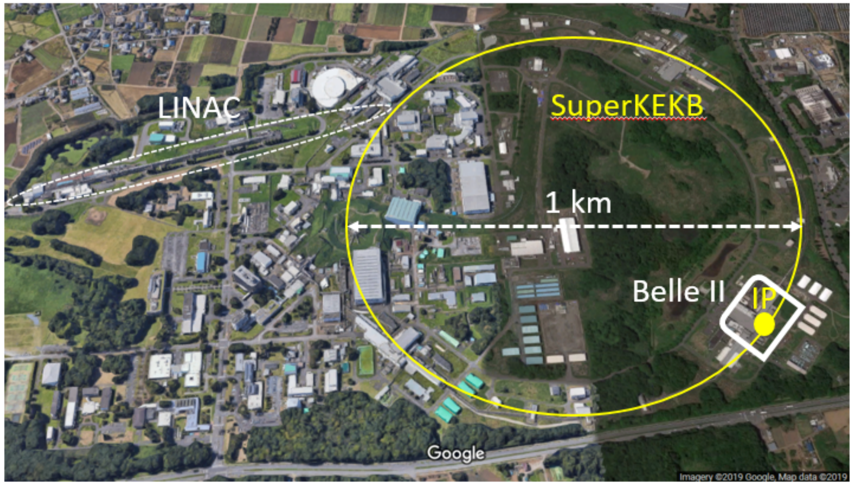
El monitor de luz de Beamstrahlung (LABM)

Pedro Luis Manuel Podesta Lerma
Universidad Autonoma de Sinaloa

Super KEKB

Google maps



Google maps

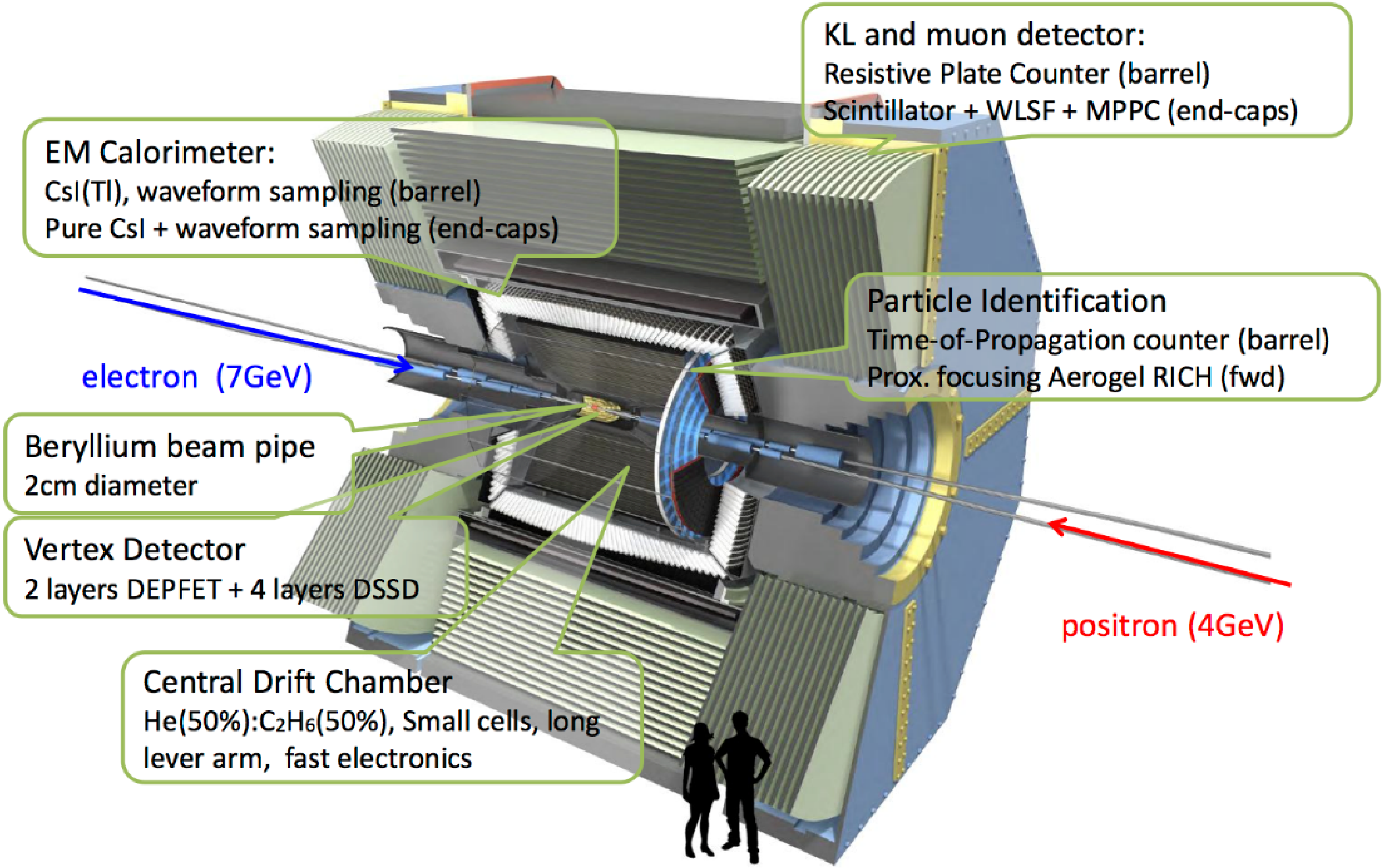
- SuperKEKB: e+e- collider located at KEK laboratory in Tsukuba (JAPAN), 70 km from Tokyo.

- e-/e+ circulate in separate storage rings and collide at interaction point (IP).

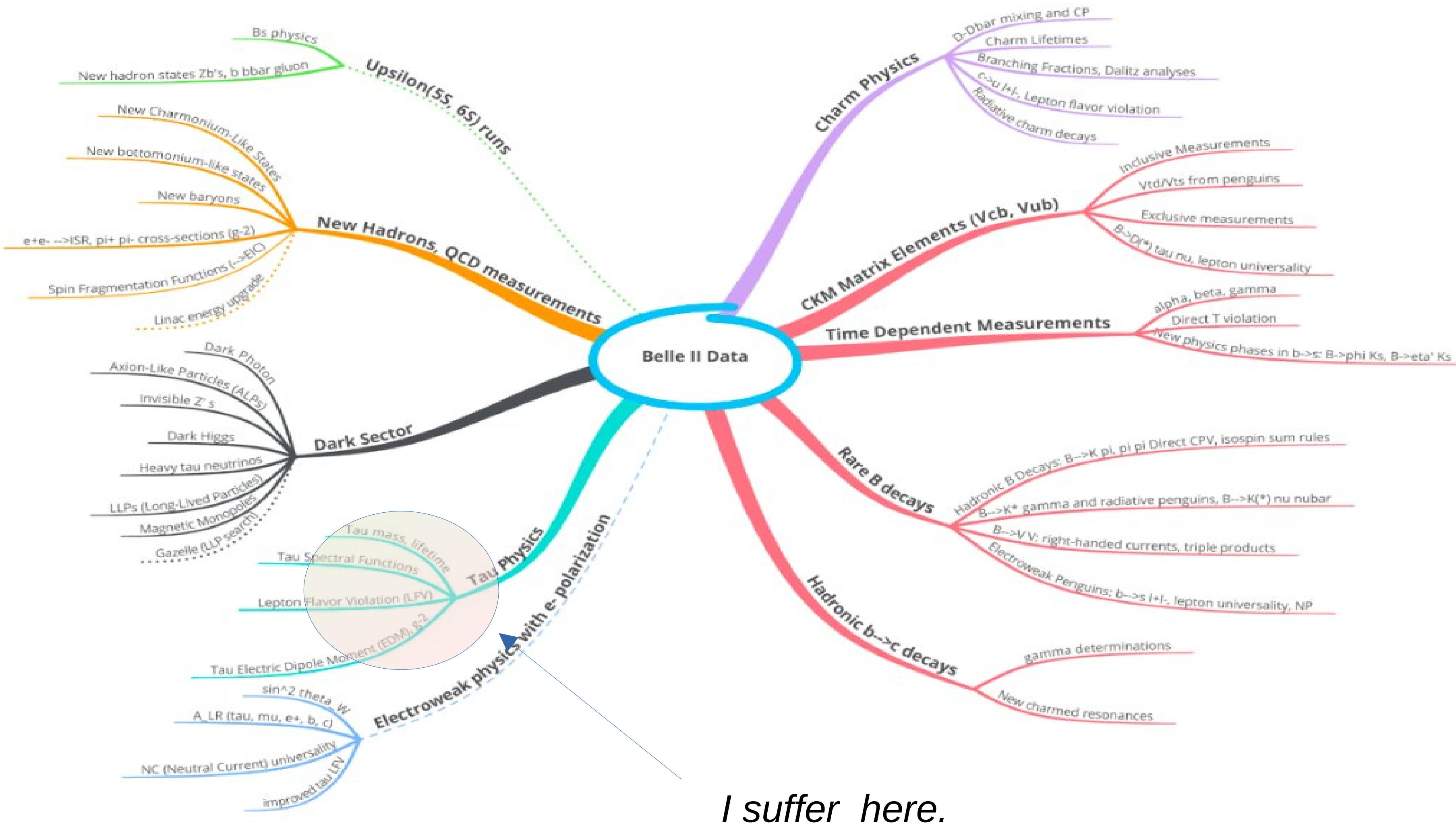
- B factory providing luminosity to Belle II experiment.

- Goal: achieve luminosity

Belle II Detector



Belle II Physics



I suffer here.

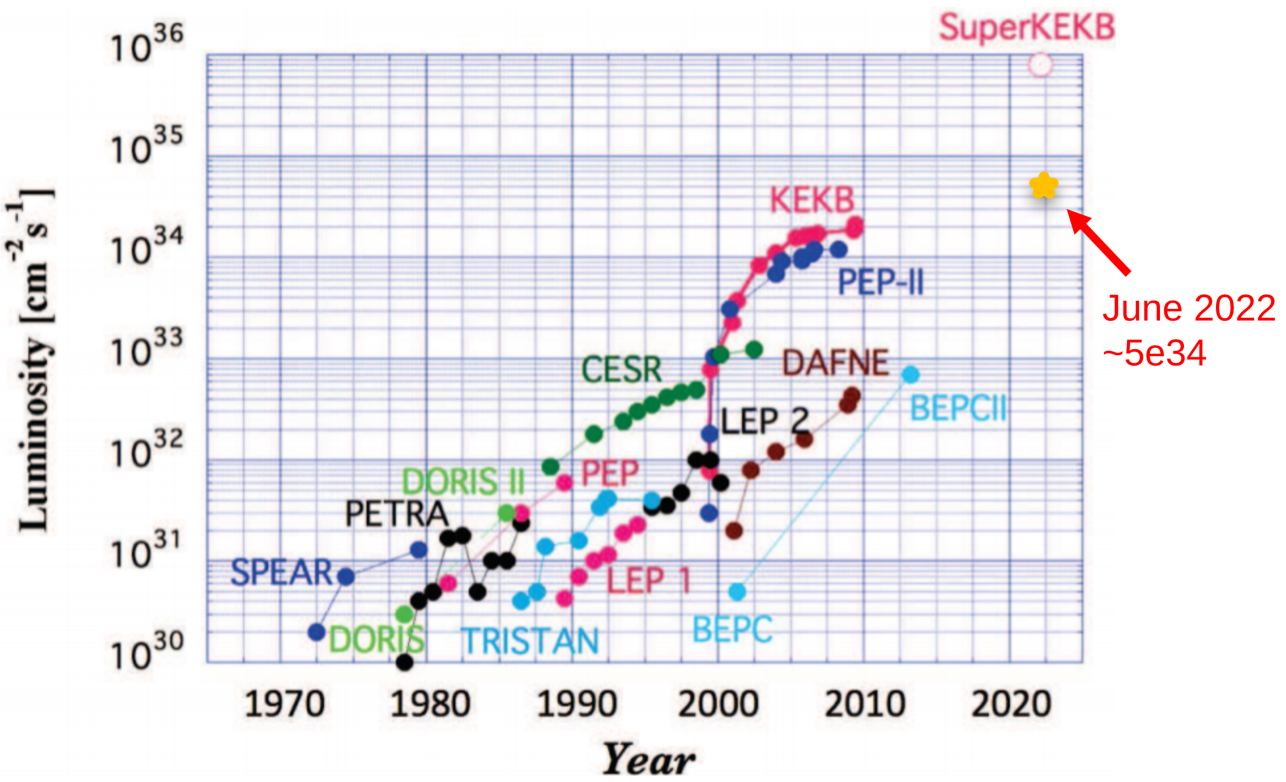
Plenty of New Physics

SuperKEKB is the luminosity frontier

- In e+/e- colliders, luminosity has increased by more than a factor 10 every decade since 1970.

- SuperKEKB is currently under ramping

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$



Luminosity trends in e+/e- colliders (Courtesy Y. Funakoshi, KEK)

$$Instantaneous\ Target\ Luminosity:\ L = 6\,x\,10^{35}\,cm^{-2}\,s^{-1}$$
$$Achieved\ Luminosity\,(world\ record):\ L = 4.7\,x\,10^{34}\,cm^{-2}\,s^{-1}$$

From KEKB to SuperKEKB

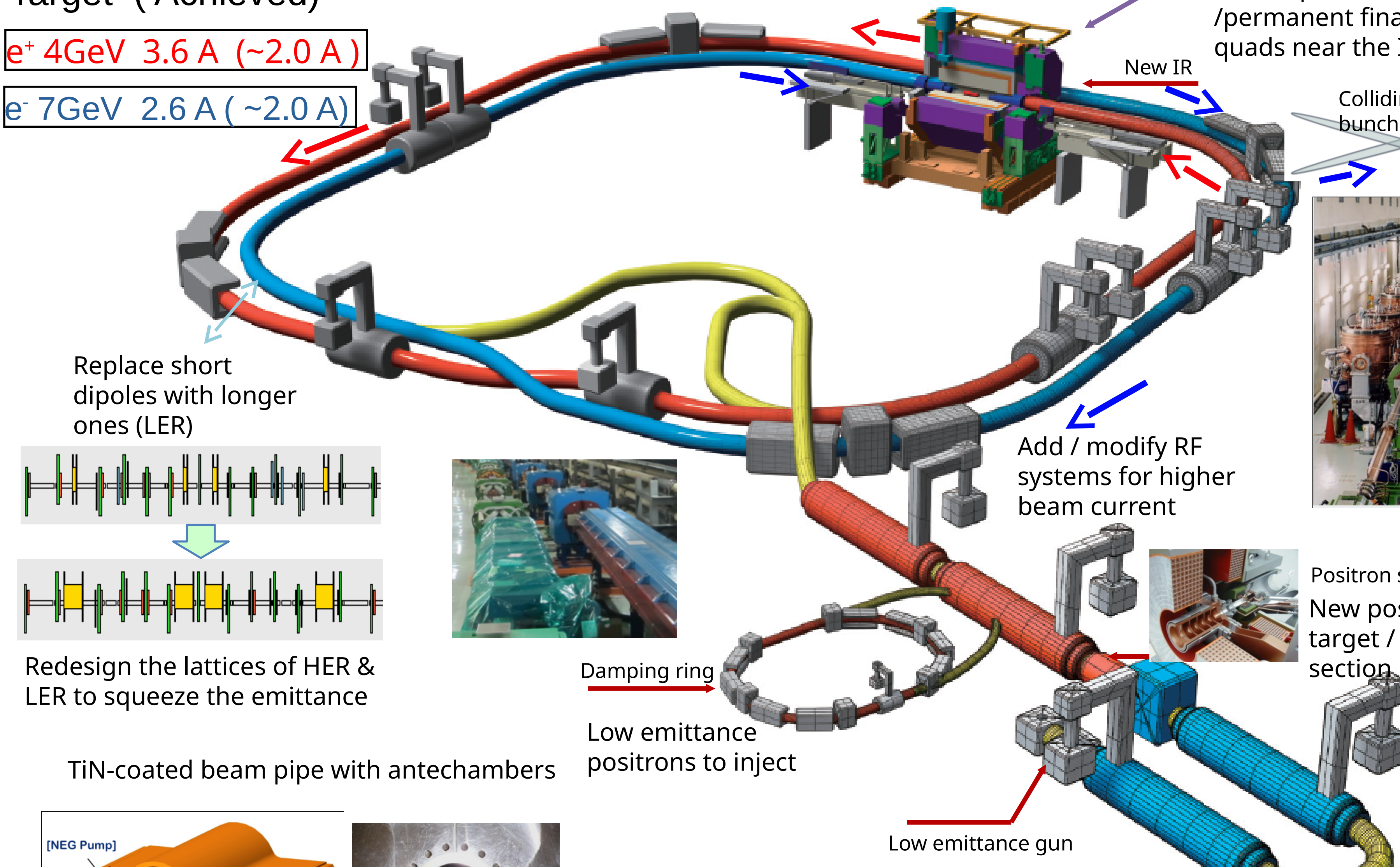
Belle II

Target (Achieved)

e^+ 4GeV 3.6 A (~2.0 A)

e^- 7GeV 2.6 A (~2.0 A)

New superconducting /permanent final focusing quads near the IP



Replace short dipoles with longer ones (LER)

Add / modify RF systems for higher beam current

Positron source

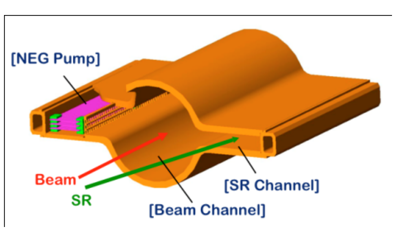
New positron target / capture section

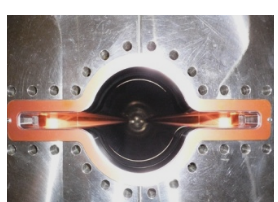
Redesign the lattices of HER & LER to squeeze the emittance

Damping ring

Low emittance positrons to inject

TiN-coated beam pipe with antechambers





Low emittance gun

Low emittance electrons to inject

6

History LABM

- Beamstrahlung was observed by first time in SLC (Stanford Linear Collider)

- 46 GeV (Lorentz factor $\gamma = 9 \times 10^4$) , with bunches of about 10^{10} electrons and 6×10^9 positrons at collision, the bunches were approximately Gaussian along all three axes, with rms length about 750 μm, and transverse rms sizes typically below 5 μm.

