Read out electronics for the ALICE Forward Calorimeter (FoCal)

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for the Brazilian ALICE community

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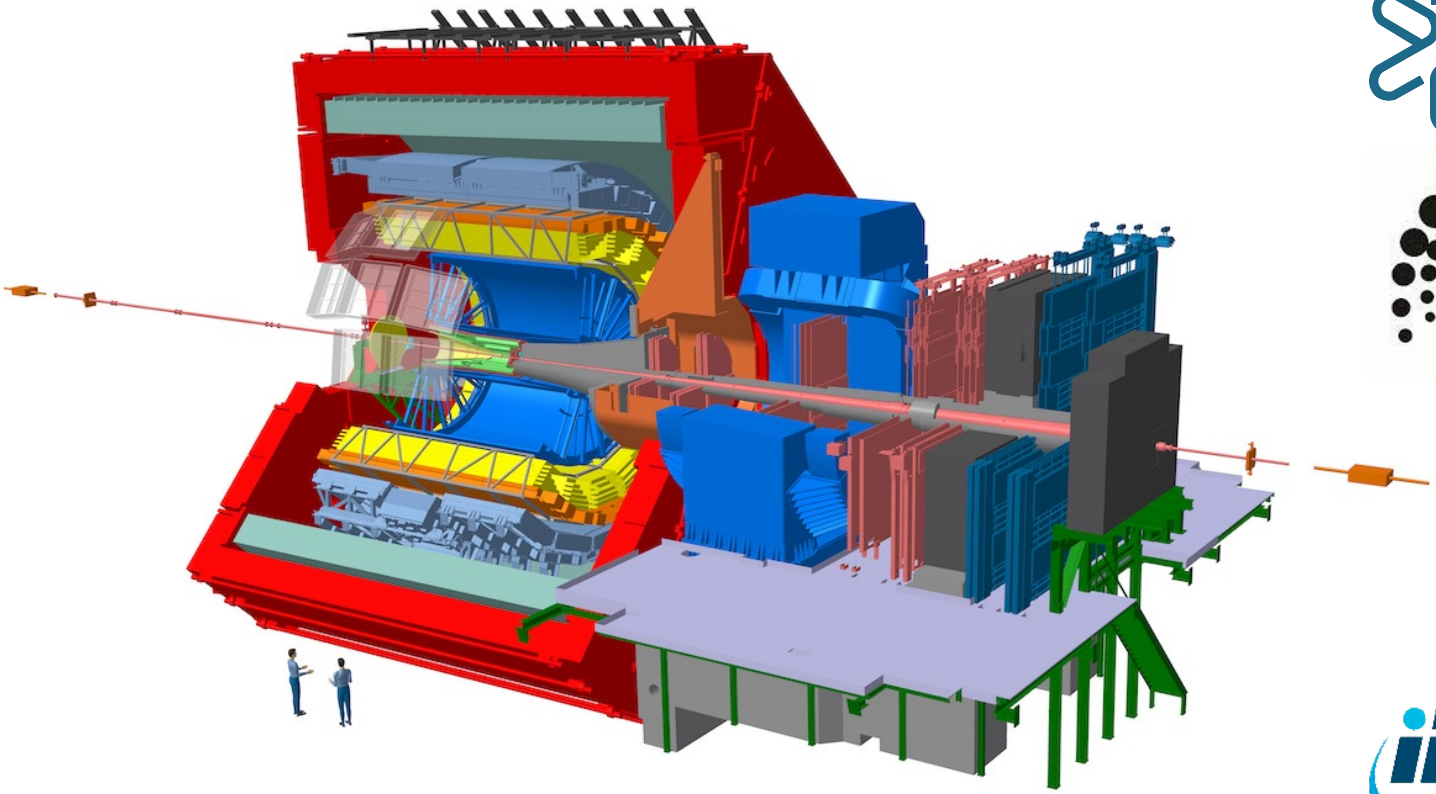
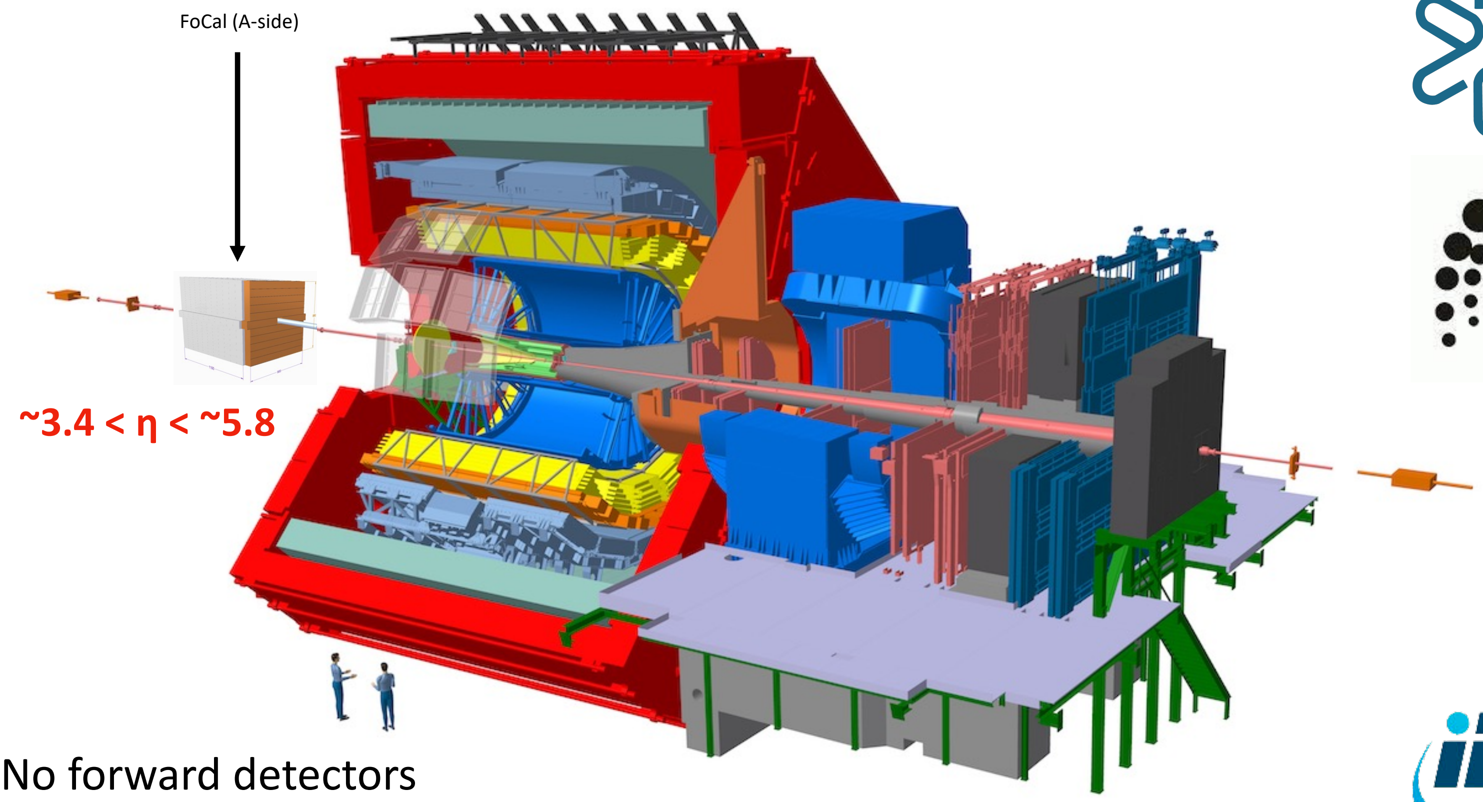
Brazil in the ALICE experiment

