Pusan-Inha Physics Workshop at PNU
PIP 2015

Hyperon Production at the LHC with ALICE

- Physics motivations
- Detection of $\Sigma(1192)^0$, $\Sigma(1385)^{\pm}$, $\Xi(1530)^0$ hyperons
- Results from pp collisions
  - The transverse momentum spectra of $\Sigma(1385)^{\pm}$, $\Xi(1530)^0$
  - The mean p_{T} of $\Sigma(1385)^{\pm}$, $\Xi(1530)^0$
  - The $\Sigma(1192)^0$ mass and width
  - The transverse momentum spectra of $\Sigma(1192)^0$
  - The cross section ratio of $\frac{\Sigma^0}{\Lambda}(p_{\mathrm{T}})$
- Proposal for the analysis of $\Lambda(1405) \rightarrow \Sigma + \pi$ decays
- Summary and Outlook

Alexander Borissov, Pusan National University, South Korea, 15.1.2015

PDG parameters of studied hyperons

Particle	Quarks	Mass(MeV/c^2)	Width/$c\tau$	Decay	Branching (%)
Λ	uds	1115.683 $\pm$ 0.006	7.89 cm	p+π^-	63.9 $\pm$ 0.5
Σ^0	uds	1192.642 $\pm$ 0.024	22 200 fm	$\Lambda + \gamma$	100
Σ^+	uus	1189.370 $\pm$ 0.07	2.404 cm	$p\pi^0$	51.57
Σ^-	dds	1197.449 $\pm$ 0.030	4.434 cm	$n\pi^-$	99.848
$\Sigma(1385)^+$	uus	1382.8 $\pm$ 0.35	36.0 $\pm$ 0.7 MeV/c^2	$\Lambda + \pi^+$	87.0 $\pm$ 1.5
$\Sigma(1385)^-$	dds	1387.2 $\pm$ 0.5	39.4 $\pm$ 2.1 MeV/c^2	$\Lambda + \pi^-$	87.0 $\pm$ 1.5
Ξ^-	dds	1321.71 $\pm$ 0.07	4.91 cm	$\Lambda + \pi^-$	99.887 $\pm$ 0.035
$\Lambda(1405)$		1405.1 $\pm$ 1.3	50 $\pm$ 2 MeV/c^2	$\Sigma + \pi$	100
$\Xi(1530)^0$	uss	1531.80 $\pm$ 0.32	9.1 $\pm$ 0.5 MeV/c^2	$\Xi^- + \pi^+$	66.7 $\pm$ 0.035

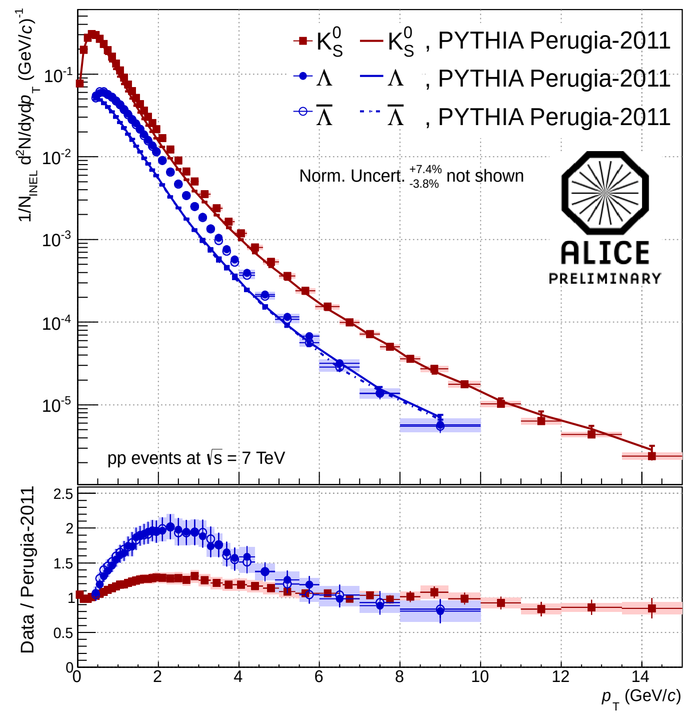
Antiparticles are not listed for brevity.

ALI–PREL–43099

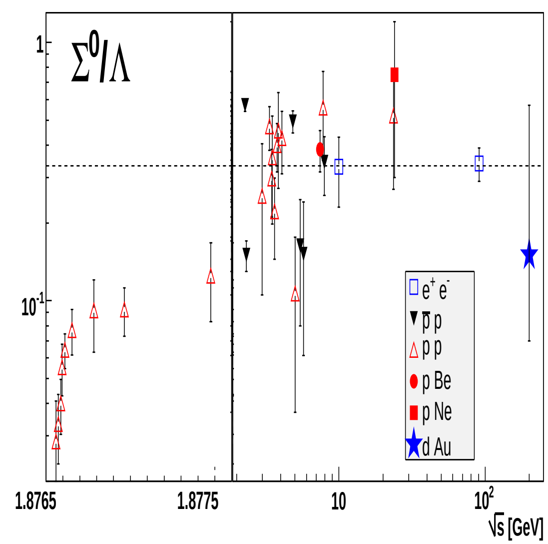
Physics motivations: pp data

- *Strangeness production in pp data is a benchmark for heavy-ion physics.*

- Precision tests of the pQCD and current parametrization of fragmentation functions from the comparison with simulations



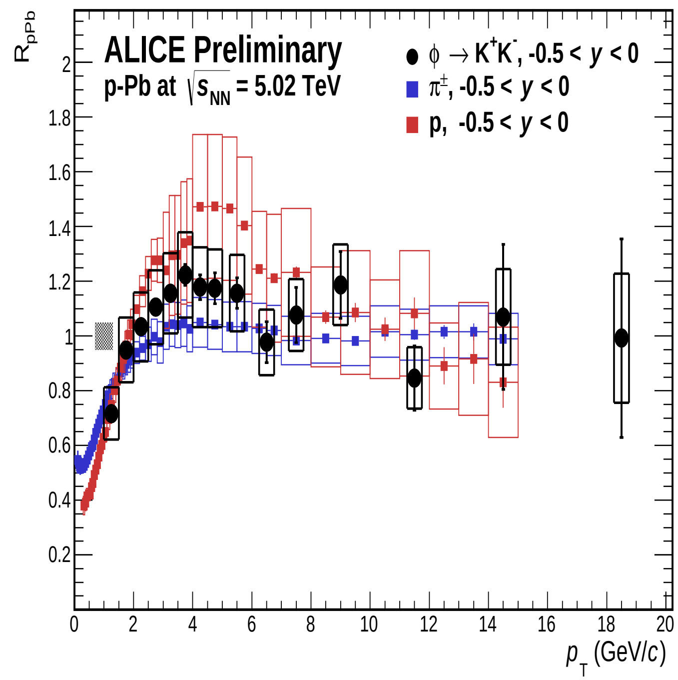
- In addition:
  - Measurement of cross section ratios. Is cross section ratio $\frac{\Sigma^0}{\Lambda} = 0.33$ at LHC energies?
  - Estimation of contamination from $\Sigma^0 \rightarrow \Lambda + \gamma$ decay for the Λ polarization measurement (J.Felix Modern Physics Letters A, Vol.14, N0. 13 (1999), 827-842).

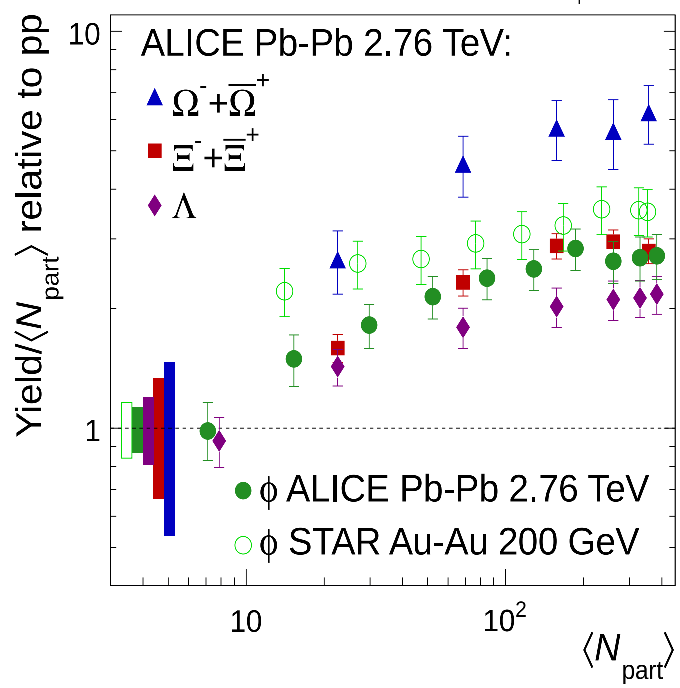


(G.Van Buren for the STAR Collaboration, arXiv:nucl-ex/0512018v1)

