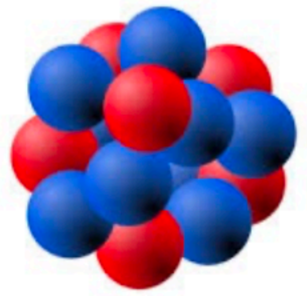
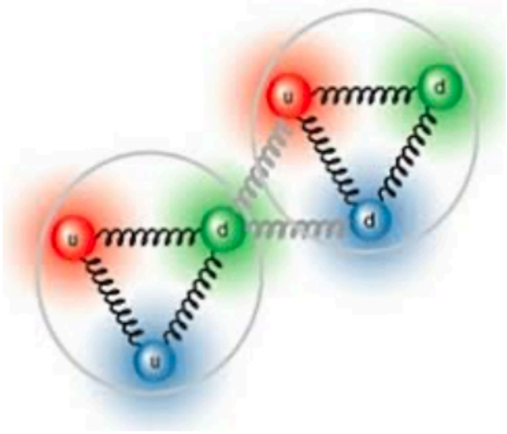
Track of Korean ALICE Team and Future of KoALICE

Bong-Hwi Lim (University of Torino) on behalf of Korean ALICE Team
Special lecture for introducing CERN
16/01/2023

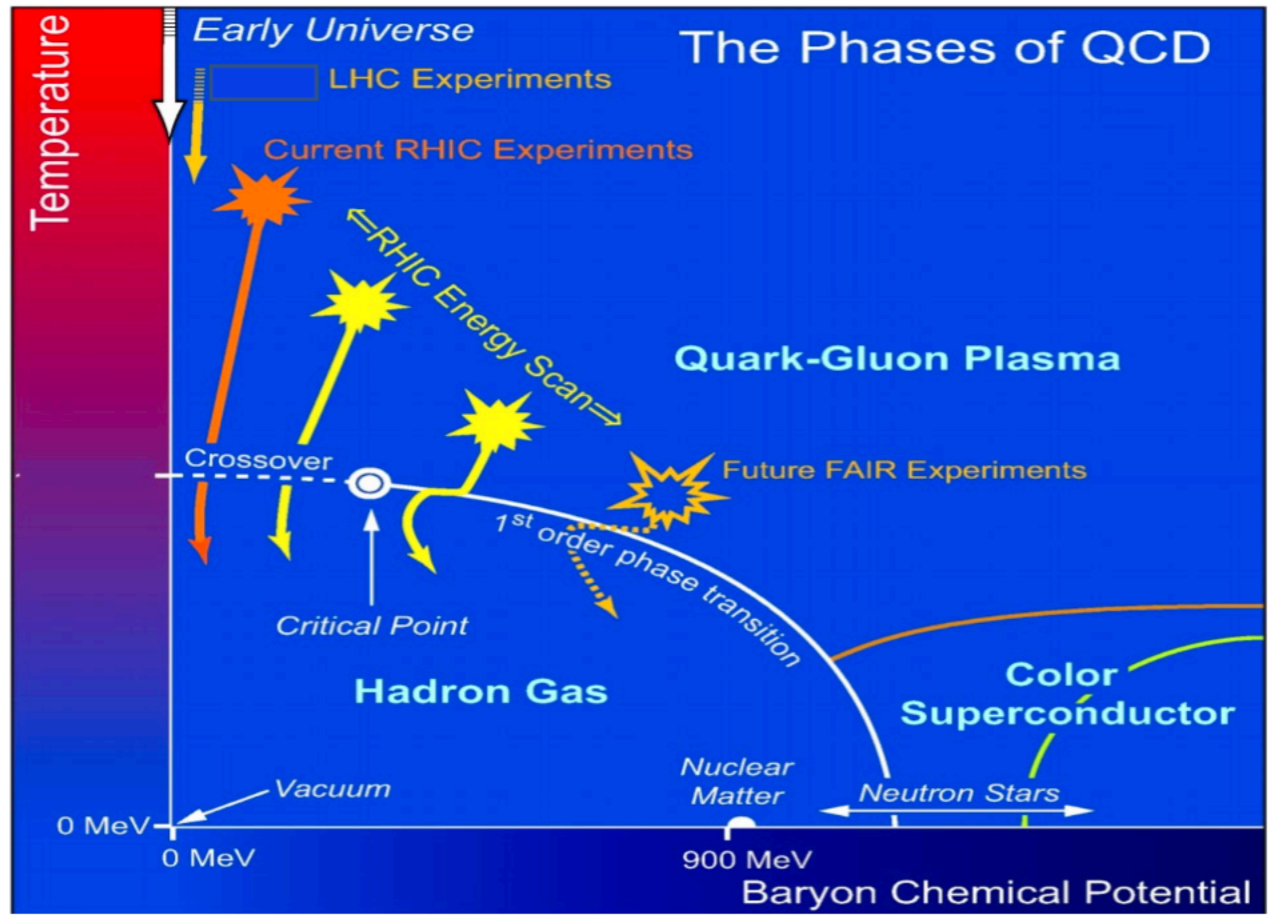
Nuclear Physics?

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





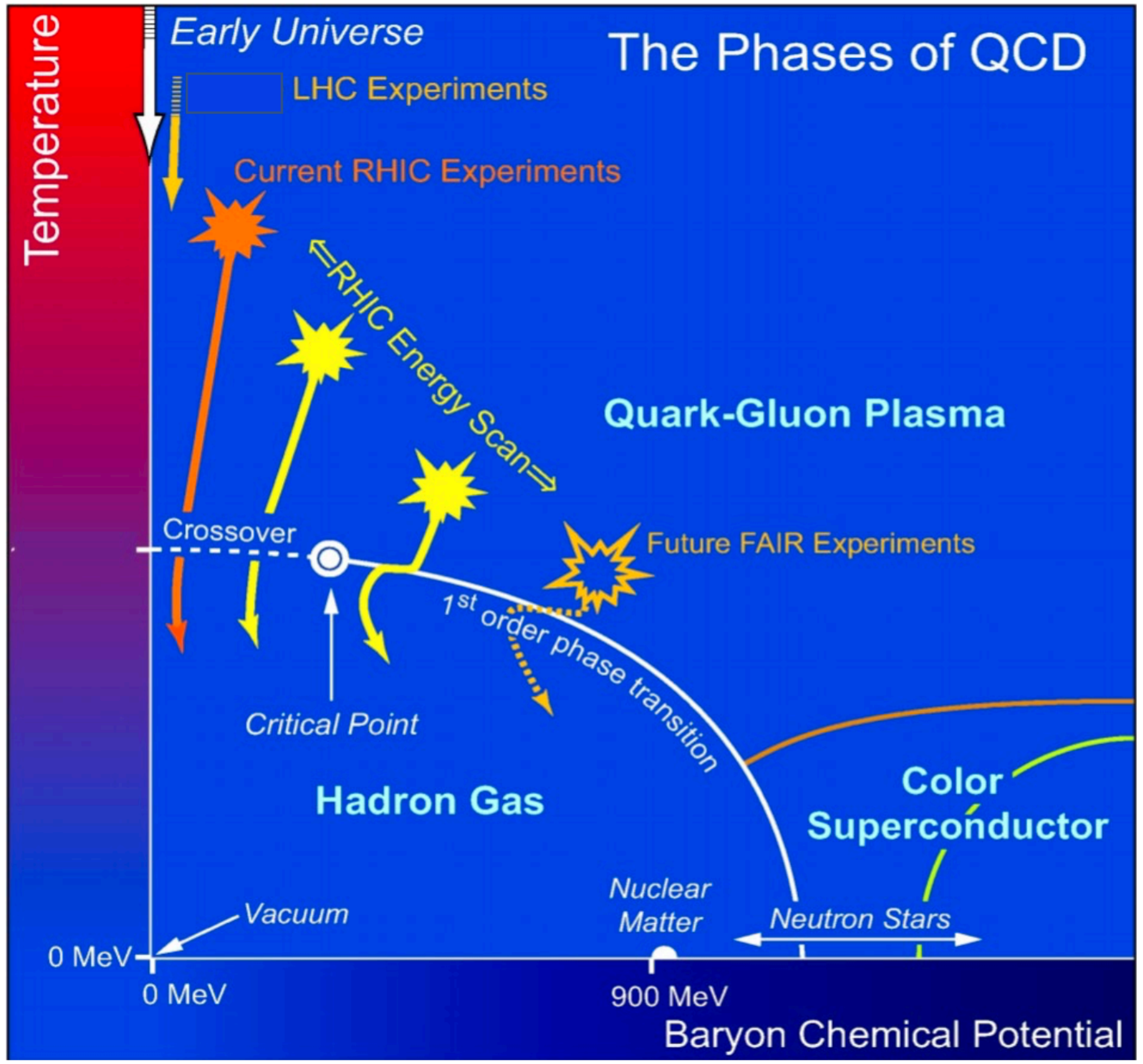
- ✓ **Bulk ← *INTERACTION***
- ✓ **bulk behavior, collective features, phase diagram, etc.**



Phase Transition and QGP

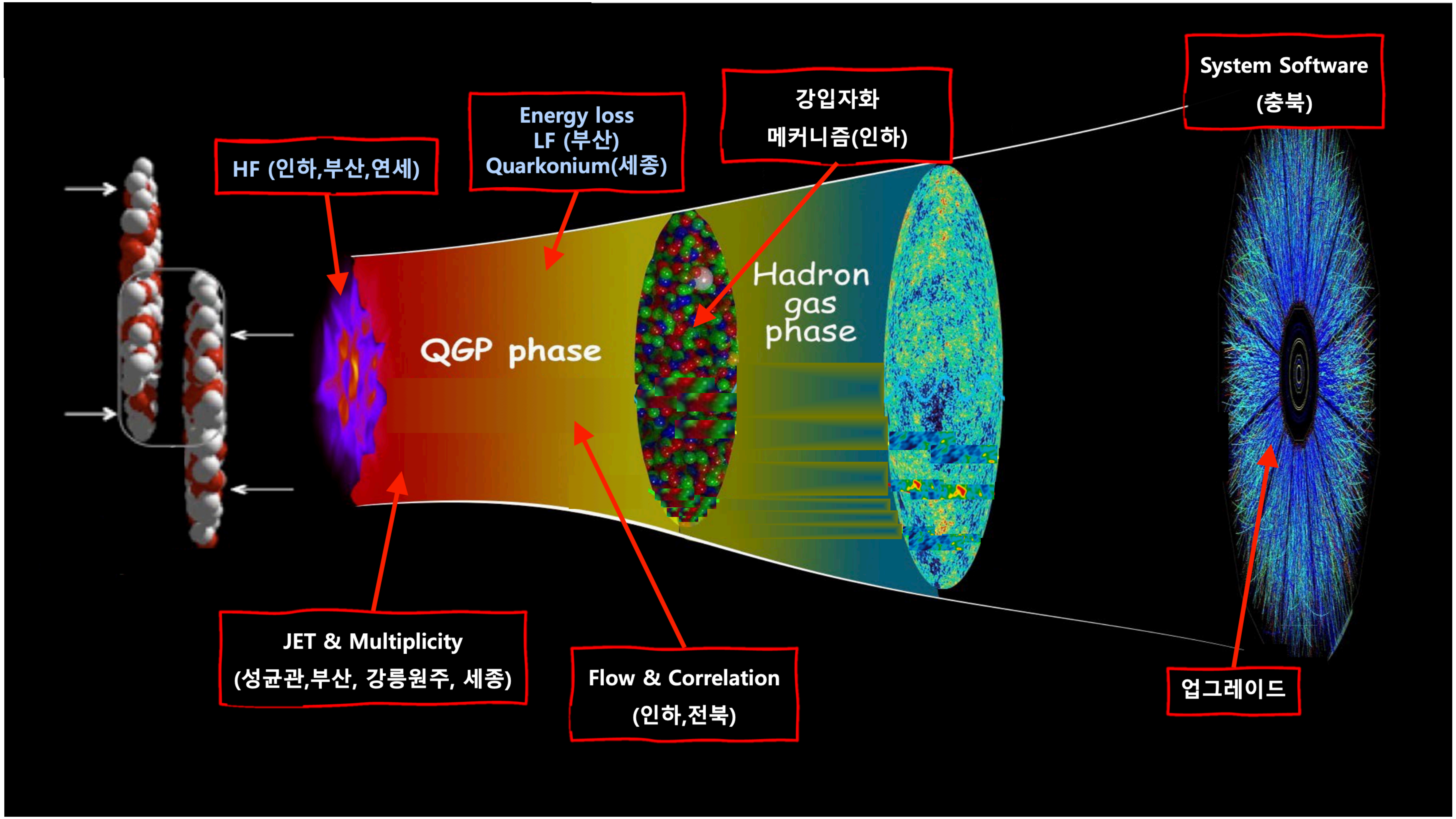
- ✓ **우주 초기 물질에서 현재까지**
  - 임계온도보다 높은 온도에서는 쿼크와 글루온이 속박되지 않고 자유롭게 존재할 수 있다.

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

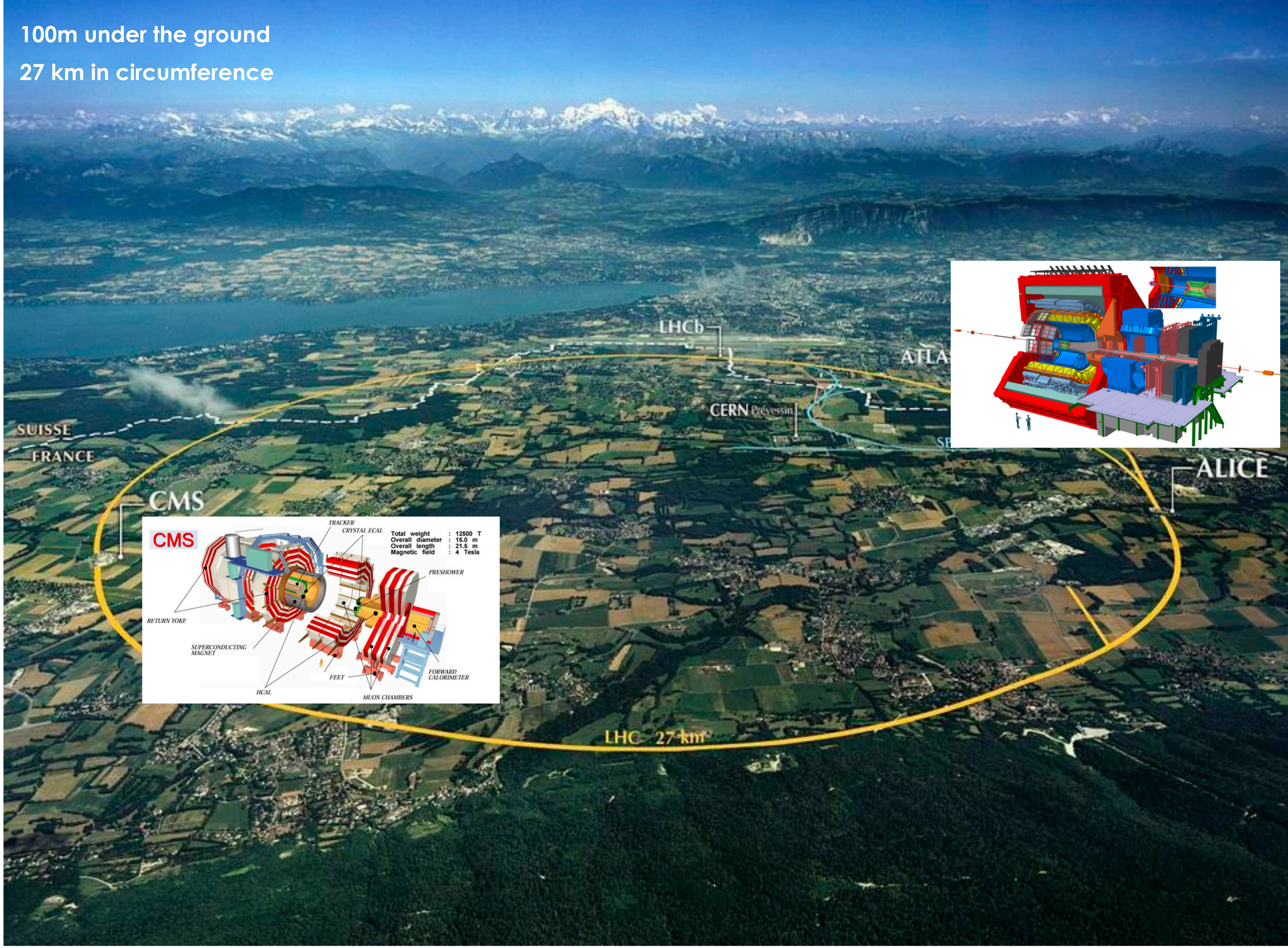


PoS(LATTICE2014, 392)

짧은 시간 작은 공간에서 물질의 상호작용은?



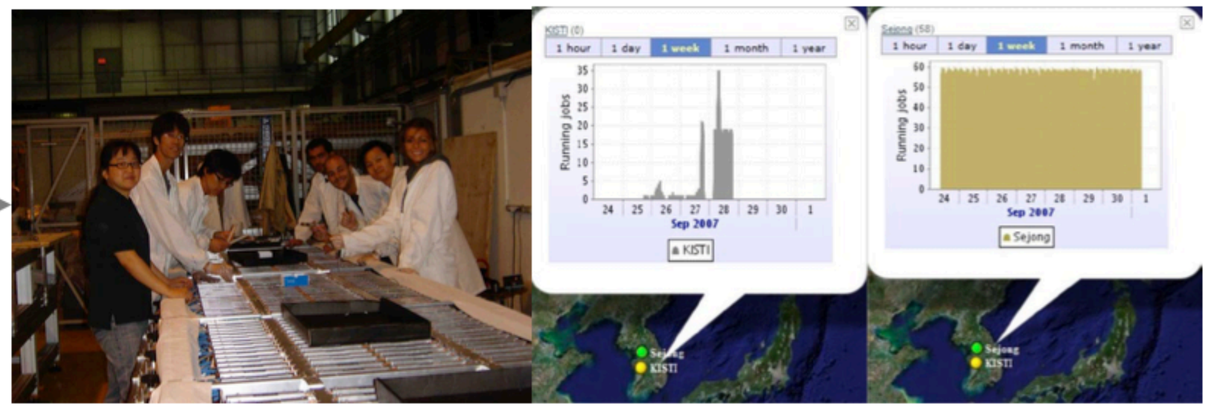
CERN


100m under the ground
27 km in circumference
SUISSE
FRANCE
CMS
LHCb
CERN Prévessin
ALICE
LHC 27 km
CMS
TRACKER
CRYSTAL ECAL
Total weight : 12500 T
Overall diameter : 15.0 m
Overall length : 21.5 m
Magnetic field : 4 Tesla
PRESHOWER
RETURN YOKE
SUPERCONDUCTING MAGNET
FEET
FORWARD CALORIMETER
HCAL
MUON CHAMBERS

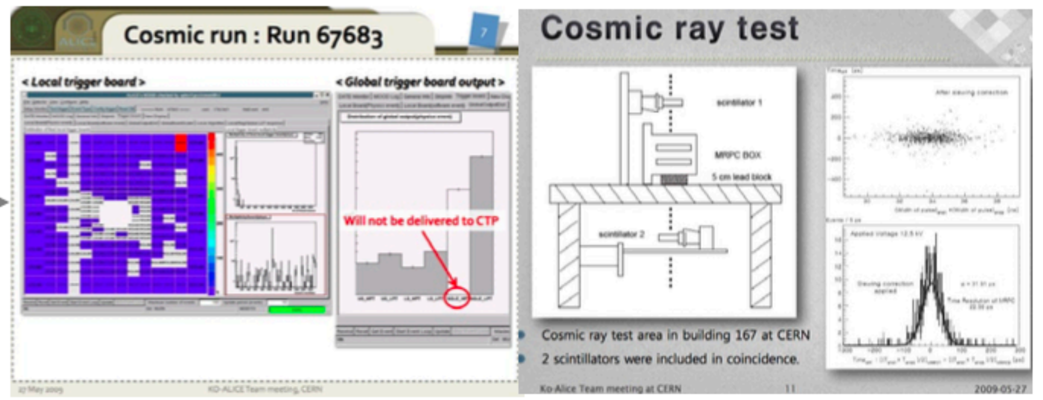
ALICE Collaboration

History

2000, DWKim with Ministry



TOF Super Module + KISTI-T2 & Sejong T3



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

2000 · 2005 · 2007 · 2009 · 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 Schukfraft**, 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

한썬협력
10주년 기념

KIAF(2011)
KISTI-T1(2012)

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.

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

Done in Geneva

on 25/10/2006

For CERN

Prof. Jos Engelen
Chief Scientific Officer

D

or

For KOSEF

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

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

2006

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	For the Government of the Republic of Korea
Robert AYMAR Director-General	Won-hwa PARK Korean Ambassador in Bern

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 detector[1];

Participation of the Korean Team in the construction of the ALICE detector was formalized in an Addendum [2] 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

28 April 2009 Page 1 ALICE-MoU, Add.#15

ALICE COLLABORATION CERN-RRB-2009-009

For the ALICE Collaboration	For CERN
(J. Schukraft) Spokesperson	(S. Bertolucci) Chief Scientific Officer
For KICOS	For the Korean ALICE Team
(Cheon Il Eom) Chairman	(In-Kwon Yoo) Team Leader
For Kangnung National University	For Pusan National University
(Jinsook Kim) Researcher	(In-Kwon Yoo) Professor
For Sejong University	For Yonsei University
(Seyong Kim) Professor	(Ju-Hwan Kang) Professor

28 April 2009 Page 3 ALICE-MoU, Add.#15

ITS Upgrade

Common Infrastructure for the Upgrade of the ALICE Detector

ALICE Collaboration ALICE RRB-2013-125

The European Organization for Nuclear Research (CERN)

and

National Research Foundation of Korea (NRF)

declare that they agree on the Present Addendum to the Memorandum of Understanding for Collaboration in the Construction of the ALICE Detector.

