Spin effects in strong laser and plasma fields

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Contents

- Introduction of the laser facilities
- Spin effects in the SF-QED regime
- Generation of polarized particle sources
- Conclusions


Shanghai Light Source
SULF 10PW
SULF
SEL 100PW
XFEL
ShanghaiTech University
XFEL parameters:
e-beams： 8-10 GeV
Photons： 0.4-25 keV
Rep.rate:1MHz
Shanghai XFEL (SHINE)
高
上海奕欧来
奥特莱斯
祝桥环城一村

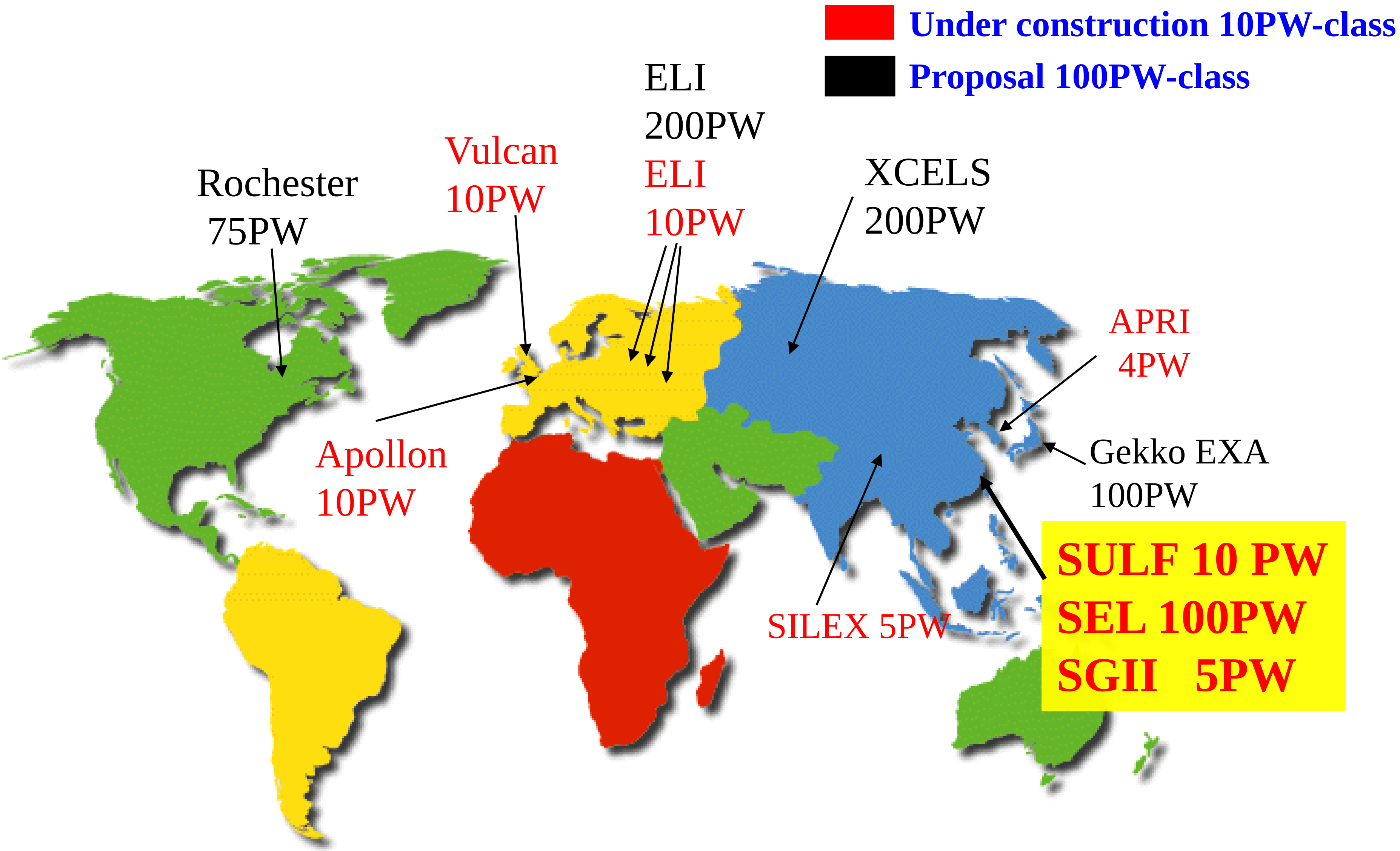
Shanghai Ultra-short and ultra-intense laser facility (SULF, 10PW)

1PW beamline:30J, 30fs, 0.1Hz

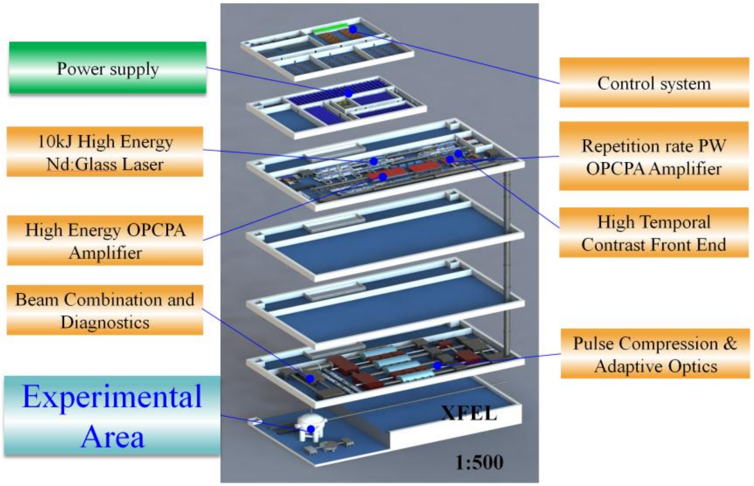
10PW beamline: 250J, 25fs

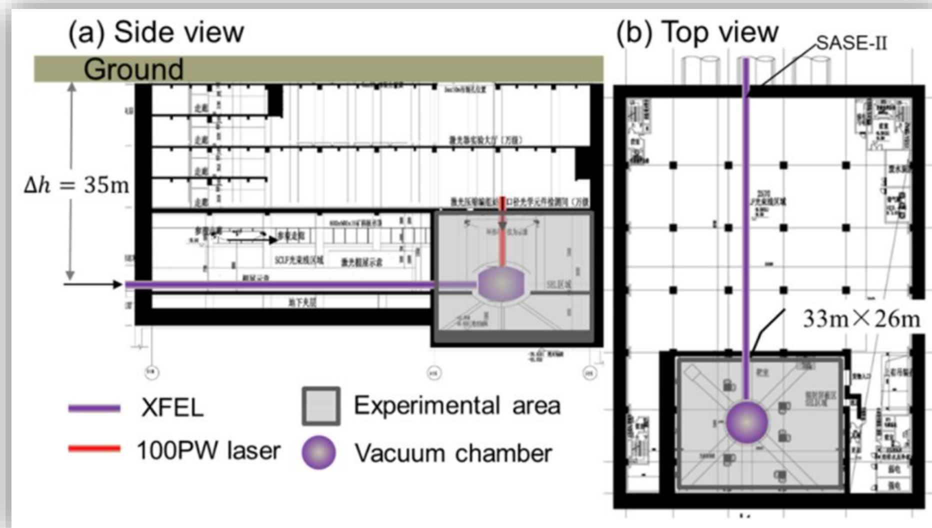
- **DMEC**： Dynamics of Materials under Extreme Conditions
- **USAP**： Ultrafast Sub-atomic Physics
- **MODEC**： Big Molecule Dynamics and Extreme-fast Chemistry

10PW-200PW laser facilities worldwide

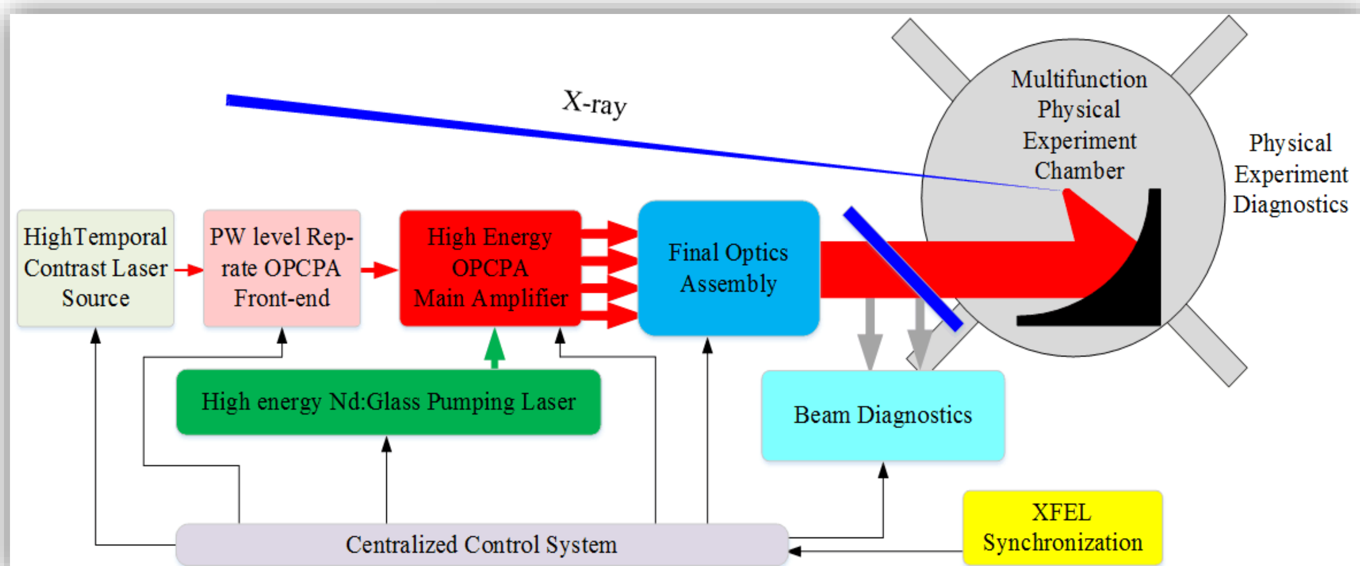


Station of Extreme Light (SEL, 100PW)





- Located in the Farthest shaft
- 35 meters underground.
- Flexible interaction-angles



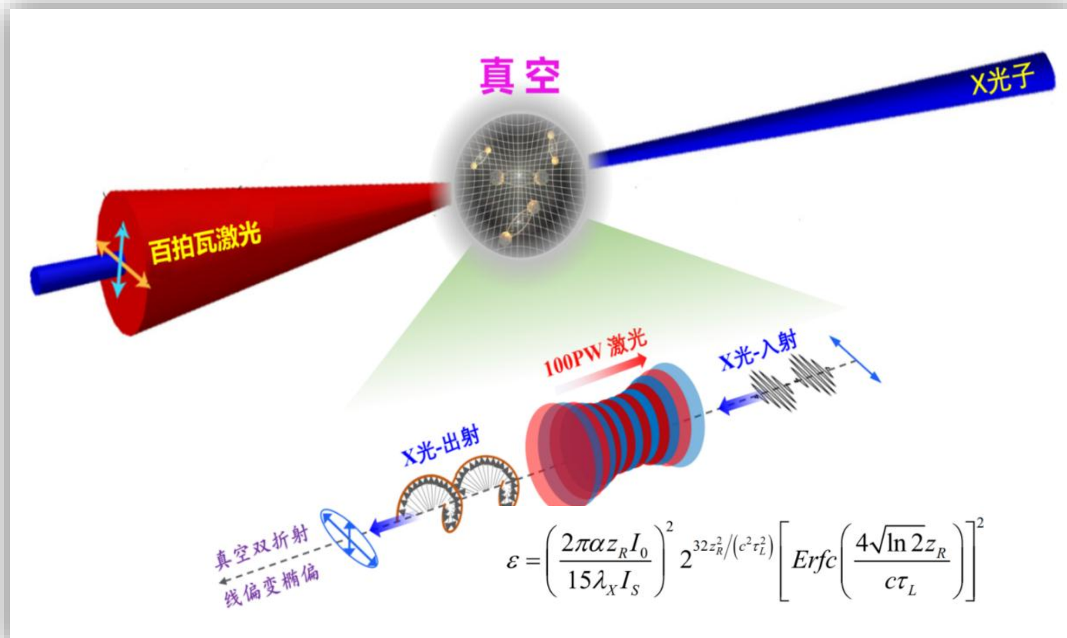
Parameters for proposed experiments in SEL

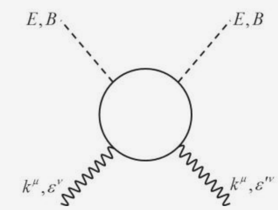
Parameters		Nominal
X-ray	Photon Energy	3 - 15 keV
	Photons per pulse	10^{11-12}
	Pulse length	20- 50 fs
	beam spot size	0.2-5 um
	Energy Resolution	0.6 eV
Laser	Focused intensity	1×10^{23} W/cm^2
	Peak power	100 PW
	Repetition rate	1Hz@0.1-1PW Single shot@100PW

- Pulse energy 1500J; duration 15fs; Central wavelength 900nm; Peak power 100 PW; Focused spot size 5μm; Intensity >10^{23} W/cm^2; Contrast ratio >10^{12}

Station of Extreme Light (SEL, 100PW)

In SEL, the 100PW laser will collide with the XFEL beam, probing "vacuum birefringence" for the first time.





$$\mathcal{L} = \mathcal{F} + 2\xi\mathcal{F}^2 + \frac{7\xi}{2}\mathcal{G}^2$$

$$\mathcal{F} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} = \frac{1}{2}\left(\boldsymbol{E}^2 - \boldsymbol{B}^2\right)$$

$$\mathcal{G} = -\frac{1}{4}F_{\mu\nu}\tilde{F}^{\mu\nu} = \boldsymbol{E}\cdot\boldsymbol{B}$$

In QED, vacuum is full of virtual particle pairs that can mediate light-light interaction forbidden in classical theory.

Plasma Phys. Control. Fusion 60 044002 (2018)

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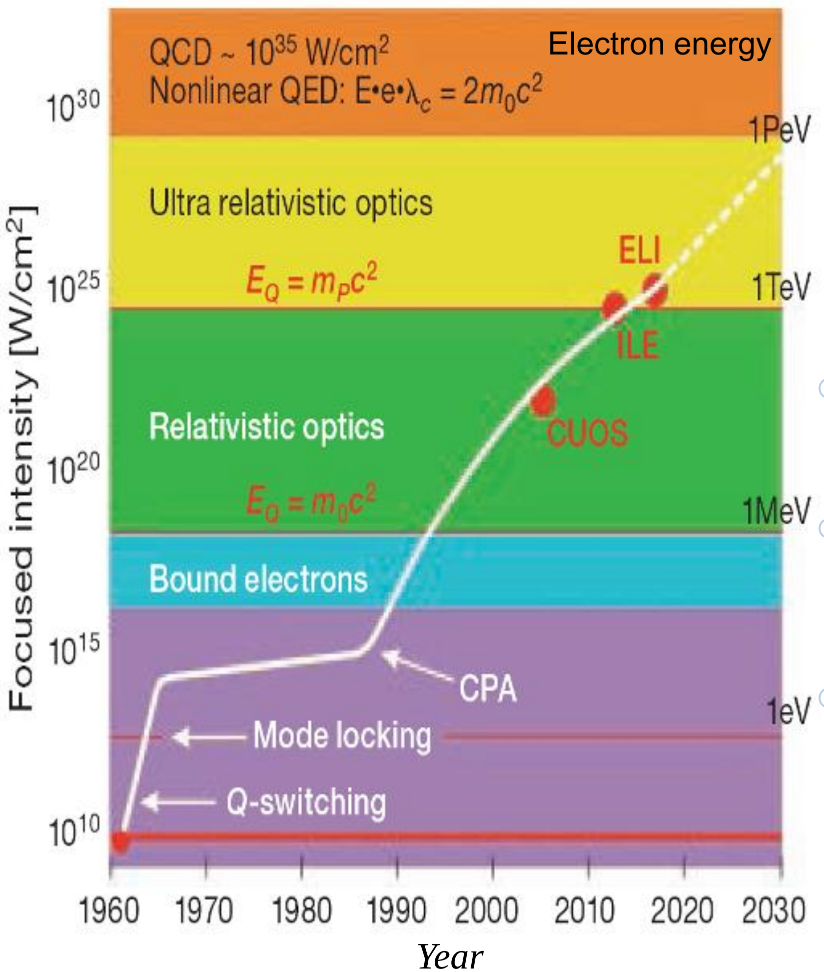
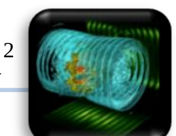
Laser intensity VERSUS interaction regimes

With 10-100PW laser, light intensity reaches beyond 10^{22}W/cm^2, light-matter interaction steps into the new Radiation-dominated & QED regime.



