# Seminar class on RHIC Physics

Richard Seto+Class
UCR
Spring 2007
April 13, 2006 2PM BNL time 11AM UCR time
bridge line 631-344-6363 room 2-787
Website:https://www.phenix.bnl.gov/WWW/publish/seto/class/UCR%20RHIC%20seminar/

# First some preliminaries

- date/time OK for everyone? or before group meeting? -
- I will go back and forth between BNL and UCR –we can usually only get a 6 port line keep for people at UCR – at BNL get a conference room
  - 631-344-6363 or 8383
  - http://www.phy.bnl.gov/schoolbell/groups/voco/calendar//
- introduce everyone

# A set of topics

- Initially Lectures
  - Introductory Material on the physics of Heavy Ions and QCD (and spin if Ken B wants)
  - Introductory Material on practical stuff like rapidity, cross sections, structure functions
  - Intro Material on PHENIX – detector, software, analysis – probably given by others
  - Introductory Material on the state of the science
- Later
  - more “advanced but fun” topics
    - QCD and mass, AdS/CFT, the CGC, viscosity, chiral symmetry
  - Periodically we will run like a journal club with the “students” becoming the teachers and we will cover recent papers
    - phenix white paper
    - charm suppression/flow, jet shapes, recomb,

# A request from Tim

- Here is a request from Tim – I propose to hand these off to others to prepare a tutorial
  - 1) Fun4All, CabanaBoy, CVS, ..... all these beginning steps/pieces of analysis? (Stefan Bathe)
  - 2) How PHENIX data is handled. That is, what happens between the signals in the EMCal, TOF, MuId, etc. and the DST files (uDST, nDST, pDST) that we analyze? (Astrid)
  - 3) The different triggers .... (what EXACTLY are they, what EXACTLY do they do, how EXACTLY do you use them...)? (Ken Barish)

- Some help from Astrid:
- I would recommend to at least take a peek at the tutorials I organized last year, where people(experts) gave excellent talks accompanied by working examples on most of the topics below with a lot of detail and insight.
- > 1) Fun4All, CabanaBoy, CVS, ..... all these beginning steps/pieces of analysis?
- > ***Stefan***
- I am not sure about cabana boy. But for the Fun4all framework:
- https://www.phenix.bnl.gov/WWW/offline/wikioff/index.php?title=Framework_of_Fun4ALL
- > 2) How PHENIX data is handled. That is, what happens between the signals in the EMCal, TOF, MuId, etc. and the DST files (uDST, nDST, pDST) that we analyze?
- > *** Astrid ***
- This took many speakers but for starters:
- EMCal: https://www.phenix.bnl.gov/WWW/offline/wikioff/index.php?title=How_to_analyze_EMCal_Cluster_Data
- Muons(which all I know is what i read from this page):
- https://www.phenix.bnl.gov/WWW/offline/wikioff/index.php?title=How_to_Extract_Muons_from_nDst
- dst's and condor:
- https://www.phenix.bnl.gov/WWW/offline/wikioff/index.php?title=How_to_Run_Jobs_at_RCF
- > 3) The different triggers .... (what EXACTLY are they, what EXACTLY
- > do they do, how EXACTLY do you use them...)?
- ***Ken Barish***
- Triggers: http://www.phenix.bnl.gov/WWW/intro/dataflow/trigger.html

Are these good enough? – or would it be useful is someone went through these tutorials in class and explained them (i.e. the folks in ****)

# Today

- A research project for Ken S and Christophe
  - Specifics
    - State of the phi analysis
    - The assignment
  - Kinematics and Cross sections

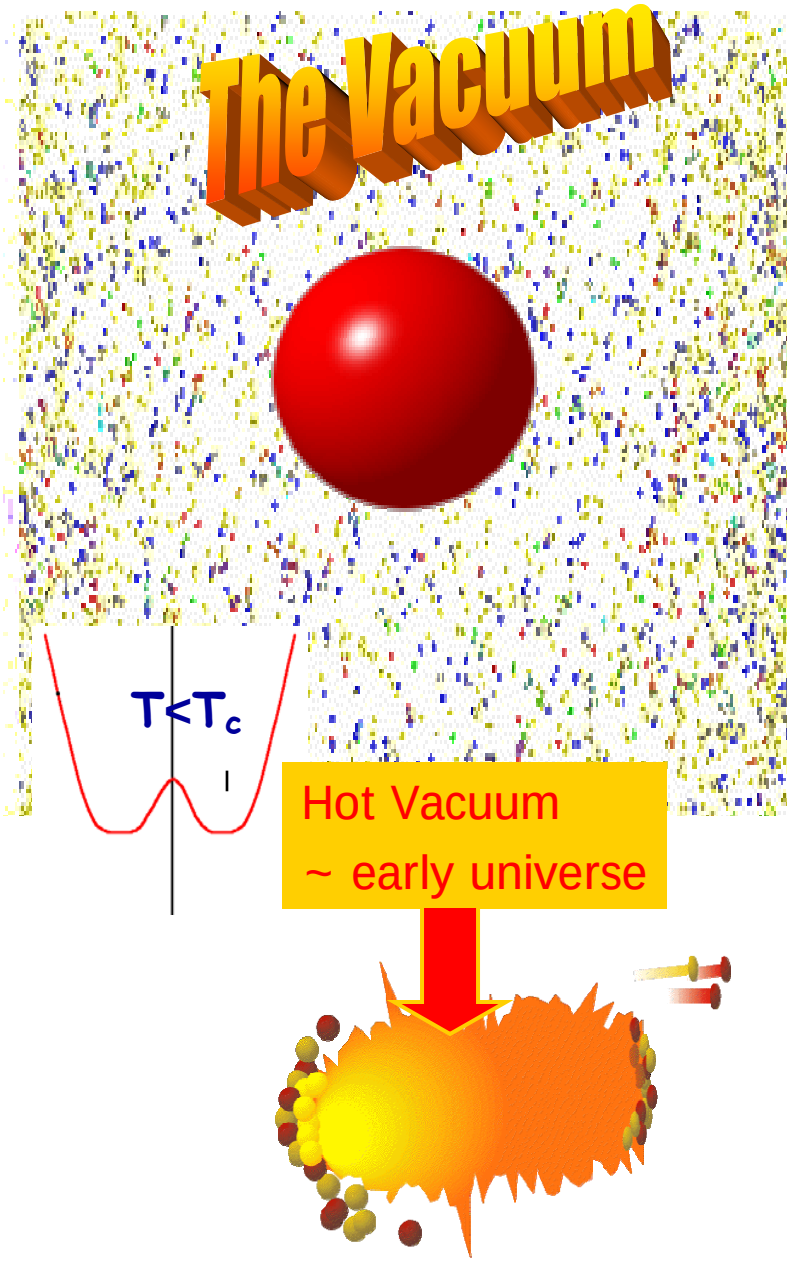
# The assignment: Part I the problem the phi to ee vs phi to KK

- In helping to solve the problem we will all learn
  - some physics about chiral symmetry (an advanced topic)
  - about cross sections
  - about how PHENIX and STAR measures things
  - About PID
  - about errors

# QCD and the vacuum

note: in a later meeting I will do the math

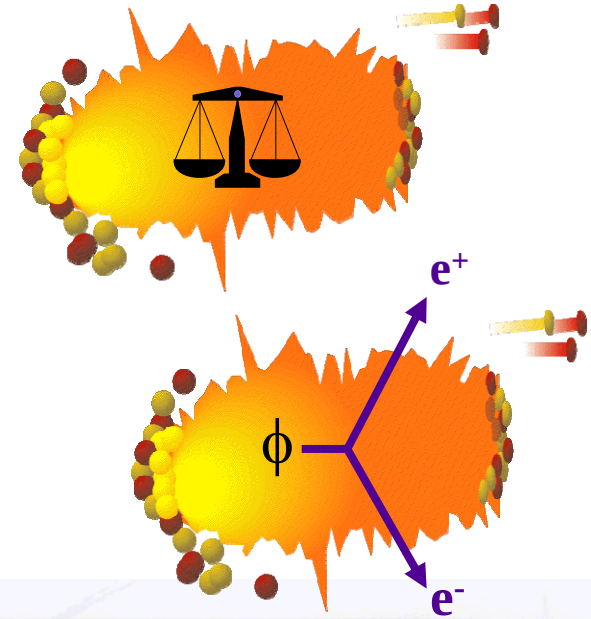
- The QCD Lagrangian ~ chiral symmetry (Is it true?)
  - ➔ all masses ~0
- Doesn't match the world we know
- What do we do?
  - Assume the vacuum is not empty – it full of stuff (the "condensate")
  - The interaction with the vacuum gives rise to mass
  - Condensate is Temperature dependent
    - I.e. at high T all masses ~ 0
- Crazy!? Can we test this idea?
- Heat up the vacuum in RHIC collisions
  - we boil it - and see if masses change go to zero ultimately
- Chiral phase transition
- Any connection to deconfinement??



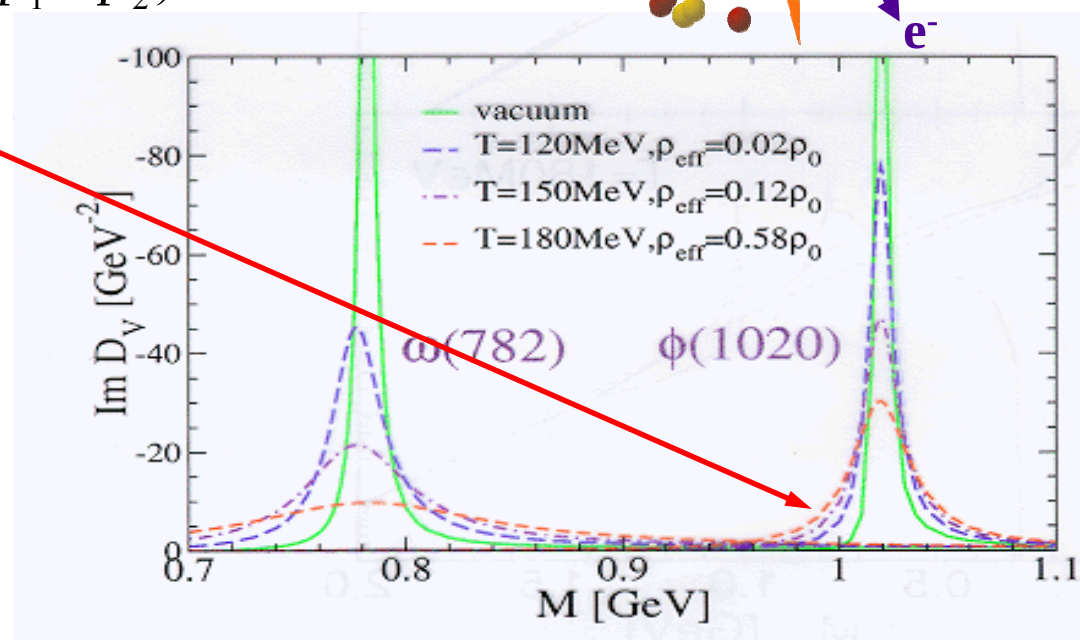
# Looking for Chiral symmetry restoration
# Vector Meson mass shifts in the dilepton channel

- "Light" Vector mesons ($\rho$, $\omega$, $\phi$)-ideal probes
  - Like putting a scale to measure mass inside the fireball
  - Short lifetime ~ few fm/c
  - ➔ Decay inside hot fireball
- Electrons are ideal messengers
  - Don't interact strongly (e.g. solar $\nu$'s)

$$m^2 = (p_1^\mu + p_2^\mu)^2 = (E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2$$



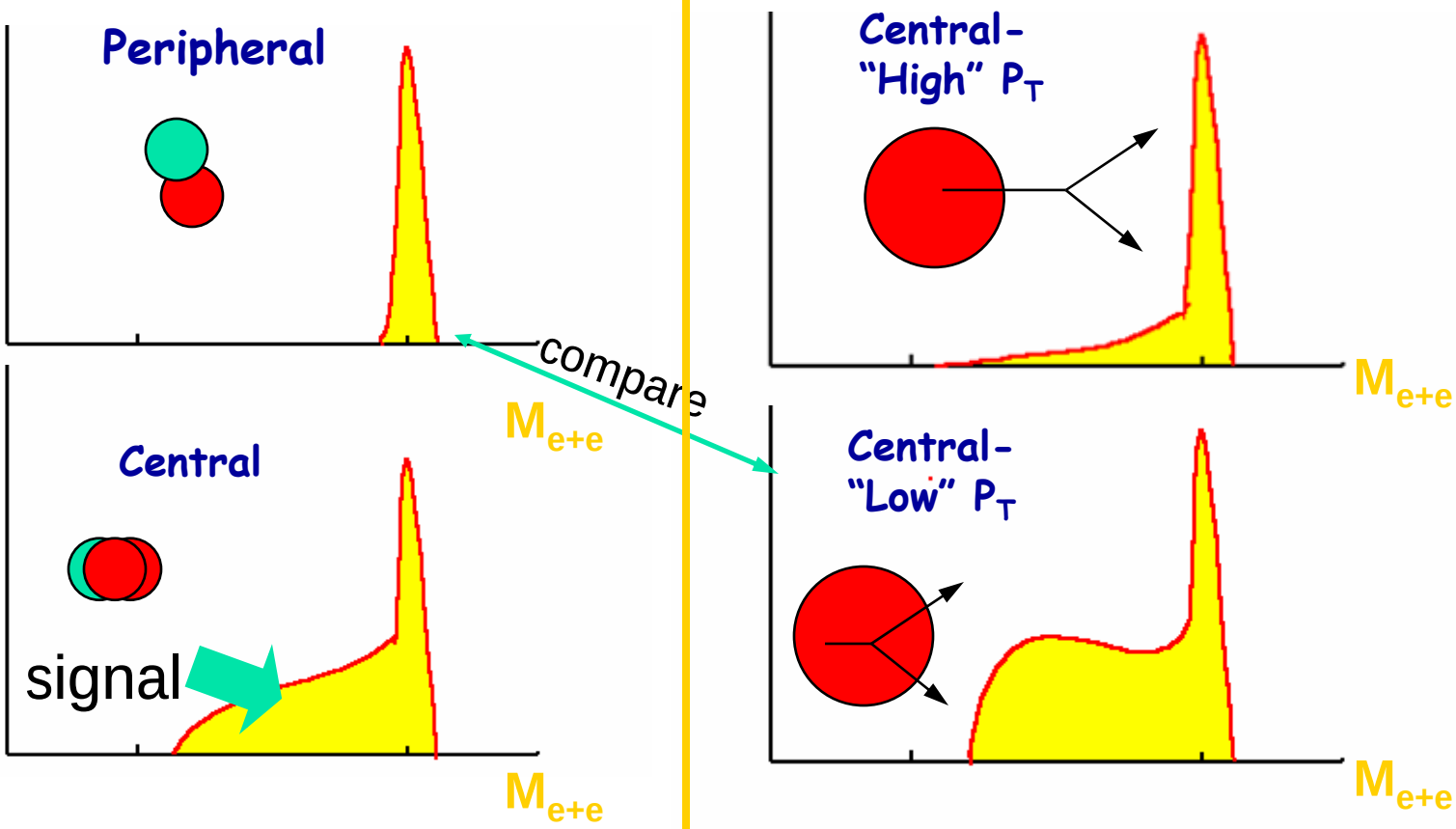

- e.g. In Medium $\rho$, $\omega$, $\phi$
  - shows low mass tail -
    - With its good mass resolution PHENIX should be able to see this




