



한국ALICE실험사업팀의 발자취와

KOALICE의 미래

Jin-Hee Yoon

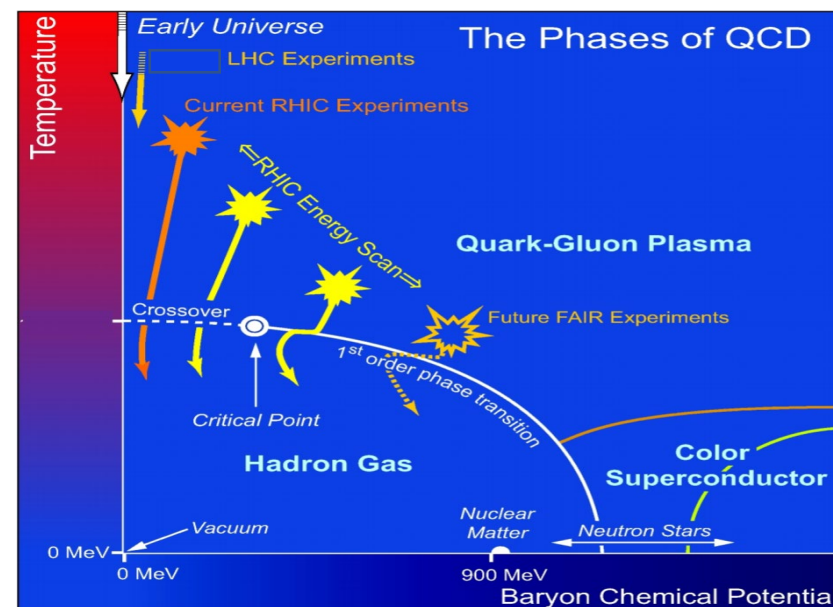
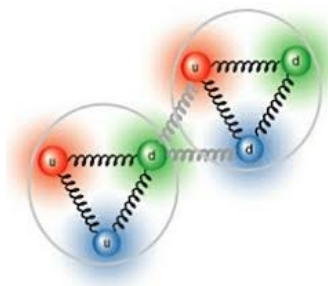
on the behalf of KOALICE collaboration



Nuclear Physics?

- ✓ What to see?
- ✓ Nucleus = bulk of proton & neutron
- ✓ proton/neutron = bulk of quarks & gluons

- ✓ Bulk ← **INTERACTION**
- ✓ bulk behavior, collective features, phase diagram, etc.



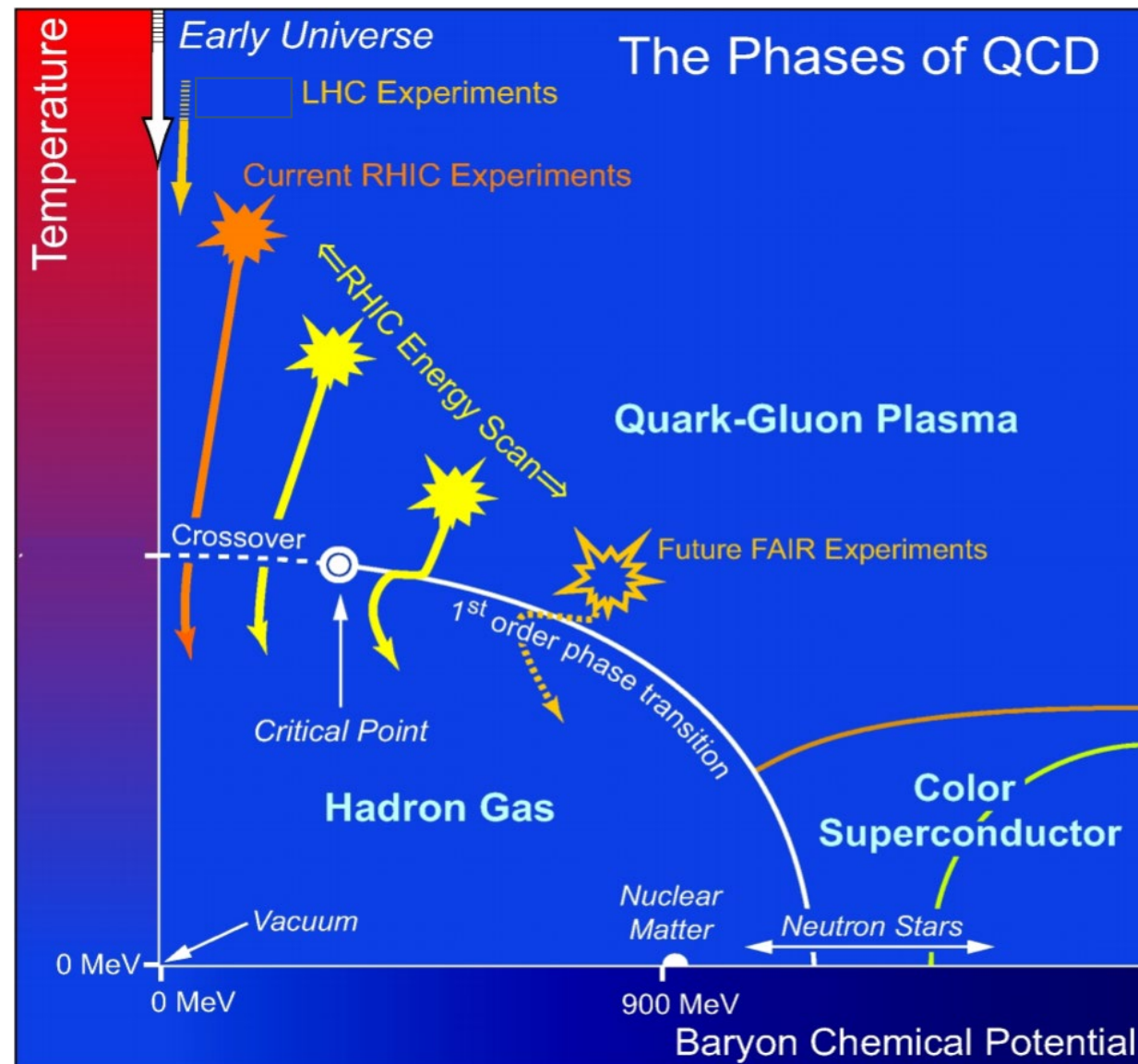
Phase Transition and QGP

✓ 우주 초기 물질에서 현재까지

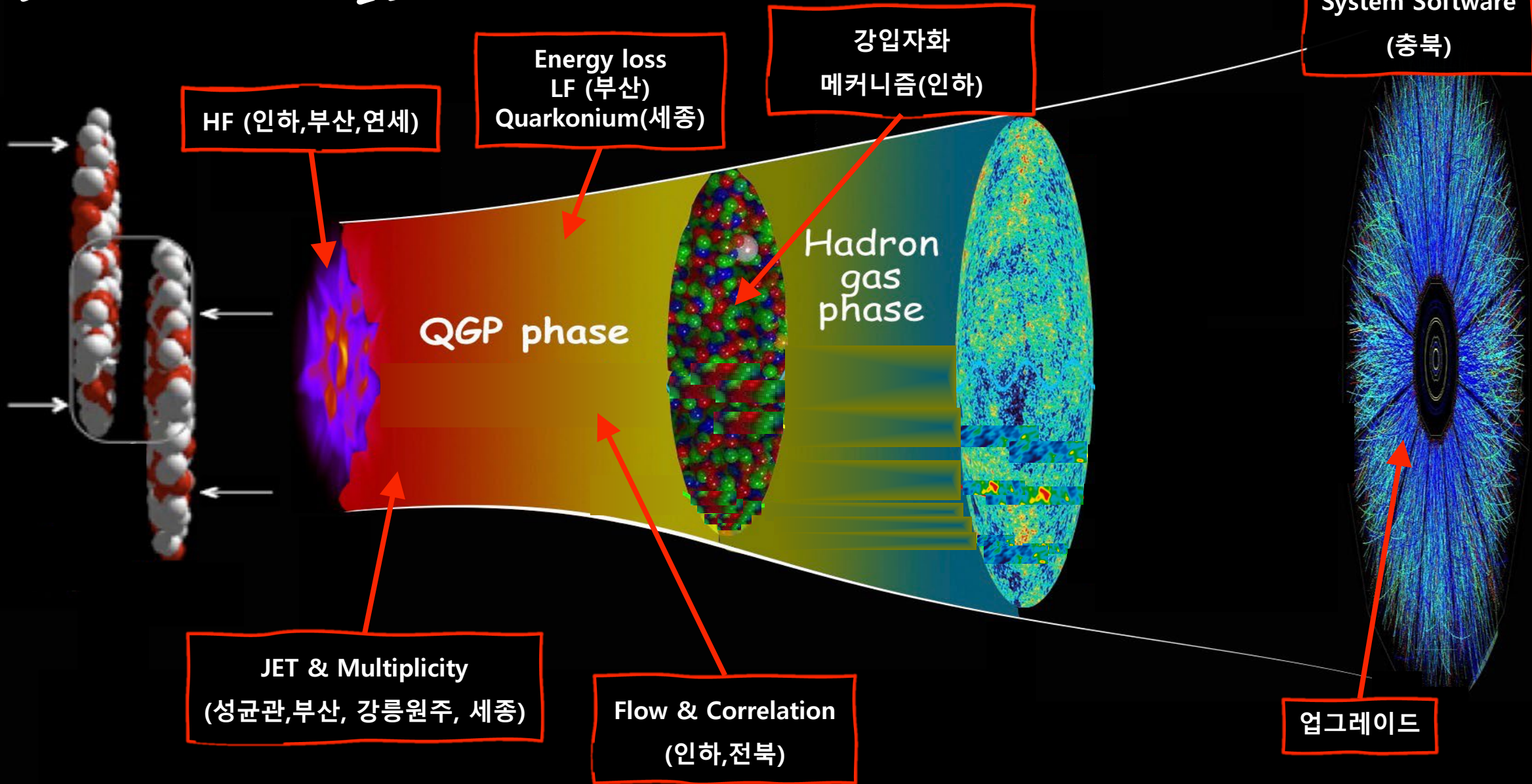
- 임계온도보다 높은 온도에서는 쿼크와 글루온이 속박되지 않고 자유롭게 존재할 수 있다.

→ QGP

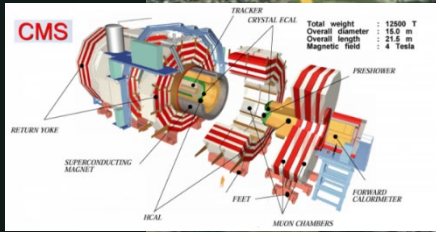
- 초기 우주에서 빅뱅 이후 물질이 형성되는 동안 거쳤을 상태
- Almost Perfect fluid!



짧은 시간 작은 공간에서 물질의 상호작용은?



