Sensitivity studies for a Compton polarimeter at SuperKEKB

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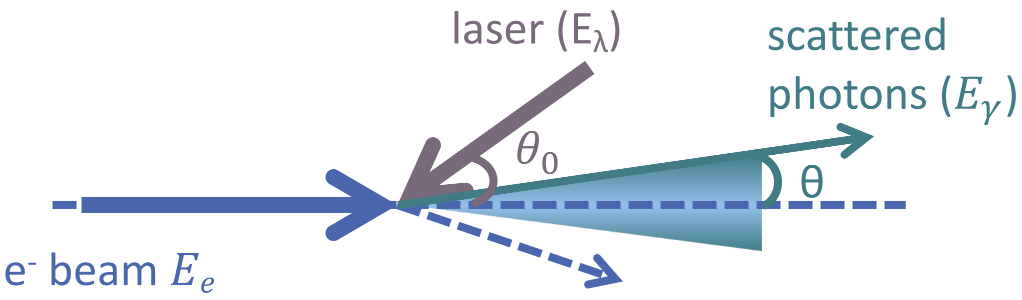
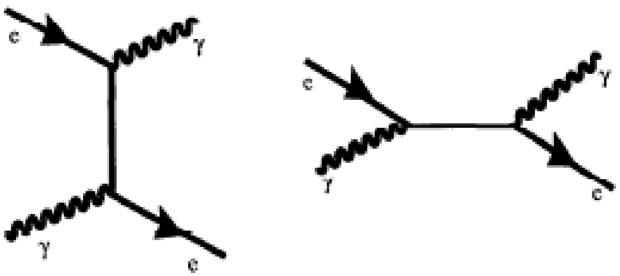
Introduction

- Compton scattering:
  - Cross section
  - Longitudinal and transverse polarimetry
- Integration aspects of Compton polarimeter (laser system and interaction region)
- Concept of photon detector
- Sensitivity studies of a photon detector

Compton back-scattering





- Initial electron energy (7 GeV)
- Initial photon energy (2.4eV at 515nm)
- Crossing angle of beams
- Emitted photon energy

Compton back-scattering

$$x = \frac{2E_e E_\lambda}{m^2}(1+\cos\theta_0) \qquad y = \frac{E_\gamma}{E_e}$$

The Compton cross-section averaged over scattered particles spins:

Differential cross-section

Transverse laser polarisation: nuisance parameter to minimize and keep under control

Transverse electron beam polarisation: intervenes as an asymmetry in the transverse plane

$$\frac{d\sigma}{dy\,d\varphi_{obs}}(x,y) = \frac{d\sigma_0}{dy}(x,y) + \frac{d\sigma_\perp}{dy}(x,y)\cos\big(2(\varphi_{obs}-\varphi_{las})\big)\boxed{\mathcal{P}_{las}^{lin}} + \frac{d\sigma_\parallel}{dy}(x,y)\mathcal{P}_{las}^{circ}\left(\boxed{P_T f_T(x,y)\cos(\varphi_{obs}-\varphi_{elec})} + P_Z f_L(x,y)\right)$$

Electron beam polarization independent *Electron beam polarization dependent*

For the Laser:

Circular pol.: $\mathcal{P}_{las}^{circ}$

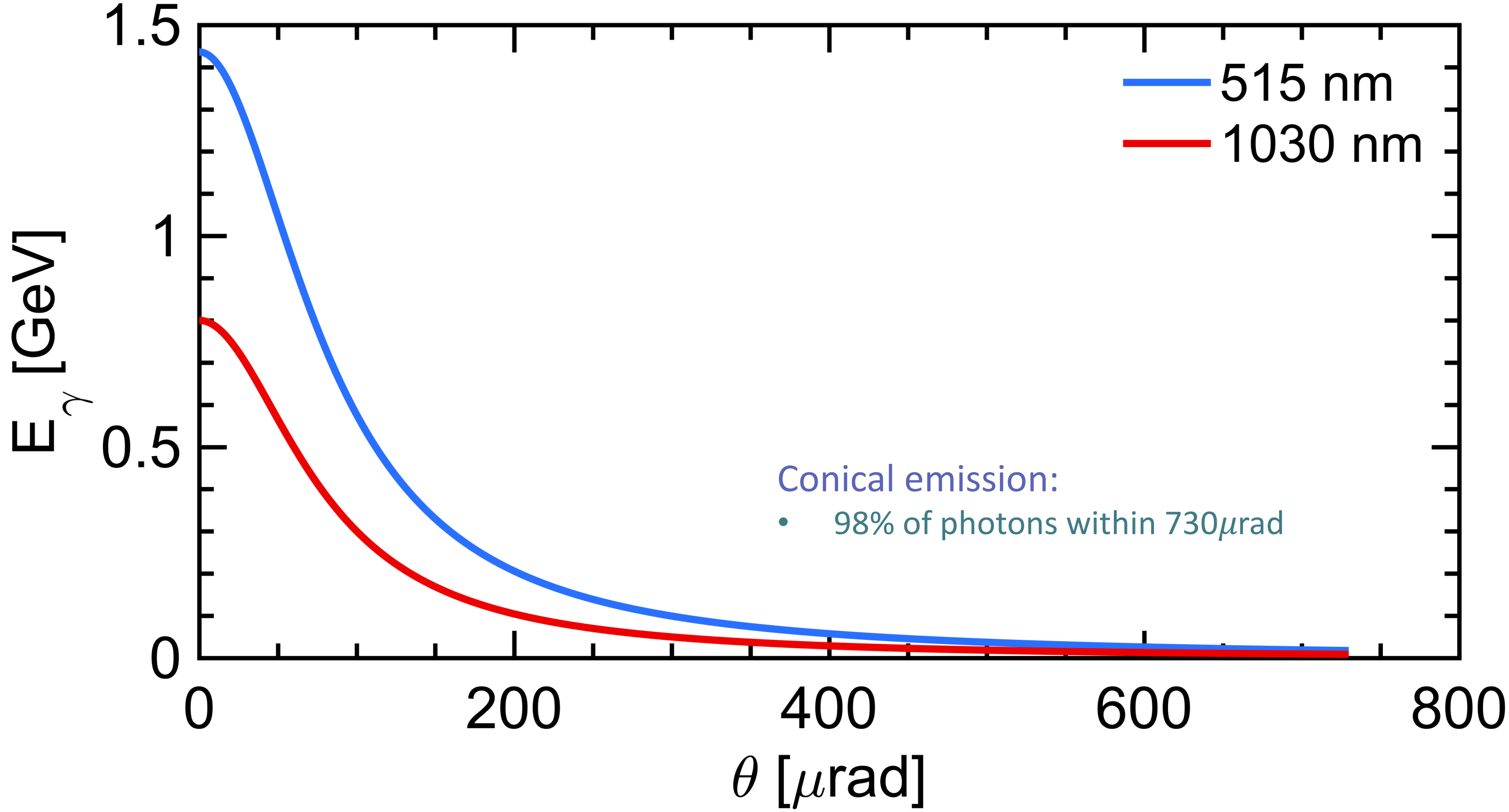
Linear pol: $\mathcal{P}_{las}^{lin}$

For the electron beam:

Longitudinal pol.: $\mathcal{P}_Z$

Transverse pol.: $\mathcal{P}_T$

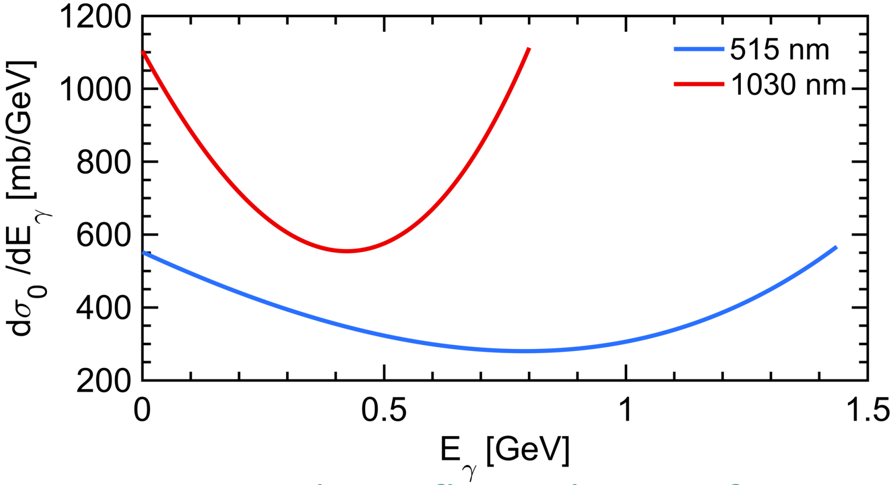
Transverse distribution of photons

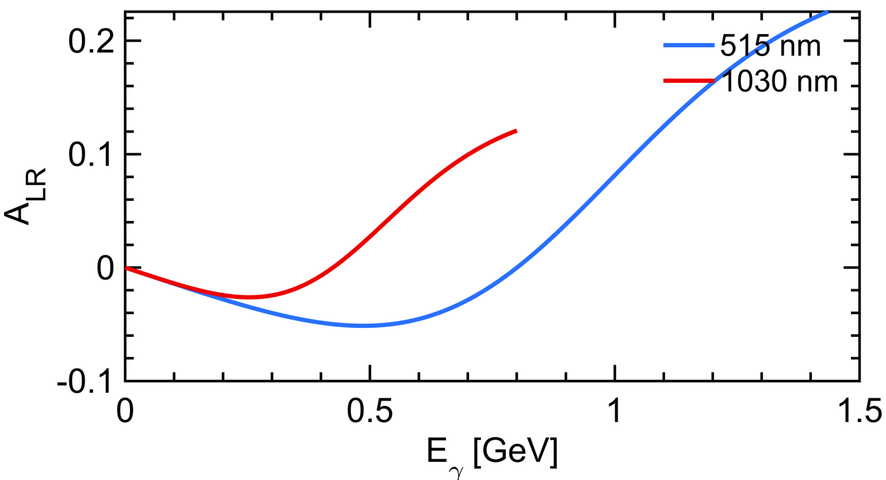


$$\frac{d\sigma}{dy}(x,y) \cong \frac{d\sigma_0}{dy}(1+\mathcal{P}_z\lambda A_{LR})$$

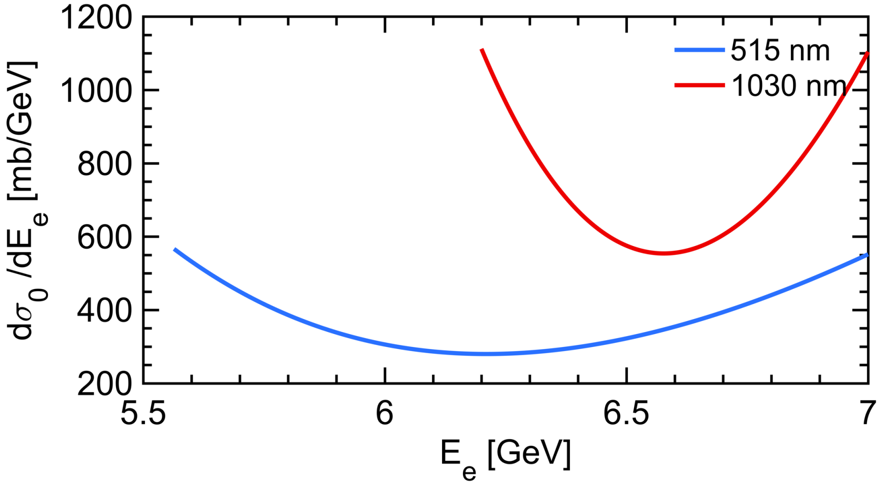
Longitudinal Compton polarimetry

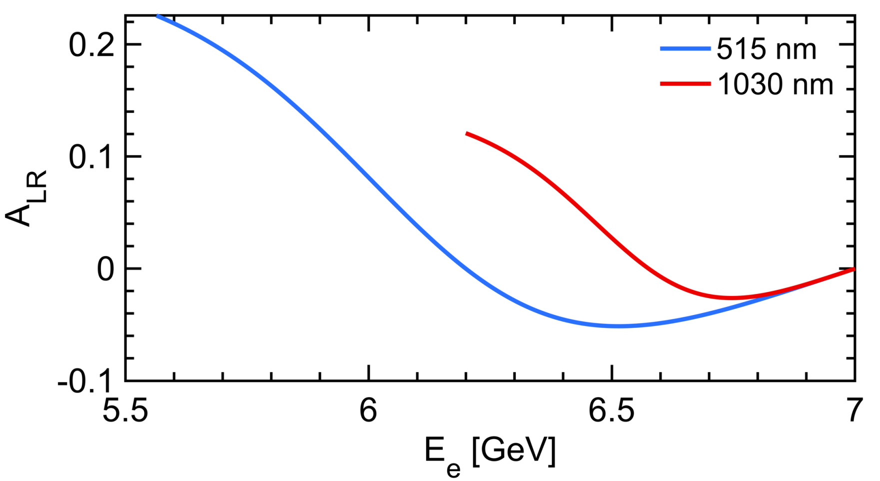
Polarization dependent term generates a left-right asymmetry function of E_γ





that reflects also as a function of the energy of the emitted electron





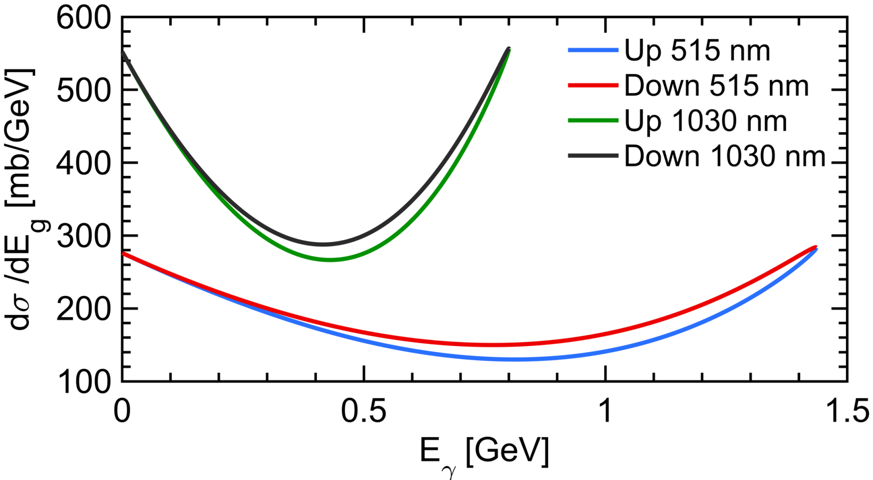
Using a 515nm laser provides higher sensitivity

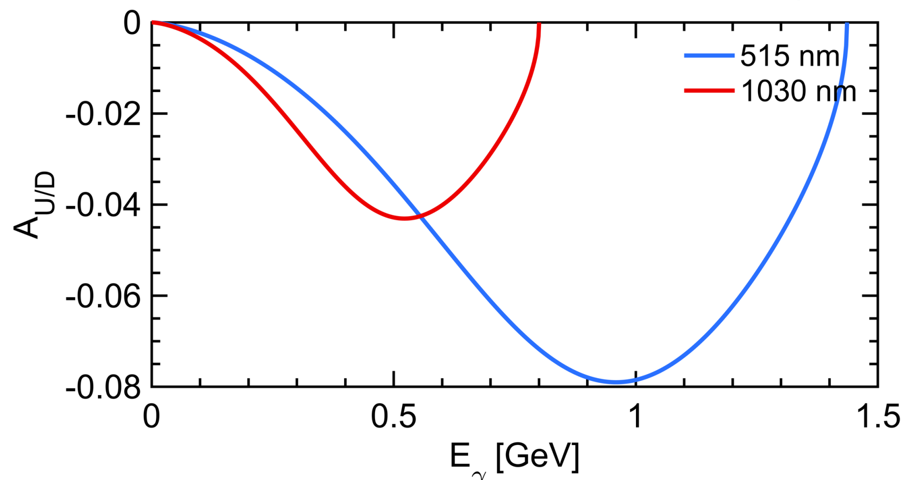
Landau-Lifshitz QED book paragaphs 86 and 87

$$\frac{d\sigma}{dy}(x,y) \cong \frac{d\sigma_0}{dy}(1+\mathcal{P}_T\lambda A_{UD})$$

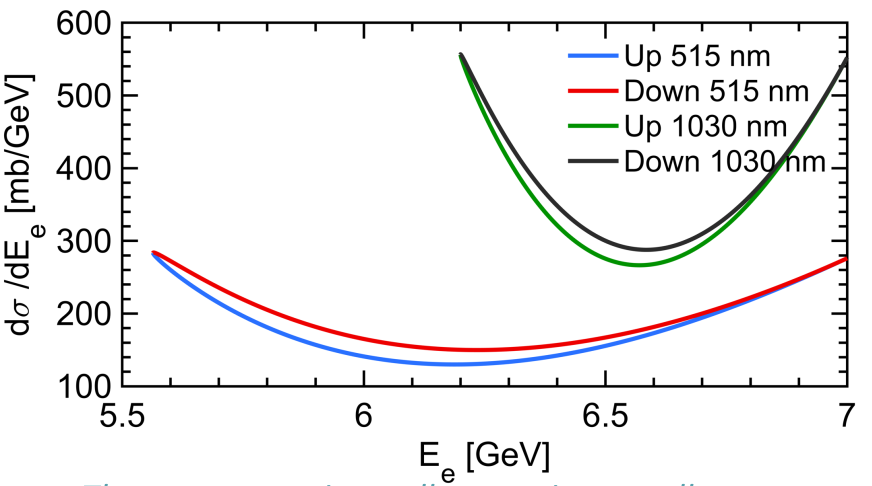
Transverse Compton polarimetry

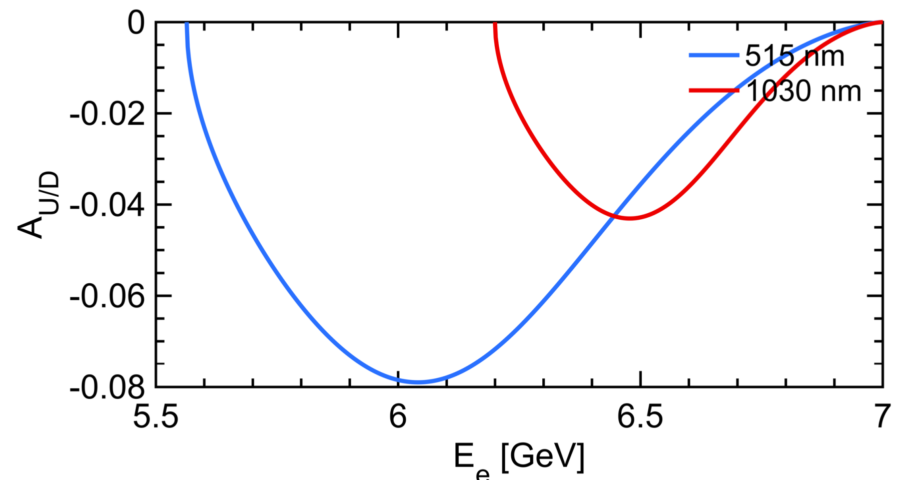
Polarization dependent term generates an up-down asymmetry function of E_γ





that reflects also as a function of the energy of the emitted electron

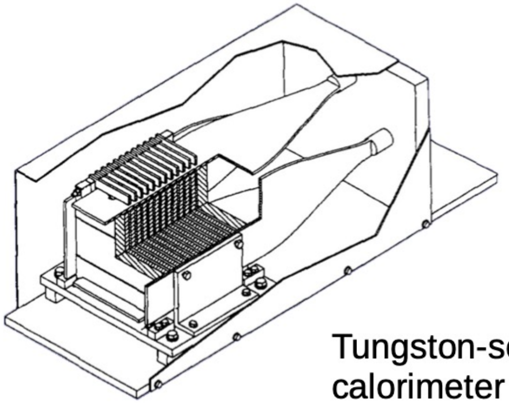




The asymmetry is smaller, requires excellent transverse alignement (and or resolution for electron detection)

