N3: New ideas for use of beams and physics at ILC

22:00 → 01:00 **N3: Beams for Accelerator and Detector R&D and Irradiation**

5-6 talks covering use of ILC complex beams for a variety of other physics studies than collider and dark sector physics, 2-4 talks about use of the beam for accelerator R&D and detector R&D

Conveners: Mark Hogan (SLAC), Steinar Stapnes (CERN), Yoshihisa Iwashita

- **22:00** Welcome — 5m
- **22:05** A programme with a low energy electron beam - CLEAR at CERN — 15m
  Speaker: Wilfrid Farabolini (CEA DAPNIA)
  A programme with ... | A programme with ...
- **22:25** Beam requirements for plasma acceleration R&D, examples from LNF planning and CERN studies — 15m
  Speaker: Patric Muggli (Max Planck Institute for Physics)
  LCWS21MugglieSP...
- **22:45** Testbeam and irradiation facilities — 15m
  Speaker: Marcel Stanitzki (Deutsches Elektronen-Synchrotron (DE))
  lcws-n3-testbeam1...
- **23:05** Exploring Strong Field QED with ILC Beams — 15m
  Speaker: Meuren Sebastian (SLAC)
  SFQED_AT_THE_IL...
- **23:25** Brilliant muon beam production at the ILC — 15m
  Speaker: Takayuki Yamazaki (KEK)
  210316_LCWS2020... | 210316_LCWS2020...
- **23:45** Photon science using gamma-rays in future linear colliders — 15m
  Speaker: Takehito Hayakawa (QST)
  LCWS2021_Hayaka...
- **00:05** New Research Opportunities with Ultrahigh Intensity Lasers at the ILC — 15m
  Speaker: James Koga (QST)
  LCWS2021-small.pdf
- **00:25** A high luminosity SC e+e-twin linear collider with energy recovery — 15m
  Speakers: Prof. Valery Telnov (Budker INP and Novosibirsk State Univ.), Valery Telnov (BINP)
  telnov-lcws21.pdf

Thanks to all speakers

~20 people in session, 8 talks

All talks are available at
https://indico.cern.ch/event/995633/timetable/
N3 session Monday 15.3 22:00-01.00 CET

Generalities

Approach: Provided a very loose guidance about ILC beams (injectors, DR, main linac) – mostly based presentation by Kaoru Yokoya at the LCWS 2019 (Sendai) (LINK)

- no reason to put too many limits now, in particular low energy beams can be envisaged which are not very constrained by ILC parameters

Three groups of ideas:

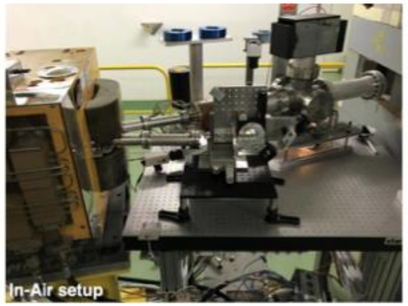
1. Use of low energy beams (~3 GeV) for accelerator R&D for many fields of science (including life medical sciences) but also laying the ground for ILC upgrades (improved "traditional" RF and/or plasma), testbeams and irradiation, huge training potential, can also envisage positrons production and use
2. Measurements one can do when combining a full energy ILC beam with a powerful laser, strong field QED and photon science
3. Two studies which point to new concepts, muon production studies, and an "energy recovery ILC" with very high luminosity

The two first I think should be explored in sessions in the fall workshop

The new ideas (muons, e-REC ILC) should be scrutinized by expert in the community

