Generating Polarization Controllable FELs at Dalian Coherent Light Source

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May 15, 2013

The 4^{th} International Particle Accelerator Conference, Shanghai, China

Outline

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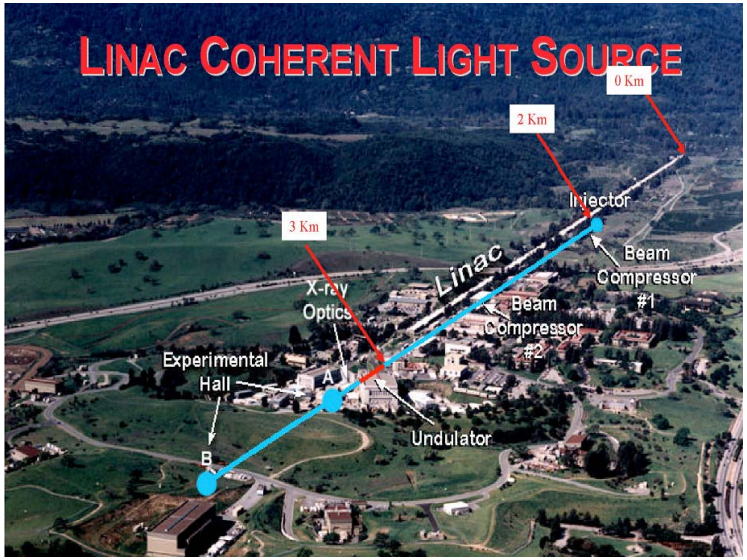
Large Free-electron Lasers Worldwide



LCLS@SLAC (2009)

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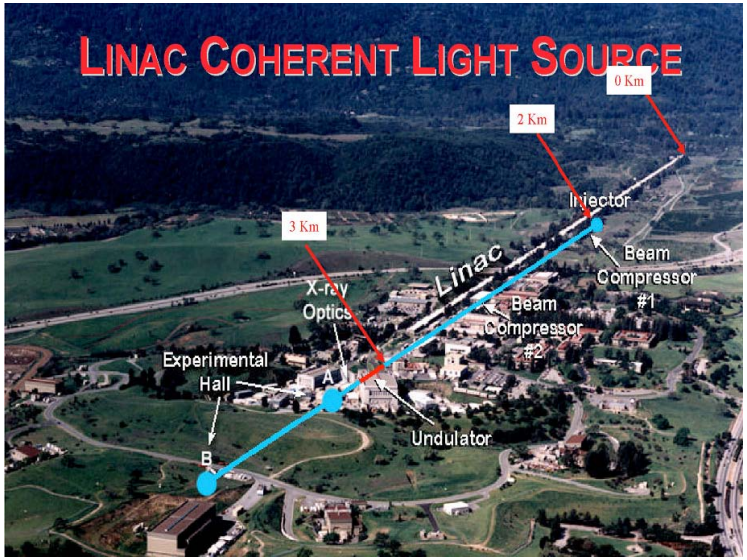

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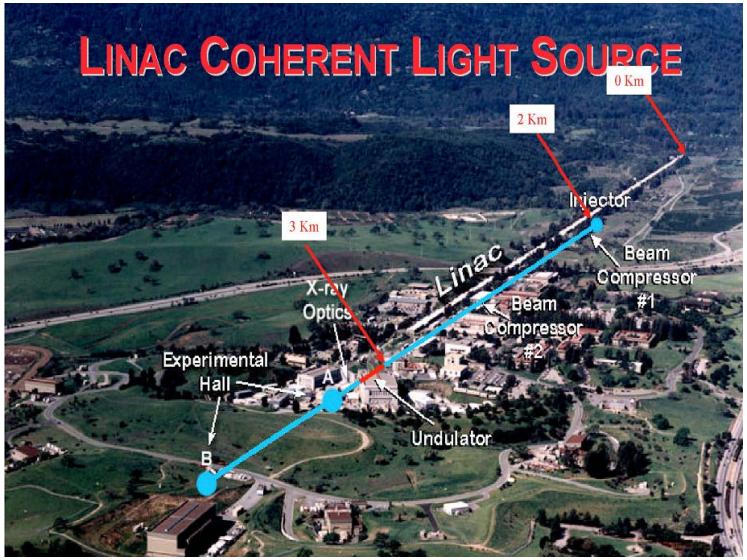

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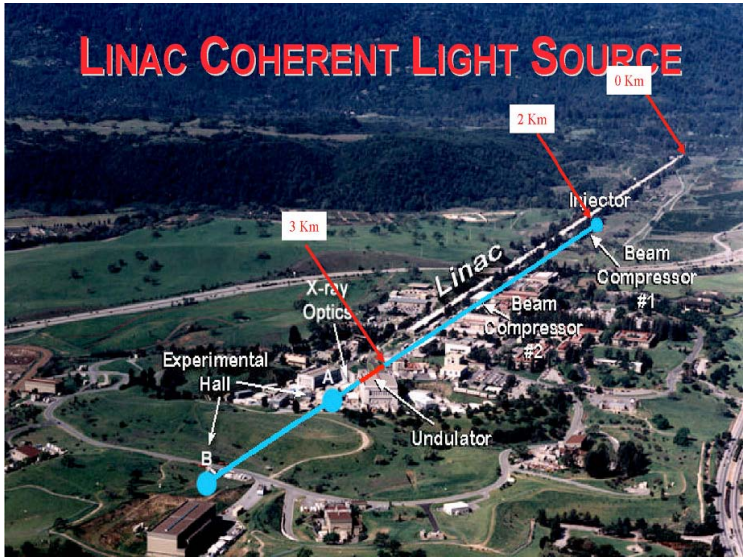


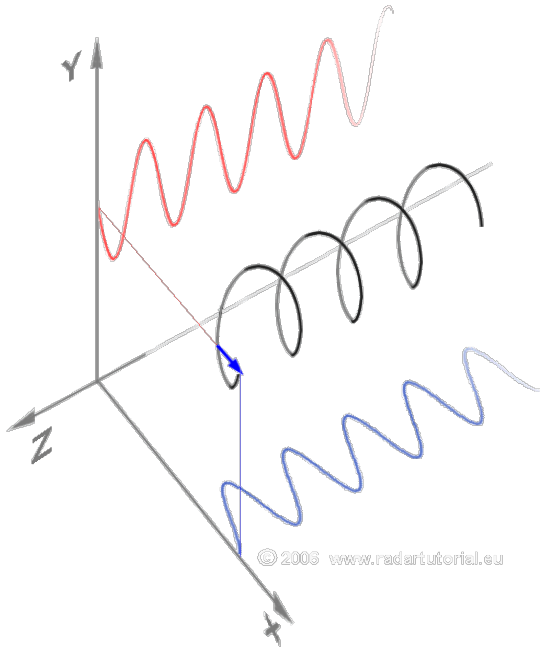
LCLS@SLAC (2009)

SACLA@Spring-8 (2011)

FERMI@Elettra (2011)

European XFEL@Germany (2015)

Polarization Property of Lightsource



▷ pictures from wikipedia.

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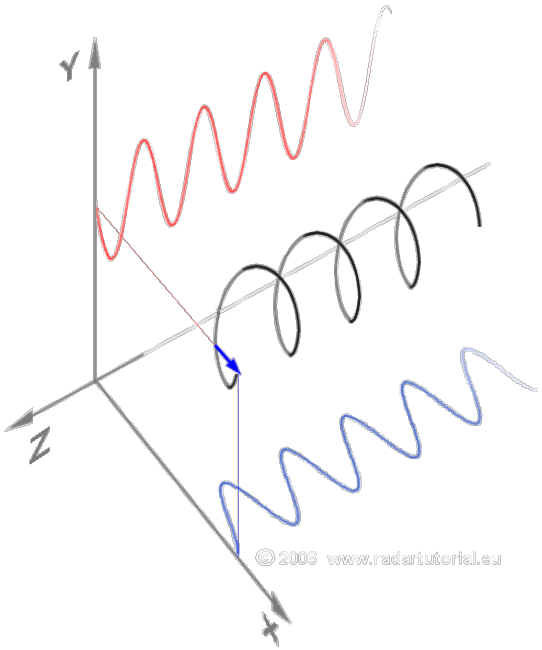

- Any light field vector ($\vec{k}$) could be projected to two orthogonal direction, $\vec{k} = \vec{k_x} + \vec{k_y}$, i.e.

$$\vec{E} = e^{i(kz-\omega t)} \cdot \begin{pmatrix} E_x^0 e^{i\phi_x} \\ E_y^0 e^{i\phi_y} \end{pmatrix} \cdot (\hat{x}, \hat{y})$$

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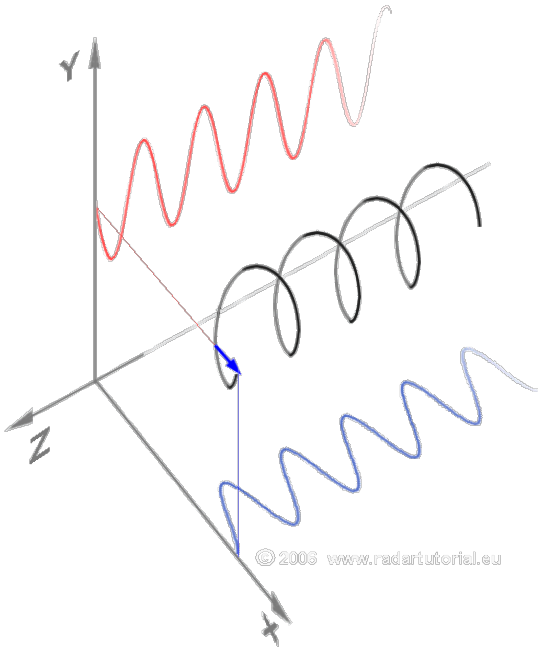

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- Jone matrix:

$$\mathbb{J} = \begin{pmatrix} 1 \\ \frac{E_y^0}{E_x^0} e^{i(\phi_y - \phi_x)} \end{pmatrix}$$

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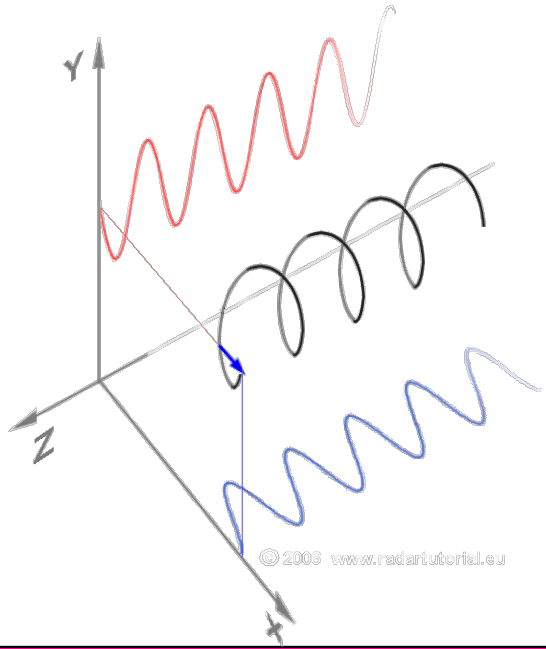
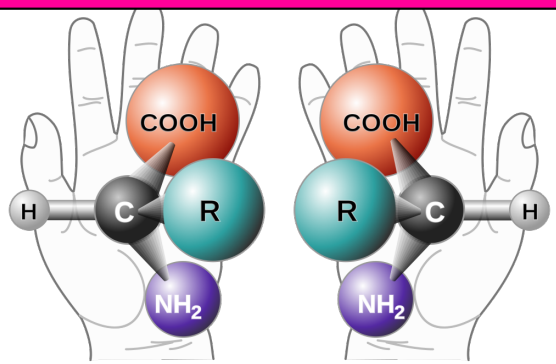


Two enantiomers of amino acid



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- Efficient tool for probing the chiral compounds.

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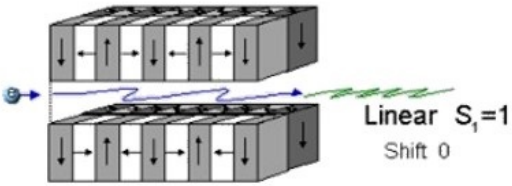
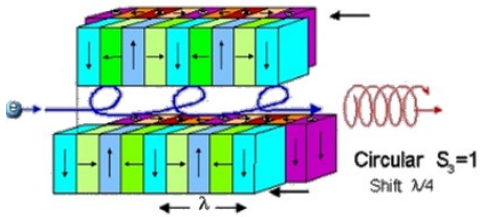
Polarization Control Approaches

Elliptical Permanent Undulator (e.g. APPLE-II)



x-linear



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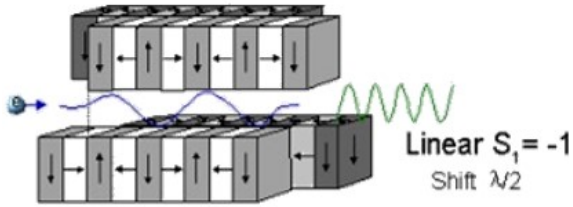

Circular

▷ http://www.helmholtz-berlin.de

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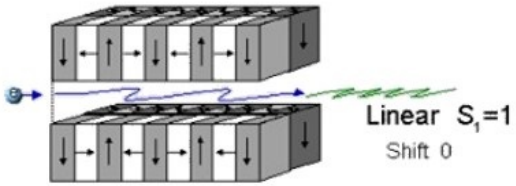

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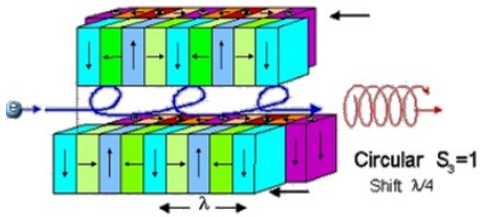

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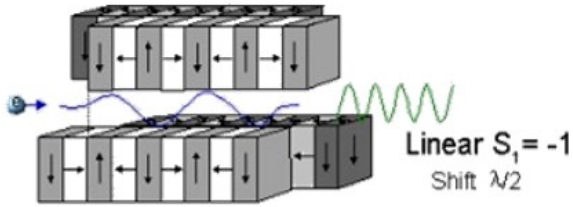

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▷ C. Spezzani, et al., Phys. Rev. Lett., **107** (2011) 084801.
▷ E. Allaria, et al., Nat.Photonics, **6** (2012) 699-704.

