TURKISH ACCELERATOR COMPLEX & STATUS OF TAC SASE FEL

Dr. Hatice DURAN YILDIZ

On the Behalf of the TAC & TAC SASE-FEL Group

TÜRK HIZLANDIRICI MERKEZİ

TURKISH ACCELERATOR CENTER

TAC

DESY

April 5, 2011

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Aim of TAC Collaboration

- To design, construct and use of high energy particle (electron, positron, and proton) accelerators for scientific research and technological developments in basic and applied sciences in Turkey and in the region.
- To collaborate with international accelerator community in the World.

Phases Of the Project

→ **1997 -2001 : First Step TAC: Feasibility project**
Particle Accelerators: What can be done in Turkey?
Collaboration: Ankara and Gazi Universities

→ **2002 – 2005 :Second step to TAC: General Design Projects**
Collaboration: Ankara and Gazi Universities

Phases of the project

2006-2013

Third step to TAC: TDR and First Facility

Technical Design Report & First Facility for TAC is supported by State Planning Organization (SPO) of Turkey

Technical Design Report of TAC & IR FEL Facility

Collaboration: 10 Turkish Universities

TAC collaboration and project team

- TAC: An Inter University Collaboration (10 Turkish Universities)
- Project Team: 52 staff with PhD + 68 graduate students

Ankara University (Coordinator)

Gazi University

İstanbul University

Uludağ University

Dumlupınar University

Boğaziçi University

Doğuş University

Erciyes University

Süleyman Demirel University

Niğde University

Proposed facilities

- **The First Facility (**Turkish Accelerator and Radiation Laboratory in Ankara **-TARLA)**

  Sc linac based IR FEL & Bremstrahlung facility

- **TAC Particle Factory**

  Electron-positron collider (charm factory), Ec.m.= 3.77 GeV

- **TAC Synchrotron Radiaton Facility**

  A third generation light source based on dedicated 4.5 GeV electron synchrotron

- **TAC SASE FEL Facility**

  A fourth generation light source based on 1 GeV electron linac

- **TAC Proton Accelerator Facility**

  A high power and high flux proton accelerator up to 3 GeV energy

Local committees & Study groups

- **Local Committees for IR FEL & Brems. Facility -TARLA)**
- Machine Committee (Head: Dr. S. Ozkorucuklu)
- Experimental Stations Committee (Head: Dr. P. Arıkan)
- Bremsstrahlung Committee (Head: Dr. İ. Akkurt)

Study Groups for TAC

- TAC Particle Factory Study Group (Director: Dr. O. Çakır)
- TAC Synchrotron Radiation Facility Study Group (Director: Dr. A.K. Çiftçi)
- TAC SASE FEL Facility Study Group (Director: Dr. H. Duran Yıldız)
- TAC Proton Accelerator Facility Study Group (Director: Dr. B. Akkuş)

International collaborations & contacts

- **ATLAS, CMS, CLIC, CAST** (CERN, Switzerland)
- **ELBE** (FZD, Germany)
- **BESSY** (HZB, Germany)
- **FLASH, HASYLAB** (DESY, Germany)
- **Cockroft Inst.** (Daresbury, England)
- **APS** (ANL, USA)
- **JLab FEL** (JLab, USA)
- **LCLS, SSRL** (SLAC, USA)
- **FNAL** (USA)
- **Koyoto Univ.** (Japan)
- **INFN** (Perugia, Italy)
- **RIKEN** (Japan)
- **PSI** (Switzerland)

Institute of Accelerator Technologies of Ankara University

- Established on February 26, 2010.
- Three main branches planned for graduate education are:

  - Particle Accelerators & Technologies
  - Accelerator Based Light Sources
  - Detector & Data AcquisitionSystems

After the approval of Higher Education Council of Turkey, we expect to start the graduate

education in Fall 2011

Location: Gölbaşı Campus of Ankara University

First Facility of TAC

- Turkish Accelerator and Radiation Laboratory in Ankara (TARLA)

- TARLA will be a **Free Electron Laser & Bremstrahlung** Facility*

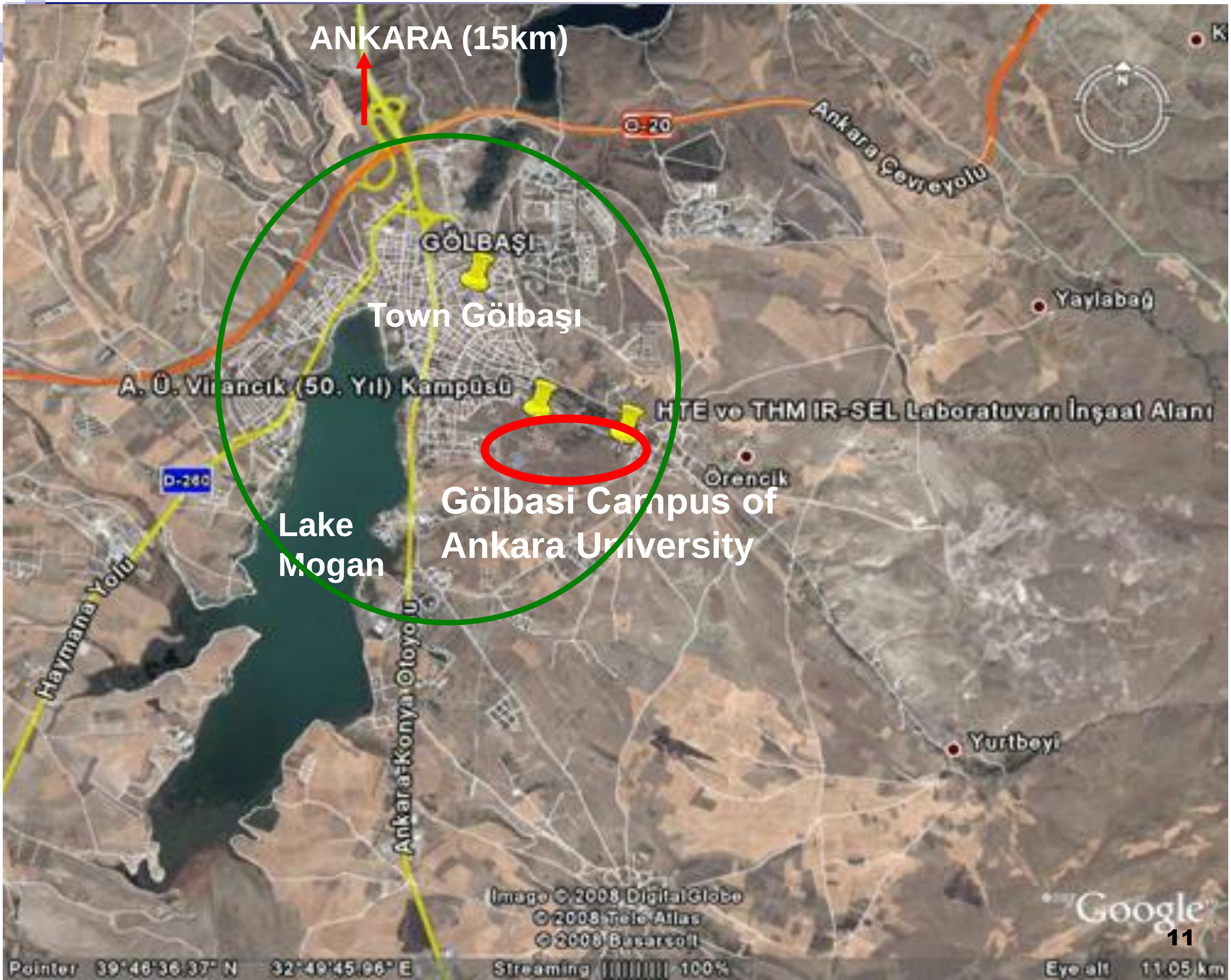
  **A. Aksoy et al. Thte Status of TAC IR FEL and Bremstrahlung Project PAC10, May 2010, Kyoto, Japan*

- Buildings of the facility was completed in 2010.

- It is planned that the facility will be completed in 2013.

- TARLA project aims to produce FEL in oscillator mode between 2-250 micron range using 15-40 MeV electron beam.

- To obtain FEL in 2-250 microns range, undulators with 2.5 and 9 cm period length will be used with two optical resonators.