Landau-Lifshitz QED book paragraphs 86 and 87

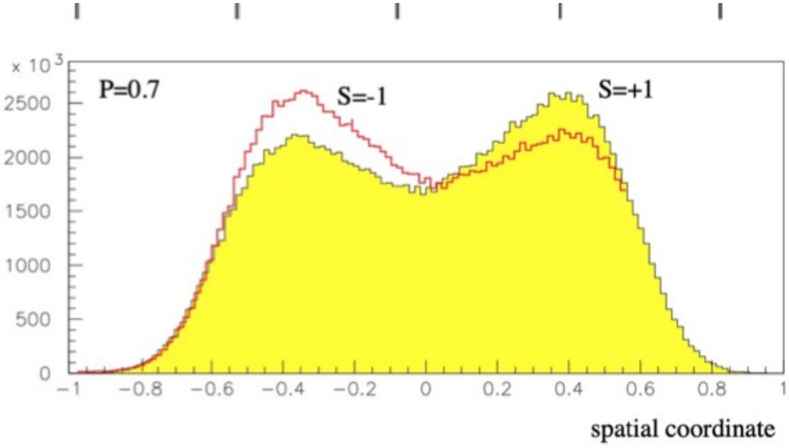
Transverse polarimetry at HERA

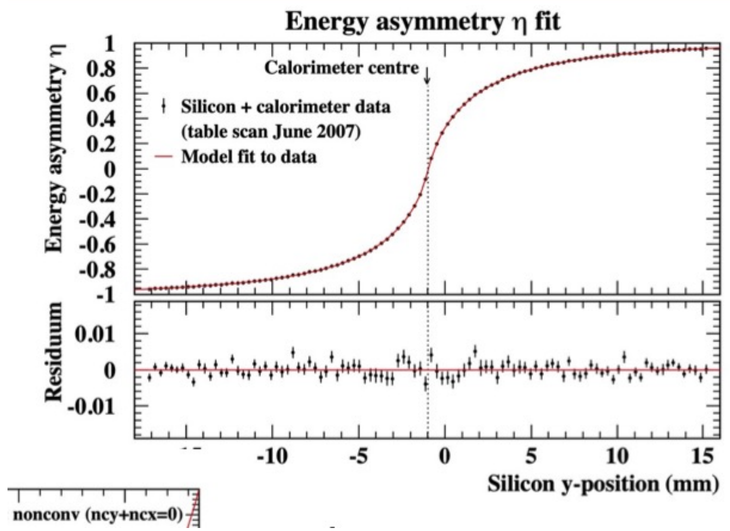


$$E = E_{up} + E_{down}$$

$$\eta = \frac{E_{up} - E_{down}}{E_{up} + E_{down}}$$

Tungston-scintillator sampling calorimeter 12×1.6 X_0
Two optically isolated halves, read-out on four sides





Exactly the operation that was done at HERA TPOL a long time ago.

Notoriously a difficult task but ‘do-able’

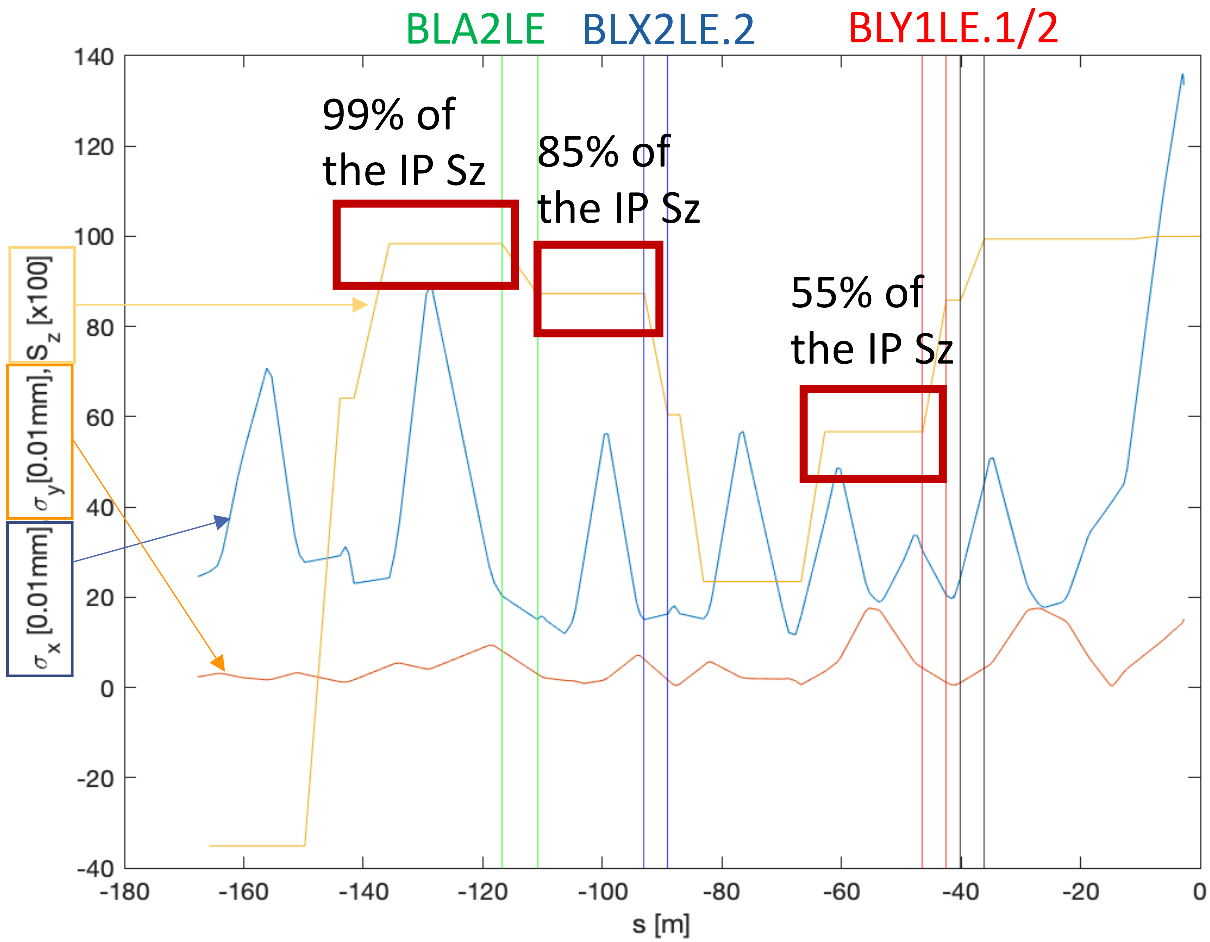
→ Requires detailed simulations

Can be eased by implementing a nicely vertically segmented electron detector.

Location

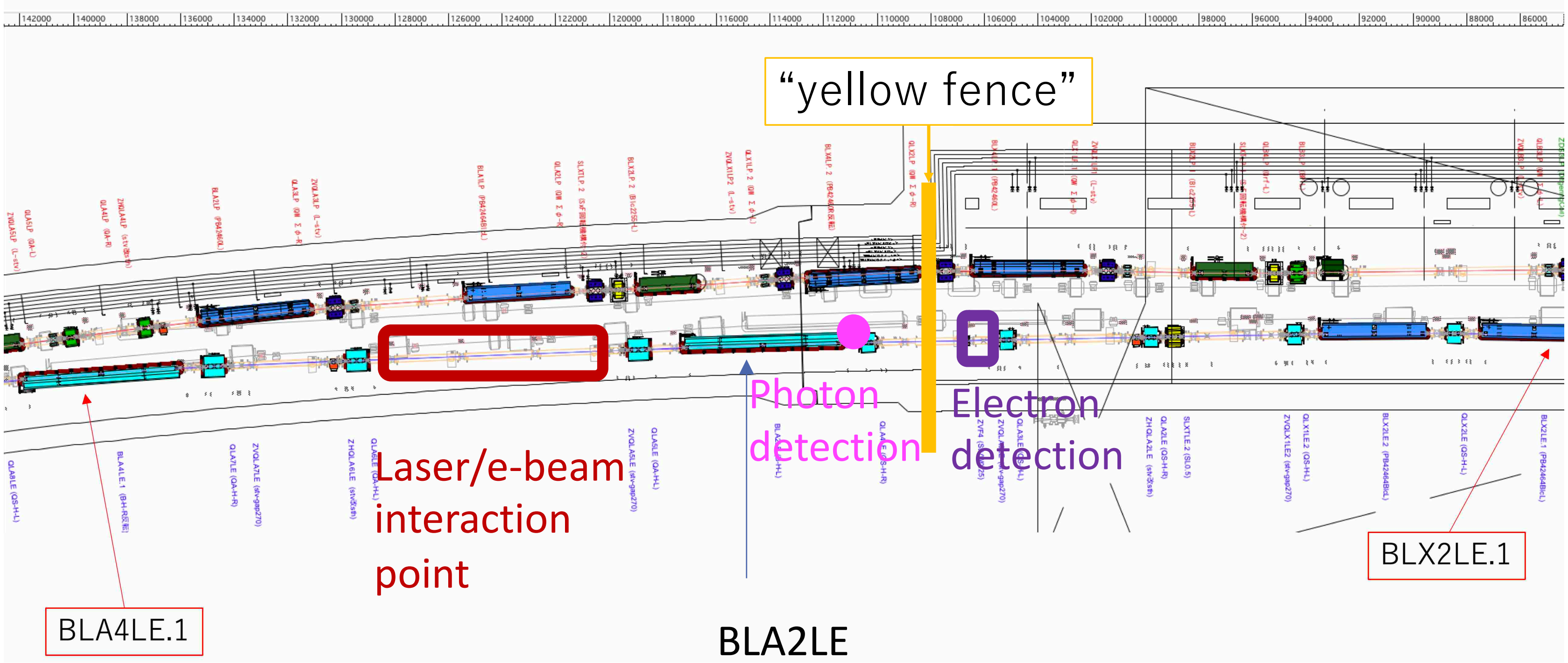
Best candidate location to install polarimeter is before BLA2LE

Beam sizes and spin projection in z:

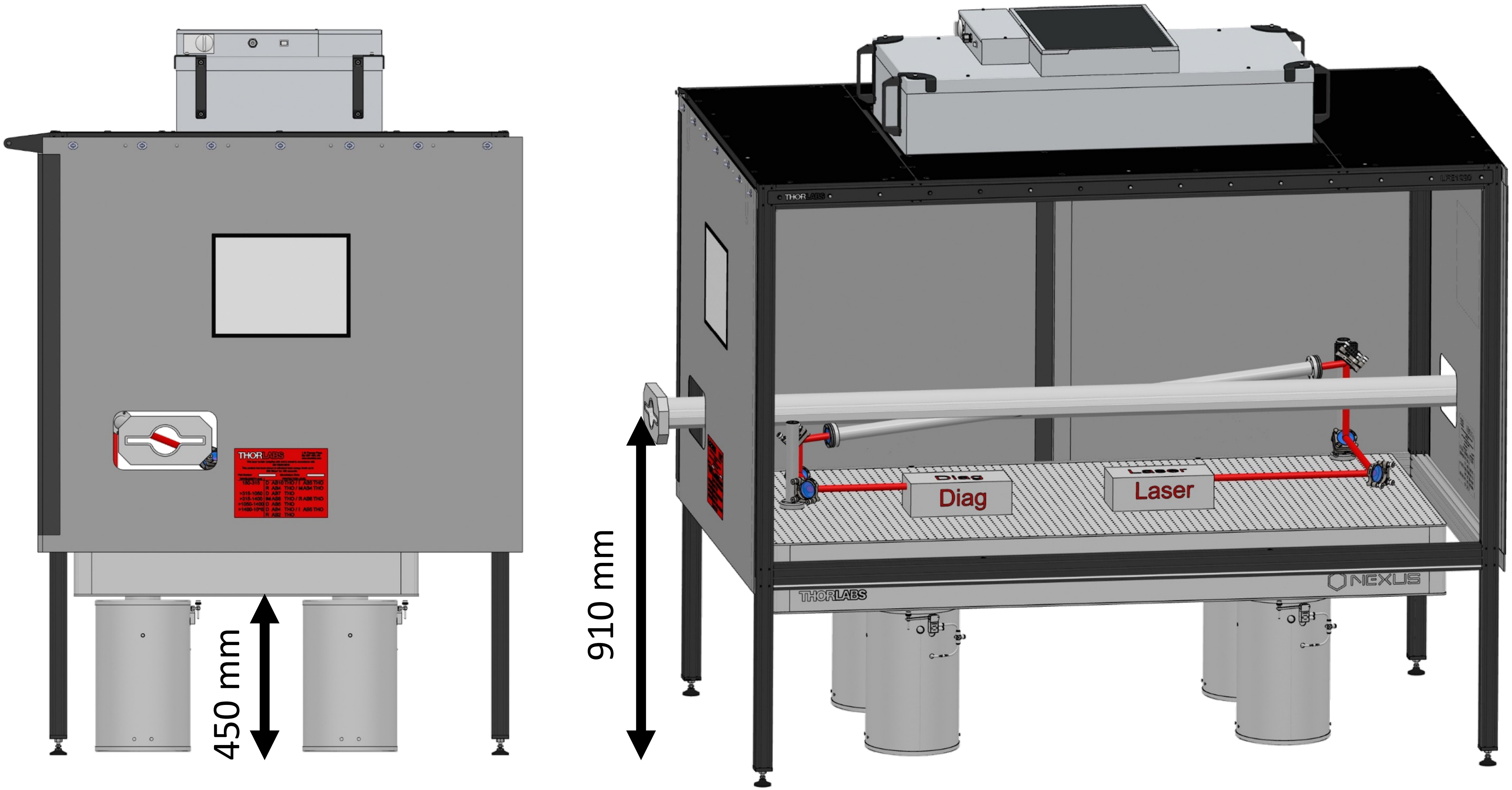


Using Yuhao data, https://indico.belle2.org/event/5306/

BLA2LE/BLX2LE.2



Mechanical system integration



Cross Angle Horizontal : 10 deg
Cross Angle Vertical : 4 deg

Zhou, Ishibashi

Beam impedance (longitudinal)

Preliminary results of impedance calculation

- Impedance calculation by T. Ishibashi
  - Longitudinal wake with 6 mm Gaussian bunch is very weak.
  - The calculated loss factor, resistance and inductance are 4.4e-5 V/pC, 3.1e-3 Ohm, and 8.0e-4 nH, respectively.
  - Comparing with Table 1 of Ref. [1], these values are very small.

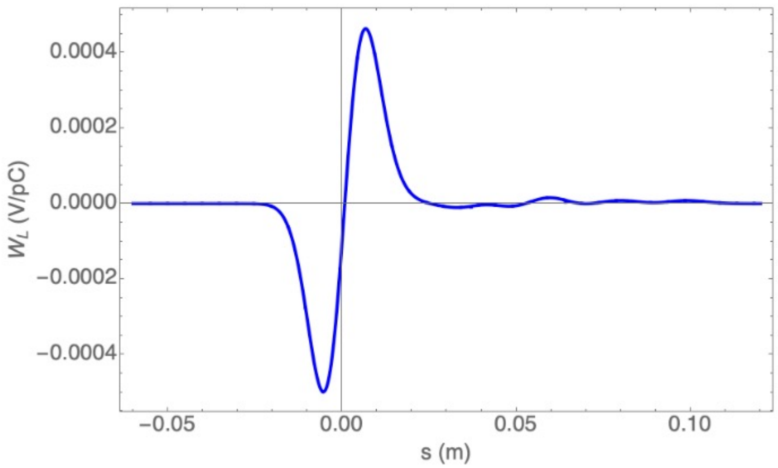


Table 1: Impedance budget for the SuperKEKB main rings. Summarised are the contributions to the loss factor $k_{||}$ [V/pC], the fitted resistance R [Ω] and inductance L [nH] for each type of components. The resistances and inductances are calculated at the nominal bunch lengths of σ_z=5 and 4.9 mm for LER and HER, respectively.

Component	LER			HER		
	$k_{\|\|}$	R	L	$k_{\|\|}$	R	L
ARES cavity	8.9	524	-	3.3	190	-
SC cavity	-	-	-	7.8	454	-
Collimator	1.1	62.4	13.0	5.3	309	10.8
Res. wall	3.9	231	5.7	5.9	340	8.2
Bellows	2.7	159	5.1	4.6	265	16.0
Flange	0.2	13.7	4.1	0.6	34.1	19.3
Pump. port	0.0	0.0	0.0	0.6	34.1	6.6
SR mask	0.0	0.0	0.0	0.4	21.4	0.7
IR duct	0.0	2.2	0.5	0.0	2.2	0.5
BPM	0.1	8.2	0.6	0.0	0.0	0.0
FB kicker	0.4	26.3	0.0	0.5	26.2	0.0
FB BPM	0.0	1.1	0.0	0.0	1.1	0.0
Long. kicker	1.8	105	1.2	-	-	-
Groove pipe	0.1	3.8	0.5	-	-	-
Electrode	0.0	0.7	5.7	-	-	-
Total	19.2	1137	36.4	29.0	1677	62.1

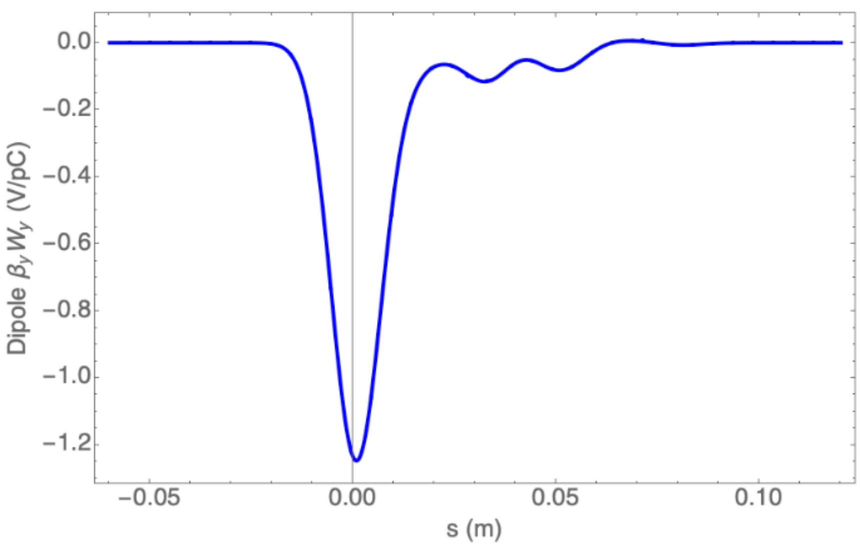
[1] D. Zhou et al., Impedance calculation and simulation of microwave instability for the main rings of SuperKEKB, in Proceedings of IPAC'14, Dresden, Germany.

