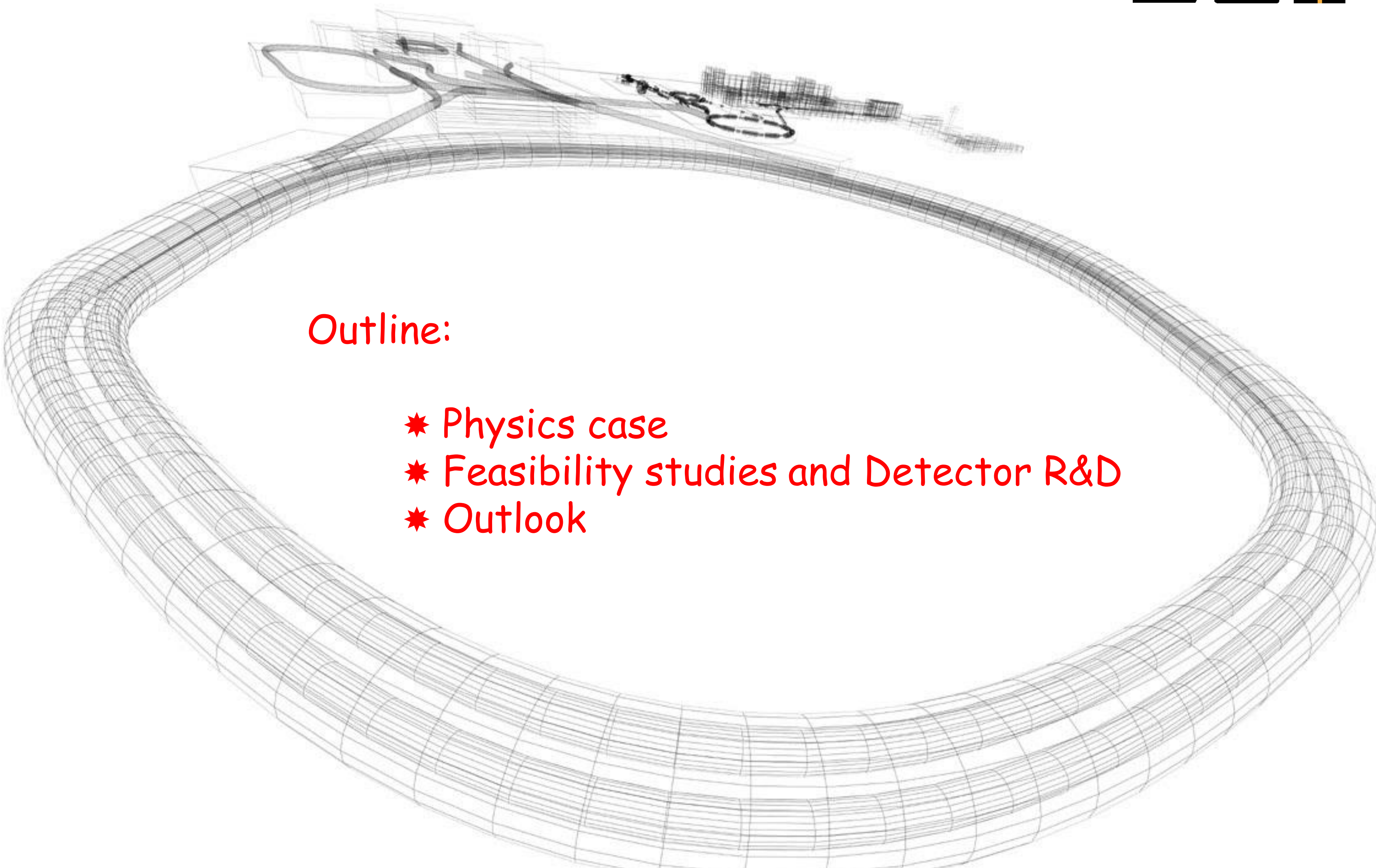
# The Compressed Baryonic Matter Experiment at FAIR

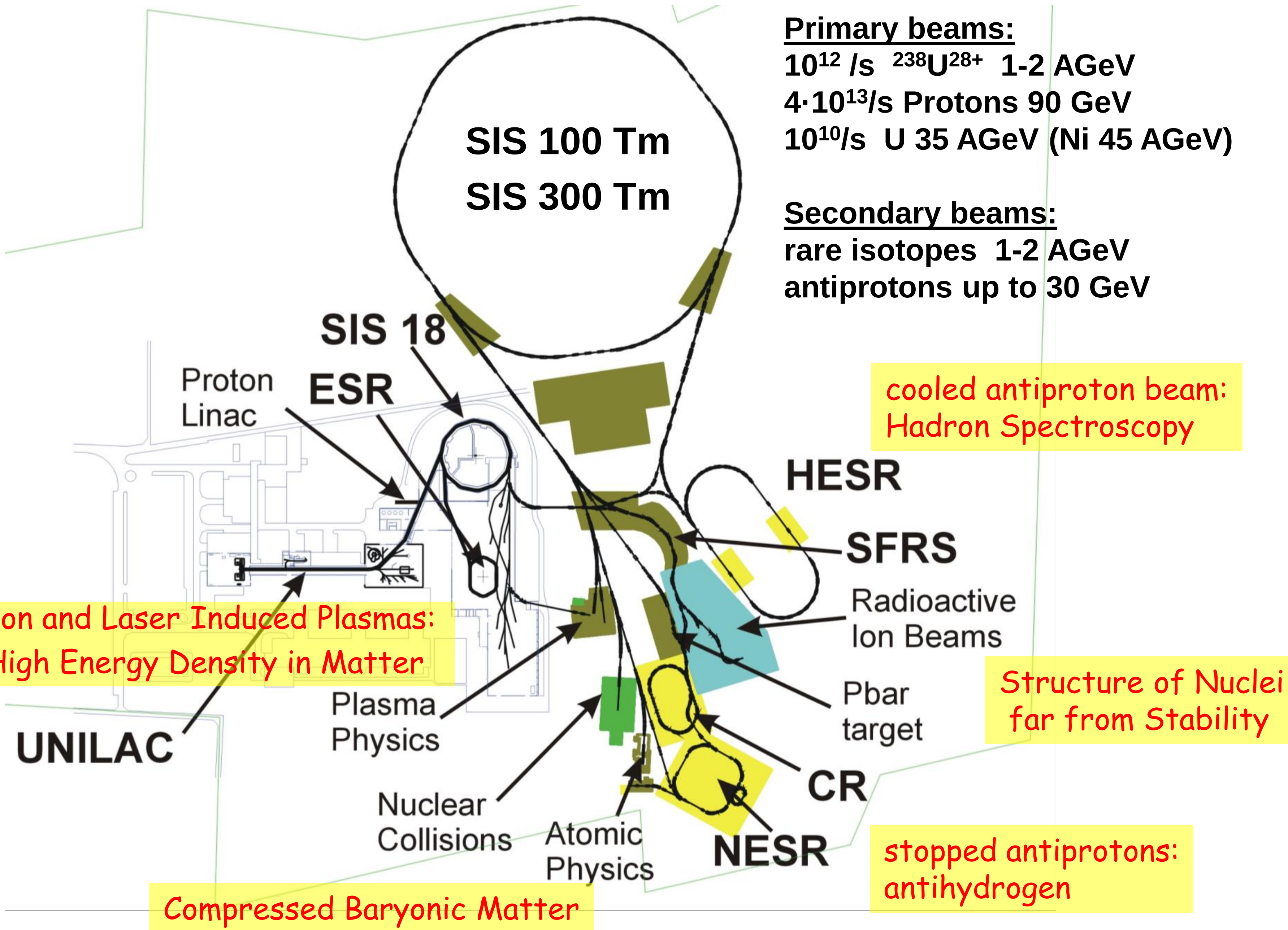
Peter Senger Seoul, April 21, 2005



Outline:

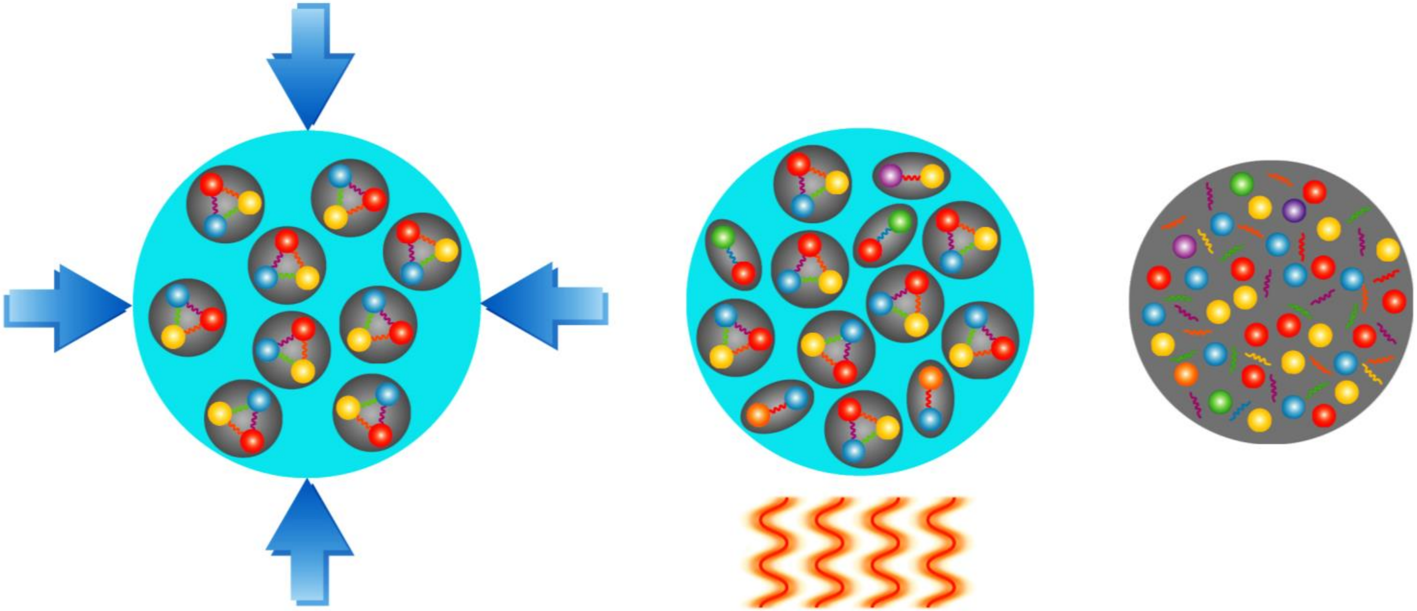
- Physics case
- Feasibility studies and Detector R&D
- Outlook

# The future Facility for Antiproton an Ion Research (FAIR)



# States of strongly interacting matter

baryons hadrons partons

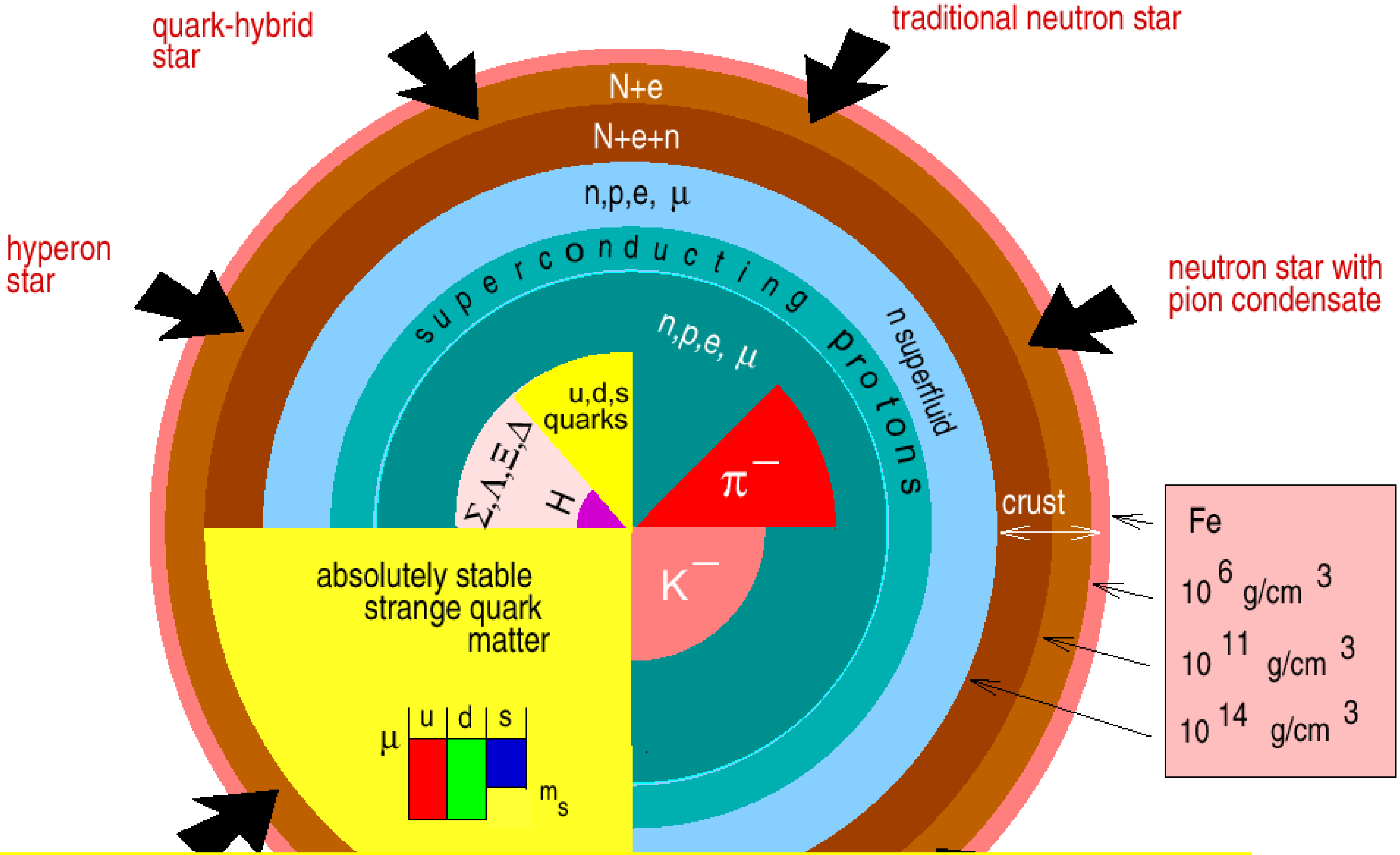


Compression + heating = quark-gluon matter

(pion production)

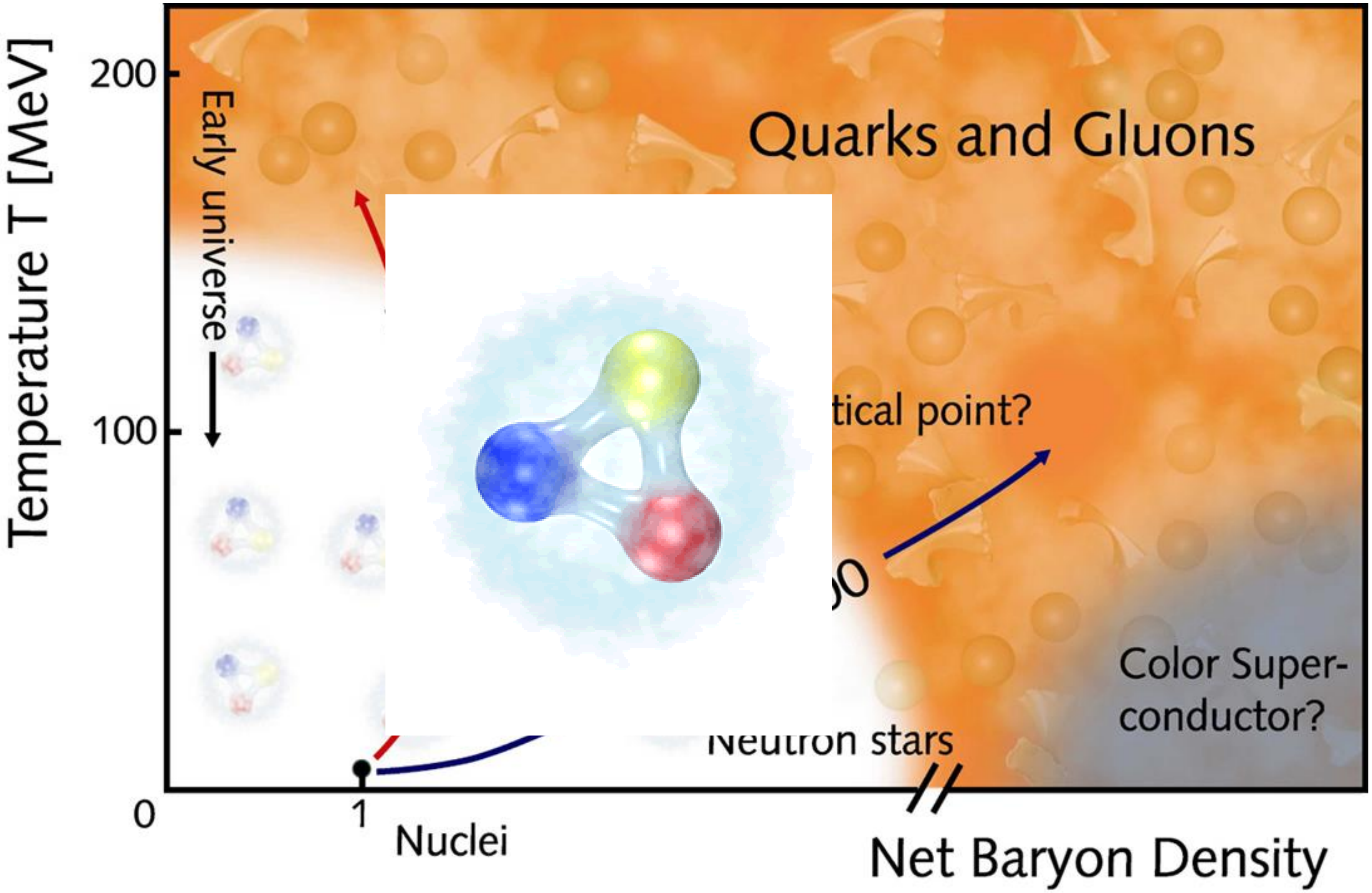
Neutron stars Early universe

# Strongly interacting matter in neutron stars




"Strangeness" of dense matter ?
In-medium properties of hadrons ?
Compressibility of nuclear matter?
Deconfinement at high baryon densities ?