ANKARA (15km)
O-20
Ankara Çevreyolu
GÖLBAŞI
Town Gölbaşı
Yaylabağ
A. Ü. Virancık (50. Yıl) Kampüsü
HTE ve THM IR-SEL Laboratuvarı İnşaat Alanı
D-260
Örencik
Gölbasi Campus of
Ankara University
Lake
Mogan
Haymana Yolu
Ankara-Konya Otoyolu
Yurtbeyi
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Google
Pointer 39°46'36.37" N 32°49'45.96" E
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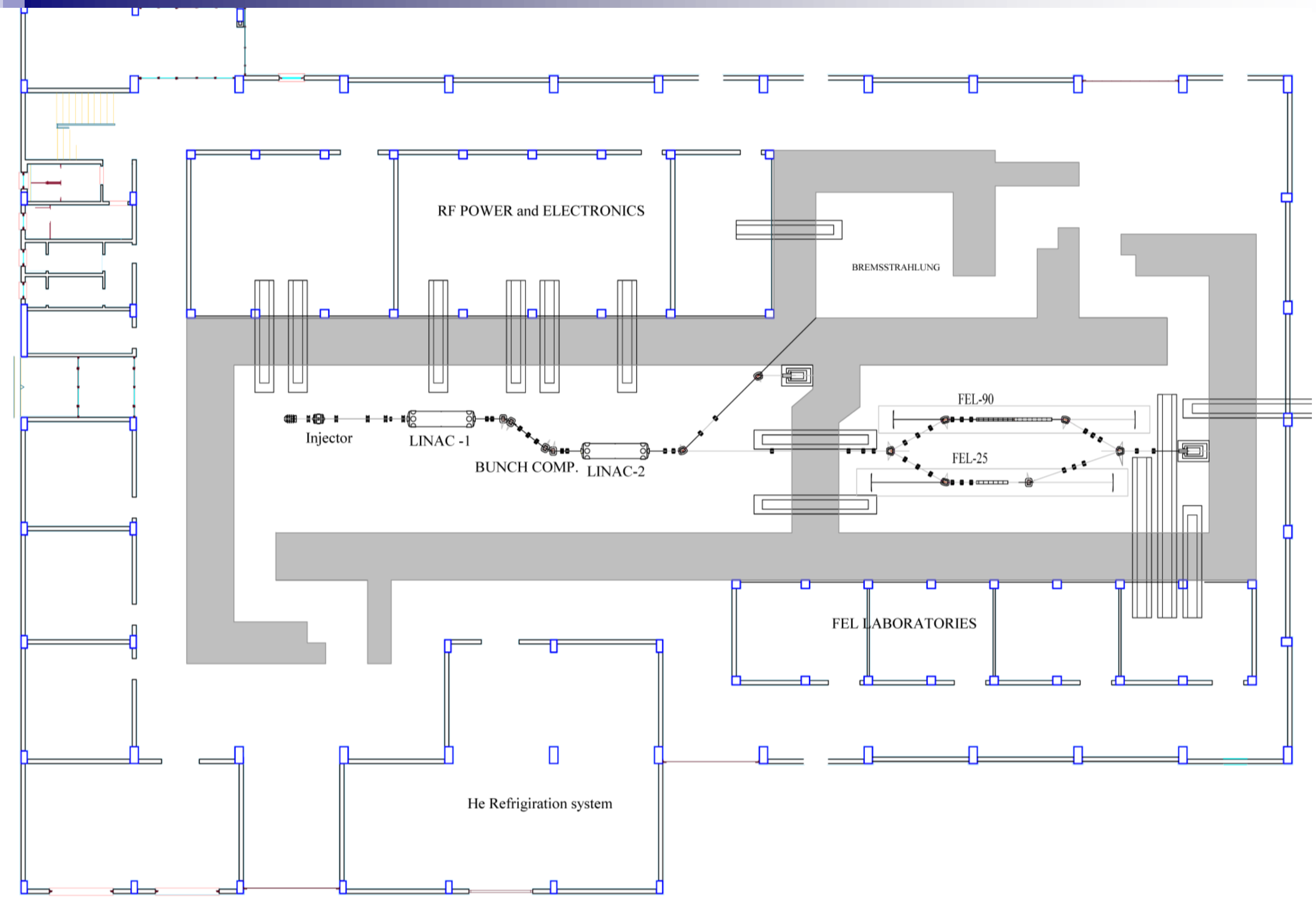
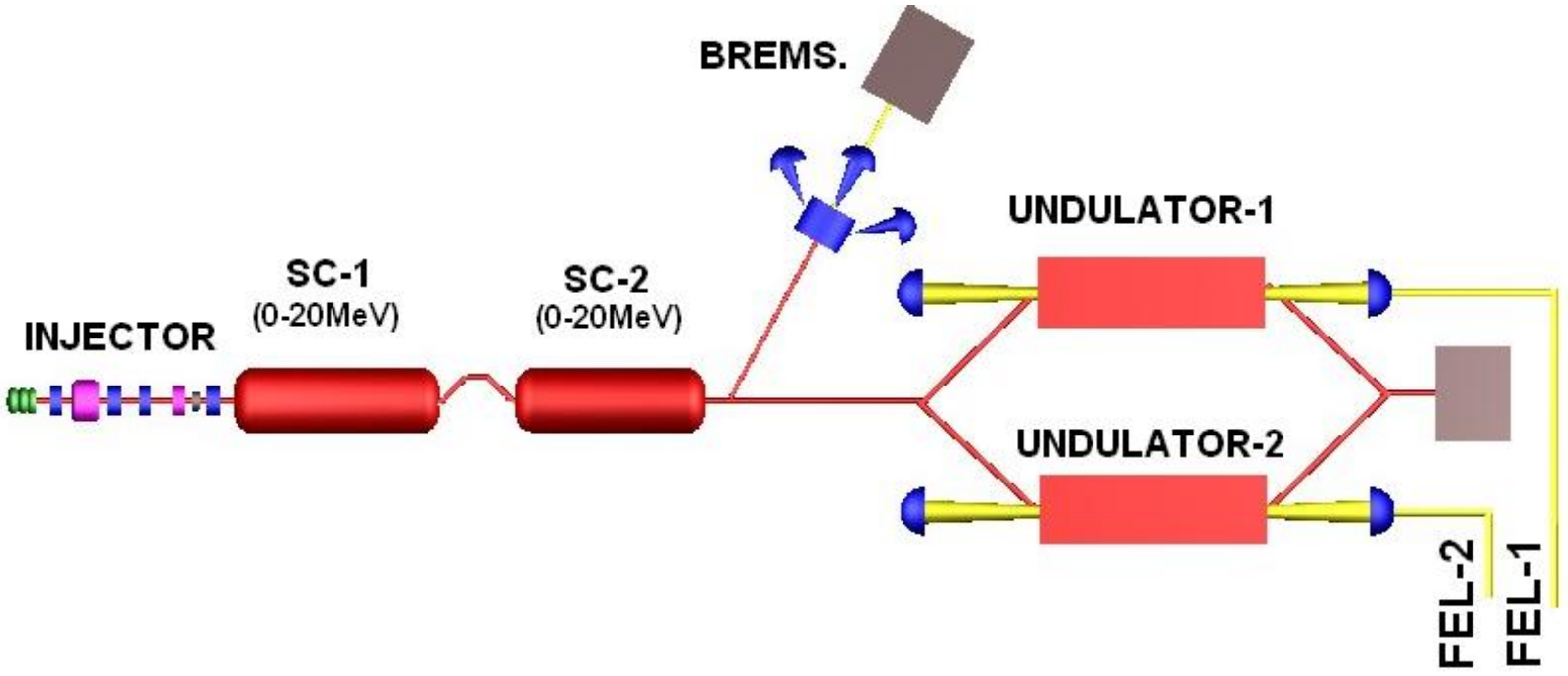
Eye alt 11.05 km


RF POWER and ELECTRONICS
BREMSSTRAHLUNG
FEL-90
Injector
LINAC -1
FEL-25
BUNCH COMP.
LINAC-2
FEL LABORATORIES
He Refrigiration system

TARLA Facility

Schematic view of TARLA Facility



ACCELERATOR TECHNOLOGIES ENSTITUTE

http://hte.ankara.edu.tr

TAC IR-FEL Parameters

Laser Parameters	U25	U90
Wavelength Range [μm]	2.5-27	18-250
Maximum Peak Power (MW) (120 pC)	5	2.5
Pulse Energy (μJ)(max)(120 pC)	10	8
Micropulse repetition [Mhz]	13	13
Average Power [W] *	0.1 - 40	0.1 - 30
Brightness [ph/(s mm² mrad² 0.1% B.W.)]*	~10^30	~10^29
Pulse length [ps]	1-10	1-10

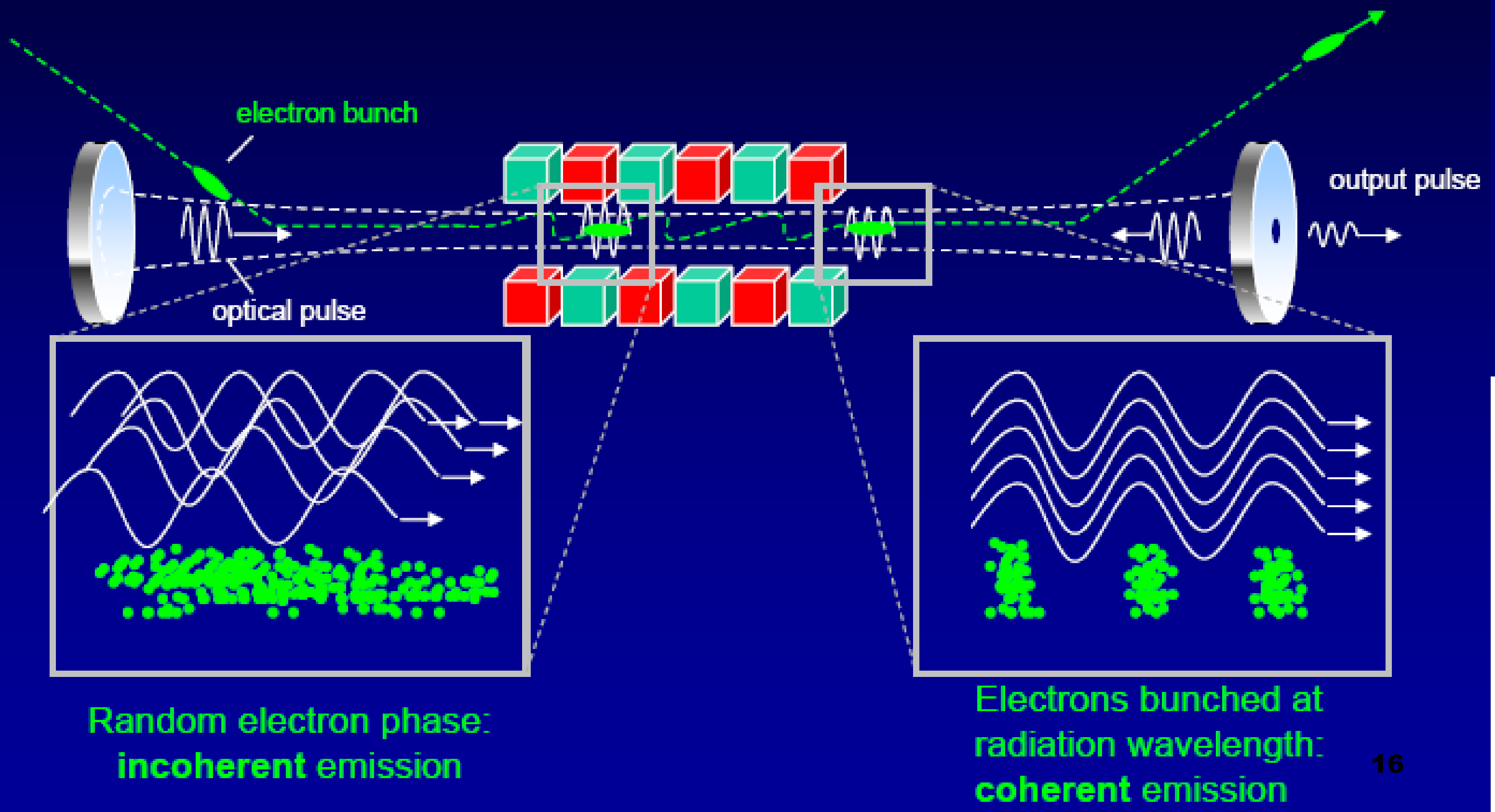
Electron Accelerator

	10(16)kW Klystron
Electron beam energy[MeV]	15-40(15-40)
Bunch charge [pC]	80(120)
Average Beam Current[mA]	(1)1.6
Normalized transverse rms emittance[mm mrad]	<15
Normalized longitudinal rms emittance [keV ps]	<50
Micropulse Duration [ps]	0.5-8
Micropulse Separation [ns]	77
Macro Atma Tekrarlama (Hz)	1-25