100m under the ground
27 km in circumference





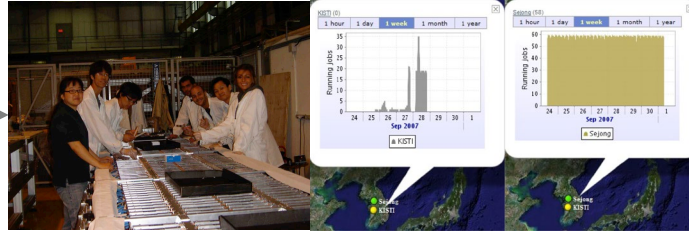
39 countries 175 institute 1934 researchers
korea ~2.5%

HISTORY



2000, DWKim with Ministry

2000

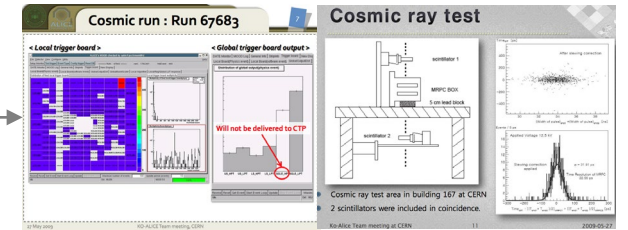


TOF Super Module + KISTI-T2 & Sejong T3

2005

2007

2009



Cosmic - MTR Monitoring + RPC test
1st Paper (NIM)

2010

DWKim, SYKim, MoST at CERN



ITS Upgrade



ALICE-Upgrade Funding

Visits

Minister of education, science and technology for the Republic of Korea, **Lee Ju-Ho**, centre left, visited the ALICE surface exhibit at CERN on 22 September with **Jurgen Schukraft**, ALICE spokesperson, far right, and **In-Kwon Yoo**, Korean contact physicist for the ALICE experiment and professor at Pusan University, centre right. The Korean party also toured the CMS control centre.



22 September

Minister CERN Visit

RUN3 ongoing

2022

2017

2013

2012

2011

한센협력
10주년 기념

KIAF(2011)
KISTI-T1(2012)



KSHEP@P on(Inha University)

1st MoU for M&O in 2002

ALICE COLLABORATION - MoU for M&O

CERN-RRB-2002-034

The European Organization for Nuclear Research (CERN)

and

Korea Science and Engineering Foundation

declare that they agree on the present Memorandum of Understanding for the ALICE Experiment.

Done in Geneva

on 25/10/2006

For CERN



Prof. Jos Engelen
Chief Scientific Officer

Di

or

For KOSEF



Dr. Eom, Cheon Il
Program Director, Nano-technology
and International S&T Program

Republic of Korea	Kangnung	University of Lisbon	
	Pohang	Kangnung National University	D. W. Kim
Romania	Bucharest	Pohang Accelerator Laboratory	J. Choi
		National Institute for Physics and Nuclear Engineering	M. Petrovici

MoU for Cooperation between CERN & Korea in 2006

ICA-KR-0096

COOPERATION AGREEMENT

between

THE EUROPEAN ORGANIZATION FOR NUCLEAR
RESEARCH

and

THE GOVERNMENT OF THE REPUBLIC OF KOREA

concerning

THE FURTHER DEVELOPMENT OF SCIENTIFIC
AND TECHNICAL COOPERATION IN
HIGH-ENERGY PHYSICS

IN WITNESS WHEREOF, the undersigned, being duly authorized by the respective Parties, have signed this Agreement.

Done in duplicate at Geneva on 25 October 2006 in the Korean and English languages, both texts being equally authentic.

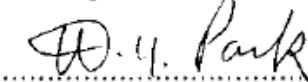
For the European Organization
for Nuclear Research



.....

Robert AYMAR
Director-General

For the Government of
the Republic of Korea



.....

Won-hwa PARK
Korean Ambassador in Bern

2006

MoU for Participation as a Collaboration in 2009

ALICE COLLABORATION CERN-RRB-2009-009

Addendum No. 15

to the Memorandum of Understanding for Collaboration in the Construction of the ALICE Detector

Definition of the Contributions of the Republic of Korea

Considering that:

The ALICE Experiment is covered by a Memorandum of Understanding (MoU) setting out the responsibilities of the different participating Institutes and Funding Agencies for the construction of the ALICE detector¹;

Participation of the Korean Team in the construction of the ALICE detector was formalized in an Addendum² to the MoU (MoU Addendum);

The composition of the Korean Team in ALICE and its supporting Funding Agency has changed.

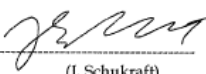
It is agreed as follows:

¹ Memorandum of Understanding for Collaboration in the Construction of the ALICE Detector, ALICE RRB-D 00-41.

² Addendum no. 8 to the ALICE Memorandum of Understanding, CERN-RRB-2006-073, 5 October 2006

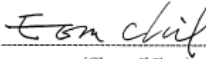
ALICE COLLABORATION CERN-RRB-2009-009

For the ALICE Collaboration




(J. Schukraft)
Spokesperson

For
KICOS




(Cheon Il Eom)
Chairman

For Kangnung National University



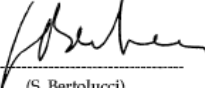
(Jinsook Kim)
Researcher

For Sejong University



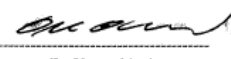
(Seyong Kim)
Professor

For CERN



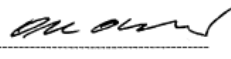
(S. Bertolucci)
Chief Scientific Officer

For the Korean
ALICE Team



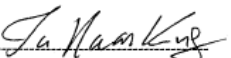
(In-Kwon Yoo)
Team Leader

For Pusan National University



(In-Kwon Yoo)
Professor

For Yonsei University



(Ju-Hwan Kang)
Professor

Participation of additional institutes

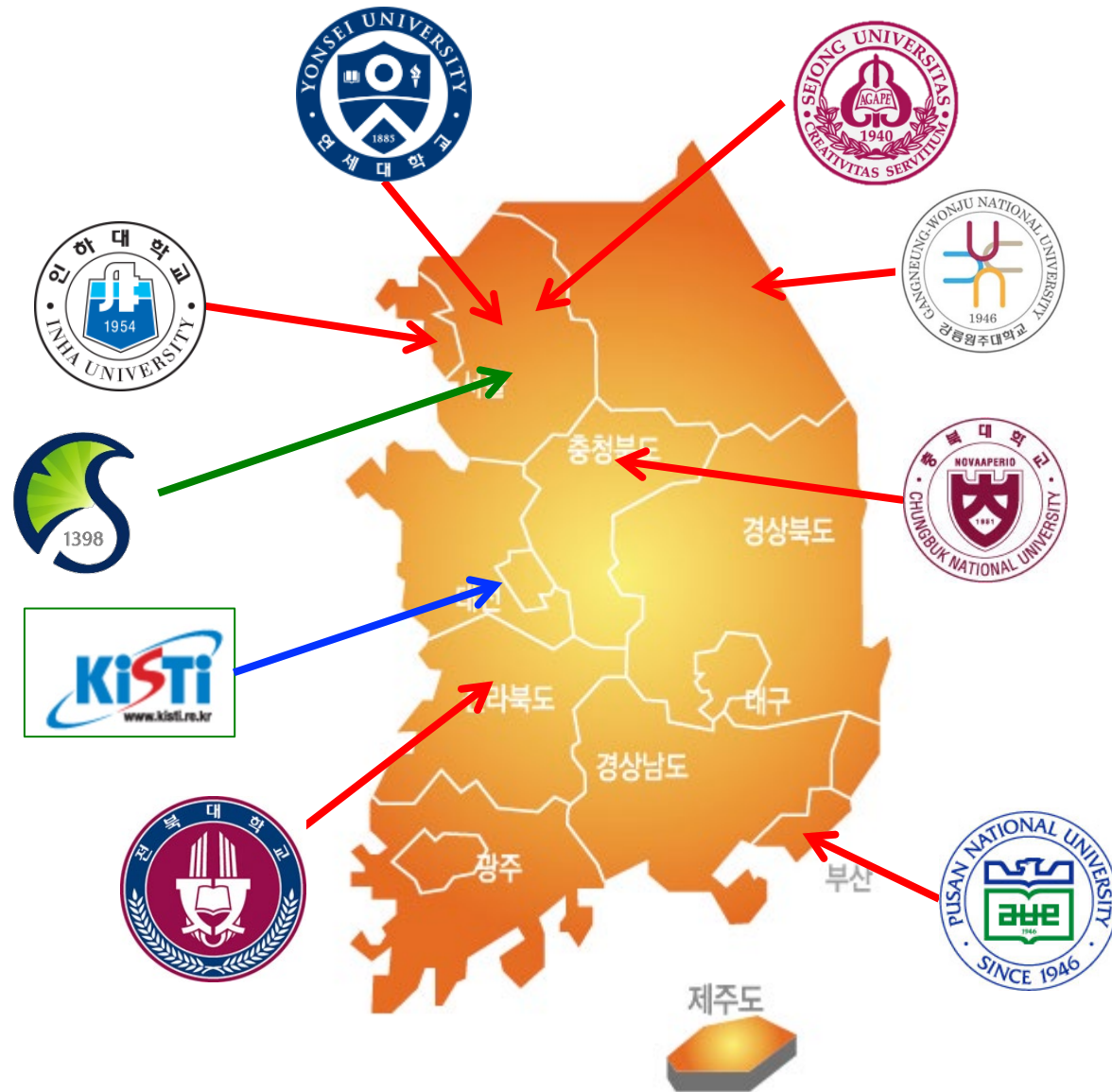
✓ Besides ITS

- MFT : 30kCHF(in kind) (ALICE-MoU-Add #39)
+ 33,618 CHF (chip series test) (ALICE-MoU-Add #40)

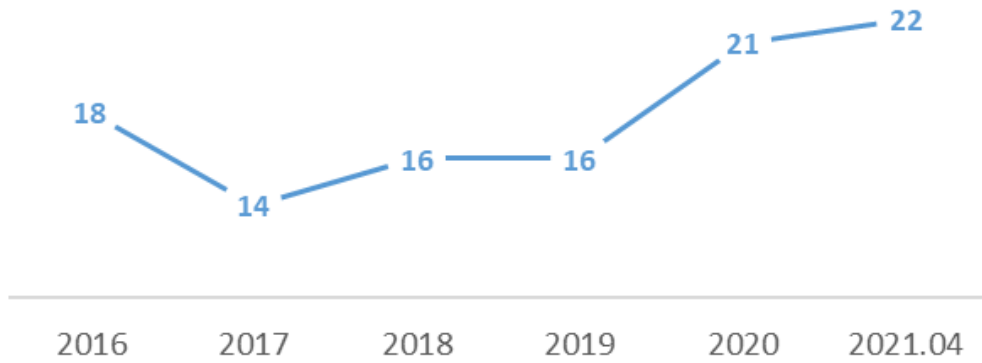
✓ 기관가입

- KISTI(2010/2012)
- 인하대(2013) (ALICE-MoU-Add #30)
- 전북대(2016) (ALICE-MoU-Add #49)
- 충북대(2019)
- 성균관대(2021)

✓ 총 52명 (교수/박사급/대학원생/기타=10/9/31/2)