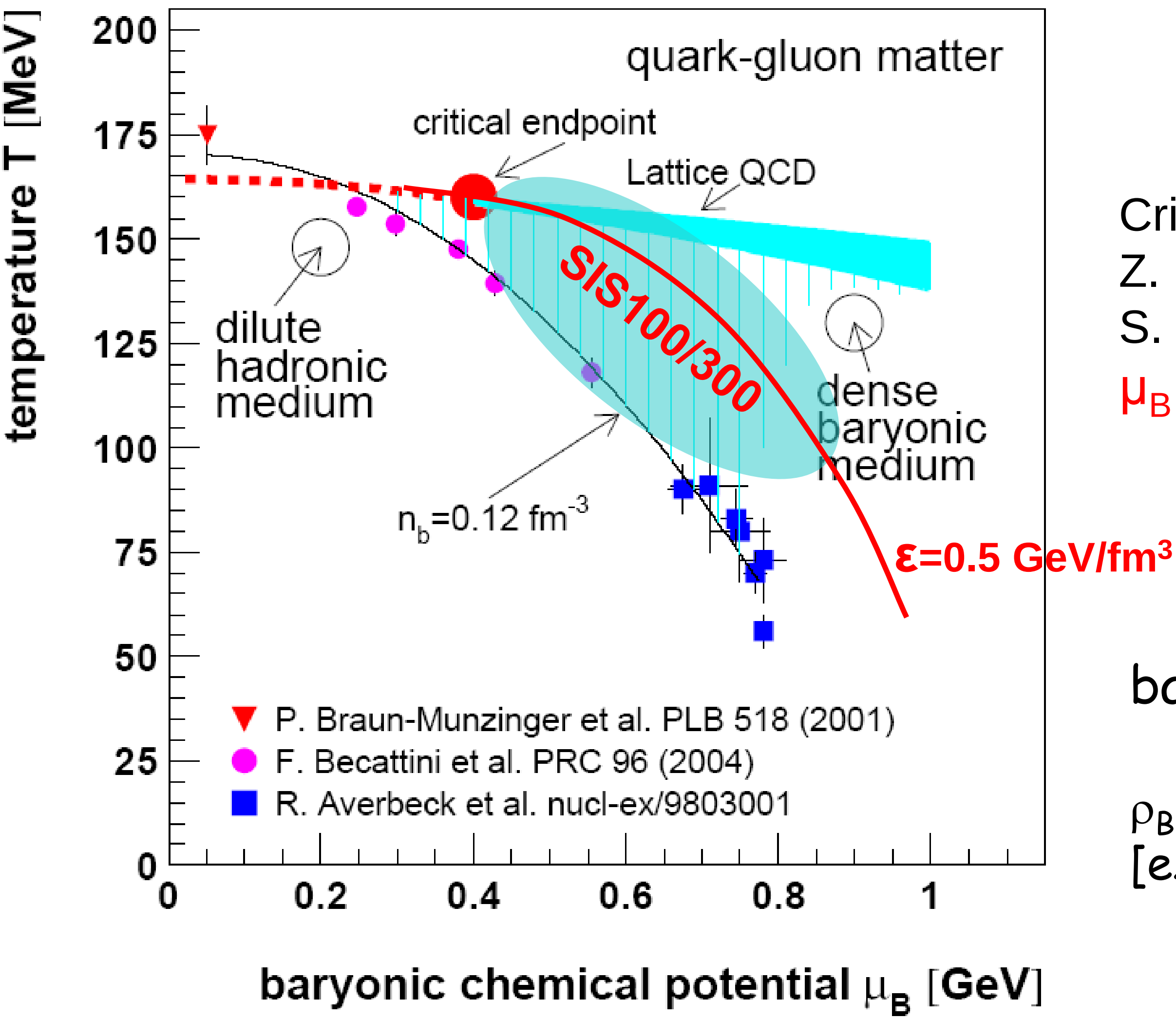
# The phase diagram of strongly interacting matter




RHIC, LHC: high temperature, low baryon density

FAIR: moderate temperature, high baryon density

# Mapping the QCD phase diagram with heavy-ion collisions



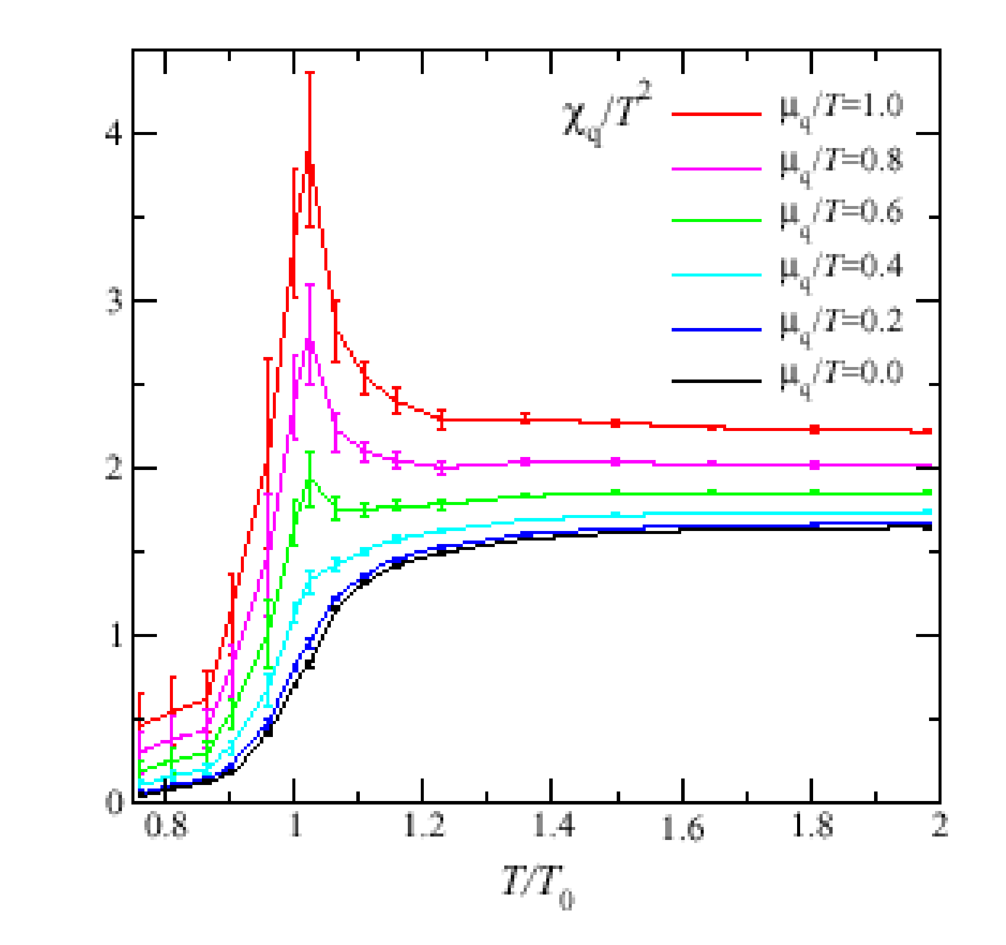

Critical endpoint:
Z. Fodor, S. Katz, hep-lat/0402006
S. Ejiri et al., hep-lat/0312006
$\mu_B <\ \approx 400$ MeV: crossover

baryon density:

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

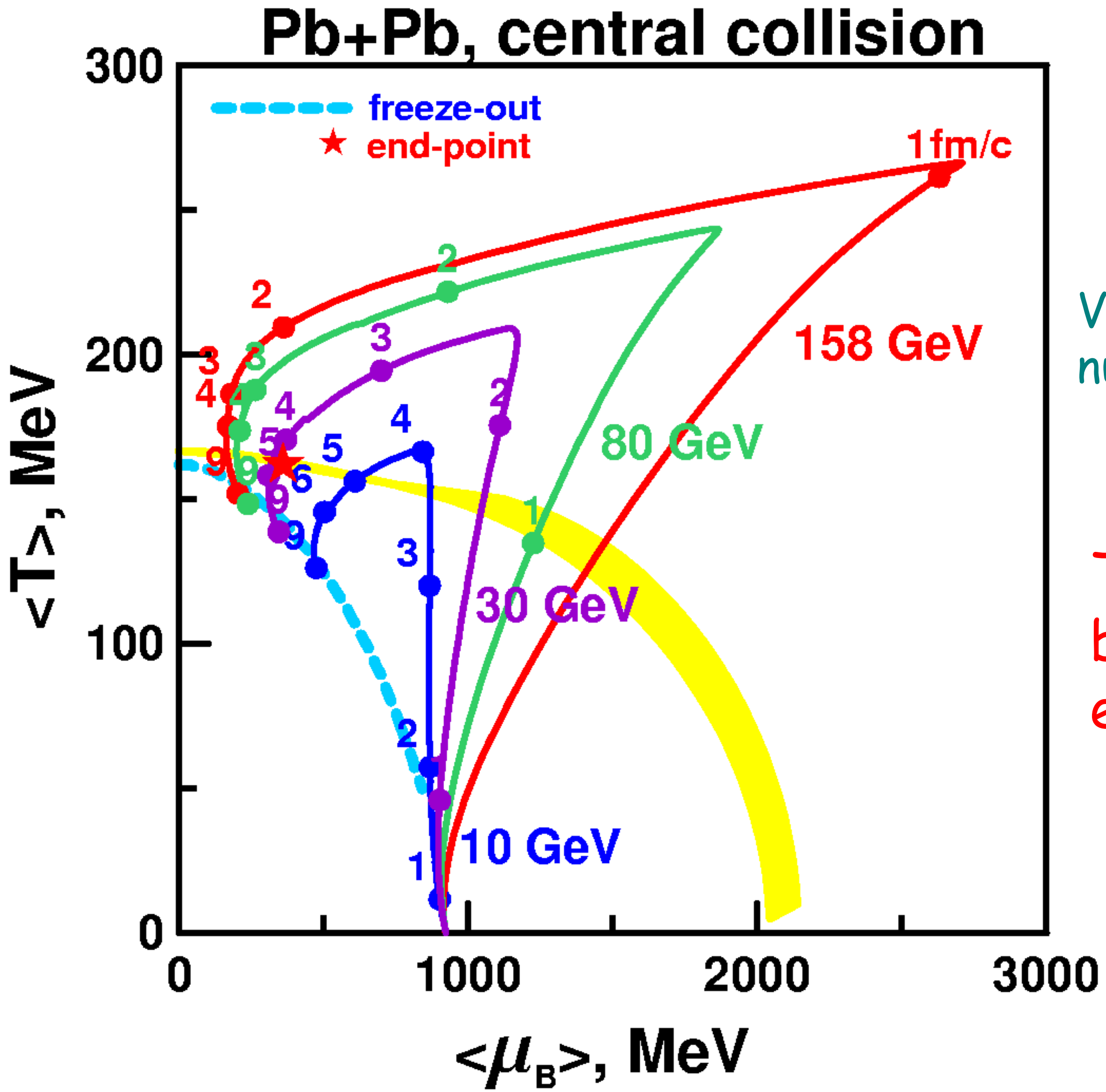
# Indication for critical endpoint at finite baryon chemical potential from lattice QCD

C. R. Allton et al, hep-lat 0305007




Lattice QCD :
maximal baryon number density fluctuations at $T_C$ for $\mu_q = T_C$ ($\mu_B \approx 500$ MeV)

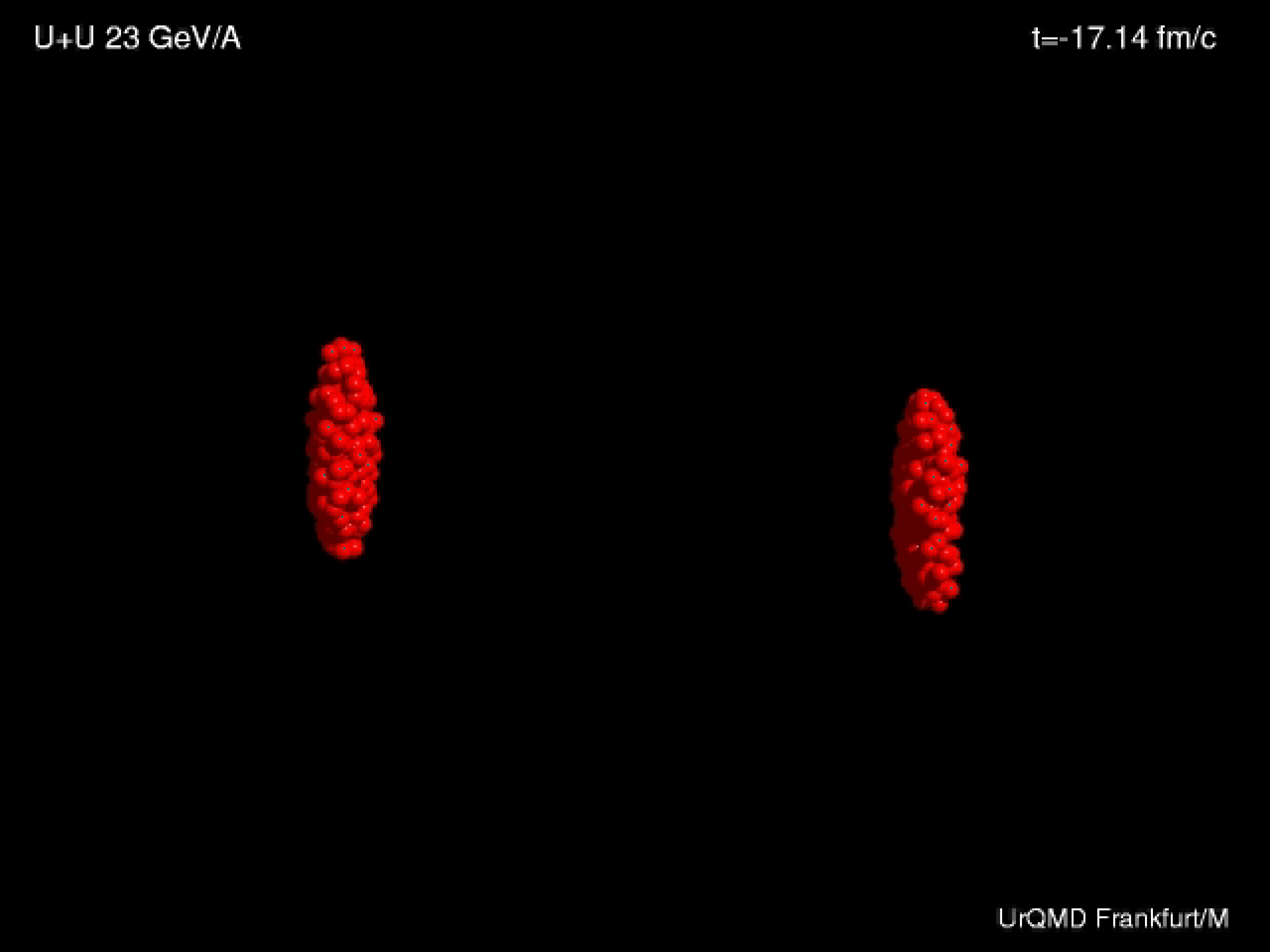
# "Trajectories" (3 fluid hydro)