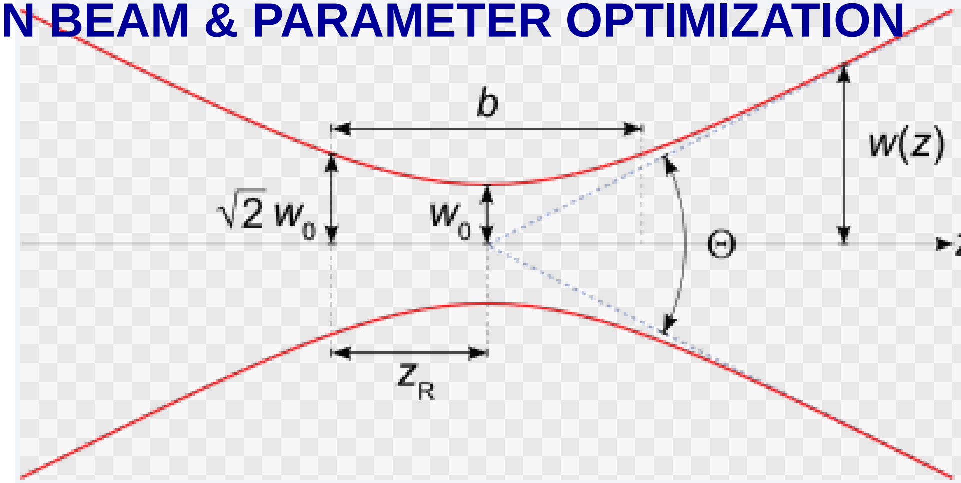
Undulator Magnet Parameters

	U25	U90
Undulator Period[cm]	2.5	9
Undulator Gap [cm]	2-3	3-9
K Parameter (rms)	0.3-0.7	0.5-2.5
Number of Undulator Periods (N)	60	40
undulator length	1,5	3,6

An Optic Cavity is a system of mirrors which forms a standing wave cavity resonator for FEL. A resonator is a device that exhibit resonant behaviour and oscillates at some certain resonance frequencies. An undulator is an insertion devices. It consists of a periodic structure design of magnet dipoles.



CHARACTERISTICS OF GAUSSIAN BEAM & PARAMETER OPTIMIZATION



$$w(z) = w_0[1 + (\frac{\lambda z}{\pi w_0^2})^2]^{1/2}$$

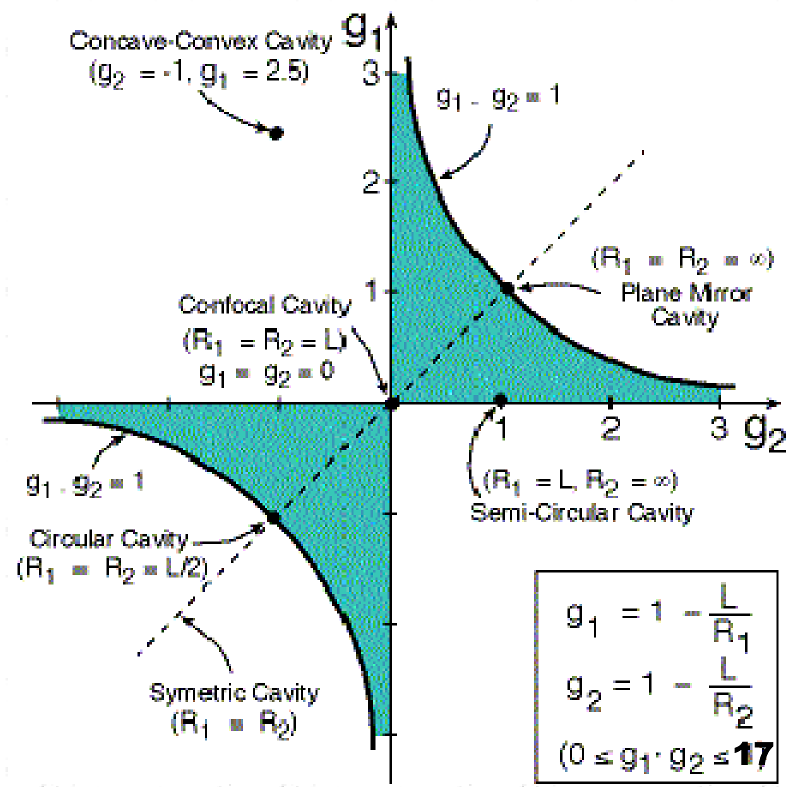
$$\theta = \lim_{z->\infty} \frac{2w(z)}{z} = \frac{2\lambda}{\pi w_0}$$

Rayleigh Length $\quad Z_R = \frac{\pi w_0^2}{\lambda_L}$

$$Z_R = \sqrt{\frac{g_1 g_2 (1 - g_1 g_2) L^2}{(g_1 + g_2 - 2 g_1 g_2)^2}}$$

$$\omega_1 = \sqrt{\frac{L_c \lambda_R}{\pi}} \left(\frac{g_2}{g_1 (1 - g_1 g_2)} \right)^{\frac{1}{4}}$$

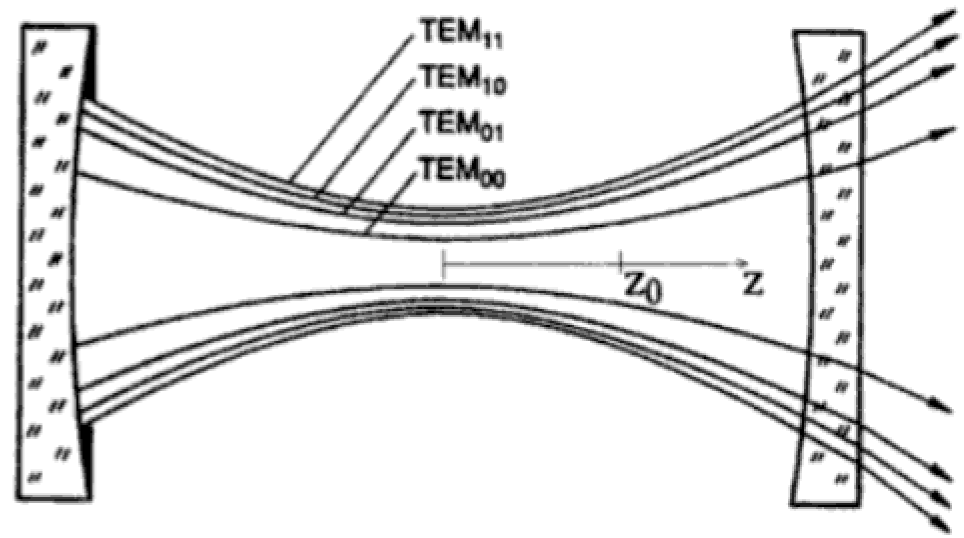
$$R(z) = z[1 + (\frac{\pi w_0^2}{\lambda z})^2]$$

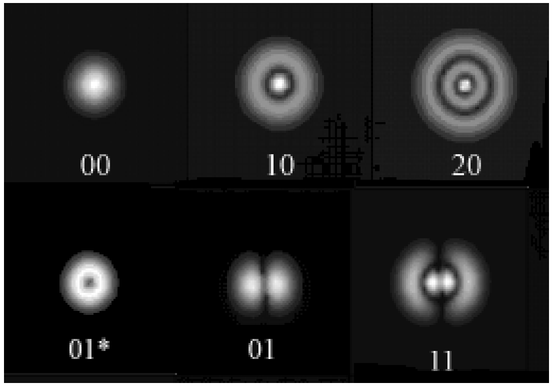


TAC IR-FEL Resonator Parameters

Parameters	U25	U90
Resonator Type	Symmetric, concentric	
Undulator Period (cm)	2.5	9
Resonator Length (m)	11.53	
Undulator Length (m)	1.68	3.6
1st Mirror, radius of curvature, R_1 [m]	5.9281	6.5140
2nd Mirror, radius of curvature, R_2[m]	5.9281	6.5140
Rayleigh Length, Z_R (m)	0.9699	2.078
Stabilty parameter, $g_{1*}g_2$	(-0.9449)*(-0.9449)	(-0.770)*(-0.770)
Beam Waist, ω_0 (m)	9.214×10^{-4} (λ_R=2.75 μm)	2.697×10^{-3} (λ_R=11 μm)
Beam Waist, ω_0 (m)	2..887x10^{-3} (λ_R=2.75 μm)	0.011 (λ_R=185 μm)
Beam spot size on m irror, ω_1 (m)	5.553×10^{-3} (λ_R=2.75 μm)	7.954×10^{-3} (λ_R=11 μm)
Beam spot size on m irror, ω_1 (m)	0.0174 (λ_R=27 μm)	0.0326 (λ_R=185 μm)
Beam spot size on m irror, ω_2 (m)	5.553×10^{-3} (λ_R=2.75 μm)	7.954×10^{-3} (λ_R=11 μm)
Beam spot size on m irror, ω_2 (m)	0.0174 (λ_R=27 μm)	0.0326 (λ_R=2.75 μm)
Mirror Material	Pyrex & coating Au/Cu	Pyrex & coating Au/Cu
Radius of out coupling hole [mm]	1.5/2	2/3

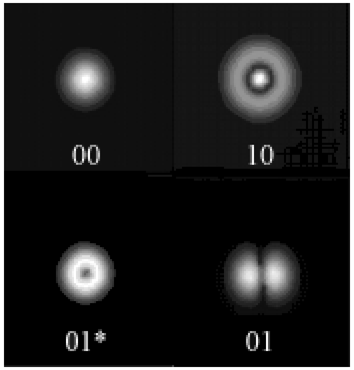
Higher Modes





- **<u>For U25</u>, also TEM_{01},TEM_{10}, TEM_{11}, TEM_{20} modes are smaller than the undulator gap.**

For U25 and for U90, we obtain TEM_{00} modes that inside the undulator gap.