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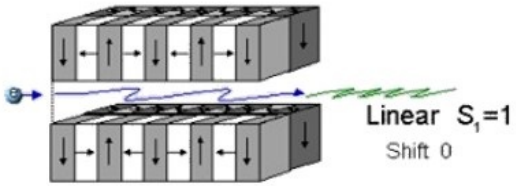

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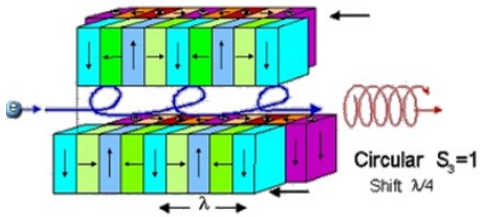

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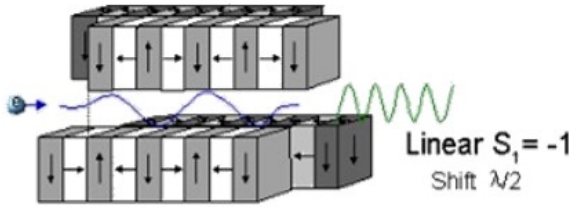
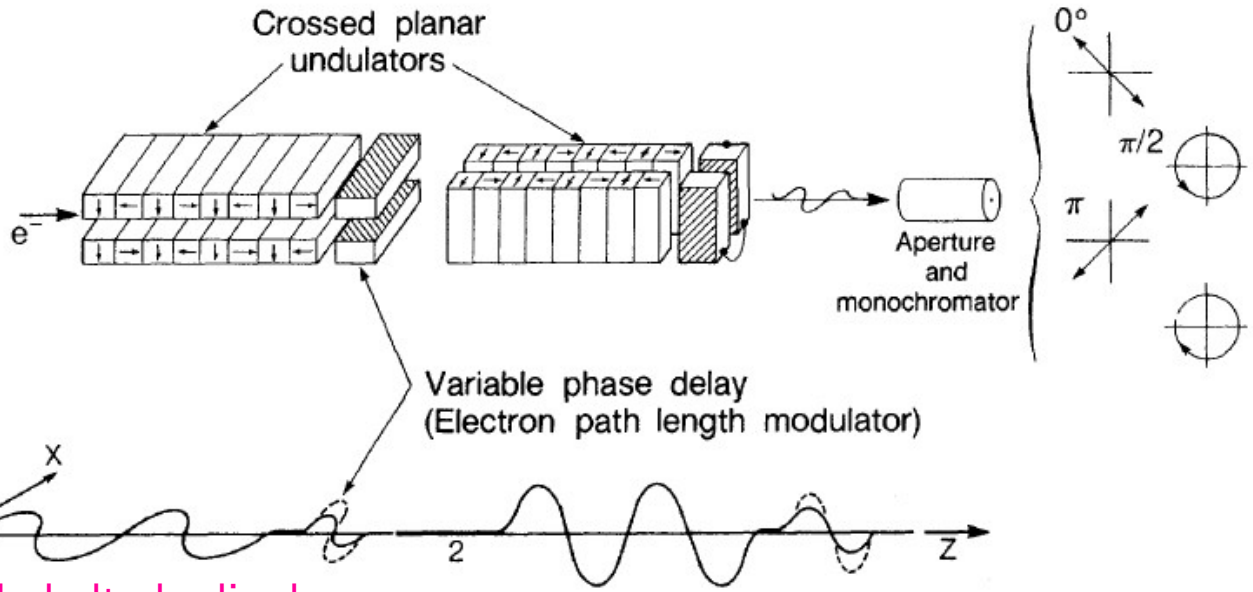


Circular

Crossed Planar Undulator



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▷ D. Attwood, K. Halbach, K.-J. Kim, *Tunable Coherent X-rays*, Science, **228** (1985) 1265-1272. and K.J. Kim, Nucl. Instr. and Meth. A, **219** (1984) 425-429.

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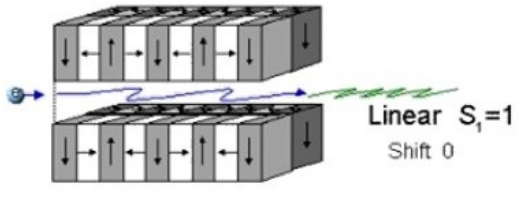

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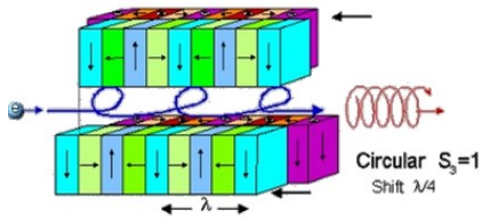

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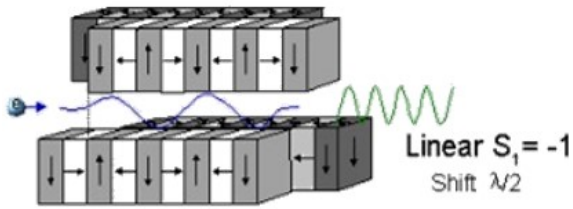

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▷ V.N. Litvinenko, et al.,Nucl. Instr. and Meth. A, **475** (2001) 407-416.

▷ Y.K. Wu, et al., Phys. Rev. Lett., **96** (2006) 224801.

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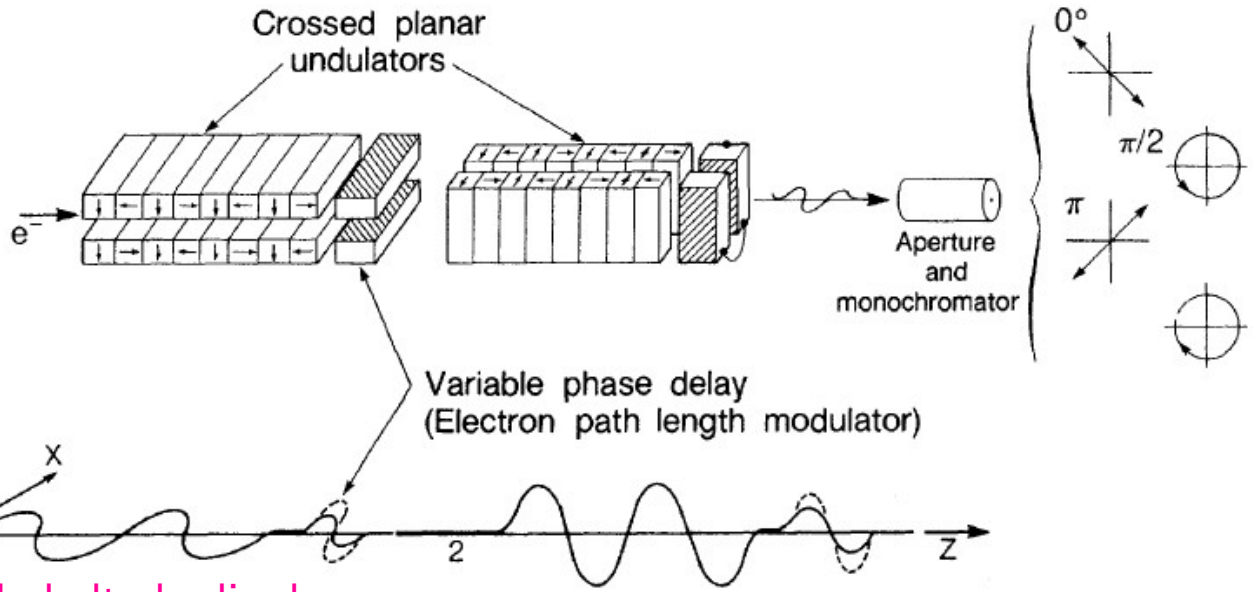

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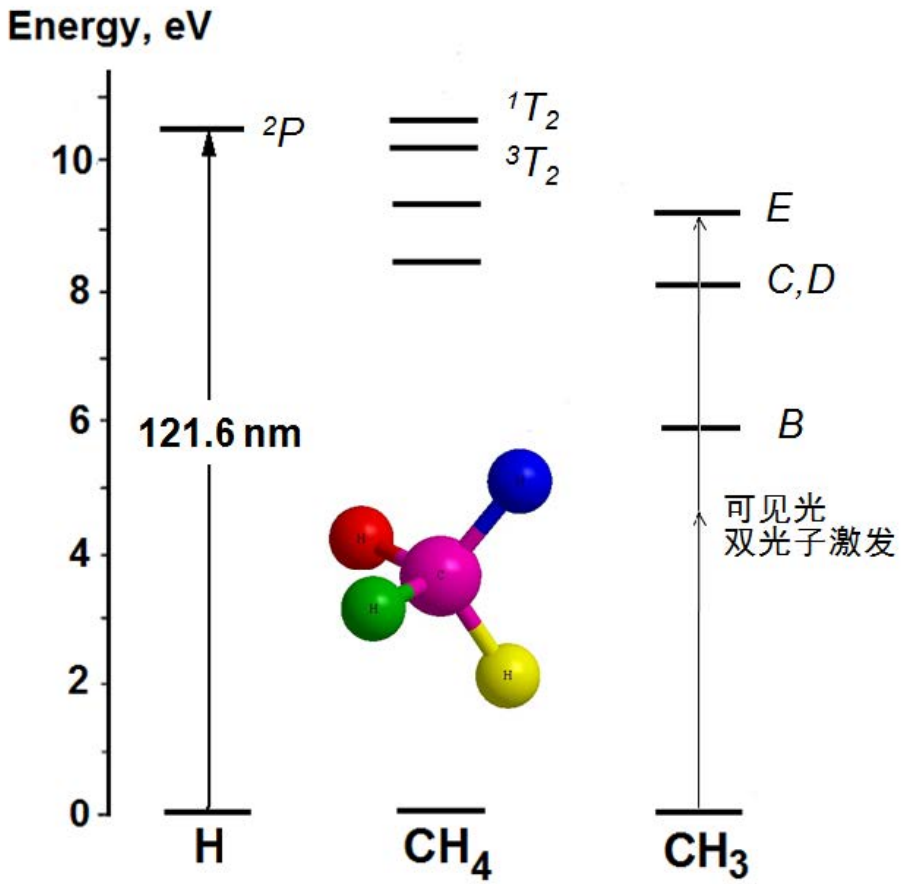

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- Dalian coherent light source, or DCLS has been approved and funded as the first FEL user facility in China.

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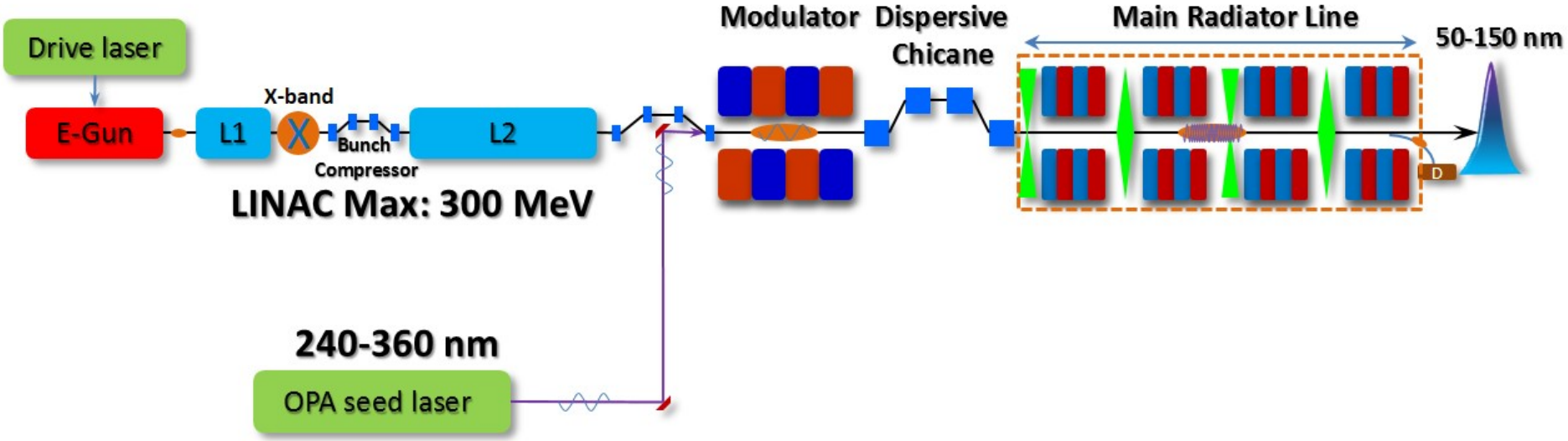
Schematic Layout of DCLS



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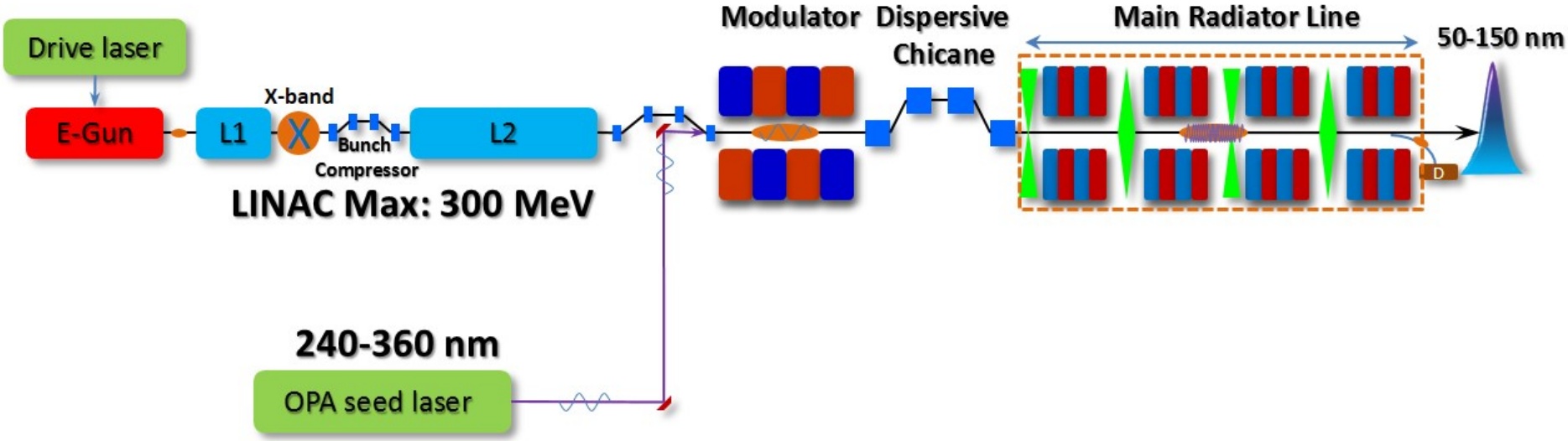
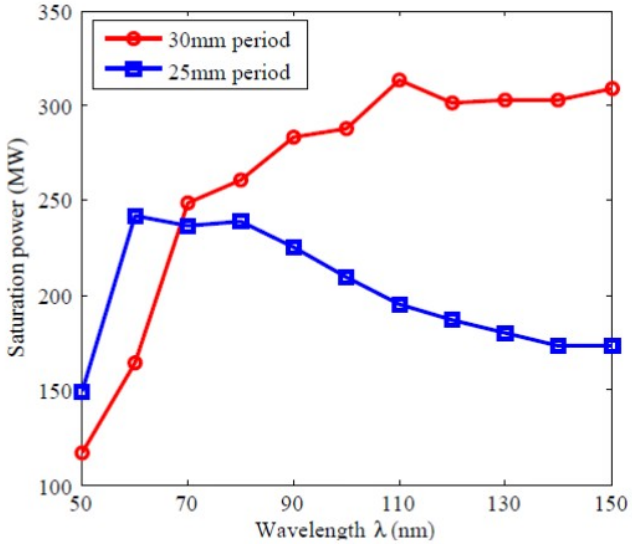
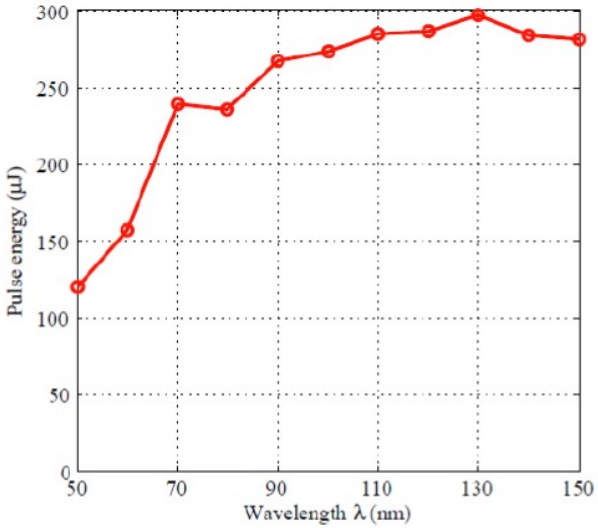