Physics motivations: p-Pb data

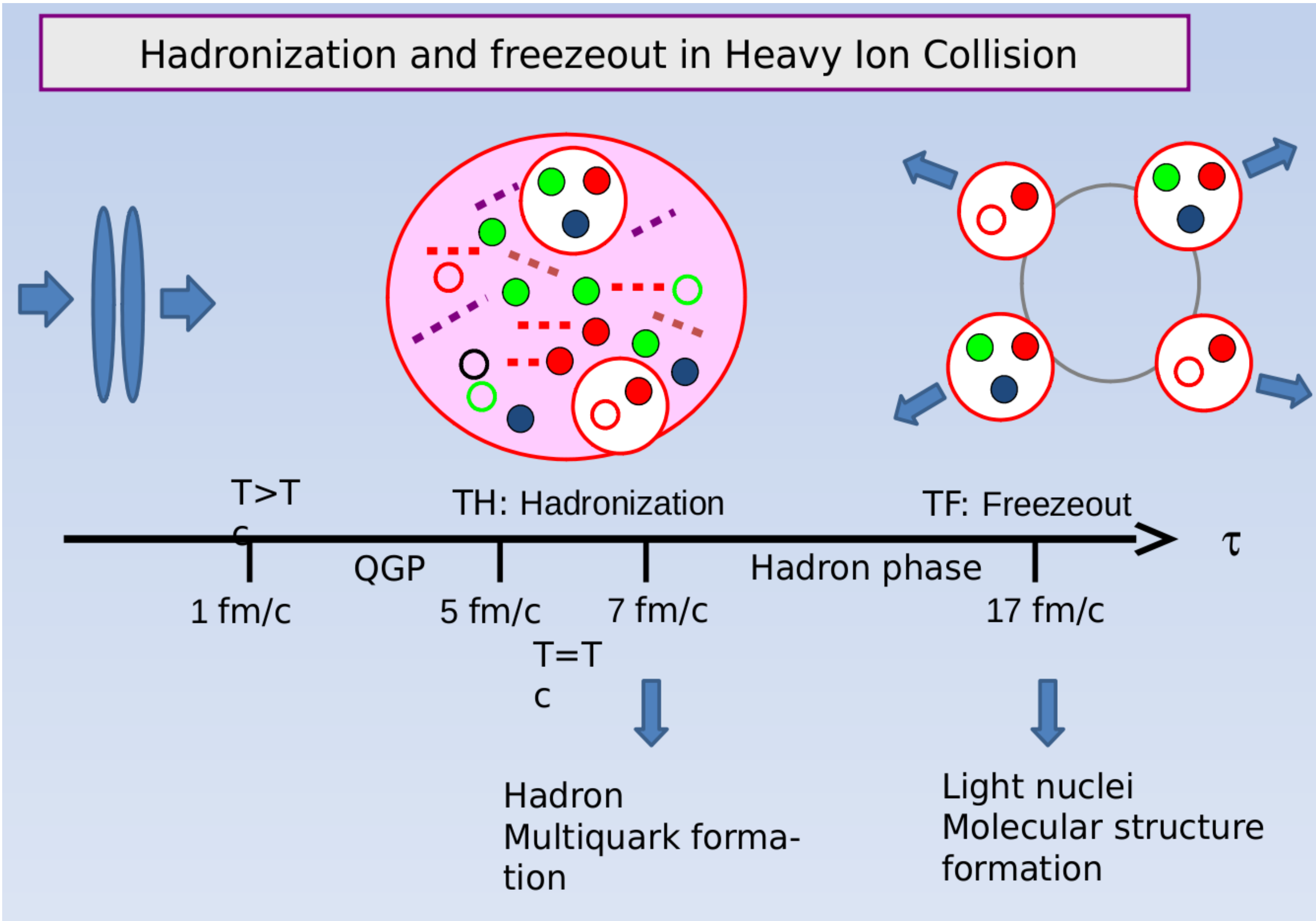
- *Intermediate system in terms of size and multiplicity: is there any collectivity?*
- Will mass dependencies be continued to strange and double-strange baryons
- What's about the attenuation and/or enhancement of strange baryon production in p-Pb data relative Pb-Pb?





Physics motivations: Pb-Pb data

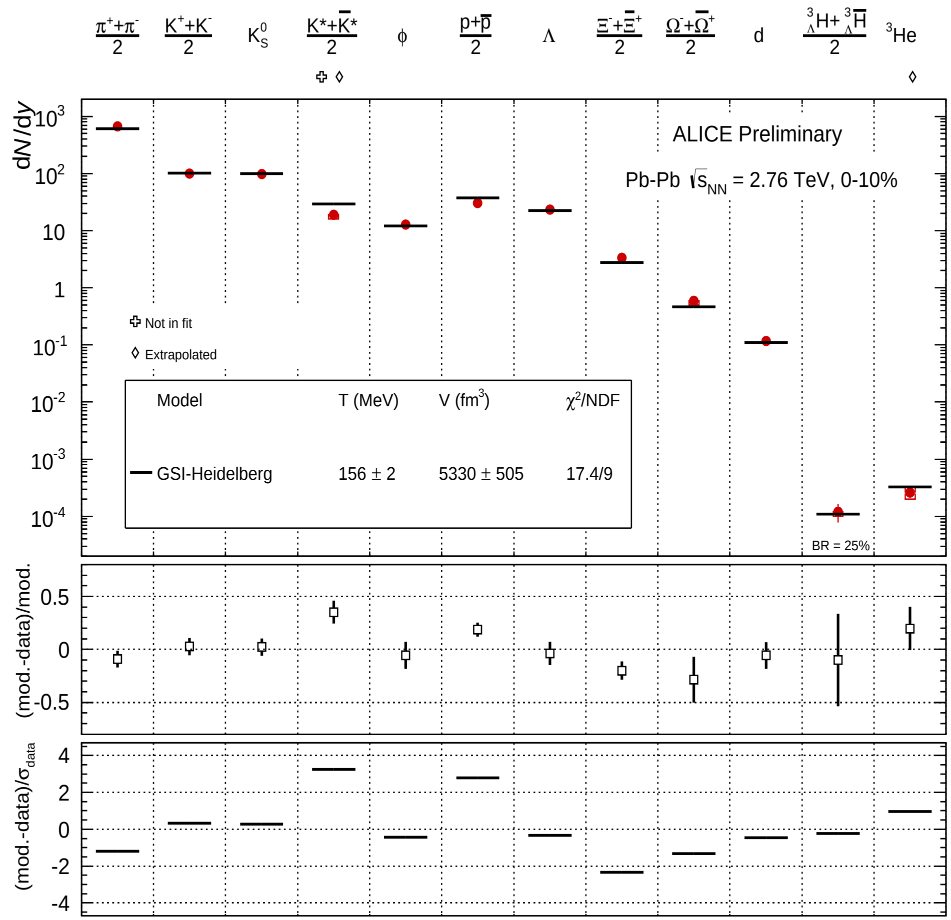
Strange quark is light enough to be produced thermally in QGP.
Early decoupling of hyperons may enable probing of earlier stages of system evolution:



(Plot from S.Lee, RSN@CT workshop November 2014, Catania, Italy)

Physics motivations: Pb-Pb data

- Data to be compared with thermal model predictions. Yields of Σ^0, $\Sigma(1385)^\pm$ and $\Xi(1530)^0$ will be between or near p, Λ and Ξ (J.Stachel,A.Andronic,P.Braun-Munzinger,K.Redlich,J.Phys.: Conf. Series 509 (2014) 012019). ⟼

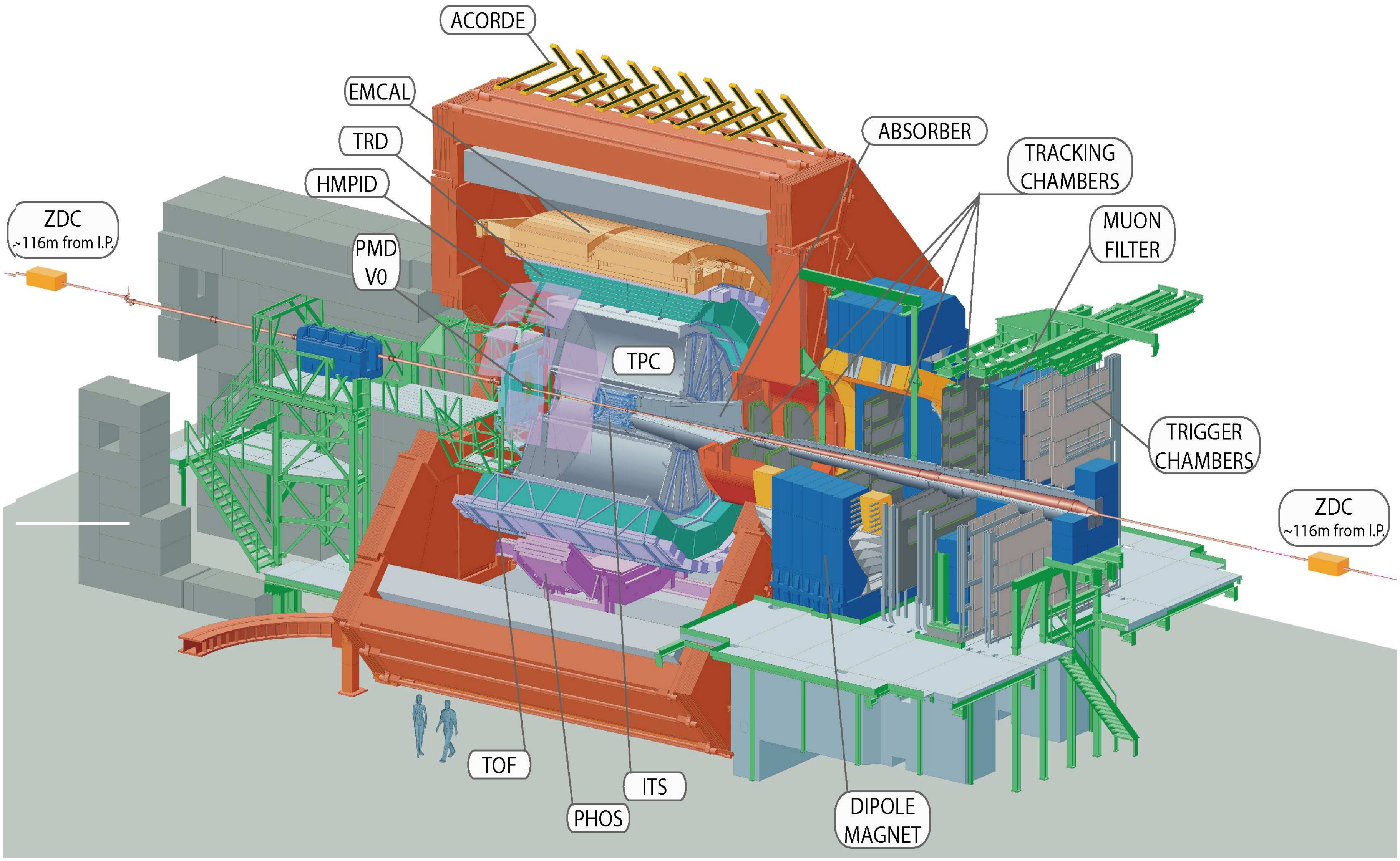


- Are those hyperons enhanced if scaled and compared to pp production? (The ALICE Collaboration, arXiv:1404.0495v1 [nucl-ex])

- Are rescattering effects also present for hyperon resonances?

- How are the transverse momentum spectra modified ?

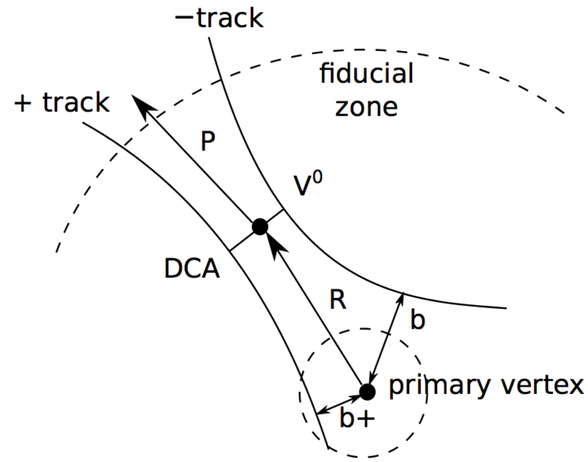
The ALICE detector



TPC and ITS are mainly used in the analysis due to the reconstruction of $\Lambda \rightarrow p + \pi^{-}$ decay (see talk of J.Song).