- **<u>For U90</u>, also TEM_{01},TEM_{10} modes are smaller than the undulator gap.**

GAIN

Since the resonator operate in low gain area, Small signal gain - g_0 is important to determine the intensity and mirror hole, besides these also gain for single pass.

Small signal gain: $$g_0 = \frac{4\pi}{\gamma} \frac{\hat{I}}{I_0} \frac{\lambda L_u}{\sum_E} f \left(\frac{\Delta\omega}{\omega}\right)_0^{-2} F(\xi) \quad \text{where} \quad f = \frac{\sum_E}{\sum_L} \quad \text{filling factor}$$

$$I_0 = 1.7 \times 10^4 \text{ A} \quad \text{Alfven current and} \quad \left(\frac{\Delta\omega}{\omega}\right) = \frac{1}{2N} \quad \text{homojen band width}$$

$$F(\xi) = \begin{cases} \frac{1}{2} \frac{k^2}{1+k^2} & \text{(helical undulator)} \\ \frac{1}{2} \frac{k^2}{1+k^2} \left(J_0\left(\frac{k^2}{2(1+k^2)}\right)\right) - J_1\left(\left(\frac{k^2}{2(1+k^2)}\right)\right)^2 & \text{(linear undulator)} \end{cases}$$

$J_{0,1}$ cylindrical Bessel Functions.

g_0=0.1544 <u>for U25</u>

Gain for single pass:

G_{max}=0.85*g_0+0.19*g_0^2+4.12*10^{-3}*g_0^3 = 1.313 x 10^{-1} <u>for U25</u>

By using g_0, one needs to find intensity profile with respect to TEM modes by using Rigrod formula, and integrate it in order to find the mirror hole.

Technical Design Studies for TAC

1. Synchrotron Radiation Facility (TAC SR)

2. SASE FEL Facility (TAC SASE FEL)

3. Particle Factory (TAC PF)

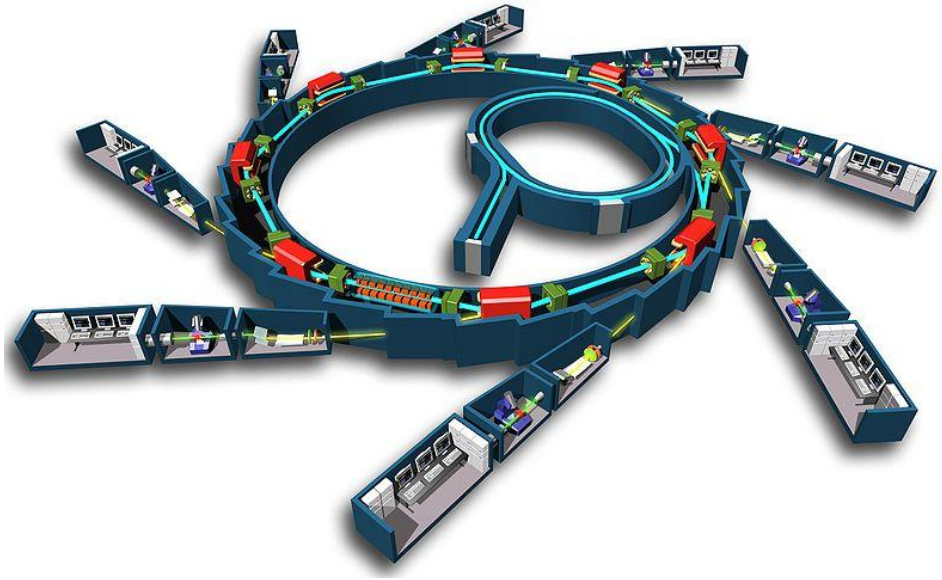
4. Proton Accelerator Facility (TAC PA)

TAC Synchrotron Radiation Facility

Up to now, 3.56 GeV positron synchrotron is proposed as 3rd generation SR source to cover 10 eV – 100 keV photon energy range.

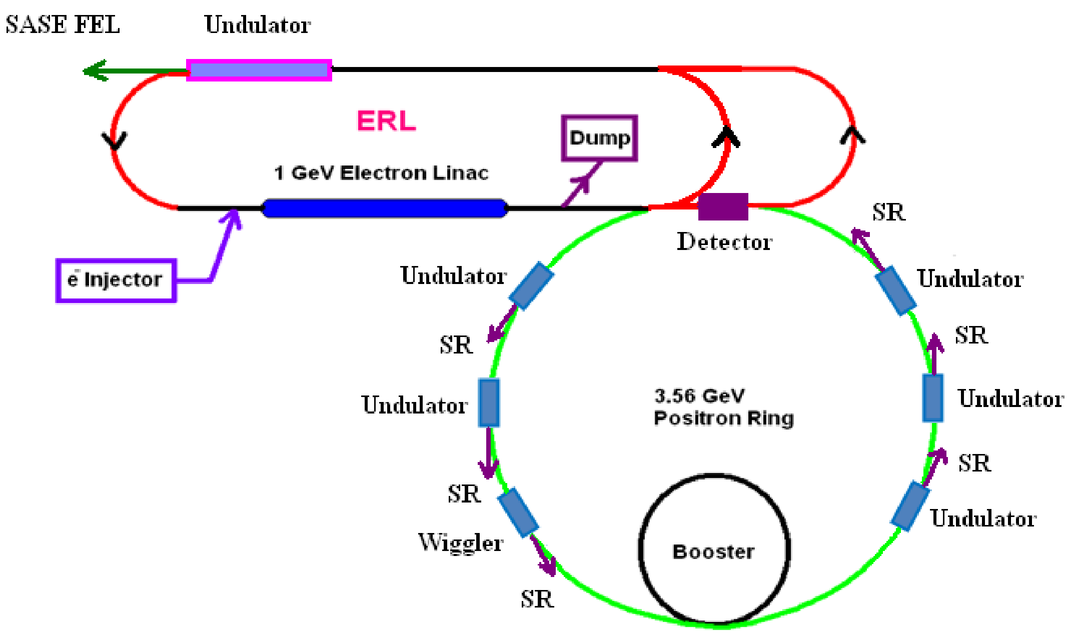
But, recently, a 4.5 GeV dedicated electron synchrotron is studied.*

**A.K. Çiftçi et al. An update of the Lattice Design of the TAC Proposed Synchrotron Radiation and Insertion Devices (PAC10, Koyoto, May 2010)*



TAC Particle (Charm) Factory

- Linac on ERL electron-positron collider

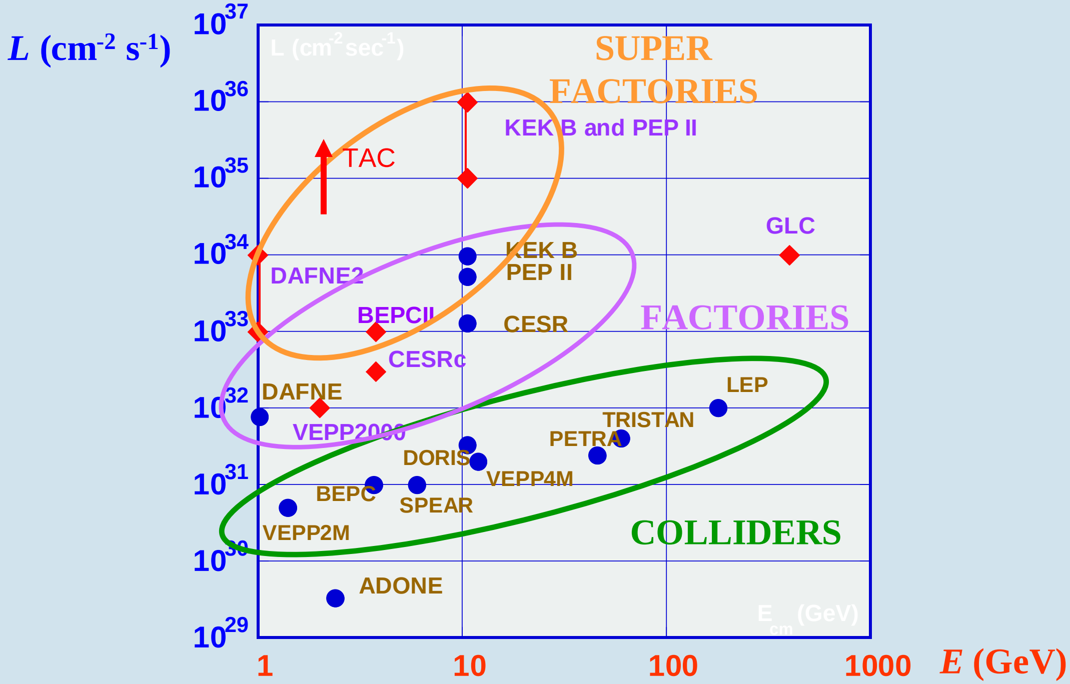


Some of the nominal parameters for $L=10^{35}$ cm^{-2}s^{-1} at Ecm=3.77 GeV are:

$E(e^+)$=3.56 GeV, $E(e^-)$=1 GeV
$N(e^+)=2\times10^{11}$, $N(e^-)=2\times10^{10}$
$b_x/b_y(e+,e^-)$=80/5 mm
$s_x/s_y(e+,e^-)$=3.6/0.5 mm
$s_z(e+,e^-)$=5 mm
$n_b(e^+)$=125, $f_{rev}(e^+)$=1.2 MHz
Circumference=250 m
$I_b(e^+)$=4.8 A, $I_b(e^-)$=4.8 A
f_c=150 MHz

