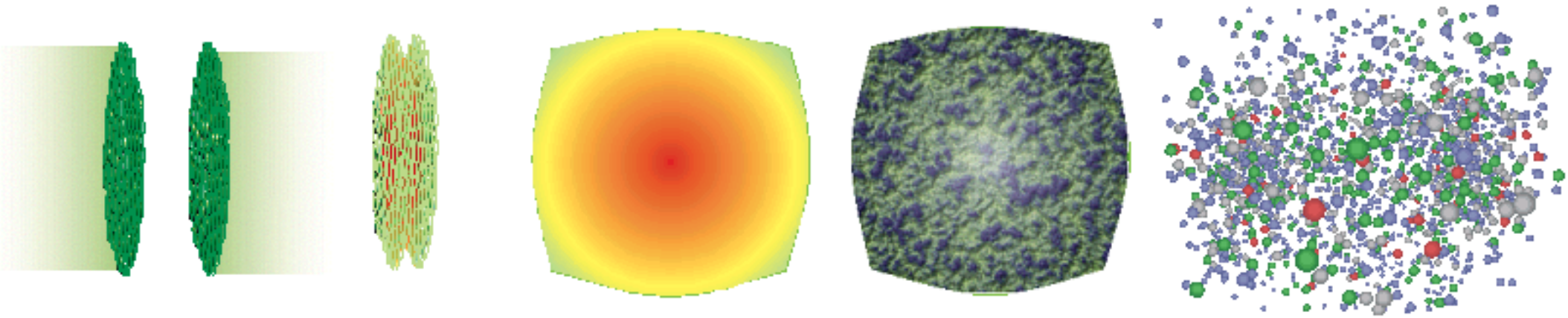
Theory at the RIKEN/BNL Research Center

Cartoon of heavy ion collisions at high energy:

(Now: RHIC @ BNL, LHC @ CERN. Future: FAIR @ GSI, NICA...)



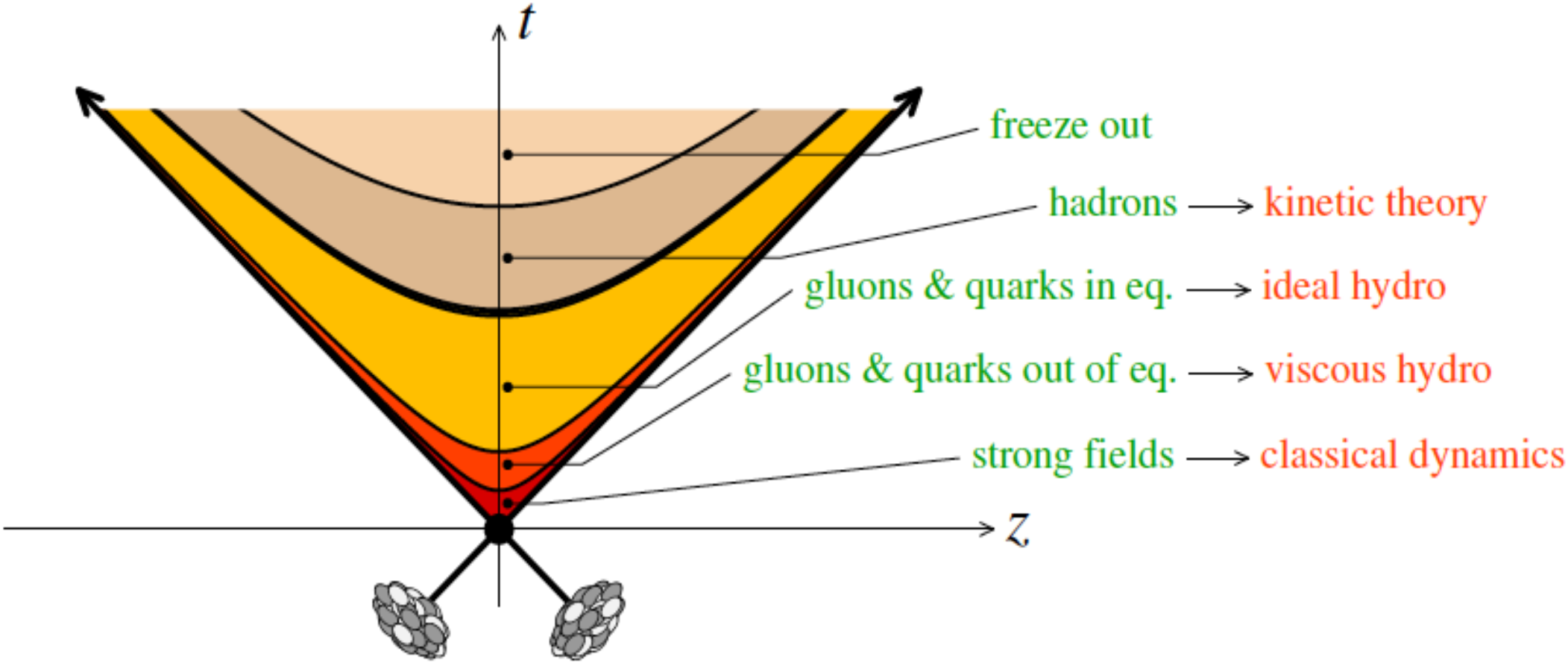
initial state "Glasma" "Quark-Gluon Plasma" hadrons

Initial state: Color Glass Condensate

Glasma: intermediate state

Quark-Gluon Plasma (QGP): thermalized state? Strongly interacting?

Another cartoon of heavy ion collisions



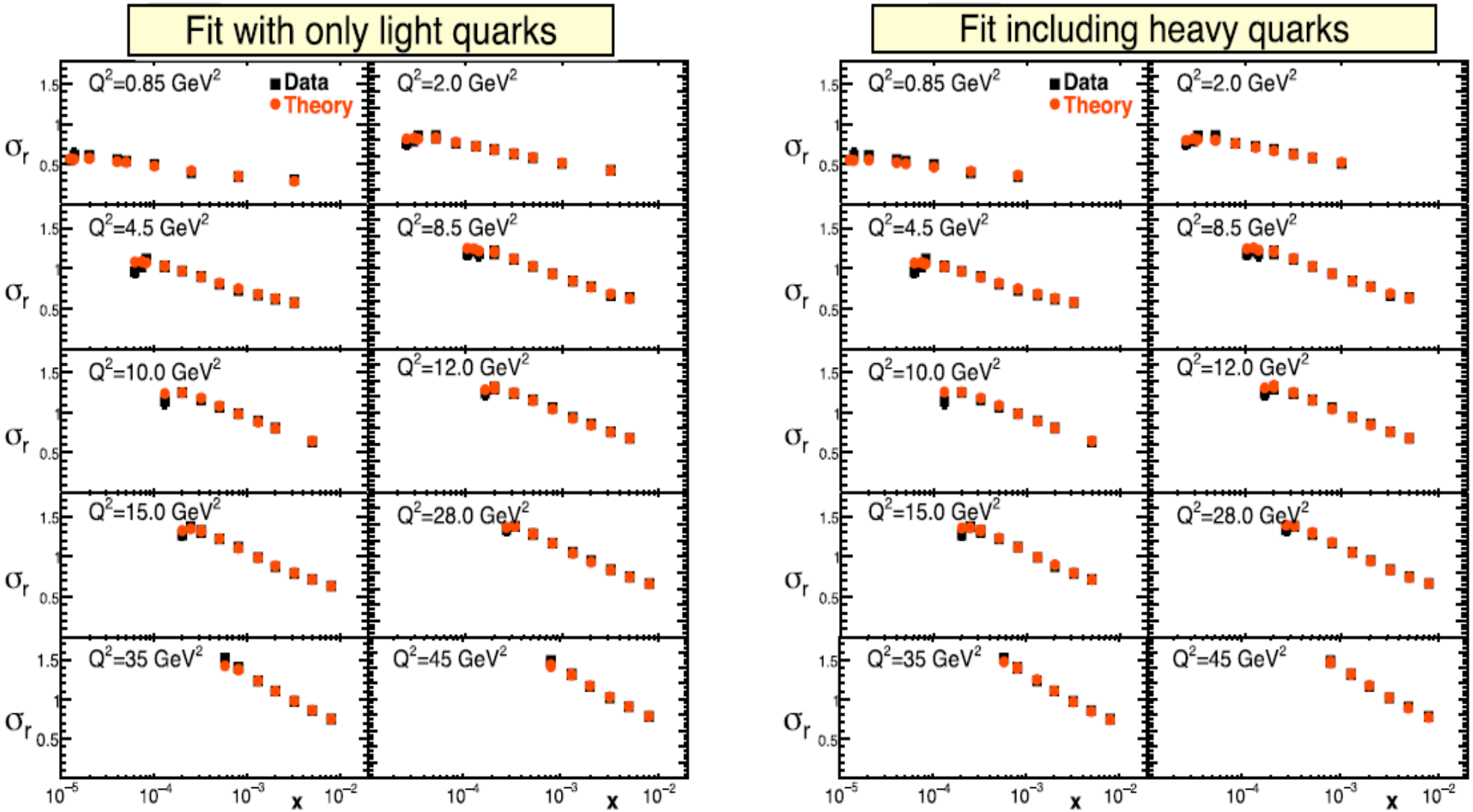
Color Glass Condensate (CGC): high gluon density, dominate at high energy