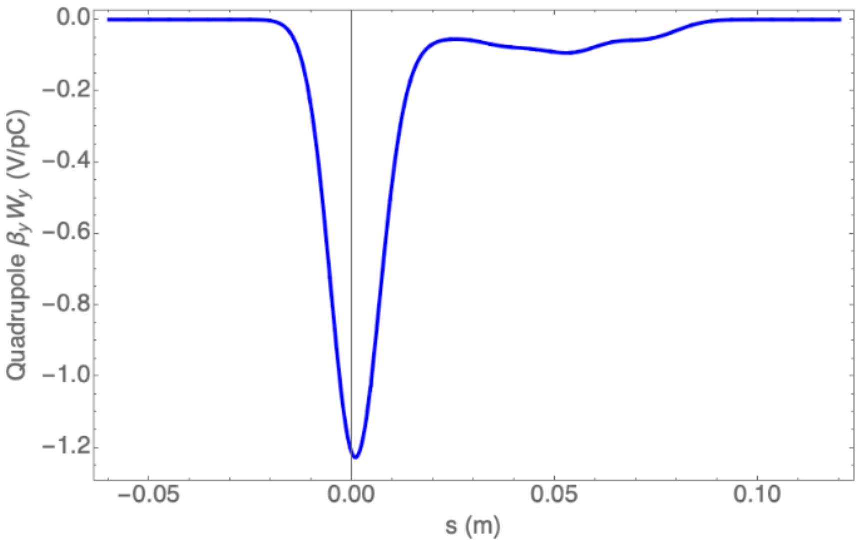
Beam impedance (vertical)

Zhou, Ishibashi

Preliminary results of impedance calculation

- Impedance calculation by T. Ishibashi
  - Vertical dipole and quadrupole wakes with 6 mm Gaussian bunch are weak.
  - The dipole and quadrupole kick factors weighted by beta function β_y=100 m are $\beta_y\kappa_y$=-0.89 V/pC and -0.88 V/pC, respectively. These values are very small, concerning the total $\beta_y\kappa_y$ of HER in the order of 10^4 V/pC.





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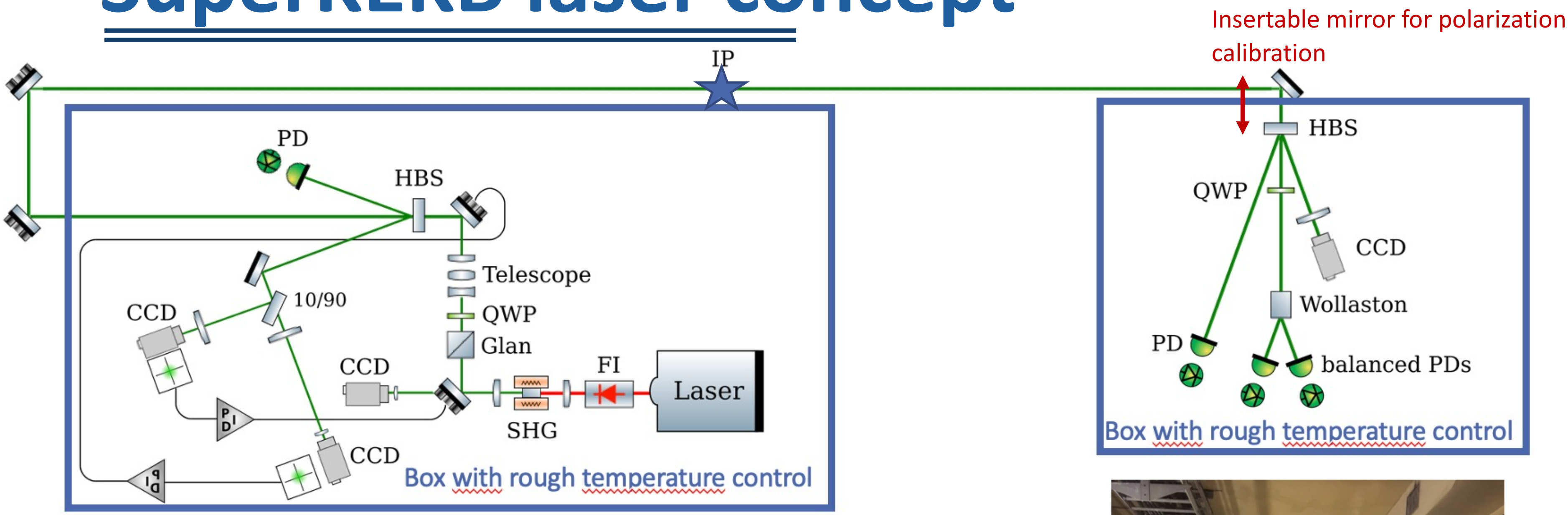
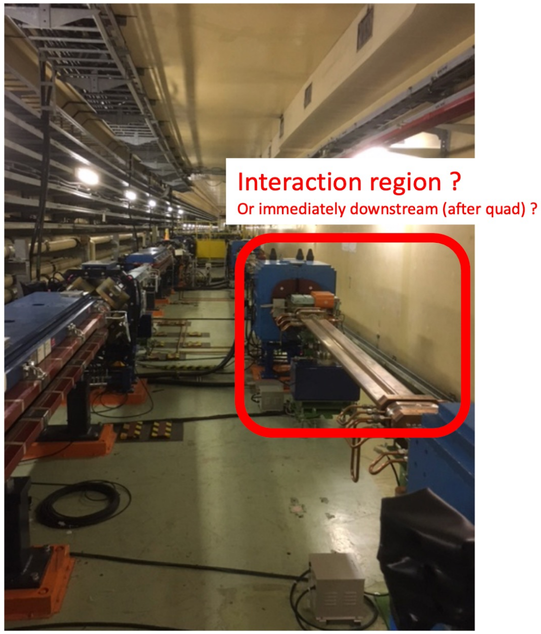
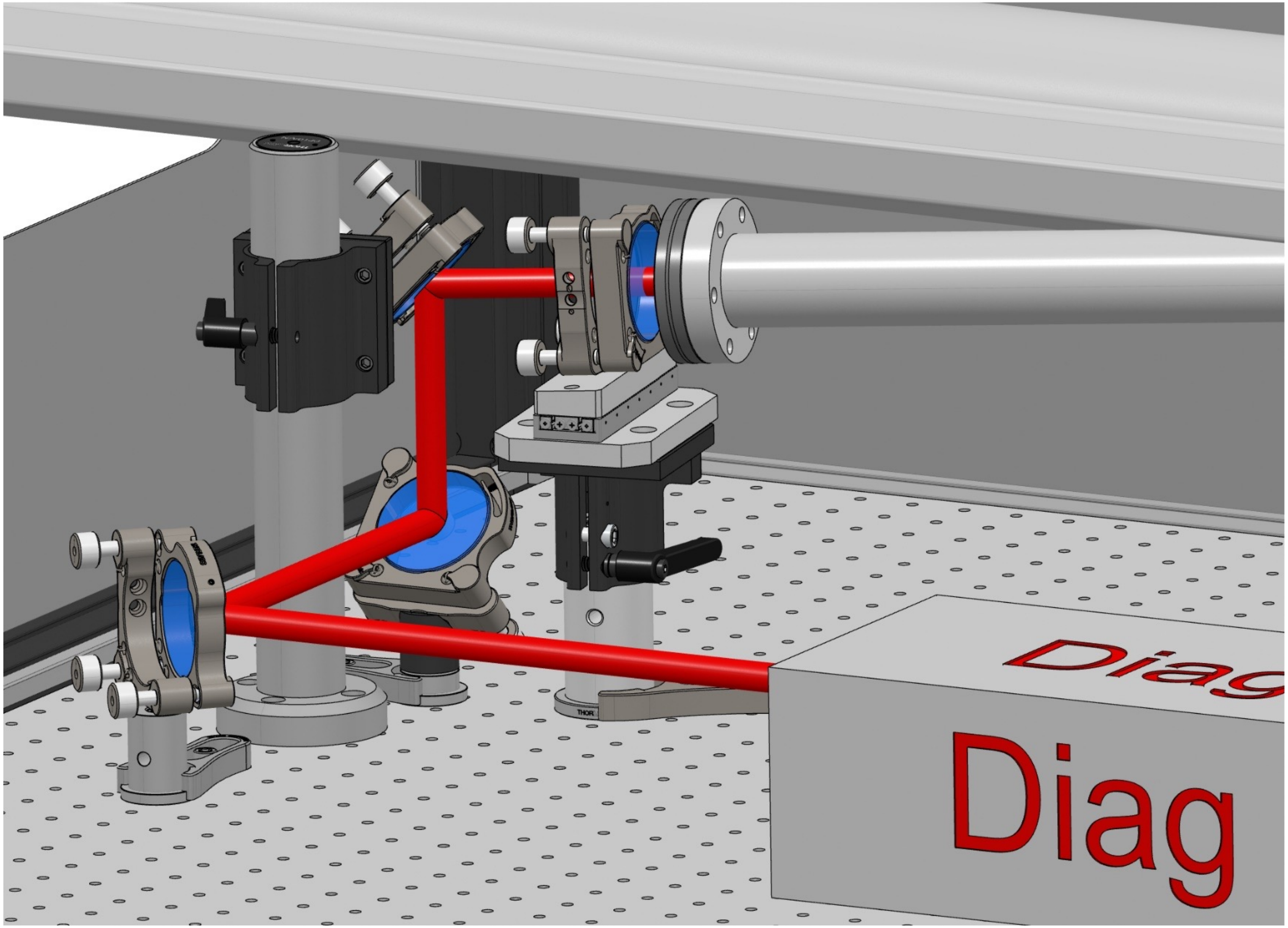
SuperKEKB laser concept



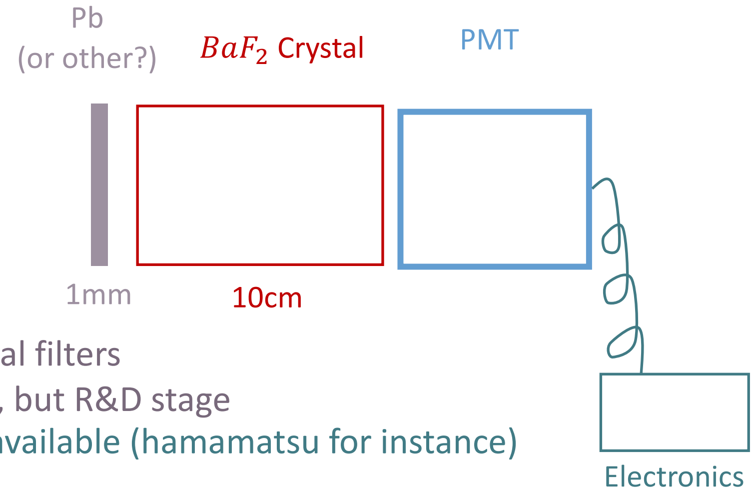
- Laser placed in accelerator bay below beam line
- Pulsed 250MHz green laser with a couple of Watts
- Automatic beam alignment and stabilization
- Currently working on real-time laser polarimetry based on photo-elastic modulation (on-going at IJCLab)
- Laser must be sync-ed to accelerator RF



Insertable mirror

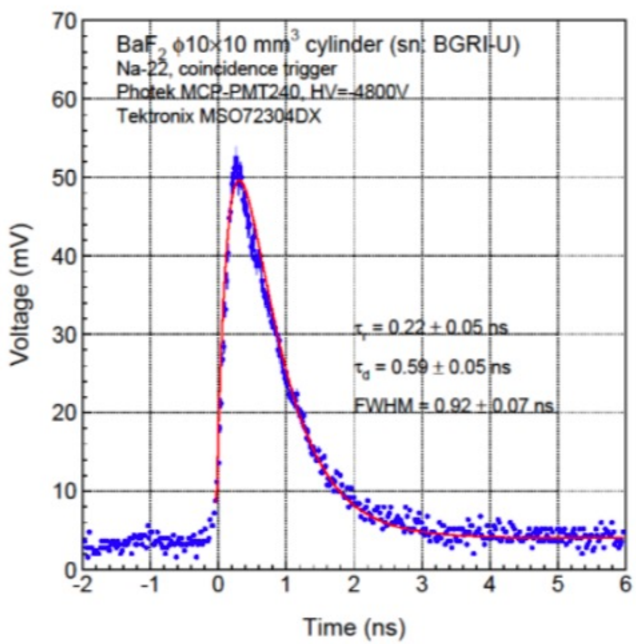


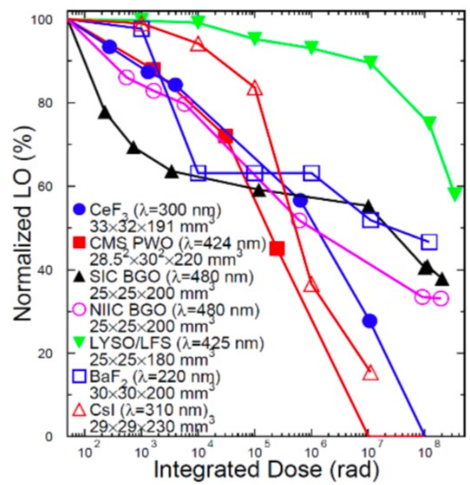
Basic idea of detector

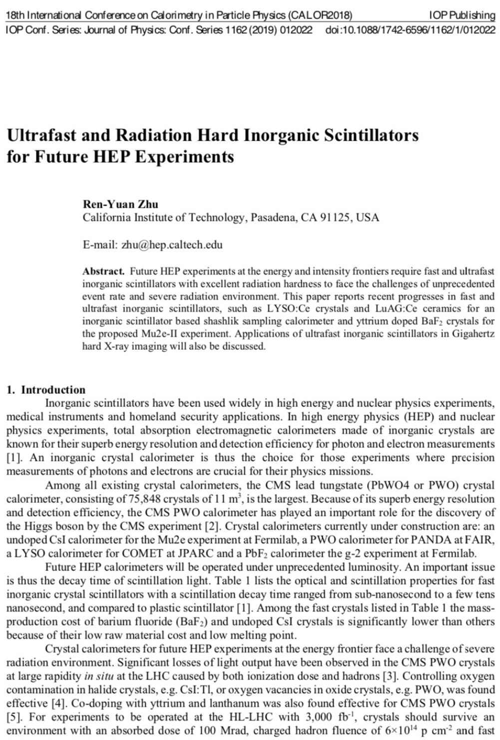


Basic elements

- a VERY FAST radhard scintillating crystal → BaF2
  - Need to filter out the slow component → UV optical filters
  - Interesting: Y doping reduces the slow component, but R&D stage
- a PMT with low transit time dispersion → commercially available (hamamatsu for instance)
- Associated electronics
- Next step: validate detection scheme







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Ultrafast and Radiation Hard Inorganic Scintillators for Future HEP Experiments

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Abstract. Future HEP experiments at the energy and intensity frontiers require fast and ultrafast inorganic scintillators with excellent radiation hardness to face the challenges of unprecedented event rate and severe radiation environment. This paper reports recent progresses in fast and ultrafast inorganic scintillators, such as LYSO:Ce crystals and LuAG:Ce ceramics for an inorganic scintillator based shashlik sampling calorimeter and yttrium doped BaF_2 crystals for the proposed Mu2e-II experiment. Applications of ultrafast inorganic scintillators in Gigahertz hard X-ray imaging will also be discussed.

1. Introduction

Inorganic scintillators have been used widely in high energy and nuclear physics experiments, medical instruments and homeland security applications. In high energy physics (HEP) and nuclear physics experiments, total absorption electromagnetic calorimeters made of inorganic crystals are known for their superb energy resolution and detection efficiency for photon and electron measurements [1]. An inorganic crystal calorimeter is thus the choice for those experiments where precision measurements of photons and electrons are crucial for their physics missions.

Among all existing crystal calorimeters, the CMS lead tungstate (PbWO4 or PWO) crystal calorimeter, consisting of 75,848 crystals of 11 m^3, is the largest. Because of its superb energy resolution and detection efficiency, the CMS PWO calorimeter has played an important role for the discovery of the Higgs boson by the CMS experiment [2]. Crystal calorimeters currently under construction are: an undoped CsI calorimeter for the Mu2e experiment at Fermilab, a PWO calorimeter for PANDA at FAIR, a LYSO calorimeter for COMET at JPARC and a PbF_2 calorimeter the g-2 experiment at Fermilab.

Future HEP calorimeters will be operated under unprecedented luminosity. An important issue is thus the decay time of scintillation light. Table 1 lists the optical and scintillation properties for fast inorganic crystal scintillators with a scintillation decay time ranged from sub-nanosecond to a few tens nanosecond, and compared to plastic scintillator [1]. Among the fast crystals listed in Table 1 the mass-production cost of barium fluoride (BaF_2) and undoped CsI crystals is significantly lower than others because of their low raw material cost and low melting point.

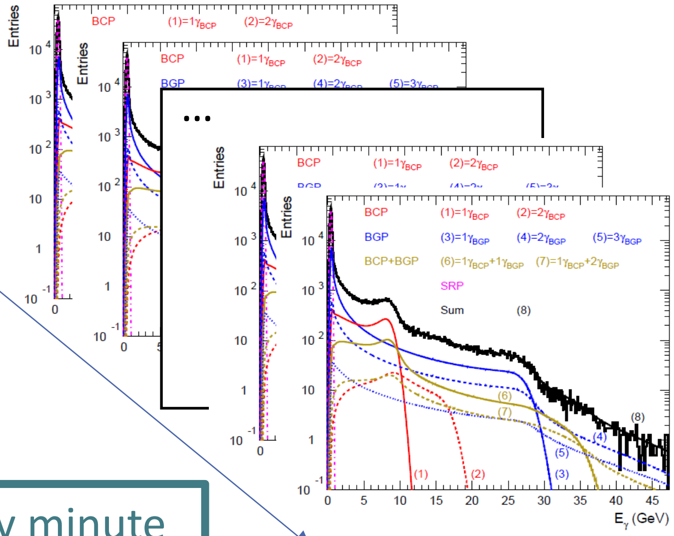
Crystal calorimeters for future HEP experiments at the energy frontier face a challenge of severe radiation environment. Significant losses of light output have been observed in the CMS PWO crystals at large rapidity *in situ* at the LHC caused by both ionization dose and hadrons [3]. Controlling oxygen contamination in halide crystals, e.g. CsI:Tl, or oxygen vacancies in oxide crystals, e.g. PWO, was found effective [4]. Co-doping with yttrium and lanthanum was also found effective for CMS PWO crystals [5]. For experiments to be operated at the HL-LHC with 3,000 fb^{-1}, crystals should survive an environment with an absorbed dose of 100 Mrad, charged hadron fluence of 6×10^{14} p cm^{-2} and fast

Basic idea of detector

Basic elements

- a VERY FAST radhard scintillating crystal → BaF2, the only solution ?
  - ☹ Need to filter out the slow component → UV optical filters
  - ☺ Interesting: Y doping reduces the slow component, but R&D stage
- a PMT with low transit time dispersion → commercially available (hamamatsu for instance)
- Associated electronics
- Next step: validate detection scheme

2500 bunches → 2500 histograms
About 1000 bins each (or less ?)
12 bits dynamics ?