- Magnetic field around the bunches is 10T deflection by magnetic and electric field, emission of synchrotron radiation, rename is an call it called Beamstrahlung radiation. Assuming round cross sections. The Energy radiation is U1, F is evaluated numerically

$$U_1 = \frac{8}{3\sqrt{\pi}} \frac{N_1 N_2^2 r_e^3 m c^2 \gamma^2}{\sigma_1^2 \lambda_2} F ,$$

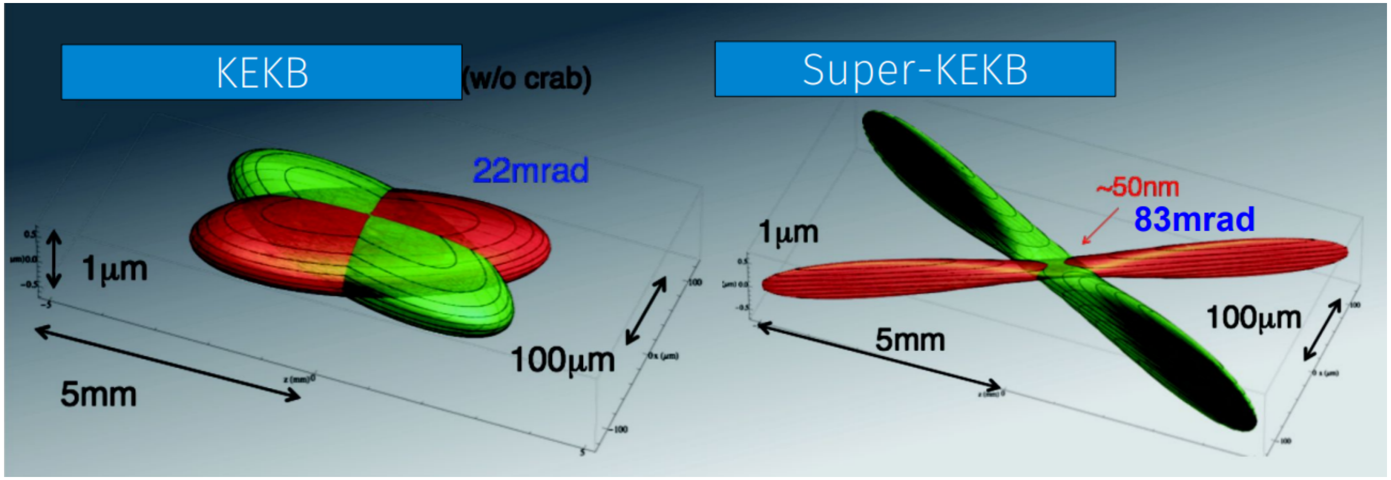
B is σ_1/σ_2, and l is $d/\sqrt{2}\sigma_1$.

$$F = \int_0^\infty \frac{1}{x} (1 - e^{(-B^2 x^2)})^2 e^{-(x^2 + l^2)} I_0(2lx)\, dx .$$

- Energies of gammas 10 -15 MeV, Gas Cherenkov counter used to detect it, main problem was radiation from synchrotron radiation, prediction was with an errror of 7% for positron and 26% fro electrons.

- G. Bonvicini, E. Gero, R. Frey, W. Koska., First Observation of Beamstrahlung Physical Review Letters, 15 May 1989.

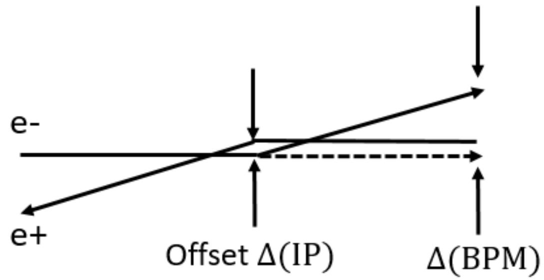
Nanobeam is the key to increase luminosity



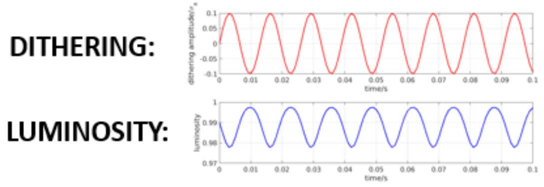
	E(GEV) HER/LER	β^*_y(mm) HER/LER	β^*_x(mm) HER/LER	2φ (mrad)	I(A) HER/LER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	1200/1200	22	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	32/25	83	3.6/2.6	80×10^{34}

IP monitoring systems

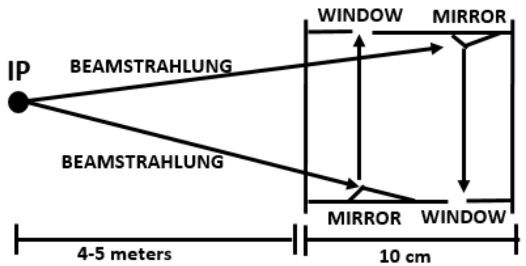
- VERTICAL OFFSET FEEDBACK: oppositely charged beams attract each other, resulting in a deflected trajectory. Beam position monitors (BPMs) measure the offset at 0.5m from the IP and estimate the offset at the IP. (PASSIVE)



- HORIZONTAL OFFSET FEEDBACK: one of the beams is dithered at a modulation frequency. Fourier analysis of the luminosity at the modulation frequency is used to estimate the horizontal offset at IP. LumiBelle2 is the input luminosity. (ACTIVE)



- LARGE ANGLE BEAMSTRAHLUNG MONITOR (LABM): Measures visible beamstrahlung from IP at large angle. Beam parameters (sizes, offsets) are estimated from polarization and frequency spectrum. (PASSIVE)



Slide from G, Bonviccini

LER (e+) HER (e-)	KEKB (2010)		SuperKEKB Design (~2025)	
	LER (e+)	HER (e-)	LER (e+)	HER (e-)
E (GeV)	3.5	8	4	7
sigma_x (um)	103	116	10.1	10.7
sigma_y (um)	1.9	1.9	0.048	0.062
sigma_z (um)	6.5	6.5	6.0	5.0
I (A)	1.6	1.2	3.6	2.6
# bunches	1585		2500	
Crossing angle	11		41.5	
L (10^34 cm^-2 s^-1)	2		80	

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

History LABM and Mexico

- Mexico group was formed to work in superB (2012) was UAS, CINVESTAV, UNAM, BUAP, later moved to Belle II
- A proposal for Belle II was approved with funding from SLAC, Wayne state university, KEK to make a Beamstrahlung Monitor.
- Mexico group was invited to work in the project.

  - Design was almost done (see next slides).

  - Missing electronics, DAQ, Software

  - Detector is and Hybrid it relates to Belle II but also to superKEK.

  - From Mexico UAS, and BUAP mainly help in that. Funding comes from a group Project by CONACYT (now SECIHTI)

History LABM

-Samuel Doeg (Undergraduate thesis 2015 by UAS)
Later he make PhD in Wayne state

- Monitor de Haz (e− e+) LABM en Belle II

Description of installation, electronics setup and slow control.

- Worked in electronics, cabling, installation of DAQ and motors.

- Later he made a PhD in Wayne state now working in private sector in USA

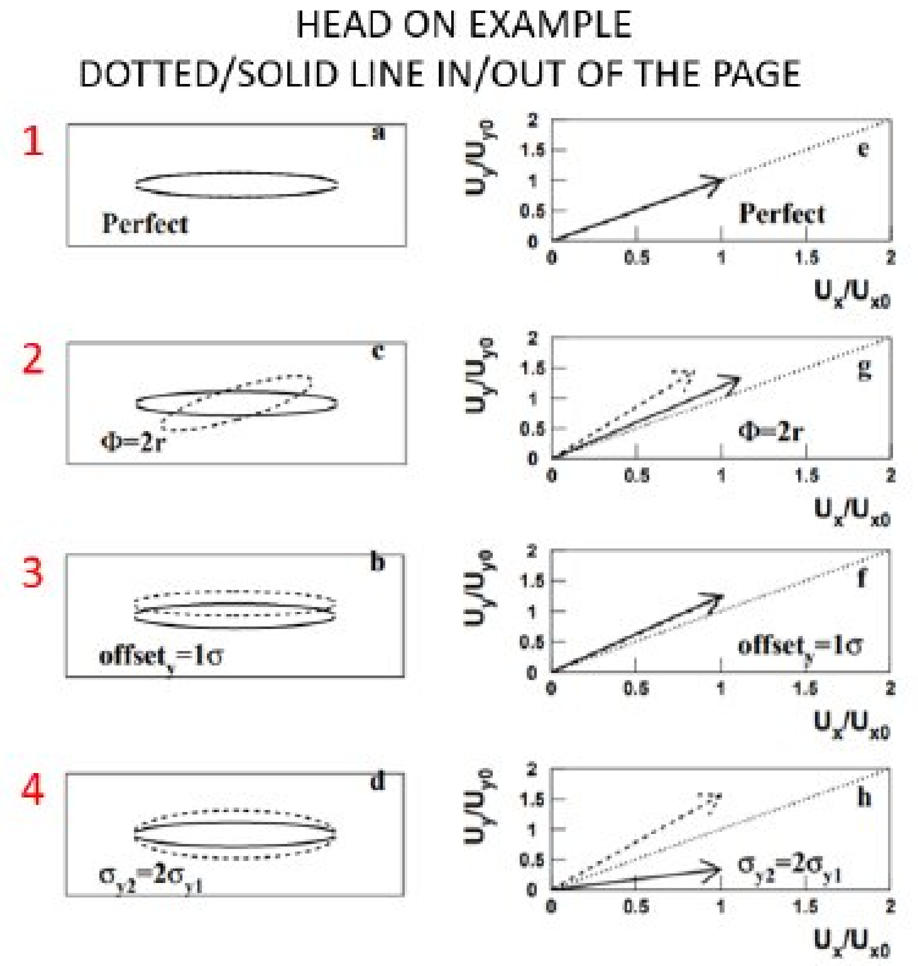
Luminosity and Beamstrahlung in Belle II

- Highest luminosity is for perfect Overlap beams at interaction point

- The pathologies are rotation, offset and bloating.

- Ratio of x to y polarization show Characteristic pattern fro mismatch

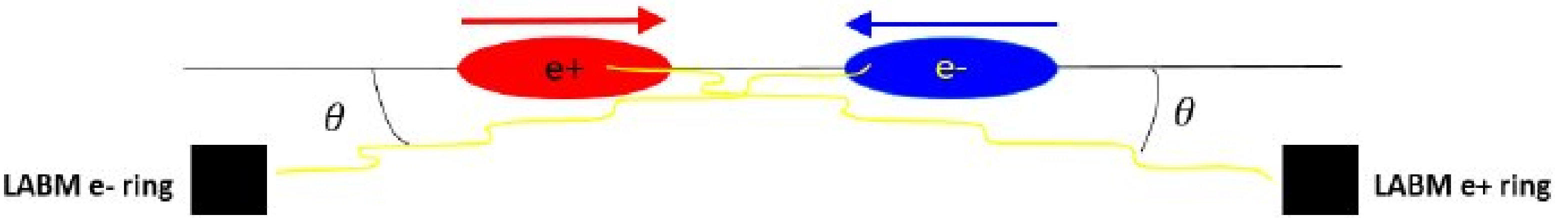
- Bloating (4) limits superKEKB



Physics Considerations

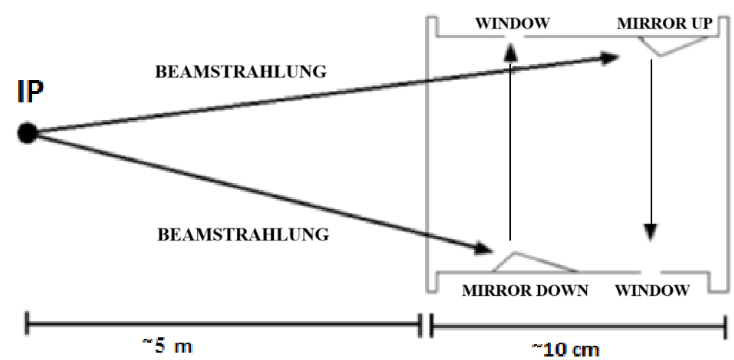
- At large angle, Beamstrahlung is strongly polarized and contamination from synchrotron radiation is small

- Visible light (350-650 nm)
  - Easy to work
  - Fraction 10^{-11} (e-) to 10^{-12} (e+) of total Beamstrahlung energy emitted but enough for LABM



