Forward direct photons with FoCal in ALICE

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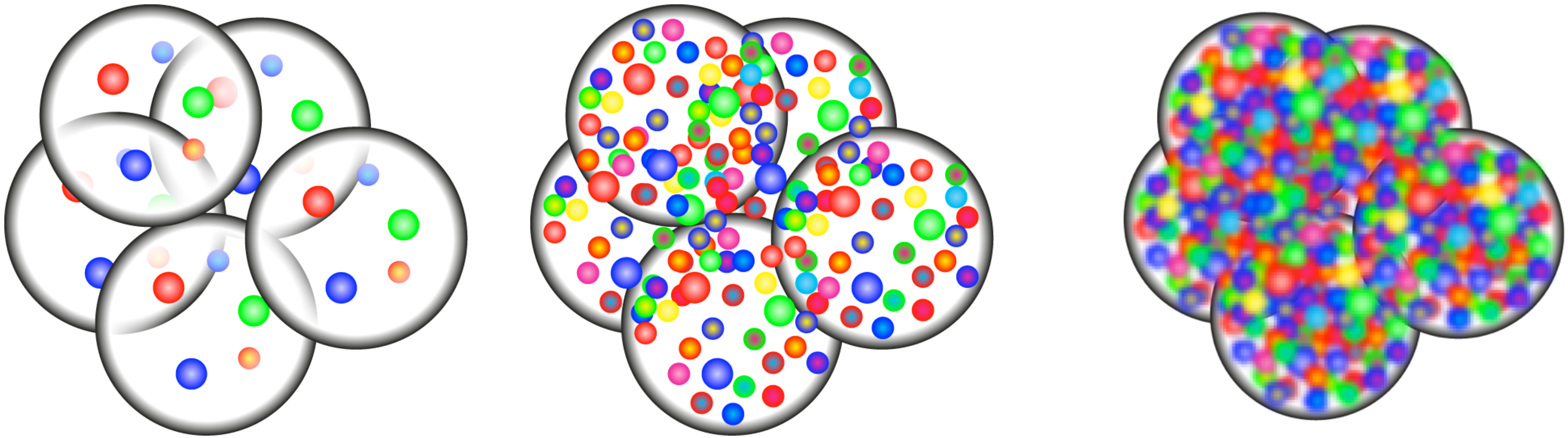
ハドロン散乱ゼロ度測定勉強会

Mar 2, 2015

Nagoya University

ALICE

筑波大学
University of Tsukuba



Outline

1. Physics motivation:
   * isolated photons at forward rapidity as a signature for small-x gluons
2. Detector requirements
3. R&D status and plan
4. Summary

CGS picture at LHC

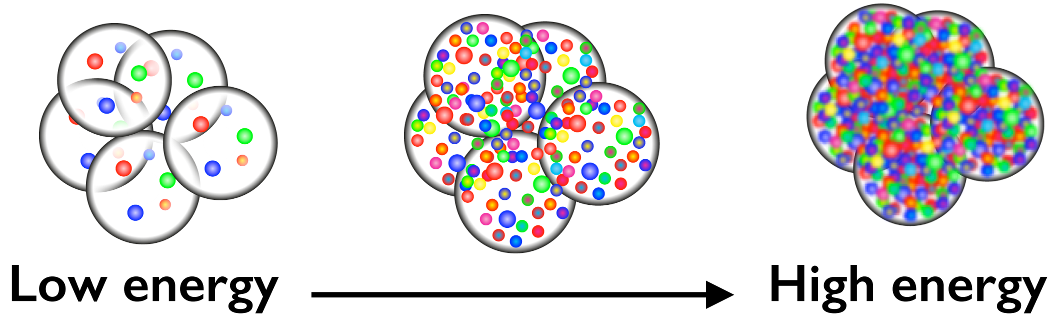
- Gluon saturation, **Color Glass Condensate (CGC)** is a fundamental feature of QCD, expected to be appeared in high energy.

- From the results in d-Au (RHIC) and p-Pb (LHC) collisions, there are indications of CGC, but not yet conclusive.

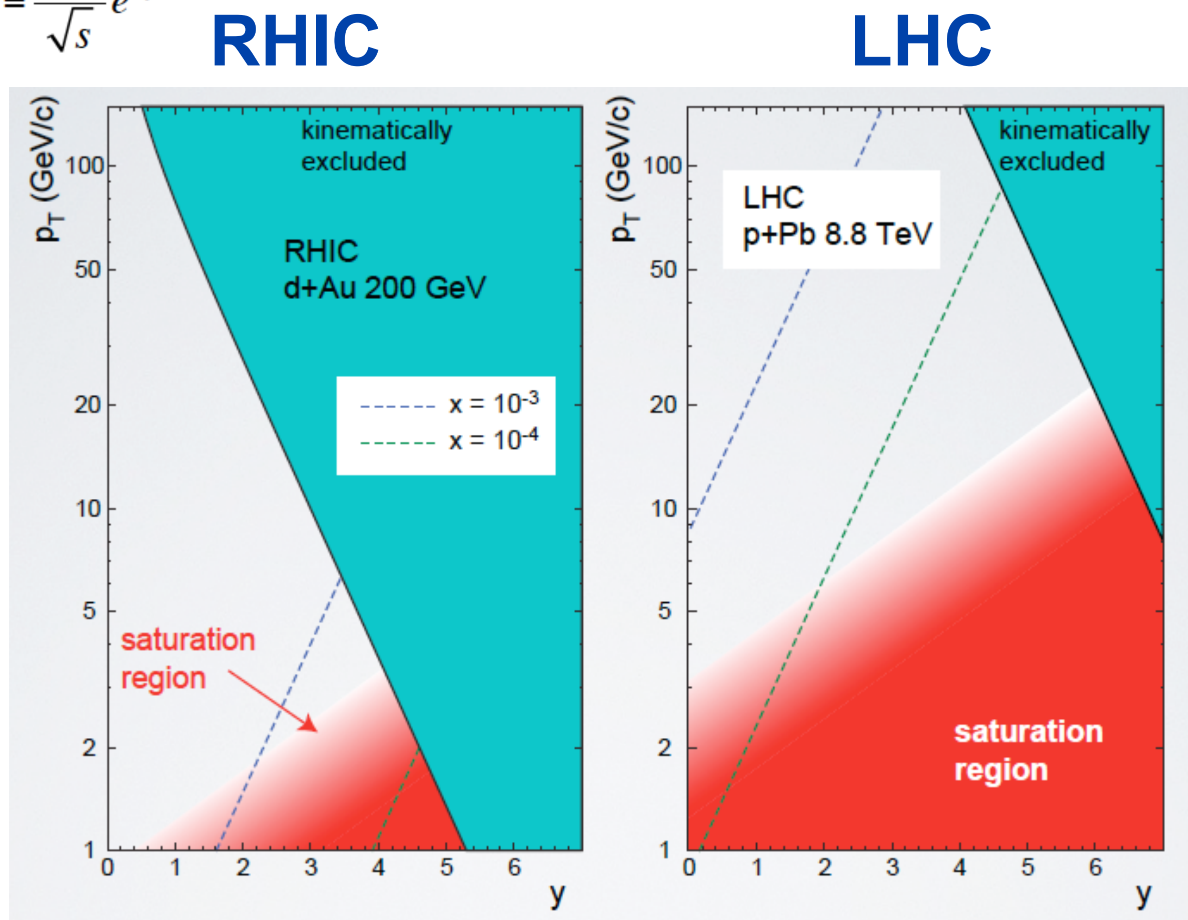
- Many observables are used hadrons, which include final state interactions.

- A cleaner probe at forward rapidity is necessary, such as **direct photons**

LHC : Larger kinematic reach in saturation region at LHC, compared to RHIC.