$> 10^{22}$ W/cm^2

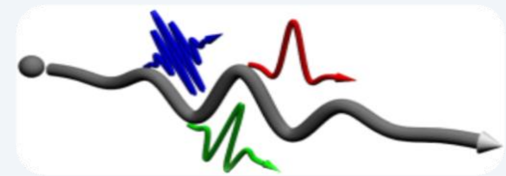
10^{18} W/cm^2



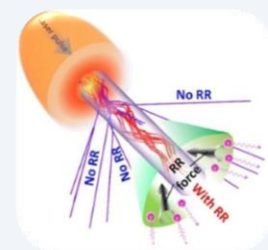
Relativity、Plasma

10^{14} W/cm^2

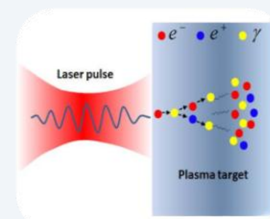
Atom, molecule



Gamma-ray emission



Radiation Reaction effect

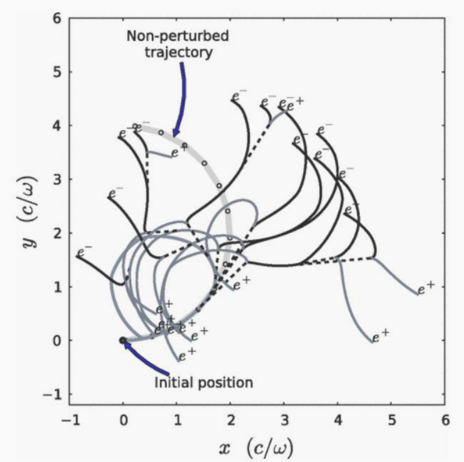


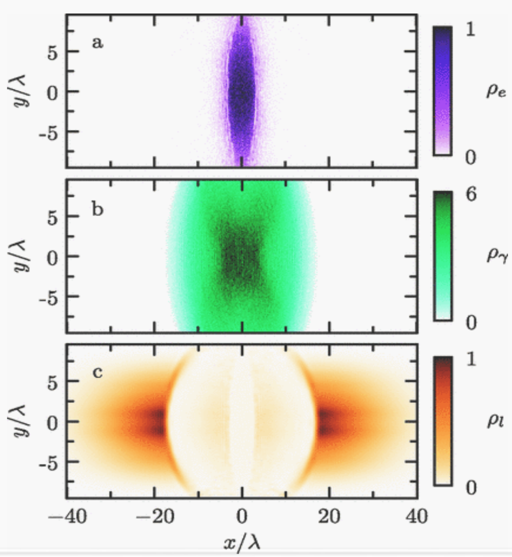
e^-/e^+ pair creation

OPN July(2011); Science 331, 41 (2011); Nature Material 15, 1(2016)

Extreme-field effects

QED cascade





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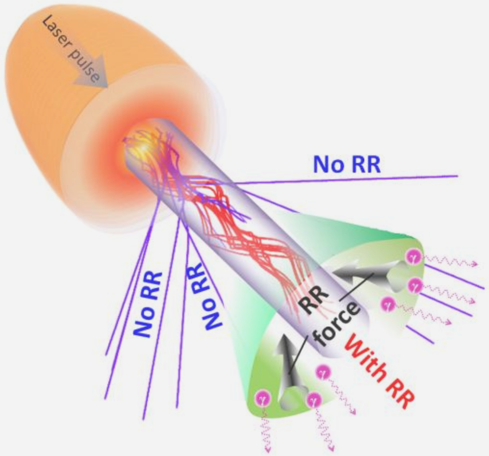
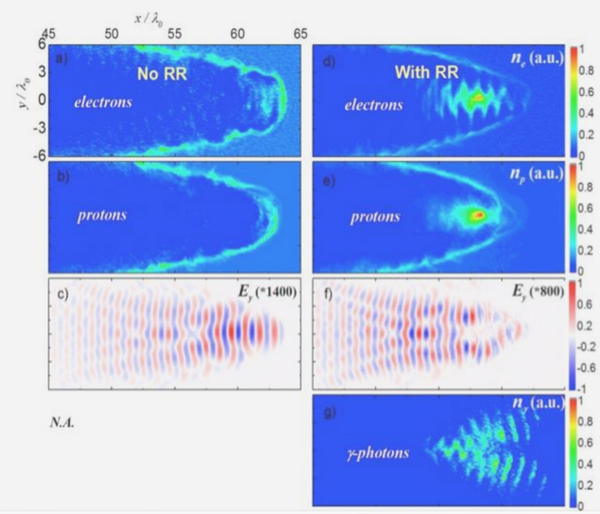
Radiation-reaction trapping





A. M. Fedotov, N. B. Narozhny, G. Mourou et al., **PRL**105, 080402 (2010)
N. V. Elkina, A. M. Fedotov, I. Yu. Kostyukov et al., **PRST-AB** 14, 054401 (2011)
E. N. Nerush, I. Yu. Kostyukov, A. M. Fedotov et al.,**PRL**106, 035001 (2011)

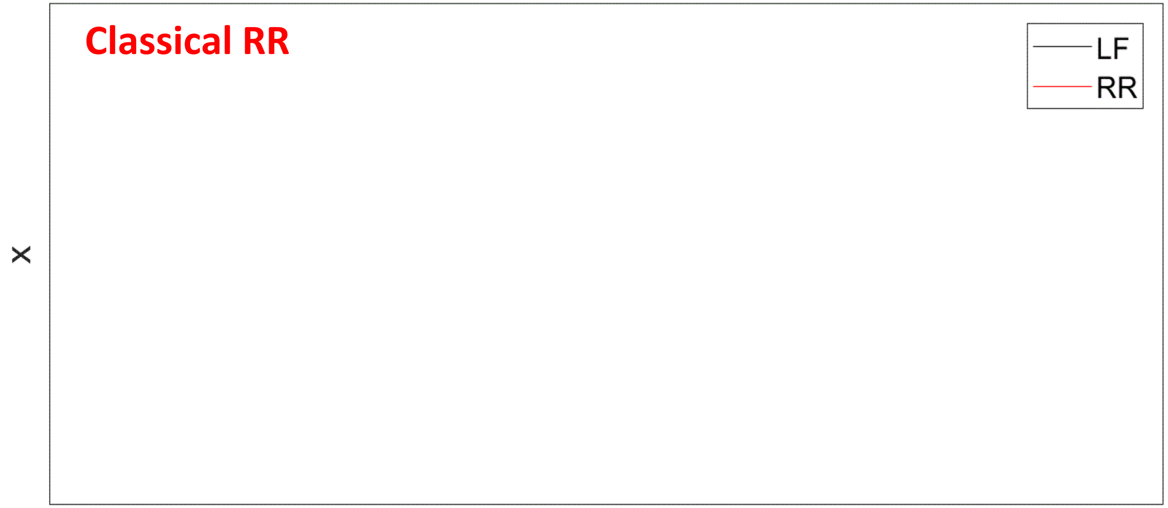
Liangliang Ji et al., **Phys.Rev.Lett.** 112, 145003 (2014).
Liangliang Ji et al., **Phys.Plasmas** 21, 023109 (2014).

Quantum behavior of relativistic particles in strong laser field

Landau-Lifschitz Equation

$$\frac{dp}{dt} = e(\mathbf{E} + \frac{1}{c}\mathbf{v}\times\mathbf{B})$$
$$+\frac{2e^3}{3mc^3}\gamma\left\{(\frac{\partial}{\partial t} + \mathbf{v}\cdot\nabla)\mathbf{E} + \frac{1}{c}\mathbf{v}\times(\frac{\partial}{\partial t} + \mathbf{v}\cdot\nabla)\mathbf{B}\right\}$$
$$+\frac{2e^4}{3m^2c^4}\left\{\mathbf{E}\times\mathbf{B} + \frac{1}{c}\mathbf{B}\times(\mathbf{B}\times\mathbf{v}) + \frac{1}{c}\mathbf{E}(\mathbf{v}\cdot\mathbf{E})\right\}$$
$$-\frac{2e^4}{3m^2c^5}\gamma^2\mathbf{v}\left\{(\mathbf{E} + \frac{1}{c}\mathbf{v}\times\mathbf{B})^2 - \frac{1}{c^2}(\mathbf{E}\cdot\mathbf{v})^2\right\}$$

L.D. Landau & E.M. Lifshitz, 1971



Laser: 5×10^{22}W/cm^2
Electron: 500 MeV

Stochastic Photon emission

Emitting intensity

$$W_{ph} = \frac{\alpha m_e^2 c^4}{3\sqrt{3}\pi\hbar\varepsilon}\int_0^\infty dx \frac{5x^2+7x+5}{(1+x)^3} K_{2/3}\left(\frac{2x}{3\chi}\right)$$

Emitting probability

$$I_{ph} = \frac{e^2 m_e c^4}{3\sqrt{3}4\pi^2\hbar^2}\int_0^\infty dx \frac{x(4x^2+5x+4)}{(1+x)^4} K_{2/3}\left(\frac{2x}{3\chi}\right)$$

J. Sov. Laser Res. 6(5), 497 (1985)

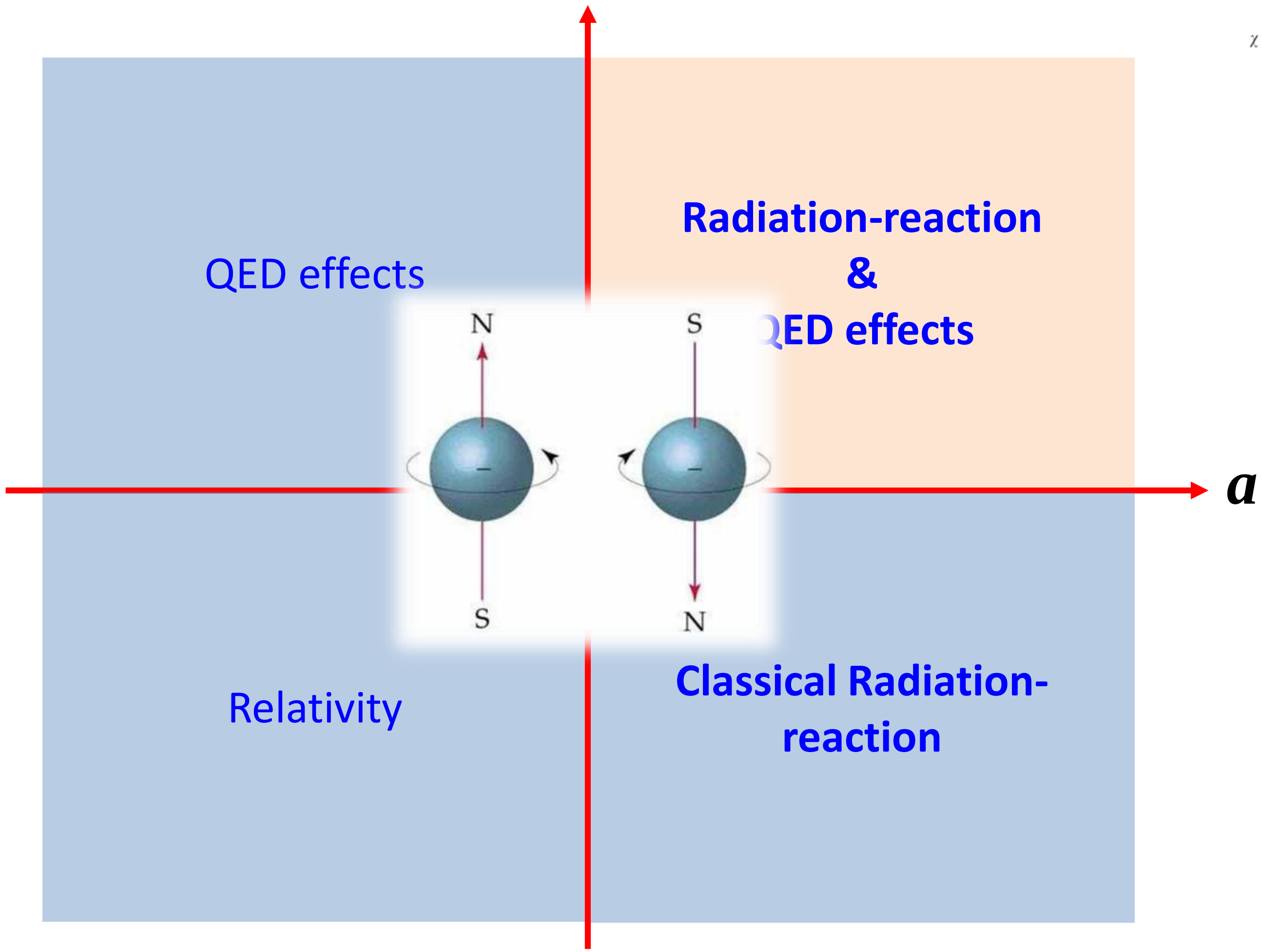
Communications Physics 2, 66 (2019)

Spin effects arise in the new regime

***a*:** dimensionless laser amplitude

***χ*:** QED parameter

$$\chi = \frac{e\hbar}{m_e^3 c^4}\sqrt{\left(\frac{\varepsilon \mathbf{E}}{c} + \mathbf{p} \times \mathbf{H}\right)^2 - (\mathbf{p}\cdot\mathbf{E})^2}$$

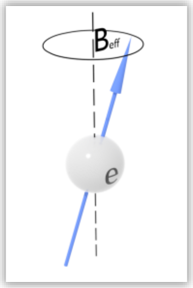


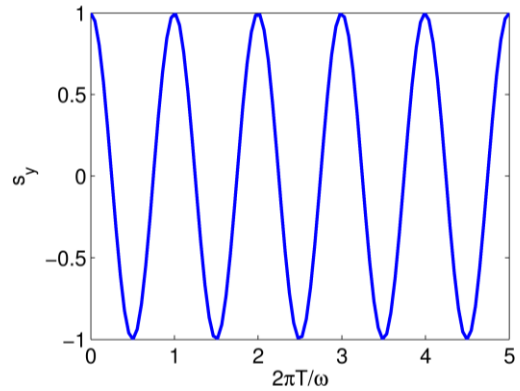
Spin dynamics: precession and deflection

Thomas-BMT equation

$$\frac{d\mathbf{s}}{dt}=\frac{e}{m}\left[\left(a_e+\frac{1}{\gamma}\right)\mathbf{B}-\frac{a_e\gamma}{\gamma+1}(\boldsymbol{\beta}\cdot\mathbf{B})\boldsymbol{\beta}-\left(a_e+\frac{1}{\gamma+1}\right)\boldsymbol{\beta}\times\frac{\mathbf{E}}{c}\right]\times\mathbf{s}$$

V. Bargmann, L. Michel, A. V. L. Telegdi. *Phys. Rev. Lett.* **2**, 435 (1959)



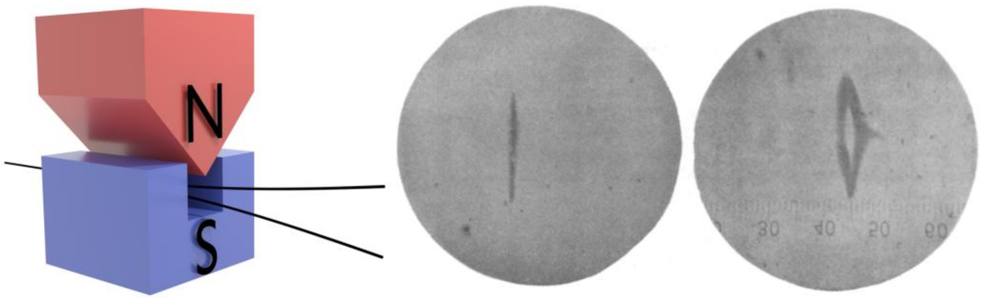


Non-radiative

The Stern-Gerlach force

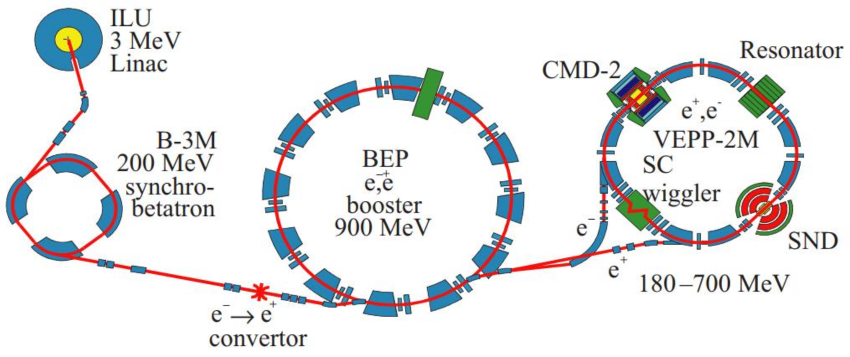
$$F_{SG}=\nabla(\mu\cdot B)$$

[1]Gerlach, Walther, and Otto Stern. 1922. *Zeitschrift für Physik* 9 (1): 349–52. https://doi.org/10.1007/BF01326983

