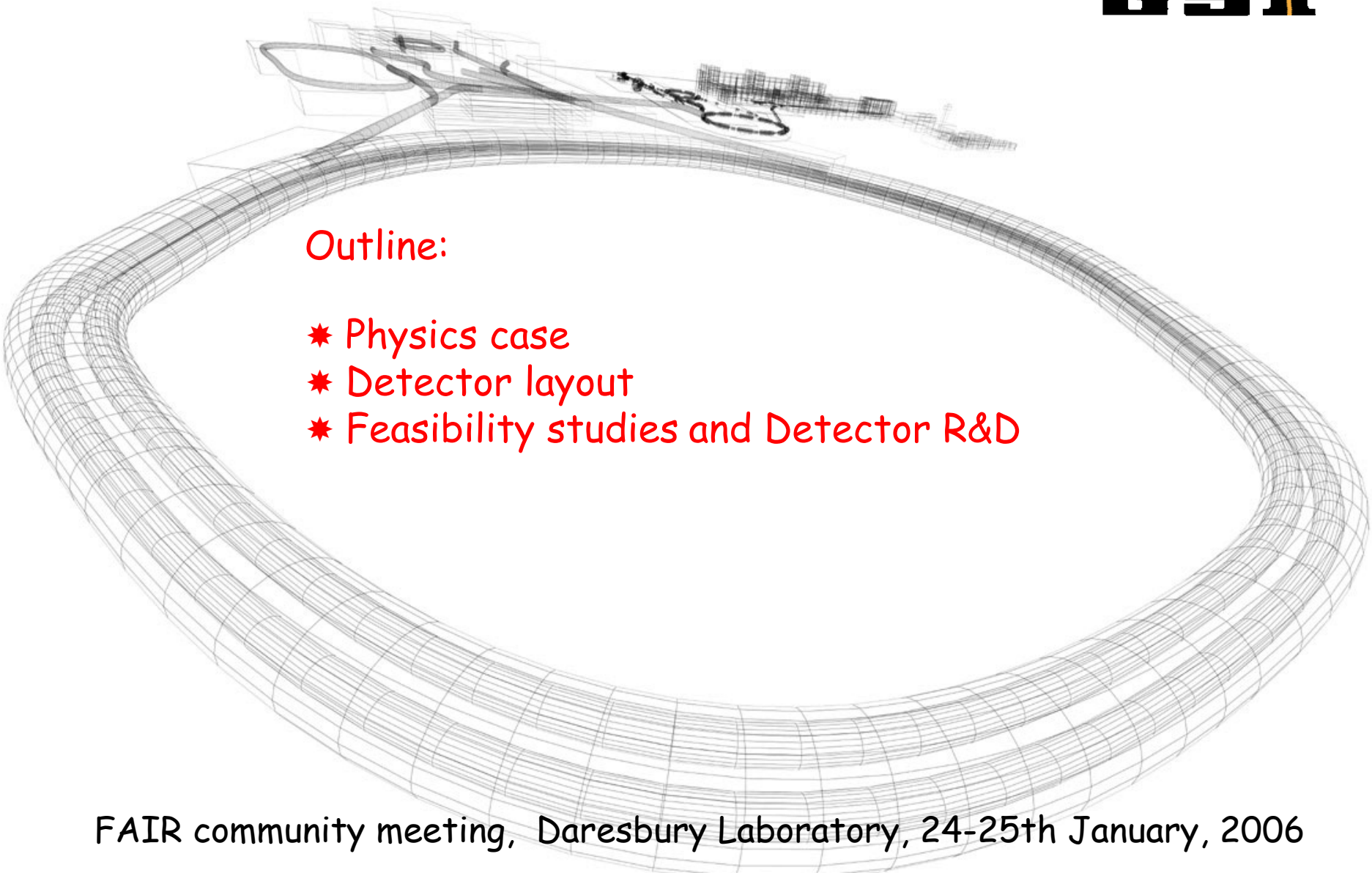
The Compressed Baryonic Matter Experiment at FAIR

Peter Senger



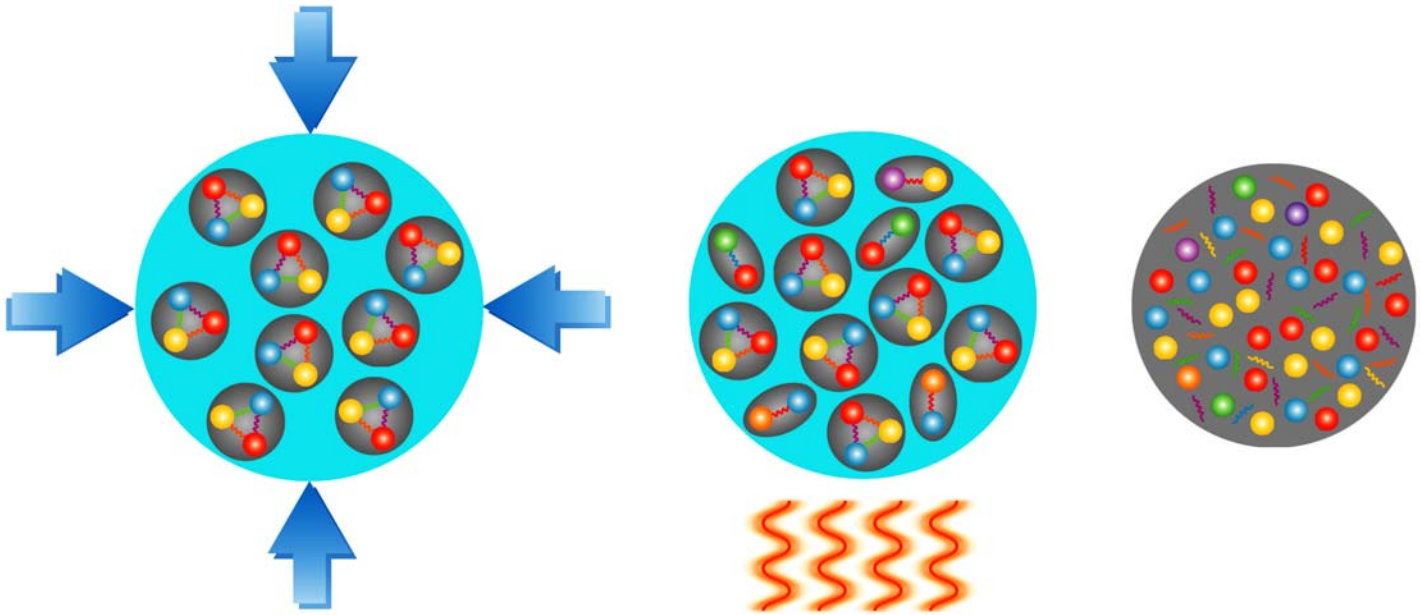
Outline:

- Physics case
- Detector layout
- Feasibility studies and Detector R&D

FAIR community meeting, Daresbury Laboratory, 24-25th January, 2006

Probing strongly interacting matter

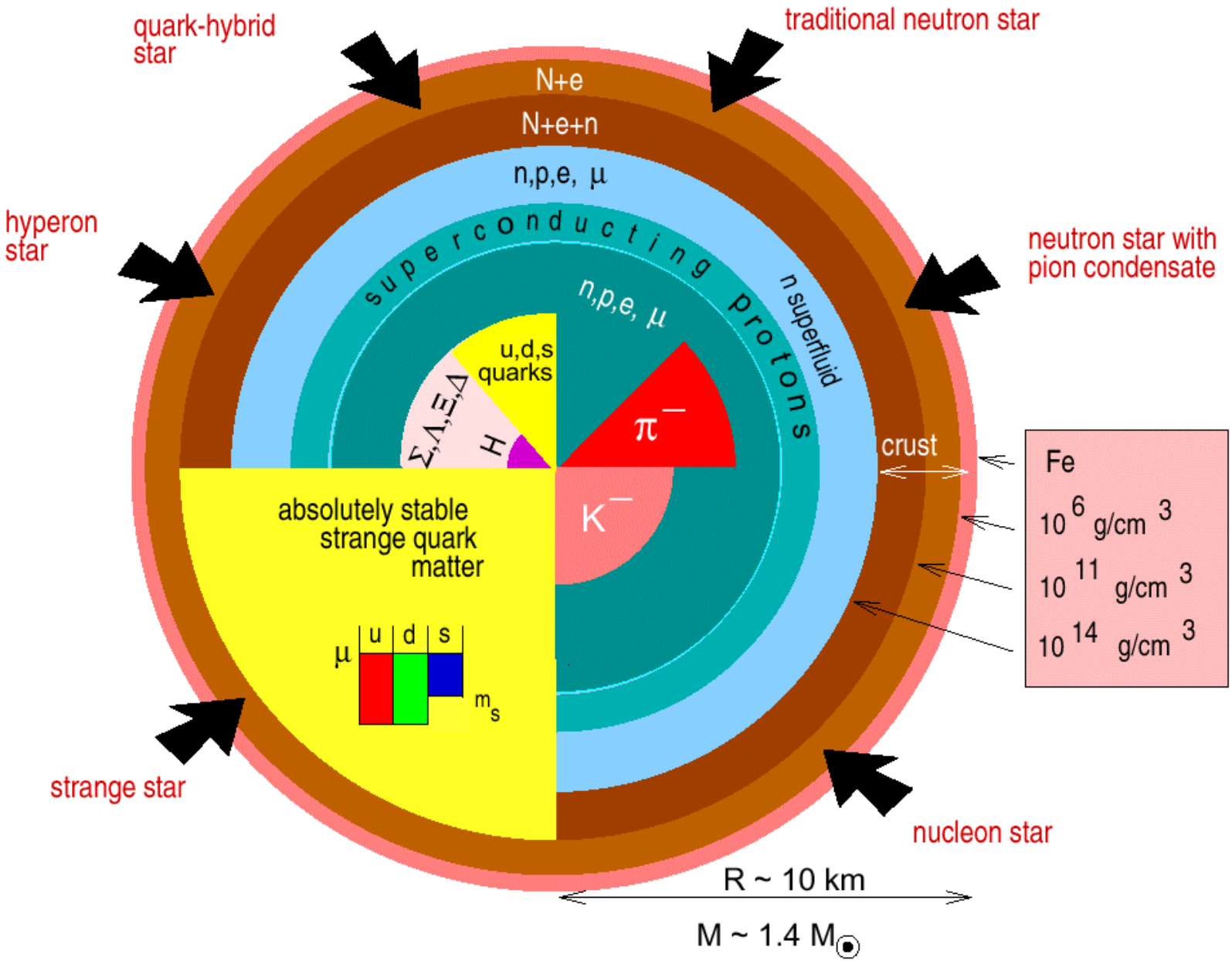
baryons hadrons partons



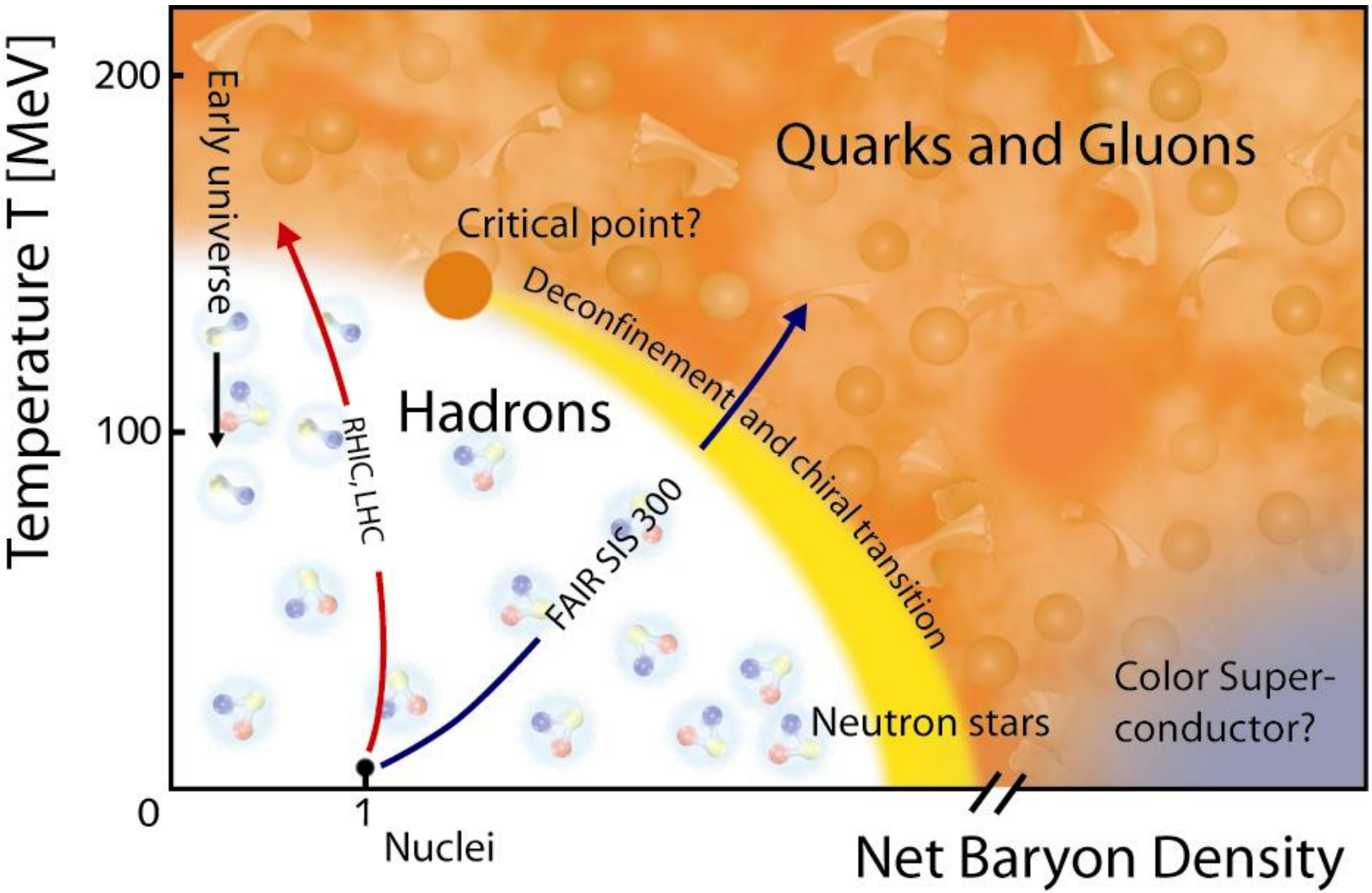
Compression + heating = quark-gluon plasma

(pion production)

Neutron stars Early universe

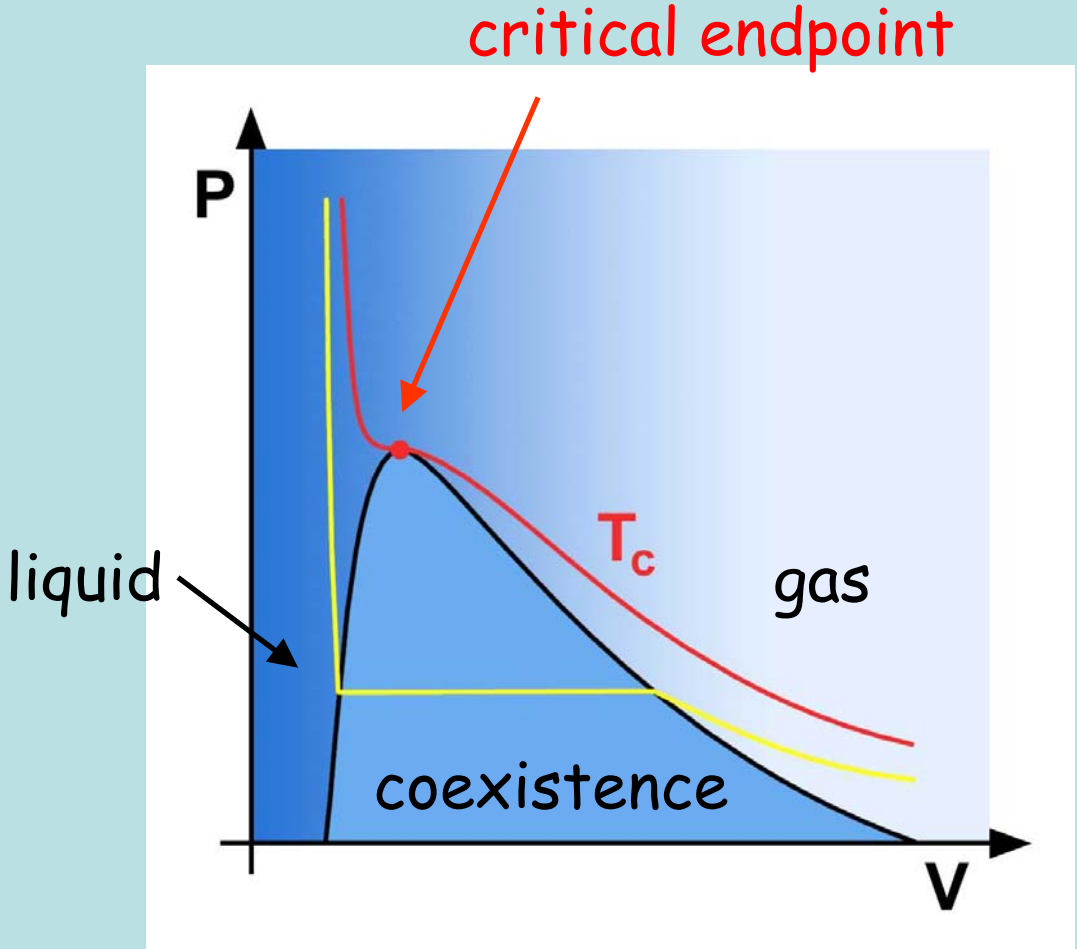

quark-hybrid star
traditional neutron star
N+e
N+e+n
n,p,e, μ
hyperon star
neutron star with pion condensate
superconducting protons
n superfluid
n,p,e, μ
u,d,s quarks
Σ,Λ,Ξ,Δ
H
π⁻
K⁻
crust
Fe
10 6 g/cm 3
10 11 g/cm 3
10 14 g/cm 3
absolutely stable strange quark matter
μ
u
d
s
m s
strange star
nucleon star
R ~ 10 km
M ~ 1.4 M⊙