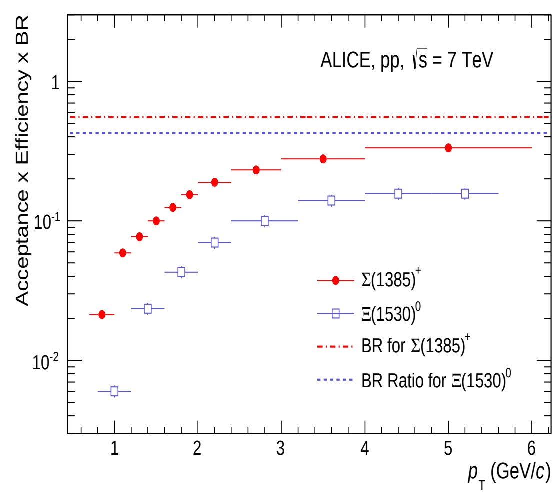
Detection and reconstruction

- $\Lambda \rightarrow p+\pi^-$ decay from V^0 vertex
  - Distance of Closest Approach (DCA) of Λ decay products > 0.05 cm
  - DCA between Λ decay products < 1.6 standard deviations
  - DCA of Λ to primary vertex < 0.3cm
  - Λ cosine of pointing angle > 0.99 (not shown)
  - Λ fiducial volume $1.4 < R < 100$ cm

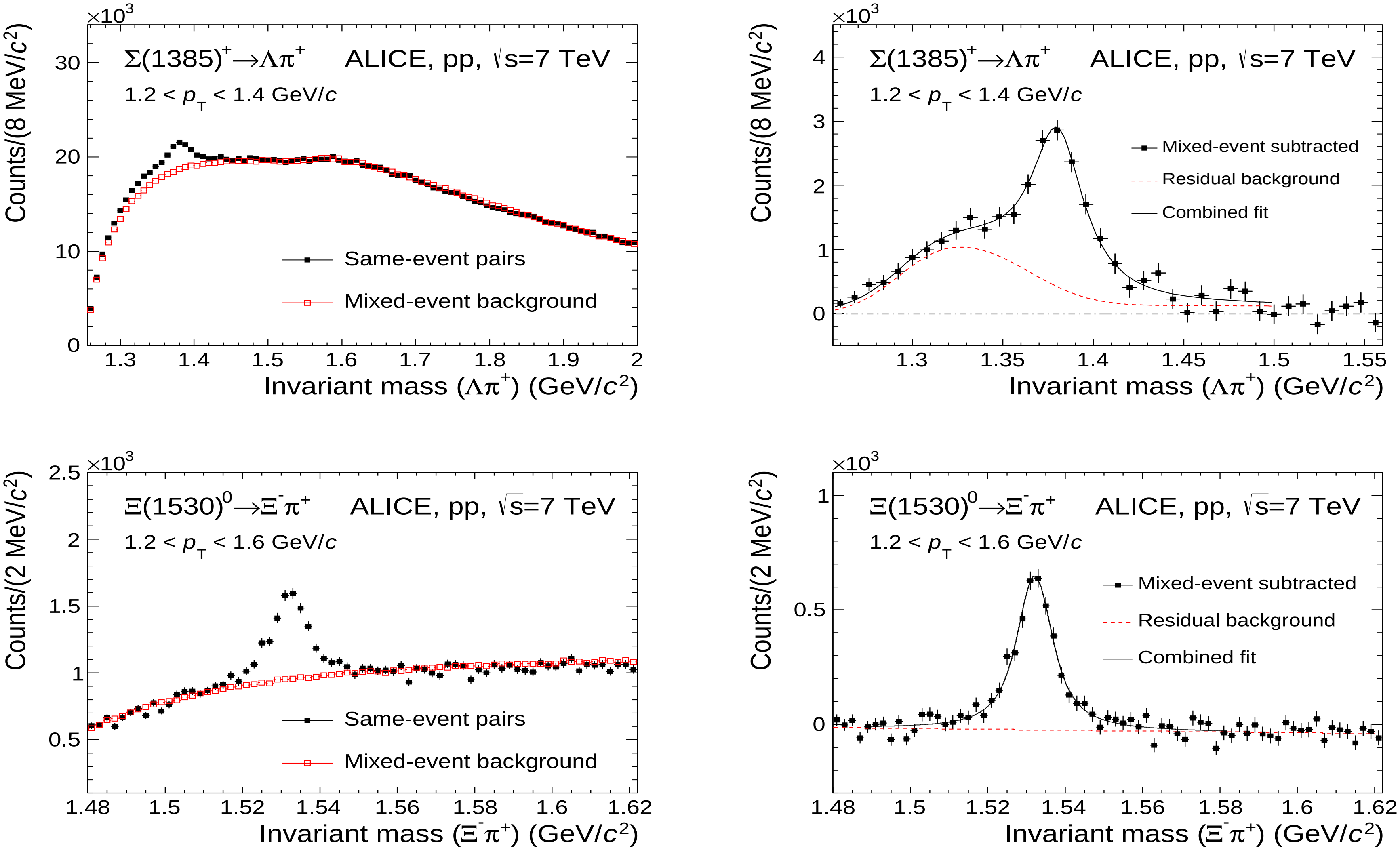


- $\Sigma^0 \rightarrow \Lambda + \gamma(\rightarrow e^+e^-)$ with γ conversion reconstructed in central tracking system, note low $E_\gamma \approx 100$ MeV.
- Decays of $\Sigma(1385)^\pm \rightarrow \Lambda + \pi^\pm$ and $\Xi(1530)^0 \rightarrow \Xi^-(\rightarrow \Lambda + \pi^-) + \pi^+$ are reconstructed from their decay chains (The ALICE Collaboration, arXiv:1406.3206 [nucl-ex], CERN-PH-EP-2014-128; talk of J.Song).
- Yields are corrected for the geometrical acceptance and reconstruction efficiency:

$$N^{corr}(p_\mathrm{T}) = \frac{N^{raw}(p_\mathrm{T})}{BR\,(A\times\epsilon)(p_\mathrm{T})}\,\epsilon_{GEANT}(p_\mathrm{T})$$



Yields of $\Sigma(1385)^{\pm}$ and $\Xi(1530)^{0}$



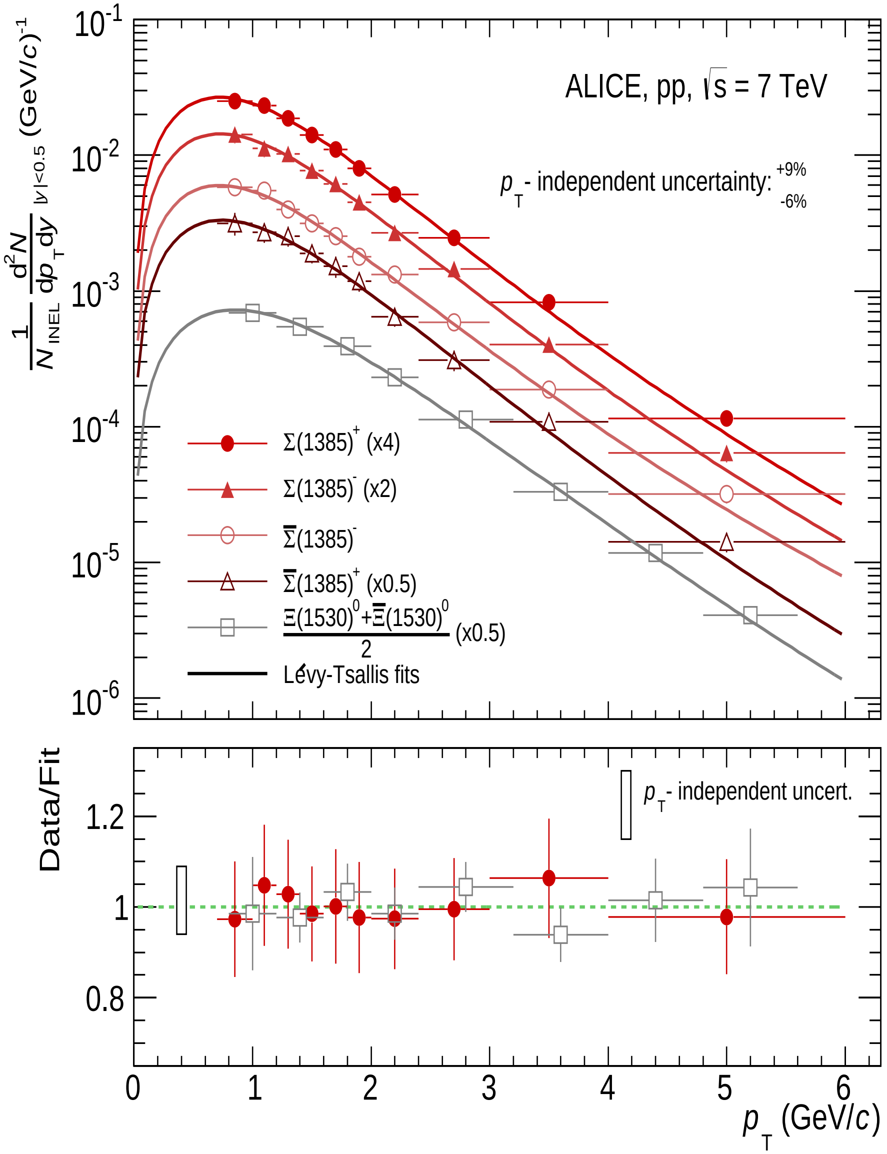
Several stages: 1/ subtraction of uncorrelated mixed-event background; 2/ the residual background is fitted alone; 3/ a combined fit of signal (convolution of Breit-Wigner and Gaussian) and fixed from background; 4/ fit of signal and background with free parameters

(The ALICE Collaboration, arXiv:1406.3206 [nucl-ex], CERN-PH-EP-2014-128).