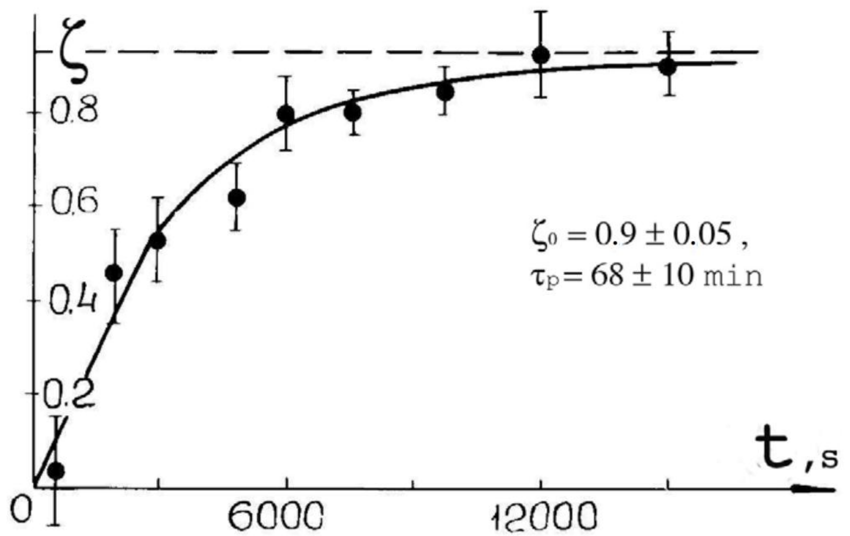


The Stern-Gerlach experiment[1]

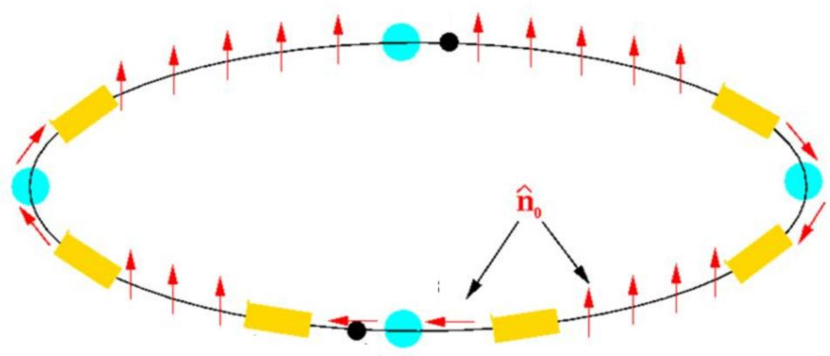
Spin dynamics: The Sokolv-Ternov effect (radiative)



Schematic layout of VEPP-2M complex.



Radiative polarization



$$W_\sigma^{\uparrow\uparrow} = W^{\mathrm{cl}}\left\{\frac{7}{8} - \xi\left(\frac{25\sqrt{3}}{12} - \zeta\right) + \xi^2\left(\frac{335}{18} + \frac{245\sqrt{3}}{48}\zeta\right) + \cdots\right\},$$

$$W_\sigma^{\uparrow\downarrow} = W^{\mathrm{cl}}\frac{\xi^2}{18},$$

$$W_\pi^{\uparrow\uparrow} = W^{\mathrm{cl}}\left\{\frac{1}{8} - \xi\frac{5\sqrt{3}}{24} + \xi^2\frac{25}{18} + \cdots\right\},$$

$$W_\pi^{\uparrow\downarrow} = W^{\mathrm{cl}}\xi^2\frac{23}{18}\left\{1 + \zeta\frac{105\sqrt{3}}{184}\right\}.$$

$$P_{\mathrm{eq}} = \frac{N_+ - N_-}{N_+ + N_-} = \frac{p_+ - p_-}{p_+ + p_-}$$

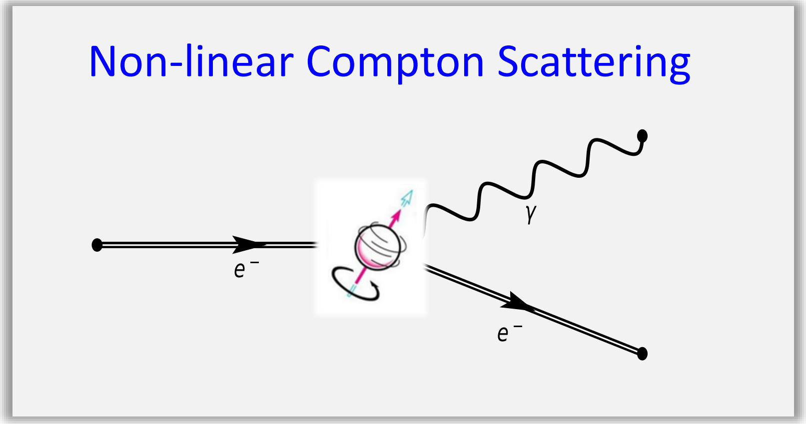
$$P(t) = P_{\mathrm{ST}}\left(1 - \mathrm{e}^{-t/\tau_{\mathrm{pol}}}\right)$$

$$\tau_{\mathrm{pol}}(\mathrm{s}) \simeq 3654\frac{(R/\rho)}{[B(\mathrm{T})]^3[E(\mathrm{GeV})]^2}$$

$$P_{\mathrm{ST}} = \frac{8}{5\sqrt{3}} \simeq 92.376\%$$

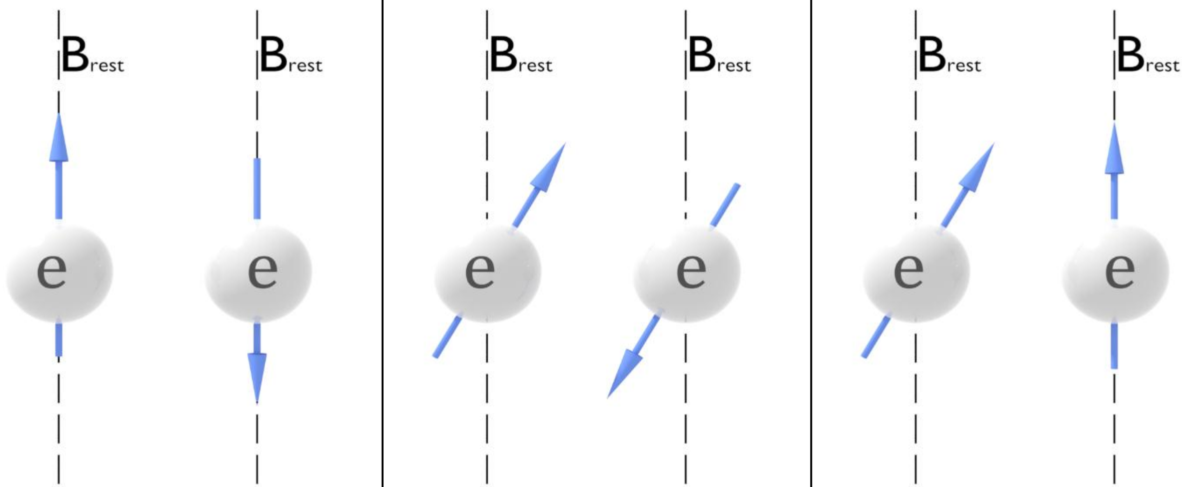
S R Mane *et al* 2005 *Rep. Prog. Phys.* **68** 1997

Spin dynamics in strong laser field



The radiation probability is dependent on the spin states [2]

$$\frac{\mathrm{d}P}{\mathrm{d}\delta\mathrm{d}\tau} = -\frac{\alpha}{2b}\left[2\mathrm{Ai}_1(z) + g\frac{4\mathrm{Ai}'(z)}{z} + s_\zeta 2t\frac{\mathrm{Ai}(z)}{\sqrt{z}}\right]$$



Sokolov-Ternov [1] | **S−*projection* [2]** | **B-projection [3]**

Spin parallel or anti-parallel to the B-field

No S-T effect

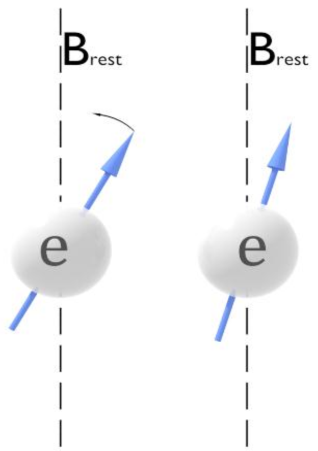
Loss of information

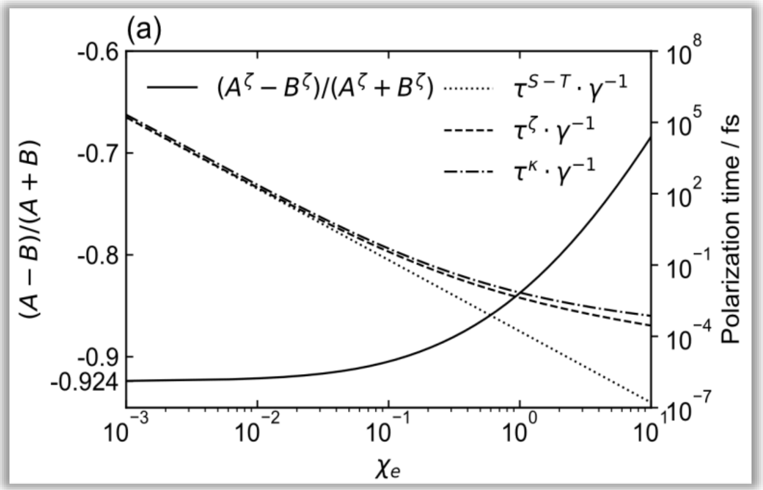
[1] Ternov, I. M. 1995. *Physics-Uspekhi* 38 (4): 409.

[2] Seipt, D., D. Del Sorbo, C. P. Ridgers, and A. G. R. Thomas.. *Physical Review A* 98, 023417 (2018).

[3] Li, Yan-Fei, Rashid Shaisultanov, Karen Z. Hatsagortsyan, Feng Wan, Christoph H. Keitel, and Jian-Xing Li, *Physical Review Letters* 122, 154801(2019).

Generalized Sokolov-Ternov theory





Geng, X. S., Z. G. Bu, Y. T. Wu, Q. Q. Han, C. Y. Qin, W. Q. Wang, X. Yan, L. G. Zhang, B. F. Shen, and L. L. Ji. 2020. *ArXiv:1912.03625 [Physics]*, March. http://arxiv.org/abs/1912.03625.

Generalized S-T

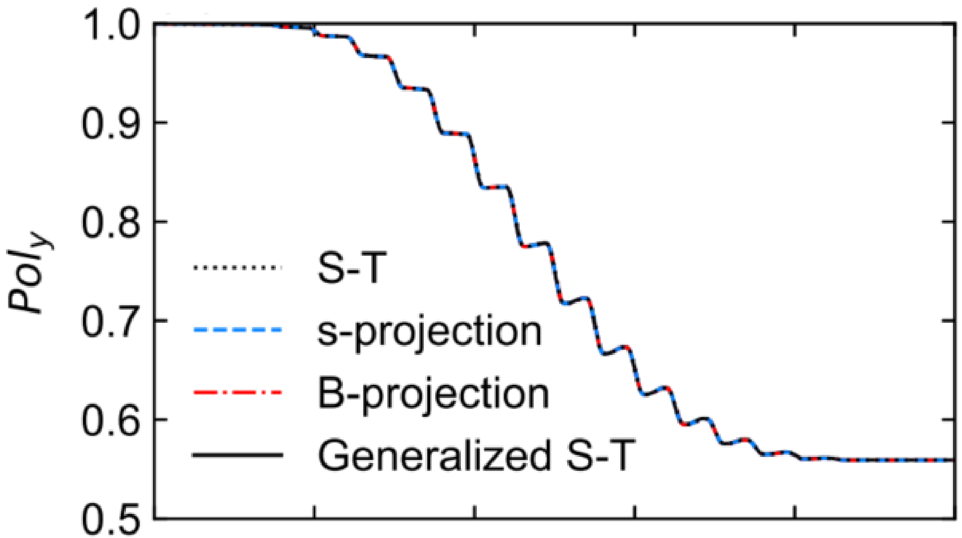
- *Define the transition probability along a complete and orthogonal axis*

$$A = P^{\downarrow\uparrow}, B = P^{\uparrow\downarrow}$$

- *Build up Polarization along ζ, η, κ from spin flip rates*

$$P(t) = \frac{A-B}{A+B}\left[1 - \exp\left(-\frac{t}{\tau}\right)\right] + P_0 \exp\left(-\frac{t}{\tau}\right)$$

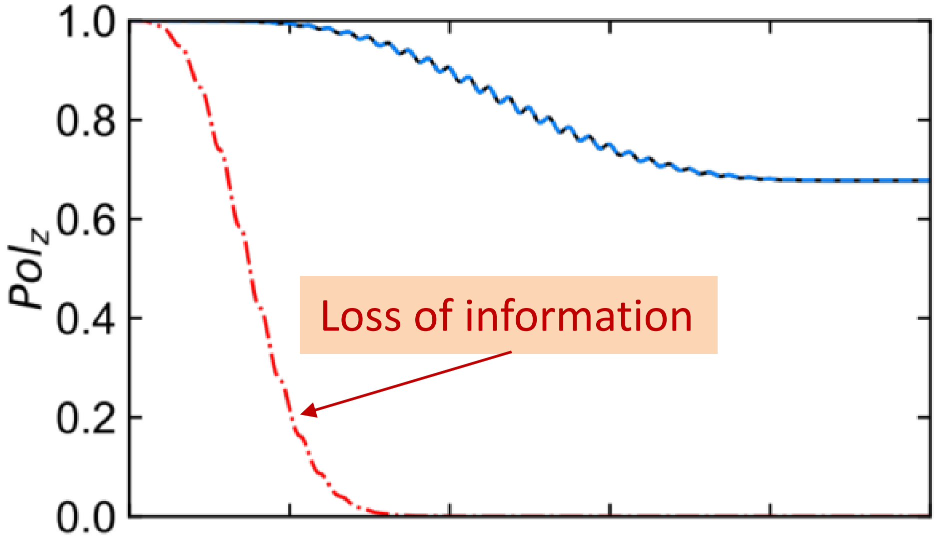
Generalized Sokolov-Ternov theory



Transverse polarization

Reproduced the S-T effect

(spin is parallel/antiparallel to the B-field)

