{\mu\mu}}$ ~ 10+ TeV

$$\mathcal{L} = (E_{\rm CM}/10\ \text{TeV})^2 \times 10\,\text{ab}^{-1}$$

point x-section
(~ rate for new p.le pair production)

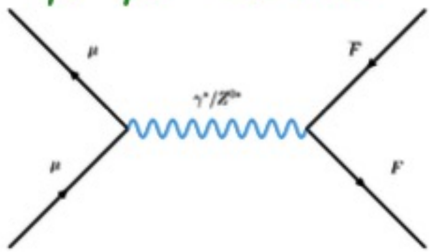
$$\sigma_{EW} \sim \sigma(\mu^+\mu^- \to \gamma^* \to e^+e^-) \sim \frac{4\pi\alpha^2}{3\,S} \to 1\,fb\,(\frac{10\,TeV}{\sqrt{S}})^2$$

$\sigma_{EW} \times \int L$ ~ 10^4 evts
→ δ_{stat} ~ 1%

allows precision on whatever is discovered !

* direct pair production of new heavy states…

$$\mu^+\mu^- \to F\bar{F}$$

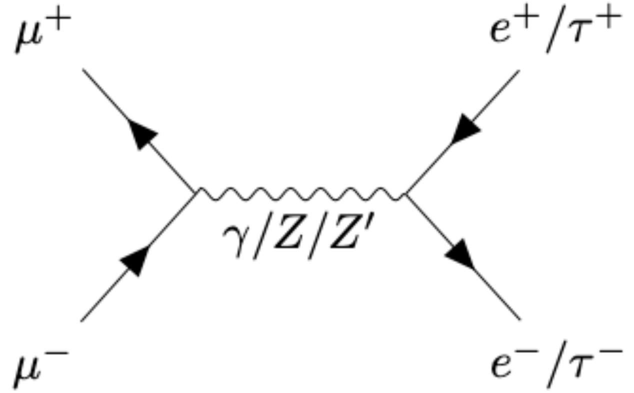


$m_F \lesssim \sqrt{S_{\mu\mu}}/2$
~ 5+ TeV !!!

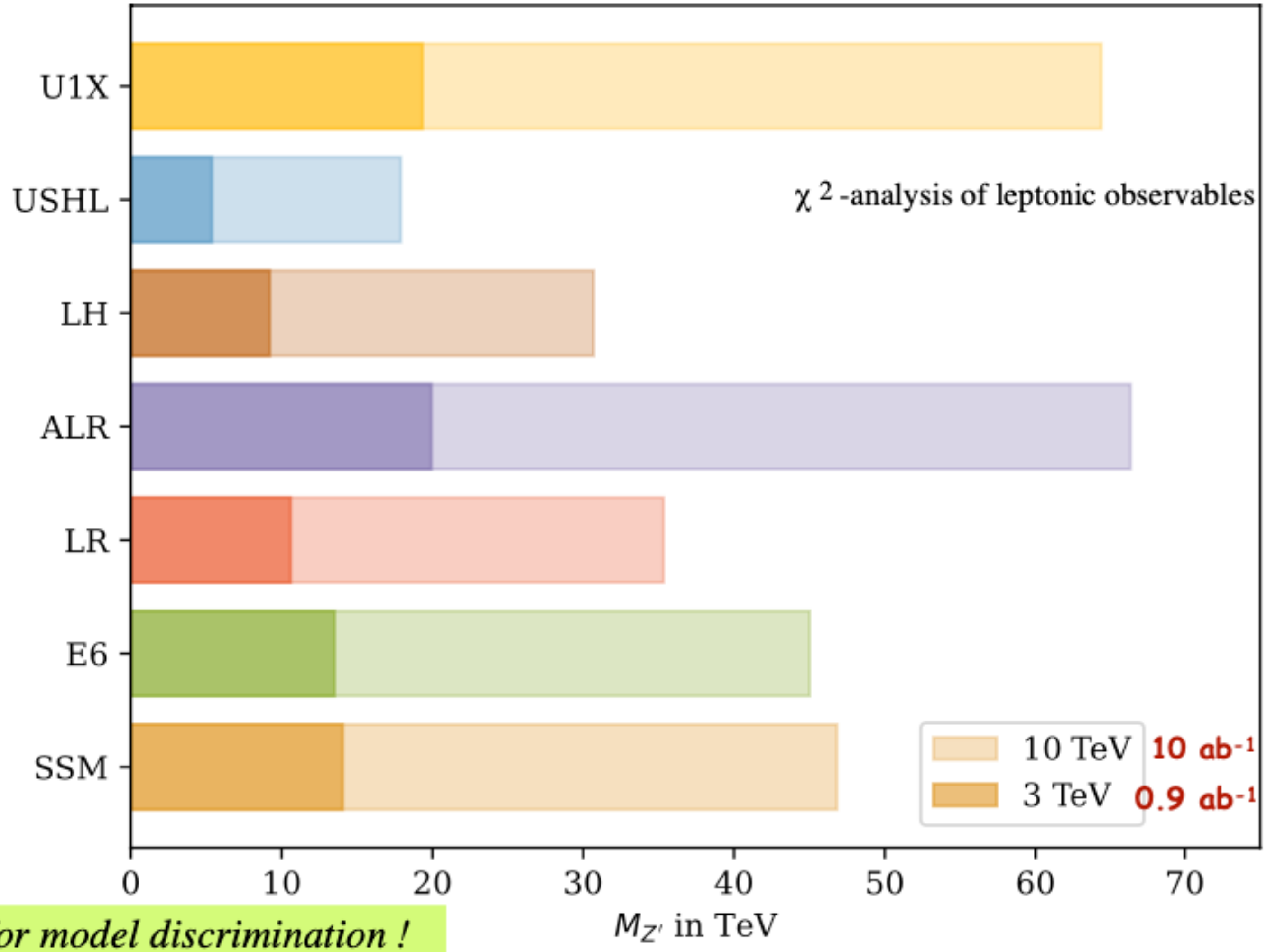
* as at LEP, it would cover searches up to almost the kinematic limit !
* huge discovery potential for $\sqrt{S_{\mu\mu}}$ ~ 10+TeV !

