Resonances in heavy ion collisions

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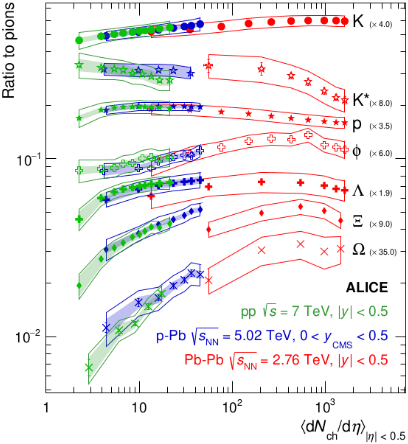
Strangeness in Quark Matter 2022

Stable hadron yields versus centrality

[ALICE, 1807.11321]



Strangeness enhancement

see talk by Livio Bianchi

- high multiplicity – equilibrated strangeness, grand-canonical statistical model describes the data
- Canonical strangeness suppression: good description, except ϕ [1807.11321]
- Thermalized core and pp corona interplay [Kanakubo et al, 1910.10556, 2108.07943]

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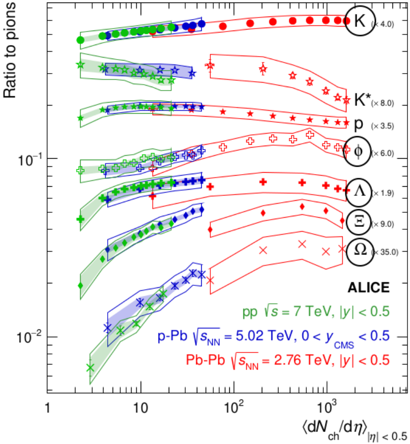

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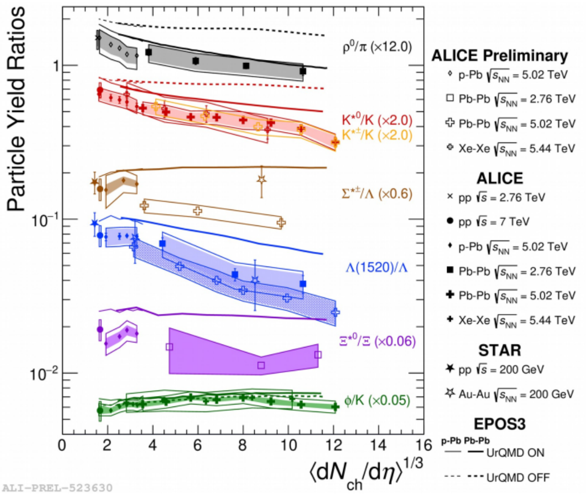
In (mid-)central PbPb: stable hadron to pion ratio stays $\simeq$ flat

Not the case for resonances

Suppression of resonances in high-multiplicity collisions

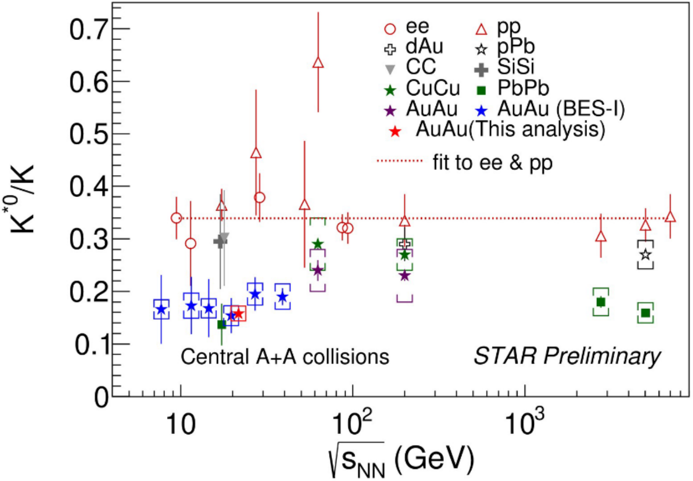


What do we know about this phenomenon?

What can we learn from it?

