Exploration of preonic models at the FCC based pp, ep, μp and γp colliders

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* with Y. Acar, U. Kaya and B. Oner

1870's: Mendeleyev Table

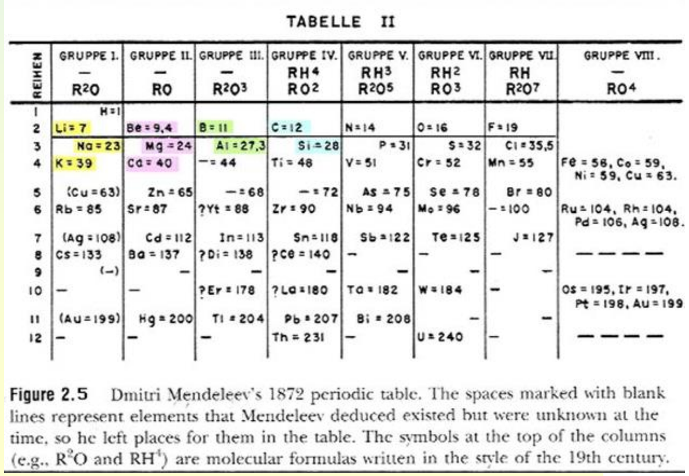
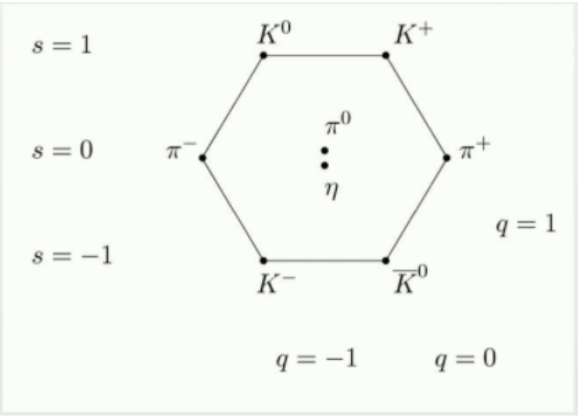


TABELLE II

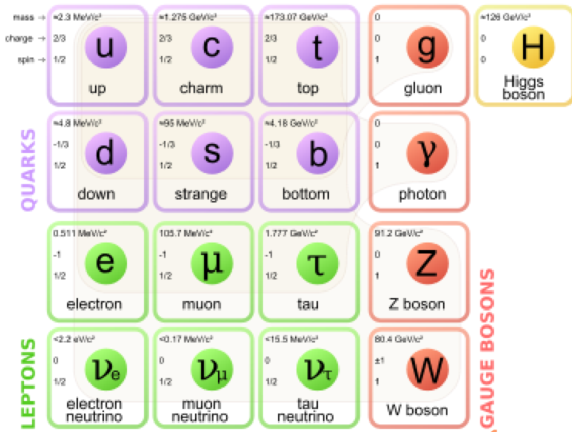
REIHEN	GRUPPE I. — R^2O	GRUPPE II. — RO	GRUPPE III. — R^2O^3	GRUPPE IV. RH^4 RO^2	GRUPPE V. RH^3 R^2O^5	GRUPPE VI. RH^2 RO^3	GRUPPE VII. RH R^2O^7	GRUPPE VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

Figure 2.5 Dmitri Mendeleev's 1872 periodic table. The spaces marked with blank lines represent elements that Mendeleev deduced existed but were unknown at the time, so he left places for them in the table. The symbols at the top of the columns (e.g., R^2O and RH^4) are molecular formulas written in the style of the 19th century.

1960's: Eight-fold Way



Today: Family Replication



Apologies

I have been down in my bed with 39C fever for the last two days. For this reason

- I could not attend Tuesday and Wednesday sessions
- For the same reason I could not prepare this presentation in the best manner (usually, I am preparing the latest version of my presentations in the last 1-2 days).

My presentation covers two topics beyond the «mainstream»:

- Energy frontier (FCC based) lp colliders
- Quark and lepton substructure

and I have only 15 minutes.

Preface

Higgs boson discovery – triumph of the SM.
But a lot of unsolved problems → BSM models.

1) ν(R) and SM4 are not BSM

- ν(R) is counterpart of d(R). Sea-saw provides small «ν(L)» mass.
- Only minimal SM4 with one Higgs doublet is excluded by the LHC data, 2HDM and doublet-triplet options are still survive. General Chiral Fourth Generation cannot be excluded by the LHC.

2) Standard extensions

- Fermion sector, i.e. İnduced by E(6) GUT ore Little Higgs
- Gauge sector (predicted by all GUT's except SU(5)), i.e. Left-Right symmetric models (LR asymmetry posted to Higgs sector, ηR >> ηL)

3) Radical extension

- Compositeness: see next slides
- SUSY: very nice idea, but hundreds free parameters put by hand → thousands if RPV !
- Extra dimensions
- …

Contents

1. *Introduction*

- SM particle's and parameter's inflation, family replication, mixings etc
- Historical arguments: Periodic Table of Elements, Eight-fold Way
- "SM" and SUSY at preonic level

2. *Manifestations*

- New particles (LQ – Monica D'Onofrio; l8 and l* - this presentation)
- New interactions (CI – Monica D'Onofrio, anomalous t – Orhan Çakır)
- Form-factors (next time)

3. *FCC based lepton-hadron and photon-hadron colliders*

4. *pp, ll, lp comparison*

5. *Conclusions*

1. *Introduction*

- SM particle’s and parameter’s inflation, family replication, mixings etc
- Historical arguments: Periodic Table of Elements, Eight-fold Way
- “SM” and SUSY at preonic level

Periodic Table of the Elementary* Particles

family	ν *(direct)*	*l*	*u*	*d*
1	< 2 eV	510.9989461(31) keV	1.8 to 3.0 MeV	4,5 to 5.3 MeV
2	< 190 keV	105.6583745(24) MeV	1.275(25) GeV	95(5) MeV
3	< 18.2 MeV	1.77686(12) GeV	173.21(1.22) GeV	4.18(3) GeV
4	> 39.5 GeV	> 100 GeV	> 700 GeV	> 675 GeV

Also,

$m_\gamma = 0$ (< 10^{-18} eV) $m_g = 0$ (< few MeV)

$m_W = 80.385(15)$ GeV $m_Z = 91.1876(21)$ GeV

$m_H = 125.09 \pm 0.24$ GeV

PDG 2016

Scale: $\eta \approx 247$ GeV

* *Elementary in the SM framework. At least one more level (preons) should exist.*

$$V_{\mathrm{CKM}} = \begin{pmatrix} 0.97427 \pm 0.00014 & 0.22536 \pm 0.00061 & 0.00355 \pm 0.00015 \\ 0.22522 \pm 0.00061 & 0.97343 \pm 0.00015 & 0.0414 \pm 0.0012 \\ 0.00886^{+0.00033}_{-0.00032} & 0.0405^{+0.0011}_{-0.0012} & 0.99914 \pm 0.00005 \end{pmatrix}$$

