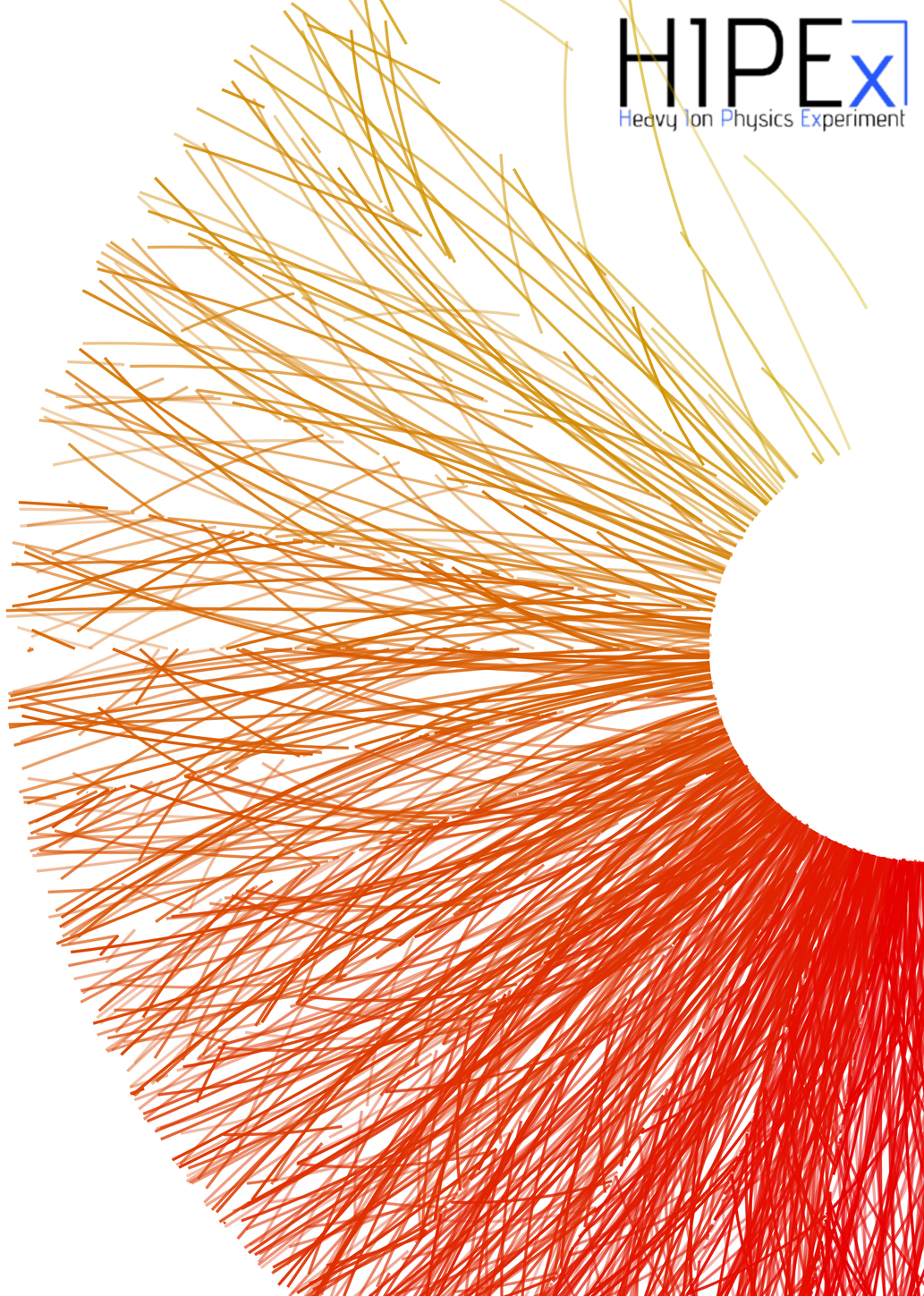
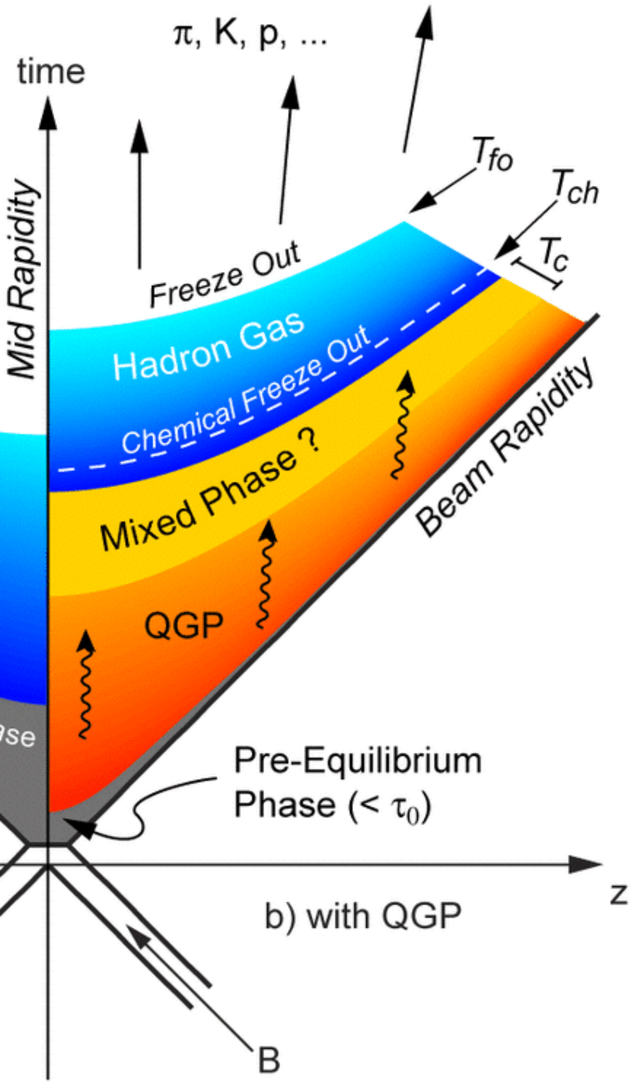
Recent Measurements Hadronic Resonances with ALICE at the LHC

Bong-Hwi Lim (Pusan National University, KR)
of be half of ALICE collaboration



Why Resonances?

In Light Flavor (Strangeness)



- **Short lifetimes**
  - Comparable to Hadronic Phase
- **Excited States**
  - Can compare results to the other particles with similar quark contents

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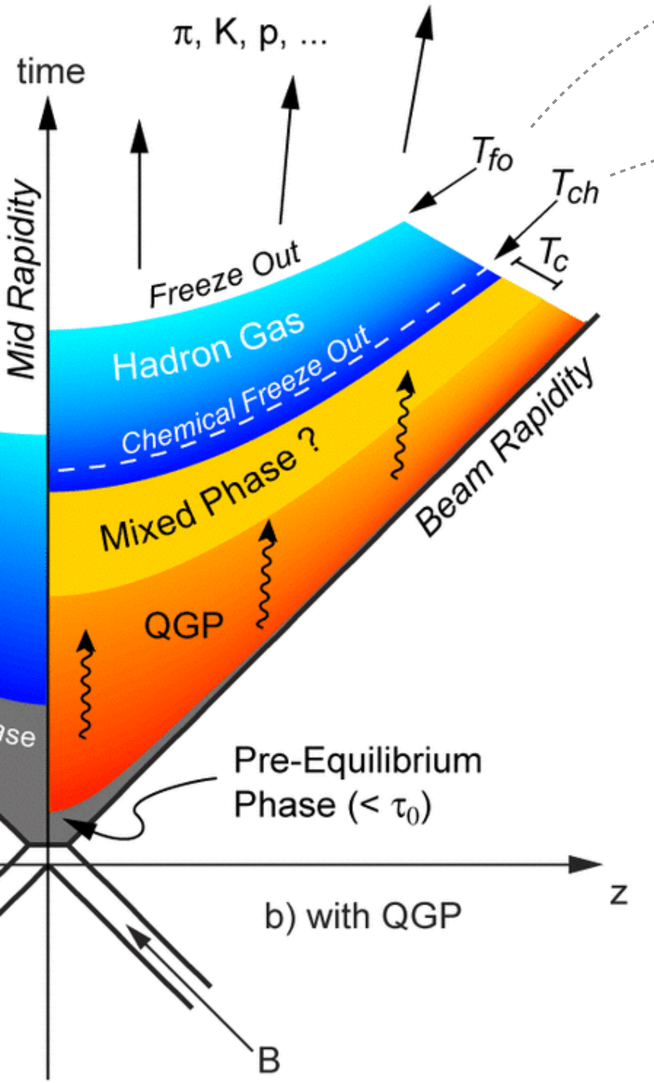

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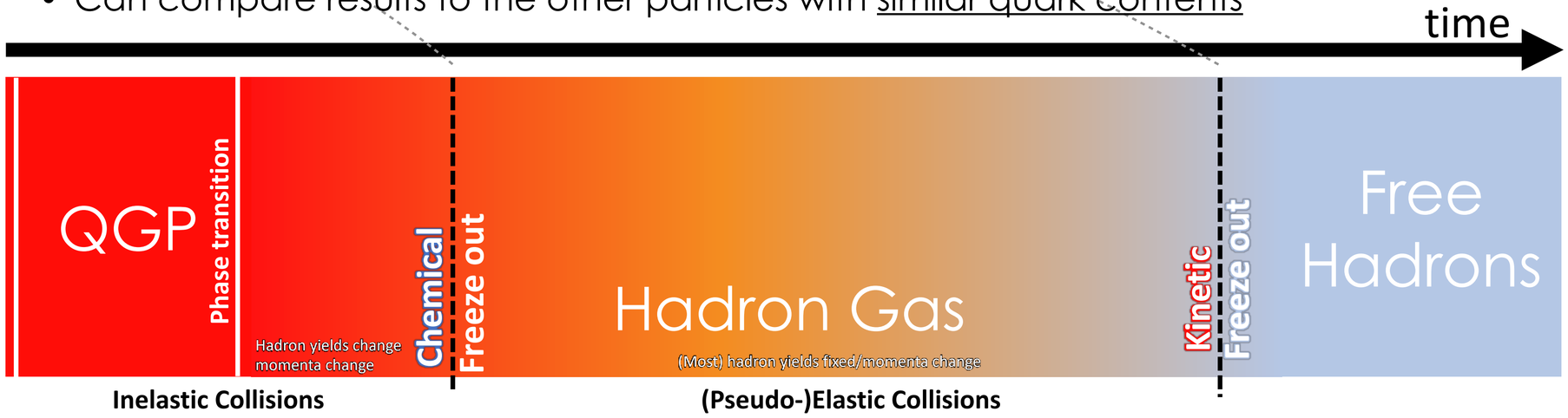

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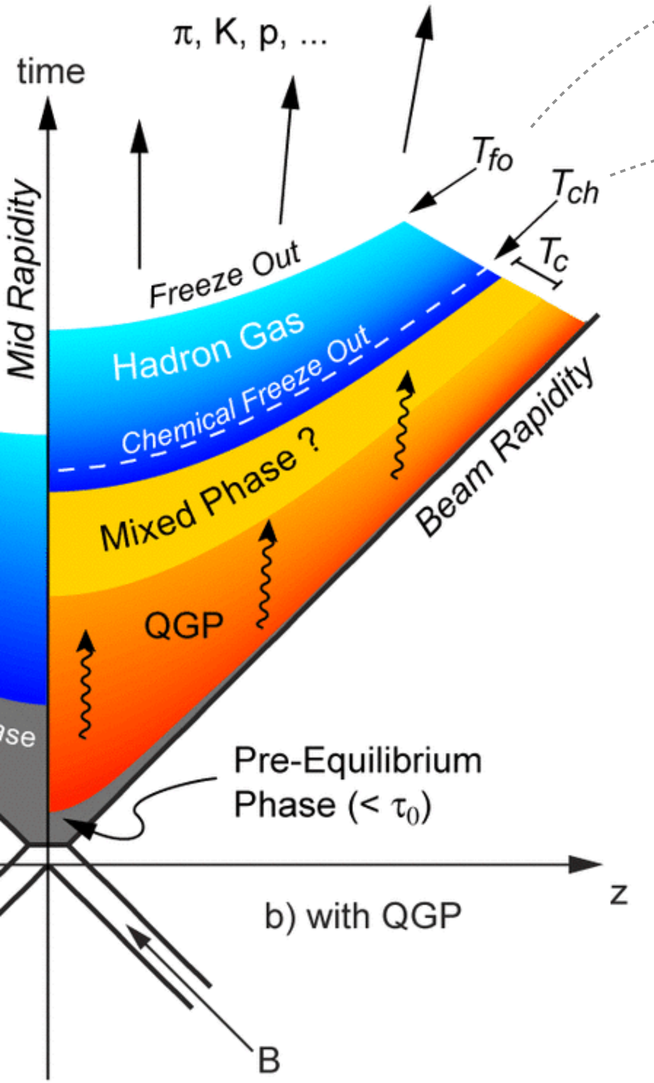

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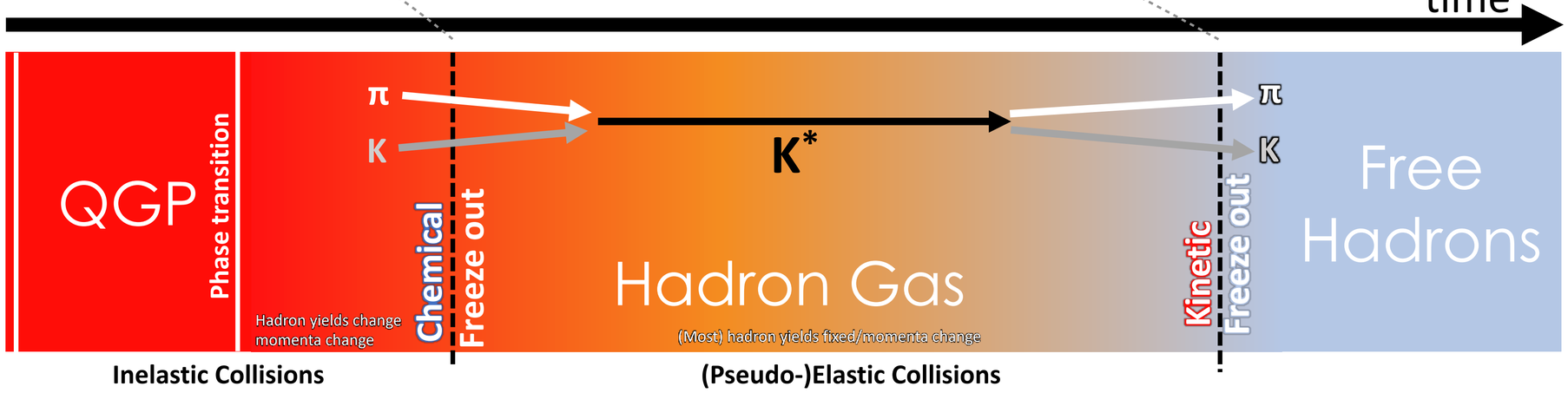

Regeneration

: pseudo-elastic scattering through resonance state

➡ **Enhanced yield**

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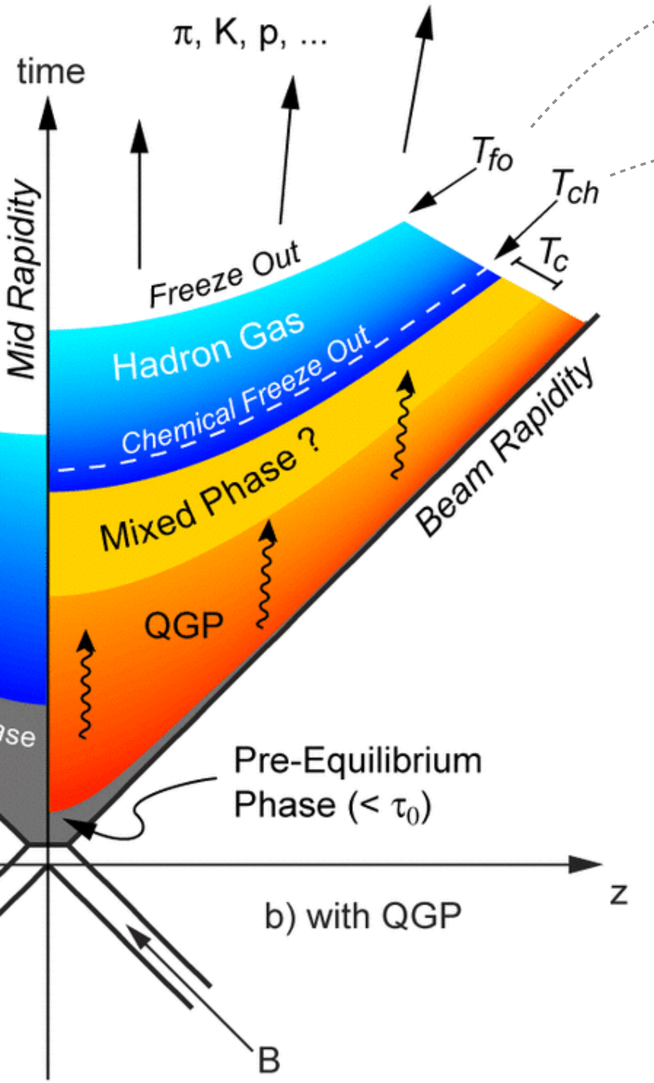

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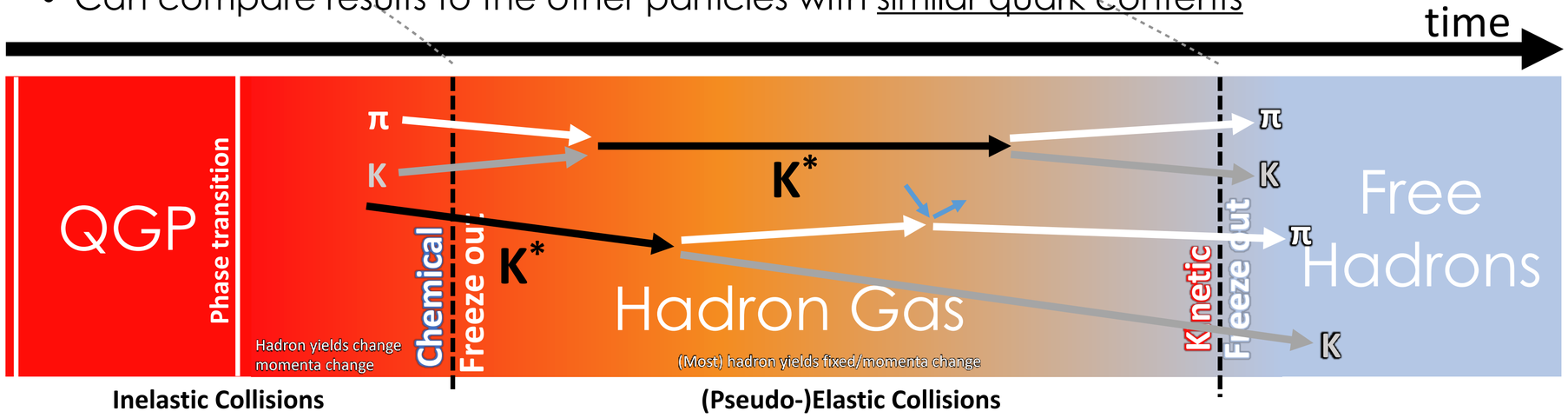

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Re-scattering

: elastic scattering smears out mass peak

➡ **Reduced yield**

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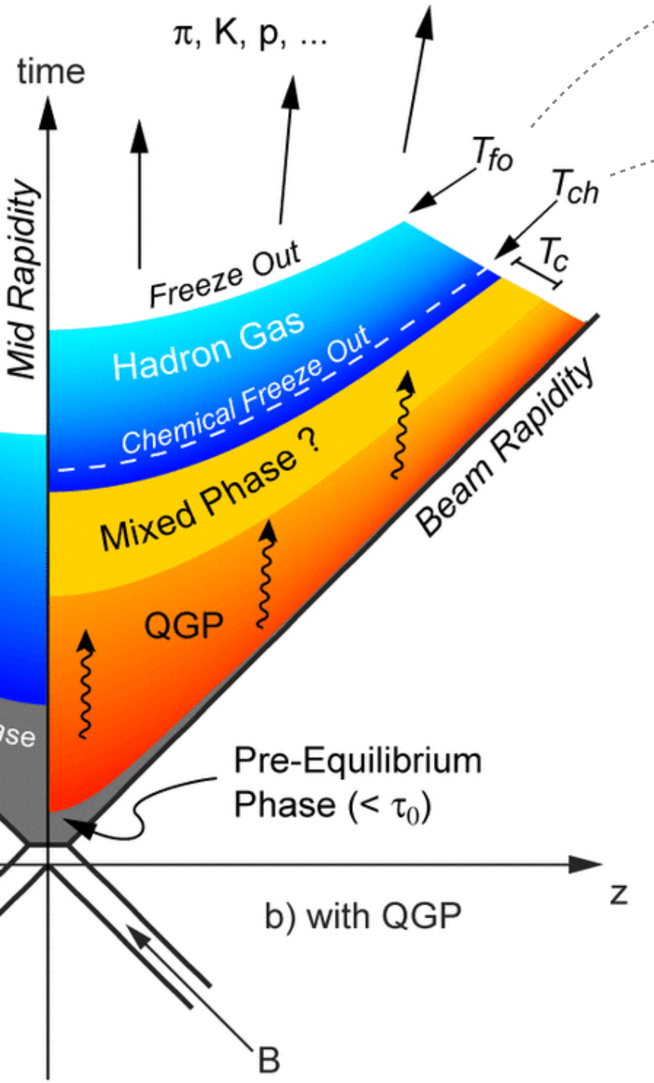