TAC Particle (Charm) Factory

e^+-e^- Colliders: Past, Present and Future



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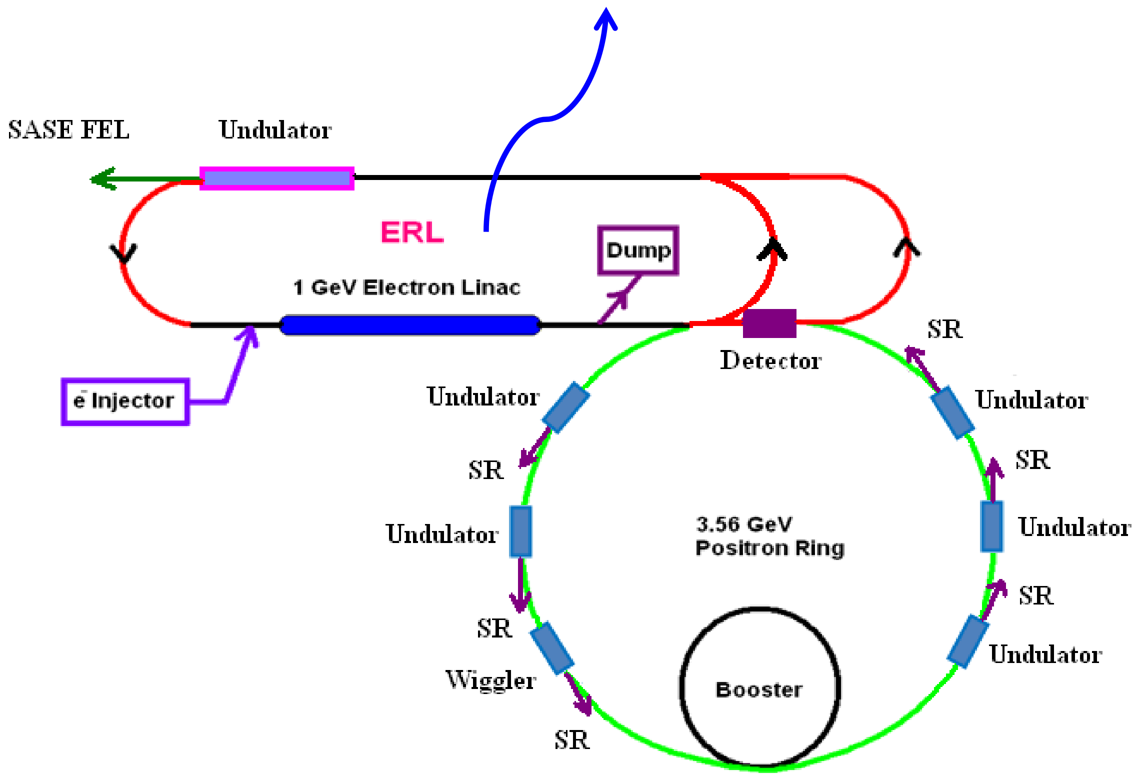
TAC Proton Accelerator Facility

- Proposed as a multipurpose facility
- Beam power 1 MW and 1-3 GeV Energy
- A 3 MeV test stand and 55 MeV DTL will be included as low energy part of chain
- A world class pulsed neutron source for neutron scattering for engineering and industrial applications
- Medical facility for cancer therapy
- Irradiation and isotope production facility
- Radioactive Ion beam facility (in future)
- Nuclear transmutation facility and ADS applications (EA etc.)

ONGOING STATUS OF THE TAC SASE-FEL PROPOSAL

cw, superconducting electron ERL



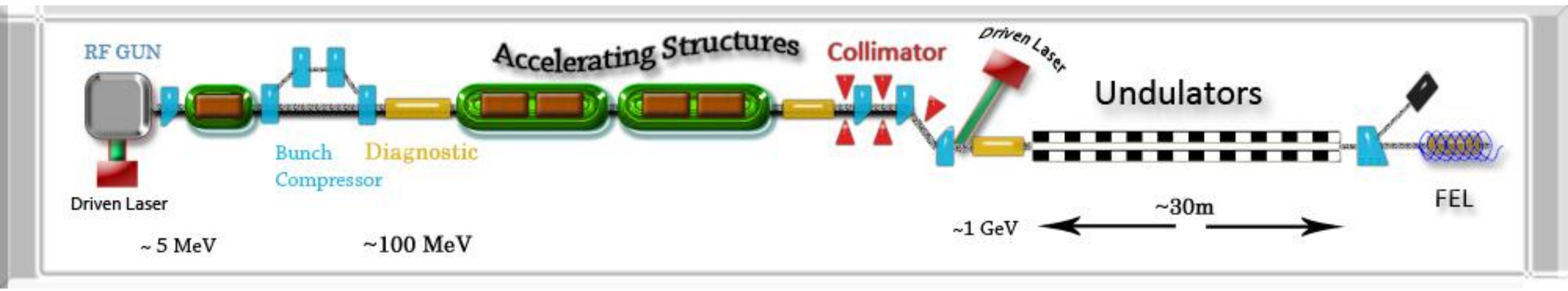
In frame of Particle Factory: In recent years, ERLs are quite favored for colliders (especially for super factories) due to their high luminosity requirements. $L \sim 10^{34} cm^{-2}s^{-1}$

In frame of SASE FEL: ERLs are ideal drivers for high power FELs ranging between VUV to soft X-rays. P_{peak} **~ GW**

Average Brightness ~ 10^{25} – 10^{30} photons/s/mrad2/mm2/%0.1BW

TAC SASE FEL Facility

- With 1 GeV electron beam, wave length range of SASE FEL is planned as 1-100 nm
- We have two options for linac structure: RF Linac or ERL



Tentative electron/photon beam parameters based on cw superconducting ERL of TAC SASE-FEL

Parameter	
Electron Beam Energy (GeV)	0.80 – 1
Number of electrons per bunch	$0{,}625.10^{10}$
Average Current (A)	0.5
Repetition rate (1/Tμ) (MHz)	500
Bunch length (tμ) @ undulator entrance (ps)	0.5
Radiation Wavelength (nm)	1-100

Undulator Choices

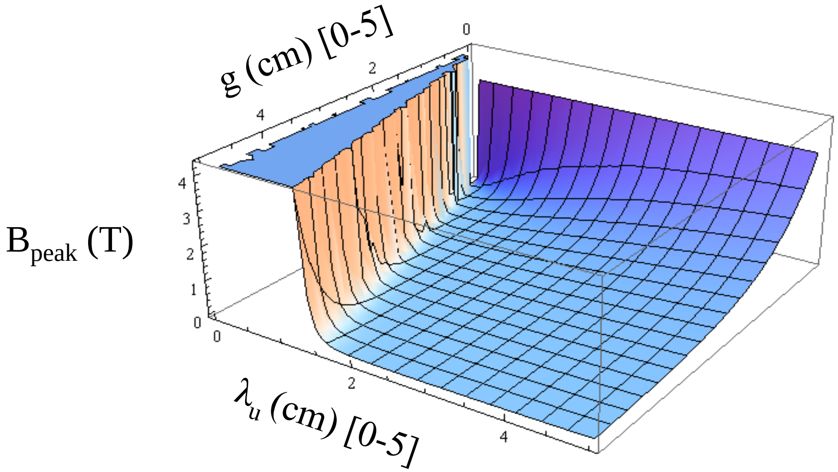
$$B_{peak} = aExp\left(b\frac{g}{\lambda_u} + c\left(\frac{g}{\lambda_u}\right)^2\right)$$

Case	Definition	a	b	c	Gap
A	PPM*, Planar, Vertical Magnetic Field	2.076	-3.24	0	$0.1 < g / \lambda_u < 1$
B	PPM*, Planar, Horizantal Magnetic Field	2.4	-5.69	1.46	$0.1 < g / \lambda_u < 1$
C	PPM*, Helical Magnetic Field	1.614	-4.67	0.62	$0.1 < g / \lambda_u < 1$
D	Hybrid with Vanadium Permendur	3.694	-5.068	1.52	$0.1 < g / \lambda_u < 1$
E	**Hybrid with Iron**	**3.381**	**-4.73**	**1.198**	$\mathbf{0.1 < g / \lambda_u < 1}$
F	Superconducting, Planar, Gap = 1.2 cm	12.42	-4.79	0.385	$1.2\ \text{cm} < \lambda_u < 4.8\ \text{cm}$
G	Superconducting, Planar, Gap = 0.8 cm	11.73	-5.52	0.856	$0.8\ \text{cm} < \lambda_u < 3.2\ \text{cm}$
H	Electromagnet, Planar, Gap = 1.2 cm	1.807	-14.3	20.316	$4\ \text{cm} < \lambda_u < 20\ \text{cm}$

***PPM = Pure Permanent Magnet (Magnet Block Material: NdFeB)**

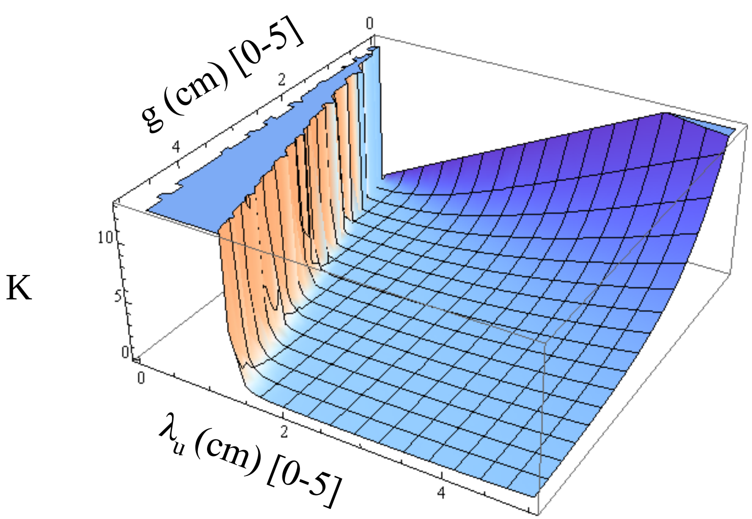
[1] P. Elleaume *et al.* / NIM-A, 455, 2000, 503-523