Neutrino mixings

$\sin^2(\theta_{12}) = 0.304 \pm 0.014$
$\Delta m^2_{21} = (7.53 \pm 0.18) \times 10^{-5}\ \mathrm{eV}^2$
$\sin^2(\theta_{23}) = 0.51 \pm 0.05$ (normal mass hierarchy)
$\sin^2(\theta_{23}) = 0.50 \pm 0.05$ (inverted mass hierarchy)
$\Delta m^2_{32} = (2.44 \pm 0.06) \times 10^{-3}\ \mathrm{eV}^2$ [i] (normal mass hierarchy)
$\Delta m^2_{32} = (2.51 \pm 0.06) \times 10^{-3}\ \mathrm{eV}^2$ [i] (inverted mass hierarchy)
$\sin^2(\theta_{13}) = (2.19 \pm 0.12) \times 10^{-2}$

Stable Neutral Heavy Lepton Mass Limits

Mass $m >$ 45.0 GeV, CL = 95% (Dirac)
Mass $m >$ 39.5 GeV, CL = 95% (Majorana)

Neutral Heavy Lepton Mass Limits

Mass $m >$ 90.3 GeV, CL = 95%
(Dirac ν_L coupling to e, μ, τ; conservative case(τ))
Mass $m >$ 80.5 GeV, CL = 95%
(Majorana ν_L coupling to e, μ, τ; conservative case(τ))

We wonder why **m_H = 125 GeV?**

But do not worry on accidental values of SM fermion masses and mixings …; i.e. **$m(e)/m(t) \sim 10^{-5}$**

More than 50 fundamental particles and **26 free parameters** in the minimal SM3 indicates that the Standard Model is manifestation of **more fundamental theory.**

Physics met similar situation two times in the past:

Stages	1870s-1930s	1950s-1970s	1970s-2020s
Fundamental Constituent İnflation	Chemical Elements	Hadrons	Quarks, leptons
Systematic	Periodic Table	Eight-fold Way	Family replication
Confirmed Predictions	New elements	New Hadrons	BSM particles
Clarifying Experiments	Rutherford	SLAC DIS	LHC or rather FCC
Building Blocks	Proton, neutron, electron	Quarks	Preons?
Energy Scale	MeV	GeV	TeV?
İmpact on Technology	Exceptional	Indirect	Exceptional?

- Periodic Table of the Elements was clarified by Rutherford's experiment
- Hadron inflation has resulted in quark model
- This analogy implies the preonic structure of the SM fermions

WHY PREONIC MODELS?

- The composite models are particularly interesting for the continued "simplification" and describe nature in terms of its most fundamental building blocks.
- These fundamental constituents were called PREONS by Pati and Salam.
- Family replication and especially SM fermion mixings can be considered as indication of preonic structure of matter.
- Could provide a solution to some of the aforementioned problems with an effective model at the preonic level.
- Quark-lepton compositeness is a well-known BSM scenario and the preonic models predict;
  - Excited leptons and quarks, leptogluons, leptoquarks, diquarks, dileptons, color sextet quarks etc
  - Contact Interactions, anomalous interactions of SM fermions and bosons, form-factors

“SM” and SUSY at preonic level

If space-time structure is not changed, then SU(3)xSU(2)xU(1) gauge symmetry, as well as SUSY, should be realized at preonic level *.

First case means that W, Z and (probably) H bosons are point-like ...

Second case means that each SM particle has:

- four «SUSY» partners in fermion-scalar (FS) models
- and eight «SUSY» partners in three-fermion (FFF) models

…

* Actually at **pre-preonic** level as mentioned by **Professor Abdus SALAM** during our private conversation in October 1989. I understood his reasons 10 years later.
(My first departure from the Soviet Union was made possible by the invitation of Abdus Salam.)

2. *Manifestations*

- New particles (LQ – Monica D'Onofrio; e8, μ8 and μ* - this presentation)
- New interactions (CI – Monica D'Onofrio, anomalous t – Orhan Çakır)
- Formfactors (next time)

Since W, Z and (probably) H bosons are point-like, then following manifestations should be considered:

- Excited leptons: lp, pp
- Excited quarks: pp, γp
- Color octet leptons: lp, pp
- Exotic colored quarks: pp
- Contact interactions: lp, pp
- Anomalous interactions of SM leptons and quarks: pp, lp, ll
- Form-factors: lp
- …

There are no W*, Z*, W8, Z8 and so on.

3. *FCC based lepton-hadron and photon-hadron colliders*

- ep and eA
- γp and γA
- μp and μA (ultimate sgrts(S) ≈ 63 TeV !!!)
- FEL γA

For details, see:

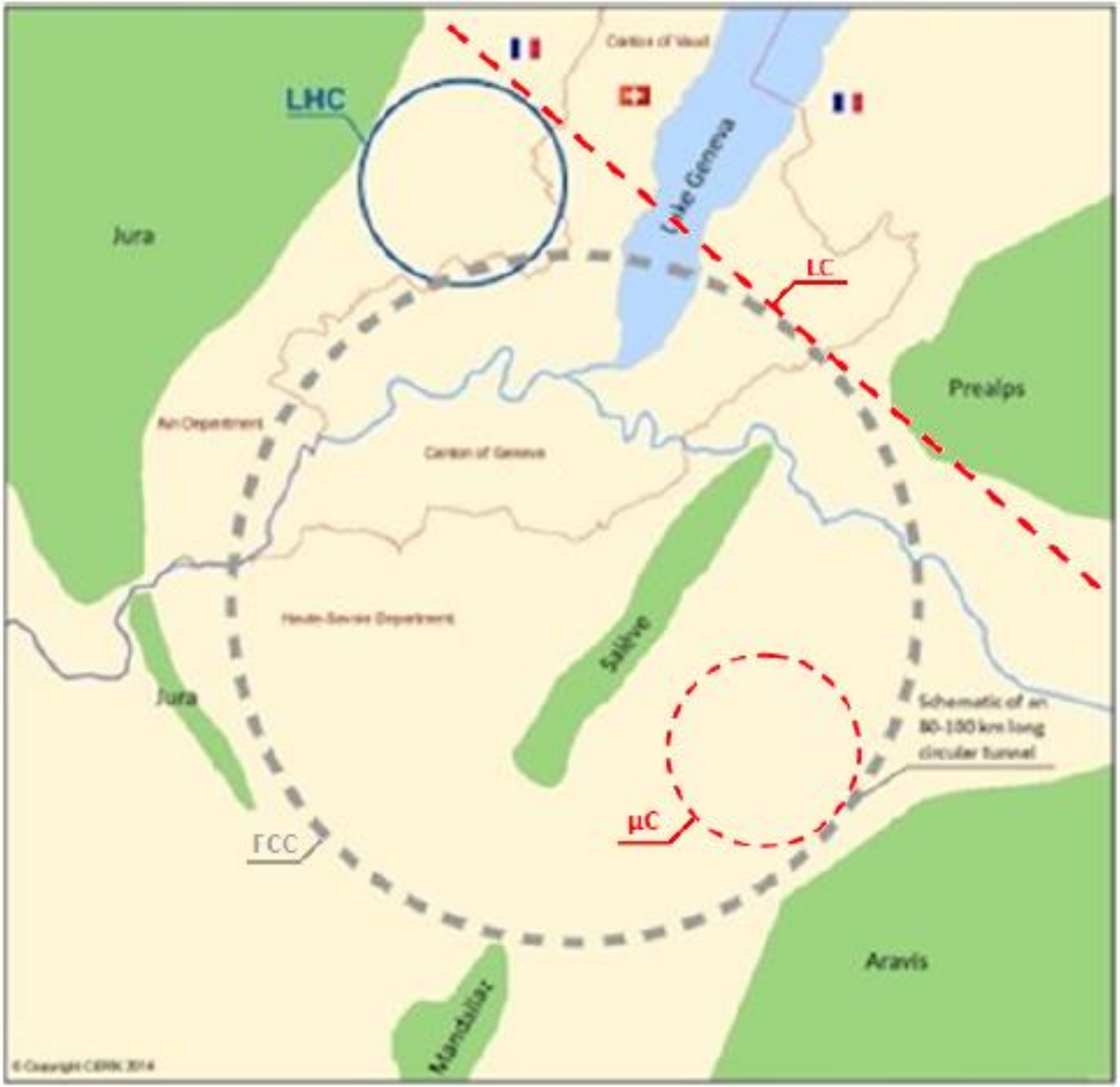
presentation at 2nd FCC Week, Rome
http://indico.cern.ch/event/438866/contributions/1085135/

and Y. Acar et al., **«FCC Based Lepton-Hadron and Photon-Hadron Colliders: Luminosity and Physics»**
https://arxiv.org/abs/1608.02190

Construction of future electron-positron colliders (or dedicated electron linac) and muon colliders (or dedicated muon ring) tangential to Future Circular Collider will give opportunity to **utilize highest energy proton and nucleus beams** for **lepton-hadron** and **photon-hadron** collisions.

LC×FCC = LC + FCC + ep + eA
$+ \gamma p + \gamma A + \mathrm{FEL}\,\gamma A$

$\mu C \times FCC = \mu C + FCC + \mu p + \mu A$



LC×FCC based ep colliders

Table IV. Main parameters of ILC⊗FCC based ep collider.

		Nominal FCC		
$E_e(GeV)$	$\sqrt{s}(TeV)$	L_{ep}, $cm^{-2}s^{-1}$	D_e	ξ_p
250	7.08	2.26×10^{30}	1.0	1.09×10^{-3}
500	10.0	2.94×10^{30}	0.5	9.40×10^{-4}
$E_e(GeV)$	$\sqrt{s}(TeV)$	Upgraded FCC		
250	7.08	55.0×10^{30}	24	1.09×10^{-3}
500	10.0	70.0×10^{30}	12	9.40×10^{-4}

Table V. Main parameters of ILC⊗FCC based ep collider corresponding to the disruption limit $D_e = 25$.

$E_e(GeV)$	$\sqrt{s}(TeV)$	$N_p(10^{11})$	L_{ep}, $cm^{-2}s^{-1}$	ξ_p
250	7.08	2.3	57×10^{30}	$1.09x10^{-3}$
500	10.0	4.6	149×10^{30}	$9.40x10^{-4}$

Table VII. Main parameters of PWFA-LC⊗FCC based ep collider.

		Nominal FCC		
$E_e(GeV)$	$\sqrt{s}(TeV)$	L_{ep}, $cm^{-2}s^{-1}$	D_e	ξ_p
250	7.08	3.44×10^{30}	1.00	5.47×10^{-4}
500	10.0	2.58×10^{30}	0.50	5.47×10^{-4}
1500	17.3	1.72×10^{30}	0.17	5.47×10^{-4}
5000	31.6	0.86×10^{30}	0.05	5.47×10^{-4}
$E_e(GeV)$	$\sqrt{s}(TeV)$	Upgraded FCC		
250	7.08	82.6×10^{30}	24	5.47×10^{-4}
500	10.0	61.9×10^{30}	12	5.47×10^{-4}
1500	17.3	41.3×10^{30}	4.0	5.47×10^{-4}
5000	31.6	20.8×10^{30}	1.2	5.47×10^{-4}

Table VIII. Main parameters of PWFA-LC⊗FCC based ep collider corresponding to the disruption limit $D_e = 25$.

$E_e(GeV)$	$\sqrt{s}(TeV)$	$N_p(10^{11})$	L_{ep}, $cm^{-2}s^{-1}$	ξ_p	IBS Growth Time (Horizontal) (h)	
					L_c=106.9 m	L_c=203.0 m
125	5.00	1.15	65.0×10^{30}	5.47×10^{-4}	721	149
250	7.08	2.30	86.0×10^{30}	5.47×10^{-4}	360	75.0
500	10.0	4.60	129×10^{30}	5.47×10^{-4}	180	37.0
1500	17.3	13.8	258×10^{30}	5.47×10^{-4}	60.0	12.0
5000	31.6	45.8	433×10^{30}	5.47×10^{-4}	18.0	3.90

LC×FCC based γp colliders

These machines can be **realised only on the base of linac-ring type** ep colliders

$\sqrt{s}(\gamma p)\sim 0.9\sqrt{s}(ep)$ and $L(\gamma p)\sim 0.6L(ep)$

Nuclear Instruments and Methods in Physics Research A 365 (1995) 317–328

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Main parameters of TeV energy γp colliders

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Received 20 February 1995

Abstract

The main parameters of TeV energy γp colliders have been investigated for HERA+LC, LHC+TESLA and LHC+e-Linac proposals in detail. In this research, the luminosity of γp collisions and the helicity of the high energy γ beam for these colliders are studied in terms of the distance between the conversion region and the collision point as well as γp invariant mass. The main design problems are also discussed.