30Mb (3.75MB) to transfer every minute

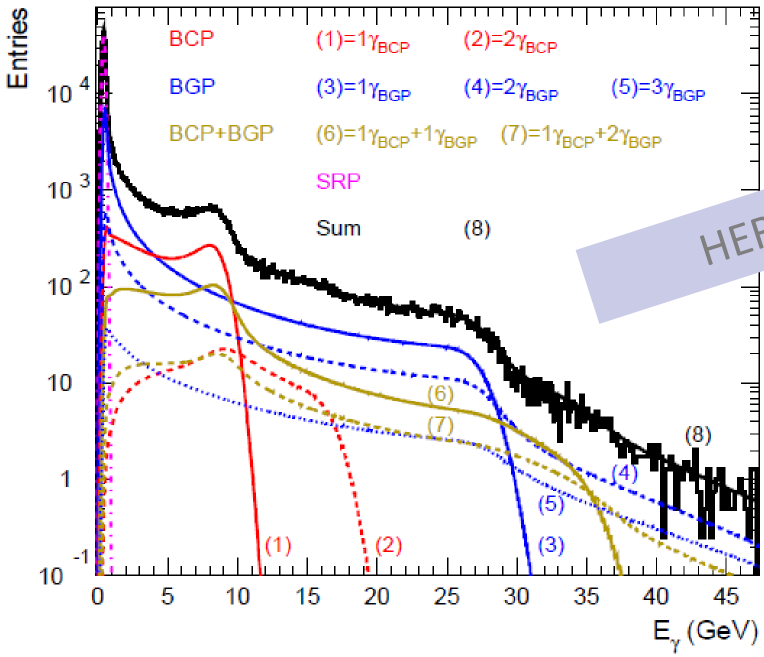
Two options

- Embarked ADC and data processing in the accelerator bay w/transfer link to storage, requires clock (laser also needs it) and bunch identification
- Deported electronics 'à la' lumi with diamonds sensors ? (expensive high BW cables)

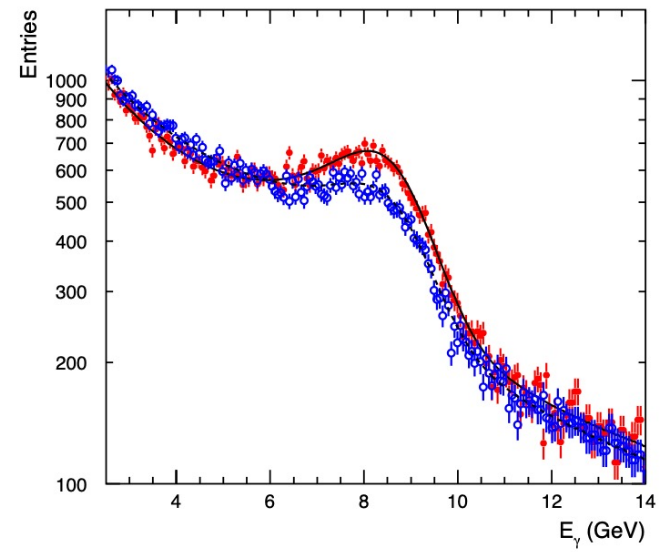
Polarization extraction

Offline: fitter

- Not immediate but can be very precise
- Account for every detail of the experiment → I start by implementing this step by step



HERA



Online: fast approximate/biased extraction

- To be investigated based on HERA work by C. Pascaud et al. (Orsay group)

Toy-MC sensitivity studies

We simulate e-/laser interaction → extract $\mathcal{P}_Z$
For the fit:

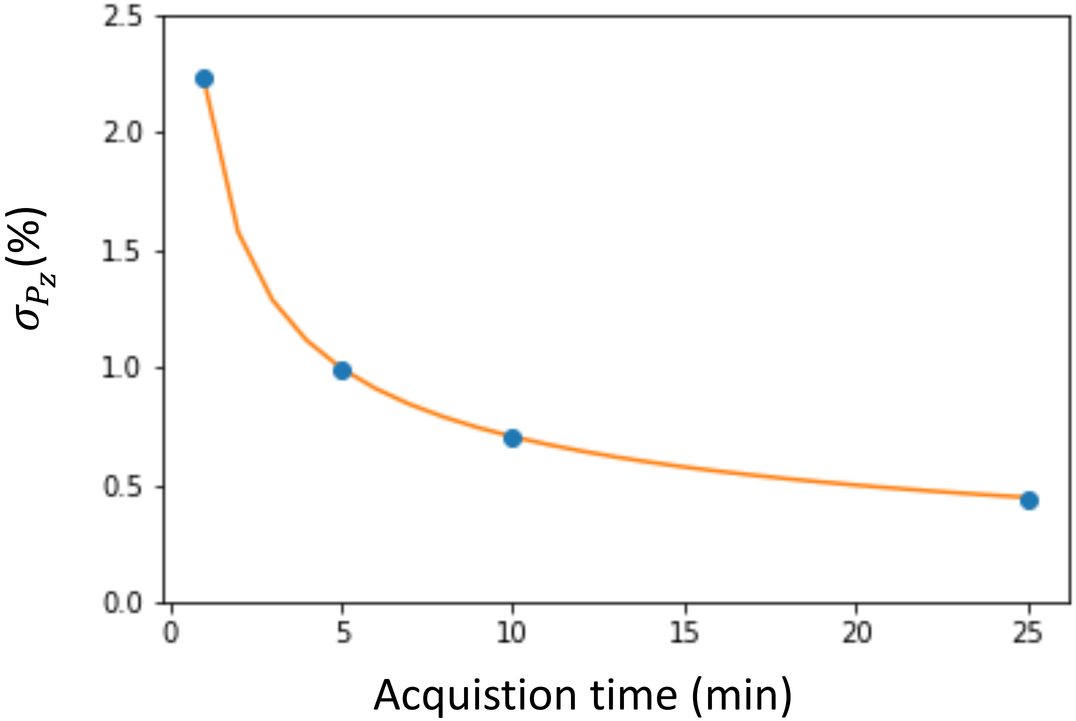
Fixed parameters: e- beam energy and spread, $\mathcal{P}_T$, $\mathcal{P}_{las}^{circ}$, $\mathcal{P}_{las}^{lin}$
Free parameters: $\mathcal{P}_Z$, miscalibration scale, relative scale of each contribution (1 or 2 Compton photons), detector energy resolution

Electron beam parameters	Variable	Value
mean energy	E_e	7GeV
relative energy spread	σ_e/E_e	6.3×10^{-4}
bunch charge	Q_e	10nC
number of electrons per bunch	N_e	6.25×10^{10}
longitudinal polarization	P_z	0.7
transverse polarization	P_T	0
horizontal beam size	σ_{x_e}	$660\mu m$
vertical beam size	σ_{y_e}	$75\mu m$
revolution period	T_{rev}	$10\mu s$
number of turns	N_{turns}	6×10^6
acquisition time	T	25min
Emittance parameters	α_x	-8.7163
Emittance parameters	β_x	96.4621m
Emittance parameters	ϵ_x	4.49×10^{-9}m.rad
Emittance parameters	η_x	-0.08333
Emittance parameters	α_y	9.4502
Emittance parameters	β_y	127.0947m
Emittance parameters	ϵ_y	4.5×10^{-11}m.rad
Emittance parameters	η_y	-1.1×10^{-9}

We focus on photon detection here

Laser beam parameters	Variable	Value
energy of each initial photon	E_λ	2.4eV
laser power	P	5W
repetition frequency	f_{rep}	250MHz
circular polarization	P_{circ}	-1
linear polarization	P_{lin}	0
horizontal beam size	σ_{x_l}	$500\mu m$
vertical beam size	σ_{y_l}	$500\mu m$
Interaction parameters	**Variable**	**Value**
crossing angle	θ_0	$3°$
luminosity	$\mathcal{L}$	$8.66 \times 10^{27} m^{-2}$
Detector (BaF_2 crystal) parameters	**Variable**	**Value**
distance to Compton IP	L	13m
size	s	2.5cm
detector energy resolution	$\simeq A\sqrt{E}$	$0.1\sqrt{E[GeV]}$
miscalibration scale	m.s.	1.1

Statistical sensitivity



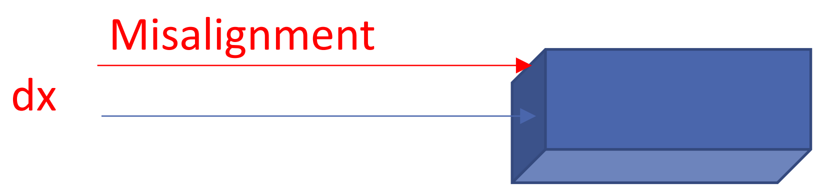
For 1 min, there's 2.2% error on the extraction of P_z

For 25 min, there's 0.5% error on the extraction of P_z

(Signal-only) Toy-MC sensitivity studies

We do 1000 toys of the interaction using several configurations and study the sensitivity on the $\mathcal{P}_Z$ extraction

type	Pz^{gen}	A^{gen}	$m.s.^{gen}$	dx^{gen}	dy^{gen}	dz^{gen}	P_T^{gen}	P_{lin}^{gen}	P_{circ}^{gen}	dE^{gen}
A	0.7	0.1	1.1	0	0	0	0	0	-1	0
C	0.7	0.03	1.1	0	0	0	0	0	-1	0
F'	0.7	0.1	1.0	0	0	0	0	0	-1	0
G'	0.7	0.03	1.0	0	0	0	0	0	-1	0
H	0.7	0.1	1.1	1mm	0	0	0	0	-1	0
I	0.7	0.1	1.1	2mm	0	0	0	0	-1	0
J	0.7	0.1	1.1	0	1mm	0	0	0	-1	0
K	0.7	0.1	1.1	0	0	0	0.3	0	-1	0
L	0.7	0.1	1.1	0	0	0	0	-0.05	-0.95	0
M	0.7	0.1	1.1	0	0	1mm	0	0	-1	0
N	0.7	0.1	1.1	0	0	10mm	0	0	-1	0
O	0.7	0.1	1.1	0	0	0	0	0	-1	$10\sigma_e$



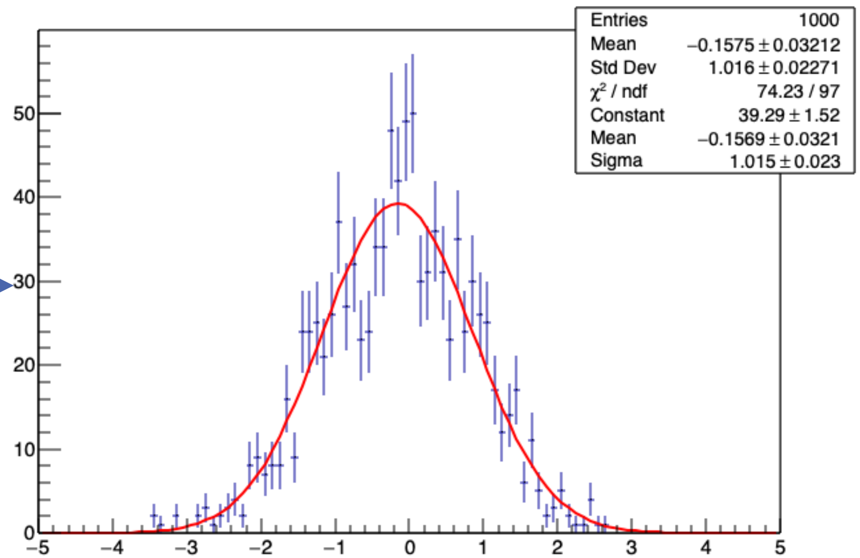
Detector Top view

Toy-MC sensitivity studies

$$\mathrm{Pull(f)} = \frac{f^{gen} - f^{fit}}{\sigma^{fit}}$$

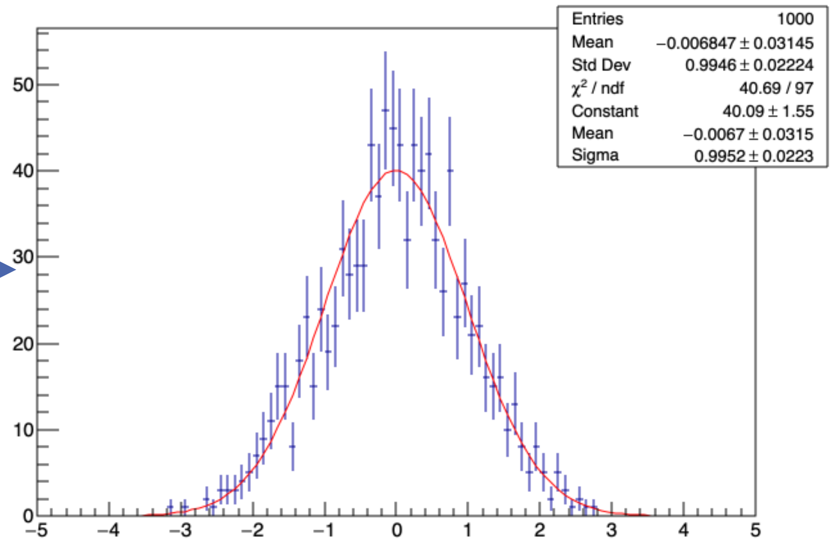
Ideally, pull =0 and $\sigma_{pull} = 1$

$\mathrm{Pull}(P_z)$ for the 'basic' configuration (A):
0.08% bias on P_z



By improving the energy resolution from 10% to 3%

$\mathrm{Pull}(P_z)$ for the configuration (C)
Bias disappears (0.002%)



Toy-MC sensitivity studies

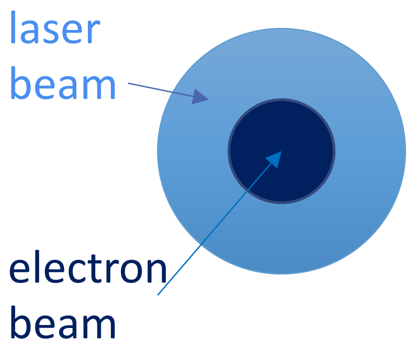
type	$< Pz >$	σ_{Pz}	μ^{pull}_{Pz}	σ^{pull}_{Pz}	$< m.s. >$	$\sigma_{m.s.}$	$\mu^{pull}_{m.s.}$	$\sigma^{pull}_{m.s.}$	$< E_{resol_A}[\%] >$	$\sigma_{E_{resol_A}}[\%]$	$\mu^{pull}_{E_{resol_A}}$	$\sigma^{pull}_{E_{resol_A}}$	χ^2
A	0.6992	0.0049	-0.1569	1.0150	1.1	0.0001	0.0022	1.011	9.9994	0.0152	-0.0455	1.0040	171.7
C	0.7000	0.0041	-0.0067	0.9952	1.1	6.7e-5	0.0825	1.017	3.0025	0.0081	0.2945	0.9799	150.5
F'	0.6992	0.0049	-0.1519	1.0060	1	0.0001	0.0035	1.004	9.9994	0.0153	-0.0422	1.001	155.4
G'	0.7000	0.0042	-0.0068	0.9947	0.9999	6.2e-5	0.0856	1.020	3.0025	0.0081	0.3022	0.9845	135.6
H	0.6992	0.0049	-0.1597	1.0130	1.1	0.0001	0.0022	1.009	9.9993	0.0152	-0.0356	1.003	171.6
I	0.6992	0.0049	-0.1559	1.0150	1.1	0.0001	0.0047	1.013	9.9993	0.0152	-0.0399	0.9968	171.6
J	0.6992	0.0049	-0.1554	1.0130	1.1	0.0001	0.0022	1.011	9.9993	0.0152	-0.0522	0.9988	171.6
K	0.6992	0.0049	-0.1571	1.0150	1.1	0.0001	0.0058	1.018	9.9994	0.0153	-0.0361	1.012	171.6
L	0.6991	0.0053	-0.1718	1.0230	1.1	0.0001	-0.0033	1.022	9.9992	0.0154	-0.0534	1.029	171.7
M	0.6992	0.0049	-0.1571	1.0100	1.1	0.0001	0.0026	0.9967	9.9993	0.0152	-0.0431	0.9971	171.7
N	0.6992	0.0049	-0.1561	1.0100	1.1	0.0001	0.0019	0.9984	9.9993	0.0152	-0.0438	0.0019	171.7
O	0.7006	0.0057	0.1232	1.0240	1.1125	0.0004	7.1970	1.0240	9.9412	0.0364	-3.9280	0.9998	198.5

We have a fit that can extract the longitudinal electron polarization, the miscalibration energy scale, the energy resolution and the scales for the Compton contributions

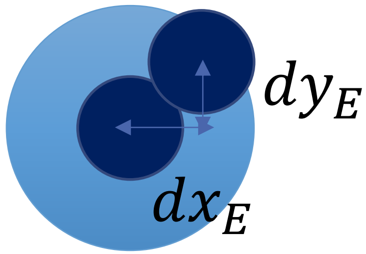
Following e-mail exchange with Oide-san.
Any mistake reflects our misunderstanding.

