2004 Muon Workshop Summary

Vince Cianciolo

Short Version…

- It was a great meeting!
- Have a great time at tonight's BBQ!
- Thanks to our LANL hosts!
- Let's do it again last year!
- Get back to work (after tomorrow ☺)

Long Version…

- There are a lot of slides, but I will try to go through them very quickly.

- Are you smiling Glenn?

J/Ψ and Continuum Dimuons

- Experiment
  - Mike Leitch (Overview)
  - Hai Qu (Polarization)
  - Raphael Granier de Cassagnac (dAu J/Ψ)
  - Hugo Pereira (AuAu J/Ψ)
  - Ben Norman (MVD Reaction Plane)
  - Sebastian Gadrat (dAu Continuum)
  - Frederic Fleuret (Background Calculation)
- Theory
  - Edward Shuryak (Dileptons in sQGP)
  - Christian Fuchs (Medium Modifications @ RHIC)

An unambiguous signature…

- Matsui & Satz carefully outlined the conditions that needed to be met for an observed suppression to be an unambiguous signature of QGP formation.
- We now know that two of these assumptions have turned out to be violated.

To assure that this J/ψ suppression in nuclear collisions indeed constitutes an observable signature of plasma formation, we must answer a number of questions:

(i) Can the J/ψ escape from the production region before plasma formation?

(ii) At what temperature does $r_D(T)$ fall below $r_{J/\psi}(T)$, and how does $r_{J/\psi}(T)$ behave as function of T? The large mass gives the J/ψ a smaller radius than that of conventional mesons, and sufficiently small hadrons could survive deconfinement as Coulombic bound states until much higher temperatures.

(iii) Are there competitive non-plasma J/ψ suppression mechanisms?

(iv) Could the J/ψ suppression in the plasma be compensated in the transition or hadronization stage?

(v) Could enhanced non-resonant production of lepton pairs ("thermal dileptons") prevent the observation of the J/ψ? In this case, we could not study deconfinement directly, although plasma formation would still be the cause for not seeing J/ψ's. We will now take up these questions.

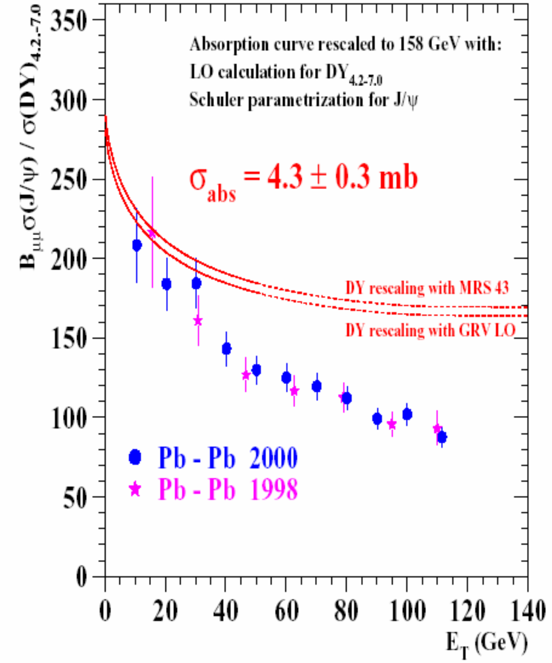
Titles from Mike's Slides…

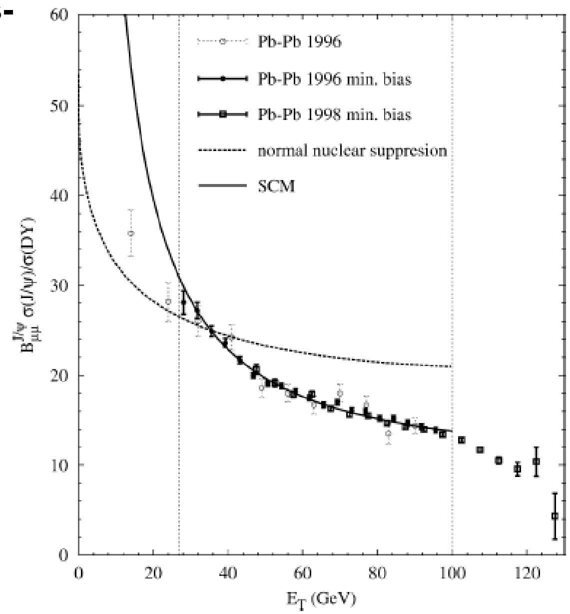
- J/Ψ production & parton level structure & dynamics
- Hadronization into J/Ψ
- J/Ψ Production—Polarization
- Feeding of J/Ψ's from Decay of Higher Mass Resonances
- Nuclear modification of parton level structure & dynamics
- Gluon Shadowing
- J/Ψ at fixed target: Absorption at mid-rapidity
- P_T Broadening at 800 GeV
- E866 - J/Ψ Nuclear dependence even for Deuterium/Hydrogen

J/Ψ Production and destruction is complicated!

J/Ψ Suppression in Pb-Pb at NA50

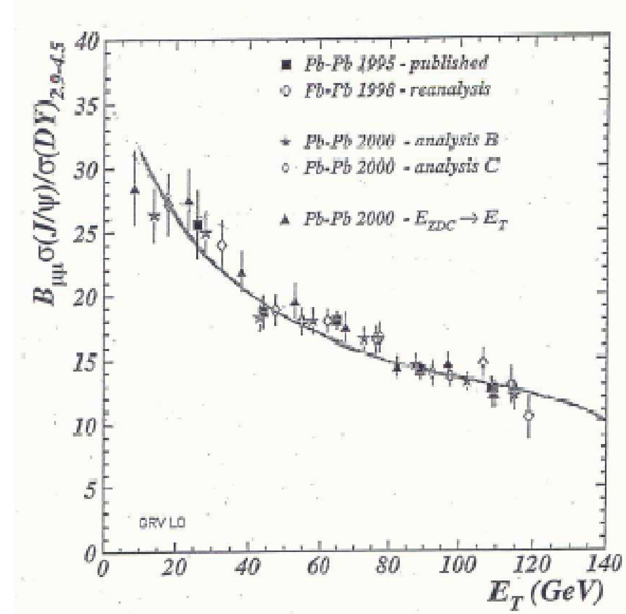
H. Santos, "Psi' production in nucleus-nucleus collisions at the CERN/SPS".





A.P.Kostyuk, M.I. Gorenstein, H. Stocker, W. Greiner, Phys. Lett B 531, 195-202

A. Capella, D. Sousa, nucl-th/0303055



- Suppression with respect to normal nuclear suppression expectations
- Detailed data collection to measure "normal nuclear suppression"→updated results
- Theorists have produced various alternative models which also reproduce data:
  - Statistical coalescence model (also needs enhanced open charm)
  - Comovers
- RHIC data on J/Ψ highly desired to give another data point(s) to compare to PbPb results and implied expectations

Theorists are unconstrained!

Constrain them with data!!

- More heavy AuAu data
- Lighter species (Run-5 CuCu >10^4 J/Ψ)
- Lower energies (crummy statistics, but still interesting)
- Higher statistics pp, dAu (and dCu)
- Measure feed-down (Si Vertex)
- Polarization
- Reaction plane

A Pallet of Prompt Probes

The **most general** way to classify QCD probes is by speed and color multiplet; different combinations give rise to different classes of high-Q^2 observables:

Why attempt pQCD in A+A?

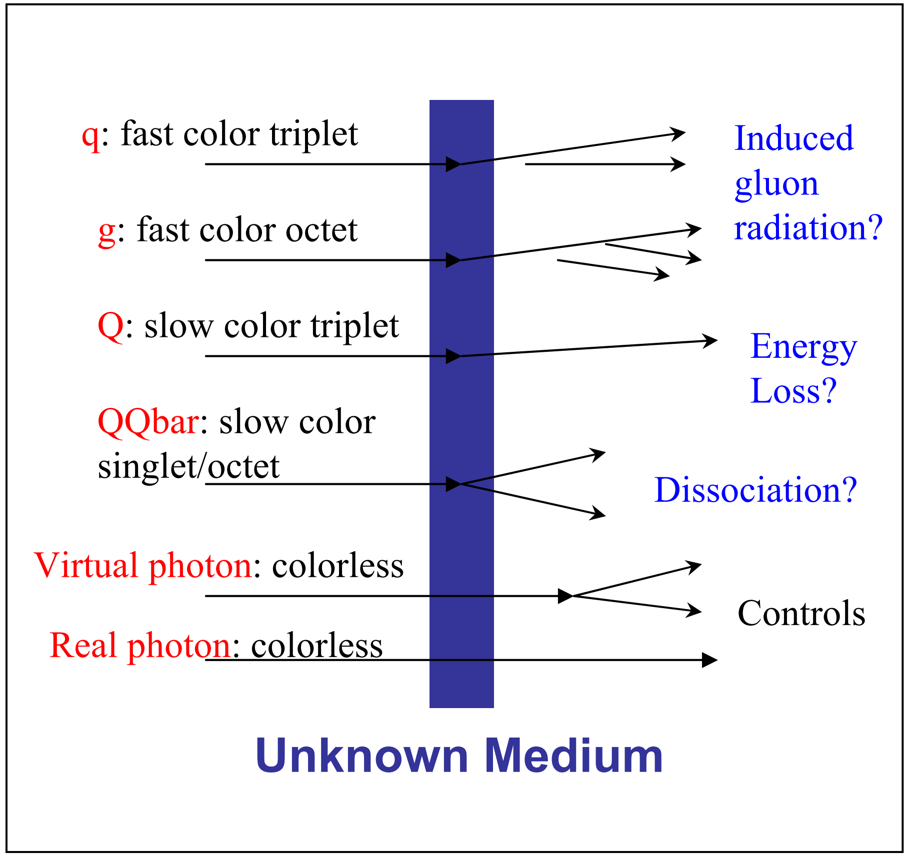
To measure (dense) nuclear medium effects on:

- Parton distributions
- parton propogation
- fragmentation process

A full program will include:

- Fast color triplet objects (light quarks → jets)
- Fast color octet objects (gluons → jets)
- Slow color triplet objects (open charm, bottom)
- Slow color singlet/octet objects (J/ψ, χ, Υ)
- Non-colored objects (direct γ, Drell-Yan)

Version 1997



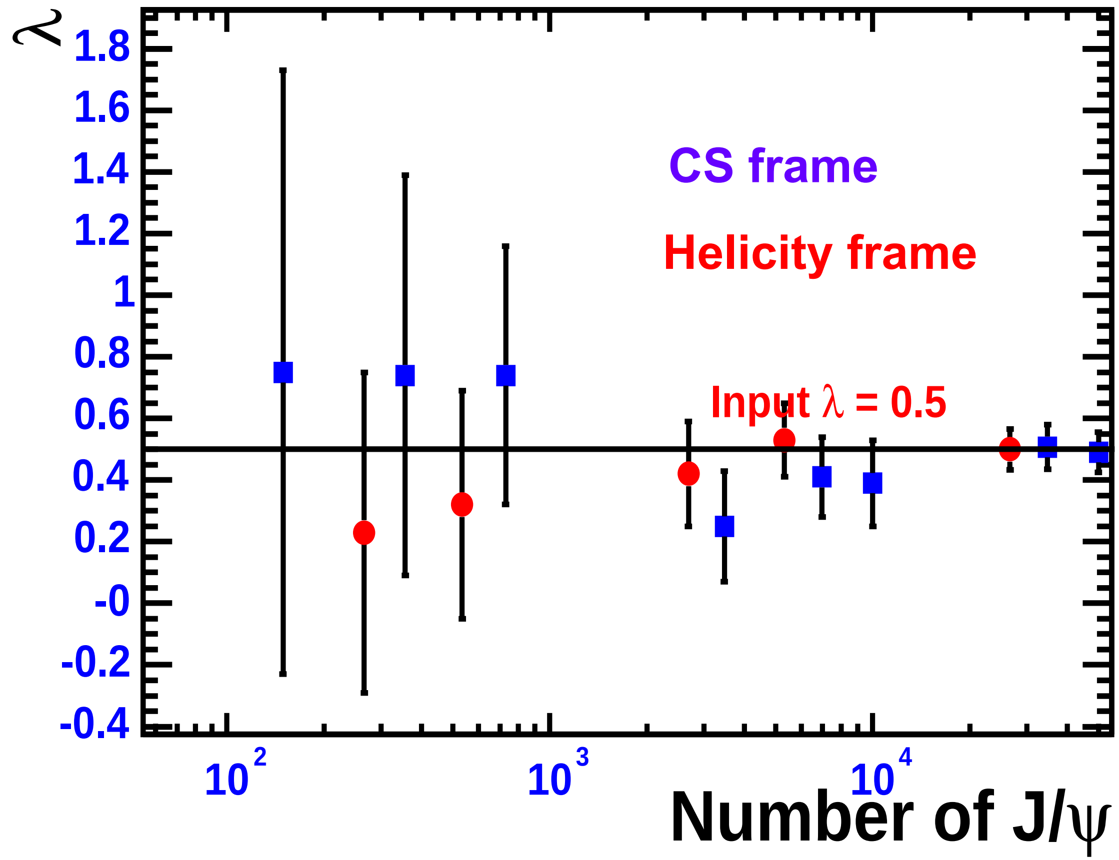
Version 2003

From P. Stankus

Statistical Error Estimation

Here different number of Fake J/ψ data events were generated in PHENIX muon arm acceptance, and were acceptance corrected using very high statistics Monte Carlo events.

The acceptance corrected cosθ distribution were fitted by $1+\lambda\cos^2\theta$. The resulting λ with error are plotted vs number of fake data events.

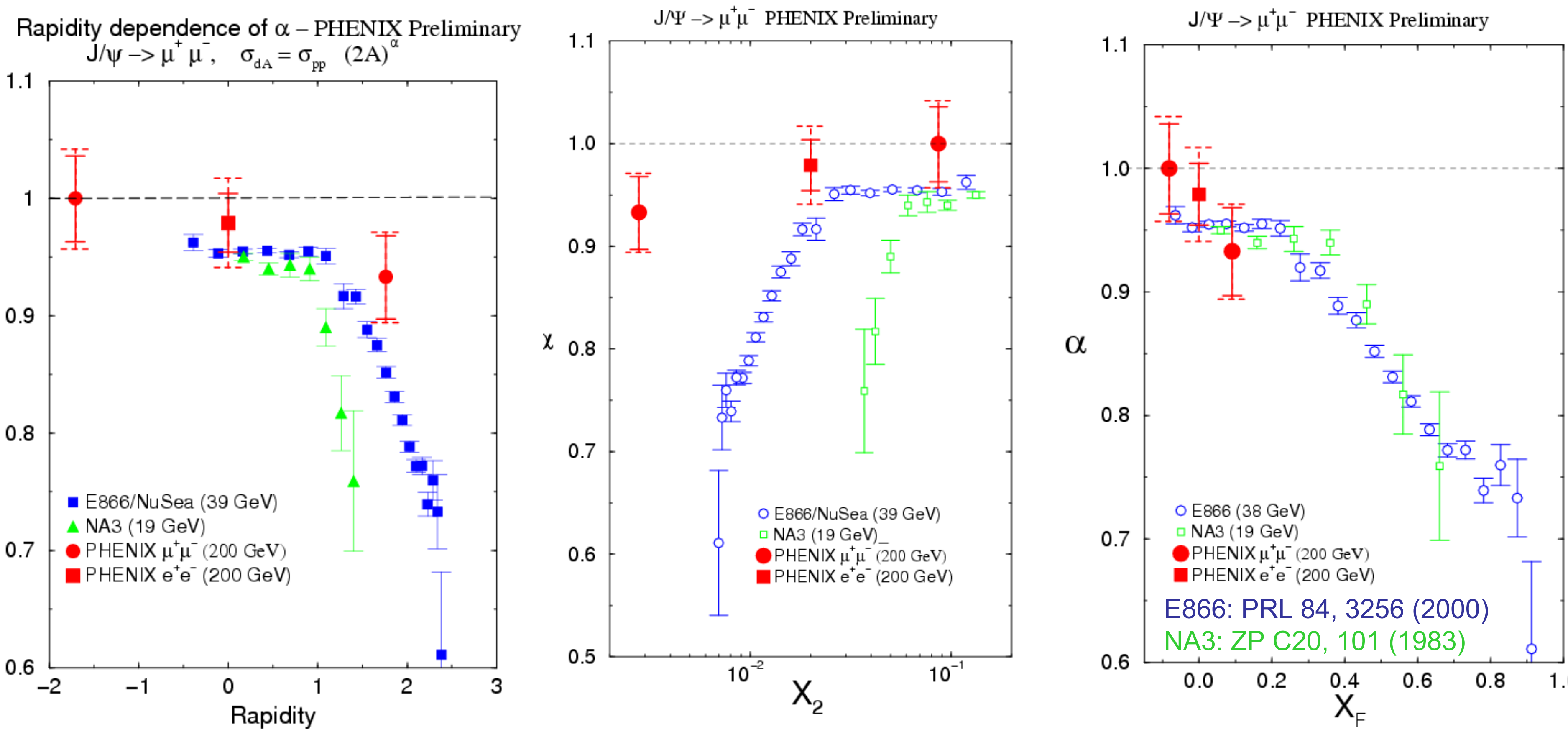


I didn't see how many J/Ψ's expected from Run-4 data set, but "we may have a shot."

Surely there will be enough in Run-5.

H.Q.

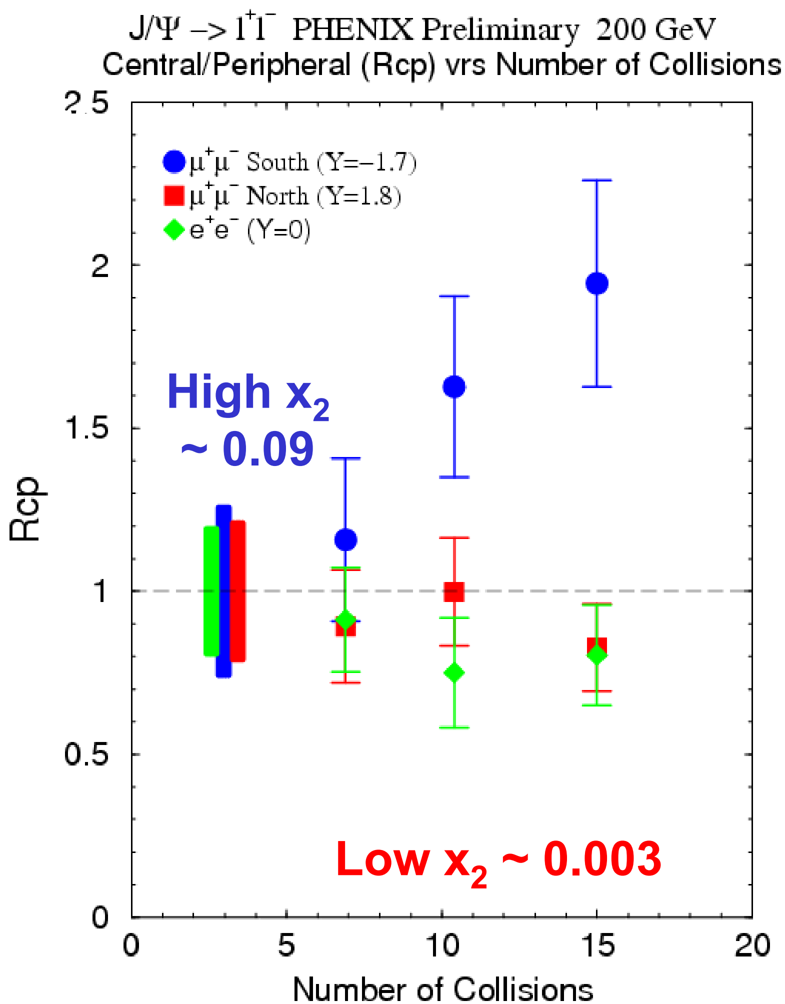
α compared to lower √s



- Not universal versus X_2 : shadowing is not the whole story (at low √s)
- Same versus X_F for diff √s. Incident parton energy loss ? (high X_d = high X_F)
- Energy loss expected to be weak at RHIC energy.

