2021 APS Fellow:
Studies of hadronic resonances in heavy ion collisions and how it resonates with my life.

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The University of Texas at Austin

APS 10th workshop GHP, April 12-14, 2023, Minneapolis MS

Remarks

I am very honored to be elected a Fellow of the American Physical Society in 2021 which changed my feelings of belonging and confidence in Physics

It brought “happy” tears to my eyes when I was reading the
2021 APS Fellowship Notification (GHP)

Being now acknowledged for my work within the APS community is amazing

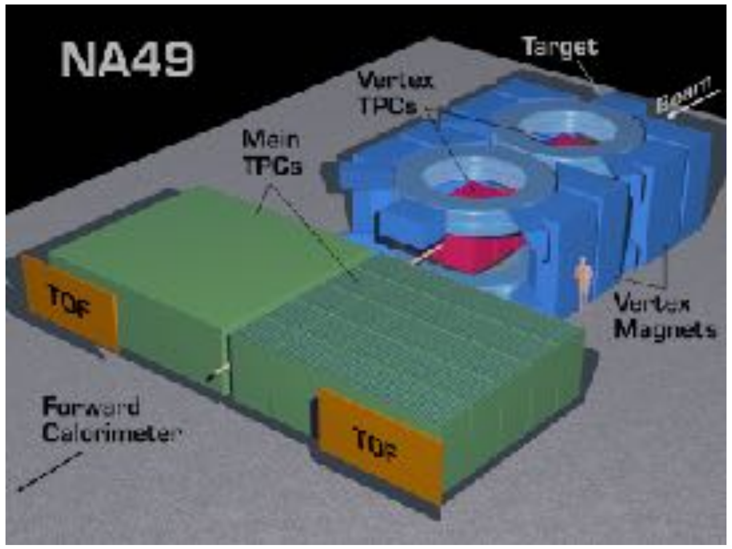
And thinking about all my obstacles and self-doubt (women) in my physics life

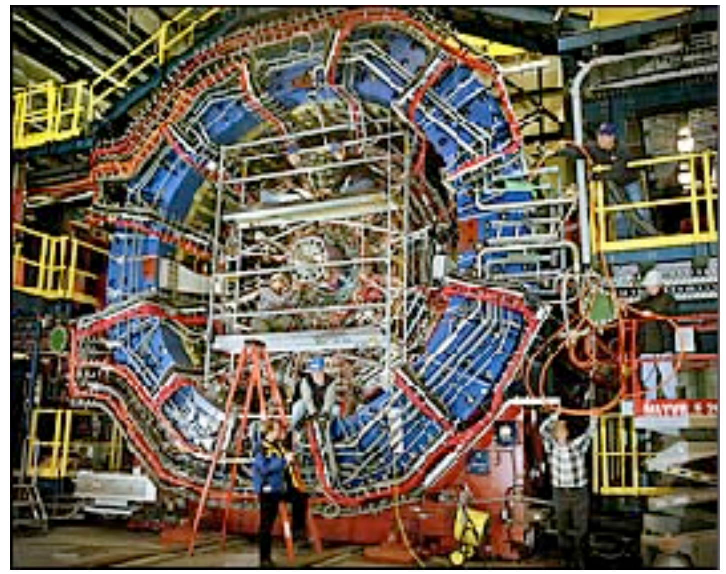
At the beginning being the only women in the Frankfurt University group.
My confidence was very low.

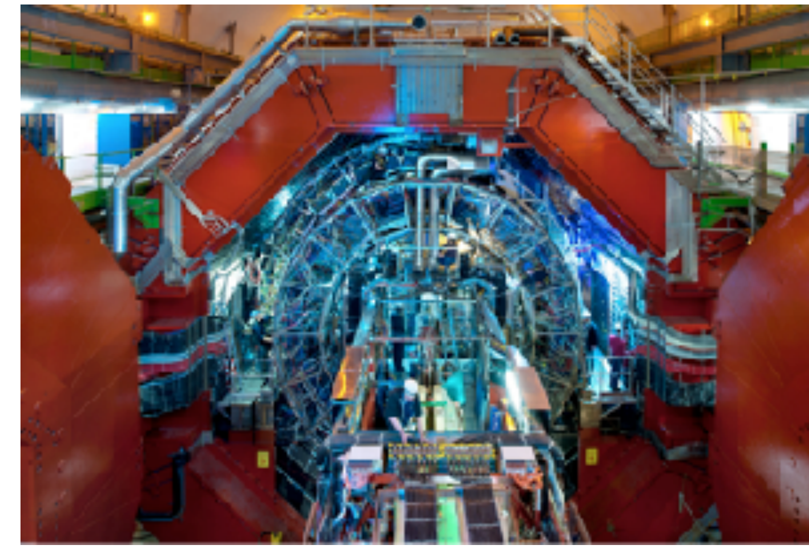
I am so happy about this award and I will give a talk about my personal journey a reflection on my feelings during my Physics career.

This talk is dedicated to all the young scientist

Heavy Ion Experiments







NA49 - SPS
Pb+Pb ~17 GeV

STAR - RHIC
Au+Au ~200 GeV

ALICE - LHC
Pb+Pb ~2.76 TeV

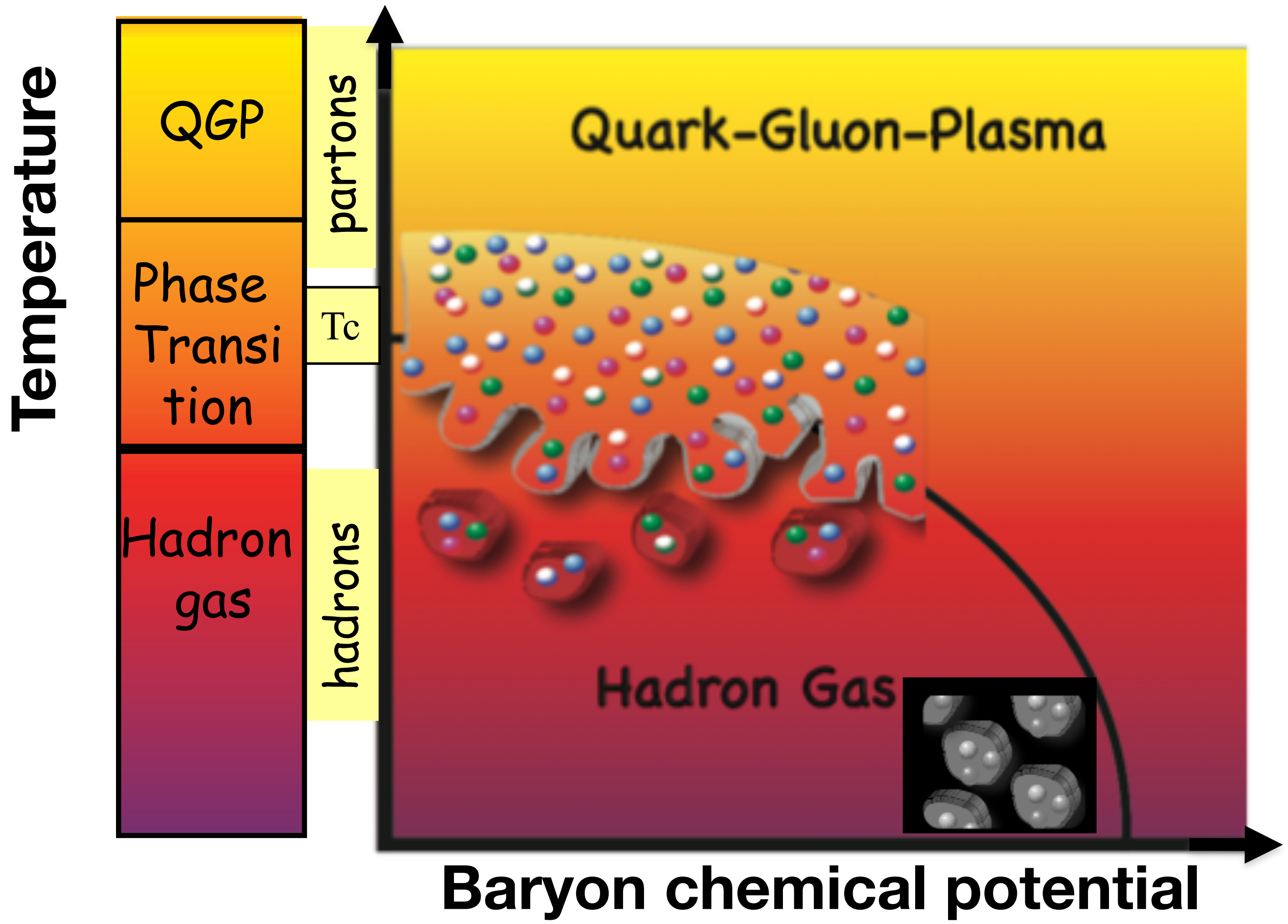
Timeline

PhD 2001 | **Post-Doc -2006** | **Faculty 2006 - now**

Center of Mass Energy range: ~17 GeV to ~ 5 (13) TeV
Collision systems size: pp, pA (dA), AA

Duration of a Heavy Ion Collision

Where Resonances play a role



Hard scattering

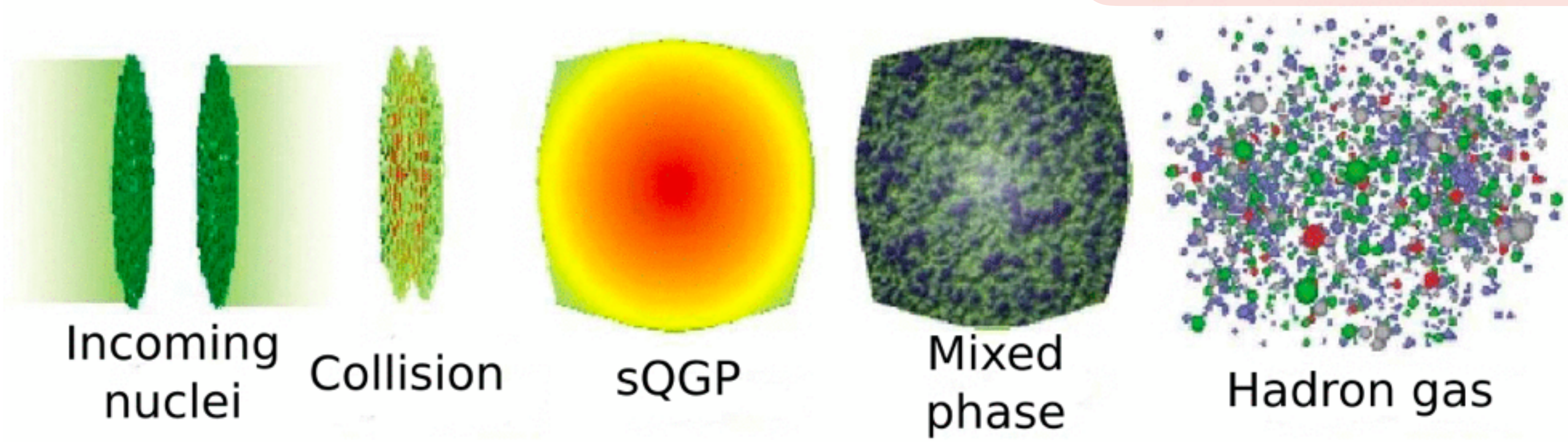
Quark Gluon Plasma:
- Deconfinement
- Chiral Symmetry Restoration (CSR)