The phase diagram of strongly interacting matter

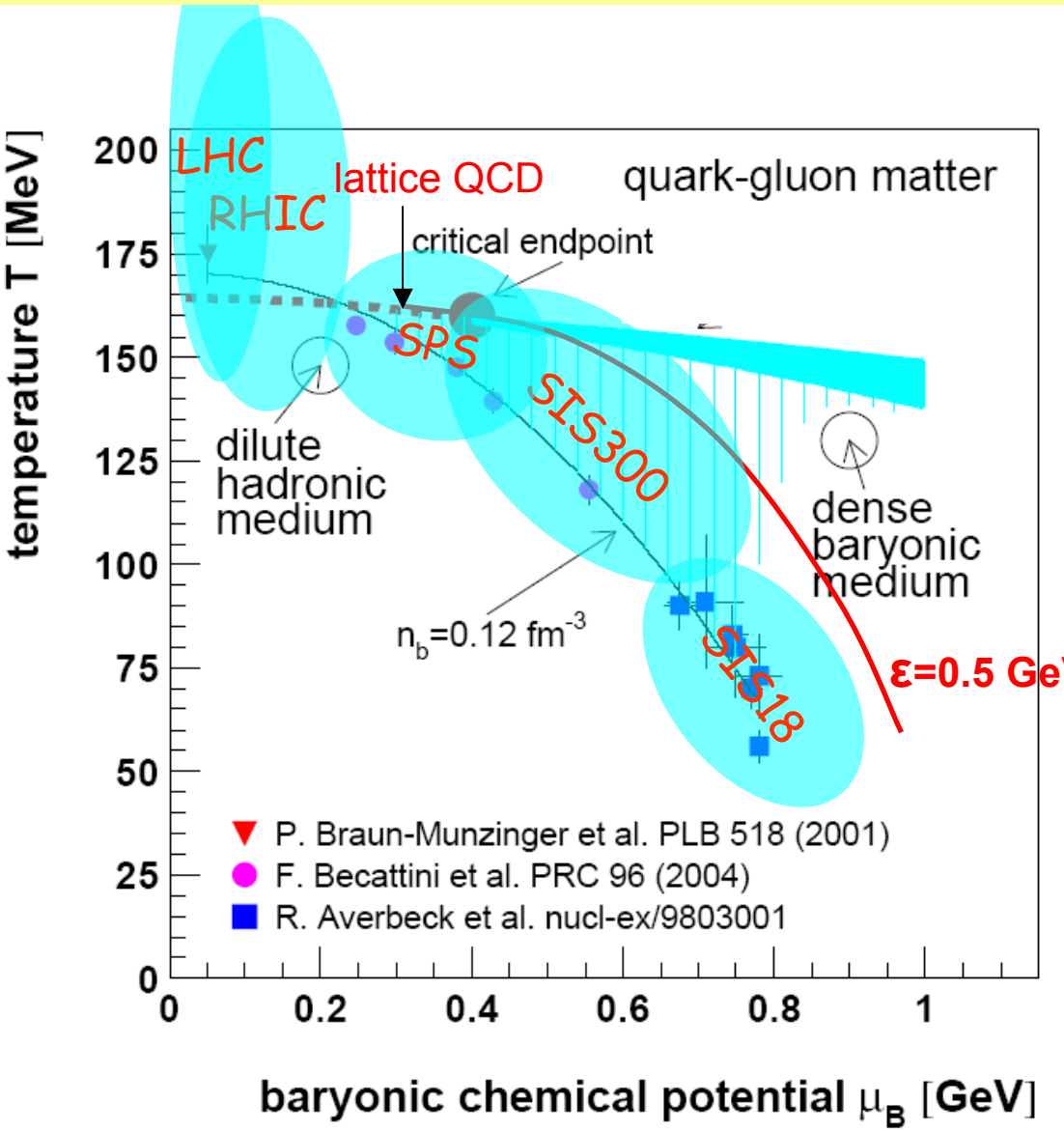


RHIC, LHC: high temperature, low baryon density

FAIR: moderate temperature, high baryon density


critical endpoint
P
liquid
T_c
gas
coexistence
V

Mapping the QCD phase diagram with heavy-ion collisions

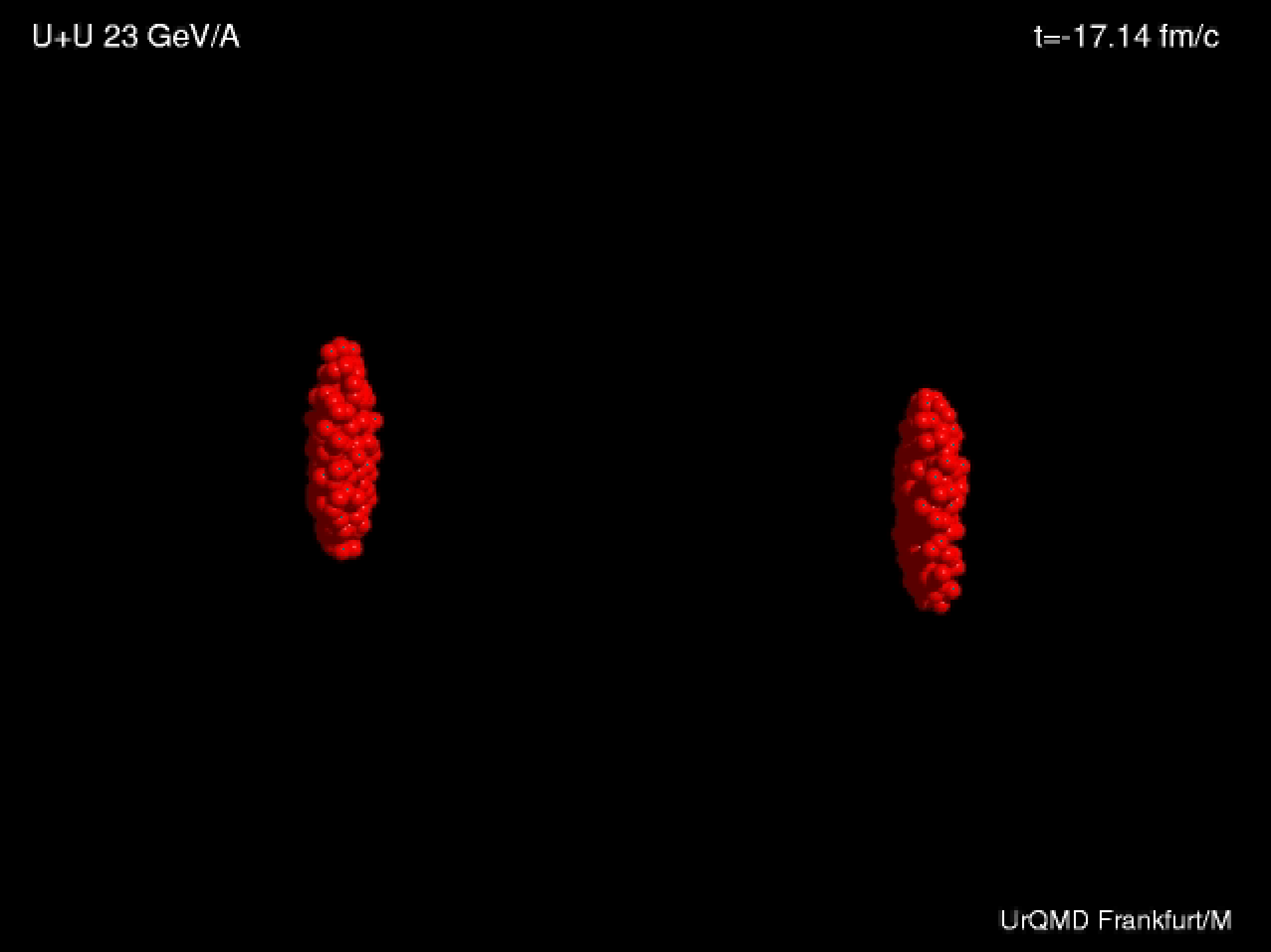


Critical endpoint:
Z. Fodor, S. Katz, hep-lat/0402006
S. Ejiri et al., hep-lat/0312006
μ_B < ≈400 MeV: crossover

baryon density:

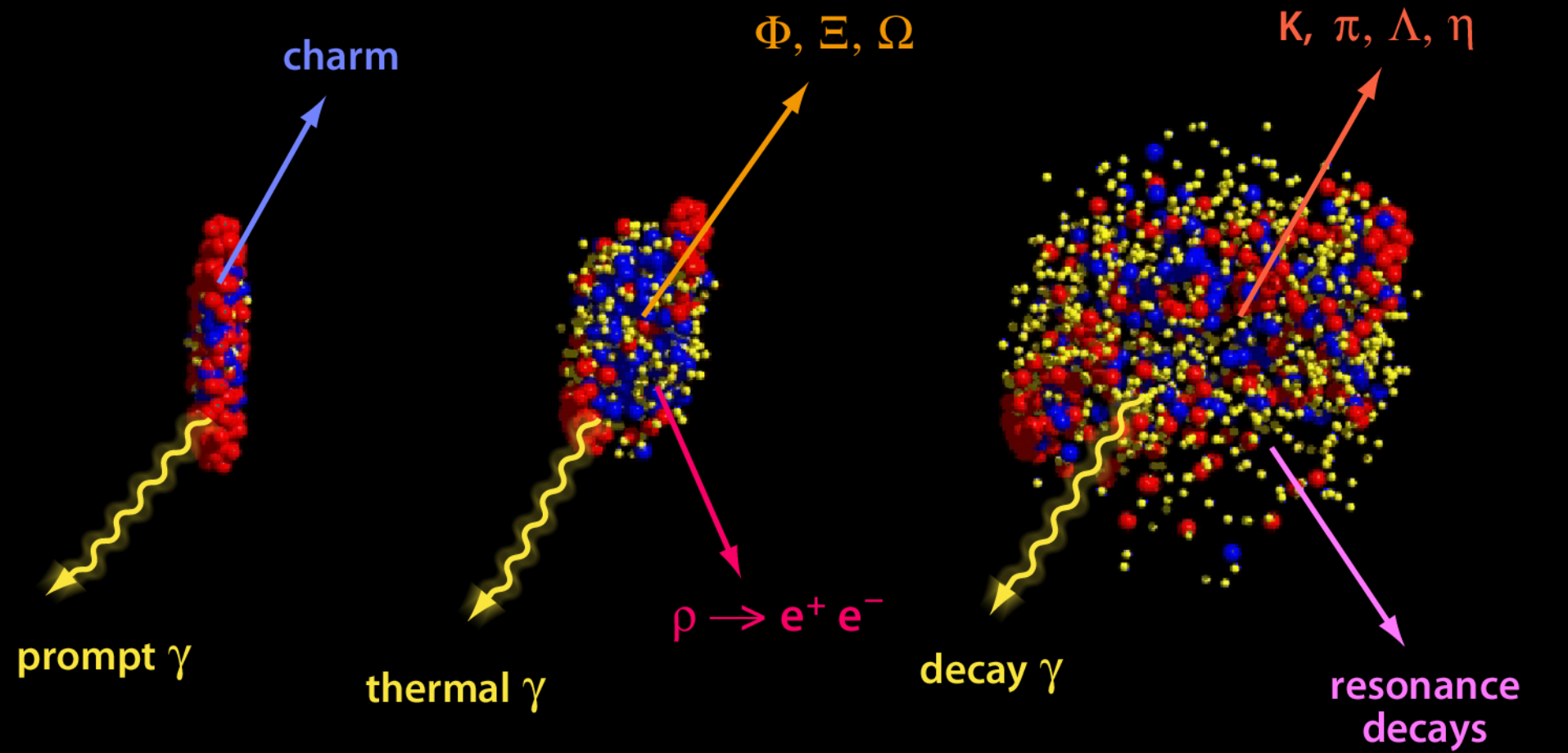
$$\rho_B \approx 4\,(mT/2\pi)^{3/2} \times [\exp((\mu_B - m)/T) - \exp((-\mu_B - m)/T)]$$

baryons - antibaryons


U+U 23 GeV/A
t=-17.14 fm/c
UrQMD Frankfurt/M

Diagnostic probes

U+U 23 AGeV



Compressed Baryonic Matter: physics topics and observables

Probing the equation-of-state at high ρ_B

Observables: collective flow of hadrons, particle production at threshold energies (open charm)

Search for the deconfinement phase transition at high ρ_B

- enhanced strangeness production ?

  Observables: K, Λ, Σ, Ξ, Ω

- anomalous charmonium suppression ?

  Observables: charmonium (J/ψ, ψ'), open charm (D^0, $D^{\pm}$)

Search for the critical endpoint

Observable: event-by-event fluctuations (K/π, p_T, ...)

Search for chiral symmetry restoration at high ρ_B

- in-medium modifications of hadrons

  Observables: ρ, ω, $\phi \rightarrow e^+e^-$, open charm, ...

Experimental program of CBM:

Observables:

Penetrating probes: ρ, ω, φ, J/ψ (vector mesons)
Strangeness: K, Λ, Σ, Ξ, Ω,
Open charm: D^0, $D^{\pm}$, D_s, Λ_c,
global features: collective flow, fluctuations, ..., exotica

Systematic investigations:

A+A collisions from 8 to 45 (35) AGeV, Z/A=0.5 (0.4)
p+A collisions from 8 to 90 GeV
p+p collisions from 8 to 90 GeV
Beam energies up to 8 AGeV: HADES

Detector requirements

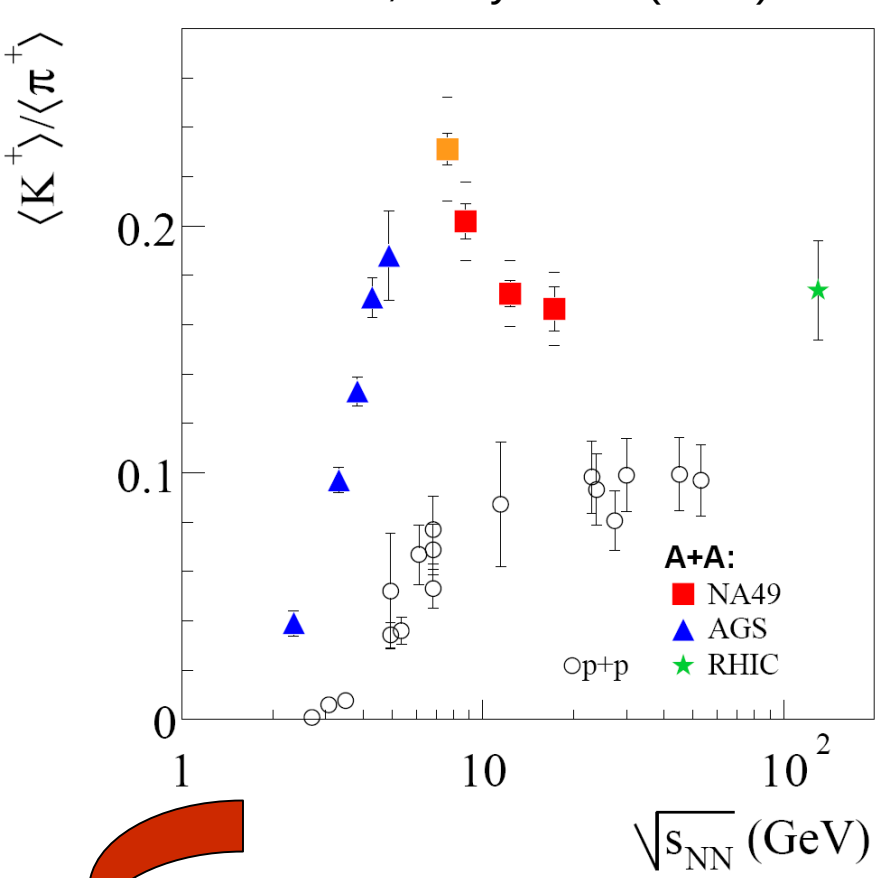
Large geometrical acceptance
good hadron and electron identification
excellent vertex resolution
high rate capability of detectors, FEE and DAQ

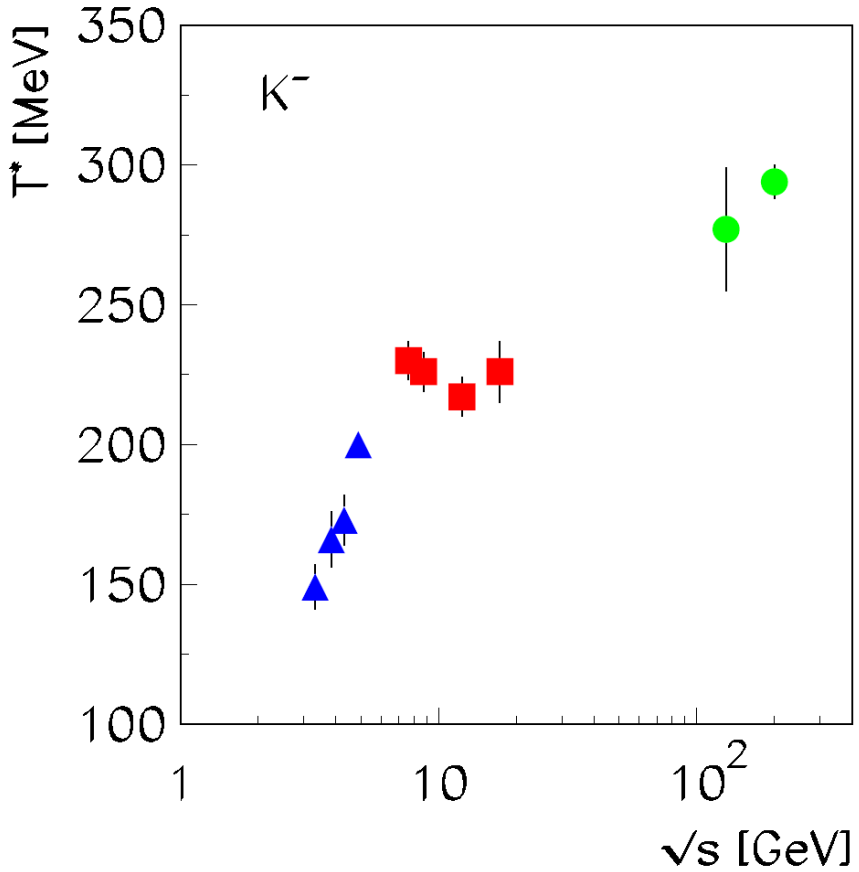
Large integrated luminosity:

