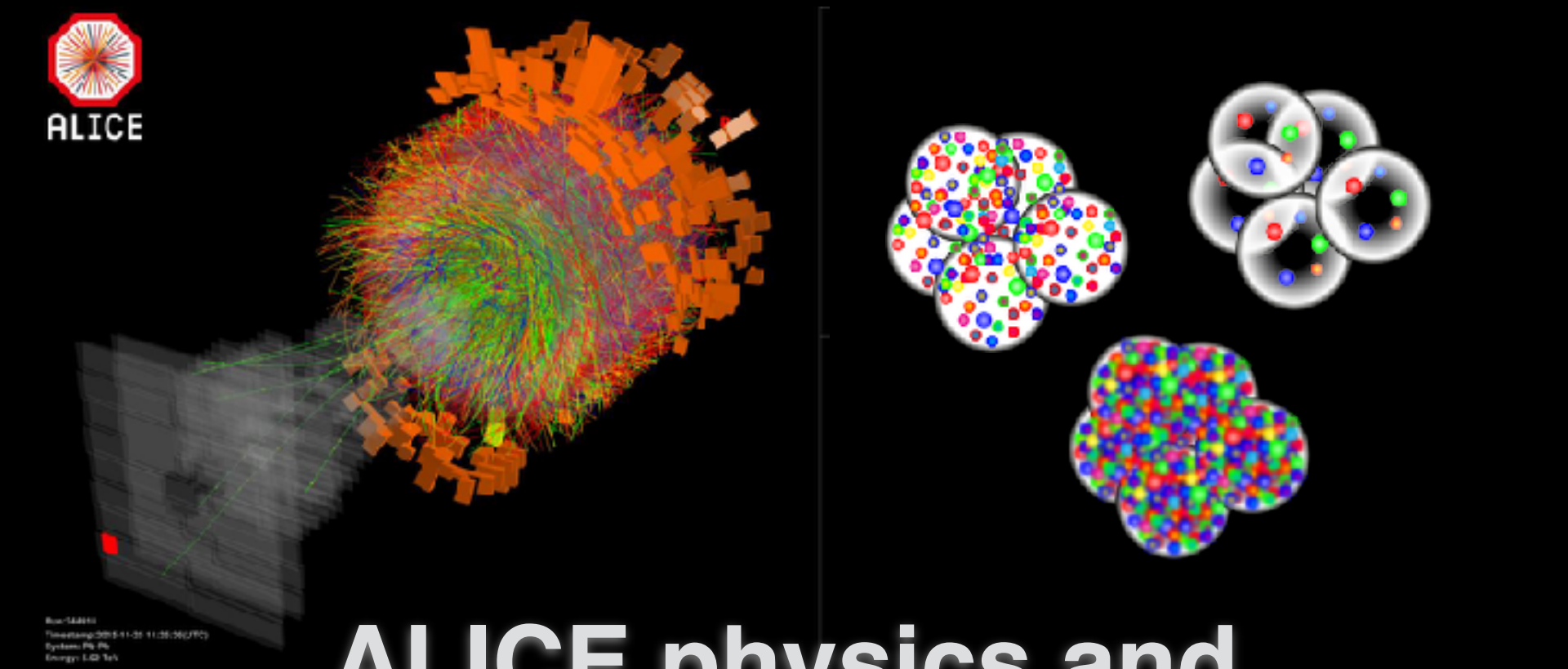
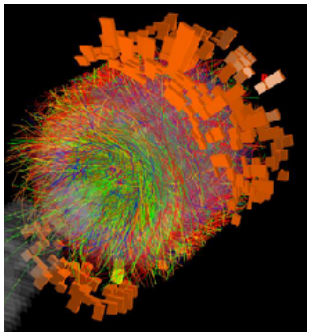


ALICE physics and FoCal upgrade proposal

Tatsuya Chujo
Univ. of Tsukuba

TCHoU meeting, June 2, 2019 @ U. Tsukuba

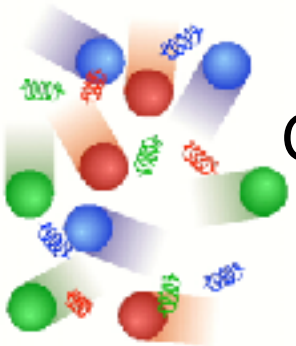


this talk

T_c

Temperature

LHC (2009-)
Creation of larger, high temp. longer lifetime sQGP than that of RHIC



QGP

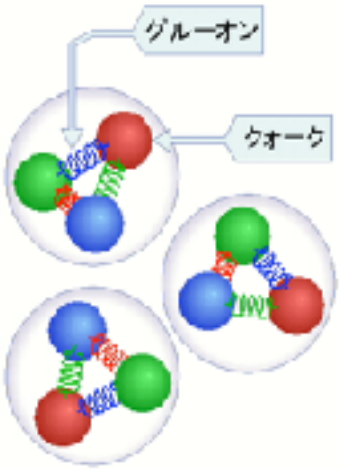
Crossover phase transition

RHIC (2000-)
Discovery of strongly coupled QGP(success of hydrodynamics)

Neutron star merger?

SPS (1986-)
low mass lepton pair enhancement
J/ψ suppression

Hadron gas



AGS (1986-1995)
Strong baryon stopping
Elliptic flow (v_2): negative →positive

chemical freeze-out

Liquid-Gas Phase transition

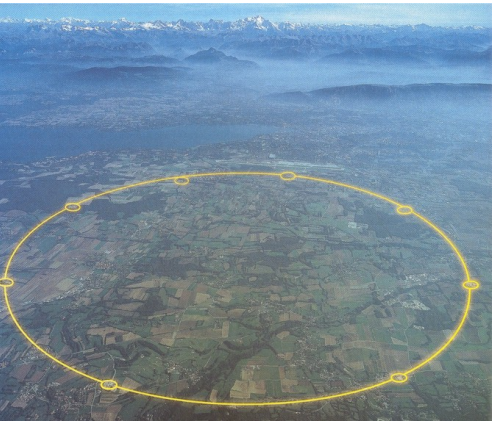
Neutron star?

Normal nuclear density

Baryon Density

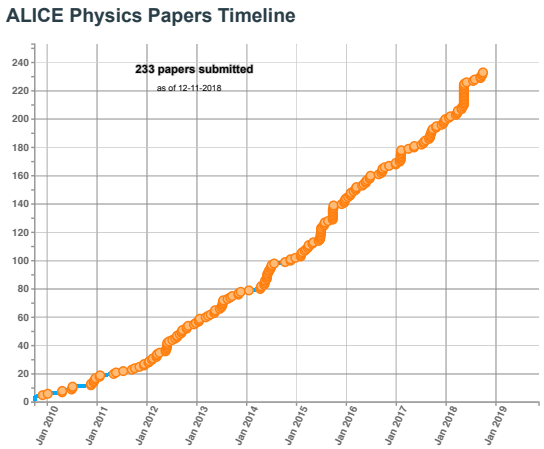
* Neutron star image: https://phys.org/news/2018-09-neutron-star-jets-theory.html

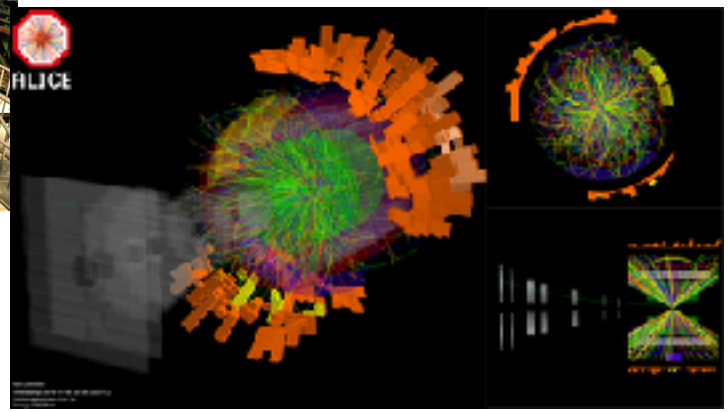
ALICE 国際共同実験 (CERN)



CERN (セルン)
欧州合同原子核研究機構（スイス）
LHC加速器 (2009-)
核子対辺り重心衝突系 Pb-Pb
$\sqrt{s_{NN}}$ = 5.02 TeV

論文：９年間で約２３０本 (PRL, PRC, JHEP など)
(約 ２５本/ 年)





40 カ国, 175 研究機関
~1,975 の研究者
LHC で唯一、重イオン実験とクォーク・グルーオンプラズマ研究に特化した実験

http://alice-collaboration.web.cern.ch

http://alice-j.org

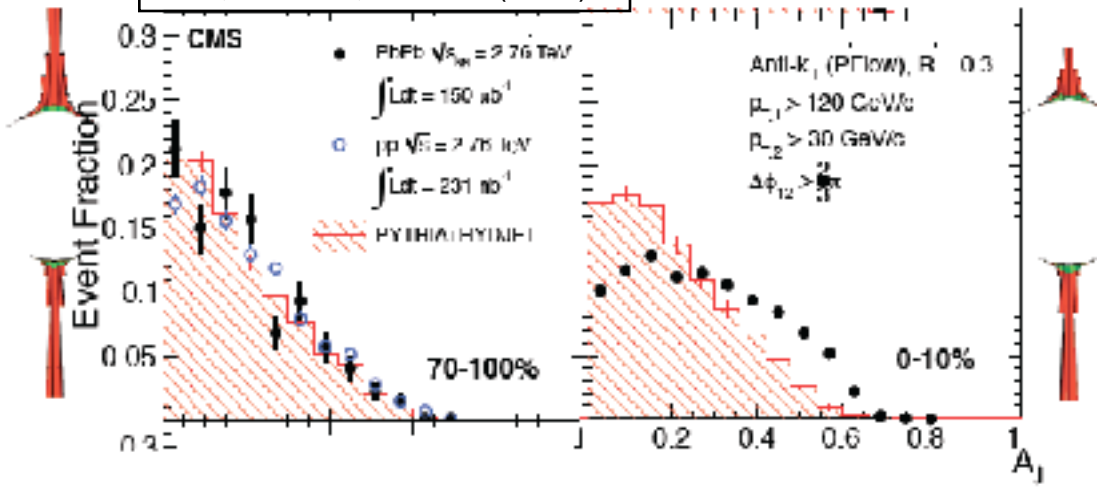
ALICE Tsukuba group

- **Largest ALICE group in Japan**
  - **staff 5, students (PD1, M 10, D 1,T 1, G 1): 19**
- Team leader: Yasuo Miake
  - Deputy team leaders: Tatsuya Chujo, ShinIchi Esumi
- **Roles in ALICE**
  - Construction, installation/ operation of **EMCal/DCal** (Y. Miake, T. Chujo)
  - **PWG JE convenor** (2017-2019), EMCal/DCal deputy project leader (2013-2017): TC
  - PWG HF-e PAG (-2018): S. Sakai
  - **Major role in FoCal upgrade project**
    - Utrecht U, CiC research invitation program (FY2017-2021)
    - Deputy PI: N. Novitzky, Utrecht PI: T. Peitzmann (ex-upgrade coordinator), M. van Leeuwen (Physics coordinator)
  - **ALICE Tier 2 center @ Tsukuba** (on-going)
  - http://alice-j.org (ALICE-J homepage, maintained by TC)

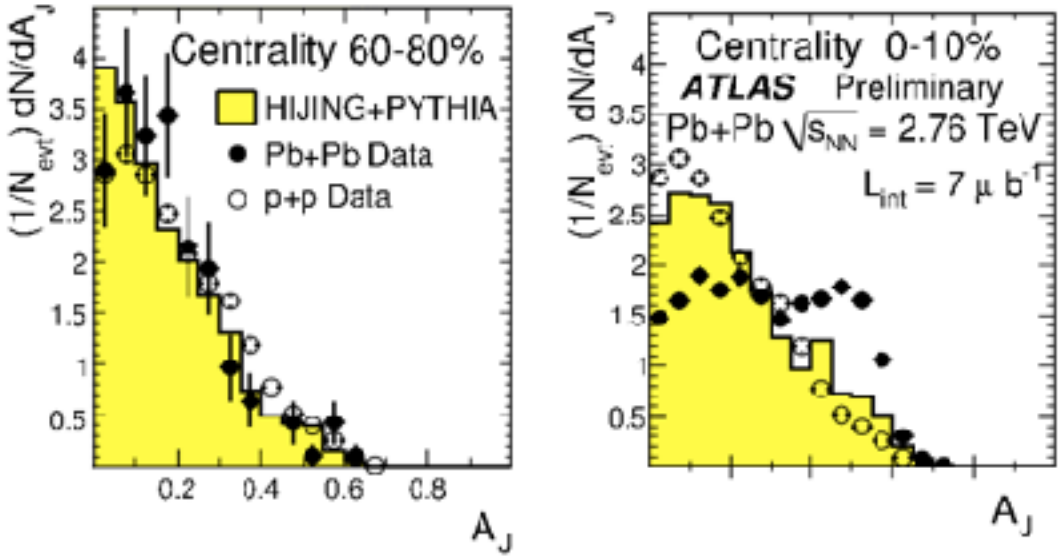
1. Jet physics in ALICE

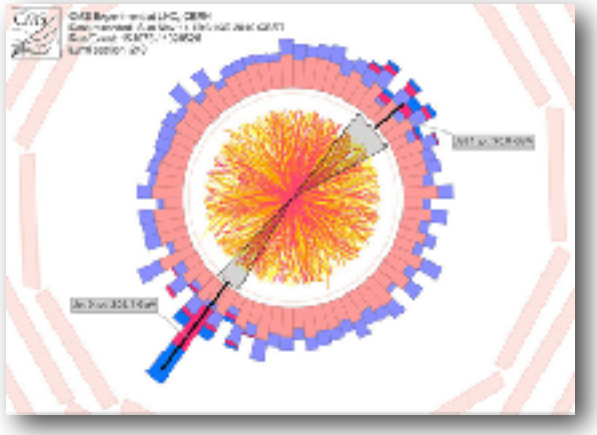
Di-jet energy imbalance

CMS, PRC 84, 024906 (2011)