Glasma: coherent gluons, turbulently evolve into thermal QGP, produce quarks

Quark-Gluon Plasma (QGP): thermal, incoherent quarks and gluons

Color Glass Condensate

At small x (momentum along beam), gluons dominate.
Below: good description from electron-hadron (protons, hadrons) scattering



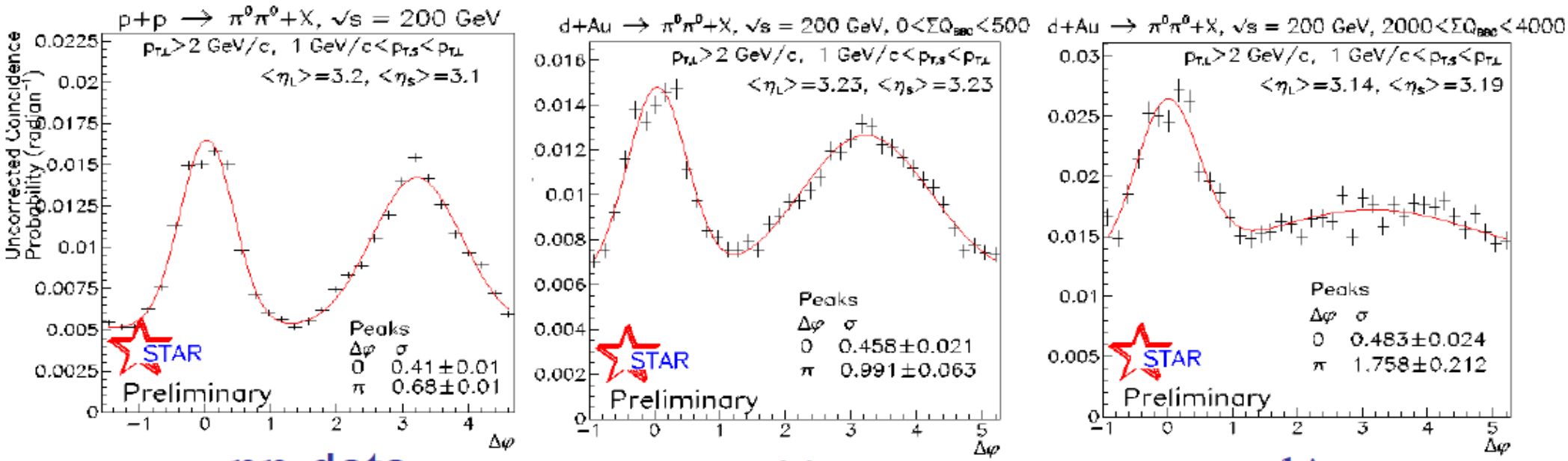
Anna Stasto: Particle production @ RHIC

Production of particles at forward rapidity (along the beam direction) in nucleus-nucleus (AA) and proton-neucleus (d A) at RHIC using Color Glass Condensate

Comparison to data from STAR @ RHIC:

Leading P_T $\pi^0 > 2$ GeV

arXiv:1005.2378



pp data

dAu peripheral

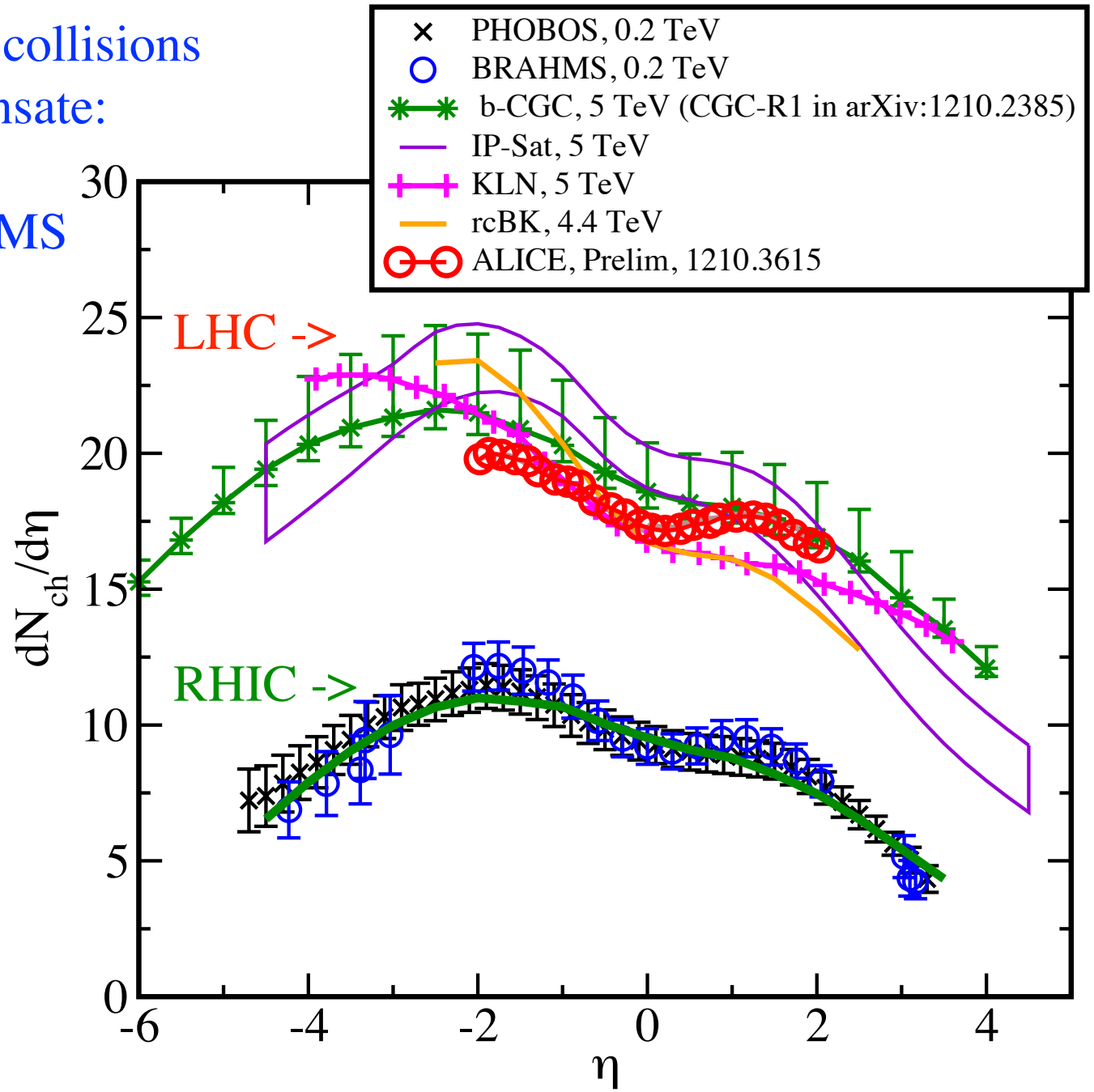
dAu central

Adrian Dumitru: Particle production @ RHIC & LHC

Particle production in dA collisions using Color Glass Condensate:

RHIC: PHOBOS, BRAHMS

LHC: ALICE

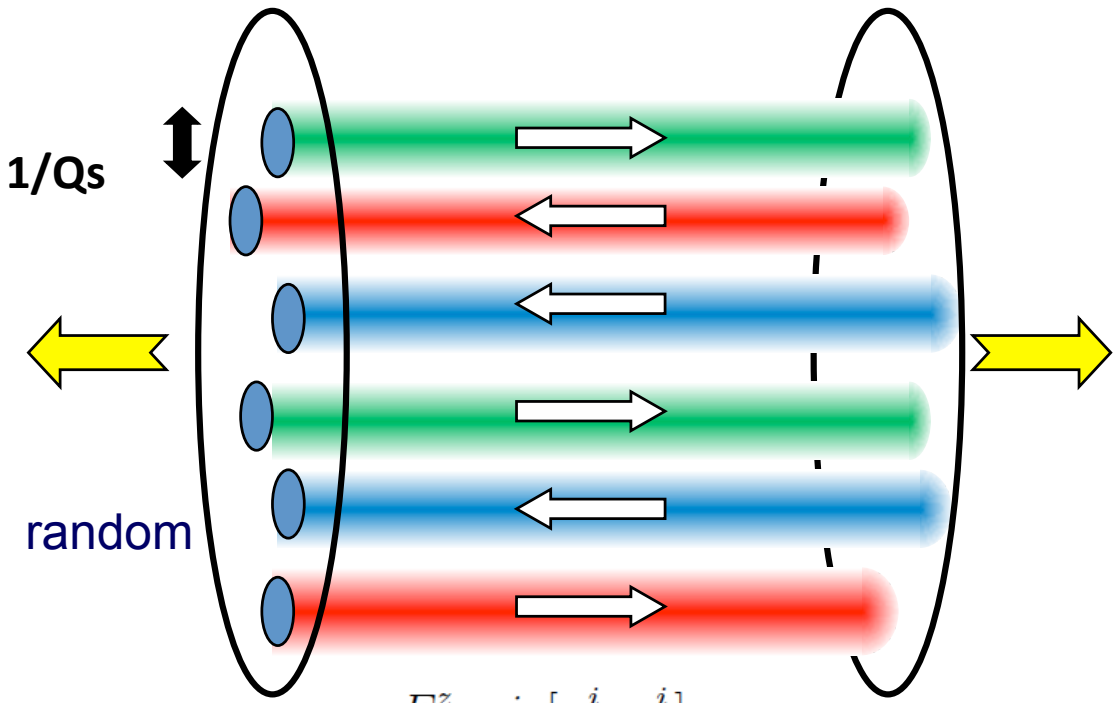


Glasma: getting to the QGP

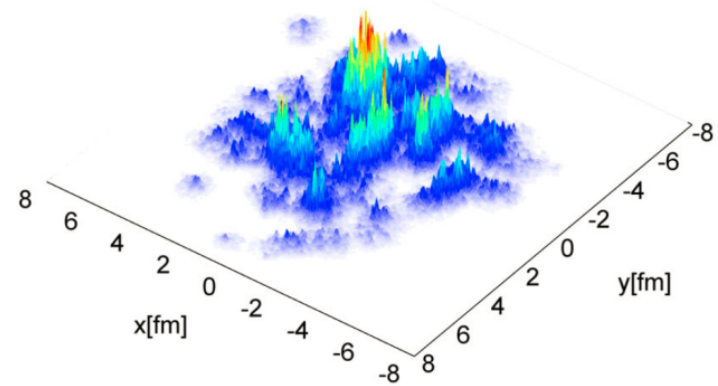
Glasma = coherent colored fields
Stringlike along beam direction
Stochastic transverse to beam

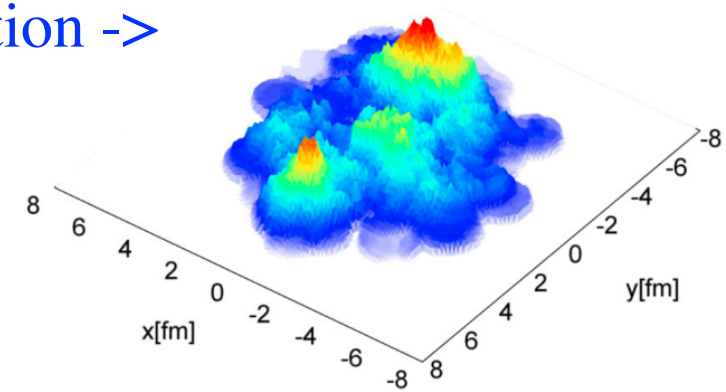
Multiplicity: negative binomial distribution

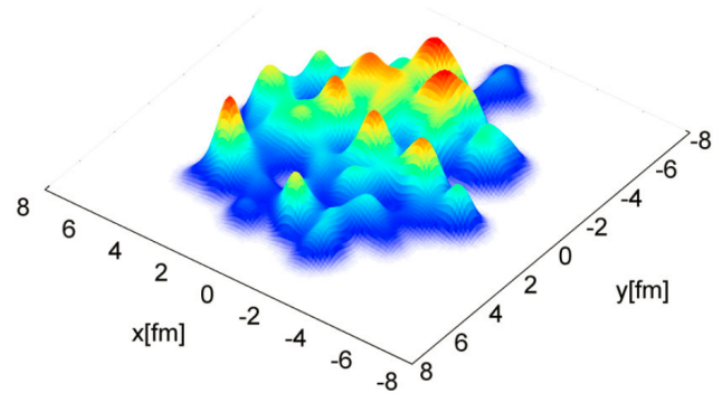
Right: evolve from lumpy to smooth distribution ->



$$E^z = ig[\alpha_1^i, \alpha_2^i]$$
$$B^z = ig\epsilon^{ij}[\alpha_1^i, \alpha_2^j].$$

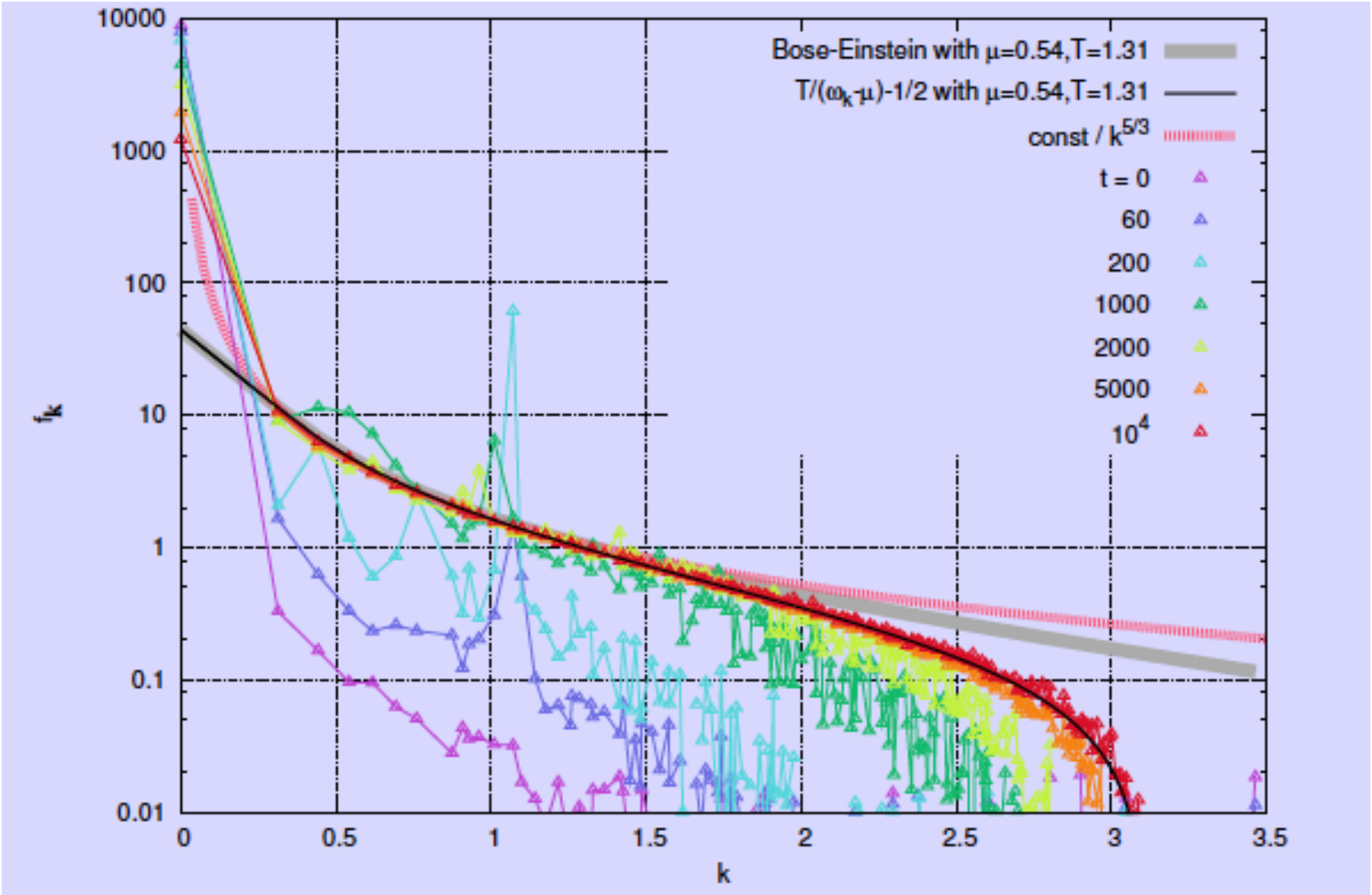






Jinfeng Liao: evolution of glasma

Evolution from Color Glass to QGP: study with classical evolution
Initially, coherent and cutoff scale same, saturation momentum
Thermal distribution: coherent ~ coupling x cutoff scale
Novel physics: Bose-Einstein condensation? Gluon chemical potential?

