The LHC-forward experiment

UNIVERSITÀ DEGLI STUDI FIRENZE

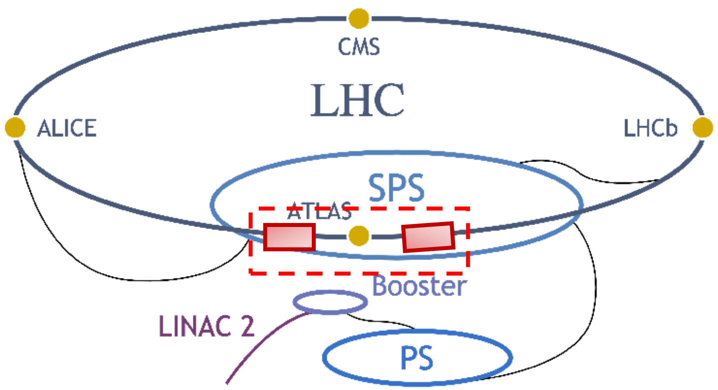
INFN Istituto Nazionale di Fisica Nucleare SEZIONE DI FIRENZE

LHCf

Elena Gensini

The LHCf experiment

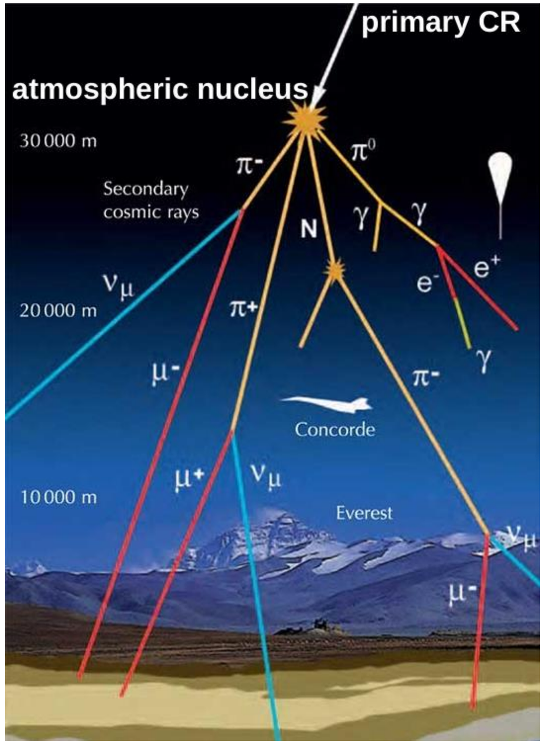
Experiment at **Large Hadron Collider** (LHC)

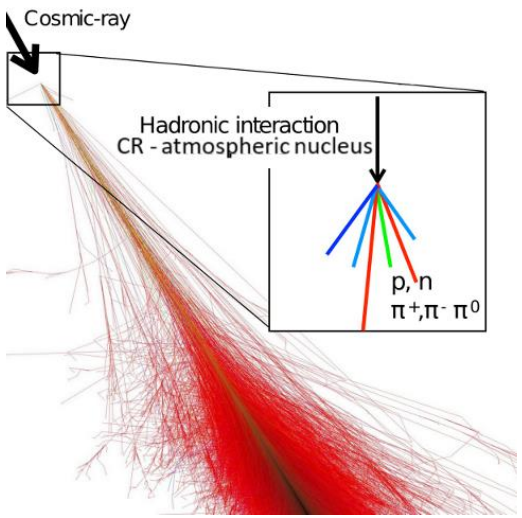


Main purpose of LHCf

Provide calibration data for hadronic interaction models used in Extensive Air Shower (EAS) simulations

Ultra High Energy Cosmic Rays (UHECRs) physics





Cosmic Rays

- Particles from outer space

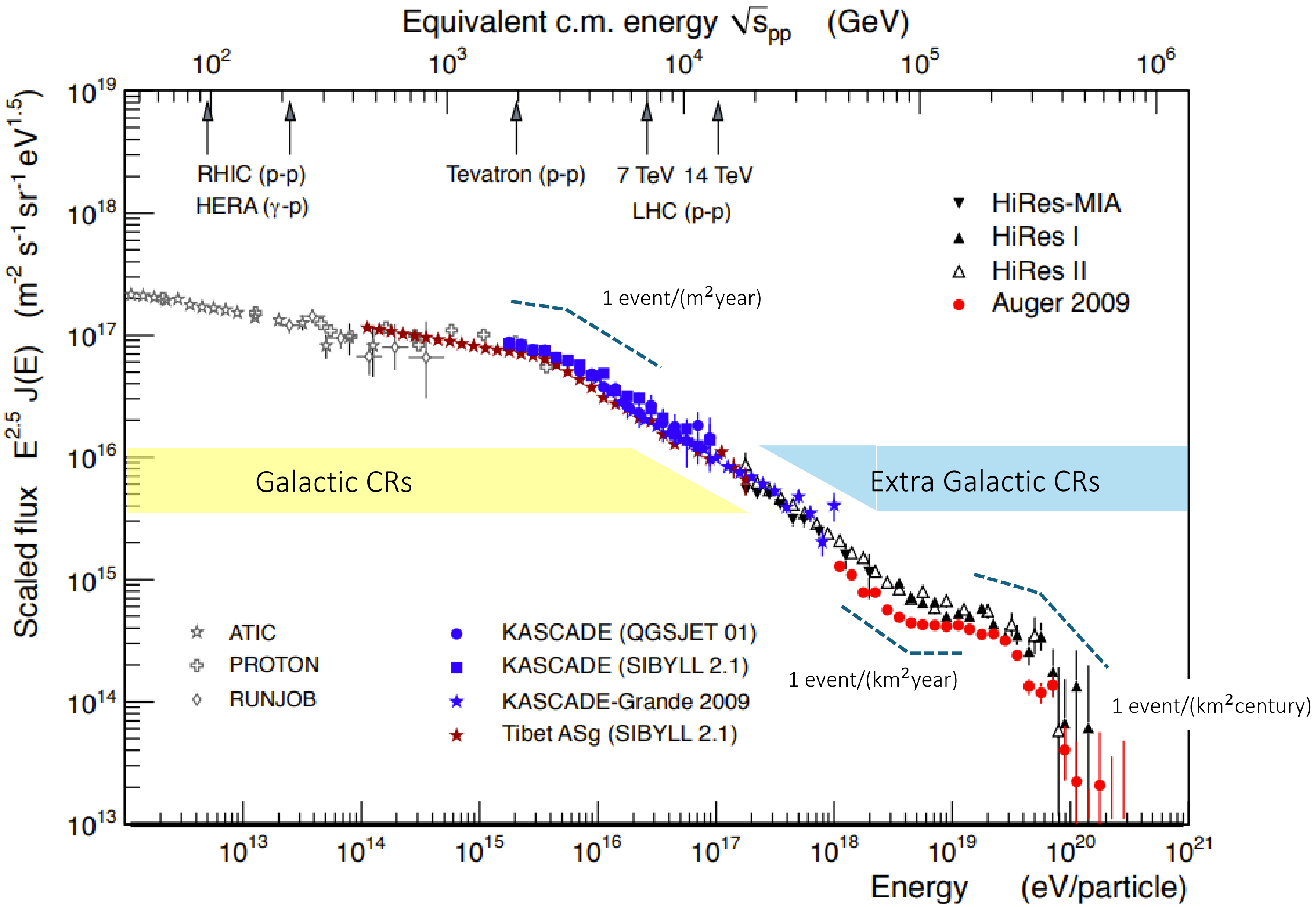
99% nuclei: p, He, …

1% e^-, γ, ν, antimatter (e^+, $\bar{p}$, $\bar{\nu}$)

- Inclusive CR differential flux vs Energy

$$J(E) = \frac{dN}{dS\,d\Omega\,dt\,dE} \rightarrow J(E) \simeq k \left(\frac{E}{1\,\mathrm{GeV}}\right)^{-\alpha}$$

$$\alpha \sim 2.6 \div 3.3$$



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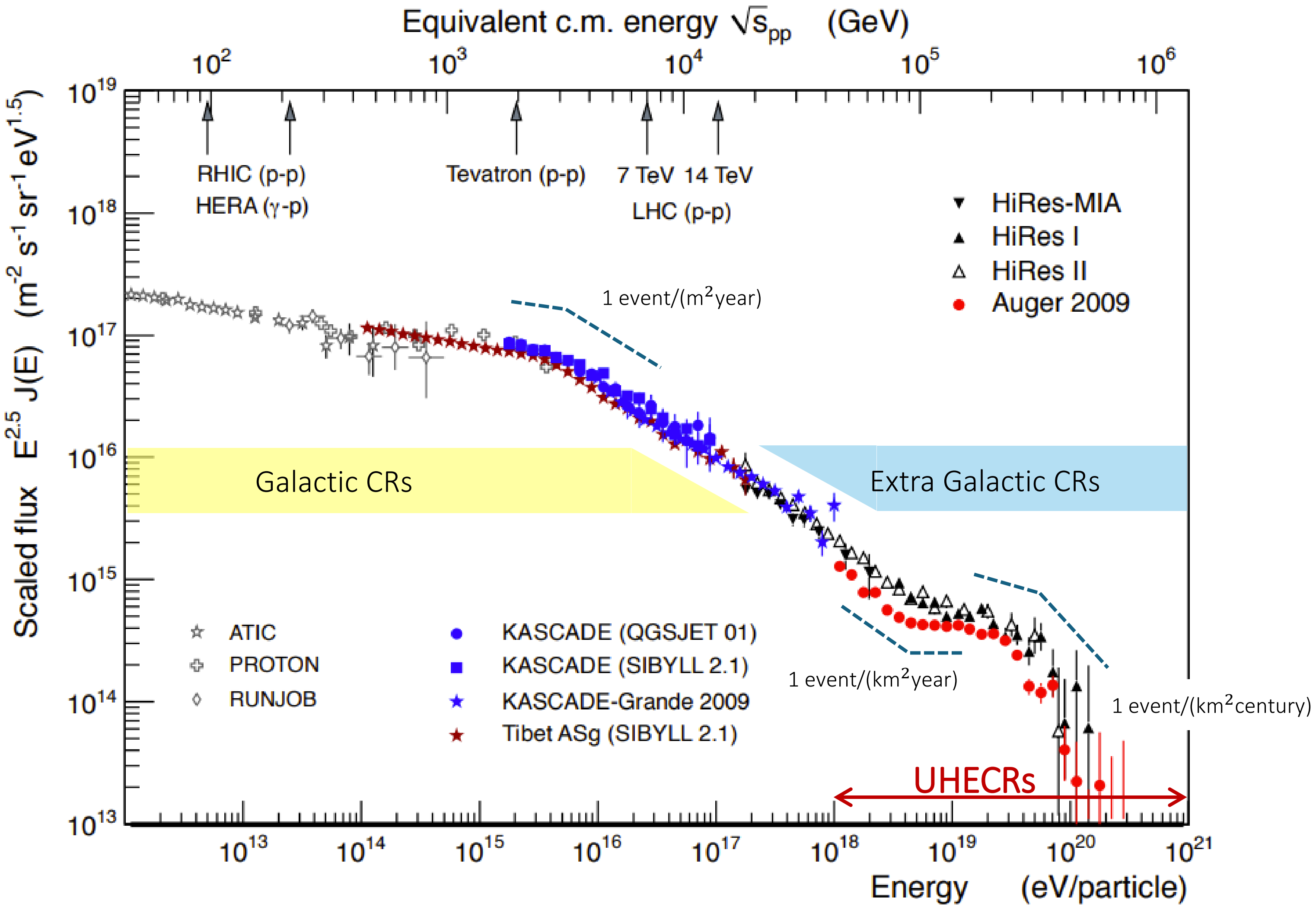
Accurate measurements of differential flux and mass composition of *Ultra High Energy Cosmic Rays*, UHECRs (E>10^{18} eV)



HOW DO WE DETECT CRs?