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Nuclear Instruments and Methods in Physics Research A 576 (2007) 287–293

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Conversion efficiency and luminosity for gamma-proton colliders based on the LHC-CLIC or LHC-ILC QCD explorer scheme

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A.K. Çiftçi et al. / Nucl. Instr. and Meth. in Phys. Res. A 365 (1995) 317–328

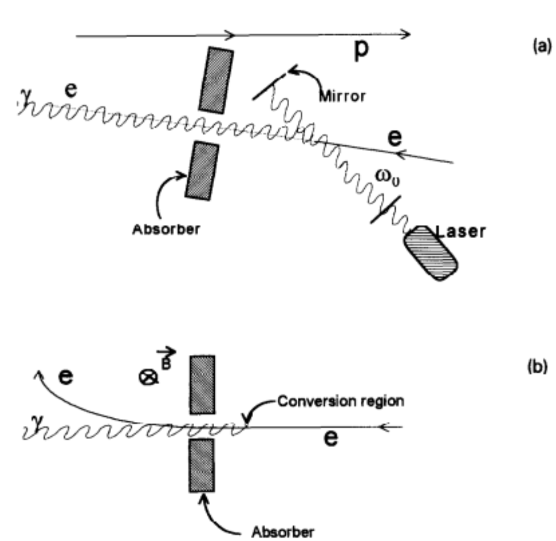
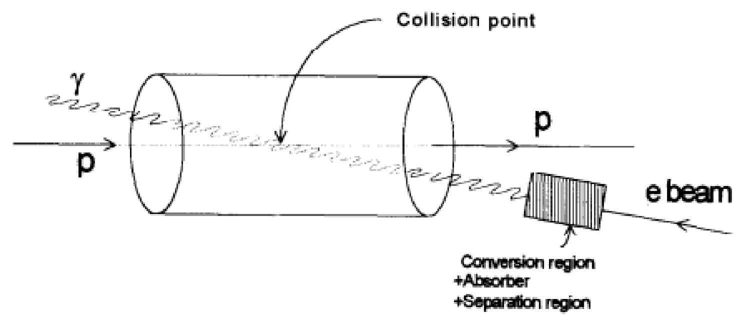


Fig. 16. Schematic view of the part of the design between the conversion region and the detector. (a) Horizontal plane, (b) vertical plane.



According to VMD **γA means ρA collider.** formation of the **quark-gluon plasma** at very high temperatures but relatively low parton densities

FCC based μp colliders

Table X. Main parameters of the FCC based μp colliders.

Collider Name	$\sqrt{s}$, TeV	$L_{\mu p}$, $cm^{-2}s^{-1}$ (Avg.)	ξ_p	ξ_μ
μ63-FCC	3.50	0.2×10^{31}	1.8×10^{-3}	5.4×10^{-4}
μ750-FCC	12.2	50×10^{31}	1.1×10^{-1}	3.3×10^{-3}
μ1500-FCC	17.3	50×10^{31}	1.1×10^{-1}	8.3×10^{-4}

Ultimate: μ20000-FCC, sqrt(s) = 63 TeV, L = 10^(33) cm^(-2) s^(-1)

For pre-decor of «ultimate» μp collider see:
S. Sultansoy «**The PostHERA era: Brief review of future lepton hadron and photon hadron colliders**», **DESY-99-159**
https://arxiv.org/abs/hep-ph/9911417

More details will be presented at the 3rd FCC Week, Berlin

4. *FCC based pp, ll, lp comparison*

- ***Color octet electron***
- ***Color octet muon***
- ***Excited muon***

In models with colored preons, leptogluons have the same status as excited leptons and leptoquarks.

For **color octet electron** comparative analysis, see:

Umit Kaya «Color Octet Electrons @ FCC-hh, CLIC, FCC-he».
Presented at «FCC Physics, Detector and Accelerator Workshop @ Istanbul», 11-12 March 2016. https://indico.cern.ch/event/405973/contributions/1852964

and Y. Acar et al «**Color Octet Electron Search Potential of the FCC Based e-p Colliders**» https://arxiv.org/abs/1605.08028

For **color octet muon** see: Y. Acar, U. Kaya and B. Öner (in preparetion)

For **excited muon** see: A. Calışkan, S.O. Kara and A . Ozansoy «**Excited muon searches at the FCC based muon-hadron colliders**» https://arxiv.org/abs/1701.03426

Color octet leptons in preonic models

- Strongly interacting partners of the SM leptons.
- Model example;

Leptons: In the framework of fermion-scalar models, leptons would be a bound state of one fermionic preon and one scalar anti-preon,

$$l = (F\bar{S}) = 1 \oplus 8 \quad (1)$$

then each SM lepton has one colour octet partner. In a three fermion model, the colour decomposition

$$l = (FFF) = 1 \oplus 8 \oplus 8 \oplus 10 \quad (2)$$

predicts the existence of two colour octet and one colour decouplet partners.

Quarks: In fermion-scalar models, anti-quarks are consist of one fermionic and one scalar preons which means that each SM anti-quark has one coloured sextet partner,

$$\bar{q} = (FS) = \bar{3} \oplus 6 \,. \quad (3)$$

According to the three fermion models

$$q = (F\bar{F}F) = 3 \oplus \bar{3} \oplus \bar{6} \oplus 15 \quad (4)$$

therefore, for each SM quark one anti-triplet, one anti-sextet and one 15-plet partners are predicted.

In this study, they choose fermion-scalar model.

Electric charges of scalar and fermionic preons

S_1	0	1/3	1/2	2/3	1
F_1	0	1/3	1/2	2/3	1
F_2	−1	−2/3	−1/2	−1/3	0
S_2	1/3	0	−1/6	−1/3	−2/3

A Search for sextet quarks and leptogluons at the LHC

A. Celikel, M. Kantar, S.Sultansoy, Phys.Lett. B443 (1998) 359-364

$$\nu_e = (F_1\bar{S}_1), \quad e = (F_2\bar{S}_1);$$

$$\bar{d} = (F_1 S_2), \quad \bar{u} = (F_2 S_2)$$

LAGRANGIAN AND DECAY WIDTH FOR COLOR OCTET LEPTONS

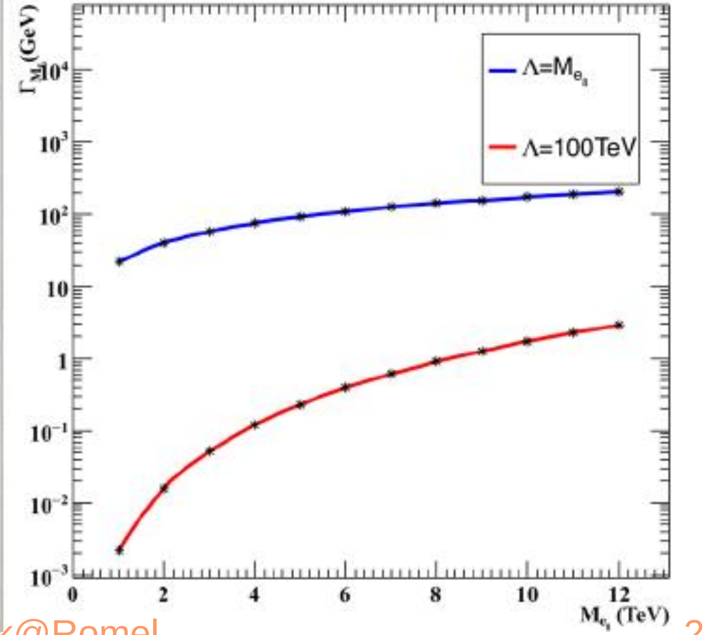
- The interaction lagrangian of color octet leptons (denoted by l_8) with their corresponding lepton (denoted by l);

$$L_{Int} = \frac{1}{2\Lambda} \sum_{l} \bar{\psi}_{l_8} g_s F^{a}_{\mu\nu} \sigma^{\mu\nu} (\eta_L \psi_{l,L} + \eta_R \psi_{l,R}) + h.c.$$

