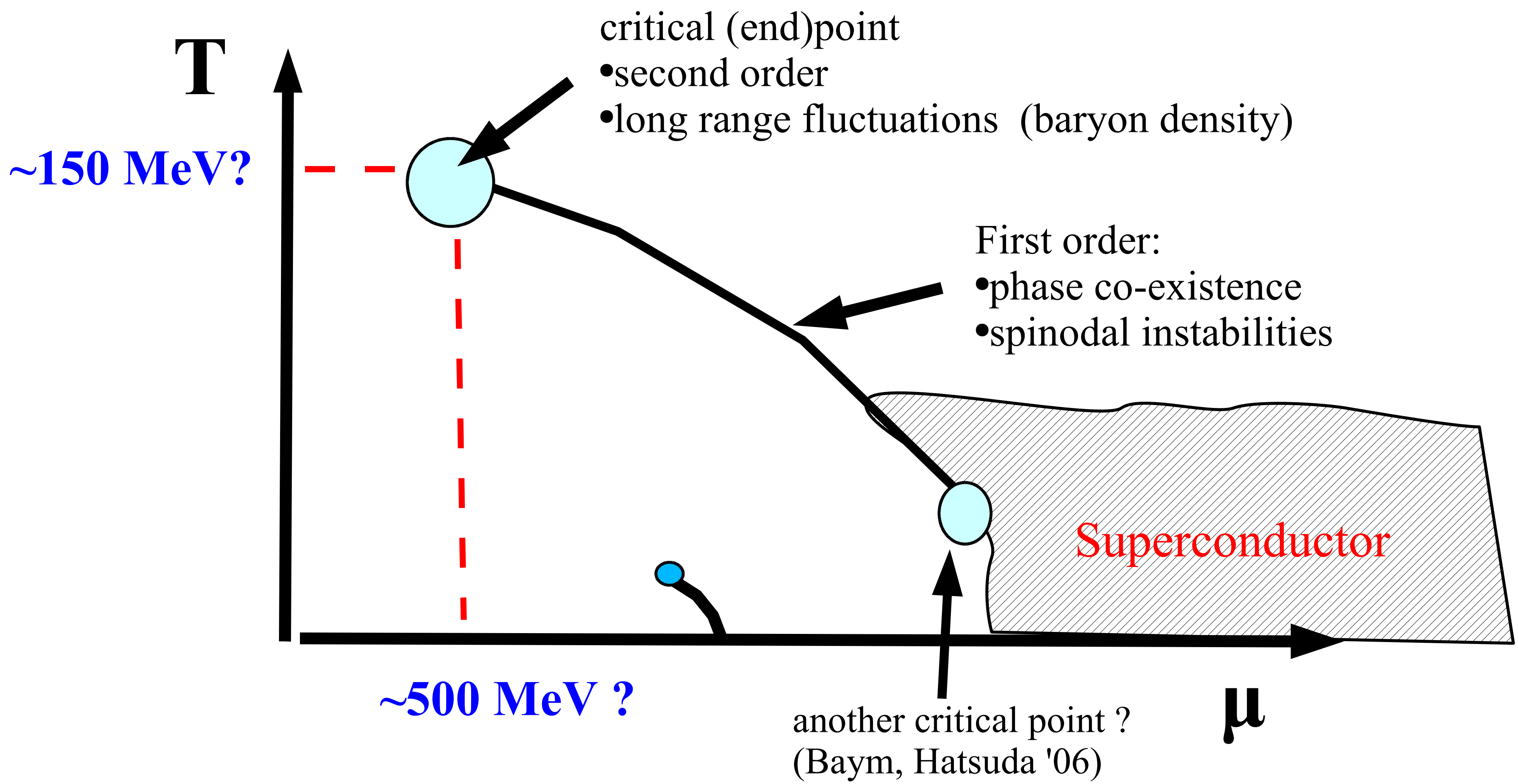
Dilepton and the QCD CP

- What is the QCD CP
- Dileptons

The QCD Phase Diagram



N.B.: Critical point of water: T_c=647.096 K, p_c = 22.064 MPa, ρ_c = 322 kg/m3

QCD critical point

- Order parameter: baryon density or scalar density
  - Actually it is a superposition
- Both scalar (chiral) an quark number susceptibilities diverge
- **Screening** ("space like") masses vanish ("omega", "sigma")
  - not accessible by (time-like) dileptons
- Density fluctuations: Not obvious how this translates into a clean dilepton measurement
- The transition is in same universality class as liquid gas! (Son, Stephanov)
  - Fluctuations are driven by density fluctuations; chiral field is just tagging on

Nambu model

(Fuji et al, hep-ph/0401028,0403039)