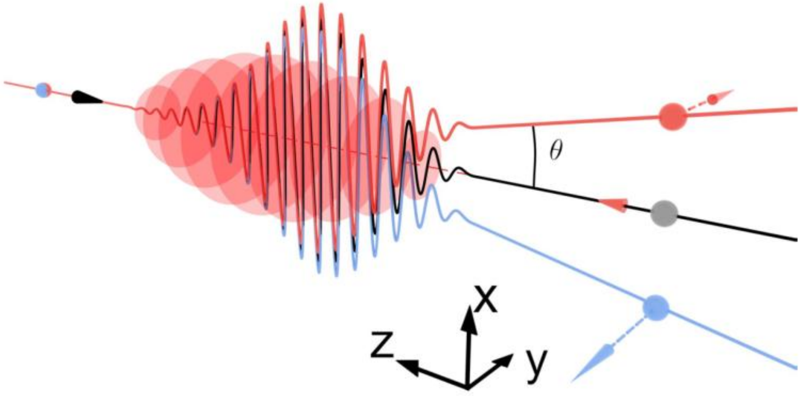


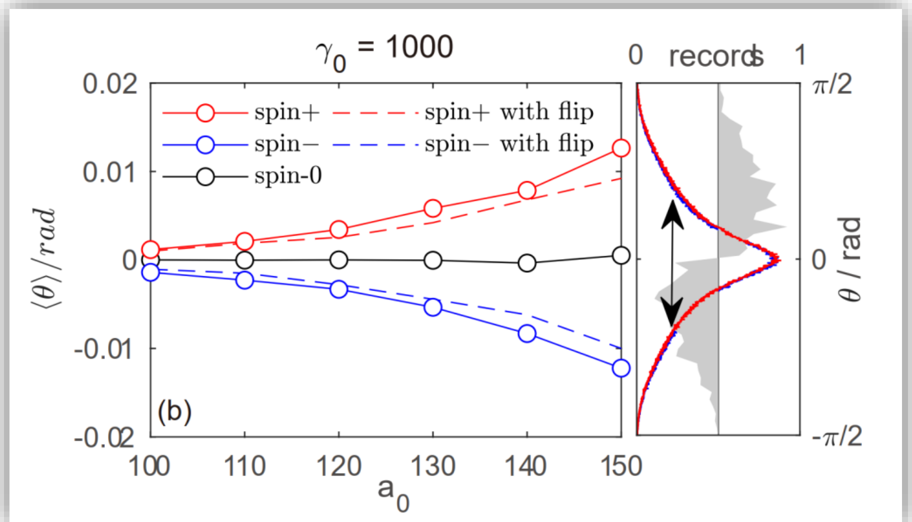
Longitudinal polarization

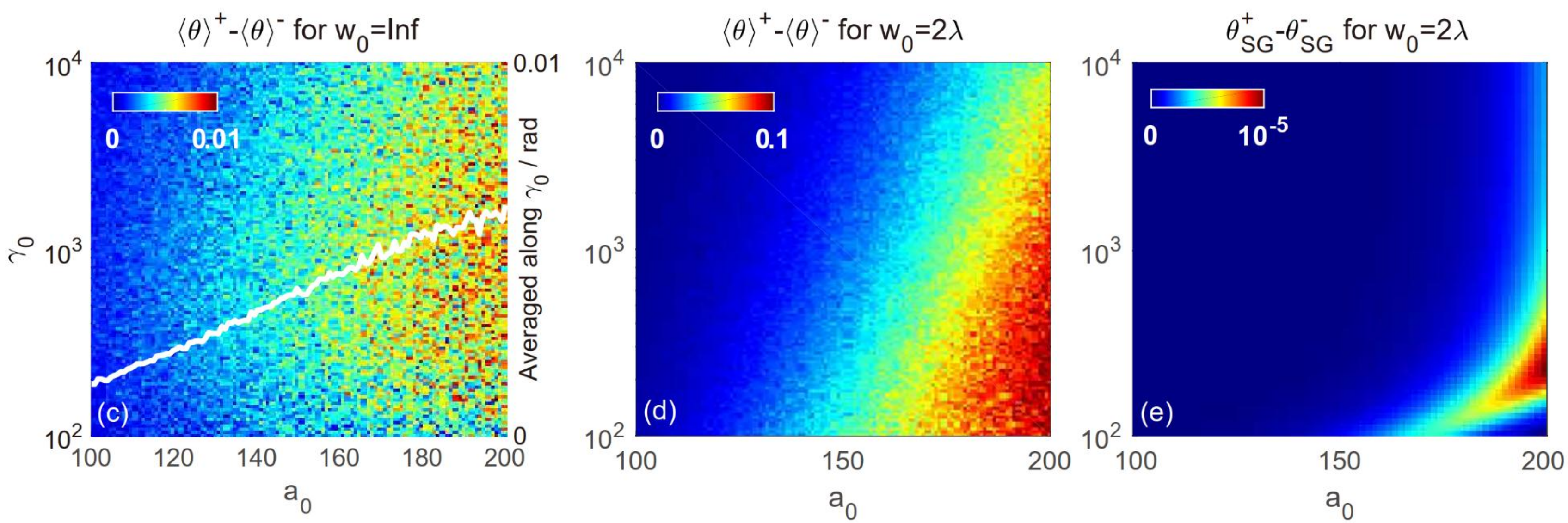
Avoid information loss

(spin is perpendicular to the B-field)

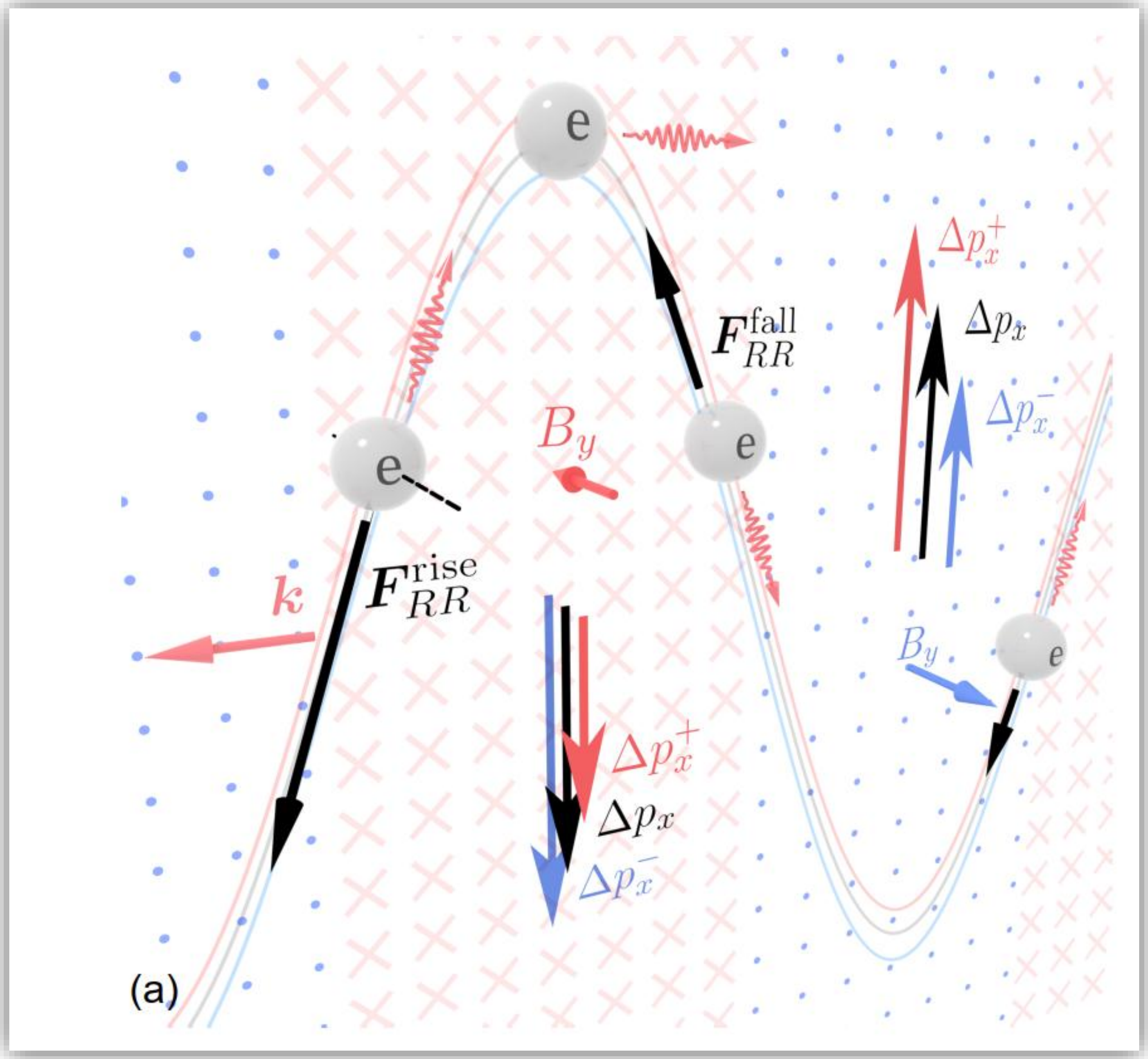
Spin-dependent deflection in the SFQED regime







Spin effects manifestation in radiation-reaction



$$\left|\int_{\text{rise}} \mathrm{d}\psi \mathbf{F}_{\text{RR}} \cdot \hat{\mathbf{x}}\right| > \left|\int_{\text{fall}} \mathrm{d}\psi \mathbf{F}_{\text{RR}} \cdot \hat{\mathbf{x}}\right|$$

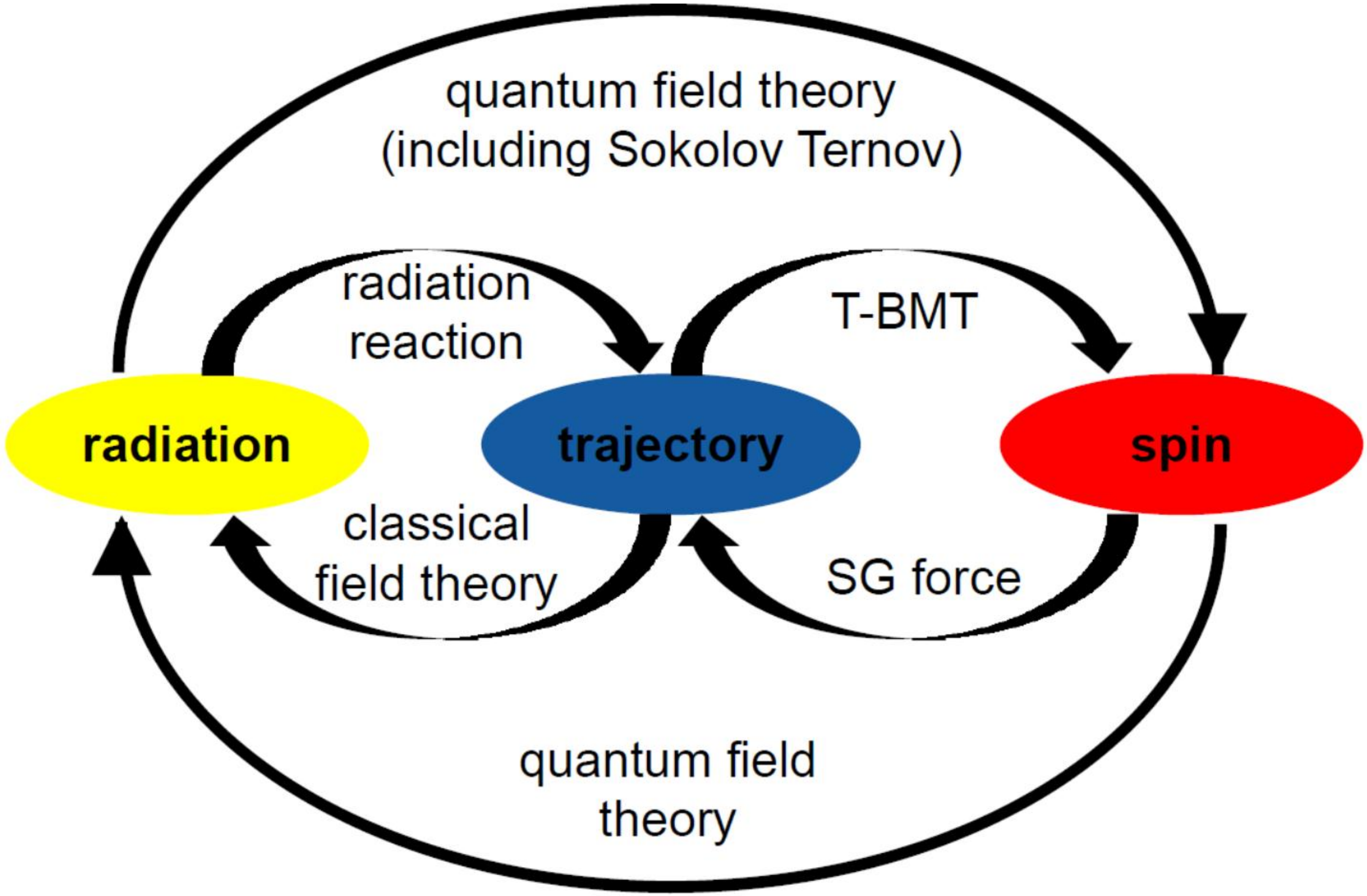
- **The radiation-reaction effect:**

  electron loses energy due to photon emission

- **The spin effect:**

  Spin anti-parallel radiates more energies than parallel.

Symmetry is broken when both effects are coupled to each other.
A net momentum shift is induced along the s×k direction



High Power Laser Science and Engineering 8 (2020)

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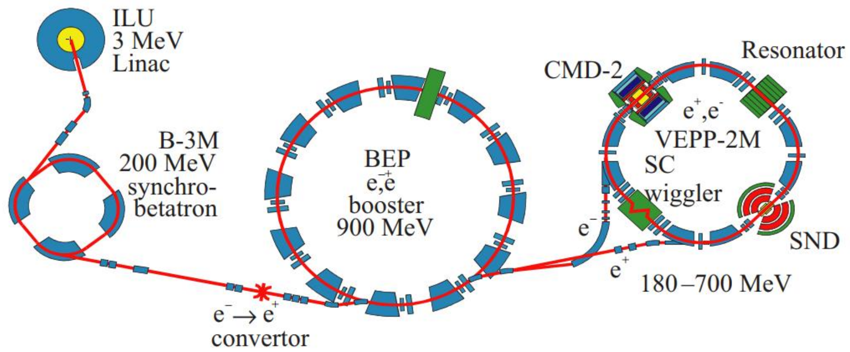
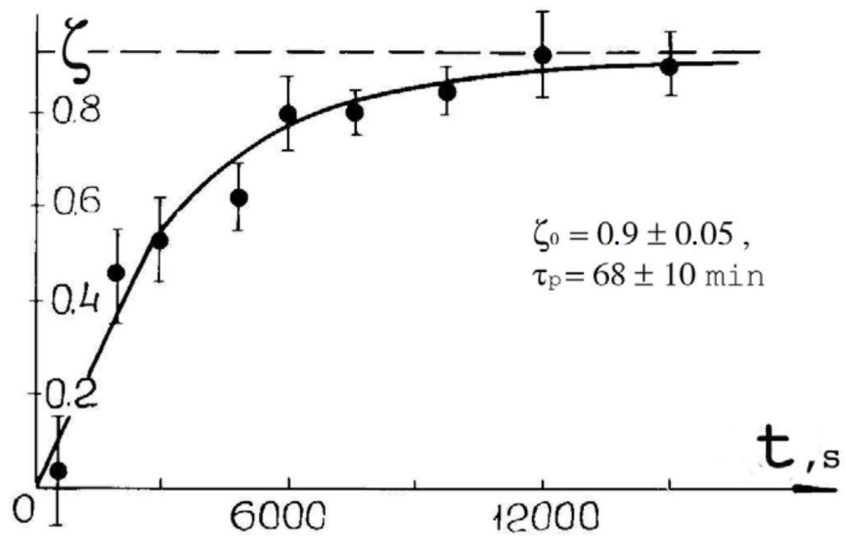
Storage rings: The Sokolv-Ternov effect

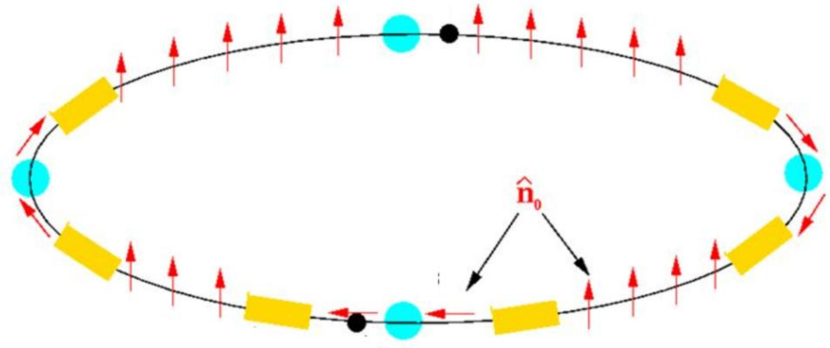


Schematic layout of VEPP-2M complex.



$$\tau_{\rm pol}(\mathrm{s}) \simeq 3654 \frac{(R/\rho)}{[B(\mathrm{T})]^3 [E(\mathrm{GeV})]^2} \qquad P_{\rm ST} = \frac{8}{5\sqrt{3}} \simeq 92.376\%$$

Radiative polarization



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$$P(t) = P_{\rm ST}\left(1 - \mathrm{e}^{-t/\tau_{\rm pol}}\right)$$

