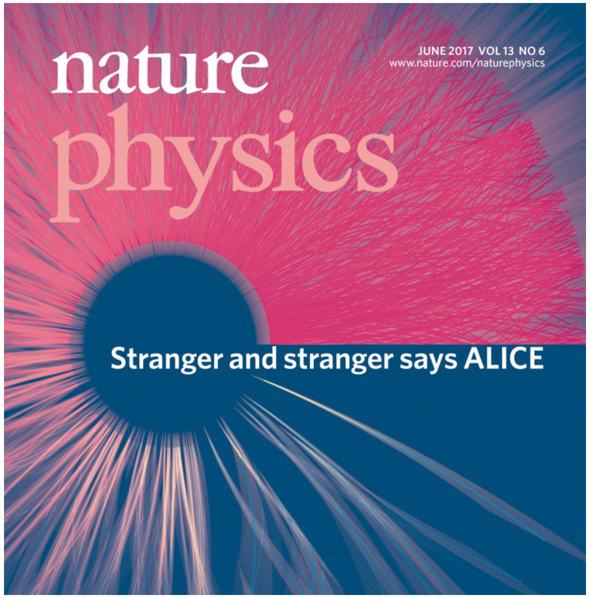

NOVEL PHENOMENA RELATED TO STRANGENESS IN PP COLLISIONS WITH ALICE AT THE LHC

Boris HIPPOLYTE (IPHC - USIAS - CERN)

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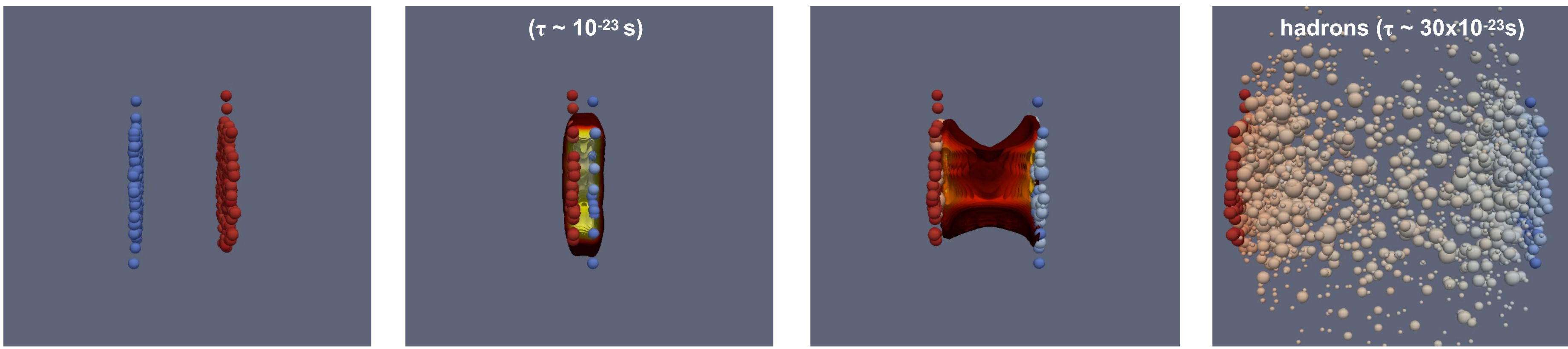
OUTLINE

- Strangeness enhancement in nucleus-nucleus collisions
  - time evolution of the Quark-Gluon Plasma (QGP)
  - the playground (ALICE) and the usual suspects (hyperons)
  - experimental and model challenges
  - measurements from SPS to RHIC… then at the LHC
- Strangeness enhancement in proton-proton collisions
  - minimum bias: reference for strangeness enhancement ?
  - multiplicity selection in proton-proton with ALICE
  - “Stranger and stranger says ALICE”
  - discussion and interpretation(s) with models
- Summary / discussion

Evolution of the Quark-Gluon Plasma created in nucleus-nucleus collisions

- Time evolution of the QGP (over-) simplified for illustration purposes
  - dynamical modelling of the different stages of the collision
  - infer a significant fraction of the dynamics from hadron measurements
  - distinguish what can be related to the first / last stages



MADAI.us

- Relevance of strangeness (measurements involving strange hadrons):
  - easy and precise measurements (require excellent tracking), abundant
  - large dynamical range (p_T) for investigating soft or hard processes

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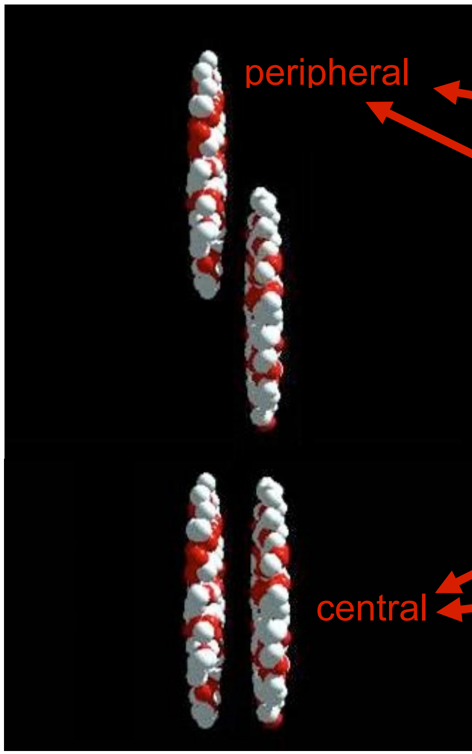
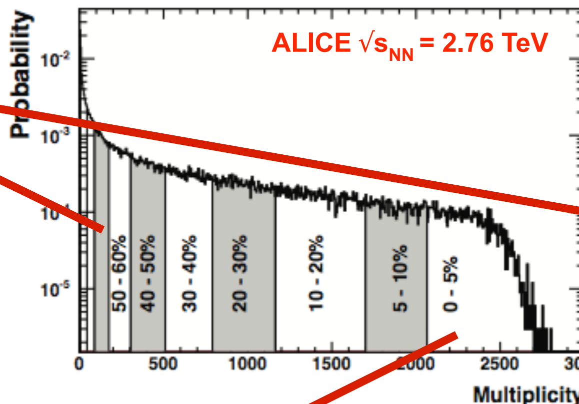
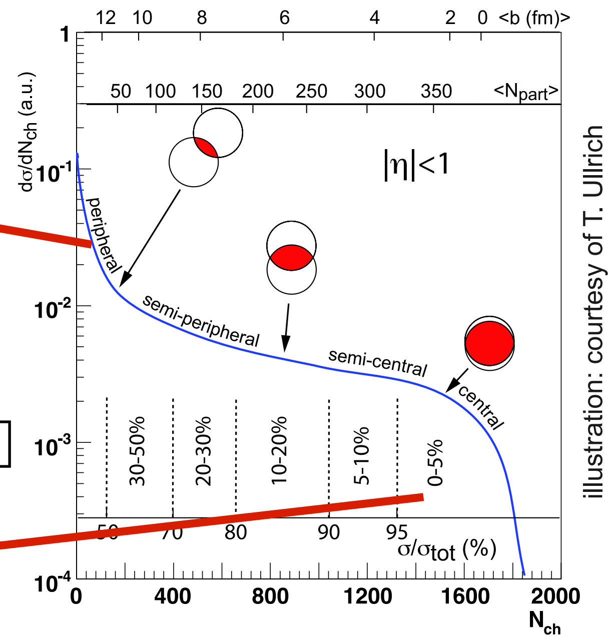
Defining the centrality for a nucleus-nucleus collision

- Correlate the multiplicity of produced particles with the geometry of the system i.e. impact parameter (not directly accessible), volume and (roughly) the shape...





ALICE, arXiv:1301.4361, Phys. Rev. C 88 (2013) 044909



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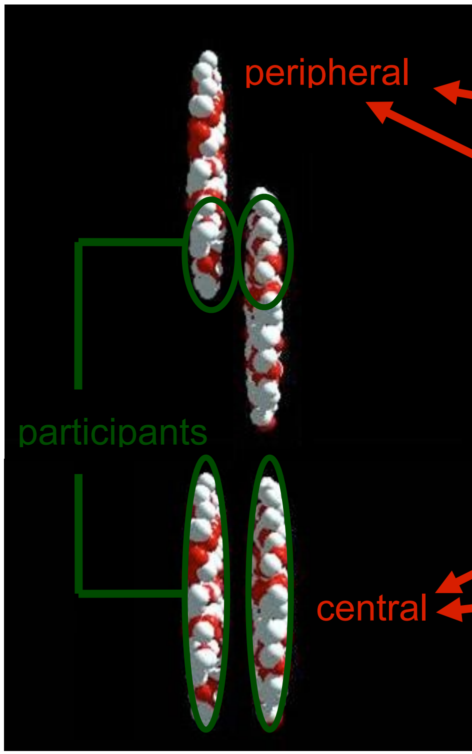

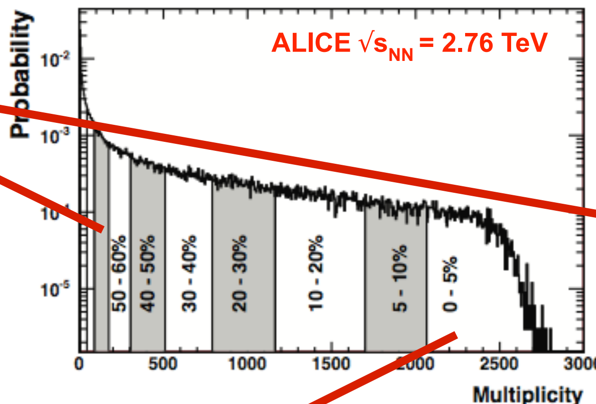

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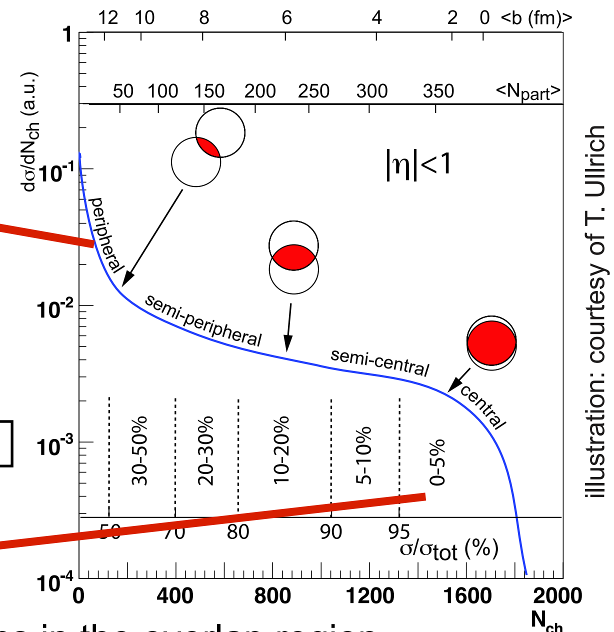

Number of participants (N_{part}): nucleons in the overlap region

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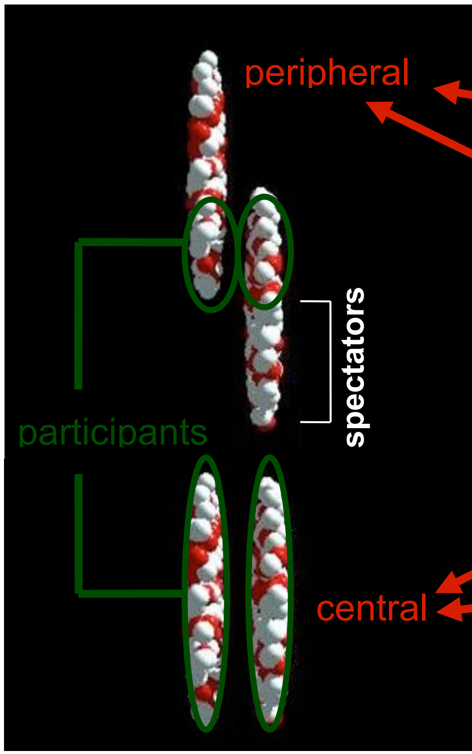

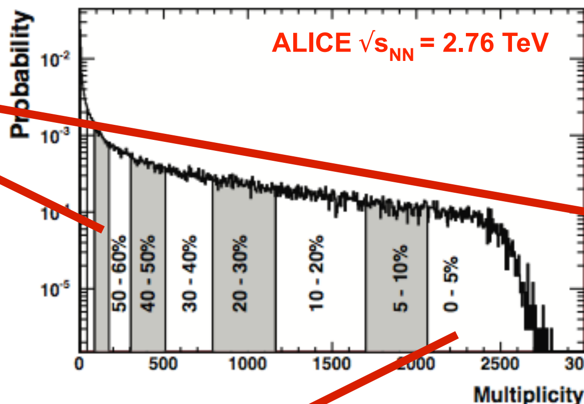

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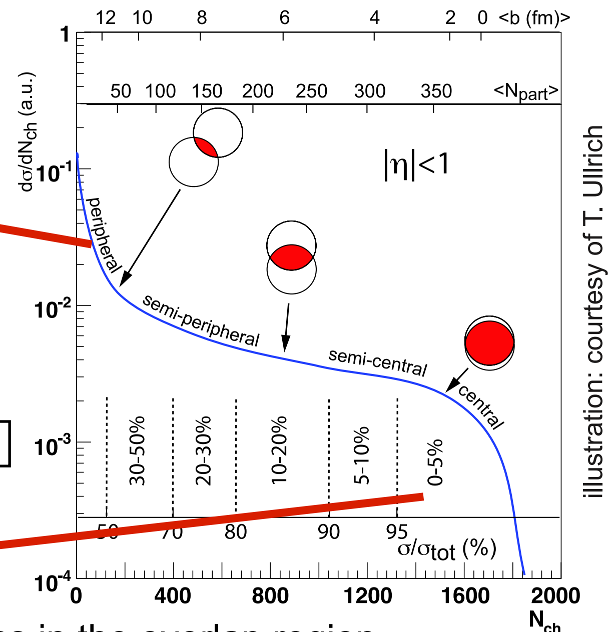

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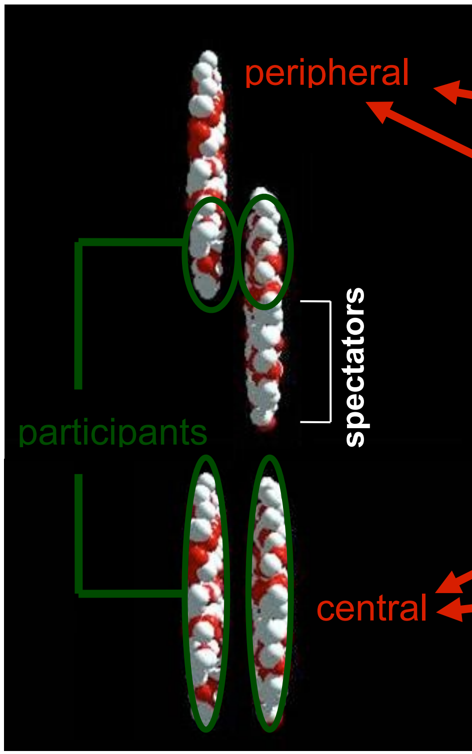
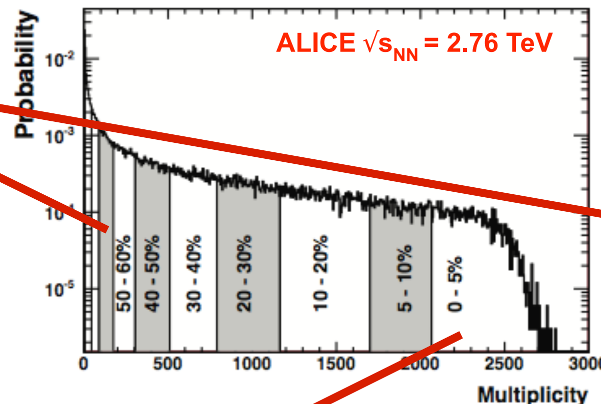
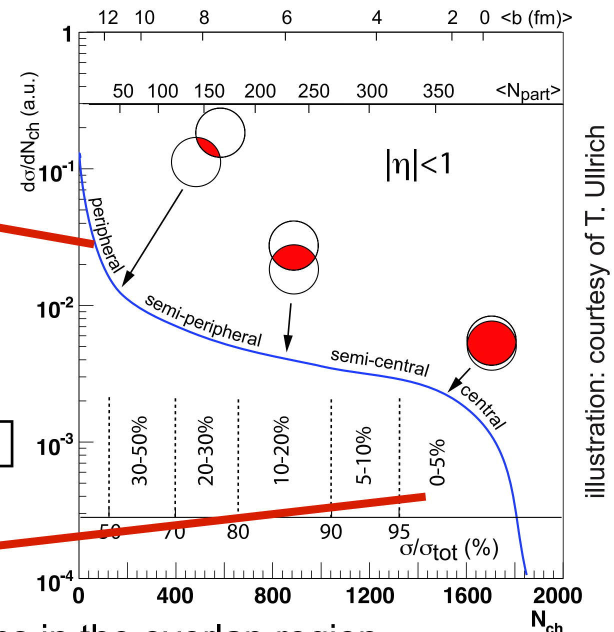




ALICE, arXiv:1301.4361, Phys. Rev. C 88 (2013) 044909



Number of participants (N_{part}): nucleons in the overlap region

Number of binary collisions (N_{coll}): nucleon-nucleon inelastic collisions

Defining the centrality for a nucleus-nucleus collision

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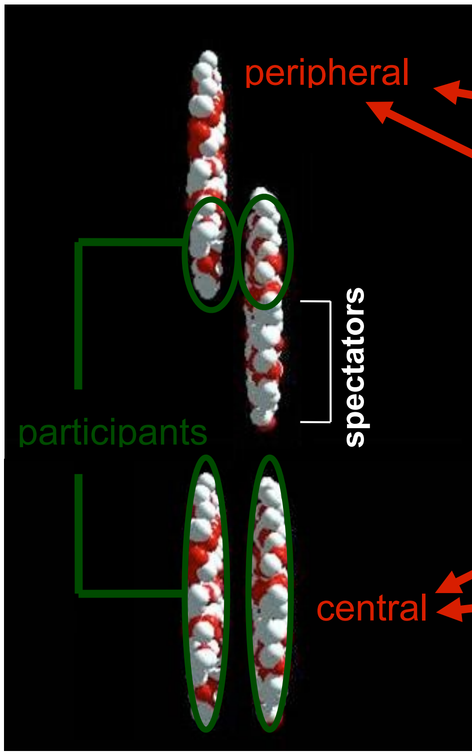

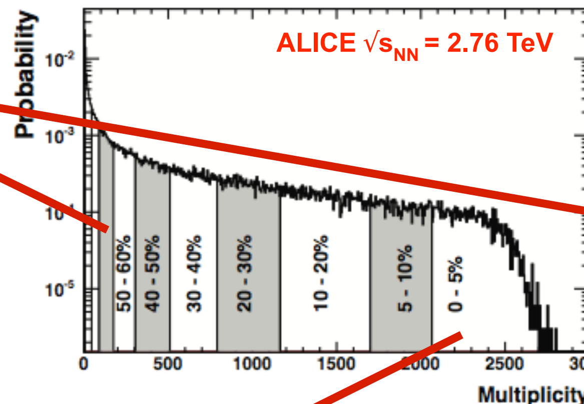

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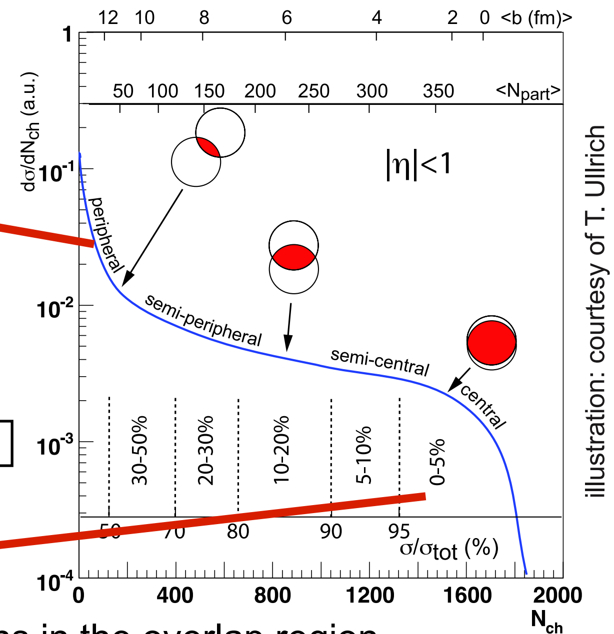

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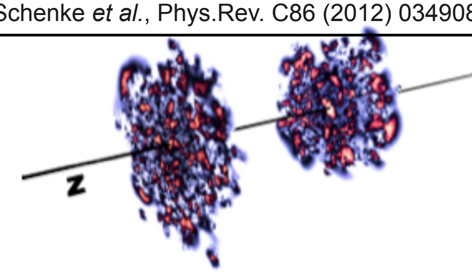
B. Schenke *et al.*, Phys.Rev. C86 (2012) 034908



In the details, the situation is "slightly" more complicated:

→ after centrality, fluctuations play an important role

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The Large Hadron Collider at CERN

	LHC
radius / circumference	4.2 km / 27 km (17 miles)
maximum energy: pp / AA	14 TeV / 5.5 TeV
ring depth	50-175 m
magnets	1232 dipoles + 392 quadrupoles

