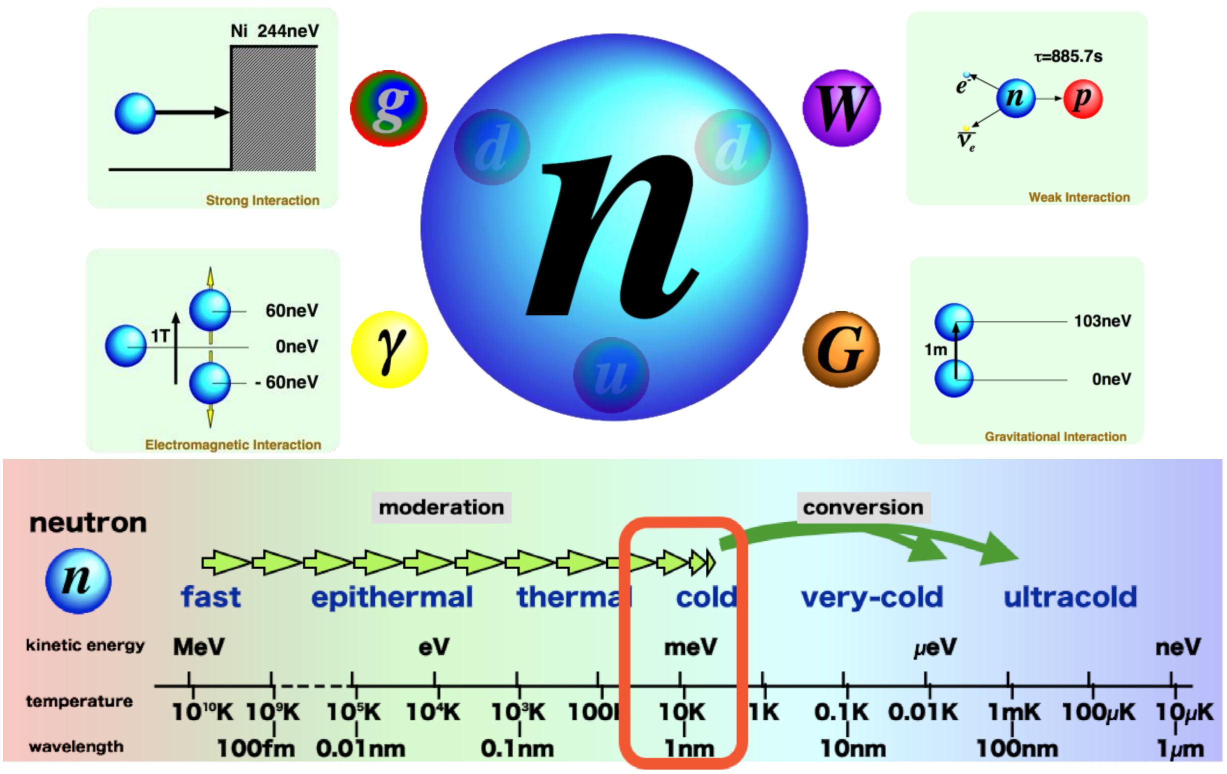
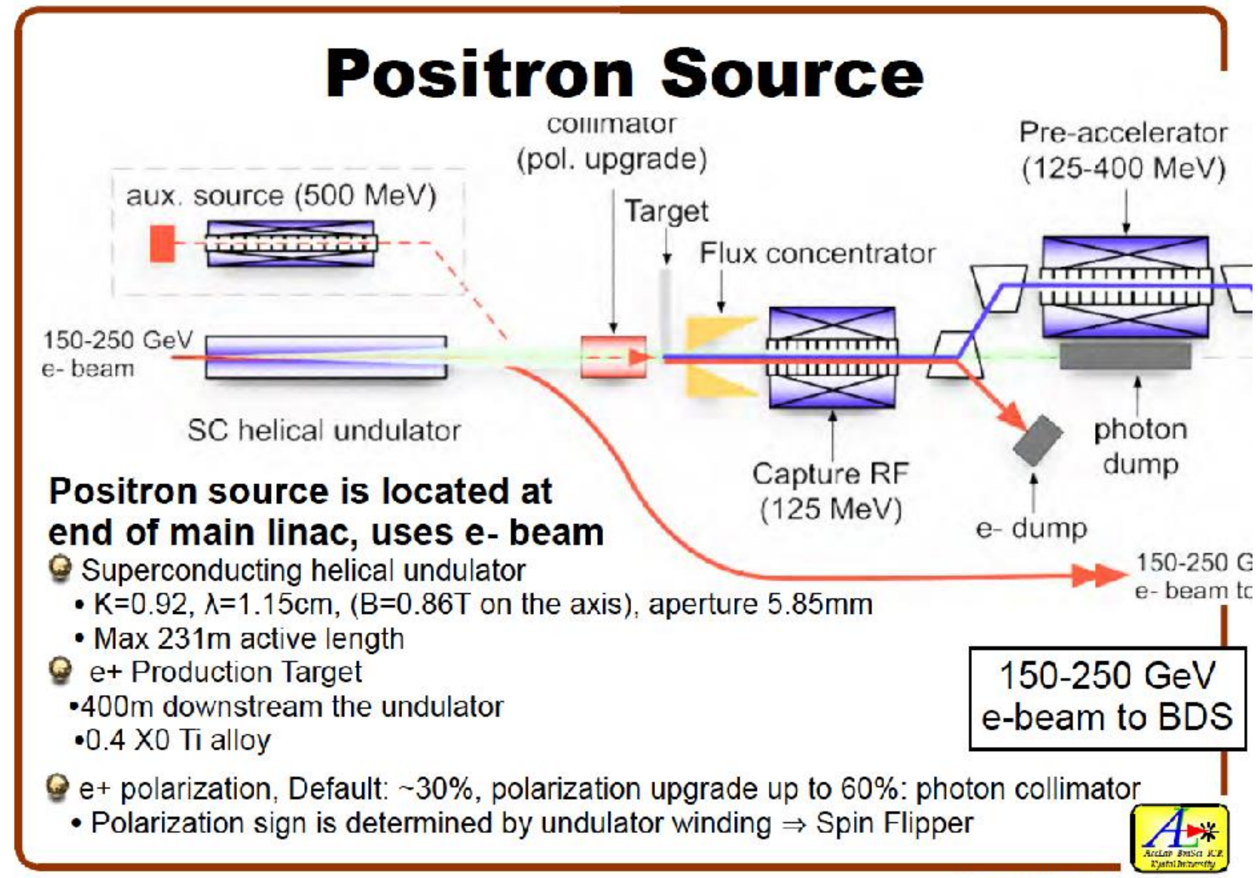
Applications of LC beams

Y. Iwashita, Kyoto University

Introduction

In order to seek new schemes for direct generation of usable energy neutron, intense MeV gamma source at positron source was picked up.



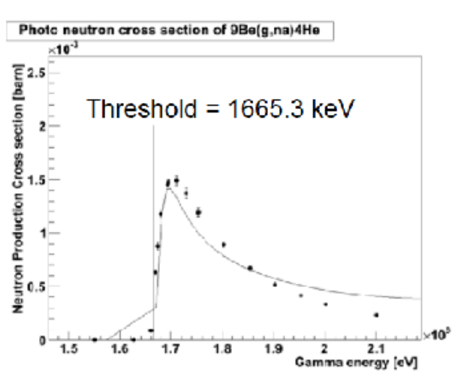


LCWS2019 Sendai, 2019.10.29

Candidates of photo-neutron targets

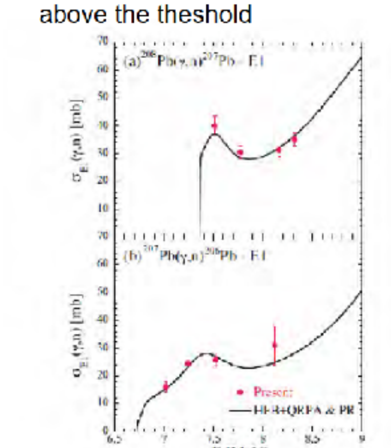
(γ,n) cross sections are not well studied, especially around threshold.

^{9}Be
- Threshold = 1665.3 keV
- σ^{9}Be(γ,nα)^{4}He at 1700 keV is 1.5 mbarn



C.W.Arnold et al., PhysRevC 85 044605
With ENDF data

$^{207-208}$Pb
- Threshold (^{207}Pb) = 6738 keV
- Threshold (^{208}Pb) = 7368 keV
- σPb(γ,n) is 10~30 mbarn at 100 keV above the theshold



T. Kondo et al., PHYSICAL REVIEW C 86, 014316 (2012)

Then, spread to other hidden users to share this unique facility. The precious facility could Contribution to widely spread science fields. Diversity of the usage enhances efficiencies to share knowledge and merits.

Tunnels or extra spaces have to be incorporated from the beginning. Raise the attention of researchers who are not interested, and dig up discussions to sublimate attractively.

WG6: divILC activities so far

In order to explore possibilities of this unique facility, events were held to discuss diversified applications on ILC and/or its facilities and to gather as many personnel who have not been interested in ILC so far.

1) **First kick off meeting**: 2017/11/29-30
   @ KEK 2Bldg.1F— Report in Japanese

2) IPAC’18 @Vancouver:
   http://accelconf.web.cern.ch/AccelConf/ipac2018/papers/mopml047.pdf

3) **2nd meeting**: 2018/7/5-6
   @ Uji Campus, Kyoto University
   https://conference-indico.kek.jp/indico/event/52

4) 3rd workshop of Concepts of neutron sources (CoNS-Ⅲ)
   2018/8/21@KEK Tokai 1-gokan Rm324
   http://www2.kek.jp/imss/kens/topics/2018/07/191648.html

5) **3rd meeting**: 2018/11/13-14
   @ KEK 3Bldg.1F — Report in Japanese

6) JAPAN-SPAIN WORKSHOP ON OPPORTUNITIES ON ACCELERATORS: 2018/12/10 Madrid

7) **Symposium at JPS meeting**: 2019/3/15 15pF303

Possible Beam Conditions in ILC

- Overview of ILC Accelerator

  (May be omitted if the audience is familiar with ILC → then, jump to page 16)
- Diversified application of ILC beam to other purpose

Kaoru Yokoya, KEK

2019.10.29 LCWS2019 Sendai

Diversified Use of the ILC Beam

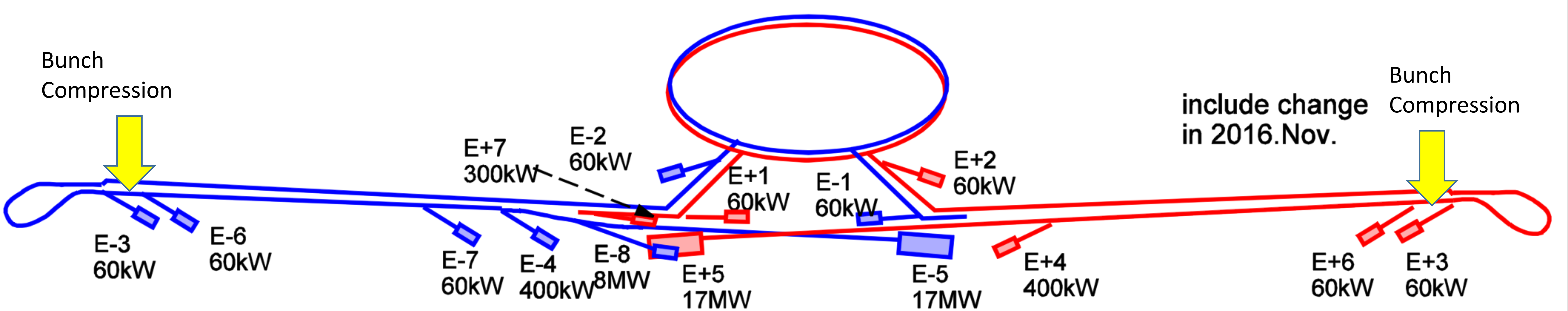
- ILC beam
  - Very high energy
  - Low emittance
  - High intensity (beam thrown away)
- Once ILC is built, people will certainly think of the possibility of using the beam for other purposes
- Expect a long life of ILC system
  - Luminosity-energy upgrade in the future desirable
- First consider parasitic usage under high-energy experiment of ILC250
  - Center-of-mass energy 250GeV
  - Beam energy maximum 125GeV

Parasitic Use of the Beam

- Destructive use of a part of the beam (extraction)
  - Take out the head (or tail) of the 1312 bunches
    - Fast kicker needed (rise/fall time < 0.5μs)
  - Take out a part of (rise/fall time < 200ms)
  - Might be possible to use the beam for a few hours/days (shutdown, summer time)
- Non-destructive use of the whole (or part) of the beam
  - For example, insert an undulator in the main beamline
  - In such a case a chicane is needed to separate the electrons and photons
  - Must not degrade the main beam emittance
- **Other possibilities not affecting the collision experiment**
  - Use of the beam after collision
  - Use of photons for producing the positron
  - Operate the electron injector (5GeV) at 10Hz, 5Hz for high energy experiment and 5Hz for parasitic use

Distribution of the Beam Dumps

- Extraction use will be most practical at the location of beam dumps
- Show below the schematic layout of the beam dumps
- Blue: electron, red : positron,. Yellow arrow : bunch compressor (bunch length 6mm at its upstream, 0.3mm downstream)
- The power number is the design upper limit of each dump (including 20% margin)
  - For commissioning or for emergency, except E-5, E+5, E+7, E-8
  - Therefore, the power of the full beam passing nearby exceeds the dump design (see next page)
  - Only E-5, E+5, E+7 can dump the full beam. (The design upper limit exceeds the full beam intensity because future upgrade is taken into account)
- It is not decided yet whether E-8 is to be constructed in ILC250GeV (Z-pole !!)



