Inverse Compton Scattering Experiments at SABER

Sven Reiche

Saber Workshop - 3/15/06

Current ICS Sources

- Most sources use beam energies in the 10 to 100 MeV range to operate in the keV photon energy range.
- Highest photon energy at Spring8 storage ring
  - Electron beam energy 8 GeV
  - Photon energy: 1.5 - 2.4 GeV (no tunability by electron energy)
  - 1 mm electron beam size, 100 mA current
  - No high rep rate to avoid reduction in life-time of stored electrons
  - Operates as user facility.

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Scientific Cases - Spin Sum Rule

- Tunable, fully circular polarized gamma beam interacting with polarized target (p, 3He)
- Asymmetry in the cross section for spin 3/2 and 1/2 allows for deduction of spin content.

- Fine resolution measurement of quasi-mesonic or baryonic state contribution to spin

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Scientific Cases - Baryonic/Hadronic Physics

- Excitation of baryonic states of nucleons

$$\gamma + n \rightarrow \Lambda$$

- Threshold productions of mesons, e.g. 2 π production

$$\gamma + p \rightarrow p + \pi_0 + \pi_0$$

- K-meson production, parity measurement.

$$\gamma + n \rightarrow \Theta^+ + K^-$$

Non-perturbative QCD theory,
Multi-body nuclear forces

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Scientific Cases - Others

- Studies for γ-γ colliders
- Gamma source for detector development (calorimeter)
- Nuclear spectroscopy
- Gamma induced fission (e.g. meta-stable states of U238)
- Quantum fluctuation dominated emission process (spectral properties etc.)

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Radiation Source at SABER

- Electron beam cannot drive FEL, nor is sufficent space available.
- Spontaneous undulator radiation only a minor improvement in wavelength, might compete with future energy upgrade of LCLS. In addition insufficient space for undulator, collimator and shielding
- Inverse Compton Scattering (ICS) requires only a drive laser with high energy per pulse (~ 1J). Short pulse and high power not necessary.
- Radiation benefits from small spotsize and high beam energy.

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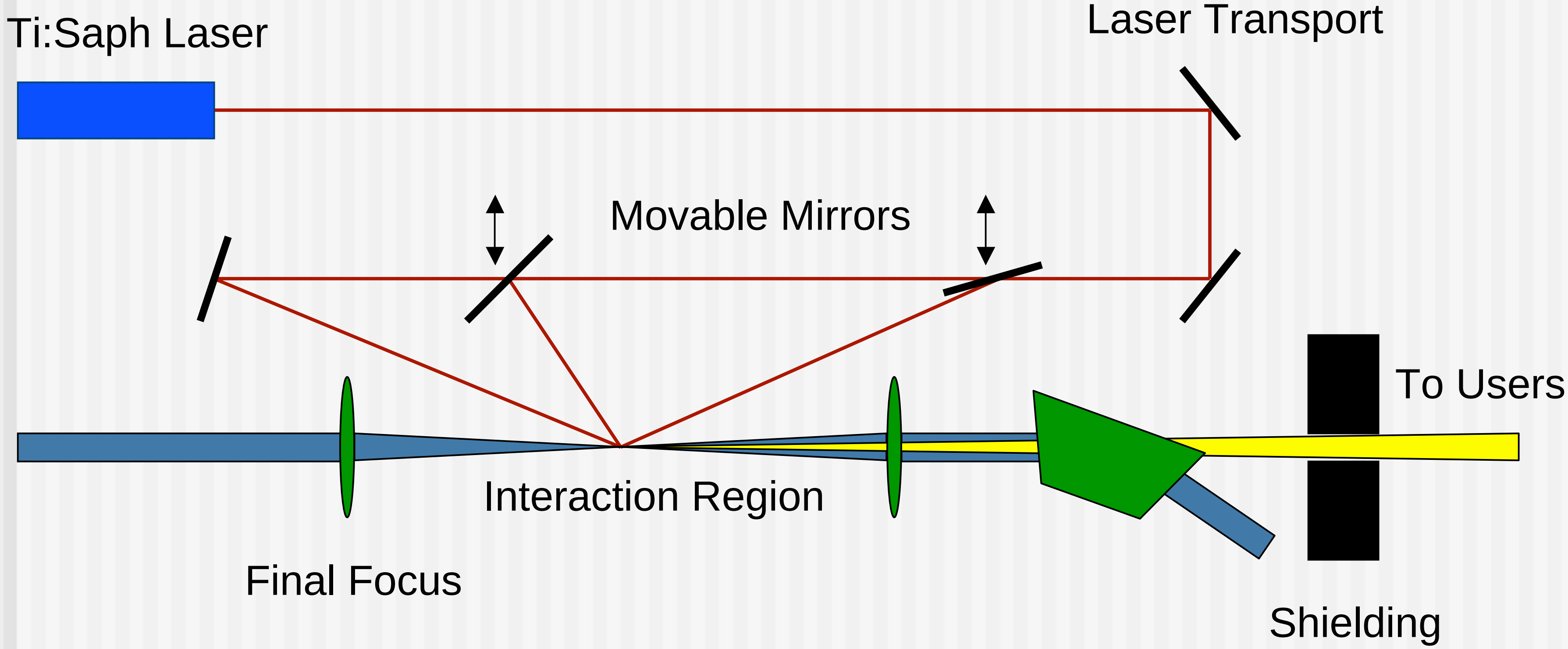
Schematic Layout



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Expected Performance

Normalized field *a* should be < 0.1 to reduce red shift and improve spectral brightness

