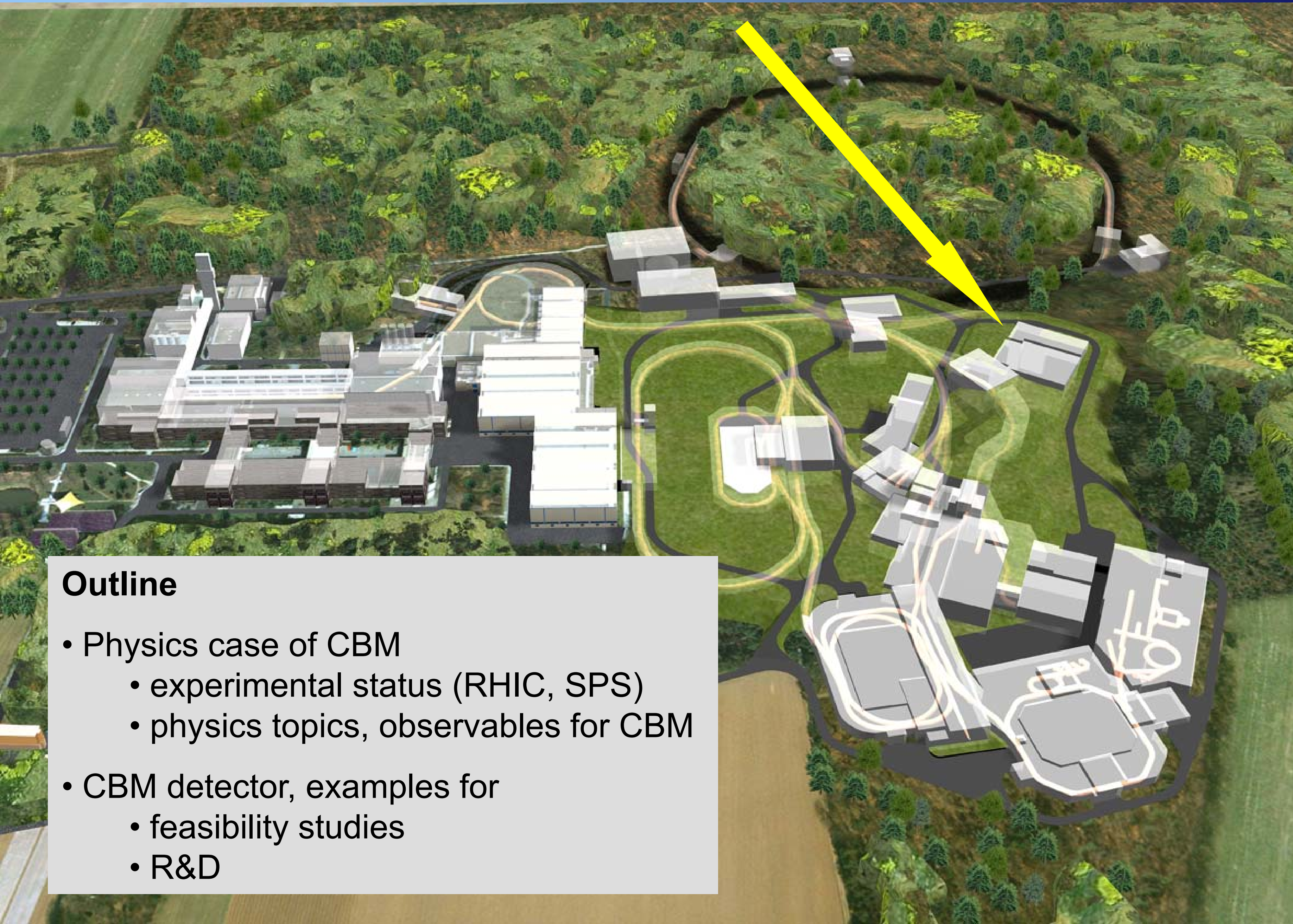
The CBM experiment at FAIR

Claudia Höhne, GSI Darmstadt

CBM @ FAIR



Outline

- Physics case of CBM
  - experimental status (RHIC, SPS)
  - physics topics, observables for CBM
- CBM detector, examples for
  - feasibility studies
  - R&D

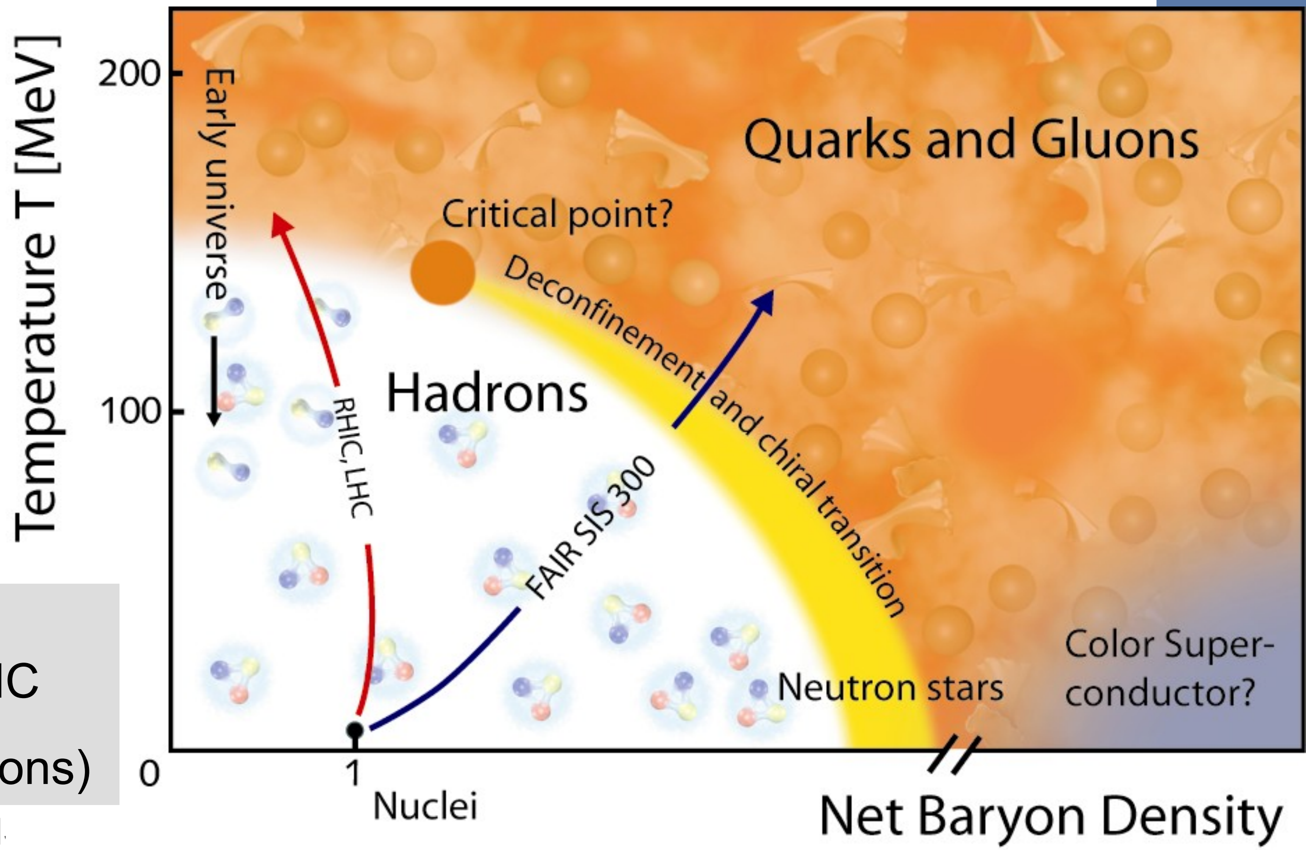
Physics case – keywords

Compressed Baryonic Matter @ FAIR – high μ_B, moderate T:

searching for the landmarks of the QCD phase diagram

- first order deconfinement phase transition
- chiral phase transition (high baryon densities!)
- QCD critical endpoint

in A+A collisions from 2-45 AGeV starting in 2015 (CBM + HADES)

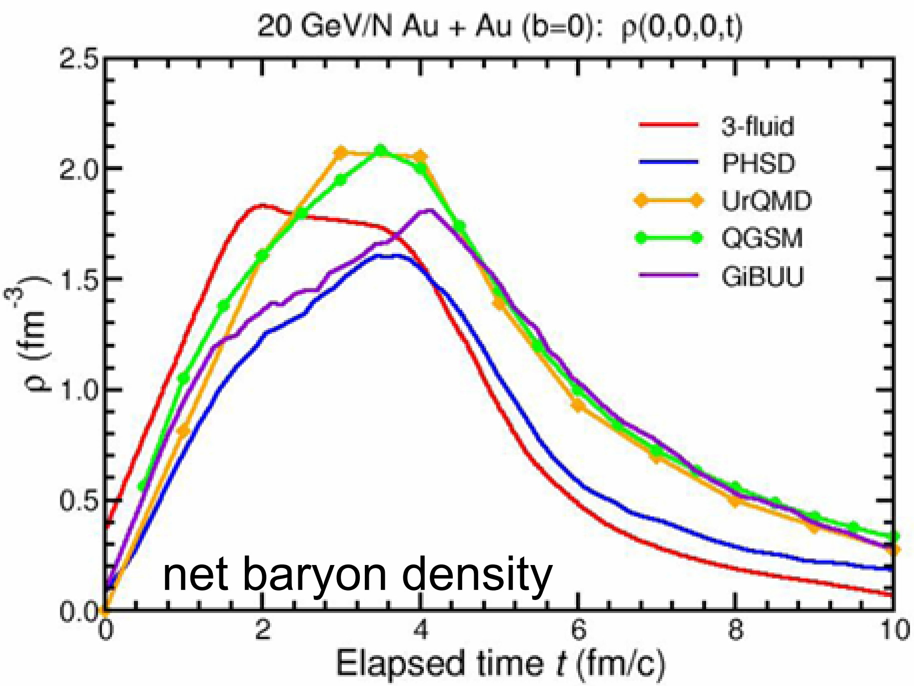


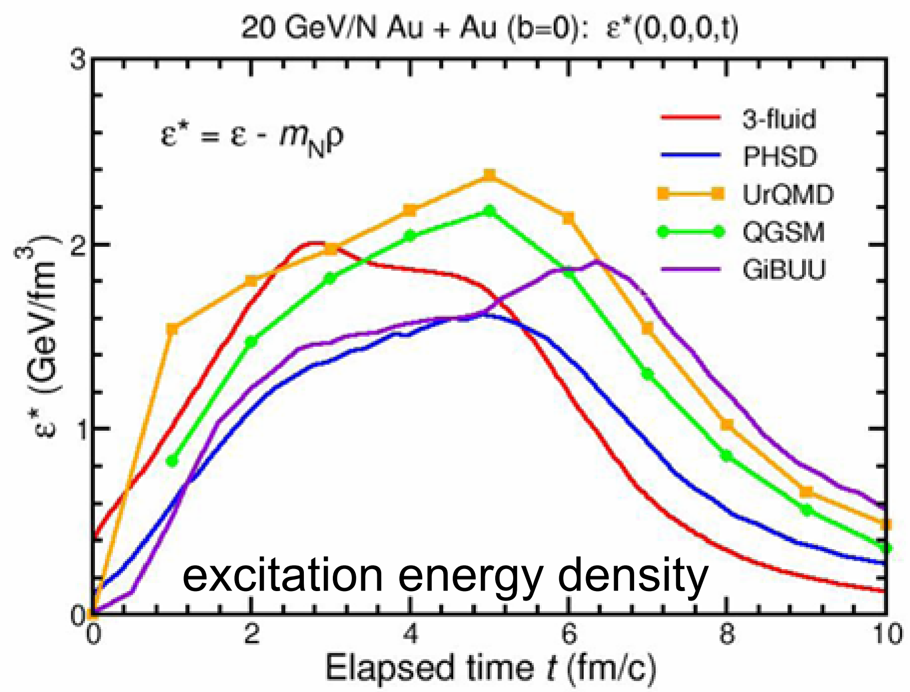
- physics program complementary to RHIC, LHC
- rare probes! (charm, dileptons)

High density matter at CBM

- high baryon and energy densities created in central Au+Au collisions
- remarkable agreement between different models
- max. net baryon densities from 5 - 40 AGeV ~ 1 - 2 fm^{-3} ~ (6 – 12) ρ_0
  (net baryon density ρ = 1 fm^{-3} ~6ρ_0)
- max. excitation energy densities from 5 - 40 AGeV ~ (0.8 – 6) GeV/fm^3
  ($\varepsilon^* = \varepsilon - m_N\rho$, ε total energy density)

[CBM physics group]



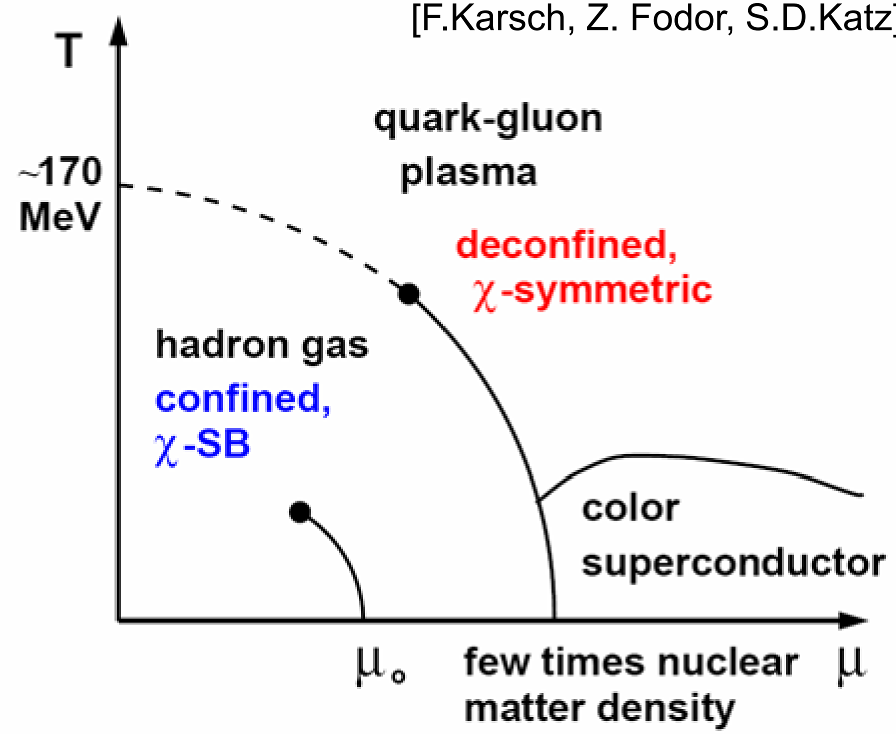


Physics case (II)

What does theory expect? → mainly predictions from lattice QCD:

- crossover transition from partonic to hadronic matter at small μ_B and high T
- critical endpoint in intermediate range of the phase diagram
- first order deconfinement phase transition at high μ_B but moderate T

[F.Karsch, Z. Fodor, S.D.Katz]



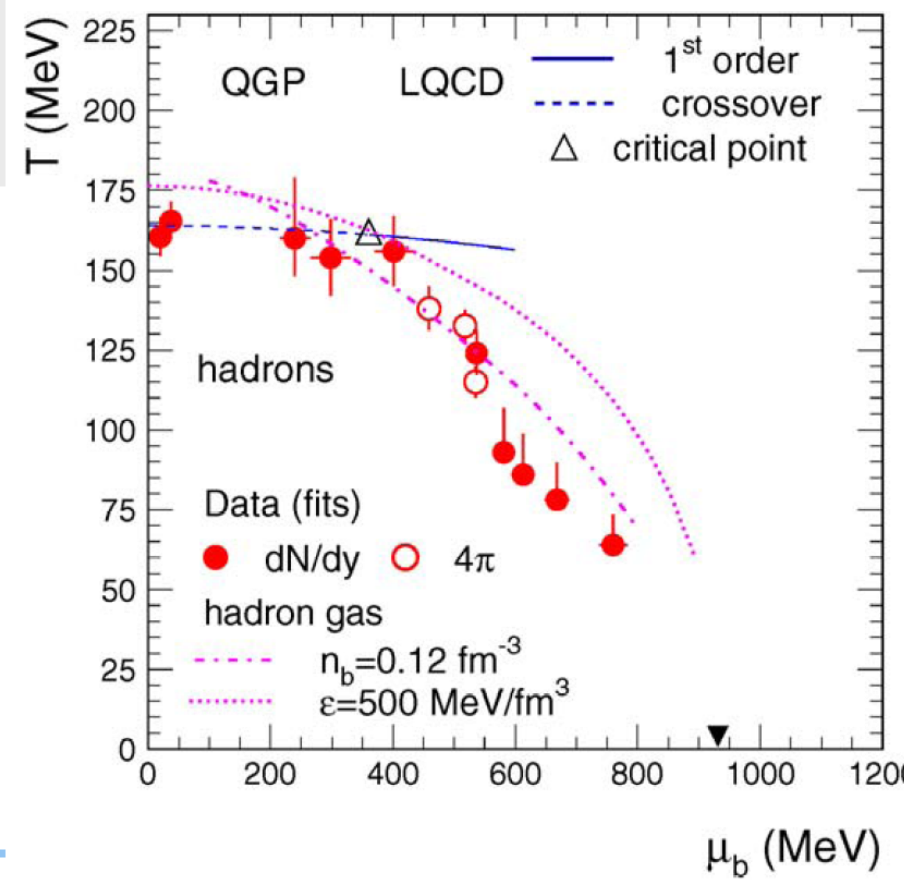
However ...