29 October 2013 6 ALICE-MoU-Add # 35

Mexico	12	104'778
Republic of Korea NRF	11	96'046
Republic of Korea - KISTI	3	26'194

Upgrade of the ALICE Inner Tracking System

ALICE Collaboration ALICE RRB-2014-104

The European Organisation for Nuclear Research (CERN)

and

National Research Foundation of Korea (NRF)

declare that they agree on the present Addendum to the Memorandum of Understanding f
Collaboration in the Construction of the ALICE Detector.

16 March 2015 6 ALICE-MoU-Add # 36

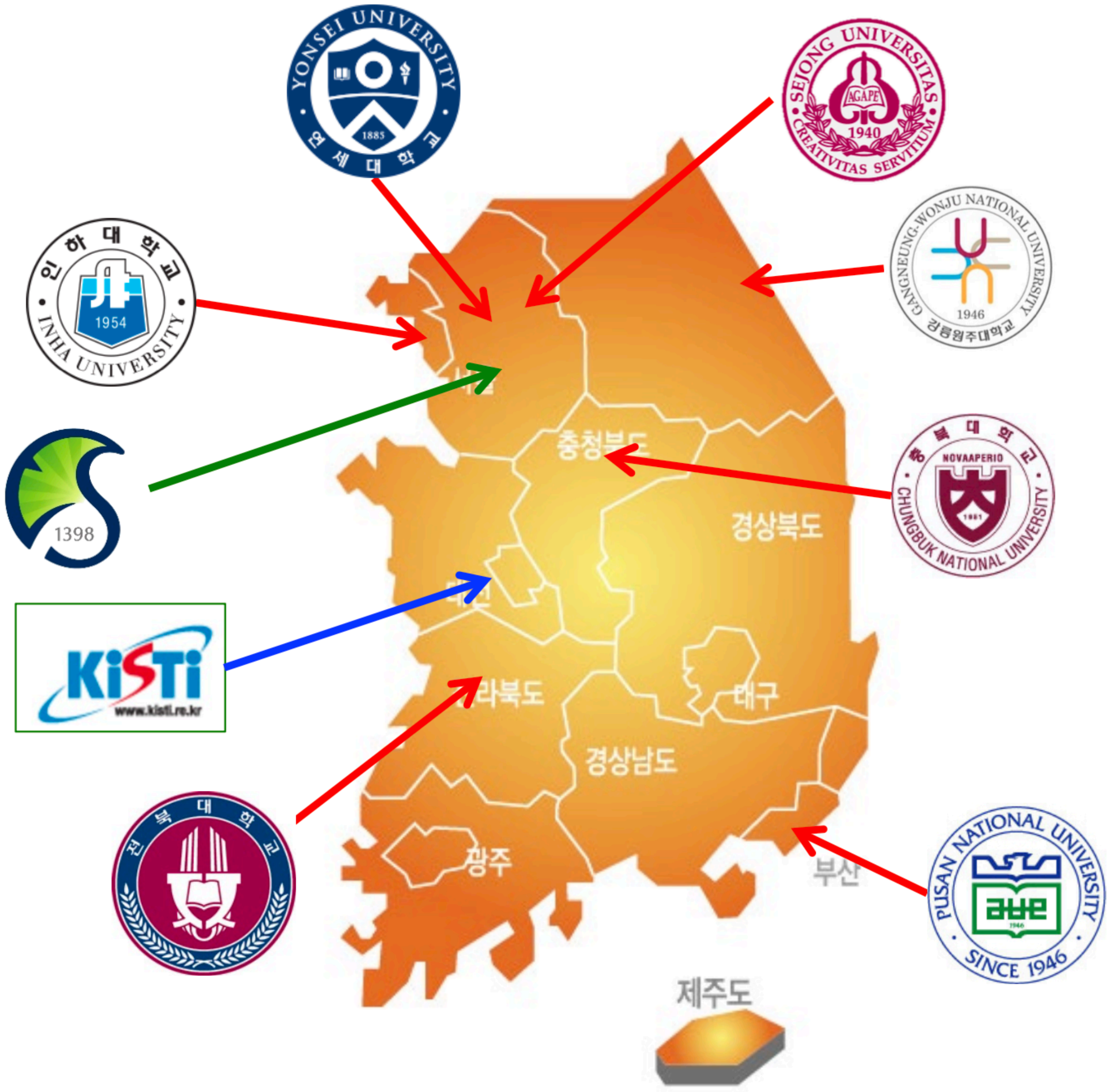
IT	KR	N
310		
63		
31		
82		
44		
70		
20		
750		
750		
2997	976	

xpected fundir

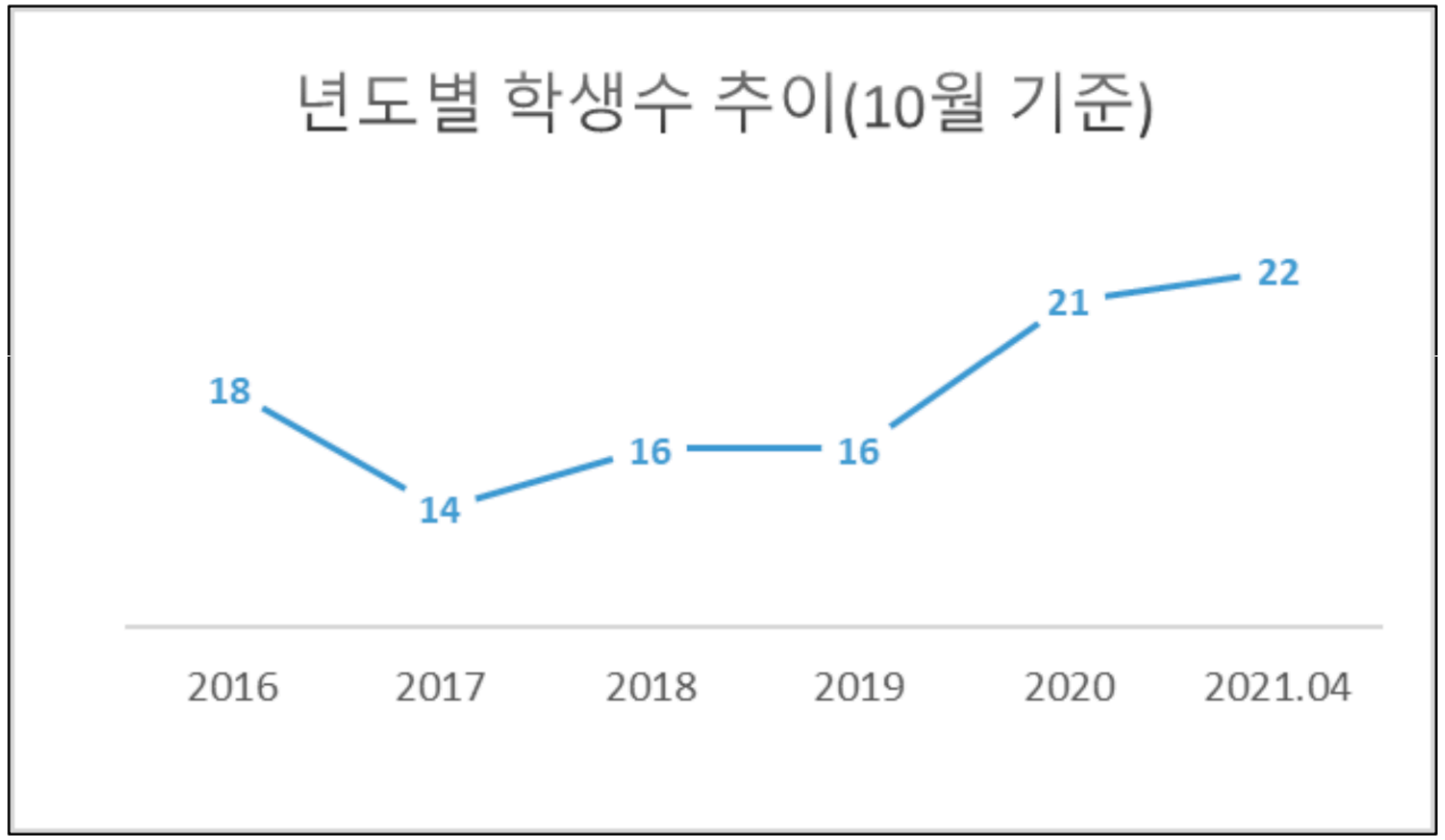
Participation of additional institutes

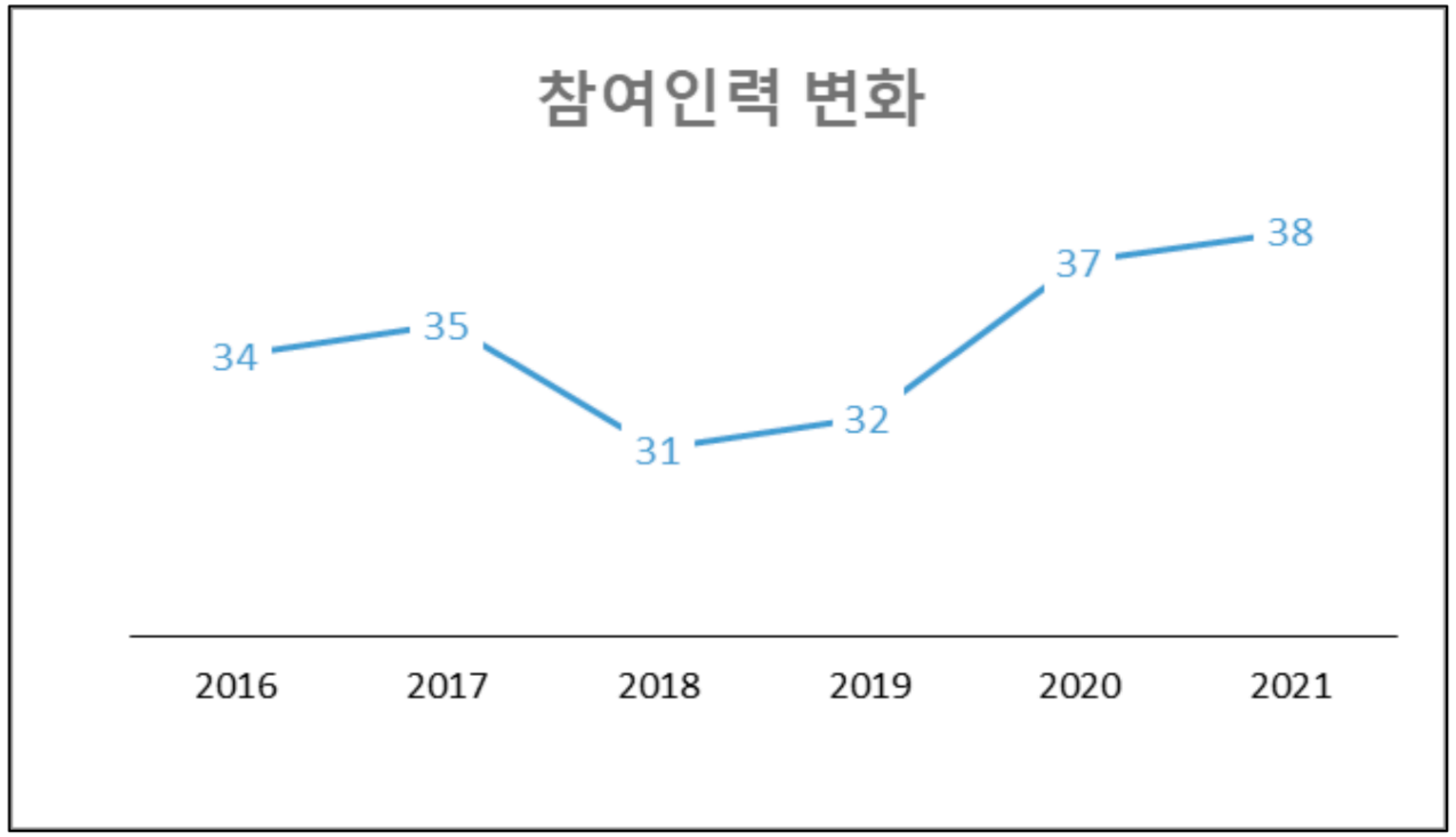
- ✓ **Besides ITS**
  - MFT : 30kCHF(in kind) (*ALICE-MoU-Add #39*)

    + 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)**



참여인력





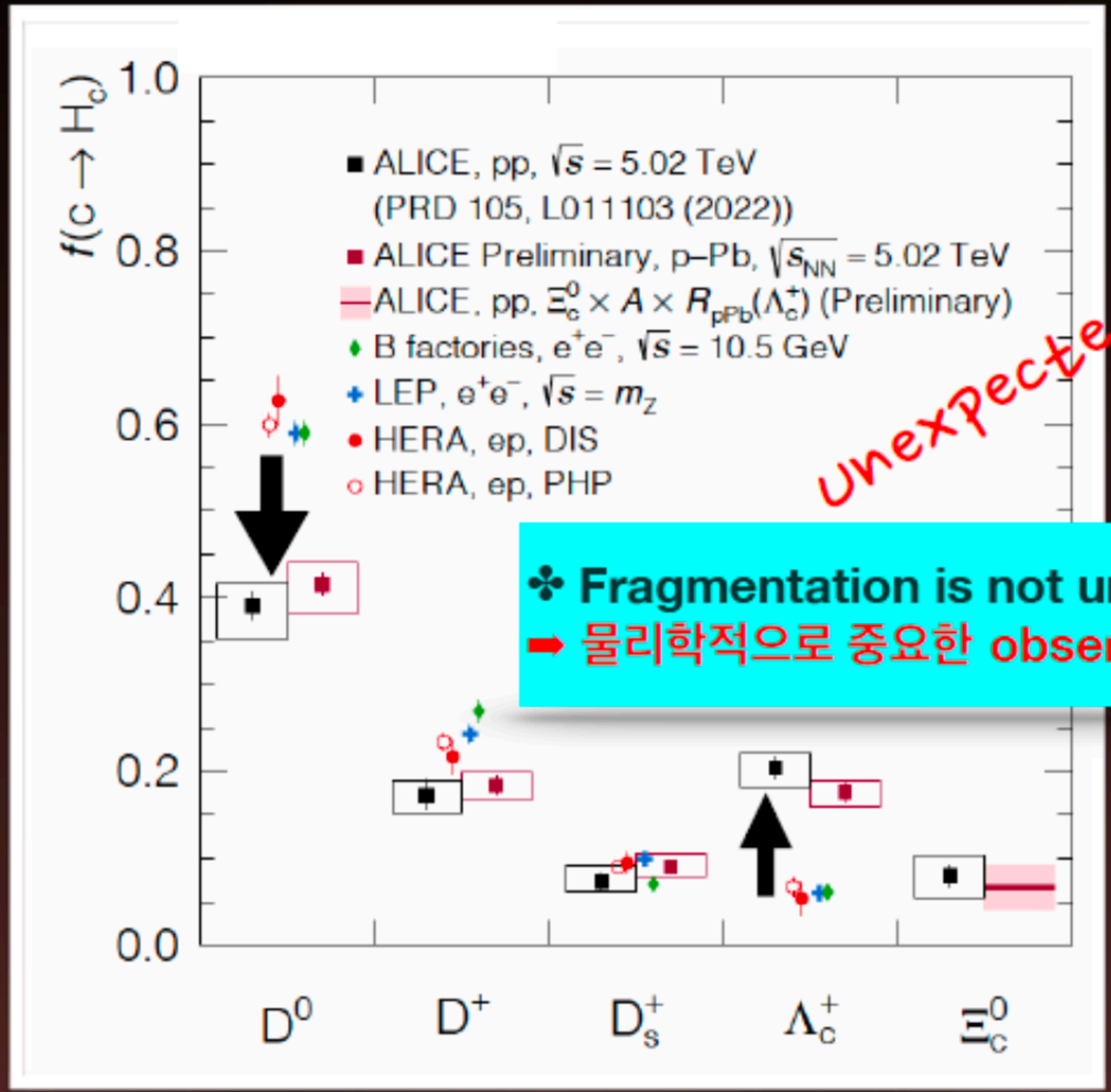
now 31 Grad. Students

now 52 Participants


KoALICE National Workshop 2021
2022. 1. 4(Tue) ~ 7(Fri)
High1 Roesort
KoALICE / KISTI

성과

KoALICE 5단계 대표업적



✤ Fragmentation is not universal!
➡ 물리학적으로 중요한 observation

✤ 국내에서 ITS2 모든 칩 테스트.
(칩테스트 머신 국내제작: 2020년 ALICE 기업체 award)
✤ 모듈 어셈블리
✤ Thinning & diciing
✤ Wire bonding
✤ Probe card 국내 제작

➡국내에 반도체 검출기 제작 기반 마련

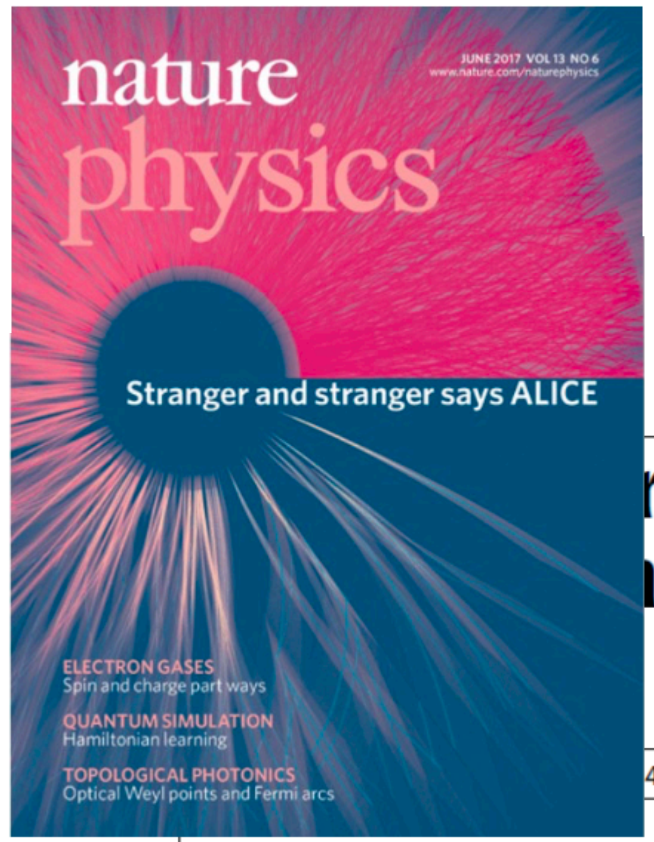
✤ 5 단계: 주저자 논문 총 6편
✤ 박사급 연구자 비율 = 15/1031 = 1.5 %
✤ 3 년 간 주저자 논문비율 = 6/105 = 5.7 %

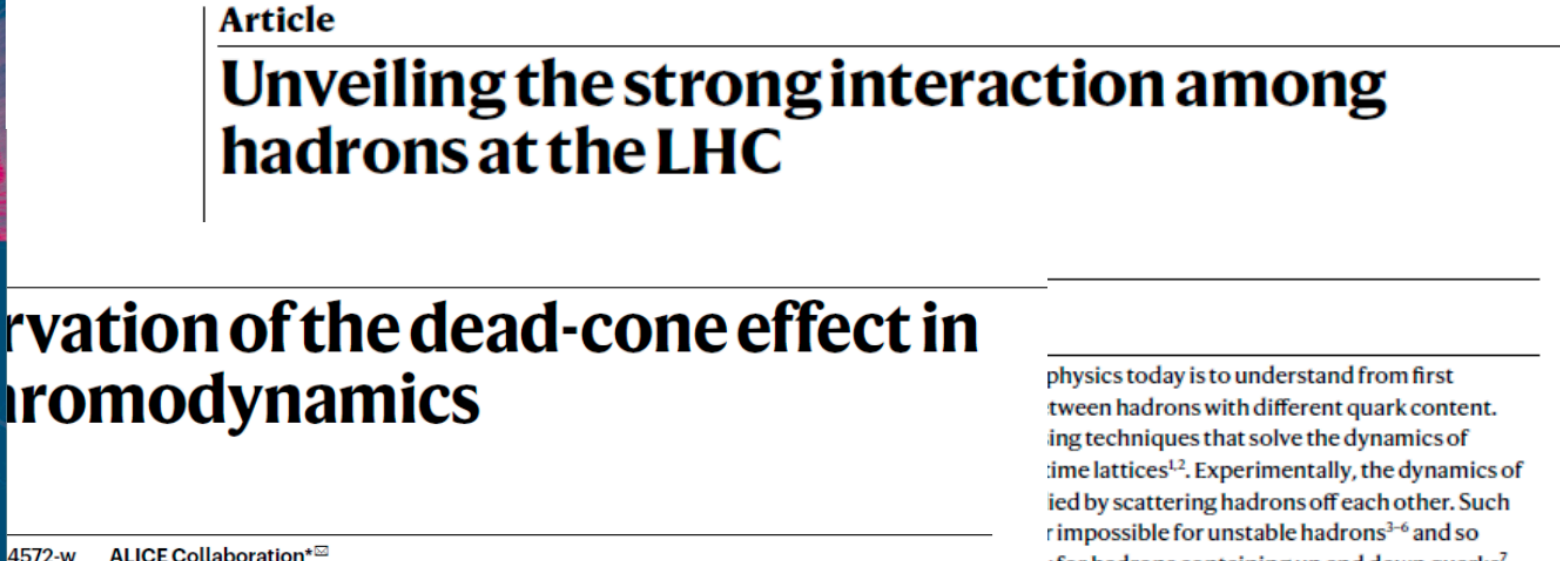
✤ ALICE 공동 논문 리뷰 커미티 및 데이터 분석 리뷰 커미티 활동 10건 이상
ex. 박사과정 서진주 학생 논문 리뷰 커미티 참여