Sigma remains massive at CP; CP driven by spacelike p-h exitations

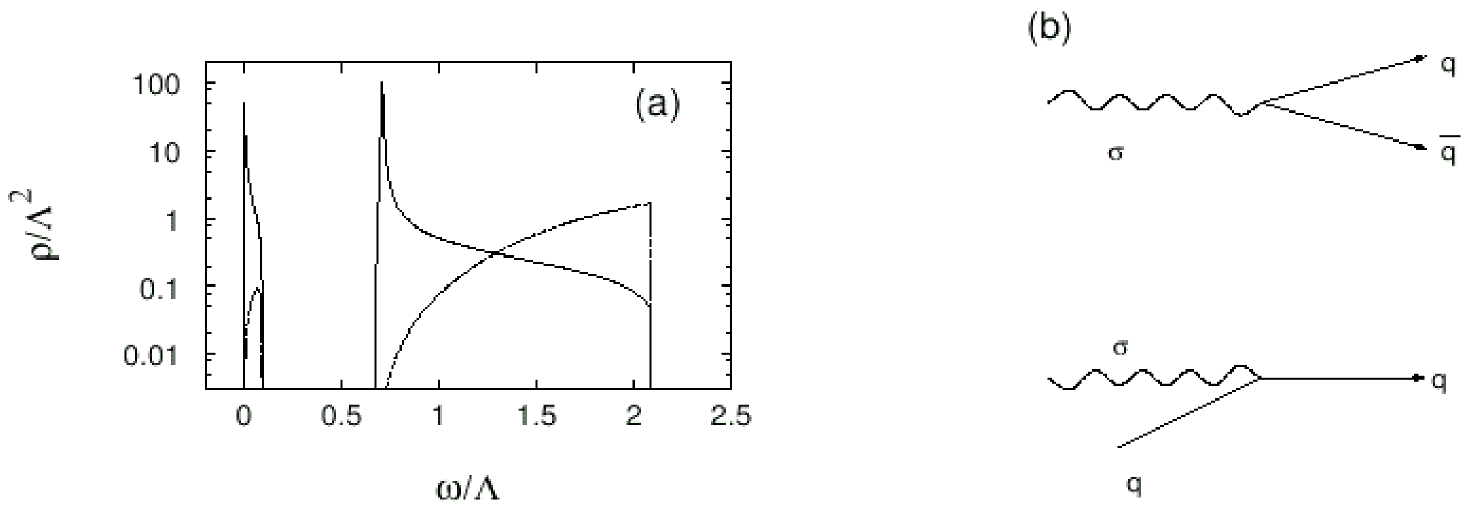


Fig. 2. (a) Spectral function in the scalar channel (solid) with $|\boldsymbol{q}|/\Lambda = 0.1$ at a CEP with $m/\Lambda = 0.01$. The free gas spectrum (dashed) is also shown for reference. (b) Typical processes contributing to the spectrum.

Nambu model
p-h excitations

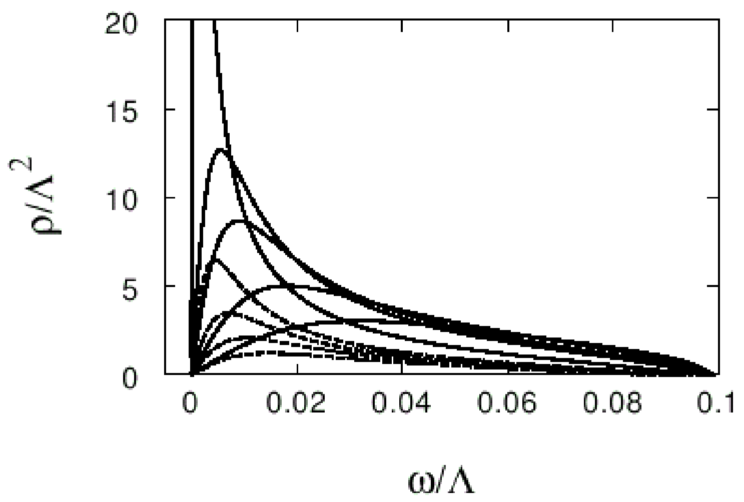
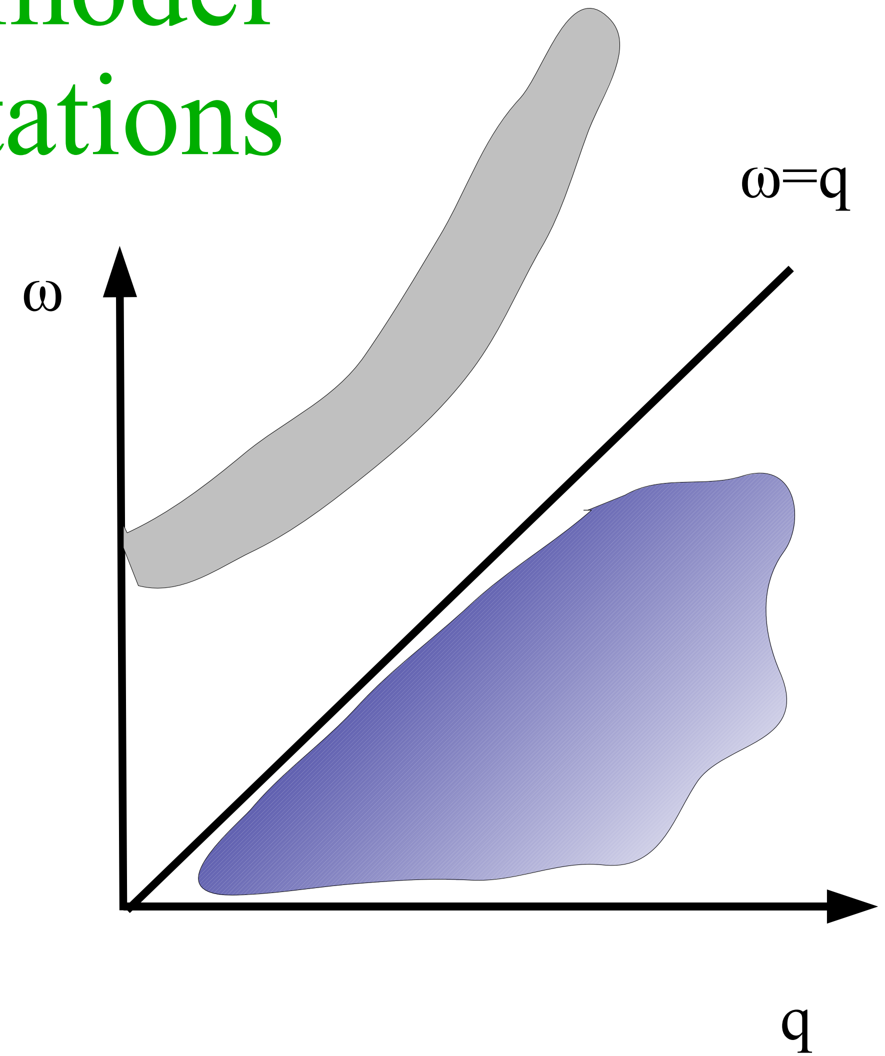


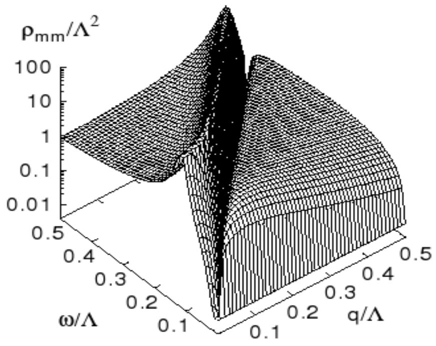
Fig. 3. Spectral function in the spacelike momentum region with $|\boldsymbol{q}|/\Lambda = 0.1$, $T = T_c$ and $m/\Lambda = 0.01$ for several μ (see text).