Summary

- There are a few places when the beam line may be used as light sources.
  - 5GeV electron injector
  - Right after 15GeV bunch compressor
  - Others
- The best parasitic mode parallel to Higgs experiment is the 5Hz+5Hz operation
- In any case possible changes of the machine design must carefully be examined
- Caution:
  - Safety in intercepting the beam
  - Tunnel access during beam operation
  - Construction at a later time

Muon Pair Production

Koichiro Shimomura (KEK IMSS)*

T. Yamazaki (KEK IMSS)
N. Kawamura (KEK IMSS)
D. Nomura (KEK IPNS)
Y. Kawashima (RCNP)

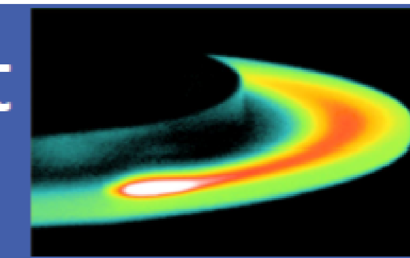
* Koichiro.shimomura@kek.jp

Possible way from ILC to muon collider

Need efficient muon pair production

- 45GeV positron beam on fix target
- Although emittance is good $O(10^{-4})$
  Intensity is not so large 2×10^{7}/s
- Use Laser Compton gamma

Preliminary study of high power density target for the LEMMA proposal

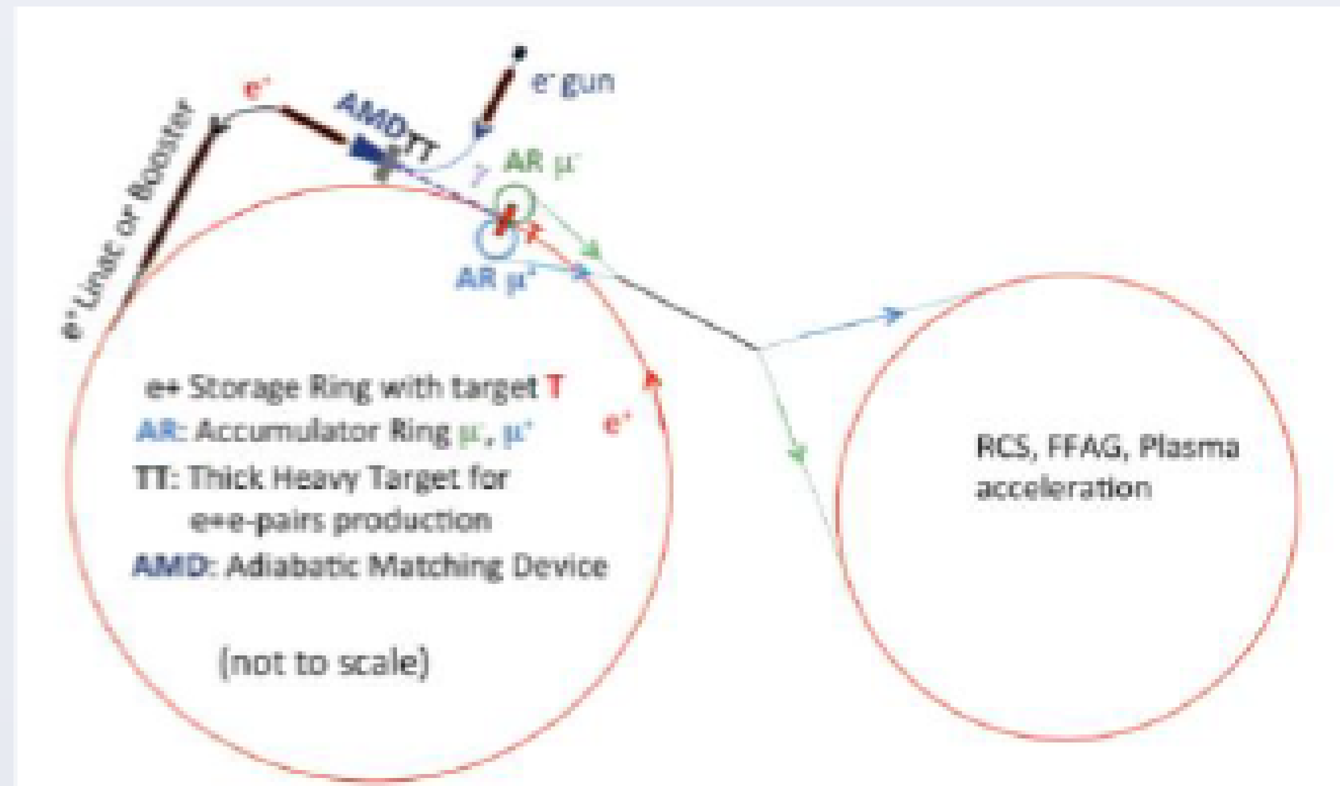


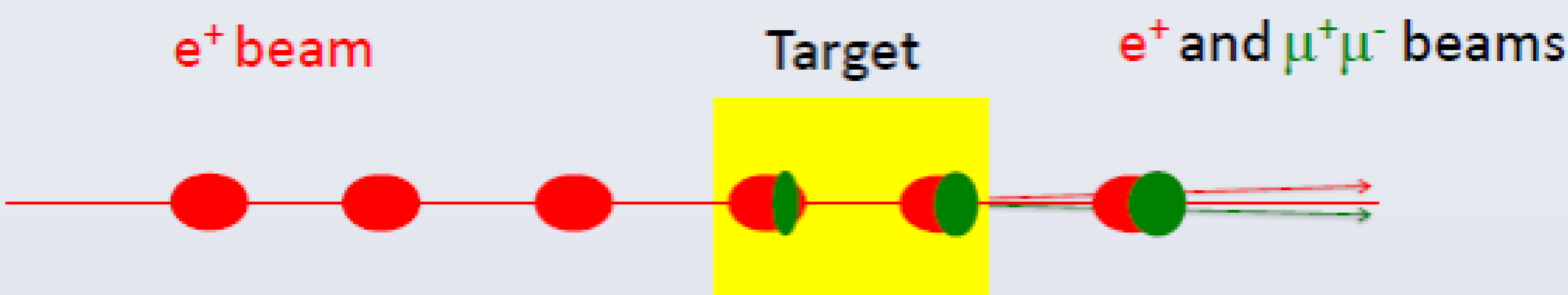
Matteo Iafrati[1,2], Mario Antonelli[2], Oscar Roberto Blanco Garcia[2], Manuela Boscolo[2], Francesco Collamati[3], Marco Dreucci[2], Francesco Edemetti[4], Susanna Guiducci[2], Roberto Li Voti[3], Emanuela Martelli[4], Luigi Pellegrino[2], Lorenzo Peroni[5], and Martina Scapin[5]

[1]ENEA - Frascati, [2]INFN - LNF, [3]INFN - Roma, [4]Univerita di Roma - La Sapienza, [5]PoliTo - Torino

Positron beam, interacting with electrons in a target material:

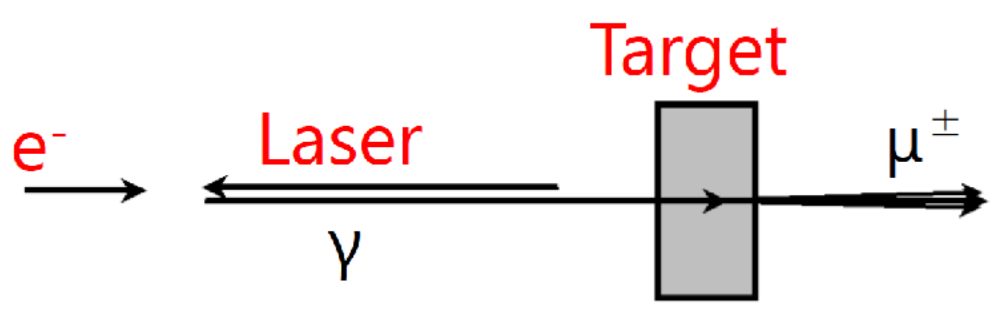
- 45GeV
- $3 \cdot 10^{11}\ e^+$ per bunches
- 200ns time bunches space
- beam dimension O(10 μm)





Muon Pair Production

Muon pair production



Study Items

Electron beam energy from ILC 5GeV and 125GeV

Laser choice

Muon pair production target

Laser Compton

E_γ [eV] γ energey F_γ [/s] Flux

$$E_\gamma = \frac{4\gamma^2 E_L}{1+(\gamma\theta)^2+4\gamma E_L/m_e}$$

$$F_\gamma = 2f\frac{\sigma}{A}N_e N_L$$

γ：electron γ factor
E_L [eV]：Laser photon energy
θ [rad]：scattering angle （～**1/γ**）
m_e [eV]：electron mas
f [/s]：collision frequency
σ [m²]：Thomas sc. Cross section
A [m²]：Area size of larger beam
※ normally laser size
N_e：number of electron per pulse
N_L：number of photon per pulse

- Assume pulsed laser simultaneously excited ILCに同期したパ
P [W], Laser power λ [m], laser wave length

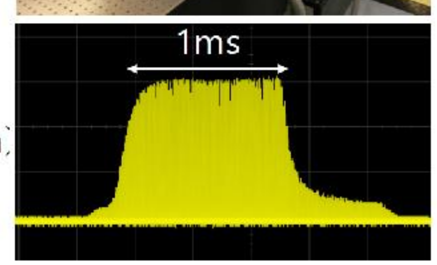
$$F_\gamma \propto f N_L/A \propto P\lambda/A \propto P/\lambda$$

→ High power, Shor wave length

About Laser Exmaple

- ILC 1 pluse structure 1312 bunch of 0.3mm length, 554ns interval
- Repetition rate5Hz

- Laser developed by AMPHOS Co.
  - ✓ 1μm wavelength
  - ✓ 200W power
  - ✓ 20J macro pulse（width 1ms）with10Hz
  - ✓ 20mJ micro pulse ~1MHz in macro pulse
  - ✓ Pulse width ~500ps
    compression with grating
    →1ps=0.3mm (94% efficiency)
  - ✓ M²<1.25（focusing factor
    focusing size ~1.25 times of wavelength）

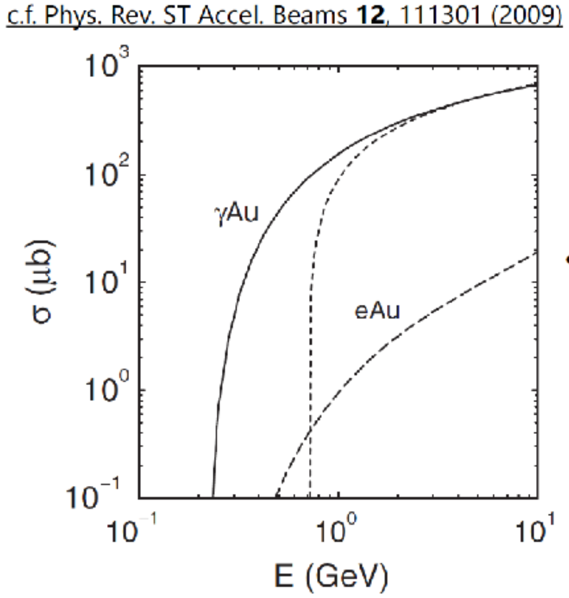


Assume every laser pulse interacts with electron beam.

muon pair production via. γA→μ⁺μ⁻A

γA→μ⁺μ A Total cosssection

c.f. Phys. Rev. ST Accel. Beams **12**, 111301 (2009)



- Dotted line is appoximate

$$\sigma \simeq \frac{28}{9}Z_A^2\alpha r_0^{\mu 2}\left(\ln\frac{2E_\gamma}{\mu}-\frac{109}{42}\right)$$

r_0^μ：classical muon adisu
μ：muon mass

- Au (Z=79, ρ=19g/cc) thickness 1cm
  - 5GeV dump、E_γ = 450MeV
  - σ ~ 30μb
  - 125GeV dump、E_γ = 90GeV
    σ ~ 1300μb

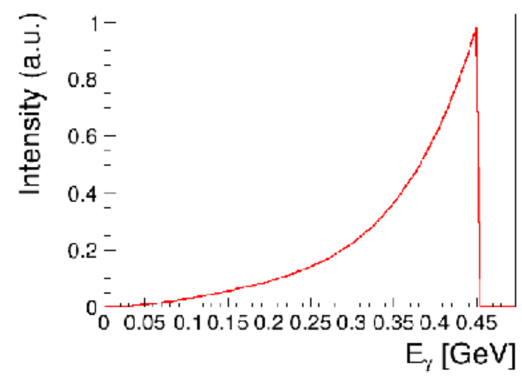
Muon Pair Production

Case1 5GeV Dump（E-1）

- Beam Power at Dump max=100kW
- Dump W=60kW

→ Assume 50kW（10μA）→1.25×10^{13} e^-/pulse（10^{10} e^-/bunch）

- $M^2<1.25$ hoever we assume w_0=10μm.
  - Because electron beam bunch length 0.3mm
  - λ=1μm
  - w_0=10μm Layleigh length $z_R=\pi w_0^2/\lambda$=0.3mm
- Use P. 3 formula
  - E_γ = 450MeV (max)
  - F = 8.4×10^{12} photons/s
  - Divergence 0.1mrad



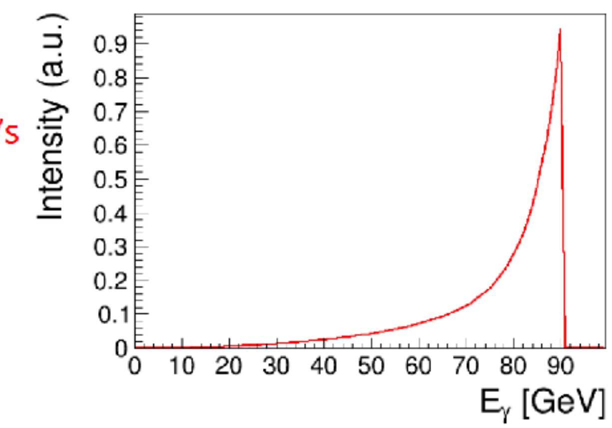
Case2 125GeV Dump（E-5）

- Beam Power at Dump max= PB max=2500kW
- Dump W=17000kW

Asuume 2500kW（20μA）2.5×10^{13} e^-/pulse（2×10^{10} e^-/bunch）

- w_0=10μm
- Use P. 3 formula、
  - E_γ = 90GeV (Max)
  - F = 1.7×10^{13} photons/s
  - Divegence 4μrad
- γ→∞で$E_\gamma\to E_e$

