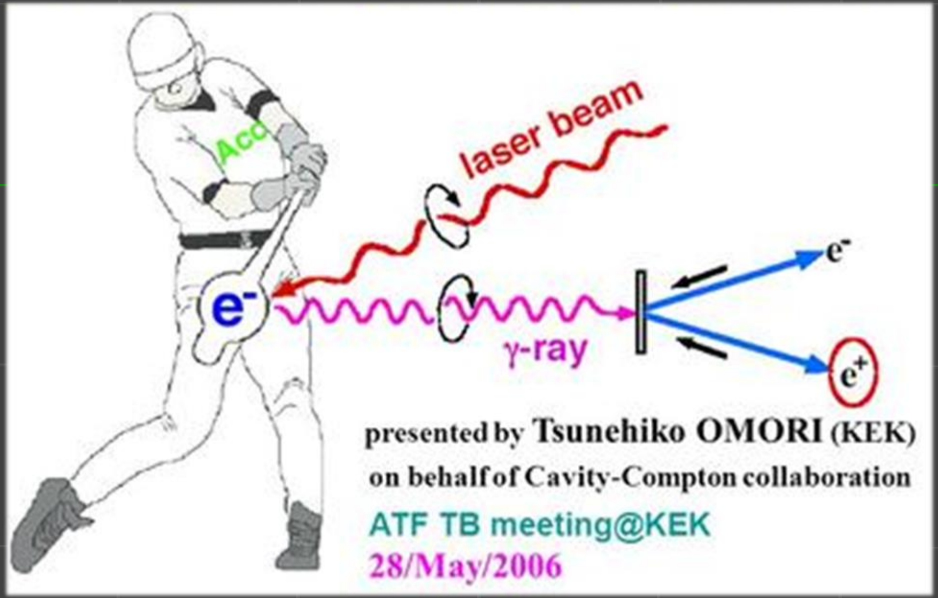
Laser Compton scattering in the collider

Illya Drebot

What is Compton Back Scattering?

$$\nu = \frac{(1+\underline{e}_k\cdot\underline{\beta})}{(1-\underline{n}\cdot\underline{\beta})+\frac{h\nu_L}{mc^2\gamma}(1-\underline{e}_k\cdot\underline{n})}\nu_L \approx 4\gamma^2\nu_L$$



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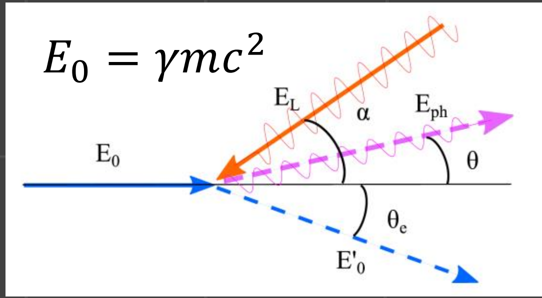

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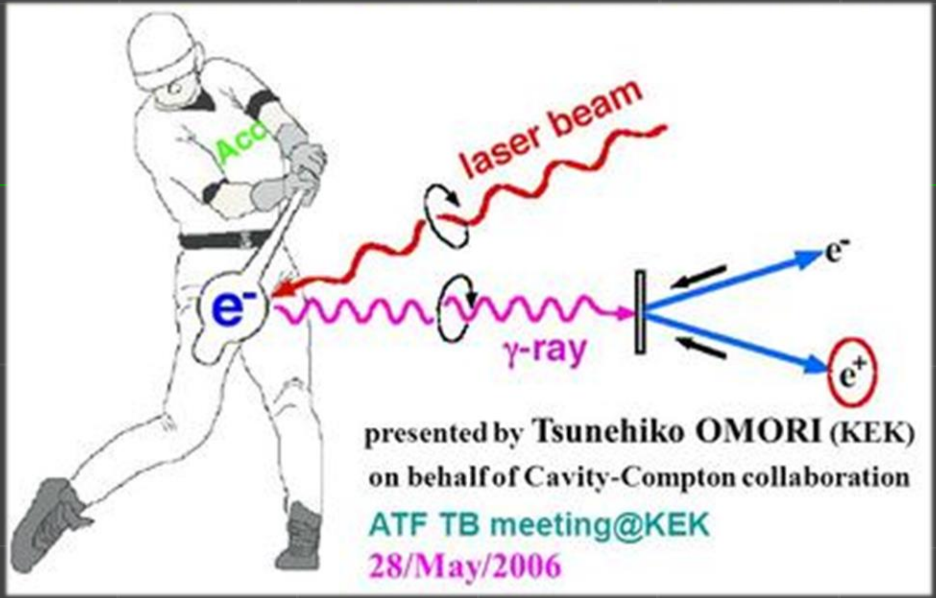
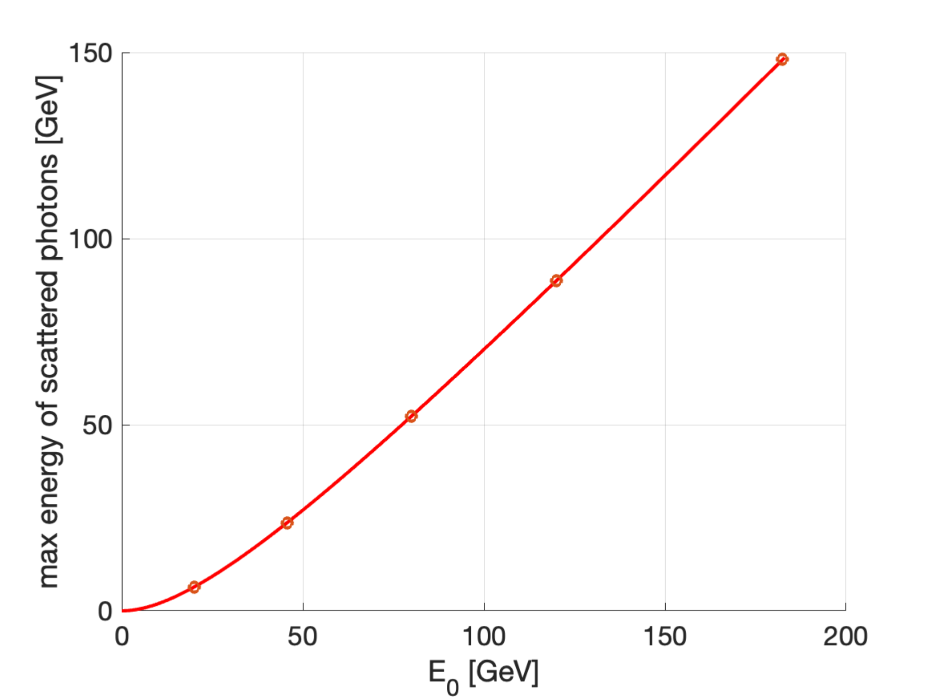
$$E_{ph} = \frac{4\gamma^2 E_l}{1 + X + \gamma^2\vartheta^2}$$

$$X \equiv \frac{4\gamma E_l}{mc^2}$$





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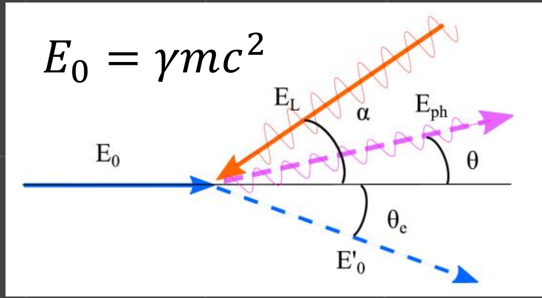

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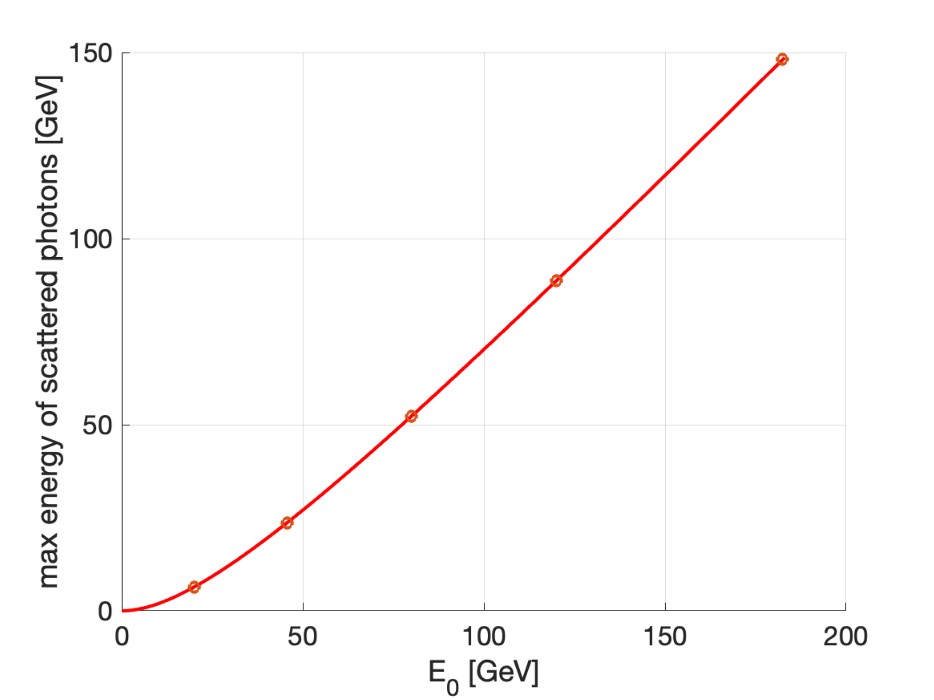


Why we CBS need it in the FCC?