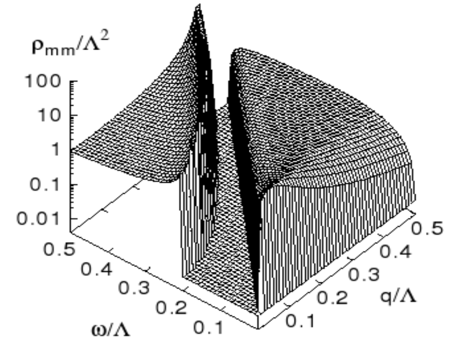
CP is and the chiral transition

Chiral transition $m_q=0$

$T>T_c$



(a)

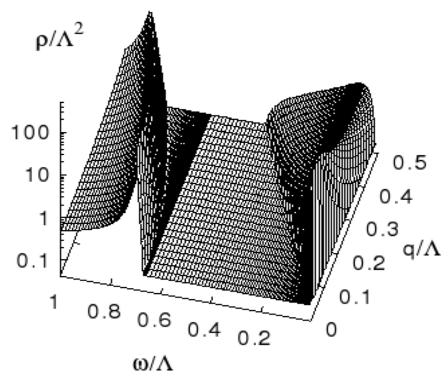


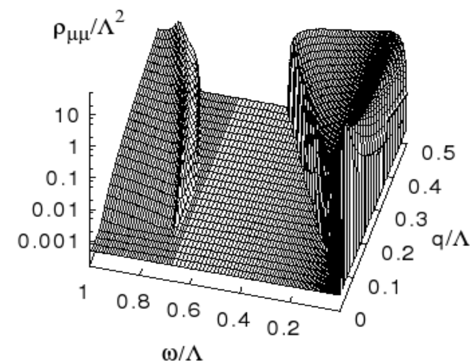
(b)

$T<T_c$

Critical point $m_q>0$

Massive Scalar

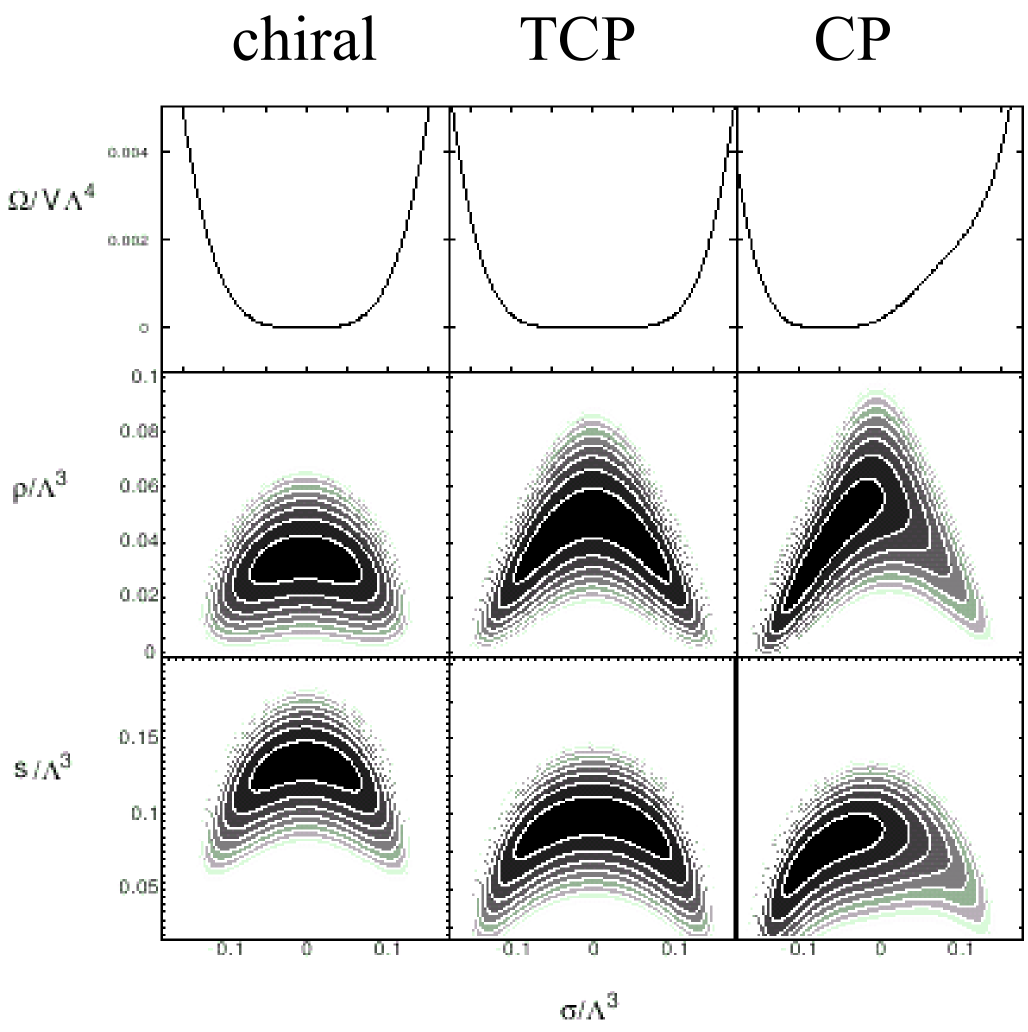




Scalar

Vector (Baryon-density)

Mixing of scalar and vector



Note: mixing of scalar vector (p-h) only for spacelike excitations close to q=0 (Friman, Soyeur et al)