ATLAS, PRL, 105 (2010) 252303





1) Large energy imbalance is observed in central Pb-Pb.

$$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}}$$

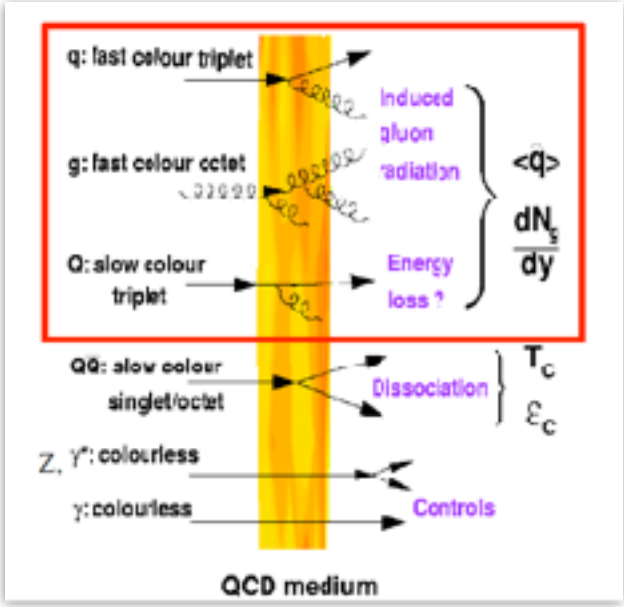
$p_{T,1}$: leading jet
$p_{T,2}$: sub-leading jet

2) Large A_J : low momentum particle (< 4 GeV/c) emitted at large angle on away side.

Hard probes in heavy-ion collisions

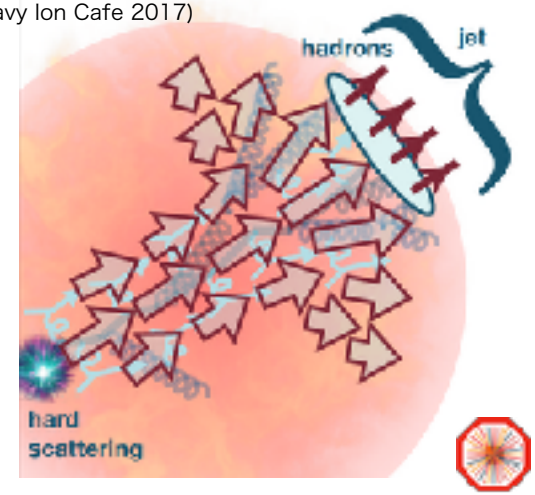
- **Hard probes:**
  - Originated at the parton hard scattering (large Q^2), prior to QGP formation time ($1/Q \ll 1$ fm/c)
  - Well calibrated (pQCD)
  - Jets: reflect a whole evolution of the system

- **Access to the medium properties:**
  - dE/dx of partons (g, q (uds, c, b)) & L dep.)
  - Large angle emissions
  - Jet tomography by different probes & techniques

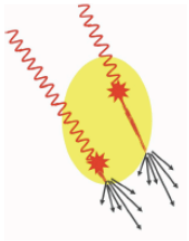


side by D. d'Enterria (slide at QGPWS, 2008)

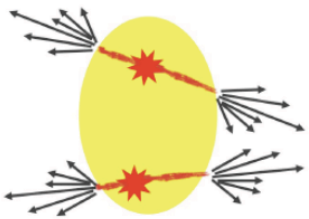
Picture form Y. Tachibana
(Heavy Ion Cafe 2017)



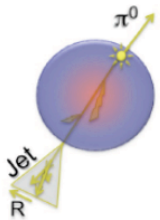
γ-Jet



Di-jet



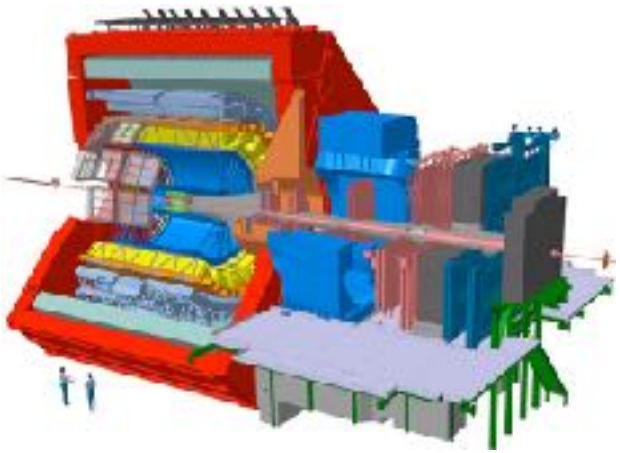
π^0-Jet

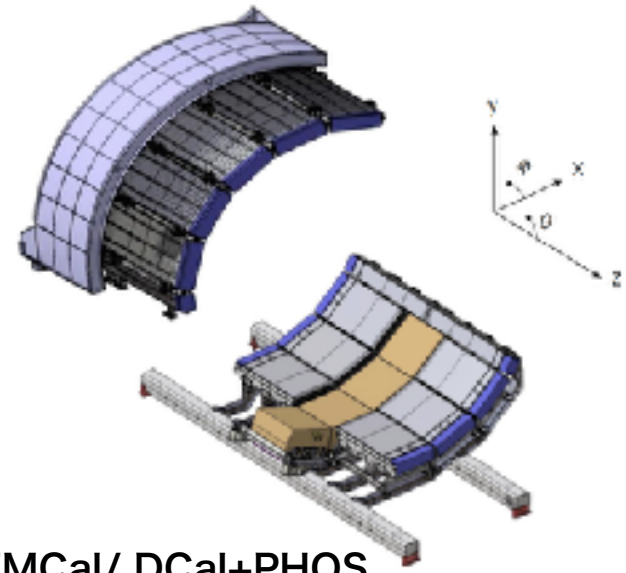


HF jet

Jets in ALICE

- Jet reconstruction by tracking (TPC+ITS) + calorimetry
- Go to **low jet p_T and low constituent p_T** (> 0.15 GeV/*c* for charged) in large heavy-ion background
  - ✓ Detailed characterization of background fluctuations (JHEP 1203 (2012), 053)
  - ✓ Gamma and jet triggers by EMCal/DCal, PHOS for high p_T
- **Measurements:**
  - ✓ High p_T hadrons
  - ✓ Inclusive jet
  - ✓ Jet + hadron correlations (soft hadron, w/ PID)
  - ✓ Gamma-jet correlations, c/b taged jets, jet-jet
  - ✓ Jet substructure



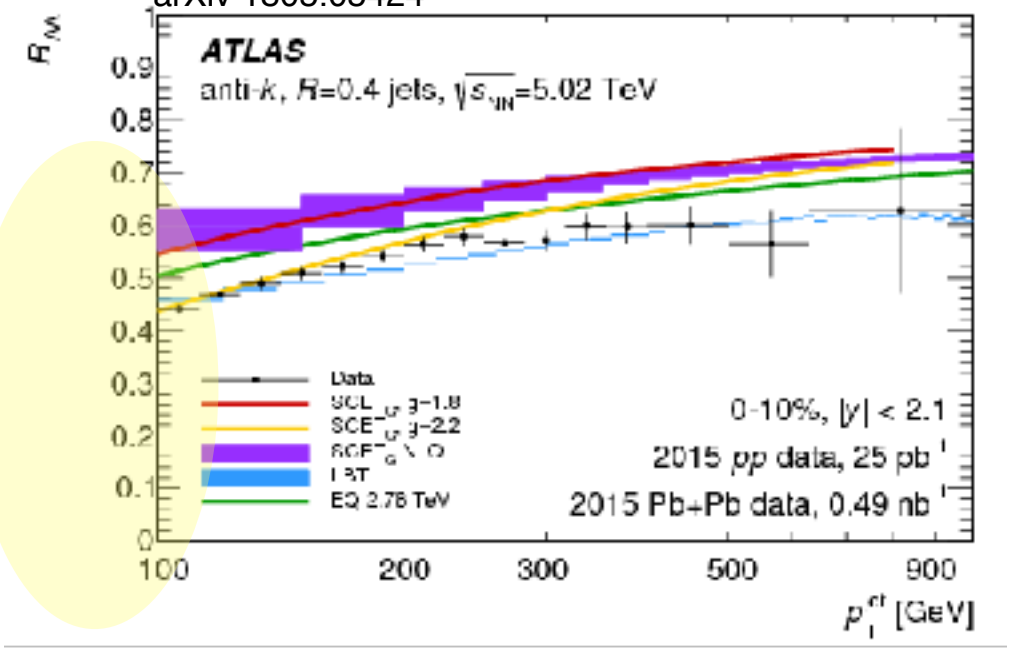


EMCal/ DCal+PHOS

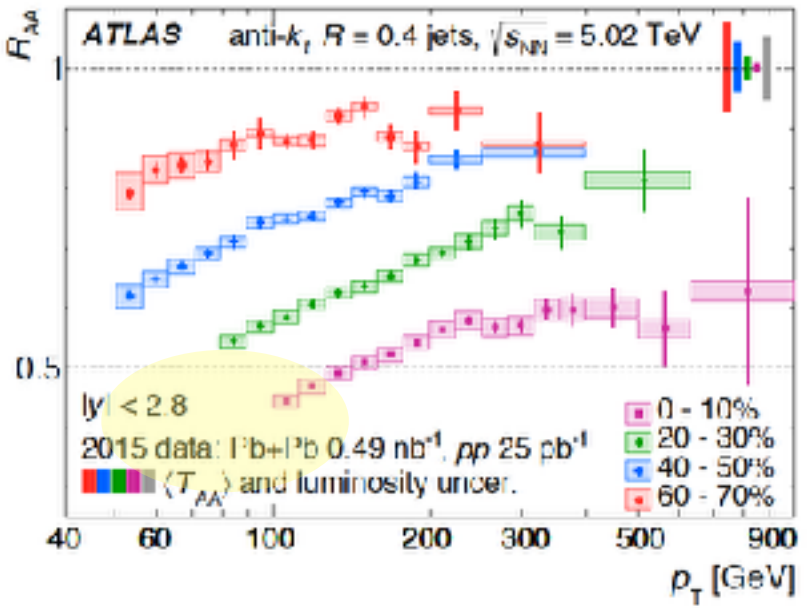
(1) Jet spectra and jet R_{AA}

$$R_{\mathrm{AA}} = \frac{\text{"hot/dense QCDmedium"}}{\text{"QCD vacuum"}} = \frac{dn_{\mathrm{AA}}/dp_{\mathrm{T}}dy}{\langle N_{\mathrm{binary}}\rangle \cdot dn_{\mathrm{pp}}/dp_{\mathrm{T}}dy}$$

arXiv 1805.05424



arXiv:1805.05635



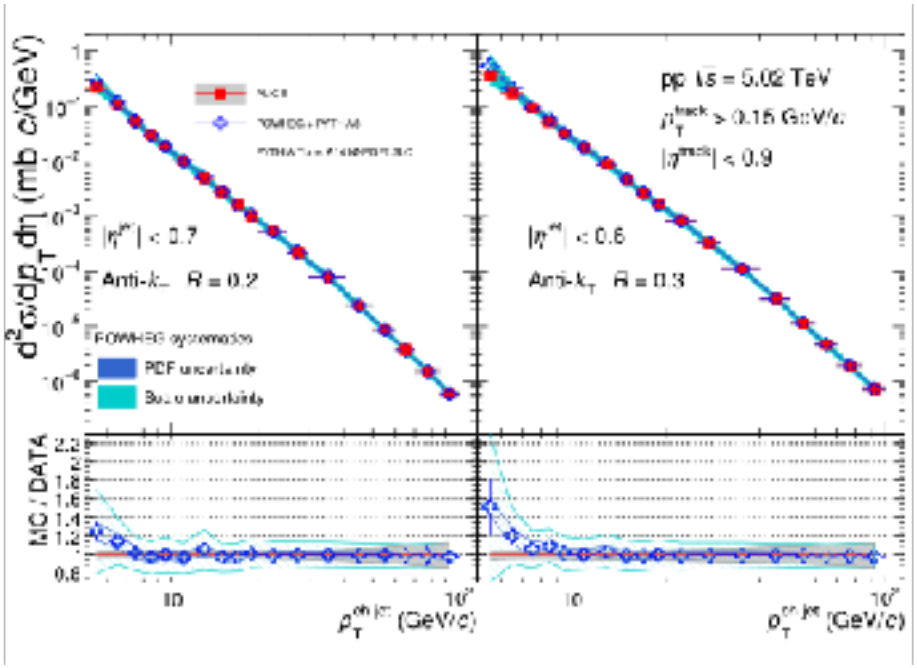
What can we learn from R_{AA} measurement of jet, beyond energy loss ?