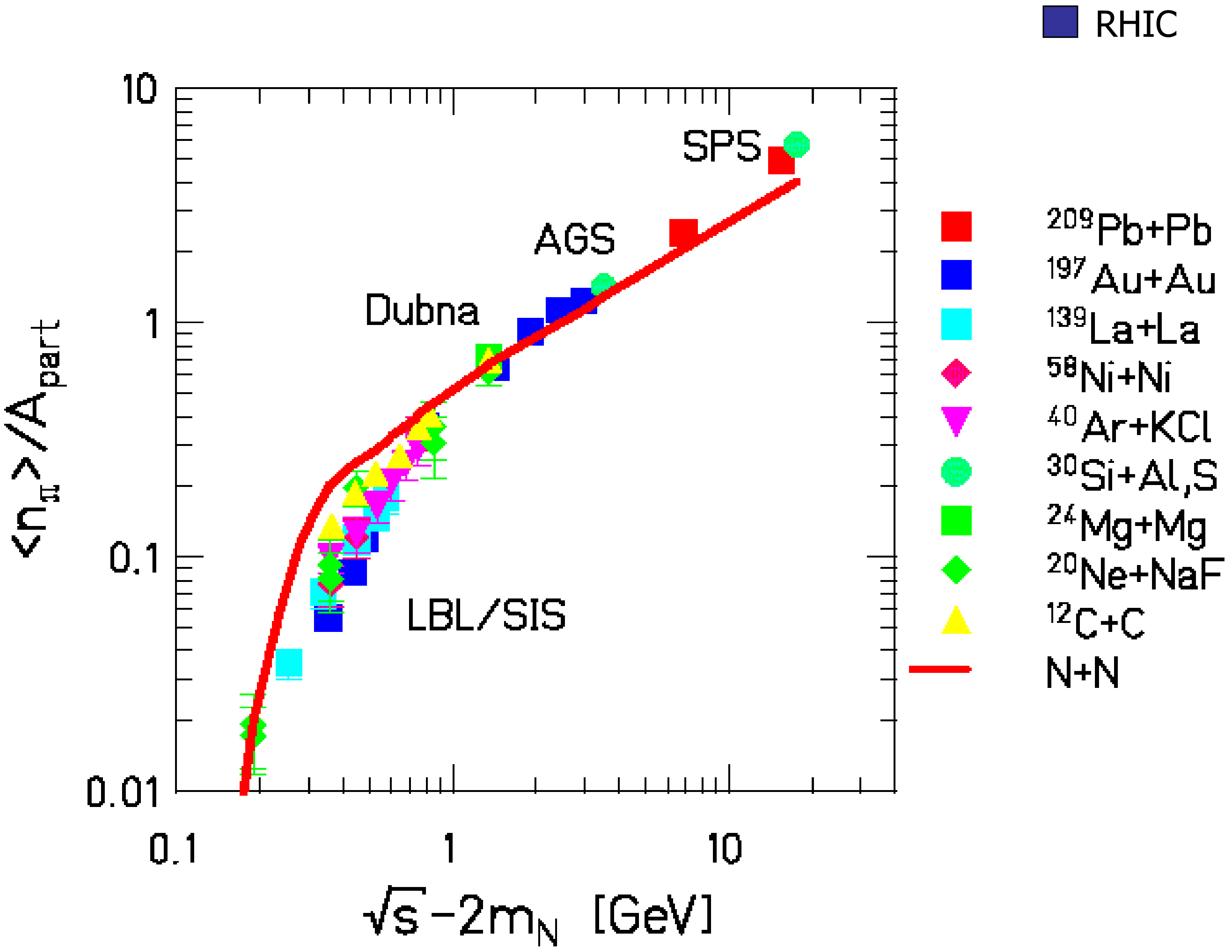

Hadron gas EOS

V.Toneev, Y. Ivanov et al.
nucl-th/0309008

Top SPS energies: baryonic matter not equilibrated

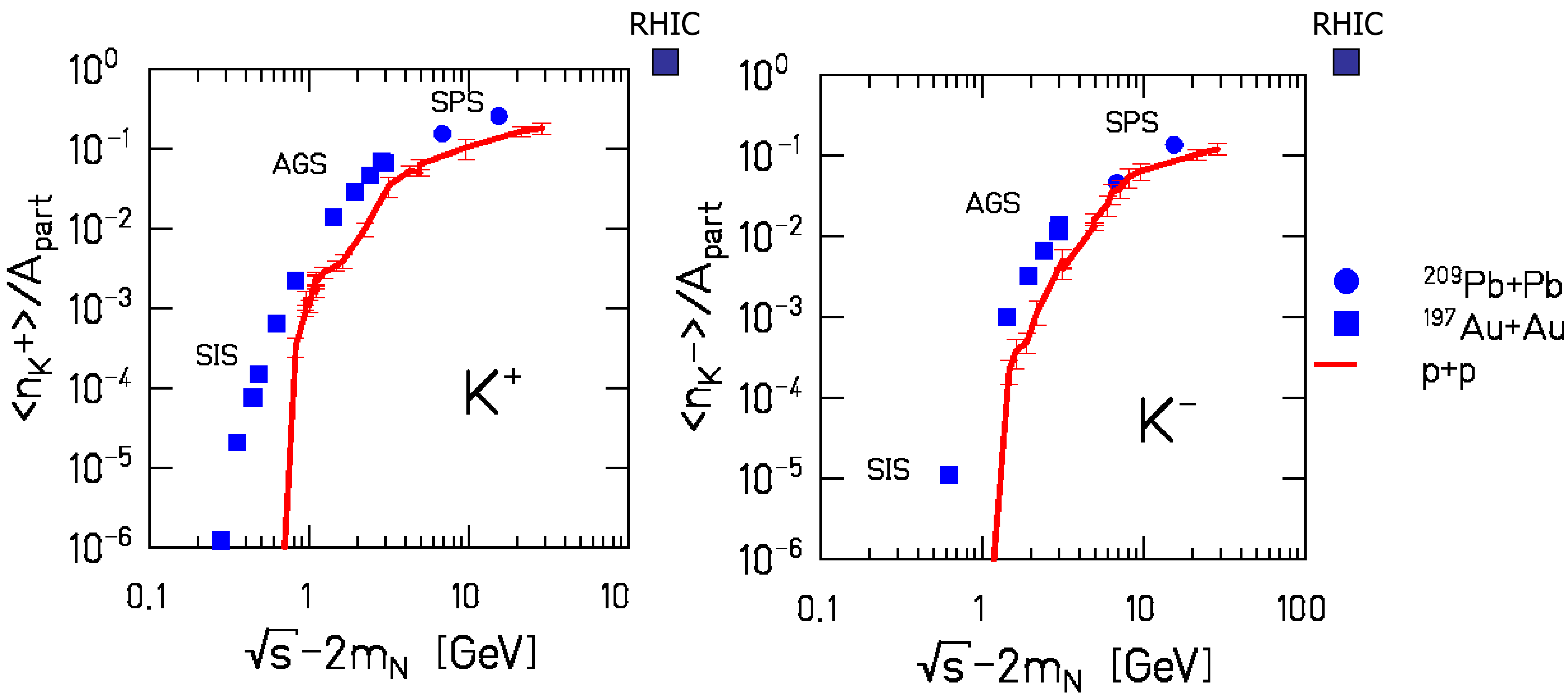

U+U 23 GeV/A
t=-17.14 fm/c
UrQMD Frankfurt/M

# Pion multiplicities per participating nucleons



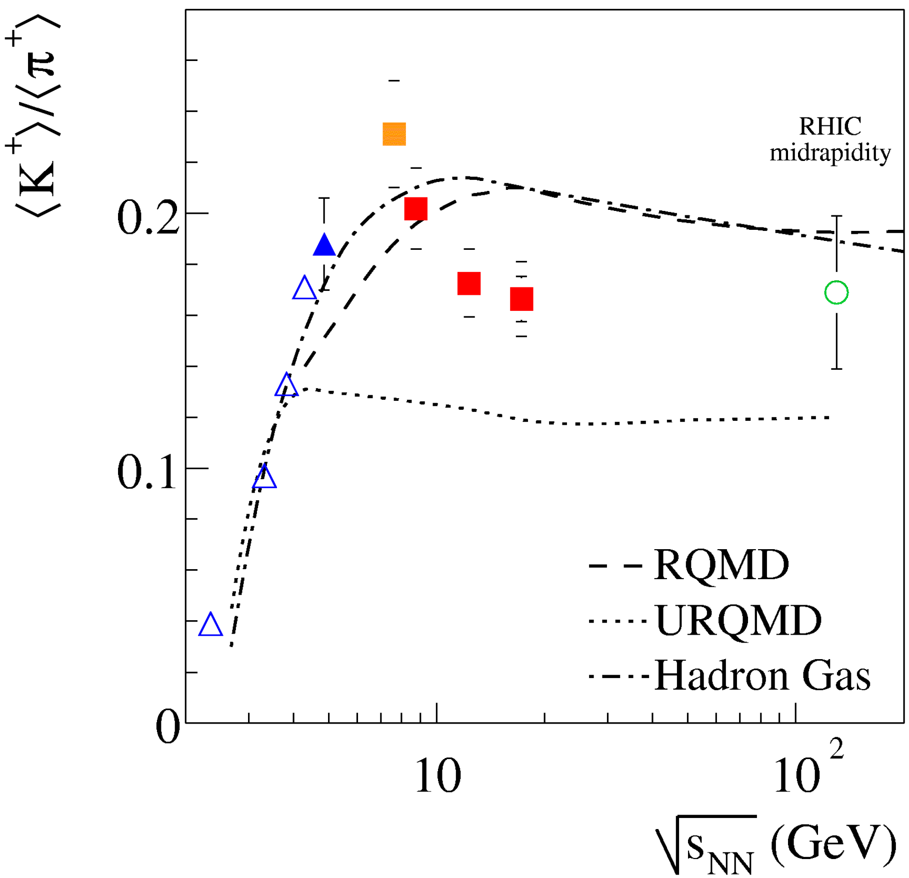
# Production of K⁺ und K⁻ mesons in central AuAu/PbPb collisions

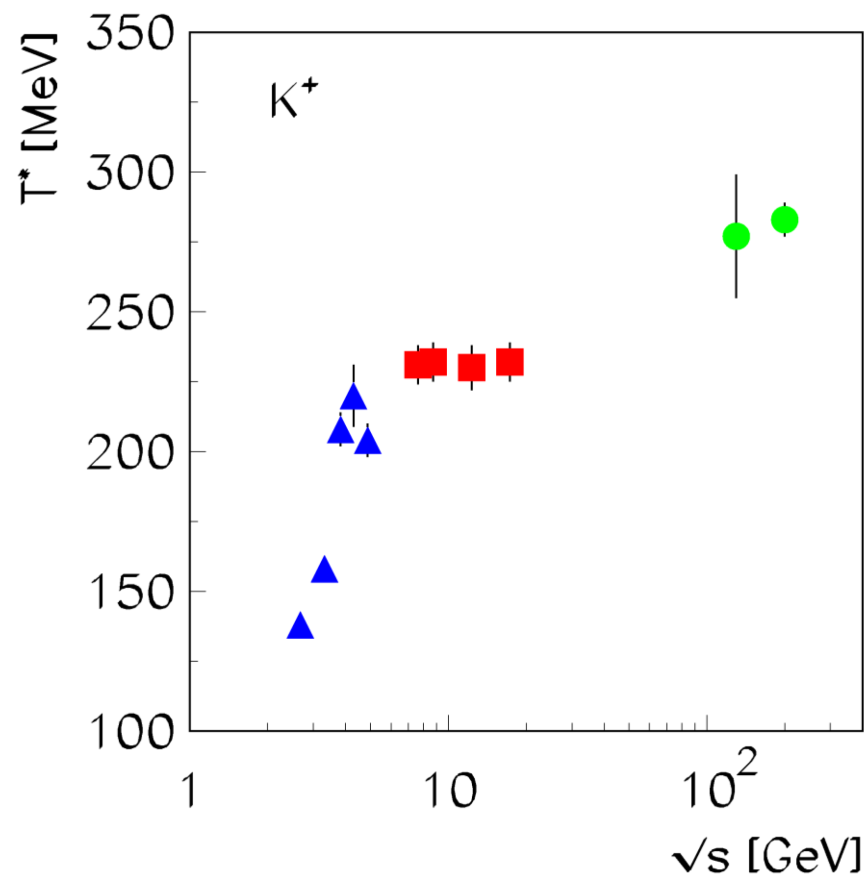
SIS: KaoS AGS: E802,E866 SPS: NA49



# Discontinuities in ratios and slopes

central Au+Au and Pb+Pb collisions: AGS, CERN-NA49, RHIC

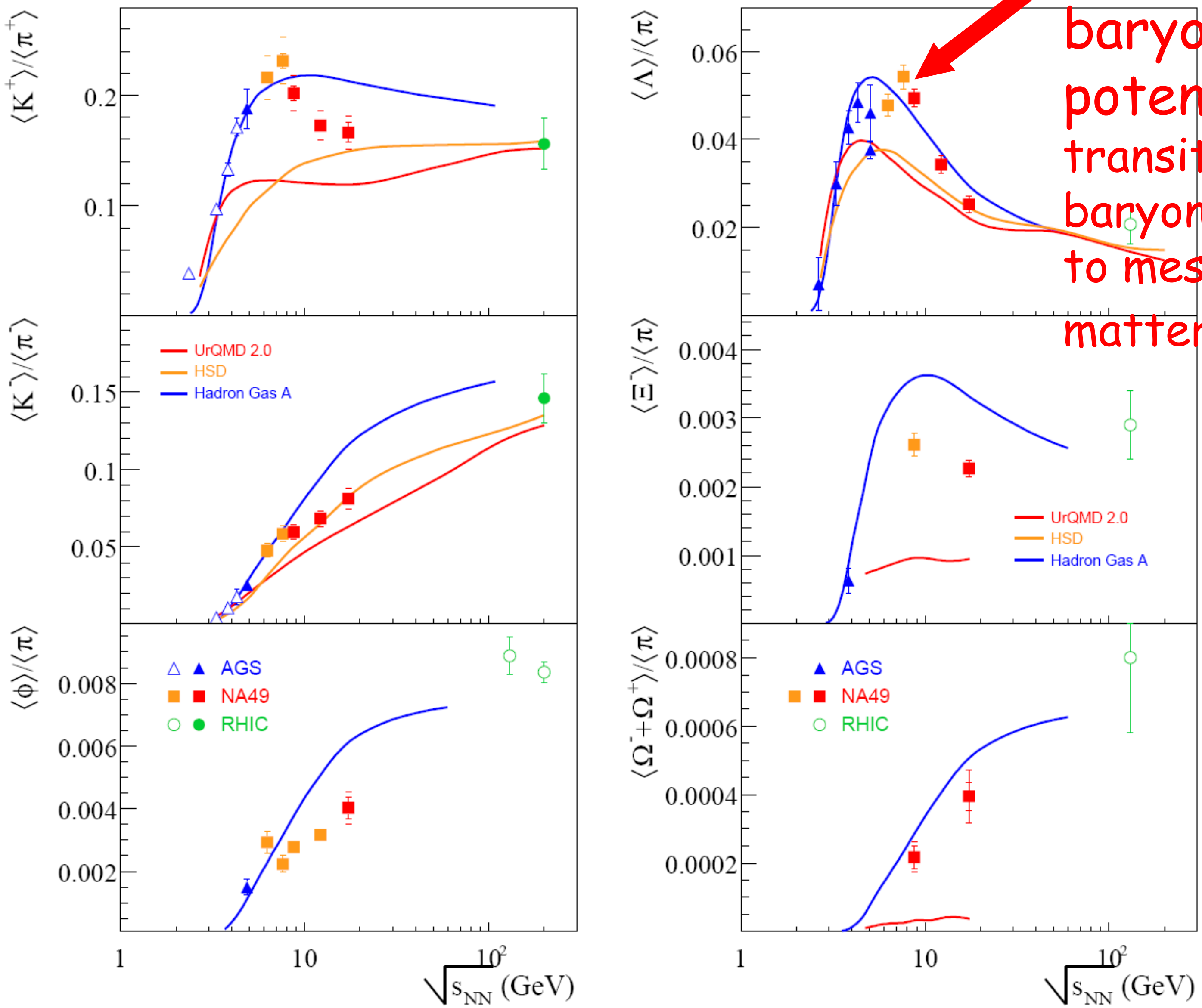



onset of phase transition at 30 AGeV ???

# Strangeness/pion ratios versus beam energy

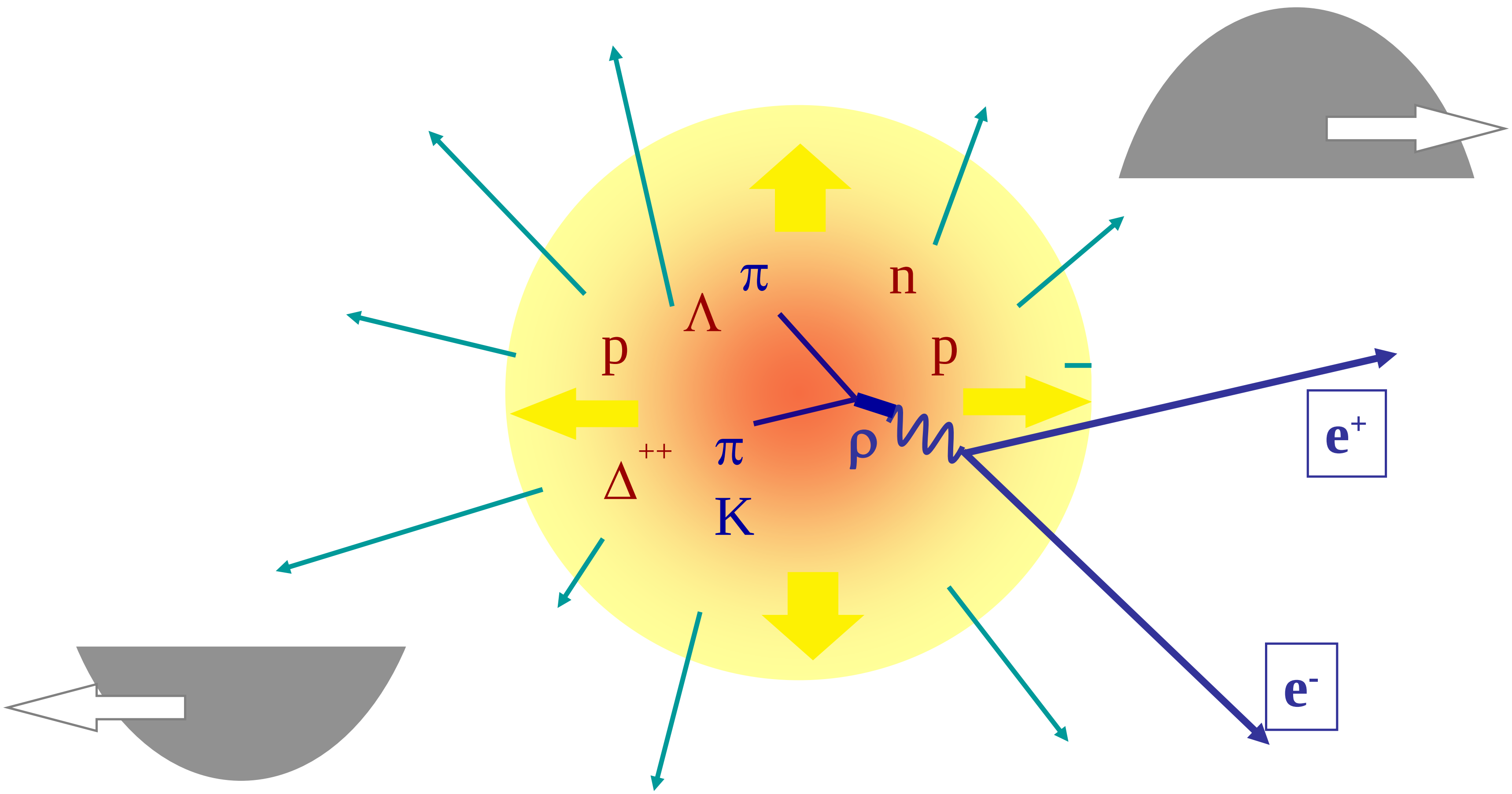
C. Blume et al., nucl-ex/0409008




Decrease of baryon-chemical potential:

transition from baryon-dominated to meson-dominated matter

# Looking into the fireball ...

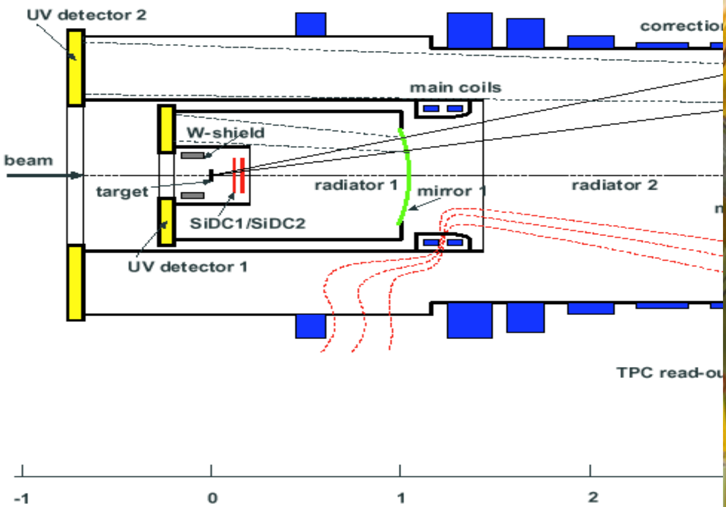



... using penetrating probes:

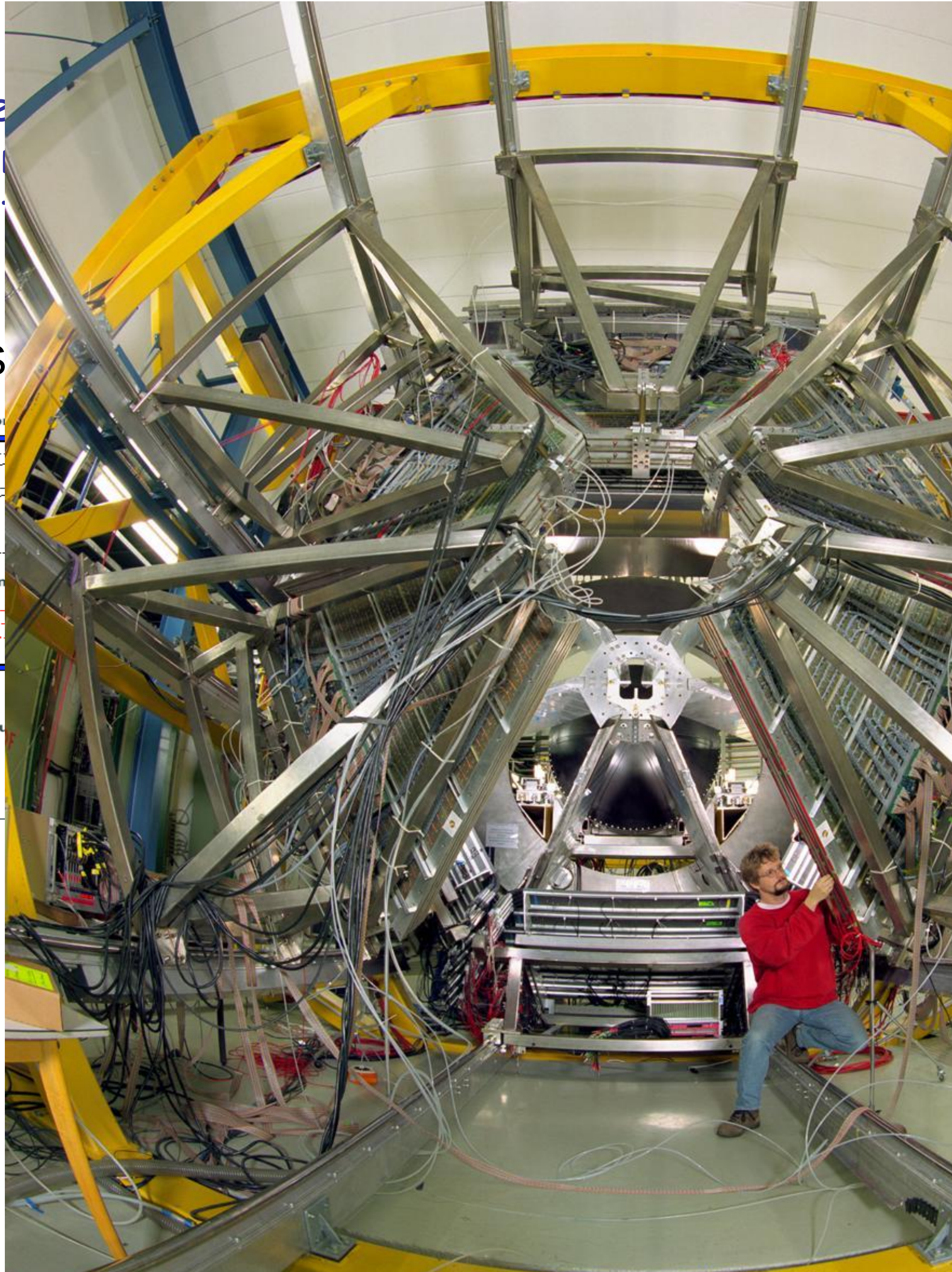
short-lived vector mesons decaying into electron-positron pairs

Measure spectral functions of ve
decay into electron-positron pai
using Ring Imaging Cherenkov de

NA45/CERES @ CERN-SPS

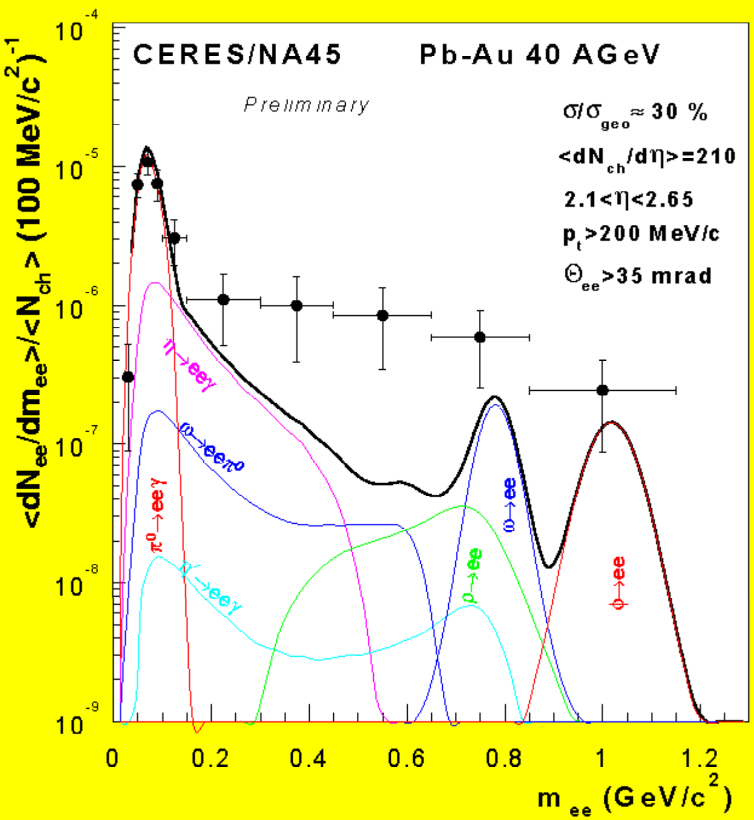



$CH_4$ radiator gas: $\gamma_{thr}$= 32



# Invariant mass of electron-positron pairs from Pb+Au at 40 AGeV

CERES Collaboration: D.Adamova et al., Phys. Rev. Lett. 91 (2003) 042301




Number of pairs for m>0.2 GeV/c2: 180+-48

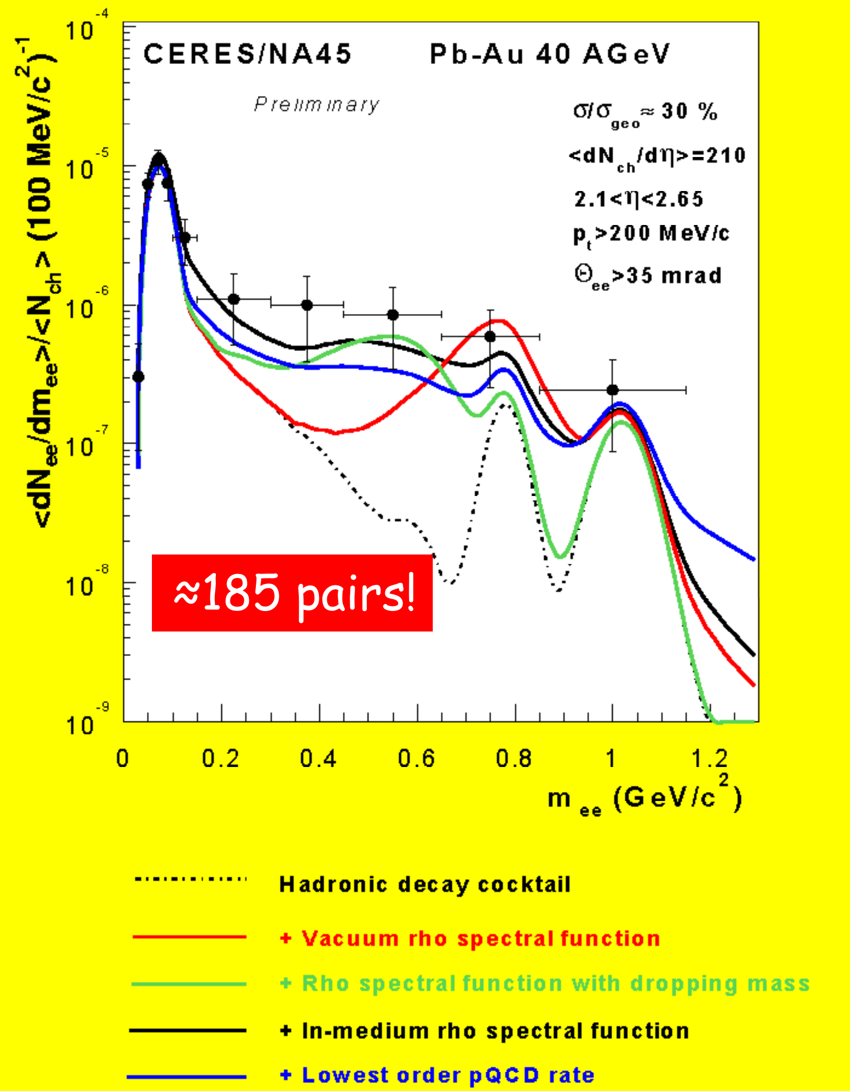
Ratio Signal/Background: 1/6

Hadronic decay cocktail:

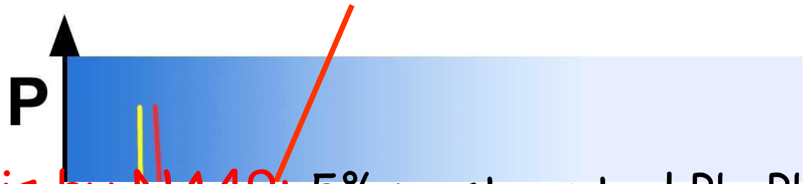
- particle ratios taken from thermal model for Pb-Pb

-rapidity and pt distributions from systematics in Pb-Pb

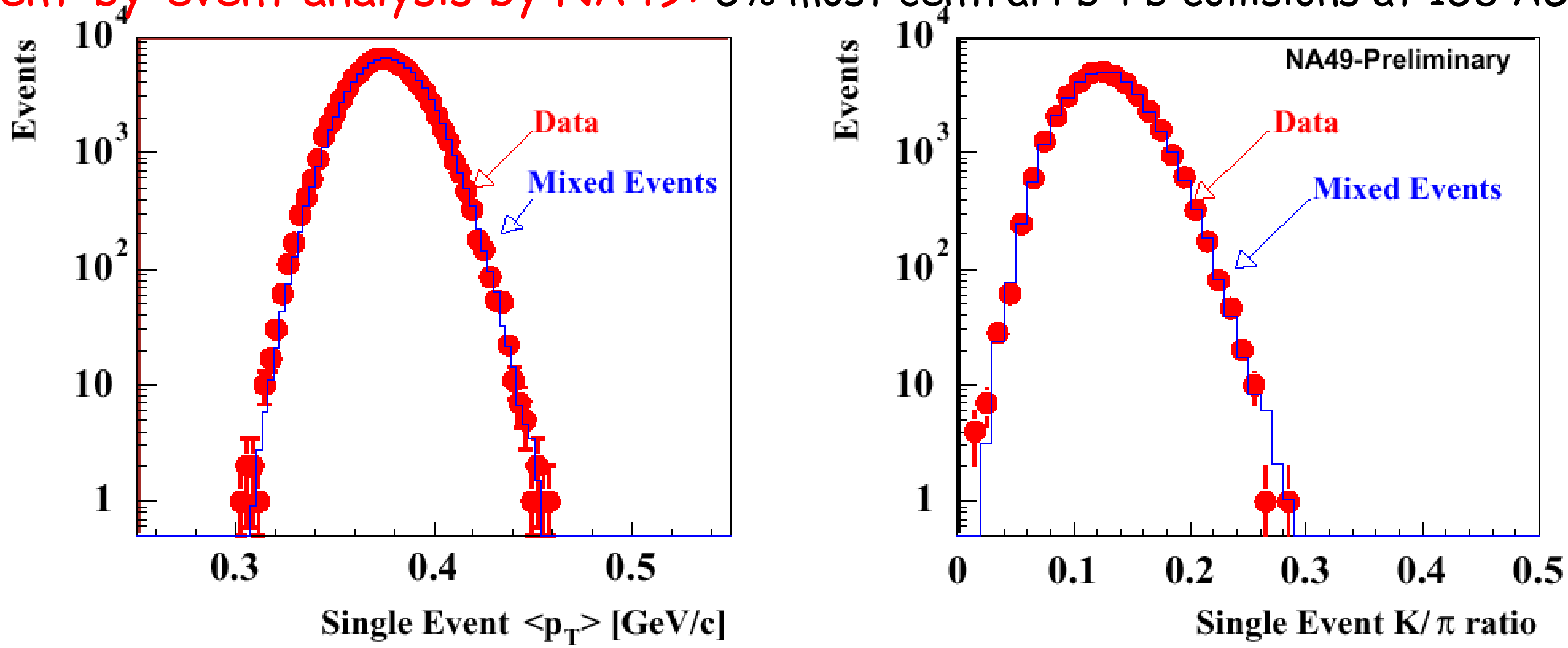
Enhancement: measured pairs/decay cocktail: 5.0 +- 1.3



