AITANA
High Granular Calorimetry activities in 2023

Adrián Irles

AITANA group at IFIC – CSIC/UV

Financiado por la Unión Europea NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia

Outline

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- ▷ Introduction to LUXE
- ▷ High Granular Calorimetry at IFIC
  - LUXE & Future Colliders
- ▷ New CERN Detector R&D collaboration on calorimetry: DRD6
- ▷ Who are we?
  - A. I.,
  - César Blanch (Mech. Engineer, only a fraction of time on CALO)
  - Shan Huang (postdoc contract in progress, 100% CALO & LUXE)
  - Jesús P. Márquez (starting 4th PhD year, 75% ILC, 25% CALO), Melissa Almanza(PhD, starting 1st year, all CALO)

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▷ New CERN Detector R&D collaboration on calorimetry: DRD6

a part time mechanical engineer is needed

▷ Who are we?

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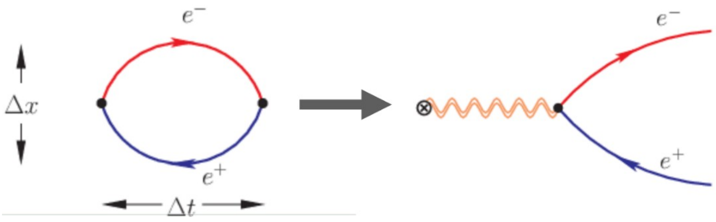
LUXE
membership of Russian institutes suspended
QUEEN'S UNIVERSITY BELFAST
ROYAL HOLLOWAY UNIVERSITY OF LONDON
UCL
UNIVERSITY OF PLYMOUTH
cnrs IN2P3
ÉCOLE POLYTECHNIQUE
cnrs IN2P3
universite PARIS-SACLAY
IJCLab Irène Joliot-Curie
UNI FREIBURG
IFIC
INFN
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA
INFN
UNIVERSITÀ DEGLI STUDI DI PADOVA
UNIVERSITAS GOTHOBURGENSIS 1891
mpsd
Max-Planck-Institut für Struktur und Dynamik der Materie
DESY.
HELMHOLTZ
Helmholtz-Institut Jena
FRIEDRICH-SCHILLER-UNIVERSITÄT JENA
UNIVERSITAS VARSOVIENSIS
AGH
KIT
ISS
TECHNION Israel Institute of Technology
TEL AVIV UNIVERSITY
WEIZMANN INSTITUTE OF SCIENCE

QED in strong fields: SFQED

▷ For large values of EM field **ε** → the **Schwinger critical** field is surpassed and **the vacuum becomes unstable** to pair production

- during the fluctuation, $E>2m_e$ is supplied



$$\mathcal{E}_{crit} = \frac{m_e^2 c^3}{\hbar e} = 1.32 \times 10^{18} V/m.$$

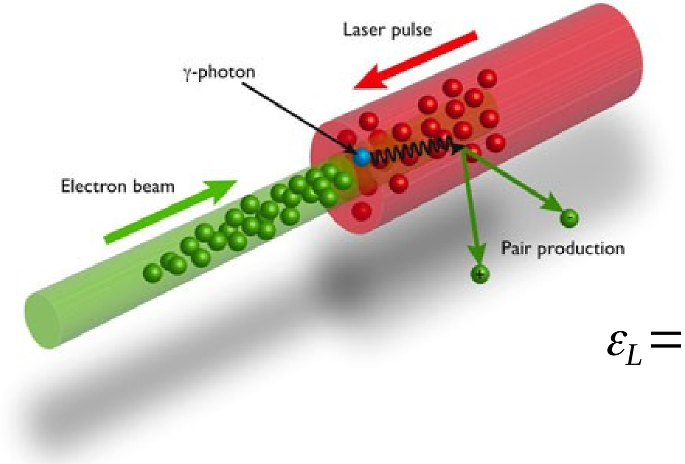
▷ Perturbative **QED breaks down** in the presence of **strong fields**

▷ **Such fields have not been reached experimentally** in laboratories although they are expected to exist:

- On surface of neutron stars
- In bunches of **future linear e+e− colliders**.

▷ **Can be reached** by colliding high intensity laser beams with a high-energy electron beam

- Lasers powerful enough don't exist yet
- A high energy e- beam is required: The EM field strength is boosted

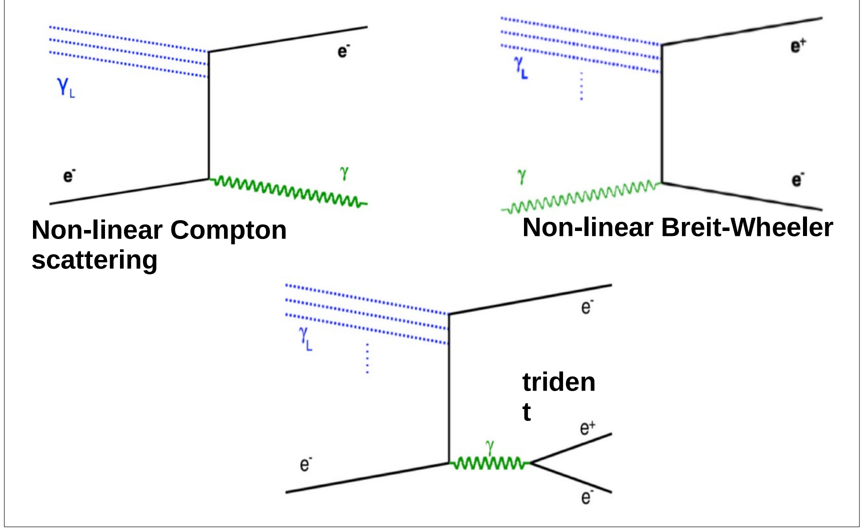


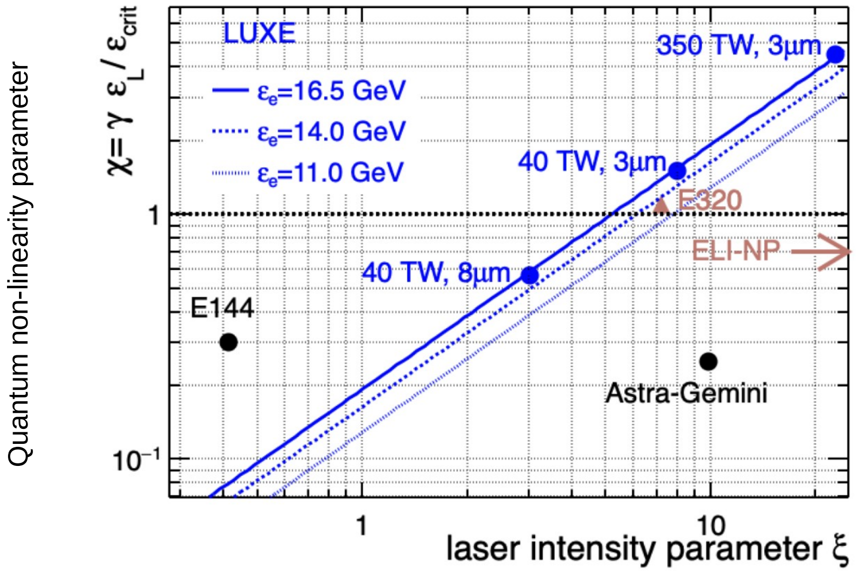
$$\varepsilon_L = \gamma\, \varepsilon (1 + \cos\theta)$$

LUXE: Laser Und XFEL Experiment

- ▷ Experiment based at **DESY-XFEL**
- ▷ **Strong EM field**: 30-350TW laser & 16.5 GeV e- beam
  - e- / laser interaction mode and γ /laser interaction mode
- ▷ **Ambitious time-scale** (start data taking in 2027)
  - CDR published, TDR in arxiv since 2023

Physics processes



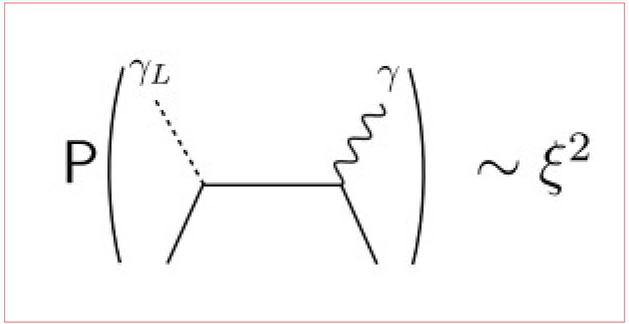


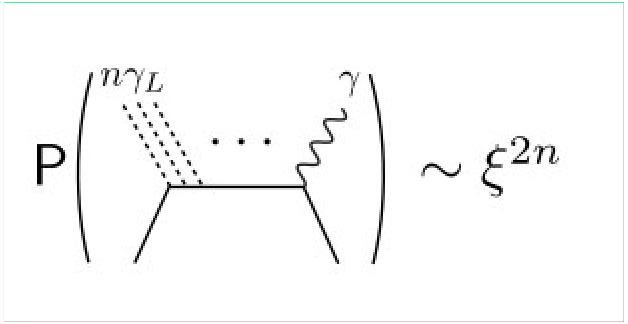
First experiment to try this E144 @ SLAC in 1990s.
Nowadays experiments : SLAC-E320 (US), Astra Gemini (UK), ELI-NP (RO)

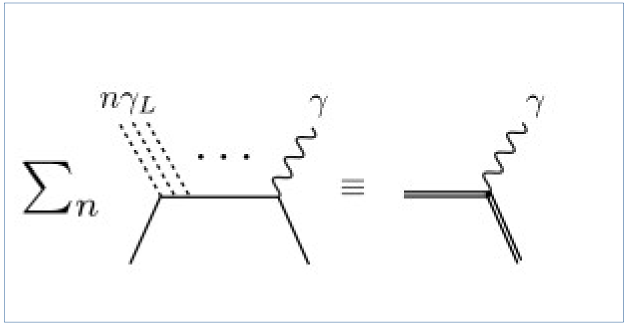
Field intensity parameter

$$\xi = \sqrt{4\pi\alpha}\left(\frac{\varepsilon_L}{\omega_L m_e}\right) = \frac{m_e \varepsilon_L}{\omega_L \varepsilon_{cr}}$$

non-linear Compton Scattering







ξ< 1

The probability to produce one Compton photon is proportional to the laser photon density

Still the electron can collide with n laser photons (non-linear compton).
The process is still perturbative if **ξ< 1**

ξ> 1
There are no more leading order processes and we are require to resum all higher order contributions in **ξ**

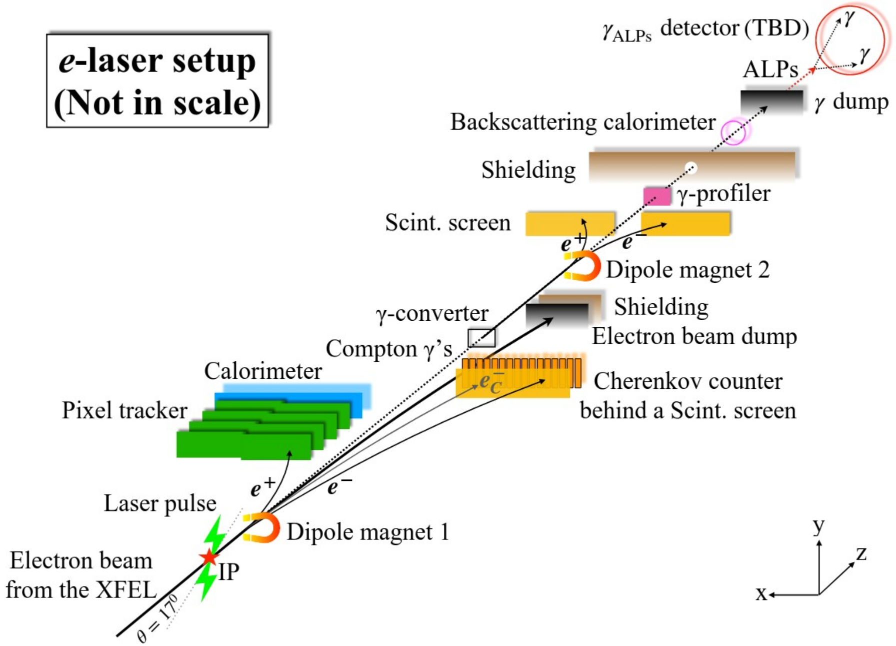
The non-perturbative resulting expression can be expressed as an effective larger electron mass:

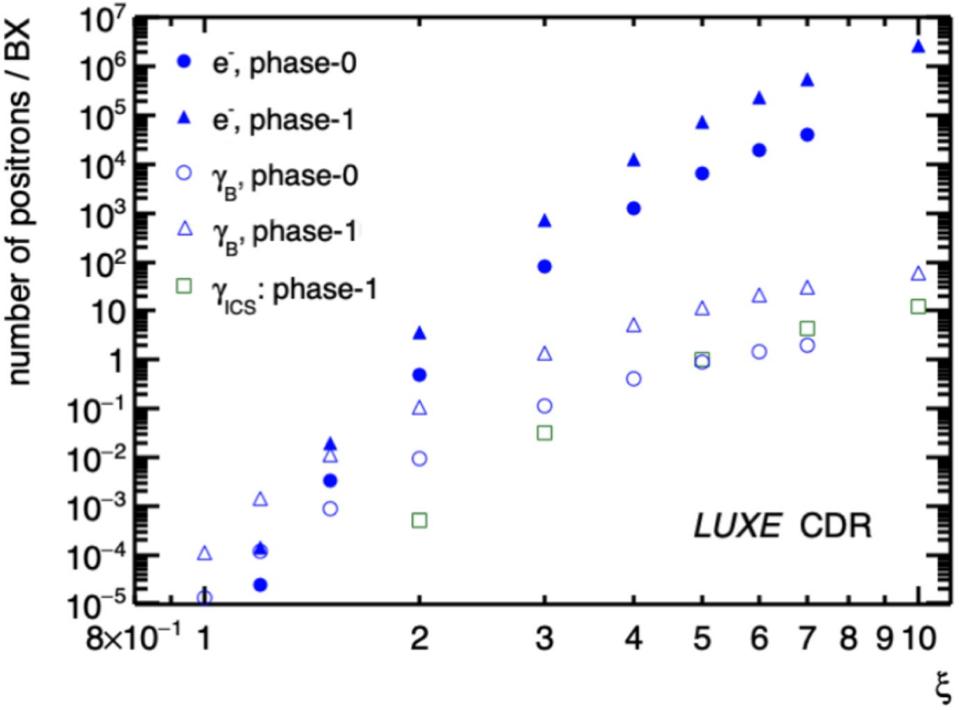
$$m_e(eff) = m_e\sqrt{1+\xi^2}$$

Detector challenges

▷ Vast range of multplicities per beam bunch depending on the mode of operation

- Physics-driven detector technologies at each location





Detector challenges

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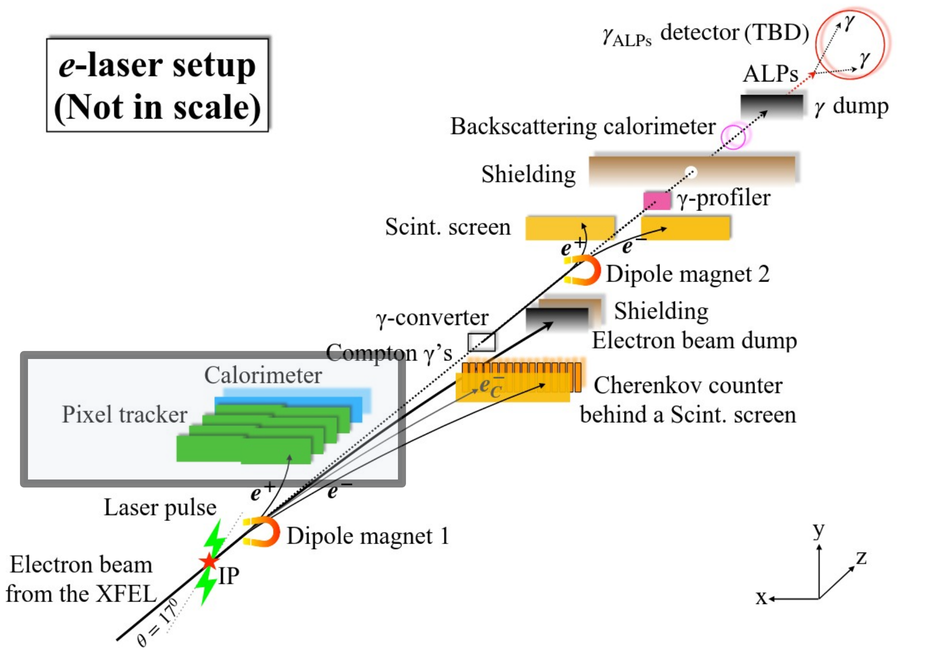
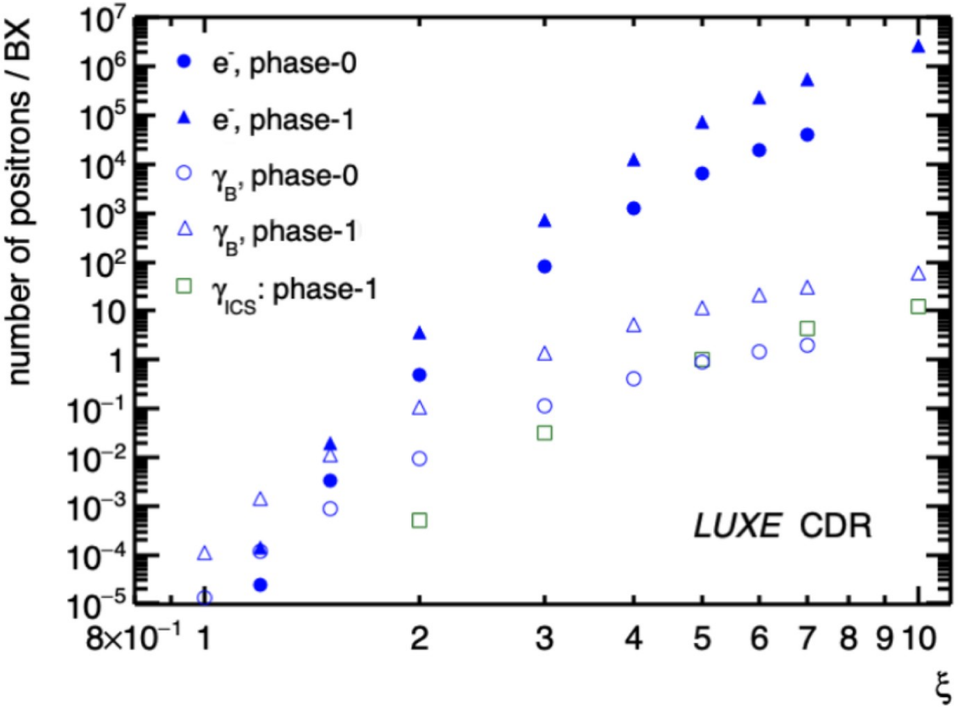
  - Physics-driven detector technologies at each location





Positron side (electron-laser mode)

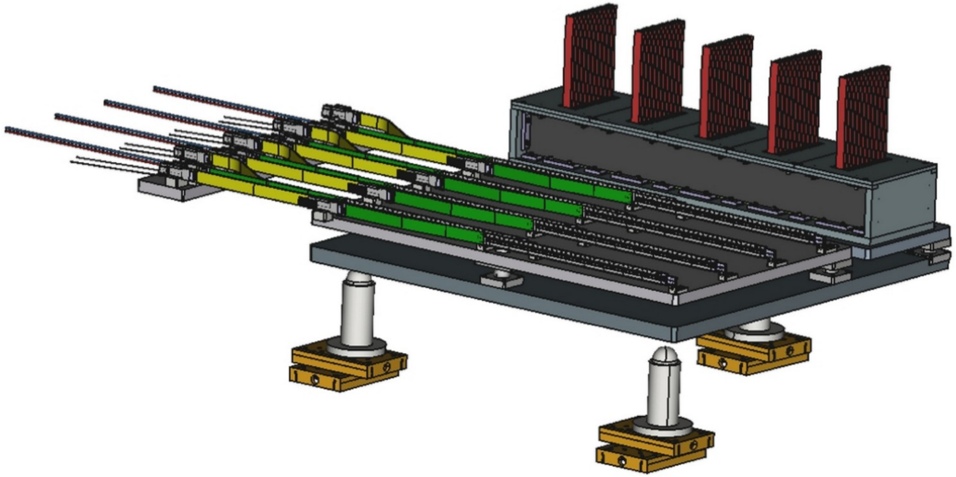
▷ Tracker based on ALPIDE sensors (developed by ALICE for phase 1 upgrade)

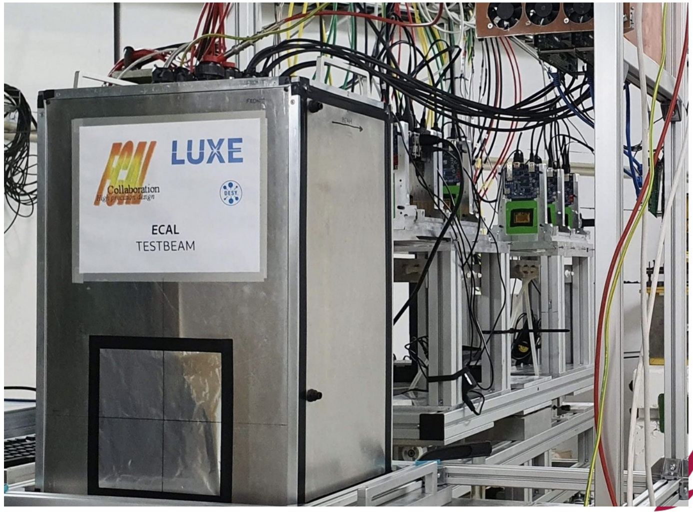
- 5um spatial resolution

▷ **Multilayer high granular calorimeters** based on linear collider prototypes (FCAL and SiWECAL-CALICE)

- $20X_0$, 5.5x5.5 mm^2 sensors (silicon and GaAs under study)
- Ultra compact to ensure minimal Molière Radius of about R_M~3.5 mm
- 1 mm between tungsten planes

▷ Dedicated algorithms for high multiplicity events





BSM direct searches with LUXE

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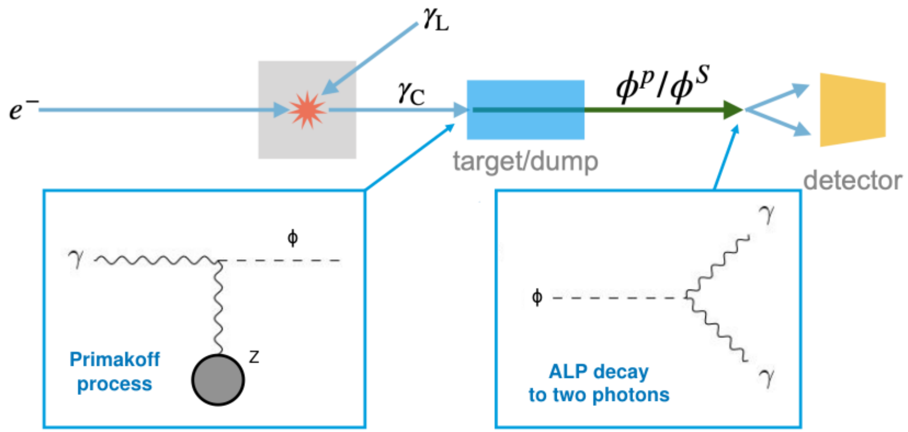
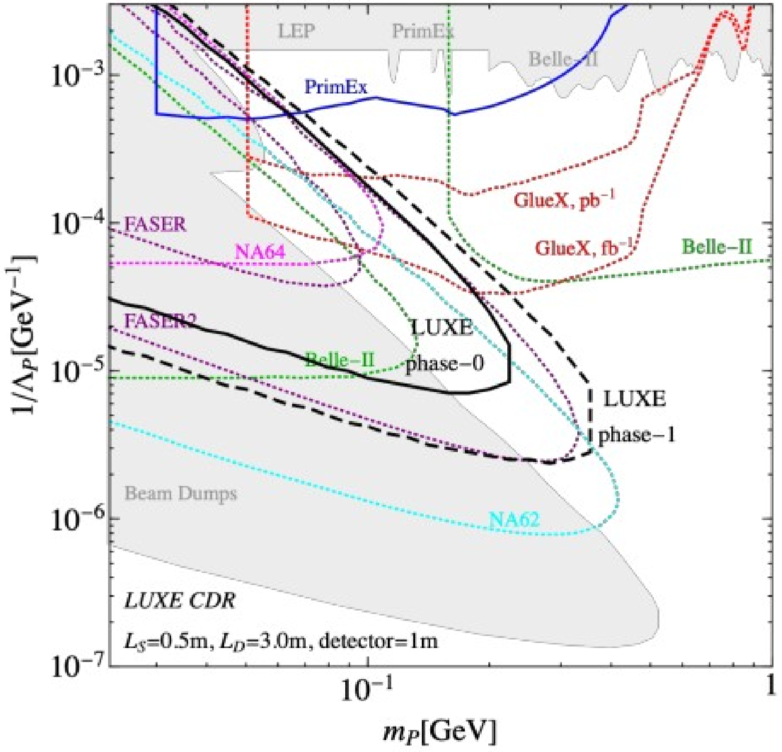
▷ High intensity photon beam produced → dumped in a wall





▷ Could be competitive with other experiments

- Estimations for 1 year of data taking with no background. WIP.

Milestones & more

- **IFIC is member of LUXE** since summer 2022
  - A. Irles as representative in the Collaboration Board
- Publications, conferences and proceedings:
  - **57th Rencontres de Moriond – EW+U , YSF talk (A.Irles)**: "Detector Challenges of the strong-field QED experiment LUXE at the European XFEL"
  - https://arxiv.org/abs/2305.07851
  - **LCWS2023 SLAC (A. Irles)** "Probing non-perturbative QED and new physics with a LUXE-type experiment at the ILC" https://arxiv.org/abs/2308.00117
  - Attendance to LUXE physics and SFQED 4-12 September 2023 (Weizmann Institue of Science, Israel)
  - **LUXE TDR** (submitted to Eur.Phys.J.ST) https://arxiv.org/abs/2308.00515

    (M. Almanza, C. Blanch, A. Irles)
- **ECAL-p workshop in Valencia – 14-16 February 2024**
  - https://indico.ific.uv.es/event/7274/

Next week

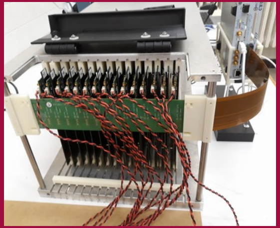
▷ **IFIC seminar: LUXE physics case by Grzegroz Grzelak (U. Warsaw)**

- Tuesday 13th at 12.

