Evolution of elliptic flow and HBT radii from RHIC to LHC – Predictions from ideal fluid dynamics*

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presented at

Heavy Ion Collisions at the LHC – Last Call for Predictions
CERN, May 29 - June 2, 2007

Collaborators:
Rupa Chatterjee, Evan Frodermann, Charles Gale, Tetsufumi Hirano, Greg Kestin,
Peter Kolb, Huichao Song, Dinesh Srivastava

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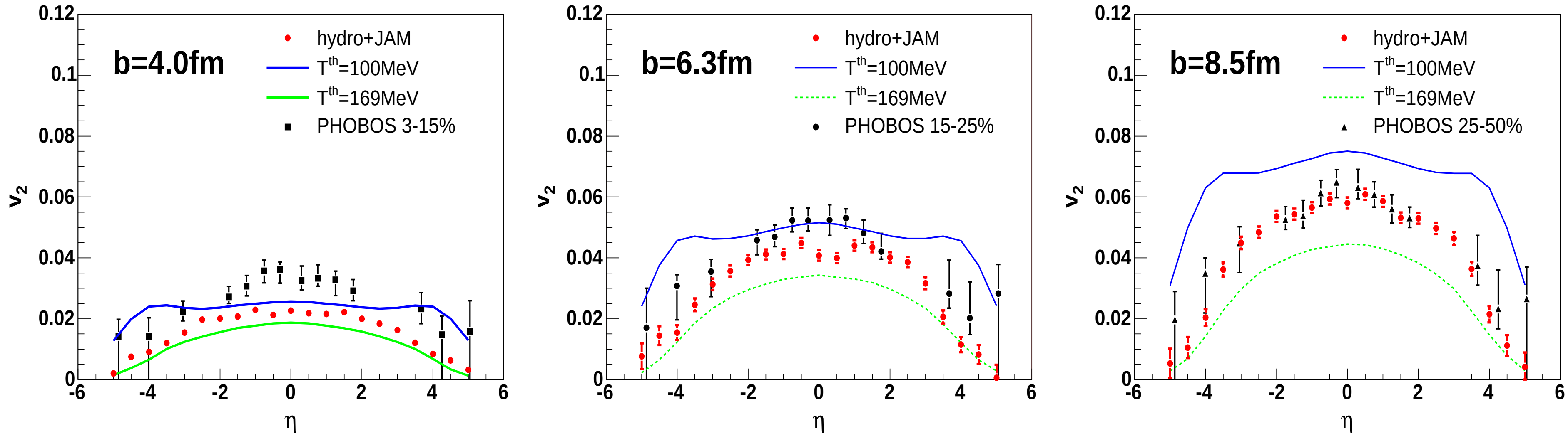
Part I:

Elliptic flow of pions and photons

RHIC: perfect QGP fluidity vs. dissipative hadron dynamics

Glauber model initl. conds. + 3D Ideal QGP Hydro + Hadron Cascade
explain all v_2 measurements in Au+Au at RHIC

T. Hirano, U. Heinz, D. Kharzeev, R. Lacey, Y. Nara, PLB 636 (2006) 299

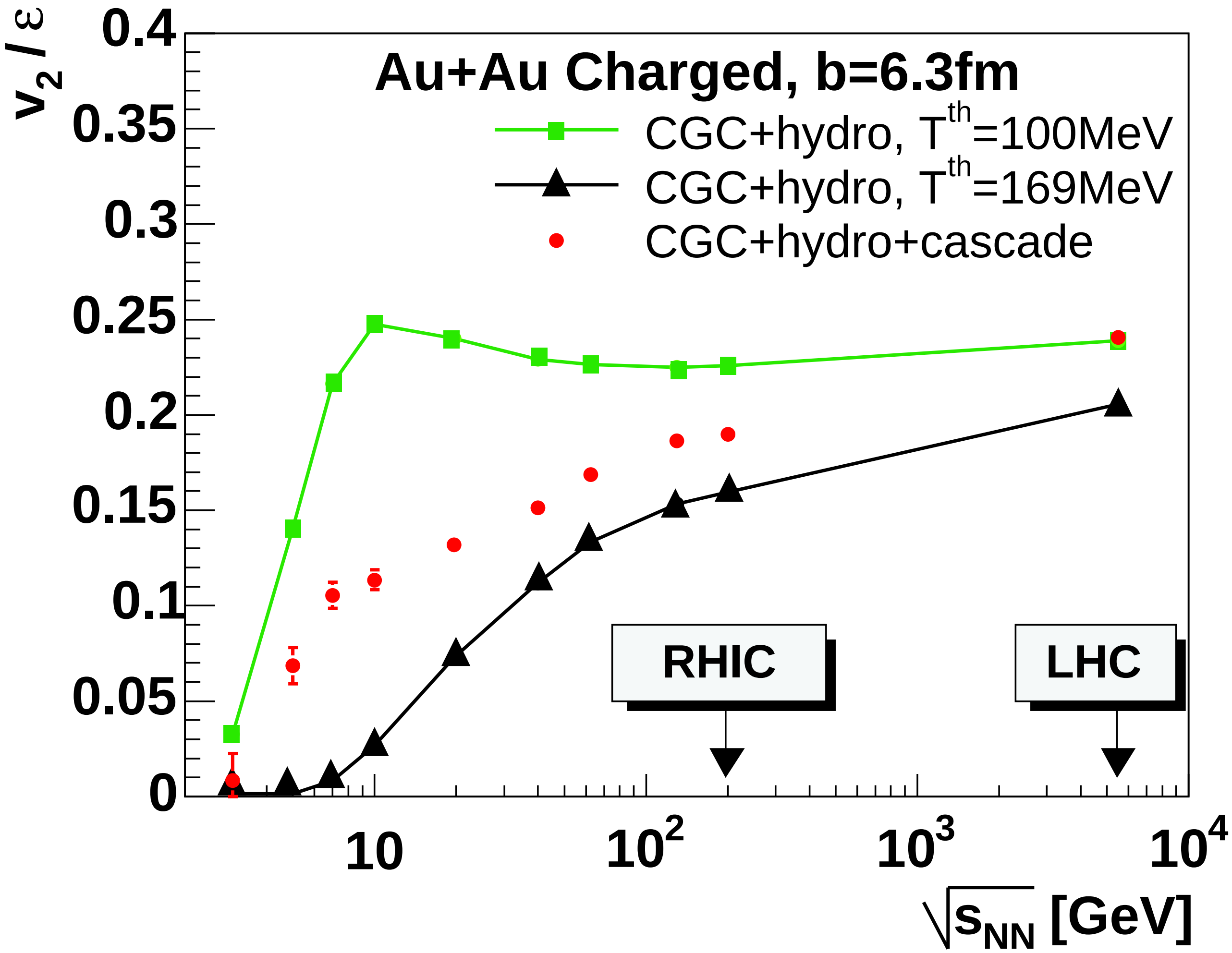


[Glauber model initial conditions (85% soft/15% hard)]

- Not enough elliptic flow from perfect QGP fluid – some hadronic contribution to v_2 still required at RHIC
- Treating the hadronic stage as ideal fluid overpredicts v_2 in peripheral collisions and at forward rapidities
- Dissipation in hadronic cascade brings theory in line with data (except for small b – excess in data due to event-by-event geometry fluctuations (Miller & Snellings, PHOBOS))

LHC: dissipative hadronic effects die out at $y=0$

T. Hirano, U. Heinz, D. Kharzeev, R. Lacey, Y. Nara, QM2006 [nucl-th/0701075]



Last Call for Predictions – but. . .

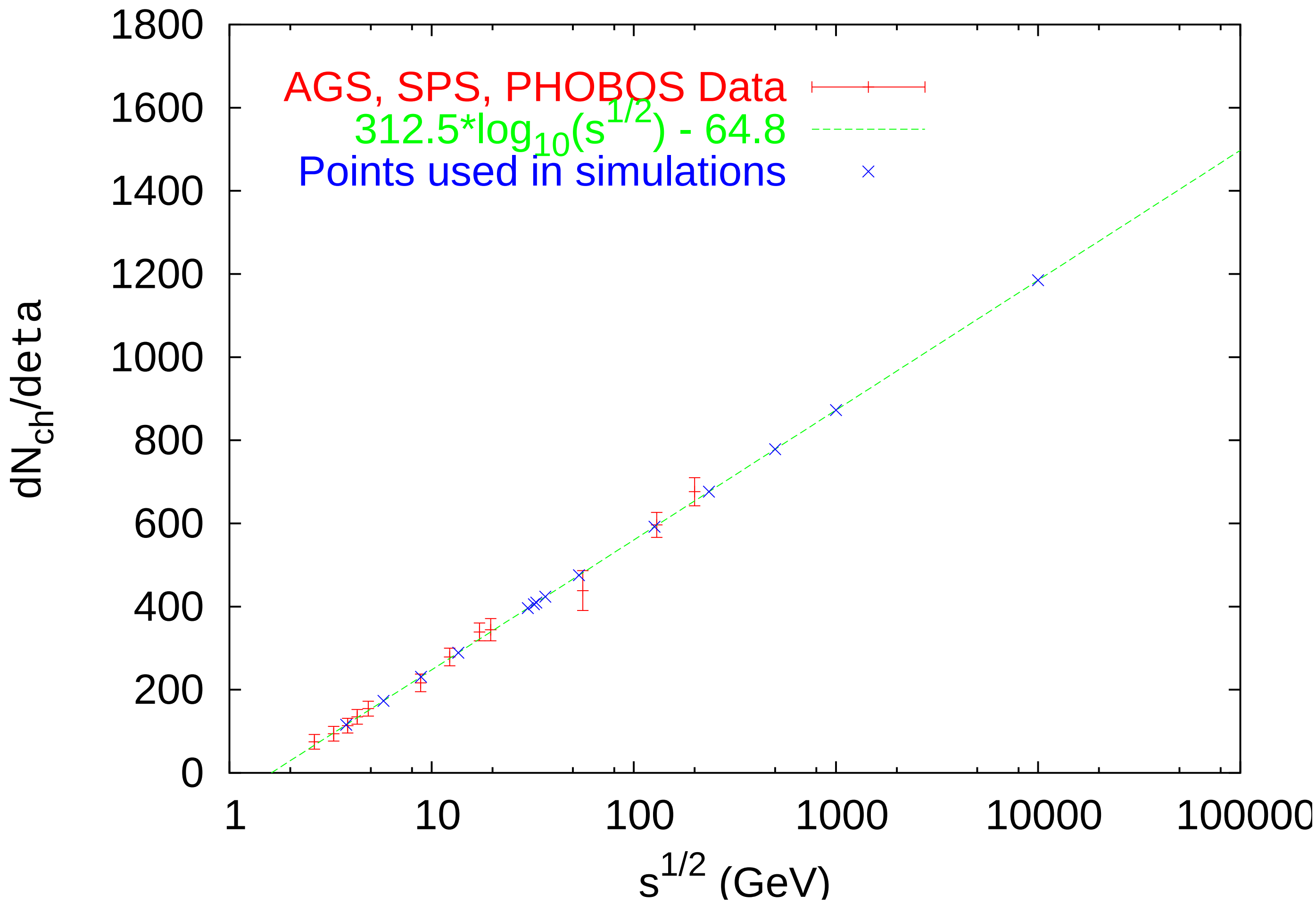
. . . not my last answer!

