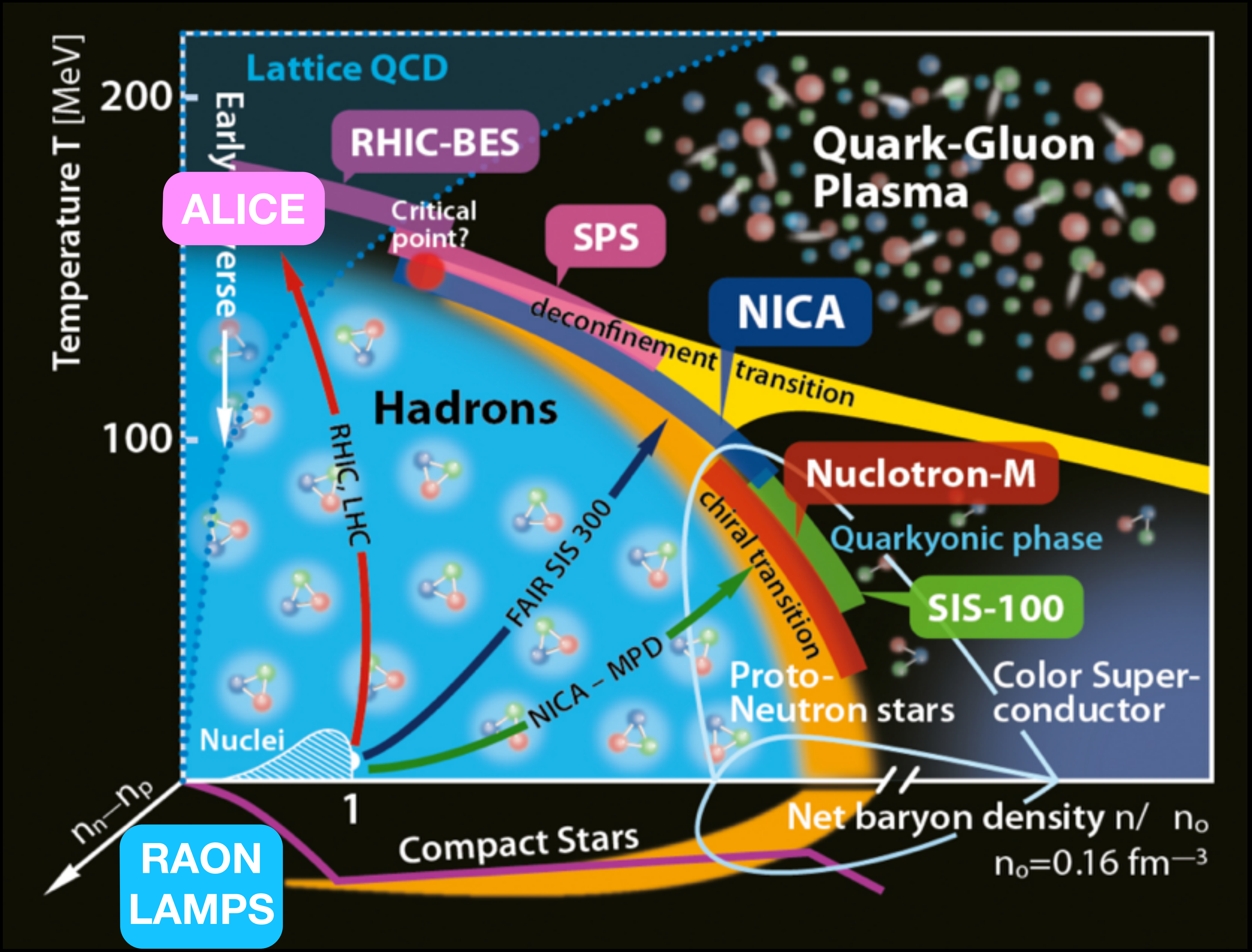
What we measure (build), and what we want to measure (build)

MinJung Kweon

Inha University

CENuM Workshop
July 4, 2020

Create hot and dense nuclear matter in lab



Control the isospin parameter (N/Z) of matter using RI beams

Interest of our group

LHC ALICE

2020 — 2024

ALICE 실리콘 검출기 R&D 및 제작 참여
(LS2)
(LS3)
(LS4)

ALICE data analysis - focusing on hard probes such as open heavy flavour

Modeling

Develop simulation package modeling multi-charm production (Shinchon)

제1그룹 이론 영역과 공동 연구

SPIRAL FAZIA

제1,2 실험그룹과 공동연구

FAZIA 실리콘 검출기 upgrade R&D 및 제작 참여

EOS and Symmetry energy 데이터 분석

RAON LAMP

LAMPS High energy 용 Start counter 제작

LAMPS High energy 용 실리콘 검출기 제작 계획중 (ALICE Type - 위치 측정)

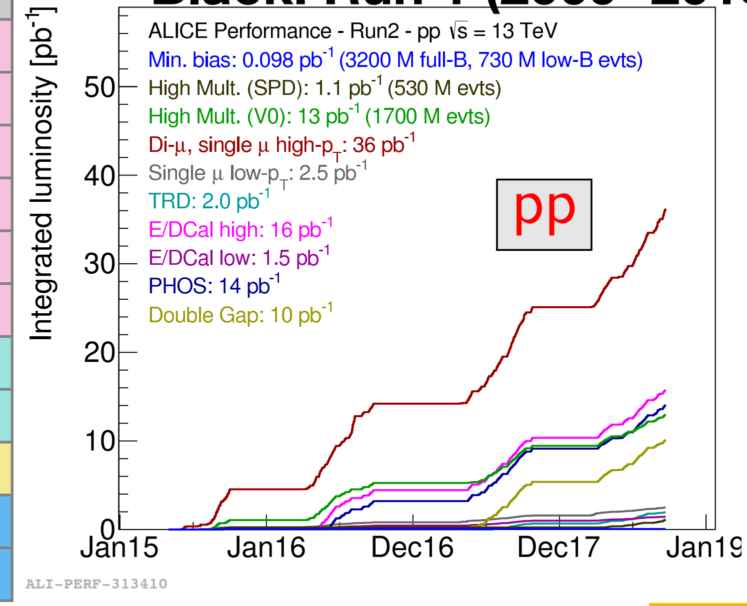
LAMPS Low energy 용 실리콘 검출기 제작 (FAZIA Type - 에너지 측정)

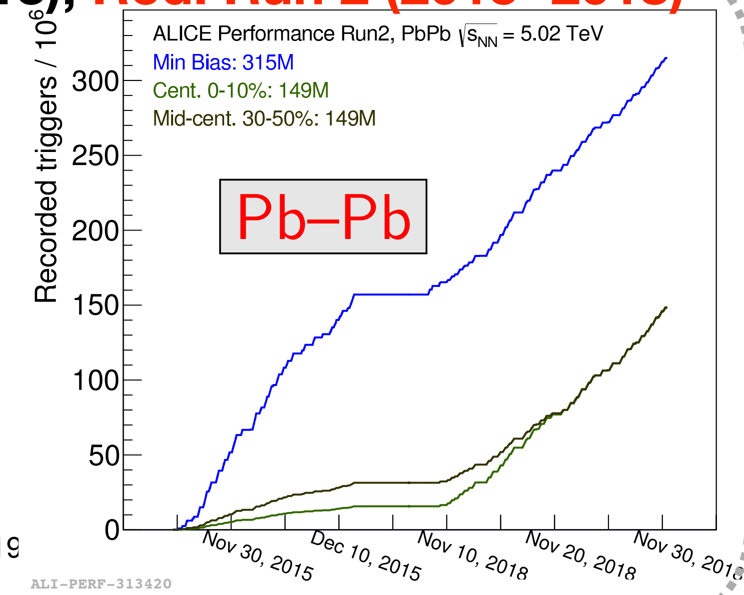
**Hard probe 기반 QGP 특성 이해, EOS & symmetry energy 이해,
에너지 및 위치 측정용 실리콘 검출기 제작 기반 확보**

ALICE Timeline: 과거, 그리고 앞으로 15년

Black: Run 1 (2009~2013), Red: Run 2 (2015~2018)