R. G. de C.

Central/peripheral vs N_{coll}



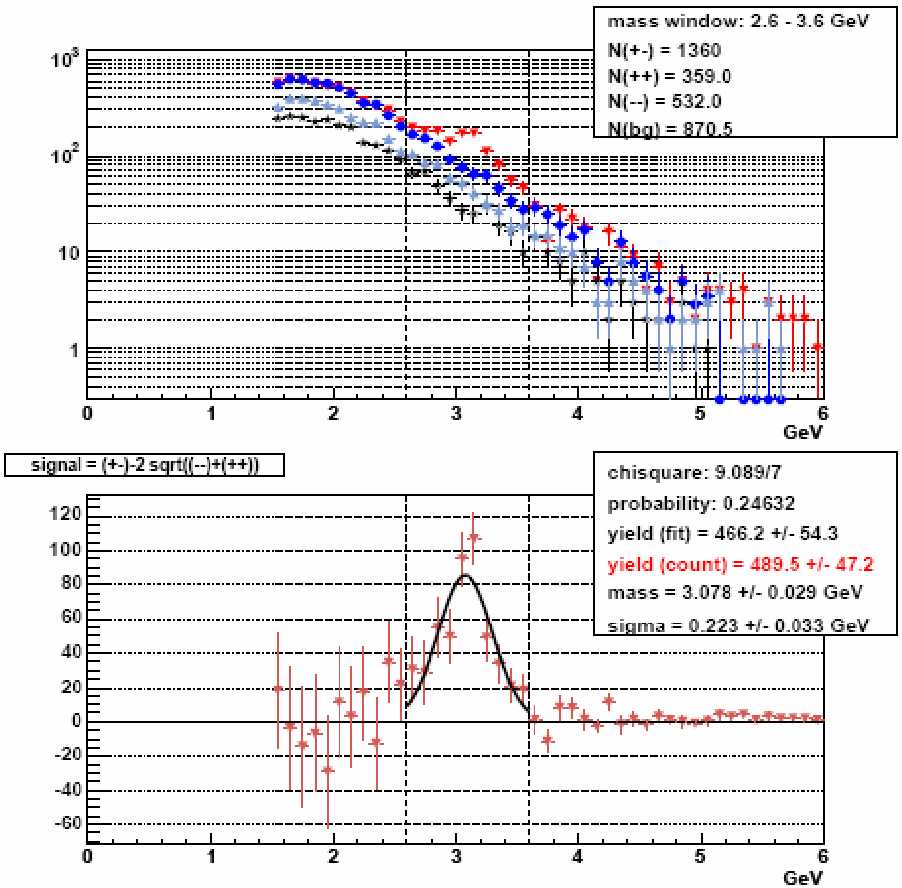
$$R_{cp}(N_{coll}) = \frac{N_{J\psi}^{cent} \times < N_{coll}^{perif} >}{N_{J\psi}^{perif} \times < N_{coll}^{cent} >}$$

- Low variations at low et mid x_2 :
  - Weak net nuclear effects
  - Small shadowing centrality dependence…
- At High x_2 surprising steep rising shape with centrality !
  - Can antishadowing be that violent ?

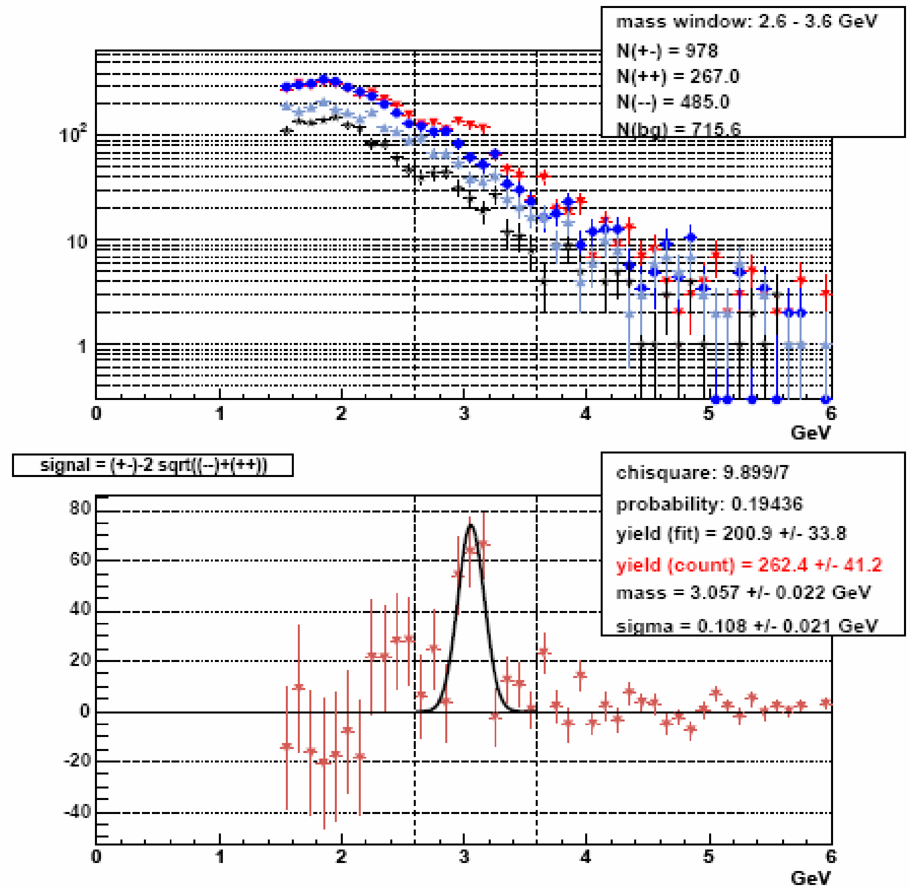
R. G. de C.

mass distributions - peripheral events $(40 - 100\ \%)$

south



north

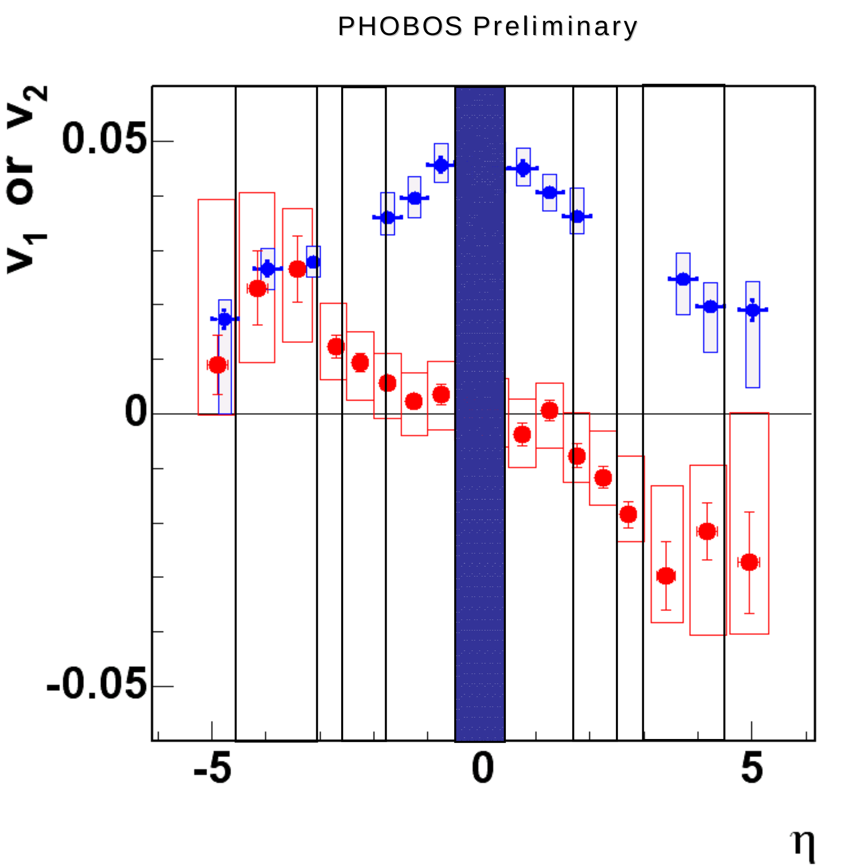


Nice to finally see J/Ψ's in AuAu events, even peripheral ones.
Obviously this gets tougher w/ even more central collisions as Hugo showed.

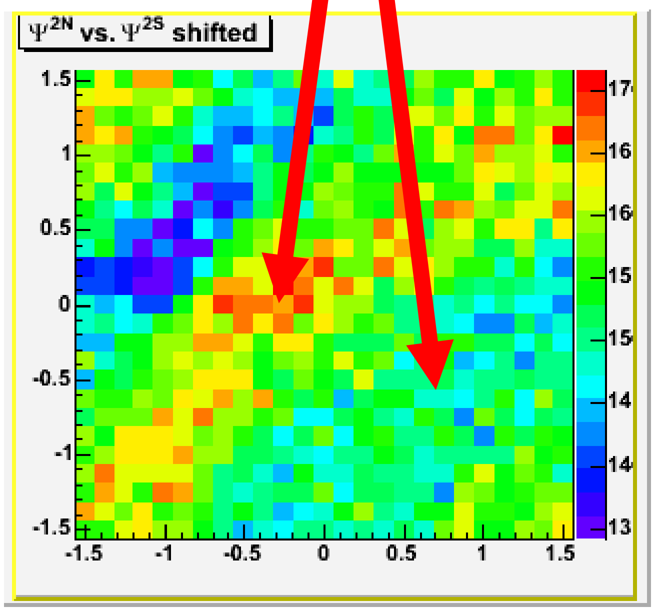
H.P.

Current status of MVD Analysis

- Motivation: Additional measurement, v_2 a little larger, v_1 quite a bit smaller.
- After massaging the data N/S correlation observed for MC.

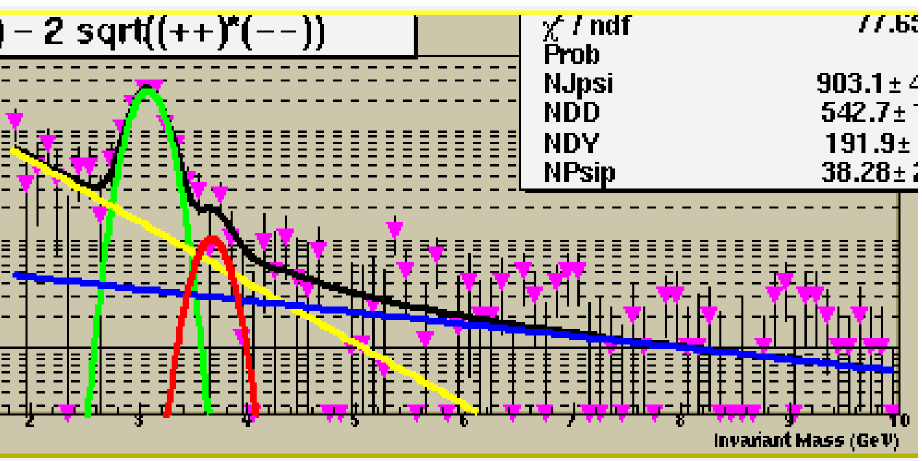


~15% peak-to-peak

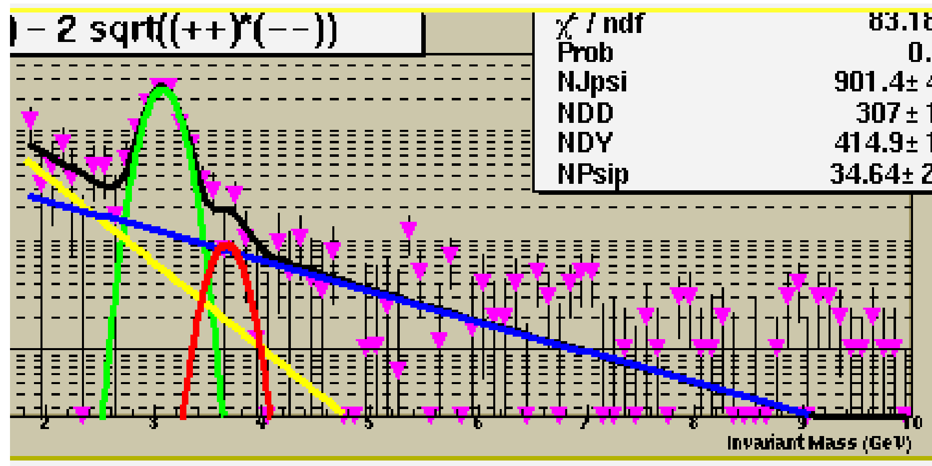


Background Subtracted dAu Continuum

Slopes from data



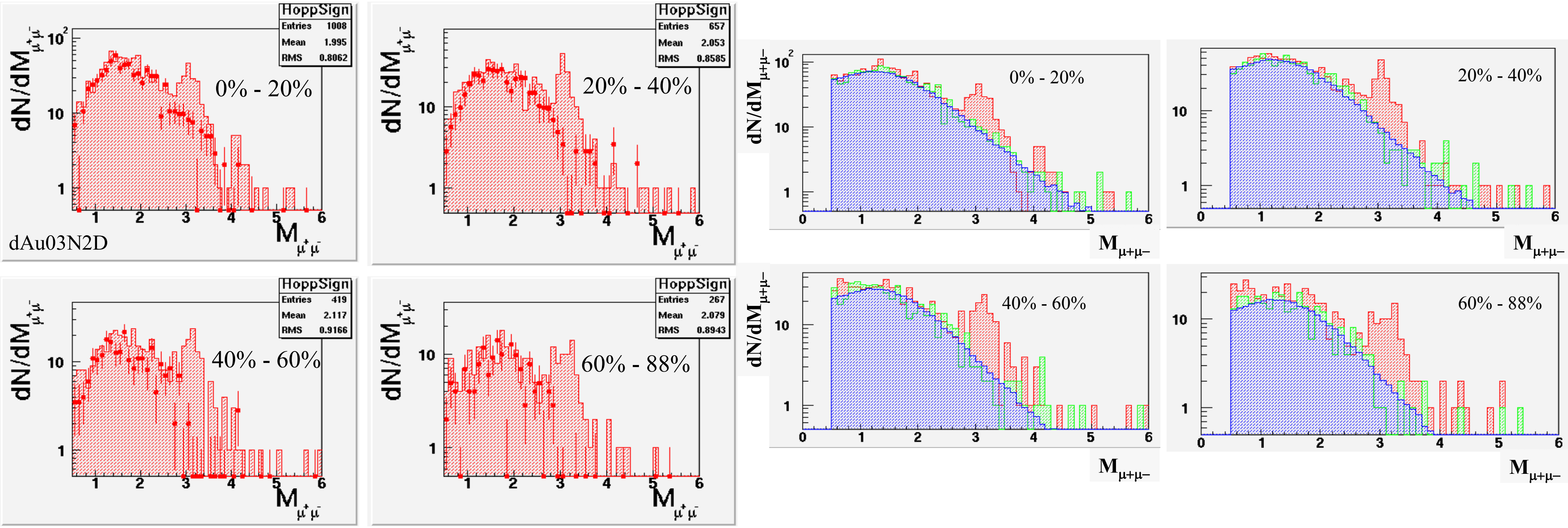
Slopes from PYTHIA



Ed.'s notes:

- Significantly different slopes extracted by two different methods S.G.
- Caveat on PYTHIA input
  - Doesn't reproduce PHENIX single electrons at high p_T.
  - Correlations (ΔY) known to be wrong at lower energies.
- Caveat on fitting technique.
  - ROOT χ^2 method fails w/ zero-bins.
- Caveat on background subtraction (Fred's talk).

dAu Background Study



Ed.'s notes:

- Bottom line – use event mixing, but be careful:
  - Event class binning
  - Application of pair cuts
  - Overmixing
- Note: Very thorough study already done by central arm folks – let's not re-invent the wheel!

F.F.

Solving for the bound states
Shuryak and Zahed, hep-ph/0403127

- **In QGP there is no confinement => Hundreds of colored channels may have bound states as well!**

channel	rep.	charge factor	no. of states
gg	1	9/4	9_s
gg	8	9/8	$9_s * 16$
$qg + \bar{q}g$	3	9/8	$3_c * 6_s * 2 * N_f$
$qg + \bar{q}g$	6	3/8	$6_c * 6_s * 2 * N_f$
$\bar{q}q$	1	1	$8_s * N_f^2$
$qq + \bar{q}\bar{q}$	3	1/2	$4_s * 3_c * 2 * N_f^2$

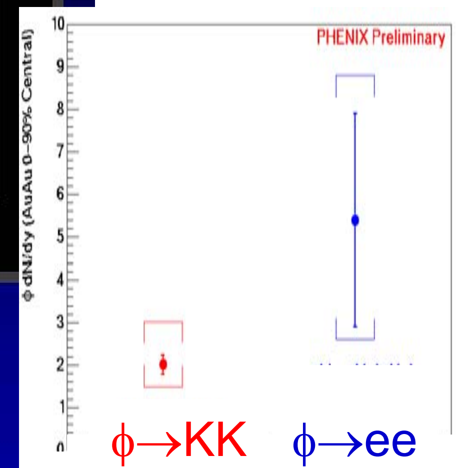
- gg color 8*8=64=27+2*10+2*8+1: only the 2 color octets $(gg)_8$ have $(16 * 3_s * 3_s = 144)$ states.

Ed.'s note: I'm not sure what it means that we haven't seen such states thus far. However, an experimental conclusion I draw is that for the continuum we should probably report dN_l/dM and let the theorists arm wrestle over what the contributions are.

E.S.