- Electron beam: $E_b \leq 300\,\mathrm{MeV}$, $\sigma_\delta = 0.01\%$, $\epsilon_n = 1 - 2\,\mu\mathrm{m}$, $I_{\mathrm{pk}} = 300\,\mathrm{A}$;
- Seed Laser: $\lambda_{\mathrm{seed}} = 240 - 360\,\mathrm{nm}$, $\tau_{\mathrm{seed}} = 1.0\,\mathrm{ps}$;
- Undulator: $\lambda_m = 50\,\mathrm{mm}$, $\lambda_r = 30\,\mathrm{mm}$, $a_r = 0.3 - 1.6$;
- FEL radiation: $\lambda_{\mathrm{FEL}} = 50 - 150\,\mathrm{nm}$, $W_{\mathrm{FEL}} \geq 100\,\mu\mathrm{J}$;

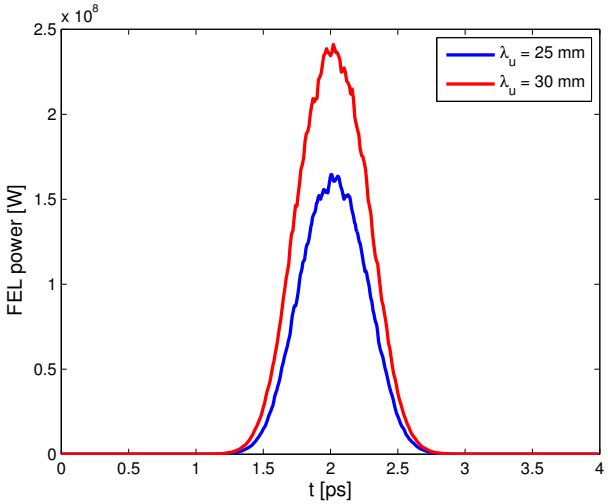
FEL simulations of DCLS



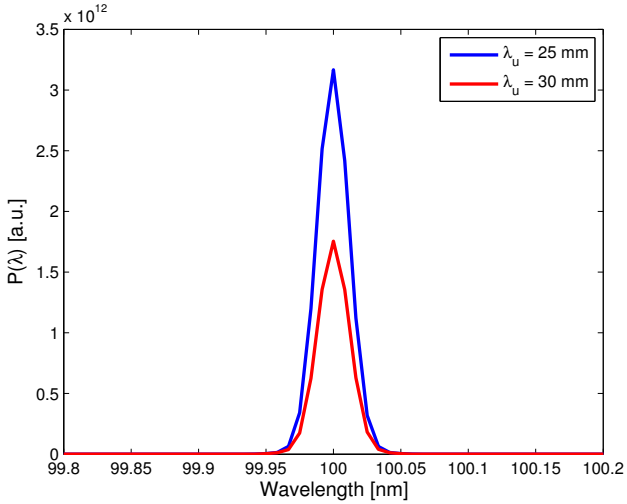
FEL Peak Power



FEL Pulse Energy



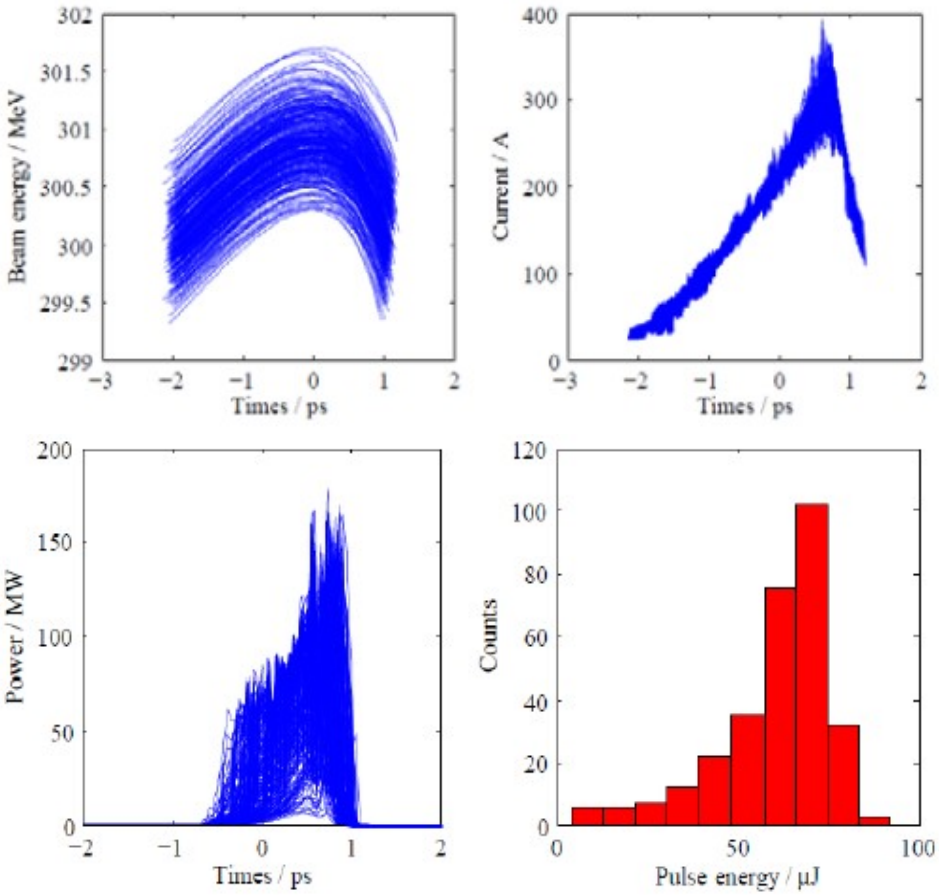
FEL power @ 100 nm



FEL spectrum @ 100 nm

FEL simulations of DCLS (s2e jitter)

X-band off



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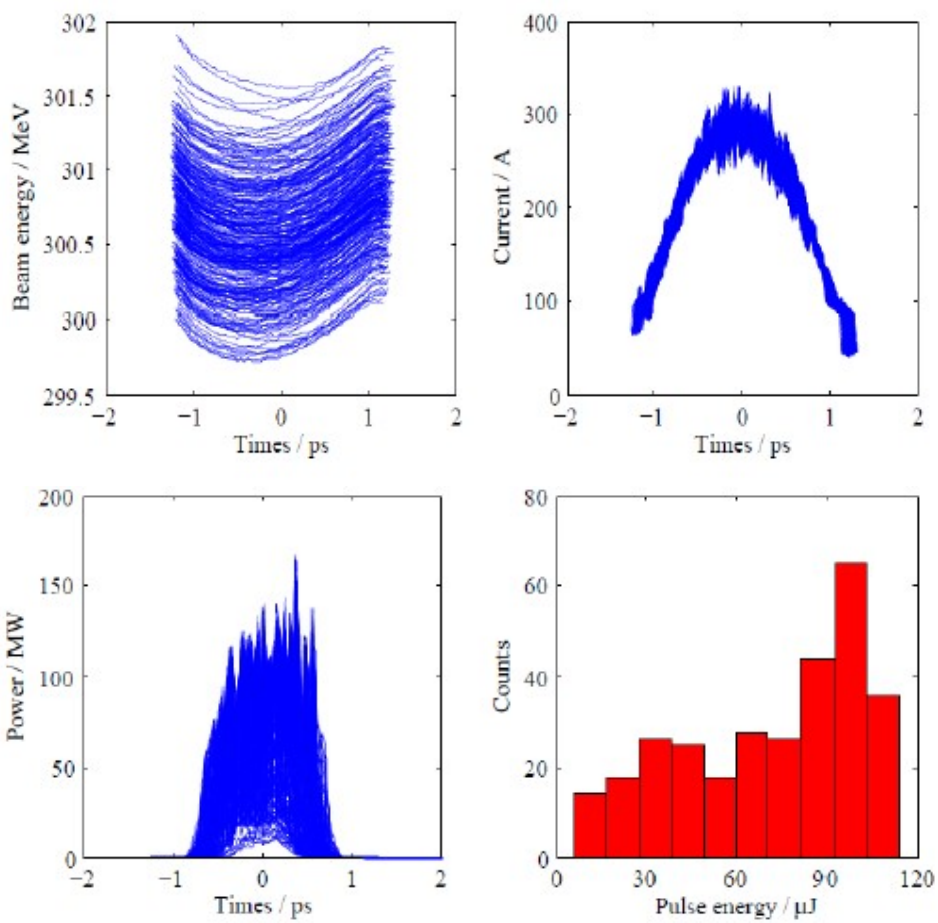

▷ H.X. Deng, et al., "Simulation studies on laser pulse stability for Dalian Coherent Light Source", arXiv:1303.6734 and DCLS CDR, 2013.

Outline

Simulation method

▷ M. Born, E. Wolf, Principles of Optics, Cambridge University Press, 1999.

Simulation method

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\begin{aligned}
E_x(t) &= E_x^0 \cos\left(k_s z - \omega_s t + \phi_x(t)\right) \\
E_y(t) &= E_y^0 \cos\left(k_s z - \omega_s t + \phi_y(t)\right)
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$$
\mathbb{S}_4 = \begin{pmatrix}
\left\langle E_x^{0\,2} \right\rangle + \left\langle E_y^{0\,2} \right\rangle \\
\left\langle E_x^{0\,2} \right\rangle - \left\langle E_y^{0\,2} \right\rangle \\
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$$

$$
\mathbb{P}_{\text{tot}} = \frac{\sqrt{\mathbb{S}_1^2 + \mathbb{S}_2^2 + \mathbb{S}_3^2}}{\mathbb{S}_0}
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\mathbb{P}_{\text{cir}} = \frac{|\mathbb{S}_3|}{\mathbb{S}_0}
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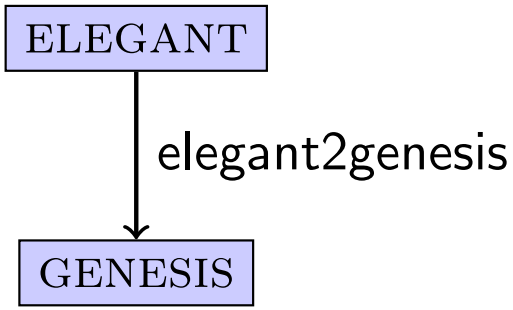

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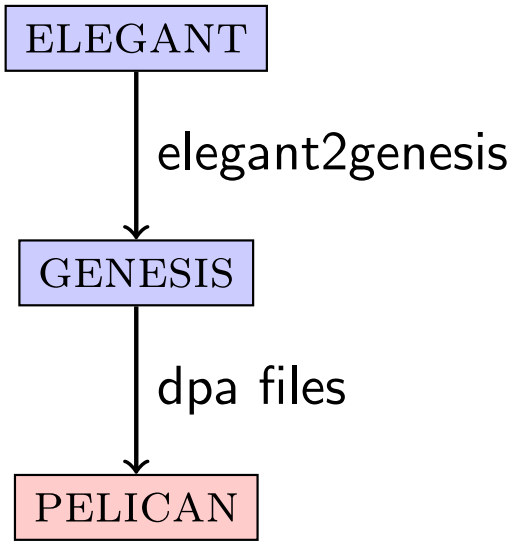
\begin{aligned}
E_x(t) &= E_x^0 \cos\left(k_s z - \omega_s t + \phi_x(t)\right) \\
E_y(t) &= E_y^0 \cos\left(k_s z - \omega_s t + \phi_y(t)\right)
\end{aligned}
$$

$$
\mathbb{S}_\downarrow = \begin{pmatrix}
\left\langle E_x^{0\,2} \right\rangle + \left\langle E_y^{0\,2} \right\rangle \\
\left\langle E_x^{0\,2} \right\rangle - \left\langle E_y^{0\,2} \right\rangle \\
2\left\langle E_x^0 E_y^0 \cos\left(\phi_x(t) - \phi_y(t)\right)\right\rangle \\
2\left\langle E_x^0 E_y^0 \sin\left(\phi_x(t) - \phi_y(t)\right)\right\rangle
\end{pmatrix}
$$

$$
\mathbb{P}_{\text{tot}} = \frac{\sqrt{\mathbb{S}_1^2 + \mathbb{S}_2^2 + \mathbb{S}_3^2}}{\mathbb{S}_0}
$$

$$
\mathbb{P}_{\text{cir}} = \frac{|\mathbb{S}_3|}{\mathbb{S}_0}
$$



▷ M. Born, E. Wolf, Principles of Optics, Cambridge University Press, 1999.