Nikhef

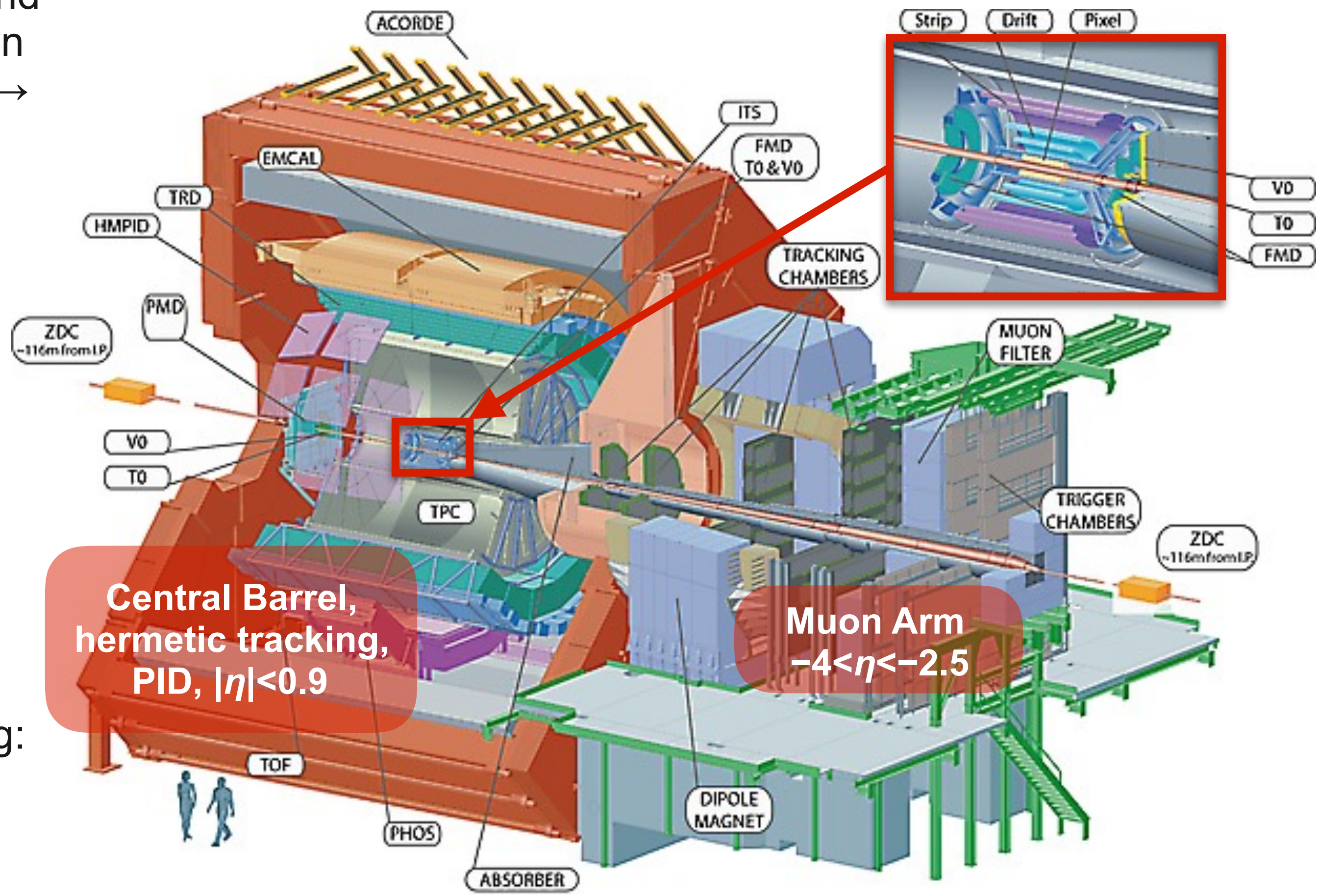
A Large Ion Collider Experiment - the detectors

- Designed to reconstruct and identify charged particles in a central rapidity window → central barrel down to low transverse momentum (p_T~100 MeV/c for pions)

- Central barrel ($|\eta|<1$):
- tracking (ITS, TPC), PID (TOF,TRD), calorimeters.
- Muon spectrometer:

  $-4 < \eta < -2.5$

- Forward detectors for triggering, centrality, timing: V0, T0, ZDC



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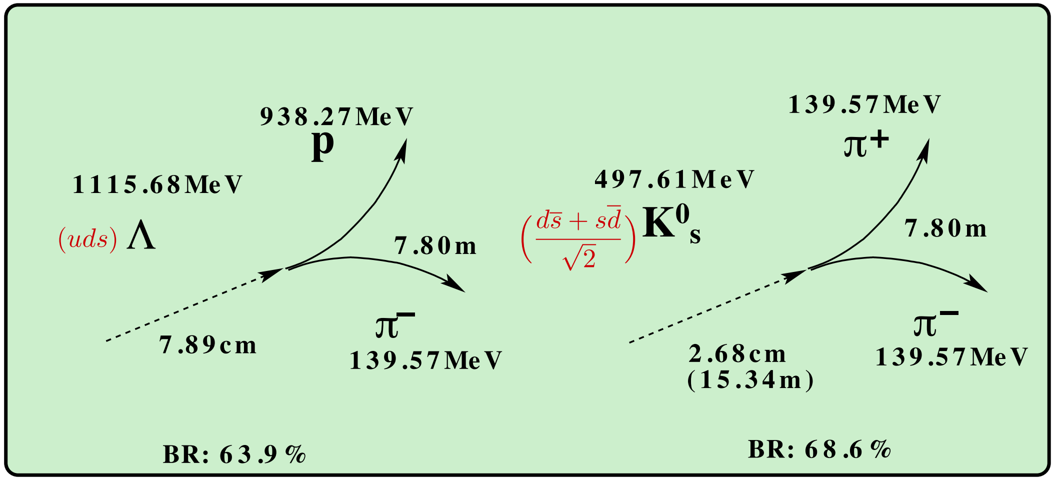
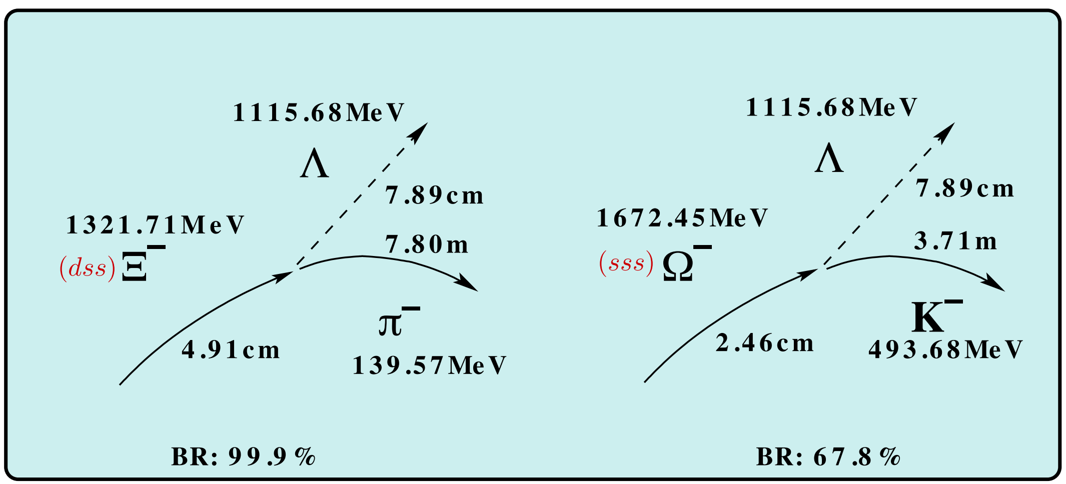
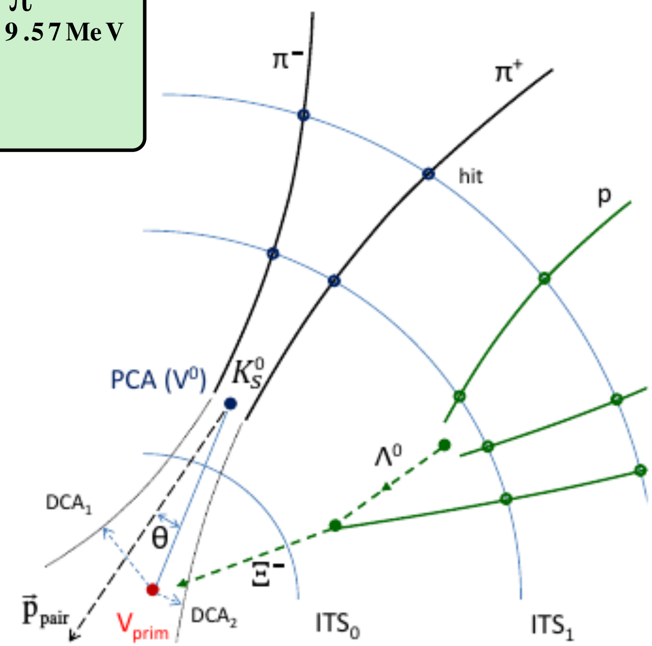
The usual suspects and the weak decay topologies

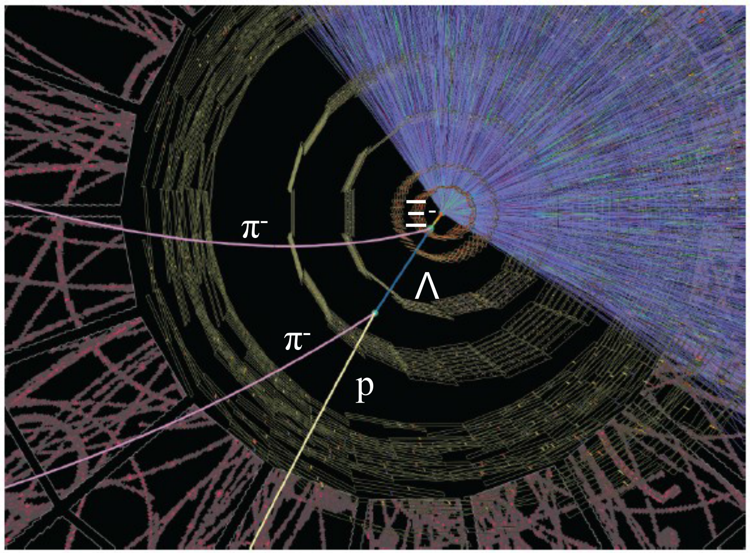






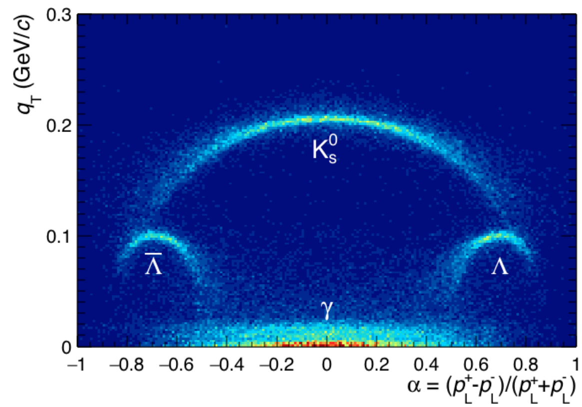
Experimental challenge: needles in a haystack

- Identification based on the weak decay topological reconstruction
  - weak decay of strange and multi-strange hadrons
    - mesons K^0_s and baryons Λ (uds) , $Ξ^-$ (dss), $Ω^-$ (sss)



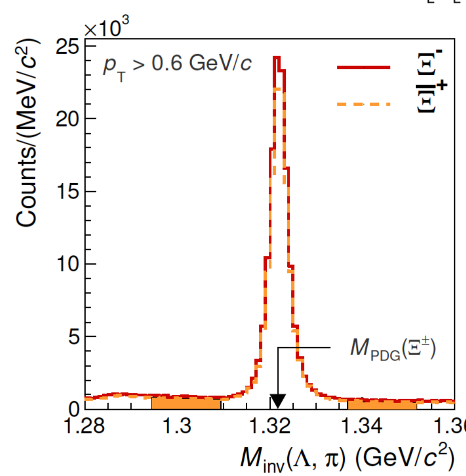
ALICE, J. Phys. G: Nucl. Part. Phys. 32 (2006) 1295

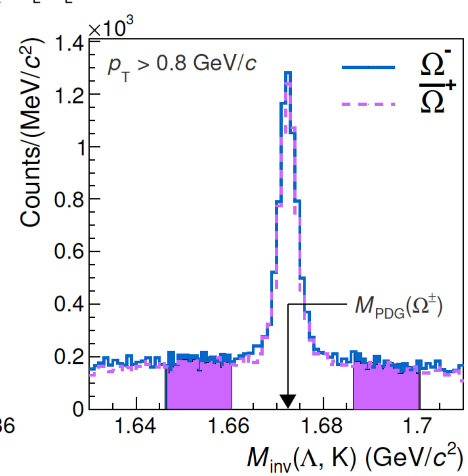
➡ large combinatorial background in Pb-Pb



➡ validation with Armenteros-Podolanski

ALICE, Eur. Phys. J. C71 (2011) 1594 and Phys.Lett. B712 (2012) 309-318





⇨ broad (p_T) range for identification

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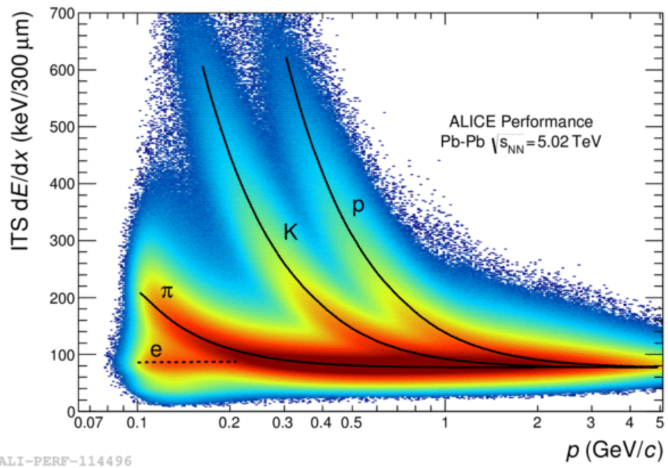
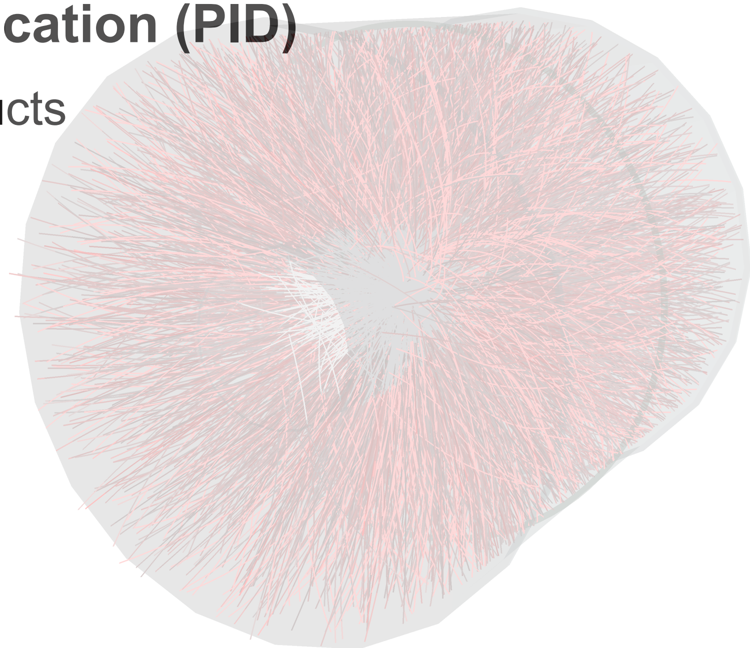
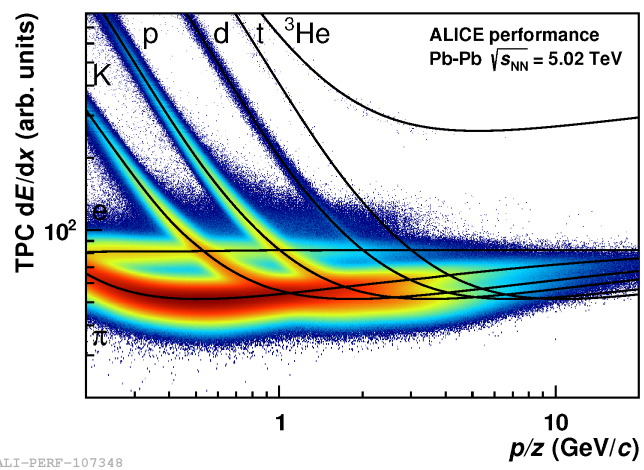
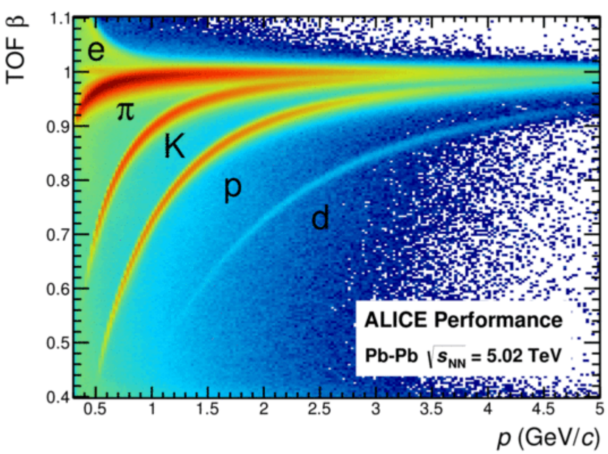
Experimental challenge: particle identification (PID)

- not only strange topologies but decay products









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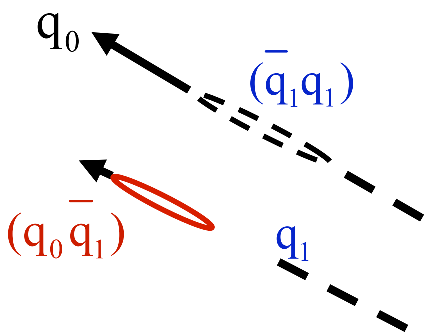
Hadron production from fragmentation (LUND / PYTHIA)



probability: $e^{-\frac{\pi m_T^2}{\kappa}} = e^{-\frac{\pi m^2}{\kappa}} \times e^{-\frac{\pi p_T^2}{\kappa}}$

κ (string tension) ≈ 1 GeV/fm ≈ 0.2 GeV²

mass suppression: u:d:s:c≈1:1:0.3:10^{-11}

In vacuum production of meson via string break-up

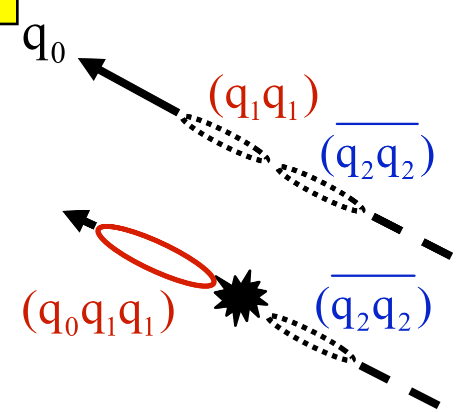
Probability to produce $(q_i \bar{q}_i)$
Probability to form $(q_{i-1} \bar{q}_i)$
Factorization: production of $(q_i \bar{q}_i)$ independent of q_{i-1} but the pair mass quark (flavour) is relevant.
➪ Fragmentation in $(q_{i-1} \bar{q}_i)$ ≡ meson

Production of $(q_i \bar{q}_i)$ via quantum mechanical tunneling:

- Classically, the pair is pulled apart by the field (no annihilation);
- Quantum mechanically, the pair is created at one point then tunnels out with a non zero probability (mass and flavor dependence).

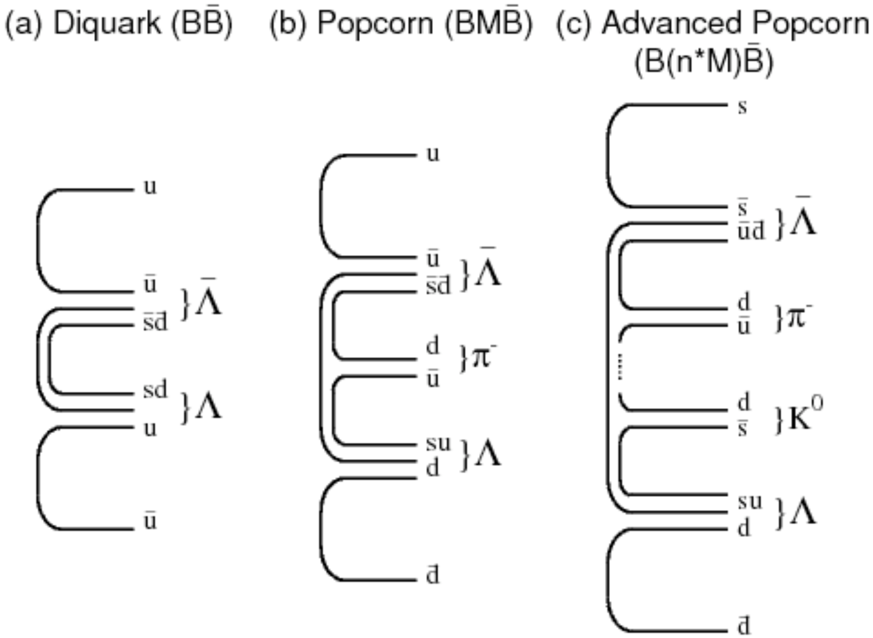
In vacuum production of baryon with the diquark model

Relative probability to produce a diquark pair wrt quark pair
Extra suppression associated to s content
Spin suppression (spin 1 diquarks wrt spin 0 diquarks)
Weighted probability relative to 3-q state symmetry
➪ Fragmentation in $(q_{i-1} q_i q_i)$≡ baryon



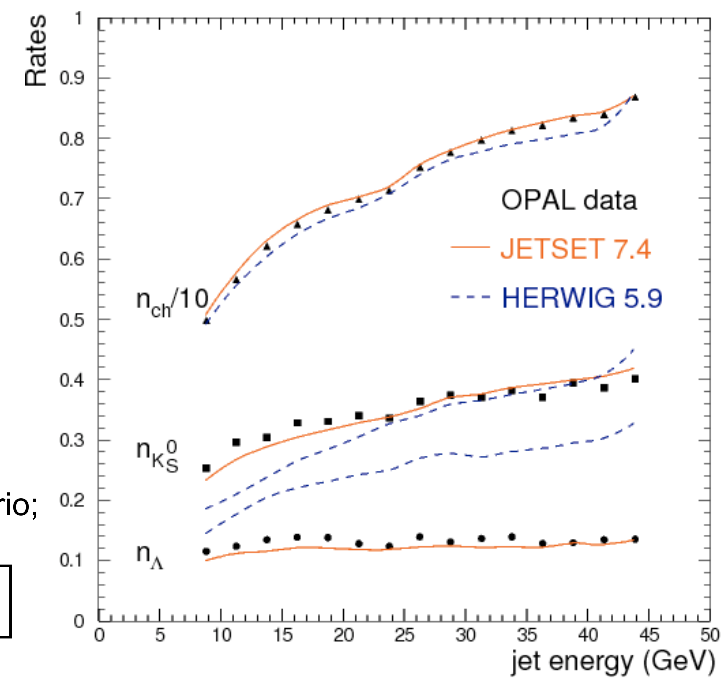
Baryon production from fragmentation (LUND / PYTHIA)

