LÉVY HBT STATUS AND OTHER PLANS

WITH PHENIX, CMS AND NA61

MÁTÉ CSANÁD @ DAY OF FEMTOSCOPY, NOV 2, 2018

EÖTVÖS UNIVERSITY, BUDAPEST, HUNGARY

NATIONAL RESEARCH, DEVELOPMENT AND INNOVATION OFFICE
HUNGARY

PROGRAM FINANCED FROM THE NRDI FUND

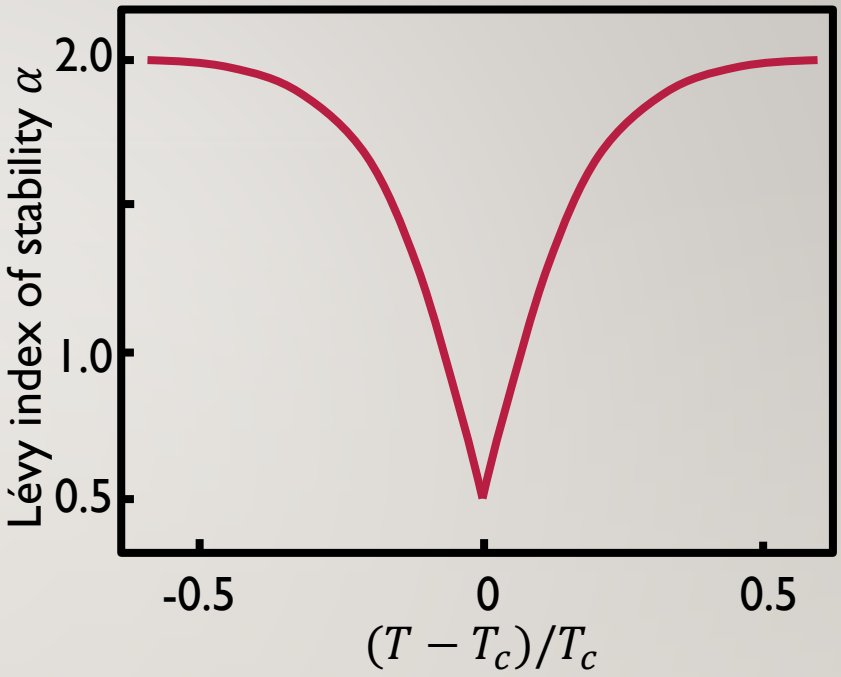
MOMENTUM OF INNOVATION

2/17 LÉVY DISTRIBUTIONS IN HEAVY ION PHYSICS

- Expanding medium, increasing mean free path: anomalous diffusion
  Metzler, Klafter, Physics Reports 339 (2000) 1-77, Csanad, Csörgő, Nagy, Braz.J.Phys. 37 (2007) 1002
- Lévy-stable distribution: $$\mathcal{L}(\alpha, R; r) = \frac{1}{(2\pi)^3} \int d^3q e^{iqr} e^{-\frac{1}{2}|qR|^\alpha}$$
  - Generalized Gaussian from generalized central limit theorem
  - α = 2 Gaussian, α = 1 Cauchy
- Shape of the correlation functions with Levy source:
  $$C_2(q) = 1 + \lambda \cdot e^{-|qR|^\alpha}$$
  $\alpha = 2$: Gaussian
  $\alpha = 1$: Exponential
- Critical behavior → described by critical exponents
- Spatial correlation ~ $r^{(d-2-\eta)}$ → defines critical exponent
- Symmetric stable distributions (Lévy) → spatial corr. ~ $r^{1-\alpha}$
- α alpha can be associated with the critical exponent eta
- Csörgő, Hegyi, Zajc, Eur.Phys.J. C36 (2004) 67, nucl-th/0310042

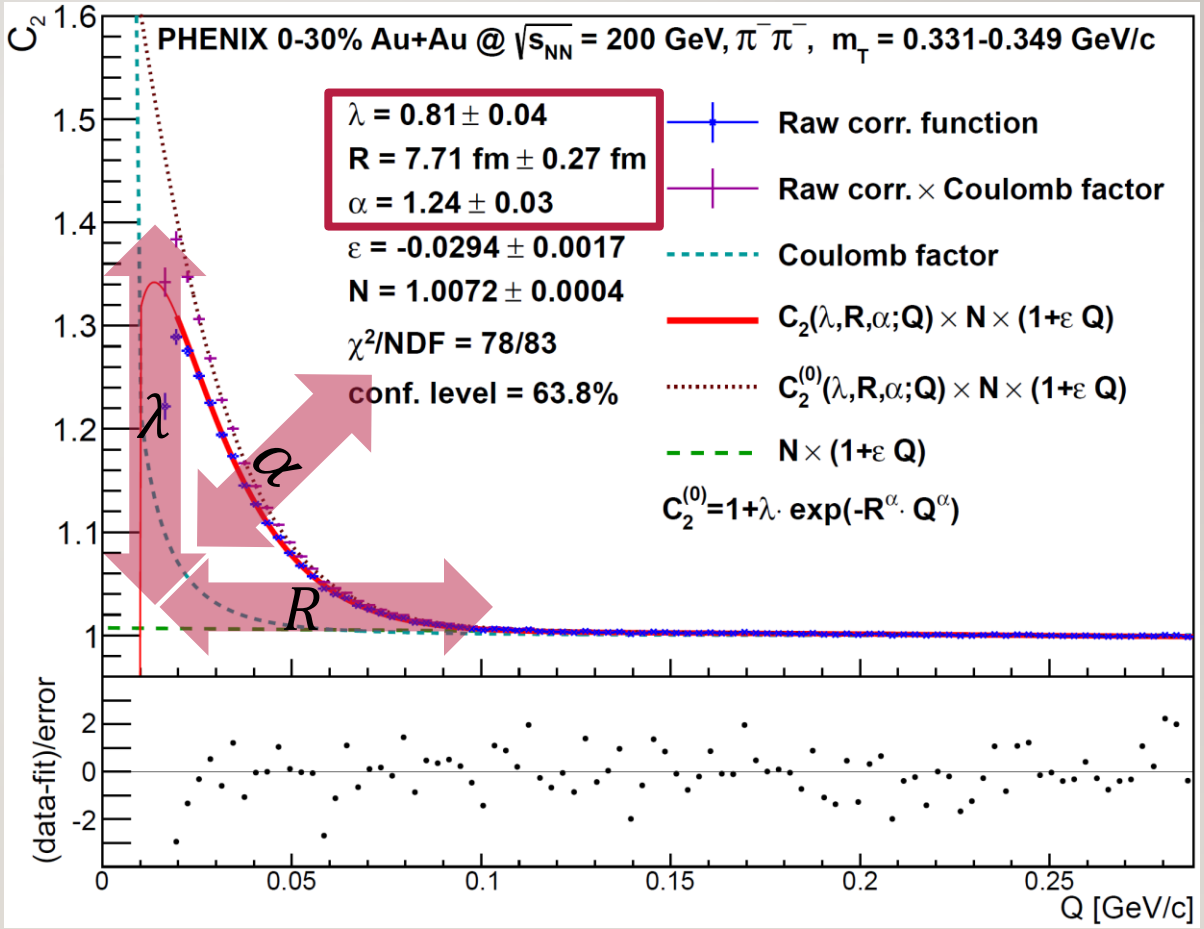
3/17 LÉVY INDEX AS A CRITICAL EXPONENT?

- QCD universality class ↔ 3D Ising
  - Halasz et al., Phys.Rev.D58 (1998) 096007
  - Stephanov et al., Phys.Rev.Lett.81 (1998) 4816
- At the critical point:
  - Random field 3D Ising: η = 0.50±0.05
    Rieger, Phys.Rev.B52 (1995) 6659
  - 3D Ising: η = 0.03631(3)
    El-Showk et al., J.Stat.Phys.157 (4-5): 869
- Modulo finite size effects
- Distance from the critical point?
- Motivation for precise Lévy HBT!
- Change in α_{Levy} proximity of CEP?
- Non-static system, finite size effects may modify all this