Working hypotheses for my two talks today:

- QGP remains perfectly fluid at LHC (α_s varies only logarithmically with T)
  [but see my talk on viscous hydrodynamics next week!]
- Glauber model initial conditions (validity needs to be checked – hard!)
- similar kinetic freeze-out energy densities at RHIC and LHC
- rapid initial thermalization at $\tau_0 = 1/T_0$ (T_0 = peak temperature in Au+Au/Pb+Pb at b=0)
  no transverse flow at τ_0
- ignore hadronic dissipation (terrible at AGS, excellent (?) at LHC)

Charged multiplicity vs. $\sqrt{s}$:

(see Wit Busza's talk yesterday)

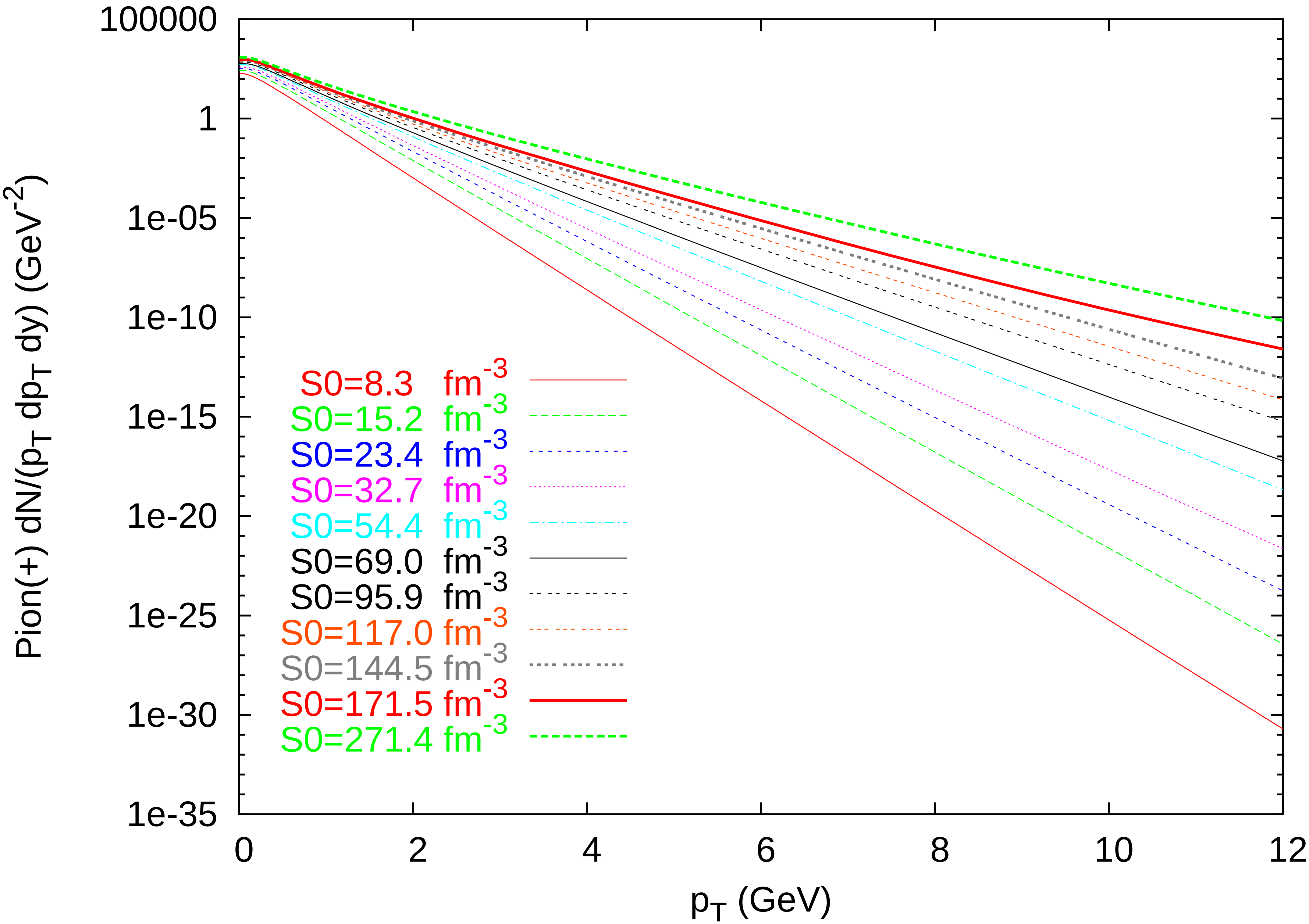


Hydrodynamics cannot predict $\sqrt{s}$-dependence of final multiplicity ($\leftrightarrow$ initial entropy density)

$\Longrightarrow$ predict all observables as functions of $\left.\dfrac{dN_{\mathrm{ch}}}{dy}\right|_{y=0} \longleftrightarrow s_0$

Evolution of pion spectra

Greg Kestin



Evolution of pion spectra

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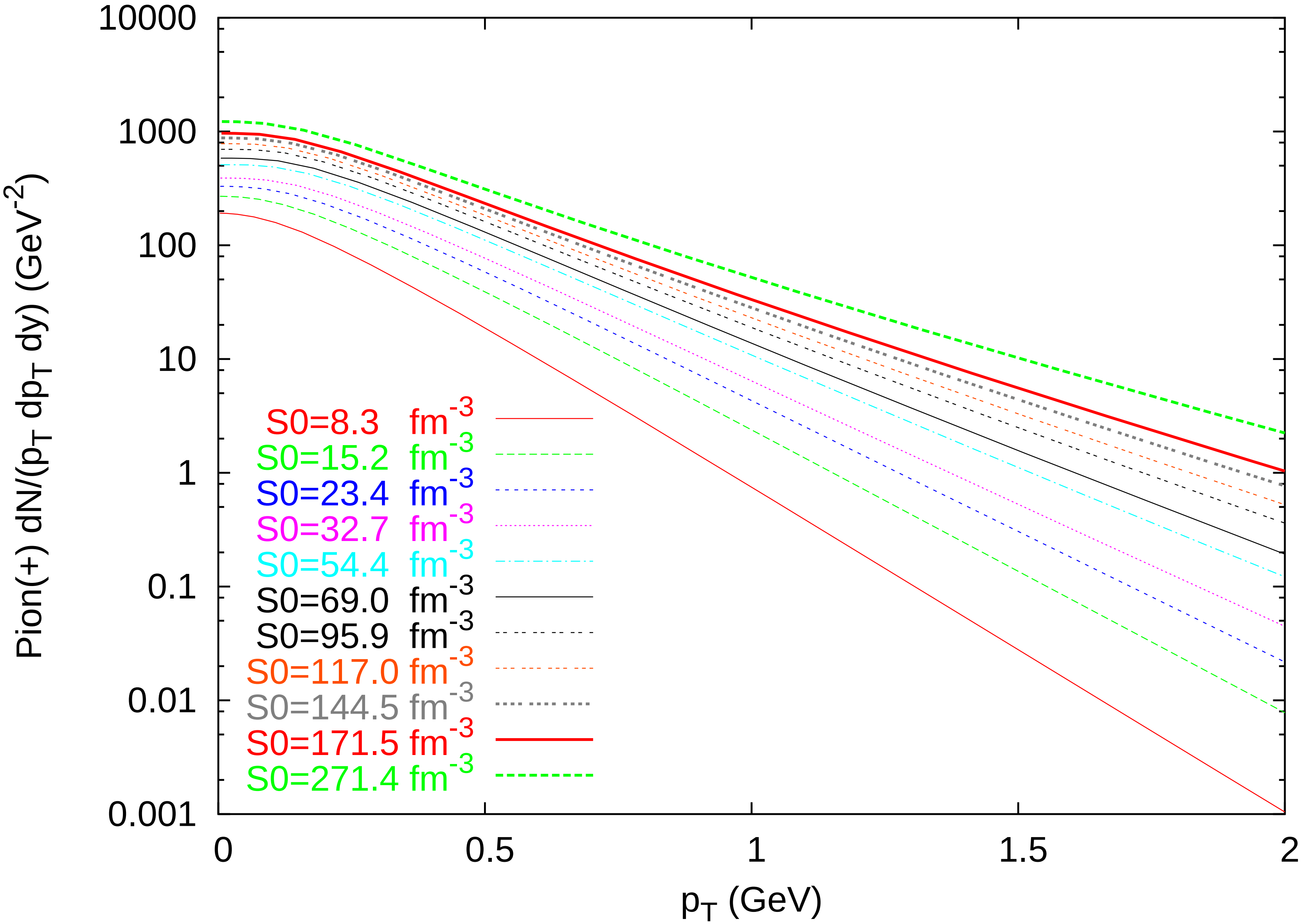
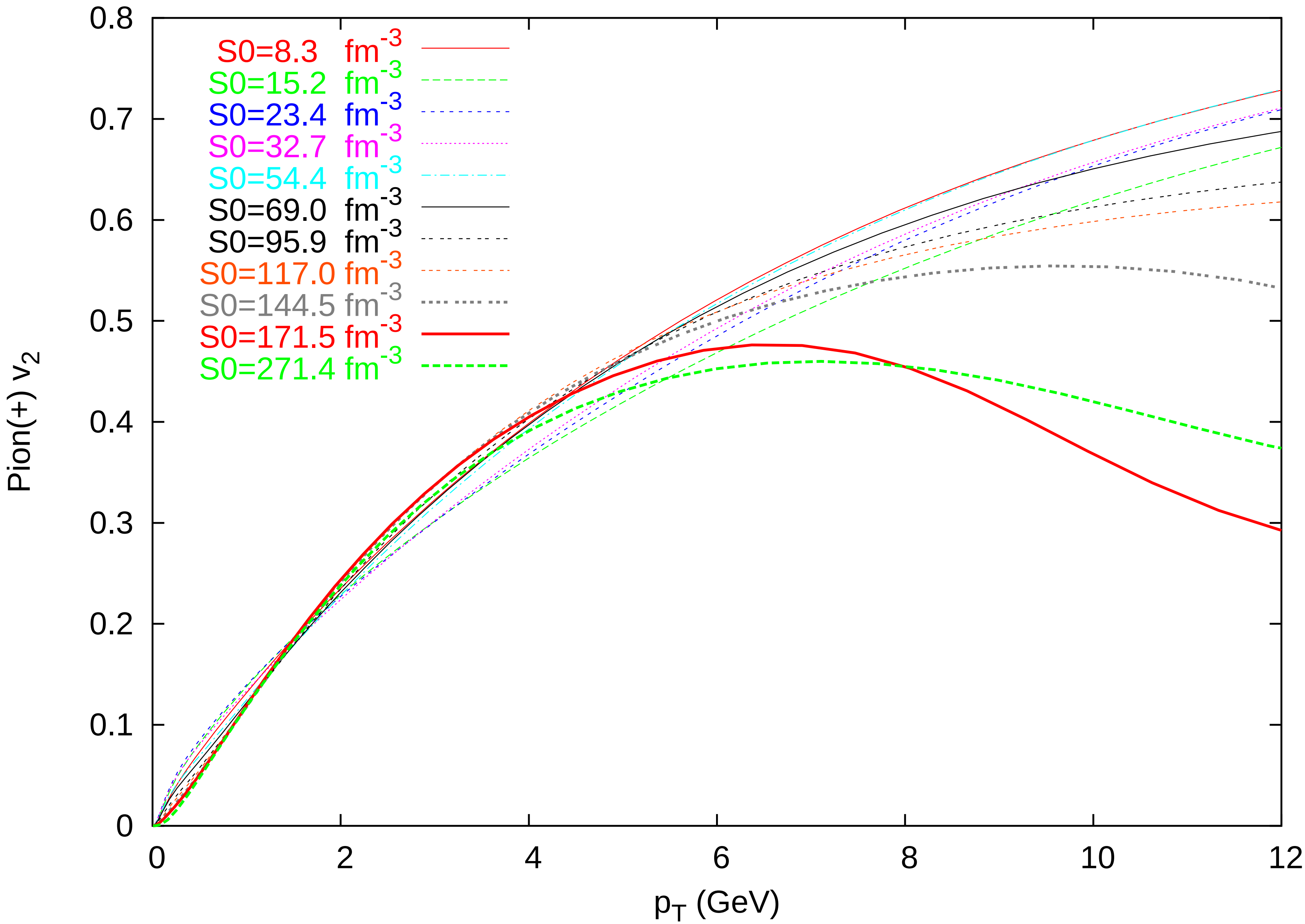


