Heavy Ion Physics and the Forward Upgrades

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UCR
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slides stolen liberally from:
Bill, Axel, Ken, Yasuyuki, Larry,…

“Fundamental Questions” from LRP

- In relativistic heavy-ion collisions, how do the created systems evolve?
  Does the matter approach thermal equilibrium?
  What are the initial temperatures achieved?
- Can signatures of the deconfinement phase transition be located as the hot matter produced in relativistic heavy-ion collisions cools?
  What is the origin of confinement?
- What are the properties of the QCD vacuum and w at are its connections to the masses of the hadrons?
  Wh
- Wh
  der
  Is the basic idea that this is best described using fundamental quarks and gluons correct?

Where are we?
the PHENIX White Paper

Do central Au+Au collisions produce a dense state of matter?

- **Answer: *Yes***

Evidence 1: ***Jet suppression*** in Au+Au collision

- Suppression of high p_T particles in Au+Au
- Jet origin of high p_T particles demonstrated by two particle correlation and x_T scaling
- Absence of suppression in d+Au
- T_{AB} scaling of direct photon and charm yield in Au+Au

These observations provide a direct evidence that ***dense*** matter formed in the final state is the cause of the suppression.

Evidence 2: Strong ***elliptic flow***

- Scaling of v2 with eccentricity shows that a high degree of collectivity built up at a very early stage of collision.
- Success of hydrodynamic models in reproducing the elliptic flow shows that the state can be well described as fluid – a dense ***state of matter.***

Is it conceivable that the state of matter consisted only of hadrons?

- **Answer: *No***
  - ***$dE_T/d\eta$*** : The lower limit of the energy densities derived are:

    $\varepsilon \geq 15$ GeV/fm^3 at formation - $\tau \leq$ 0.35 fm/c

    $\varepsilon \geq 2.8$ GeV/fm^3 at thermalisation - $\tau \leq 2$ fm/c
  - ***Elliptic Flow***: hydro-models require early thermalization (τ_{therm}<1fm/c) and high initial energy density ε > 10 GeV/fm^3
  - ***Jet suppression***: Initial gluon density dn_g/dy~1000 and initial energy density ε~15 GeV/fm^3 are obtained from GLV model. A similarly high initial energy density is obtained by others.

All these estimates of energy density are well in excess of ~1 GeV/fm^3 obtained in lattice QCD as the energy density needed to form a deconfined phase.

Is the state of matter a QGP?

or a **s**trongly interacting **Q**uark **G**luon **P**lasma?

- **Answer: We don't know.**
  - \+ We know that the matter is *extremely dense* and it *thermalizes very rapidly*. The estimated energy densities are all well in excess of the density needed for a QGP.

But

  - – We currently do not have a consistent model of Au+Au collision that can describe spectra, v_2, and HBT. This prevents us from drawing *quantitative conclusions* on the properties of the matter such as the equation of state and the presence of a mixed phase.

In addition

  - – There is no obvious and common definition of QGP. – no evidence for **QUARKS** and **GLUONS** as the **DEGREES OF FREEDOM**

What now?

Key Scientific Questions

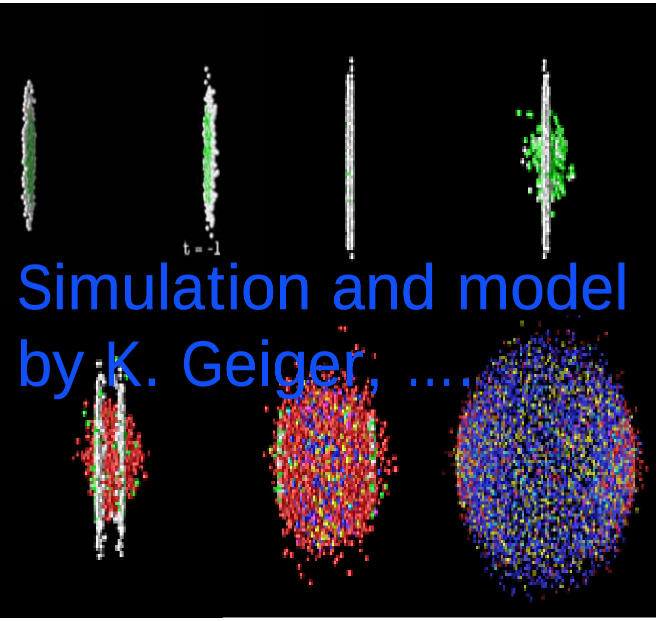
- ***Deconfinement?***
- ***Degrees of freedom?***

new measurements

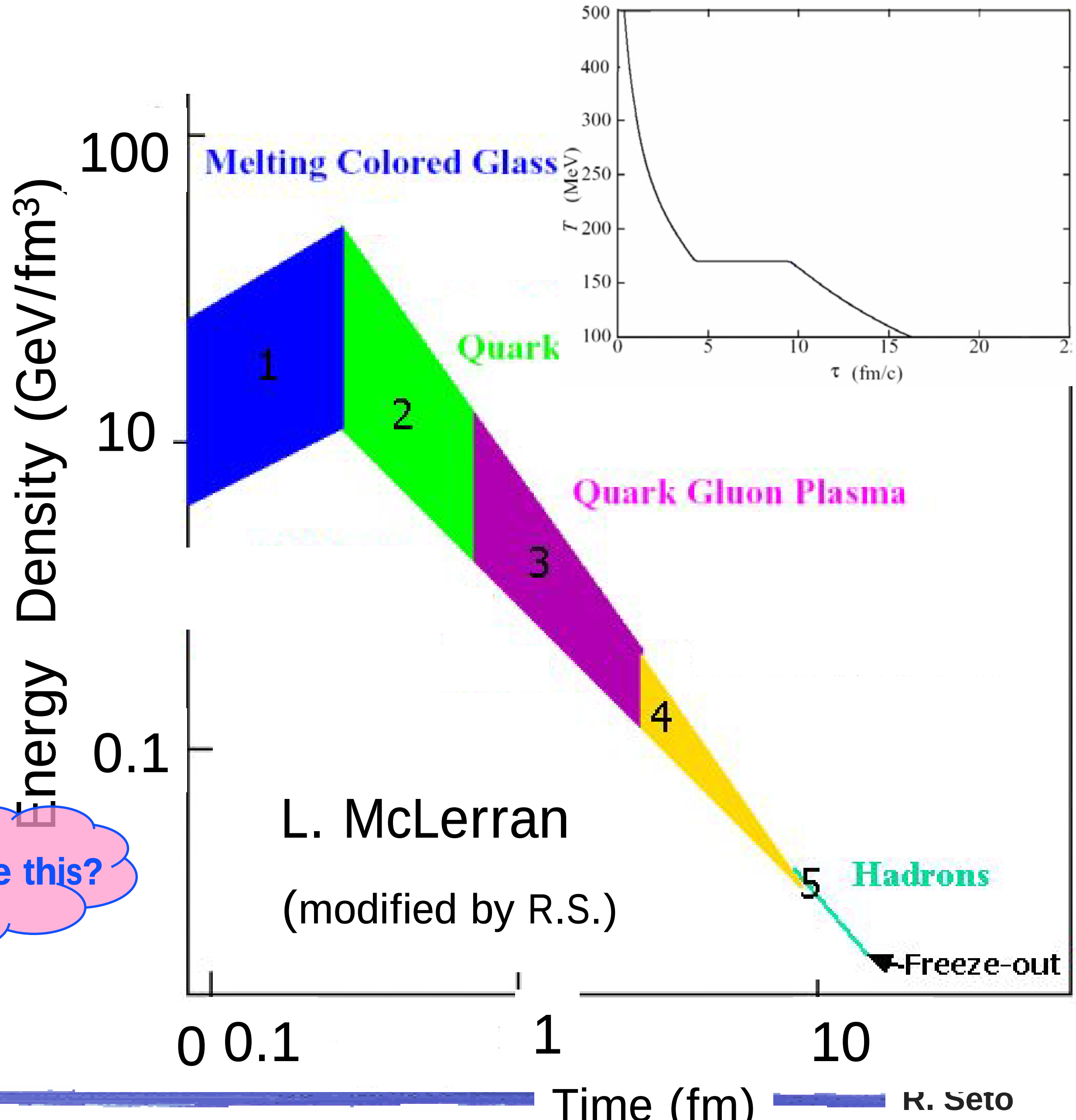
Upgrades

note: we probably don't need all of these to declare "victory"

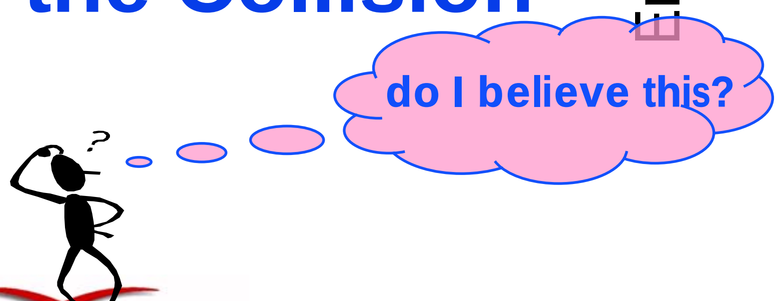
Upgrades in the context of a General Theoretical Picture



Simulation and model by K. Geiger, ….

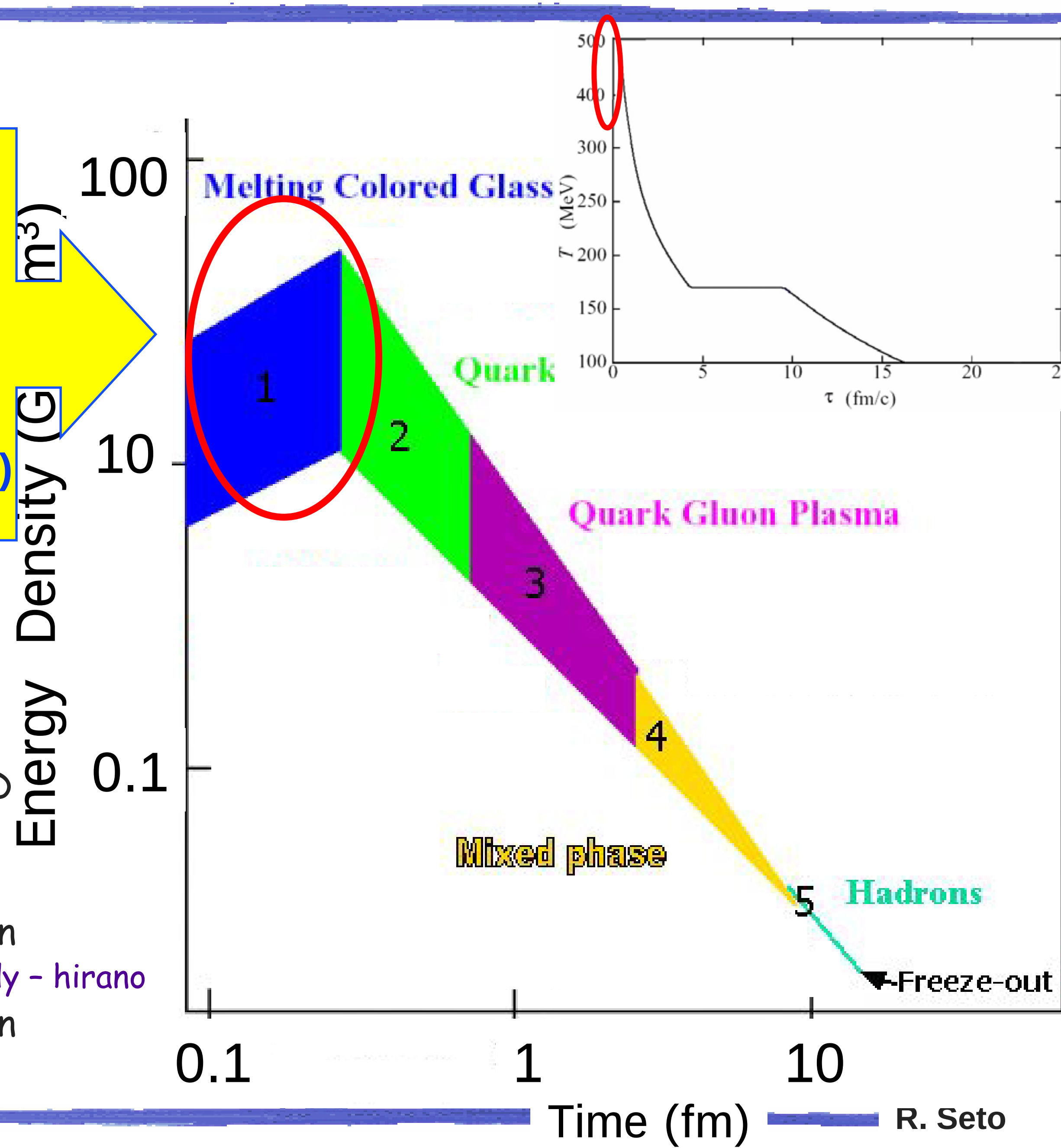


Stages of the Collision



Initial State – a CGC

low-x processes
dA – x,Q²,√s,centrality
high pt photons
jet- high pt hadron
heavy quarks
correlations (back-to-back)

