



UNIVERSITÉ
DE GENÈVE

FACULTÉ DES SCIENCES
Département de physique
nucléaire et corpusculaire



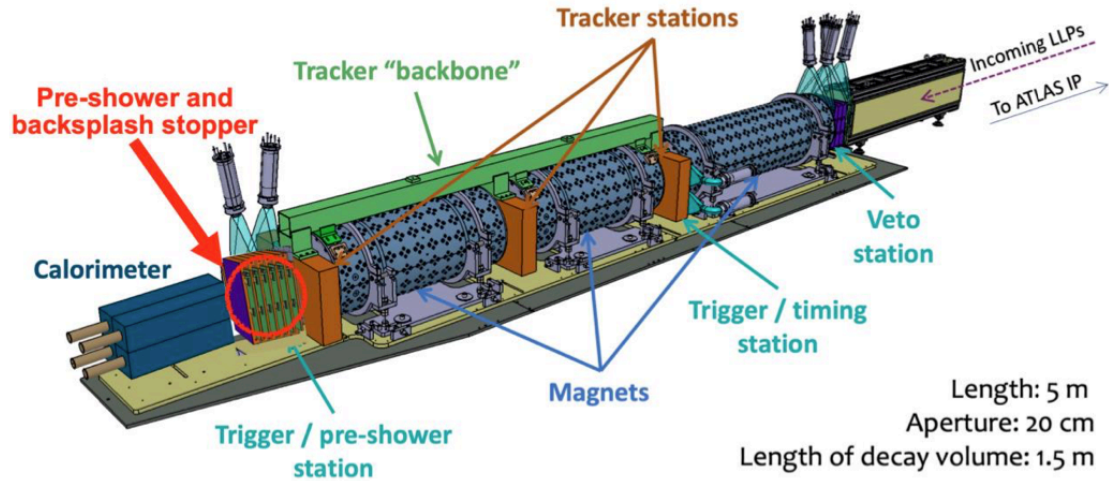
An Upgraded Preshower Detector for the FASER Experiment at the LHC

CHIARA MAGLIOCCA

on behalf of the FASER Preshower Upgrade team

Young Researchers' Day | 16.09.2022

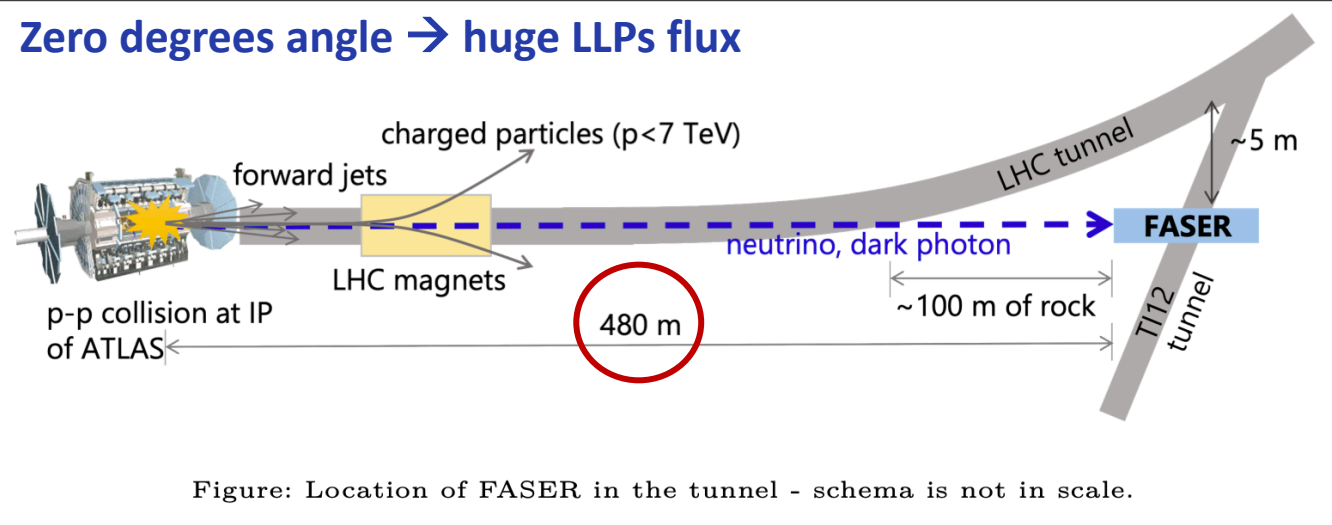
The FASER Experiment at LHC



- Fluxes of high-energy SM particles are suppressed
- Muons and neutrinos only exception
- FASER can probe **Axion-Like-Particles** (ALPs) model

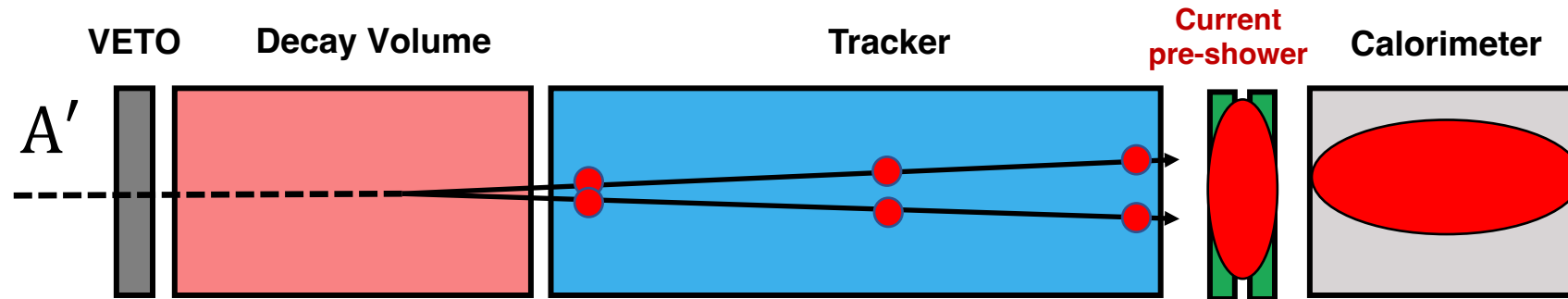
- **ForwArd Search ExpeRiment**
- Designed to search for **light and weakly-interacting particles** + study the **interactions of high-energy neutrinos** (FaserNu)

Zero degrees angle → huge LLPs flux

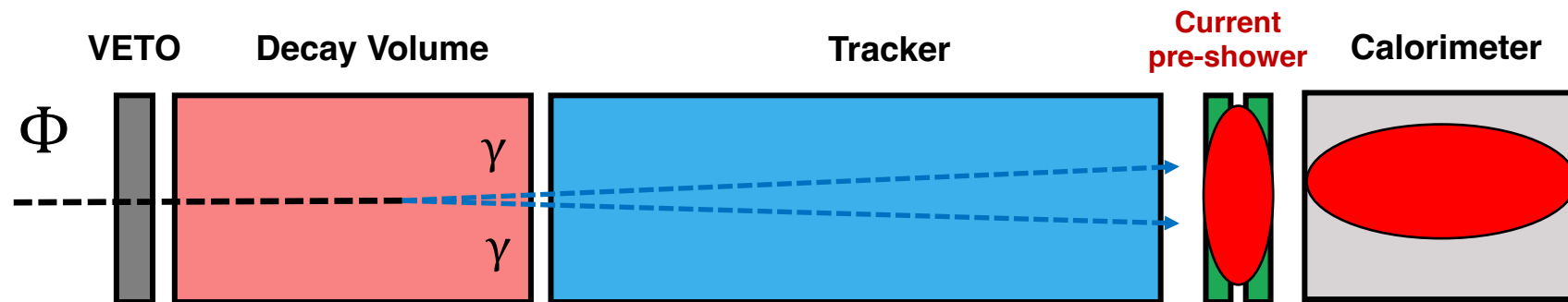


What Are We Able to Detect Well: Two Fermion Signal

Two Fermion signal

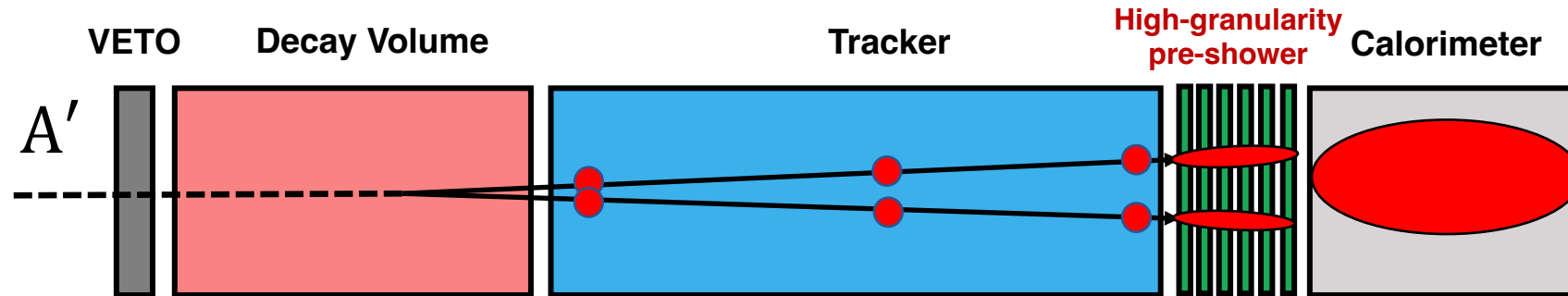


Two Photon signal

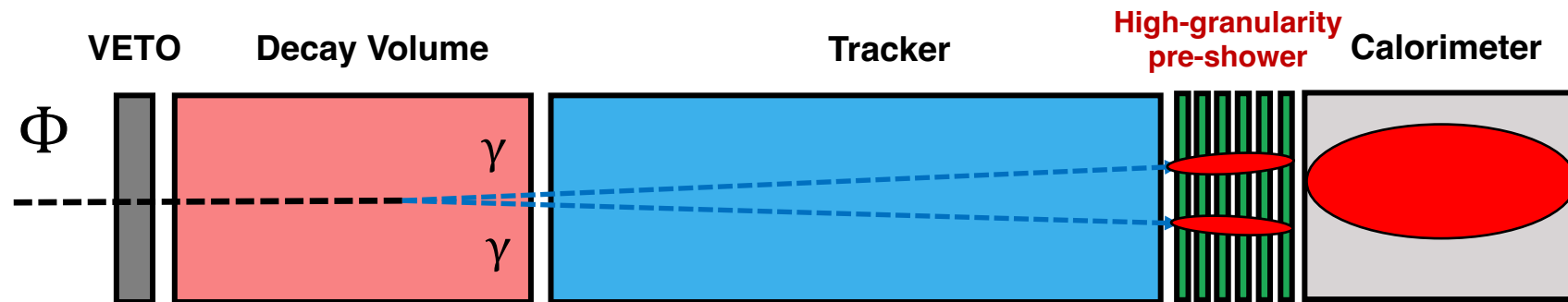


What Are We Willing to Detect: Two Photon Signal

Two Fermion signal



Two Photon signal

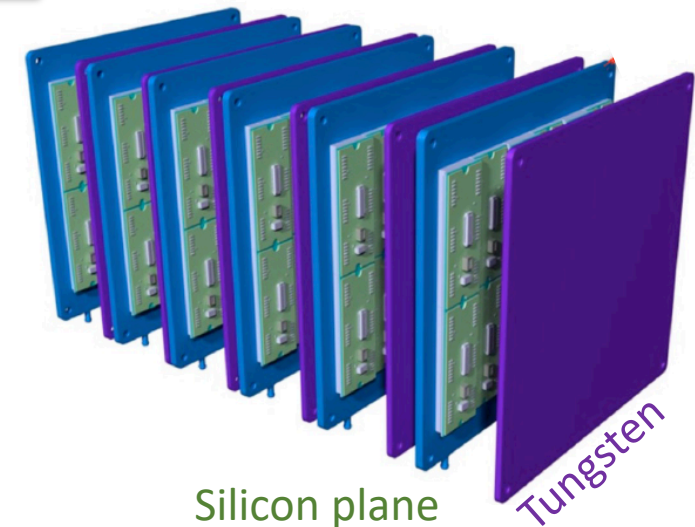
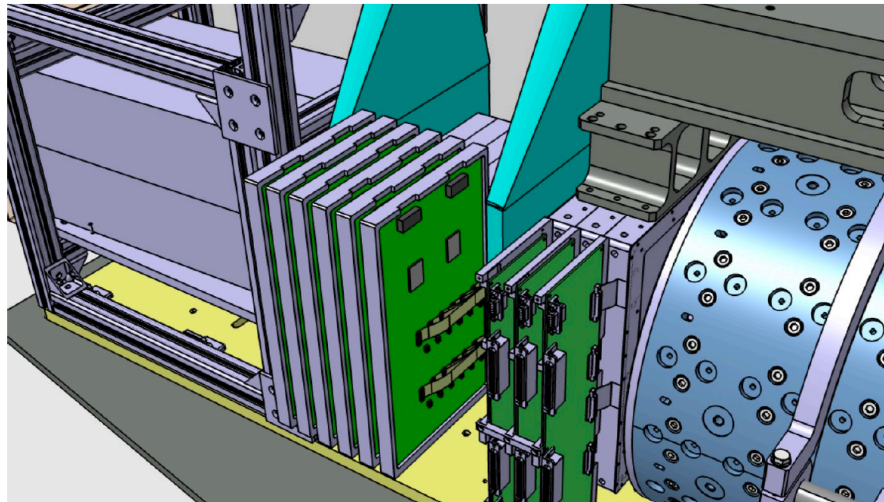
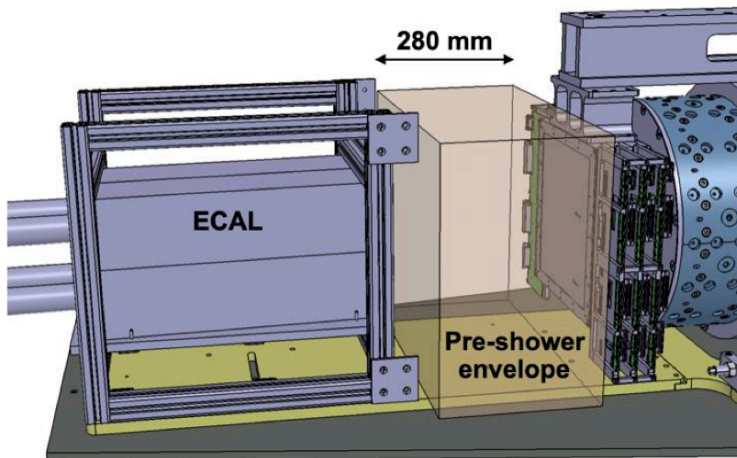