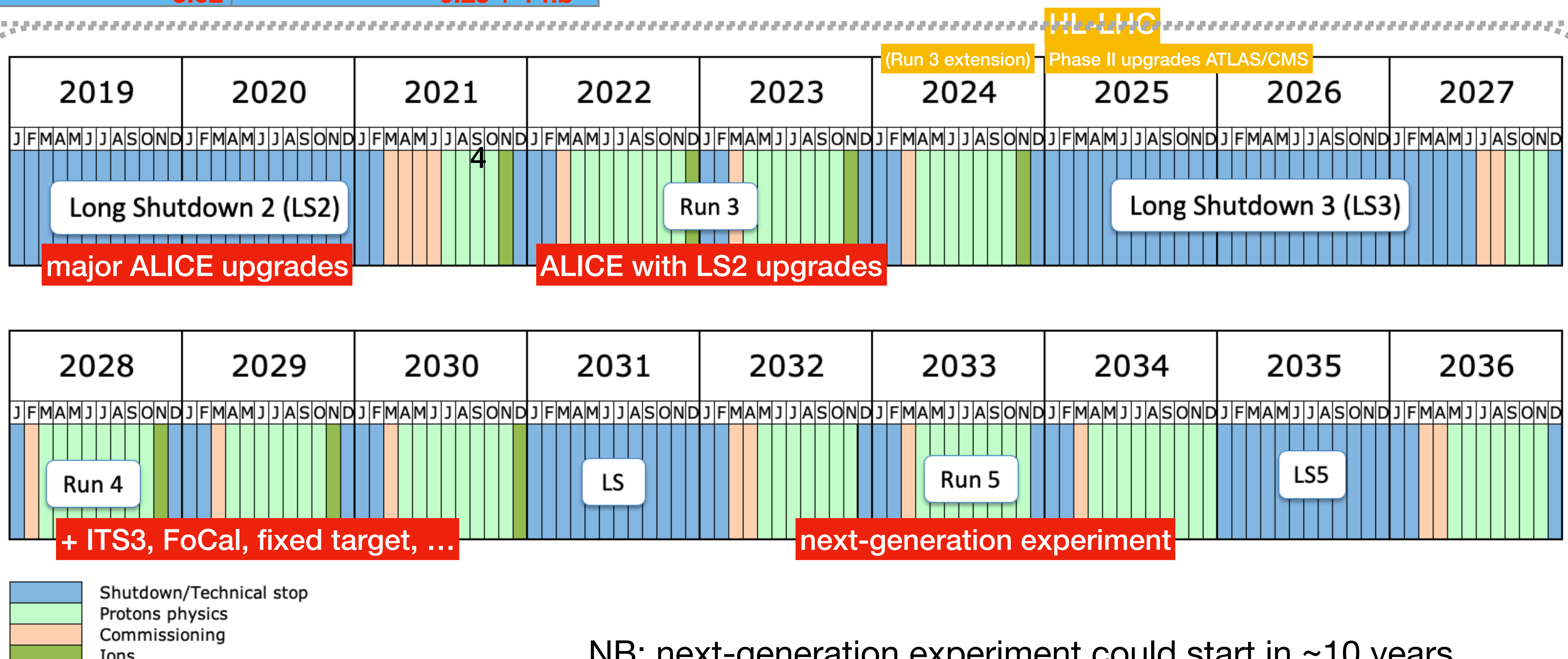
system	$\sqrt{s_{NN}}$ (TeV)	L_{int}
pp	0.9	~ 200 μb^{-1}
	2.76	~ 100 nb^{-1}
	5.02	~ 1.3 pb^{-1}
	7	~ 1.5 pb^{-1}
	8	~ 2.5 pb^{-1}
	13	~ 25 pb^{-1}
p-Pb	5.02	~ 15 + 3 nb^{-1}
	8.16	~ 25 nb^{-1}
Xe-Xe	5.44	~ 0.3 μb^{-1}
Pb-Pb	2.76	~ 75 μb^{-1}
	5.02	~ 0.25 + 1 nb^{-1}





Past

Future



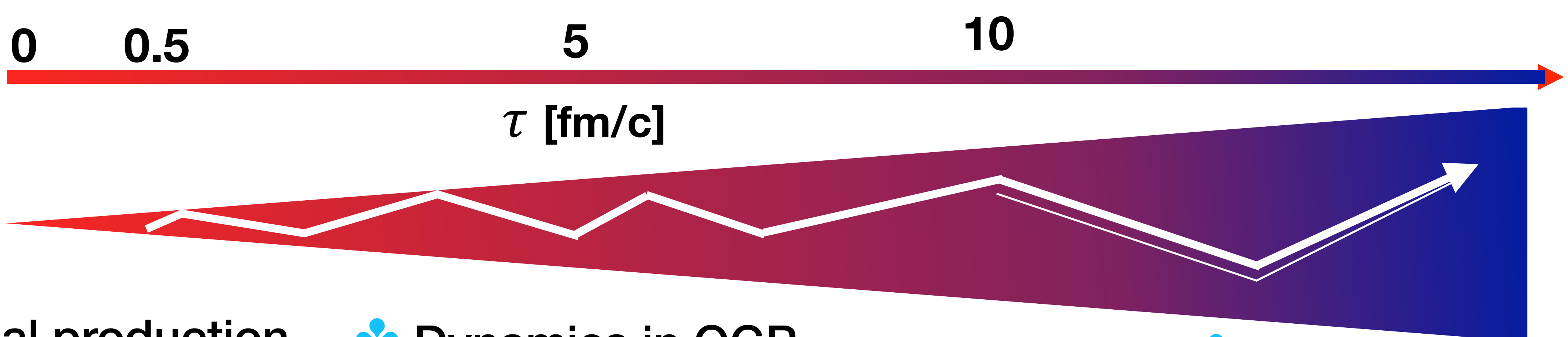
NB: next-generation experiment could start in ~10 years, similar time line to current upgrades!

Pb-Pb in Run 3+4: $\mathscr{L}$ = 13 nb^{-1}

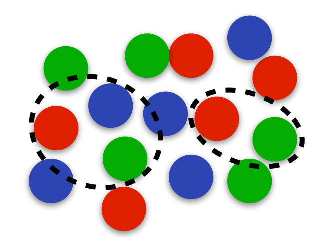
Basic scales and physics of heavy flavour in HI collisions

- $m_{c,b} \gg \Lambda_{QCD}$ **pQCD initial production**
- $m_{c,b} \gg T_{RHIC,LHC}$ **negligible thermal production**
- $\tau_0 \approx 1/2m_Q$ (<0.1 fm/c) $\ll \tau_{QGP}$ (O(10fm/c)) **witness of all the QGP**

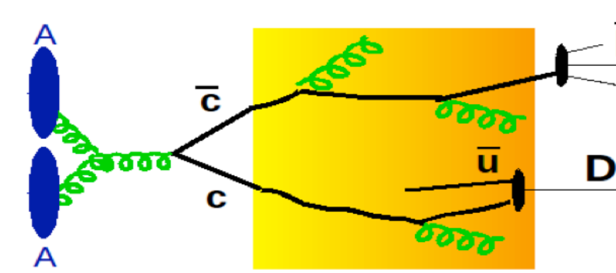
⇨ **"Calibrated probes" of the medium**



- **Initial production**
  - pQCD-NLO
  - MC-NLO
  - CNM effect
- **Dynamics in QGP**
  - energy loss via radiative ("gluon Bremsstrahlung") and collisional processes
    - color charge (Casimir factor)
    - quark mass (dead-cone effect)
    - path length and medium density
- **Hadronization**



  - via quark coalescence and/or fragm.
  - hadronic rescattering



How can we measure the medium effects?

Nuclear modification factor (R_{AA}): compare particle production in Pb-Pb with that in pp scaled by a geometrical factor

$$R_{AA} = \frac{dN_{AA}/dp_T}{\langle N_{coll} \rangle \times dN_{pp}/dp_T} = \frac{dN_{AA}/dp_T}{\langle T_{AA} \rangle \times d\sigma_{pp}/dp_T}$$

Binary scaling based on the Glauber Model

- $R_{AA} = 1$: binary scaling
- $R_{AA} \neq 1$: medium effect

Trivial but important caveat:

$$\frac{dN^{D}_{PbPb}}{dp_T} = PDF(x_1)PDF(x_2) \otimes \frac{d\hat{\sigma}^c}{dp_T} \otimes P(\Delta E) \otimes D_{c\rightarrow D}(z)$$

- $PDF(x_1)PDF(x_2)$: Initial-state effects
- $\frac{d\hat{\sigma}^c}{dp_T}$: "Vacuum" parton spectra
- $P(\Delta E)$: Parton interaction with the medium
- $D_{c\rightarrow D}(z)$: (Modified?) hadronization
- $P(\Delta E) \otimes D_{c\rightarrow D}(z)$: What we want to probe

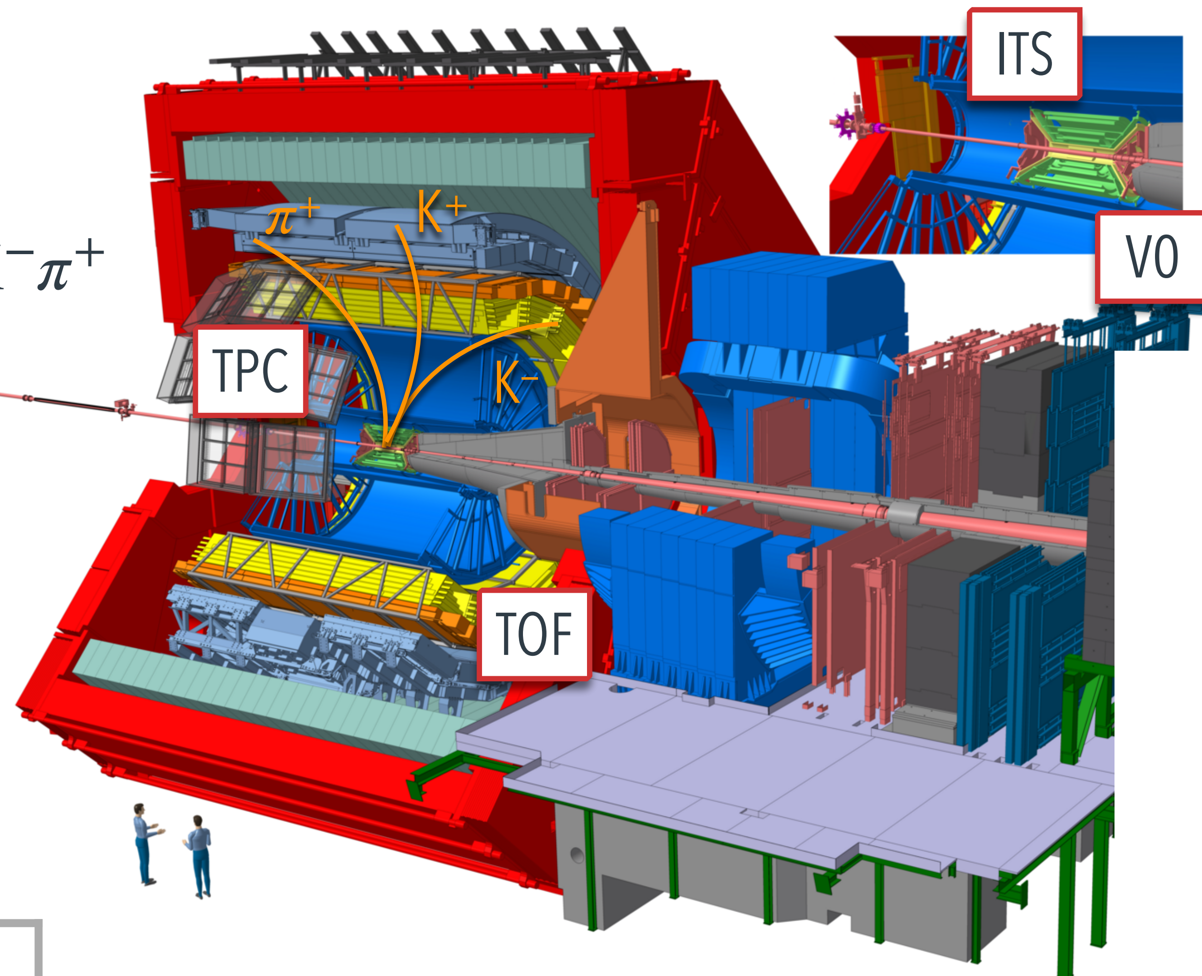
Measured spectra in AA collisions result from a convolution of many pieces