▷ **ECAL-p for LUXE workshop in Valencia – 14-16 February 2024**

- https://indico.ific.uv.es/event/7274/

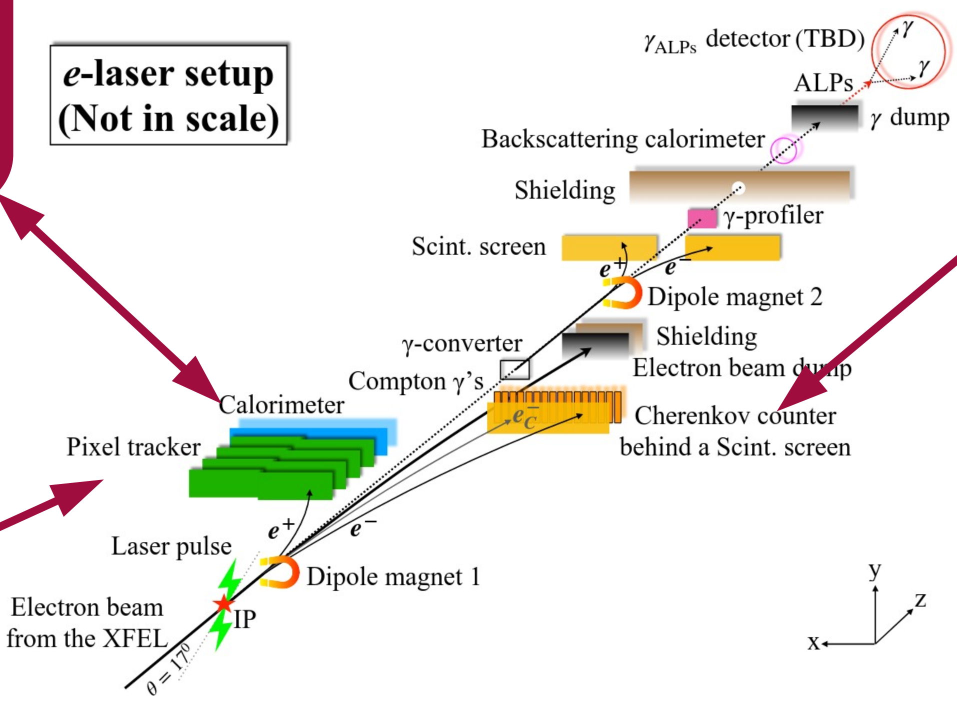
ILC-LUXE detector R&D synergies

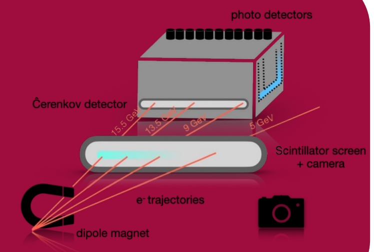


CALICE -type calorimeter

FCAL-type calorimeter

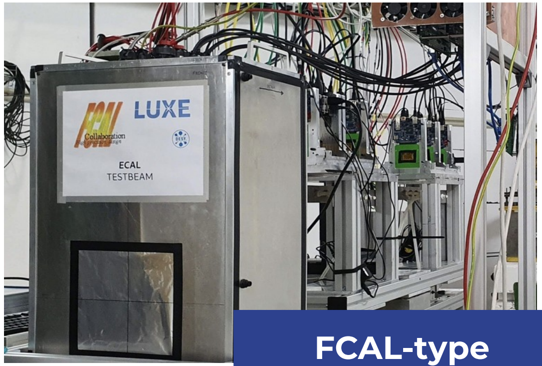
ALPIDE sensors (ALICE)





ILC polarimeter

ECAL -p

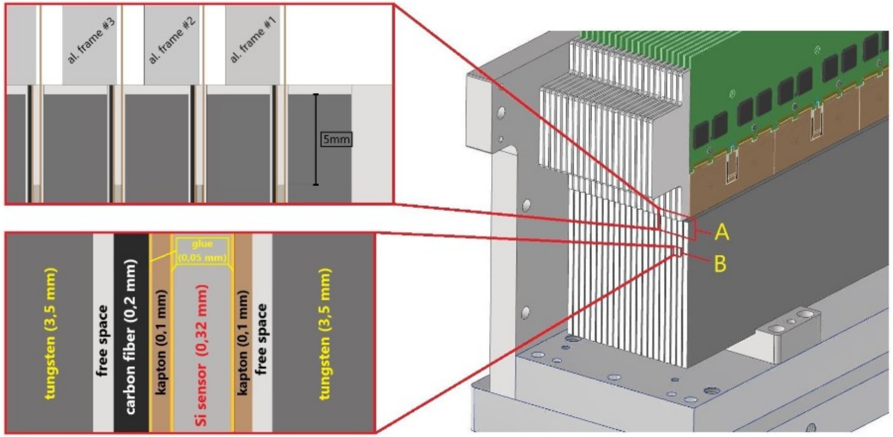


FCAL-type calorimeter

▷ **ECALp: positrons**

- Main calorimeter system.
- Tel-Aviv, Romania, Poland and IFIC collaboration.
- **IFIC is responsible of sensor assembly/hybridization** and module validation.

  FULL CALORIMETER (20 layers of 6 sensors)



▷ (some) **Challenges:**

- The calorimeter is designed for the Forward Calorimetry of ILC → **Ultra compact calorimeter**

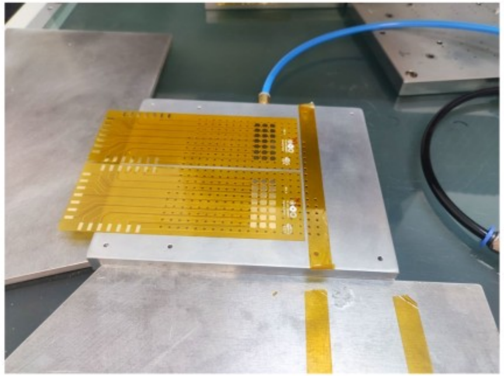
  (RM ~3mm)
- Each module is 1mm thick

  including sensors, supports, fanouts **and GLUE**

- **IFIC (hybridization) & Warsaw U. (mechanical frame)**

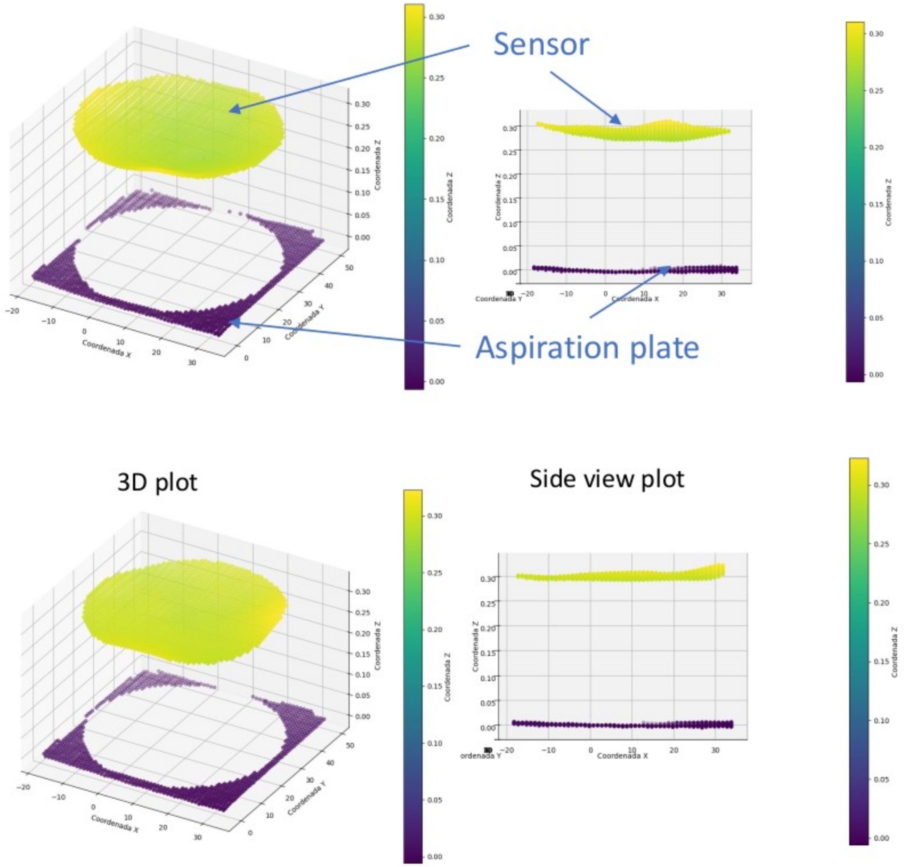
Sensors glueing metrology

- The goal is to measure the glue thickness after glueing process.
- Vision measurement machine
- Vacuum aspirated to ensure the position
  1. Flex PCB thickness measurements
  2. Sensor thickness measurements
  3. To Ggue the PCB to the sensor
  4. Final thickness measurements PCB+glue+sensor



Sensors glueing metrology

- 6 fake Si sensors already measured
  - Still the data needs to be analysed
  - The aspiration plate is not completely plane so it seems that it induces an error in the thickness measurement.
  - So the aspiration plate will be measured and subtracted to the sensor measurement to compensate the error.
- PCB measurements in progress (expected to be finished by the end of this week)
- Then we will glue the sensor to the PCB and will measure again the pack



Gluing tests for glue thickness measurements

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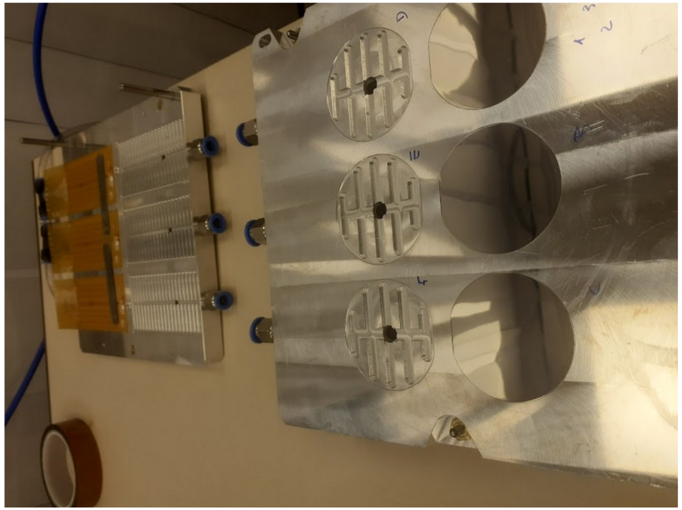
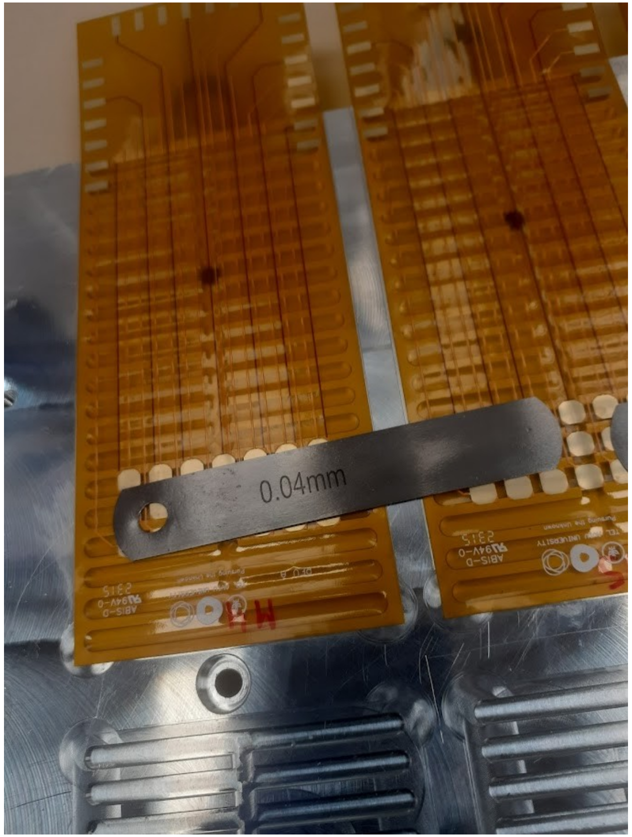
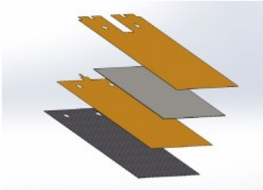
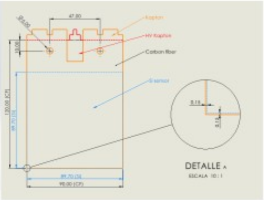
- ▷ Using the robot and procedure defined and tested with the ECALe modules
- ▷ Play with different approaches to define thickness:
  - Feeler gauges, glue dots size, etc
- ▷ Perform metrology after the gluing.