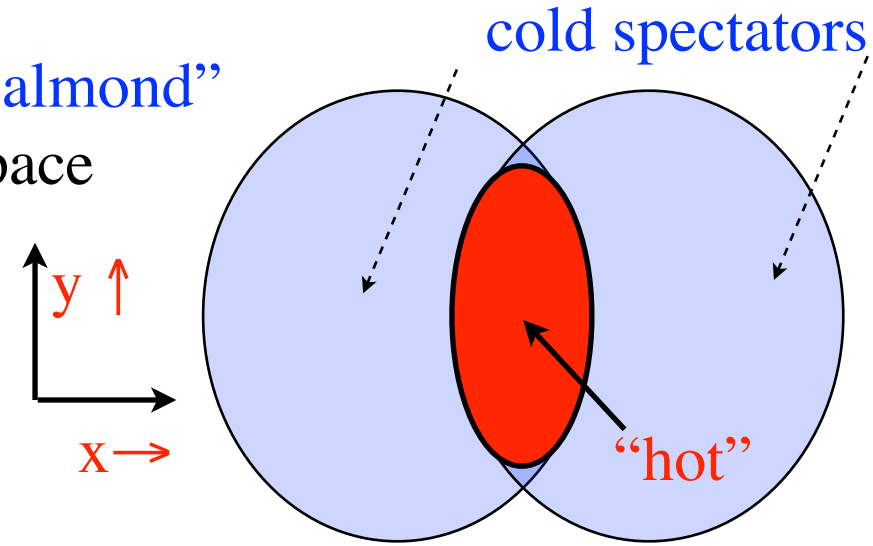


Searching for the Quark-Gluon Plasma

Before RHIC: mythical creature?
After RHIC & LHC: bountiful evidence for a new state of matter
Concentrate here on unexplained puzzles

"Elliptic Flow"

For peripheral collisions, overlap region is "almond" in coordinate space, sphere in momentum space



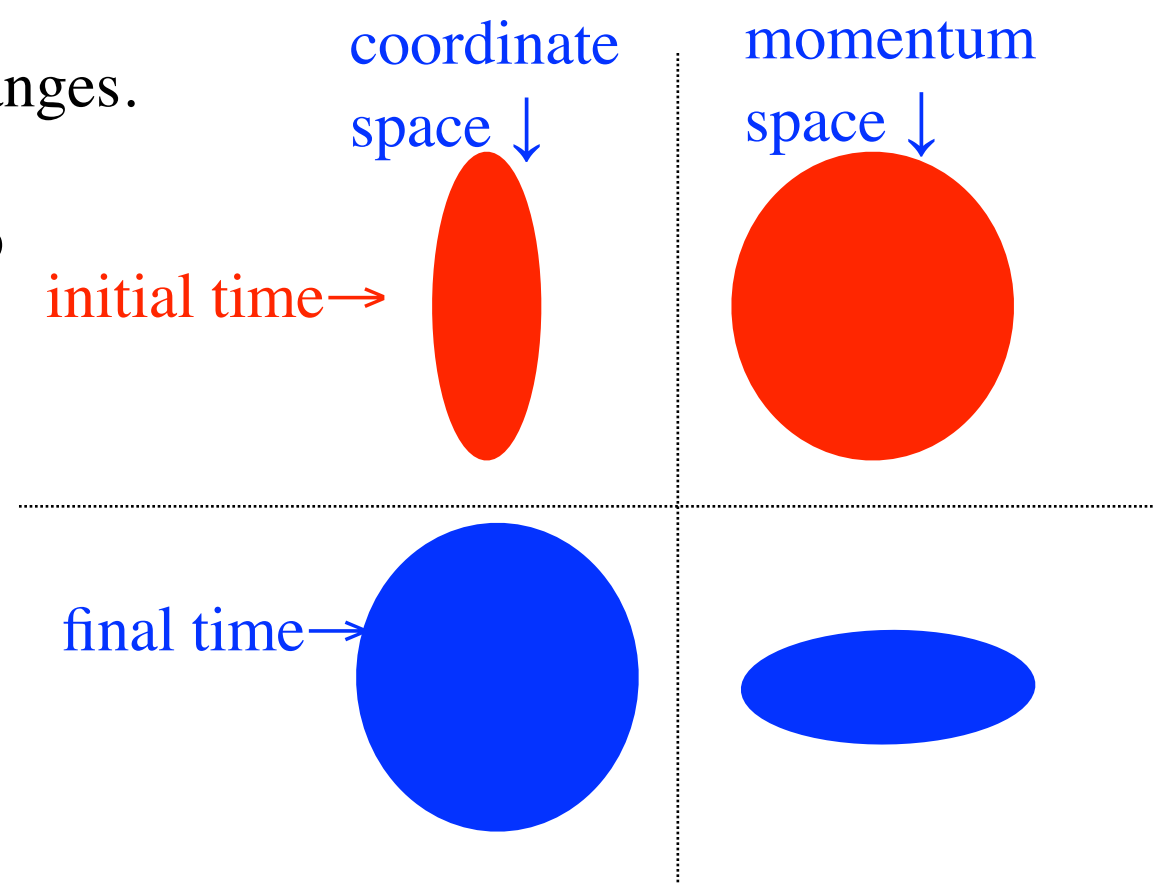
So start with spatial anistropy,

$$\epsilon = \frac{\langle y^2 - x^2 \rangle}{\langle x^2 + y^2 \rangle}$$

If particles free stream, nothing changes.

If collective effects present, end up with sphere in coordinate space, almond in momentum space: "elliptic flow"

$$v_2 = \frac{\langle p_y^2 - p_x^2 \rangle}{\langle p_x^2 + p_y^2 \rangle}$$



Rainer Fries: photons from heavy ion collisions

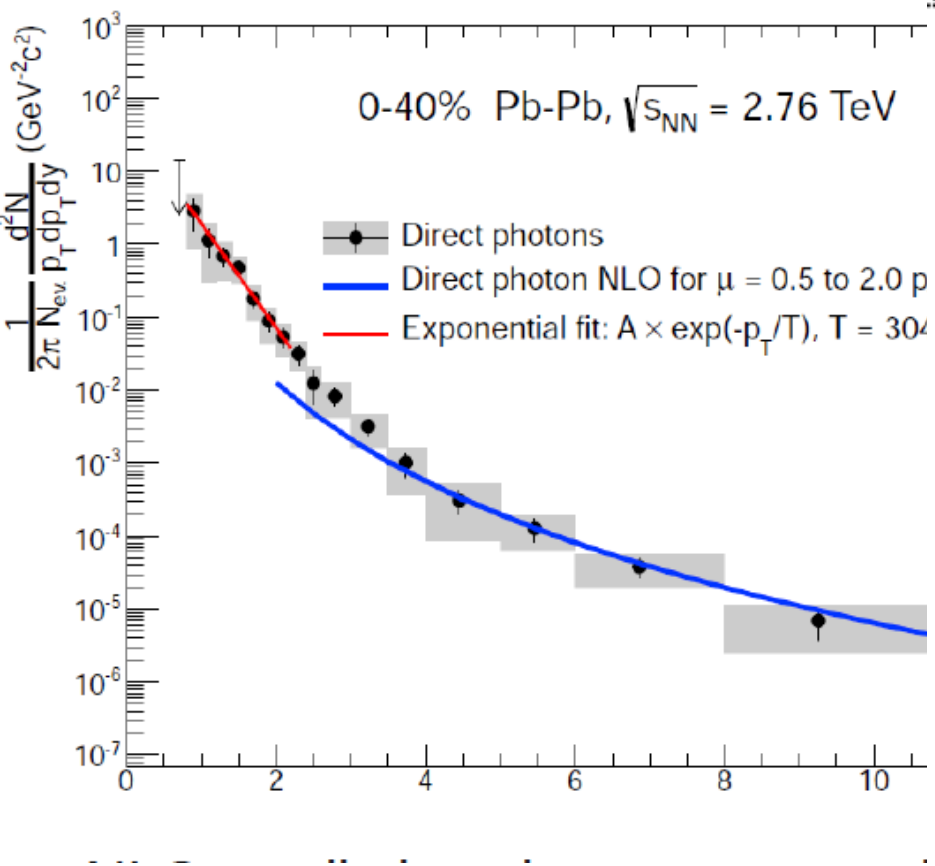
Observe excess of photons at low (transverse) momentum: thermal?