Probing the CSR (with Resonances)
- Mass shift
- Width broadenings

Hadronic Interactions:
- Resonances and decay and Regeneration
- Re-scattering of decay daughters

Chemical Freeze-out
- Statistical model T, m

Kinetic Freeze-out



Resonances in search for CSR

- **Initial idea: Measure mass shift and width broadening as signatures of Chiral Symmetry Restoration (CSR) at phase transition.**

- **Later results: Understanding of hadronic phase interactions, lifetime of hadronic phase**

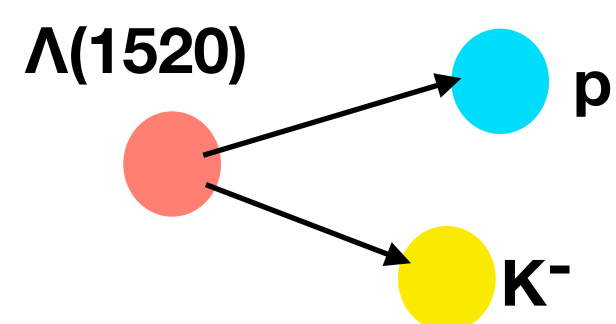
Suggested resonance: measurable width of ~10-20 MeV,
hadronic decay (PID of charged hadrons TPC, TOF)

—> Lambda(1520) is a good candidate for CSR

	Λ (*uds*)	**Λ(1520) (*uds*)**
Spin Parity:	1/2 +	3/2 –
Mass m :	1115.7 MeV/c^2	1519.5 MeV/c^2
Width Γ :	< 1 MeV/c^2	15.6 MeV/c^2
Lifetime τ :	7.9 cm/c	12.8 fm/c
	weak dacay	strong decay

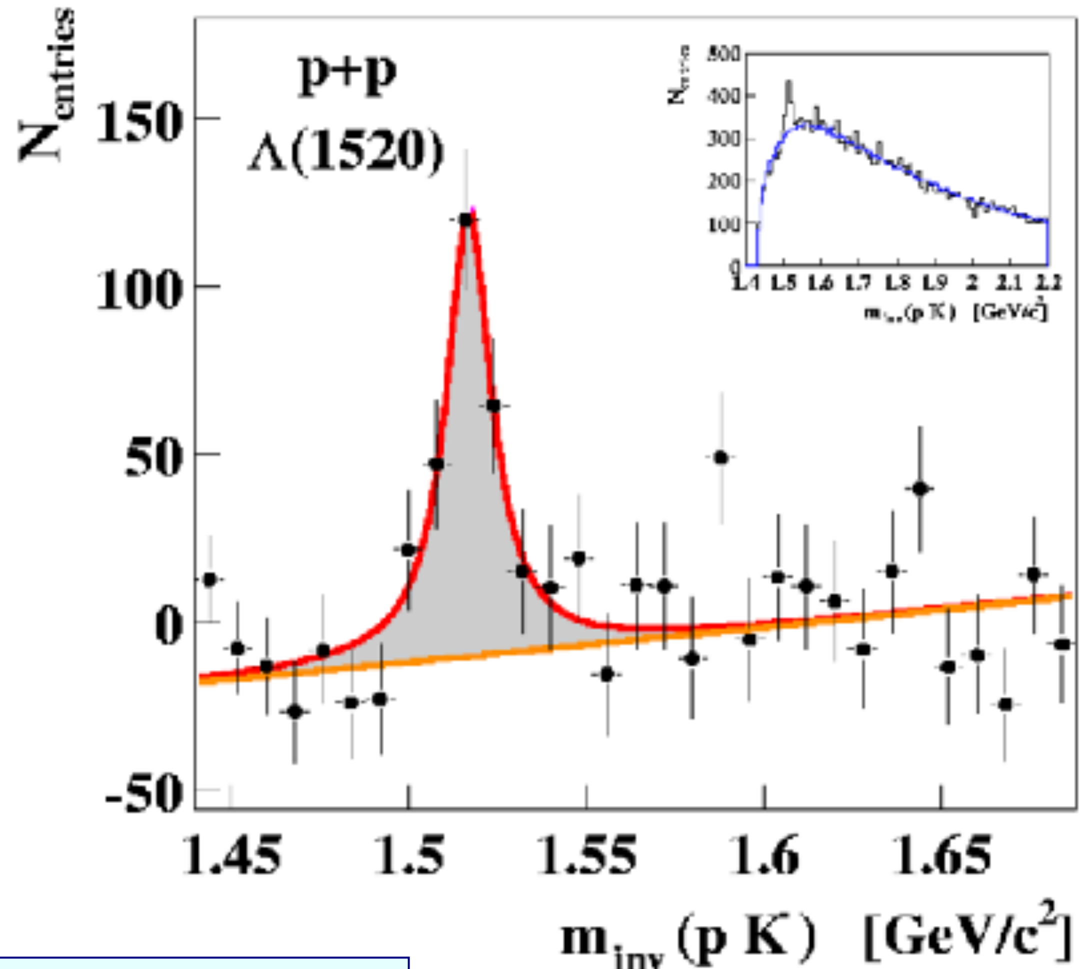
Decay channel Λ(1520):

$p + K^-$:	22.5 %
$N + K^0$:	22.5 %
$\Lambda + \gamma$:	0.8 %
$\Sigma + \pi$:	42.0 %
$\Lambda+\pi+\pi$:	0.9 %

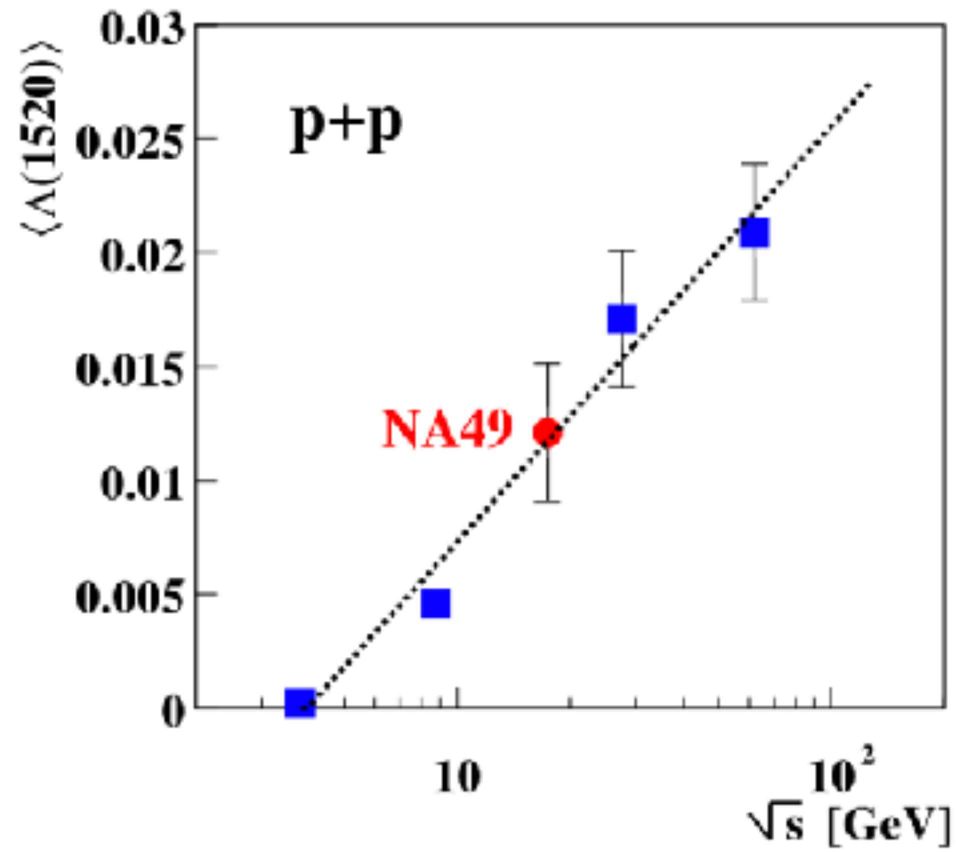


Λ(1520) in pp collisions at the SPS

First check: Signal in elementary pp collisions



Breit-Wigner-fit:
m = 1517.1 ± 1.5 MeV/c^2
Γ = 15.4 ± 3.8 MeV/c^2
Particle Data Group:
1519.5 ± 1.0 MeV/c^2
15.6 ± 1.0 MeV/c^2

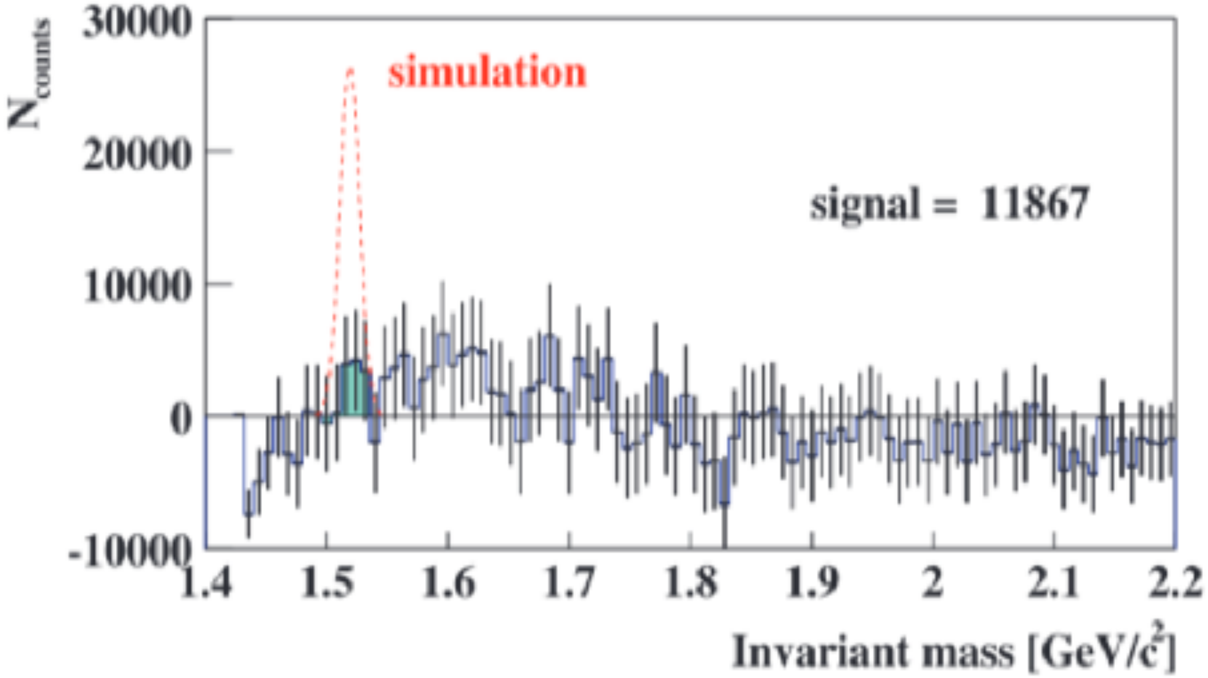


R.E. Ansorge et al., Phys. Rev. D10 (1974) 32
V.R. Krastev et al., Preprint JINR, Dubna (1988)
M. Aguilar-Benitez et al., Z. Phys. C50 (1991) 405
G.J. Bobbink et al., Nucl. Phys. B217 (1983) 11