# First order phase transition and the critical endpoint




Event-by-event analysis by NA49: 5% most central Pb+Pb collisions at 158 AGeV

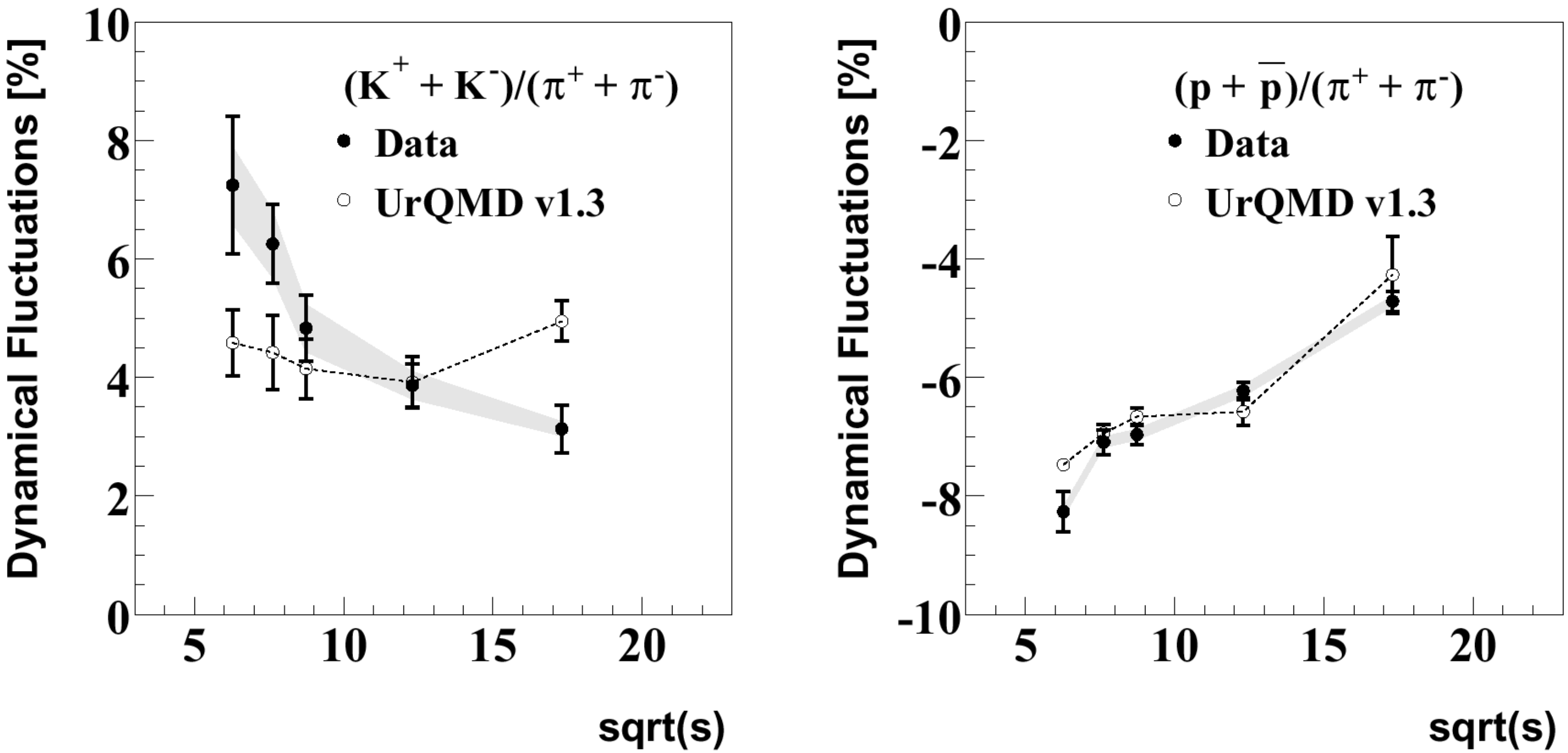



above $T_c$: no phase boundary

At the critical point:
Large density fluctuations,
critical opalescence

# Fluctuations from NA49

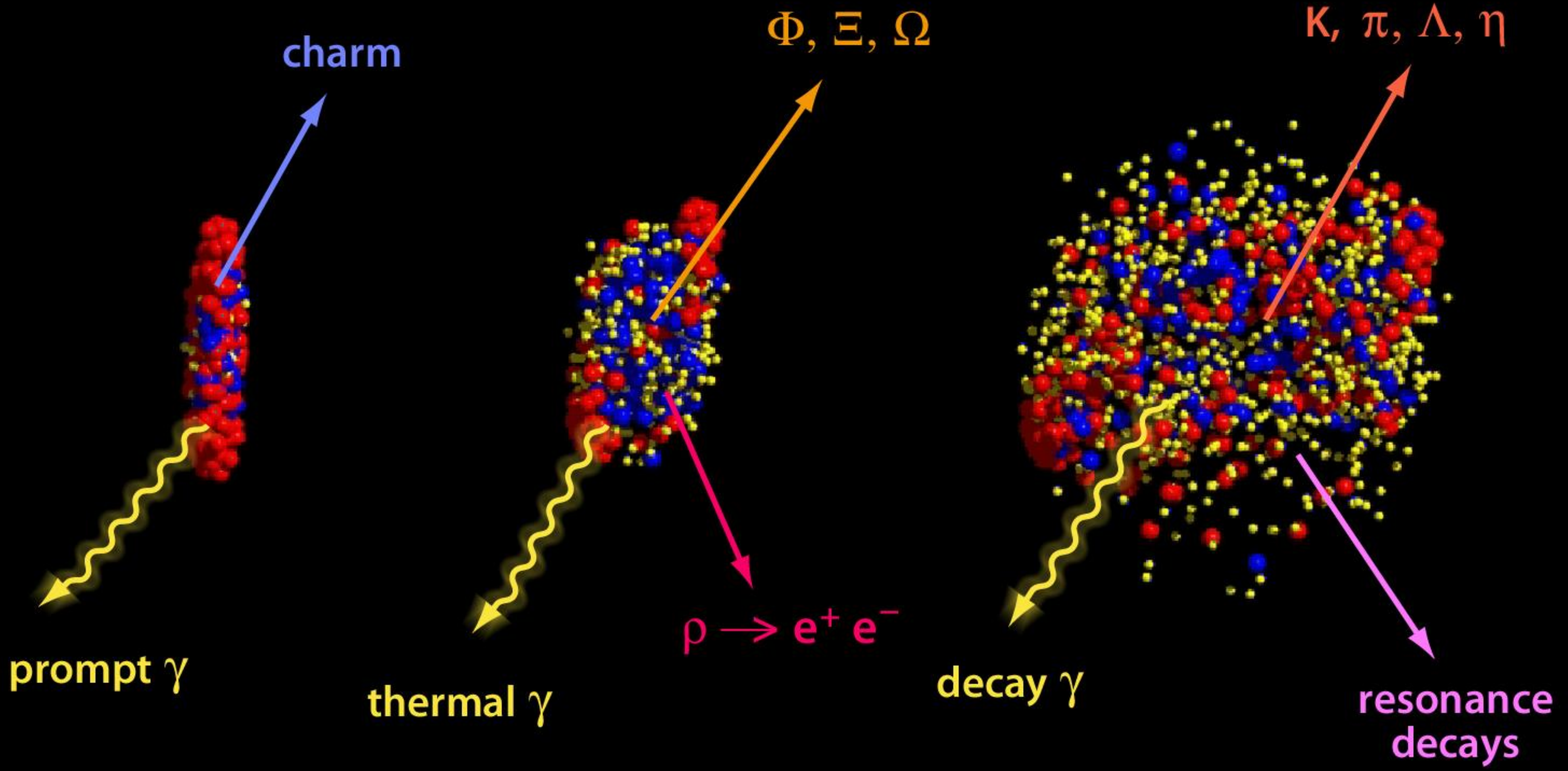
nucl-ex/0403035




- dynamical fluctuations reported by NA49
- increase towards low energies
- K/π : not reproduced by UrQMD
- p/π : correlation due to resonance decays

# Diagnostic probes of compressed baryonic matter

U+U 23 AGeV



# CBM physics topics and observables

- In-medium modifications of hadrons
  - onset of chiral symmetry restoration at high $\rho_B$

    measure: $\rho$, $\omega$, $\phi$ $\rightarrow$ $e^+e^-$

    open charm (D mesons)

- Strangeness in matter
  - production and propagation of strange particles

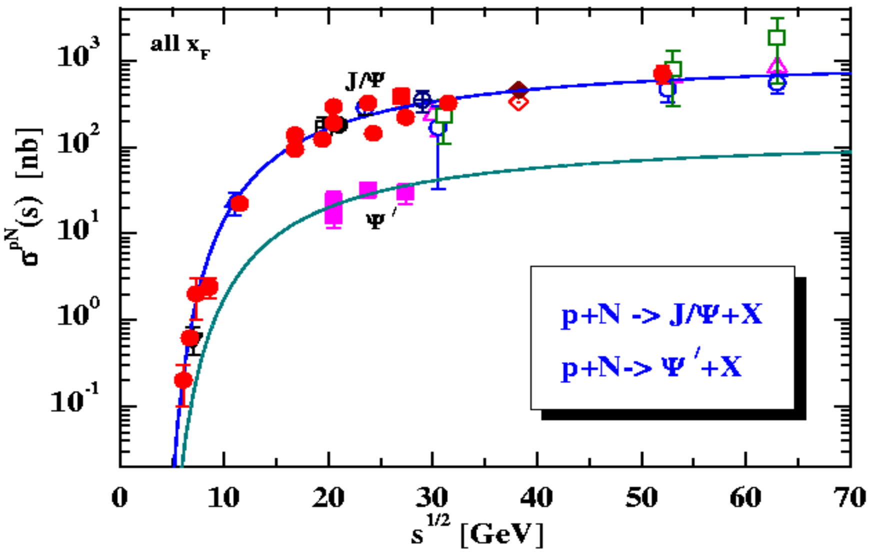
    measure: K, $\Lambda$, $\Sigma$, $\Xi$, $\Omega$

- Indications for deconfinement at high $\rho_B$
  - production and propagation of charm

    measure: $J/\psi$, D

- Critical point
  - event-by-event fluctuations

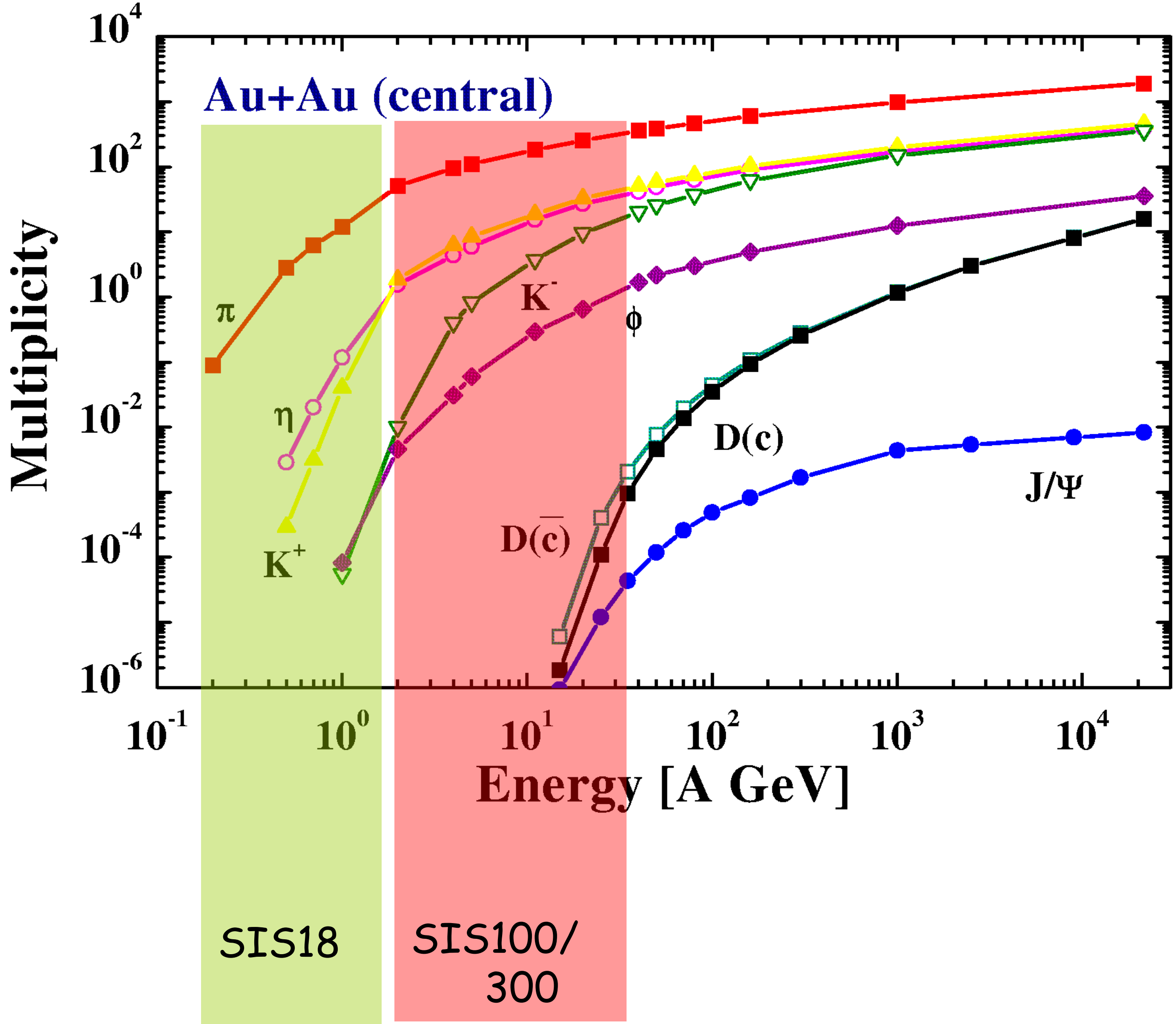
# J/ψ measurement requires high beam intensities and lepton identification




| central collisions | 25 AGeV Au+Au | 158 AGeV Pb+Pb |
|---|---|---|
| J/ψ multiplicity | $1.5\cdot10^{-5}$ | $1\cdot10^{-3}$ |
| beam intensity | $1\cdot10^{9}$/s | $2\cdot10^{7}$/s |
| interactions | $1\cdot10^{7}$/s (1%) | $2\cdot10^{6}$/s (10%) |
| central collisions | $1\cdot10^{6}$/s | $2\cdot10^{5}$/s |
| J/ψ rate | 15/s | 200/s |
| 6% $J/\psi \rightarrow e^+e^-$ ($\mu^+\mu^-$) | 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 |
| | ≈ $1\cdot10^{5}$/week | ≈ $1.8\cdot10^{5}$/week |

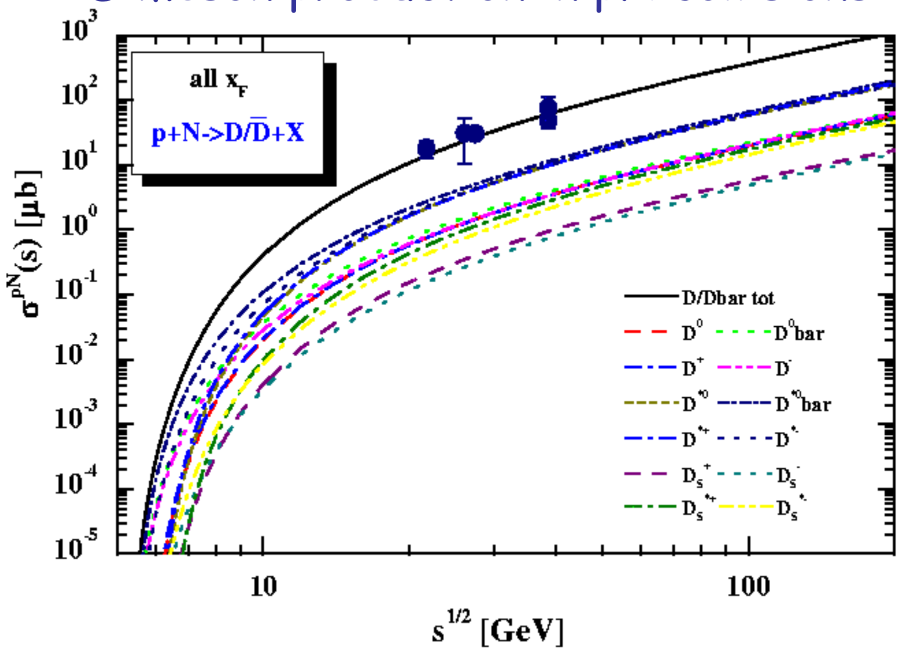
# Meson production in central Au+Au collisions

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



# D-meson measurement requires vertex resolution

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%)

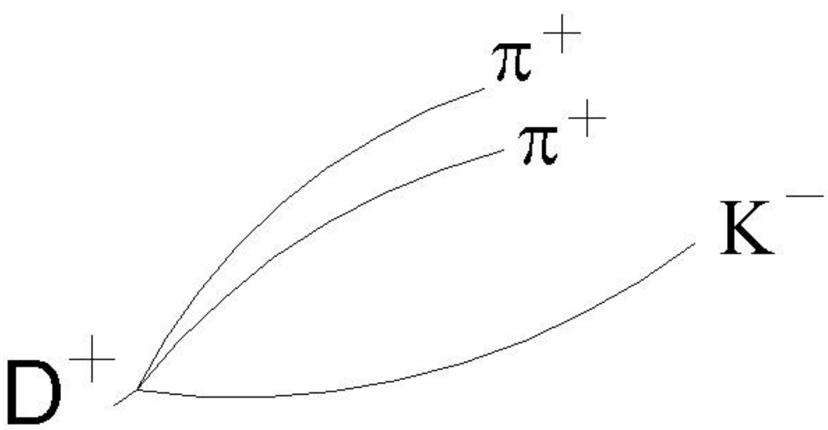
$D^+ \rightarrow K^-\pi^+\pi^+$ (9 ± 0.6%)

$D^0$ ($c\tau$ = 124.4 μm):

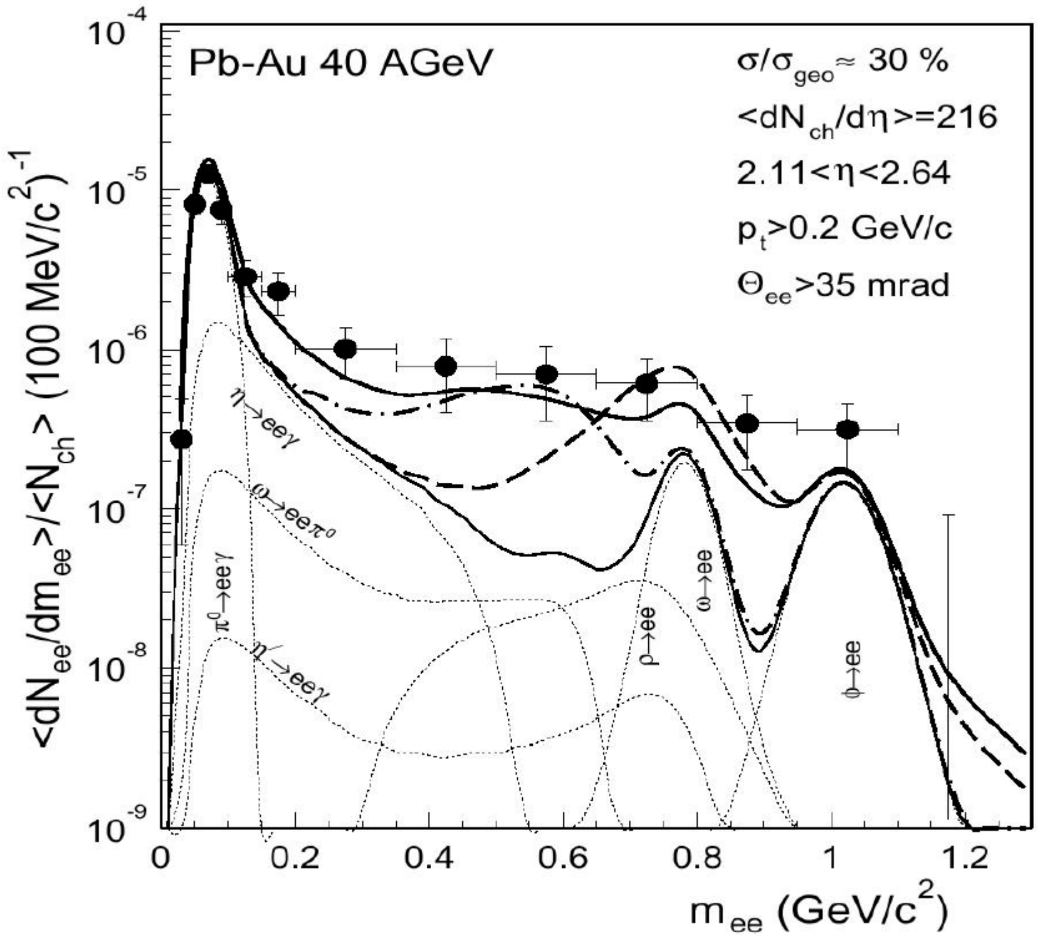
$D^0 \rightarrow K^-\pi^+$ (3.9 ± 0.09%)

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

Measure displaced vertex
with resolution of ≈ 50 μm !