Today's layout



Brazil in the ALICE experiment



IFUSP Instituto de Física da USP

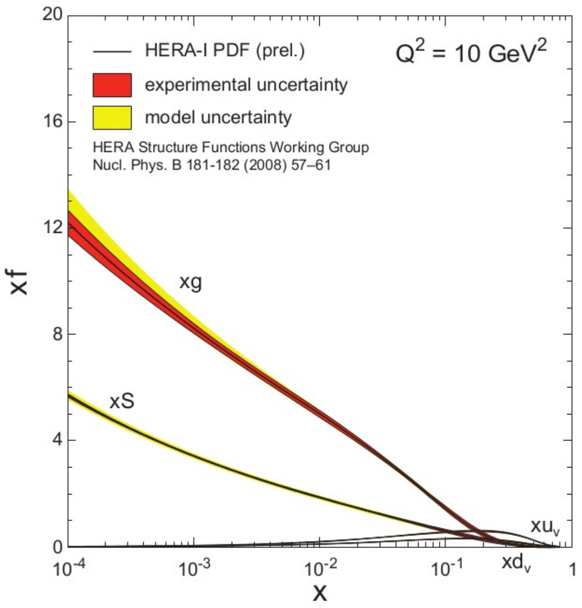
IFGW Instituto de Física Gleb Wataghin

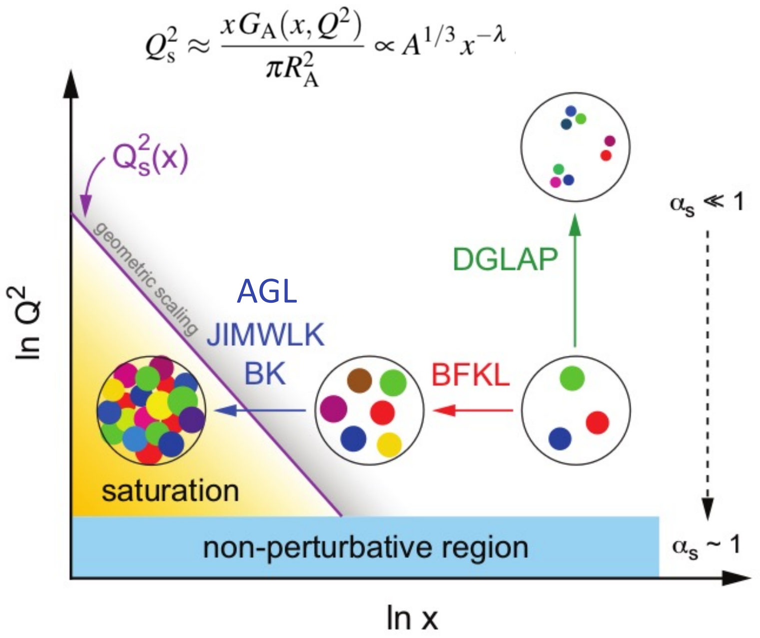
Universidade Federal do ABC

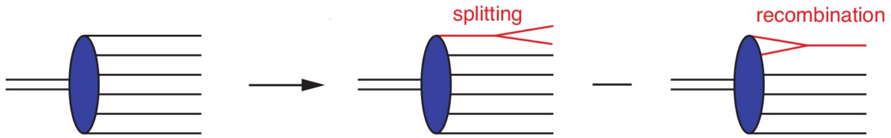
Instituto de Física

No forward detectors
on A-side => FoCal proposal

Main physics motivation: Gluon PDF at small x



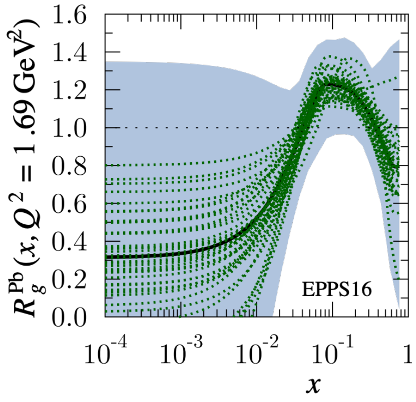


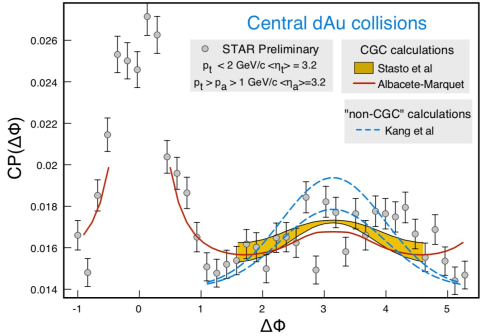


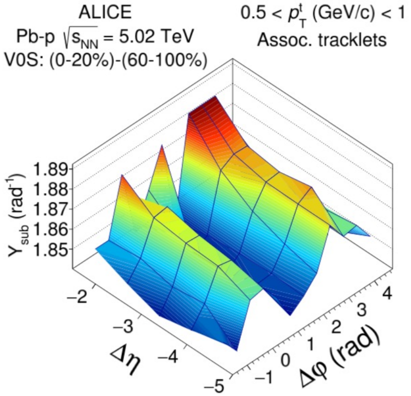
- Rise of gluon density natural for linear QCD evolution describing parton splitting
- Expected to be tamed by non-linear QCD evolution functions describing parton recombination, perhaps leading to saturation at the saturation scale Q_s