A generic R&D facility

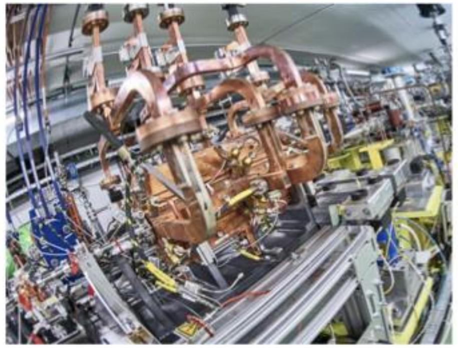
CLEAR Layout & main installations



In-air test stand

Testing ground for beam diagnostics R&D and THz radiation studies

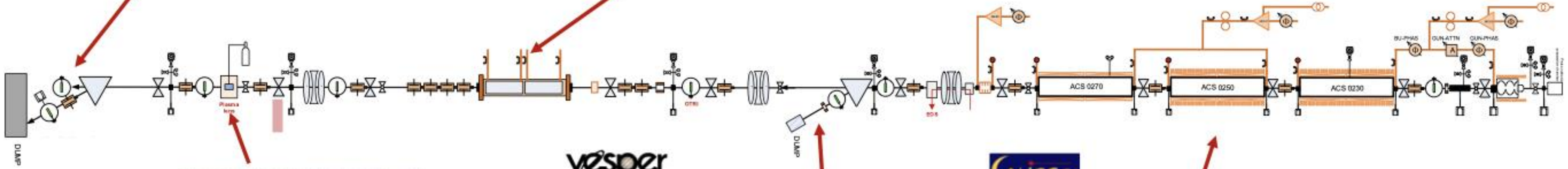
Irradiation for medical and other applications

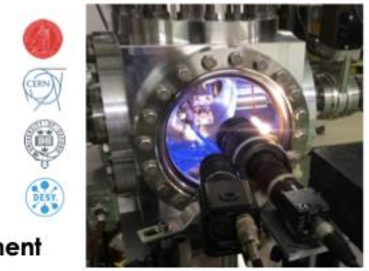


CLIC Test-Stand and high resolution cavity BPMs

High-gradient and linear colliders R&D

Beam direction

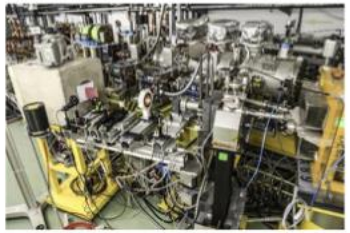




The Plasma Lens Experiment

Novel concepts of plasma-based focusing and acceleration

vesper



VESPER

Beam irradiation facility for studies on radiation damage of electronics and medical applications

CALIFES

CALIFES electron linac

Flexible accelerator providing up to 220 MeV electron beams to all CLEAR users

Additionally:

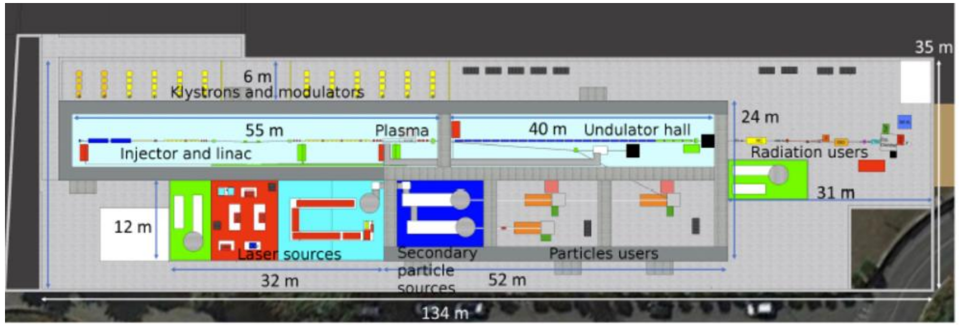
- Training/Schools
- Medical accelerators, VHEE and Flash RT