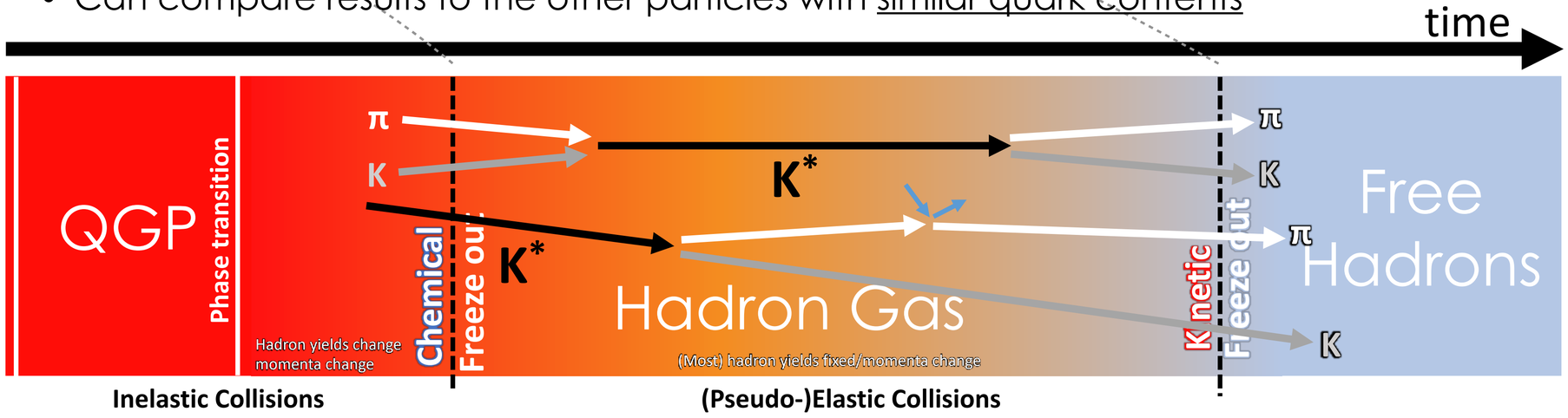

Regeneration

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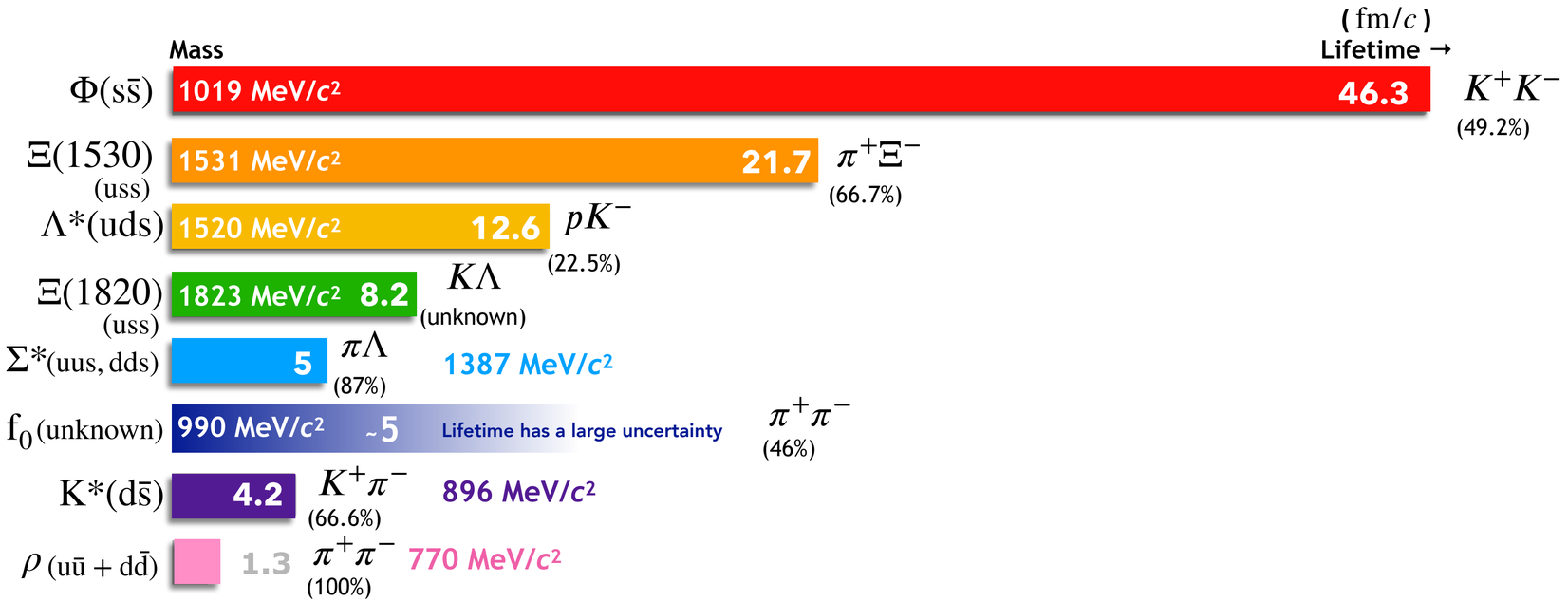
: elastic scattering smears out mass peak

➡ **Reduced yield**

- **Chemical freeze out temperature(T_{ch})**
- **Lifetime of Hadronic Phase**
- **Lifetime of resonance itself**
- **Scattering cross-sections of decay products**

Overview: Light Flavour Resonances

Characteristics // knobs



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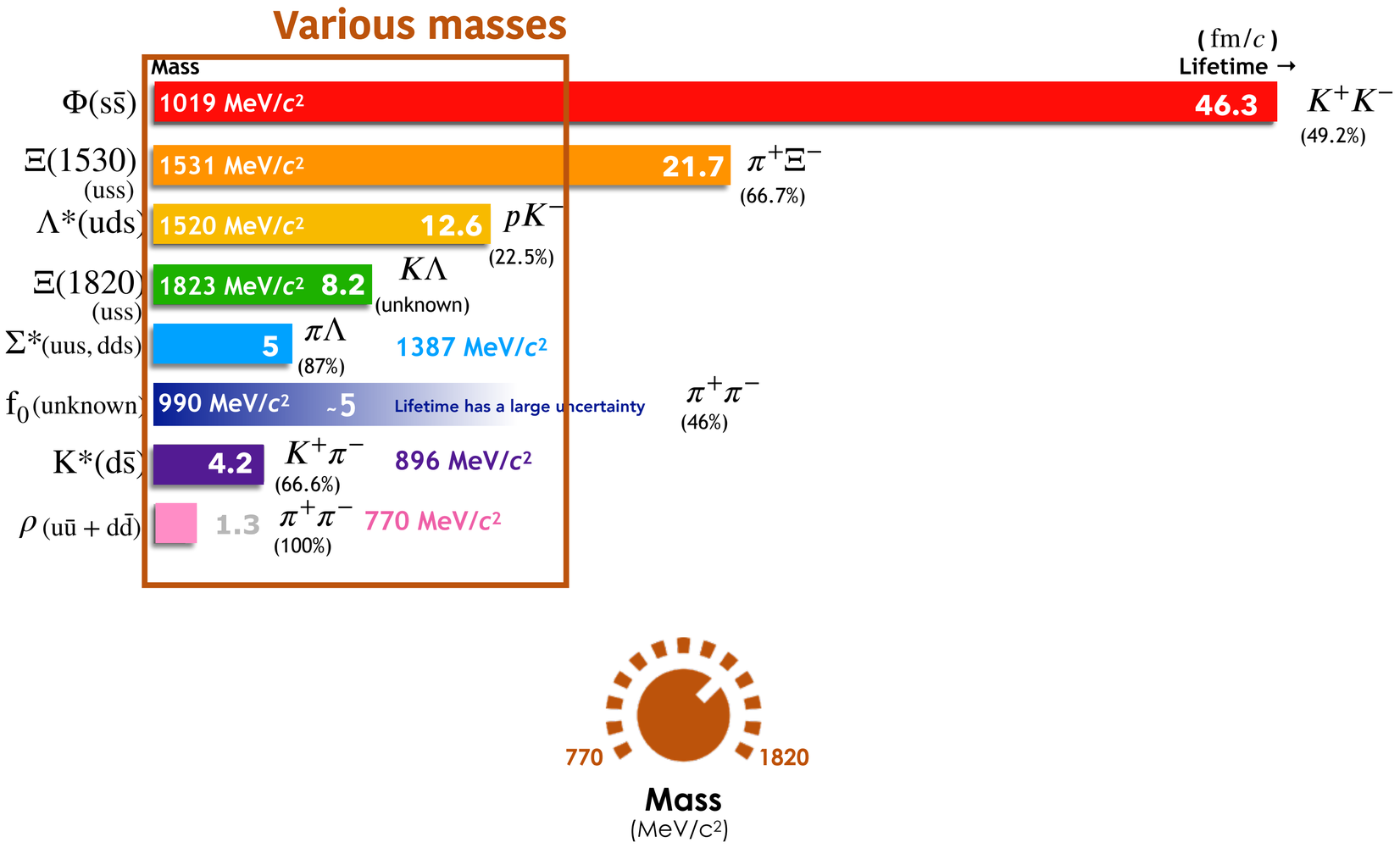

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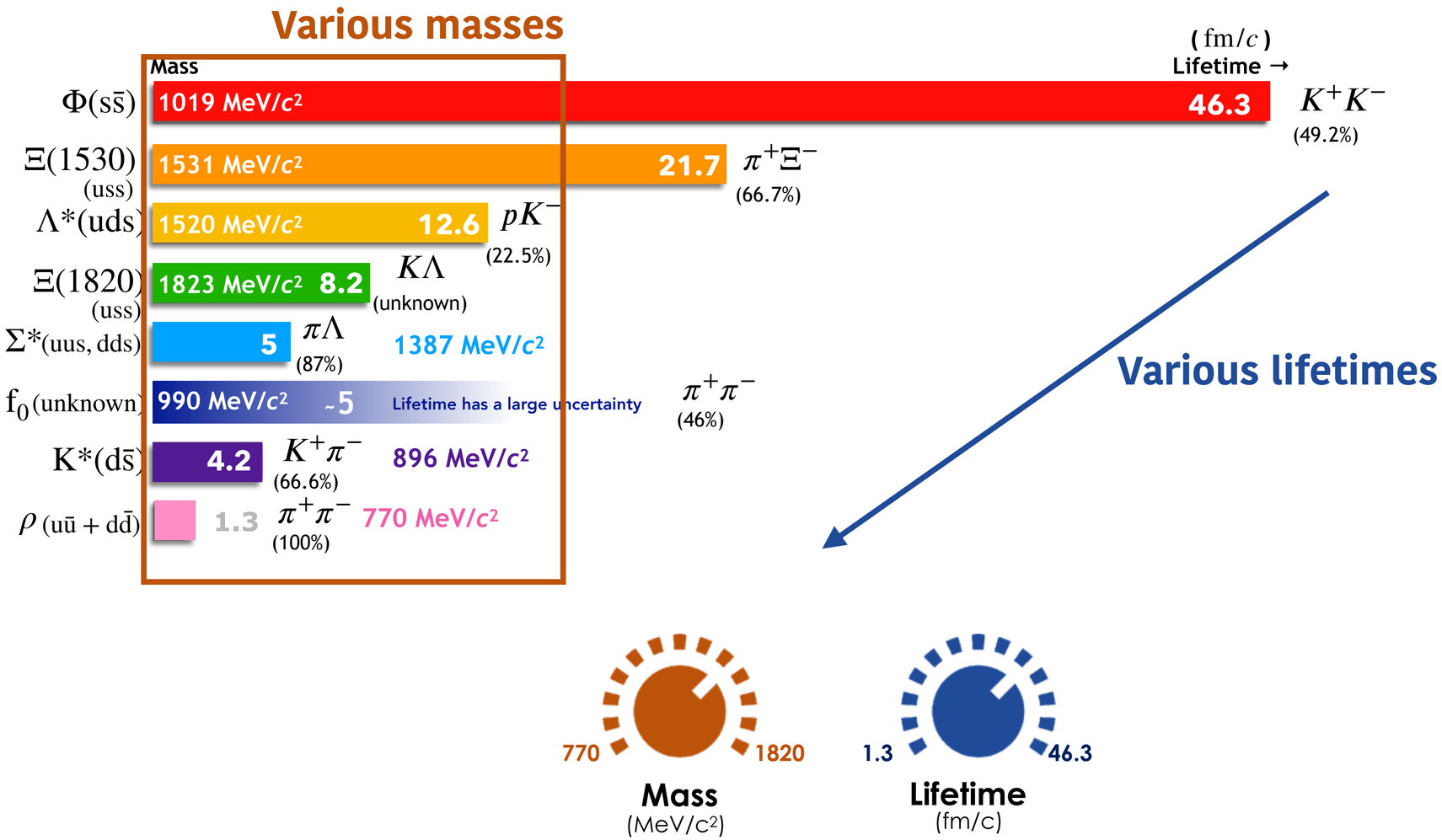

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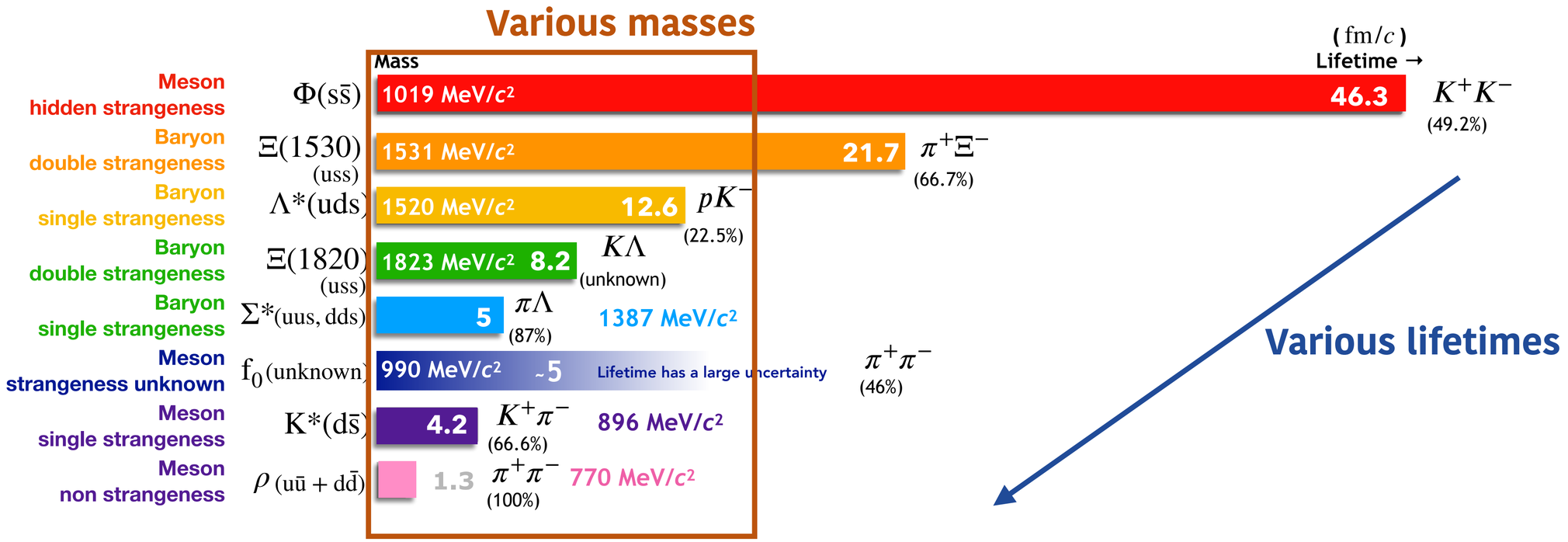
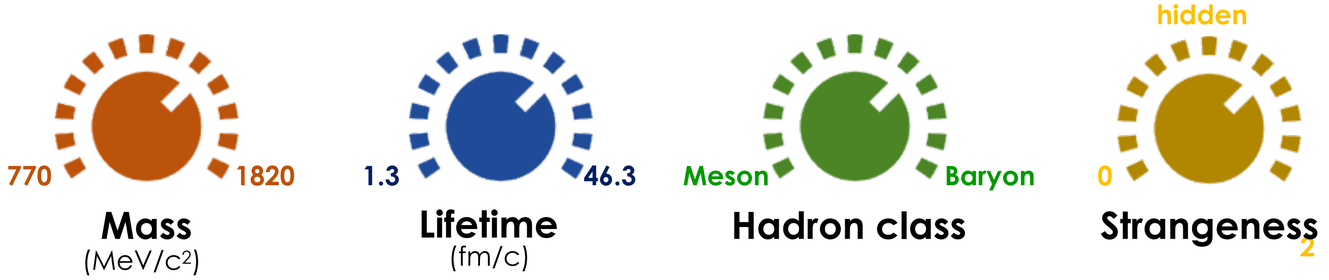
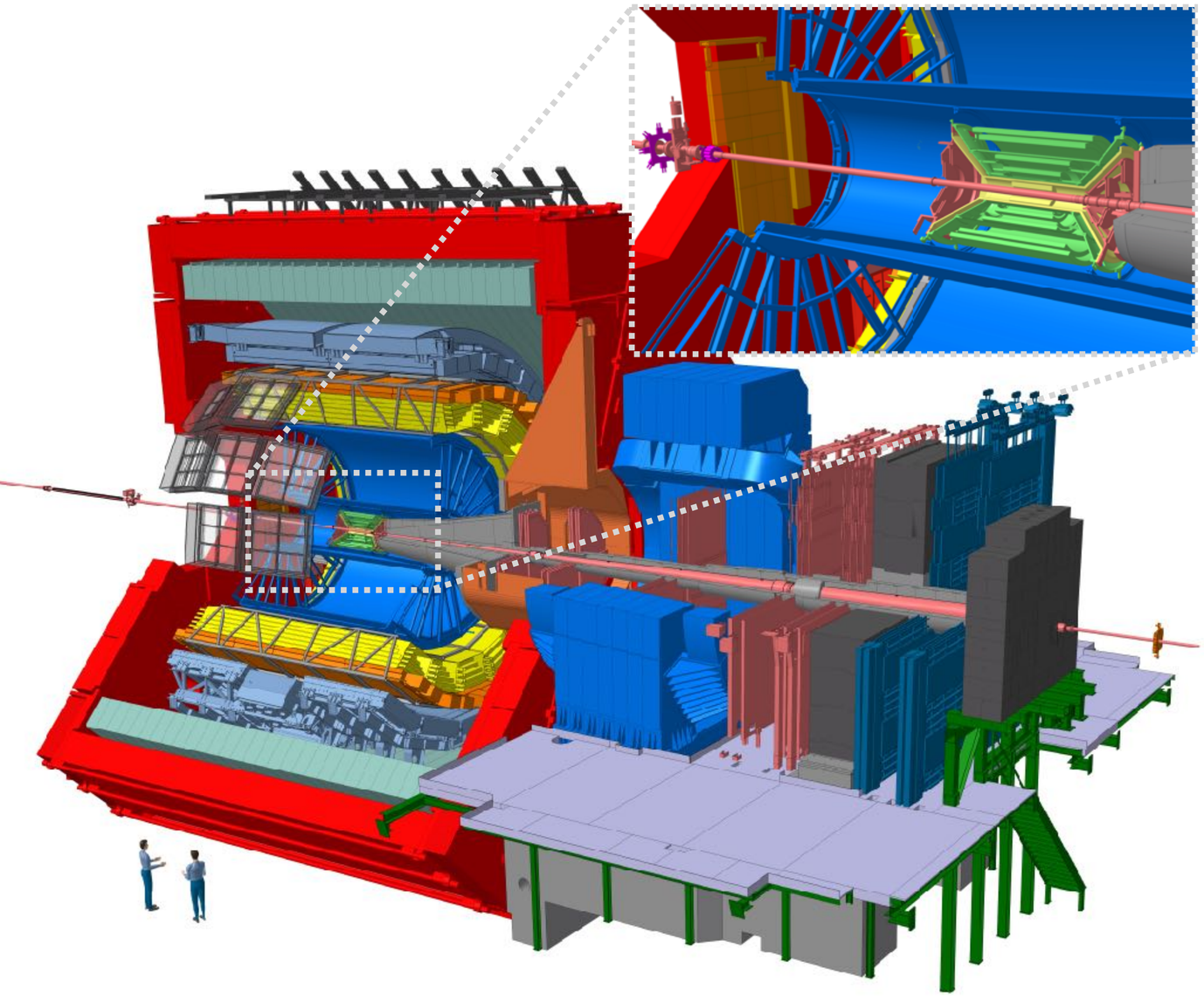


Different hadron class / Strangeness



RESONANCES may have knobs that can be used to study the hadronic phase.

