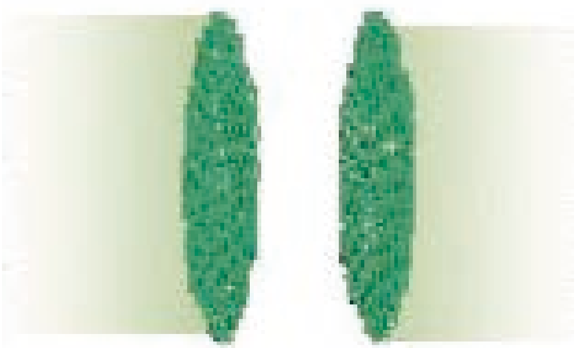
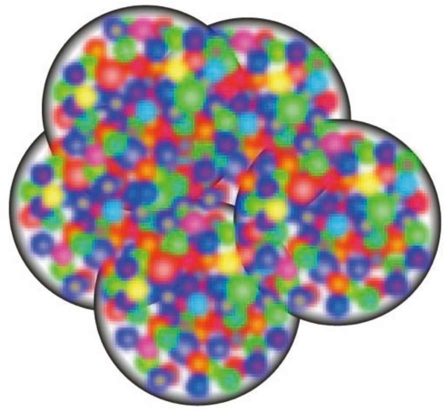
Forward Calorimeter upgrade in ALICE



Tatsuya Chujo
Univ. of Tsukuba



Oct. 29, 2016

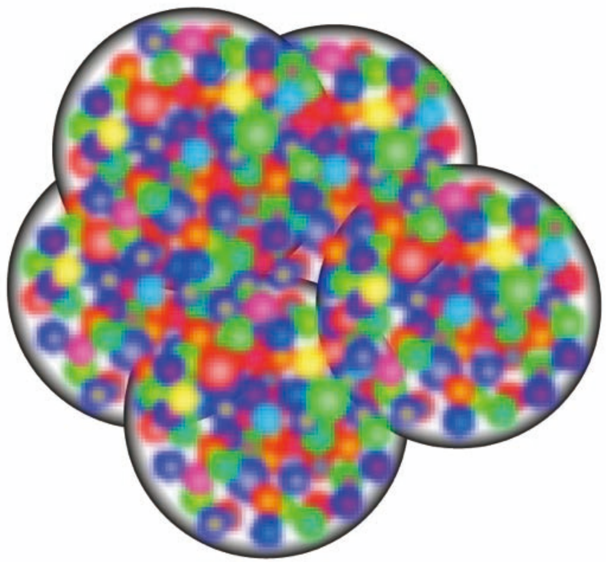
France-Japan SAKURA Workshop on small-x physics at the LHC

Univ. of Tokyo, Komaba

筑波大学
University of Tsukuba

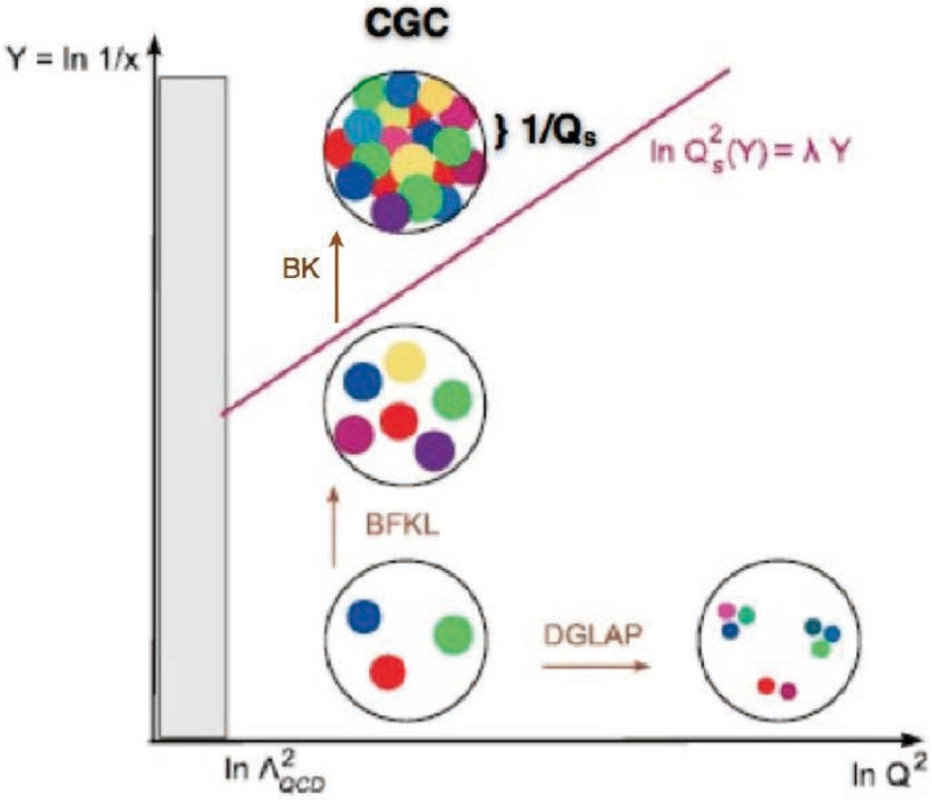
Outline

1. **Physics motivations**
2. **Forward Calorimeter Project in ALICE**
   - Detector design, organization
   - MAPS detector
   - PAD detector
3. **Schedule**
4. **Summary**



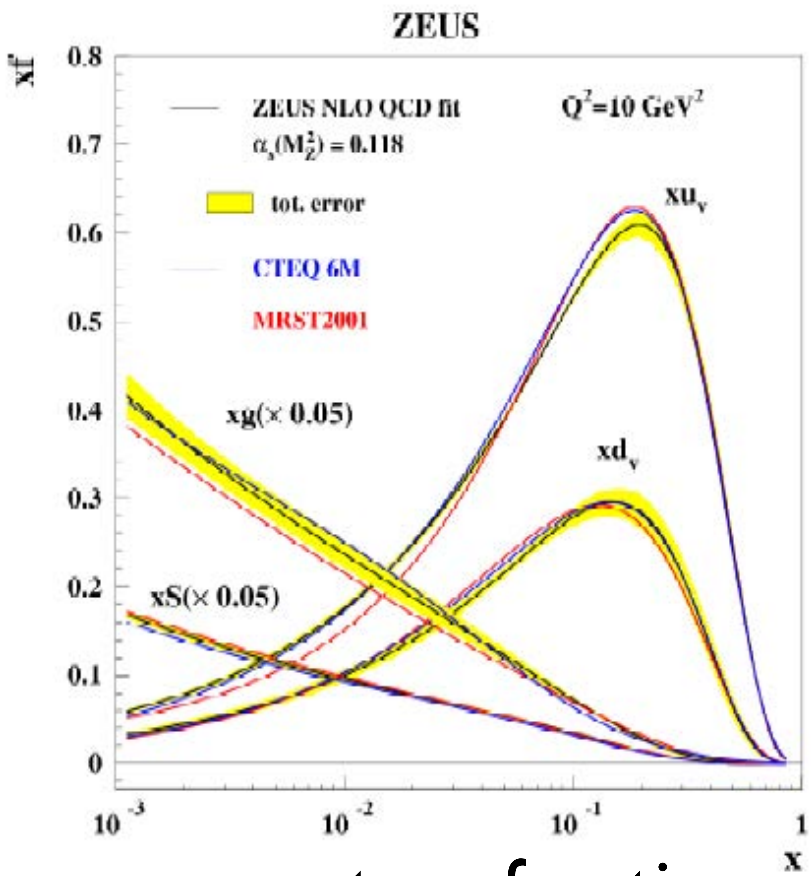
Gluon Density in nucleon/ nuclear at high energy

high energy



hard process

distribution function



momentum fraction

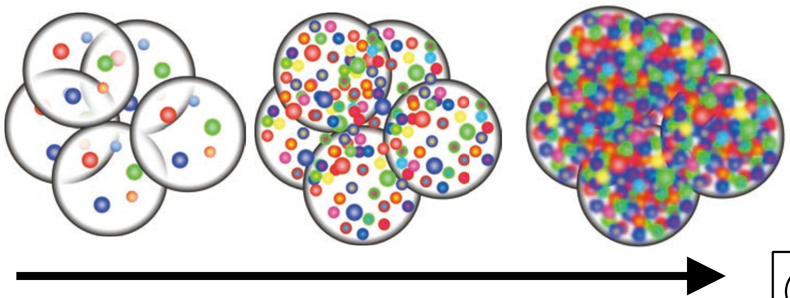
At small x and small Q^2, the parton density
will become large by non-linear effects due to gluon fusion

➡ Gluon density saturate, called;

- Gluon Saturation, or
- Color Glass Condensate (CGC)

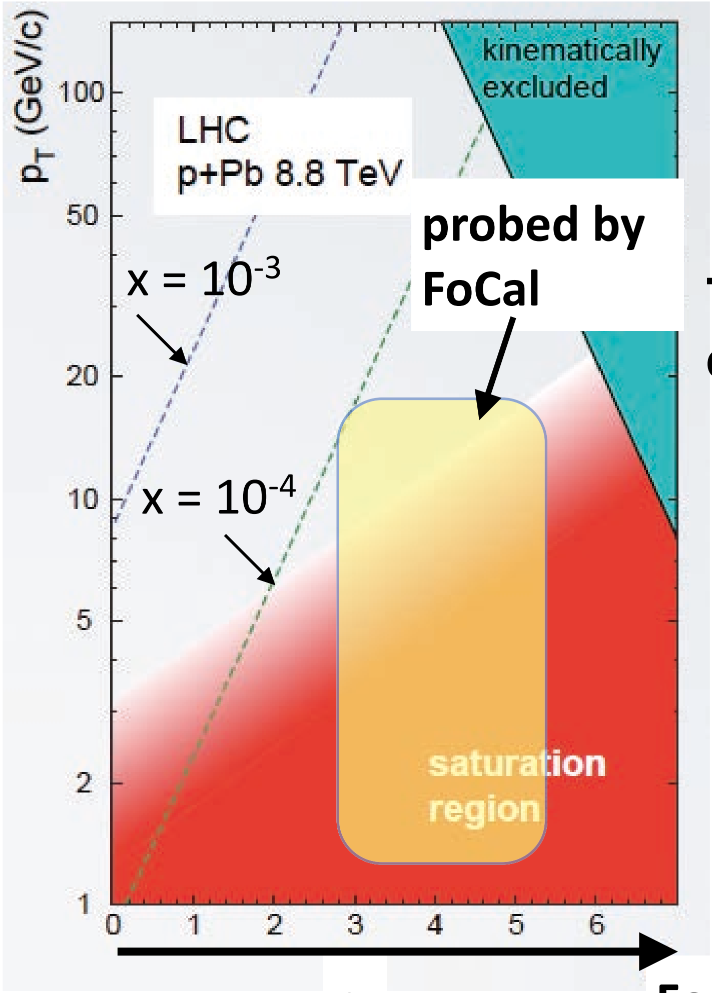
Color Glass Condensate (CGC)

3 quarks CGC



High energy, forward

① Saturated gluon state by the quantum fluctuation
② Universal picture at high energy nucleus and nucleon
③ But no clear experimental evidence for the creation of CGC