Wilfred Farabolini, CEA and CERN

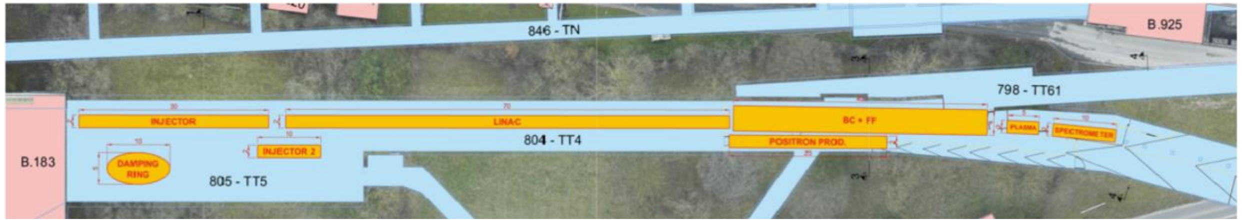
Patric Muggli, Max Planck Munich

Beamlines 50-70 m long, 1-3.5 GeV, followed by experimental area

Examples: EuPRAXIA@SPARC_Lab LNF/INFN



and CERN study with compact 3.5 GeV linac (~70m)



MAX-PLANCK-INSTITUT FÜR PHYSIK

SUMMARY

- Two facilities planned, opportunity to test PWFA stage for linear e⁻e⁺ collider
  - eSPS injector, CERN
  - SPARC_LAB linac LNF/INFN
- Opportunities to address collider-related topics thanks to:
  - >1GeV D-beam energy
  - Repetition rate
  - Independent W-bunch (e⁻)
  - Bunch shaping
  - e⁺ W-bunch
  - e⁻ D-bunch + e⁺ W-bunch
- D- and W-bunch parameters can be inferred from scaling
  - Requires short, tight, high charge bunches
- Self-consistent parameter set must be determined from numerical simulations
- Example for SLAC FACET II parameters
- Start-to-end simulations at LNF (FEL)
- Bunch parameters challenging …
- Decrease transverse size and length to lower Q?
- Synergy with CERN/AWAKE plasma source development laboratory (eSPS)

D- and W-bunch parameters inferred from PWFA scaling to reach ~1 and ~10GV/m accelerating fields

E_{WB} (GV/m)	1	10
Plasma		
n_{e0} (cm^{-3})	1.2×10^{14}	1.2×10^{16}
Drive Bunch		
γ_0	$> 10^6$	$> 10^6$
σ_z (μm)	700	70
σ_r (μm)	500	50
N	3×10^{10}	3×10^{9}
Q (nC)	5	0.5
Witness Bunch		
γ_0	300	300
ϵ_N (mm-mrad)	2	2
σ_{r0} (μm)	9	3
β_0 (mm)	12	1.4
σ_z (μm)	<700	<70
Q (nC)	<5	<0.5

12/12

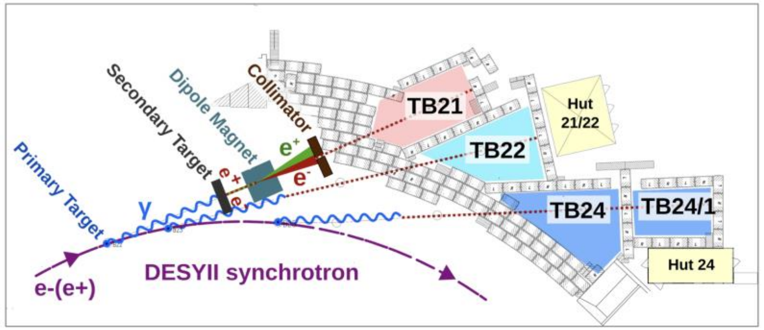
P. Muggli, LCWS 15/03/2021

Testbeam – Irradiation

DESY II Test Beam Facility

Beam Generation & Beam lines

- One of two user facilities offering multi-GeV test beams in Europe
  - The other one being the CERN PS&SPS
  - Worldwide : Fermilab & SLAC
- Beam Generation Carbon fiber targets in the electron beam generate bremsstrahlung photons
  - Conversion at thin metal plate target to e+/e-
  - Momentum selection by dipole + collimator
  - Three individual beam lines
- Already meets many requirements
  - Energy 1-6 GeV (1-100 GeV)
  - Rate ~ 10 kHZ (100 kHz)
  - Spread <5 % (a few %)
  - 1 e/ Bunch/mm^2 (few/bunch/mm^2)
  - Independently operated
- Very reliable operation
  - Beam always available