The ϕ puzzle

channel	dN_ϕ/dy	stat. error	sys. error
$\phi \mapsto K^+K^-$	2.01	$\pm$0.22	+1.01/-0.52
$\phi \mapsto e^+e^-$	5.4	$\pm$2.5	+3.4/-2.8

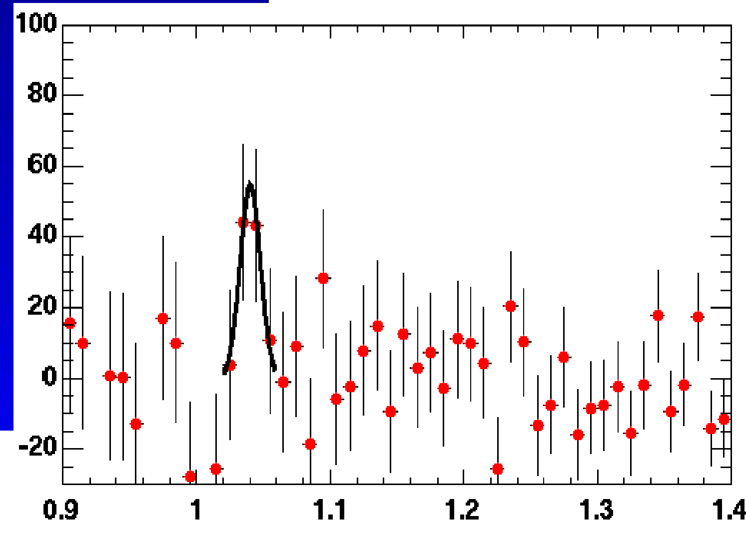


Au+Au @ 200 AGeV
PHENIX: Nagle et al., nucl-ex/0209015
similar observation by NA49/NA50

$\Longrightarrow$ in-medium ϕ width ?

Lissauer & Shuryak '91 $\uparrow$

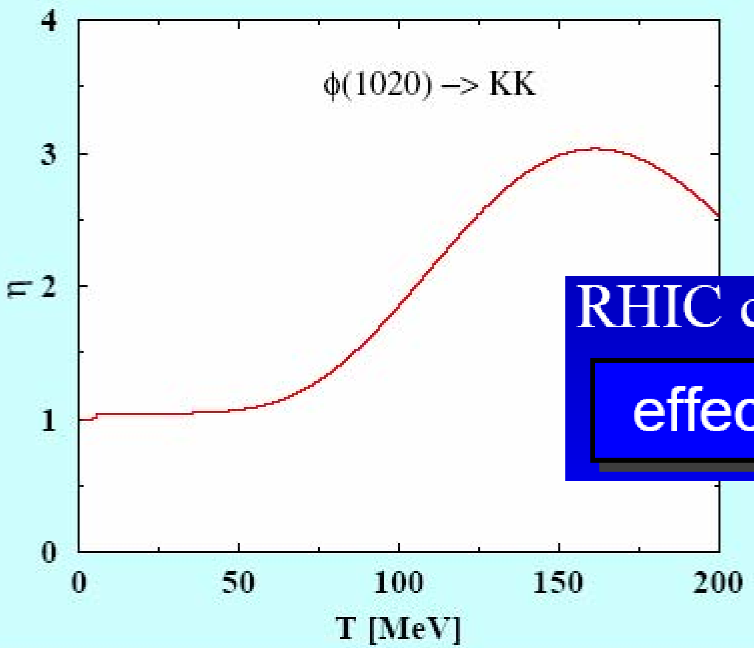
Blaizot & Galain '91 $\downarrow$



C.F.

Final result

$\Sigma < 0 :\Longrightarrow$ enhanced $\phi \to K\bar{K}$ decay
@ $T = 170$ MeV : $\Gamma_\phi^{\rm med} \sim 3\Gamma_\phi^{\rm vac} = 12$ MeV

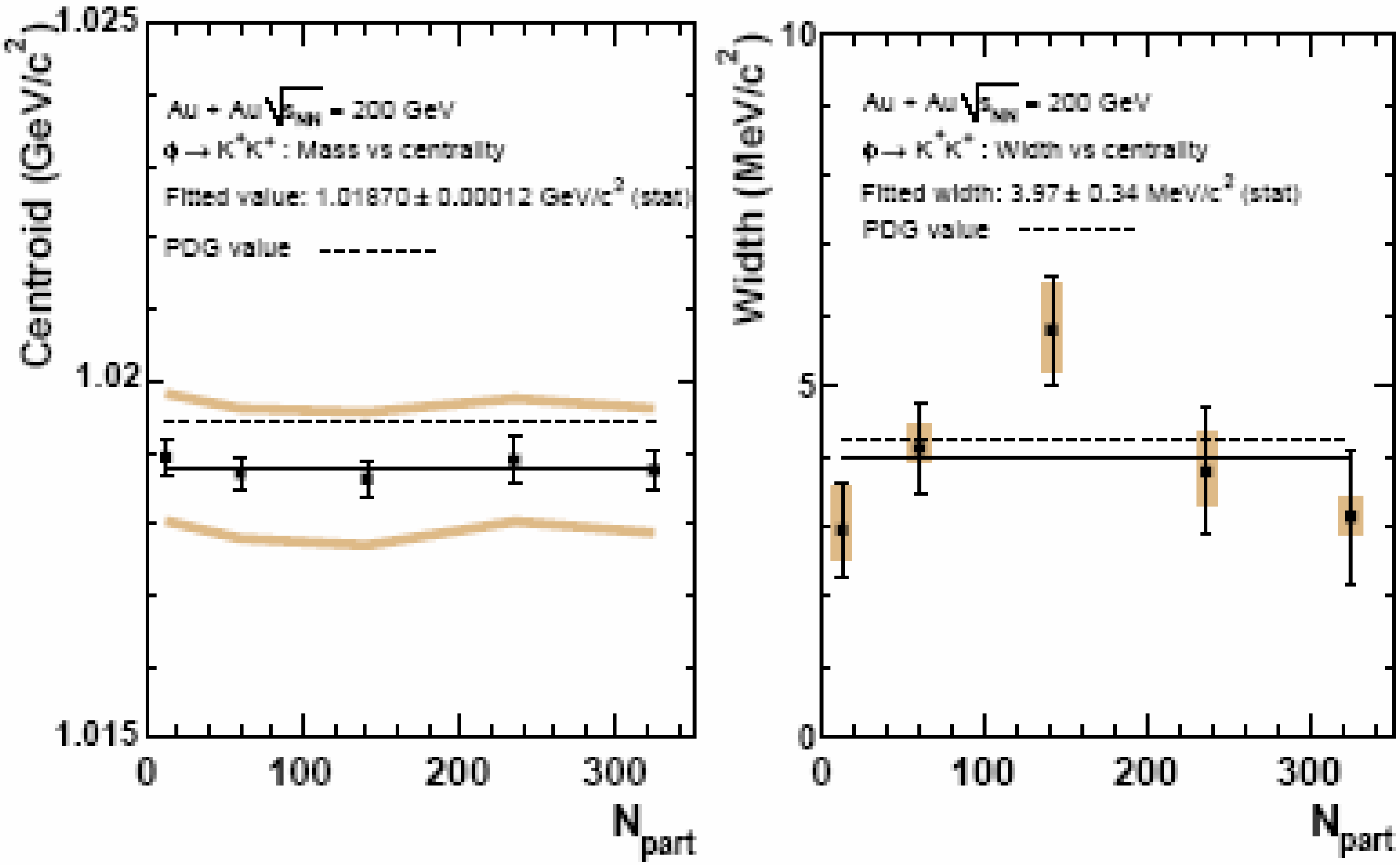


RHIC conditions: $T = 120 \div 170$ MeV

effective e^+e^- enhancement of $2 \div 3$

C.F.

Mass and Width Mods in the KK Channel



- Nothing seen so far
- PHENIX has excellent mass resolution
- Hopefully we'll have *ee* results from Run-4

Single Muons

- Experiment
  - Ming Liu (Overview)
  - Doug Fields (Spin)
  - Ken Read (Open Charm)
  - Kazuya Aoki (Single Muons in Run-5)
  - Chun Zhang (Hadron R_{cp})
- Theory
  - Pavel Nadolsky (Spin)
  - Magdalena Djordjevic (Charm Energy Loss)
  - Yuri Kovchegov (Saturation)

Primordial Muons

- Free decay before nose cone, light & heavy hadrons
- Decay inside nose cone
- Decay after nose cone
- Punch-throughs

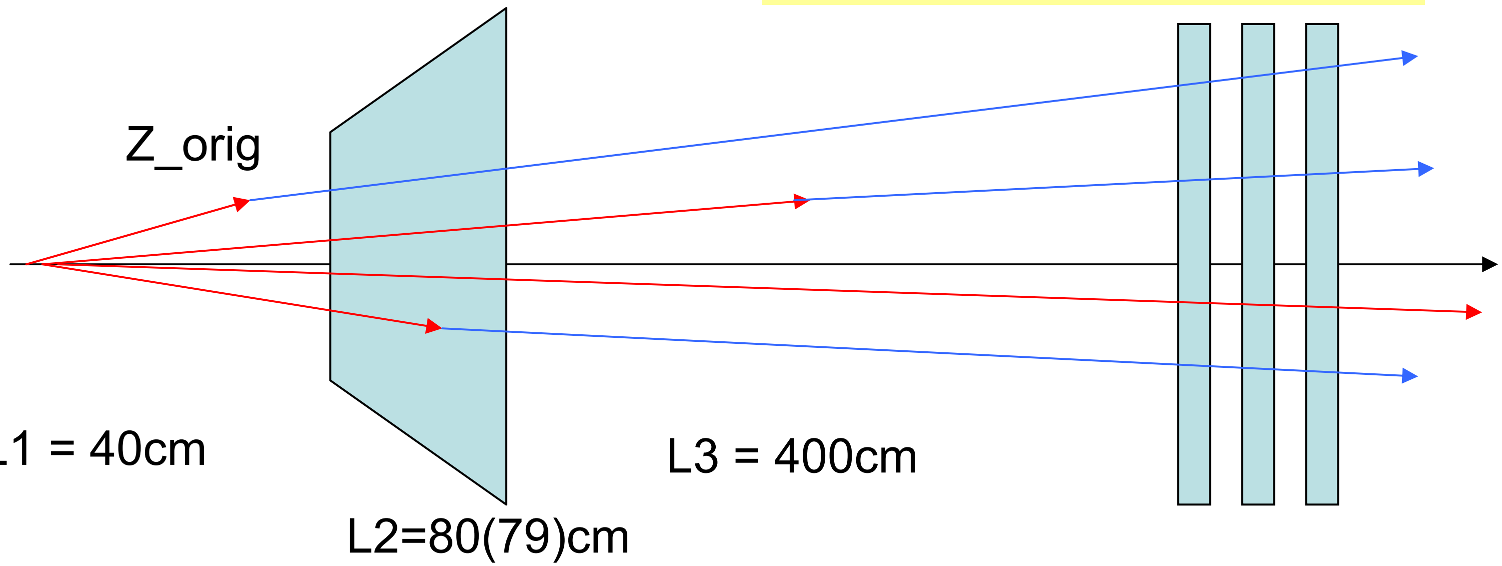
$$P_1 = (1 - e^{-L_1/\lambda}) \approx \frac{L_1}{\lambda} \sim 10^{-2}$$

$$P_2 \approx (1 - e^{-\lambda_I/\lambda}) \approx \frac{\lambda_I}{\lambda} \sim 50\% P_1;$$

$$\lambda_I \approx 20 \sim 30cm$$

$$P_3 \approx e^{-L_2/\lambda_I}(1 - e^{-L_3/\lambda}) = 10^{-2}\frac{L_3}{\lambda} \sim 10\% P_1$$

$$P_{punch} \approx e^{-L_2/\lambda_I}(a + b \cdot p)$$



M.L.

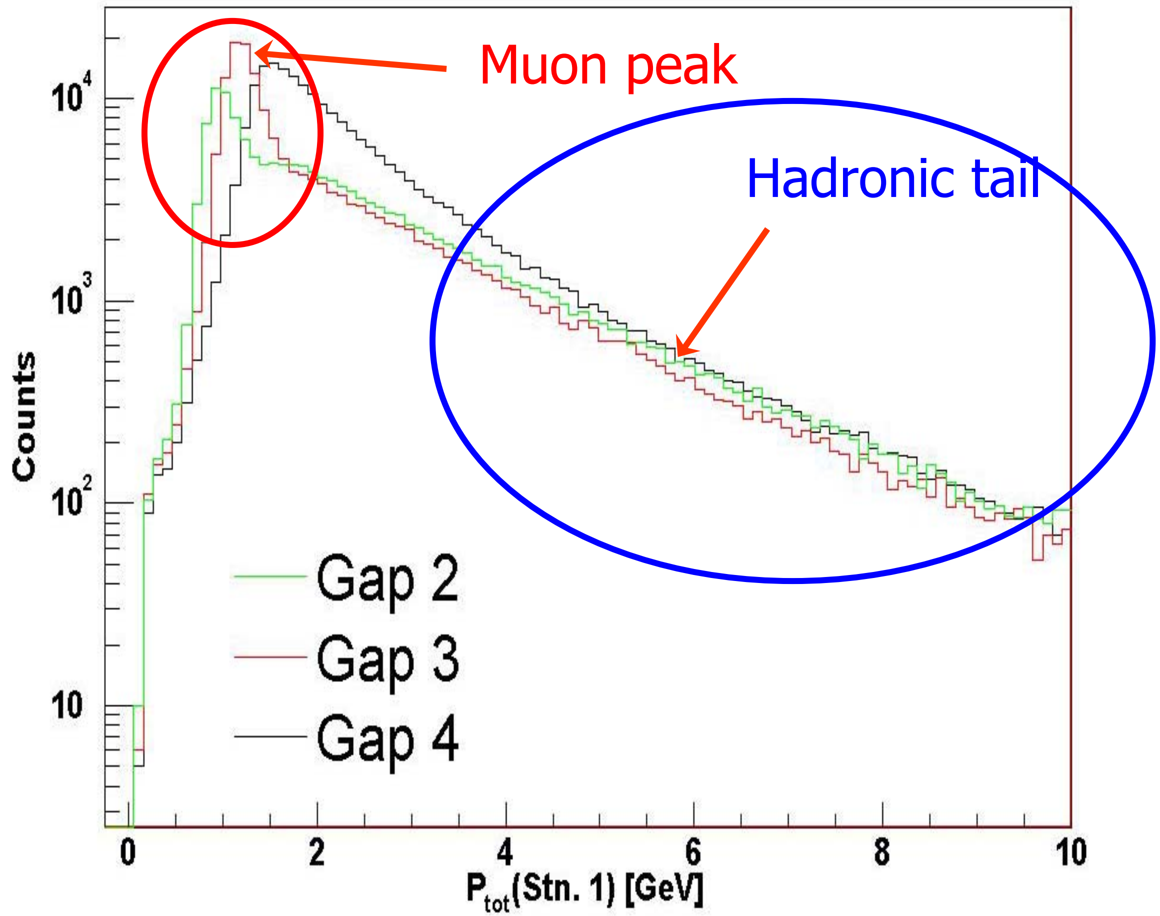
Measurement of Stopped Hadrons

Stopping power:

Use shallow MuID absorber layers to select stopped hadrons

for Ptot > 1.9GeV:
muon contamination < 3%

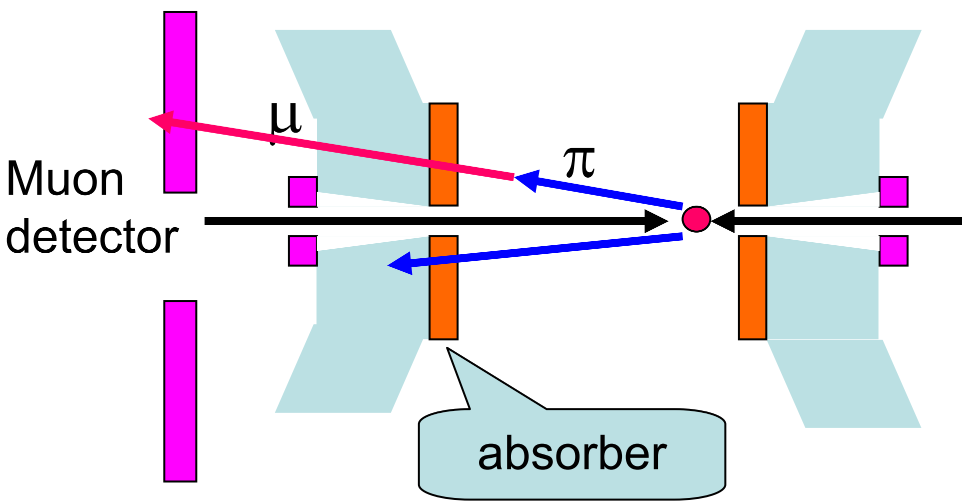
Good Run Selection
- Data QA (WooJin)

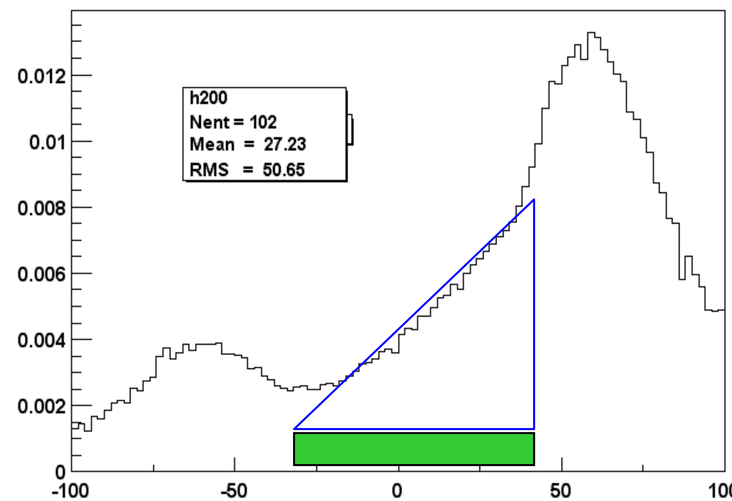


M.L.