Cosmic Rays

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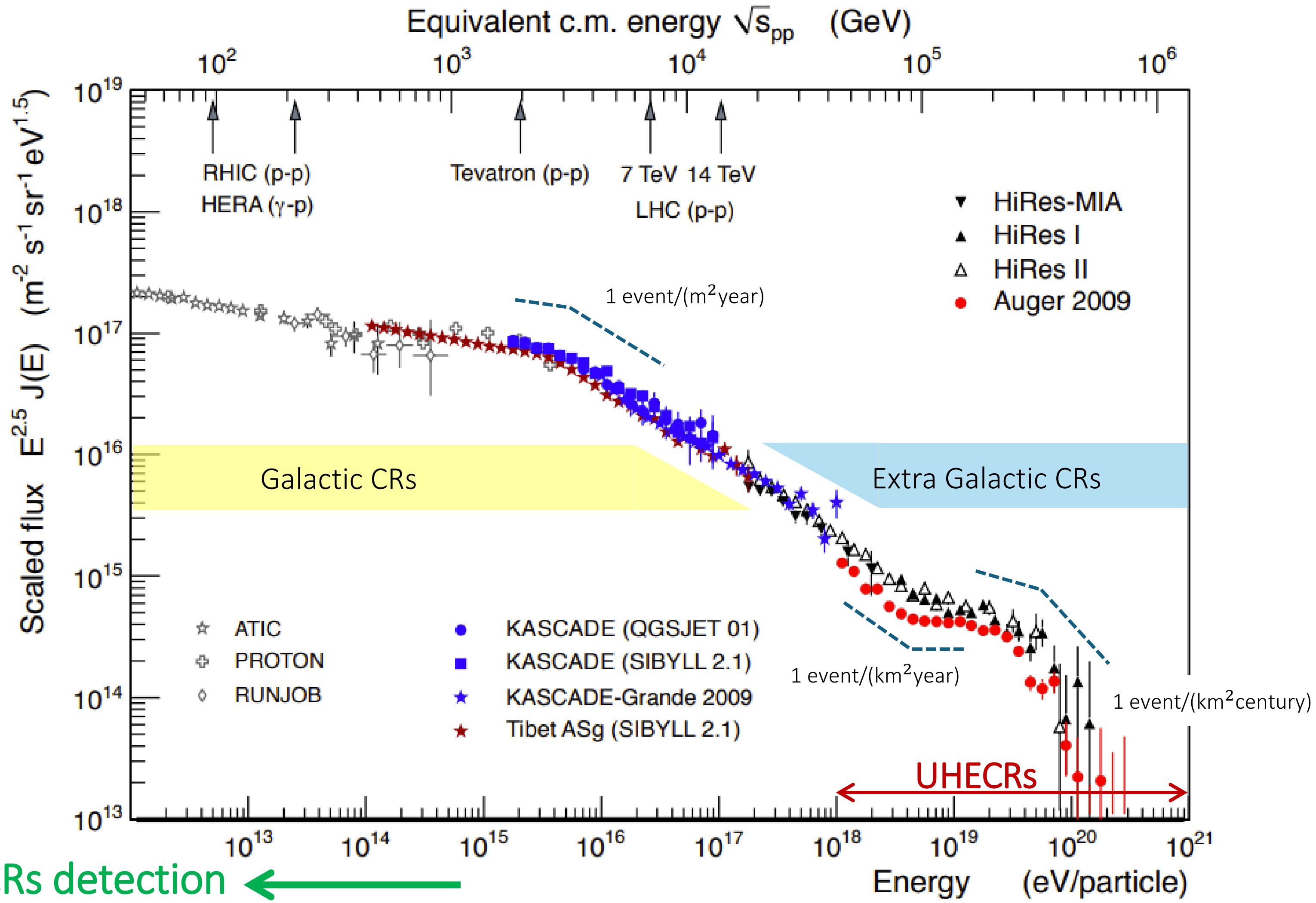
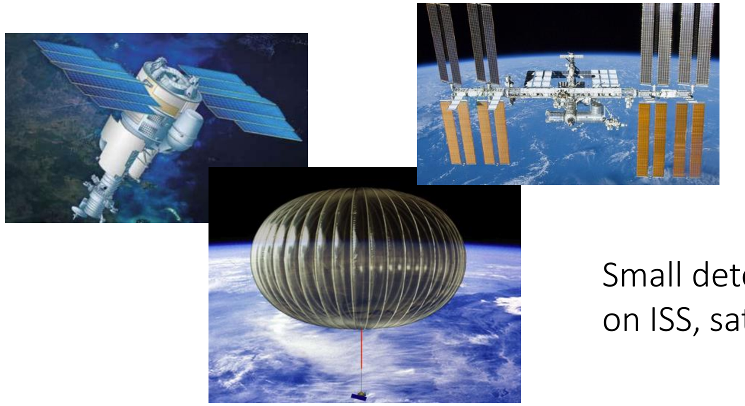


Direct CRs detection



Small detectors ($S \sim 1\mathrm{m}^2$)
on ISS, satellites, balloons

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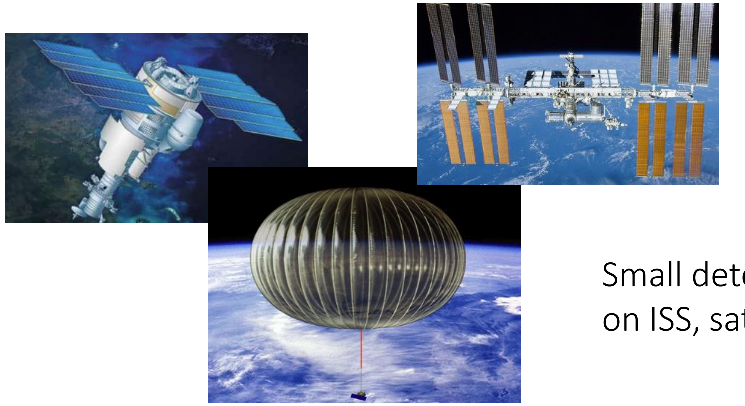

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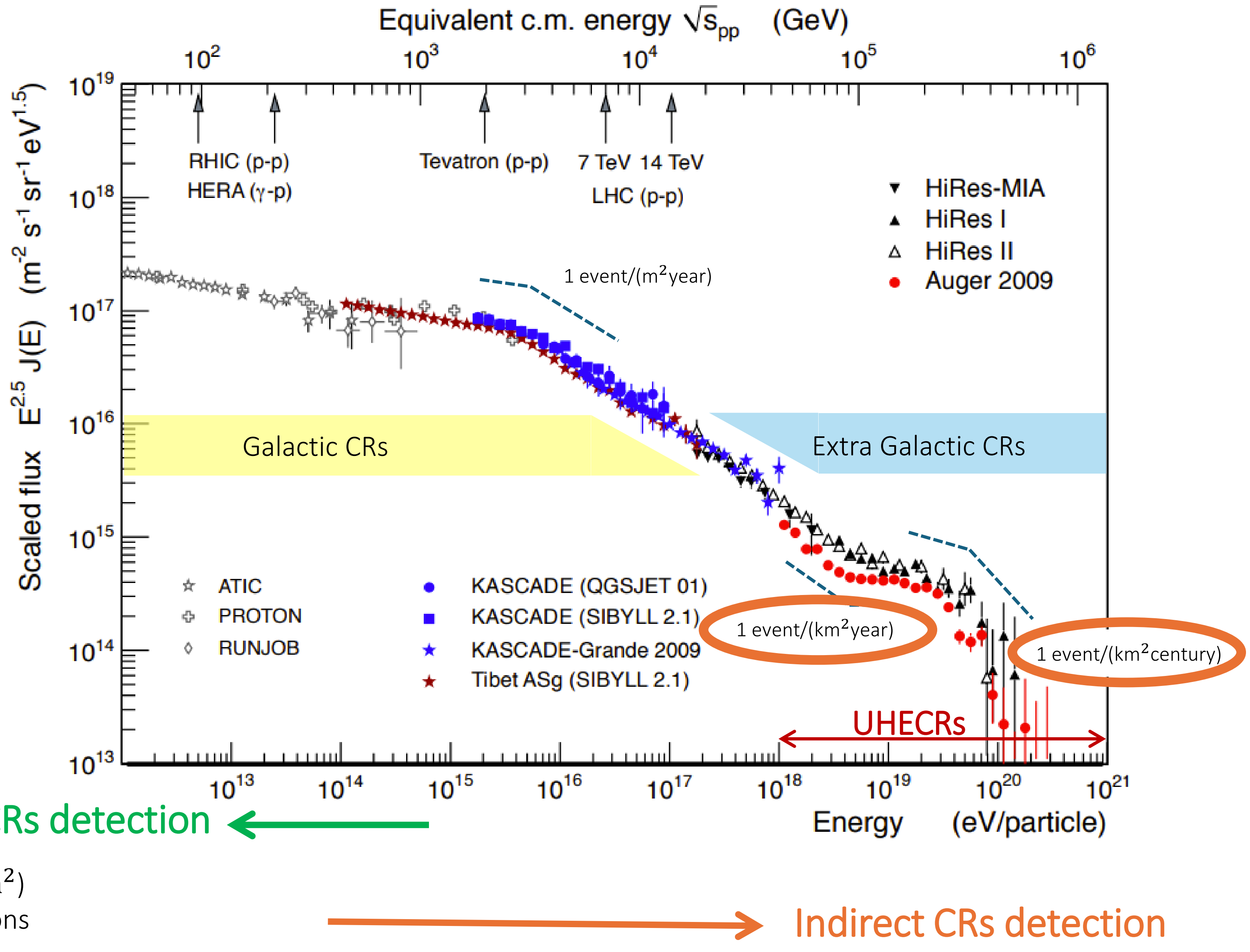


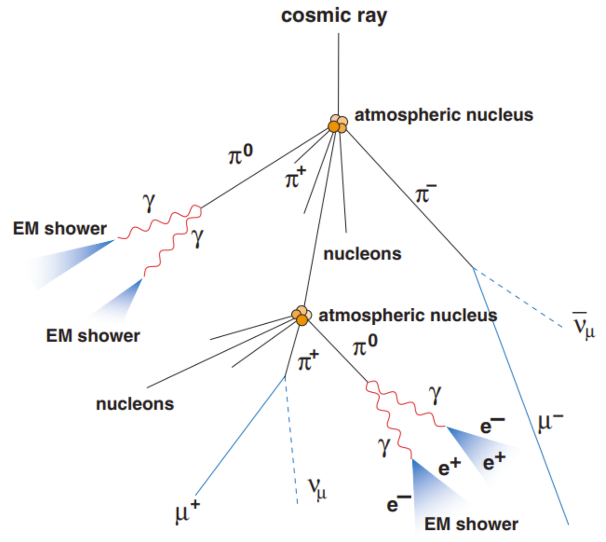
Mass composition measurements of UHECRs

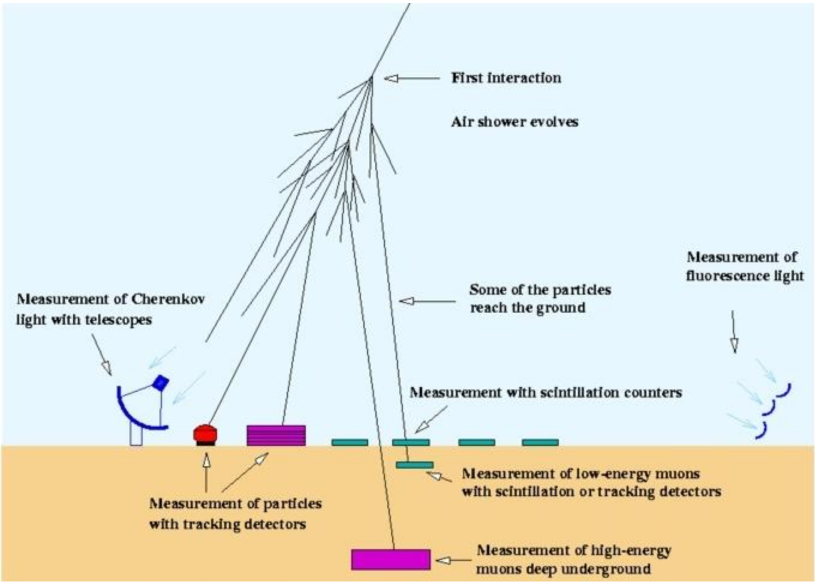
Indirect detection of UHECRs

↓

detection of secondary particles of the Extensive Air Shower (**EAS**)

with large arrays of detectors on ground level (total S $\sim 10 \div 100\ \mathrm{km}^2$)





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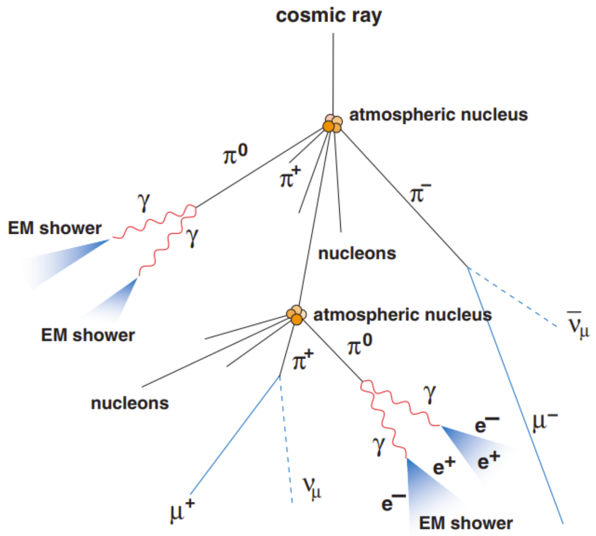