- deconfinement = chiral phase transition ?
- hadrons and quarks at high μ?
- signatures (measurable!) for these structures/ phases?
- how to characterize the medium?

Physics case (III)

What do we know from experiment? → Heavy-ion collisions:

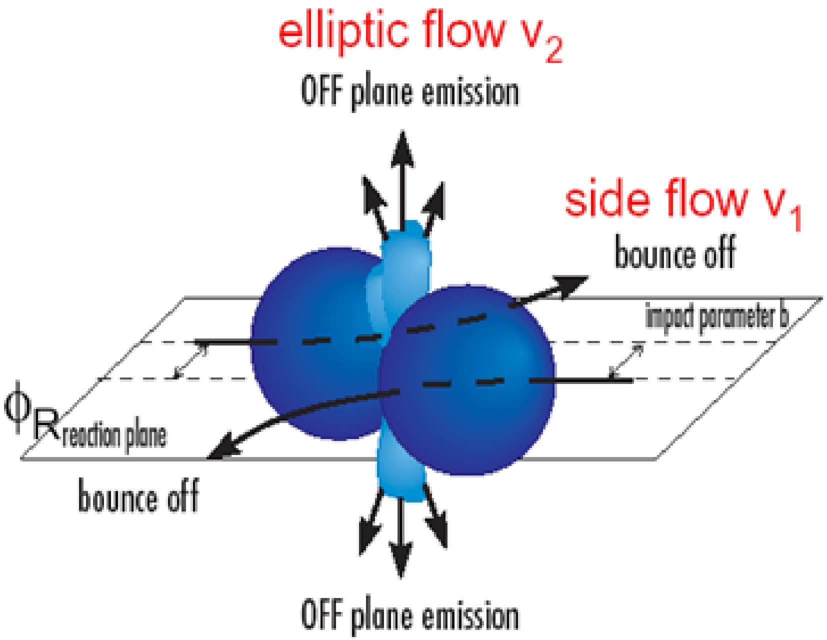
- chemical freeze-out curve
- top SPS, RHIC (high T, low μ_B): partonic degrees of freedom ?
- RHIC: first steps towards a quantitative characterization of the medium (gluon density, viscosity, energy loss...)
- lower SPS, AGS (intermediate T-μ_B): intriguing observations around 30 AGeV!



[Andronic et al. Nucl. Phys. A 772, 167 (2006).

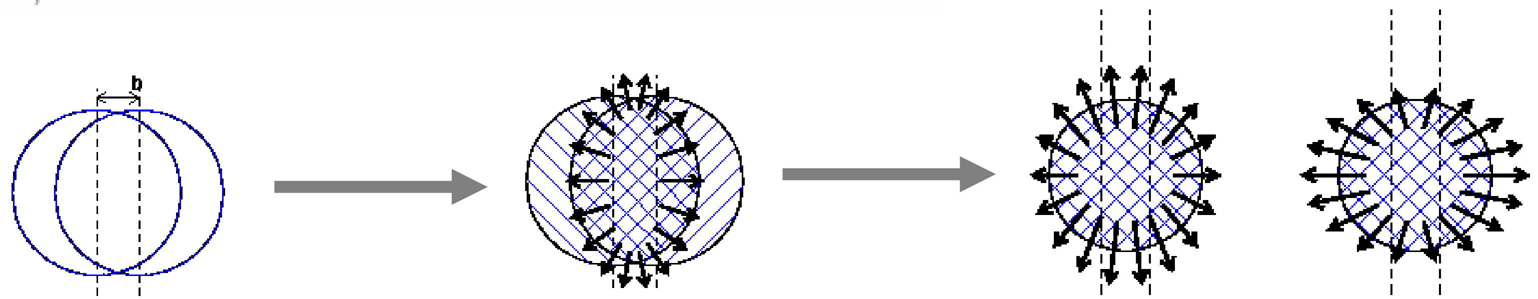
Introduction: elliptic flow v2

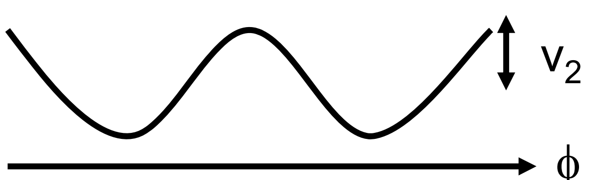
- particle emission pattern in plane transverse to the reaction plane
- initial overlap eccentricity is transformed in momentum anisotropy
- driven by pressure from overlap region
- relation to stiffness of medium (EOS)



Fourier expansion of the dN/dϕ distribution:

$$\frac{dN}{d\phi} \sim [1 + 2v_1 \cdot \cos(\phi) + 2v_2 \cdot \cos(2\phi)]$$



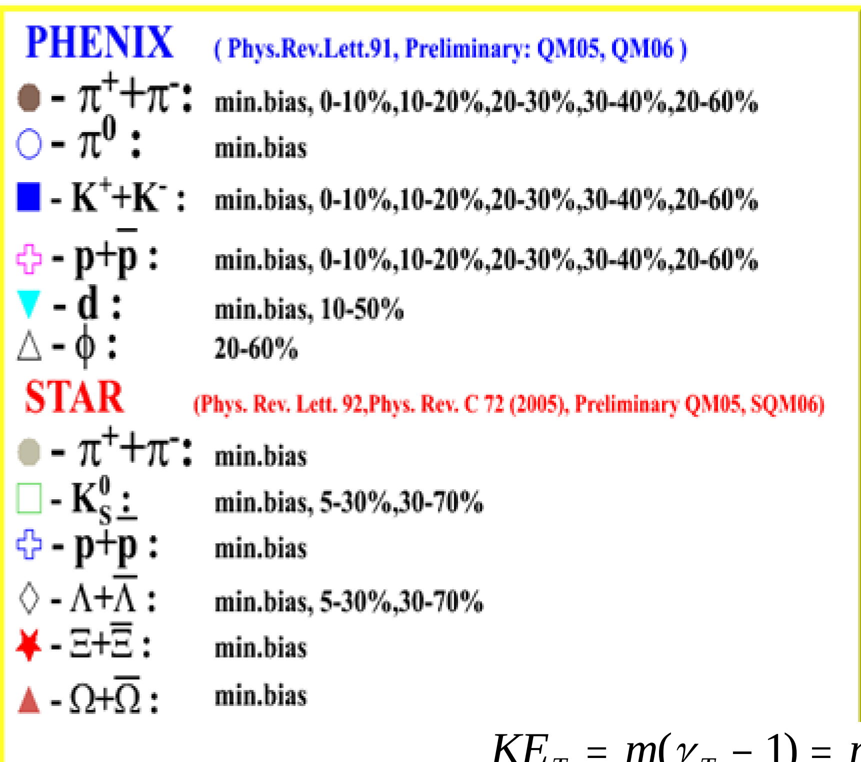


RHIC results (selection)

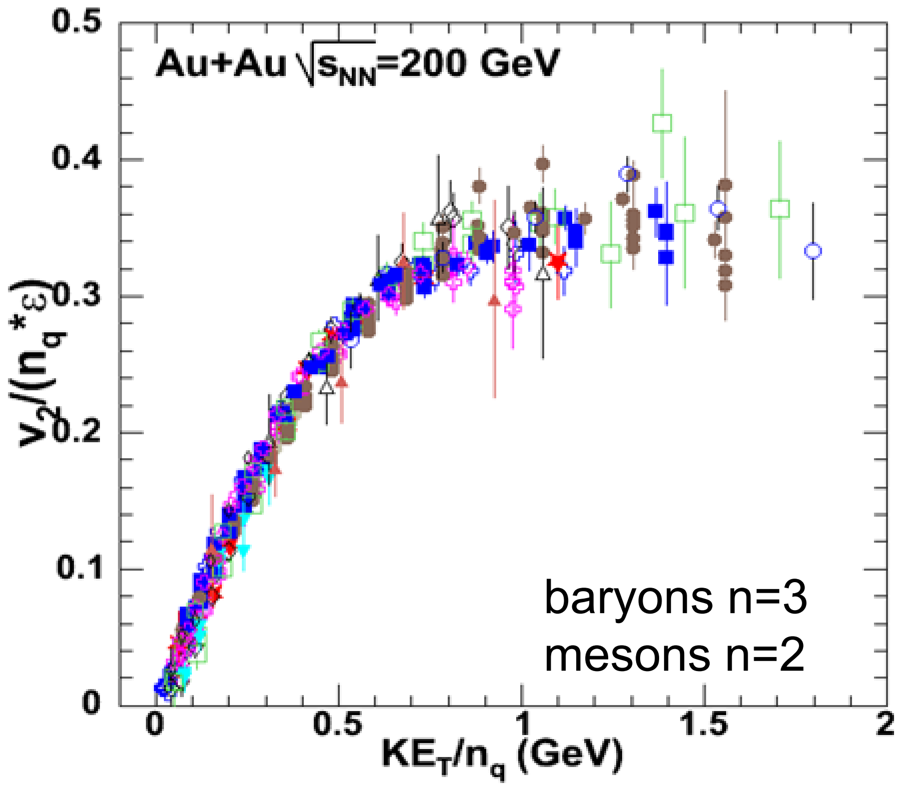
- all particles (even D-mesons!) flow
- scaling if taking the underlying number of quarks into account!
- flow also seen for charm quarks!

→ like (all!) quarks flow and combine to hadrons at a later stage (hadronisation)

- data can only be explained assuming a large, early built up pressure in a nearly ideal liquid (low viscosity!)



$$KE_T = m(\gamma_T - 1) = m_T - m$$

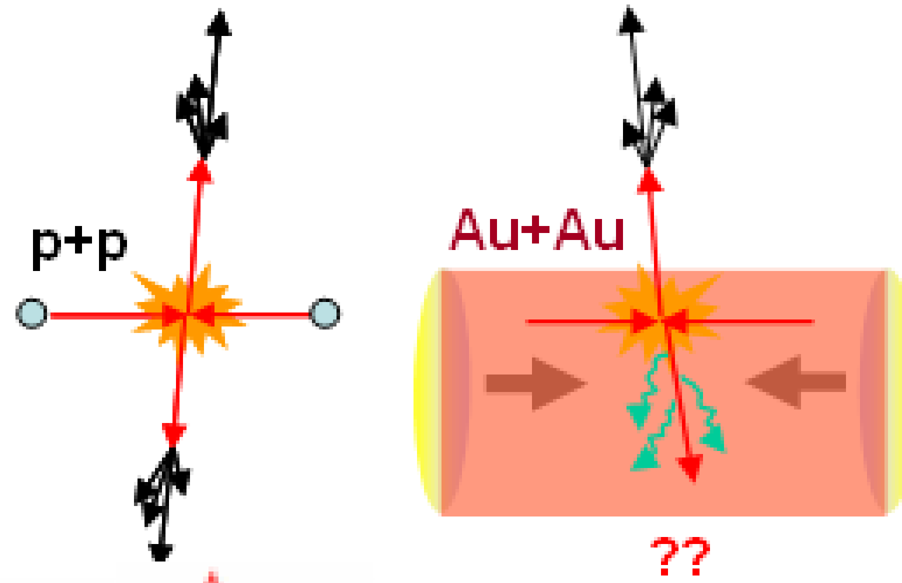


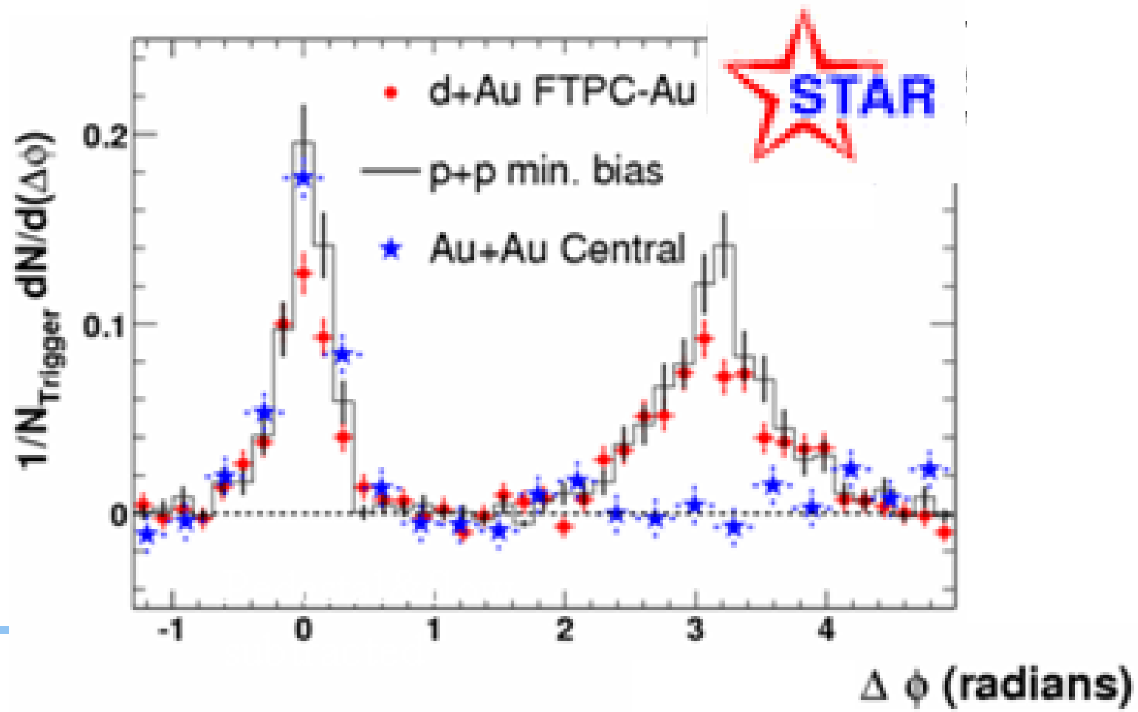
RHIC results (selection) (II)

- partons should loose energy in a dense and hot medium

→ jet suppression!

→ results imply huge gluon densities corresponding to an initial temperature of ~$2T_{crit}$ and ε ~ 14-20 GeV/fm^{-3} in the fireball!