- η_L and η_R $\rightarrow$chirality factors
- $\psi_{l,L}$ and $\psi_{l,R}$ denote left and right spinor components of lepton
- $F^{a}_{\mu\nu}$ $\rightarrow$ gluon field strength tensor
- $\sigma_{\mu\nu}$ $\rightarrow$ antisymmetric tensor
- g_s $\rightarrow$ strong coupling constant

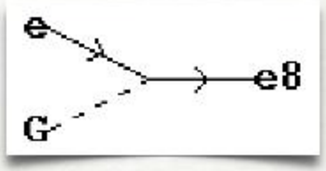
$$\Gamma_{e_8} = \frac{\alpha_s(M_{e_8}) M_{e_8}{}^3}{4\Lambda^2}$$

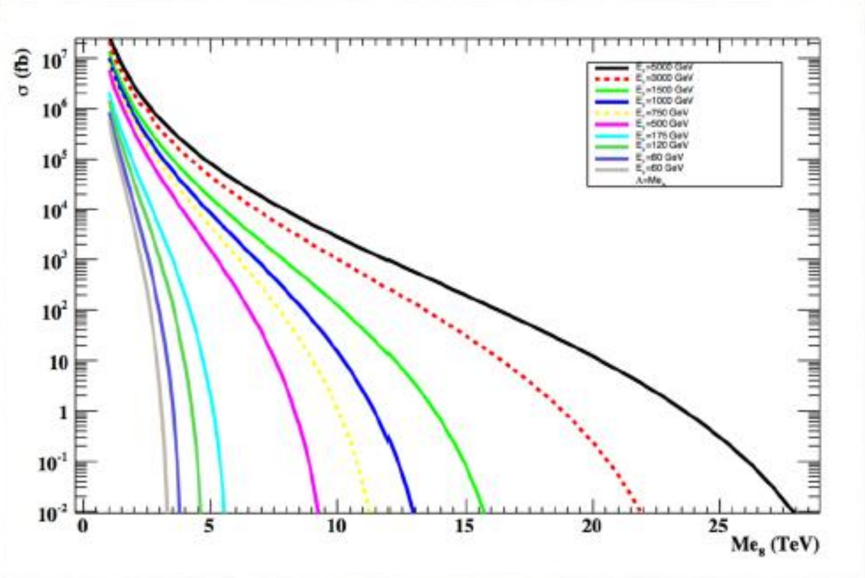
- $\Lambda \rightarrow$ compositeness scale



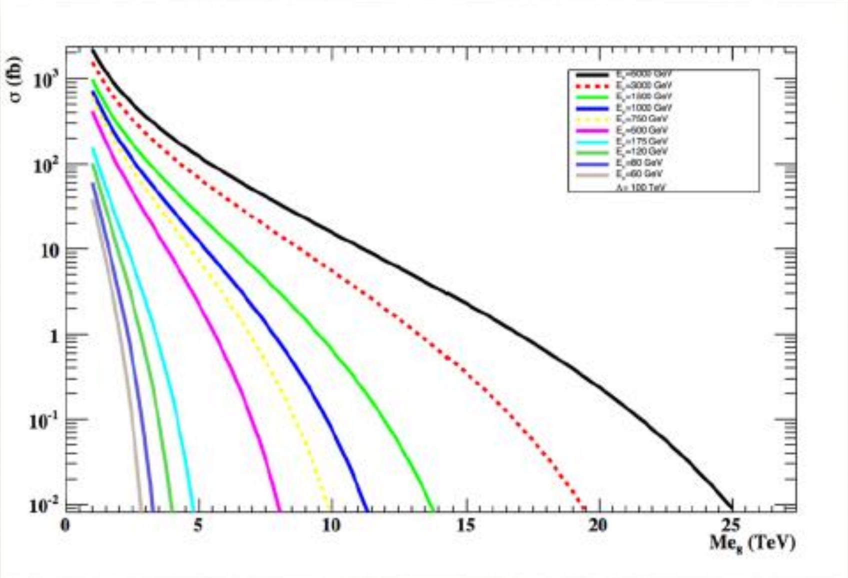
PRODUCTION CROSS SECTION OF e_8 @ FCC-pe