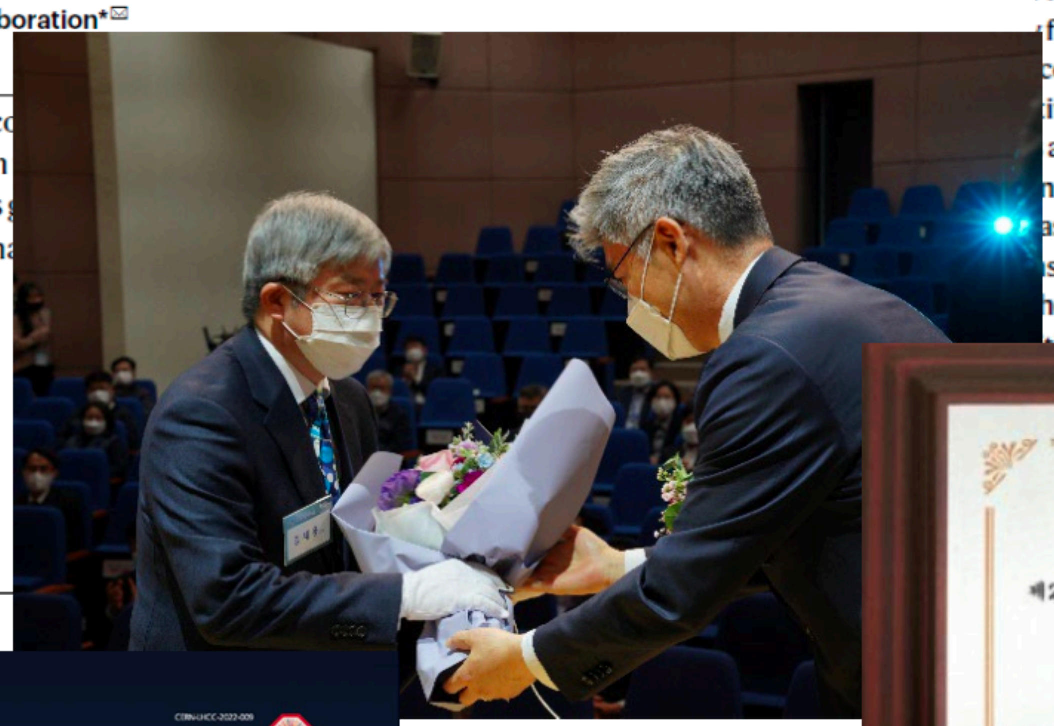
➡ 대학원생을 포함한 연구자들의 국제적 연구역량과 인지도가 강화됨

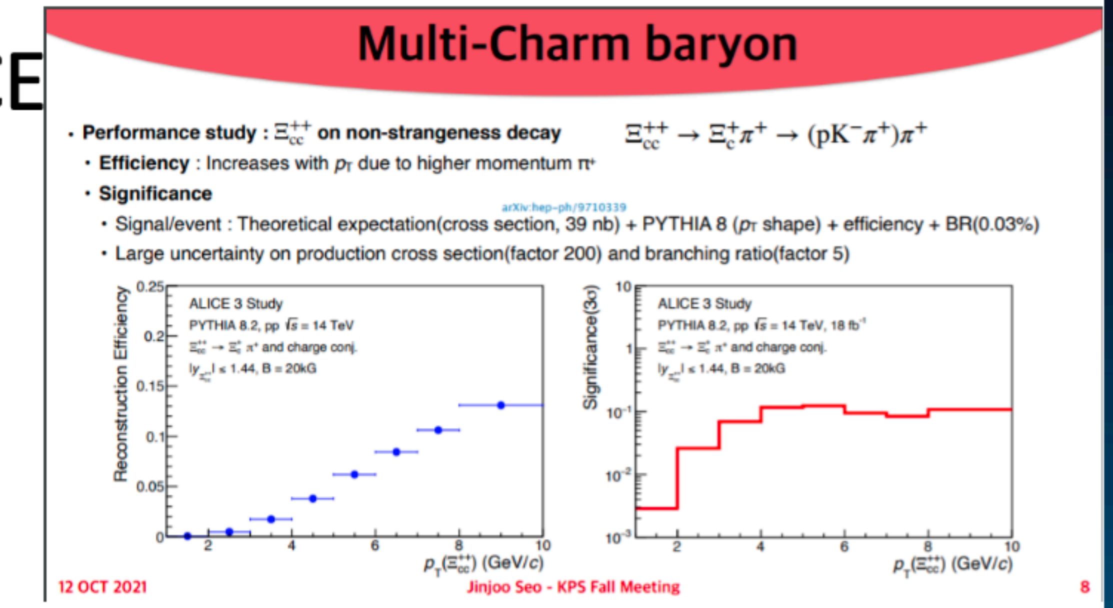
성과

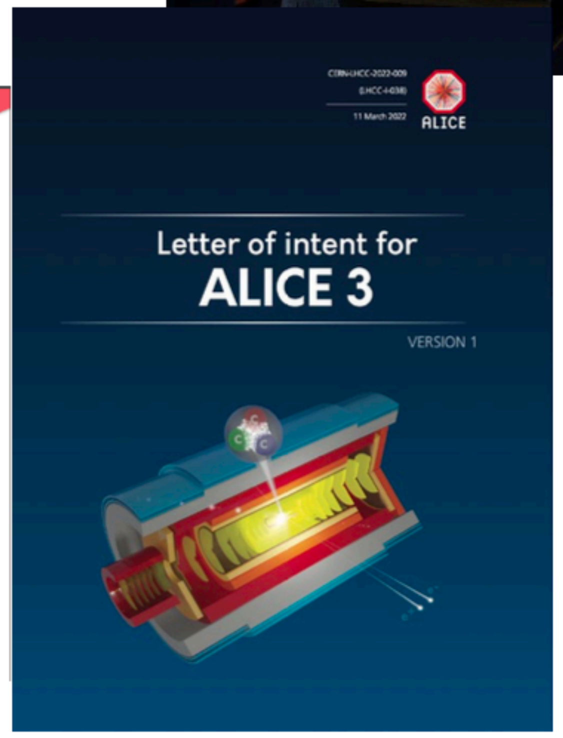
- ✓ 30~35 papers / year
- ✓ 2 NATURE papers (2020, 2021)
- ✓ 1 NATURE Physics (2017)
- ✓ 총 11명의 박사 + 32명의 석사 배출
- ✓ 대통령 근정포장(2021)
- ✓ 한국팀 분석결과가 ALICE
- ✓ 최우수 논문상(2021)



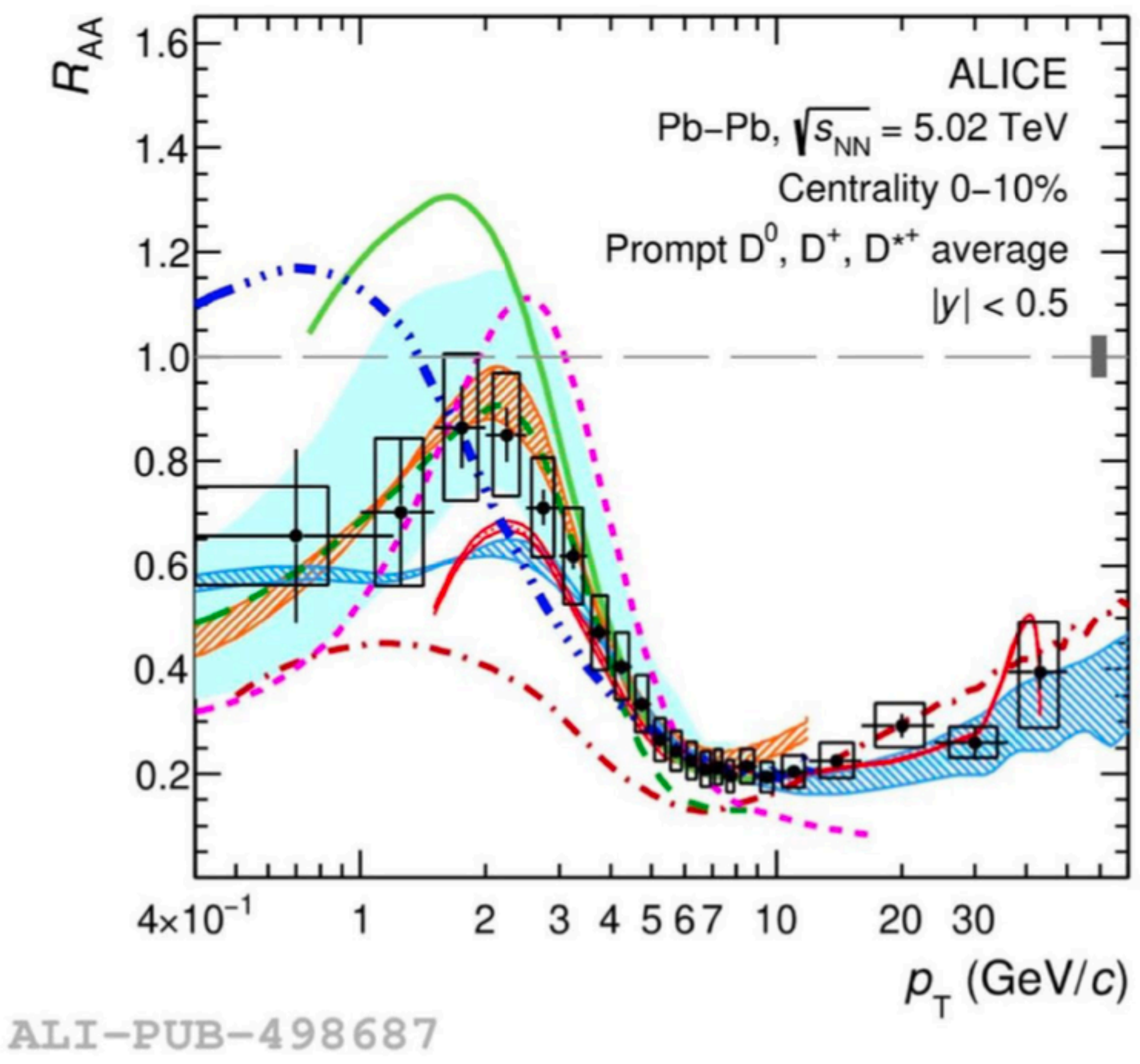


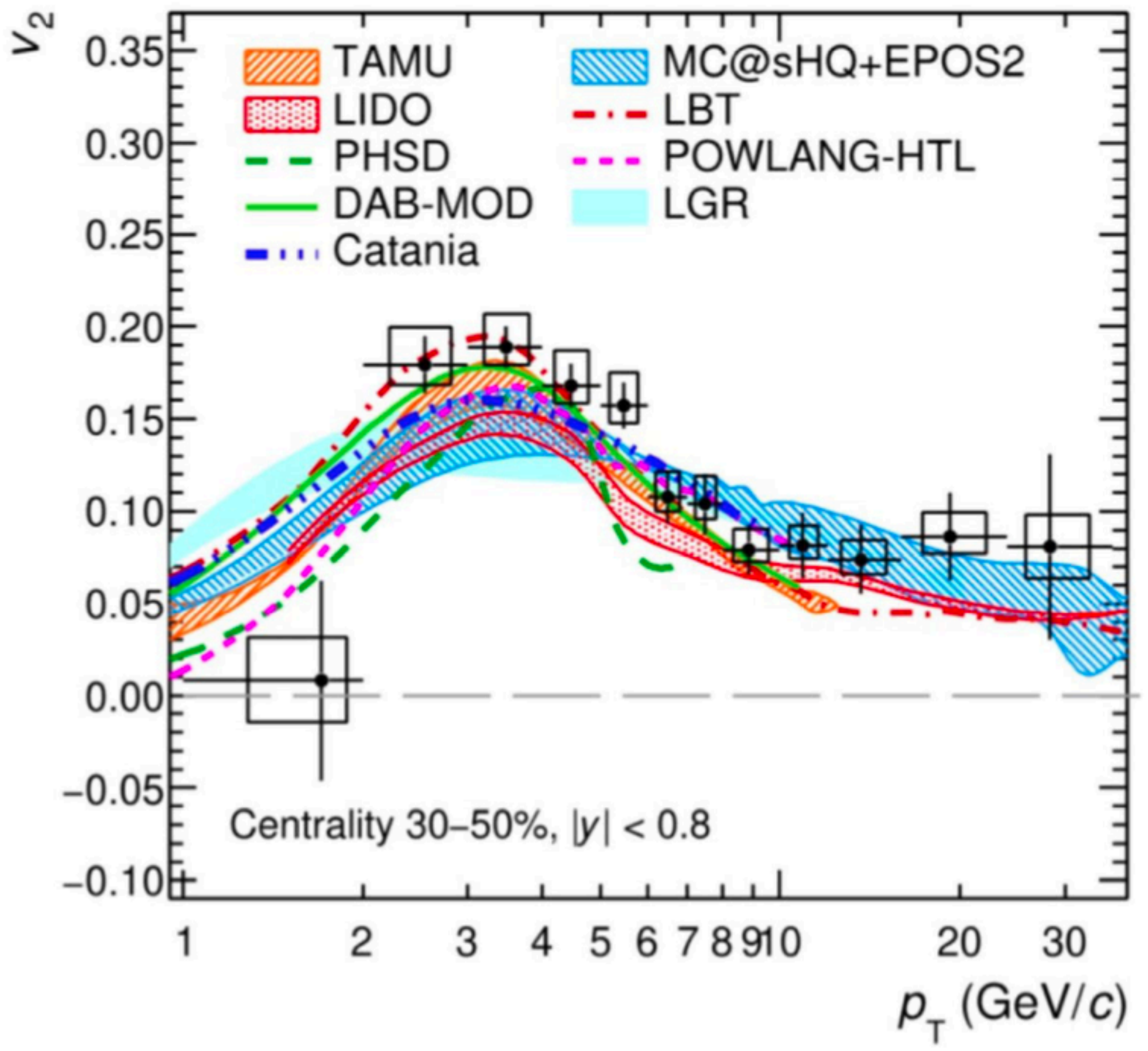




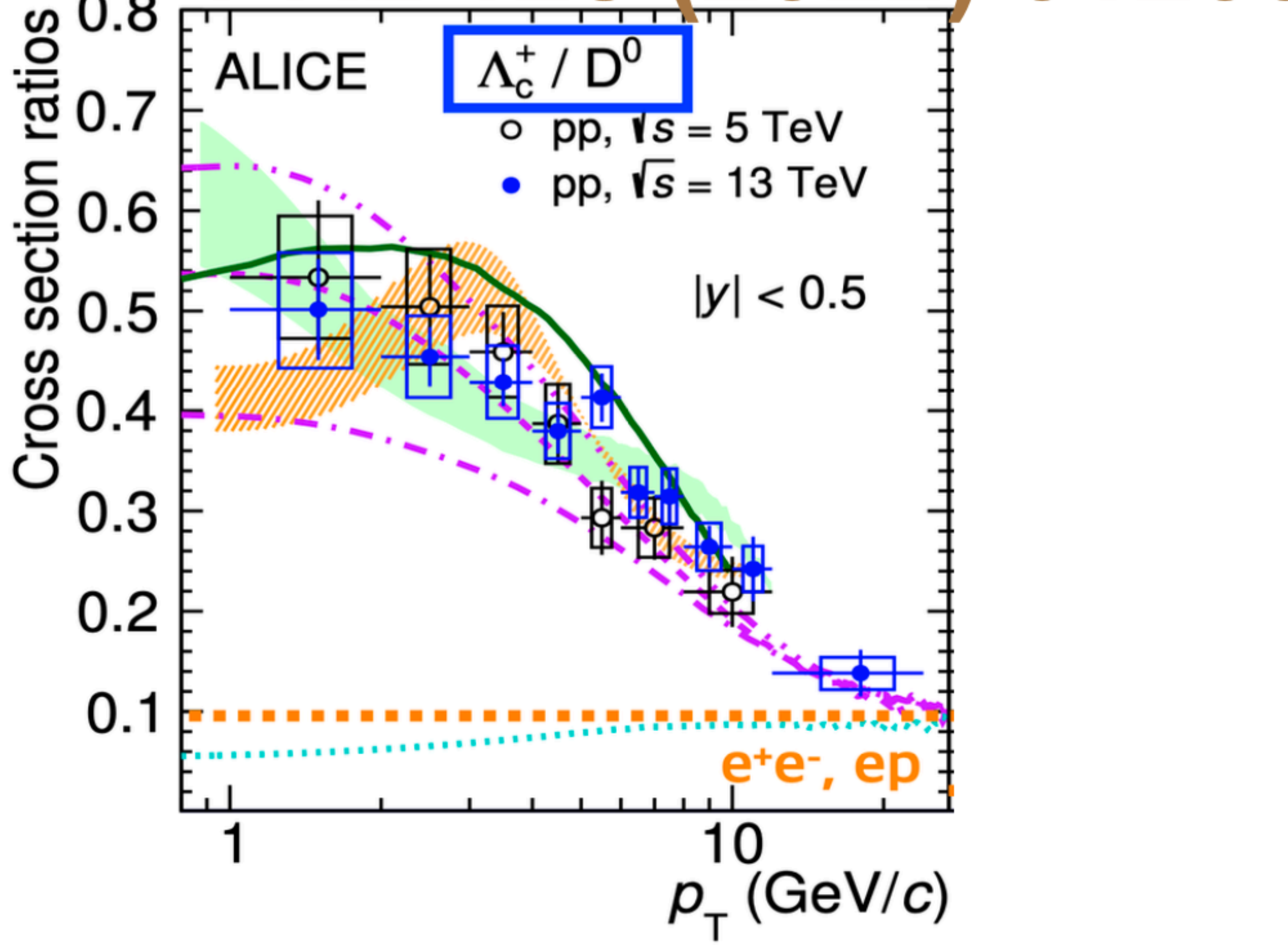


Observables





PRL 128 (2022) 01200



Schedule

2010-2012 | 2015-2018 | 2022-2025 | 2029-2032 | 2035-2037

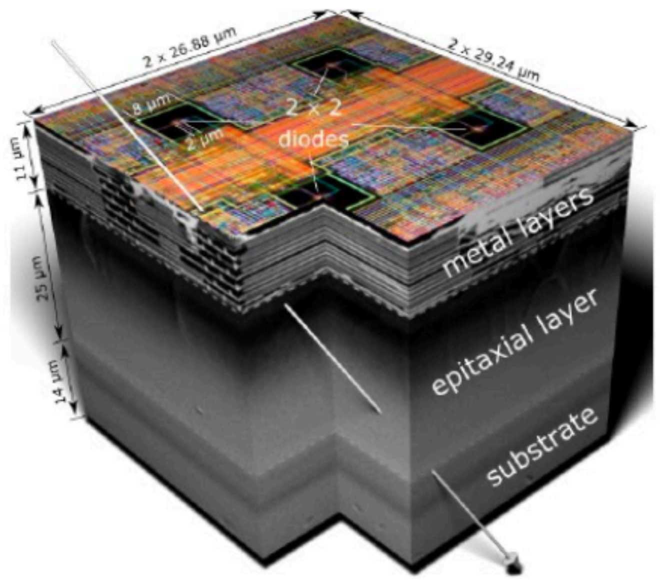
Run 1 → LS1 → Run 2 → LS2 → Run 3 → LS3 → Run 4 → LS4 → Run 5 → LS5 → Run 6