The ALICE detector



- Multi-purpose detector at the LHC with unique **particle identification** capabilities and tracking down to **very low momenta**
- **Central Barrel Detectors ($|\eta| < 1$)**
  - ITS ($|\eta| < 0.9$)
    - 6 layers of silicon detectors
    - Trigger, tracking, vertex, PID ($\mathrm{d}E/dx$)
  - TPC ($|\eta| < 0.9$)
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  - V0 [V0A ($2.8 < \eta < 5.1$) & V0C ($-3.7 < \eta < -1.7$)]
    - Arrays of scintillators
    - Trigger, beam gas rejection, **Multiplicity estimator**

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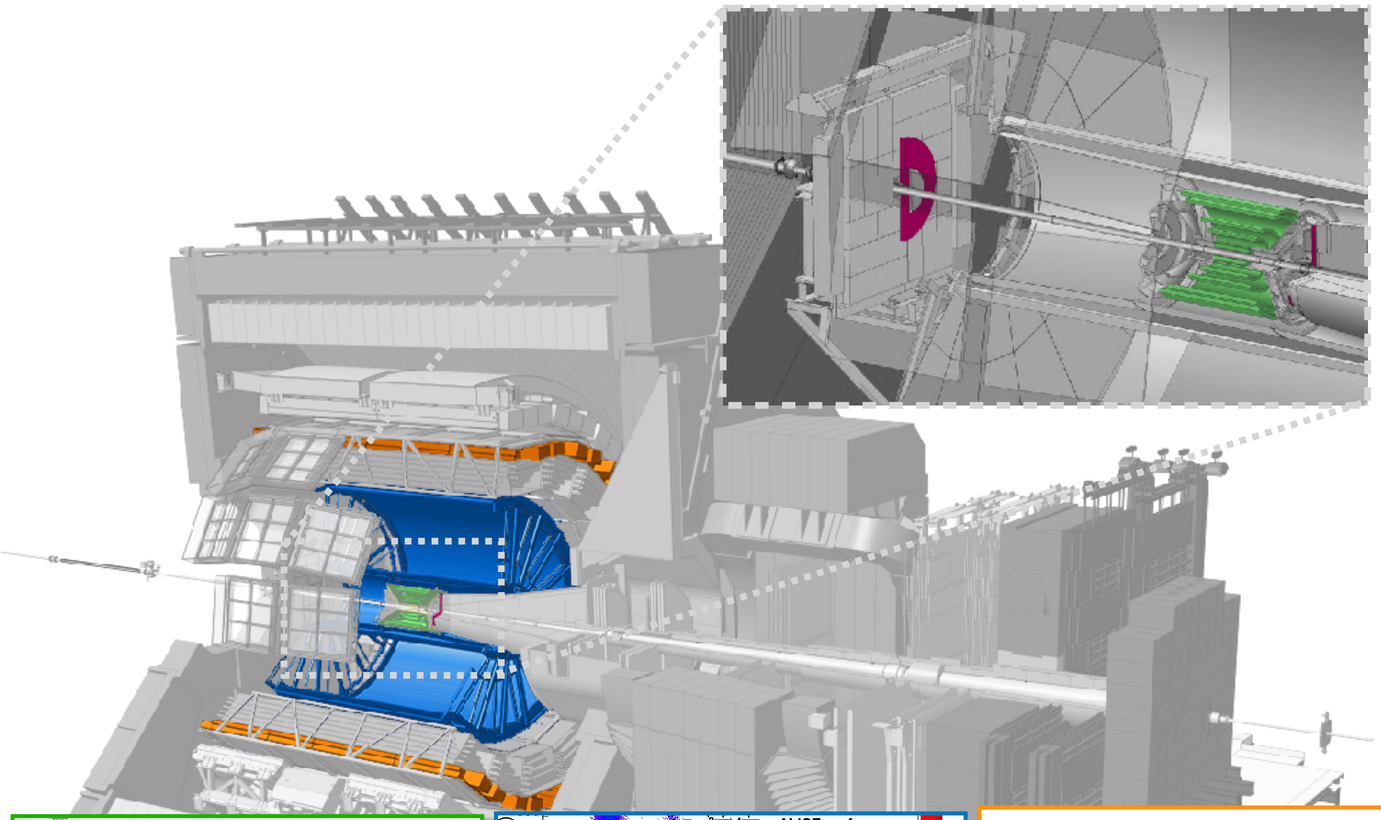

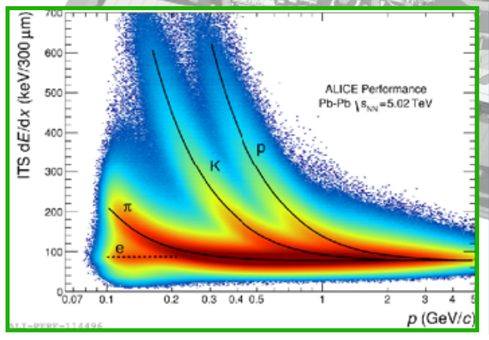

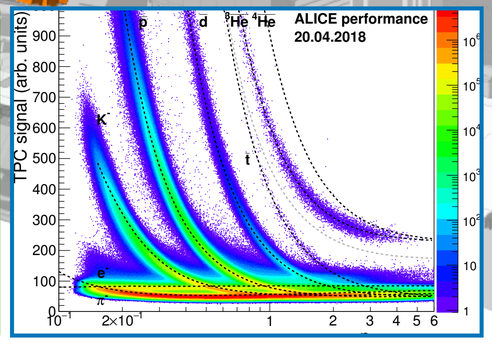

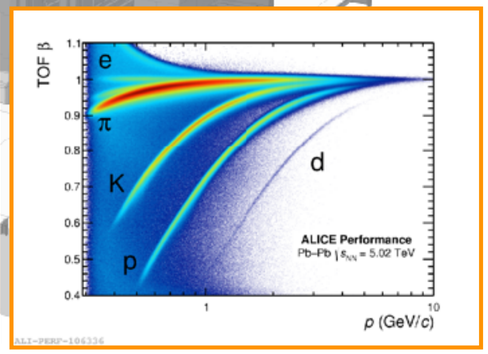

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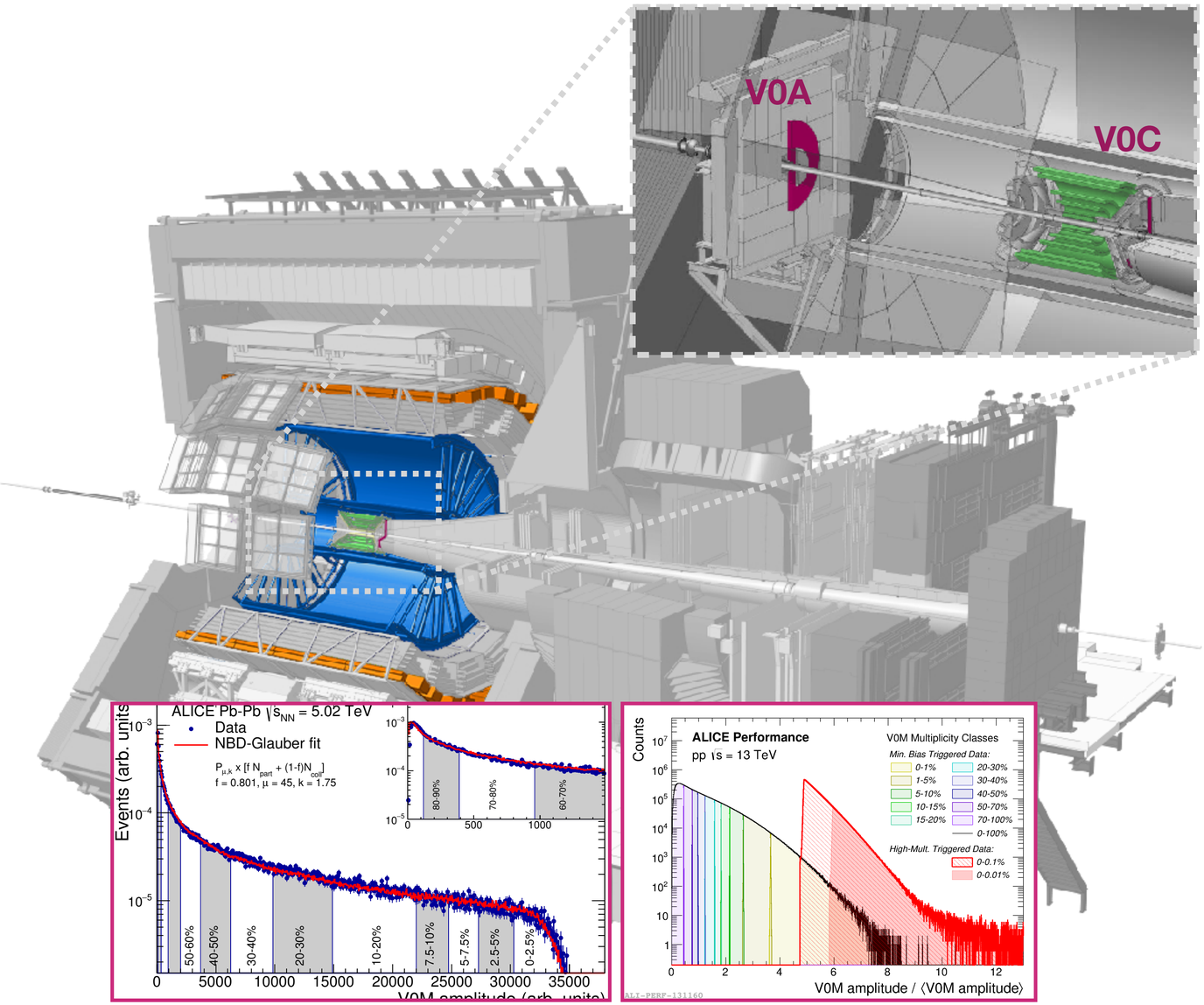

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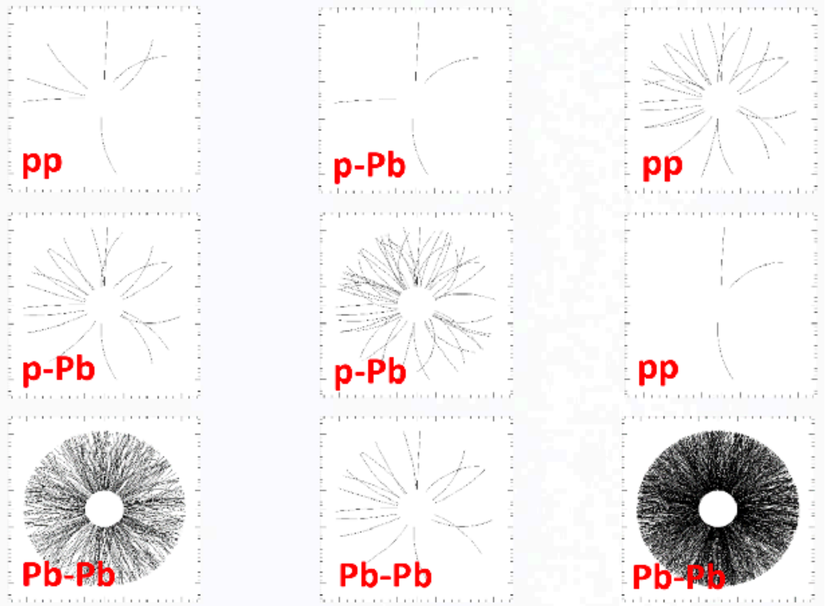
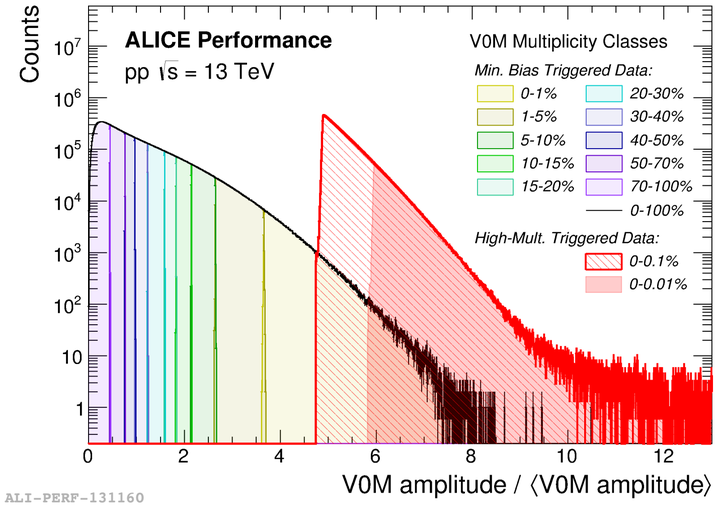
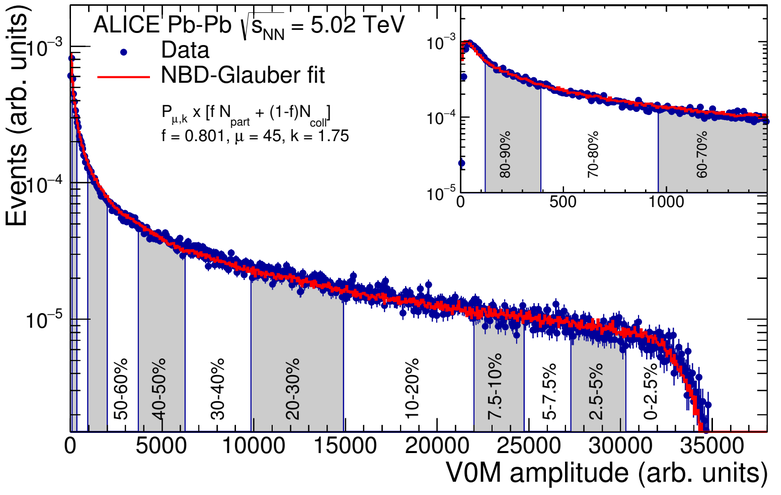
“Multiplicity”

Small system // Large system

- **System size** may refer…
  - *Size of the colliding objects*
    - Common way of thinking
    - (ee <) pp < p-A < A-A
  - *Size of the created medium*
    - Correspondence to the previous true only on average
    - N_{part}, N_{coll}, **Multiplicity**
- **Multiplicity**: Number of particles produced in a defined kinematic region.
  - Estimated by Multiplicity estimator
    - Categorize each event according to its multiplicity

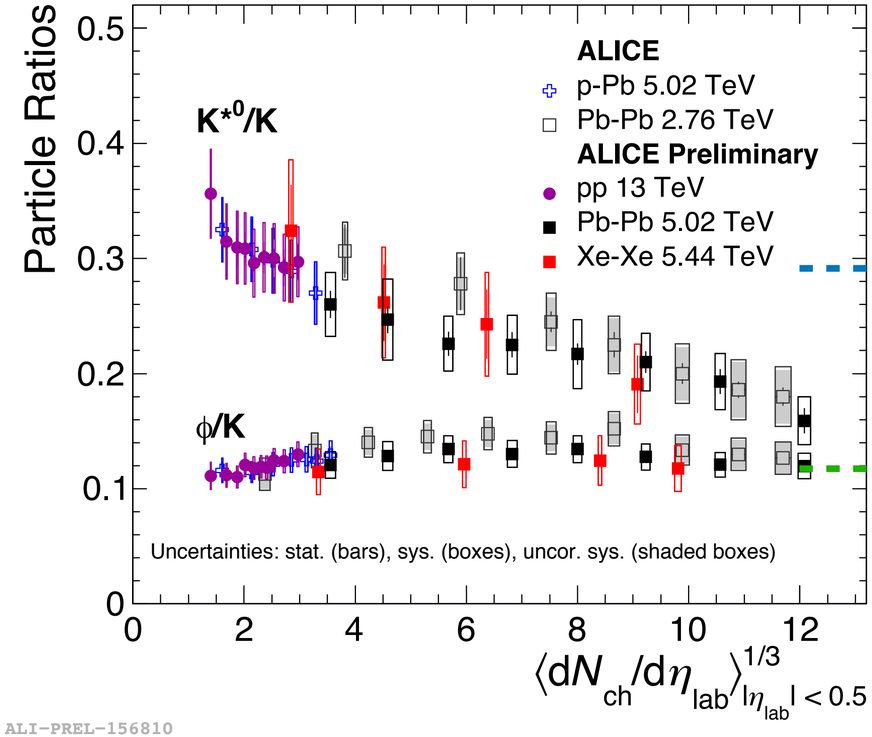






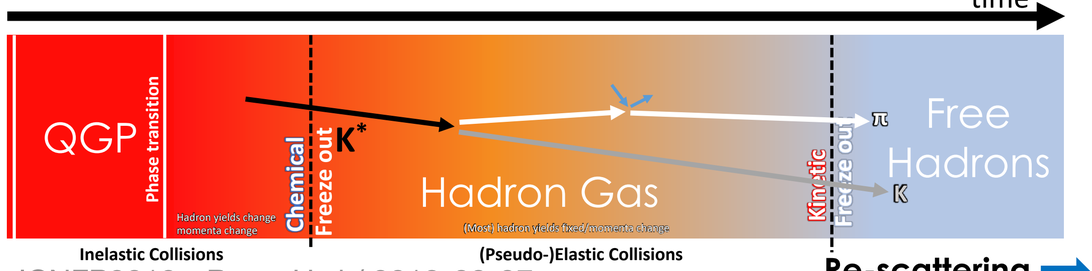
Focus on particle ratios: K* and Φ

Suppression vs Constant



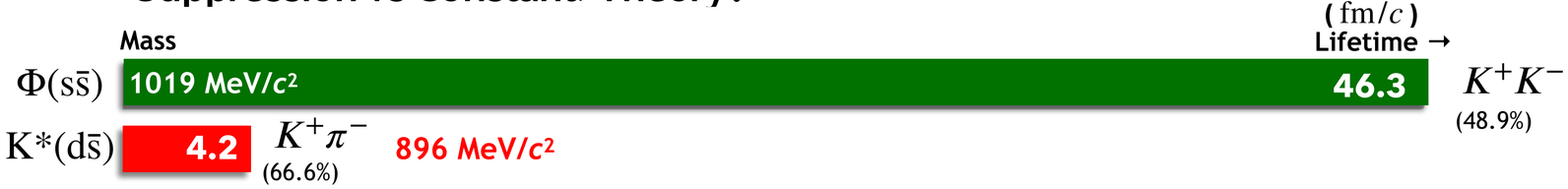
ALI-PREL-156810

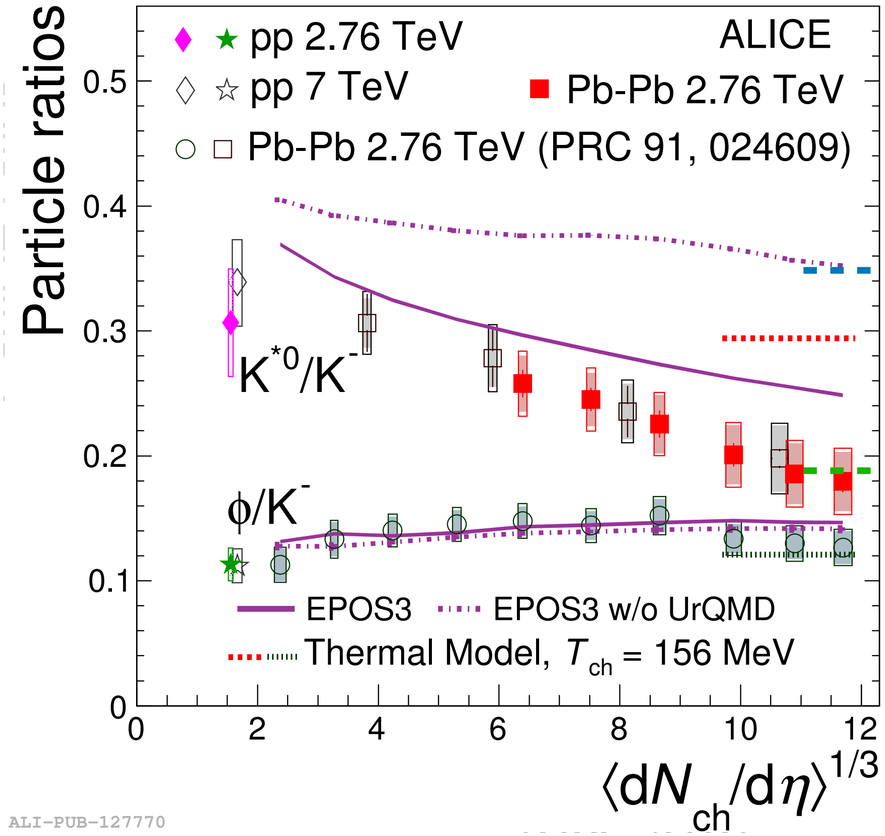
- **Suppression of K*/K yield ratio in high multiplicity events (A+A)**
  - Shows reducing yield trend from low(p+p) to high multiplicity
  - Yields in central A+A below Thermal model prediction.
- **Constant Φ/K yield ratio**
  - Consistent with Thermal model prediction.
  - Φ lifetime is ~ 10 times longer than K*
- **Small system**
  - K*/K yield suppression in high-multiplicity p+p, p+Pb?
  - Smooth transition from p+p to A+A:
    → System size (Multiplicity) controls Resonance yields
- **Suggests Re-scattering of K* decay products in hadronic phase.**



Focus on particle ratio: K* and Φ

Suppression vs Constant; Theory?