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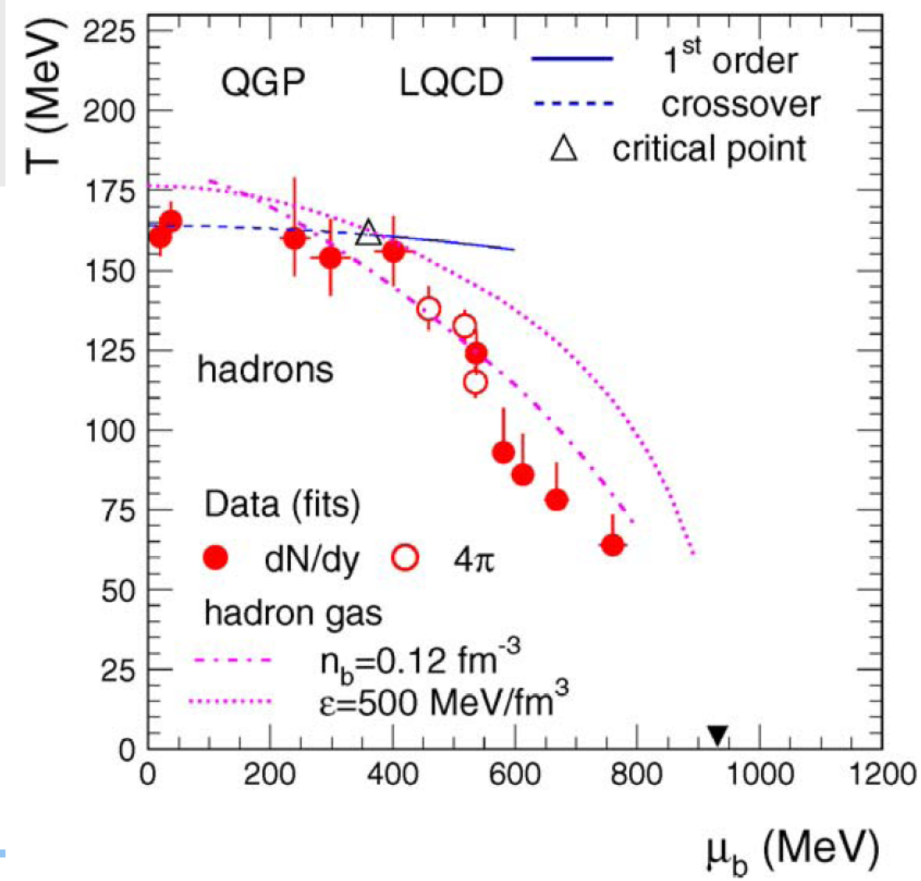
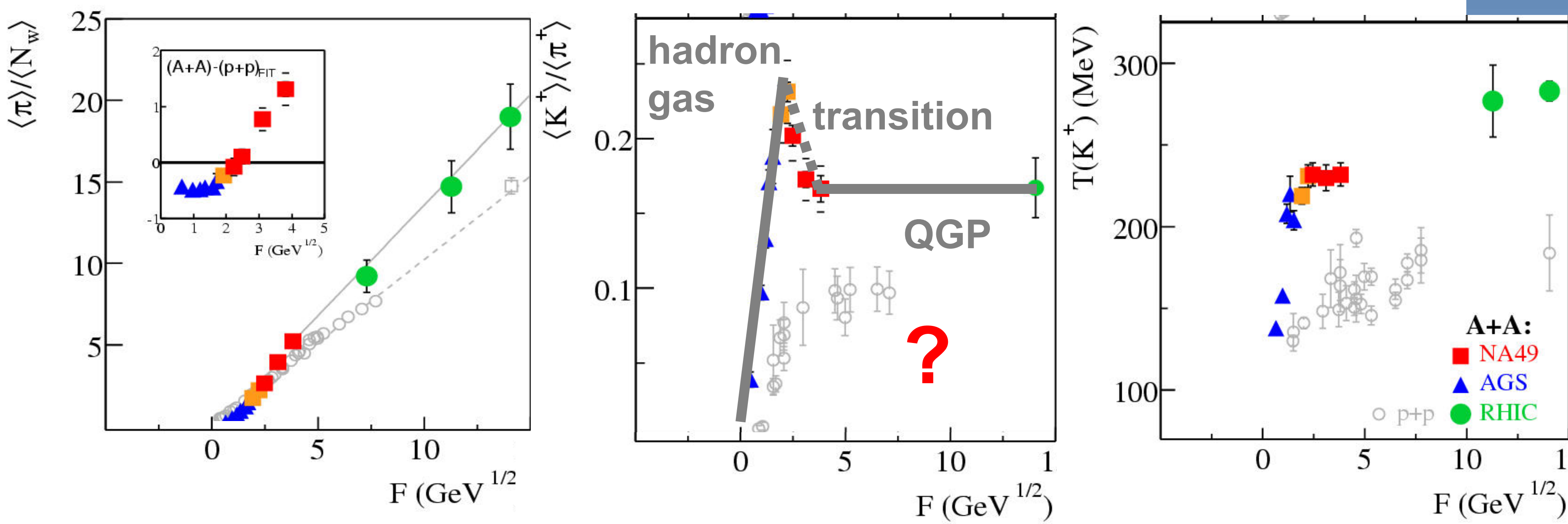


[Andronic et al. Nucl. Phys. A 772, 167 (2006).

SPS results (selection)

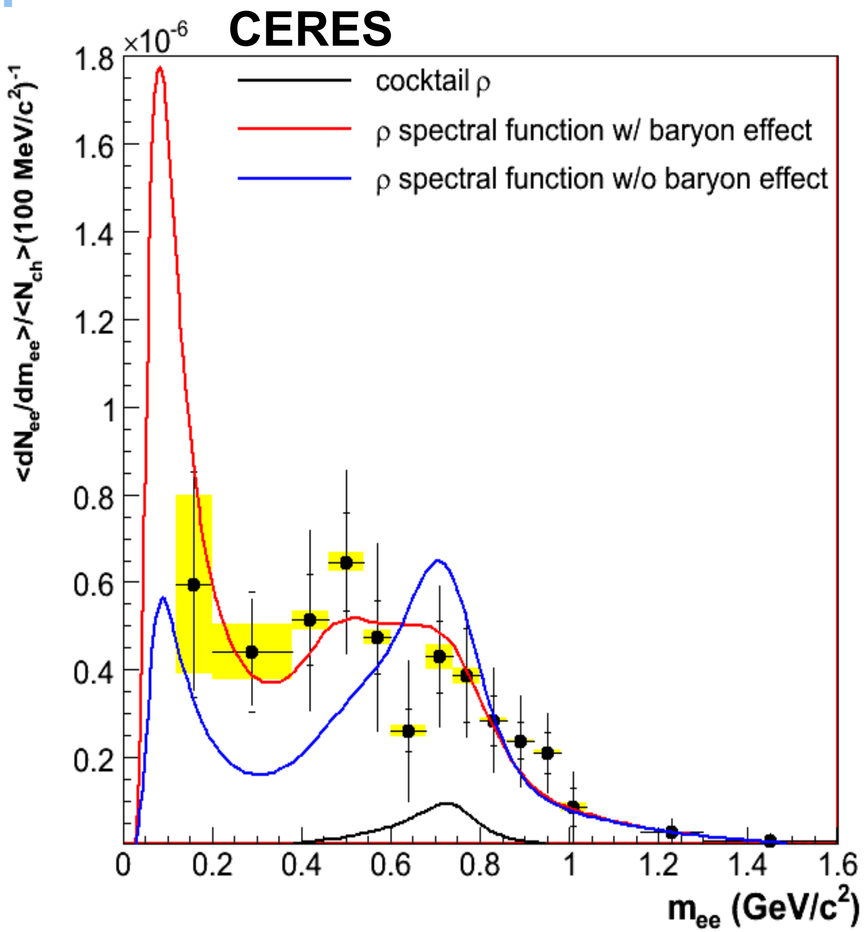
- energy dedendence of hadron production
  → changes in SPS energy regime
- discussions ongoing:
  - hadron gas → partonic phase
  - baryon dominated → meson dominated matter

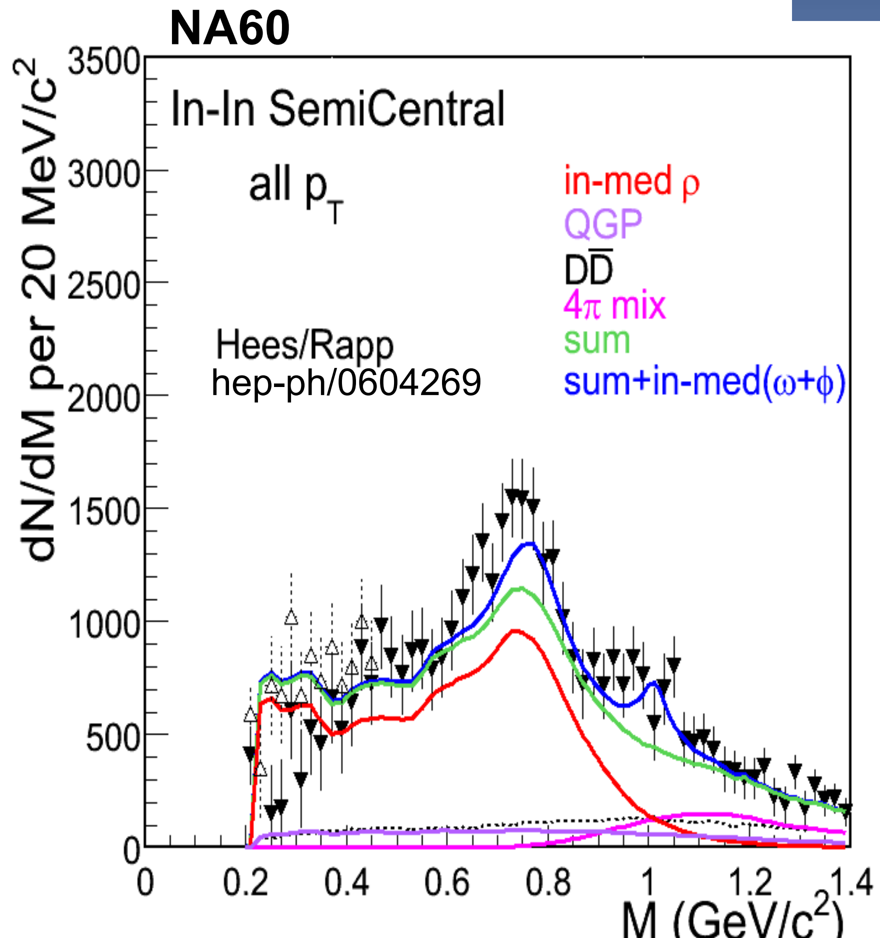


$$F = \frac{\left(\sqrt{s_{NN}} - 2m_N\right)^{3/4}}{\sqrt{s_{NN}}^{1/4}} \approx \sqrt{\sqrt{s_{NN}}}$$

SPS results (selection) (II)

- modification of ρ spectral function, importance of baryons!
- in addition: HADES (1-2 GeV/nucleon) – importance of resonances!





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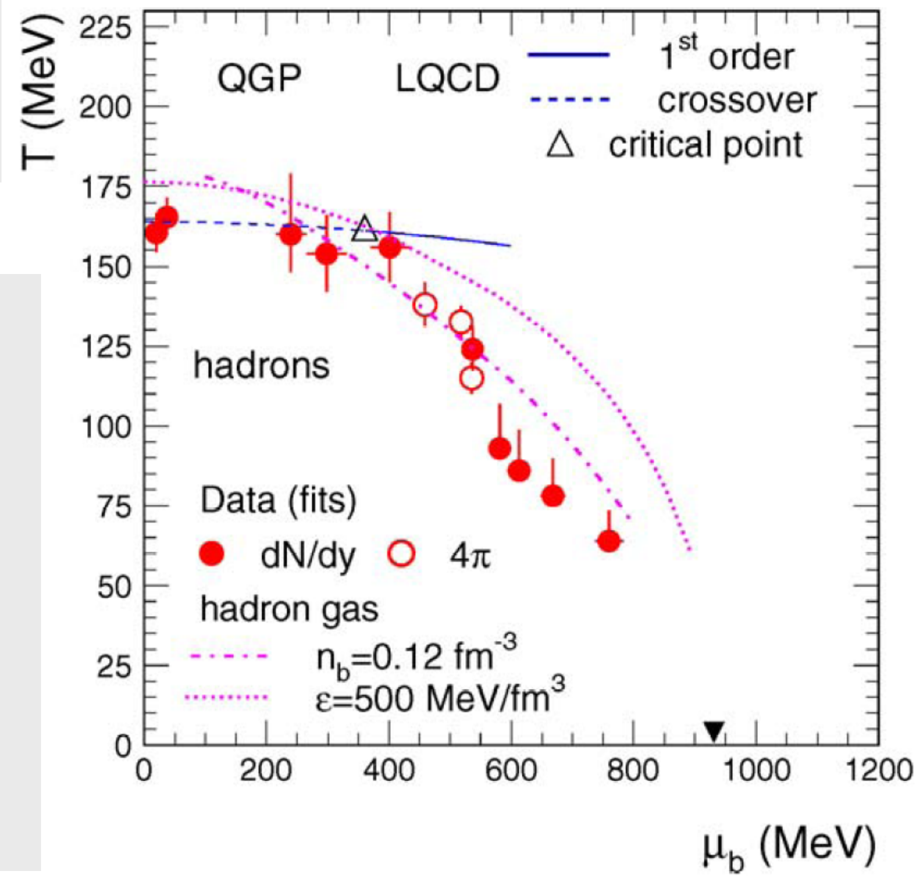
missing (2-40 AGeV, high ρ_B!):

- high precision measurements, systematic investigations, correlations

→ energy dependence of RHIC, SPS results!!

- rare probes: charm, dileptons
  → in particularly sensitive to medium!
- charaterize medium quantitatively!



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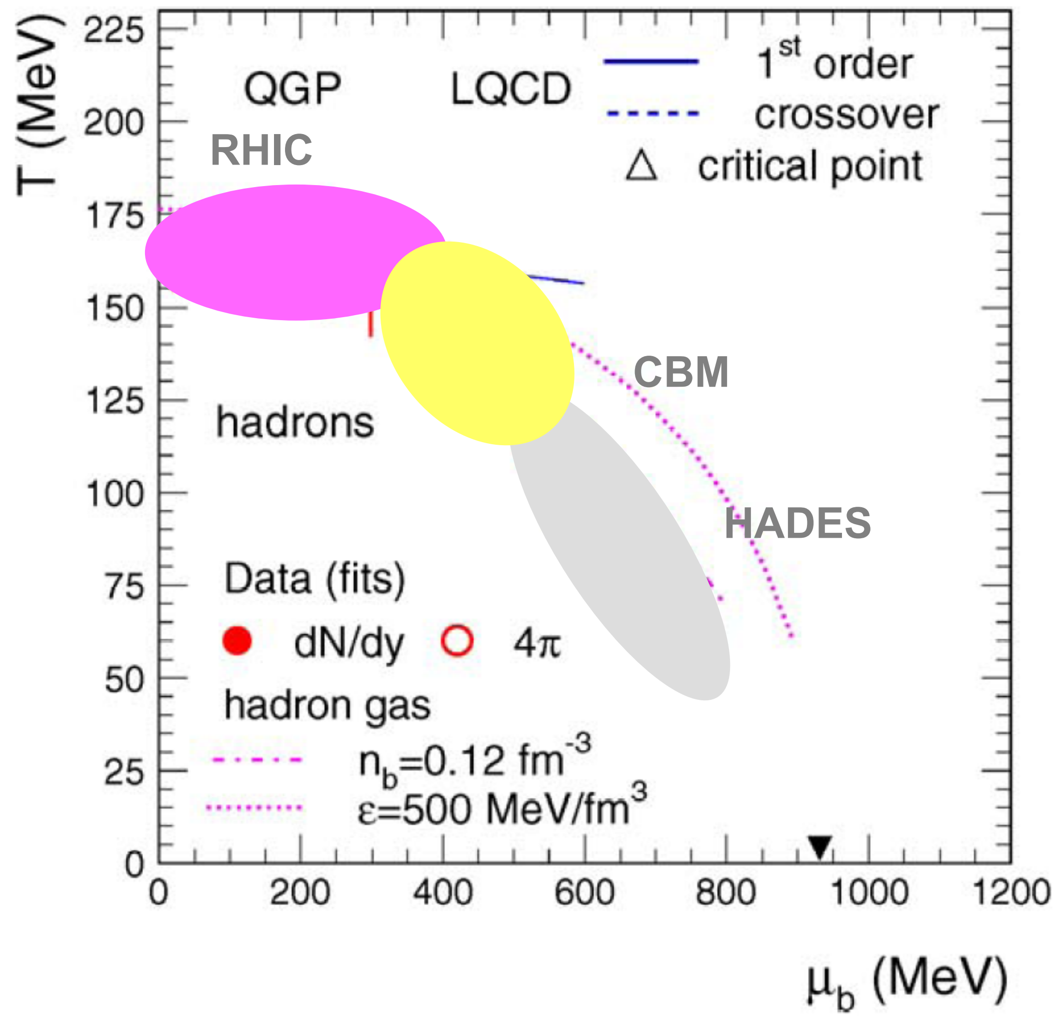
Experimental scan of QCD phase diagram

Within the next years we'll get a **complete scan of the QCD phase diagram** with 2nd generation experiments

- low energy RHIC: bulk observables $\sqrt{s}$ ~ 10 GeV – 200 GeV
- CBM: bulk observables **and** rare probes (charm, dileptons) beam energy 10 – 45 GeV/nucleon
- HADES: bulk observables, dileptons beam energy 2 – 10 GeV/nucleon



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CBM: Physics topics and Observables

The equation-of-state at high ρ_B

- collective flow of hadrons
- particle production at threshold energies (open charm)

Deconfinement phase transition at high ρ_B

- excitation function and flow of strangeness (K, Λ, Σ, Ξ, Ω)
- excitation function and flow of charm (J/ψ, ψ', D^0, $D^{\pm}$, Λ_c)
- charmonium suppression, sequential for J/ψ and ψ' ?