η Forward

To find/ test CGC by experiment…

(1) more forward
(2) Higher energy
(3) proton < nucleus
(4) cleanness: h < gamma

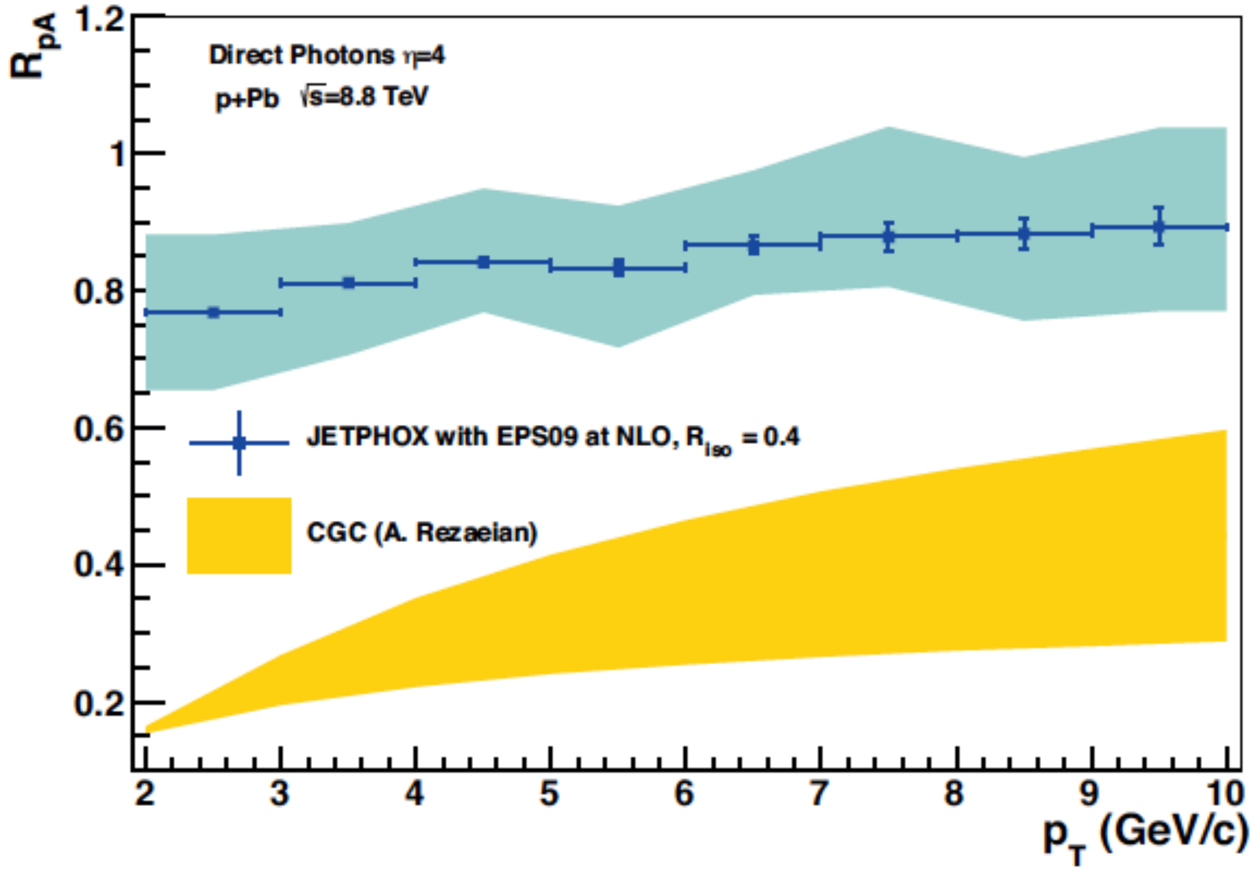
$$x_{\rm min} = \frac{2p_T}{\sqrt{s}}\exp(-\eta),$$

1. High particle flux at forward region
2. Difficult to measure direct photon at forward

But…

👉Measurement is possible by Si technics (CMOS-MAPS, PAD) !

Signal of CGC: R_{pA}



A. Rezaeian, PLB 718, 1058

Two scenarios for forward γ production in p+A at LHC:

- Normal nuclear effects linear evolution, shadowing
- Saturation/CGC running coupling BK evolution

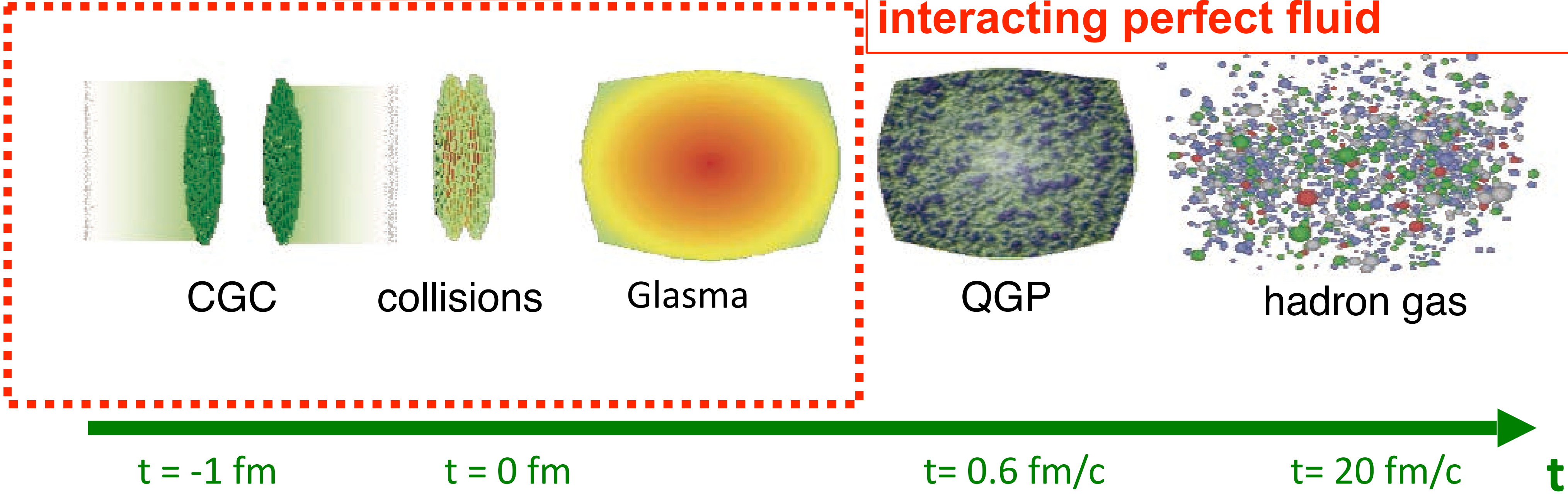
$$R_{pA} \equiv \frac{d^3N/dp_T^3(pA)}{\langle N_{coll}\rangle \cdot d^3N/dp_T^3(pp)},$$

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

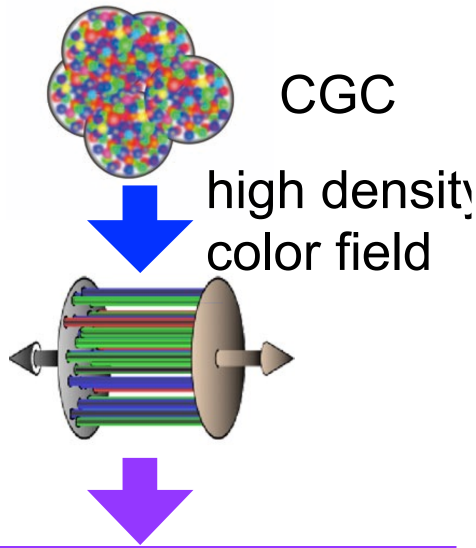
QGP thermalization mechanism

Unknown !

QGP (known):
rapid thermalization, strongly interacting perfect fluid



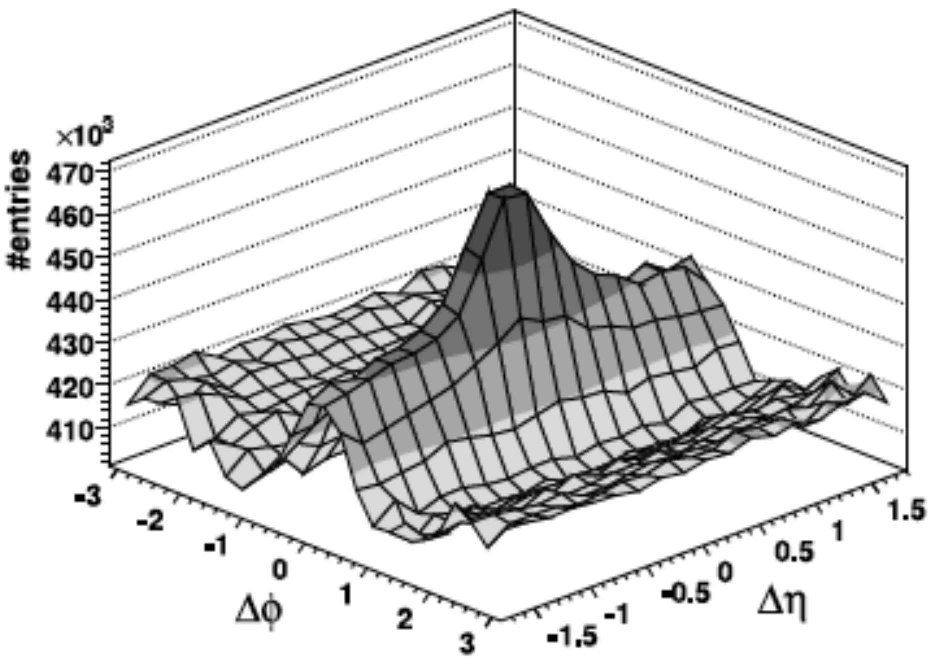
- **High energy nucleus ＝ What is the initial condition?**
- **Why so rapidly thermalized (t=0.6 fm/c)?**
  - **Instability of strong color field？→ need to determine the initial condition clearly.**
- **Find the clear evidence for CGC formation as an initial condition (or exclude it).**



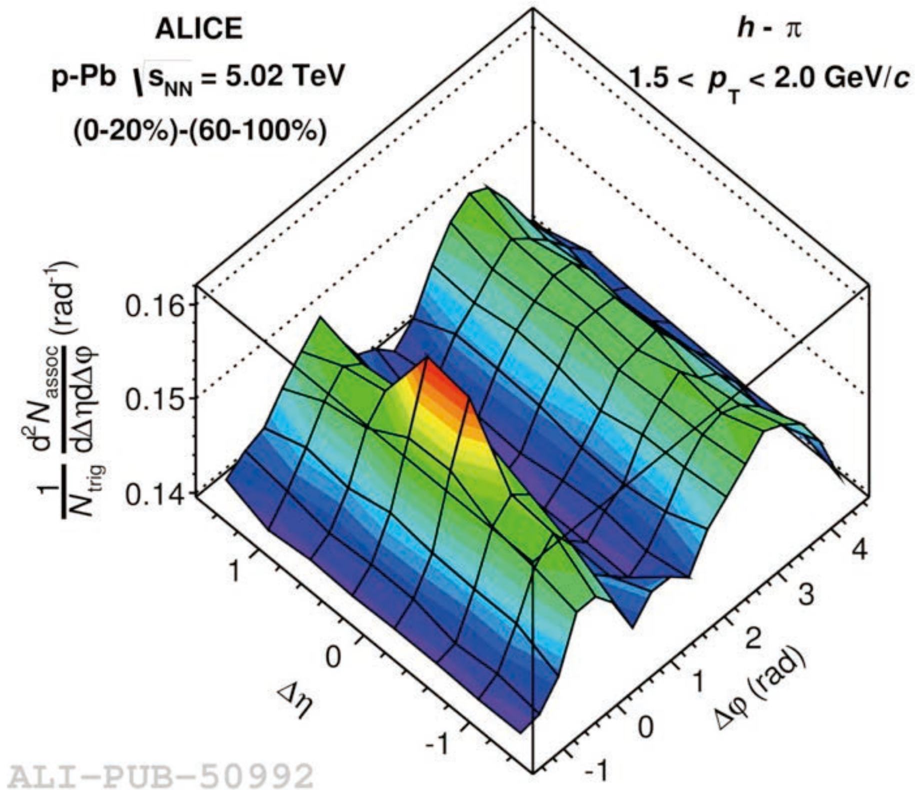
QGP rapid thermalization?

Long range correlations in AA and pA (“Ridge”)

RHIC (STAR, Au+Au 200 GeV)



LHC (ALICE, pPb, 5.02 TeV)

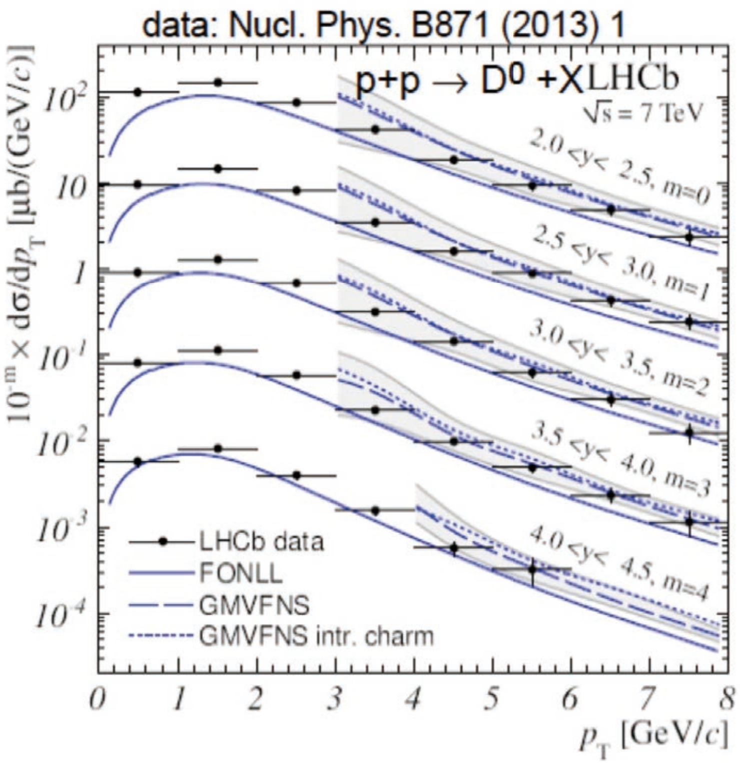


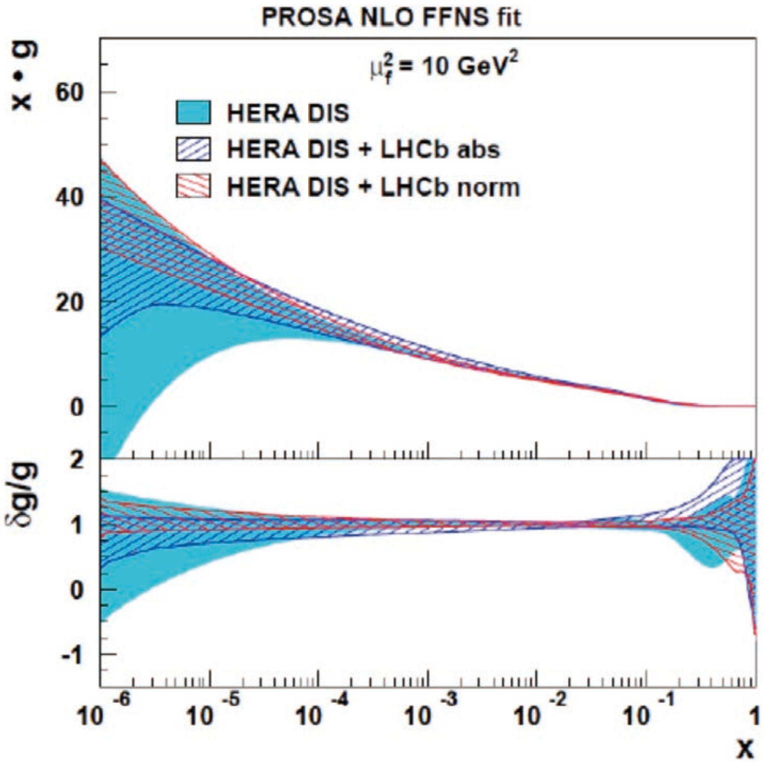
- long range Δη correlations (ridge) at RHIC and LHC.
- Origin is still unknown.
- by CGC (initial condition) or others?