High beam intensity and duty cycle,
Available for several month per year

Data at FAIR energies : pion and kaon production in central Au+Au and Pb+Pb collisions

M. Gazdzicki, J.Phys. G30 (2004) S161

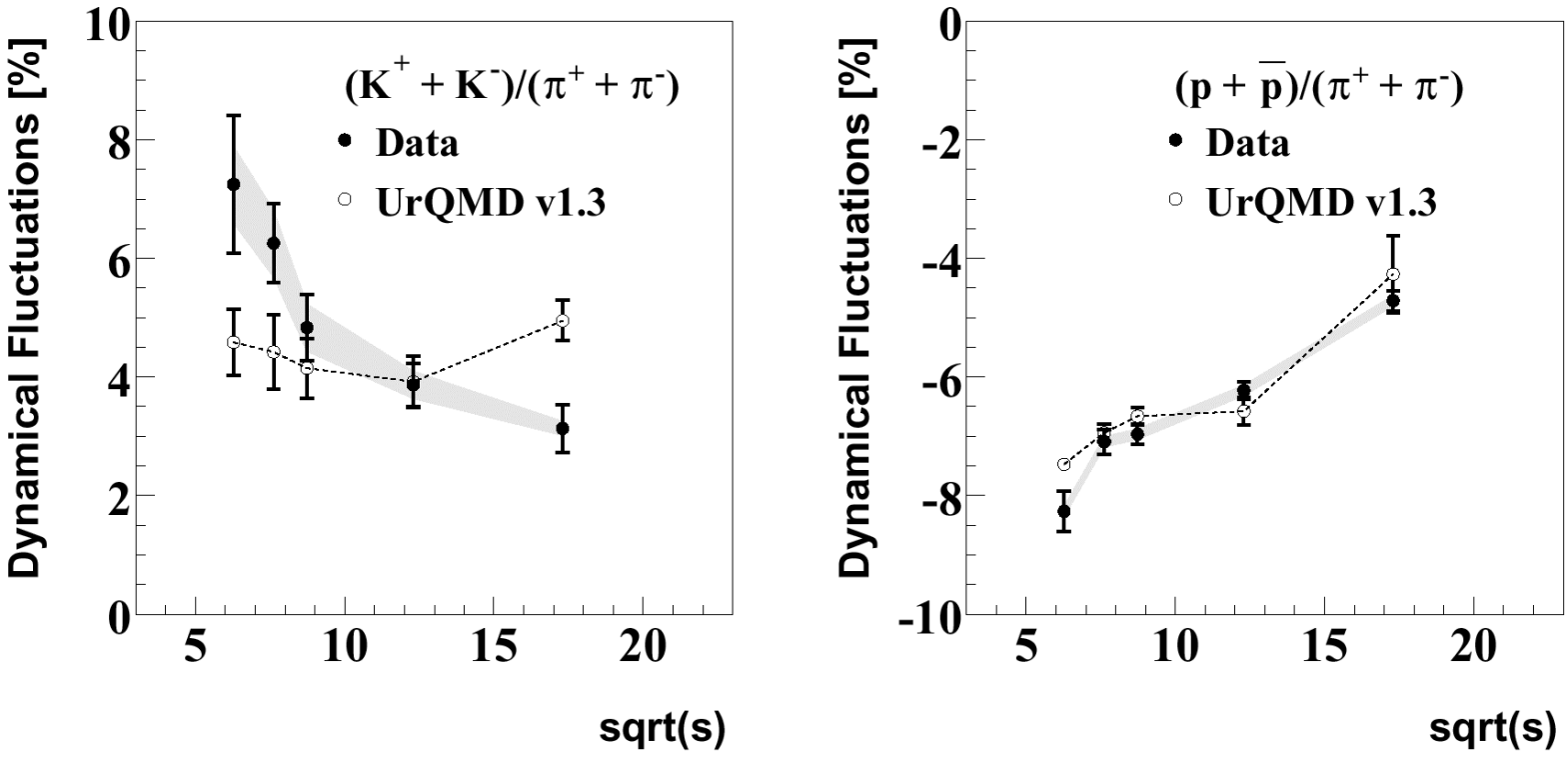




signature of a phase transition around 30 AGeV ?

Data at FAIR energies: dynamical fluctuations of particle ratios measured event-by event

NA49, nucl-ex/0403035

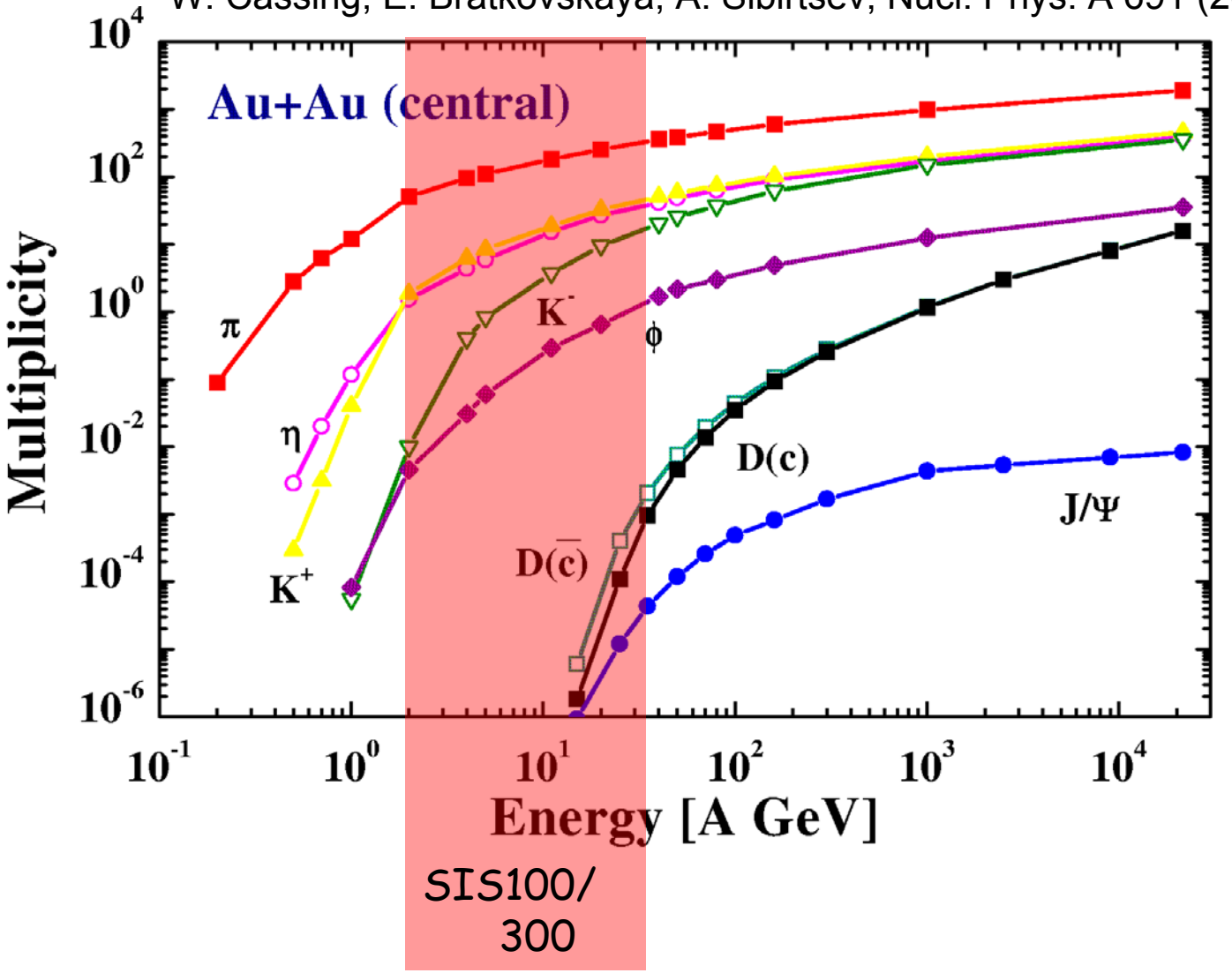


- K/π : increase towards low energies (20 AGeV) , not reproduced by UrQMD transport code
- p/π : correlation due to resonance decays

Theoretical prediction of meson production in central Au+Au collisions

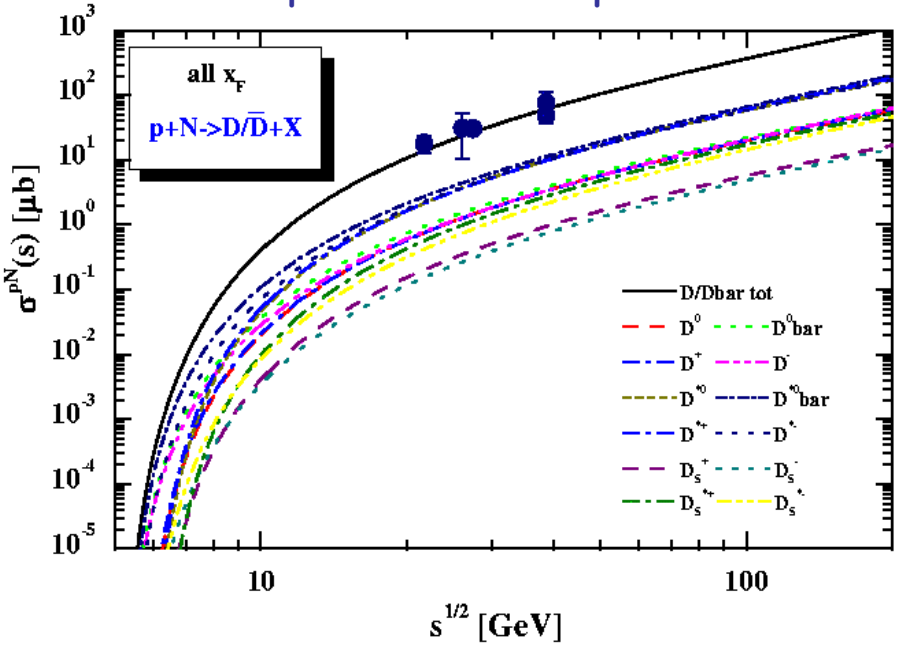
Hadron String Dynamics transport calculation

W. Cassing, E. Bratkovskaya, A. Sibirtsev, Nucl. Phys. A 691 (2001) 745



D-meson measurements

D meson production in pN collisions



Some hadronic decay modes

$D^{\pm}$ ($c\tau$ = 317 μm):

$D^+ \rightarrow K^0\pi^+$ (2.9±0.26%)

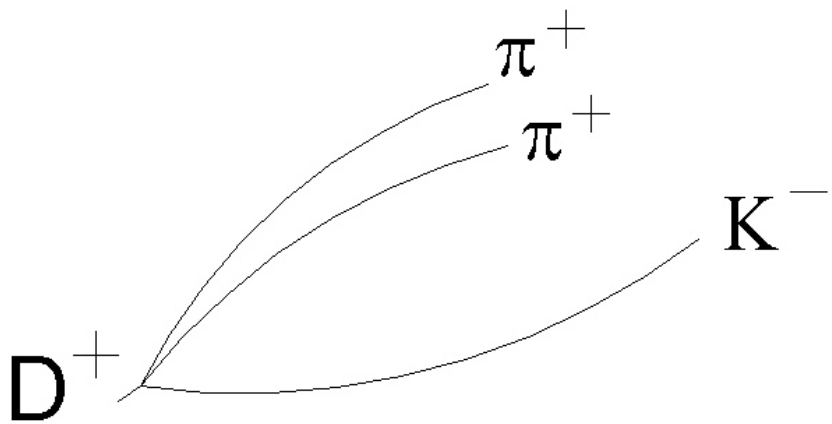
$D^+ \rightarrow K^-\pi^+\pi^+$ (9 ± 0.6%)