Muons from Light Meson Decays

- Muon event collision vertex distribution





Collisions Vertex Z

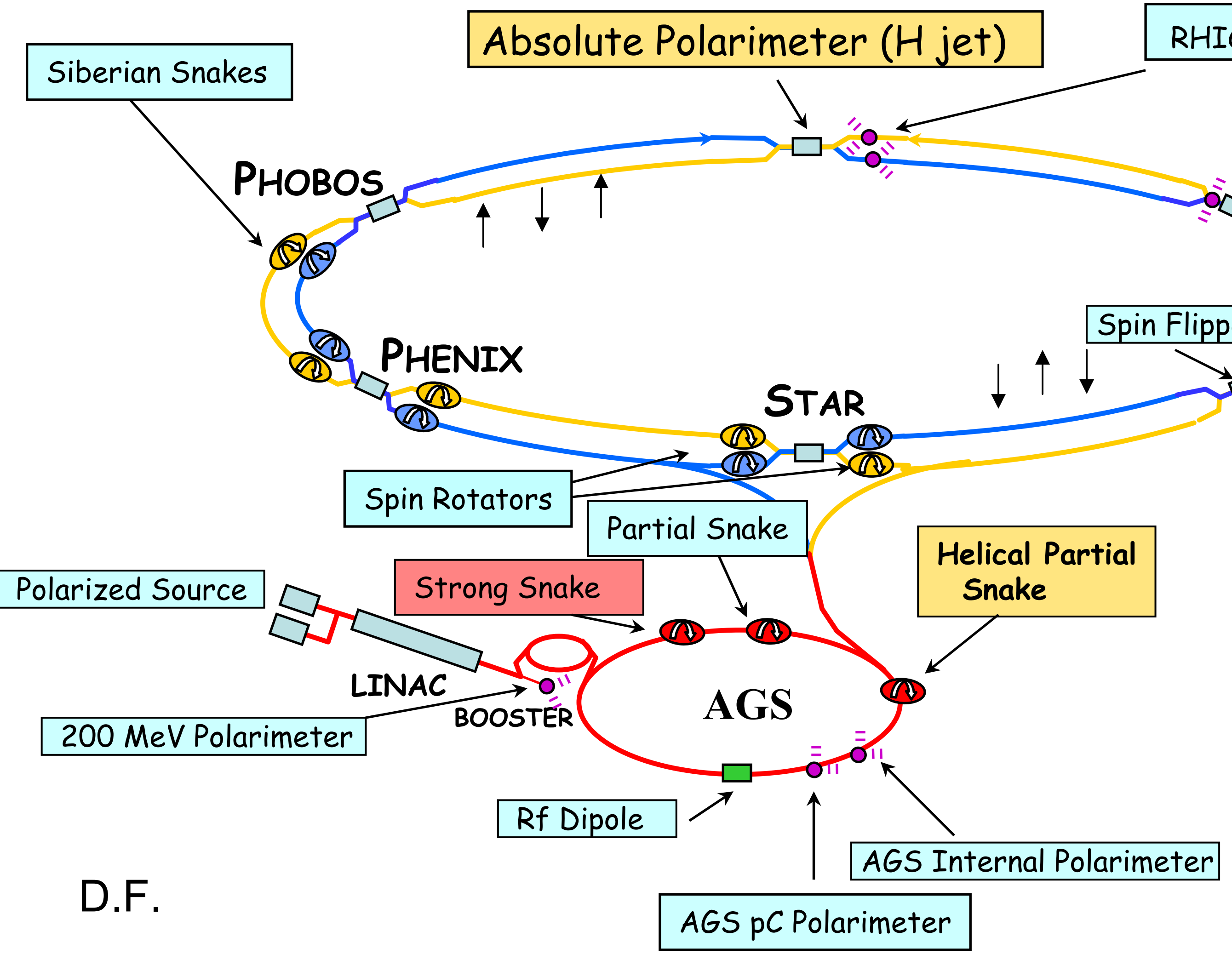
- Reco Efficiency etc. (Xiaorong)
- Ref VTX, data QA (WooJin)

M.L.

The successful Development of a novel Experimental Method:

Polarized Proton Collisions!

source: Thomas Roser, BNL



D.F.

Run 04 achieved:

$\sqrt{s} = 200\,\text{GeV},\ L_{peak} \sim 6\times10^{30}\ \text{cm}^{-2}\,\text{s}^{-1}$

$P_b \sim 45\%$, 55 bunches

New working point with long beam and polarization lifetimes

Run 05 planned:

Time to tune accelerator complex

Measure: A_{LL}(jets), $A_{LL}(\pi^0)$

Commission strong supercon-ducting AGS snake (see M. Bai's talk)

Run 04: The Polarized Jet Target for RHIC

Courtesy Sandro Bravar, STAR
and Yousef Makdisi, CAD

Polarized Hydrogen Gas Jet Target

thickness of $> 10^{12}$ p/cm^2

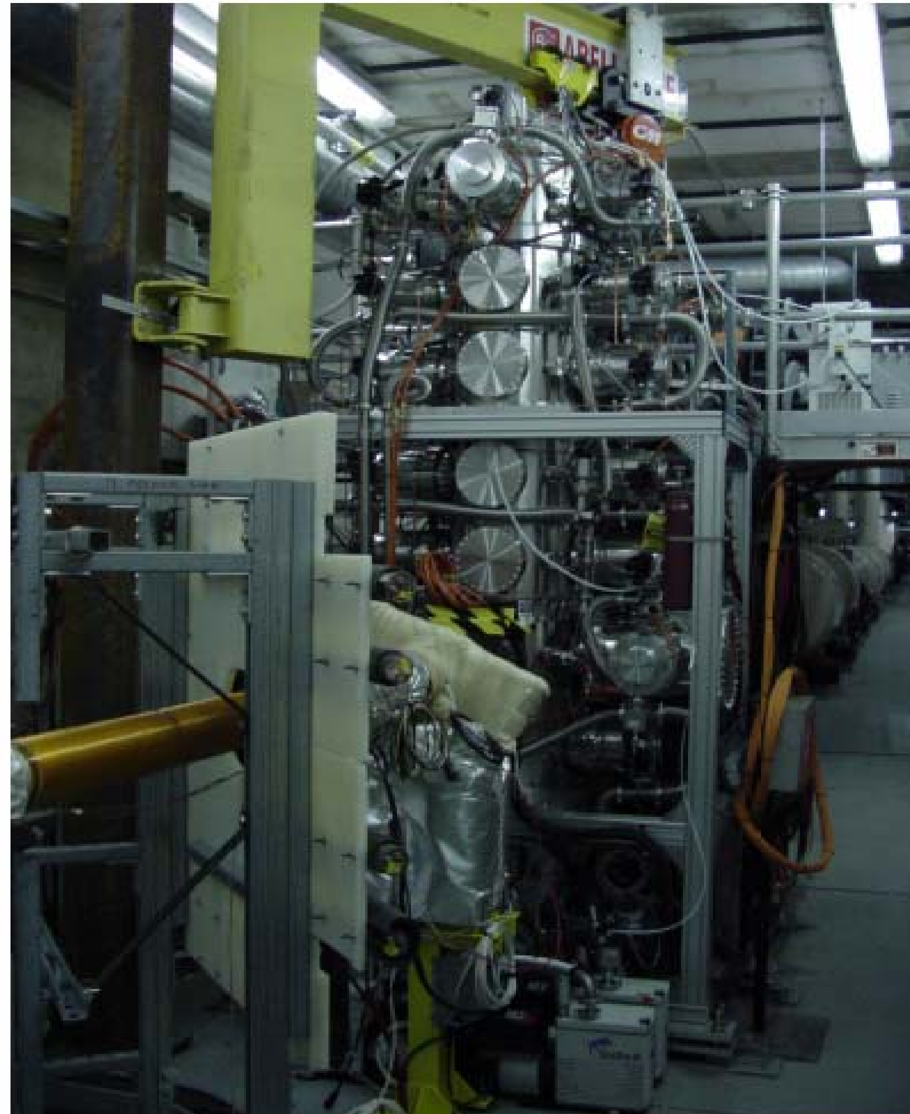
polarization $>$ 93% (+1 −2)%!

no depolarization from beam wake fields

Silicon recoil spectrometer to measure

- The left-right asymmetry A_N in pp elastic scattering in the CNI region to $\Delta A_N < 10^{-3}$ accuracy.
- Transfer this to the beam polarization
- Calibrate the p-Carbon polarimeters
- In 2004 we expect to measure P_B to 10%

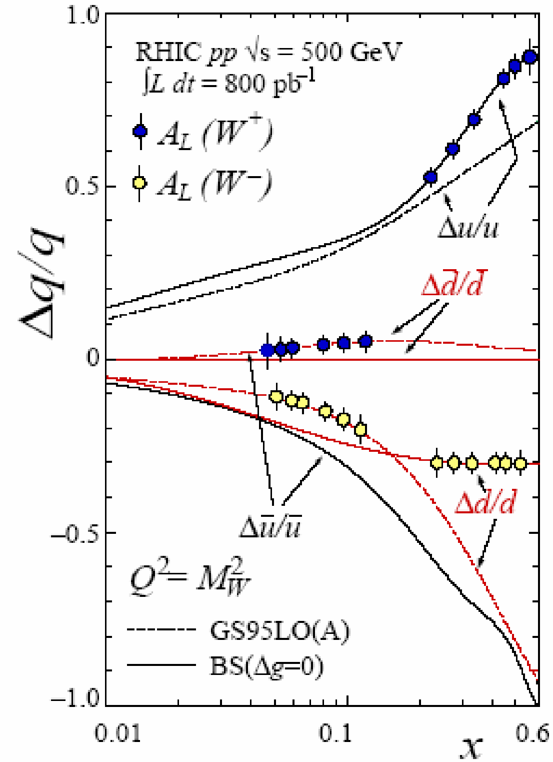
D.F.



Leading order single-spin asymmetries for W boson rapidity distributions

$$A_L^{W^+}(y_W) = \frac{-\Delta u(x_a)\bar{d}(x_b) + \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)} = \begin{cases} -\Delta u(x_a)/u(x_a), & x_a \to 1 \\ \Delta\bar{d}(x_a)/d(x_a), & x_b \to 1 \end{cases}$$

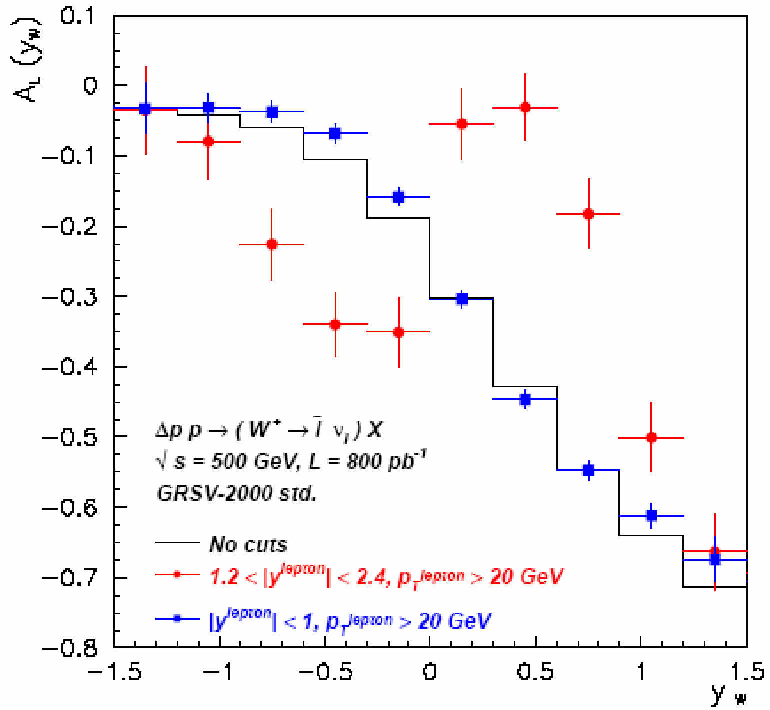
$$A_L^{W^-}(y_W) = \frac{-\Delta d(x_a)\bar{u}(x_b) + \Delta\bar{u}(x_a)d(x_b)}{d(x_a)\bar{u}(x_b) + \bar{u}(x_a)d(x_b)} = \begin{cases} -\Delta d(x_a)/d(x_a), & x_a \to 1 \\ \Delta\bar{u}(x_a)/\bar{u}(x_a), & x_b \to 1 \end{cases}$$



Source: G. Bunce et al., hep-ph/0007218

Would be a convenient test of $\Delta q/q$ and $\Delta\bar{q}/\bar{q}$ if $W^{\pm}$-bosons were observed directly

P.N.



$\Delta pp \to (W^\pm \to l\nu)X$: asymmetry $A_L(y_\ell)$ with respect to the rapidity y_ℓ of the decay charged lepton

$$A_L(y_\ell) \equiv \frac{\frac{d\sigma^{\vec{p}p}}{dy_\ell} - \frac{d\sigma^{\overleftarrow{p}p}}{dy_\ell}}{\frac{d\sigma^{\vec{p}p}}{dy_\ell} + \frac{d\sigma^{\overleftarrow{p}p}}{dy_\ell}}$$

A better alternative to the commonly discussed single-spin asymmetry $A_L(y)$ with respect to the rapidity y_W of the W boson

- ☼ Directly measurable
- ☼ Not distorted by limited acceptance of RHIC detectors (while $A_L(y_W)$ is strongly distorted)

P.N.

Single Muons From Heavy Flavor

Prompt μ^- vs PHENIX $p + p \rightarrow e + X$

Two data are consistent within errors and the extrapolation systematics.

Ed.'s note: I think all the pieces are there for this important analysis, but we do need to pull it all together.

K.R., Y.K

D^0 Measurements in Run-5 pp

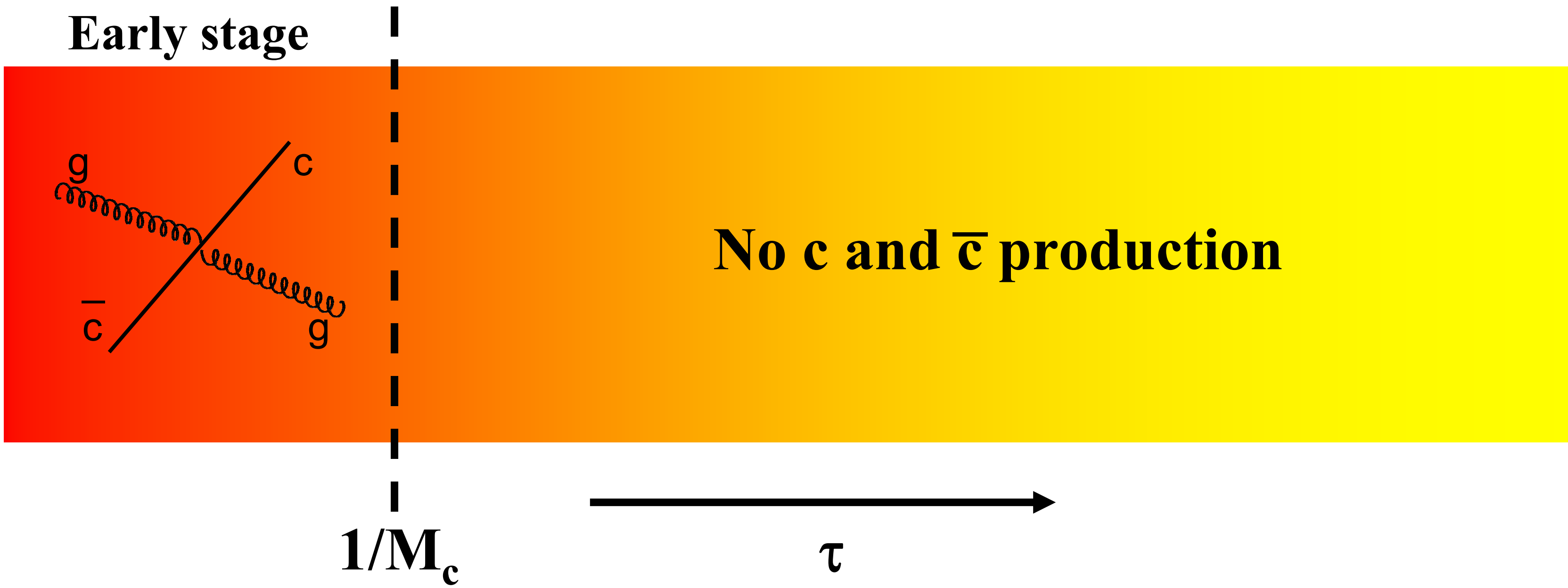
- $D^0 \rightarrow \pi K$ search in central arm
  - 2 major issues
    - Large background
      - displaced vertex cut reduces background dramatically
        → need silicon vertex tracker.
    - Lack of trigger
- μ trigger enhances $D^0 \rightarrow \pi K$ in central arm
  - Currently available solution of the 2 issues above.
  - I'd like to propose the prescale factor for single μ trigger set to be as low as possible in RUN5
  - μ channel is unique to PHENIX

Ed.'s notes:
Check luminosity numbers (experts disagree).
What about triggering on accompanying electron?

K.A.

Why is charm quark a good probe?

Charm quark can be produced only during the early stage of QCD matter



M.D.

Charm quark mass is large enough

M_{charm} ? Λ_{QCD}

Perturbative calculations of charm production and energy loss are possible

M.D.

Charm quark mass is small enough

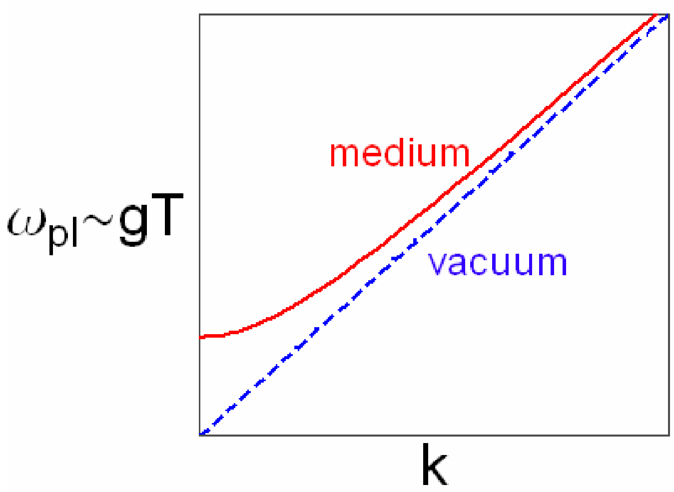
Significantly interacts with surrounding light quarks and gluons

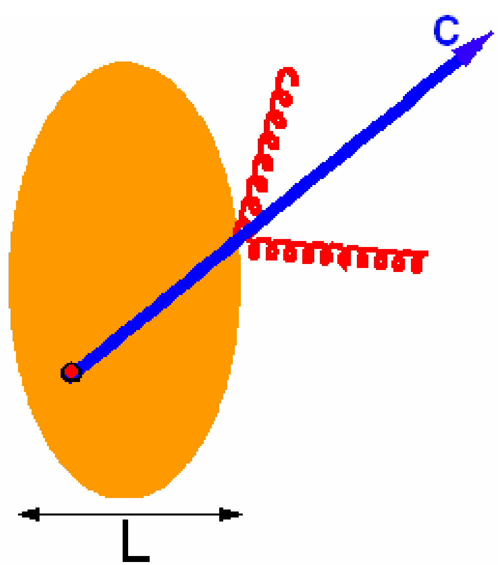
Sensitive to the properties of the medium

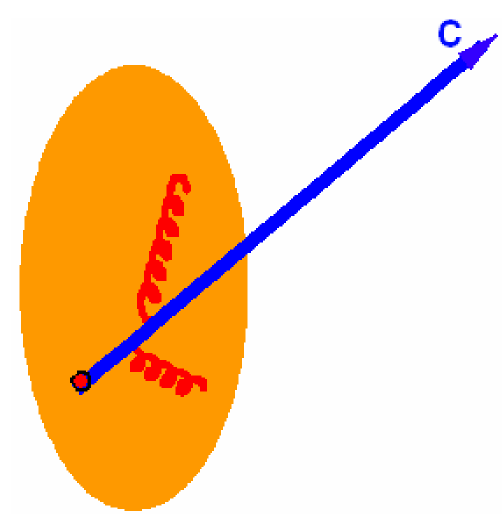
Radiative heavy quark energy loss

There are three important medium effects that control the radiative energy loss at RHIC