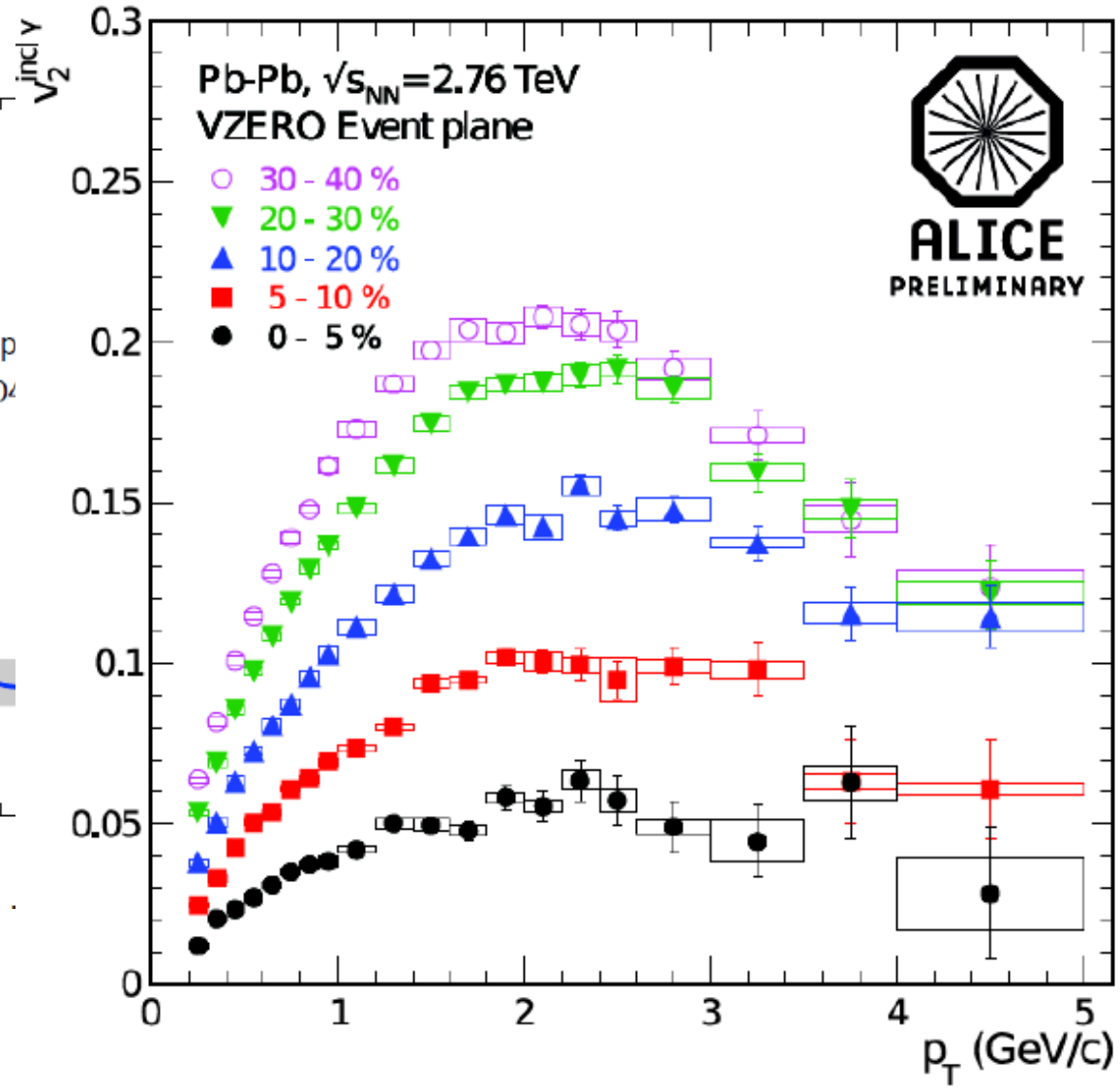
Peripheral collisions: hadrons "flow" (spatial anistropy -> momentum anistropy)

Photons flow as much as hadrons! Does *not* agree with hydro!

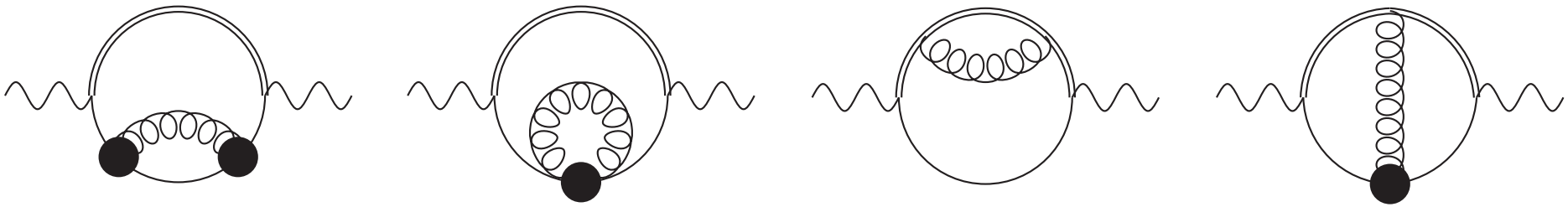
Left: photon excess, ALICE @ LHC

Right: photon "flow" - too big!





Derek Teaney: production of thermal photons

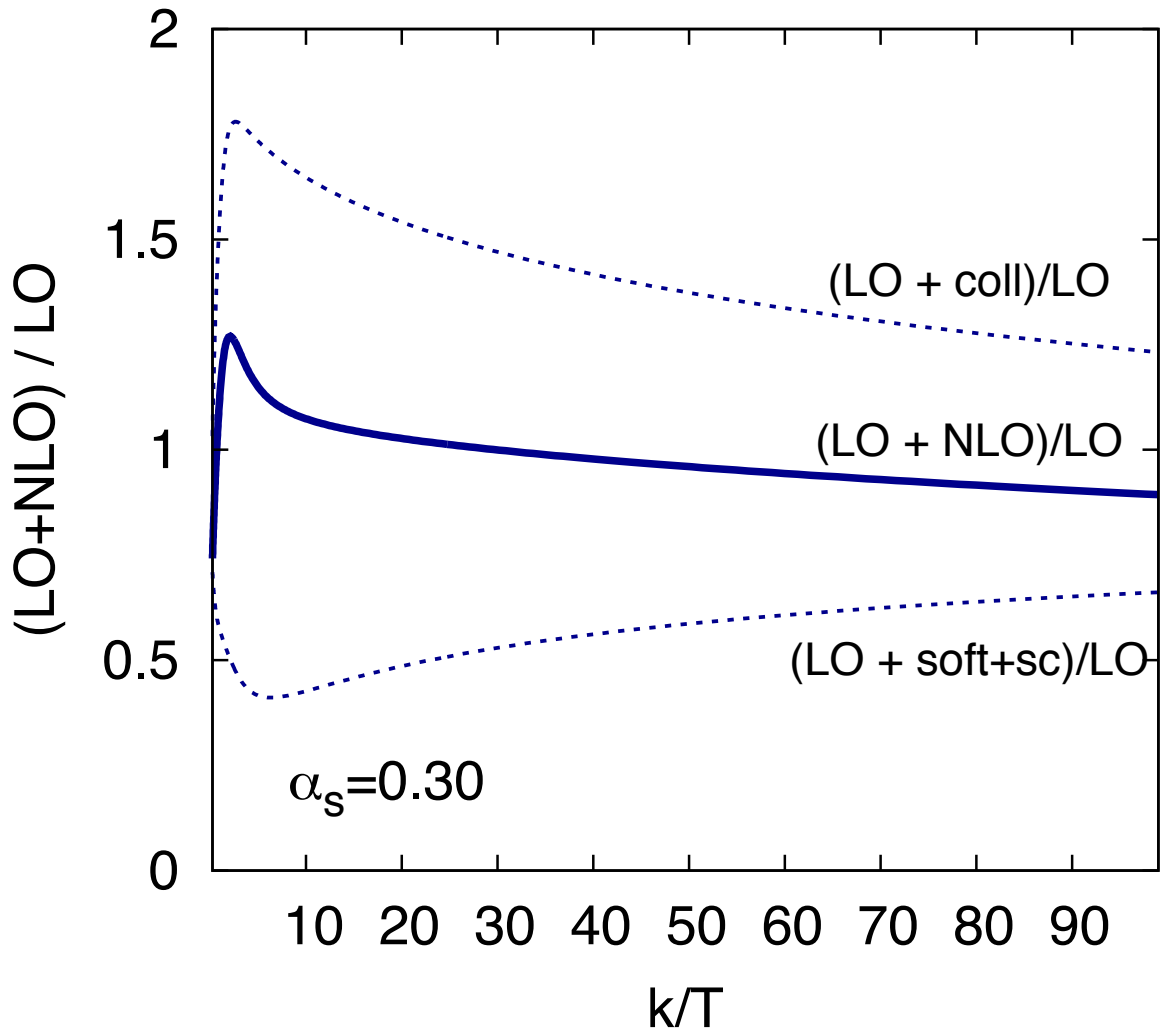


Compute in perturbation theory:
go from Leading Order (LO)
to Next to Leading Order (NLO)
in coupling constant