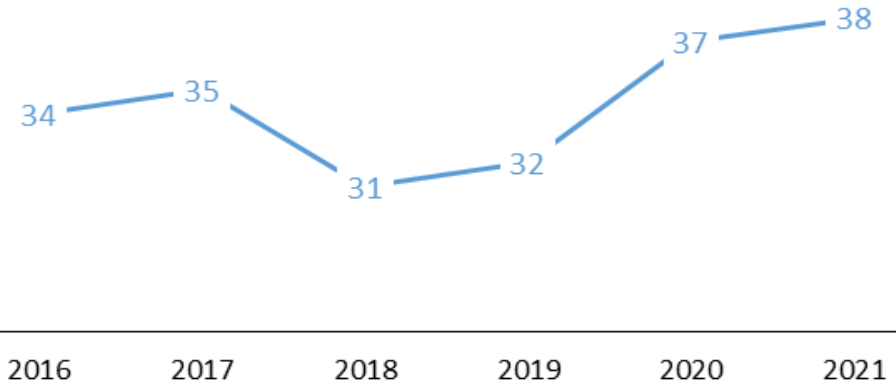


년도별 학생수 추이(10월 기준)



now 31 Grad. Students

참여인력 변화



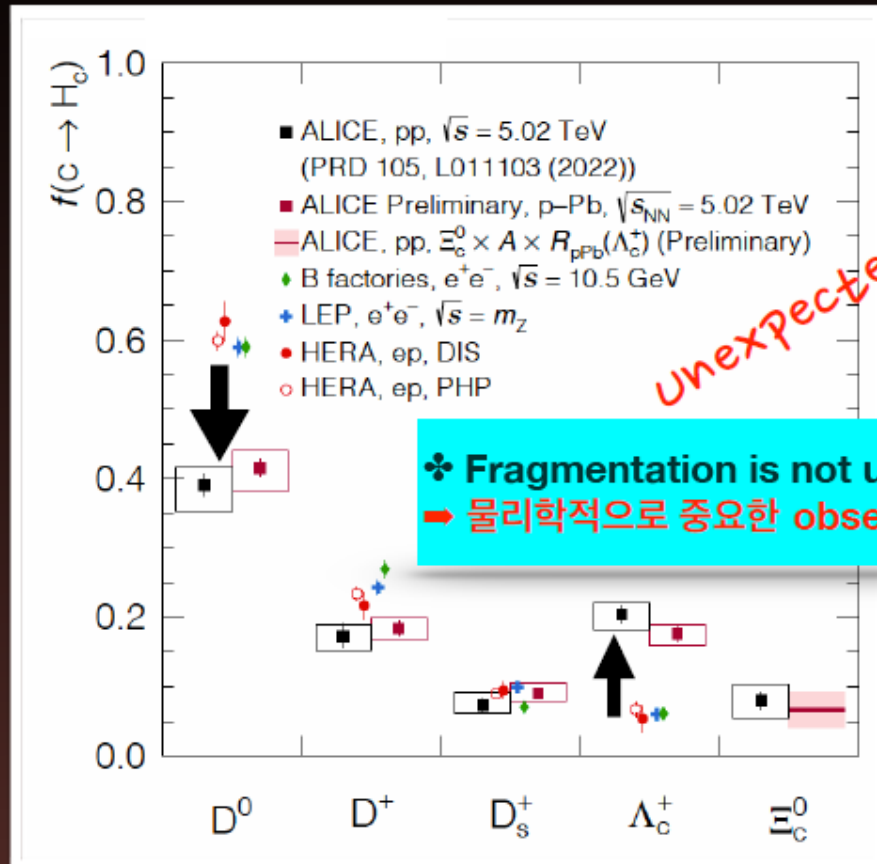
now 52 Participants

KoALICE National Workshop 2021

2022. 1. 4(Tue) ~ 7(Fri) High1 Roesort KoALICE / KISTI



KoALICE 5단계 대표업적



- ❖ 5 단계: 주저자 논문 총 6편
- ❖ 박사급 연구자 비율 = $15/1031 = 1.5\%$
- ❖ 3년 간 주저자 논문비율 = $6/105 = 5.7\%$



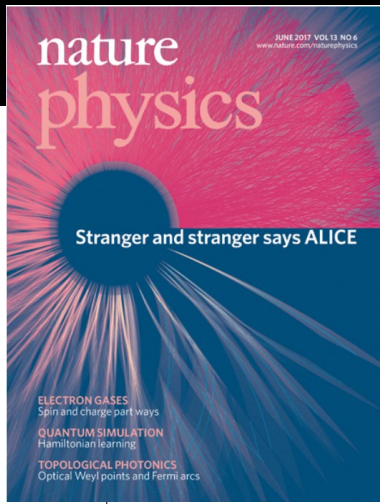
- ❖ 국내에서 ITS2 모든 칩 테스트.
(칩테스트 머신 국내제작: 2020년 ALICE 기업체 award)

- ❖ 모듈 어셈블리
- ❖ Thinning & dicing
- ❖ Wire bonding
- ❖ Probe card 국내 제작

➔ 국내에 반도체 검출기 제작 기반 마련

- ❖ ALICE 공동 논문 리뷰 커미티 및 데이터 분석 리뷰 커미티 활동 10건 이상
ex. 박사과정 서진주 학생 논문 리뷰 커미티 참여

➔ 대학원생을 포함한 연구자들의 국제적 연구역량과 인지도가 강화됨



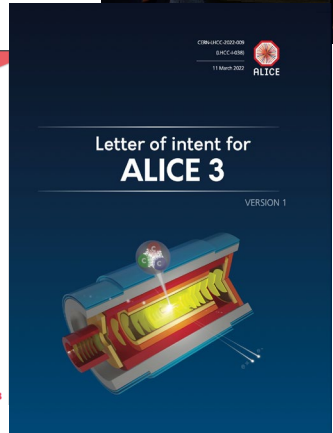
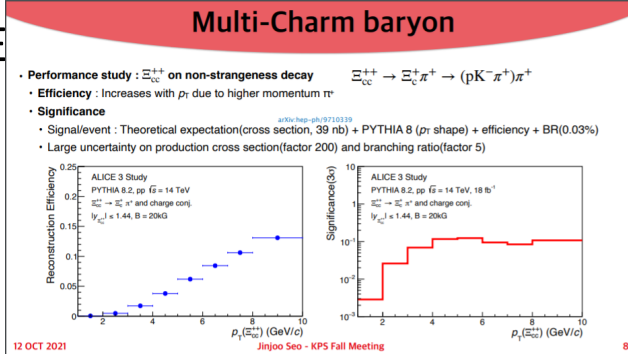
Accepted: 21 February 2022
 Published online: 18 May 2022
 Open access

Article Unveiling the strong interaction among hadrons at the LHC

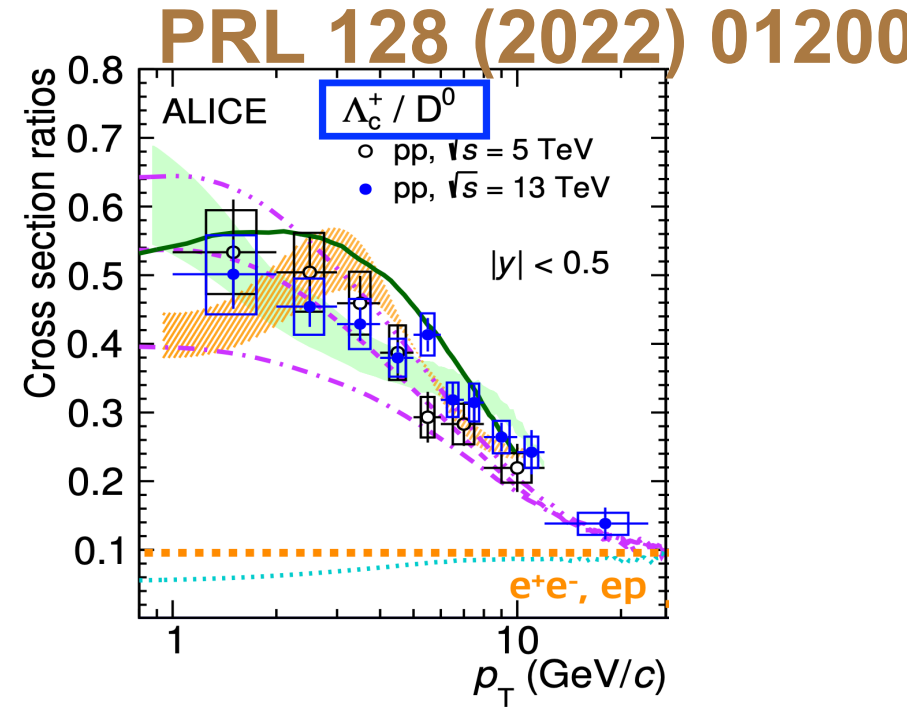
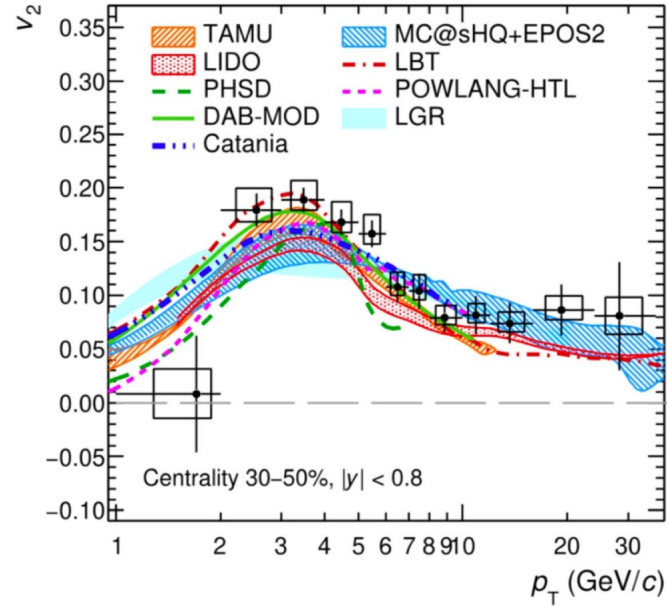
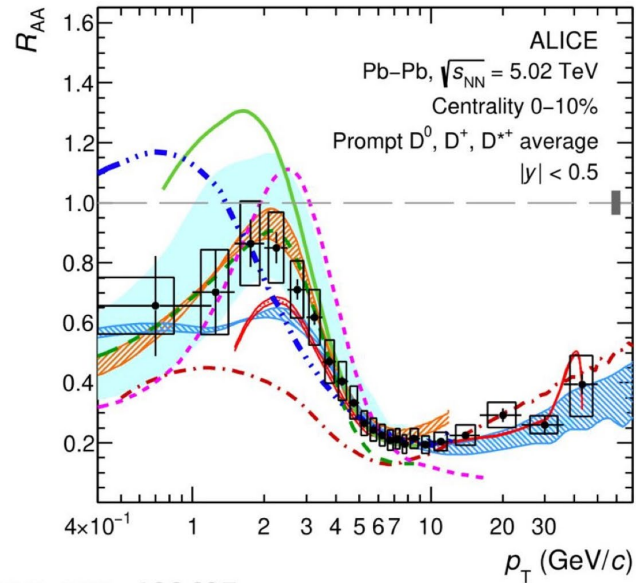
Observation of the dead-cone effect in chromodynamics

physics today is to understand from first between hadrons with different quark content. ing techniques that solve the dynamics of time lattices^{1,2}. Experimentally, the dynamics of ied by scattering hadrons off each other. Such r impossible for unstable hadrons³⁻⁶ and so for hadrons containing up and down quarks⁷. correlations in the momentum space between ivistic proton-proton collisions at the CERN a precise method with which to obtain the n dynamics between any pair of unstable ase of the interaction of baryons containing strate how, using precision measurements of the effect of the strong interaction for this