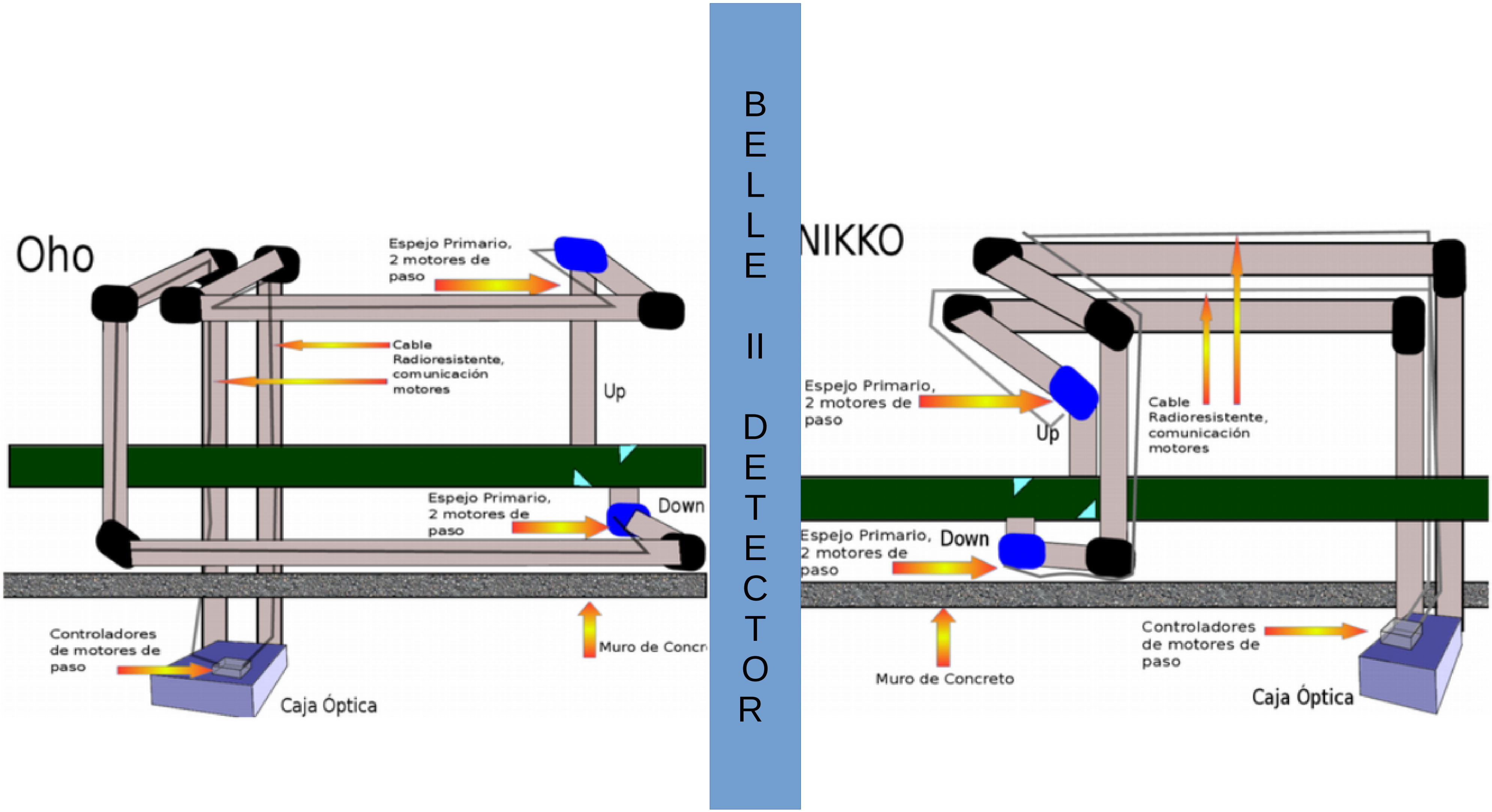
Vacuum mirror

Window in beam line

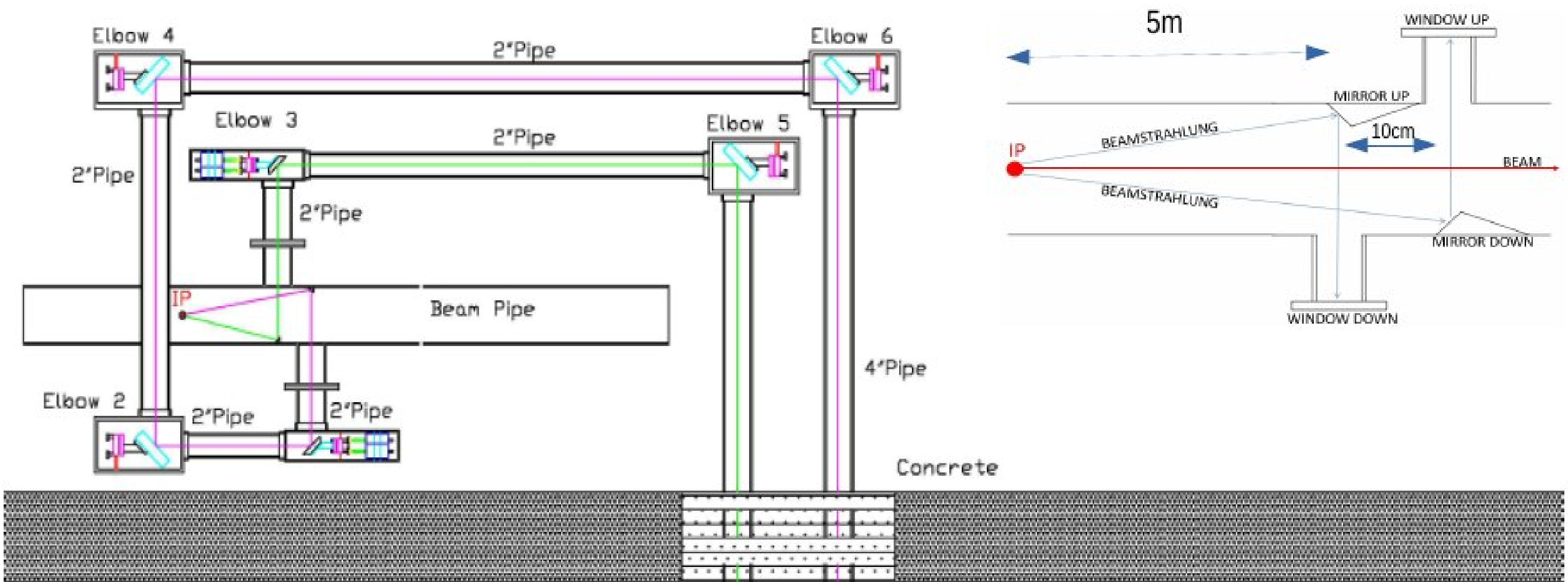


LABM diagram (v1.0)

- Twin detectors one on each side of the Belle II detector
- From point interaction Oho aprox. **4.5m**, Nikko . **4.7m**.



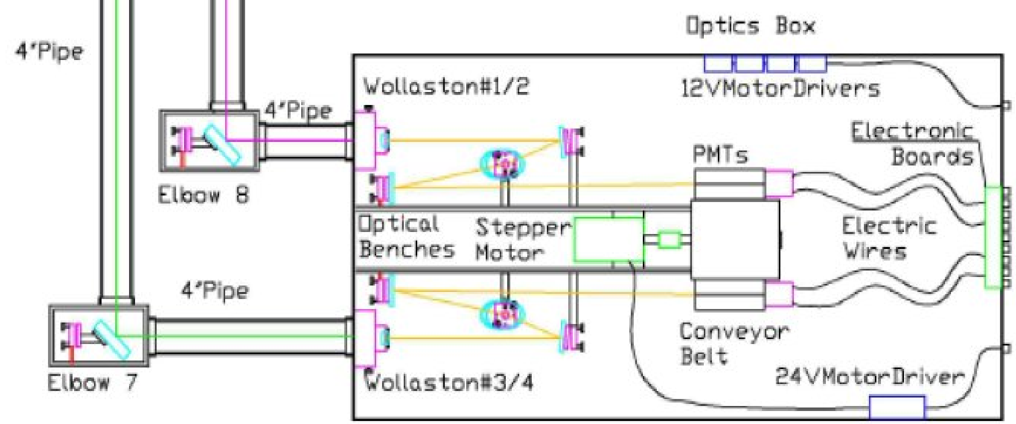
LABM diagram (v1.0)



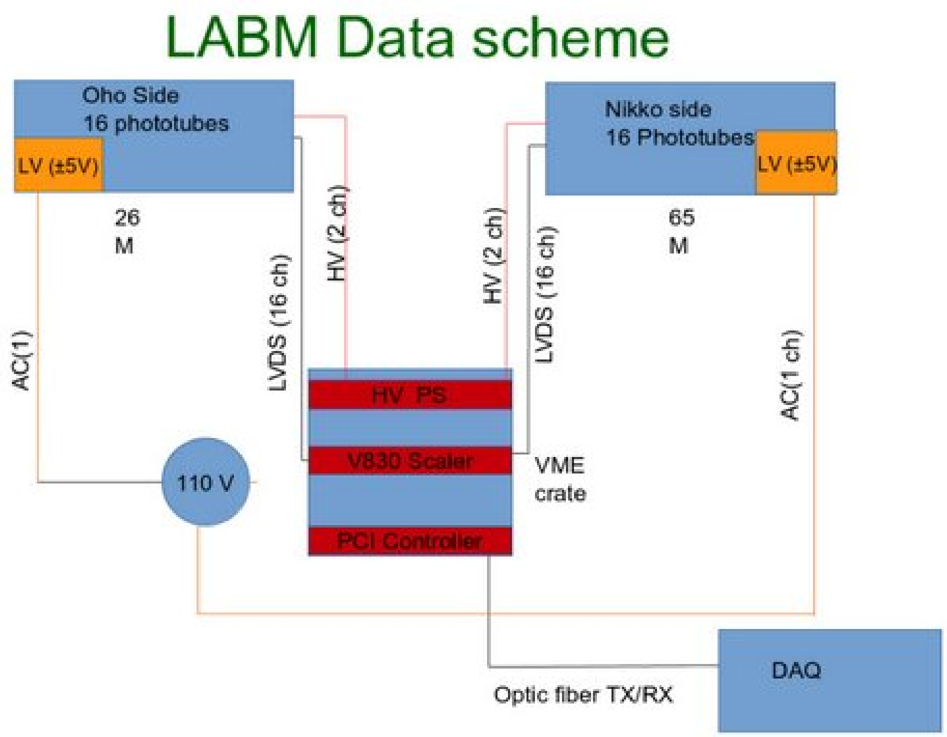
Four telescopes

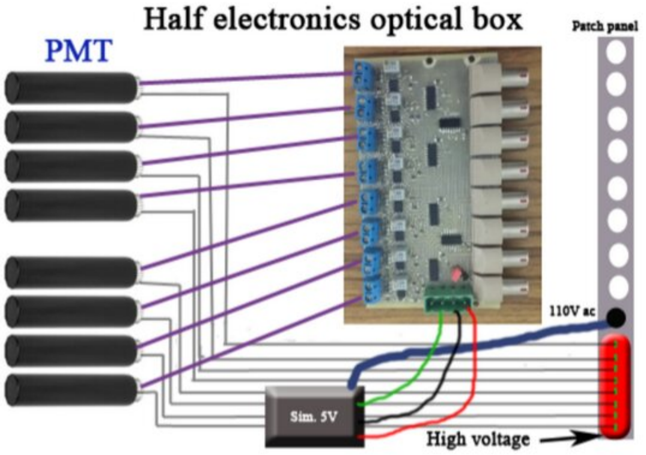
Two for High Energy Ring e-
Two for Low Energy Ring e+

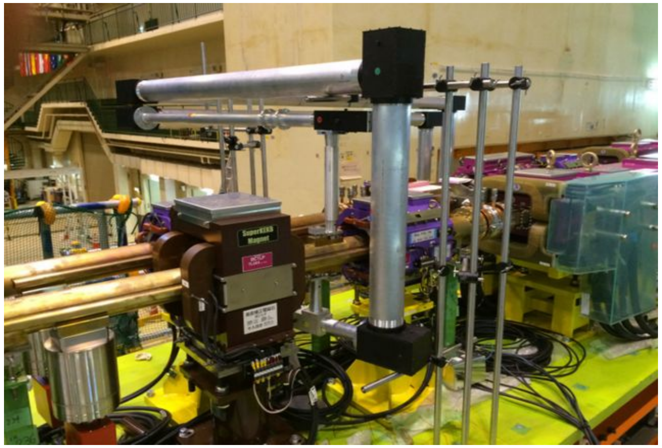
32 PMT



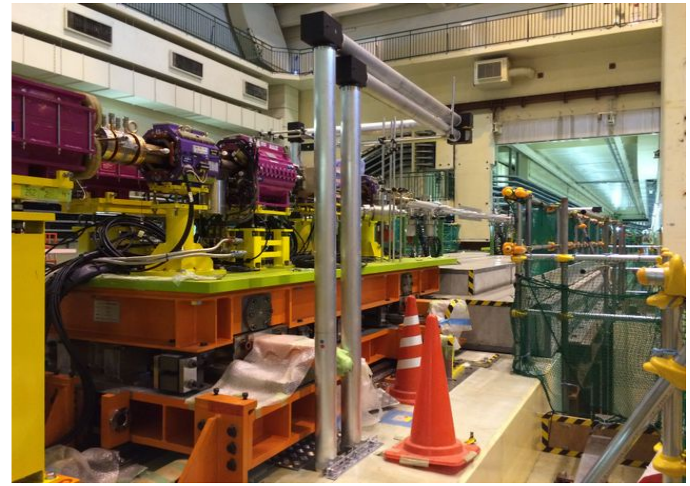
Electronics LABM diagram (v1.0)



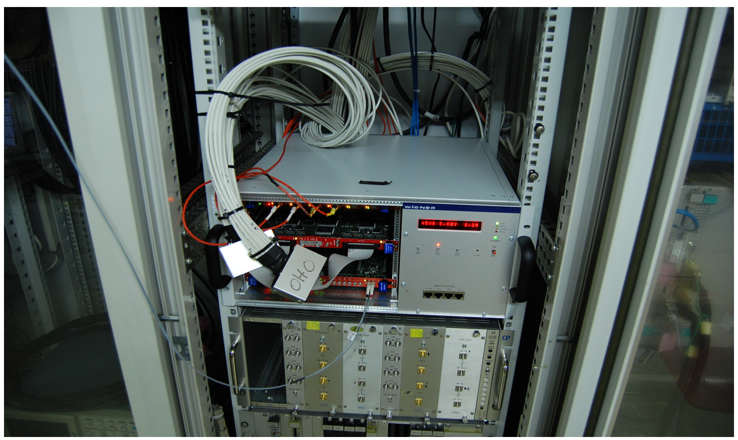




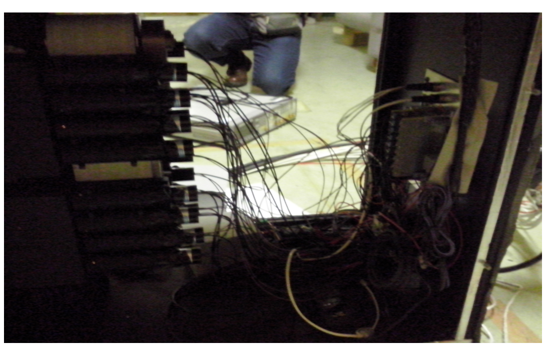
Connection to beam line



Optical line (4)



Scaler, power supply (16)



Photomultipliers (32)

Issues an things we learn

- Drill holes in surface to fix pipes
(use contractor radiated area)
- Last detector to be installed.
- Cabling should be radiation resistant
- Issues of misalignment
- Have to black paint later because of reflections
-The signal over the nikko lime over 90 meter
have to have to take into account or pulse
Deformation.
- Conveyor Belt and cabling,

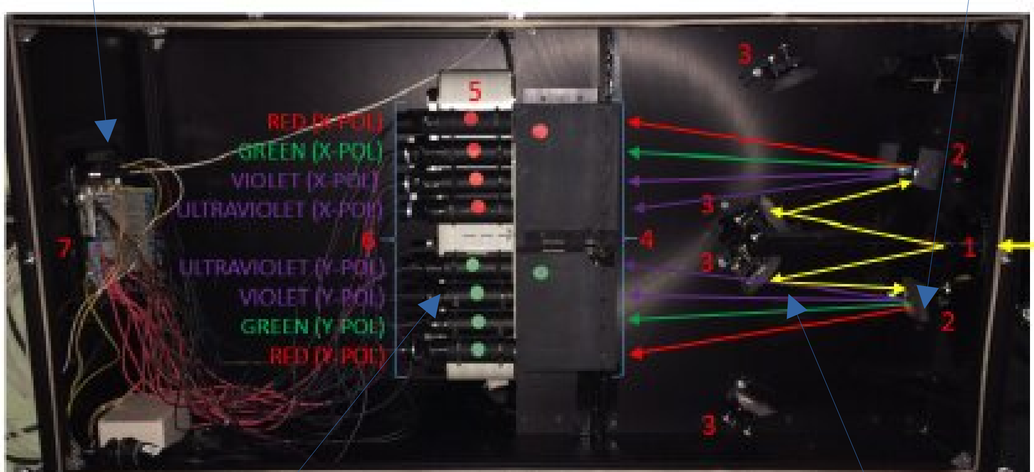
LABM   (v1.0)

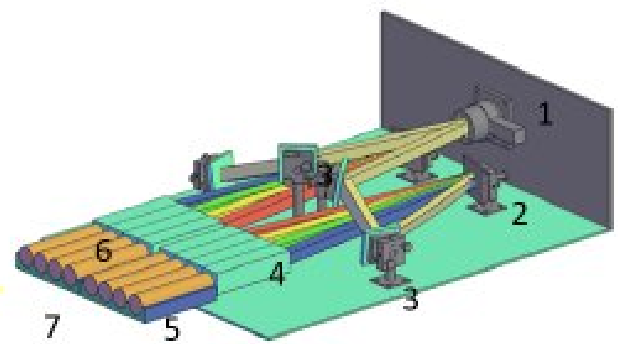
Optic Box setting 2015 -2023

Electronics (Pulse counter windows around 90 nanoseconds)

Conveyor belt
For calibration

Focusing lens





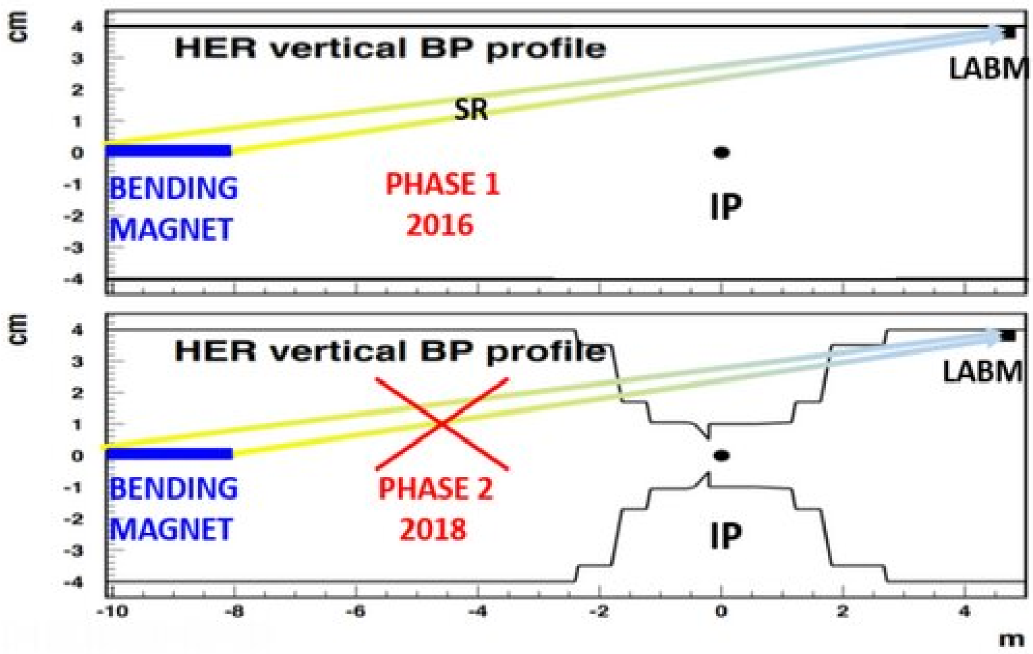
1) Wollanston prism
(separtion of polarization)