R. Rapp (Nucl. Phys A661(1999) 238c

# Experimental "Knobs"

- Signal should increase with centrality
- Signal should increase at low pt



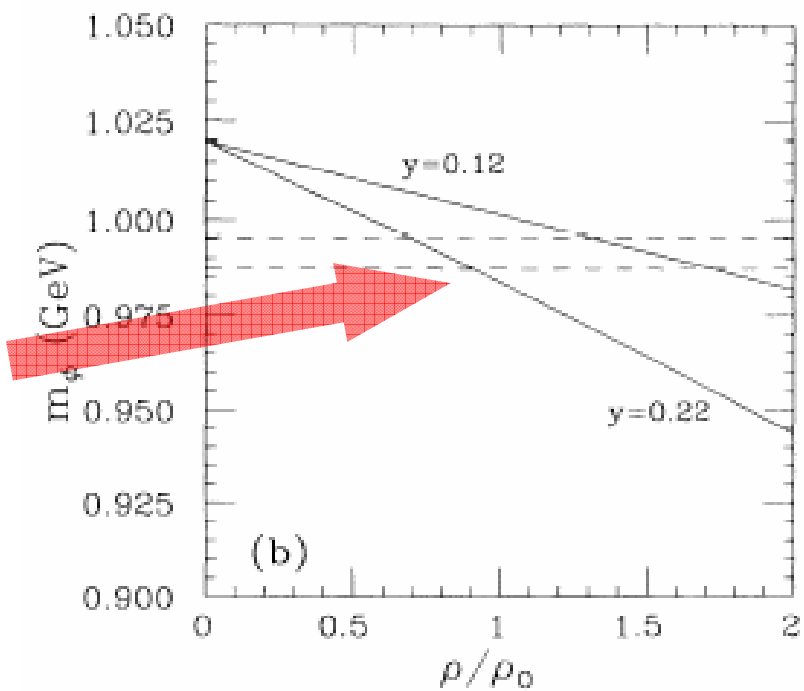

- Today : dAu – min bias only – but there is a "trick"
  : Au-Au – function of centrality

# What do we look for?

- Chiral symmetry restored
  - High temperature vacuum – Au-Au Central
  - High baryon density
    - even normal nuclear density.
- Look for
  - Mass shifts/broadening
  - A nice trick:
    - Q value of $\phi \rightarrow KK$ is small

$$\frac{BR(\phi \rightarrow ee)}{BR(\phi \rightarrow KK)}$$

    - Should be sensitive to mass changes in either $\phi$ or K




T.Hatsuda and S.Lee

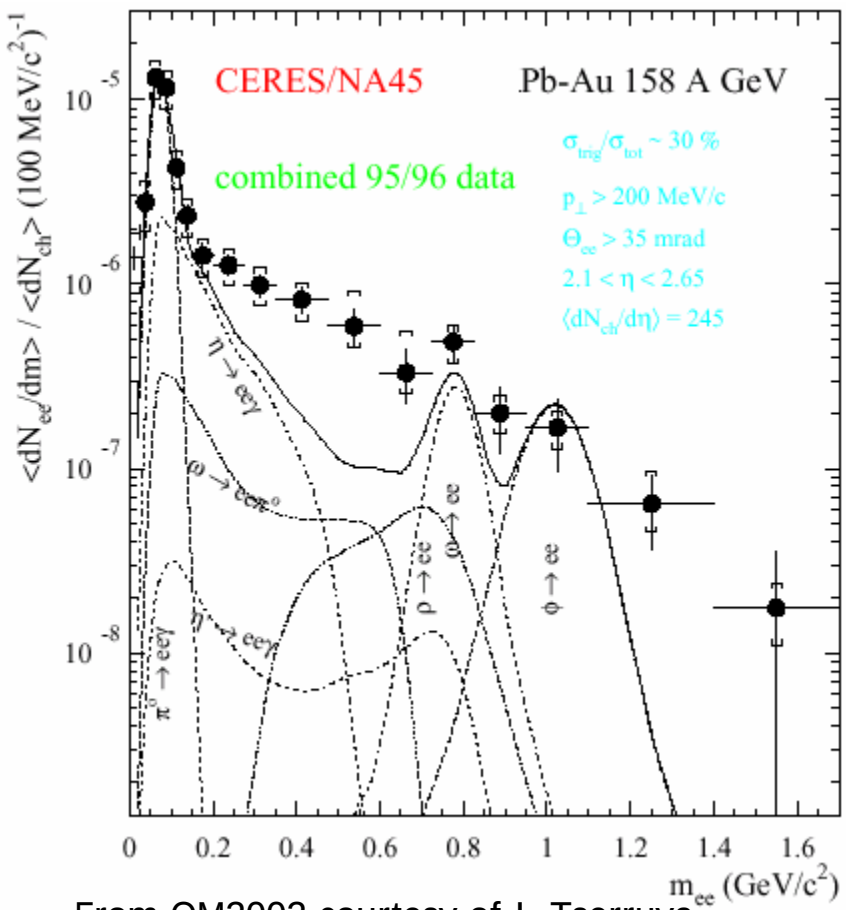
QCD sum rules for vector mesons in the nuclear medium

(Phys.Rev.C46-R34-38, 1992)

Lissauer and Shuryak, Phys. Lett. **B253**, 15 (1991).

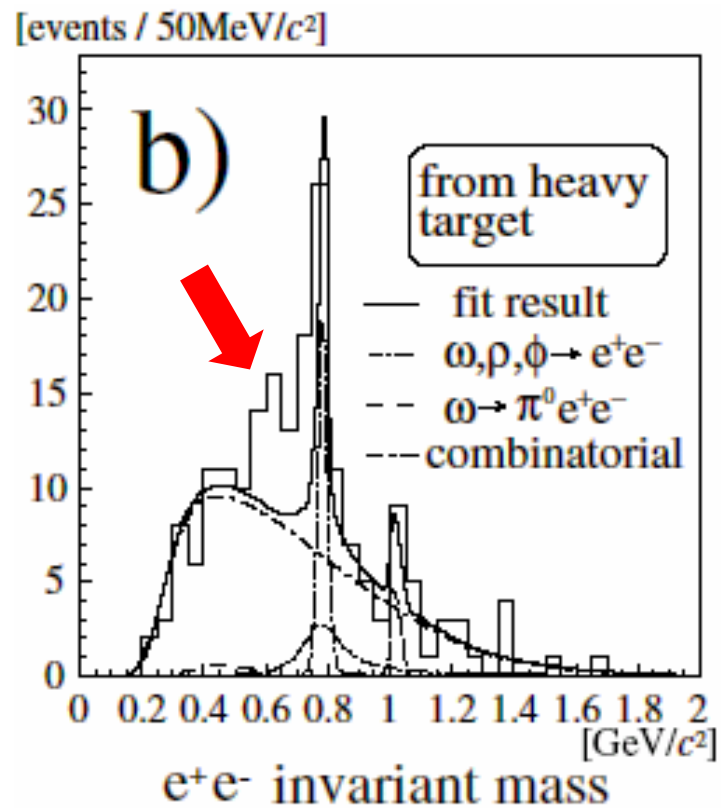
# Has anyone seen such effects?
# $e^+e^-$ invariant mass spectra

- CERES Pb-Au
  - High T vacuum




From QM2002 courtesy of I. Tserruya

- KEK E325 – proton Nucleus
  - "high" baryon density




K.Ozawa et al.

Observation of ρ/ϖ Meson Modification in Nuclear Matter (Phys.Rev.Lett 86-22)

# Let's Look at RHIC (PHENIX)

## Outline

- Compare BR (normal nuclear density)
  - dAu $\phi \rightarrow ee$
  - dAu $\phi \rightarrow KK$
- Mass shifts/broadening
  - Au-Au $\phi \rightarrow KK$
    - Guess: cannot see this to hadronic decays (only see stuff which decays outside fireball) – or the kaons which do decay and make it out rescattering

# dAu Collisions: comparing the

$$R = \frac{BR(\phi \rightarrow ee)}{BR(\phi \rightarrow KK)}$$

# at normal nuclear density in PHENIX @ RHIC

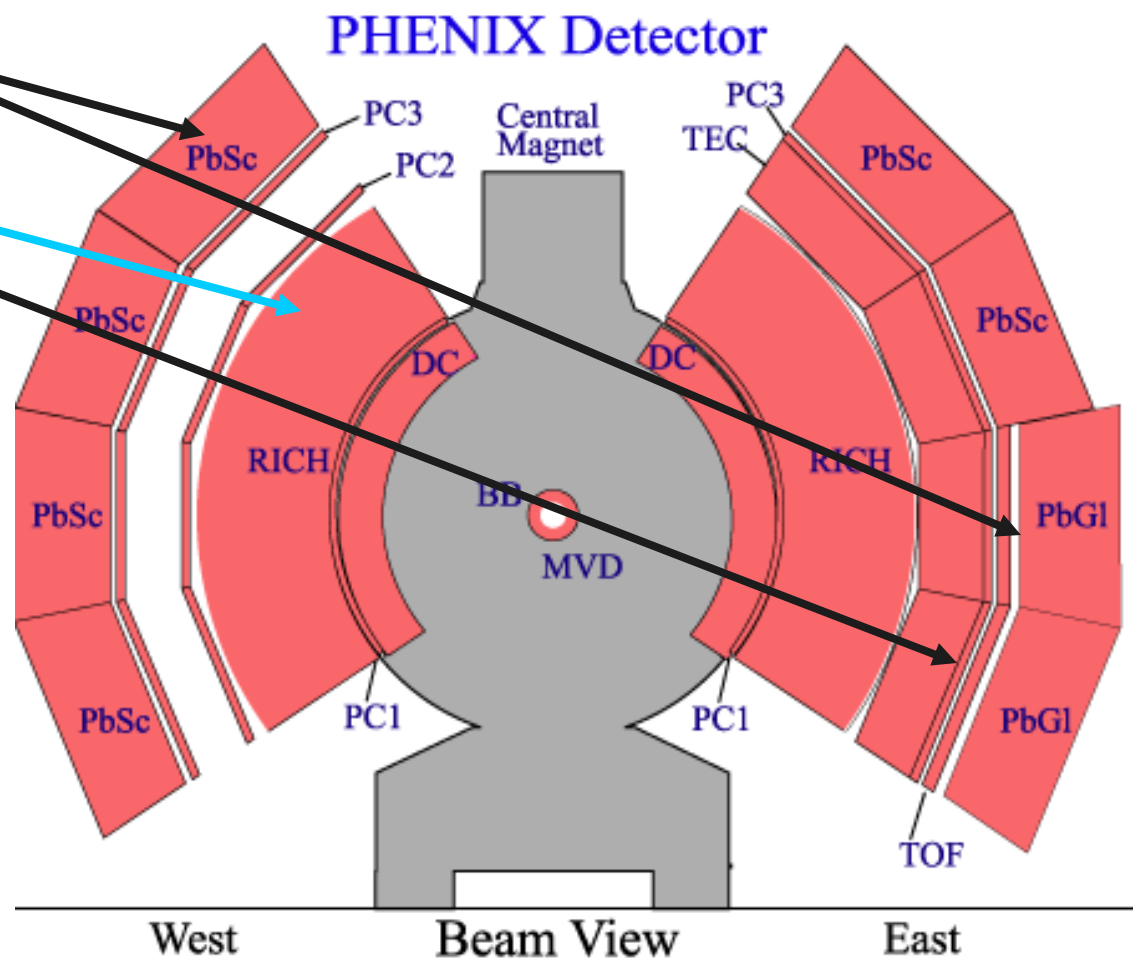
mass phi = 1020 MeV(/c^2)
mass K = 494 MeV
electron mass = .005 MeV

2x494=990
If mass of phi shifts down below 990
then ALL decays to ee so R goes to infinity
if smaller mass shift then R gets bigger

# PHENIX– designed for such measurements

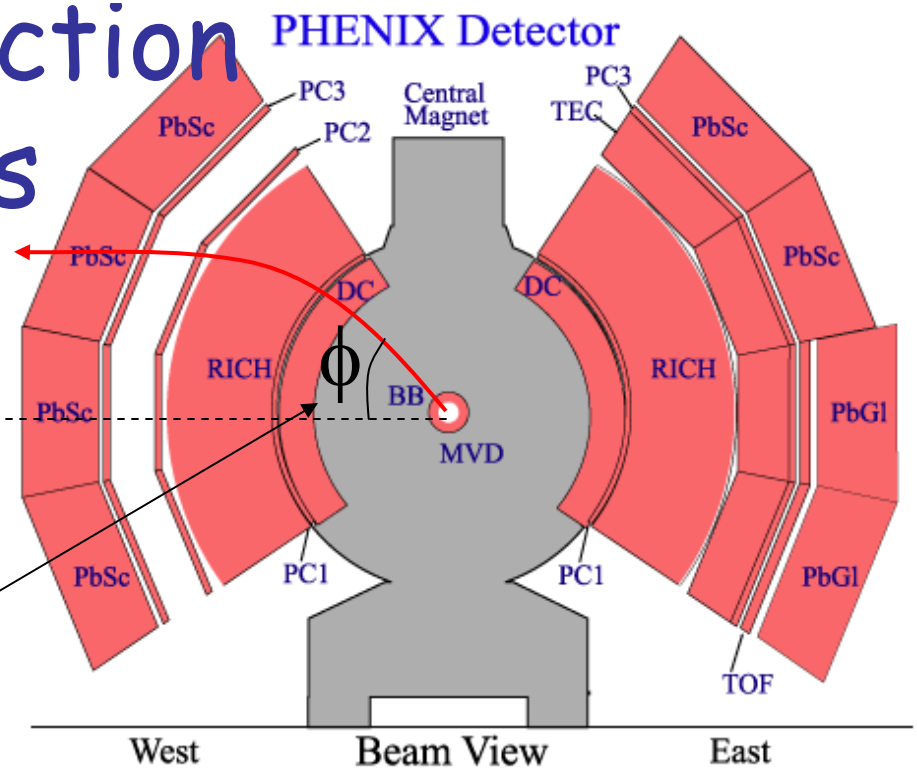
Need everything working in concert to get a di-electron low mass vector Meson measurement!