Preshower Detector Upgrade

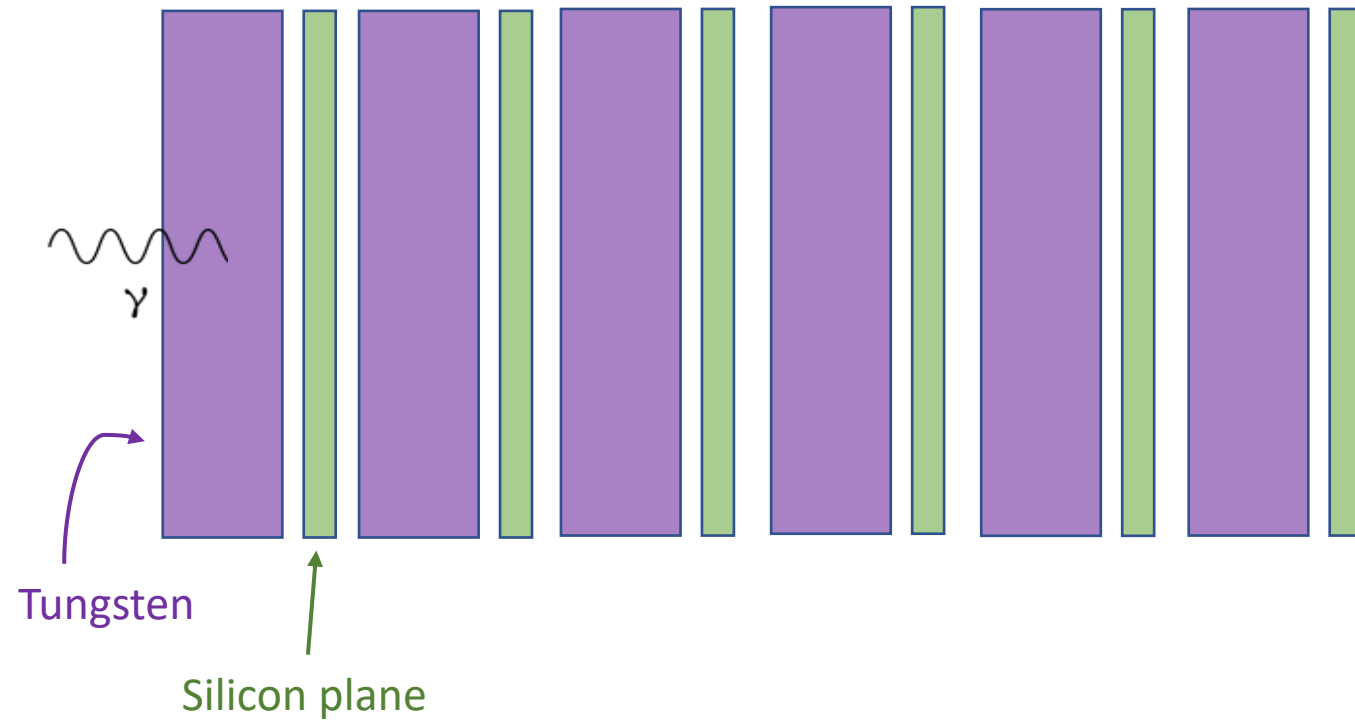
- 6 detector planes
- Each detector plane: **1 X0 of tungsten** + plane of **monolithic Si-pixel sensors**

H. Abreu et al. "The FASER W-Si High Precision Preshower Technical Proposal"
CERN-LHCC-2022-006 ; LHCC-P-023
<https://cds.cern.ch/record/2803084>

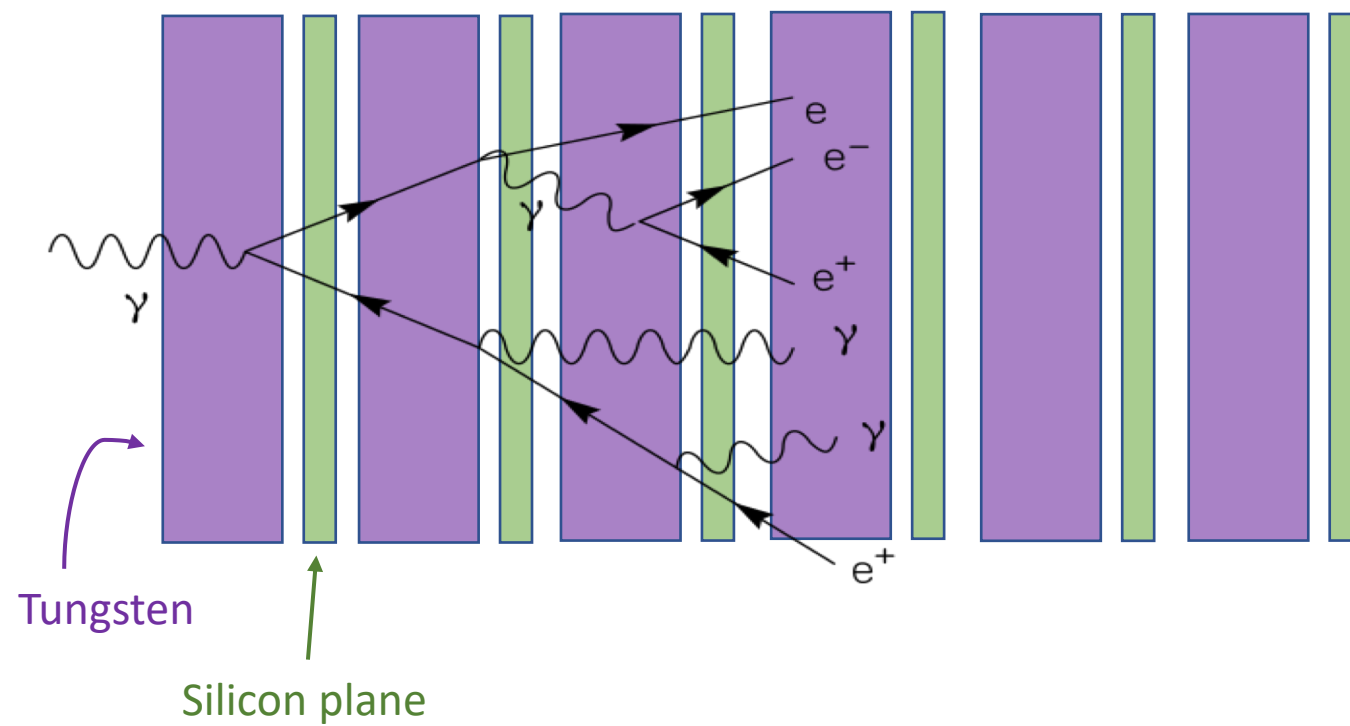
Independent measurement of two very collimated photons at TeV energy scale



Why 6 Layers?

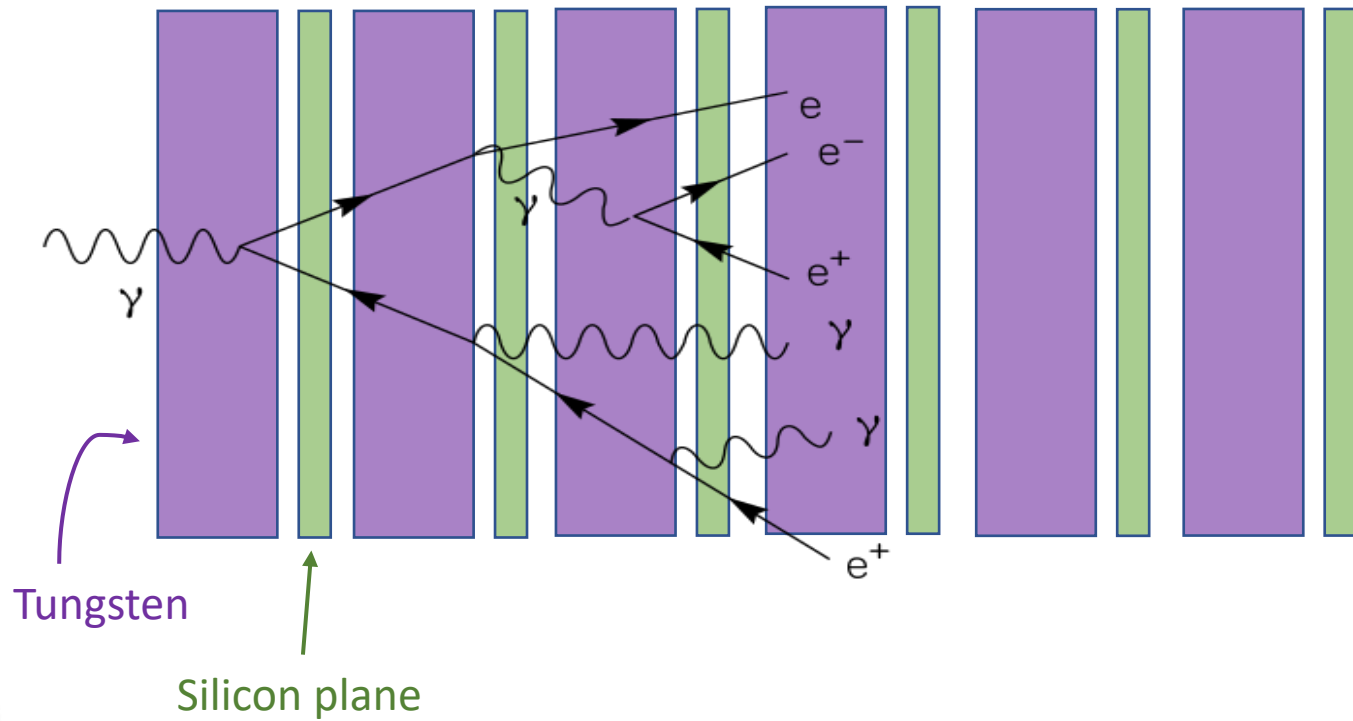


Why 6 Layers?



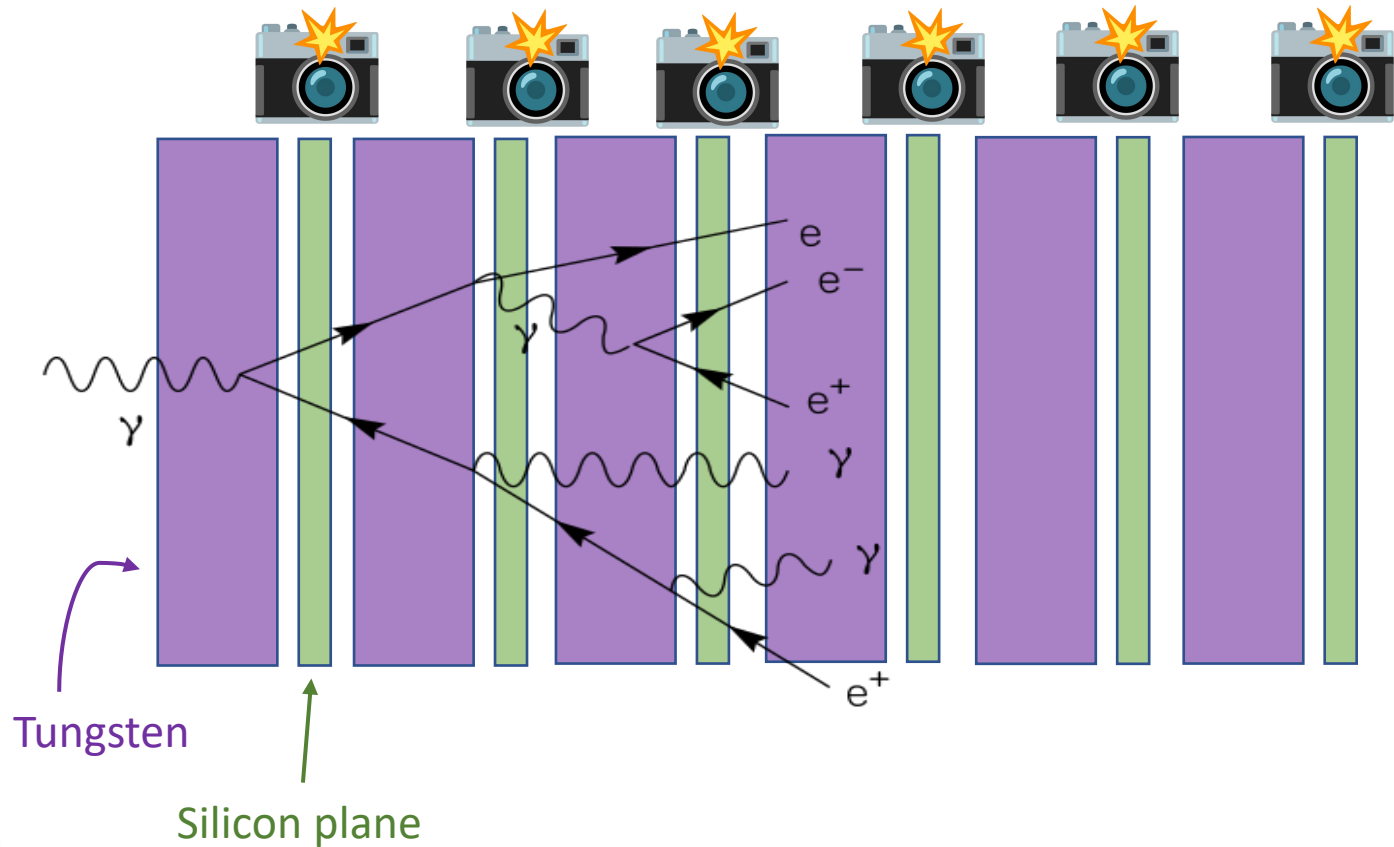
Why 6 Layers?

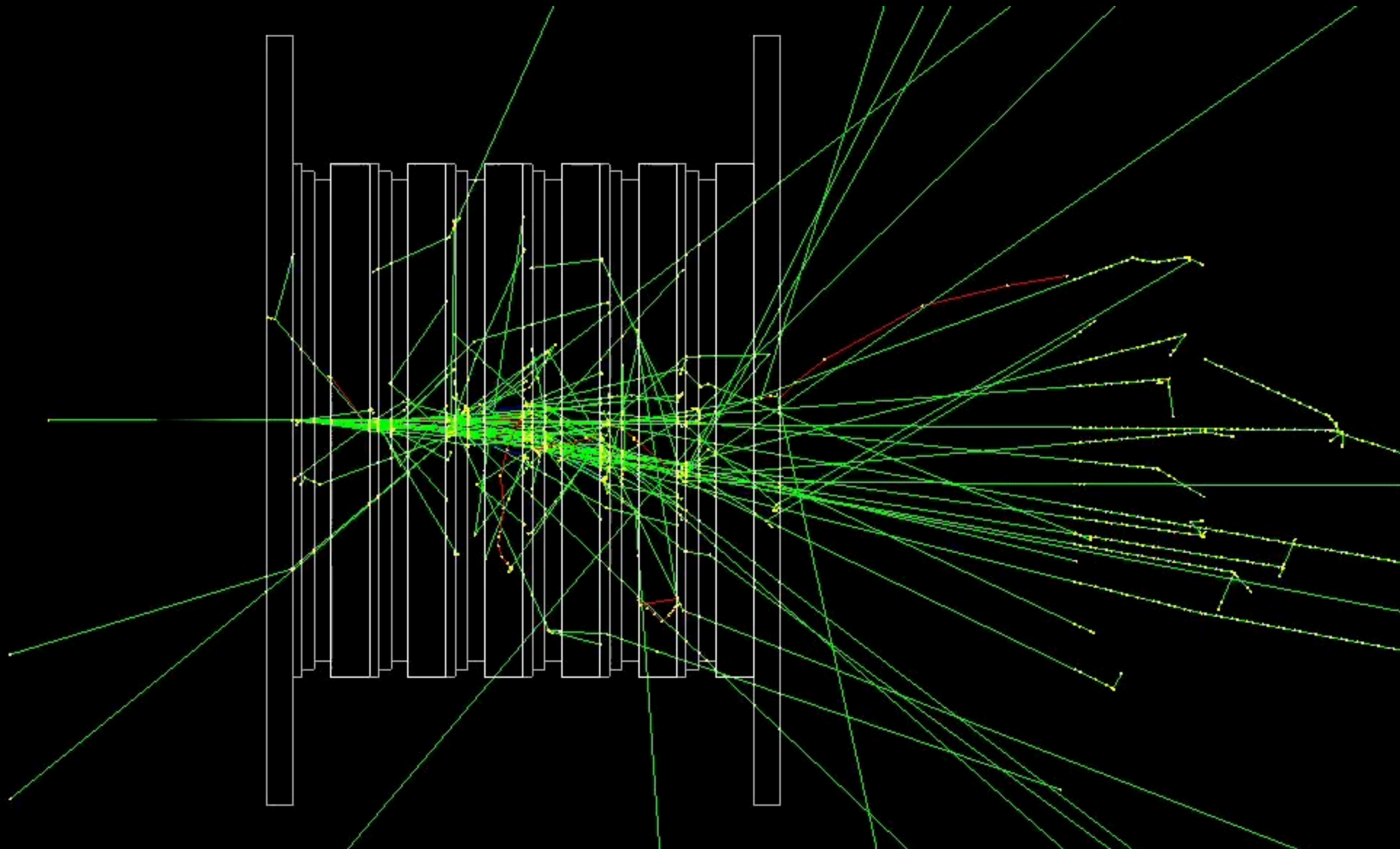
(Very)
Young Researcher



Why 6 Layers?