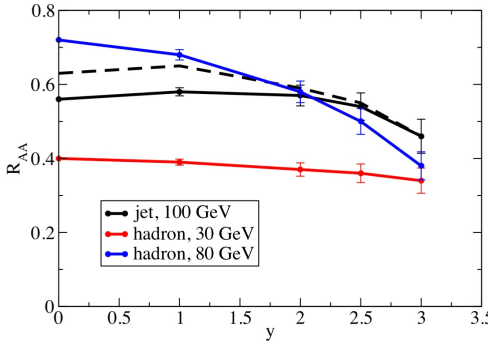
Physics programme a forward calorimeter

- Quantify nuclear modification of the gluon density at small-x
  - Isolated photons in pp and pPb collisions
- Explore non-linear QCD evolution
  - Azimuthal π^0-π^0 and isolated photon-π^0 (or jet) correlations in pp and pPb collisions
- Investigate the origin of long range flow-like correlations
  - Azimuthal π^0-h correlations using FoCal and central ALICE (and muon arm) in pp and pPb collisions
- Explore jet quenching at forward rapidity
  - Measure high p_T neutral pion production in PbPb
- Other measurements
  - Jets and dijets in pp/pPb and UPC
  - Quarkonia in UPC (and pp*)
  - Photon and pion HBT (*)
  - W,Z in pp/pPb?
  - Isolated photons in PbPb (*)
  - Measurements at 14 TeV
    - Universality at small-x
    - Saturation in pp



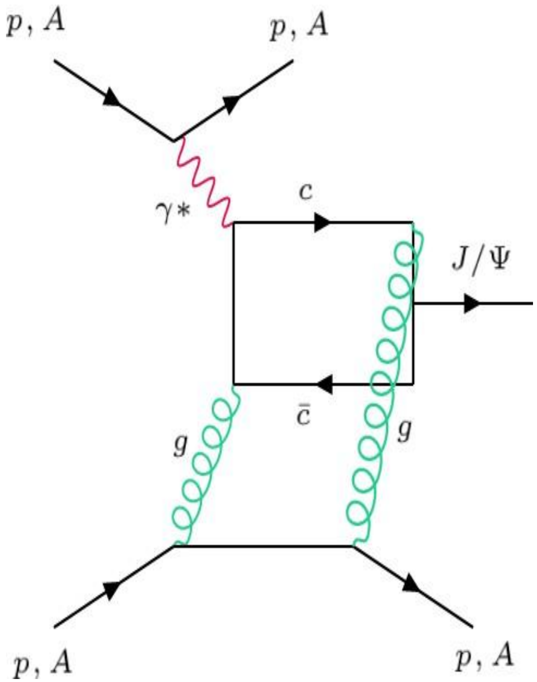






One example of interesting measurement

J/ψ photoproduction in ultra-peripheral p-Pb collisions



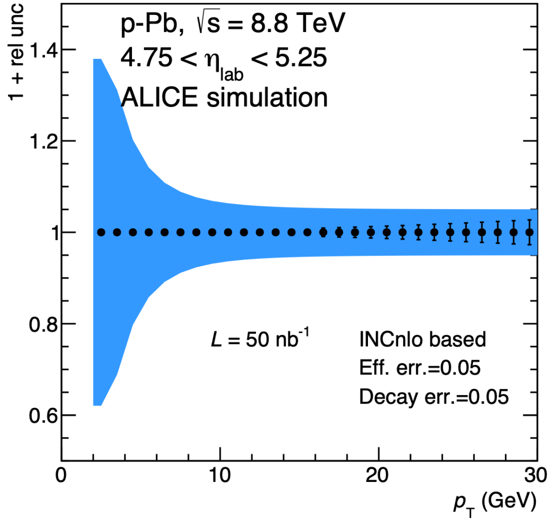
A possibility to investigate the gluon saturation by measuring J/ψ in the forward region:

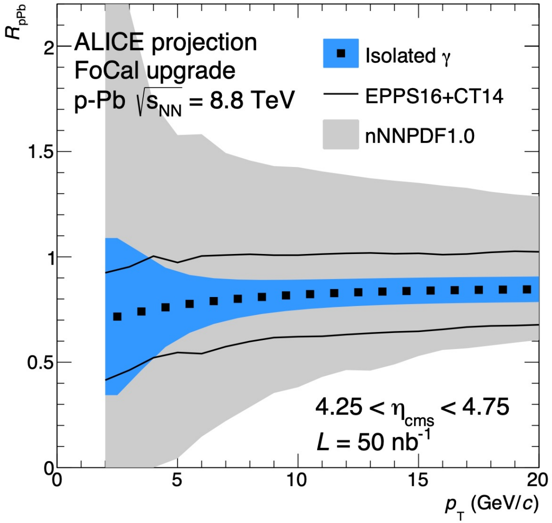
FoCal will allow to detect J/ψ decaying in lepton/antilepton.