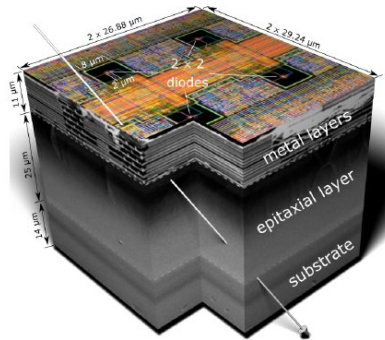
- ✓ 30~35 papers / year
- ✓ 2 NATURE papers (2020, 2021)
- ✓ 1 NATURE Physics (2017)
- ✓ 총 11명의 박사 + 32명의 석사 배출
- ✓ 대통령 근정포장(2021)
- ✓ 한국팀 분석결과가 ALICE
- ✓ 최우수 논문상(2021)



Observables



Schedule



**ITS2 : Mass Chip
Test & HIC Assembly**

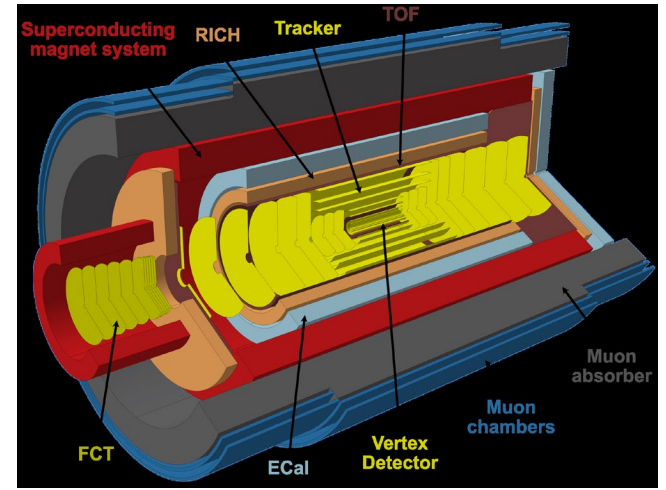
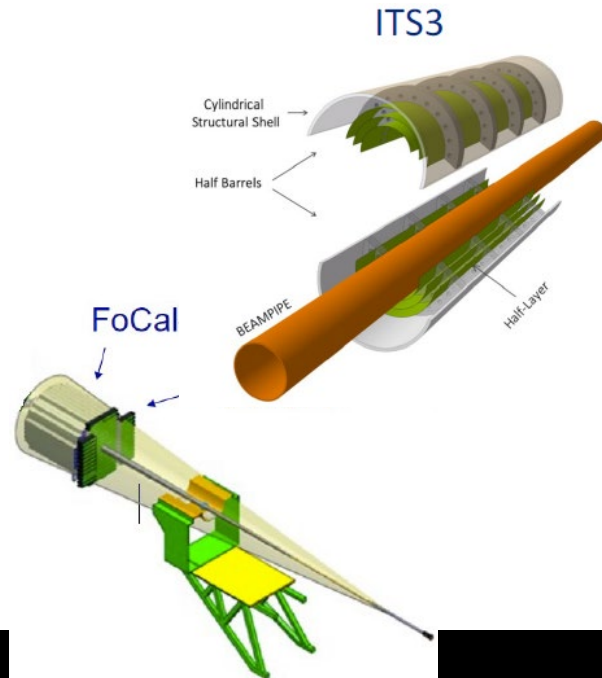
ITS3

ALICE3



2020 ALICE Industry Awards

The ALICE collaboration presents the
ALICE Industry Award 2020
to
C-ON Tech
NamdongGu Incheon, South Korea
in recognition of the exceptional
contribution to the development of a high-
precision automated system for the mass
production of visual inspection and electrical
test of the ALPIDE monolithic pixel sensor
and the extraordinary dedication of C-
ON Tech contributed to the successful
production of the ALICE Inner Tracking
System and Muon Forward Tracker.



- ✓ 낮은 운동량까지 측정 가능
- ✓ x3, x5 더 좋은 위치 분해능

6 layers:

2 hybrid silicon pixel
2 silicon drift
2 silicon strip

Inner-most layer:

radial distance: 39 mm
material: $X/X_0 = 1.14\%$
pitch: $50 \times 425 \mu\text{m}^2$

rate capability: 1 kHz

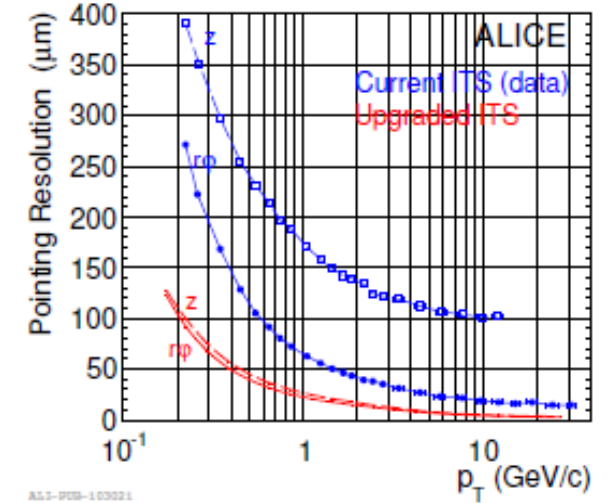
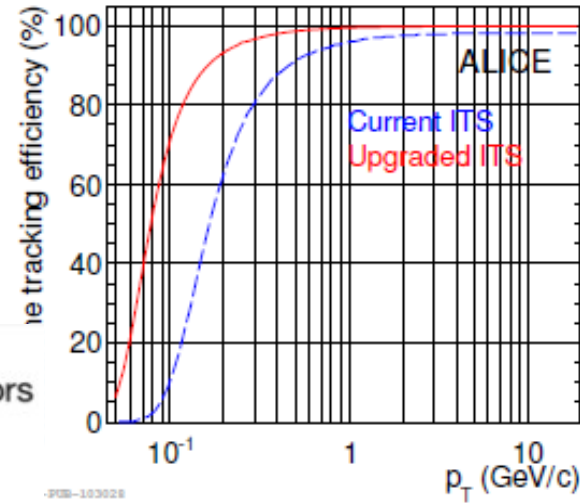
7 layers:

all Monolithic Active Pixel Sensors

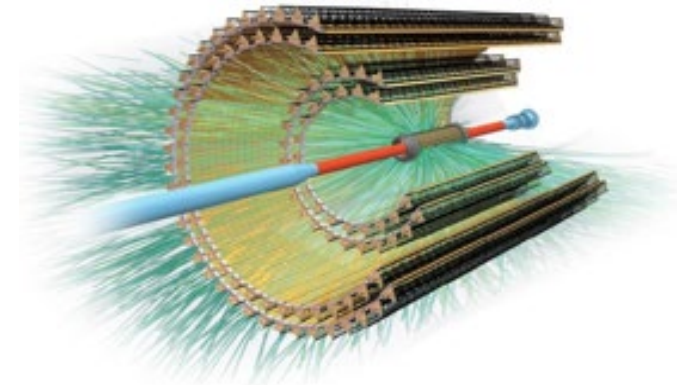
Inner-most layer:

radial distance: 23 mm
material: $X/X_0 = 0.3\%$
pitch: $O(30 \times 30 \mu\text{m}^2)$

rate capability: 100 kHz (Pb-Pb)



chip 5만개 전량 test 및 HIC assembly 1/5



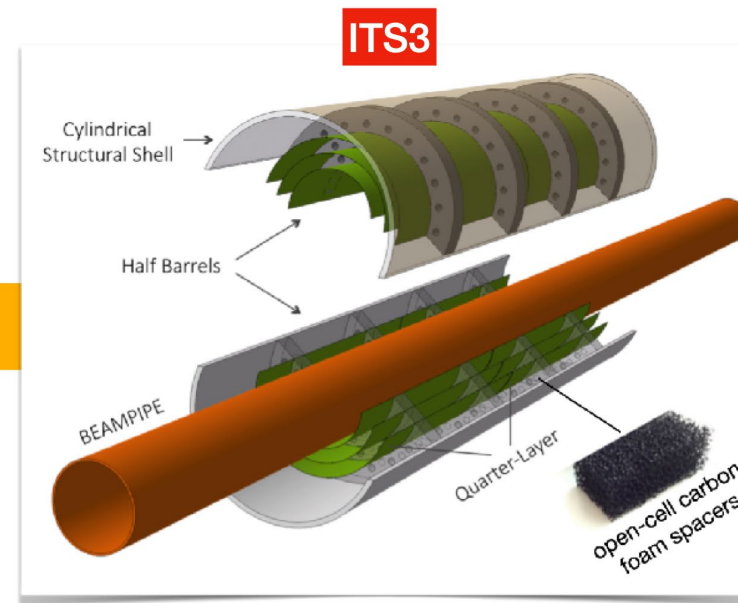
ITS3

in a nutshell

replace



by



in LS3

key improvements:

- closer to beam pipe: 23 → 18 mm
- less material: 0.3 → ~0.03 % X_0

main benefit:

- better tracking performance
- especially at low p_t

based on:

- wafer-scale (up to ~28x10 cm),
 - ultra-thin (20-40 μm),
 - bent ($R=18, 24, 30$ mm)
- Si sensors (MAPS)

Silicon Genesis: 20 μm thinned wafer



Korean Role in ITS3

- ✓ ITS2 화소 센서 설계
- ✓ 시뮬레이션을 통한 실리콘 센서 특성 연구
- ✓ 구부러진 칩의 빔테스트 데이터 분석
- ✓ KOMAC 빔테스트
- ✓ 구부러진 칩과 PCB의 wire bonding (together with MEMSPACK)
- ✓ 검출기 시스템 소프트웨어 개발
- ✓ 하이테크 기술의 국내이전 및 중소기업의 세계 시장 진출 협력

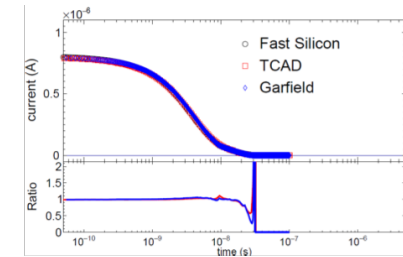
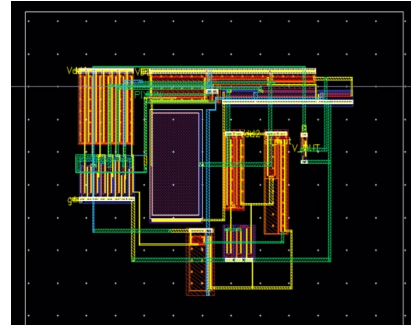
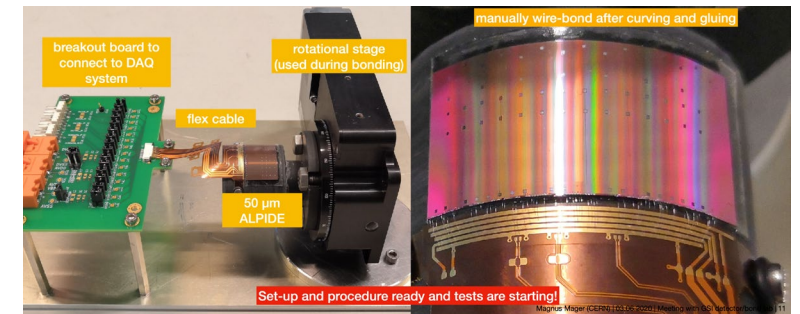


Fig. 9. Total currents in the FSD Simulation, TCAD and Garfield++. The bottom panel shows ratios of the currents in the upper panel. The red (blue) solid line in the ratio plot indicates I_{TCAD}/I_{FSD} ($I_{Garfield++}/I_{FSD}$).