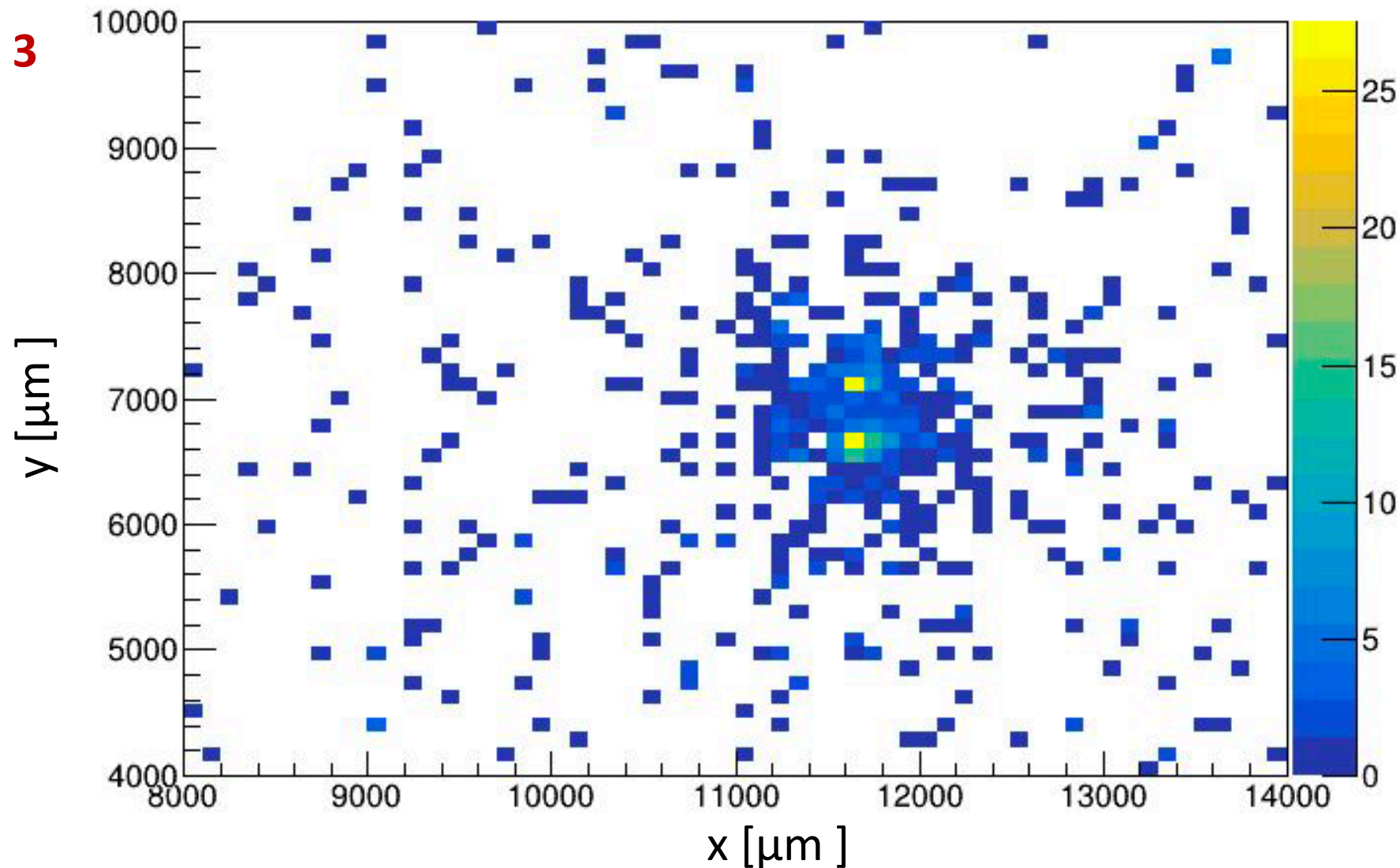
(Very)
Young Researcher





Electromagnetic Shower Development

PLANE 3



$$E_{\gamma 1} = 1 \text{ TeV}$$

$$E_{\gamma 2} = 1 \text{ TeV}$$

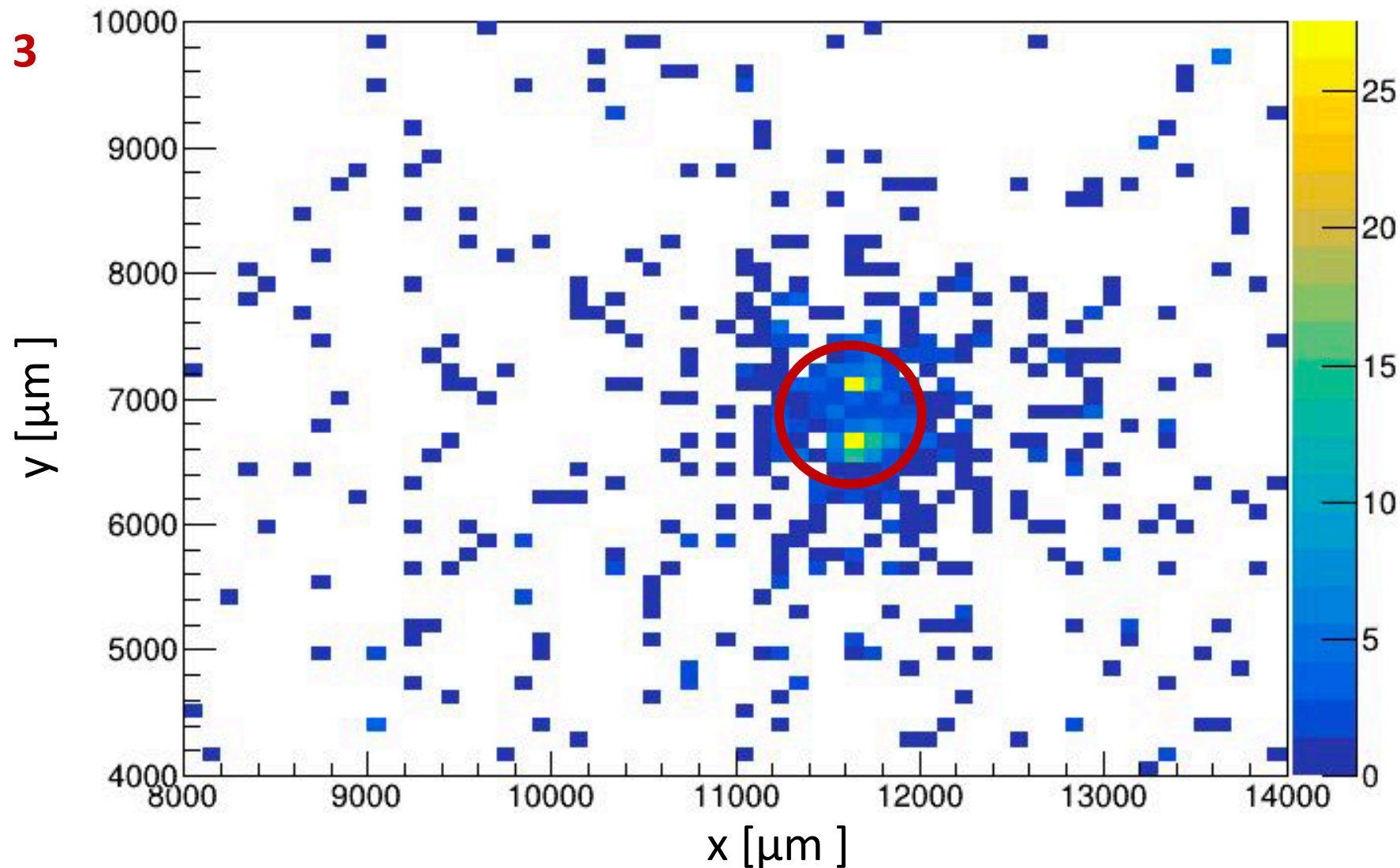
$$d(\gamma 1, \gamma 2) = 500 \mu\text{m}$$



Events simulated
using Allpixsquared

Electromagnetic Shower Development

PLANE 3



$$E_{\gamma 1} = 1 \text{ TeV}$$

$$E_{\gamma 2} = 1 \text{ TeV}$$

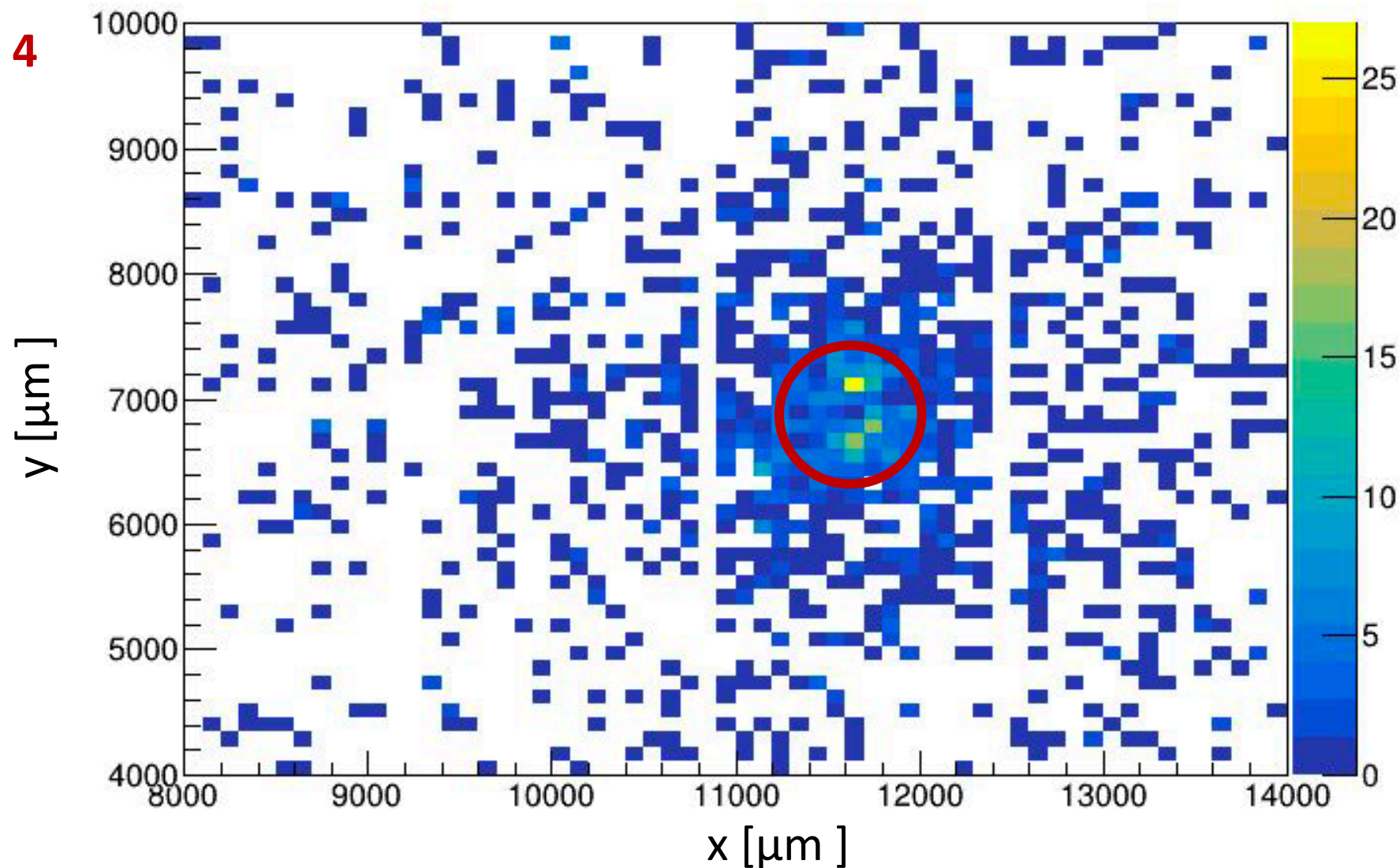
$$d(\gamma 1, \gamma 2) = 500 \text{ } \mu\text{m}$$