warning:
new kind of machine bckgr from muon beam decays…!!

Reach di massa dello Z` off shell

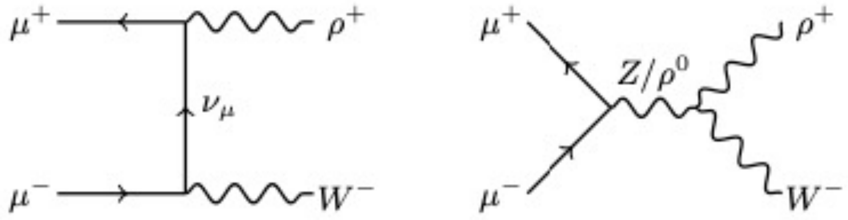


Model	$g_{Z'}$	$2v_l$	$2a_l$
SSM	$\frac{e}{s_W c_W}$	$2s_W^2 - \frac{1}{2}$	$-\frac{1}{2}$
E_6	$\frac{e}{c_W}$	$\frac{2\cos\beta}{\sqrt{6}}$	$\frac{\cos\beta}{\sqrt{6}} + \frac{\sqrt{10}\sin\beta}{6}$
LR	$\frac{e}{c_W}$	$\frac{1}{\alpha} - \frac{\alpha}{2}$	$\frac{\alpha}{2}$
ALR	$\frac{e}{s_W c_W \sqrt{1-2s_W^2}}$	$\frac{5}{2}s_W^2 - 1$	$-\frac{1}{2}s_W^2$
LH	$\frac{e}{s_W}$	$-\frac{c}{4s}$	$-\frac{c}{4s}$
USLH	$\frac{e}{c_W\sqrt{3-4s_W^2}}$	$\frac{1}{2} - 2s_W^2$	$\frac{1}{2}$
$U(1)_X$	$\frac{e}{4c_W}$	-8	2