D^0 ($c\tau$ = 124.4 μm):

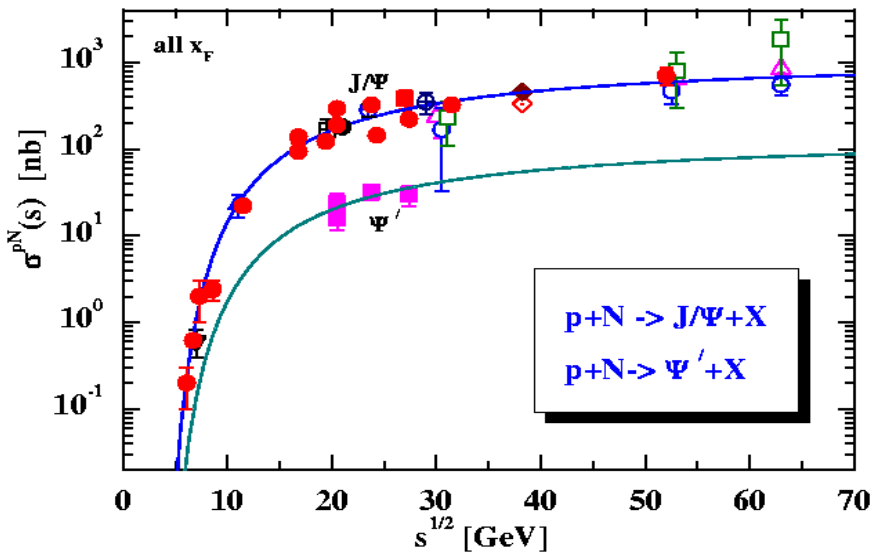
$D^0 \rightarrow K^-\pi^+$ (3.9 ± 0.09%)

$D^0 \rightarrow K^-\pi^+ \pi^+ \pi^-$ (7.6 ± 0.4%)

Measure displaced vertex
with resolution of ≈ 50 μm !



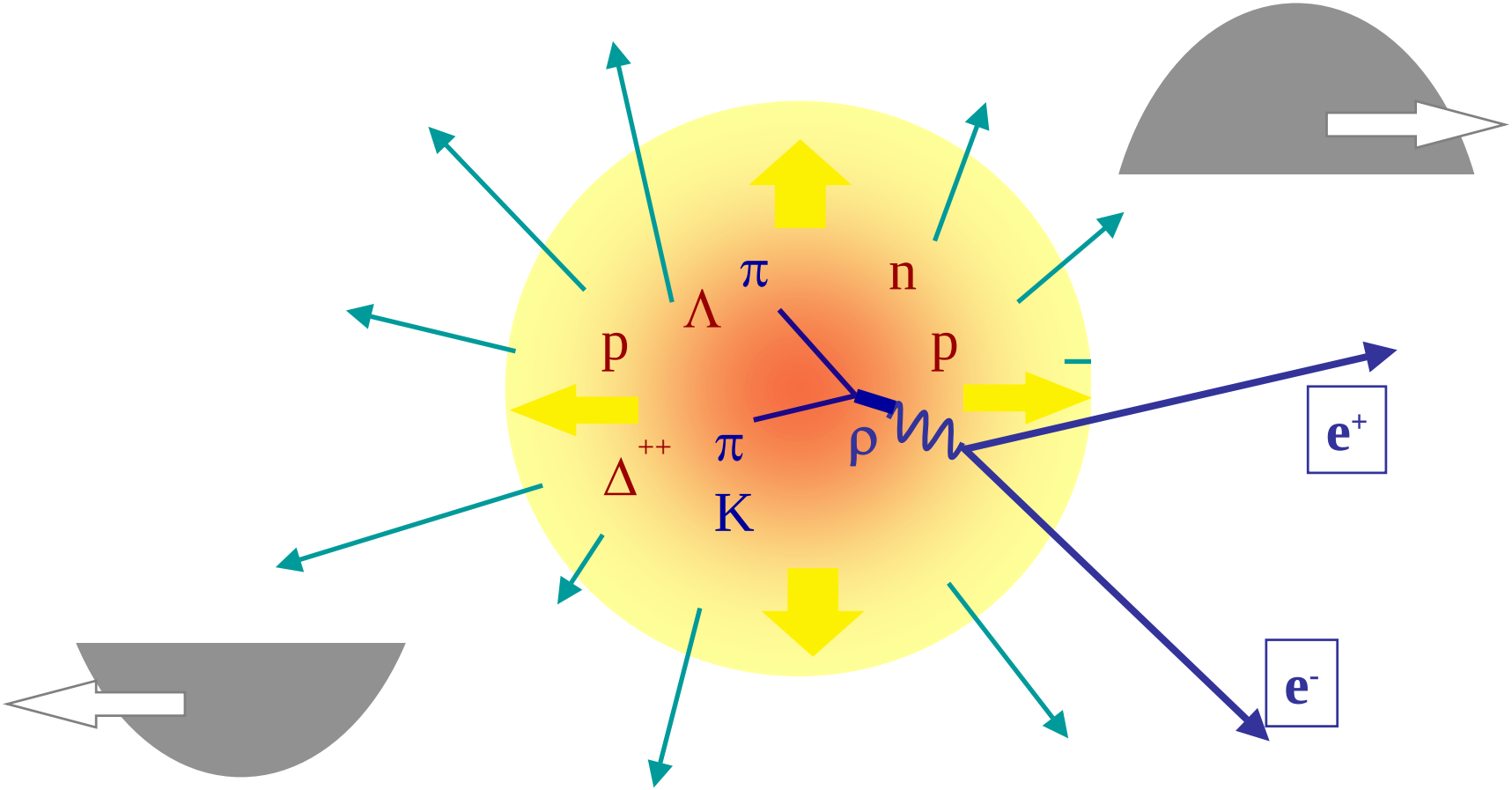
J/ψ measurements at FAIR energies



central collisions 25 AGeV Au+Au 158 AGeV Pb+Pb

J/ψ multiplicity	$1.5 \cdot 10^{-5}$	$1 \cdot 10^{-3}$
beam intensity	$1 \cdot 10^{9}$/s	$2 \cdot 10^{7}$/s
interactions	$1 \cdot 10^{7}$/s (1%)	$2 \cdot 10^{6}$/s (10%)
central collisions	$1 \cdot 10^{6}$/s	$2 \cdot 10^{5}$/s
J/ψ rate	15/s	200/s
6% J/ψ $\rightarrow e^+e^-$ ($\mu^+\mu^-$)	0.9/s	12/s
spill fraction	0.8	0.25
acceptance	0.25	≈ 0.1
J/ψ measured	0.17/s	≈ 0.3/s
	≈ $1 \cdot 10^{5}$/week	≈ $1.8 \cdot 10^{5}$/week

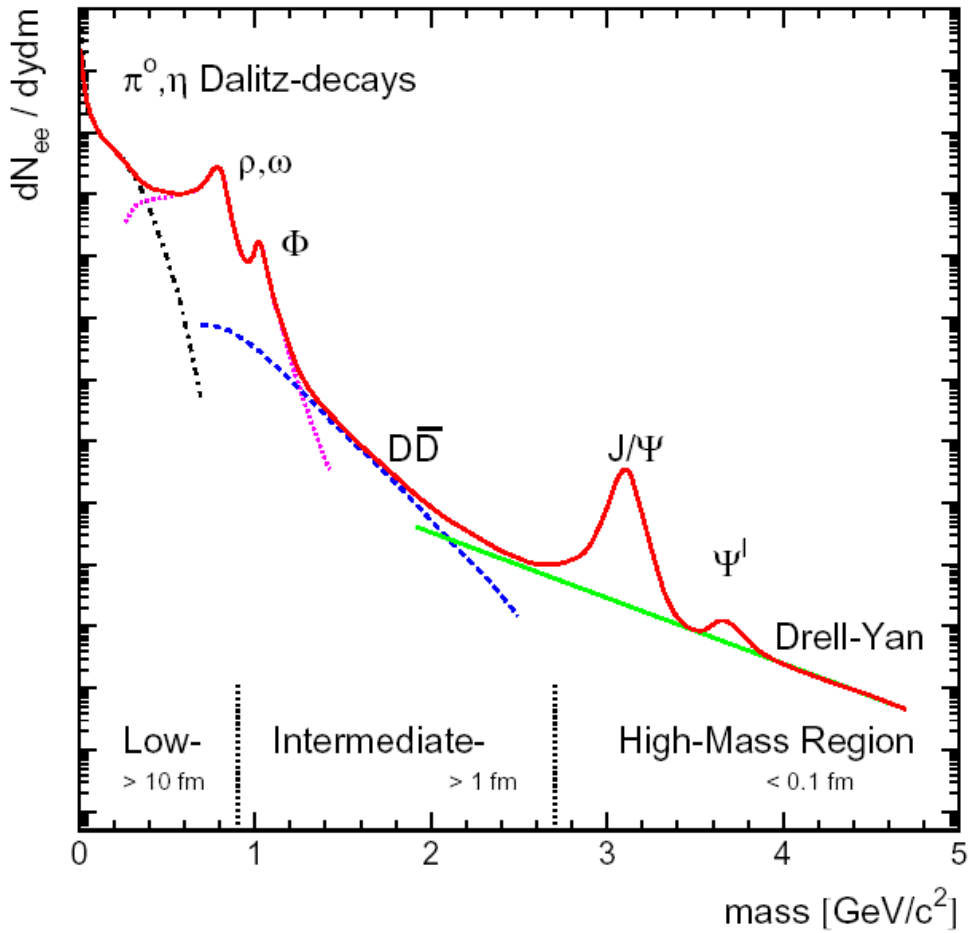
Looking into the fireball …



… using penetrating probes:

short-lived vector mesons decaying into electron-positron pairs

Dilepton Sources in Heavy-Ion Collisions

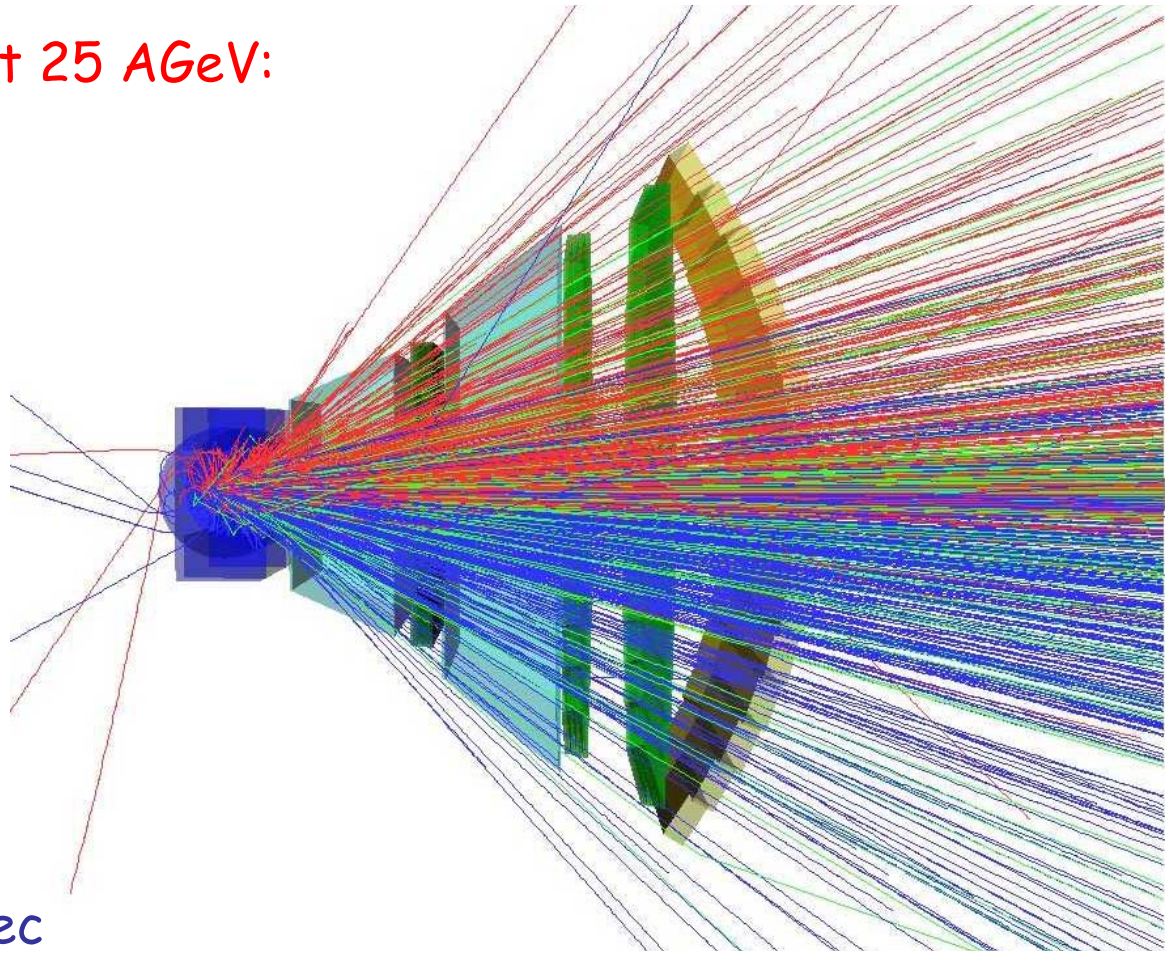


no ρ,ω,φ → e^+e^- measurement between 2 and 40 AGeV
no J/ψ → e^+e^- ($\mu^+\mu^-$) measurement below 160 AGeV
no D-meson measurement below RHIC energies

Experimental challenges

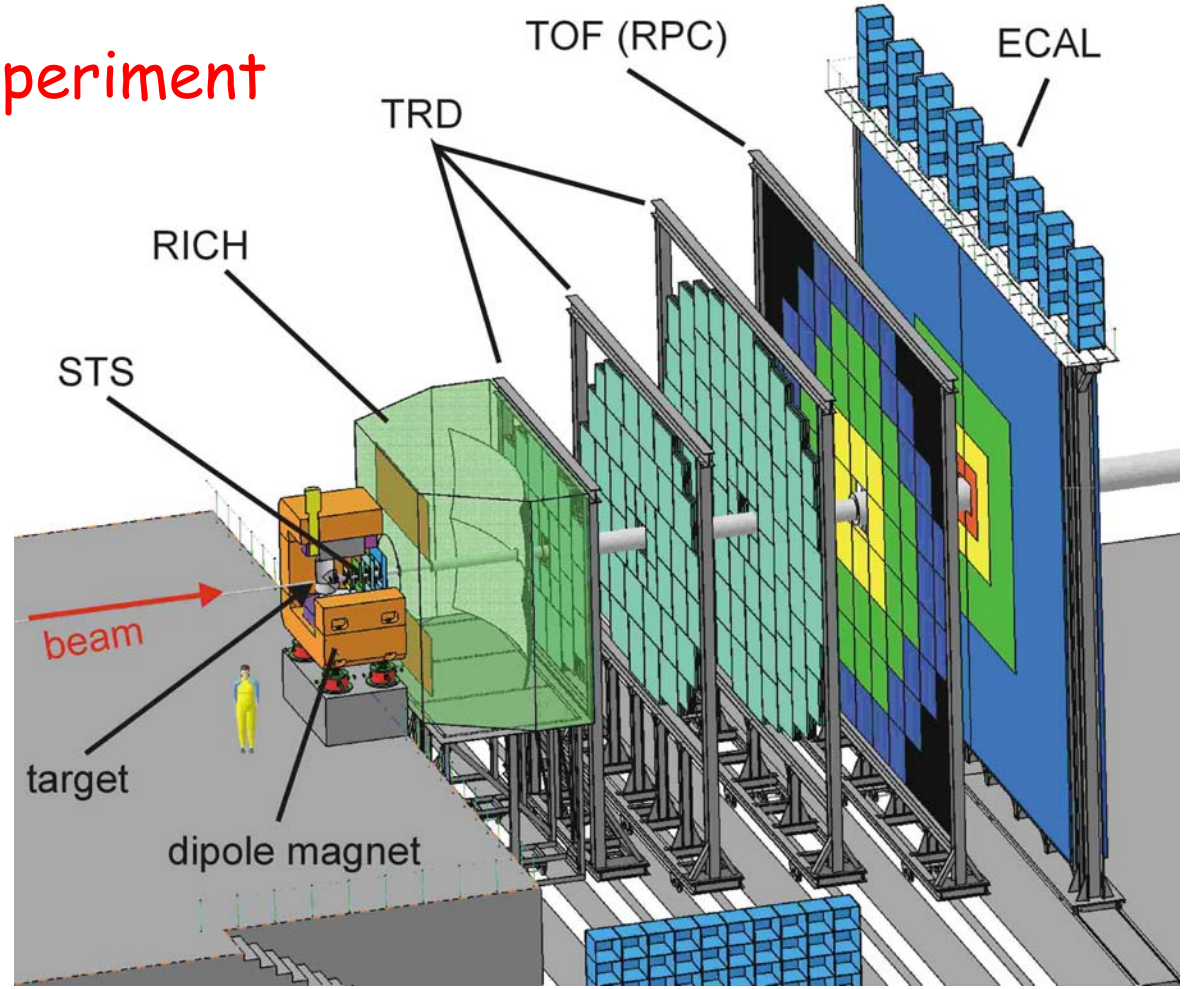
Central Au+Au collision at 25 AGeV:
URQMD + GEANT4

160 p
400 π^-
400 π^+
44 K^+
13 K^-



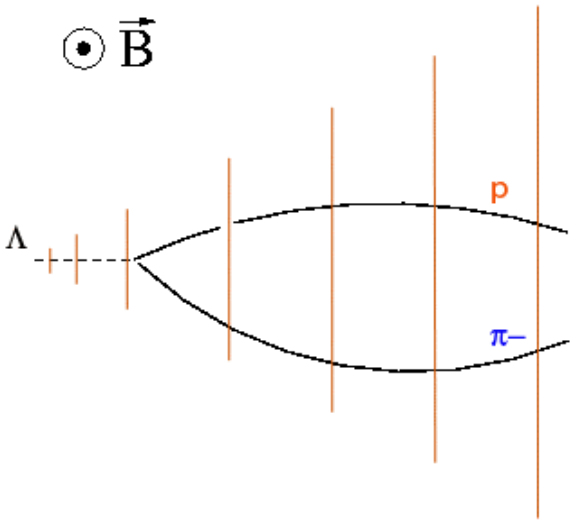
- 10^7 Au+Au reactions/sec
  (beam intensities up to 10^9 ions/sec, 1 % interaction target)
- determination of (displaced) vertices with high resolution ($\approx$ 50 μm)
- identification of electrons and hadrons

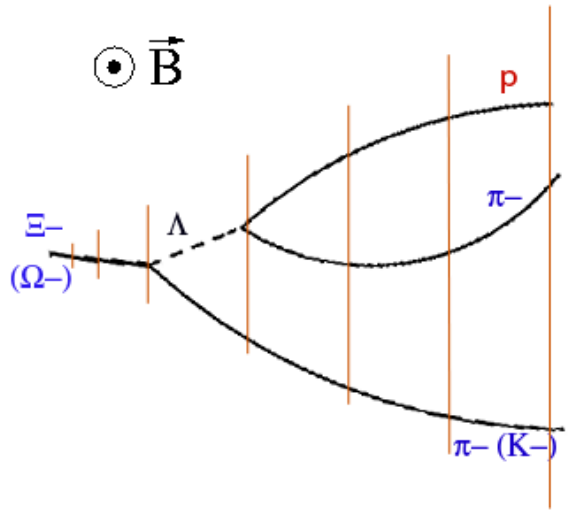
The CBM Experiment

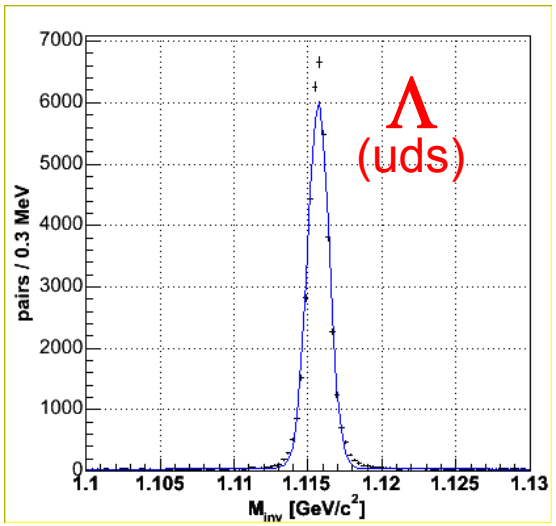


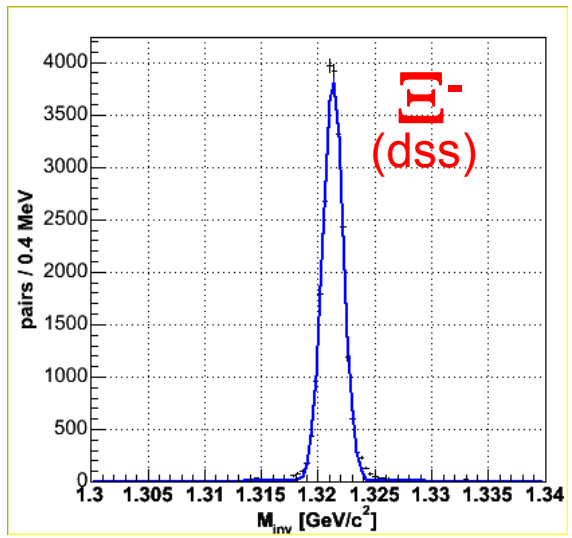
- Radiation hard Silicon (pixel/strip) Tracking System in a magnetic dipole field
- Electron detectors: RICH & TRD & ECAL: pion suppression better 10^4
- Hadron identification: TOF-RPC
- Measurement of photons, π, η, and muons: electromagn. calorimeter (ECAL)
- High speed data acquisition and trigger system

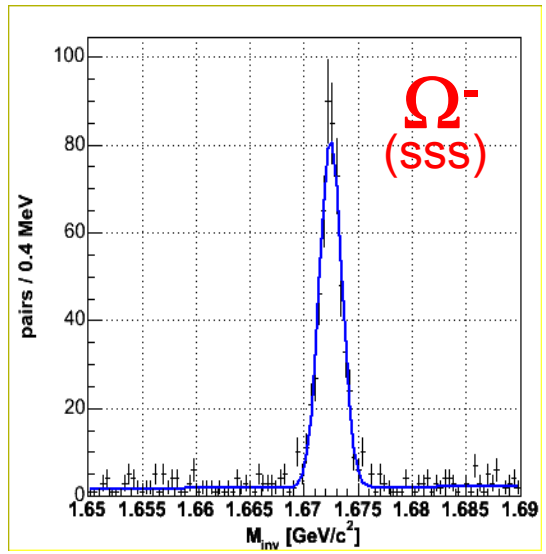
Hyperon detection with STS without p, K, π identification