Modified "popcorn" scenario from the diquark model for baryon production



Studied at LEP e.g. OPAL:

1. baryon yields vs. jet energy
2. baryon correlations vs. η gap between the baryon pair



Distinguishing between different scenario for fragmentation

- JETSET (now PYTHIA): anisotropic string decay
- MOPS : (now advanced/Popcorn in PYTHIA) MOdified Popcorn Scenario;
- HERWIG: isotropic clustering

OPAL, Eur. Phys. J. C13 (2000) 185, arXiv:hep-ex/9808031

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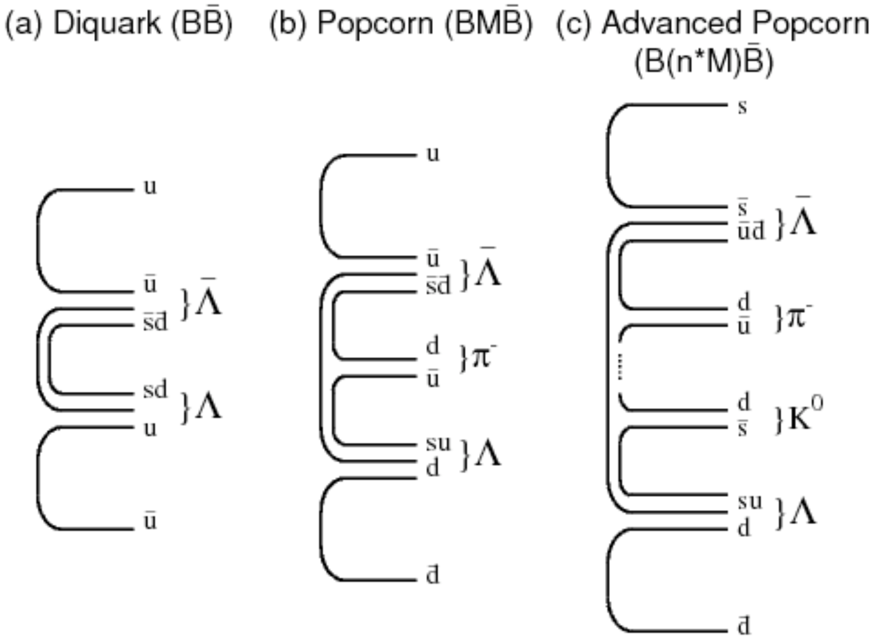

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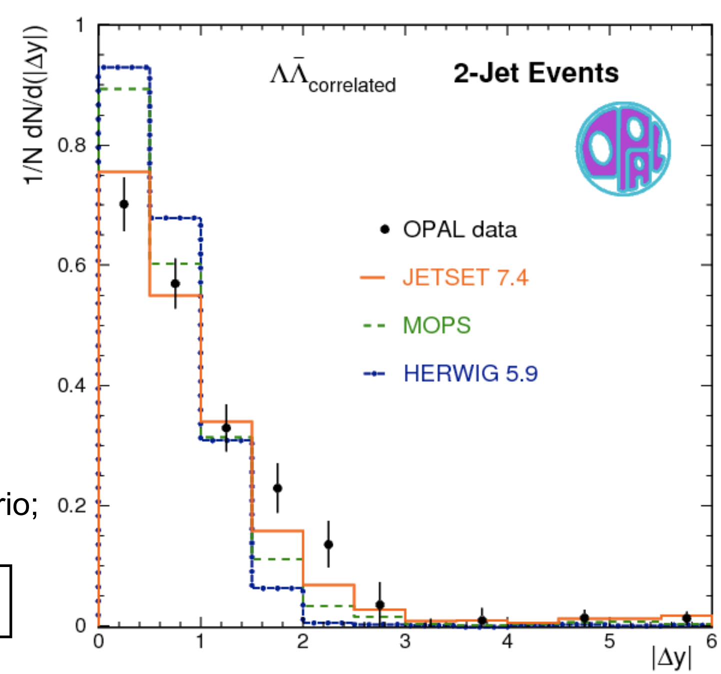

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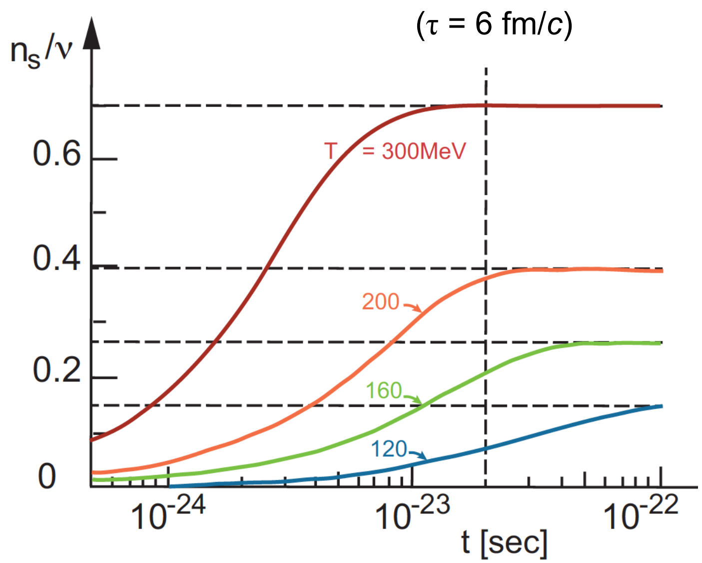
Strangeness enhancement in the QGP

- prediction (1982): favoured production of strange quarks in the QGP
  - ➡ QGP: $s\bar{s}$ pairs creation by gluon fusion
  - ➡ hadron gas: hyperons (rarely produced)
    - energy (and/or time) cost if created by direct (and/or indirect) reactions

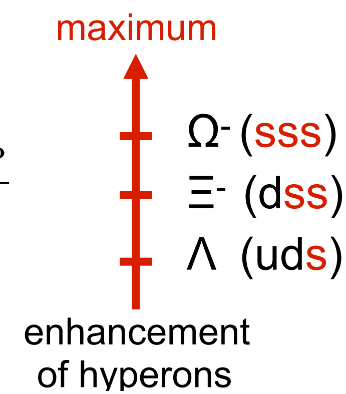
J. Rafelski and B. Müller, Phys. Rev. Lett 48 (1982) 1066

- historical signature of the QGP

strange quark concentration divided by baryonic concentration →



$$\frac{Y|_{QGP}}{Y|_{HG}}$$



- statistical thermal model formalism:
  - ➡ γ_s = 1 means absence of undersaturation in high energy nucleus-nucleus collisions

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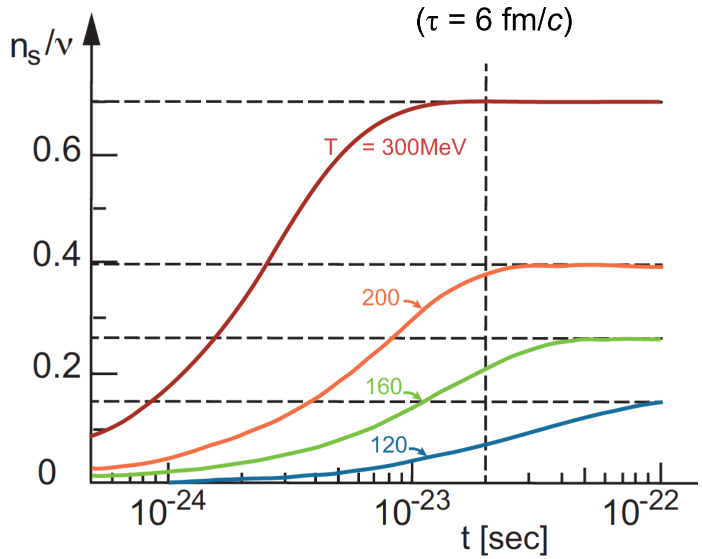
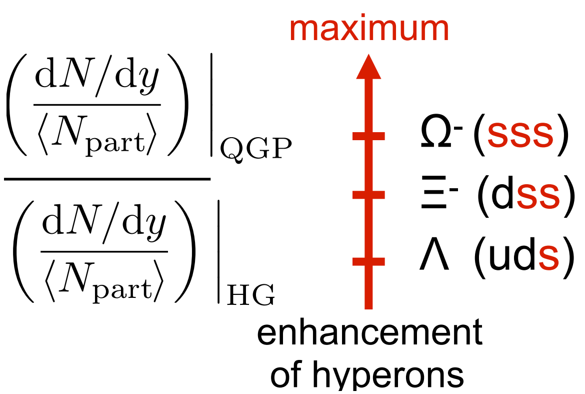


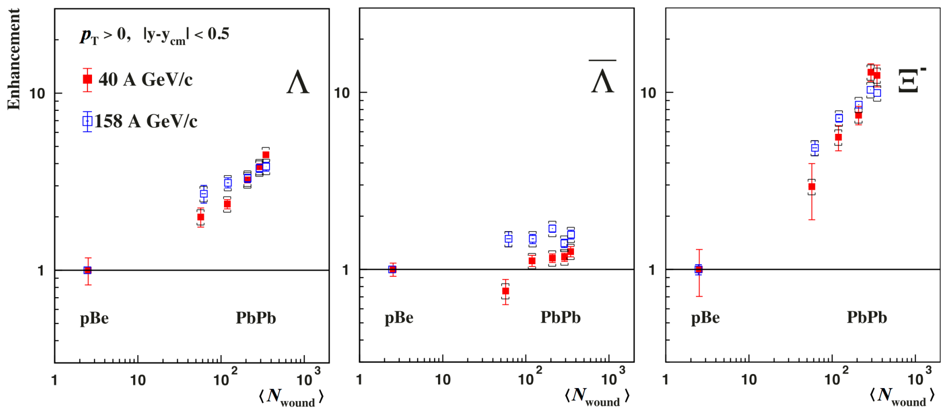


- statistical thermal model formalism:
  - ➡ γ_s = 1 means absence of undersaturation in high energy nucleus-nucleus collisions
- measures: variation of production yields of strange baryons as a function of $\langle N_{\mathrm{part}}\rangle$

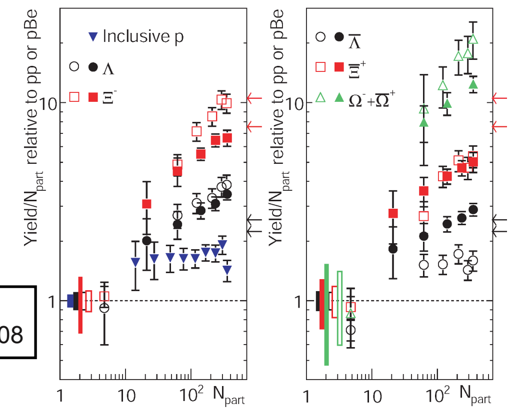
A series of measurements during last 35 years

- at the SPS, then at RHIC and eventually at the LHC

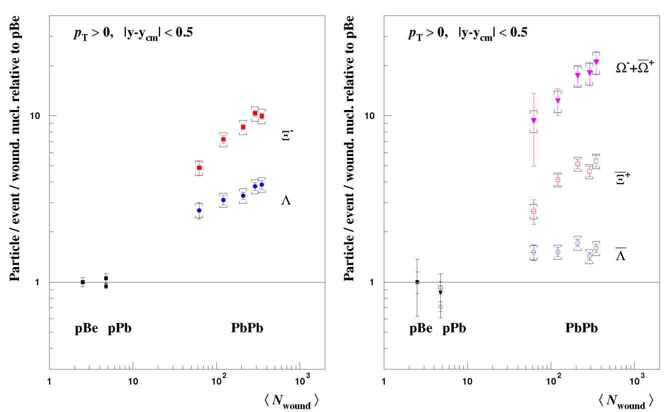
Many results and ways of displaying strangeness enhancement in nucleus-nucleus collisions



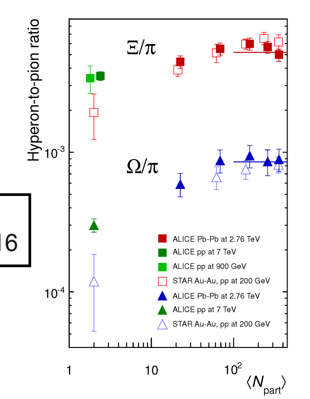
NA57, arXiv:1001.1884
J. Phys. G 37 (2010) 045105



STAR, arXiv:0705.2511
Phys. Rev. C 77 (2008) 044908



NA57, nucl-ex/0601021
J. Phys. G 32 (2006) 427



ALICE, arXiv:1307.5543
Phys. Lett. B 728 (2014) 216

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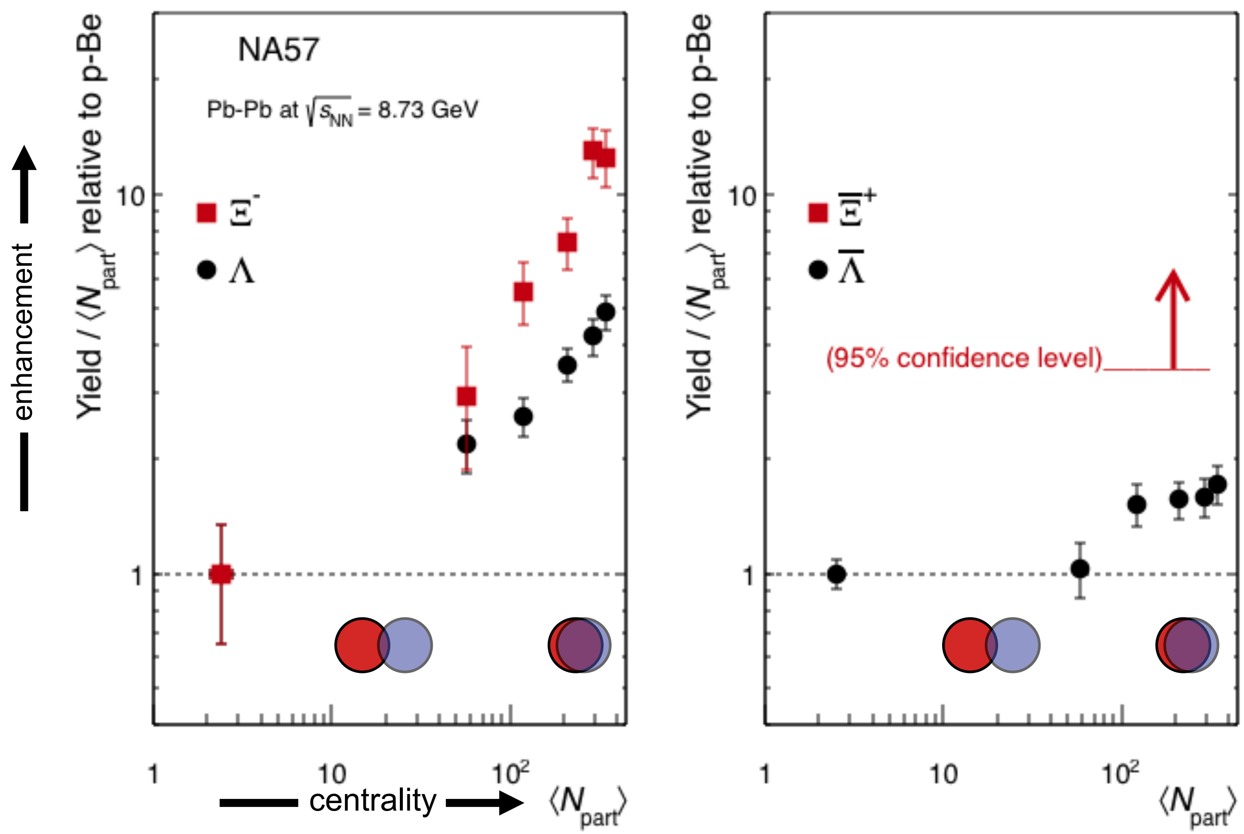
Measuring the strangeness enhancement at the SPS

- evolution as a function of $\langle N_{part} \rangle$ and for increasing beam energy:



double normalisation:
$\langle N_{part} \rangle$ and pp or p-A collisions of similar energy

energy $\sqrt{s_{NN}}$

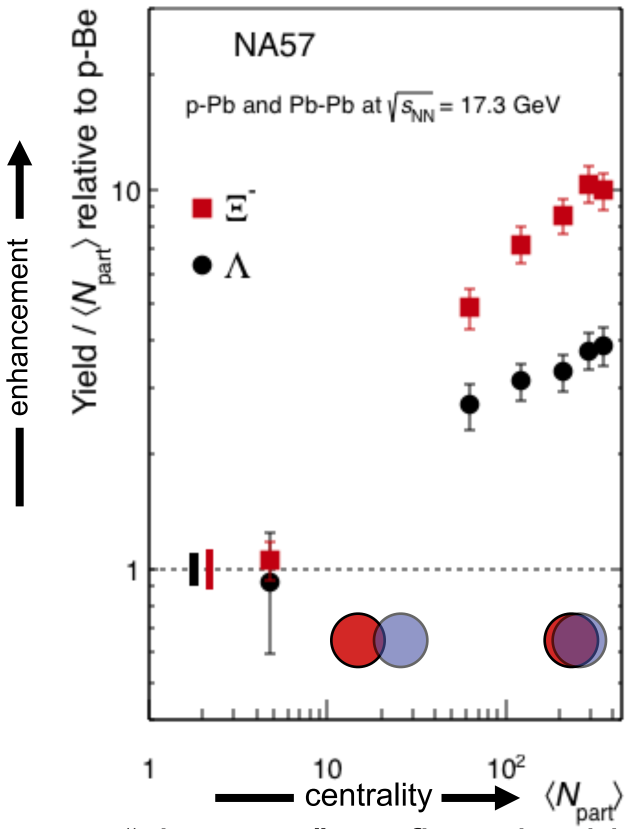
Pb-Pb at LHC:	2.76 TeV
Au-Au at RHIC:	200 GeV
Pb-Pb at SPS:	17.3 GeV
Pb-Pb at SPS:	8.73 GeV

NA57 Collaboration, arXiv:1001.1884
J. Phys. G 37 (2010) 045105

- the higher the enhancement is:
  - ➡ with more central collisions;
  - ➡ when the baryon contains more strange valence quarks (but low stat. for anti-hyperons).

Measuring the strangeness enhancement at the SPS

- evolution as a function of ⟨N_{part}⟩ and for increasing beam energy:



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Pb-Pb at SPS:	8.73 GeV

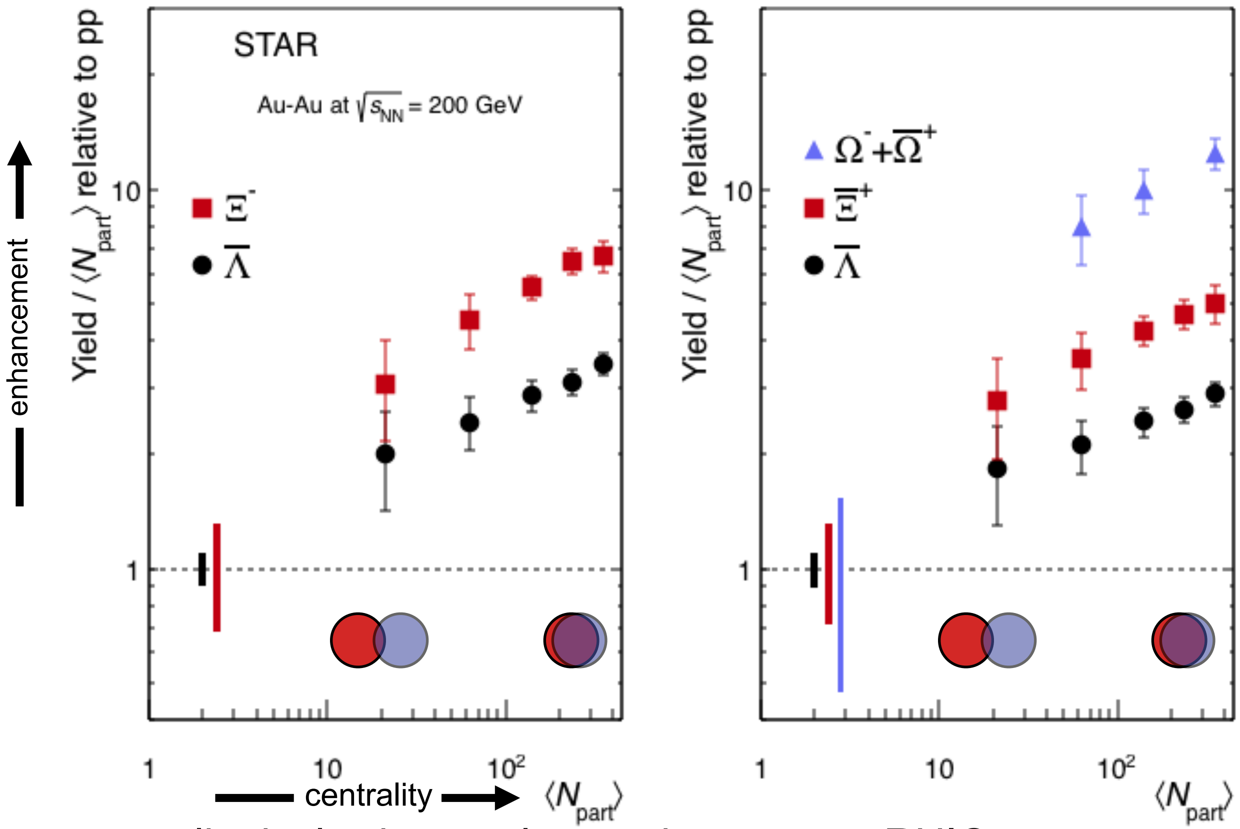
x2

NA57 Collaboration, nucl-ex/0601021
J. Phys. G 32 (2006) 427

- "signature" confirmed at higher energy (still at the SPS):
  - ➡ higher energy: sufficient statistics for the anti-hyperons (and Ω^-)
  - ➡ enhancement up to a factor 20 for the most central collisions
  - ➡ strong argument for the QGP discovery announcement in 2000

Measuring the strangeness enhancement at RHIC

- evolution as a function of $\langle N_{part} \rangle$ and for increasing beam energy:



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energy $\sqrt{s_{NN}}$

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Pb-Pb at SPS:	17.3 GeV
Pb-Pb at SPS:	8.73 GeV

x11

STAR Collaboration, arXiv:0705.2511
Phys. Rev. C 77 (2008) 044908

- qualitatively, the results are the same at RHIC:
  - ➡ higher energy: more centrality intervals and better statistics (more precise results)
  - ➡ however: slightly lower enhancement (x15 for the Ω) whereas the beam energy increases (?)