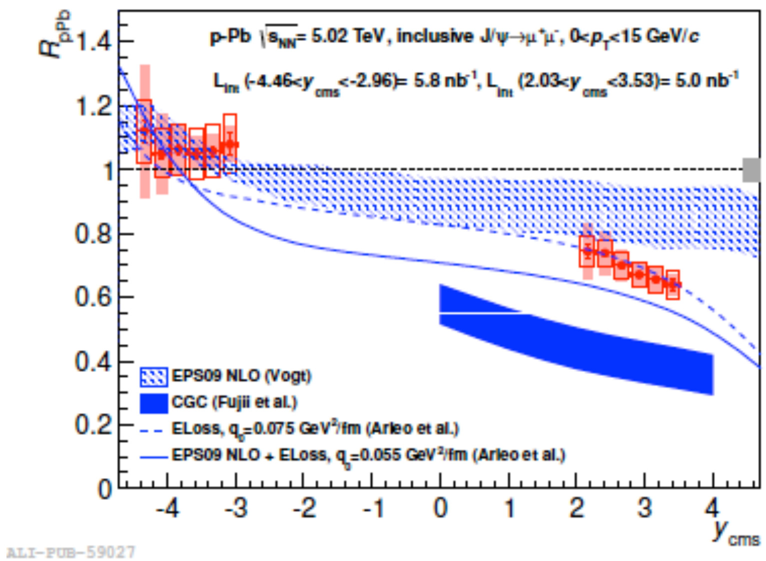


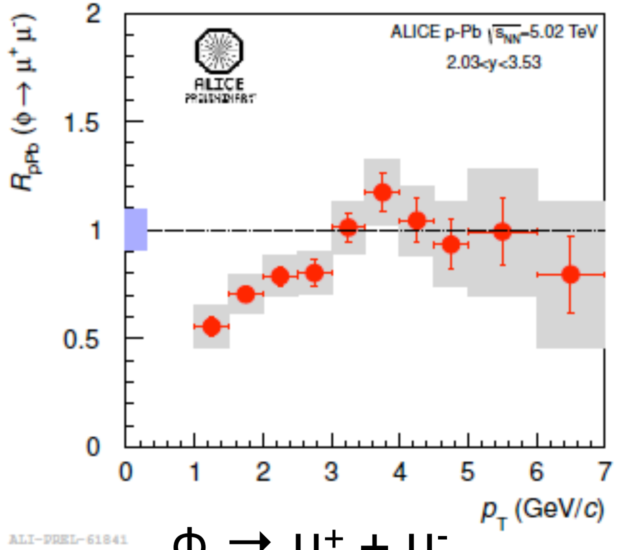
$$x = \frac{2p_T}{\sqrt{s}} e^{-y}$$

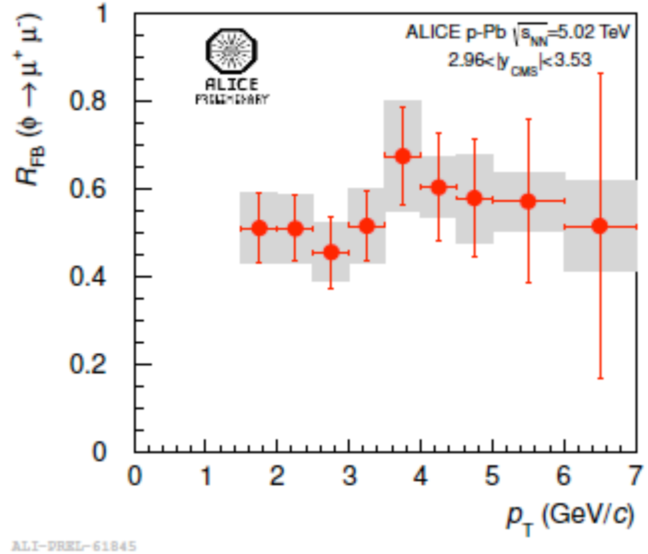


Forward Hadron Production in p-A at LHC

ALICE, arXiv:1308.6726







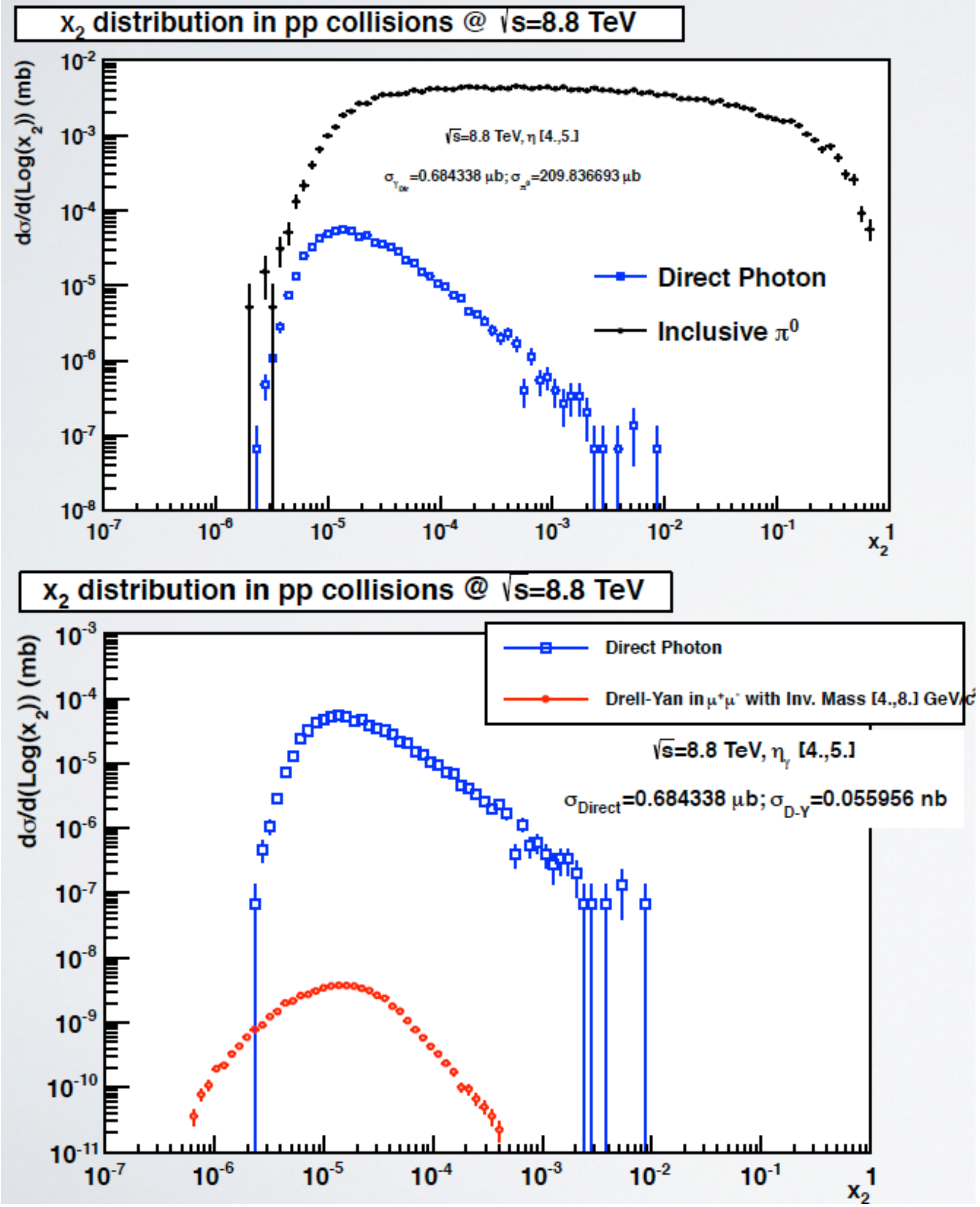
J/ψ → μ⁺ + μ⁻
- R_{pPb} compared to models

φ → μ⁺ + μ⁻
- R_{pPb} at forward rapidity (left) forward/backward ratio (right)

- **Hadron suppression on forward (proton-going) side at low p_T.**
- J/ψ not described by nPDFs nor by a CGC calculation
- Uncertainties on:
  - Production mechanism (x sensitivity etc.)
  - Other nuclear modifications (e.g. energy loss, thermalization in pA?)
- **Difficult to obtain conclusive data by hadrons only.**

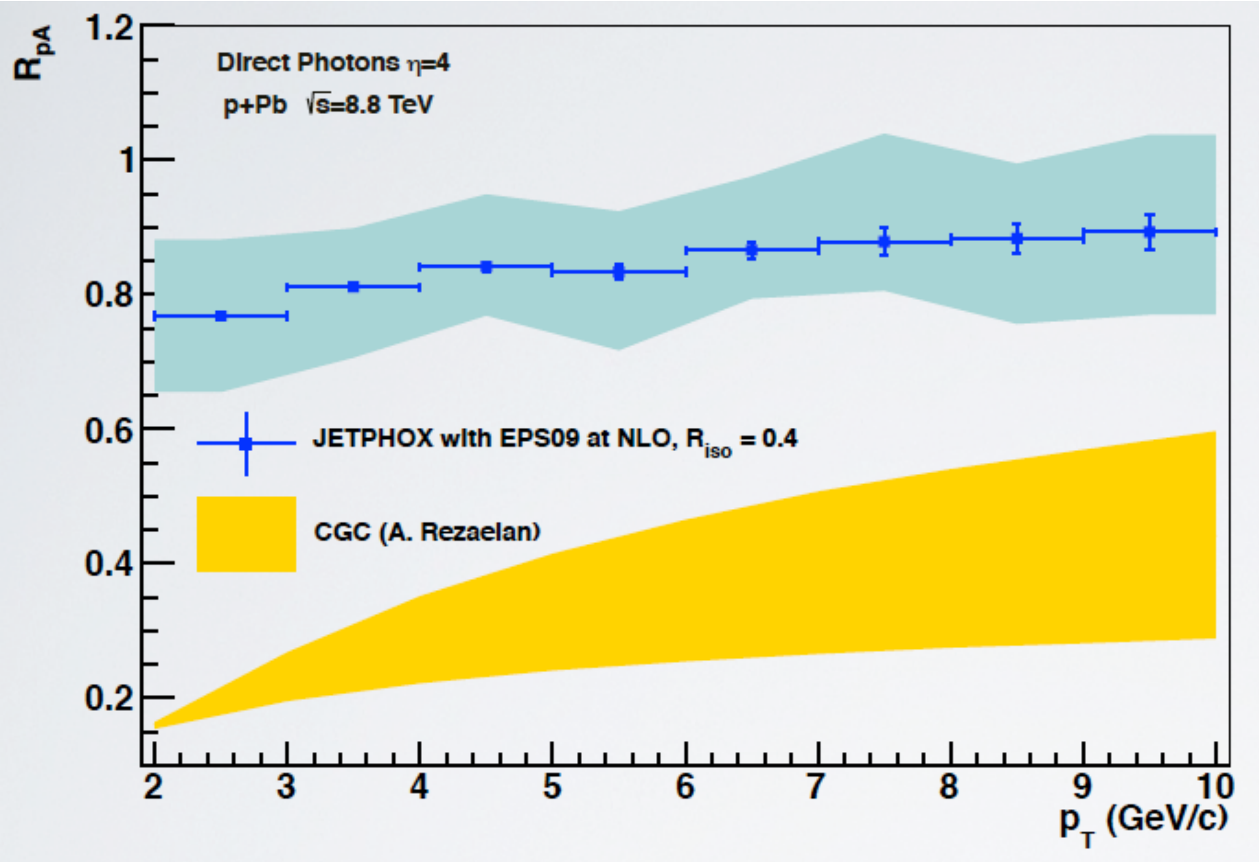
x-Sensitivity from PYTHIA

neutral pions: p_T > 2.5 GeV/c
direct photons: p_T > 4 GeV/c
Drell-Yan: 4 GeV/c² < M < 9 GeV/c²



- Very limited sensitivity with light hadrons
- Much better sensitivity with Drell-Yan and direct photons
- Much lower cross section for Drell-Yan
  - Not sufficient for measurement in p-Pb
- Direct photons are optimum prove for a gluon saturation

nPDF/DGLAP vs. CGC



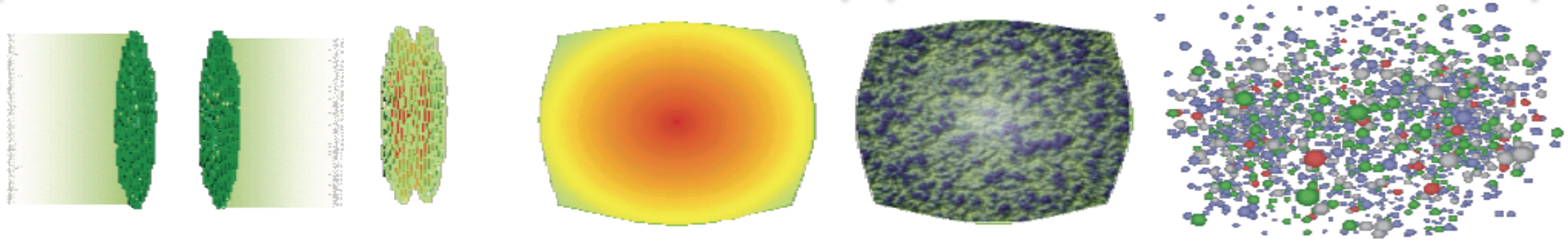
- Two scenarios for forward γ production in p+A at LHC:
  - Normal nuclear effects linear evolution, shadowing
  - Saturation/CGC running coupling BK evolution

- Strong suppression in direct γ R_{pA}.
- Signals expected at forward η, low-intermediate p_T.

Initial condition and thermalization

Initial condition, CGC, early thermalization

sQGP production, thermal dynamics QGP



Color Glass Condensate (CGC) | Collision | "Glasma" | strongly coupled Quark Gluon Plasma (sQGP) | Hadron gas

t = -1 fm | t = 0 fm | t= 0.6 fm/c | t= 20 fm/c

Time

RHIC/LHC data suggests an early thermalization of QGP (< 0.2 fm), and it is still a **big missing link** between initial condition to QGP.