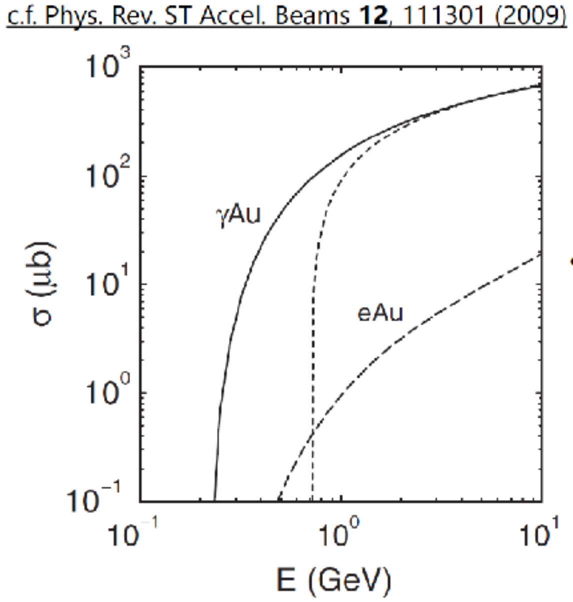
→、Better than 5GeV dump



muon pair production via. $\gamma A\to\mu^+\mu^-A$

$\gamma A\to\mu^+\mu^-A$ Total cosssection

c.f. Phys. Rev. ST Accel. Beams **12**, 111301 (2009)



- Dotted line is appoximate

$$\sigma \simeq \frac{28}{9} Z_A^2 \alpha r_0^{\mu 2}\left(\ln\frac{2E_\gamma}{\mu} - \frac{109}{42}\right)$$

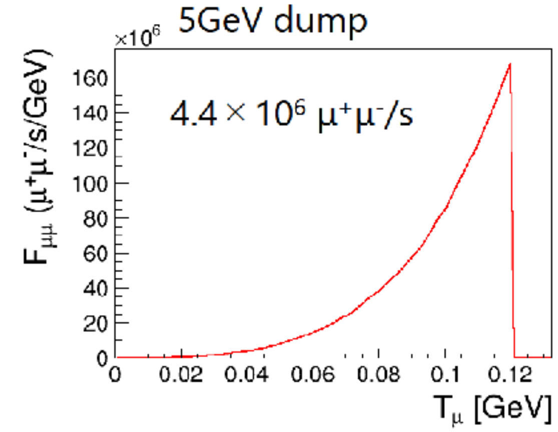
r_0^μ：classical muon adisu
μ：muon mass

- Au (Z=79, ρ=19g/cc) thickness 1cm
  - 5GeV dump、E_γ = 450MeV
  - σ ~ 30μb
  - 125GeV dump、E_γ = 90GeV σ ~ 1300μb

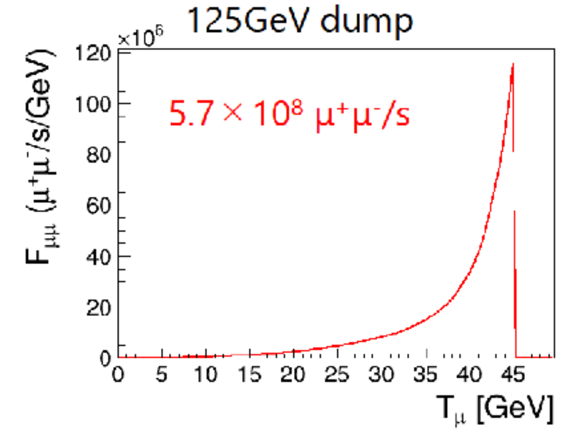
Muon Beam Intensity

- Au（Z=79, A=197, ρ=19.3g/cm³）

5GeV dump



125GeV dump



- 125GeV dump $\theta\sim2m_\mu/E_\gamma$=O(1) mrad
- Beam size
- 5GeV dump 1mm
- 125GeV dump 40μm

Comparison

Production method	~1GeV p	45GeV e^+	5GeV e^-	125GeV e^-
K.E (GeV)	10^{-3}～10^{-2}	22	**0.1**	**45**
Energy width (%)	10	20	**20**	**10**
emittance (mm*mrad)	$O(10^3)$	$O(10^{-4})$	**$O(10^3)$**	**O(0.1)**
Instensity (/s)	$O(10^8)$	2×10^7	**4×10^7**	**6×10^8**
		$\mu^+\mu^-$	**$\mu^+\mu$**	**$\mu^+\mu^-$**

- **Suitable for muon collider !**

Improvement:

- How about 500GeV, 1TeV case ?
- Other particle pair production（π, K, B, τ etc.）
- Any other photon source ?
- Cavity enhancement ?（c.f. H. Shimizu, et al., NIMA **745** (2014) 63-72）

Production of a coherent bremsstrahlung photon beam with several tens of GeV at ILC

Norihito Muramatsu
ELPH, Tohoku University
LCWS @Sendai, 29 Oct 2019

Contents

Proposing the production of ***70~80 GeV photon beam with linear polarization****, as* ***a diversified use of ILC.***

Motivation

Development of an ***unprecedented*** *photon beam for* ***hadron photoproduction*** *using a fixed target.*

- Unique feature of a photon beam
  - It can couple with a **$q\bar{q}$** component in a hadron.
  - Easily **polarized**. ⇒ Usable for spin-related studies.
- ILC energy can produce **heavy hadrons** including charm & bottom quarks.

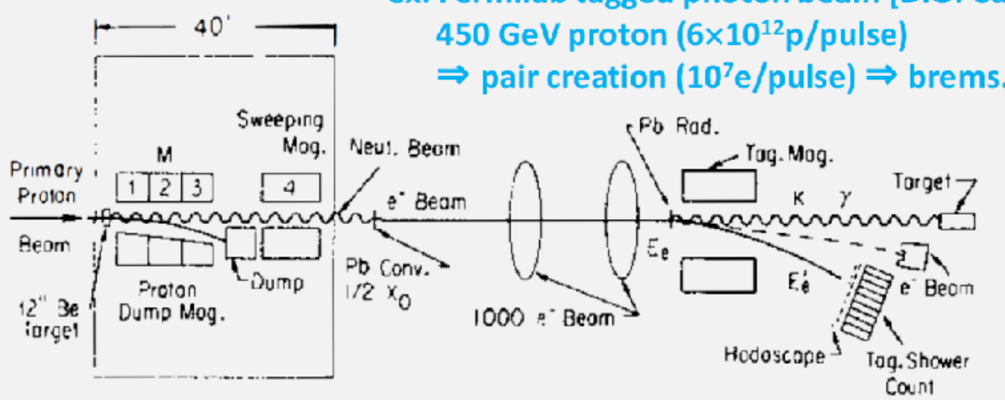
Past experiments

Brems. beam with Pb/W radiator in 1970s-1980s

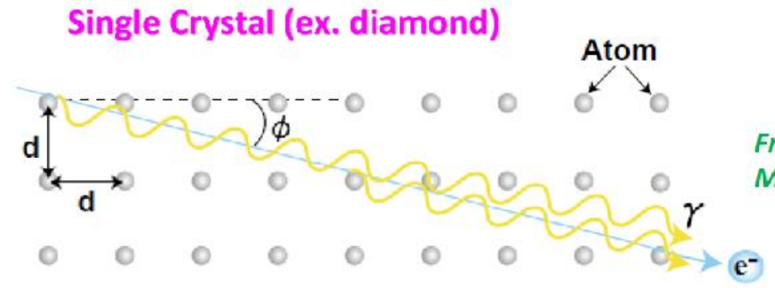
- **CERN SPS** ($25<E_\gamma<70$ GeV)
- **Fermilab Tevatron** ($18<E_\gamma<185$ GeV)

⇒ **Polarization did not attract much attention** maybe because of a beam divergence problem.

ex. Fermilab tagged photon beam [D.O. Caldwell]
450 GeV proton (6×10^{12}p/pulse)
⇒ pair creation (10^7e/pulse) ⇒ brems. (10^6 γ/pulse)



Coherent bremsstrahlung



From K. Sasahara Master Thesis (2001)

Interference of γ-rays in **a periodic nuclear EM field**.

- **Monochromatic** & **Linearly polarized**.
- Now **in practical use** for hadron photoproduction experiments. (MAMI, ELSA, J-Lab, etc.)

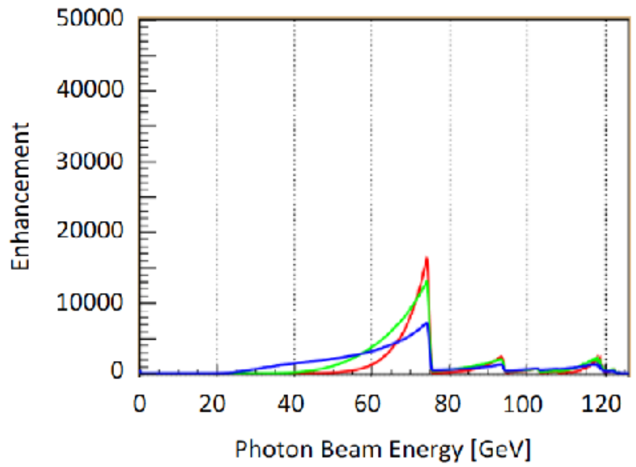
Why at ILC?

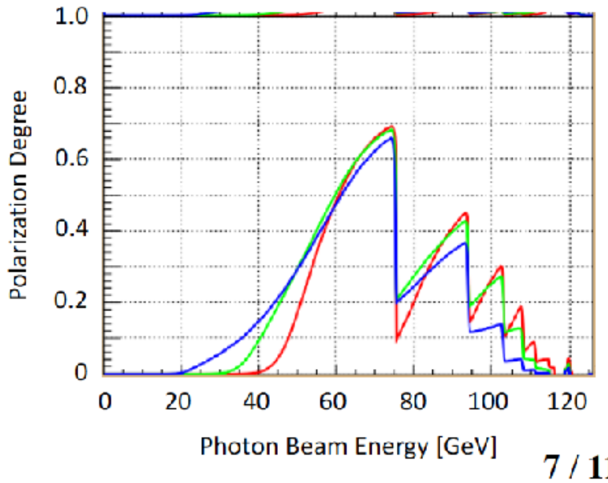
- The **energy of e$^{\pm}$ beam** (125 GeV) is attractive.
  Coherent brems. $\Rightarrow$ **E_{γ} range : 20-80% of E_e**
- **High e$^{\pm}$ current** results in high γ intensity.
- **High quality e$^{\pm}$ beam** is available.
  - ✓ Characteristic cone angle
    $\theta = 1/\gamma \sim 4$ μrad > **divergence ~ 1 μrad**
  - ✓ Multiple scattering @ radiator (**$t \leq 50$ μm**) is suppressed to be less than 4 μrad with the high energy e$^{\pm}$ beam.

Photon beam properties

Collaboration with **Dr. Ken Livingston (Univ. of Glasgow)**

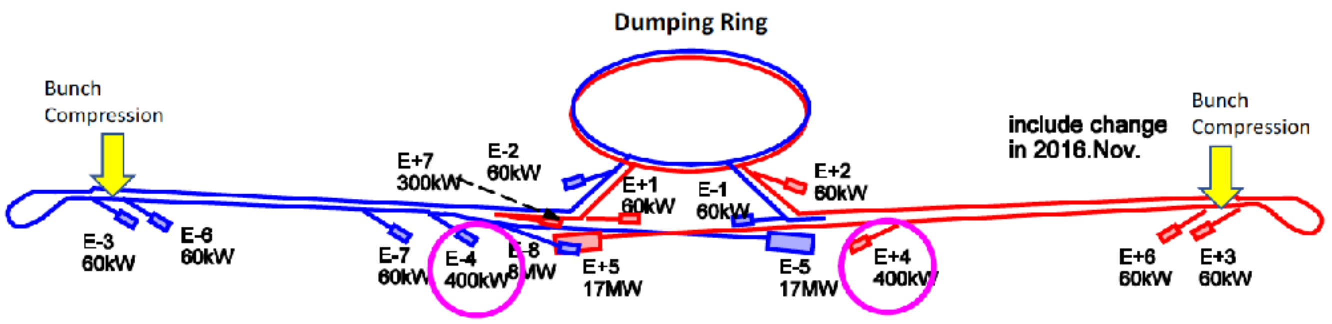
- Peak energy setting by **radiator angle**
  ex. **$E_{\gamma} = 0.6E_e$ (75 GeV)** $\Rightarrow$ **$P_{lin}^{max} \sim 70\%$**
- A **collimator** reduces incoherent contribution.