EXAMPLE $C_2(Q_{LCMS})$ CORRELATION FUNCTION

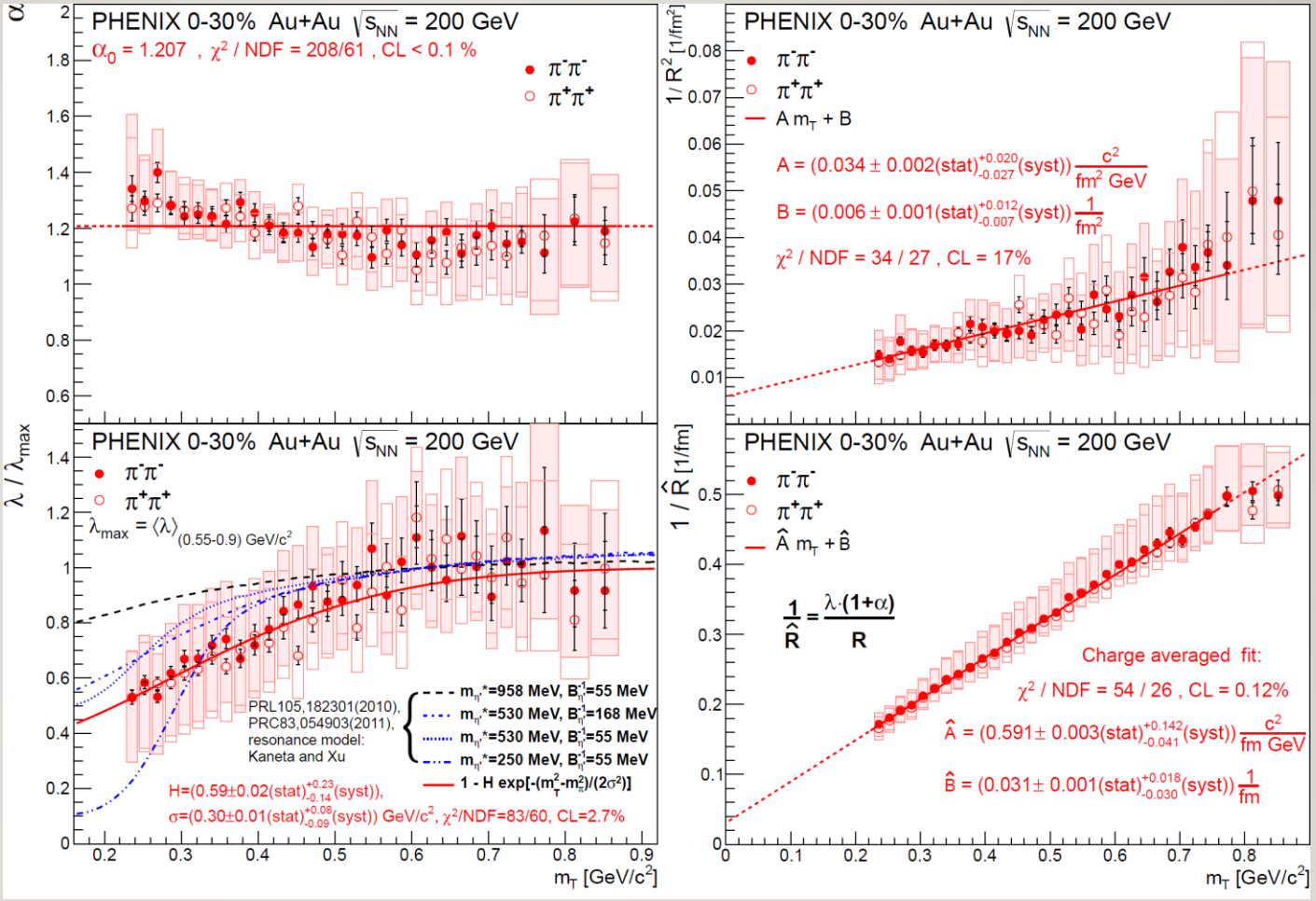
- Measured in 31 m_T bins
- Fitted with Coulomb-incorporated function
- Coulomb-factor displayed separately
- All fits converged
- Confidence levels all acceptable
- χ values scatter around 0 properly
- Physical parameters: R, λ, α measured versus pair m_T



PHENIX, arXiv:1709.05649

5/17 PHYSICAL FIT PARAMETER RESULTS

- α: between 0.5 and 2.0
- R: hydro scaling
- λ: „hole”, compatible with mass modification
- $\hat{R}$: new scaling variable



LÉVY HBT STATUS FROM 39 TO 200 GEV

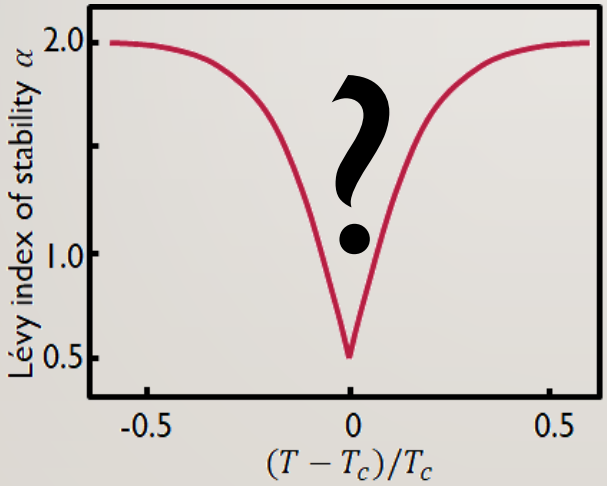
- Bose-Einstein correlation functions measured from 39 to 200 GeV
- Levy fits yield statistically acceptable description
- Fine m_T binned Levy source parameters (R, λ, α)
  - Nearly constant α, away from 2, 1 and 0.5 ↔ distance to CEP?
  - Linear scaling of $1/R^2$ vs m_T ↔ hydro?
  - Low-m_T decrease in $\lambda(m_T)$ ↔ chiral restoration, in-medium η' mass?
- New, empirically found scaling parameter $\hat{R}=\frac{R}{\lambda\cdot(1+\alpha)}$
- Centrality and collision energy dependence also explored
  - No α decrease down to 39 GeV, non-monotonic α vs N_{part} dependence
  - "Hole" in $\lambda(m_T)$ present down to 39 GeV (c.f. SPS result without hole!)
  - No change in $1/R^2$ and $1/\hat{R}$ scaling with centrality and $\sqrt{s_{NN}}$

OPEN QUESTIONS

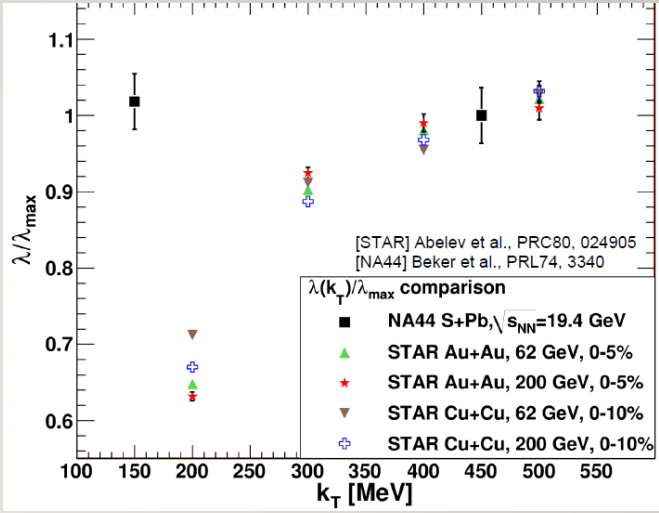
- Collision energy and centrality dependence?
  - Non-monotonicity in $\alpha(\sqrt{s_{NN}})$ or α(centrality)? Hole in $\lambda(m_T)$ at low $\sqrt{s_{NN}}$? Really due to η'?
  - Lower energies (<39 GeV) currently analyzed, filtering η' decay products investigated
- How does the shape look in 3D (out-side-long)?
  - Is the Lévy exponent still around unity?
  - How are the radii modified as compared to Gaussian ones? The $1/R^2 \sim mT$ scaling still valid?
  - $R^2_{\mathrm{out}} - R^2_{\mathrm{side}}$ non-monotonicity modified if R is the Lévy scale?
- What about kaons?
  - What is the Lévy exponent for kaons?
  - Kaons have smaller total cross-section thus larger mean free path, heavier tail?
  - Does m_T scaling hold for Lévy scale R?
- Correlation strenght versus core-halo picture: are there other effects?
  - Three-particle correlations may show if coherence or other effects play a role
  - Other effects may also play a role (finite meson sizes, random field phase shift, etc)

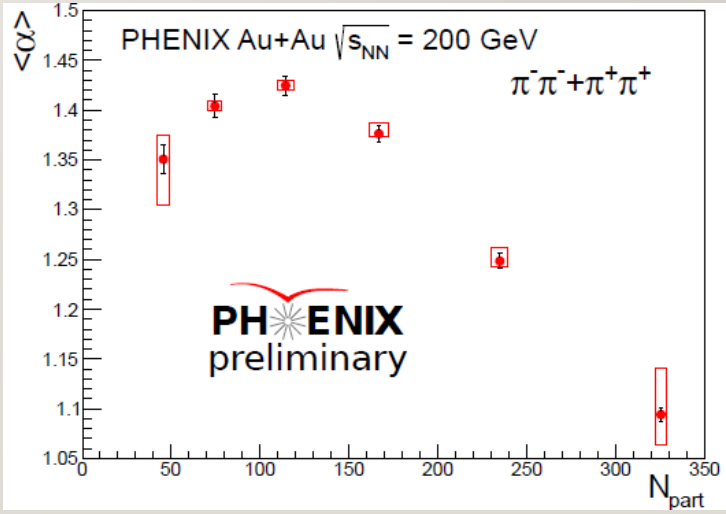
8/17 COLL. ENERGY & CENTRALITY DEPENDENCE

- D. Kincses, S. Lökös (supervisors: M. Cs. + T. Cs.)
- Hole in $\lambda(m_T)$ at lower energies?
  - Filtering of η' decay products to be investigated, based on Eur. Phys. J. A (2011) 47: 76
- Non-monotonicity in α vs centrality or s_{NN}?