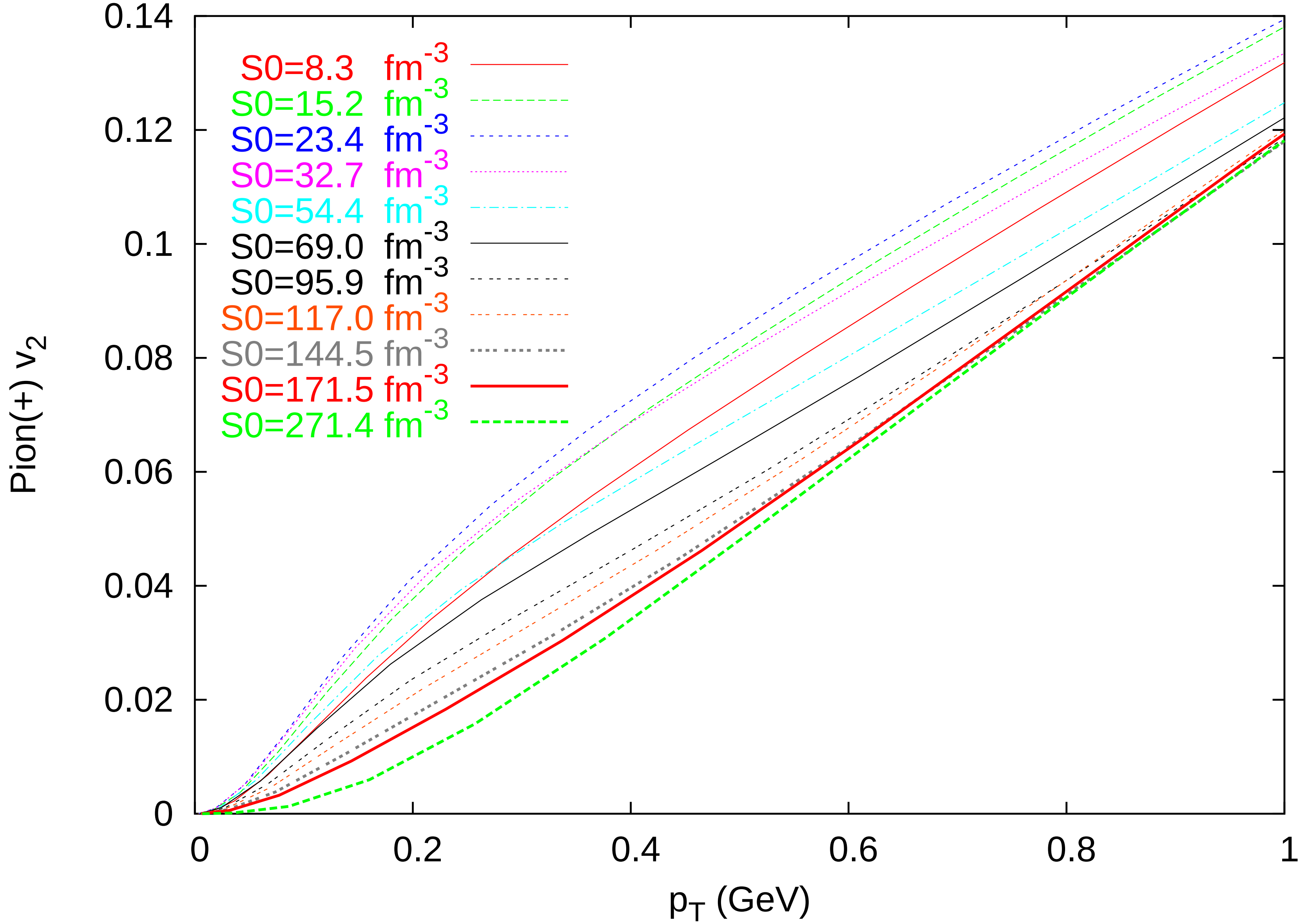
Monotonic increase of radial flow!