Beam jitters at injection

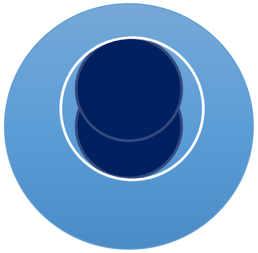
Injection of fresh electrons affects the beam dynamics in two ways:



Shift of the center of gravity of e bunch:
Damped by the feedback in ~100turns



Emittance growth:
Damped by radiation in ~10000turns



Goal: study the jitters and their impact on the sensitivity of the polarimetry

Center of gravity shift

Displacement of electron beam:

Proposed model of dx_E, dy_E the center of gravity shift:

$di_E(t) = 3\,\sigma_i\, e^{\frac{-turn}{N_1}}$;(i=x,y) N_1=100

Luminosity formula with the center of gravity shift:

$$\mathcal{L}(dx_E, dy_E) = \mathcal{L}(0,0)exp\Big[-\frac{dy_E^2}{2({\sigma_y}_e^2 + {\sigma_y}_l^2)} - \frac{dx_E^2}{2({\sigma_x}_e^2 + {\sigma_x}_l^2 + ({\sigma_z}_e^2 + {\sigma_z}_l^2)tan^2\phi)}\Big]$$

with:

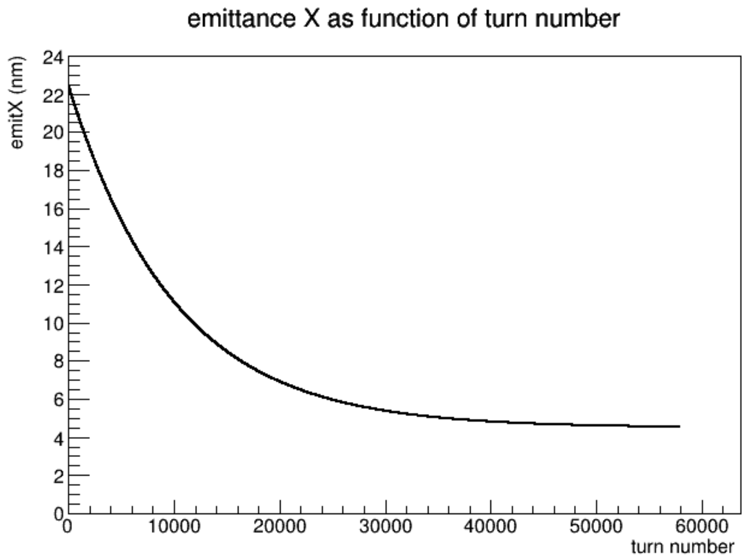
$$\mathcal{L}(0,0) = \frac{fBN_eN_lcos\phi}{2\pi\sqrt{{\sigma_y}_e^2 + {\sigma_y}_l^2}\sqrt{({\sigma_x}_e^2 + {\sigma_x}_l^2)cos^2\phi + ({\sigma_z}_e^2 + {\sigma_z}_l^2)sin^2\phi}}$$

Emittance growth

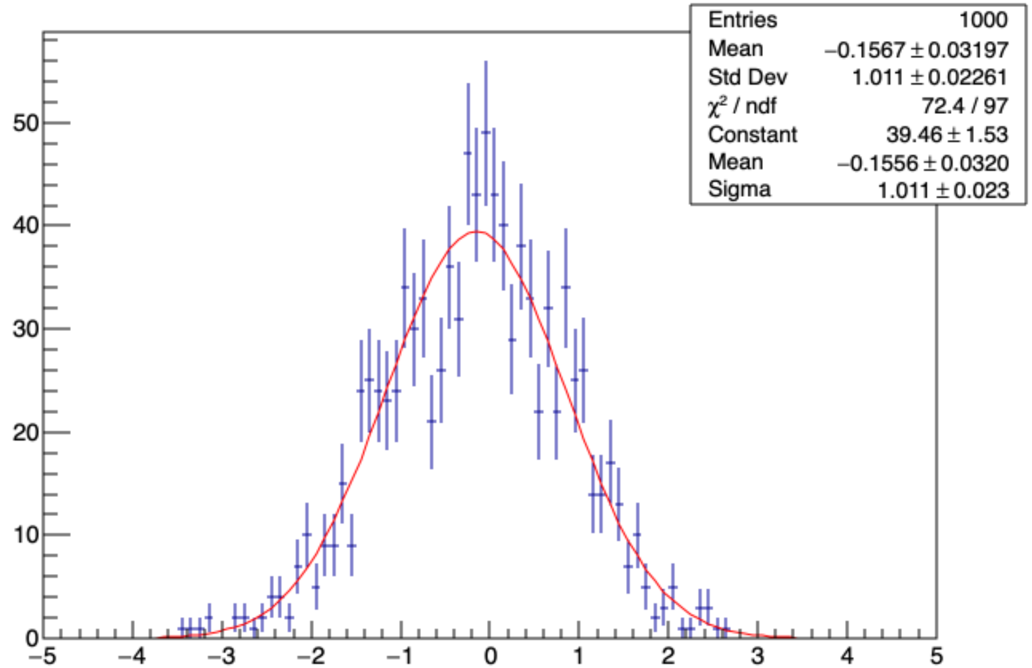
Emittance growth on the x-y plane:
Proposed model:

$$\epsilon_i(t) = \epsilon_{0i} + 4\,\epsilon_{0i}\, e^{\frac{-turn}{N_2}}\text{; (i=x,y) } N_2\text{=10000}$$

This leads to a change in the e- beam size and the luminosity

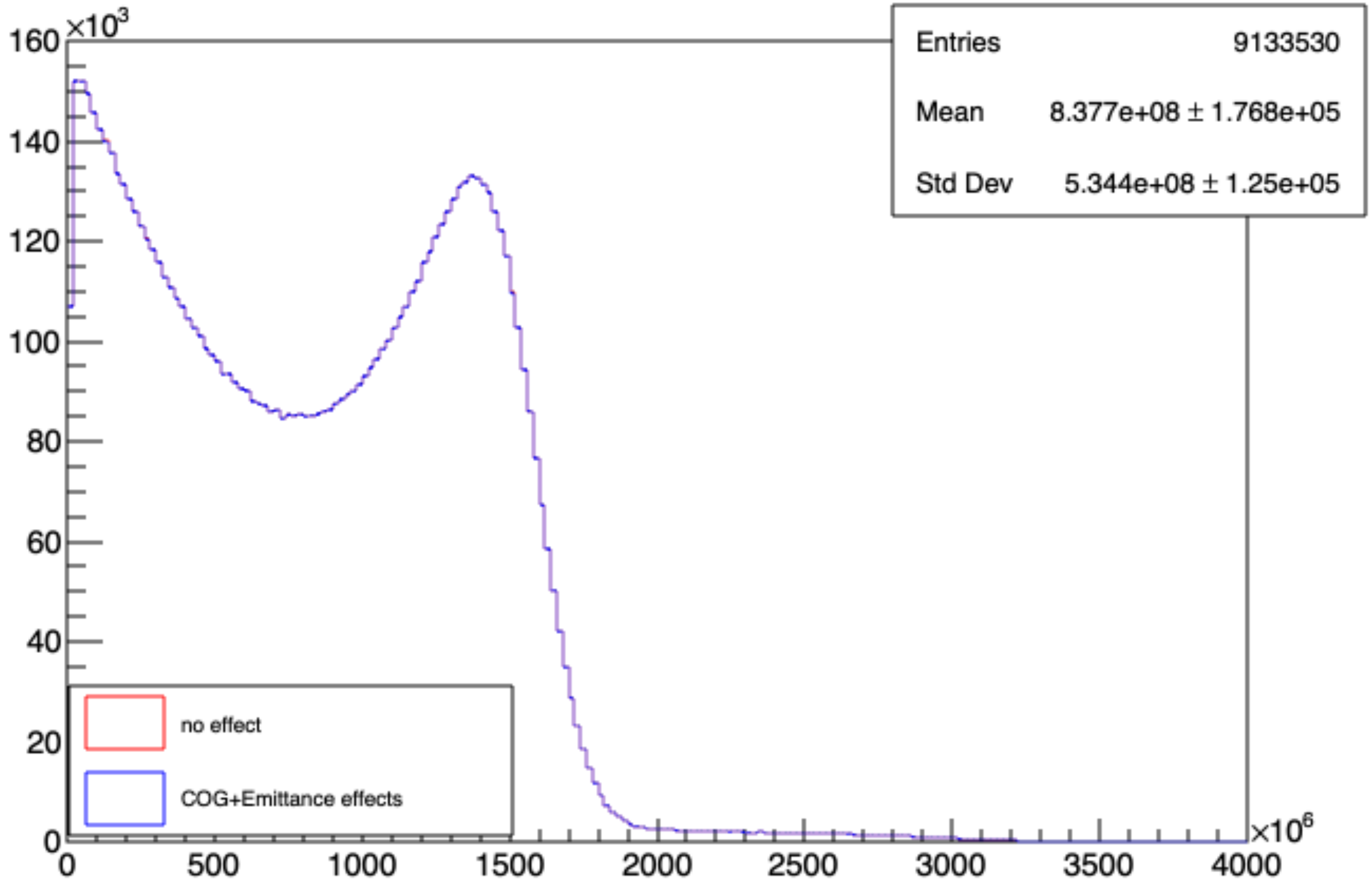


$\mathrm{Pull}_{\mathrm{P_z}}$ for basic configuration (A) including jitter effects → no additional bias on P_z



Effect on energy spectrum

For configuration A, including the jitter effects:



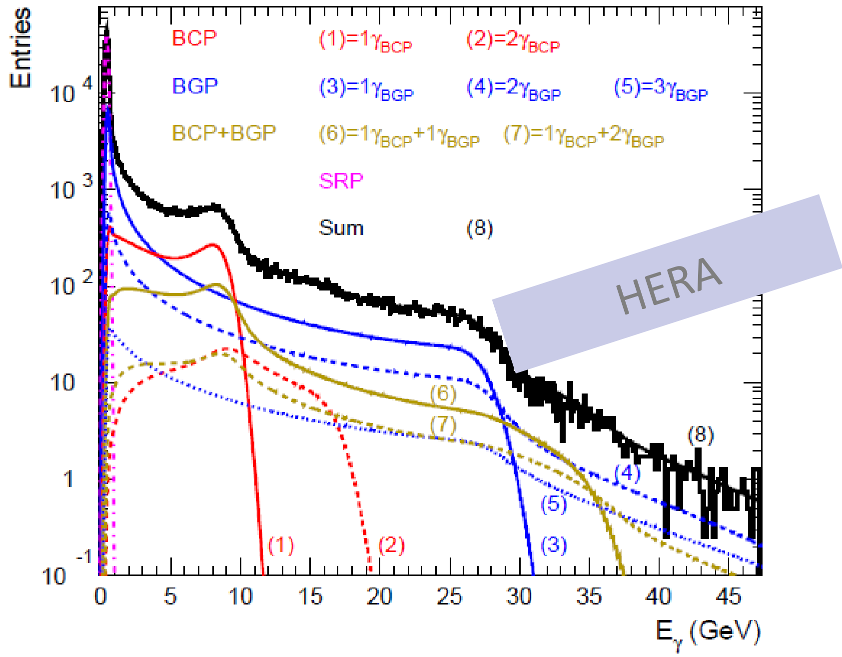
No effect except for statistical fluctuations for a few bins

So the shifts on the electron beam and the emittance do not affect the energy spectrum

Backgrounds

List of background contributions:

- Bremsstrahlung radiation
- Synchrotron radiation
- Compton on blackbody radiation



Main Contribution ?

Just as at HERA, we suppose bremsstrahlung radiation is one of the dominant contributions

We try to make a first rough estimate here

Synchrotron radiation

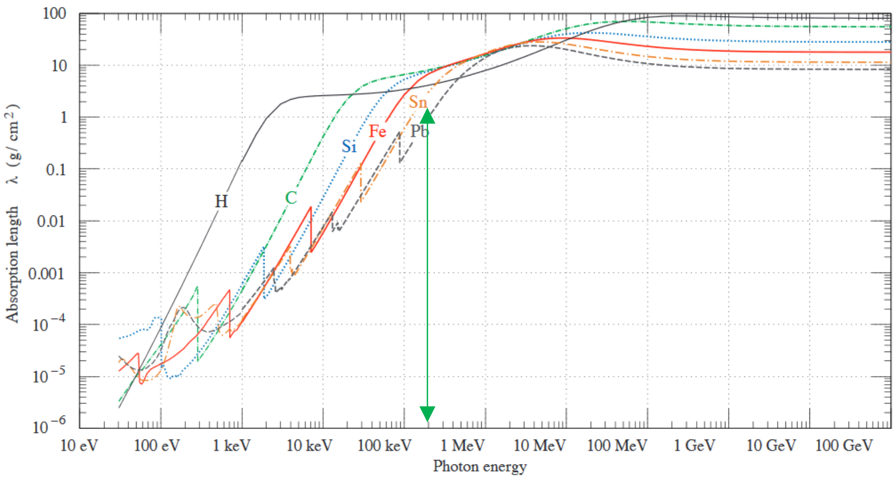
“Critical energy” of synchrotron radiation: $E_c = \frac{3}{2}\gamma^3\frac{c}{\rho} \sim 5keV$

ρ: radius of curvature ~ 146 m

Total number of synchrotron radiation photons E_0 :

$$N_{tot\ sync}(E_X \geq E_0) = \sqrt{\frac{3\pi}{2}}\alpha\gamma\Gamma(\frac{1}{2},\frac{E_0}{E_c})\frac{L}{2\pi\rho}$$

E_0~200keV $\longleftrightarrow$ $1g\ cm^{-2}$



Jackson Book, Classical Electrodynamics

Density of lead: $11.34g\ cm^{-3}$

Solution: put a ~1 mm (or more) lead plate in front of the detector to get rid of synchrotron radiation

Bremstrahlung

Bremsstrahlung radiation :

Z: mean atomic number of the residual gas nucleus , taken as 2.2 or 7

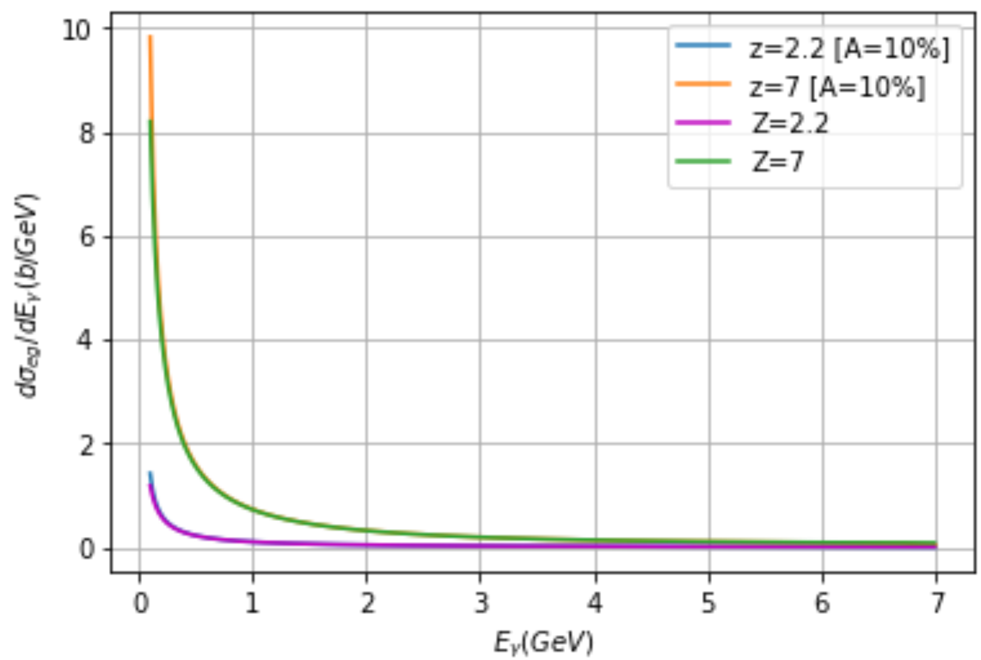
$e + g \longrightarrow e + g + \gamma$

The cross section averaged over scattered particles spins :

$$y = \frac{E_\gamma}{E_e}$$

$$\frac{d\sigma}{dy} = \frac{4\alpha r_e^2}{y}\left\{\left(y^2 - \frac{4}{3}y + \frac{4}{3}\right)\left(Z^2 \ln\left(184.15 Z^{-1/3}\right) + Z \ln\left(1194 Z^{-2/3}\right)\right) + \frac{1}{9}\left(Z^2 + Z\right)(1 - y)\right\}$$

Detector energy resolution has no effect except for small energies



Yung-Su Tsai: Pair production and bremsstrahlung of charged leptons. Rev Mod. Phys. 46 (1974) 815

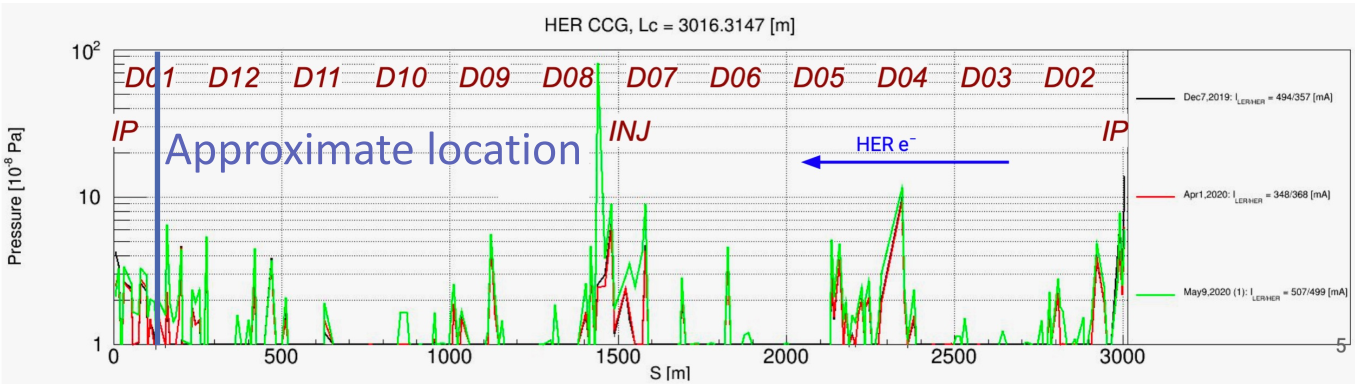
P.M Lewis et al. First measurements of beam backgrounds at SuperKEKB. NiMA 914 (2019) 69

PHYSICAL REVIEW ACCELERATORS AND BEAMS 26, 013201 (2023)

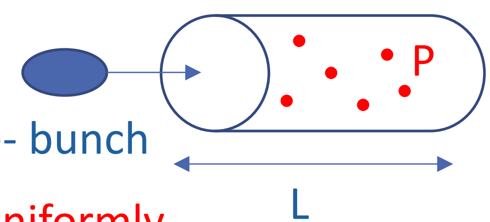
Following e-mail exchange with Andrii Natochi.
Any mistake reflects <u>our</u> misunderstanding.