photons vs. charm: D^0 meson (LHCb)

charm production in pp and pQCD at forward rapidity LHCb data

data: Nucl. Phys. B871 (2013) 1





for a recent summary of data and pQCD predictions see:
Guzzi, Geiser, Rizatdinova, 1509.04582 and Beraudo, 1509.04530
additional constraint of gluon PDF in particular at low x (down to 5 10^{-6})

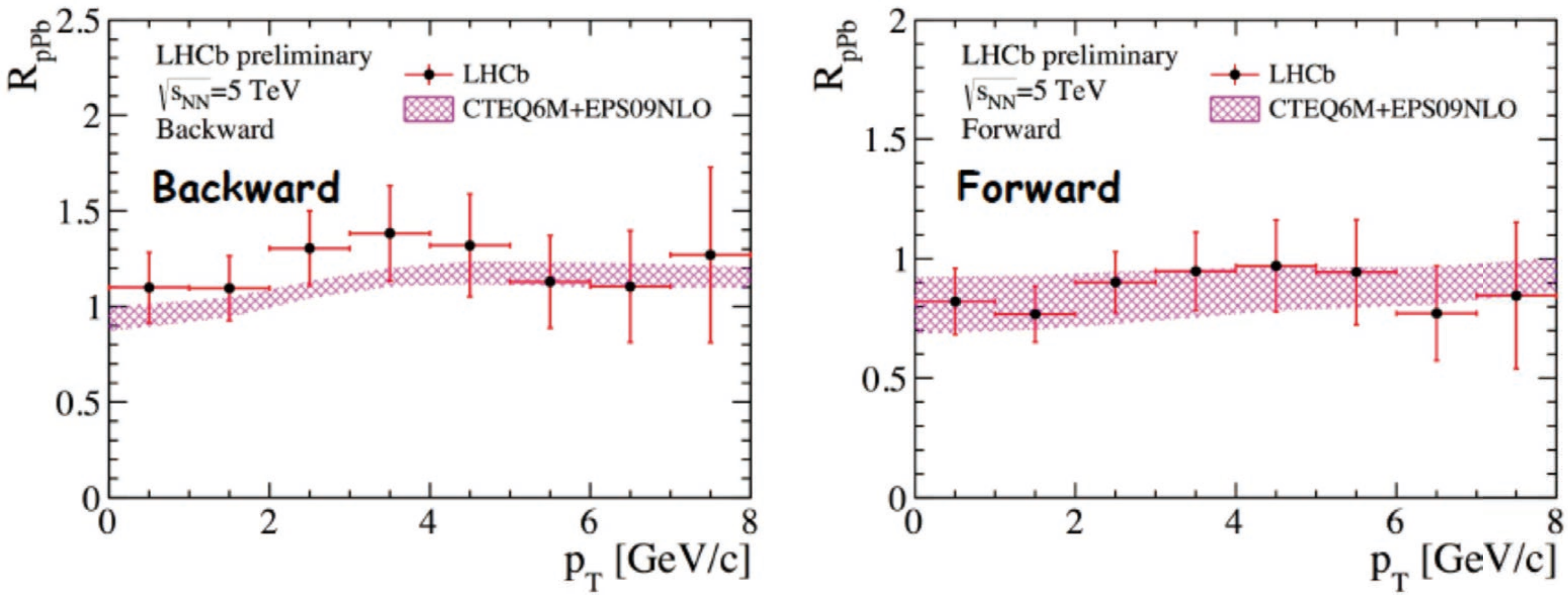
R_{pPb} for D^0 (LHCb)

Prompt D^0 nuclear modification factor

LHCb-CONF-2016-003

New

- Calculated as: $R_{pPb}(y, p_T) = \frac{1}{A} \times \frac{\sigma_{pPb}(y^*, p_T, \sqrt{s_{NN}})}{\sigma_{pp}(y^*, p_T, \sqrt{s_{NN}})}$, A=208
- D^0 cross-section in pp collision at $\sqrt{s} = 5$ TeV extrapolated using LHCb measurements at 7 and 13 TeV Nucl. Phys. B87 (2013), arXiv:1510.01707
  - ➢ pp data at $\sqrt{s} = 5$ TeV are being analyzed, will be updated soon



MNR with CTEQ6M+EPS09NLO: Nucl. Phys. B373 (1992) 295, JHEP 10 (2003) 046, JHEP 04 (2009) 065

25/03/2016 Moriond QCD, 2016 11

Isolated photons vs. hadrons

Isolated direct photons can provide strong constraints on the gluon PDFs

- LO dominant process: quark-gluon Compton.
- Quark-anti-quark annihilation contributing mostly at large x.

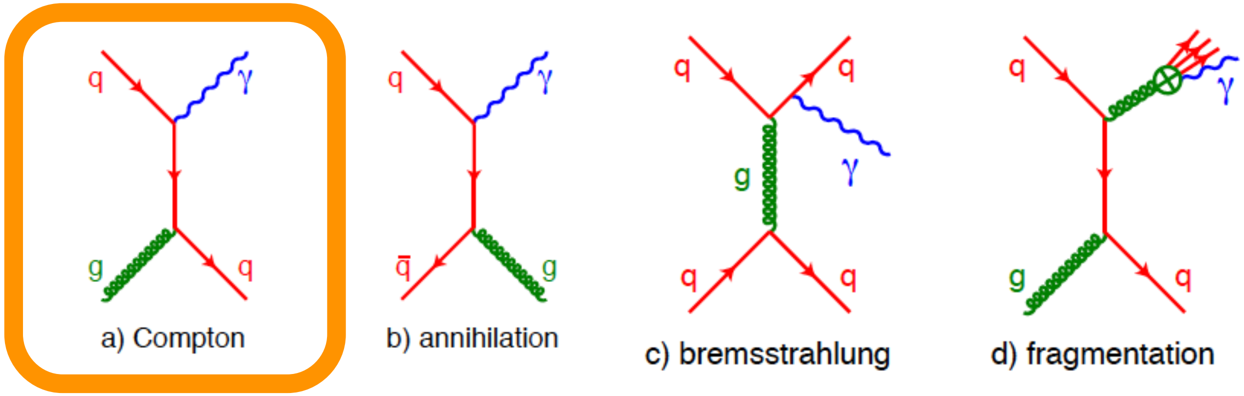
- NLO: At LHC, the majority of prompt photons are produced in the fragmentation process

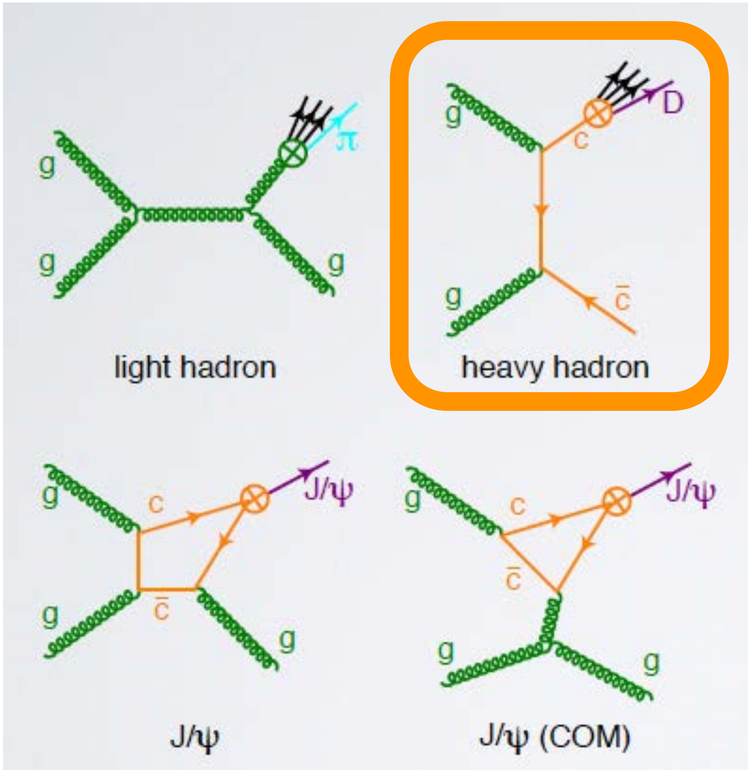
- Fragmentation photon can be largely suppressed by the isolation cut.

→quark-gluon Compton process dominant, more direct access to the gluon PDFs and saturation physics

photons

R. Ichou and D. d'Enterria, Phys. Rev. D 82, 014015 (2010)





hadrons

by T. Peitzmann

Uniqueness of this measurement

High density gluon matter ↔Hot Quark Matter

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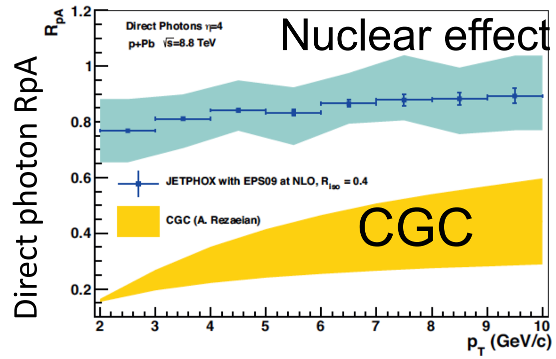


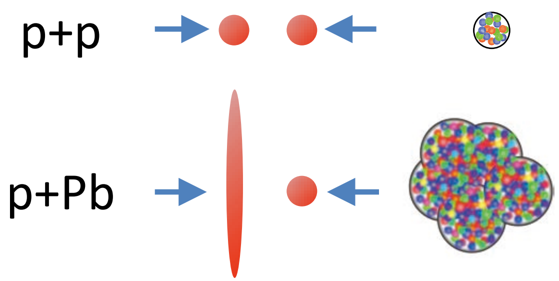
① Evidence for CGC

- direct photon ＝ most clean signal for CGC
- Forward direct photon: R_{pA} → CGC or not.

② Nature of CGC

- Direct photon R_{pA}: system, multiplicity, y & p_T dep.

  → characterize CGC size, structure, onset.