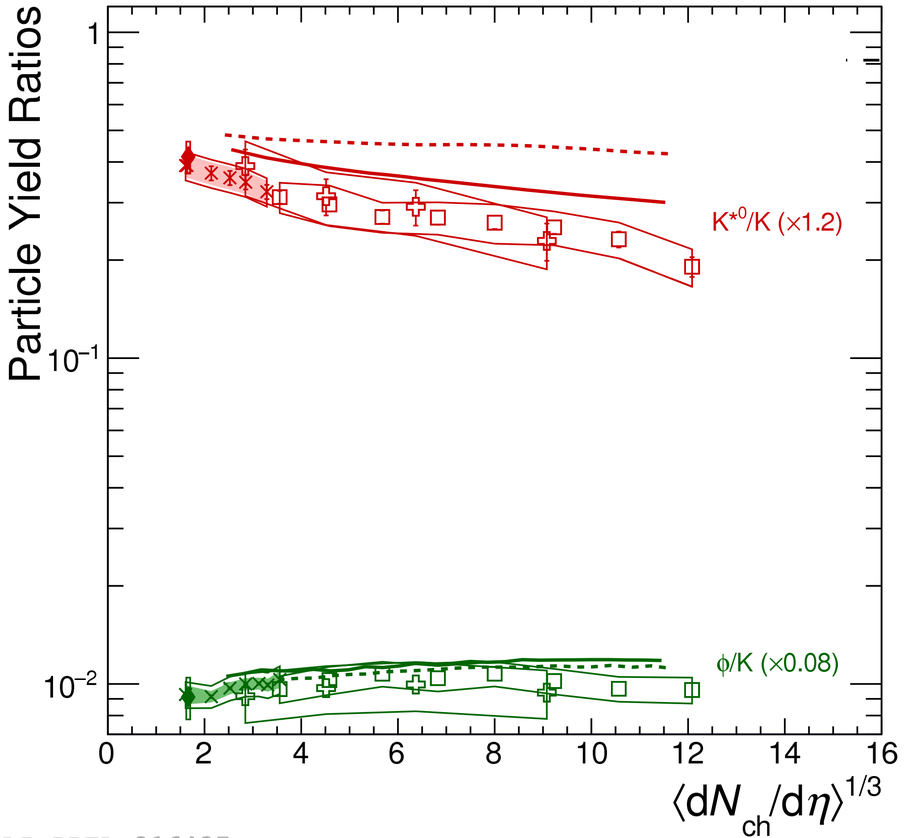


- **EPOS3 with UrQMD**
- (Re-)Scattering effects modeled with UrQMD [1]
  - The effect is more pronounced in K* than Φ
- Qualitatively describes the trend from low to high multiplicity in K*

[1] PRC **93** 014911 (2015) arXiv:1509.07895

Full Story: Particle Ratio in Resonances

Suppression vs Constant



ALI-PREL-316435

ALICE Preliminary
- ◊ pp $\sqrt{s}$ = 7 TeV
- ○ p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
- □ Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
- ✣ Xe-Xe $\sqrt{s_{NN}}$ = 5.44 TeV

ALICE
- ● pp $\sqrt{s}$ = 2.76 TeV
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STAR
- ★ pp $\sqrt{s}$ = 200 GeV
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– – – THERMUS

— EPOS3 PRC **93** 014911 (2015)

- - EPOS3 (UrQMD OFF)

Full Story: Particle Ratio in Resonances

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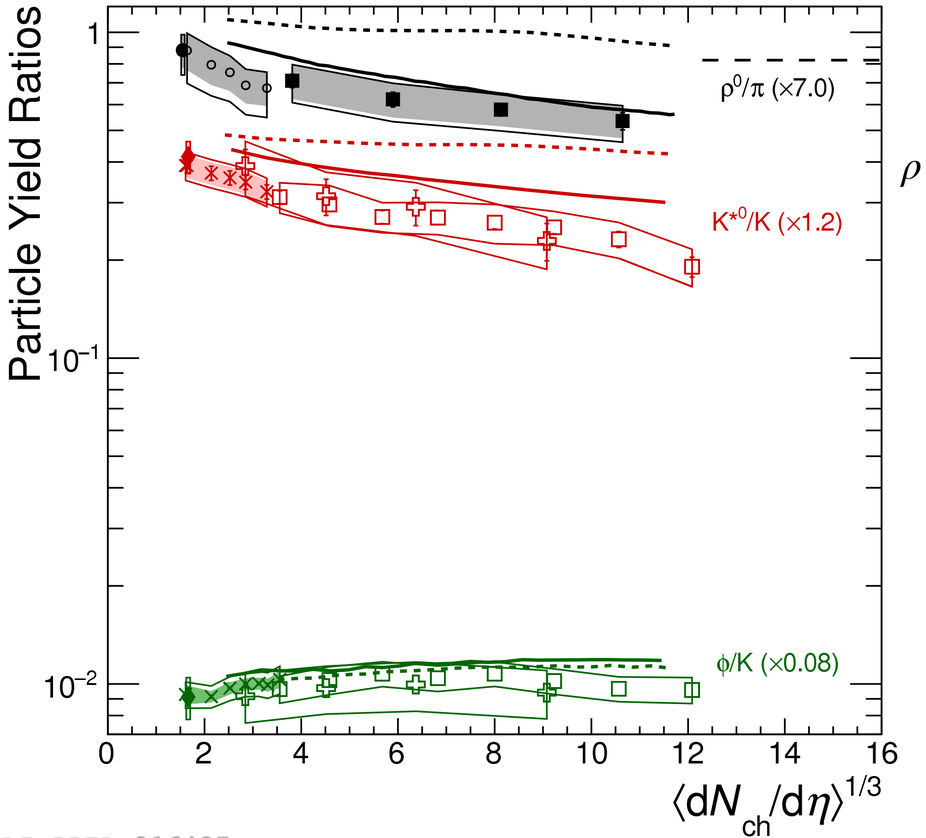

- ρ - **Short lifetime**
  - Suppression of ρ/π yield ratio in high multiplicity events (A+A)
  - Same story with K*
    - Shows reducing yield trend from low(p+p) to high multiplicity
    - Yields in central A+A below Thermal model prediction.
  - Hint of suppression in high-multiplicity p+Pb

Full Story: Particle Ratio in Resonances

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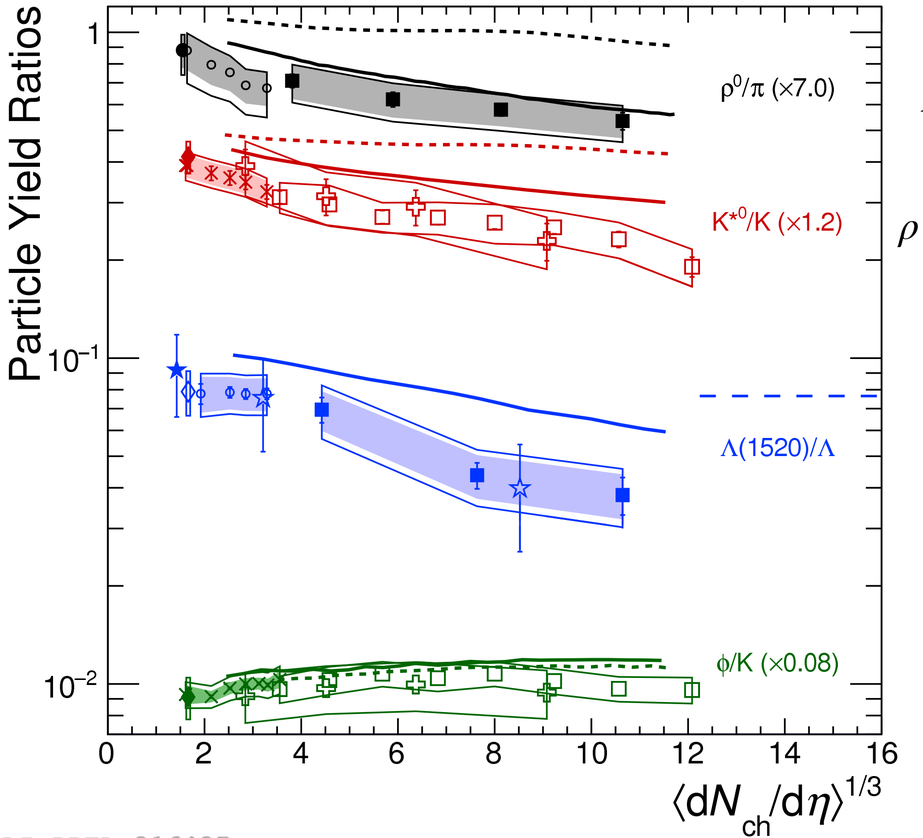

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- – – – GSI-Heidelberg
- — EPOS3 PRC **93** 014911 (2015)
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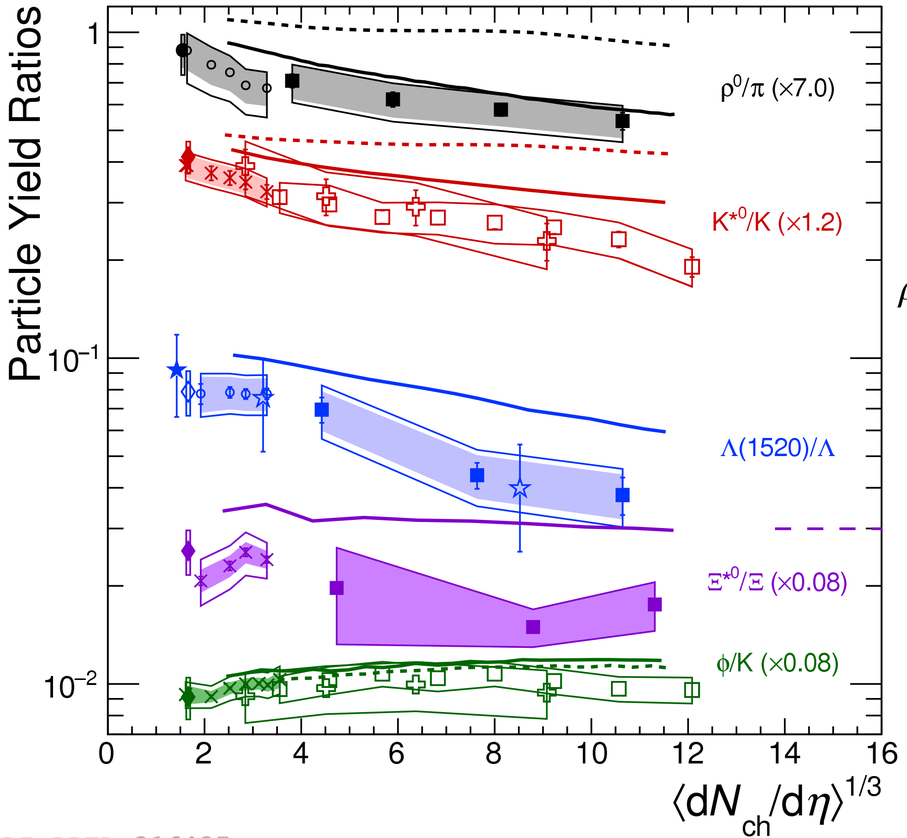
- $\Lambda(1520)$ - **Short lifetime**
  - Suppression of $\Lambda(1520)/\Lambda$ yield ratio in high multiplicity events (A+A)
    - No suppression in p+Pb region.
  - Yields in central A+A below Thermal model prediction

Full Story: Particle Ratio in Resonances

Suppression vs Constant



ALI-PREL-316435

ALICE Preliminary	ALICE	STAR
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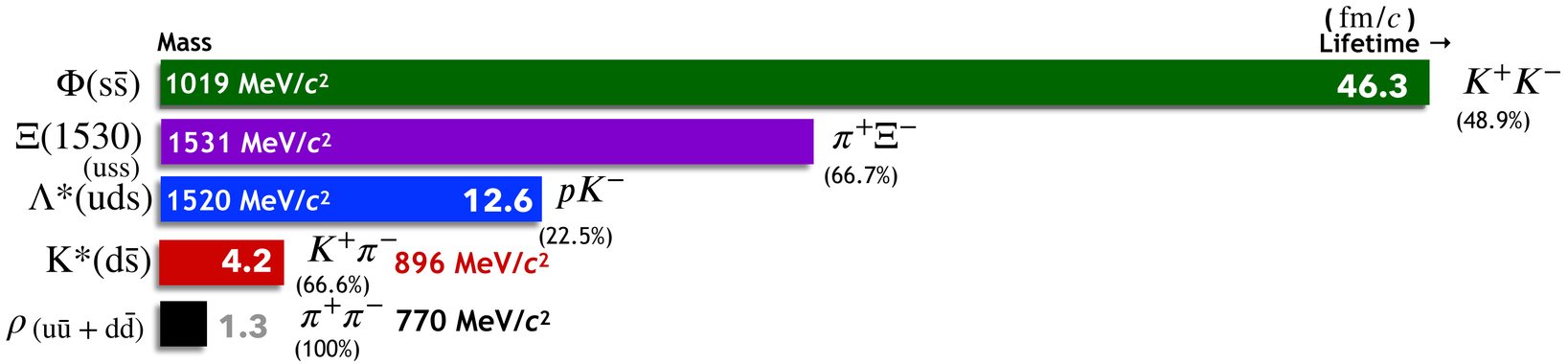
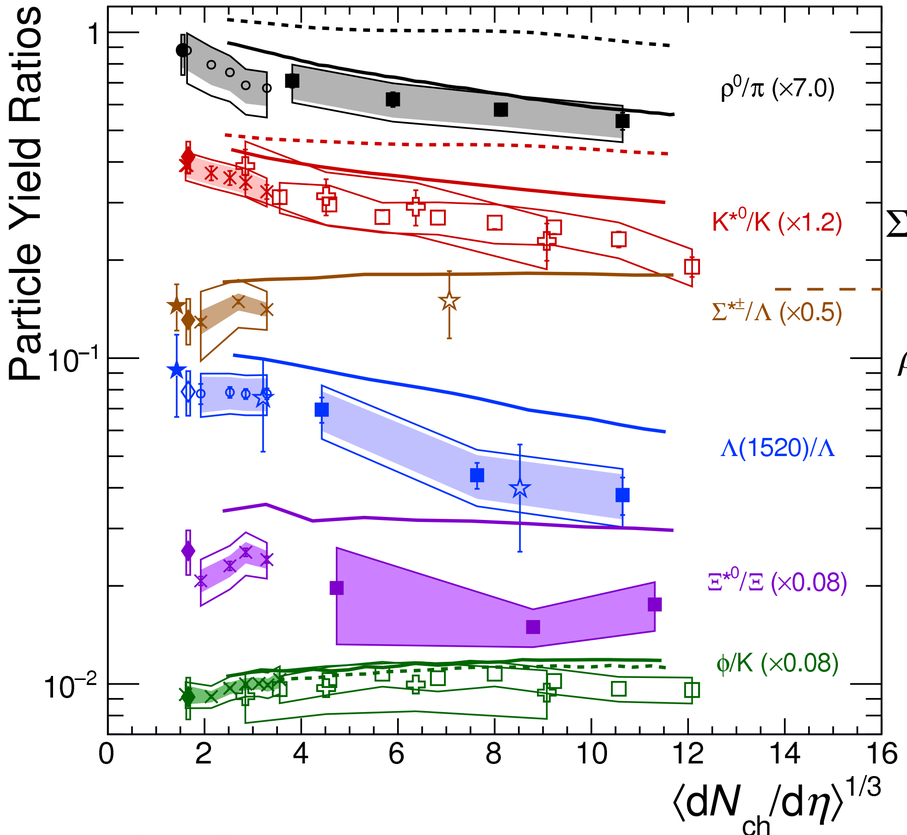


- $\Xi(1530)^0$ - **Intermediate lifetime**
  - No significant multiplicity dependent suppression.
  - Lower than Thermal model prediction
  - Systematically lower result in central A+A than p+p, p+Pb
    - Hint of weak suppression?

Full Story: Particle Ratio in Resonances

Suppression vs Constant



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- – – – GSI-Heidelberg
- — EPOS3 PRC **93** 014911 (2015)
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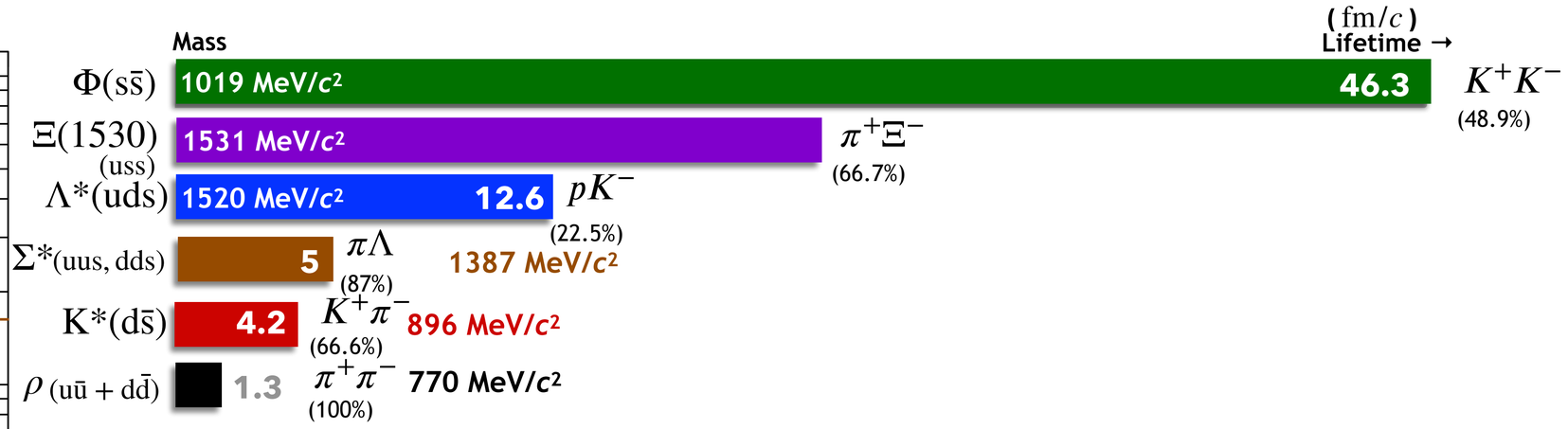
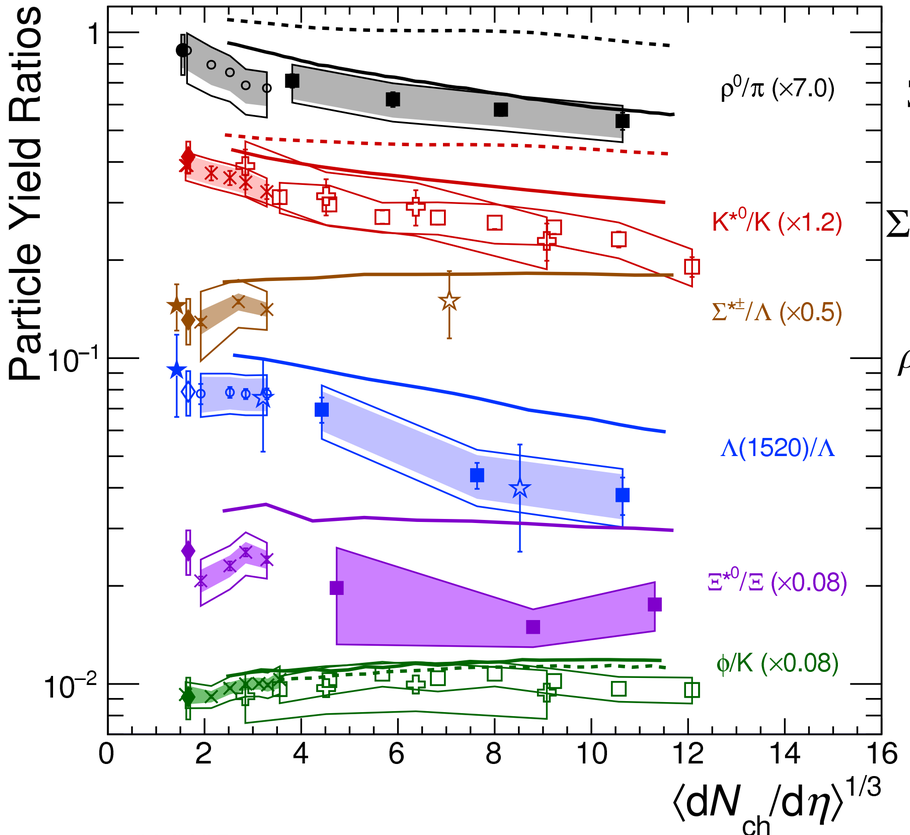


- $\Sigma(1385)^{\pm}$ - **Short lifetime**
  - Flat in p+p, p+Pb
    - Consistent with Thermal model prediction
  - No measurement in A+A from ALICE
    - No suppression in result from STAR (Au+Au)
  - EPOS prediction: No suppression

- **Resonance yield is not only affected by lifetime**

Full Story: Particle Ratio in Resonances

Suppression vs Constant



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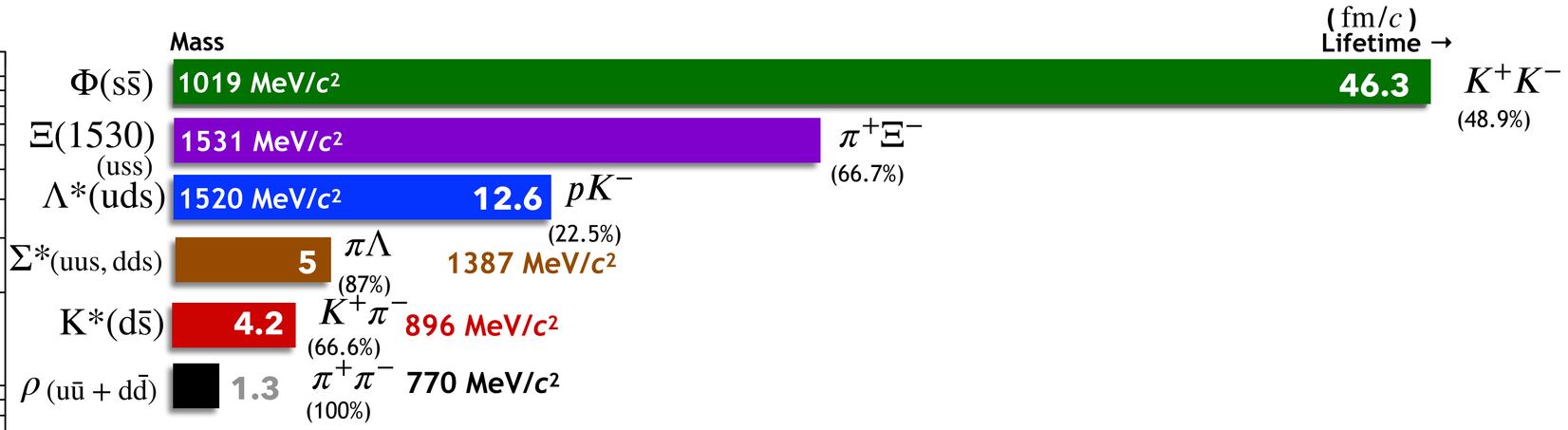
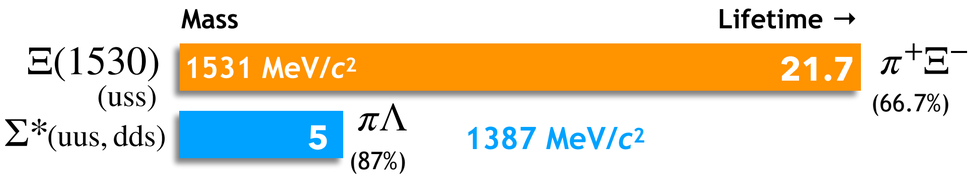
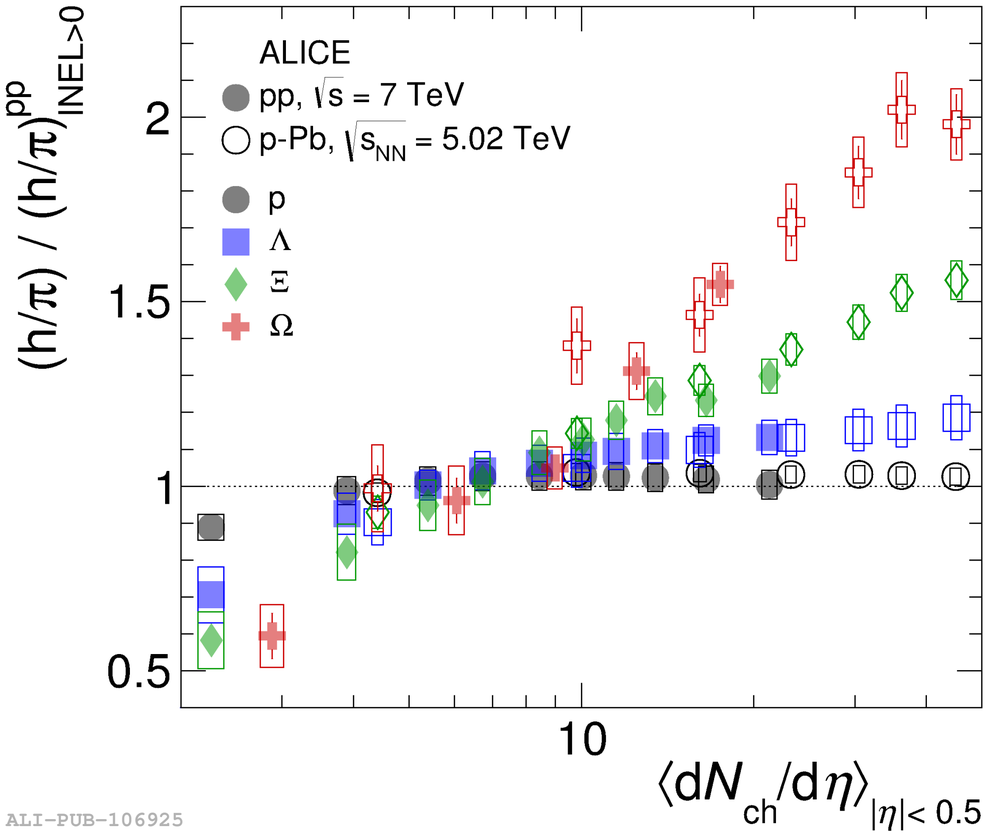