ALICE 1 | phase I upg | ALICE 2 | ALICE 2.1 | phase II upg | ALICE 3

ITS2 : Mass Chip Test & HIC Assembly

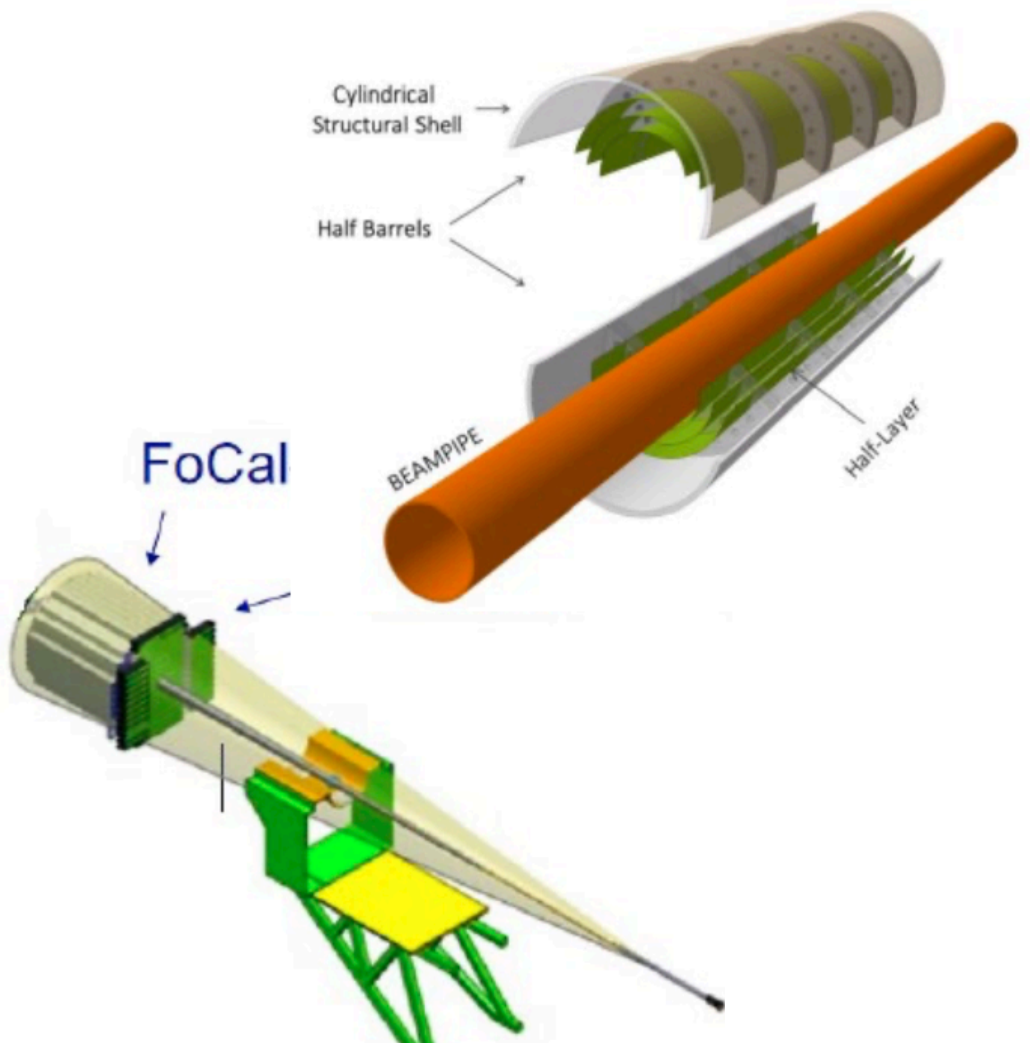
ITS3

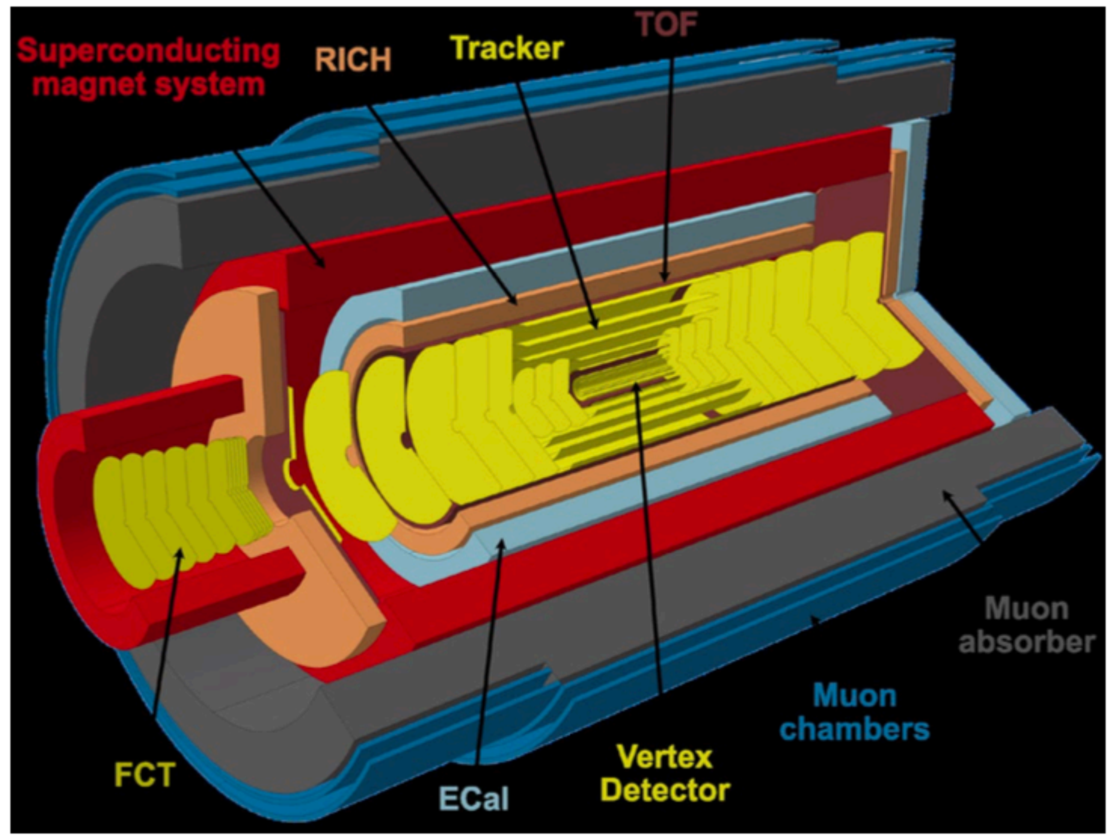
ALICE3




...he ALICE collaboration presents the
...ICE Industry Award 2020
to
C-ON Tech
...NamdongGu Incheon, South Korea
...exceptional ...ent to the development of a high-... automated system for the mass ...on visual inspection and electrical ...the ALPIDE monolithic pixel sensor ...he extraordinary dedication of C-...ch contributed to the successful ...on of the ALICE Inner Tracking ...and Muon Forward Tracker.

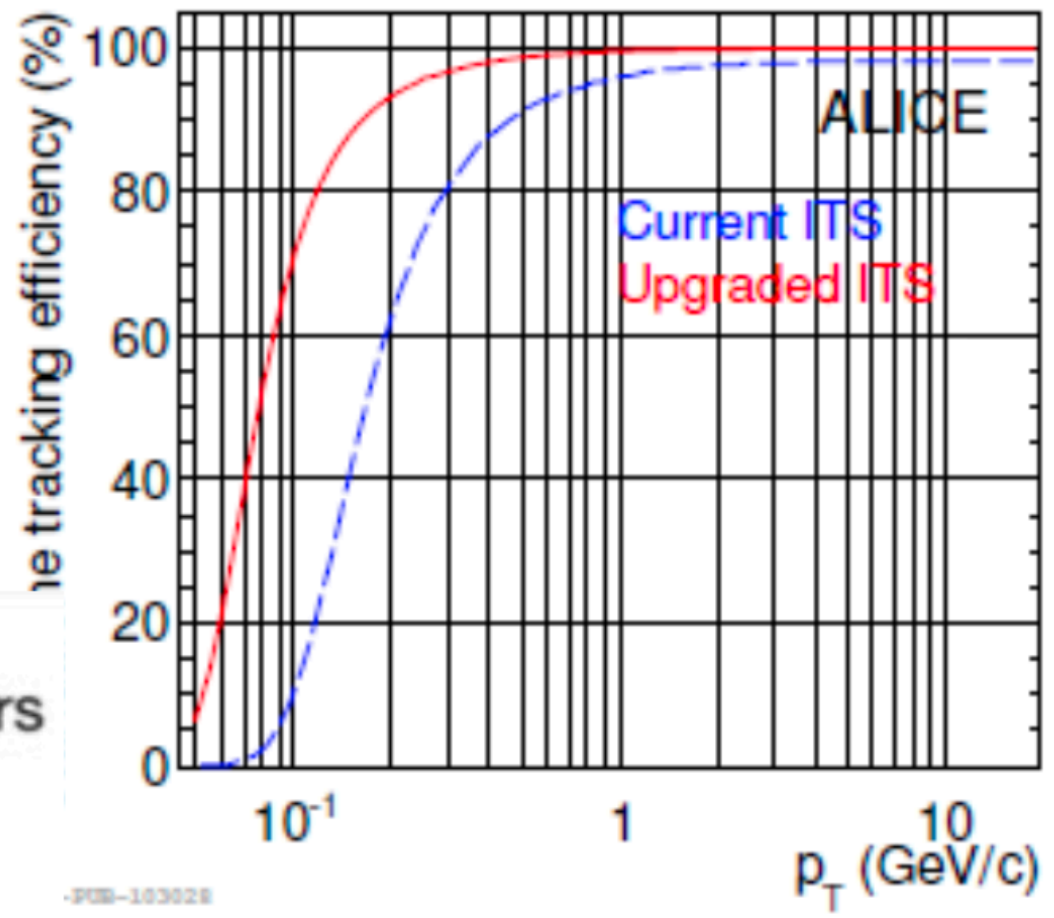
ITS3

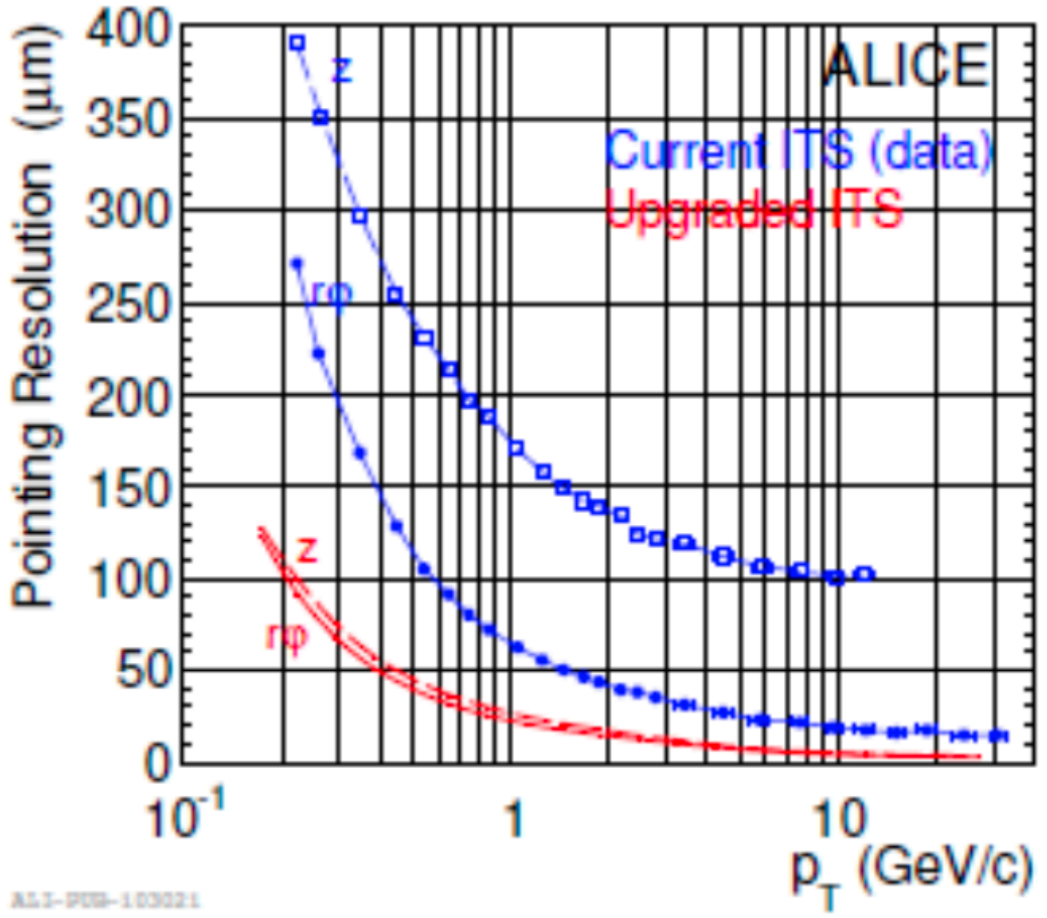




ITS2

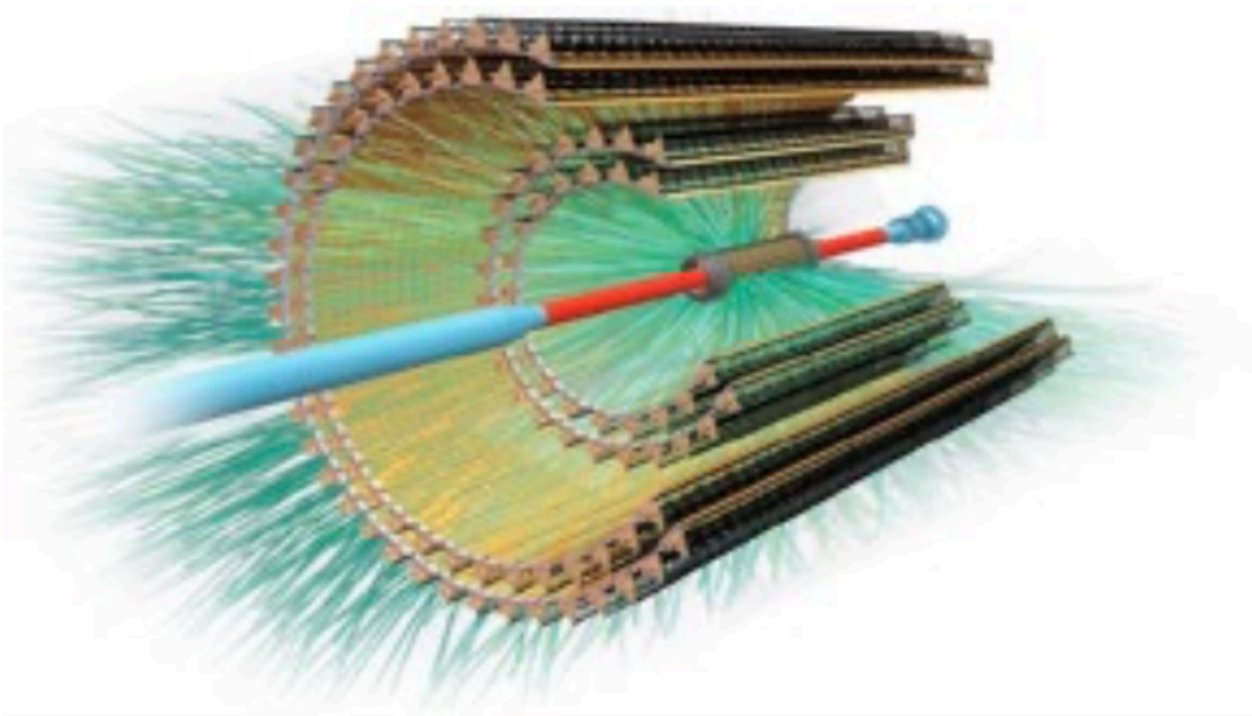
- ✓ 낮은 운동량까지 측정 가능
- ✓ x3, x5 더 좋은 위치 분해능





6 layers:	**7 layers:**
2 hybrid silicon pixel	all Monolithic Active Pixel Sensors
2 silicon drift	
2 silicon strip	
Inner-most layer:	**Inner-most layer:**
radial distance: 39 mm	radial distance: 23 mm
material: X/X_0 = 1.14%	material: X/X_0 = 0.3%
pitch: 50 x 425 μm²	pitch: O(30 x 30 μm²)
rate capability: 1 kHz	**rate capability:** 100 kHz (Pb-Pb)

chip 5만개 전량 test 및 HIC assembly 1/5



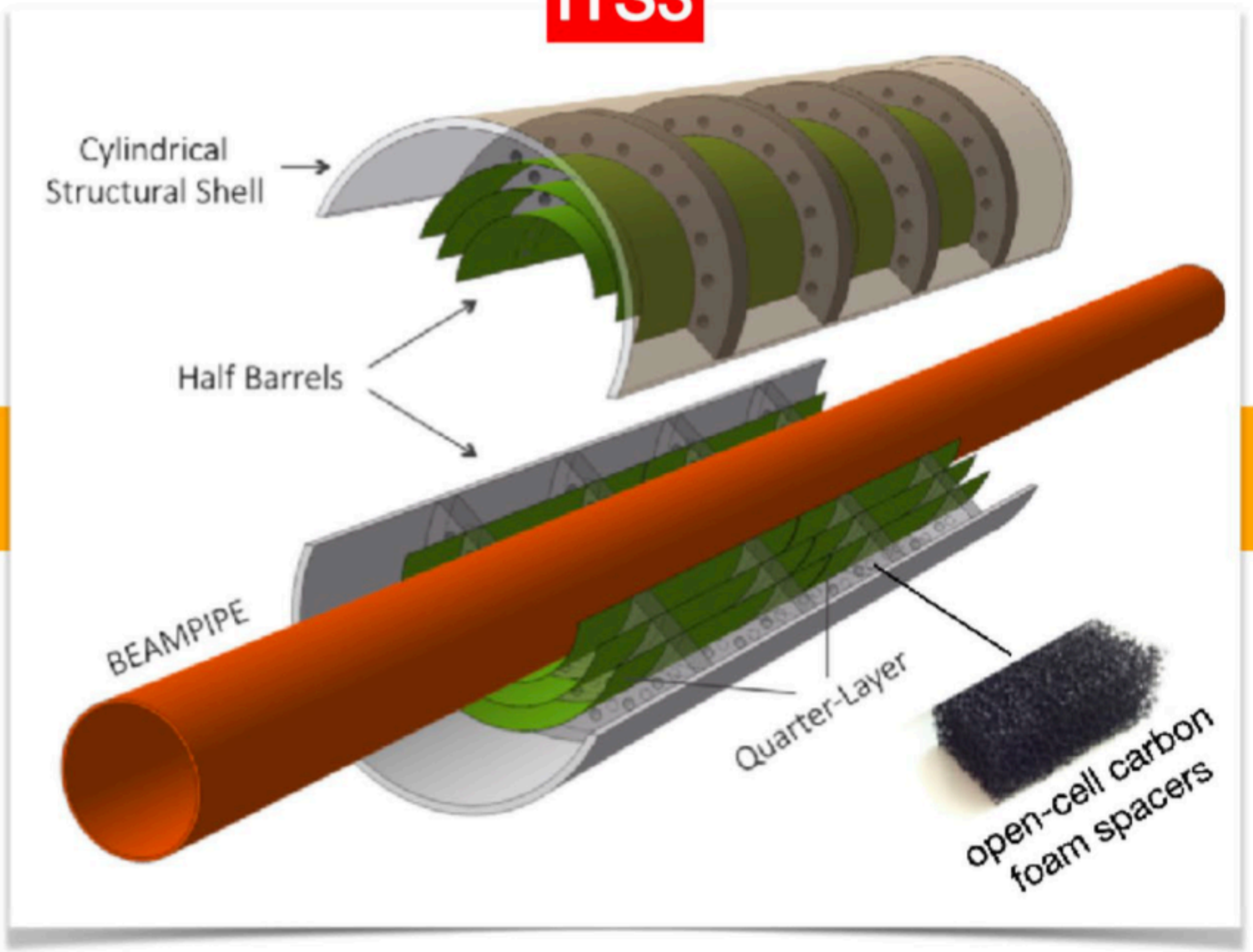
ITS3
in a nutshell

replace

ITS2 IB

by

ITS3



in LS3

based on:
- wafer-scale (up to ~28x10 cm),
- ultra-thin (20-40 μm),
- bent (R=18, 24, 30 mm)

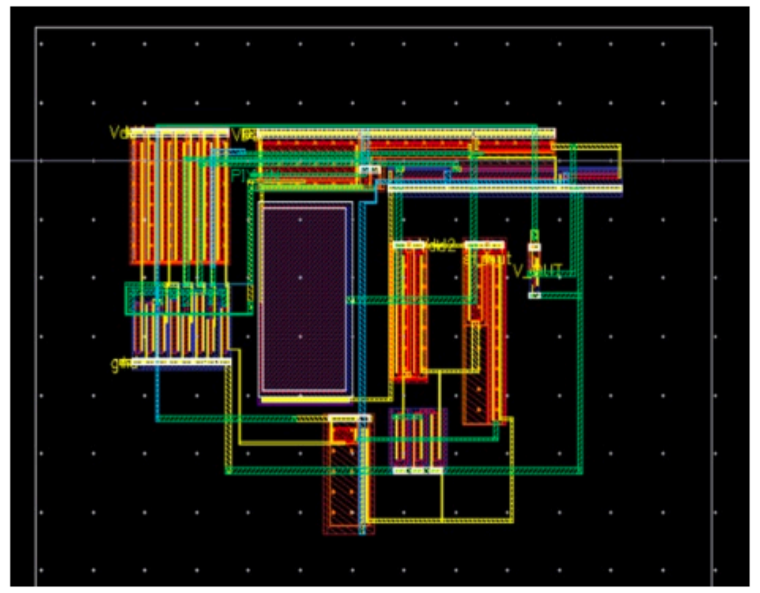
Si sensors (MAPS)

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 pt

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



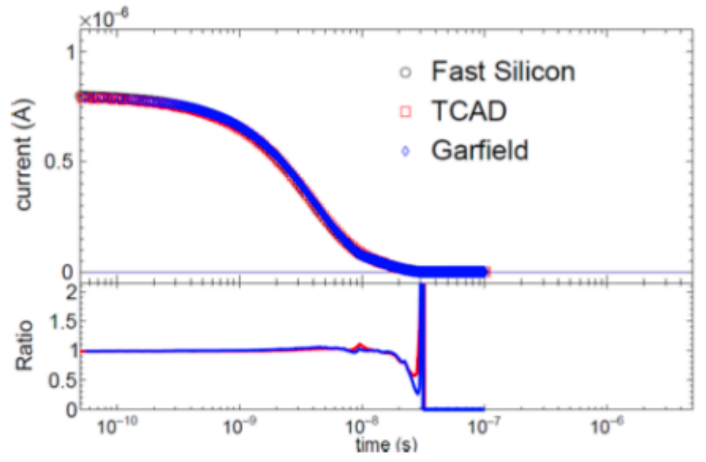
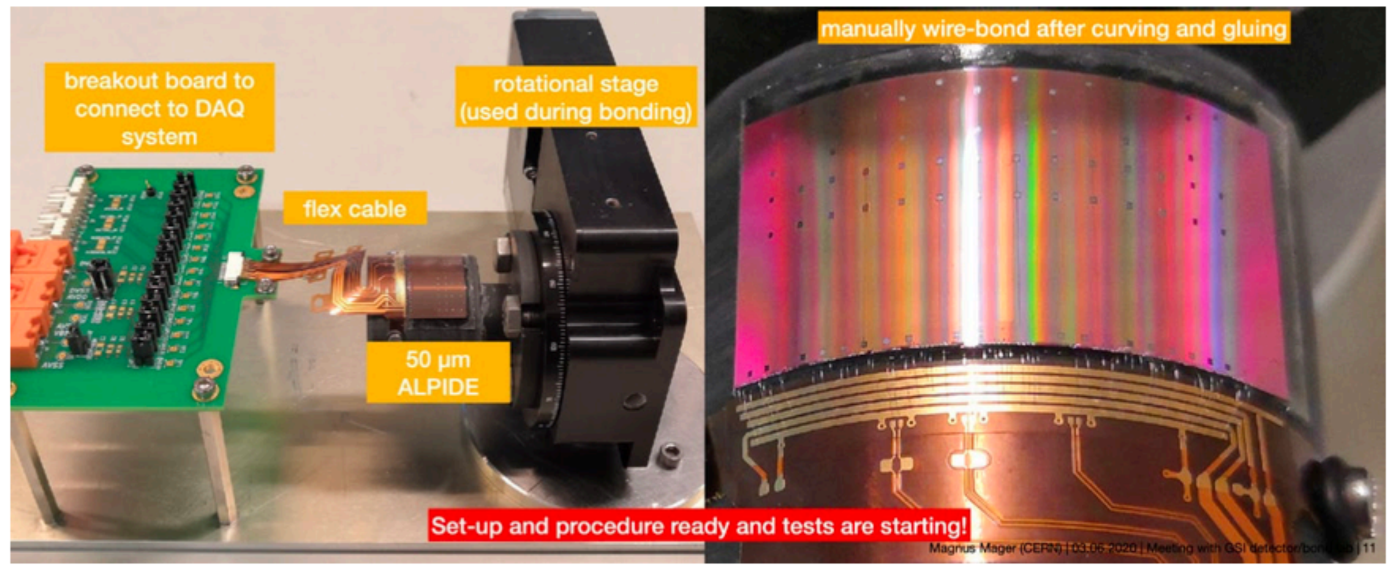


Fig. 9. Total currents in the FSD Simulation, TCAD and Garfield++. The bottom panel shows ratios of the currents in the upper panel. The red (blue) solid line in the ratio plot indicates I_{TCAD}/I_{FSD} ($I_{Garfield++}/I_{FSD}$).