Suppression of resonances in central collisions II

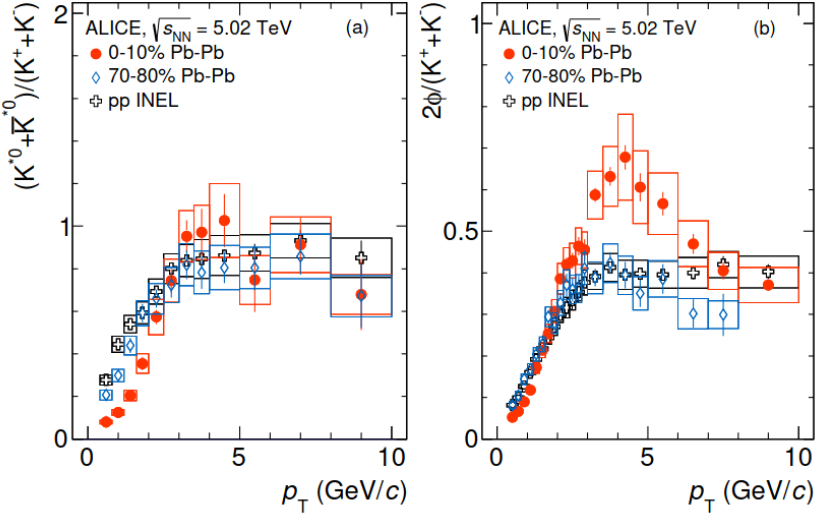
talk by Aswini Kumar Sahoo



Suppression occurs across large range of energies

Suppression of resonances in central collisions III

talks by Dukhishyam Mallick [ALICE, 1910.14419], Junlee Kim



Suppression occurs at low p_T

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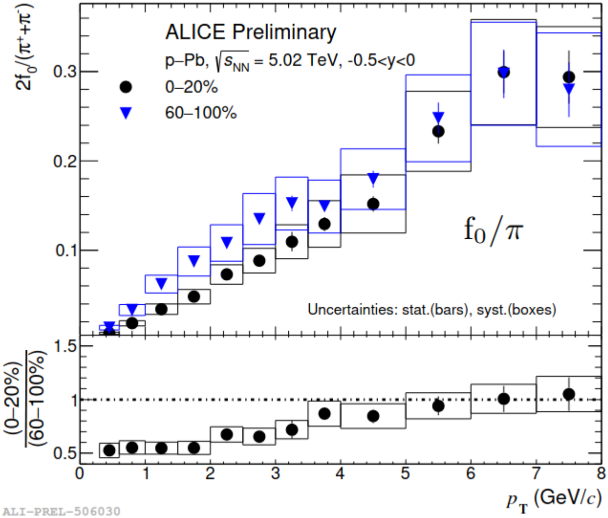

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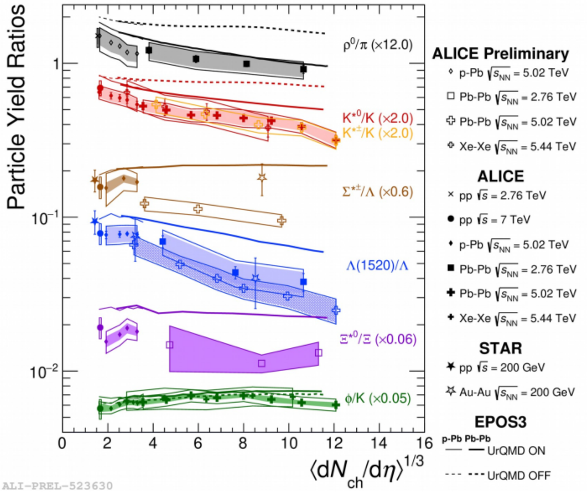
Origin of suppression: late stage hadronic interactions



Knospe et al, 1509.07895, 2102.06797; DO, Shen, 2105.07539

Need afterburner to explain resonance yields

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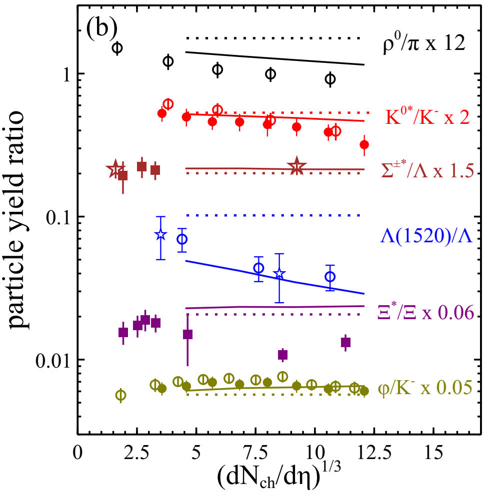
Knospe et al, 1509.07895, 2102.06797; DO, Shen, 2105.07539