Gamma source

Beam intensity control

Beam diagnostic (Polarimetry)

FCC POLARIMETER

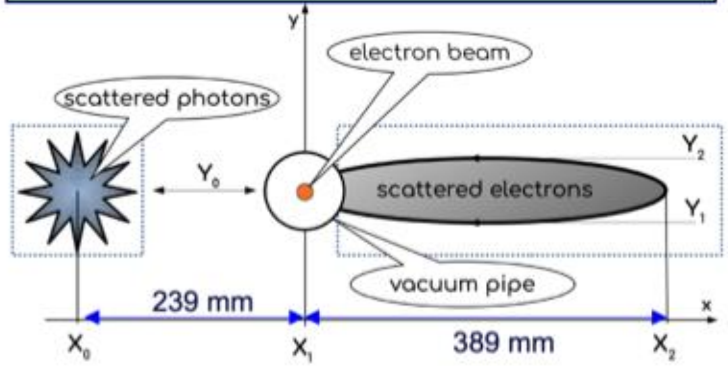
Number of scattering particle 10^3-10^4 per one shot

FCC 13 june / FCC week Robert Kieffer 2

The FCC Compton polarimeter

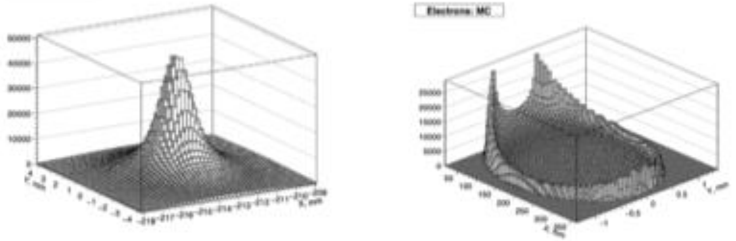
- **Centre of mass energy calibration** is obtained from the resonant depolarization scans (RDP) on pilots.
- **Direct energy measurement** by pattern position
- Precise **longitudinal polarization measurement** on physics bunches (expected to be zero at 10^{-5}).
- **Free spin precession** (looks challenging).

Profiles At 96 m from Laser IP



Implementation needs

- Dedicated powerful laser and adapted hutch
- Laser Compton interaction chamber LIP
- Spectrometer magnet stuffed with Hall sensors
- Compton electron/photon extraction line chamber
- Particle sensors (silicon pixels detectors)
- Polarizing wigglers to speedup polarization buildup.
- RF kickers to apply resonant depolarization.



8 x 10 mm²

350 x 2 mm²

From N.Muchnoi

Courtesy Robert Kieffer

Beam intensity control

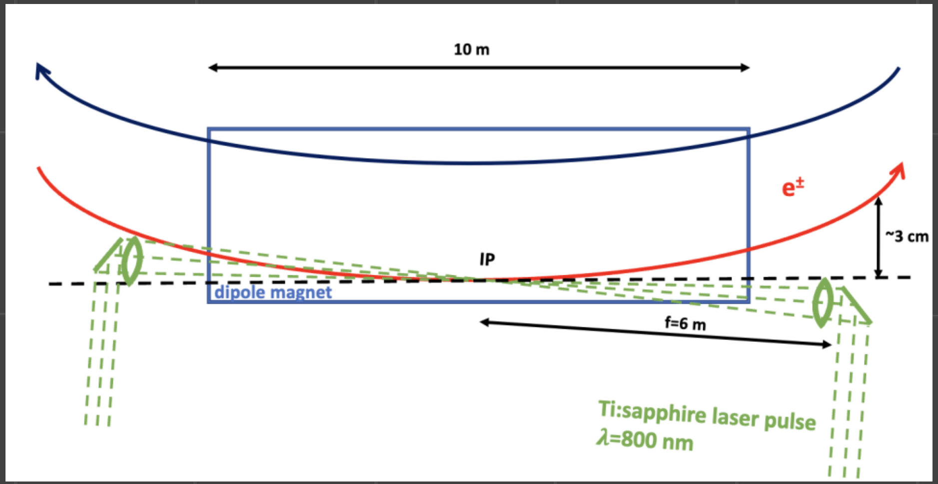
Why we need?
Asymmetry in the bunch current leads to Flip-flop instability. To avoid this bunches at IP must be bunches should be tightly controlled, with a maximum charge imbalance between collision partner bunches of less than 3–5%.

How to realise it?
Compton Back Scattering (CBS)

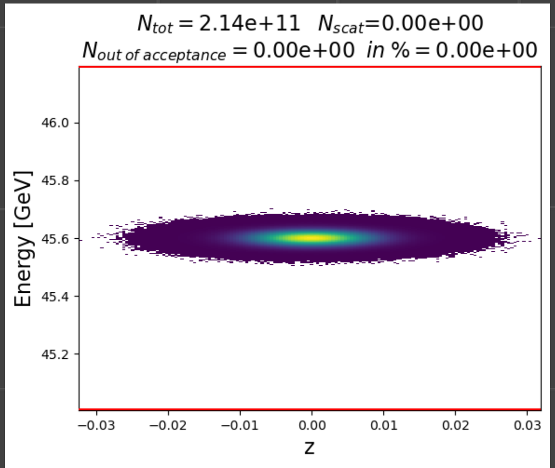
Laser parameters

Specifications THALES

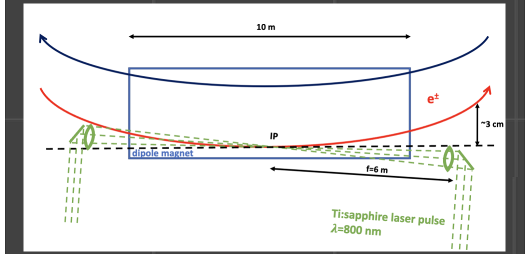
Version	Alpha kHz
Repetition rate (kHz)	1 to 10
Energy per pulse (mJ) after compression	10 to 50
Pulse duration FWHM (fs)	Down to 25
Pulse to pulse energy stability (% rms)	≤ 1.5
M^2	< 1.8

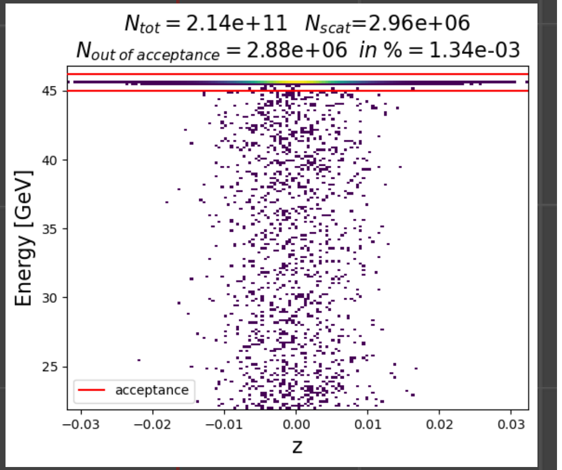


Beam intensity control



Beam ps before CBS





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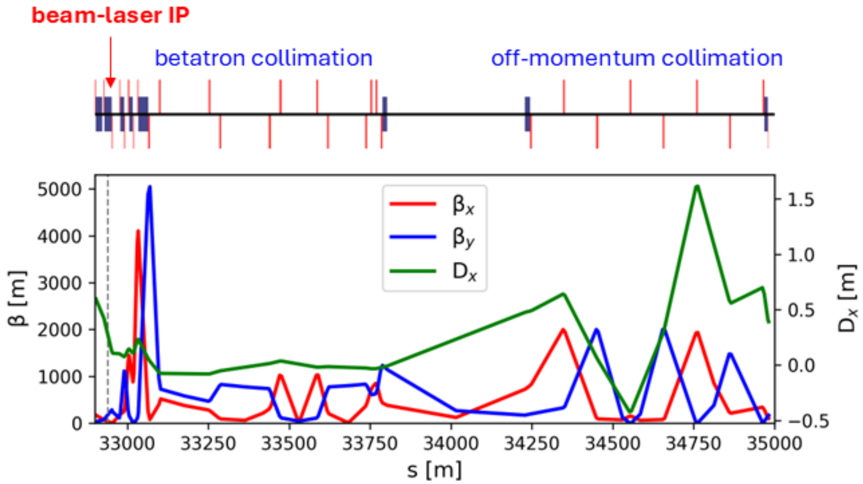
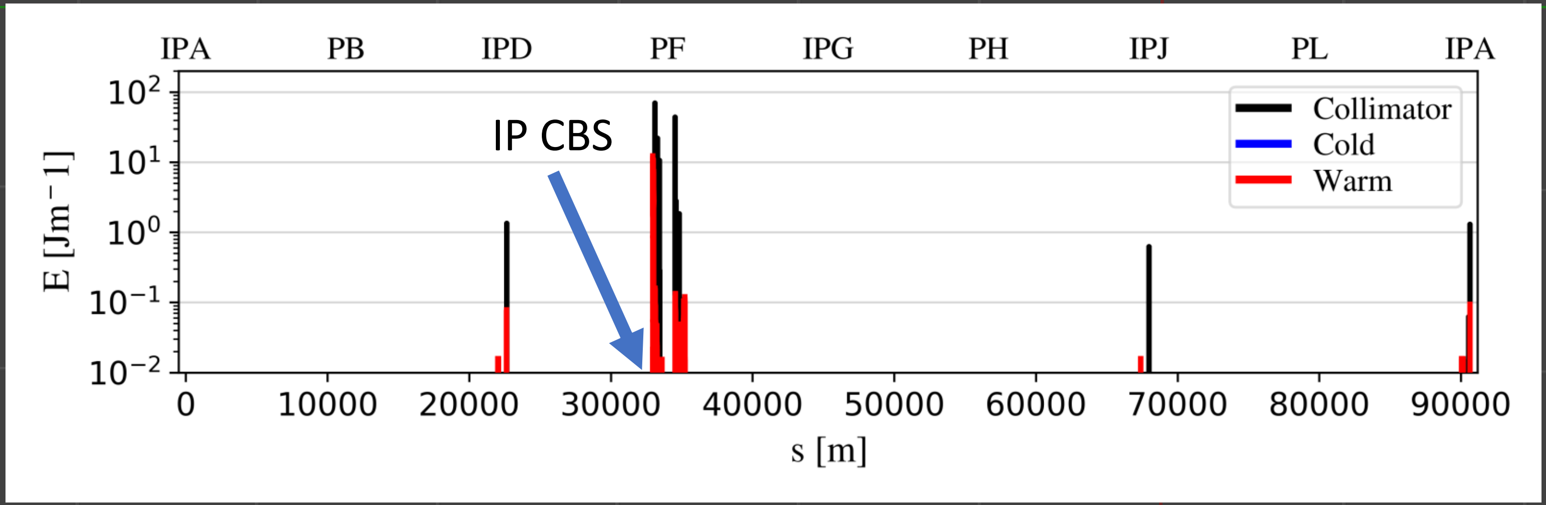
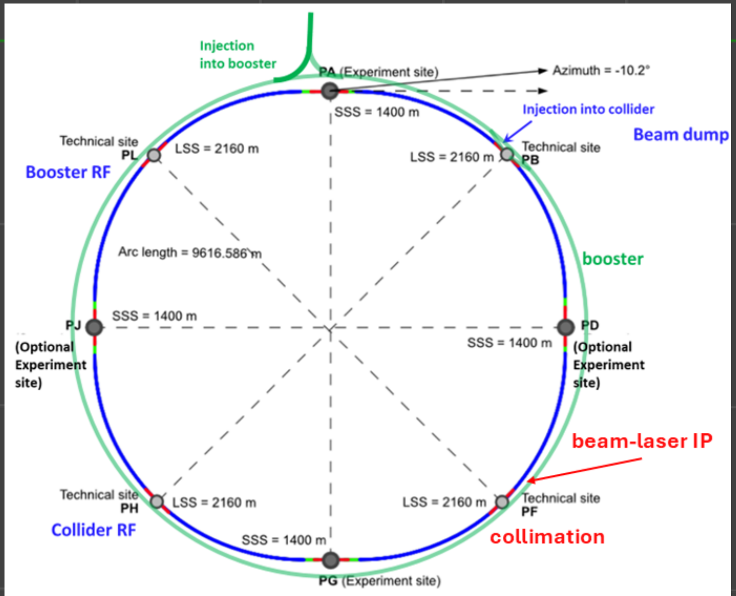