Events simulated
using Allpixsquared

Electromagnetic Shower Development

PLANE 4



$$E_{\gamma 1} = 1 \text{ TeV}$$

$$E_{\gamma 2} = 1 \text{ TeV}$$

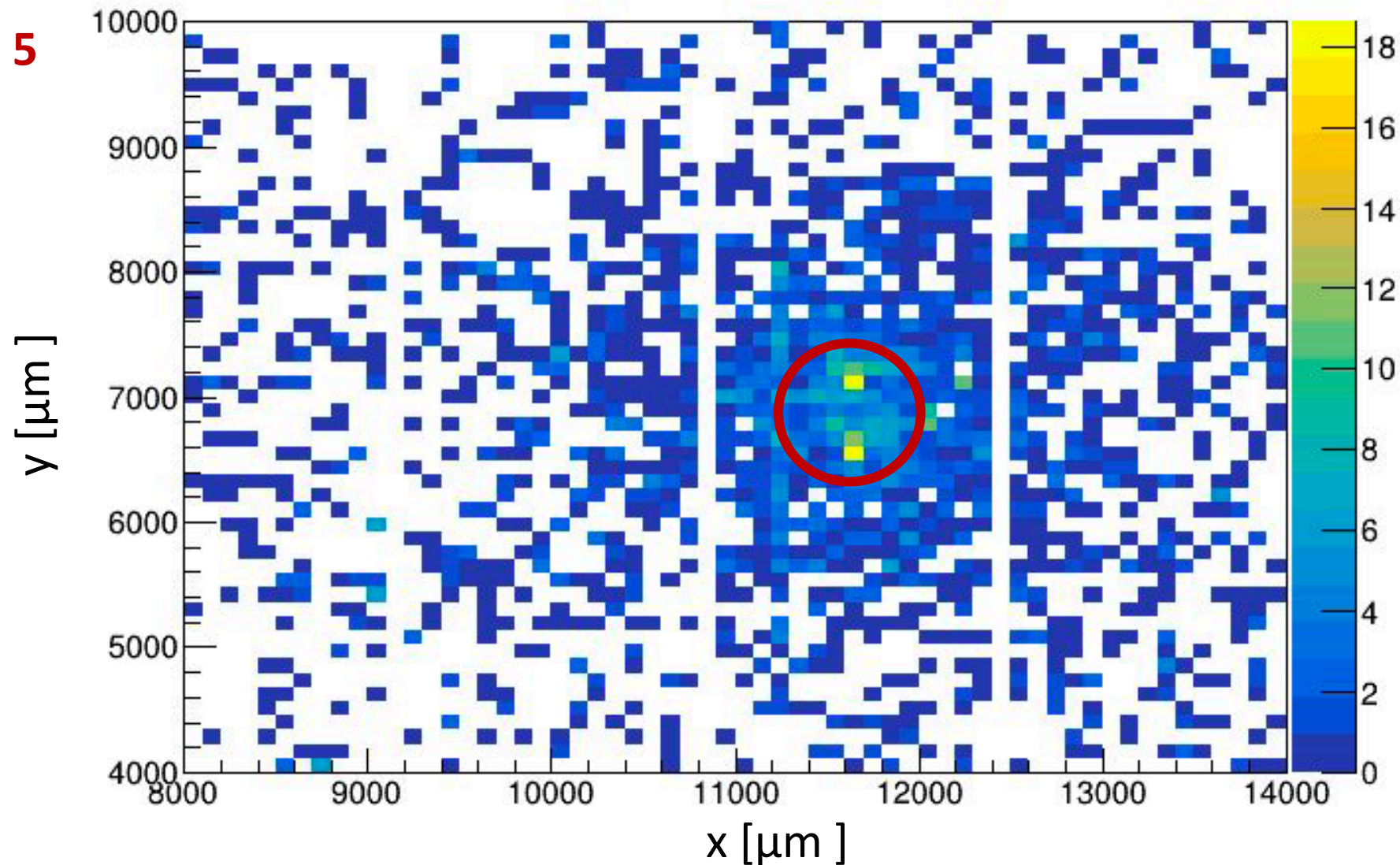
$$d(\gamma 1, \gamma 2) = 500 \text{ } \mu\text{m}$$



Events simulated
using Allpixsquared

Electromagnetic Shower Development

PLANE 5



$$E_{\gamma 1} = 1 \text{ TeV}$$

$$E_{\gamma 2} = 1 \text{ TeV}$$

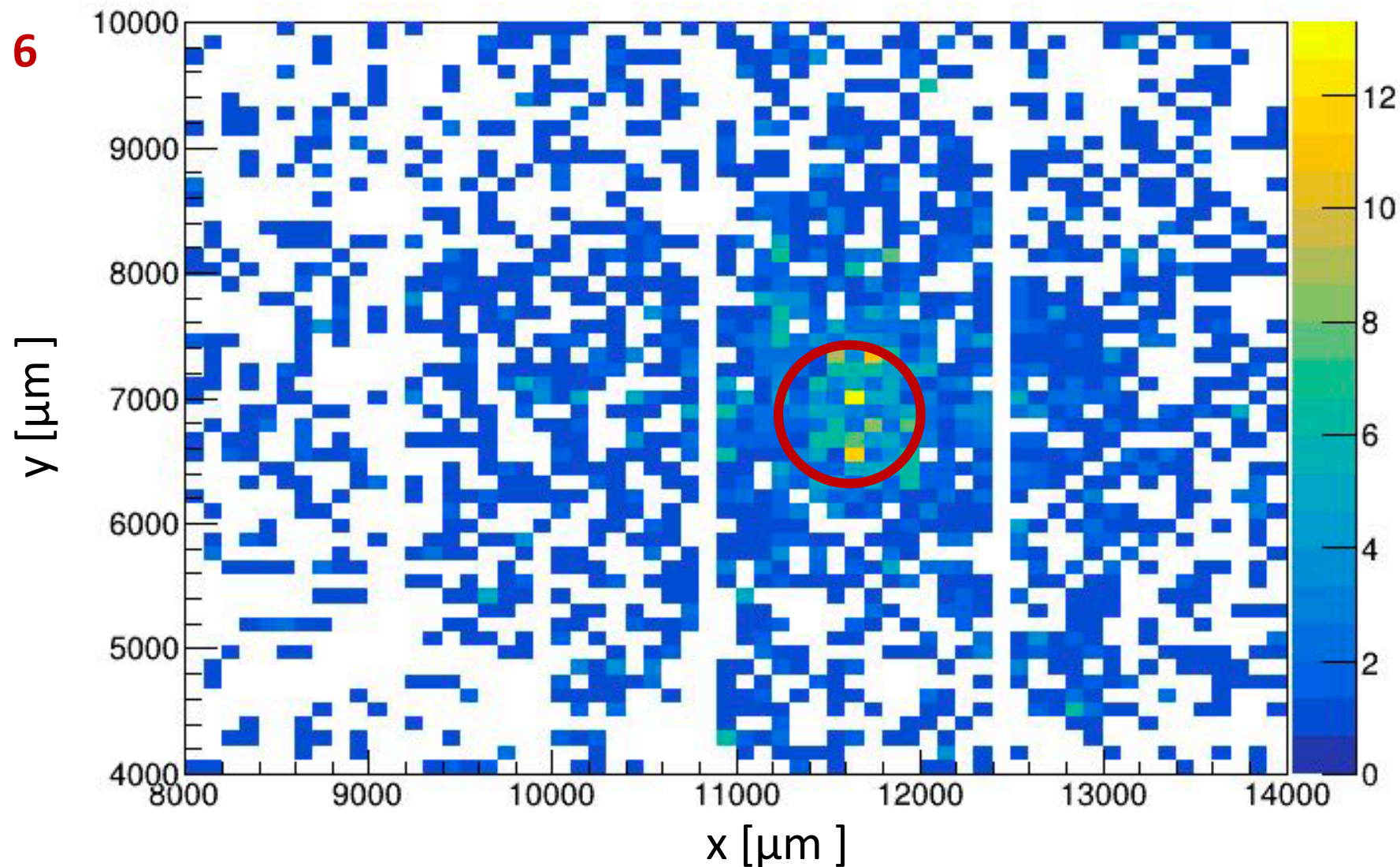
$$d(\gamma 1, \gamma 2) = 500 \mu\text{m}$$



Events simulated
using Allpixsquared

Electromagnetic Shower Development

PLANE 6



$$E_{\gamma 1} = 1 \text{ TeV}$$

$$E_{\gamma 2} = 1 \text{ TeV}$$

$$d(\gamma 1, \gamma 2) = 500 \text{ } \mu\text{m}$$



Events simulated
using Allpixsquared

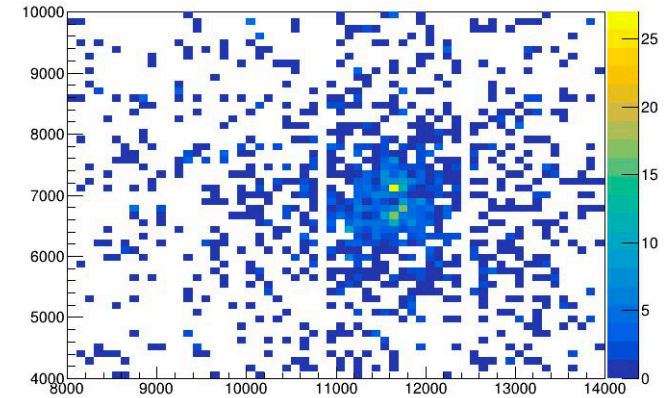
On-going Activities at the DPNC

Simulations and Event Reconstruction

**PRESHOWER
UPGRADE**

Team:

Giuseppe Iacobucci
Anna Sfyrta
Stefano Zambito
Jorge Sabater
Chiara Magliocca
Théo Moretti
Rafaella Eleni Kotitsa
Noshin Tarannum

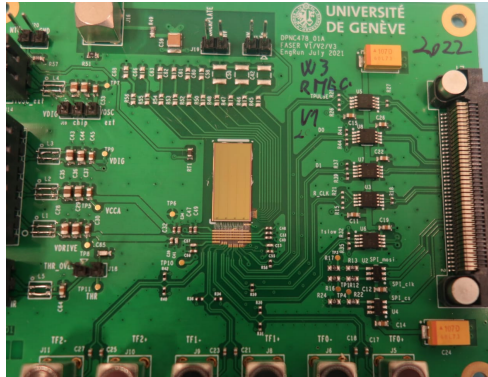


On-going Activities at the DPNC

ASIC and PCB Design

Team:

Giuseppe Iacobucci
Lorenzo Paolozzi
Roberto Cardella
Fulvio Martinelli
Pierpaolo Valerio

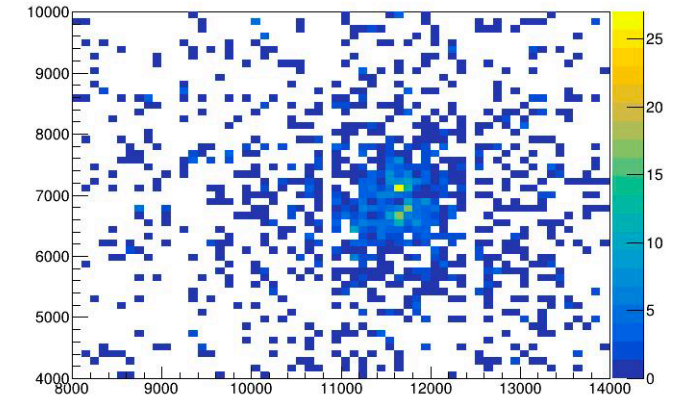


PRESHOWER UPGRADE

Simulations and Event Reconstruction

Team:

Giuseppe Iacobucci
Anna Sfyrla
Stefano Zambito
Jorge Sabater
Chiara Magliocca
Théo Moretti
Rafaella Eleni Kotitsa
Noshin Tarannum

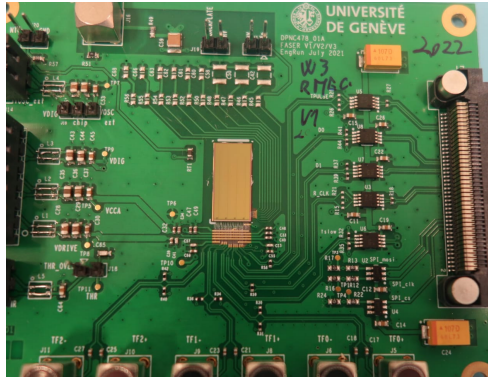


On-going Activities at the DPNC

ASIC and PCB Design

Team:

Giuseppe Iacobucci
Lorenzo Paolozzi
Roberto Cardella
Fulvio Martinelli
Pierpaolo Valerio



PRESHOWER UPGRADE

Lab Tests and Firmware Development

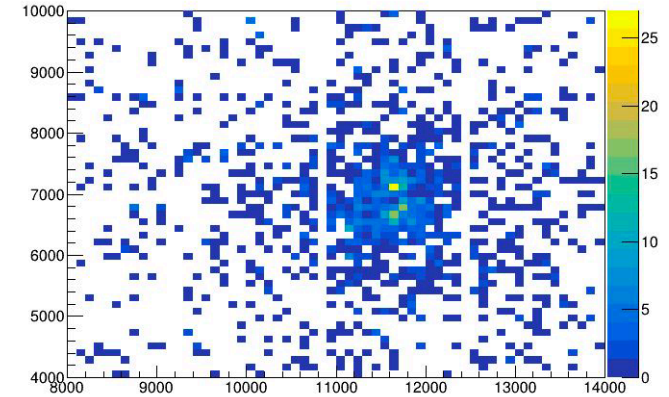
Team:

Lorenzo Paolozzi	Chiara Magliocca
Stefano Zambito	Théo Moretti
Fulvio Martinelli	Rafaella Eleni Kotitsa
Carlo Alberto Fenoglio	Noshin Tarannum

Simulations and Event Reconstruction

Team:

Giuseppe Iacobucci
Anna Sfyrla
Stefano Zambito
Jorge Sabater
Chiara Magliocca
Théo Moretti
Rafaella Eleni Kotitsa
Noshin Tarannum

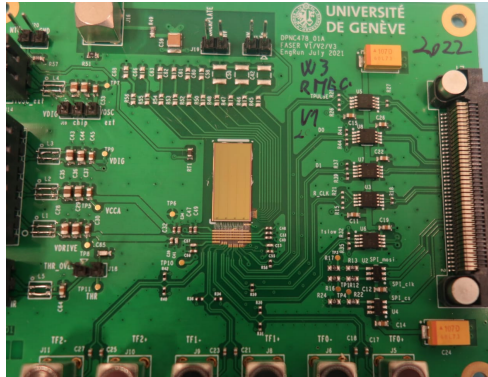


On-going Activities at the DPNC

ASIC and PCB Design

Team:

Giuseppe Iacobucci
Lorenzo Paolozzi
Roberto Cardella
Fulvio Martinelli
Pierpaolo Valerio

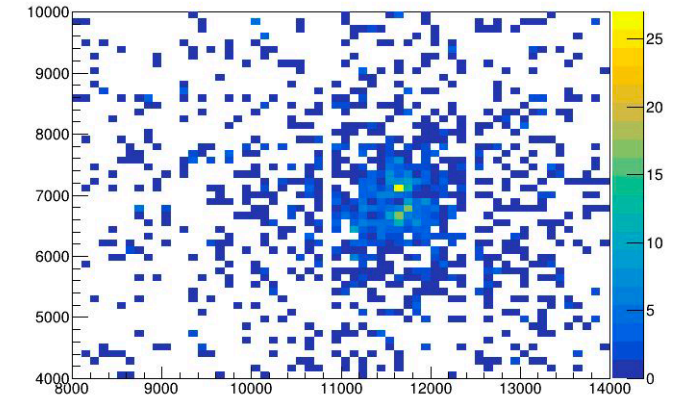


PRESHOWER UPGRADE

Simulations and Event Reconstruction

Team:

Giuseppe Iacobucci
Anna Sfyrla
Stefano Zambito
Jorge Sabater
Chiara Magliocca
Théo Moretti
Rafaella Eleni Kotitsa
Noshin Tarannum



Lab Tests and Firmware Development

Team:

Lorenzo Paolozzi	Chiara Magliocca
Stefano Zambito	Théo Moretti
Fulvio Martinelli	Rafaella Eleni Kotitsa
Carlo Alberto Fenoglio	Noshin Tarannum

Readout Specifications

Team:

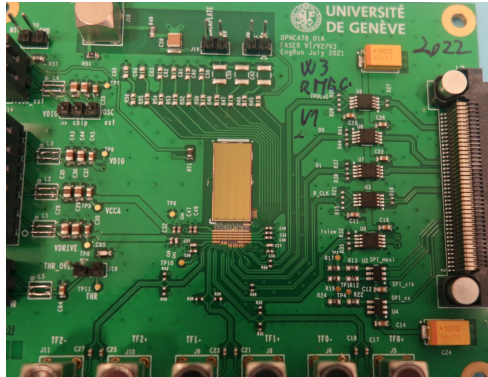
Giuseppe Iacobucci	Stéphane Debieux
Anna Sfyrla	Claire Antel
Yannick Favre	Lorenzo Paolozzi
Sergio Gonzalez	Dider Ferrère