# ρ, ω, φ → e+e- requires electron identification




D.Adamova et al., PRL 91 (2003) 042301

**Dominant background:** $\pi^0$-Dalitz decay and gamma conversion.

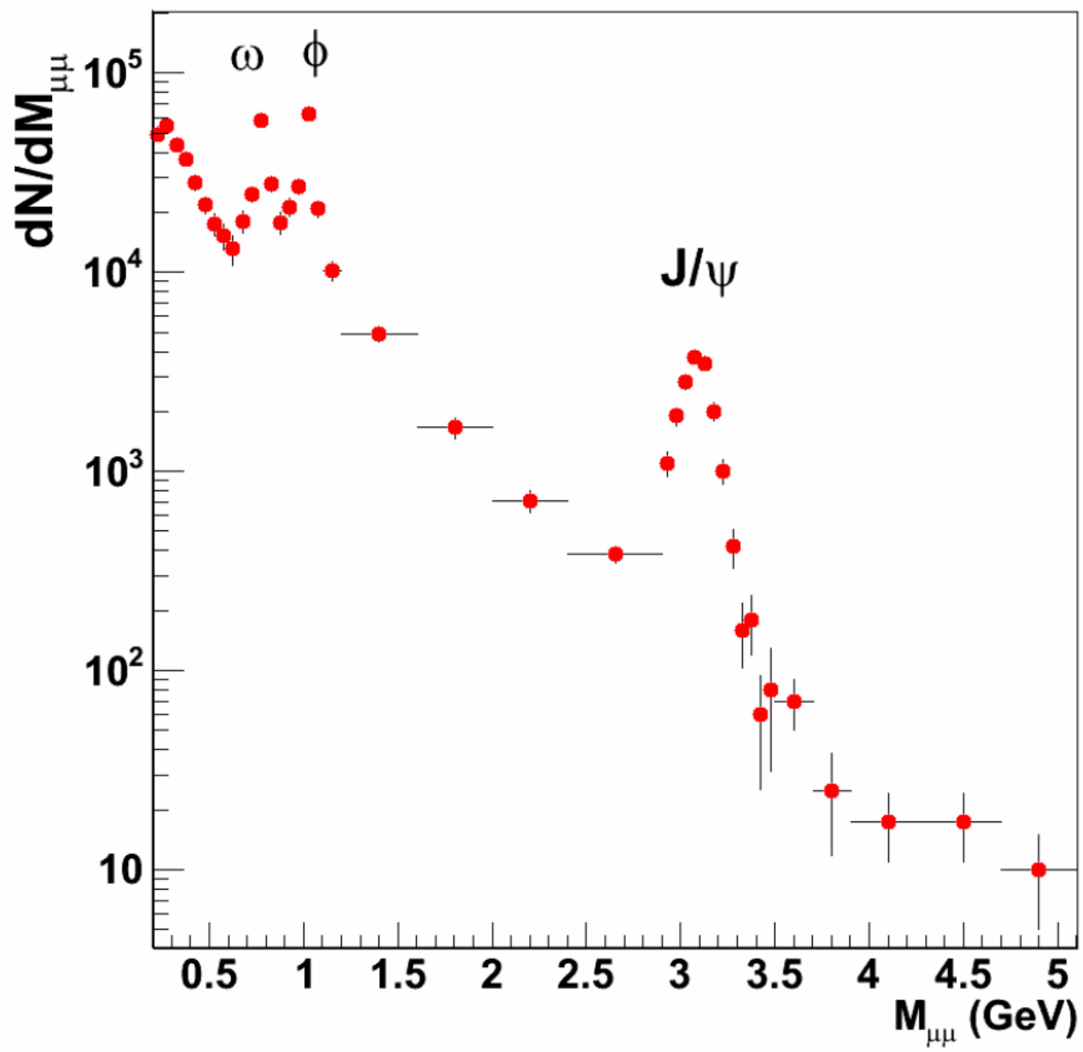
**Important:** identification of soft electrons/positrons !

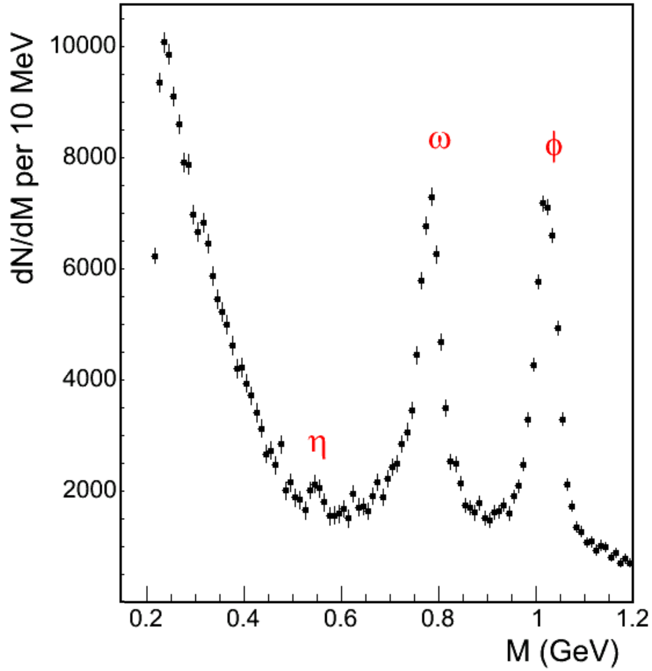
CERES 2000: 159 AGeV Pb+Au
beam intensity: $10^6$ ions / spill
1 spill = 4 s beam and 15 s pause
targets: 13 x 25 μm Au ( ~ 1 % interaction)
trigger: 8% most central
Event rate = 470 / spill (~ 25 Hz = 15 Mio events/week)

# Alternative option: ρ, ω, φ, J/ψ → μ+μ-

NA60 preliminary: In+In 158 AGeV

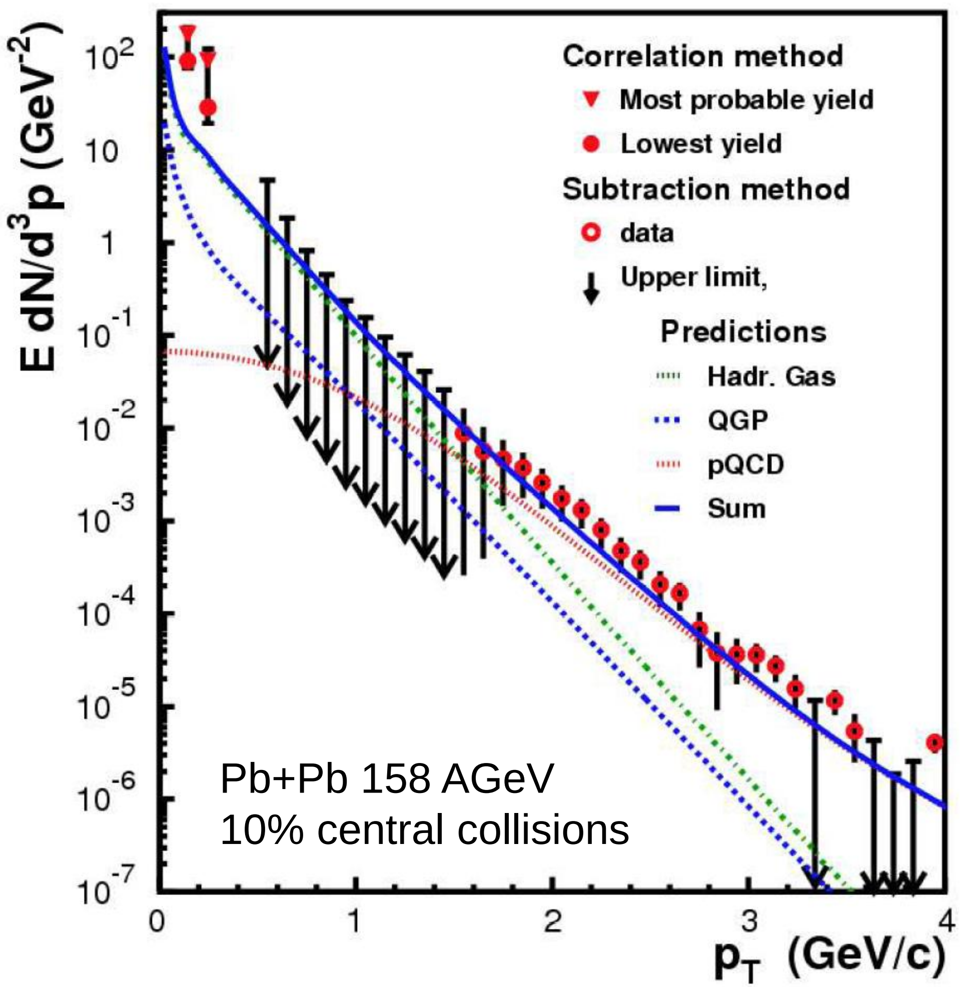
H. Ohnishi, SQM2004, Capetown

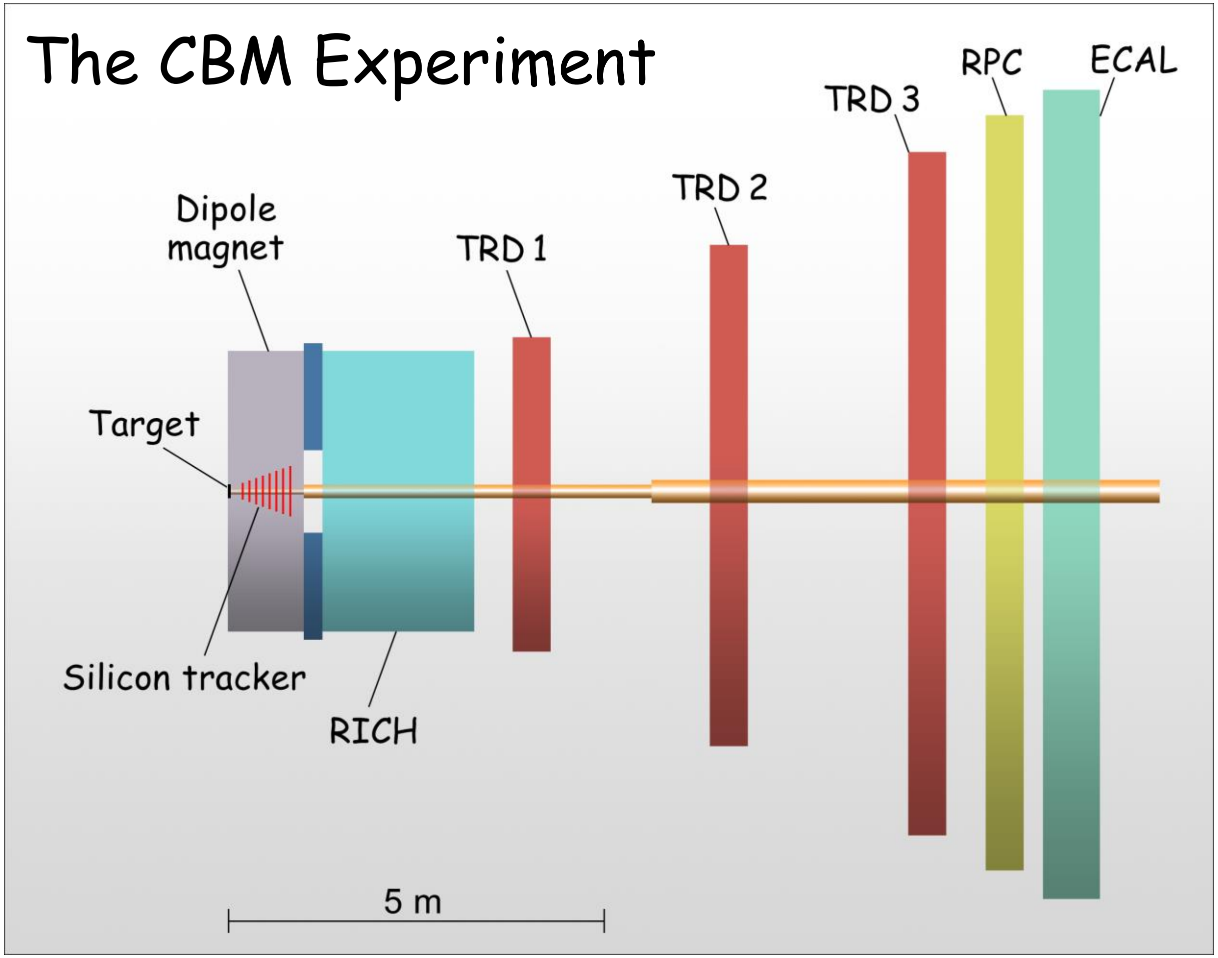


# Photon ($\pi^0$, η) measurements: electromagnetic calorimeter

Photon yield measured by WA98
Phys. Rev. Lett. 93 (022301), 2004



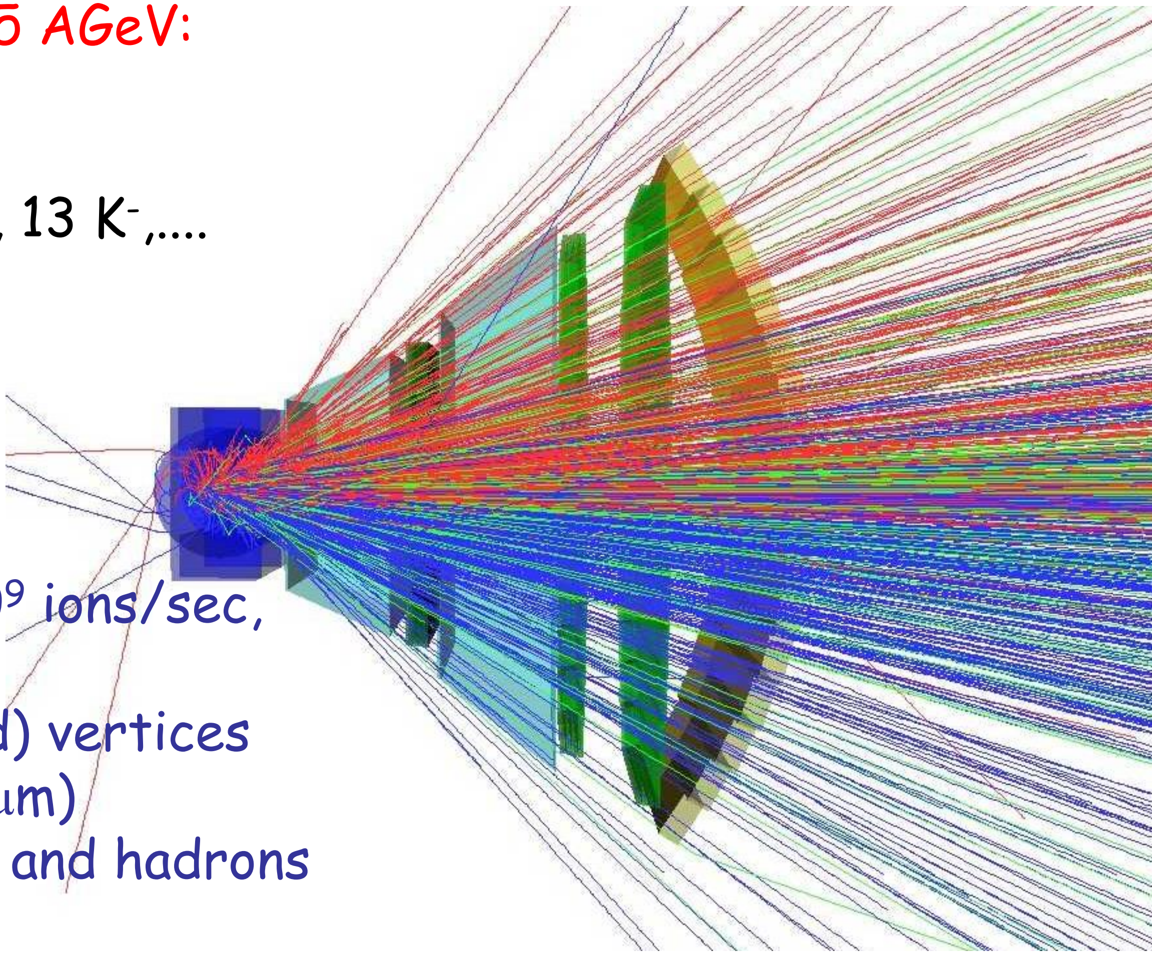



- Radiation hard Silicon (pixel/strip) Tracking System in a magnetic dipole field
- Electron detectors: RICH & TRD & ECAL: pion suppression better $10^4$
- Hadron identification: TOF-RPC
- Measurement of photons, $\pi^0$, $\eta$, and muons: electromagn. calorimeter (ECAL)
- High speed data acquisition and trigger system

# Experimental challenges

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

160 p, 400 $\pi^-$, 400 $\pi^+$, 44 $K^+$, 13 $K^-$,....