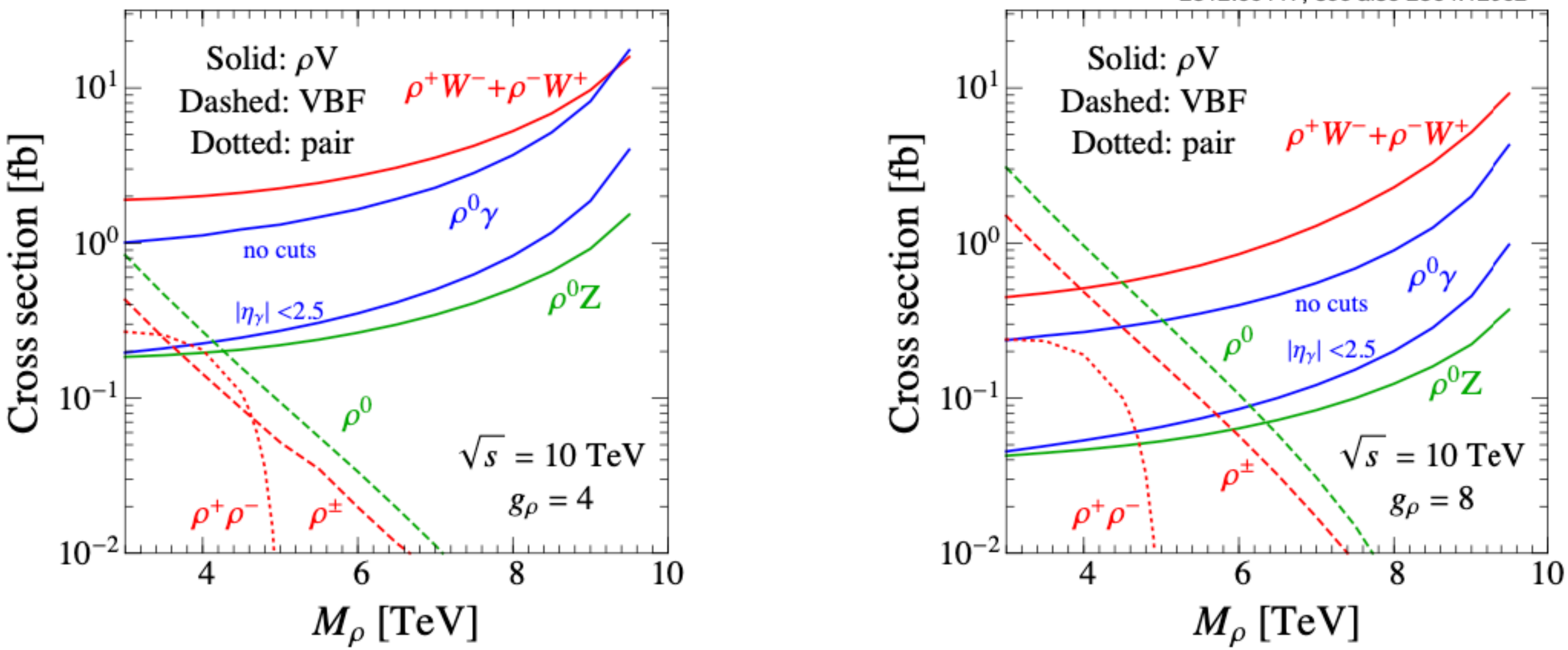


also good resolution power for model discrimination !

Produzione di risonanze tramite irraggiamento W/Z



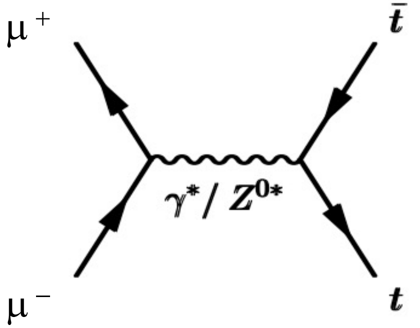
2312.09117, see also 2304.12362



Istituto Nazionale di Fisica Nucleare

eventi VBF (verde) + $\sigma_{WW\to X} / \sigma_{\mu\mu\to X}$ (rosso)