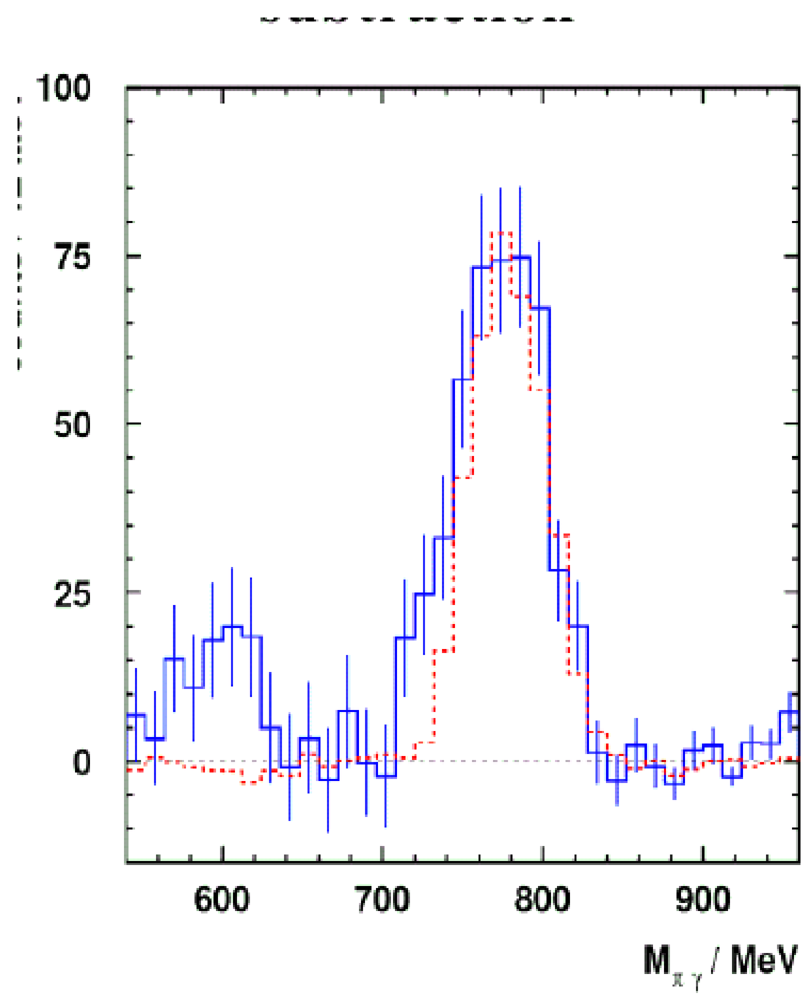
Summary CP

- Critical point true second order phase transition
- Universality class of liquid gas
- Dominated by space-like p-h excitations
  - No good news for Dileptons
  - Can it leak over into time-like? Nambu model suggests not
- Massive sigma!!!
  - No good news for "in medium effects" of the usual kind
- **CP is different from the chiral transition we are used to. Need to rethink the approach**

QCD first order transition

- Order parameter: baryon density or scalar density
- Both scalar (chiral) and quark number density are discontinuous
- Density fluctuations / blobs due to spinodal instability.
  Not obvious how this translates into a clean
  dilepton measurement
- If latent heat is sizable: Long lived mixed phase
  - two peak structure of omega a la C.M. Ko for phi.
  - assuming the TAPS results hold up in this case you want to measure **low p_t** omegas

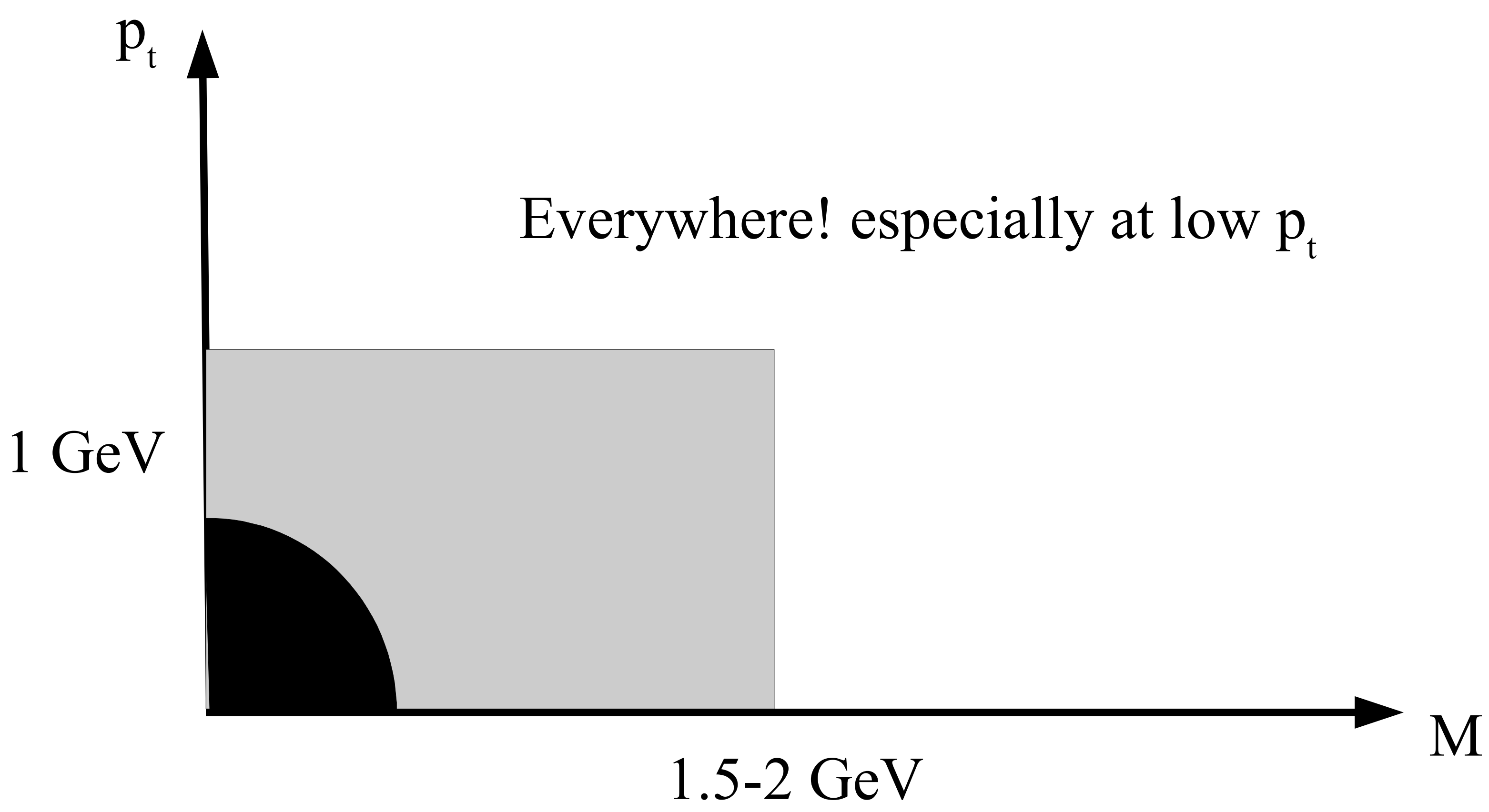
Double Omega peak?