Education and Outreach with a test beam

E.g. at the DESY II Test Beam Facility

Summer Students

- Since several years very successful
- Full life-cycle: setup → data taking → analysis

Teacher Education

- Nation-wide and going in its third year
- Test Beam as one of the "lab experiments"

Beam Line for Schools (BL4S)

- Very successful project at CERN
- Teams of high school students can propose experiments at a beam line
- Two winning teams can perform their experiments supported by scientists

EDIT 2020 School for Instrumentation

- EDIT2020 https://edit2020.desy.de

Summary

Test beam and Irradiation facilities

- Test Beams and Irradiation facilities are essential infrastructures for detector R&D
- Both enhance the ILC Laboratory in the long term
  - Attract new users to the lab
  - Broaden usage beyond ILC community
  - Train next generation
- The ILC project view
  - As these facilities will come up in parallel with the ILC, they'll come very late
- The ILC as a long-term infrastructure view
  - Shows the long-term future of the ILC laboratory
- Infrastructure
  - It's not just the beam, the infrastructure for the Users is key for its success
- Operations
  - The amount for FTE required to run such a facility is small (5-10)
  - To be successful, it has to be long-term commitment

Marcel Stanitzki, DESY
Important need, significant user community, any large lab needs such facilities, training/education aspects, timeline to be considered carefully for initial phase

My comment: if such a beamline is build independently as part of the ILClab then the timeline can be different (for all three purposes mentioned in the last three slides)

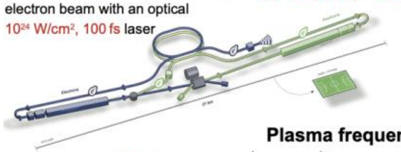
Exploring strong field QED with ILC beams

Probing the “QED Plasma Regime”
Combining the ILC 125 GeV beam with a 100 PW laser

SLAC

Combination of an extremely dense ($\sim10^{24}$ cm^{-3}), high-energy (125 GeV) electron beam with an optical 10^{24} W/cm², 100 fs laser

$Q \approx 3$nC, $\sigma_z \approx 300\mu$m, $\sigma_x \approx 0.5\mu$m, $\sigma_y \approx 0.008\mu$m

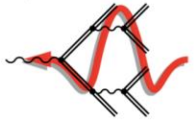


Quantum parameter

$$\chi \approx 0.6 \frac{\mathcal{E}}{10\,GeV}\sqrt{\frac{2I}{10^{20}\,W/cm^2}}$$

Classical intensity parameter

$$a_0 = \frac{eE}{\omega_L mc} \approx 0.6 \frac{\lambda_L}{1\,\mu m}\sqrt{\frac{2I}{10^{18}\,W/cm^2}}$$



Plasma frequency

$$\left(\frac{\hbar\omega_{plasma}}{1\,eV}\right)^2 \approx \frac{n_{plasma}}{10^{21}\,cm^{-3}}\frac{1}{\gamma}$$

$\gamma \sim a_0 \approx 850 \rightarrow n_{plasma} \sim 10^{24}$ cm^{-3}
→ probe overcritical pair plasma

Astrophysics: magnetars, neutron-star merger, etc.

Qu et al., arXiv:2001.02590 (2020)
Meuren et al., arXiv:2002.10051 (2020)

Producing a pair plasma via a QED cascade

- Cascade multiplicity: $\sim\chi\sim 10^3$: 10^3 pairs per primary particle
- Final gamma factor: $\gamma \sim a_0 \sim 10^3$: transfer of ~GeV per particle → 10^9 primary particles (~100 fs vs. 300 μm), 10^{12} secondaries: ~kJ energy transfer → laser depletion
- Transverse acceleration + (generalized) ponderomotive force: 100+ MeV temperatures, rapid plasma expansion (nm → μm)