➠ Direct access to initial condition by direct photon

Initial conditions of Heavy Ion Collisions

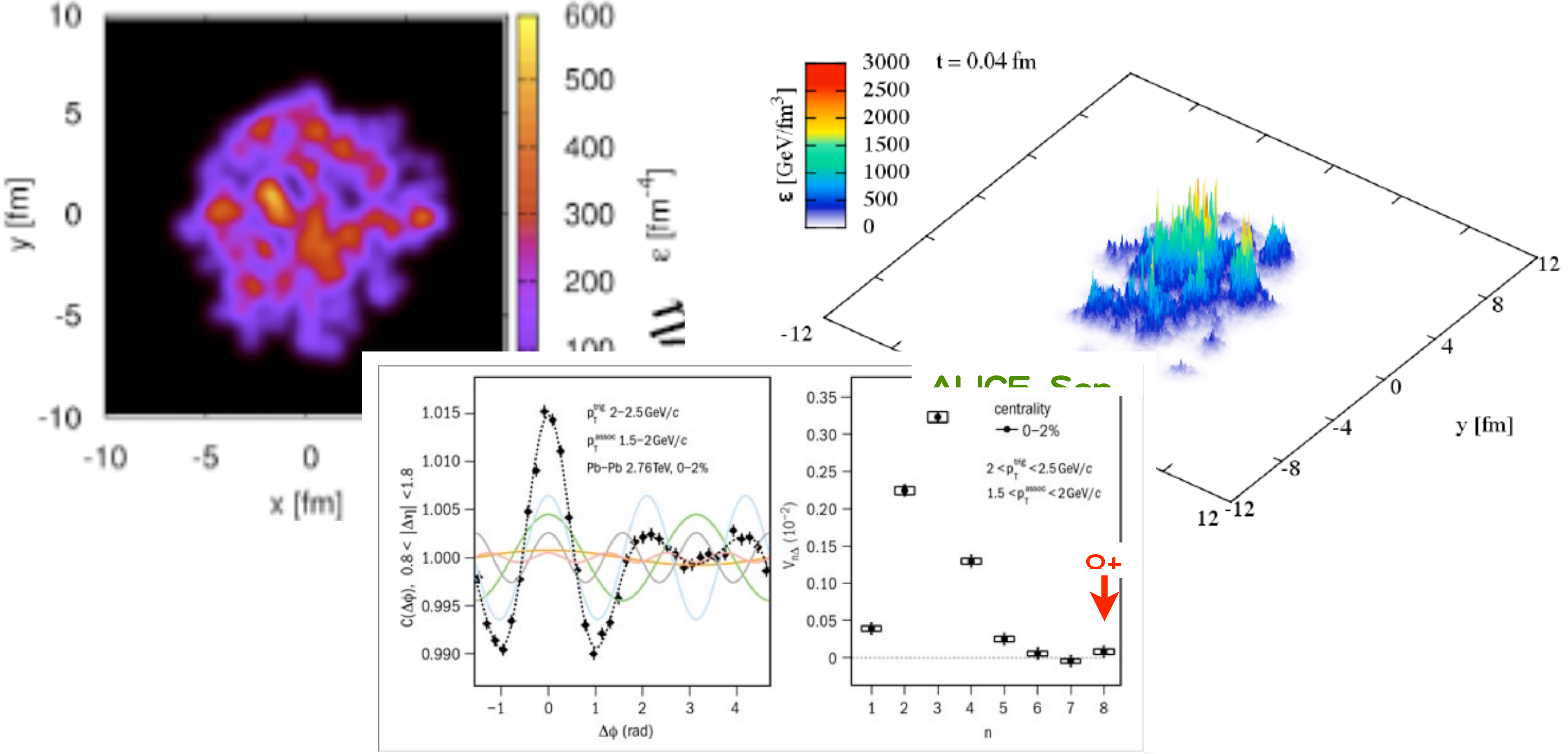
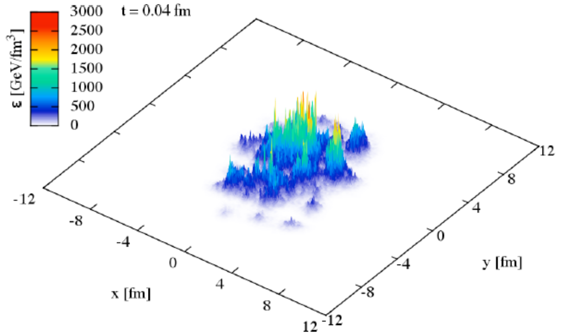


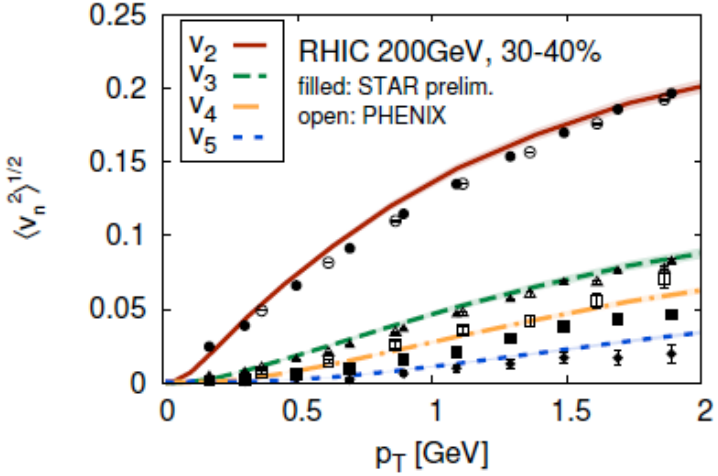
Fig. 1. Left: correlation function for charged hadron pairs from head-on Pb–Pb collisions. Right: corresponding spectrum of Fourier harmonic amplitudes vs n.

Understanding of initial condition:
→key to understand the QGP properties (e.g. η/s), early thermalization.

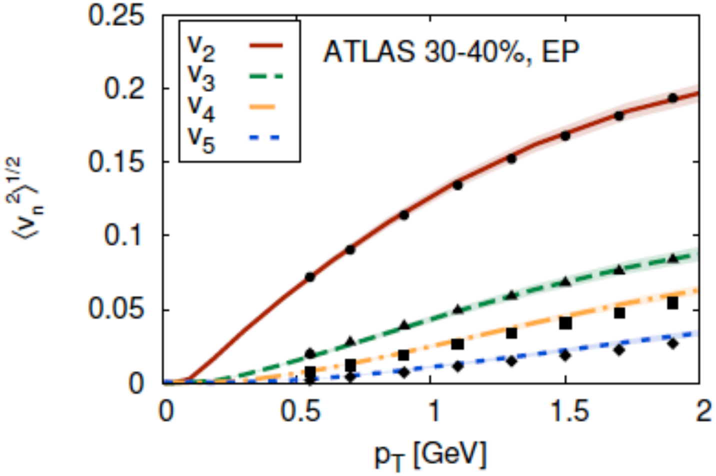


η/s, temperature dependence

RHIC $\eta/s = 0.12$



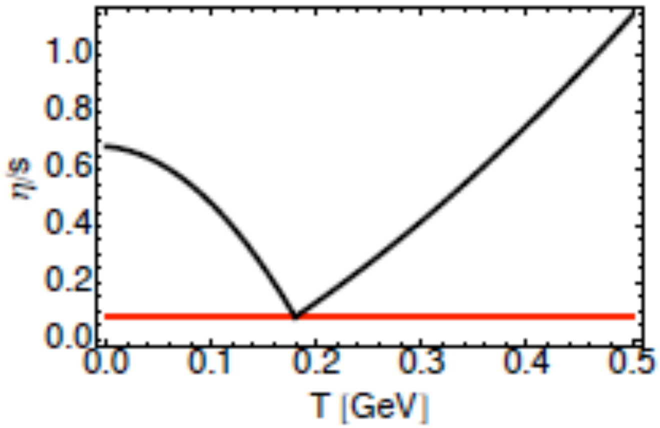
LHC $\eta/s = 0.2$



- IP-Glasma Model (color charge fluctuation)
- Higher harmonics ➔ η/s constraints

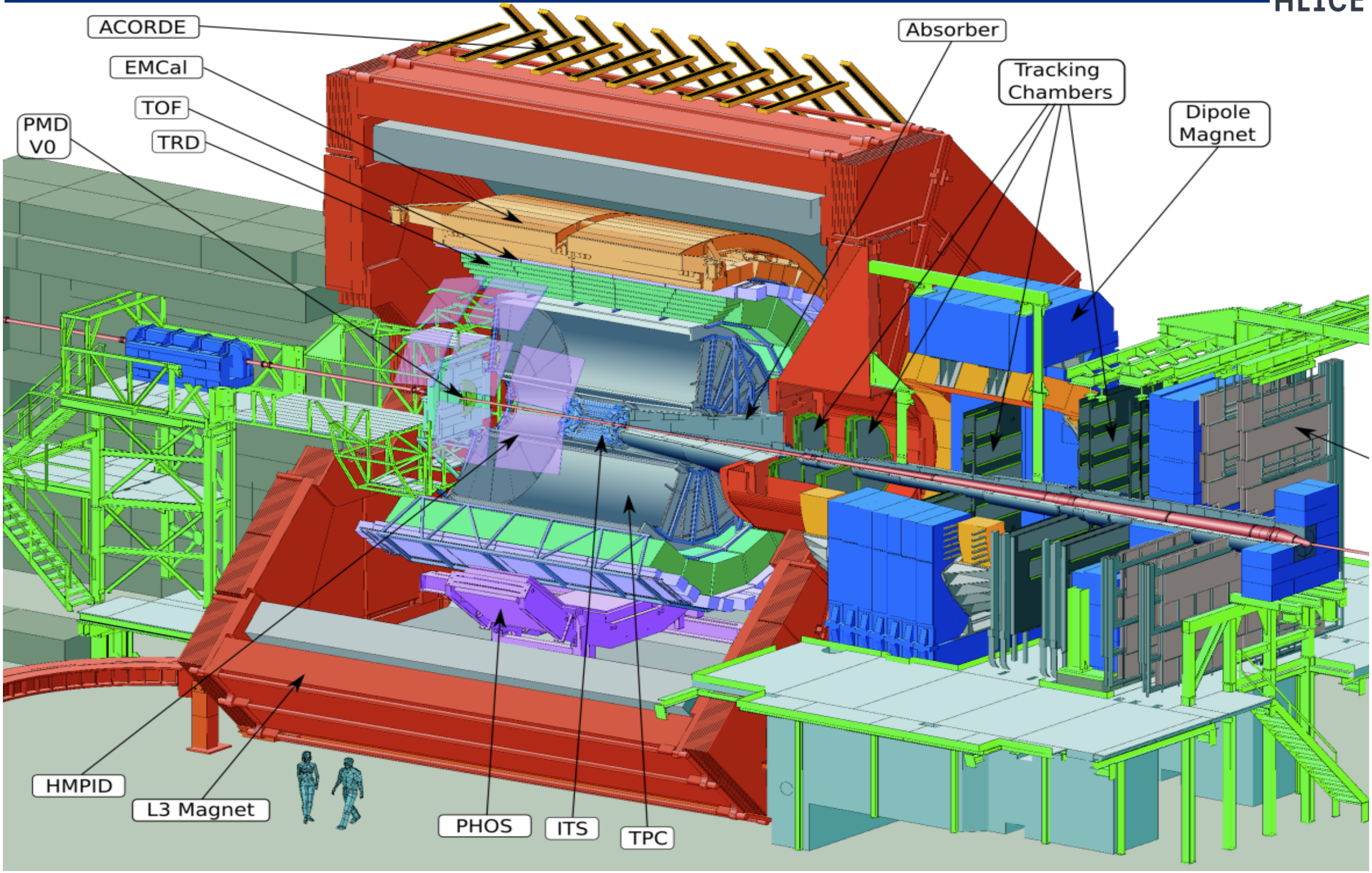
Minimum η/s at RHIC？

- Temperature dep?

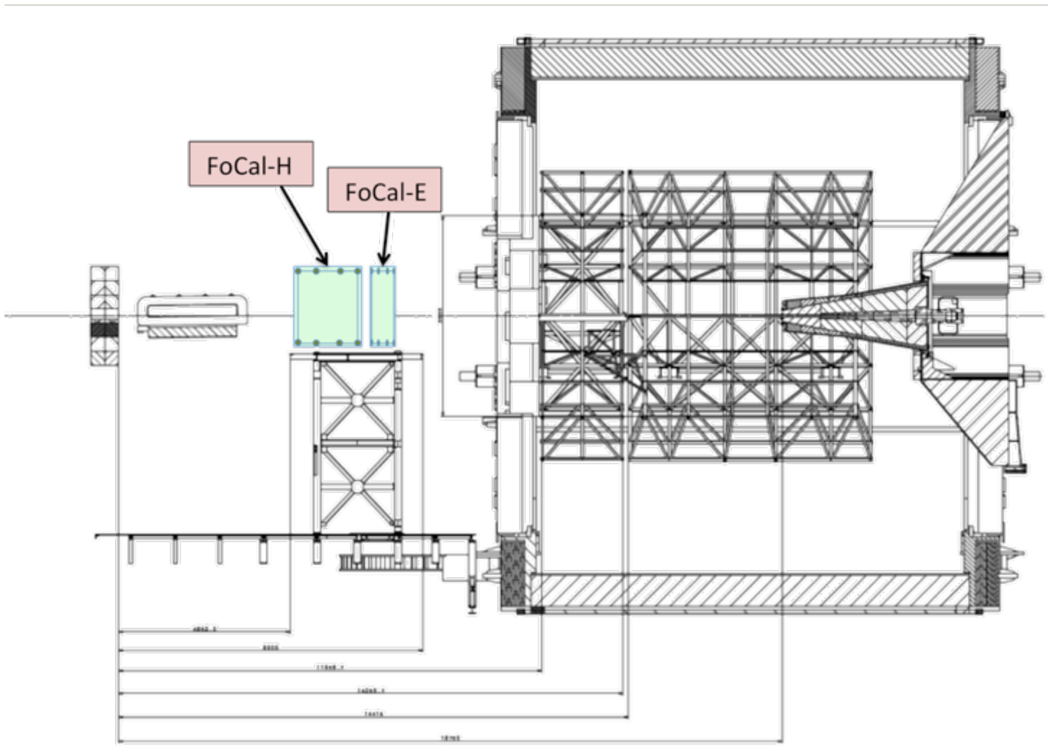


Björn Schenke (BNL) RHIC AGS Users' Meeting 2013, BNL
C. Gale, S. Jeon, B.Schenke,
P.Tribedy, R.Venugopalan, PRL110, 012302 (2013)