Evolution of pion elliptic flow

Greg Kestin

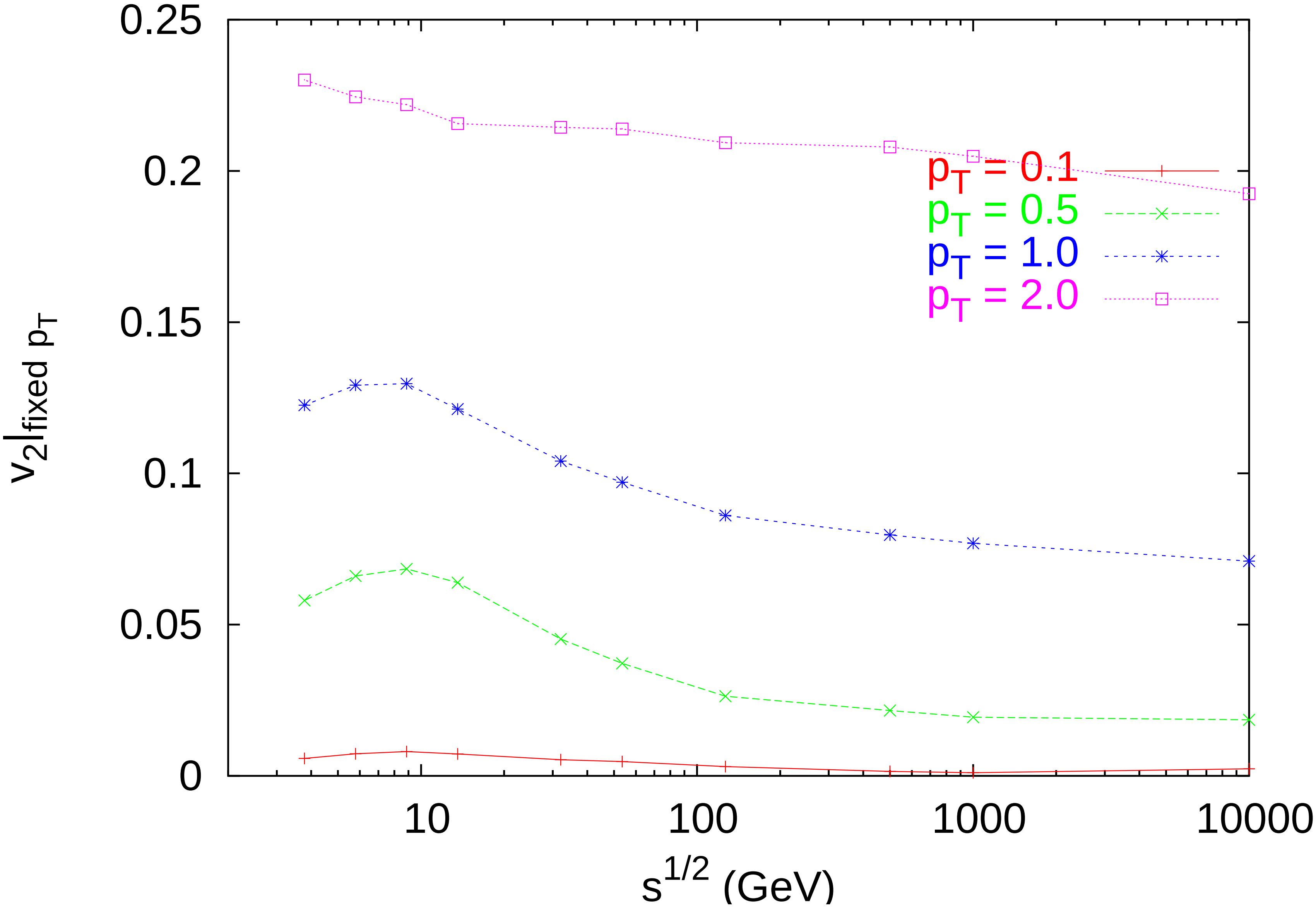


Evolution of pion elliptic flow



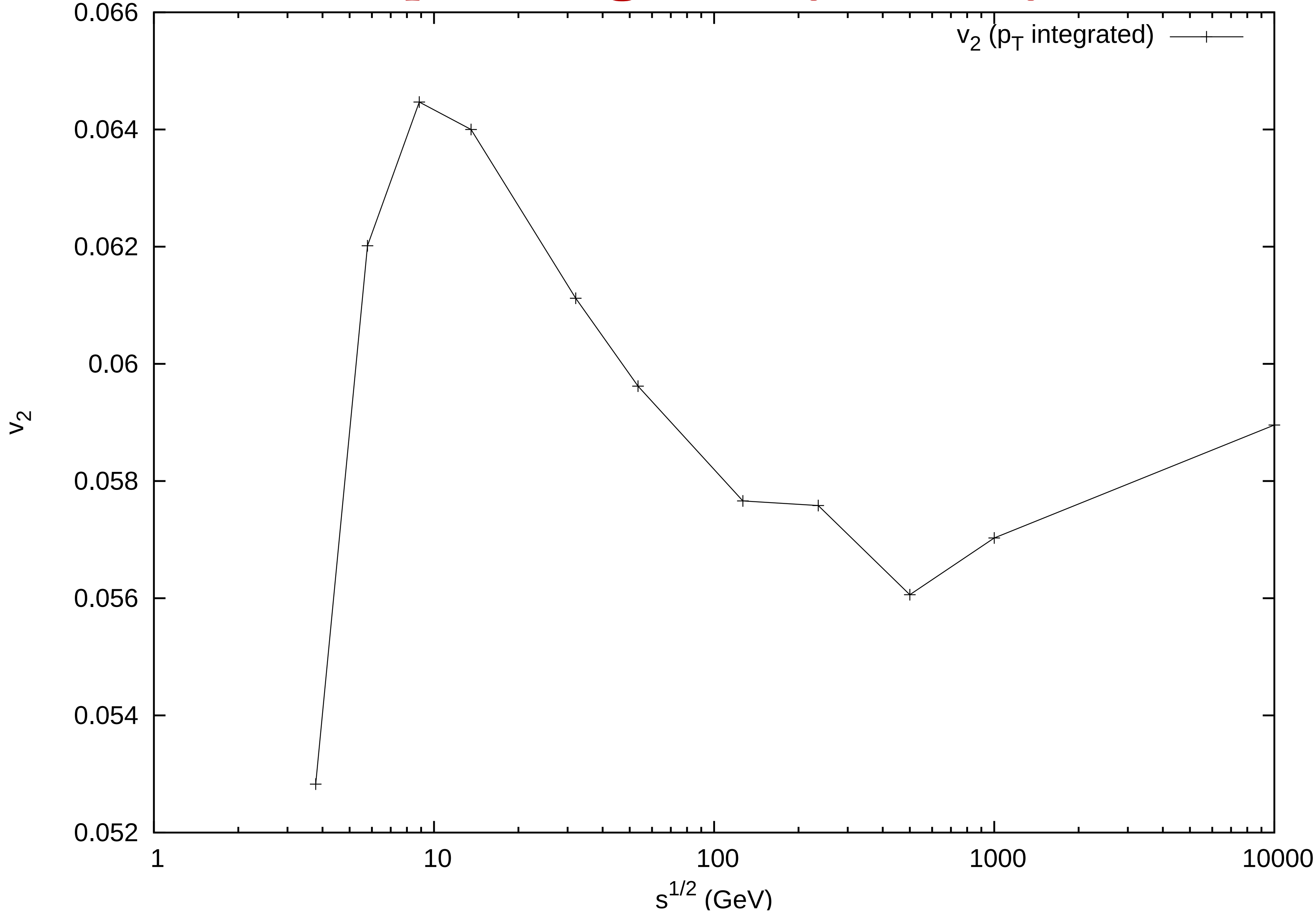
v_2 at fixed p_T does not increase monotonically! (It decreases from RHIC to LHC, due to increased radial flow which flattens pion spectrum.)

Evolution of v_2 at fixed p_T



Once fully developed, v_2 at fixed p_T decreases with increasing $\sqrt{s}$, due to increased radial flow which flattens the pion spectrum!

Evolution of p_T-integrated pion elliptic flow



p_T-integrated pion v_2 shows similar excitation function as charged hadron v_2. (Increases from RHIC to LHC, due to increased radial flow which flattens the pion spectrum.)

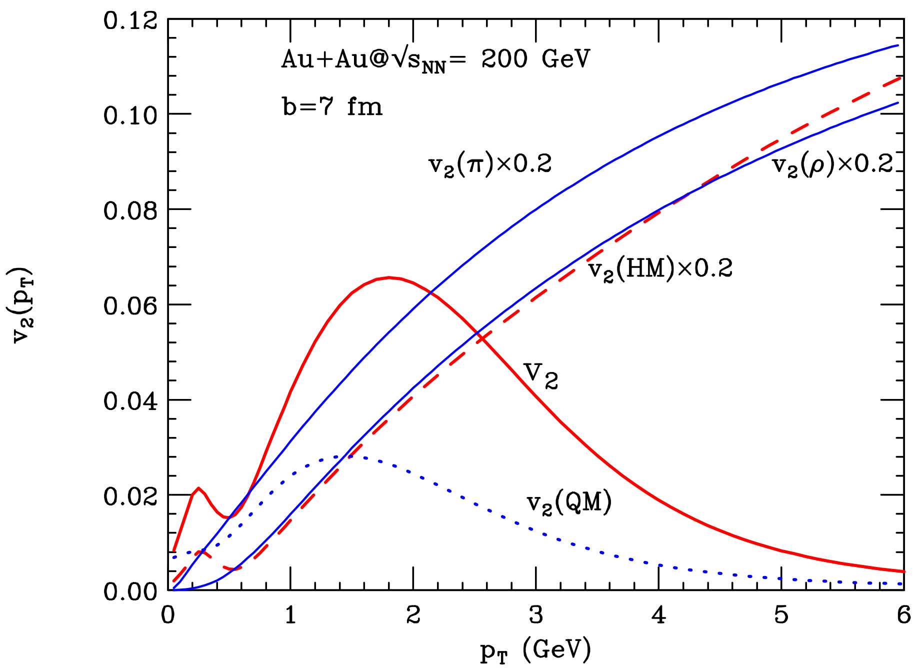
Early evolution of elliptic flow via photons and dileptons

Photon and dilepton elliptic flow at RHIC:

High-p_T photons and high-mass dileptons probe early fireball evolution:

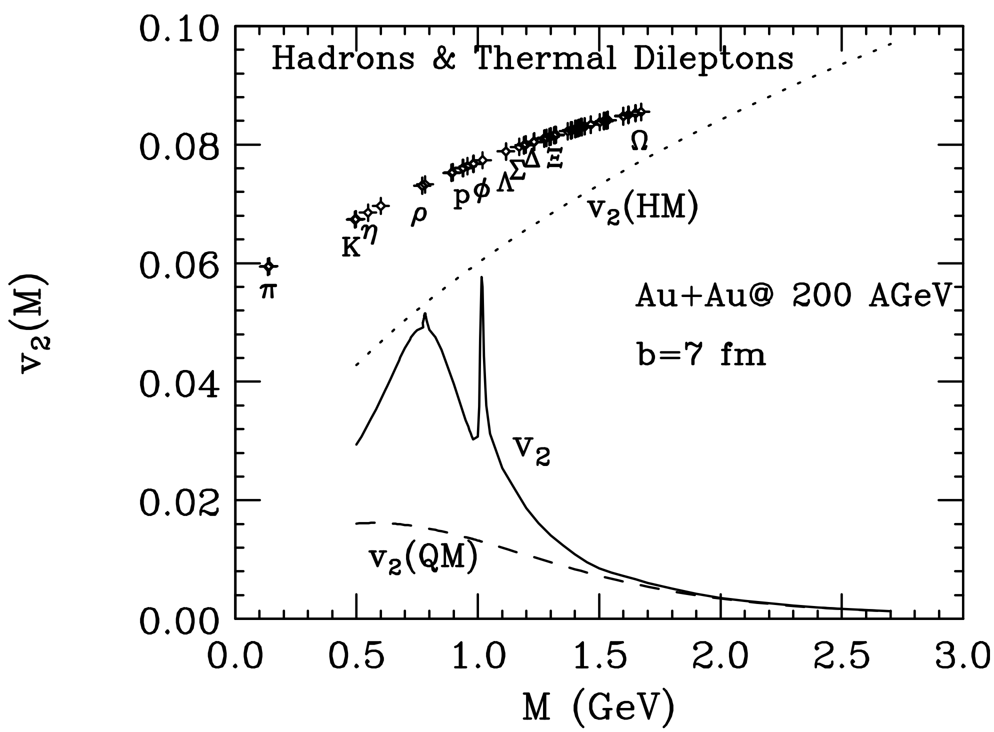
R. Chatterjee, E. Frodermann, UH, D.K. Srivastava,
PRL 96 (2006) 202302

Photon elliptic flow:



R. Chatterjee, D.K. Srivastava, UH, C. Gale,
nucl-th/0702039 (PRC, in press)

Dilepton elliptic flow:

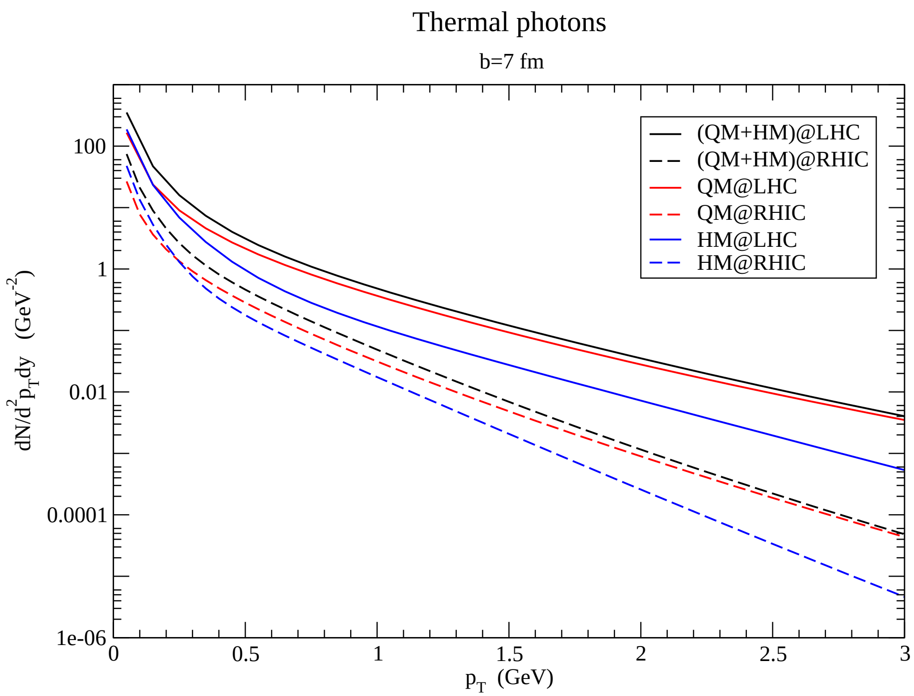


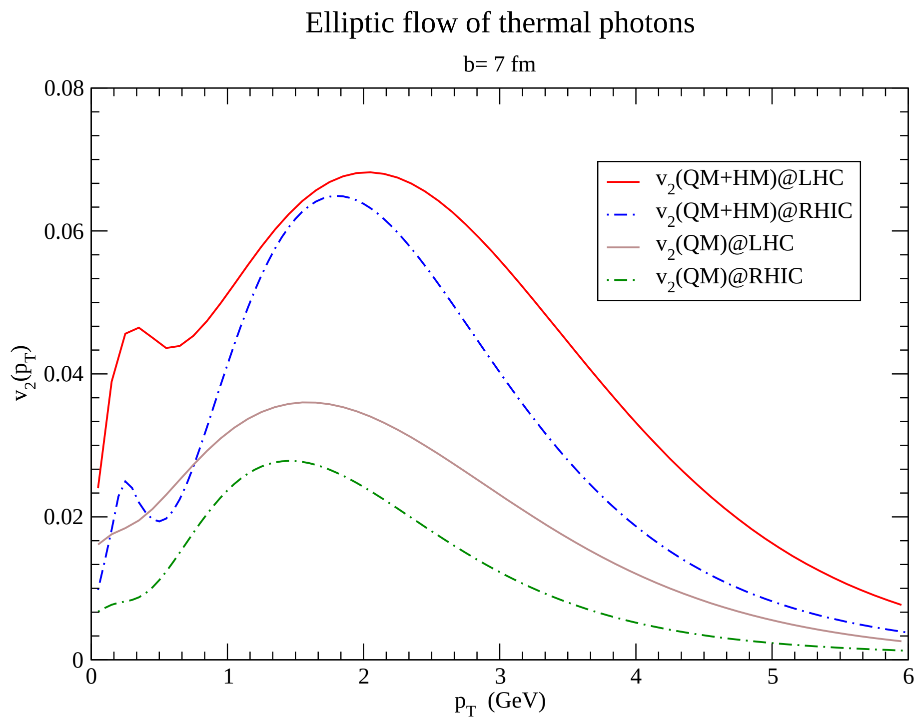
Used $s_0 = 351\,\mathrm{fm}^{-3}$ at $\tau_0 = 0.2\,\mathrm{fm}/c$.

Photon spectra and elliptic flow at LHC:

Rupa Chatterjee

Used $s_0 = 2438\,\mathrm{fm}^{-3}$ at $\tau_0 = 0.1\,\mathrm{fm}/c$ $\Longrightarrow \left.\frac{dN_{\rm ch}}{dy}\right|_{y=0} = 2350.$





- Photon spectra flatter at LHC, due to more radial flow
- QM dominance shifts to lower p_T
- Photon elliptic flow much larger at LHC, due to twice larger v_2 of QM radiation at high p_T and . . .

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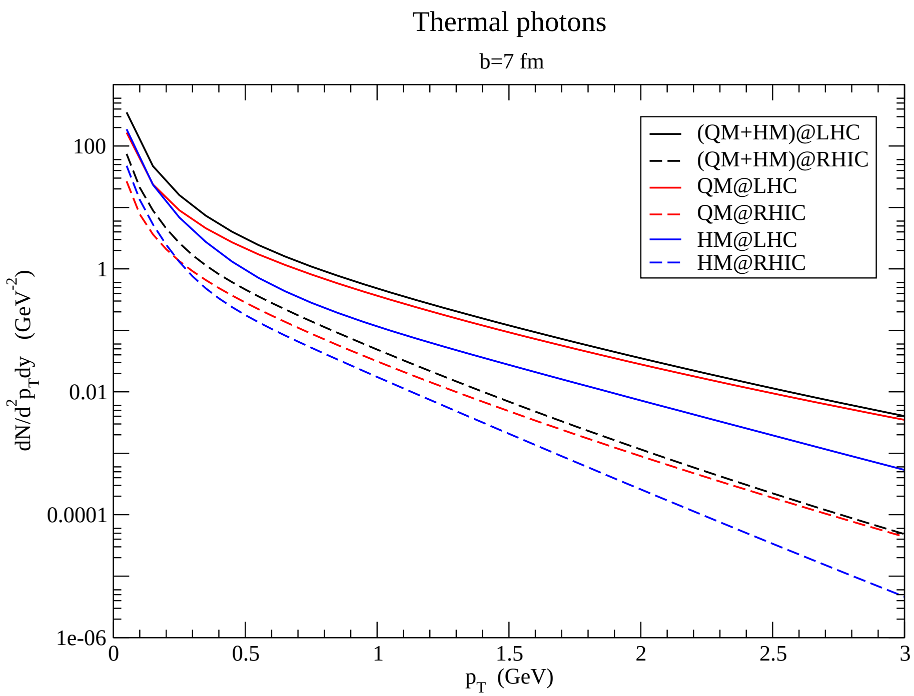
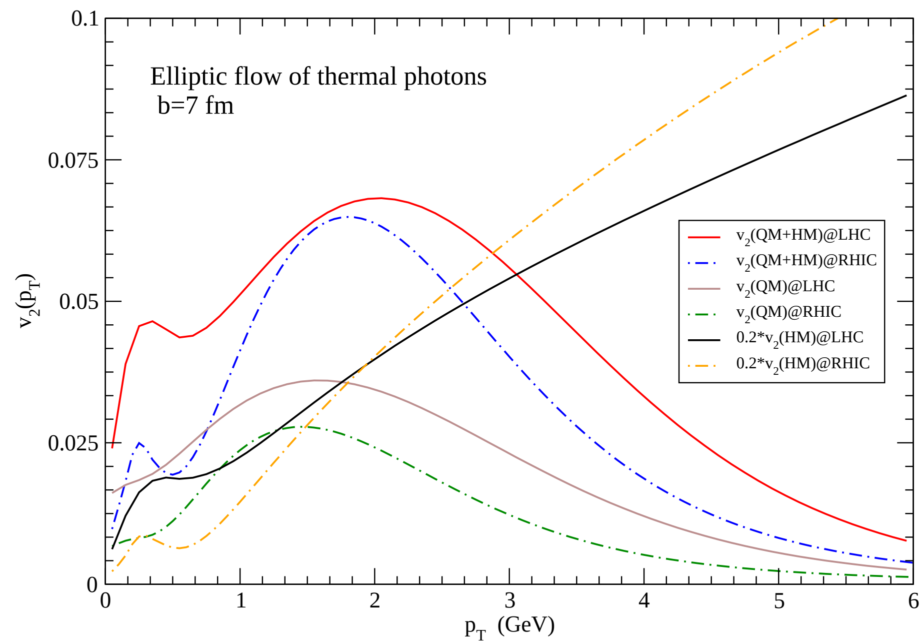




- Photon spectra flatter at LHC, due to more radial flow
- QM dominance shifts to lower p_T
- Photon elliptic flow much larger at LHC, due to twice larger v_2 of QM radiation at high p_T and increased v_2 of hadronic photons at low p_T

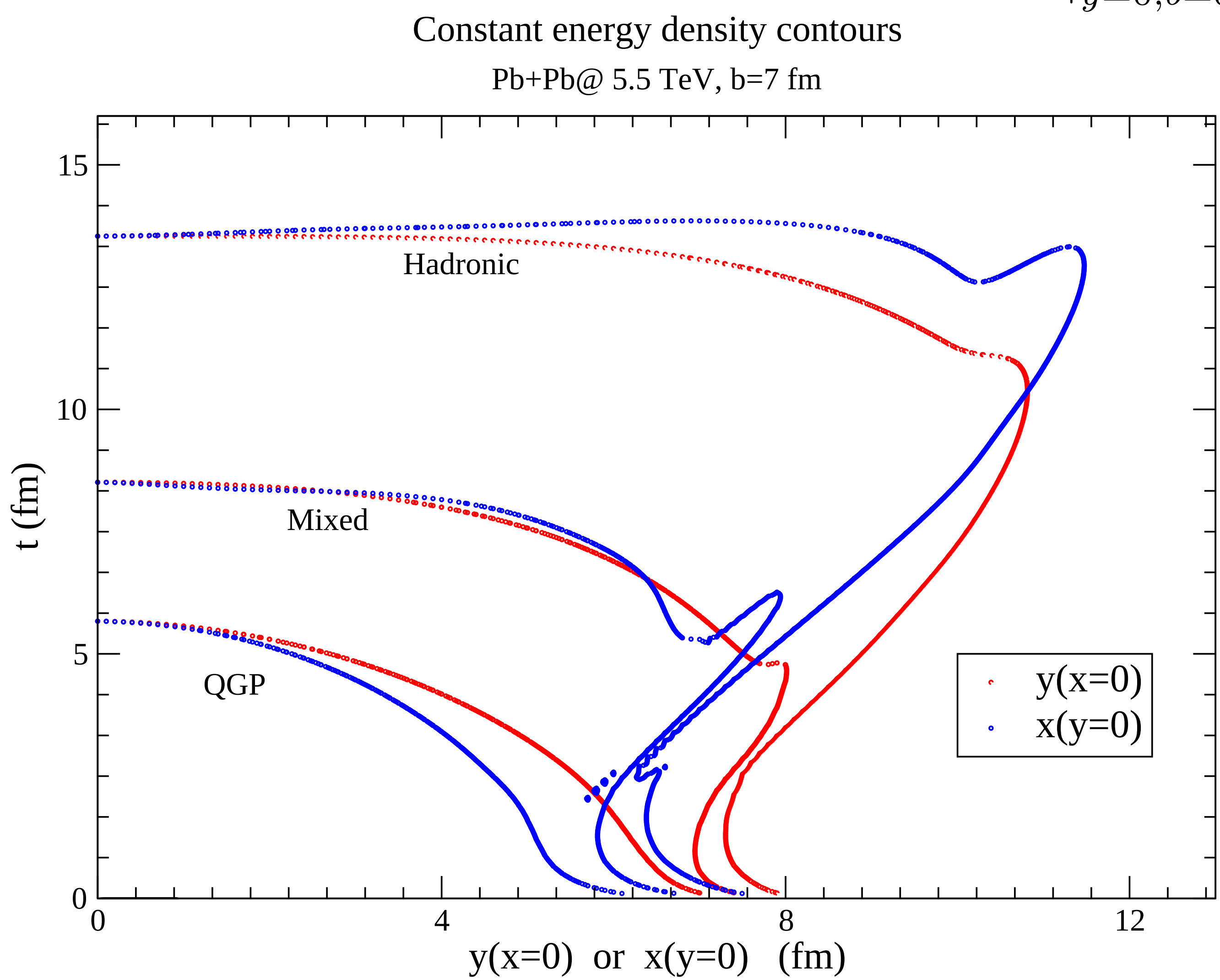
Part II:

Pion HBT radii

Hydrodynamic freeze-out surface at the LHC

Rupa Chatterjee

Pb+Pb at b=7 fm; $s_0 = 1735\,\text{fm}^{-3}$ at $\tau_0 = 0.1\,\text{fm}/c$; $\left.\dfrac{dN_{\rm ch}}{dy}\right|_{y=0,b=0} = 2035.$



Evolution out-of-plane $\longrightarrow$ in-plane; explore with HBT microscope

Caveat:

Ideal fluid dynamics fails to reproduce transverse HBT radii (R_s, R_o) at RHIC (magnitude, ratio, and K_T-dependence).

No reason for trusting hydro predictions any better at LHC.

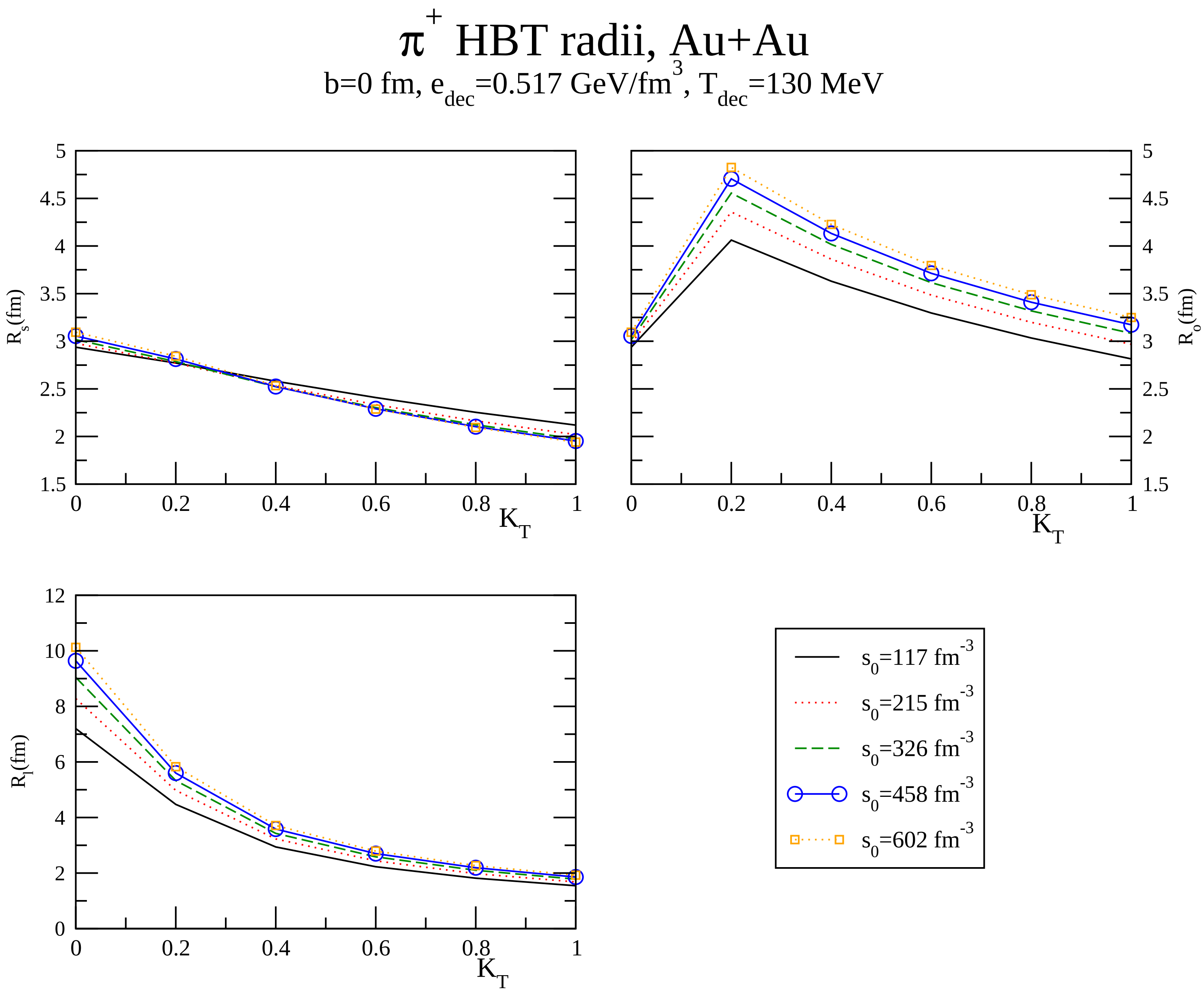
However, ideal hydro gets normalized azimuthal oscillation amplitudes of R_s, R_o right.

Use ideal hydrodynamics to develop feeling for expected trends, but not for quantitative predictions (yet).

Numerical problems with realistic EoS $\Longrightarrow$ so far only results for ideal gas EoS ($p = e/3$). With this EoS $e_{\rm dec} = 0.075\,$GeV/fm^3 $\leftrightarrow$ $T_{\rm dec} = 80\,$MeV while $T_{\rm dec} = 130\,$MeV $\leftrightarrow$ $e_{\rm dec} = 0.517\,$GeV/fm^3.

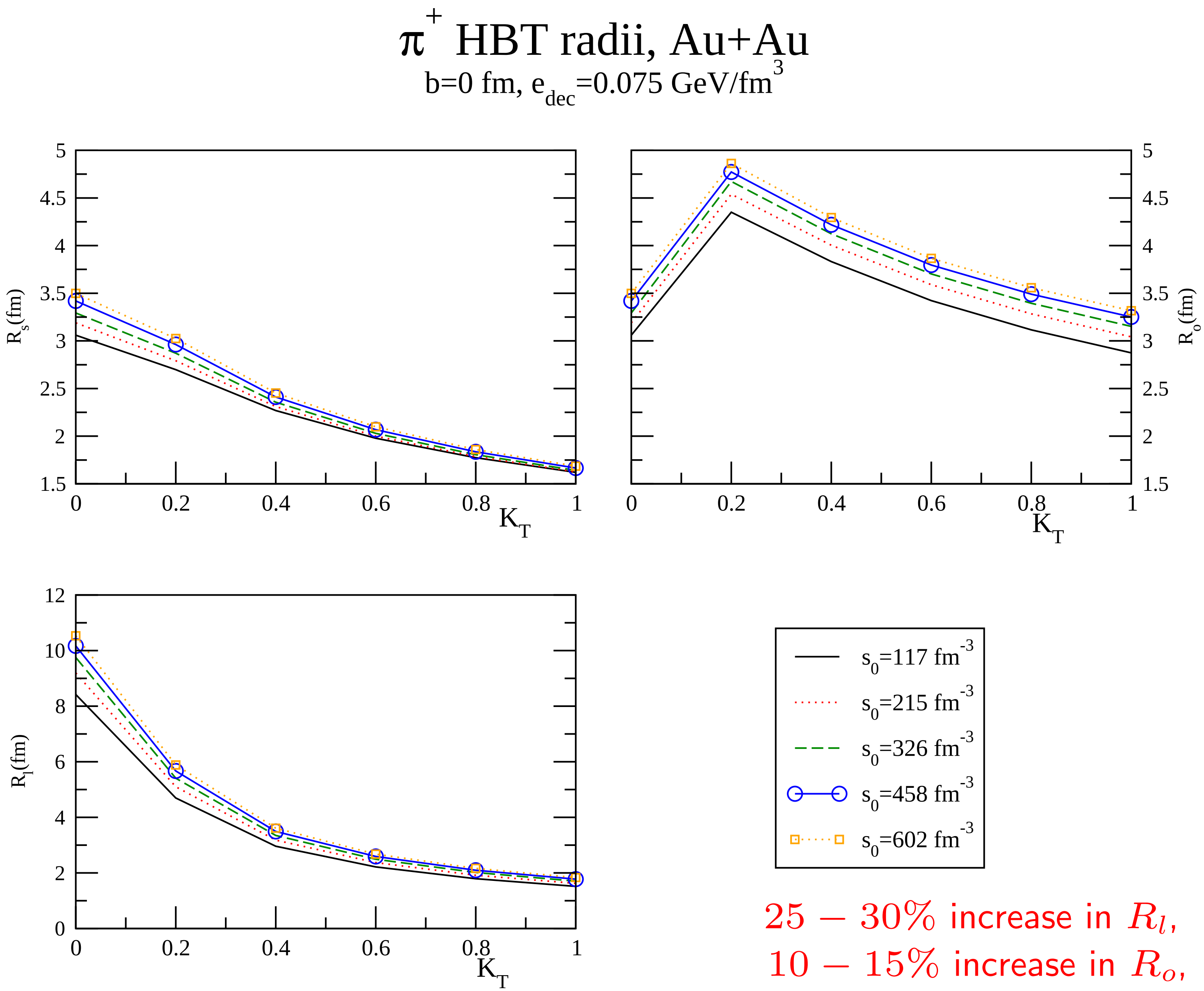
HBT radii for $b=0$: magnitude, K_T-dependence