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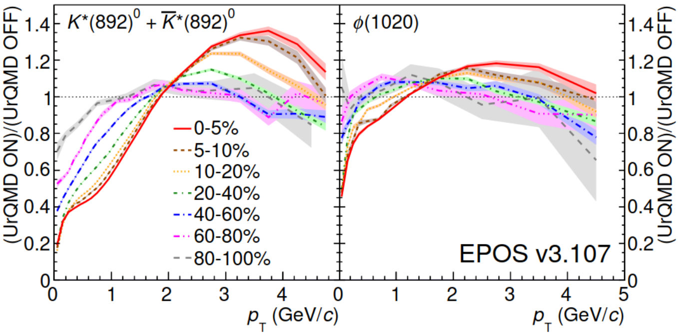
Origin of suppression: late stage hadronic interactions II

Knospe et al, 1509.07895, 2102.06797



- Suppression of low p_T: slow resonance decay products have high chance to scatter $\implies$ resonance is not detected
- Enhancement at higher p_T: "radial flow", "pion wind", resonance gets kicked to higher p_T by pions
  $\pi R \to \pi R$ or $\pi R \to R^* \to \pi R$

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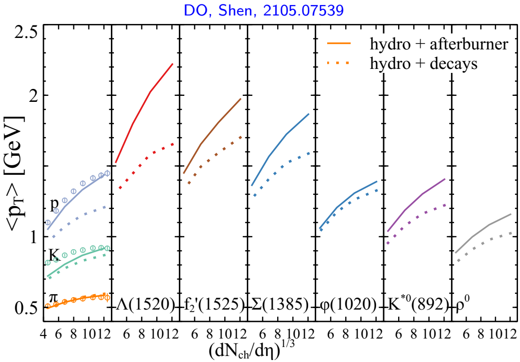

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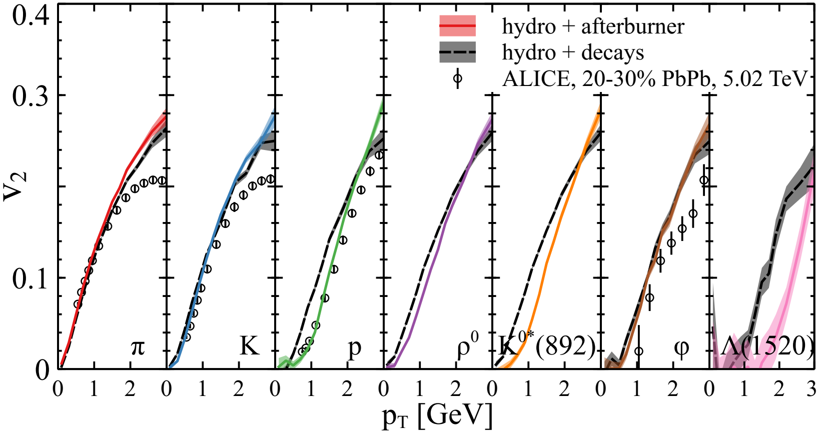
Resonance flow