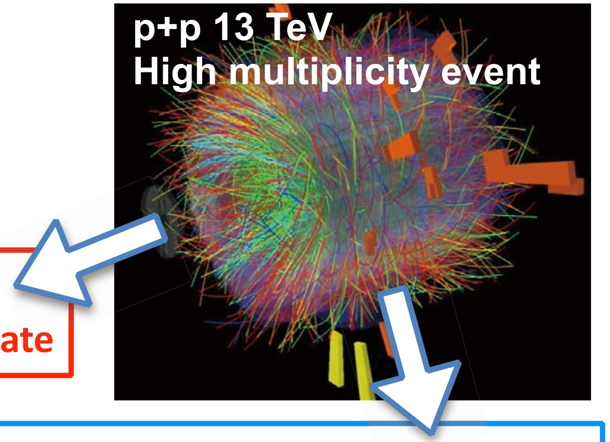
③CGC and QGP thermalization mechanism

- Size of CGC (direct photon) and QGP temperature,

  expansion velocity, fluctuation.
- Forward photon /hadron vs. mid. photon / hadron

  👉 correlation between CGC size and QGP thermalization (e-by-e)

  → Mechanism of rapid thermalization



ALICE Forward photon ＝CGC state

ALICE mid (DCal, PHOS, TPC)
photon ＝temperature
hadron＝expansion velocity

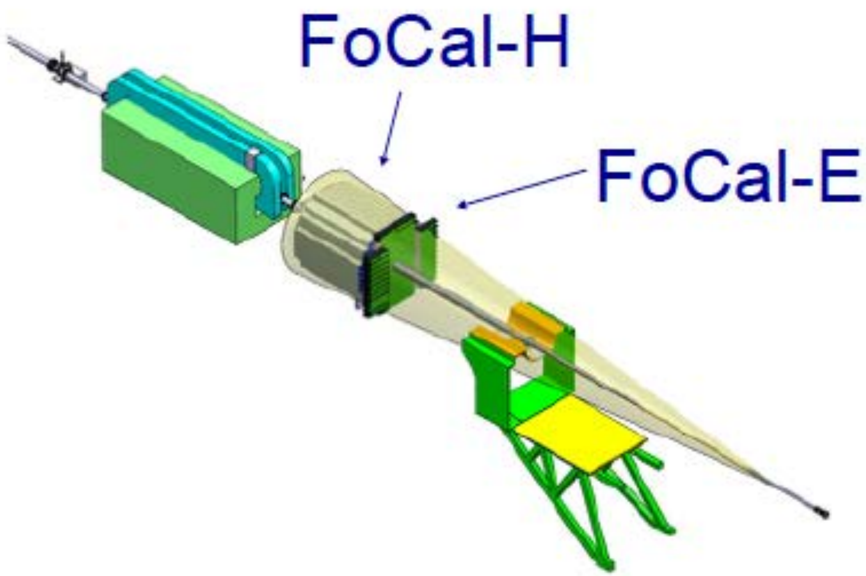
④ Connection to other research fields

- 「strong field」：QCD color (gluon) field vs. QED field (Neutron star)
- 「forward」 ：High energy cosmic rays

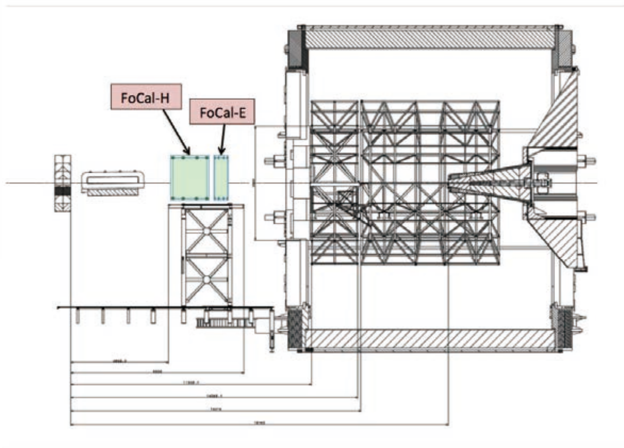
ALICE FoCal Project

- p+Pb: looking for CGC effects at low x
  - Direct photons
  - pi0
  - di-hadron correlations
- p+p: forward particle production
  - Direct photons
  - pi0
  - di-hadron correlations
- Pb+Pb: medium density at fwd rapidity
  - pi0 at 4 < eta < 4.5
    - Handle on longitudinal evolution of medium
    - Provide light meson baseline for J/psi, muon suppression
  - di-hadron correlations (TBC)

plus other capabilities: quarkonia, jets, mostly in p, p+Pb

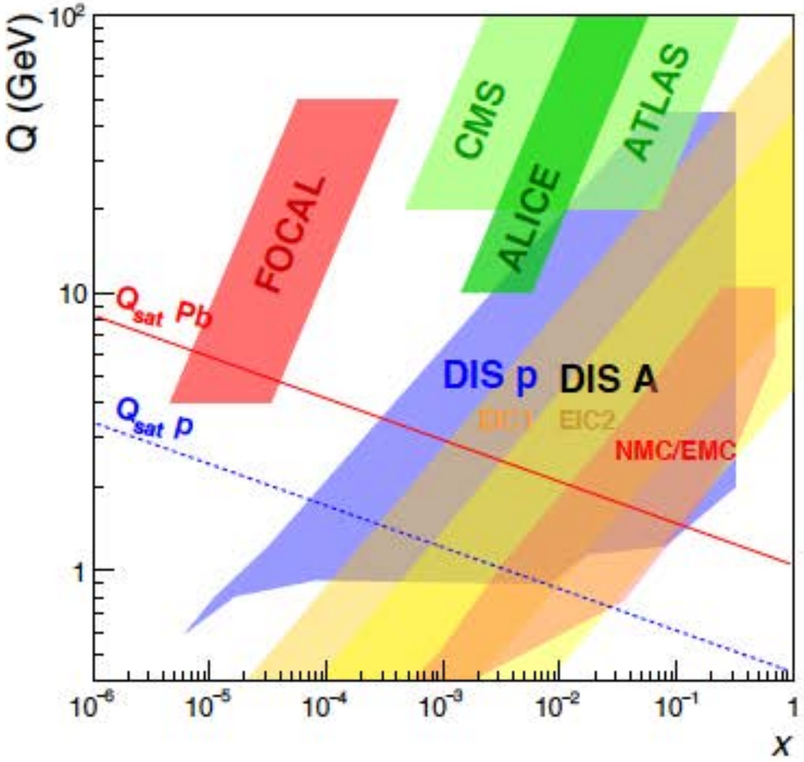


$3.2 < \eta < 5.3$



Kinematic reach by FoCal

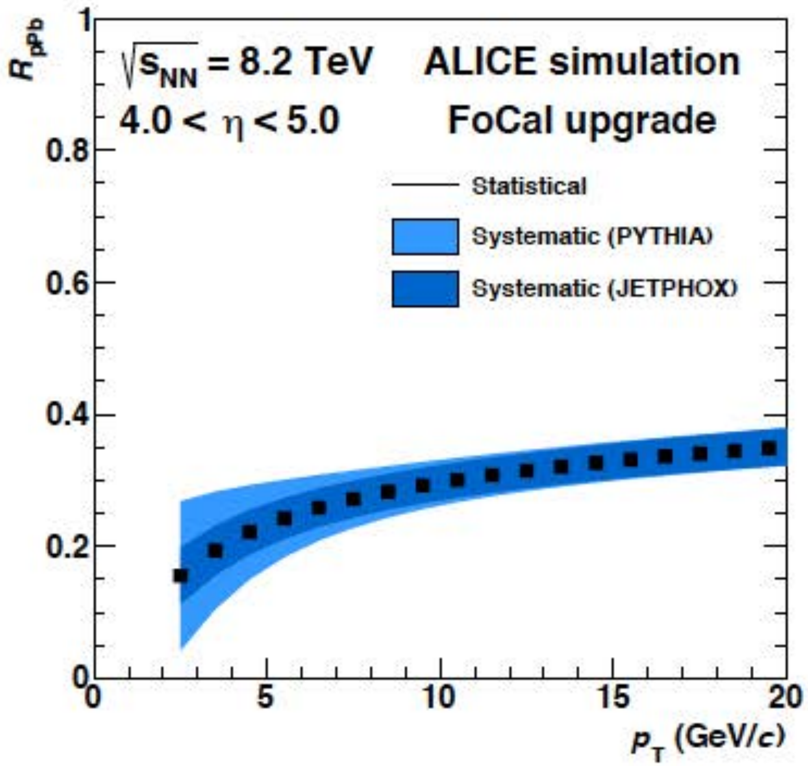
x-Q ranges for photons and DIS



Forward measurements at LHC access unique range in x, Q^2

Remark hadronic probes

Projected uncertainty for direct γ R_{pPb}

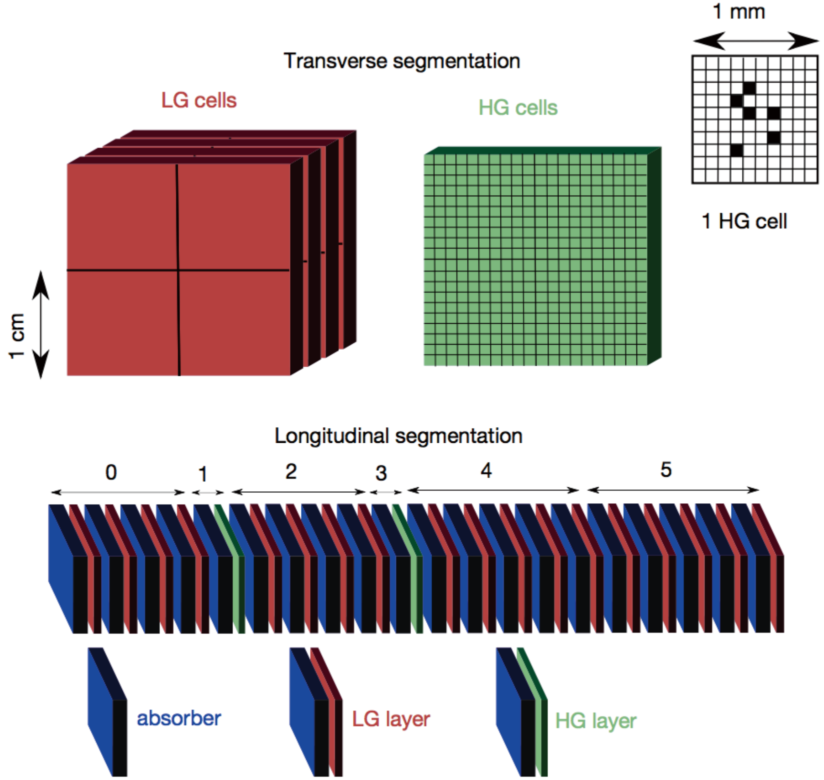


FoCal can measure direct photons in this range

Cleanest probe of PDFs

p0, eta, omega as well....

FoCal-E prototypes



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

LG segments

- 4 (or 5) layers
- Si-pad with analog readout
- cell size 1 x 1 cm^2
- longitudinally summed

HG segments

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

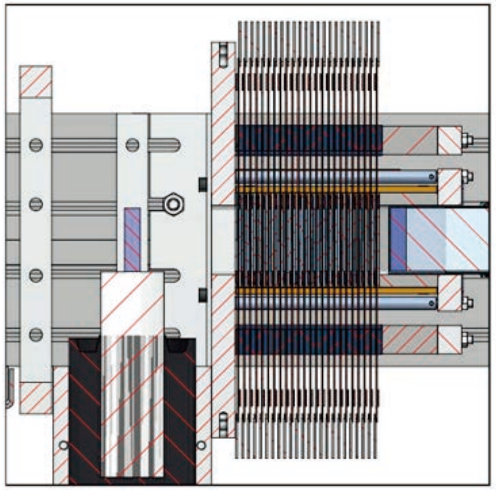
*MAPS = Monolithic Active Pixel Sensor (cm)

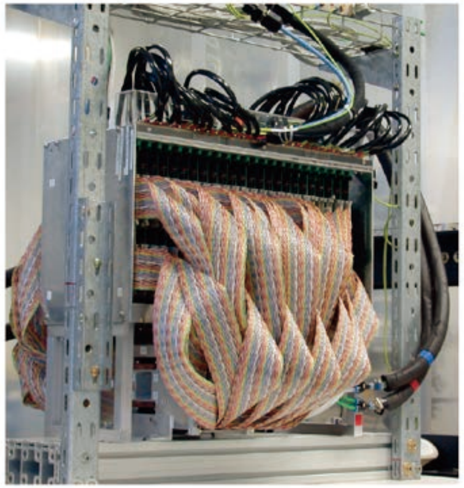
FoCal project (Institutes)

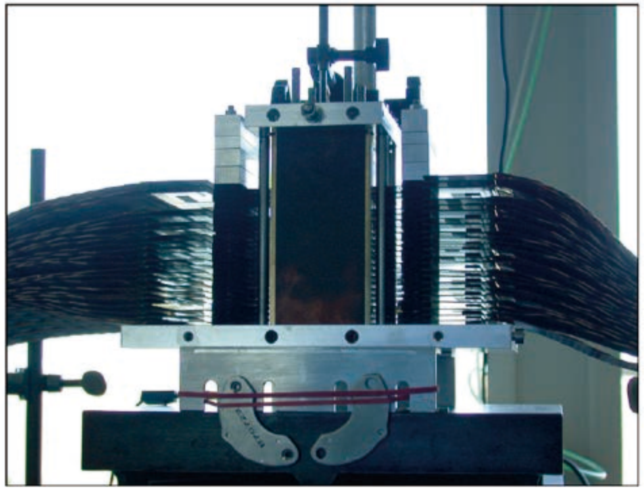
Short Name	Full Name	Representative
Amsterdam	Nikhef, Amsterdam, Netherlands	M. van Leeuwen
BARC	Bhaba Atomic Research Centre, Mumbai, India	V.B. Chandratre
Bergen	University of Bergen, Bergen , Norway	D. Roehrich
Bose	Bose Institute, Kolkata, India	S. Das
Detroit	Wayne State University, Detroit, USA	J. Putschke
Hiroshima	Hiroshima University, Hiroshima, Japan	T. Sugitate
IITB	Indian Institute of Technology Bombay, Mumbai, India	R. Varma
Indore	Indian Institute of Technology Bombay, Indore, India	R. Sahoo
Jammu	Jammu University, Jammu, India	A. Bhasin
Jyväskylä	University of Jyväskylä, Jyväskylä , Finland	J. Rak
Knoxville	University of Tennessee, Knoxville, USA	K. Read
Nagasaki	Nagasaki Inst. of Applied Science, Nagasaki, Japan	K. Oyama
Nara[§]	Nara Women's University, Nara, Japan	M. Shimomura
Oak Ridge	Oak Ridge National Laboratory (ORNL),Oak Ridge, USA	T. Cormier
Prague	Czech Technical University of Prague, Prague, Czech Republic	V. Petracek
Sao Paulo	Universidade de Sao Paulo (USP), Sao Paulo, Brazil	M. Munhoz
Tokyo	Center of Nuclear Study (CNS), Tokyo, Japan	T. Gunji
Tsukuba	University of Tsukuba	T. Chujo
Tsukuba Tech	Tsukuba University of Technology	M. Inaba
Utrecht	Utrecht University, Utrecht, Netherlands	T. Peitzmann
VECC	Variable Energy Cyclotron Centre, Kolkata, India	T. Nayak