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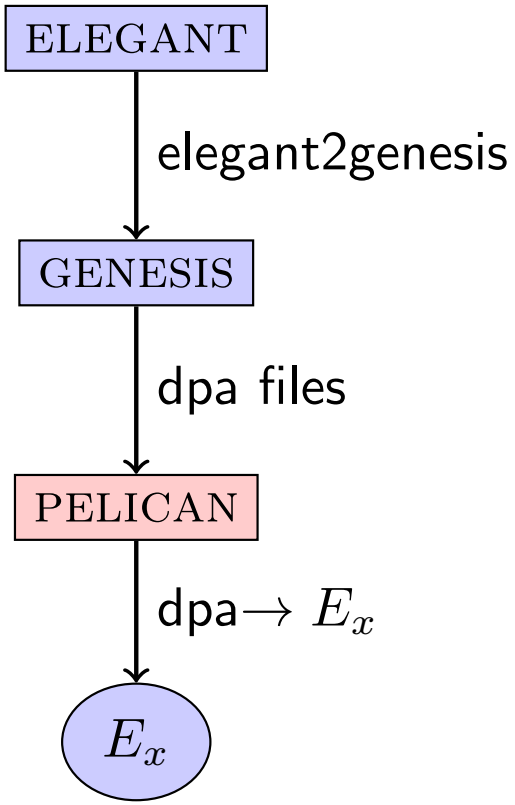

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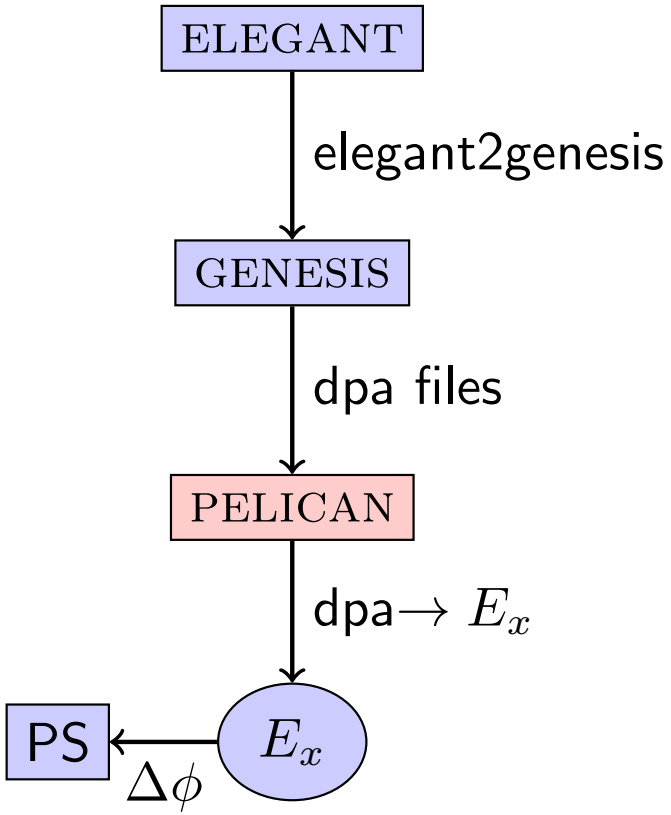

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E_y(t) &= E_y^0 \cos\left(k_s z - \omega_s t + \phi_y(t)\right)
\end{aligned}
$$

$$
\mathbb{S}_1 = \begin{pmatrix}
\left\langle E_x^{0\,2} \right\rangle + \left\langle E_y^{0\,2} \right\rangle \\
\left\langle E_x^{0\,2} \right\rangle - \left\langle E_y^{0\,2} \right\rangle \\
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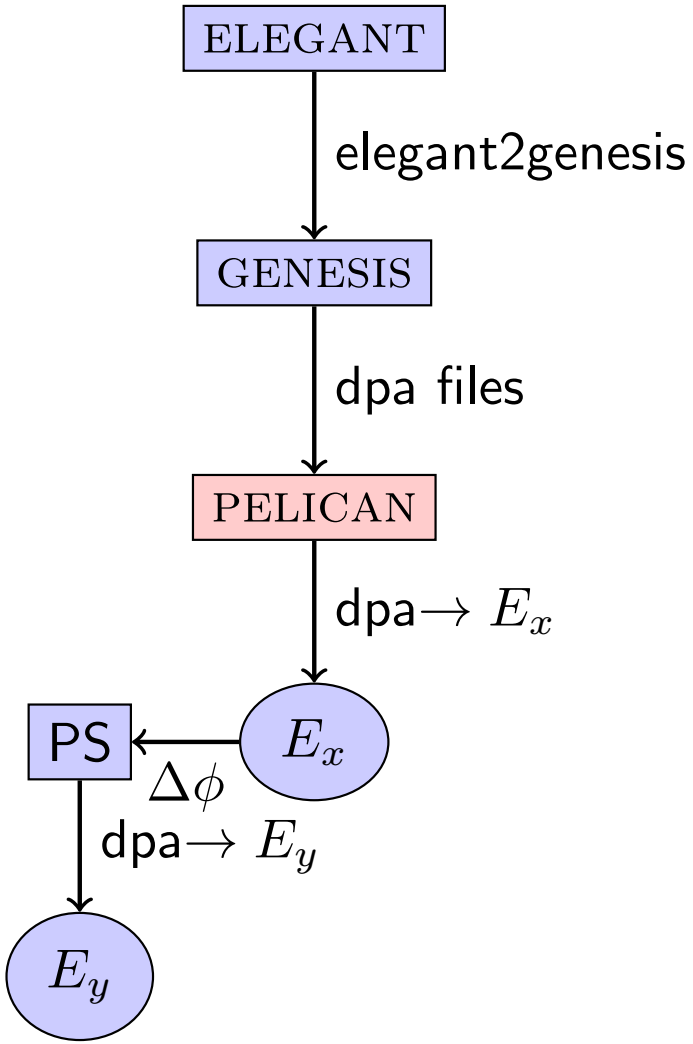

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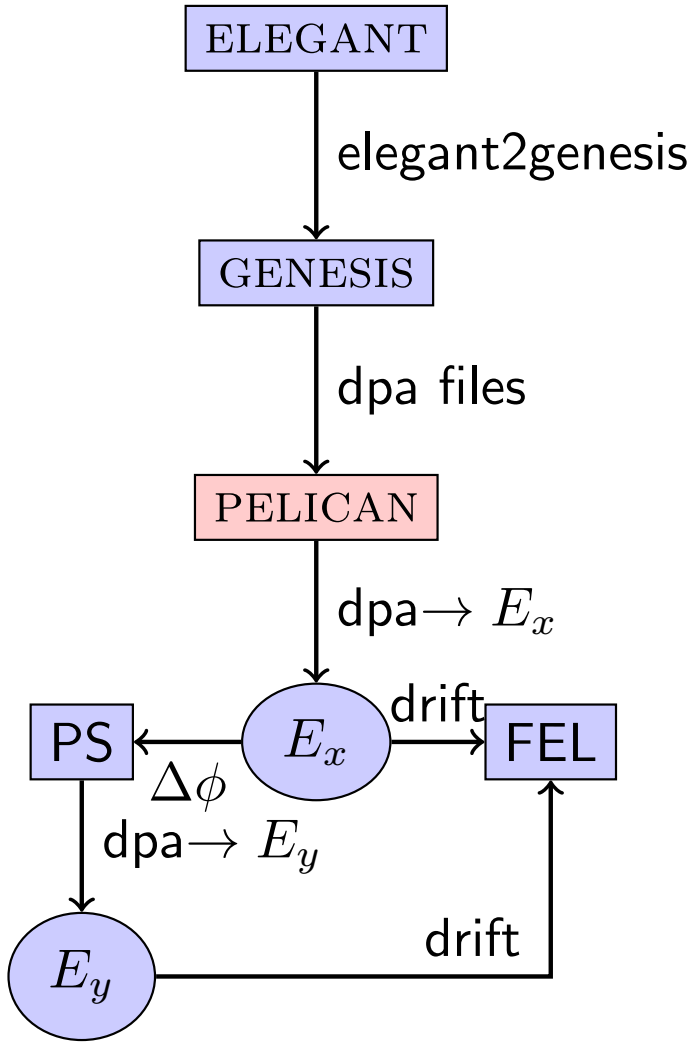

▷ M. Born, E. Wolf, Principles of Optics, Cambridge University Press, 1999.

Control FEL Polarization at DCLS

- PCM configuration: CPU ($\lambda_u = 30\,\mathrm{mm} \times 50$ for vertical/horizontal) or EPU ($\lambda_u = 30\,\mathrm{mm} \times 100$);

▷ T. Zhang, et al., "FEL Polarization Control Studies on Dalian Coherent Light Source", Chinese Physics C, to be published, 2013.

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- PCM configuration: CPU ($\lambda_u = 30\,\mathrm{mm} \times 50$ for vertical/horizontal) or EPU ($\lambda_u = 30\,\mathrm{mm} \times 100$);
- With DCLS main radiator line opening up, approaches CPU-I or EPU-I;

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- With DCLS main radiator line opening up, approaches CPU-I or EPU-I;
  - CPU-I: Fast modulated polarization;
  - EPU-I: Good circularly polarized FELs.

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- With DCLS main radiator line opening up, approaches CPU-I or EPU-I;
  - CPU-I: Fast modulated polarization;
  - EPU-I: Good circularly polarized FELs.
- Append EPU module at the end of DCLS's main radiator line, approach EPU-II.

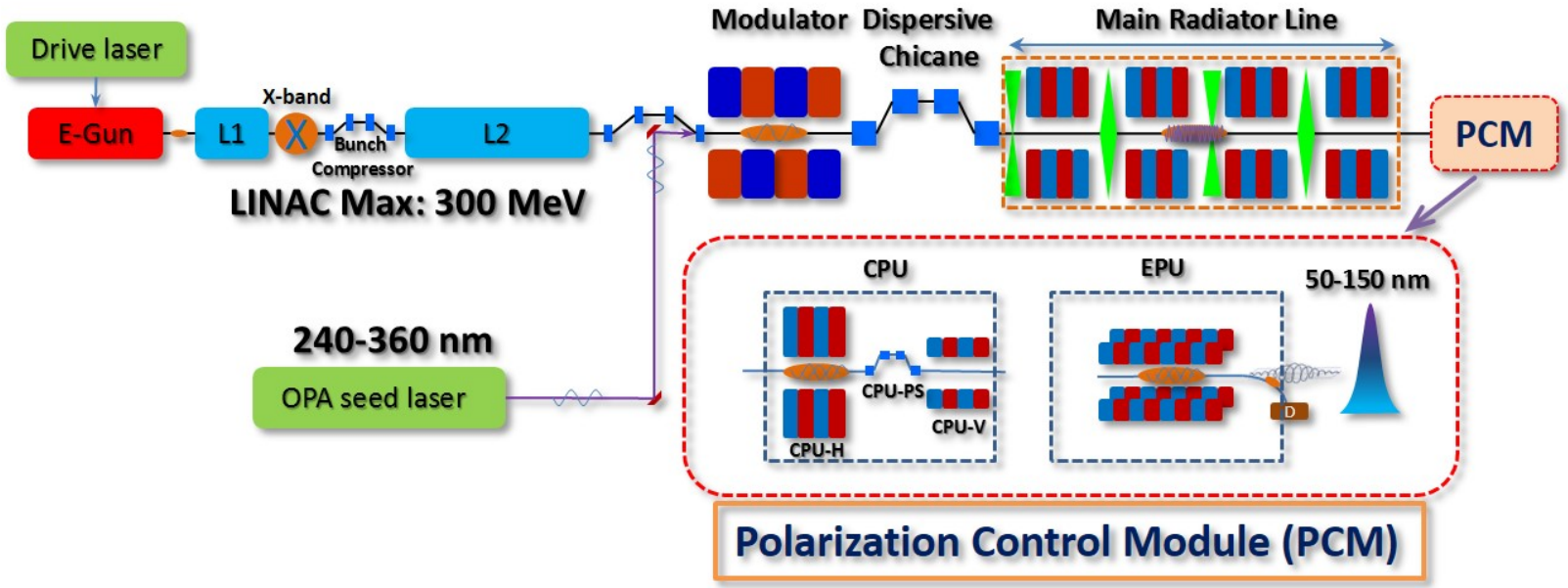
▷ T. Zhang, et al., "FEL Polarization Control Studies on Dalian Coherent Light Source", Chinese Physics C, to be published, 2013.

Control FEL Polarization at DCLS

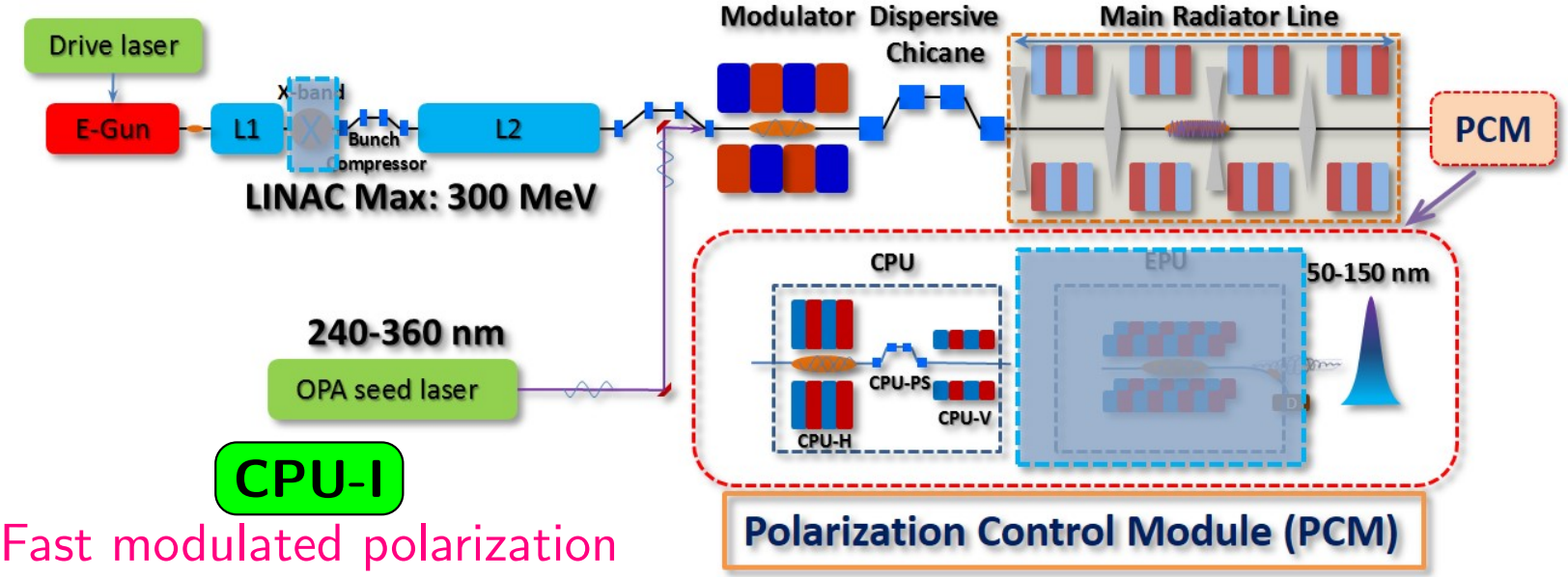
- PCM configuration: CPU ($\lambda_u = 30\,\mathrm{mm} \times 50$ for vertical/horizontal) or EPU ($\lambda_u = 30\,\mathrm{mm} \times 100$);
- With DCLS main radiator line opening up, approaches CPU-I or EPU-I;
  - CPU-I: Fast modulated polarization;
  - EPU-I: Good circularly polarized FELs.
- Append EPU module at the end of DCLS's main radiator line, approach EPU-II.
  - EPU-II: High power circularly polarized FELs.

▷ T. Zhang, et al., "FEL Polarization Control Studies on Dalian Coherent Light Source", Chinese Physics C, to be published, 2013.