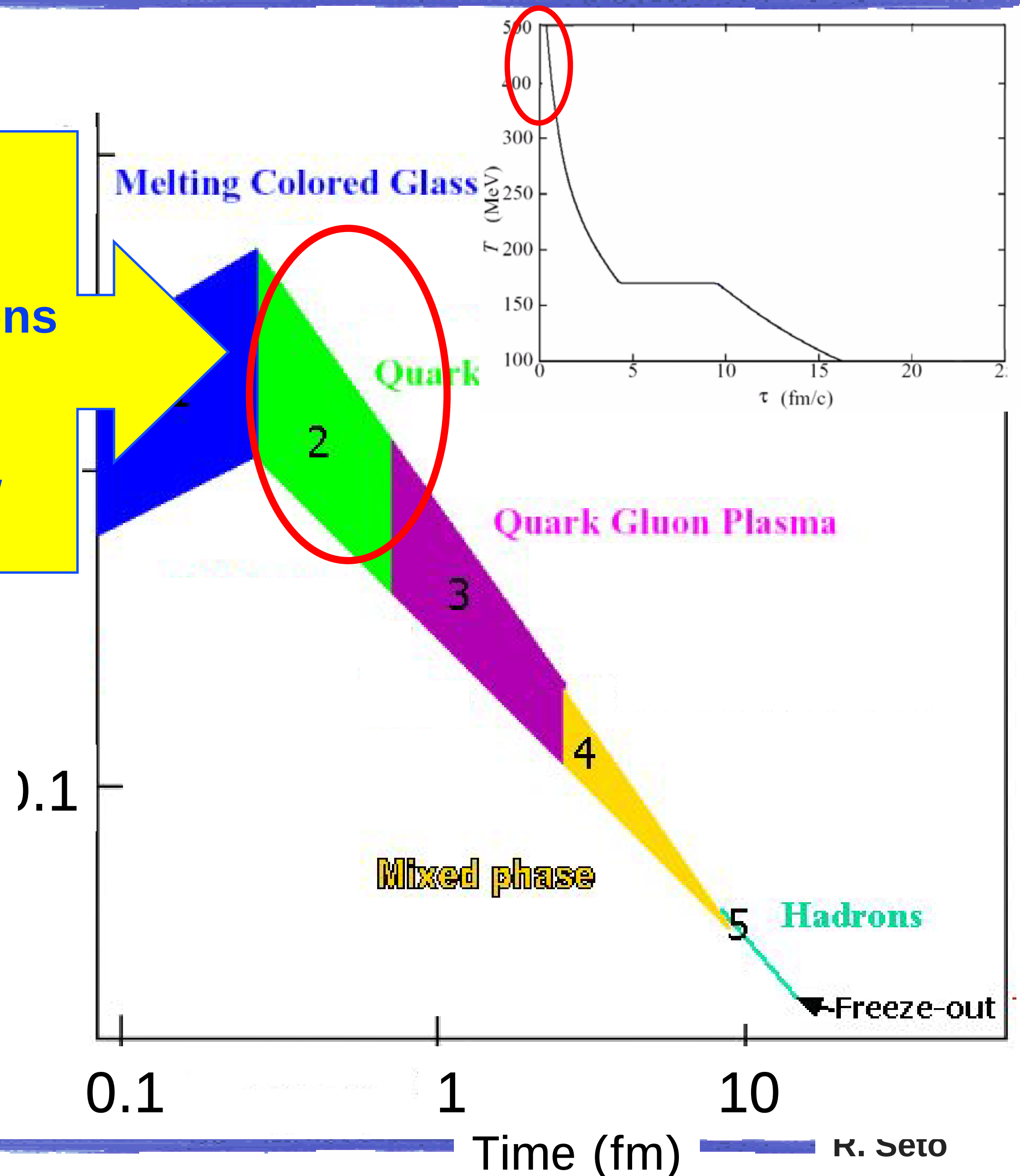


- **Formation**
  - » $t \sim 1/Q_{sat} \sim 0.2$ fm
  - » $\varepsilon \sim 15$ GeV/fm^3
  - » Hard processes - PQCD
    - – hard probes
- **Evidence for CGC**
  - » Multiplicity distribution
    - – consistency of dET/dy - hirano
  - » dA forward suppression

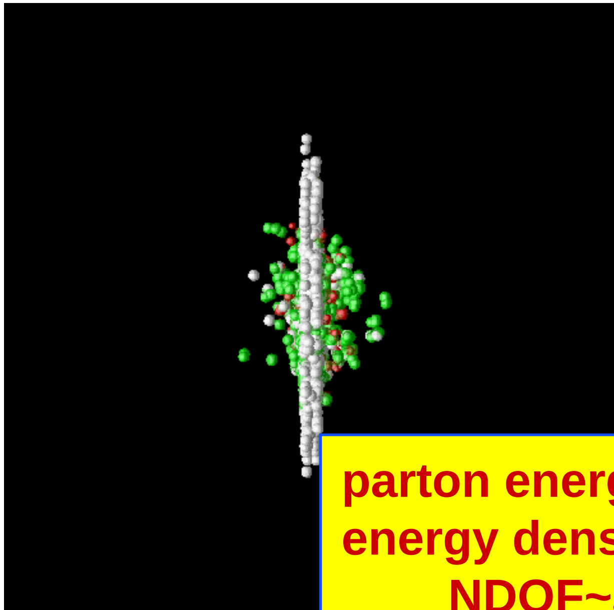
Equilibration – Elliptic flow starts

Initial Temperature !
→NDOF ~ε/T^4
Intermediate mass dileptons
thermal photons
heavy quark production
onium spectroscopy, flow
flow measurements? (vtx,NCC)

- **Equilibration**
  - » t~0.6 fm
  - » ε~3-15 GeV/fm^3
  - » Strong coupling
  - » Flow (elliptic) starts to develop
  - » Early Thermalization
- Evidence
  - » Elliptic flow strength
  - » coupled to theoretical arguments –

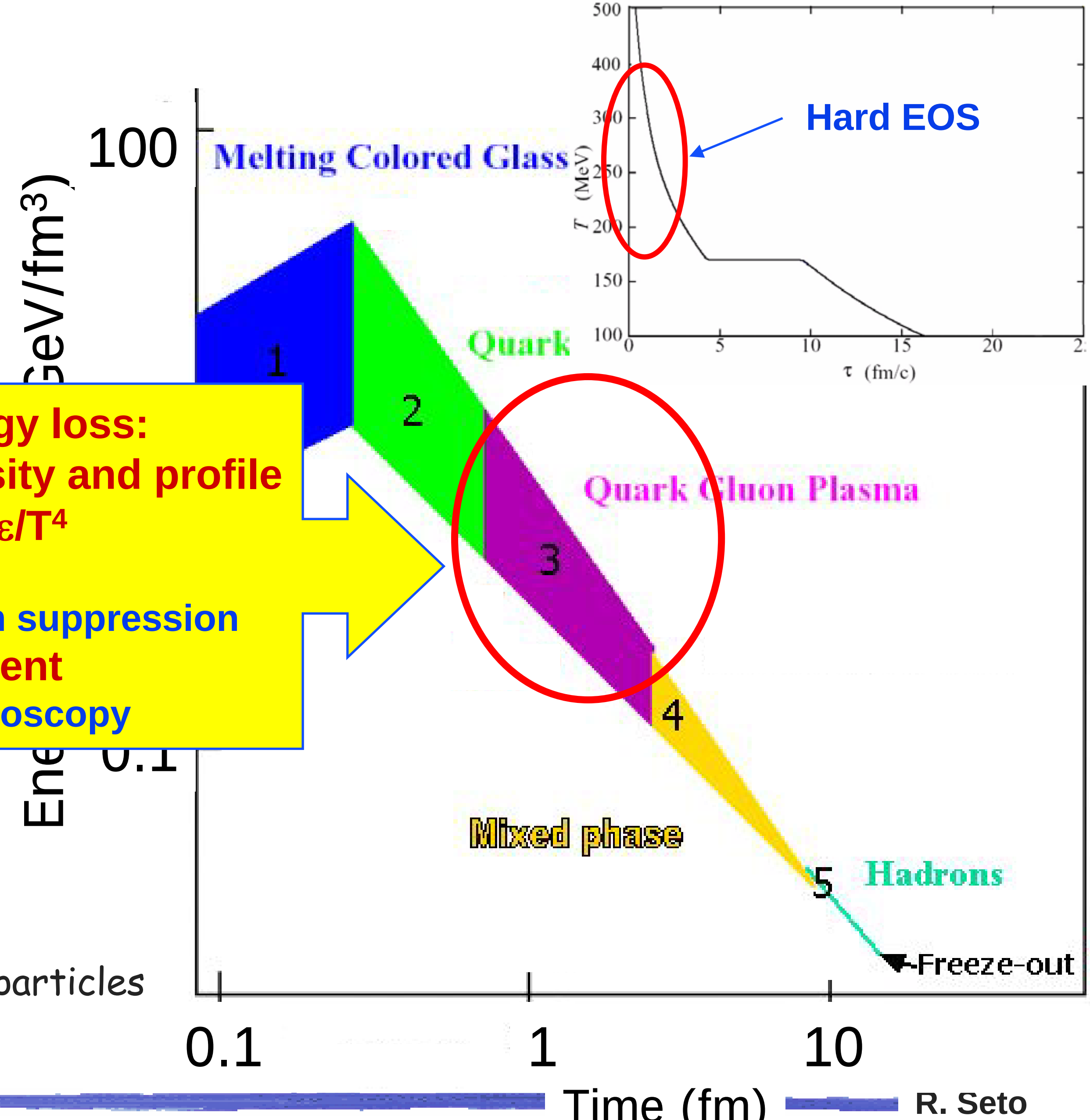


s.....QGP.....

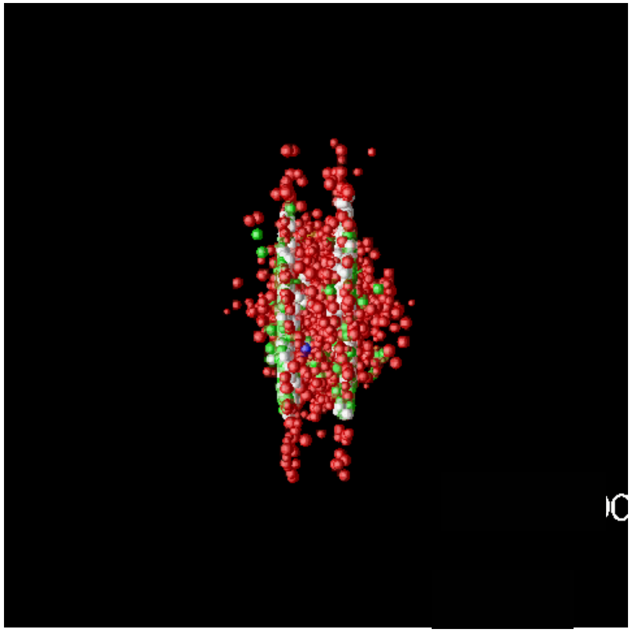


- **sQGP**
  - » viscocity
  - » Hard EO
  - » Parton e
- Evidence:
- strong coupling
  - » Elliptic flow
- partonic energy loss
  - » suppression of high pt particles

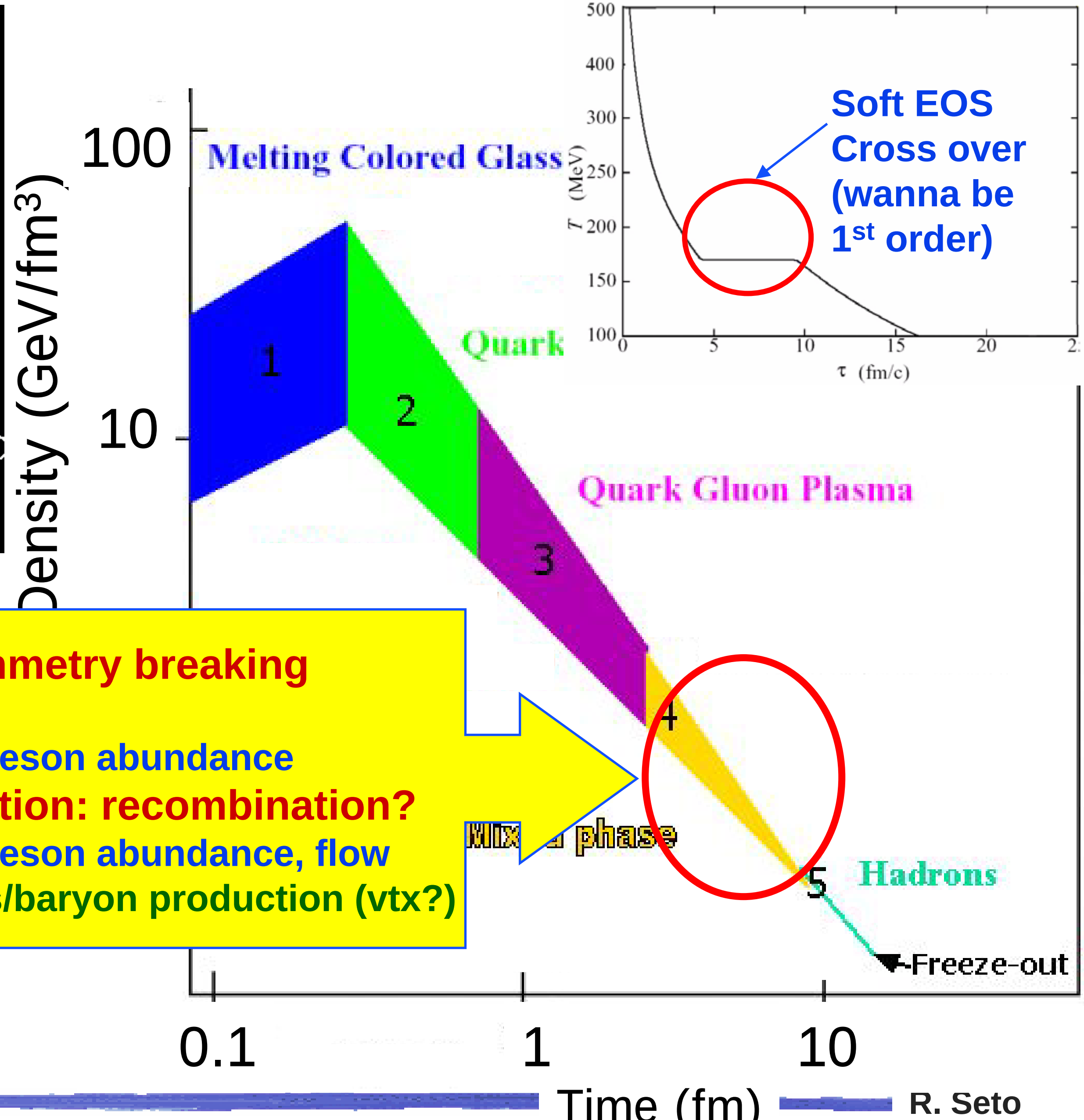
parton energy loss:
energy density and profile
NDOF~ε/T^4
gamma-jet
high pt charm suppression
Deconfinement
Onium spectroscopy