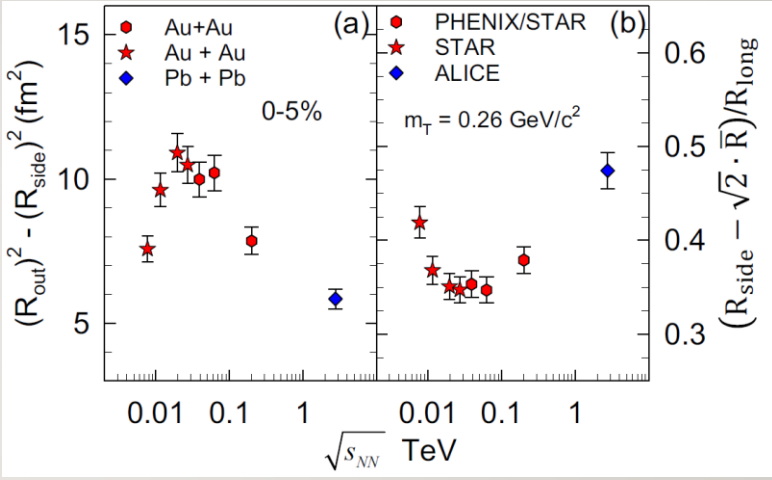
- New prelim. (15-27 GeV) and PPG(s) by mid 2018

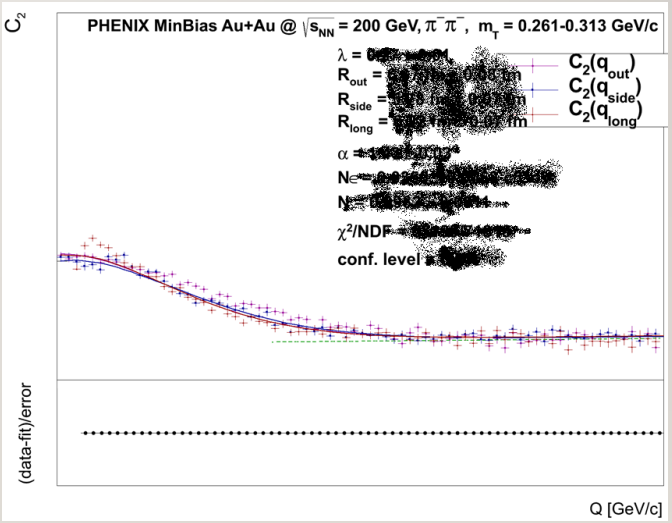




9/17 3D ANALYSIS

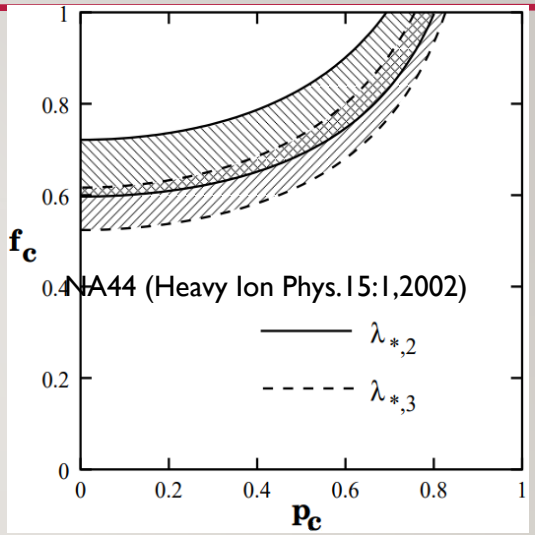
- B. Kurgyis (supervisor: M. Cs. and D. K.)
- Lévy radii at 200 GeV:
  - $R_{\mathrm{out}} \approx R_{\mathrm{side}}$ still true for Lévy scales?
  - $1/R^2 \sim m_T$ scaling still true?
- How do Lévy radii change with energy?
  - Non-monotonicity still there in $R_{\mathrm{out}}^2 - R_{\mathrm{side}}^2$?
  - α versus energy in 3D: same as for 1D?
- Analysis started with 200 GeV data
- Many issues still
  - Fits harder to visualize in 3D
  - Coulomb effect complicated in 3D
- Preliminary before QM18

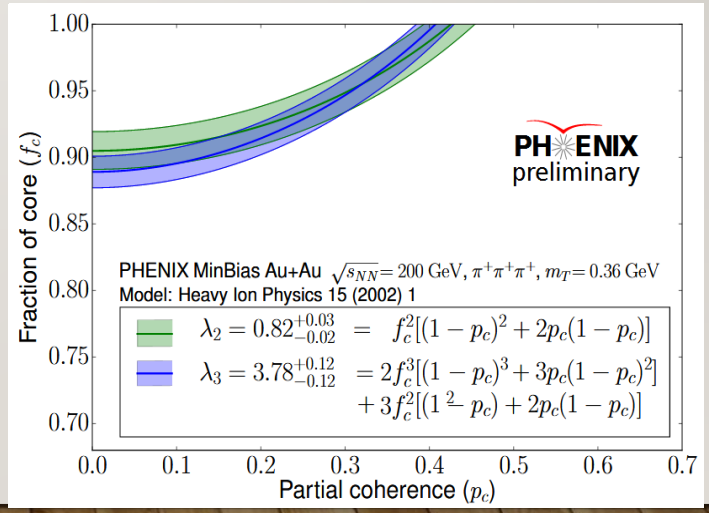




THREE-PION CORRELATIONS

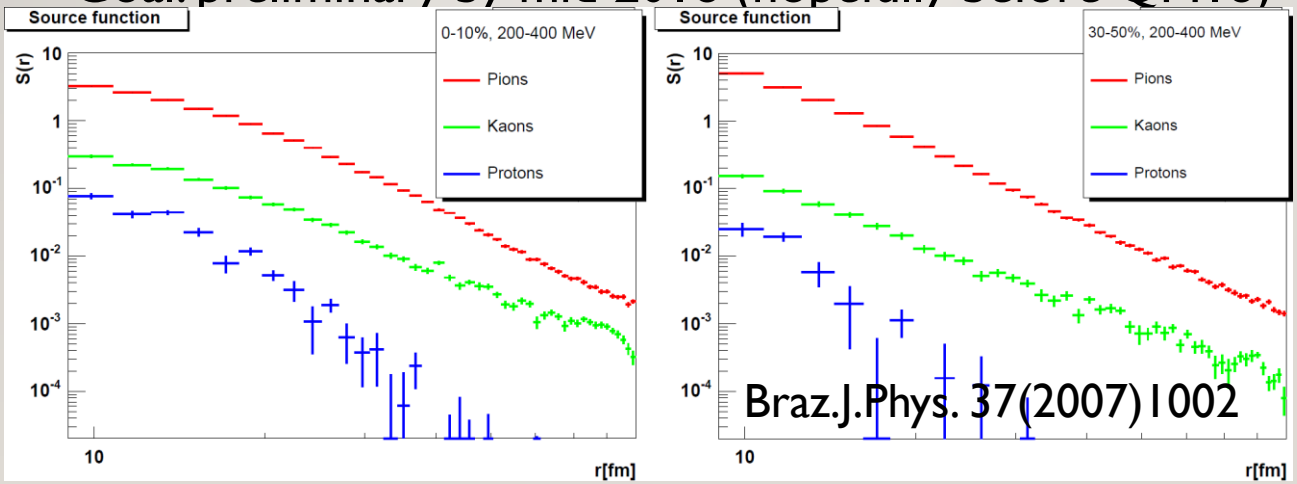
- J. Báskay & A. Bagoly (supervisor: M. Cs.)
- Recall: $\lambda_2 = f_C^2$ only if no other effects!
- E.g. if there is partial coherence (p_C):
  - $\lambda_2 = f_C^2[(1-p_C)^2 + 2p_C(1-p_C)]$
  - $\lambda_3 = 2f_C^3[(1-p_C)^3 + 3p_C(1-p_C)^2] + 3f_C^2[(1-p_C)^2 + 2p_C(1-p_C)]$
- Coherence effects: centrality dependent!
- Measure in 0-30% and maybe 40-70%?
- Finalize data
- PPG formation by mid 2018



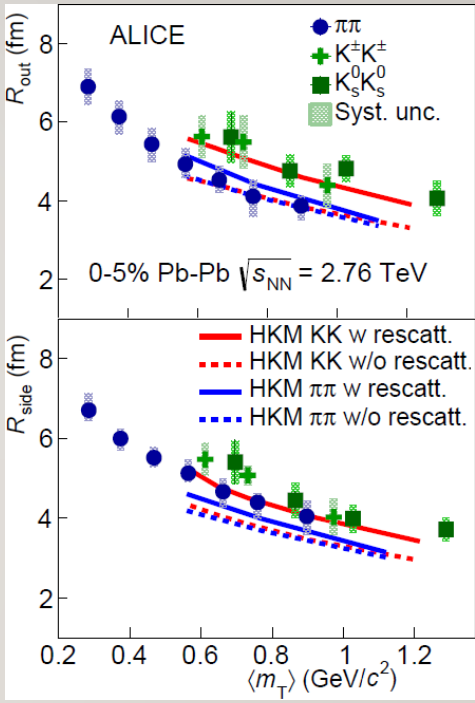


KAON ANALYSIS

- D. Joti (supervisor: M. Nagy and M. Cs.)
- Kaon: PID possible, recalibrators by M. Nagy suitable
- Transverse mass scaling of Lévy HBT radii for kaons?
- HRC prediction for kaons:
  - Smaller cross-section, larger mean free path, heavier tail
- Goal: preliminary by mid 2018 (hopefully before QM18)