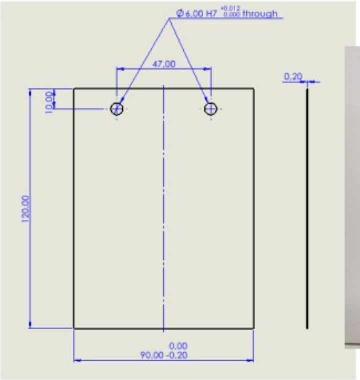


Carbon frame metrology

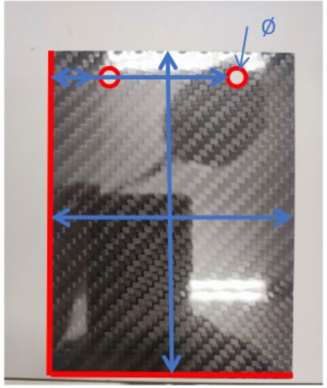


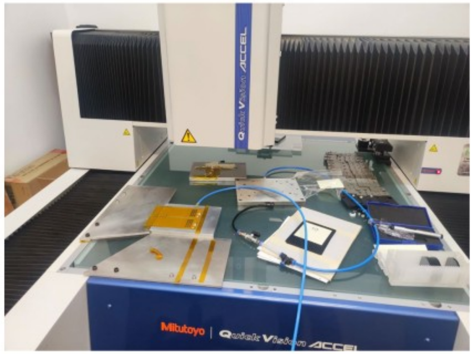


- 10 CF samples received manufactured according to the drawing
  - Dimensions: 90x120x0,2mm
  - 2 holes Ø6 mm for positioning pins



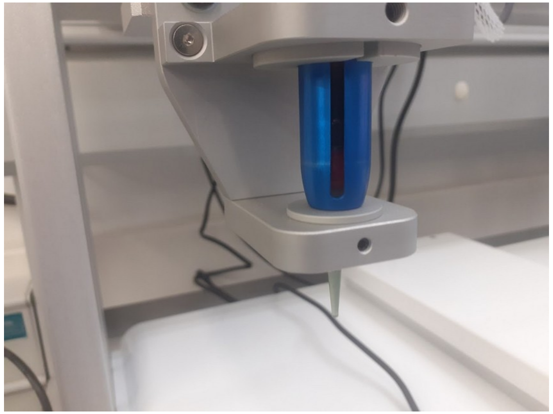
- Metrology in progress
  - Vision measurement machine
    - 2 measurement methods:
      - Focus by vision (slower but seems more accurate)
      - Focus by laser (faster but seems less accurate)
  - Measure dimensions, thickness, and alignment holes position
  - Vacuum aspirated to ensure the position
    - Need to measure the aspiration tooling (for thickness measurements)





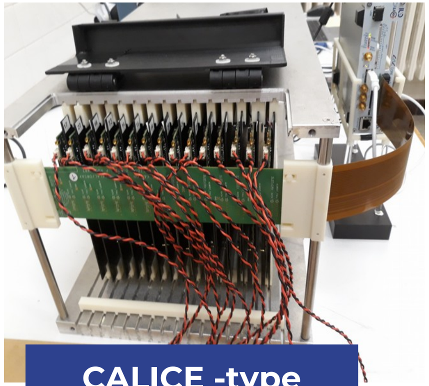
ECAL -p: Clean room

- ▷ Probe bench **with CERN-made** probe card
  - Still waiting for equipment to arrive LCR, switch card, chuck for sensor (purchase or made at IFIC?)
- ▷ 3d robot + volumetric professional dispensing methods
- ▷ System for dehumidification & vacuum packaging
- ▷ Dry cabinet and curing cabinets
- ▷ Sensors purchased to Hamamatsu
- ▷ Still waiting for the benches…
  - CSIC bureacray is just #~½#!



Your installation, sir

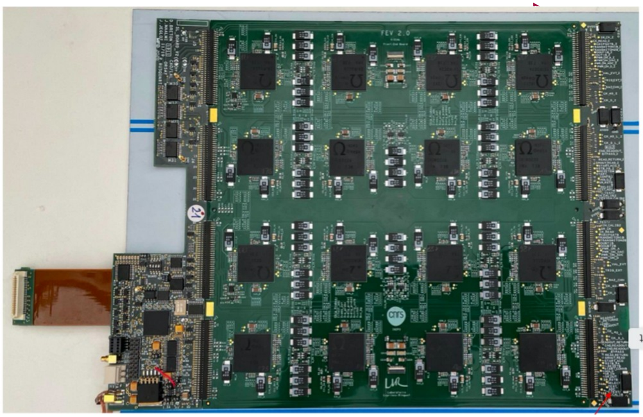
ECAL-e



CALICE -type calorimeter

▷ **ECALe** (aka **SiW-ECAL** de **CALICE**): electron calorimeter

- Second calorimeter of LUXE (could also be the ALPs calorimeter?)
- Project with IJCLab, LLR, Tokyo U (Taikan moved from Kyushu to Tokyo)
- IFIC has been playing a technical coordination role and tesbteam preparation/running/analysis with the “old 15 layer prototype”
- **IFIC is responsible of the R&D on improved hybridization** during 2024/25. Including a small batch of module prototypes.



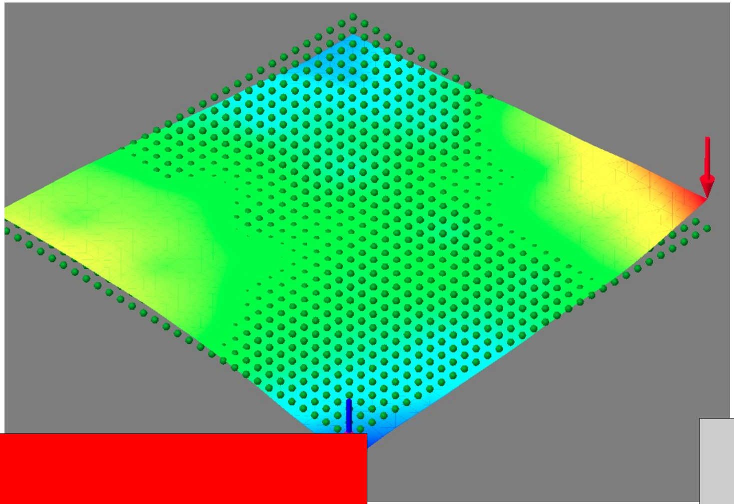
▷ Open **challenge**

- Delamination of wafers observed… ¾ of the latest prototype are not usable anymore.
- Very busy-dense PCBs → uncontrollable(?) mechanical properties

ECAL-e: sensor delamination

Gluing procedure?
Glue choice,
Mixing,
curing process...

Glue degradation?
Chemical oxidation
(silver vs aluminum),
Lifetime of glue...



Mechanical deformation of the PCBs
Complex PCBs with “intense” thermal processes
for the assembly of the components

Storage and manipulations
Lots of traveling
Commissioning procedure
etc

ECAL-e: sensor delamination

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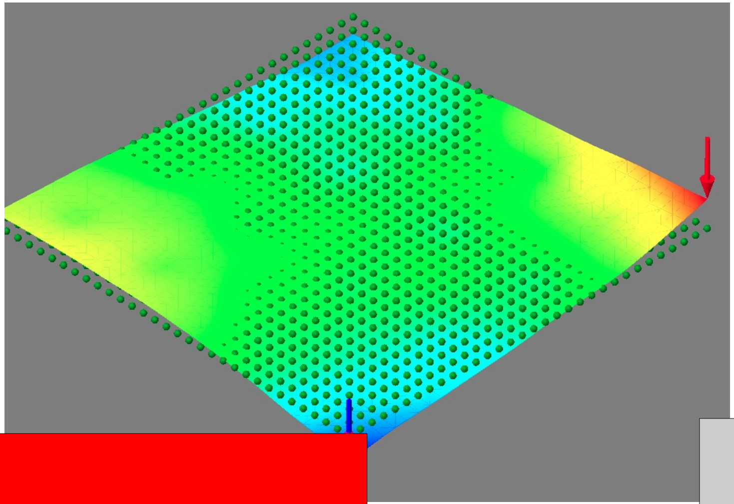

Clean room.
Cold plasma to clean sensors.
Alternative epoxies.
Dry-cabinet.
Dry-curing-cabinets

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ECAL-e: sensor delamination

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Volumetric dosification and deposition
More modern robot

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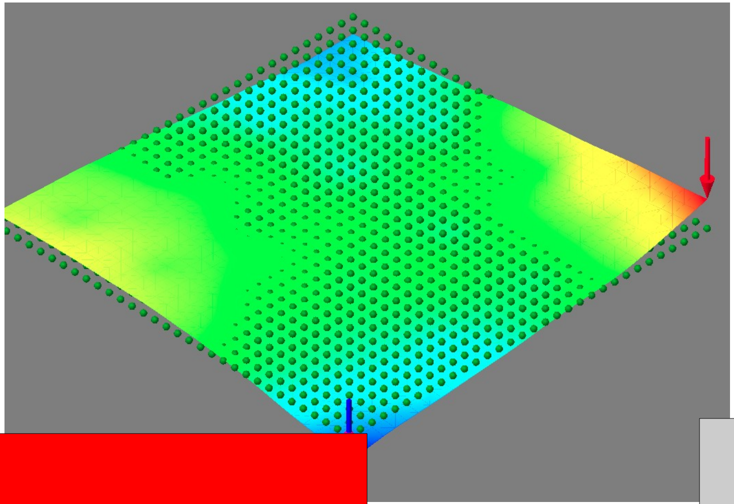

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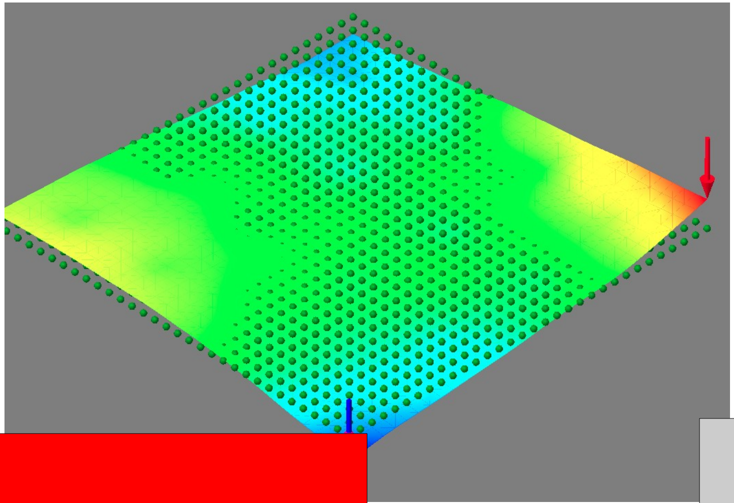

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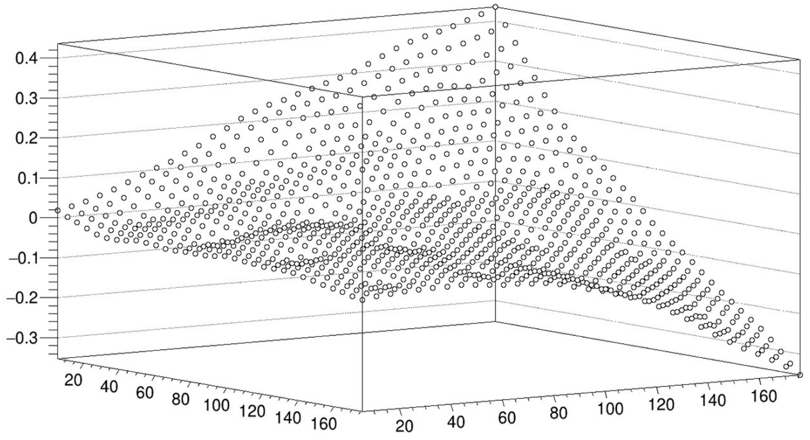
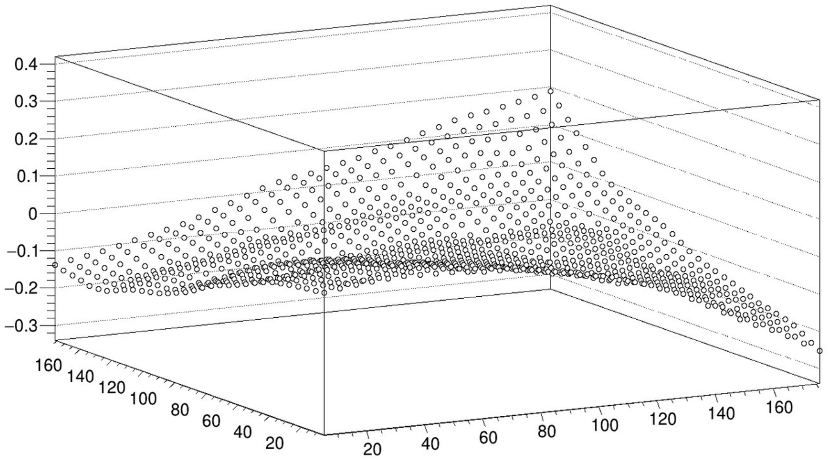
ECAL -e: slide 1

- **PCB metrology at IFIC**
  - First time this is systematically done in the project with this precision

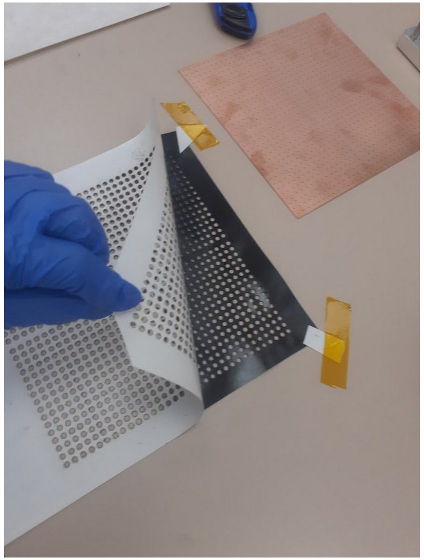




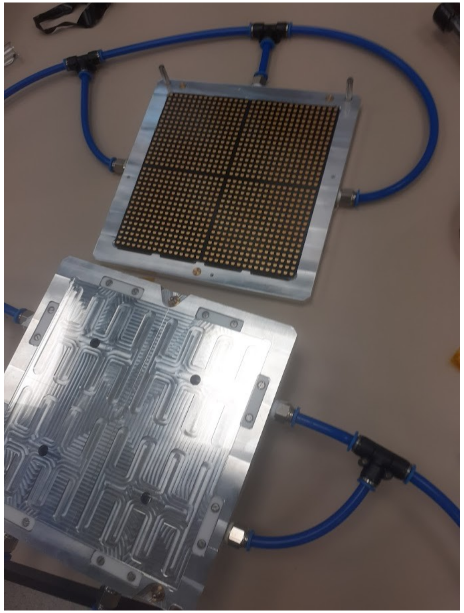
- First results are surprising(?) !
  - **Left**: the metrology of a equipped PCB after receival from IJCLab → up to ~**800um deformation**
  - **Right:** same PCB after being carefully “dried-out” → deformation reduced to **~450um**
- **Systematic study to be conducted during early 2024**