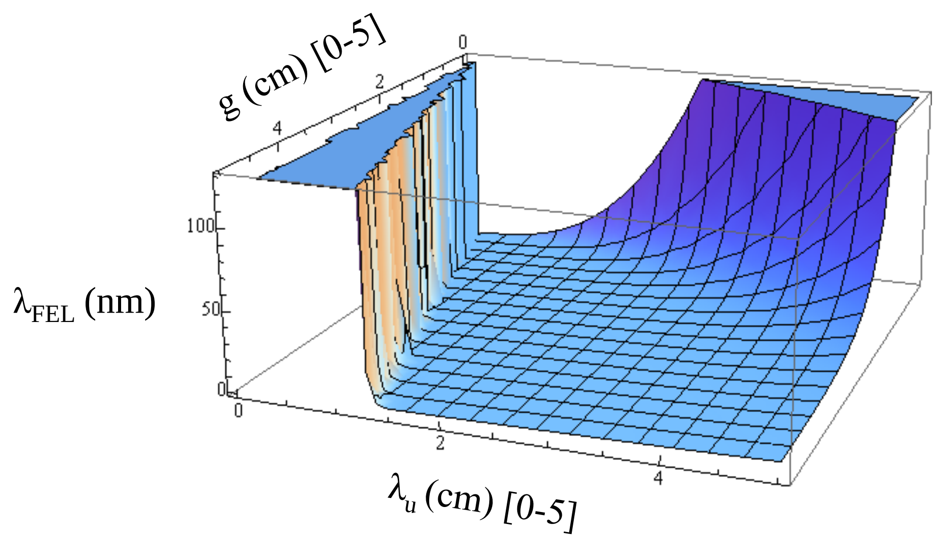
B_{peak} (T) vs g (cm) & λ_u (cm) for Case E: (E_{beam} = 1 GeV)



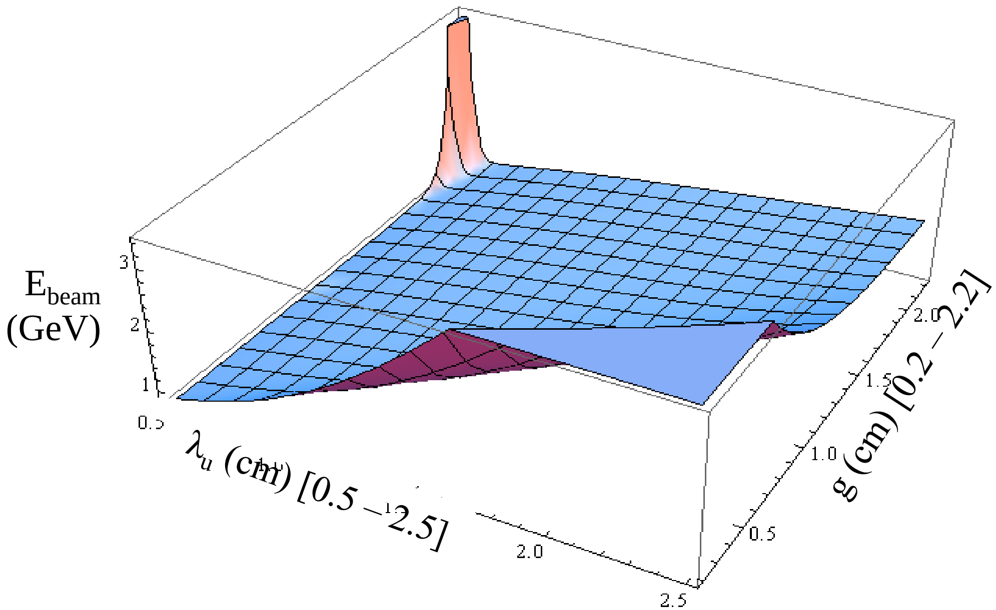
a = 3.381, b = - 4.73, c = 1.198

$0.1 < g / \lambda_u < 1$

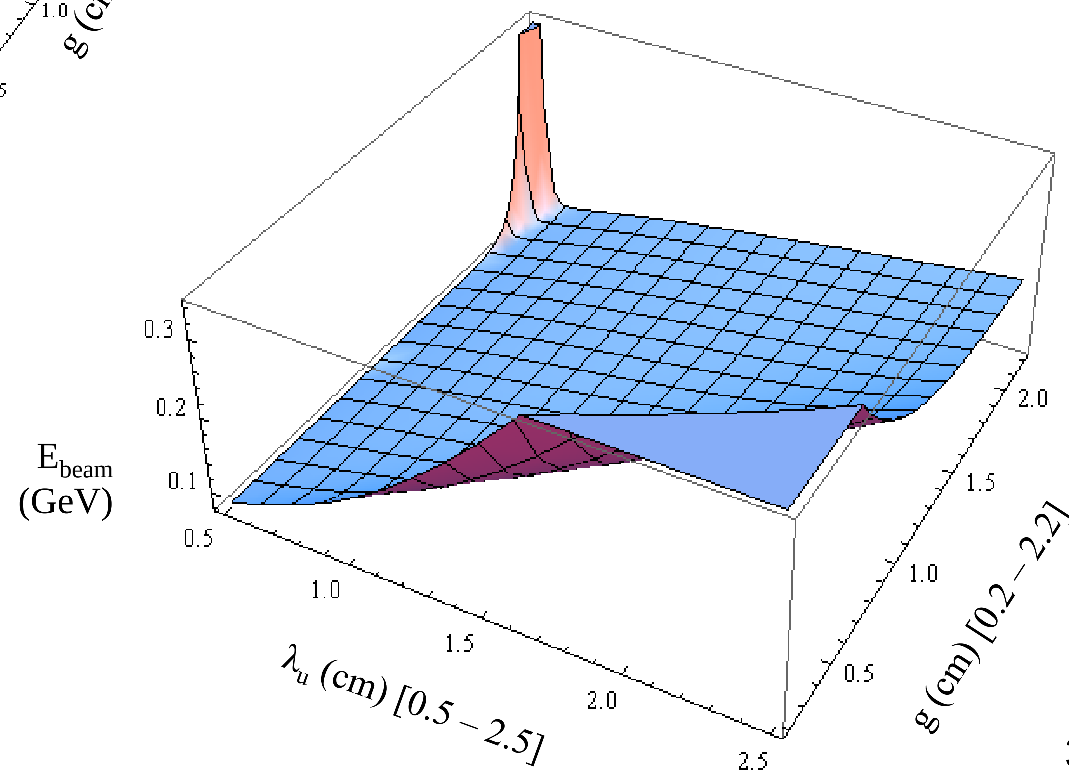




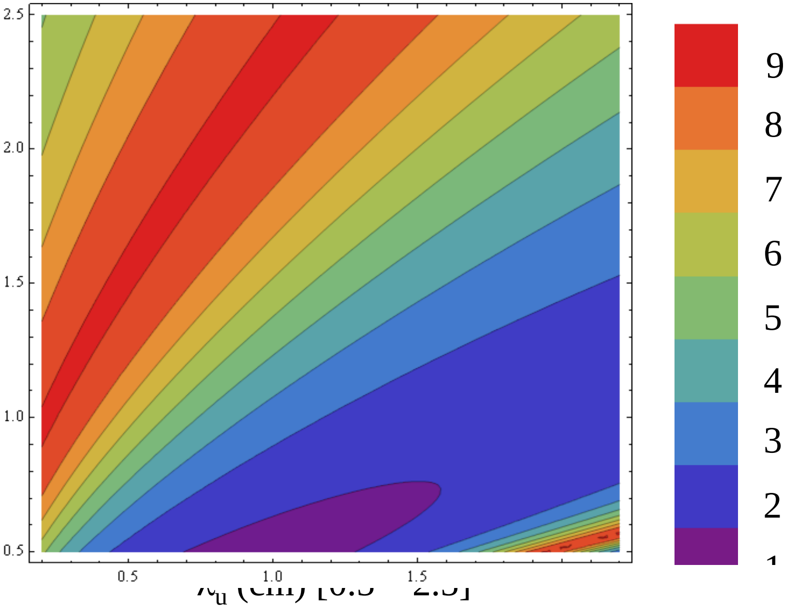
For Case E: E_{beam} (GeV) vs λ_u (cm) & g (cm), λ_{FEL} = 1 nm



For Case E: E_{beam} (GeV) vs λ_u (cm) & g (cm), λ_{FEL} = 100 nm



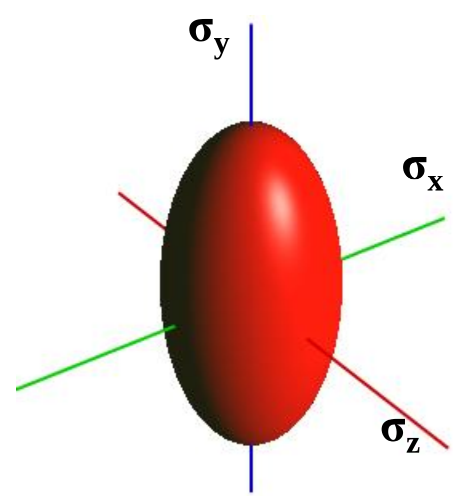
For Case E: q vs λ_u (cm) & g (cm) (E_{beam} = 1 GeV)