High Granularity (HG) Prototype, MAPS

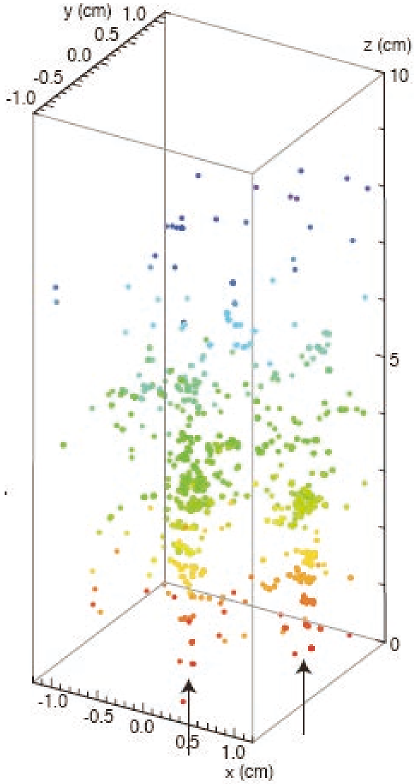
MAPS prototype

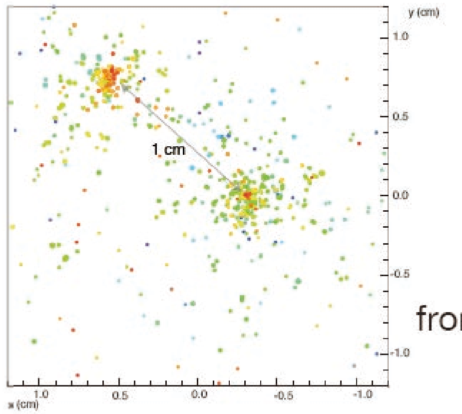






- 4x4 cm^2 cross section, 28 X_0 depth
- 24 layers: W absorber + 4 MAPS each
- MIMOSA PHASE 2 chip (IPHC Strasbourg)
  - 30 µm pixels
  - 640 µs integration time
    (needs upgrade – too slow for experiment)
- 39 M pixels total
- Test with beams at DESY, CERN PS, SPS