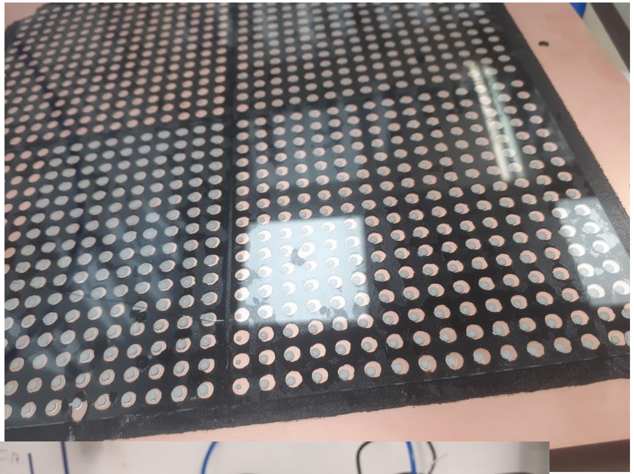
ECAL -e: slide 2

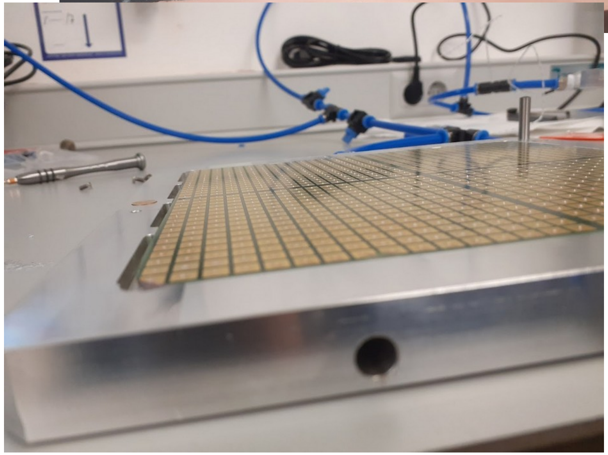
- **Mixed solution:**
  - **Perforated stencil** of thin (250um) double tape VHB 5907F **for adherence**
  - **Silver Epoxy dots for electrical conductivity**



Stencil made at IFIC (laser drill)







2024 plans

▷ Clean room

- Install the benches and move everything inside
- Install the sensor probe station (purchase LCR, design mechanical supports, etc)

▷ ECALp

- Establishment of the hybridization process.
- Analysis of 2022 beam test data (we did not participated in it).
- Module production for Autumn 2024 beam test at DESY.
- Contribution to DAQ developments?(depending on Krakow U. personpower)
- Shan Huang (currently, postdoc in TAU) will join us → LUXE studies.

▷ ECALe

- TB2022 data and simulation studies (work-in-progress, Jesús)
- Establishment of the hybridization process.
- Coordination of the mechanical metrology of PCBs.
- Production of 1-2 full modules for testbeam in June 2024 at DESY.

Milestones, etc

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▷ **Conferences/workshops:**

- CALICE Collaboration Meeting at FZU Prague 27-29 September https://agenda.linearcollider.org/event/10098/
- **LCWS** https://indico.slac.stanford.edu/event/7467/ (A. Irles contributions)

  Plenary talk "Calorimetry for Higgs Factory Detectors"

  Plenary (summary) talk "Detector Closeout".

  Paralel talk: "Commissioning and noise study of the ultra-thin chip-on-board PCB for the CALICE SiW-ECAL prototype"
- CALICE Collaboration Meeting at University of Gottingen 29-31 March https://agenda.linearcollider.org/event/9877/

▷ Other events

- ECFA WG3: Topical workshop on calorimetry, PID and photodetectors 3-4 May https://indico.cern.ch/event/1256374/
- Jornadas de la Red Espanola de Futuros Colisionadores 6-7 March https://indico.ific.uv.es/event/6952/
- Instrumentation for the future of particle, nuclear and astroparticle physics and medical applications in Spain : 6-7 March https://indico.cern.ch/event/1220045/

Milestones, etc

▷ **Publications:**

- "Performance of the CMS High Granularity Calorimeter prototype to charged pion beams of 20-300 GeV/c" (**CMS** and **CALICE Collaborations)**

  https://arxiv.org/abs/2211.04740 Published in: JINST 18 (2023) 08, P08014
- "Design, construction and commissioning of a technological prototype of a highly granular SiPM-on-tile scintillator-steel hadronic calorimeter" (**CALICE Collaboration)**

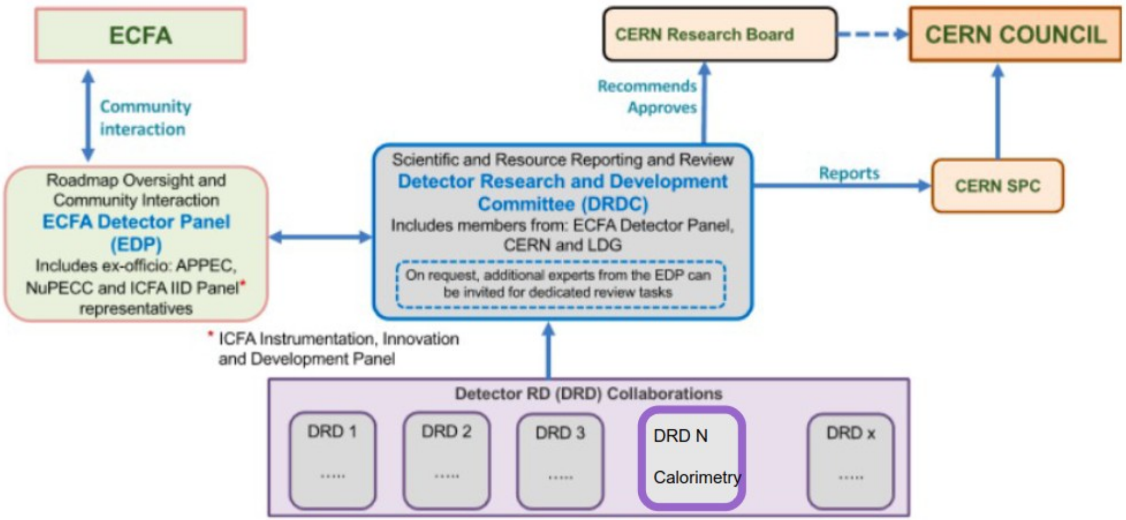
  https://arxiv.org/abs/2209.15327 Published in: JINST 18 (2023) 11, P11018

- A. Irles with DESY affiliation…

▷ Proposal team for the **DRD6**.

- **Collaboration started in January 2024**
- More in the following slides.

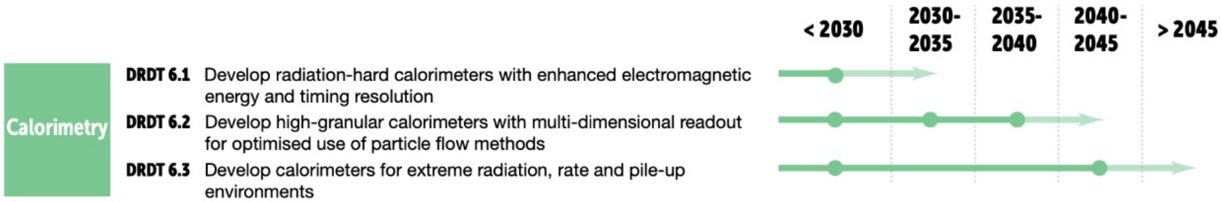
Coming organization of detector R&D



- ▷ DRD have a CERN recognition
  - Significant participations by non-European groups is explicitly welcome and needed
- ▷ The progress and the R&D will be overseen by a DRDC that is assisted by ECFA
  - Availability and usage of resources, monitoring of progress, vetting agains Roadmap objectives
  - CERN Research Director is preparing setting up the DRDC
- ▷ The funding will come from national resources (plus eventually supranational projects)

Coming organization of detector R&D

1. Strategic R&D via DRD Collaborations **vision**
   (long-term strategic R&D lines)
   (address the high-priority items defined in the Roadmap via the DRDTs)
2. Experiment-specific R&D **focus**
   (with very well defined detector specifications)
   (funded outside of DRD programme, via experiments, usually not yet covered within the projected budgets for the final deliverables)
3. "Blue-sky" R&D **agility**
   (competitive, short-term responsive grants, nationally organised)



DRD6 collaboration

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DRD 6: Calorimetry

Proposal Team for DRD-on-Calorimetry

January 15, 2024

Martin Aleksa[1], Etiennette Auffray[1], David Barney[1], James Brau[2], Sarah Eno[3], Roberto Ferrari[4], Gabriella Gaudio[4], Alberto Gola[5], Adrian Irles[6], Imad Laktineh[7], Marco Lucchini[8], Nicolas Morange[9], Wataru Ootani[10], Marc-André Pleier[11], Roman Pöschl[9], Philipp Roloff[1], Felix Sefkow[12], Frank Simon[13] Tommaso Tabarelli de Fatis[8], Christophe de la Taille[14], Hwidong Yoo[15] (**Editors**)

[1]CERN, Geneva, SWITZERLAND
[2]University of Oregon, Eugene, OR USA
[3]University of Maryland, College Park, MD USA
[4]INFN, Pavia, ITALY
[5]FBK, Povo, ITALY
[6]IFIC, CSIC-Unversity of Valencia, Valencia, SPAIN
[7]IP2I Lyon, Villeurbanne, FRANCE
[8]University and INFN Milano-Bicocca, Milano, ITALY
[9]IJCLab, Université Paris-Saclay, Orsay FRANCE
[10]University of Tokyo, Tokyo, JAPAN
[11]Brookhaven National Laboratory, Upton, NY USA
[12]Deutsches Elektronen-Synchrotron DESY, GERMANY
[13]Karlsruhe Institute of Technology, Karlsruhe, GERMANY
[14]OMEGA, Palaiseau, FRANCE
[15]Yonsei University, Seoul, SOUTH-KOREA

DRD6 collaboration

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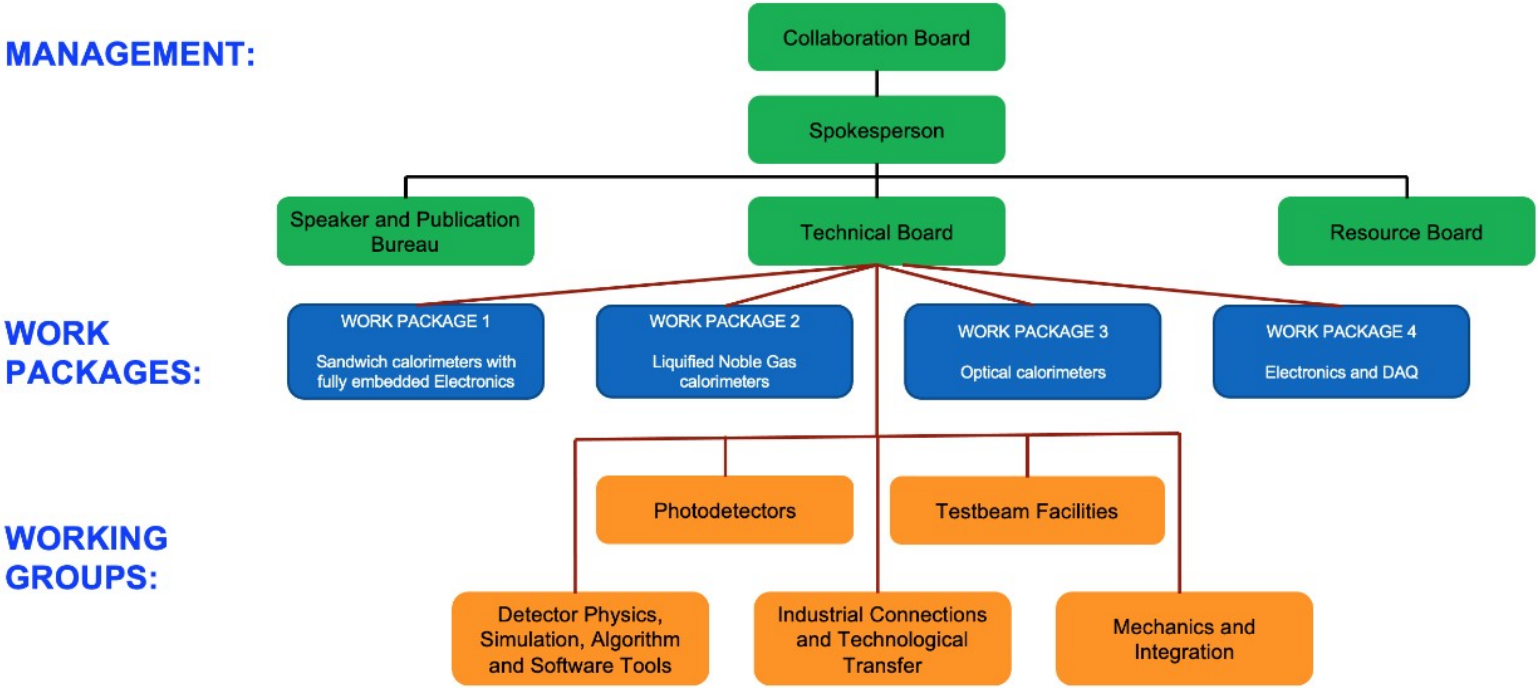