Possible location of CBS IP



Loss map

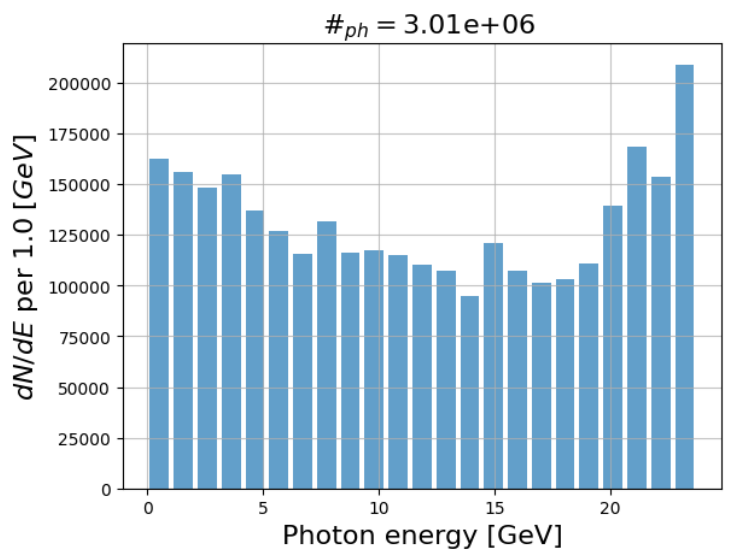


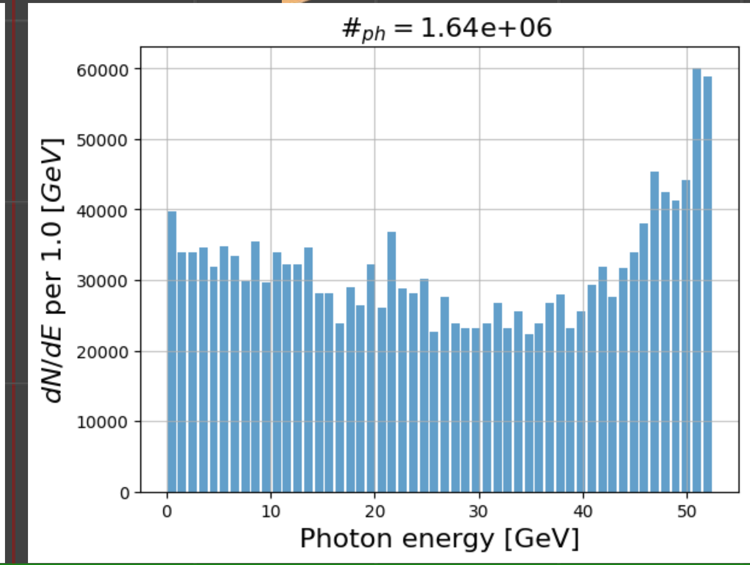
Courtesy Giacomo Broggi

Spectrums

For 50 mJ with rep rate 3.7 kHz

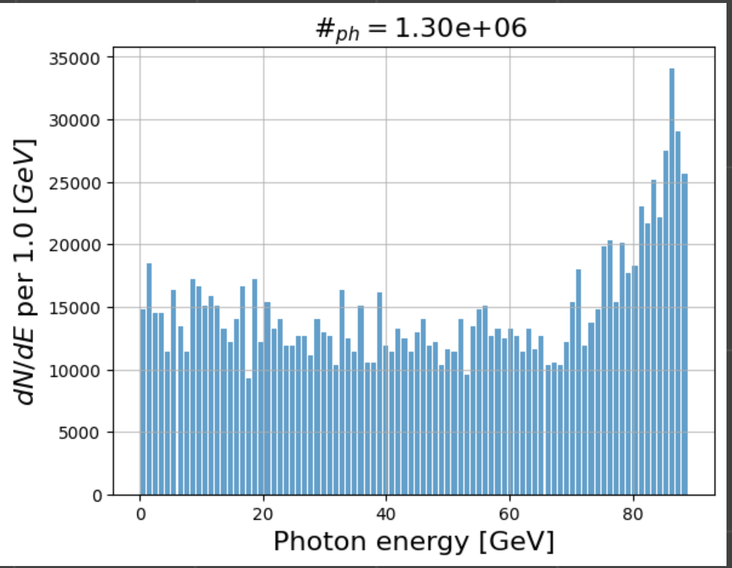
Z
E= 45 GeV
E_{phmax}=24 GeV

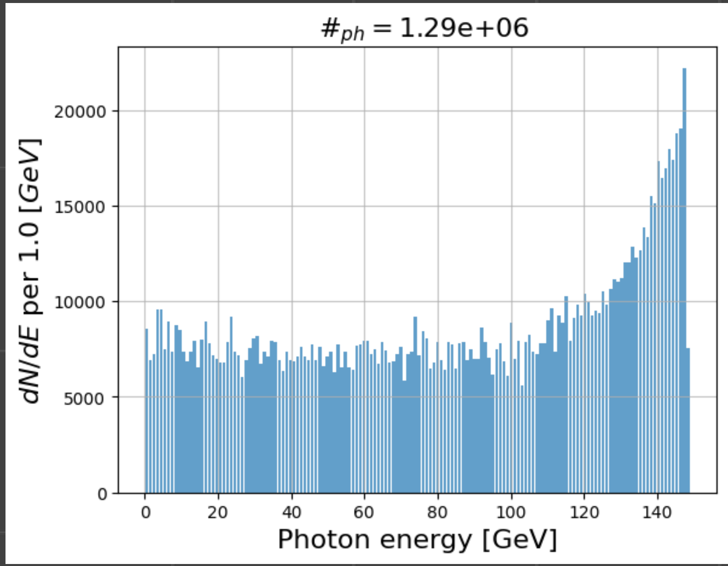




W
E= 80 GeV
E_{phmax}=52 GeV

ZH
E= 120 GeV
E_{phmax}=89 GeV





$t\bar{t}$
E= 180 GeV
E_{phmax}=149 GeV

Booster as light source

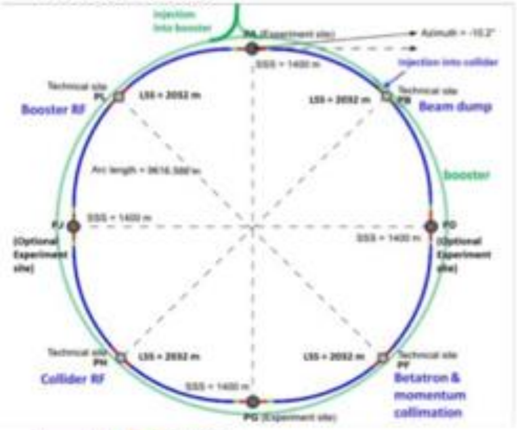
2nd FCC Italy & France Workshop 05/11/2024 Antoine CHANCE FCC booster design 15

Proposal of to use the booster as a light source

Courtesy: Sara Casalbuoni

FCC-ee booster as a Light Source

FCC-ee booster



European XFEL

3

Present parameters used for study of FCC-ee booste as photon source

	U_0 x 3	U_0 x 94
beam energy [GeV]	**20**	**20**
avg. beam current [mA]	**6**	**6**
number of bunches	1120	1120
rms bunch length [mm]	7.9	9.5
rms relative energy spread [10^{-3}]	1.8	2.2
beta at wiggler /undulator [m]	1.6	1.6
wiggler field [T]	1	1
wiggler period [mm]	40	40
magnetic gap [mm]	10	10
tot. length wiggler [m]	6.4	264
hor. emittance [pm rad]	**15**	**0.5**
vert. emittance [pm rad]	**<1.5**	**<0.05**

circumference = 90.7 km

without wigglers

U_0 = energy loss / turn = 1.33 MeV

hor. em. = 46 pm rad; vert. em. < 5 pm rad

FCC-ee booster as a Light Source 4

FCC-ee booster operated as photon source

- Fixed-field chicane: the beam automatically moves out of the wiggler during acceleration

top view

- **U_0 x 3 : 1 U40 6.4 m → ε_x = 15 pm rad**
- **U_0 x 94 : 53 U40 5 m → ε_x = 0.5 pm rad**