QCD critical endpoint

- excitation function of event-by-event fluctuations (K/π,...)

Onset of chiral symmetry restoration at high ρ_B

- in-medium modifications of hadrons ($\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$, D)

predictions? clear signatures?
→ prepare to measure "everything"
→ systematic studies! (pp, pA, AA, energy)
aim: probe & characterize the medium! - importance of rare probes!!

The CBM Physics Book

Broad Interest by Theory

More than 50 theoreticians participating

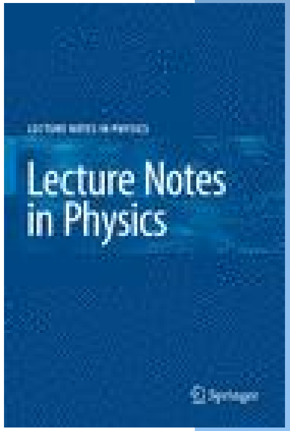
Comprehensive survey of CBM physics

<u>Content</u>

Bulk Properties of Strongly Interacting Matter
In-Medium Excitations
Collision Dynamics
Observables and Predictions
The CBM Experiment

Will appear in

submission September 2008



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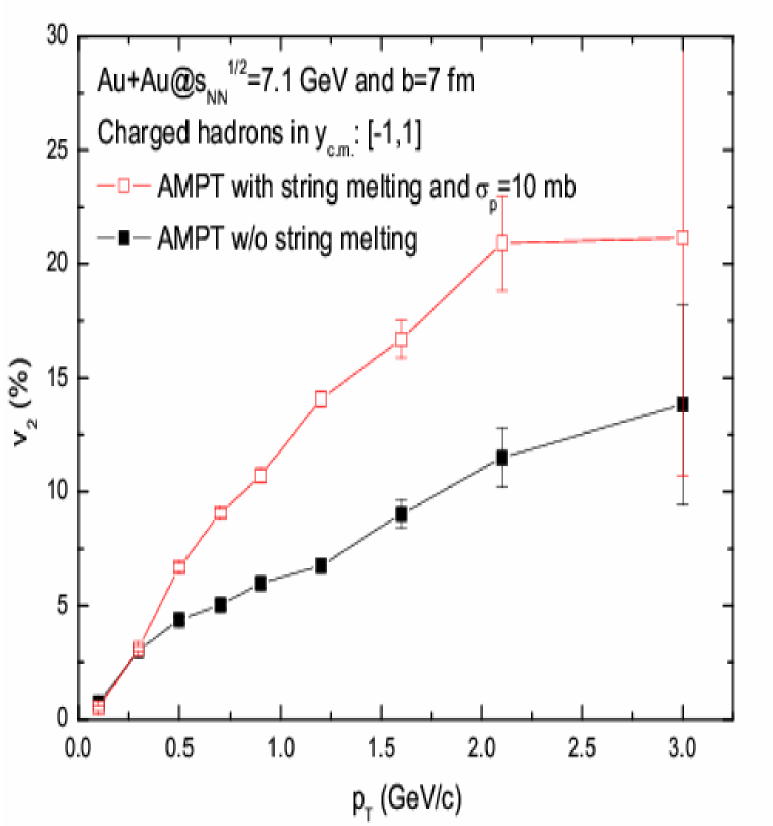
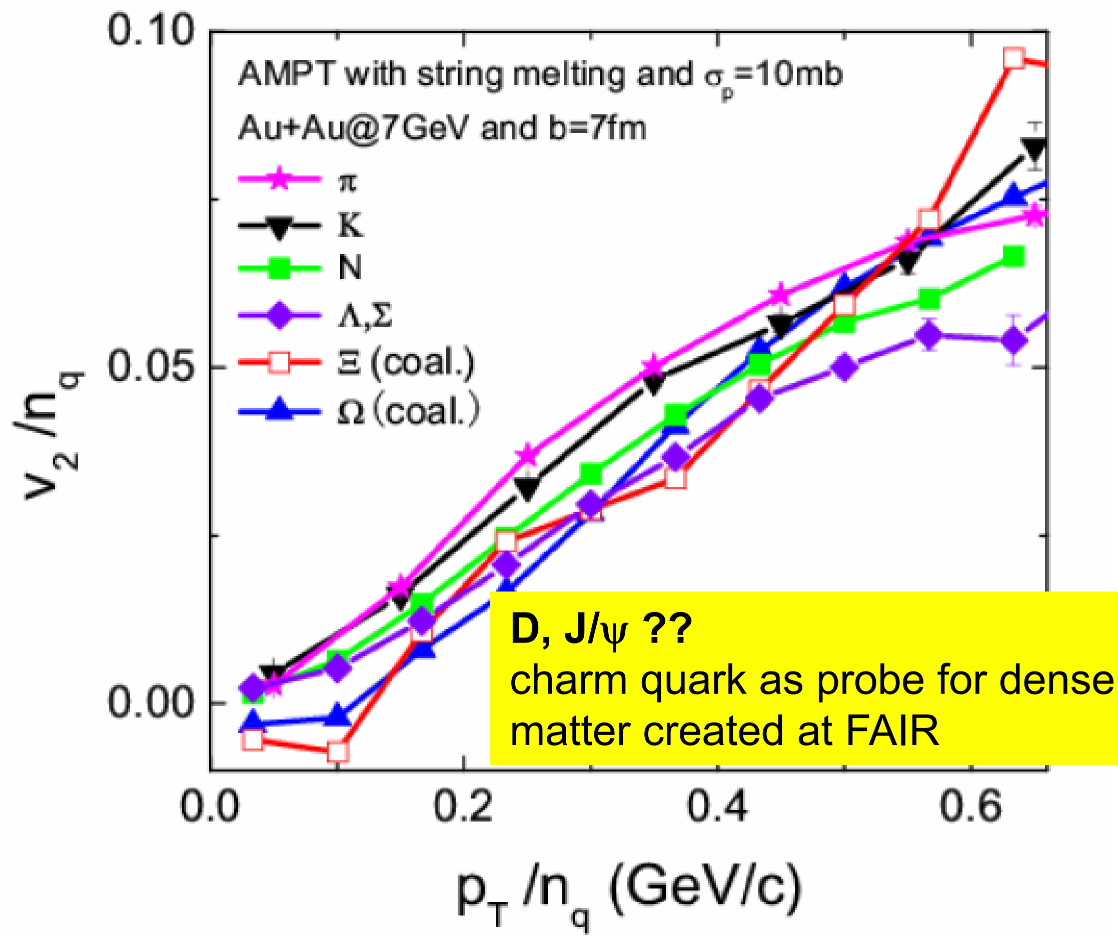
Elliptic flow at FAIR

AMPT calculations: C.M. Ko at CPOD 2007





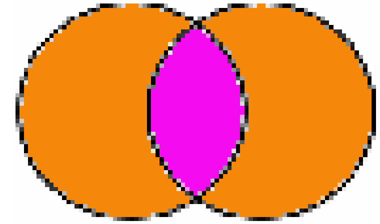
D, J/ψ ??
charm quark as probe for dense matter created at FAIR

Partonic scattering enhances elliptic flow

Approximate constituent quark number scaling !

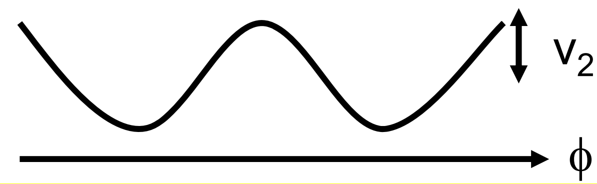
Measure flow for all particles over CBM energy range

Collective flow



elliptic flow v_2:

initial overlap eccentricity → particle azimuthal distributions



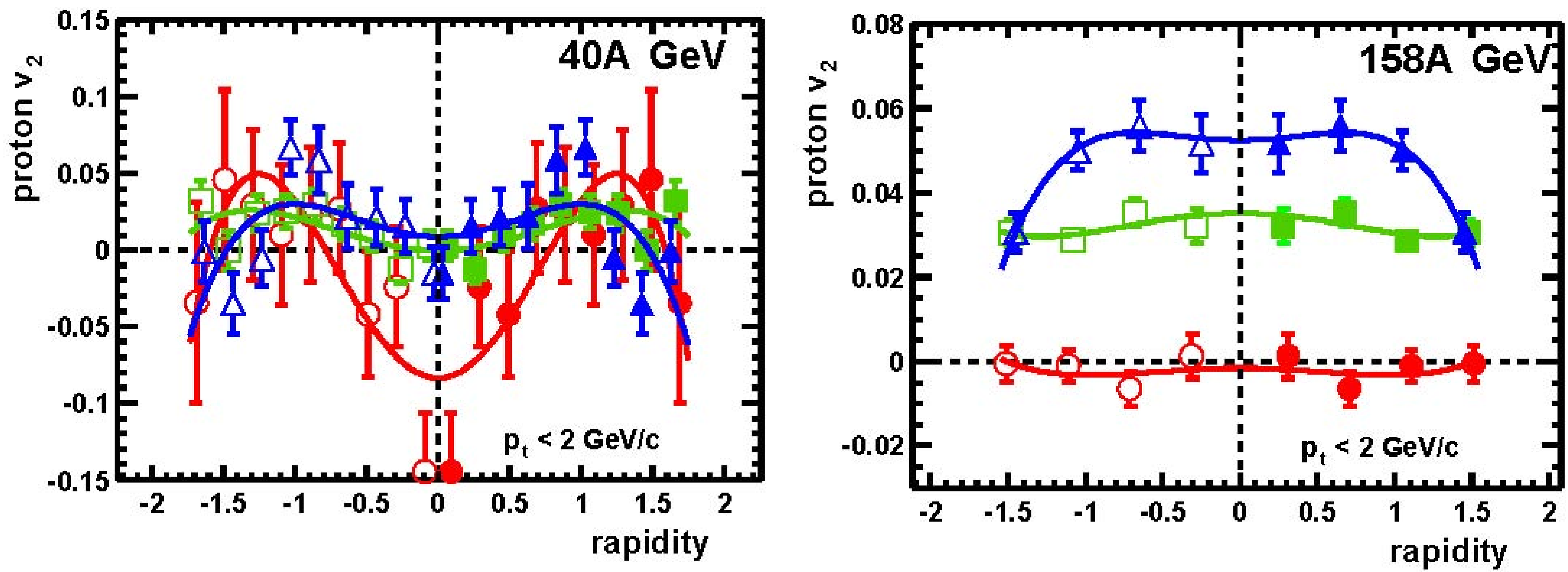
→ stiffness of medium (EOS), pressure

- collapse of elliptic flow of protons at lower energies signal for first order phase transition?!
[e.g. Stoecker, NPA 750 (2005) 121, E. Shuryak, hep-ph/0504048]

- full energy dependence needed!

● central
■ midcentral
▲ peripheral

[NA49, PRC68, 034903 (2003)]



Charm production at threshold

• CBM will measure charm production at threshold

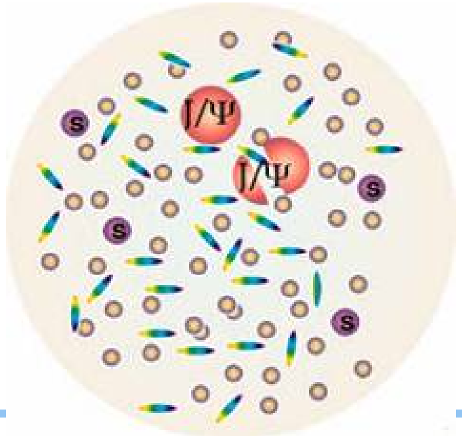
→ after primordial production, the survival, momentum and distribution amongst different hadrons of charm depends on the interactions with the dense and hot medium!

→ direct probe of the medium!

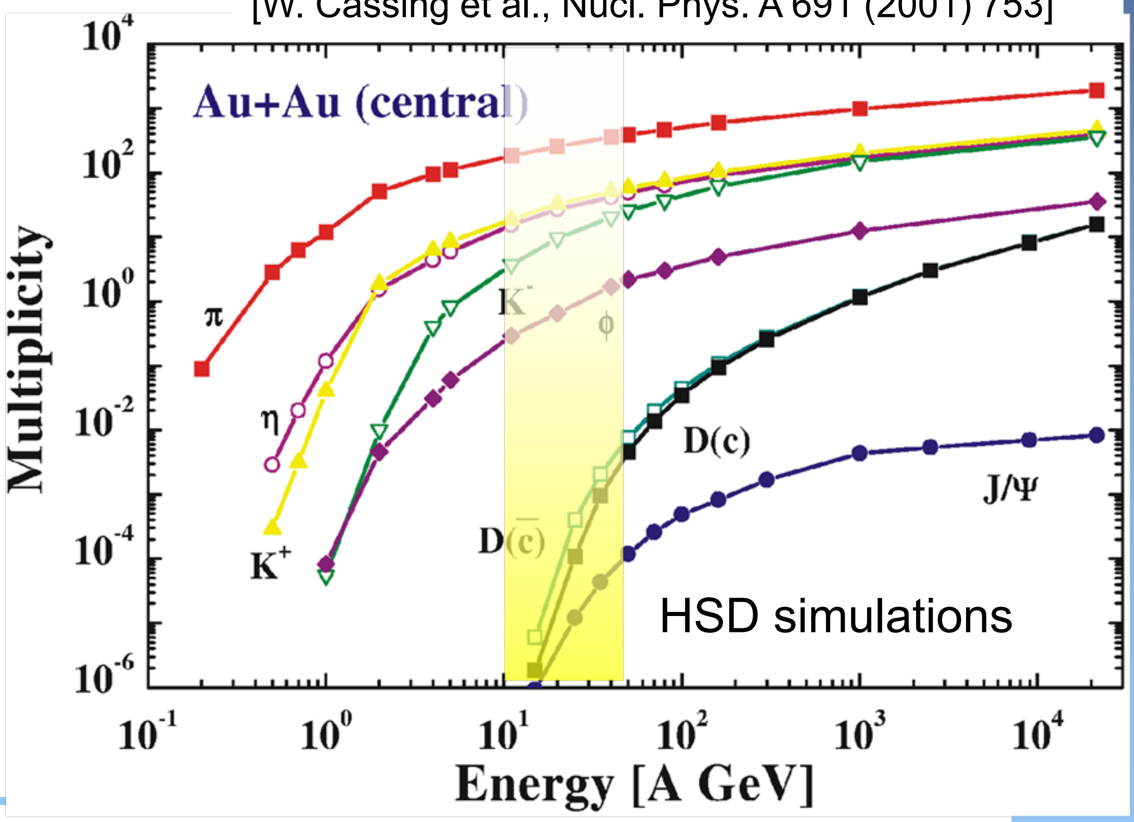
• charmonium in hot and dense matter?