The ALICE Experiment



Forward Calorimeter (FoCal) in ALICE



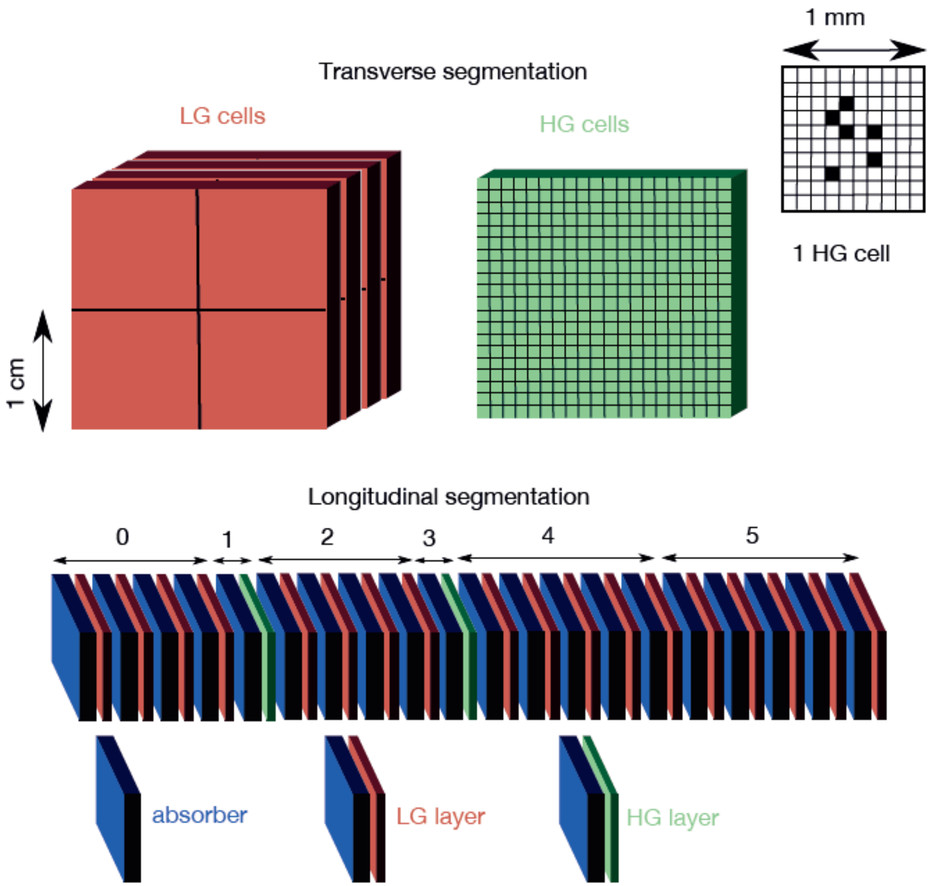
- Electromagnetic calorimeter for γ and π^0 measurements, with Hadron Calorimeter.

- At $z \approx 8$m (outside magnet) $3.3 < \eta < 5.3$

- **Proposed schedule:**
  - mini-FoCal: 2018- (after LS2)
  - full FoCal: 2023- (after LS3)

Main challenge: **separate γ/π^0** at high energy
- Need small Molière radius, high-granularity read-out
- Si-W calorimeter, granularity ≈ 1mm^2

FoCal-E Strawman Design



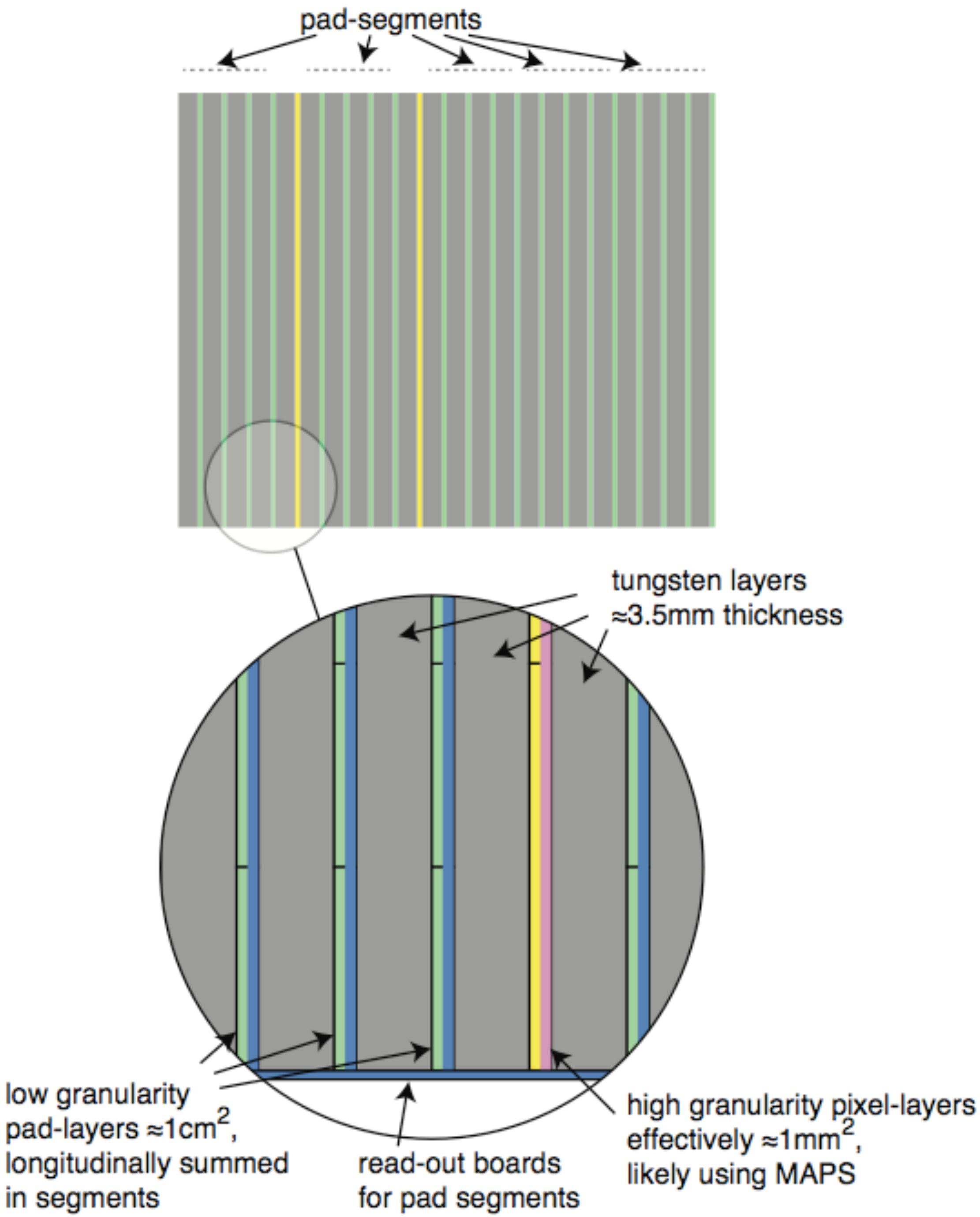
- **Si/W** sandwich calorimeter layer structure:
  - W absorbers (thickness $1X_0$)+ Si sensors
- Longitudinal segmentation:
  - 4 segments low granularity (LGL)
  - 2 segments high granularity (HGL)

- **LGL segments (PAD)**
  - 4 (or 5) layers of Si/W
  - Si-PAD with analog readout
  - cell size 1 x 1 cm^2
  - 8 x 8 = 64 PADs per layer
  - signal are longitudinally summed

- **HGL segments (MAPS)**
  - single layer with W.
  - CMOS-pixel (MAPS*).
  - pixel size ≈ 25 x 25 μm^2
  - digitally summed in 1mm^2 cells

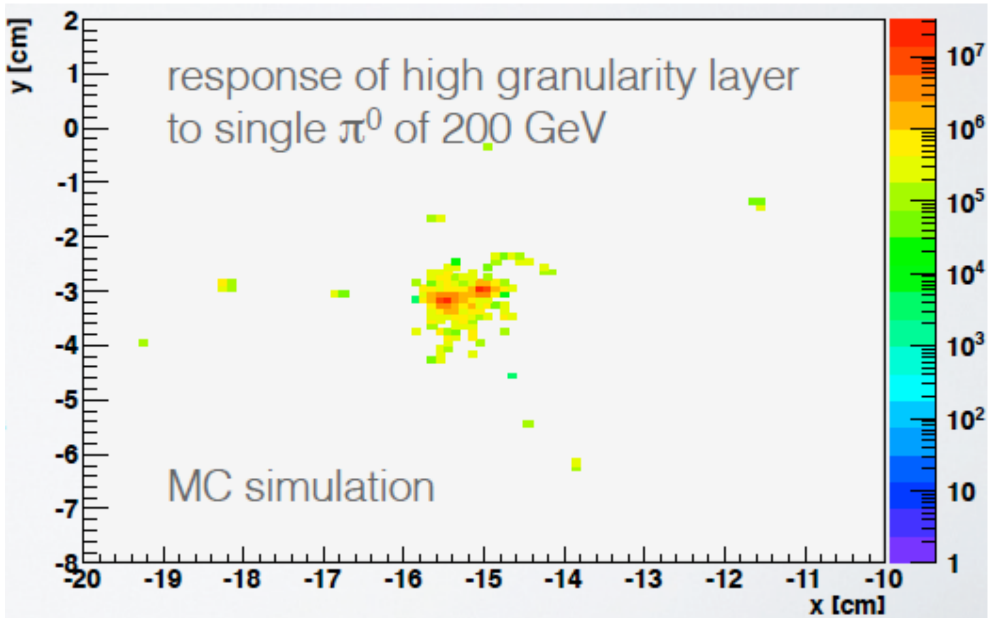
**MAPS = Monolithic Active Pixel Sensor*