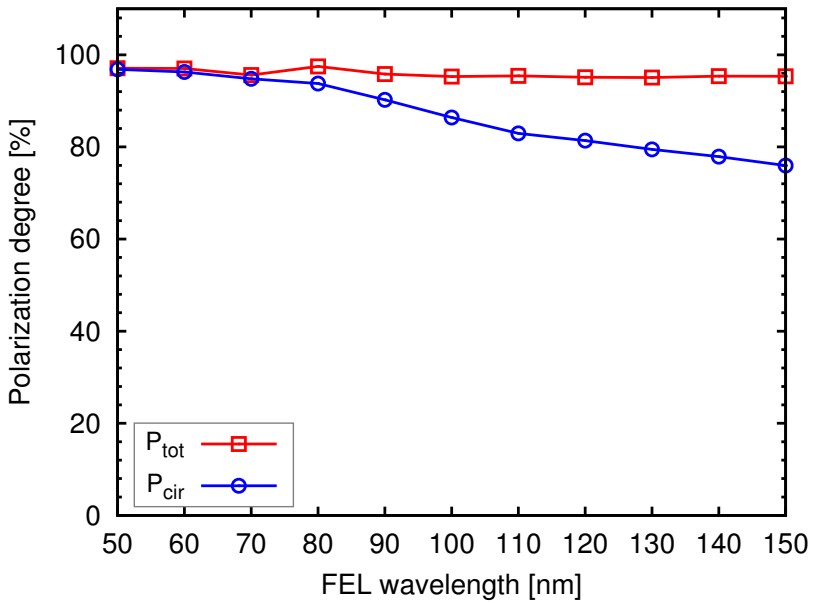
Polarization Control Module for DCLS

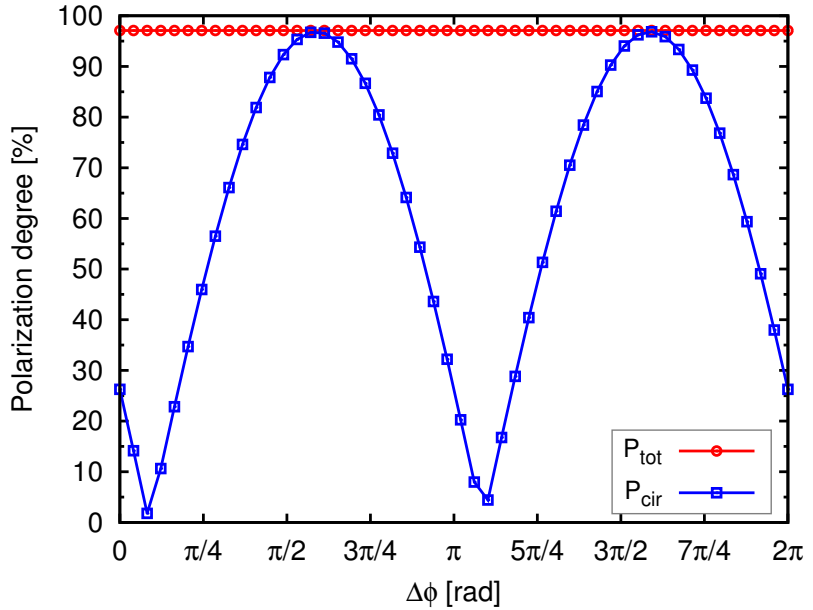


Polarization Control Module for DCLS

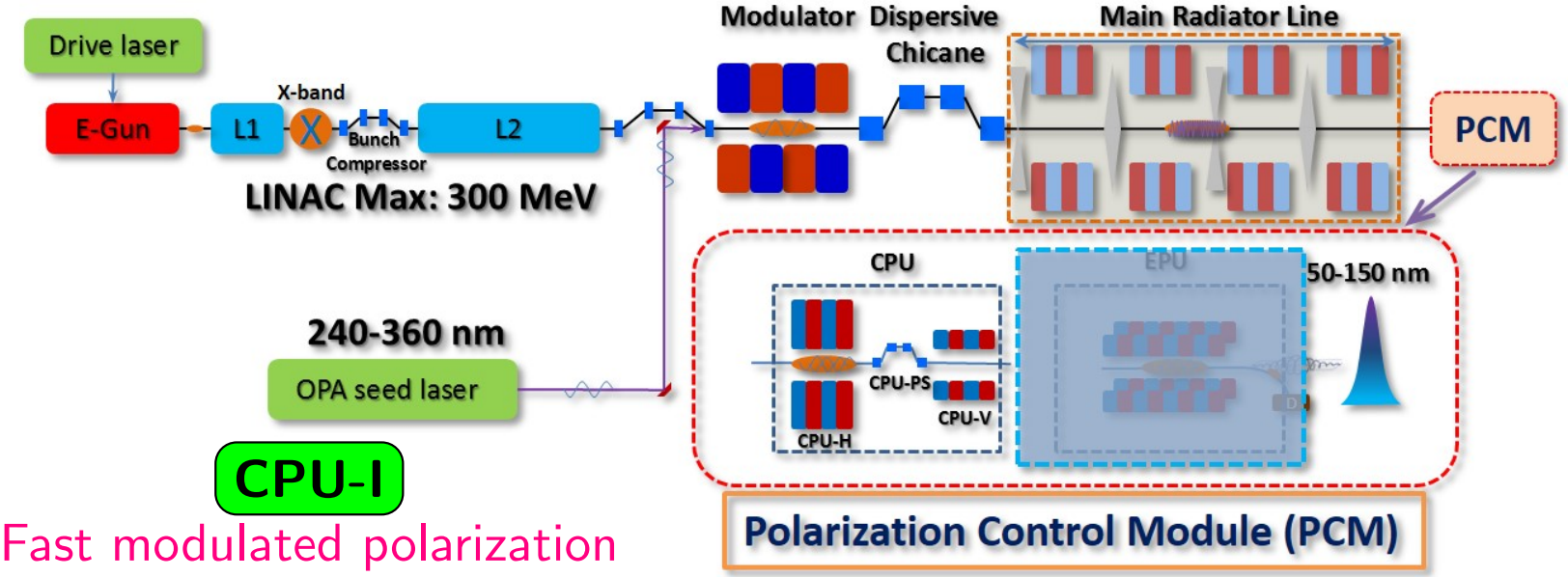


Fast modulated polarization

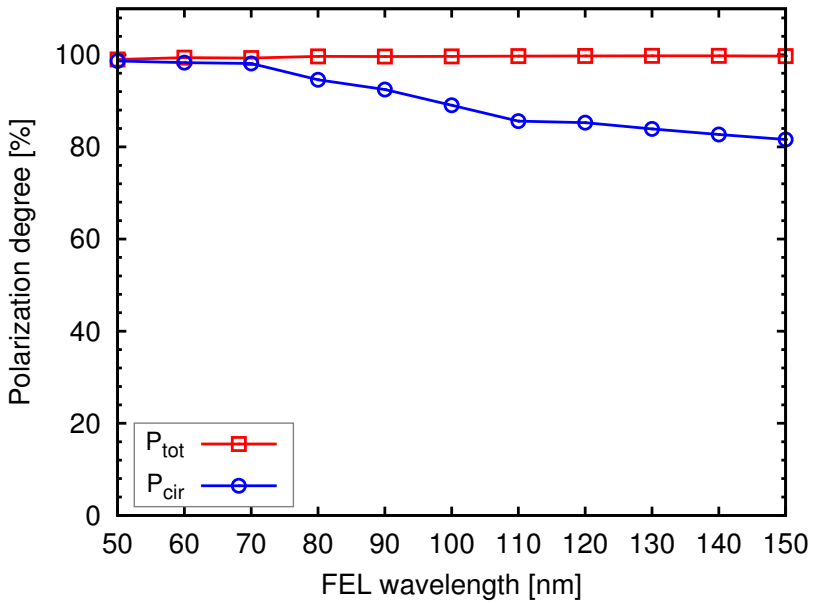


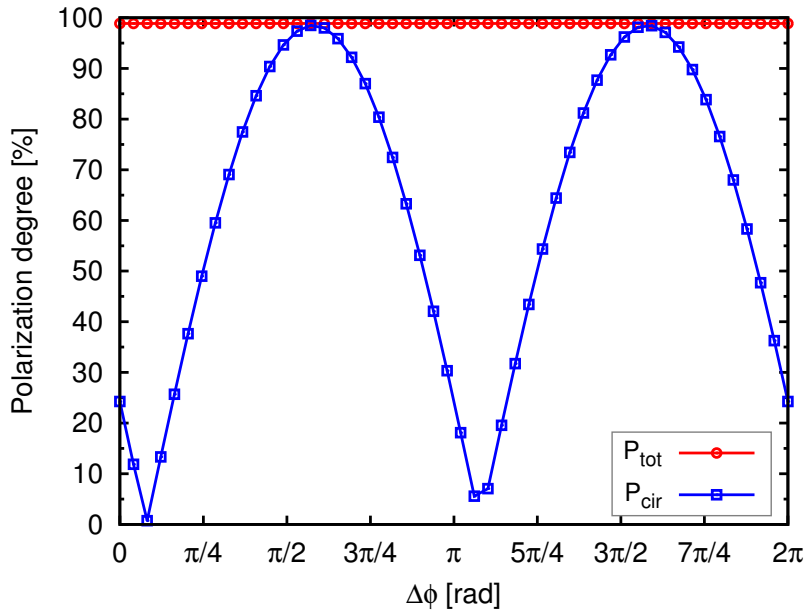


Polarization Control Module for DCLS

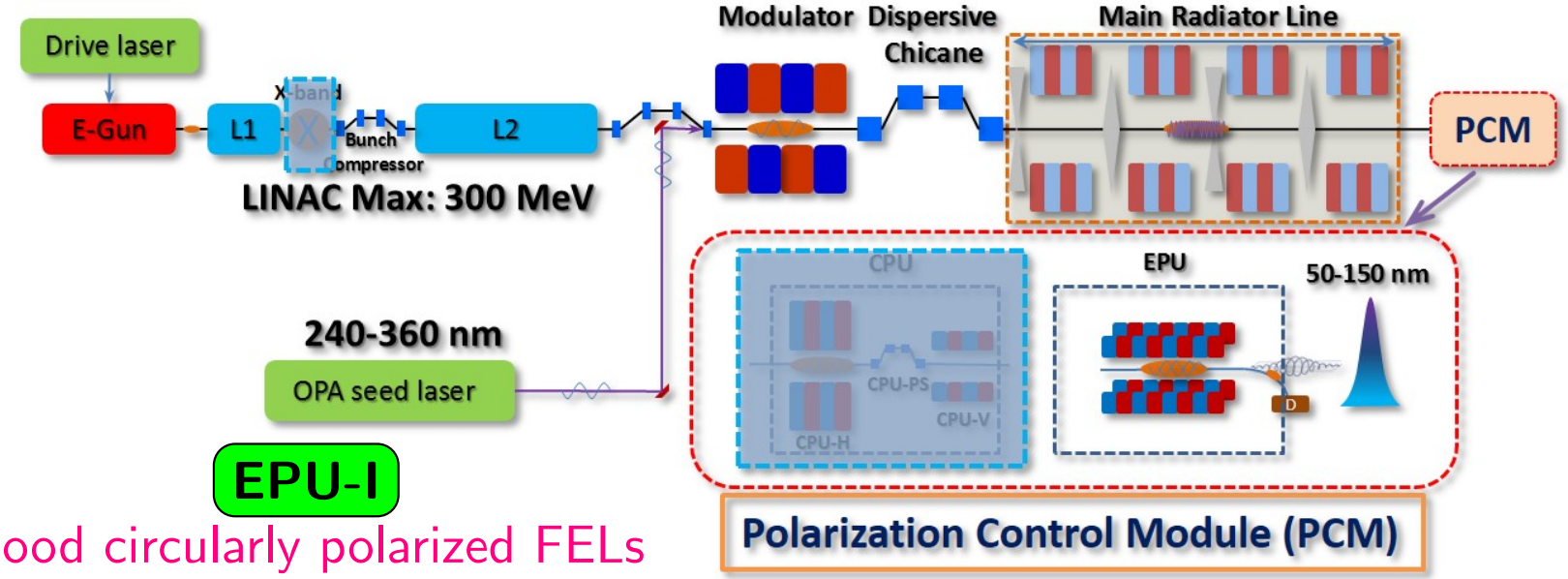


Fast modulated polarization

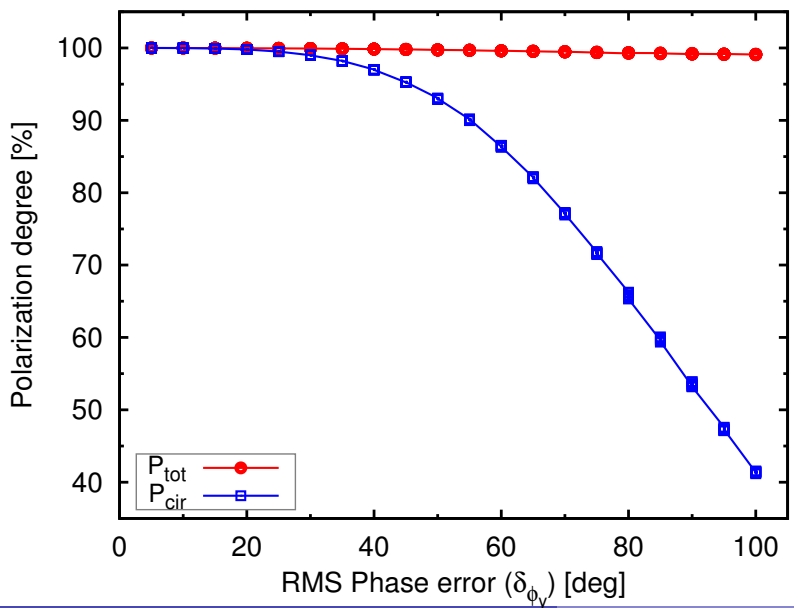


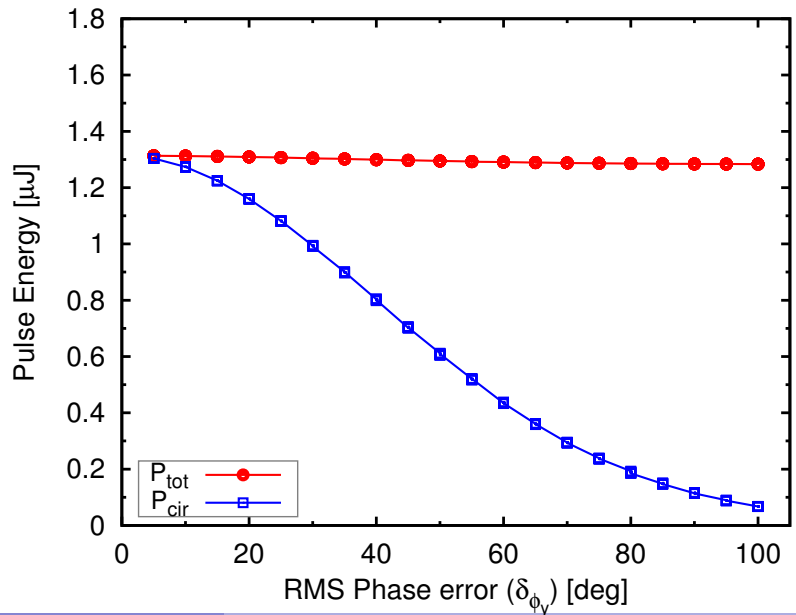


Polarization Control Module for DCLS



Good circularly polarized FELs





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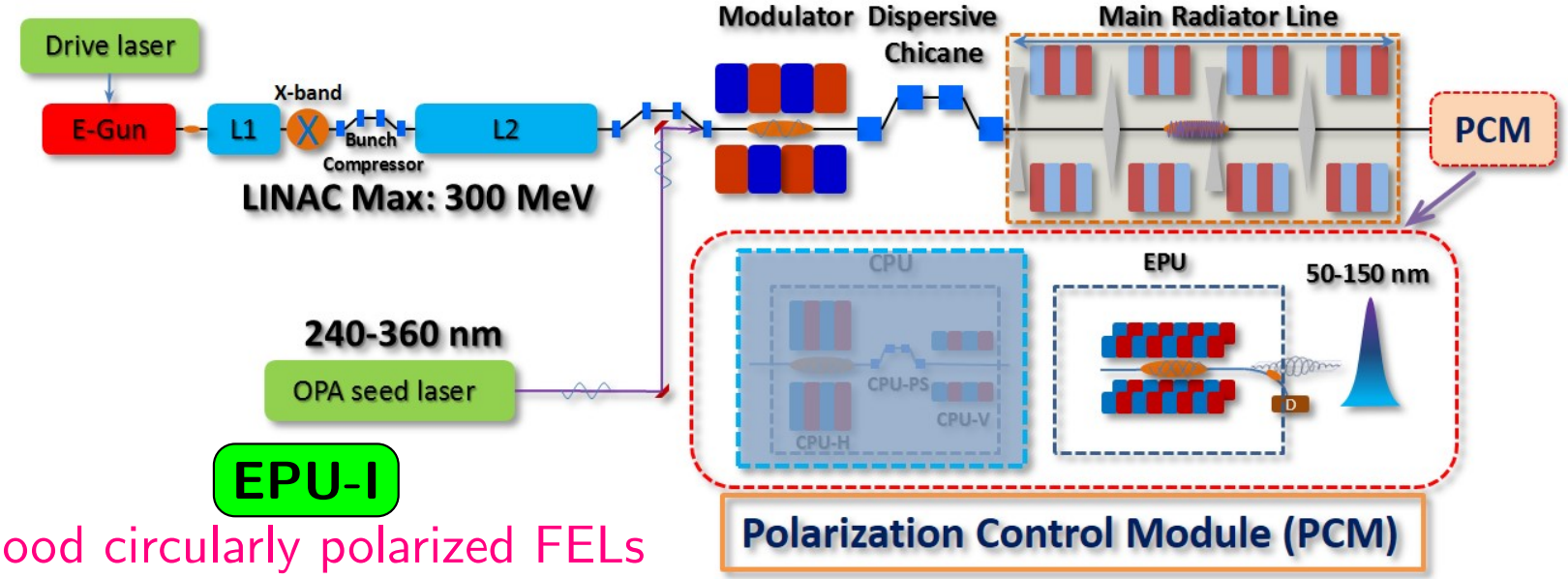