- Collaboration approved by CERN and DRDC
- Structure designed (à la CERN+CALICE collaboration)
- We are working on the filling of the squares.
- First collaboration meeting in April 9-11th 2024 https://indico.cern.ch/event/1368231/

Spanish members of DRD6

- CIEMAT
  - Mary Cruz - SDHCAL
- IFIC:
  - AI (CB representative): CALICE SiWECAL y FCAL ECAL que se van a unir en uno solo para el DRD6
  - L. Fiorini - TileCal,
  - J. Mazorra -SpaCAL
- DIPC Donostia
  - Roberto Soleti - CRILIN
- UB-ICCUB:
  - Eduardo Picatoste - SpaCAL
- UCO (Córdoba)
  - José Berenguer T-SDHCAL
- UVO (Oviedo)
  - Pietro Vischia - Software

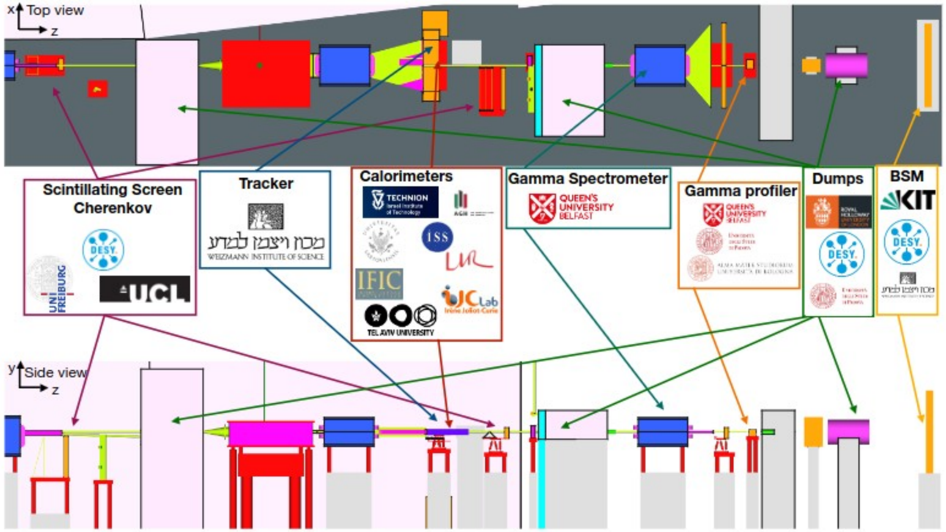
thanks


D.M. Calendar Blitz
Jim
DWIGHT
MISSION STATEMENT
DUNDER MIFFLIN

backup

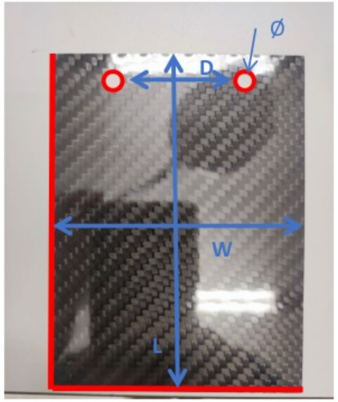
ONE WORD ON THE PLANING

- LUXE initiated in 2017 (A. Ringwald, B. Heinemann)
- 2022: international collaboration with ~20 institutional members, significant contributions to the experiment by external partners envisioned.
- Nov 2022: LUXE officially recognized as a DESY experiment!
- In parallel of review continue detector R&D, and experiment planification. Foresee three-year construction period, after which data-taking could start
  - Depending on approval time-scale this could be as early as 2027
- Extensive material on detailed design and planning available
  - TDR was released during summer 2023.

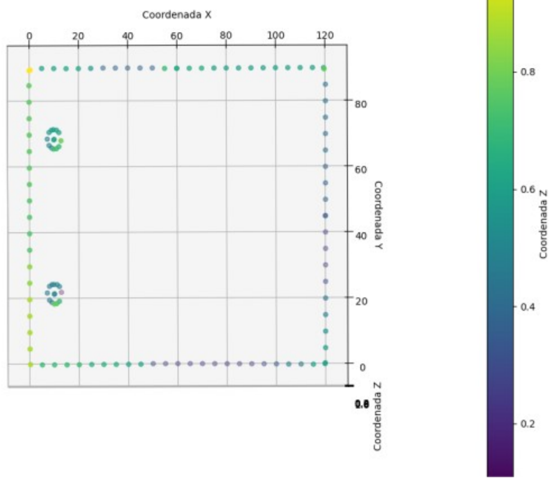


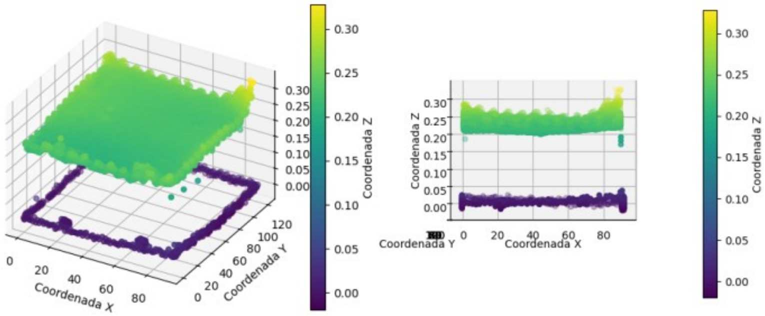
Carbon frame metrology

- Vision machine measurements
  - Measurements with focus by laser method in progress
  - XY measurements to determine dimensions.
  - Z measurements to determine thickness



- Some results for sample 1:
  - W= 89,93mm
  - L= 119,89mm
  - D= 46,98mm
  - Ø= 5,94mm
  - Z= 0,215mm (average plane)
  - Z values increase on the edges of the CF, probably due to the lack of aspiration on that place





ECAL -p: slide 2

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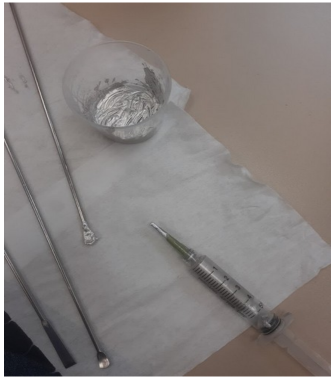
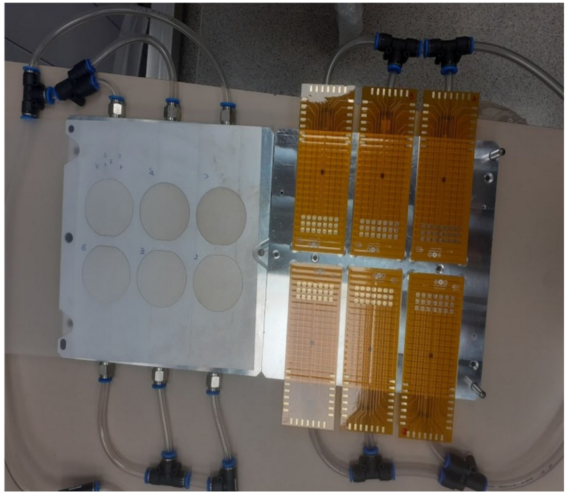
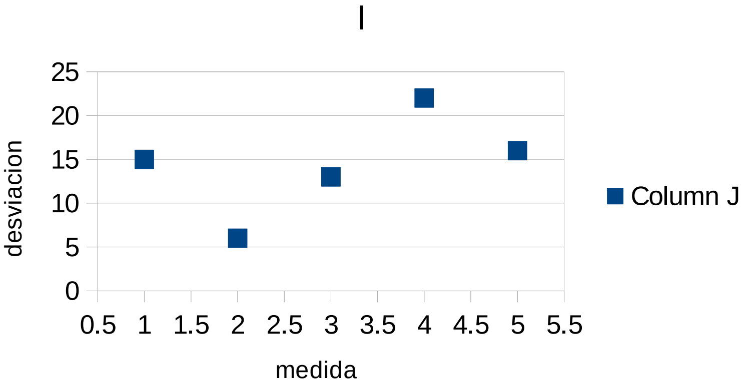
▷ **Several "manual" tests during 2023**

- Learning curve for epoxy / robot usage
- Learning curve for mechanic tooling design / construction / usage

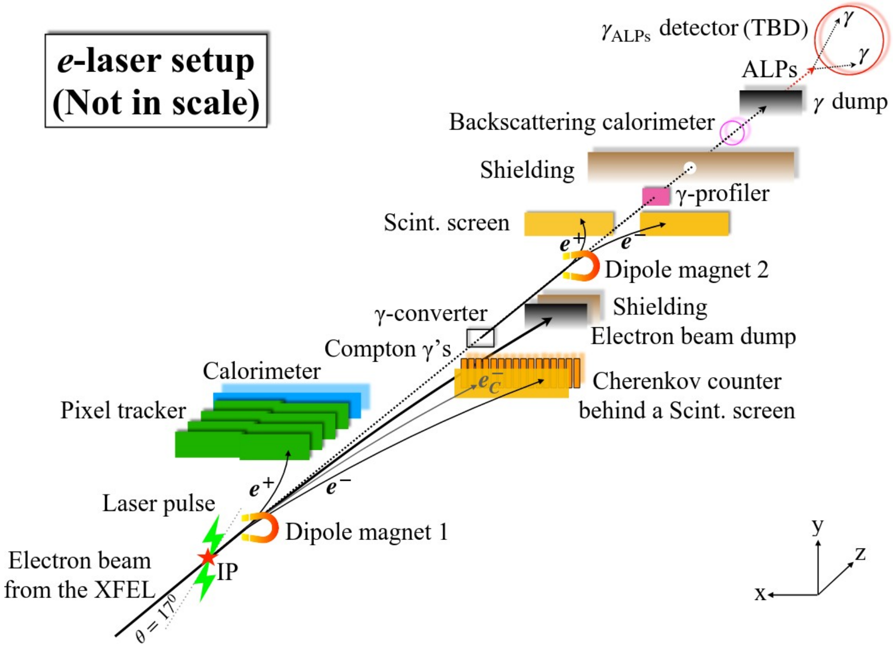


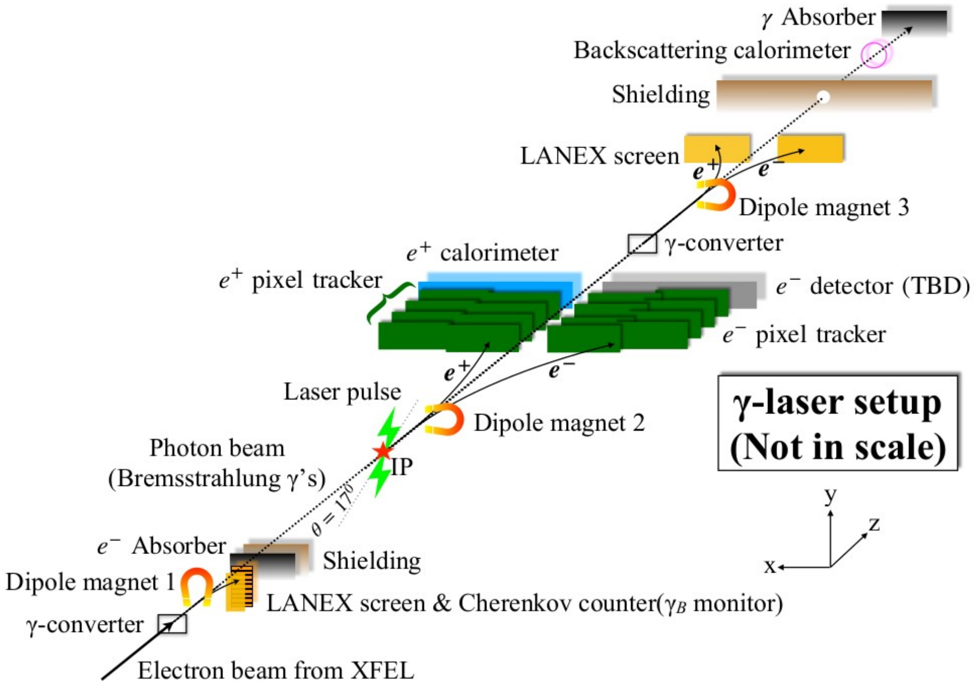


	I
1	15
2	6
3	13
4	22
5	16
av	*14.4*
stdev	**5.8**



Operation modes





SFQED at LUXE

Charge field coupling → work done by the EM field over electron Compton wavelenght in units of EM field

~ number of laser photons interacting with the electron beam at a given time

Laser photon density ~ ξ^2

	Theory Parameter	Definition	Range accessed in LUXE phase-0	phase-1
ξ	Classical non-linearity parameter	$\xi = \frac{m_e}{\omega_L}\frac{\mathcal{E}_L}{\mathcal{E}_{cr}}$	≤ 6	≤ 19
η_i	Energy parameter	$\eta_i = \frac{\omega_L \varepsilon_i}{m_e^2}(1+\beta\cos\theta)$	$\eta_i \leq 0.2$	
χ_i	Quantum non-linearity parameter	$\chi_i = \frac{\varepsilon_i}{m_e}\frac{\mathcal{E}_L}{\mathcal{E}_{cr}}(1+\beta\cos\theta)$	≤ 1	≤ 3