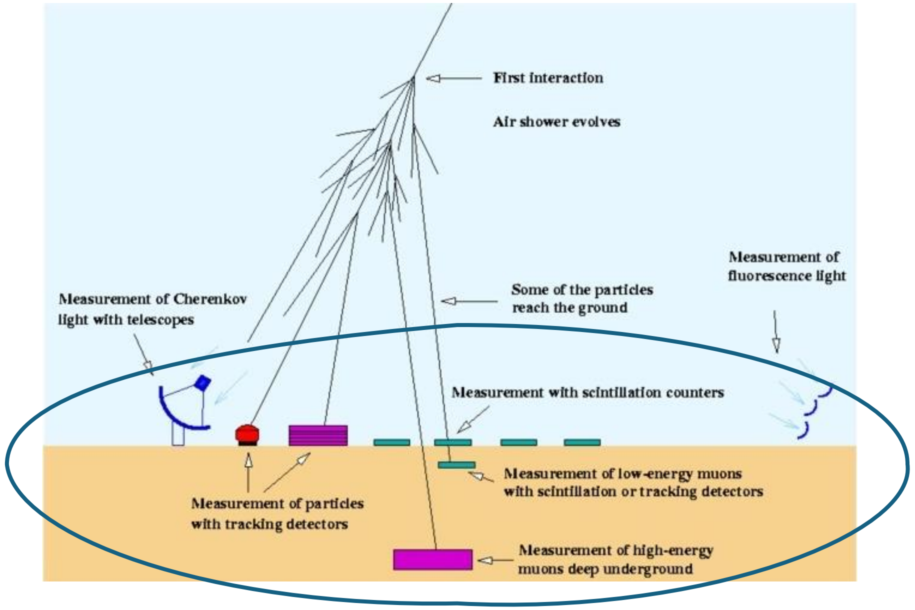

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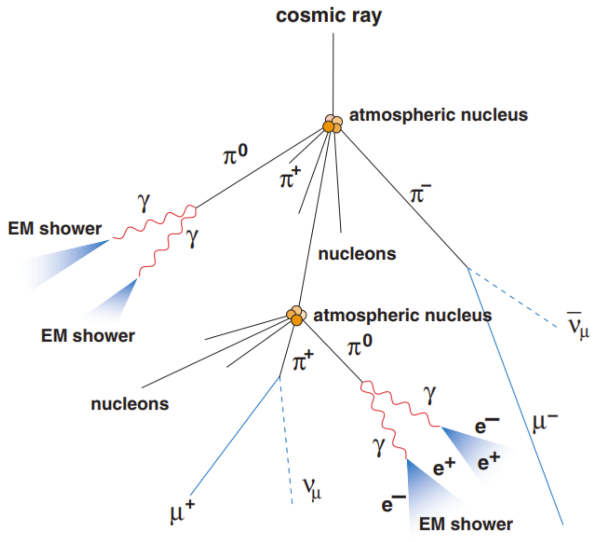

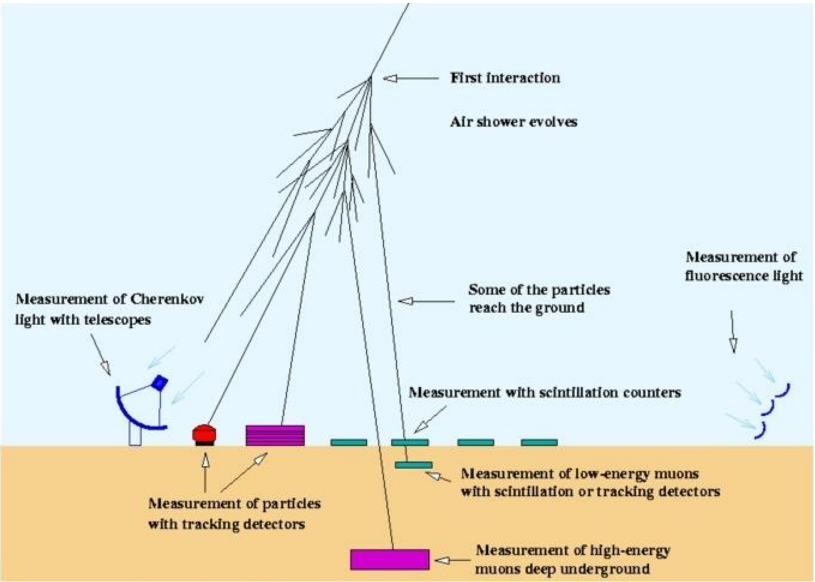

Comparison between
data of EAS detection experiments
and
outputs of EAS simulation

⇩

We can extract
CR mass composition

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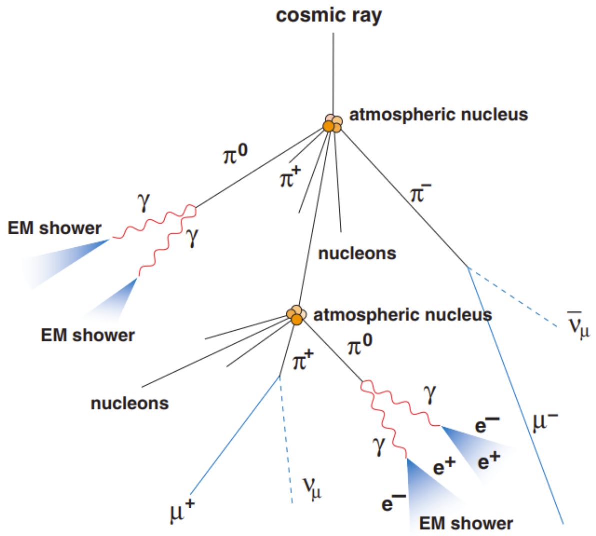

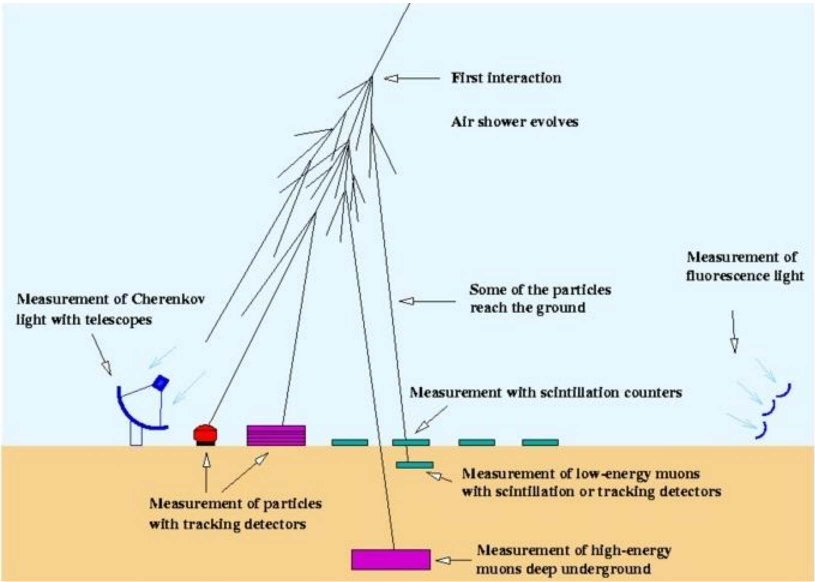

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PROBLEM!

Mass composition measurements of CRs with E>$10^{16\div17}$eV are affected by a large **systematic** uncertainty

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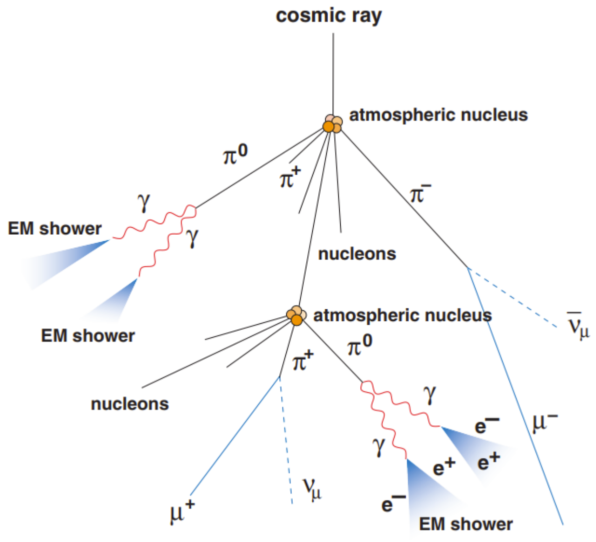

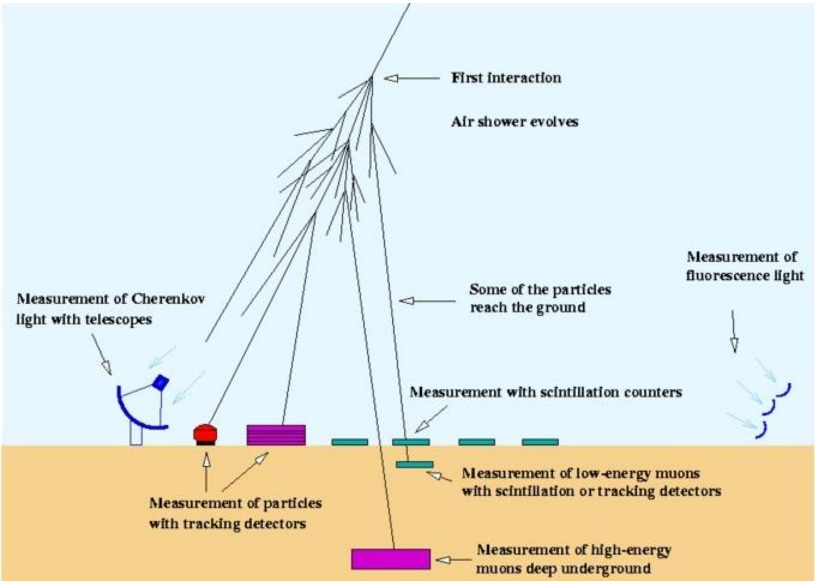

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WHY?

EAS simulations based on **hadronic interaction models**

affected by

large **theoretical** uncertainties at such high energies

Mass composition measurements of UHECRs

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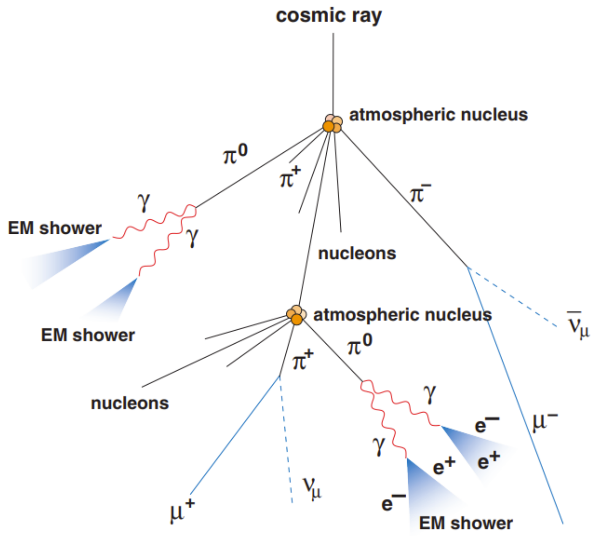

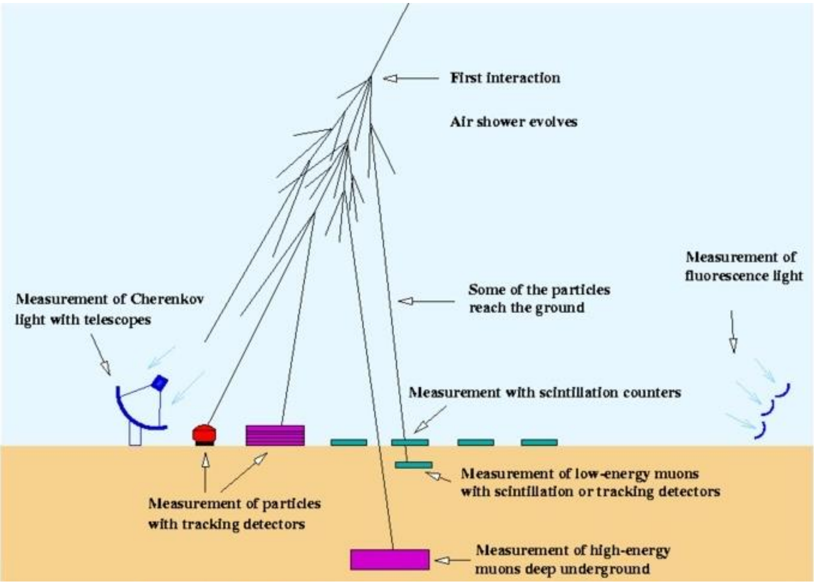

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LACK OF CALIBRATION DATA

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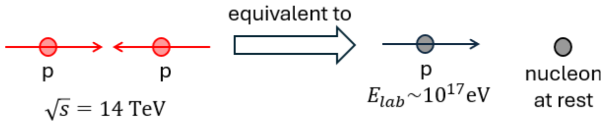
Calibration of hadronic interaction models