S R Mane *et al* 2005 *Rep. Prog. Phys.* **68** 1997

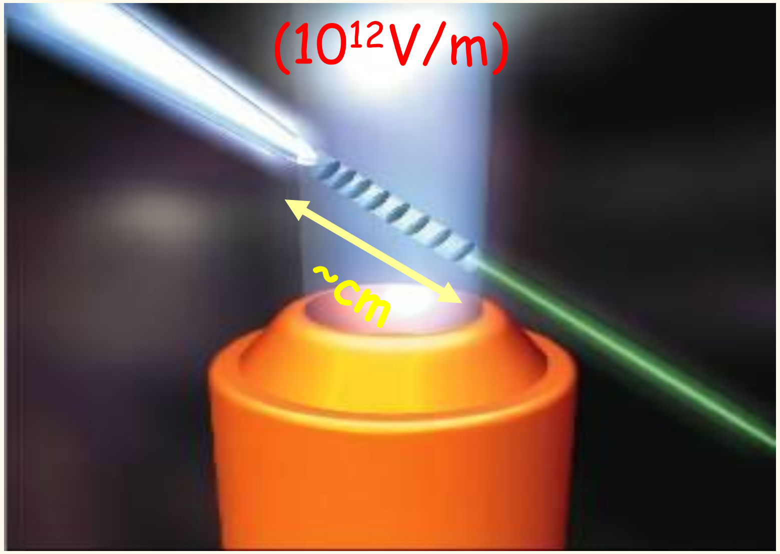
Laser acceleration: High acceleration gradient

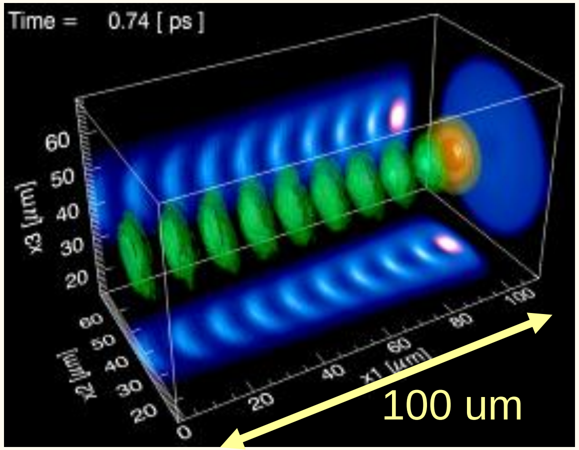
Conventional Accelerator (1km)

LHC,Higgs Boson, Nobel Prize(2013)

Radiofrequency cavity (1 m-long)

Laser Acceleration (1cm)





W. Mori & L.O. Silva

$$E_z = \frac{m_e c \omega_p}{e} \approx 300GV/m$$

(for $n_e=10^{19}$ cm^{-3})

Is it possible to generate polarized electron in laser-driven wakefield acceleration?

Polarized electron acceleration： the S-T effect

- **Accelerate** and then **polarize** in Storage rings due to Sokolov-Ternov Effect

  Sov.Phys. J. 10, 39–47 (1967)

- Extract from polarized atoms/photocathodes and accelerate in Linacs

  J. Phys. Conf. Ser. 295, 012151(2011). Appl. Phys.Lett. 26, 670(1975)

- Spin filters & Beam splitters

  Phys. Rev. Lett. 82, 4216 (1999). Phys. Rev. Lett. 118, 070403(2017).

$$T^{-1}_{\mathrm{pol,electron}} = \frac{5\sqrt{3}}{8}\hbar\frac{e^5F^3\gamma_e^2}{m_e^5c^8}$$

For typical LWFA

γ_e~10^3 and F~10^{16}V/m.

One finds $T_{\mathrm{pol,S\text{-}T}}$~1μs

>> acceleration duration (~ns scale)

Phys. Rev. ST-AB 23, 064401(2020)

Polarized electron acceleration: spin splitter

- Accelerate and then polarize in Storage rings due to Sokolov-Ternov Effect

  Sov.Phys. J. 10, 39–47 (1967)

- Extract from polarized atoms/photocathodes and accelerate in Linacs

  J. Phys. Conf. Ser. 295, 012151(2011). Appl. Phys.Lett. 26, 670(1975)

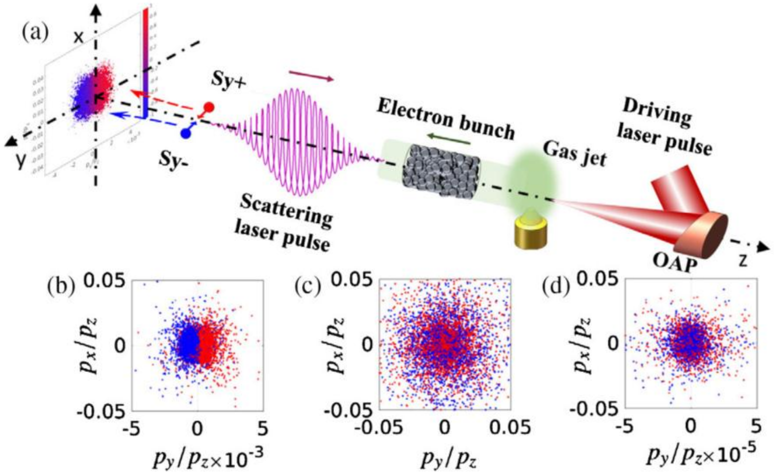
- **Spin filters & Beam splitters**

  Phys. Rev. Lett. 82, 4216 (1999). Phys. Rev. Lett. 118, 070403(2017).

$$|F_{SG}/F_L| \sim |\nabla(\boldsymbol{S}\cdot\boldsymbol{B})/\gamma_e^2 c\boldsymbol{B}m_e| \sim \hbar/\lambda m_e c\gamma_e^2 << 1$$

The Stern-Gerlach Force is negligible compared to laser-plasma fields

PRST-AB, in preparation



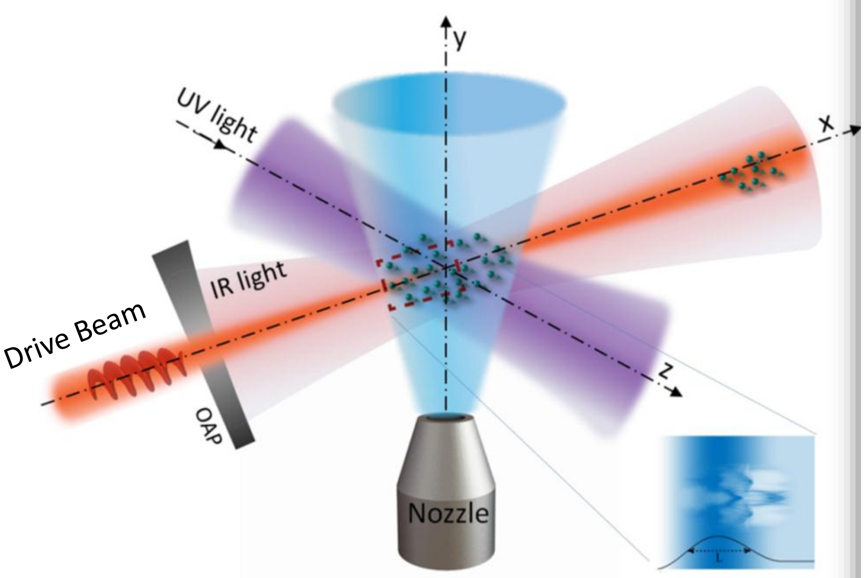
Colliding a 10 PW laser with multi-GeV electrons to split electrons of different spin states (spin-flip rates depending on the states)

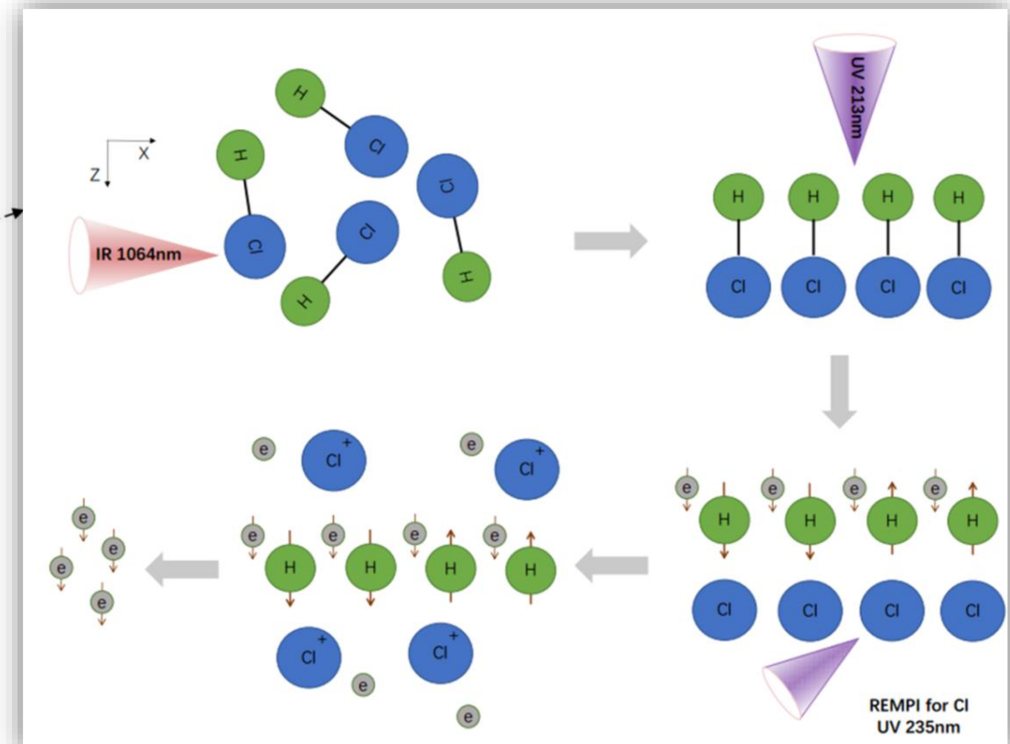
PHYSICAL REVIEW LETTERS 122, 154801 (2019)

Pre-polarization + LWFA

- How to prepare a 100% polarized electron target?
- Is it possible to preserve the beam polarization during LWFA?

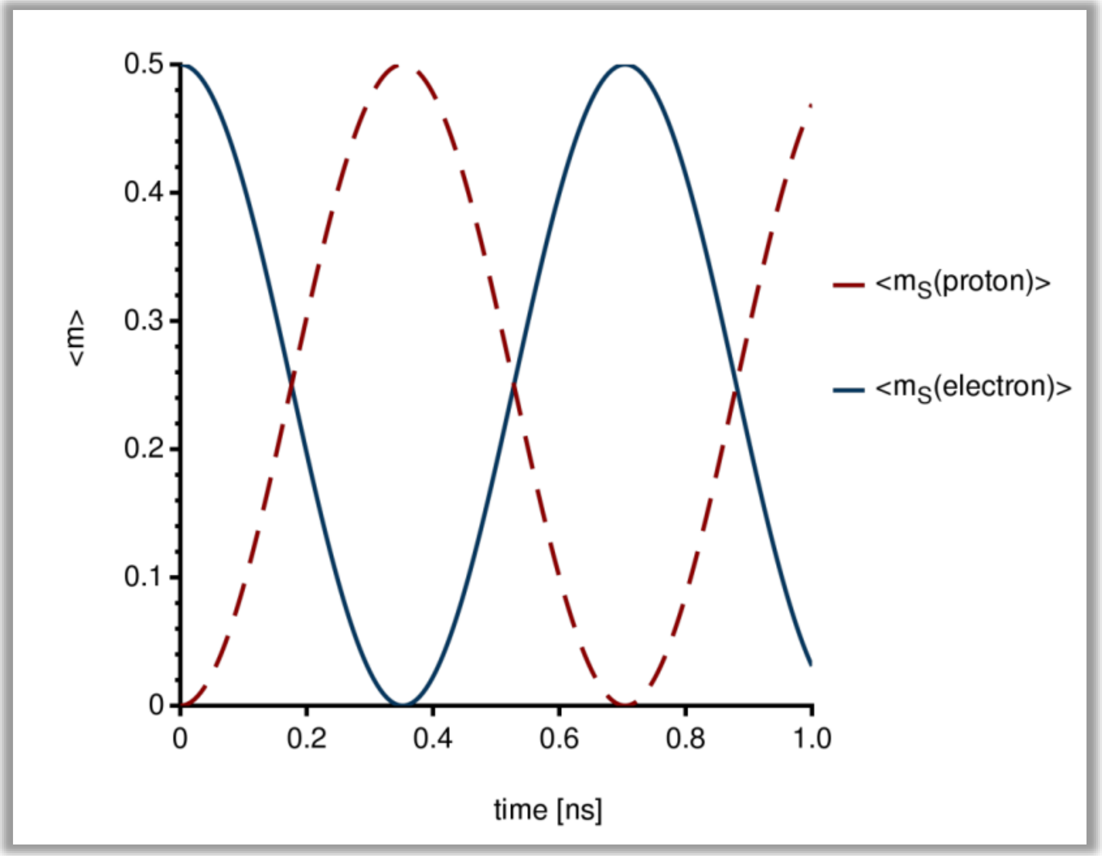
100% pre-polarized electron target is feasible





Science 300, 1936 (2003); Eur. J. Chem. Phys. Phys. Chem. 5 1489 (2004); Phys. Rev. Lett. 121 083001 (2018)

Pre-polarization + LWFA



Particle spin in PIC simulations

$$\frac{d\boldsymbol{s}^n}{dt} = \frac{d{\boldsymbol{s}_\perp}^n}{dt} = -\boldsymbol{\Omega}^n \times \boldsymbol{s}^n = -\boldsymbol{\Omega}^n \times {\boldsymbol{s}_\perp}^n$$

$${\boldsymbol{s}_{//}}^n = \frac{\boldsymbol{\Omega}^n \cdot \boldsymbol{s}^n}{|\boldsymbol{\Omega}^n|}\frac{\boldsymbol{\Omega}^n}{|\boldsymbol{\Omega}^n|}, {\boldsymbol{s}_\perp}^n = \boldsymbol{s}^n - {\boldsymbol{s}_{//}}^n$$

$$\boldsymbol{r}^n = \frac{-\boldsymbol{\Omega}^n \times {\boldsymbol{s}_\perp}^n}{|\boldsymbol{\Omega}^n|}$$

⬇

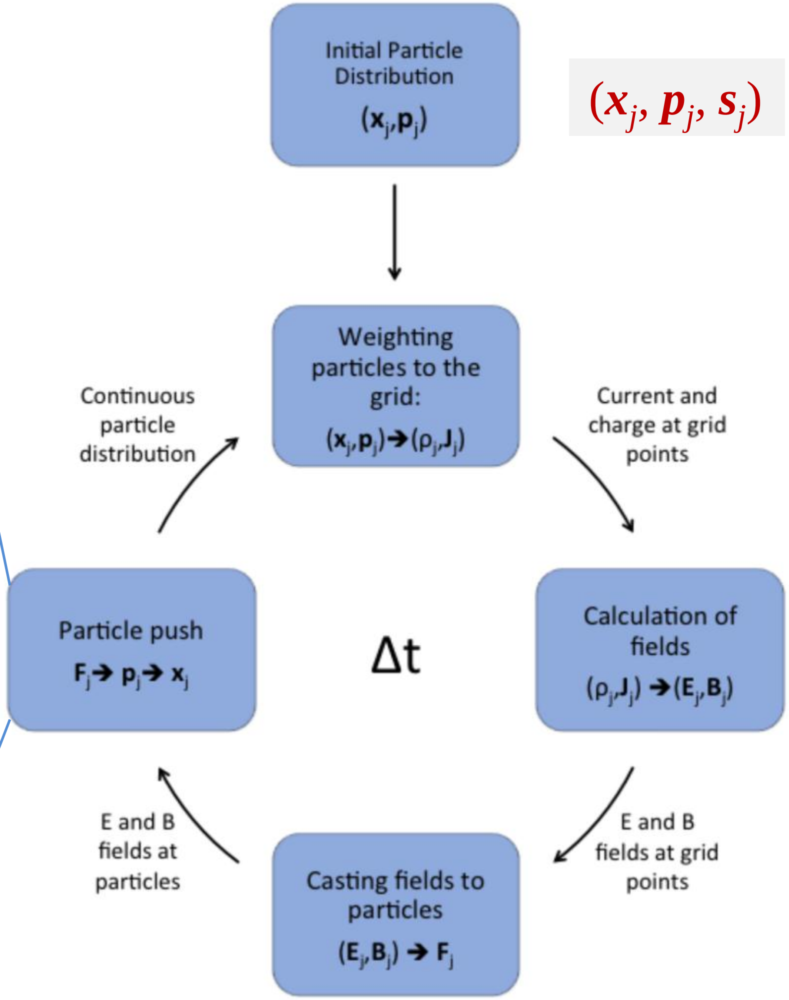
$$\theta^n = |\boldsymbol{\Omega}^n| \Delta t$$

$${\boldsymbol{s}_\perp}^{n+1} = {\boldsymbol{s}_\perp}^n \cos(\theta^n) + \boldsymbol{r}^n \sin(\theta^n)$$