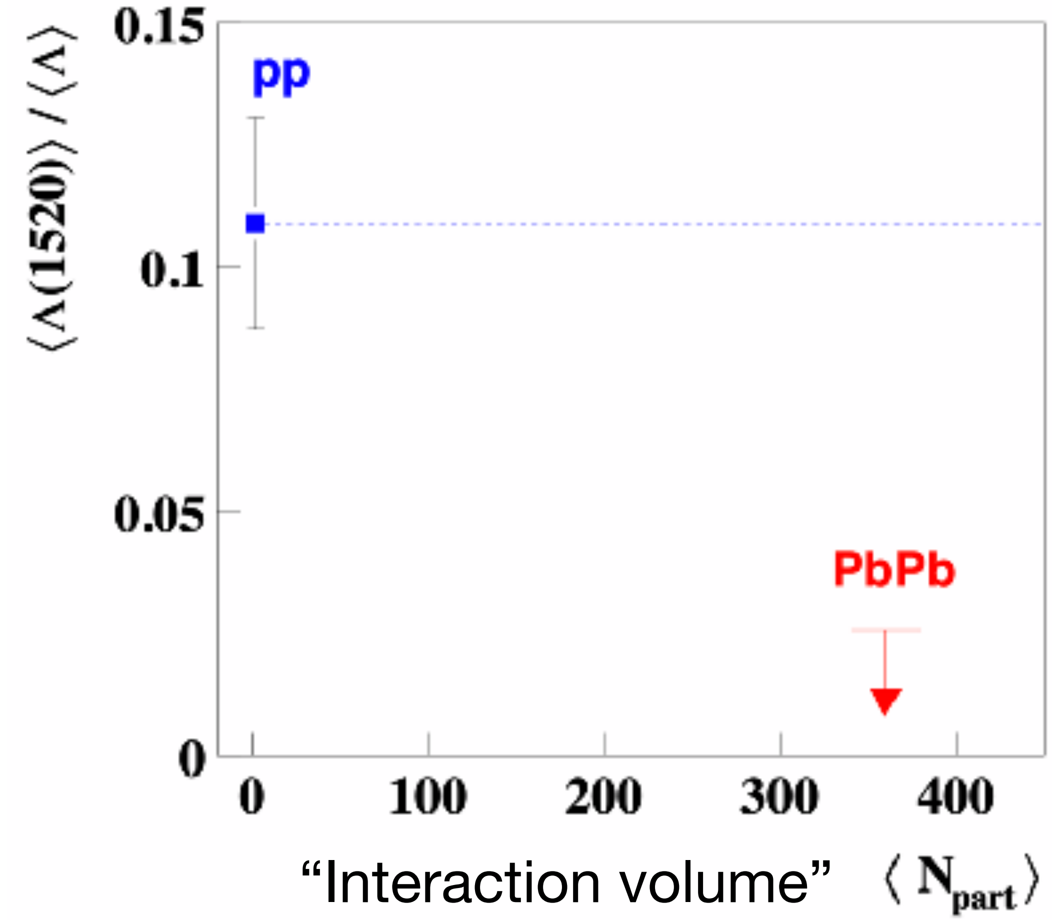
All looks good!
Reconstruction of Λ(1520) is in agreement with PDG and yield fits into trend of previously measured data

Search for the Λ(1520) in Pb-Pb

Missing Λ(1520) signal —> Upper Limit for yield



SQM2000 Berkeley: R. Barton et. all. (CM) J. Phys. G 27 (2001) 367–374



My first problem signal is not present and upper limit lower than expected (Λ(1520)/Λ scaled from pp)

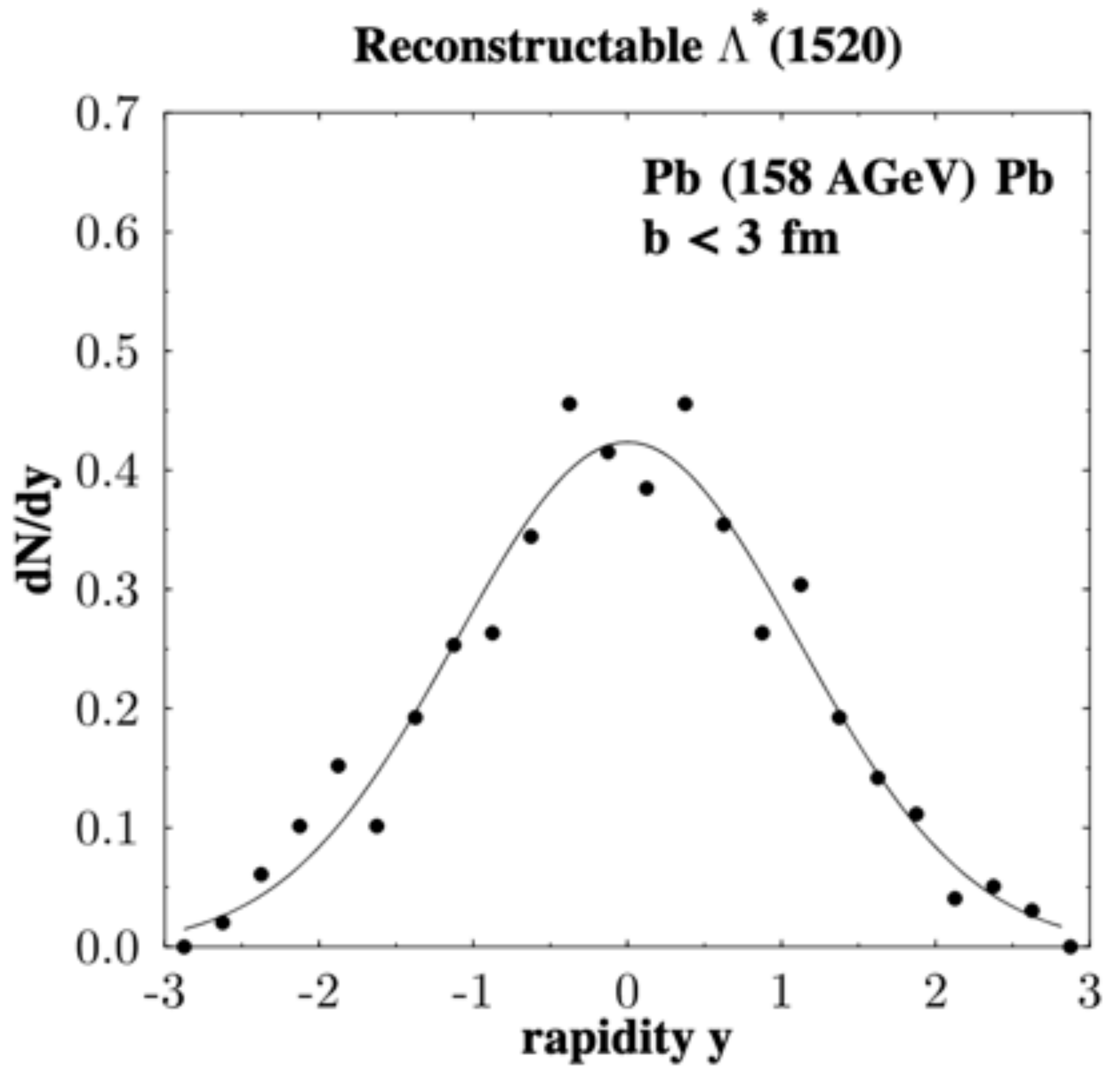
—> Problem with analysis? (many checks has been done)

—> Thinking about the reason of signal suppression/loss —> Talk to theorists UrQMD (Frankfurt) (S. Soff and M. Bleicher)

Remark: I was able to ask the theorists questions without feeling bad about myself.

—> Normal respect (human) for each other, being positive, working together is very important

UrQMD - Hadronic Interactions



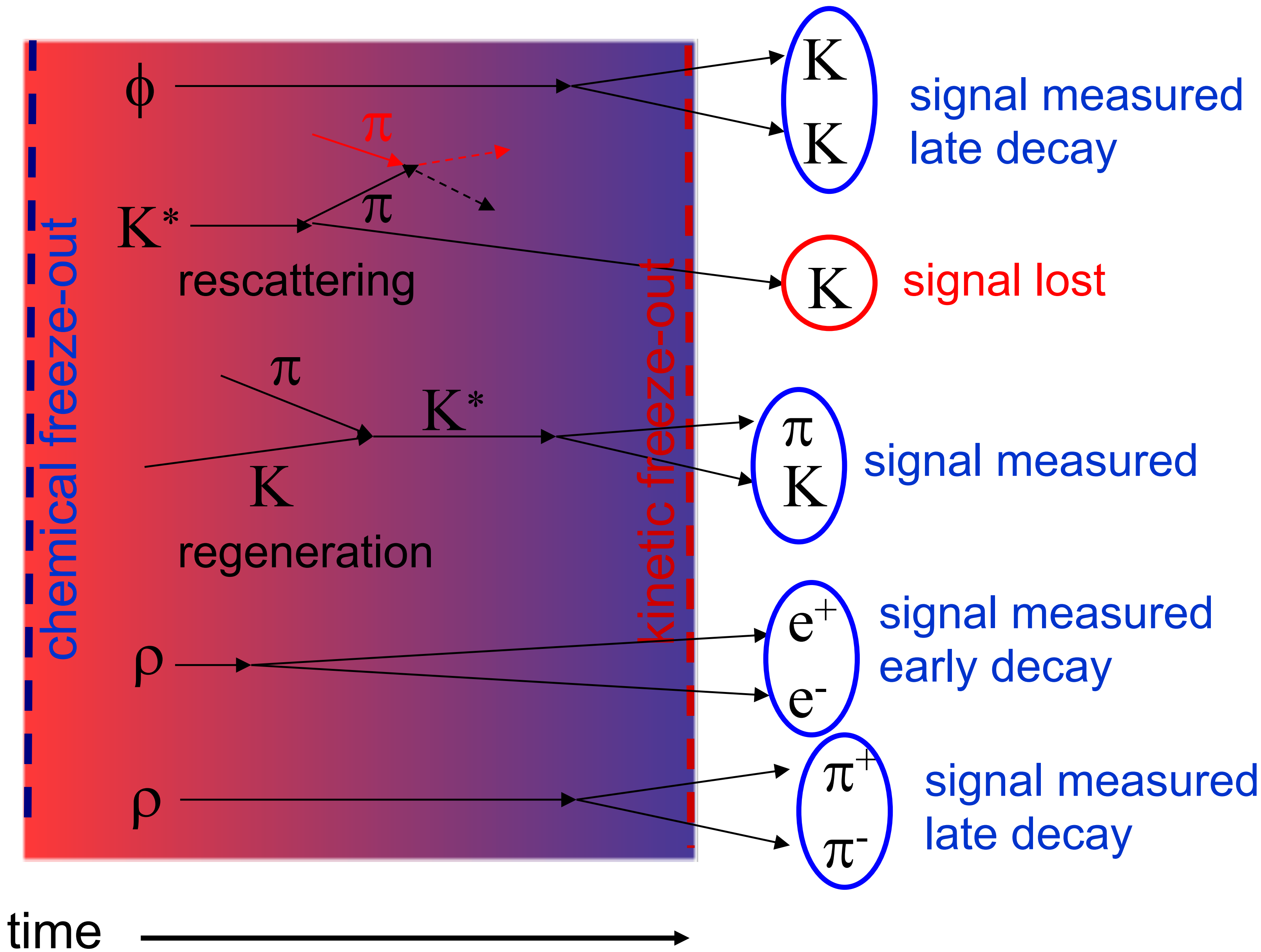
SQM2000:
S. Soff, D. Zschiesche, M. Bleicher, C. Hartnack, M. Belkacem, L. Bravina, E. Zabrodin, S. A. Bass, H. Stoecker, and W. Greiner
J. Phys. G 27 (2001) 449–458