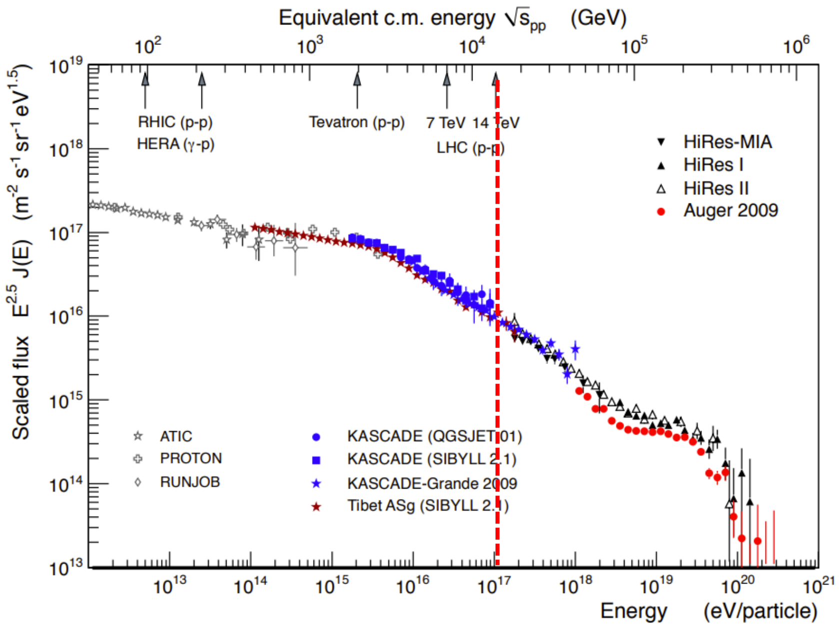
Calibration data:

- **collisions** between **hadrons**
- collected under **controlled conditions**
- at **high energies**

→ *Large Hadron Collider* **LHC** (p-p, p-Pb, …)

→ p-p a $\sqrt{s} = 14\ \text{TeV} \rightarrow E_{lab} \sim 10^{17}\ \text{eV}$





LHC collisions mimic CR - atmospheric nucleus interactions

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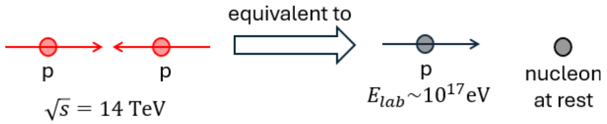
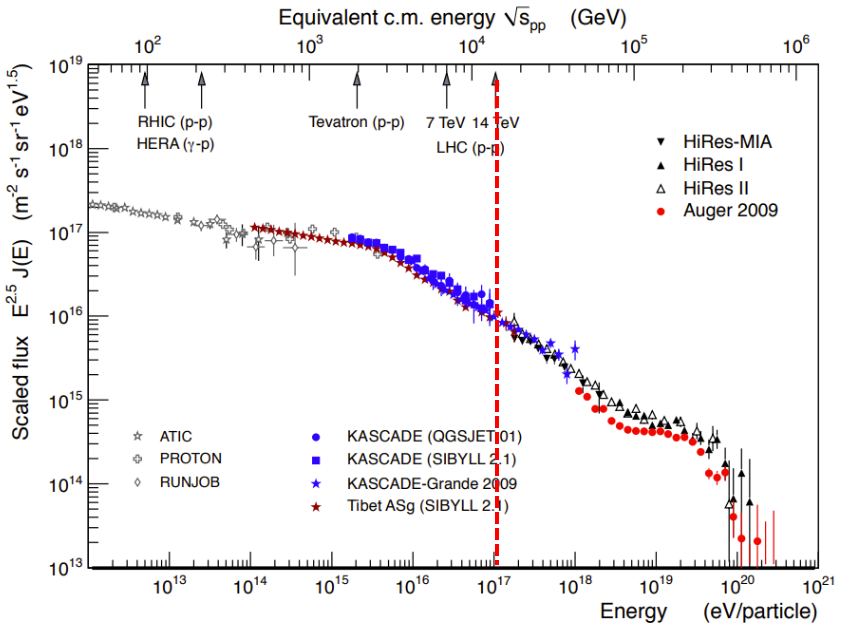
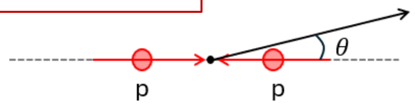




LHC collisions mimic CR - atmospheric nucleus interactions

- **forward** region of the interaction

  Small angles wrt the direction of the colliding particles



Region of interest for the study of EAS development → the **energy flux** is mainly focused in the **forward** region

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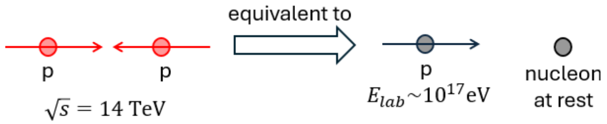

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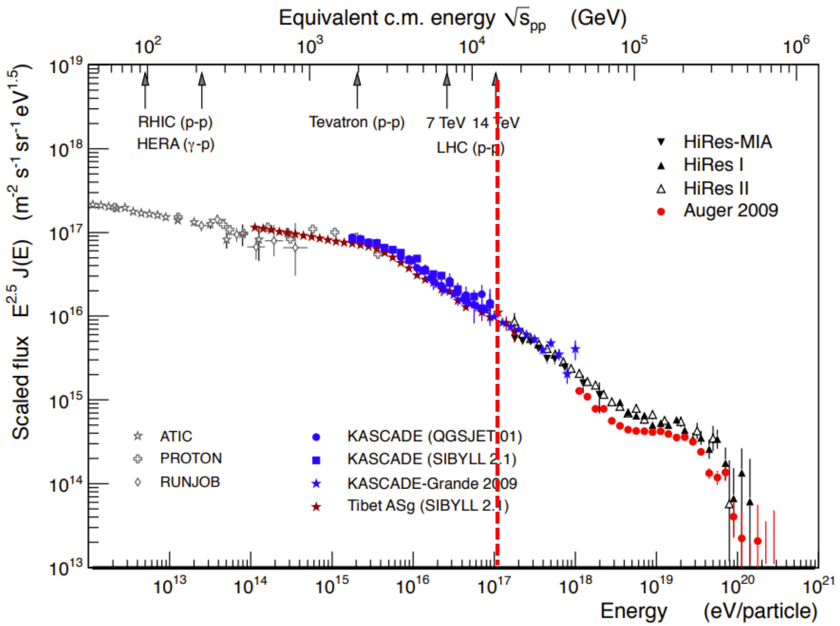

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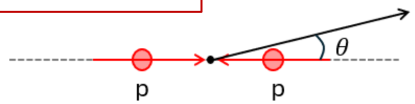

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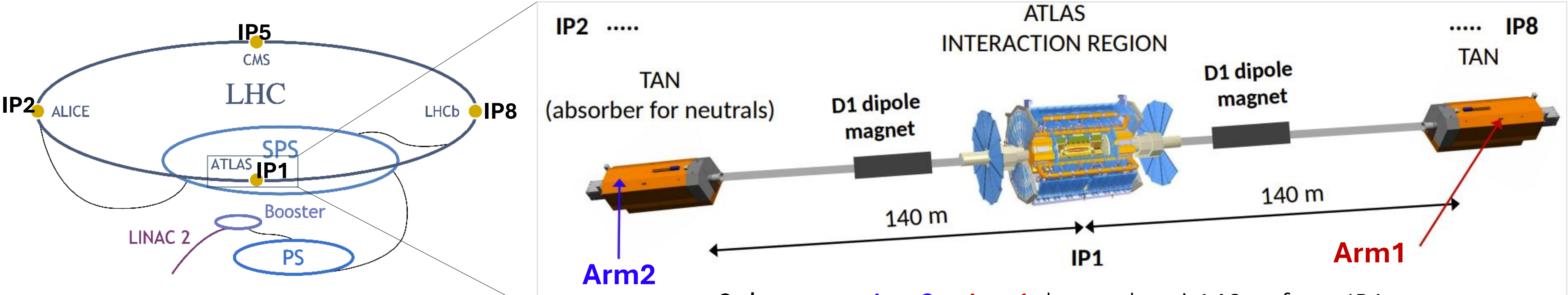
The LHC-forward (LHCf) experiment

Study of the hadronic interaction products in order to calibrate the models used in EAS simulations



2 detectors, Arm2 e Arm1, located at $\pm$140 m from IP1

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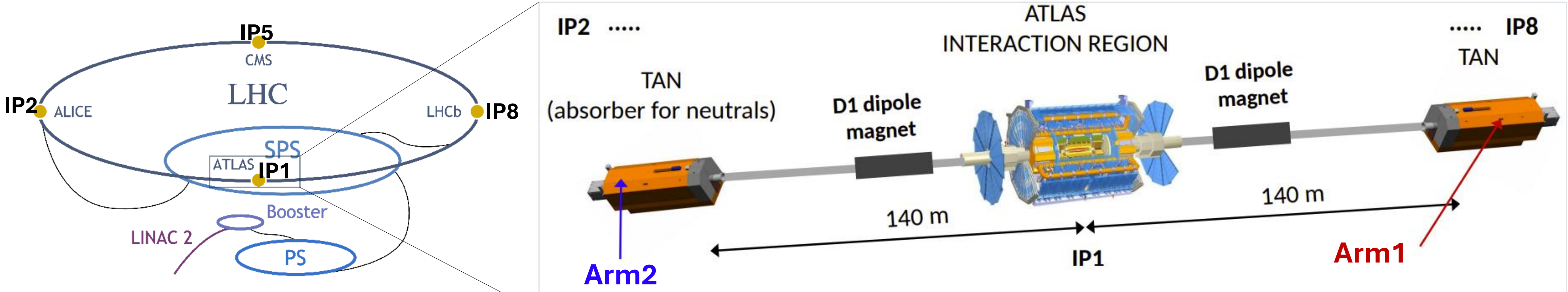

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Neutral particles

n

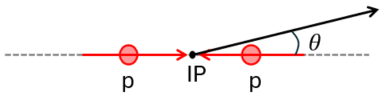
γ

$\pi^0 \rightarrow \gamma + \gamma$

$\eta \rightarrow \gamma + \gamma$

...

emitted at $\theta < 0.03°$



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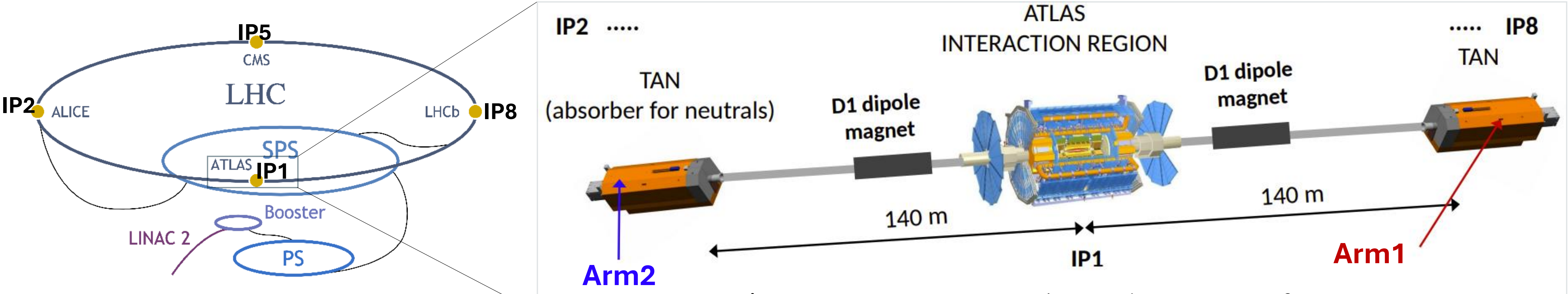

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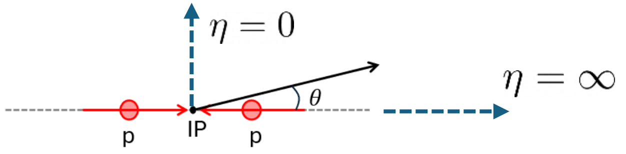
$$\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$$

pseudorapidity $\eta > 8.4$

Forward region



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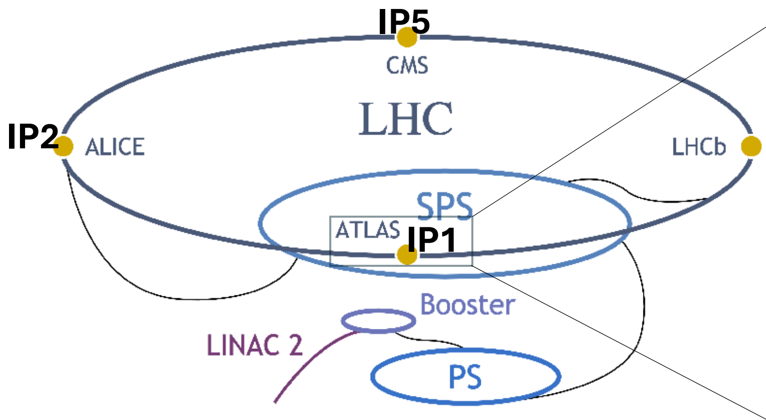