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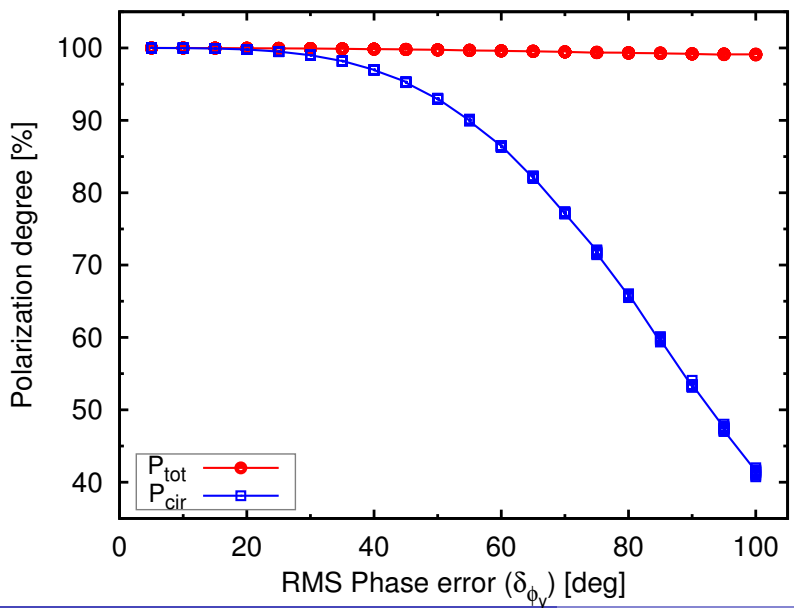

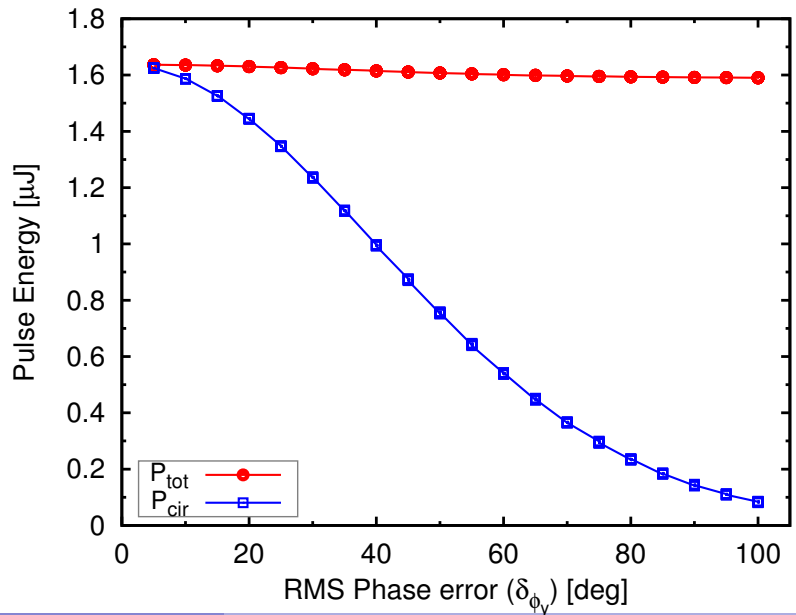

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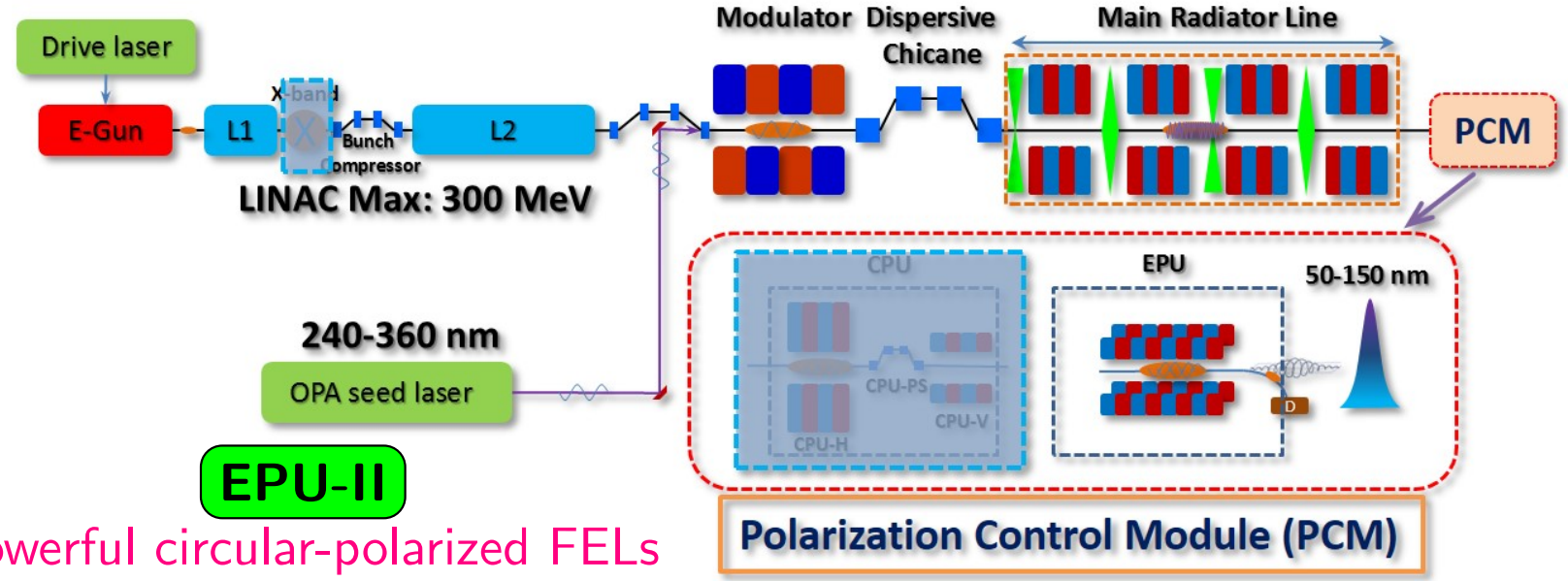
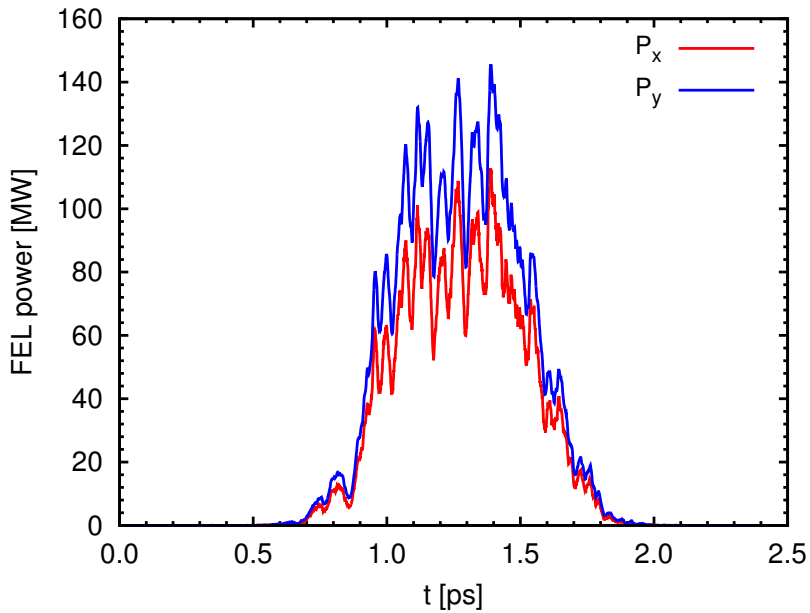
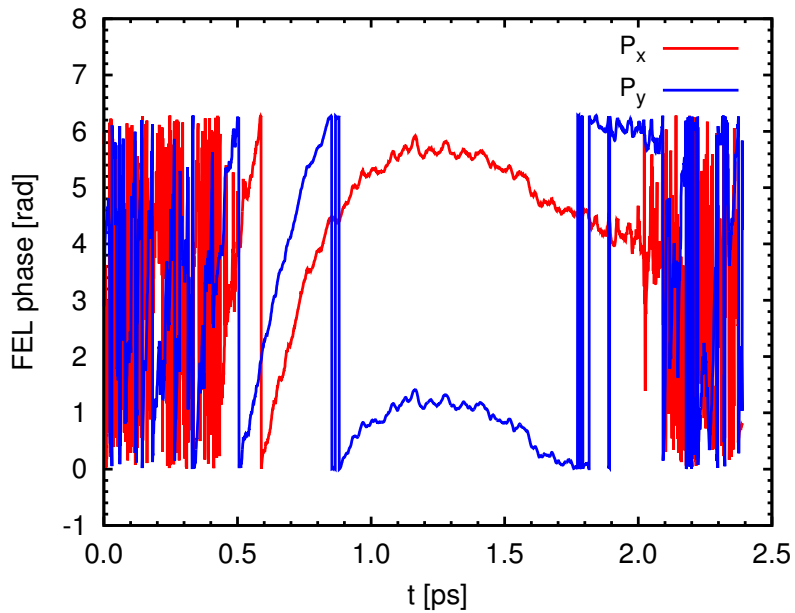


