Energy Recovery Linac as an Alternative Option for TAC and QCD-E Projects

Bora KETENOĞLU*
Ankara University

*On behalf of the TAC Collaboration

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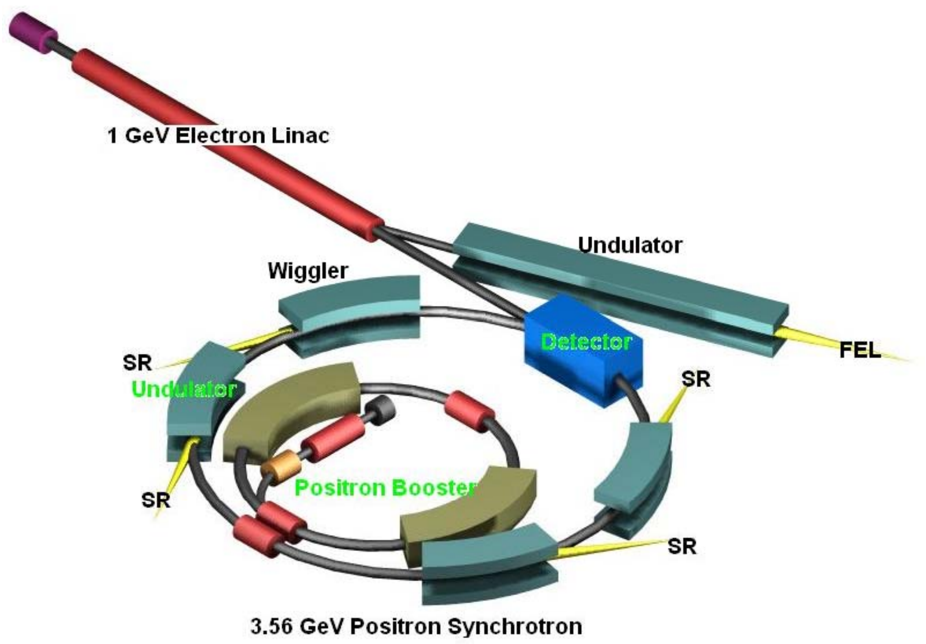
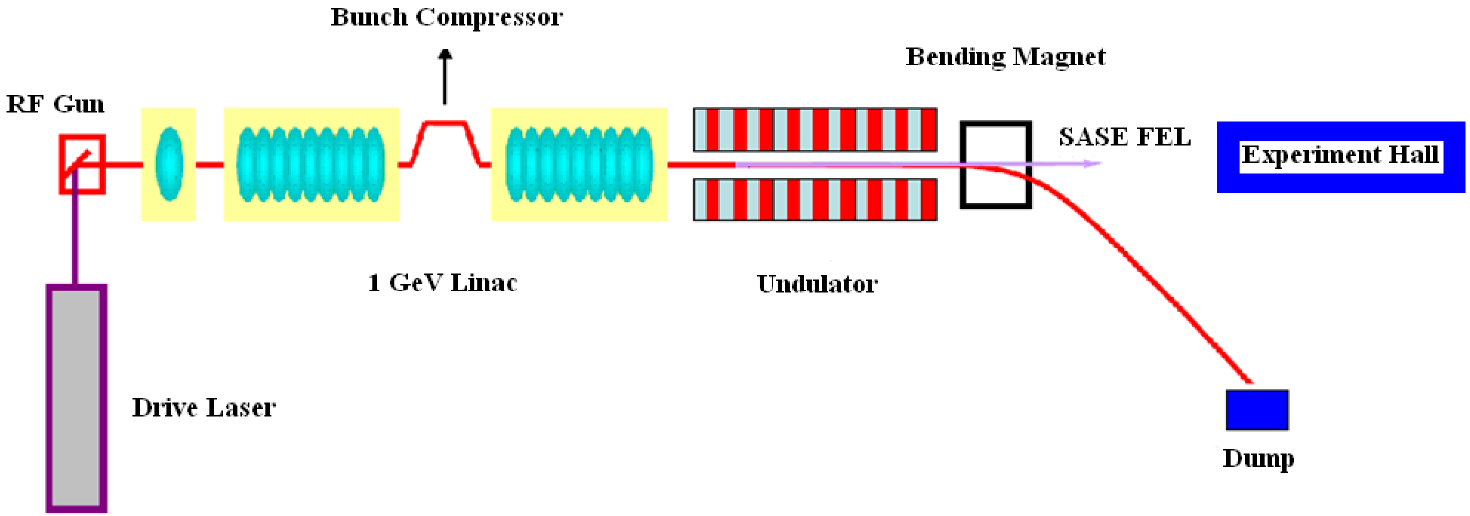
The Turkish Accelerator Center (TAC) Project
SASE FEL Facility Proposal



A SASE FEL facility was proposed for the TAC project in 2000 [1]. It was first planned to use the 1 GeV electron linac of the linac-ring type collider (Charm Factory) asynchronously.