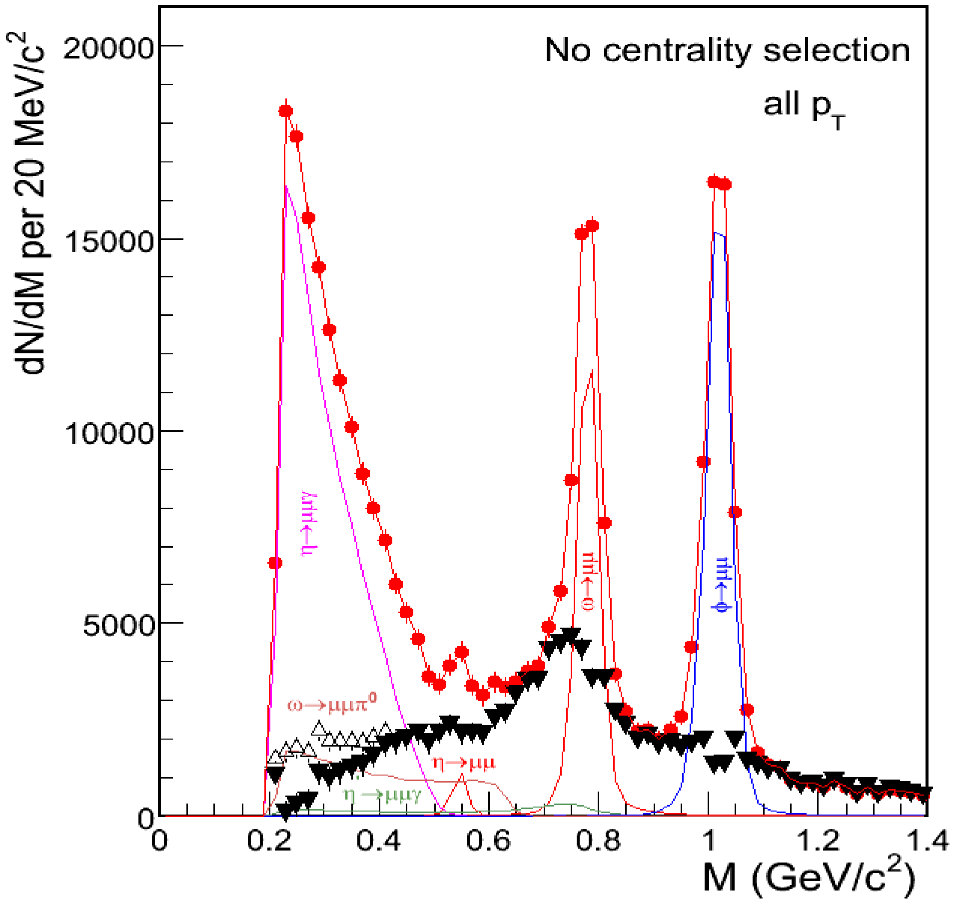
V. Metag, QM 06

TAPS, preliminary

Where should we measure?



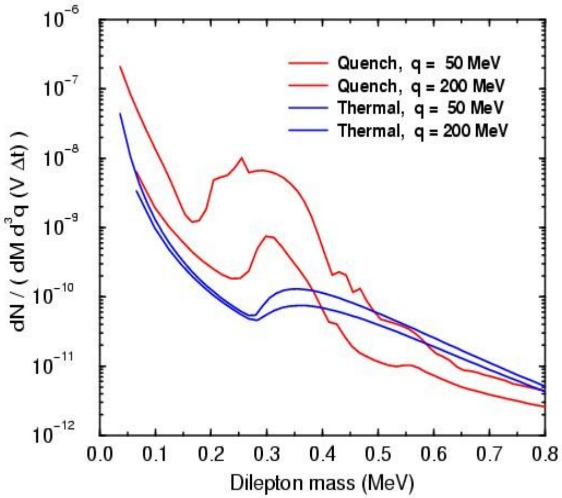
The “gold” standard

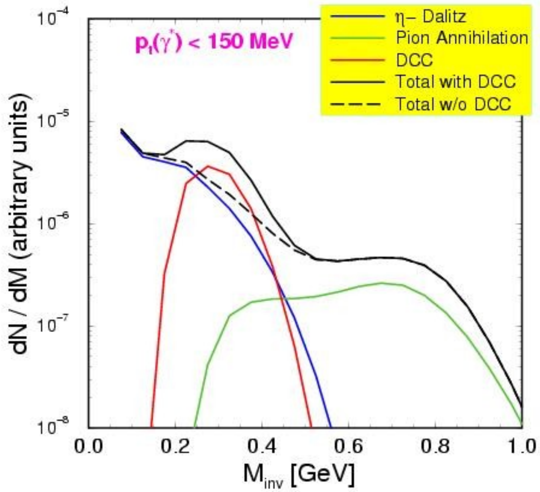


/home/vkoch/Documents/talks/GSI_02_07/koch.odp

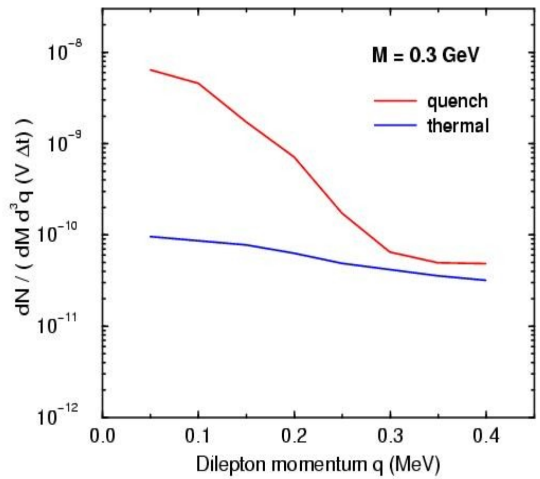
Example:DCC dileptons

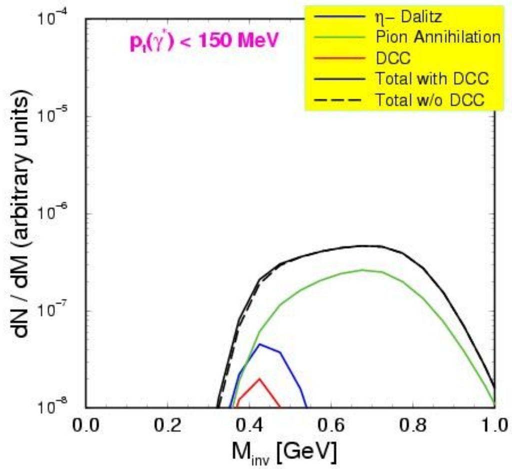
Factor 100 enhancement!