Heroic computation: many
diagrams, need to resum, etc

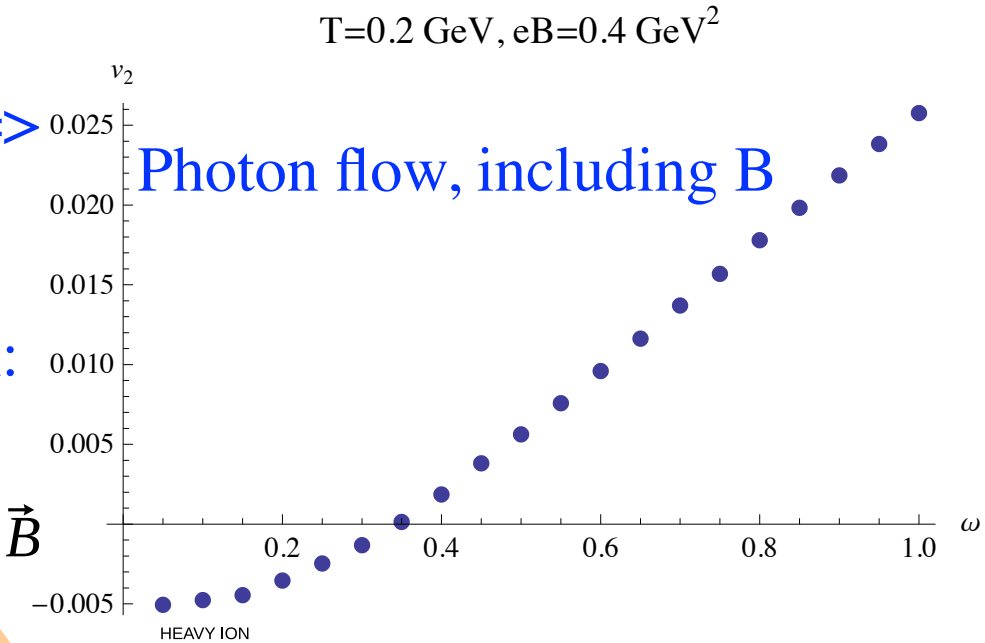
Find: complete results
very insensitive to perturbative
corrections!

Photon puzzle remains



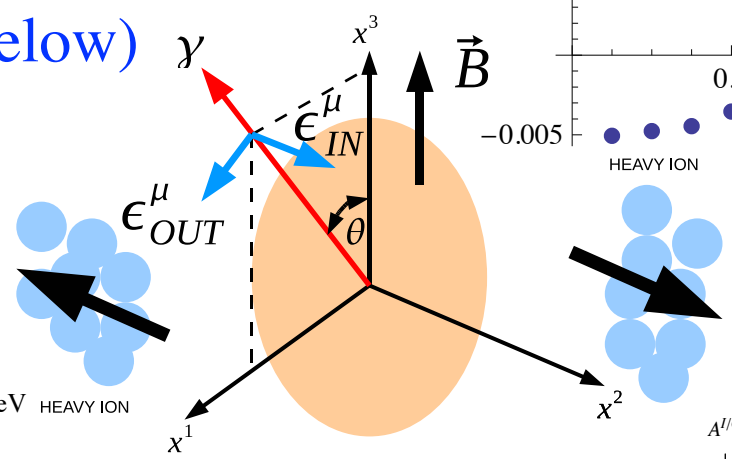
Ho-Ung Yee: Photons & magnetic fields

Includes effects of magnetic field B through anomaly terms. Photon flow =>

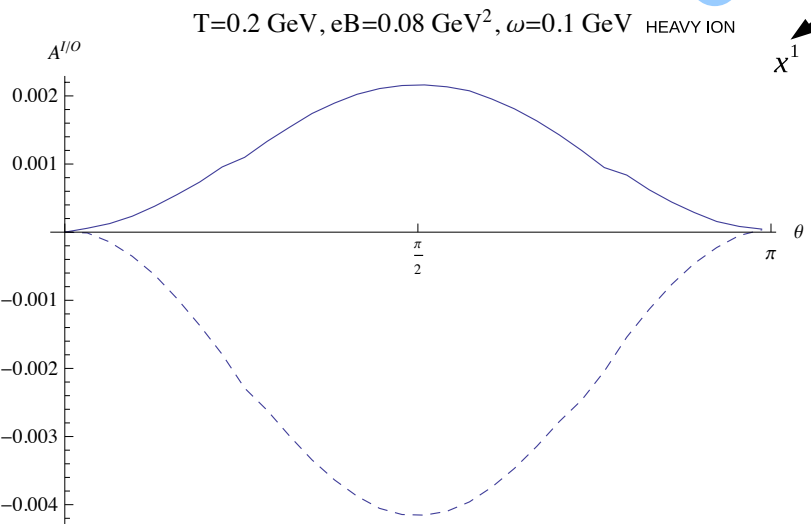


Also predicts energy dependent effects for ratios of photon polarization:

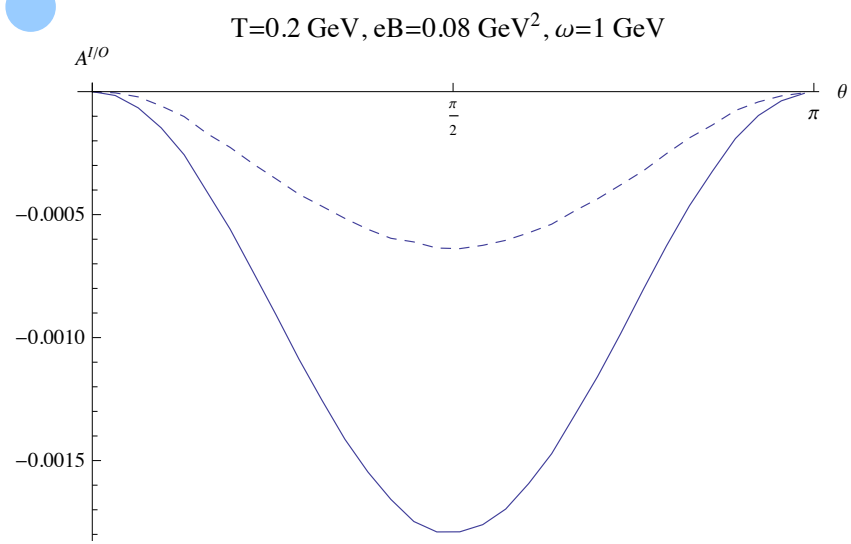
(ignore dotted lines below)