Braz.J.Phys. 37(2007)1002

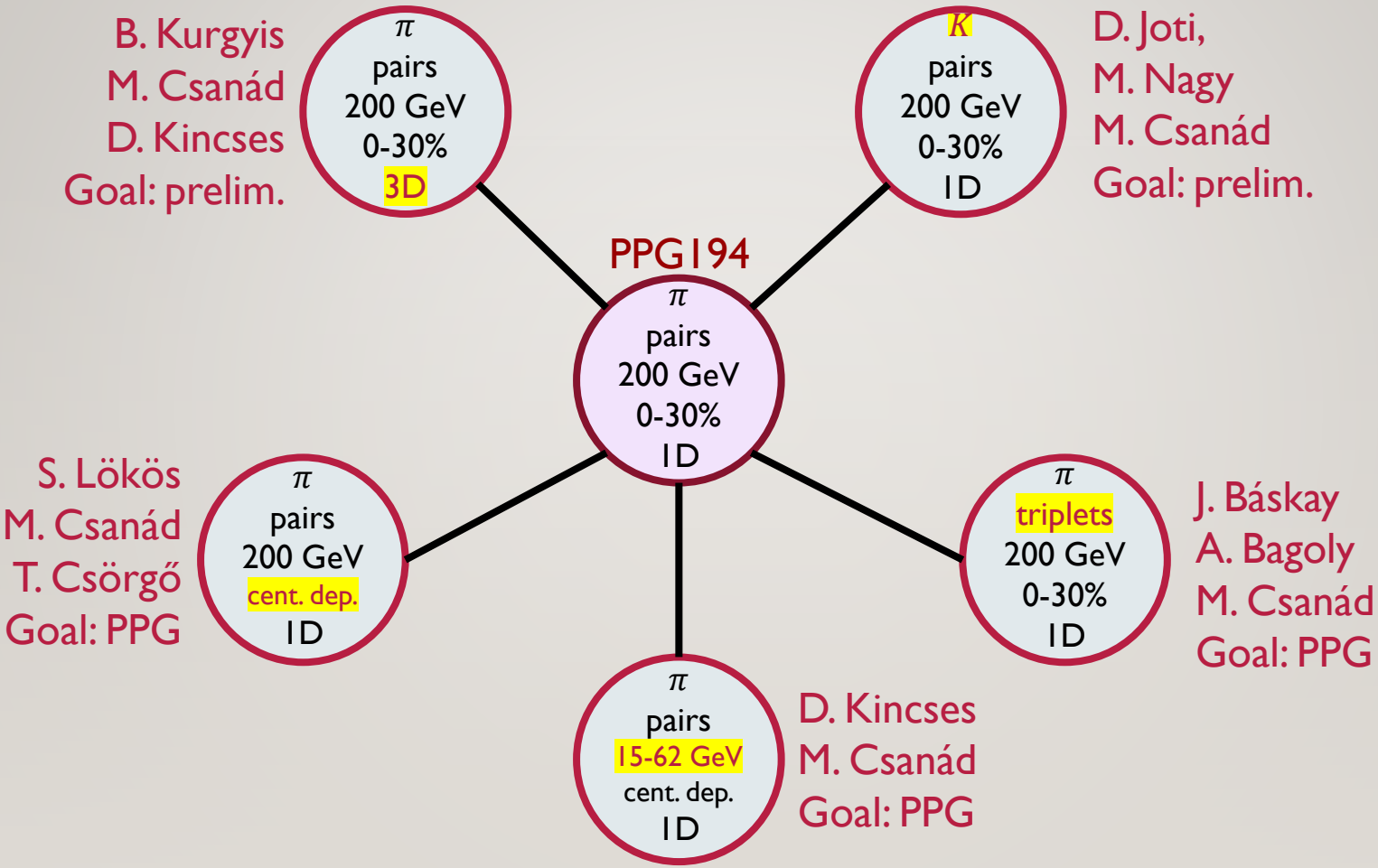


ALICE Coll.
arXiv:1709.01731

PLANNING

- $\sqrt{s_{NN}}$ & centrality dependence: S. Lökös, D. Kincses (M. Cs., T. Csörgő)
  - Preliminary results available for 39-200 GeV, various centralities
  - Goal: preliminary for 15-27 GeV, PPG formation for final analysis (early 2018)
- How does the shape look in 3D: B. Kurgyis (M. Cs., D. Kincses)
  - Analysis started, hope to reach preliminary in early 2018
- Kaon Lévy HBT: D. Joti (M. Nagy, M. Cs.)
  - Analysis started, hope to reach preliminary by mid 2018
- 3pion HBT: core-halo picture and coherence: J. Báskay and A. Bagoly (M. Cs.)
  - Preliminary obtained in early 2017, goal: PPG formation by mid 2018
- Additional phenomenological work needed: refinements for Coulomb
  - Work ongoing by B. Gazdag (not PHENIX-related, supervised by M. Nagy and M. Cs.)

13/17 ONE-PAGE SUMMARY OF PHENIX HBT PLANS



NA61 AND CMS LÉVY HBT PLANS

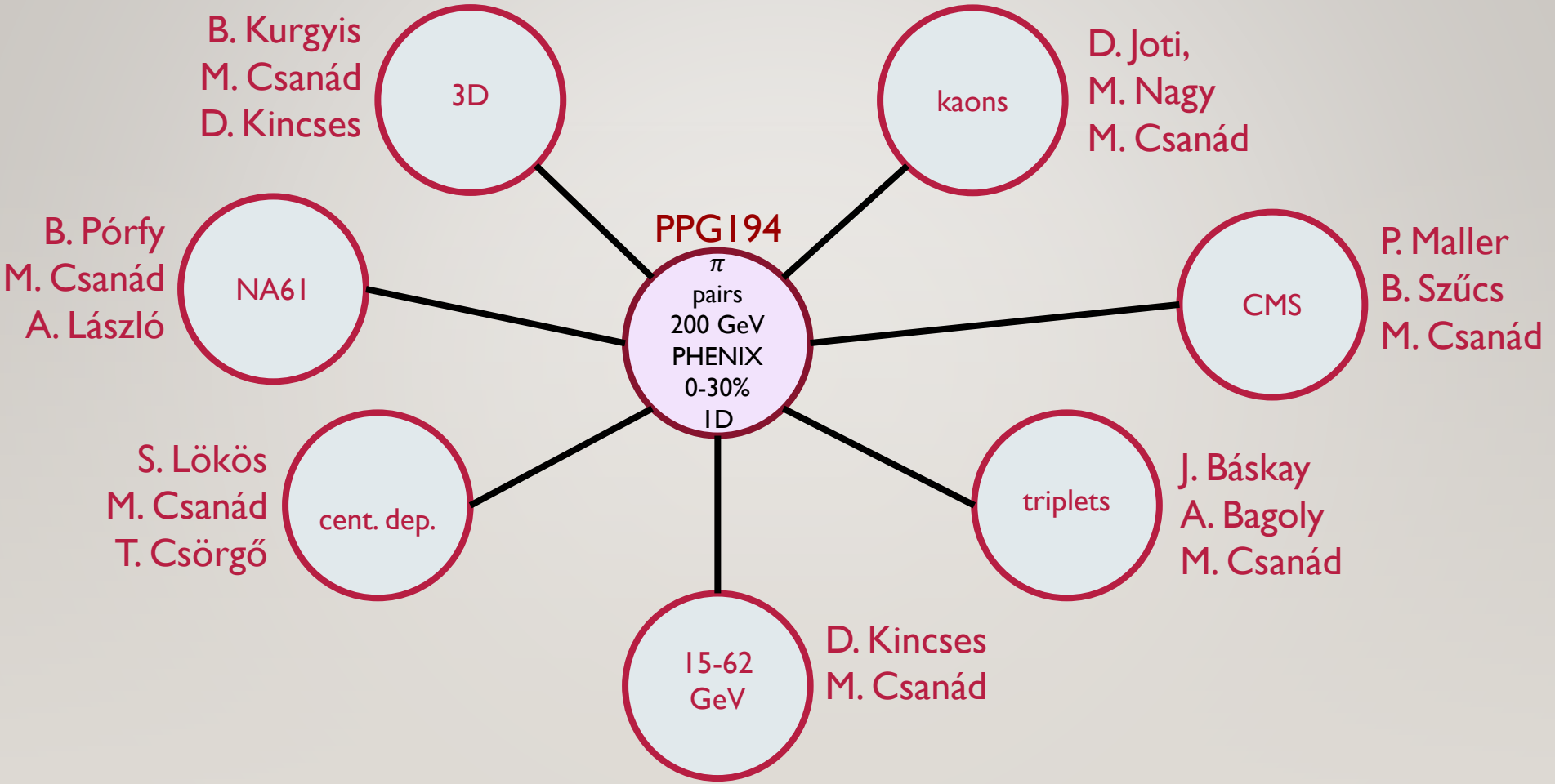
NA61

- First step is 3D Lévy analysis for a well calibrated energy and system
- Main analyzer: B. Pórfy (supervisors: M. Cs. and A. László)