Permanent magnet technology

magnetic gap [mm]	10		
undulator field [T]	0.71-0.32		
undulator period [mm]	28		U28
undulator unit length [m]	5		
wiggler field [T]	1		
wiggler period [mm]	40		U40
	U_0 x 3	U_0 x 94	
wiggler unit length [m]	6.4	5	

European XFEL

Booster as light source

Proposal of to use the booster as a light source

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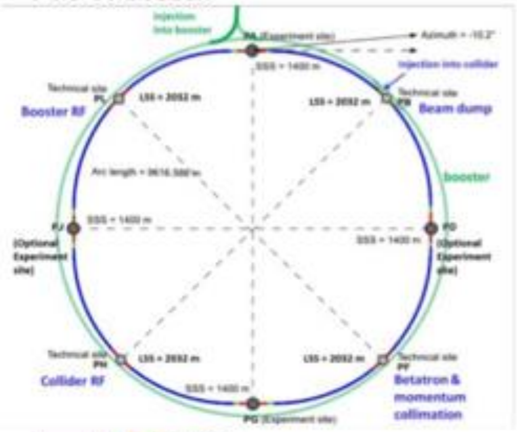
FCC-ee booster



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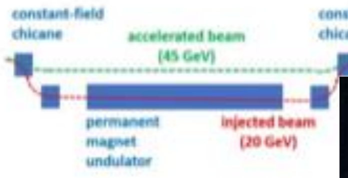

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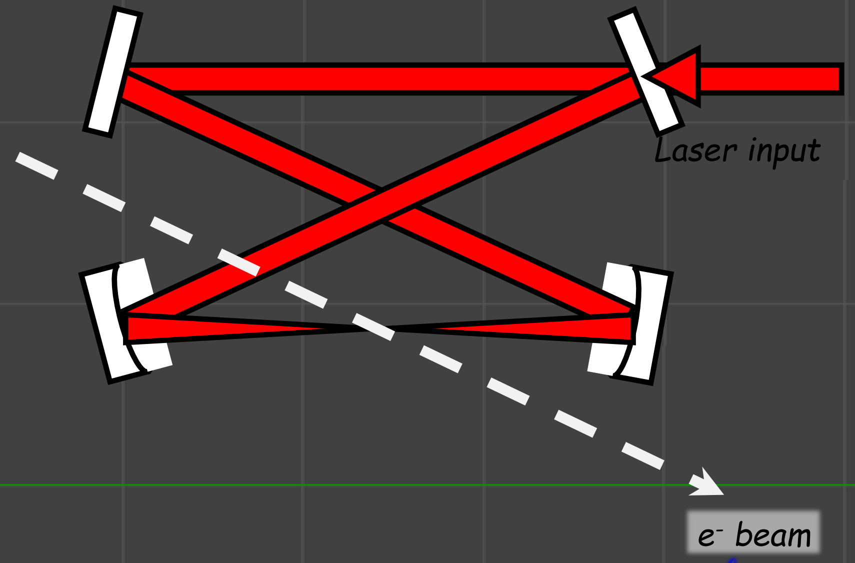
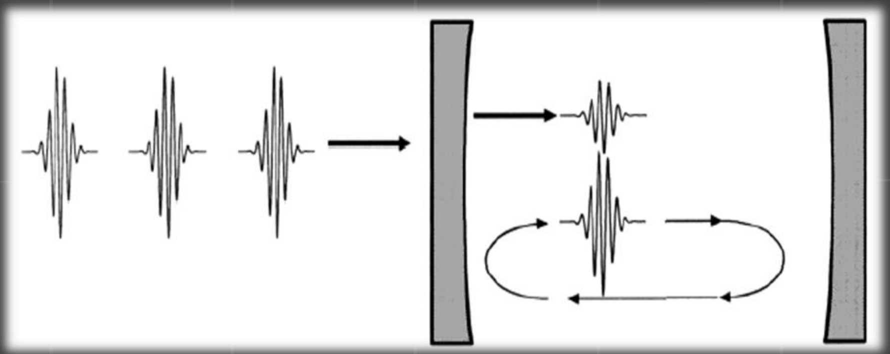
Permanent magnet technology

Laser & Fabry-Perot cavity

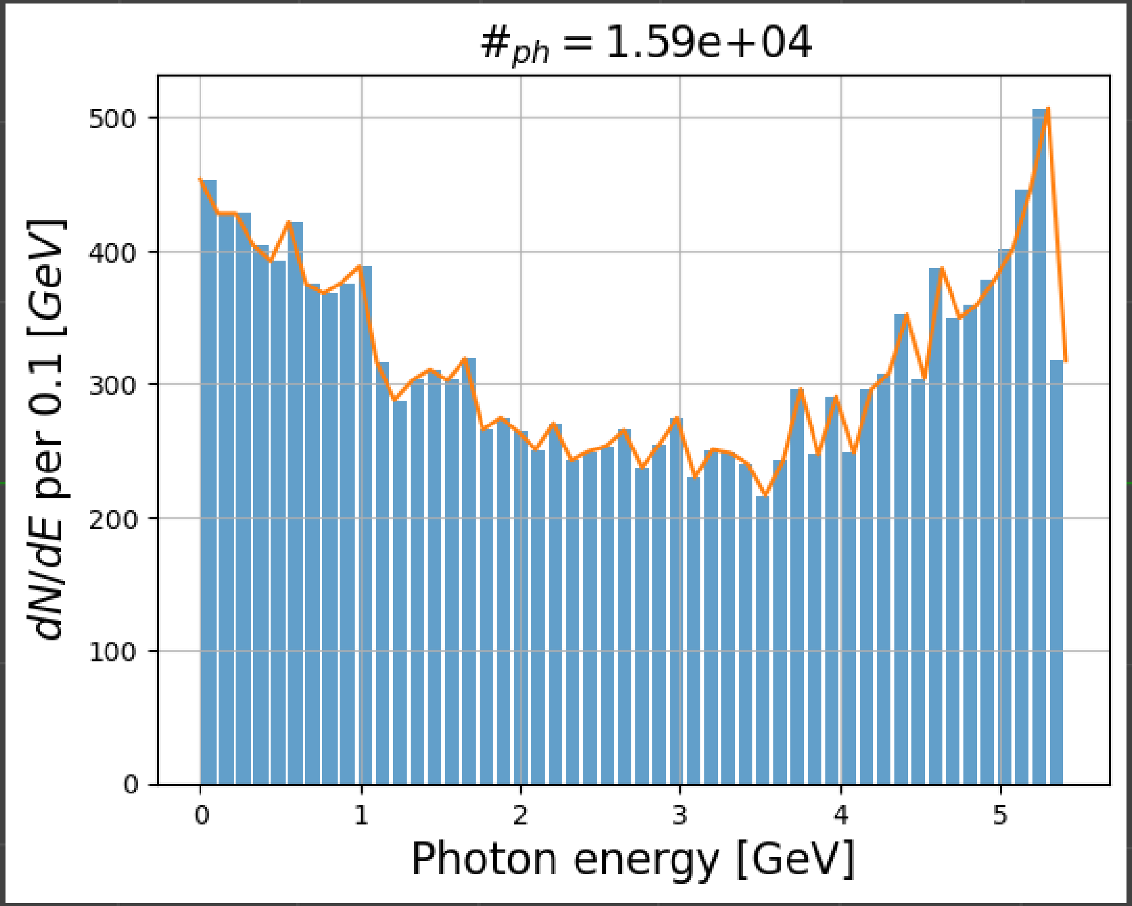




Laser and FP cavity	ThomX
Laser wavelength	1030 nm E_{las}=1.2 eV
Laser and FP cavity Frep	33 MHz
Pulse energy	15 mJ
FP waist	70 μm
Laser pulse length	1 ps

Laser and Fabry-Perot cavity accumulate photons.
It give us possibility to collide photons with pulse energy of 15 mJ