The main goal of the proposal is to cover VUV and soft X-rays region of the spectrum besides IR-FEL, Bremsstrahlung and Synchrotron radiation proposals of the project.

Schematic View of the TAC SASE FEL Facility



Similar to FLASH @ DESY

Proposed Electron Beam Parameters Based on a Pulsed RF Electron Gun for TAC SASE FEL Facility

Electron Beam*	
Beam Energy (GeV)	1
Number of Electrons per Bunch (x 10^9)	5.5
Beam Current (mA)	26.4
Peak Current (A)	2106
Energy Spread (%)	0.1
Normalized Emittance (μm.rad)	3.1
Transverse Beam Sizes (μm)	75.2
Longitudinal Bunch Length (mm)	0.05

*General Design of SASE and Oscillator Mode Free Electron Lasers in Frame of the Turkish Accelerator Complex Project, S. Yigit, PhD. Thesis, Ankara University, 2007.

Optimized Undulator Parameters Based on a Samarium Cobalt Planar Undulator

Undulator*	
Period Length, λ_u (cm)	3
Gap, g (cm)	1.2
Peak Magnetic Field, B_u (T)	0.498
K Parameter	1.395
Saturation Length (m)	36
Number of Periods, (N)	1200

*General Design of SASE and Oscillator Mode Free Electron Lasers in Frame of the Turkish Accelerator Complex Project, S. Yigit, PhD. Thesis, Ankara University, 2007.

Calculated FEL Parameters

SASE FEL*	
Wavelength, λ_{SEL} (nm)	7.7
Photon Energy (eV)	160.5
ρ parameter	0.0018
Peak Power (GW)	1.4
Average Power (kW)	21.8
Gain Length, L_g (m)	0.75
Gain Length, 3D L_g (m)	1.57
Peak Flux (photons/s)	1.5×10^{26}
Peak Brightness (Photons/s/mrad^2/0.1%bg)	1.7×10^{29}
Peak Brilliance (photons/s/mm^2/mrad^2/0.1%bg)	2.9×10^{30}

*General Design of SASE and Oscillator Mode Free Electron Lasers in Frame of the Turkish Accelerator Complex Project, S. Yigit, PhD. Thesis, Ankara University, 2007.

Ongoing Difficulties on Parameter Optimization

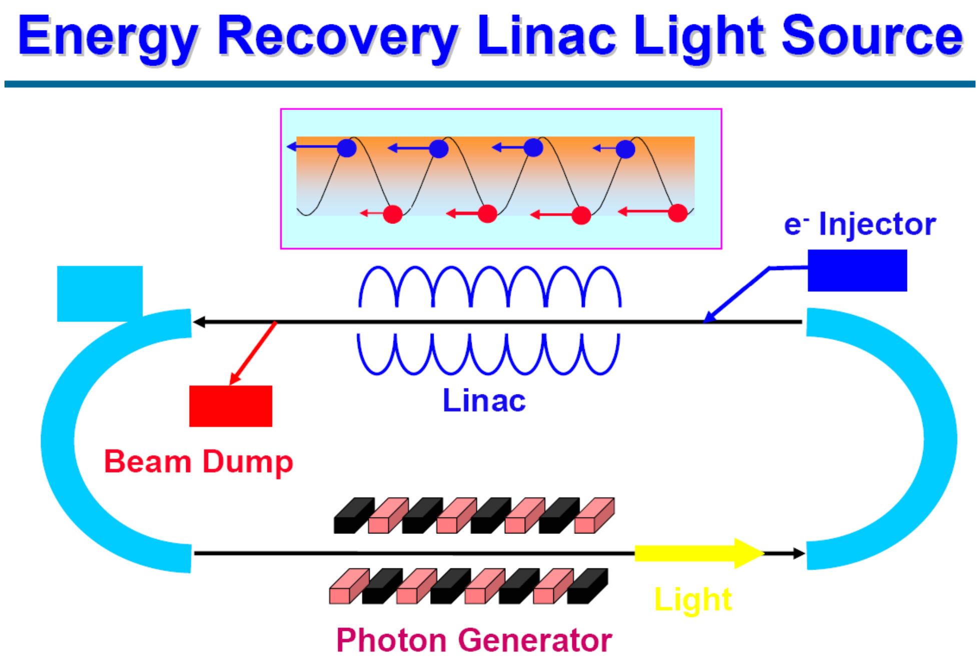
Atfer optimization studies, it was shown that [2] some of the electron beam parameters make linac design complicated for both SASE FEL production and collider.

i) To achieve SASE FEL with a peak power about GWs, a peak current about kAs is required.

ii) Modifications on bunch sizes and emittance to arise the peak current show that, the linac for SASE FEL production must disparately be designed from the collider's.