RESONANT PRODUCTION



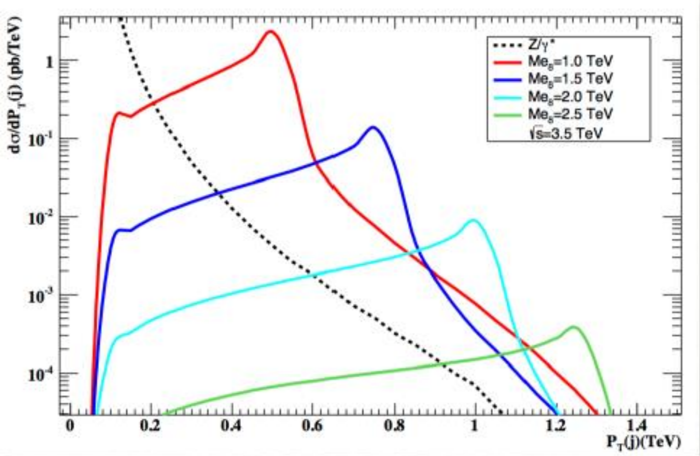


$\Lambda = Me_8$

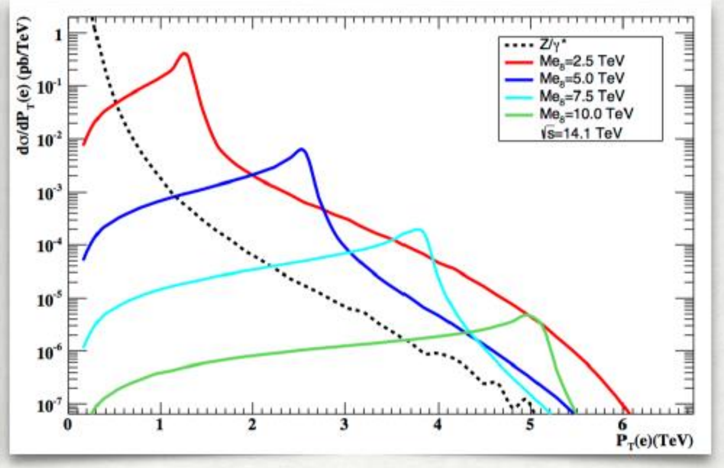


$\Lambda = 100$ TeV

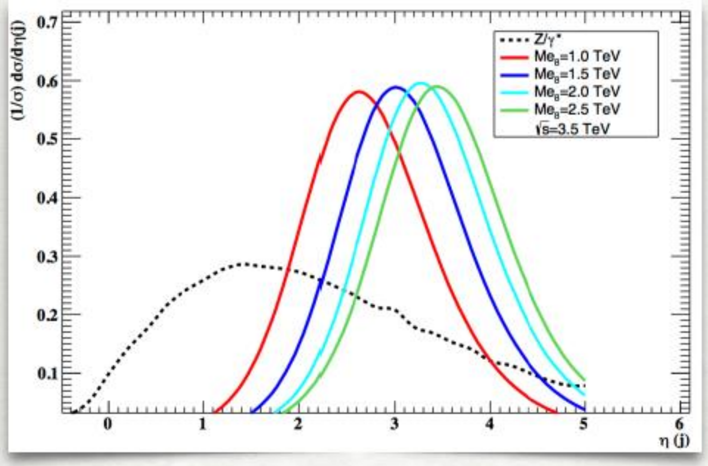
SIGNALS AND BACKGROUNDS



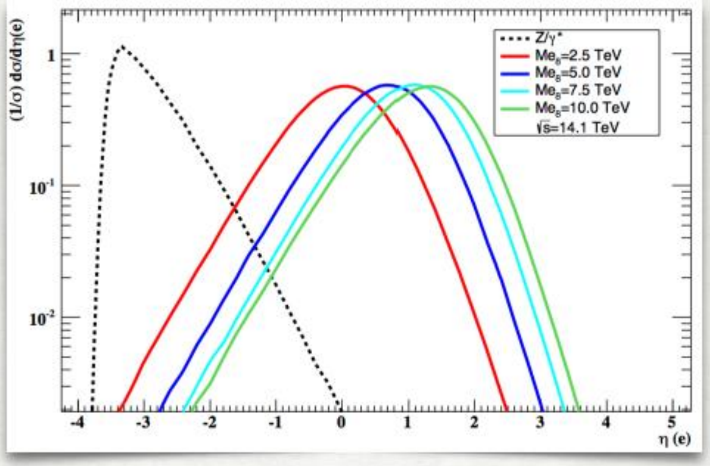
Transverse momentum distribution of **jet** for signals and backgrounds at ERL60-FCC



Transverse momentum distribution of **electron** for signals and backgrounds at OPL1000-FCC

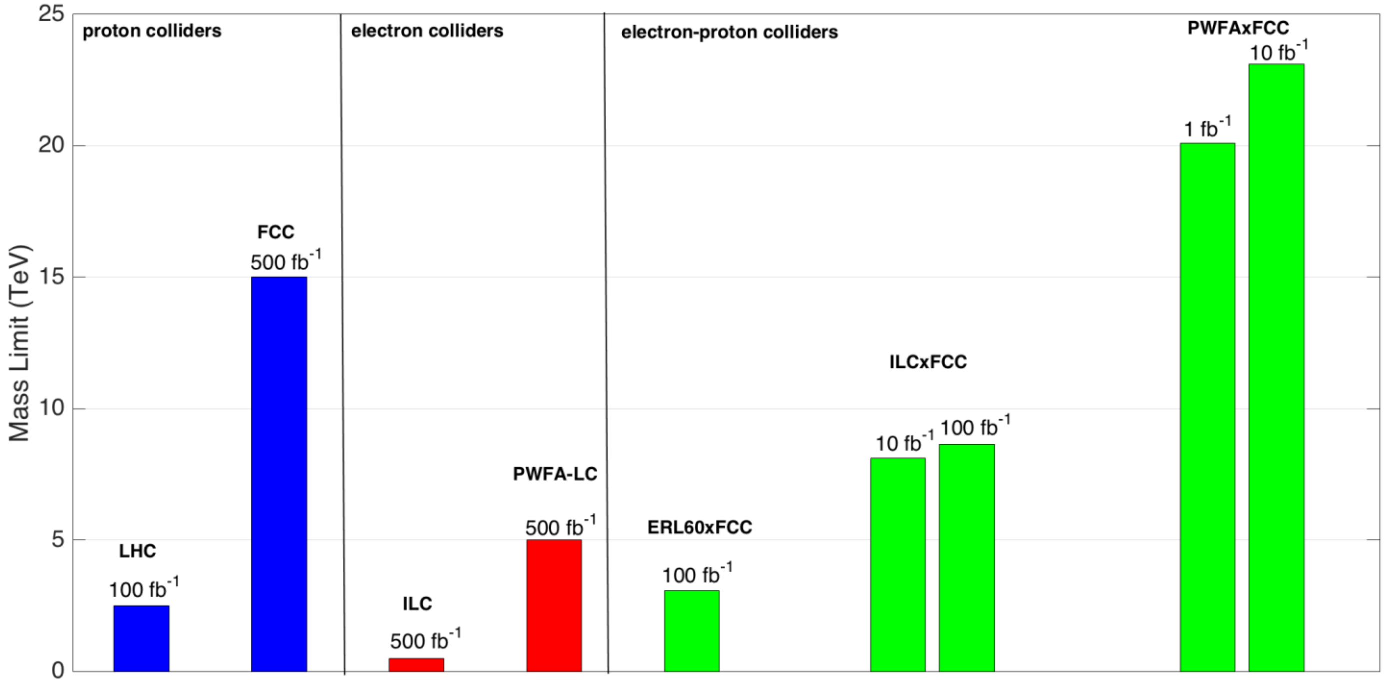


Normalised pseudo-rapidity distribution of **jet** for signals and backgrounds at ERL60-FCC



Normalised pseudo-rapidity distribution of **electron** for signals and backgrounds at OPL1000-FCC

Discovery limits for color octet electron ($\Lambda = m_{e8}$)



If FCC will discover e_8, LC×FCC will give opportunity to determine Lorentz structure of e_8-e-g vertex using longitudinal polarization of electron beam, as well as to probe compositeness scale up to hundreds TeV.

Otherwise, PWFA-LC×FCC will discover e_8, if its mass is below 25 TeV.