✓ Beyond Run 4

- Still remained the fundamental questions open:
- Fundamental QGP properties driving its constituents to equilibration?
- Hadronization mechanisms of the QGP?
- Partonic equation of state and its temperature dependence?
- Underlying dynamics of chiral symmetry restoration?

✓ Next-generation heavy-ion exp.

- First ideas at Heavy-Ion town meeting 2018 (arXiv:1902.01211) → Letter of Intent for ALICE 3:
- Review concluded with very positive feedback by the LHCC in March 2022,
- and recommended to proceed with R&D (CERN-LHCC-2022-009)



✓ Experimental challenges

- *Compact, ultra-lightweight all-silicon tracker*

$$\rightarrow \sigma_{p_T}/p_T \approx 1\sim 2\%$$

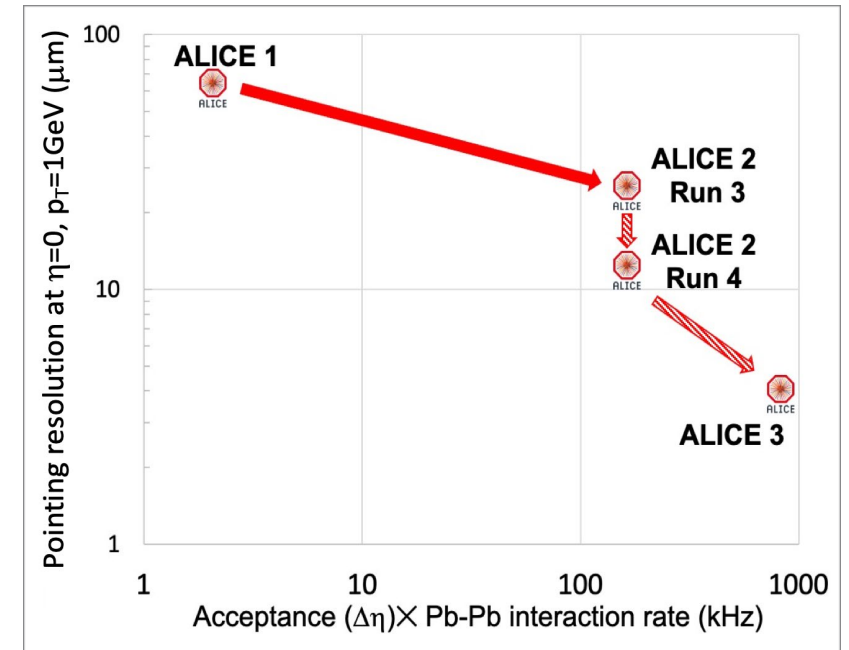
- Vertex detector with unprecedented pointing resolution \rightarrow

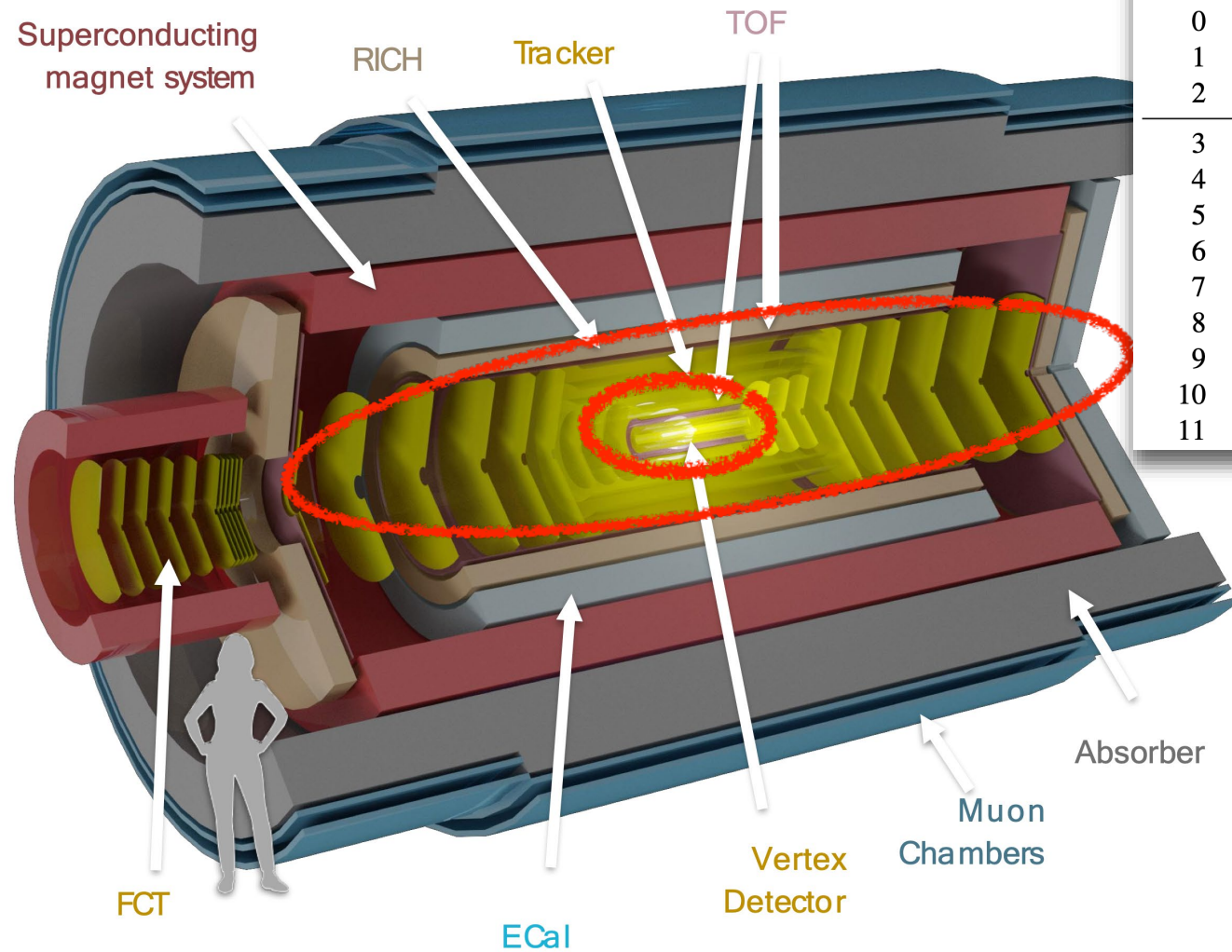
$$\sigma_{\text{DCA}} \approx 10 \mu\text{m} \text{ (} p_T = 200 \text{ MeV)}$$

- Particle Identification over large acceptance ($-4 < \eta < 4$) $\rightarrow \gamma, e^\pm, \mu^\pm, K^\pm, \pi^\pm$

- Continuous read-out and online processing

\rightarrow Detector with *unique and unprecedented* features at the LHC

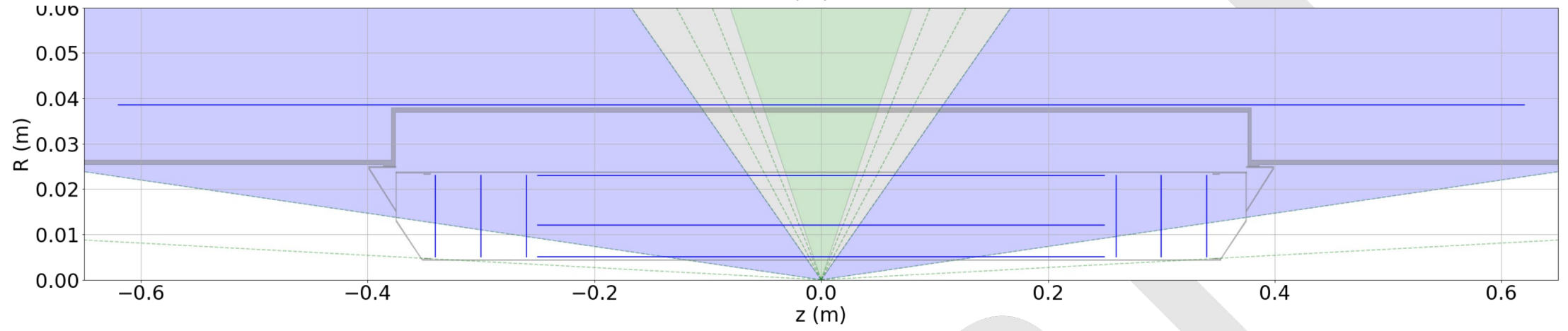
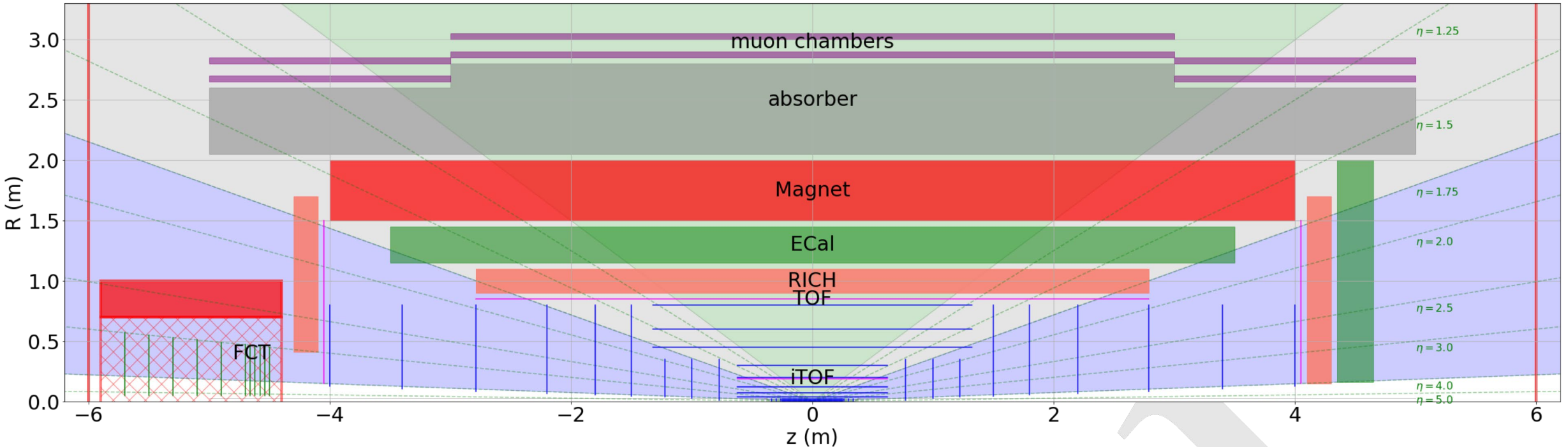