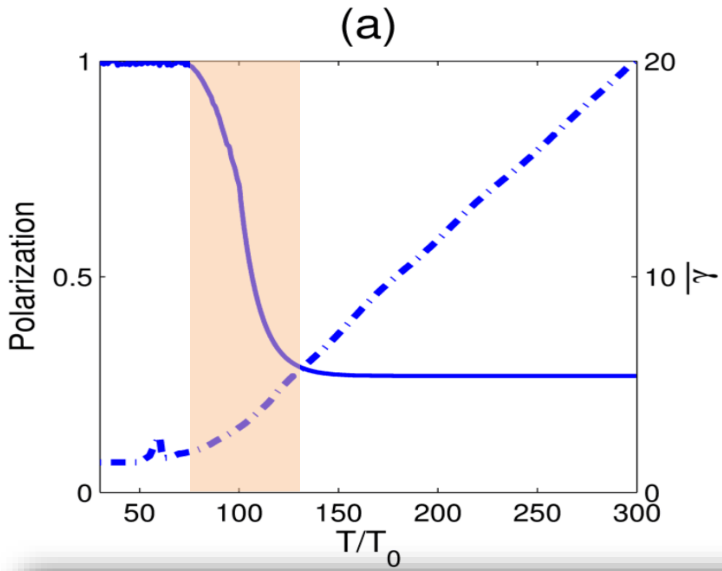
$$\boldsymbol{s}^{n+1} = {\boldsymbol{s}_\perp}^{n+1} + {\boldsymbol{s}_{//}}^n$$

Particle-In-Cell

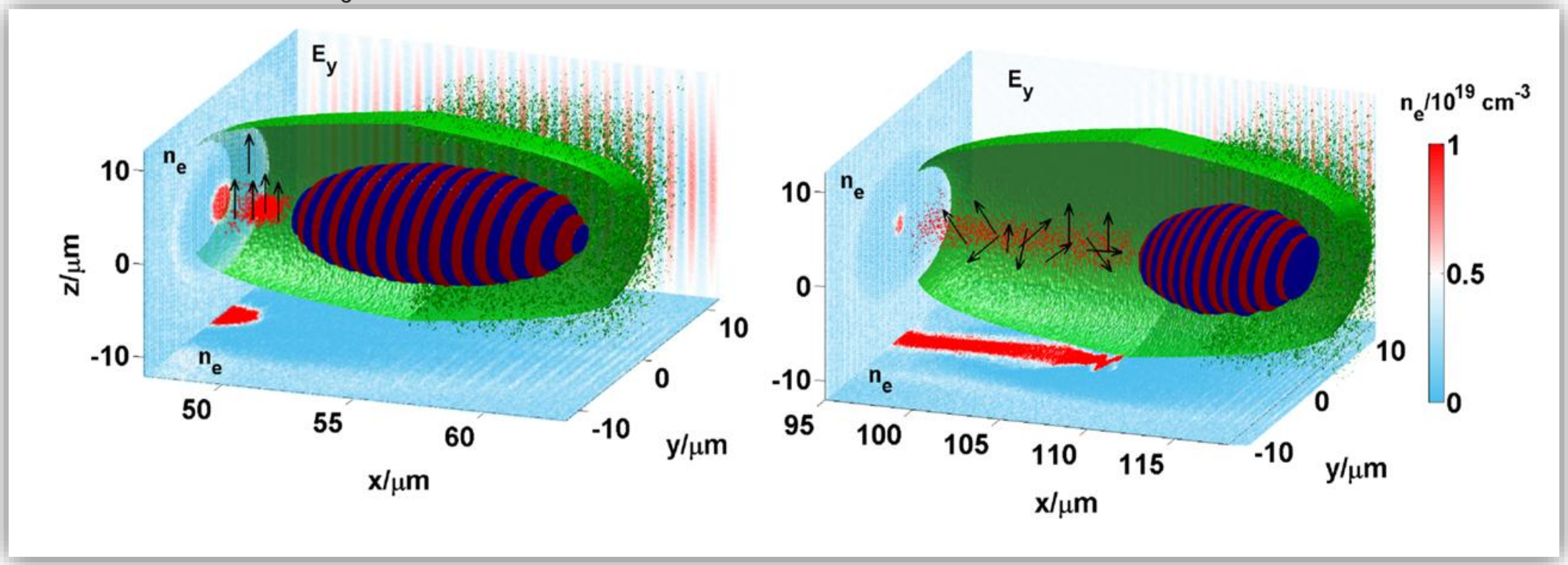
(x_j, p_j, s_j)



Polarization in LWFA



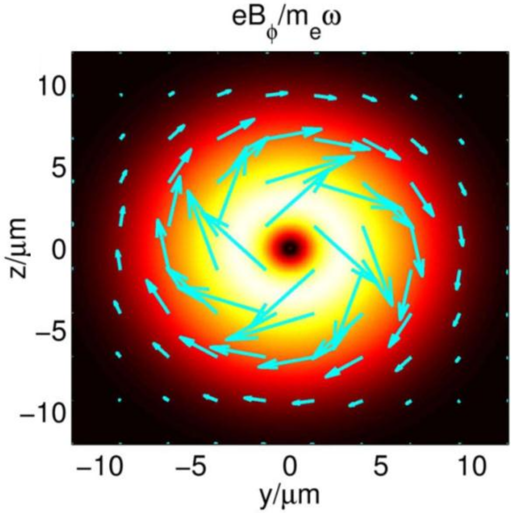
- **Stage I: Laser-electron interaction**
- **Stage II: Injection (depolarization)**
- **Stage III: Acceleration**



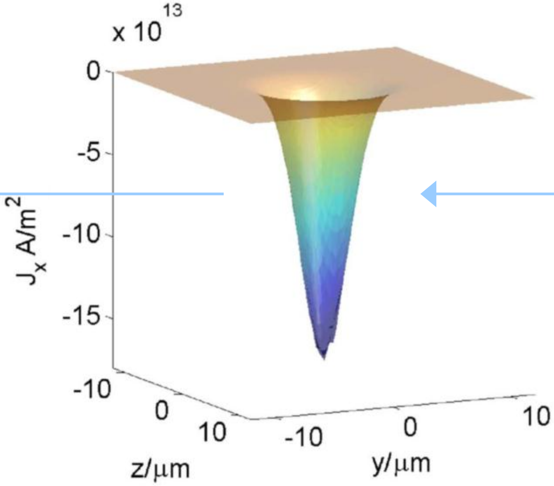
8.6×10^{18} W/cm^2 , 21.4 fs, 10um, n_0=10^{18}cm^{-3}

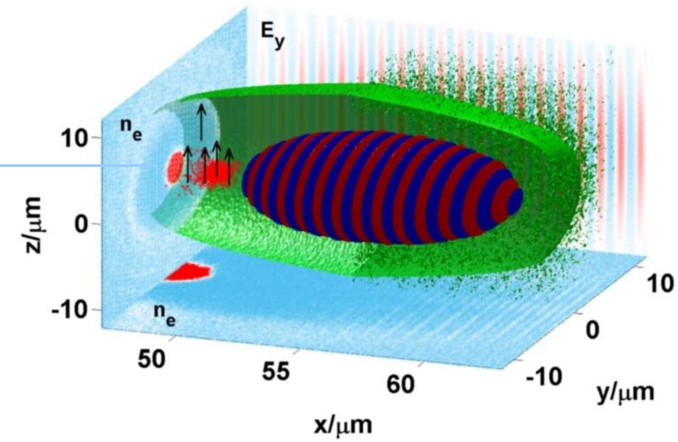
Depolarization : self-generated fields

Azimuthal B-field



Current density





Spin precession frequency

$$a_e = (g-2)/2 \approx 1.16 \times 10^{-3}$$

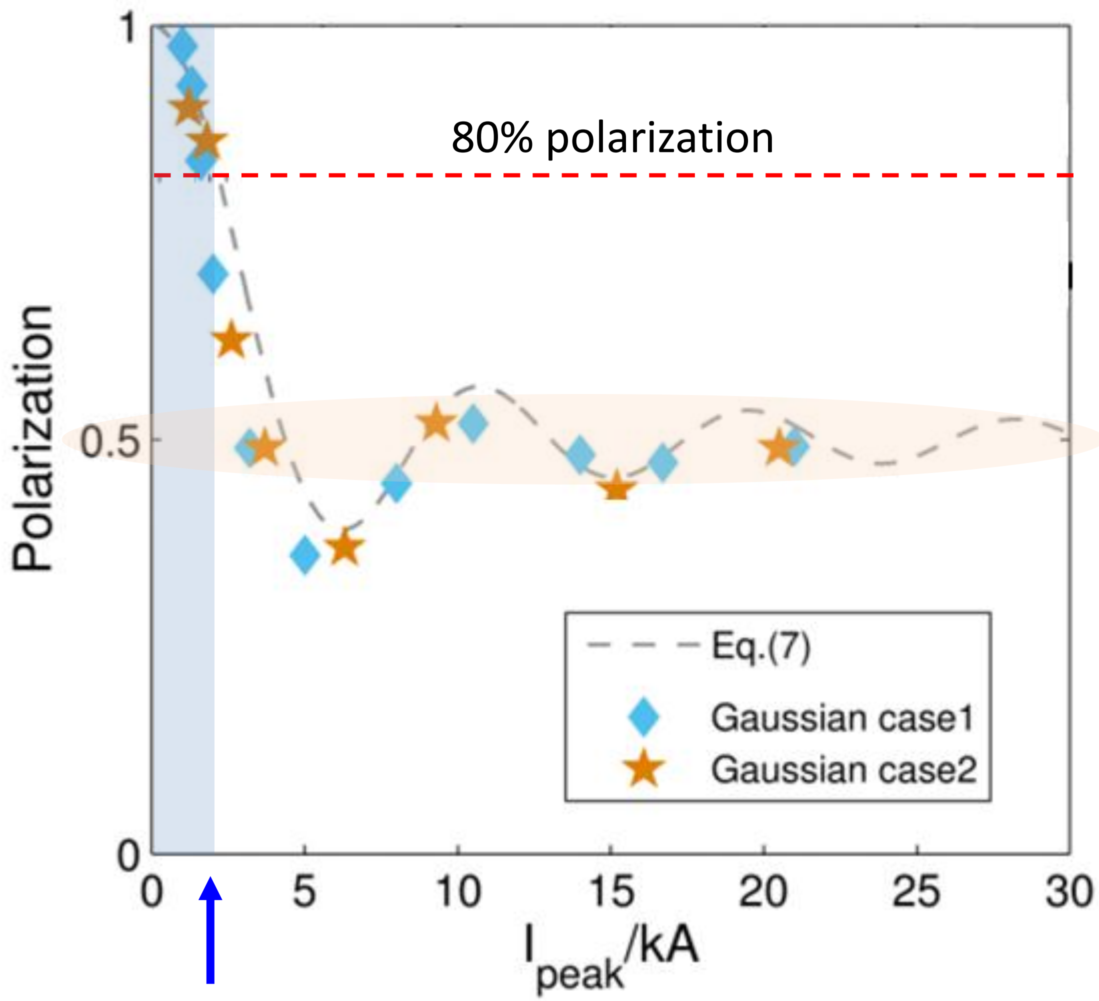
$$\boldsymbol{\Omega} = \frac{e}{m}\left(\frac{\boldsymbol{B}}{\gamma} - \frac{1}{\gamma+1}\frac{\boldsymbol{v}}{c^2} \times \boldsymbol{E}\right) + a_e\frac{e}{m}\left(\boldsymbol{B} - \frac{\gamma}{\gamma+1}\frac{\boldsymbol{v}}{c^2}(\boldsymbol{v}\cdot\boldsymbol{B}) - \frac{\boldsymbol{v}}{c^2} \times \boldsymbol{E}\right)$$

$$B \sim B_\phi, E_r \sim -B_\phi$$

$$\boldsymbol{\Omega} \approx eB_\phi(2+\beta_x)/2m\boldsymbol{e}_\phi$$

Strong restriction on beam flux to preserve polarization

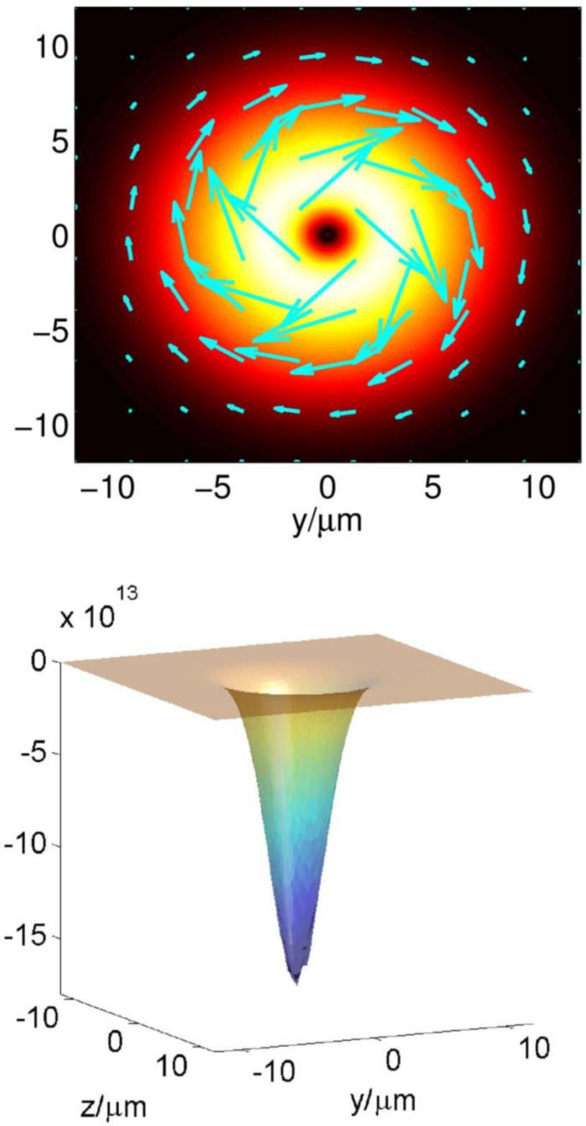
$$P \approx 0.5 + \frac{1}{2}\int_0^{\Delta r} cos[\pi e n_p c \alpha r^2]\, dr^2\,/\Delta r^2) \quad = \frac{1+\text{sinc}(\alpha I_{peak})}{2}$$