1) Ter-Mikayelian effect **(Djordjevic-Gyulassy)**
2) Transition radiation **(Zakharov)**
3) Energy loss due to the interaction with the medium **(DG)**

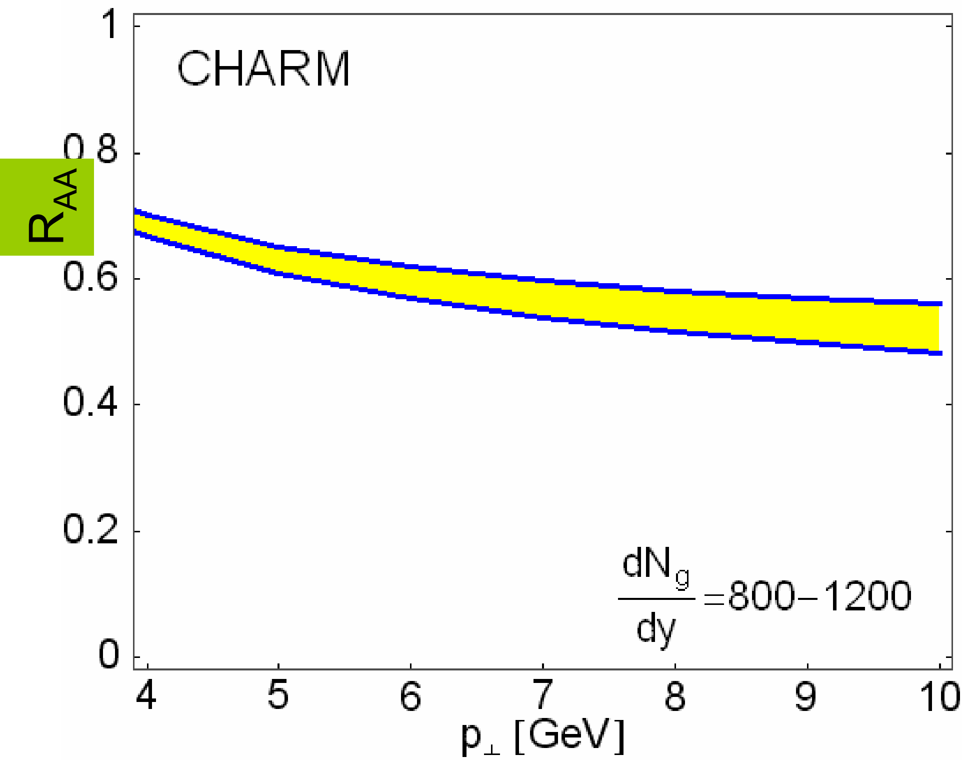


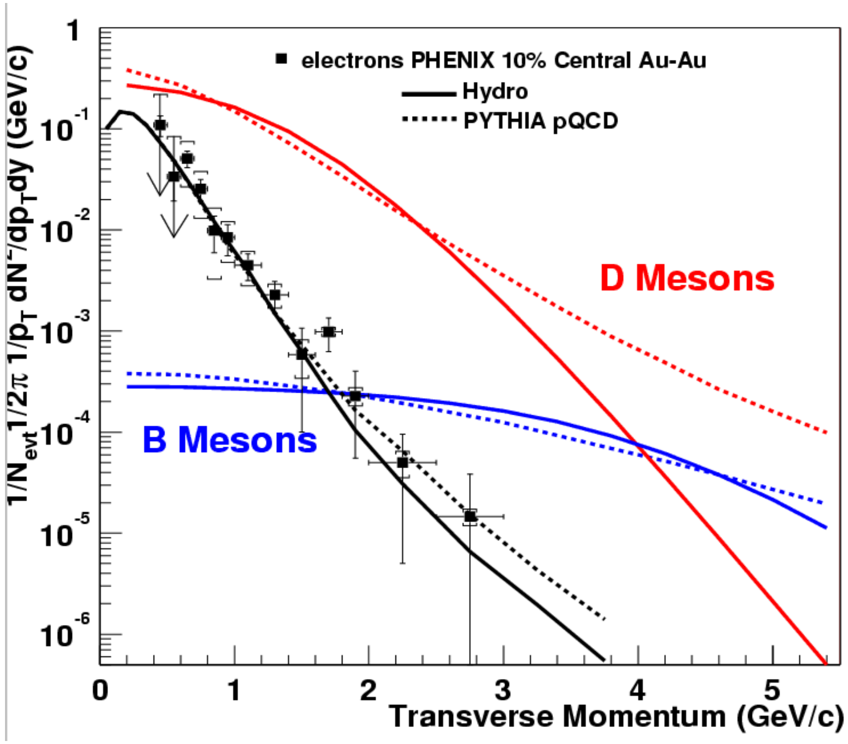




M.D. 1) 2) 3)

D meson suppression is obtained by dividing Au+Au and d+Au D meson pt distributions.

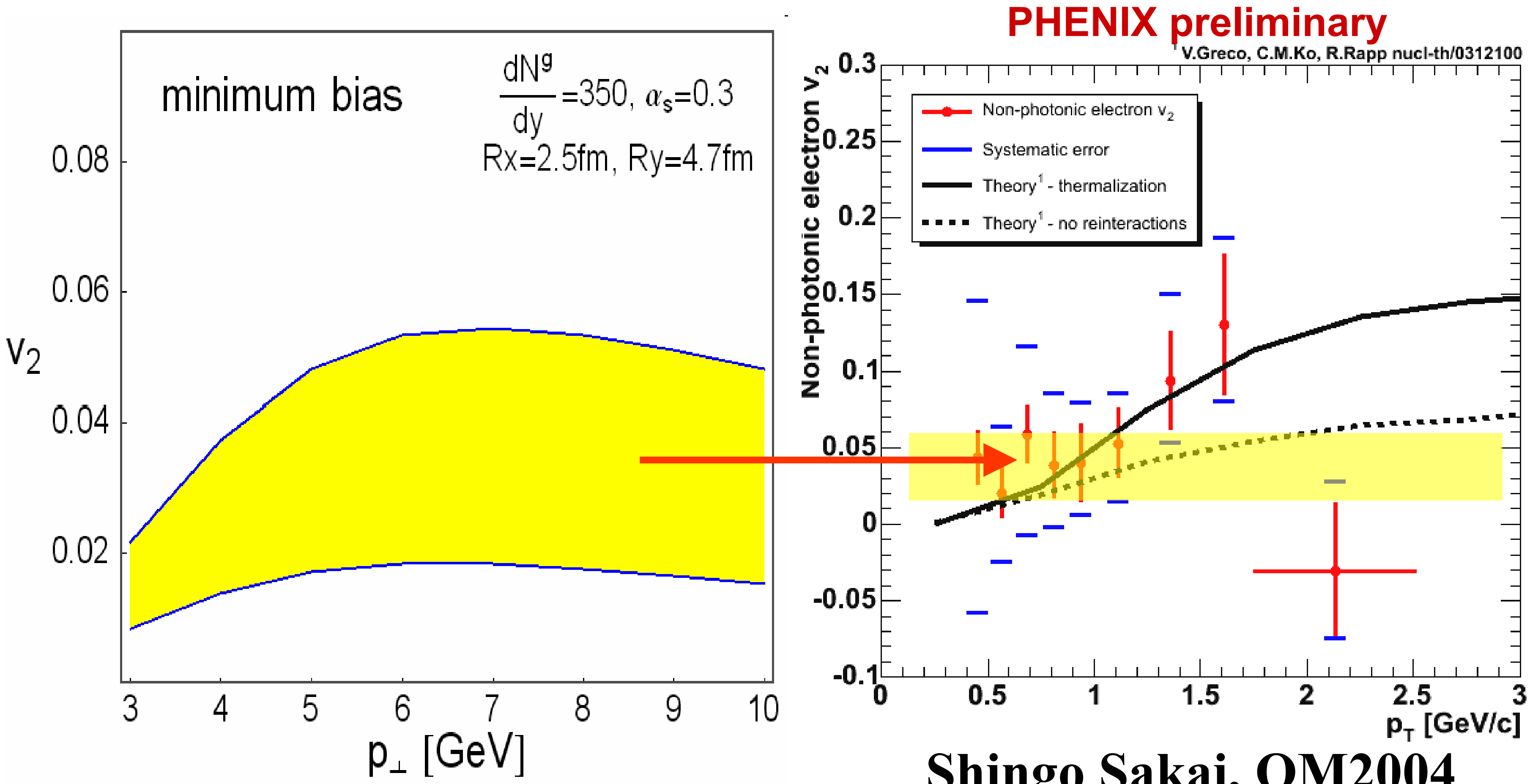




D-meson suppression is "consistent" w/PHENIX central arm measurements (but we haven't measured there yet).

M.D.

We have estimated v_2 for minimum bias case. Here, we have assumed 1+1D Bjorken longitudinal expansion.



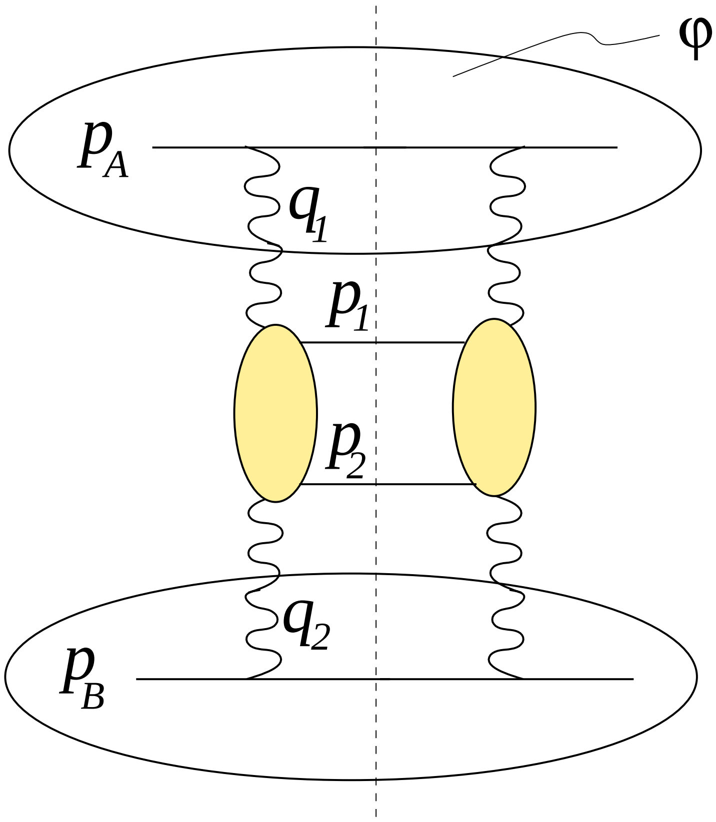
Shingo Sakai, QM2004

According to our estimates, we expect small charm quark v_2 at RHIC (0.02-0.06).

M.D.

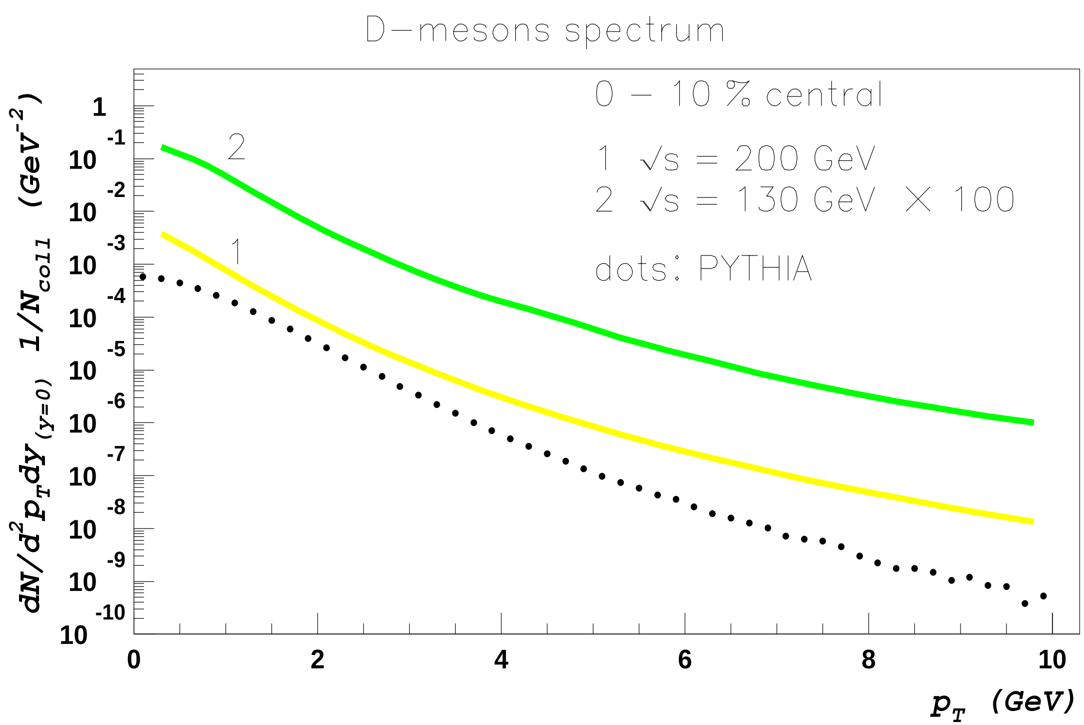
Open Charm Production

Kharzeev and Tuchin model open charm production in the saturation/Color Glass formalism by the following model:



Y.K.

It results in the spectra which fall off slower than PYTHIA:

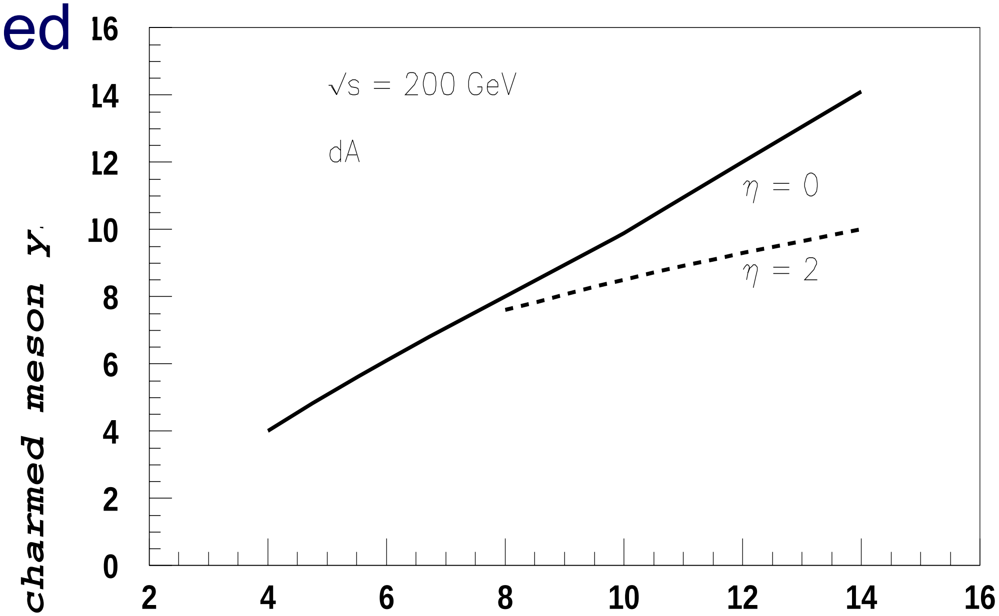


Caution: only a model, for exact calculation see Tuchin '04 and Blaizot et al, '04.

Open Charm Production

Similar suppression applies to heavy flavors, in particular to open charm. The figure below demonstrates that in going from mid-rapidity to forward rapidity open charm production should start scaling slower than N_{coll} , which indicates suppression.

Charmed Meson Yield



N_{coll}

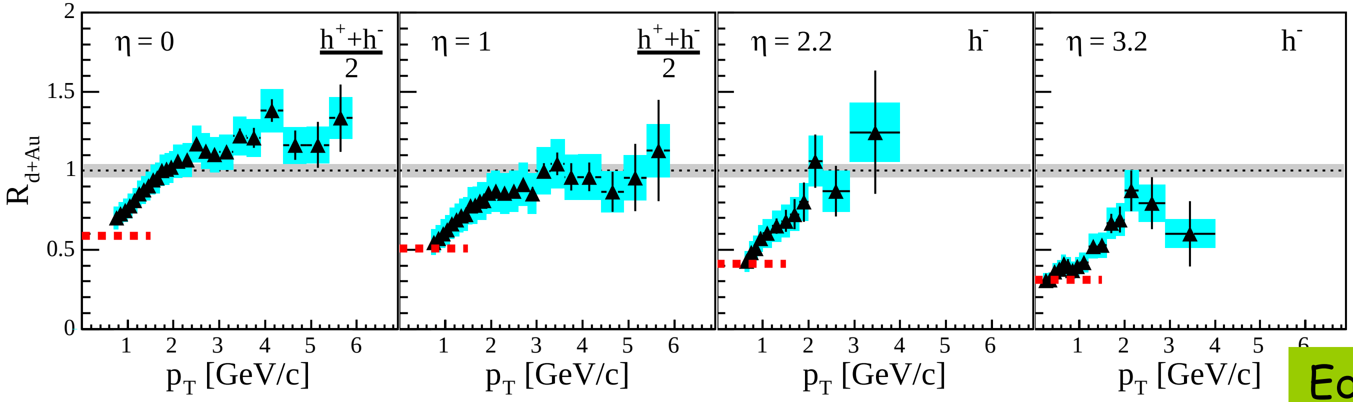
Y.K

from D. Kharzeev and K. Tuchin, hep-ph\0310358

R_{cp} verse p_T,η

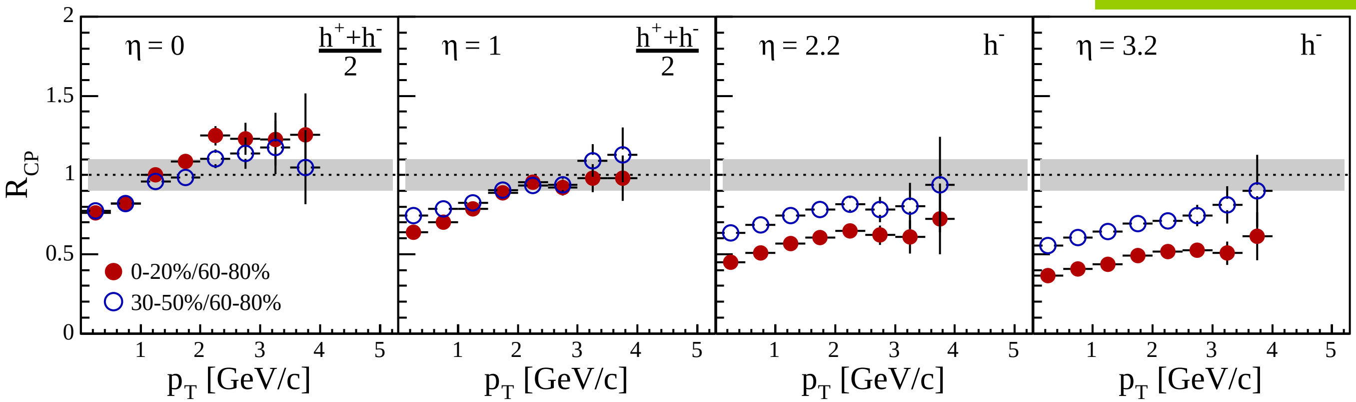
R_{dAu} at different rapidities

R^{dAu}



Ed.'s note: How about η<0??