How much the QED deviates from the classical limit

non-linear Compton Scattering

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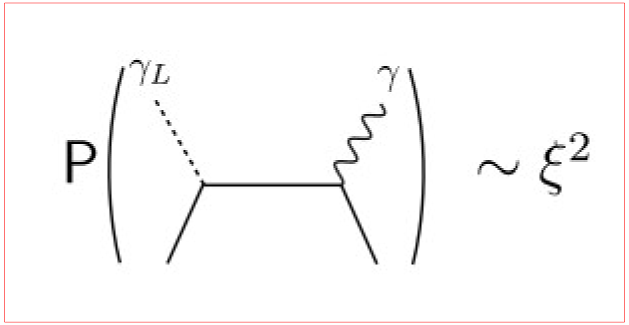

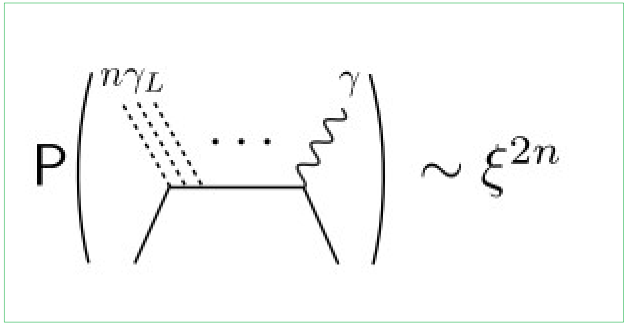

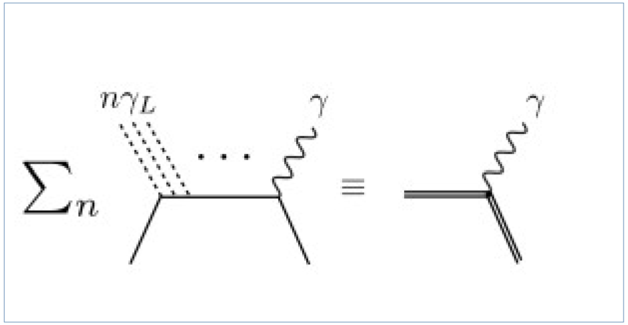

$\xi < 1$

The probability to produce one Compton photon is proportional to the laser photon density

Still the electron can collide with n laser photons (non-linear compton).
The process is still perturbative if **$\xi < 1$**

$\xi > 1$
There are no more leading order processes and we are require to resum all higher order contributions in ξ

The non-perturbative resulting expression can be expressed as an effective larger electron mass:

$$m_e(eff) = m_e\sqrt{1+\xi^2}$$

non-linear Compton Scattering

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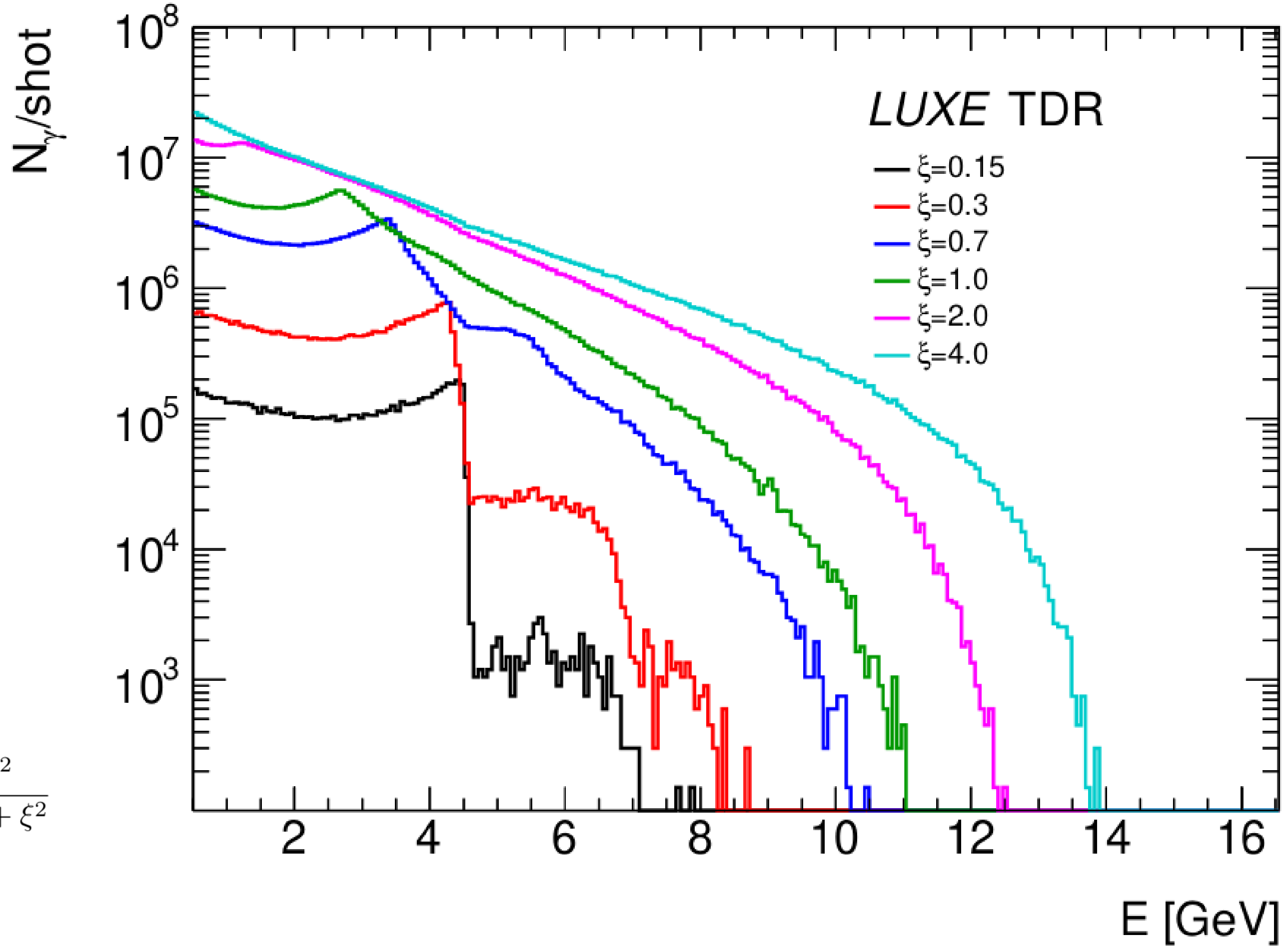
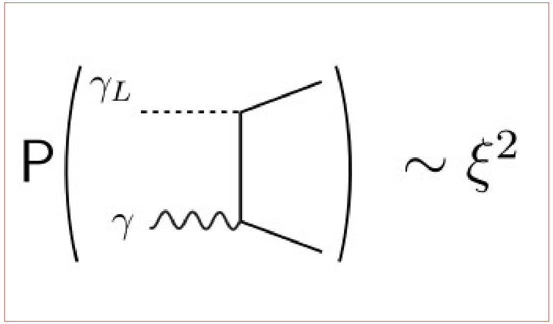
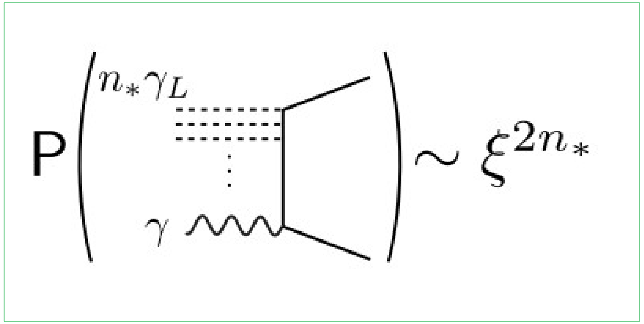
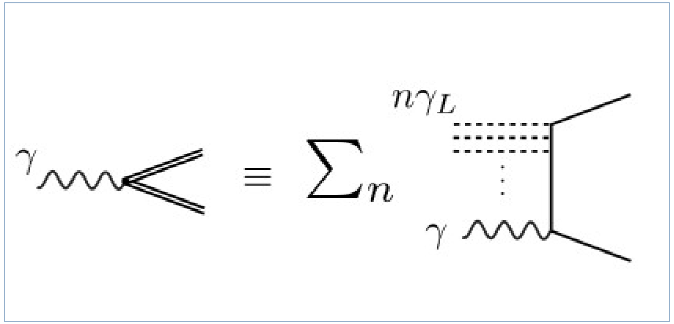


$$E^{e}_{edge}(\xi) = E_e \frac{1+\xi^2}{2\eta + 1 + \xi^2}$$

non-linear Breit-Wheeler







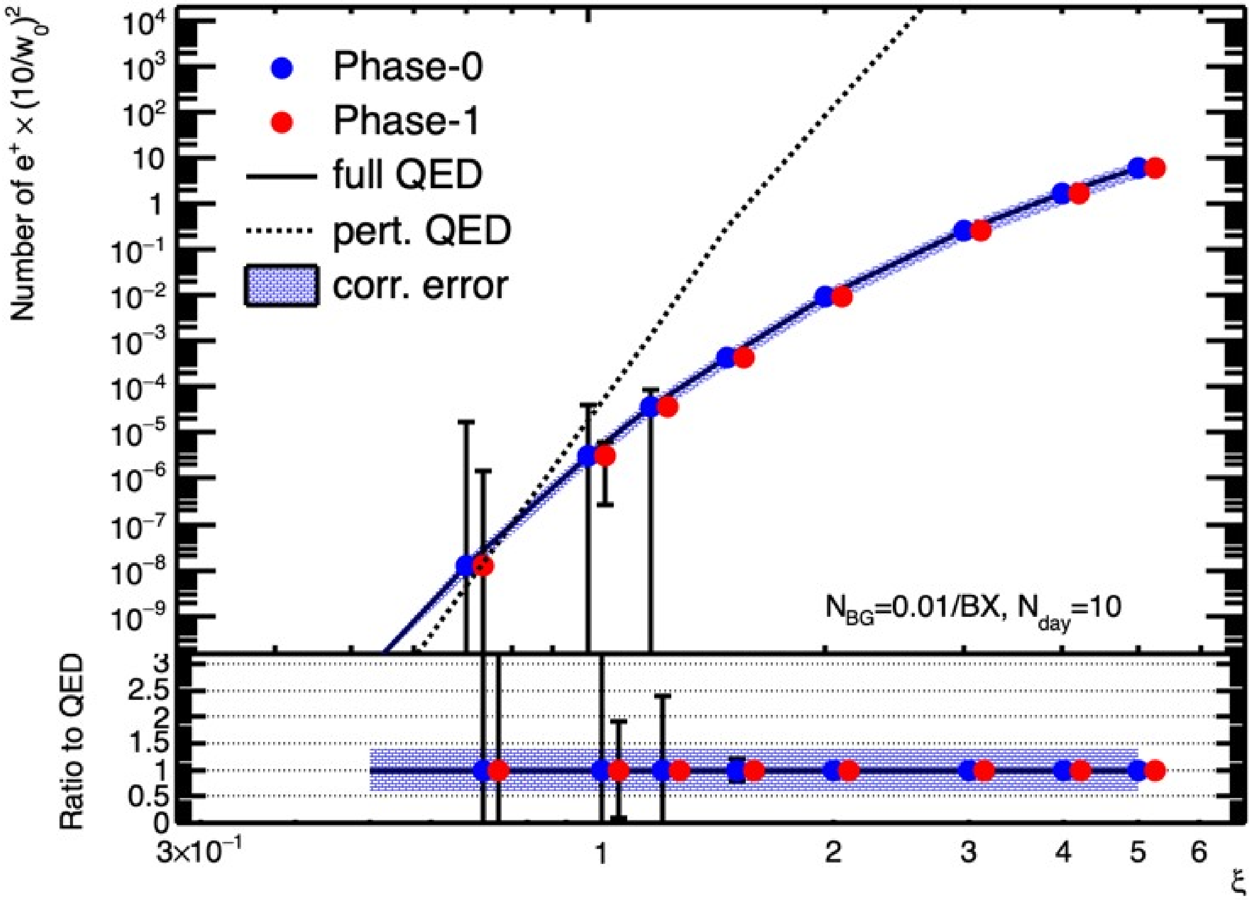
ξ< 1

One photon colliding with one laser photon (linear)

Still the photon can collide with n* laser photons (non-linear BW).
The process is still perturbative if **ξ< 1**

ξ> 1
Sum of all orders of **ξ** resulting in a non-linear non-perturbative BW process

non-linear Breit-Wheeler



Electron side (electron-laser mode)

▷ Very large rates of electrons (10^9)