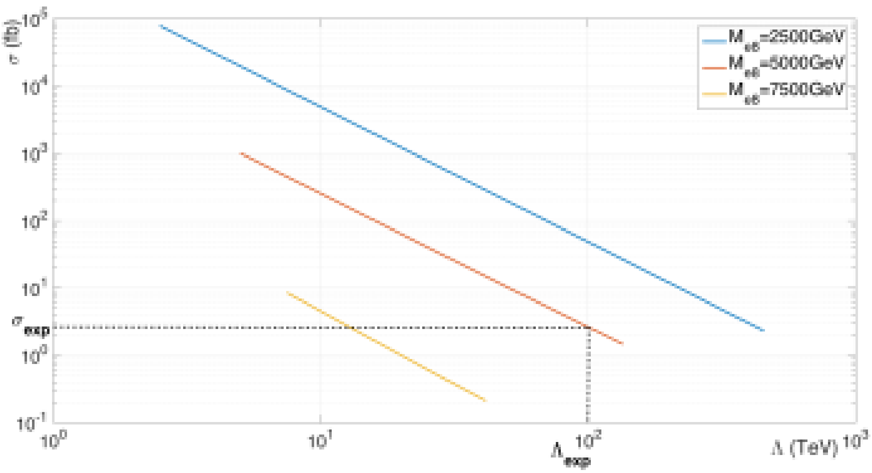
Similar situation for a lot of BSM phenomena (i.e. LQ, RPV, l* etc)

A. e8 is discovered by FCC but not observed at e-FCC

Table V. Lower limits on compositeness scale in TeV units at the FCC based ep colliders

Collider	L_{int}, fb^{-1}	$M_{e_8} = 2.5$ TeV		$M_{e_8} = 5.0$ TeV		$M_{e_8} = 7.5$ TeV		$M_{e_8} = 10$ TeV	
		3σ	5σ	3σ	5σ	3σ	5σ	3σ	5σ
ERL60⊗FCC	100	44	34	-	-	-	-	-	-
ILC⊗FCC	10	250	195	75	58	22	15	-	-
	100	450	350	135	105	42	32	-	-
PWFA-LC⊗FCC	1	220	170	200	150	190	145	110	80
	10	400	305	390	300	360	275	200	155

B. e8 is discovered by FCC and observed at e-FCC



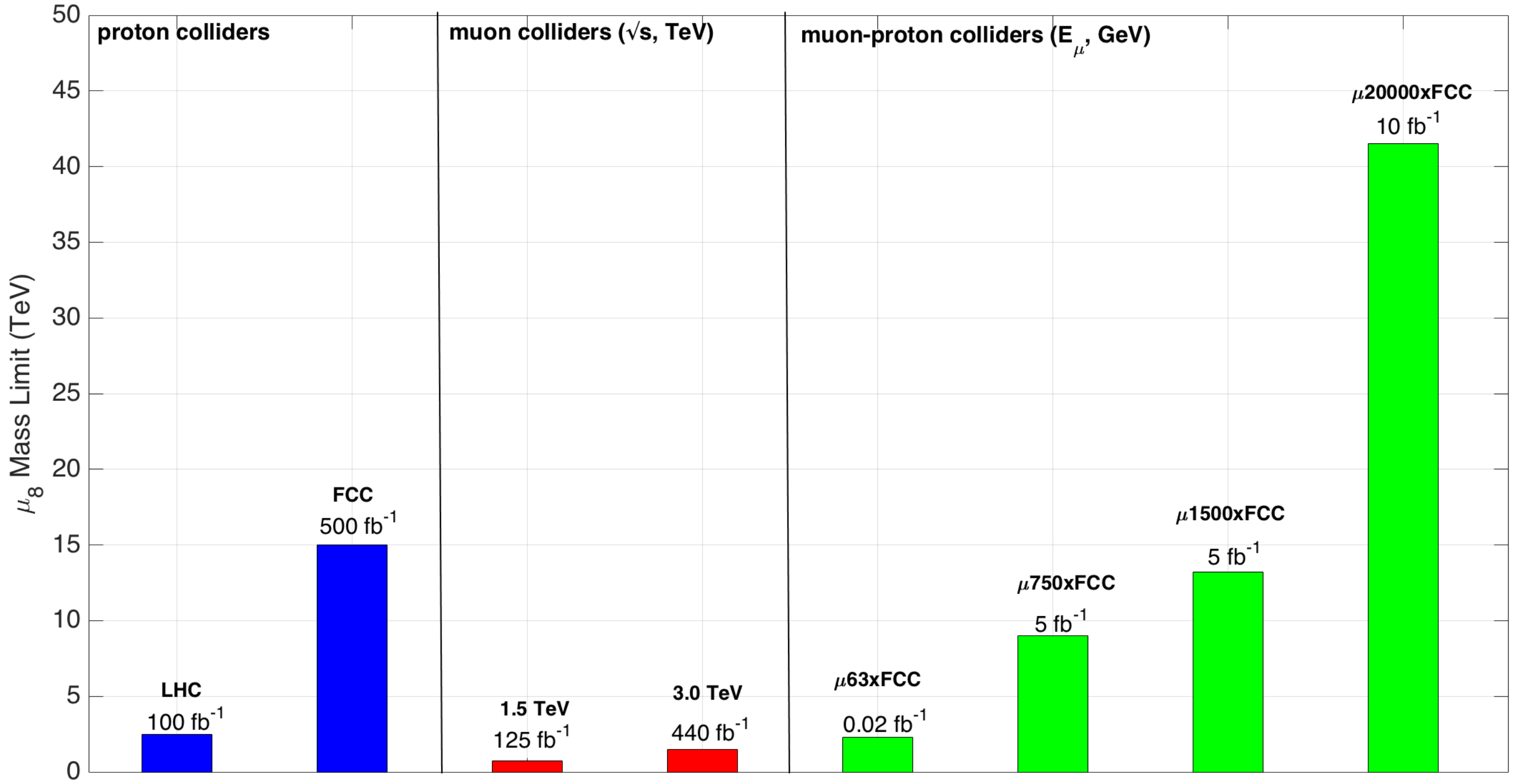
Determination of Λ:

1) FCC discover e8 with 5 TeV mass

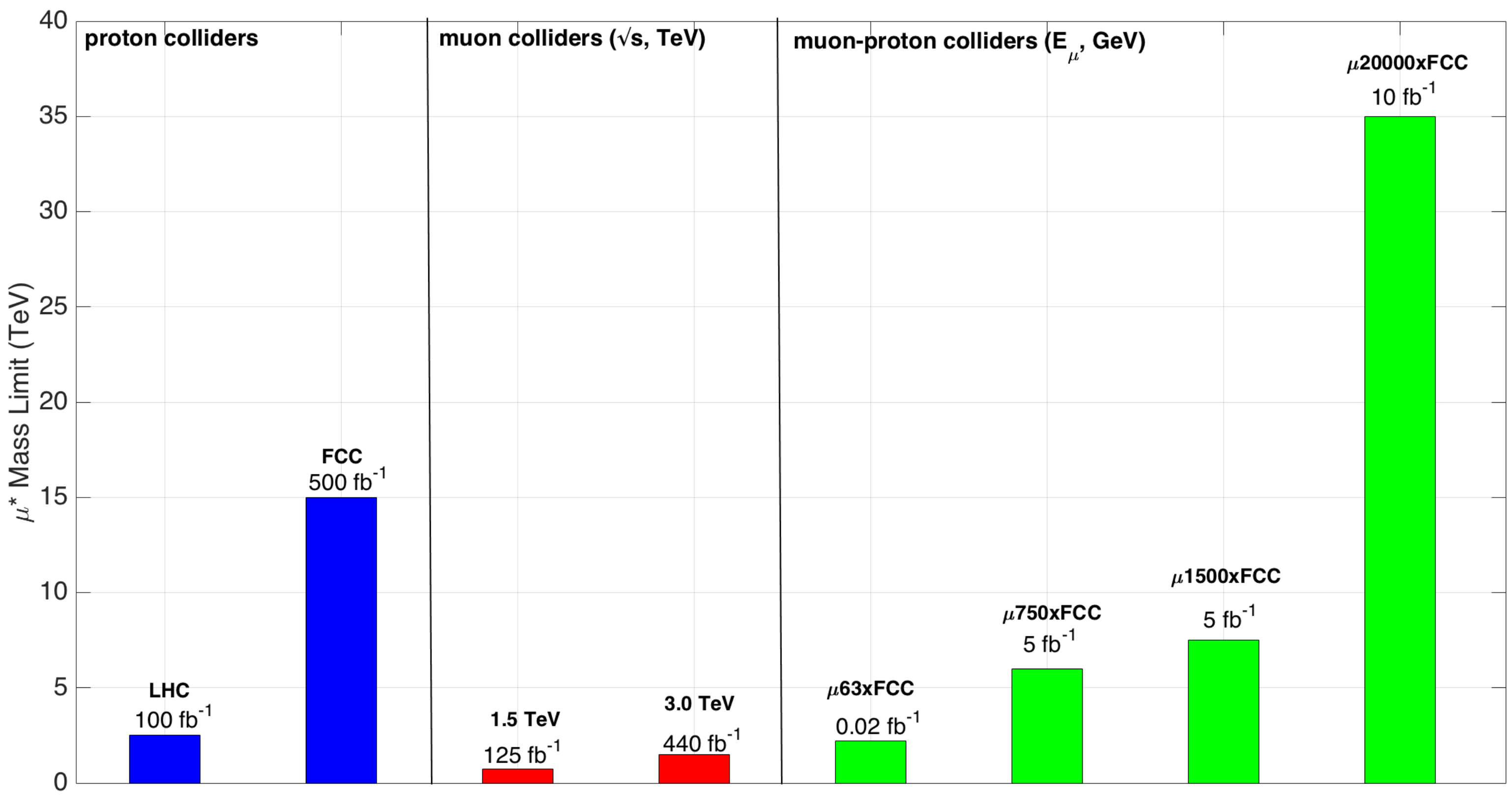
2) e-FCC measure cross section as σ ~ 2.50 f b

Therefore, compositeness scale is Λ ≈ 100 TeV

Discovery limits for color octet muon ($\Lambda = m_{\mu 8}$)



Discovery limits for excited muon ($\Lambda=m_{\mu*}$)



5. Conclusions

LC-FCC and μ-FCC will provide great search potential for a lot of BSM phenomena.

Their potentials are far beyond that of ERL60-FCC and ll colliders and sometimes exceed the FCC pp potential

γ options will essentially enlarge the LC-FCC potential

Concerning QCD basics, x up to 10^(-7) will be measured at Q^(2) ≈ 1oo GeV^(2)

…

Possible stages for FCC hl colliders are presented in the next slide

Frank’s presentation

FCC-he key parameters

$e^{\pm}$ energy = 60 GeV

***p* energy = 50 TeV** (or equiv. *A* energy)

#IPs = 1, goal $L \geq 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

to measure Higgs self coupling

spot size determined by *p*

options for FCC-he:

1) e⁻ from LHeC (or other) ERL

~~*2) $e^{\pm}$ from FCC-ee*~~

~~(if co-existing with *FCC-hh*)~~

2) LC-FCC, including gamma options

3) μ-FCC

Thank You for your attention.

Any questions or comments?

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BACKUP SLIDES

The PostHERA era: Brief review of future lepton hadron and photon hadron colliders

S. Sultansoy (DESY & Ankara U. & Baku, Inst. Phys.)

Oct 1999 - 19 pages

DESY-99-159, AU-HEP-99-02
e-Print: hep-ph/9911417 | PDF

Abstract
Options for future lp, lA, gamma-p, gamma-A and FEL gamma-A colliders are discussed

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  4.3. Multi-TeV μp

5. CONCLUSION

2. First stage: TESLA⊗HERA, LEP⊗LHC and μ–*ring*⊗TEVATRON

2.1. TESLA⊗HERA complex

Construction of future lepton linacs tangentially to hadron rings (HERA, Tevatron or LHC) will provide a number of additional opportunities to investigate lepton-hadron and photon-hadron interactions at TeV scale (see [1-3] and references therein). For example:

TESLA⊗HERA = TESLA ⊕ HERA
⊕ TeV scale *ep* collider
⊕ TeV scale *γp* collider
⊕ *eA* collider
⊕ *γA* collider
⊕ FEL *γA* collider.

4.2. LSC⊗ELOISATRON

For obvious reasons I prefer to discuss a linac, e. g. Linear Super Collider [38], as a source of high-energy electron beam. Combination of LSC with ELOISATRON (see Table VI) will give an opportunity to achieve $L_{ep}=3\cdot10^{32}cm^{-2}s^{-1}$ at $\sqrt{s}$=63.2 TeV. Further increasing of luminosity will require application of "dynamic" focusing scheme and/or cooling of proton beam.

As in the case of TESLA⊗HERA complex, *γp*, *eA*, *γA* and FEL *γA* options essentially extend the capacity of LSC⊗ELOISATRON complex.

4.3. 100 TeV μp

This is a most speculative (however, very attractive) one among the lepton-hadron collider options, which can be foreseen today. Using the luminosity estimation $L_{\mu\mu}=10^{36}cm^{-2}s^{-1}$ for $\sqrt{s}$=100 TeV $\mu^+\mu^-$ collider [39] one can expect at $n_p=n_\mu$

$$L_{\mu p}=\frac{0.25cm}{10cm}\cdot\frac{105MeV}{940MeV}\cdot\frac{8.7}{30}L_{\mu\mu}=10^{33}cm^{-2}s^{-1}.$$