Astrophysics: from Fast Radio Bursts to Neutron-Star Mergers
QED plasma regime: highly relevant for multi-messenger astronomy

SLAC

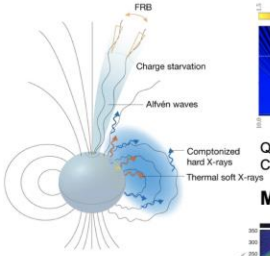
NEWS · 09 JUNE 2020

Astronomers spot first fast radio burst in the Milky Way

The nearby burst came from a magnetized star – and provides a close-up view of one of astronomy's biggest puzzles.

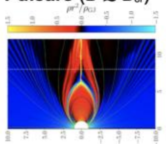
https://arxiv.org/abs/2005.12164 Nature Astron. (2021)
https://arxiv.org/abs/2005.11479 Nature 587, 63 (2020)
https://arxiv.org/abs/2005.11178 Nature Astron. (2021)
https://arxiv.org/abs/2005.11071 Nature Astron. (2021)
https://arxiv.org/abs/2005.10828 Nature 587, 59 (2020)
https://arxiv.org/abs/2005.10324 Nature 587, 54 (2020)

Magnetars ($B \gtrsim B_{cr}$)



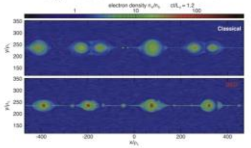
Progenitors of FRBs: e⁻e⁺ plasma in the QED regime
Zhang, Nature 587, 45 (2020)

Pulsars ($B \lesssim B_{cr}$)

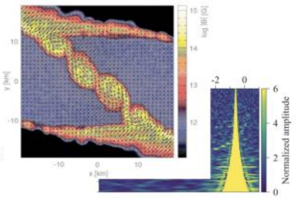


QED cascades in the magnetosphere
Chen et al., ApJ 889:69 (2020)

Magnetic reconnection



Neutron-star mergers ($B \gg B_{cr}$)



Gravitational waves & exotic matter in supercritical magnetic fields
Price & Rosswog, Science 312, 719 (2006)
LIGO/VIRGO, PRL 119, 161101 (2017)

Qualitative changes in QED-critical fields
Schoeffle et al., ApJ 870:49 (2019)

5

- The QED vacuum breaks down in the presence of an electrical background field $E \gtrsim E_{cr}$
- This corresponds to a laser intensity of $I_{cr} = c\varepsilon_0 E_{cr}^2 \sim 10^{29}$ W/cm²
- 100 PW optical laser, focused to 10 μm² results in 10^{24} W/cm²
  → requires ultrarelativistic particles to reach the QED critical field in a boosted frame

Nonperturbative QED Collider
Beamstrahlung mitigation with ultra-short bunches

SLAC

PHYSICAL REVIEW LETTERS **122,** 190404 (2019)

Prospect of Studying Nonperturbative QED with Beam-Beam Collisions

V. Yakimenko,[1,*] S. Meuren,[2] F. Del Gaudio,[3] C. Baumann,[4] A. Fedotov,[5] F. Fiuza,[1] T. Grismayer,[3] M. J. Hogan,[1] A. Pukhov,[4] L. O. Silva,[3] and G. White[1]
[1]SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA
[2]Department of Astrophysical Sciences, Princeton University, Princeton, New Jersey 08544, USA
[3]GoLP/Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal
[4]Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany
[5]National Research Nuclear University MEPhI, Moscow, 115409, Russia