• relation to deconfinement?

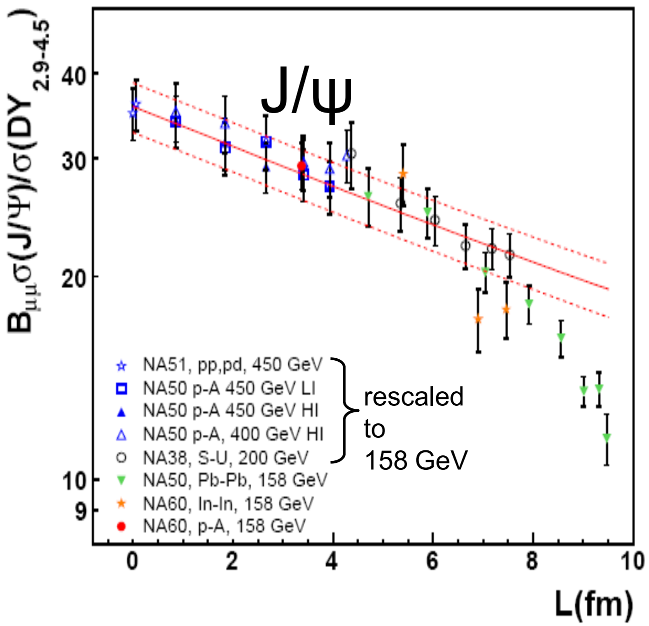
• relation to open charm?

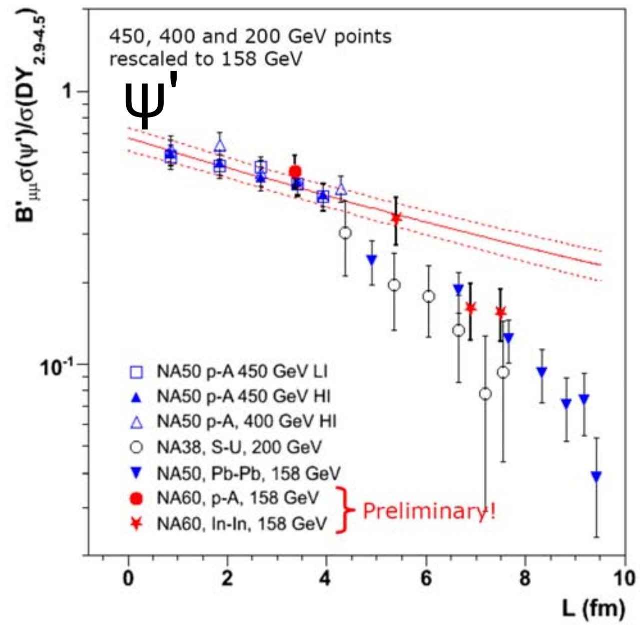


[W. Cassing et al., Nucl. Phys. A 691 (2001) 753]



Probing the QGP with charmonium





Quarkonium dissociation temperatures:
(Digal, Karsch, Satz)

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

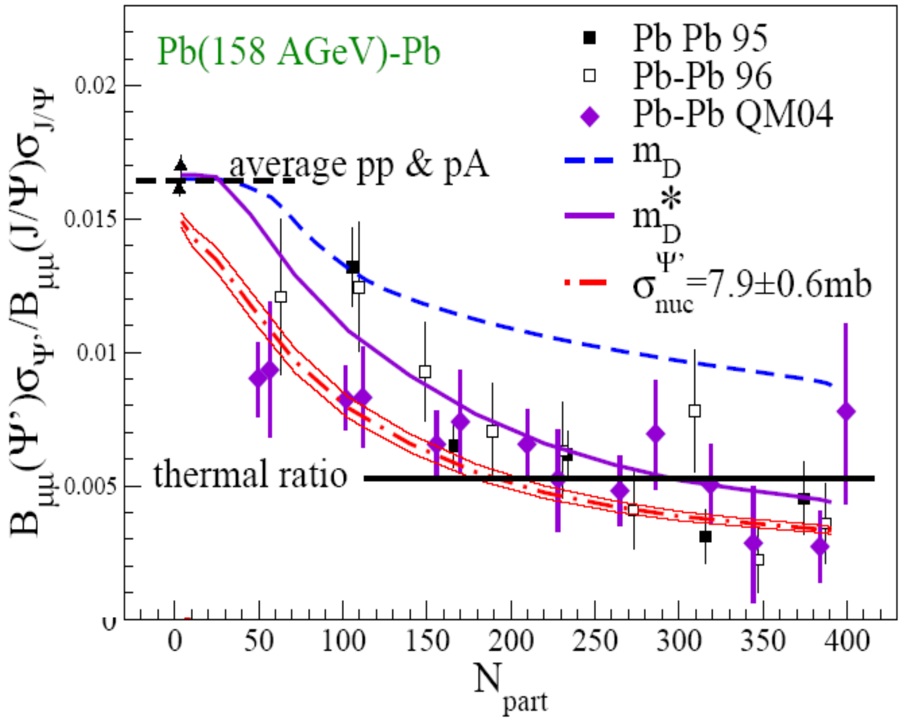
sequential dissociation?

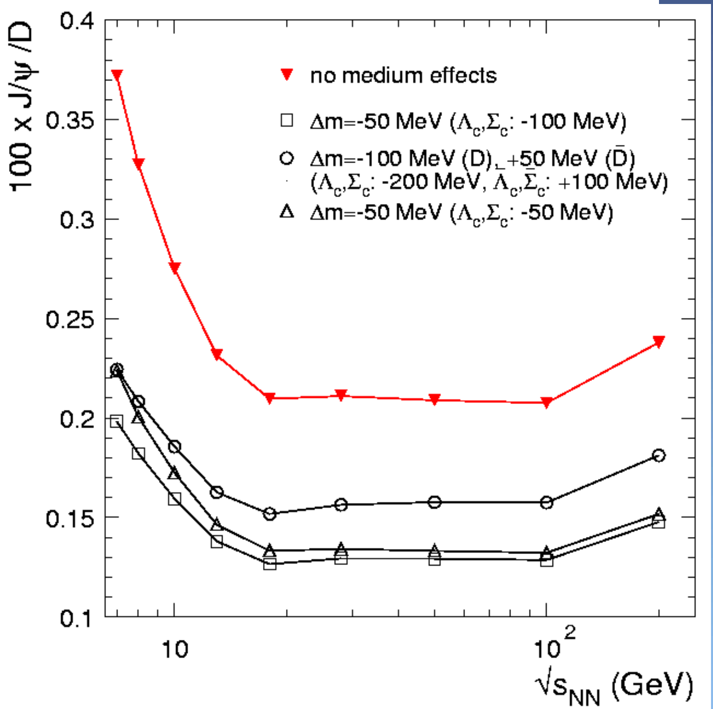
Measure excitation functions of J/ψ and ψ' in p+p, p+A and A+A collisions !

In medium modification of D

L. Grandchamp, R. Rapp and G. E. Brown, J.Phys. G30 (2004) S1355

A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, arXiv:0708.1488





Mass modifications of D mesons and charmed hyperons affect the ratios ψ'/ψ and charmonium to open charm

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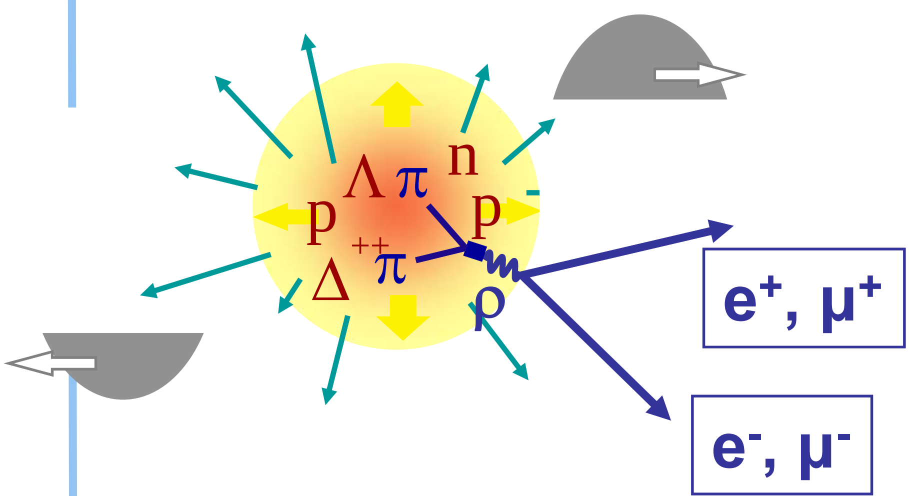
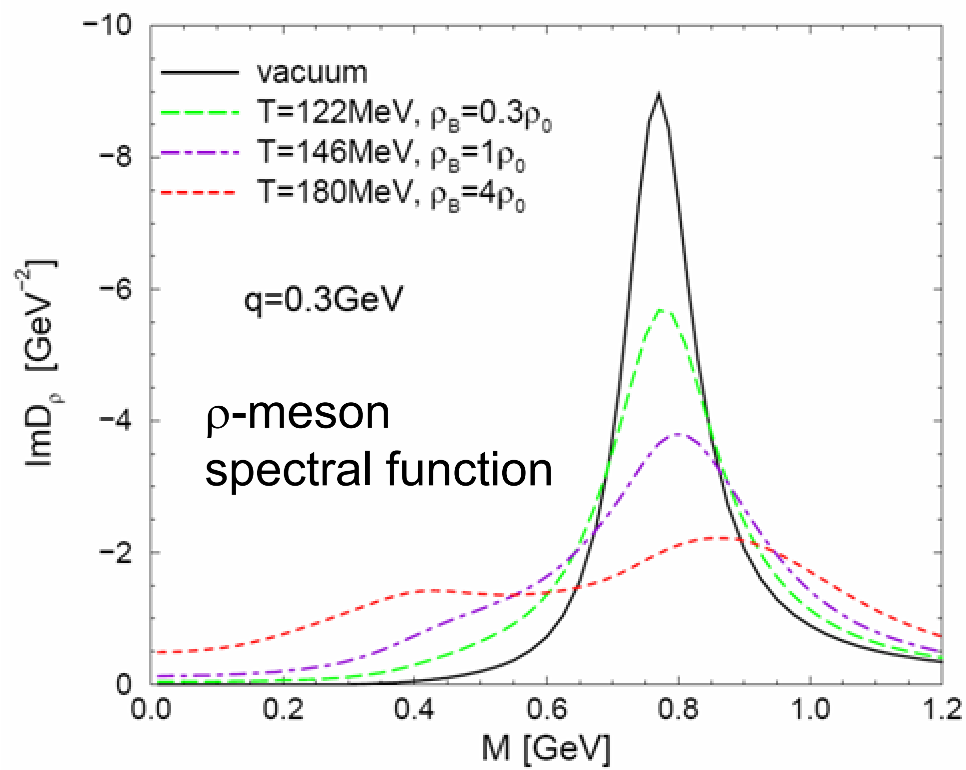
ρ – meson

- hadronic properties are expected to be effected by the high density matter
- ρ-meson couples to the medium, direct radiation from the early phase
- vacuum lifetime τ_0 = 1.3 fm/c → dileptons = penetrating probe
- connection to chiral symmetry restoration?





[Rapp, Wambach, Adv. Nucl. Phys. 25 (2000) 1, hep-ph/9909229]

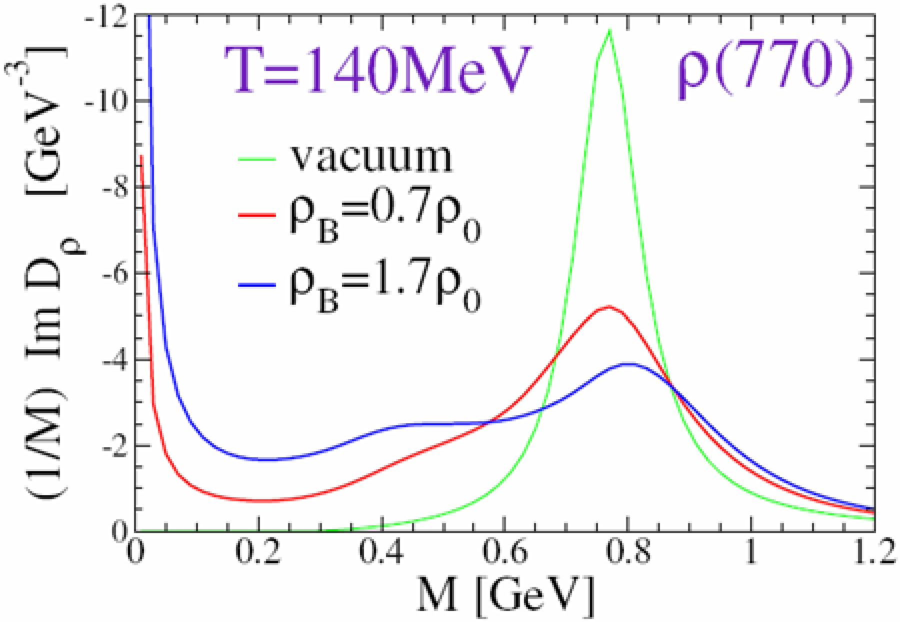
ρ-meson spectral function (II)

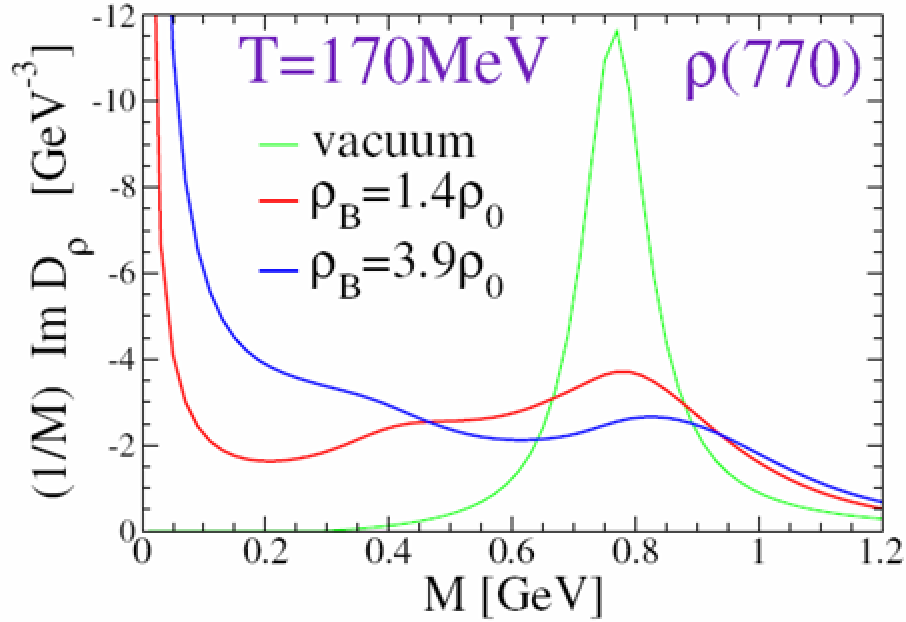
• illustrate sensitivity to modifications caused by the baryonic component of the medium:

ρ-meson spectral function weighted by a factor 1/M to resemble the dilepton rate, Bose-factor will further amplify the low-mass part

• region with $m < 0.4$ GeV/c^2 of special interest!