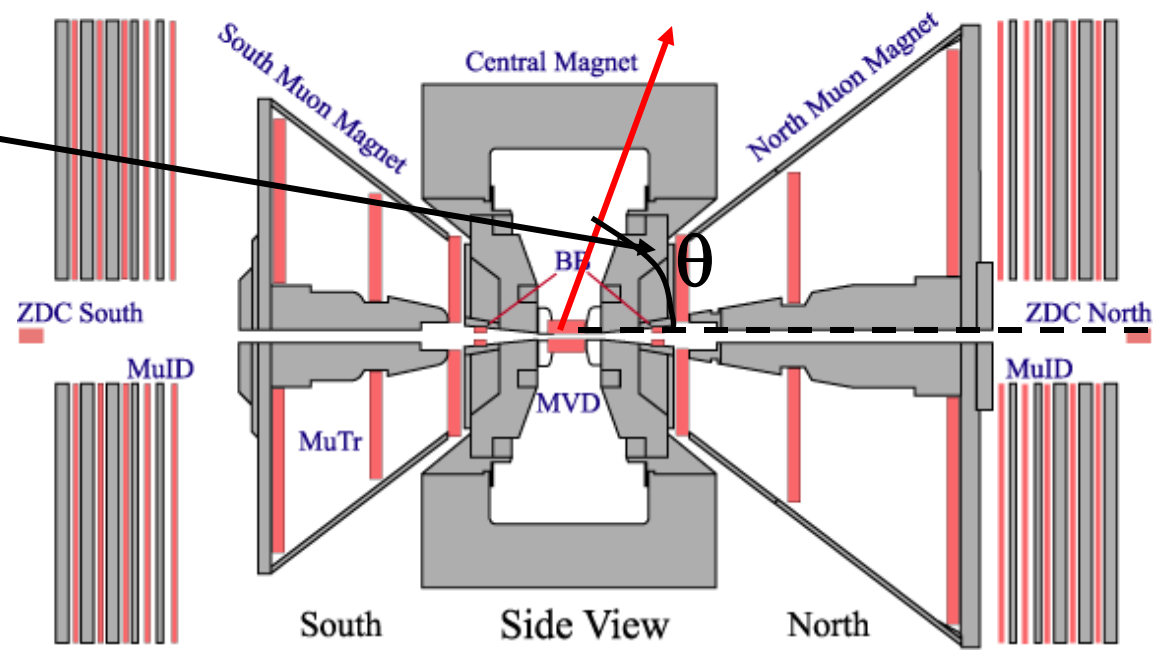
- Superb (and redundant) electron PID
  - EMC(PBSc, PbGl)
  - RICH
- PID (for kaons)
  - Via TOF to 2GeV
  - Via EMC to 1 GeV
- Good momentum resolution
- High rate capability
- Triggering capability on electron at Level-1
  - EMC-RICH-Trigger (ERT)
  - Require energy in EMC+RICH firing in coincidence



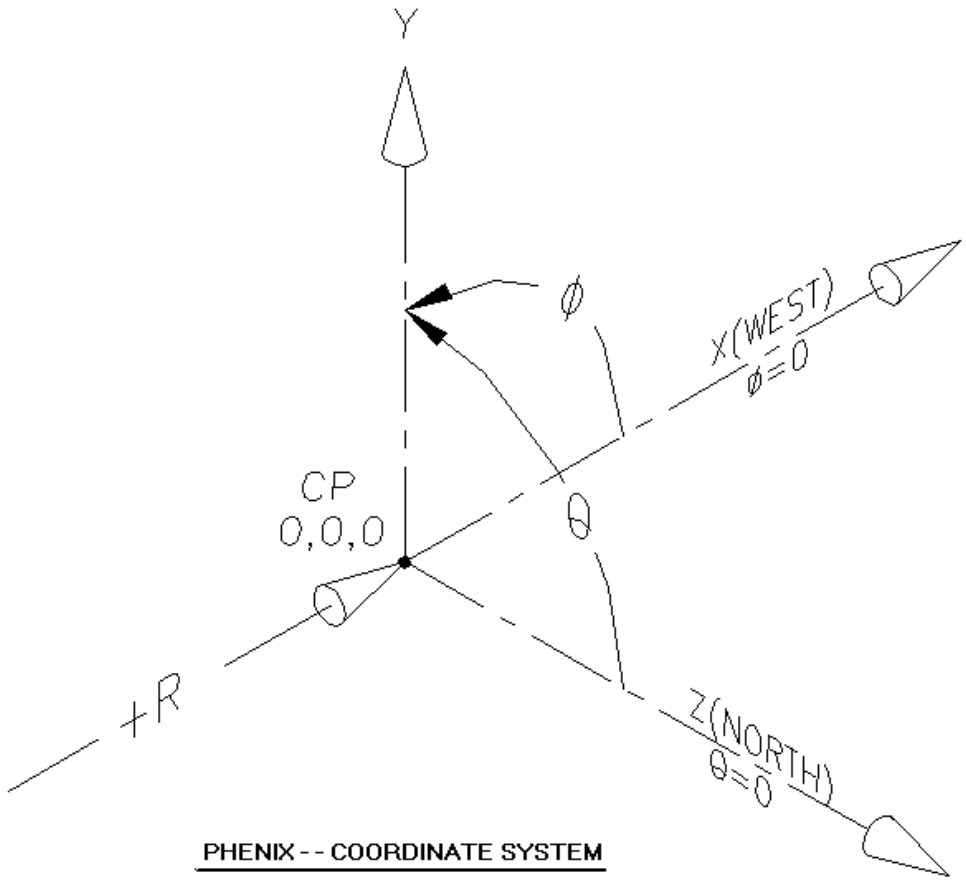
# First An introduction to Cross sections

- See in background abbotkinematics and yvesschutz
- What do we measure?
  - Number of particles per unit (solid) angle in our detector
  - two angles – phi and theta



# FYI - PHENIX coord system




PHENIX - - COORDINATE SYSTEM

PHENIX local orgin (0,0,0) is referenced to the RHIC secondary survey control network

Beam is on th Z axis

Position of detector assemblies in the central arms is measured in r, phi, and Z (at least most of them)

Position of detector assemblies in the muon arms is measured in X, Y, and Z

6/13/95

# rapidity and pseudorapidity

- Theta is something not nice to use since it is not boost invariant along the beam direction – define a new variable y
  - next week we will spend time on y and understand its properties

$$y = \tan^{-2}\left(\frac{p}{E}\right) = \frac{1}{2}\ln\left(\frac{p+E}{p-E}\right) = \frac{1}{2}\ln\left(\frac{1+\beta\cos\theta}{1-\beta\cos\theta}\right)$$

  - We usually cant measure y, but we can measure theta which we convert into something that is "Almost" y which we call the pseudorapidity

$$\eta = \frac{1}{2}\ln\left(\frac{1+\cos\theta}{1-\cos\theta}\right)$$

# Measuring Yields

- What can the yield depend on?
  - 3-momentum
  - lets break this down into transverse momentum Pt, y, and phi)
- How do you measure how many particles were produced in a collision when your detector only measures some?
  - Make some assumptions
  - uniform in phi (makes sense)
  - pick a central area around y=0 (theta=0) and just say you measure there i.e. dN/dy (y=0 for a region of $\Delta y=1$)
    - There is an assumption that the yield is flat in y around y=0

# Mt=sqrt(m^2+pt^2)

Transverse momentum is tougher – use experience – a funny magic variable Mt

Mt=sqrt(m^2+pt^2)

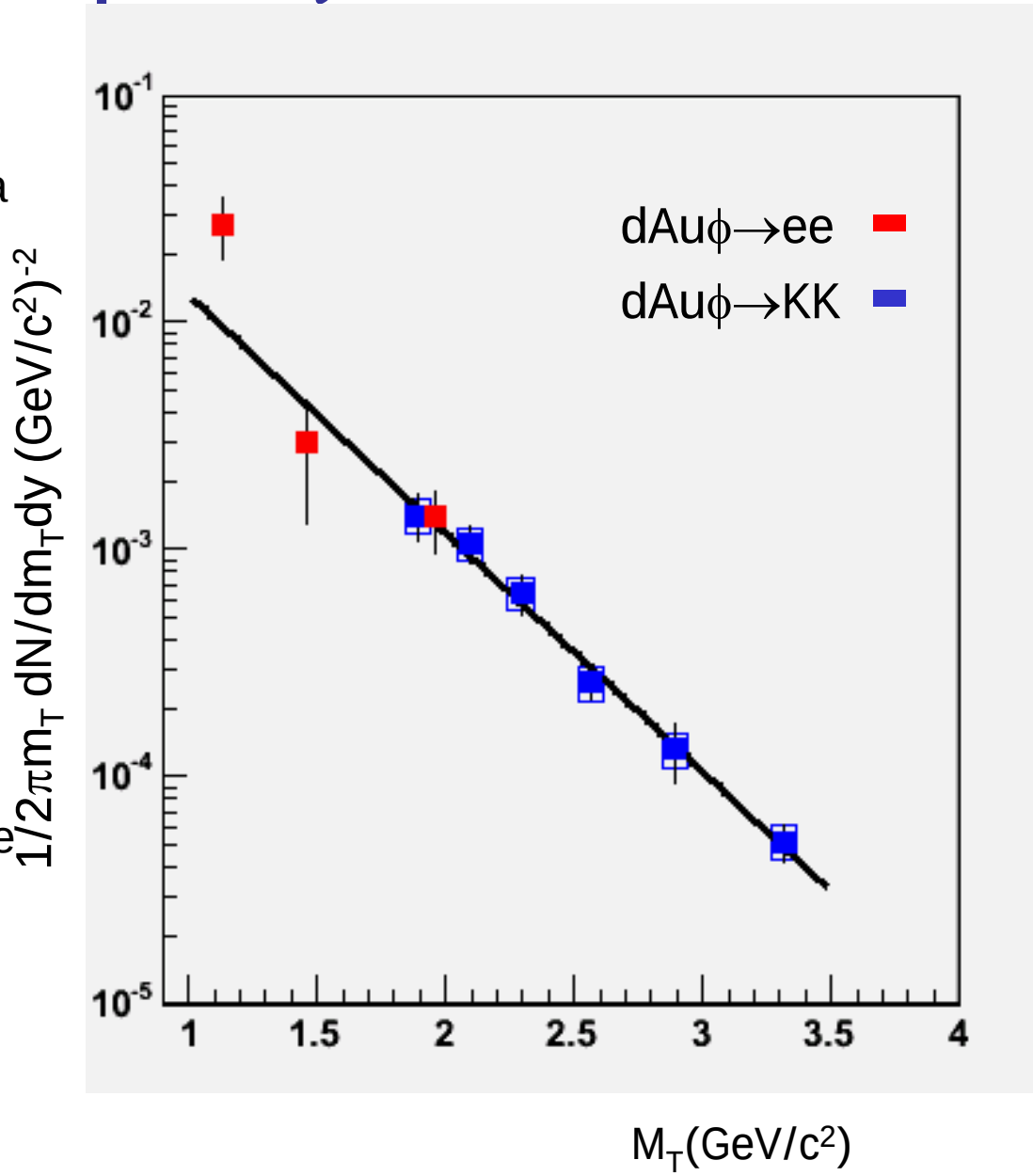
from experience particle distrbution look like this

Note the log plot

$1/2\pi m_T \, dN/dm_T dy$

Is a pretty good exponential

We will try to make some sense
of this later
but for now we just will assume its an exponential on Mt



# Light vec[illegible] (φ) from PHENIX

A talk from jan 2004 old analysis - here is where things were

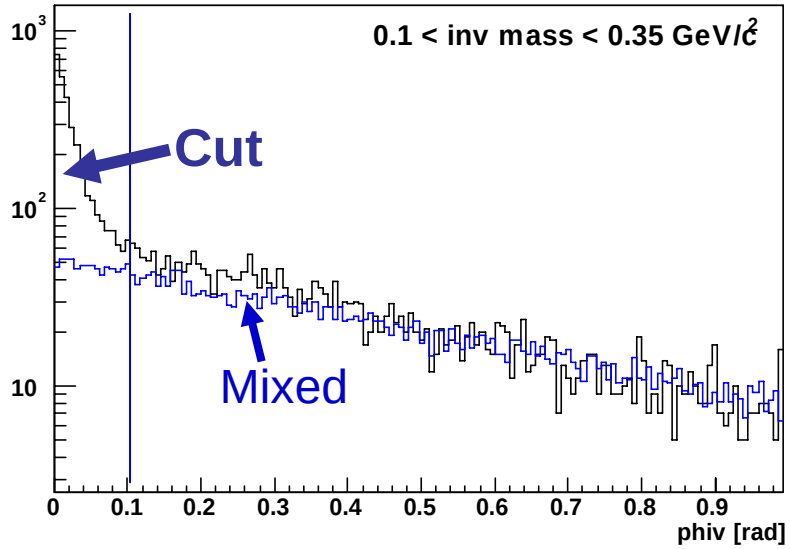
[illegible] Seto
[illegible]y of California, Riverside
for the PHENIX Collaboration

Quark Matter 2004

January 13, 2004

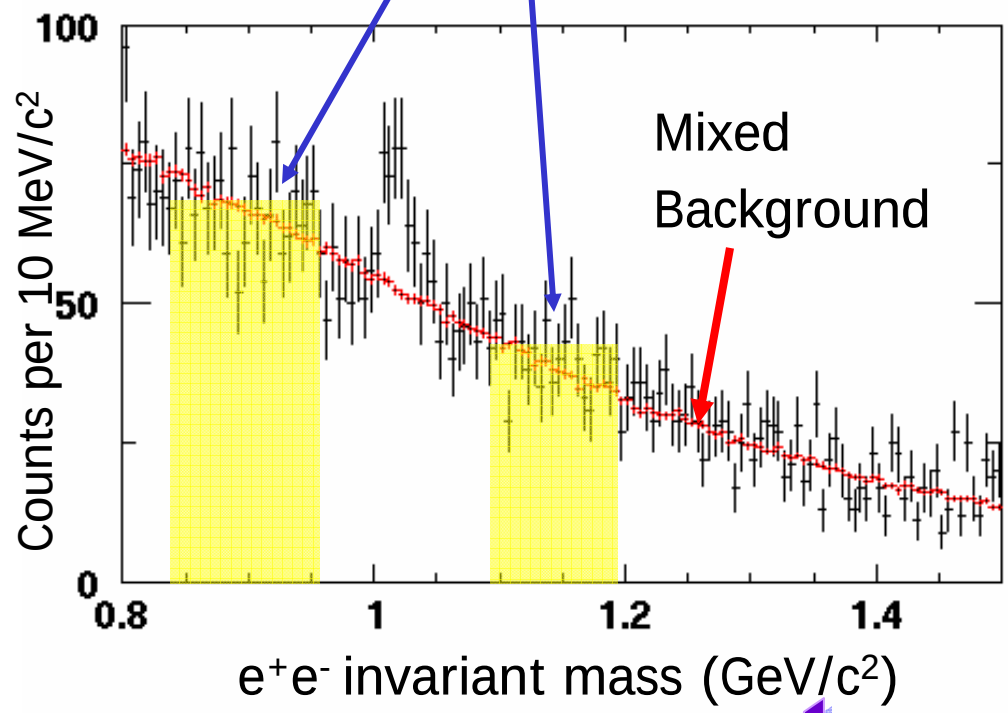
# Conversion cuts, mixed background

PhiV ( 100<mass<400MeV )