Powerful circular-polarized FELs





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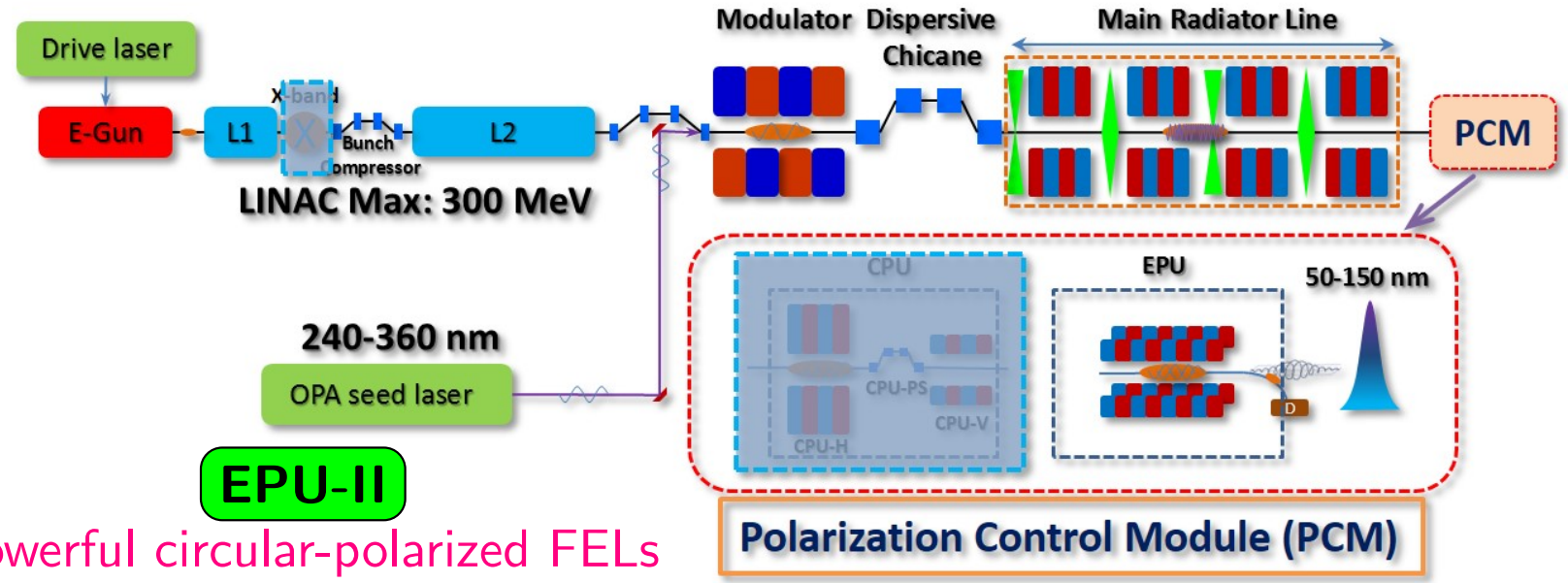
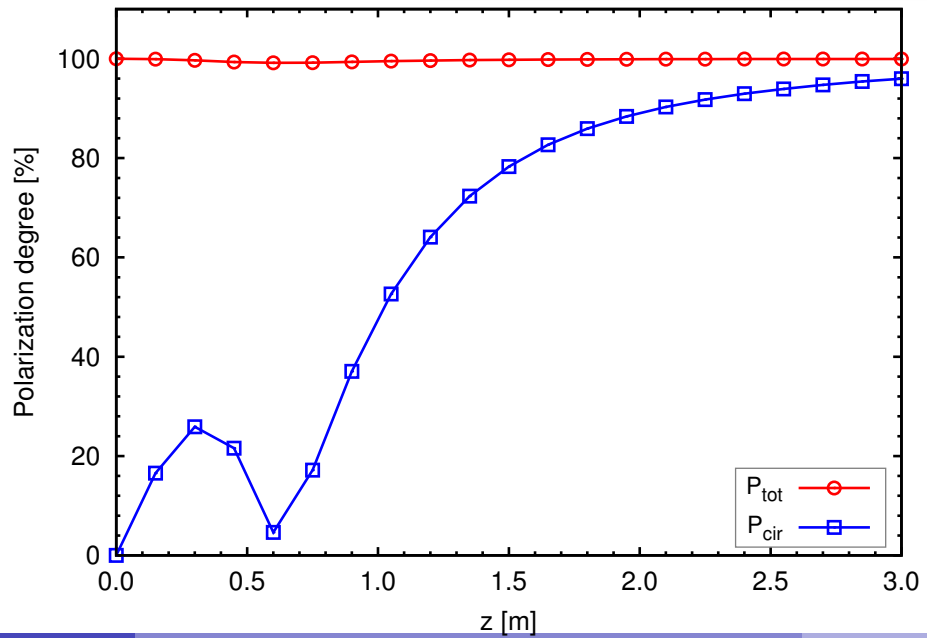
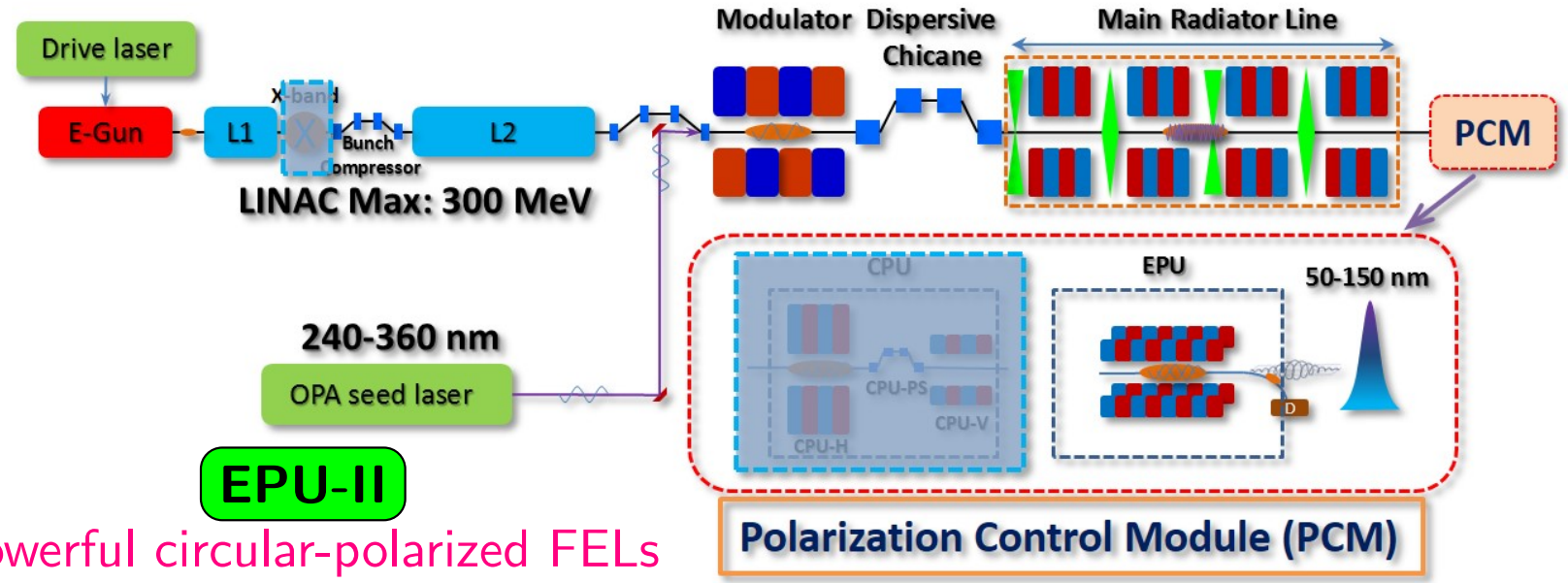


Powerful circular-polarized FELs



$$W_{\mathrm{FEL}} \simeq 130\,\mu\mathrm{J}$$
$$\mathbb{P}_{\mathrm{cir}} \simeq 95\%$$

Polarization Control Module for DCLS



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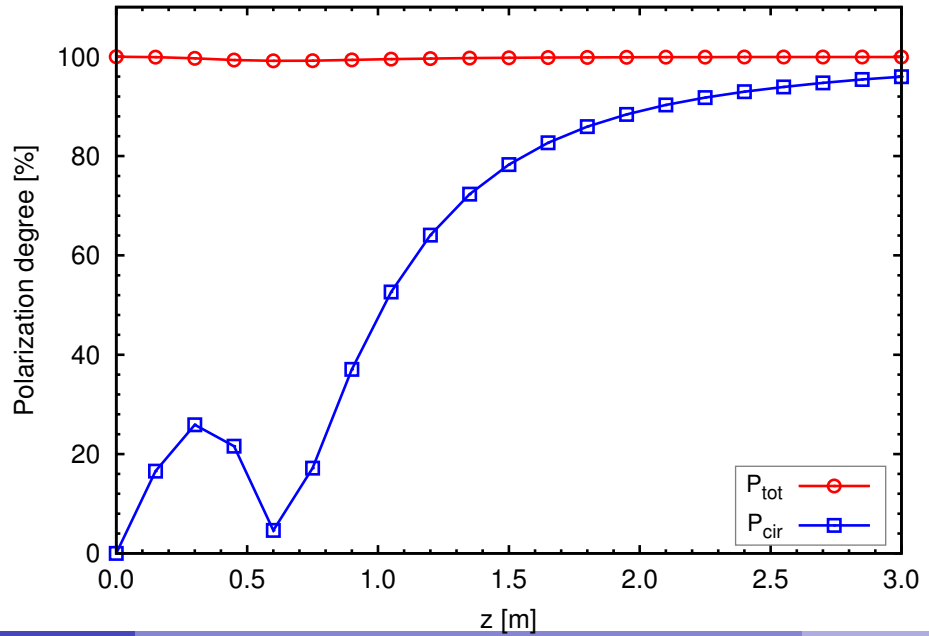

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Timeline of FEL experiments at SDUV-FEL

2009/04-08:	Linac commissioning
2009/09-12:	Light from SASE-FEL
2010/01-03:	Ready for Seeded FEL
2010/05:	Seeded FEL experiments start
2010/05-07:	HGHG signal
2010/05.22:	First coherent signal from EEHG micro-bunching
2010/10:	Slice energy spread measurement
2010/12:	HGHG saturation
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2011/07-08:	Two-staged cascaded-HGHG experiments begin
2011/08.13:	Coherent signal with spectra from 1st stage
2011/12:	Tunable HGHG and temporal coherence measurement
2012/04:	Coherent signal with spectra from 2nd stage
2012/05-now:	prepare/upgrade hardwares
2013/06-:	Higher harmonic EEHG (EEHG-10,20), polarization control, etc.

Some publications:

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▷ Z.T. Zhao, et al., *Nat. Photonics*, **6** (2012) 360-363.

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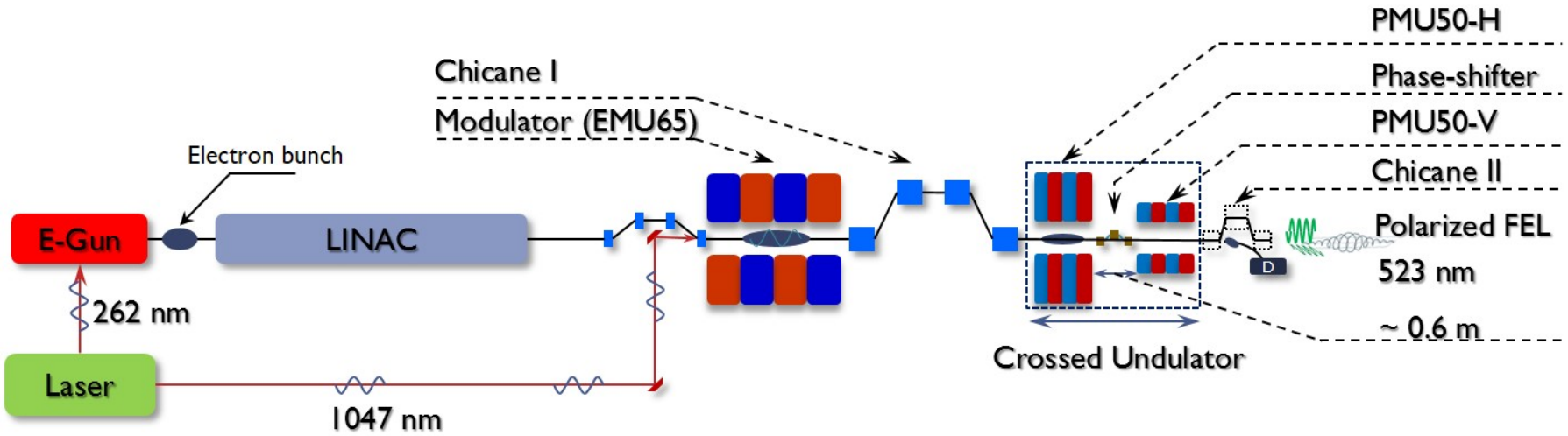
Proof-of-principle of CPU at SDUV-FEL



▷ T. Zhang, et al., Nucl. Instr. and Meth. A **680**, 112 (2012).

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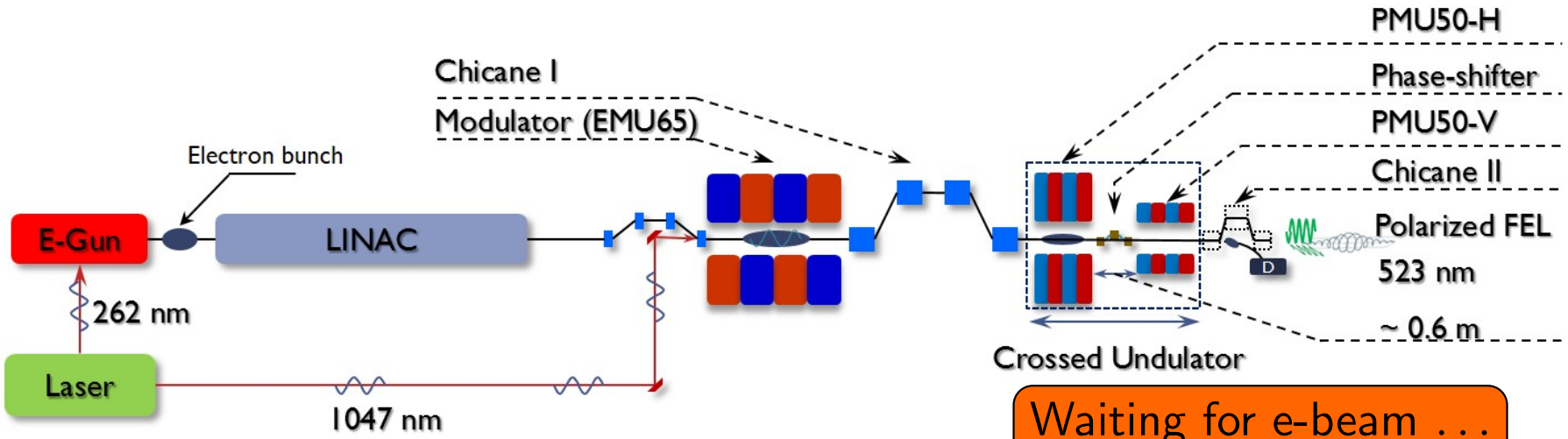
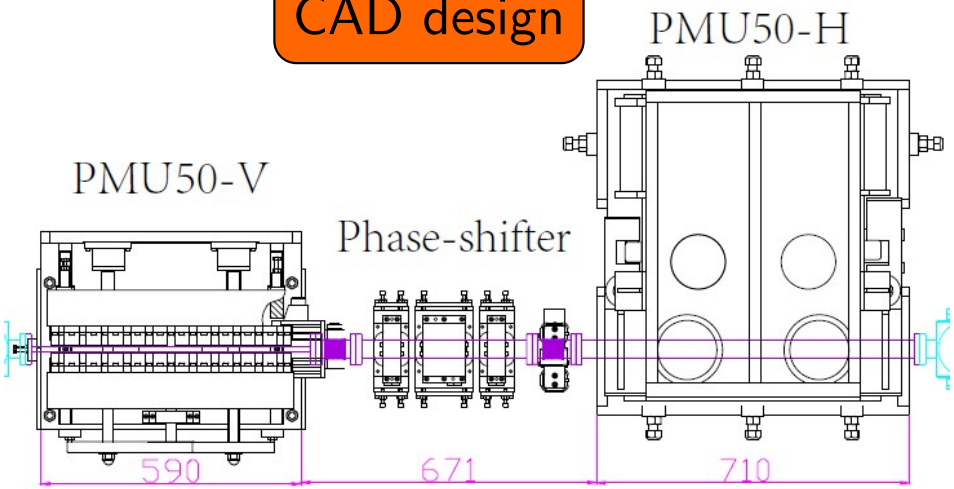
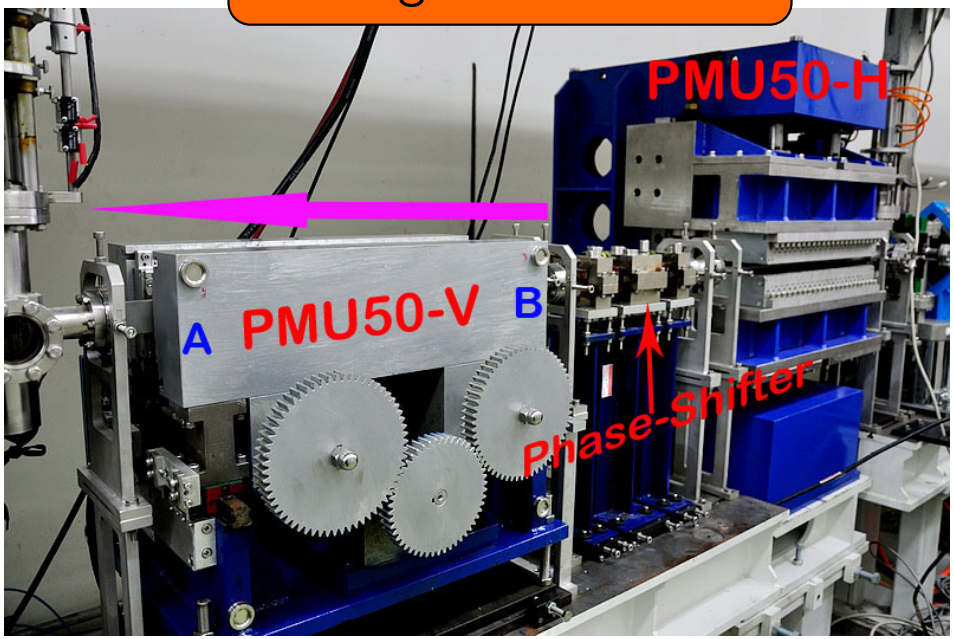


CAD design

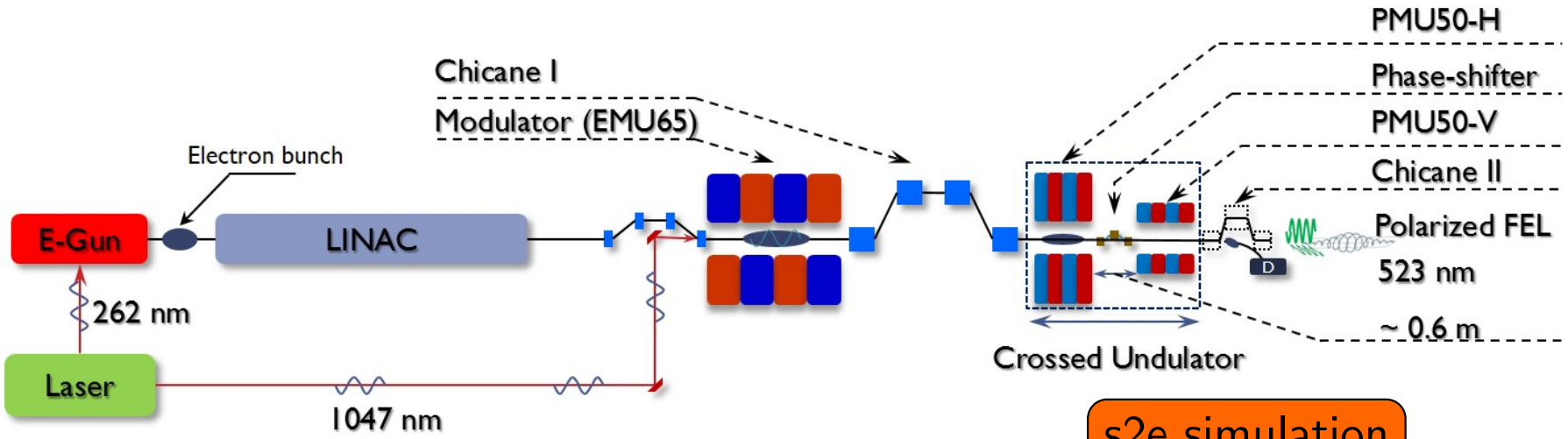


Waiting for e-beam ...