ALICE3

✓ **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)

ALICE3

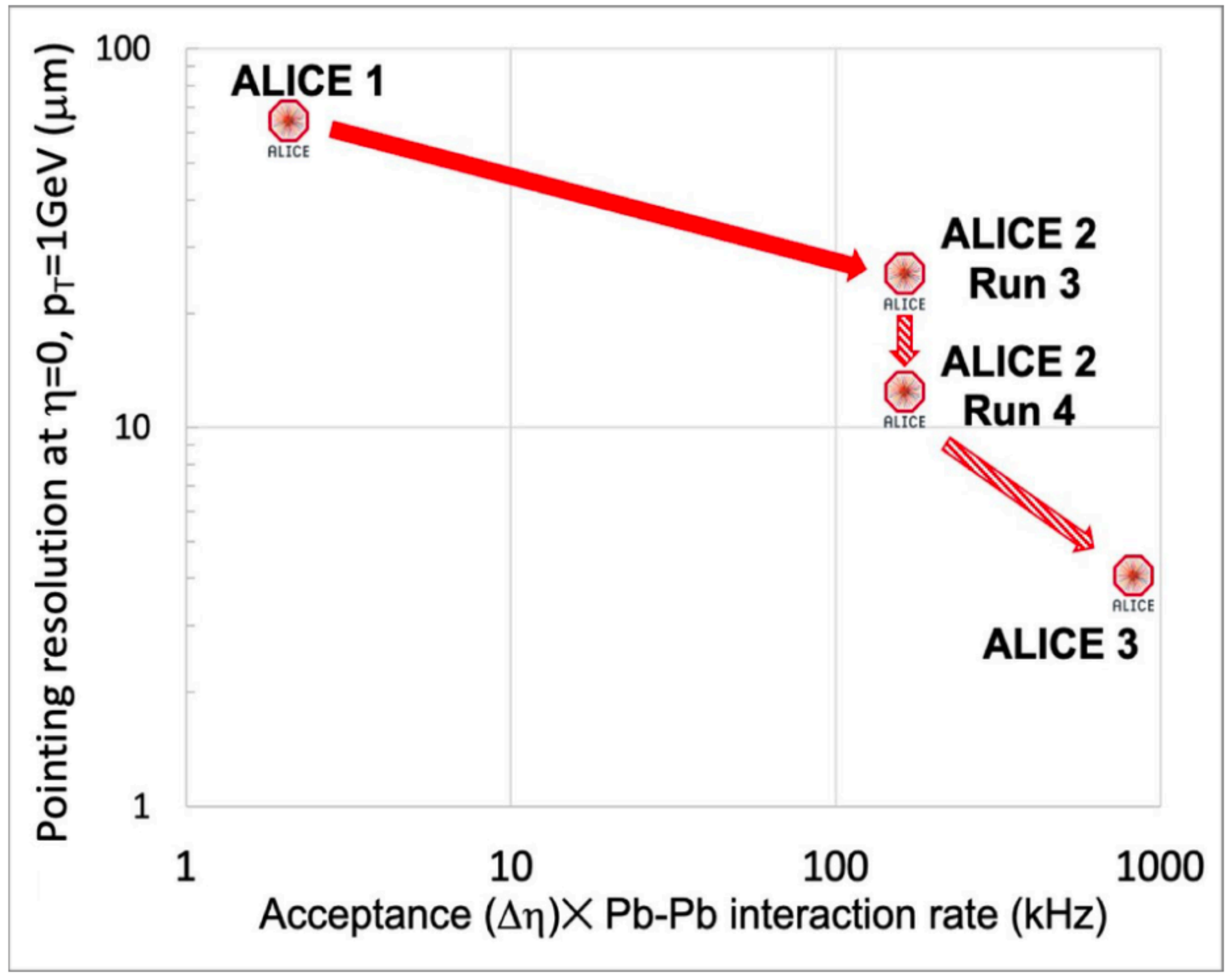
✓ **Experimental challenges**

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

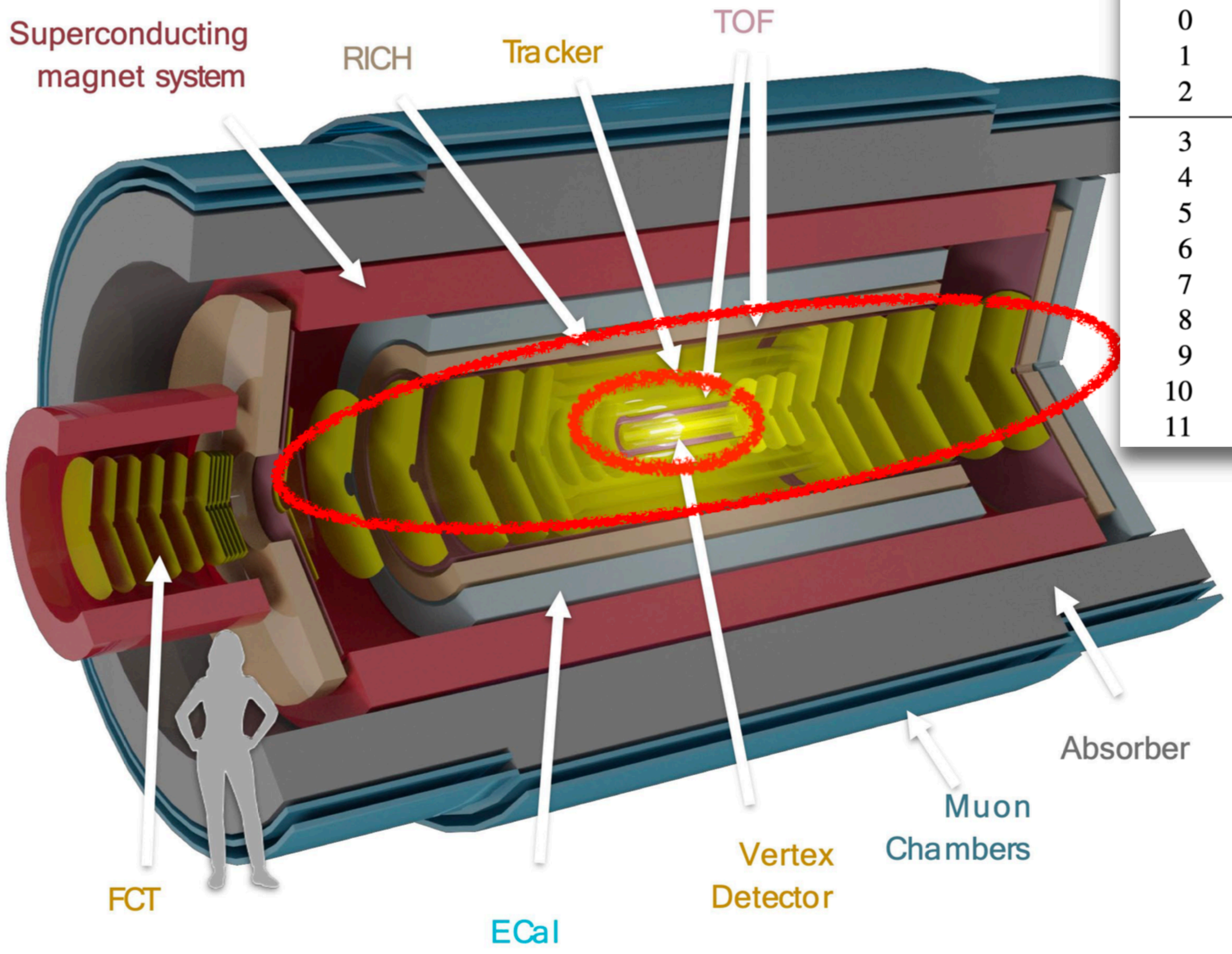
  → $\sigma_{\mathrm{pT}}/p_T \approx 1\text{~}2\%$

- **Vertex detector with unprecedented pointing resolution →** $\sigma_{\mathrm{DCA}} \approx 10\ \mu$**m (pT = 200 MeV)**
- **Particle Identification over large acceptance (−4 < η < 4) → γ, e±, μ±, K±, π±**
- **Continuous read-out and online processing**

→ **Detector with *unique and unprecedented* features at the LHC**

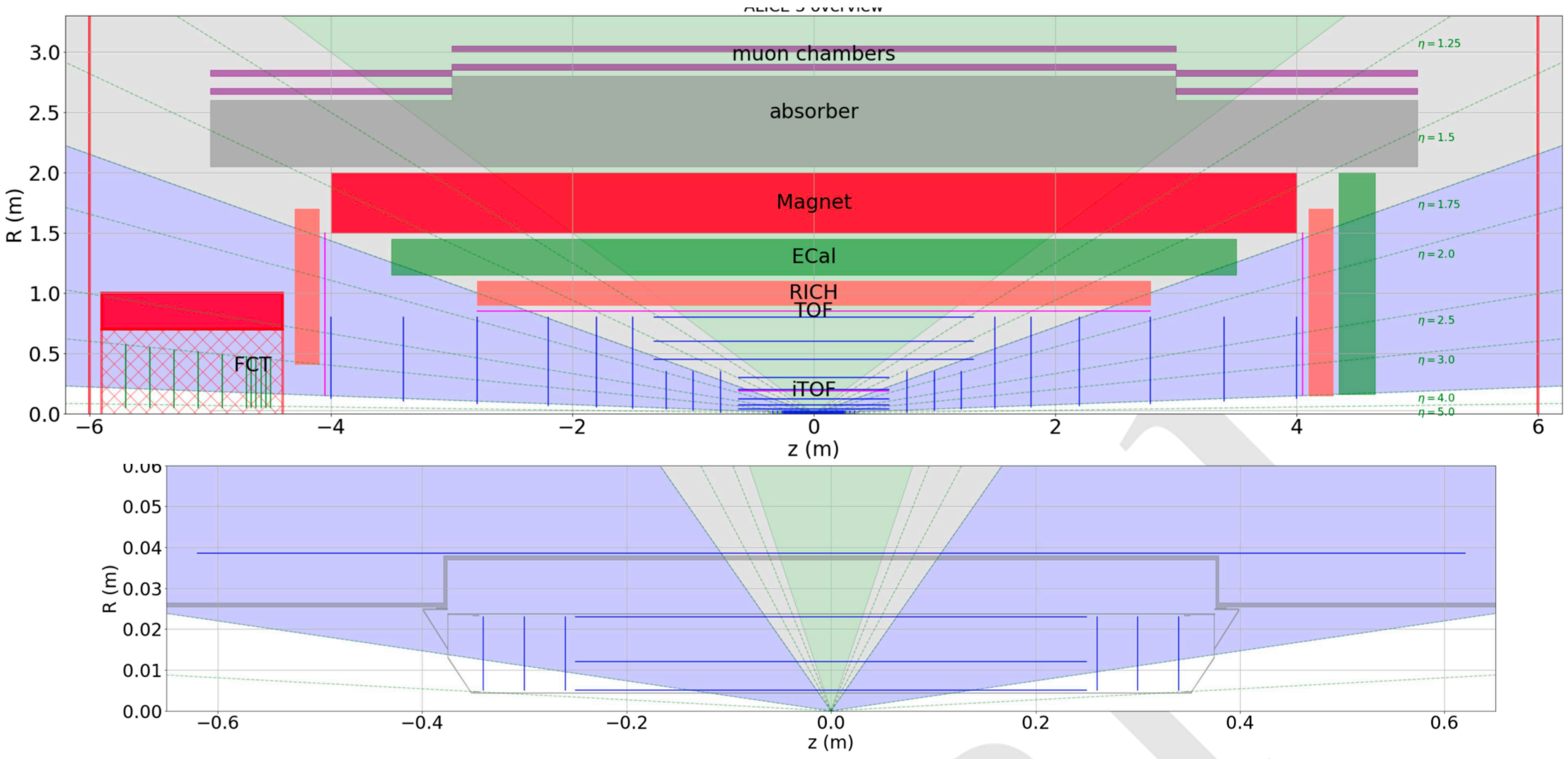


ALICE3



Layer	Material thickness (%X_0)	Intrinsic resolution (µm)	Barrel layers Length (±z) (cm)	Barrel layers Radius (r) (cm)	Forward discs Position (|z|) (cm)	Forward discs R_{in} (cm)	Forward discs 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



Vertex Detector

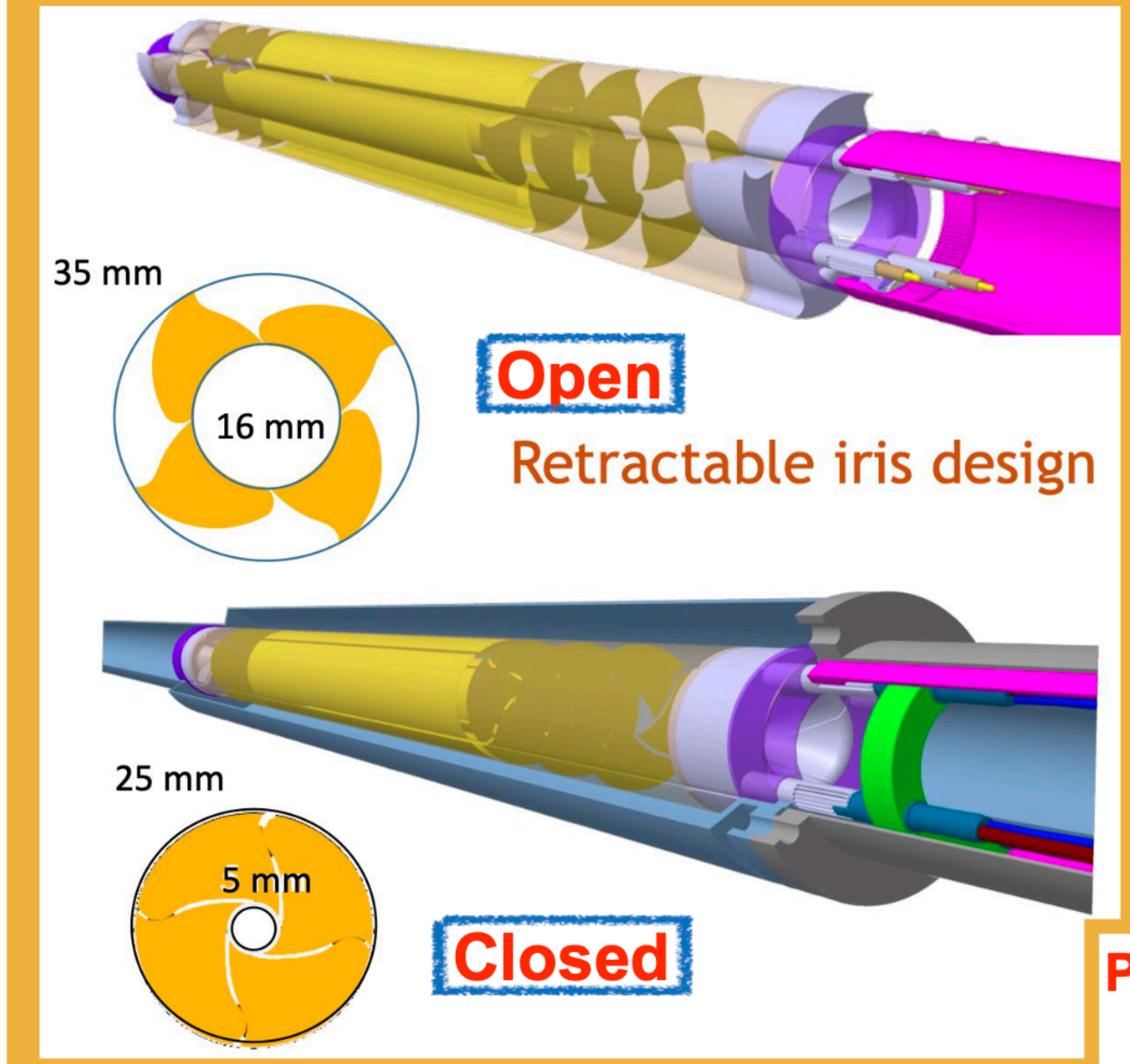
Conceptual study of iris tracker

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: $\sigma_{pos} \approx 2.5\ \mu m$

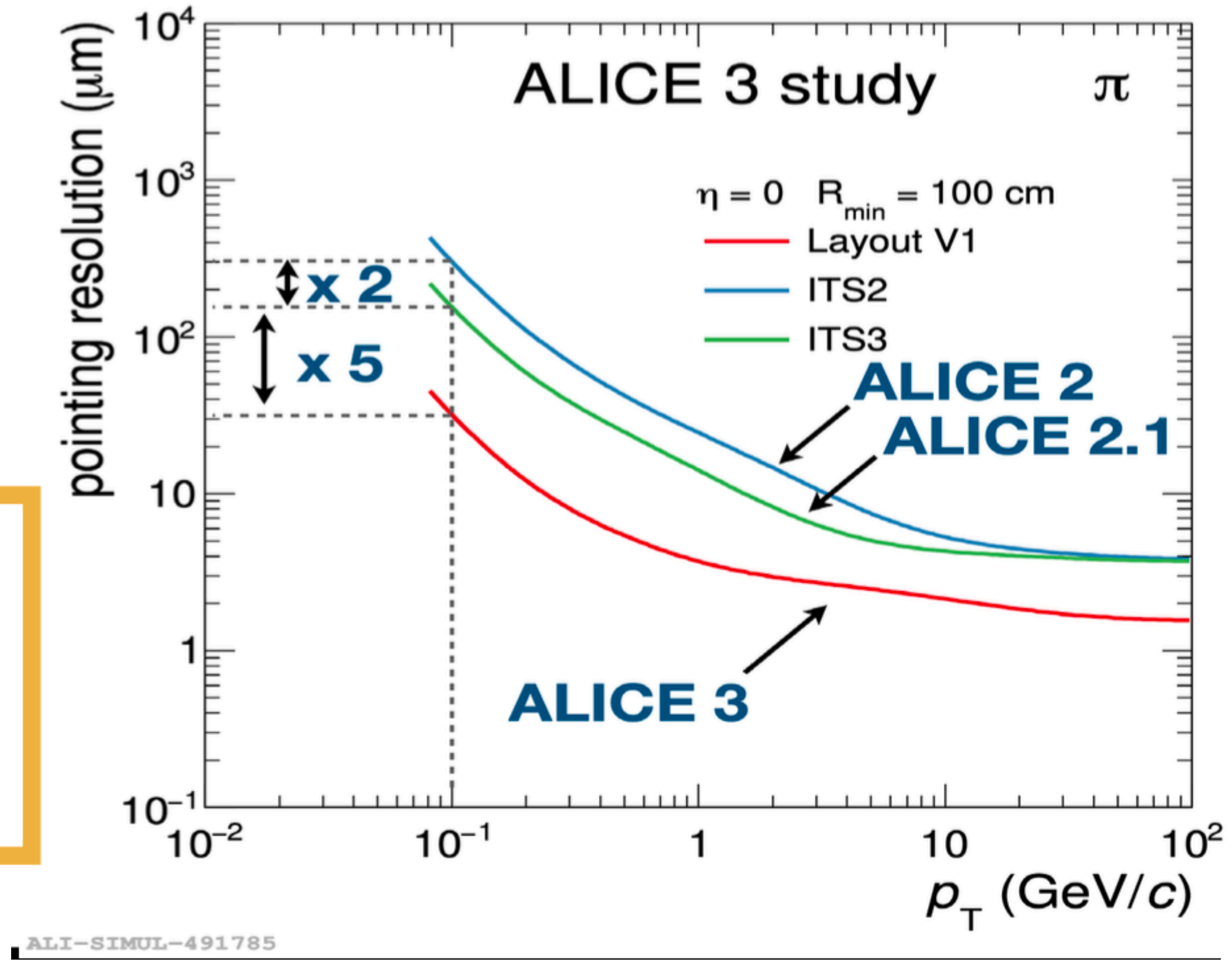
Extremely low material budget 1‰ X_0 per layer