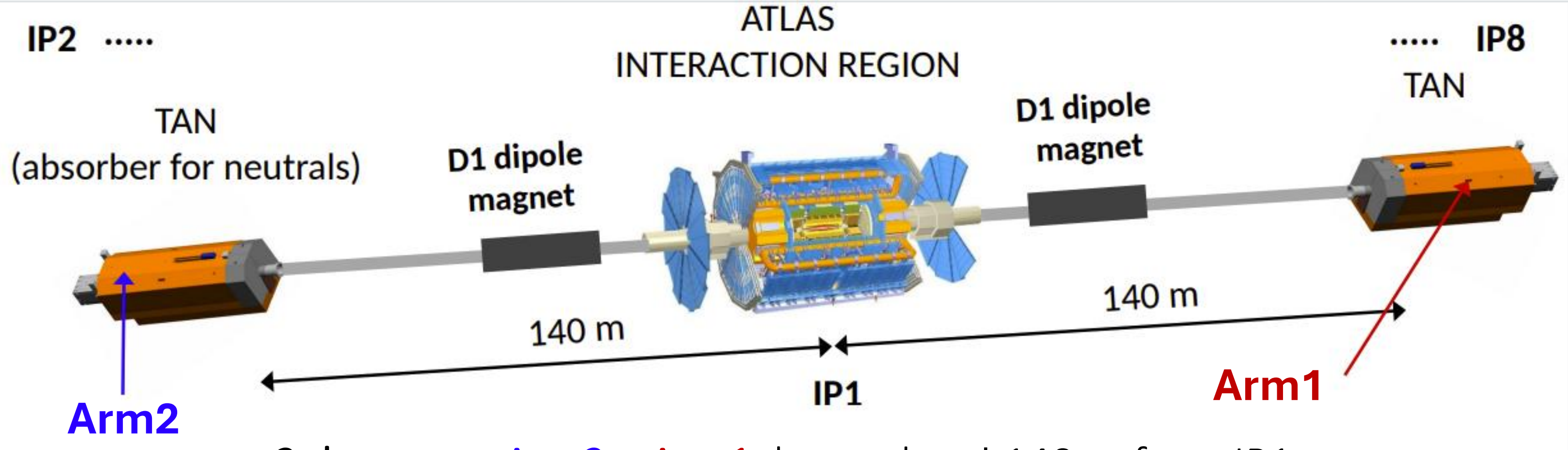

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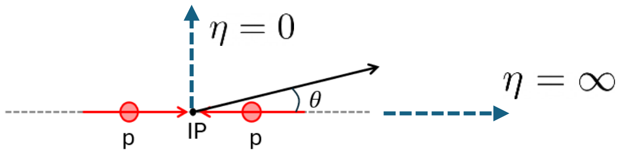
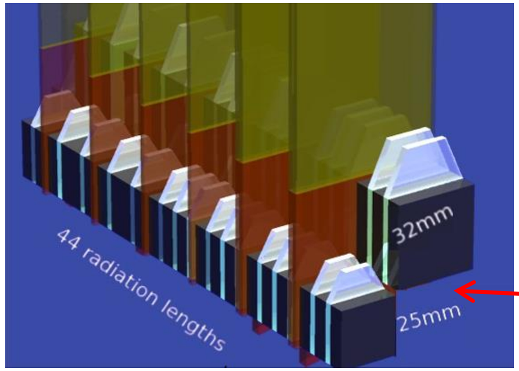


Measurement of the forward n, π^0, η… production rate in LHC collisions at different center of mass energies

- p-p at $\sqrt{s} = 0.9, 2.76, 7, 13, 13.6$ TeV
- p-Pb at $\sqrt{s_{NN}} = 5.02, 8.1$ TeV
- Next Run in 2025 **p-O** at $\sqrt{s_{NN}} \sim 9.9$ TeV

The detector



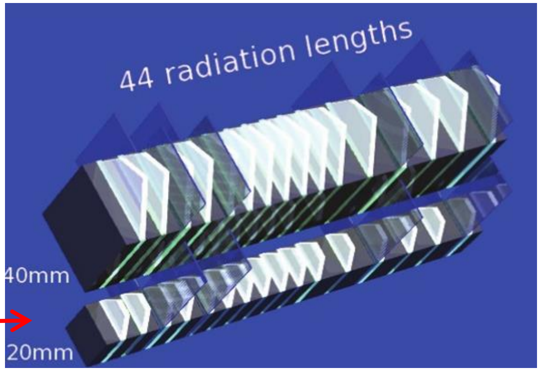
Arm2 and Arm1

2 sampling and **imaging calorimetric towers**

primary interaction products

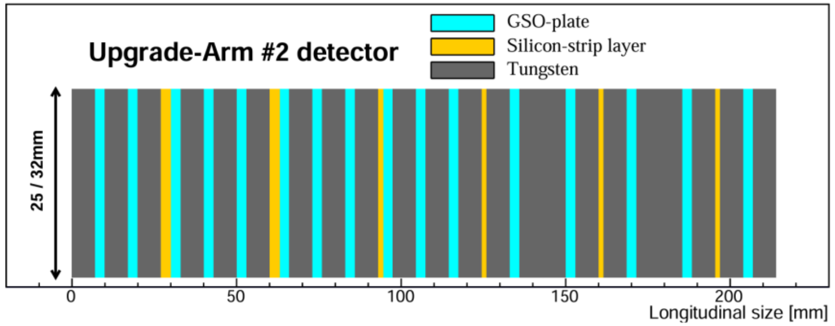
IP1

primary interaction products



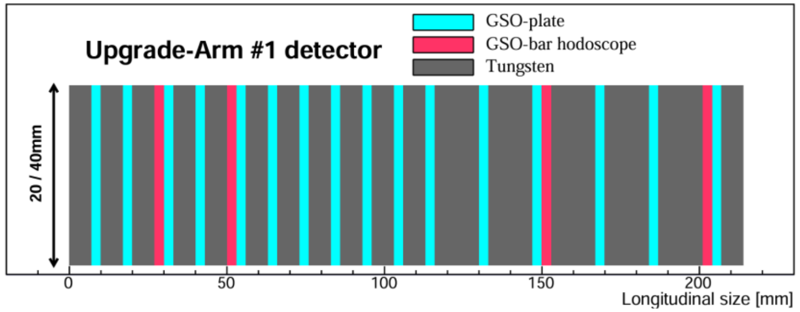
ARM2

IP1



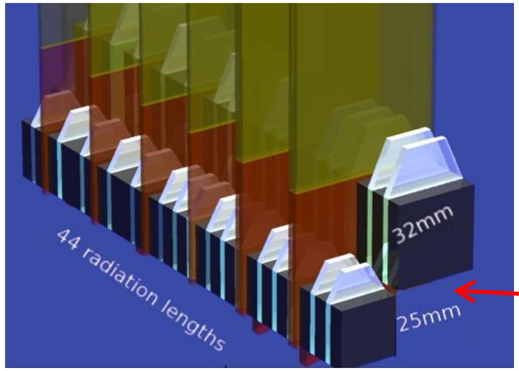
ARM1

IP1



Total depth of the towers: $\sim 21\ \mathrm{cm},\ \sim 44\ X_0, \sim 1.6\ \lambda_I$

The detector



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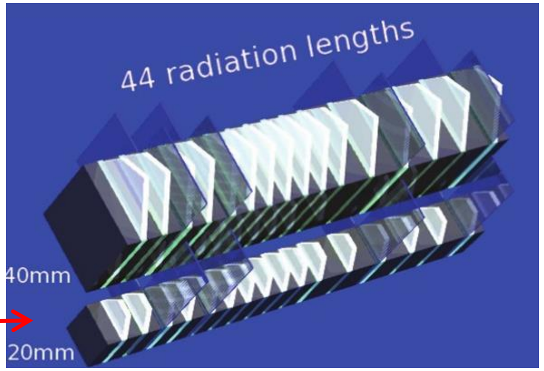
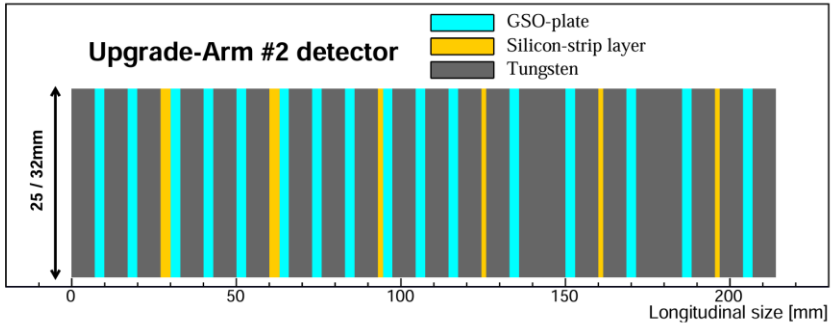


ARM2

IP1



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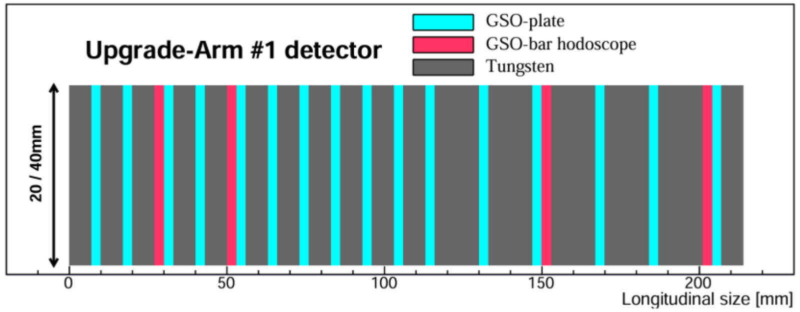


Total depth of the towers: ~ 21 cm, $\sim 44\ X_0$, $\sim 1.6\ \lambda_I$

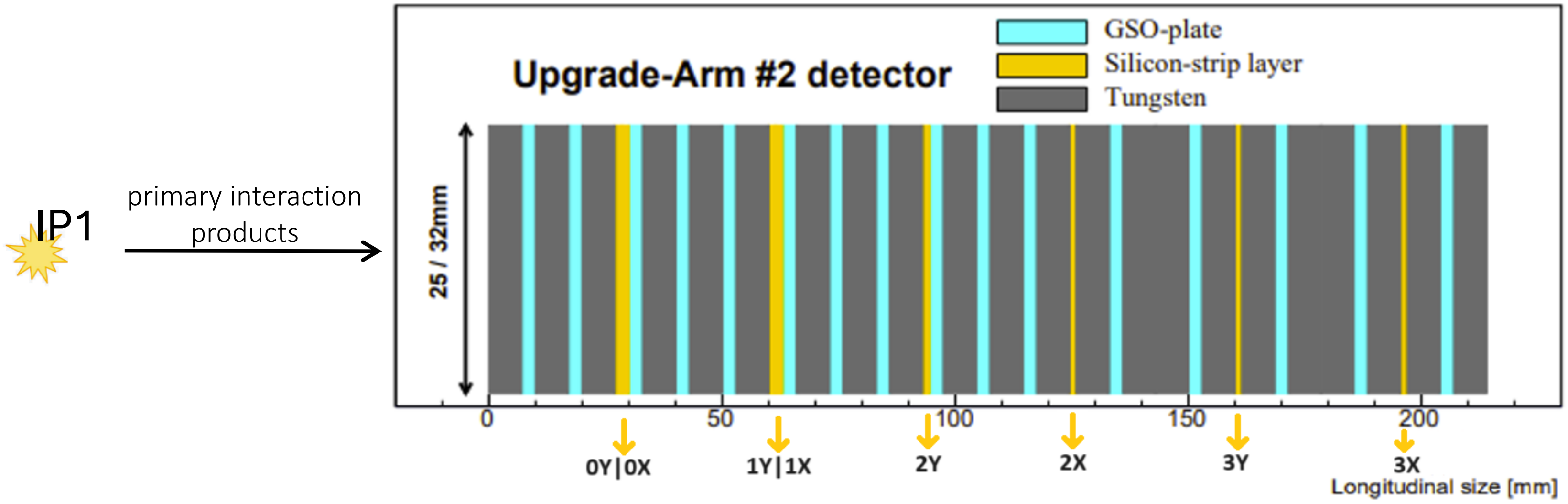
Energy resolution $< 2\%$ for γ above 100 GeV

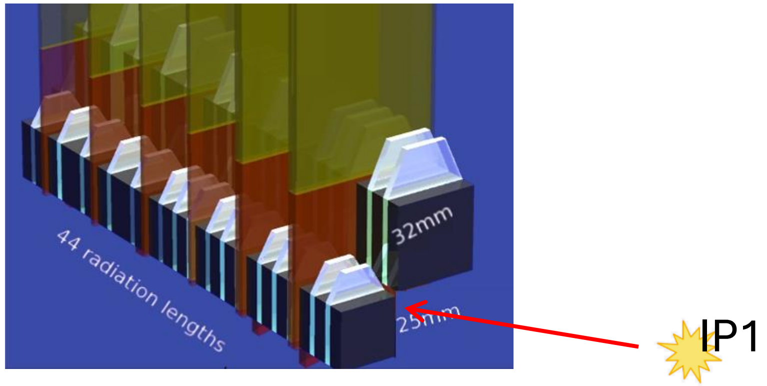
Position resolution $< 40\ \mu\text{m}$ for γ above 100 GeV