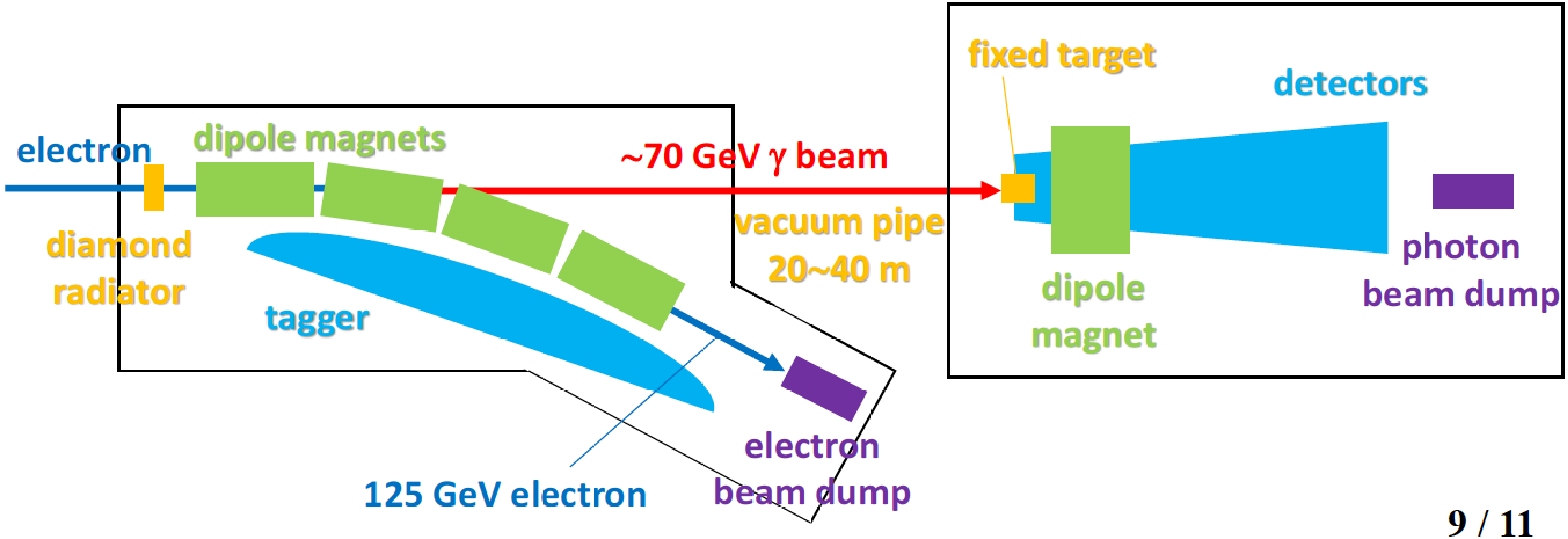
Possible experimental areas at ILC

- Tune-up dump for main linac (125 GeV) : **E–4 / E+4**
- **10% bunch steal** is OK for the **dump power** (400 kW).
  $\Rightarrow$ 20 μA × 10% = **2 μA [enough beam intensity]**
  cf. J-Lab (12 GeV) Hall-D : 10^7 γ/sec with **200 nA**



Concept of experimental setup

- ***Diamond radiator*** : **t=20-50 μm** with a Goniometer.
- ***Tagger*** : Fine-segmented detector for **recoil electrons**.
  Event-by-event measurement of E_{γ}.
- ***Spectrometer*** w/ a fixed target like **CERN COMPASS exp.**



Summary

- Proposing a facility to produce **a coherent bremsstrahlung photon beam** at **a beam dump** (E±4).
- An **unprecedented** photon beam with **E_γ~75 GeV** & **P_{lin}^{max}~70%** can be obtained at ILC.
- **Heavy exotic hadrons** including **charm** or **bottom** quarks can be explored with the extremely high energy & linearly polarized photon beam.

Ultrahigh Intensity Lasers at the ILC: Applications and Fundamental Physics

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)]

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

International Workshop on Future Linear Colliders (LCWS 2019)
Sendai, Japan, **October 28~ November 1, 2019**

Introduction

- Green ILC

- 500 GeV Beam Dumps 18 MW [4.5 GW peak]
  (ILC TDR, P. Satyamurthy et al. NIMA 2012)
  - Water - radioactivation, gas generation, heating, …
  - Gas – long distance 1000 m

- Plasma decelerator or plasma beam dump
  (Wu et al., PRSTAB 2010, Bonatto et al., POP 2015, Hanahoe et al., POP 2017)
  - Beams decelerated over short distance, large decelerating fields
  - The front part of electron/positron bunch not decelerated.

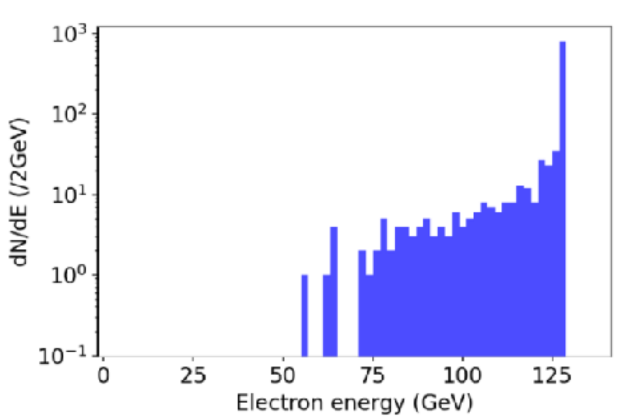
New proposal

- Using a High Intensity Laser in addition to beam dump

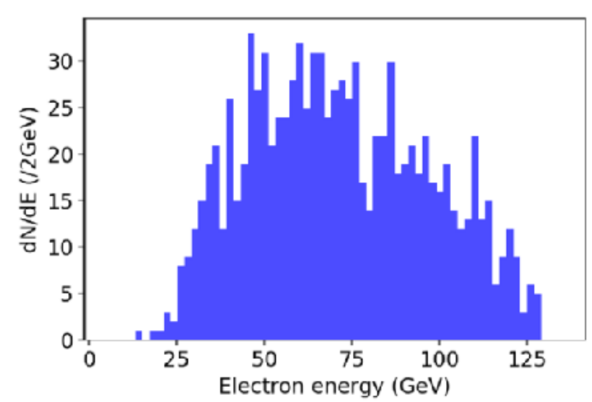
1. X-FEL Facilities: SACLA, LCLS, EXFEL,… → High Power Laser systems
2. The interaction of very high energy electrons with intense lasers is one of the active research fields in high-field science!

SIMLA results: 127.5 GeV e-

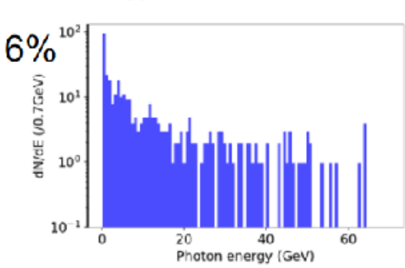
- RUN000: a0=0.6, 50fs, N=1000



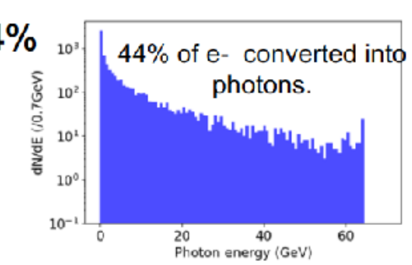
- RUN001: a0=0.6, **1ps**, N=1000



- e-Dump 3.16%

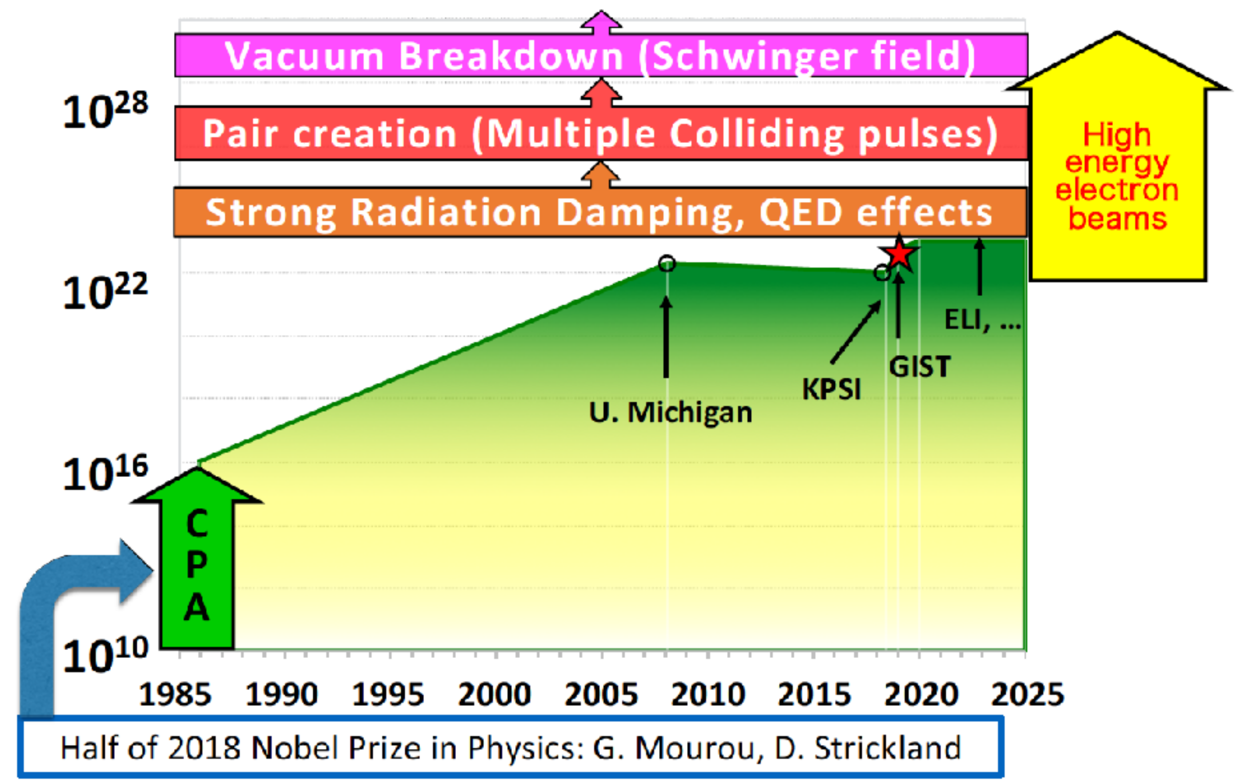


- e-Dump **44%**



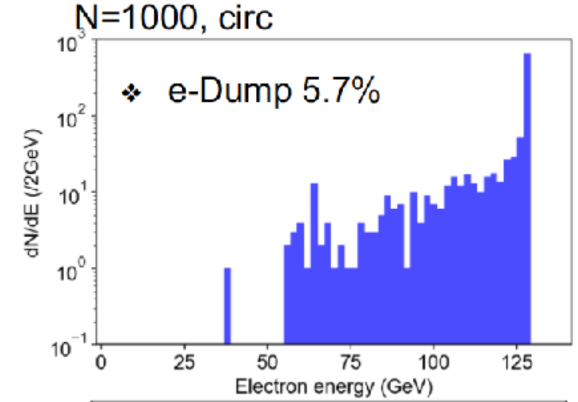
➢ Longer pulse duration is better

Peak Laser Intensity (W/cm^2)