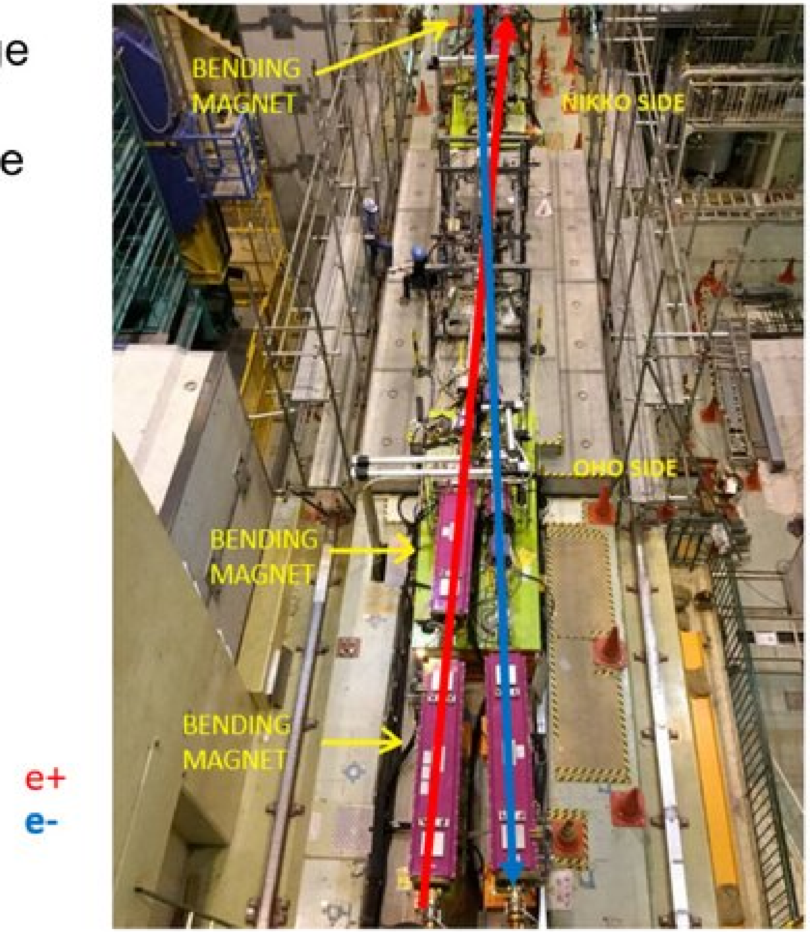
Photo multipliers
(460- 640 nm)

Gratings
(separation by wavelength)

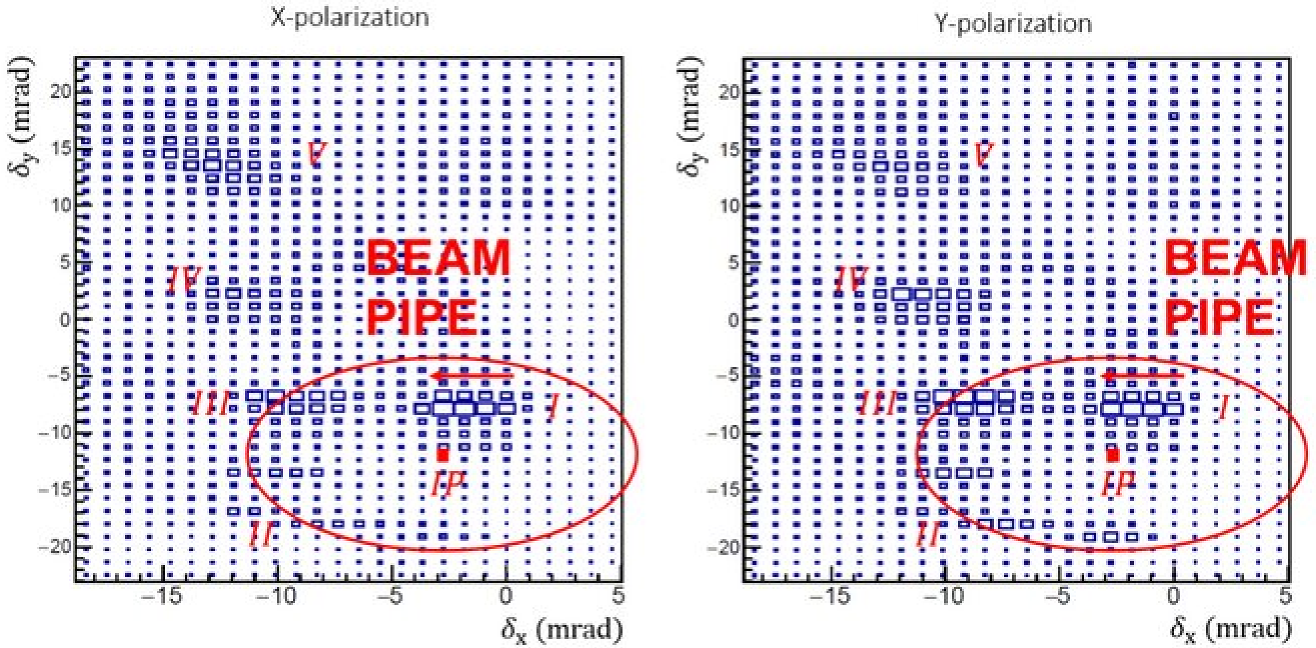
Synchrotron Radiation (SR)

- Background measured originates from SR from bending magnets.
- Phase 1: vacuum chamber's diameter at IP is large (8 cm) and synchrotron radiation can reach the LABM. From Phase 2 (2018), suppressed because diameter becomes 1 cm.





Synchrotron Radiation (SR)



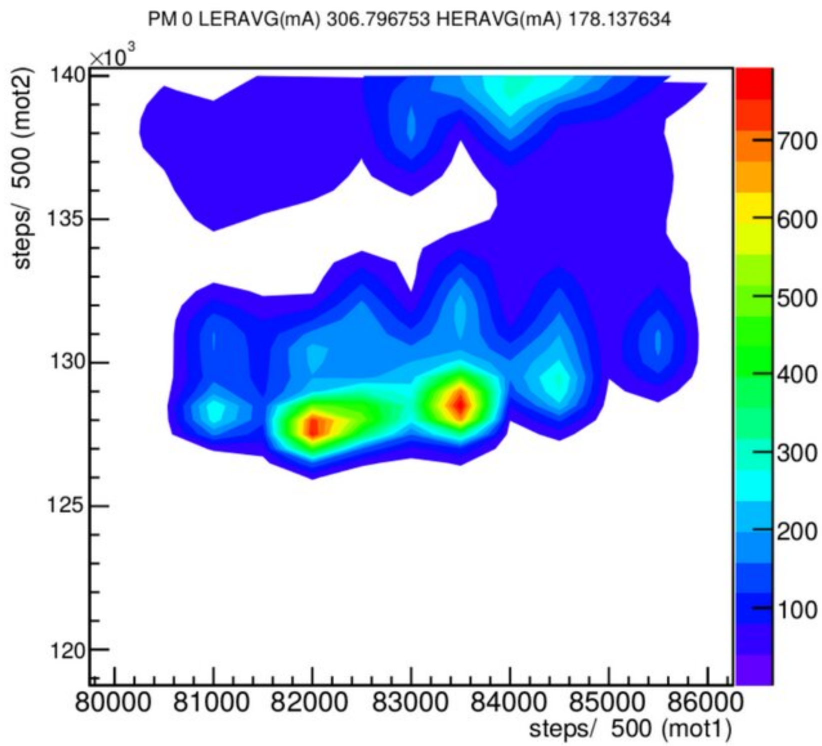
- 2D Scan of solid angle inside vacuum chamber
- Rates in x-y transverse plane
- Resolution
- The mirror moves to each pixel while data are recorded

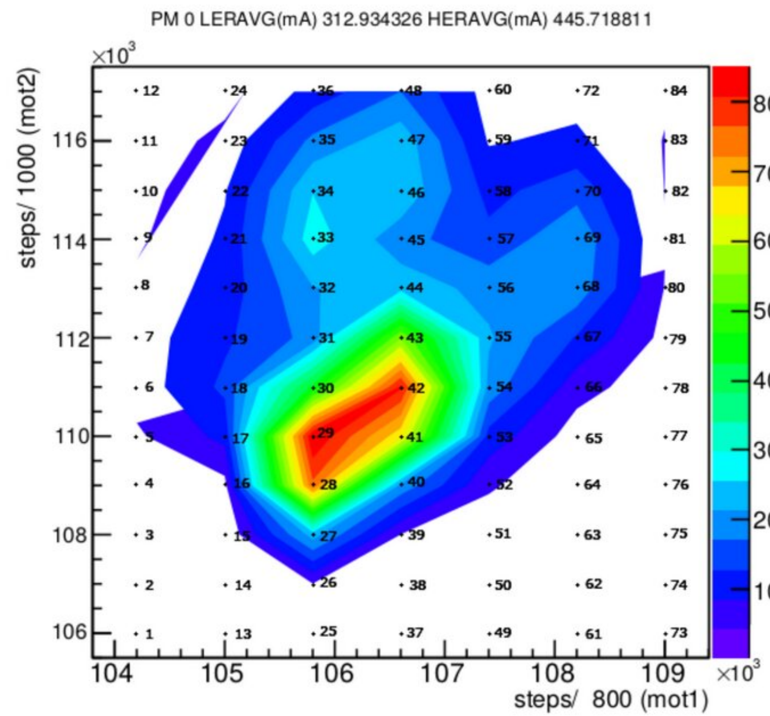
- SR sweeps produced when beams progress through bending magnet
- 1 direct sweep (I) + multiple internal reflections (II,III,IV,V)

LABM results (V1.0)

- Scanning means move the mirrors to get cover a mirror area of 2x2 mm²

- Red zone is Beamstrahlung, Green may be Coulumb and Touscheck tails with quadrupole blue are reflections (This redundancy is welcome)





Heat map for signal (parallell vs vertical position of the primary mirror) Blue C. and T. radiation, Red Beamstrahlung radiation .

UAS Master Thesis Daniel Ricalde, later PhD Thesis in Wayne now posdoc in Tabuk Saudi Arabia

Machine Learning aproach

Classical analysis:

- “Side band” background subtraction method attempted for years without success:
  - Varying beam conditions;
  - Rapidly varying beam tails in the quadrupoles;
  - Time delays in going from point to point in 2D scans.

- Analytical formulas not available:
  - Beamstrahlung formula at large polar angle is available for collinear beams but not for large x-z crossing angle like SuperKEKB;
  - SR radiation formulas are suitable only for small polar angles.

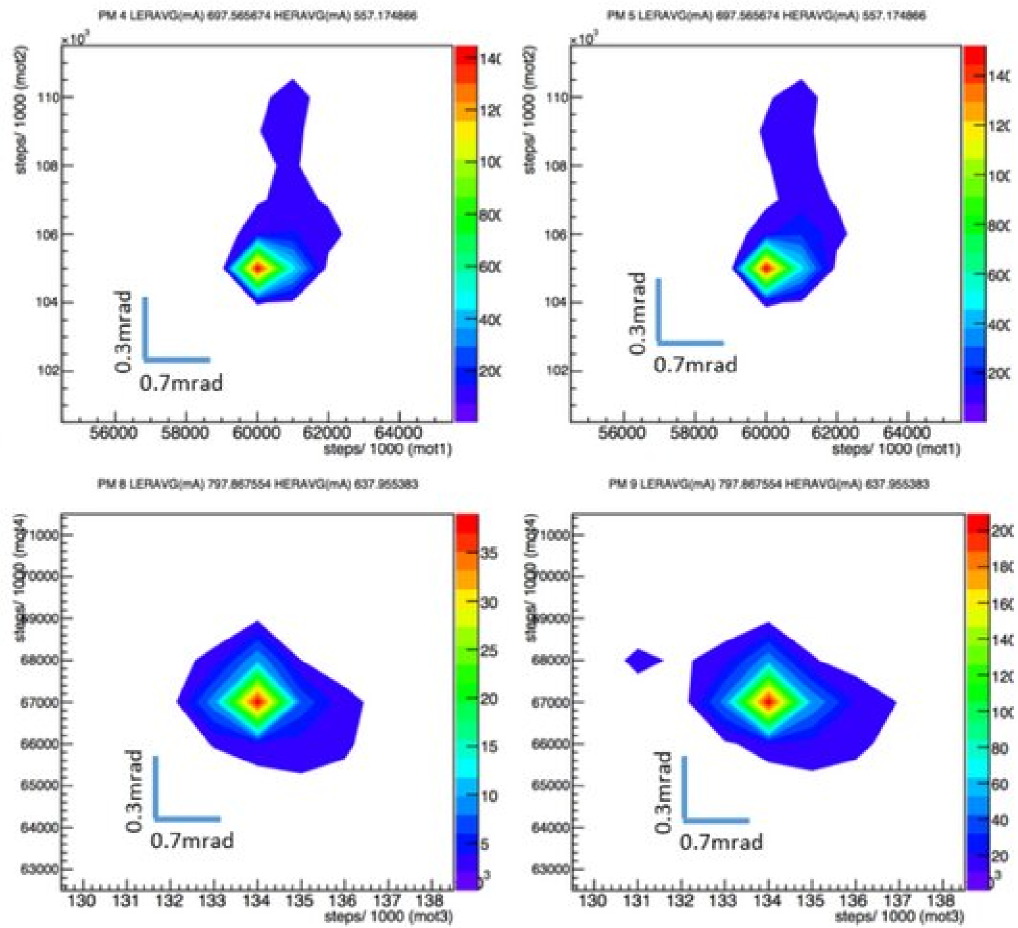
Neural Network analysis:

- Able to automatically disentangle Beamstrahlung and SR quadrupole radiation.

- Possibility to extend the neural network to include imaging:
  - Add data from IP image to NN input;
  - Use Convolutional Neural Network.

Beamstrahlung analysis (2022)

- 2D scan performed and IP position found for e- telescope
- Continued issues with movable mirrors on e+ side, likely related to shared data bus. Upgrade expected during 2022-2023 shutdown.
- Results shown next only use electron side observations (16PMTs) at IP.
- Physics run data only, 11 days, 5Hz
- GOAL: reproduce beam parameters from other monitors

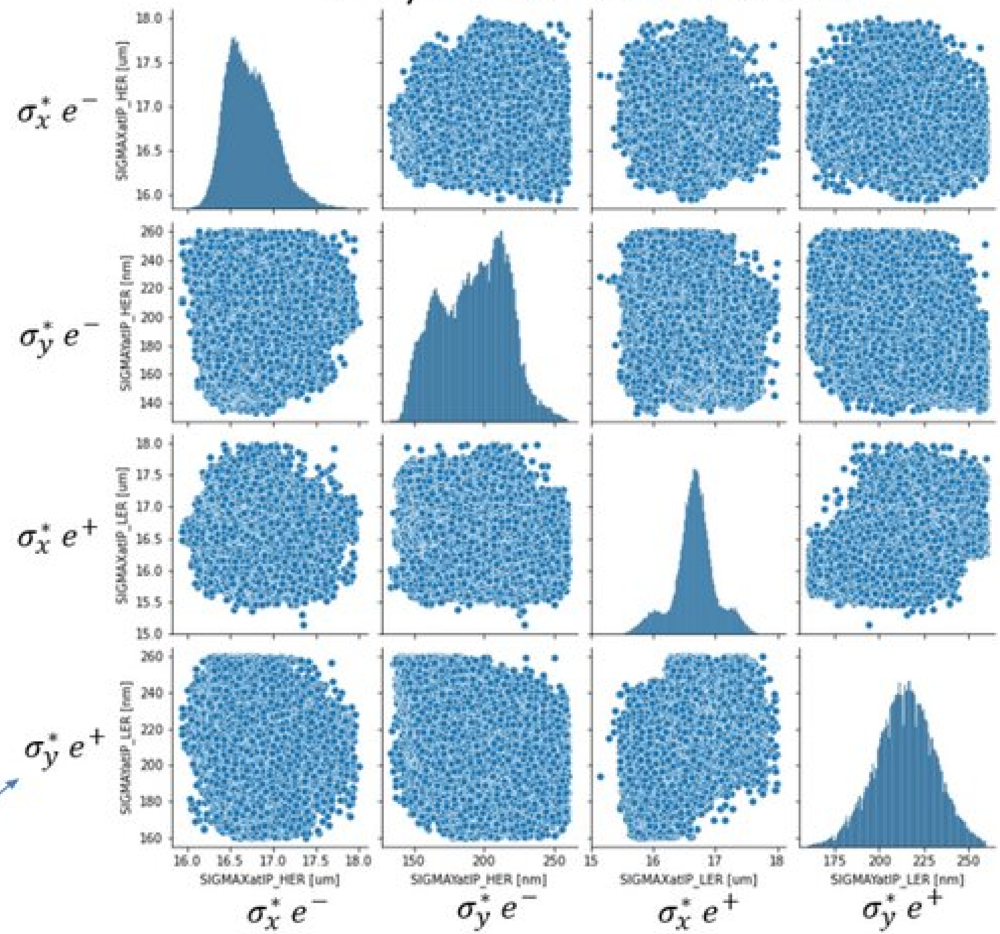


Data selection

Average parameters

$Beam$	LER (e^+)	HER (e^-)
$L(cm^{-2}s^{-1})$	2.8×10^{34}	
$E(GeV)$	4	7
$N(10^{10})$	3.8	3.1
$\beta_x^*(m)$	0.08	0.06
$\beta_y^*(m)$	0.001	0.001
$\varepsilon_x(nm)$	3.5	4.7
$\varepsilon_y(pm)$	46.4	37.7
$\sigma_x^*(\mu m)$	16.7	16.7
$\sigma_y^*(nm)$	214.8	192.7
$\sigma_z^*(mm)$	6	5