Future Prospects for the TAC SASE FEL Facility:

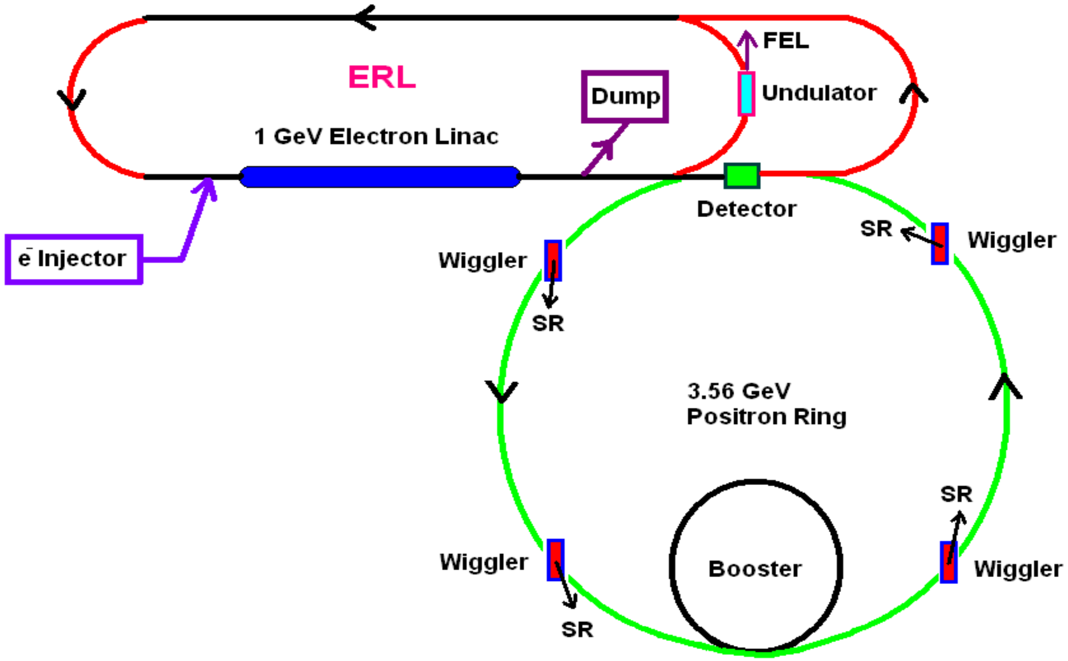
ERL !...



Electrons are released from the injector at the upper right, and are accelerated in a long linear superconducting accelerator (main linac). After emerging from this linac, the electrons pass through undulators that wiggle the electron beam and produce the x-rays in the usual way.

Electrons are continuously injected, make one trip around the ring, and return to the main linac where their energy is recovered. The spent beam is directed to the dump.

Schematic View of TAC ERL-Ring Type Collider & SASE FEL Facility



Proposed 1 GeV ERL Parameters for TAC

ERL*	
Electron beam energy (GeV)	1
Number of electrons per bunch ($x10^{10}$)	2
Normalized emittances ε_x^N / ε_y^N (μm)	3.92 / 0.06
σ_x / σ_y (μm)	6.32 / 0.12
σ_z (mm)	6
Beam current (A)	0.48
Beta functions at IP β_x / β_y (mm)	20 / 0.5

* Recepoglu, E., Sultansoy, S. A high luminosity ERL on ring e^-e^+ collider for a super charm factory, e-Print: 0809.3233 [physics.acc-ph] .