⇒ interpretation of the results requires **comparison with models**

⇒ must measure **observables with different sensitivity** to the various ingredients

Measurements of heavy-flavour hadrons with ALICE

- $D^0 \rightarrow K^-\pi^+$
- $D^+ \rightarrow K^-\pi^+\pi^+$
- $D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+$
- $D^{*+} \rightarrow D^0\pi^+$
- $\Lambda_c^+ \rightarrow pK^-\pi^+$
- $\Lambda_c^+ \rightarrow pK_s^0$
- $\Sigma_c^{0,++} \rightarrow \Lambda_c^+\pi^{-,+}$
- $\Xi_c^0 \rightarrow \Xi^-\pi^+$
- $\Xi_c^+ \rightarrow \Xi^-\pi^+\pi^+$



서진주 @ pp 13 TeV
복정수 @ pPb 5 TeV

- $\Xi_c^0 \rightarrow \Xi^-e^+\nu_e$
- $c, b \rightarrow e^{\pm}X$
- $c, b \rightarrow \mu^{\pm}X$
- $c\bar{c}, b\bar{b} \rightarrow e^+e^-X$

박종한 @ PbPb 5 TeV
권지연 @ pp 13 TeV

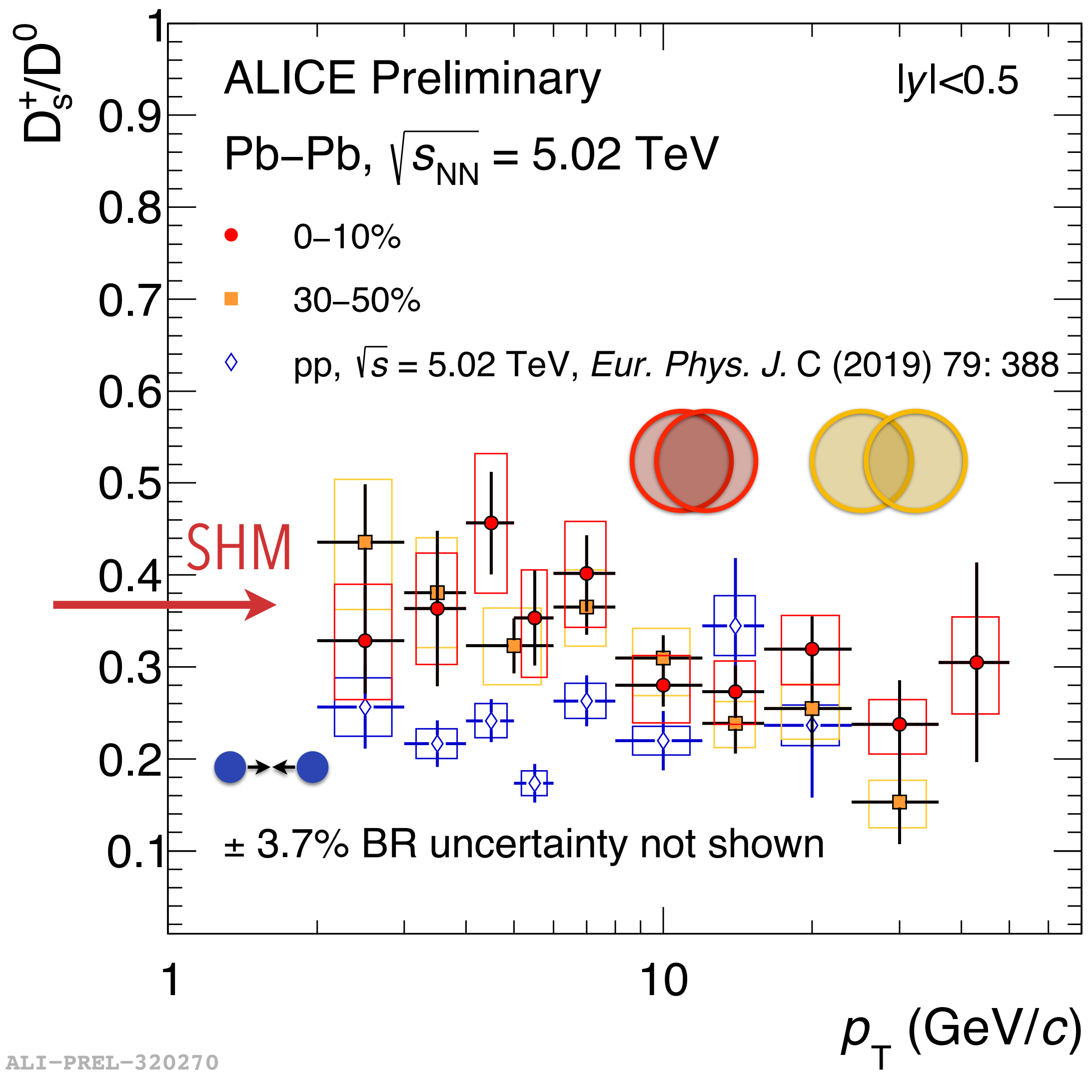
도재현 @ pp 13 TeV high multiplicity

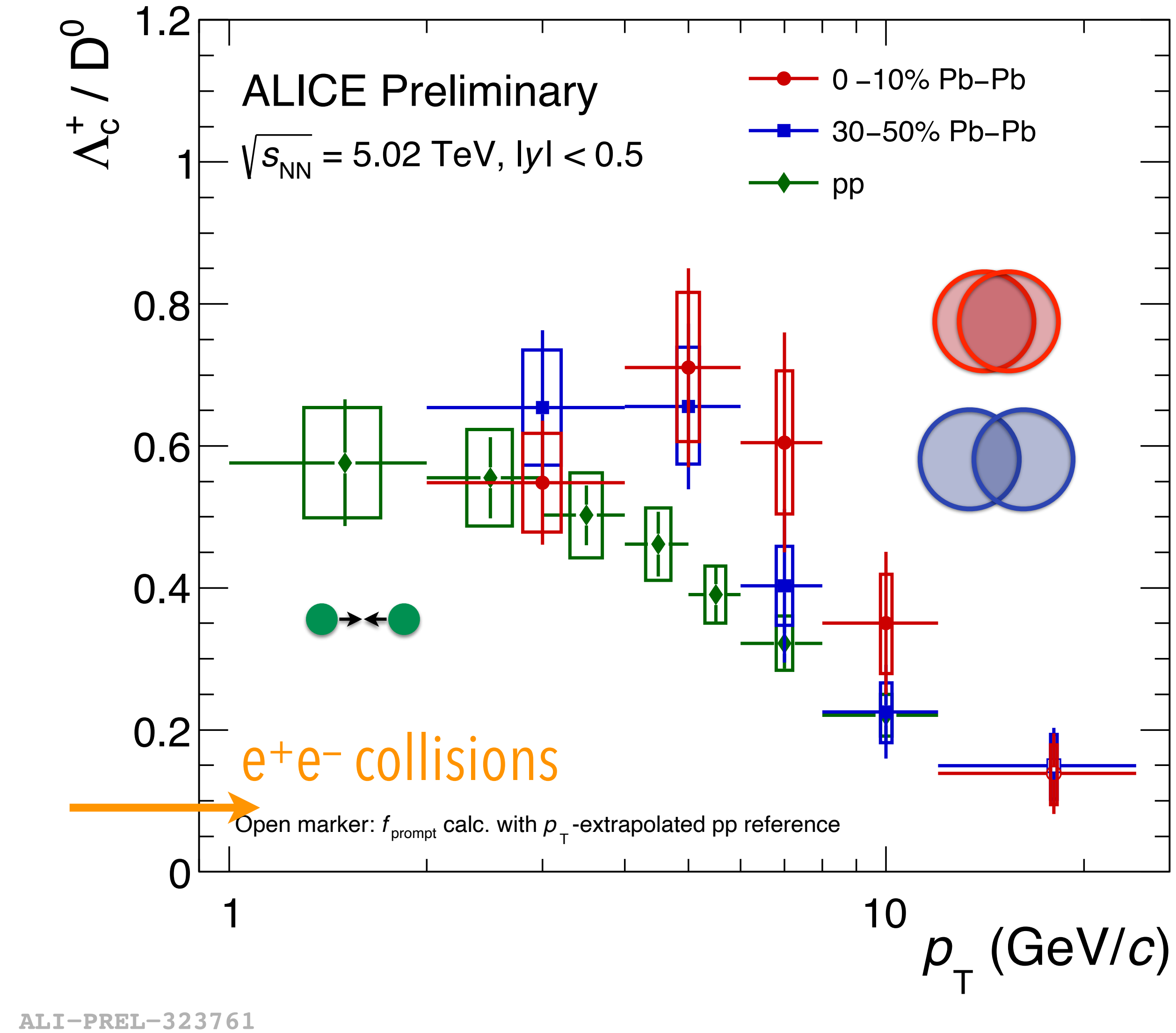
조재윤 @ ITS3 upgrade physics performance

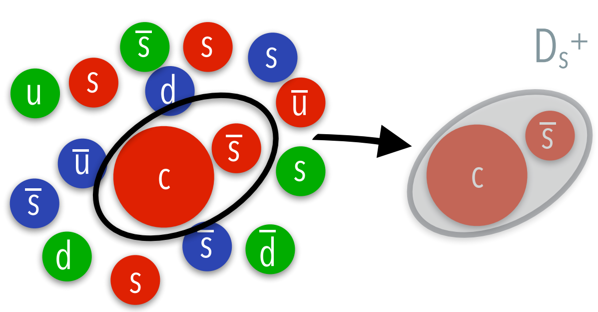
$\Xi_c^{0,+}$ & $\Sigma_c^{0,++}$ is not yet measured in p-Pb and Pb-Pb.
Ξ_c^0 in p-Pb will be finalized within several months
Next run (run3) for Pb-Pb result (after inner tracking detector upgrade)!

Why toward measuring charmed baryons?

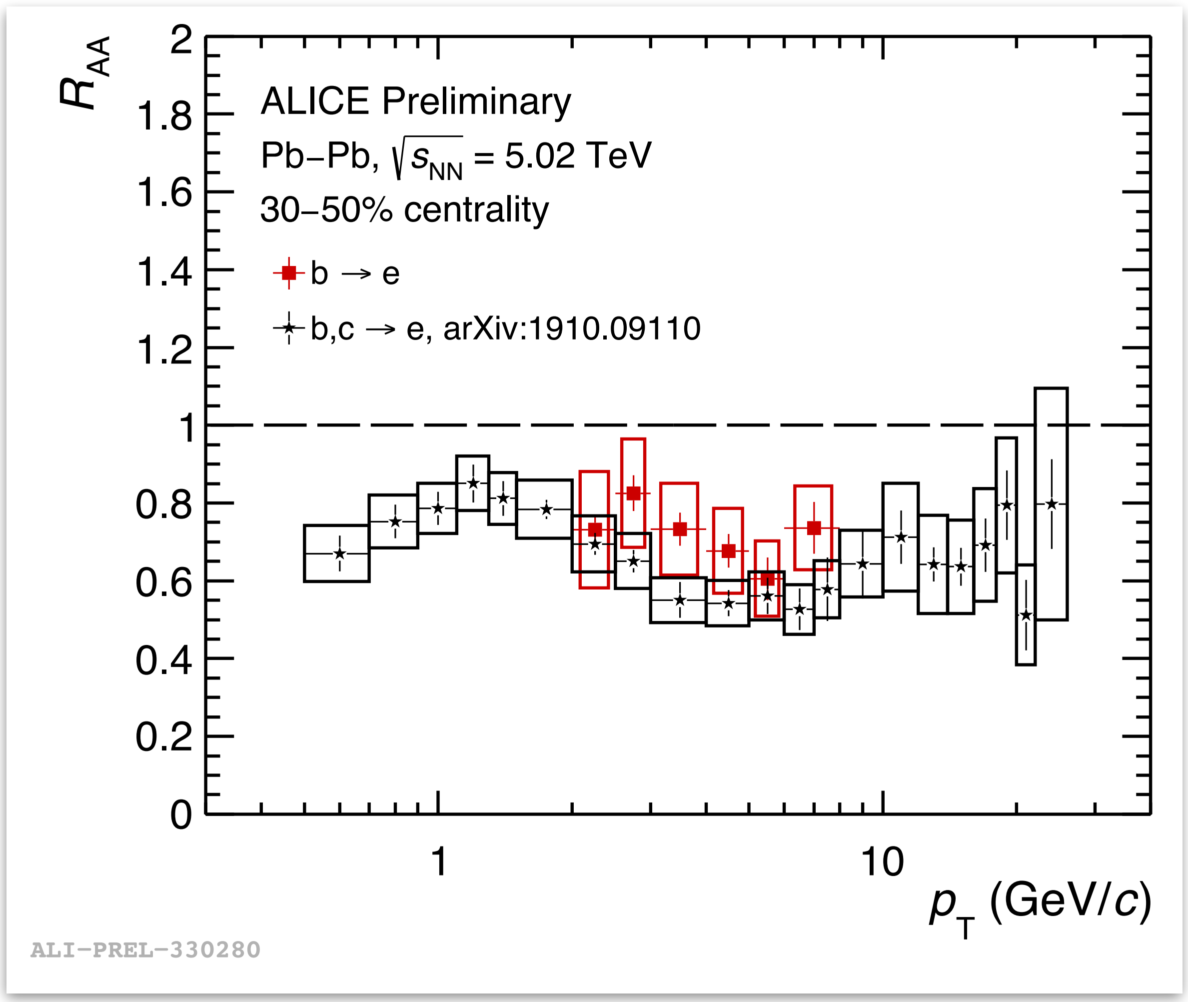
;more than the energy loss in the medium