Strawman Design



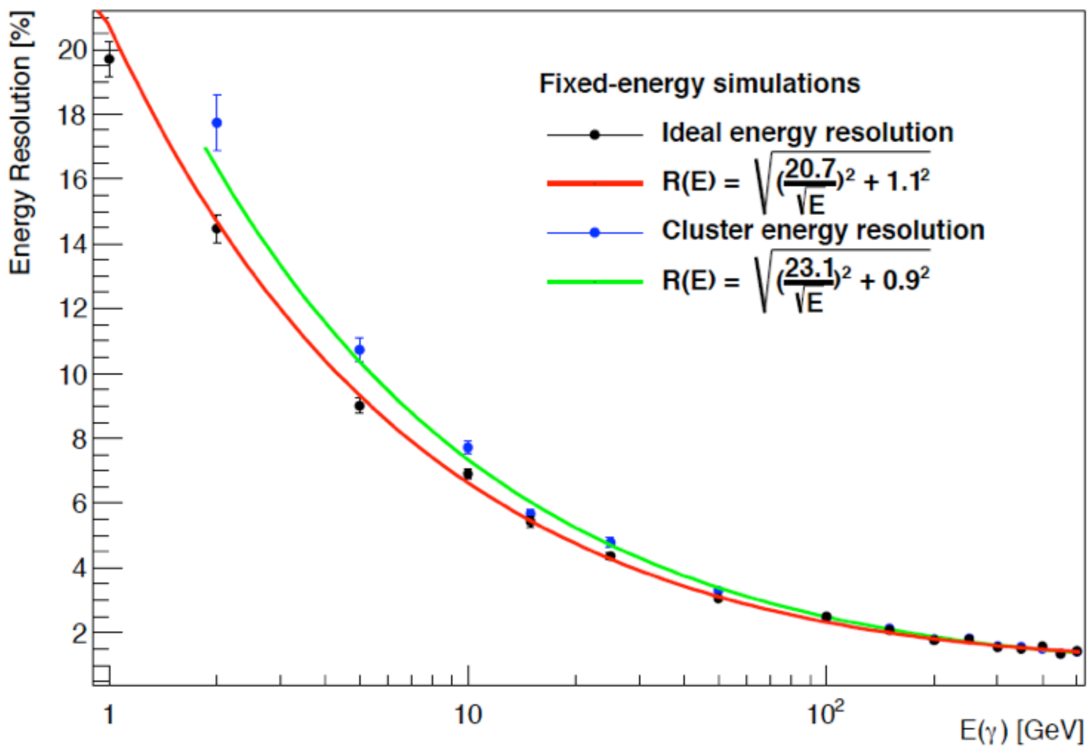
Studied in performance simulations:
24 layers:

W (3.5mm ≈ 1 X_0) + Si-sensors (2 types)
- low granularity (≈ 1 cm²), Si-pads
- high granularity (≈ 1 mm²), obtained with pixels (e.g. CMOS-MAPS)

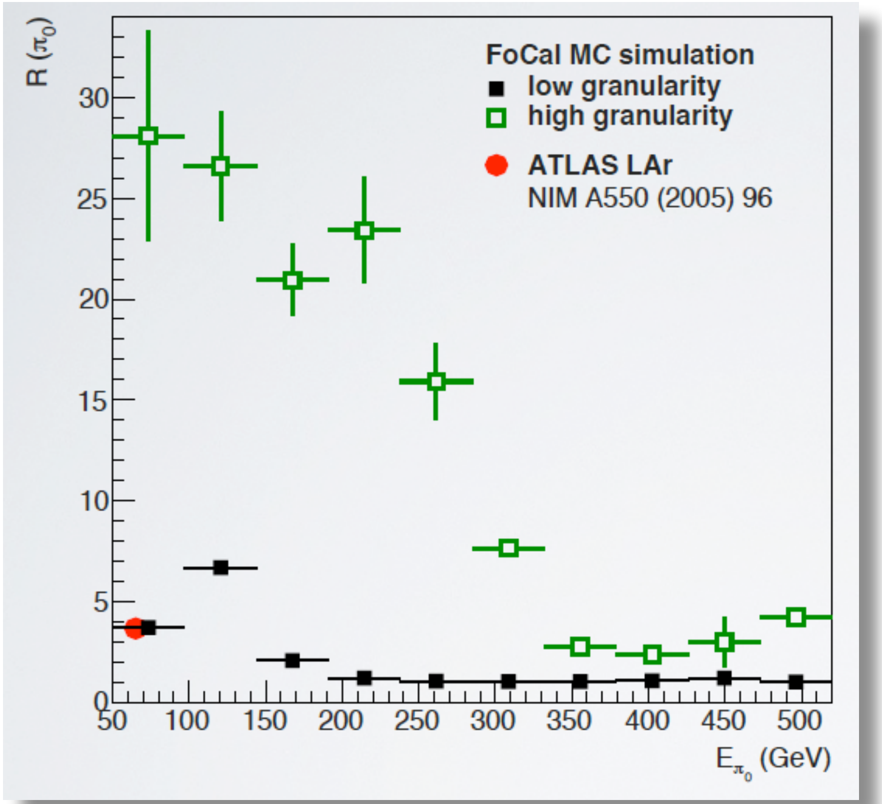


Detector Performance (simulation)

Energy resolution (FoCal-E)

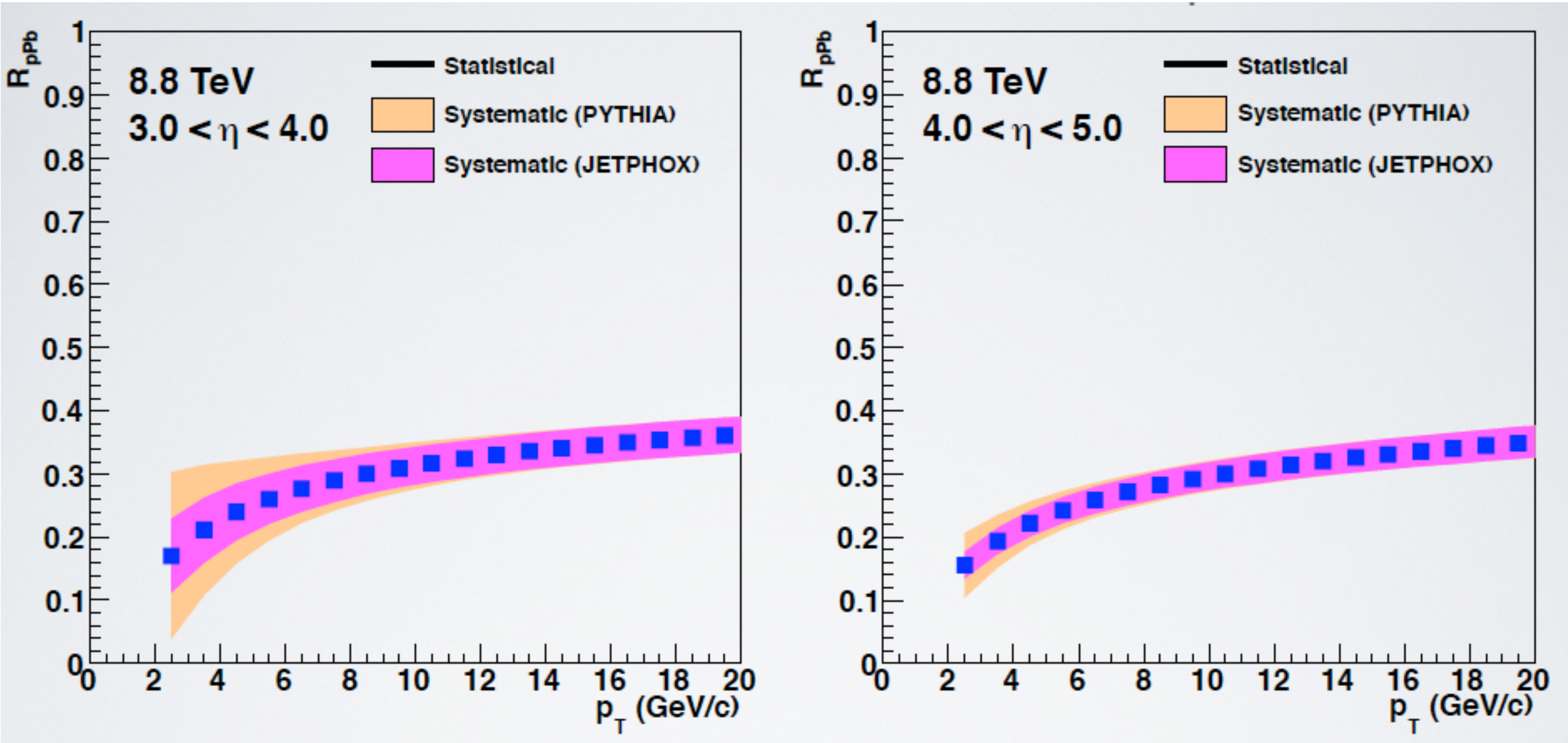


Pion rejection factor



- Reasonable energy resolution, extremely good two-shower separation with HG segments (~0.2 mm position resolution at E_γ > 100 GeV)
- Efficient for pion rejection (via shower shape analysis)

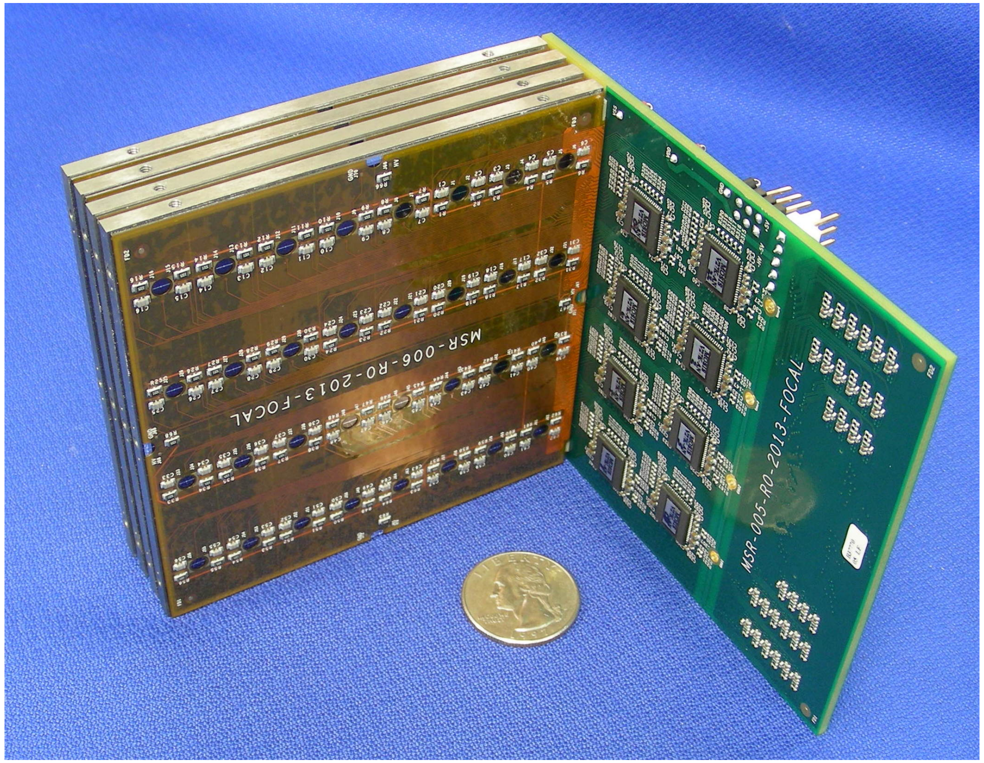
Performance on R_{pPb}

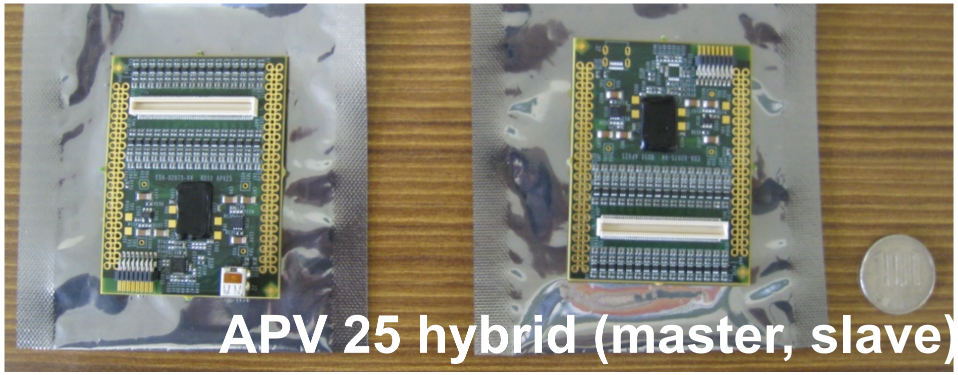


- Expect significant constraint on direct photon R_{pPb}
- Confirm or refine the CGC effect, constrain nPDF