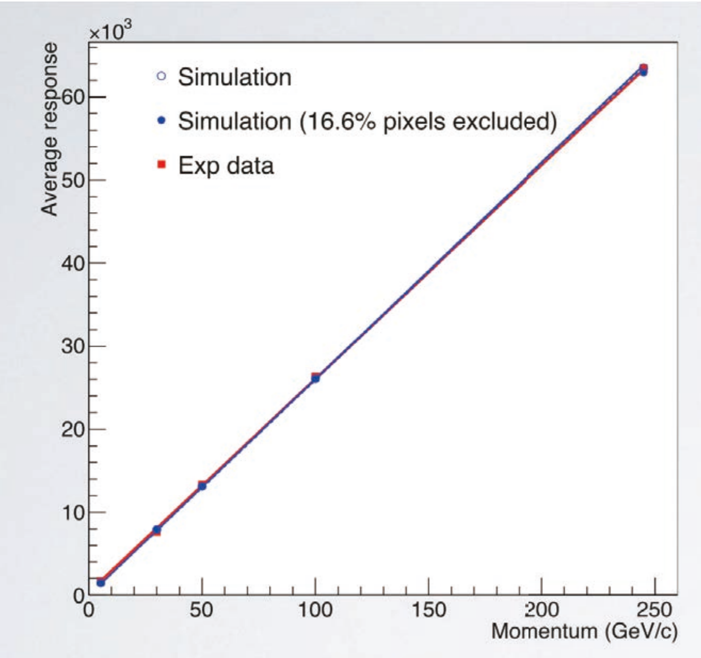




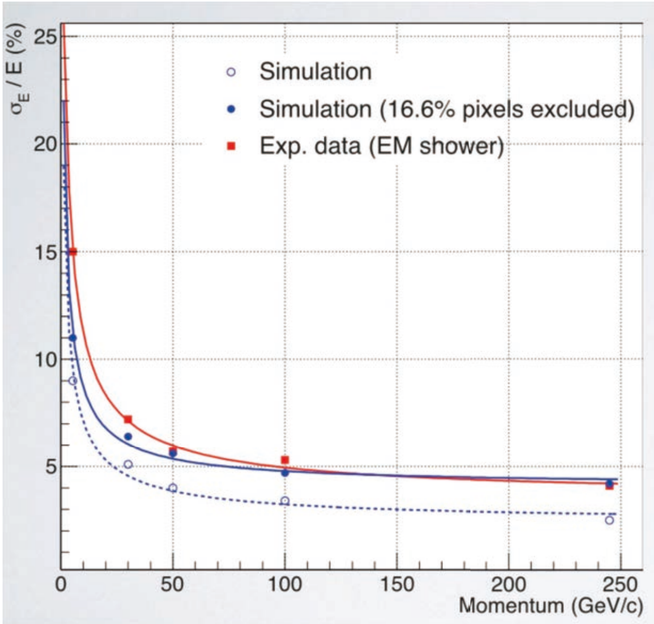
front view

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

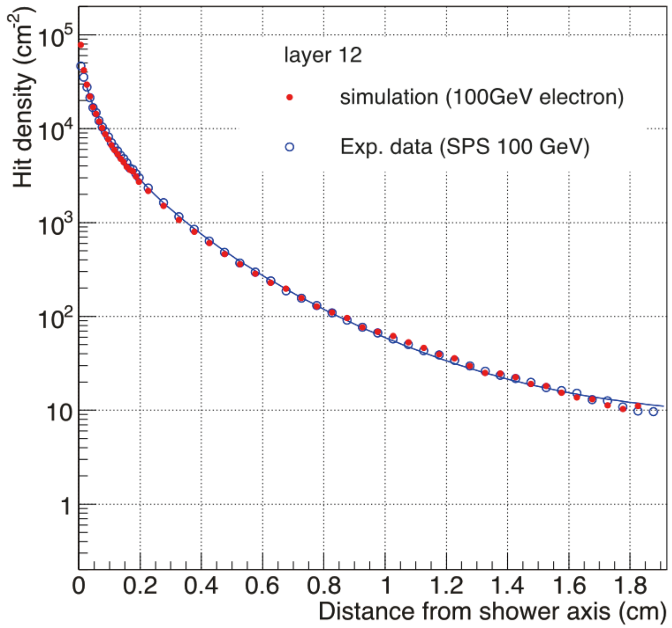
High Granularity (HG) Prototype, MAPS



Linearity

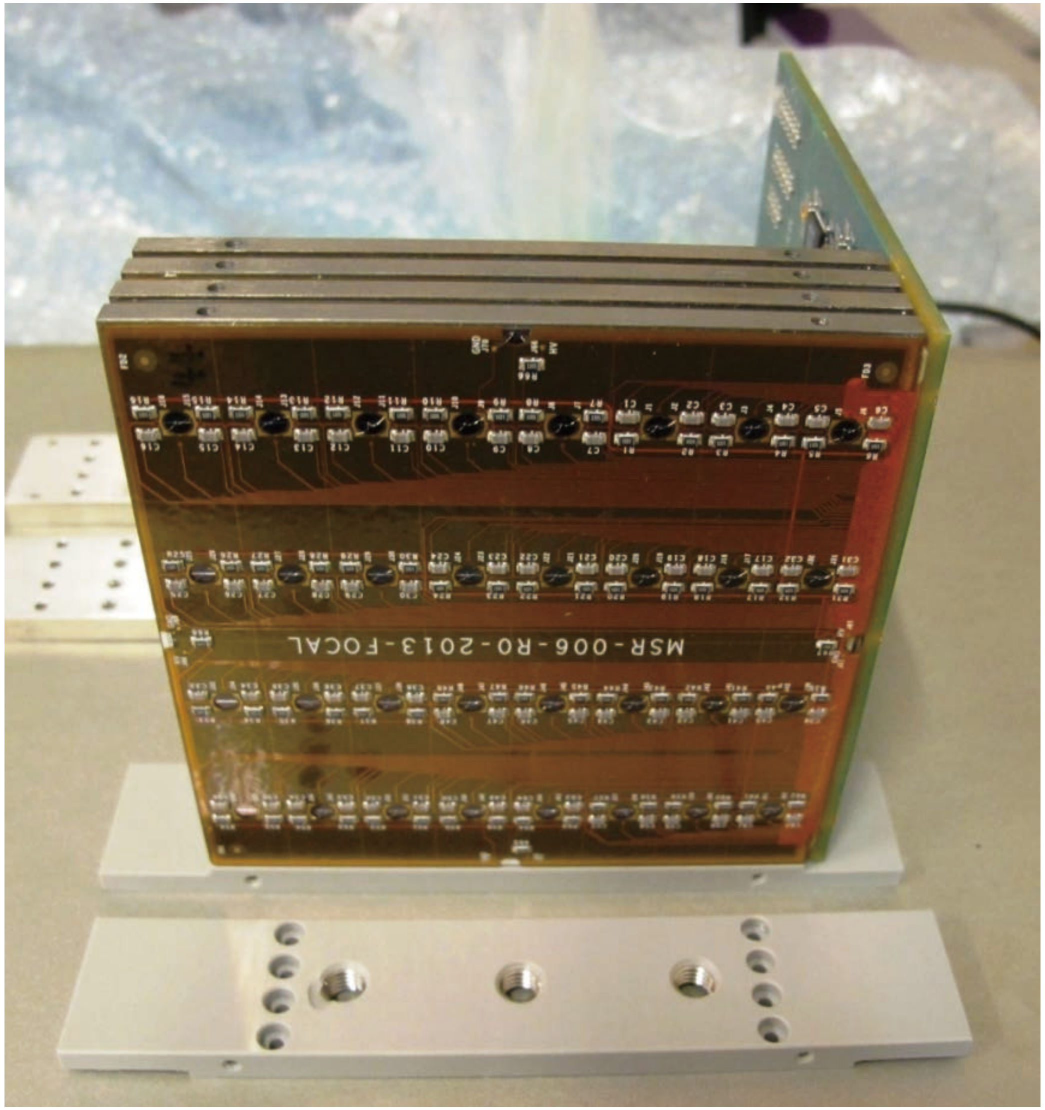


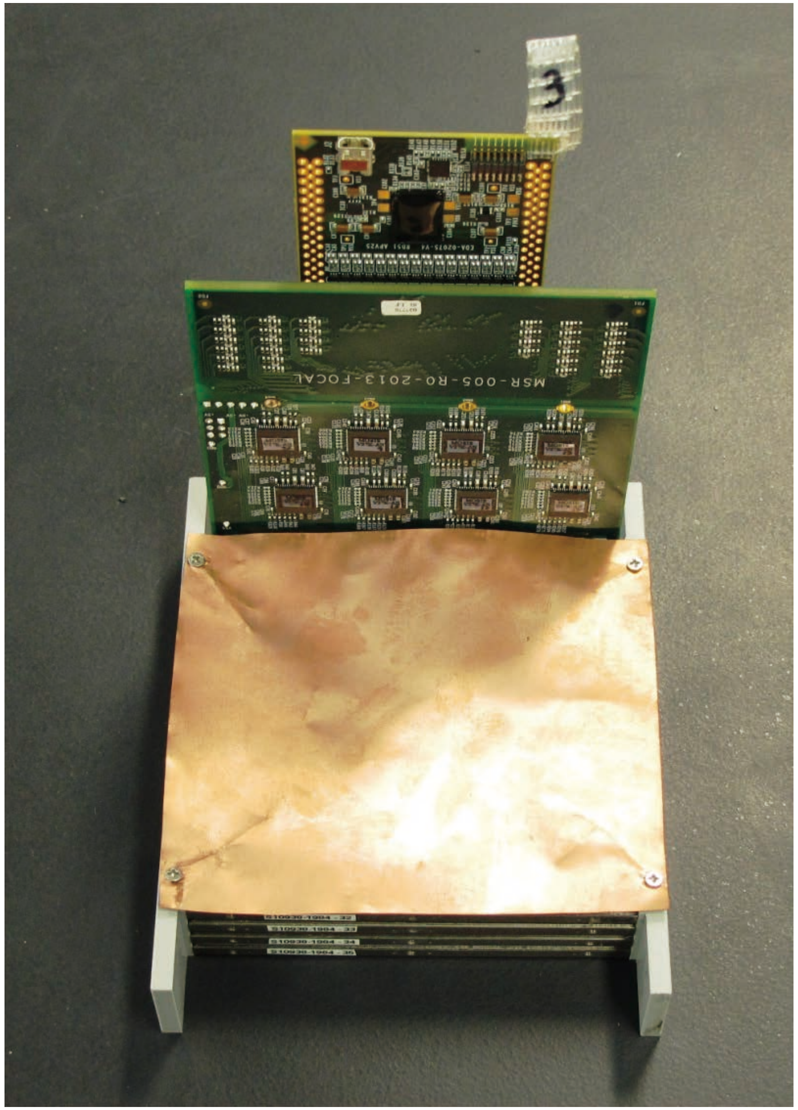
Energy resolution



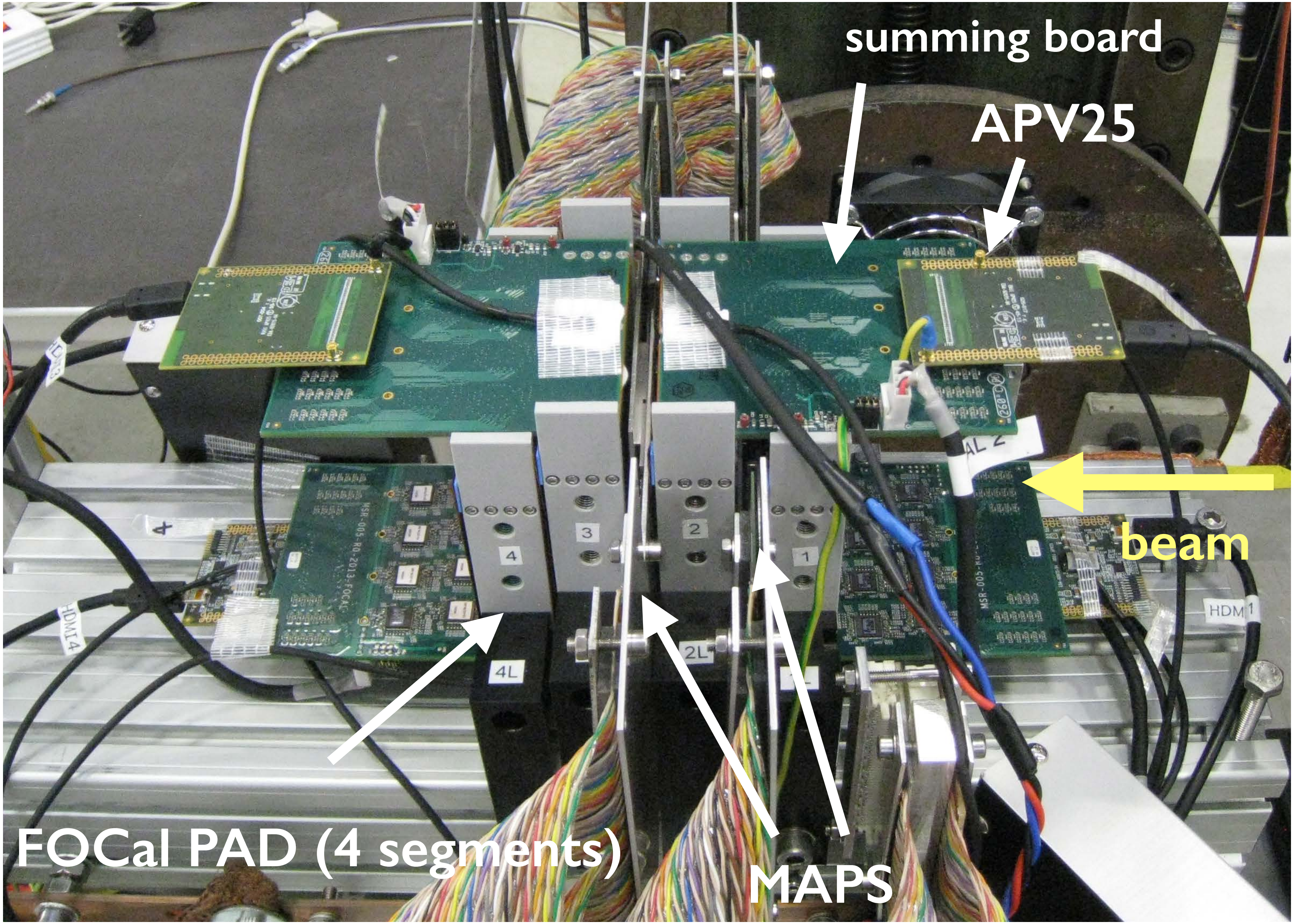
Shower profile

Low Granularity (LG) Prototype, PAD (JP, US)



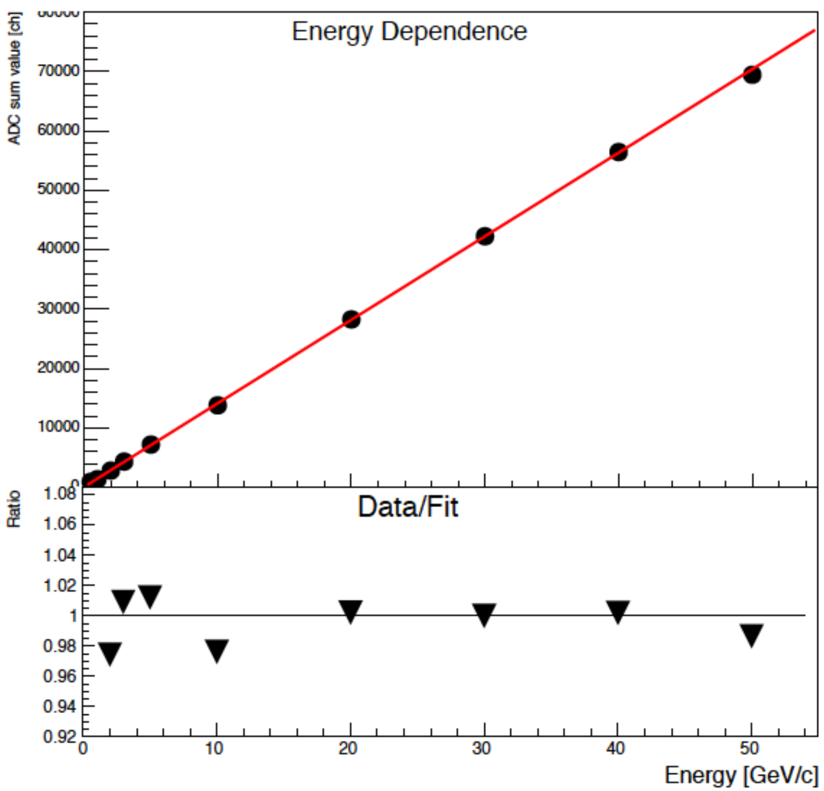


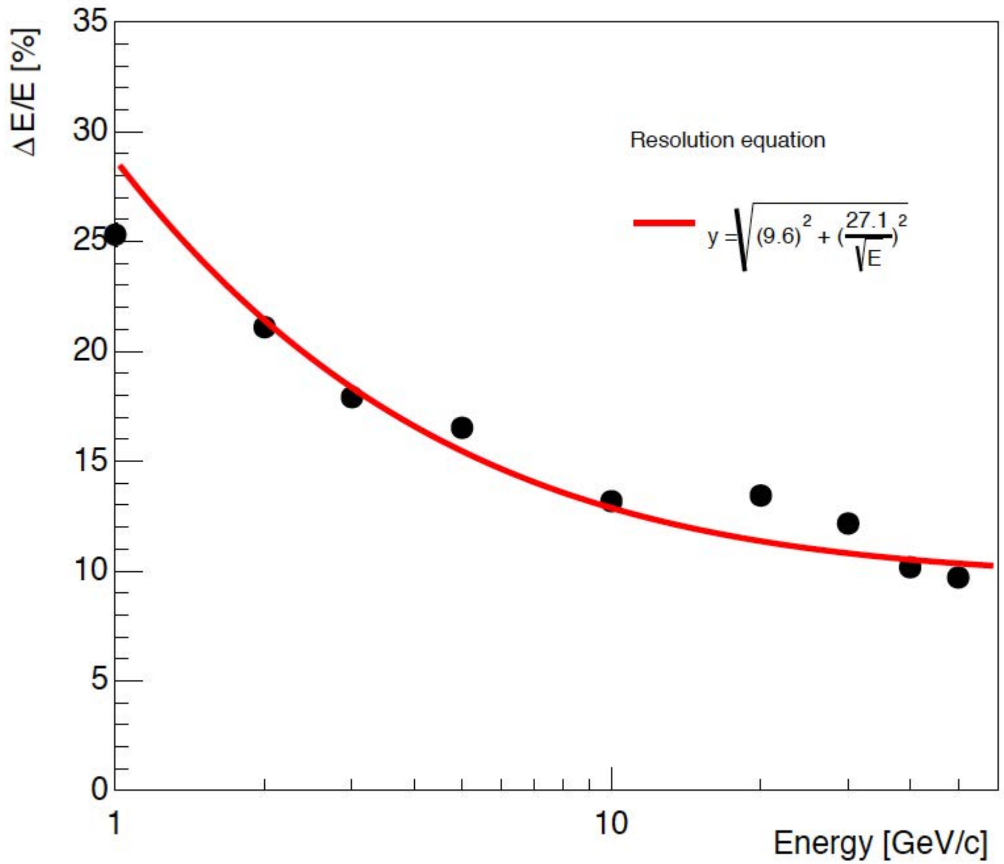
FoCal PAD proto type, 1 segment (ORNL, Tsukuba, CNS-Tokyo)



Test beam setup @ PS (same for SPS) in 2015

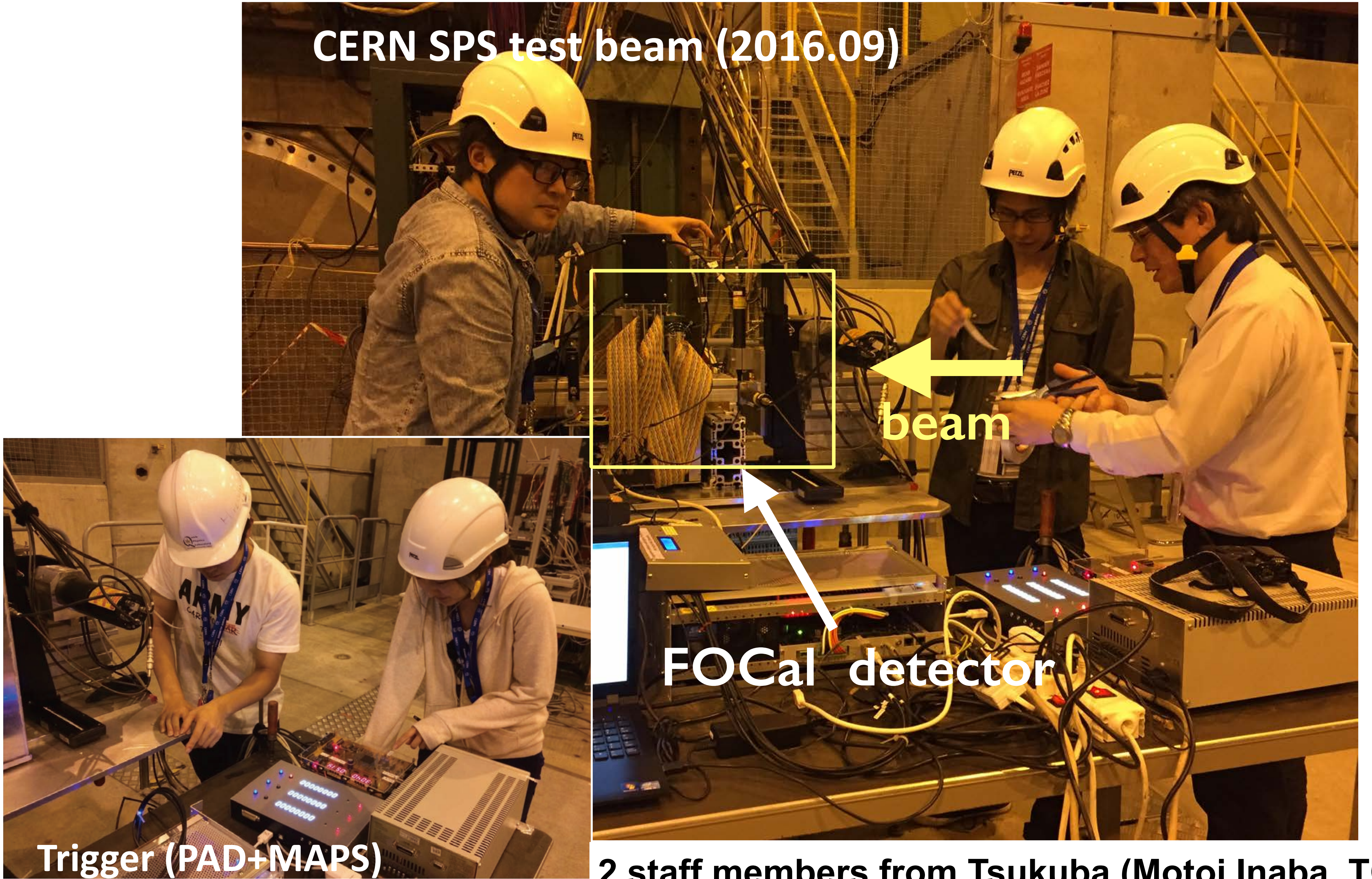
Linearity and energy resolution (2015 beam test, Tsukuba)