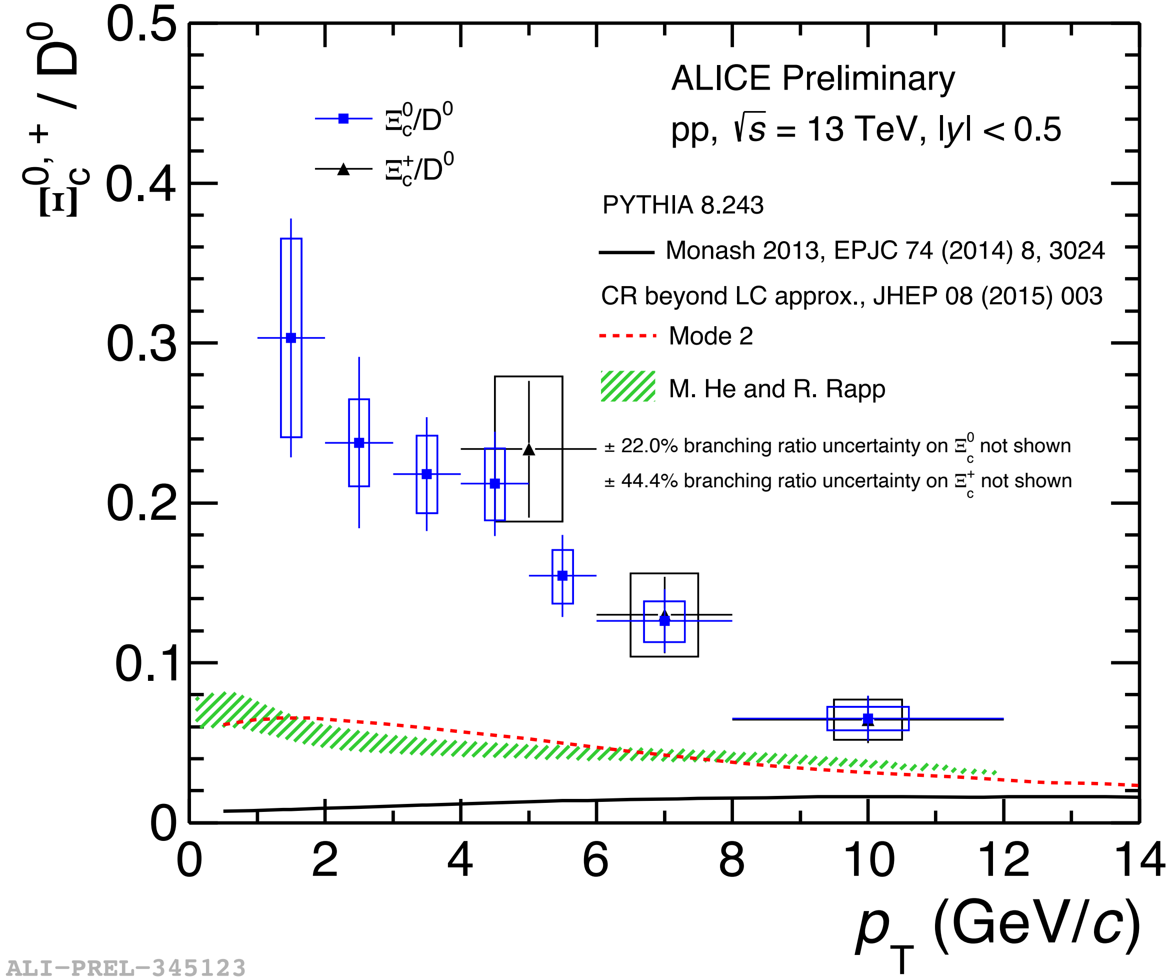
Highlight of the analysis; b→e in Pb-Pb

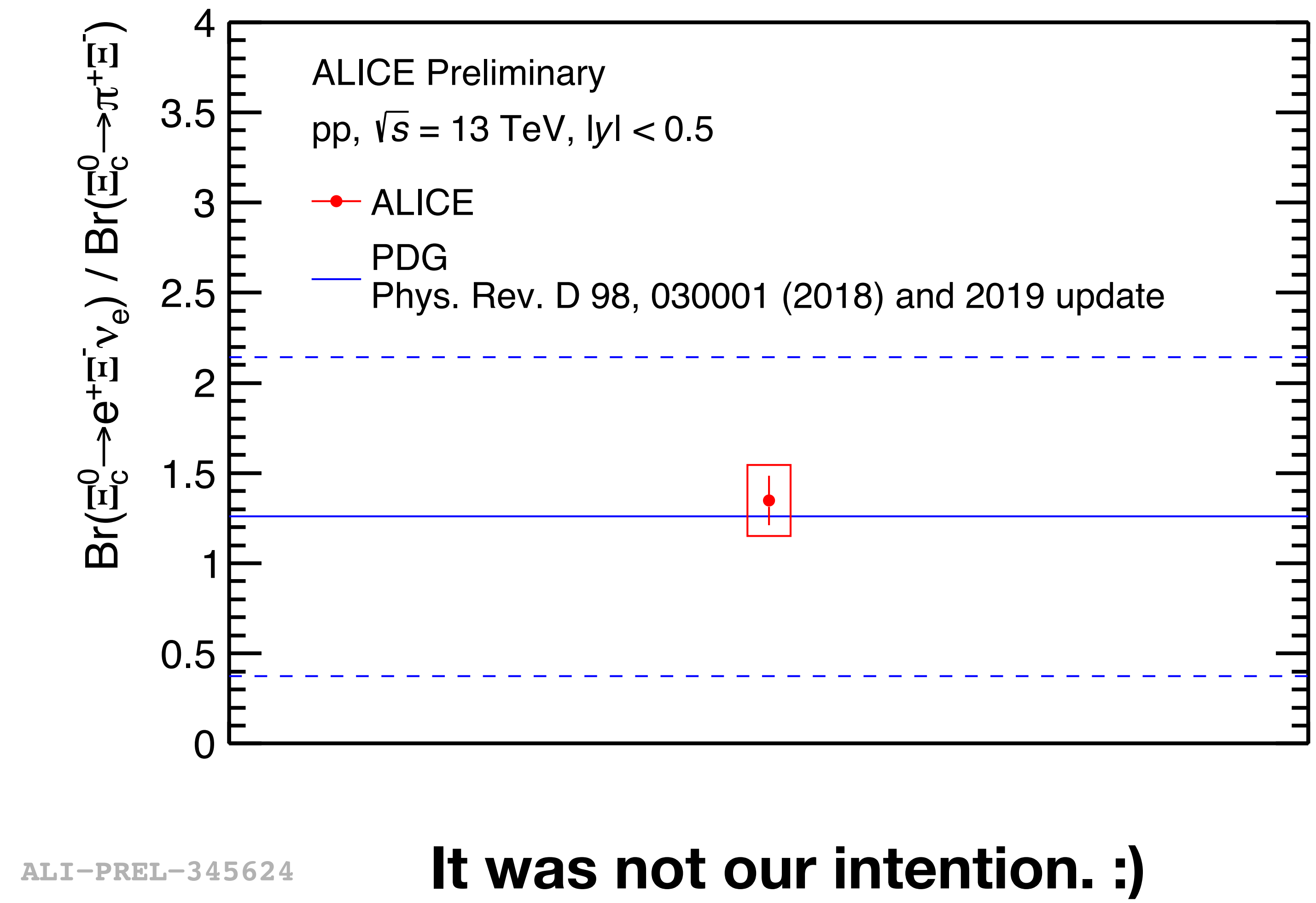


Hint of quark mass dependence of the energy loss in medium!

Highlight of the analysis; Ξ_c^0 in pp

Baryon/Meson ratio in charm sector!





It was not our intention. :)

Interest getting toward… not only the energy loss in the medium but also production mechanism of heavy flavour in PbPb (even in pp, especially high multiplicity events)

Going further! for next-generation experiment

Multi-HF hadrons: strategy and plan

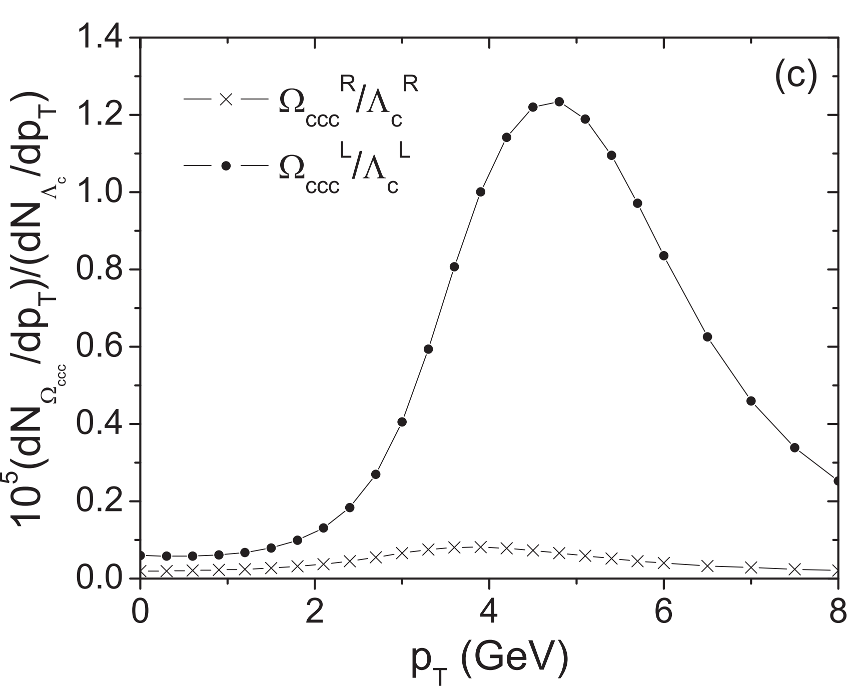
M. Kweon[1], A. Rossi[2], J. Seo[1], S. Trogolo[2]

1. Inha University
2. INFN and University - Padova

Post-LS4 experiment - meeting
15/06/2020

조성태 교수님과 공동연구할 영역이 많음!

Hadron	Yield in central Pb-Pb (full phase space)	Expected enhancement w.r.t. pp
Ξ_{cc}, Ω_{cc}	0.02-0.38	1-10
Ξ_{bc}, Ω_{bc}, B_c	3×10^{-4} - 0.02	>10 for Ξ_{bc}
Ξ_{bb}, Ω_{bb}	2.6×10^{-6} - 7×10^{-5}	-
Ω_{ccc}	10^{-3} - 0.03	100-1000



S. Cho and SH Lee, PRC 101, 024902 (2020)

Test of coalescence models and of statistical-hadronisation expectations