X-Ray monitors measurements

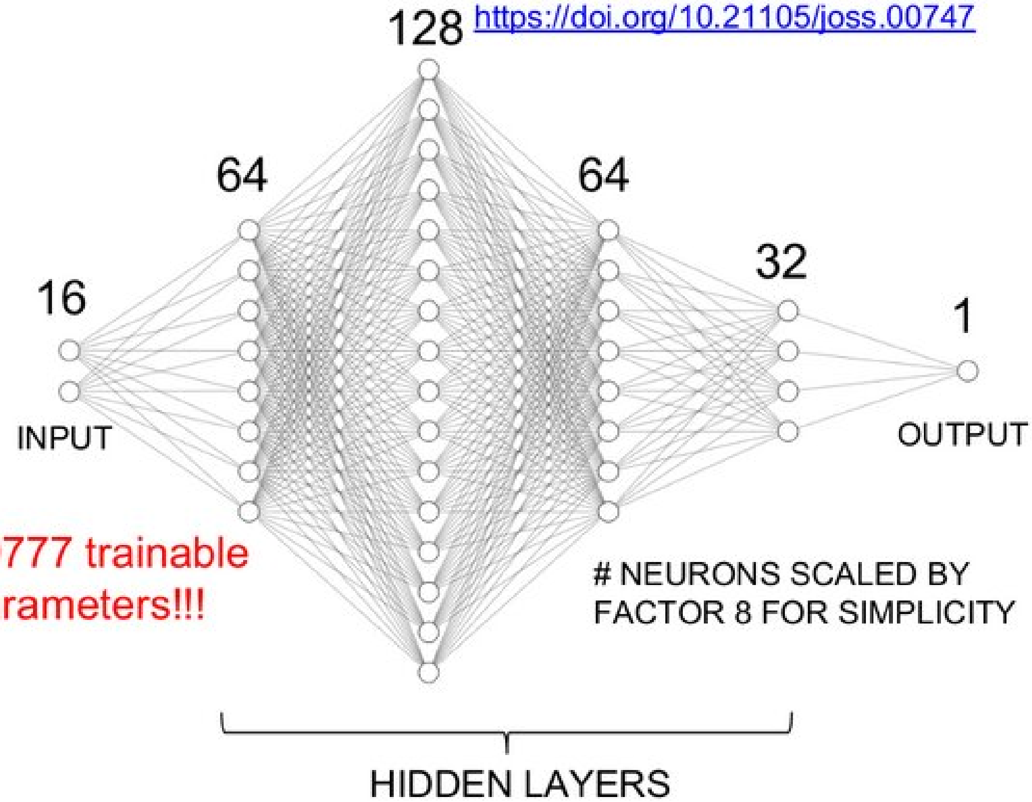


Weak correlation between any pair of parameters, good parameter space coverage, I>100mA

Neural Network Model

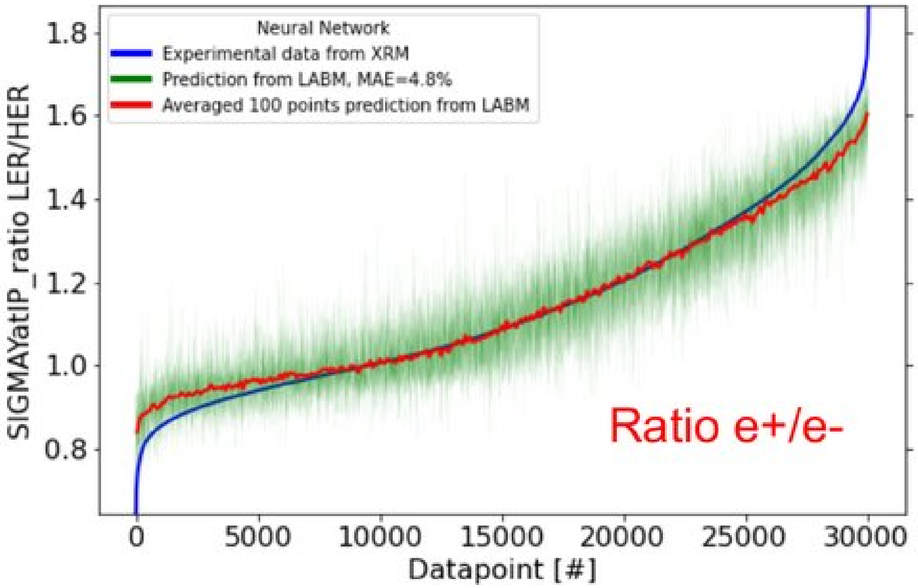
- Fully connected neural network with Keras
- 6 Layers, neurons per layer: 16 (input), 64, 128, 64, 32, 1 (output)
- 96k data-points used for training, 24k for validation, 30k for testing (shown in the following as lift charts)
- Regression problem: we try to reproduce one parameter measured by another instrument.

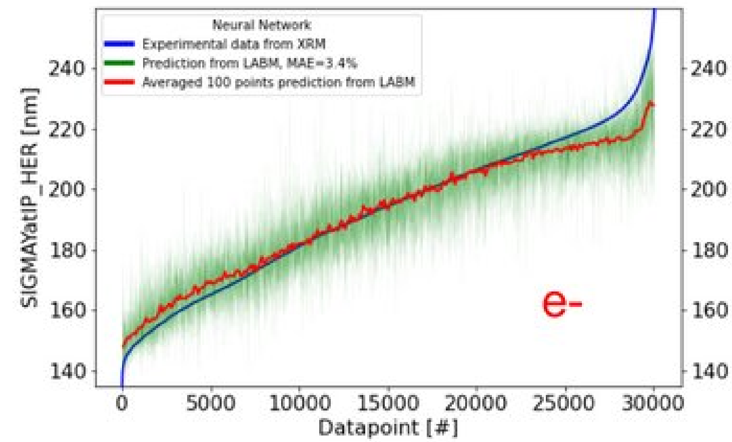
Visualization:
LeNail, (2019). NN-SVG: Publication-Ready Neural Network Architecture Schematics. Journal of Oper Source Software, 4(33), 747, https://doi.org/10.21105/joss.00747



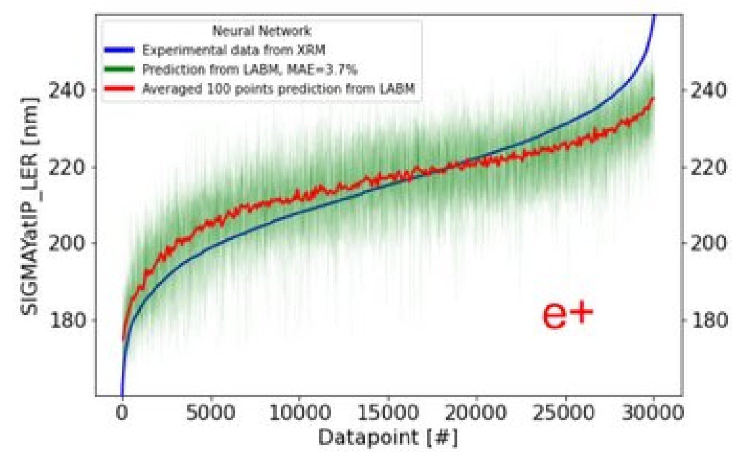
19777 trainable parameters!!!

Vertical beam size





NN reproduced SuperKEKB vertical beam sizes at IP at a few percent!



A Neural Network approach to reconstructing SuperKEKB beam parameters from beamstrahlung, S. Di Carlo et al., arXiv:2206.11709 [physics.acc-ph], submitted to Nucl. Instrum. Meth. A. on June 18, 2022

Results discussion

- Neural Network approach shows strong correlation between LABM signal and luminosity/beam size
- Ratio of beam heights should be measured well, but with minimal sensitivity to each beam height -> quadrupole SR contamination?
- Parameters reproduced at few percent level but will improve with large dataset availability.

Mean Absolute Error (MAE)

$Model$	NN
L_{sp}	3.5%
$\sigma_{y,eff}$	2.2%
$\sigma_{x,LER}$	0.7%
$\sigma_{x,HER}$	0.9%
$\sigma_{x,LER}/\sigma_{x,HER}$	1.1%
$\sigma_{y,LER}$	3.7%
$\sigma_{y,HER}$	3.4%
$\sigma_{y,LER}/\sigma_{y,HER}$	4.8%

Opportunity areas

- Mirror motors show hysteresis,
- Scan take hours (days) in this time if there were significant changes in the beam parameters we can not measured it.
- PMT need calibration every time we open the box
- Signal in the Nikko side was very low

- Solution: Use a detector with a wider aceptance

  Option 1 : ccd, silicon, dedicated, very fast and expensive

  Option 2: CMOS camera, not so fast but very easy to work on.

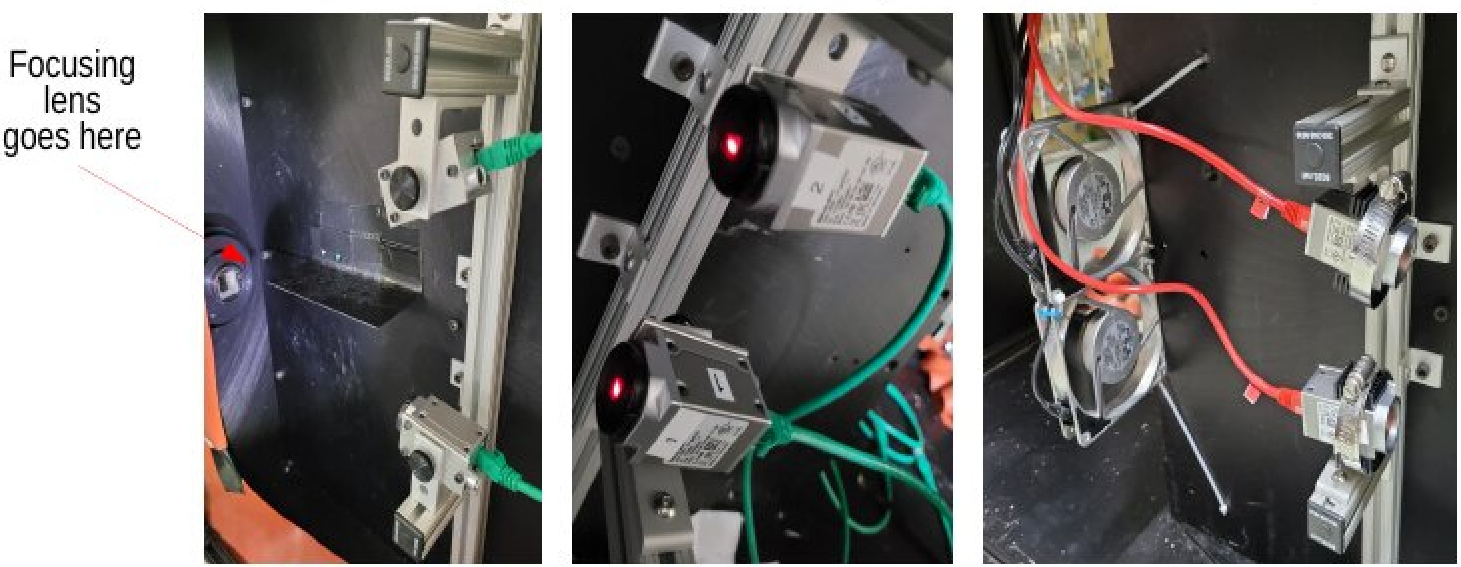
Upgrade in 2023

- Replace PMT with basler CMOS cameras in the optic box

- Remove PMT, lens, conveyor belt, electronics card.

- Only one scan to find the spot

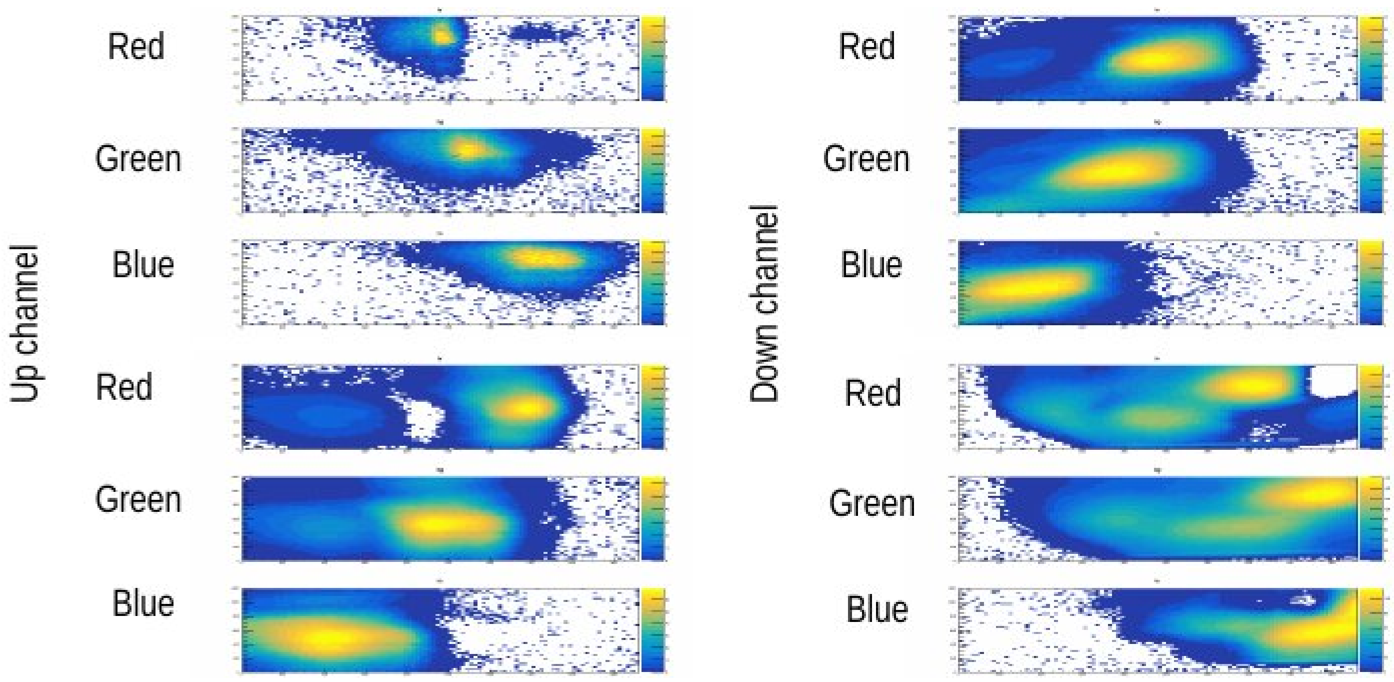
- Accurate position of cameras needed since sensor size is 6.68 x 4.20 mm