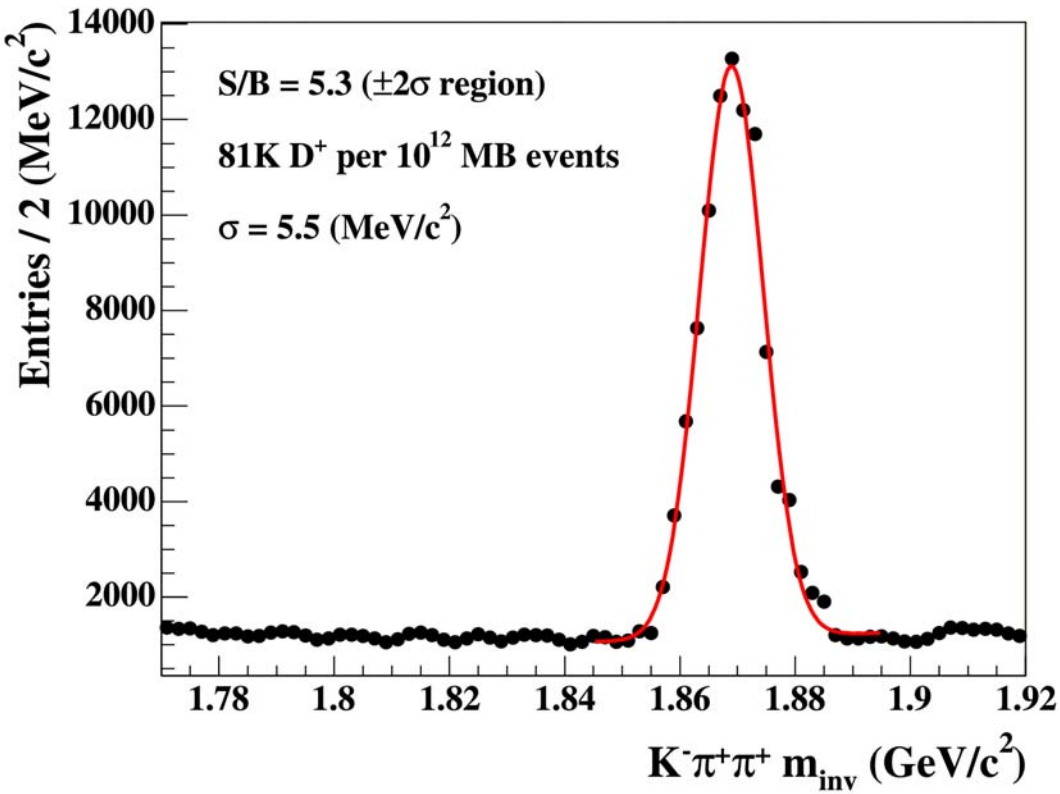


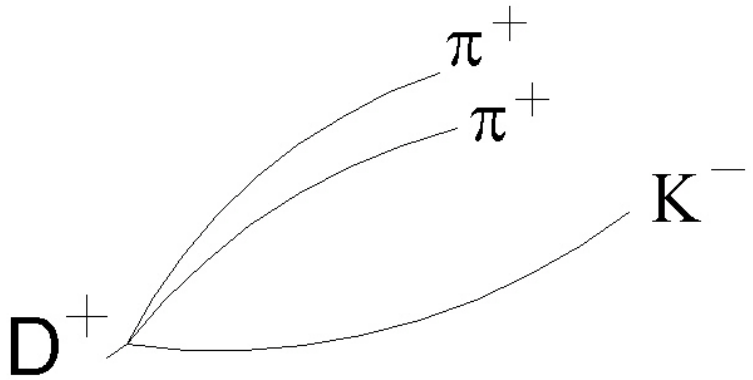
efficiency 15.8% 6.7% 7.7%

D^+ mesons from Au+Au collisions at 25 AGeV

Track reconstruction:
realistic magnetic field,
7 pixel detectors (no strips yet),
no particle ID required

D^+ production cross section from HSD
25 AGeV Au+Au from UrQMD



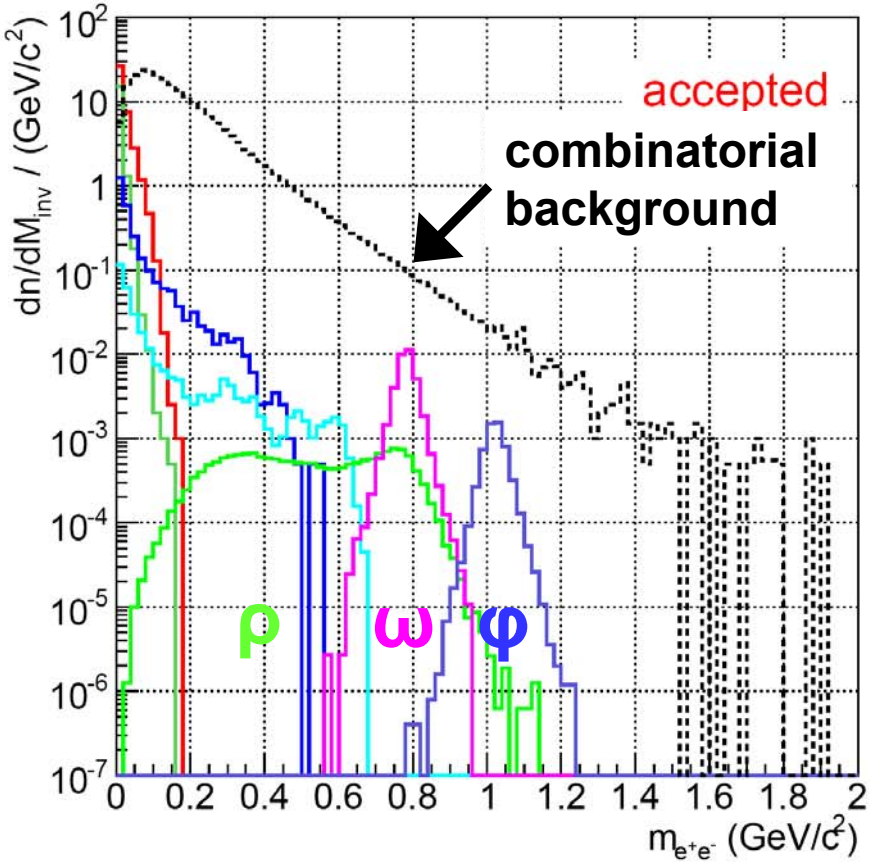


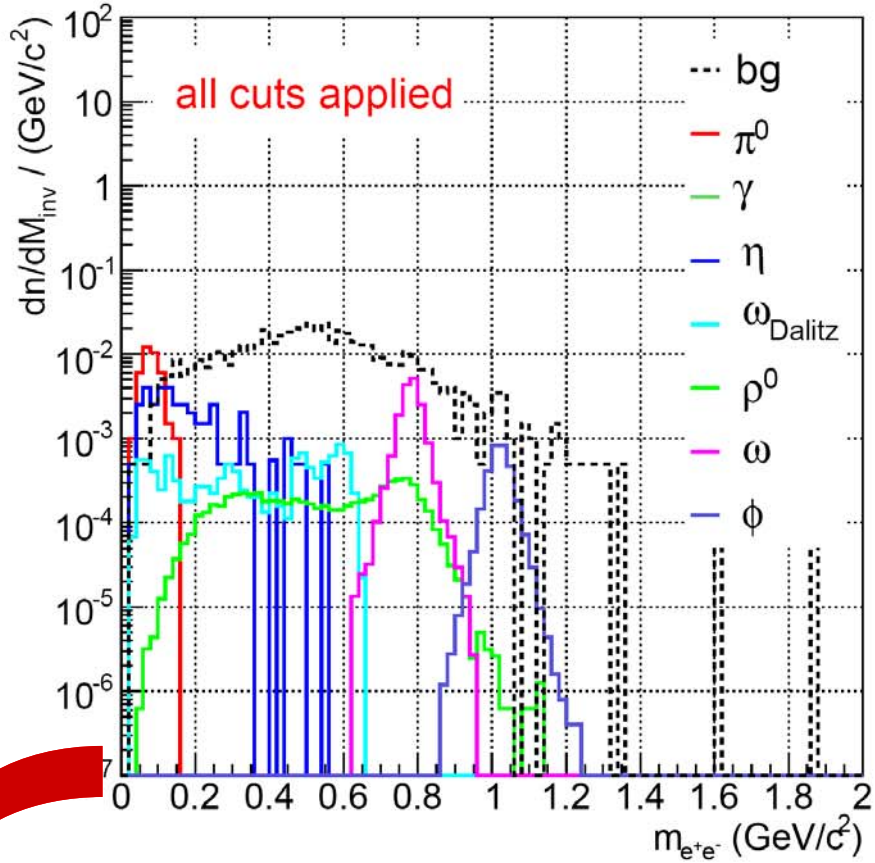
81000 D^+ mesons registered in 10^{12} min. bias Au+Au collisions at 25 AGeV
(→ 1 – 100 days depending on read-out speed of Silicon vertex detector)

Electron-positron pairs from Au+Au collisions at 25 AGeV

Simulations without track reconstruction & electron identification

Experimental challenge: branching ratios ~ 10^{-5}-10^{-4} for $\rho,\omega,\varphi \rightarrow e^+e^-$





major sources of physical background:

- Dalitz decays $\pi^0 \rightarrow e^+e^-\gamma$
- gamma conversion $\gamma \rightarrow e^+e^-$

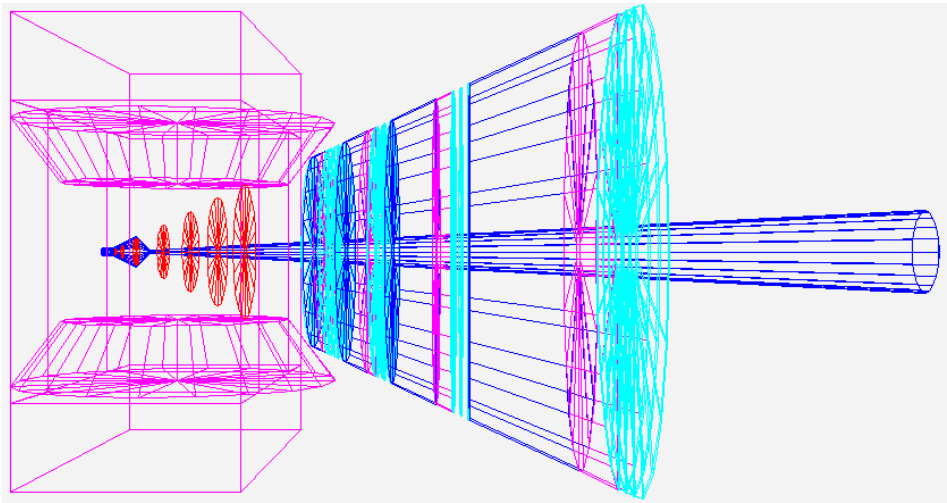
Signal/Background (±1.4 σ):