- Ξ_{cc} and Ω_{ccc} yields from different models are consistent within a factor 2
- Ω_{ccc} decays suggested in JHEP 08 (2011) 144, assumption: BR=5%

Decay	B.R.
$\Omega_{ccc}^{++} \to \Xi_{cc}^{++} + \bar{K}^0$	5% x 0.5
$\Xi_{cc}^{++} \to \Lambda_c^+ + K^- + \pi^+ + \pi^-$	5%
$\Lambda_c^+ \to p + K^- + \pi^+$	6.35%
$\bar{K}^0 : 50\,\%\, K_s^0 \to \pi^+ + \pi^-$	70%
	0.0055%

Decay	B.R.
$\Omega_{ccc}^{++} \to \Xi_{cc}^{++} + \bar{K}^0$	5% x 0.5
$\Xi_{cc}^{++} \to \Xi_c^+ + \pi^+$	5%
$\Xi_c^+ \to p + K^- + \pi^+$	2.2 ± 0.8%
$\bar{K}^0 : 50\,\%\, K_s^0 \to \pi^+ + \pi^-$	70%
	0.0019%

Decay	B.R.
$\Omega_{ccc}^{++} \to \Xi_c^+ + D^+$	5%
$\Xi_c^+ \to p + K^- + \pi^+$	2.2%
$D^+ \to K^- + \pi^+ + \pi^-$	9%
	0.0099%

Decay	B.R.
$\Omega_{ccc}^{++} \to \Omega_{cc}^+ + \pi^+$	5%
$\Omega_{cc}^+ \to \Omega_c^0 + \pi^+$	5%
$\Omega_c^0 \to \Omega^- + \pi^+$	5%
$\Omega^- \to \Lambda + K^-$	67.8%
$\Lambda \to p + \pi^-$	63.9%
	0.0054%

We have a plan…
not only the plan, the R&D started!

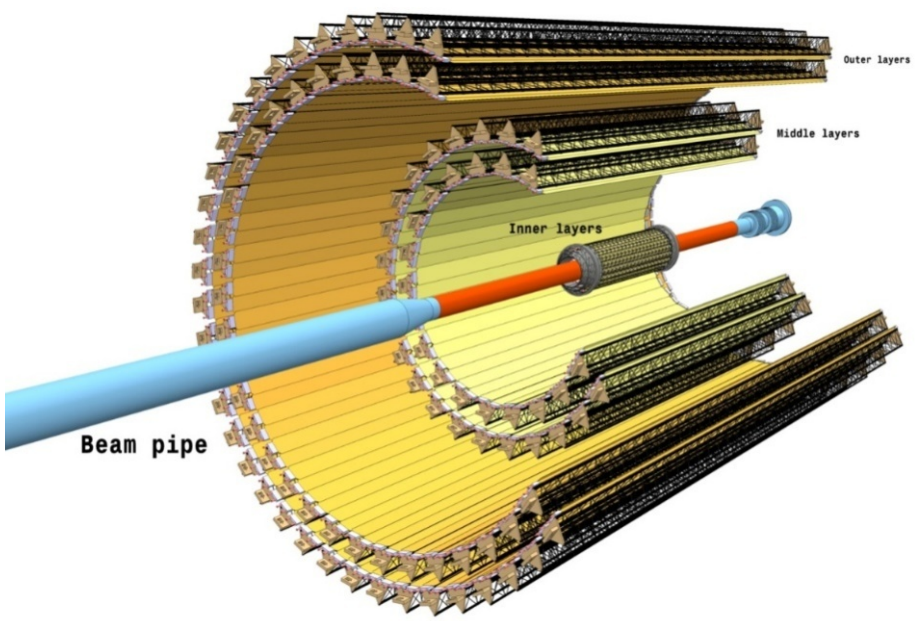
Highly connected to the heavy flavour.