- **Overview**
  - No energy dependence for RHIC to LHC
  - EPOS3 with UrQMD describes the result qualitatively.
  - Lifetime is not the only consideration
    - Re-scattering vs Re-generation?
    - Different scattering cross-section

Strangeness Enhancement in Resonances

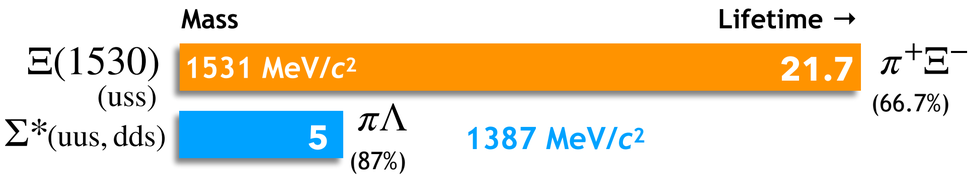


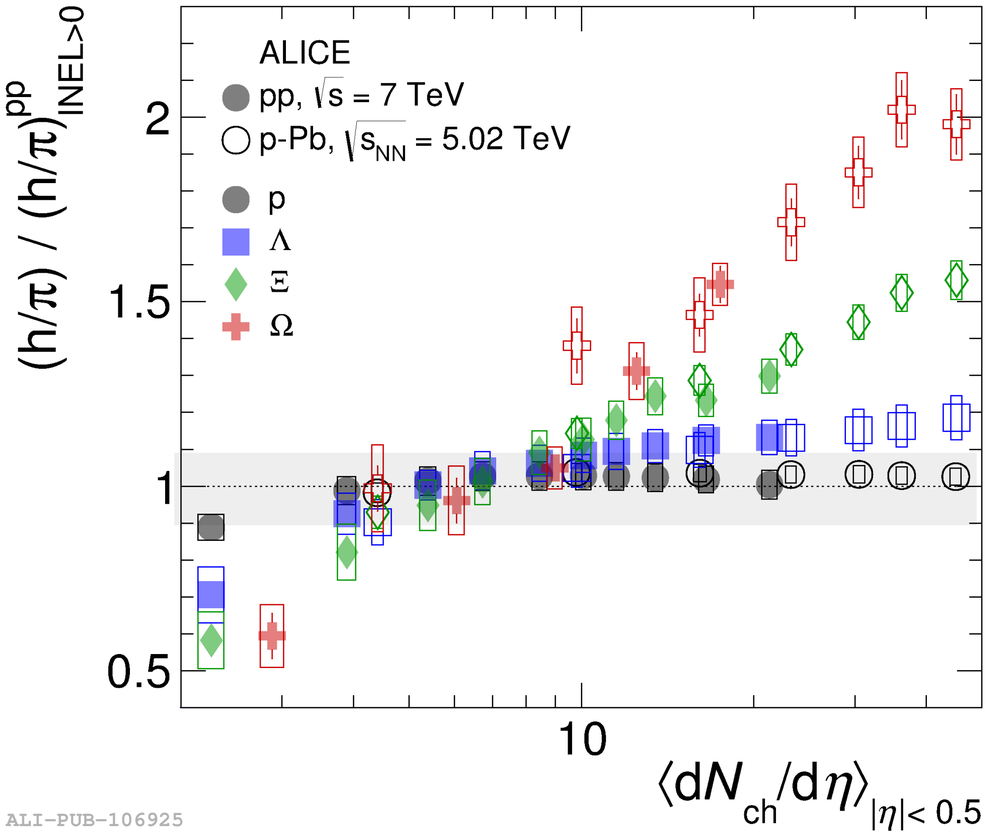


- **Strangeness enhancement in small systems**
  - Does it really come from the strangeness?
  - How about baryon number, mass?
    - Baryon number? -
    - Mass? -

Baryon	Mass (MeV/c²)	|S|
Ω	1672	3
Ξ	1530	2
Σ*	1385	1
Ξ	1322	2
Λ	1116	1
p	938	0

Strangeness Enhancement in Resonances





- **Strangeness enhancement in small systems**
  - Does it really come from the strangeness?
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    - Baryon number? - X
      - p/π ratio is almost 1
    - Mass? -

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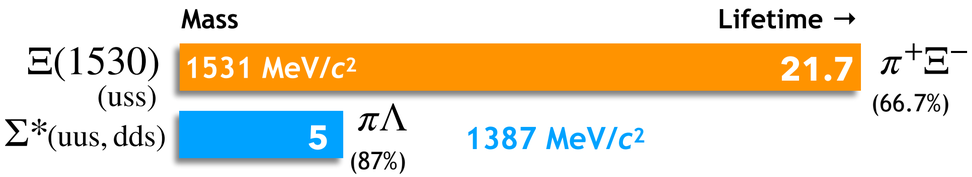

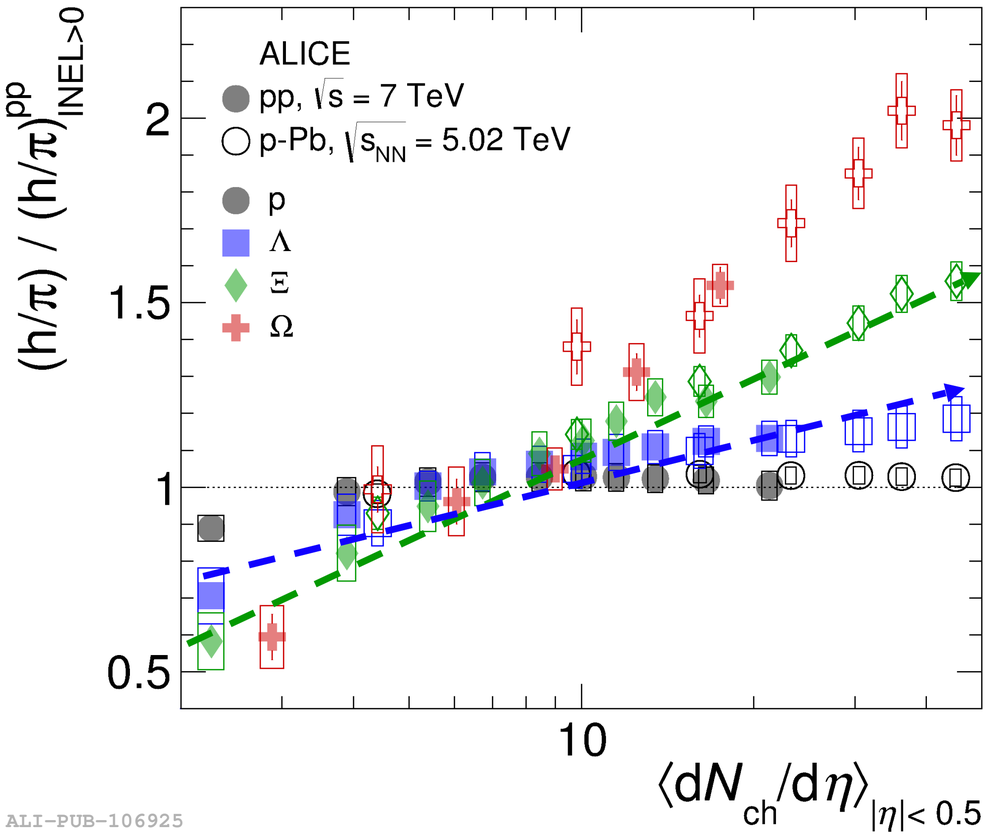

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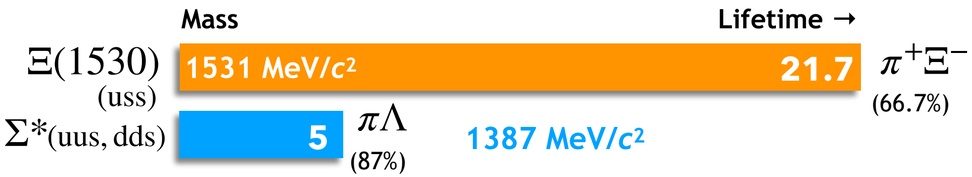

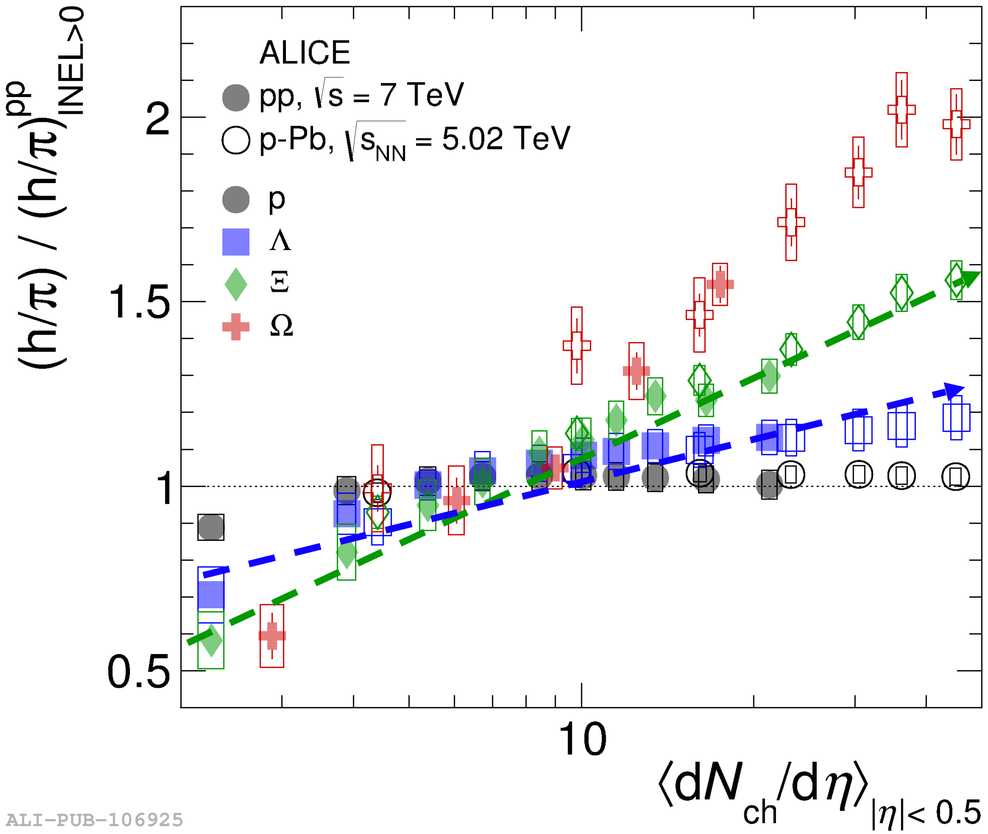

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- Solid conclusion: O Strangeness enhancement in small system comes from **Strangeness**

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Ω	1672	3
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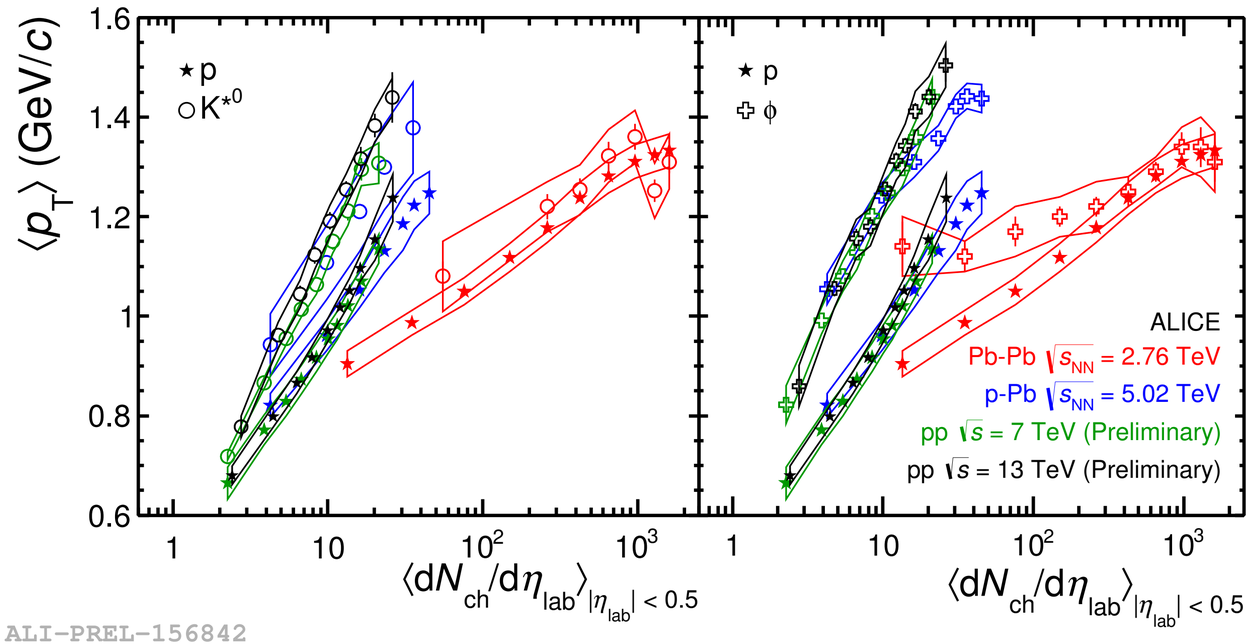
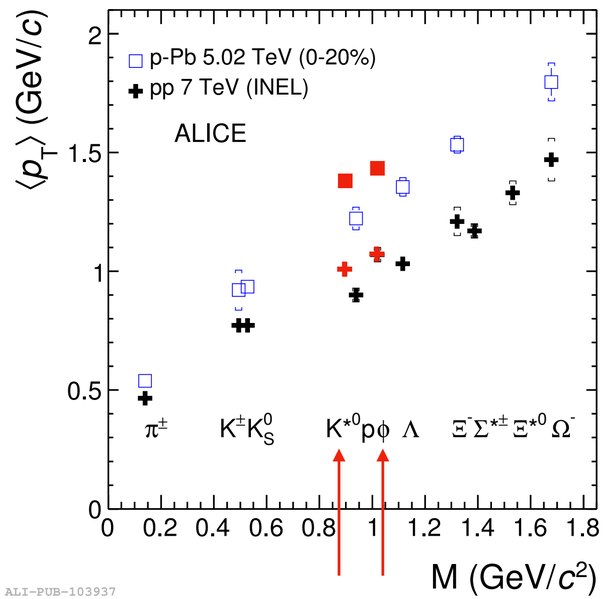
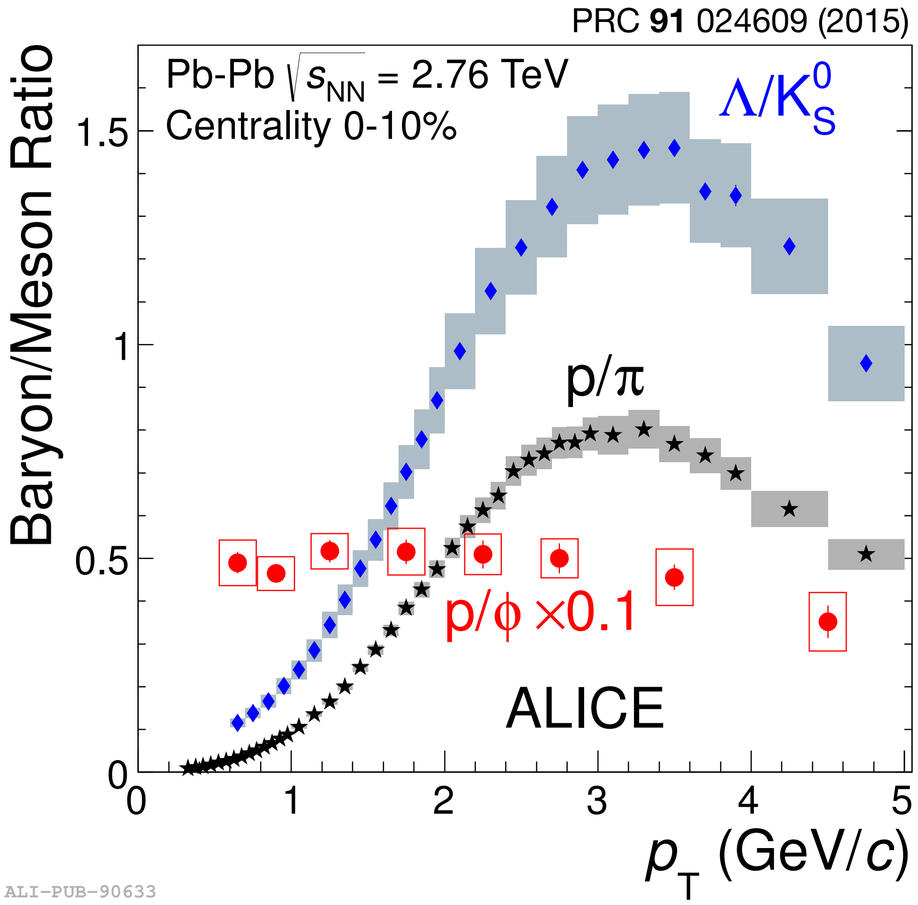
Mean p_T - Φ, K* with p



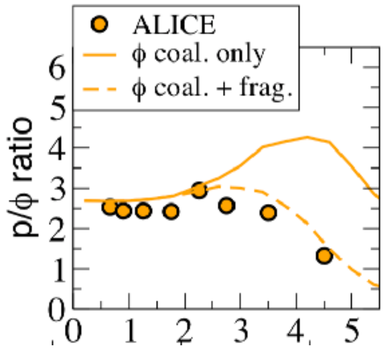


- **Hydro expectation**: Φ, K* and p will have similar mean p_T at central A+A on their similar masses
  - $M(\mathrm{p}) = 938\,\mathrm{MeV}/c^2$, $M(\mathrm{K}^*) = 896\,\mathrm{MeV}/c^2$, $M(\Phi) = 1019\,\mathrm{MeV}/c^2$
- **Broken Mass ordering in small system**
  - p is heavier than K*, but K* has higher mean p_T
  - Steeper increasing trend in small system observed → **Different particle production mechanism?**

Baryon/Meson Ratio - Φ, p

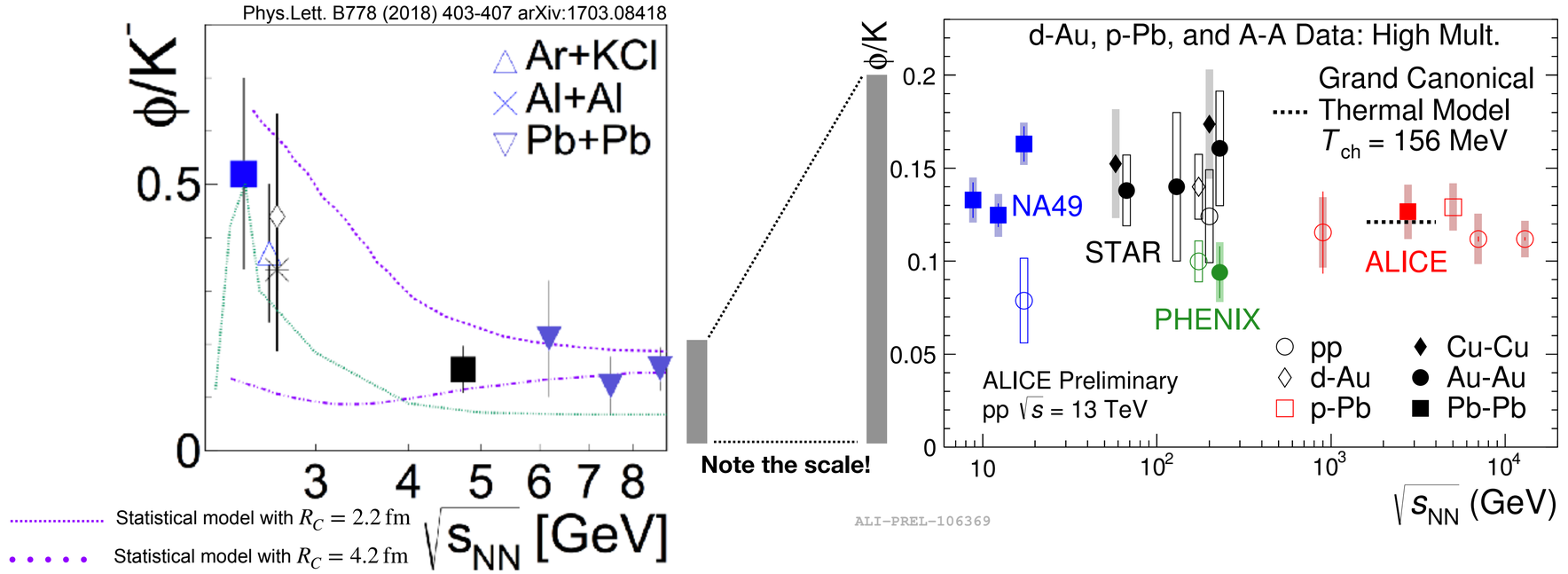


- **Detailed baryon/meson ratio story is covered by M.Toppi yesterday**
- **Φ/p ratio is flat in low p_T region ($p_T < 4\mathrm{GeV}/c$)**
  - A+A, centrality 0-10%
  - Expected from hydrodynamics based on their similar masses
  - Some recombination(coalescence) models (+ fragmentation) [1] can also describe this behavior