DO, Shen, 2105.07539

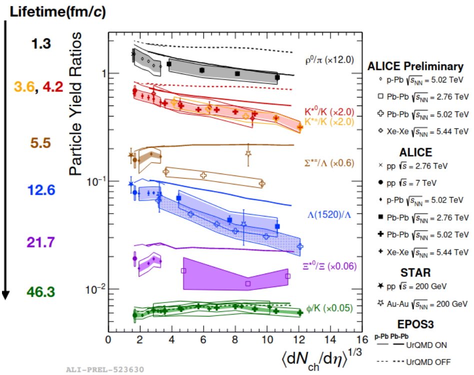


Afterburner suppresses flow v_2 of resonances at small $\langle p_T \rangle$

General understanding of resonance production

- Resonances in full equilibrium at chemical freeze-out
- Hadronic stage (dense mesonic medium):
  - Rescattering of decay products, resonance cannot be detected
    $K^* \to K\pi$, $\pi\pi \to \rho \to \pi\pi$
  - Rescattering of resonance itself with excitation or without
    $K^*\pi \to K\rho$, $K^*\rho \to K\pi$, $K^*\pi \to K(1270) \to \rho K$
    $\Lambda(1520) \to \pi\Sigma^* \to Kp$
  - Regeneration from decay products
    $\pi\pi \to \rho$, $\Lambda\pi\pi \to \Lambda(1520)$
- Kinetic freeze-out: resonance yields stop changing
  Kinetic freeze-out may be not unique for all resonances

Vacuum lifetime ordering conjecture



- “Shorter vacuum lifetime $\implies$ more suppression”
  Fails with $\Lambda(1520)$, Σ^*, ρ
- “Vaccum lifetime $>$ hadronic stage duration $\implies$ no suppression”
  What about $\Xi(1530)$?
- Vacuum lifetime is not enough
  Resonance mass, decay channels, cross section with pions matter

Intermediate summary

- Seems that we have some understanding of resonance production, both theoretical and experimental

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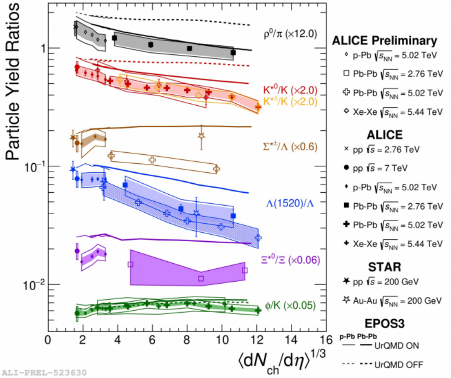
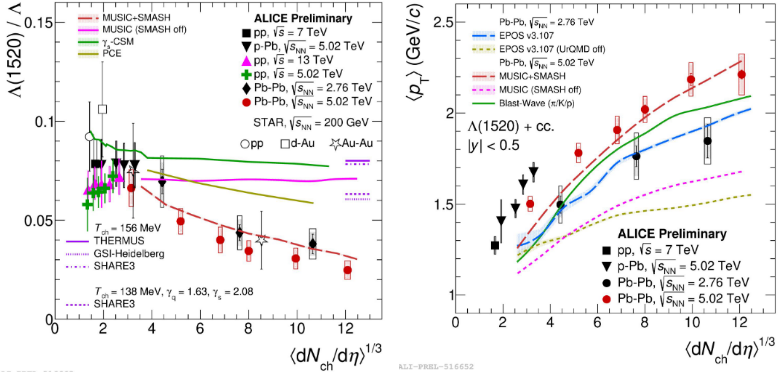
- Seems that we have some understanding of resonance production, both theoretical and experimental
- Do we? Not all resonance yields are reproduced by models
- What can we learn from measured resonance production?



$\Lambda(1520)$



MUSIC + SMASH: better $\Lambda(1520)$ description.

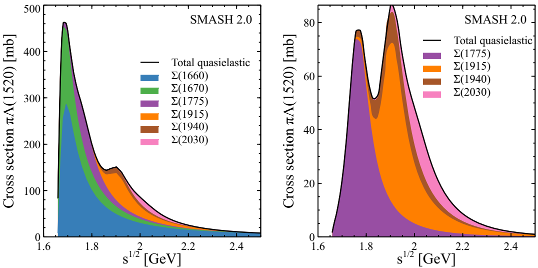
What is the difference between MUSIC + SMASH and EPOS + UrQMD?

Same class of models, hydro + transport.