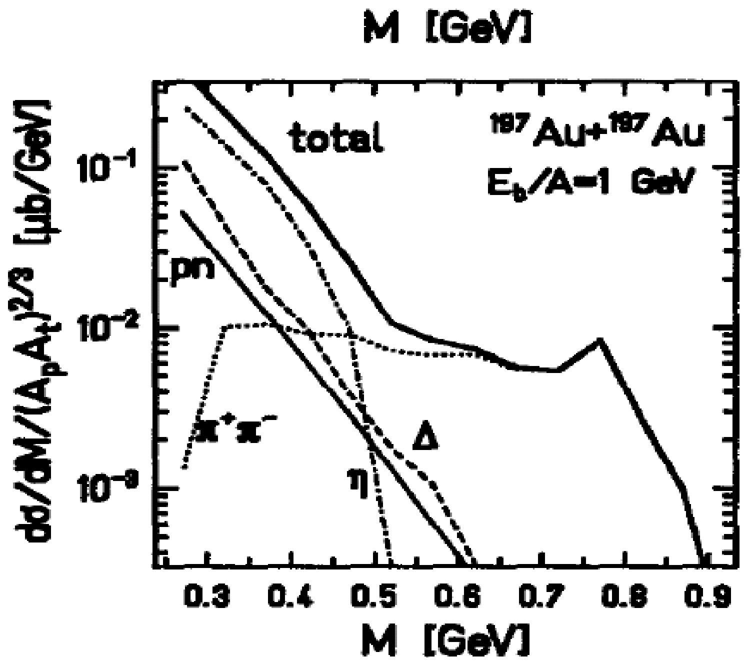
Softer cut p_t>60 MeV

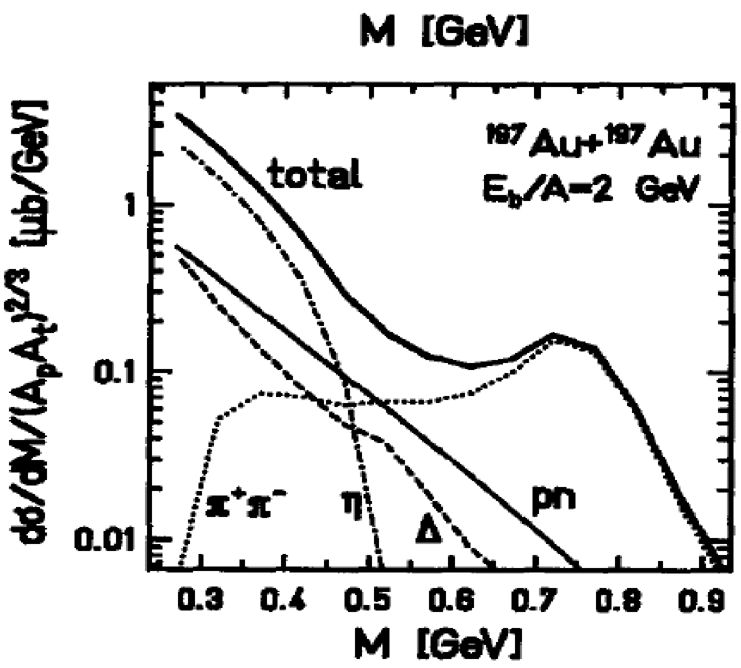




Original cuts p_t>200 MeV

Dileptons at lower energy





G. Wolf et al, Prog. Part. Nucl. Phys. VoL 30, 273-295,1993.

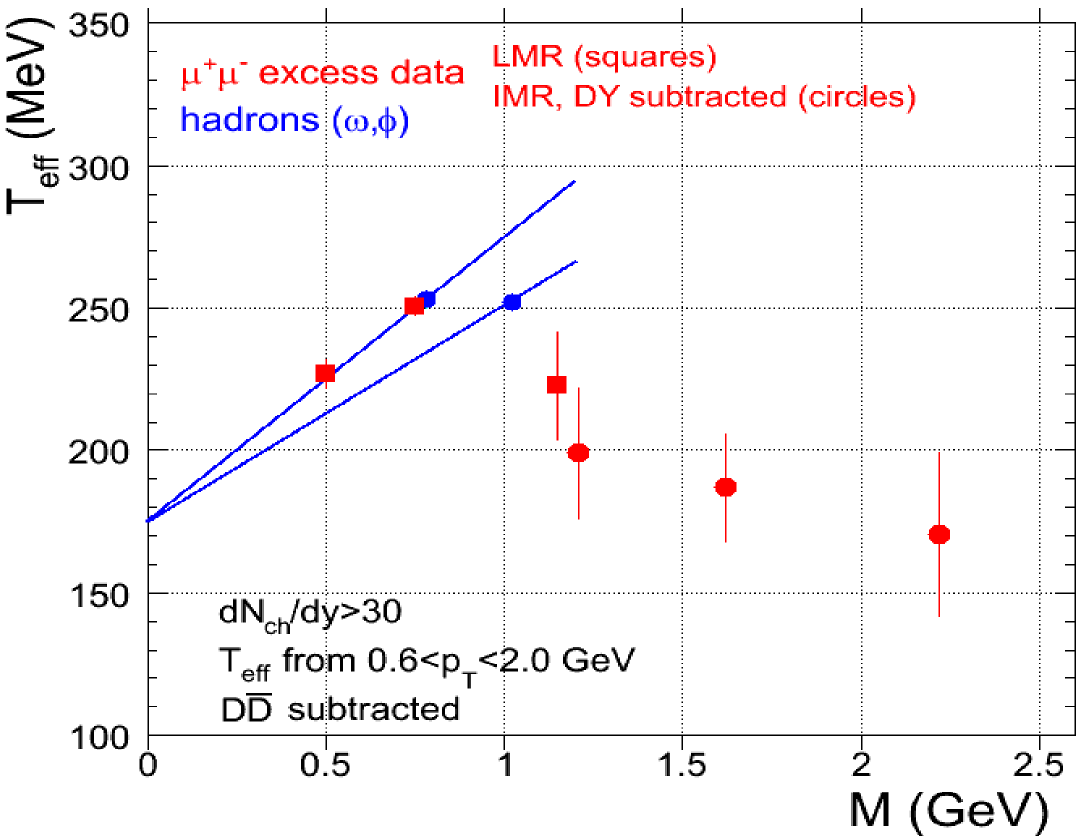
Peters questions

Caution:
Theorist at work!