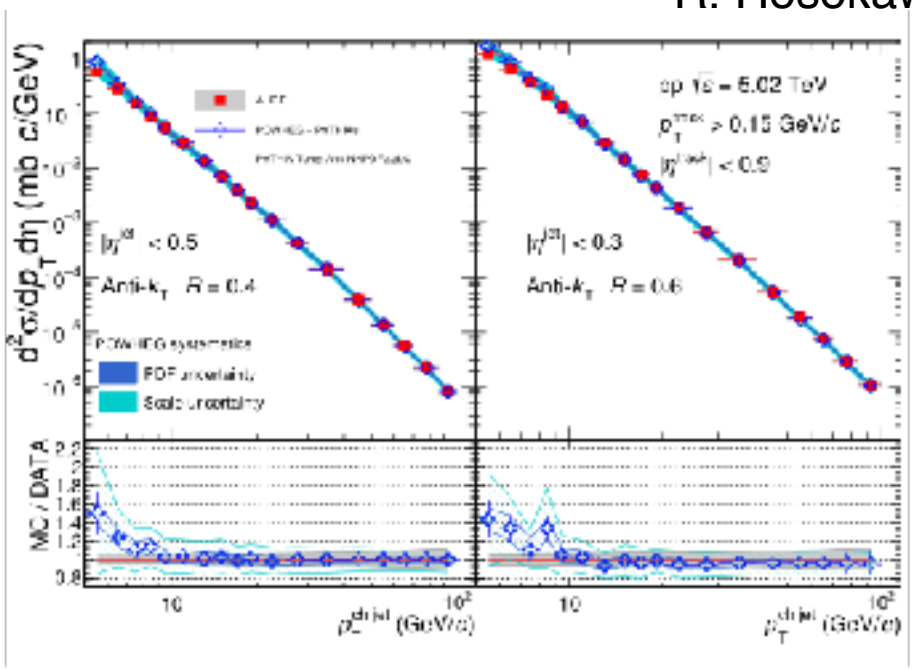
ALICE:

- Low p_T (< 100 GeV/c): p_T dependence of R_{AA}
- High p_T up to 200 GeV/c by using the current statistics
- Complementary to ATLAS/CMS

Inclusive charged jet production

R. Hosokawa

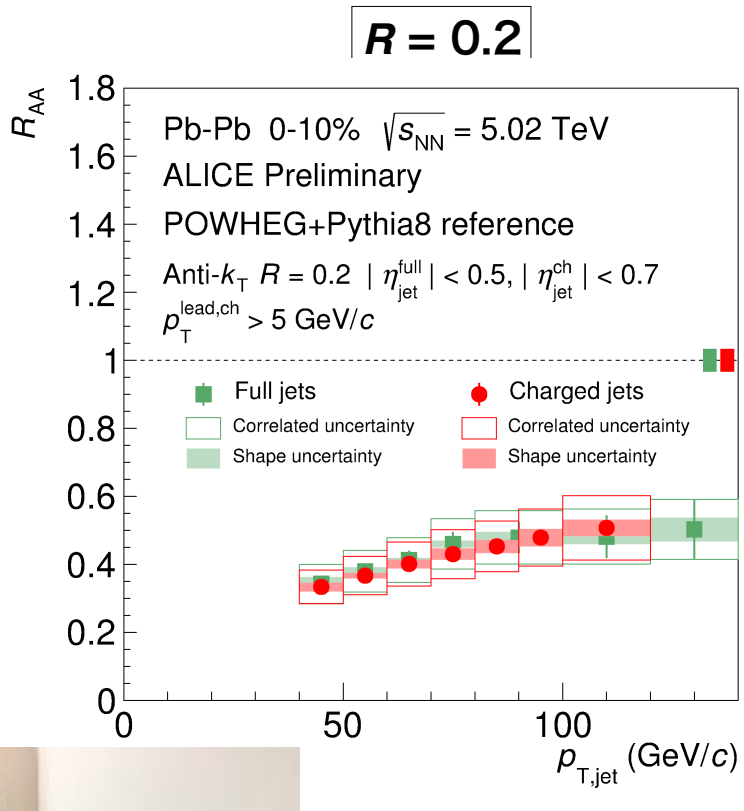


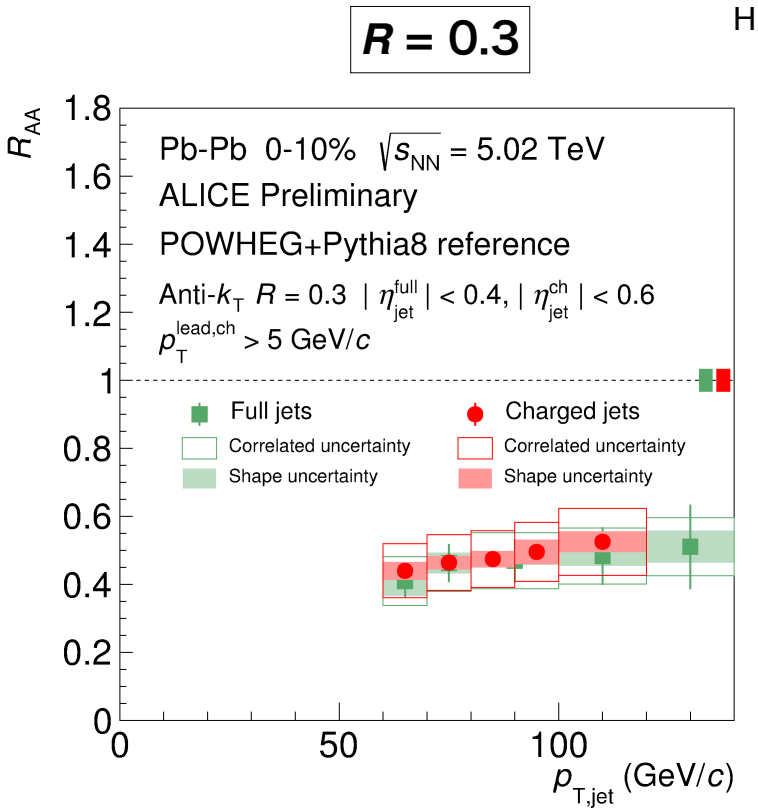


- Submitted to arXiv https://arxiv.org/abs/1905.02536
- Comparison to a NLO pQCD-based model prediction (POWHEG+Pythia8)
- Good agreement within large theoretical uncertainty
  - Higher-order (NNLO) calculation will improve scale uncertainties in pQCD calculation
  - Further understanding of non-perturbative effects (e.g. Underlying events) will also be crucial for low p_T region

Jets in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV (Run-2)

H. Yokoyama

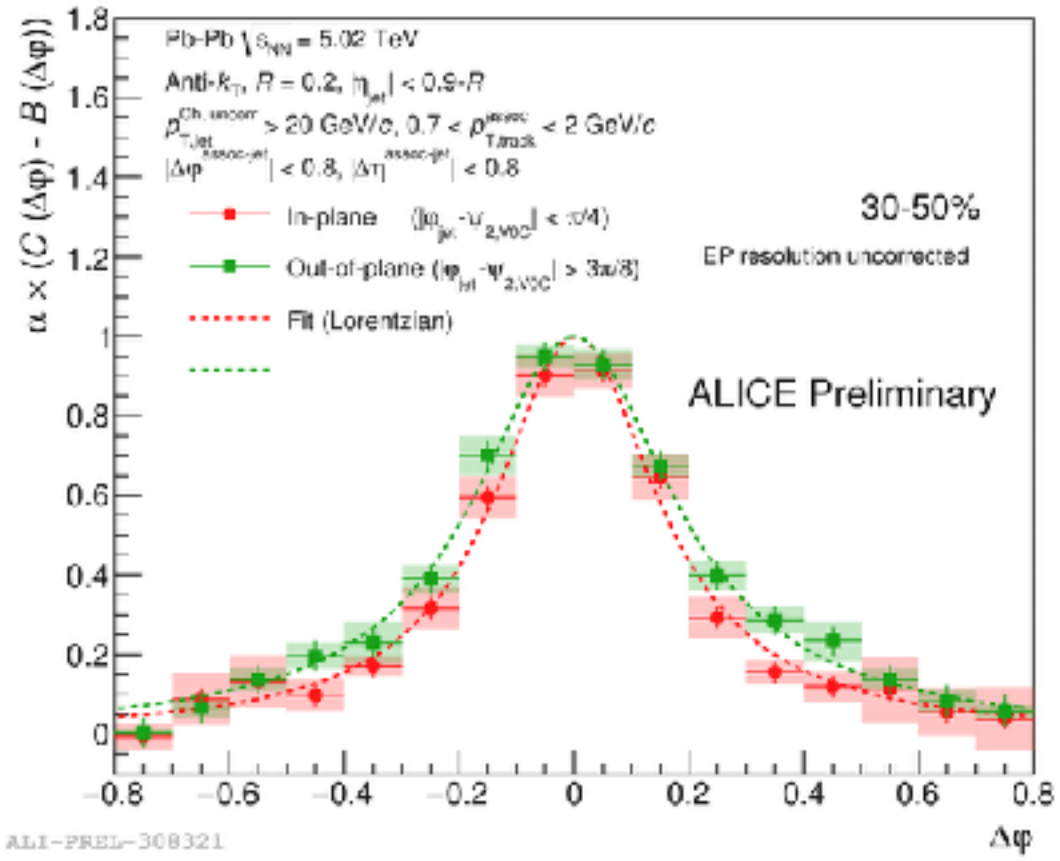




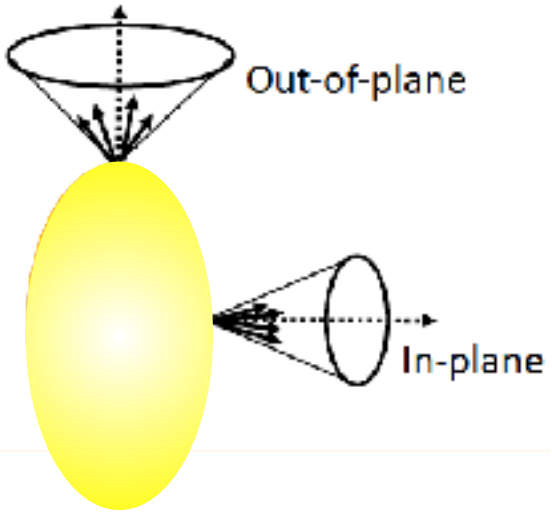
ALI-PREL-159653

- Strong suppression of jet in Pb-Pb central.
- p_T dependence espacial for R=0.2 at lower p_T
- Little R dependence
- Charged particle jets and full jets are consistent