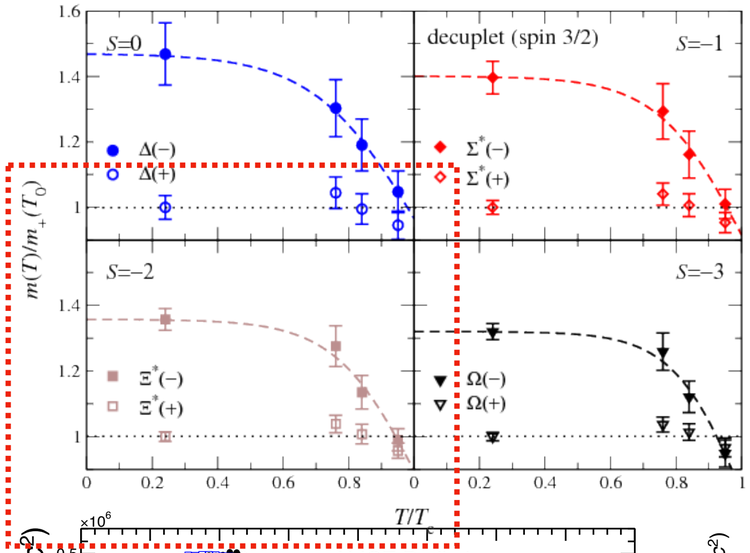
[1] Phys.Rev. **C92** (2015) no.5, 054904

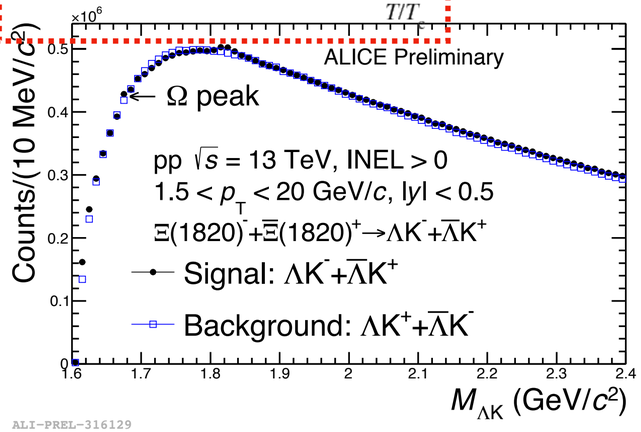
Energy dependence of Φ/K



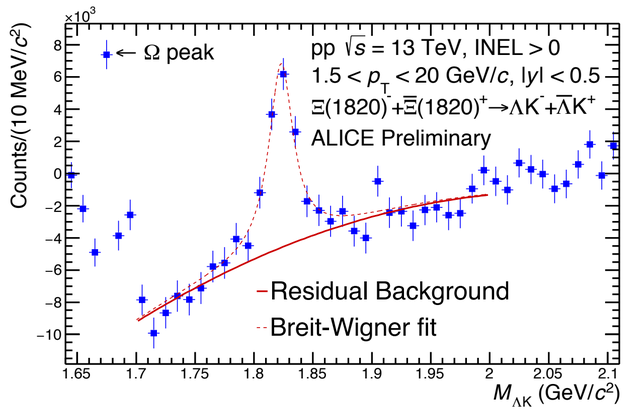
- **Saturated Φ/K ratio to ~ 0.15 after $5\,\mathrm{GeV}$**
  - Stable at higher energies → **regeneration and re-scattering are balanced in these energies?**
- **Increase at low energy** ($< 5\,\mathrm{GeV}$)
  - Qualitatively described by statistical model with strangeness correlation radius $R_C = 2.2\,\mathrm{fm}$
  - Sizable feed-down from Φ to K^- → **partially explains the difference of the slope in spectra of K^+ and K^-**

Parity doubling - $\Xi(1820)$





ALI-PREL-316129



ALI-PREL-316134

- **Parity doubling:** Proposed as a signature for chiral symmetry restoration from FASTSUM Collaboration [1] [2] [3]
  - Emerging degeneracy around T_C for chiral partners
  - **Positive parity masses - $\Xi(1530)$**
    - Nearly temperature independent
  - **Negative parity masses - $\Xi(1820)$**
    - Drop as temperature increases
- **The first measurement of $\Xi(1820)$ is in preparation - Stay tuned!**

[1] PRD **92** (2015) 014503 (arXiv:1502.03603)
[2] JHEP **06** (2017) 034 (arXiv:1703.09246)
[3] EPJ WoC **171** (2018) 14005 (arXiv:1710.00566)

Summary

- **Resonances are useful tools to probe the characteristics of the hadronic phase.**
  - Various masses, lifetimes, particle types, strangeness…
- **ALICE has measured a rich set of resonance particles in various systems.**
- **(Non-)Suppression of Resonances in large collision system**
  - Short-lived particles (ρ, K*, Λ*) - Suppressed
    - Re-scattering > Re-generation
    - $\Xi(1530)$ could be suppressed
  - Long-lived particles (Φ) - not suppressed
  - **Lifetime is not the only consideration** ($\Sigma(1385)$)
- **Mean p_{T} and Baryon/Meson ratio in central A+A** - consistent with hydrodynamics
- **Strangeness enhancement in p+Pb** was due to the strangeness, not mass, baryon number
- Interesting new observation of $\Xi(1820)$ for **parity doubling** is in preparation.

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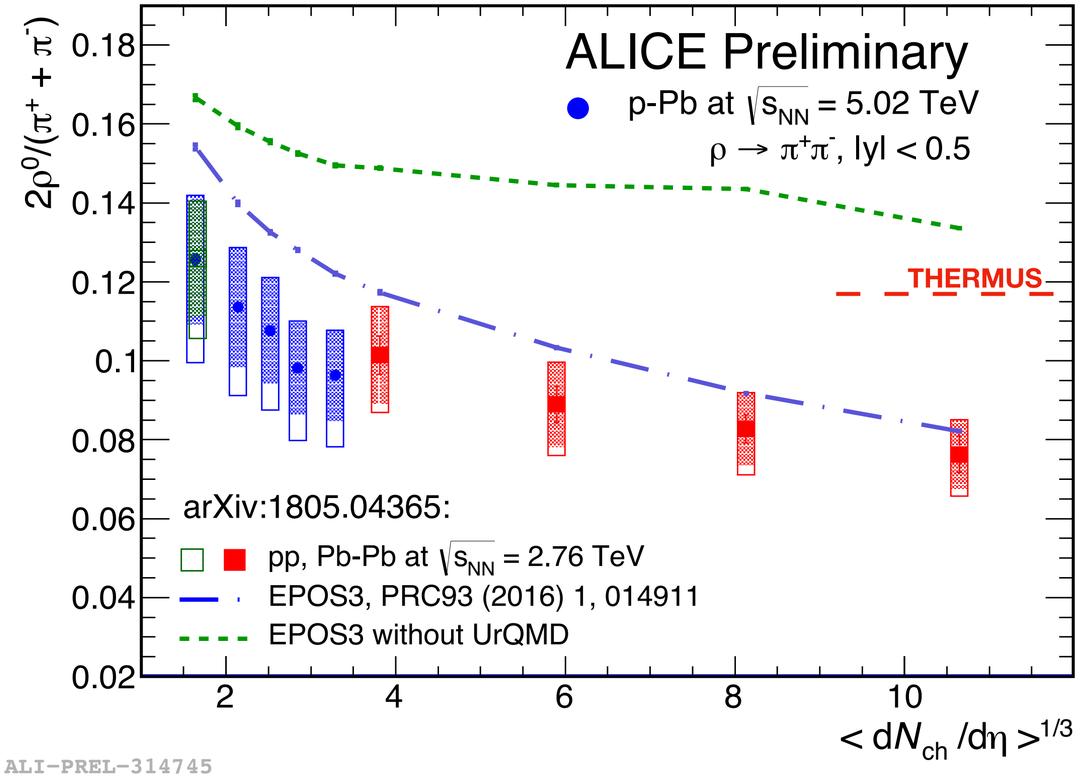
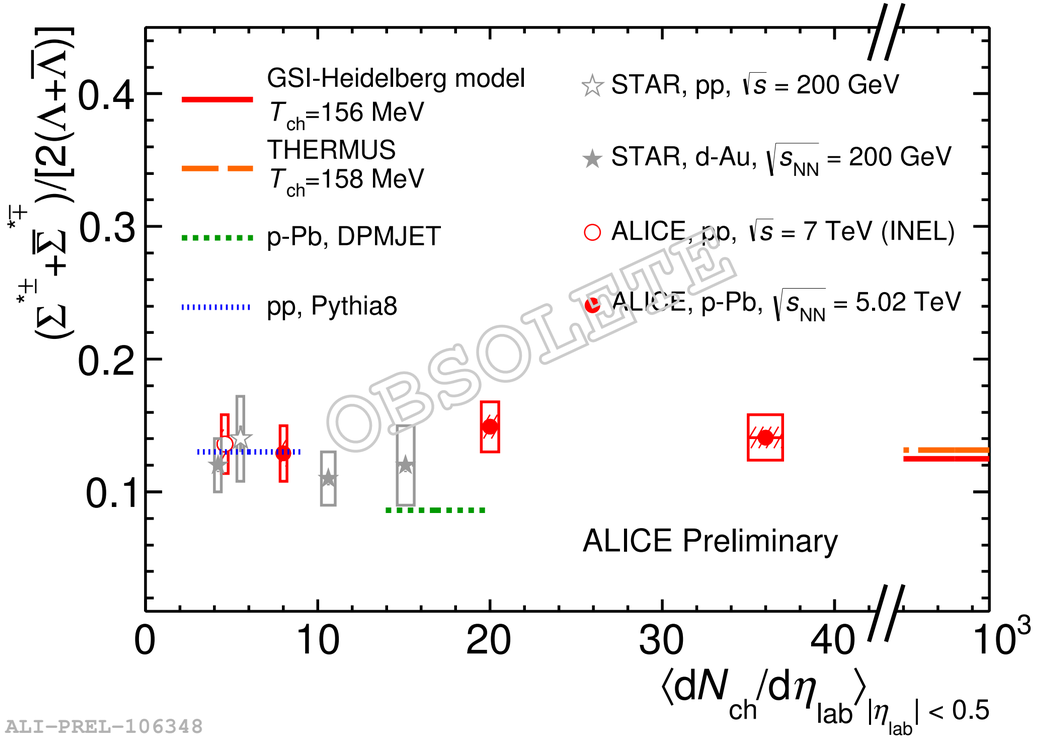
Thanks!

Backup

$\rho(770)$, $\Sigma(1385)^{\pm}$

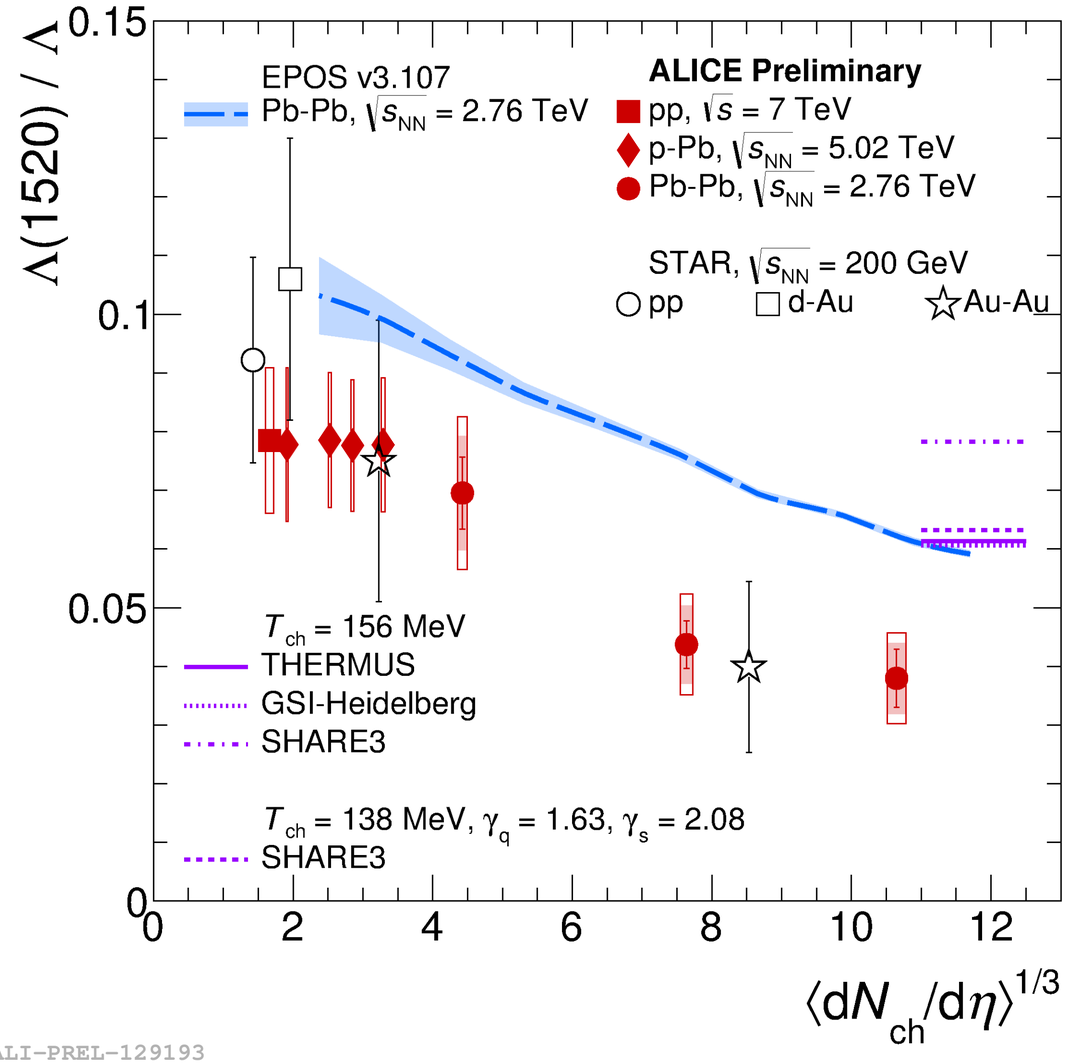


ALI-PREL-314745

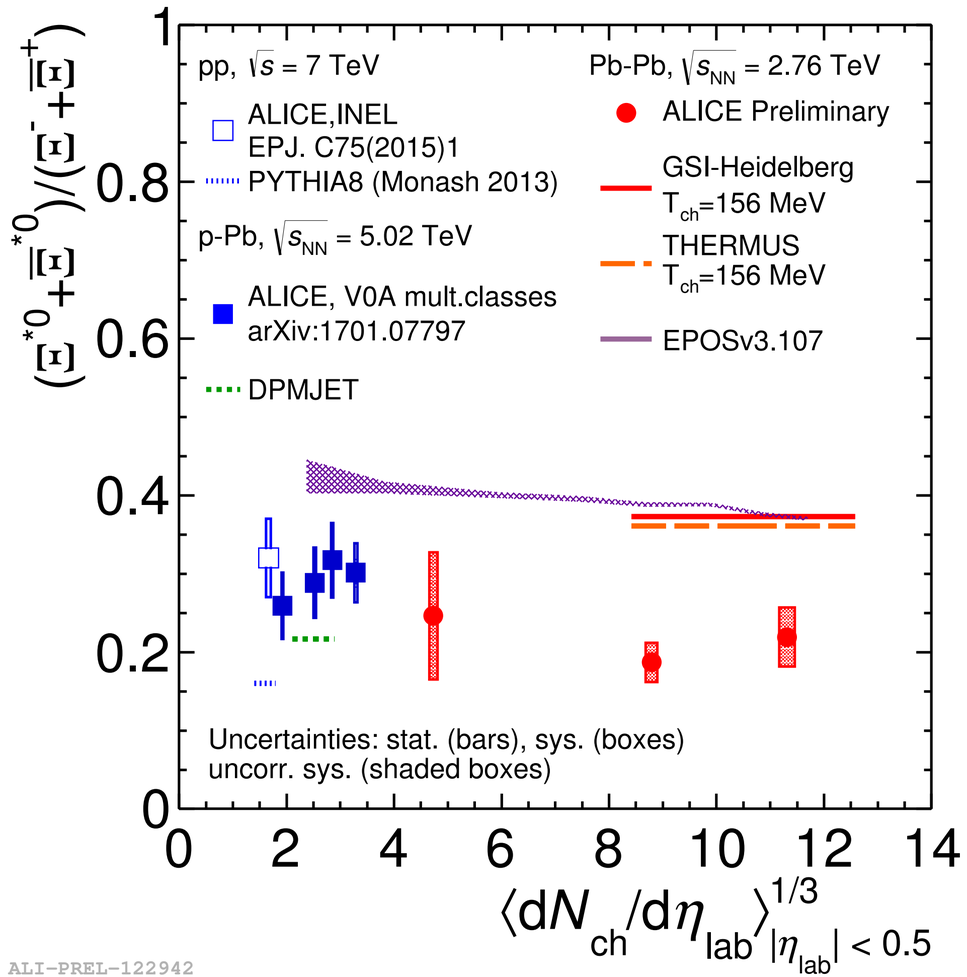


ALI-PREL-106348

$\Lambda(1520)$, $\Xi(1530)^0$



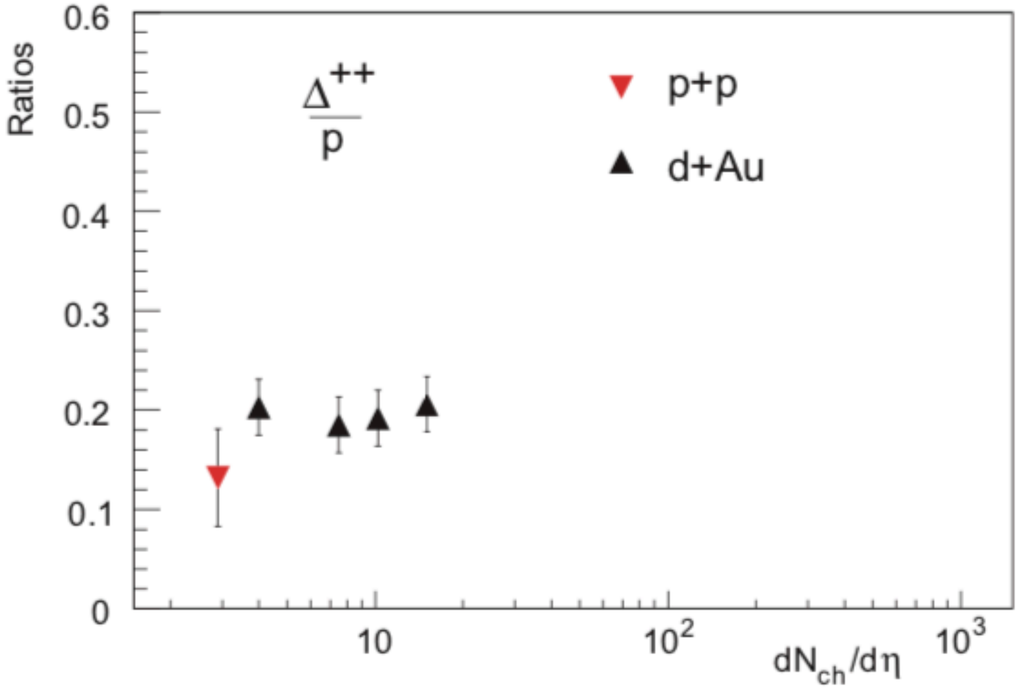
ALI-PREL-129193



ALI-PREL-122942

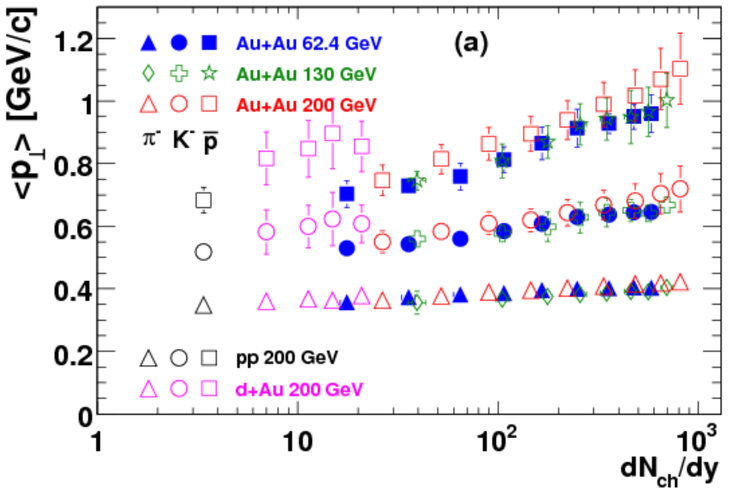
Δ^{++} in RHIC

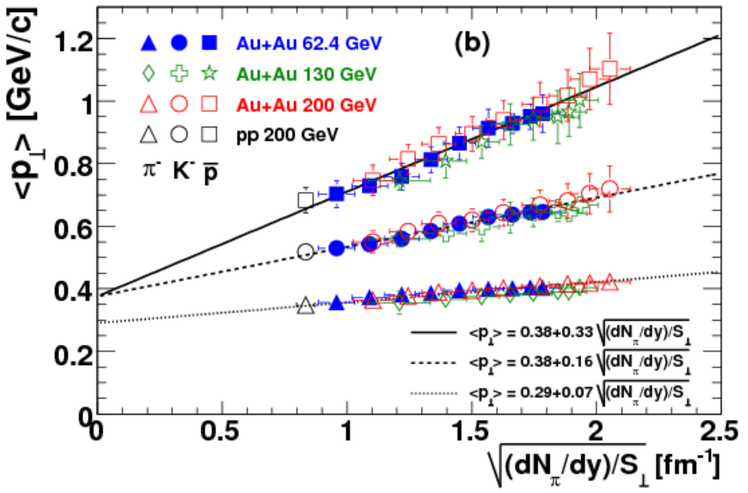
Phys.Rev. C78 (2008) 044906, t = 1.6 fm



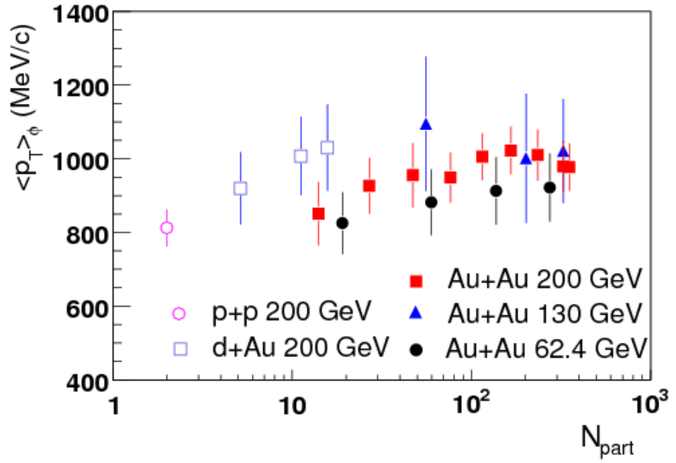
Φ, K* Mean pt at RHIC

Phys.Rev. C79 (2009) 034909 arXiv:0808.2041 [nucl-ex]