- Rejecting conversions
  - PhiV=Angle plane of pair makes with plane normal to beam direction
    - Zero mass pairs➔PhiV~0
  - Reject conversion pairs if
    - If $M_{ee}$<100
    - If 100<$M_{ee}$<400 and phiV<100 mrad

Sidebands for background normalization

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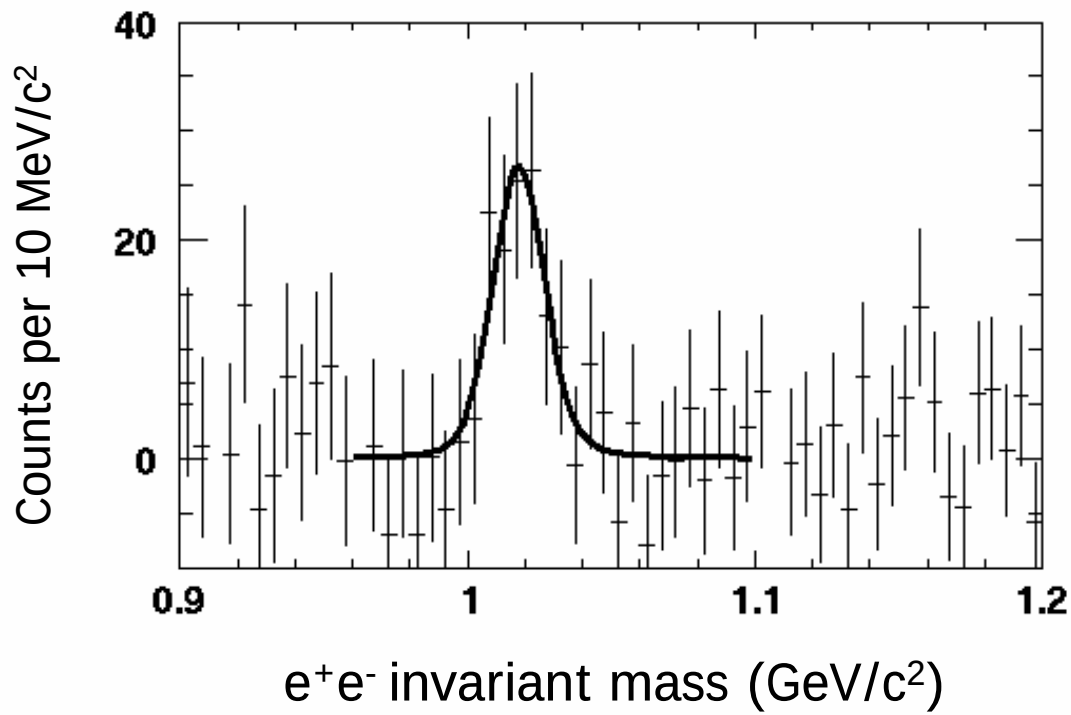
# ee Invariant Mass Spectra 200 GeV dAu- all $m_T$

- $N_\phi$~120
- Fit is to relativistic B-W convoluted with Gaussian
  - M=1.0177 ± 0.0023 GeV
  - $\Gamma$=0.00446 GeV(fixed)
  - $\sigma_{exp}$=0.0081 ± 0.0021 GeV
  - $\chi^2$/DOF=13.6/13
- Consistent with PDG




- Now
  - break into 3 $m_T$ bins
  - count signal by summing mass bins ±3σ around mass peak
  - Do corrections and

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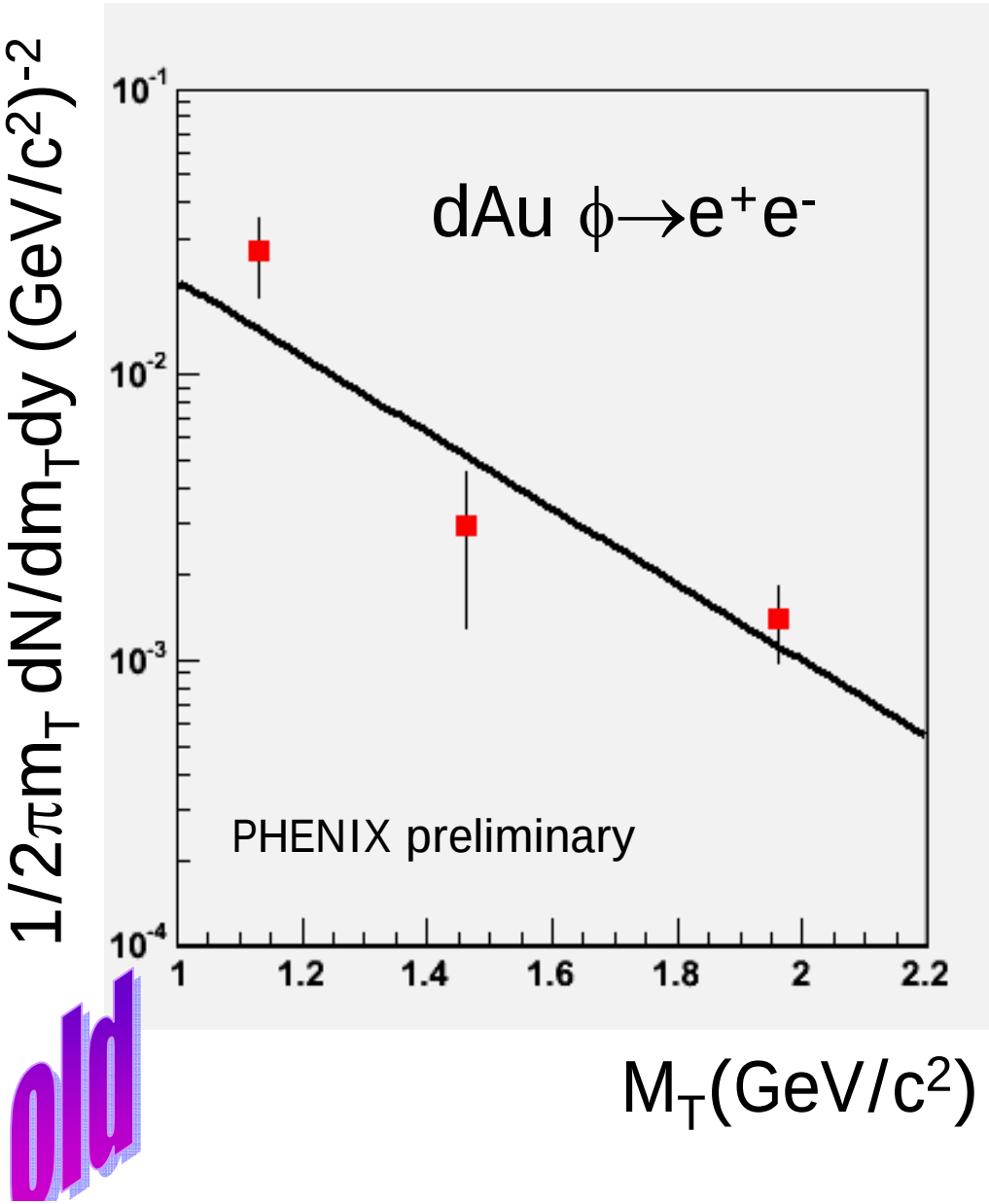
Poster: Electro 4
Yuji Tsuchimoto

# $dN/dm_T$ and yield

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dN/dy=.056±.015(stat) ±50%(syst)
T=326 ±94(stat) ± 53%(syst) MeV
(PHENIX preliminary)

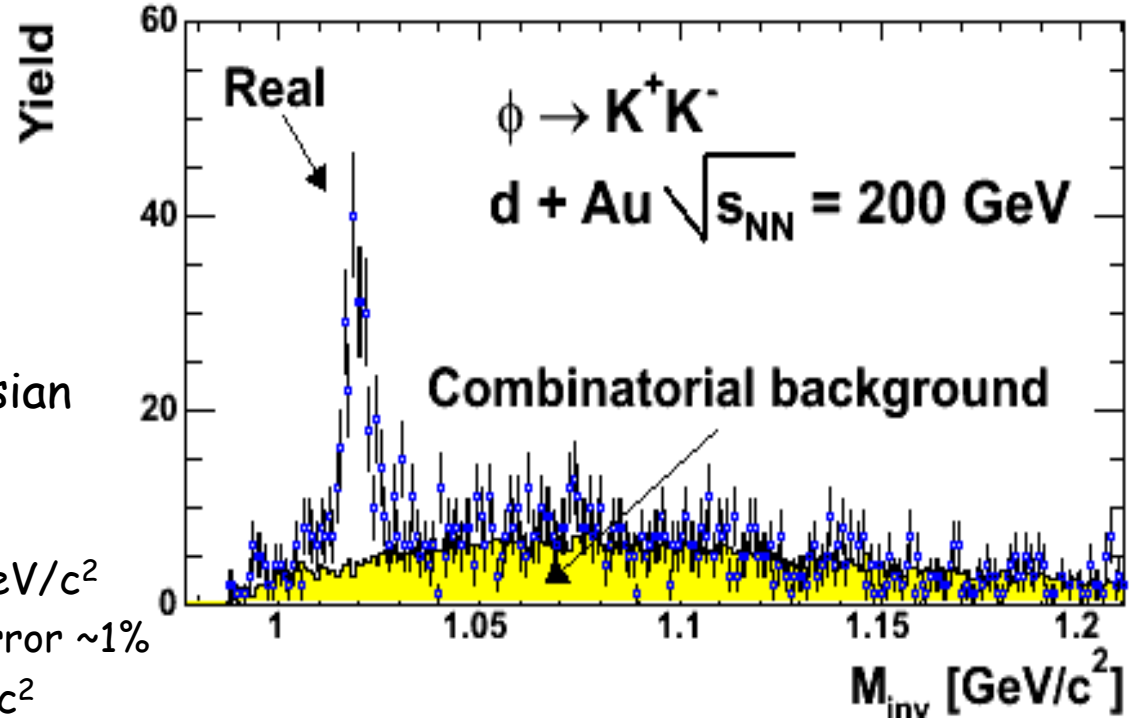
- major contributions to the systematic error
  - normalization of the background and signal extraction and the way the variations affect T and hence dN/dy
  - run-by run variation from the Electron-RICH-Trigger

# 200 GeV dAu – $K^+K^-$ invariant mass

- PID in TOF only (smaller acceptance)
  - Higher pt
- Nevt = 62 M
- Min. bias

- Fit to Relativistic BW convoluted with a Gaussian
  - N = 207 ± 16
  - S/B ~ 5/1
  - m= 1.0193 ± 0.0003 GeV/$c^2$
    - Momentum scale error ~1%
  - $\Gamma$= 4.750 ± 0.67 MeV/$c^2$
  - $\sigma$=1.2 MeV (fixed)

  - PDG M=1.01946 GeV/$c^2$
    $\Gamma$= 4.26 MeV/$c^2$

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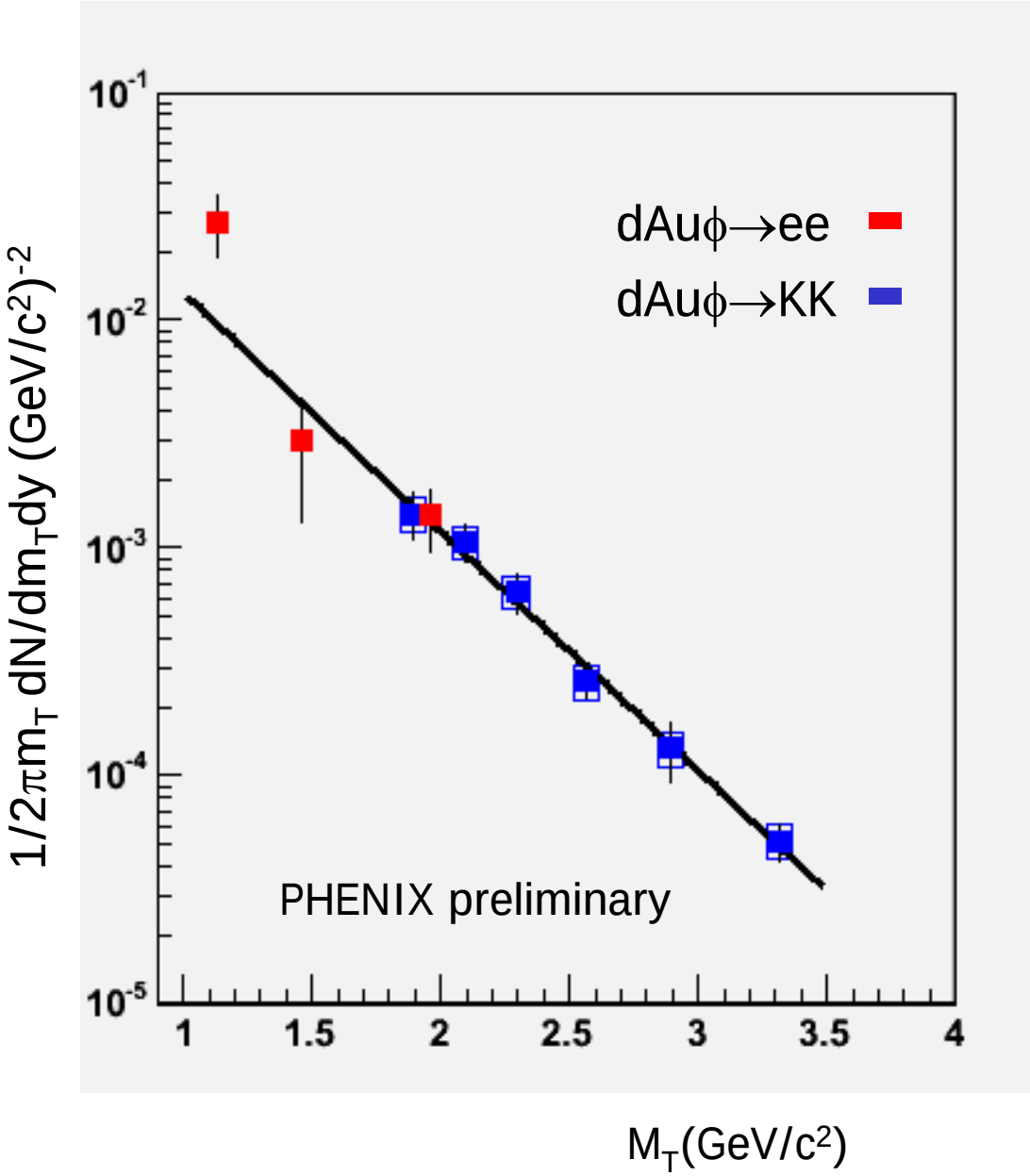
Poster: Spectra 9
Dipali Pal