Evan Frodermann



HBT radii for b=0: magnitude, K_T-dependence

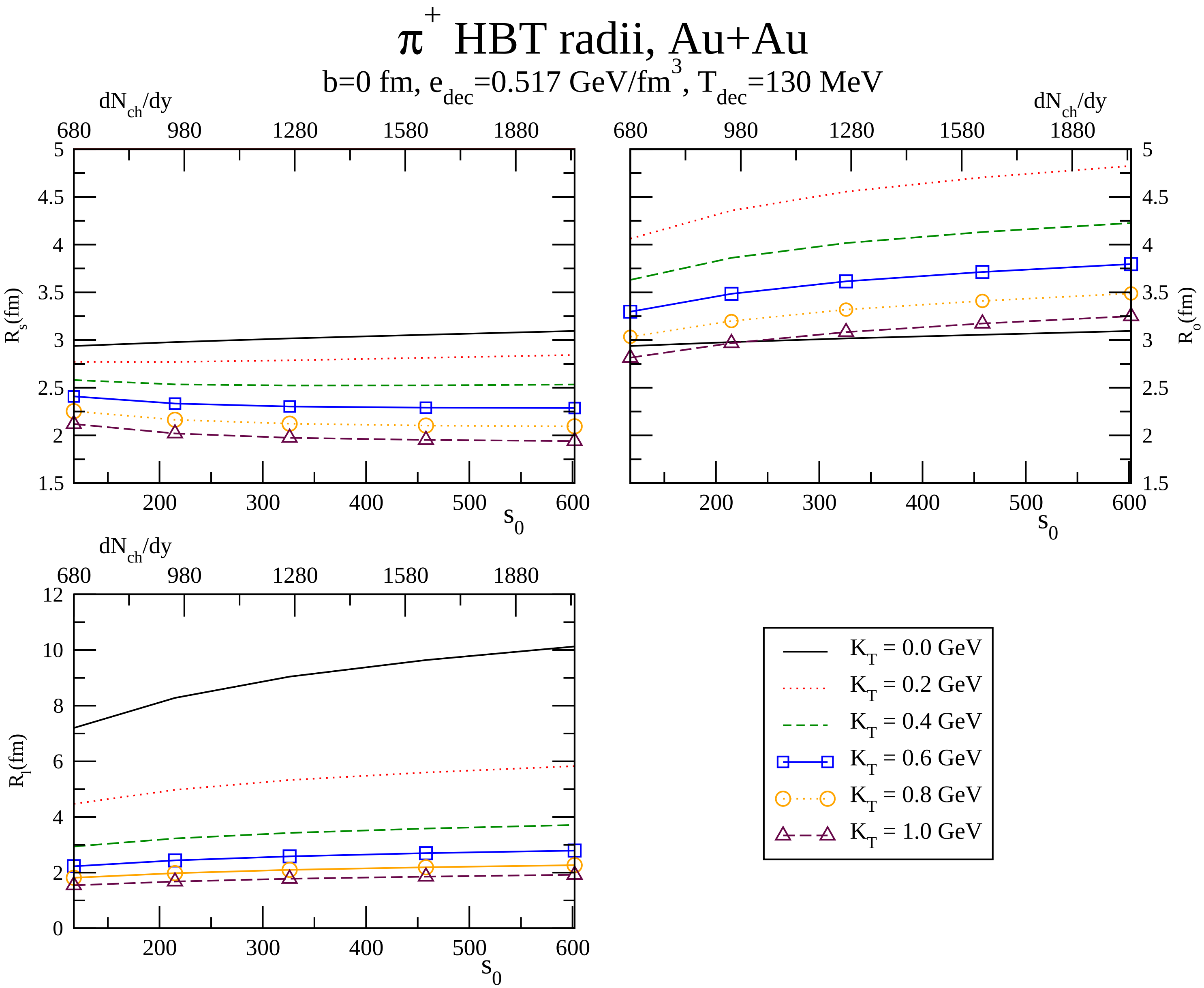
$T_{\rm dec} = 80$ MeV



$25 - 30\%$ increase in R_l,
$10 - 15\%$ increase in R_o,
$< 10\%$ increase in R_s.

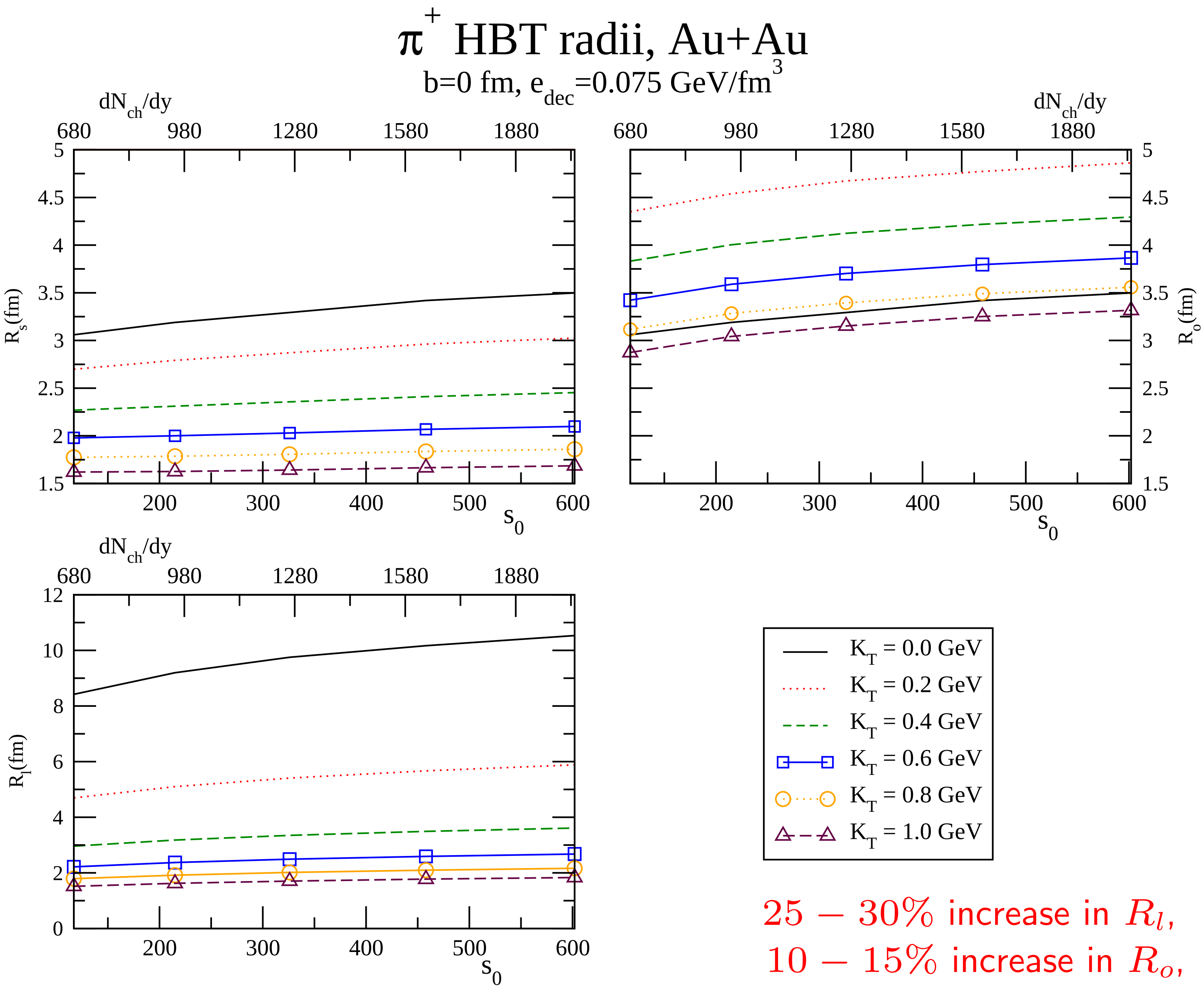
HBT radii for $b=0$: $\sqrt{s}$-dependence