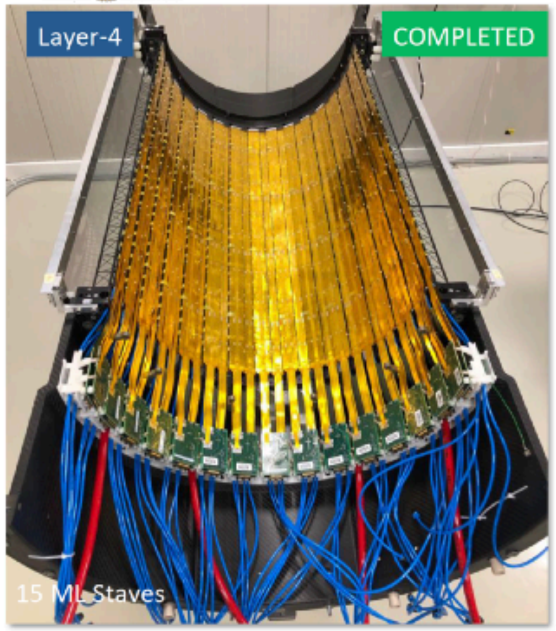
LS2 upgrades - tracking particles close to interaction point

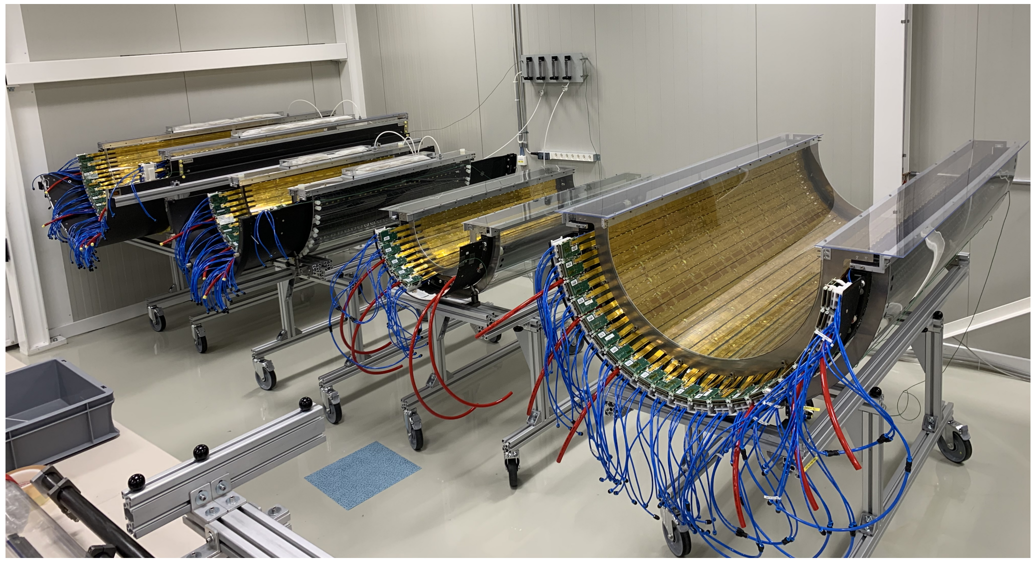
Brand new Inner Tracking System:

➡ **Construction & commissioning is ongoing**

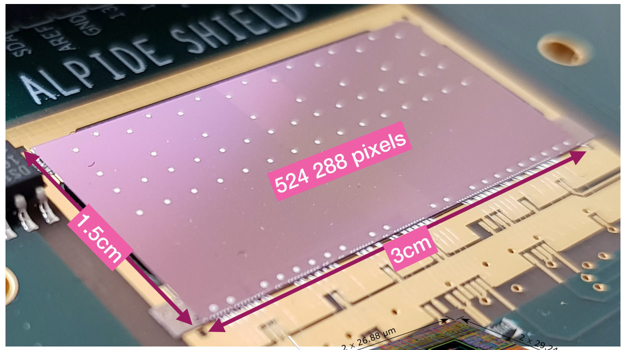
- 7 layers (10 m^2) silicon pixel (MAPS) sensor tracker
- 22-406 mm to Interaction Point with spatial resolution O(5 μm)

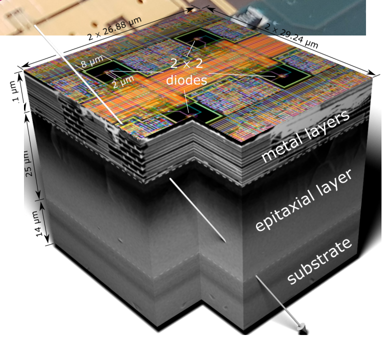






➡ B_s, B_c, Λ_b , b-jet measurements



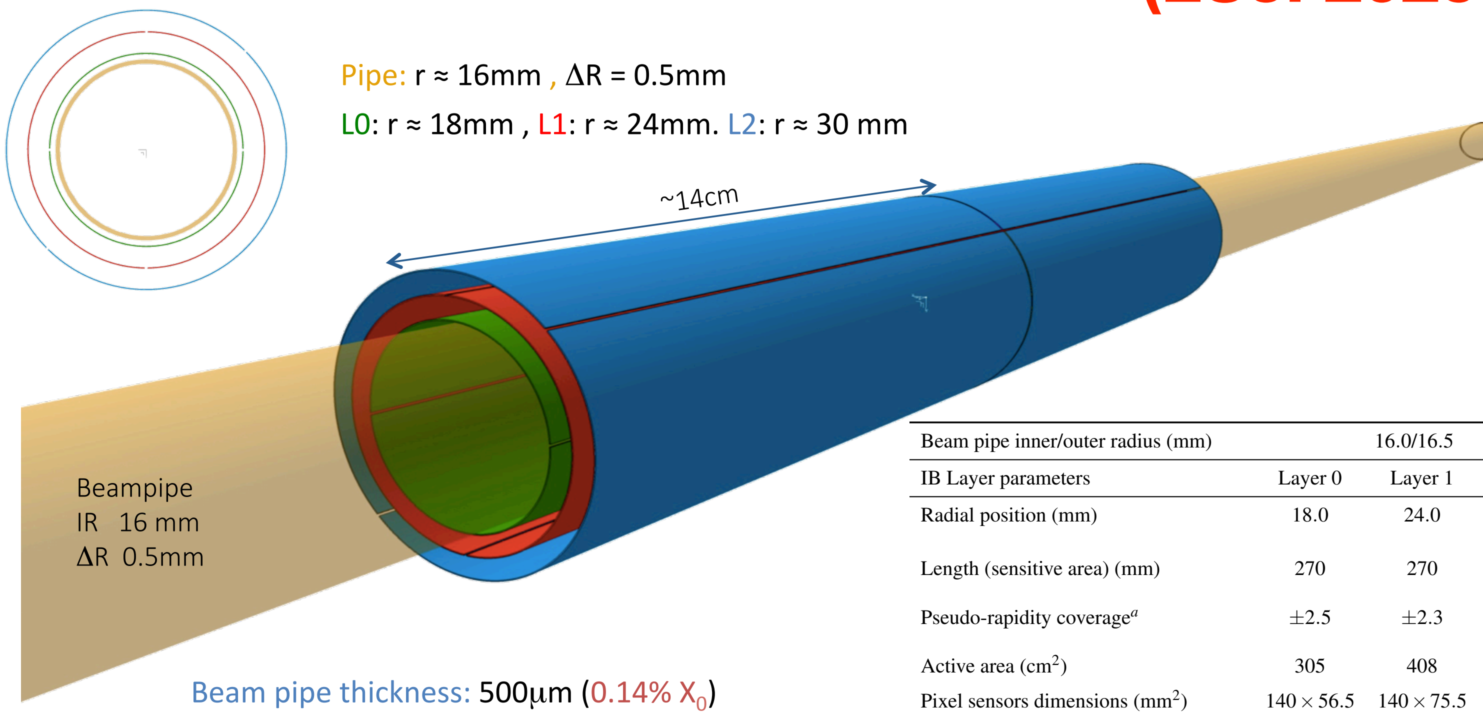


Inha: contributed significantly on chip characterization, mass chip testing, module assembly, commissioning at CERN (ongoing)

박종한, 권지연, 서진주

After LS3 (Run 4): flexible silicon detector

(LS3: 2025-2027)



Beam pipe thickness: 500µm (0.14% X_0)

Sensor thickness: 20 – 40µm (0.03 - 0.05% X_0)

L. Musa (CERN) – ALICE Physics Week, 23 Oct 2018

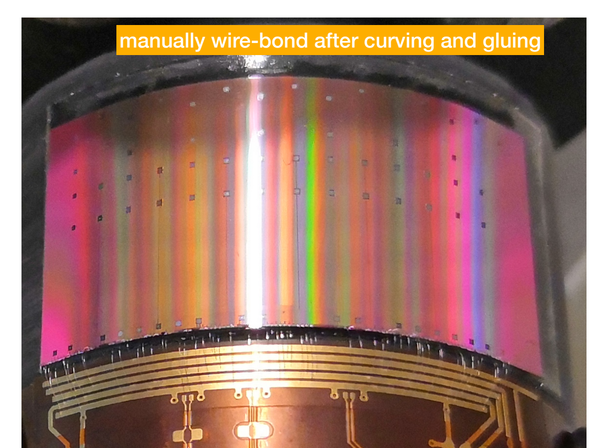
Beam pipe inner/outer radius (mm)	16.0/16.5		
IB Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	270	270	270
Pseudo-rapidity coverage[a]	±2.5	±2.3	±2.0
Active area (cm^2)	305	408	508
Pixel sensors dimensions (mm^2)	140 × 56.5	140 × 75.5	140 × 94
Number of pixel sensors / layer	4		
Pixel size (μm^2)	$O(30 \times 30)$		

구부러지는 칩으로 얇은 검출기 제작!