# Minimum-bias $m_T$ distribution of $\phi$




**$\phi\rightarrow$KK min bias**

**dN/dy = 0.0468 +/- 0.0092(stat) (+0.0095,-0.0092) (syst.)**

**T (MeV) = 414 +/- 31 (stat) +/- 23 (syst)**

**(PHENIX preliminary)**

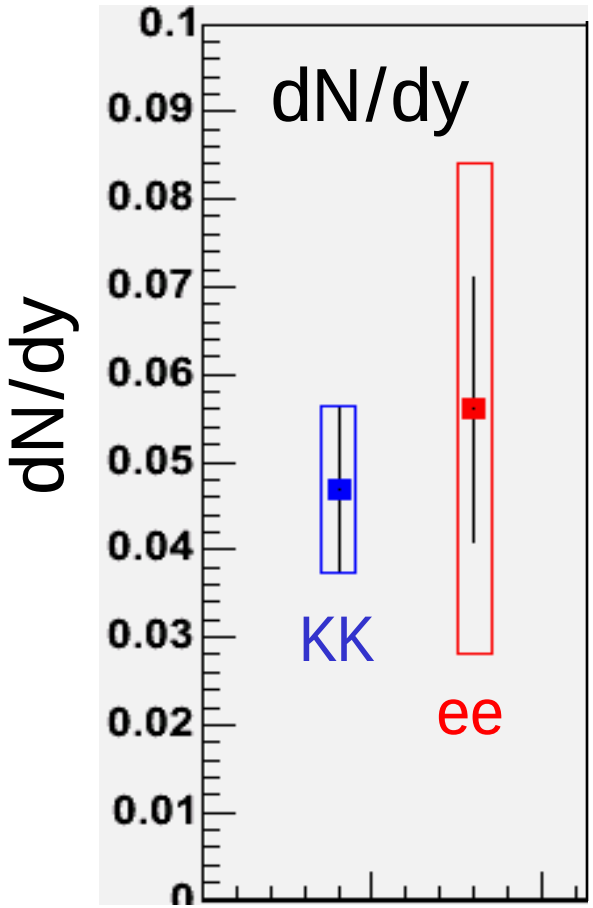
Overall fit
dN/dy~ .0485
T~408
$\chi^2$/DOF=6.7/7

old

# Compare ee with KK results

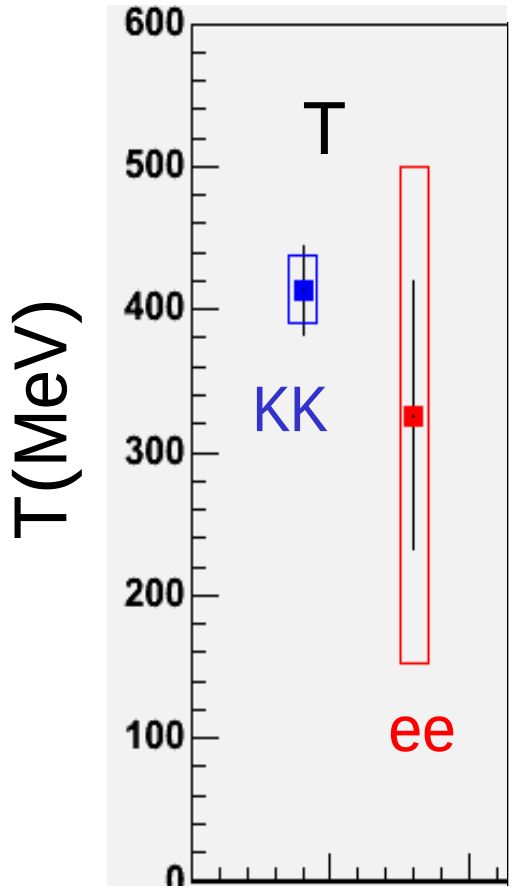
KK channel
dN/dy = 0.0468 +/- 0.0092(stat)
(+0.0095,-0.0092) (syst.)

ee channel
dN/dy=.056±.015(stat) ±50%(syst)




KK channel
T (MeV) = 414 +/- 31 (stat)
+/- 23 (syst)

ee channel
T=326 ±94(stat) ±53%(syst) MeV




- Yields consistent with each other
  - BR in normal ratio

PHENIX preliminary

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# Conclusion

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dAu $\phi \rightarrow e^+e^-$

dN/dy=.056±.015(stat) ±50%(syst)

T=326 ±94(stat) ±53%(syst) MeV

dAu $\phi \rightarrow K+K-$

dN/dy = 0.0468 +/- 0.0092(stat) (+0.0095,-0.0092) (syst.)

T (MeV) = 414 +/- 31 (stat) +/- 23 (syst)

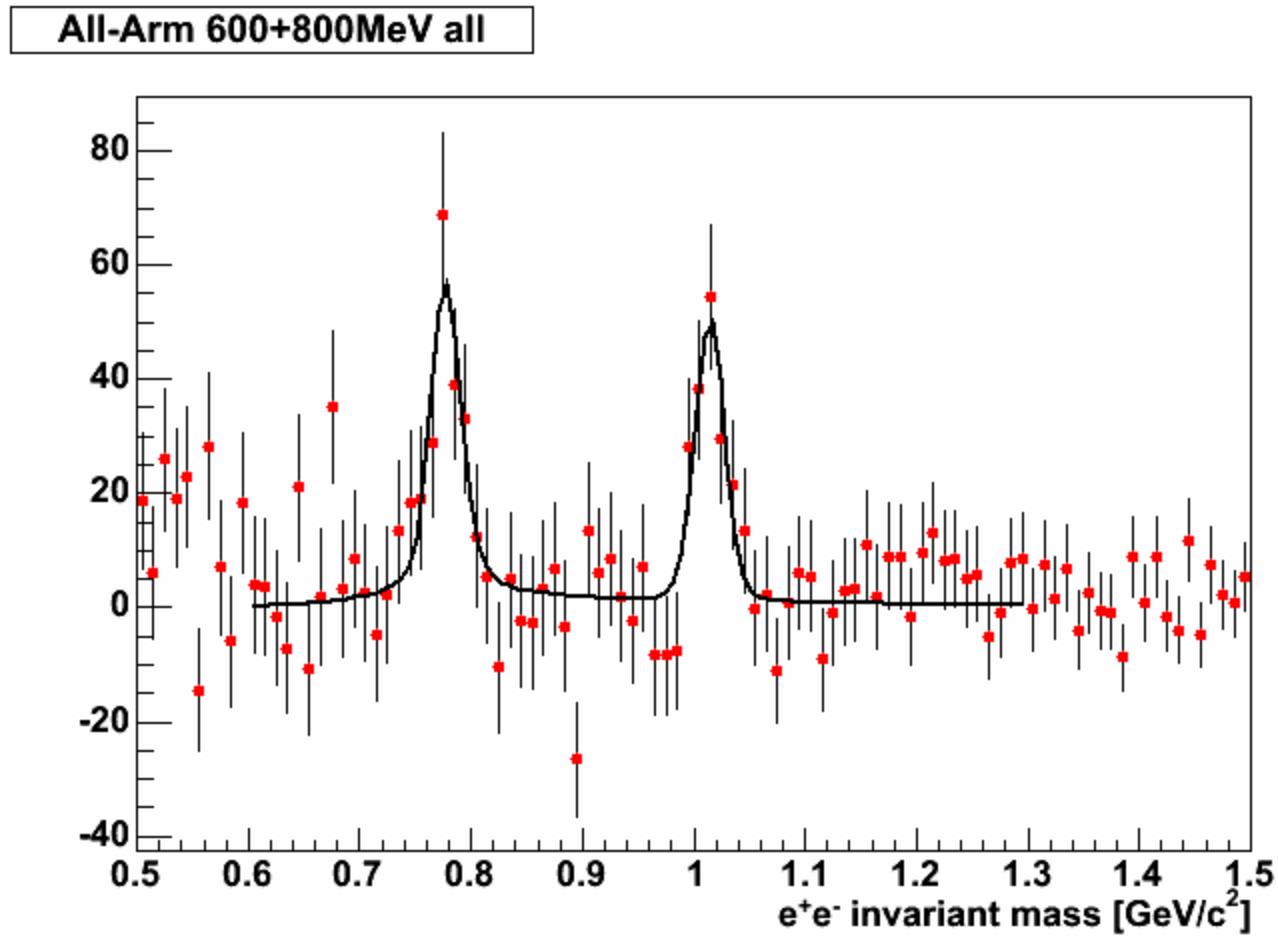
- Summary:
  - A first measurement has been made of the $\phi$ to ee channel in dAu collisions at 200 GeV. Within error bars it agrees with the KK result.
  - For overall shapes in Au-Au $\phi$ to KK, mass and width stay consistent with PDG as a function of centrality
  - $\phi$ Enhancement as a function of centrality, similar to kaons

# Outlook to the future

Note: early in the story of lmvm ee physics at RHIC

- Near term : this data
  - Use rest of statistics (ert threshold>800 MeV, min bias)
  - Better control of systematics
  - Centrality,pt dependence (dAu-KK, ee?)
  - omega
- run 4
  - $\phi$ flow (poster Flow 7: Debsankar Mukhopadhyay)
  - ee in Au-Au 50x run-2
- The far future
  - Upgrades- the Hadron Blind Detector (Cerenkov)
  - RHIC II

# Full data sample – the future

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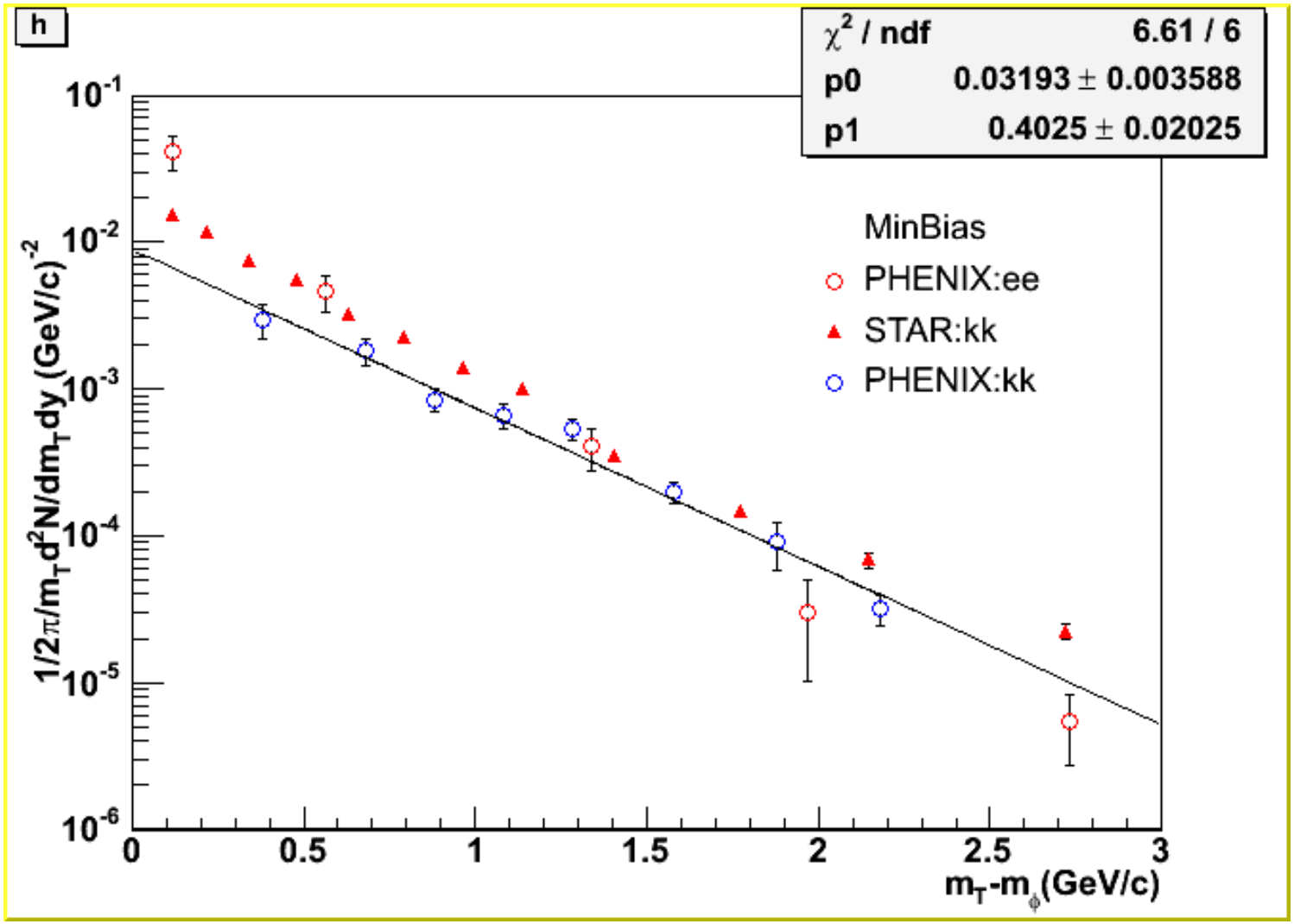
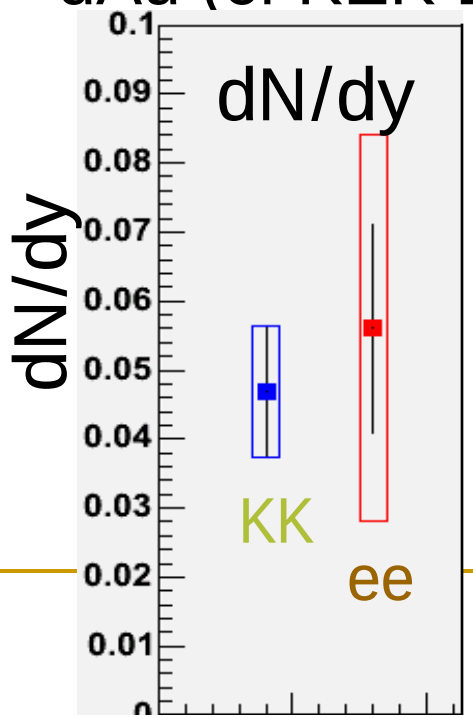
The future is now
New Analysis
much more complete