Present Situation of TAC SASE FEL
Based on 1 GeV ERL

First condition for SASE FEL: $\varepsilon < \dfrac{\lambda_{FEL}}{4\pi}$

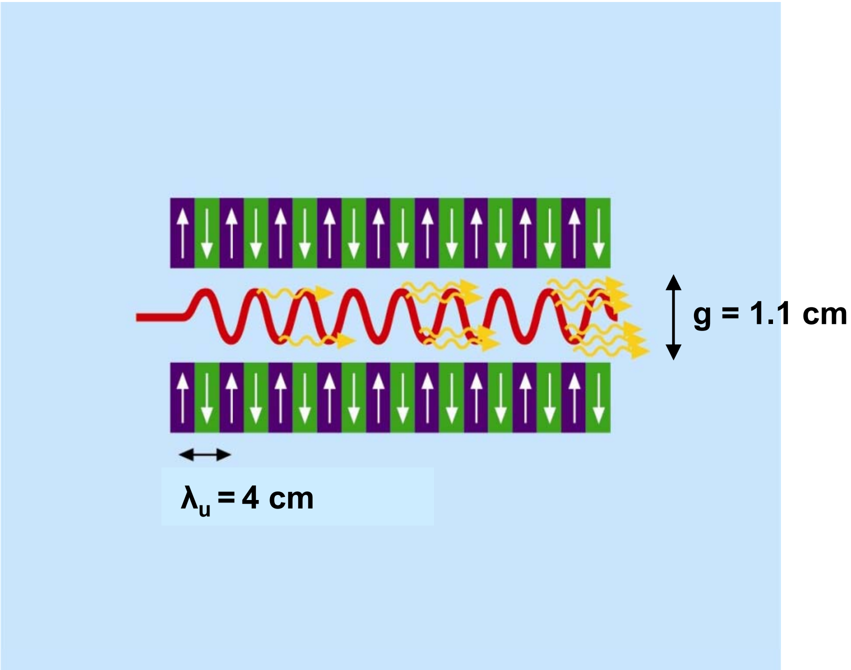
Tranverse emittances:

$\varepsilon_x \cong 2$ nm → $\lambda_{FEL} > 12.56\varepsilon_x \cong 26$ nm

$\varepsilon_y \cong 0.03$ nm → $\lambda_{FEL} > 12.56\varepsilon_y \cong 0.4$ nm

$$\lambda_{FEL} > 26 \text{ nm}$$

For Samarium Cobalt Planar Undulator:



g = 1.1 cm

λ_u = 4 cm

$$\frac{g}{\lambda_u} = 0.275$$

$$0.07 < \frac{g}{\lambda_u} < 0.7 \quad ✓$$

$$B_u(T) = 3.33 \exp\left\{-\frac{g}{\lambda_u}\left(5.47 - 1.8\frac{g}{\lambda_u}\right)\right\} = 0.848 \text{ T}$$

0.275

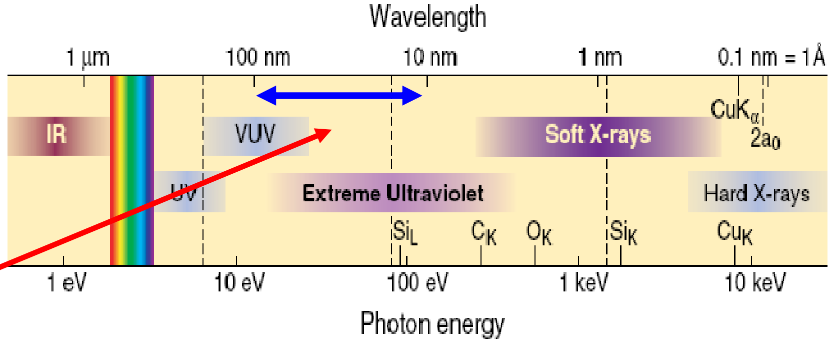
λ_u = 4 cm,

$\gamma_{1\ \mathrm{GeV}\ e^-} \cong 1957$

$$\lambda_{FEL}[cm] = \frac{\lambda_u[cm]}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

$$K = 0.934\lambda_u[cm]B_u[T]$$

$\lambda_{FEL} \cong$ 32 nm > $4\pi\varepsilon_x$ (26 nm)