Results

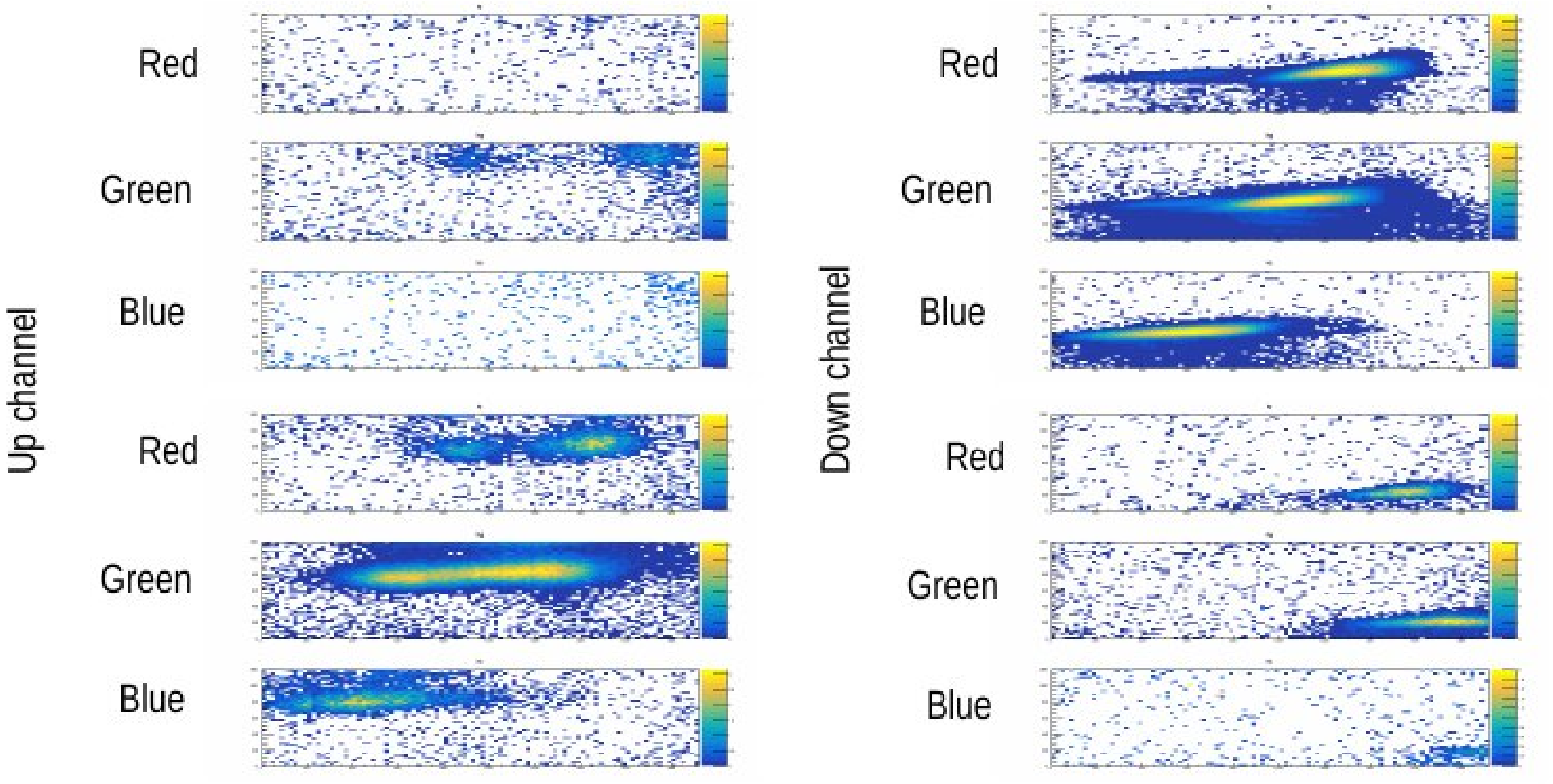
- Positron Beam (LER) optic channel, with   4 polarization

- Different position due to chromaticity of Wollanston prism



- Electron Beam (HER) optic channel, with 4 polarization

- Results look not good mainly due to long optics.



We are looking for a method to extract the beam parameters online, a neural network approach is good but we need something enough fast and reliable

Image processing:

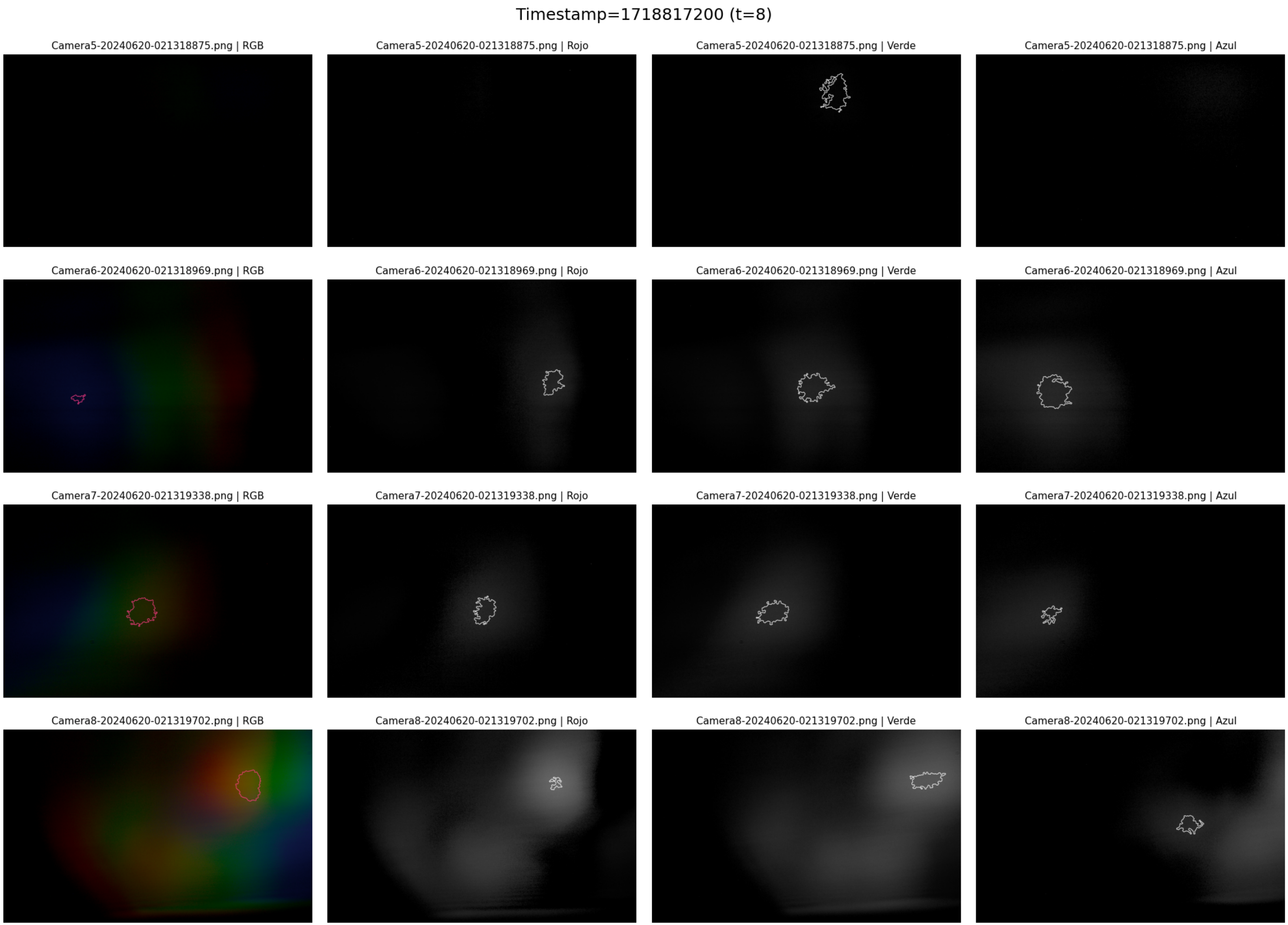
1) Clean the image (Data selection)
2) Reduce the size
3) Detect region in a automatic way
4) Correlate the region with other parameter
5) Validate the methods

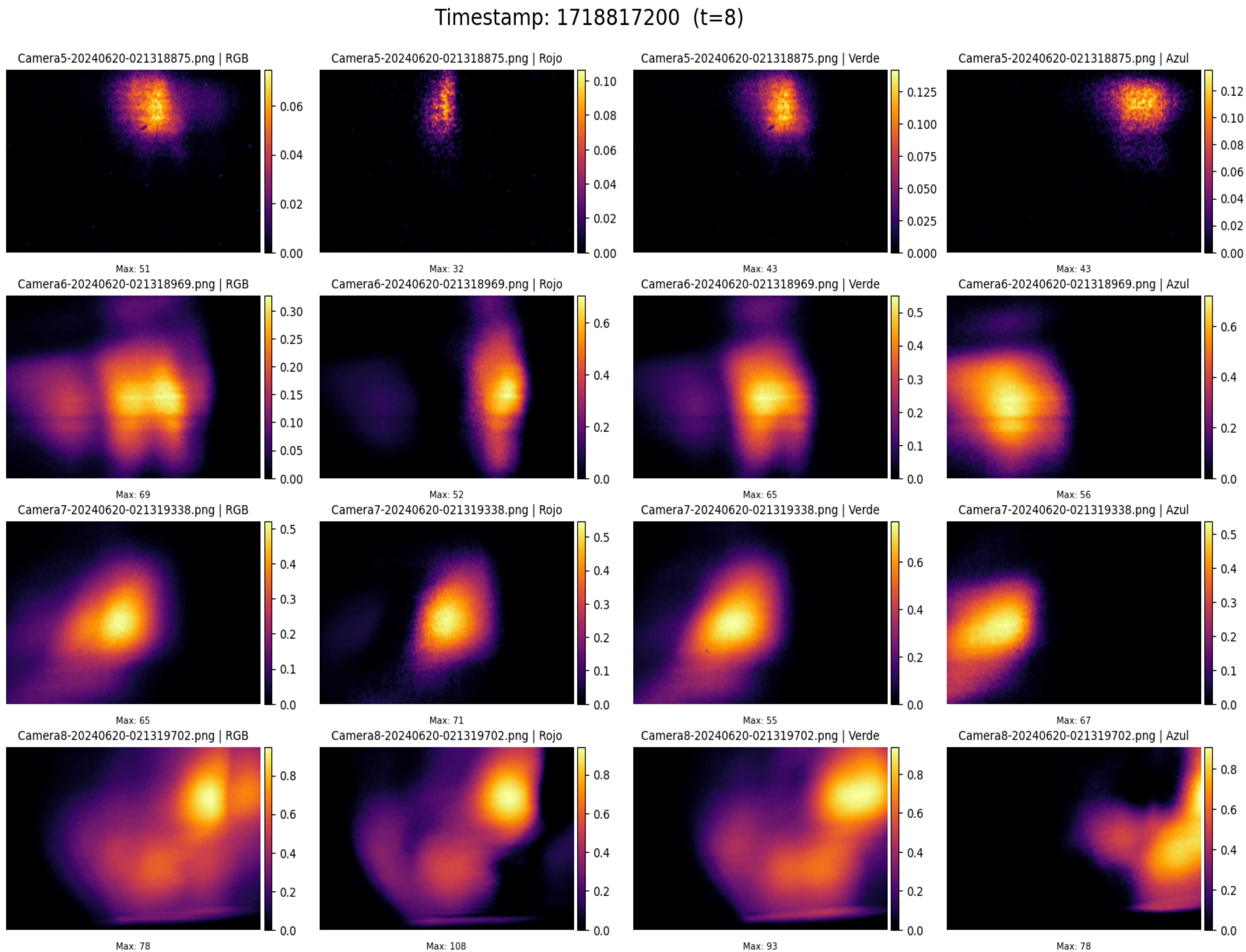
Undergraduate thesis Raul Castro (Now in Master in UAS)

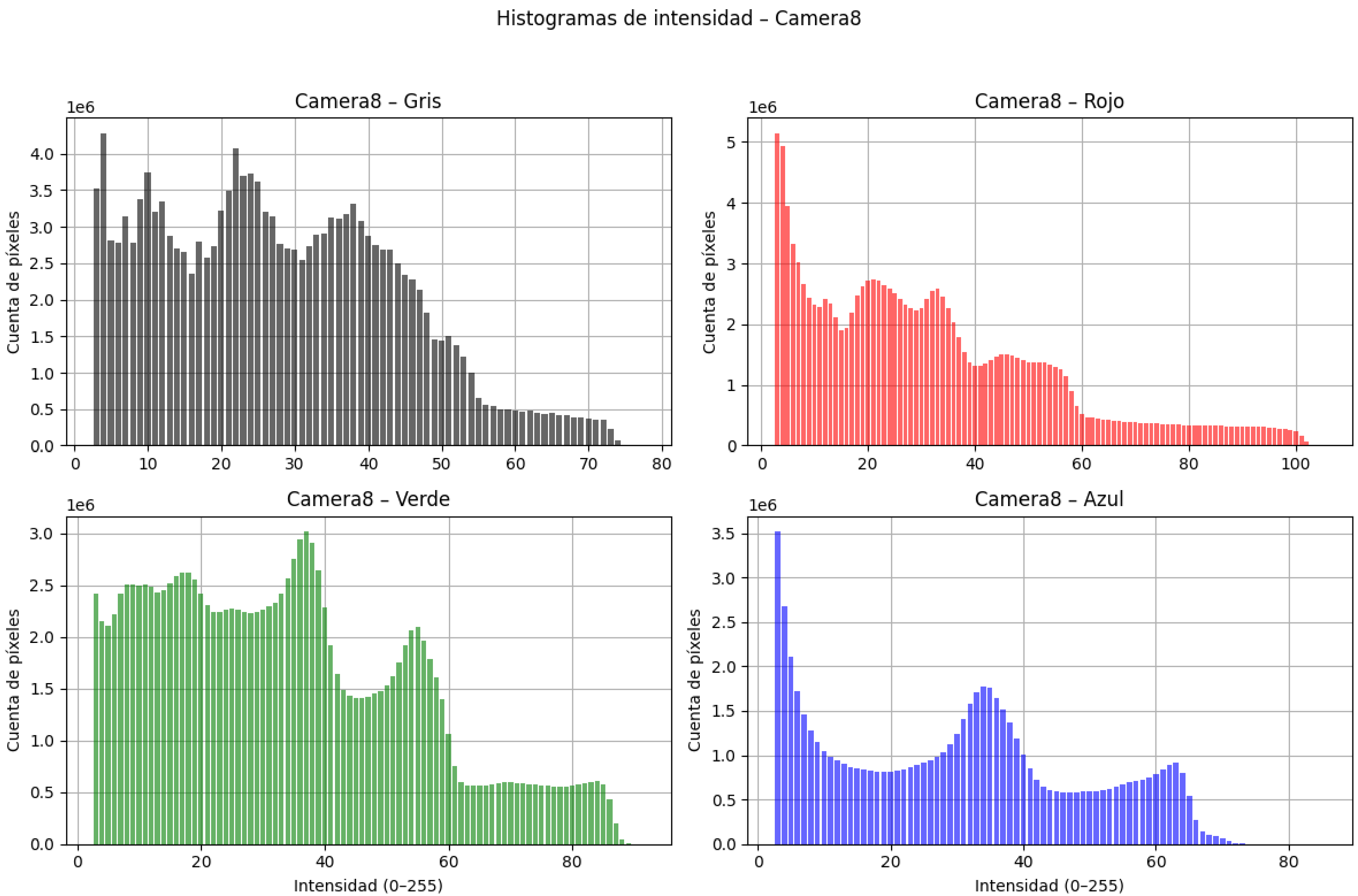
"Detección de luz de beamstrahlung mediante análisis de imágenes en el detector LABM (2025) "

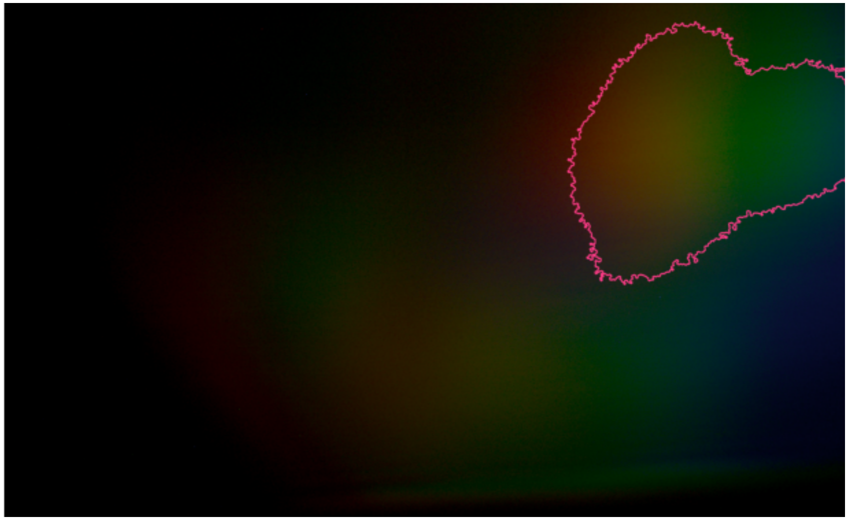
To found blobs we use: k Means (0-5 s), Mean shift (210 s), water sheet(2.5s), adaptive threshold (0.25s),

	Dimensión en μm		Dimensión en píxeles		Factor s
Configuración	Δx	Δy	Δx	Δy	$D_{\text{nuevo}}/D_{\text{viejo}}$
Presente ($\approx 14\ m$)	126–630	108–810	26–131	23–169	1.00
Futuro ($\approx 4.7\ m$)	43–214	37–275	9–45	8–57	0.34