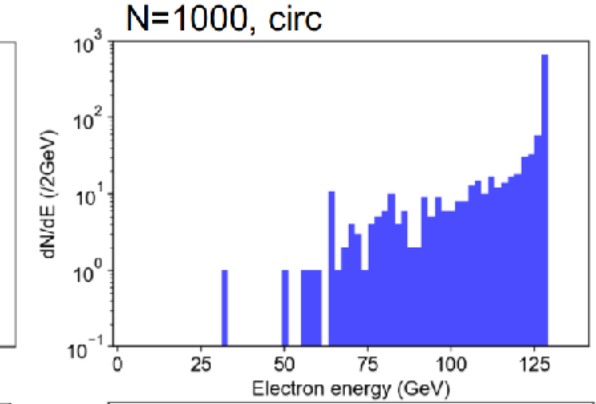


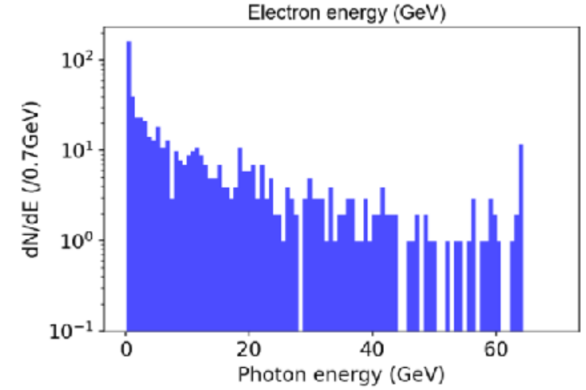
SIMLA results: circular polarization

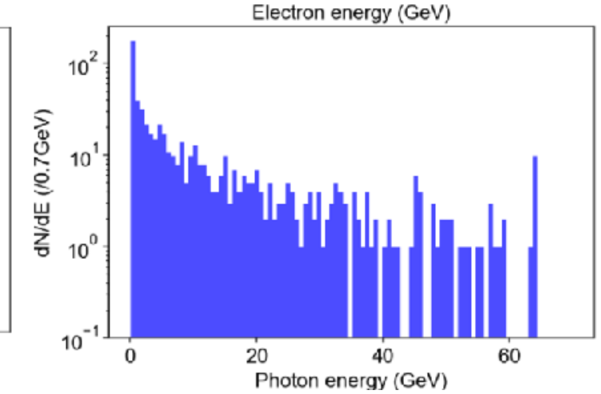
- RUN002: a0=0.6, 50fs, N=1000, circ



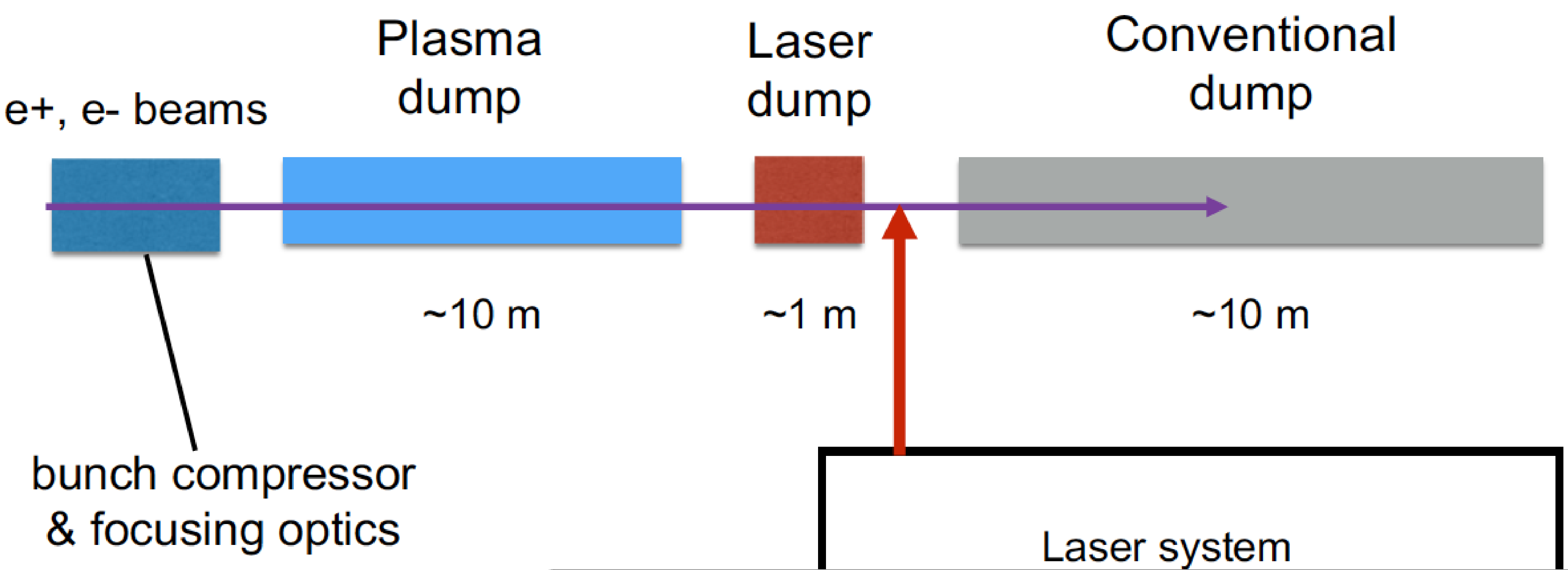
- RUN003: a0=0.65, 50fs, N=1000, circ







Hybrid dump or plasma research facility



Conclusions

- Substantial conversion of beam energy to e^+e^- possible at ILC Beam dumps
- Moderate intensity lasers
- Simulations show possibility

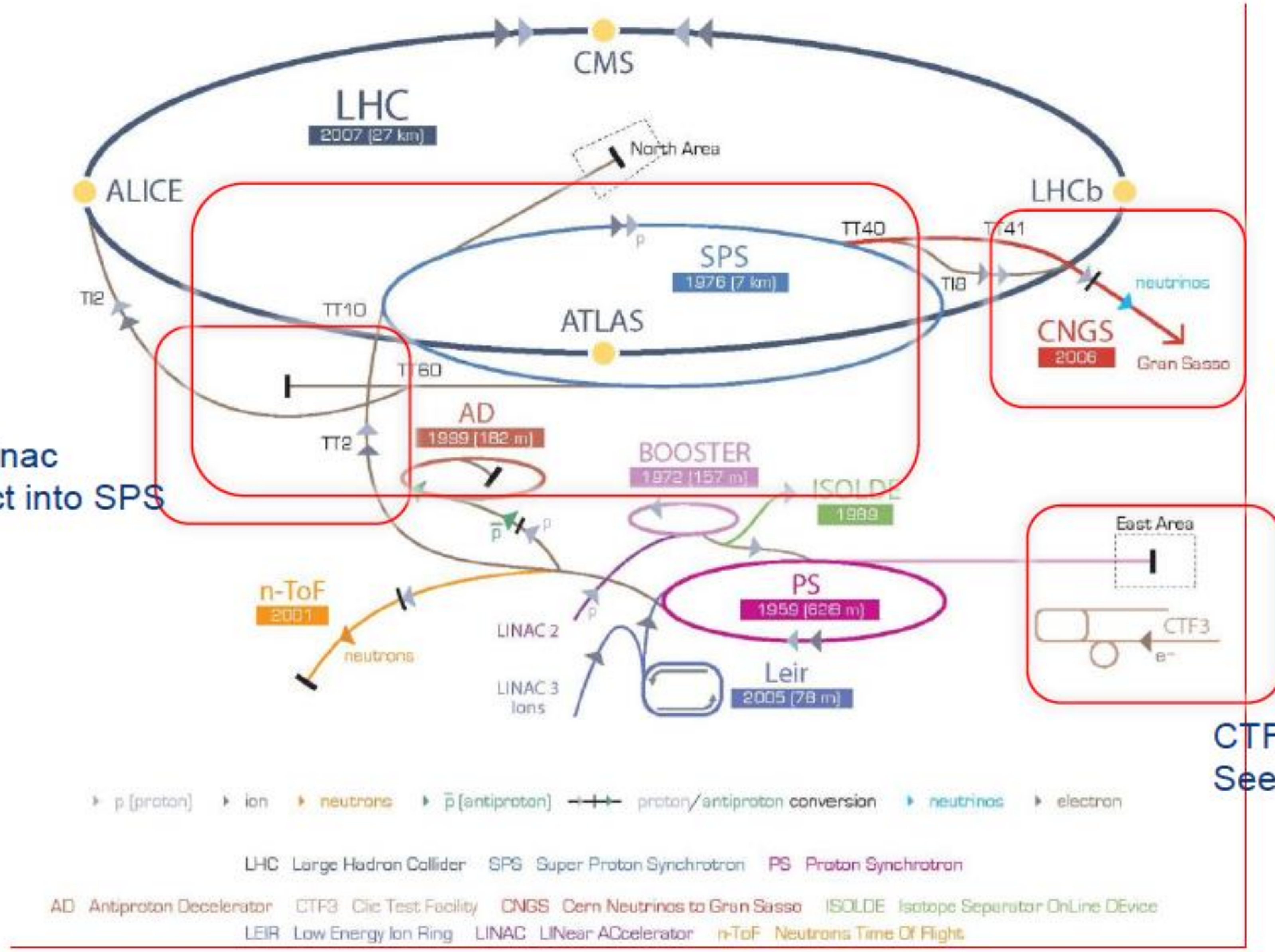
Next steps

- Particle-in-cell with QED effects
  - J. Magnusson et al., PRL **122** (2019).
  - Shower cascade, prolific e^+e^- production
  - e^+e^- plasma interacting with plasma
  - Plasma instabilities, nuclear fusion, transmutation…
- **Energy recovery!**

Electron beams at CERN

LCWS - Sendai October 2019

S. Stapnes (CERN)



eSPS x-band linac proposed, inject into SPS

Now AWAKE, plasma acc. experiment

CTF3 - now CLEAR
See talk of Roberto Corsini

Physics Beyond Colliders

Next workshop next week: https://indico.cern.ch/event/827066/

- **Exploitation of SPS/North Area**
  - Conventional North Area beams **(NA62+, KLEVER, NA64+, COMPASS…)**
  - Beam Dump Facility for **SHiP/TauFV**
  - eSPS for **LDMX**
  - nuSTORM for **neutrino cross-section etc.**
- **Novel approaches**
  - EDM proton storage ring, Gamma Factory, AWAKE++
- **LHC**
  - LHC fixed target **(gas, crystals)**
  - Long Lived Particles **(FASER, MATHUSLA, CODEX-b, milliQan)**
- **Technology**
  - Various options **(Helioscopes, "light-shining-through-walls"…)**

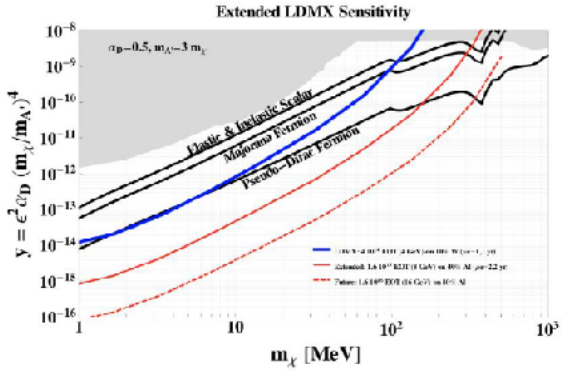
Motivations for eSPS

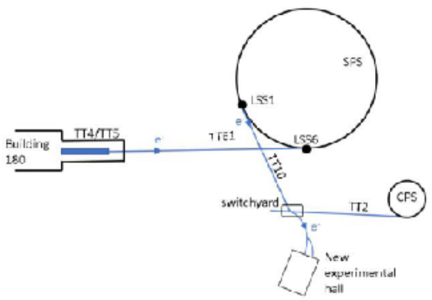
Physics: Large increasing interest in Light Dark Matter – using e-beams, the original trigger for the "eSPS proposal" – LDMX talks: Granada slides, FPS slides

Accelerator R&D:
Any next machine at CERN is "beyond LHC", i.e. 15+ years away – what can be done using smaller setups on a much shorter timescale ?

- Linac an important next step for X-band technology
- Relevant for FCC-ee, possible RF tests for example
- Strategic: Will bring electrons back at CERN fairly rapidly (linacs and rings) – important relevance for the developments and studies needed for future e+e- machines at CERN – being linear or circular

- Future accelerator R&D more generally: Accelerator R&D and project opportunities with e-beams as source
- Main directions: Novel Acc. studies (AWAKE) and CLEARER

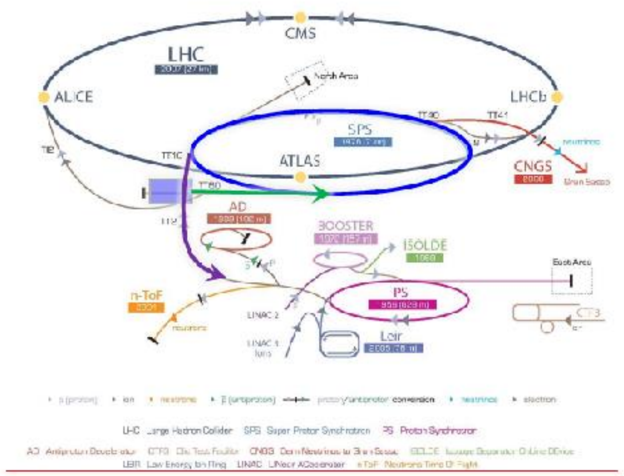




eSPS, overview

Accelerator implementation at CERN of LDMX type of beam

- X-band based 70m LINAC to ~3.5 GeV in TT4-5
- Fill the SPS in 1-2s (bunches 5ns apart) via TT60
- Accelerate to ~16 GeV in the SPS
- Slow extraction to experiment
- Experiment(s) considered by bringing beam back on Meyrin site using TT10

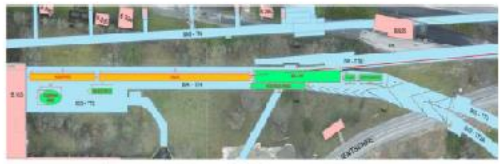


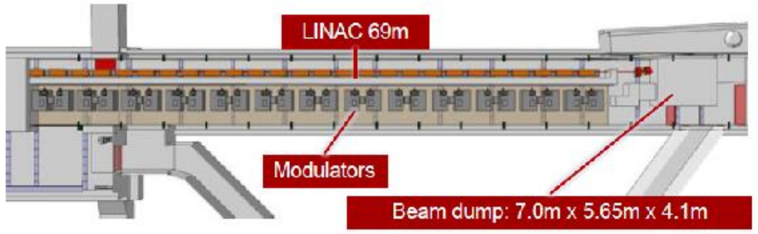
Beyond LDMX type of beam, other physics experiments considered (for example heavy photon searches)

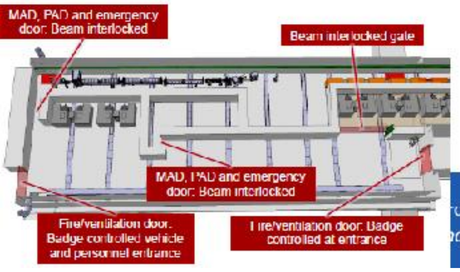
Acc. R&D interests (see later): Overlaps with CLIC next phase (klystron based), future ring studies (FCC-ee), FEL linac modules, e-beams for plasma, medical/irradiation/detector-tests/training, impedance measurements, instrumentation, positrons and damping ring R&D

Linac in TT5/TT4

- Flexible bunch pattern provided by photo-injector 5ns, 10ns, … 40ns bunch spacing (only constrained by the SPS) – consider now 800 MHz (1.25 ns)
- High repetition rate, for example
  - 200 ns trains at 100 Hz
- To be installed in the available transfer tunnels TT4, in line with the SPS
- Room for accelerator R&D activities at end of linac (duty cycle in many cases low for SPS filling so important potential)

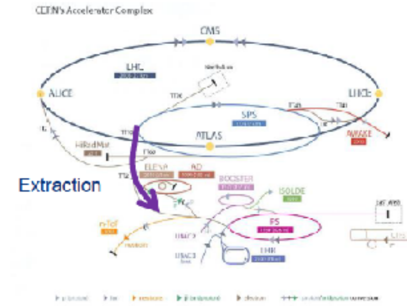


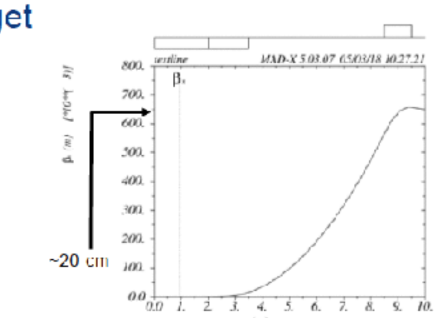




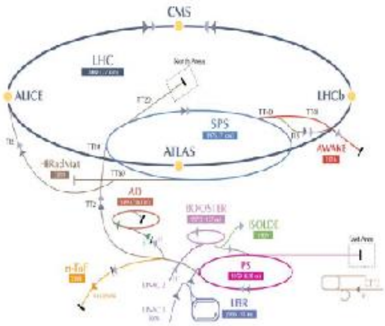
Electron beam transfer line from the SPS to experiments

- Uses existing TT10 line, designed to transport 10/20 GeV beams
- Collimation in the line for control of beam distribution and intensity
  - ~ Gaussian beam can be made almost flat by careful collimation
- Beam size might be increased greatly at the target
  - Size of beam-spot chosen to deliver number of electrons/cm²/bunch-crossing on target
  - For instance a 2cm vertical and 20cm horizontal beam is feasible
  - There is flexibility on the choice of both horizontal and vertical beam sizes





AWAKE

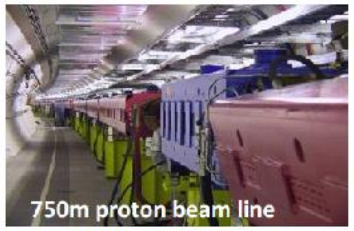


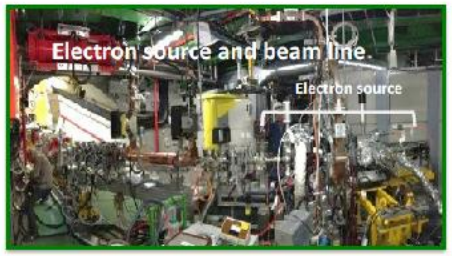
Advanced WAKEfield Experiment: Use protons beam as drive beam → powerful drivers at CERN, allow acceleration of electron to very high energies

→ PWA experiment dedicated to high energy physics applications!