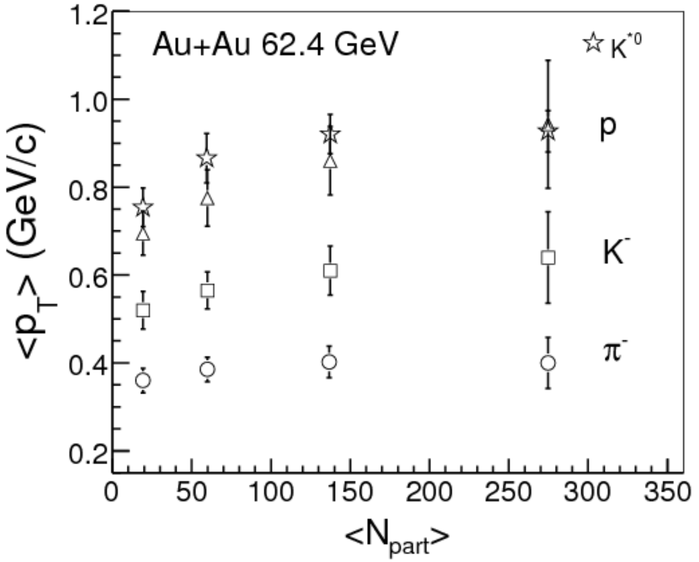




Phys.Rev. C79 (2009) 064903 arXiv:0809.4737 [nucl-ex]

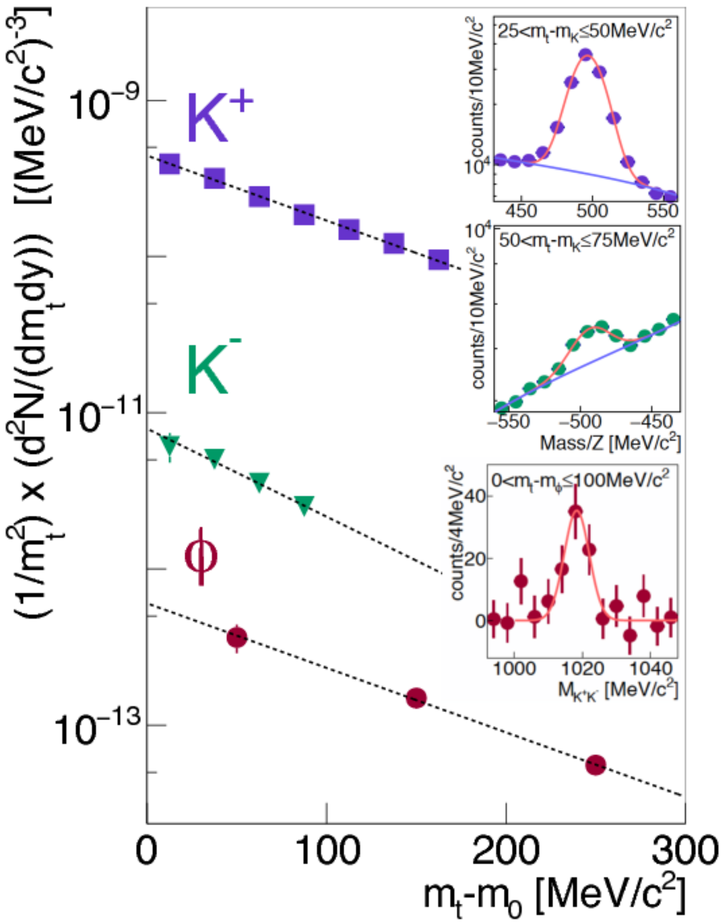


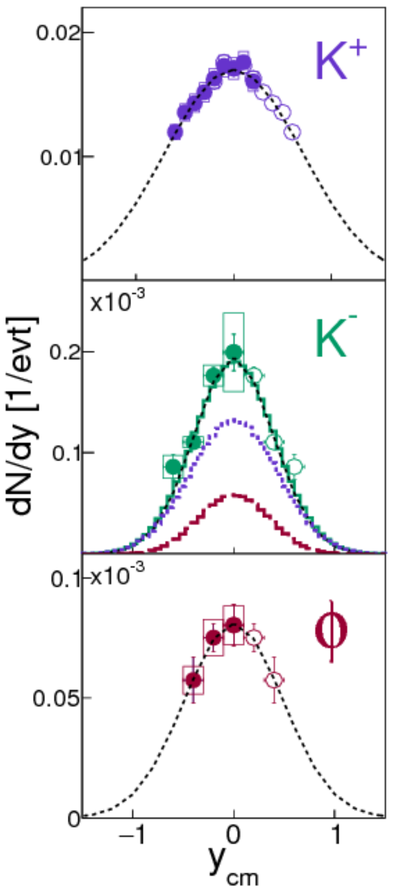
Phys.Rev. C84 (2011) 034909 arXiv:1006.1961 [nucl-ex]

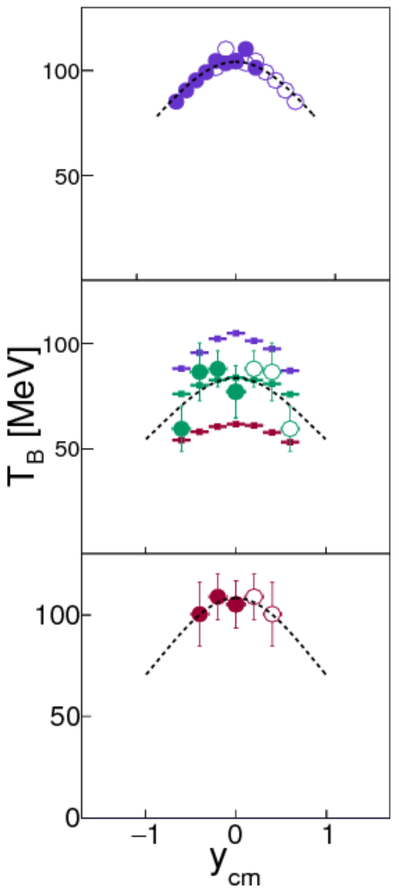


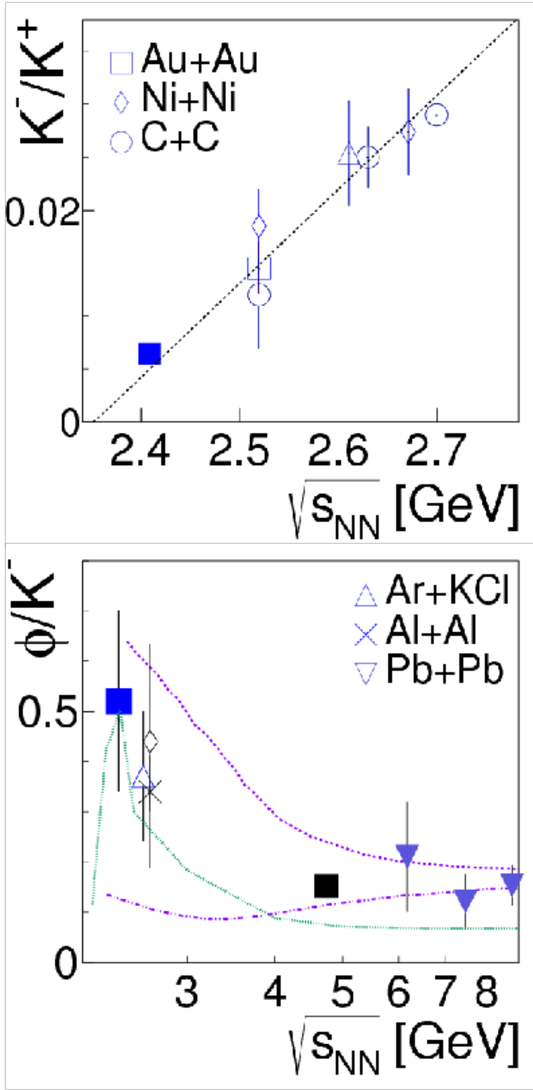
Particle ratio Φ/K

Phys.Lett. B778 (2018) 403-407 arXiv:1703.08418









Strangeness in Quark Matter 2021 in Busan, Korea

In-Kwon YOO (on behalf of HIM)
Pusan National University

Previous SQMs since 1991

21st SQM 2021 Busan, Korea

SQM 2019 Bari, Italy

SQM 2017 Utrecht, Netherland

SQM 2016 Berkeley, USA

SQM 2015 Dubna, Russia

SQM 2013 Birmingham, UK

SQM 2011 Krakow, Poland

SQM 2009 Busios, Brazil

SQM 2008 Beijing, China

SQM 2007 Levoča, Slovakia

SQM 2006 Los Angeles, USA

SQM 2004 Cap Town, South Africa

SQM 2003 Duke, USA

SQM 2001 Frankfurt, Germany

SQM 2000 Berkeley, USA

SQM 1998 Padova, Italy

SQM 1997 Santorini, Greece

SQM 1996 Budapest, Hungary

SQM 1995 Tucson (Arizona), USA

SQM 1994 Crete, Greece

SQM 1991 Aarhus, Denmark

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Strangeness in Quark Matter (SQM 2019)
10-15 June 2019, Bari (Italy)

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Strangeness in Quark Matter

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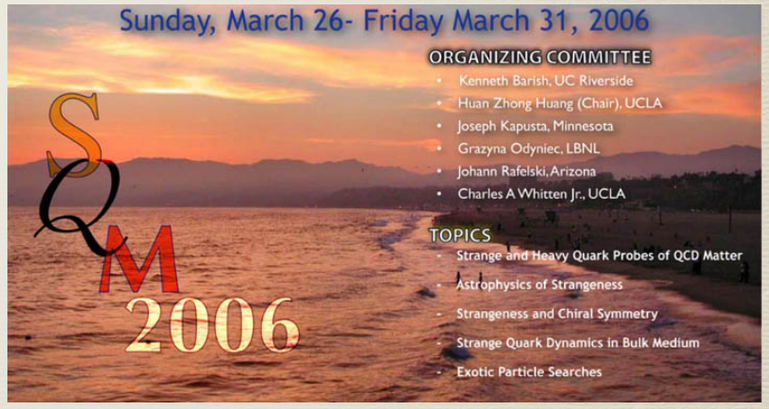
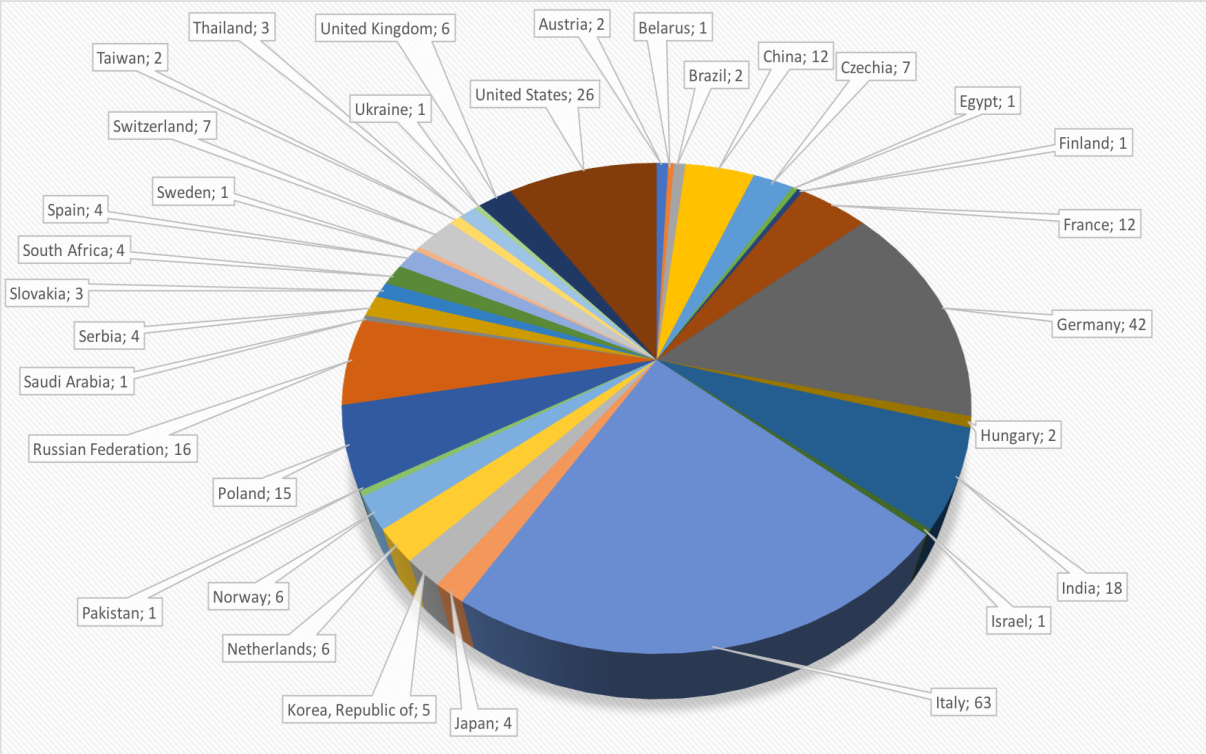


SQM 2019 IAC meeting

SQM2019: statistics

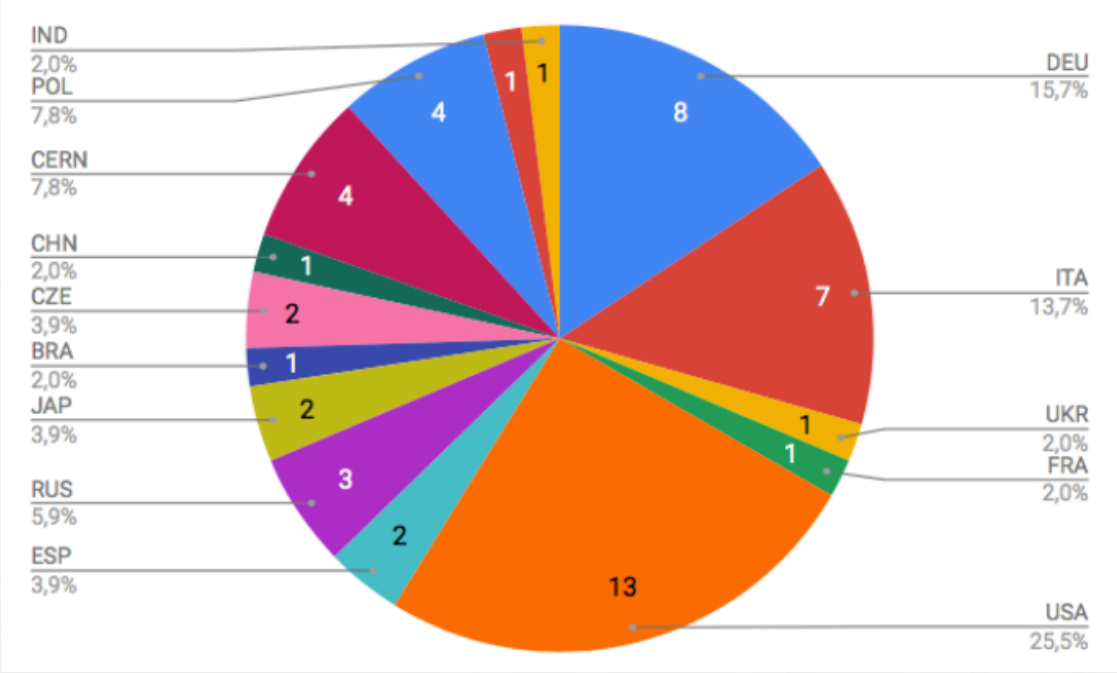
- **270 participants** (279 registered)



- **Largest participation** ever reached!
- **32 Countries** represented
- Gender balance: **25% female**
- **56 students** supported

SQM2019: scientific programme

- plenary sessions:
  - **50 talks** + Black Holes (Rezzolla) + Diversity (Jona)



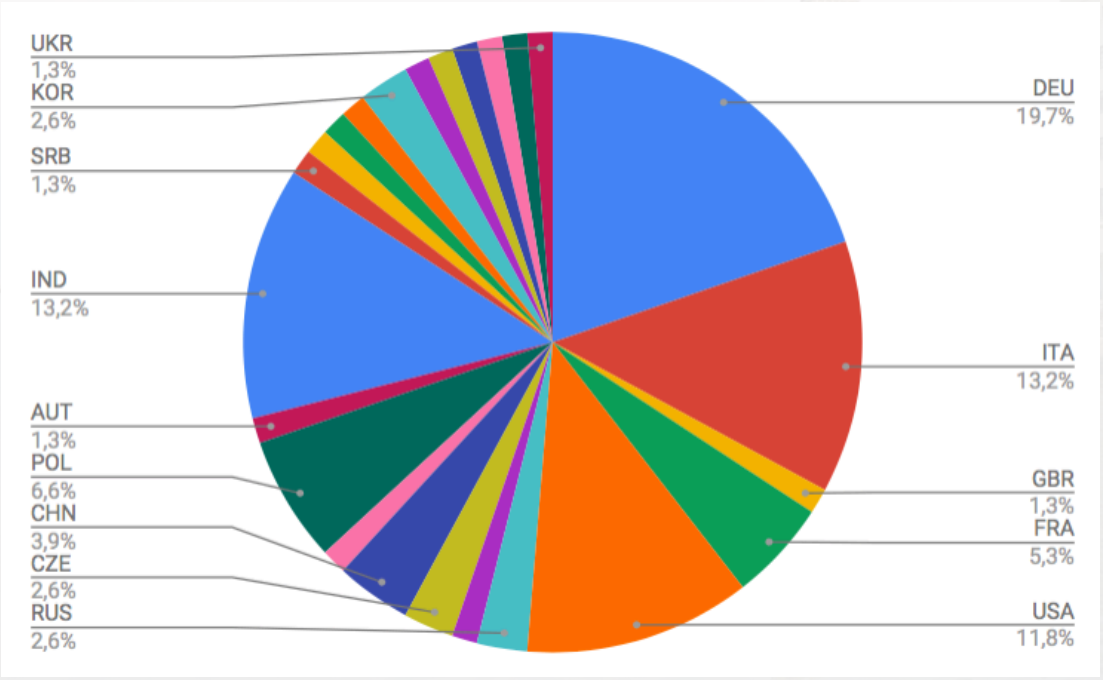
- Country balance:
  64% EU
  28% USA (+ BRA)
  8% ASIA

- Gender balance:
  26% female

SQM 2019 IAC meeting

SQM2019: scientific programme

- parallel sessions:
  - **76 talks**



- Country balance:
  60% EU
  31% ASIA
  8% USA
  1% AFRICA

- Gender balance:
  26% female

SQM 2019 IAC meeting

SQM2019: scientific programme

	Talk		Poster	
	Proposed	Accepted	Proposed	Accepted
COLLABORATION				
ALICE	33	21	29	35
CMS	10	6	0	1
LHCb	5	3	1	3
ATLAS	0	0	0	0
STAR	10	7	2	3
PHENIX	1	1	0	0
NA61/SHINE	3	3	0	0
HADES	6	4	0	2
SIDDHARTA-2	1	0	0	1
BM@N	1	0	1	2
CBM	1	1	1	1
NICA	1	0	0	1
AMADEUS	1	1	0	0
THEORY	72	29	10	49
TOTAL	**145**	**76**	**44**	**98**

- **Paralell talks: 76**
  147 proposed
- **Posters: 58**
  44 proposed
  54 downgraded talks
- **Large number of proposals**
  overall good balance and high quality ...