Pointing resolution

~10 μm at p_T = 200 MeV/c

~2 μm at high p_T



Large Acceptance Tracker

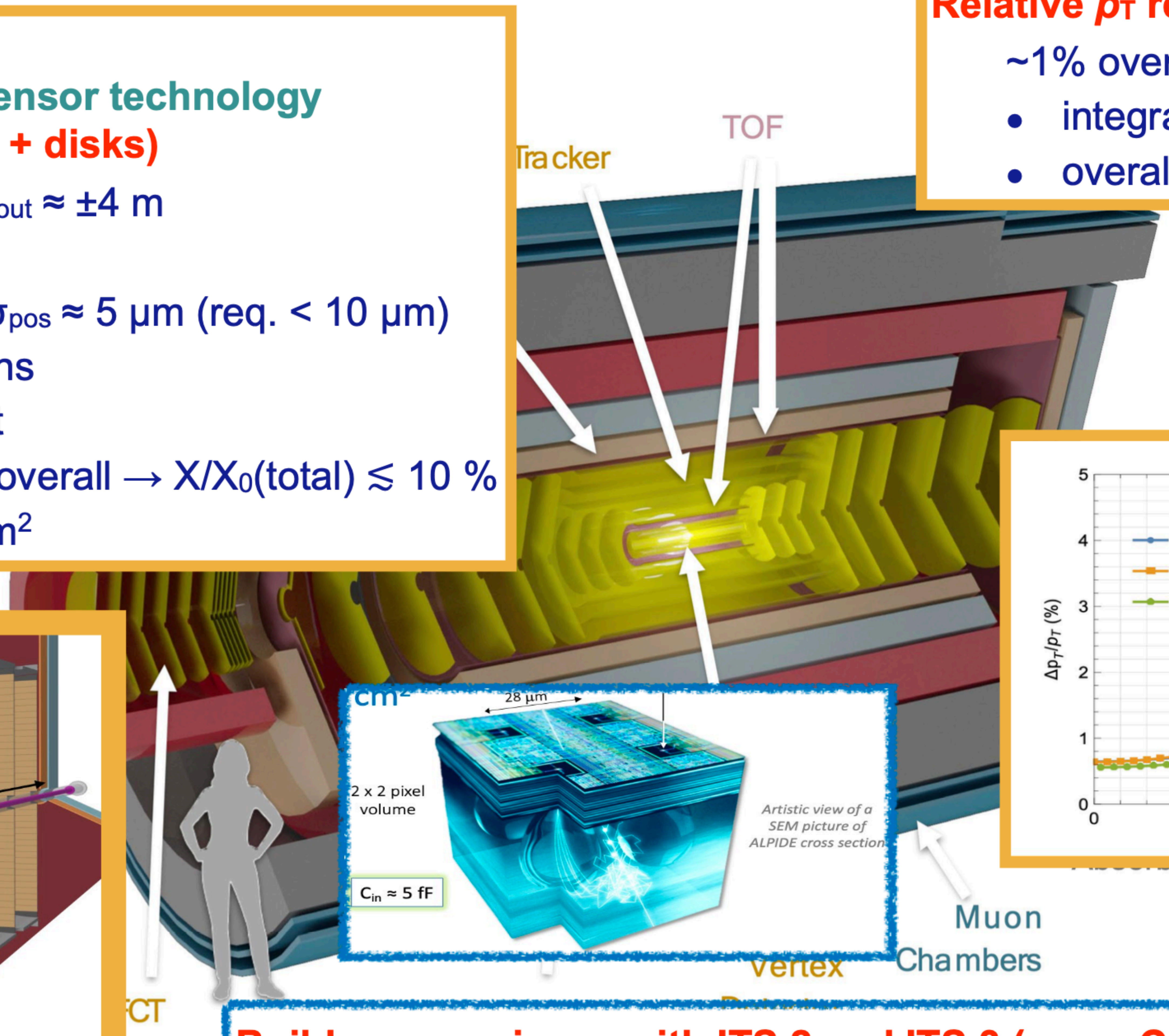
60 m^2 silicon pixel detector
based on CMOS Active Pixel Sensor technology
8 + 2 x 9 tracking layers (barrel + disks)

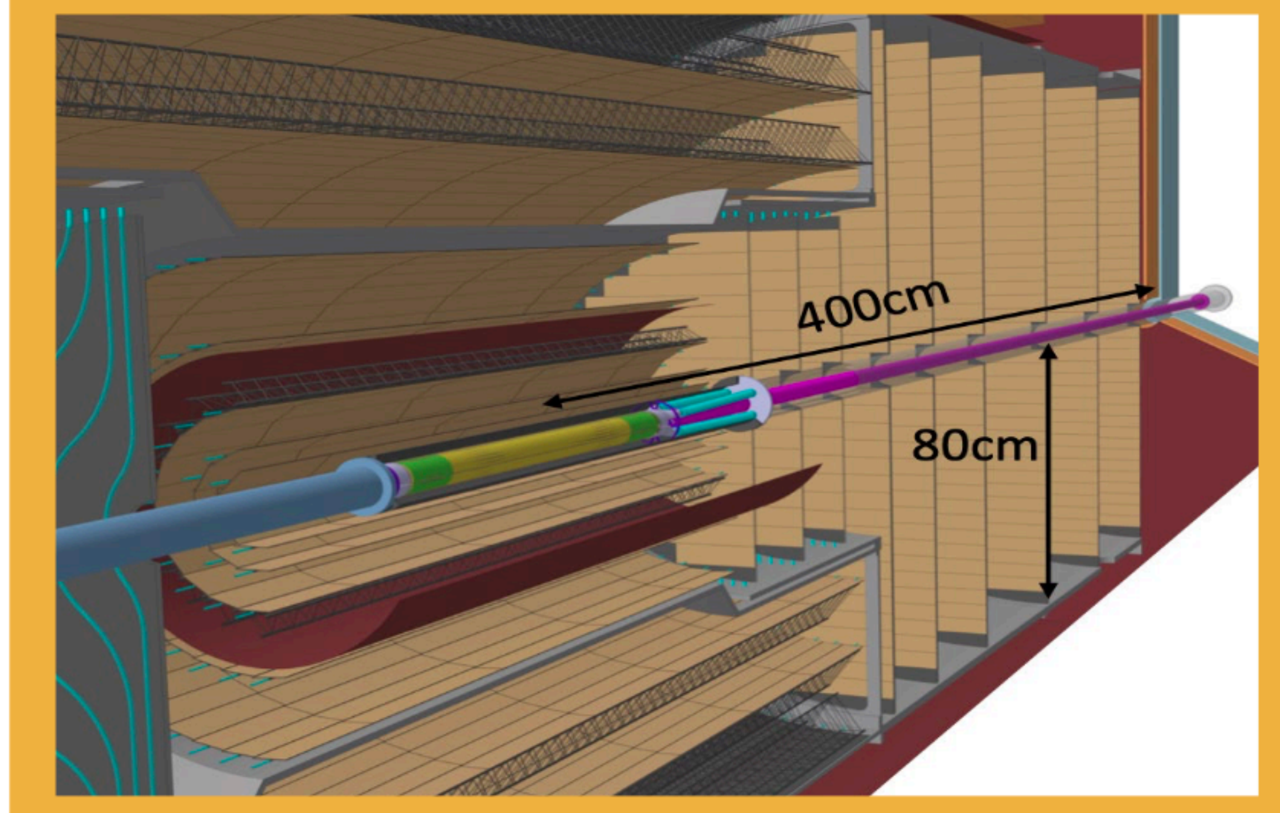
- Compact: $r_{out} \approx 80$ cm, $z_{out} \approx \pm 4$ m
- Large coverage: ±4η
- High-spatial resolution: $\sigma_{pos} \approx 5$ μm (req. < 10 μm)
- Timing resolution ~ 100 ns
- Very low material budget
    - 1% X_0 per layer overall → X/X_0(total) $\lesssim$ 10 %
- Low power: ≈ 20 mW/cm^2

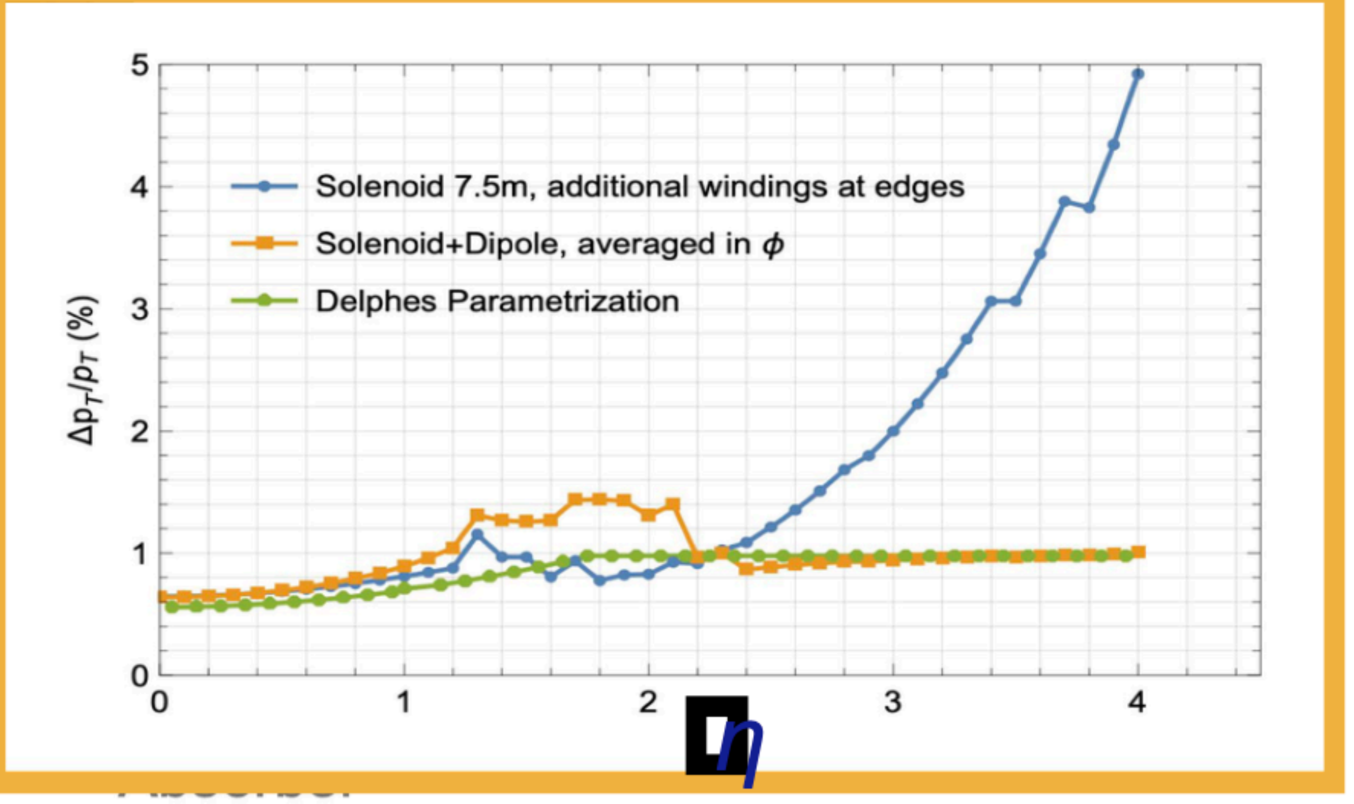
Relative p_T resolution

~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 m^2 → 60 m^2: challenges on industrialisation

Particle ID from ToF

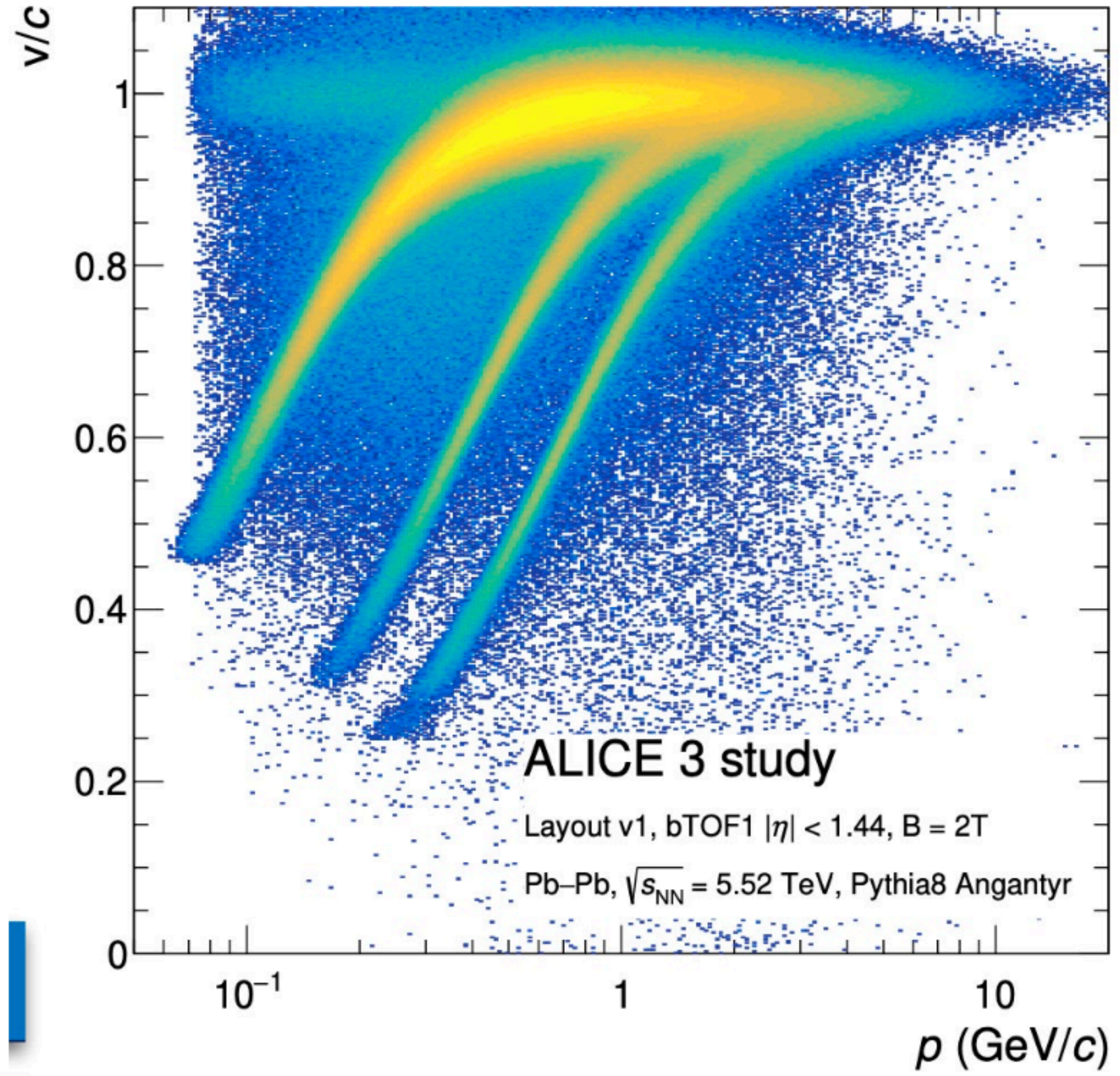
Separation power ∝ L/σ_{TOF}
→ Distance and time resolution crucial
→ Larger radius results in lower p_T bound

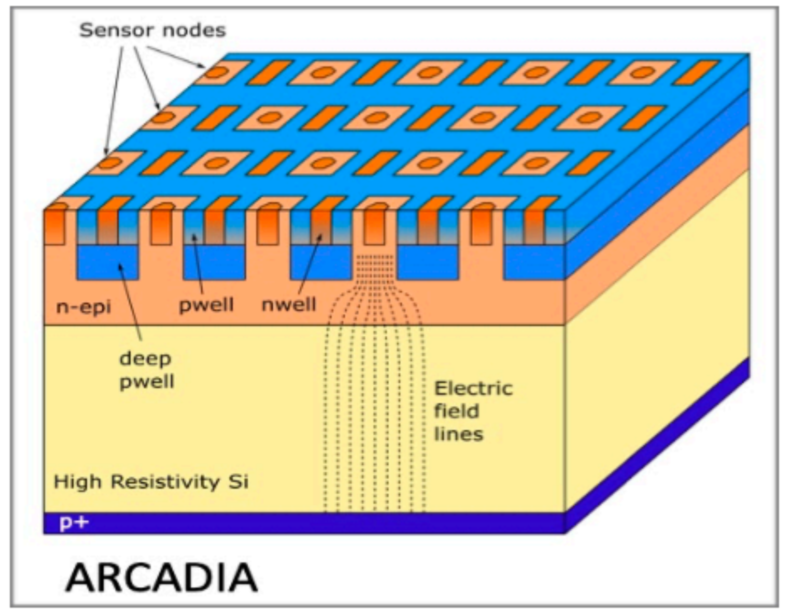
2 barrel TOF layers (|η| < 1.75)
Outer TOF at $r \approx 85$ cm, surface: 30 m^2, pitch: 5 mm
Inner TOF at $r \approx 19$ cm, surface: 1.5 m^2, pitch: 1 mm
1 forward TOF layers (1.75 < |η| < 4)
Inner radius = 15 cm, outer radius = 150 cm,
$z \approx 405$ cm, surface: 14 m^2, pitch: 1mm to 5 mm