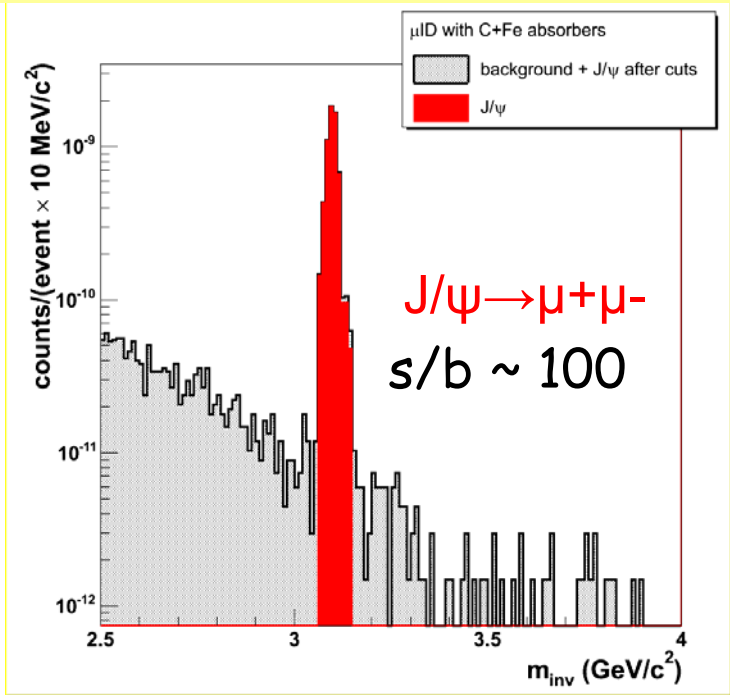
s/b = 0.5 at mass of ω meson

s/b = 0.3 at mass of φ meson

Alternative option: μ ID system with absorber

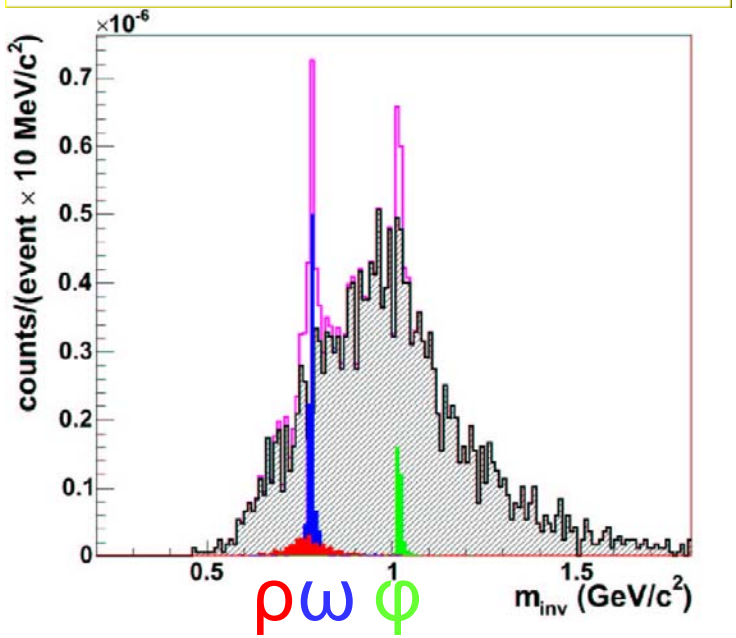
C/Fe absorbers + detector layers





Simulations Au+Au 25 AGeV:

- track reconstruction from hits in STS and muon chambers
- muon ID: tracks from STS to muon chamber behind absorber
- vector meson multiplicities from HSD transport code



Experimental requirements and ongoing R&D

Silicon Pixel Detector:
- low materal budget: d < 200 μm
- single hit resolution < 20 μm
- radiation hardness (dose 10^{15} n_{eq}/cm^2)
- fast read out

Si-Strip detectors:
- pitch 50 μm
- thickness 200 μm
- double sided, stereo angle 15°
- Area 2 m^2

Ring Imaging Cherenkov Detector:
- e/π discrimination > 100
- hadron blind up to about 6 GeV/c
- low mass mirrors
- fast UV detector

Muon detection system:
- fast gas chambers (GEM)
- high granularity

Transition Radiation Detector:
- e/π discrimination of > 100 (p > 1 GeV/c)
- High rate capability up to 100 kHz/cm^2
- Position resolution of about 200 μm
- Large area (≈ 450 - 650 m^2, 9 – 12 layers)

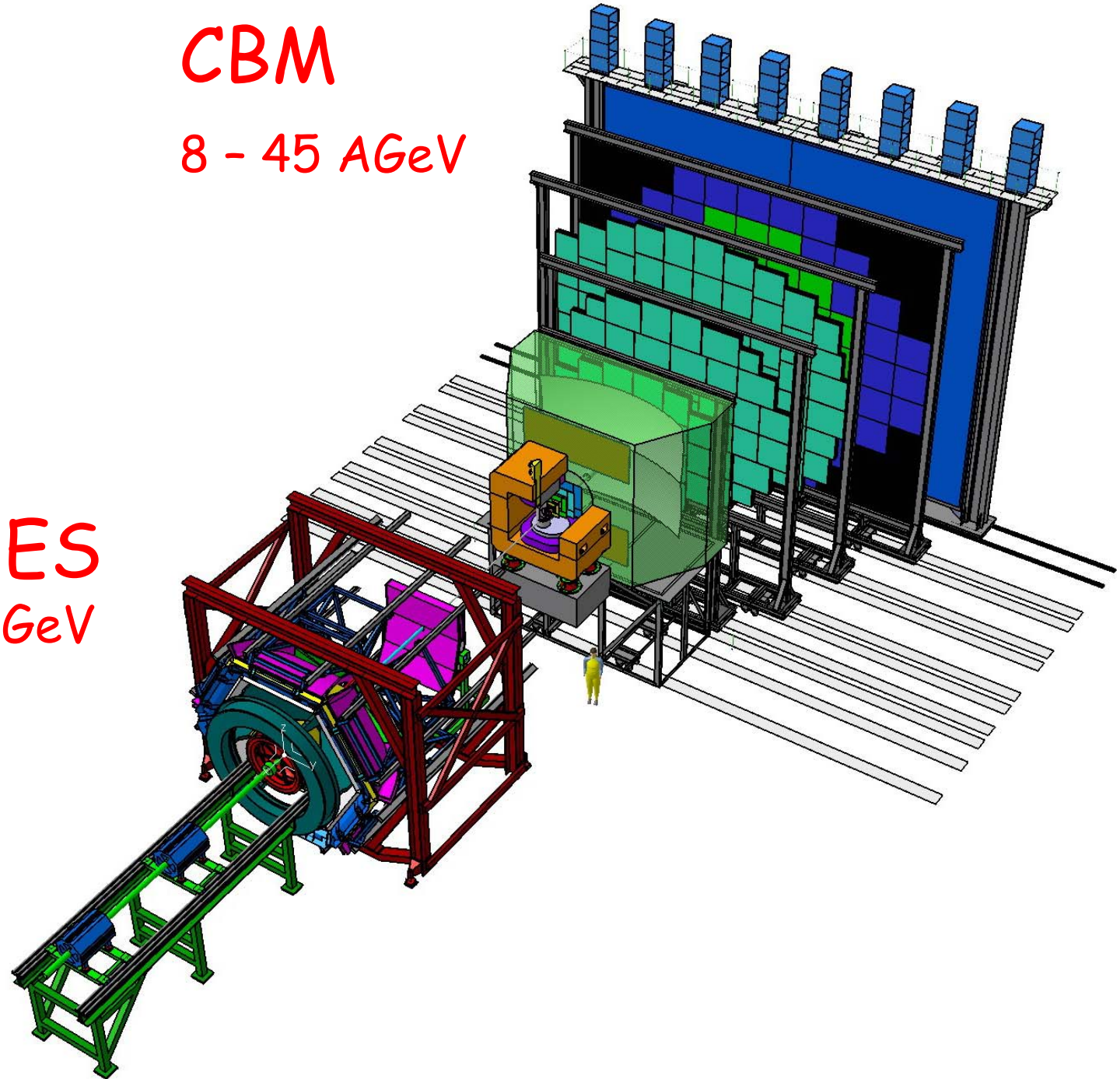
Resistive Plate Chamber (ToF-RPC):
- Time resolution ≤ 80 ps
- High rate capability up to 25 kHz/cm^2
- Efficiency > 95 %
- Area 100 m^2

Electromagnetic Calorimeter:
- energy resolution of $5\%/\sqrt{E(GeV)}$
- high rate capability up to 15 kHz
- e/π discrimination of 50-200
- Area 100 m^2

FEE and DAQ:
self triggered digitization, dead time free

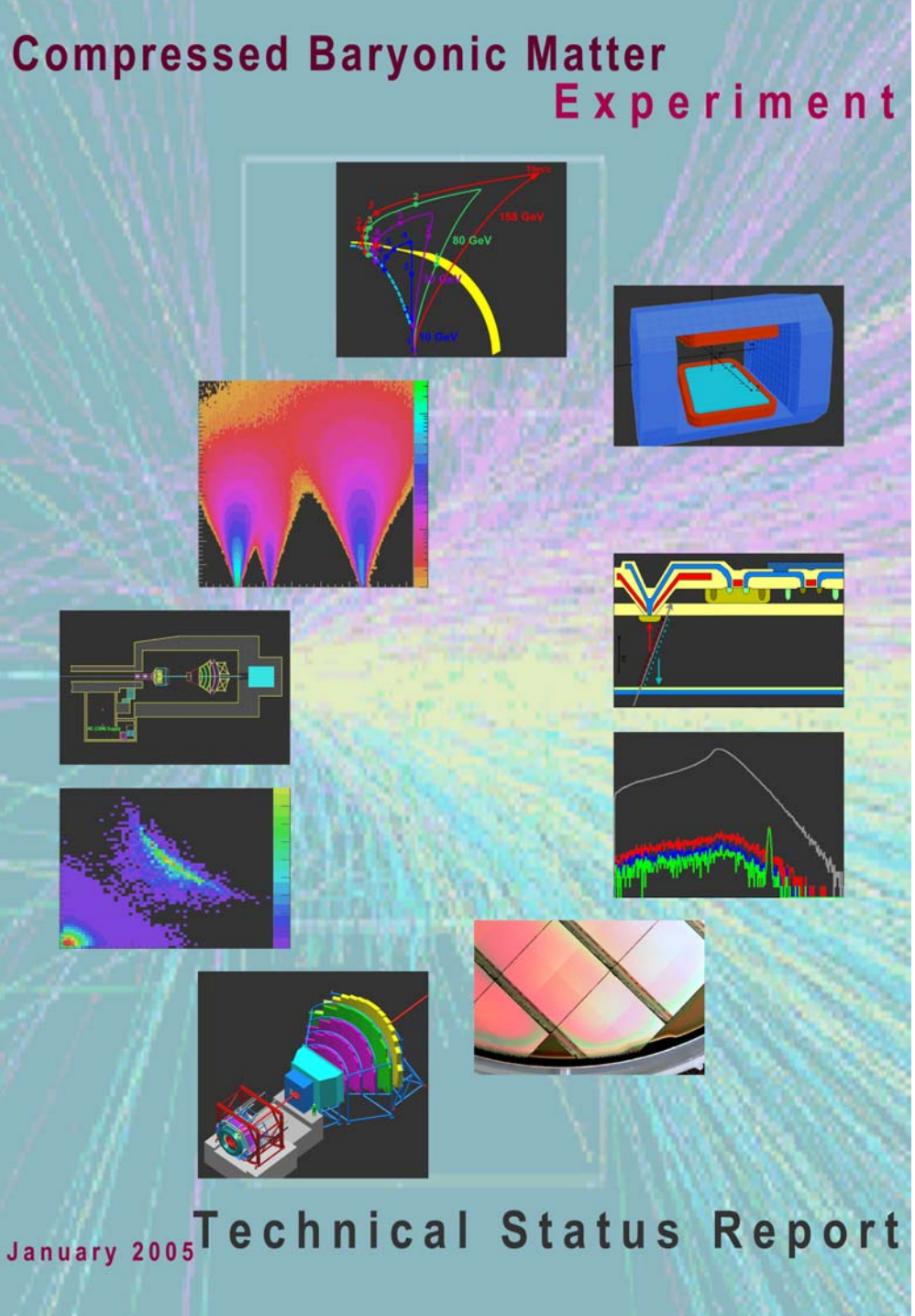
CBM

8 – 45 AGeV



HADES

2 – 8 AGeV



http://www.gsi.de/fair/experiments/CBM

Next steps:

- CBM Technical Proposal 2007
- CBM Physics Book
  Workshop at ECT* in Trento
  May 29 - June 2, 2006
  "The physics of high baryon density"

CBM Collaboration : 41 institutions, > 350 Members

Croatia:
RBI, Zagreb

China:
Wuhan Univ.
Hefei Univ.

Cyprus:
Nikosia Univ.

Czech Republic:
CAS, Rez
Techn. Univ. Prague

France:
IReS Strasbourg

Hungaria:
KFKI Budapest
Eötvös Univ. Budapest

India:
VECC Kolkata

Korea:
Korea Univ. Seoul
Pusan National Univ.

Norway:
Univ. Bergen

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

Poland:
Krakow Univ.
Warsaw Univ.
Silesia Univ. Katowice

Portugal:
LIP Coimbra

Romania:
NIPNE Bucharest

Russia:
CKBM, St. Petersburg
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:
Shevshenko Univ. , Kiev