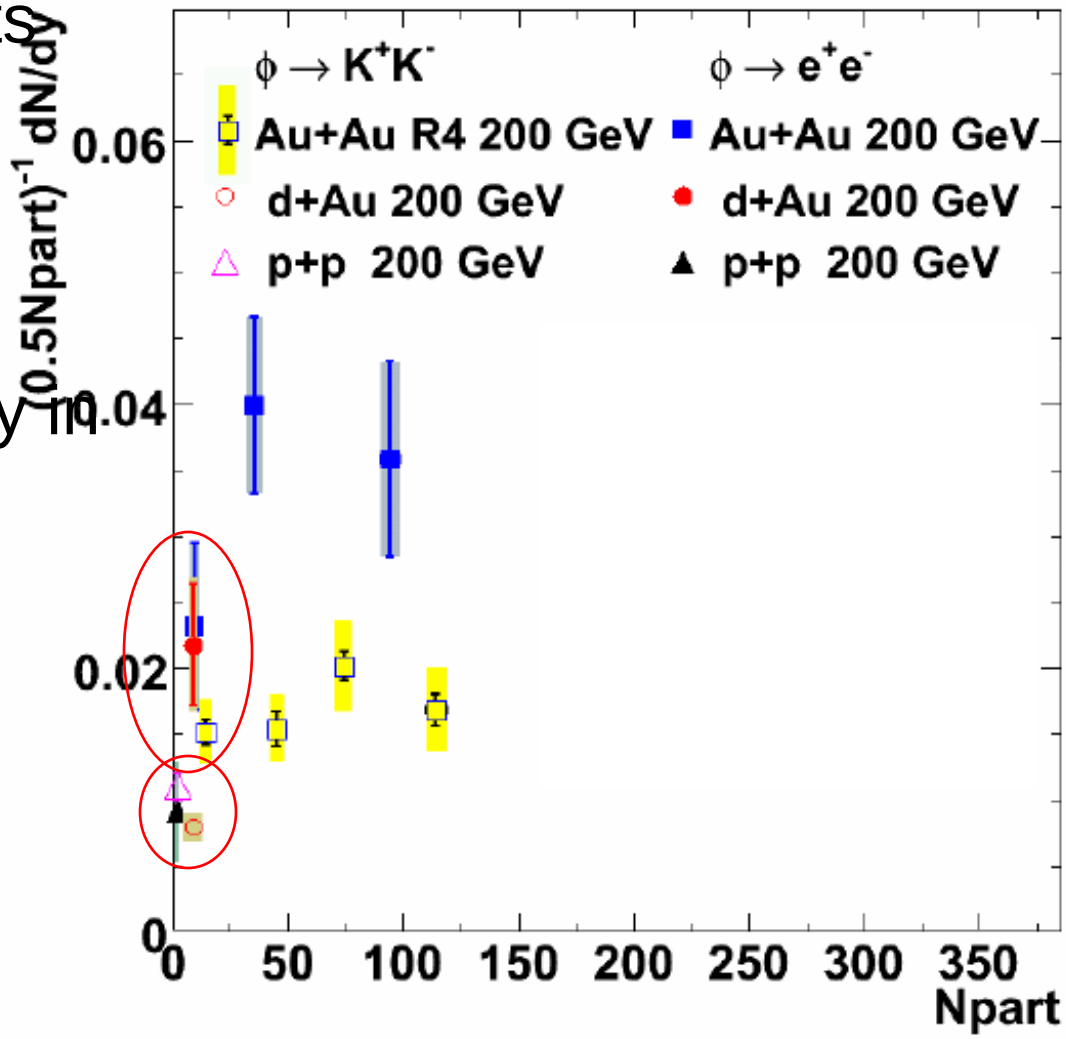
# dAu data - yesterday



# the main plot

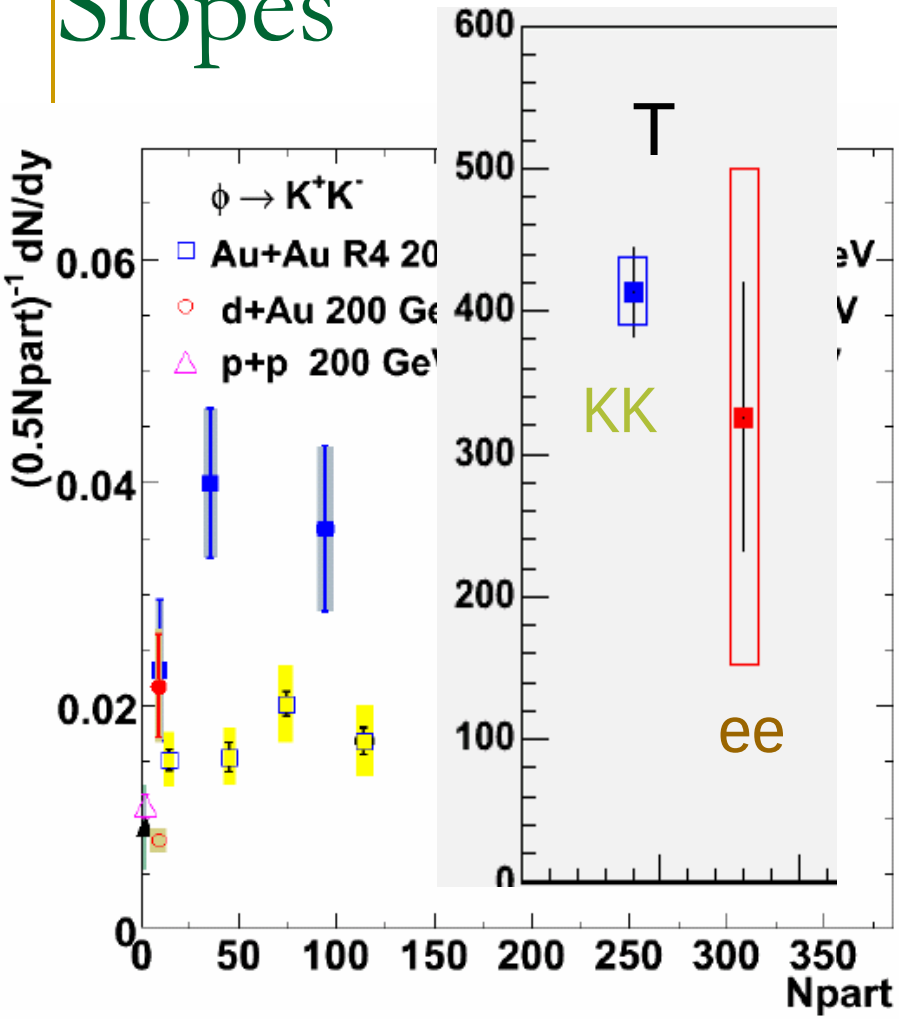
- The Npart>150 points don't have enough statistics to give a meaningful peak
- At the moment the excess exists already in dAu (cf KEK E325)

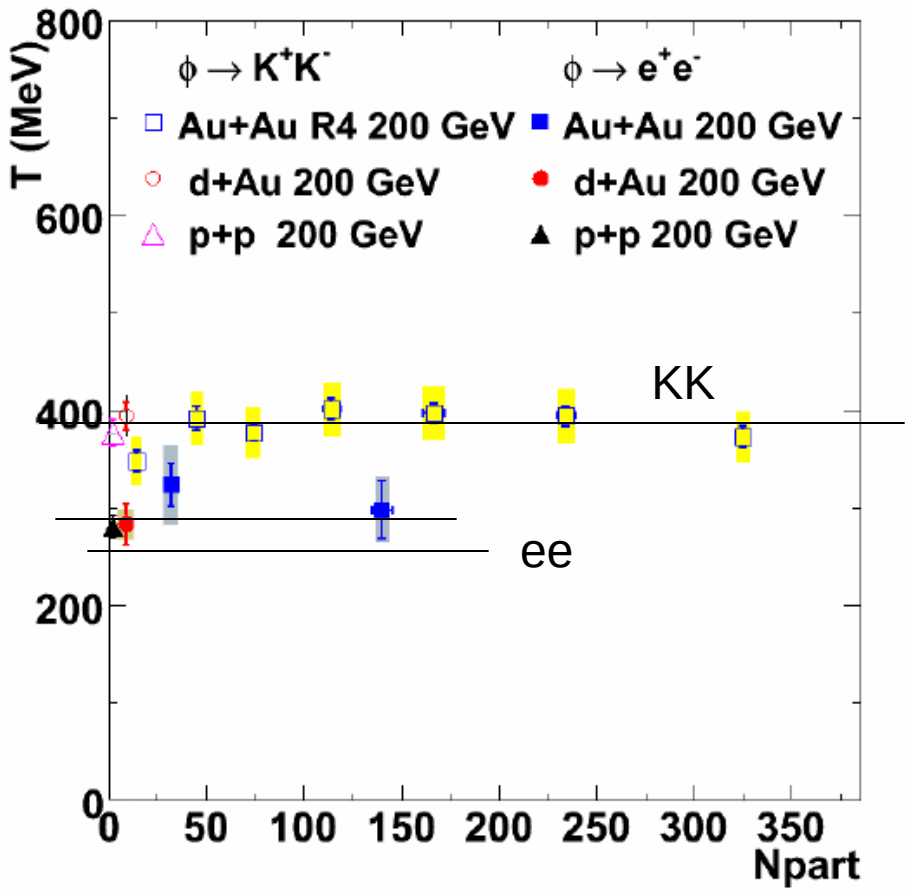



sasha

# Slopes

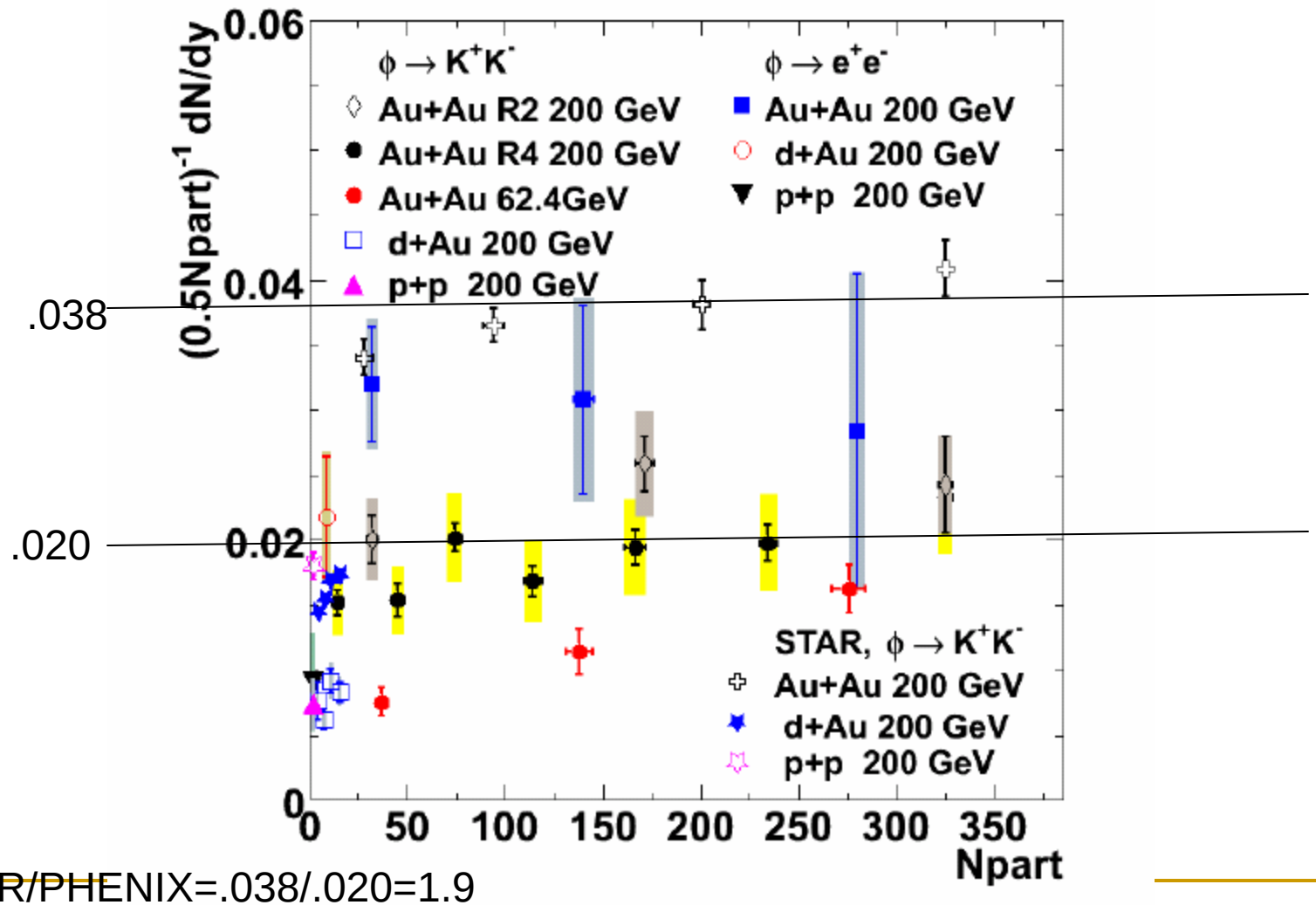



all ee slopes ~300, all KK slopes ~400.

HW: is our excess due to the fit? or do our real data point show an excess?

# Comparison to STAR



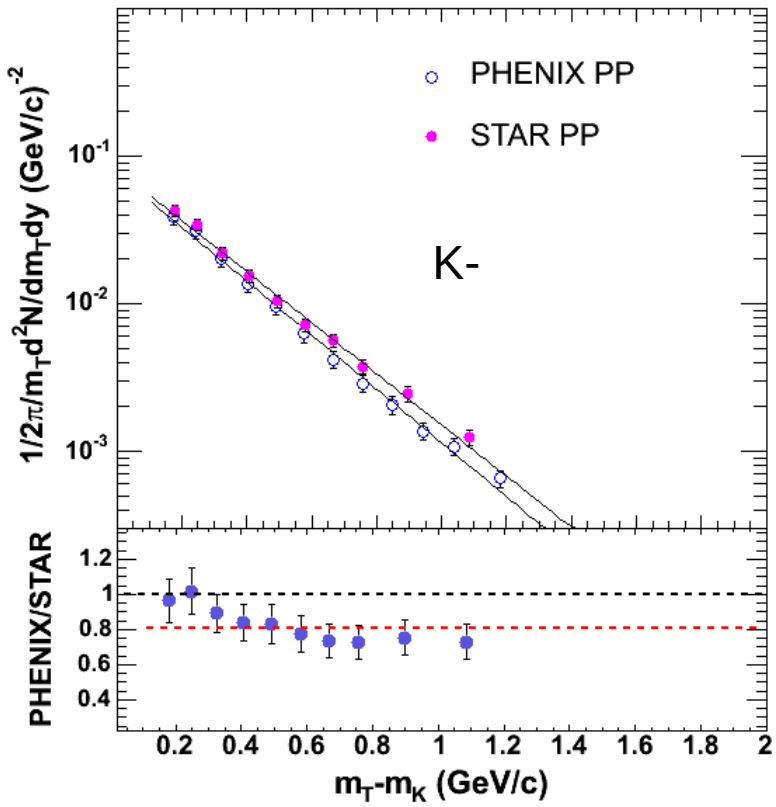

STAR/PHENIX=.038/.020=1.9

*Alexander Kozlov, $\phi$ meeting, 2/8/07*

# Make comparisons

- PHENIX to STAR
- PHENIX to PHENIX!
- Many data sets
  - pp, dAu, AuAu
  - 200 GeV, 63 GeV
- Many particles
  - phi,
  - K+, K-, Ks
  - e+, e-
  - pi+ pi- pi0