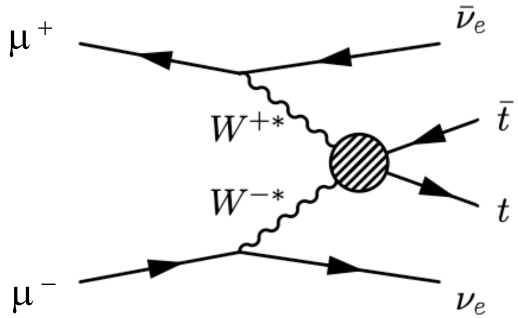
$\sigma_{\mu\mu\to X}$ ~1/s



# events	3 TeV/5/ab	(VBF)/(s-ch)3TeV	14 TeV/20/ab	(VBF)/(s-ch)14TeV	30 TeV/100/ab	(VBF)/(s-ch)30TeV
H	2,5E+06		1,9E+07		1,2E+08	
HZ	4,9E+04	7	9,0E+05	700	7,4E+06	5300
HZZ	6,0E+02	1,5	3,2E+04	180	3,7E+05	1500
HWW	1,5E+03	0,3	6,8E+04	30	7,6E+05	190
HH	4,1E+03		8,8E+04		7,4E+05	
HHZ	4,7E+01	0,3	2,8E+03	40	3,3E+04	300
HHZZ	4,6E-01	0,1	7,8E+01	16	1,2E+03	130
HHWW	1,2E+00	0,02	1,8E+02	1	2,9E+03	1
HHH	1,5E+00		1,4E+02		1,9E+03	
HHHZ	2,4E-02	0,3	3,8E+00	12	5,1E+01	100

[MadGraph]

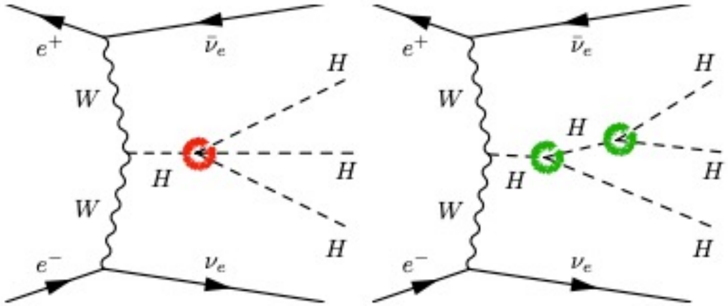
$\sigma_{WW\to X}$ ~ $\log^n s$



tt	2,6E+04	0,3	4,2E+05	24	3,1E+06	160
ttH	6,5E+01	0,03	3,0E+03	5	3,1E+04	40
ttZ	5,5E+02	0,07	2,6E+04	7	2,8E+05	50
ttHH	1,7E-01	0,006	1,3E+01	1	1,6E+02	10
ttHZ	1,8E+00	0,01	2,0E+02	2	2,7E+03	14
ttZZ	7,0E+00	0,03	1,2E+03	4	1,7E+04	30
ttWW	1,4E+01	0,008	2,2E+03	0,8	3,0E+04	5
tttt	3,4E-01	0,01	2,2E+01	0,4	2,1E+02	2

a multi-TeV MC could make a robust measurement of λ'H⁴ !!

$$V_h = \frac{m_h^2}{2} h^2 + (1 + \kappa_3)\lambda_{hhh}^{SM} v h^3 + \frac{1}{4}(1 + \kappa_4)\lambda_{hhhh}^{SM} h^4$$



$$\mu^+\mu^- \to HHH\nu\bar{\nu}, \ (\nu = \nu_e, \nu_\mu, \nu_\tau)$$

(2003.13628)

($\kappa_i \to \delta_i$)

$\sqrt{s}$ (TeV)	Lumi (ab^{-1})	Constraints on δ_4 (with $\delta_3 = 0$) x-sec only 1 σ	x-sec only 2 σ	threshold + $M_{HHH} > 1$ TeV 1 σ
6	12	$[-0.60, 0.75]$	$[-0.90, 1.00]$	$[-0.55, 0.85]$
10	20	$[-0.50, 0.55]$	$[-0.70, 0.80]$	$[-0.45, 0.70]$
14	33	$[-0.45, 0.50]$	$[-0.60, 0.65]$	$[-0.35, 0.55]$
30	100	$[-0.30, 0.35]$	$[-0.45, 0.45]$	$[-0.20, 0.40]$
3	100	$[-0.35, 0.60]$	$[-0.50, 0.80]$	$[-0.45, 0.65]$

bckgr can be tamed by b-tagging (soft?) / Higgs reconstruction / Z,W vetoes !

Table 5: Summary of the constraints on the quartic deviations δ_4, assuming $\delta_3 = 0$, for various muon collider energy/luminosity options, as obtained from the total expected cross sections (1σ and 2σ CL). The third column shows the bounds obtained from the combination of the constraints corresponding to the setups $M_{HHH} < 1$ TeV and $M_{HHH} > 1$ TeV.