Operating ERLs Around The World as FEL Drivers

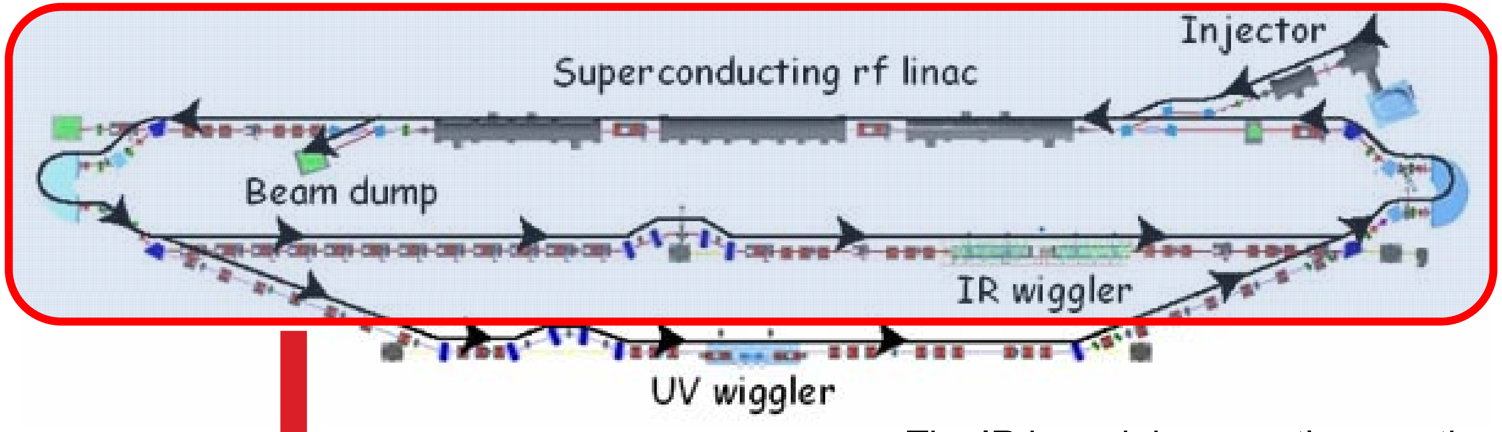
Today, there are 3 operating ERLs, all of which are used as FEL drivers:

I. The Jlab IR-FEL
II. The Japan Atomic Energy Agency (JAEA) FEL
III. The Novosibirsk High Power THz FEL

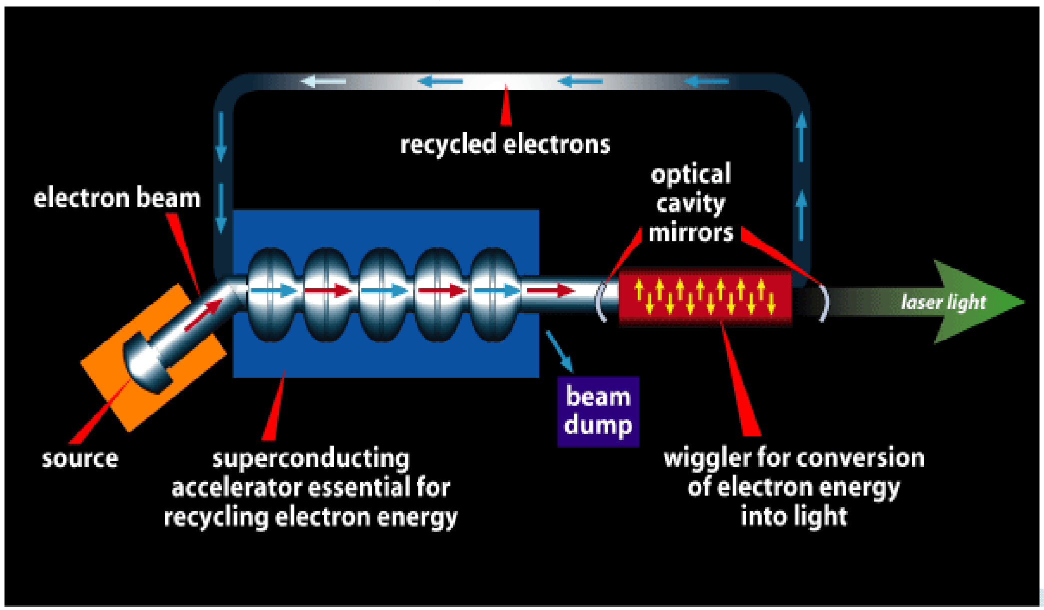
	JLAB Design / Achieved*	JAEA	Novosibirsk Operating / Upgrade
E [MeV]	145 / 160	17	12 / 14
I_{ave} [mA]	10 / 9.1	8.3**	20 / 150
q [pC]	135 / 270	400	1700
ε_n [μm], rms	30 / 7	30	30 / 15
Bunch Length	200 / 120 fs (rms)	12 ps (fwhm)	0.07 / 0.1 ns
Bunch Rep. Rate [MHz]	75	20.8	11.2 / 90