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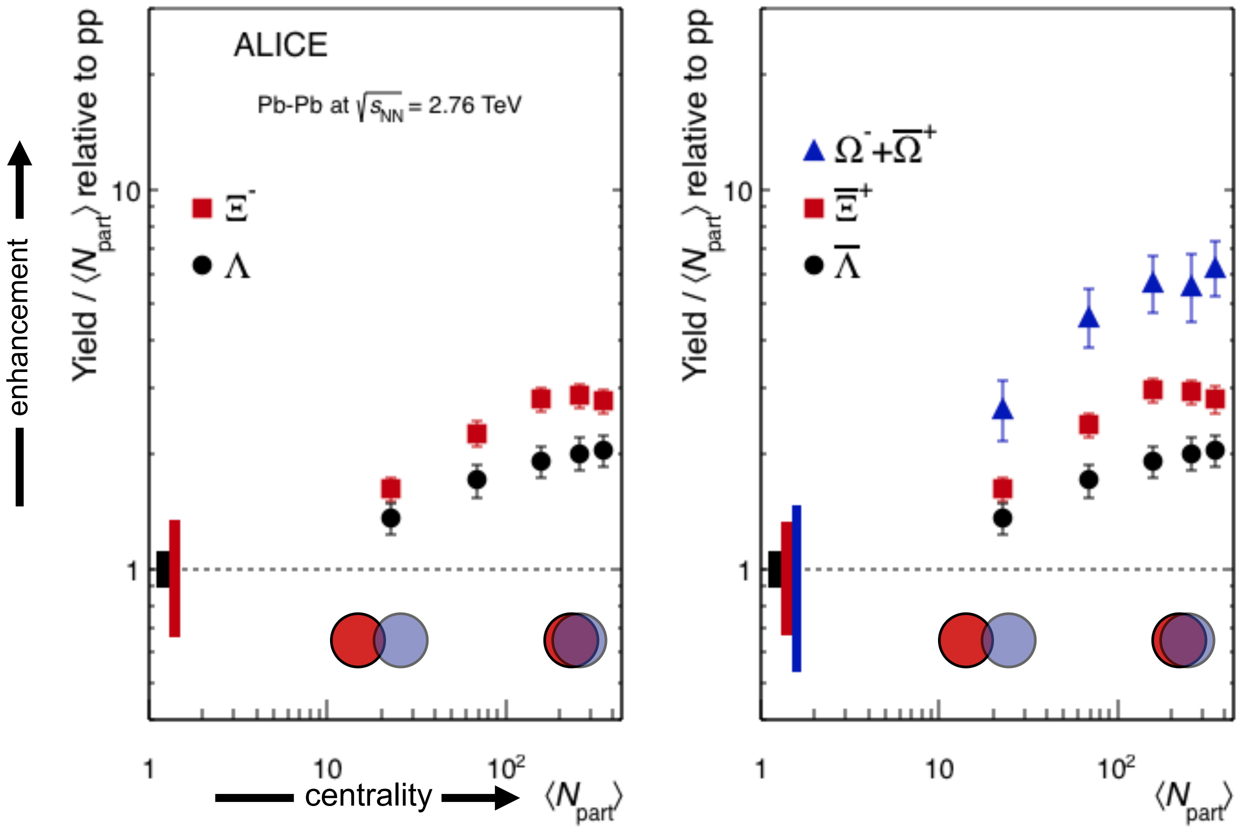
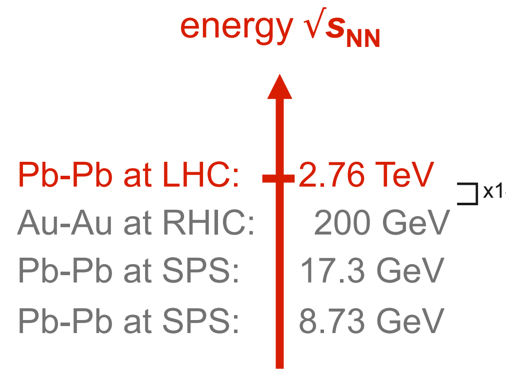
Measuring the strangeness enhancement at the LHC

- evolution as a function of $\langle N_{part} \rangle$ and for increasing beam energy:



double normalisation:
$\langle N_{part} \rangle$ and pp or p-A collisions of similar energy



ALICE Collaboration, arXiv:1307.5543
Phys. Lett. B 728 (2014) 216

- results eventually obtained at the LHC with ALICE:
  - ➡ confirmation of a lower enhancement (x6 for the Ω) with increasing colliding energy…

Measuring the strangeness enhancement: summary

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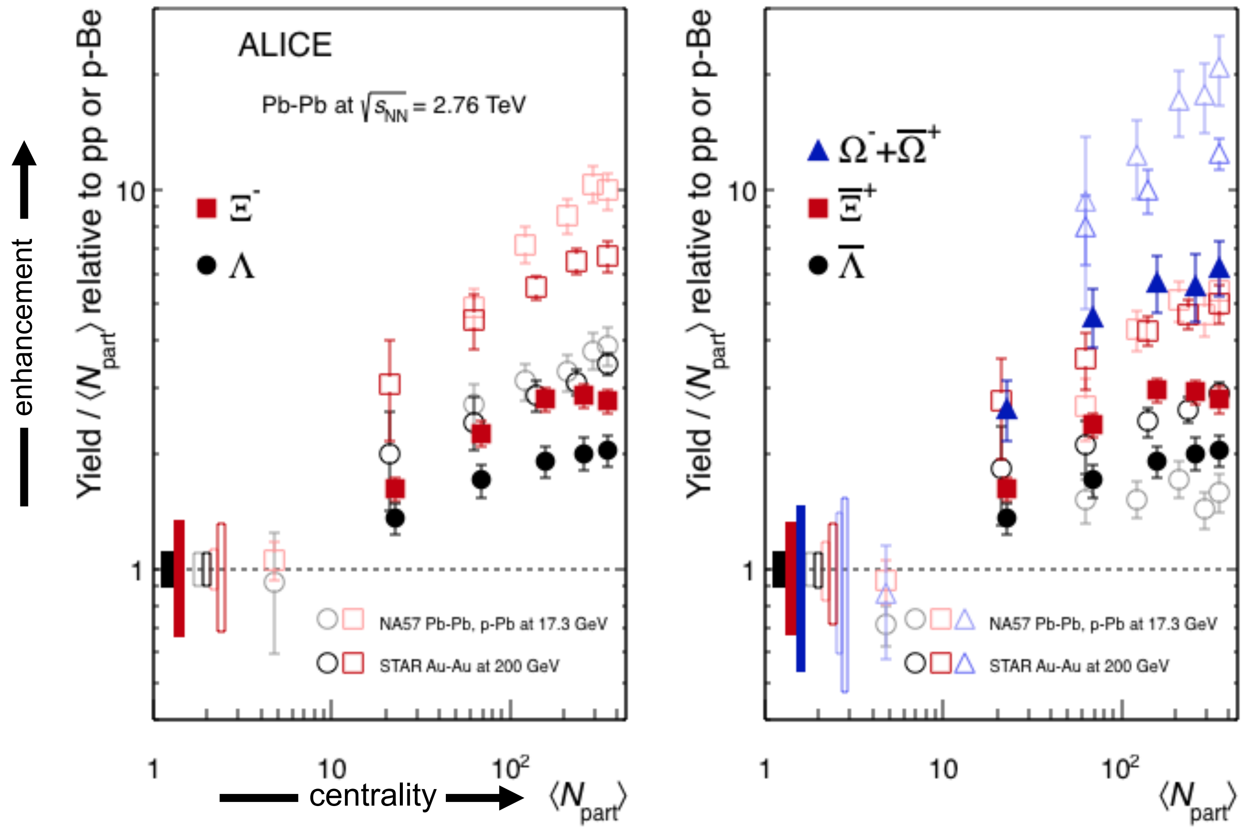

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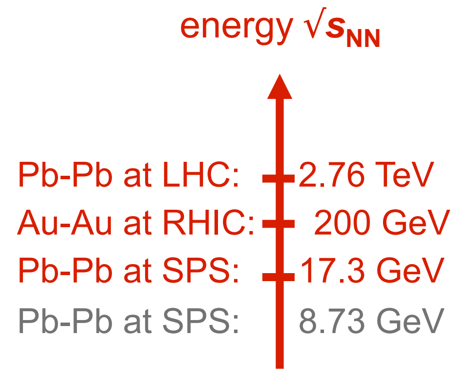
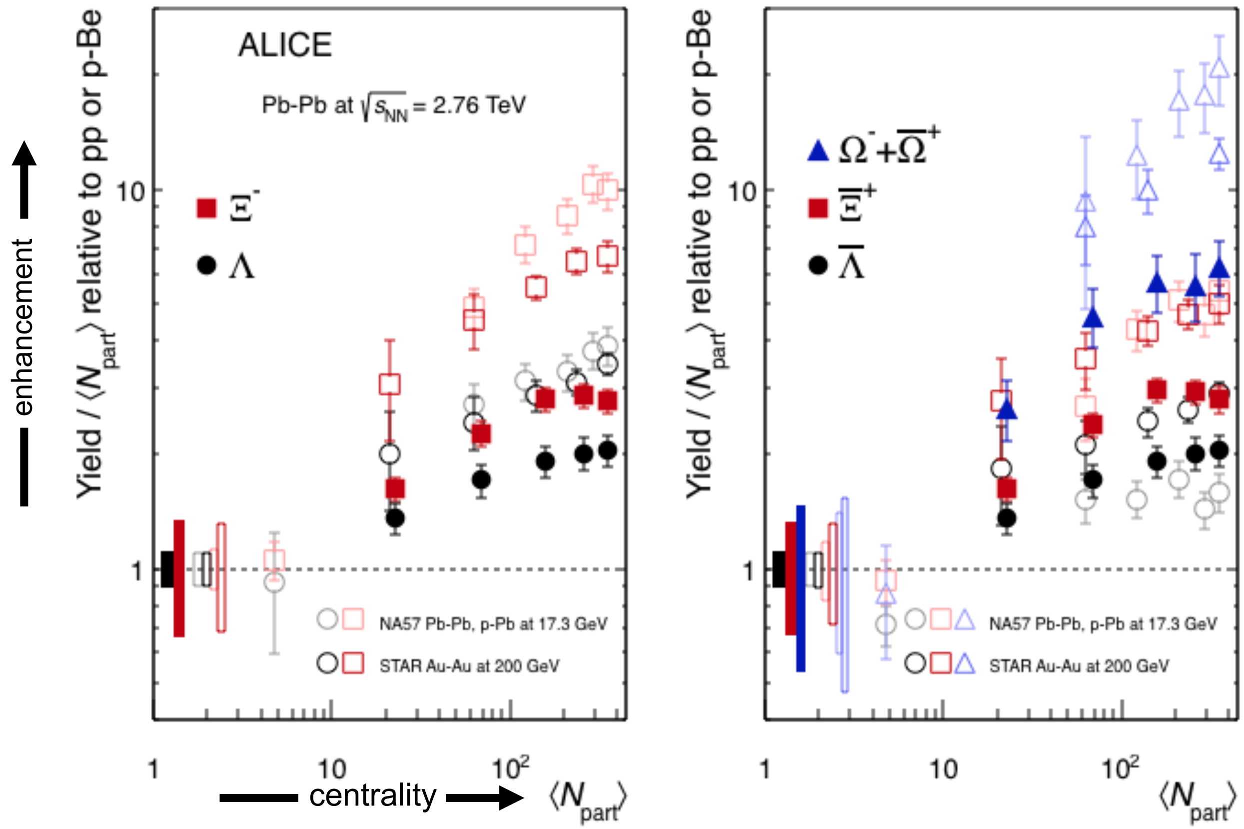


ALICE Collaboration, arXiv:1307.5543
Phys. Lett. B 728 (2014) 216

- the hierarchy predicted as a signature of the QGP for the hyperons is still valid !
- the enhancement decreases with increasing beam (and colliding) energy

Measuring the strangeness enhancement: next at 5.02 TeV

- evolution as a function of $\langle N_{part} \rangle$ and for increasing beam energy:



double normalisation: $\langle N_{part} \rangle$ and pp or p-A collisions of similar energy

energy $\sqrt{s_{NN}}$

Pb-Pb at LHC: 5.02 TeV]x1.8
Pb-Pb at LHC: 2.76 TeV
Au-Au at RHIC: 200 GeV
Pb-Pb at SPS: 17.3 GeV
Pb-Pb at SPS: 8.73 GeV

Last summer, during SQM'17 in Utrecht, measurements at top LHC energy…

➡ any saturation for the strange baryon production ?

➡ is $<N_{part}>$ the right scale ? is minimum bias pp a good reference ?

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Reference colliding system(s) and comparisons

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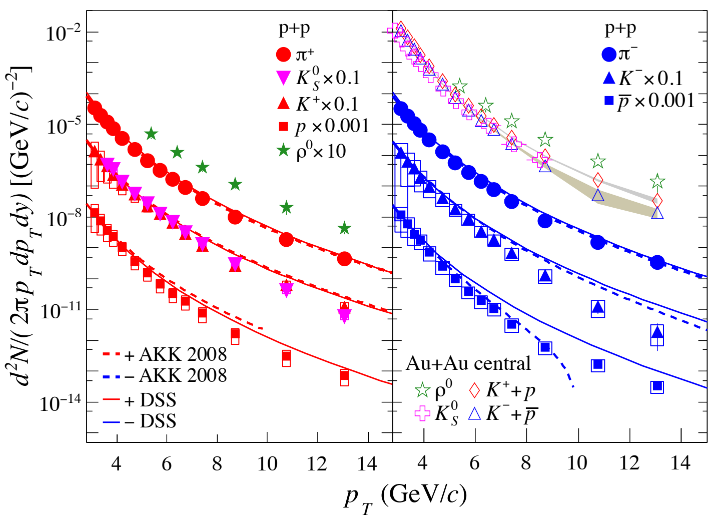
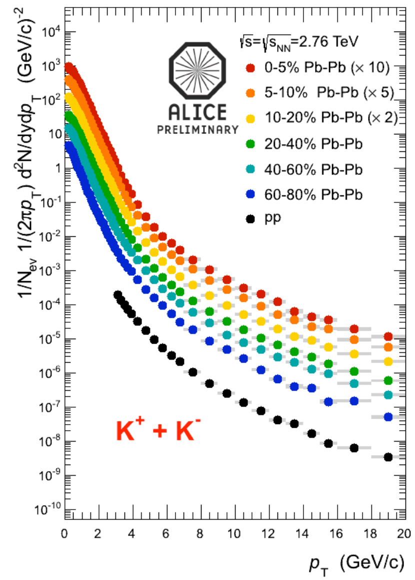
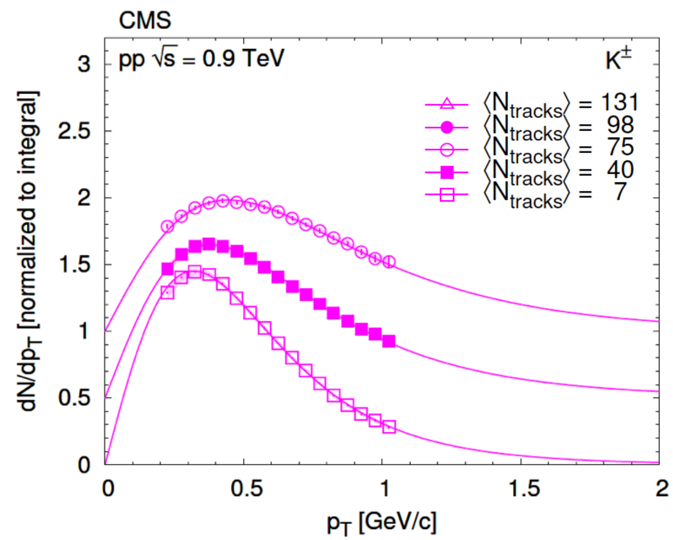


STAR Collaboration,
PRL 108 (2012) 072302, arXiv:1110.0579



M. Ivanov (ALICE Collaboration),
NPA 904-905 2013 (2013) 162c



CMS Collaboration, CMS-FSQ-12-014,
EPJC 72 (2012) 2164, arXiv:1207.4724

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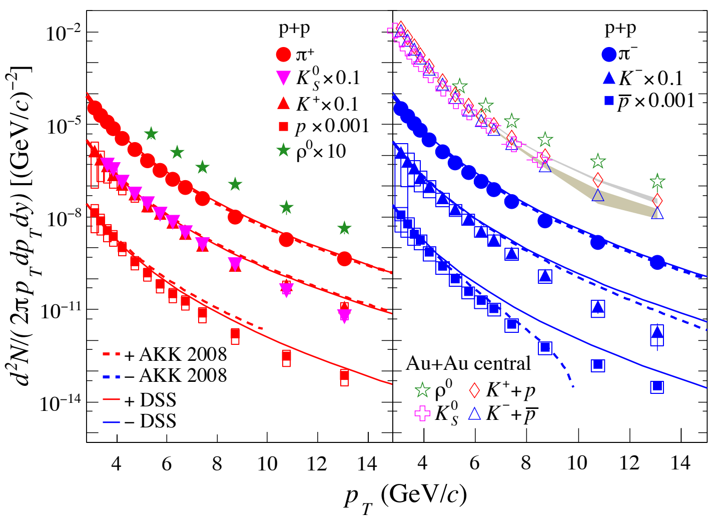

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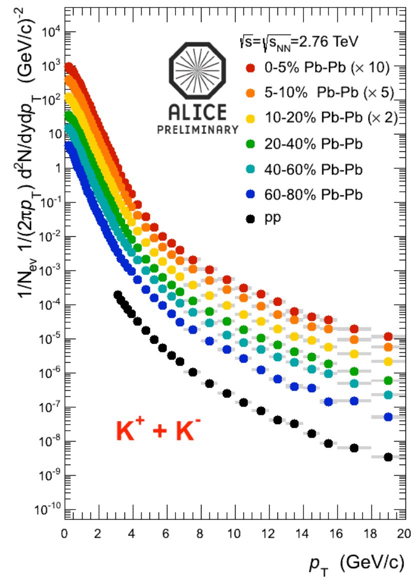

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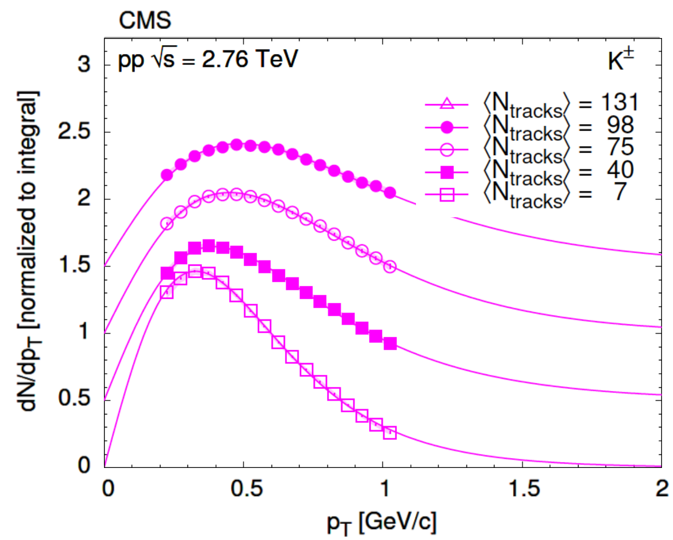

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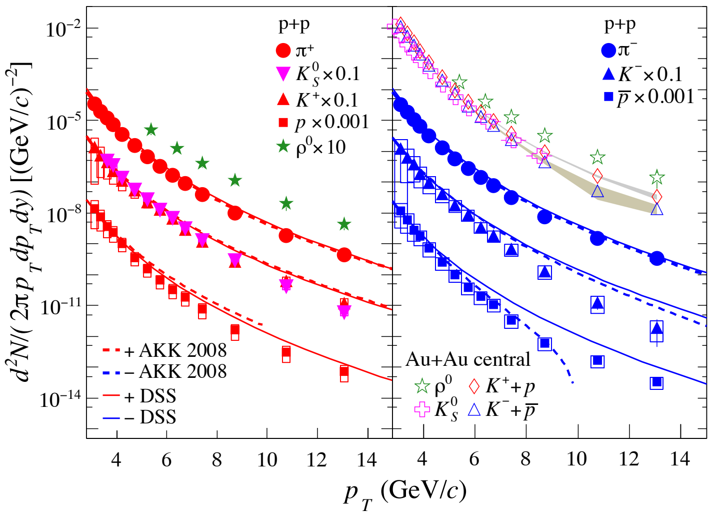

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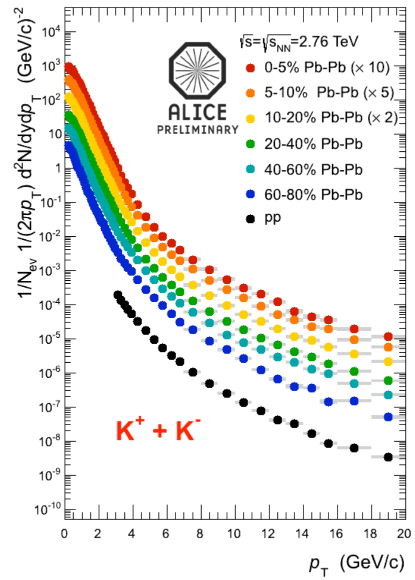

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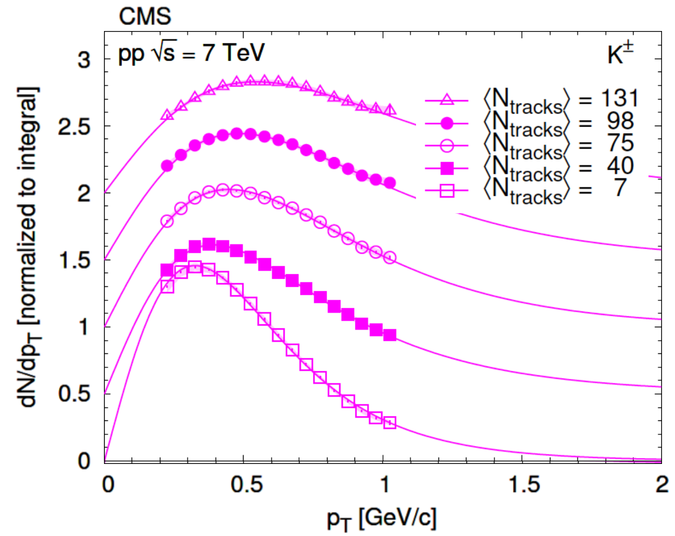