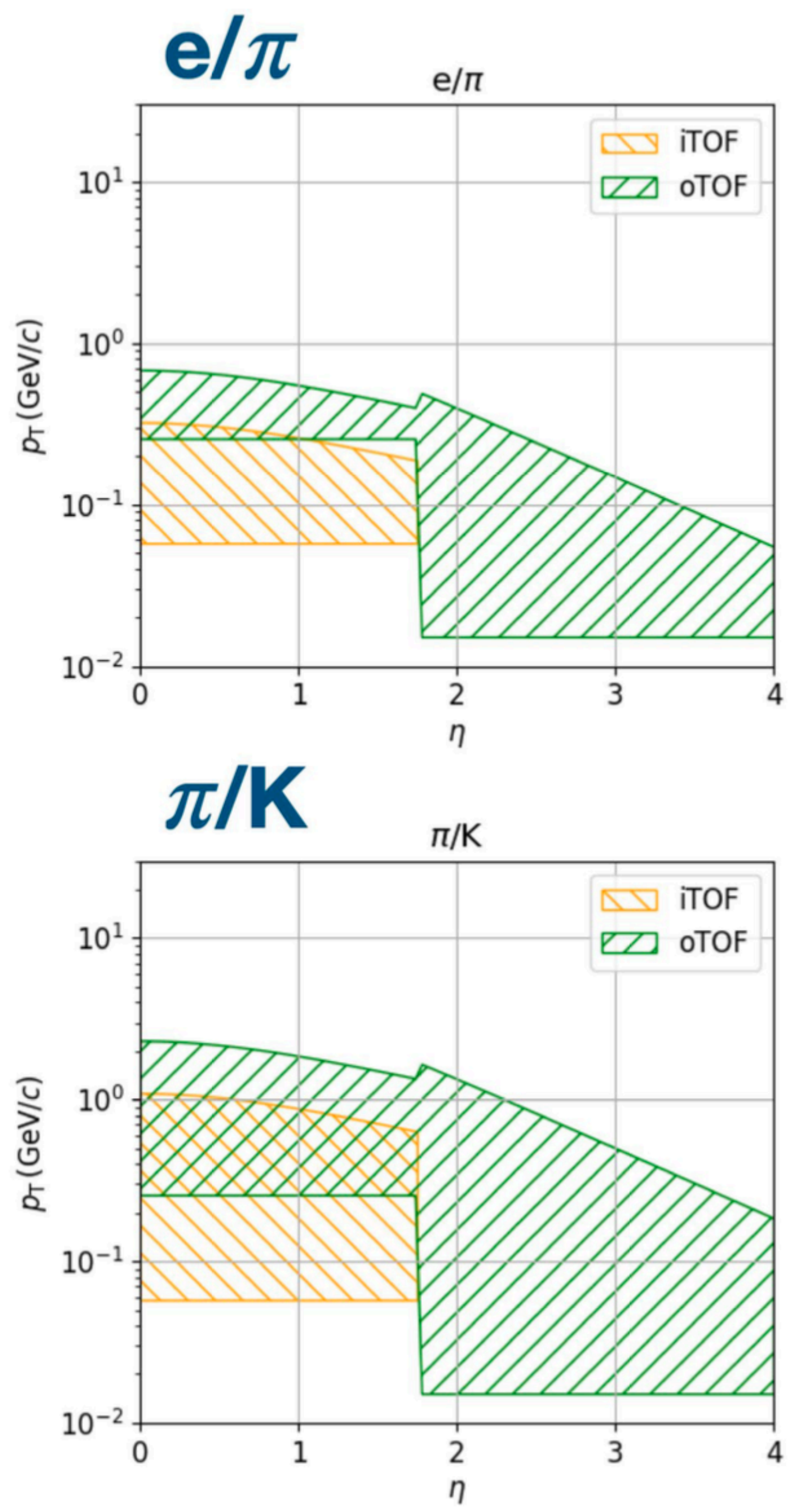
$\sigma_{TOF} \lesssim 20$ps

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







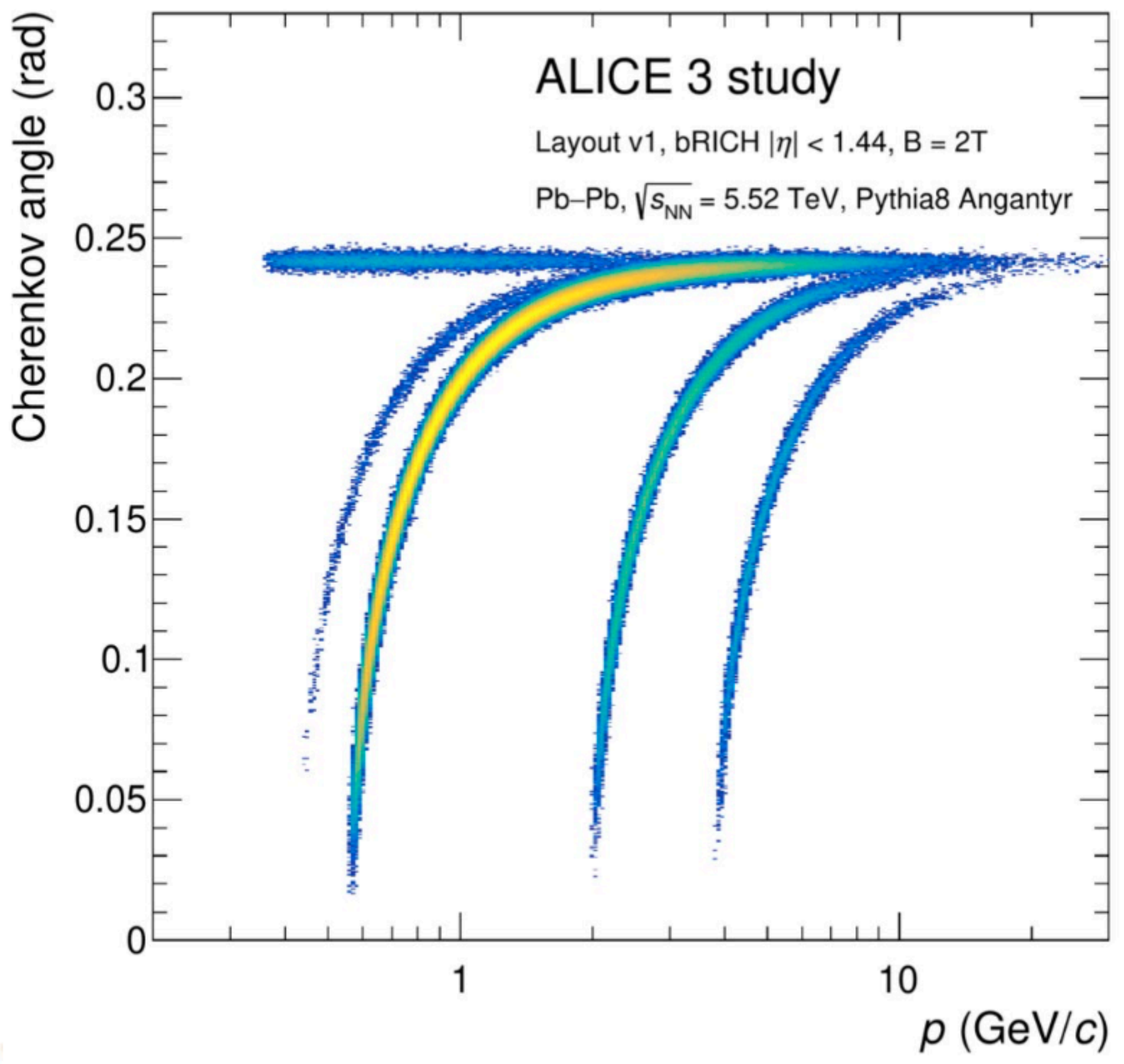
PID from RICH

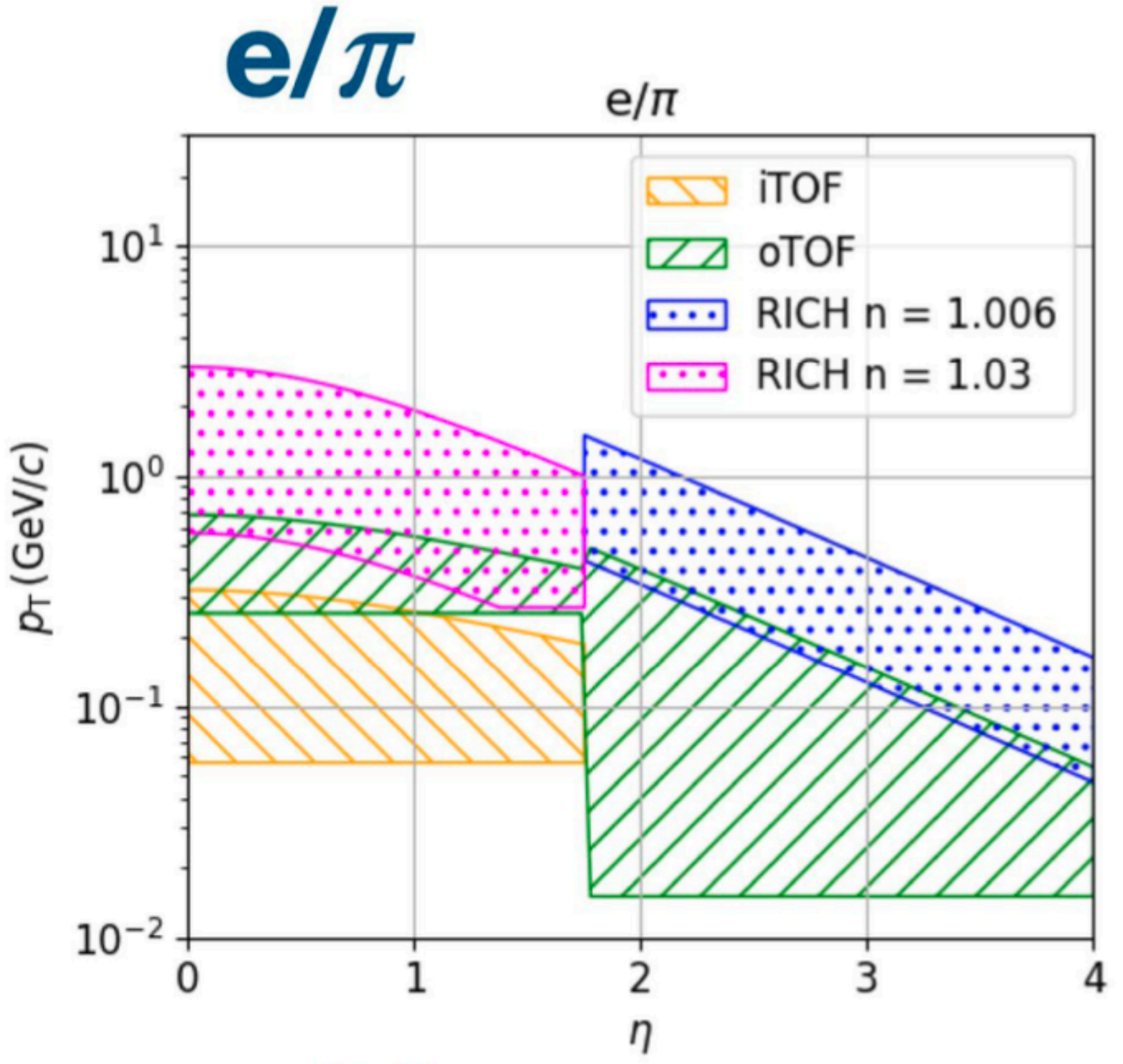
Complement PID reach of outer TOF to higher p_T with Cherenkov detector
→ Ensure continuous coverage with the TOF

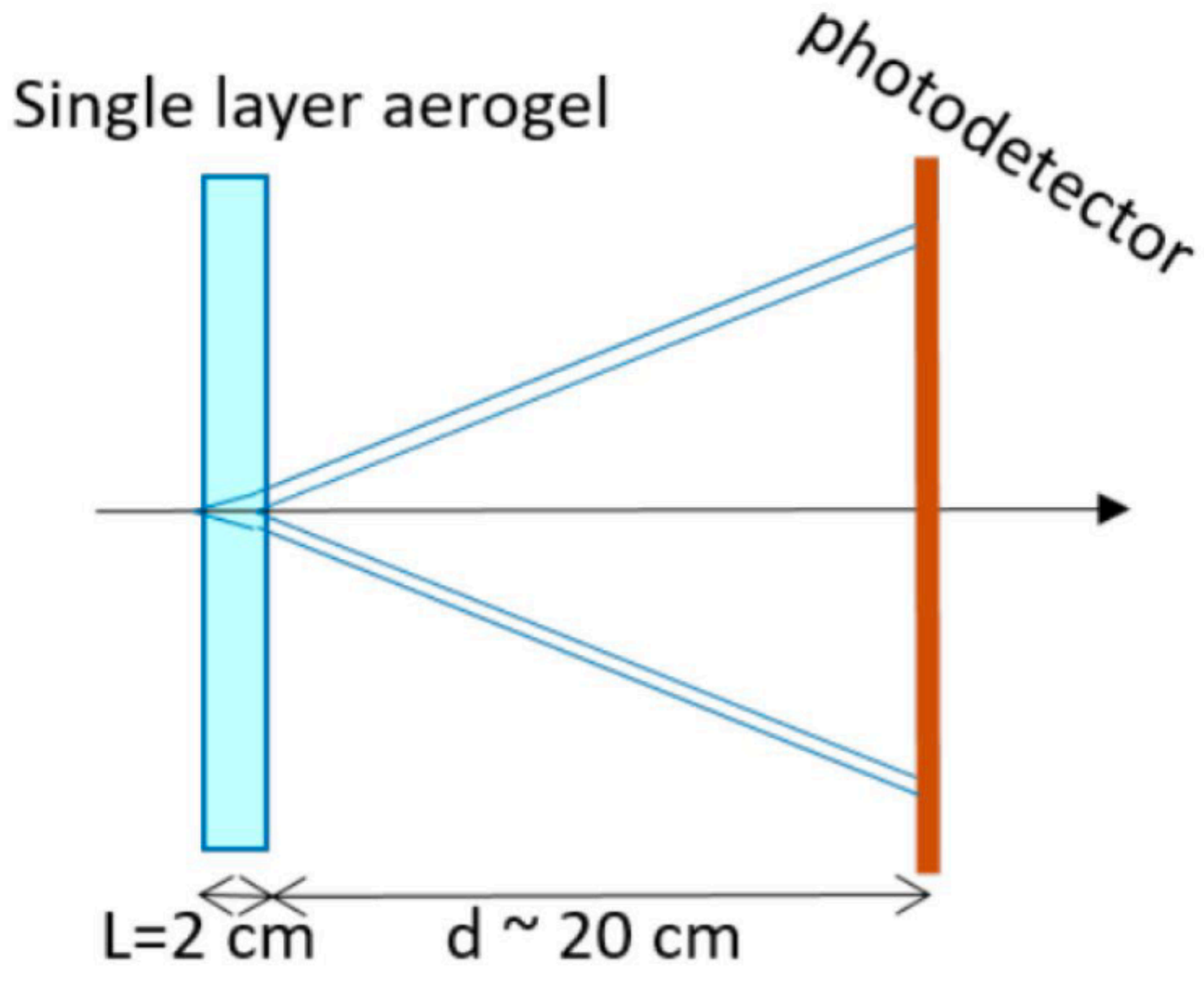
Aerogel radiator

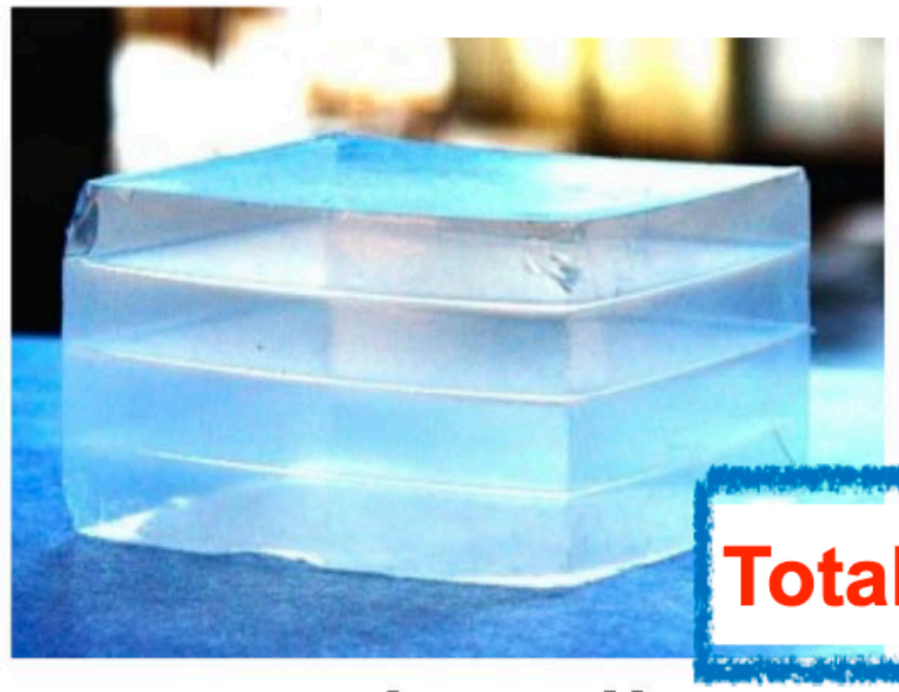
- Refractive index n = 1.03 (barrel)
- Refractive index n = 1.006 (forward)