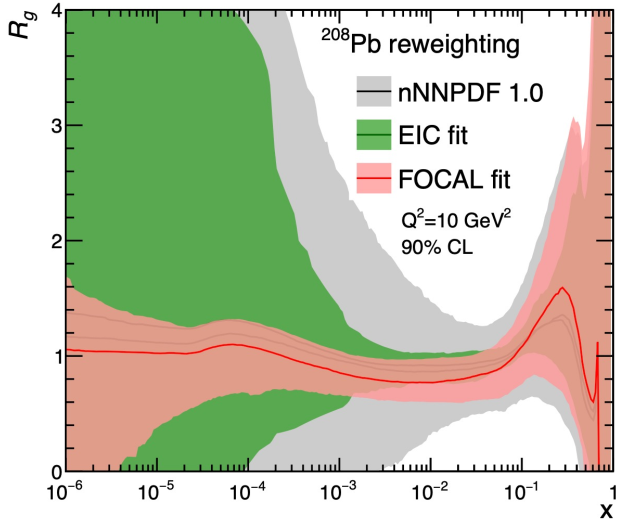
Available experimental results already point to saturation effects, as well as not perturbative nature of QCD theory when x goes smaller ($x \rightarrow 10^{-6}$)
Strong interest in experimental results for $x<10^{-6}$ to better constrain nuclear PDF.

Expected performance an impact on nPDF

R. Khalek et al., arXiv:1904.00018





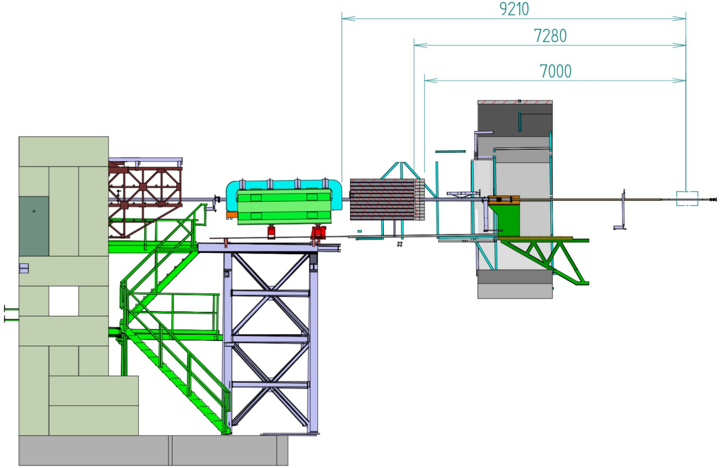


- Systematic uncertainty ~20% at ~4 GeV
- Below ~6 GeV, uncertainty rises due to remaining background

- Significant improvement (up to factor 2) on EPPS16 gluon PDF
- Similar improvement as from open charm
  - Test factorization/universality
- Below 4 GeV: challenging regime
  - Also measure direct photons by statistical subtraction

Recent nuclear PDFs: nNNPDF from DIS and minimal theoretical assumptions
- No constraints for $x < 10^{-2}$ from DIS
- FOCAL provides significant constraints over a broad range: ~10^{-5} - 10^{-2}
- Outperforming the EIC for $x < 10^{-3}$

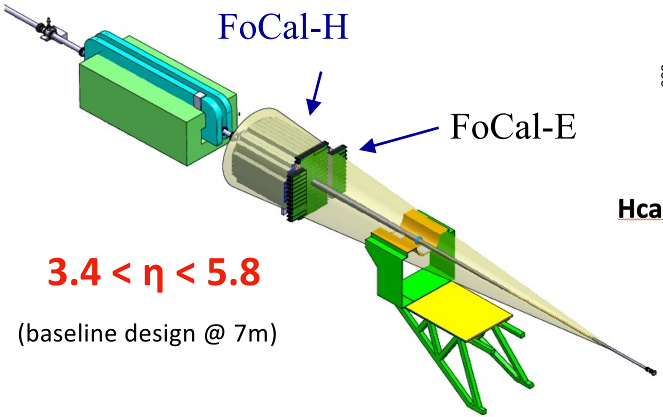
FoCal Proposal



FoCal-E: high-granularity Si-W sampling calorimeter for photons and π^0

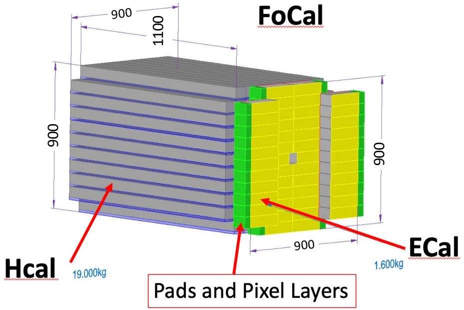
FoCal-H: conventional metal-scintillator sampling calorimeter for photon isolation and jets

Observables:
- π^0 (and other neutral mesons)
- Isolated (direct) photons
- Jets (and di-jets)
- J/ψ (Υ) in UPC
- W, Z
- Event plane and centrality

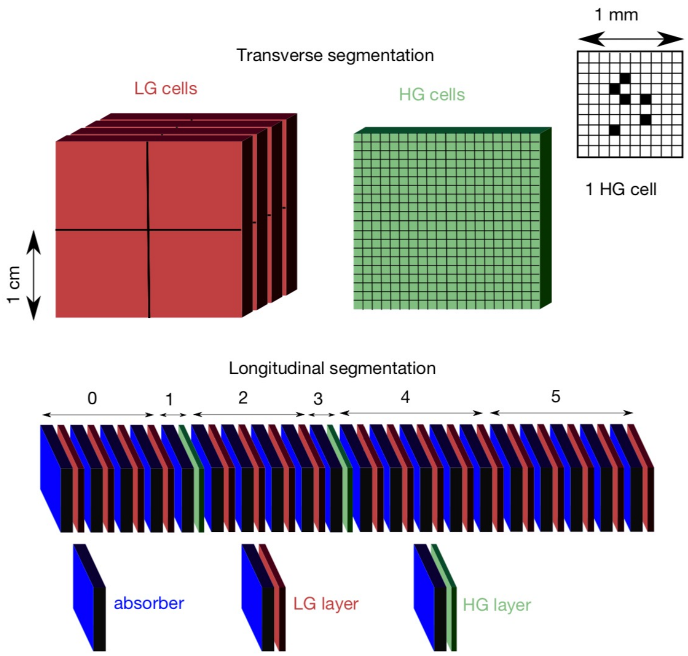


$3.4 < \eta < 5.8$

(baseline design @ 7m)