Low Granularity Layer (LGL) Prototype, PAD

ALICE



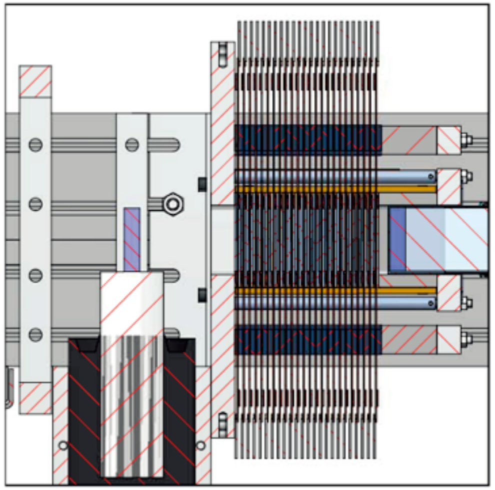

APV 25 hybrid (master, slave)

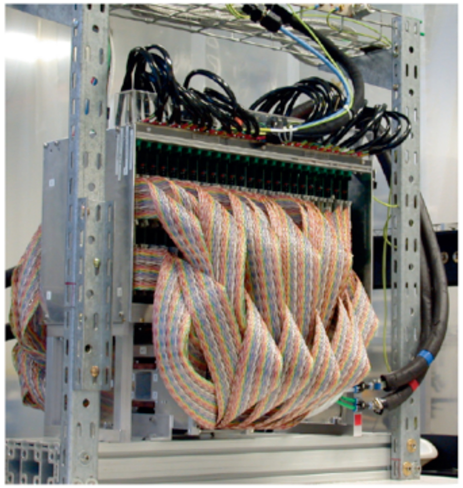
- **LGL (PAD) prototype (ORNL):**
  - Si-PAD (Hamamatsu S10938)
  - cell size 1x1 cm^2
  - longitudinally summed (4 layers), analog readout = 1 segment
  - 4 or 5 LGL segments
  - W layer per Si-PAD
- **Readout system:**
  - ORNL ASICs, on a summing board.
  - RD-51 SRS readout system:
    - APV25 hybrid (128 ch, pre-amp, shaper)
    - SRS Front End Card (FEC) and ADC.
      - ◉ SRS: Scalable Readout System (point-to-point readout)

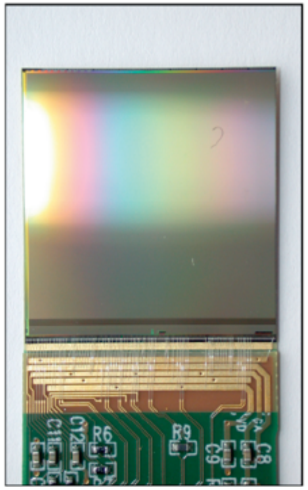
◉ **Responsibility: Tsukuba, ORNL**

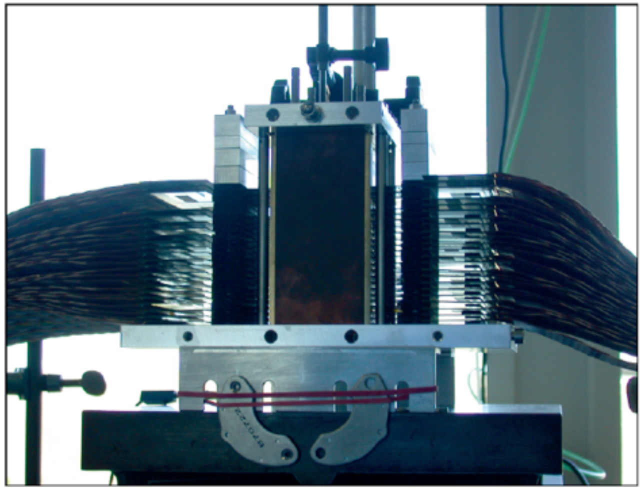
High Granularity Layer (HGL) Prototype, MAPS

MAPS prototype

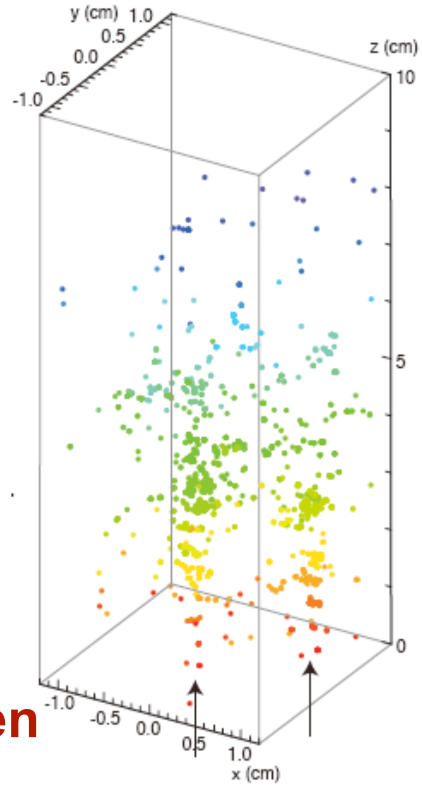


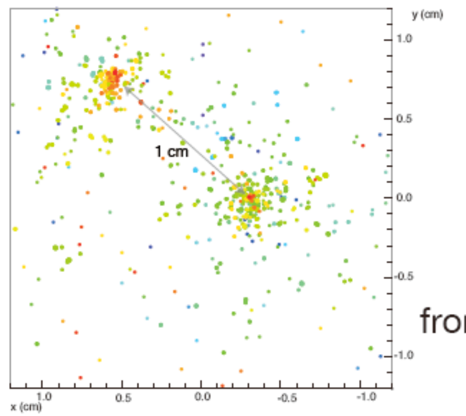






- 4x4 cm^2 cross section, 28 X_0 depth
- 24 layers: W absorber + 4 MAPS each
- MIMOSA PHASE 2 chip (IPHC Strasbourg)
  - 30 µm pixels
  - 640 µs integration time
    (needs upgrade – too slow for experiment)
- 39 M pixels total
- Test with beams at DESY, CERN PS, SPS





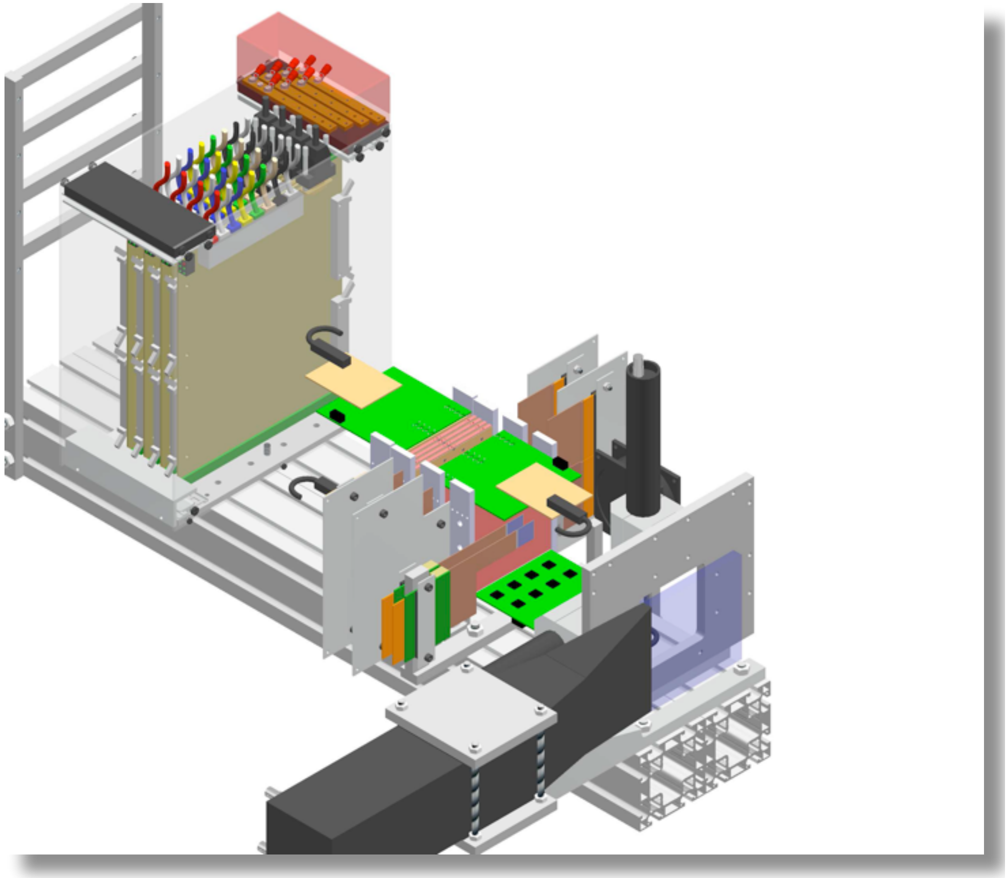
front view

Event Display:
measurement (DESY) of pile-up of two 5.4 GeV electrons, demonstrates two-shower separation capabilities

◉ **Responsibility: <u>Utrecht</u>, NIKHEF, Bergen**

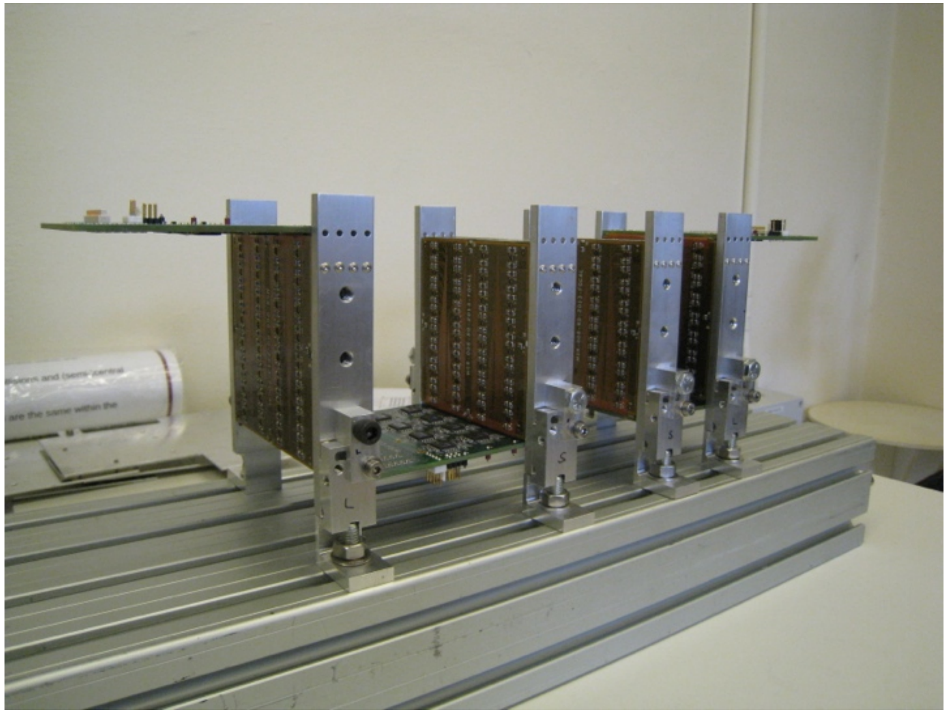
CERN PS/SPS beam test (2014)

- ✓ **Beam time:**
  - – PS: Sep. 17 - Oct. 1, 2014
  - – SPS: Nov. 10-18, 2014
- ✓ **Beam line:** PS T9, SPS H8
- • **Beam energy:**
  - – 2 - 10 GeV/c
  - – 30, 50 GeV/c
- ✓ **Trigger:** 10x10 cm^2 & 1x1 cm^2 Scinti. + Cherenkov (ON/OFF)
- ✓ **Responsibility:**
  - – LGL (PAD) :Tsukuba, ORNL
  - – HGL (MAPS) Utrecht, NIKHEF, Bergen