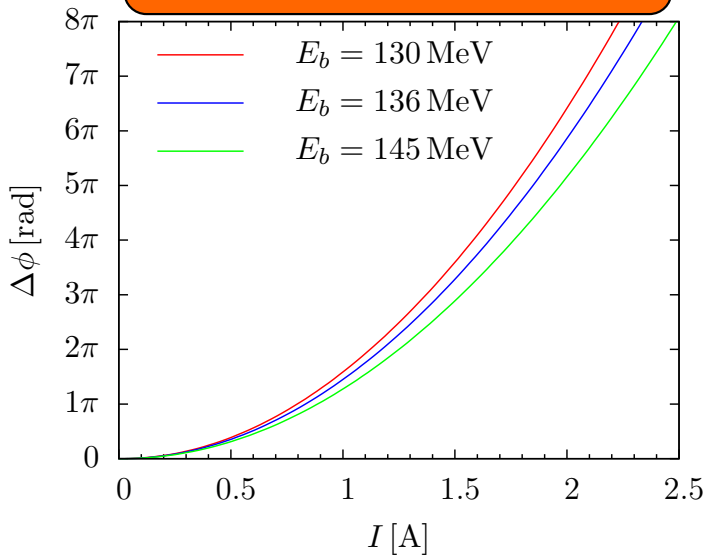


▷ T. Zhang, et al., Nucl. Instr. and Meth. A **680**, 112 (2012).
▷ H. Deng, et al., in FEL'12 (TUPD10) and in these proceeding (TUPEA032).

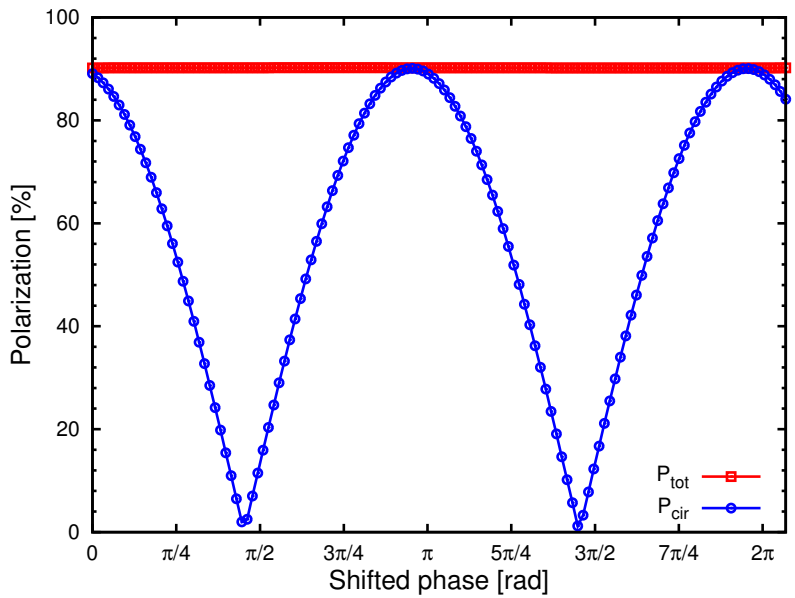
Proof-of-principle of CPU at SDUV-FEL



Calculated from measurement



s2e simulation



▷ T. Zhang, et al., Nucl. Instr. and Meth. A **680**, 112 (2012).
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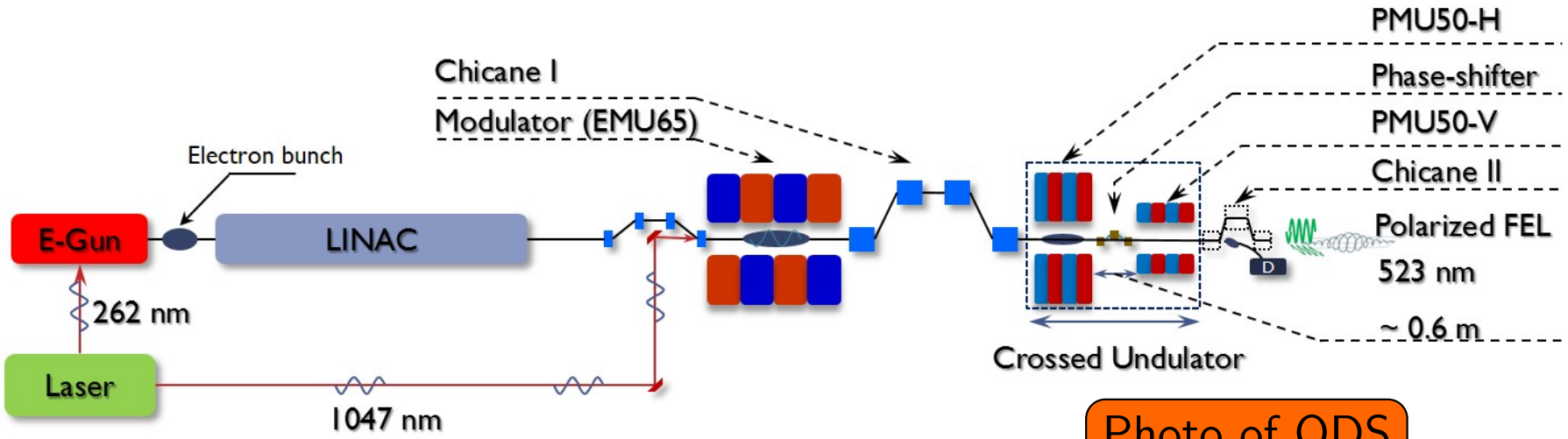


Design optics for in-situ polarization diagnostics

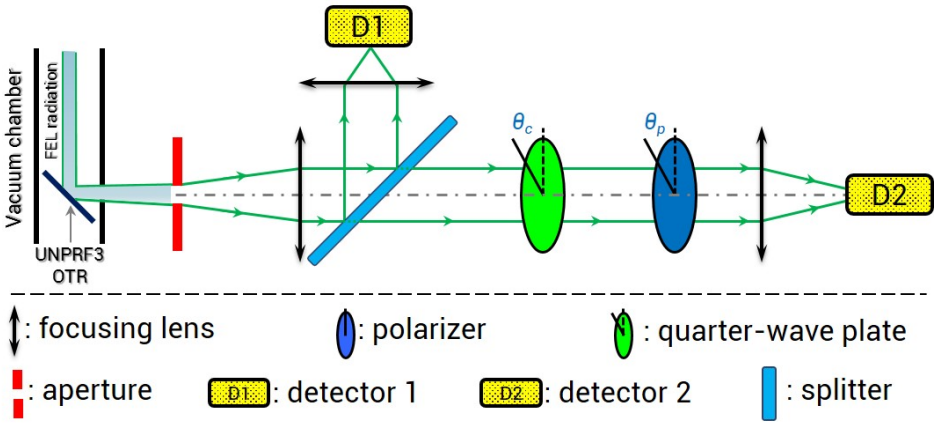
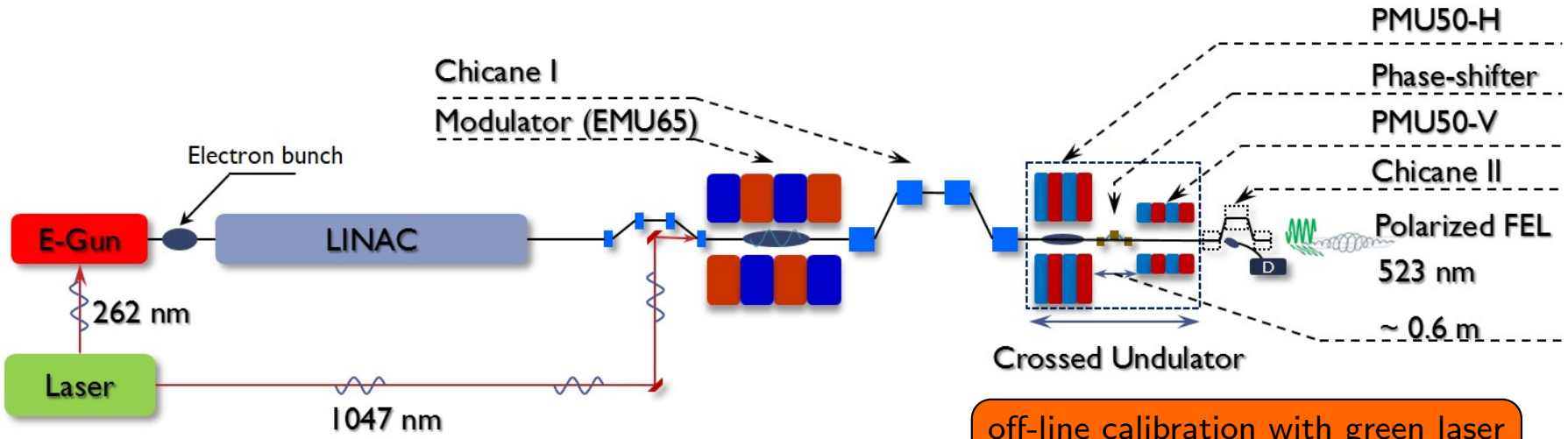


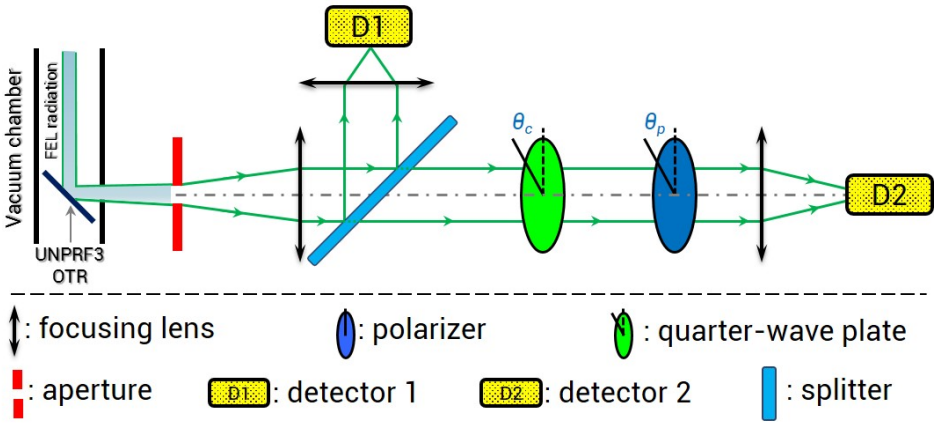
Photo of ODS

▷ T. Zhang, et al., Nucl. Instr. and Meth. A **680**, 112 (2012).
▷ H. Deng, et al., in FEL'12 (TUPD10) and in these proceeding (TUPEA032).

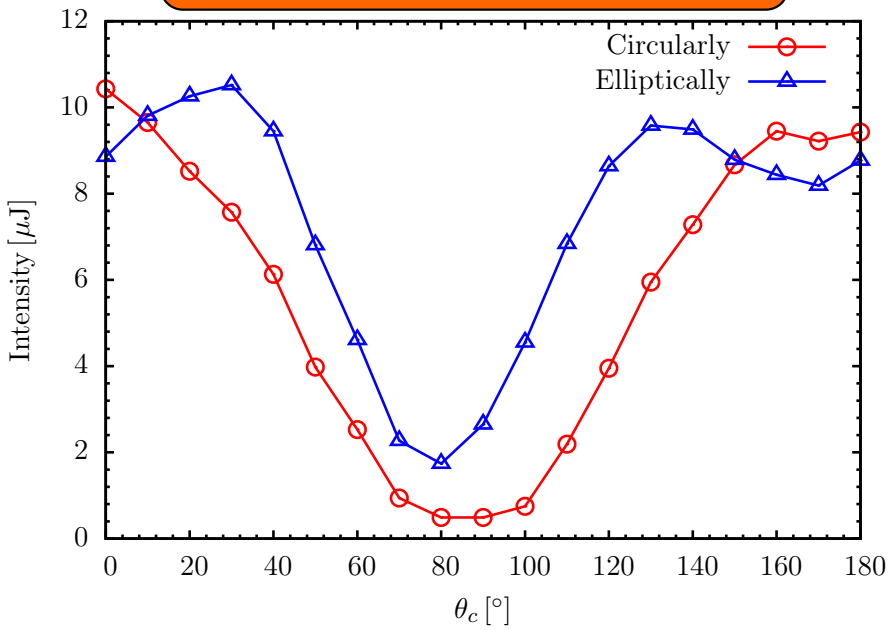
Proof-of-principle of CPU at SDUV-FEL



Design optics for in-situ polarization diagnostics



off-line calibration with green laser



▷ T. Zhang, et al., Nucl. Instr. and Meth. A **680**, 112 (2012).
▷ H. Deng, et al., in FEL'12 (TUPD10) and in these proceeding (TUPEA032).

Outline

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- Numerical code is developed for fair comparative study for crossed planar undulator and elliptical permanent undulator in the FEL polarization control;
- It is promising to generate powerful coherent EUV radiations with flexible polarization control at Dalian coherent light source;
- Much more will be learnt from the polarization control experiments on-going at SDUV-FEL.

Acknowledgments

On behalf of the FEL physics group and other involved groups from SINAP and DICP, etc.

Thank you for your attention!