Jet-hadron corr. in Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

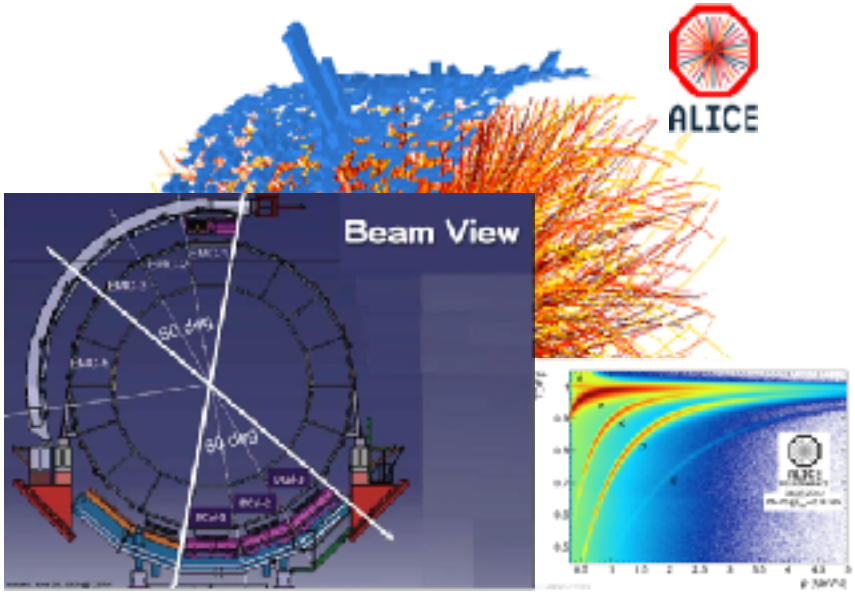


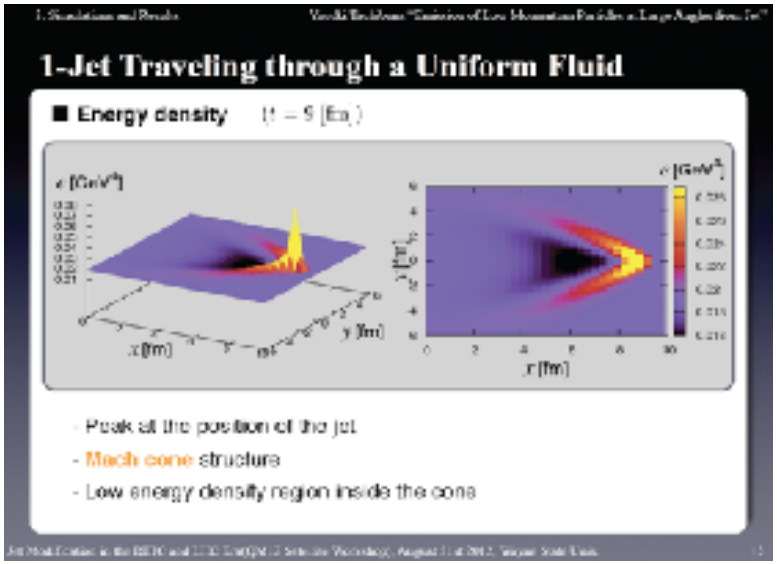
R. Hosokawa



A slightly wider distribution for out-of-plane in lower p_T associated tracks ($0.7 < p_T < 2$ GeV/c)

A future direction of jet physic in ALICE





3+1 hydro + jet (Tachibana, Hirano) QM2012

- ALICE: PID capability for charged hadrons (0.15 – 20 GeV/c), photon, di-jets
  - Constituents of bulk vs. medium response (large angle emission)
  - A_J (di-jet energy asymmetry) as a parameter for the energy deposit.
  - Use di-jets, γ-jet events.
- **Possible new window** to : **c_s, EOS** by comparing with theories
- Need high rate data taking with jets.

2. Heavy Flavor physics in ALICE

Heavy flavours in heavy-ion collisions

- Heavy flavour (charm & beauty)
  - Large mass : m_c (~1.5 GeV/c), m_b (~4.5 GeV/c) >> Λ_{QCD} (0.2 GeV/c)
    - Produced initial hard partonic scattering processes
      - Gluon scattering is dominant LHC → sensitive to gluon nPDF
    - Cross section calculate by perturbative QCD (pQCD)
  - Short formation time $\tau \sim 1/2\ m_q \sim 0.07$ fm < QGP (~0.1-1 fm)
    - Produce before QGP and go through the medium

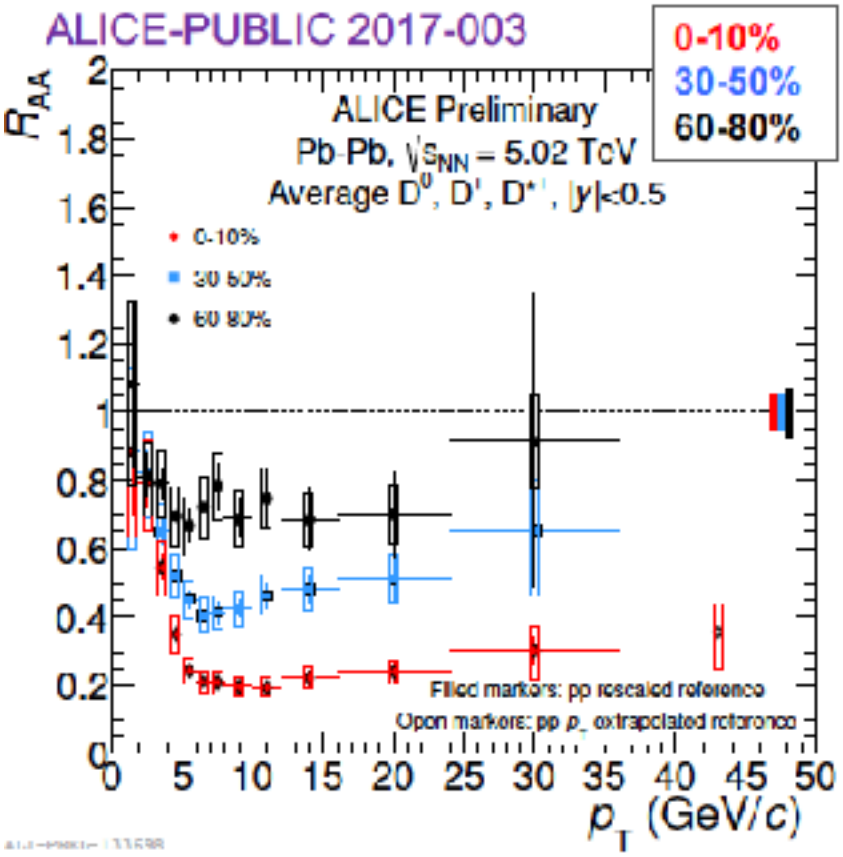
- Heavy flavour in QGP
  - Brownian motion
    - Sensitive to QGP transportation coefficient
  - Energy lose via collisional & radiative
    - QCD prediction ; $\Delta E(u,d,s) > \Delta E(c) > \Delta E(b)$
      - a test for QCD in extremely high and dense matter

Large suppression HF production in Pb-Pb

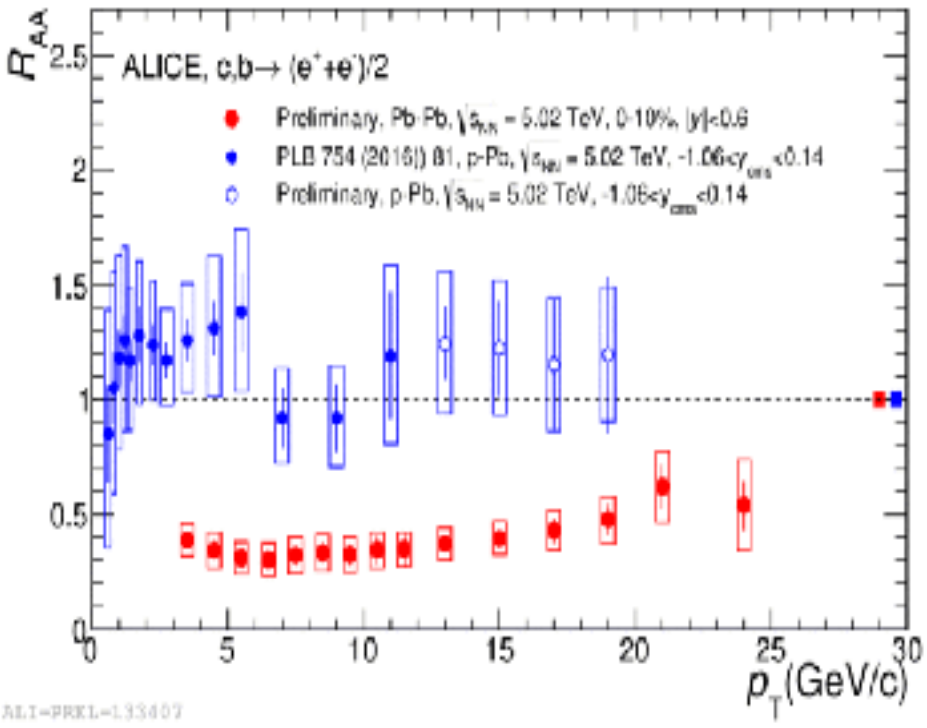
D meson

$$R_{AA}(p_T) = \frac{d\,N_{AA}/dp_T}{\langle T_{AA}\rangle \times d\sigma_{pp}/dp_T}$$

S. Sakai



HF e

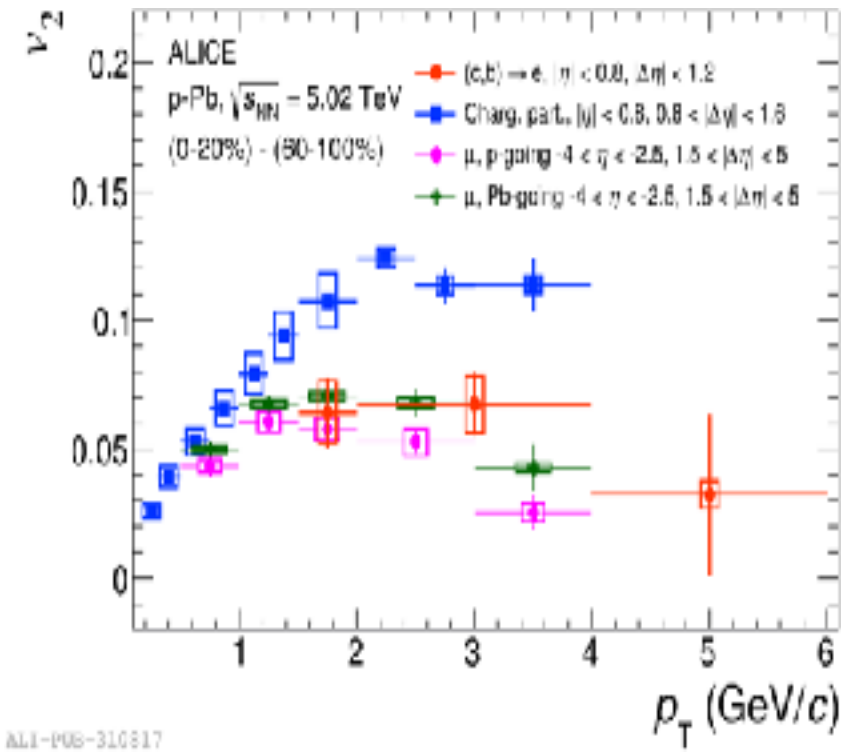


- Large Suppression of D meson productions in Pb-Pb at 5.02 TeV
- Large suppression of electrons from D and B in Pb-Pb at 5.02 TeV
  - Indicates significant energy loss of charm and beauty in the QGP