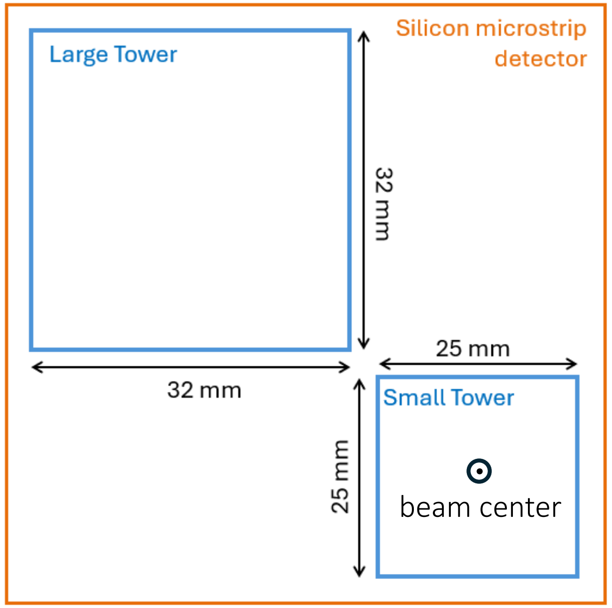
Energy resolution $< 2\%$ for γ above 100 GeV

Position resolution $\sim 200\ \mu\text{m}$ for γ above 100 GeV

The Arm2 detector







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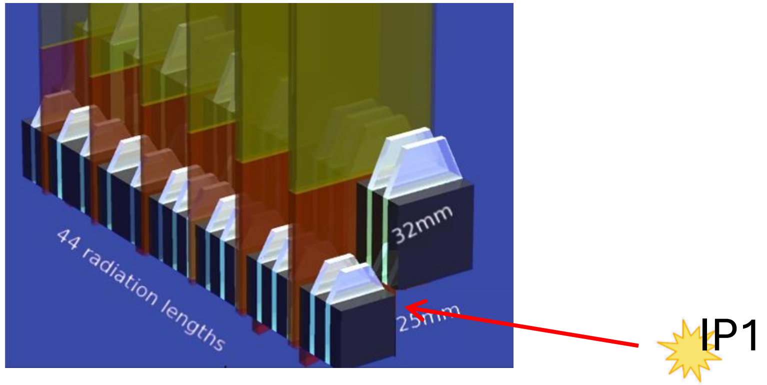
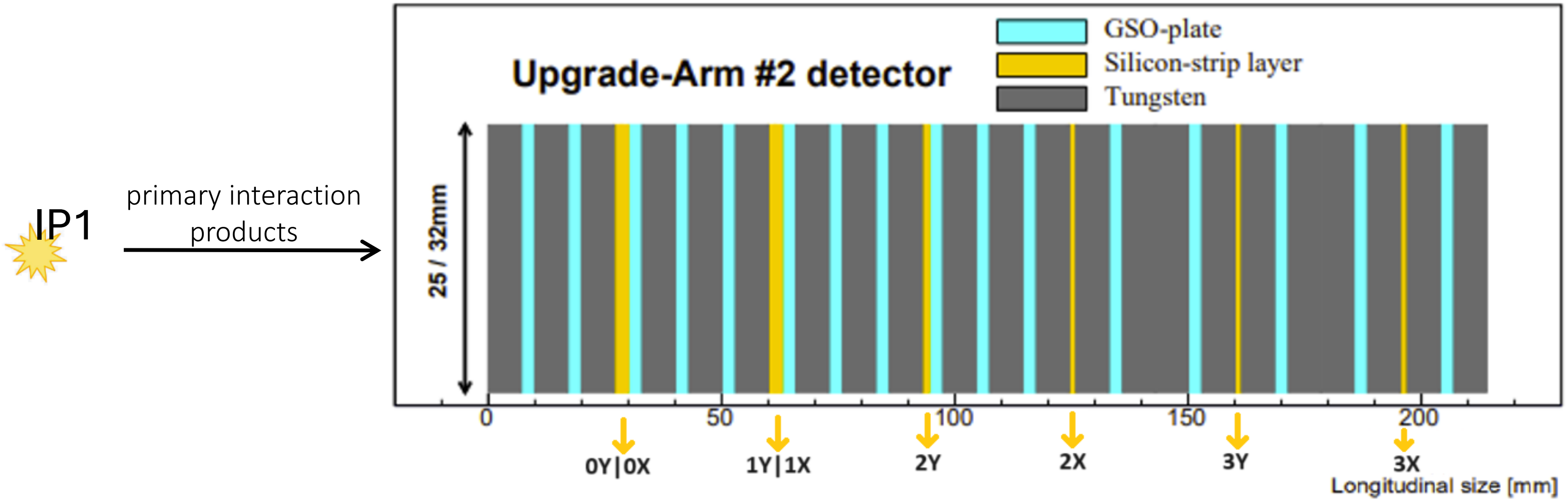
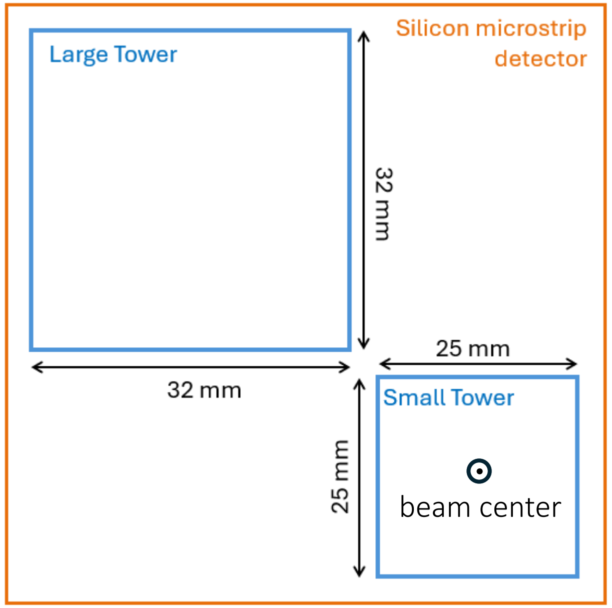
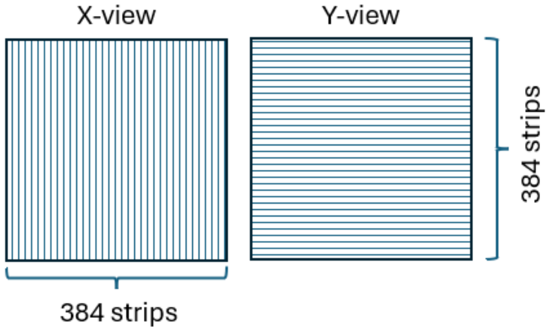


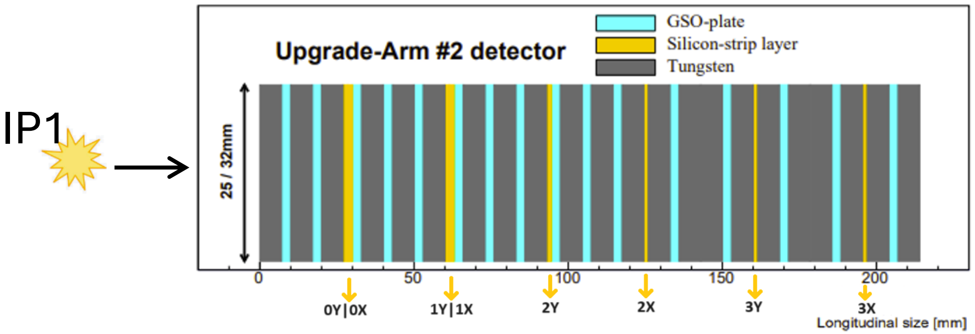


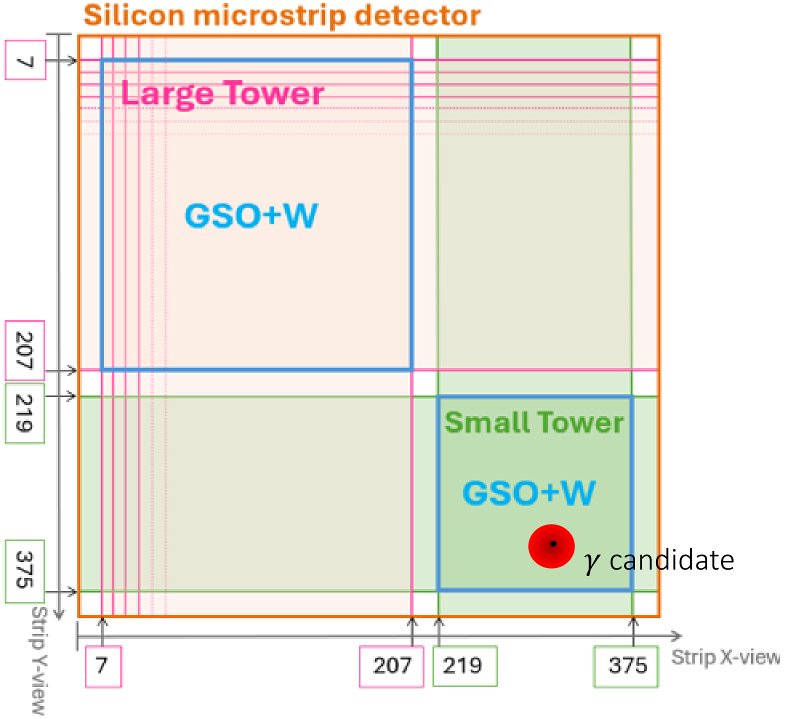


- **16** layers of **<u>GSO scintillator</u>** (for each tower): <u>energy</u> reconstruction
- **8 <u>silicon microstrip</u>** layers, 4 x-views and 4 y-views: reconstruction of the shower <u>transverse profile</u>