On-going Activities at the DPNC

ASIC and PCB Design

Team:

Giuseppe Iacobucci
Lorenzo Paolozzi
Roberto Cardella
Fulvio Martinelli
Pierpaolo Valerio

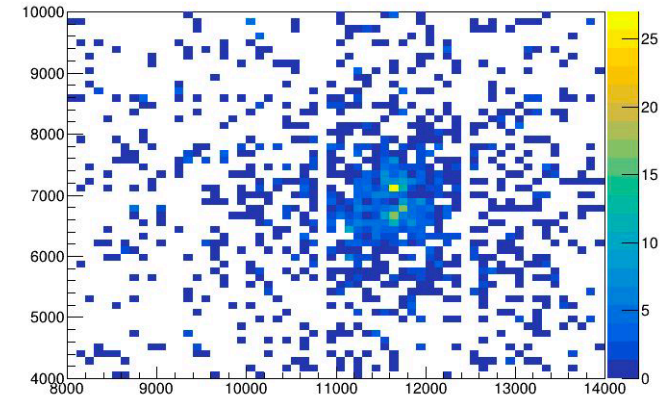


PRESHOWER UPGRADE

Simulations and Event Reconstruction

Team:

Giuseppe Iacobucci
Anna Sfyrla
Stefano Zambito
Jorge Sabater
Chiara Magliocca
Théo Moretti
Rafaella Eleni Kotitsa
Noshin Tarannum



Lab Tests and Firmware Development

Team:

Lorenzo Paolozzi	Chiara Magliocca
Stefano Zambito	Théo Moretti
Fulvio Martinelli	Rafaella Eleni Kotitsa
Carlo Alberto Fenoglio	Noshin Tarannum

Readout Specifications

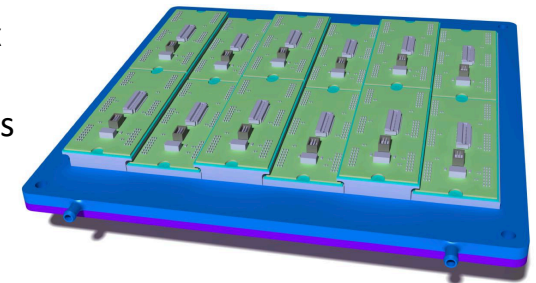
Team:

Giuseppe Iacobucci	Stéphane Debieux
Anna Sfyrla	Claire Antel
Yannick Favre	Lorenzo Paolozzi
Sergio Gonzalez	Dider Ferrère

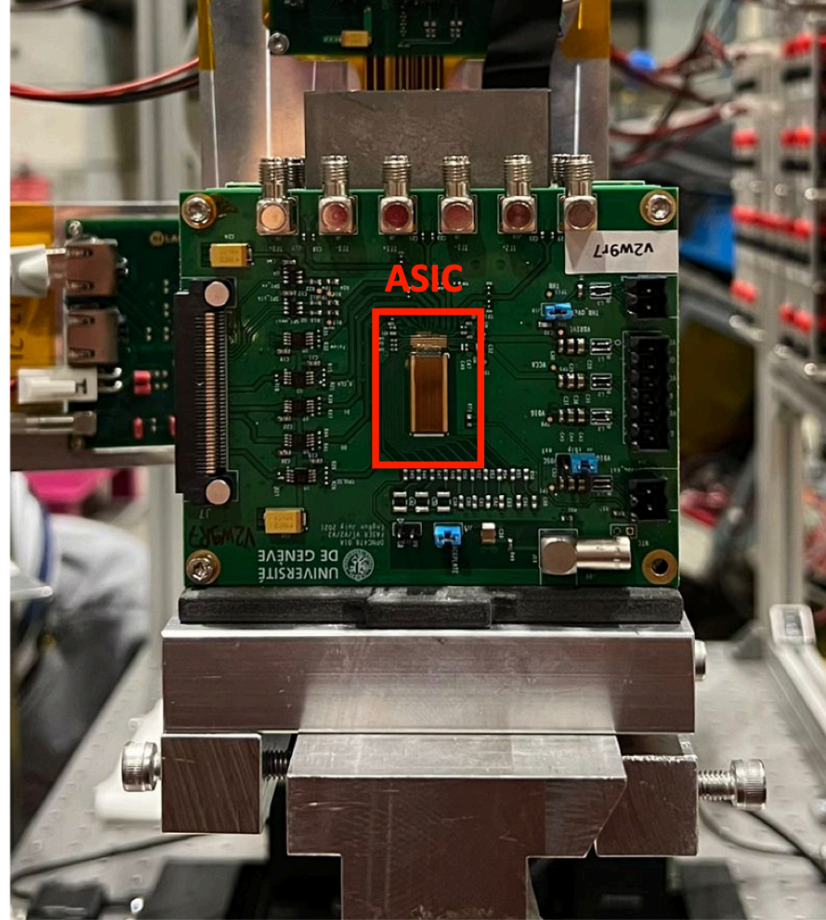
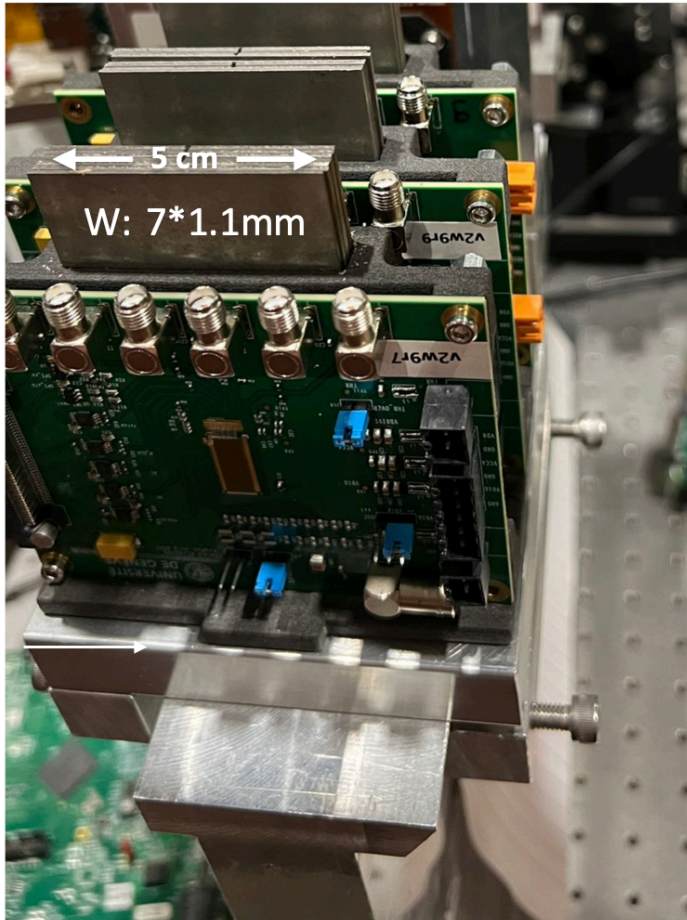
Mechanics

Team:

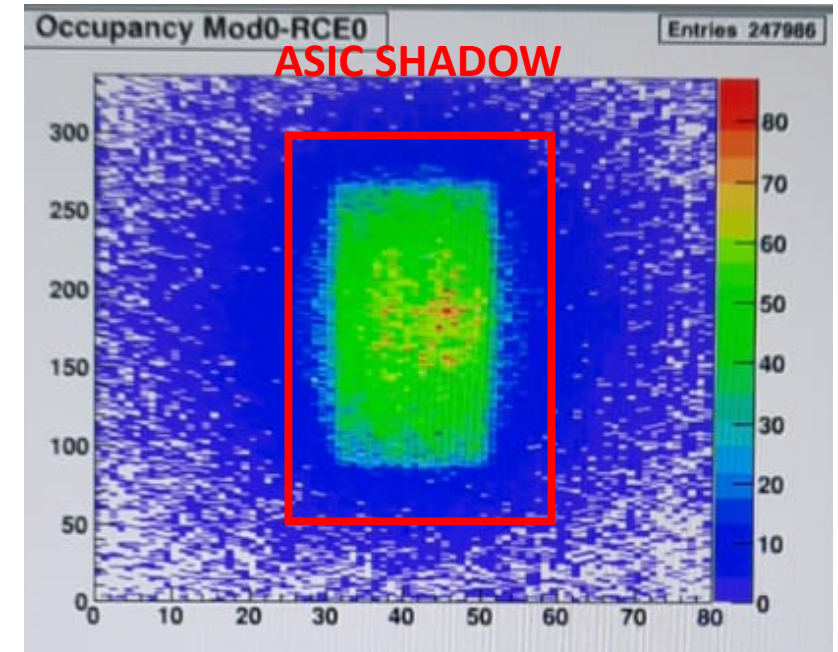
Franck Cadoux
Didier Ferrère
Laurent Nicolas



A Test Beam of the Preshower Just Ended



Electron beam with
energies from 20 GeV to
150 GeV





**UNIVERSITÉ
DE GENÈVE**

FACULTÉ DES SCIENCES
Département de physique
nucléaire et corpusculaire

Stick around for the POSTER SESSION



**Development and simulation of
a new preshower detector for
the FASER experiment at the LHC**

Rafaella Eleni Kotitsa

**First testbeam of the FASER
experiment**

Noshin Tarannum



UNIVERSITÉ
DE GENÈVE

FACULTÉ DES SCIENCES
Département de physique
nucléaire et corpusculaire



Thank you !

Chiara Magliocca

chiara.magliocca@unige.ch

And if you want to know more:

H. Abreu et al. "The FASER W-Si High Precision
Preshower Technical Proposal"

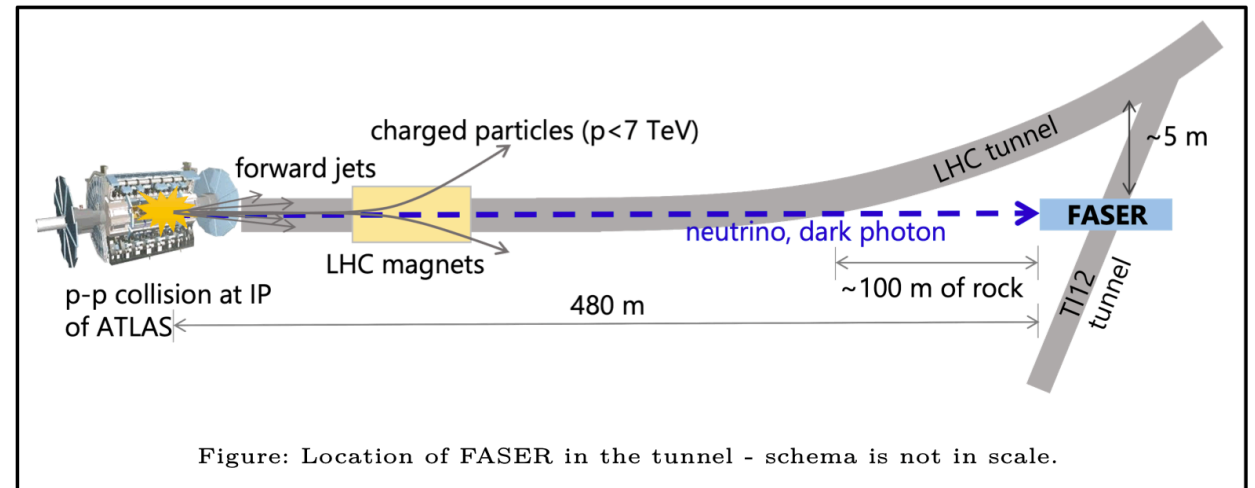
CERN-LHCC-2022-006 ; LHCC-P-023

<https://cds.cern.ch/record/2803084>

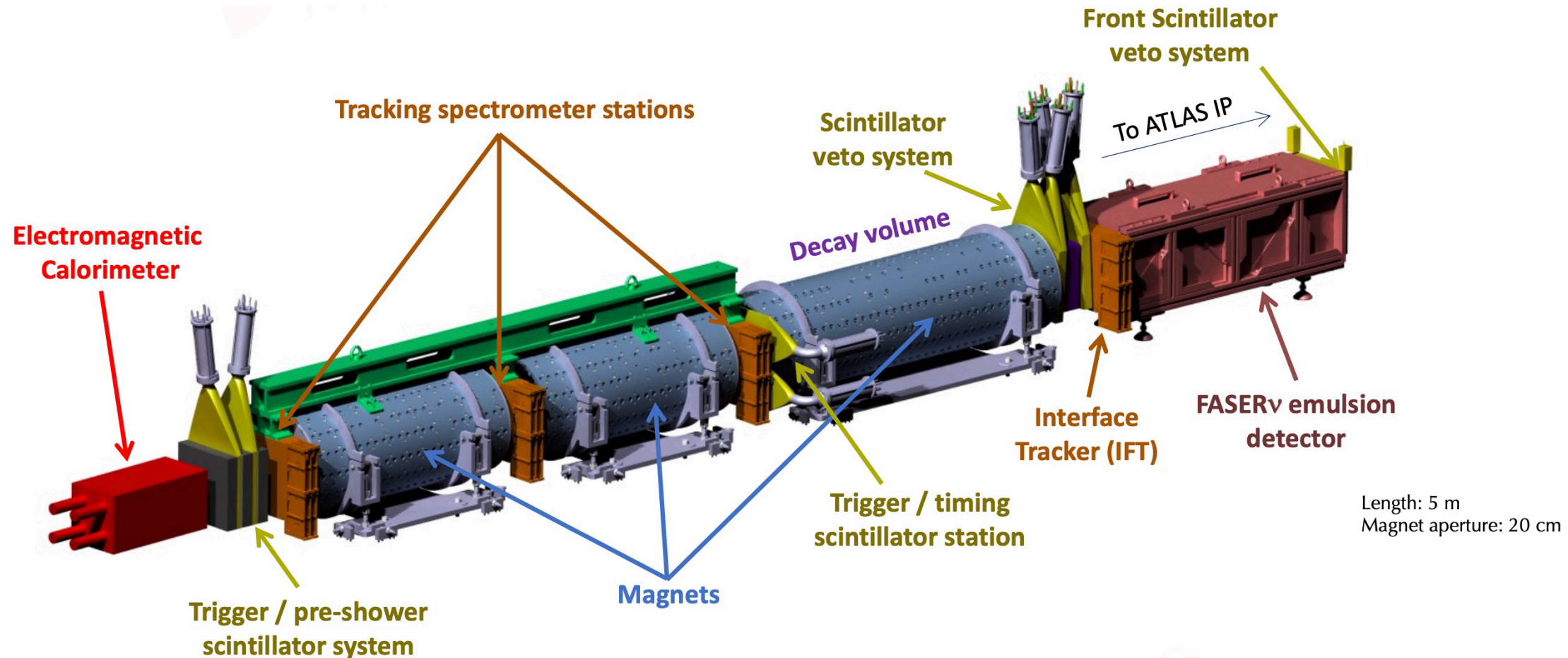
BACKUP SLIDES

The LHC Forward Physics

- Most LHC detectors sensitive to transverse particles coming from head-on pp collisions
- **Large forward cross section currently wasted and not probed**
- Forward particles are **highly collimated**: only $\sim 1\text{cm}$ spread for 100 m longitudinal travel
- **A small detector far away could potentially see a large flux of Long-Lived Particles (LLPs) with very small background**
- ForwArd Search ExpeRiment
- Proposal submitted in 2018 and approved by Cern in March 2019