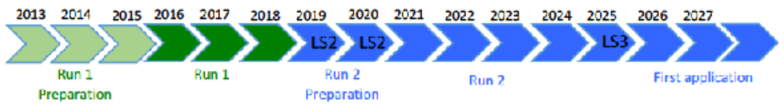
International Collaboration: 20 collaborating institutes, 3 associate institutes

Timeline:
2013: Approved
2016-2018: AWAKE Run 1: proof-of-concept experiment: demonstrated seeded self-modulation of the proton bunch and acceleration of electrons
2020- LS3: AWAKE Run 2: Accelerate electrons to high energies while preserving beam quality
After Run 2: Particle physics applications kick-off





AWAKE Run 2

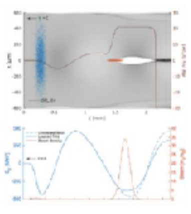


Goal:

Accelerate an electron beam to high energy (gradient of 0.5-1GV/m) → Freeze the modulation with **density step** in first plasma cell

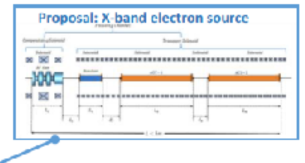
Preserve electron beam quality as well as possible (emittance preservation at 10 mm mrad level) → For emittance control: need to work in **blow-out regime and do beam-loading**

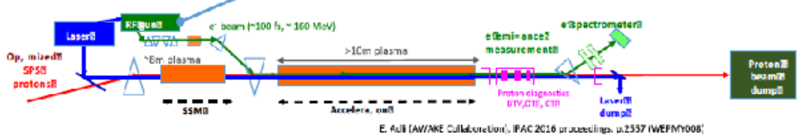
Demonstrate scalable plasma source technology (e.g. helicon prototype) → **R&D on different plasma source technologies**



Preliminary Run 2 electron beam parameters

Parameter	Value
Acc. gradient	>0.5 GV/m
Energy gain	10 GeV
Injection energy	$\gtrsim$ 50 MeV
Bunch length, rms	40–60 μm (120–180 fs)
Peak current	200–400 A
Bunch charge	67–200 pC
Final energy spread, rms	few %
Final emittance	≤ 10 μm





E. Adli (AWAKE Collaboration), IPAC 2016 proceedings, p.2557 (WEPMY008)

V. Olsen, E. Adli, P. Muggli, PRL 21, 011301 (2018)
K. Lotov, Physics of Plasmas 22, 103111 (2015)

→ External injection, Independent drive and witness beam, 10m long plasma cell, proton beam

→ Requirements on emittance are moderate for fixed target experiments and e/p collider experiments, so first experiments in not-too far future!

27

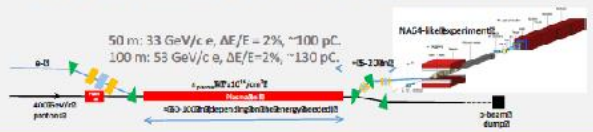
Applications with AWAKE-Like Scheme

→ Requirements on emittance are moderate for fixed target experiments and e/p collider experiments, so first experiments in not-too far future!

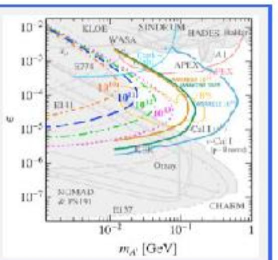
First Application:

→ **Fixed target test facility:** Use bunches from SPS with **3.5 E11 protons** every ~5sec,
→ electron beam of up to O (50GeV), **3 orders of magnitude increase in electrons** (compared to NA64)

→ deep inelastic scattering, non-linear QED, **search for dark photons a la NA64**

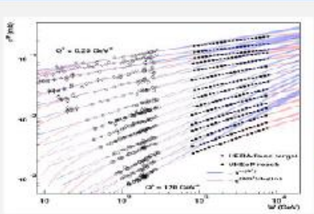


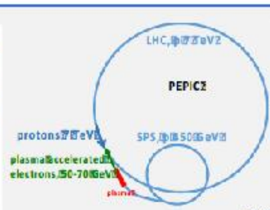
Parameter	AWAKE-upgrade-type	HL-LHC-type
Proton energy E_p (GeV)	400	450
Number of protons per bunch N_p	3×10^{11}	2.3×10^{11}
Longitudinal bunch size protons σ_z (cm)	6	7.55
Transverse bunch size protons σ_r (μm)	200	100
Proton bunches per cycle n_p	8	320
Cycle length (s)	5	20
SPS supercycle length (s)	40	40
Electrons per cycle N_e	2×10^{9}	5×10^{9}
Number of electrons on target per 12 weeks run	4.1×10^{15}	2×10^{17}

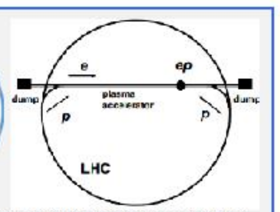


Using the **SPS** or the **LHC** beam as a driver, TeV electron beams are possible → Electron/Proton or Electron/Ion Collider

- **PEPIC:** LHeC like collider: E_e up to O (70 GeV), colliding with LHC protons → exceeds HERA centre-of-mass energy
- **VHEeP:** choose E_e = 3 TeV as a baseline and with E_p = 7 TeV yields $\sqrt{s}$ = 9 TeV. → CM ~30 higher than HERA. Luminosity ~ $10^{28} - 10^{29}$ cm^{-2} s^{-1} gives ~ 1 pb−1 per year.







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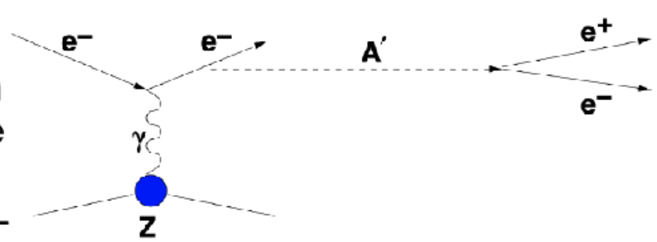
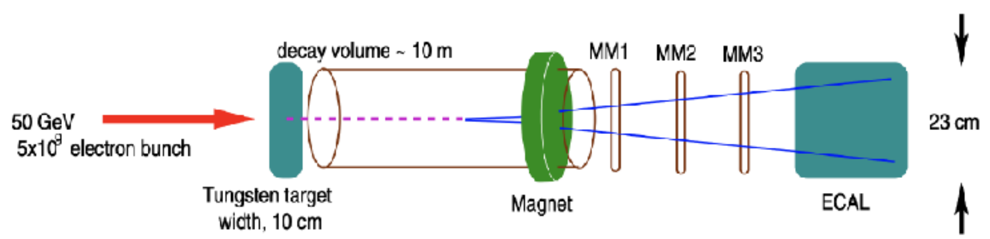
Search for dark photons using an AWAKE-like beam

- NA64 are making great progress investigating the dark sector:
  - Dark sectors with light, weakly-coupling particles are a compelling possibility for new physics.
  - Search for dark photons, *A′*, up to *GeV* mass scale via their production in a light-shining-through-a-wall type experiment.
  - Use high energy electrons for beam-dump and/or fixed-target experiments.



- An AWAKE-like beam will have higher intensity than the SPS secondary beam.
- Provide upgrade/extension to NA64 programme.
- Using NA64 software and similar detectors.



Concluding remarks

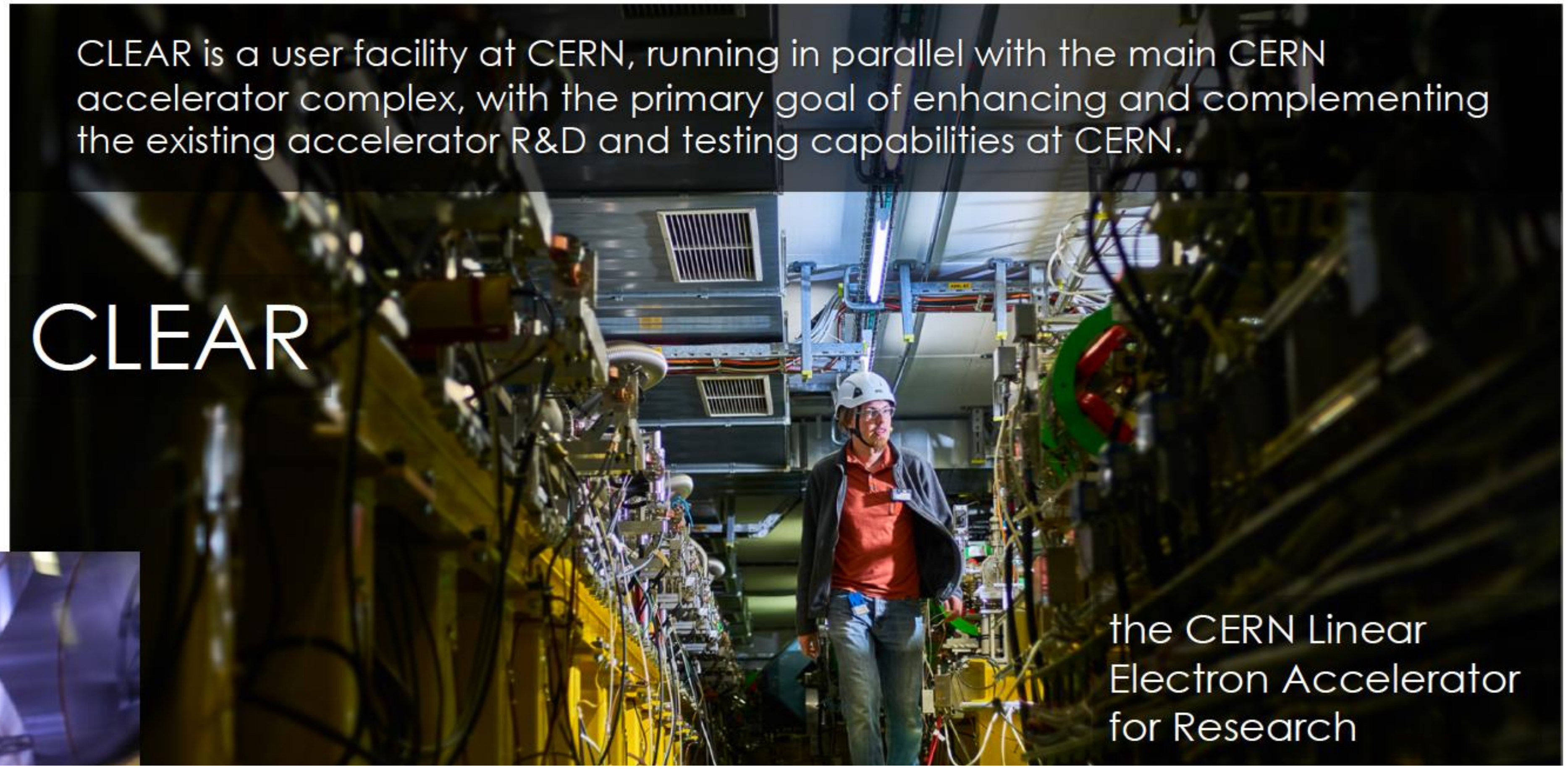
- Important physics opportunities with e-beams at CERN
  - Worth keeping in mind these physics (and acc. R&D) opportunities during construction, commissioning or in parallel with LC operation

- At CERN:
  - eSPS: Based on previous usage of the CERN accelerator complex, and building on the accelerator R&D for CLIC and HiLumi/FCC, an electron beam facility would be a natural next step
    - No show-stoppers have been found when exploring this option
    - LDMX interest in pursuing this option as beam close to ideal
    - Will also provide many opportunities for important and strategic accelerator R&D at CERN – and opens the door to future electron facilities in general

  - AWAKE++ can provide high energy electrons for Dark Photon Searches and e-proton / e-ion studies

Slides "collected" from Mike Lamont, Edda Gschwendtner (link) and Matthew Wing (link) – with thanks

CLEAR, an electron beam facility at CERN



R. Corsini - CERN

CERN Linear Electron Accelerator for Research

The CLIC Test Facility (CTF3) - completed its experimental program in 2016

Proposal to reuse the CLEX area and the CALIFES e- linac for accelerator R&D

Motivation

CLEAR - Scientific and strategic goals:

- Providing a test facility at CERN with hig
  - Performing R&D on accelerator compor high gradient RF technology realistic be
  - Providing an irradiation facility with high collaboration with ESA or for medical pu
  - Performing R&D on novel accelerating t particular developing technology and s beam emittance preservation for reachi
- Maintaining CERN and European expert (e.g. CLIC and ILC, but also AWAKE anc strengthening collaboration in this area.
- Using CLEAR as a training infrastructure f engineers

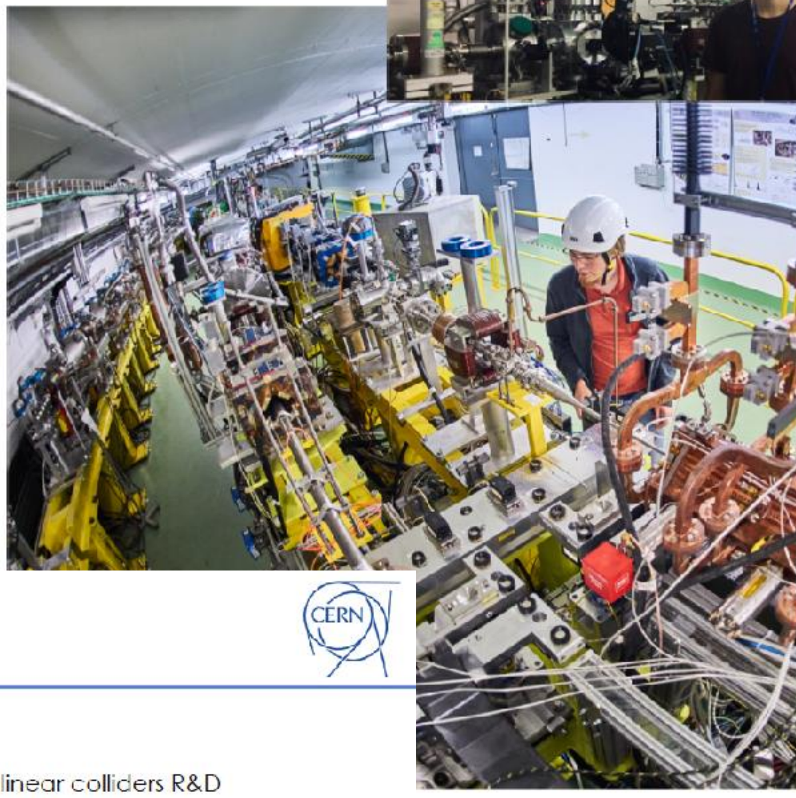
CLEAR operation 2017-2019

Start with beam August 2017

- 19 weeks of operation in 2017
- 36 weeks in 2018
- So far 31 weeks in 2019 (38 planned)

Main activities:

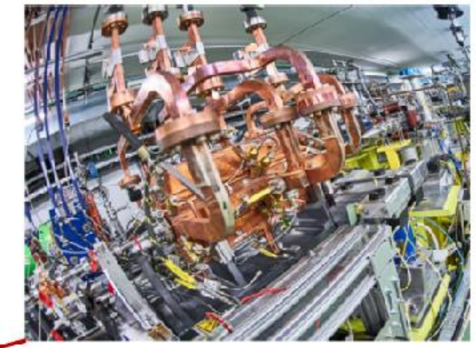
- CLIC & high-gradient X-band
- Instrumentation R&D
- VESPER irradiation test stand:
  - Electronic components for space applications (with ESA)
  - Medical applications (VHEE, FLASH)
  - Electronic components for accelerators and detectors



CLEAR Layout & main installations

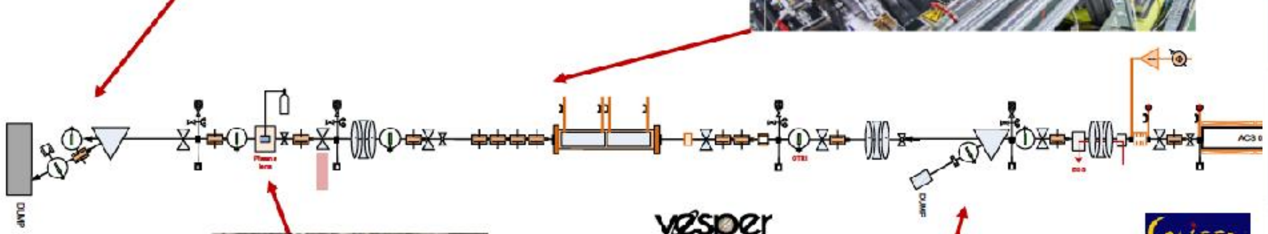
In-air test stand

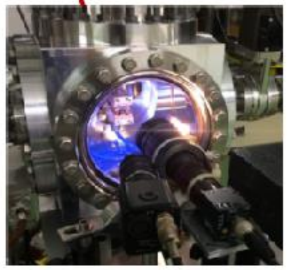
Testing ground for beam diagnostics R&D and THz radiation studies



CLIC Test-Stand

High-gradient and linear colliders R&D

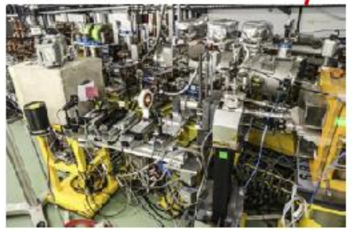




The Plasma Lens Experiment

Novel concepts of plasma-based focusing and acceleration

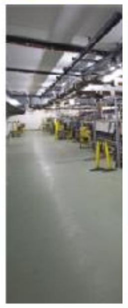
vesper



VESPER

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

CALIFES



CLEAR Beam Parameters

Beam parameter	Range
Energy	60 – 230 MeV
Energy Spread	< 0.2 % rms (< 1 MeV FWHM)
Bunch Length	0.2 ps – 10 ps
Bunch Charge	5 pC – 3 nC
Number of bunches per pulse	1 to >150
Maximum total pulse charge	30 nC
Normalized emittances	3 mm to 30 mm (bunch charge
Repetition rate	0.8 to 10 Hz
Bunch spacing	1.5 GHz (from Laser)

Beam Instrumentation R&D

Many activities planned (most ongoing)

Two main goals:

1) Con... instru...

2) Dia...

- Diffr...
- Elec...
- ...

Collab... group ... collabo...

Direct ... accele... for futu...

S. Mazzoni, ...

CLIC related activities

Ongoing experiments:

Tests of Wakefield Monitors at CLEAR — K. Sjobaek, Tue 22
Wake-fields measurements on the CLIC structure — A. Gilardi, Thu 24

- W...
- W...
- CL...

Main ...

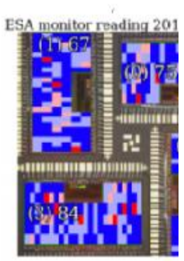
- Univ...
- CEA...
- Univ...
- RHU...

Next s... the co... possib...

- RF ...
- Bre...
- RF ...
- Sta...

VESPER irradiation facility

alignment screen

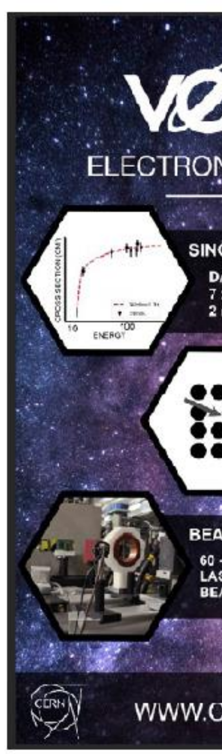


- Installed in a spectrometer line

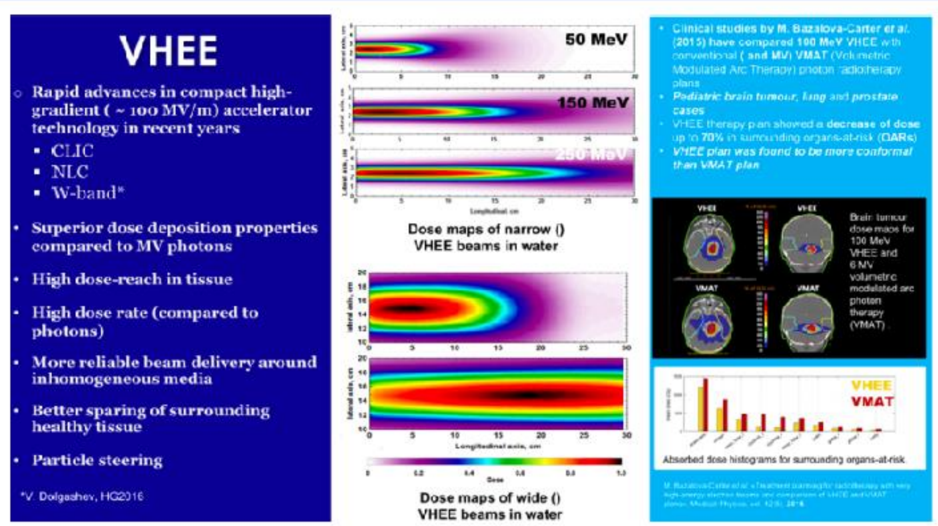
Medical applications (VHEE, FLASH)

VESPER irradiation facility R2E

- Beam line already developed and tested in 2016, in collaboration with the CERN R2E team
- In CLEAR we improved diagnostics, stability and energy range (60 - 220 MeV)



Medical irradiation tests in VESPER



Manchester University: A. Lagzda, R. Jones and other
- Project to characterize VHEE irradiation on radiosensitive films

Initial interest: Manchester Univ. (A. Langzda, R. Jones)

- Three measurements campaigns (2017-2018)

Further requests from:

Nat. Phys. Lab. UK (A. Subiel et al.)

- Two measurement campaigns (end 2018, spring 2019)

Strathclyde University (K. Kokurewicz et al.)

- One campaign completed (end 2018)

Oldenburg University and PTW (B. Poppe, D. Poppinga et al.)

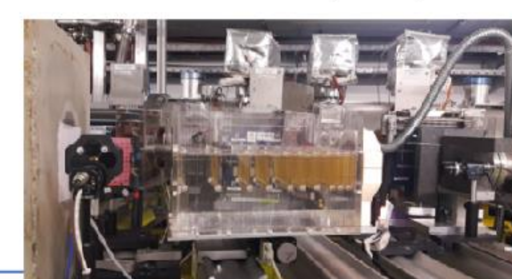
- Two campaigns completed (end 2018, September 2019)

CHUV Lausanne (M.C. Vozenin, C. Bailat, R. Moeckli et al.)

- Preliminary tests (end 2018, spring 2019)

Activities:

- Experimental verification of dose deposition profiles in water phantoms
- Calibration of operational medical dosimeters – nonlinear effects with short pulses
- Demonstration of "Bragg-like peak" deposition with focused beams



Relative Insensitivity to Inhomogeneities on Very High Energy Electron Dose Distributions

Very-High Energy Electron (VHEE) Studies at CERN's CLEAR User Facility

clear Plasma lens

Activity started and led by University of Oslo

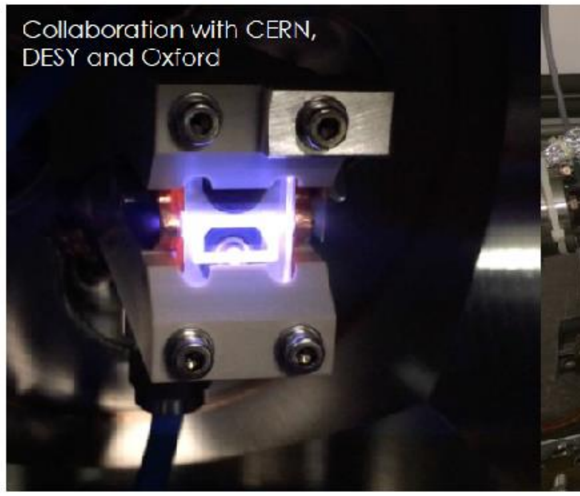
Collaboration with CERN, Desy and Oxford Univ.

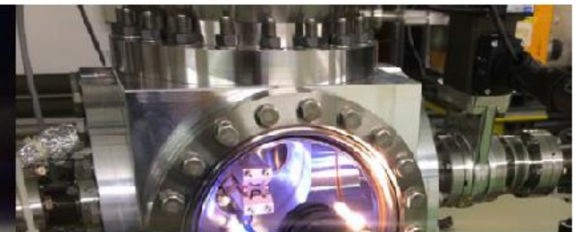
Several measurements campaigns

One PhD (Carl Lindstrom)

Very relevant results, clarifying seemingly contradictory observations

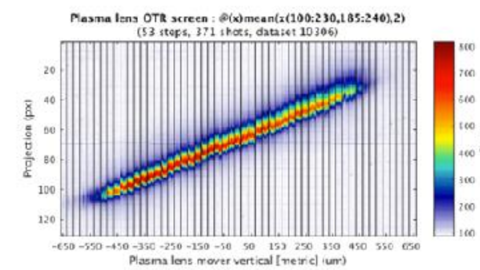
Lead by University of Oslo





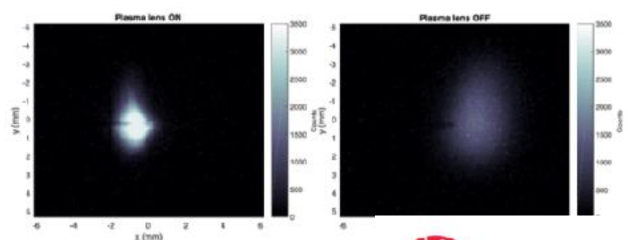
clear

Recent result from the CLEAR Plasma Lens Exp. – Obtained Dec 12, 2017



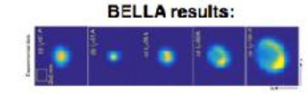
Vertical offset of the plasma lens using a pencil beam.
Dipole kicks measured as offset downstream.

Plasma lens on/off

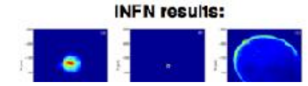


- **No evidence of nonuniform focusing** in the first direct measurement of the field.
- Measurements thus far were only indirect measurements showing spherical aberrations.