"SPS"
"FAIR"





[R. Rapp, priv. com. (CBM physics book)]

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The CBM experiment

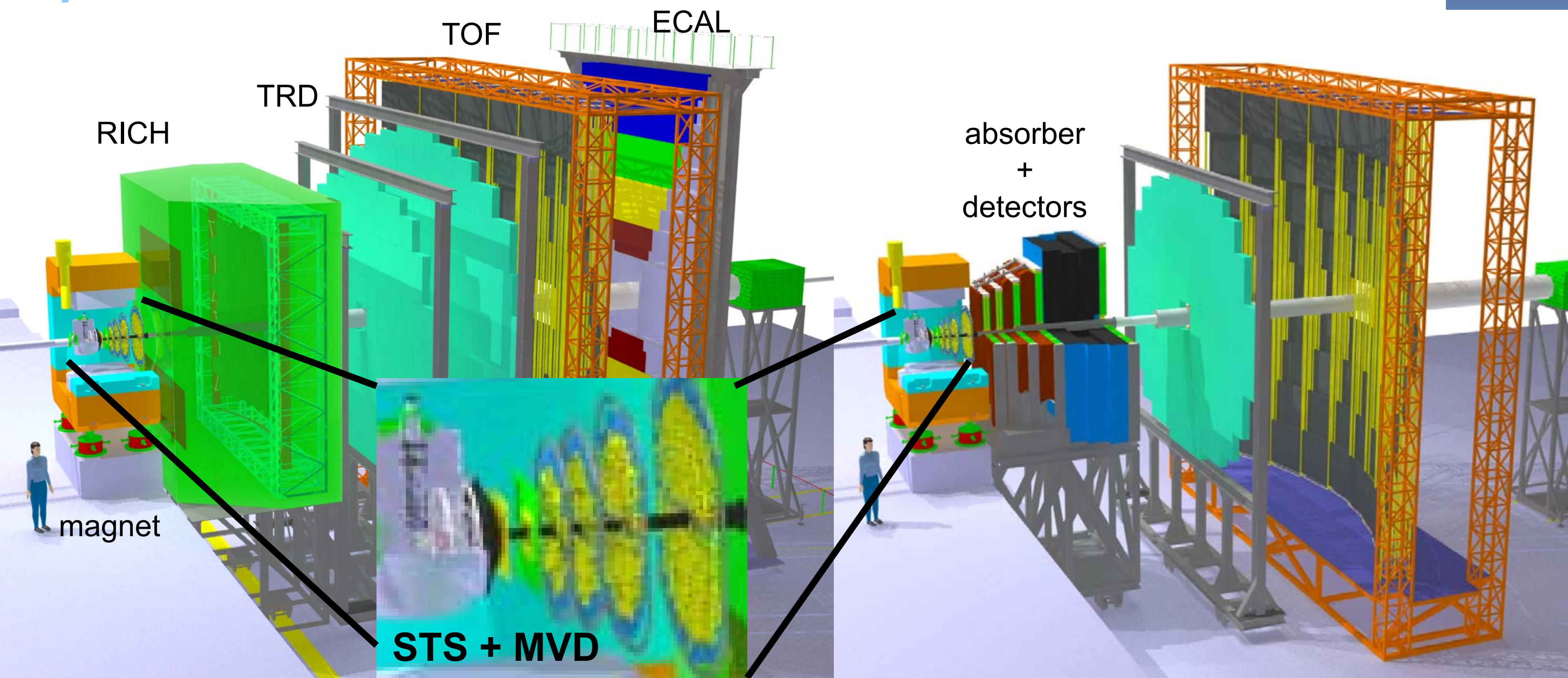
- tracking, momentum determination, vertex reconstruction: radiation hard silicon pixel/strip detectors (STS) in a magnetic dipole field

- hadron ID: TOF (& RICH)
- photons, π^0, η: ECAL

- PSD for event characterization
- high speed DAQ and trigger → **rare probes!**

- **electron ID**: RICH & TRD
  → π suppression $\geq 10^4$

- **muon ID**: absorber + detector layer sandwich
  → move out absorbers for hadron runs



Interaction rates

- FAIR will provide high intensity beams up to 10^9 ions/s
- high availability of beam due to parallel operation of FAIR
- 1% interaction target → **10 MHz interaction rate**

→ **rare probes!**

(rates for D limited because of readout speed of silicon pixel detectors)

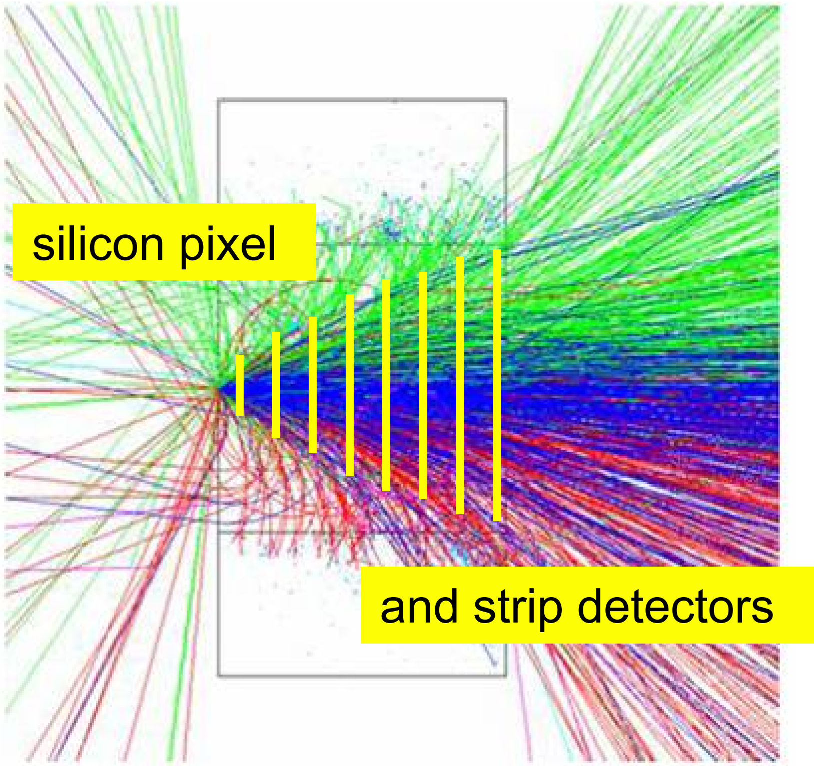
particle, mass (MeV)	N	decay mode	BR	R/s (MHz)	T	ε (%)	Y/s	Y/10 w
ρ (770)	4.6	e^+e^-	$4.7 \cdot 10^{-5}$	0.025	n	5.4	0.29	$1.8 \cdot 10^6$
ρ (770)	4.6	$\mu^+\mu^-$	$4.6 \cdot 10^{-5}$	0.25	y	2.7	1.4	$8.6 \cdot 10^6$
D^0 (1864)	$7.5 \cdot 10^{-6}$	$K^-\pi^+$	0.038	0.1	y	3.25	$8.5 \cdot 10^{-4}$	$5.1 \cdot 10^3$
D^0 (1864)	$7.5 \cdot 10^{-6}$	$K^-\pi^+\pi^+\pi^-$	0.075	0.1	y	0.37	$2.1 \cdot 10^{-4}$	$1.3 \cdot 10^3$
D^0 (1864)	$2.3 \cdot 10^{-5}$	$K^+\pi^-$	0.038	0.1	y	3.25	$2.6 \cdot 10^{-3}$	$1.6 \cdot 10^4$
J/ψ (3097)	$3.8 \cdot 10^{-6}$	e^+e^-	0.06	1-10	y	14	0.032 - 0.32	$1.9 \cdot 10^{5-6}$
ψ' (3686)	$5.1 \cdot 10^{-8}$	e^+e^-	$7.3 \cdot 10^{-3}$	1-10	y	15	$5.6 \cdot 10^{-(5-4)}$	$3.4 \cdot 10^{2-3}$
J/ψ (3097)	$3.8 \cdot 10^{-6}$	$\mu^+\mu^-$	0.06	10	y	16	0.36	$2.2 \cdot 10^6$
ψ' (3686)	$5.1 \cdot 10^{-8}$	$\mu^+\mu^-$	$7.3 \cdot 10^{-}$[illegible]	10	y	19	$7.1 \cdot 10^{-4}$	$4.3 \cdot 10^3$

BR = branching ratio
T = trigger?

ε = efficiency
Y/10w = yield in 10 weeks

STS tracking – heart of CBM

Challenge: high track density
≈ 600 charged particles in ± 25°

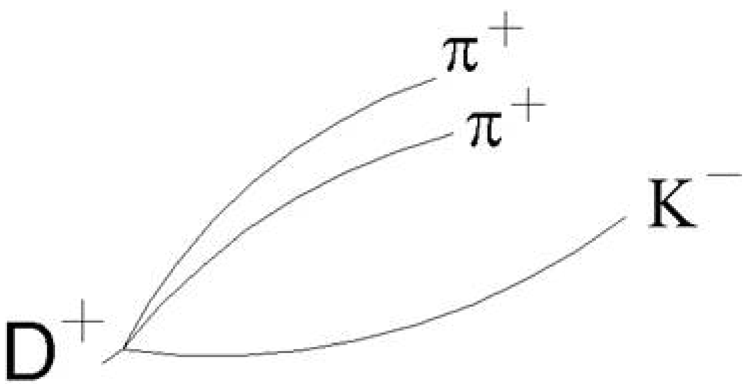


$D^+ \rightarrow \pi^+\pi^+K^-$ ($c\tau$ = 312 μm)

$D^0 \rightarrow K^-\pi^+$ ($c\tau$ = 123 μm)

Task

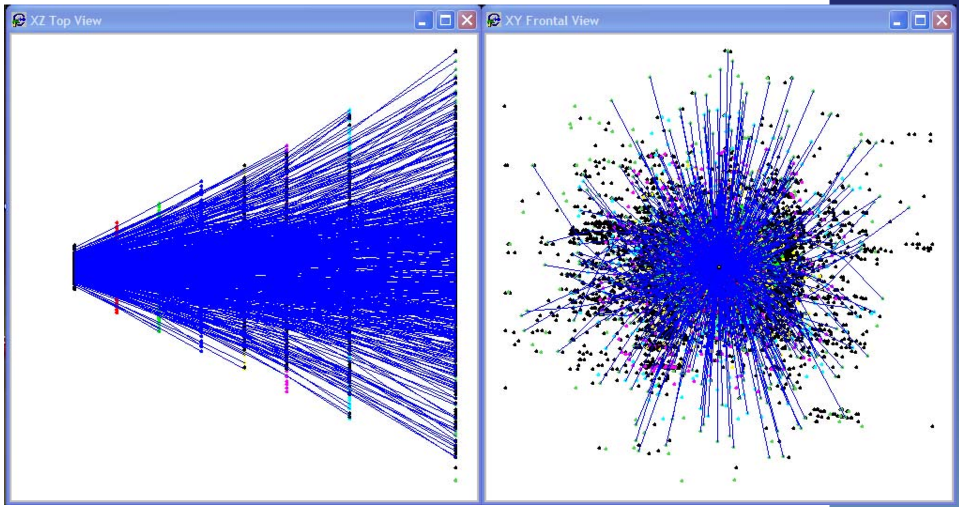
- track reconstruction:
  0.1 GeV/c < p ≤ 10-12 GeV/c
  Δp/p ~ 1% (p=1 GeV/c)
- primary and secondary vertex reconstruction (resolution ≤ 50 μm)
- V_0 track pattern recognition



add detectors for particle identification behind the STS

→ challenge for di-leptons!

Track reconstruction



• up to ~10^9 tracks/s in the silicon tracker (10 MHz, ~100 tracks/event)

→ **fast track reconstruction!**

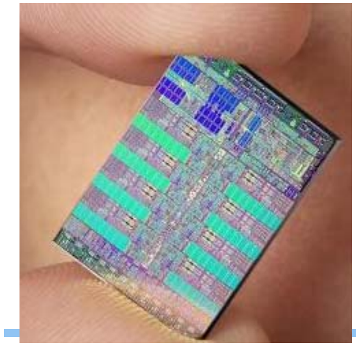
• optimize code

• port to cell processor

• parallel processing

→ today: factor 120000 speedup of tracking code achieved!

• long term aim: make use of multicore architectures of new generation graphics cards etc. (port C++ routines to dedicated hardware!)

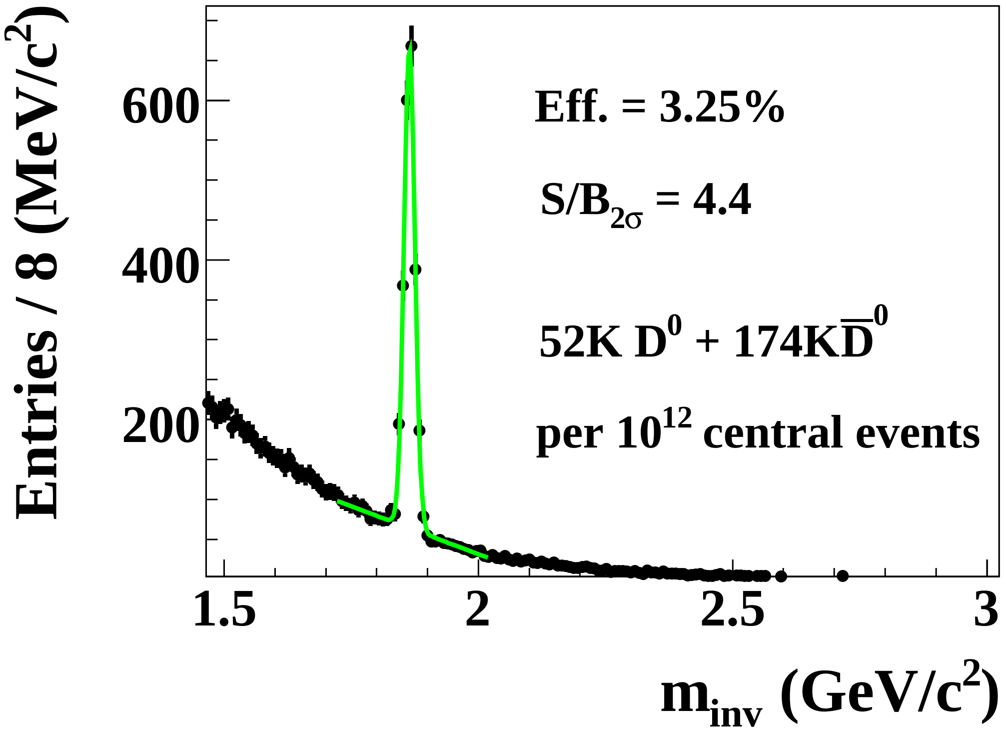


D-meson Simulations

- CbmRoot simulation framework, GEANT3 implemented through VMC
- full event reconstruction: track reconstruction, particle-ID (RICH, TRD, TOF), 2ndary vertex finder
- feasibility studies: central Au+Au collisions at 25 AGeV beam energy (UrQMD)
- several channels studied: D^0, $D^\pm$, D_s, Λ_c

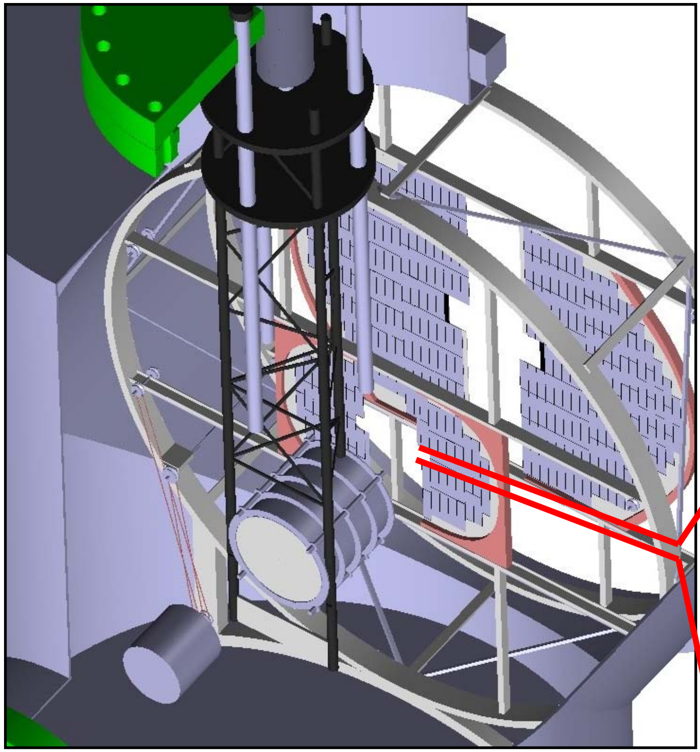
strong dependence on material budget of MVD:

thickness of MVD	efficiency [%]	$S/B_{2\sigma}$
150 μm	3.25	4.4
300 μm	1	0.4
500 μm	0.7	0.3



Micro Vertex Detecor (MVD) Development

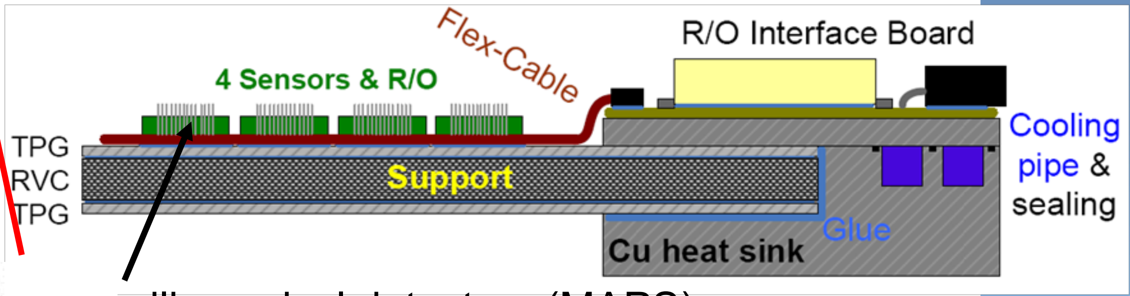
Artistic view of the MVD



- mechanical system integration
- material for cooling!