Levy-Tsallis fit of $\Sigma(1385)^{\pm}$, $\Xi(1530)^{0}$ yields

ALICE

$$\frac{1}{N_{inel}}\frac{d^2N}{dydp_T} = \frac{(n-1)(n-2)}{nC[nC+m_0(n-2)]}\frac{dN}{dy}p_T\left(1+\frac{m_T-m_0}{nC}\right)^{-n}, \text{ where } m_T = \sqrt{m_0^2+p_T^2}$$



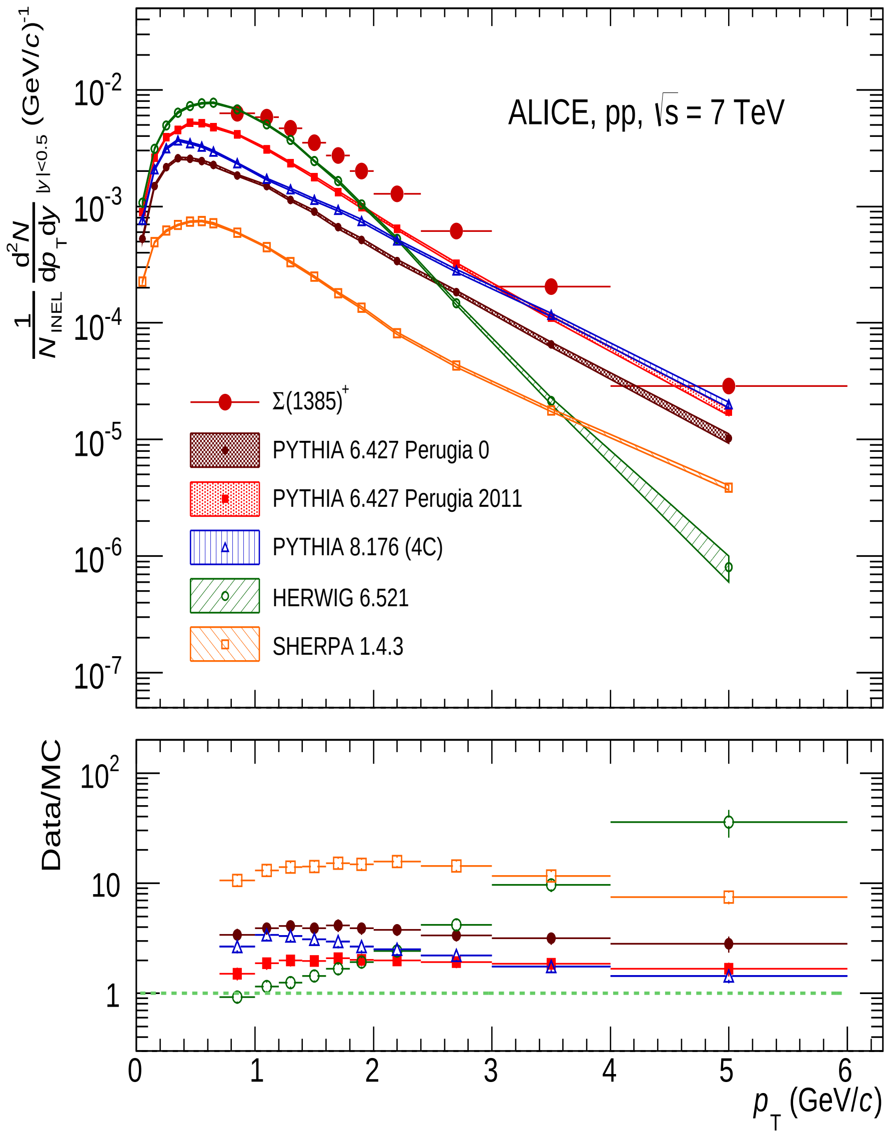
- The anti-baryon to baryon ratios:
  $\bar{\Sigma}(1385)^{-}/\Sigma(1385)^{+} \approx 1$
  $\bar{\Sigma}(1385)^{+}/\Sigma(1385)^{-} \approx 1$
- Fit results are comparable for $\Sigma(1385)^{+}, \Sigma(1385)^{-}, \bar{\Sigma}(1385)^{+}, \bar{\Sigma}(1385)^{-}$:

  $9.0\pm0.2\pm0.9 \leq \frac{dN}{dy}(\times10^{-}3) \leq 10.6\pm0.2\pm1.1$
  $294\pm43\pm17 \leq C(MeV) \leq 308\pm38\pm20$
  $8.9\pm3.5\pm0.6 \leq n \leq 9.8\pm3.7\pm0.8$
- For $\Xi(1530)^{0}$:

  $\frac{dN}{dy}(\times10^{-}3) = 2.48\pm0.07\pm0.24$
  $C(MeV) = 404\pm20\pm21$
  $n = 16.9\pm3.9\pm1.9$.

$\Longrightarrow$ *Different fit results between $\Sigma(1385)$ and $\Xi(1530)^{0}$.*

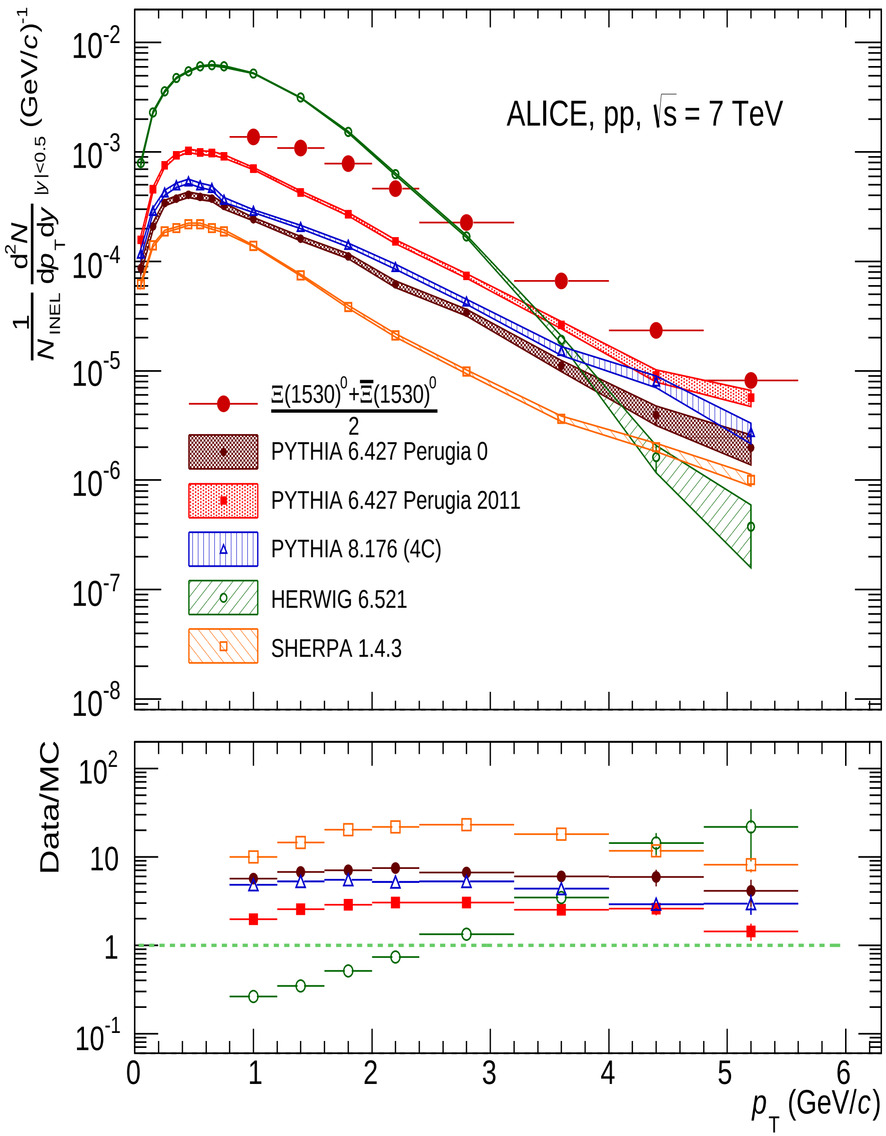
p_{T} spectrum of $\Sigma(1385)^{\pm}$



- Similar results are obtained for the other $\Sigma(1385)$ species.
- PYTHIA Perugia 2011, accounting LHC minimum-bias and underlying events and describing reasonably well charged particle spectra, underpredicts the data of $\Sigma(1385)$ on factor about two.
- PYTHIA 4C with color reconnection gives better agreement in spectral shape.
- HERWIG predicts a much softer production than other models and data. It is likely to describe the data at low $p_{\mathrm{T}} < 2$ GeV/c only.
- SHERPA describes the spectral shape, but largely underestimate the yields.

$\Longrightarrow$ *No good agreement with the simulations.*

p_{T} spectrum of $\Xi(1530)^0$



- Similar to $\Sigma(1385)$ results of comparison with MC productions, but ratio Data/MC looks like slightly larger.

- *The ratios of integrated $\frac{\mathrm{dN}}{\mathrm{dy}}$ yields, which are sensitive to the temperature T, are in good agreement with thermal model predictions*

  (F.Becattini et al, J. Phys. G 38 (2011) 025002, arXiv:0912.2855)

$\Sigma(1385)^+/\Lambda = 0.131 \pm 0.002 \pm 0.021$ vs 0.13

$\Xi(1530)^0/\Xi^- = 0.32 \pm 0.01 \pm 0.05$ vs 0.38

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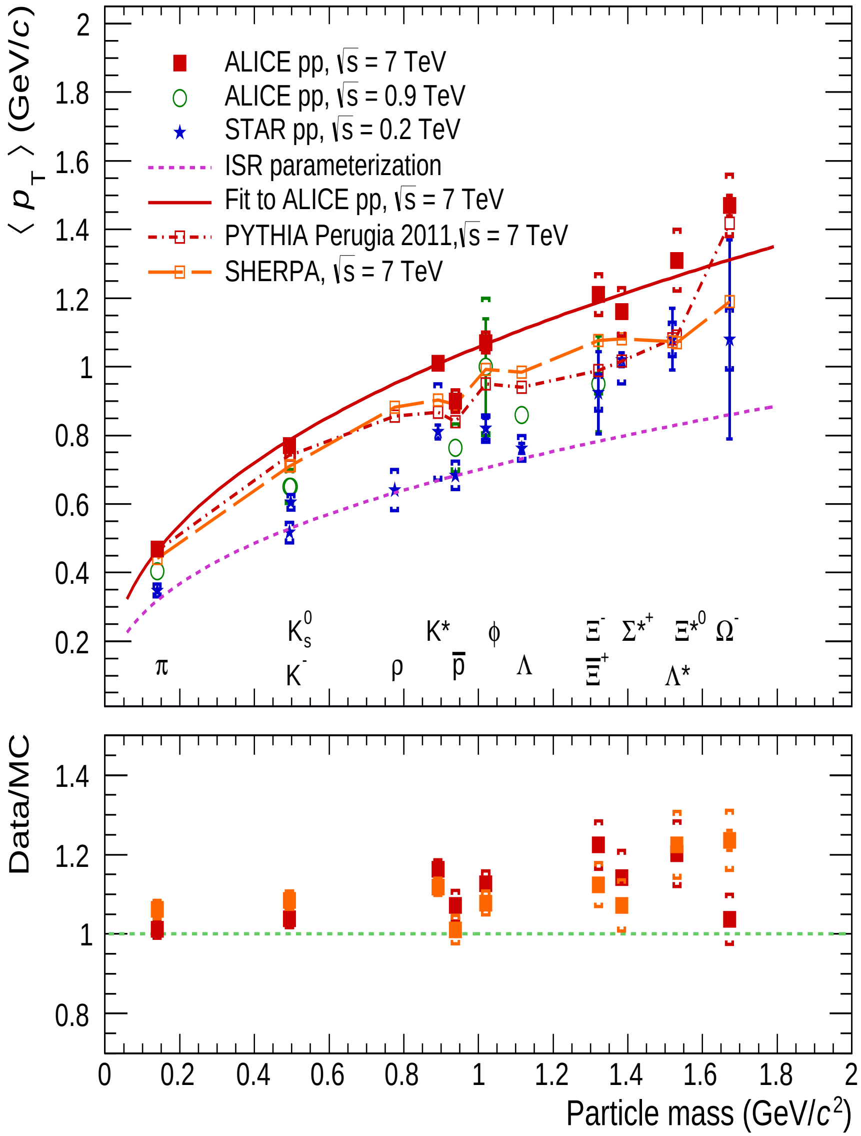
Mean transverse momentum $\langle p_{\mathrm{T}} \rangle$