R&D on monolithic silicon photon sensors



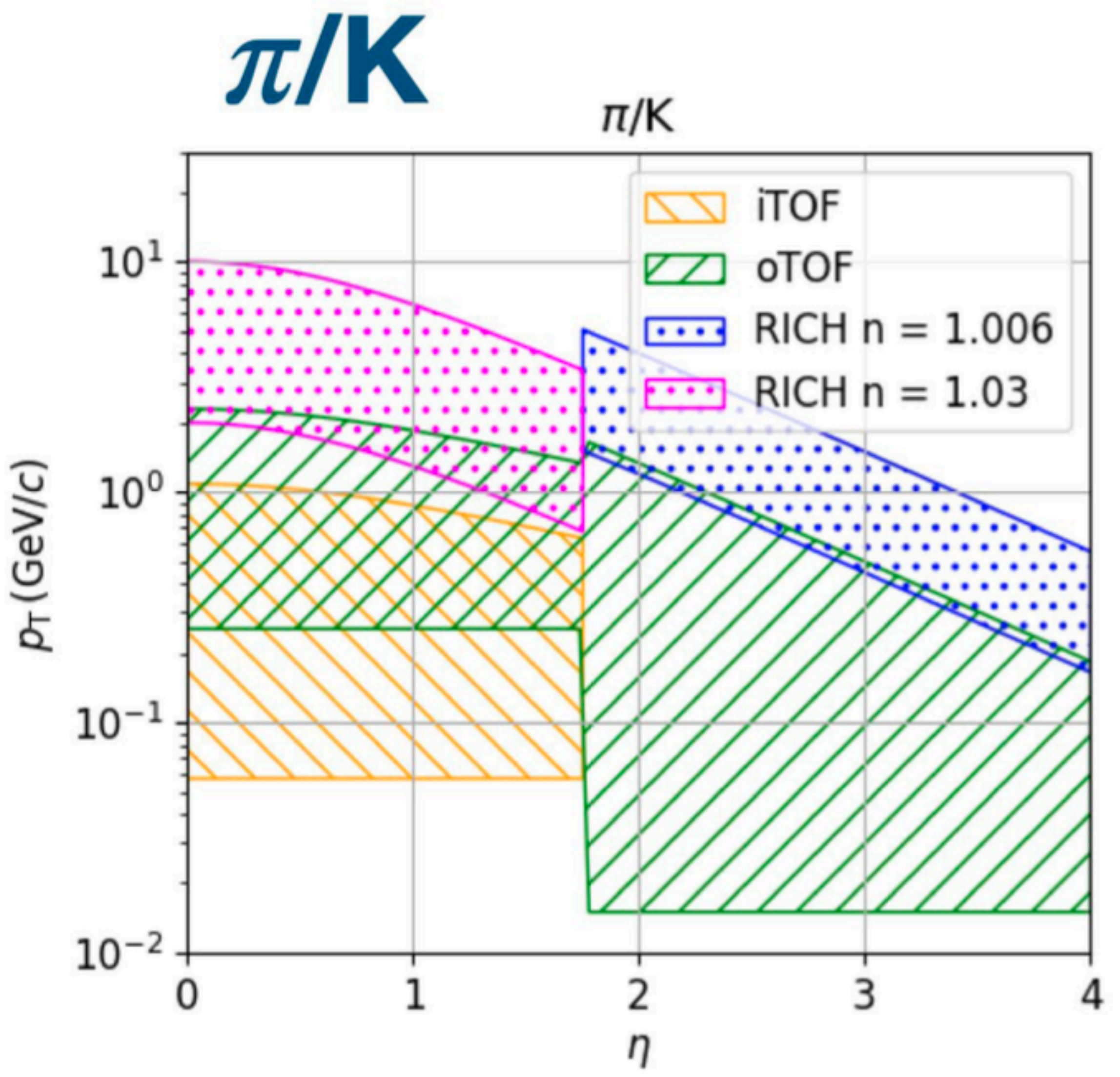


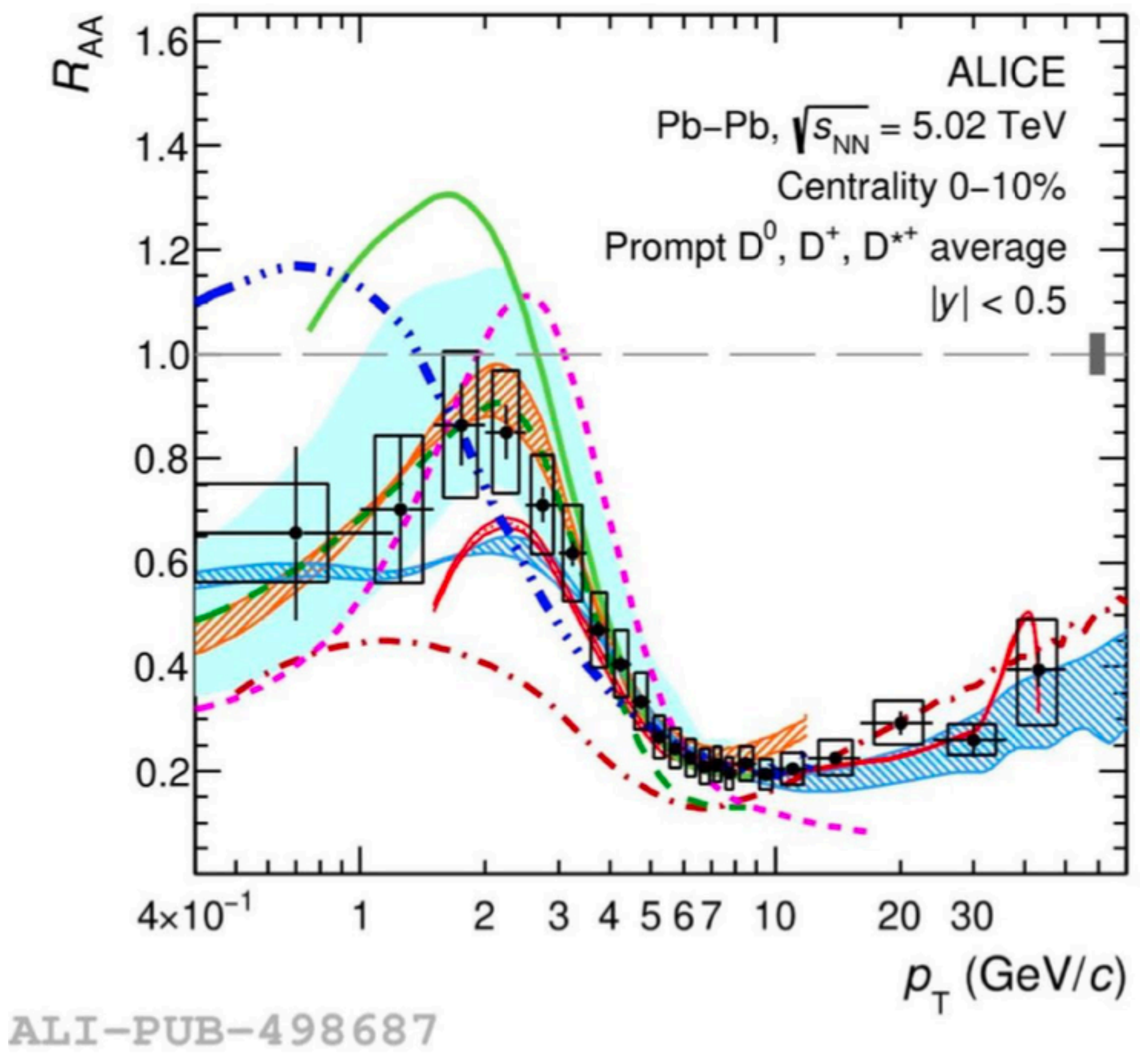


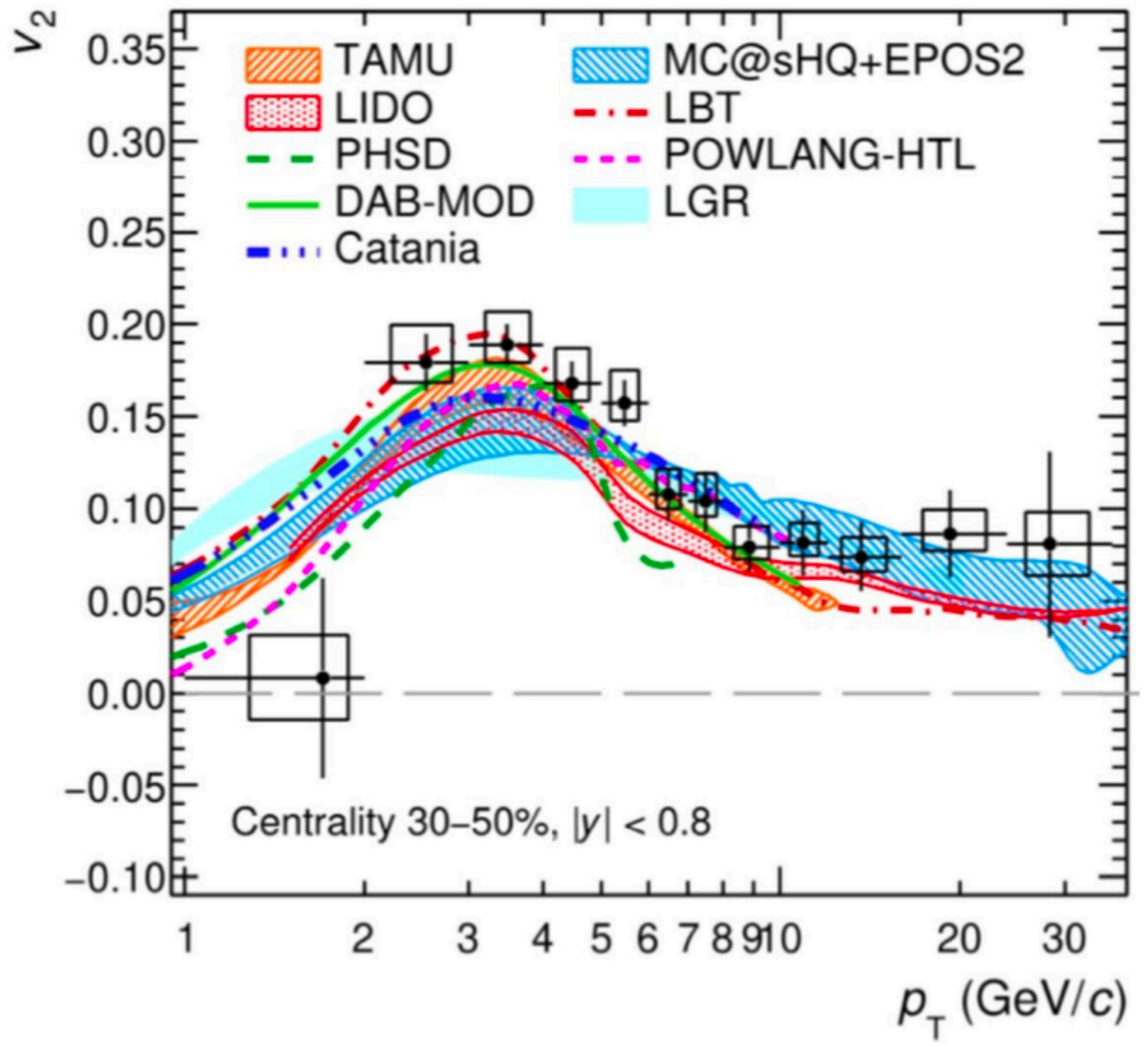


aerogel radiator

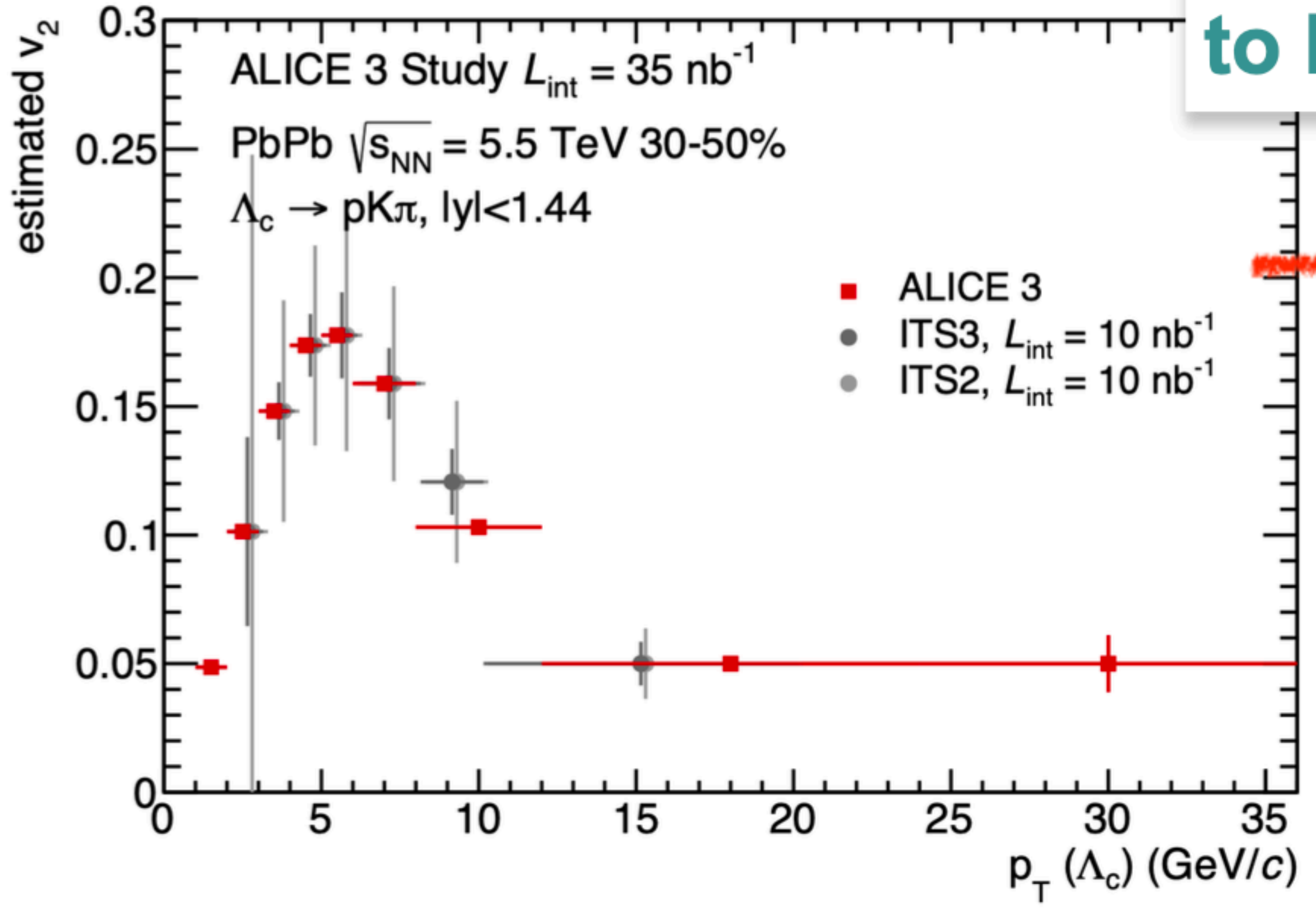
Total SiPM area ~ 60 m²





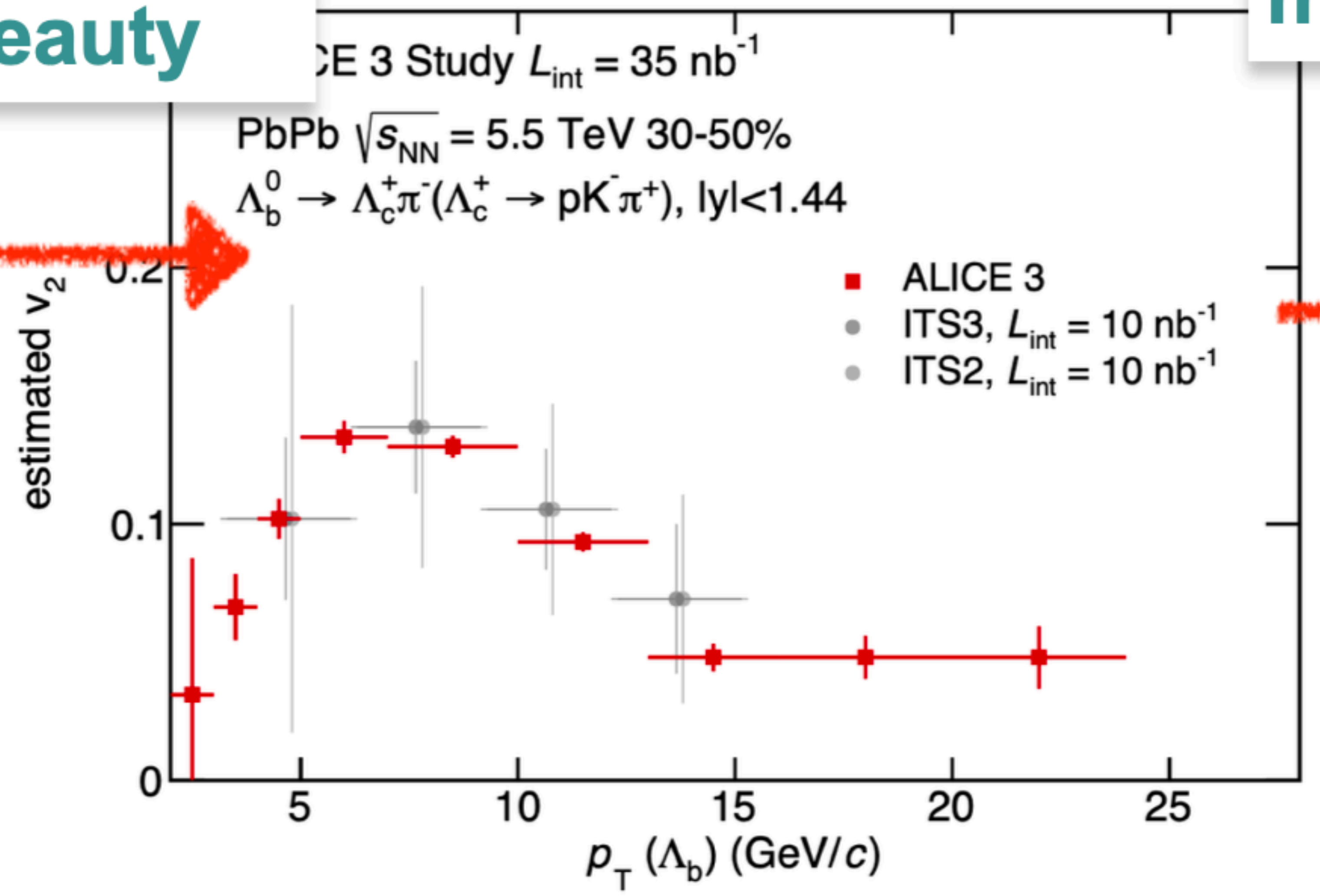


Λc v2 performance

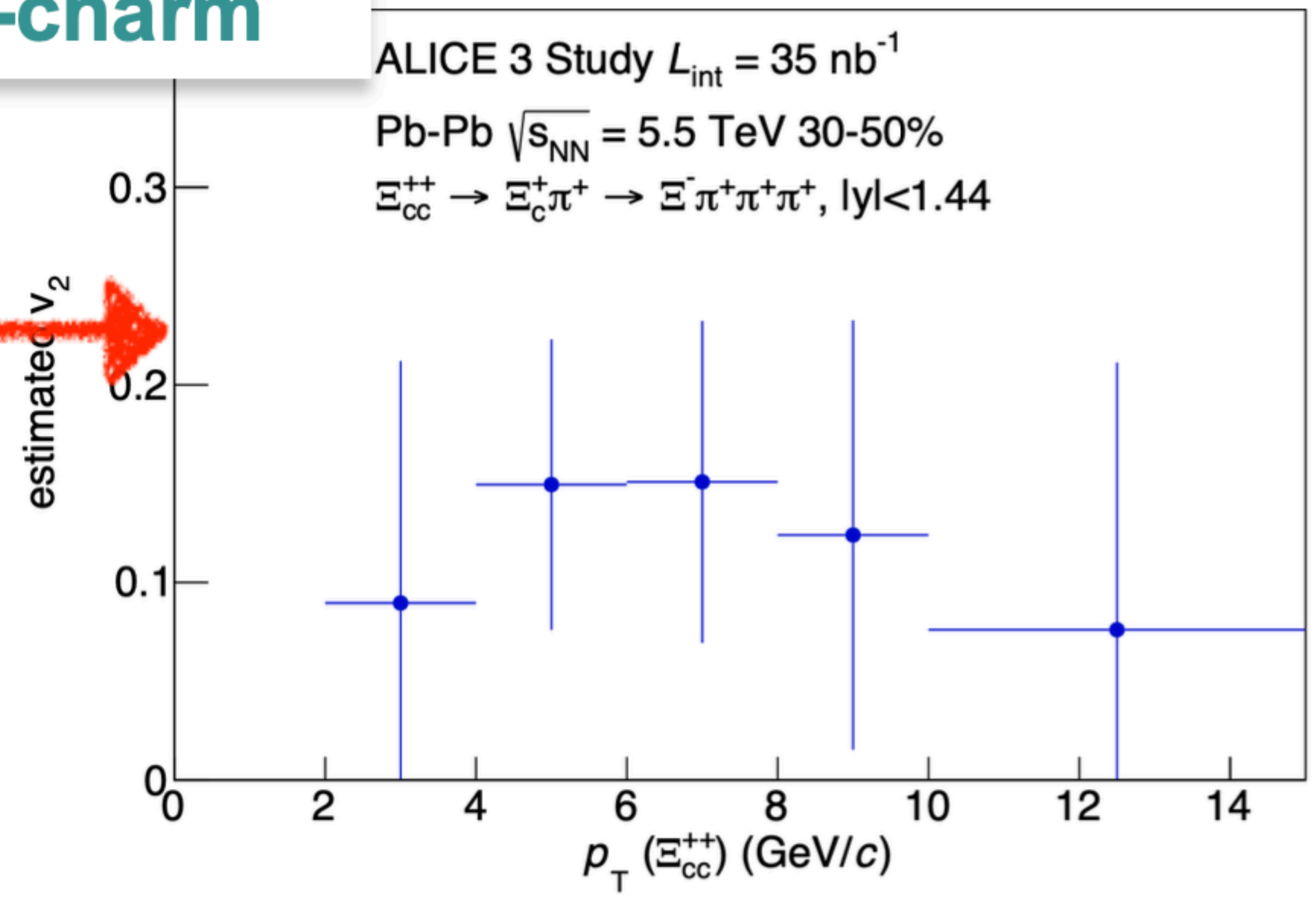


Extension to beauty

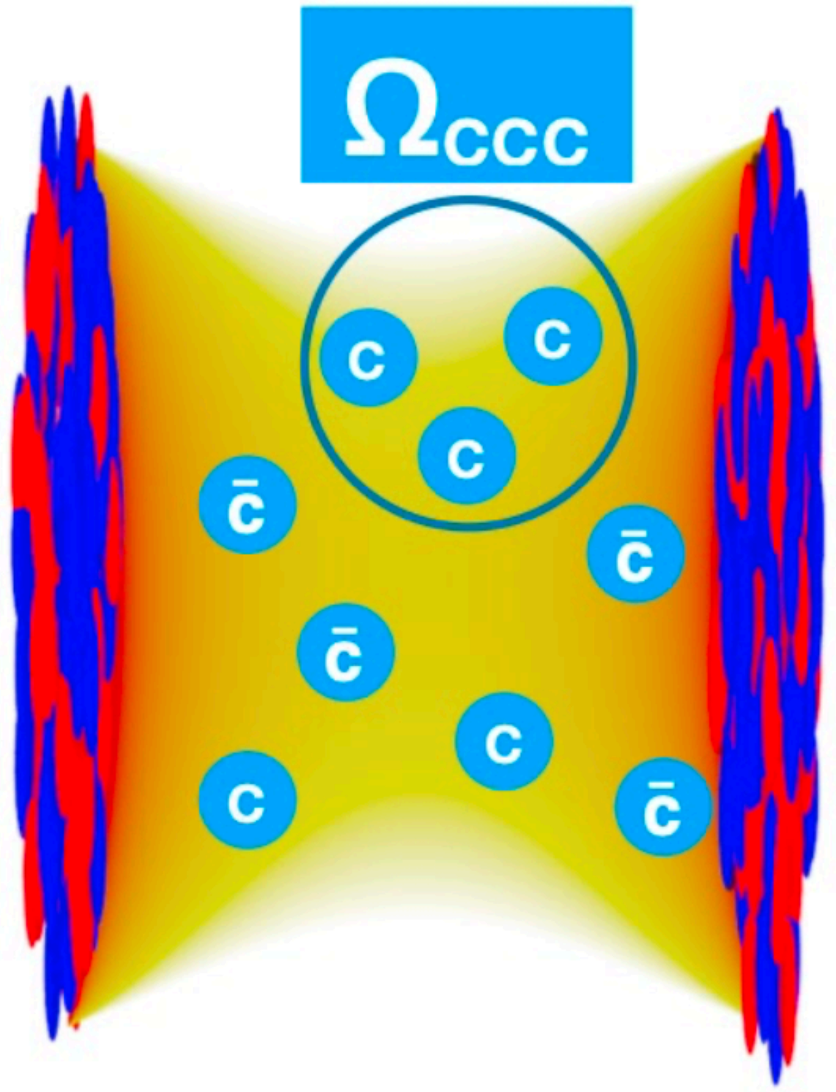
Λb v2 performance



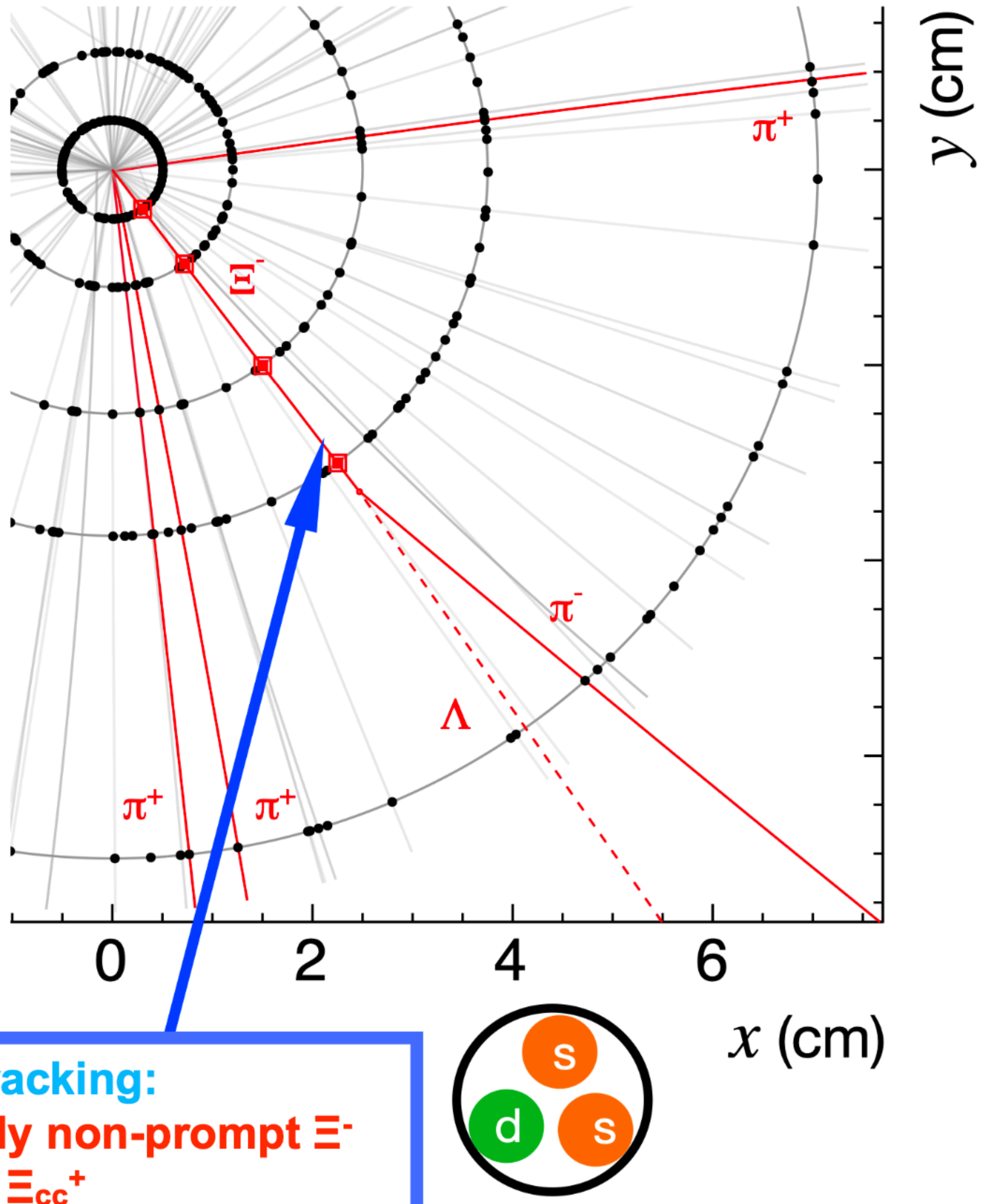
Extension to multi-charm



Mulitcharm hadrons



$$\Xi_{cc}^{++} \rightarrow \Xi_c^{+} + \pi^{+} \rightarrow \Xi^{-} + 3\pi^{+}$$



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

감사합니다!

Thanks for your attention!