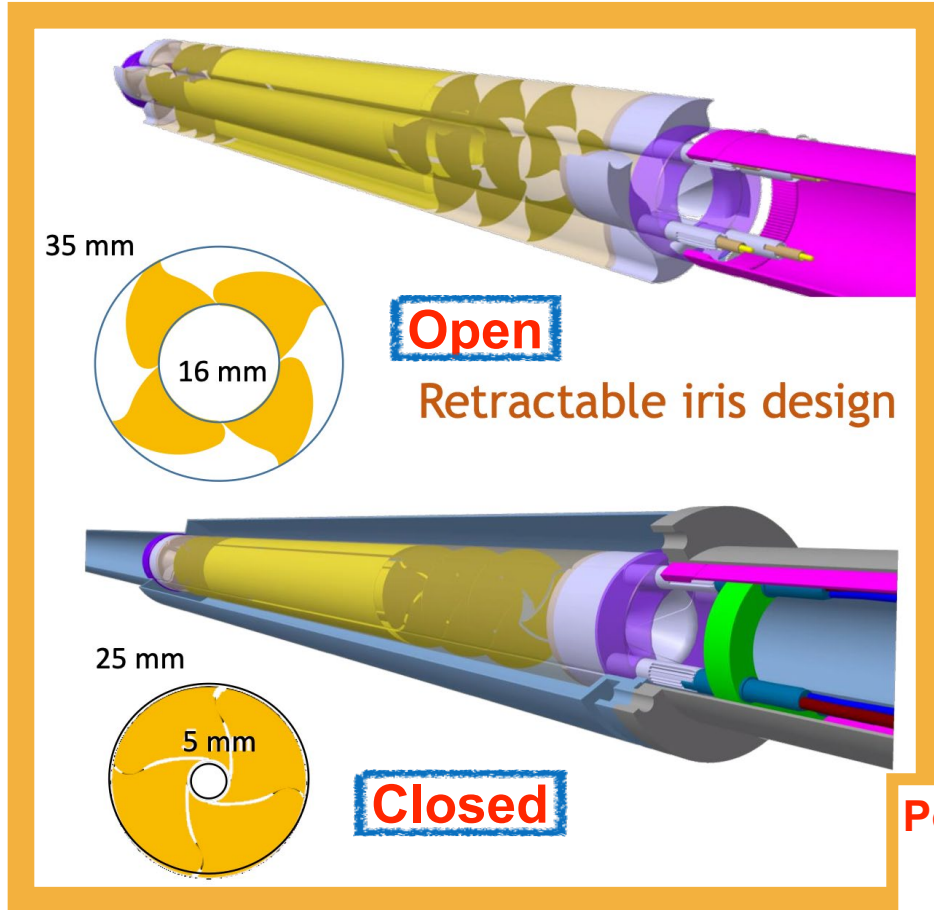
Layer	Material thickness (% X_0)	Intrinsic resolution (μm)	Barrel layers		Forward discs		
			Length ($\pm z$) (cm)	Radius (r) (cm)	Position ($ z $) (cm)	R_{in} (cm)	R_{out} (cm)
0	0.1	2.5	50	0.50	26	0.005	3
1	0.1	2.5	50	1.20	30	0.005	3
2	0.1	2.5	50	2.50	34	0.005	3
3	1	10	124	3.75	77	0.05	35
4	1	10	124	7	100	0.05	35
5	1	10	124	12	122	0.05	35
6	1	10	124	20	150	0.05	80
7	1	10	124	30	180	0.05	80
8	1	10	264	45	220	0.05	80
9	1	10	264	60	279	0.05	80
10	1	10	264	80	340	0.05	80
11	1				400	0.05	80

Schematic View of ALICE 3

ALICE 3 overview



Vertex Detector



Conceptual study of iris tracker

Wafer-size, ultra-thin, curved, CMOS Active Pixel Sensor

→ **Ultimate performance (same for ITS 3)**

First layer at mid-rapidity: 5 mm from the beam

→ **Inside beam pipe, retractable configuration**

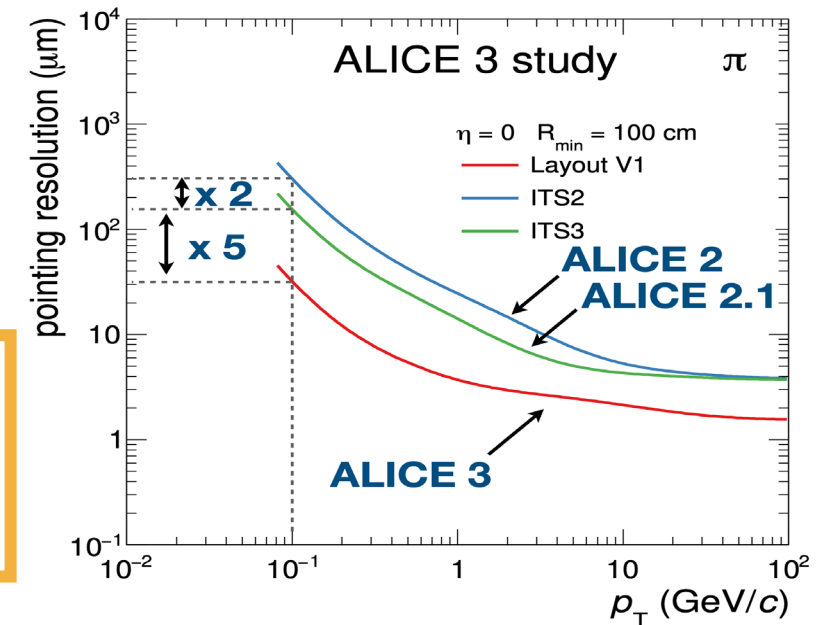
Unprecedented spatial resolution: $\sigma_{\text{pos}} \approx 2.5 \mu\text{m}$

Extremely low material budget 1‰ X_0 per layer

Pointing resolution

$\sim 10 \mu\text{m}$ at $p_T = 200 \text{ MeV}/c$

$\sim 2 \mu\text{m}$ at high p_T



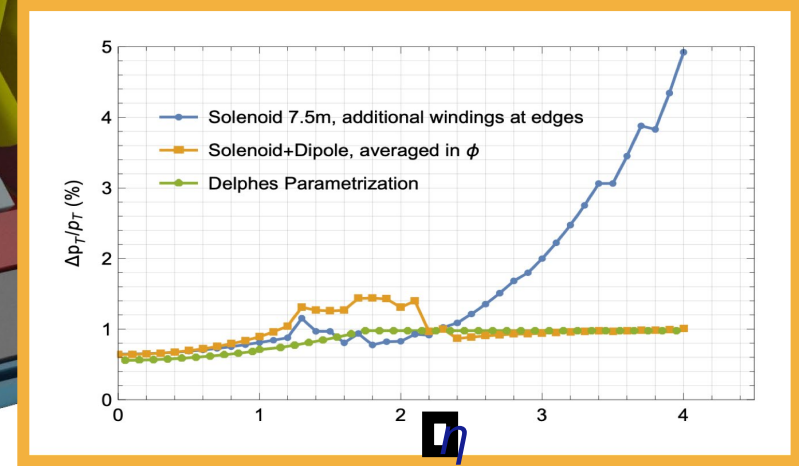
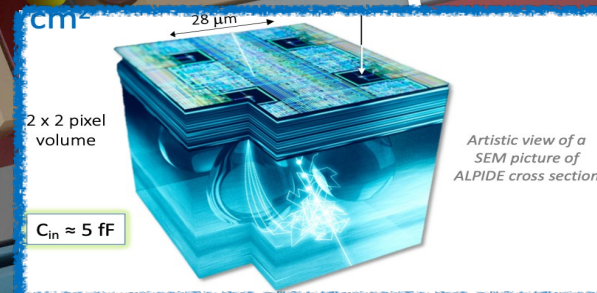
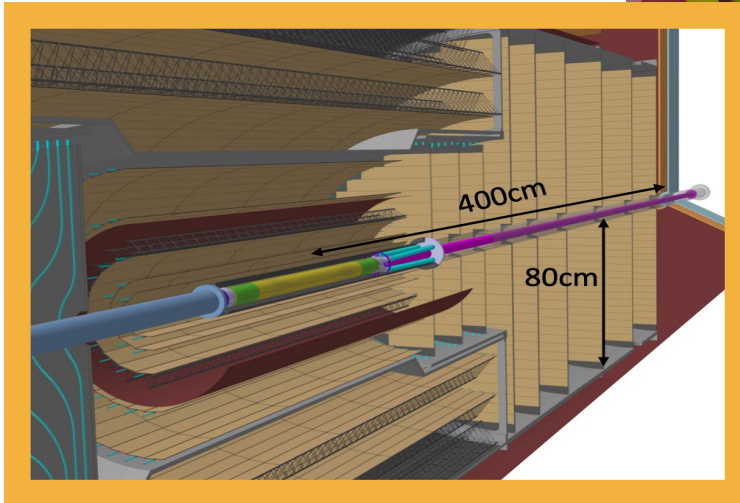
Large Acceptance Tracker

60 m² silicon pixel detector
based on CMOS Active Pixel Sensor technology
8 + 2 x 9 tracking layers (barrel + disks)

- Compact: $r_{out} \approx 80$ cm, $z_{out} \approx \pm 4$ m
- Large coverage: $\pm 4\eta$
- High-spatial resolution: $\sigma_{pos} \approx 5$ μm (req. < 10 μm)
- Timing resolution ~ 100 ns
- Very low material budget
 - 1% X_0 per layer overall $\rightarrow X/X_0(\text{total}) \lesssim 10$ %
- Low power: ≈ 20 mW/cm²

Relative p_T resolution

- $\sim 1\%$ over large acceptance
- integrated magnetic field crucial (2T)
- overall material budget critical



Build on experience with ITS 2 and ITS 3 (same CMOS process)
10 m² \rightarrow 60 m²: challenges on industrialisation

Particle ID from ToF

Separation power $\propto L/\sigma_{\text{TOF}}$

→ Distance and time resolution crucial

→ Larger radius results in lower p_T bound

2 barrel TOF layers ($|\eta| < 1.75$)