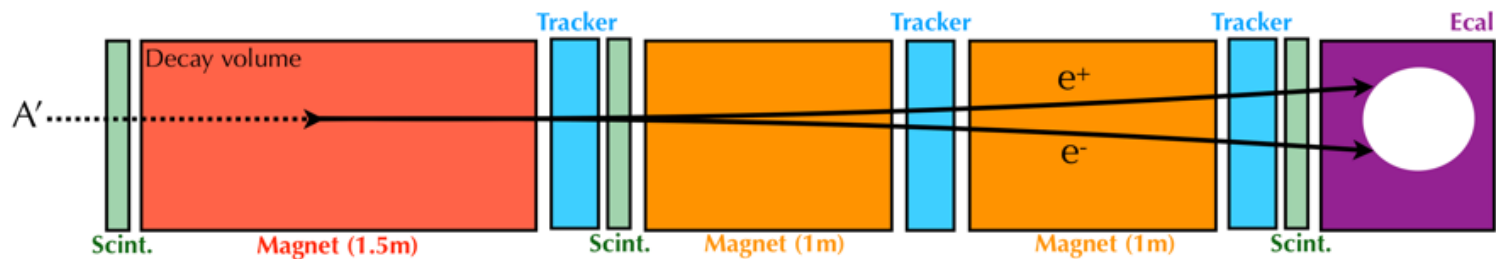
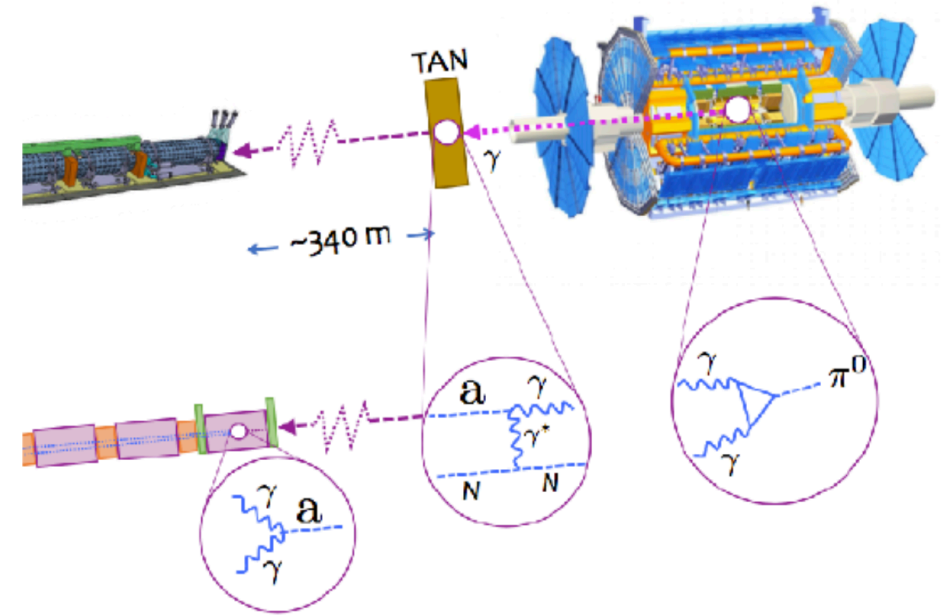


The FASER Experiment

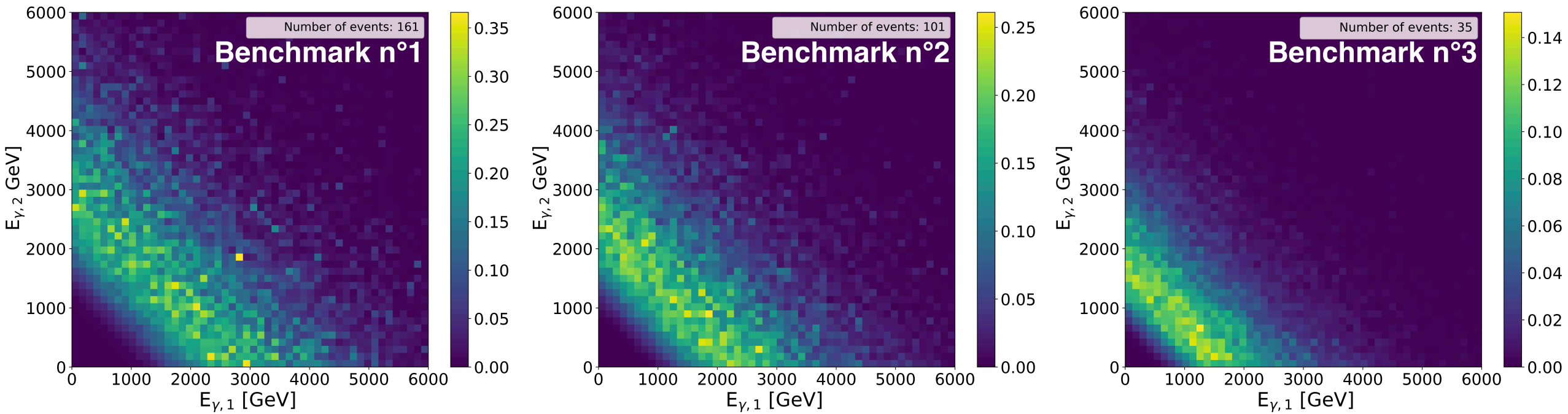


Primakoff Process

- ALPs can decay in two photons via $a\gamma\gamma$ coupling
 - Photons in the TeV range are produced at ATLAS IP
 - Collide with the TAN particle absorber
 - The ALPs are produced (via e.g. the Primakoff process)
 - ALPs decay to photon-pair within the FASER volume
 - The photons will then produce an electromagnetic shower

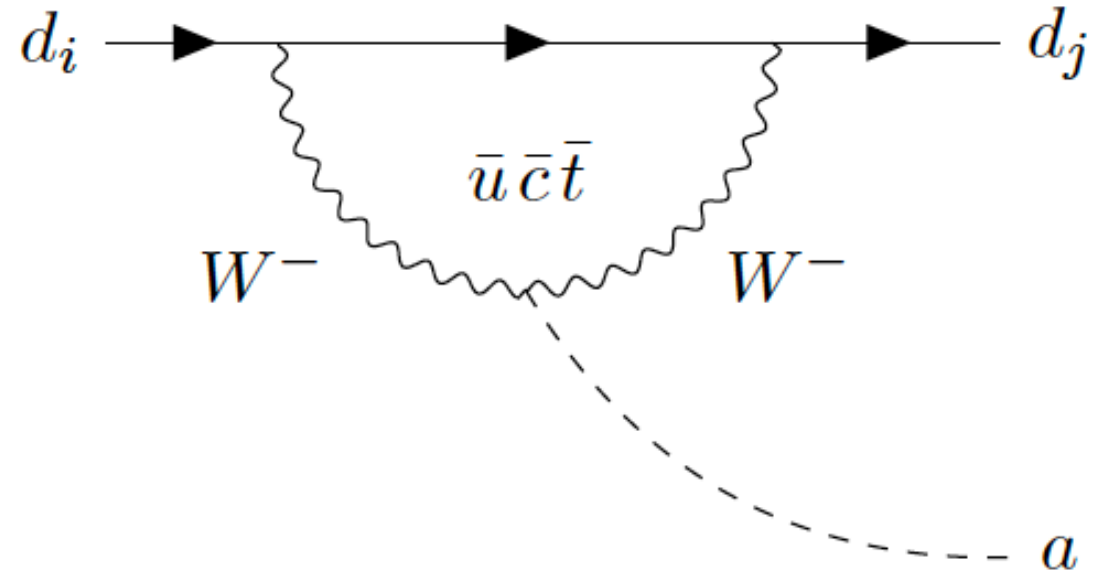


Di-photon Signal Energy Distributions



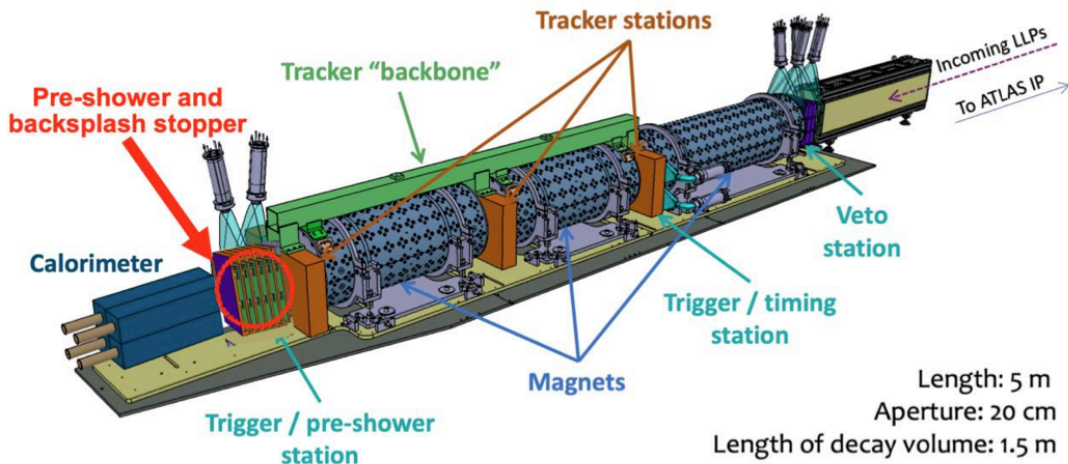
ALPs Production - FCNC

- Down type quark becomes an up type quark
- Emits a charged boson which will itself radiate an ALP
- It then interacts with the up type quark which changes flavor again to become a down type quark



The FASER Pre-shower Detector Upgrade

- MAIN CHALLENGE: **Resolve separate photon signatures** before coarser calorimeter → preshower needed



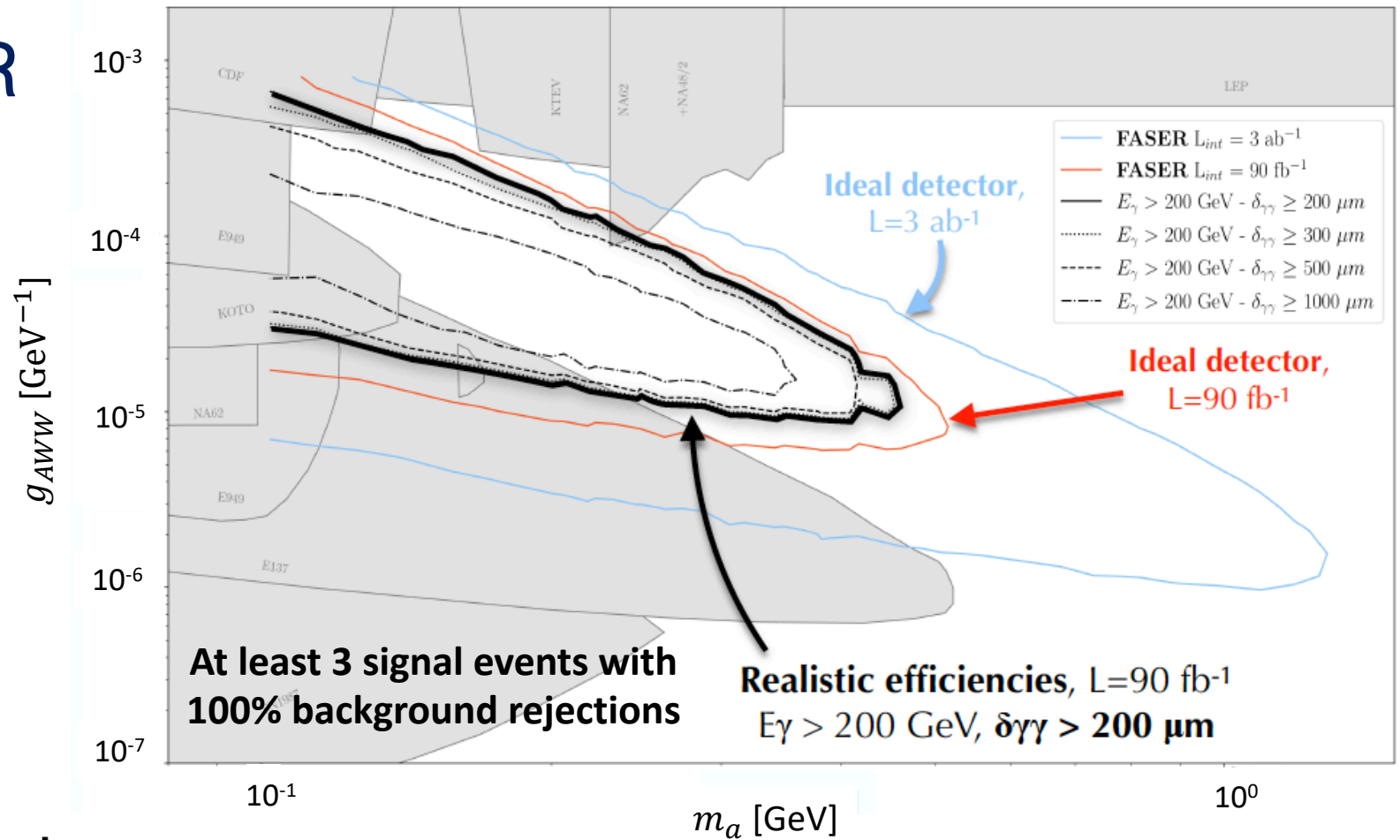
- Current preshower:**

2 layers of tungsten (1X0) + scintillating detectors
→ no XY granularity

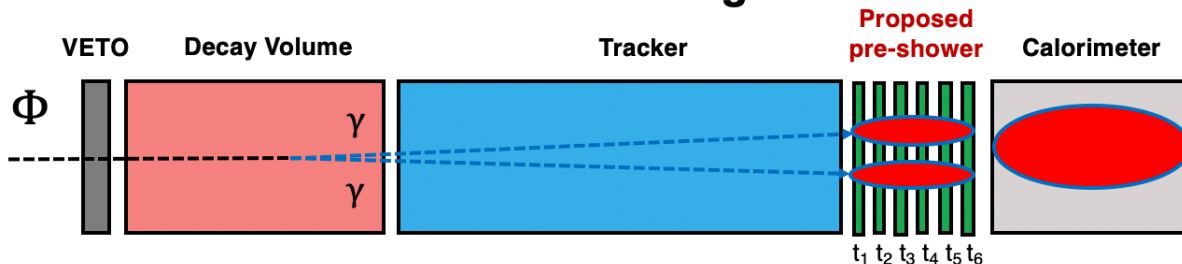
- Main goal of the upgraded preshower detector:
 - High granularity/high dynamic range** for charge measurements
 - Pre-shower based on **monolithic silicon pixel sensors**
 - Discriminate **TeV scale electromagnetic showers**
 - Targeting data-taking in 2024/2025, during LHC Run3 and during HL-LHC

Physics with FASER

- FASER can probe **Axion-Like-Particles** (ALPs) model
- ALPs produced via the aWW coupling
- ALPs **decay into a photon-pair** within FASER volume