Parameter	[Unit]	NPQED Collider	FACET-II	ILC	CLIC
Beam energy	[GeV]	125	10	250	1500
Bunch charge	[nC]	0.14–1.4	1.2	3.2	0.6
Peak current	[kA]	1700	300	1.3	12.1
Energy spread (rms)	[%]	0.1	0.85	0.12	0.34
Bunch length (rms)	[μm]	0.01–0.1	0.48	300	44
Bunch size	[μm]	0.01	3	0.47	0.045
(rms)		0.01	2	0.006	0.001
Pulse rate ×	[Hz]×	100×	30×	5×	50×
Bunches/pulse	N_{bunch}	1	1	1312	312
Beamstrahlung	χ_{av}	969		0.06	5
Parameter	χ_{max}	1721		0.15	12
Disruption	$D_{x,y}$	0.001–0.1		0.3	0.15
Parameters		0.001–0.1		24.4	6.8
Peak electric field	[TV/m]	4500	3.2	0.2	2.7
Beam power	[MW]	0.002–0.02	10^{-4}	5	14
Luminosity	[cm^{-2} s^{-1}]	6×10^{30} -4×10^{32}		10^{34}	10^{34}

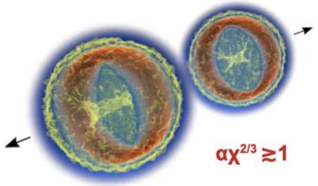
Luminosity
(per bunch crossing)

$$L \propto \frac{N^2}{\sigma_x \sigma_y}$$

Strong-field quantum parameter
(beam-beam collisions)

$$\chi \propto \frac{\alpha N \lambda_c^2 \gamma}{(\sigma_x + \sigma_y)\sigma_z}$$

- Reaching $\chi \gg 1$ requires ultrashort laser pulses / beams: interaction time has to be shorter than the radiation time
- Design of ILC: employ long & flat bunches to minimize χ
- NpQED collider: same energy, but short & round bunches
- Idea: compressing particle bunches is “easier” than light beams: we need attosecond-scale interaction times at the 100 GeV scale



10

Sebastian Meuren, SLAC – linking also to:

Probing Strong-field QED in beam-laser interactions
E-320: combining the 13 GeV FACET-II beam with a 20 TW laser

New Research Opportunities with Ultrahigh Intensity Lasers at the ILC

James K. Koga[1], Masaki Kando[1], Timur Zh. Esirkepov[1], Sergei V. Bulanov[1,2], Stepan S. Bulanov[3], Joel Magnusson[4], Arkady Gonoskov[5], Tom G. Blackburn[5], Mattias Marklund[5]

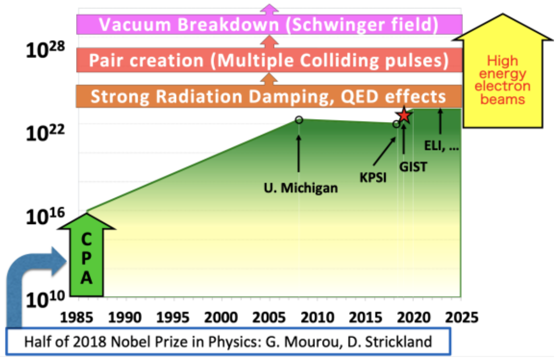
[1] KPSI, QST, Japan
[2] ELI Beamlines, Czech Republic
[3] LBNL, USA
[4] Chalmers Univ. of Tech., Sweden
[5] University of Gothenburg, Sweden

New proposal

- Using a High Intensity Laser ahead of beam dump

1. X-FEL Facilities: SACLA, LCLS, EXFEL,… → High Power Laser systems
2. The interaction of very high energy electrons with intense lasers is one of the active research fields in high-field science!
3. LCLS and LUXE experiments → electron-positron pair creation

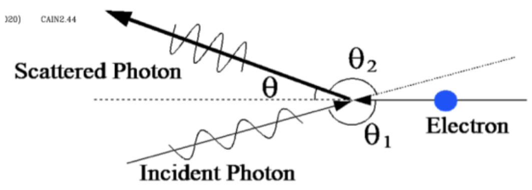
Peak Laser Intensity (W/cm²)