Mixed Phase – Latent heat-recombination

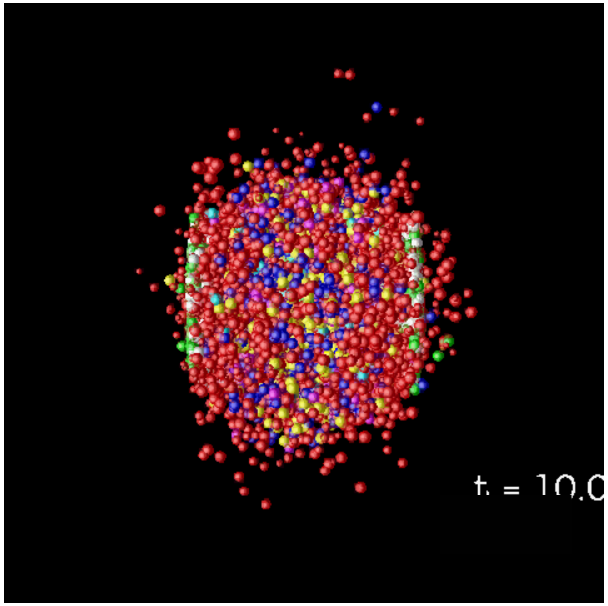


- **Mixed Phase**
  - » Phase Transi
    - – (Cross ov
  - » Latent Heat
  - » Soft EOS –
    - – hydro mo
  - » Hadronizatio
    - – baryon to
    - – v2

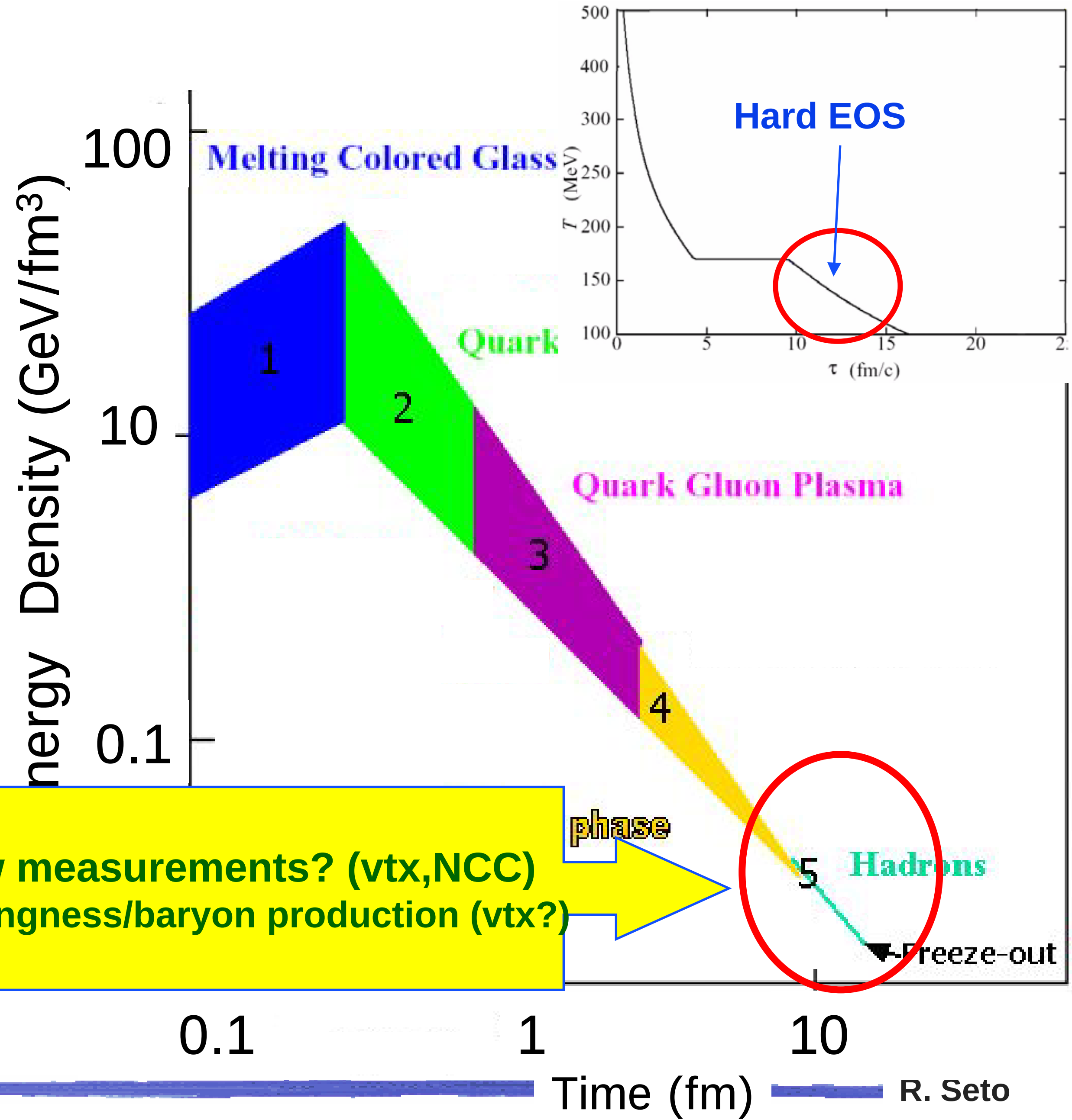


chiral symmetry breaking
phi->μμ
charmed meson abundance
hadronization: recombination?
charmed meson abundance, flow
Strangness/baryon production (vtx?)

Hadronic phase



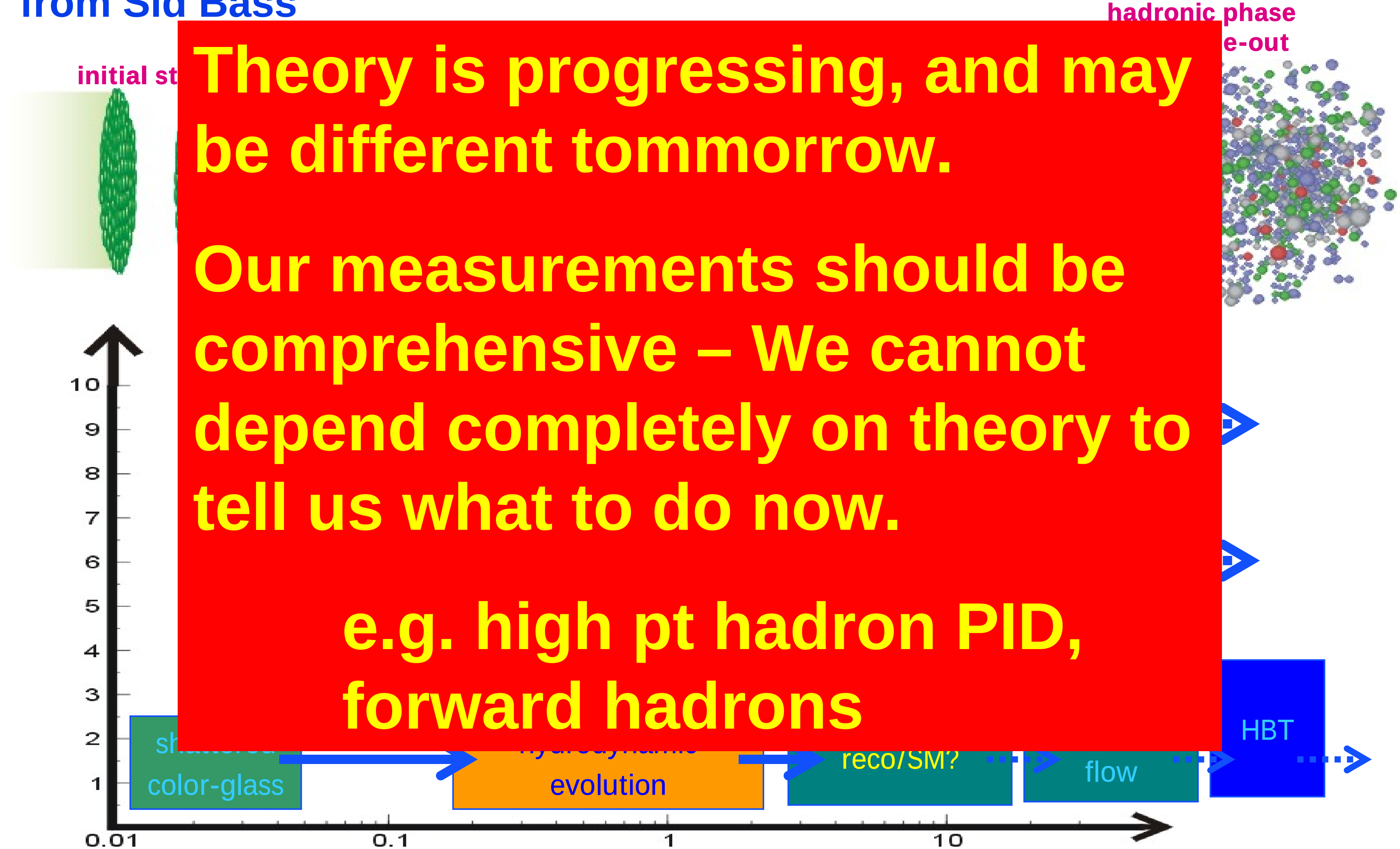
- **Hadronic Phase**
  - » Tch ~ 160 MeV
  - » Hard EOS again
  - » flow continues to d
  - » radial flow develops



flow measurements? (vtx,NCC)
Strangness/baryon production (vtx?)

Models:

from Sid Bass



Theory is progressing, and may be different tommorrow.

Our measurements should be comprehensive – We cannot depend completely on theory to tell us what to do now.

e.g. high pt hadron PID, forward hadrons

Key measurements

- ***Thermal di-leptons, photons***
- ***Photon-jet measurements***
- ***Onium spectroscopy***
- ***Open heavy flavor production***

Intermediate mass thermal dileptons thermal photons A measure of the temperature 1

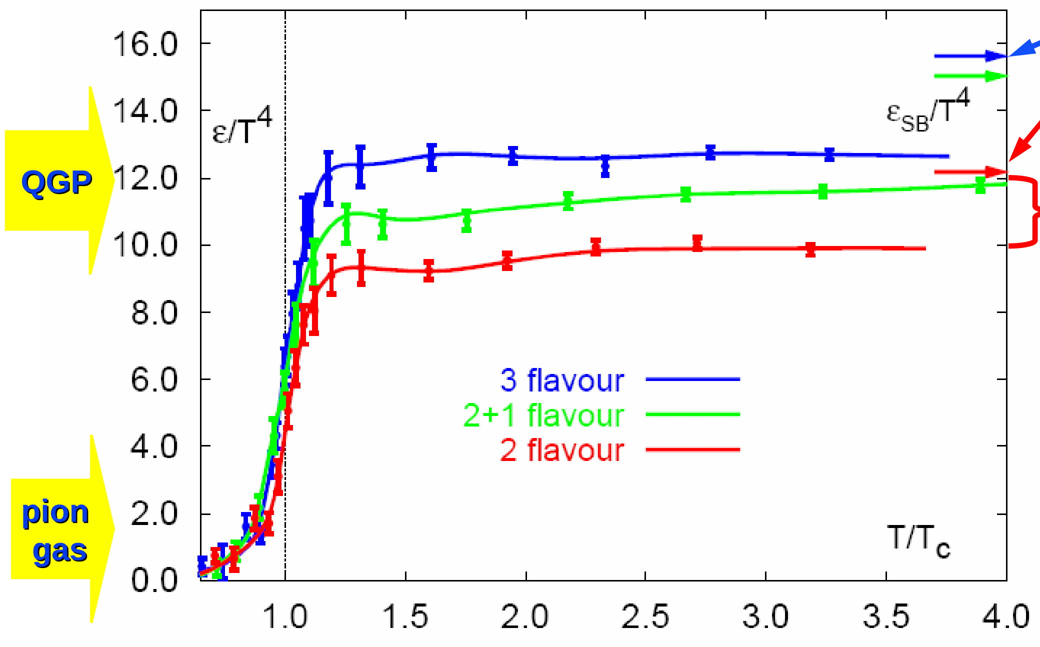
NDOF $\sim \varepsilon / T^4$

We want the NDOF – just count em!