Outer TOF at $r \approx 85$ cm, surface: 30 m², pitch: 5 mm

Inner TOF at $r \approx 19$ cm, surface: 1.5 m², pitch: 1 mm

1 forward TOF layers ($1.75 < |\eta| < 4$)

Inner radius = 15 cm, outer radius = 150 cm,

$z \approx 405$ cm, surface: 14 m², pitch: 1mm to 5 mm

$$\sigma_{\text{TOF}} \lesssim 20\text{ps}$$

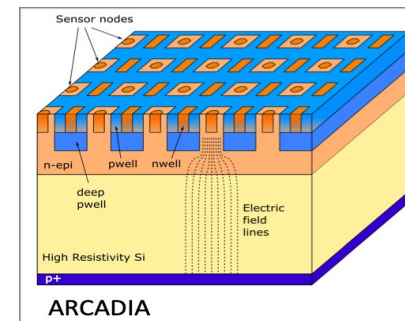
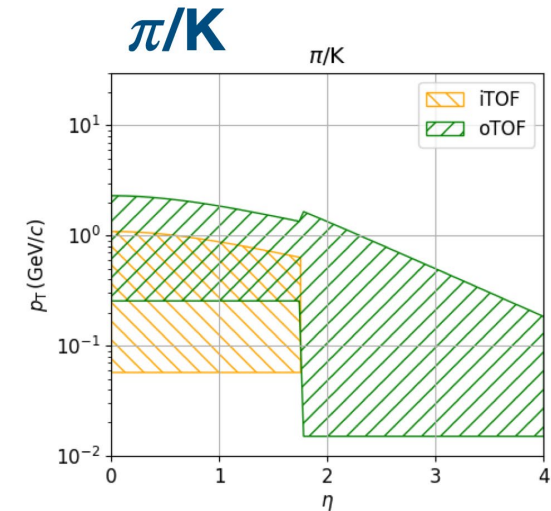
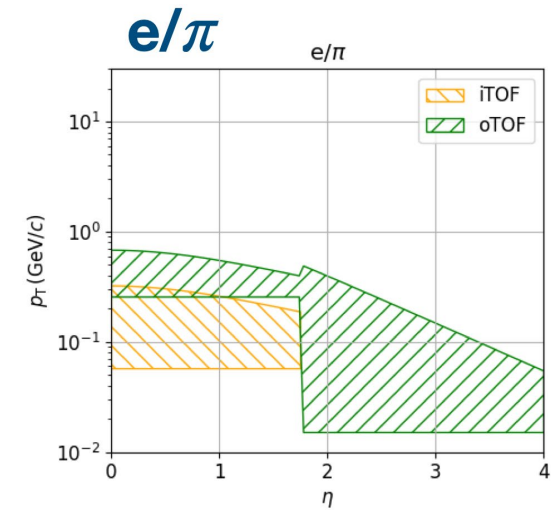
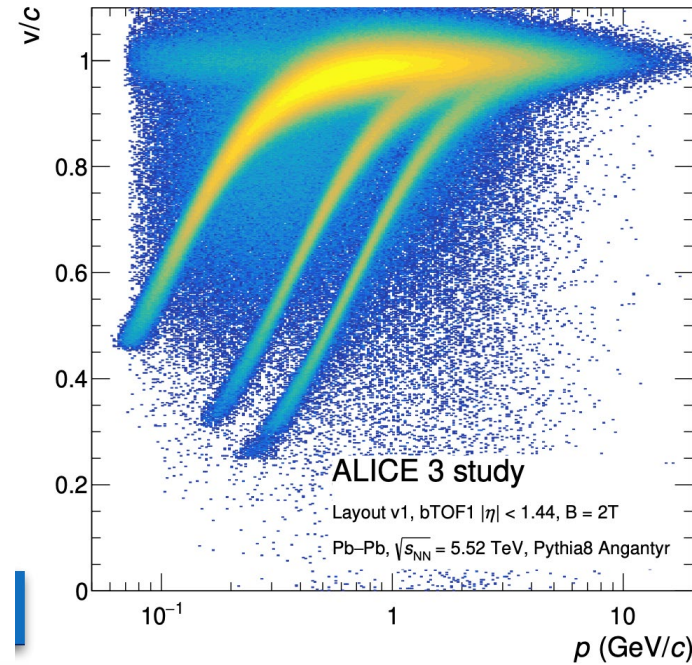
Silicon timing sensors

CMOS sensor with gain (baseline)

- R&D on monolithic CMOS sensors with integrated gain layers

Conventional LGADs (fallback)

- R&D with very thin sensors



PID from RICH

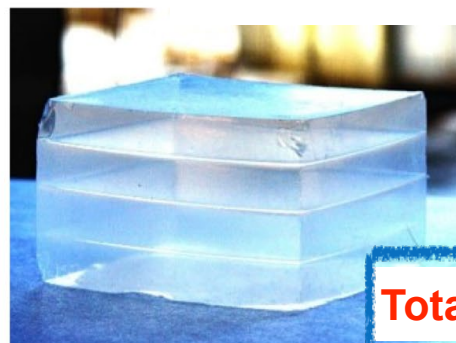
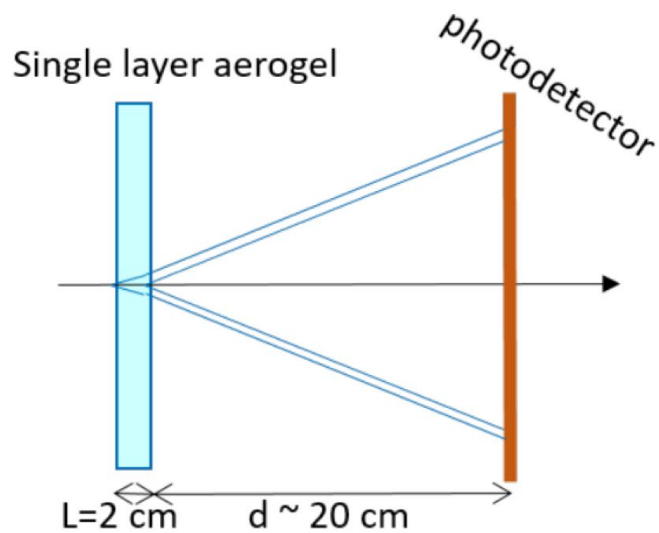
Complement PID reach of outer TOF to higher p_T with Cherenkov detector

→ Ensure continuous coverage with the TOF

Aerogel radiator

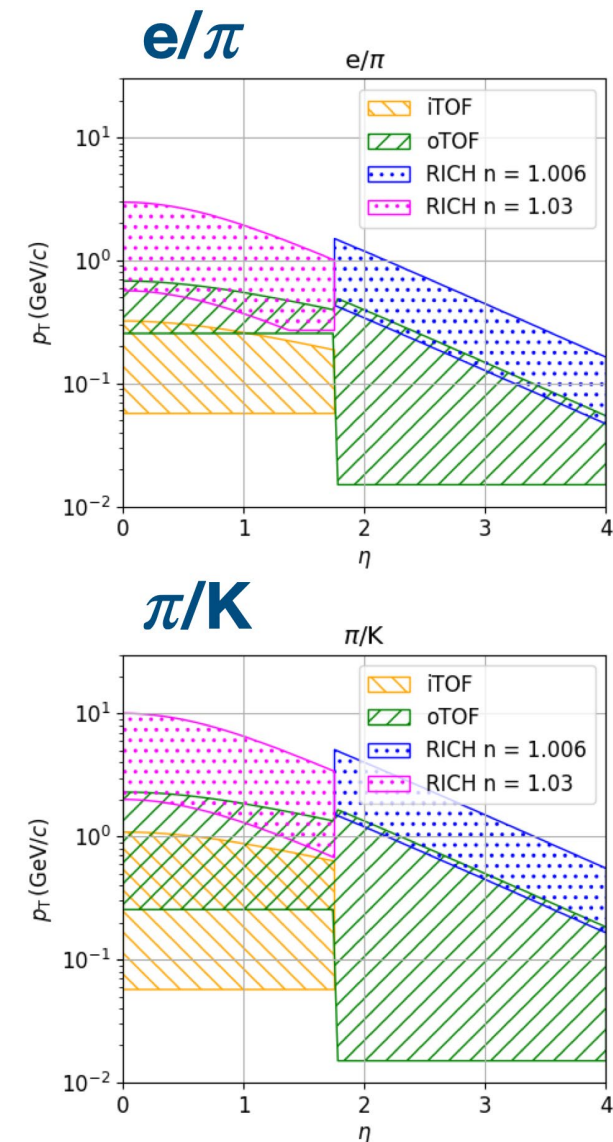
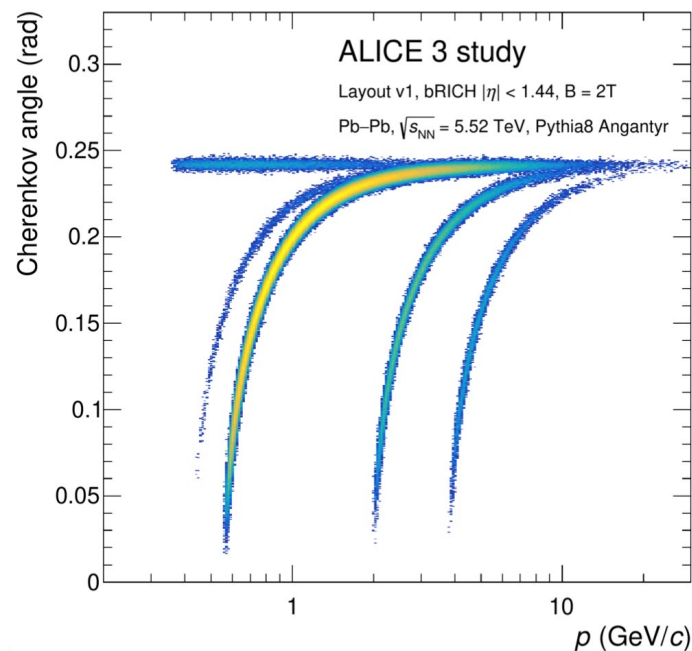
- Refractive index $n = 1.03$ (barrel)
- Refractive index $n = 1.006$ (forward)