Ultra-thin chip (<50 um): flexible with good stability

- Heavy-flavour (charm, bottom): focus on low transverse momenta
  → production yields, flow, in jets, vs event shape, …
  - Exclusive reconstruction of D, D_s, B, B_s, Λ_c, Λ_b, Ξ_c, Ω_c decay channels
  - Analysis of non-prompt signals

박종한, 서진주, 조재윤



Inha: test-beam data analysis, searching thinning & wire bonding company for curved wafer bonding. searching people to contribute on chip design. discussing the possibility to import chips and electronics for LAMPS in the future.

After LS4 (Run 5)

(LS4: 2031-2032)

A new experiment based on a "all-silicon" detector

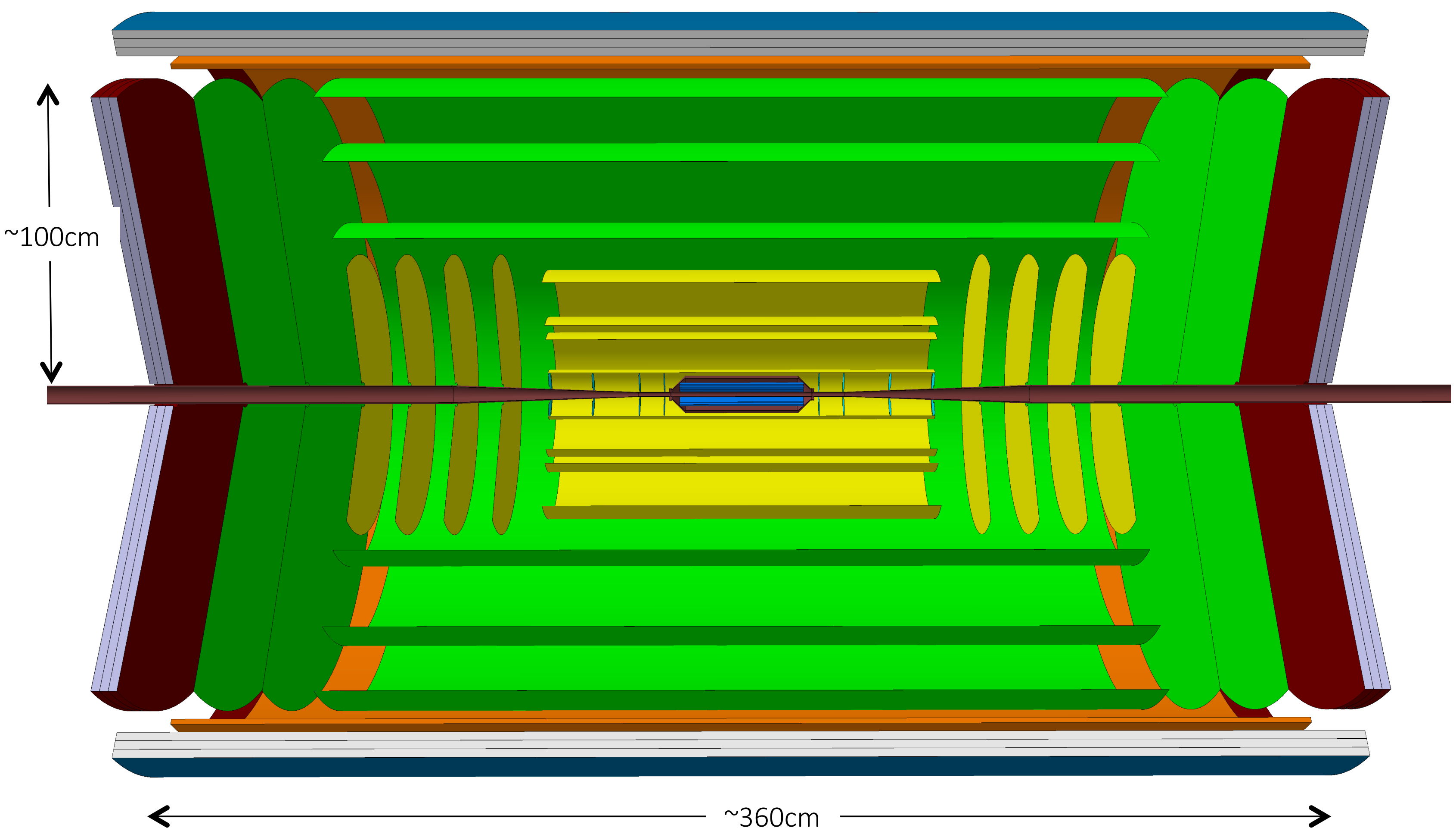
ALICE

Tracker: ~10 tracking barrel layers (blue, yellow and green) based on CMOS sensors

Hadron ID: TOF with outer silicon layers (orange)

Electron ID: pre-shower (outermost blue layer)

Extended rapidity coverage: **up to 8 rapidity units**
+ FoCal



Preliminary studies

Magnetic Field
- B = 0.5 or 1 T

Spatial resolution
- Innermost 3 layers: $\sigma \sim 1\mu m$
- Outer layers: $\sigma \sim 5\mu m$

Time Measurement
Outermost layer integrates high precision time measurement (σ_t < 30ps)

L. Musa (CERN) – ALICE Physics Week, 23 Oct 2018

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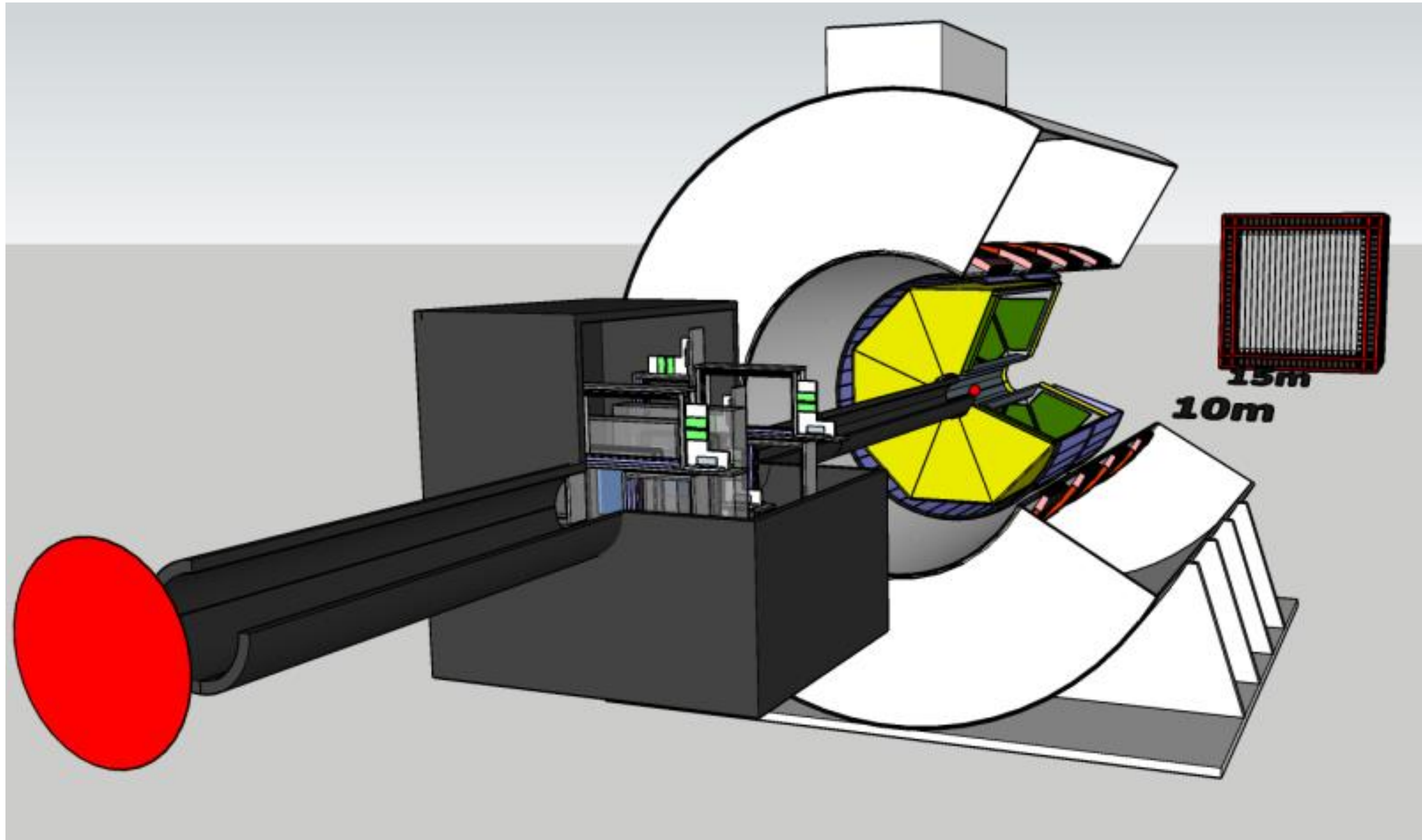
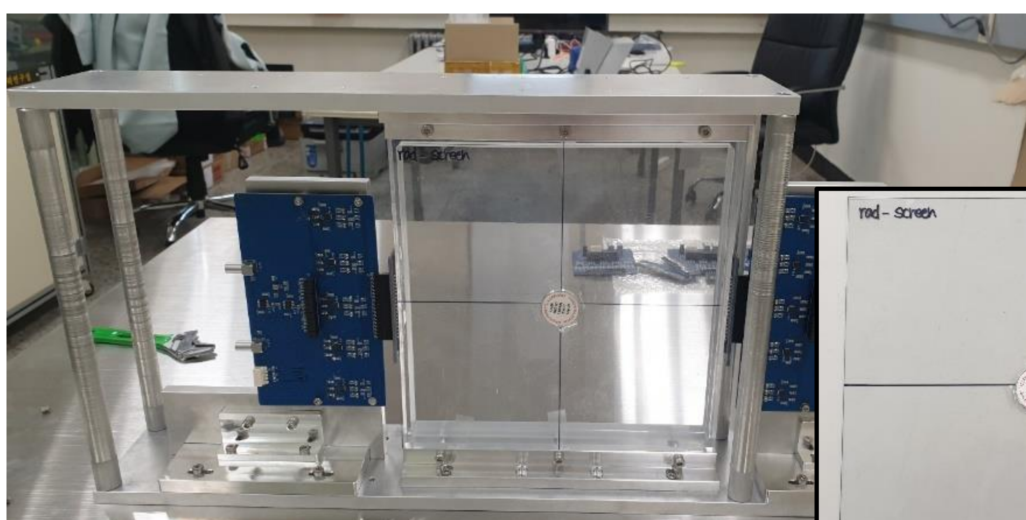
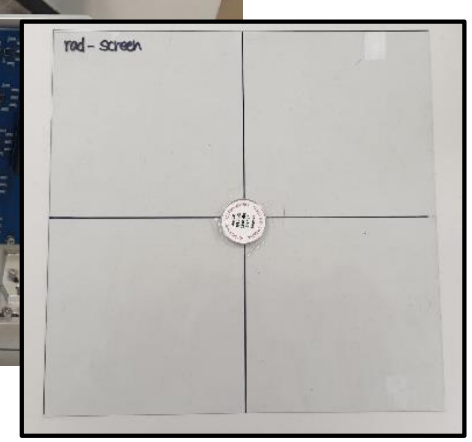
Inha: multi-charm physics performance study