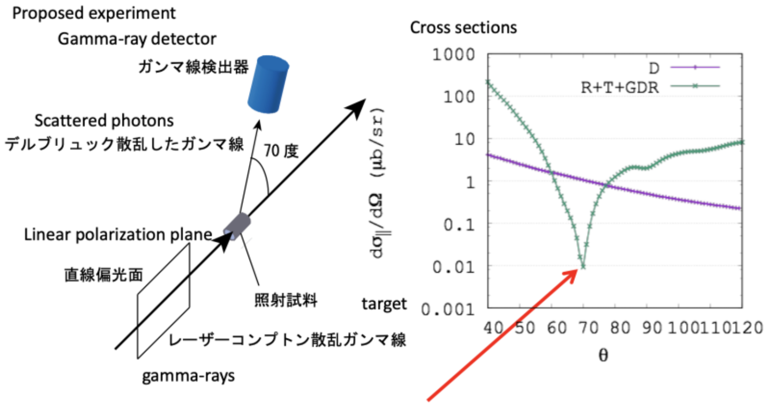
Photon science using gamma-ray in future linear colliders

T. Hayakawa
National Institutes for Quantum and Radiological Science and Technology (QST)

Inverse Compton scattering with laser



Non-linear inverse Compton scattering with high intense laser



If we use a linearly polarized gamma-rays as the incident beam, we can selectively measure the cross section of the Delbruck scattering at 70 degree.

J. Koga and T. Hayakawa, Phys. Rev. Lett. 118, 204801 (2017).

Summary

It is expected to generate strong gamma-rays in future linear colliders.
They can be used for photon science.

Delbrück scattering : non-linear effect of QED

J. Koga and T. Hayakawa, Phys. Rev. Lett. 118, 204801 (2017).

Photon vortex generation and detection : photon as the eigen state of angular moment

Proposal of light vortices by non-linear inverse Compton scattering

Y. Taira, T. Hayakawa, M. Katoh, Sci.c Rep. 7, 5018 (2017).

Theoretical calculation of photon vortex generation in high-order harmonic radiations in synchrotron radiations.

T. Maruyama, T. Hayakawa, T. Kajino, M.-K. Cheoun, arXiv:1908.11545 [astro-ph.HE]

Calculation of Compton scattering with photon vortex

T. Maruyama, T. Hayakawa, T. Kajino, Sci. Rep. 9, 51 (2019)

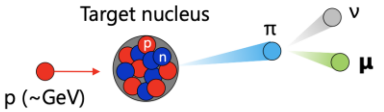
Brilliant muon beam production at the ILC

Takayuki YAMAZAKI*, K. Shimomura, N. Kawamura (KEK IMSS),
D. Nomura, S. Makimura (KEK IPNS),
Y. Kawashima (RCNP)

* takayuki@post.kek.jp

Overview

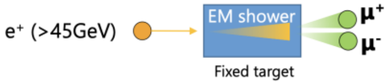
- Conventional way to produce a muon beam from a proton beam



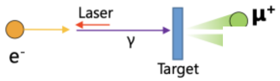
T = O(1~10) MeV
I = O(1e8) μ^+/s
ε = O(10^3) mm*mrad

@J-PARC MLF
- Graphite, t=2mm
- Rotating target

- From a positron/electron beam, a low emittance and high energy muon beam can be produced.
  1. 45GeV positron beam on a fixed target



  2. $\gamma A \rightarrow \mu^+\mu^- A$, γ is generated via Laser Compton Scattering (LCS)



Comparison

	~1GeV p	45GeV e+	LCS γ
Kinetic energy (GeV)	10^{-3}	22.5	0~85GeV
Energy width (%)	10	20	broad
Emittance (mm*mrad)	O(10^3)	O(10^{-4})	O(0.1)
Flux (/s)	10^8	3×10^7	5×10^8
Others		$\mu^+\mu^-$対	$\mu^+\mu^-$対

- Conventional method is suitable for material sciences like μSR or element analysis using muonic X rays which needs muons to stop in a sample.
- A low emittance and high energy muon beam is suitable for radiography of large structure, which is currently conducted using cosmic ray muons. And input to muon collider?
- "e^+&fixed target" is best to generate a low emittance beam, but "LCS method" is better in intensity.