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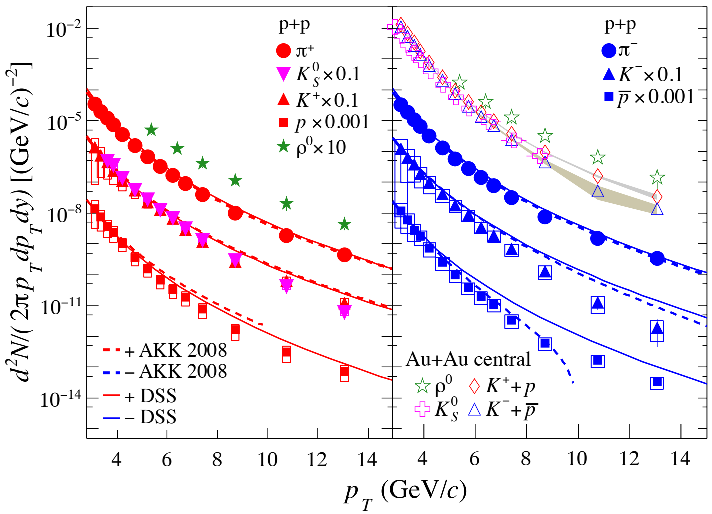

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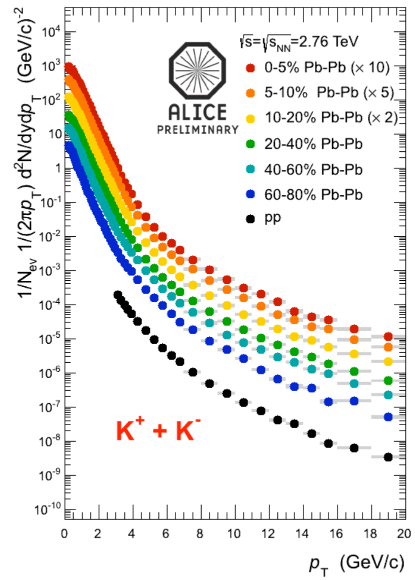

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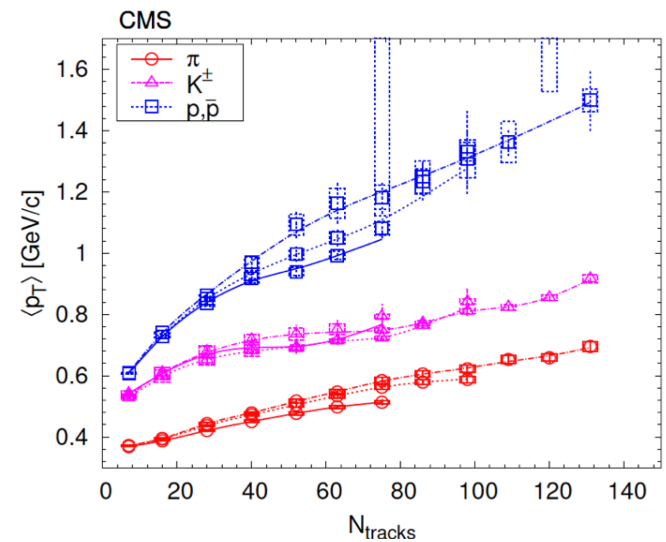

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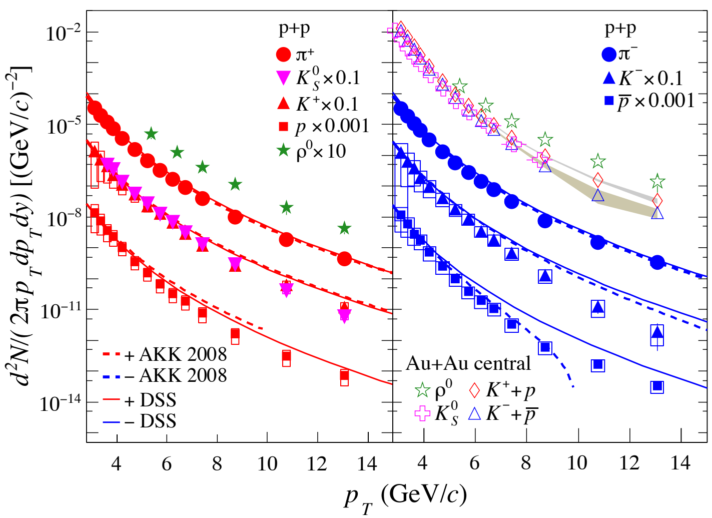

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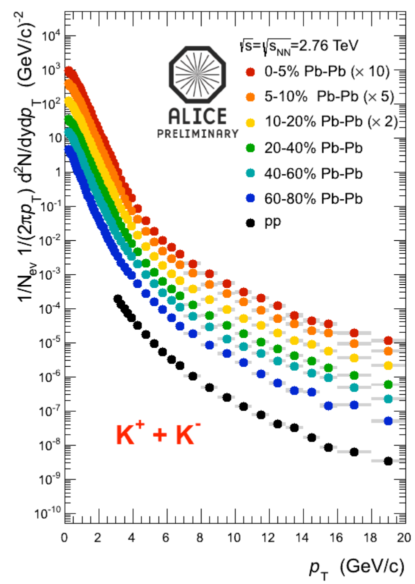

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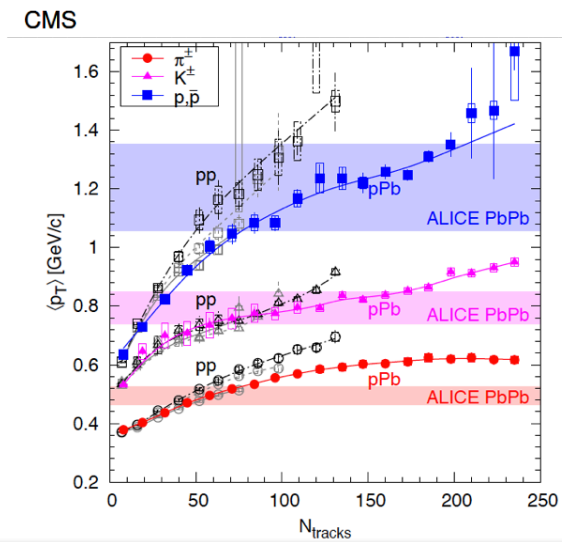

CMS Collaboration, CMS-FSQ-12-014,
EPJC 72 (2012) 2164, arXiv:1207.4724
+ arXiv:1307.3442 (pPb)

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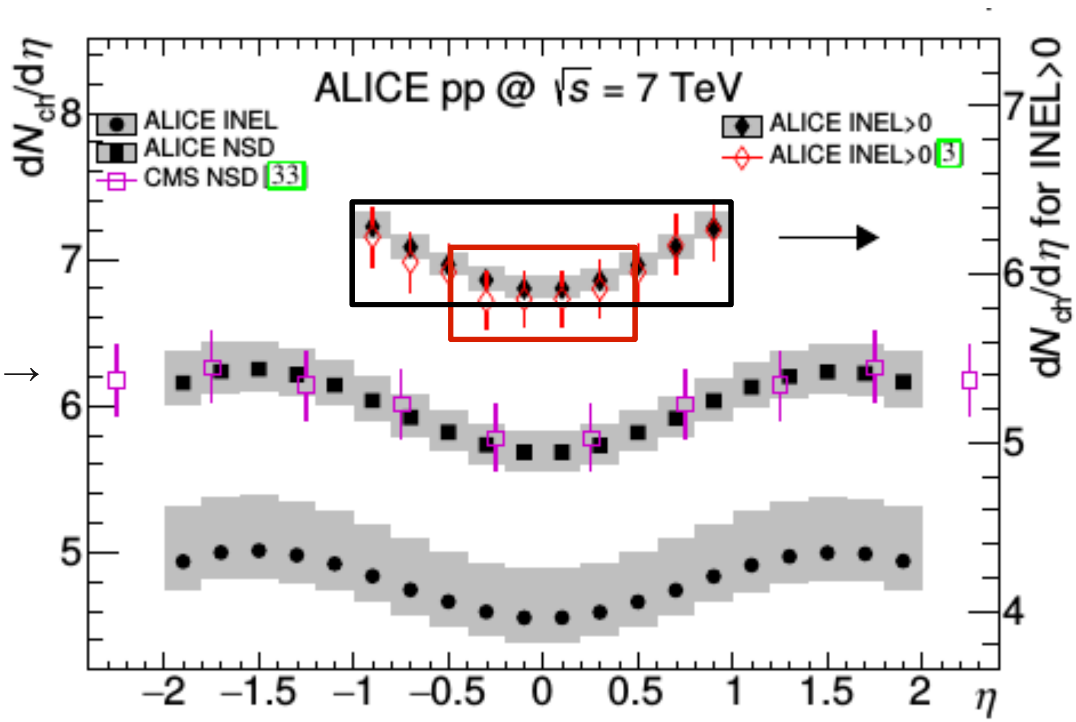
Event selection for proton-proton collisions

- Global event class… several possibilities to select events
  - relevant for consistency checks between experiment and model comparisons

non single diffractive ? inelastic ? (with one charged track in a selected η interval ?)

NSD (ALICE and CMS) →



← INEL>0 measured in $|\eta|<1$

➡ choice: INEL>0 measured in $|\eta| < 0.5$

ALICE Collaboration, arXiv:1509.07541
Eur. Phys. J. C 77 (2017) 33

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Multiplicity selection for proton-proton collisions

- Multiplicity event class… with minimising auto-correlation bias
  - using V0 detectors in the forward region
    - V0A ($2.8 < \eta < 5.1$)
    - V0C ($-3.7 < \eta < -1.7$)

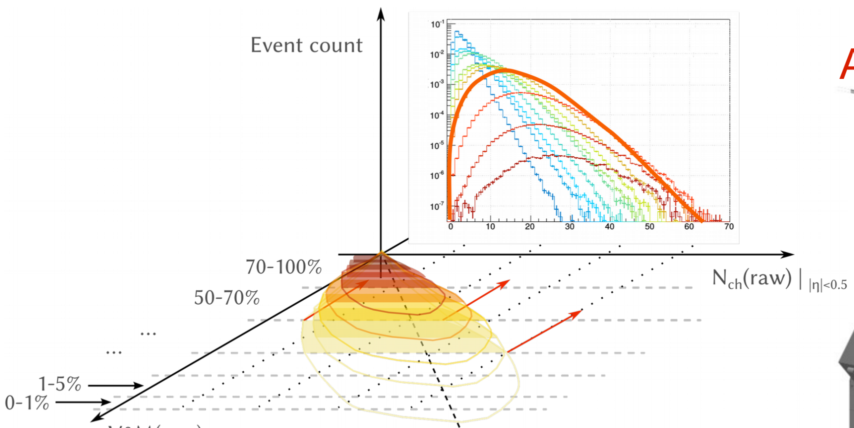
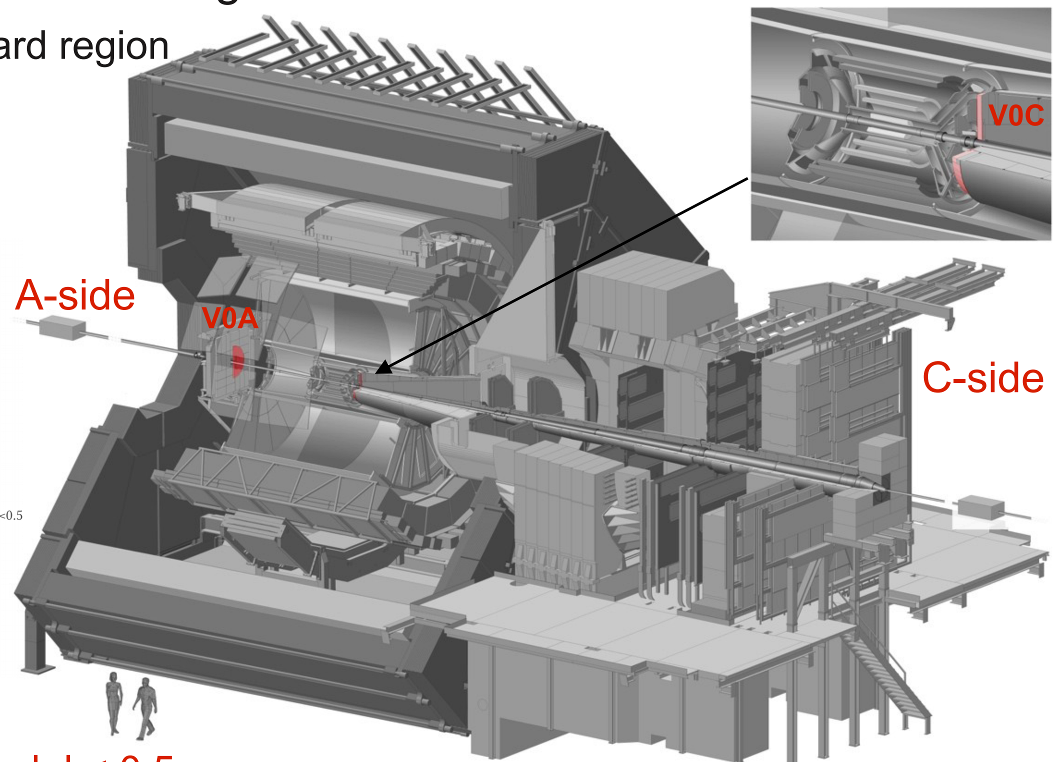


illustration: courtesy of A. Maire

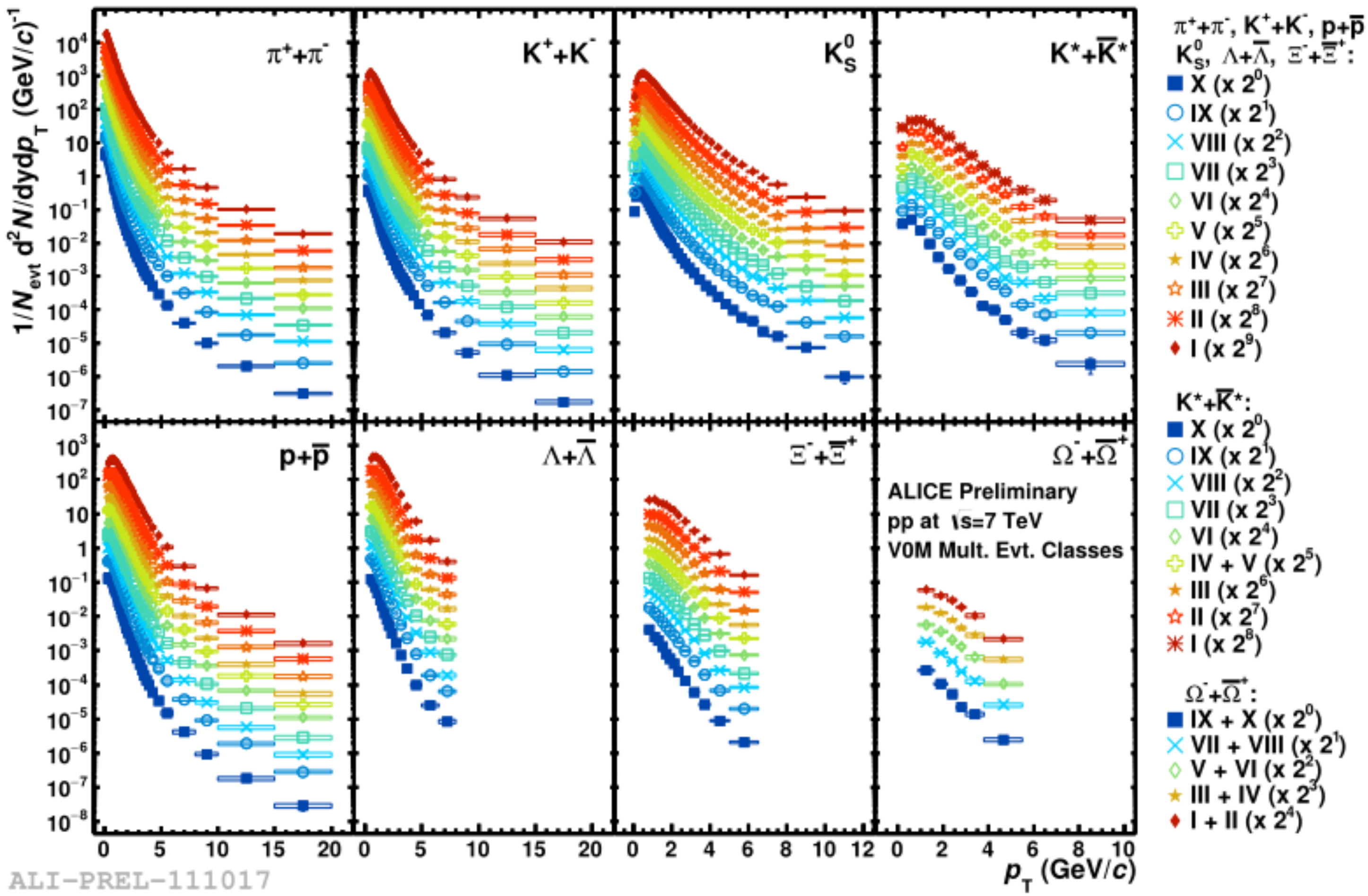


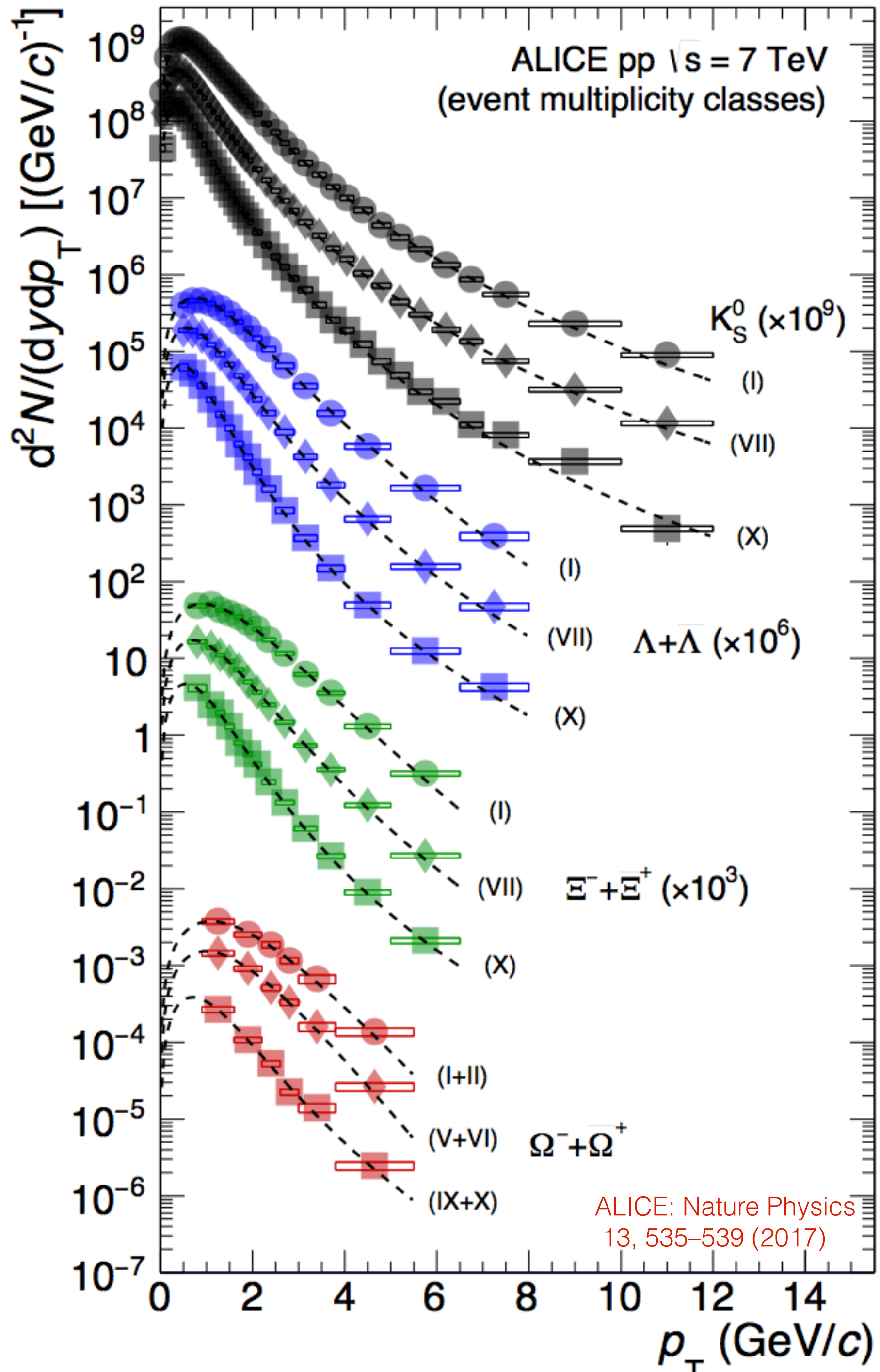
1) select events with INEL>0 measured in $|\eta| < 0.5$
2) compute V0M = sum (V0A+V0C signals)
3) for each V0M percentile interval, extract the $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ corresponding to a corrected distribution of charged tracks in the central region $|\eta| < 0.5$

Transverse momentum spectra

- V0M multiplicity classes $\left[\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle^{\mathrm{INEL}>0} \simeq 6.0\right]$

$$\begin{cases} I \longrightarrow \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle \simeq 3.5 \times \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle^{\mathrm{INEL}>0} \\ \vdots \\ X \longrightarrow \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle \simeq 0.4 \times \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle^{\mathrm{INEL}>0} \end{cases}$$