Conjecture: larger branching ratios of $\Sigma^* \to \Lambda(1520)\pi$ in SMASH

What can we learn: unknown branching ratios

$\Sigma^* \to \Lambda(1520)\pi$



- Cross section $\Lambda(1520)\pi \to \Sigma^*$: $\sigma_{max} \sim \frac{B.R.(\Sigma^* \to \Lambda(1520)\pi)}{m_{\Sigma^*} - (m_{\Lambda(1520)} + m_\pi)}$
- Huge cross sections $\Lambda(1520)\pi \to \Sigma(1660), \Sigma(1670)$

  . . . or zero depending on unknown $B.R.(\Sigma^* \to \Lambda(1520)\pi)$
- Larger $B.R.(\Sigma^* \to \Lambda(1520)\pi) \implies$

  More $\Lambda(1520)$ suppression due to $\Lambda(1520)\pi \to \Sigma^* \to Kp$ chain

  Larger $\Lambda(1520)$ $\langle p_T \rangle$ due to pion wind $\Lambda(1520)\pi \to \Sigma^* \to \Lambda(1520)\pi$

  DO, Shen, 2105.07539; Kuznetsova, Rafelski, 0811.1409
- But: such large cross sections mean $l_{mfp} < l_{Compton}$

  Out of transport applicability for $\Lambda(1520)$, need G-matrix approach

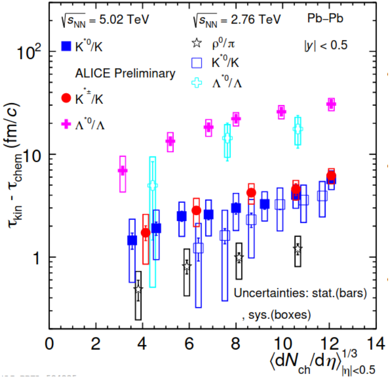
  Cabrera, 1406.2570; Ilner et al, 1707.00060

Conjecture

“Transport practitioner’s conjecture”

Transport not reproducing resonance suppression (e.g. $\Xi(1530)$) $\implies$ missing branching ratios and/or reactions

Duration of hadronic stage



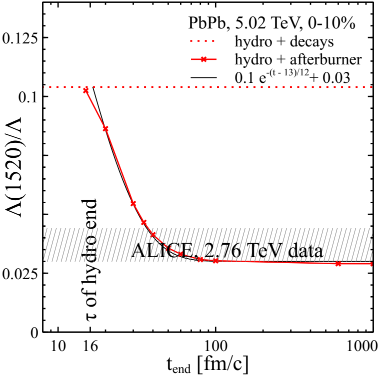
talk by Dukhishyam Mallic

- Assume no regeneration, no excitation
  only rescattering of products
- Fit resonance yield $\frac{dN}{dy}|_{measured} = \frac{dN}{dy}|_{HRG}\, e^{-\Delta\tau/\tau_R}$
- Unrealistic assumptions $\implies$ large spread of obtained τ

Duration of hadronic stage from transport

Stopping the simulation at earlier time t_{end}

DO, Shen, 2105.07539



Duration of Λ(1520) scattering stage ≃ 12 fm/c

Times from other resonances can be different. It is ok: kinetic freeze-out of different reactions should not be simultaneous.

Limiting case of transport: Rate equation models

Torrieri, Rafelski, hep-ph/0103149, nucl-th/0608061
Kuznetsova, Rafelski, 0811.1409, 0804.3352; Cho, Lee, 1509.04092; Le Roux et al, 2101.07302

- Start from chemical freeze-out, always in kinetic equilibrium
- Assume some $V(\tau)$ and $T(\tau)$ or get $T(\tau)$ by fixing entropy
- Solve coupled rate equations of type

$$\frac{dN_R}{d\tau} = \sum_{a,b} \langle \sigma v_{rel} \rangle_{ab \to R} n_a N_b - \langle \Gamma_R \rangle N_R +$$

$$\sum_{a,b,c} \langle \sigma v_{rel} \rangle_{ab \to cR} n_a N_b - \sum_{a,b,c} \langle \sigma v_{rel} \rangle_{cR \to ab} n_c N_R$$

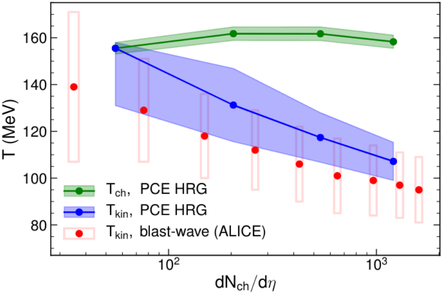
- End at fixed T or V_{kin}/V_{ch}

What one learns: relative importance of reactions, T_{kin}, V_{kin}/V_{ch}, hadronic phase lifetime $\Delta\tau_{kin}$