Summary

- un collisore circolare e^+e^- che funziona a ZH, tt , WW, Z, (H) con L ~ $10^{(34-36)}$ $cm^{-2}s^{-1}$ può andare ben oltre la portata di (HL-) LHC in diversi settori della fisica
- non è “solo” una meravigliosa sonda di precisione per Higgs!
  – EWPT: miglioramenti nell'ordine di grandezza rispetto al LEP (estremamente necessario: progressi nella precisione teorica!)
  – configurazione ideale per scoprire particelle che interagiscono (molto) debolmente
- Collisori lineari: comparabili nel settore dell’Higgs, più deboli sull'EWPT, ma possono estendere √S !! Qualunque deviazione dalle previsioni SM verrà osservata.
- Tutto ciò richiede una macchina di Energy Frontier! Al momento ci sono alcune ottime opzioni...nessuna ancora tecnologicamente matura...

BACKUP

Steps in the Update Process

ESPP Update 2024-2026

1. **Mandate by the CERN Council:**
   – The update process begins when the CERN Council issues a **mandate to review and update the current strategy**. This mandate outlines the scope, goals, and timeline for the update. ✓
2. **Community Involvement and Call for Input:**
   – A **public call for input is issued**, inviting contributions from the global particle physics community, including researchers, institutions, and national funding agencies. This step ensures that a wide range of perspectives and ideas are considered. ✓
3. **Establishment of the Physics Preparatory Group (PPG):**
   – A **Physics Preparatory Group (PPG)** is formed, consisting of experts from the field. This group is responsible for collecting input, organizing discussions, and preparing a draft of the updated strategy. The PPG typically includes representatives from CERN, member states, and prominent physicists. coming up
4. **Open Symposium:**
   – An **Open Symposium is held**, gathering scientists and stakeholders to discuss the input received and the key scientific questions that the updated strategy should address. This symposium serves as a platform for debate on the future direction of the field, including potential projects, experiments, and technologies. a Venezia
5. **Drafting the Strategy Update:**
   1. Based on the discussions and input, the **PPG drafts the updated strategy**. This draft, **the Briefing Book**, outlines the recommended scientific priorities, technological developments, and necessary investments for the coming years.
6. **Submit the European Strategy Update recommendations to the CERN Council:**
   – The **Briefing Book is reviewed by the European Strategy Group** (ESG), which includes representatives from CERN, member states, and observer states. Additional feedback is sought to refine and adjust the recommendations. A final document based is issued by the ESG to the CERN Council

Streamlining the process and form of national inputs

da Paris Sphicas

3. **Questions to be considered by individual countries/regions in forming and furnishing a "national input" to the ESPP:**

   a. **Which is the preferred next major/flagship collider project for CERN**

   b. **What are the most important elements in the response to (3a)?**

      - Physics potential
      - Long-term perspective
      - Financial and human resource requirements – and implications for other projects
      - Timing
      - Careers and training
      - Sustainability

European Strategy Update

Streamlining the process and form of national inputs

c. **Should CERN/Europe proceed with the preferred option set out in 3a) or should alternative options be considered:**
   i. if Japan proceeds with the ILC in a timely way?
   ii. if China proceeds with the CEPC on the announced timescale?
   iii. if the US proceeds with a muon collider?
   iv. if there are major new (unexpected) results from the HL-LHC or other HEP experiments?

d. **Beyond the preferred option in 3a), what other accelerator R&D topics (e.g. highfield magnets, RF technology, alternative accelerators/colliders) should be pursued in parallel?**

e. **What is the prioritised list of alternative options if the preferred option set out in 3a) is not feasible (due to cost, timing, international developments, or for other reasons)?**

f. **What are the most important elements in the response to 3e)? (The set of considerations in 3b should be used).**

CERN Convention

Streamlining the process and form of national inputs

4) The remit given to the ESG also specifies that “The Strategy update should also indicate areas of priority for exploration complementary to colliders and for other experiments to be considered at CERN and at other laboratories in Europe, as well as for participation in projects outside Europe.” It would thus be most useful if the national inputs explicitly included the preferred prioritisation for non-collider projects. Specific questions to address:

a) What other areas of physics should be pursued, and with what relative priority?
b) What are the most important elements in the response to 4a)? (The set of considerations in 3b should be used)
c) To what extent should CERN participate in nuclear physics, astroparticle physics or other areas of science, while keeping in mind and adhering to the CERN Convention? Please use the current level and form of activity as the baseline for comparisons.

what's so challenging about the Higgs (TH)

$$\mathcal{L}_{\text{Higgs}} = (D_\mu \phi)^\dagger (D^\mu \phi) - V(\phi^\dagger \phi) - \bar{\psi}_L \Gamma \psi_R \phi - \bar{\psi}_R \Gamma^\dagger \psi_L \phi^\dagger$$