- Counting the Degrees of freedom
  - » Assume Stefan-Boltzman (S-B)

$$\frac{\varepsilon}{T^4}(2\,flavor) = (2_f \cdot 2_s \cdot 2_q \cdot 3_c \cdot \frac{7}{8} + 2_s \cdot 8_g)\frac{\pi^2}{30} = 37\frac{\pi^2}{30} = 12(2\,flavor);\ 15(3\,flavor)$$

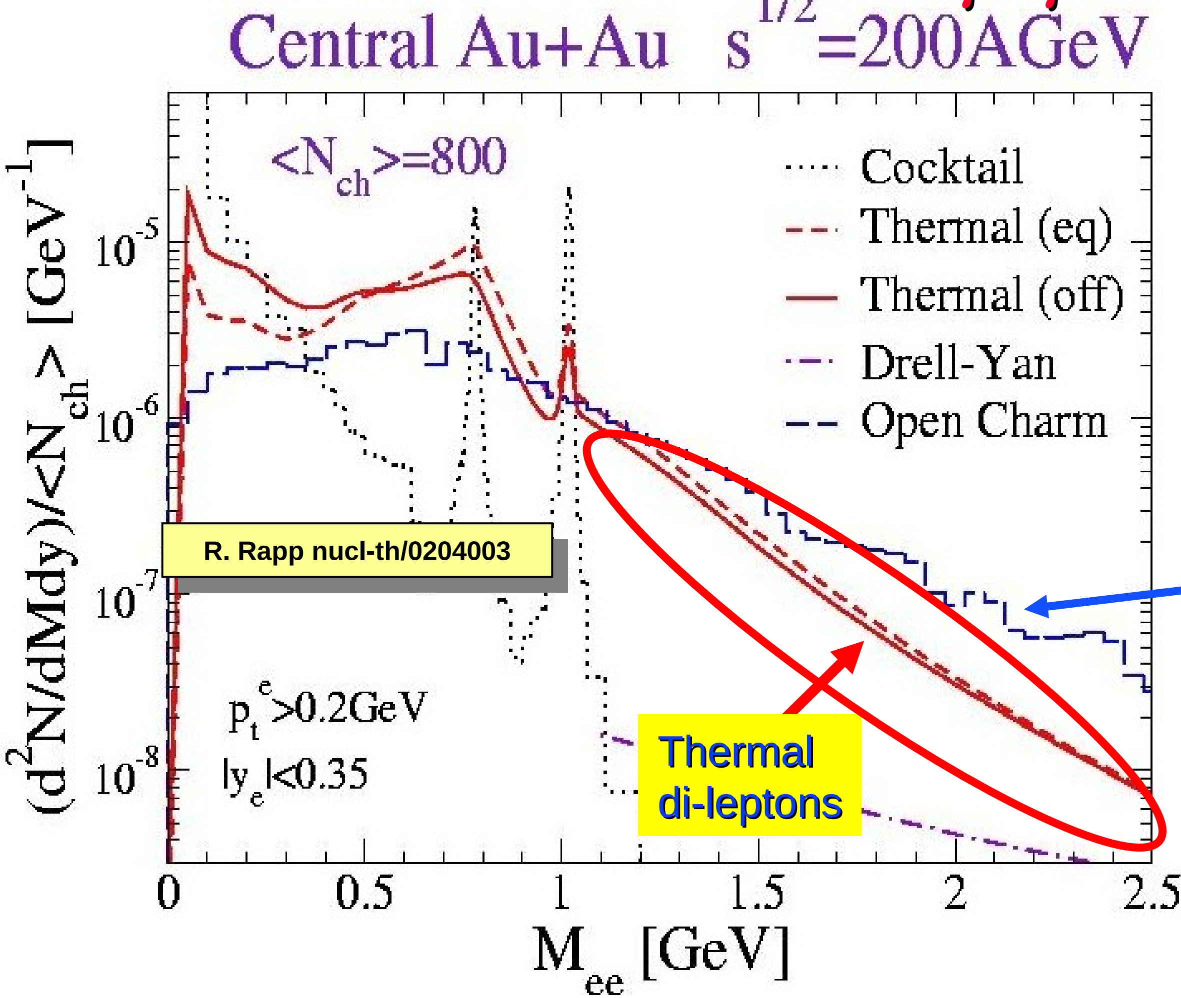
  - » Do it “for real” on the lattice

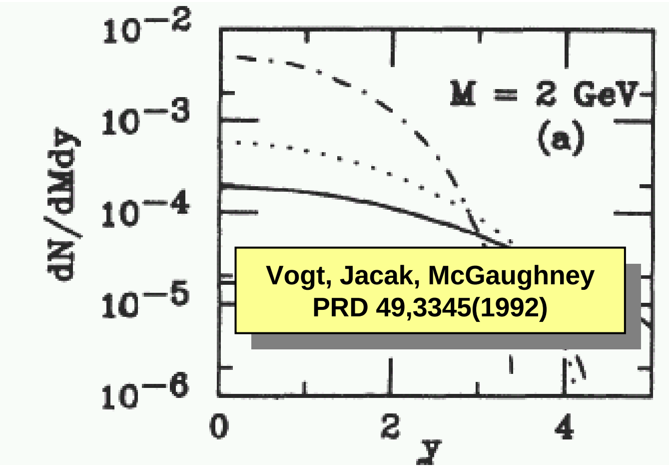


difference between S-B and lattice ⇒ **interactions**

- We know ε
- ***We need upper limit on T***
  - » Thermal dileptons are radiated primarily at early times
- Reality check : sensitivity to T
  - » take ε=15 GeV/fm^3
  - » T=.300 ε/T^4 ~15
  - » T=.500 ε/T^4 ~2
- Reality check: We need much better constraints on $\varepsilon(\tau)$

Measureing the Temperature
Intermediate mass $\mu^{+}\mu^{-}$ Pairs at RHIC





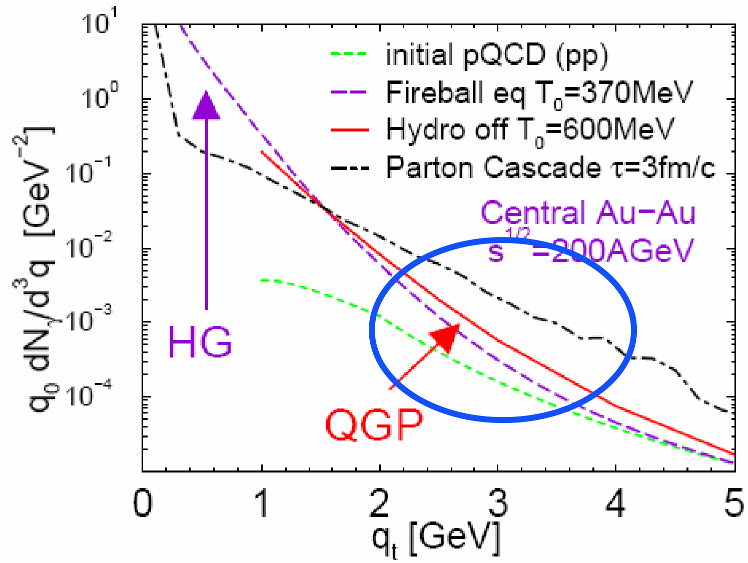
BUT

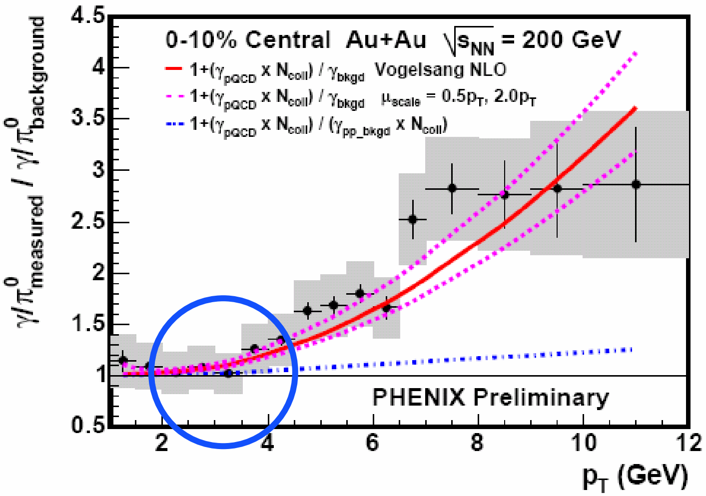
Significant contribution from open charm

- Sensitive to Thermal signal
- Accurate open charm measurement - CRITICAL

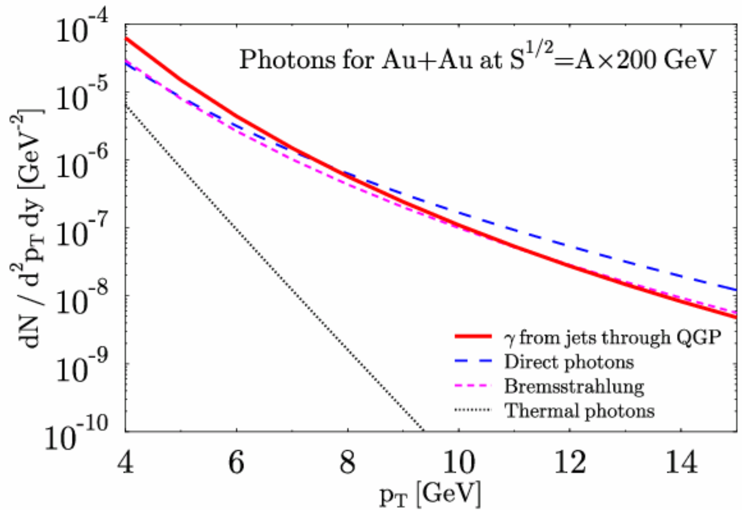
Measureing the temperature: "Thermal" Photons

- QGP shows up for $p_T > 1.5$ GeV





- BUT a second source?
  » PHOTONS FROM JETS THROUGH QGP.
  Fries et al, PRL 90:132301, 2003



- PHENIX early limits already set
  » Need to measure (with statistical subtraction of π^0) down to ~2 GeV in p_T

Jet Tomography

Measuring the energy density

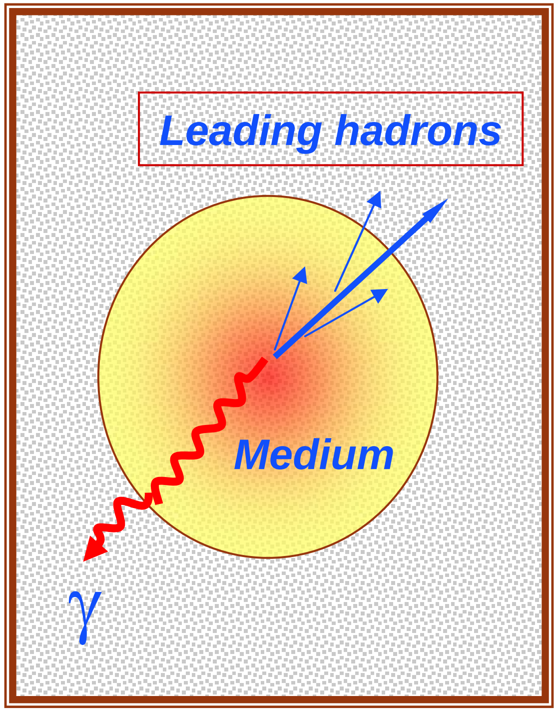
Jet quenching

- High pt particle suppression was THE major find at RHIC
- Assuming partonic energy loss, we get
  - » dN/dy_{gluons}
  - » Energy density
    - [needs some assumed EOS,consistent with hydro-flow, dN/dE_T (τ~.35 fm)]
- But energy loss depends on
  - » Order of QCD calculation
  - » Detailed balance or not
  - » EOS
  - » ...
  - » Time evolution of system
  - » Path length traveled
  - » identity of leading parton
    - light quark?
    - heavy quark?
    - gluon?

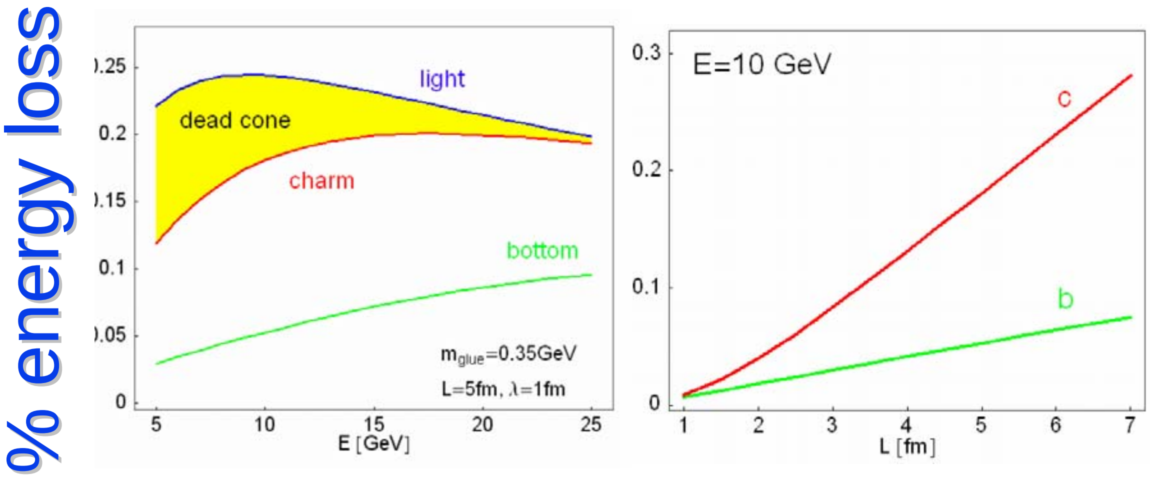
But we need reliable ways to turn our measurements into an energy density

We (theorists and experimentalists) must identify the correct ingredients to a calculation

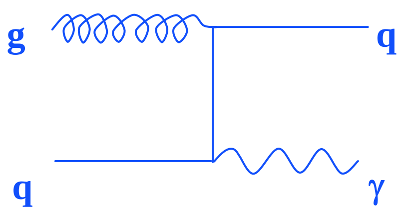
Tagged, Identified Jet Tomography



- Energy loss calculation
  - » M. Djordjevic, M. Gyulassy



Quark gluon Compton scattering:

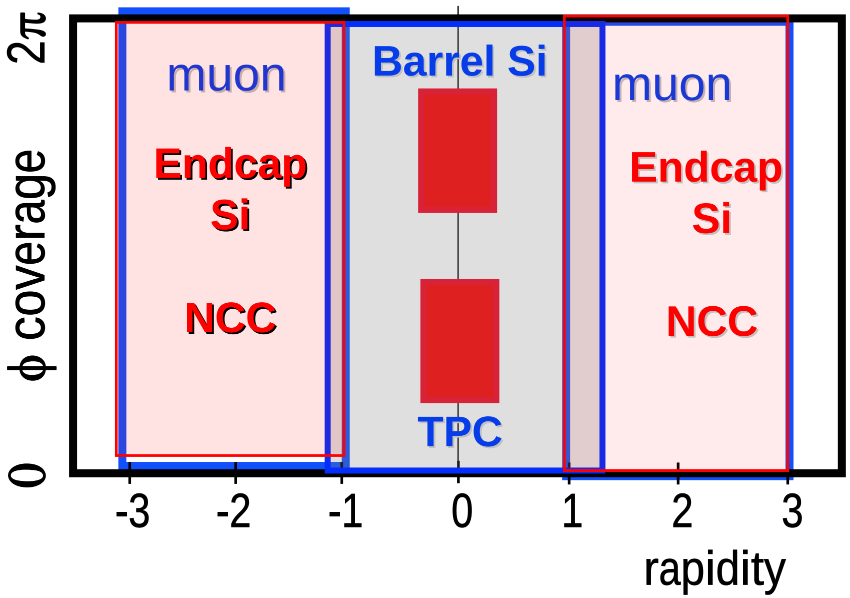


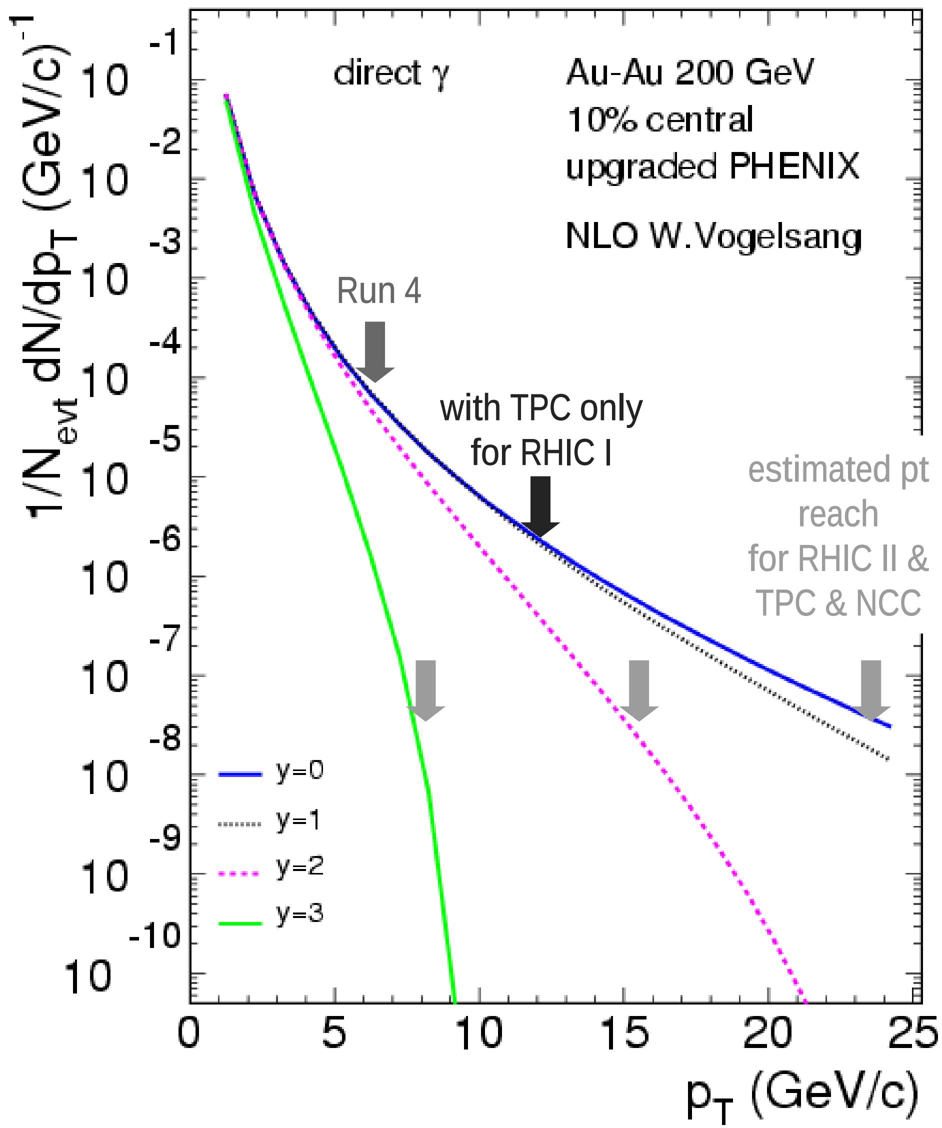
$E_\gamma \sim E_{\text{jet-before energy loss}}$

γ & Jet direction fix kinematics

- We must measure energy loss vs
  - » Energy of Parton
  - » PID of parton
  - » Path length traveled
    - – (reaction plane)
  - » PID of leading particle (p/π)

Coverage for γ-jet Tomography





- *Addition of*
  - » Barrel Si
  - » TPC
  - » Endcap Si
  - » NCC
- *Greatly expands coverage*
- *is critical for this measurement*
  - » e.g. coverage for γ x16

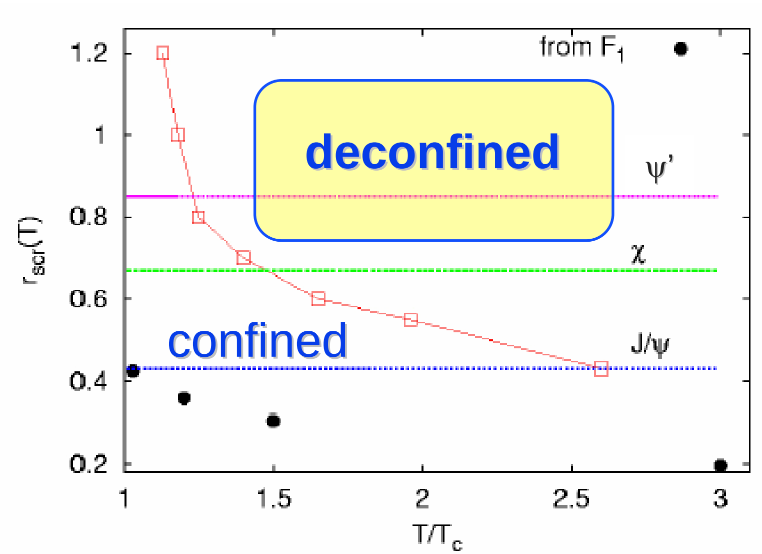
Onium Spectroscopy

Deconfinement

A measure of the temperature 2

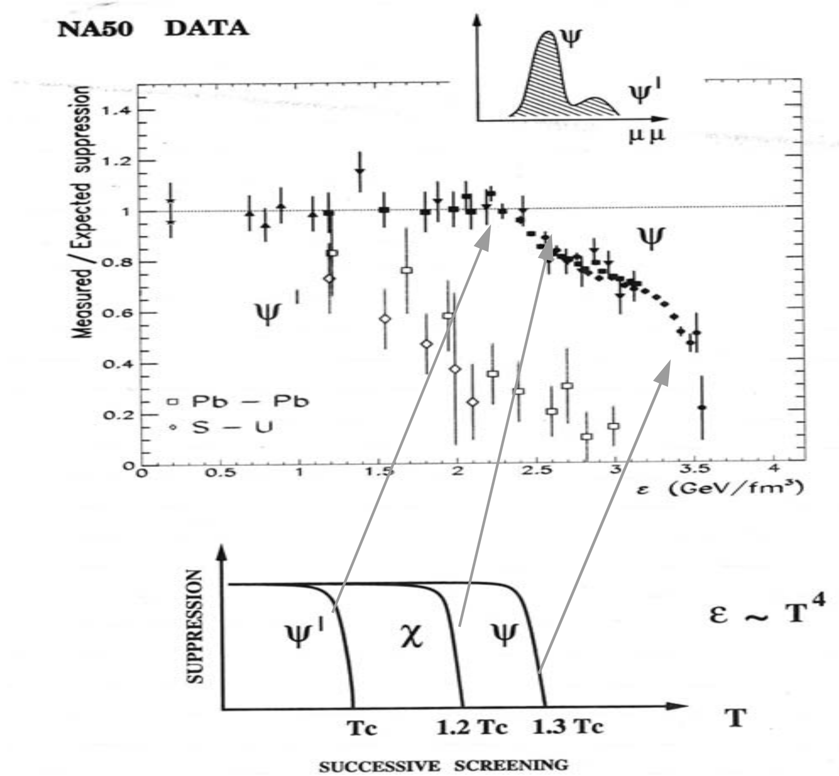
Onium sytem as a signature of deconfinement- a thermometer

- Recently the lattice calculations show that the J/ψ persists to 3 T_c



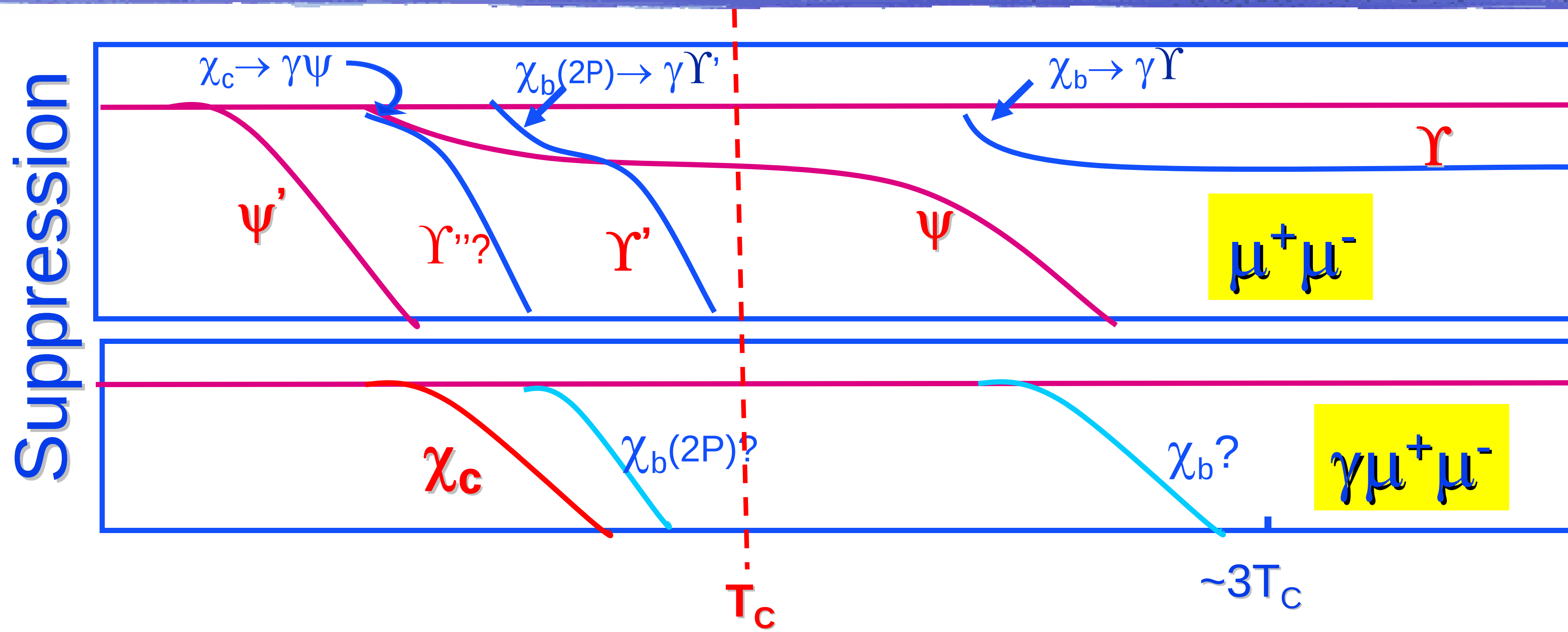
  - » Onium system as thermometer
    - – p_T Dependence
    - – $x_{1,2,F}$ Dependence
    - – Study vs system size and energy
  - » Problem: J/ψ from χ_c and Υ decays

- SPS :is the "kink" real?



Solution: measure them and more

Can PHENIX do this?



state	J/ψ	χ_c	ψ'	$\Upsilon(1s)$	χ_b	$\Upsilon(2s)$	χ_b'	$\Upsilon(3s)$
Mass [GeV}	3.096	3.415	3.686	9.46	9.859	10.023	10.232	10.355
B.E. [GeV]	0.64	0.2	0.05	1.1	0.67	0.54	0.31	0.2
T_d/T_c	---	0.74	0.15	---	---	0.93	0.83	0.74

Note: this chart is NOT consistent with figure on previous slide!

ψ from recombination of thermally cooked quarks??

» ψ flow measurements important!

» bottom-onium states important!