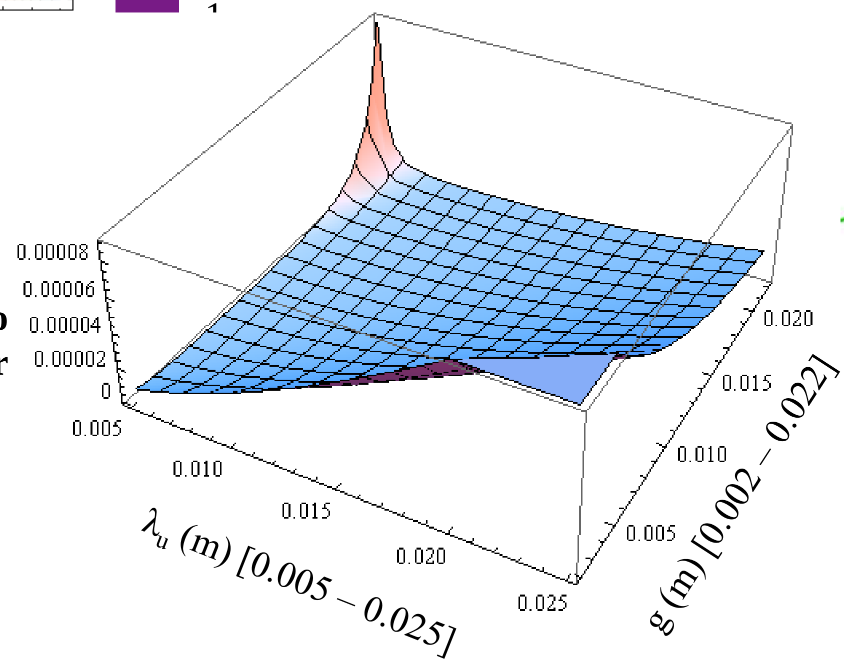
$$q = (\gamma F_1)^{\frac{1}{3}}$$

g (cm) [0.2 – 2.2]

Considering ellipsoidal bunch:



Rho Parameter

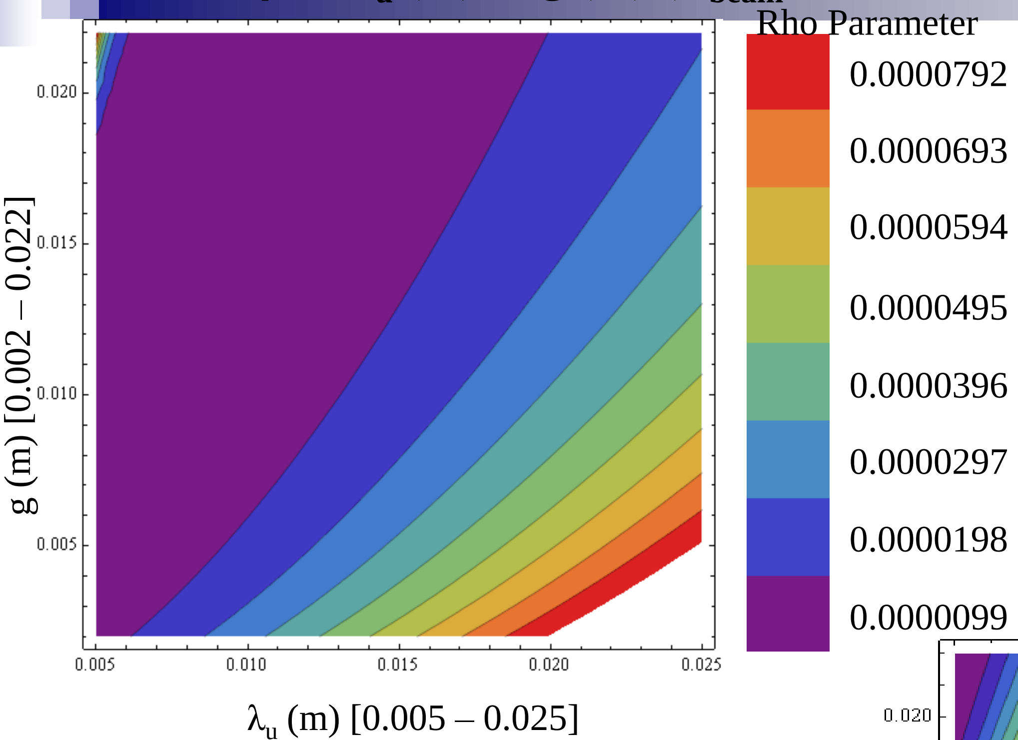


For Case E:
ρ vs λu (m)&g(m)
(Ebeam = 1 GeV,
Q = 1 nC)

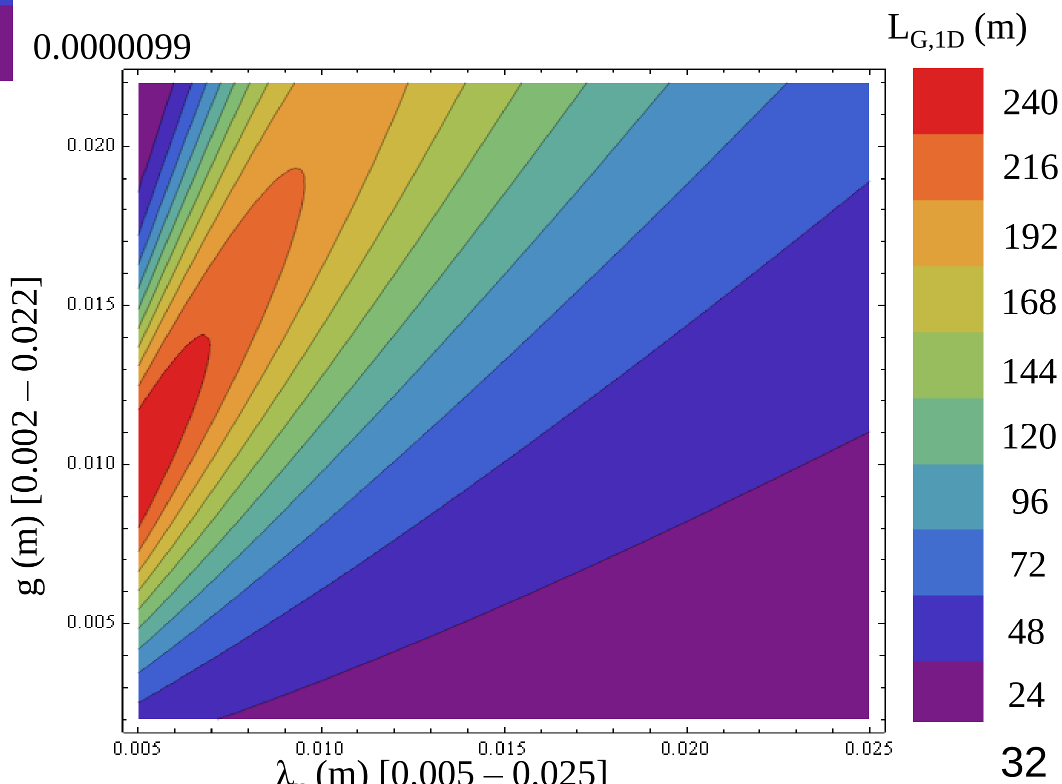
Beam sizes @ undulator entrance:

σ_x = 180 μm
σ_y = 180 μm
σ_z = 150 μm

For Case E: ρ vs λ_u (m) & g (m) (E_{beam} = 1 GeV, Q = 1 nC)



For Case E:
L_G,1D (m) vs λ_u (m) & g (m)
(E_{beam} = 1 GeV, Q = 1 nC)



$$F_1(K) = \frac{K^2}{\left(1 + \frac{K^2}{2}\right)^2} \left(\mathrm{BesselJ}\left[0, \frac{\frac{K^2}{4}}{\left(1 + \frac{K^2}{2}\right)}\right] - \mathrm{BesselJ}\left[1, \frac{\frac{K^2}{4}}{\left(1 + \frac{K^2}{2}\right)}\right] \right)^2$$

$$q = (\gamma F_1)^{\frac{1}{3}}$$

$$K = 0.934\, \lambda_u\, a\, \mathrm{Exp}\left[b \frac{g}{\lambda_u} + c \left(\frac{g}{\lambda_u}\right)^2\right]$$

$$\lambda_{FEL} = \frac{\lambda_u}{2\gamma^2} \left\{1 + \frac{\left[0.934\, \lambda_u\, a\, \mathrm{Exp}\left(b \frac{g}{\lambda_u} + c \left(\frac{g}{\lambda_u}\right)^2\right)\right]^2}{2}\right\}$$

[2] SCSS X-FEL Conseptual Design Report (CDR), 2005.

SASE FEL Pierce (ρ) Parameter

$$\rho = \left(\frac{\gamma\, (\lambda_{FEL})^2\, r_e\, n_e}{8\,\pi} \, \frac{K^2}{\left(1 + \frac{K^2}{2}\right)^2} \left(\text{BesselJ}\left[0, \frac{\frac{K^2}{4}}{\left(1 + \frac{K^2}{2}\right)}\right] - \text{BesselJ}\left[1, \frac{\frac{K^2}{4}}{\left(1 + \frac{K^2}{2}\right)}\right] \right)^2 \right)^{\frac{1}{3}}$$

γ = Lorentz Factor
λ_{FEL} = Laser Wavelength
r_e = Classical Radius of Electron (≈ 2.82 fm)
n_e = Electron Density
K = Undulator Parameter
J_0 = 0^{th} Order Bessel Function
J_1 = 1^{st} Order Bessel Function

[2] SCSS X-FEL Conseptual Design Report (CDR), 2005.

1D & 3D Models [2,3]:

1D model is an ideal case in which the electron beam has a uniform tranverse spatial distribution with zero emittance and energy spread. Some quantities in this model are:

$L_{G,1D}$: 1D Gain Length = $\frac{\lambda_u}{4\pi\sqrt{3}\rho}$

$P_{sat} \approx \rho P_{beam} = 1.6\rho\left(\frac{L_{G,1D}}{L_{G,3D}}\right)^2 P_{beam}$

L_{sat}: Saturation Length = $L_{G,1D}\, ln\left(\frac{P_{sat}}{\alpha P_n}\right)$

Main performance parameters for SASE

$$\eta = a_1\eta_d^{a_2} + a_3\eta_\varepsilon^{a_4} + a_5\eta_\gamma^{a_6} + a_7\eta_\varepsilon^{a_8}\eta_\gamma^{a_9} + a_{10}\eta_d^{a_{11}}\eta_\gamma^{a_{12}} + a_{13}\eta_d^{a_{14}}\eta_\varepsilon^{a_{15}} + a_{16}\eta_d^{a_{17}}\eta_\varepsilon^{a_{18}}\eta_\gamma^{a_{19}}$$

$$L_R = \frac{4\pi\sigma_x^2}{\lambda_{FEL}} \qquad \eta_d = \frac{L_{G,1D}}{L_R}$$

Gain decrement due to diffraction (a 3D spatial effect)

$$L_{G,1D} = \frac{\lambda_u}{4\pi\sqrt{3}\rho} \qquad \eta_\varepsilon = \frac{4\pi\varepsilon L_{G,1D}}{\beta\lambda_{FEL}}$$

Gain decrement depending on electrons' longitudinal velocity spread due to emittance

$$L_{G,3D} = (1+\eta)\, L_{G,1D} \qquad \eta_\gamma = \frac{4\pi\sigma_e L_{G,1D}}{\lambda_u E_0}$$

Gain decrement depending on electrons' longitudinal velocity spread due to energy spread

Universal Scaling Function: F (η_d, η_ε, η_γ) = 1 / (1+η)

Proposed TAC SASE-FEL Parameters?