UrQMD is a microscopic model

Figure 6: Rapidity distribution dN/dy of reconstructable $\Lambda^*(1520)$'s, i.e. $\Lambda^*(1520)$'s whose decay products do not rescatter, in central ($b < 3\,\mathrm{fm}$) Pb(158 AGeV)Pb collisions as predicted by the UrQMD model. The total number of $\Lambda^*(1520)$ decays is about twice the number of reconstructable $\Lambda^*(1520)$'s.

Explanation: Hadronic scattering of resonance decay hadrons causes signal loss of reconstructable resonances in invariant mass spectrum
—> 50% loss of Lambda(1520) signal

Resonance Re-scattering and Regeneration



Life-time [fm/c] :	
ρ	= 1.3
Δ^{++}	= 1.7
K(892)	= 4.0
Σ(1385)	= 5.7
Λ(1520)	= 13
φ (1020)	= 45

New Data: Found Λ(1520) signal (better PID)

490c *V. Friese / Nuclear Physics A698 (2002) 487c–490c*

QM2001 - Poster CM
Talk V. Friese (proceedings)

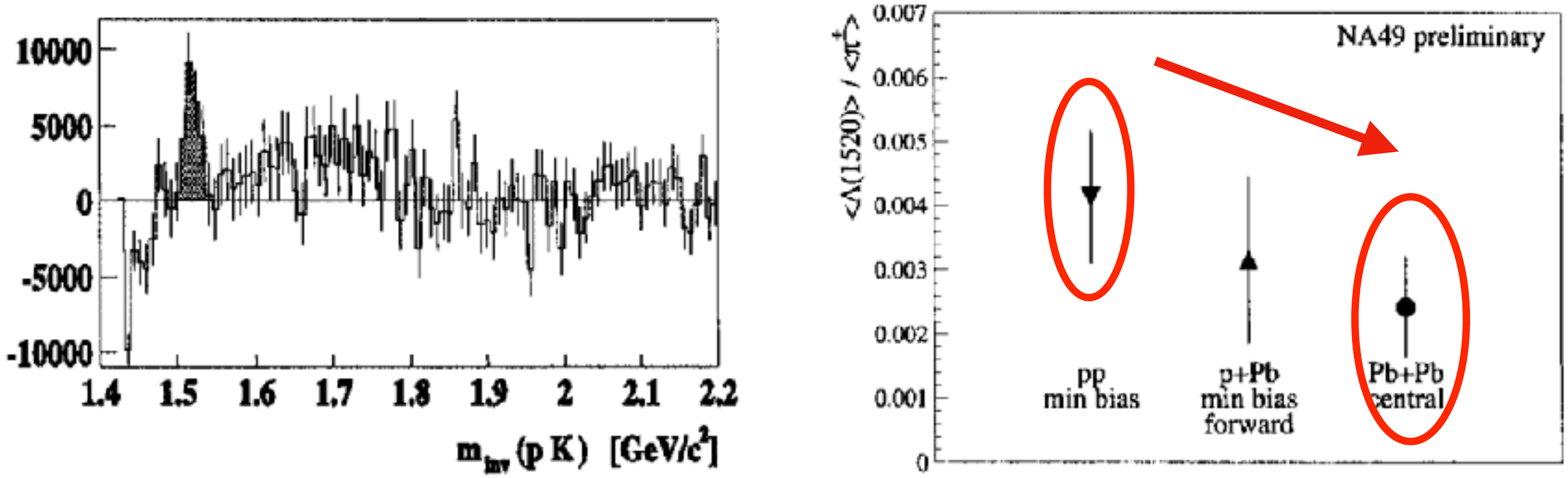
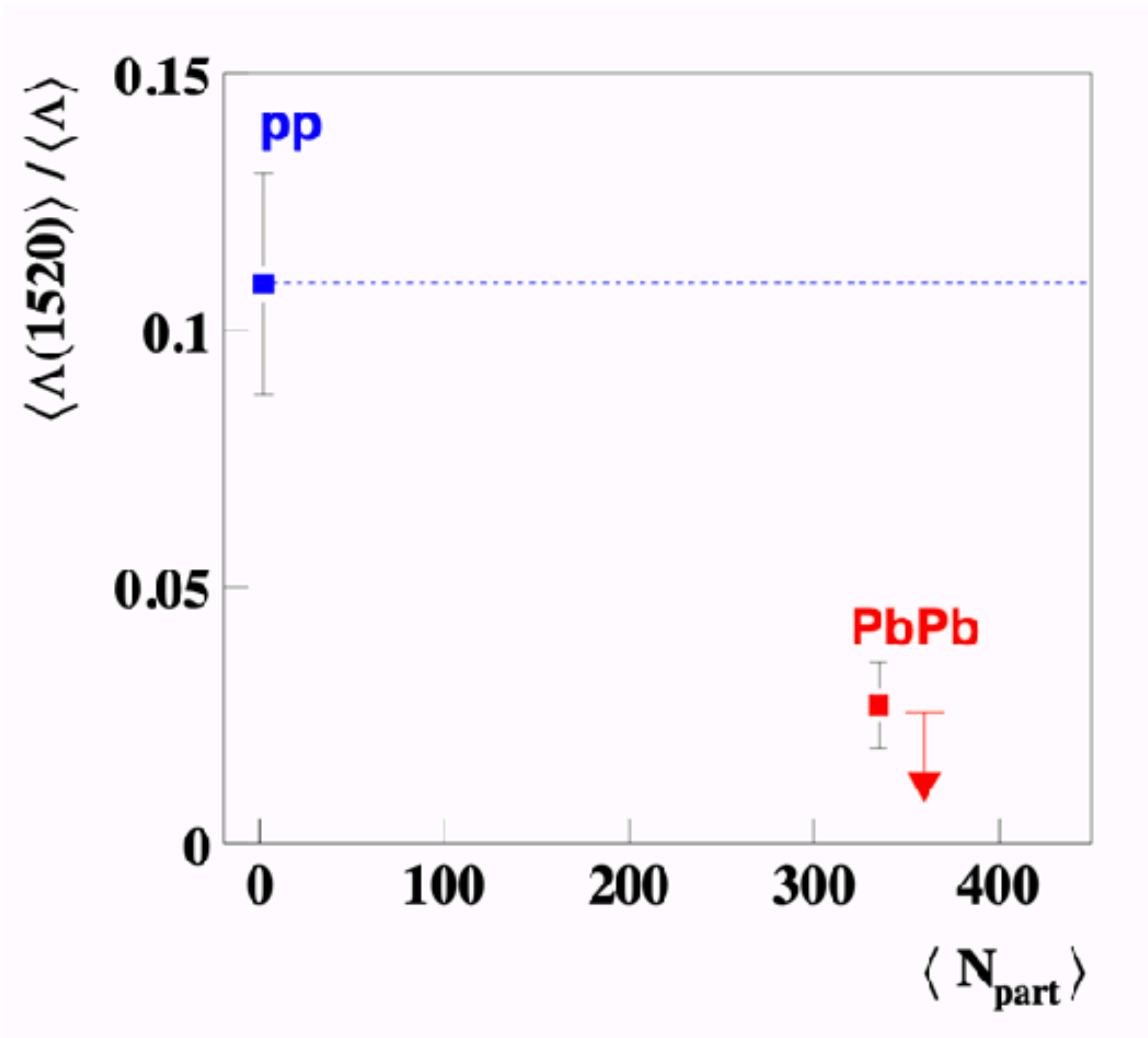


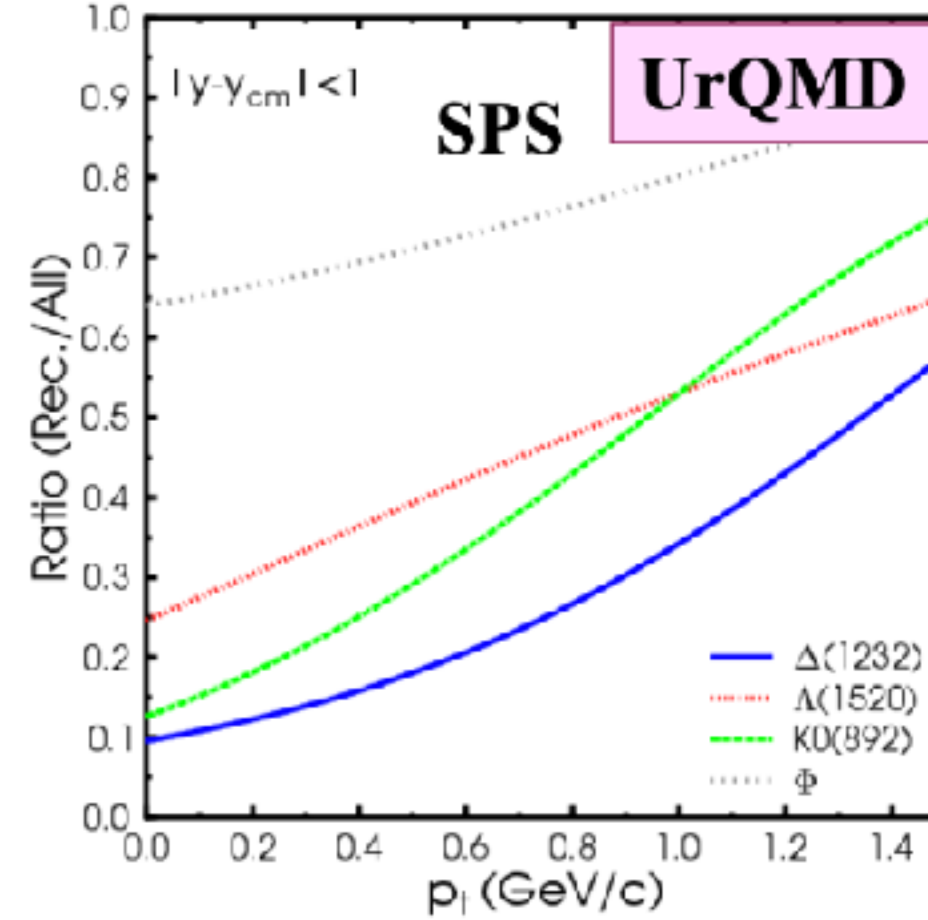
Figure 3. (left) pK^- background subtracted invariant mass spectrum in central Pb+Pb; (right) Λ(1520) yield, normalised to the pion yield in p+p, p+Pb and central Pb+Pb

Better detector calibration (PID) in new data set:
I found the Lambda(1520) signal!!!! Juhuuu!!!
—> ~50% loss of signal in invariant mass spectrum (consistent with theory)
Result of many discussions with theorists while having a coffee together and brainstorming ideas!