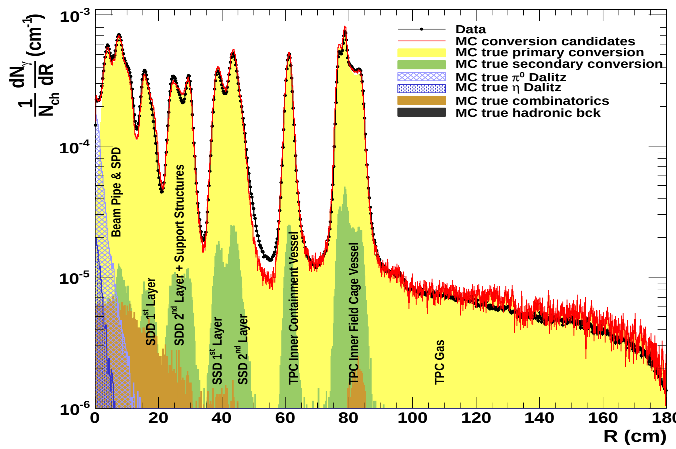
- $\langle p_{\mathrm{T}} \rangle$ characterizes the soft part of the particle spectra.
- ALICE points at 7 TeV fitted as:

  $$\langle p_{\mathrm{T}} \rangle = \alpha \, (\frac{M}{1\mathrm{GeV}/\mathrm{c}^2})^{\beta},$$

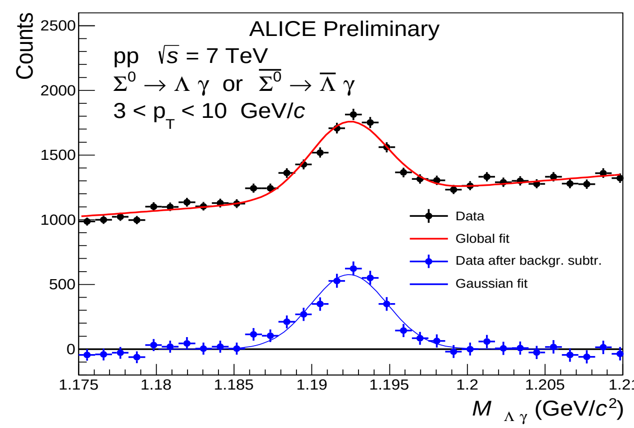
  with $\alpha = 1.06 \pm 0.02\mathrm{GeV}/c$,
  $\beta = 0.43 \pm 0.02$.
- Empirical ISR parametrization:
  $\alpha = 0.7\mathrm{GeV}/c, \quad \beta = 0.4.$
- PYTHIA Perugia 2011 and SHERPA predict softer $\langle p_{\mathrm{T}} \rangle$.

$\Sigma^0 \to \Lambda + \gamma$ and $\bar{\Sigma}^0 \to \bar{\Lambda} + \gamma$ decays

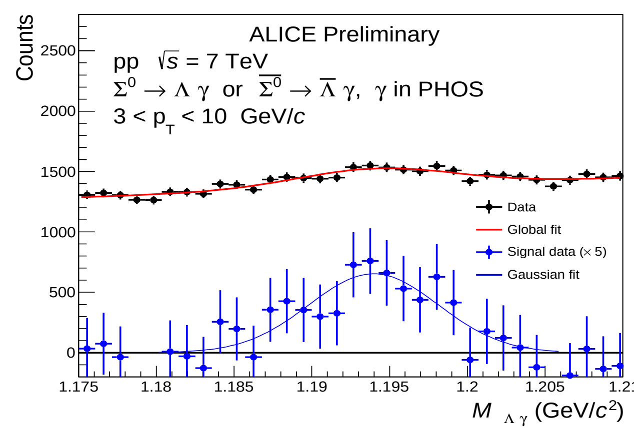
- The ALICE material is well reproduced with photon conversion method (PCM)



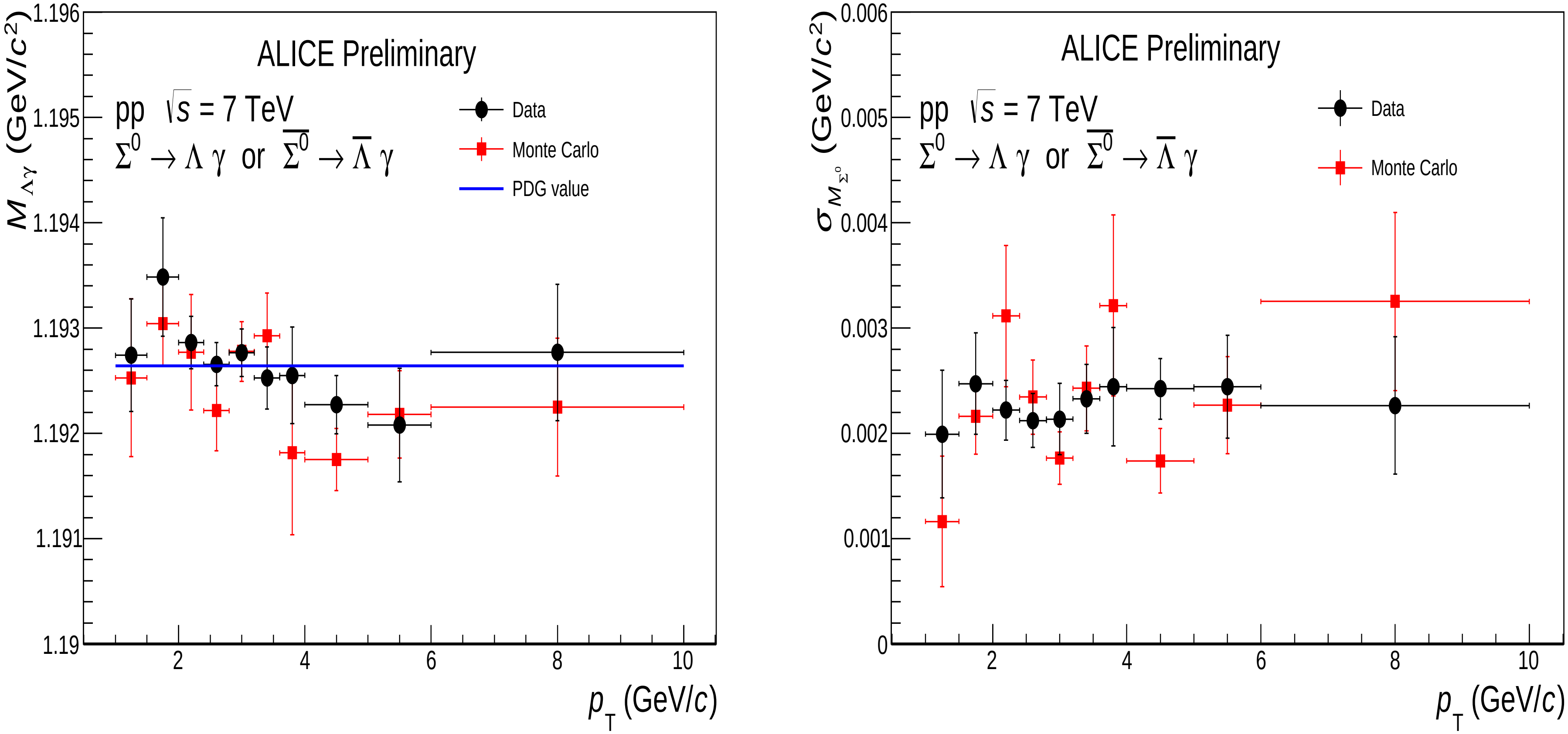
- Amount of detected Σ^0 with PCM is limited by the probability of photon conversion in ALICE central tracking system $\sim 8\%$.



- Proof-of-principle: Σ^0 peak is also observed with photon detected in calorimeter PHOS, but with worse resolution:
  $M^{\Sigma^0} = 1194.1 \pm 0.6$ MeV
  $\sigma_M = 5.1 \pm 0.5$ MeV



Σ^0 mass and width at $1 < p_T < 10$ GeV/c



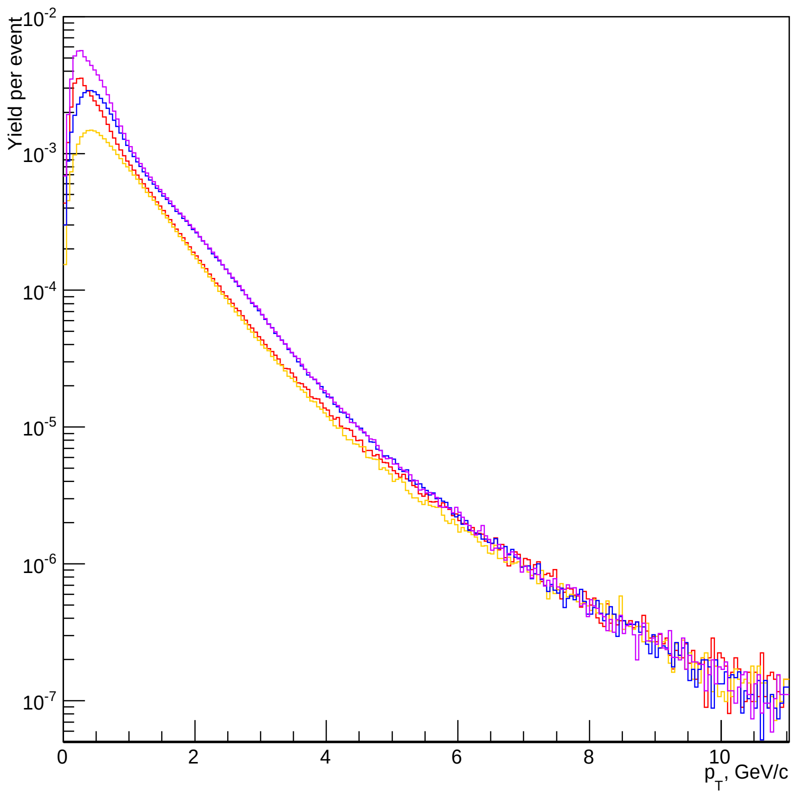
$\Sigma^0 + \bar{\Sigma}^0$ data: $M = 1192.65 \pm 0.099$ MeV, $\sigma_M = 2.27 \pm 0.12$ MeV