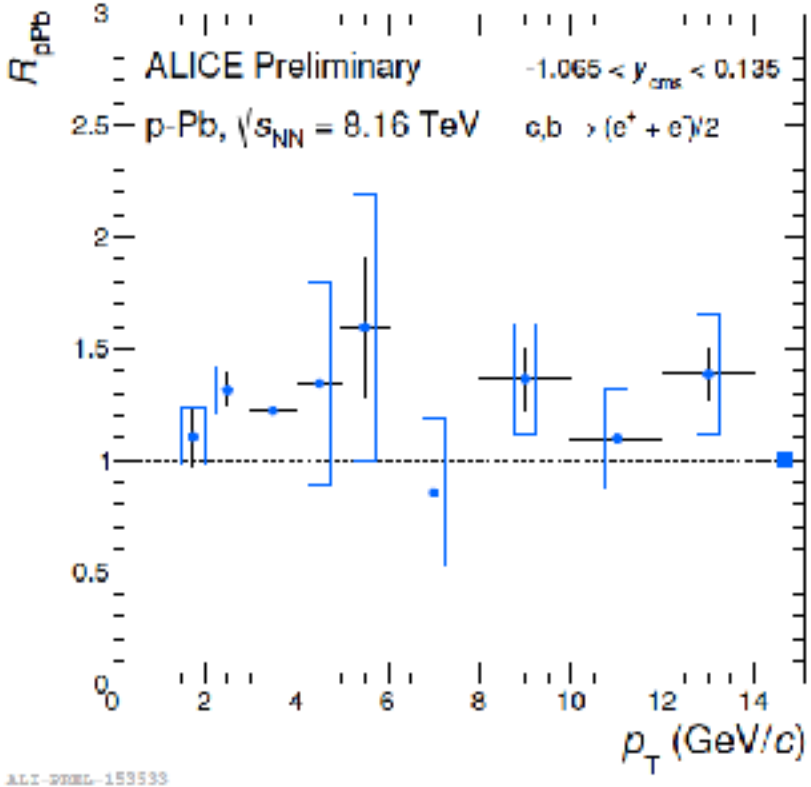
Heavy Flavor electrons in small system

S. Sakai, D. Kawana
T. Suzuki et al.

HF-e v_2

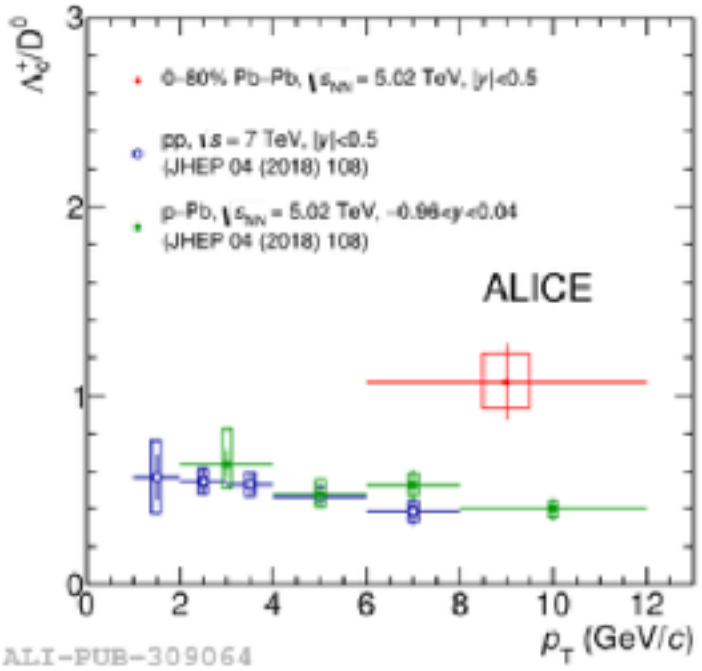


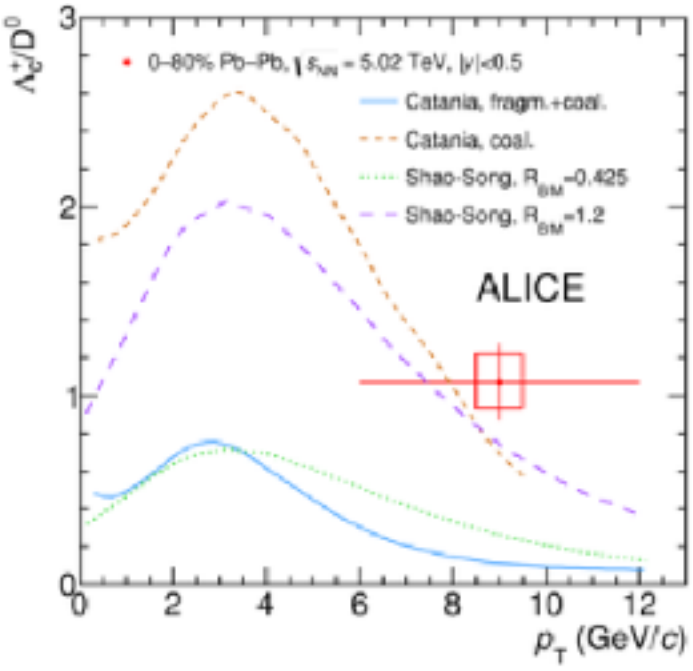
HF-e R_{pPb}



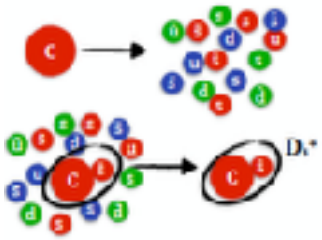
- Positive v_2 of heavy flavours in p-Pb collisions
- R_{pPb} ~ 1 within uncertainties in the whole p_T interval
  - No suppression of heavy-flavour production is observed

Λ_c production in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

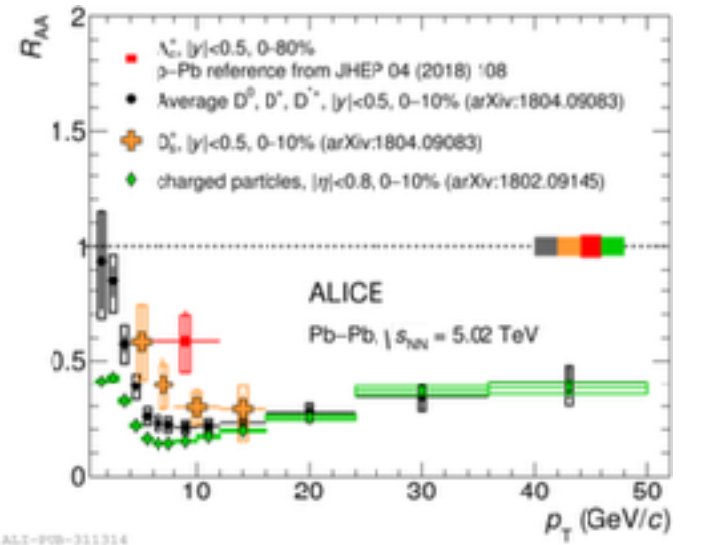




Y. Watanabe et al.



Phys. Lett. B 793 (2019) 212



Ratio to D^0 meson

- Larger than that of pp and p–Pb collisions
- Described by a model
- With **charm quark hadronization via quark coalescence** without vacuum fragmentation

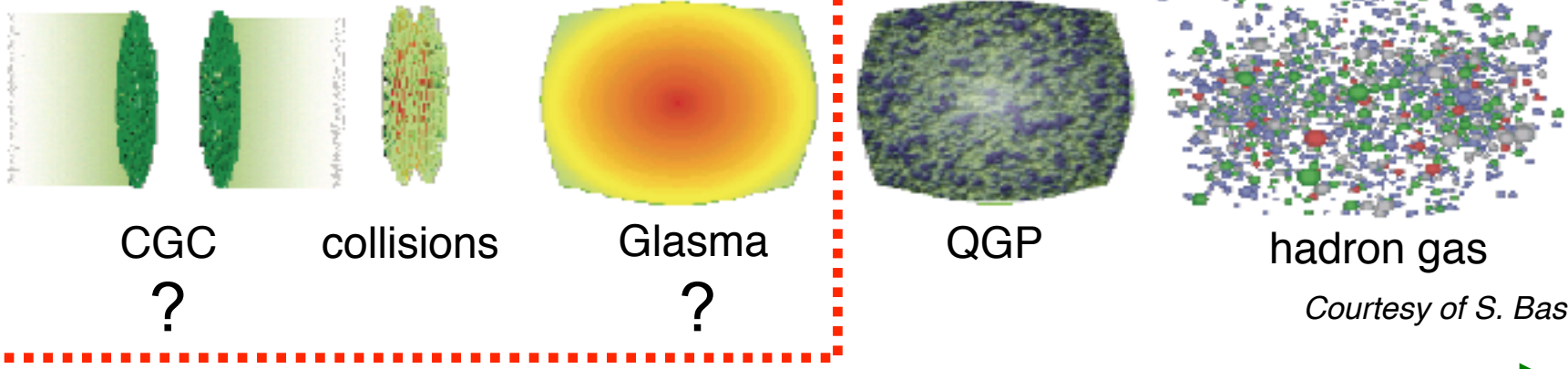
Nuclear modification factor

- Suggest less suppression than inclusive charged hadrons and D mesons

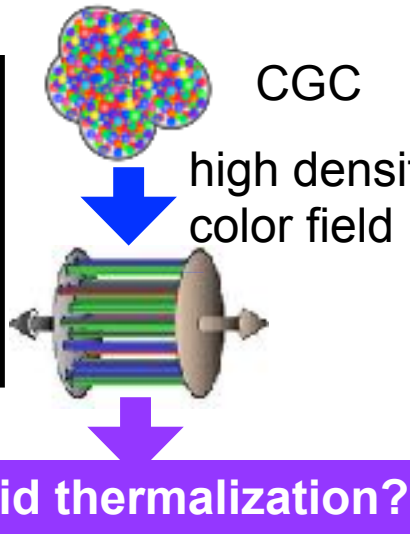
3. Open questions

Q1) How QGP is thermalized so quickly ?

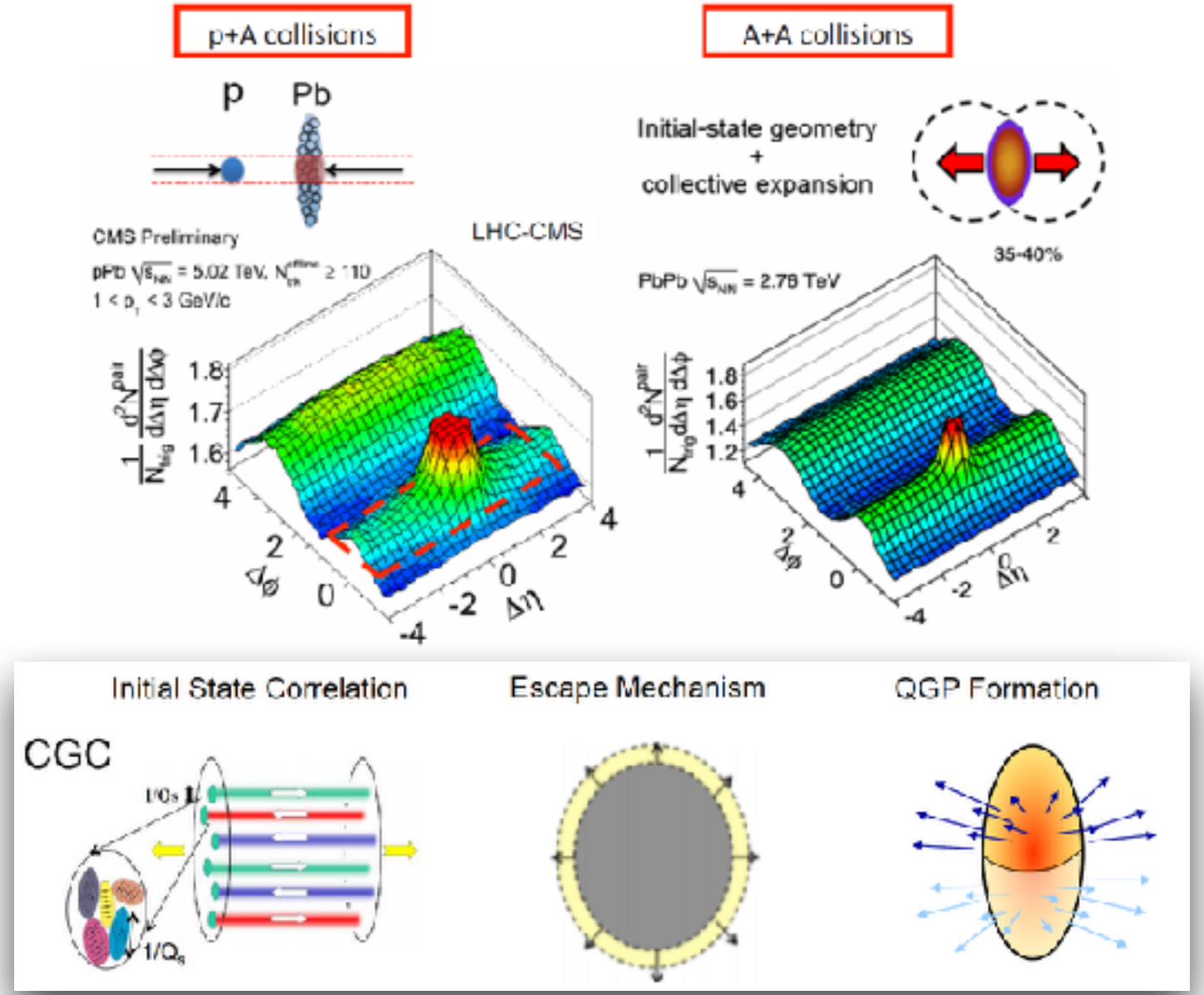
Unknown !



- **What is the initial condition?**
- **Why so rapidly thermalized (t=0.6 fm/c)?**
  - **Instability of strong color field ?**
- **No clear evidence for CGC as an initial condition yet.**
- **initial condition ⇔CGC strong color fields⇔ thermalized QGP**



Q2) Origin of ridge, collectivity in small system?