Λ(1520) results NA49



5-10 fm/c between chemical and thermal freeze out

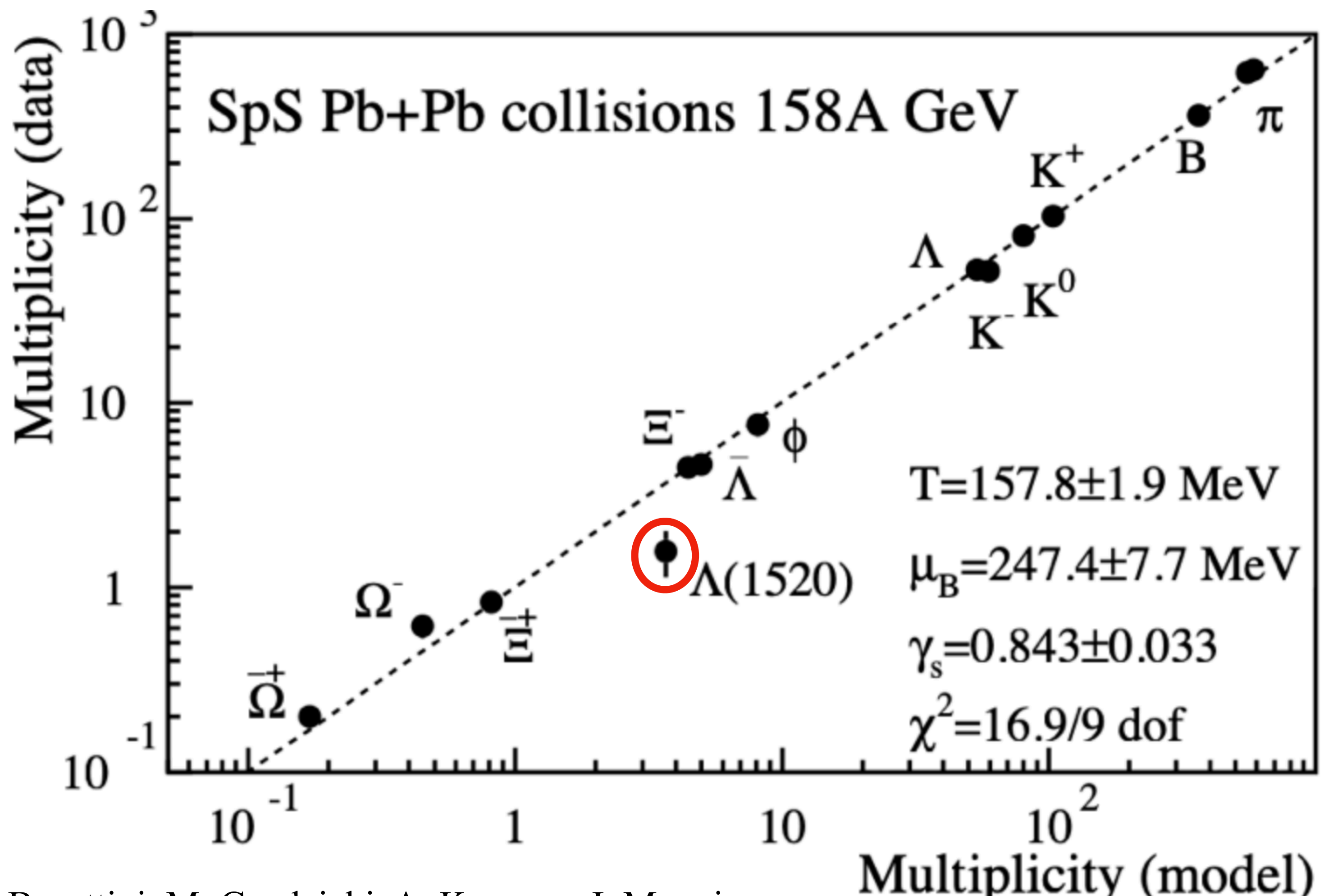


STRANGE RESONANCE PRODUCTION: PROBING CHEMICAL AND THERMAL FREEZEOUT IN RELATIVISTIC HEAVY ION COLLISIONS.
M. Bleicher, J. Aichelin *Phys.Lett.B* 530 (2002) 81-87

Sad part: NA49 results never got published besides the proceedings.
There was still some doubt about the results since it did not show expected yield as predicted by a statistical model

Λ(1520) yield in Pb-Pb lower than expected

Doesn’t fit statistical model prediction



Becattini, M. Gazdzicki, A. Keranen, J. Manninen, R. Stock, Phys.Rev.C 69 (2004) 024905

Unexpected findings:
Yield is lower than statistical model
emotional crisis: -
—> “There is a problem in your analysis”
My results never got published in
NA49 experimental paper
—> data point only in thermal model publication
(Becattini et al. Phys Rev C69 (2004) 024905

Remarks: Takeaway: If results don’t show expected values just continue investigating the system in all directions. You will always learn something.
It is hard to believe in yourself if you are a young scientist.

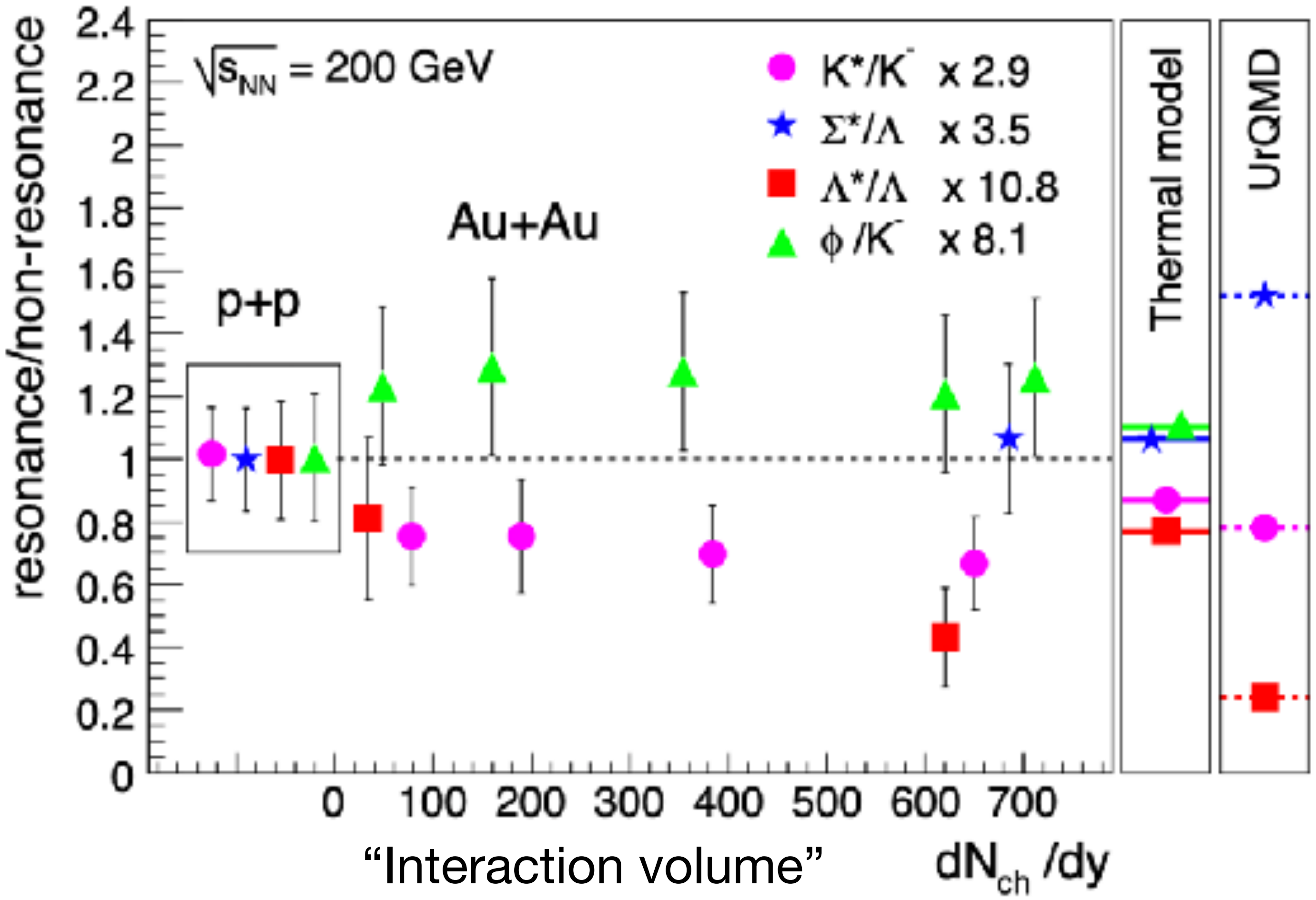
RHIC

-> higher collision energy (Au+Au 200 GeV)