CMS

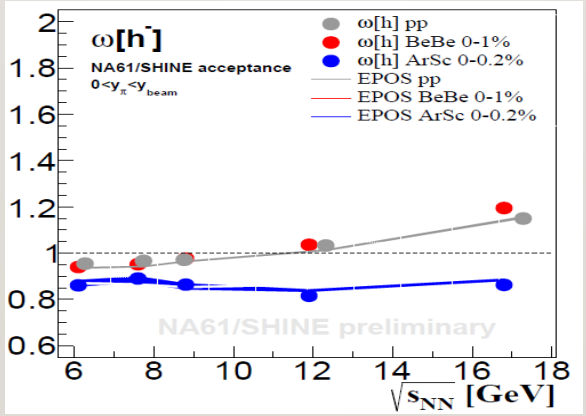
- First step is 1D or 3D Lévy analysis for PbPb
- Two- and three-particle correlations also to be analyzed
- Main analyzers: B. Szűcs and P. Maller (supervisor: M. Cs. and ???)
- Proton-proton analysis by Sandra Padula: under finalization, no real Lévy or dip analysis

15/17 SUMMARY OF SPS-RHIC-LHC HBT PLANS



OTHER NA61 RESULTS (FOR THE FK GRANT)

- FTPC system operational (pA spectra for NA61 neutrino analysis)
- 17.3 GeV pp and pPb analysis ongoing
  - Centrality dependent midrapidity p_T spectra
  - Model independent R_{AA} analysis performed
  - Main analyzer: K. Márton (PhD topic, superv.: A. L.)
- Xe+La energy scan data taking underway
  - Large signal expected if there is a critical point
  - Scaled variance ω
  - No anomaly so far



NATIONAL RESEARCH, DEVELOPMENT AND INNOVATION OFFICE
HUNGARY

PROGRAM FINANCED FROM THE NRDI FUND
MOMENTUM OF INNOVATION

17

THANK YOU FOR YOUR ATTENTION

If you are interested in these subjects, come to our
Zimányi-COST School 2017
December 4-8., Budapest, Hungary