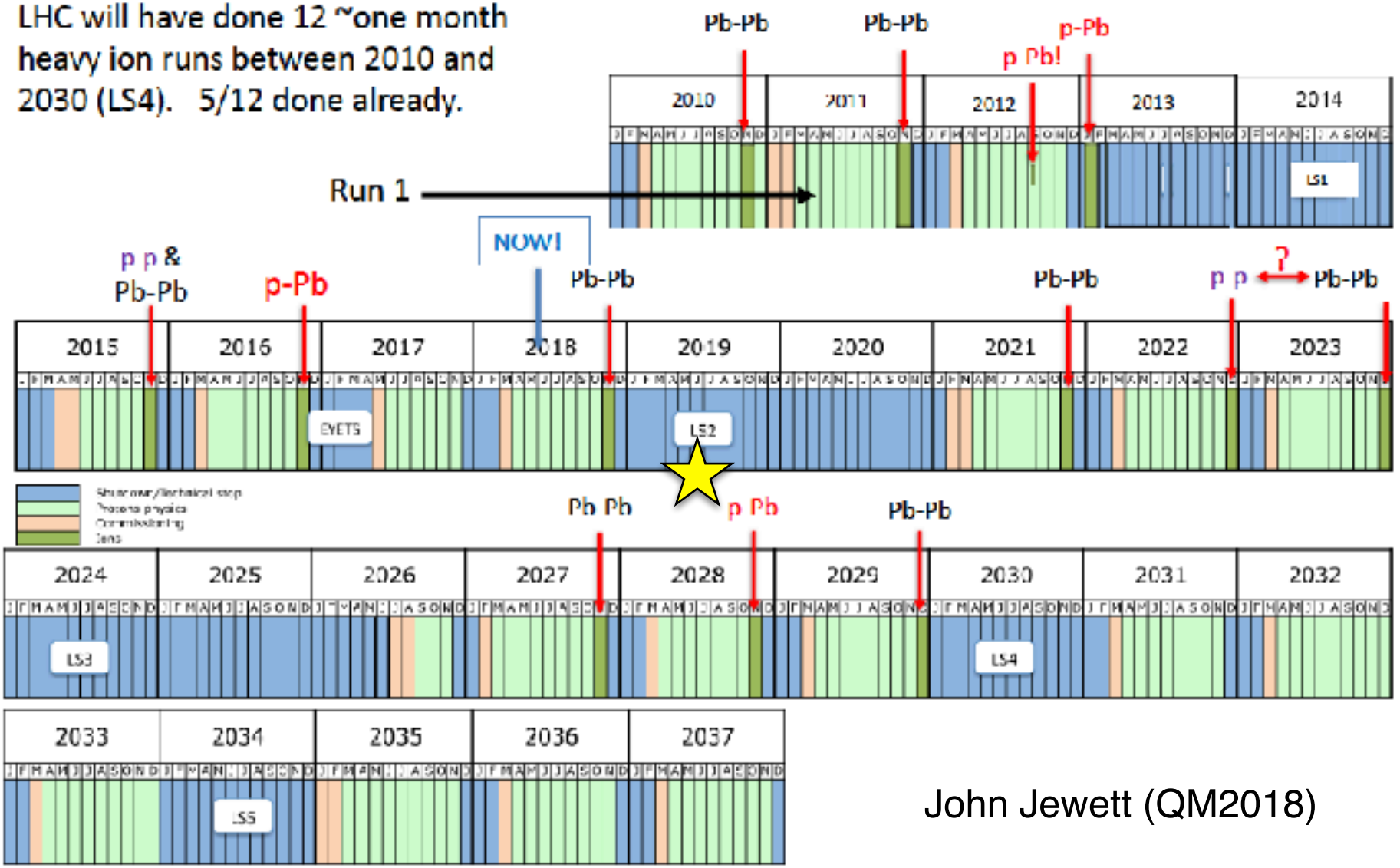
Yen-Jie Lee, heavy ion town meeting (2018)

4. ALICE FoCal upgrade proposal

LHC timeline

LHC heavy-ion runs, past & baseline future
+ species choices according to ALICE 2012 LoI (under review in HL-LHC workshop) `

LHC will have done 12 ~one month heavy ion runs between 2010 and 2030 (LS4). 5/12 done already.



John Jewett (QM2018)

LHC timeline

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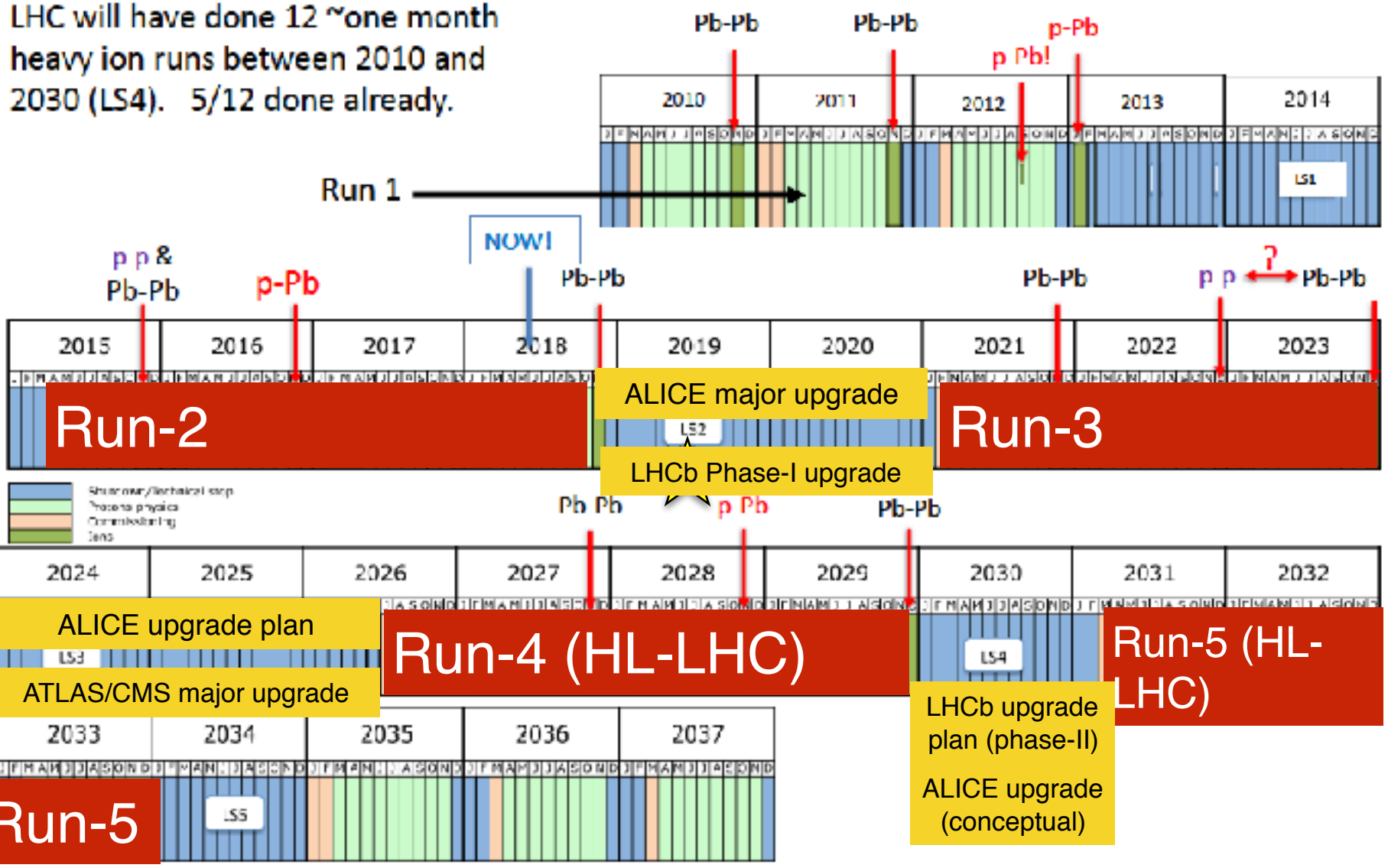
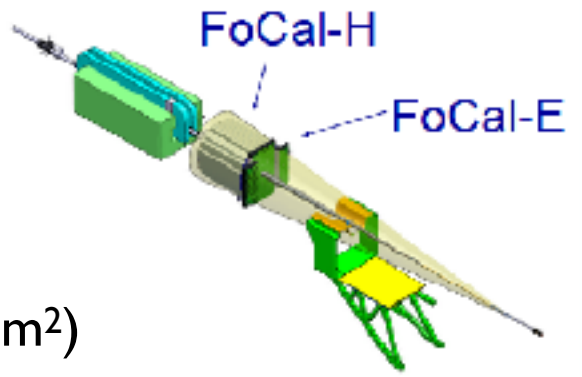


ALICE FoCal

FoCal = Forward Calorimeter:

FoCal-E: EM Calorimeter
FoCal-H: Hadronic Calorimeter

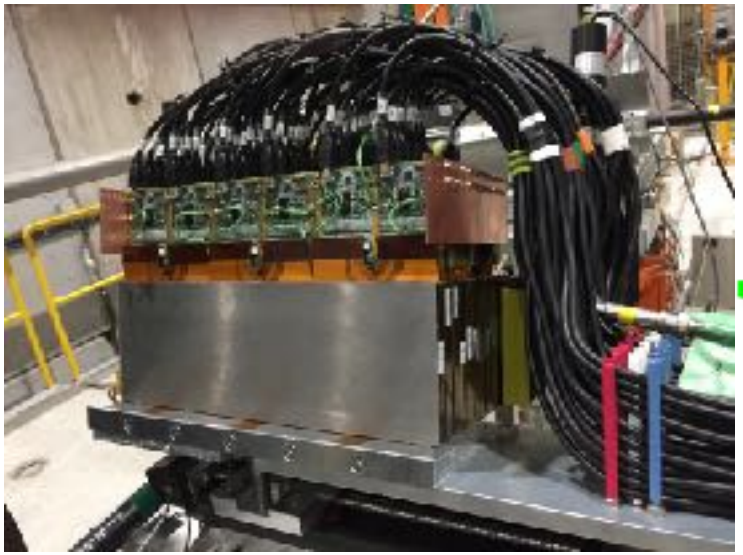


- ~7 m away from the interaction point
- main challenge: separate γ/π^0 at high energy
- Si-W calorimeter (hybrid Si: pad 1cm^2 & MAPS 30μm^2)
- Considered as an ALICE upgrade for Run-4

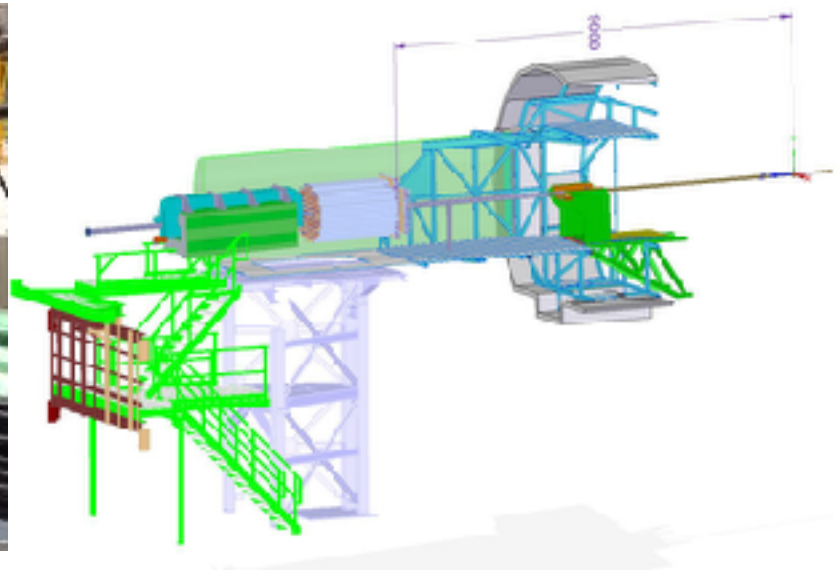
- **Look for CGC effects at small-x (~10^{-5})**
- **Origin of Quark Gluon Plasma**
  - main observables: Direct photons, π^0 ,π^0-π^0 correlations