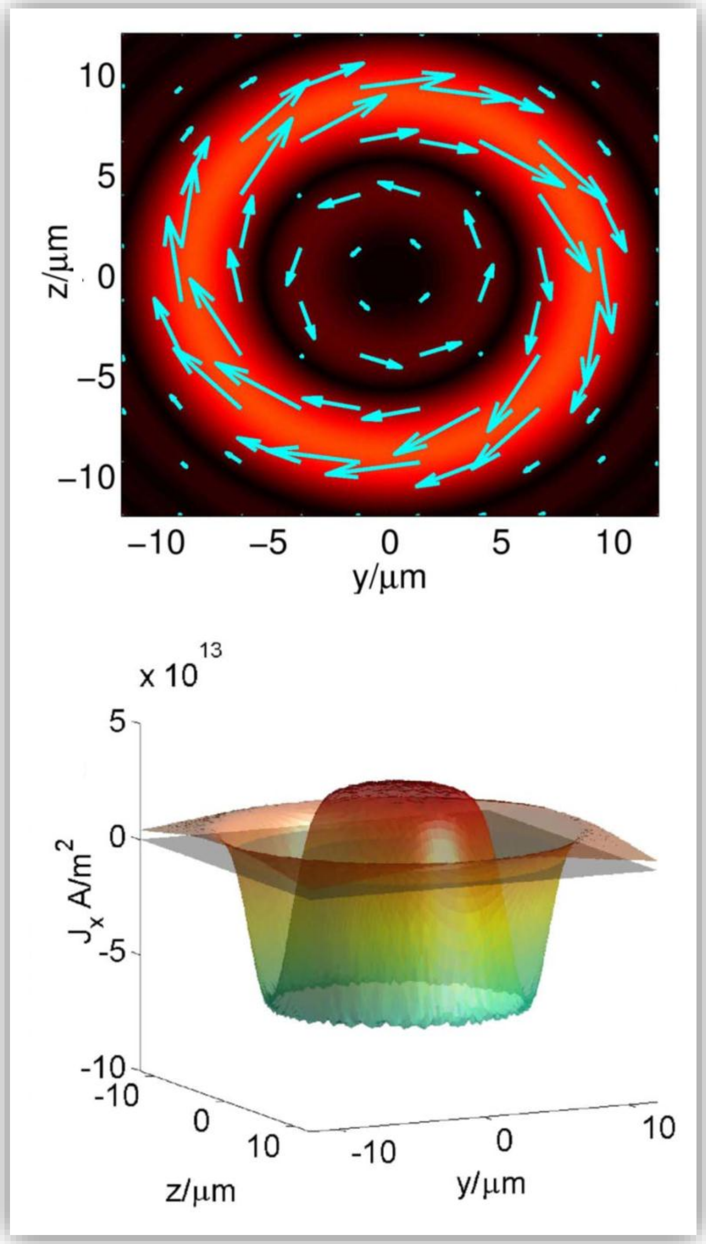


I_{peak} <2.2kA

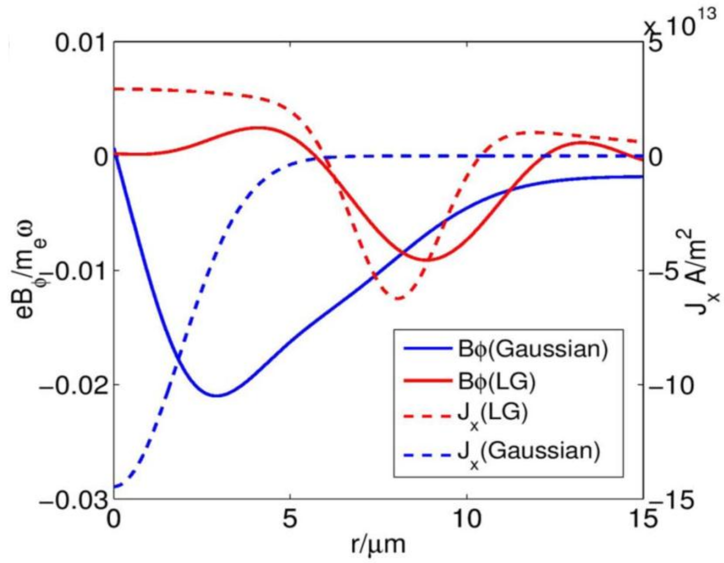
Preserving the beam polarization imposes strong restriction on the loaded beam charge / flux

Preserving polarization: new geometry?

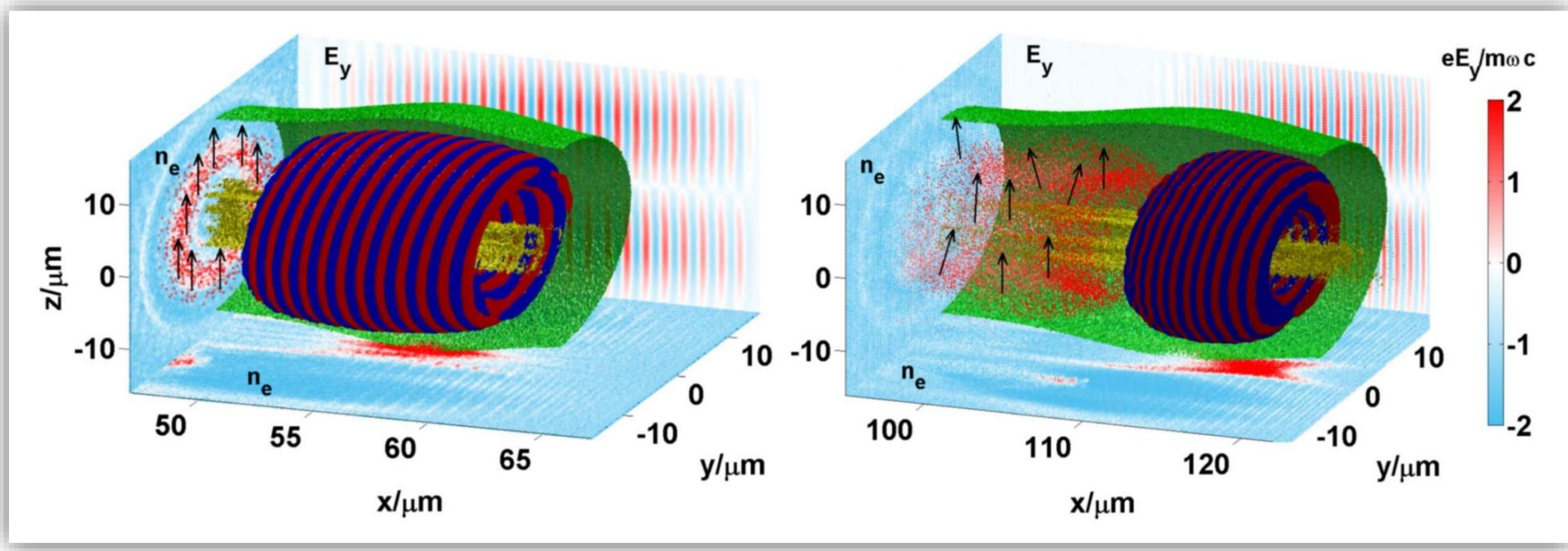




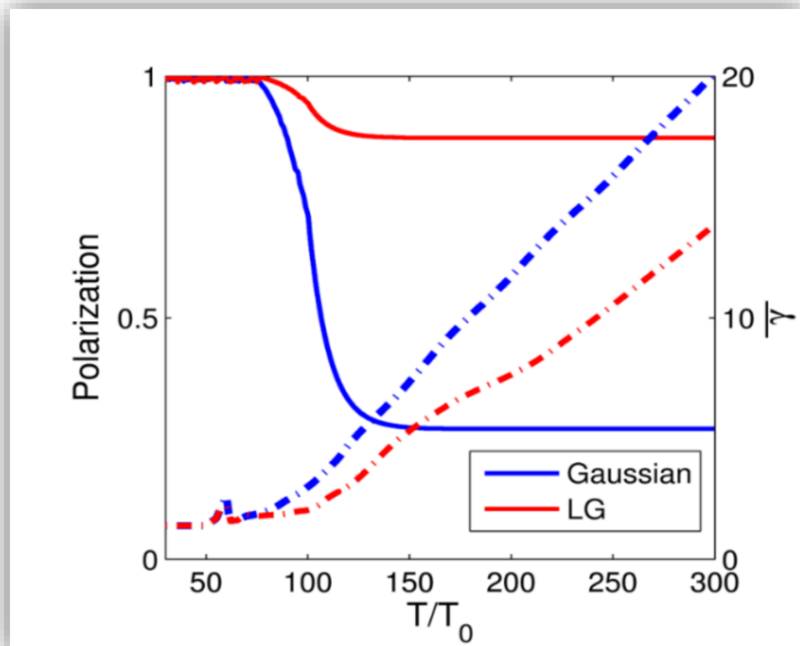
Vortex LWFA: high beam charge but low current density

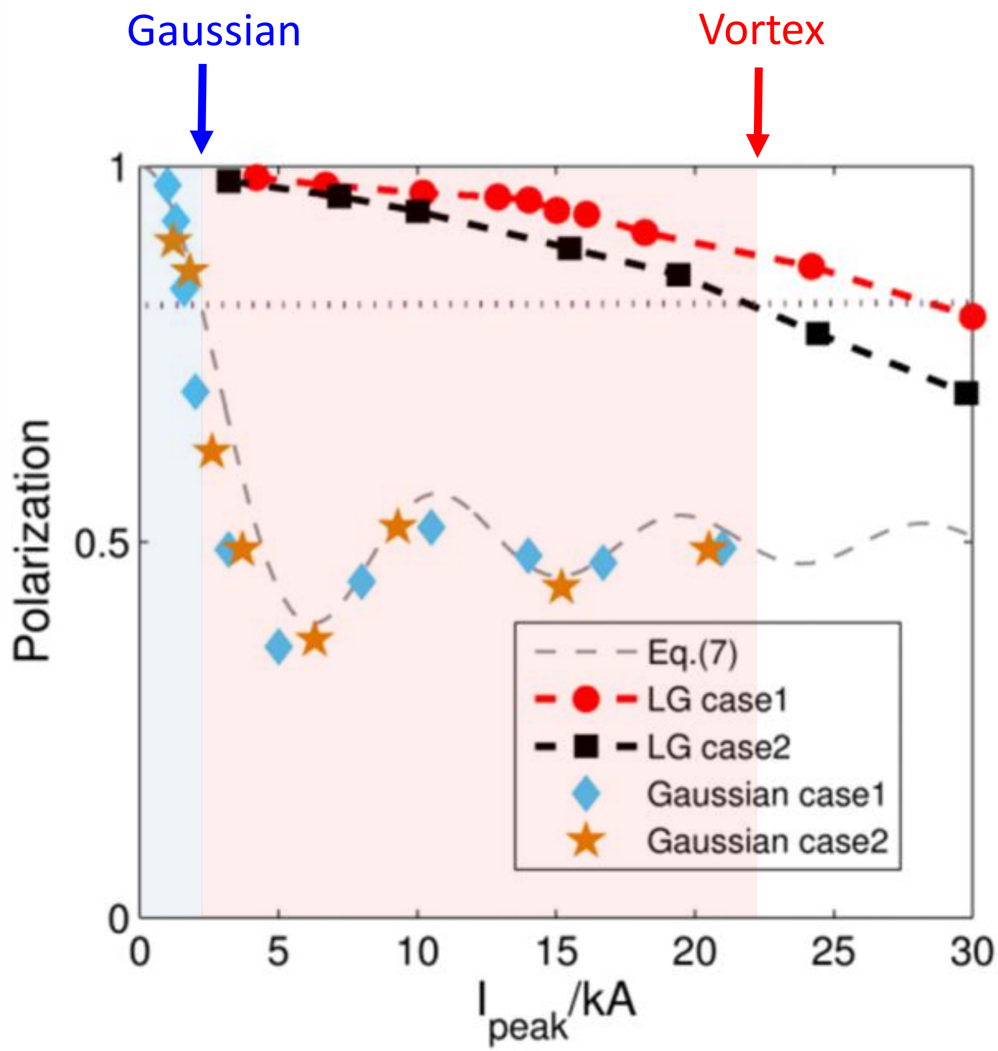


- **Peak current density and B-field are 1/3 of the Gaussian beam driver.**
- **The region of magnetic field is significantly reduced.**



Polarized electron acceleration: vortex LWFA



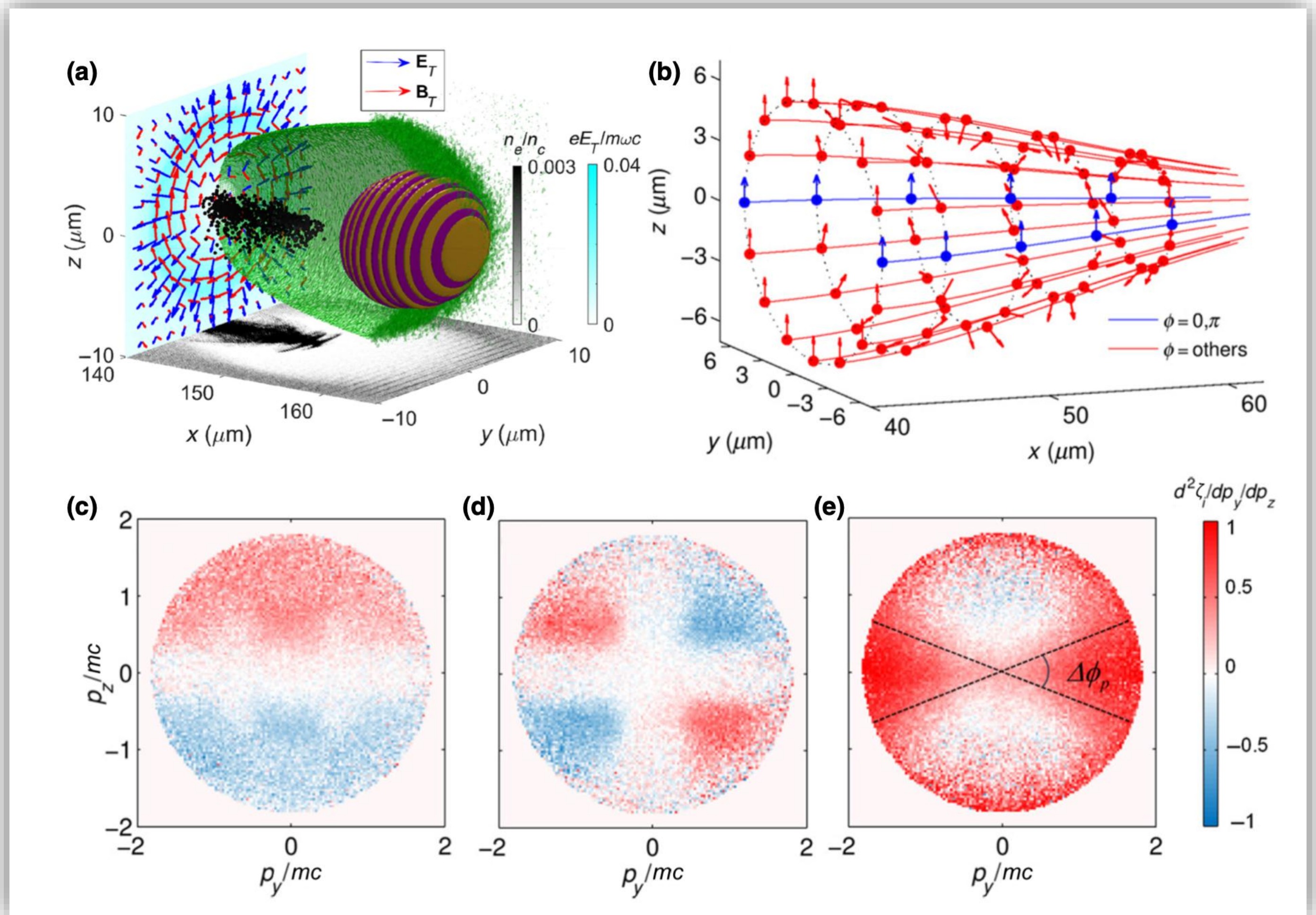


- Vortex LWFA preserves the beam polarization at very high beam charge/flux
- 10* enhancement at 80% polarization

New J. Phys. 21 073052(2019)

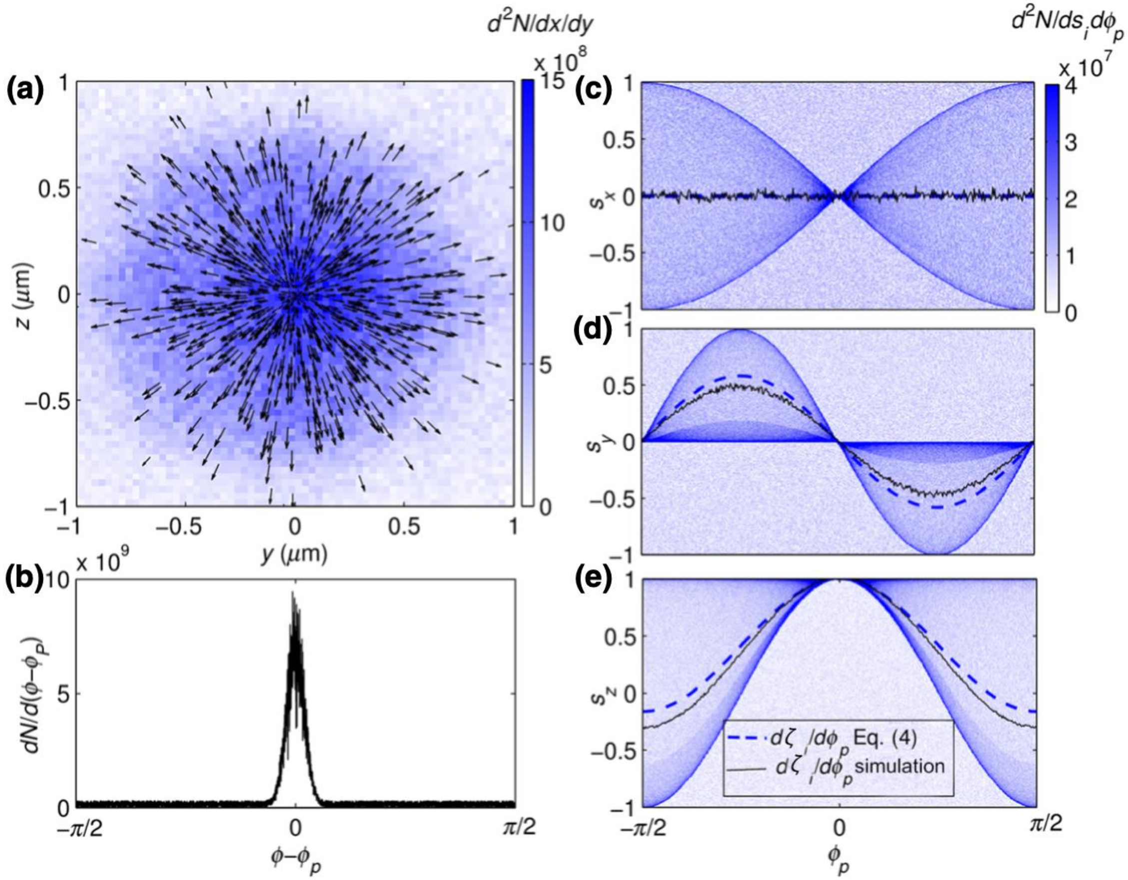
Physical Review E 100, 043202 (2019)