SQM2019: budget

INCOMING	
Internal funding (INFN, Uniba, Poliba, SIF, Centro Fermi)	20 K€
External funding (CERN, GSI, EMMI, NWO, IUPAP, NuPECC, IN2P3, JINR, TEXAS U., CCNU, TSINGUA U.)	25 K€
Other sponsors (CAEN, SPRINGER, WSP, AGRIDE')	4 K€
Fee	105 K€
	154 K€
EXPENSES	
Rooms and equipment	20 K€
Catering, excursions, proceedings, participant material, secretariat	114 K€
Student support	15 K€
Poster awards, diversity initiative	2 K€
	151 K€

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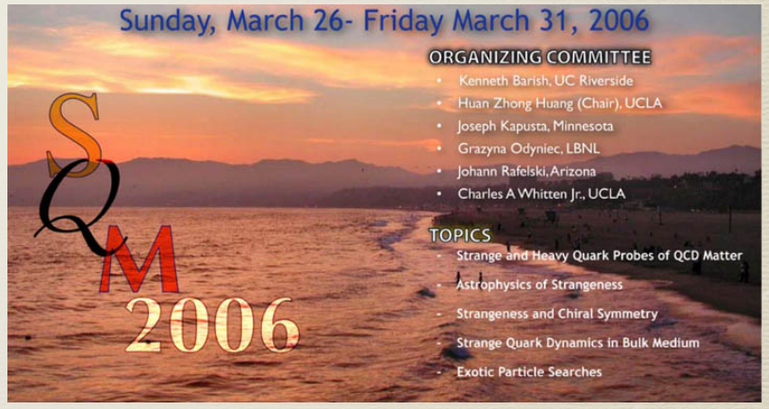

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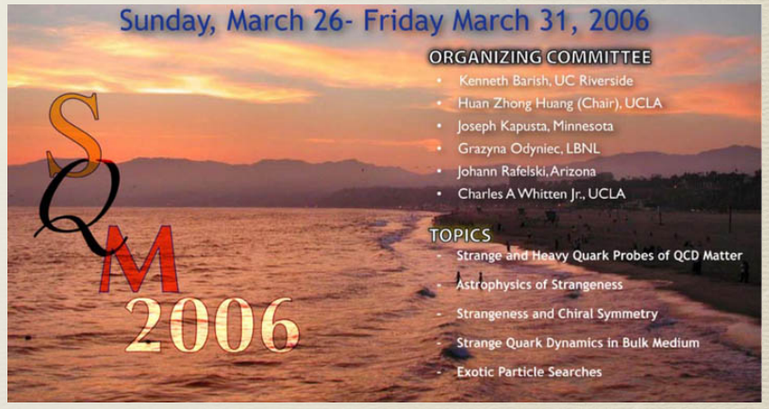

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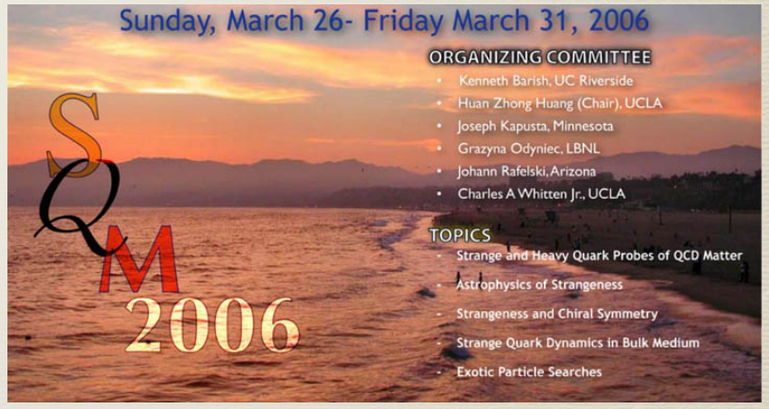

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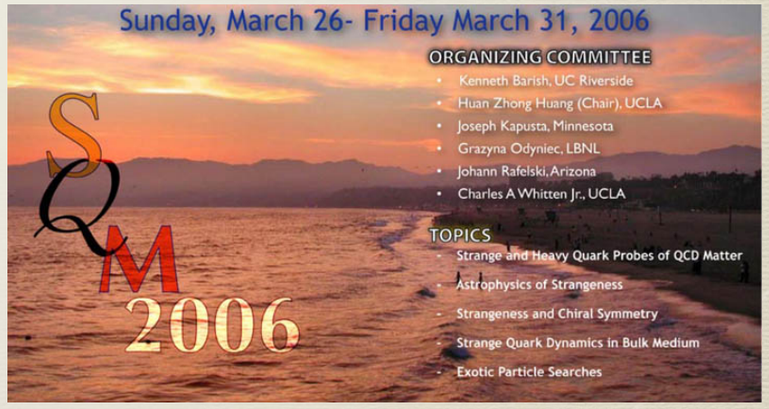

SQM Venues


Iceland
Sweden
Finland
Norway
Russia
Denmark
United Kingdom
Ireland
Belarus
Poland
Germany
Ukraine
Austria
France
Romania
Kazakhstan
Mongolia
Italy
Spain
Portugal
Greece
Turkey
Uzbekistan
Kyrgyzstan
Turkmenistan
China
South Korea
Japan
East Sea
Syria
Iraq
Iran
Afghanistan
Pakistan
East China Sea
Tunisia
Morocco
Algeria
Libya
Egypt
Nepal
India
Western Sahara
Saudi Arabia
Oman
Myanmar (Burma)
Philippine Sea
Mauritania
Mali
Niger
Chad
Sudan
Yemen
Thailand
Burkina Faso
Guinea
Nigeria
Gulf of Aden
Arabian Sea
Bay of Bengal
Vietnam
Philippines
Ghana
South Sudan
Ethiopia
Gulf of Thailand
Laccadive Sea
Malaysia
Gulf of Guinea
Somalia

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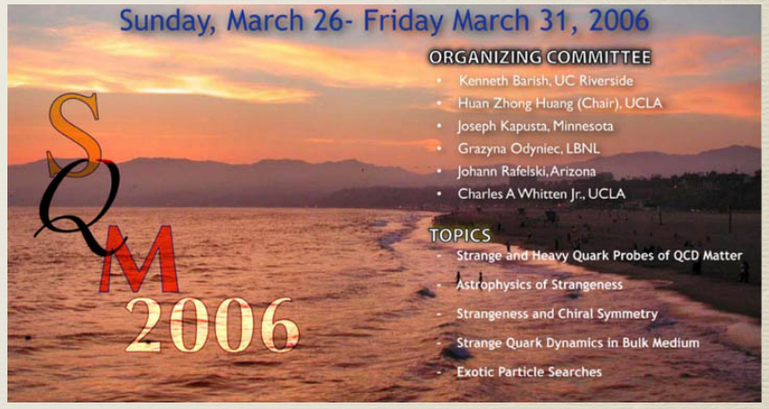


Transportation

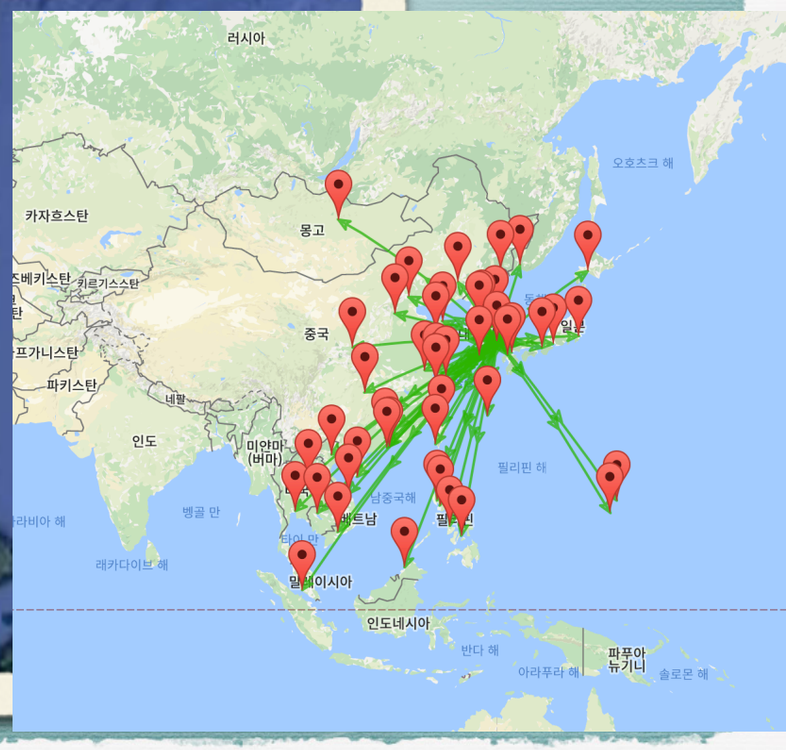
ICN: International Airport

Direct transit at ICN to Busan
- Morning 1
- Afternoon/evening 4

KTX from ICN
- 6 direct connections/day
- 3.5 hours

flights via dom. airport (GMP)
- 20 connections every 30 min.
- 1 hour

PUS: International Airport



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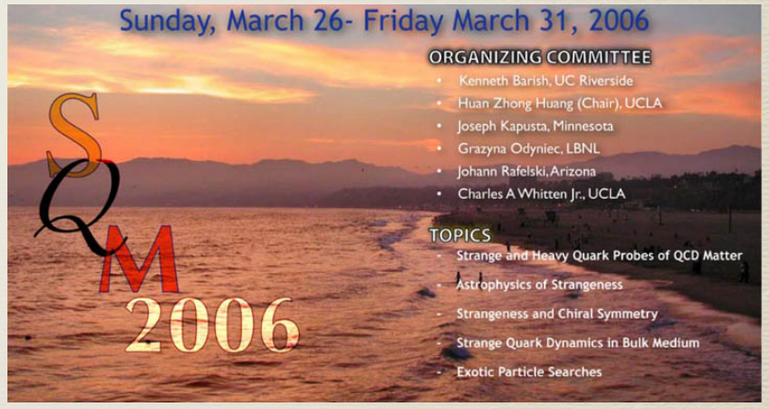

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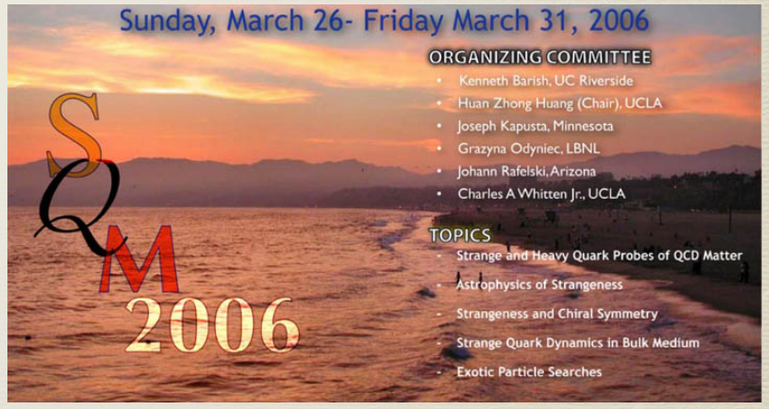

Organization

- LOC ~ 15
  - IKY (chair) + BHong (Co-chair) + SHLee (Co-chair)
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  - Experiences: HIM (20
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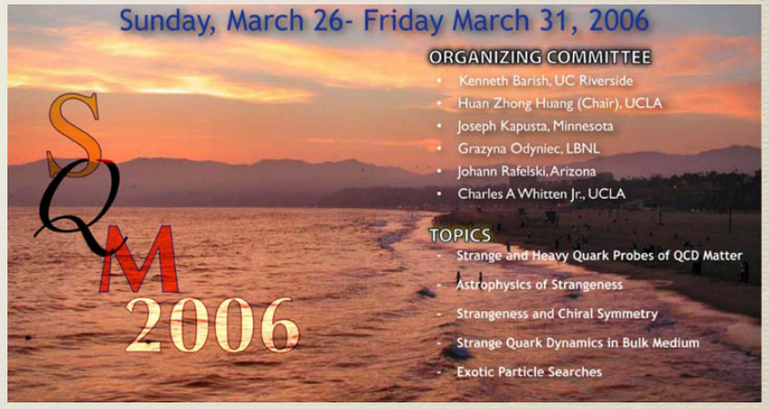

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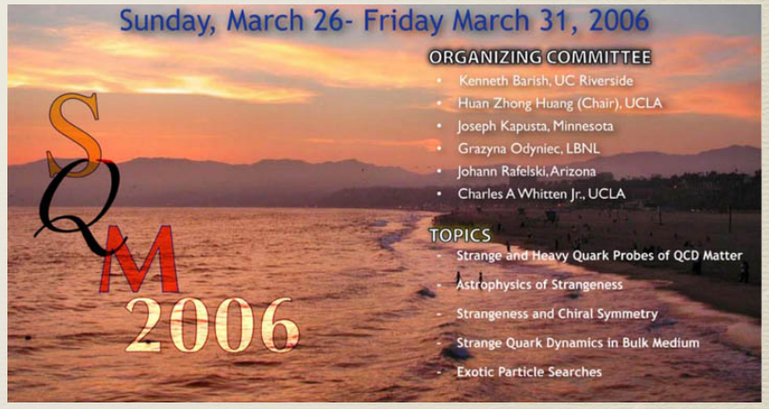

체크 리스트

	날짜	SQM2021@Busan	Resonance2020@Busan
☑	2019/08/15	Fix LOC for SQM2021 / Chair: IKY, 홍병식, 이수형 Secretary: 권민정, 조성태 문동호O, 김용선O, 김은주O, 권영일O, 박인규O, 임상훈O 김영만O, 윤진희O, 전상용O, 이창환O, 남승일O	
☐	2019/09/01		Fix dates for RESONANCE2020
☐	2019/09/03		Resonance 2020 APCTP Proposal - circulate
☐	2019/09/10	Fix plan - timeline	
☐	2019/09/30		LOC & IAC for RESONANCE2020
☐	2019/10/01	Public offering - SQM Logo -	
☐	2019/10/30		1st Announcement of Resonance2020 (Website + Abstract etc.)
☐	2019/11/01		Registration open
☐	2019/12/15		Abstract submission start
☐	2020/01/10	IAC - ROC start	
☐	2020/01/10	Fund raising	
☐	2020/01/15		Abstract submission 1st close
☐	2020/01/15		2nd announcement
☐	2020/01/31		abstract submission close
☐	2020/02/15		1st draft program
☐	2020/03/02		Poster distribution
☐	2020/03/15		2nd draft program
☐	2020/03/30		Registration 1st close
☐	2020/04/10		Final program
☐	2020/04/15		Registration final close (Inv. letter, VISA etc.)
☐	2020/04/30		Final announcement
☐	2020/05/01	Fund raising 2	
☐	2020/05/18		RESONANCE2020@Busan D-0 Local Registration
☐	2020/05/19		RESONANCE2020@Busan DAY1 Reception
☐	2020/05/20		RESONANCE2020@Busan DAY2 Excursion
☐	2020/05/21		RESONANCE2020@Busan DAY3 Banquet
☐	2020/05/22		RESONANCE2020@Busan DAY4 Final Day
☐	2020/08/15	SQM2021@Busan Proposal to APCTP	
☐	2020/10/31	1st announcement (Website, Registration)	
☐	2020/11/01	Funding collection	
☐	2020/11/01	Abstract submission start	
☐	2020/12/31	Abstract 1st closure	
☐	2021/01/02	2nd Announcement	
☐	2021/01/10	Abstract Close	
☐	2021/02/10	1st draft program	
☐	2021/03/10	2nd Draft program	
☐	2021/03/31	Registration 1st close	
☐	2021/03/31	3rd Announcement	
☐	2021/04/10	Final program	
☐	2021/04/10	4th announcement	
☐	2021/04/15	Registration Close	
☐	2021/04/30	Final announcement	
☐	2021/05/16	SQM2021@Busan DAY0 Local Registration	
☐	2021/05/17	SQM2021@Busan DAY1 Reception	
☐	2021/05/18	SQM2021@Busan DAY2 Local Dinner	
☐	2021/05/19	SQM2021@Busan DAY3 - Excursion	
☐	2021/05/20	SQM2021@Busan DAY4 - Banquet	
☐	2021/05/21	SQM2021@Busan DAY5 - Social Dinner	
☐	2021/05/22	SQM2021@Busan DAY6 - Leaving day	
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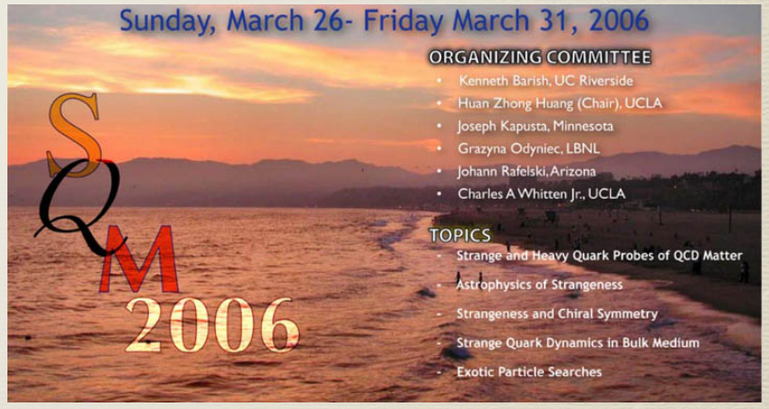
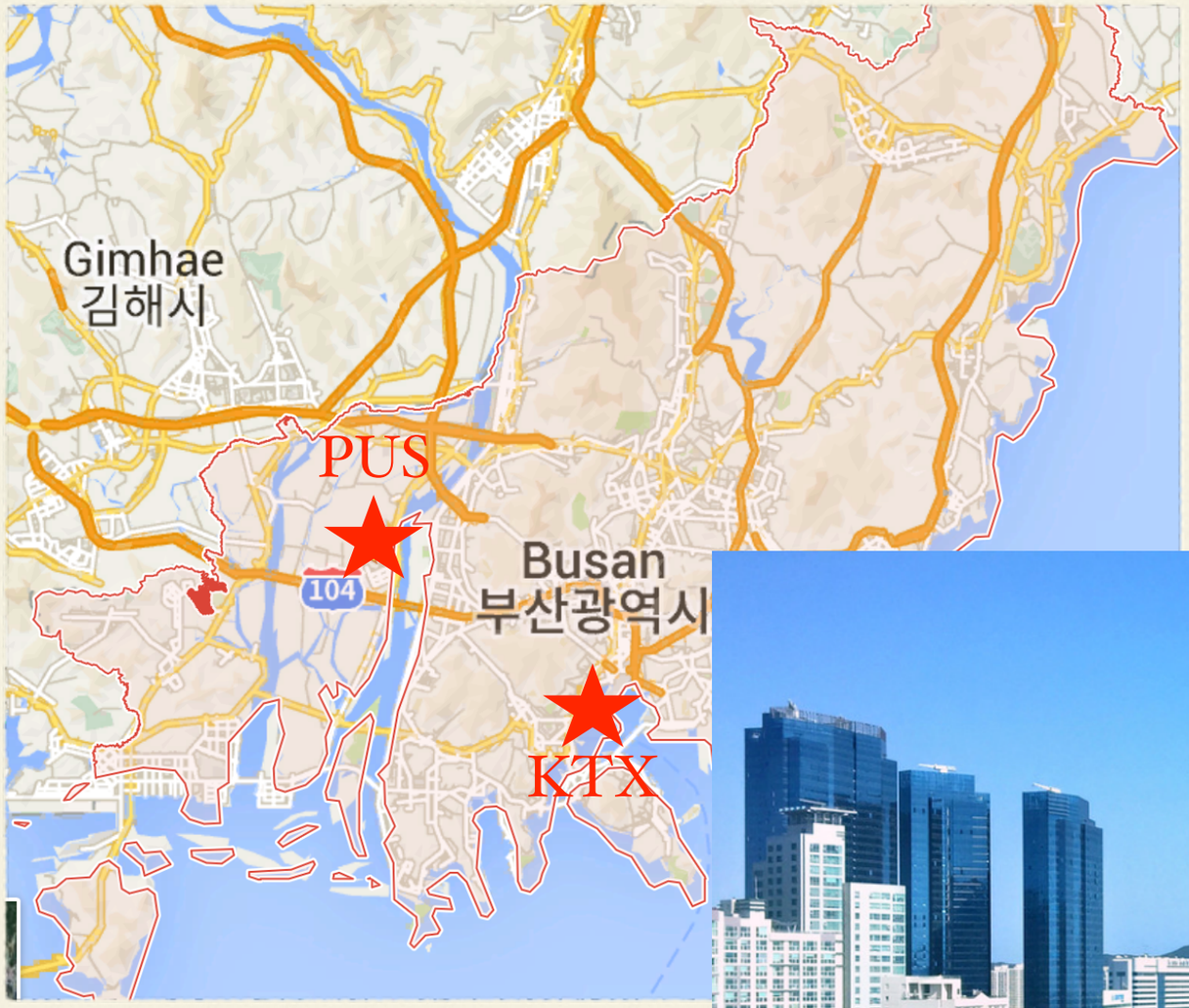


Transportation inside Busan



PUS (airport)

- Limousin Bus (<$10) ~ 1 hour
- Taxi (~$20) ~ 0.5 - 1 hour

KTX (train station)

- Taxi (~$20) ~ 0.5 - 1 hour

Conference Venue - Haeundae (海雲臺) Grand Hotel

Accommodations
- 80 - 150 USD/day for > 3★
- may be shared for students (2 for 1 twin)
- 30 Hotels (★3-5) within 200 m
- residence hotel as well

around the venue

~ 30 Hotels, 50 Restaurants, 30 Cafés, 30 bars etc.

At ATHIC2012@Busan

SQM2021@Busan.KR

- Final Schedule: May 17 - 22, 2021
- Target: $N_{part,max}$ ~ 300
- Budget Plan (total ~ 170 kUSD)
  - Local Sponsors:
    APCTP/PNU/KISTI/KoALICE/KCMS/Busan ~ 30 kUSD
  - Reg. Fee ~ 430-480 USD/p incl. Reception, Banquet, Lunch
  - Other traditional sponsors: GSI, CERN, BNL etc.

    ➡ support to students depending on sponsors and N_{part}
- Excursion: ~ 50 USD/p
  - Gyungju (historical millennium Capital, since AD. 5c) or Beach-Cliff tour
- A special session (*Dr. Strangers in QM*) for the undergraduates on Wed. evening (‖ poster session)

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- LOC ~ 15
  - IKY (chair) + BHong (Co-chair) + SHLee (Co-chair)
  - MJKweon (Sci. sec. Exp.) + STCho (Sci. sec. Th.)
  - KR: 5 Exp (DHMoon, YSKim, EJKim, YKwon, SHLim) + 5 Theory (SYJeon, CHLee, SINam, JYoon, YKim)
    - Experiences: HIM (2004 -), ATHIC 2006 @ Seoul, ATHIC 2012@Busan, ISMD2016@Jeju, ICHEP2018@Seoul
- ROC ~ 10
  - ATHIC (Asian Triangle HIC) young experts: ~ 10 LOC
- IAC of SQM ~ 25 members

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