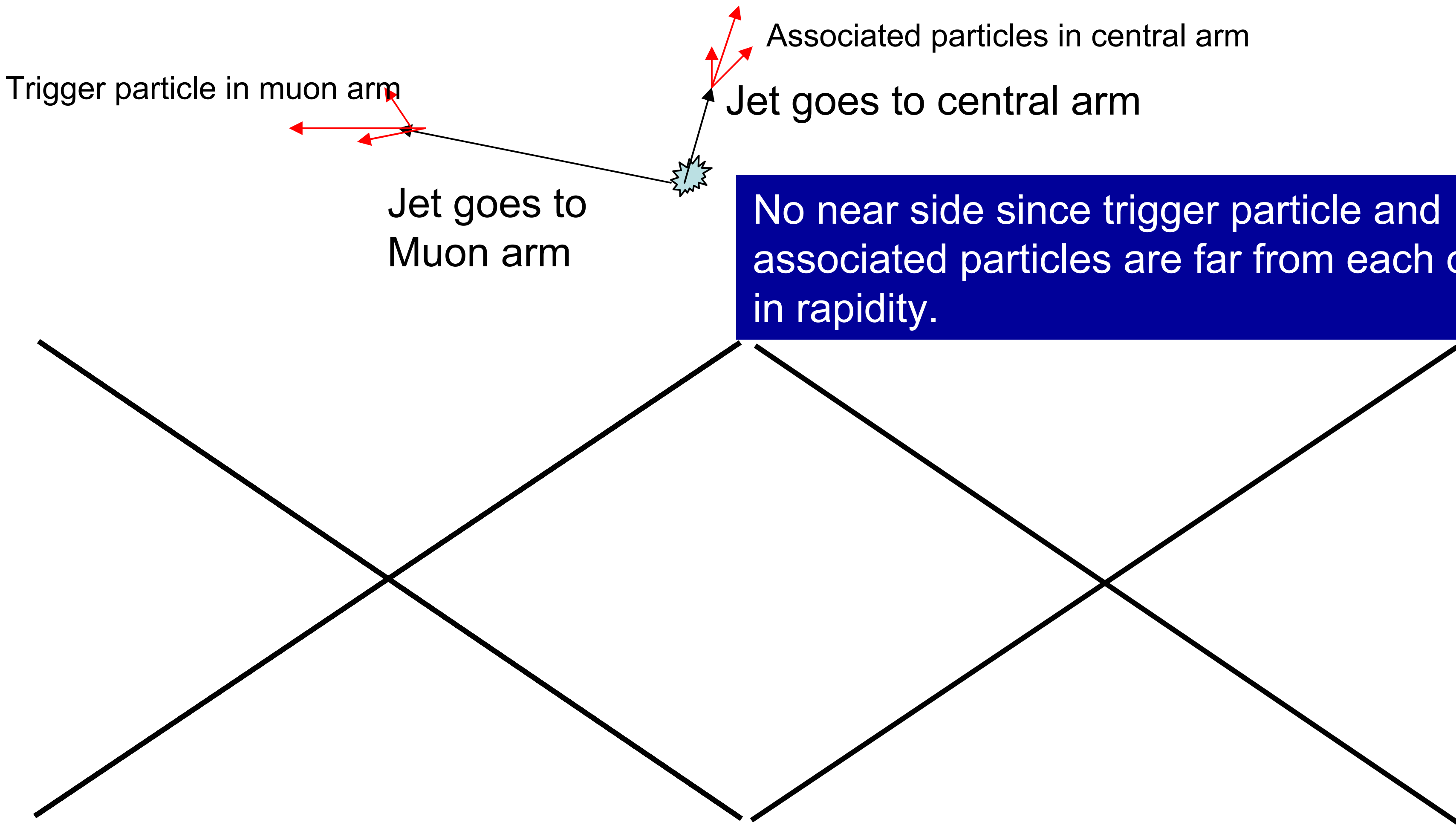
R^{CP} – central to peripheral ratio



Most recent data from BRAHMS Collaboration nucl-ex/0403005

Y.K. Our prediction of suppression was confirmed!

Two particle correlation analysis with muon arms

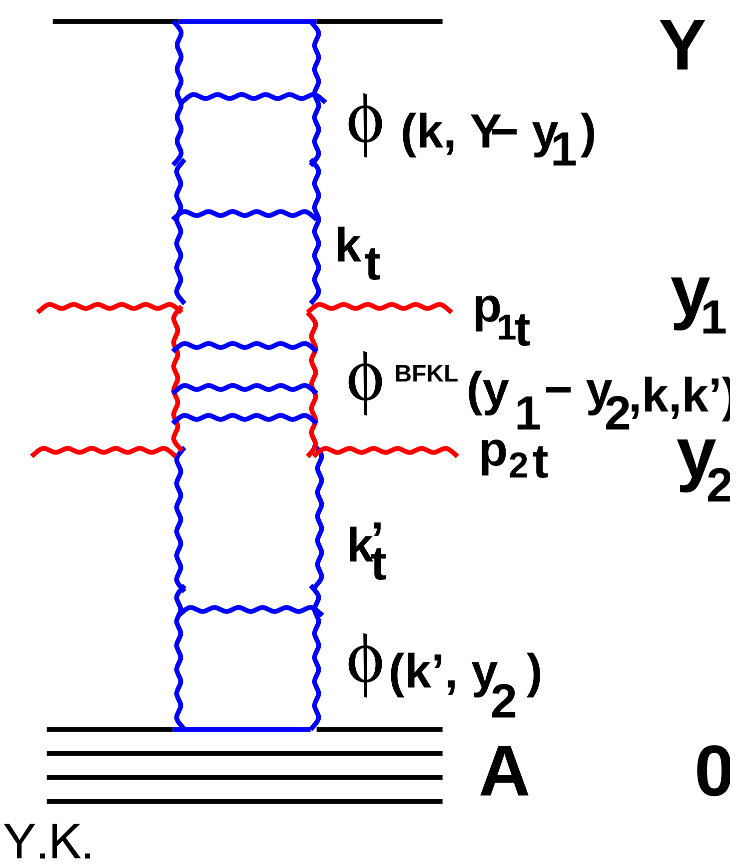


No near side since trigger particle and associated particles are far from each other in rapidity.

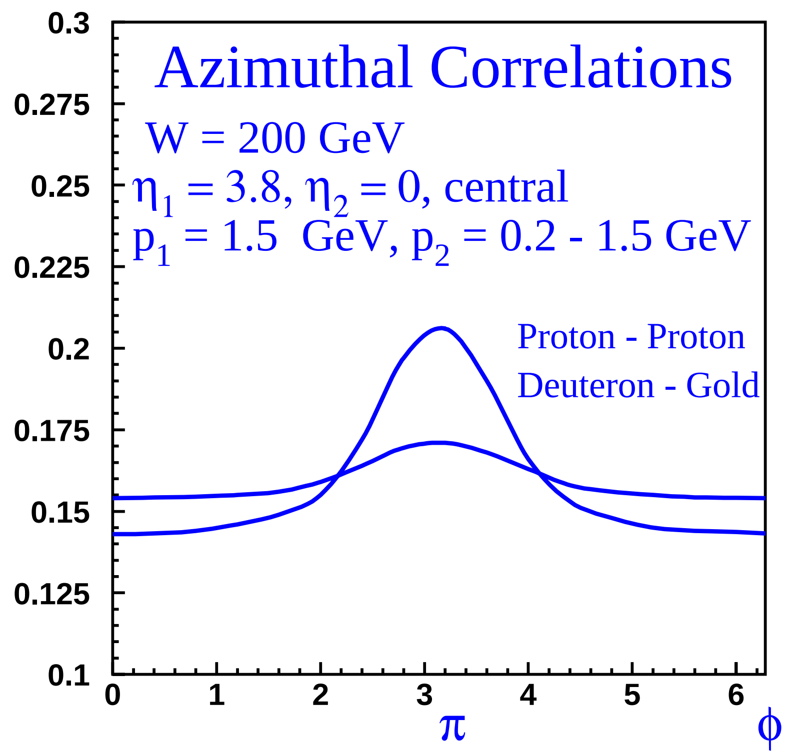
C.Z.

Back-to-back Correlations

An interesting process to look at is when one jet is at forward rapidity, while the other one is at mid-rapidity:



The evolution *between* the jets makes the correlations disappear:



from Kharzeev, Levin, McLerran, hep-ph/0403271

Detector/Software/Trigger Performance & Outlook

- Software status
  - Raphael Granier de Cassagnac (Coordinator's Report)
  - ViNham Tram (Efficiencies)
  - Xiaorong Wang (Efficiencies vs. Kinematic Variables)
  - Hugo Pereira (LVL2)
  - Ken Read (SSC)
- Hardware status
  - MinJung Kweon (HV Status)
  - Woojin Park (DST QA)
- Shutdown activities
  - Rusty Towell (MuTR Shutdown Activities)
  - Atsushi Taketani (Alignment System Upgrade)
  - Imran Younus (Multi Event Buffering)
  - Ken Read (Shielding the MuID)
- Triggering
  - Jamie Nagle (Triggering in Run-5)
  - John Lajoie (MUID LL1)
  - Tony Frawley (Triggering in the Future)

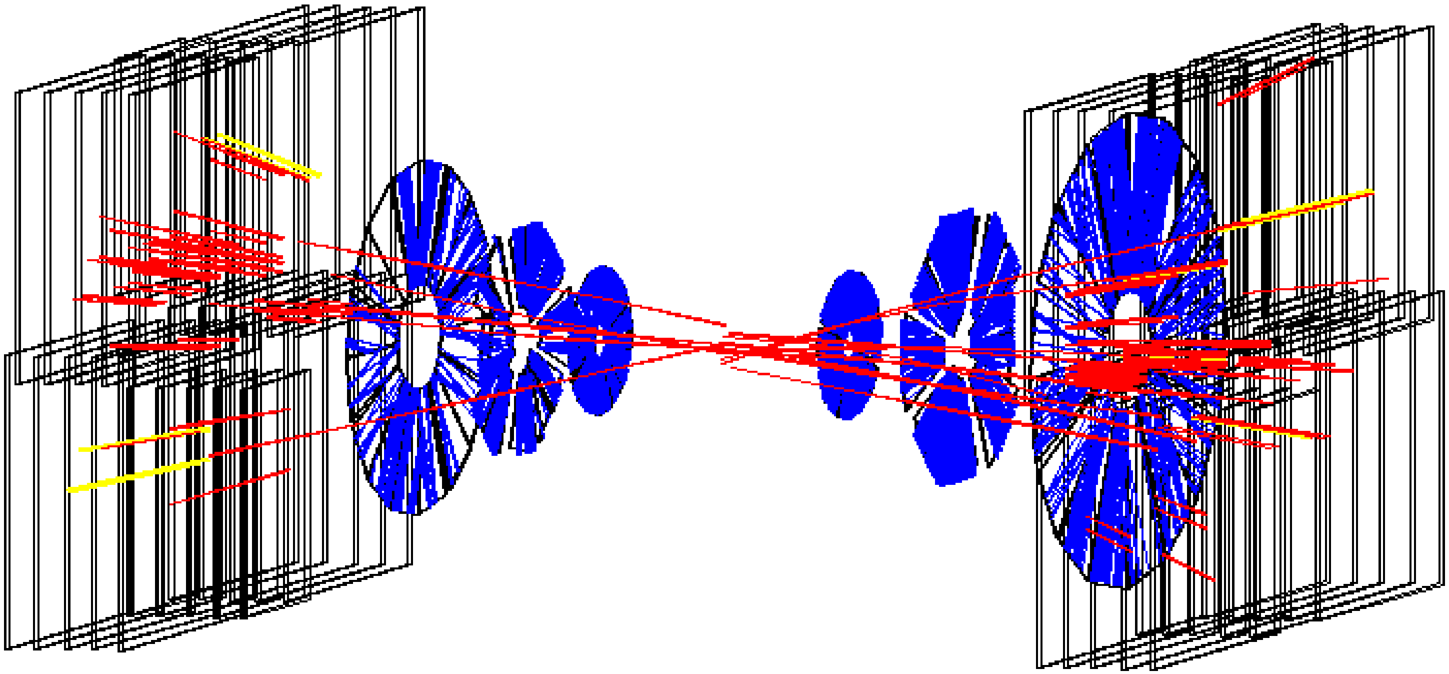
The good : MUTOO

- MUTOO is our one and only framework !

- It has fulfill all its goals :
  - More robust wrt indexes and memory leaks
  - More documented (doxygened)
  - Equivalent performances before the jump

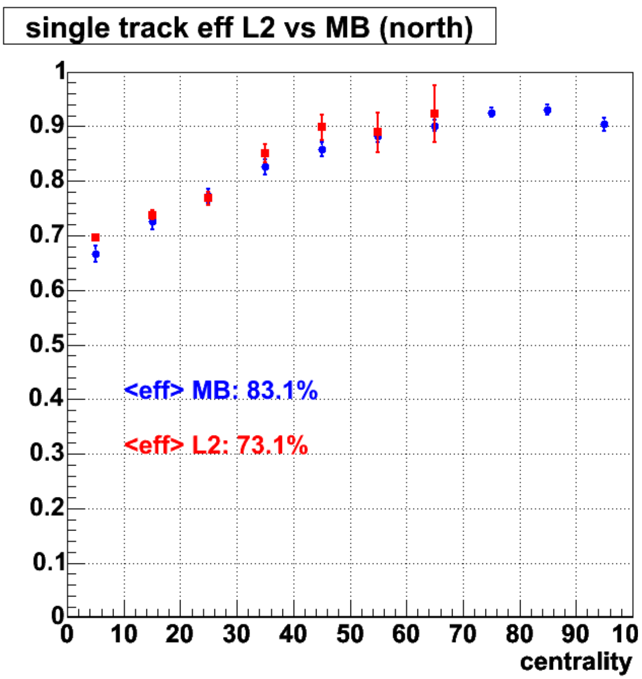
Except maybe raising the number of active coding people ☺

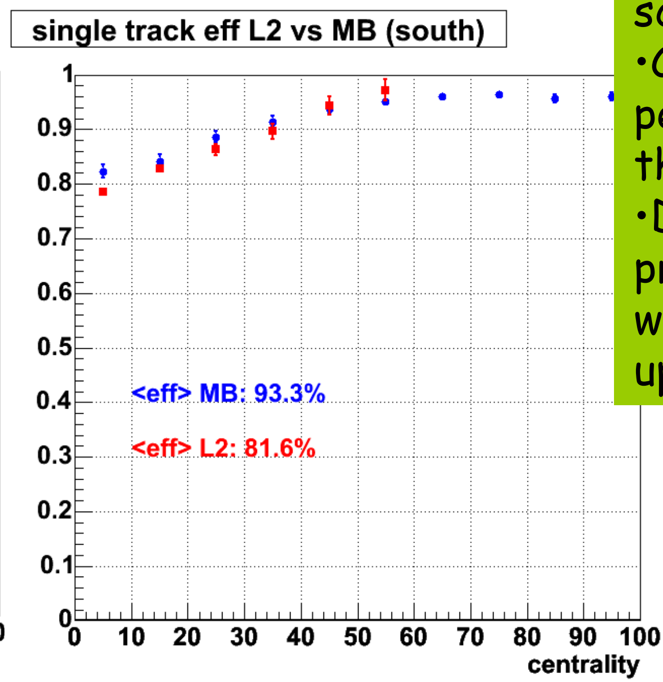
The bad



R. G de C.

Single track efficiency* vs AuAu centrality





- N/S difference due to scratched cathodes?
- Can we look at efficiency for a perfect detector to answer this conclusively?
- Do we understand what the primary loss sources are? Can we influence the trigger upgrade in a way that will help?

V.T.

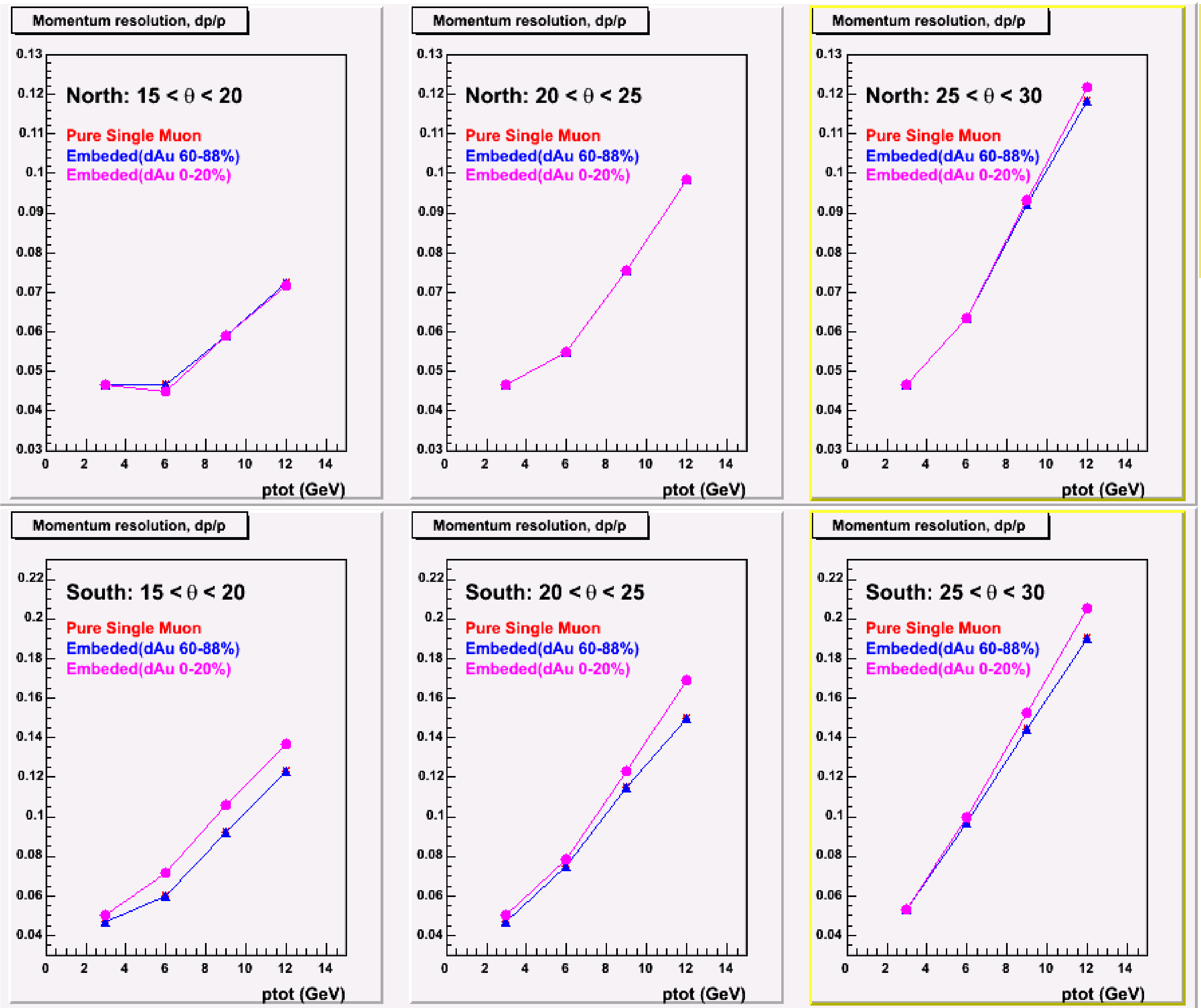
Consider that a track is successfully reconstructed if dP/P_mc < 0.3