Bremstrahlung luminosity

Luminosity of collision between the electron bunch and the gas particles in the beam pipe of length L:

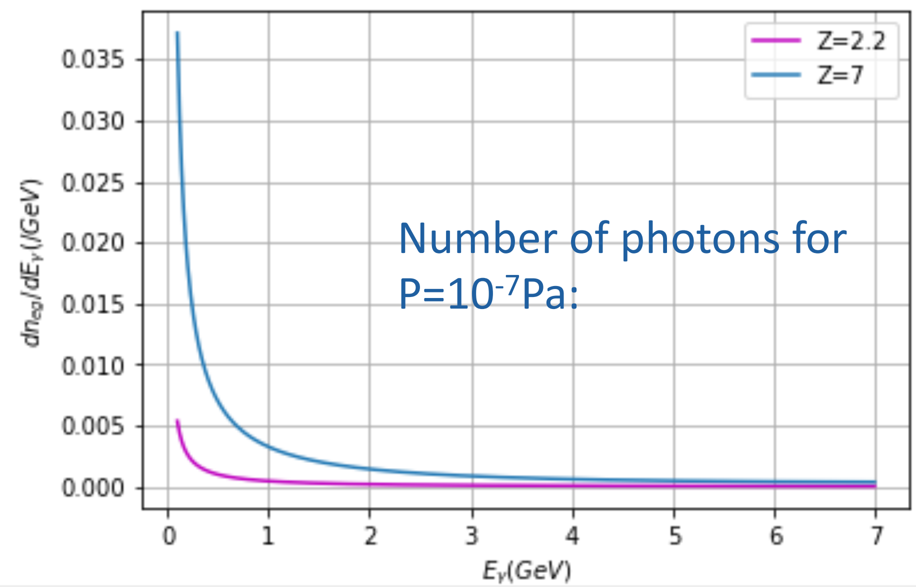


L=30m
P<$10^{-7}\,Pa$
T=300K
N_e=10nC

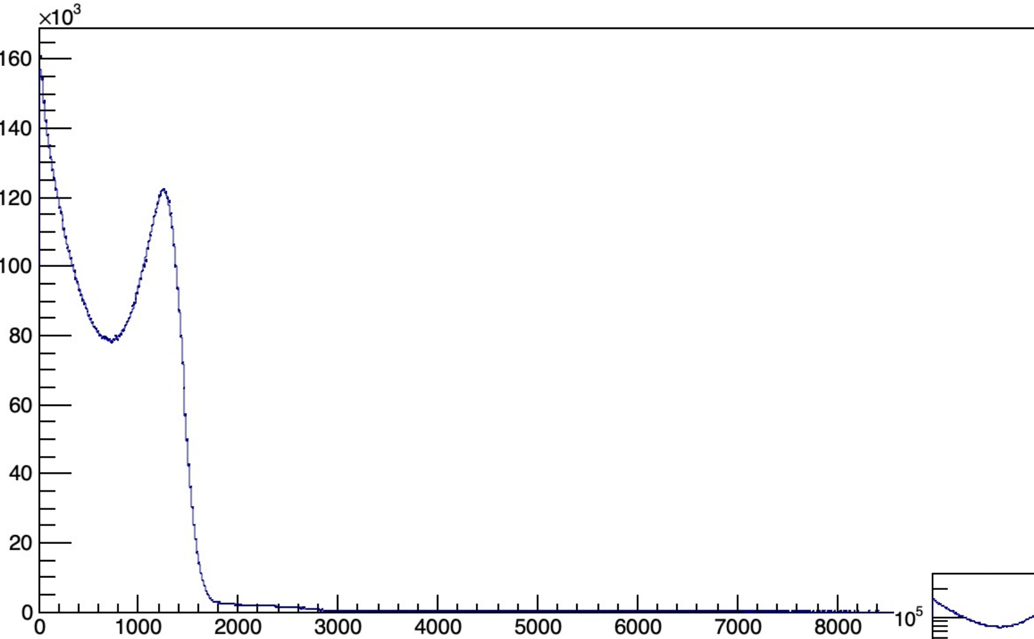


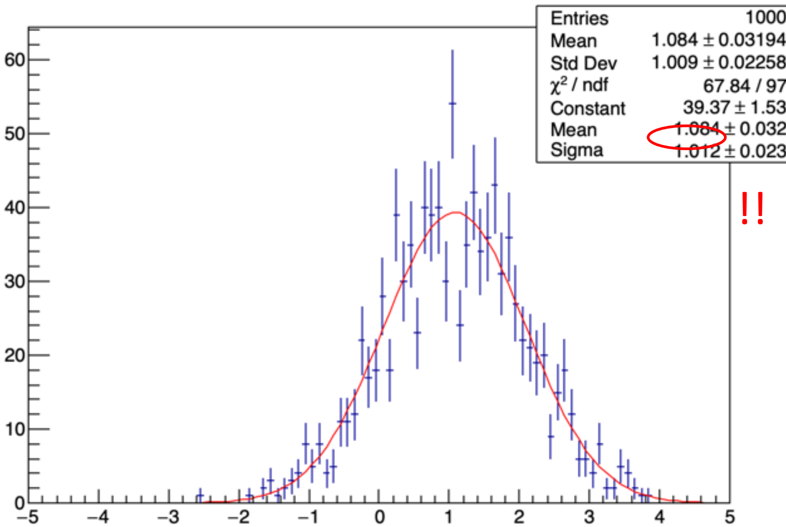
gas particles uniformly distributed in the beam pipe, having pressure P

$$L_{brem} = \beta\, N_e \frac{L\, P}{k_B T}$$



Signal+background Toy-MC





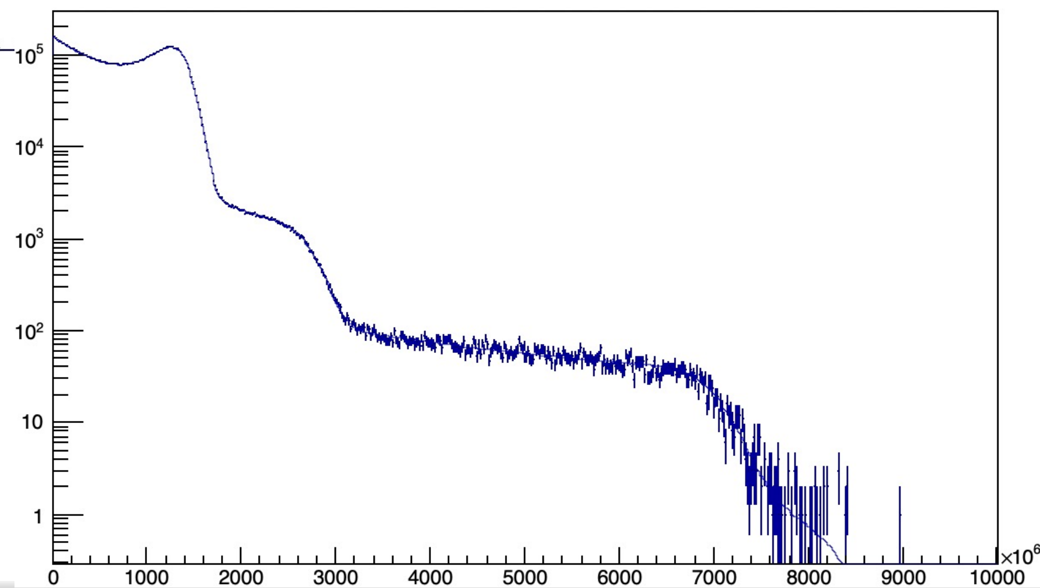


Table of systematics

Source	Variable	Value	Uncertainty on P_z(%)
Fit procedure	n/a	n/a	0.08
Transverse misalignment	dx, dy	1mm	negligible ($\ll 0.08$)
Longitudinal misalignment	dz	10mm	negligible ($\ll 0.08$)
Angular misalignment	θ_x, θ_y	100μrad	negligible ($\ll 0.08$)
Beam energy	E_e	$10\sigma_e$	0.07
Transverse electron beam polarisation	P_T^{gen}	0.3	negligible ($\ll 0.08$)
Backgrounds	n/a	n/a	0.45
Total	n/a	n/a	0.46

Summary and next steps

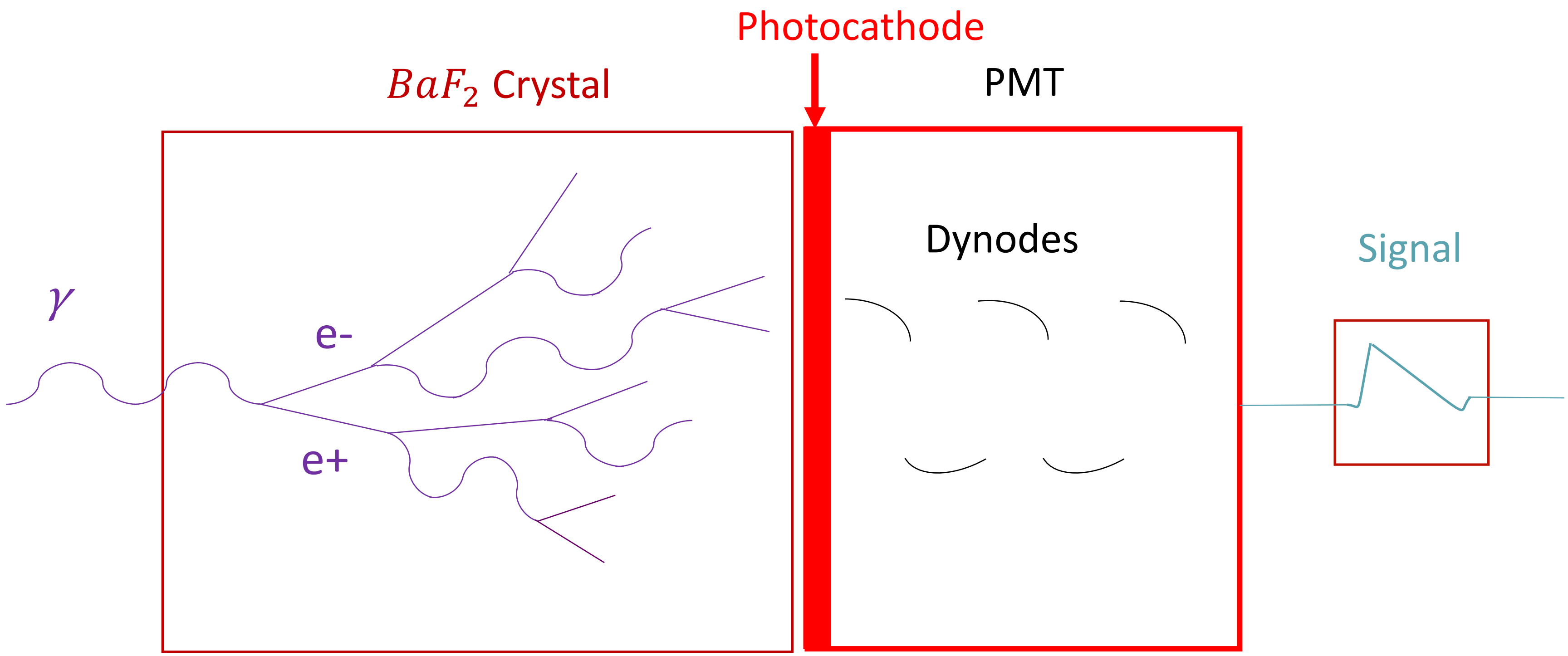
- Transverse polarimetry is a difficult subject (at least for a photon detector)
- Location for the polarimeter in existing ring is proposed with minimal impact on beam and current design
- Proposal for a photon detector is made
- Extensive studies based on toy MC have been made
- First systematic uncertainties have been estimated

Next steps:

- Populate CDR document + JINST publication
- R&D BaF_2 detector + realistic GEANT simulation ← French funding applied (hardware + manpower)
- Laser R&D setup has been prepared and progressing well (see presentation by Aurelien): more progresses expected in the following months

Backup

Basic idea of detector



Compton on blackbody

The beam pipe emits photons through blackbody radiation, these photons scatter on the electron beam and the scattered photons contribute in the background effects and have an impact on the energy spectrum.

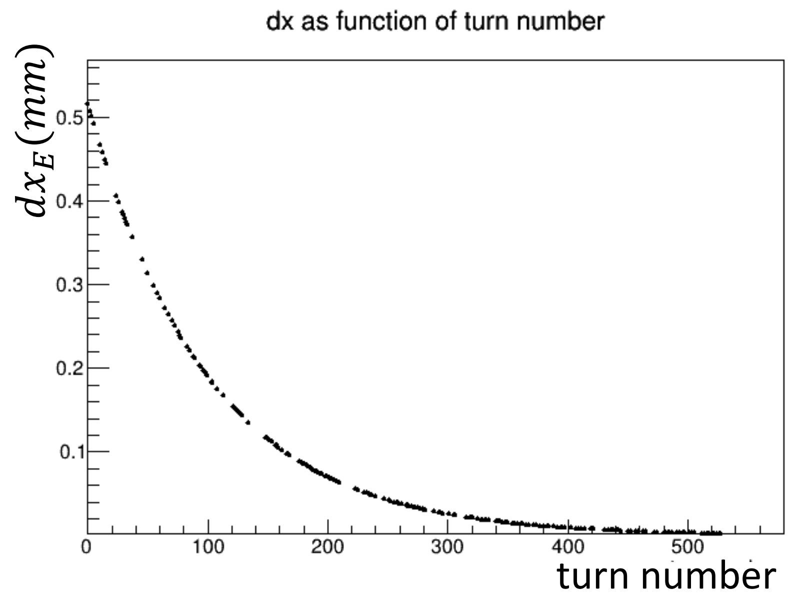
The blackbody energy spectrum: $\frac{dn(E_\lambda)}{dE_\lambda} \propto \frac{E_\lambda^2}{e^{E_\lambda/k_B T}-1}$

Center of gravity shift

Displacement of electron beam:

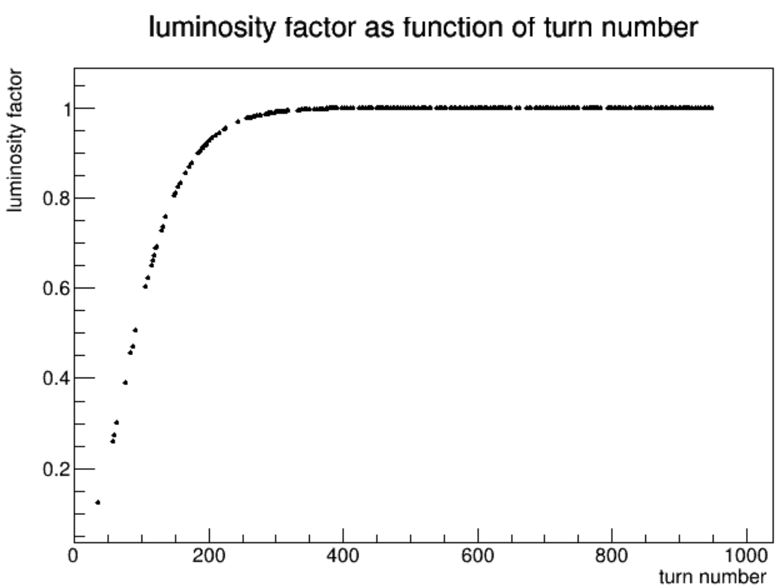
Proposed model of dx_E, dy_E the center of gravity shift:

$di_E(t) = 3\,\sigma_i\, e^{\frac{-turn}{N_1}}$ (i=x,y) N_1=100



Luminosity formula with the center of gravity shift:

$$\mathcal{L}(dx_E, dy_E) = \mathcal{L}(0,0)exp\Big[-\frac{dy_E^2}{2(\sigma_{y_e}^2+\sigma_{y_l}^2)} - \frac{dx_E^2}{2(\sigma_{x_e}^2+\sigma_{x_l}^2+(\sigma_{z_e}^2+\sigma_{z_l}^2)tan^2\phi)}\Big]$$



$$\mathcal{L}(0,0) = \frac{fBN_eN_lcos\phi}{2\pi\sqrt{\sigma_{y_e}^2+\sigma_{y_l}^2}\sqrt{(\sigma_{x_e}^2+\sigma_{x_l}^2)cos^2\phi+(\sigma_{z_e}^2+\sigma_{z_l}^2)sin^2\phi}}$$

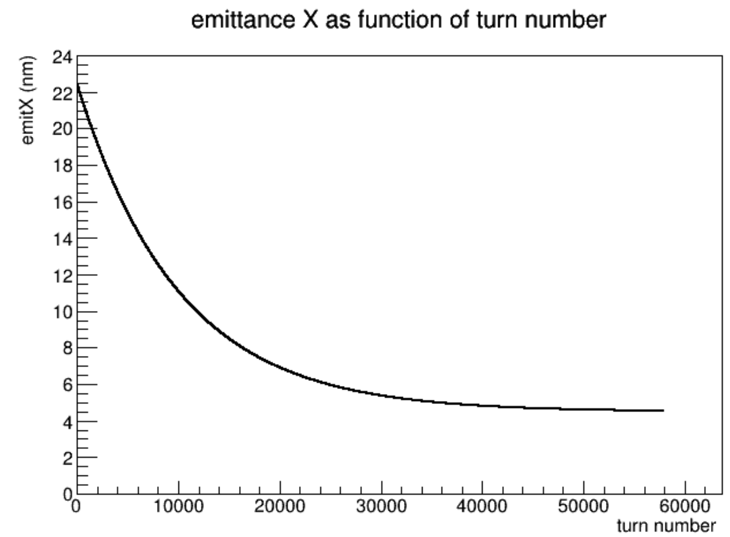
Emittance growth

Emittance growth on the x-y plane:
Proposed model:

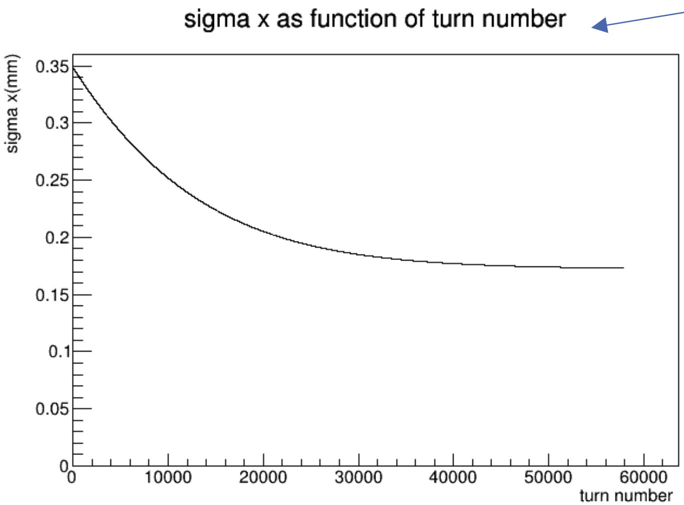
$$\epsilon_x(t) = \epsilon_{0x} + 4\,\epsilon_{0x}\,e^{\frac{-turn}{N_2}}$$

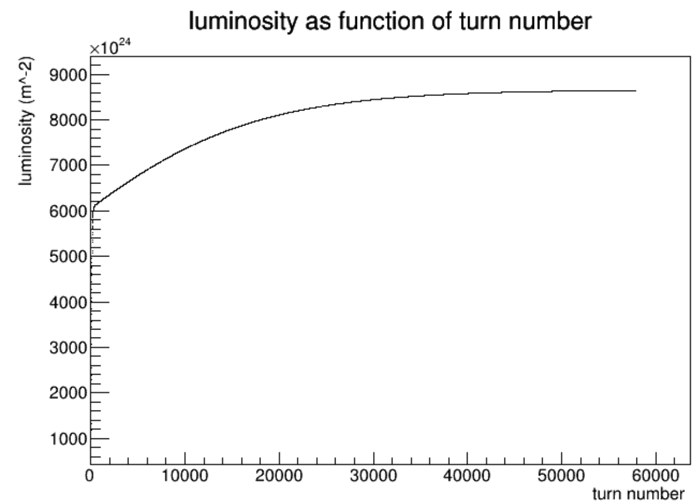
$$\epsilon_y(t) = \epsilon_{0y} + 4\,\epsilon_{0y}\,e^{\frac{-turn}{N_2}}$$

N_2=10000

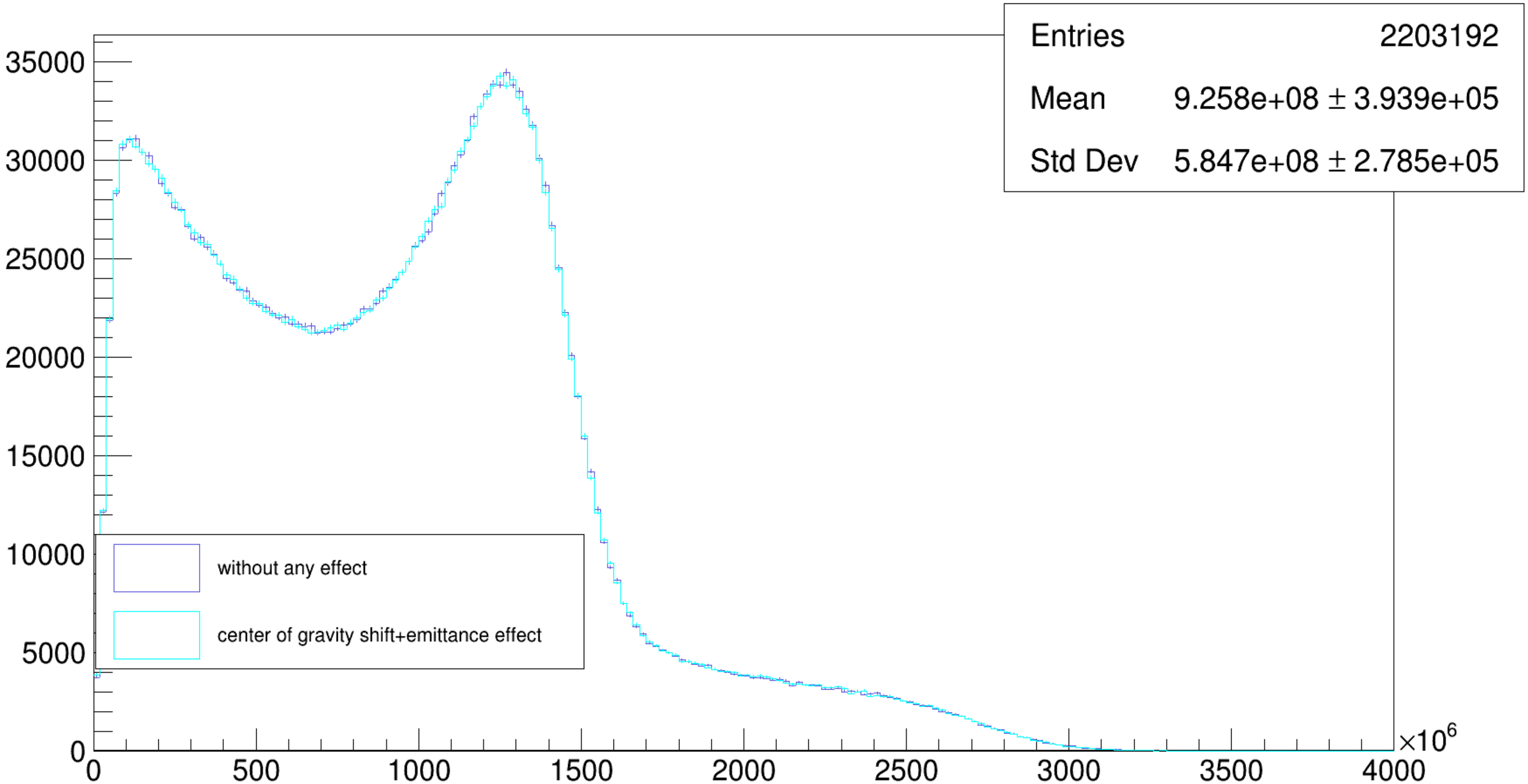


This leads to a change in the e- beam size and the luminosity !