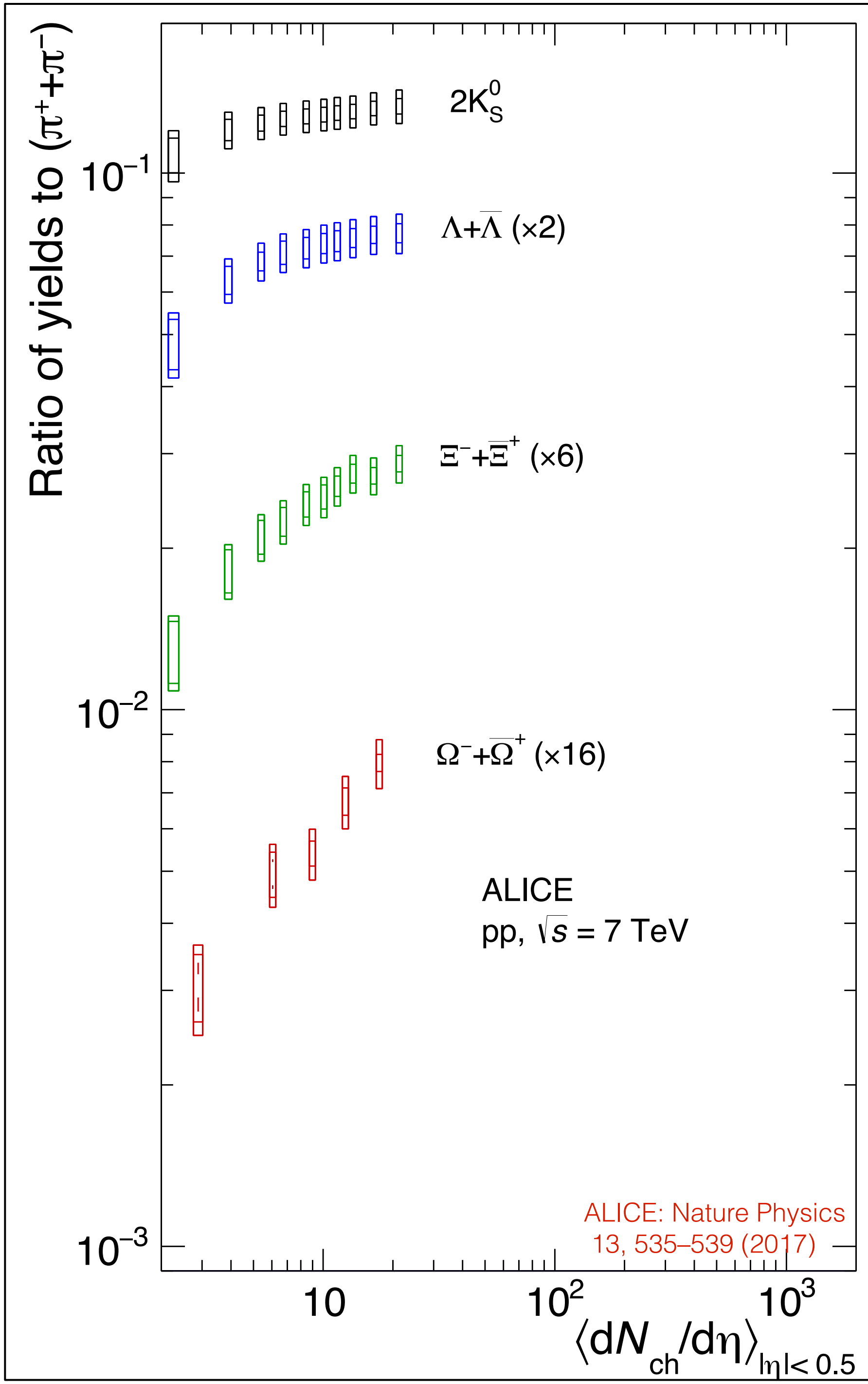




Nikhef

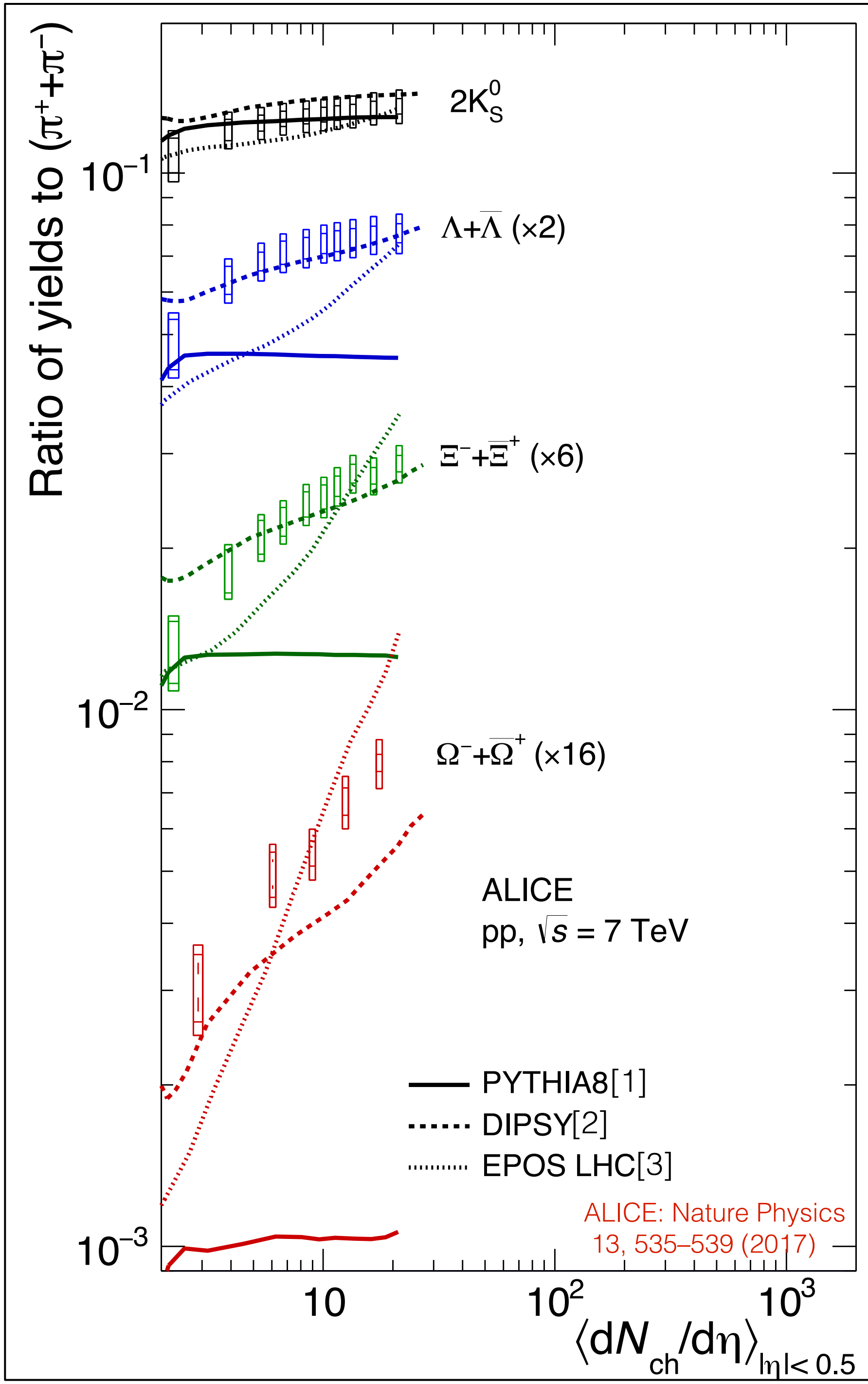
Strangeness production vs p_T

- Transverse momentum (p_T) spectra for strange and multi-strange hadrons
- Evolution with multiplicity $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$



Strangeness production relative to pions vs multiplicity

- Quantified via strange to non-strange integrated particle ratios vs $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$
- Significant enhancement of strange and multi-strange hadron production



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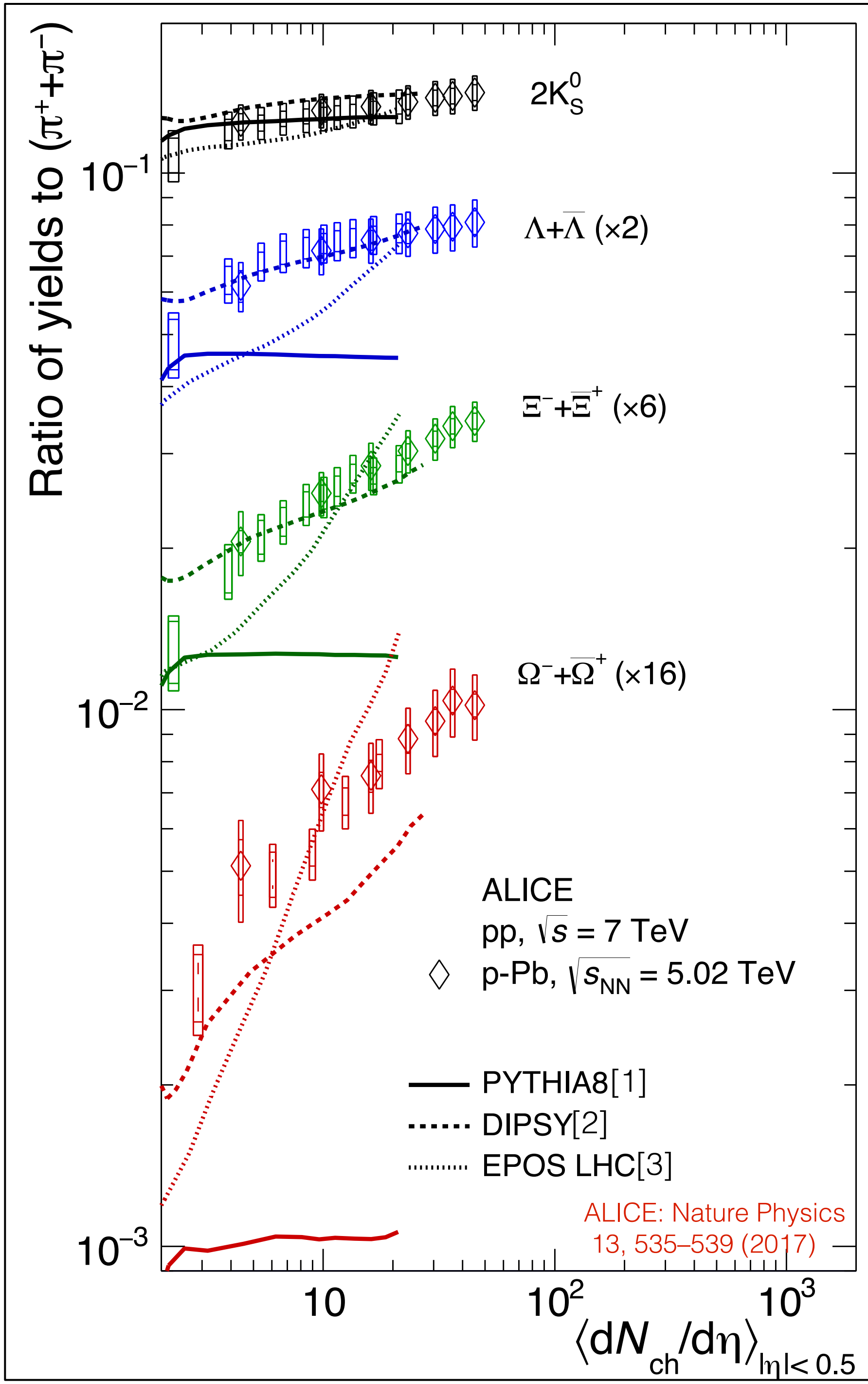
- MC predictions do **not** describe this observation satisfactorily

[1] Comput. Phys. Commun. 178 (2008) 852–867
[2] JHEP 08 (2011) 103
[3] Phys. Rev. C 92, 034906 (2015)



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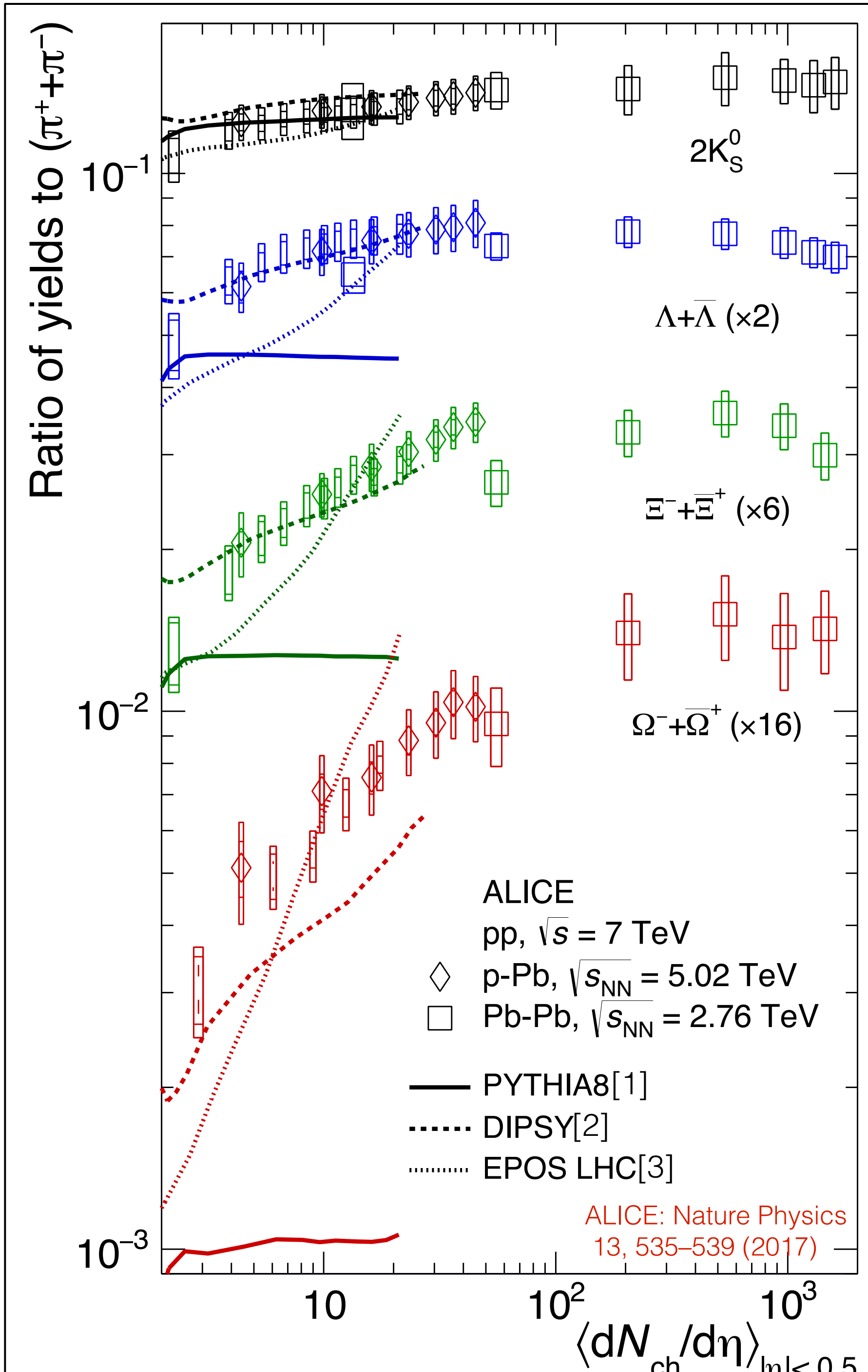

Strangeness production relative to pions vs multiplicity

- Quantified via strange to non-strange integrated particle ratios vs $\langle dN_{ch}/d\eta \rangle$
- Significant enhancement of strange and multi-strange hadron production
- MC predictions do **not** describe this observation satisfactorily
- Follow the trend observed in p-Pb despite differences in initial state
- Particle ratios reach values that are similar to those observed in central Pb-Pb collisions

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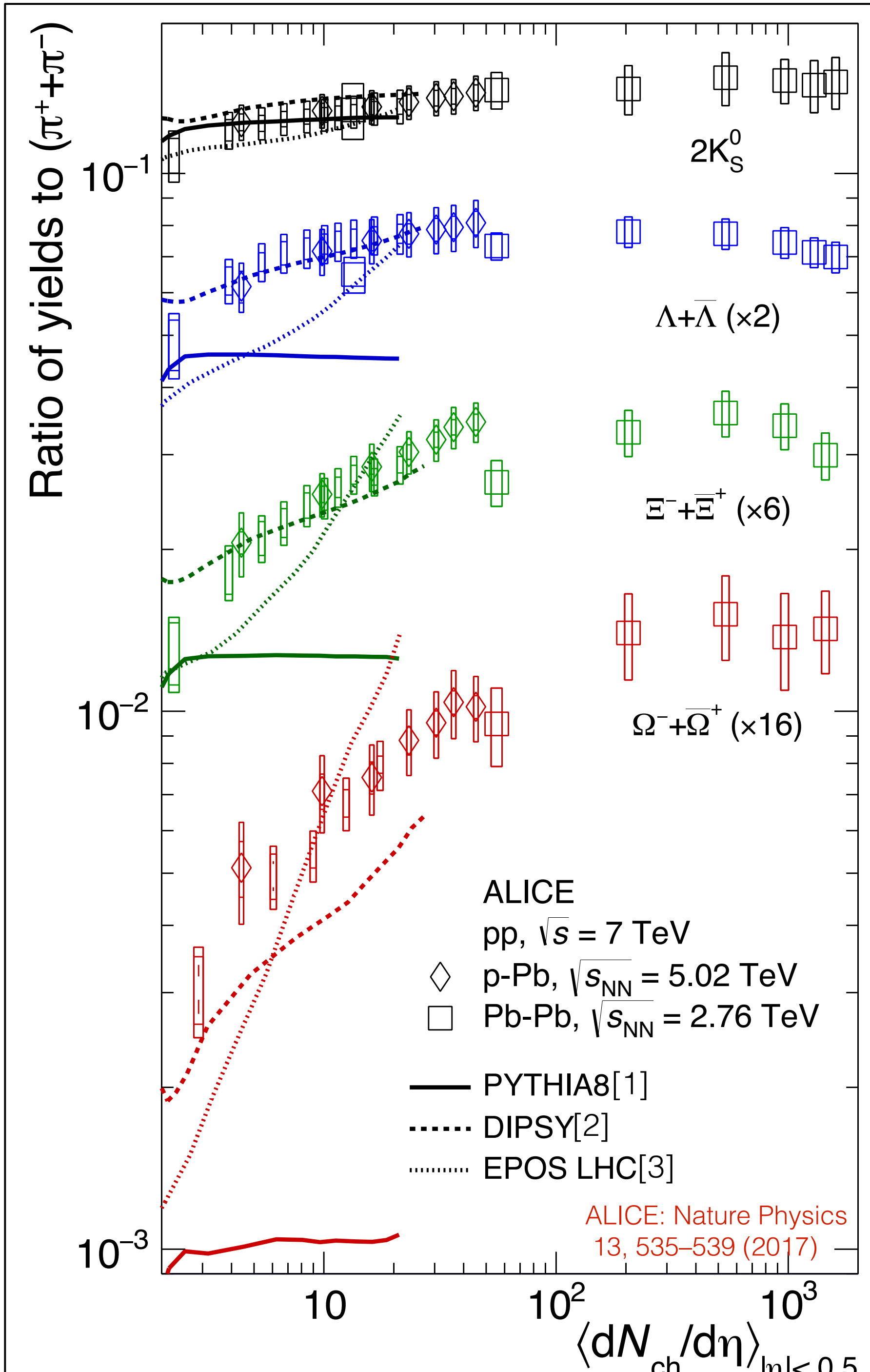
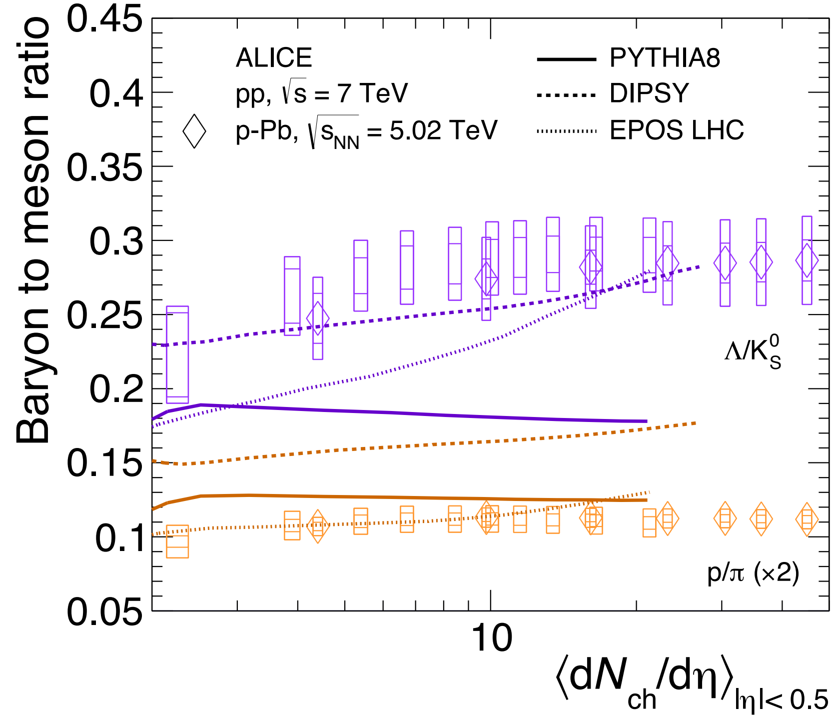


Baryon-to-meson ratio



- Contrary to models such as DIPSY no increase for protons (non-strange)