⇒No relevant difference between LVL2 and MB events in the same centrality bin

⇒ North eff < South eff

*done before Melynda latest's improvement

Momentum Resolution



$\Delta p/p$:

Strongly

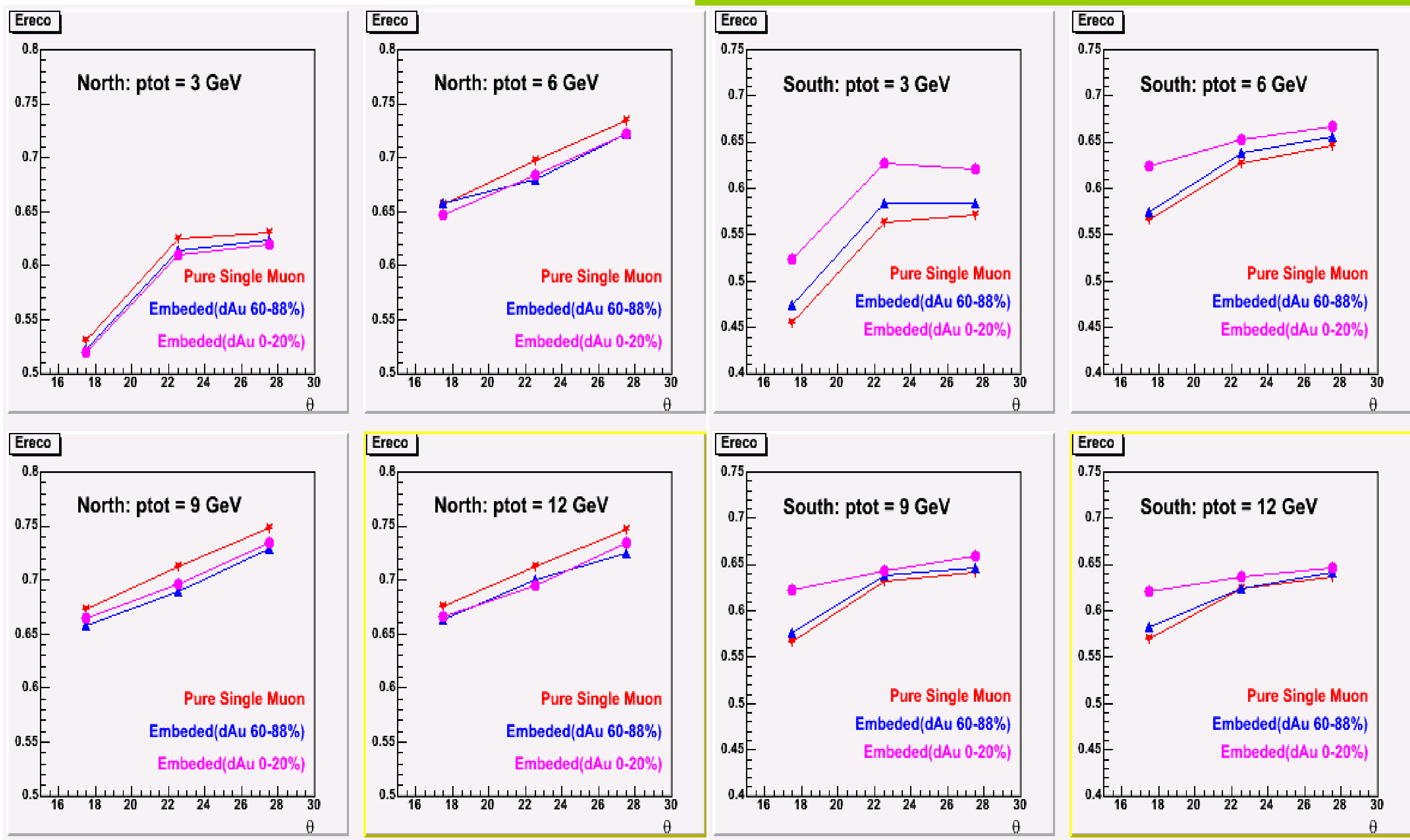
p_{tot} dependence

θ dependence

X.W.

Muon Reco Eff.

I don't understand why these #'s are lower, but it is an important point that the resolution and efficiencies can depend on Θ, p.



X.W.

10% centrality dependence was observed for South, but not for North;

Ereco increased around 10% as θ goes up from 15 to 30;

Effect is stronger for low momentum;

MuID LVL2 Used for Filtering

Rejection power and timing

Level2 muid trigger on Run4 real data sample

depth	north	south
shallow shallow	4	4
deep shallow	9	9
deep deep	40	36

$$\text{rejection power} = \frac{N_{\text{minbias}}}{N_{\text{L2accepted}}}$$

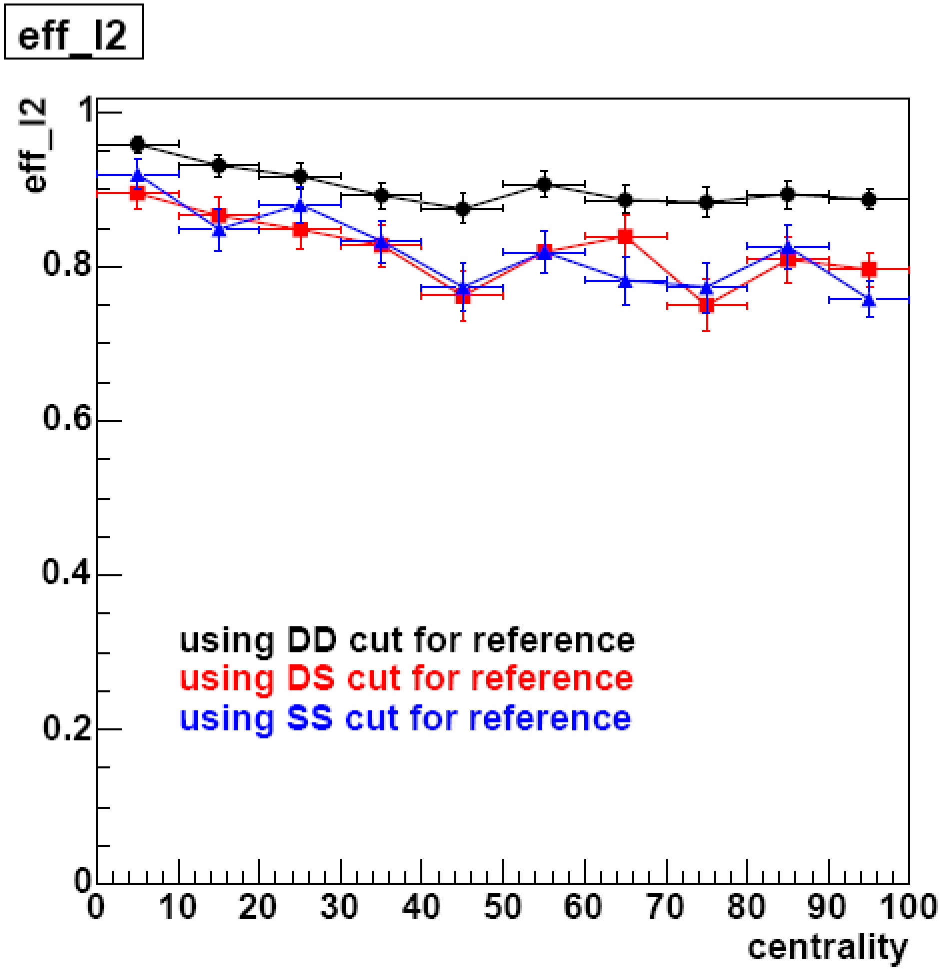
Level2 and offline timing on Run4 realdata sample

	minimum bias	level2 filtered
Average time/event in lvl2 reco	-	51 ms
Average time/event in offline reco	1200 ms	5600 ms
Total time for one segment	1.6×10^7 ms	3.6×10^6 ms

H.P.

$\Rightarrow$ filtered reconstruction $\sim$ 3 to 4 times faster (here 4.4)

Level2 efficiency for realistic RUN4 muid efficiency (run 109656)



muid efficiency/gap:

gap	0	1	2	3	4
south arm	97.5	96.5	96.6	97.1	96.5
north arm	97.5	95.9	95.9	97.2	96.0

average = 96.7 %

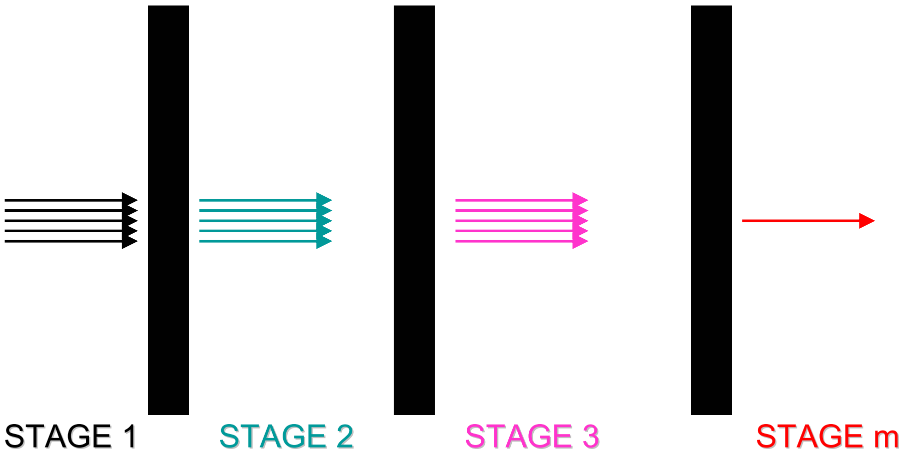
average level2 efficiency:

depth cut on MC	level2 (%)
deep deep	90.3
deep shallow	82.0
shallow shallow	81.8

H.P.

using 3k pythia J/ψ embedded in RUN4 real data

Successive Sampling/Cloning Simulation



Ed.'s note: Need to demonstrate proper statistical fluctuation behavior!

Traditional Number of Events Needed

- (10^3 to overcome π/μ rejection factor)(10^3 events/bin)(10 bins in z)(10 bins in η)(5 bins in p_T)(6 bins for particle ID: $\pi\pm$, K$\pm$, p$\pm$)(2 hadronic interaction packages)(2 different MuID square hole shields) = 1.2×10^{10} events!!
- (10^{10} events)/(10^5 single particle events / 2 CPU-days) = 2×10^5 CPU-days for this analysis
- 2000 days on a farm where we manage to monopolize 100 CPUs 24 hours/day!
- Then, consider subsequent years and other analyses that could benefit.
- Bottom line: If this works, there is a big potential on-going market for it!

K.R.

Compare sim and real data : HV config

Inner anodes off to reduce occupancy
Gas gain (HV) increased at end of January
Modified 0-suppression code

M.K.

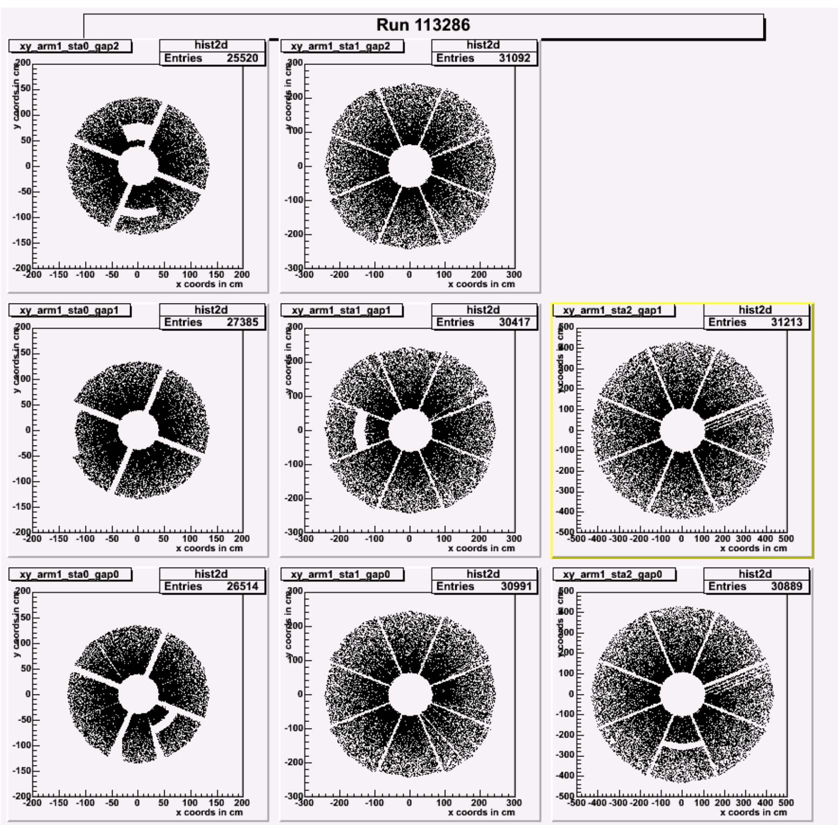
Get disabled HV channel info from HV log

put this info (HV config file) at the mc step

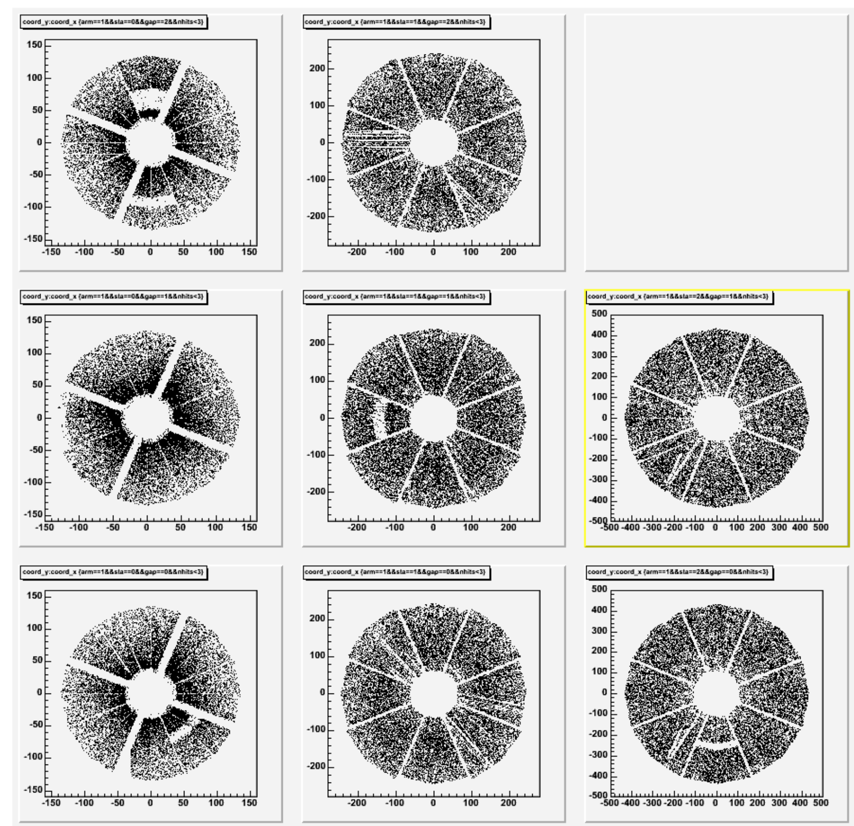
MC and real data hit distributions are well matched at the HV channel point of view

we can say the real HV situation is properly reflected to the simulation

North : from MC



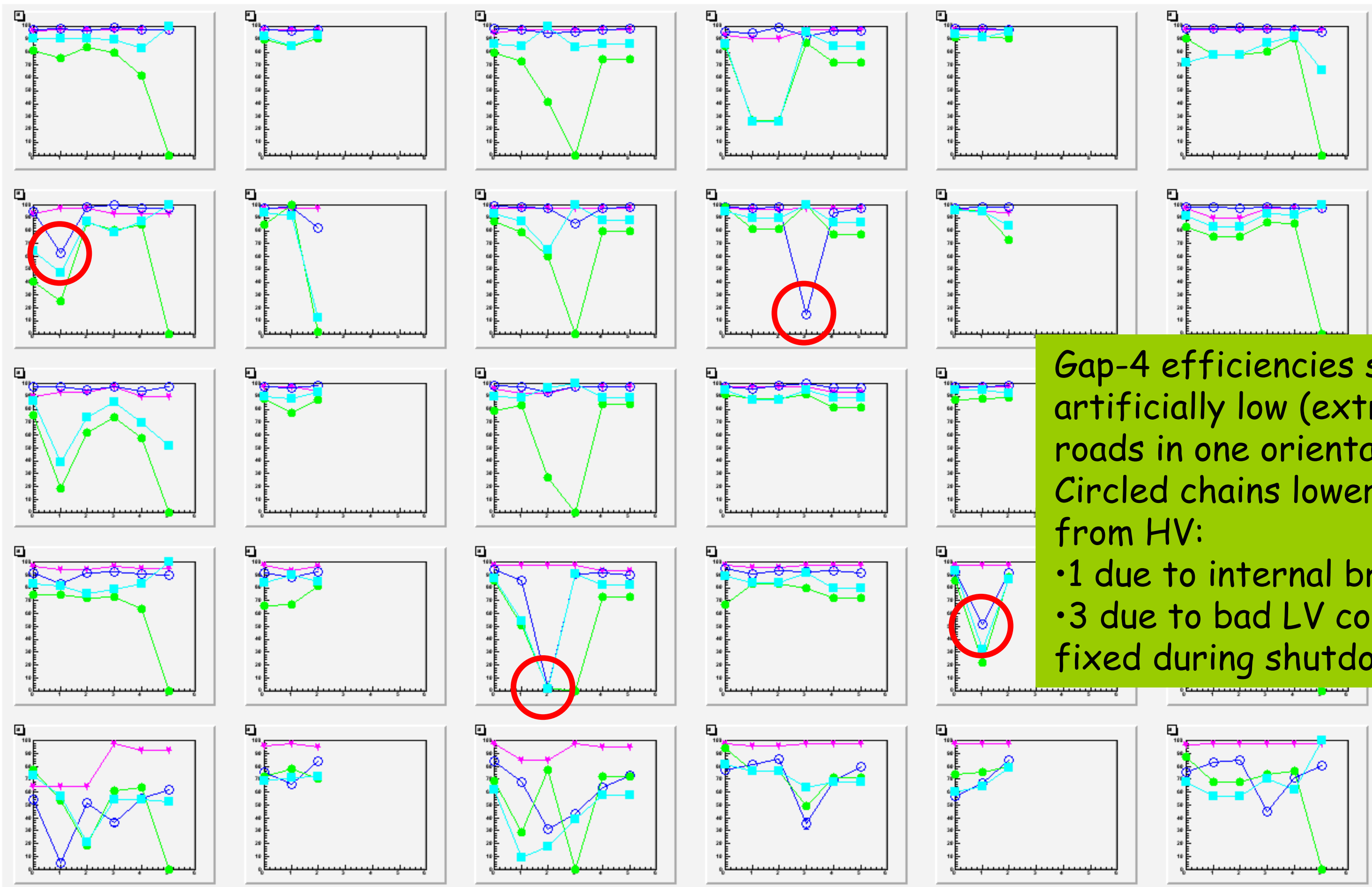
North : from Real data



– plot by DongJo Kim

Muid Tube efficiency

- 80 runs(~ 150M events) from pro.54 production
- These 80 runs are good runs in the muid point of view (overall muid tube efficiency calculated by HVmasked method > 92%)



South Arm

Gap

Gap-4 efficiencies systematically, artificially low (extra hits extend roads in one orientation, not both)
Circled chains lower than expected from HV:
•1 due to internal break
•3 due to bad LV connections (being fixed during shutdown)

M.K.