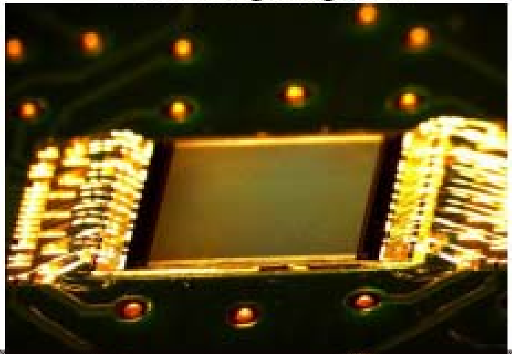
→ material budget!

- vacuum compatibility of system



silicon pixel detectors (MAPS)

Second gluing trial



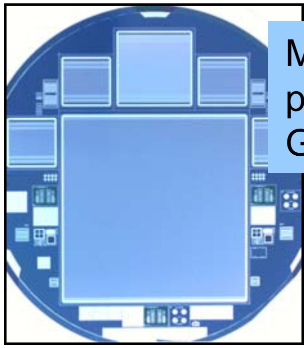
die thinned to 50 m glued to support.

IPHC, Strasbourg (M. Winter et al.)

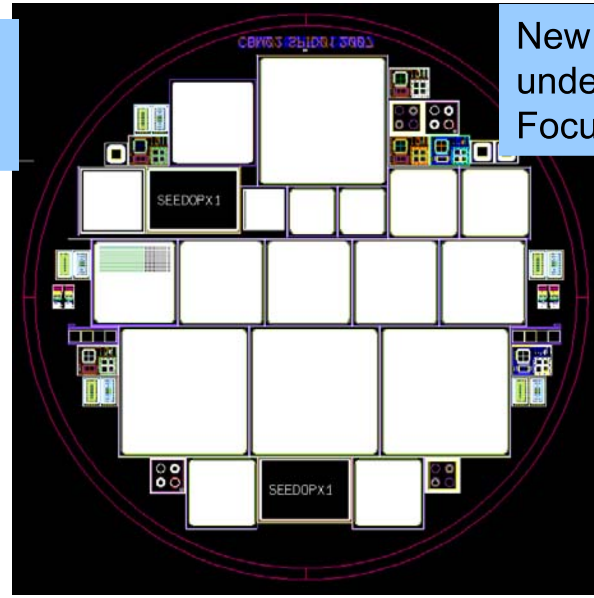
Monolithic **A**citive **P**ixel **S**ensors in commercial CMOS process

$10\times10\ \mu m^2$ pixels fabricated, $\varepsilon > 99\%$, $\Delta x \sim 1.5 - 2.5\ \mu m$

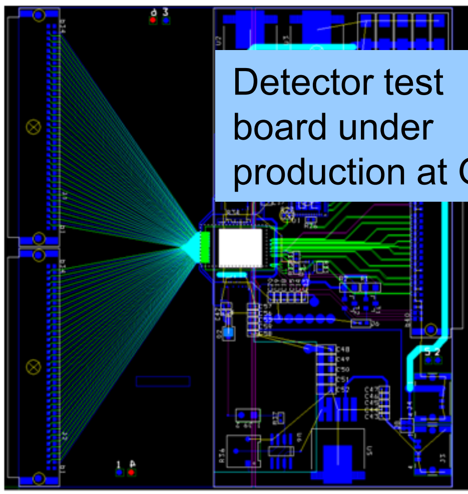
Silicon Tracking Station (STS) R&D



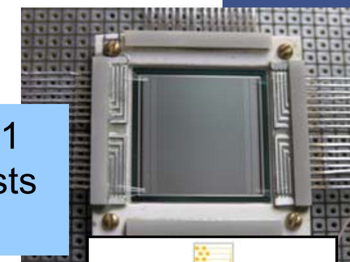
Micro-strip detector prototype CBM01, GSI-CIS (2007).

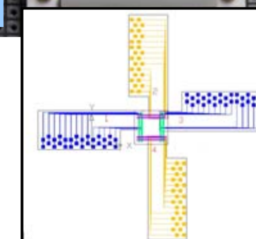


New "Technology wafer" under production at CIS: Focus on radiation hardness.

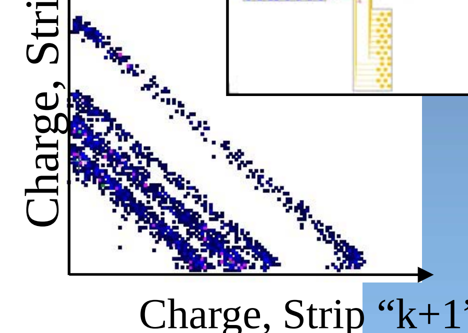


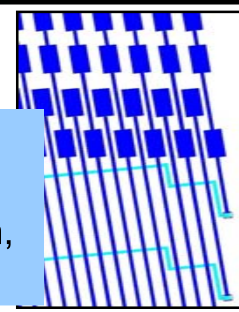
Detector test board under production at GSI.



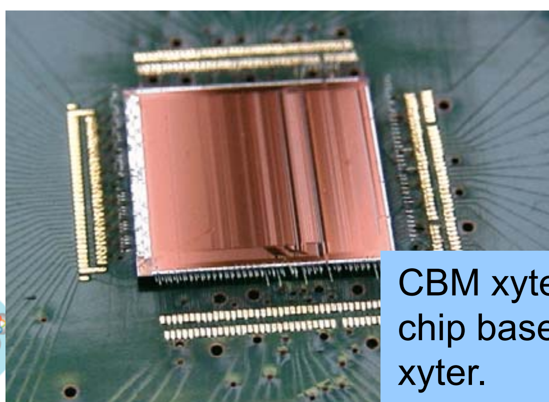


First CBM01 detector tests @ KINR.





Detector design & technology characterization, MSU Moscow.



CBM xyter FE chip based on n-xyter.

Analog readout cable, first pre-prototype. SE SRTIIE Kharkov.

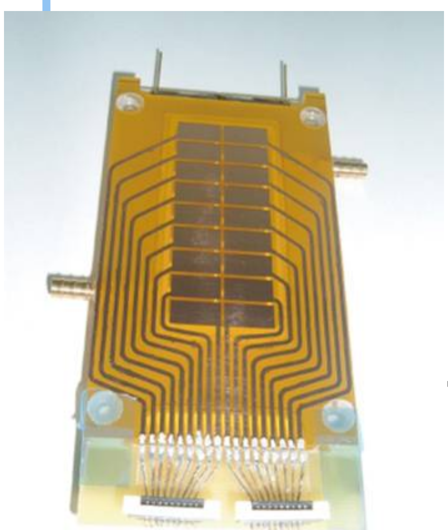
Challenges of the di-electron measurement

- **clean electron identification** (π suppression ≥ 10^4)
- **large background from physical sources**

  γ-conversions in target and STS, π^0 Dalitz decays

  → use excellent tracking and two hit resolution (≤ 100 μm) in first pixel detectors in order to reject this background:

  → optimize detector setup (STS, B-field), use 1‰ interaction target



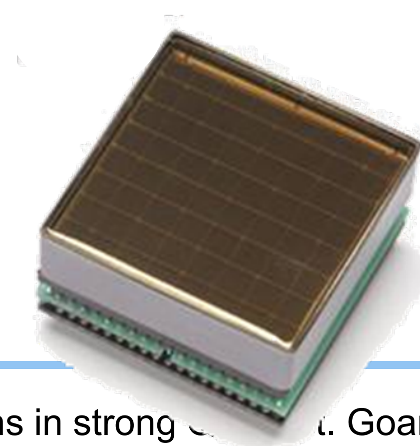
RICH

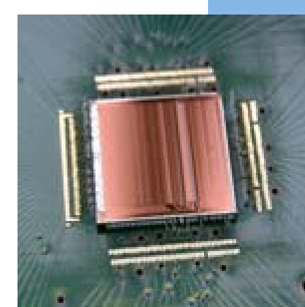
high ring densities and interaction rates
→ MAPMTs + fast self triggered read out electronics

TRD

high rates!
→ reduce gas gap

prototype:double-sided pad plane



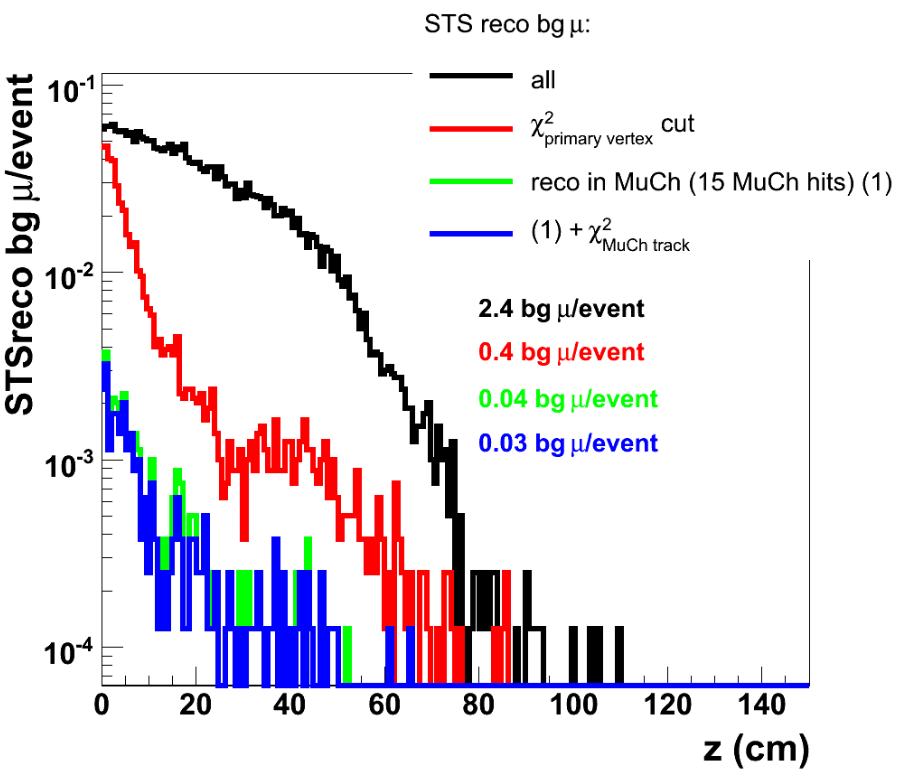


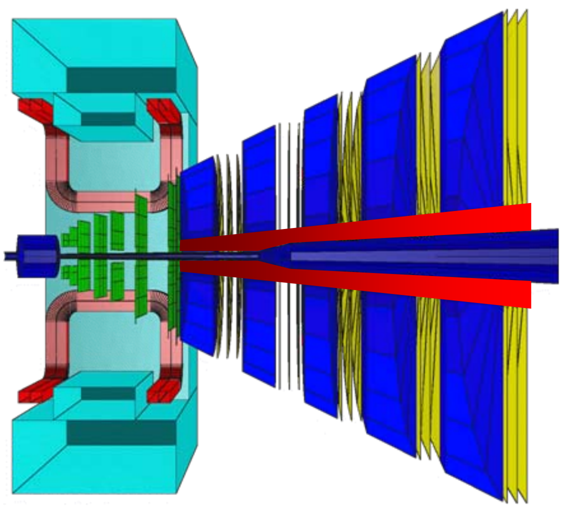
Challenges of the di-muon measurement

- **major background from π,K decays into $\mu\nu$, punch through of hadrons and track mismatches**

→ use TOF information to reject punch through K,p
→ compact layout to minimize K,π decays
→ use excellent tracking to reject π,K decays in the STS by kink detection
→ absorber-detector sandwich for continous tracking

- **low momentum μ!**





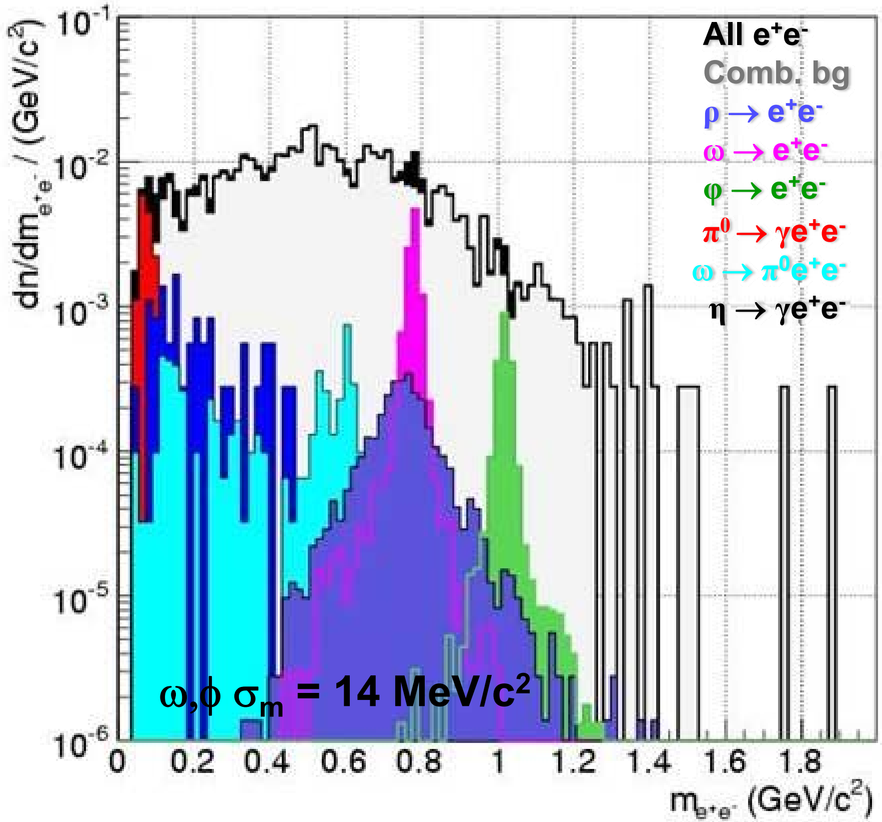
125 cm Fe ≡ 7.5 λ_I → p > 1.5 GeV/c
225 cm Fe ≡ 13.5 λ_I → p > 2.8 GeV/c