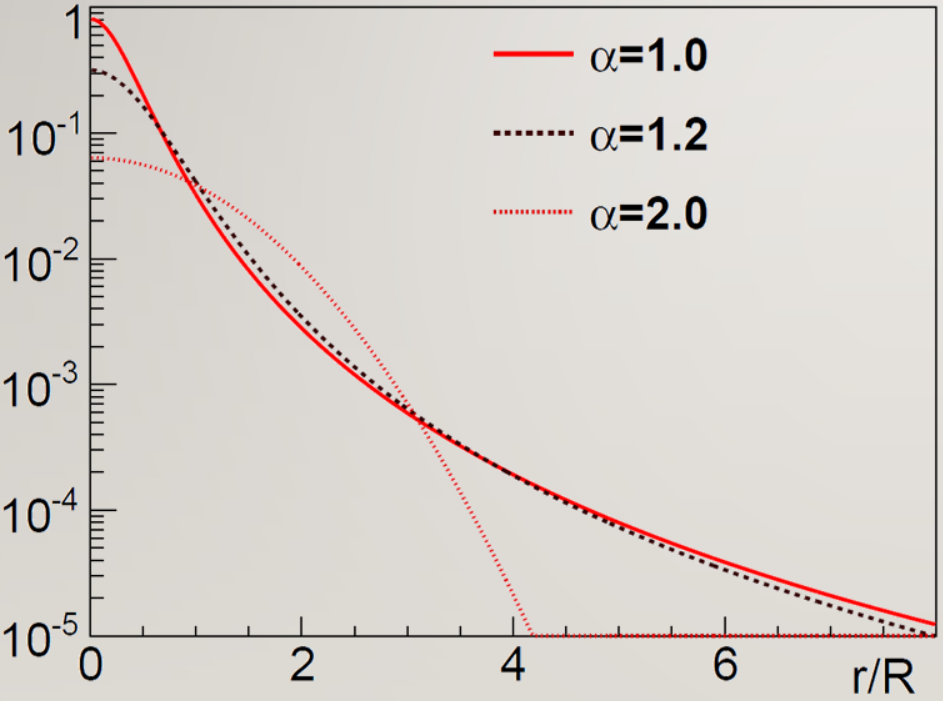
http://zimanyischool.kfki.hu/17

18 BACKUP

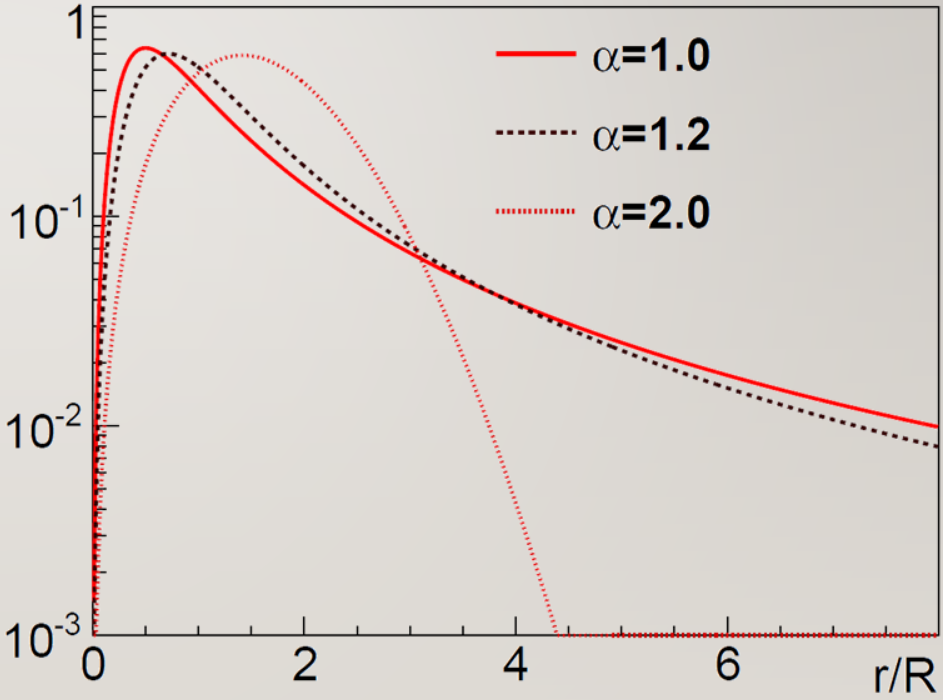
LÉVY VERSUS GAUSS VERSUS EXPONENTIAL

- No tail if $\alpha = 2$, power law if $\alpha < 2$

$R^3 S_{\mathrm{core}}(r)$



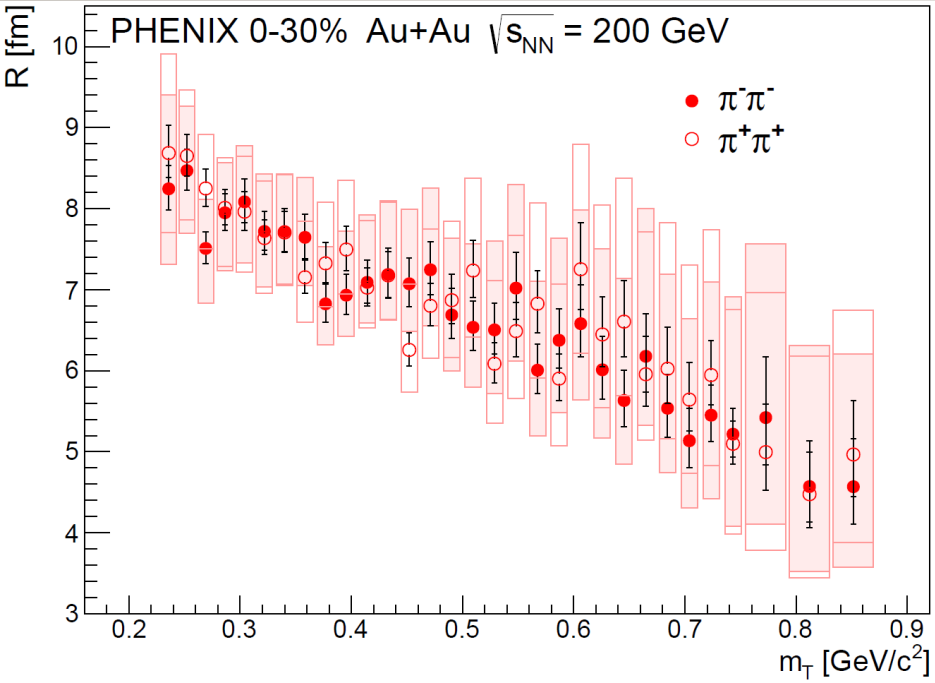
$R 4\pi r^2 S_{\mathrm{core}}(r)$

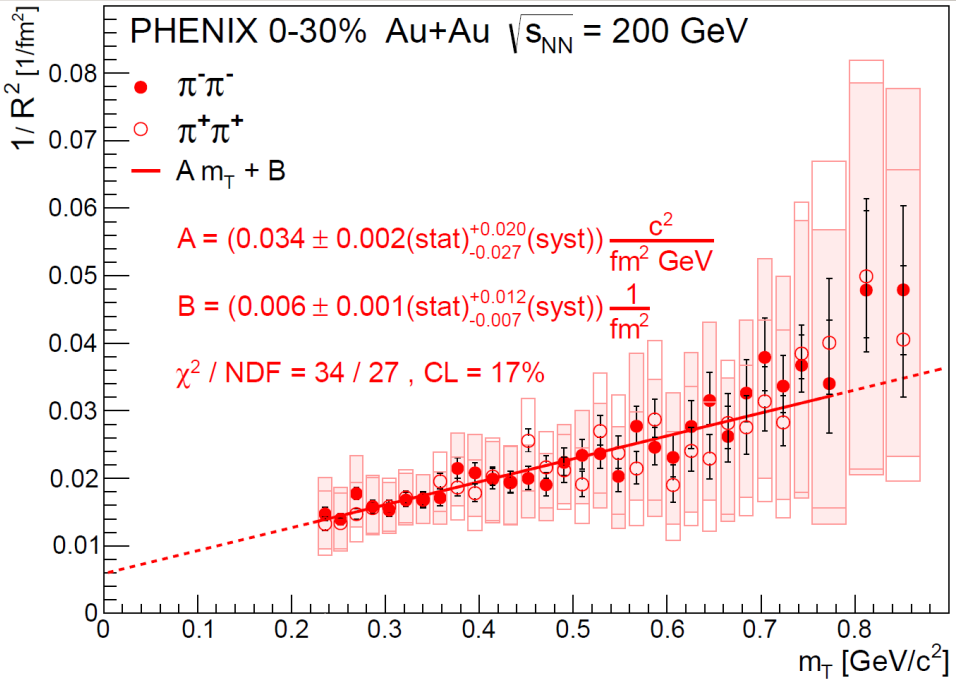


200 GEV LEVY HBT ANALYSIS

- Dataset used for the analysis:
  - Run-10, Au+Au, $\sqrt{s_{NN}}$ = 200 GeV, $7.3 \cdot 10^9$ events
  - Additional offline requirements: vertex less than 30 cm away from center
  - Particle identification:
    - time-of-flight data from PbSc East/West, TOF East/West, momentum, flight length
    - 2σ cuts on m^2 distribution
  - Single track cuts: 2 σ matching cuts in TOF & PbSc for pions
  - Pair-cuts:
    - A random member of pairs assoc. with hits on same tower were removed
    - customary shaped cuts in $\Delta\phi$ - Δz plane for Drift Chamber, PbSc East/West, TOF East/West
- 1D corr. func. as a function of $|k|_{LCMS}$ in various m_T bins
  - k_{LCMS} is 3-momentum difference in longitudinal co-moving system
  - Levy fits for 31 m_T bins ($0.228 < m_T < 0.871$ GeV/c) with Coulomb effect

21/17 LÉVY SCALE PARAMETER R



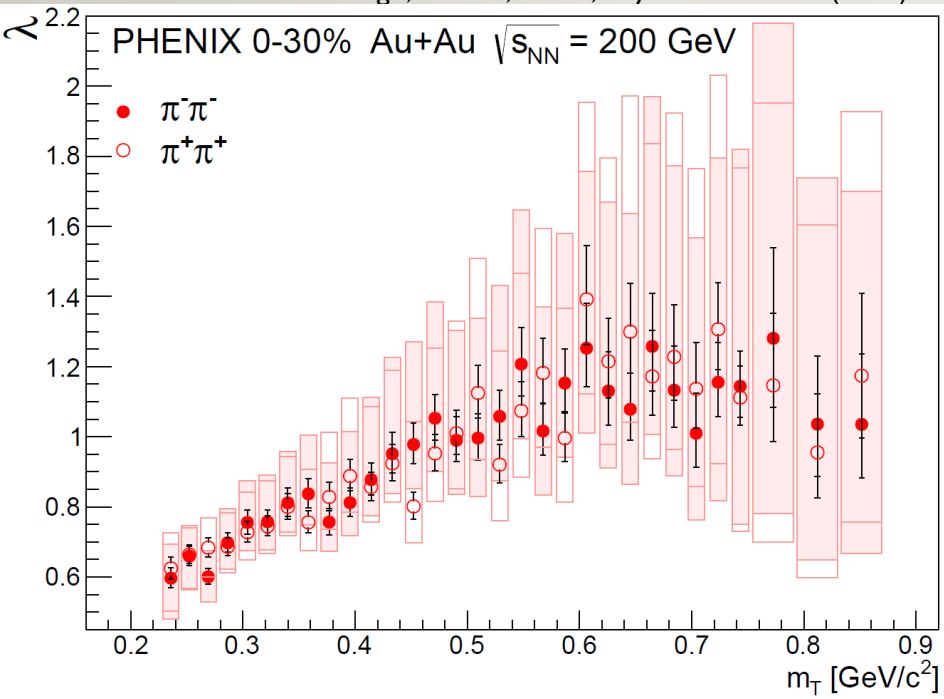


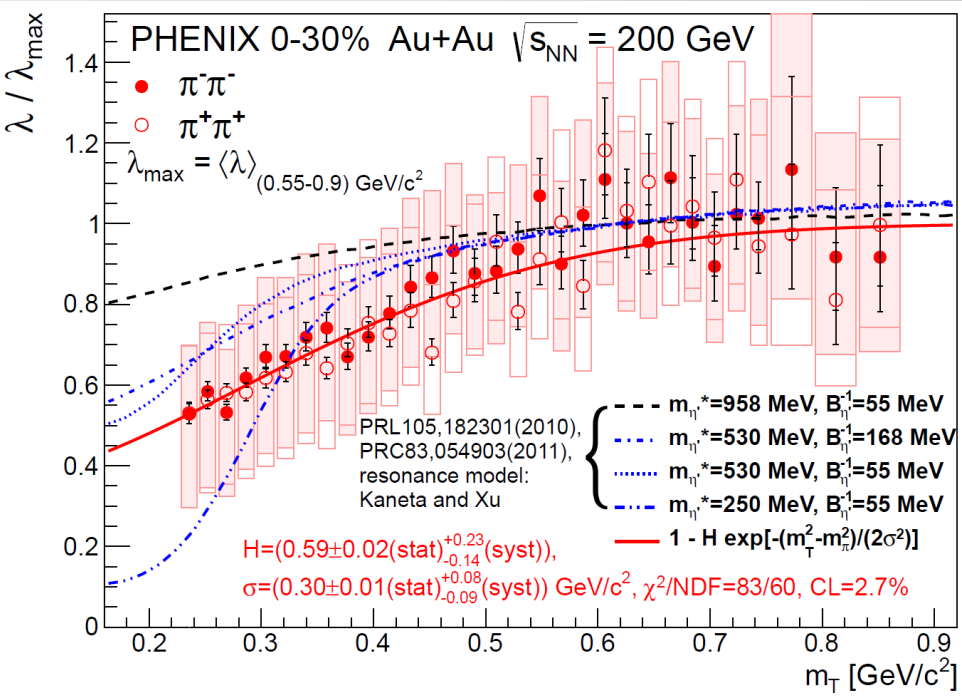
- Similar decreasing trend as Gaussian HBT radii
- Hydro behavior not invalid
- The linear scaling of $1/R^2$, breaks for high m_T

CORRELATION STRENGTH $\lambda(m_T)$

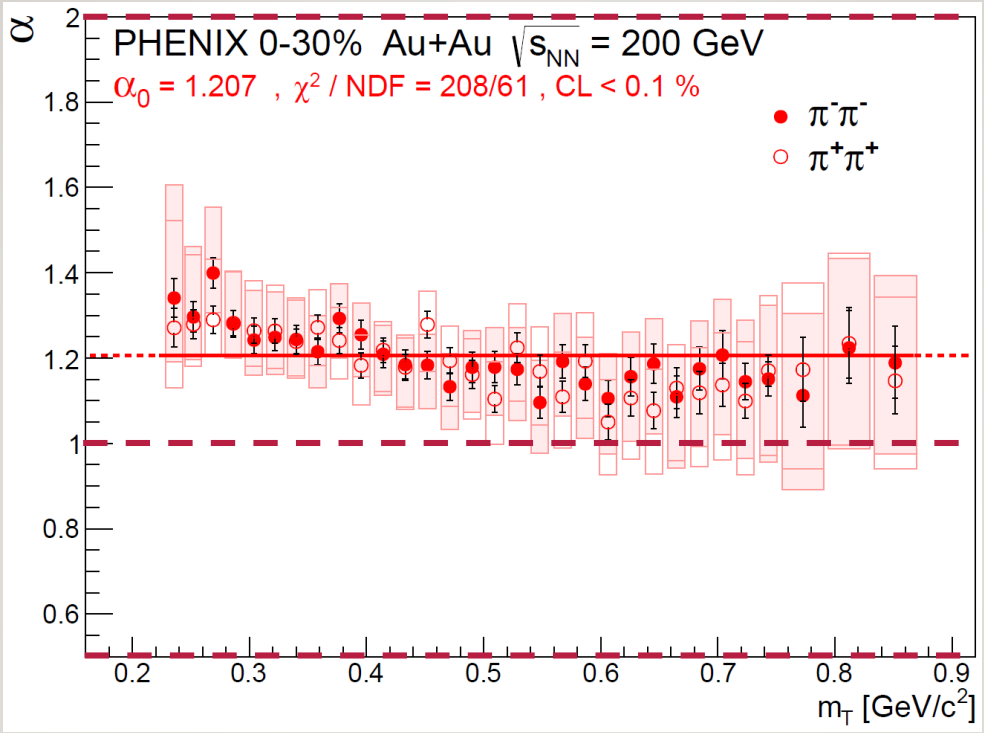
- $\lambda(m_T)$: core/(core+halo) fraction, may be connected to chiral restoration
  - Decreased η' mass → η' enhancement → halo enhancement
  - Kinematics: η' decay pions will have low m_T → decreased $\lambda(m_T)$ at low m_T
  - Compatibility with unmodified in-medium η' mass?