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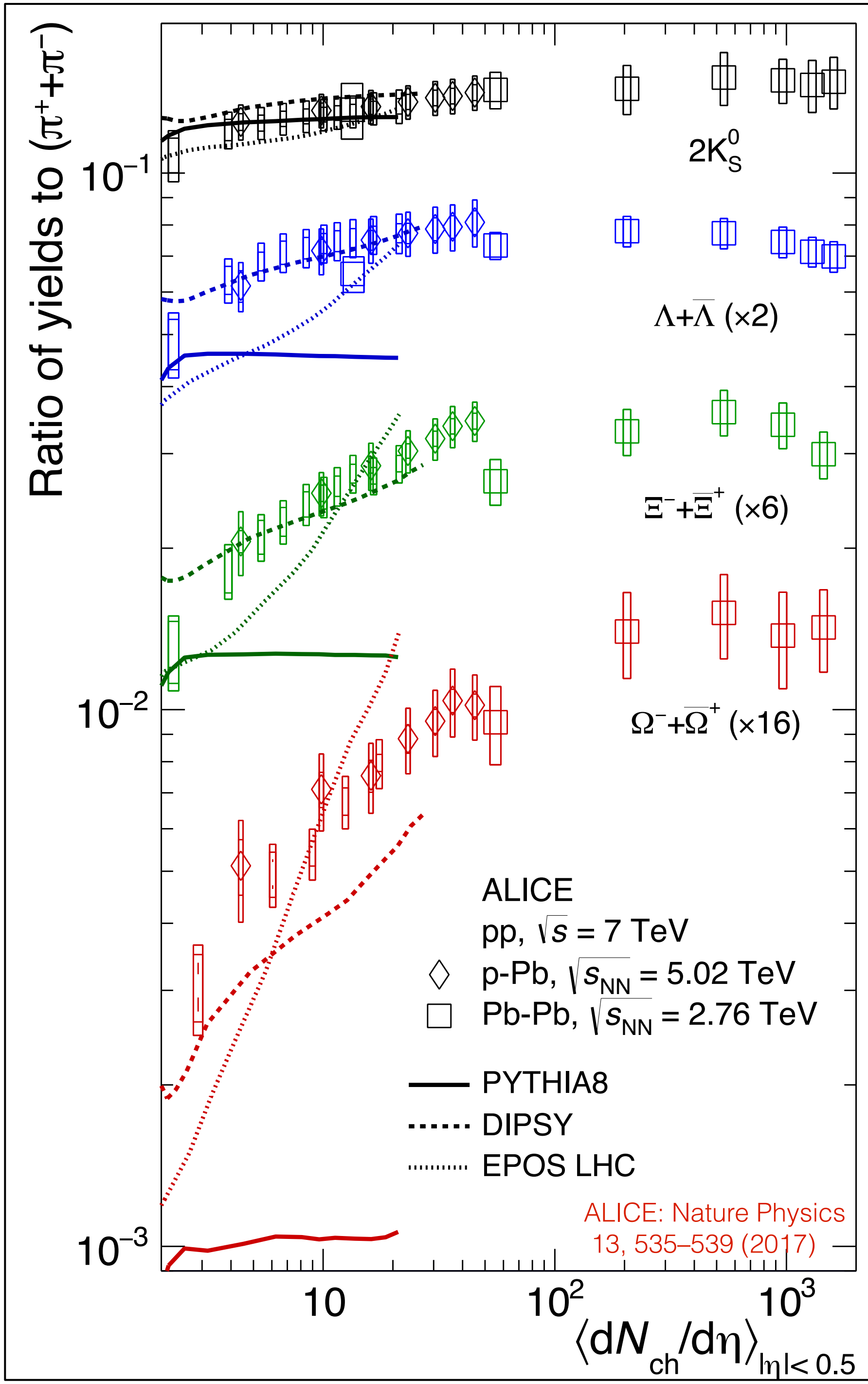
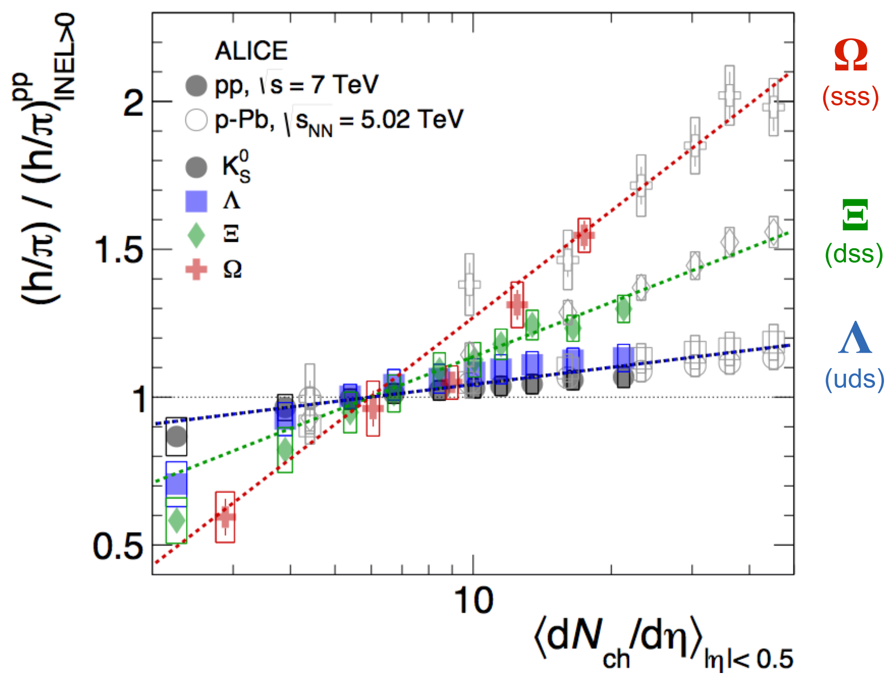


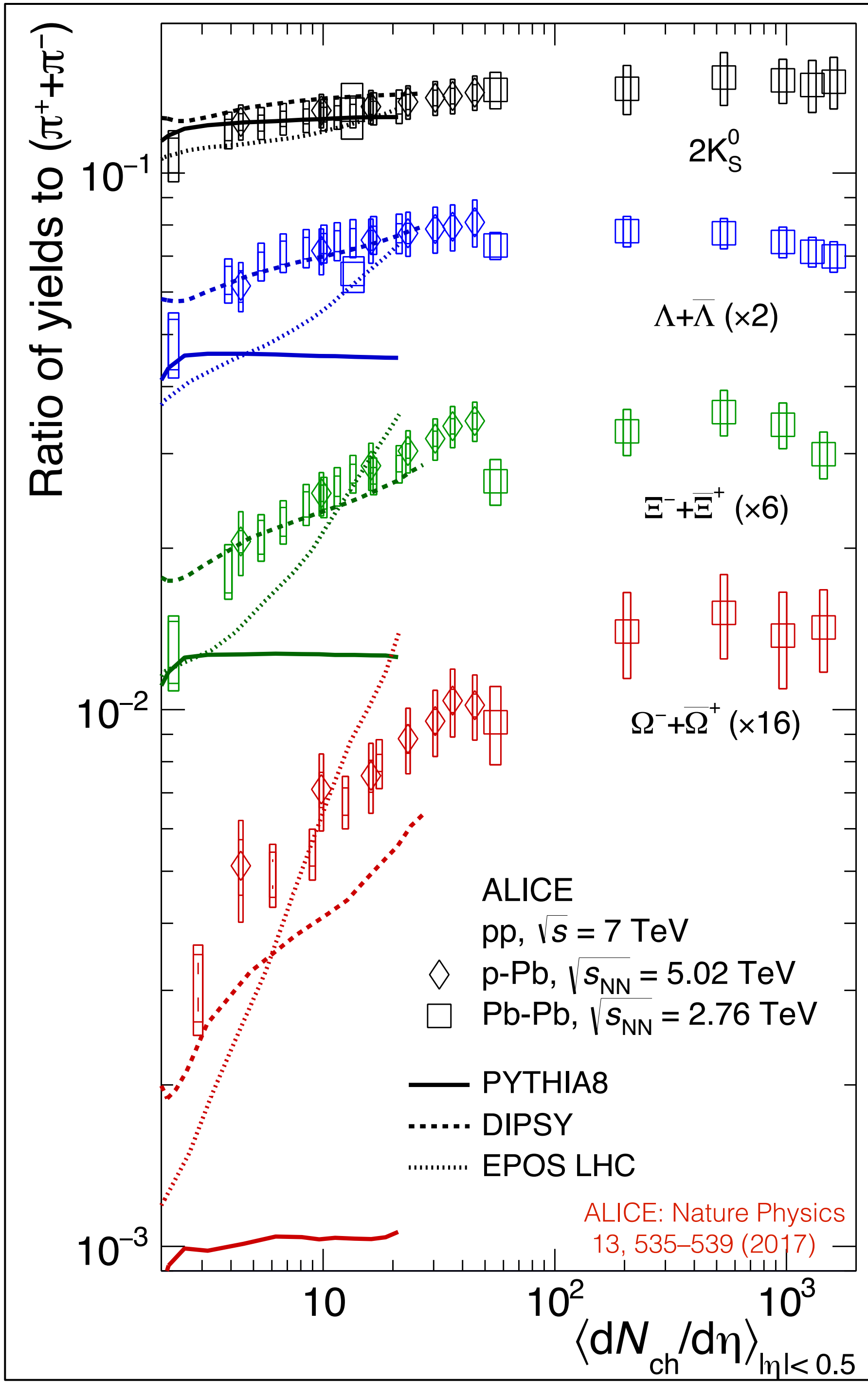
Nikhef

Double ratio:

$$(\text{hyperon}/\pi)^{pp}_{[i]} \;/\; (\text{hyperon}/\pi)^{pp}_{\text{INEL}>0}$$



- The higher the strangeness content the more pronounced the increase is for baryons



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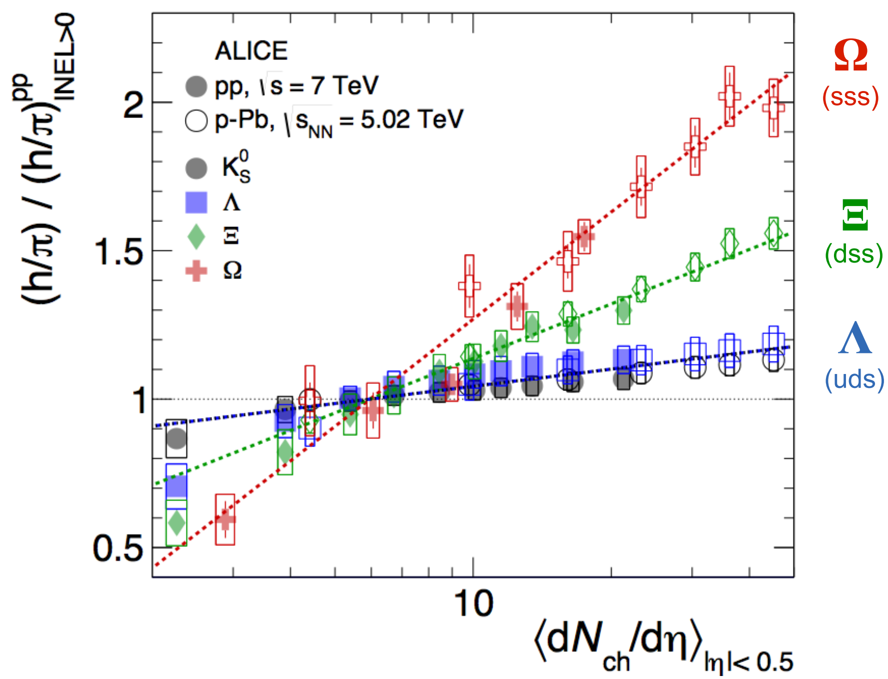


- The higher the strangeness content the more pronounced the increase is for baryons similarly to p-Pb

Discussion and interpretation

- A couple of words on comparison with models
  - PYTHIA8 Monash Tune → strong disagreement which means Color Reconnection among Multiple Parton Interactions does not help (option on/off)
  - EPOS LHC → general trend reproduced with Core-Corona approach with multiple scattering but does not match the data straight away
  - DIPSY → (best agreement) Color ropes seem to capture the main aspect but deviation for Ω and too much stress on baryon production

Discussion and interpretation

- PYTHIA8 follow-up:

Thermodynamical String Fragmentation by N. Fischer & T. Sjöstrand

(arXiv:1610.09818, JHEP 1701 (2017) 140)

The observation of heavy-ion-like behaviour in pp collisions at the LHC suggests that more physics mechanisms are at play than traditionally assumed. The introduction e.g. of quark-gluon plasma (~ EPOS...) or colour rope formation (~ DIPSY...) can describe several of the observations, but as of yet there is no established paradigm.

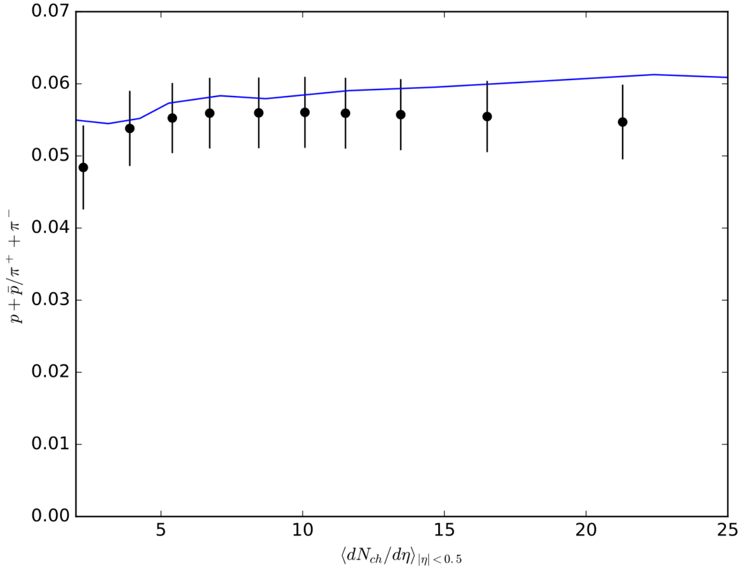
In this article we study a few possible modifications to the Pythia event generator, which describes a wealth of data but fails for a number of recent observations. Firstly, we present a new model for generating the transverse momentum of hadrons during the string fragmentation process, (i) inspired by thermodynamics, where heavier hadrons naturally are suppressed in rate but obtain a higher average transverse momentum.

Secondly, close-packing of strings is taken into account by making the temperature or (ii) string tension environment-dependent. Thirdly, a simple model for (iii) hadron rescattering is added.

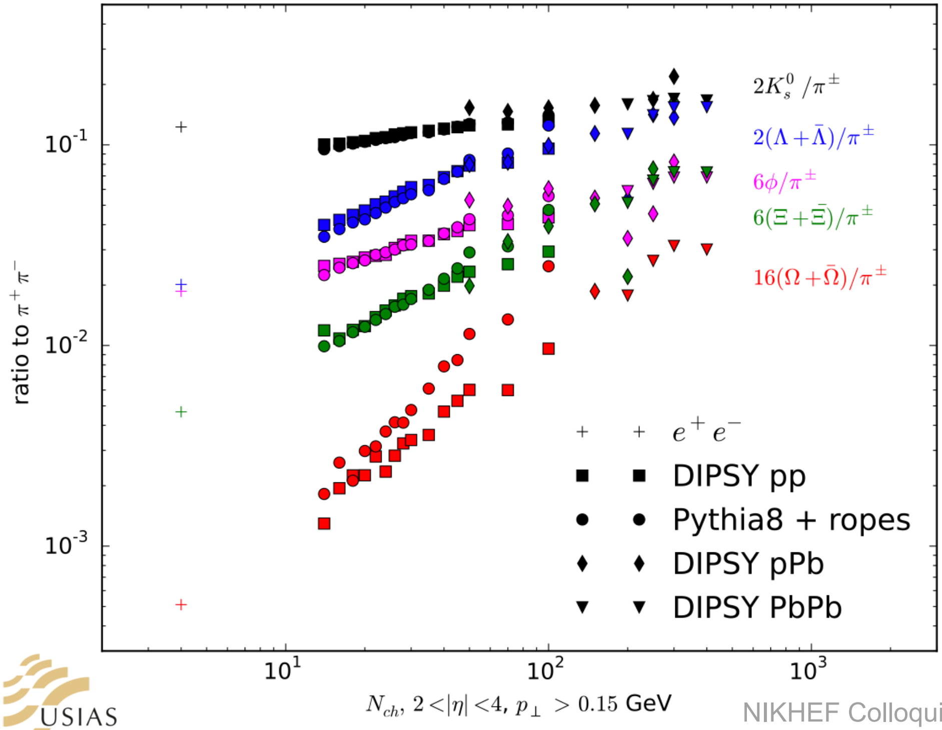
The effect of these modifications is studied, individually and taken together, and compared with data mainly from the LHC. While some improvements can be noted, it turns out to be nontrivial to obtain effects as big as required, and further work is called for.

Discussion and interpretation

- DIPSY follow-up: (presented by C. Bierlich at SQM'17 in Utrecht)
  - better agreement for baryon production (still room for adjustment wrt LEP data)



  - trying to reproduce pp but also pPb and PbPb



summary: strangeness enhancement from pp to A-A

- An enhanced production of strange and multi-strange particles has been observed in high-multiplicity pp collisions (Nature Physics13, 535–539 (2017))
- The multiplicity dependence of strangeness production is strikingly similar in pp and p-Pb, and approaches values corresponding to central Pb-Pb
- None of the current MC models are successful at fully describing these observations (yet… "3D pandora box").

- Open questions:
  - Will the relative strangeness production in pp and p-Pb eventually saturate ?
  - How do charged-particle multiplicities and collision energy relate for pp,13 TeV ?
  - What would be the minimal changes in microscopic models to reproduce data ?

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Many thanks for your attention !

Thanks a lot to the organisers for the invitation...

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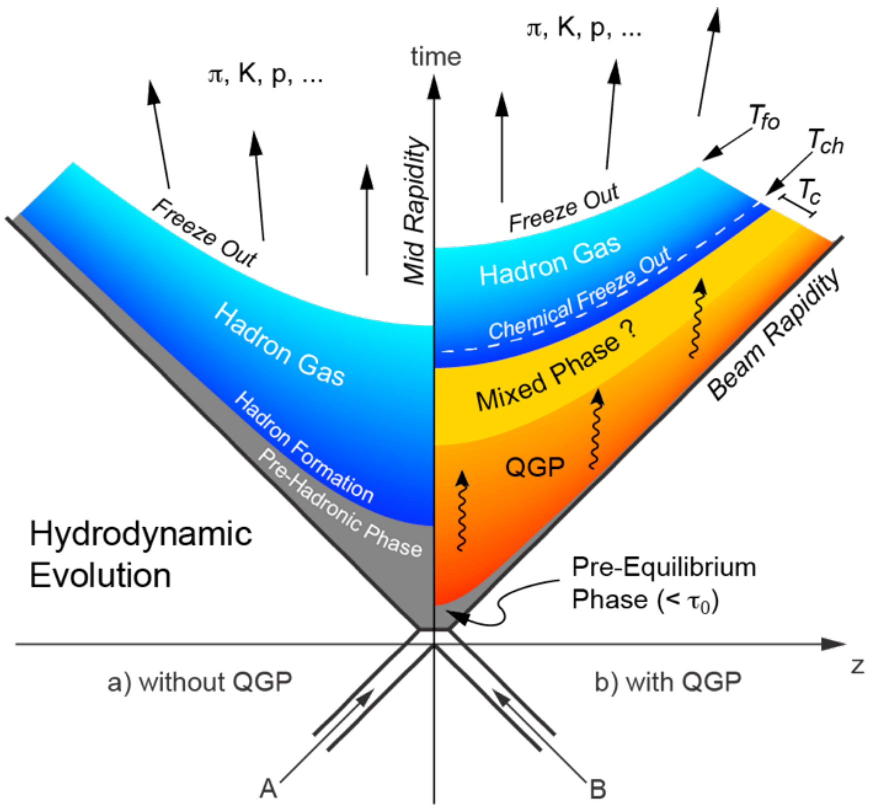
Evolution of the QGP created in nucleus-nucleus collisions

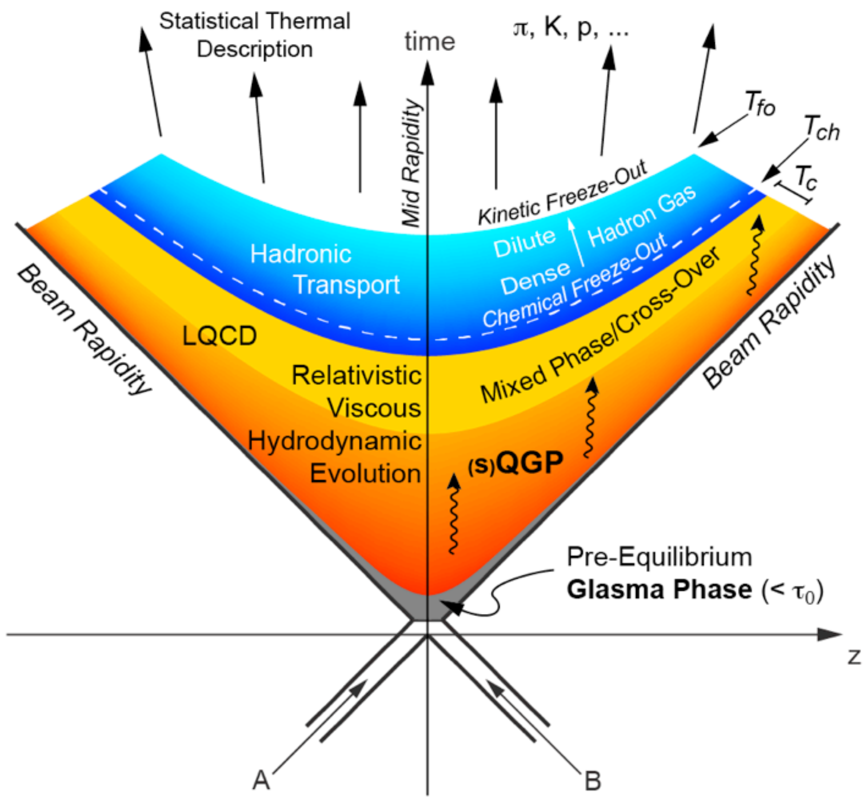


- Initial pre-equilibrium state
- hard parton scattering & jet production
- QGP formation
- QGP expansion and cooling
- Phase transition:
- Hadronic phase:
  - chemical freeze-out
  - rescattering then kinetic freeze-out.

With hadronic states, many observables can be studied in order to characterise the properties of the Quark Gluon Plasma

Probing the whole evolution of the system with the strange hadrons created in heavy-ion collisions: jet flavour content, R_{AA}, strange particle flow, resonances, multi-strange (with low hadronic x-section)...