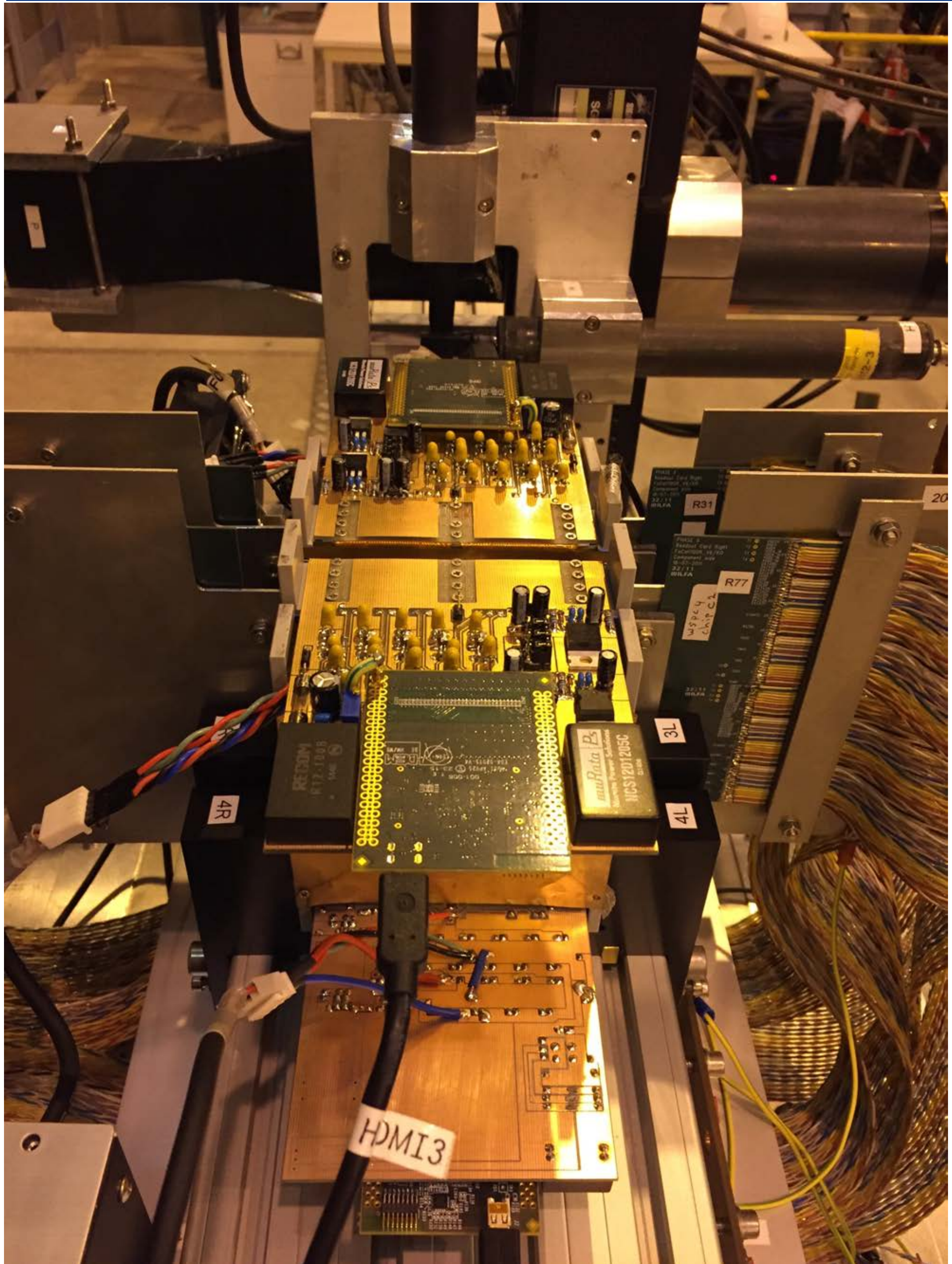
- Good linearity within ~3% from PS to SPS energies.

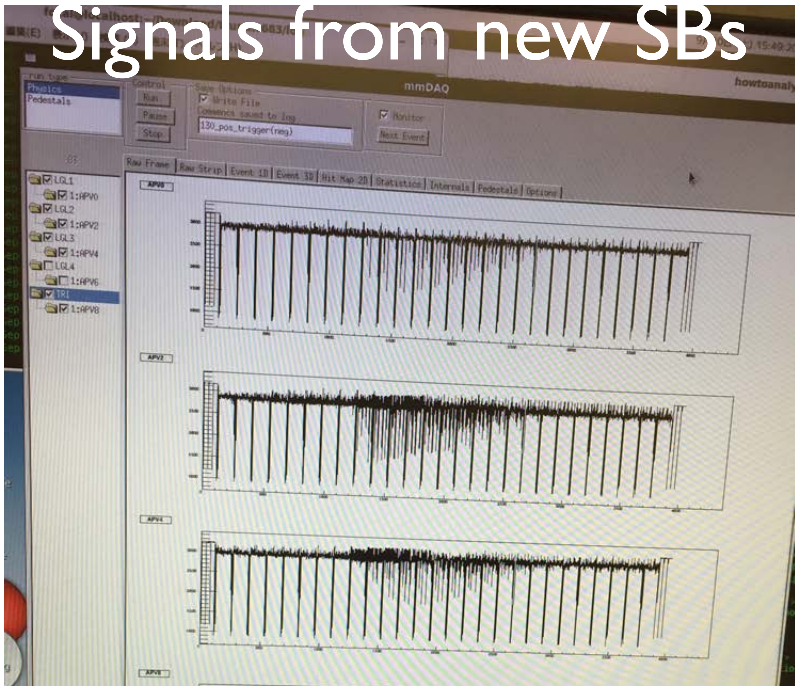
- Stochastic term: close to the expected value.
- Constant term: < 10%



2 staff members from Tsukuba (Motoi Inaba, TC)
4 undergrad students from Tsukuba
1 master student from Nara W. U.
4 from Utrecht (MAPS)
<u>Total: 11</u>

2016 SPS test beam (Sep. 7-12)

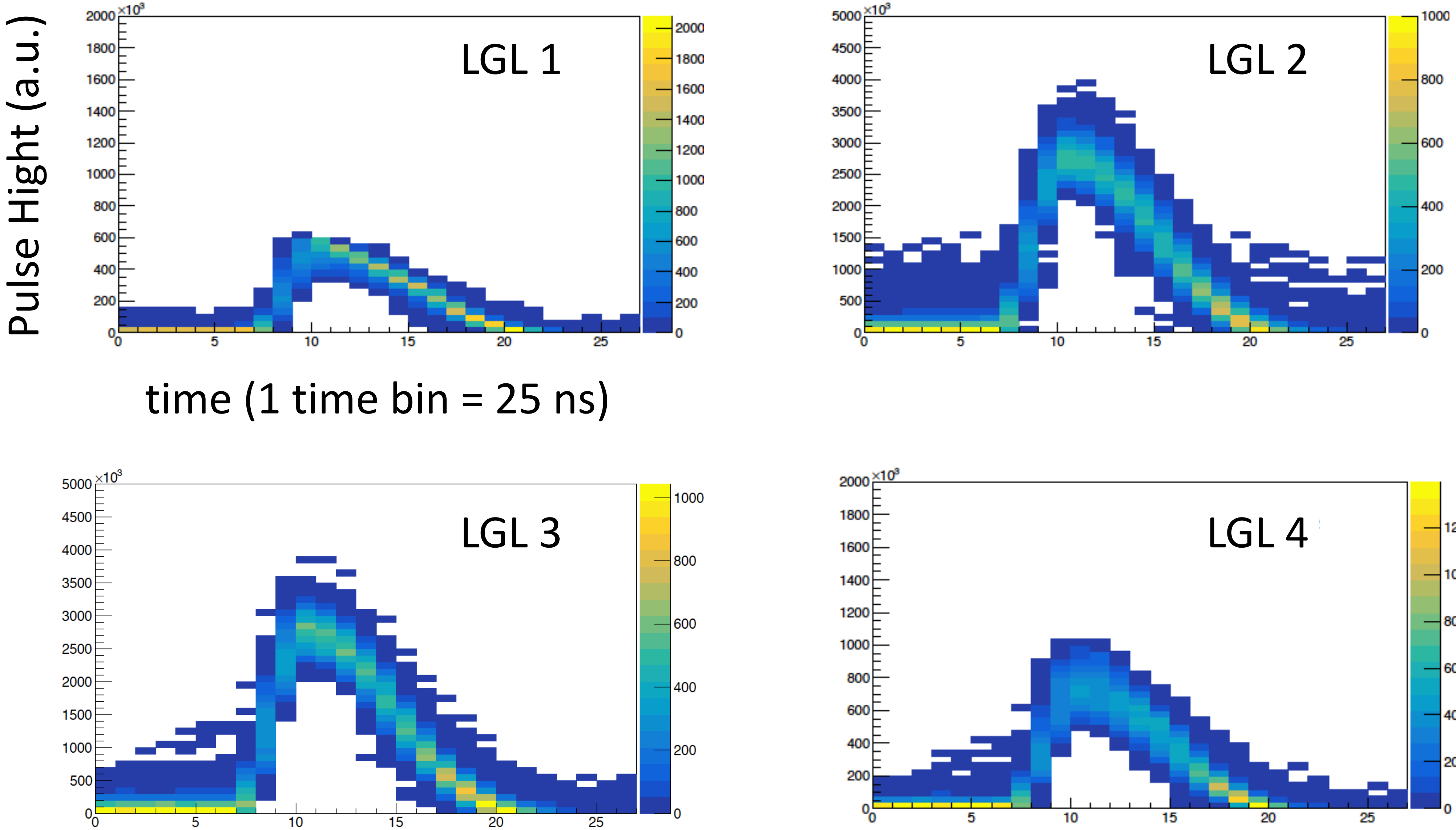




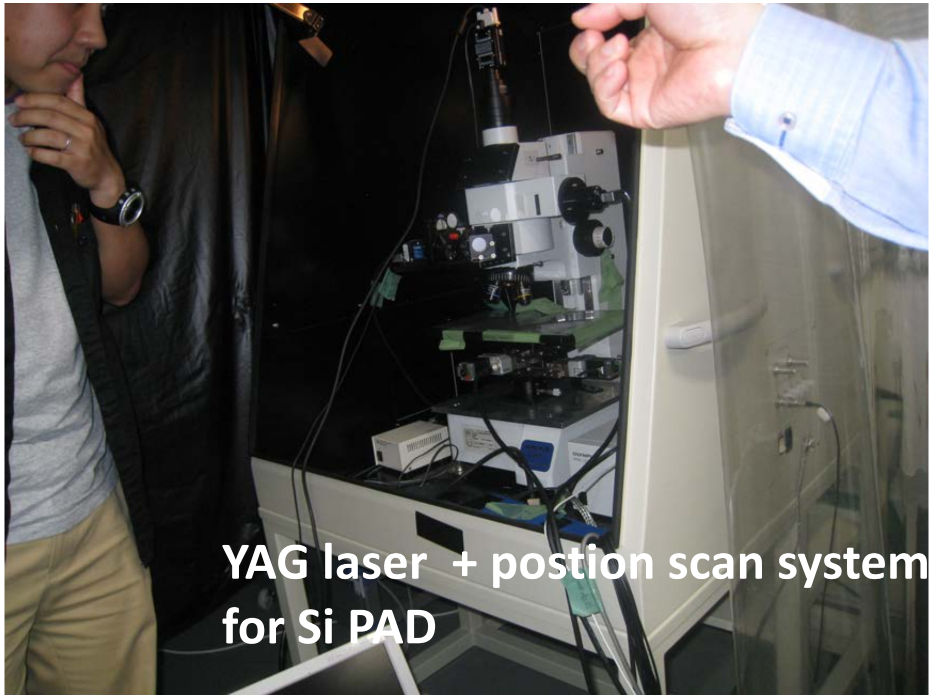
- New summing board (by M. Inaba) installed for all 4 LGLs, tested with beams (<140 GeV/c).
- Wider dynamic range and
- Also the data matching between MAPS and PAD (LGL) is possible by the trigger bits recording in the both data stream