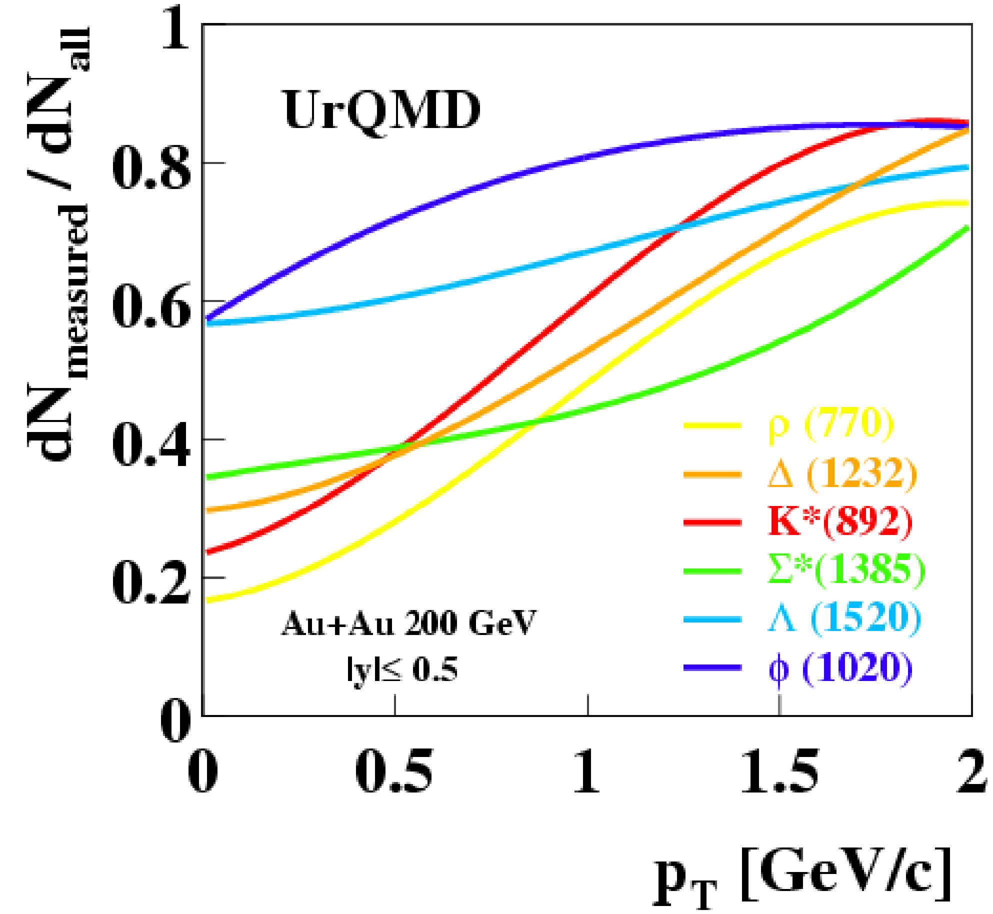
Question: Do we see same suppression?

Measure more Resonances

RHIC STAR Resonances



STAR Collaboration B.I. Abelev et al. (CM, S.Salur) *Phys. Rev. Lett*. 97 (2006) 132301



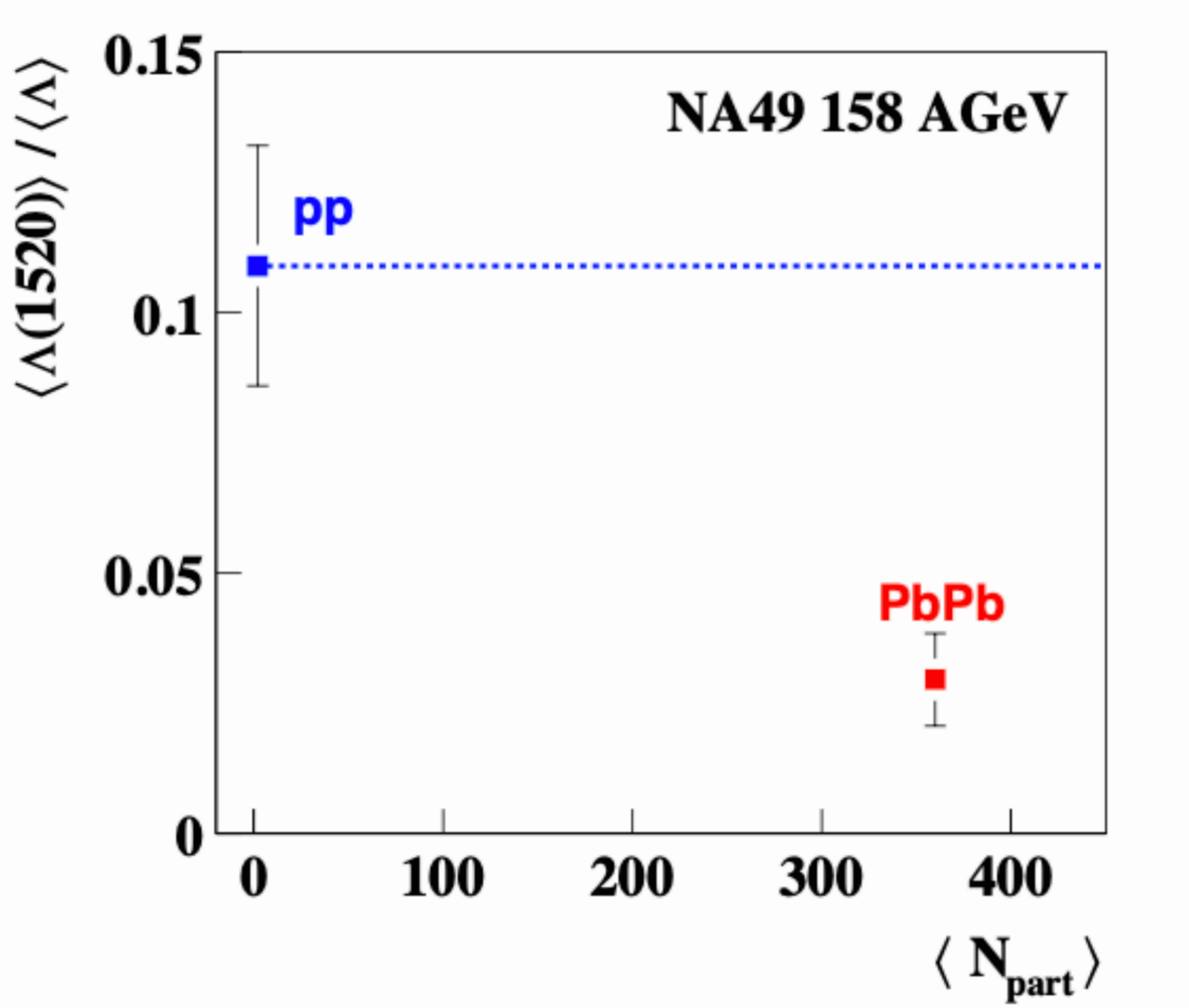
M. Bleicher and J. Aichelin Phys. Lett. B530 (2002) 81-87.

- **Hadronic Phase Matters! (Publication in PRL)**
- **UrQMD includes re-scattering and regeneration of Resonances**
  Largest signal loss due to re-scattering in low pT region
- **Hadronic Phase can change single particles spectra and correlations, leptonic decay**

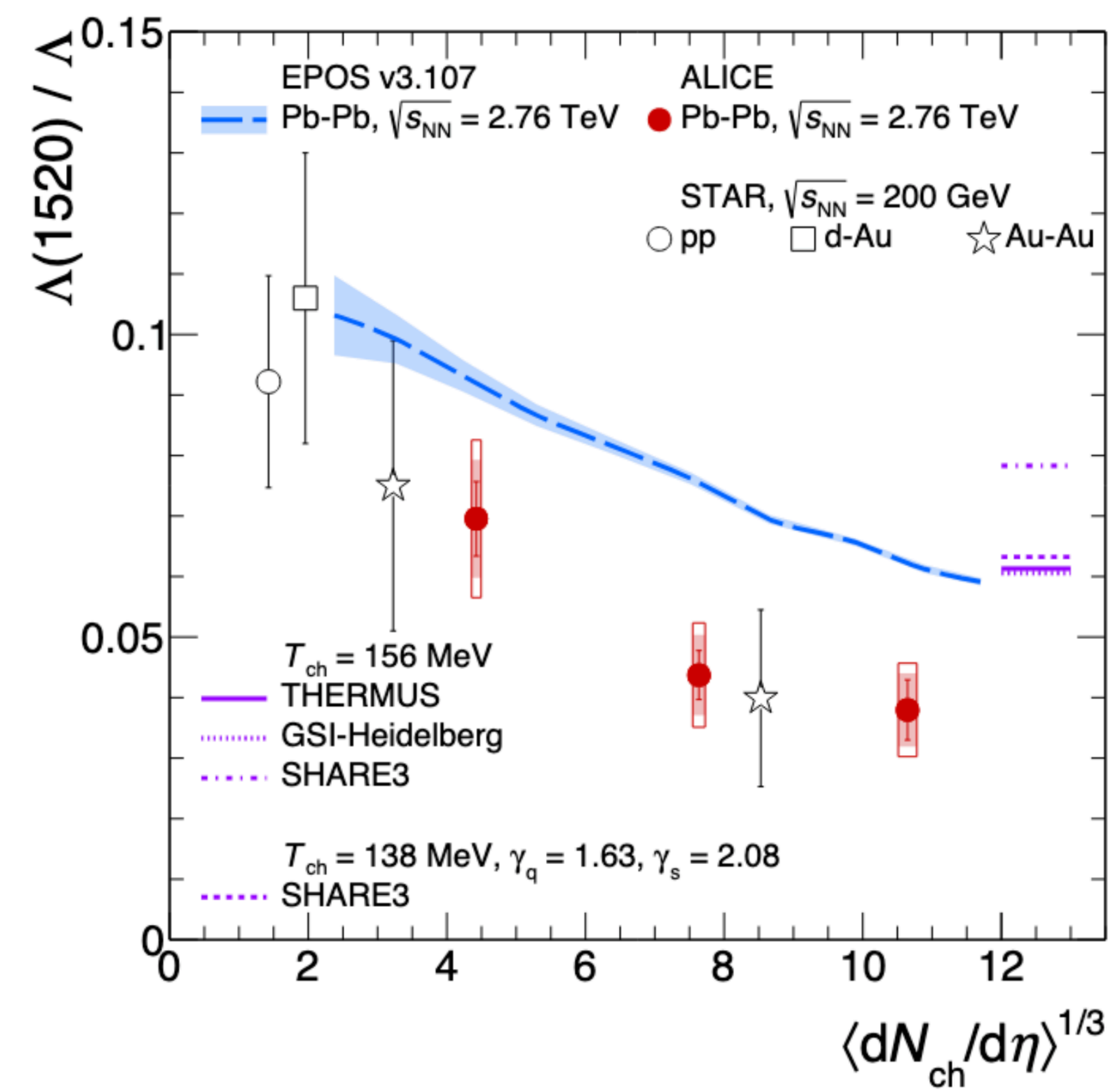
LHC - ALICE
Even higher energy (Pb+Pb 2.76 TeV)

Lambda(1520)