BELLA results:



INFN results:

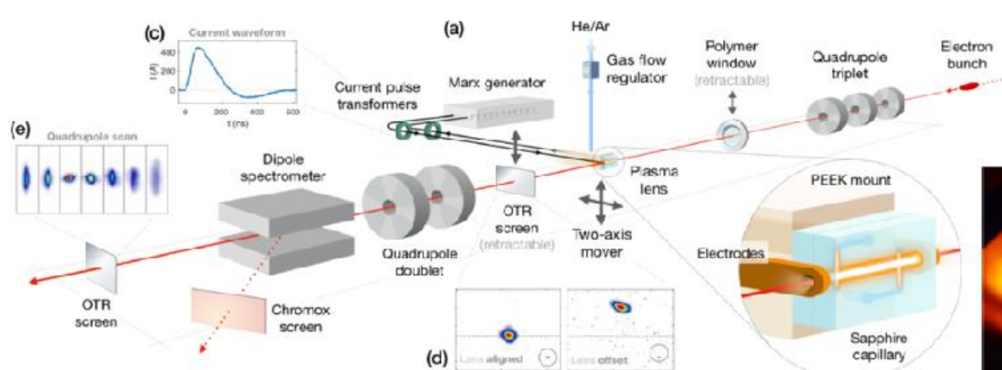


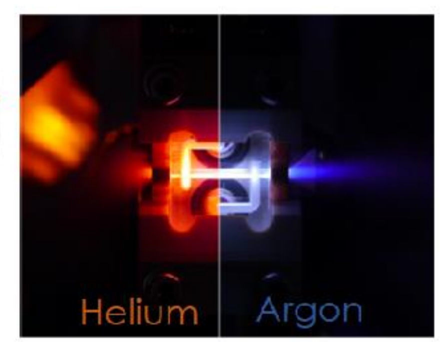
C. Lindstrom, E. Adli, K. Sjobaek et al.

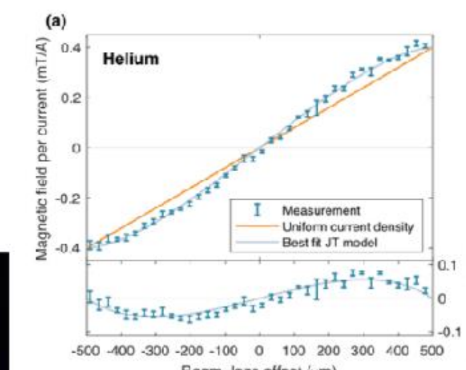
clear Plasma lens

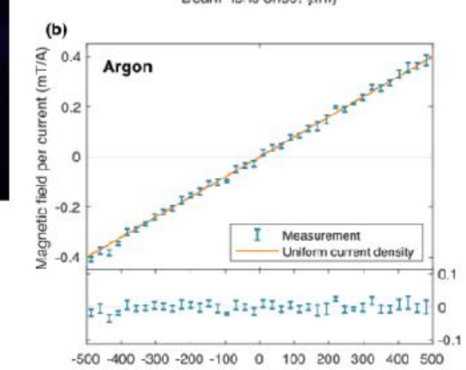
Emittance Preservation in an Aberration-Free Active Plasma Lens

C. A. Lindstrøm, E. Adli, G. Boyle, R. Corsini, A. E. Dyson, W. Farabolini, S. M. Hooker, M. Meisel, J. Osterhoff, J.-H. Röckemann, L. Schaper, and K. N. Sjobak
Phys. Rev. Lett. **121**, 194801 – Published 7 November 2018









- Emittance preservation in an active plasma lens demonstrated for the first time with the use of an argon-based discharge capillary.
- Direc[...] Last week – record magnetic field gradient of 5.2 kT/m ! [...]n and nonlin[...]
- Quadrupole scans demonstrated expected emittance preservation and growth (respectively) consistent with the measured field profiles.

THz studies

- First tests in sub-THz region, demonstrated use as bunch length diagnostics
- Characterization of beam-produced THz radiation from TR screen + shadowing studies, using THz camera from Univ. Roma
- Bunch length diagnostics for CLEAR
  - Close to be operational - Teflon conical Cherenkov diffraction radiator, 4 frequency detection bands.
- High power THz from different sources
  - Tested so far: diamond, TR screens, Teflon, gratings, metamaterials

Many possibilities beyond that…

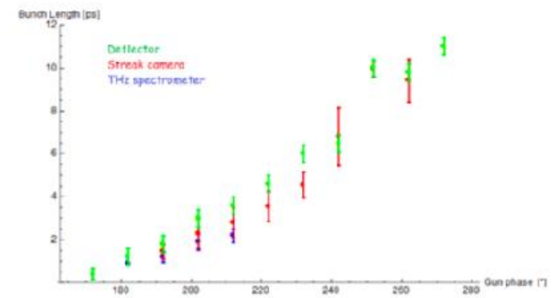


Figure 2: Bunch length measurement with different techniques/detectors. The bunch length compression in this case was made only by varying the gun phase, March 2018.

A. Curcio, M. Bergamaschi, T. Lefevre et al.

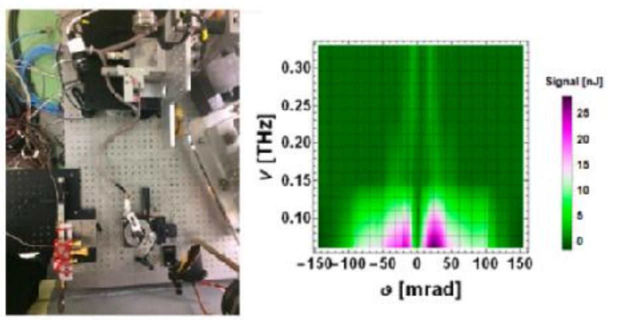
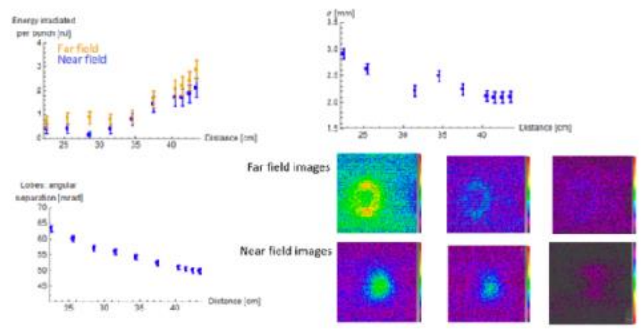


Figure 3: **Left:** Experimental setup for the spectral-angular characterization of CTR light. **Right:** Experimental results on spectral-angular characterization of the CTR light emitted by a 215 MeV, 40 pC, 1.5 ps long electron bunch, April 2018.



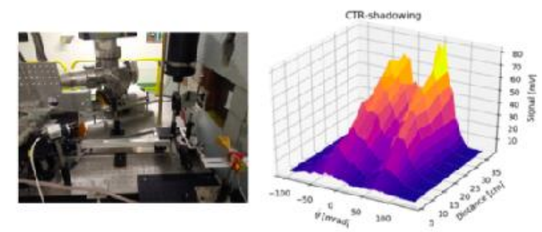
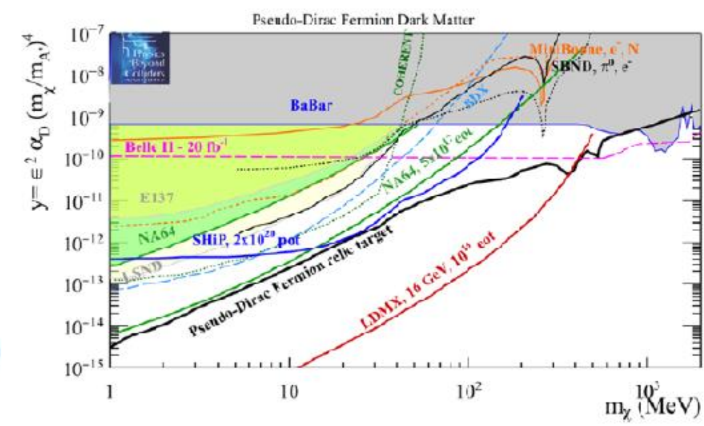


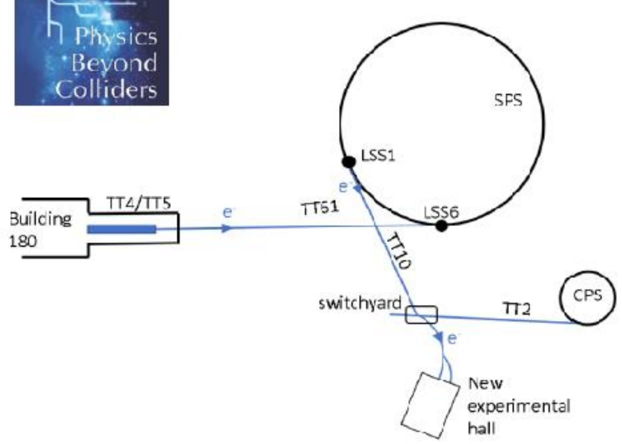
Figure 4: **Left:** Experimental setup for the two-screens experiment. **Right:** Experimental results on the electromagnetic shadowing at $\lambda = 4$ mm. The distance axis is understood to be the distance between the two CTR screens, May 2018.

The e-SPS / LDMX proposal

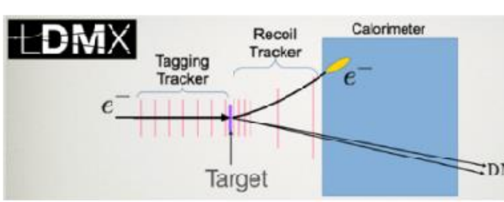
Accelerator implementation of e-beams at CERN for physics – Light Dark Matter search

- **70 m long X-band based linac (CLIC technology) in TT4-5 accelerates e- to 3.5 GeV**
- SPS filled in 1 to 2 s via TT60
- Acceleration to 16 GeV in the SPS
- Slow resonant extraction down the TT10 transfer line in ~10 s
- Beam delivered via the existing TT10 line to the Meyrin site
- A new, short beamline would branch from TT10 to the experimental hall (LDMX)





- Input to EU Strategy for Particle Physics Update
- Preparing CDR (beginning 2020)



S. Styapnes, today

CLEARER*, perspectives for a 3 GeV linac

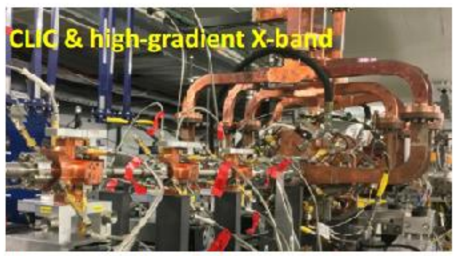
* CERN Linear Electron Accelerator for Research, Extended Energy Range

CERN Linear Electron Accelerator for Research

- User facility for general accelerator R&D and component studies for existing and possible future machines at CERN
- 200 MeV, S-band electron linac

- The 3.5 GeV Linac injector has to be be very similar to CLEAR → **present baseline is re-use CLEAR linac**
- In-house know-how available in any case
- 3.5 GeV Linac may be used to **extend** in a significant way the present CLEAR program – by sharing beam time with e-SPS

Relevance in different areas



The 3.5 GeV linac itself is a perfect show-case for the technology. Dedicated tests.

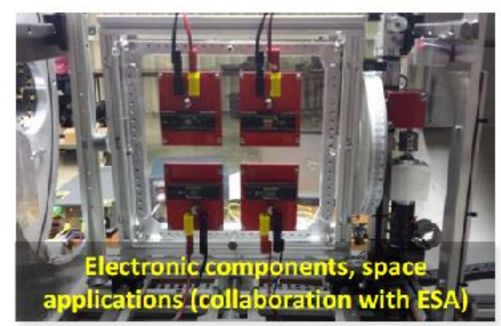
A 3.5 GeV, better quality beam will extend the R&D scope dramatically (e.g., for diffraction radiations studies, high-res BPMs) .

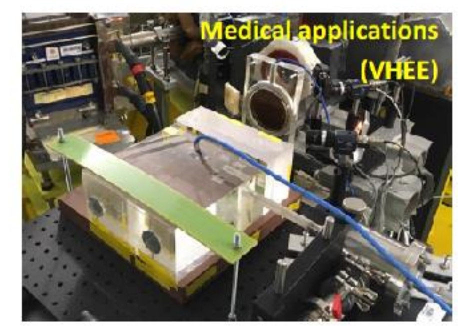
Potentially important options: single bunch capability, two independent-timing sources, positrons?

Higher beam energy makes easily accessible extended interaction regions and staging.

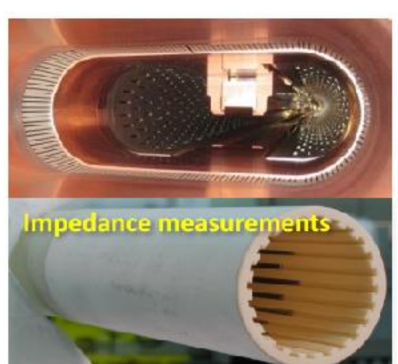
CLEARER*, perspectives for a 3 GeV linac

* CERN Linear Electron Accelerator for Research, Extended Energy Range





Potential of higher energy reach unclear. Continuation of present program (intermediate stations along the linac) desirable.



Impedance measurements in time domain (wake-fields) may reach higher precision with a 3.5 GeV beam.

An electron test beam:

- Electron beams can also be used for detector tests of course - 200 MeV in CLEAR low, but 3-15 GeV interesting – repetition rates can be very high
- A good example of a successful facility is the LNF BTF up to 750 MeV (BTF: Beam Test Facility - see recent summary (link)
  - Used 200day/year, 25-30 groups, 150-200 users
  - Examples of use: calorimeter studies, diamond detector studies, calibration systems, air shower plasma, etc
- DESY another example, several e-beams up to ~6 GeV (recent workshop) very much used