Caveats: $\Delta\tau_{kin}$ is determined by $V(\tau)$, no way to get suppression only al low momenta, momentum distribution is assumed always thermal

Partial Chemical Equilibrium limit

- Assume reaction rates much faster than expansion rate
- Expansion conserving entropy and stable particle yields
- Variables: T, stable hadron fugacities
- Stop at temperature T_{kin} same for all species
- What one learns: T_{kin}, V_{kin}/V_{ch}



Motornenko et al, 1908.11730

Conclusions

- Resonances production is sensitive to hadronic stage
  For some resonances in central collisions yield is suppressed at low p_T,
  so $\langle p_T \rangle$ is enhanced, v_2 is suppressed
  For $\Lambda(1520)$ these effects are particularly strong.
- Vacuum lifetime ordering conjecture fails
  because excitations $R\pi \to R^*$ matter
- What can one learn from resonances?
  - Infer existence of unknown resonances, e.g. Ξ^* tower
  - Constrain unknown branching ratios
  - Kinetic freeze-out temperature T_{kin}
  - Volume ratio V_{kin}/V_{ch}
  - Maybe hadronic stage duration time using $V(\tau)$ parametrization
  - Infer resonance nature (e.g. does $f_0(980)$ contain s-quarks)
    see talk by Junlee Kim
  - (not in this talk) Spin effects, chiral symmetry restoration
    see talk by Jihye Song

In memory of Prof. Kyrill Bugaev (1963 – 2021)

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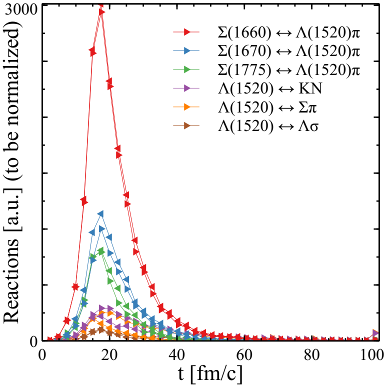
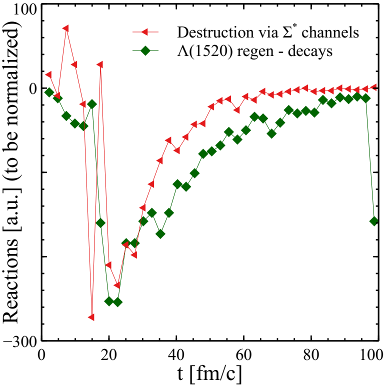
Backup

Reaction rates from SMASH, Λ(1520)

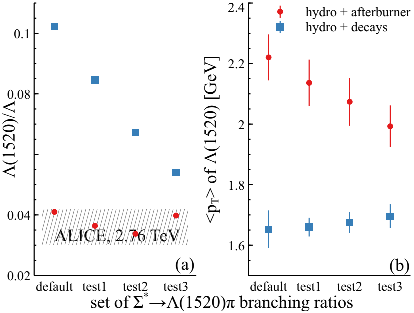




Λ(1520) destruction and production occur at rather similar rates

of course in the end destruction wins

What can we learn from $\Lambda(1520)$ suppression?



	SMASH		THERMUS		PDG
	default	test 1	test 2	test 3	> 0
$\Sigma(1660)$	0.2	0	0	0	> 0
$\Sigma(1670)$	0.14	0	0	0	> 0
$\Sigma(1750)$	0	0	0	0	> 0
$\Sigma(1775)$	0.26	0.26	0.2	0	0.17-0.23
$\Sigma(1915)$	0.59	0.59	0	0	-
$\Sigma(1940)$	0.17	0.17	0	0	> 0
$\Sigma(2030)$	0.195	0.195	0.15	0	0.1-0.2

Measured $\langle p_T \rangle$ of $\Lambda(1520)$ puts (rather weak) constraints on $\Sigma^* \to \Lambda(1520)\pi$ branching ratios