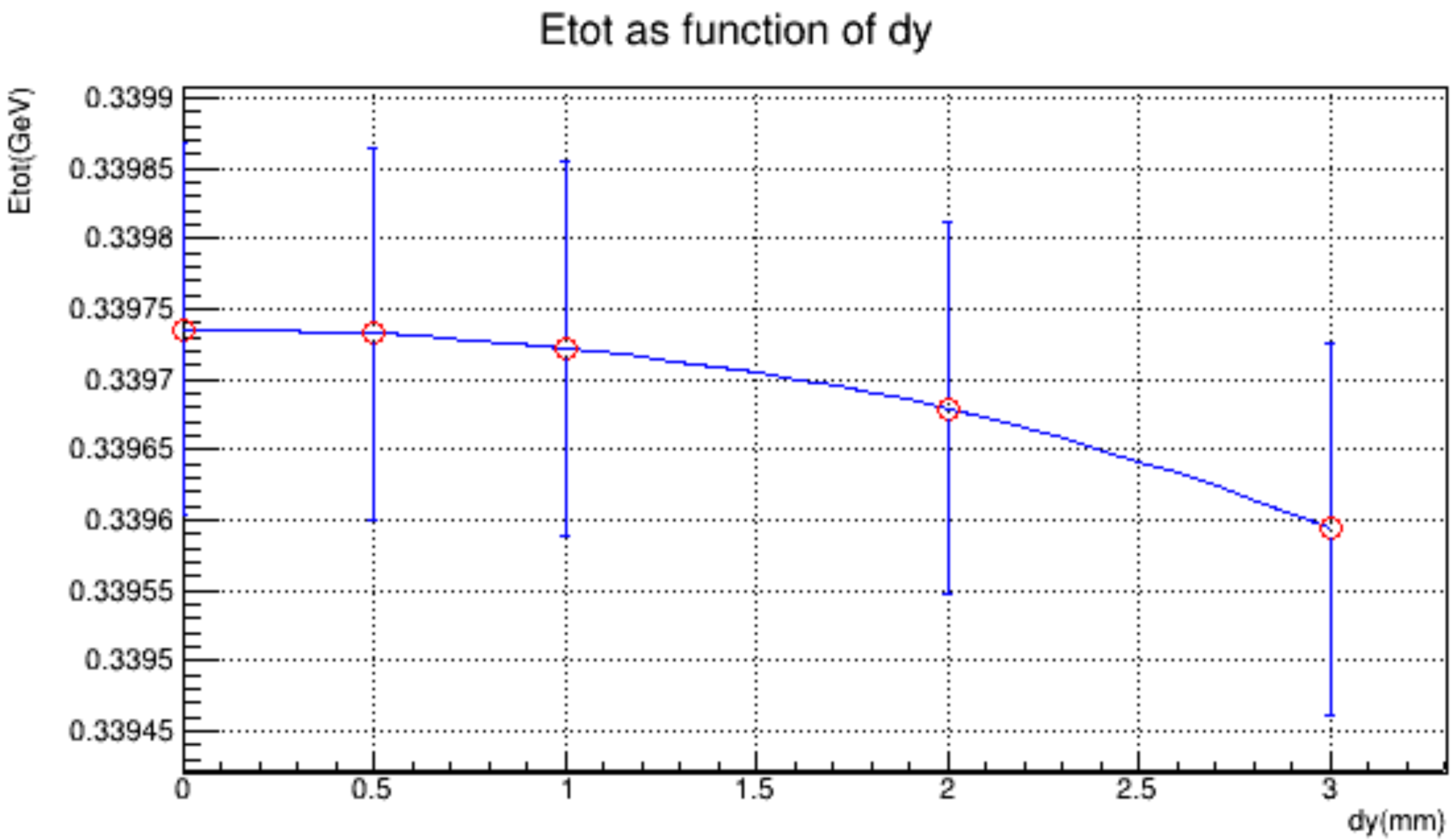


Effect on energy spectrum



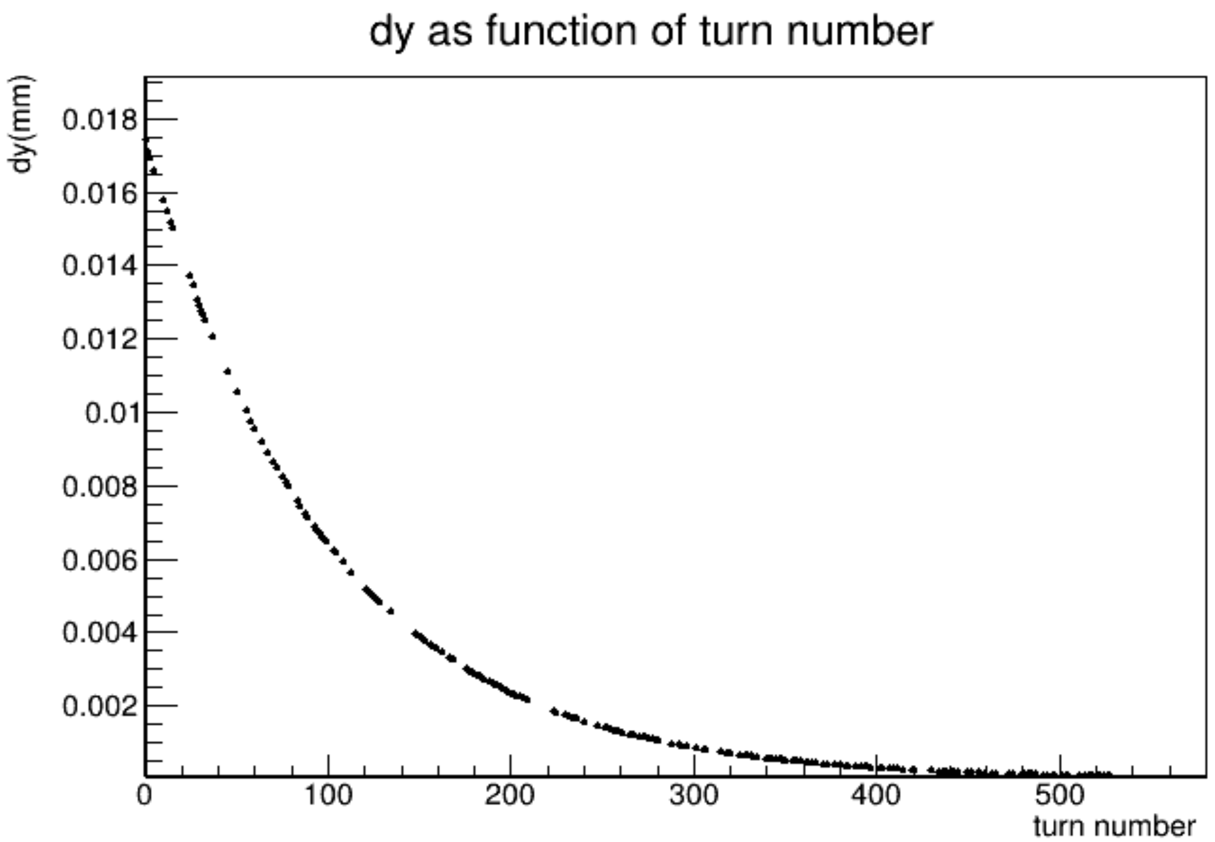
Basic Alignment of detector

Deposited energy in the detector with misalignment :



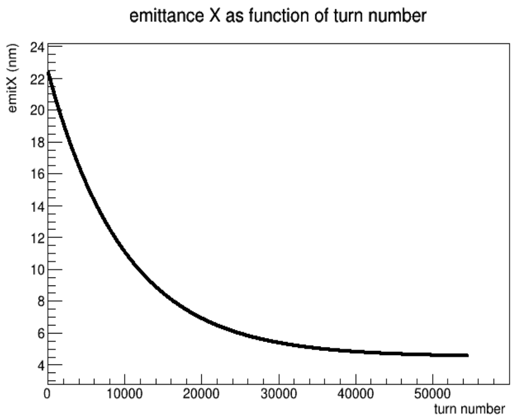
Jitter issues

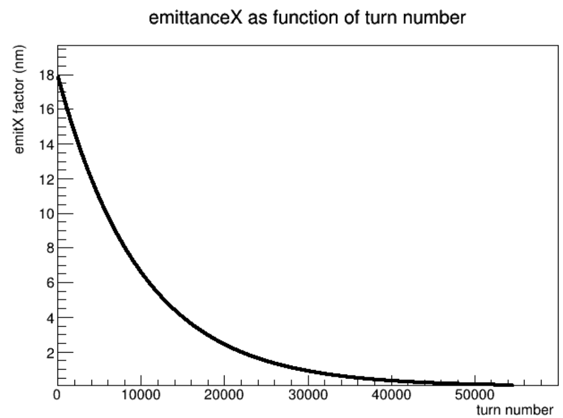
Misalignment of the e beam: (w/o emittance growth)

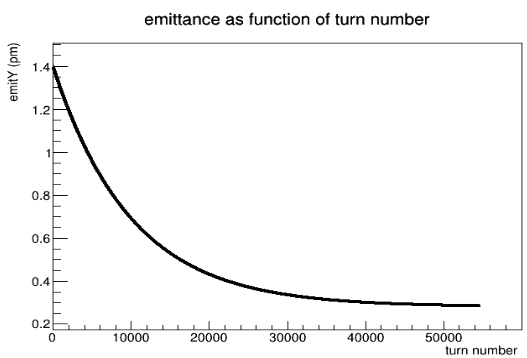


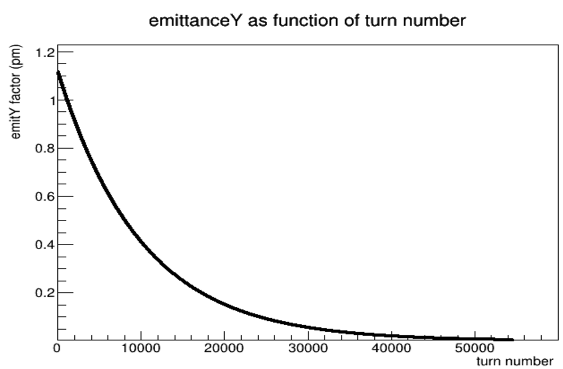
Jitter issues

Taking into consideration misalignment on e- beam + Emittance growth :



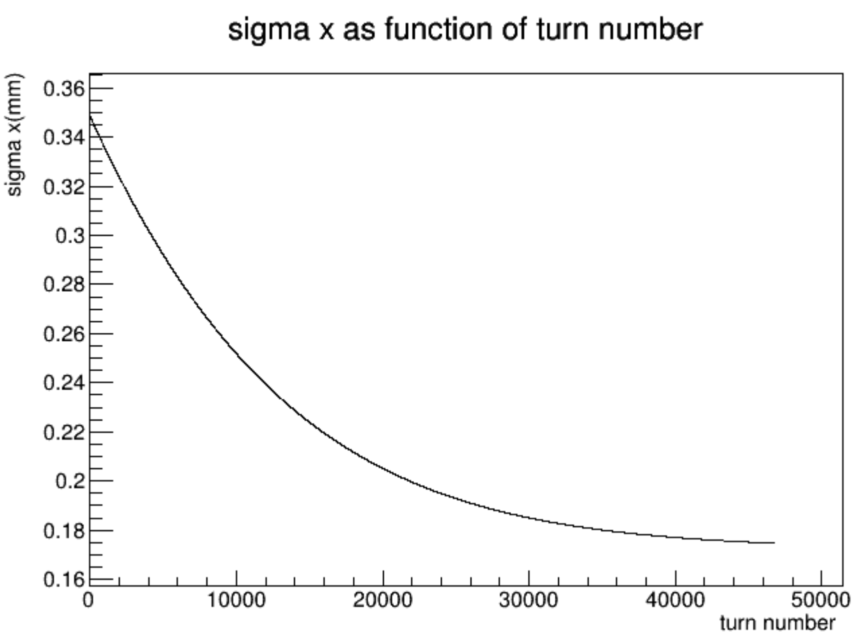


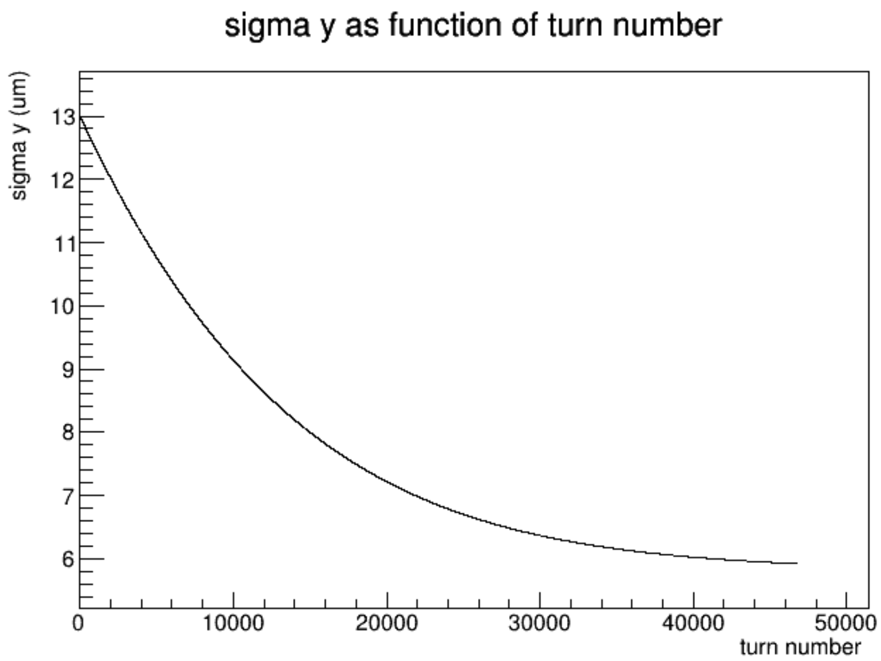




Jitter issues

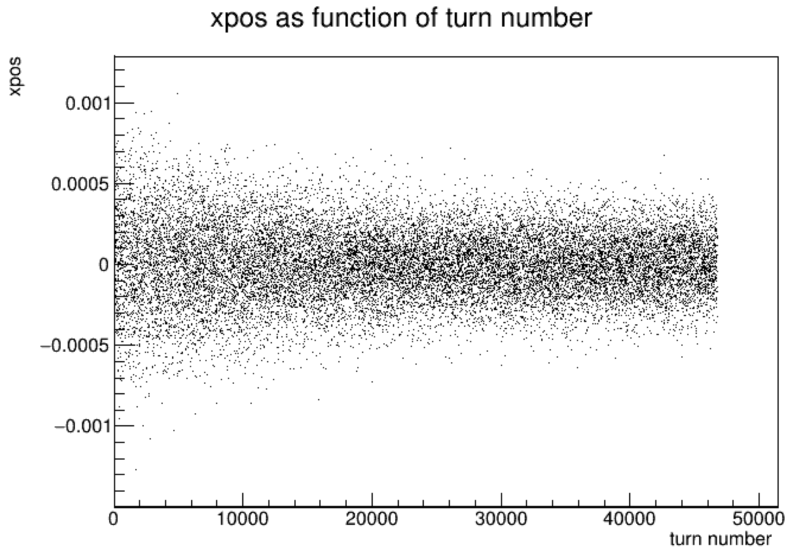
Taking into consideration misalignment on e- beam + Emittance growth :



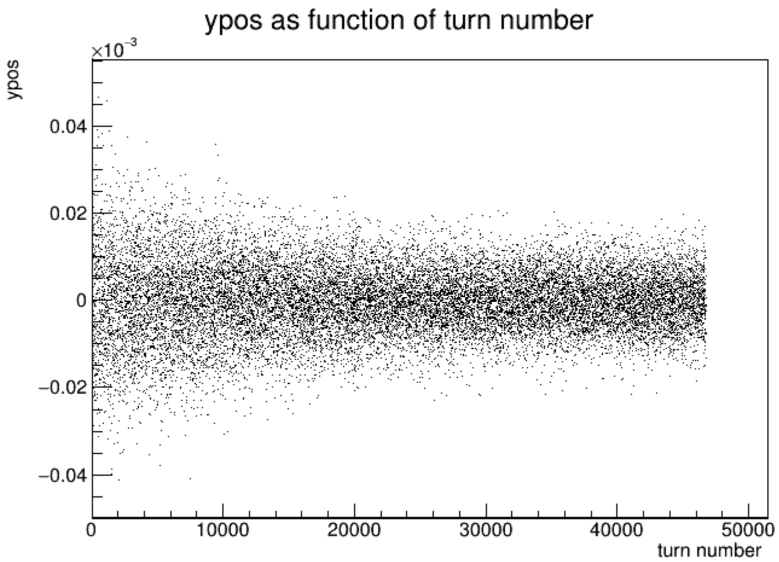


Jitter issues

Taking into consideration misalignment on e- beam + Emittance growth :