Polarized electron acceleration: spin filter



- Spin precession is dependent on the azimuthal angle
- Precession is significant suppressed when spin is parallel/anti-parallel to the magnetic field

Polarized electron acceleration: spin filter



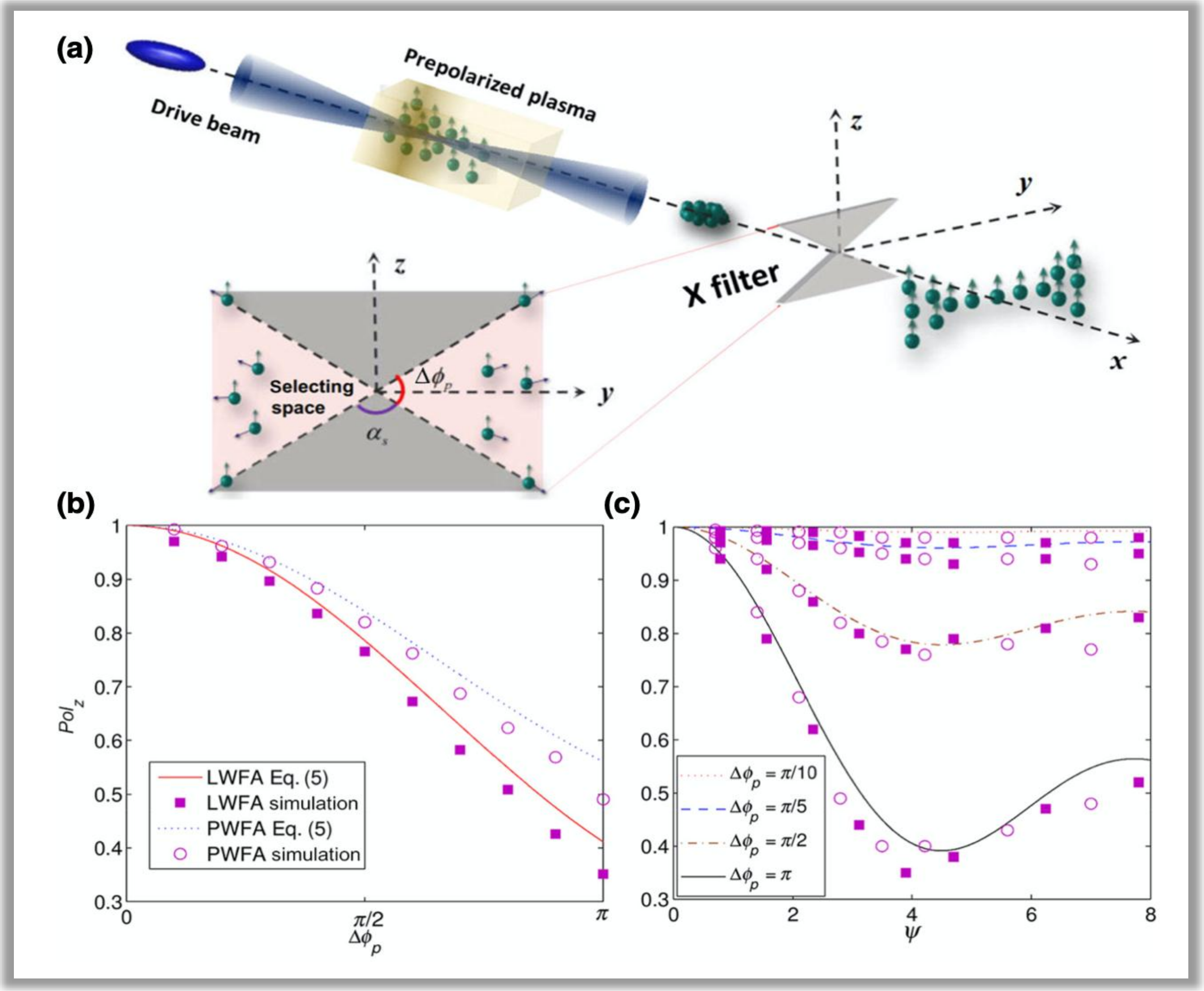
- **Due to the symmetric bubble structure, the azimuthal angle is locked with the angle where electrons are emitted.**
- **High polarization purity observed at certain angles**

Spin filter is possible by identifying electrons located in certain azimuthal angle region

Wu, **Ji*** et al., ***Phys. Rev. Applied*** (2020).

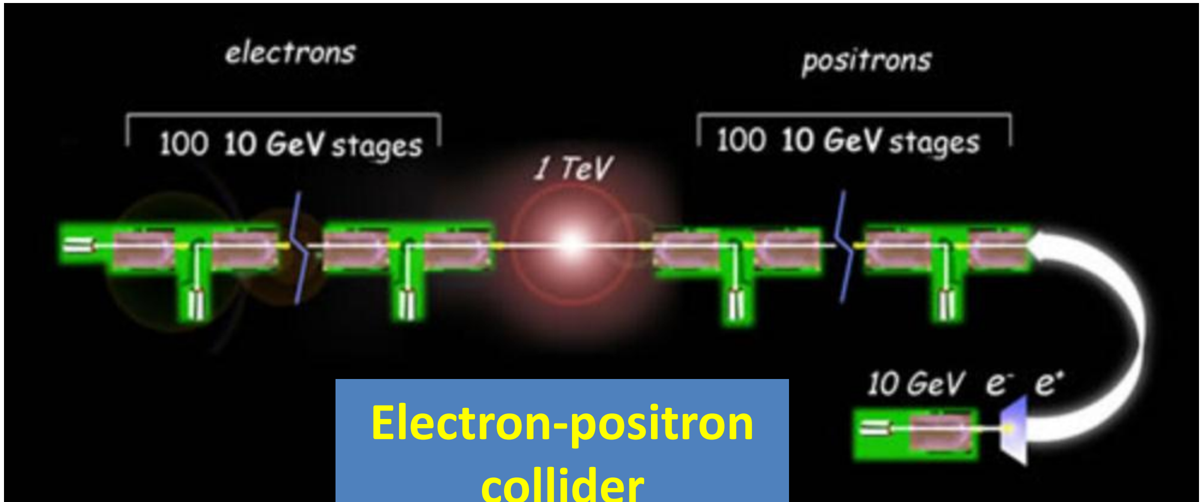
Polarized electron acceleration: spin filter

An X-shaped spin filter purifies electron polarization at any injected beam charge.

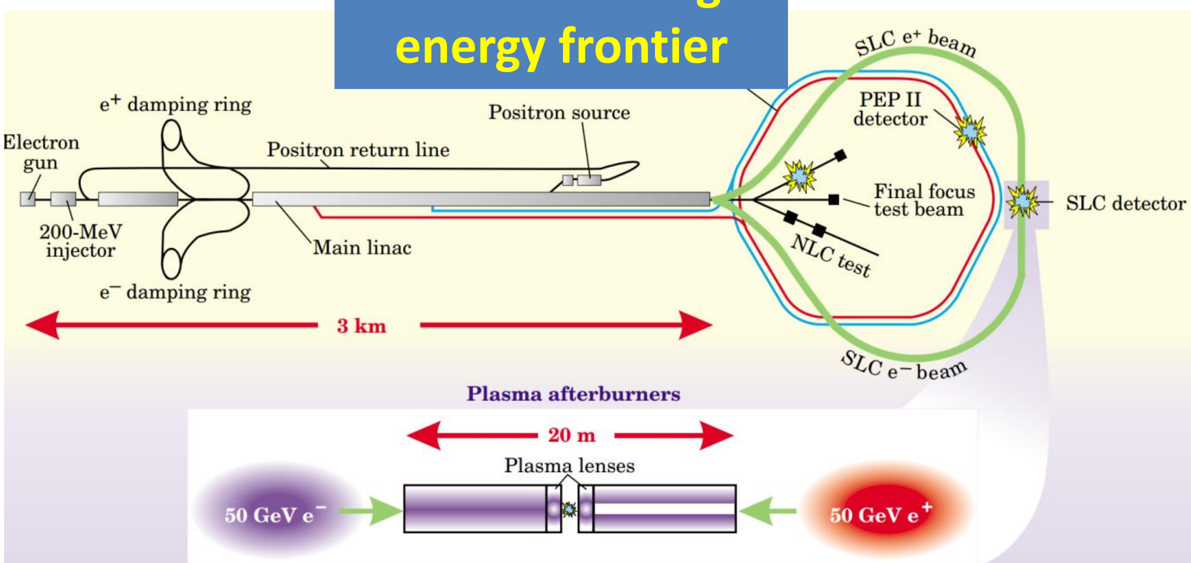


Wu, **Ji*** et al., **Phys. Rev. Applied** (2020).

LWFA towards the high energy frontier



Electron-positron collider
Towards the high energy frontier



Multi-staged

LWFA or PWFA

towards 100GeV

High beam

polarization

for e-e+ collider

$$\frac{d\sigma}{d\Omega}(e^+e^- \to \mu^+\mu^-) = \frac{r_0^2}{16\gamma^2}\beta_\mu\{2-\beta_\mu^2\sin^2\theta[1-|P_1||P_2|\cos(2\phi)]\},$$

$$\frac{d\sigma}{d\Omega}(e^+e^- \to e^+e^-) = \frac{r_0^2}{16\gamma^2}\left(\frac{3+\cos^2\theta}{1-\cos\theta}\right)^2\left\{1+\frac{|P_1||P_2|\sin^4\theta}{(3+\cos^2\theta)^2}\cos(2\phi)\right\},$$

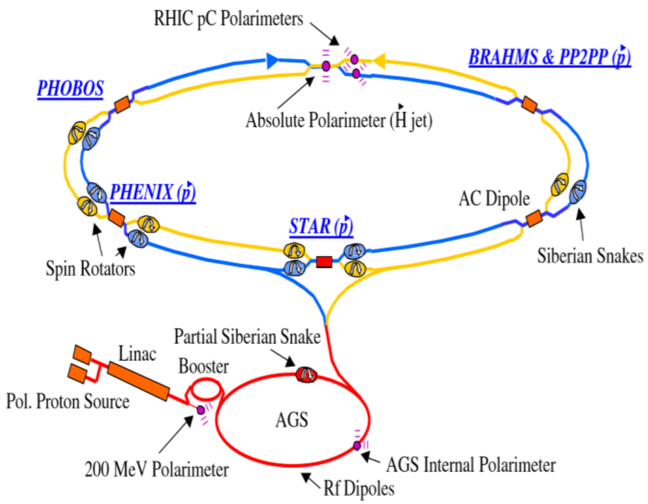
$$\frac{d\sigma}{d\Omega}(e^+e^- \to \gamma\gamma) = \frac{r_0^2}{4\gamma^2(1-\beta_e^2\cos^2\theta)}\{1+\cos^2\theta+|P_1||P_2|\sin^2\theta\cos(2\phi)\},$$

Baier V N 1969

Joshi, Physics Today, 2003

High energy polarized particle beam

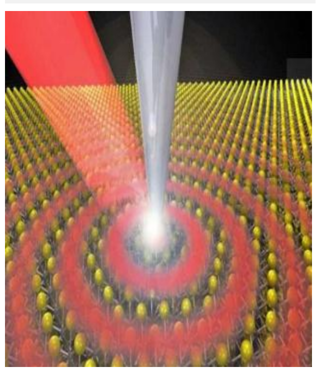
Particle physics, nuclear physics and material science



***e-e⁺* collider**

Nuclear physics

Material science



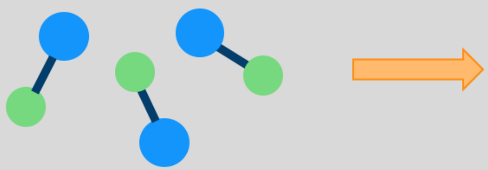
Institution	Location	Machine	Acronym
ANL	Argonne, IL, USA	ZGS	Zero Gradient Synchrotron
Berlin	Berlin, Germany	BESSY-I, II	—
BINP	Novosibirsk, Russia	VEPP-(2, 2M, 3, 4)	Colliding Electron–Positron Beams
BNL	Upton, NY, USA	AGS	Alternating Gradient Synchrotron
		RHIC	Relativistic Heavy–Ion Collider
CERN	Geneva, Switzerland	LEP	Large Electron–Positron Project
Cornell	Ithaca, NY, USA	CESR	Cornell Electron Storage Ring
DESY	Hamburg, Germany	DORIS	(Doppel Ring Speicher)
		HERA	Hadron–Elektron Ring Anlage
		PETRA	Positron–Electron Tandem Ring Accelerator
ELSA	Bonn, Germany	ELSA	Electron Stretcher Accelerator
IUCF	Bloomington, IN, USA	IUCF Cooler	Indiana University Cyclotron Facility Cooler
KEK	Tsukuba, Japan	KEK-B	KEK B-Factory
		KEK-PS	KEK Proton Synchrotron
		TRISTAN	(Tri-Ring Intersecting Storage Accelerators at Nippon)
LBNL	Berkeley, CA, USA	ALS	Advanced Light Source
MIT-Bates	Middleton, MA, USA	SHR	South Hall Ring
NIKHEF	Amsterdam, Netherlands	AmPS	Amsterdam Pulse Stretcher
Orsay	Gif-sur-Yvette, France	ACO	Anneau de Collisions d'Orsay
PSI	Villigen, Switzerland	SLS	Swiss Light Source
Saclay	Gif-sur-Yvette, France	SATURNE	—
SLAC	Palo Alto, CA, USA	PEP-2	PEP B-Factory
		SLC	Stanford Linear Collider
		SPEAR	(Stanford Positron Electron Asymmetric Rings)
TJLab	Newport News, VA, USA	CEBAF	Continuous Electron Beam Accelerator Facility

S R Mane *et al* 2005 *Rep. Prog. Phys.* **68** 1997

Preparing 100% pre-polarized electron target

Courtesy of M. Buescher

100 mJ @ 1064 nm



Alignment of HCl bonds

20 mJ @ 213 nm

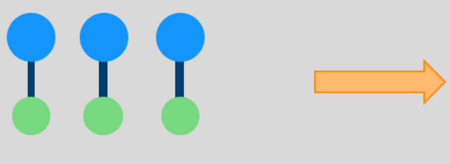
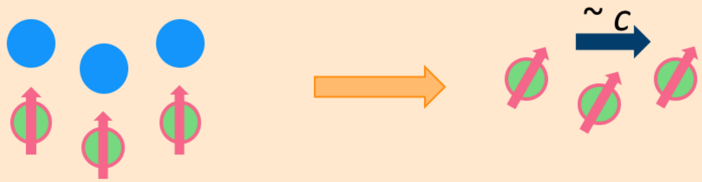


Photo-dissociation and polarization of the H nucleus

SIOM

300 J @ 800 nm



Acceleration of the protons in gas jet

Conclusions

- **The world-leading 10-100PW laser facilities (SULF and SEL) in China take strong-field QED research as one of the major science cases.**
- **Spin is a new degree of freedom manifesting the essence of strong-field QED.**
- **Laser-driven wakefield acceleration is promising in providing compact polarized particle sources.**

Thank you for your attention!