Soft photons

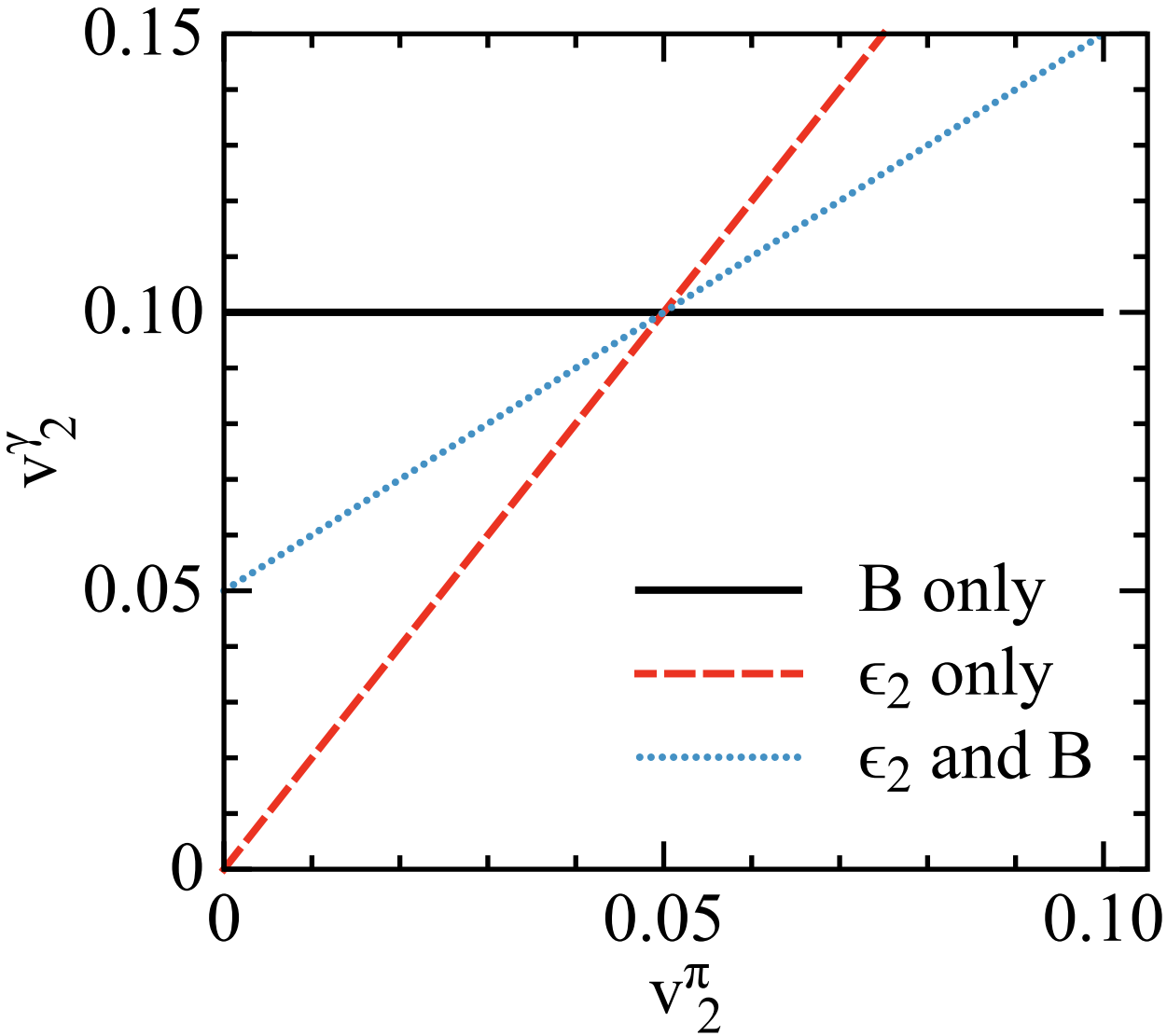


Hard photons



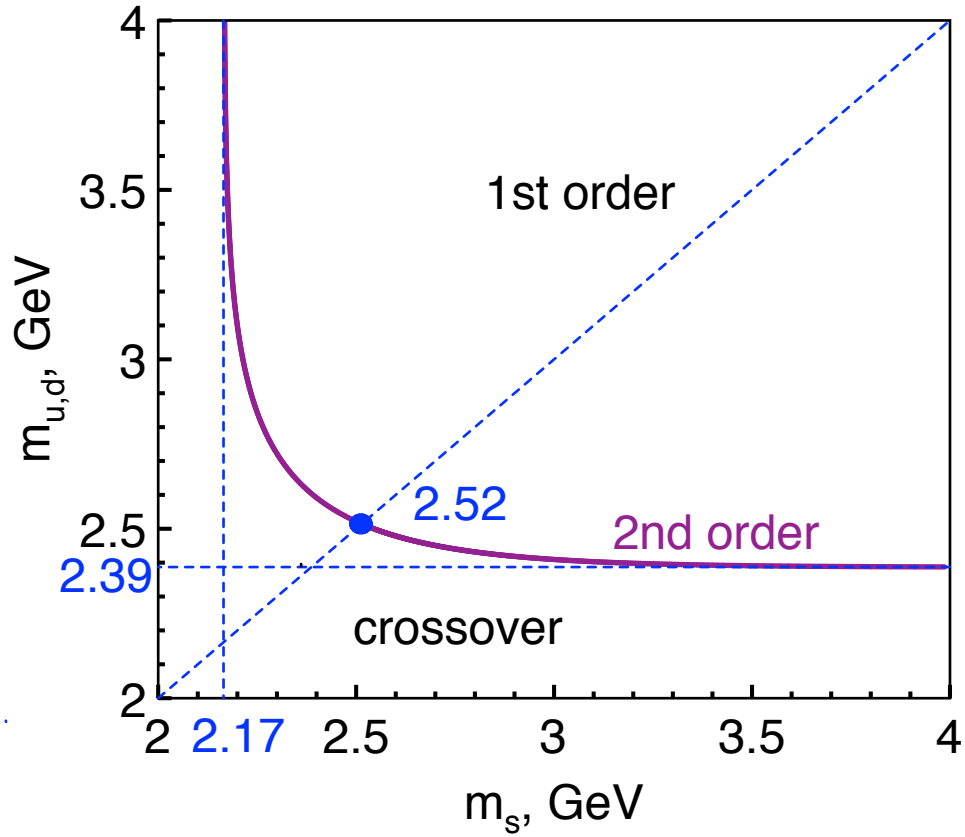
Adam Bzdak: photons, magnetic field & eccentricity

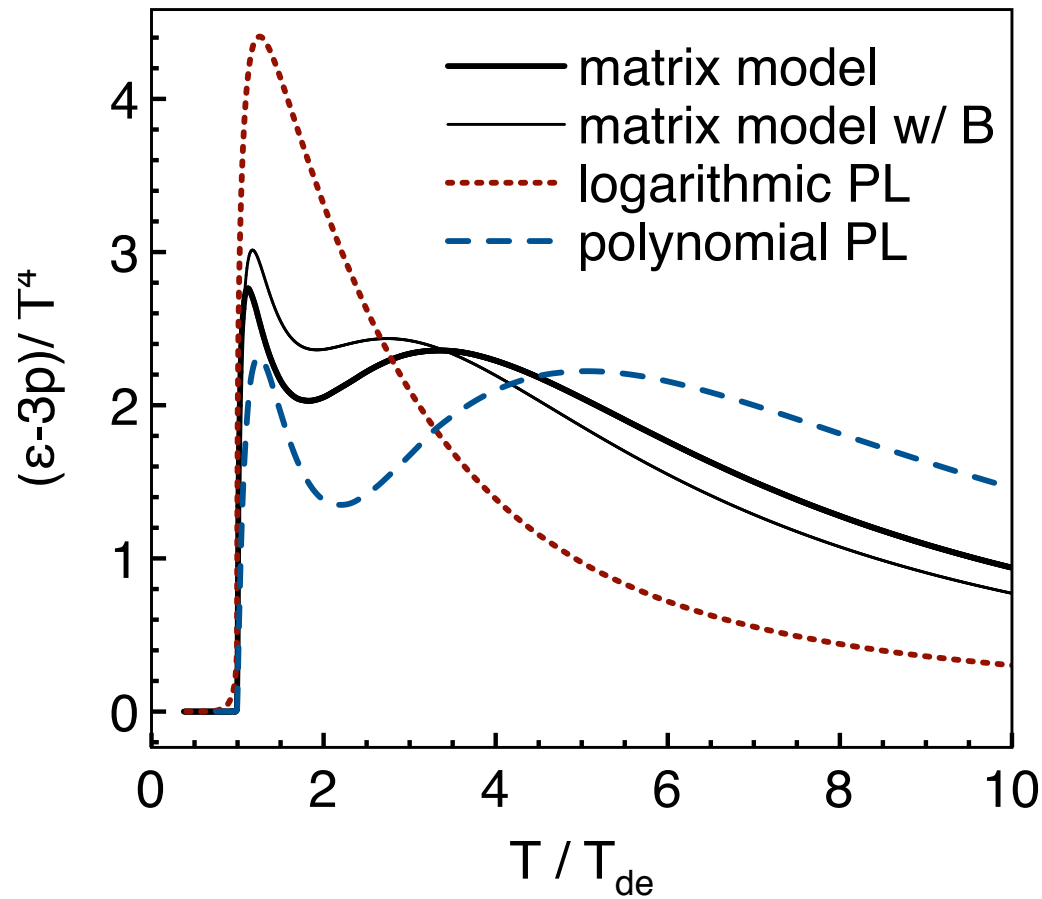
Consider effects of initial magnetic field B and eccentricity
eccentricity = how almond shaped initial state is
Predicts correlation of pion and photon "flow"



Koji Kashiwa: phase diagram for heavy quarks

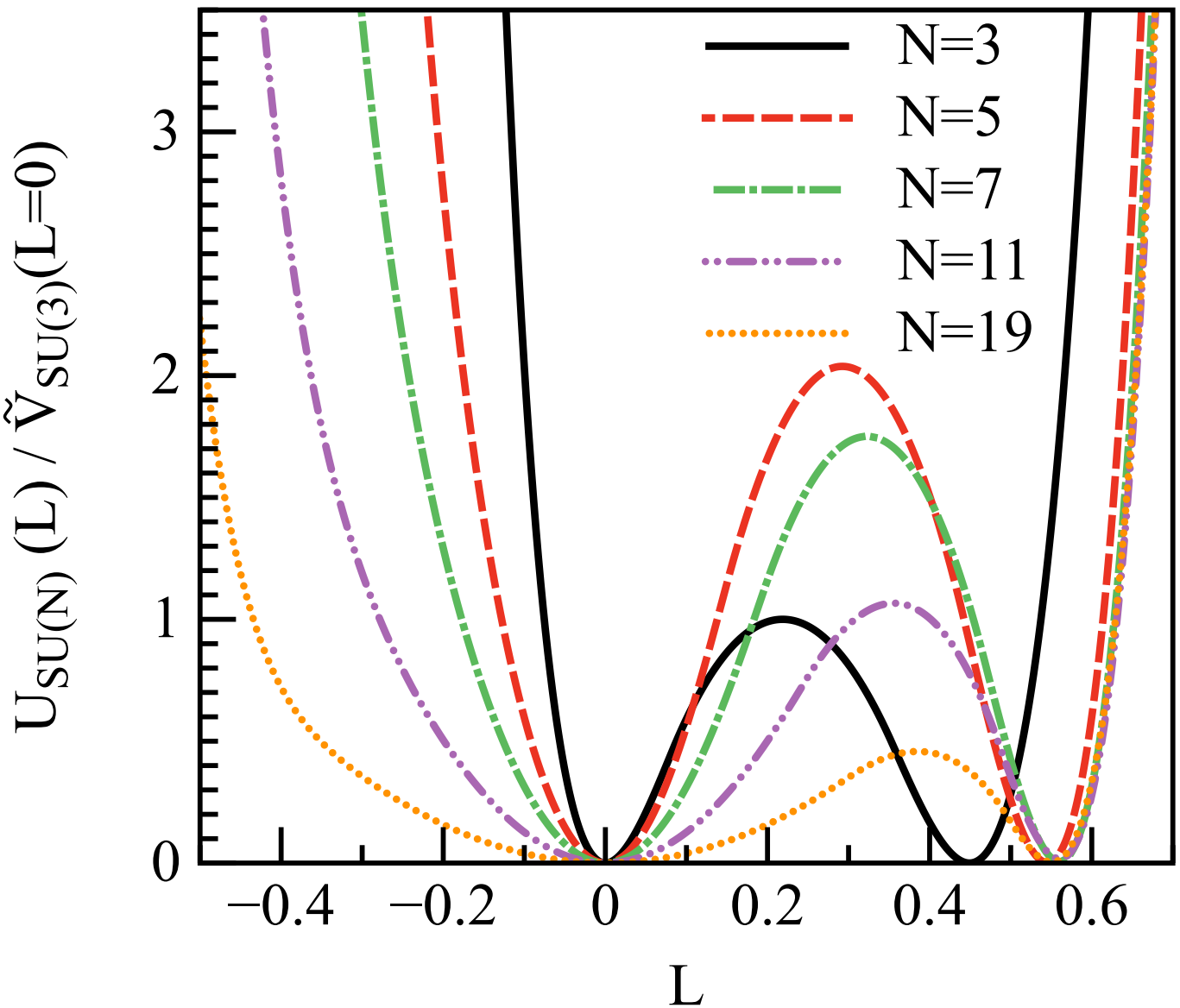
Use matrix model for pure glue to compute phase diagram for heavy quarks
Compute position of "deconfining critical endpoint"; agrees with lattice
Predicts characteristic signal for lattice thermodynamics