Incident Angle	Photon Energy*	Comments
180°	2.5 - 15 GeV	Highest energy
45°	0.25 - 2 GeV	Shortest pulses
10°	20 - 200 MeV	Lowest energy

* Electron Beam Energy : 10 - 30 GeV

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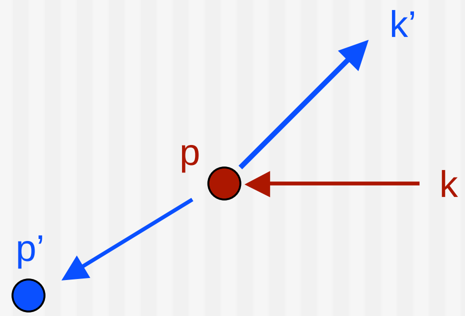
Radiation Wavelength

- Recoil effect is not negligible (Compton Scattering)
- In rest frame:

$$p^\mu = \begin{pmatrix} m \\ 0 \\ 0 \\ 0 \end{pmatrix} \qquad k^\mu = \begin{pmatrix} k \\ 0 \\ 0 \\ -k \end{pmatrix} = \gamma(1+\beta)\begin{pmatrix} k_0 \\ 0 \\ 0 \\ -k_0 \end{pmatrix}$$



$$p'^\mu = \begin{pmatrix} E \\ -p\sin\theta' \\ 0 \\ -p\cos\theta' \end{pmatrix} \qquad k'^\mu = \begin{pmatrix} k' \\ k'\sin\theta \\ 0 \\ k'\cos\theta \end{pmatrix}$$

- In lab frame:

$$k'_0 = \underbrace{\gamma(1+\beta)}_{\text{LT I}} \; \underbrace{\frac{m}{m+\gamma(1+\beta)k_0\left(1+\dfrac{\cos\theta'_0-\beta}{1-\beta\cos\theta'_0}\right)}}_{\text{Recoil}} \; \underbrace{\gamma\left(1+\beta\frac{\cos\theta'_0-\beta}{1-\beta\cos\theta'_0}\right)}_{\text{LT II}} \; k_0$$

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Radiation Wavelength

- Maximum Photon energy (30 GeV e-beam and Ti:Saph laser):

$$\hbar\omega = 15\,\text{GeV}$$

- Reduction by recoil effect (deviation from Thomson Scattering): 25%
- Significant blow-up in energy spread (up to 50% losses inn electron energy)

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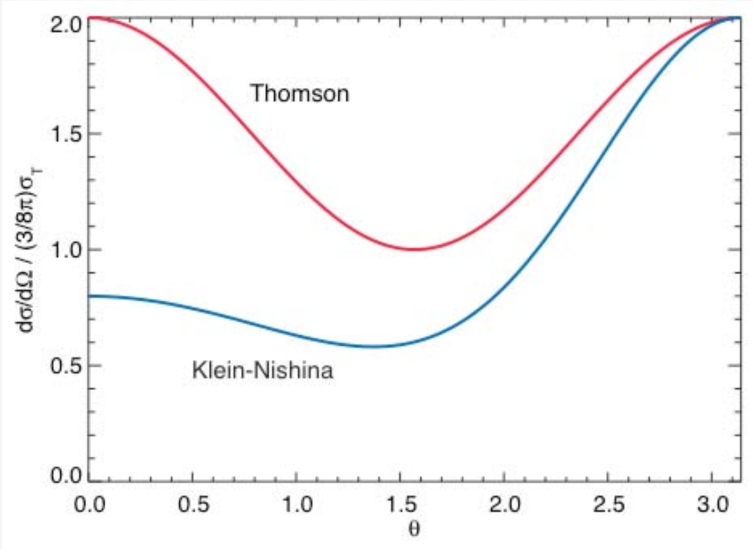
Cross Section

- Klein-Nishina Formula (rest frame)

$$\frac{d\sigma}{d\Omega} = \frac{3}{8\pi}\sigma_T\left(\frac{k'}{k}\right)^2\left(\frac{k'}{k}+\frac{k}{k'}-\sin^2\theta\right)$$



- The Lorentz invariant total cross section is 35% smaller than the Thomson cross section

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Estimate for Photon Numbers

- Photons (Thomson scattering with K.-N. correction f_c)

$$N_\gamma = \sigma L = f_c \frac{8\pi}{3} r_e^2 \frac{N_L N_e}{4\pi\sigma_x^2} = f_c \cdot 1.2 \cdot 10^9 \cdot U[J] \cdot Q[nQ]$$

- ICS requires rather large pulse energy than high power.
- High intensities should be avoided (a > 1) to exclude non-linear broadening of the spectrum
- Due to high electron energy quantum effects (recoil of Compton scattering) blow up of electron energy spread can be expected.

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Outlook / Conclusion

- Needs quantum mechanic calculation of spectrum (Thomson scattering is not applicable).
- Klein-Nishina formula is not gauge invariant, polarization for non-head-on calculation not calculated.
- Requires high energy laser, laser transport and focusing for interaction point.
- Laser can be used for other experiments
- Nuclear physics experiments are large 'scale' experiments.

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Beam Parameter Demands for ICS

- Beam size 10 microns
- Beam charge > 1nQ
- Beam energy 10 - 30 GeV
- Beam Current ~ 1kA (though of low importance)
- Energy Spread ~ 1% (though of low importance)
- Timing at IP ~ 1 ps (head-on collision)
- Laser ~ 1J (scales linearly with photon count)
- Laser spot size at IP: w_0 ~ 20 microns
- Laser intensity: a < 1 preferred.

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