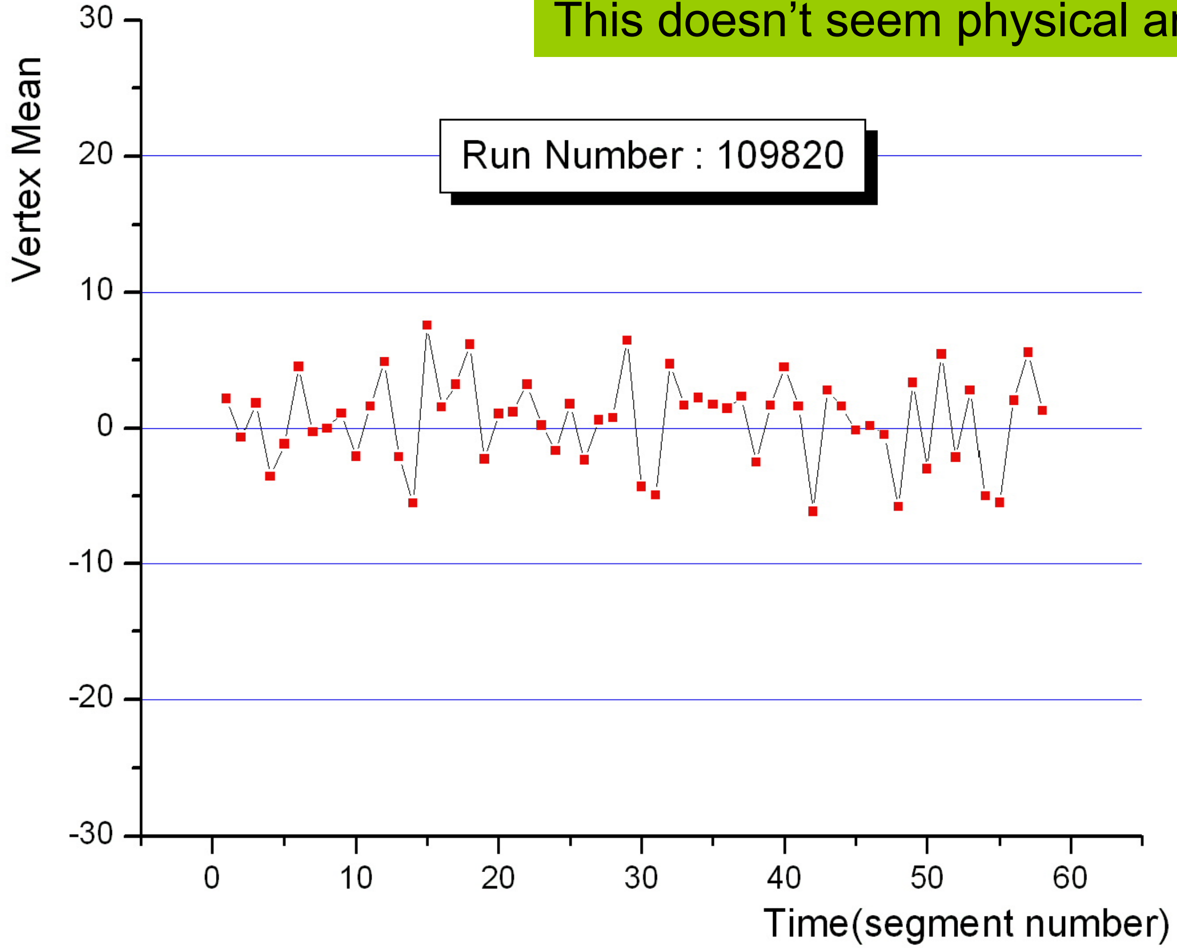
pink,red:HVmasked, blue:run4AuAu, green:run3pp, skyblue:run3dAu from Colorado method

Panel

- we have much improved efficiency than those of run3 except for last gap and only a few of other segments.
- Most of the parts show high efficiency and also even good agreement with the HVmasked method

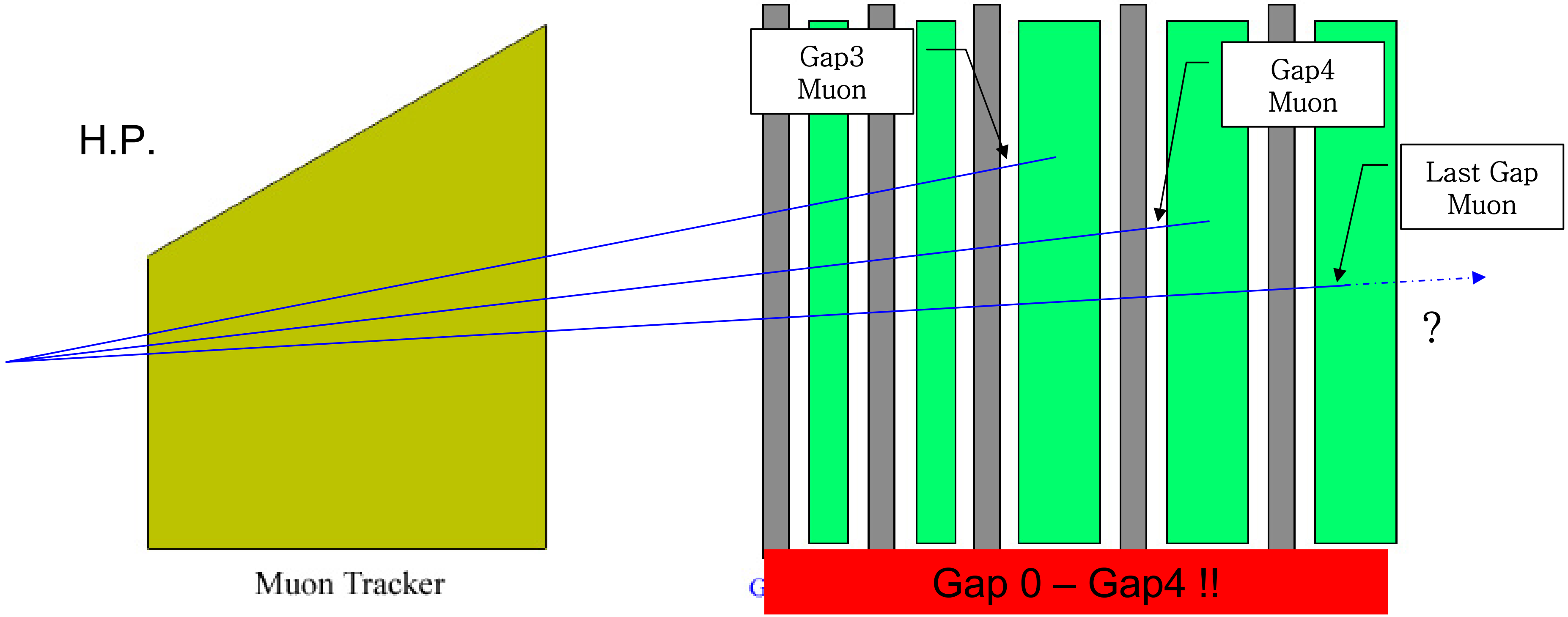
Variation within a run - Run4 AuAu

This doesn't seem physical and needs to be understood



H.P.

QA - Last Gap Muon for Open Charm



- Muon from the open charm has large momentum as compared with other muons
- There is every probability that it can be reached to the MuID last gap
- But we cannot measure the number of last gap muons directly

Ed.'s note: Probably want to use a less deep gap for QA, otherwise subject to background hits.

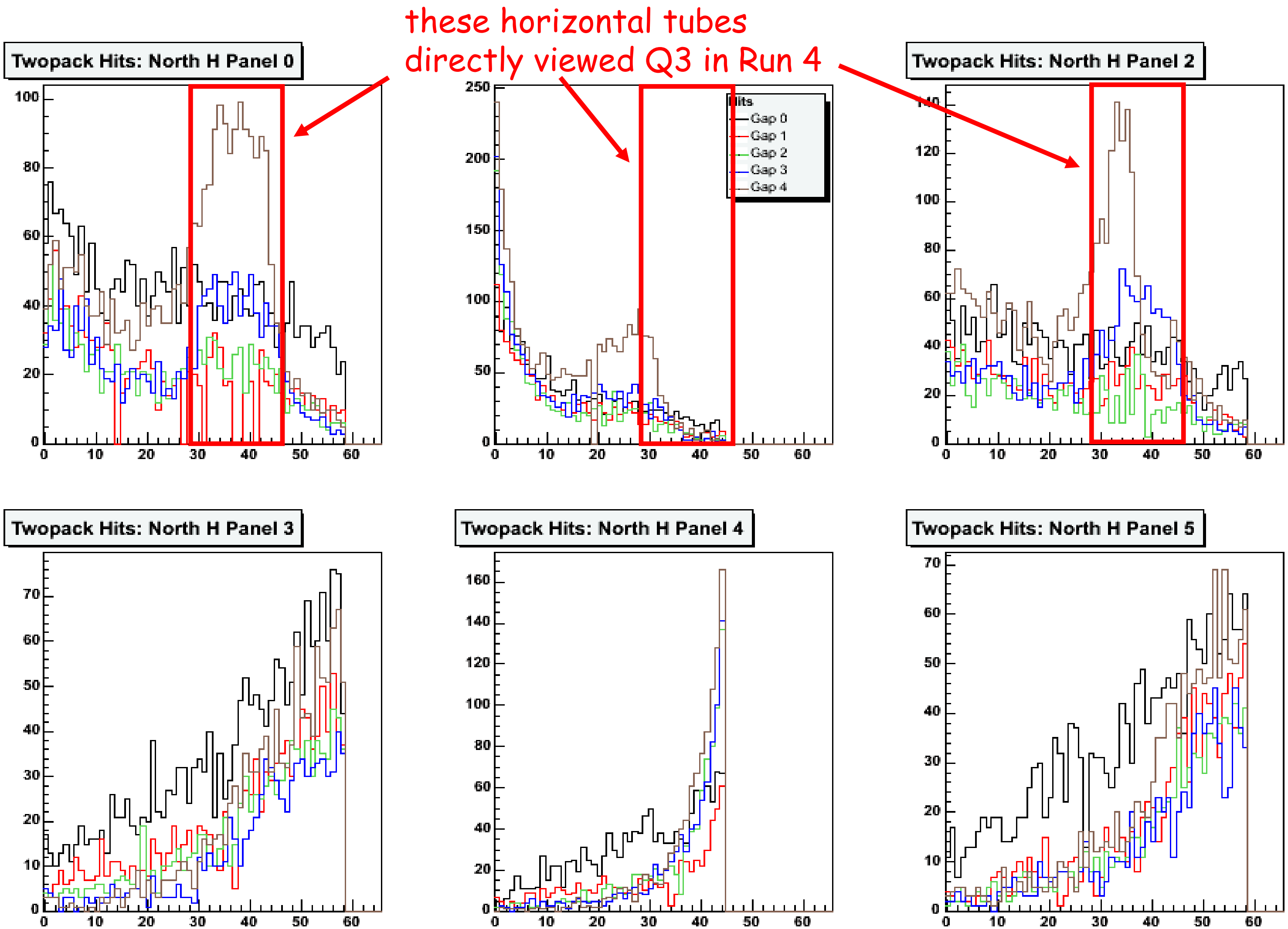
MuTR Shutdown Activities

- 1) HV problems in station-1 north
- 2) problems in south sta-3 oct-7
- 3) LV distribution control replacement
- 4) FPGA code
- 5) Building more spare RX cards
- 6) Optical alignment DAQ replacement
- 7) Dallas chip readout software rework

R.T.

MuID Shutdown Activities

Primarily shielding; also need to coax soaked panels back to health



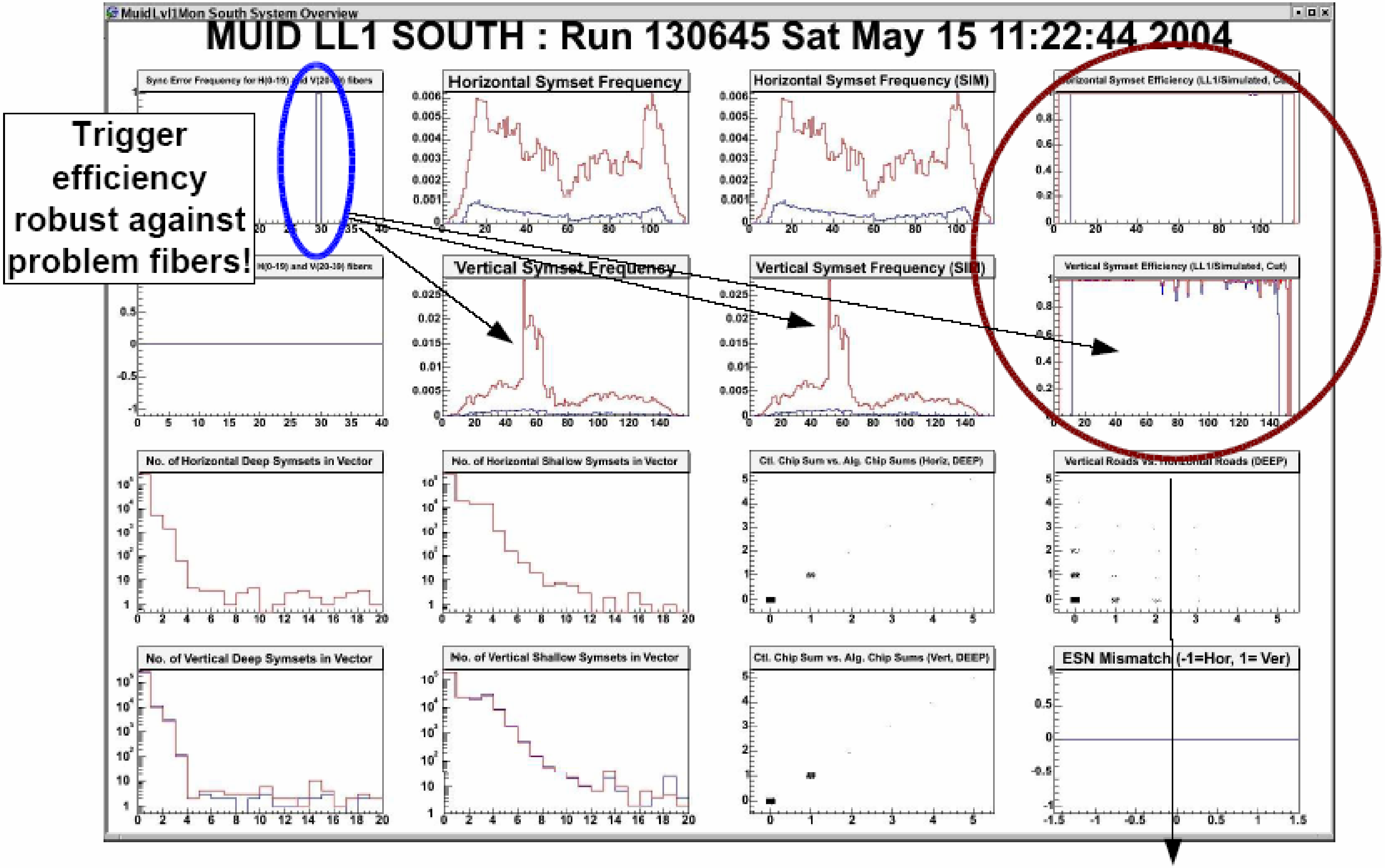
K.R.

Triggering Outlook

- We require MUID and ERT LL1 at the start of Run-5
- Updated rejection/efficiency studies underway

J.N.

MuID LL1 Efficiency (May 2004)



Rejection Factors

AuAu

4/5 gap requirement for deep w/strip rej:

South 1 Deep rejection = **7.6519**
South 1 Deep 1 Shallow rejection = 8.1180
South 2 Deep rejection = 33.7573
North 1 Deep rejection = **7.9220**
North 1 Deep 1 Shallow rejection = 8.7331
North 2 Deep rejection = 39.2454

pp

With square hole rejection:

South 1 Deep rejection = **1014.66**
South 1 Deep 1 Shallow rejection = 50225.8
South 2 Deep rejection = 200903
North 1 Deep rejection = **752.446**
North 1 Deep 1 Shallow rejection = 50225.8
North 2 Deep rejection = 100452

J.L.

Run-5 Preparation

- Study Trigger Rejection for Light Ions
  - Si+Si (or Cu+Cu)?
  - Straightforward study
    - HIJING with pisaToPRDF (Is this working for MuID?)
    - Run through MuID LL1 simulator
  - Additional algorithm development?
  - Backgrounds?
- Hardware Setup
  - Square hole rejection logic implemented
    - crosscheck with cosmics
  - Run blue logic and MuID LL1
    - switch to MuID LL1 when satisfied

MuID LL1 Ready for Physics in Run-5

Editor's note: add 1-shallow for hadron measurements (R_{cp}, punchthroughs)

J.L.

Triggering in the future – Come to tomorrow's session!

T.F.

Things don't look so bad!

We have to assume that the forward muon trigger upgrade will appear in time for W physics at RHIC II, and that the Nose Cone Calorimeter trigger will have a suitable high energy trigger.

Single muons from MUIDLL1 will have to be prescaled at highest luminosities. Problem for **beauty**, and for **charm correlations**.

- The forward muon trigger upgrade will help for high p_T muons, although details are still fuzzy. Is that enough?
- Can the VTX detector be used to increase single muon rejection?

A good minbias trigger for p-p would be nice - possibly the VTX. This is being looked at.

Hadron R_{cp} in muon arms - is 1D trigger really OK?

$D \rightarrow K\pi$ is a problem, but I have not discussed it here because it is a central arm issue. Possibly use single lepton triggers (detecting the recoil c quark).