Kapusta, Kharzeev, McLerran, Phys.Rev. D53 (1996) 5028, hep-ph/9507343
Vance, Csörgő, Kharzeev, Phys.Rev.Lett. 81 (1998) 2205, nucl-th/9802074
Csörgő, Vértesi, Sziklai, Phys.Rev.Lett. 105 (2010) 182301, arXiv:0912.5526





LÉVY EXPONENT α



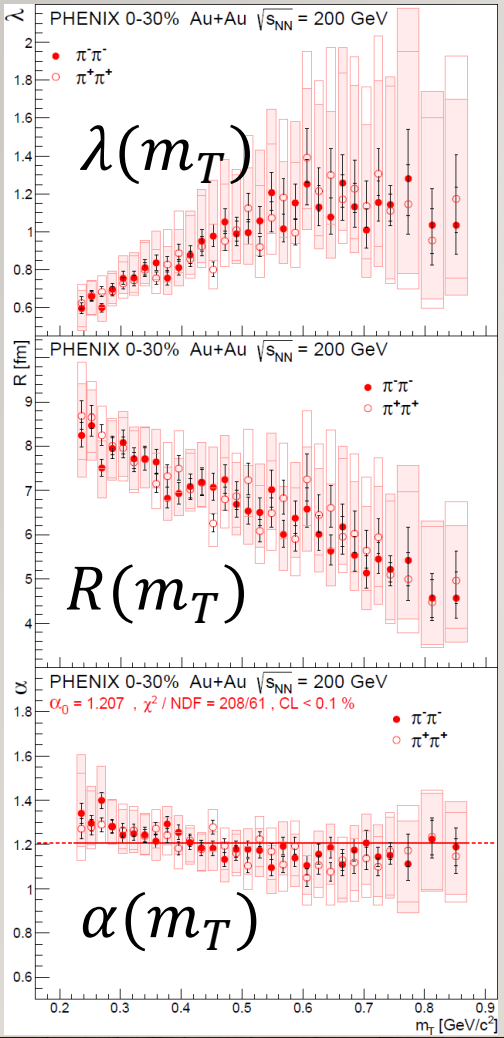
$\alpha = 2.0$

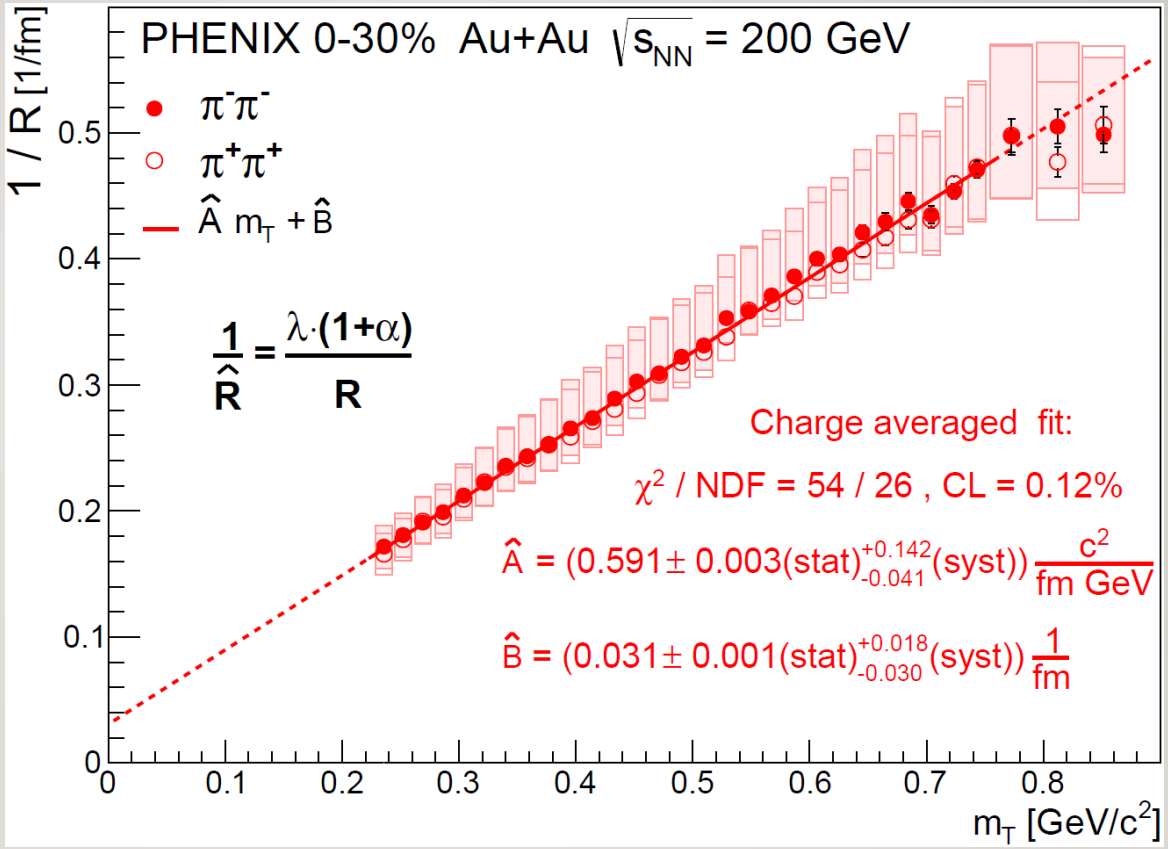
$\alpha = 1.0$

$\alpha = 0.5$

- Measured value far from Gaussian (α = 2), inconsistent with expo. (α = 1)
- Also far from the random field 3D Ising value at CEP (α = 0.5)
- More or less constant (at least within systematic uncertainties)
- Trend observable with statistical uncertainties only

24/17 NEWLY DISCOVERED SCALING PARAMETER $\hat{R}$

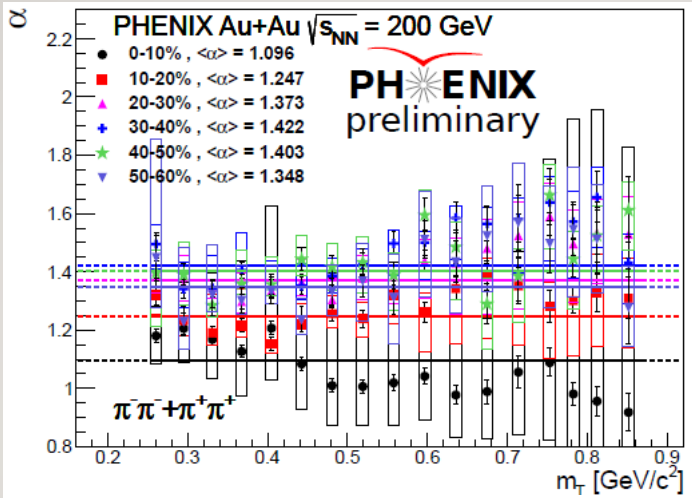


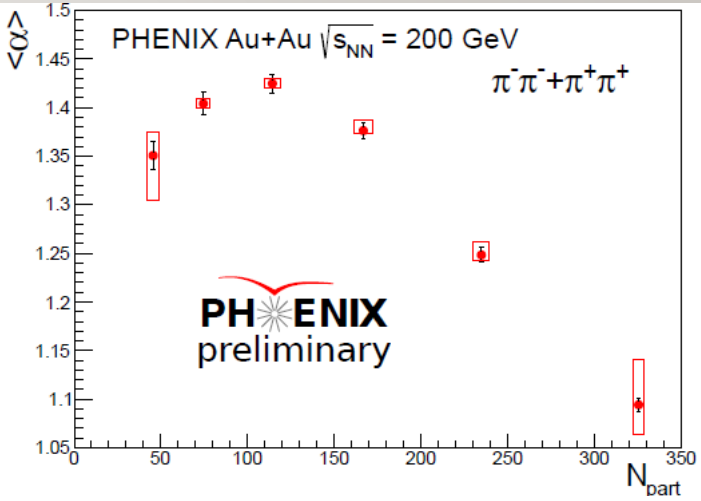


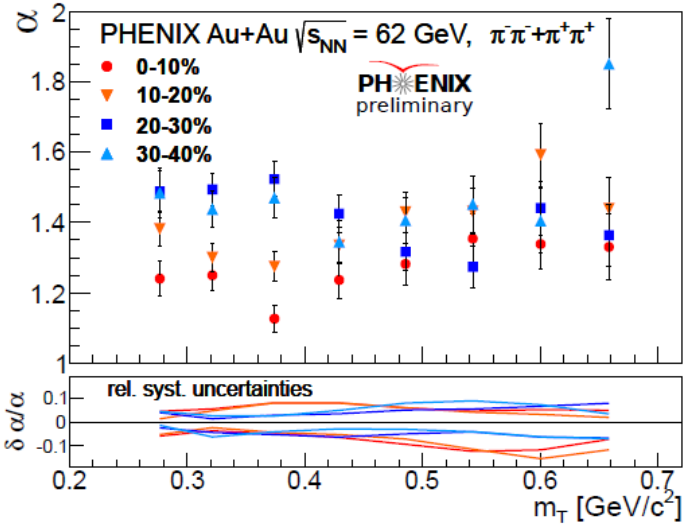
- Empirically found scaling parameter
- Linear in m_T
- Physical interpretation: open question