FoCal-E conceptual design



- Main challenge: Separate γ/π^0 at high energy
  - Two photon separation from π^0 decay (p_T=10 GeV, η=4.5) ~5mm
  - Requires small Molière radius and high granularity readout
  - Si-W calorimeter with effective granularity ≈ $1mm^2$

Studied in simulations 20 layers:

W(3.5 mm ≈ $1X_0$) + silicon sensors

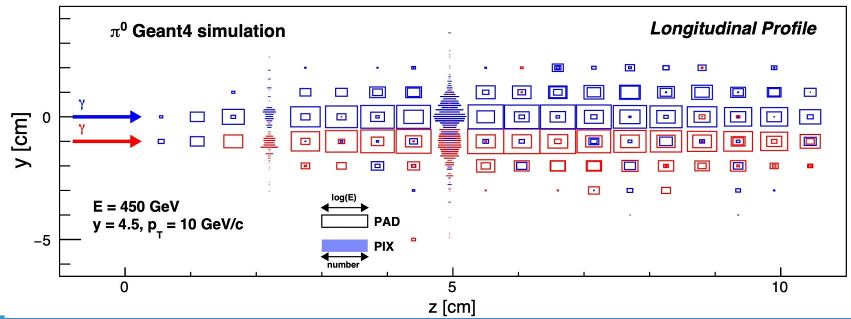
Two types: Pads (LG) and Pixels (HG)

- Pad layers provide shower profile and total energy
- Pixel layers (ALPIDE) provide position resolution to resolve overlapping showers

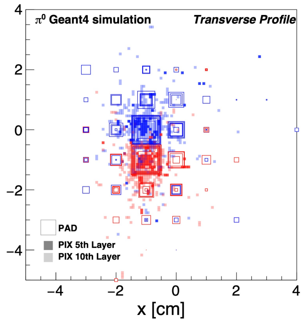
Final layout optimization ongoing for TDR:

- Location of pixel layers
- Number of pad layers
- Sensitive area at front for CPV/eID
- Conflicts with other detectors and services.

Longitudinal profile (2γ showers)



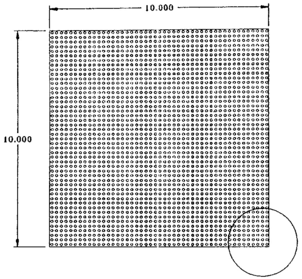
Trans. profile

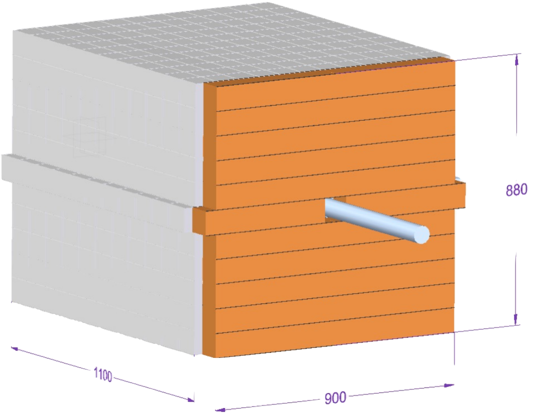


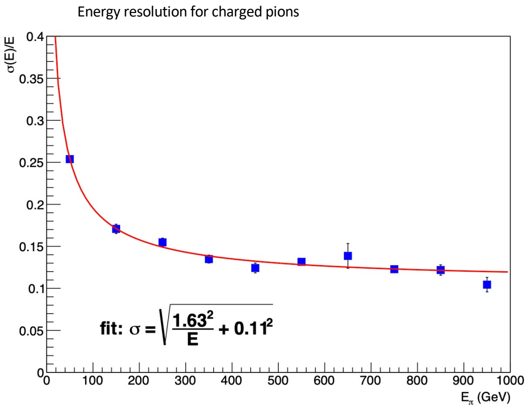
FoCal-H conceptual design

Geometry can be based on
SPACAL design: spaghetti calorimeter

Nuclear Instruments and Methods in Physics Research A 406 (1998) 227–258







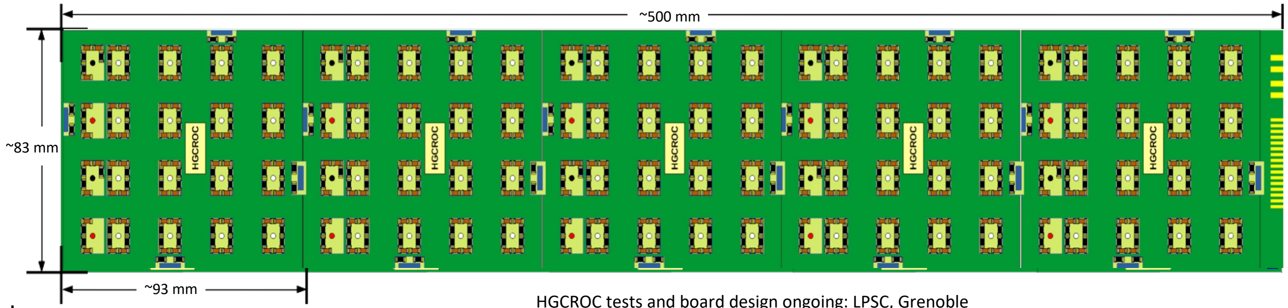
- Simulation uses sandwich-structure:
  - 34 layers of 3cm absorber and 0.2cm scintillator
- Good performance for isolation and jets
  - Single hadron energy resolution of 10-25%
  - E_T = 2 GeV for isolation about E = 100 GeV at η = 4.5
  - Constant term (e/h compensation) more, sampling-fraction less important
- Conventional metal-scintillator design
  - Sampling / tower structure: copper as metal, understudy if stacked plates capillary tubes (~2 mm diameter)
  - No longitudinal readout required