Peters questions

- What did we learn from dilepton experiments so far?
  - collisional broadening (NA60)
  - some intriguing things above M>1GeV, possibly partonic ?
  - Hades similar below the rho; obviously density effects
  - no visible effects on omega; decay outside
- Which information is contained in the width and position of the spectral function of low-mass vector mesons measured in heavy-ion collisions?
  - Many things; collision rate, mixing of modes, possibly mean field
  - Rather model dependent.

NA60

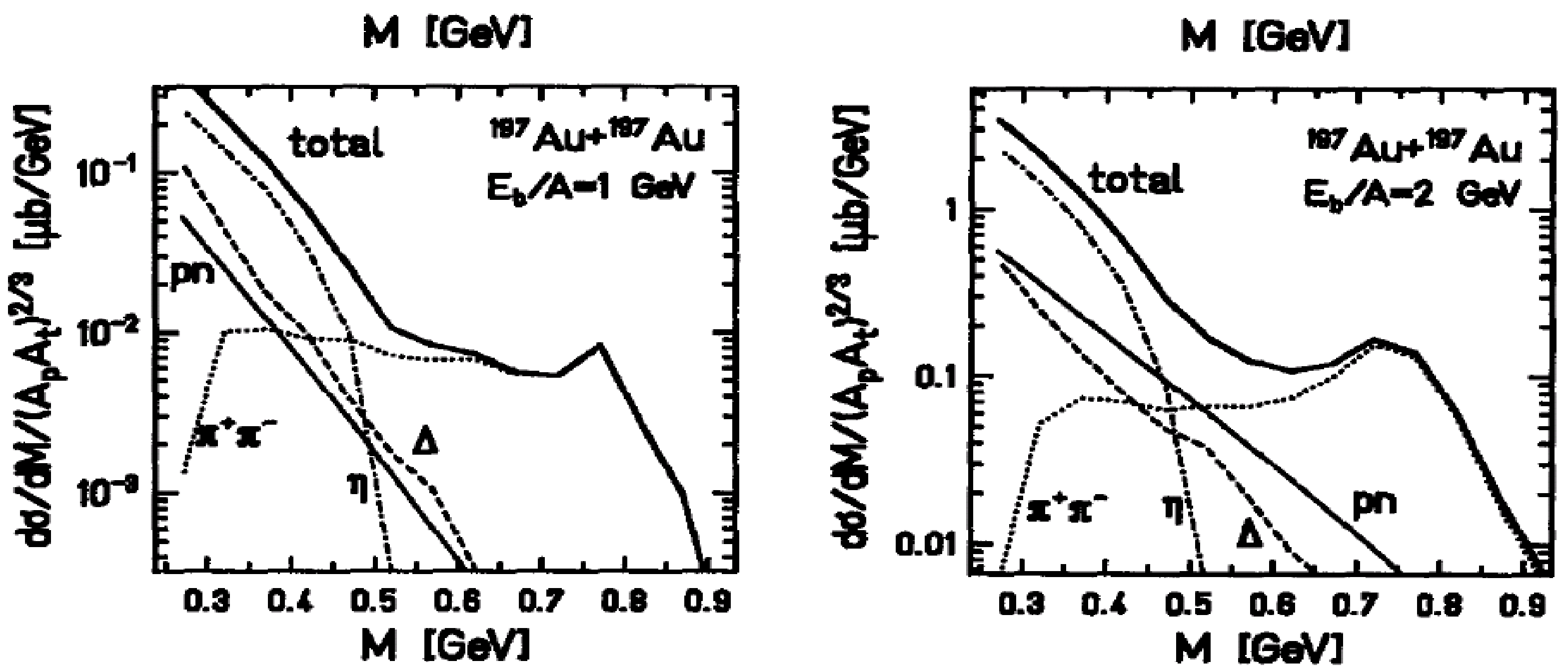


T_{eff} (MeV)
350
300
250
200
150
100
$\mu^+\mu^-$ excess data
hadrons (ω,ϕ)
LMR (squares)
IMR, DY subtracted (circles)
$dN_{ch}/dy>30$
T_{eff} from $0.6<p_T<2.0$ GeV
$D\bar{D}$ subtracted
0
0.5
1
1.5
2
2.5
M (GeV)

Peters questions II

- Which experimental observation would be a signature for the onset of chiral symmetry restoration?
  - Good question! Best bet at the moment: vector vs axial
    - requires gamma-pi measurement in addition to dileptons
- In which range of beam energies, invariant masses, rapidity and transverse momentum does one expect relevant signals?
  - another good one! Hades/DLS shows that "broadening" happens already at ~1 GeV
  - If chiral/critical point: low transverse momentum
  - Small mass would be great but not at the price of otherwise low resolution