SPS

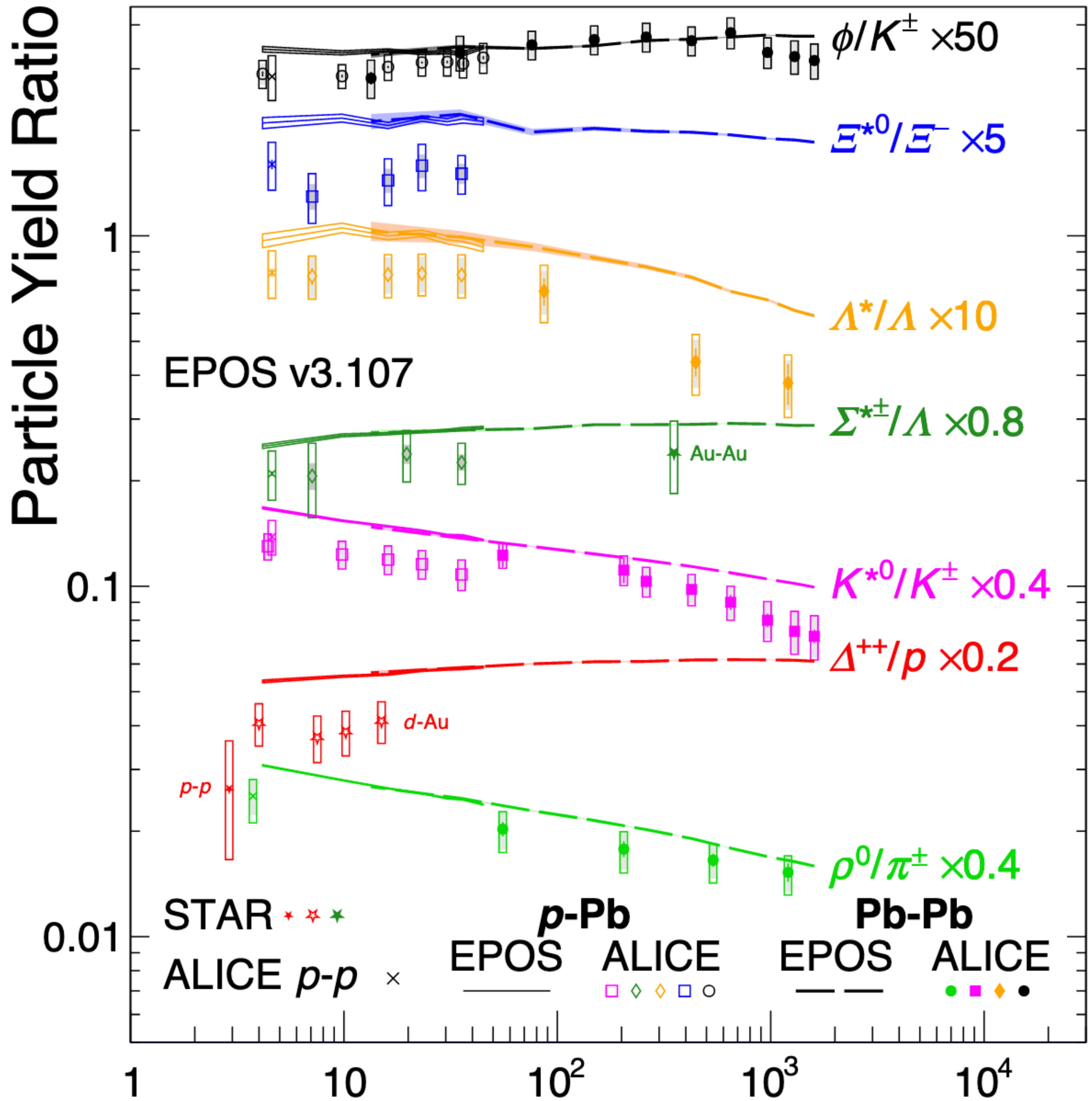


RHIC and LHC



- **Same suppression with increasing interaction volume at all energies**
- **Lifetime and expansion velocity is different**

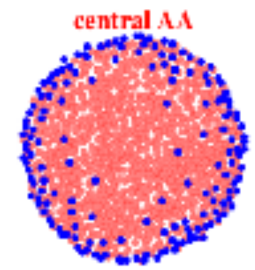
ALICE - Resonances and EPOS(+UrQMD) Model



A.G. Knospe, C. Markert, K. Werner, J. Steinheimer, M. Bleicher, *Phys.Rev.C* 93 (2016) 1, 014911, Phys. Rev. C 104 (2021) 054907

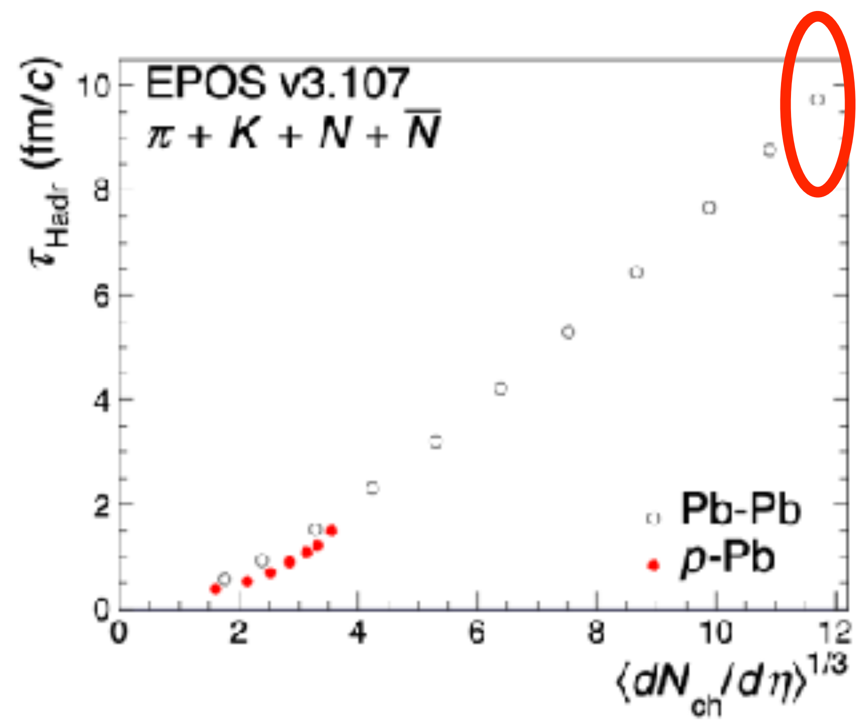
EPOS - Model

(Werner, Guiot, Pierog, Karpenko, Nucl.Phys.A931(2014)83)



Core (red)
= partons with multiple interactions
—> hydro —> statistical decay
—> MEDIUM

Corona (blue)
= partons with no interactions
—> string decay
—> VACUUM



Good understanding of hadronic interactions throughout the evolution of the collisions from small to large system size (central Pb-Pb: hadronic lifetime ~ 10 fm/c)

Thinking about Alternative explanations

PYTHIA with color reconnection

Describing resonance suppression in small systems (p+p) via color reconnection mechanism which breaks up larger strings more often —> more low mass hadrons are produced

R. Acconcia, D.D. Chinellato, R. Derradi de Souza, J. Takahashi, G. Torrieri, C. Markert
"Resonance suppression from color reconnection." Phys.Rev. D97 (2018) no.3, 036010

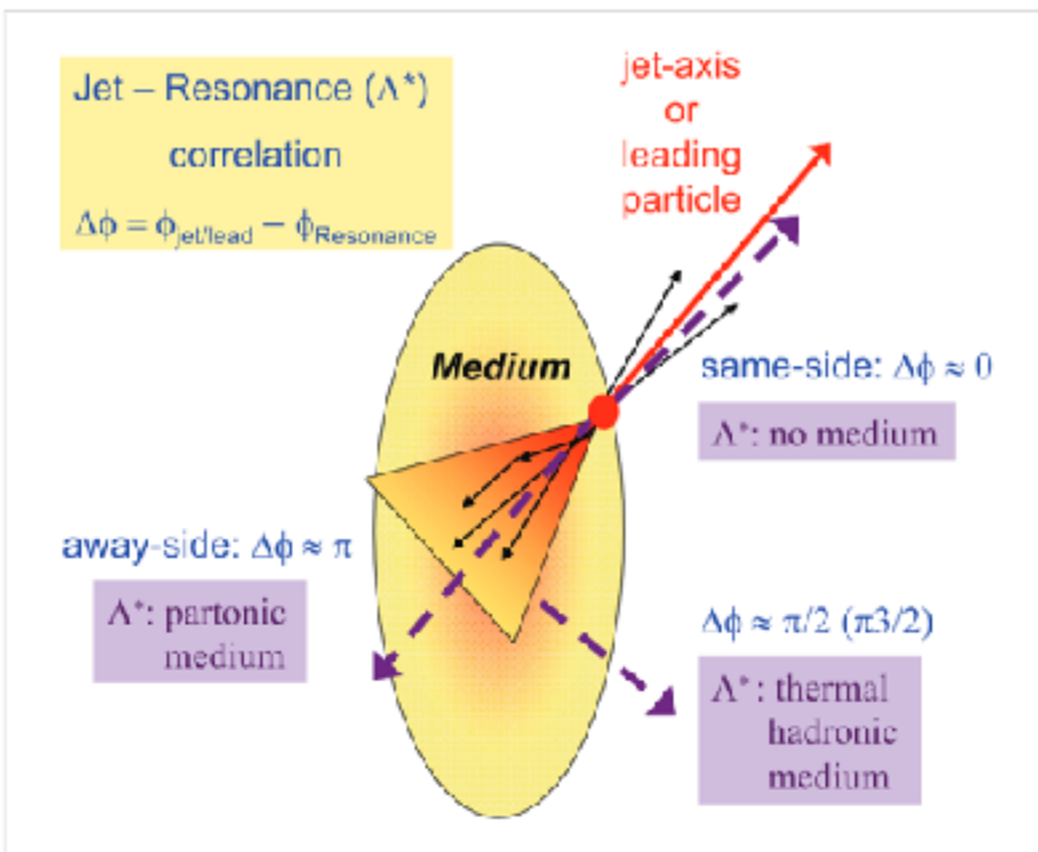
Color reconnection shows smaller resonance/non-resonance ratio,
(but effect is very small)