* Not simultaneously ** In the macropulse

Jefferson Lab Superconducting ERL Based FEL

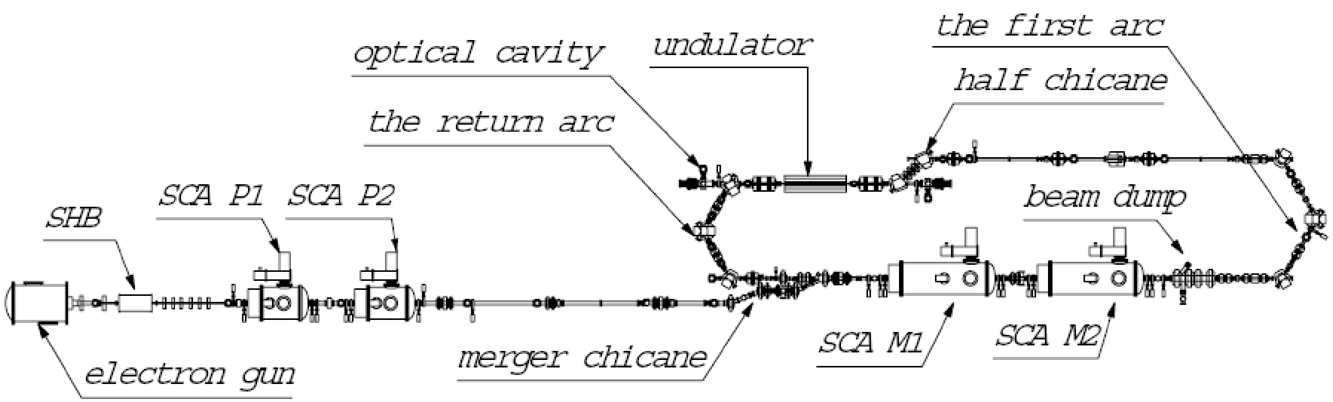


The IR branch is currently operational, the UV branch will be commissioned during 2009.



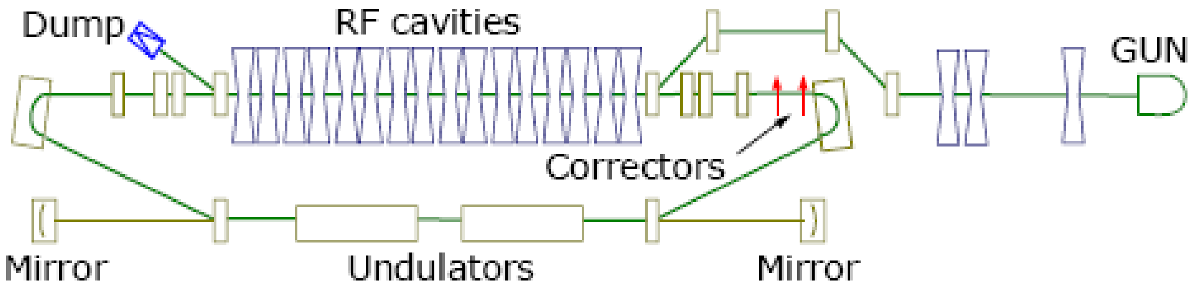
FEL Parameters	IR	UV
Wavelength range (µm)	1.5 – 14	0.25 – 1
Bunch length (FWHM ps)	0.2 – 2	0.2 – 2
Laser power / pulse (µJ)	100 – 300	25
Laser power (kW)	> 10	> 1
Rep. Rate (cw, MHz)	4.7 –75	4.7 – 75

JAEA Superconducting ERL Based FEL



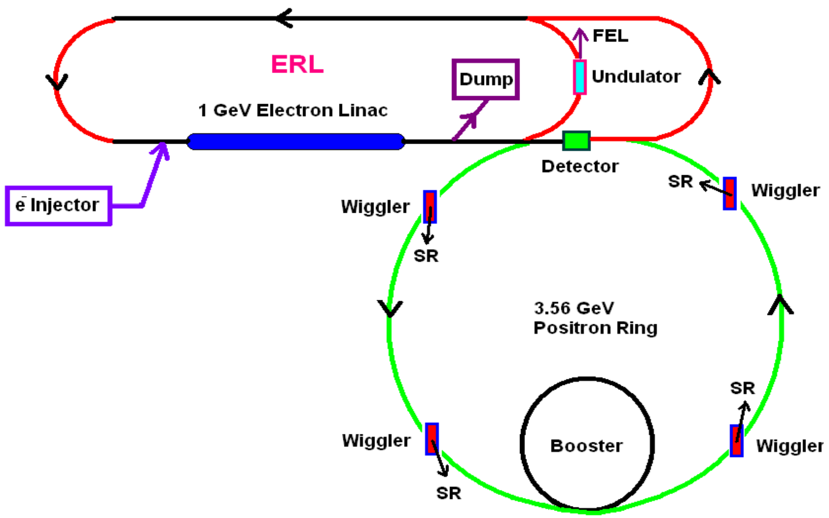
Undulator & FEL Parameters	IR
Wavelength (μm)	22
Bunch length at undulator (FWHM ps)	12
Undulator period (cm)	3.3
Number of periods	52
Bunch Repitation (MHz)	20.825
Undulator parameter (rms)	0.7
Macropulse	1 ms x 10 Hz