1.1 m long: ~6 λ_I
Tower size: 2-5 cm
~1k towers

PAD module design

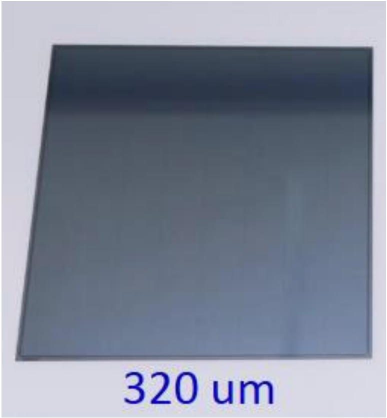
Read-out ASIC: HGCROC (CMS HGCAL)
- 72 channels per chip: ADC + TOT
- Dynamic range: MIP to 2 fC
- Internal buffer; data shipped on readout

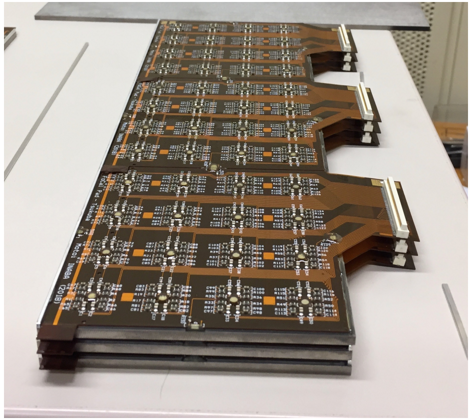
PCB carries 5 sensors (72 pads each), 5 HGCROC: ~50x8.3 cm



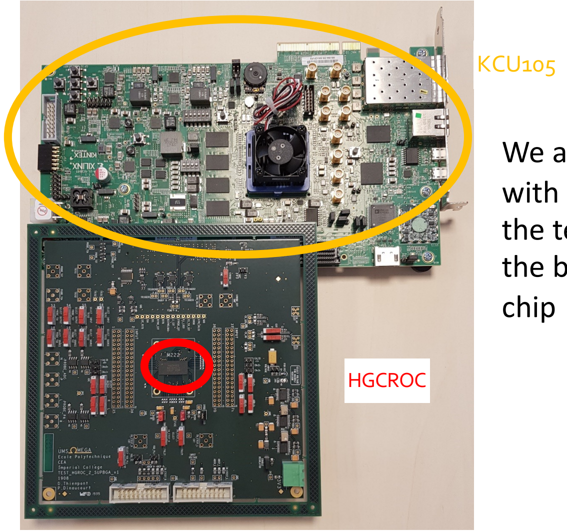
HGCROC tests and board design ongoing: LPSC, Grenoble

sub-module: PCB+Sensors+W plate





Experience with module assembly and design
at Tsukuba Univ., Tsukuba Tech

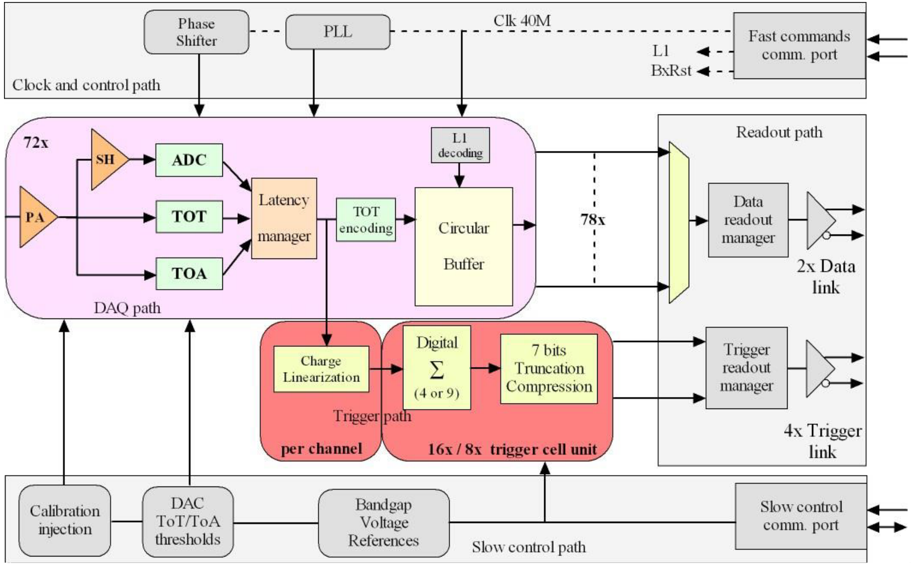


We are collaborating with the LPSC group in the test and qualifying of the board and HGCROC chip

HGCROC

ASIC designed by OMEGA-IN2P3 for HGCAL in CMS

- 72 channels + 4 channels for common mode subtraction + 2 special calibration channels
- 32b Digital Data continuously stored in 512 length DRAM @40MHz
  - 72 ch. x 32b x 40MHz: **huge data volume**
  - ➔ Only **Local-L1-triggered** data are read out
- Idle packet is continuously sent out when no L1-trigger is activated
- The data processing for the trigger "information" path
  - 32b: 4b header + 7b x 4
  - Sum of 4 or **9 channels** depending on the sensor



Brazilian contribution to the Si-Pads electronics

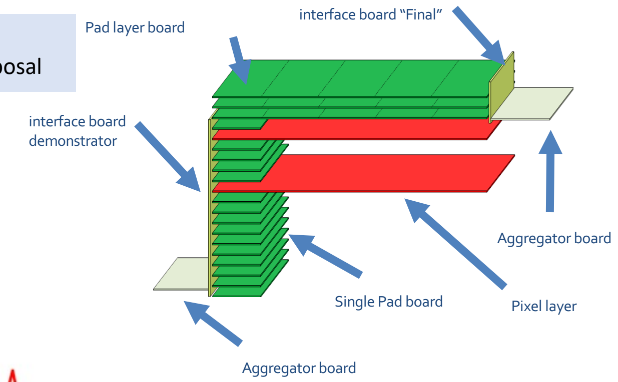
IFUSP and UFRGS have experience in readout electronics and test/validation of detectors, ASICs, and FECs.