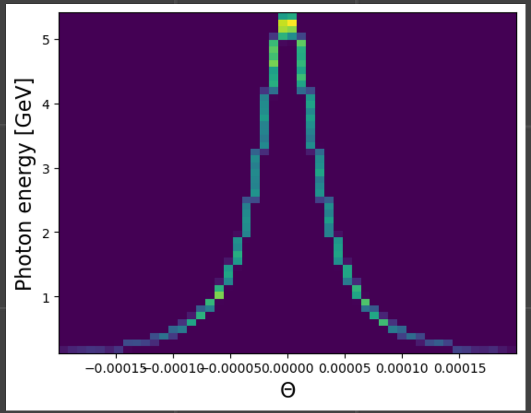
Booster as light source

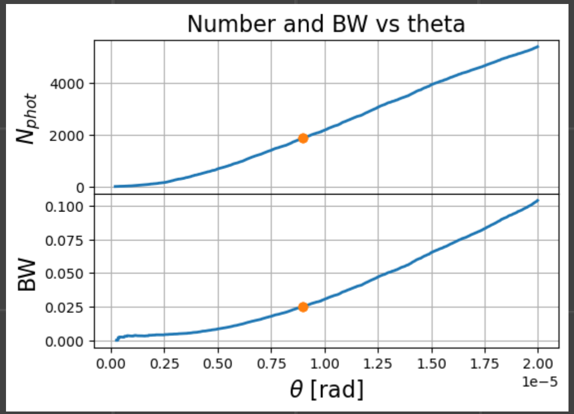


(3e8*1120/90.7e3)/1e6=3.7 MHz

33MHz/3.7MHz=8.9

Total # of photons 1.59e4*3.7 MHz=5.8e10





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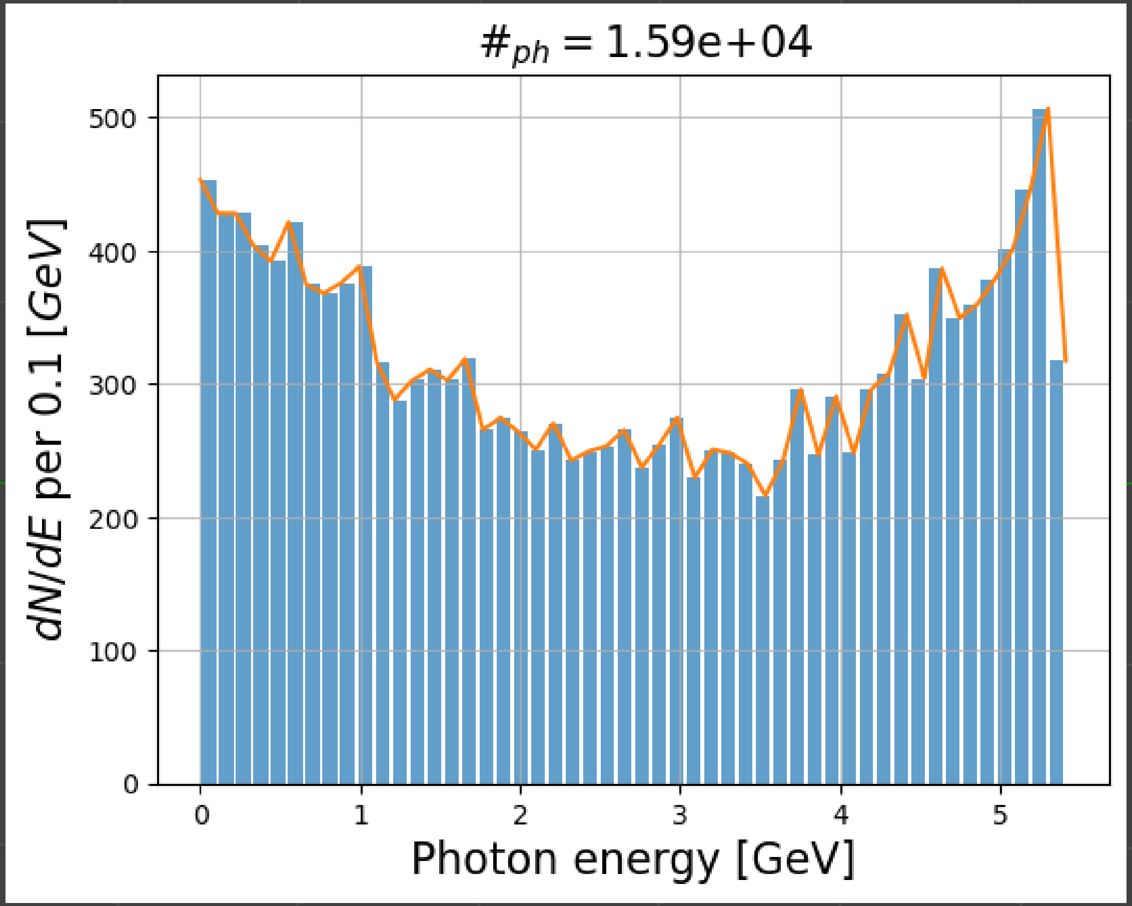

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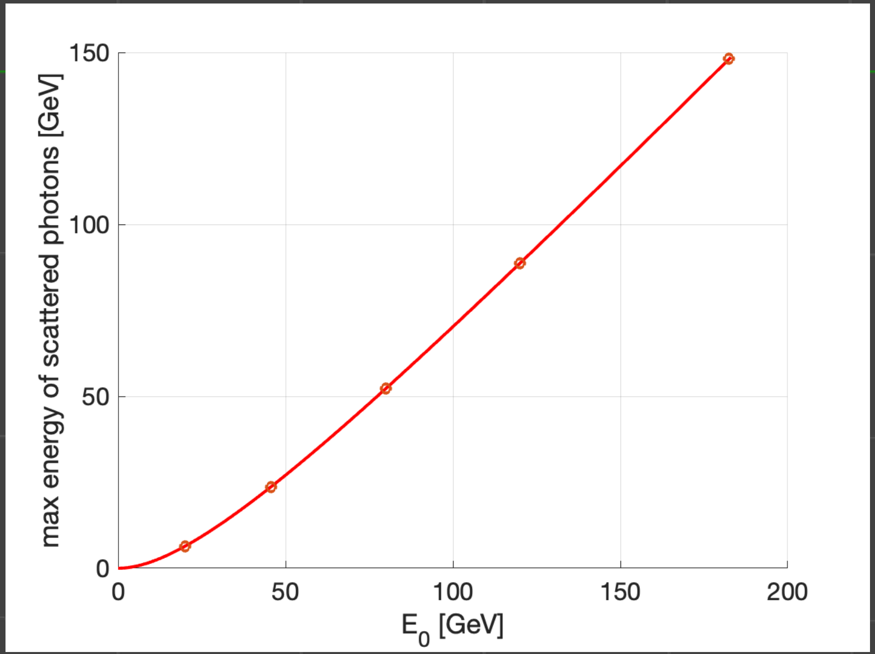


Experiment proposal at FACET-II

Facility for Advanced Accelerator Experimental Tests

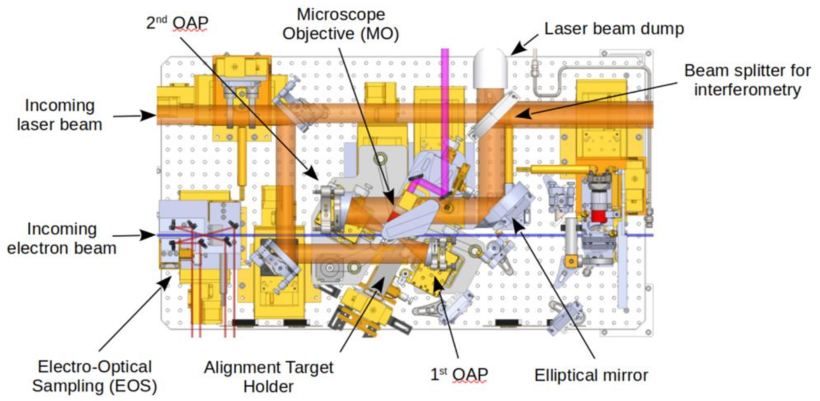
Leverage the E320 infrastructure at FACET-II to provide an R&D platform for:

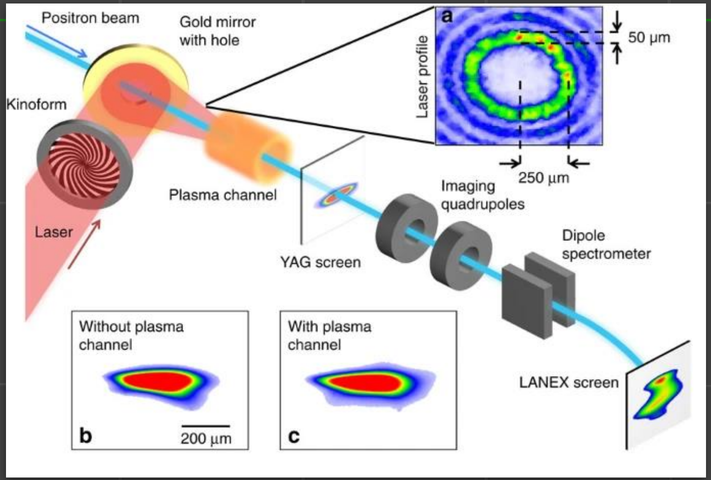
- Bunch-to-bunch laser intensity control.
- Halo collimation.
- Diagnostics to demonstrate collimation and control of high energy beams.

FACET-II is the only User Facility in the world that combines 10 GeV beams with high-power lasers to accommodate this type of R&D.

Current electron beam parameters	
Energy	10 GeV
Bunch charge	$0.7-2$ nC
Peak current	$1-10$ kA
Bunch radius (rms)	$\sim 30-50$ µm
Collision angle	150°
Quantum parameter χ	0.3–0.6

Current laser beam parameters	
Pulse energy (on OAP)	0.1–0.3 J
Pulse duration (FWHM)	~ 50 fs
Photon energy	1.55 eV
Beam waist	2 µm
Peak intensity (Strehl: 0.5)	$2-6 \times 10^{19}$ W/cm^2
Classical intensity parameter a_0	3–5





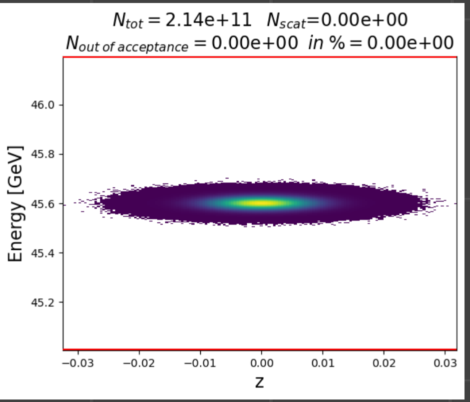
Courtesy Spencer Gessner

Thank you

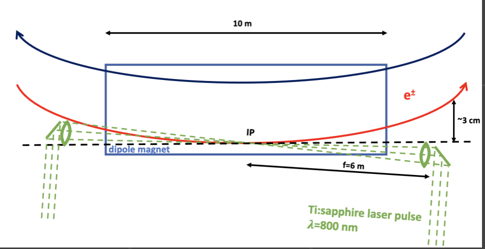
Please find here spectrums and photons distribution