Evolution of the QGP created in nucleus-nucleus collisions



- Initial pre-equilibrium state
  - ➡ gluonic fields (Color Glass Condensate) **Glasma**
- hard parton scattering & jet production
- QGP formation
  - ➡ thermalisation of **strongly** interacting partons
- QGP expansion and cooling
  - ➡ **3D+1** relativistic **viscous** hydrodynamics
- Phase transition:
  - ➡ Lattice QCD, **Cross-Over**
- Hadronic phase:
  - chemical freeze-out
  - rescattering then kinetic freeze-out.

With hadronic states, many observables can be studied in order to characterise the properties of the Quark Gluon Plasma

Probing the whole evolution of the system with the strange hadrons created in heavy-ion collisions: jet flavour content, R_{AA}, strange particle flow, resonances, multi-strange (with low hadronic x-section)...

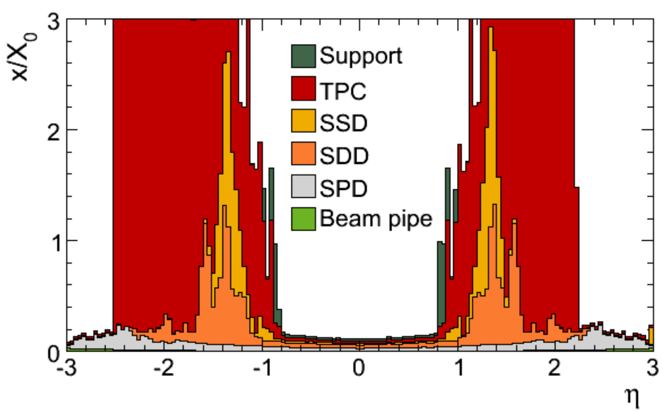
The Large Hadron Collider at CERN

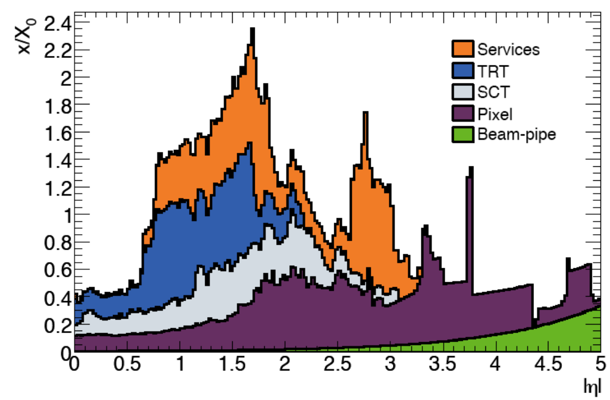
	RHIC	LHC
radius / circumference	0.6 km / 3.8 km (2.4 miles)	4.2 km / 27 km (17 miles)
maximum energy: pp / AA	500 GeV / 200 GeV	14 TeV / 5.5 TeV
ring depth	3.65 m (12 feet)	50-175 m
magnets	1740	1232 dipoles + 392 quadrupoles

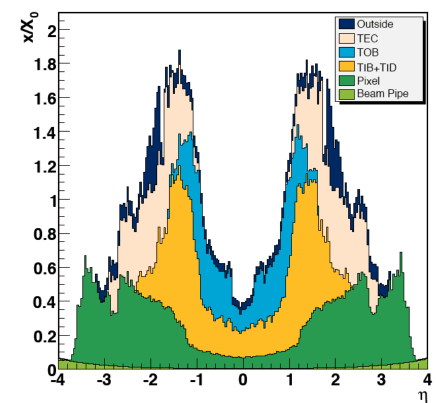
MATERIAL BUDGET

Cumulative mid-rapidity material budget for ALICE, ATLAS and CMS

ALICE	x/X_0 (%)	ATLAS	x/X_0 (%)	CMS	x/X_0 (%)
Beam pipe	0.26	Beam pipe	0.45	Beam pipe	0.23
Pixels (7.6 cm)	2.73	Pixels (12 cm)	4.45	Pixels (10.2 cm)	7.23
ITS (50 cm)	7.43	SCT (52 cm)	14.45	TIB (50 cm)	22.23
TPC (2.6 m)	13	TRT (1.07 m)	32.45	TOB (1.1 m)	35.23







⇨ Ideal Reconstruction and identification low p_T : lowest material budget

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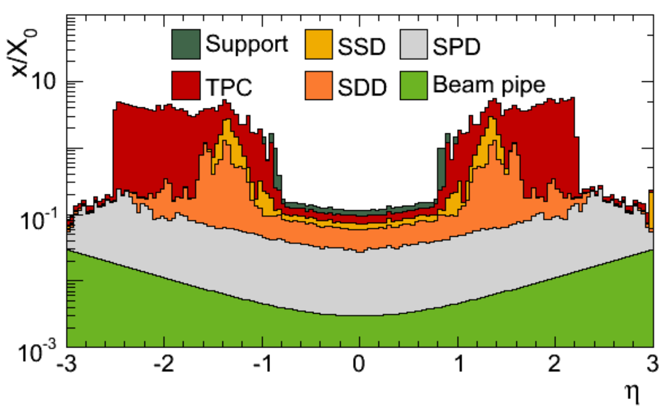
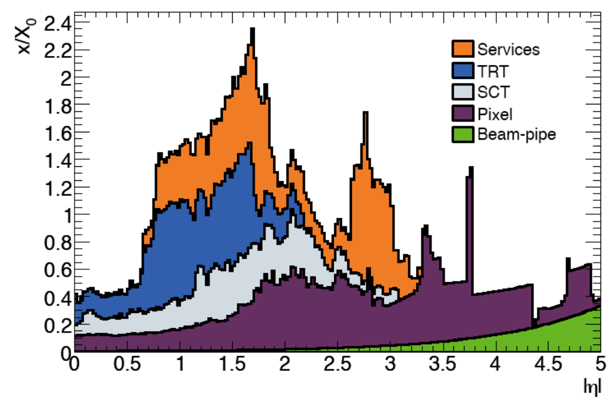
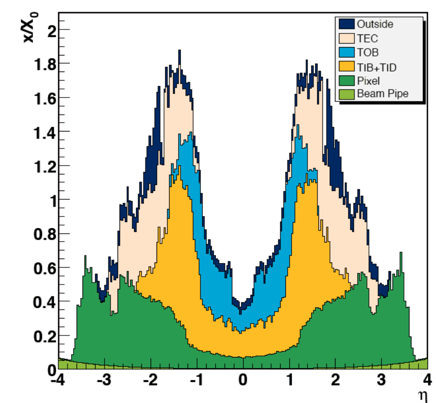


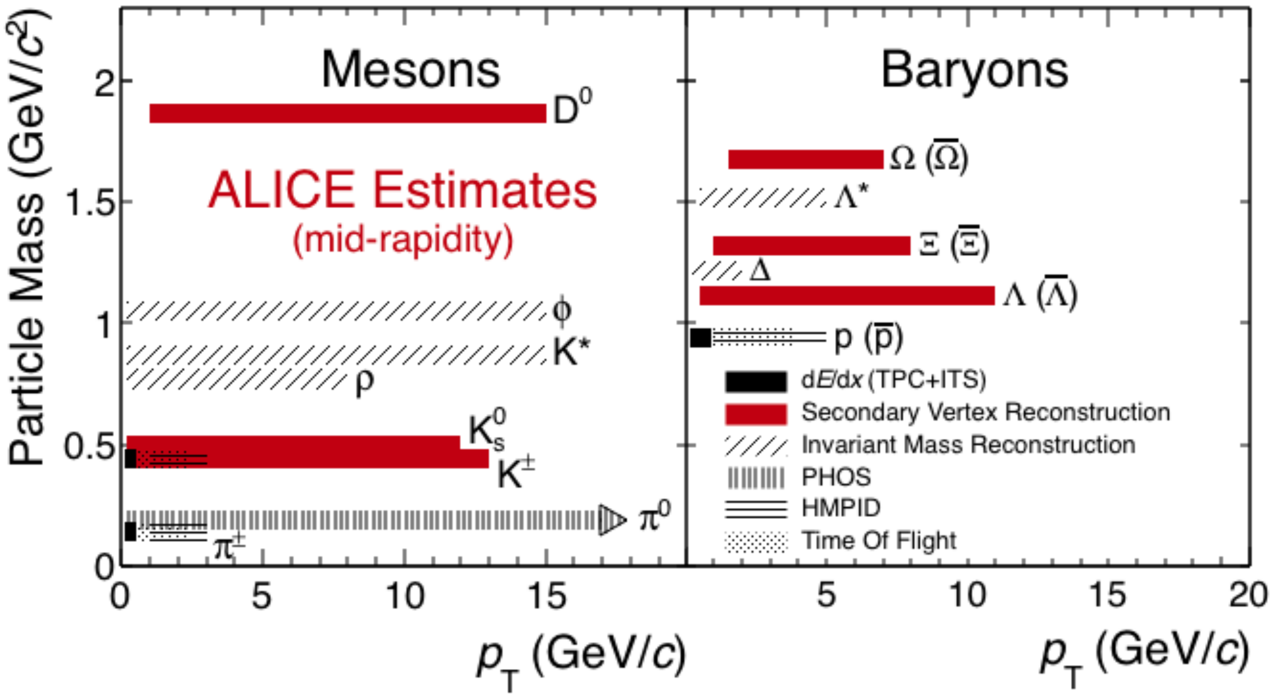




⇨ Ideal Reconstruction and identification low p_T : lowest material budget

Particle identification vs p_T

Estimated p_T ranges for 10 M central Pb-Pb events (PPR vol. II).



⇨ low p_T : thermal emission and hydrodynamics;

⇨ intermediate to high p_T : hadronization mechanisms, tomography.

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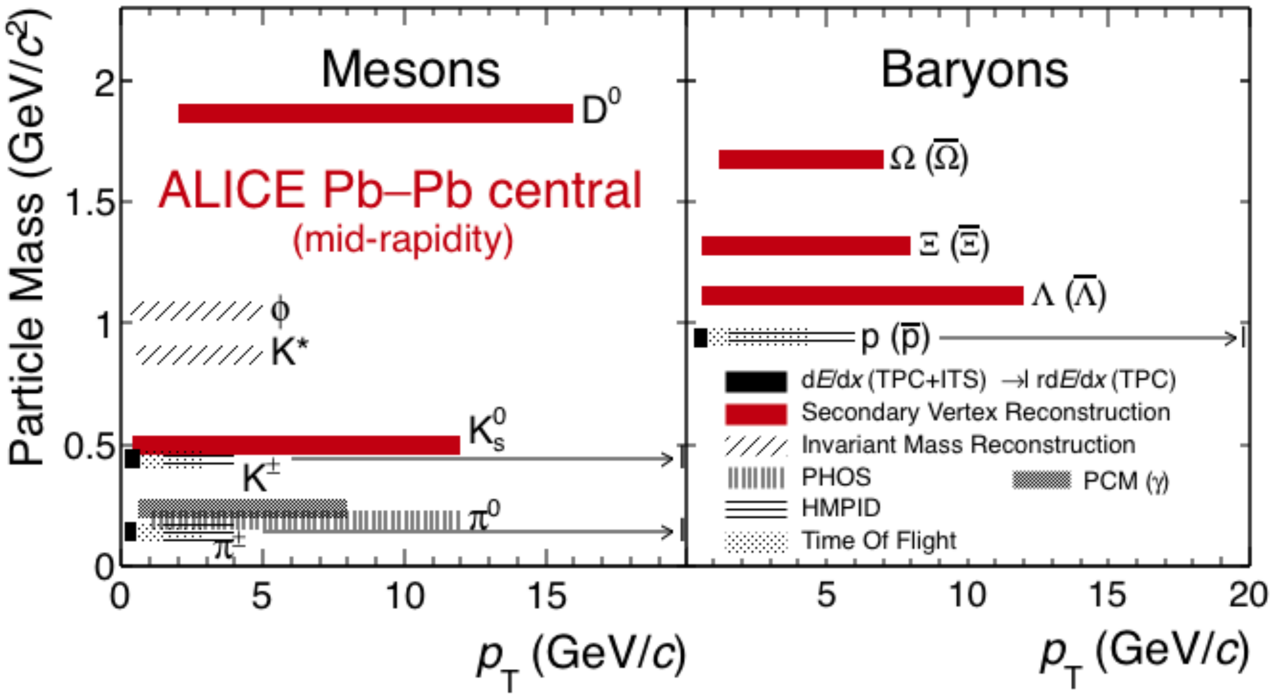
Estimated p_T ranges for 10 M central Pb-Pb events (PPR vol. II).

And measures published with RUN 1



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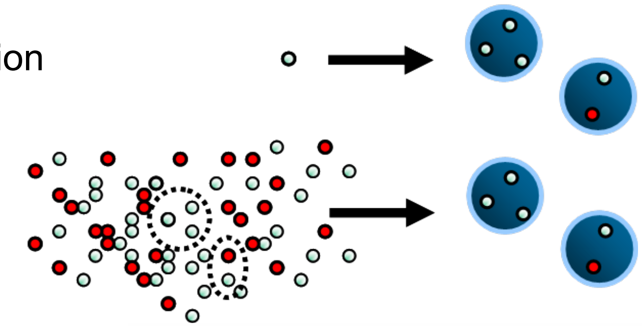
➪ intermediate to high p_T : hadronization mechanisms, tomography.

HADRONISATION: Recombination vs. Fragmentation

Hadronisation of 1 parton: fragmentation

If phase space is filled with partons: hadronisation via recombination/coalescence

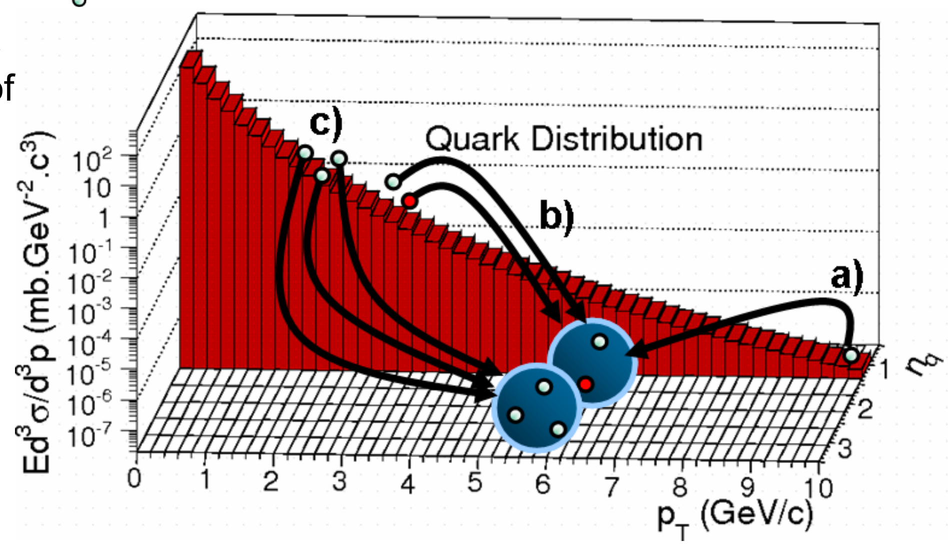


Dilute partonic system
High virtualities

Dense partonic system
Low virtualities

The in vacuo fragmentation of a high p_T quark competes with the in medium recombination of lower momentum quarks

a) 6 GeV/c pion from 1x 10 GeV/c quark fragmentation
b) 6 GeV/c pion from 2x 3 GeV/c quark recombination
c) 6 GeV/c proton from 3x 2 GeV/c quark recombination



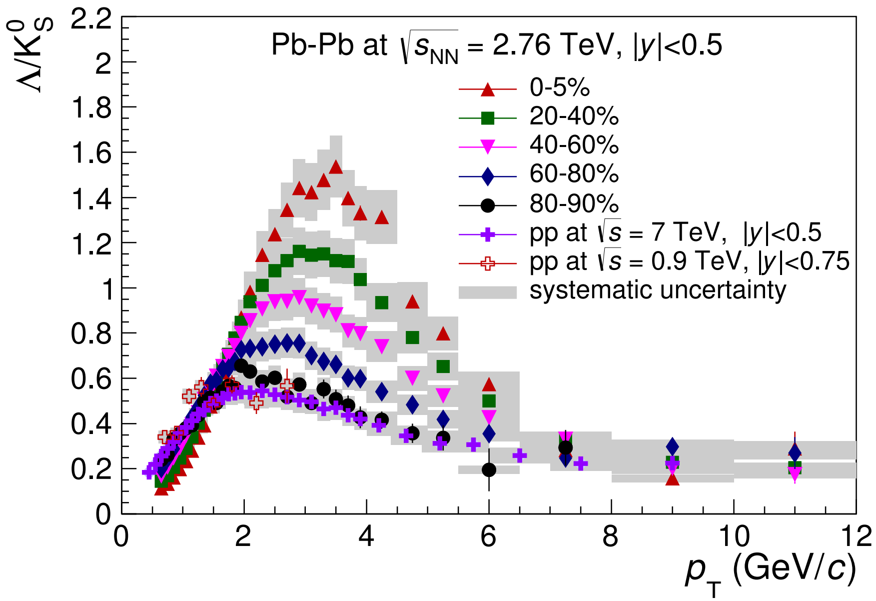
Baryon/Meson ratios
Constituent Quark Scaling (e.g. v_2)
Correlations via Soft+Hard contributions

- ➡ "...requires the assumption of a thermalized parton phase... (which) may be appropriately called a quark-gluon plasma." Fries *et al.*, PRC 68, 044902 (2003)
- ➡ fully compatible with an explosive system and "sudden hadronisation" ?
- ➡ validate recombination with light quarks before invoking it for heavy flavours...

baryon / meson : measurement at the LHC

ALICE Collaboration, arXiv:1307.5530
Phys. Rev. Lett. 111 (2013) 222301

- Observable: choice of the Λ/K^0_s ratio
  - ➡ same identification (topological reconstruction) on the whole p_T interval
  - ➡ precise measurements and partial cancellation of systematical uncertainties



- ➡ ratio above unity for the most central collisions (>40%)
- ➡ so called "intermediate p_T region" spans between 2 and 5 GeV/c
- ➡ after p_T ~ 7 GeV/c, Λ/K^0_s is then compatible with Lund fragmentation

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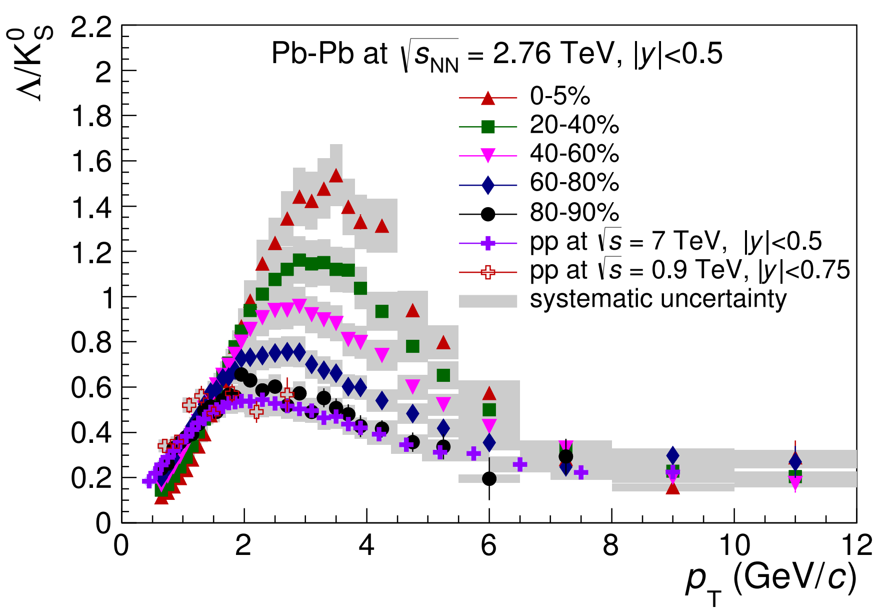

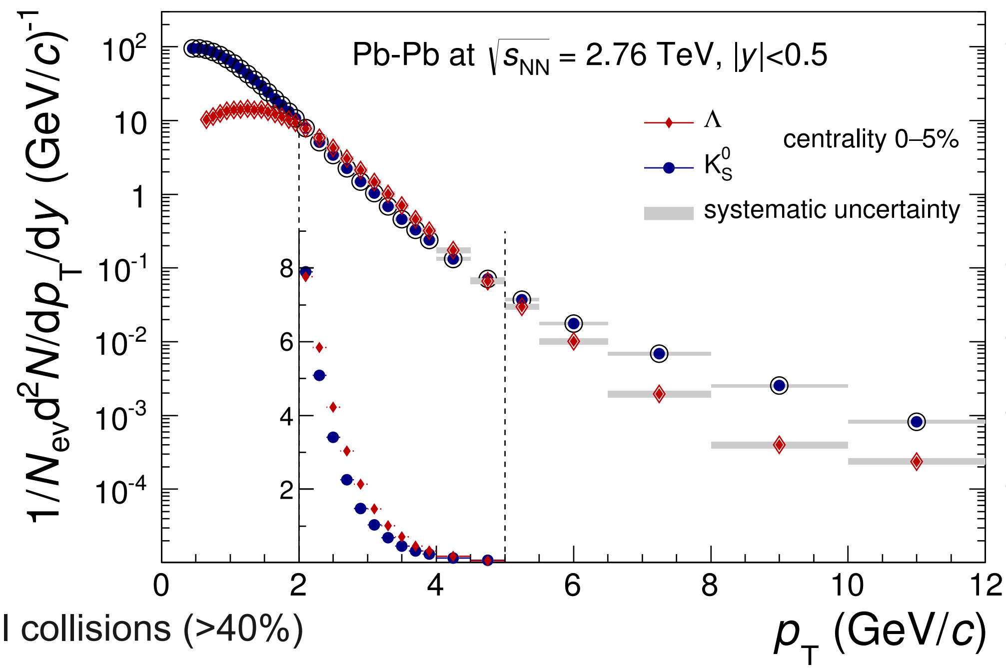

  - ➡ ratio above unity for the most central collisions (>40%)
  - ➡ so called "intermediate p_T region" spans between 2 and 5 GeV/*c*
  - ➡ after p_T ~ 7 GeV/*c*, Λ/K^0_s is then compatible with Lund fragmentation
- Note: the fraction of integrated yields potentially associated to recombination is small !
  - ➡ for p_T between 2 and 5 GeV/*c*: 2% of the Λ are measured above K^0_s (in central collisions)