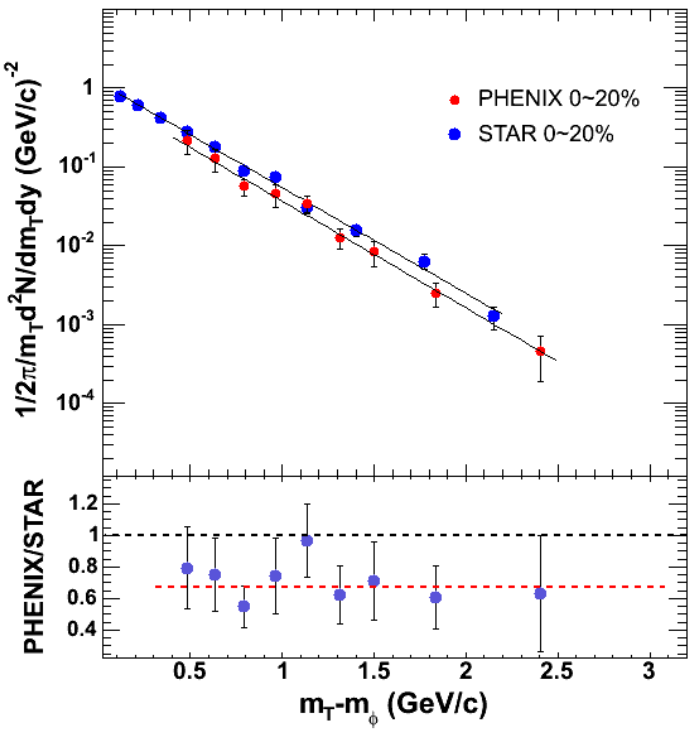
# pp comparison of Kaons




STAR is ~1/.8=1.25 or 25% higher than PHENIX

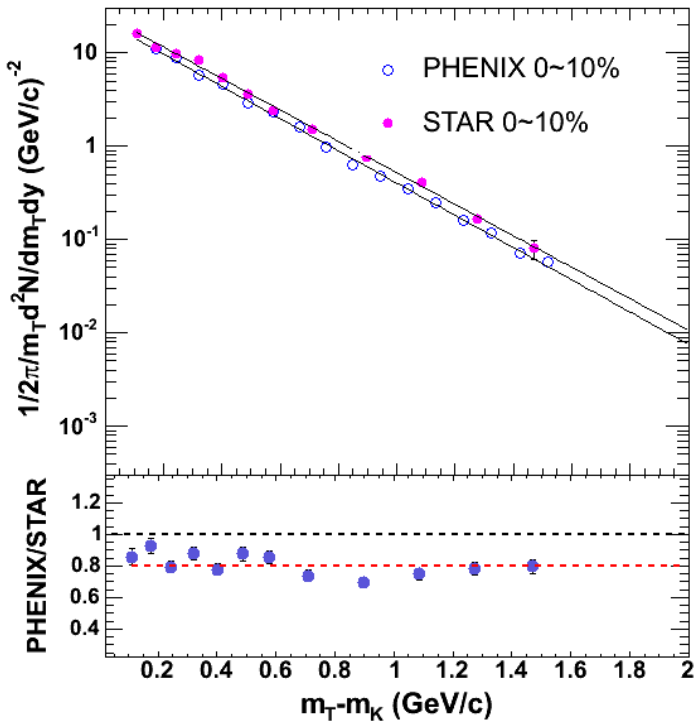
# 62GeVAuAu

Phi->kk@62GeV




~67% of STAR, no clear pT dependence

Single kaon(-)@62GeV

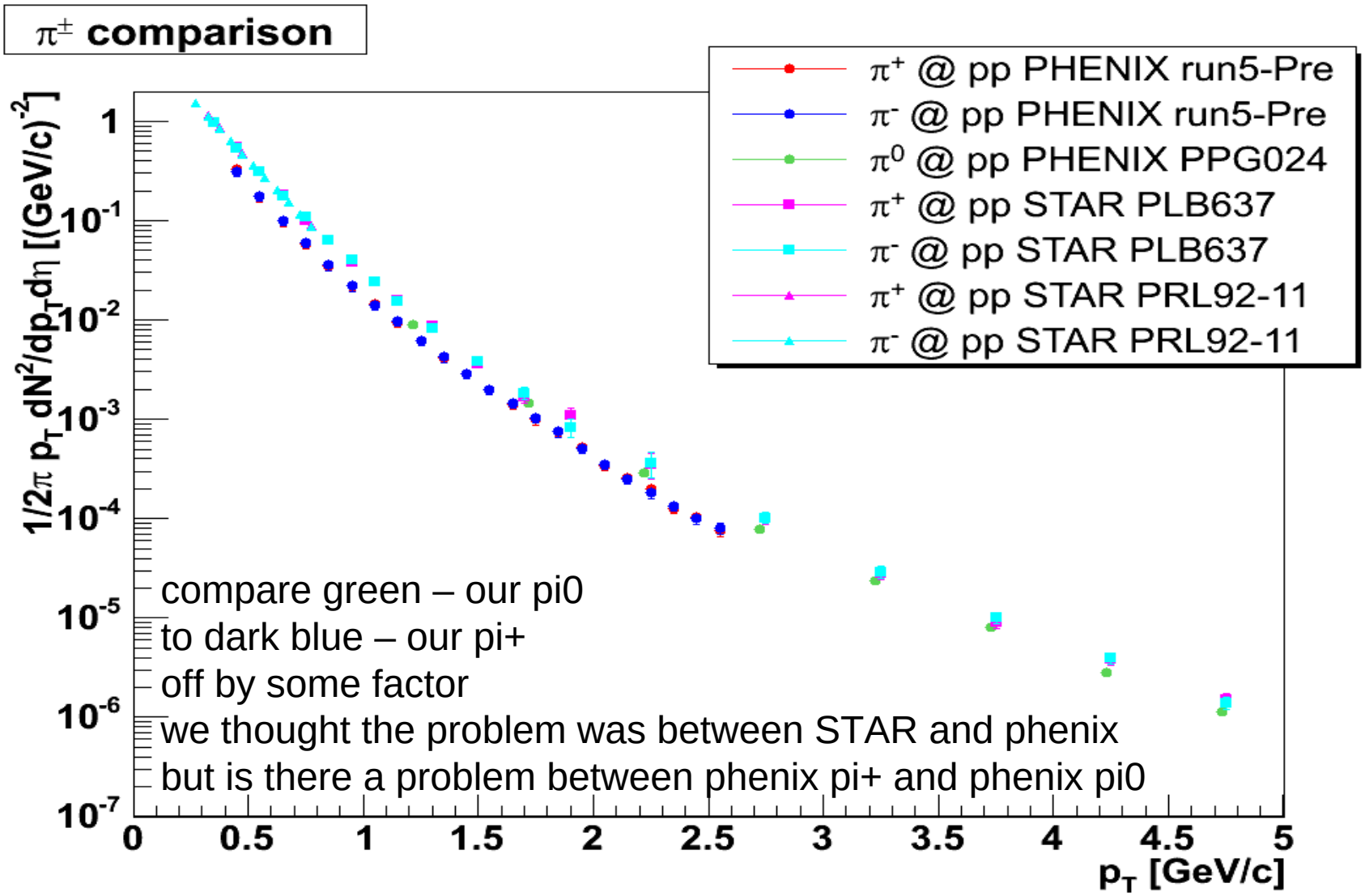



need sqrt(1/.67)=1.22 or 22%  we see 1/.85=1.18  or 18% in the TOF

# STAR comparisons
## (question of importance – but continue)

- .kaons seem to be consistently off by ~20% in pp, dAu and AuAu
  - comment
    - 1.2^2=1.44
    - 1.4^2=2
  - Is it PID? or something else
  - pions seem to match (check how well this is really true)
- So folks have asked about Ks

# Single pion spectra in pp

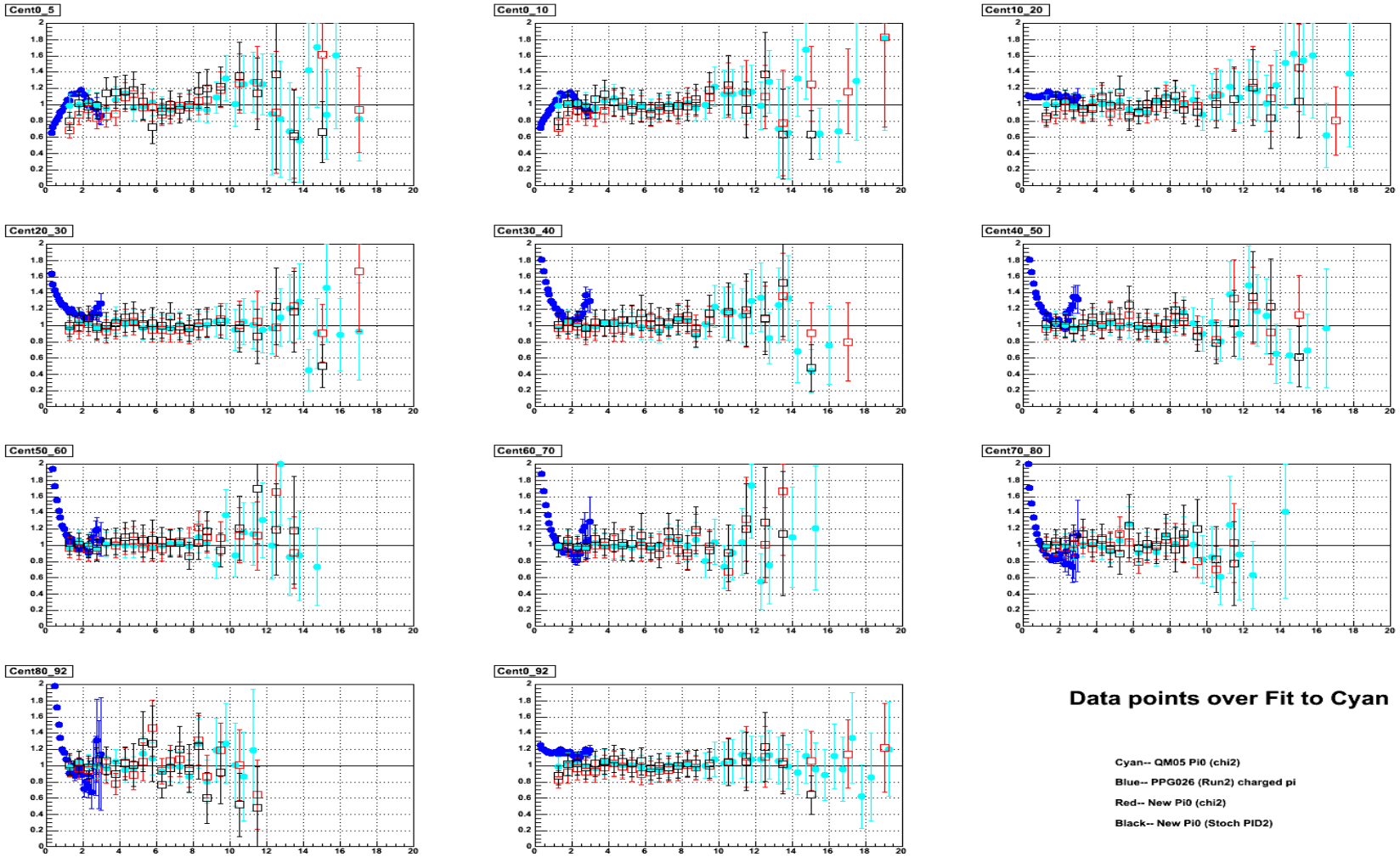



can Yuji show us the numbers? (I will show some for AuAu
Would be nice if ppg045 had some tables, ppg045 is still not published)

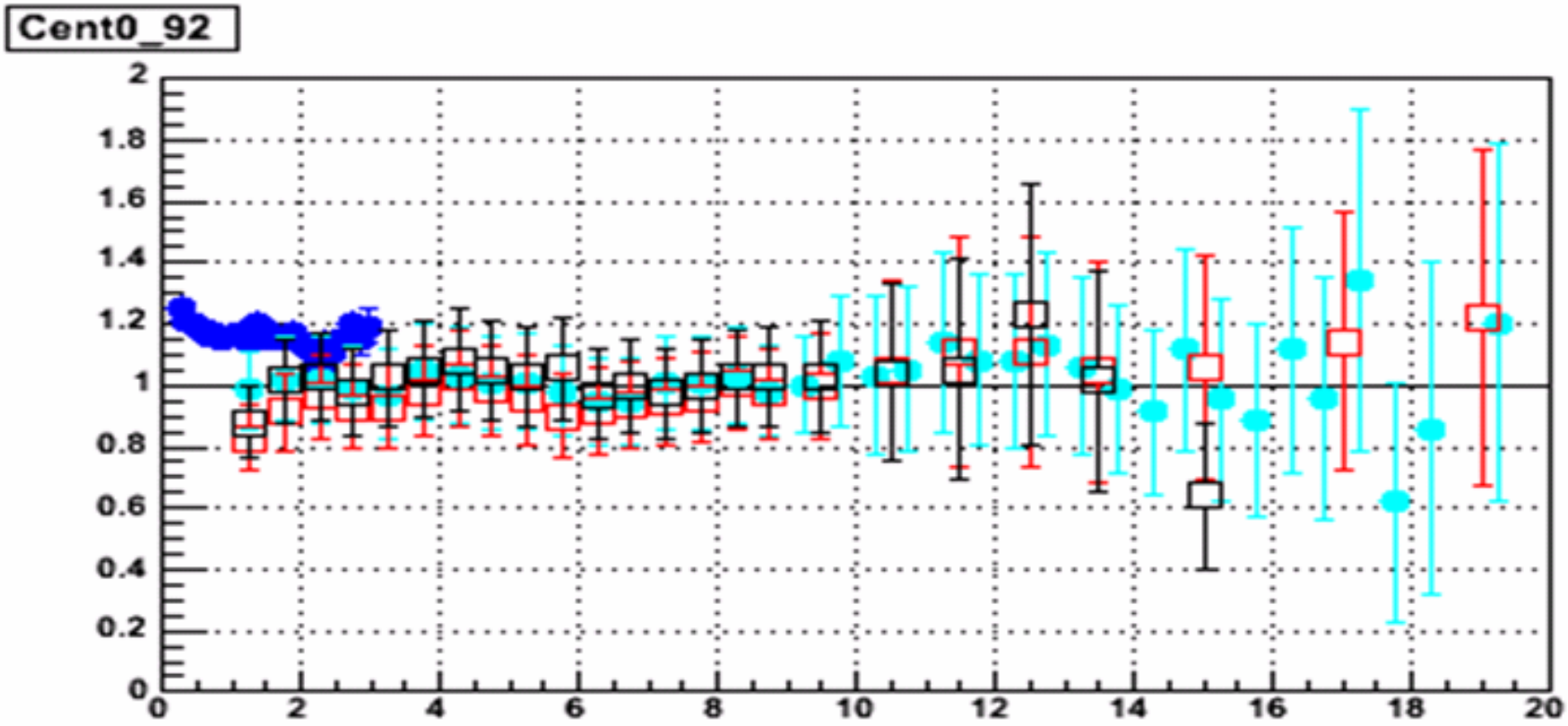
From Takao TadaAki's analysis

# Comparison of PbSc pi0 AuAu

- Denominator: Fit to QM05 pi0 (Cyan)
- Numerator: Charged pi(Blue: PPG026), New Pi0 with chi2 cut(Red), New Pi0 with Stoch PID2 (Black):: Converged in ~10%