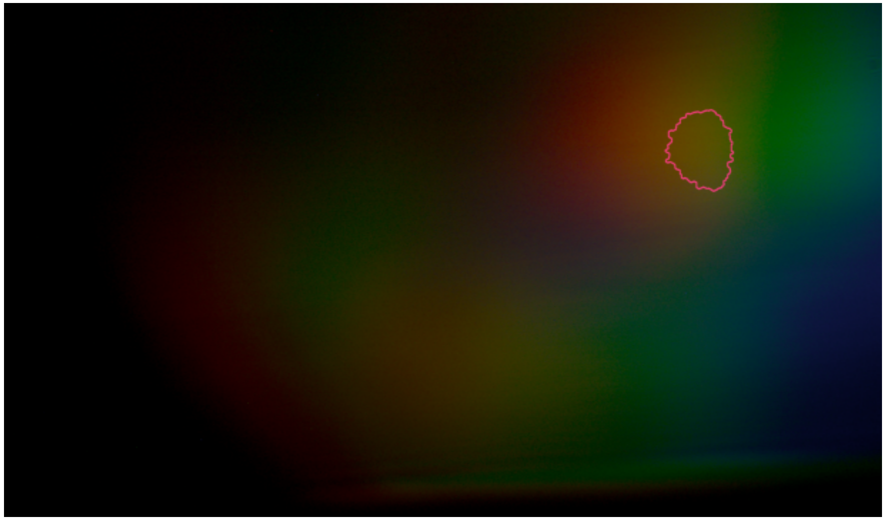

Timestamp=1718817200 (t=8)
Camera5-20240620-021318875.png | RGB
Camera5-20240620-021318875.png | Rojo
Camera5-20240620-021318875.png | Verde
Camera5-20240620-021318875.png | Azul
Camera6-20240620-021318969.png | RGB
Camera6-20240620-021318969.png | Rojo
Camera6-20240620-021318969.png | Verde
Camera6-20240620-021318969.png | Azul
Camera7-20240620-021319338.png | RGB
Camera7-20240620-021319338.png | Rojo
Camera7-20240620-021319338.png | Verde
Camera7-20240620-021319338.png | Azul
Camera8-20240620-021319702.png | RGB
Camera8-20240620-021319702.png | Rojo
Camera8-20240620-021319702.png | Verde
Camera8-20240620-021319702.png | Azul


Timestamp: 1718817200 (t=8)
Camera5-20240620-021318875.png | RGB
Max: 51
Camera5-20240620-021318875.png | Rojo
Max: 32
Camera5-20240620-021318875.png | Verde
Max: 43
Camera5-20240620-021318875.png | Azul
Max: 43
Camera6-20240620-021318969.png | RGB
Max: 69
Camera6-20240620-021318969.png | Rojo
Max: 52
Camera6-20240620-021318969.png | Verde
Max: 65
Camera6-20240620-021318969.png | Azul
Max: 56
Camera7-20240620-021319338.png | RGB
Max: 65
Camera7-20240620-021319338.png | Rojo
Max: 71
Camera7-20240620-021319338.png | Verde
Max: 55
Camera7-20240620-021319338.png | Azul
Max: 67
Camera8-20240620-021319702.png | RGB
Max: 78
Camera8-20240620-021319702.png | Rojo
Max: 108
Camera8-20240620-021319702.png | Verde
Max: 93
Camera8-20240620-021319702.png | Azul
Max: 78

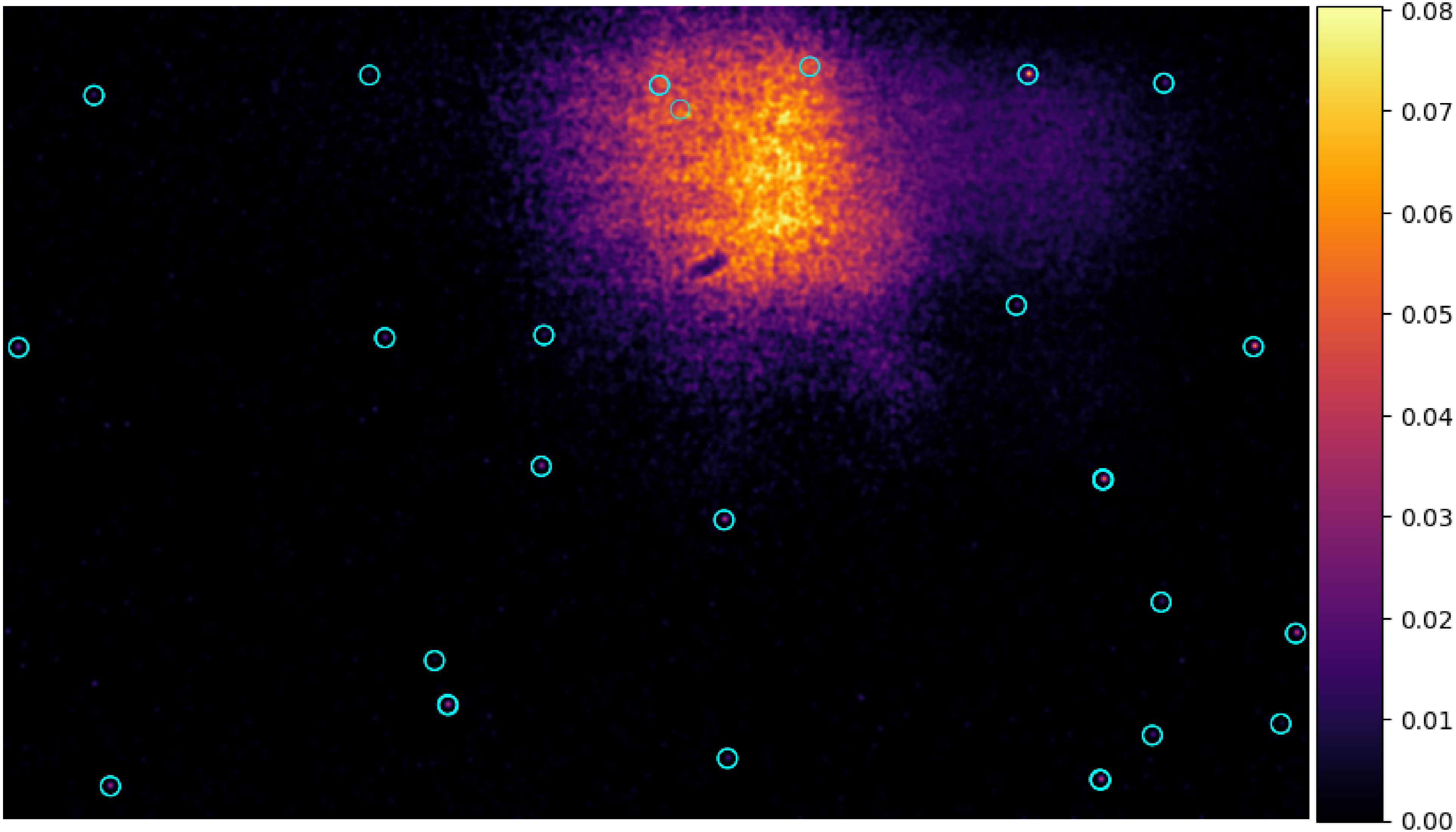

Histogramas de intensidad – Camera8
Camera8 – Gris
Camera8 – Rojo
Camera8 – Verde
Camera8 – Azul
1e6
Cuenta de píxeles
Intensidad (0–255)



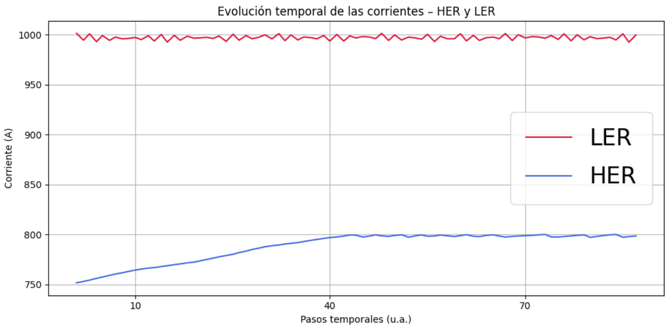
Deafult reconstruction

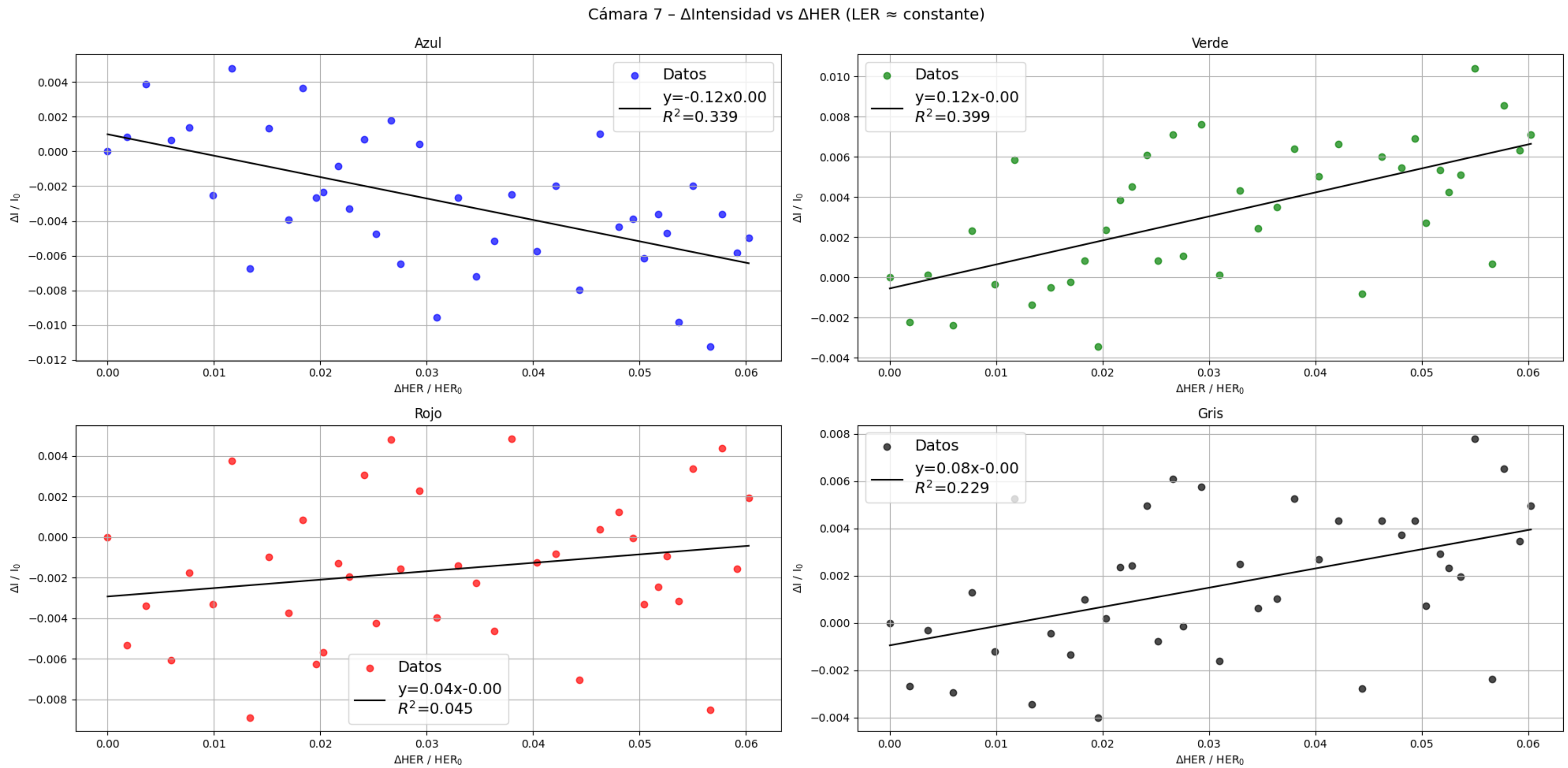


After apply cuts



We also develop a cut to eliminate hot pixels (this will be usefull for 2025 upgrade)

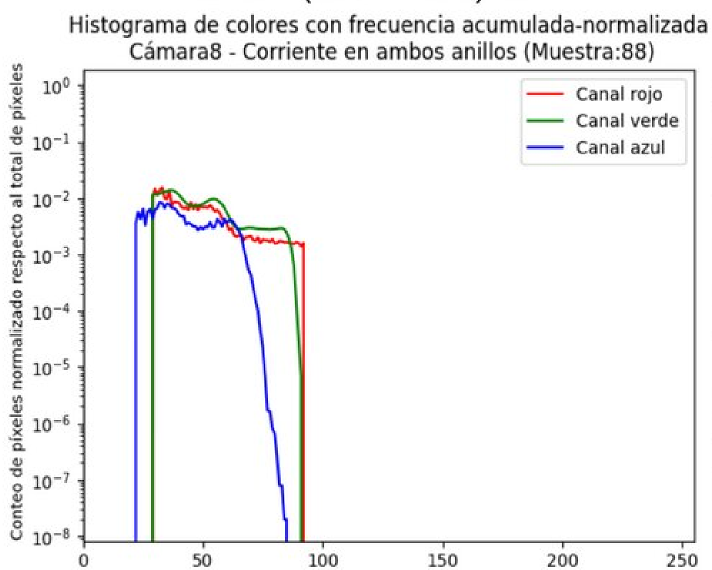

Evolución temporal de las corrientes – HER y LER
LER
HER
Corriente (A)
Pasos temporales (u.a.)


Cámara 7 – ΔIntensidad vs ΔHER (LER ≈ constante)
Azul
Datos
y=-0.12x0.00
R^2=0.339
Verde
Datos
y=0.12x-0.00
R^2=0.399
Rojo
Datos
y=0.04x-0.00
R^2=0.045
Gris
Datos
y=0.08x-0.00
R^2=0.229
ΔI / I_0
ΔHER / HER_0

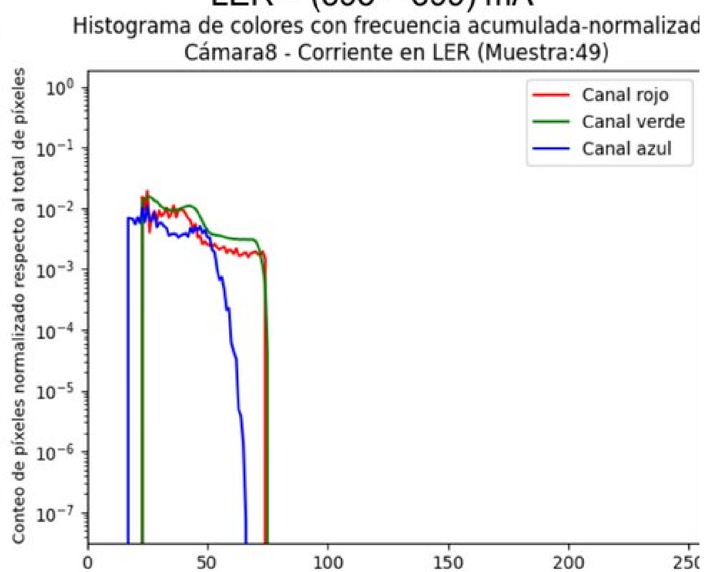
Beamstrahlung comes from two beams only one should get you background

Conjunto	Configuración	Corriente HER (mA)	Corriente LER (mA)	Beamstrahlung	Tamaño de muestra	Cámaras
1	HER-off_LER-off	$I \cong 0$	$I \cong 0$	NO	101,90,69,85	5,6,7,8
2	HER-on_LER-off	$641 < I < 720$	$I \cong 0$	NO	47	6,7,8
3	HER-off_LER-on	$I \cong 0$	$593 < I < 599$	NO	49	6,7,8
4	HER-off_LER-on	$I \cong 0$	$990 < I < 1002$	NO	100	7
5	HER-on_LER-on	$695 < I < 800$	$992 < I < 1001$	SÍ	88	6,7,8
6	HER-on_LER-on	$766 < I < 799$	$991 < I < 1000$	SÍ	100	7

HER = (695 – 800) mA,
LER = (992 – 1001) mA



HER = (-0.04 – -0.03) mA,
LER = (593 – 599) mA



Raymundo Bueno (UAS PhD student Computing)

Sean los histogramas a comparar H1 y H2. OpenCV cuenta con las siguientes métricas para comparar la similitud de 2 histogramas.

$$\bar{H}_k = \frac{1}{N}\sum_J H_k(J)$$

N: *número de intervalos*

- Correlación $$d(H_1,H_2) = \frac{\sum_I (H_1(I)-\bar{H}_1)(H_2(I)-\bar{H}_2)}{\sqrt{\sum_I (H_1(I)-\bar{H}_1)^2 \sum_I (H_2(I)-\bar{H}_2)^2}}$$
- Intersección $$d(H_1,H_2) = \sum_I \min(H_1(I),H_2(I))$$

1 = Máxima similitud

- Chi-cuadrada $$d(H_1,H_2) = \sum_I \frac{(H_1(I)-H_2(I))^2}{H_1(I)}$$
- Distancia Bhattacharyya $$d(H_1,H_2) = \sqrt{1-\frac{1}{\sqrt{\bar{H}_1\bar{H}_2N^2}}\sum_I \sqrt{H_1(I)\cdot H_2(I)}}$$