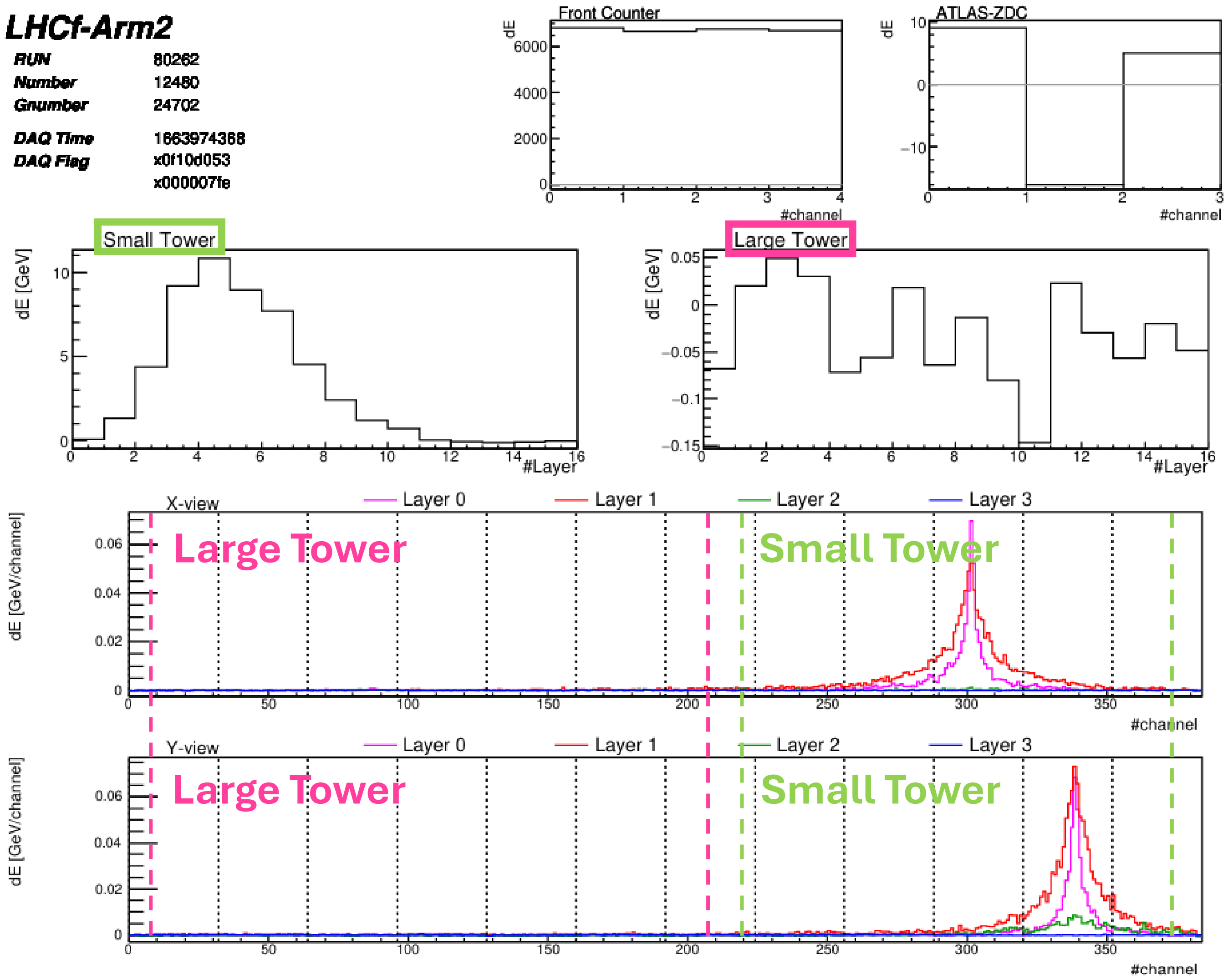


An event in Arm2



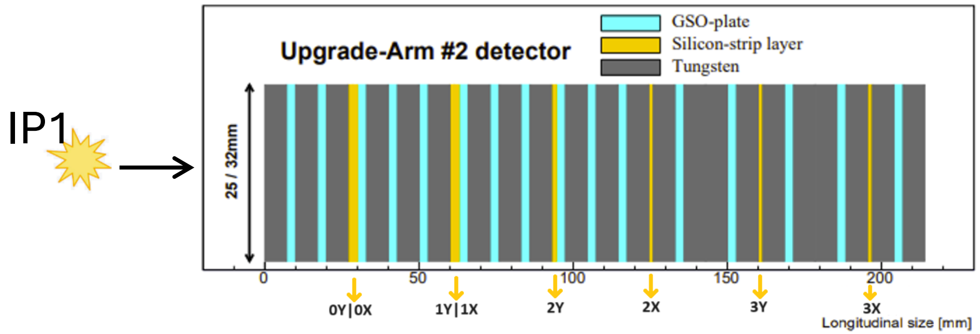


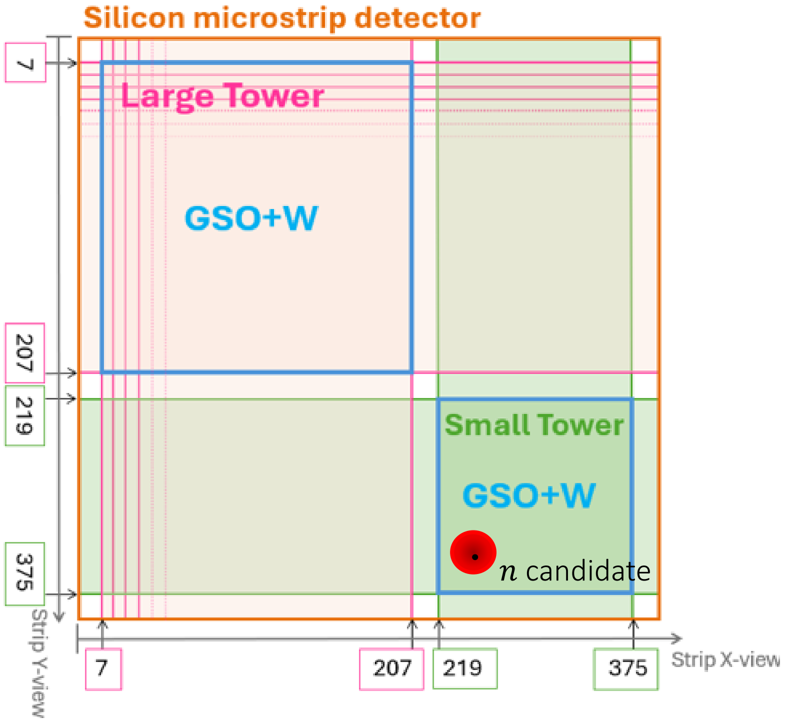
Event: γ candidate in Small Tower

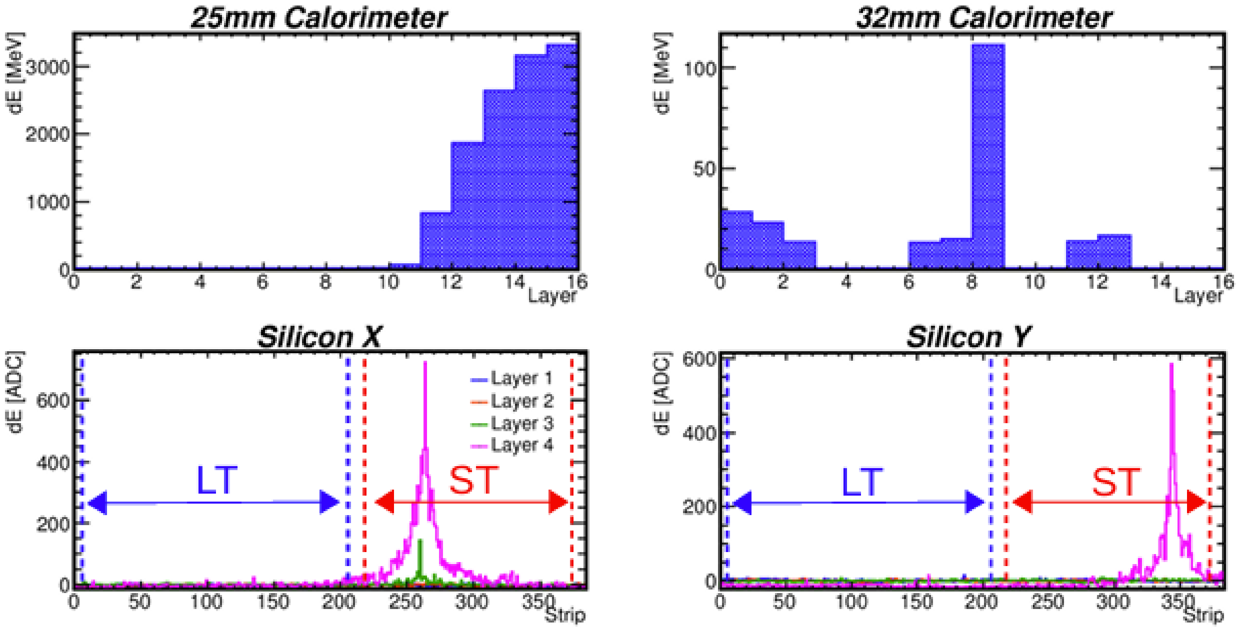


An event in Arm2

Event: n candidate in Small Tower







EM-hadronic shower discrimination

Total depth of the towers: ~ 21 cm, $\sim 44\ X_0$, $\sim 1.6\ \lambda_I$

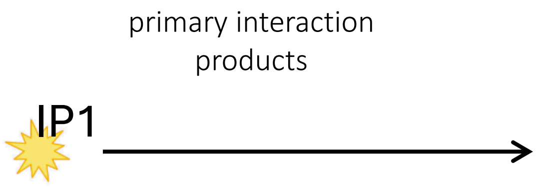
Every information from every GSO and silicon layers of Arm2

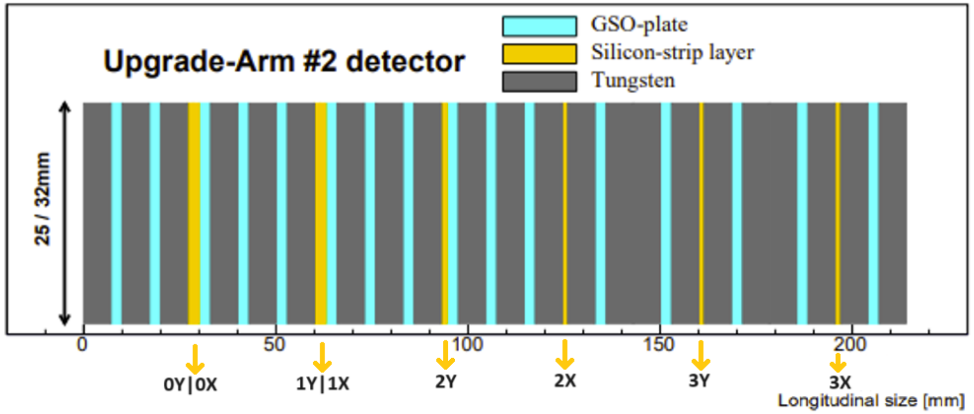
Discriminate between **hadronic** and **electromagnetic** shower

↓

Discriminate between incident **hadrons** (such as neutrons) and incident **photons**

EM-hadronic shower discrimination





Total depth of the towers: $\sim$21 cm, $\sim 44\ X_0$, $\sim 1.6\ \lambda_I$

Every information from every GSO and silicon layers of Arm2

Discriminate between **hadronic** and **electromagnetic** shower

↓

Discriminate between incident **hadrons** (such as neutrons) and incident **photons**

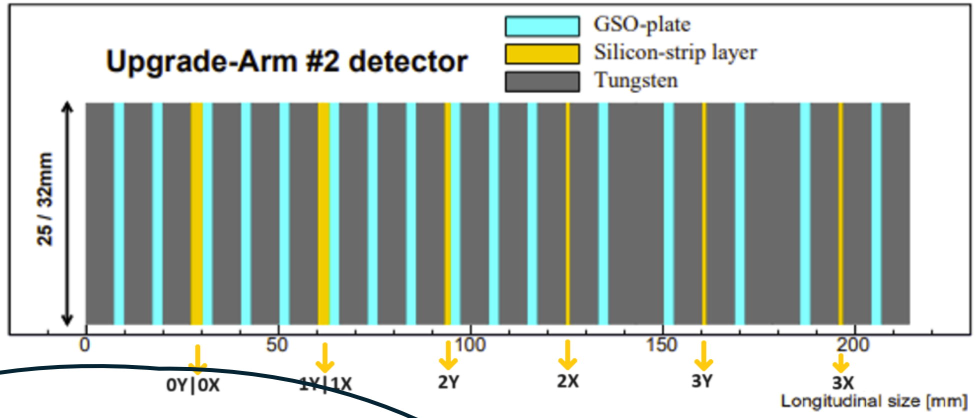
Qualitative features of showers

- **EM showers**: early development in the calorimeter and longitudinally cointained in $\sim$20-30 X_0
- **Hadronic showers**: late development in the calorimeter and longitudinally contained in $\sim 10\ \lambda_I$

EM-hadronic shower discrimination

primary interaction products

IP1



Total depth of the towers: $\sim$21 cm, $\sim$44 X_0, $\sim$1.6 λ_I

Every information from every GSO and silicon layers of Arm2

Discriminate between **hadronic** and **electromagnetic** shower

↓

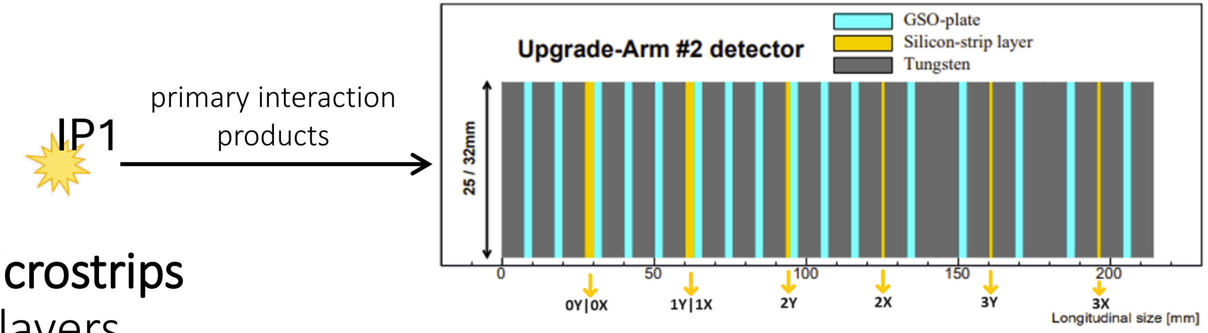
Discriminate between incident **hadrons** (such as neutrons) and incident **photons**

WE CAN USE ML TO DO IT !!!