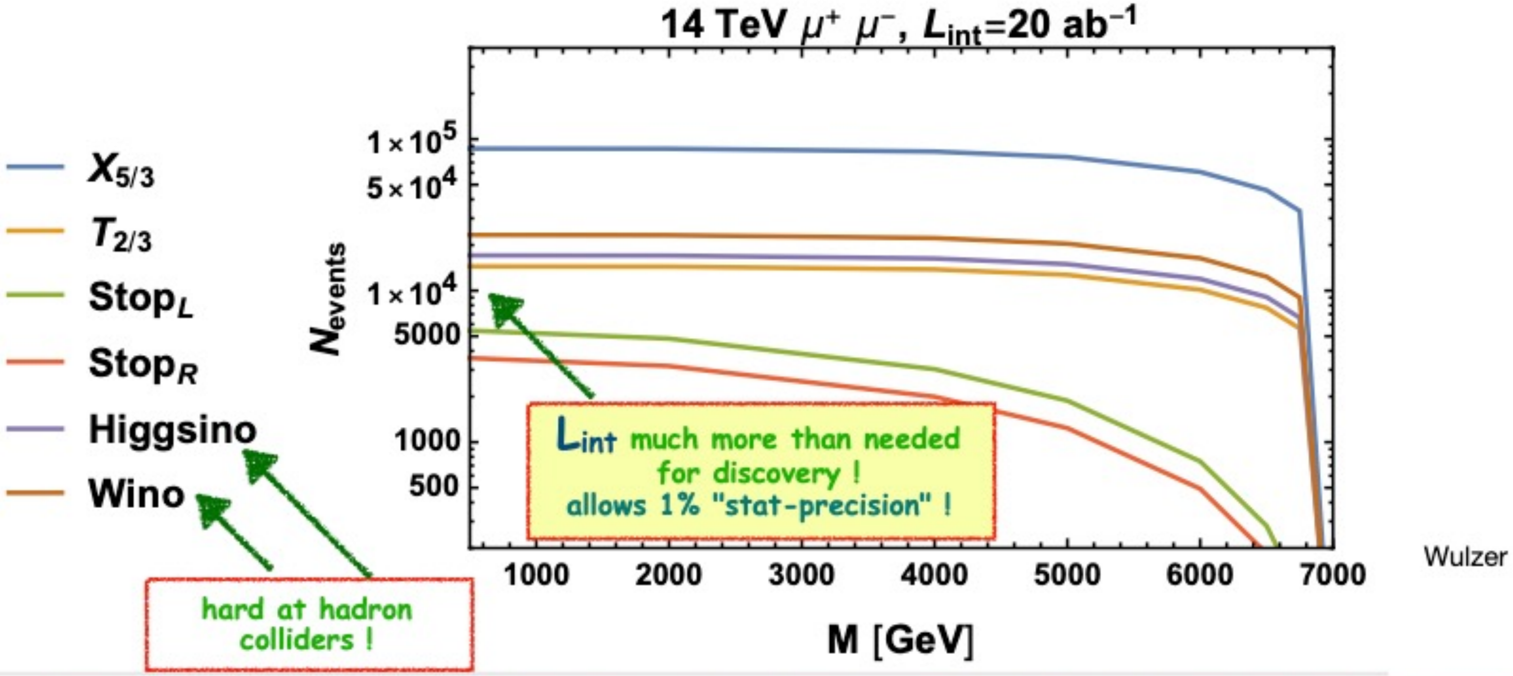
$$V(\phi^\dagger \phi) = -\mu^2 \phi^\dagger \phi + \frac{1}{2} \lambda (\phi^\dagger \phi)^2$$

$$m_H^2 = 2\mu^2 = 2\lambda v^2$$

- the only "fundamental" scalar particle (microscopic interpretation ?)
- not protected by symmetries (the less constrained SM sector):
  - naturalness problem : $m_H \sim g \times \Lambda_{cutoff}$
- many different couplings all fixed by masses (?)
  - proliferation of parameters historically leads to breakdown in TH models
- fermion masses/Yukawa's hierarchy (?)
  - have neutrinos a special role ?!!!
- λ determines shape and evolution of Higgs potential → cosmology !