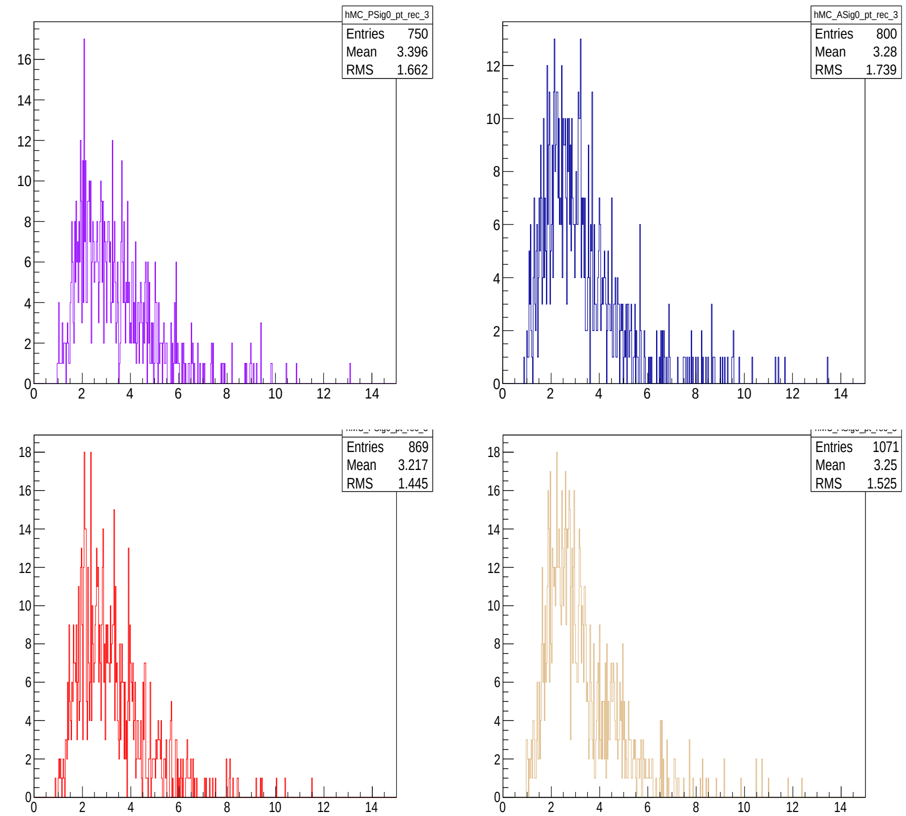
Simulated $\Sigma^0, \bar{\Sigma}^0$: $M^{MC} = 1192.43 \pm 0.13$ MeV, $\sigma_M^{MC} = 2.08 \pm 0.13$MeV

PDG: $\Sigma^{0PDG} = 1192.642 \pm 0.024$ MeV

$\Longrightarrow$ *Good agreement with PDG and simulations.*

Simulated and reconstructed Σ^0, $\bar{\Sigma}^0$ spectra



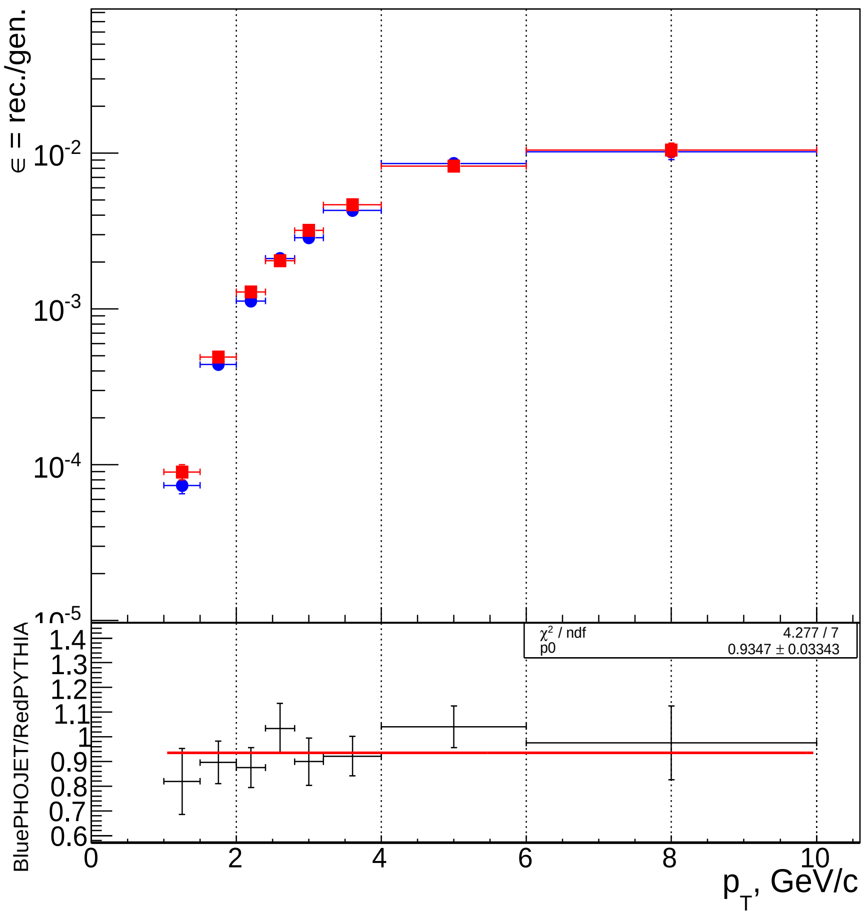


- $|y| < 0.8$ for Σ^0 and $\bar{\Sigma}^0$
- Σ^0, $\bar{\Sigma}^0$: PHOJET, LHC10f6 with ~ 172 M events, rec. ~ 120 Mevents at $|z_v| < 10$ cm
- Σ^0, $\bar{\Sigma}^0$: PYTHIA, LHC10f6a with ~ 174 M events, rec. ~ 140 Mevents at $|z_v| < 10$ cm

$\Longrightarrow$ Reconstructed Σ^0 and $\bar{\Sigma}^0$ spectra are quite similar

Acceptance&efficiency from PYTHIA and PHOJET

$$A \times \epsilon = \frac{N^{rec}}{N^{gen}}$$

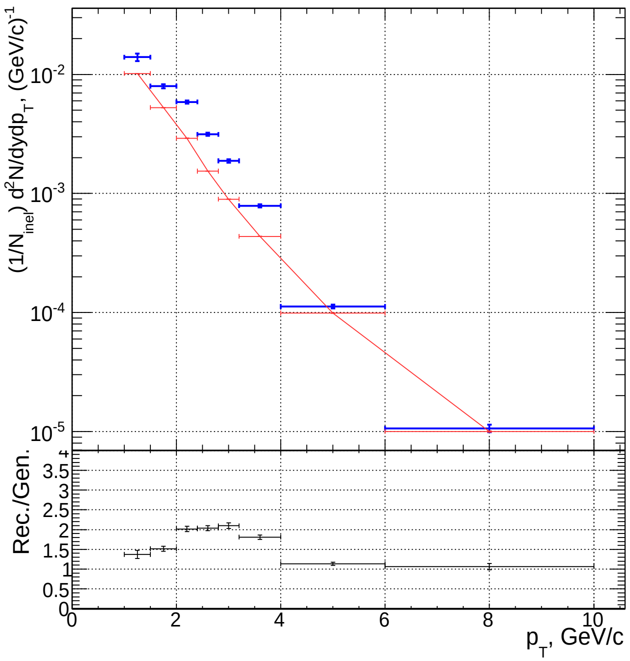


⟹ Acceptance&efficiency corrections were used from PYTHIA and/or from PHOJET.

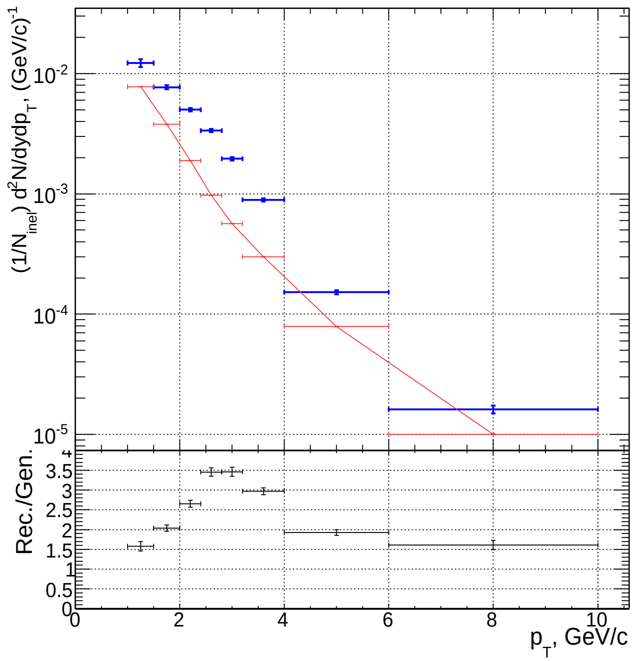
Σ^0 (df:$\Sigma^0 + \bar{\Sigma}^0$) yields from 2010 data vs PHOJET and PHYTHIA and its sum

Results of MC tests presented on the previous meeting.
Systematic uncertainties are under extraction, see talk of J.Song.