Evan Frodermann



HBT radii for $b = 0$: $\sqrt{s}$-dependence

$T_{\rm dec} = 80$ MeV



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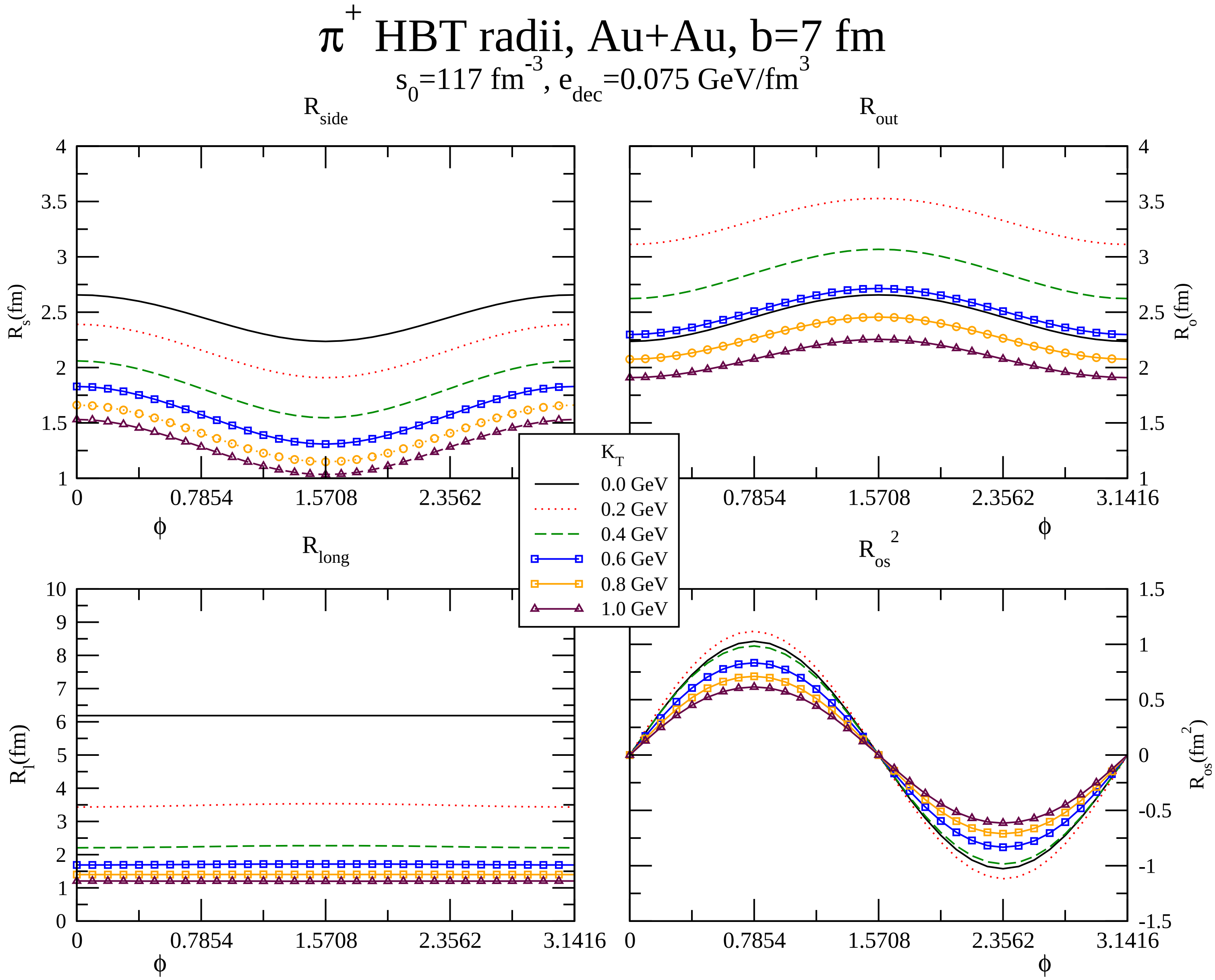
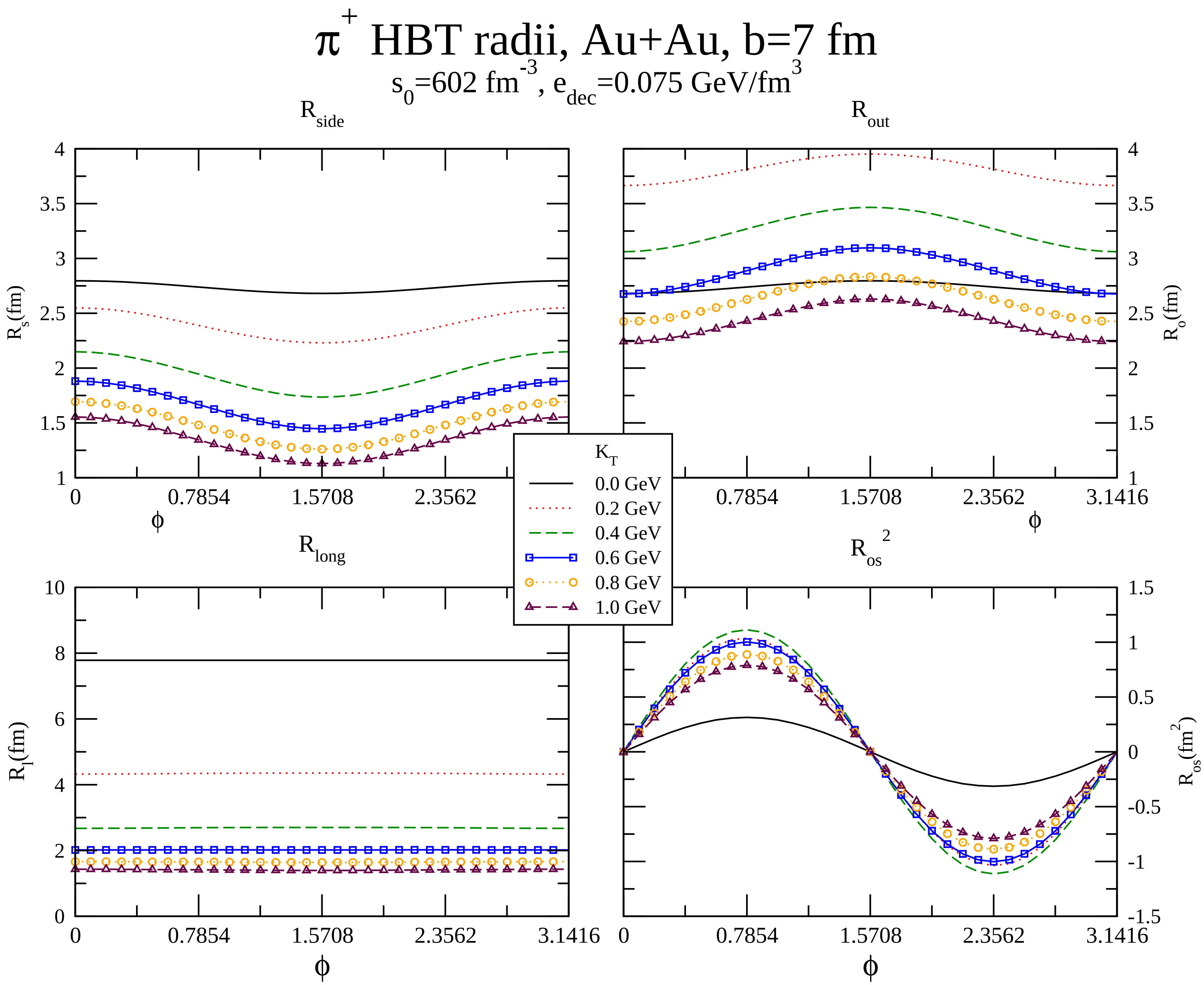
HBT oscillations for Au+Au at b=7 fm: RHIC

Evan Frodermann



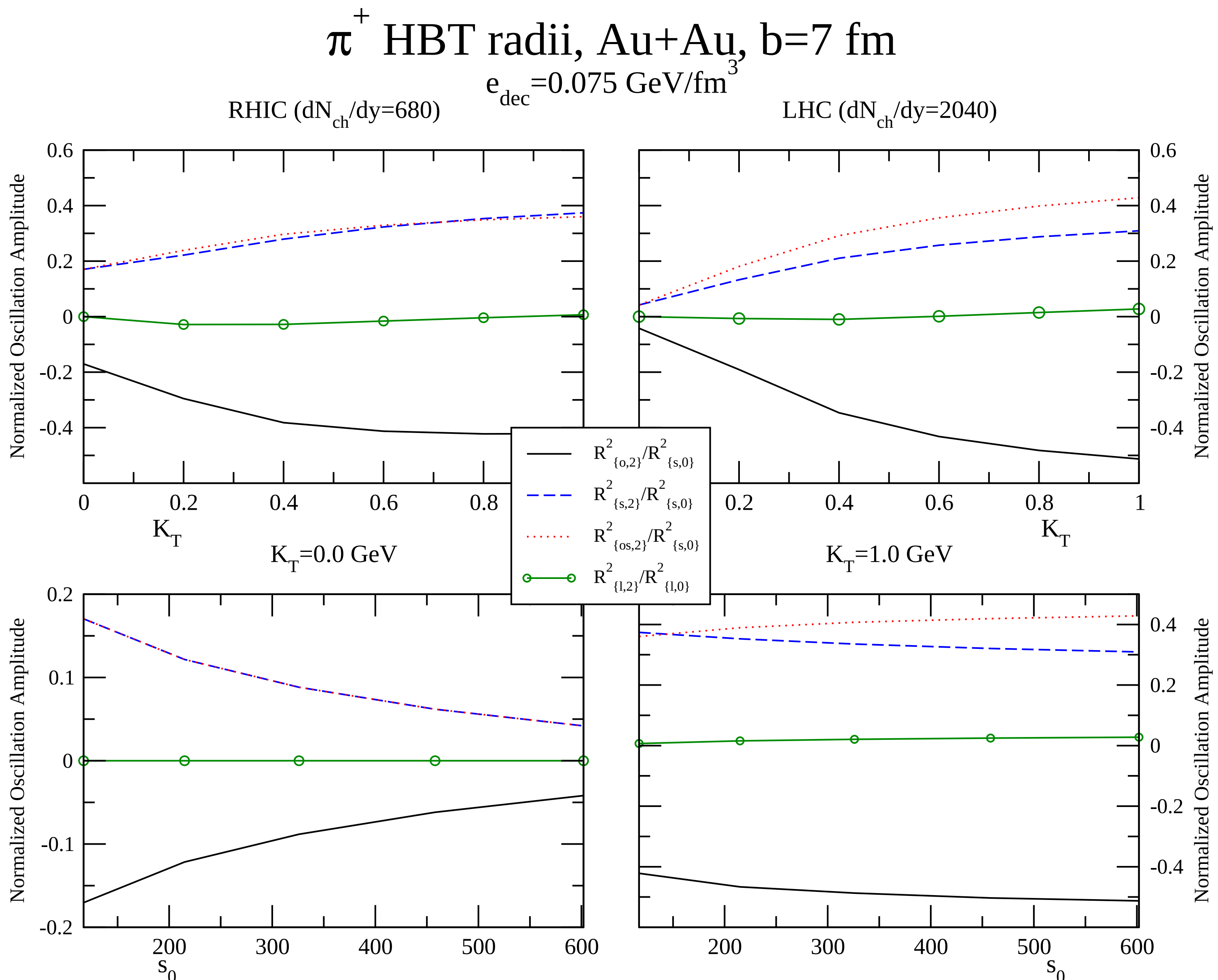
HBT oscillations for Au+Au at b=7 fm: LHC

Evan Frodermann



Normalized HBT oscillation amplitudes

(Lisa & Retiere 2003)



Eccentricity at pion freeze-out decreases from RHIC to LHC to almost zero!

Summary of hydrodynamic predictions

- Charged hadron v_2 increases by at most 20% from RHIC to LHC (mostly due to elimination of hadronic dissipation effects, very little increase in ideal fluid v_2)
- Inverse pion slope increases by $\sim 20\%$ from RHIC to LHC due to larger radial flow.
- Pion v_2 at fixed p_T decreases from RHIC to LHC (by $\simeq 50\%$ at $p_T = 200\,\text{MeV}/c$, by a few % at $p_T = 1\,\text{GeV}/c$.)
- Thermal photon v_2 from QM increases by up to a factor 2 between RHIC and LHC, leading to significant (up to 50%, depending on p_T) increase of total photon elliptic flow.
- HBT radii change very little between RHIC and LHC (increases of 25-30% for R_l, 10-15% for R_o, $< 10\%$ for R_s at K_T=0, less at higher K_T).
- Azimuthal HBT oscillations decrease dramatically at low K_T, since freeze-out source becomes almost round in Pb+Pb at LHC.