Forward Calorimeter upgrade in ALICE

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Outline

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

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

To find/test CGC by experiment...

1. More forward
2. Higher energy
3. Proton < nucleus
4. Cleanness: h < gamma

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

But...

Measurement is possible by Si technics (CMOS-MAPS, PAD)!
Signal of CGC: $R_{pA}$

Two scenarios for forward $\gamma$ production in p+A at LHC:

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

• Strong suppression in direct $\gamma$ $R_{pA}$.
• Signals expected at forward $\eta$, low-intermediate $p_T$.

\[ R_{pA} \equiv \frac{d^3N/dp_T^3(pA)}{\langle N_{coll} \rangle \cdot d^3N/dp_T^3(pp)}, \]
**QGP thermalization mechanism**

- **CGC collisions**
- **QGP hadron gas**

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

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

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- **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).**
Long range correlations in AA and pA ("Ridge")

- long range $\Delta \eta$ 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

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 $5 \times 10^{-6}$)
Prompt $D^0$ nuclear modification factor

- 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
  - $pp$ data at $\sqrt{s} = 5$ TeV are being analyzed, will be updated soon

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.
Uniqueness of this measurement

High density gluon matter ↔ Hot Quark Matter

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.

3. CGC 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

4. Connection to other research fields
   - 「strong field」: QCD color (gluon) field vs. QED field (Neutron star)
   - 「forward」: High energy cosmic rays

\includegraphics[width=\textwidth]{figure.png}
ALICE FoCal Project

- p+Pb: looking for CGC effects at low $x$
  - Direct photons
  - $\pi_0$
  - di-hadron correlations
- p+p: forward particle production
  - Direct photons
  - $\pi_0$
  - di-hadron correlations
- Pb+Pb: medium density at fwd rapidity
  - $\pi_0$ at $4 < \eta < 4.5$
    - Handle on longitudinal evolution of medium
    - Provide light meson baseline for J/ψ, muon suppression
  - di-hadron correlations (TBC)

plus other capabilities: quarkonia, jets, mostly in p, p+Pb
Kinematic reach by FoCal

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

Remark hadronic probes

FoCal can measure direct photons in this range

Cleanest probe of PDFs $p_0$, 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 \(\approx 25 \times 25 \mu m^2\)
  - digitally summed in 1mm\(^2\) cells

*MAPS = Monolithic Active Pixel Sensor (cm)
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High Granularity (HG) Prototype, MAPS

- 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

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 prototype, 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)
Total: 11
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⁺

Pulse Height (a.u.)

LGL 1

LGL 2

LGL 3

LGL 4

Y. Kawamura, T. Suzuki

time (1 time bin = 25 ns)
Visited the ILC group @ Kyushu Univ. (2016.09)

Si PAD I-V, C-V measurements

5 x5 mm^2 Si PAD

Hex Si PAD

YAG laser + position scan system for Si PAD
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)
Tentative schedule

Physics prototypes, beam test and analysis (2016-2019)

- Finalize detector spec (2017)
- Final prototype (Mini-FoCal), TDR (2018/2019)
- Final design (2020)
- Production & test (2021-2023)

Pre-assembly (2023)

Production & test (2021-2023)

Physics w/ Mini-FoCal (2021-2023)

Installation and commissioning (2024-2025)

Physics (2026-2029)

Physics w/ Mini-FoCal (2021-2023)

Production & test (2021-2023)

Final design (2020)

Production & test (2021-2023)

Physics (2026-2029)
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.

- **PLAN:**
  - beam background study (and hopefully initial physics measurement) by the prototype during the Run-2 (2018).
  - mini FoCal (3 <η<4) in Run-3 (2021-2023).
  - full FoCal (3.2 <η < 5.3) in Run-4 (2026-2029).