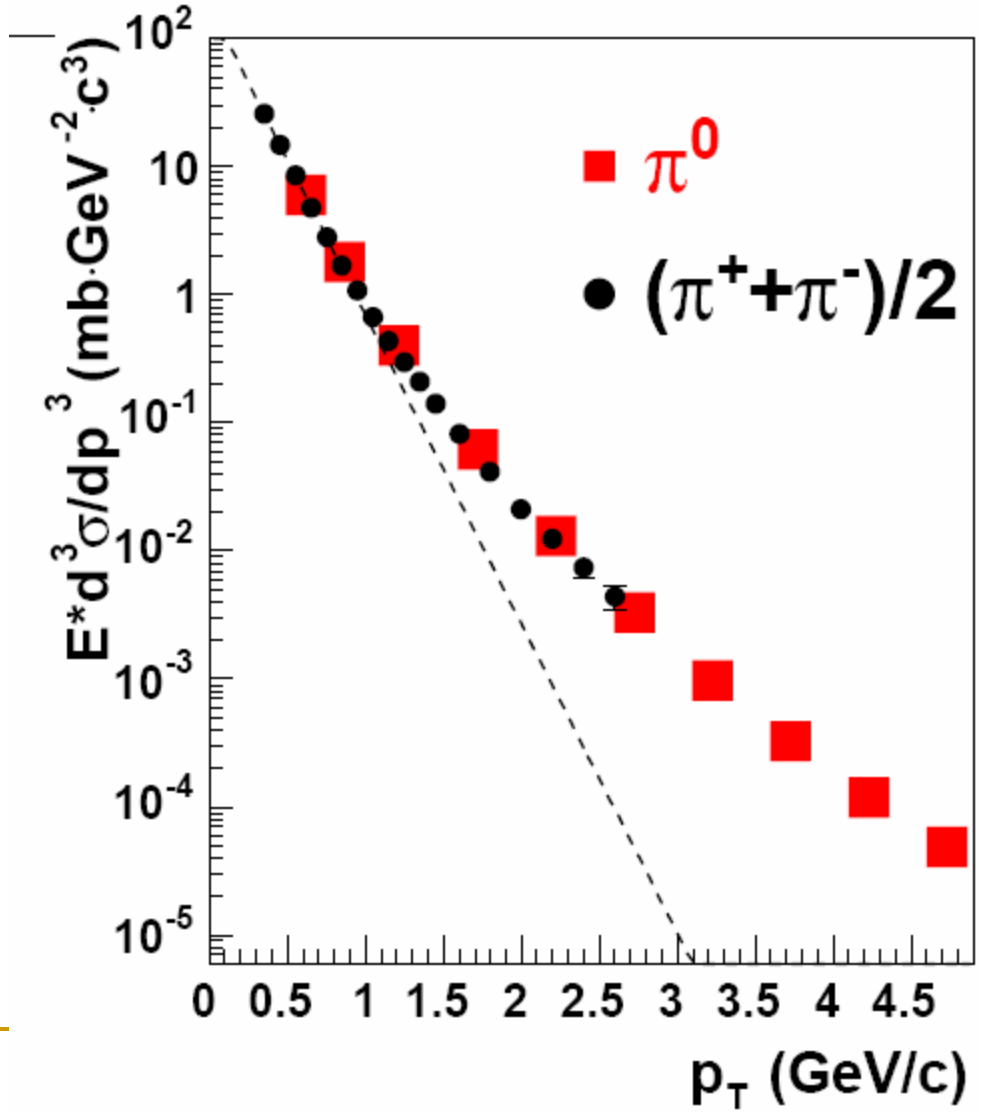
# Blow up of 0-92%



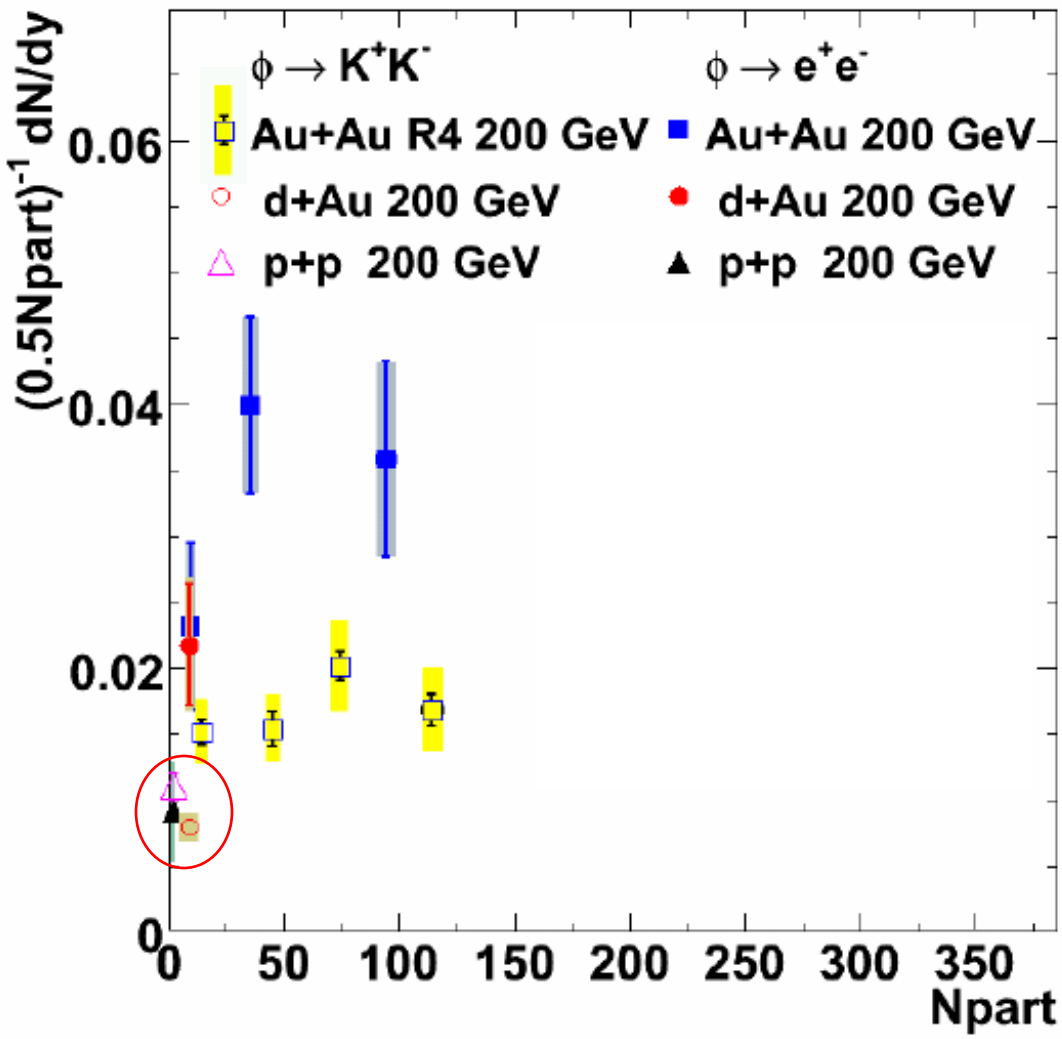
# new comparison from ppg063

can someone look into where they get the spectra and look at the numbers

Are they good to better than 20%



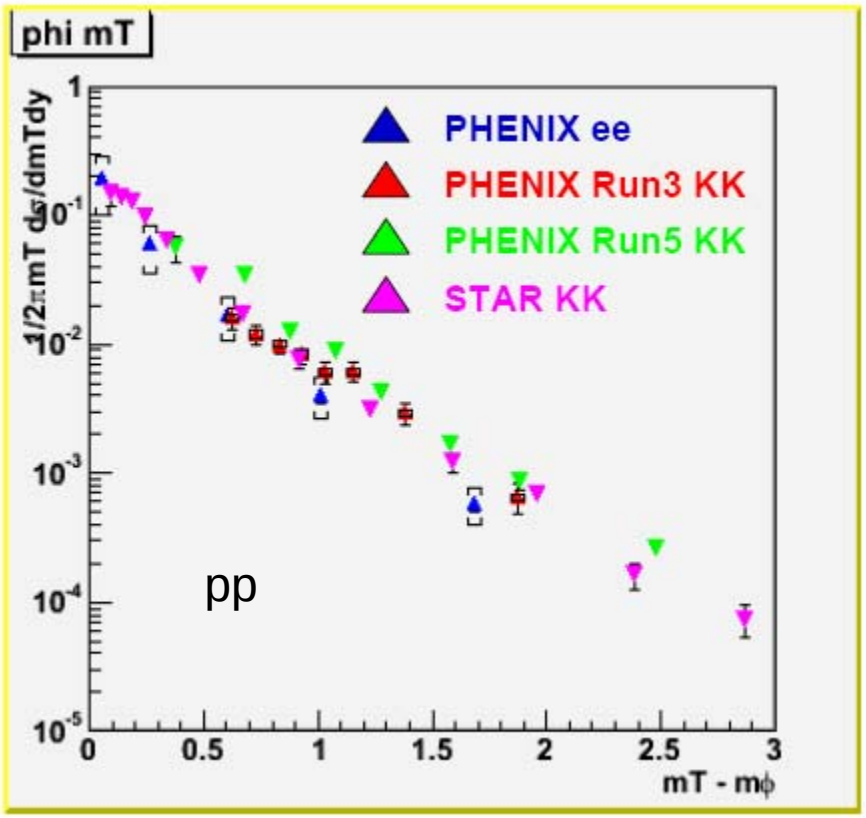
Is there a way to prove that we have the normalization right?
Yes – look at pp (which matches between ee and KK)




sasha

Is there a way to prove that we have the normalization right?
Yes – look at pp (which matches between ee and KK)

But do we trust the pp point?

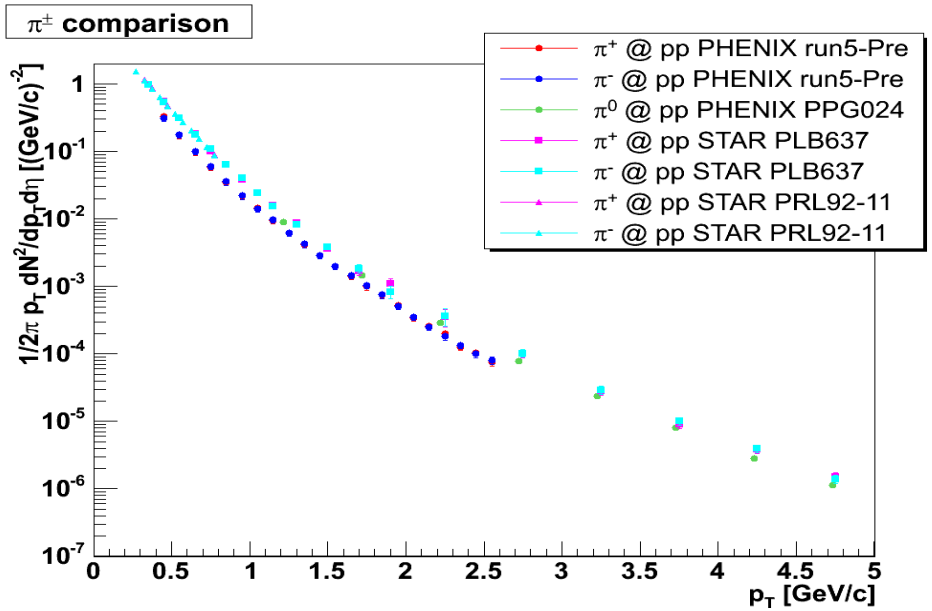



- Problems
  - phenix Run 5 and Run 3 don't match
  - We seem to be higher than STAR over much of the range (STAR rises at low mt) This is not consistent with the Kaons where we are lower than STAR

# The assignment-figure out if things are different – if we are right

- Tasks
  - get data sets from phenix and star
  - compare phenix to phenix
    - old and new dAu ee and KK
  - Compare phenix to STAR
  - Where do we get data?
    - http://www.phenix.bnl.gov/WWW/talk/pub_papers.php
    - https://www.phenix.bnl.gov/WWW/p/talk/papers.php
    - http://www.star.bnl.gov/
  - How do we plot data – root!
  - Christophe and Ken S – compare old and new dAu analysis
    - Lets talk again monday

# Single pion spectra in pp




So pions in pp match between STAR and PHENIX

Protons – we could not compare because STAR does not do a feedown correction

But we had to correct for STAR's trigger cross section (NSD)

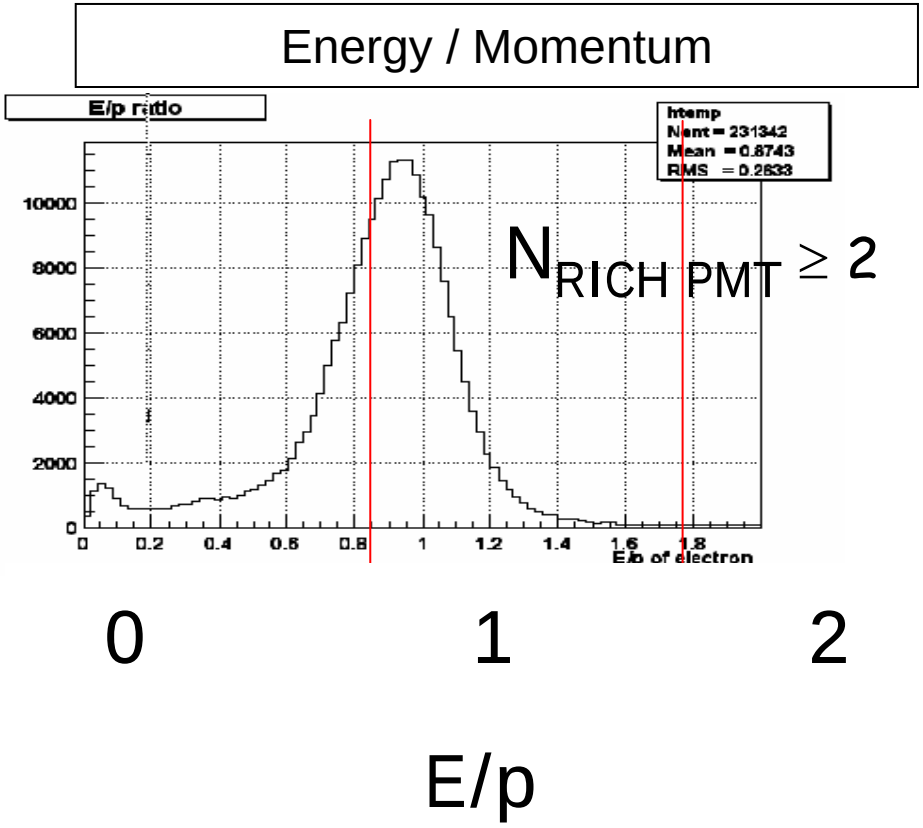
Cross section is calculated from measured invariant yields.

42 mb (For PHENIX)

30 mb (For STAR)

are used.

Yugi

# Data sample, electron cuts

- Analyzed 31M of EMC-RICH-Trigger triggered Events.
  - Corresponds to 1.9G minimum bias
  - 50% of total data taken during run3