Two Photon signal

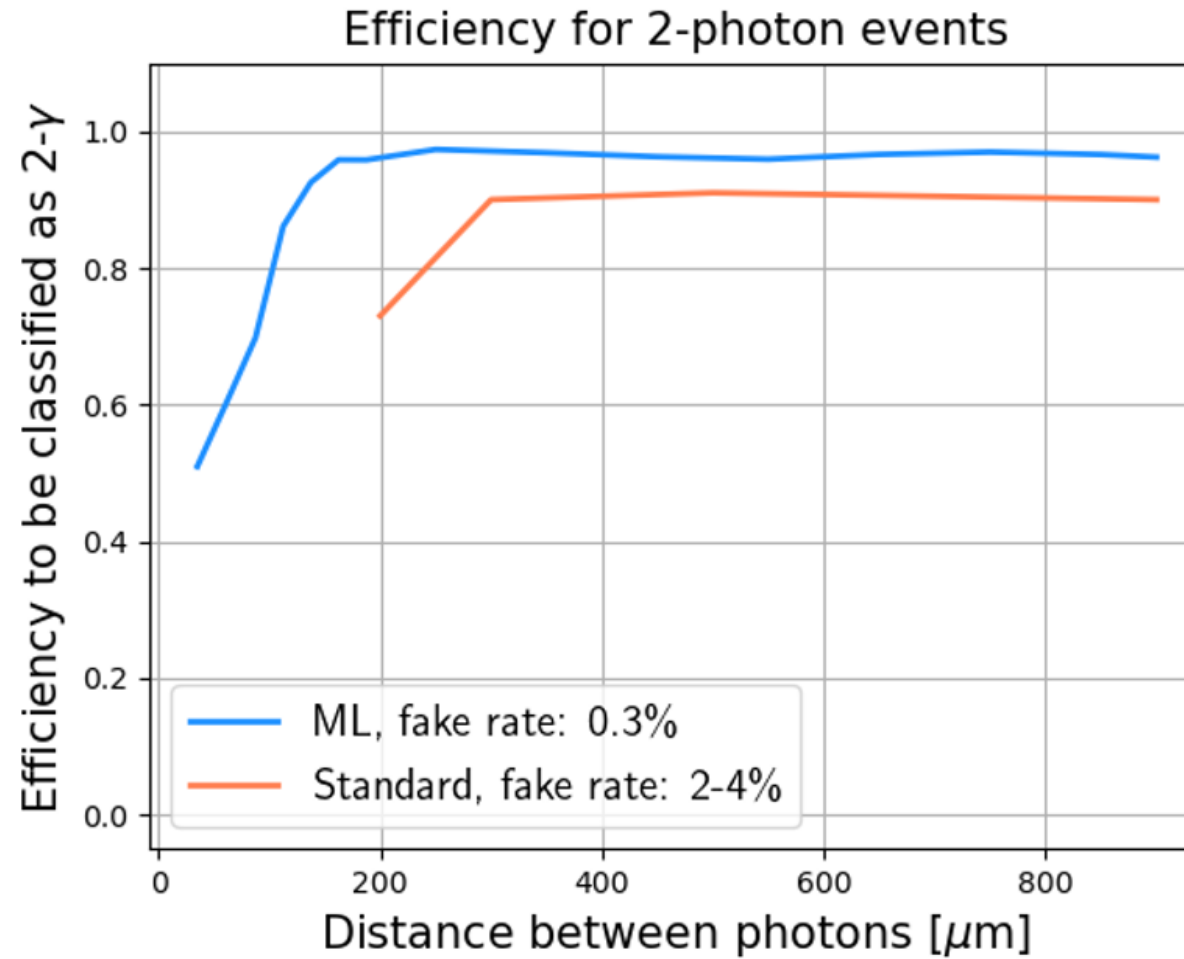


H. Abreu et al. "The FASER W-Si High Precision Preshower Technical Proposal"
 CERN-LHCC-2022-006 ; LHCC-P-023
<https://cds.cern.ch/record/2803084>

Di-Photon Reconstruction Efficiencies

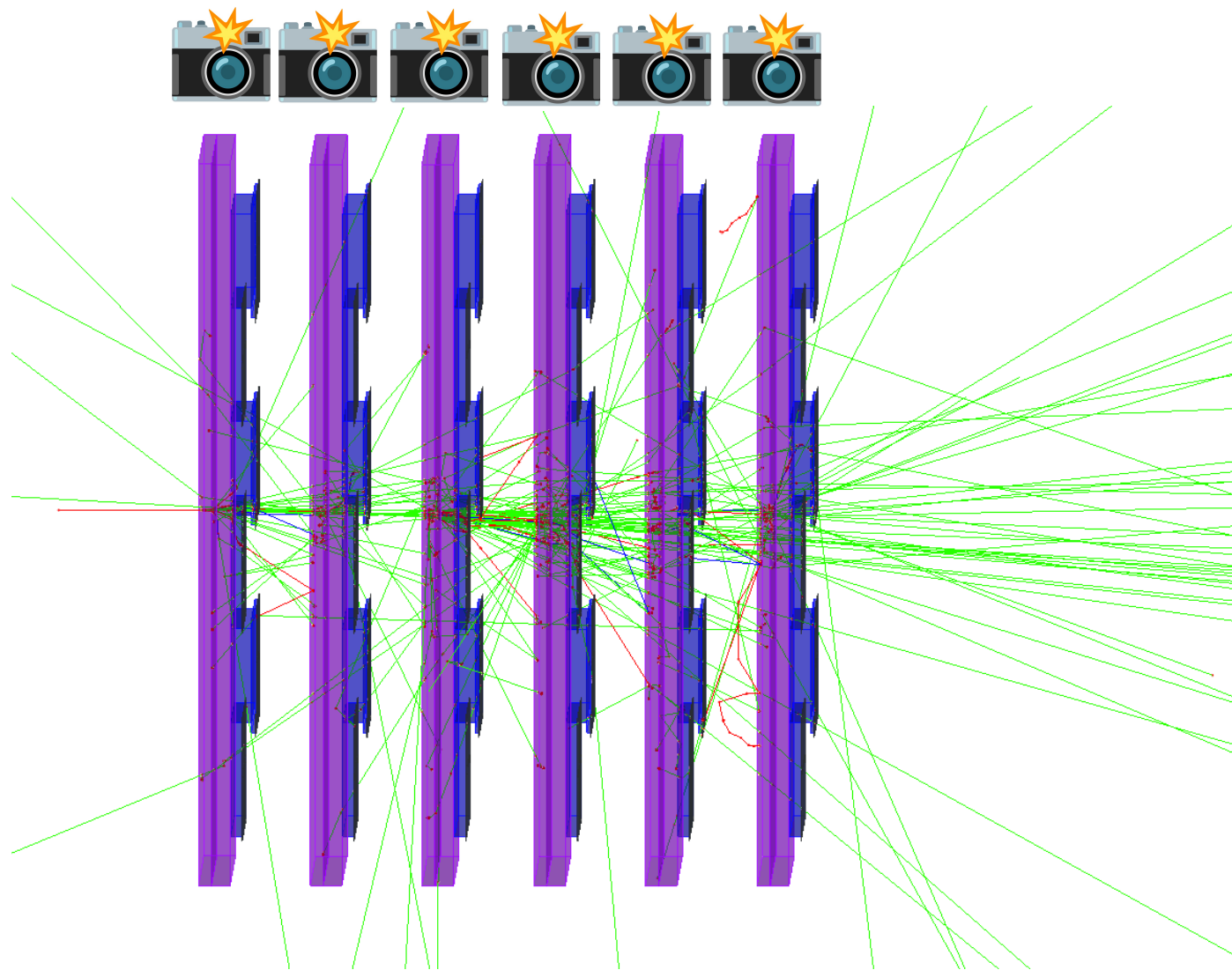
$$E_{\gamma 1} = 1 \text{ TeV}$$

$$E_{\gamma 2} = 1 \text{ TeV}$$



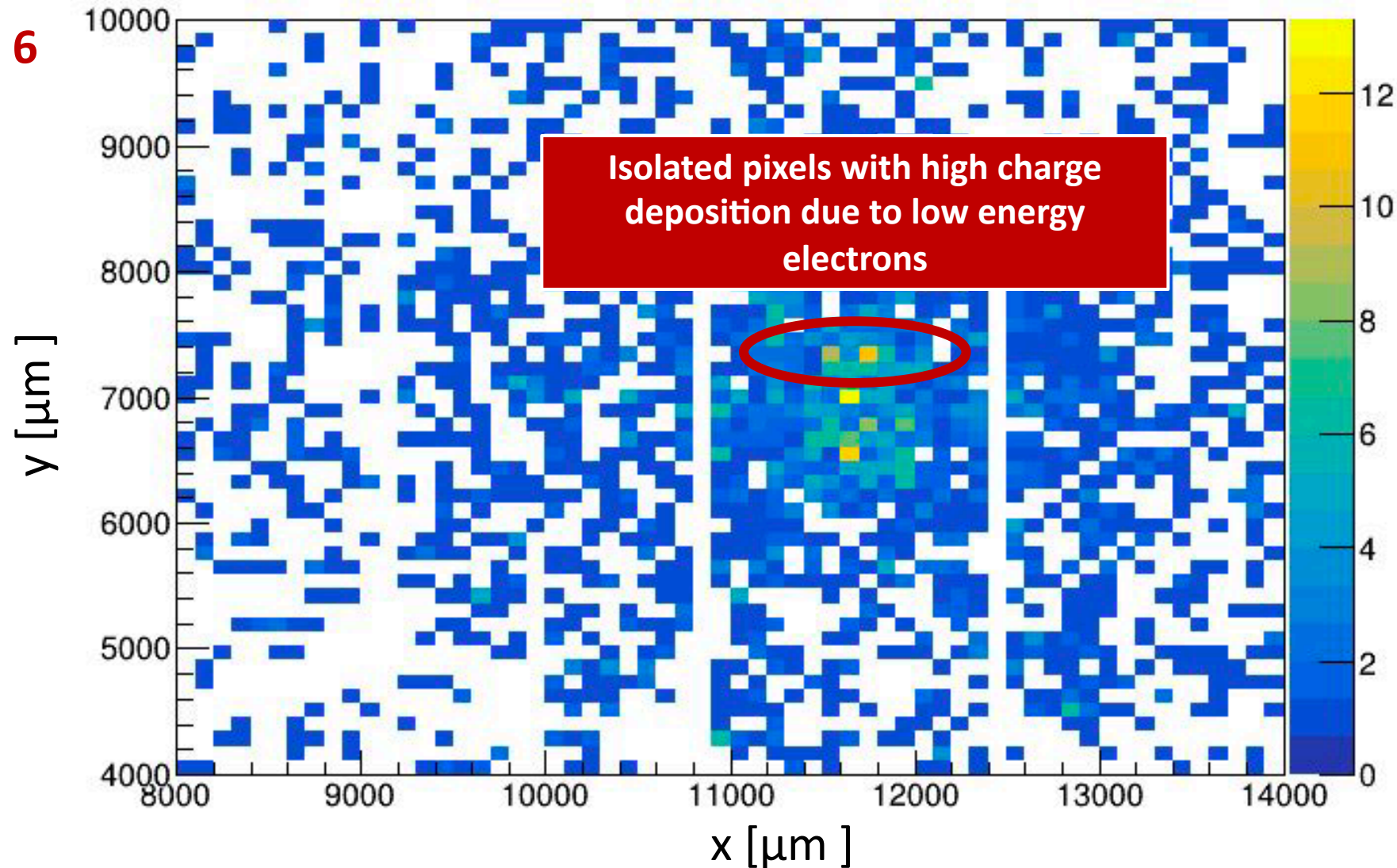
Why 6 Layers?

(Very)
Young Researcher



Electromagnetic Shower Development

PLANE 6



$$E_{\gamma 1} = 1 \text{ TeV}$$

$$E_{\gamma 2} = 1 \text{ TeV}$$

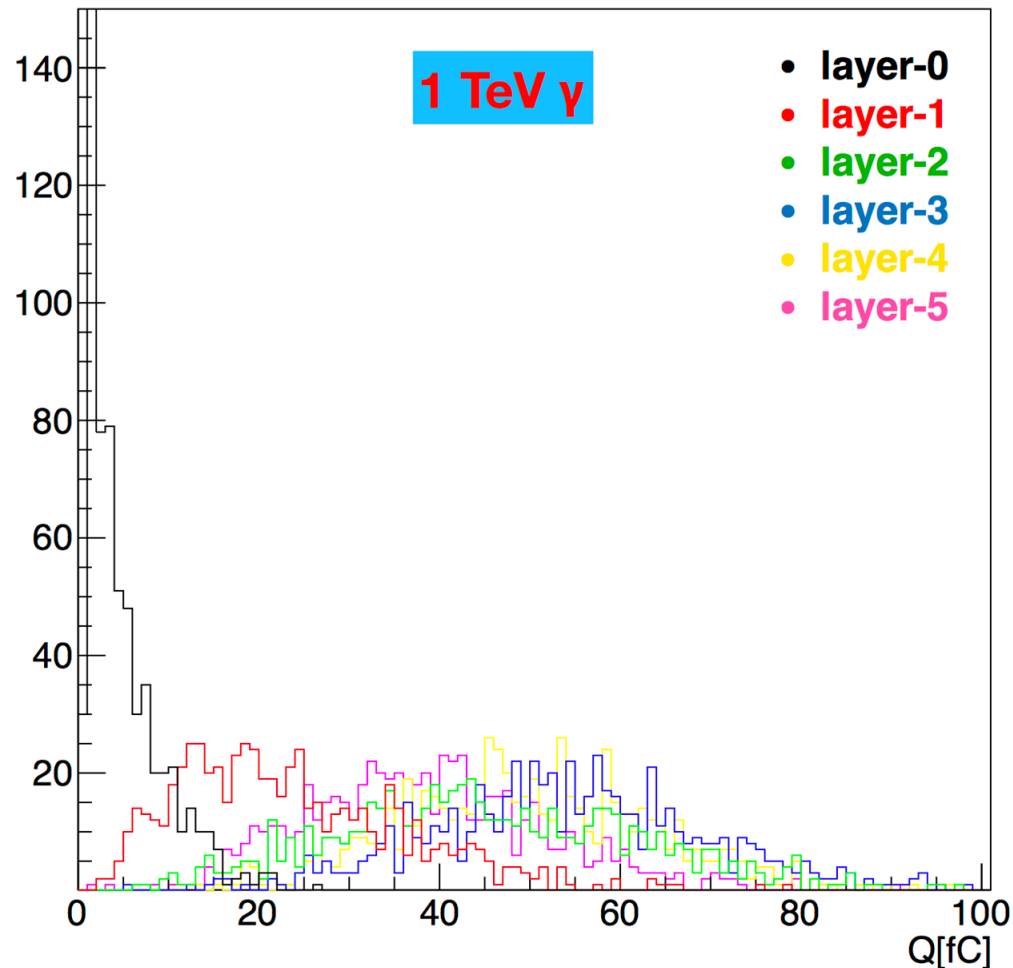
$$d(\gamma 1, \gamma 2) = 500 \text{ } \mu\text{m}$$