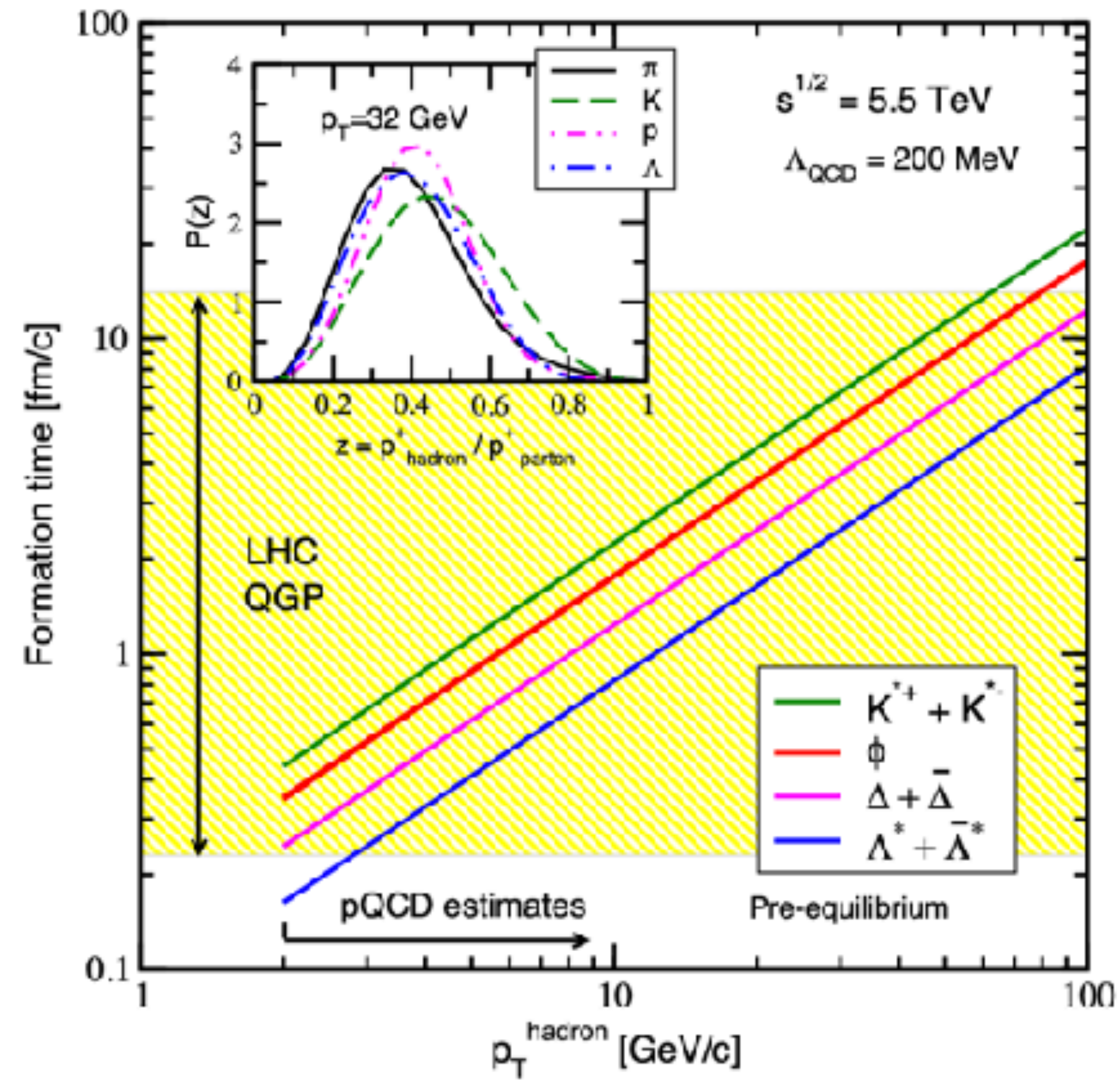
Remarks: Always asking questions
Find alternative explanations

Understanding Medium modifications

Investigate CSR with Resonances from Jets

Select early decaying resonances (formation time)





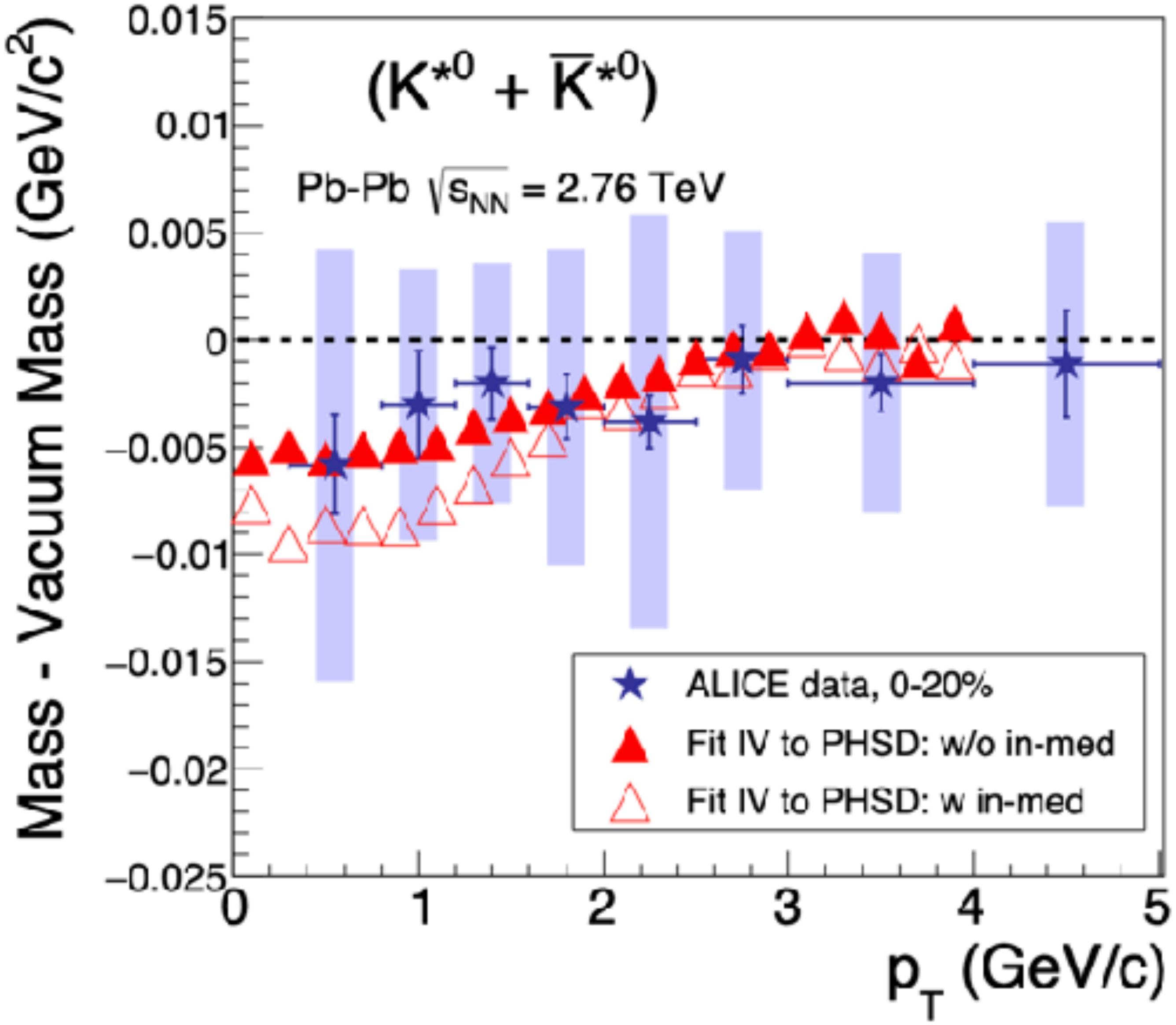
- C. Markert, R. Bellwied, I. Vitev, “Formation and decay of hadronic resonances in the QGP”
- Phys.Lett.B 669 (2008) 92-97, 0807.1509 [nucl-th]

New idea of measuring resonances in jets:
Not useful for CSR because of large background
but useful to study strangeness enhancement in jets and medium

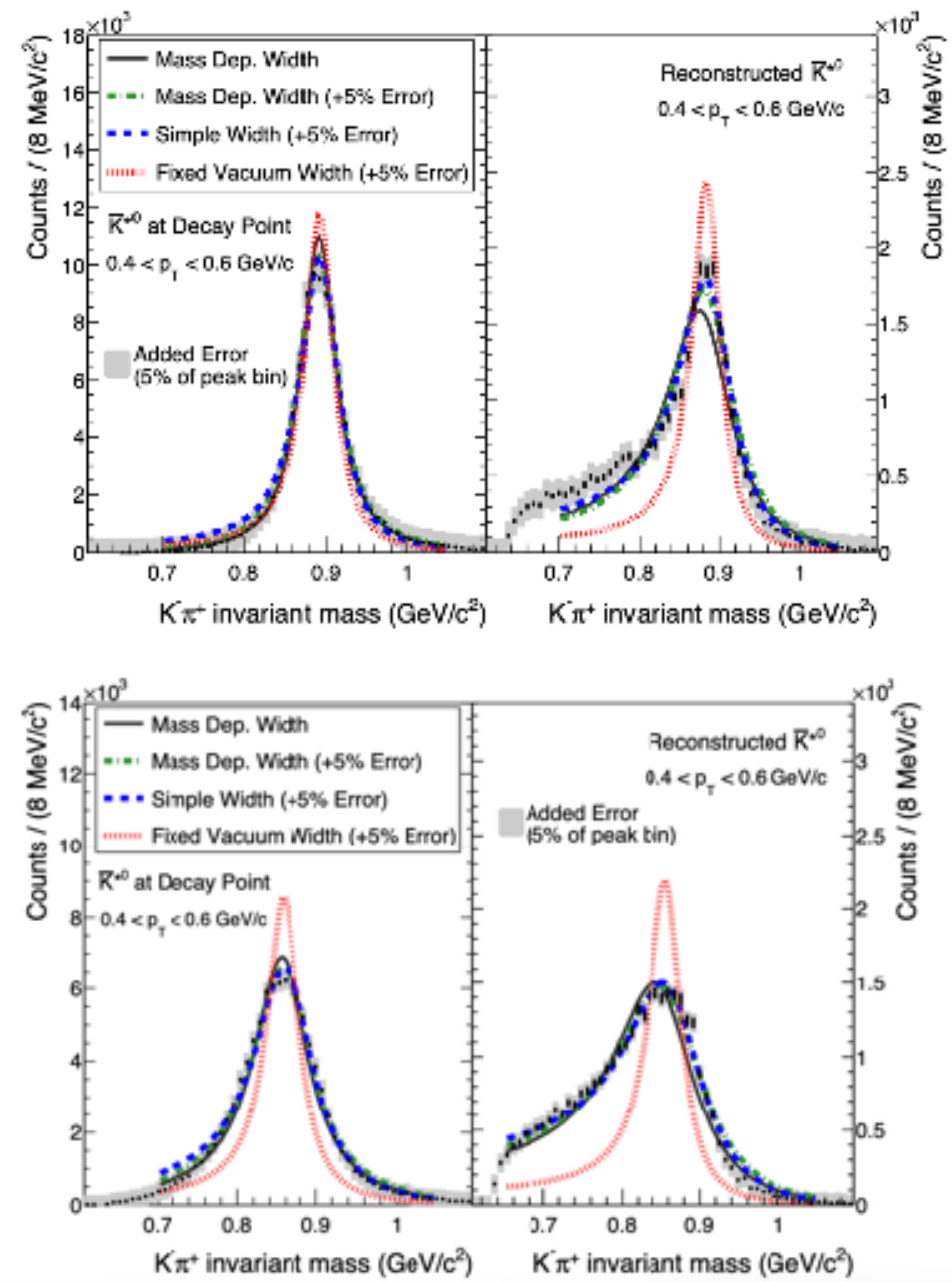
Investigate CSR with PHSD

Parton-Hadron-String Dynamics (*PHSD*) is a microscopic off-shell transport model

- Study chiral symmetry restoration via mass shifts and width broadenings



A. Ilner, J. Blair, D. Cabrera, C. Markert, E. Bratkovskaya,
Phys. Rev. C99 (2019) no.2, 024914.



Observed mass shift (large errors) of K*(892) can be explained by change of spectral function from regenerated resonances in hadronic medium

Remarks

This was a great journey
Trying to find signature of CSR
Found the lifetime of hadronic phase and its impact
I am so thankful for this award
It changed my life and my confidence
believing in myself

Thanks!