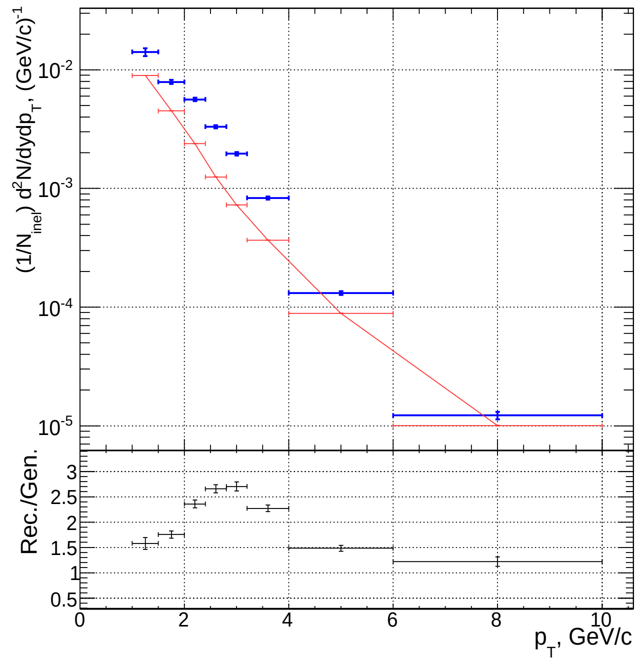
data/PHOJET



data/PHYTHIA



data/PYTHIA+PHOJET



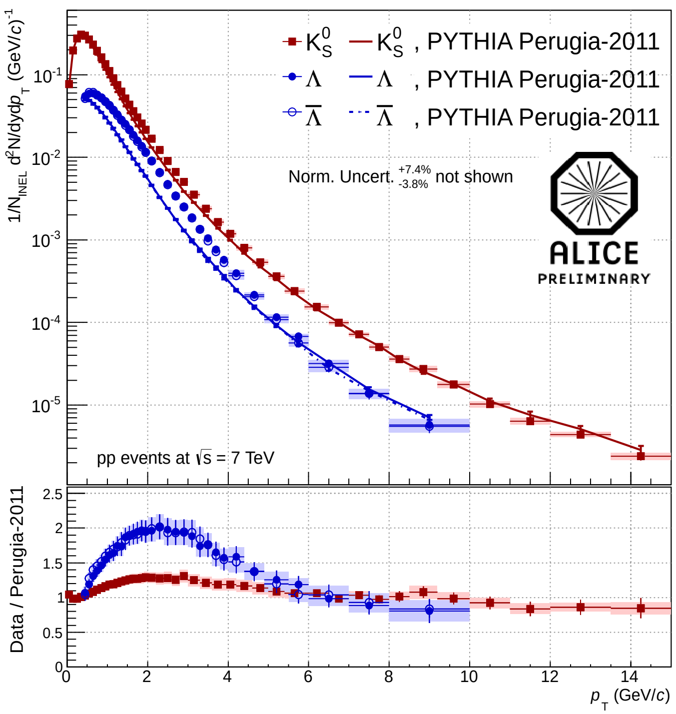
$\Longrightarrow$ Larger $\Sigma^0 + \bar{\Sigma}^0$ yield is in data than in MC.

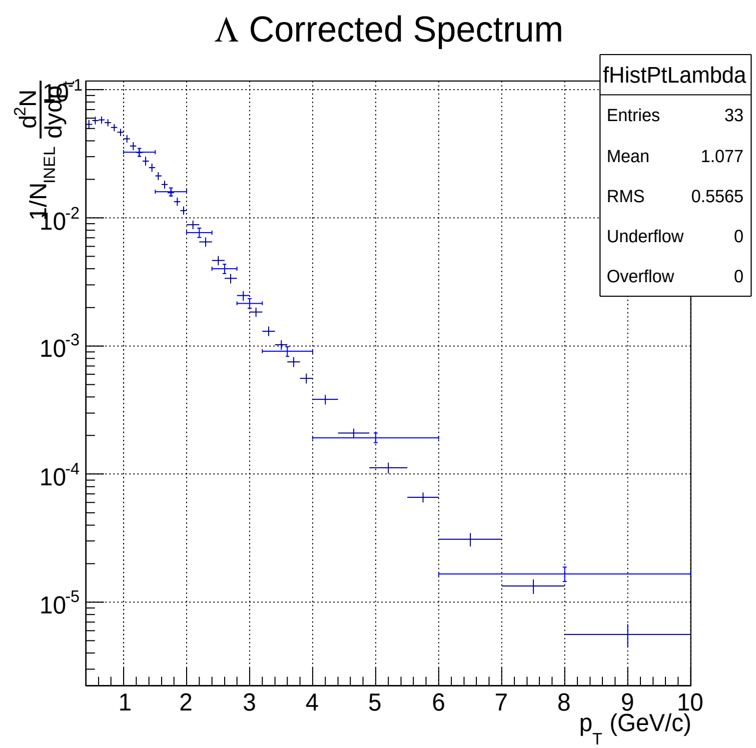
$\Longrightarrow$ Weak dependence of reconstructed yield on the correction factor from MC generators, $\sim 10\%$.

ALI−PREL−43099

Λ yields from rebinned ALI-PREL-43099

Rebinned ALI-PREL-43099



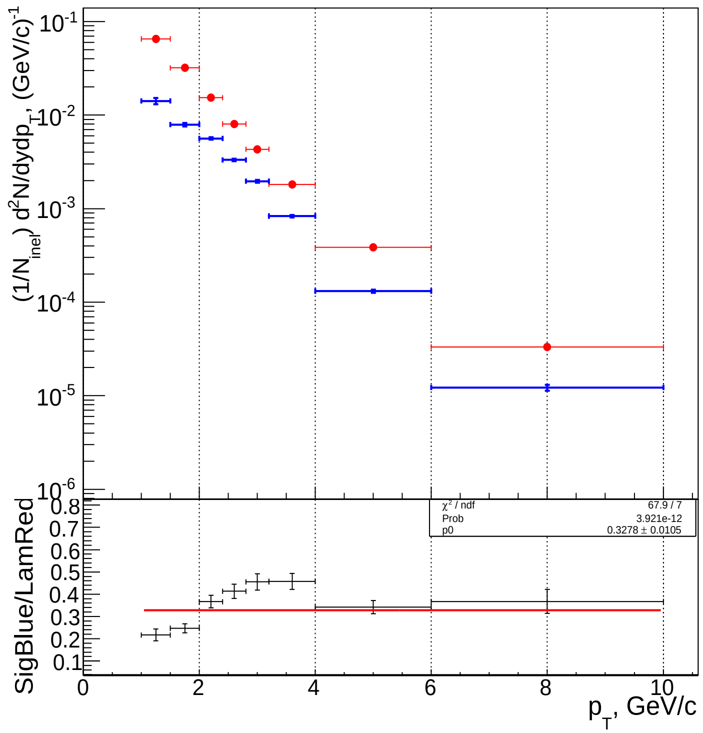


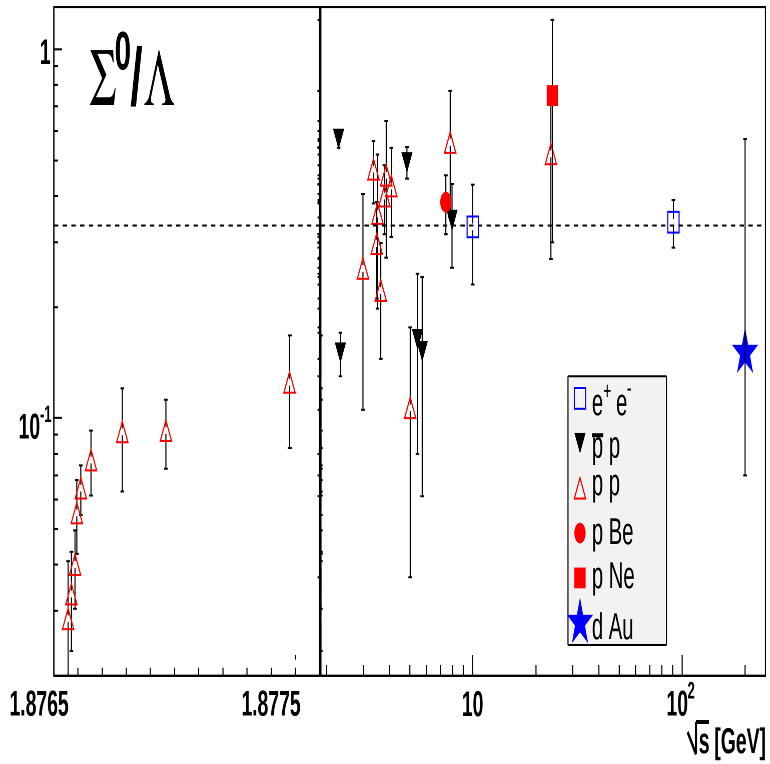
Note that $\Lambda \simeq \bar{\Lambda}$ and inrease of Data/MC ratio at $1 < p_{\mathrm{T}} \leq 3$ GeV/c.

Bins for rebinned Λ are determined by Σ^0 data.

$\frac{\Sigma^0}{\Lambda}(p_\mathrm{T})$ ratio from data with corrections from PHOJET+PYTHIA vs world data

DataPHOJET+PYTHIA/ALI-PREL-43099 (G.Van Buren for the STAR Collaboration, arXiv:nucl-ex/0512018v1)





$\langle\frac{\Sigma^0}{\Lambda}(p_\mathrm{T})\rangle \approx 0.328 \pm 0.011$ at 7 TeV agreeds with L3 (also in P2) data at $\sqrt{s} = 100$ GeV.
Feeddown corrections have not been applied.

Ratio increases at $1 < p_\mathrm{T} \leq 4$ GeV/c. $\Longrightarrow$ Detailed systematic studies are going on.

Status of $\Sigma^0 \rightarrow \Lambda + \gamma$ analysis

- 2010 pass 2 data almost analyzed: yields extracted, systematic of background subtraction estimated, as well as $\Sigma^0/\Lambda(p_{\mathrm{T}})$ cross section ratio.
  MC productions LHC10f6 (170 M) + LHC10f6a (170 M events) are used.
- TTree output is fully operational for the analysis of the data. Thanks to H.Kim and J.Song!
- Codes for Σ^0 analysis are under commissioning. Its location is fixed as a separate task in the new dedicated PWGGA/Hyperon directory. Installation of Hyperon library is going on.

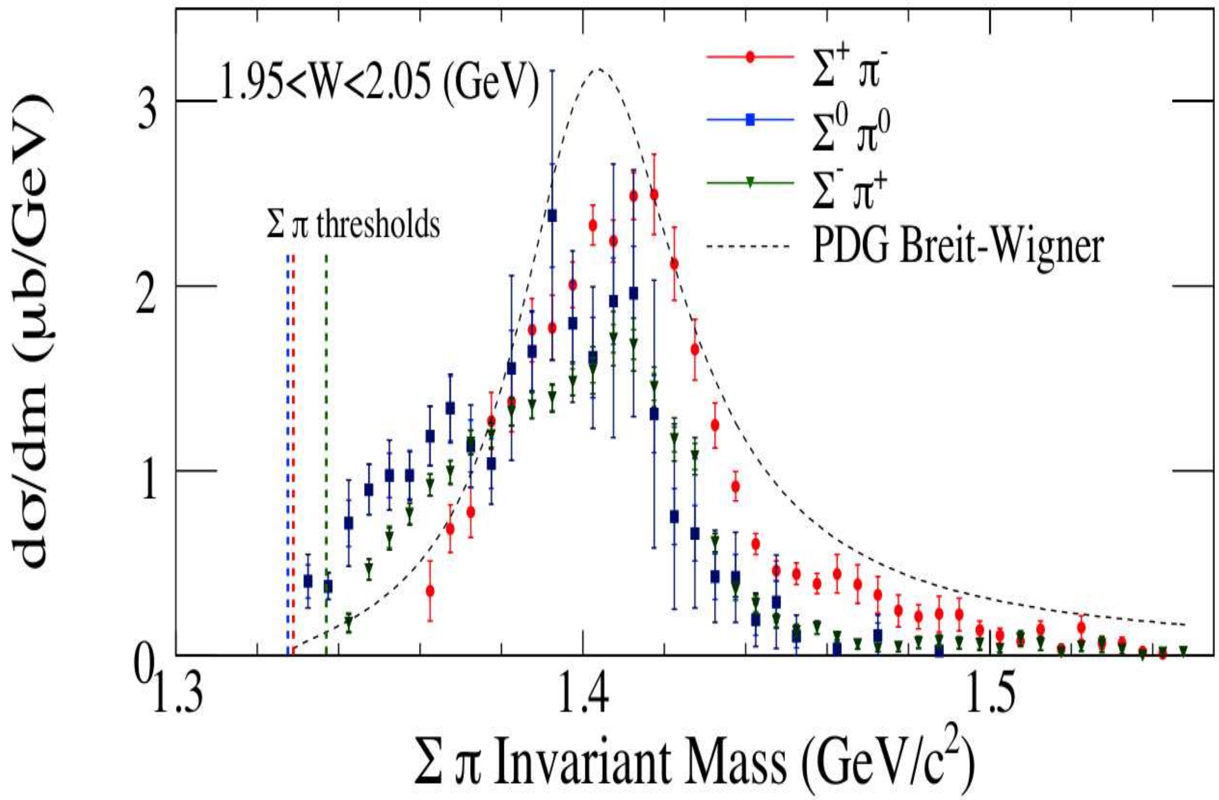
- *Now the new pass 4 2010 pp data exist with better tracking and better calibrated runs. MC productions for 2010 pass 4 data was announced a few days ago with 570 M events, but yesterday I was informed that generator was not properly configured.*