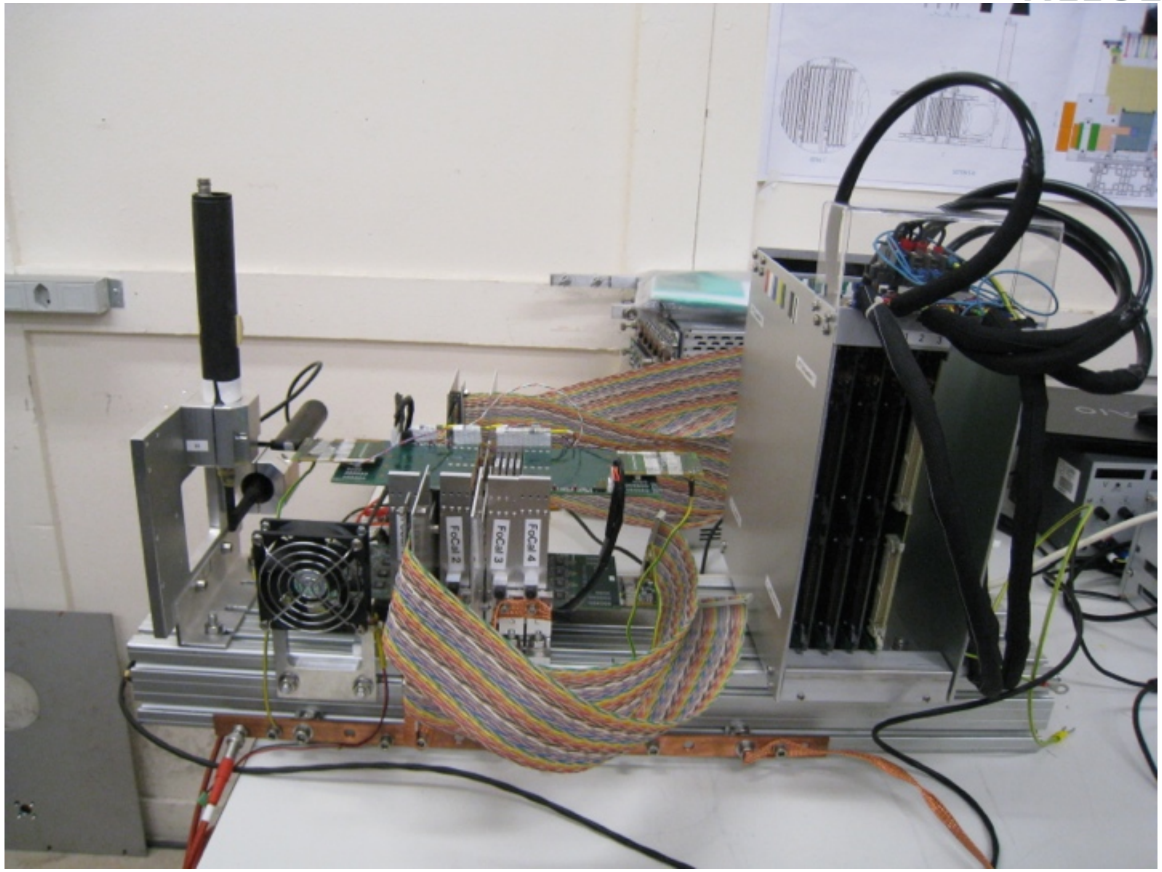


Drawing by Brink, A. van den (Utrecht Univ.)

Prototype of "a strawman design"



LGL (PAD), 4 segments
w/ summing board



LGL (PAD) + HGL (MAPS x2)
"strawman detector"

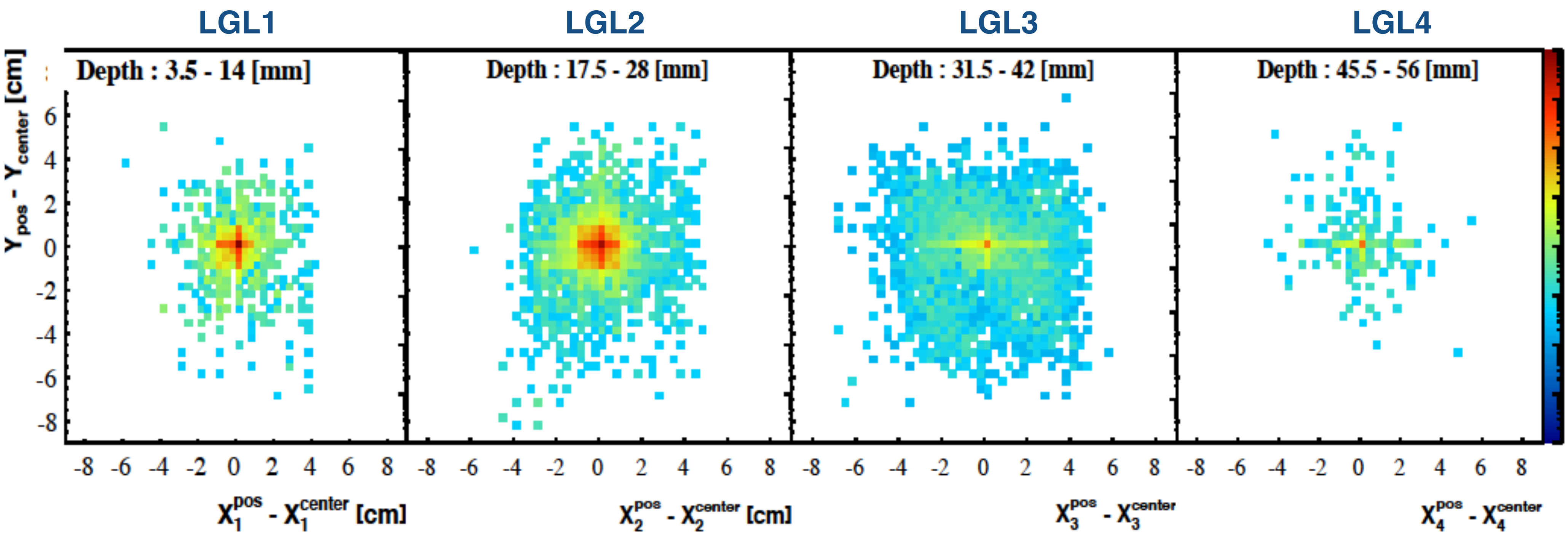
PS results (show profile)

K. Ito

- **Longitudinal shower profile:**
  - shower max d (for W) = 19.3 mm (2nd LGL)

$$d = 0.35 ln(\frac{E_{incident}}{8.11[MeV]} - 0.5)[cm]$$

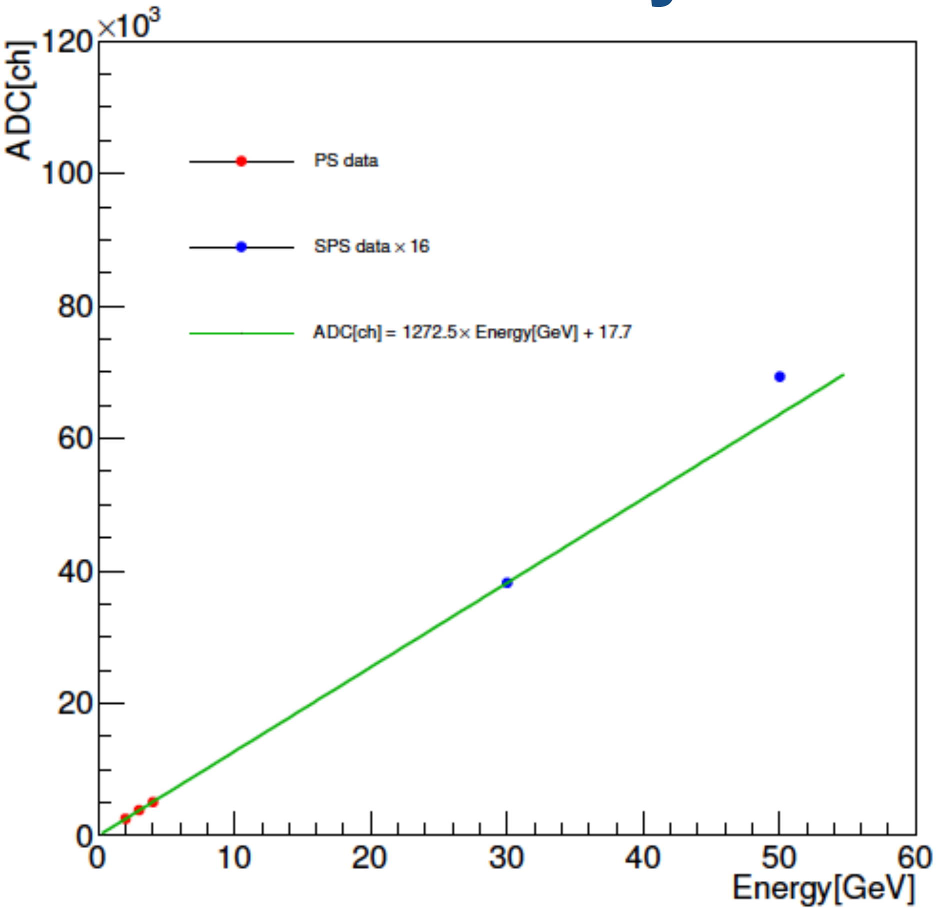
- **Transverse shower profile:**
  - re-calculate shower center (centroid)
  - Moliere radius (for W): 9.16 mm
- Both longitudinal and transverse shower profiles are consistent with the expectations.



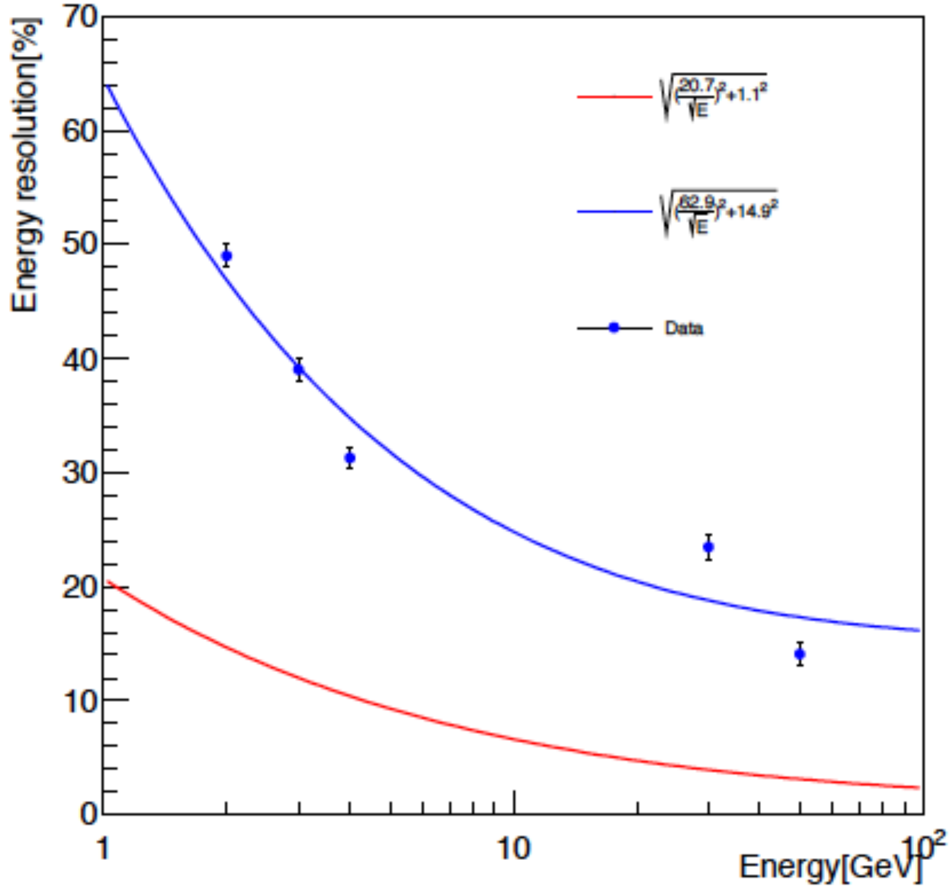
FoCal PAD performance (2014 beam test)