Summary

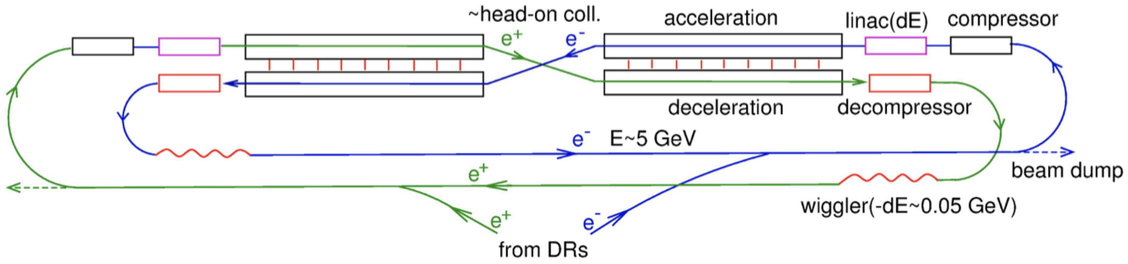
- We considered two methods to generate a muon beam from a $e^\pm$ beam.
  - ✓ 45GeV positron on fixed target ($e^+ + e^- \rightarrow \mu^+ + \mu^-$)
    - E=22.5 GeV, F=3×10^7 $\mu^+\mu^-$/s, ε~2×10^{-4} mm*mrad
  - ✓ LCS γ from e- and laser on fixed target ($\gamma + A \rightarrow \mu^+ + \mu^- + A$)
    - E=0~85 GeV, F=5×10^8 $\mu^+\mu^-$/s, ε~0.3 mm*mrad
- These beams have much higher energy and much lower emittance compared to the conventional muon beams generated from proton beams. Applications like radiography and large structure analysis are promising.

Twin e^+e^- LC with the energy recovery

Valery Telnov
Budker INP and Novosibirsk State Univ.
LCWS 2021

The proposed LC scheme

Twin LC with the energy recovery



1) LC consists of two parallel SC linac connected with each other with rf-coulpers, so that the fields are equal at any time. One line is for acceleration, the other for deceleration.
2) Damping is provided by wigglers (no damping rings) at the "return" energy about E~5 GeV. The energy loss per turn dE/E~1/100. Damping is needed to reduce the energy spread arising from collision of beams.
3) In the presence of a return path, e + and e- are always correctly focused by their own FF.
4) The duration of one cycle (several seconds) is determined by the refrigeration system (rise of temperature on ~0.1 K at 1.8 K).

Total power

For $N=2\cdot 10^{10}$, d=3 m , DC=1/3, 2E=250 GeV.

$$L = 10^{36}\ \mathrm{cm}^{-2} s^{-1}$$

The number of circulating bunches n_b =2×(30 km/3 m) = 2×10^4 (both beams) .
If bunches are prepared once per >3 s, the average power for beam generation (with ε=10%) will be less than 10 MW.
Radiation in wigglers P_{SR}~6 MW (with ε~50%).
Refrigeration power P_{ref} ~110 MW

The total wall plug power ~130 MW

Unclear questions:
- minimum distance between bunches (wakefields, high harmonics)
- RF-coupling between linacs

Summary

Three groups of ideas:

1. Use of low energy beams (~3 GeV) for accelerator R&D for many fields of science (including life medical sciences) but also laying the ground for ILC upgrades (improved "traditional" RF and/or plasma), testbeams and irradiation, huge training potential, can also envisage positrons production and use
2. Measurements one can do when combining a full energy ILC beam with a powerful laser, strong field QED and photon science
3. Two studies which point to new concepts, muon production studies, and an "energy recovery ILC" with a very high luminosity

The two first could be explored in sessions in the fall workshop (needs to be prepared)

The new ideas (muons, e-REC ILC) should be scrutinized by expert in the community