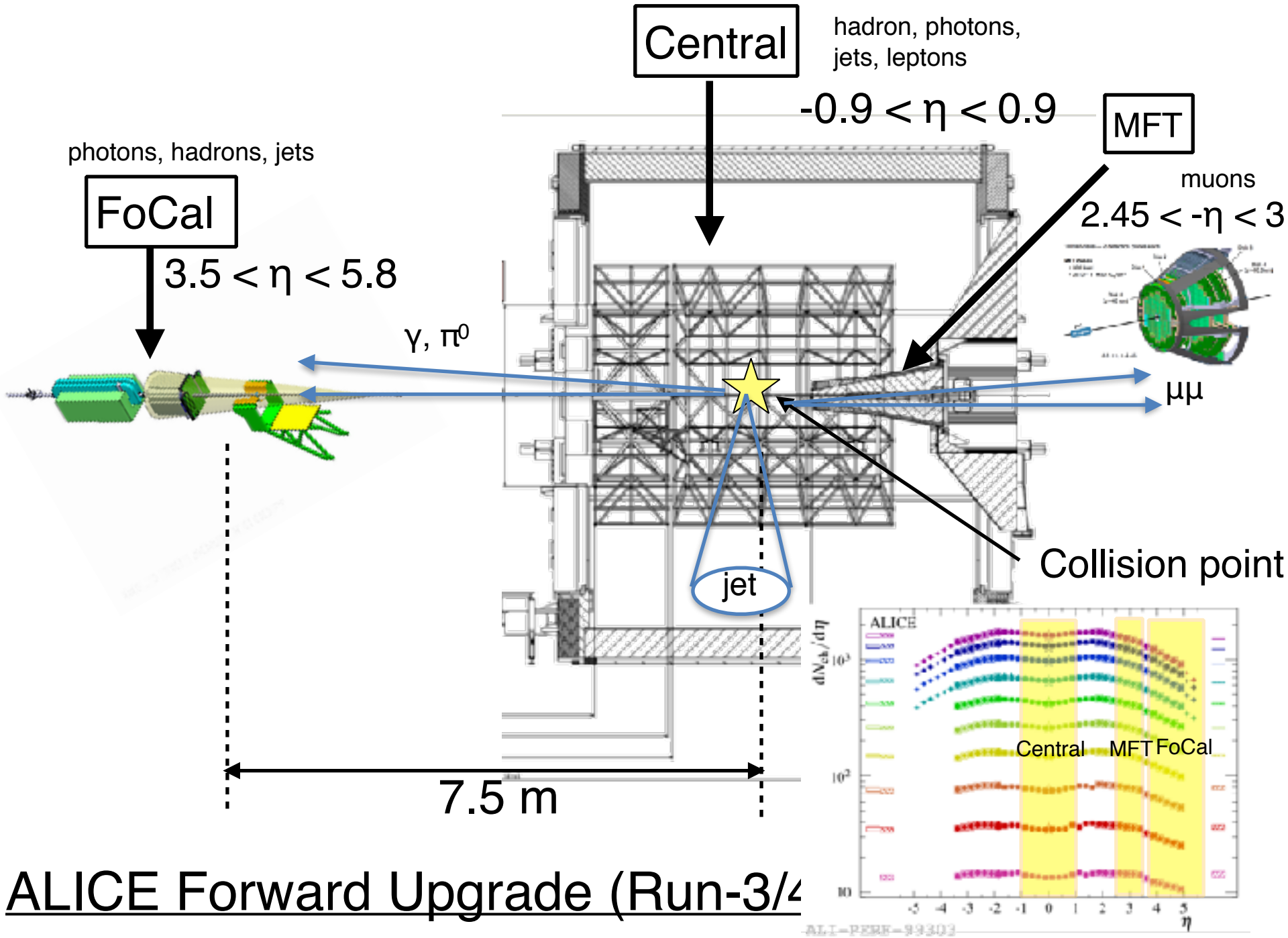
$3.2 < \eta < 5.3$

MAPS detector



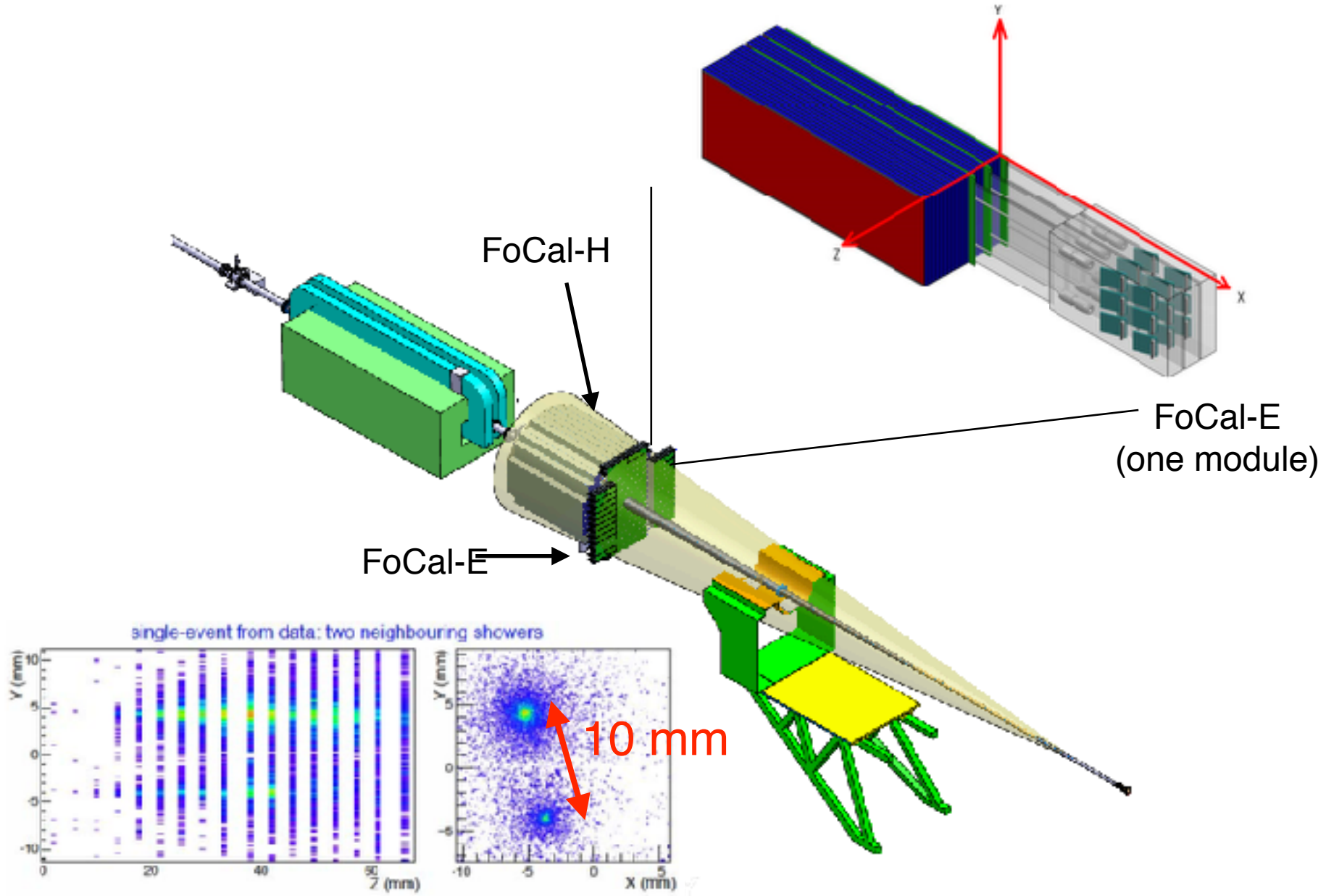
mini-FoCal (PAD)



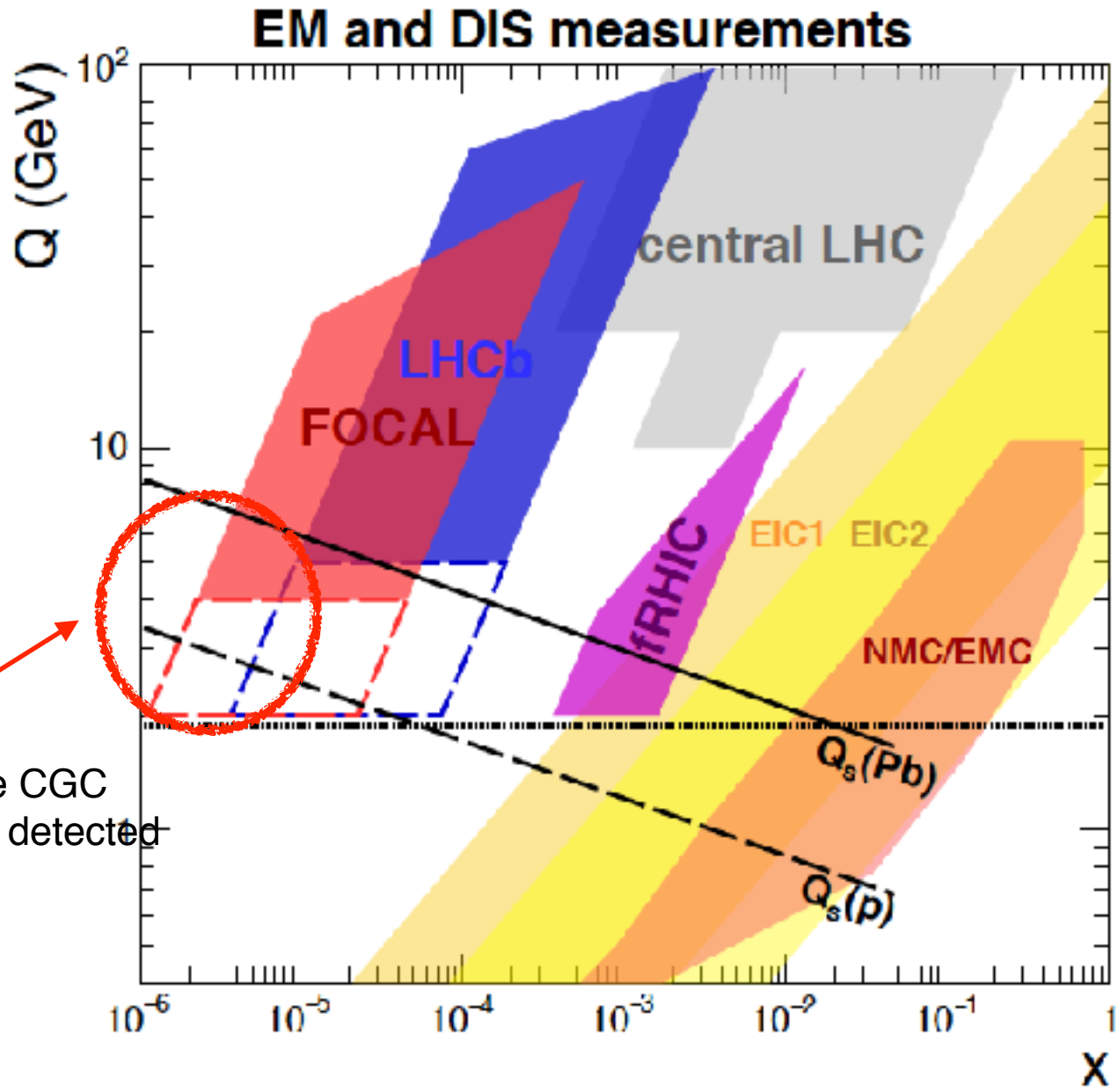


ALICE Forward Upgrade (Run-3/4

EM shower separation by FoCal



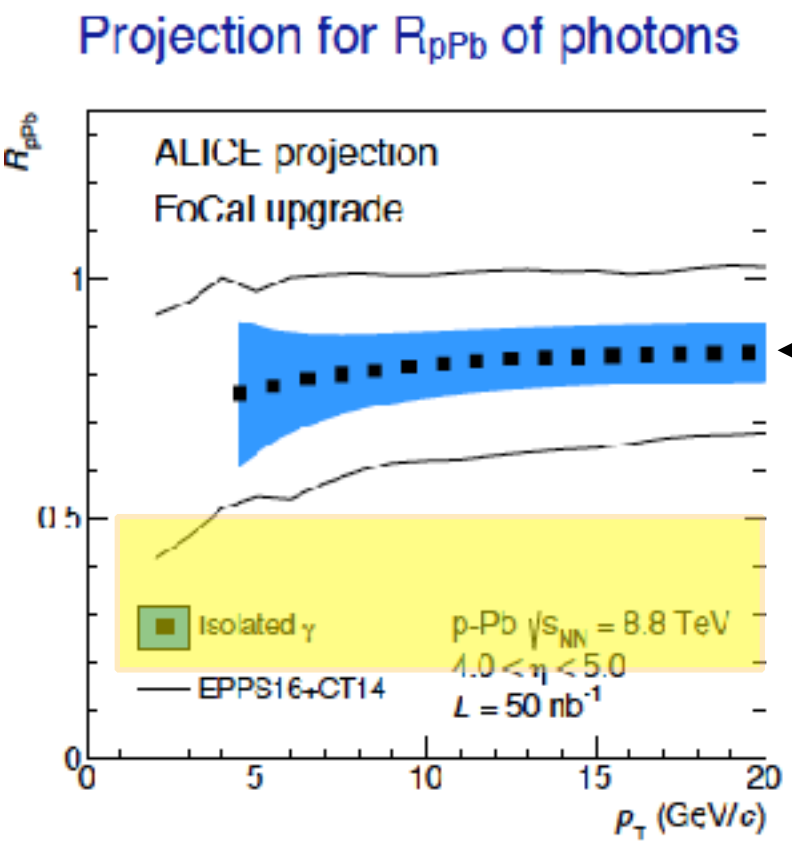
New kinematic regime explored by FoCal



A region where CGC signals can be detected

FoCal による単光子測定の精度
とカラーグラス凝縮 (CGC) の明確なシグナル

単光子の収量比：(p+Pb)/ (p+p)



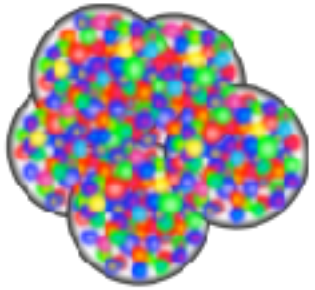
単光子の横運動量

CGC なし

(通常の原子核効果)