W. Sato

Linearity



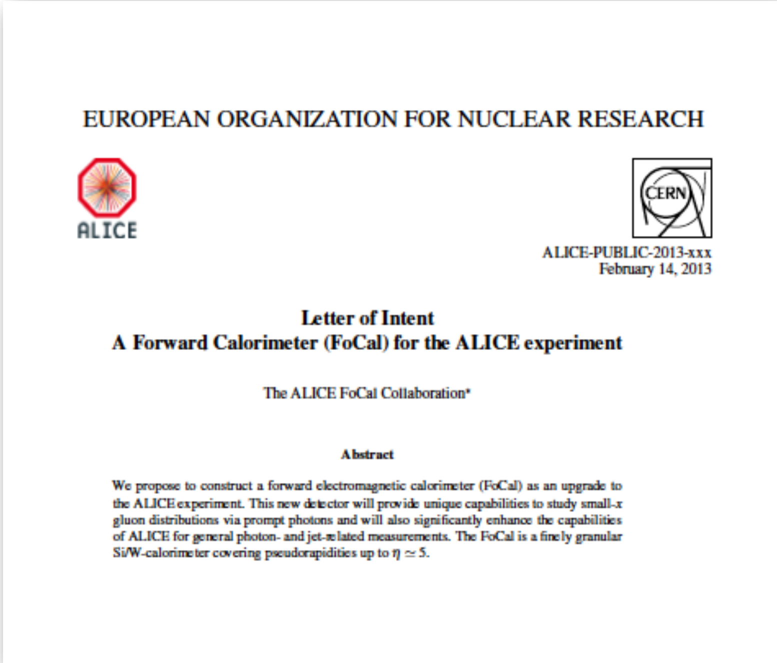
Energy Resolution



- Reasonable linearity (except 50 GeV).
- Worse energy resolution in data than simulation due to a noise problem, to be improved in 2015 test beam experiment.

Plan (2015-)

- Preparation for Nov. 2015 PS/SPS beam test.
- Ask the FoCal LoI approval by ALICE in June, then the LHCC approval in Nov.
- **Under discussion: Mini-FoCal:**
    - FoCal-E prototype (< 10% of acceptance)
    - to be installed significantly before LS3 (possibly around LS2), no modifications to ALICE setup
- **R&D with RD51:**
    - Tsukuba G. will join RD-51 in 2015 spring officially.
    - Communication with Hans M. (RD51) started for VMM2 (and/or Beatle) readout system for FoCal.
    - Need to check that VMM2 SRS system meets our requirement for a faster (~ few 100 kHz w/o trig.) readout. (c.f. APV25 < 200-300 Hz)



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

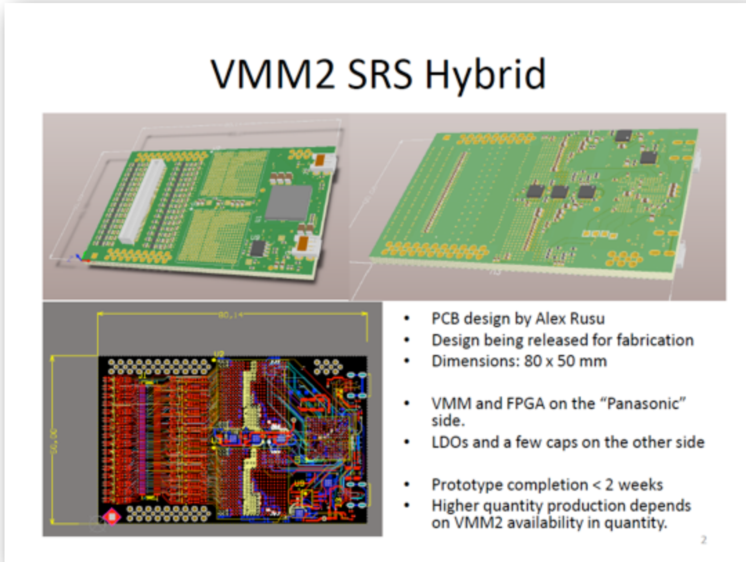
ALICE-PUBLIC-2013-xxx
February 14, 2013

Letter of Intent
A Forward Calorimeter (FoCal) for the ALICE experiment

The ALICE FoCal Collaboration*

Abstract

We propose to construct a forward electromagnetic calorimeter (FoCal) as an upgrade to the ALICE experiment. This new detector will provide unique capabilities to study small-x gluon distributions via prompt photons and will also significantly enhance the capabilities of ALICE for general photon- and jet-related measurements. The FoCal is a finely granular Si/W-calorimeter covering pseudorapidities up to $\eta \simeq 5$.



FoCal on C-side?

- Place detector at end of conical section of C-side beam pipe?
  - –possible coverage $5.5 < \eta < 6.5$
    - interesting for low-x physics
  - –very limited space, measurement feasible?
    - particle density (Pb–Pb) and background tolerable?
  - –no overlap with muon arm
    - Pb–Pb case with QGP physics questionable
  - –possible as extension to FoCal on A-side?

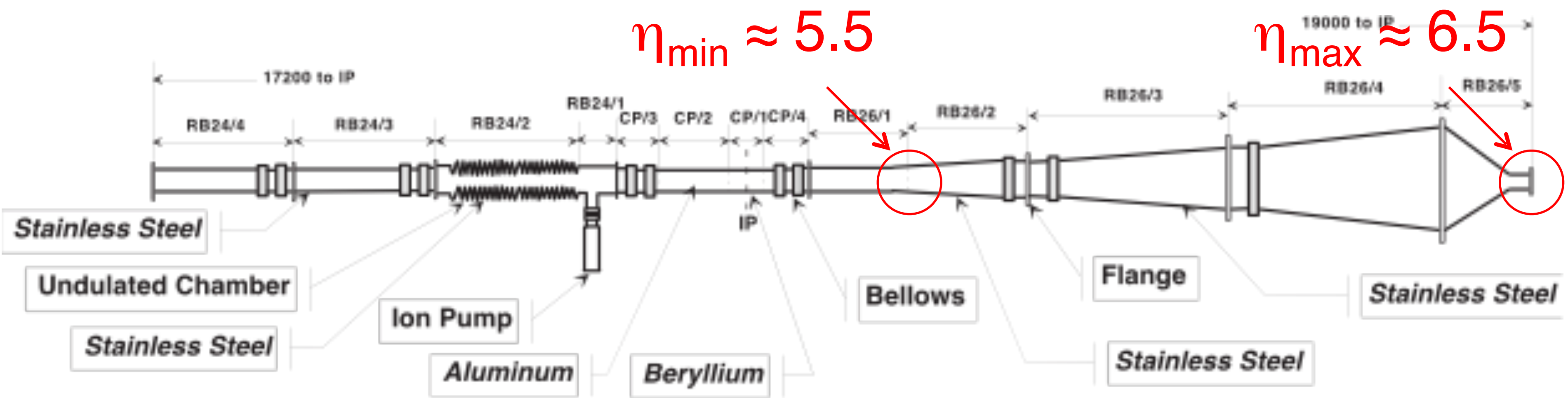
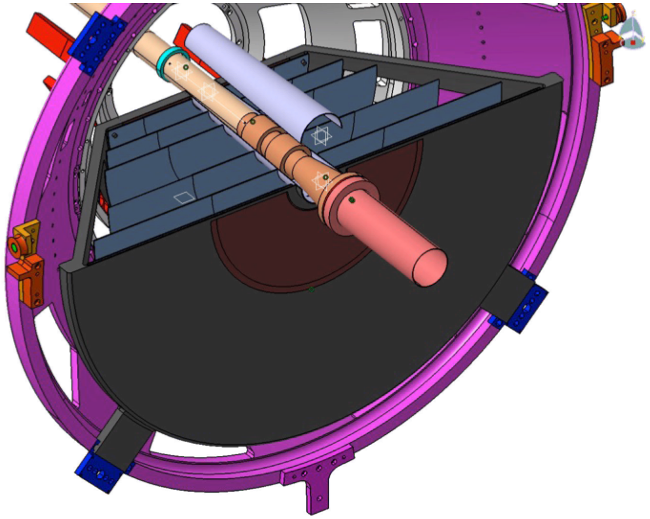


Figure 8.15: Conceptual layout of the ALICE vacuum chamber system.

Idea of Forward Spectrometer in ALICE

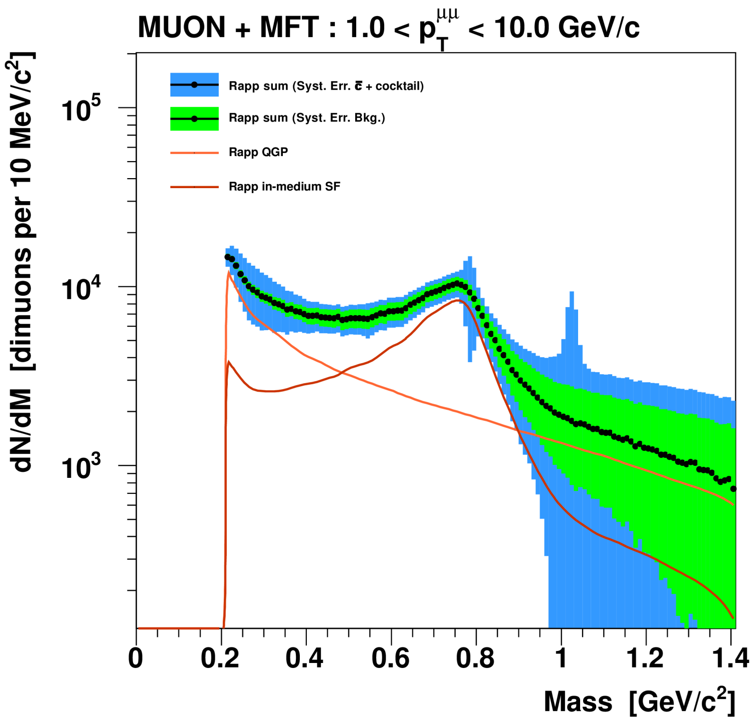
- Limited physics case
  - –diffraction?
  - –baryon stopping considered interesting
    - expected at η = 6-7
    - no competing theoretical predictions
- Would need tracking, magnet, particle ID at large η
  - –very challenging, in particular PID
  - –may need z > 19m

Muon Forward Tracker (MFT) Project



MFT: Muon Forward Tracker, proposed in ALICE ($-4.0 < \eta < -2.5$)

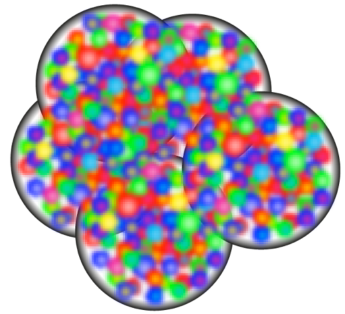
- Silicon pixel tracker in Muon Spectrometer
- Separation of charm/beauty down to very low p_T
- Precise ψ(2s) measurement even in central Pb-Pb
- Prompt and non-prompt J/ψ separation
- Improve S/B ratio and mass resolution for Low Mass di-muons



The MFT project has been approved by the ALICE Collaboration to be part of the ALICE upgrade planned for the LHC LS 2017/2018

Hiroshima G. joined for this project in 2014.

Summary



- **Forward isolated direct photons at LHC are unique signal for low-x gluons and saturation.**
- Mini-FoCal installation ~LS2 (2018), and full installation after LS3 (2023-).
- MFT upgrade project.
- **Schedule on 2015:**
  - LoI submission to ALICE and then to LHCC after the approval.
  - Beam test on Nov. 2015
  - New readout R&D with CERN RD-51 (VMM2)