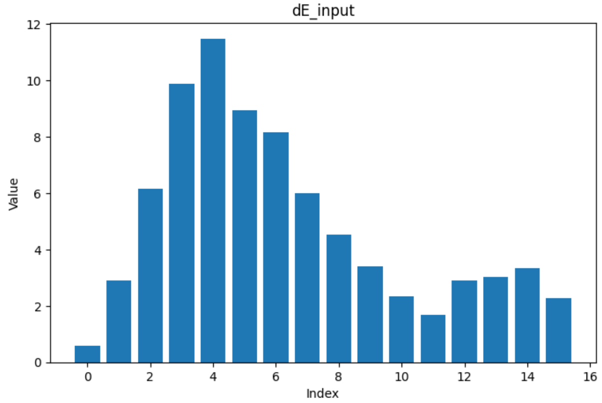
Qualitative features of showers

- **EM showers**: early development in the calorimeter and longitudinally cointained in $\sim$20-30 X_0
- **Hadronic showers**: late development in the calorimeter and longitudinally contained in $\sim$10 λ_I

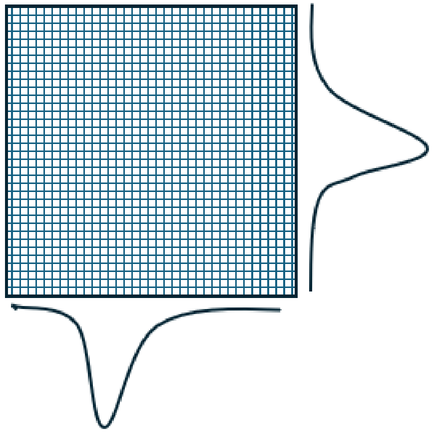
Input data from Arm2



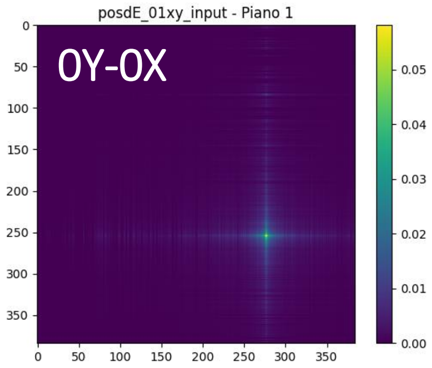
dE in 16 layers GSO scintillator

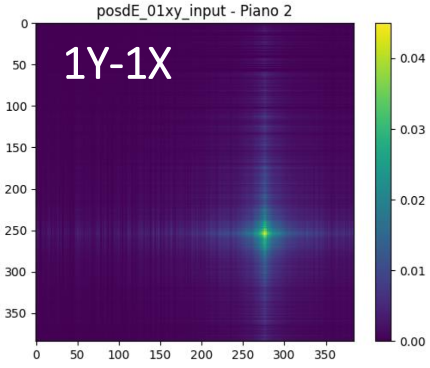


dE/strip in silicon microstrips
0Y-0X and 1Y-1X layers

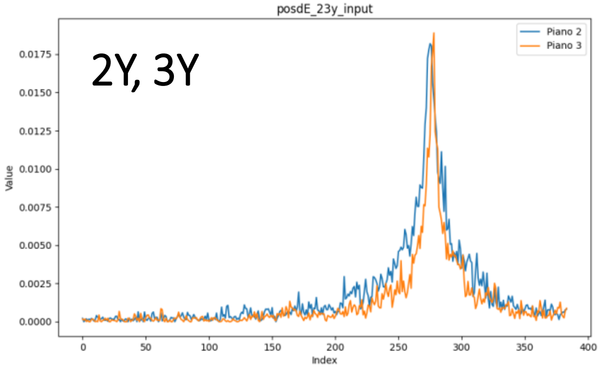


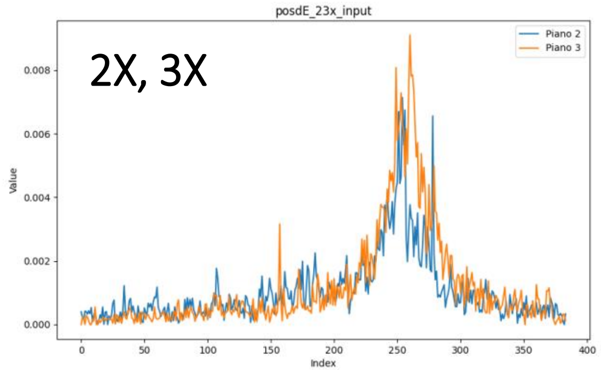
$$\sqrt{dE_{x,i} \cdot dE_{y,j}} \qquad i, j = 0, ..., 383$$



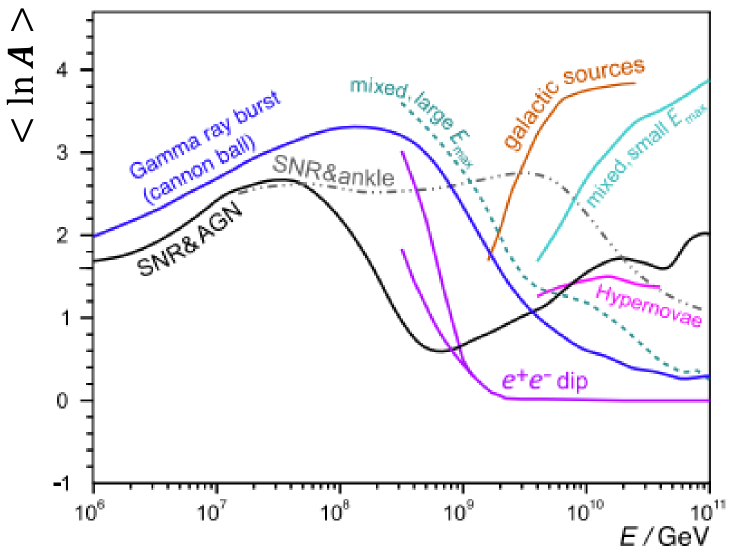


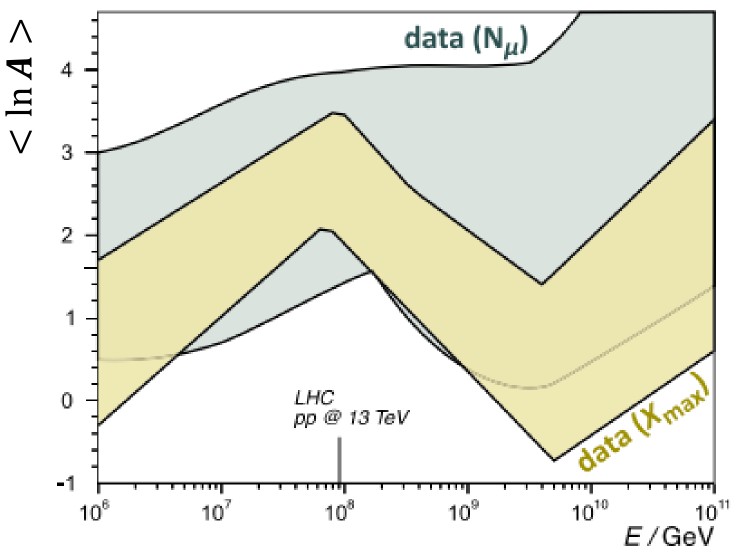
dE/strip in silicon microstrips
2Y, 2X, 3Y, 3X layers





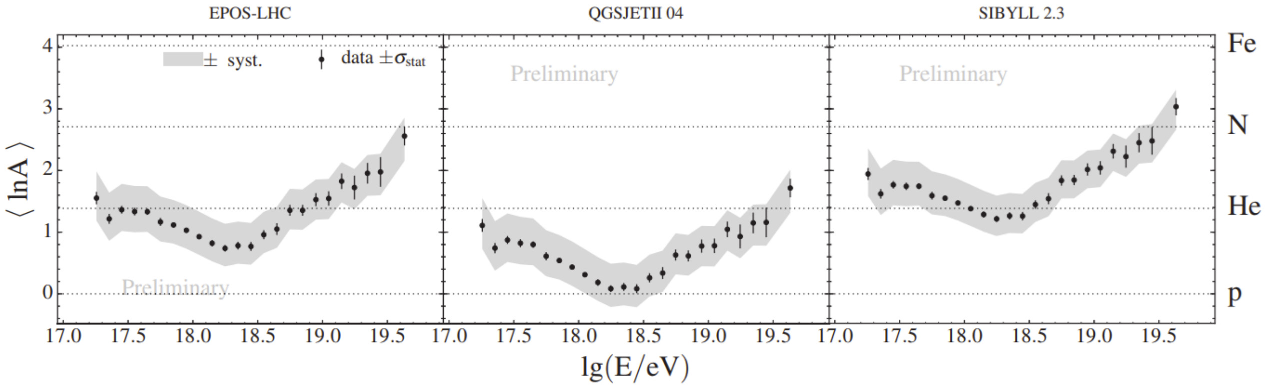
Misure di composizione (UHECR)





X_{max} → profondità di max sviluppo sciame

N_μ → n° μ nello sciame



Misure di composizione (UHECR)

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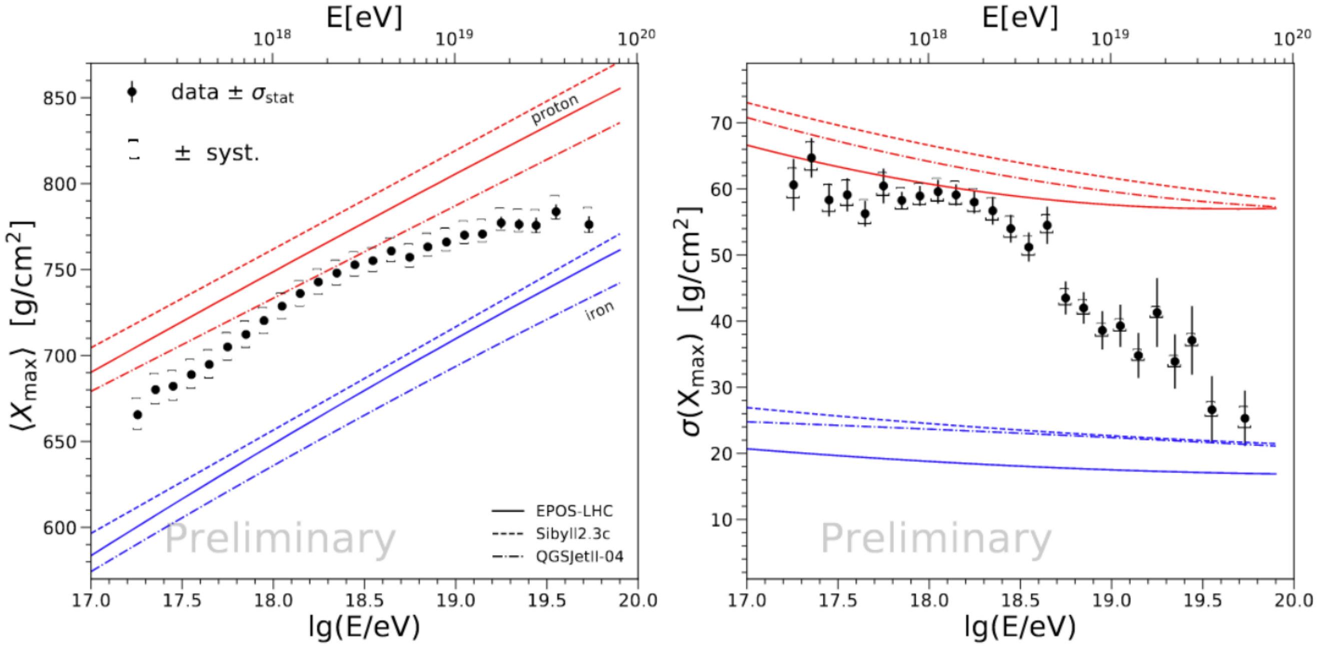

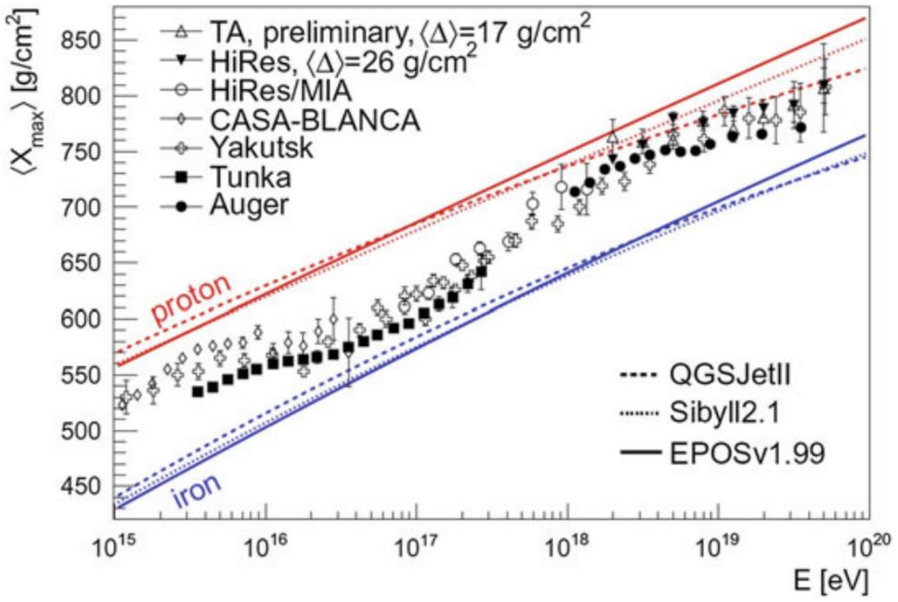

$X_{max} \rightarrow$ profondità di max sviluppo sciame

Modelli di interazione adronica (Muon Puzzle)