Electron beam parameters

Electron beam energy[GeV]	1
Bunch charge [nC]	1
Peak Current[kA]	2
Normalized transverse rms emittance[μm rad]	< 2
MacroPulse Repetition Rate (Hz)	10
Energy Spread (%)	<0.2
Bunch Length [μm]	200-300

Accelerator parameters

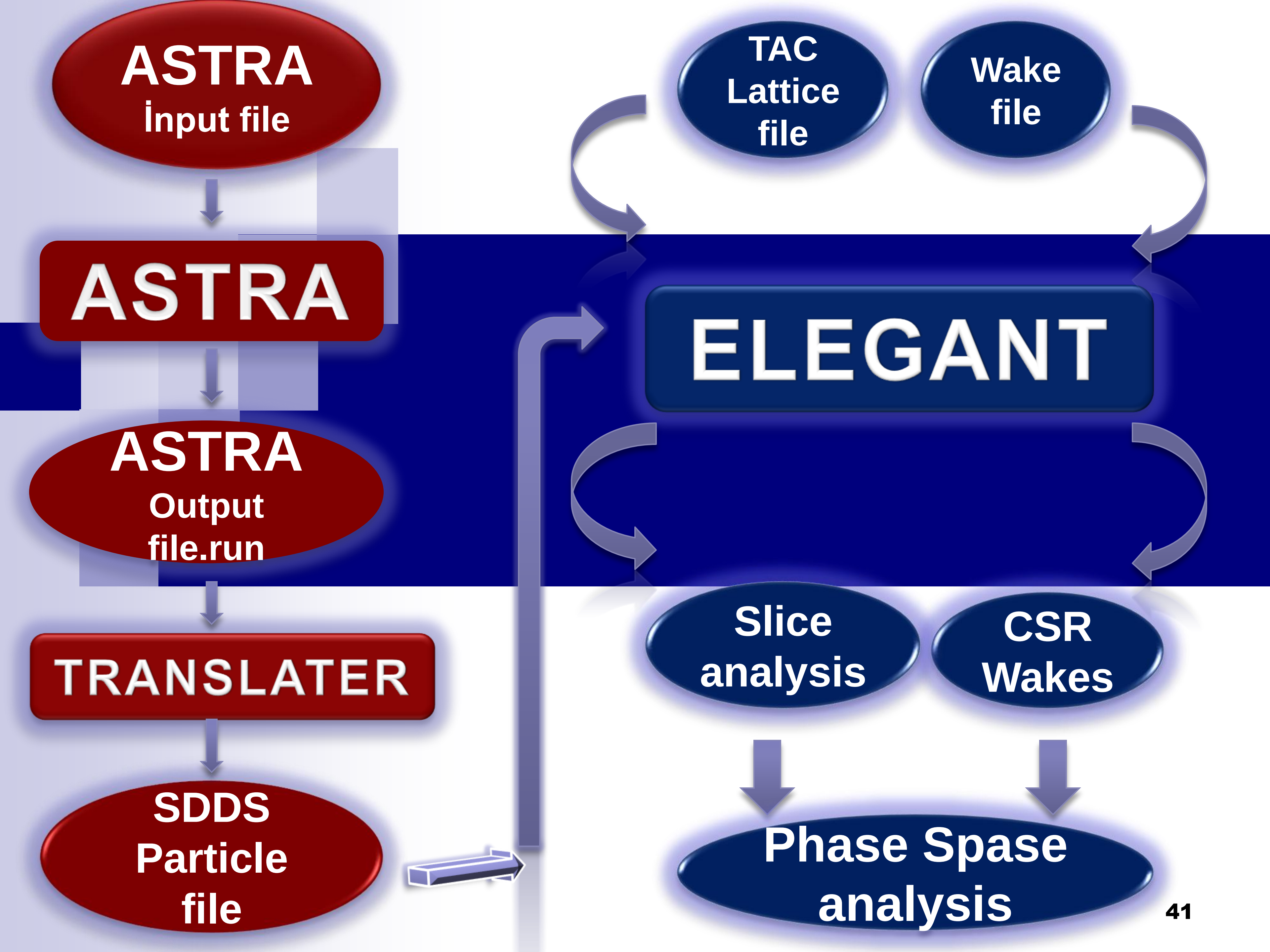
	TESLA Structure	S Band Linac
Frequency (GHz)	1.3	3
Gradient (MV/m)	30	30
Input power (MW)	10	25
Pulse Length (μs)	~10	~10
Number of Structure	35	12
Linac length (m)	~ 100	45

Undulator Magnet Parameters:

Undulator a Period length [mm]	27.3
Peak Magnetic Field [T]	0.48
Undulator Gap [mm]	12
K Parameter (max)	1.23
Undulator length (m)	30

Free Electron Laser Parameters:

Laser Parameters	
Wavelength Range [nm]	4 - 60
Maximum Peak Power (GW)	1
Peak Brillance (photons/s/mrad^2/mm^2/0.1%bw)	~10^{29}
Peak Energy (μJ)	130 (Average 75)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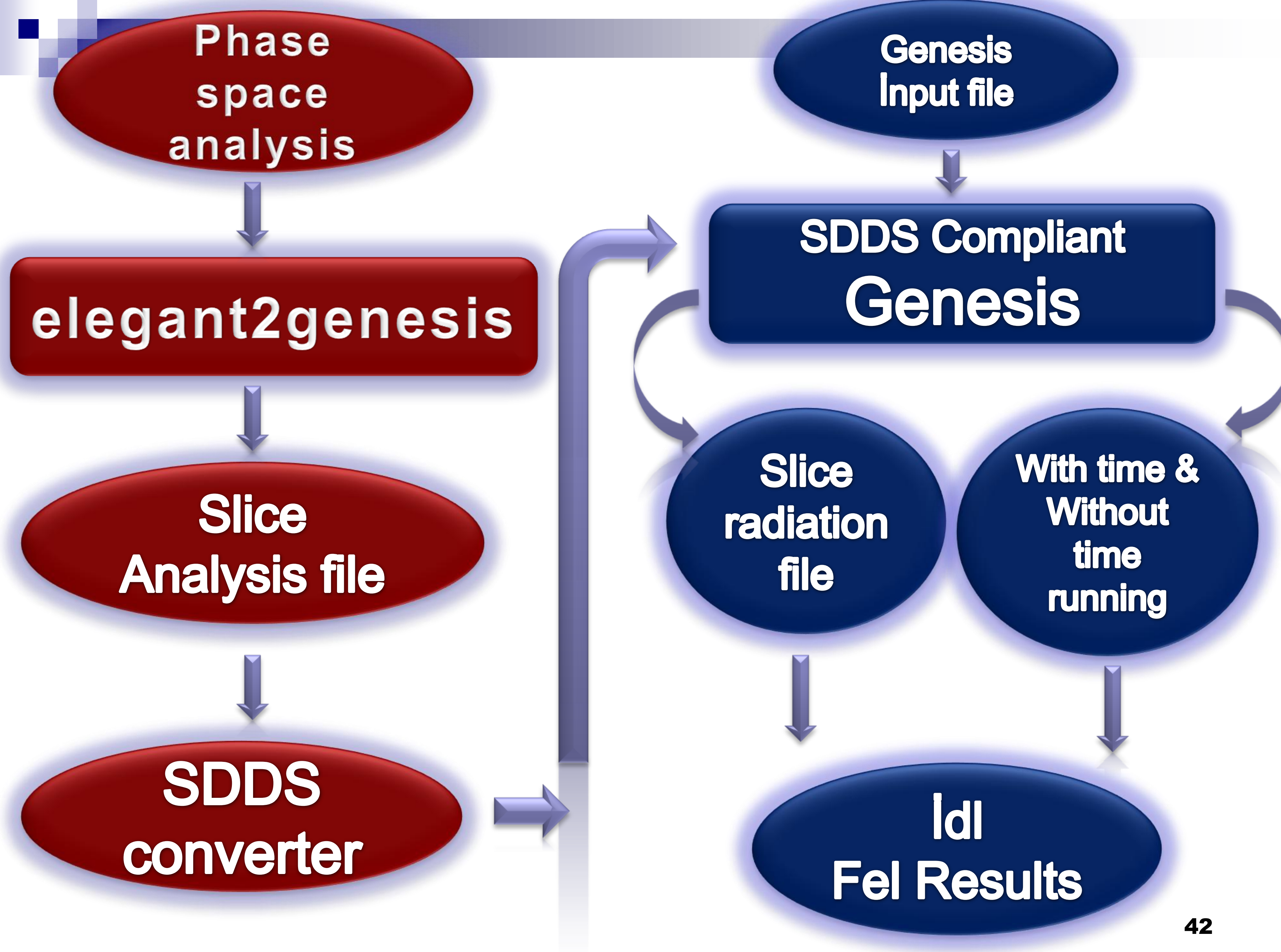
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Slice radiation file
With time & Without time running
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Possible User Potantial

- TAC SASE-FEL can be used for
  Life Sciences
  Chemistry
  Physical research
  Material Science Applications

- There is a many scientists in Turkey who can use SASE beam after it is produced.
- In 2011, we plan to make a small workshop together with SR group. http://physics.dogus.edu.tr/tac-sr/