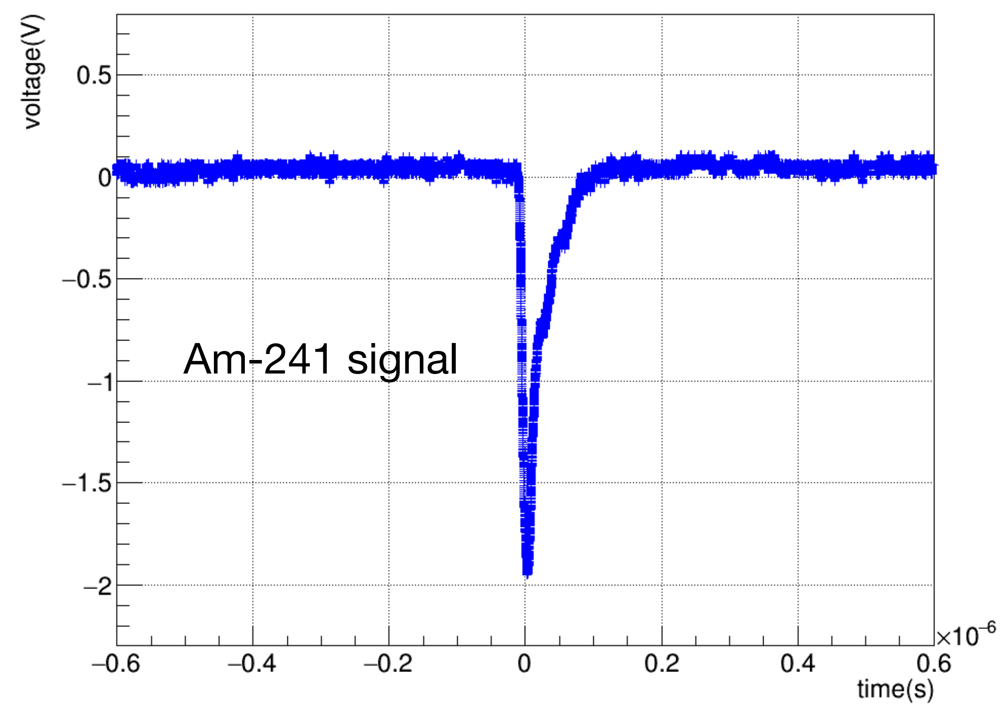
Toward heavy-ion physics with RI beam

LAMPS starting counter







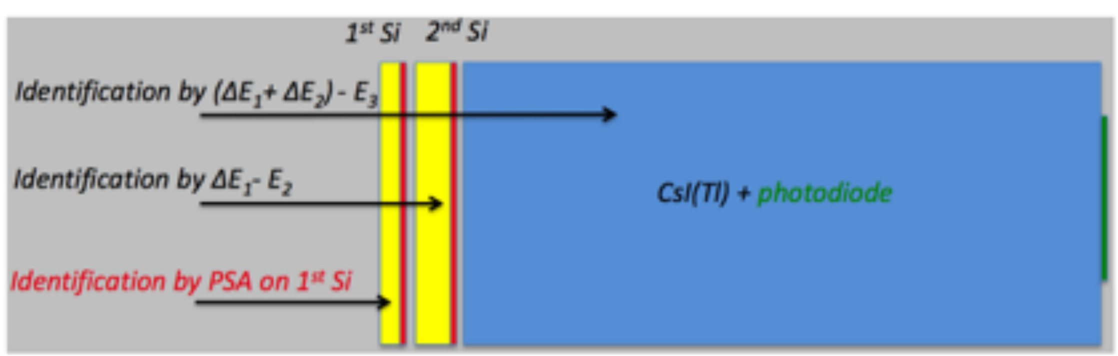


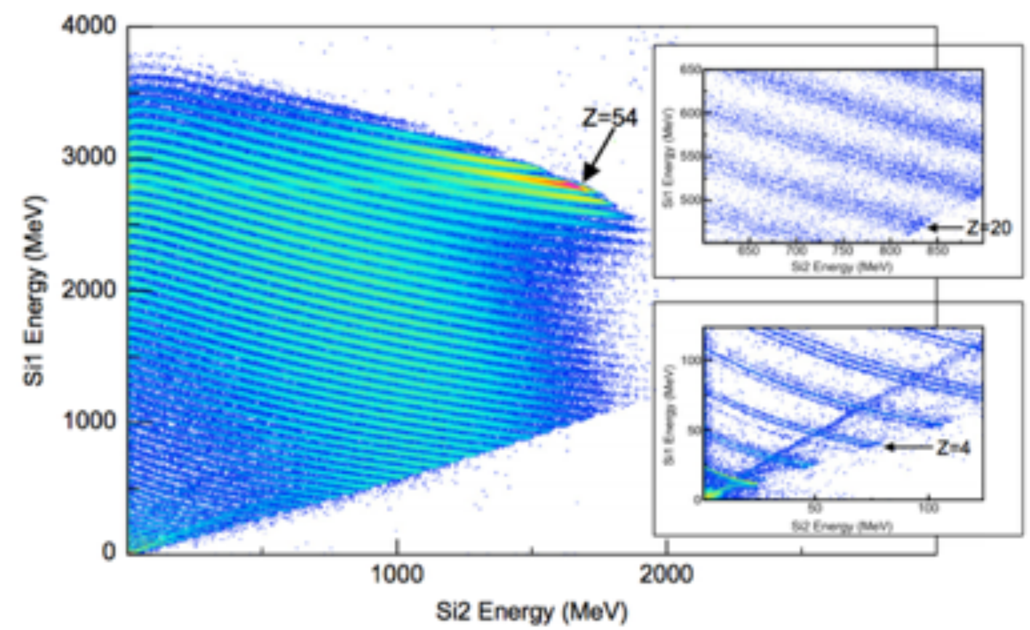
Dr. 도재현, 이형준

2020.7	2020.12	2021.6	2021.10
Proto-type 완성 및 테스트	본제품 제작 시작	본제품 제작 완료	Beam Test

Low energy silicon detectors: FAZIA (SPIRAL) & LAMPS

- FAZIA 검출기는 중이온 충돌 실험에서 생성된 isotope을 구분하는데 최적화된 검출기
- 두 개의 실리콘 검출기와 한 개의 CsI 신틸레이터로 구성, 에너지 손실량(ΔE)과 총 에너지(E)를 측정하고, 실리콘 검출기에서 생성되는 펄스의 모양을 측정해 핵의 A 및 Z를 구분
- ~5 < Z < ~54, 10 MeV/n <핵자당 에너지< 30 MeV/n 범위 내의 입자 구별 가능
- 현재 FAZIA 실험에서는 검출되는 입자 에너지의 kinematic range를 넓히고, Z=1 까지 측정 범위를 넓히기 위한 업그레이드 R&D 중 (논의 시작단계)





- FAZIA와의 공동연구 진행 시 업그레이드 용 웨이퍼 수급, 가공, 전자보드 제작은 국내 개발을 목표로 하며 논의 진행 중

Dr. 도재현, 이형준

  - NOTICE와 협력해 FAZIA upgrade용 electronics board 개발 → Low energy RAON 실험 실리콘 검출기에 응용
  - 국내 업체 및 연구소를 통해 Wafer 수급 및 공정 → Low energy RAON 실험 검출기에 응용
  - 실리콘 검출기 시뮬레이션 **(조재윤)**

Show goes on beyond 2024...