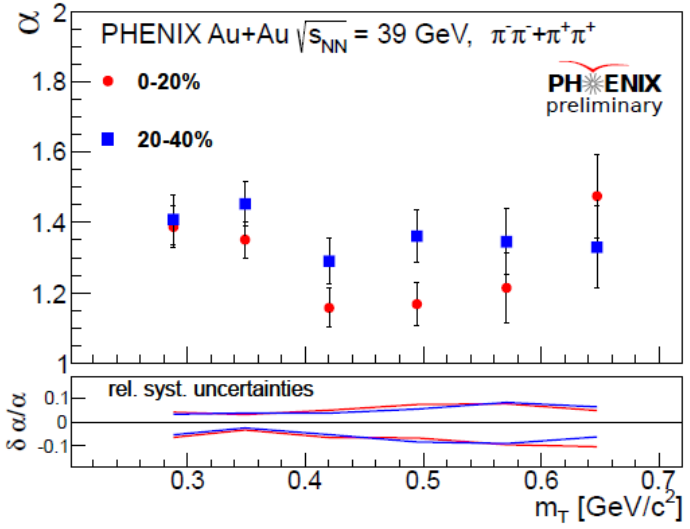
25/17 LÉVY EXPONENT α AT 200 GEV

- Slightly non-monotonic vs m_T
- Non-monotonic vs N_{part}
- No significant change vs $\sqrt{s_{NN}}$

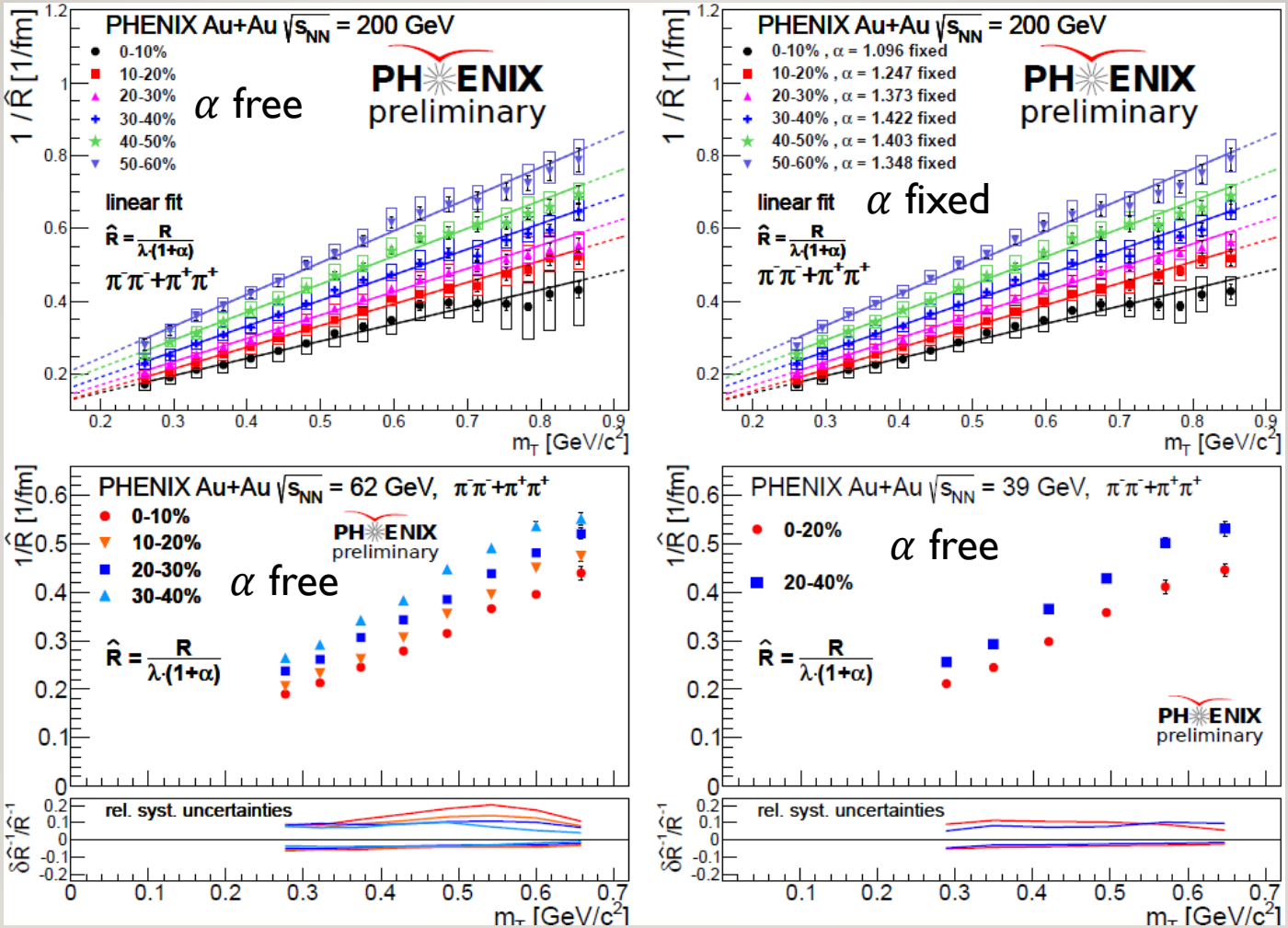






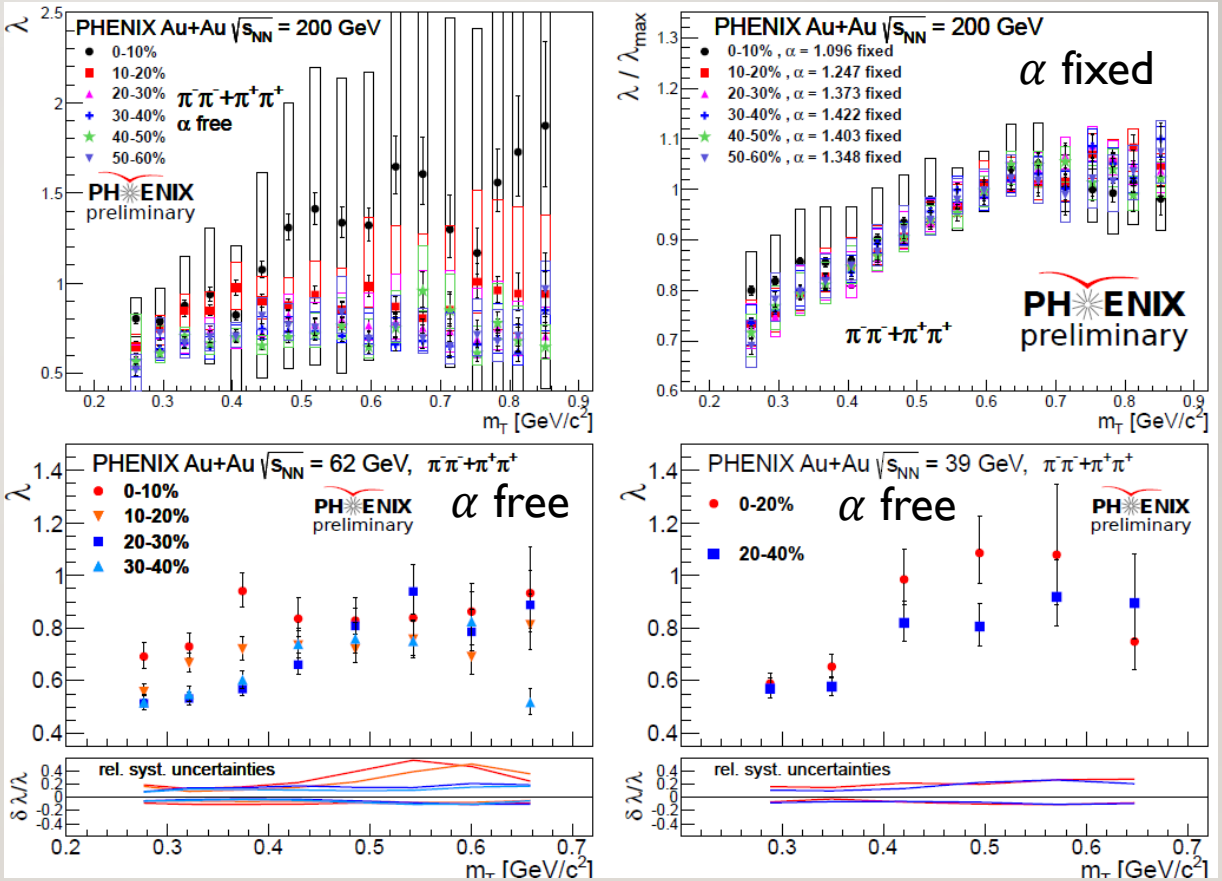


26/17 $\hat{R}$ SCALING: ALL ENERGIES AND CENTRALITIES



HOLE IN $\lambda(m_T)$: ALL INVESTIGATED ENERGIES

- Hole apparent for $\sqrt{s_{NN}} \geq 39$ GeV, all centralities
- Due to reduced η' mass?
- Sign for chiral restoration?
- To be cross-checked with photons, dileptons, etc.



28/17 LEVY R: SIMILAR HYDRO TRENDS FOR ALL CASES