Electron signals at 130 GeV/c

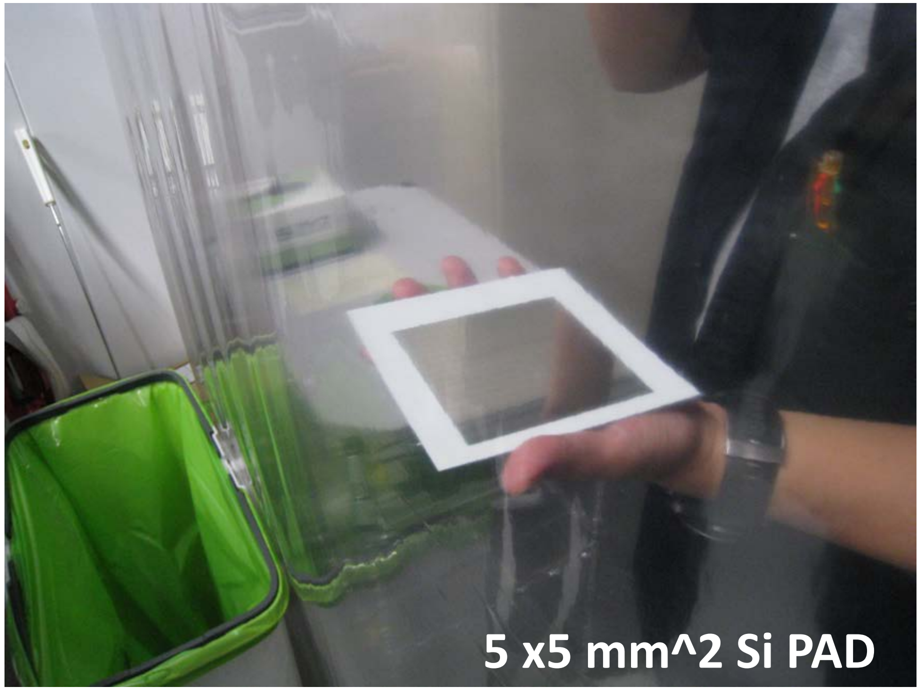
SPS; 130 GeV/c, e^+



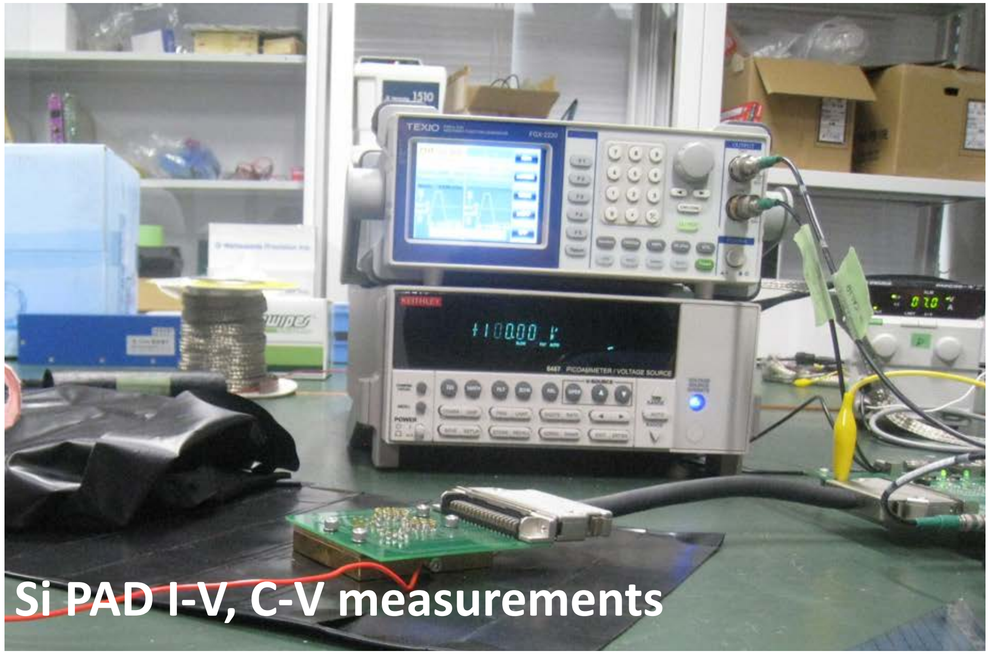
Y. Kawamura, T. Suzuki



YAG laser + postion scan system for Si PAD



5 x5 mm^2 Si PAD



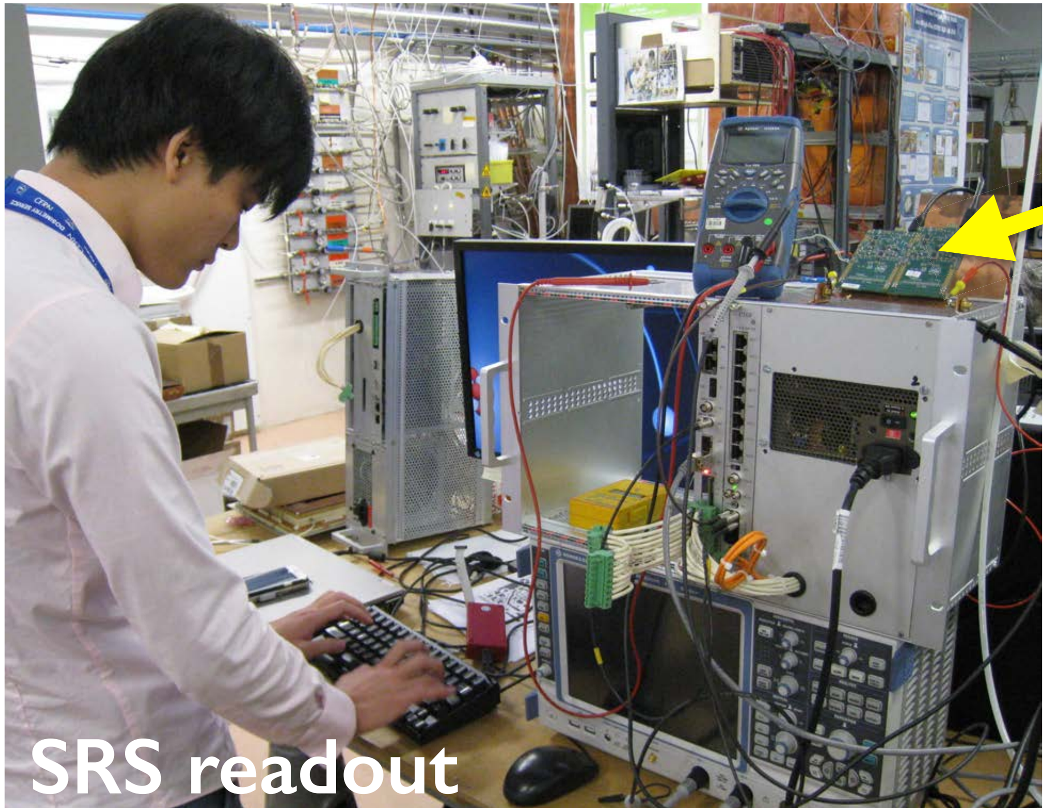
Si PAD I-V, C-V measurements

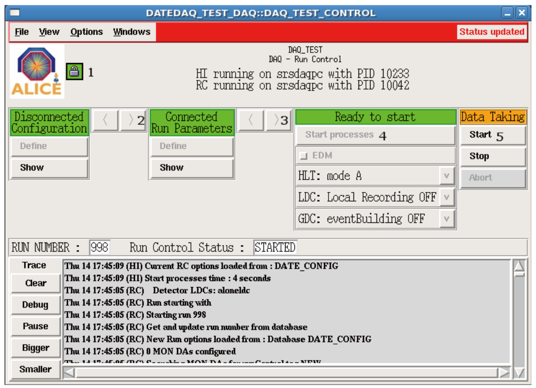
Hex Si PAD

Visited the ILC group @ Kyushu Univ. (2016.09)

R&D for fast readout: RD51 (VMM2/3)

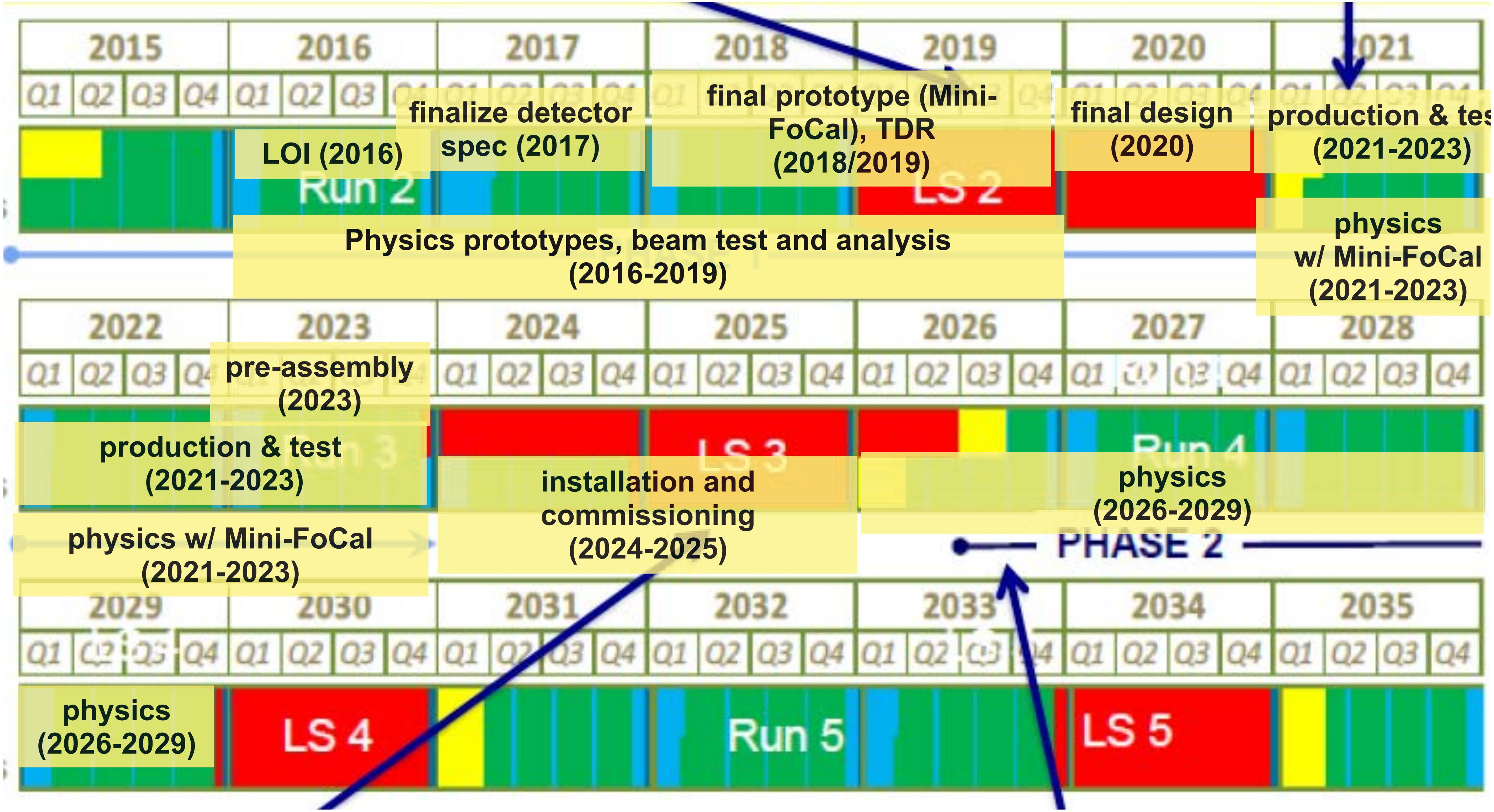
- R&D and test for VMM2 and VMM3 hybrid boards with SRS + DATE (ALICE DAQ) system.
- R&D of combined design; on-board VMM2/3 on FoCal summing board, and modification for FoCal needs (dynamic range & trigger capability)





ALICE DATE for VMM (developed by RD51)

Tentative schedule



Summary and Future Plan

- **Rich physics and unexplored region @ forward rapidity at LHC**
  - CGC, nature of CGC (size, structure, ..).
  - Connection to QGP thermalization mechanism and strong field (origin of QGP, initial condition).
  - Long range delta eta correlations (origin of ridge)
  - Extensive ongoing R&D efforts, well defined targets.
- **<u>PLAN</u>:**
  - beam background study (and hopefully initial physics measurement) by the prototype during the Run-2 (2018).
  - mini FoCal ($3 < \eta < 4$) in Run-3 (2021-2023).
  - full FoCal ($3.2 < \eta < 5.3$) in Run-4 (2026-2029).