Dileptons at lower energy



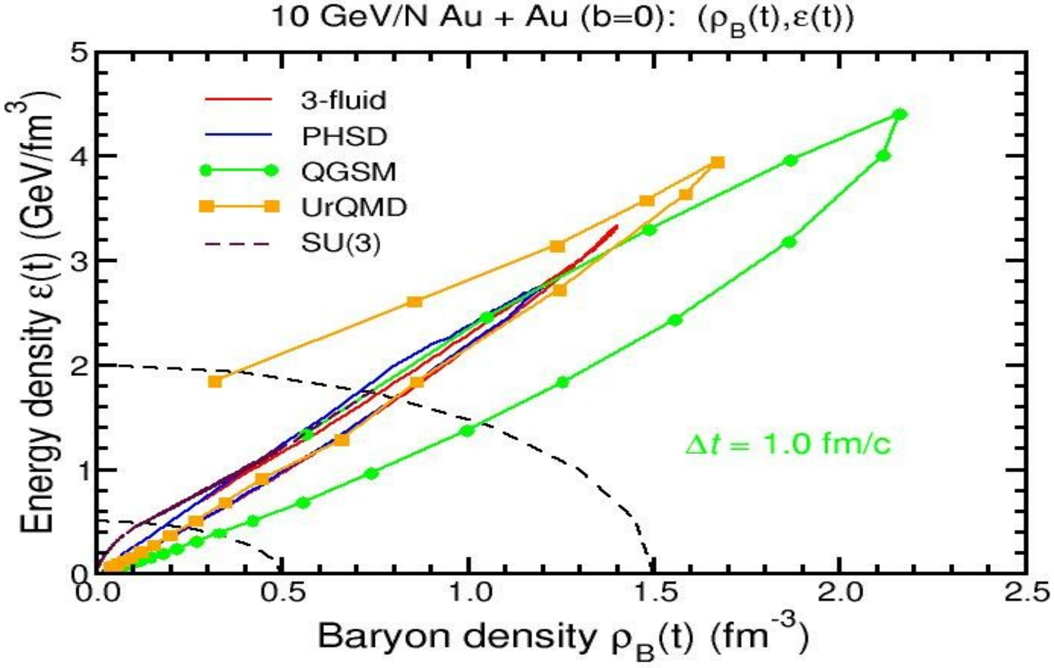
G. Wolf et al, Prog. Part. Nucl. Phys. VoL 30, 273-295,1993.

Peters questions III

- Which physics cases can be addressed in di-electron experiments at beam energies up to 10 AGeV (using the HADES detector)?
  - Potentially the same as with CBM. We don't know yet where the critical point is. Definitely worth a look!
- Which dilepton observables are sensitive to the deconfinement phase transition?
  - The NA60 p_t spectra look interesting. Can we see a change with energy?

Phase trajectories

(more in talk by J. Randrup)



10 AGeV!!!!!

Is there a chance to start experiments already with SIS 100?

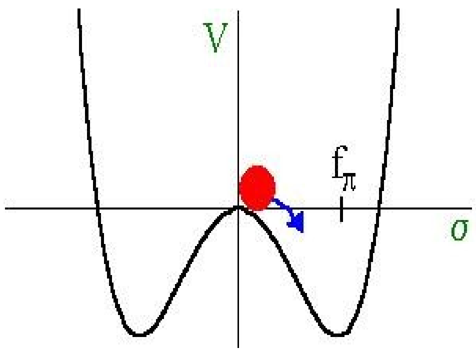
Peters questions III

- What is the discovery potential of charmonium measurements (excitation function of J/ψ and ψ' production, collective flow of J/ψ mesons, density dependence of charmonium production and propagation, ...) ?
  - None as far as I am concerned. That's why you should measure it!

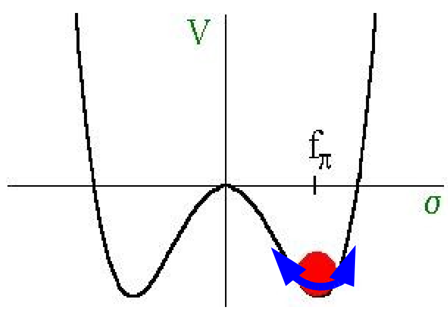
Summary

- CP need some serious rethinking as far as phenomenology is concerned.
- Signature in Dilepton channel not obvious (at present...)
- Low momentum pairs will be essentiall
- Low mass would be good but difficult
- High mass resolution (>= NA60). Omega line shape

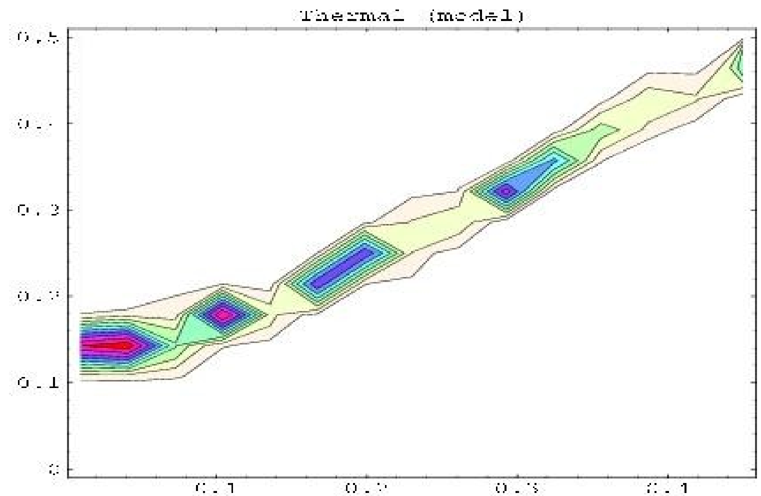
“DCC” dispersion relation



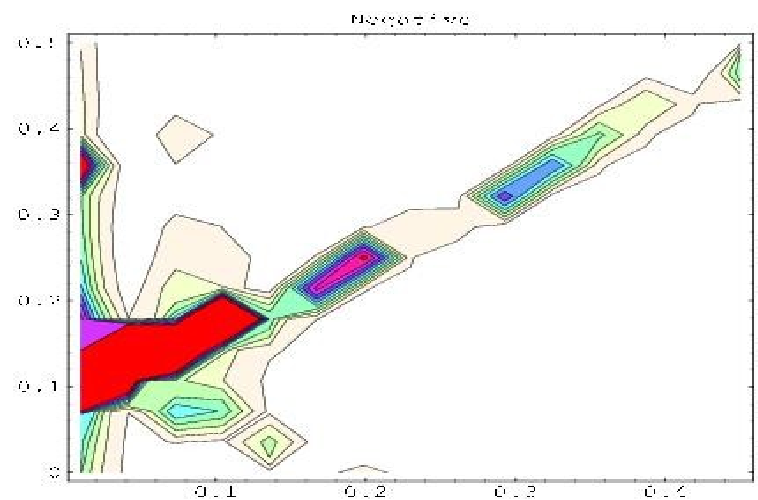
“Quench”



“Parametric resonance”



Thermal



DCC