0 = Máxima similitud

Comparación de Cámara 8 - NikkoDX

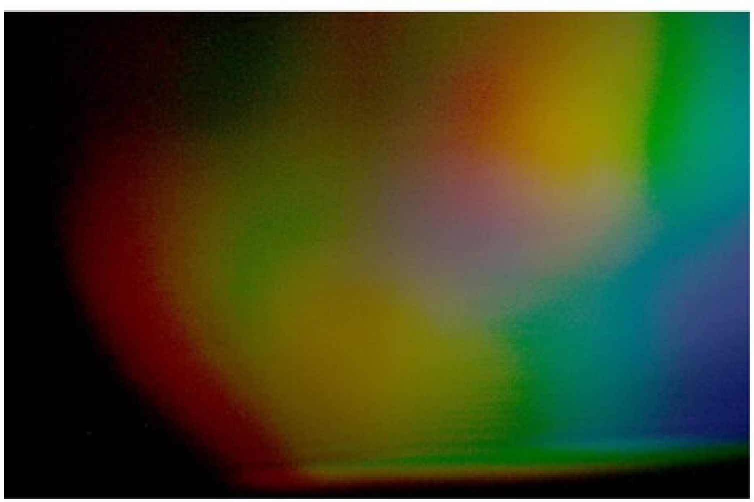


Imagen original

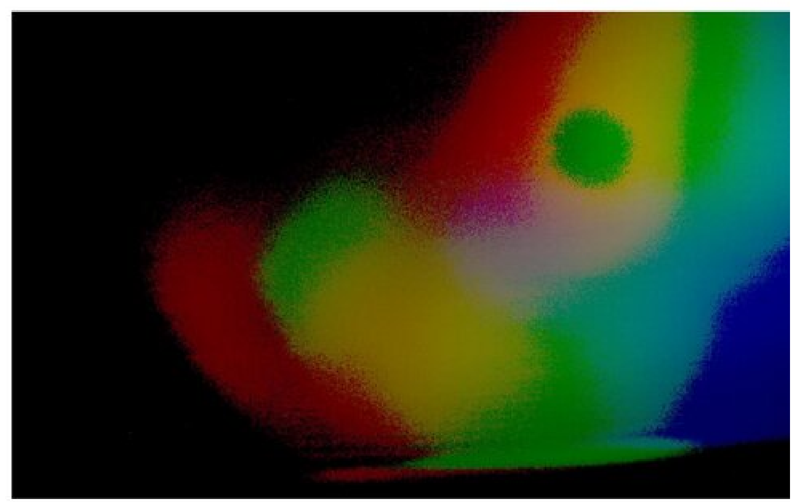


Imagen limpia

Raymundo Bueno (UAS PhD student Computing)

Issues

- Poor signal in Oho side, since we change the optics, very sensitive to misalignment

  Solution :

  1) Get even wider cameras

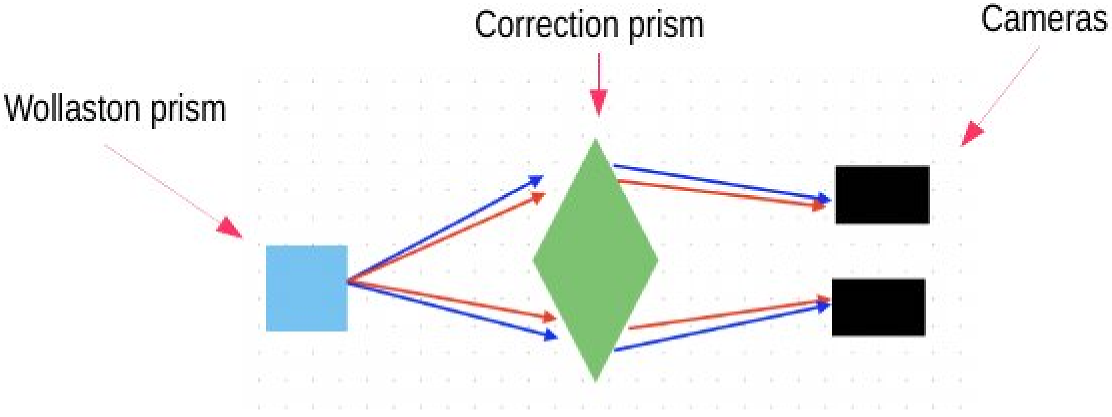
  2) Move the cameras closer to the radiation area. Risky but worthless

Upgrade 2025

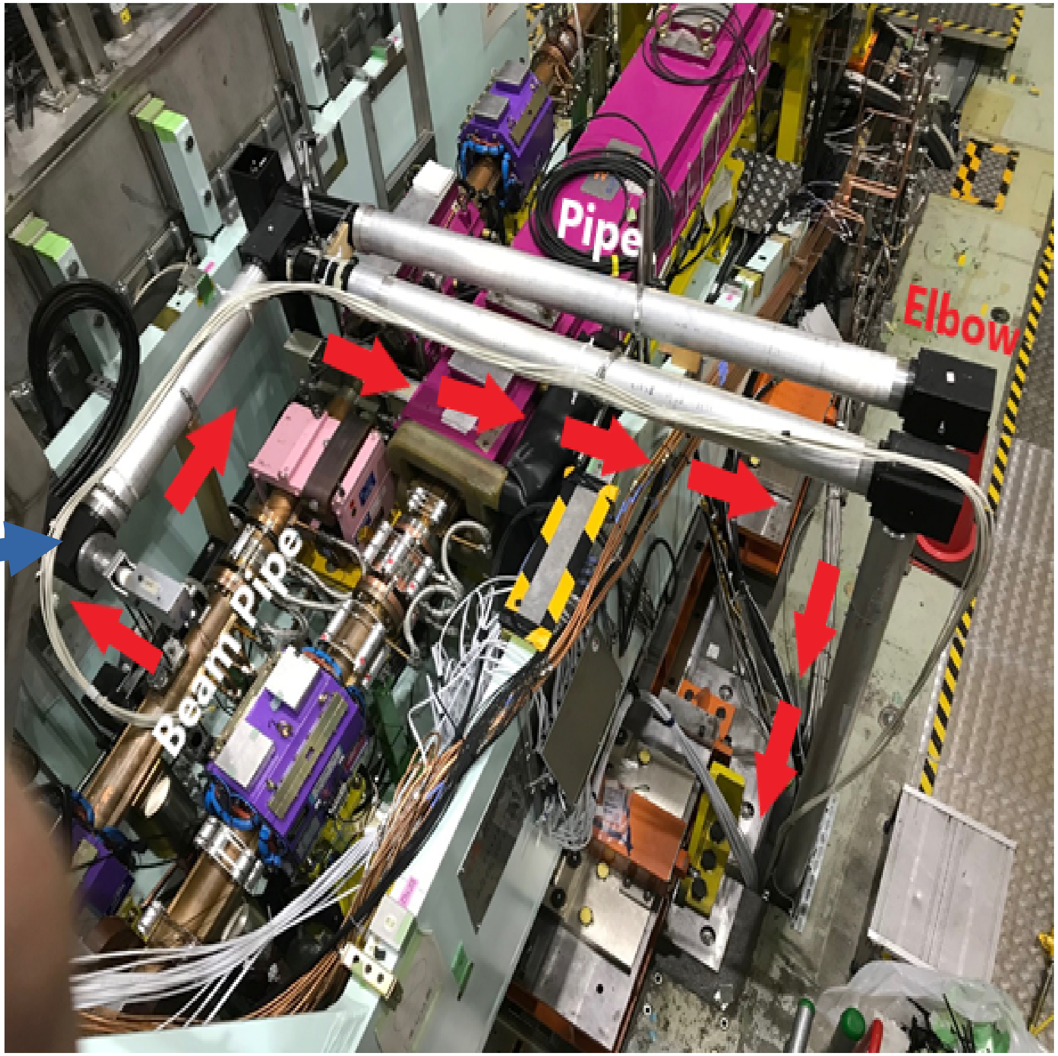
- The main problem for alignment is the long optical channel. So we plan to move cameras closer to primary mirrors

  - Radiation damage to cameras could be an issue !!!

- One side HER up is already in place and the other was installed fall 2025



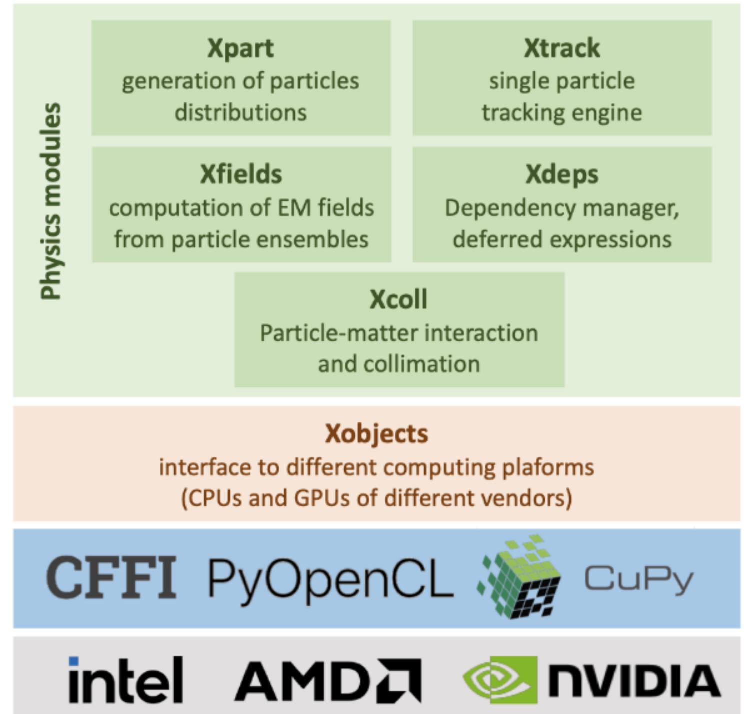
Put cameras Here



Xsuite Overview

- Developed at CERN, since 2021
- Collection of python packages
    - Integrates learning from many previous CERN tools including MAD, Sixtrack, COMBI and PyHEADTAIL
- Supports both CPUs and GPUs
- Demonstrated at: PS, SPS, LHC and more…
- Used for design of: FCC

Image credit: Giovanni Iadarola



https://indico.cern.ch/event/1471245/contributions/6205668/attachments/2957512/5200891/superkekb_xsuite_model.pdf

Xsuite Functionality

- Collection of python packages: different functionality in different packages
- Recent addition of Strong-Strong 6D Particle in Cell solver (summer 2024)
- Open source and python based:
  - Functionality can be added by users
  - Possible to submit merge requests for your own features once tested
- Development driven by user requirements
  - HL-LHC and FCC significantly push development

Image credit:
Peter Kicsiny

	Weak-strong 6D	Quasi-strong-strong 6D	Strong-strong 6D SG	Strong-strong 6D PIC	Beamstrahlung	Bhabha-scattering	Transverse wakefields	Longitudinal wakefields	Linear tracking	Lattice tracking	Open source	Runs on GPU
GUINEA-PIG [2]	Available	Not available	Not available	Available	Available	Available	Not available	Not available	Not available	Not available	Available	Not available
COMBI [3]	Available	Available	Available	Available	Not available	Not available	Available	Not available	Available	Not available	Available	Not available
BBWS [4]	Available	Not available	Not available	Not available	Available	Not available	Available	Available	Available	Available	Not available	Not available
BBSS [5]	Not available	Not available	Available	Available	Available	Not available	Available	Available	Available	Not available	Not available	Not available
SCTR [6]	Not available	Not available	Available	Available	Available	Not available	Available	Available	Available	Available	Not available	Available
IBB [7]	Not available	Not available	Available	Not available	Available	Not available	Available	Available	Available	Not available	Not available	Not available
LIFETRAC [8]	Available	Available	Not available	Not available	Available	Not available	Not available	Not available	Available	Available	Not available	Not available
BeamBeam3D [9]	Available	Not available	Available	Available	Available	Not available	Available	Not available	Available	Not available	Available	Not available
Xsuite [10]	Available	Available	Available	Available	Available	Available	Available	Available	Available	Available	Available	Available

Xsuite already implented in some part of SuperKEKB but some featurea are still not done like Beamstrahlung, we are working on that

Summary

- Beamstrahlung   can be used to monitor beam parameters and beams relative positions.

- Implementation of LABM in superKEK went a long way and many improvements were made over the original design, more to come.

- Analysis is under way

- One side option is enough to determine both beam parameters

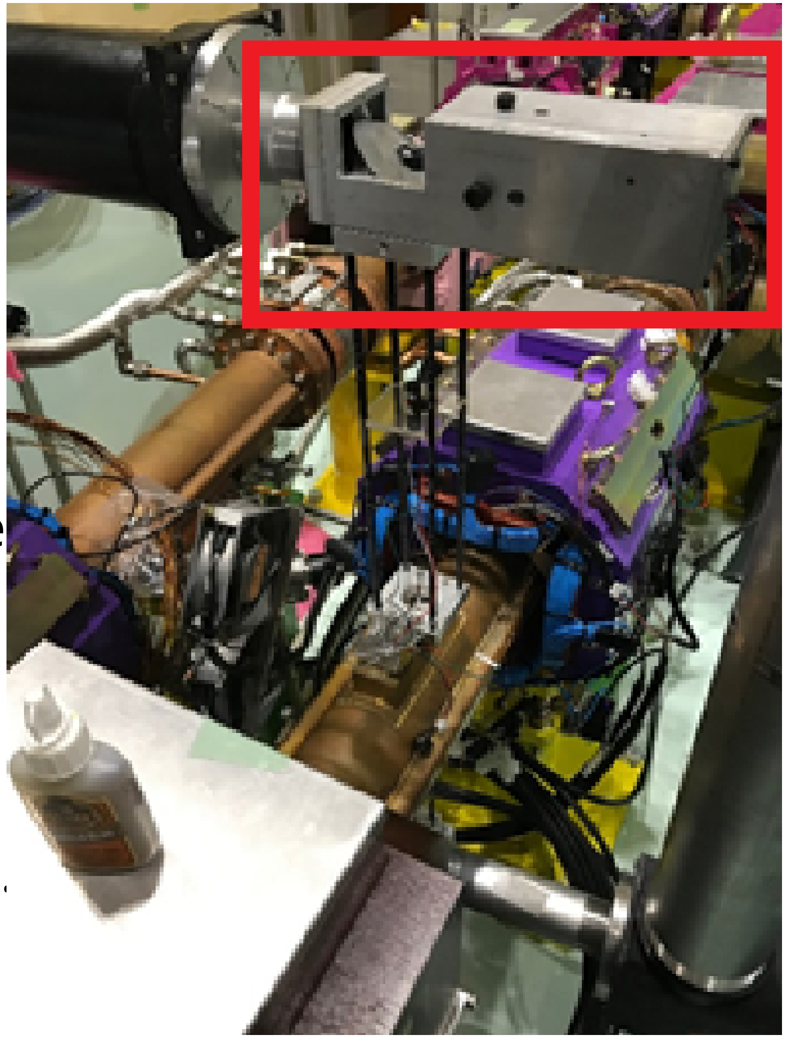
- Neural network and other computing techniques determinant to extract beam parameters

- LABM can be installed in EIC, superLHC

Backup

Codos primarios

- En el codo primario se encuentra un **espejo primario**, el cual mide **12.7mm** de eje menor, y **17.96mm** de eje mayor.
- Estos espejos cuentan con dos motores para poder redireccionar los haces.
- Estos espejos se conectan al **canal óptico**.



Análisis de Pedestal

- Sirve para remover el ruido de los datos obtenidos.

- Debido a la electrónica en el acelerador, **la corriente de los haces no será cero**, sino que fluctuará **alrededor de cero**.
- Por lo tanto se establecen **cortes de corriente**, que son condiciones para guardar o descartar datos de los PMT.
- En este caso se tomaron los cortes como $\text{media} \pm 3 * \sigma$.

Haz	Media (mA)	Sigma (mA)	Limite inferior (mA)	Limite superior (mA)
LER	-0.005	0.0096	-0.0338	0.0238
HER	-0.055	0.0179	-0.1087	-0.0013

Análisis de barrido

- Se realizan moviendo los motores del espejo primario en dos direcciones, buscando los picos de radiación.

- Los motores se mueven por pasos, donde una **vuelta completa** son **51,200** pasos, lo que equivale a un movimiento lineal de **0.3175mm**.

- La **posición de origen** para los motores se determinó en la posición **100,000**, por lo que el área efectiva va **desde 0 hasta 200,000**.

Polarización	Oho arriba	Oho abajo	Nikko arriba	Nikko abajo
Polarización en "x"	4 al 7	8 al 11	24 al 27	16 al 19
Polarización en "y"	0 al 3	12 al 15	28 al 31	20 al 23

*Asignaciones de fotomultiplicadores tomados como ejemplo de la tesis de maestría de Daniel Ricalde.