Events simulated
using Allpixsquared

Electromagnetic Shower Development

Total charge deposited at the peak of the electromagnetic shower



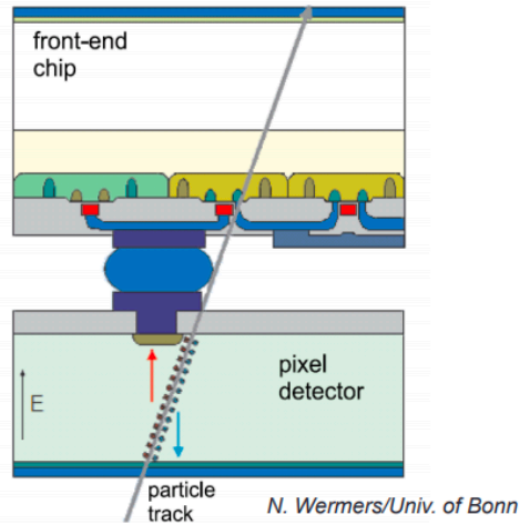
1 photon at $E = 1\text{TeV}$
converting in the first layer

- The charge deposited increases while traversing more tungsten
- After 4 layer (= $4X_0$) the amount of charge deposited decreases $\rightarrow$ the EM shower begins to die

Hybrid VS Monolithic Pixel Detectors

ATLAS

Hybrid Pixel Detector



cost ratio

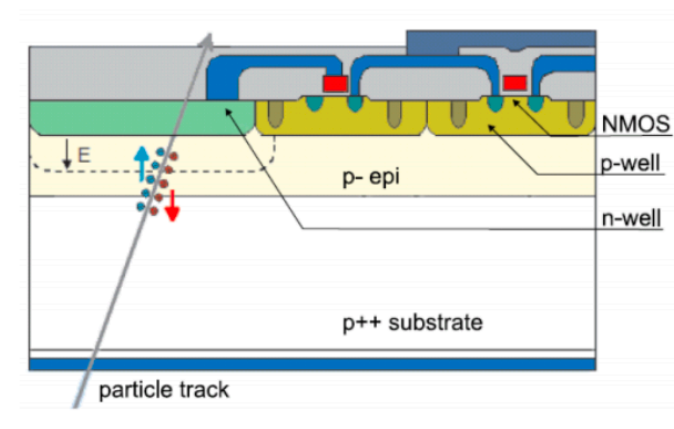
Readout chip : sensor chip : bump bonding $\cong 1:2:7$

PROS: better optimization of sensors and electronics

CONS: generally high production costs

FASER

Monolithic Pixel Detector (example)



Sensor integrated in the readout, **only CMOS processing**

PROS: lower production costs

CONS: more difficult design

The FASER Small Prototype Chip

F. Martinelli et al.
2021 *J. Inst.* **16** P12038
<https://doi.org/10.1088/1748-0221/16/12/P12038>

Purpose

study **different level of INTEGRATION OF THE FRONT-END** electronics inside the sensitive area of the pixels

Final aim

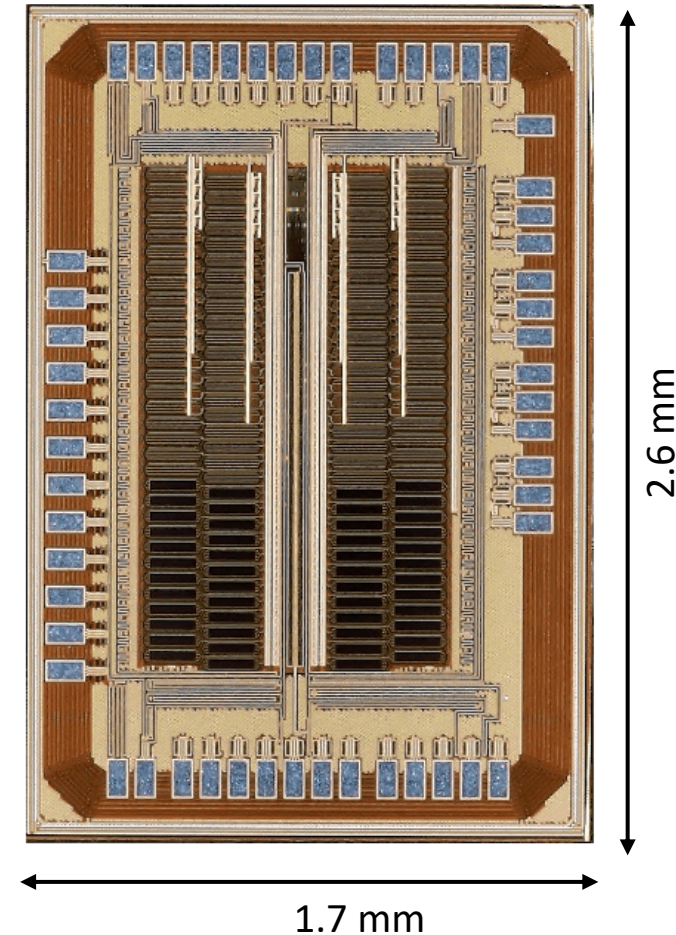
identify the BEST FRONT-END CONFIGURATION for the pre-production chip of the FASER Pre-shower (submitted in June 2021)

200 μm x 50 μm PIXELS

shape to reduce the electric field at the edge of the sensitive areas

Tested in 2021

2 superpixels
16x4 pixels each



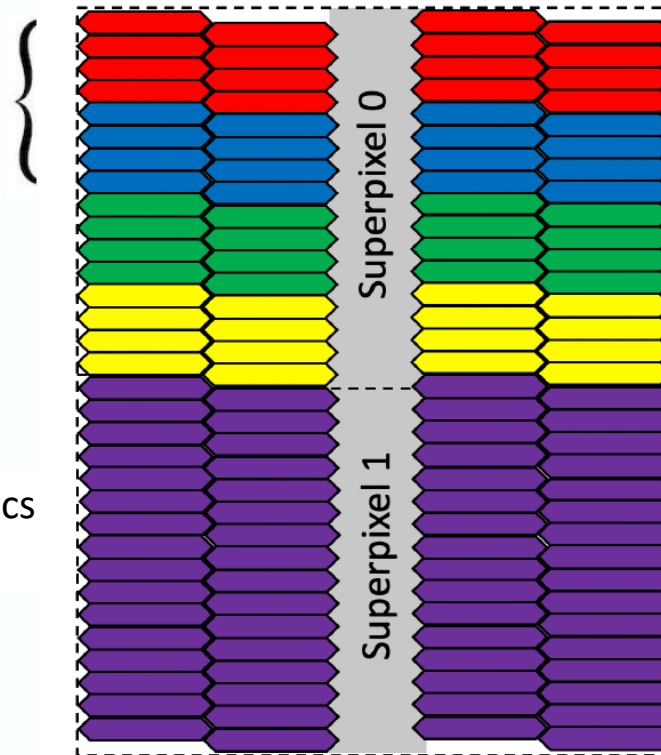
Small Prototype: Front-end Configurations

F. Martinelli et al.
2021 *J. Inst.* **16** P12038
<https://doi.org/10.1088/1748-0221/16/12/P12038>

5 Different front-end configurations

Configurations we would like to include

Backup configurations to still study electronics elements for the pre-production chip



From all electronics in pixel

-  All front-end system in Pixel
-  Driver in Pixel, discriminator outside
-  Everything in Pixel, featuring an inverting stage.
-  Only pre-amplifier in Pixel
-  All front-end system outside

To all the electronics outside the pixel

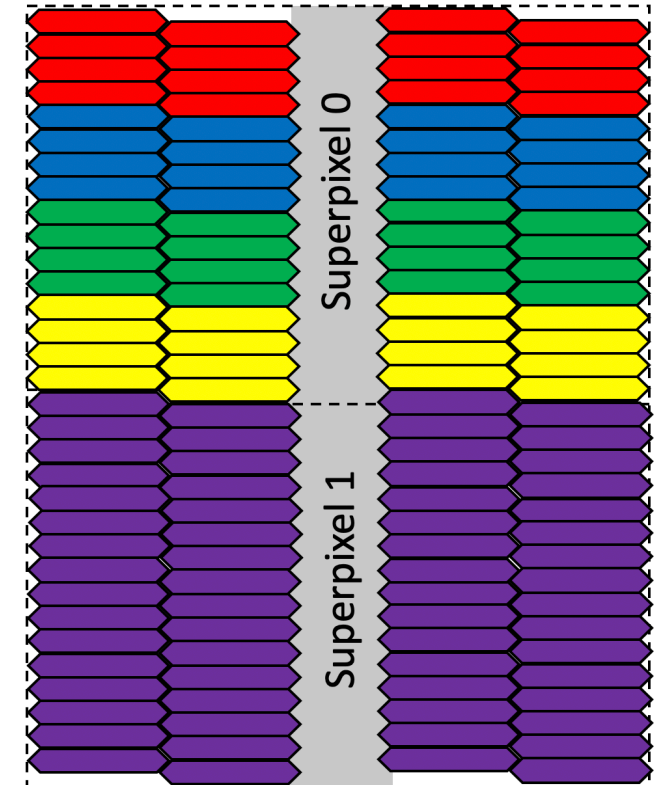
Small Prototype: Results and Comments

F. Martinelli et al.
2021 *J. Inst.* **16** P12038
<https://doi.org/10.1088/1748-0221/16/12/P12038>

-  All front-end system in Pixel
-  Driver in Pixel, discriminator outside
-  Everything in Pixel, featuring an inverting stage.
-  Only pre-amplifier in Pixel
-  All front-end system outside

Configuration	σ_v [mV]	G_c [mV/fC]	ENC [e^-]	$\sigma_{V_{th}}$ [mV]
All f.e. outside pixel	4.2 ± 0.2	159 ± 1.0	165 ± 9	32.3
Only pre-amp. in pixel	2.5 ± 0.1	96.8 ± 0.5	161 ± 9	26.9
All f.e. in pixel, inv. stage	6.9 ± 0.5	179 ± 1.0	241 ± 19	30.8
Pre-amp. and driver in pixel	3.8 ± 0.2	133.7 ± 0.6	178 ± 9	23.4
All f.e. in pixel	5.4 ± 0.4	148 ± 1.0	228 ± 20	27.1

- The **last two configurations** represent a good compromise between compactness and performance
- Configurations integrated in the pre-production chip



Monolithic ASIC Specifications

Main specifications	
Pixel Size	65 μm side (hexagonal) $\sim$ 100 μm pitch
Pixel dynamic range	0.5 $\div$ 65 fC
Cluster size	O(1000) pixels
Readout time	< 200 μs
Time resolution	< 300 ps
Power consumption	< 150 mW/cm ²

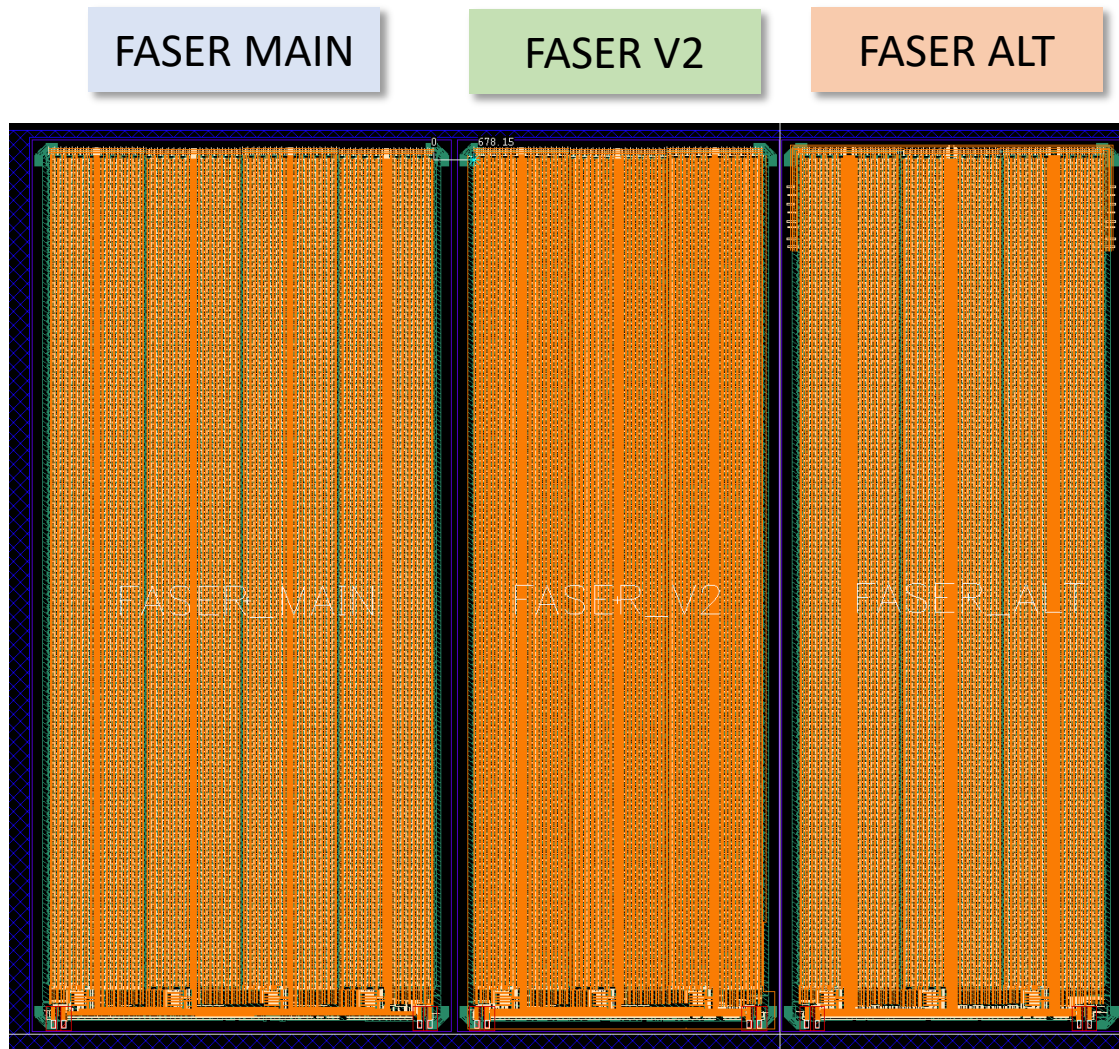
Selected technology: SG13G2, by IHP microelectronics.

ASIC design: University of Geneva, with support from KIT and CERN

- Monolithic ASIC in **130nm SiGe BiCMOS**
- Pixel size: **hexagonal pixels with 65 μm side** ($\sim$ 100 μm pitch)
- Chip size: 1.5 x 2.5 cm²
- **Local analog memories** to store the charge
- **Ultra fast readout** with no digital memory on-chip to minimize the dead area

In between an imaging chip and a HEP detector

FASER Pre-production Chip



FASER MAIN

128x64 pixels

Pre-amplifier + driver in pixel, discriminator outside

FASER V2

128x48 pixels

Everything integrated in pixel (discriminator also)

FASER ALT

128x48 pixels

Conservative configuration dedicated to the test of the digital readout

Disadvantage: much more dead area

Sensor Cross Section

- Low resistivity heavily p-doped substrate as a support
- Negative high voltage applied to the substrate
- High resistivity 50 μm epitaxial layer
- Triple – well design
- **Analog electronics inside the pixel**
- **Digital electronics outside the pixel**
- Electronics inside the guard ring isolated from substrate using a deep n-well
- Digital electronics in a separate well
- Positive low voltage applied to pixels and electronics deep n-wells
- $\approx 6\%$ dead area in the pixel matrix