$\chi_b \to \gamma\Upsilon$	35%
$\chi_b(2p) \to \gamma\Upsilon$	10%
$\to \gamma\Upsilon'$	21%

PHENIX

R. Seto

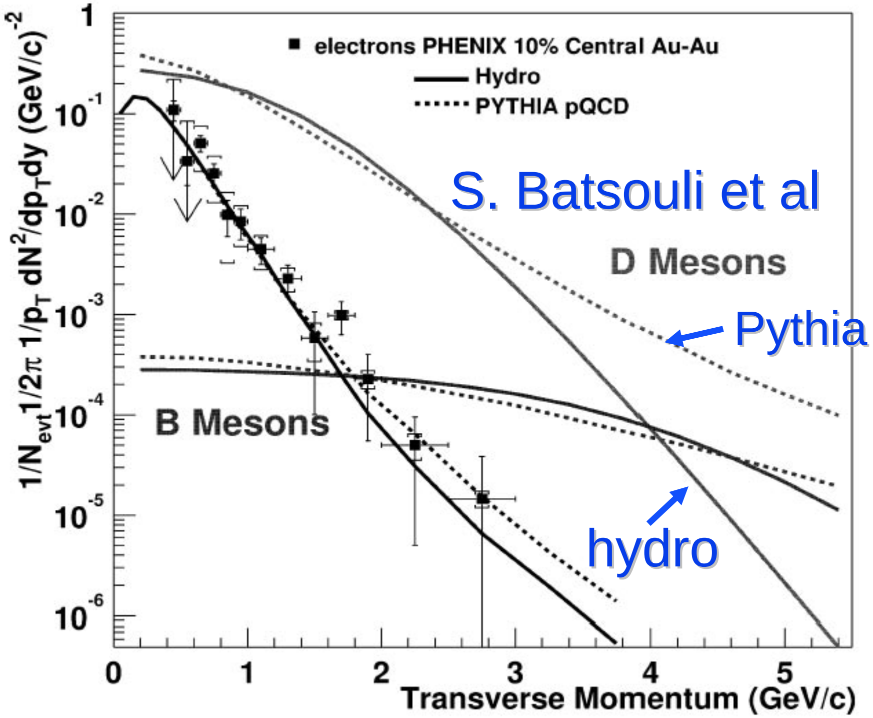
Open heavy flavor

energy loss
temperature
chiral symmetry

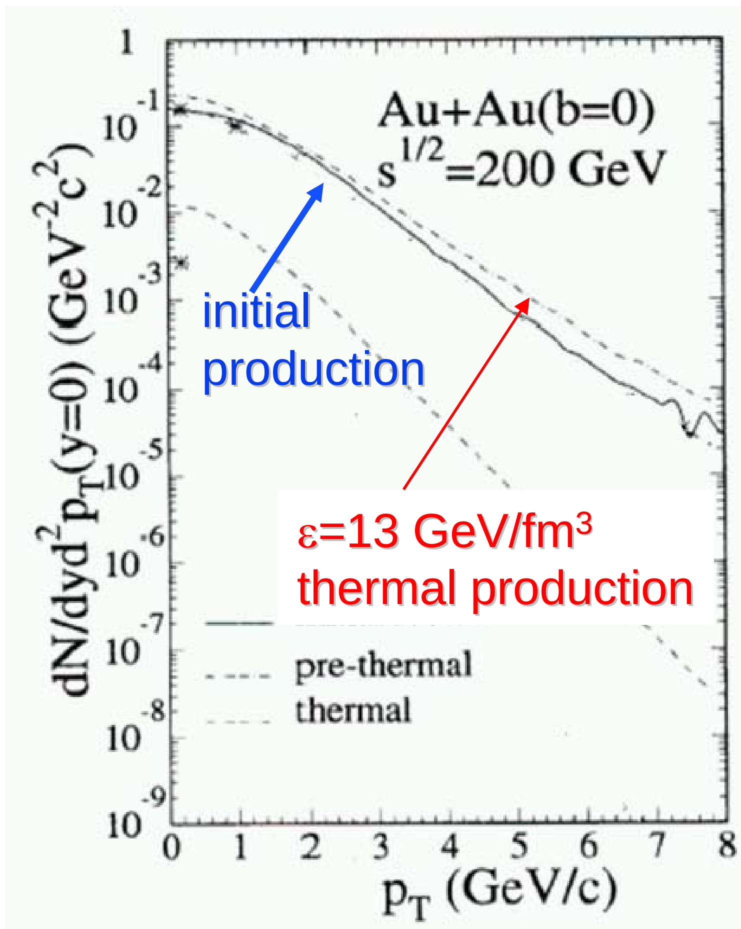
Why open heavy flavor?

- Does charm thermalize with other quarks?
  ➔ charm flow
- Charm as another thermometer
  – Is there thermal (or pre-thermal?) charm formed after the initial hard collision –
  ➔ charm enhancement
- D mesons and chiral symmetry restoration?
  ➔ affect production of various D meson states
- Heavy quark energy loss
  – constraint of jet quenching models
- Background to thermal di-leptons

Open heavy flavor



Is there pre-thermal charm production?



Charm could be enhanced at high energy densities

- Electrons from Charm match pythia
  - » Hypothesis 1: Charm quarks do not loose energy
  - » Hypothesis 2: Charm flows
- Look for eliptic flow
- Measure charm quarks directly

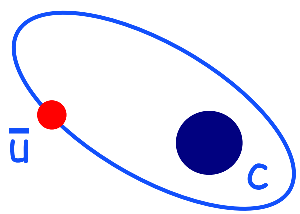
Can the forward upgrades say anything about chiral symmetry restoration?

Chiral partners of D-mesons?

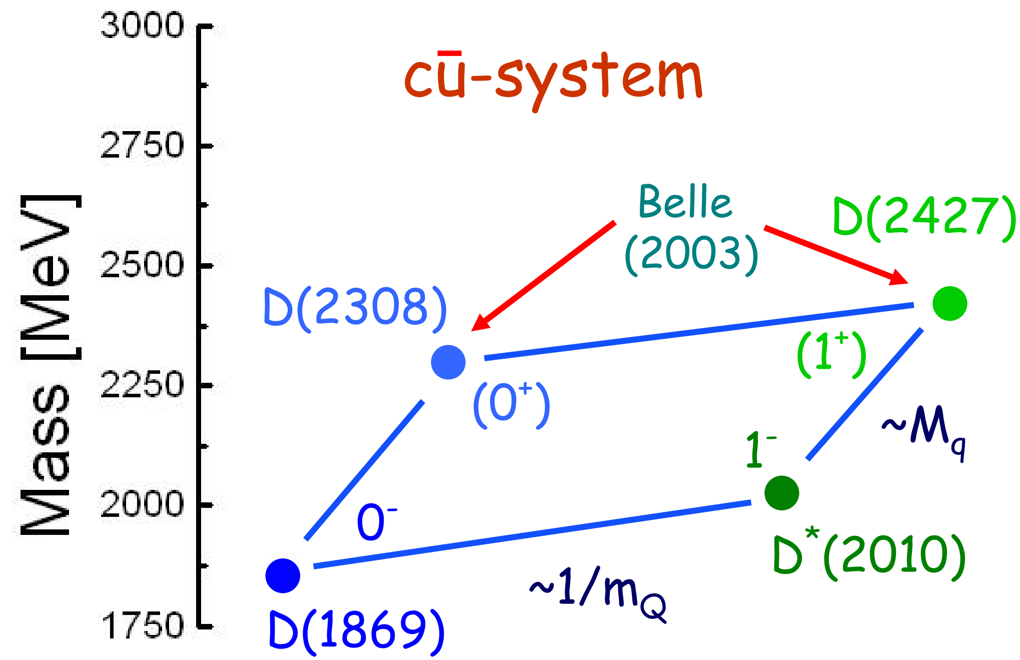
from B. Friman

D-mesons:

- heavy-light system
- hydrogen atom of QCD



Light-quark-cloud probes chiral symmetry



Chiral mass shifts ≈ 420 MeV (constituent quark mass)

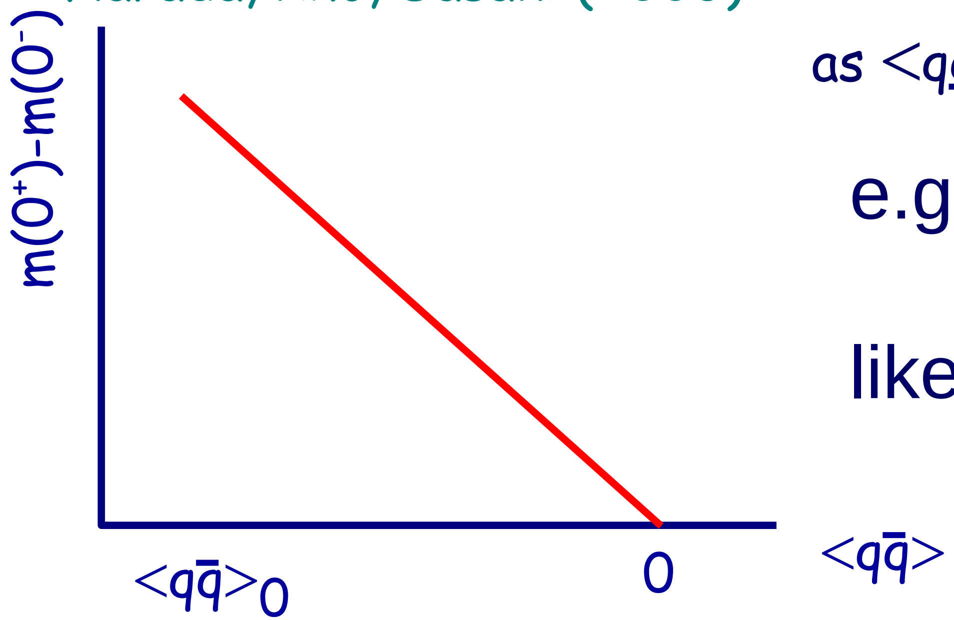
Heavy-quark-symmetry
+ chiral symmetry:
chiral doubling of D-mesons
(Nowak-Rho-Zahed and Bardeen-Hill, 92-93)

$D(0^+) \rightarrow D(0^-) + \pi$

Chiral symmetry restoration in the D system?

If chiral doubling scenario for D mesons correct

Harada, Rho, Sasaki (2003)



then $m(0^+)-m(0^-) \rightarrow 0$ etc.

as $\langle q\bar{q} \rangle \rightarrow 0$ (chiral limit)

e.g. $m_{D(0+)} = m_{D(0-)}$

like $m_\rho = m_{A1}$

Will D-meson production of the various types change at high temperature matter? Can phenix see it?

Summary

- ***Critical Scientific questions for RHI***
  - ***Deconfinement?***
  - ***Degrees of freedom?***
  - ***Chiral symmetry restoration?***
- ***Key measurements***
  - ***Thermal di-leptons, photons***
  - ***Photon-jet***
  - ***Onium spectroscopy***
  - ***Open heavy flavor production***
- ***Upgrades***
  - ***Endcap Silicon***
  - ***Muon Trigger***
  - ***Nosecone Calorimeter***

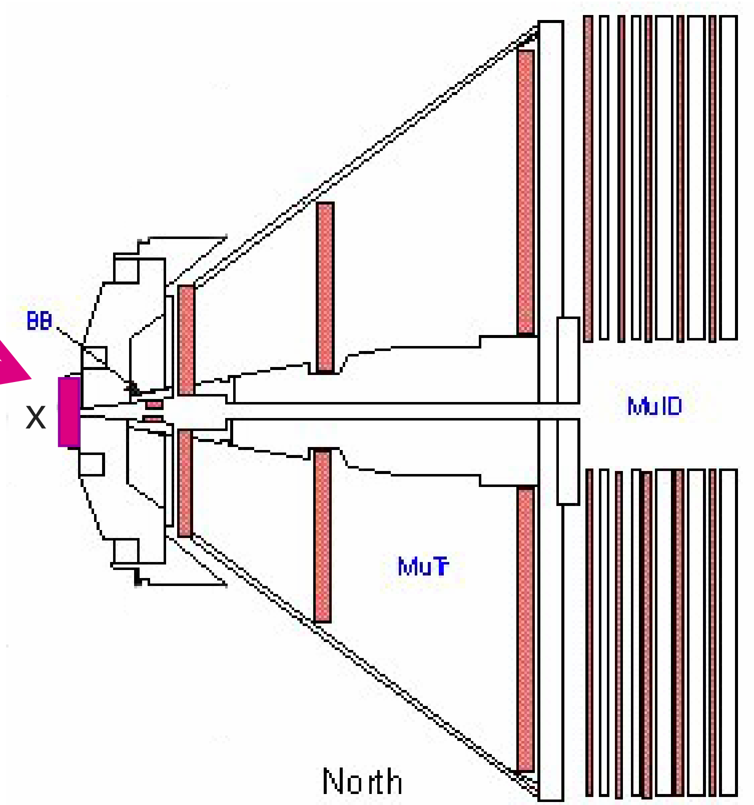
we probably don't need all of these to declare "victory"

Some Nosecone calorimeter physics simulations

What is proposed?

- **Nose cone calorimeter (NCC)**
  - 0.9 < |y| < 3.0

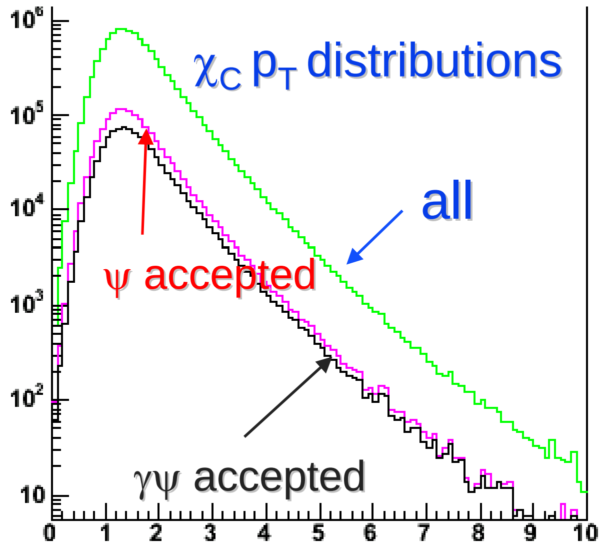
- Questions
  - Can you really find the χ_c?
    - use invariant mass
  - Can you find direct photon for γ-jet
    - go to higher p_T
  - Use a toy MC