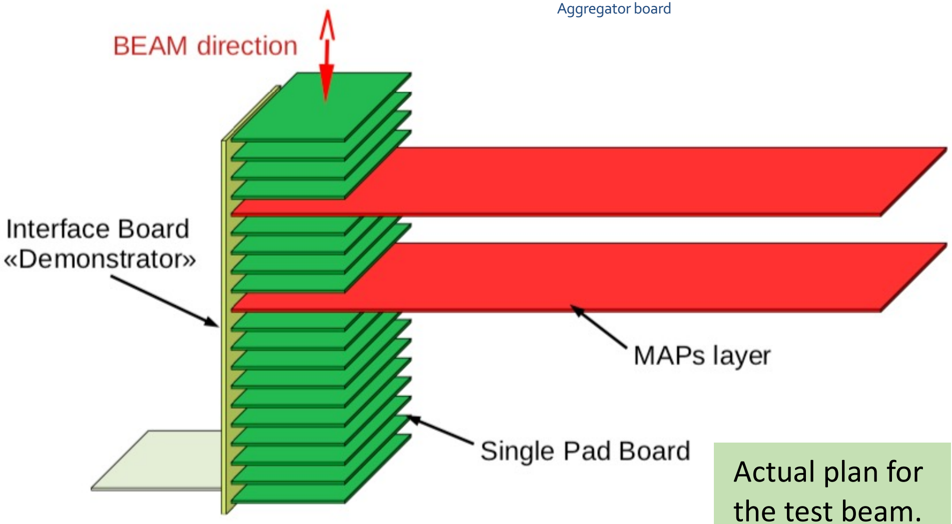
- Test stations are going to be mounted at IFUSP (and at UFRGS too, at least a set up for developing protocols and code for test procedures) aiming:
  - "Independent" test and validation of the PAD-readout front-end board
  - Possibility to test the electronics (both the HGCROC and the complete board) against harsh conditions (mainly temperature and radiation)
  - Long term stability and aging tests
  - Qualifying the HGCROC before mounting it on the board

FoCal status: test beam in September

- Pad sensor geometry being optimized
  - pad location for better coupling with the electronics
- Starting analysing the finest details of integration (e.g. cables “invading”, narrowing, the corridor to go inside the L3 magnet, to the inner detectors)
- Prototyping the front-end boards, as well as interface boards to DAQ
- Possibility to generate a trigger still under study
- Pandemic introduced, it is still introducing, several delays for all labs (a bit more for us in Brazil)
- A test beam is presently scheduled for late September:
  - Testing in real conditions the “unitary” board (1 sensor, 72 pads), as well as interface to DAQ
  - Testing integration PAD-Pixels
  - Studying the performance of the 18 (LG) + 2 (HG) stack, and the effects of the gaps due to the electronic boards

Original, more ambitious proposal





Actual plan for the test beam.

Summary

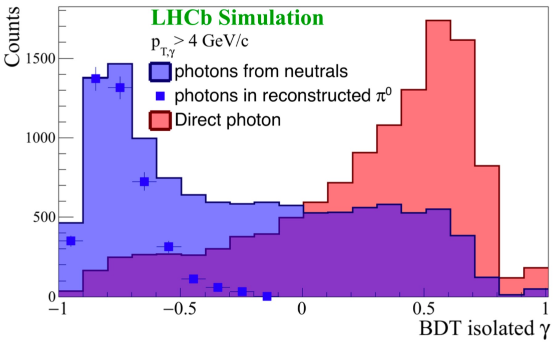
Project	Alice FoCal (Read-out electronics for the Si-Pads detector)
Institutions	*Brazil*: IF/USP; IFGW/UniCamp; UFABC; IF-UFRGS. *main international collaborators*: LPSC (Fr); Tsukuba (Jp).
Timeline	2021: R&D (prototyping FECs, testbeam, etc.) 2022: TDR 2023: finalizing & freezing the design 2024-2026: construction and test of modules 2025-???: pre-assembling and calibration; Installation and commissioning
Cost and funding	contribute to the construction of the low granularity (Si-PADs) readout: ≈150 kCHF, submitted to FAPESP (as part of a wider 'tematico' project presently under evaluation)
possible synergies	sharing experience in testing and validating ASIC and read-out electronics. Development of dedicated boards/circuits for dedicated tests. Sharing experience on FPGAs use.
possible spin-off	Yes, generic. In the context of development of ASIC and Readout systems (electronics for local application; build up experience and partnership for future activities)