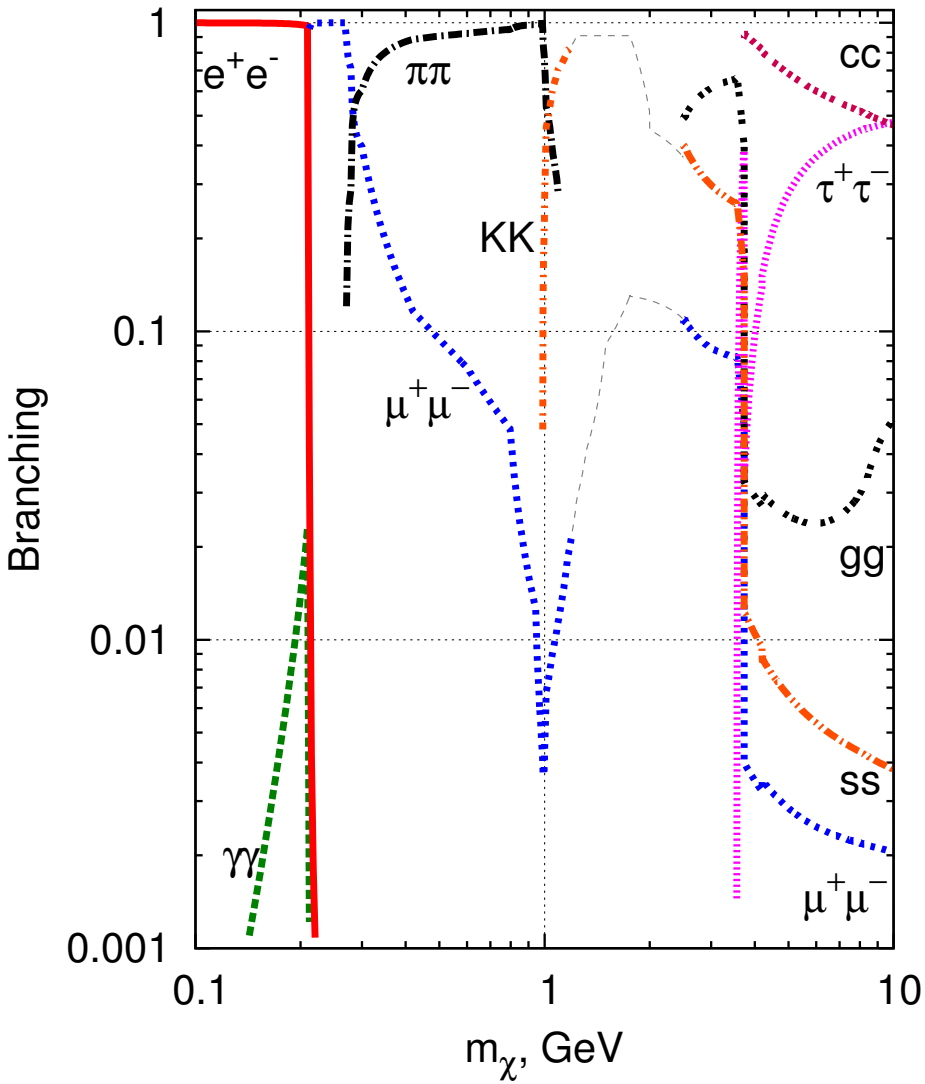
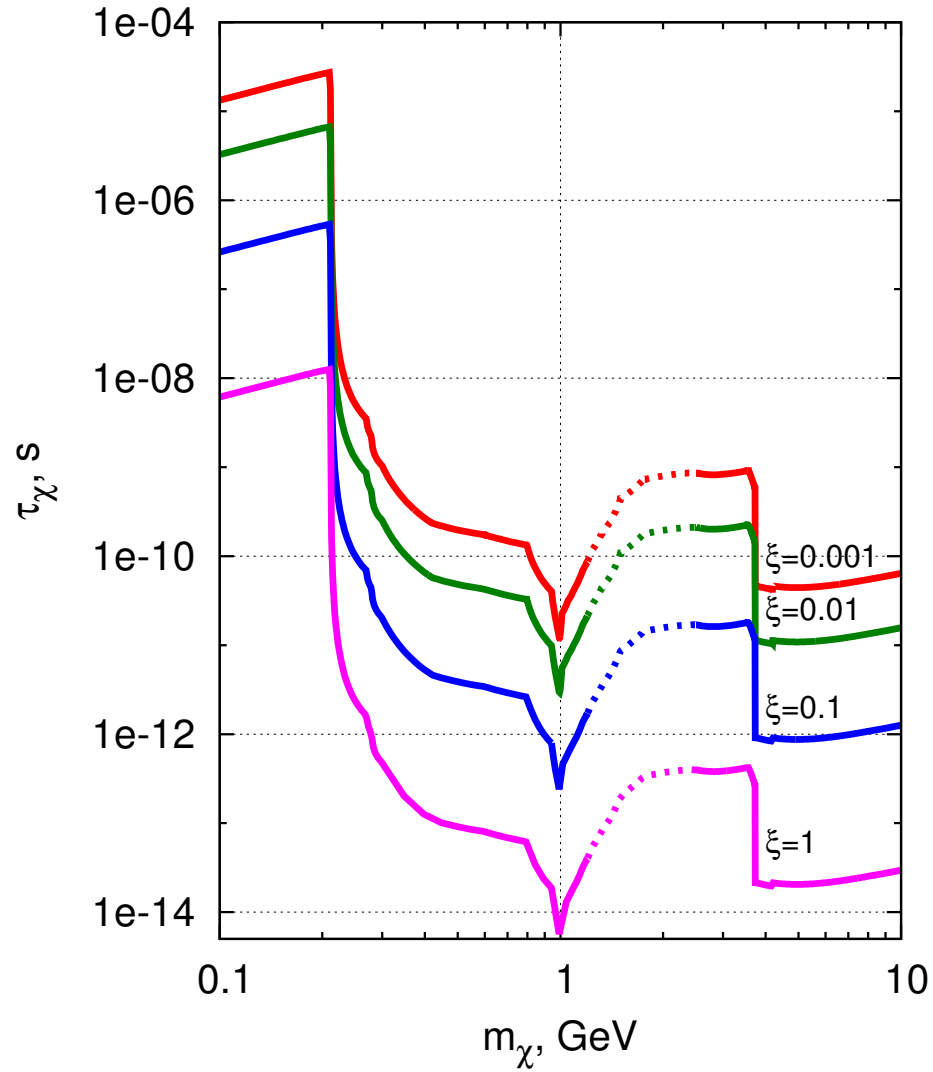


Shu Lin: phase diagram for heavy quarks

Use matrix model to compute interface tensions in SU(N) for large N
Predicts first order transition, but with *zero* interface tensions
Suggests novel transition at infinite N



Fedor Bezrukov: Light inflaton

Inflaton potentials, using data from LHC and WMAP

Below: branching ratios (left) and lifetime (right, seconds) for inflation ~ 1 GeV