Novosibirsk ERL Based FEL
(Low Frequency-Normal Conducting)



FEL Parameters	IR
Wavelength range (μm)	120 - 240
Bunch length (continious train, ps)	40 - 100
Maxiumum average output power (W)	400
Peak power (MW)	> 1
Rep. Rate (MHz)	2.8 – 11.2

TAC ERL-Ring Type Super Charm Factory Proposal



ERL-ring type super charm factory will give an opportunity to achieve L = $2.3 \cdot 10^{35}$ $cm^{-2}s^{-1}$, which essentially exceed the luminosity values of existing and proposed standard type (ring-ring) charm factories. This leads to an obvious advantage in search for rare decays. Another important feature of linac-ring type charm factory is the asymmetric kinematics. This will be important in investigation of oscillations and CP-violation in the charm sector of the SM*.

* Recepoglu, E., Sultansoy, S. A high luminosity ERL on ring e^-e^+ collider for a super charm factory, e-Print: 0809.3233 [physics.acc-ph]

TAC ERL Based Super Charm Factory Collider Parameters

Collider*	
Crossing angle θ (mrad)	34
Collision frequency (MHz)	150
Geometric Luminosity ($cm^{-2}s^{-1}$)	$1.14 \cdot 10^{35}$
Luminosity enhancement factor, H_D	2.03
Luminosity ($cm^{-2}s^{-1}$)	$2.31 \cdot 10^{35}$

* Recepoglu, E., Sultansoy, S. A high luminosity ERL on ring e^-e^+ collider for a super charm factory, e-Print: 0809.3233 [physics.acc-ph]

The QCD-E Project

The QCD-E project is a linac-ring type electron-proton collider with a center of mass energy $\sqrt{s}$ = 1.4 TeV based on CERN-LHC. Nowadays, ERL option is coming into question and seems as a more promising option.

Energy of the electron beam: 70 GeV **(ERL)**

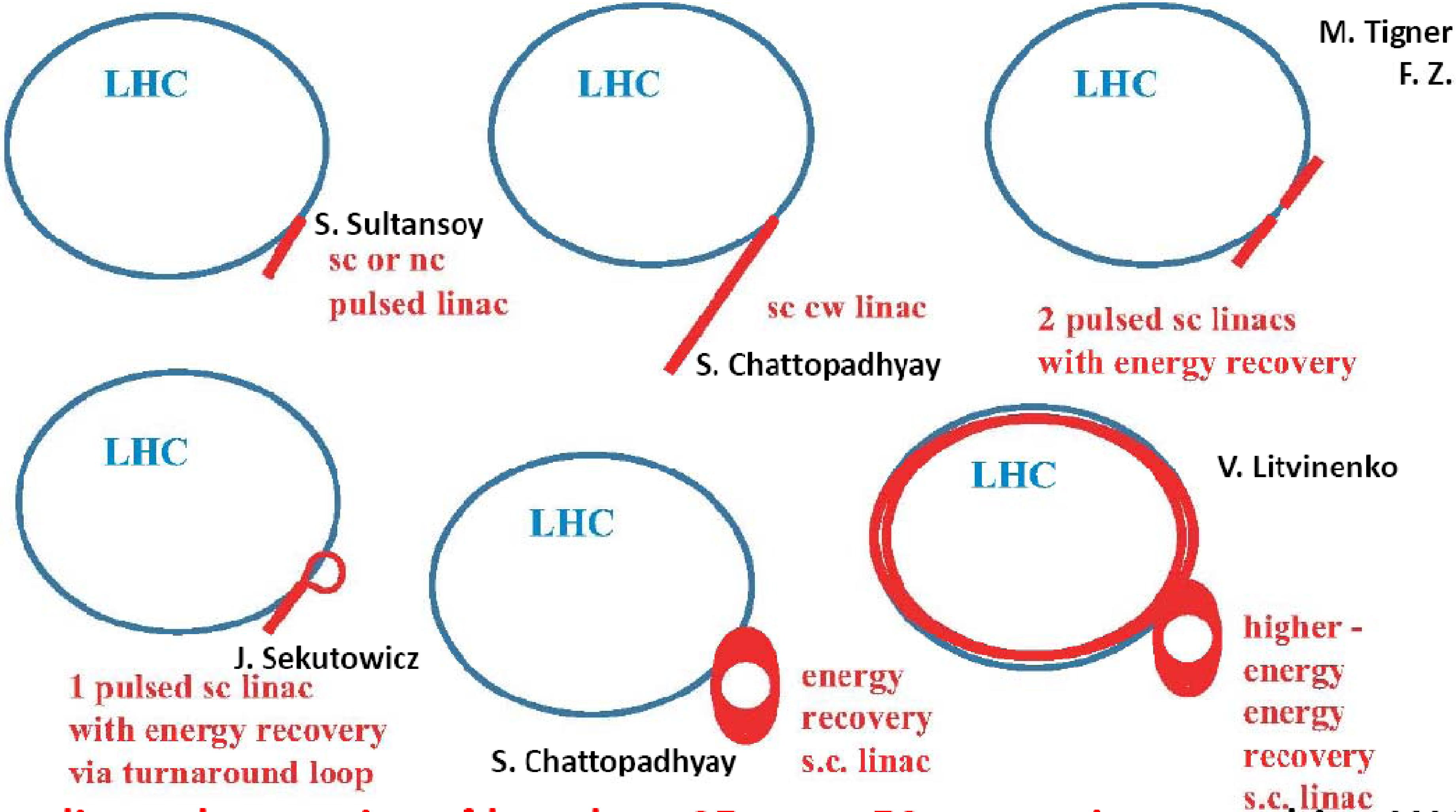
Energy of the proton beam: 7 TeV **(LHC)**