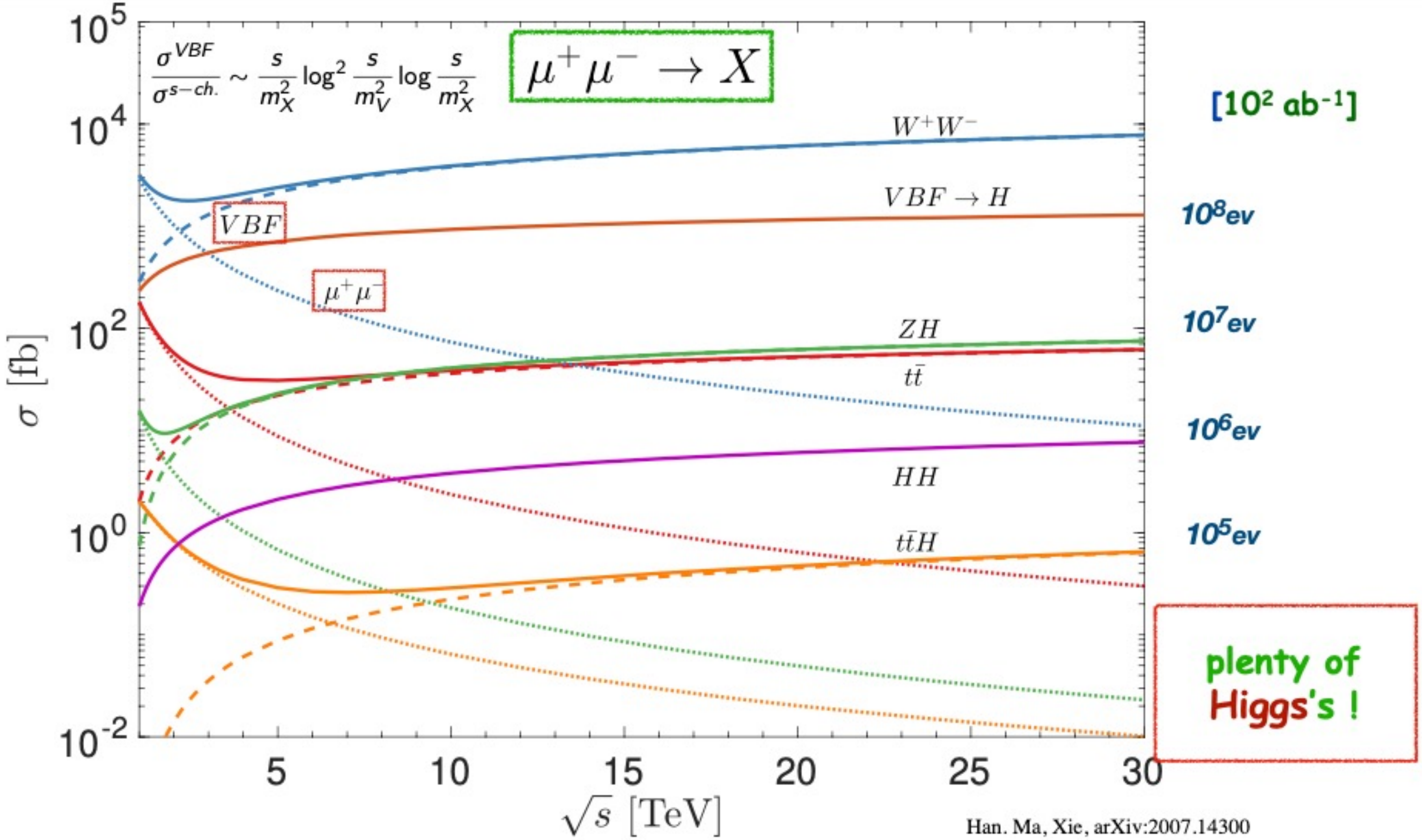
Direct pair production μμ → XX

$\sigma_{\mu\mu \to XX}$ ~ uniform up to threshold ⟶ $m_F \sim \sqrt{S_{\mu\mu}}/2$!



$\int L$ /100 would be enough for discovering pairs of new EW multi-TeV particles !

at $\sqrt{S_{\mu\mu}}$ >a few TeV's, "point $\sigma_{\mu\mu\to X}$" (~1/s) superseded by $\sigma_{WW\to X}$ (~log^n s) !



VBF for BSM

VV fusion as an extra mechanism for production of heavy new p.les !

stop production

arXiv:2005.10289