Low mass vector mesons

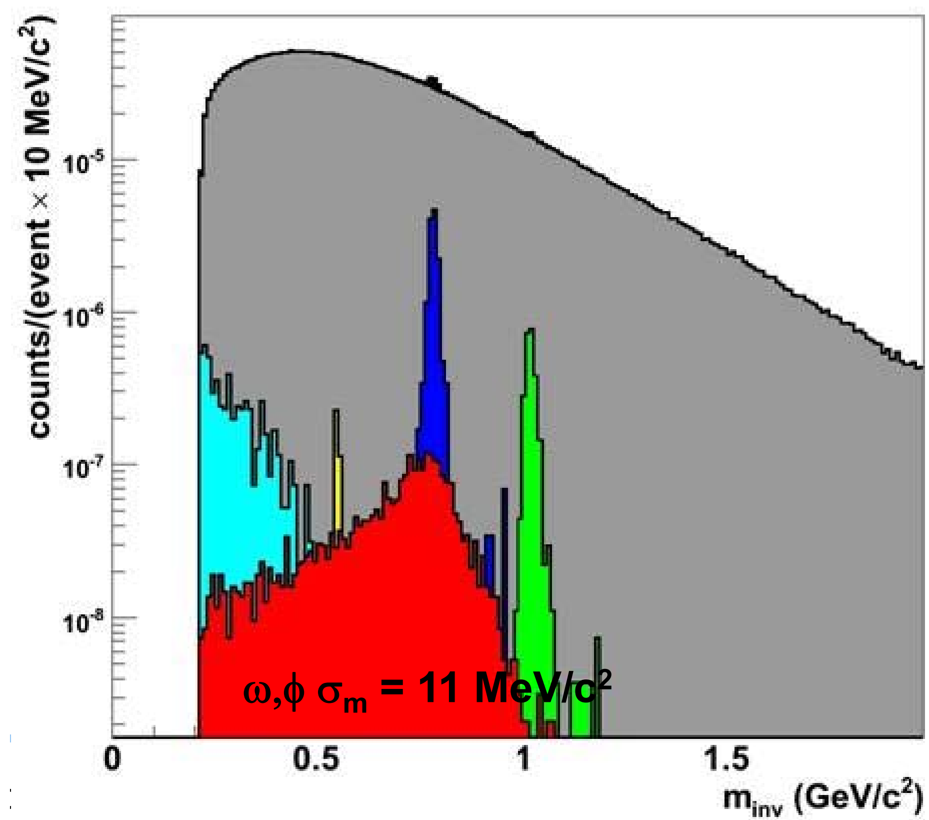
invariant mass spectra

- electrons: pt > 0.2 GeV/c
  background dominated by physical sources (75%), 1‰ int. target
- muons: intrinsic p>1.5 GeV cut (125 cm Fe absorber),
  background dominated by misidentified muons, 1% int. target

electrons: 200k events



muons: $4 \cdot 10^8$ events

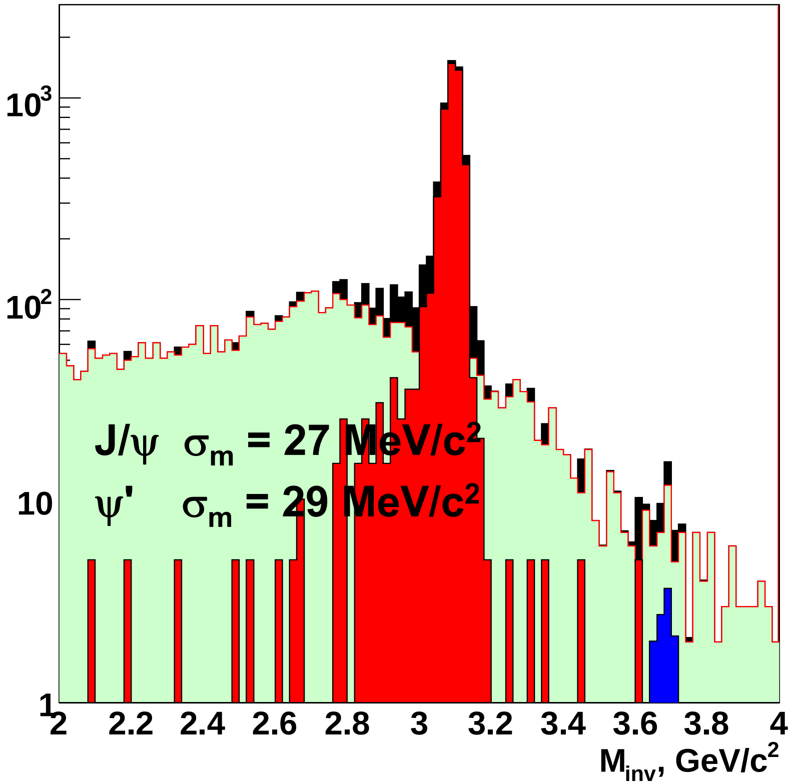


J/ψ and ψ'

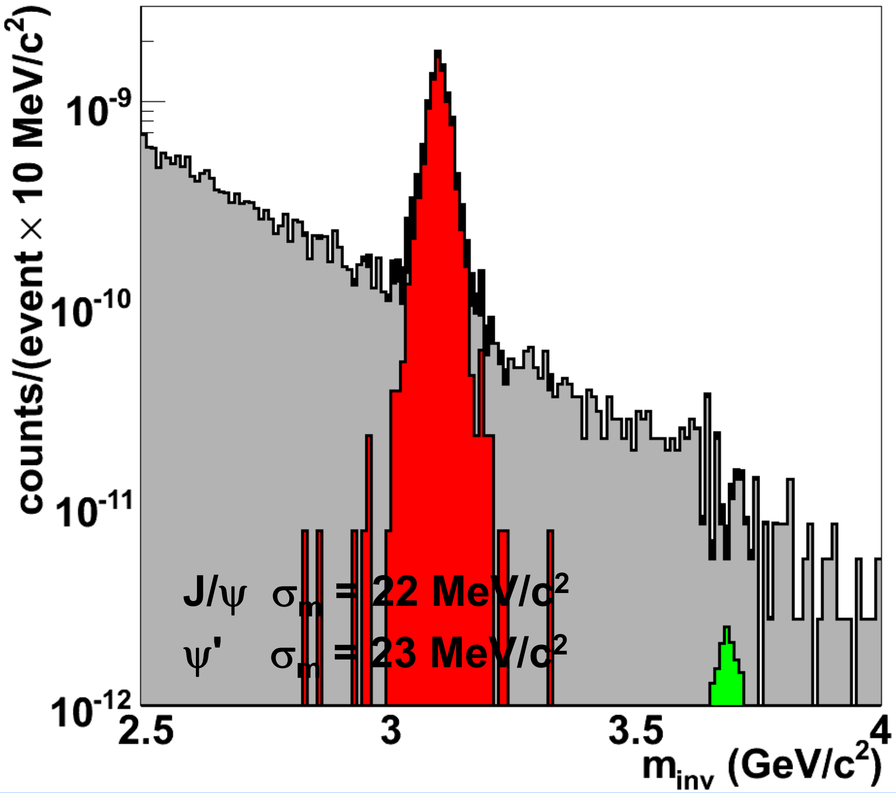
invariant mass spectra

- electrons: p < 13 GeV/c, pt > 1.2 GeV, 1‰ interaction target (25 μm Au)
- muons: 225 cm Fe absorber, pt > 1 GeV/c, 1% int. target

electrons: 4 $\cdot 10^{10}$ events



muons: 3.8 $\cdot 10^{10}$ events

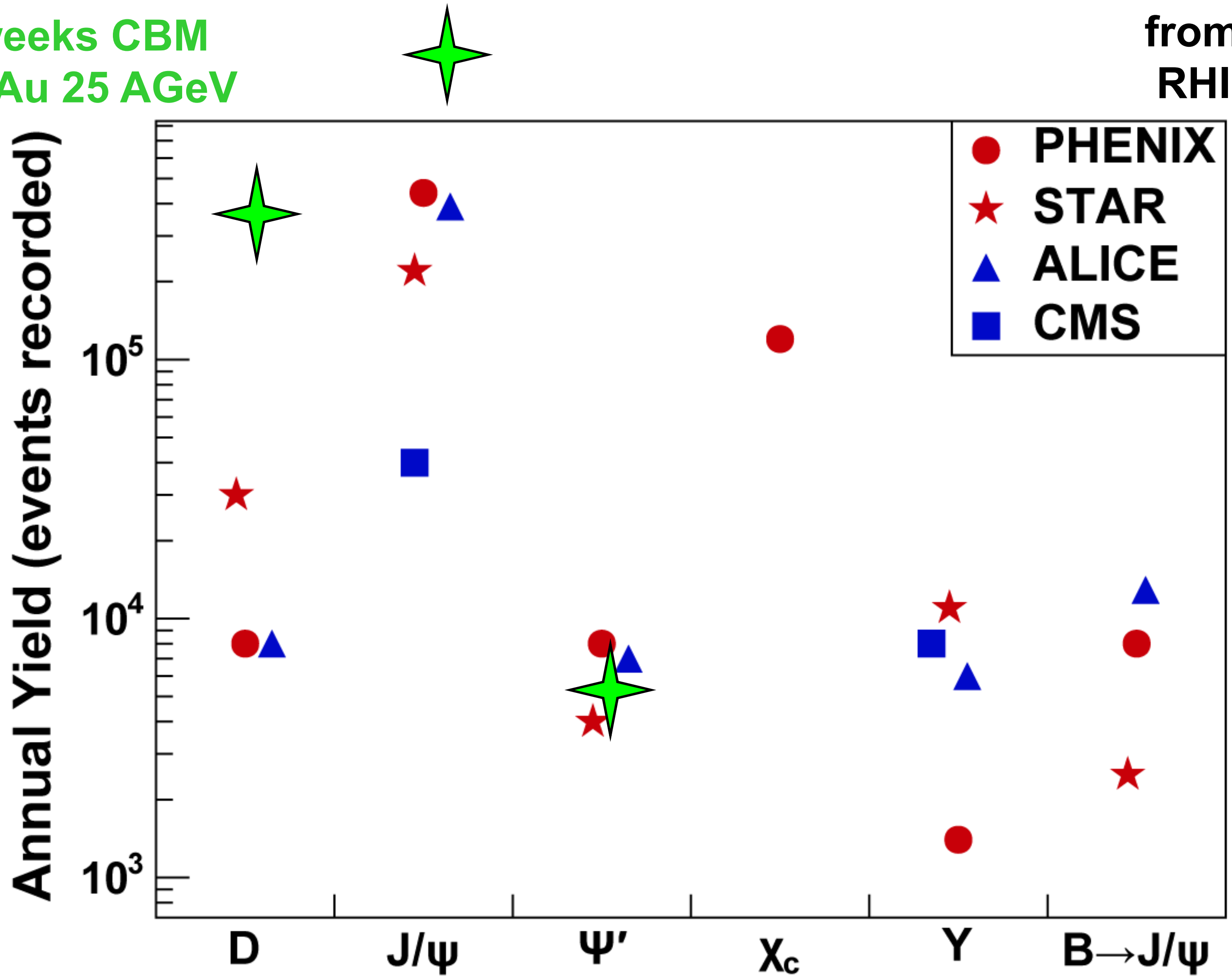


Annual yields at RHIC II and LHC

10 weeks CBM
Au+Au 25 AGeV

from Tony Frawley
RHIC Users mtg.

B. Jacak
QM2006



at LHC: (10-50) x σ ~10% of $\mathcal{L}$ 25% running time

Summary – physics of CBM

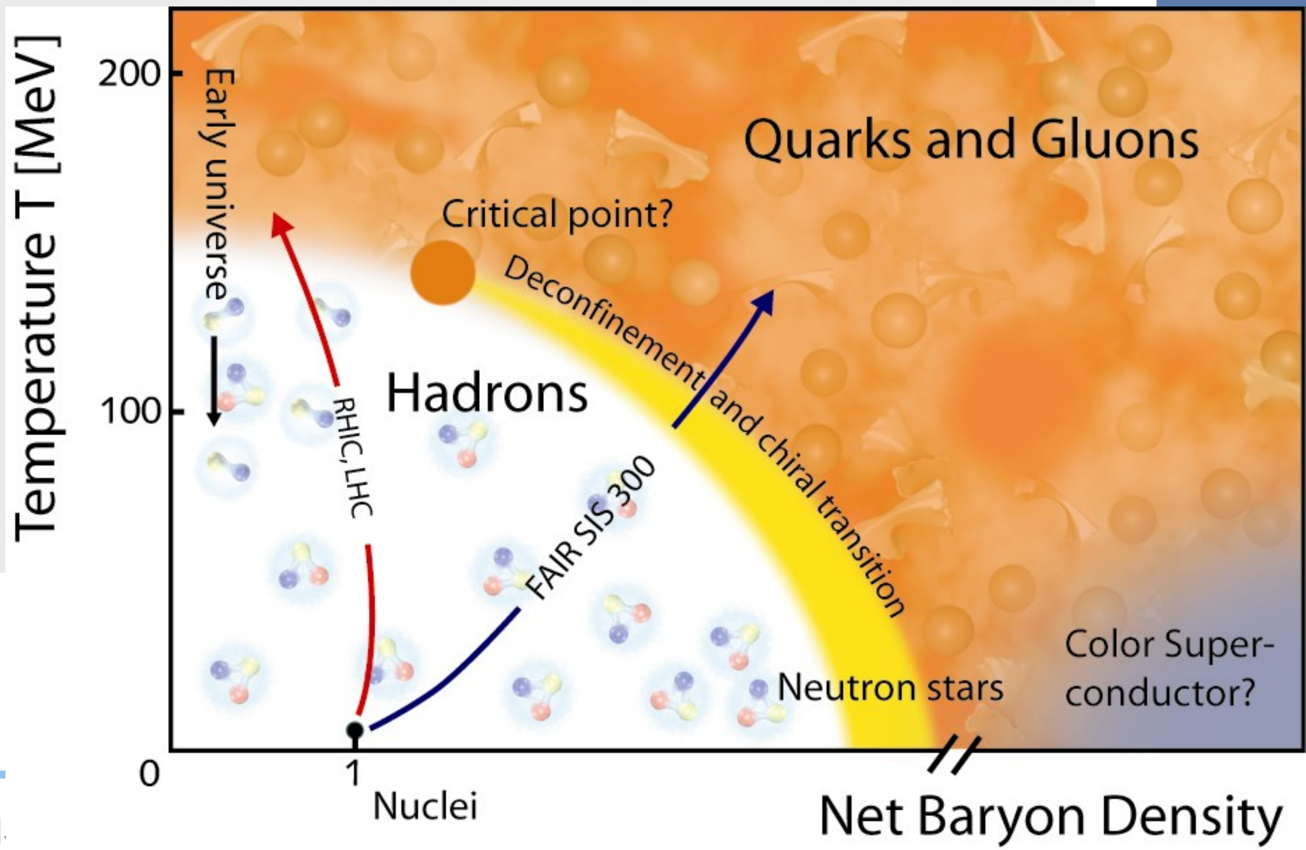
CBM@FAIR – high μ_B, moderate T:

- searching for the landmarks of the QCD phase diagram
  - first order deconfinement phase transition
  - chiral phase transition
  - QCD critical endpoint

→ systematic measurements, rare probes

- characterizing properties of baryon dense matter
- in medium properties of hadrons?

in A+A collisions from
10-45 AGeV
($\sqrt{s_{NN}}$ = 4.5 – 9.3 GeV)
starting in 2015



CBM collaboration

China:
CCNU Wuhan
USTC Hefei

Croatia:
University of Split
RBI, Zagreb

Cyprus:
Nikosia Univ.

Czech Republic:
CAS, Rez
Techn. Univ. Prague

France:
IPHC Strasbourg

Germany:
Univ. Heidelberg, Phys. Inst.
Univ. HD, Kirchhoff Inst.
Univ. Frankfurt
Univ. Mannheim
Univ. Münster
FZ Rossendorf
GSI Darmstadt

Hungaria:
KFKI Budapest
Eötvös Univ. Budapest

India:
Aligarh Muslim Univ., Aligarh
IOP Bhubaneswar
Panjab Univ., Chandigarh
Univ. Rajasthan, Jaipur
Univ. Jammu, Jammu
IIT Kharagpur
SAHA Kolkata
Univ Calcutta, Kolkata
VECC Kolkata
Univ. Kashmir, Srinagar
Banaras Hindu Univ., Varanasi

Korea:
Korea Univ. Seoul
Pusan National Univ.

Norway:
Univ. Bergen

Poland:
Krakow Univ.
Warsaw Univ.
Silesia Univ. Katowice
Nucl. Phys. Inst. Krakow

Portugal:
LIP Coimbra

Romania:
NIPNE Bucharest

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg
Kurchatov Inst. Moscow
LHE, JINR Dubna
LPP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP, Moscow State Univ.
St. Petersburg Polytec. U.

Ukraine:
Shevchenko Univ. , Kiev

51 institutions, > 400 members