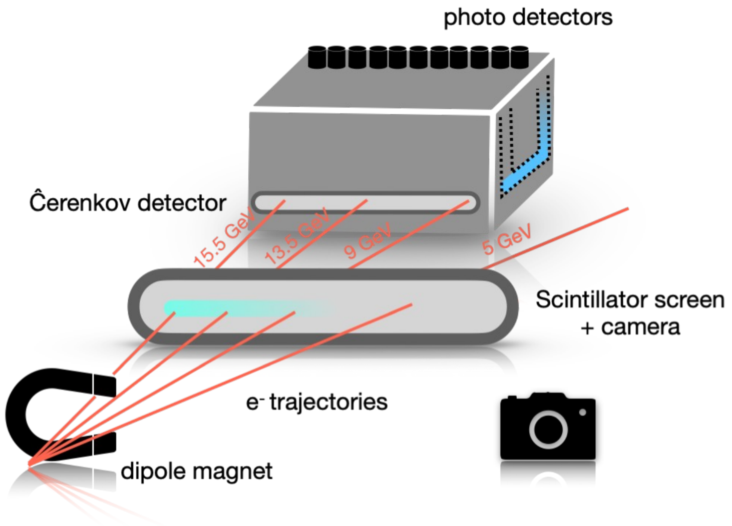
- Measurement of the non linear Compton spectrum

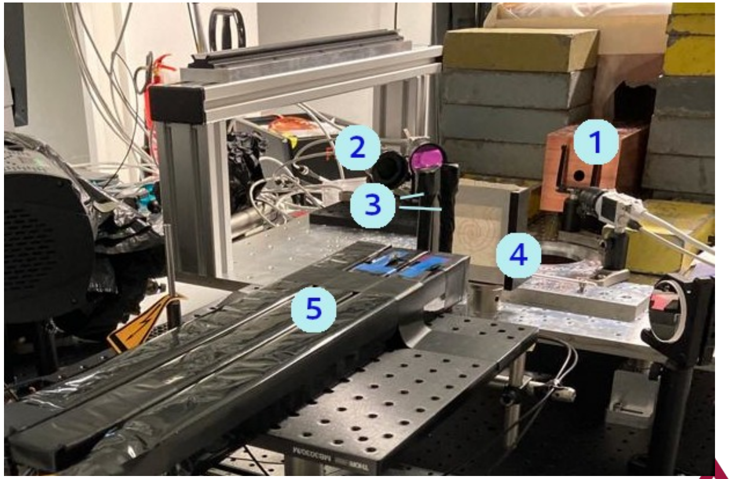
▷ **Scintillator screen**

- Used by the AWAKE collaboration at CERN
- Camera takes pictures of the scintillation light. Resolution ~ 500 µm.
- Signal/Background ~100 & Radiation hard (100 MGy)

▷ **Cherenkov gas detector**

- Ar gas developed for ILC polarimeter
- Low refractive index gas helps to reduce light yield (Cherenkov threshold 20 MeV)
- Signal/background>1000





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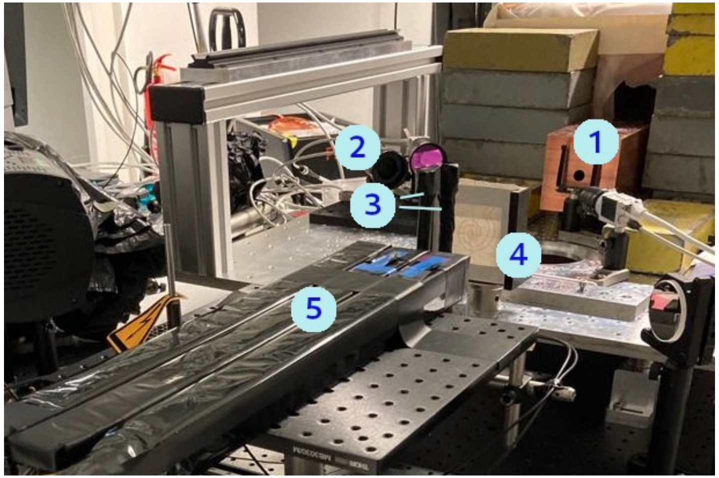

LUXE detectors test beam setup photo.
1 - collimator, 2 - cameras, 3 - Cherenkov detector
straws, 4 - scintillator screen, 5 - lead glass

LUXE in SFQED parameter space

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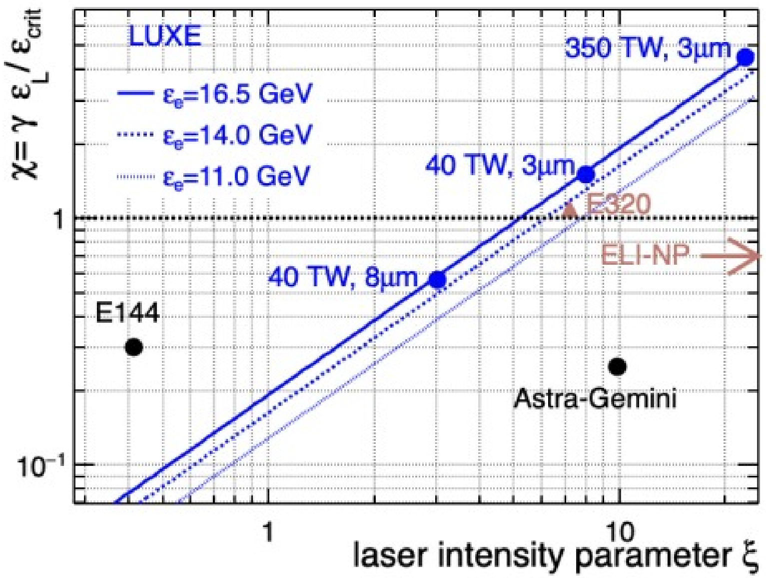

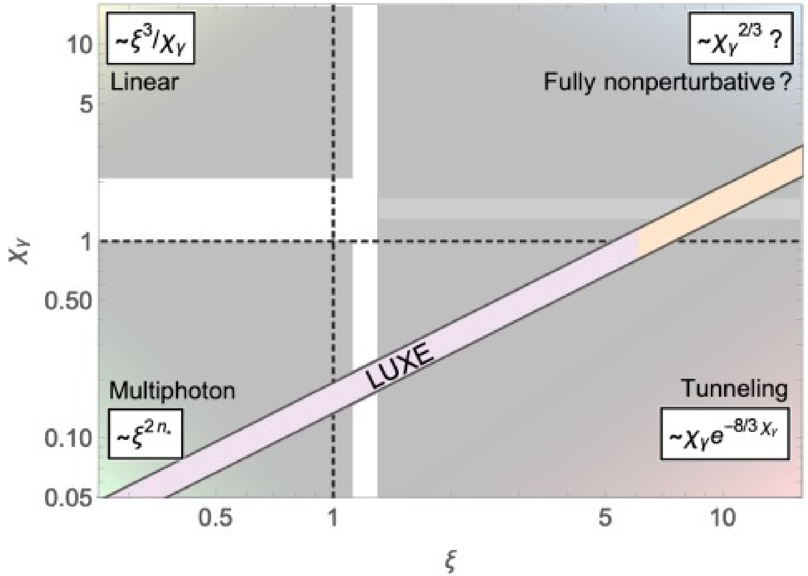

- E144: SLAC experiment in 1990's, using 46.6 GeV electron beam *[Bamber et al. (SLAC 144) '99]*
  → reached χ ≤ 0.25, ξ<0.4, observed $e^- + n\gamma_L \rightarrow e^-e^+e^-$ process
  → observed start of the ξ^{2n} power law

- LUXE: - good chance to be first to enter ξ>1 and χ>1 regime!
  - directly study collisions between LASER and real GeV photons

Irles A., 1st Feb 2024

LUXE and LHC light-by-light scattering

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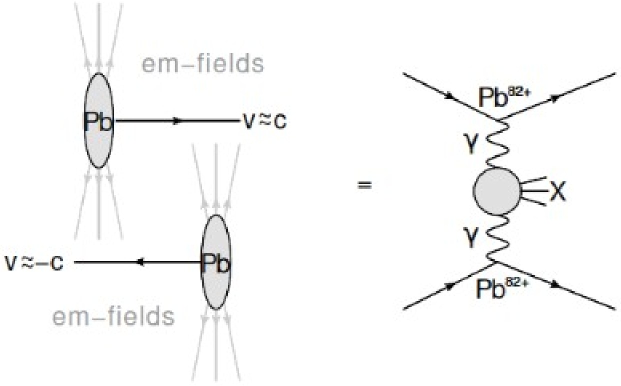
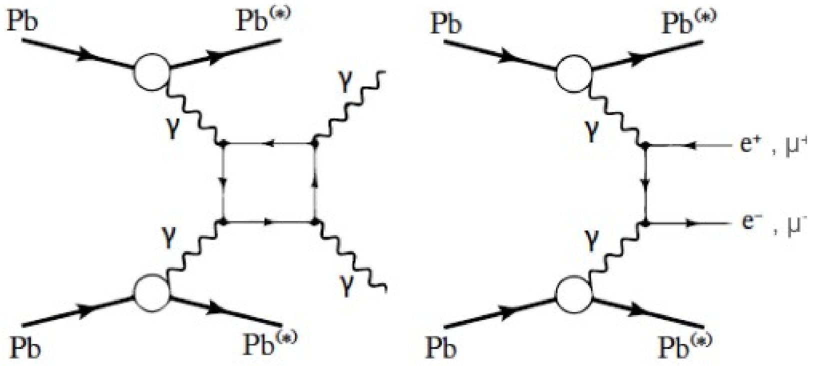
- ▷ LHC: photon-photon interaction in ultra-perophERIAL heavy-ion collissions (UPC)
- ▷ UPD: fields above the Schwinger limit can be reached in the lab
  - Main difference to LUXE: in UPC, EM fiel is extremely short-lived (not travelling macroscopics distances)
  - This regime is still covered by linear perturbative QED



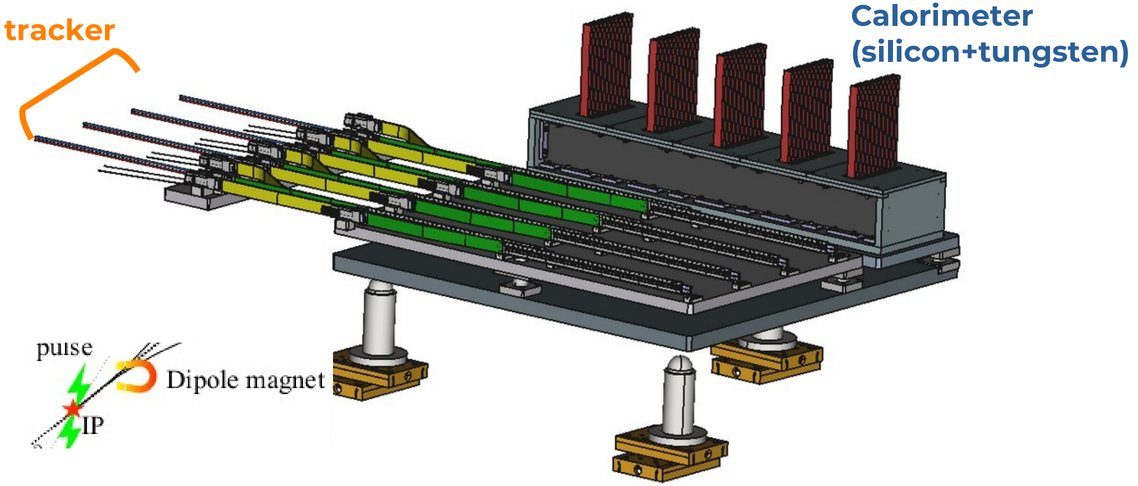


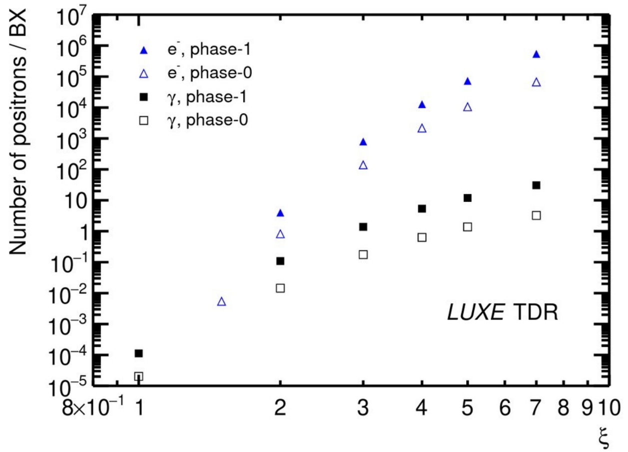
Figures from: arXiv:2010.07855v3
(Also a nice review to read, if you want to know more!)

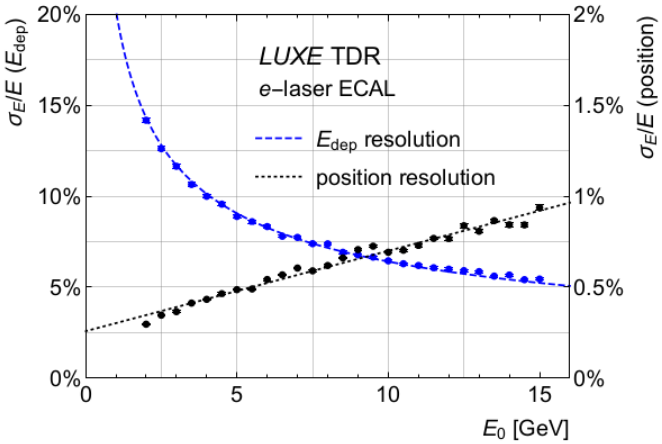
DESY. 13

Slide from R. Jacobs

Positron detector system: ECAL-p







- ▷Correlation between tracker and calorimeter information
- ▷The High granularity and **extreme compactness** of the calorimeter allows for a precise energy and position measurement
- ▷For the high positron afluence scenarios → the showers start to overlap
  - Energy Flow algorithm to estimate the total energy and the number of positrons.