Upgraded muon trigger and NCC also on South side

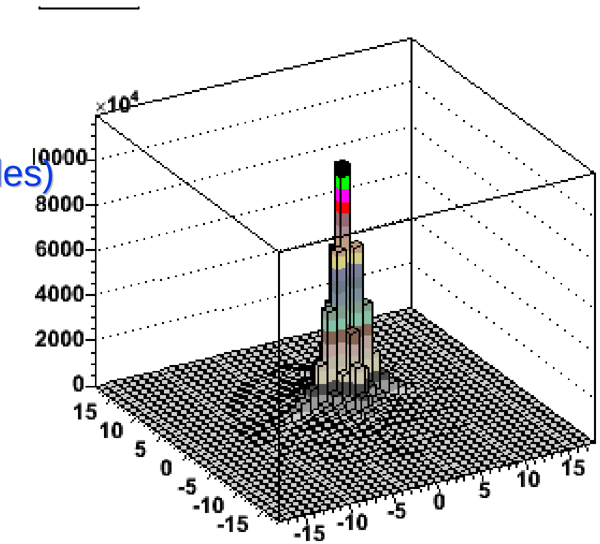
Measuring the χ_c

NCC in Au-Au Central

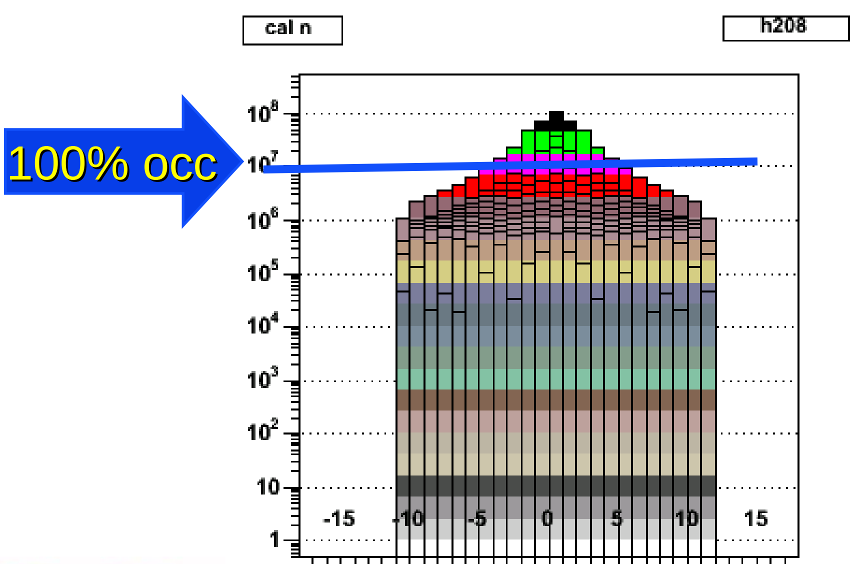


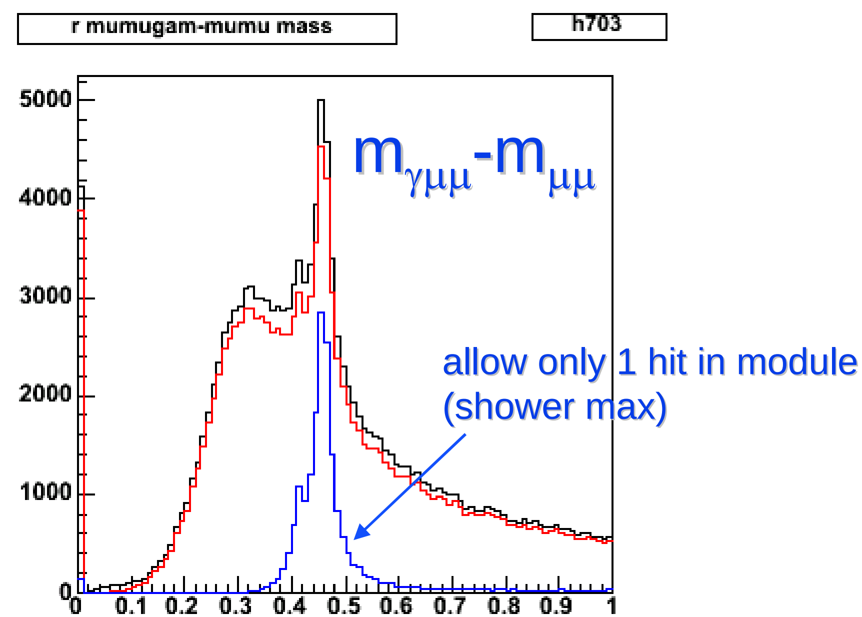
if ψ accepted ~60% of $\gamma\psi$ accepted

number of photons in NCC cal modules (2x2 tiles) 10^7 events

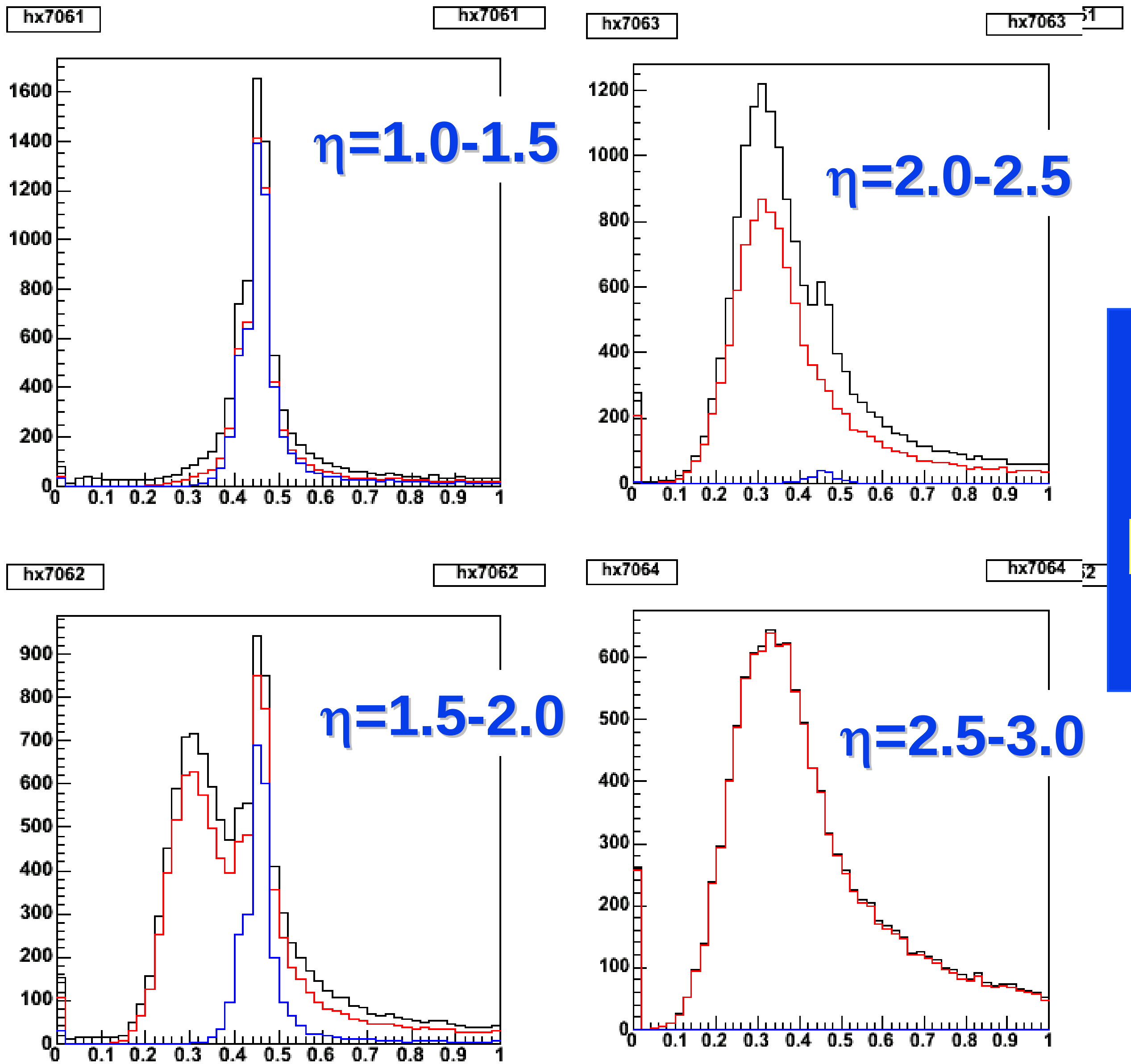


occupancy at high η-inner radius very high



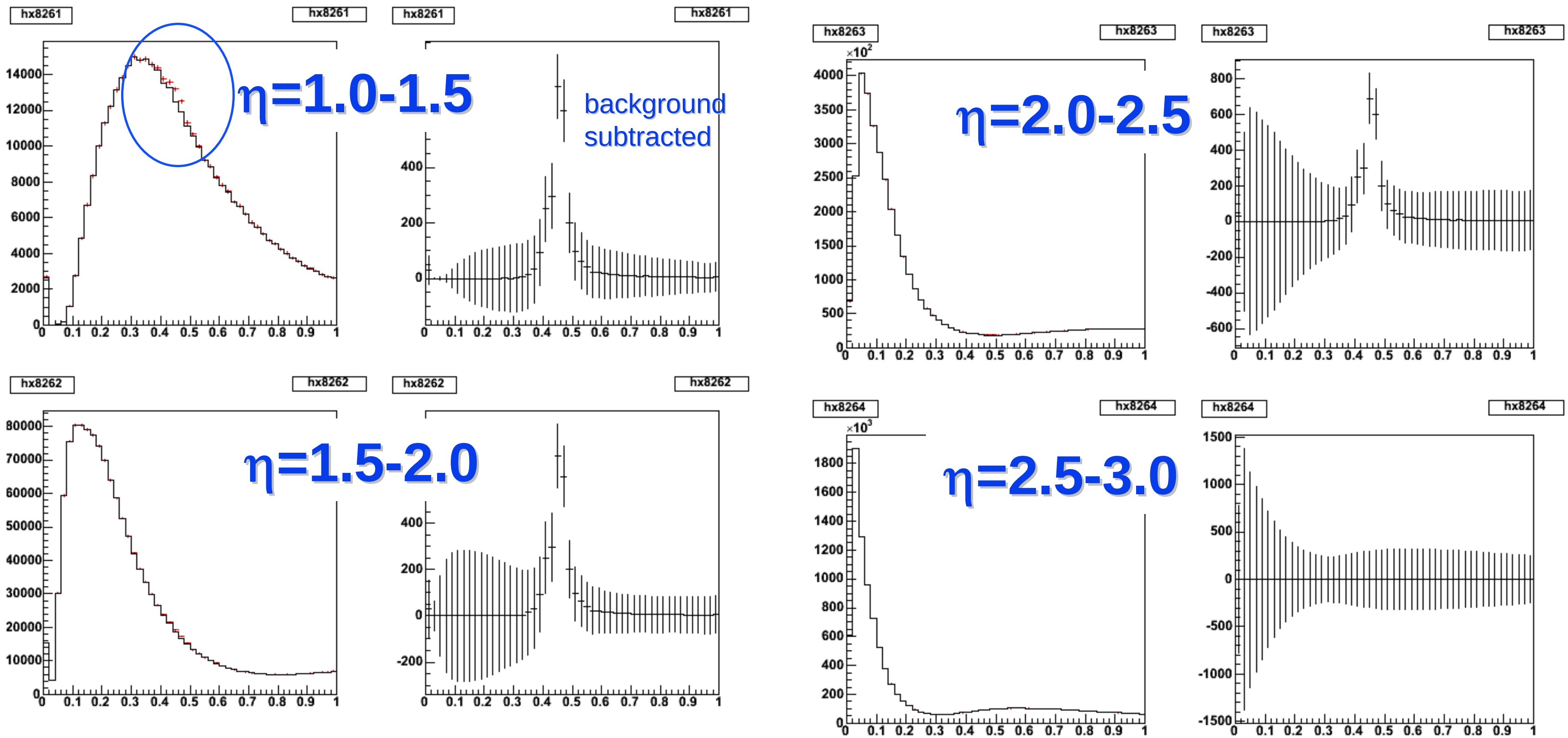


$m_{\gamma\mu\mu}$-$m_{\mu\mu}$ (real χ_C only)



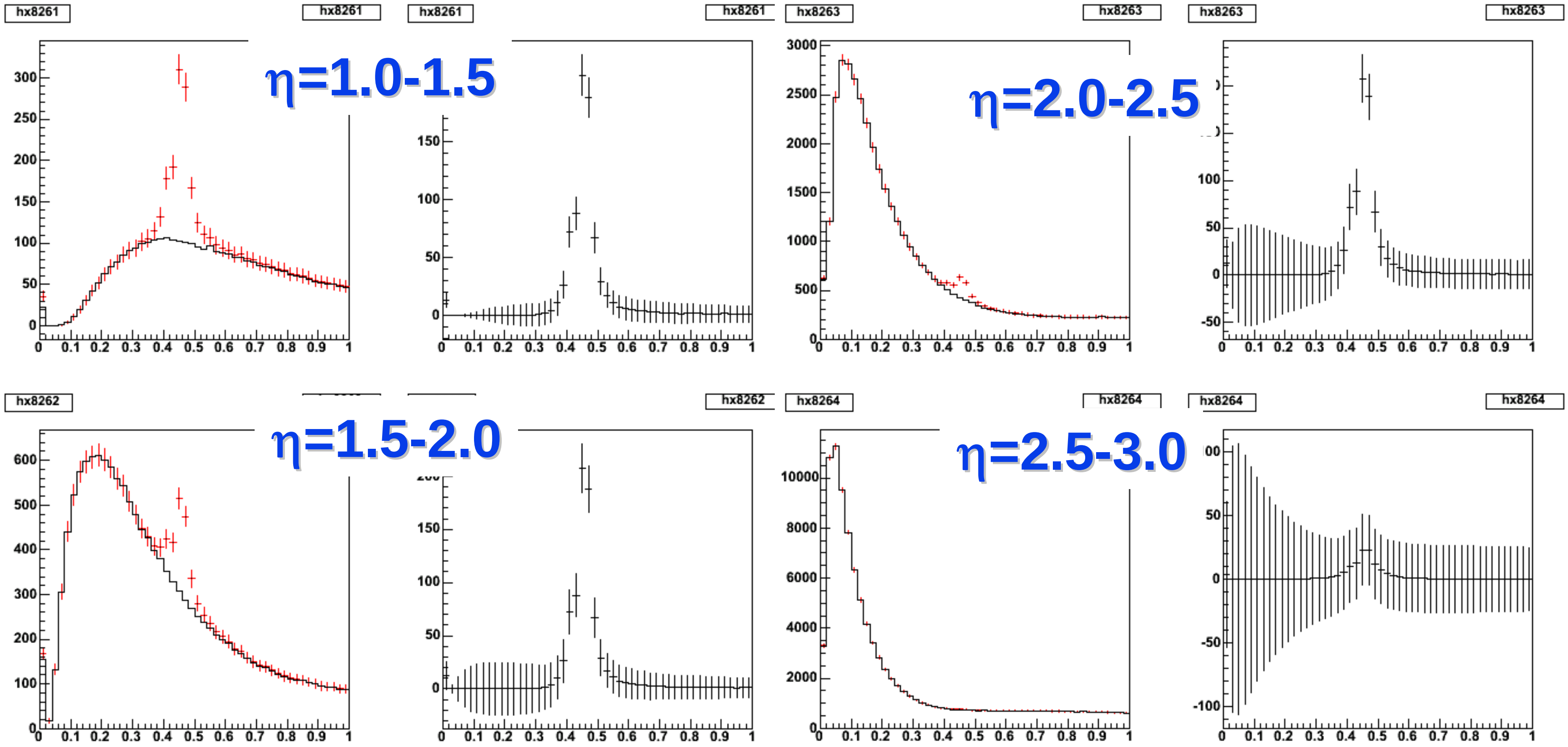
now add background

Central 0-10% Au-Au $m_{\gamma\mu\mu}$-$m_{\mu\mu}$ (with background)