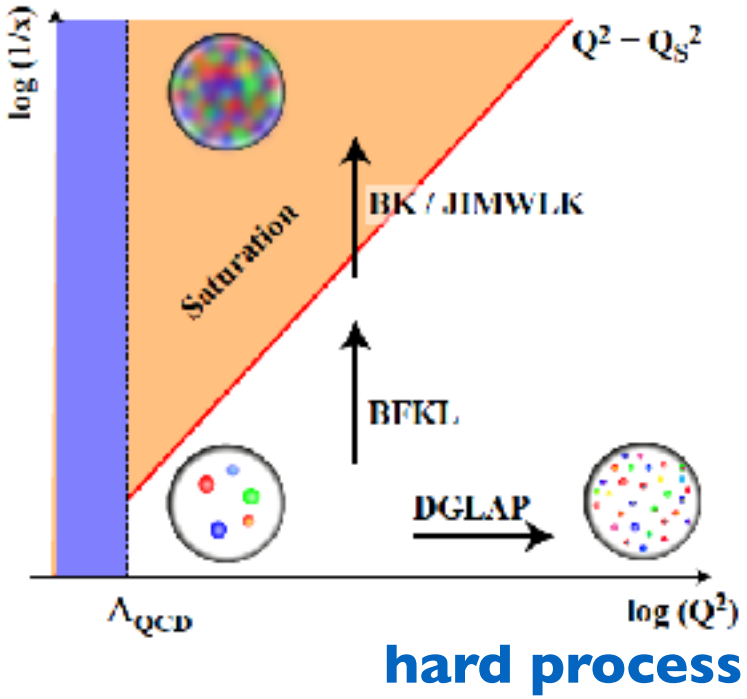
CGC あり

A. Rezaeian, PLB 718, 1058



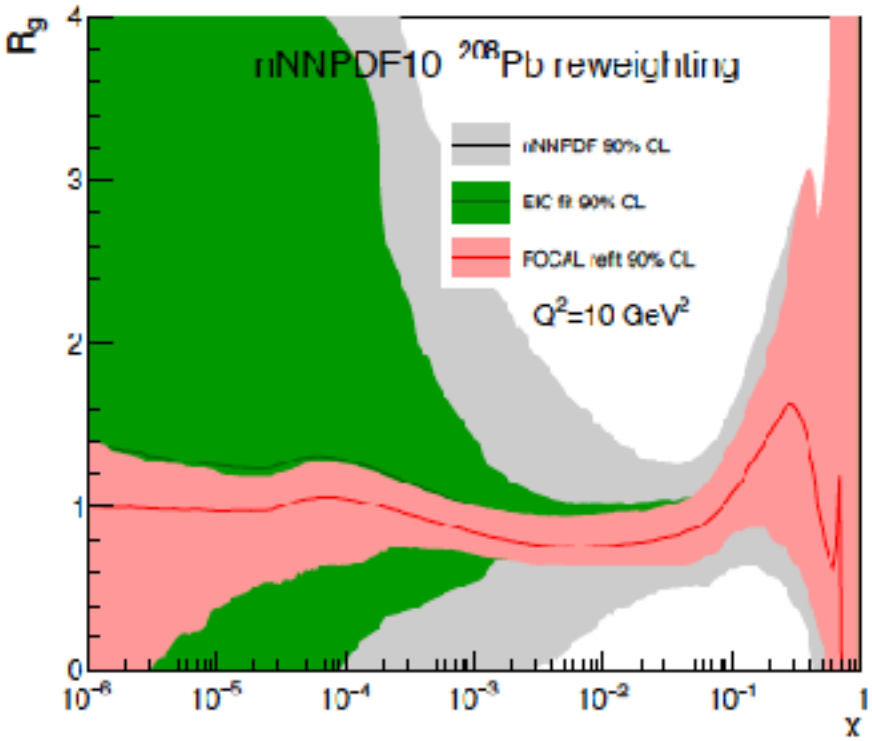
Saturation physics at small-x

small-x



hard process

Physics Impact on PDF for gluons by FoCal

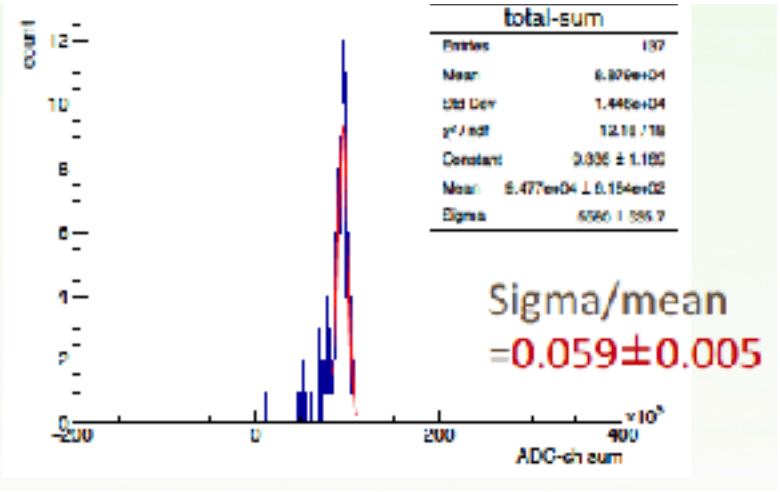


- At small x and small Q^2, the parton density becomes large and non-linear effects (gluon fusion) may set in
  ➡Gluon Saturation, Color Glass Condensate (CGC)
- Large uncertainties of nPDFs at small-x

mini-FoCal 検出器, CERN-PS/SPS ビーム実験

ユトレヒト大学と日本グループで実施 (2018)

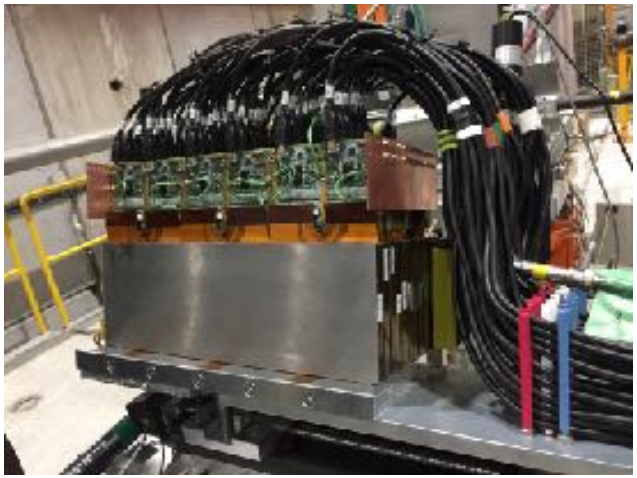
SPS テストビーム実験の様子



↑ エネルギー分解能

ΔE/E ~ 6 % @ 150 GeV/c 陽電子

(未発表, 暫定結果)



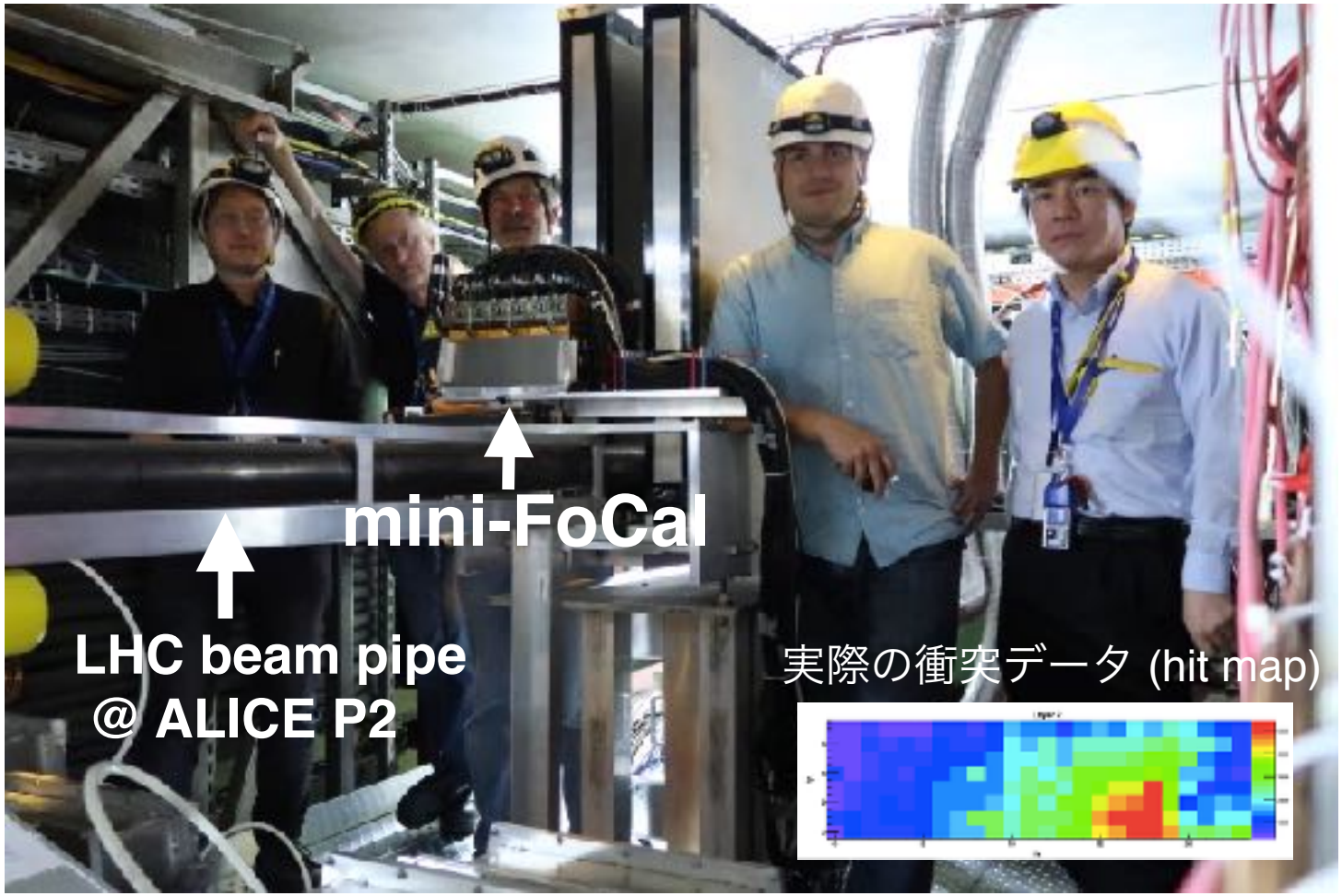
← 日本グループが新たに開発した

mini-FoCal 検出器

* 日本グループ：筑波大、筑波技術大、広島大、奈良女子大、東大CNS、長崎総合科学大

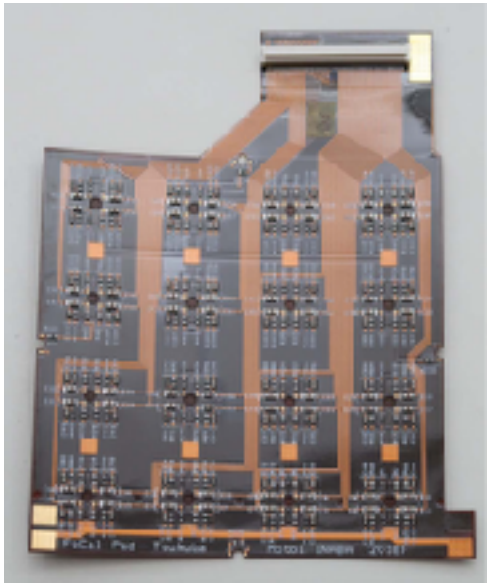
2018 年 ALICE に mini-FoCal 設置

13 TeV pp 衝突でのmini-FoCal データ収集に成功



FoCal 検出器開発とこれからの国際協力

FoCal-E
PAD 部



FoCal-E
MAPS 部

新たな参加機関

フランス　ブラジル　米国

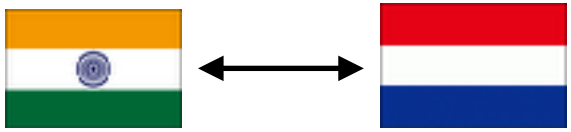
PAD読出
ASIC

PAD読出
SAMPA

FoCal-H

日本

インド　オランダ



PAD
Si センサー

MAPS

現在の主要な参加機関

Forward Workshop in Tsukuba (2019.03)

ALICE実験代表、物理部会長を含む国内外の招待講演者を招き、“International Workshop on Forward Physics and Forward Calorimeter Upgrade in ALICE”を開催（国外 10名、国内28名、計38名）

https://indico.cern.ch/event/783989/

筑波大における ALICE Grid Tier2 構築

- **LHC ALICE Run-3 に向けて**
  - 日本における ALICE コンピューティング資源の確保・拡充
  - 2019年2月、実効 168 TB RAID ディスク購入(本新学術予算)
  - 2019年5月、SINET5 (Hepnet-J 経由) に 10 Gbps で接続する光ファイバー新規導入
  - （予定）2019年6-7月、Tsukuba T2 運用再開
    - Worker node の増設

↑

購入した RAID ディスク

ZE-G824F16-4G-N8000x24

(8TB SATA HDD x 24,

effective 168 TB (RAID6/SPARE1))

https://www.sinet.ad.jp/aboutsinet/interconnectivities

Summary and future plan

✓ Physics:

- One journal submission in pp (jet)
- Two preliminaries in Pb-Pb, and paper is in preparation (jet)
- HF: New preliminary (2), p-Pb & Pb-Pb papers (2)
- two PhD double degrees (Grenoble-Tsukuba)
  - H. Yokoyama (2018), R. Hosokawa (2019)
- Towards jet with PID
  - Heavy flavor, baryon/ meson with Jets
  - March cone?
- **HF-e (Sakai), Gamma (Novitzky), Jet (Chujo)**

✓ FoCal upgrade proposal:

- mini-FoCal projection and successful data taking at PS/SPS and LHC-ALICE (2018)
- in 2019: towards LoI and TDR
- Final design
- Forming new international collaboration (FR, USA, BR)