  $\Longrightarrow$ Σ^0 p_{T}-yields and $\frac{\Sigma^0}{\Lambda}(p_{\mathrm{T}})$ ratio have to be reproduced from pass 4 data for the proposal of the publication.

- $\Longrightarrow$ Feasibility study of Σ^0 observation in Pb-Pb and p-Pb data will be started soon. TTree outputs are available for the separation of centrality regions.

Motivations for $\Lambda(1405) \to \Sigma + \pi$ study

- $\Lambda(1405)$ melts: mass peak can be seen in in pp data, but no one in PbPb.
  Different R_{AA} ratios for $\Lambda(1405)$, $\Sigma(1195)$, $\Sigma(1385)$, $\Lambda(1115)$ at LHC were calculated with Parton-Hadron-String-Dynamics (PHSD) approach, codes are available Elena Bratkovsaya (Frankfurt Uni.), priv. comm., arXiv:1406.2570 14.11.2014, workshop RSN@CT, November 2014
- $\Lambda(1405)$ looks like molecule with size around 1.7 fm (Sekihara et al. 2011).
  Can light resonances and/or multiquark states be discriminated at HIC?
  E.g. $\Lambda(1405) \to \pi^+\Sigma^-$ vs $\pi^-\Sigma^+$? Su Houng Lee (Yonsei Uni.) RSN@CT, priv. comm.
- $\Lambda(1405)$ is observed recently at CLAS@JLAB: Kei Moriya (Arizona State Uni.) RSN@CT, K. Moriya, R. Schumacher et al. [CLAS Collaboration] PRC 87, 035206 (2013)



Decays of $\Lambda(1405)(\bar{\Lambda}) \rightarrow \Sigma(\bar{\Sigma}) + \pi$

- Modes of $\Lambda(1405) \rightarrow \Sigma + \pi$ $(Br = 100\%)$ decay:
  $\Lambda(1405) \rightarrow \Sigma^0(\Lambda + \gamma) + \pi^0$ (total $Br = 33.3\%$)
  $\Lambda(1405) \rightarrow \Sigma^+(p + \pi^0, Br = 52\%) + \pi^-$ (total $Br = 33.3\%$)
  $\rightarrow \Sigma^+(n + \pi^+, Br = 48\%) + \pi^-$
  $\Lambda(1405) \rightarrow \Sigma^-(n + \pi^-, Br = 99.8\%) + \pi^+$ (total $Br = 33.3\%$)

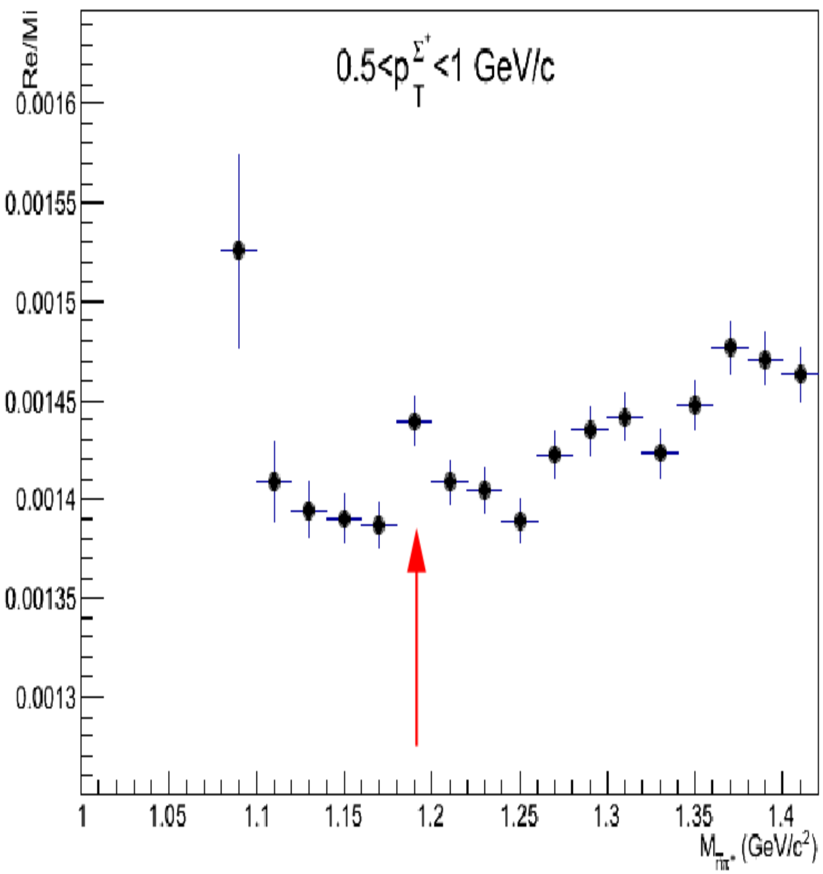
  Note very slow $\pi^{0,+,-}$ with $p_{\mathrm{T}} \sim 70$ Mev from $\Lambda(1405)$ decay and π^0 from Σ^{+-} decay with $p_{\mathrm{T}} \sim 110$ MeV.
  $\Longrightarrow$ π^0 detection with so small p_{T} is very challenging.
  $\Longrightarrow$ $\pi^{+,-}$ detection with so small p_{T} can be done with good PID (talk of J.Song).

- Modes of $\bar{\Lambda}(1405) \rightarrow \bar{\Sigma} + \pi$ $(Br = 100\%)$:
  $\bar{\Lambda}(1405) \rightarrow \bar{\Sigma}^0(\bar{\Lambda} + \gamma) + \pi^0$ (total $Br = 33.3\%$)
  $\bar{\Lambda}(1405) \rightarrow \bar{\Sigma}^+(\bar{p} + \pi^0, Br = 52\%) + \pi^-$ (total $Br = 33.3\%$)
  $\rightarrow \bar{\Sigma}^+(\bar{n} + \pi^+, Br = 48\%)) + \pi^-$!!!
  $\bar{\Lambda}(1405) \rightarrow \bar{\Sigma}^-(\bar{n} + \pi^-, Br = 99.8\%) + \pi^+$ (total $Br = 33.3\%$) !!!

  Note a very new possibility to detect $\bar{n}$ in PHOS with cluster energy $\approx 2m_n \approx 1.8$ GeV

$\Longrightarrow$ Perform feasibility study the decays labeled with !!! on the base of Σ^0 package.

Hint on $\bar{\Sigma}^+$ detection at ALICE PHOS



Looking at the channel (Br=99,8%) $\bar{\Sigma}^+ \to \bar{n}\pi^+$

Yu.Kharlov, ALICE PHOS meeting, 5.9.2014

PHOS: $\delta E/E \sim 3\%/\sqrt{E_\gamma(\text{GeV})} \oplus 1.1\%$

EMCAL: $\delta E/E \sim 10\%/\sqrt{E_\gamma(\text{GeV})} \oplus 2\%$

Feasibility study:

- discussion with PHOS experts in January 2015
- follow the examples of $\bar{n}$ detection in PHOS.
- planned pp data from 2015 at $\sqrt{s} = 13$ TeV look like the most appropriate due to the larger statistics and enlarged acceptance and efficiency of PHOS.
- data from Pb-Pb collisions can be analyzed after $\Lambda(1405)$ detection in pp collisions.

Summary and Outlook

- First observation of $\Sigma^0 \to \Lambda + \gamma$ and $\bar{\Sigma}^0 \to \bar{\Lambda} + \gamma$ decays in pp collisions at $\sqrt{s} = 7$ TeV at $1 < p_\mathrm{T} < 10$ GeV/c.

- Paper on $\Sigma(1385)^\pm$ and $\Xi(1530)^0$ was accepted by EPJ C (The ALICE Collaboration, arXiv:1406.3206 [nucl-ex], CERN-PH-EP-2014-128).

- Feasibility study of $\Lambda(1405)$ detection in pp data are foreseen.

- *Yields of $\Sigma^0(p_\mathrm{T})$ and cross section ratio $\frac{\Sigma^0}{\Lambda}(p_\mathrm{T})$ from pass 4 2010 pp data at $\sqrt{s} = 7$ TeV are under analysis.*
- *Hyperons are observed in p-Pb data and $R_{pA}(p_\mathrm{T})$ will be evaluated.*
- *Analysis of hyperon production in Pb-Pb data is going on.*

$\Longrightarrow$ **New data on strange and double-strange baryons will be very interesting!**

Guten Appetit!

Anti-neutron identification with PHOS

Yu.Kharlov, ALICE PHOS meeting, 5.9.2014

- Hadronic interaction length of PbWO4: λ =19.7 cm
- Nuclear material budget of the PHOS crystal: 0.91 λ
- The probability for hadrons to interact strongly along their path through the crystal is 0.4.
- Anti-nucleon annihilation cross section is large, the energy released from annihilation by secondary particles is about $2m_n$=1.8 GeV with good accuracy.
- Anti-neutrons can be identified by a large deposited energy, shower shape and absence of track matching
- Momentum of antineutrons can be measured by the flight time.
- Antineutron advantage w.r.t. antiprotons:
  - Antiprotons can be detected by tracking system at $p_{\mathrm{T}} >$ 150 MeV/c while antineutrons have no low p_{T} limit (!)
  - Some resonances decay to n and $\bar{n}$ with considerable branching

E.g., PHENIX, Anti-neutron identification with EMCAL: arXiv:nucl-ex/0404001v1