To achieve the luminosity more than 10^{33} $cm^{-2}s^{-1}$, ERL usage is required for the electron beam.

Following three slides are quoted from F. Zimmermann *et al.* LHeC Ring-Linac options, 1^{st} ECFA-CERN LHeC Workshop, 2008.

- colliding 7 TeV p's with 25-140 (-300) GeV e-'s:
  - → extending LHC discovery reach
  - → enabling LHC precision physics
- history: - Ankara workshop 1997, Turkish JP, 22, 7 (1998)
  - -S. Sultansoy, Aachen 2003, EPJ C33: S1064 (2004)
  - -D.Schulte,F.Zimmermann, EPAC'04 (CLIC-1/LHC p s-bunch)
  - -H. Aksakal et al, NIM A576: 287 (2007) (CLIC & ILC vs LHC)
  - - S. Chattopadhyay: ***cw!, ERL!*** (2007), A. Eide's report (2008)
  - -V. Litvinenko, CERN AB Form 11 March 2008
  - -F. Zimmermann et al, EPAC'08
  - -J. Skrabacz' report (2008)
- e- linac offers several distinct advantages
  e.g.: separation from LHC, high beam quality, synergies

LR scenarios



s.c. linac , long trains of bunches, 25-ns or 50-ns spacing, matching LHC p beam (*PLACET: stable*); long pulse or cw → high luminosity; optional energy recovery → higher luminosity; 1.3 GHz (ILC) or 700 MHz (SPL)

Linac-Ring Potential

100 MW wall plug power

20 GeV 98% energy recovery	**60 GeV w/o energy recovery**	**60 GeV 98% energy recovery**	140 GeV 98% energy recovery
5×10^{34} $cm^{-2}s^{-1}$	**5×10^{32} $cm^{-2}s^{-1}$**	**1×10^{34} $cm^{-2}s^{-1}$**	4×10^{33} $cm^{-2}s^{-1}$

proton parameters from LHC “phase-2” upgrade

$N_b = 5 \times 10^{11}$, 50 ns spacing, $\gamma\varepsilon = 3.75\ \mu m$, $\beta^* = 0.1$ m

References

[1] Ciftci, A. K. *et al.* Linac-Ring Type Ø Factory for Basic and Applied Research, Turkish J. of Physics, 24 (2000), 747-758.
[2] General Design of SASE and Oscillator Mode Free Electron Lasers in Frame of the Turkish Accelerator Complex Project, S. Yigit, PhD. Thesis, Ankara University, 2007.
[3] Merminga, L. Energy Recovery Linacs, Proceedings of PAC07, 2007.
[4] Recepoglu, E., Sultansoy, S. A High Luminosity ERL on ring e^-e^+ collider for a super charm factory, e-Print: 0809.3233 [physics.acc-ph].
[5] Sultansoy, S. Eur. Phys. J. C33, 01 1064 (2004).
[6] Sultansoy, S., Karadeniz, H. QCD-Explorer Proposal: e-linac versus e-ring, Proceedings of EPAC06, 2006.
[7] Zimmermann, F. *et al.* Linac-LHC ep Collider Options, Proceedings of EPAC08, 2008.
[8] Zimmermann, F. *et al.* LHeC Ring-Linac options, 1st ECFA-CERN LHeC Workshop, 2008.
[9] www.flash.desy.de
[10] http://thm.ankara.edu.tr

Thanks a lot for your attention…