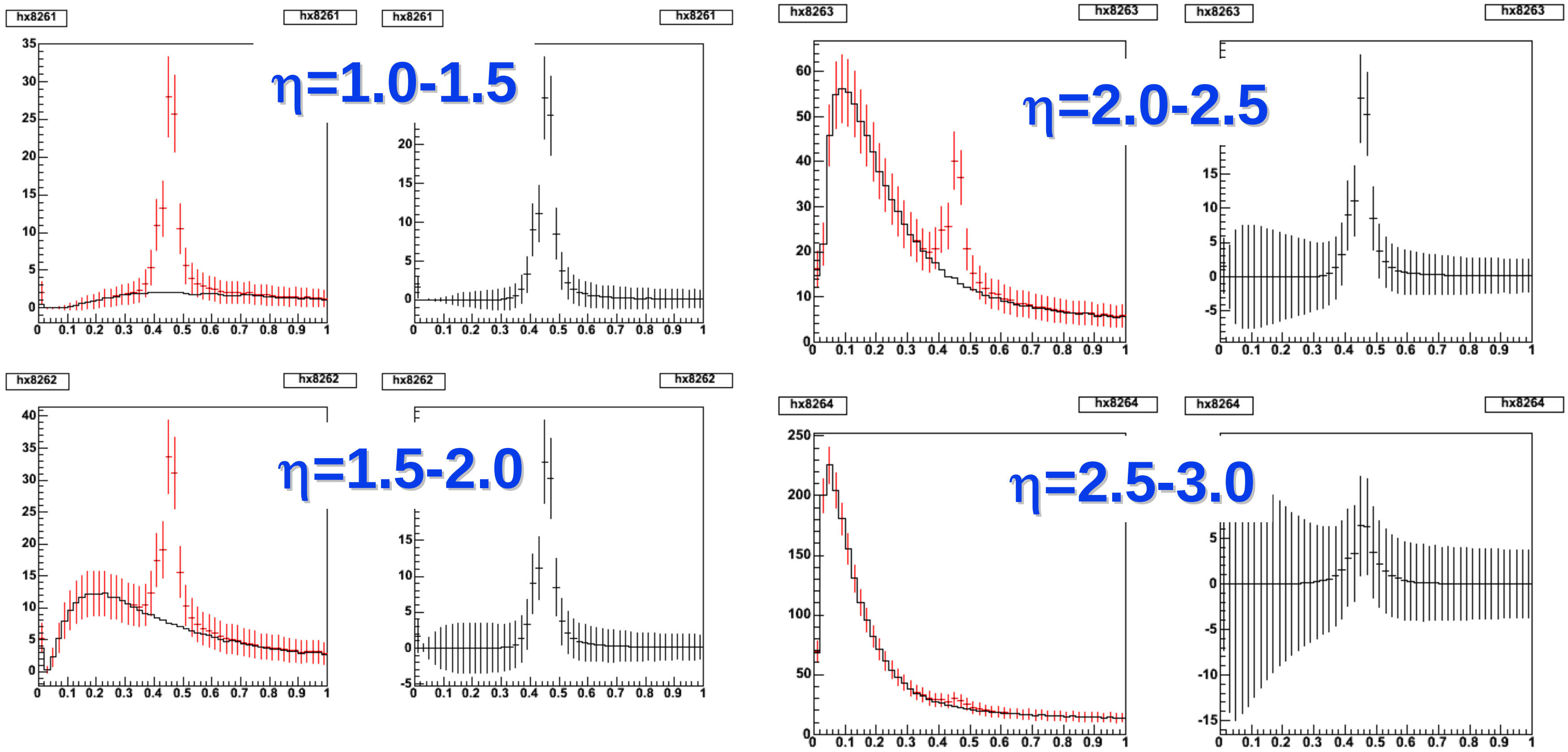


- Assume RHIC II statistics, i.e. 10x our plan
  - » use 10X (10% central of run 8 – 1500 ub-1)

dAu – Central 0-20%



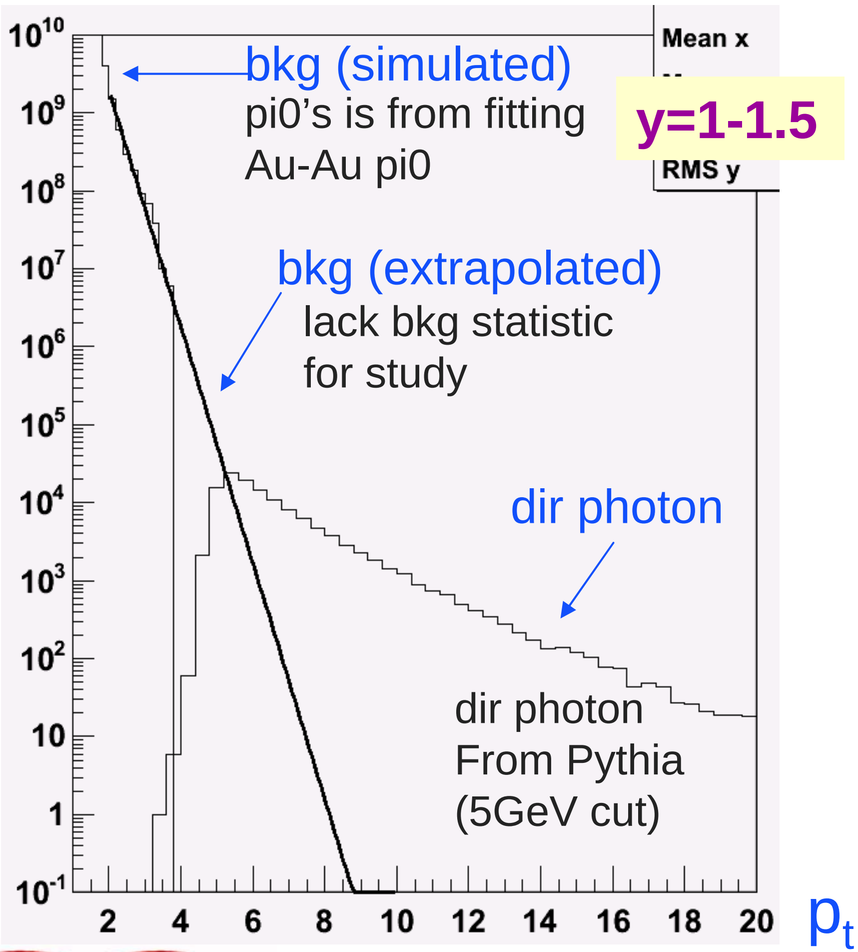
pp min bias

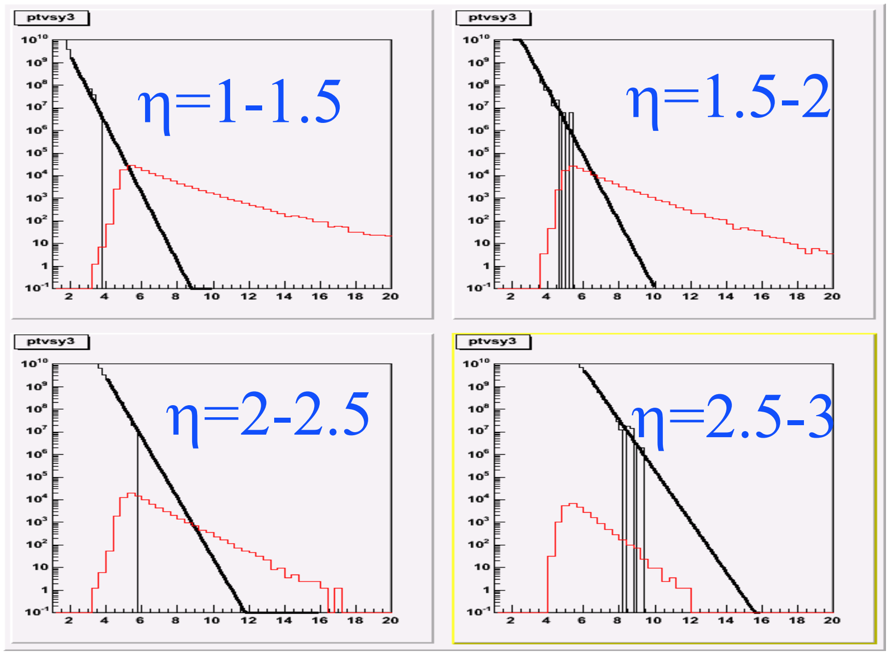


Measuring Direct Photons

NCC in central Au+Au

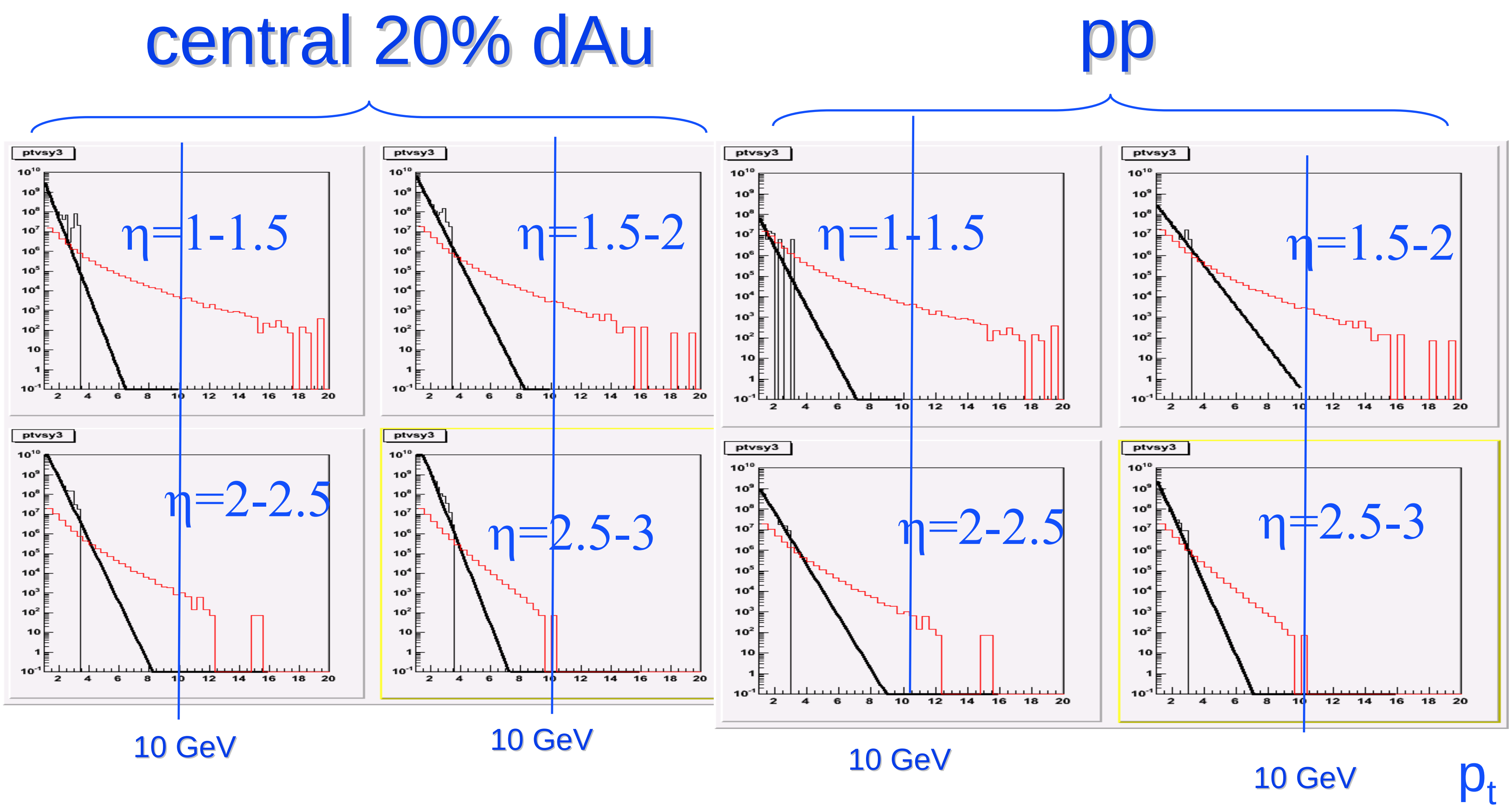
- Problem is pile up faking a photon, pessimistic evaluation
- Problem worst at high y since the effective segmentation is larger
- Statistics is central 10% of run 8 – 1500 ub-1





- Ok to η~2.5
- At η~1. require pT~6 GeV
- Below that we have to subtract statistically

A summary of the π^0 pile up problem – dAu, pp



- *All η OK*

Summary

First look at occupancy problems in NCC with Toy MC

- χ_C
  - measurements possible to η~2.5 in central Au-Au
- Direct photon measurements
  - in Au-Au (for γ-jet measurements)
    - η~1, p_T> 6
    - η~1.5, p_T> 8
    - η~2, p_T> 10
  - in pp and dAu
    - all η~2, p_T> 2-4 depending on η
  - in Au-Au using statistical methods – can we go after thermal photons - ???? homework…