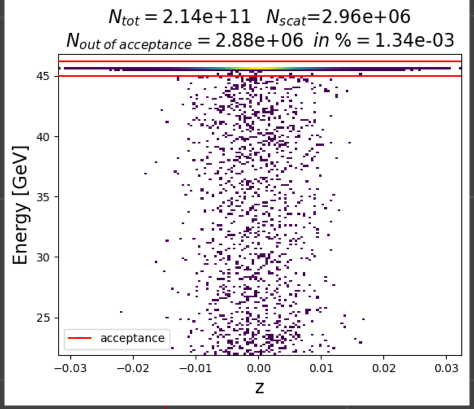
https://cernbox.cern.ch/s/4k86vWKIqMD23np

Beam intensity control



Beam ps before CBS





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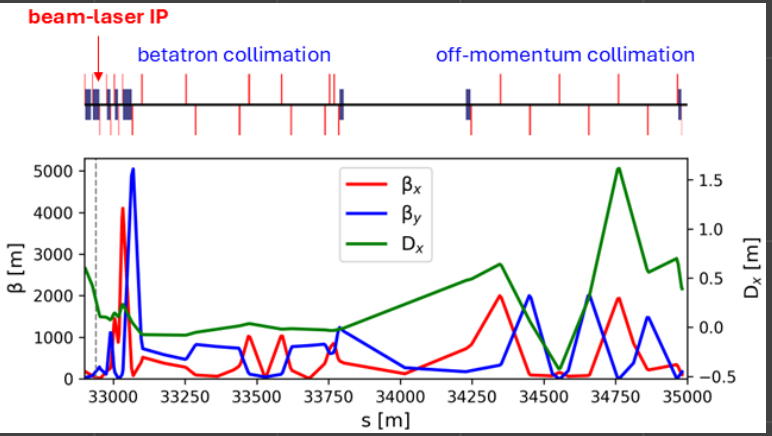
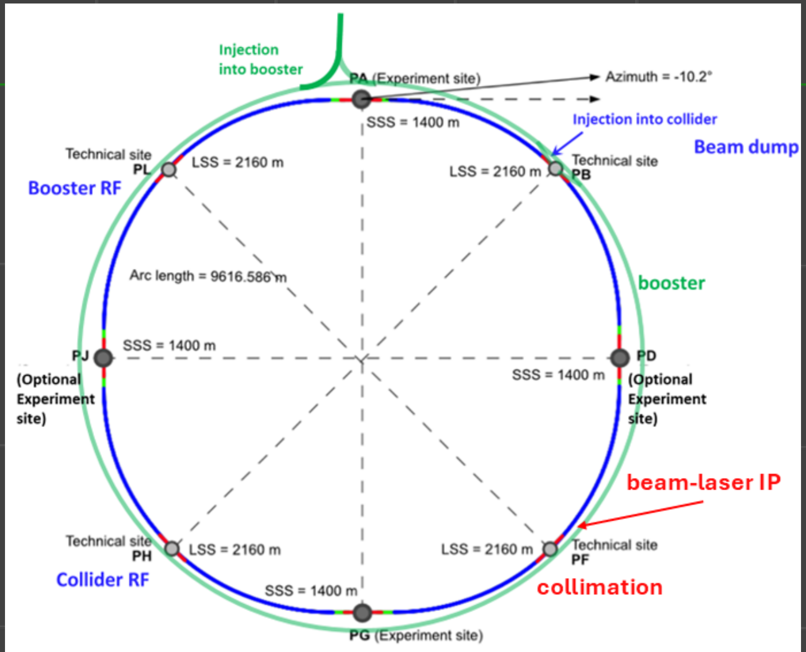


Possible location of CBS IP



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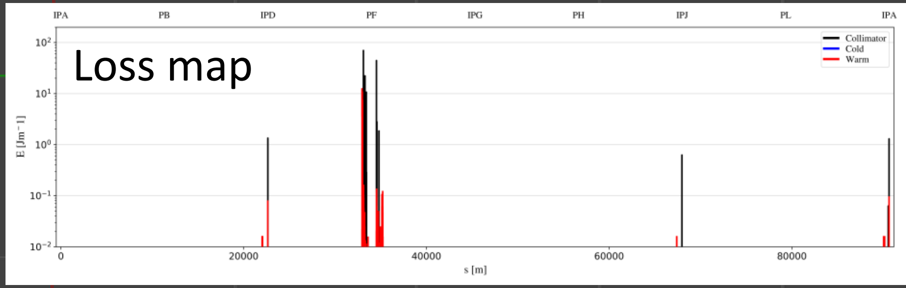

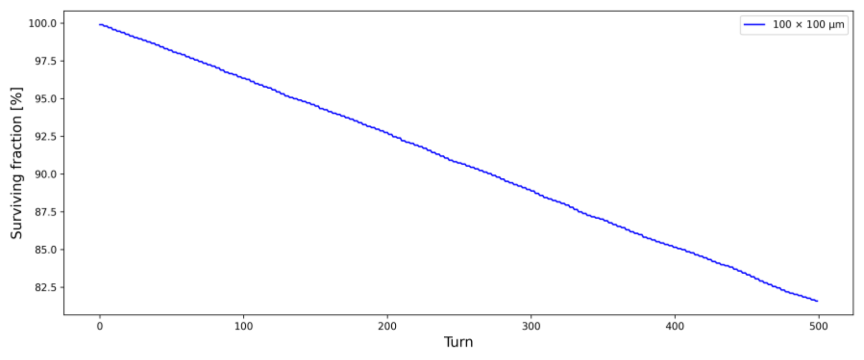

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Beam intensity control

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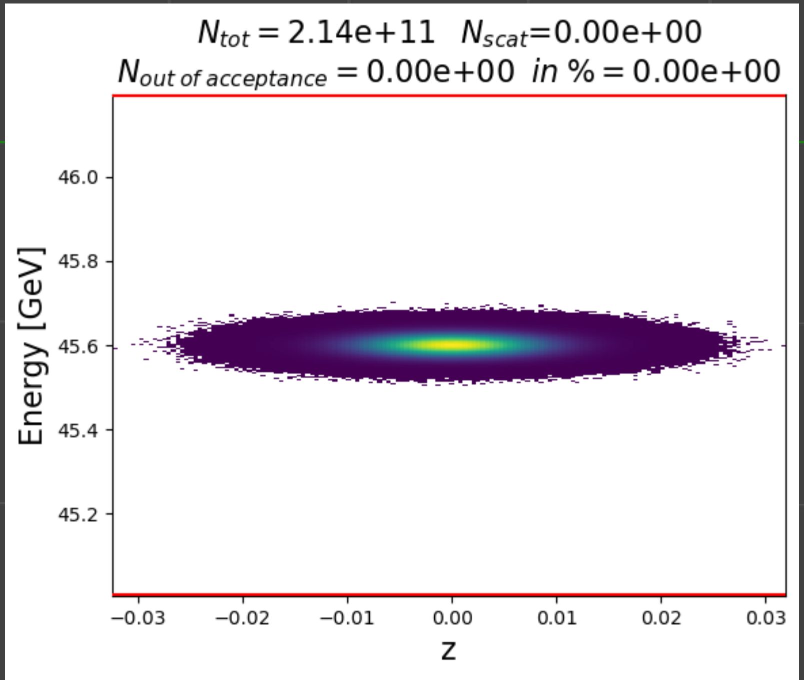
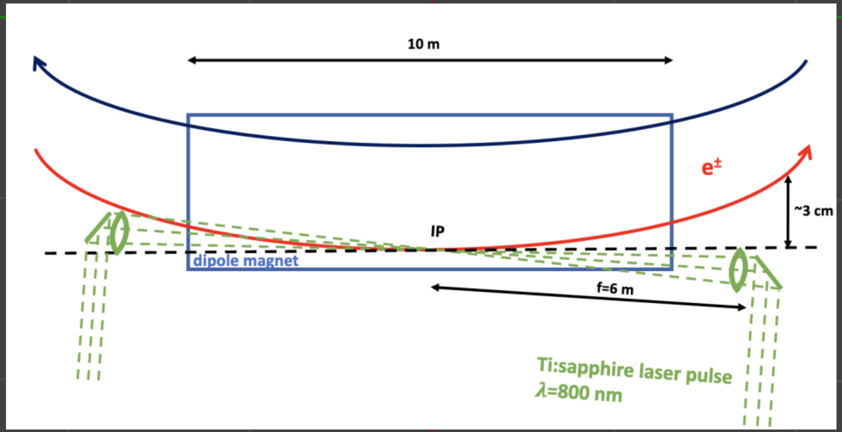
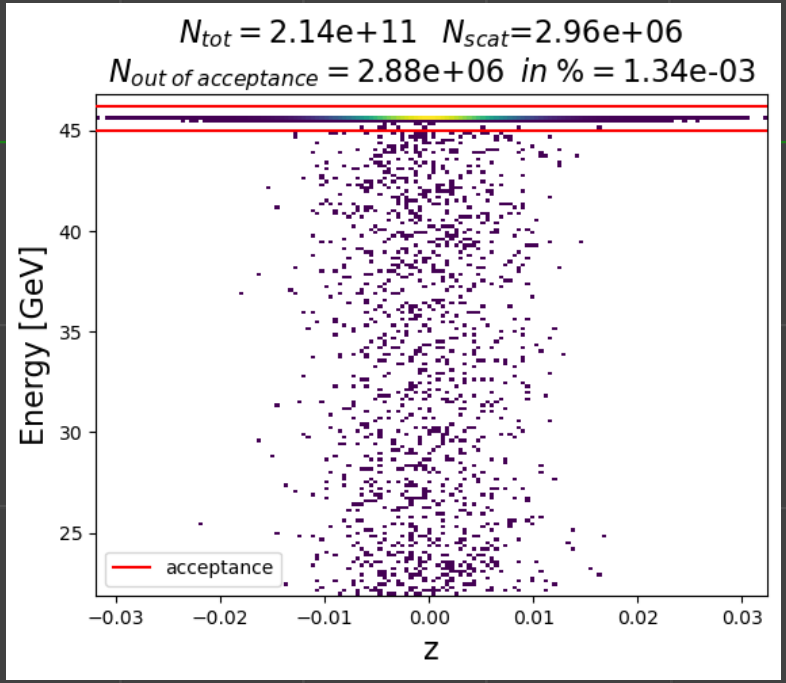
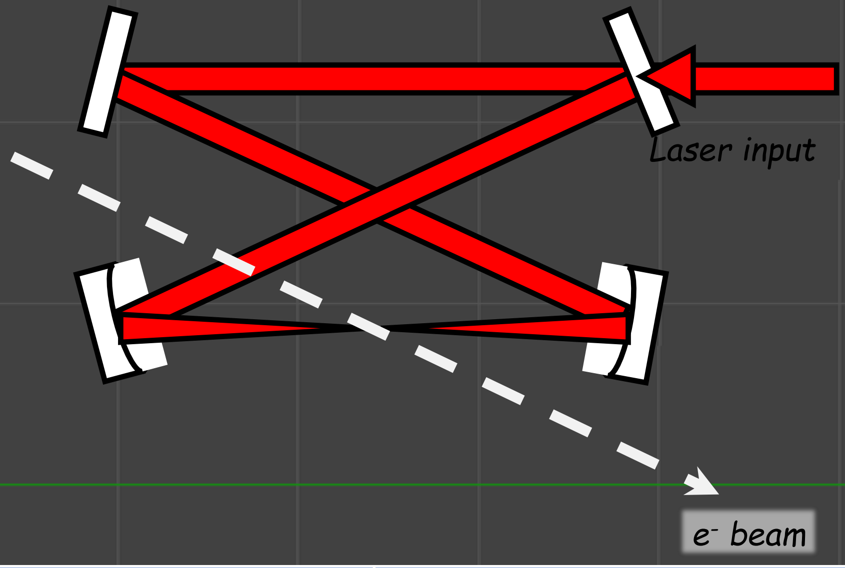
Asymmetry in the bunch current leads to Flip-flop instability. To avoid this bunches at IP must be bunches should be tightly controlled, with a maximum charge imbalance between collision partner bunches of less than 3–5%.