Backup slides

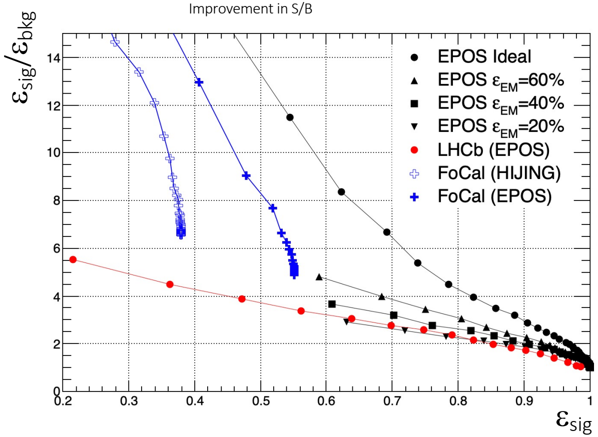
FoCal vs LHCb: sensitivity to nPDF

LHCb-FIGURE-2020-006

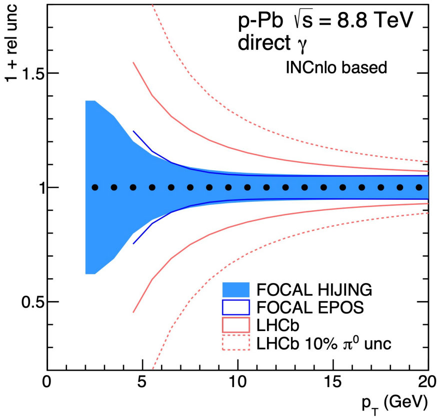
BDT response



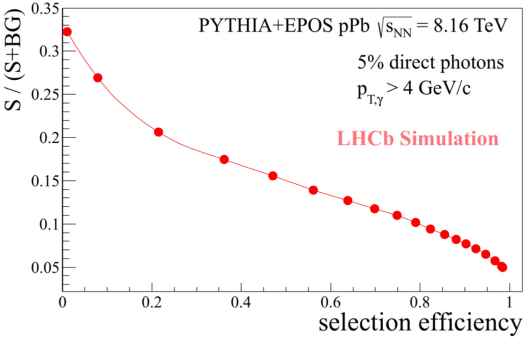
Improvement in S/B



Performance in pPb



Purity vs efficiency of BDT cut



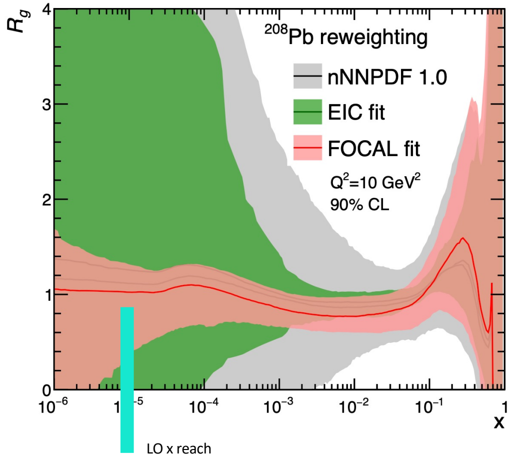
- LHCb analysis approach: identify signal by BDT based on a combination of variables, e.g. isolation energy
- Improvement in S/B significantly smaller than of FoCal
- Leads to factor 2 or larger systematic uncertainty compared to FoCal
  - Expected performance depends on uncertainty on remaining background

(WP at ε_{sig}=0.2 for LHCb,

at ε_{sig}~0.4 for FoCal)

FoCal vs LHCb: sensitivity to nPDF

η=4.5 (FoCal)

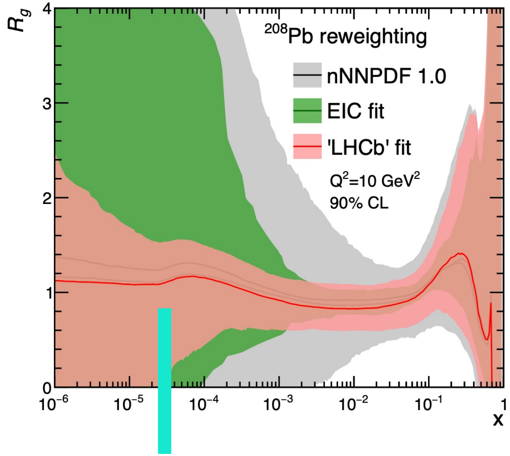


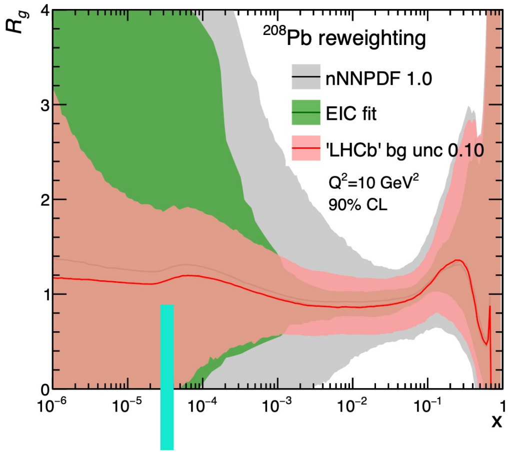
LO x reach

$$x \approx \frac{Q}{\sqrt{s}} \exp(-y)$$

FoCal uncertainties

η=3.5 (LHCb)



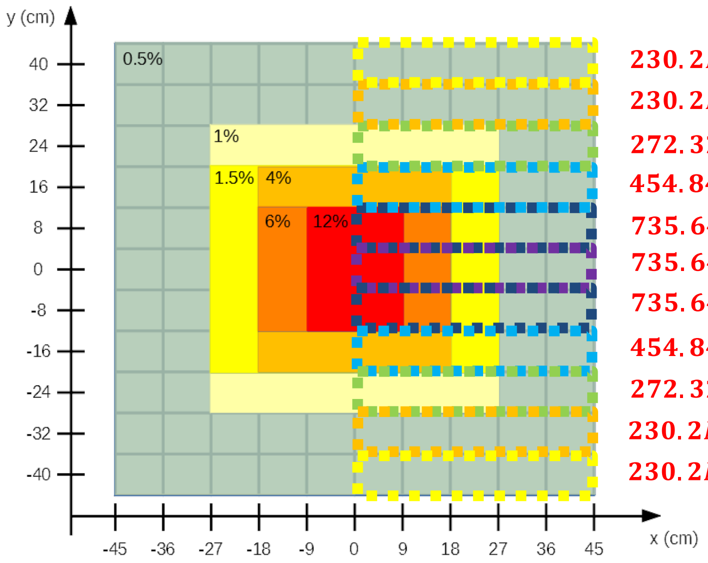


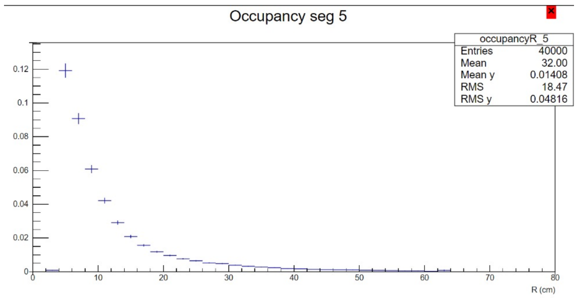
LHCb projected uncertainties
(5% vs 10% uncertainty on the background)

Significantly better performance on nuclear PDF expected by FoCal measurement
(in addition one unit higher reach in pseudorapidity, i.e. factor 3 smaller x reachable)

Data rate estimate: pp@1Mhz

- Data rate estimation for each pad layer





Possible to share GBT-FPGA to several pad layers

➔ **Design for the maximum rate**

→ **@3.2Gb/s with FEC (80b @40MHz)**

→ @4.8Gb/s w/o FEC (112b @40MHz)

➔ **Reduce the number of needed GBT-FPGA**

➔ **Reduce the number of needed CRU**