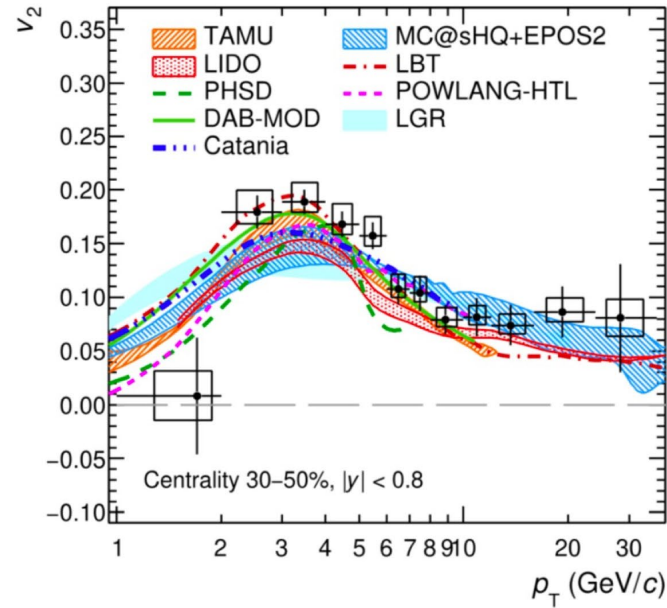
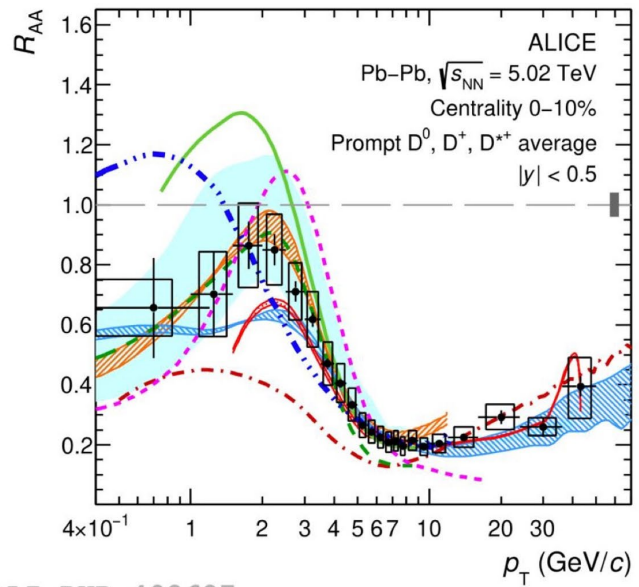
R&D on monolithic silicon photon sensors



aerogel radiator

Total SiPM area ~ 60 m²





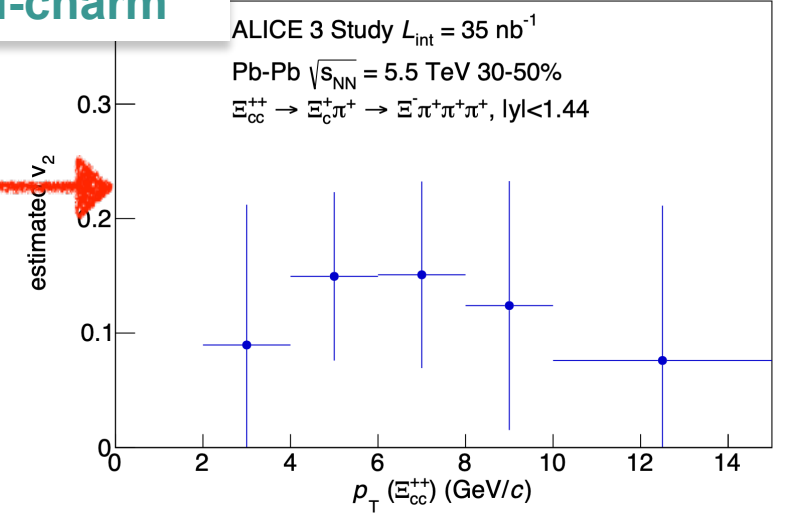
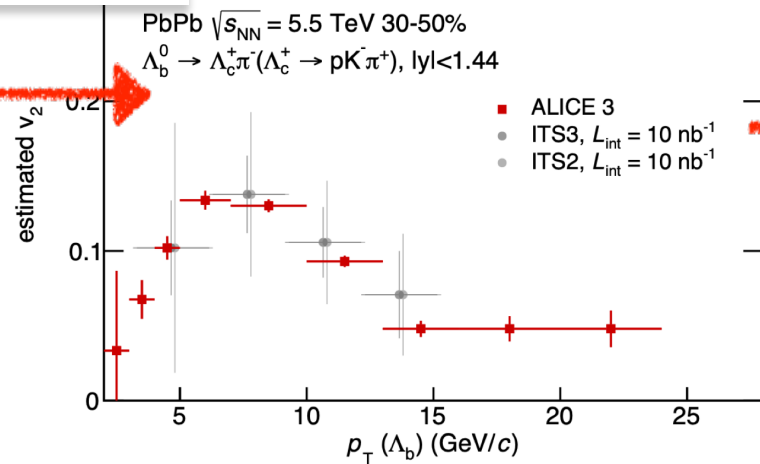
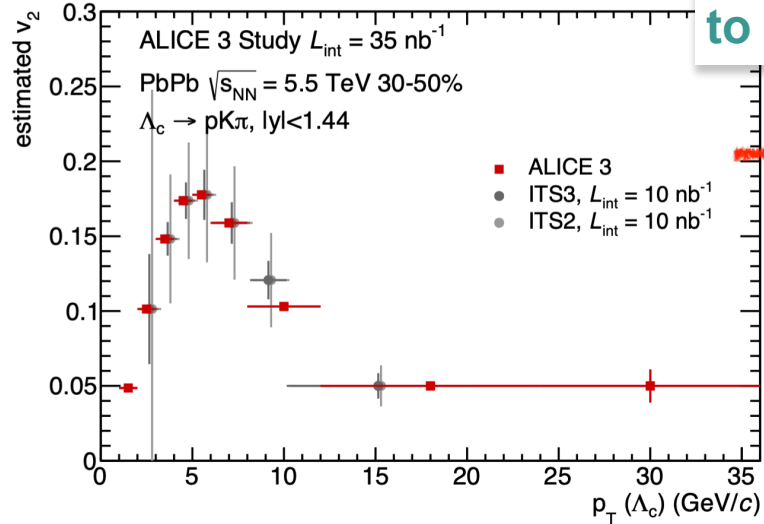
ALI-PUB-498687

Λ_c v_2 performance

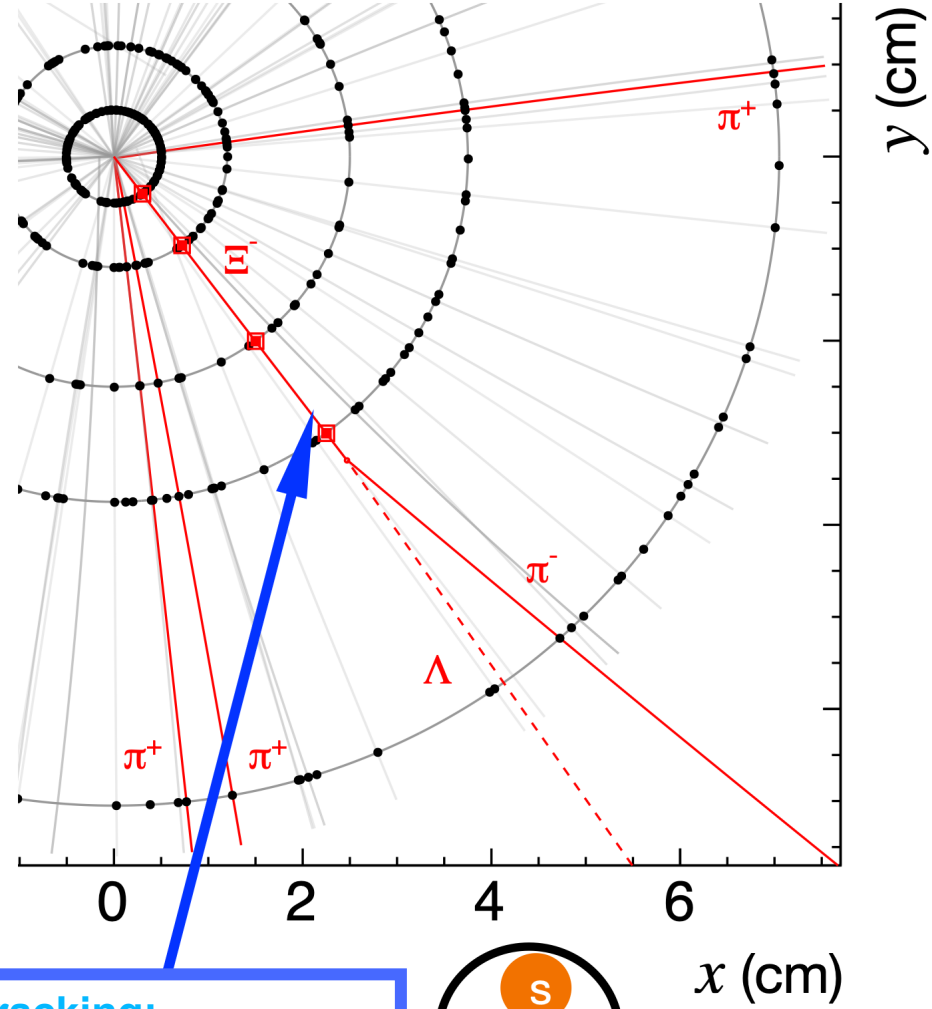
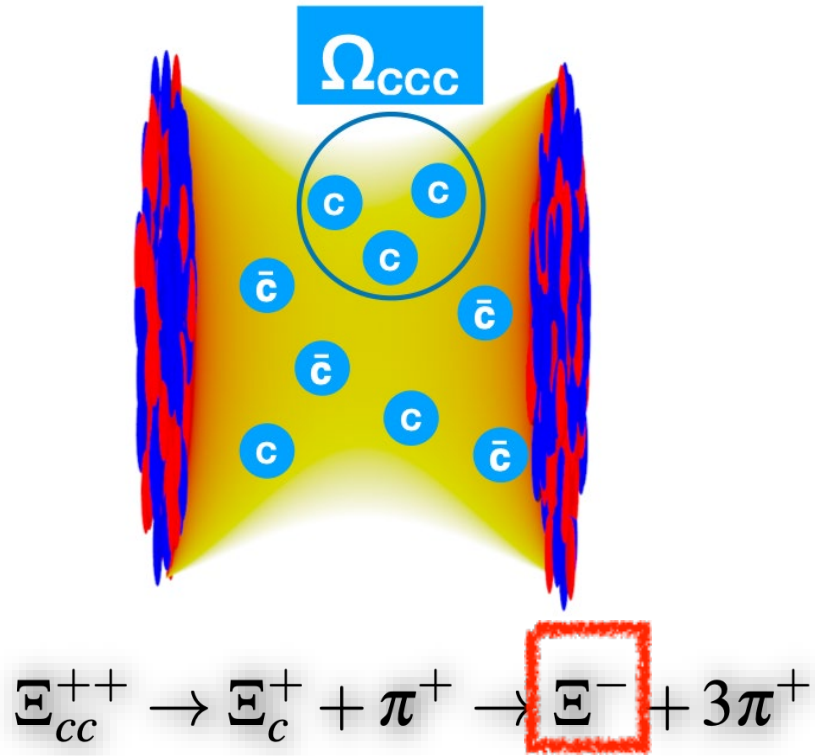
Extension to beauty

Λ_b v_2 performance

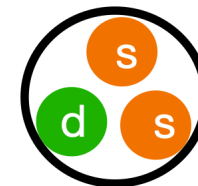
Extension to multi-charm



Multicharm hadrons



Strangeness tracking:
tracking directly non-prompt Ξ^-
decaying from Ξ_{cc}^+



Thank you!

“This is impossible.”

Alice

“Only if you
believe it.”

The Mad Hatter



Goalcast