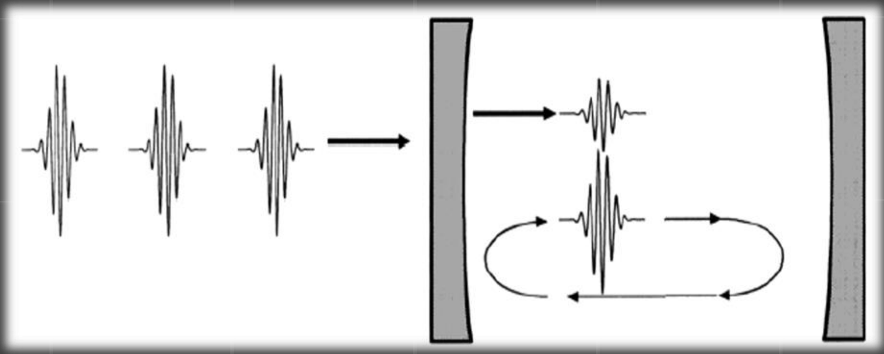






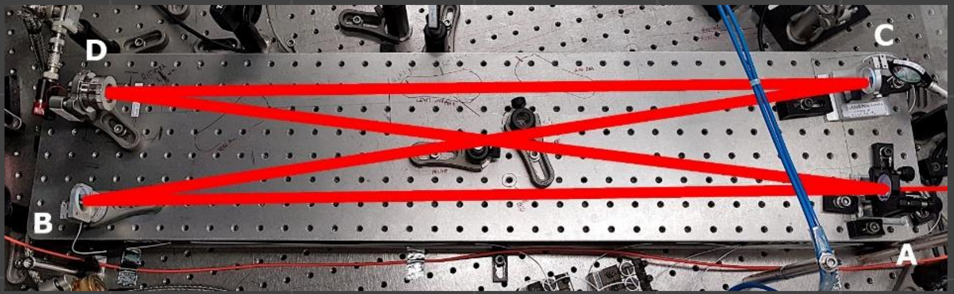
Laser & Fabry-Perot cavity





Laser and Fabry-Perot cavity accumulate photons.
It give us possibility to collide photons with pulse energy of 3 mJ

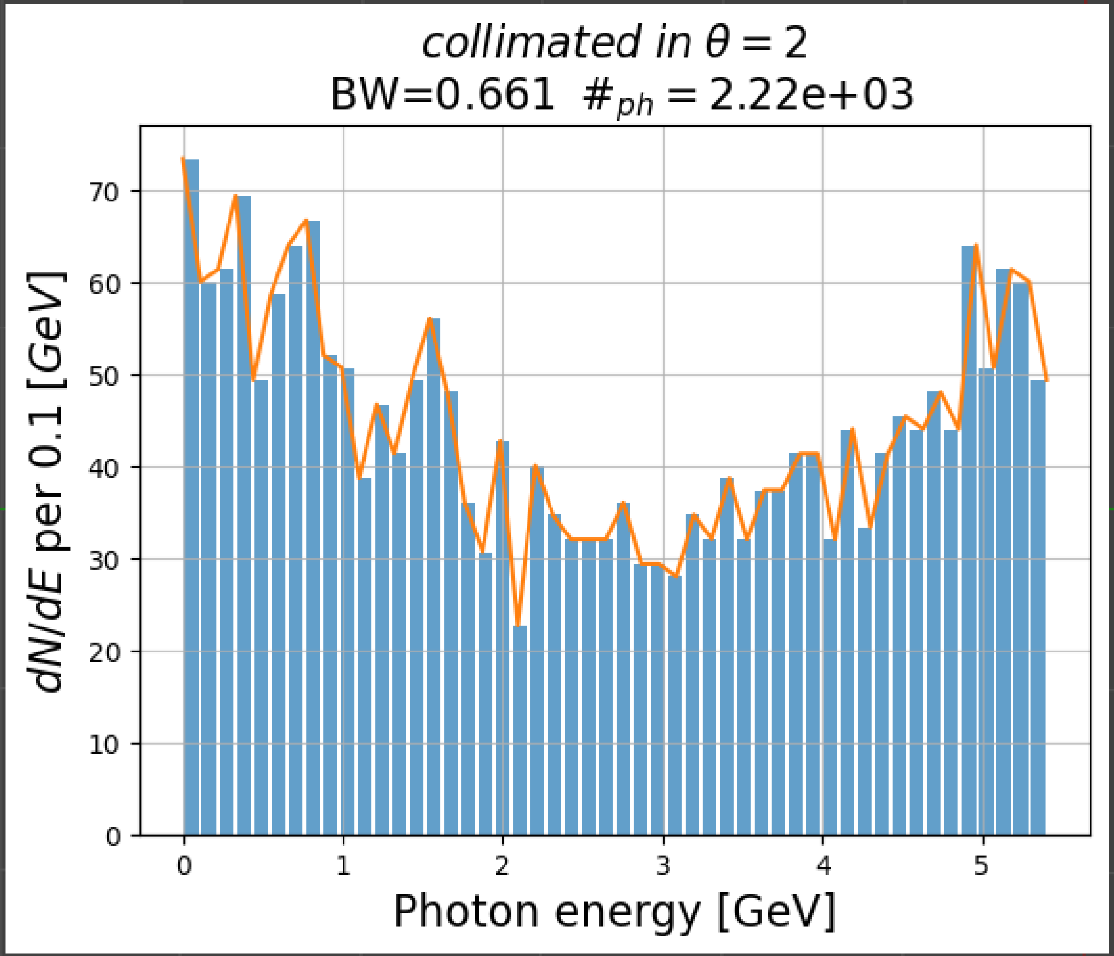
Laser and FP cavity	
Laser wavelength	1030 nm E_{las}=1.2 eV
Laser and FP cavity Frep	96 MHz
Pulse energy	2.7 mJ
FP waist	40 μm
Laser pulse length	1 ps



BriXSinO Fabry-Perot cavity

BriXSinO TDR: https://marix.mi.infn.it/brixsino-docs/

Booster as light source

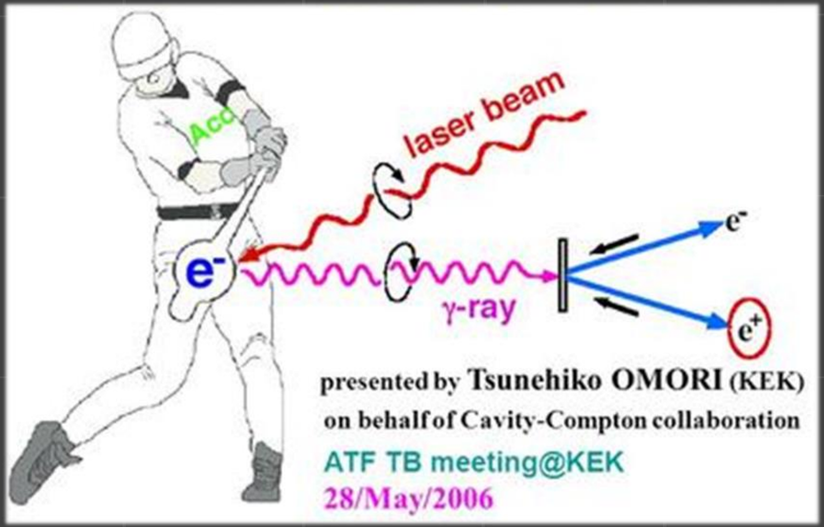


(3e8*1120/90.7e3)/1e6=3.7 MHz

96MHz/3.7MHz=25.9

Total # of photons 2.22e3*3.7 MHz=8.2e9

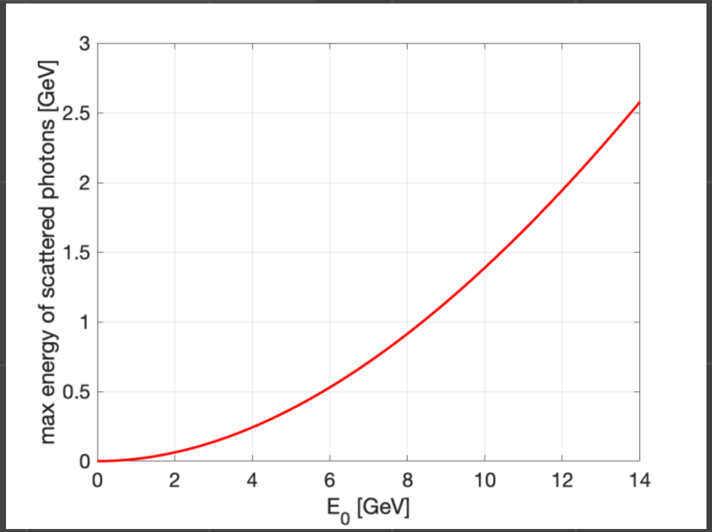
What is Compton Back Scattering?