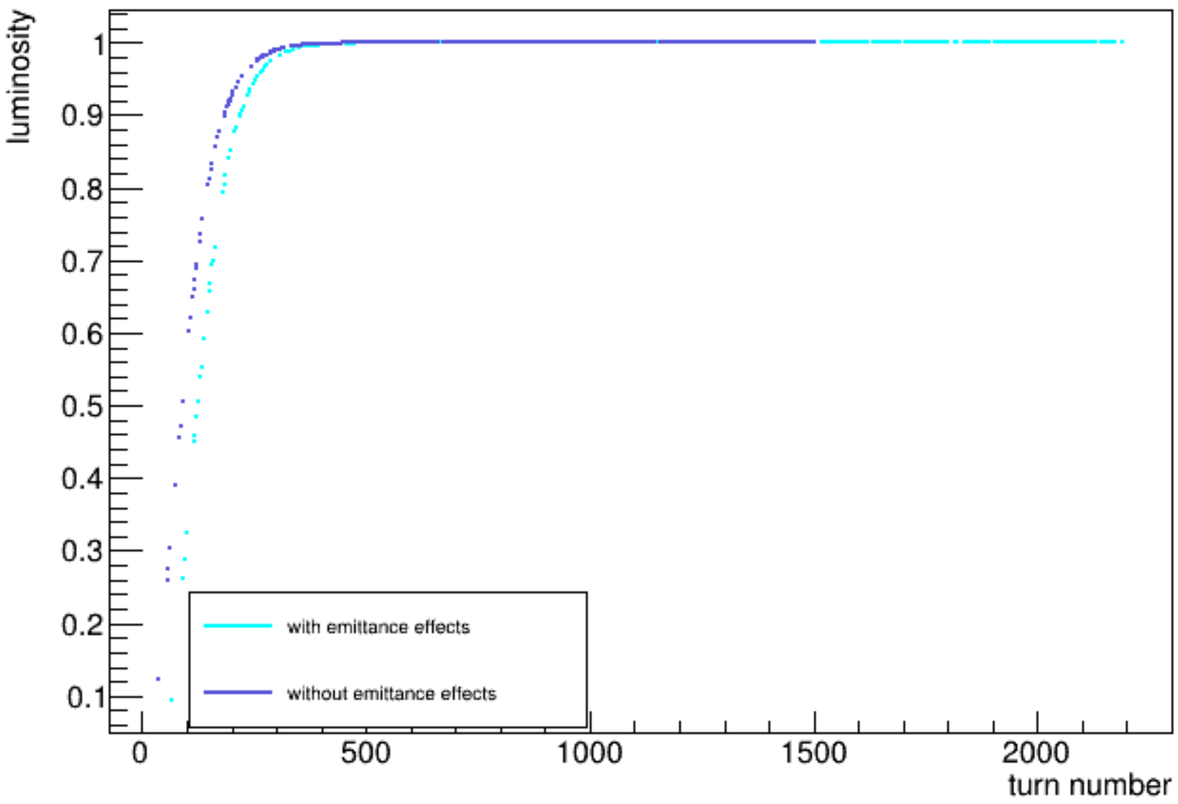


xpos and ypos are the positions of electrons inside the bunch on the x and y axis



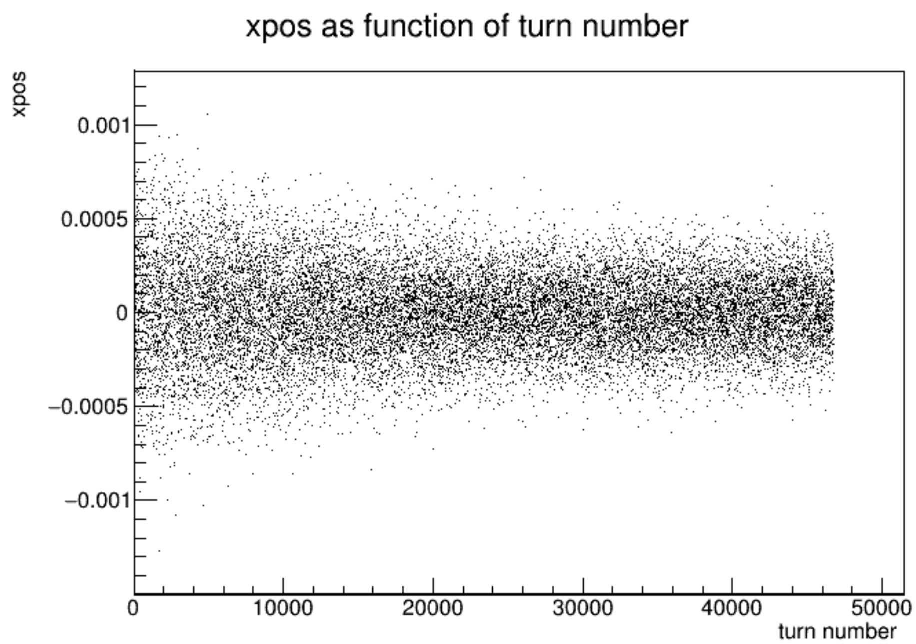
Jitter issues

Comparison:

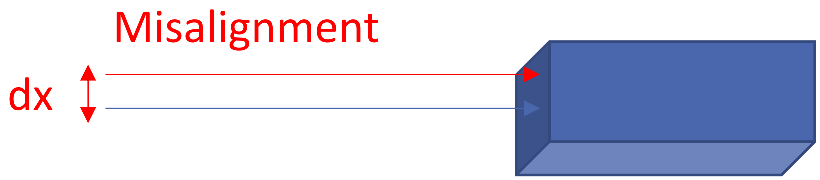


Jitter issues

Taking into consideration misalignment on e- beam + Emittance growth :
xpos: the positions of electrons inside the
bunch on the x axis

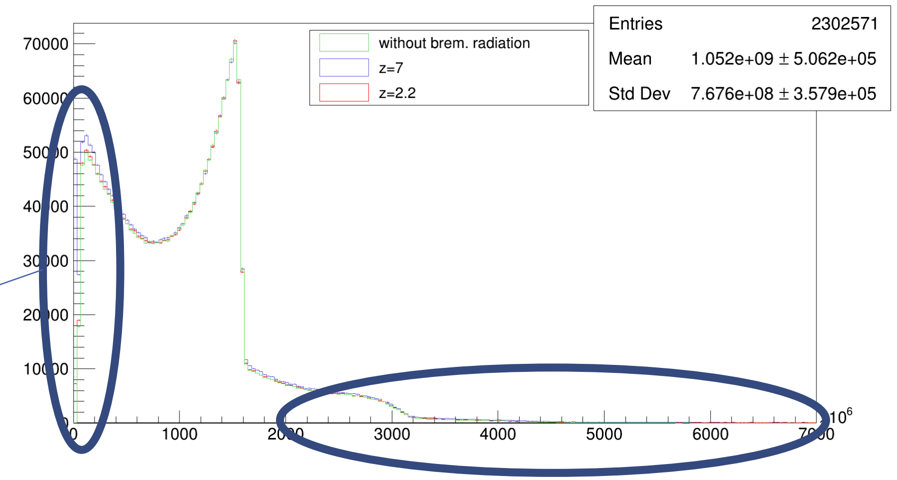


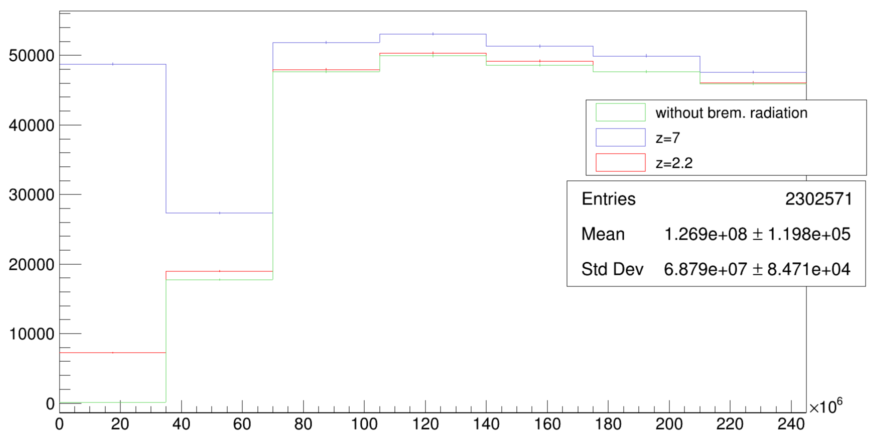
Misalignments on the detector

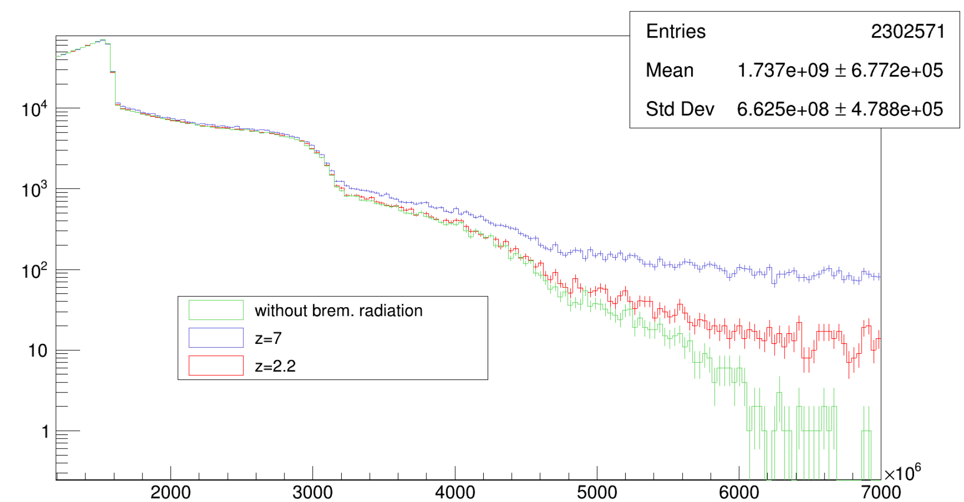


Energy spectrum

At low energy: we see an increase of the number of photons emitted with bremsstrahlung radiation for a beam gas of effective z=7







At high energy, we see photons emitted with bremsstrahlung radiation for a beam gas of effective z=7

Touschek lifetime as a (transverse) polarimeter

A quick history

- Touschek described the lifetime of electrons in AdA ('accumulation ring') in 1963 (Bernardini et al., Phys. Rev. Lett 10 (1963) 407)
- Baier & Khoze, pointed out that Touschek lifetime is sensitive to polarization (At. Energ. 25 (1968) 440)
- It was then used in the VEPP-2M ring to measure depolarization (and thus beam energy): Derbenev Part. Acc. 8 (1978) 115
  - Measuring the counting rate of scattered electrons
- Ex: Allowed first precision mass measurement of J/Psi (3096.93+-0.09 MeV) then superseded in 1993 (E760)
- Continously improved at VEPP-4M (KEDR at VEPP-4M: 3096.900 ± 0.002 ± 0.006 MeV): Phys. Lett 96B (1980) 214; Blinov et al., proc. of EPAC (2002) 1954

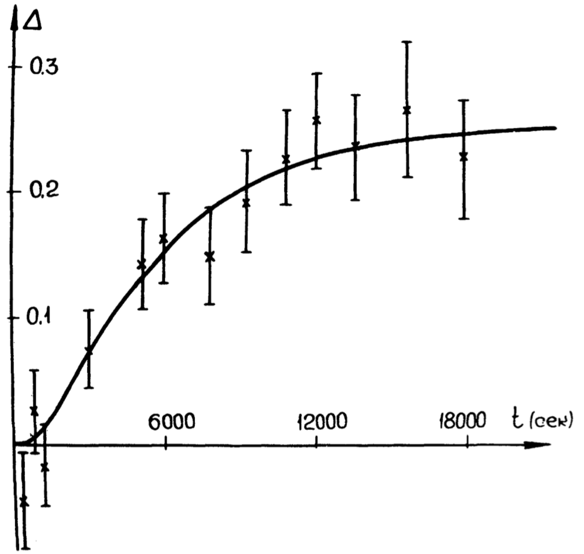


FIGURE 5 The jump in the counting rate during depolarization versus time from the beginning of a polarization cycle.

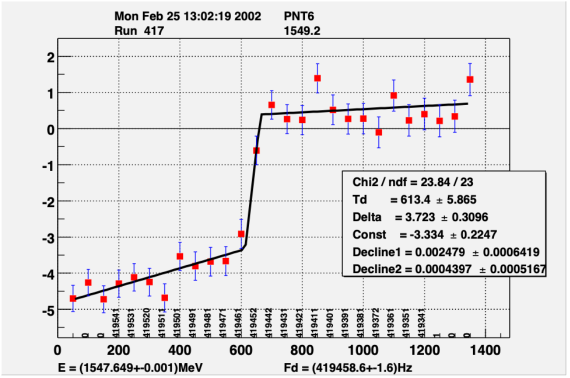


Figure 6: The jump ΔS during the scan of the depolarizer frequency. Abscissa is the time in seconds.

A slightly more modern use

- Used at :
  - HIgS (DUKE): NIMA 614 (2010) 339
  - SOLEIL, NIMA 697 (2013) 1
  - Diamond Light Source, PRAB22 (2019) 122801
  - Based on expressions given in NIMA 554 (2005) 85
  - Also proposed for FCCee: arXiv1909.12245

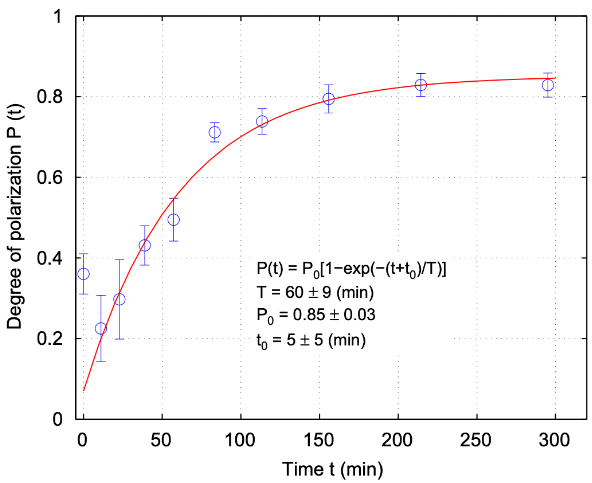


Fig. 6. The build-up process of the electron beam polarization $P(t)$. The solid line is the exponential fit of the data. The fitting model as well as the fit results are also shown in the plot.

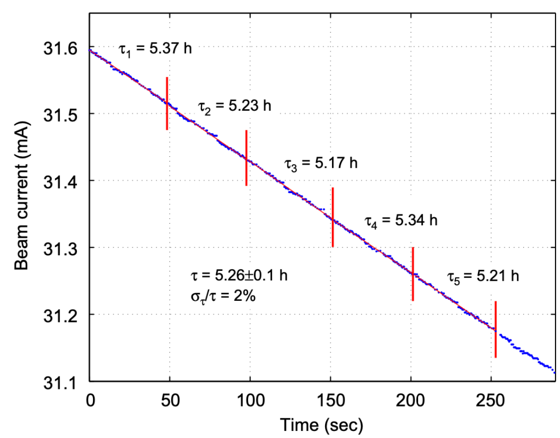


Fig. 4. Illustration of beam lifetime determination around the current of 31 mA of the first run.

$$C(\epsilon) = \epsilon \int_{\epsilon}^{\infty} \frac{1}{u^2}\left\{\left(\frac{u}{\epsilon}\right) - \frac{1}{2}\ln\left(\frac{u}{\epsilon}\right) - 1\right\} e^{-u}\, du$$

$$F(\epsilon) = \frac{\epsilon}{2}\int_{\epsilon}^{\infty} \frac{1}{u^2}\ln\left(\frac{u}{\epsilon}\right) e^{-u}\, du$$

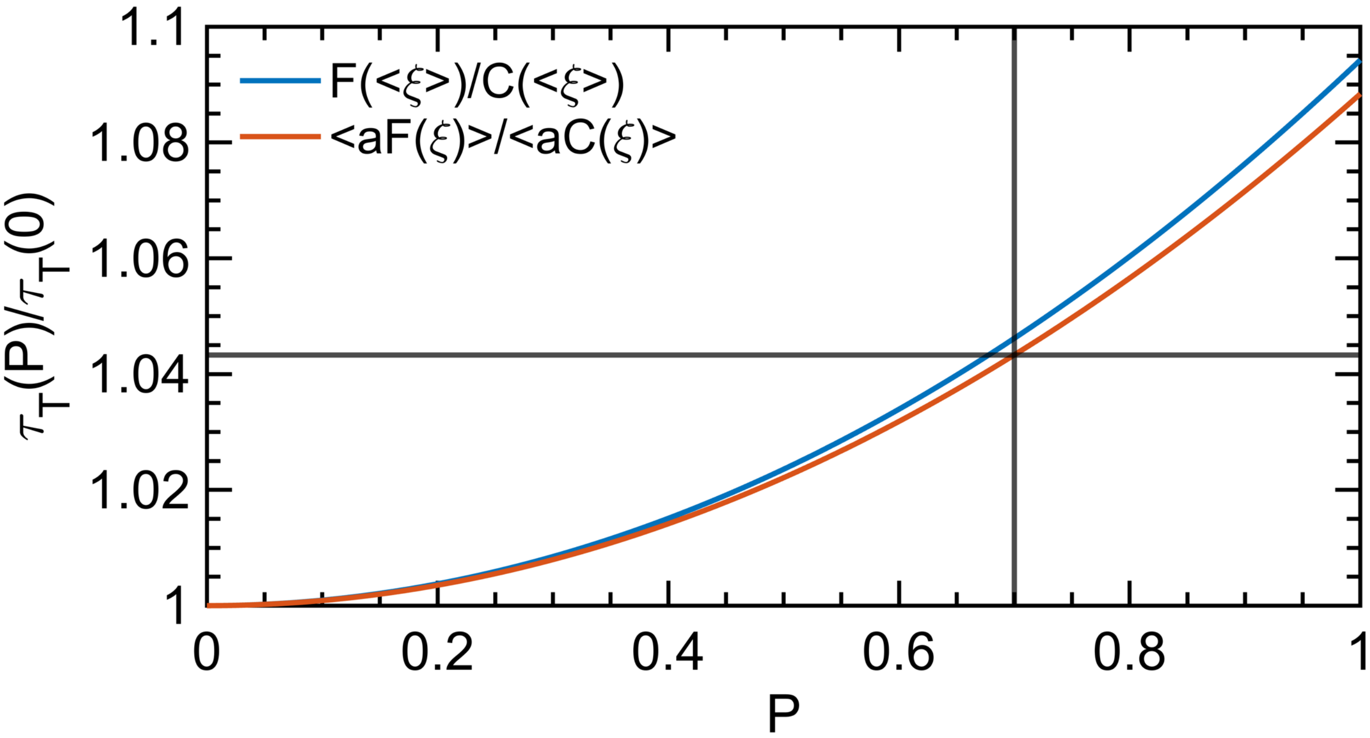
$$\epsilon = \left(\frac{\Delta p_m / p_0}{\gamma \sigma_{x'}}\right)^2$$

$$P(t) \approx \sqrt{\frac{1}{A}\frac{I(t)\tau(P) - I_0\tau(0)}{I(t)\tau(P)}}$$

$$A = \frac{\langle aF(\epsilon)\rangle}{\langle aC(\epsilon)\rangle}$$

$$a = \frac{\sqrt{\pi} c r_e^2}{\gamma^3 V \sigma_{x'} (\Delta p_m / p_0)^2}$$

For SuperKEKB



- It is ~4% effect assuming (overall) momentum acceptance of 0.6%, and using her_2021-06-09_231636.388_MeasOpt
- Needs some detailed evaluations if this is observable in SuperKEKB
- May need to inject both polarized and unpolarized beams and measure bunch/bunch intensity with time to minimize systematics
- Maybe F/C factor could be calibrated by comparing measurements with various momentum acceptances ? (linked to RF voltage ?)