$$\nu = \frac{(1+\underline{e}_k \cdot \underline{\beta})}{(1-\underline{n}\cdot\underline{\beta}) + \frac{h\nu_L}{mc^2\gamma}(1-\underline{e}_k\cdot\underline{n})}\nu_L \approx 4\gamma^2\nu_L$$

$1-\beta\cos\theta$

Frequency-angle correlation



Total acceptance

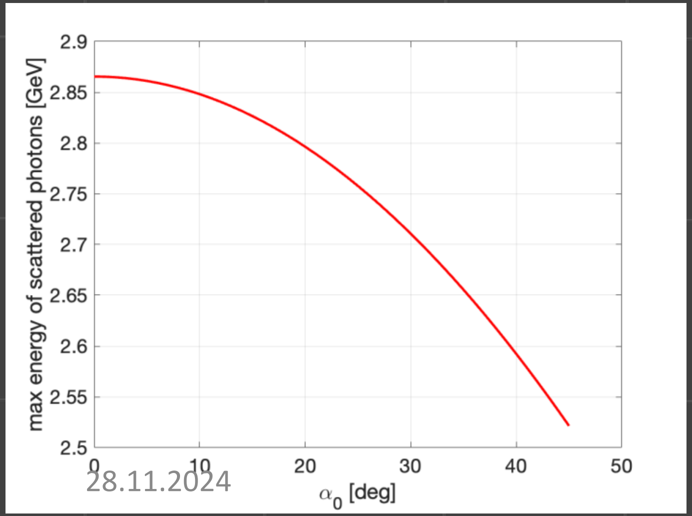
$\Psi_{max} = \gamma\theta_{max} = 1$

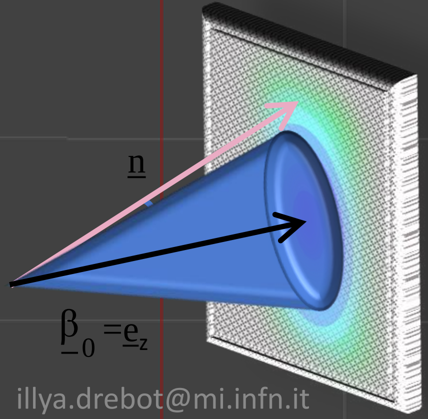
$\theta_{max} = 1/\gamma$

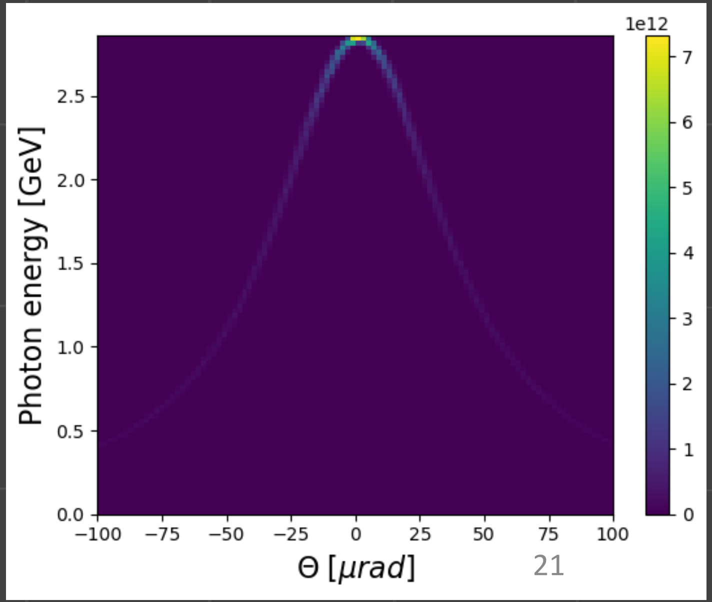
$$\varepsilon_{\gamma m} = \frac{4\gamma^2\varepsilon_L\cos^2\frac{\alpha_0}{2}}{4\gamma\frac{\varepsilon_L}{mc^2}\cos^2\frac{\alpha_0}{2}+1} \approx 4\gamma^2\varepsilon_L cos^2\frac{\alpha_0}{2}$$

E=14 GeV-> γ = 2.7e+04

Θmax=37 μrad

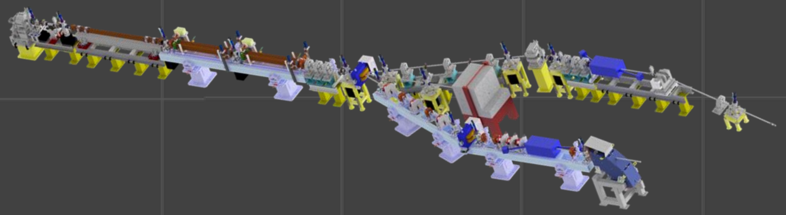






3 possible

Based on linear accelerators



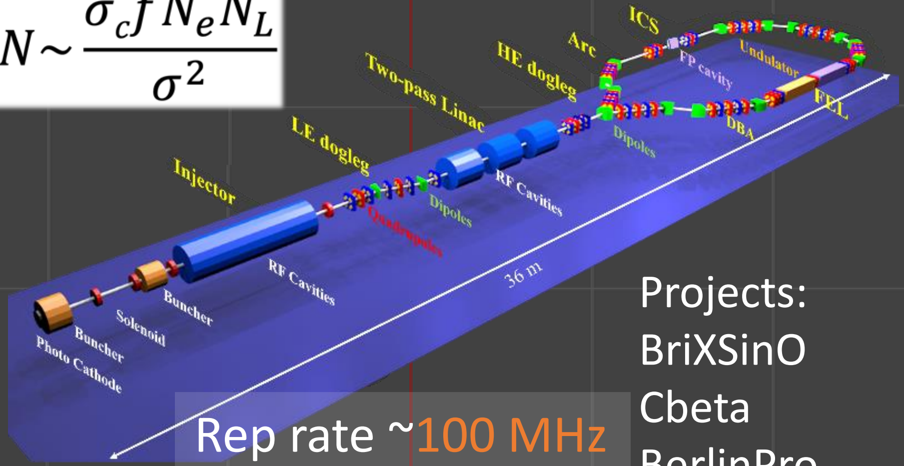
Projects:
STAR2
SMART*LIGHT

Advantage:
- Small emittance 2-3 mmrad
- Possibility to focus beam at 5-10 µm
- Hight flexibility in tuning

Disadvantage
- Low repetition rate 100 Hz

Based on ERL

$$N \sim \frac{\sigma_c f N_e N_L}{\sigma^2}$$

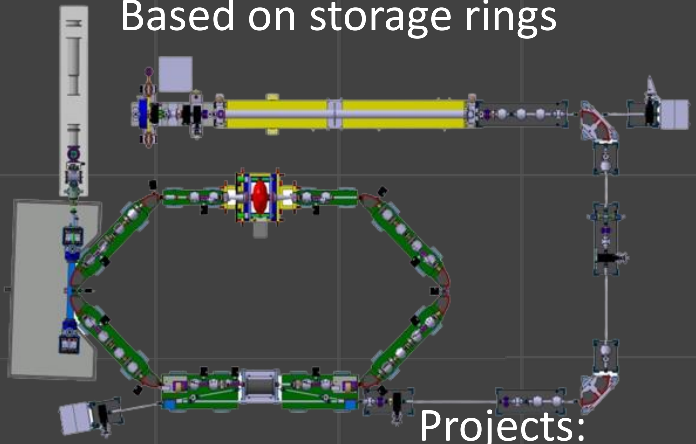


Rep rate ~100 MHz

Projects:
BriXSinO
Cbeta
BerlinPro

Parameter	Value
Energy (MeV)	20-45
Bunch charge (pC)	50 - 200
Repetition rate (MHz)	100
Average Current (mA)	<5
Beam power @ dump (W)	400
$\epsilon_{n,x,y}$ (mm mrad)	1.0
energy spread (%)	< 0.2
Bunch separation (μs)	> 1
Beam energy fluctuation (%)	< 0.2
Pointing jitter (μm)	50.

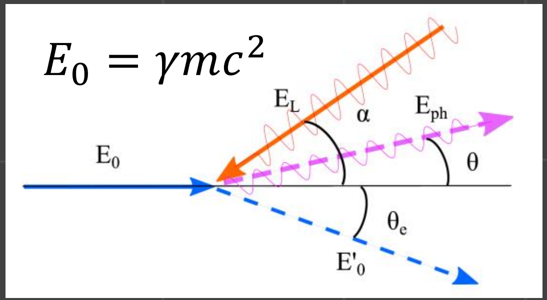
Based on storage rings



Projects:
MuCLS
HIGS
ThomX
NESTOR

Advantage:
- Hight repetition rate 17.8 MHz

Disadvantage
- Bigger emittance 60 mmrad
- Bigger transvers size at IP ~70 µm



$$E_{ph} = \frac{4\gamma^2 E_l}{1 + X + \gamma^2 \vartheta^2}$$

$$X \equiv \frac{4\gamma E_l}{mc^2}$$