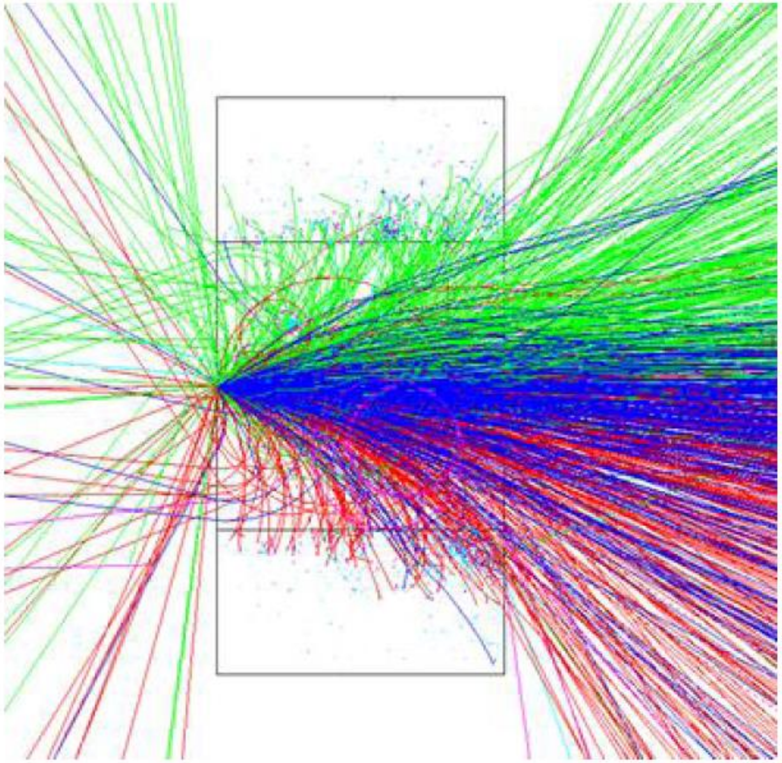


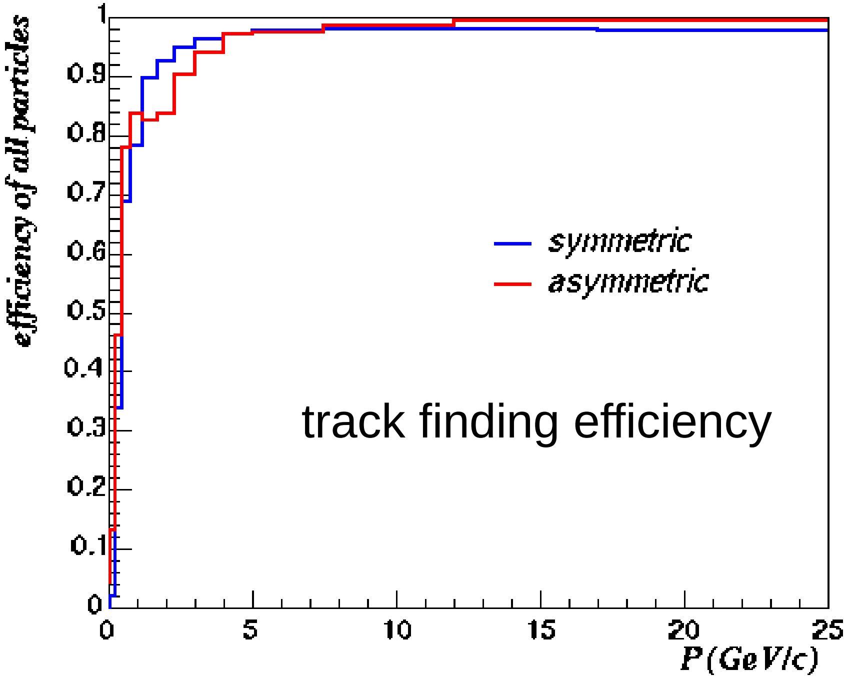
- $10^7$ Au+Au reactions/sec
  (beam intensities up to $10^9$ ions/sec,
  1 % interaction target)
- determination of (displaced) vertices
  with high resolution ($\approx$ 50 $\mu$m)
- identification of electrons and hadrons

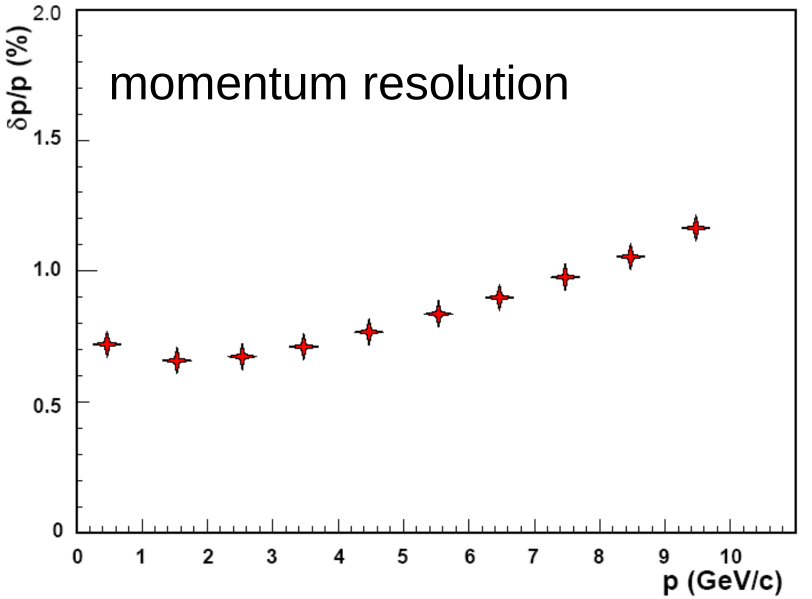
**Simultaneous measurement of all observables is not possible: optimized beam intensities and dedicated subdetectors**

# Tracking with the Silicon Tracking System

High track density:
≈ 600 charged particles in ± 25°






<u>Assumptions:</u>
ideal detector response,
hit resolution 10 μm,
no pile-up events
<u>Requirements:</u>
track hits more than 3 stations

# Silicon Pixel Vertex Detector

Silicon Tracking System: 2 (3) Pixel Stations/ 5 (4) Strip Stations
Vertex tracking: two pixel layers (5 cm and 10 cm downstream target)

## Design goals:

- low materal budget: d < 200 μm
- single hit resolution < 20 μm
- radiation hard (dose $10^{15}$ $n_{eq}/cm^2$)
- read-out time 25 ns

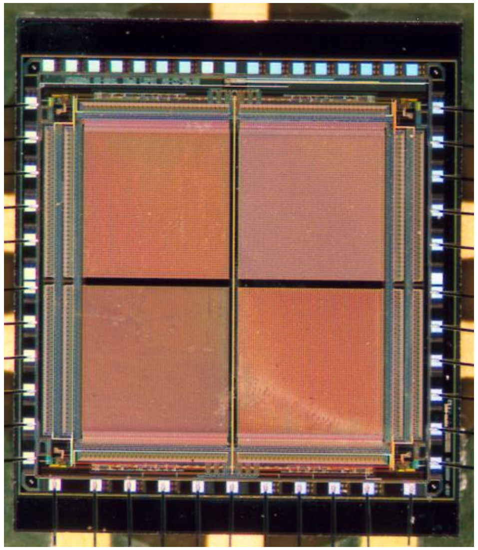
## Roadmap:

R&D on Monolithic Active Pixel Sensors (MAPS)

- thickness below 100 μm ✓
- pitch 20 μm, single hit resolution : ≈ 3 μm ✓
- radiation tolerant ($10^{13}$ $n_{eq}/cm^2$)
- ultimate read-out time few μs

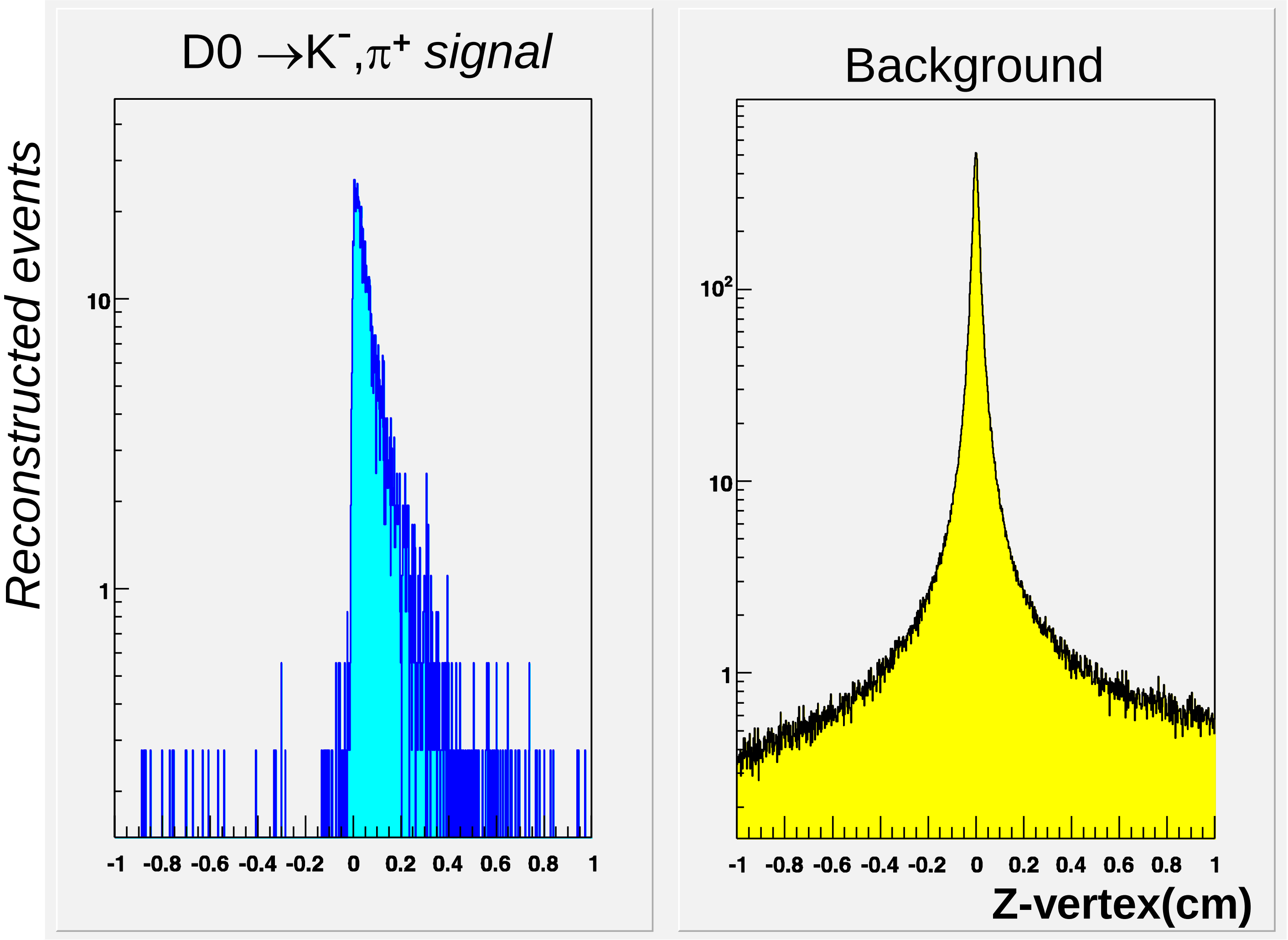
## Alternative:

next generation of thin, radiation hard, fast hybrid detectors



MIMOSA IV
IReS / LEPSI Strasbourg

# Benchmark for vertexing: $D^0 \rightarrow K^-\pi^+$ reconstruction




Simulations: UrQMD (incl. hyperons) + D meson

# D-meson: online event selection

Track reconstruction (Kalman filter) without magnetic field, dp/p = 1%

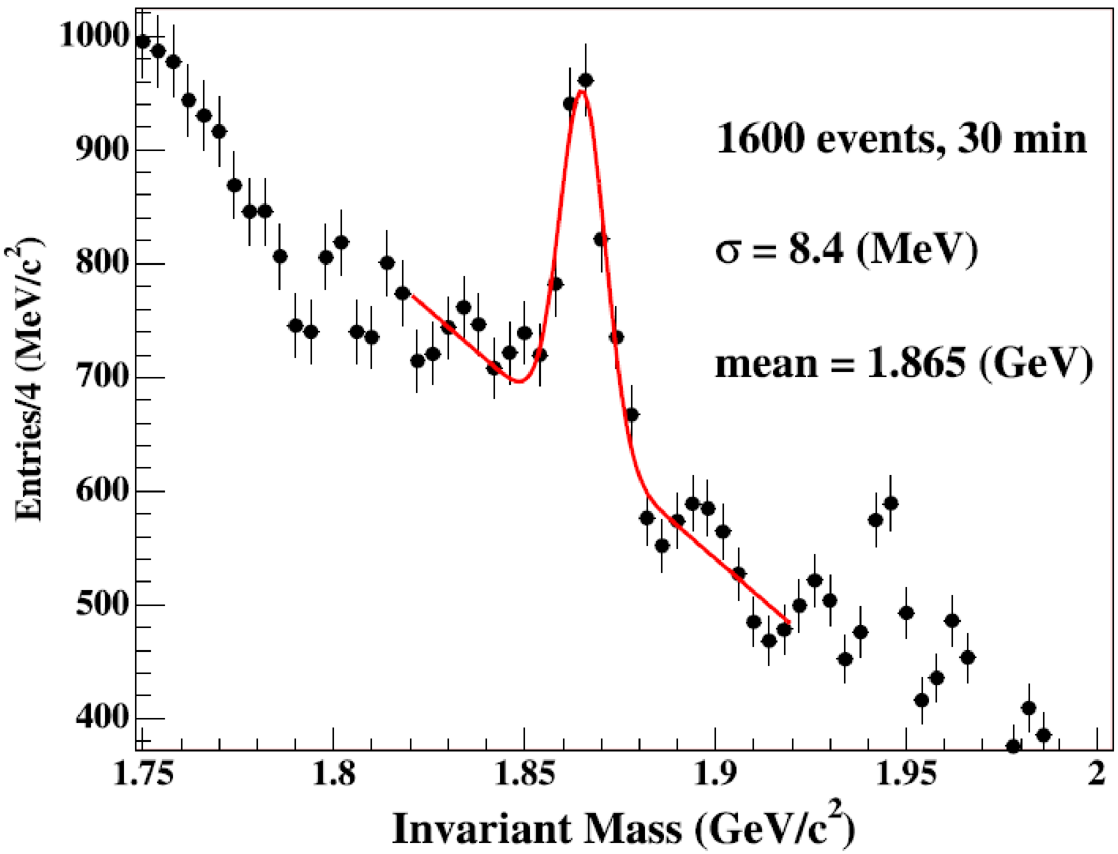
( Similar results with magnetic field)

using track information from MAPS Silicon Tracker only (no particle ID)

Cuts include:

impact parameter 80 μm < b < 500 μm

z-vertex 250 μm < b < 5000 μm




| cut | optimised value | signal efficiency [%] |
|---|---|---|
| *track IP cuts* | 80 <IP< 500 $\mu$m | 28 |
| *p-cut* | 1.0 *GeV/c* | 72 |
| *pt-cut* | 0.5 *GeV/c* | 61 |
| *z-vertex cut* | 250 $\mu$m | 54 |
| *$D^0$ pointing cut* | 30 $\mu$m | 99 |
| *vertex $\chi^2$ cut* | $\leq 5$ | 91 |
| *all cuts* | - | 5.3 |

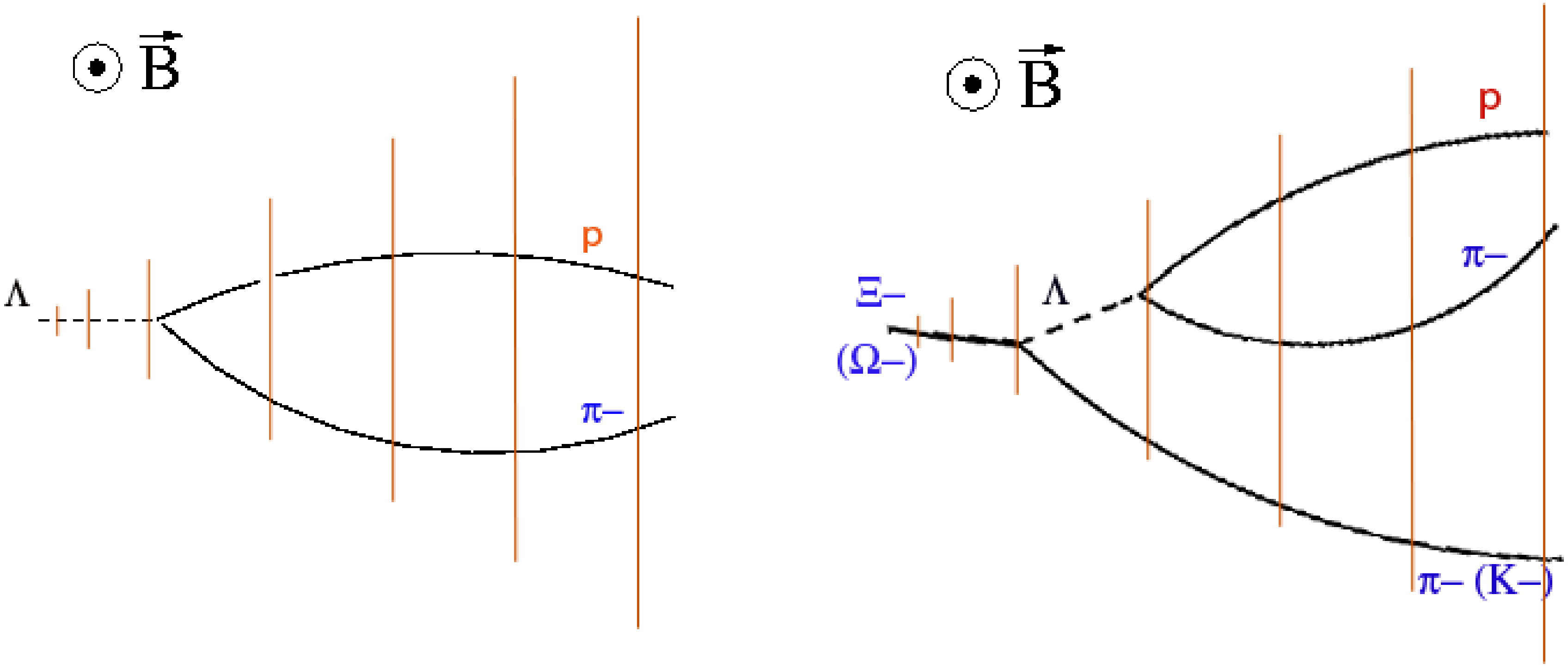
event reduction by factor 1000: 10 MHz → 10 kHz

Vertex trigger with MAPS:

≈ 1 MHz reaction rate

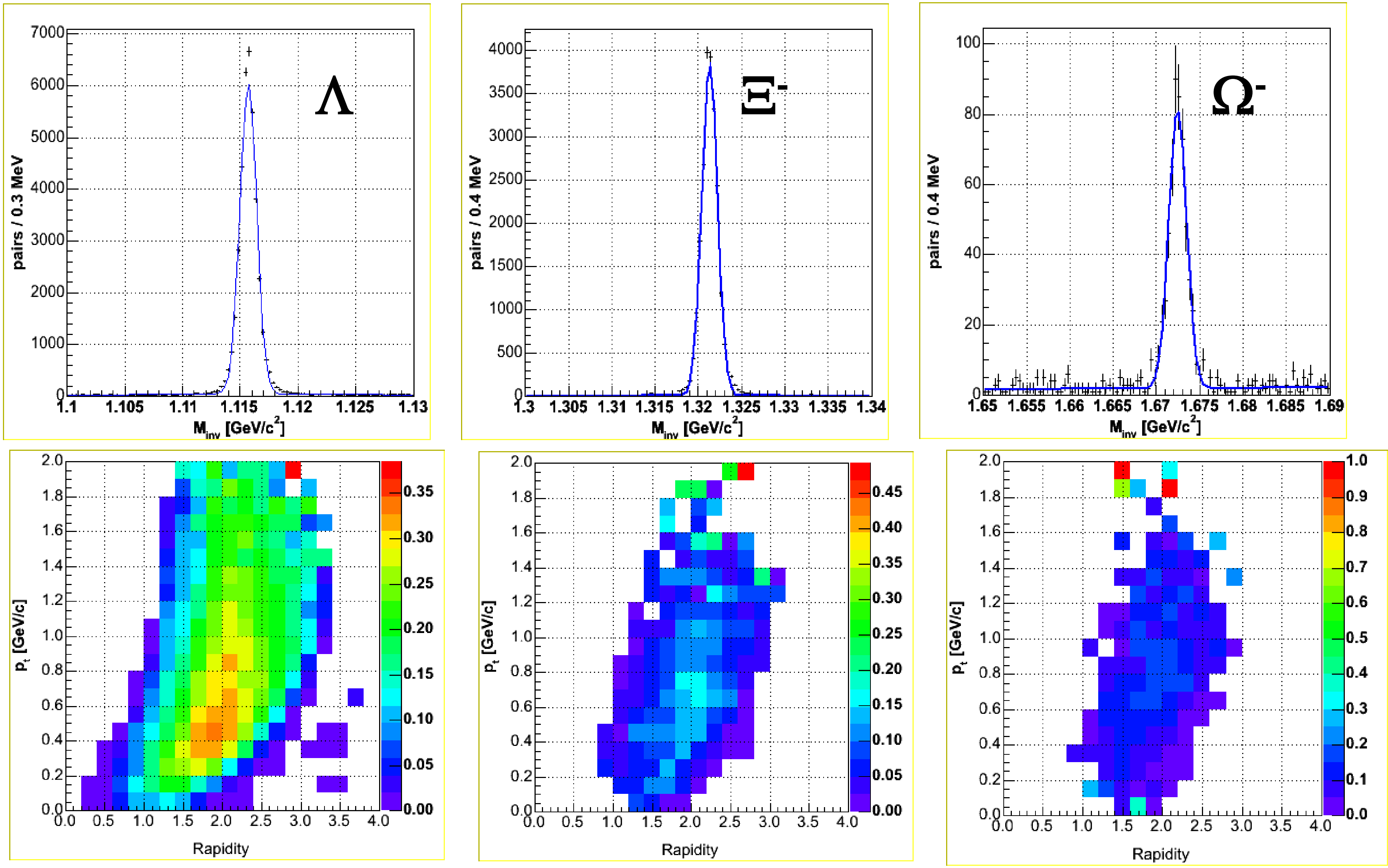
➩ ≈ 300 D mesons per hour

# Hyperon detection with STS without p, K, π identification




- UrQMD central events 25 AGeV
- Magnetic field
- Silicon detector hits with 10 μm resolution
- Ideal track finding (at least 4 MC points)
- Momentum and vertex reconstruction with Kalman filter

# Invariant mass distributions after topological cuts

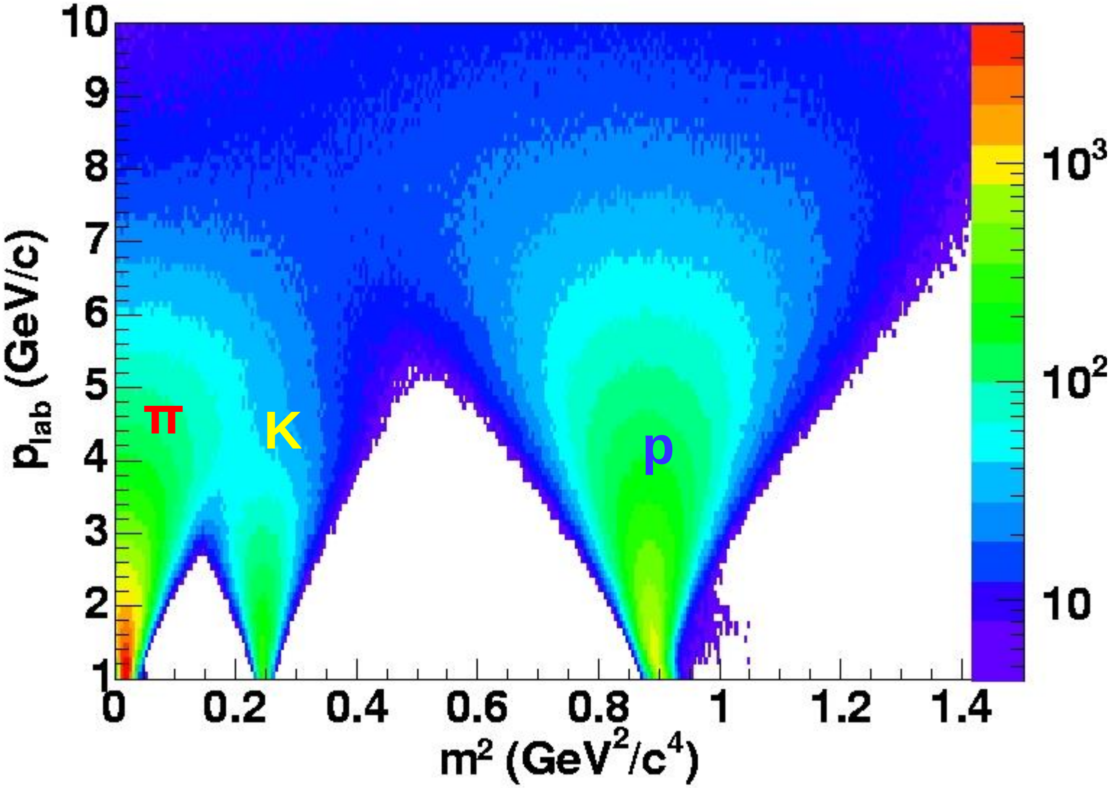



efficiency 15.8% 6.7% 7.7%

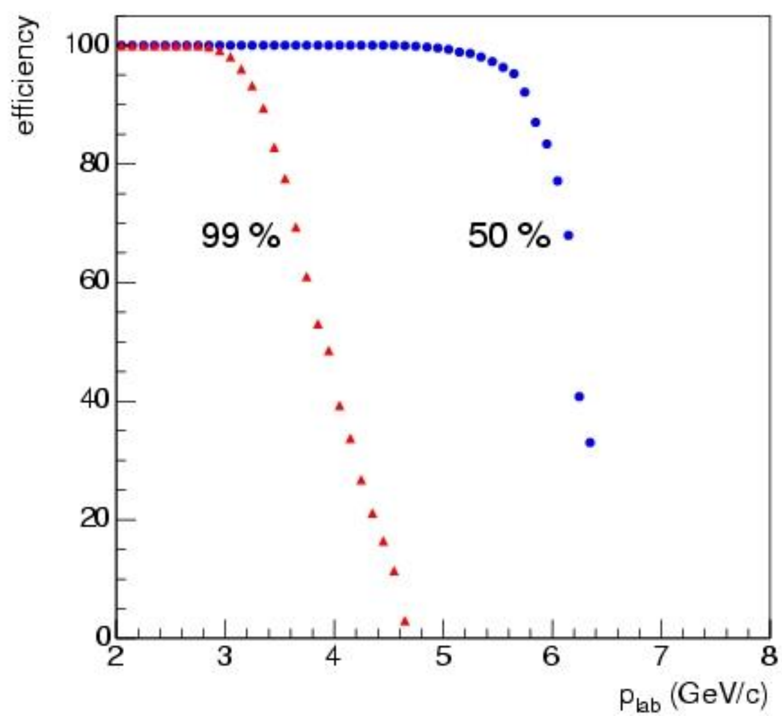
# Particle identification by TOF

Simulations: UrQMD central Au + Au at 25 AGeV
GEANT4 with B-field, geometry and material
time resolution 80 ps, 10 m distance

Squared mass measured with TOF

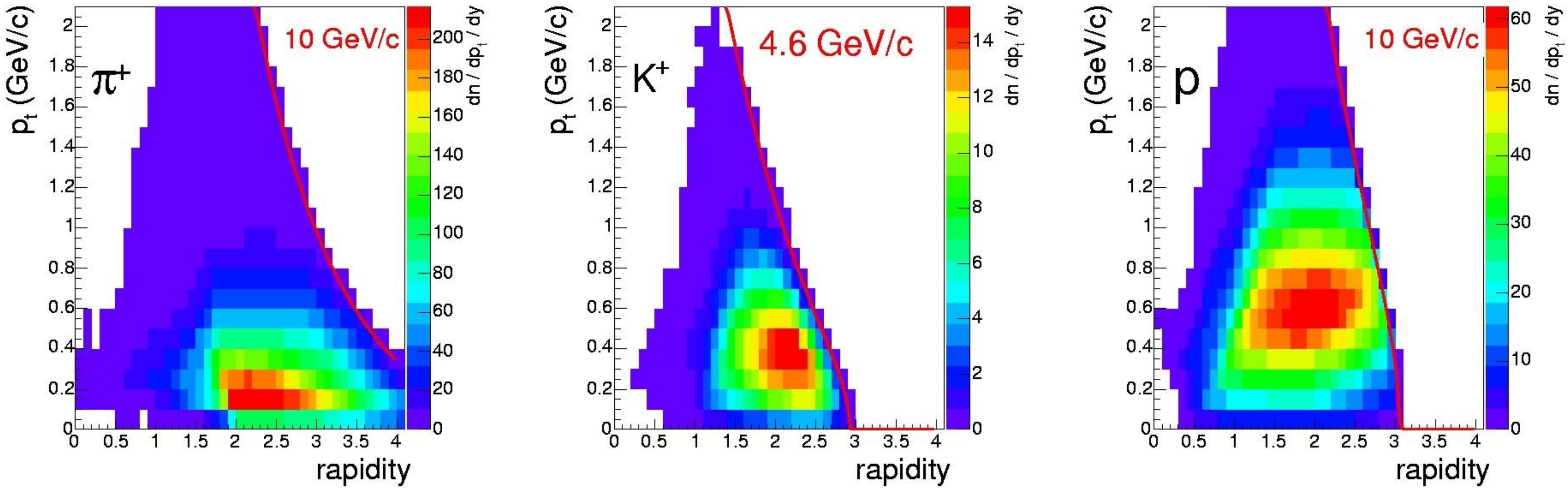



Kaon efficiency



# Acceptance for particles identified by TOF

99 % purity:



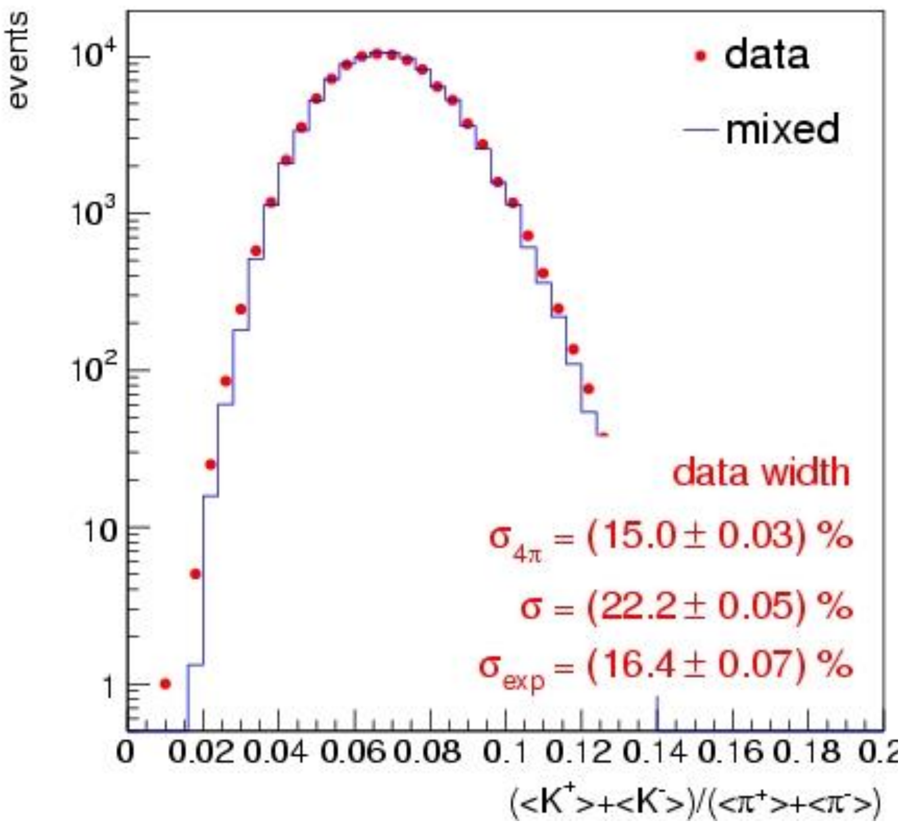

**Dynamical fluctuations in particle ratios ?**

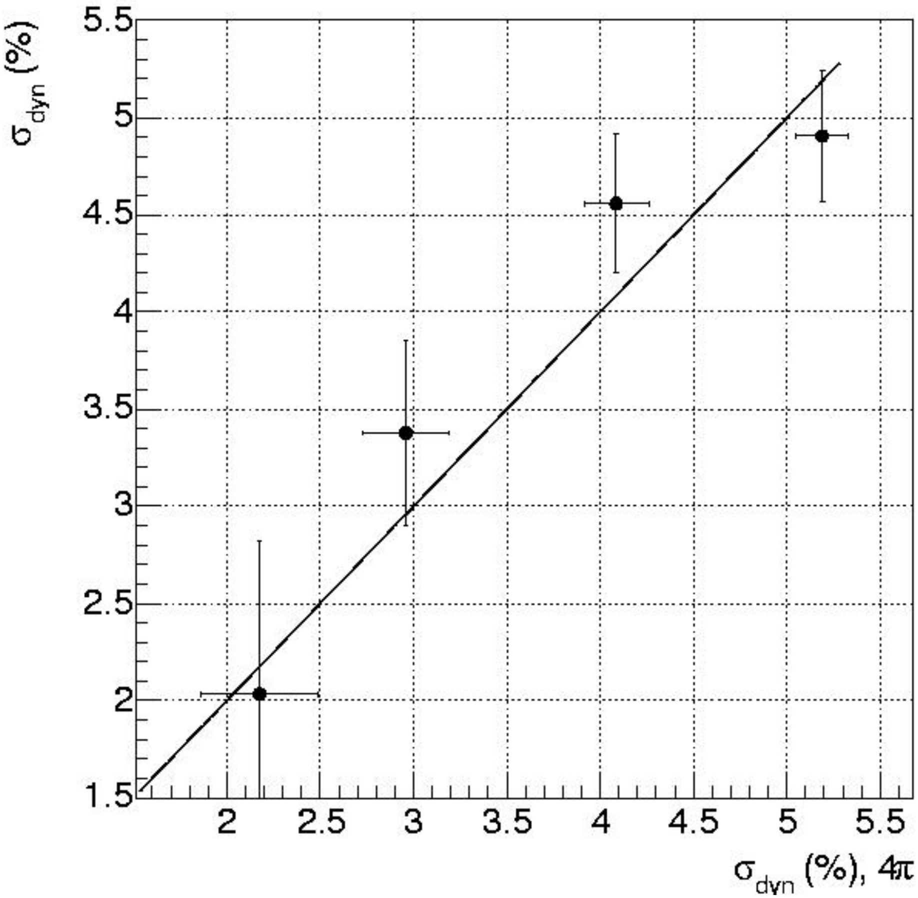
# Sensitivity on dynamical fluctuations

Generic model based on UrQMD particle yields:
central Au+Au collisions at 25 AGeV: 694 $\pi$, 54 K, 161 p

Signals with amplitudes above 2% are well reproduced

TOF distance 10 m
time resolution 80 ps



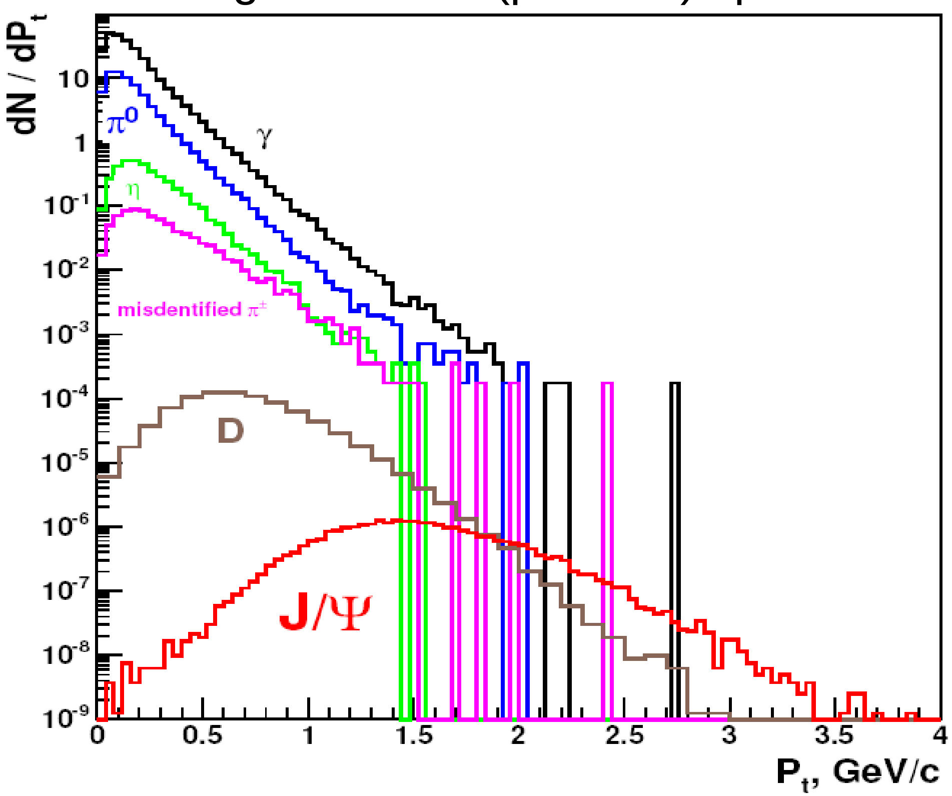



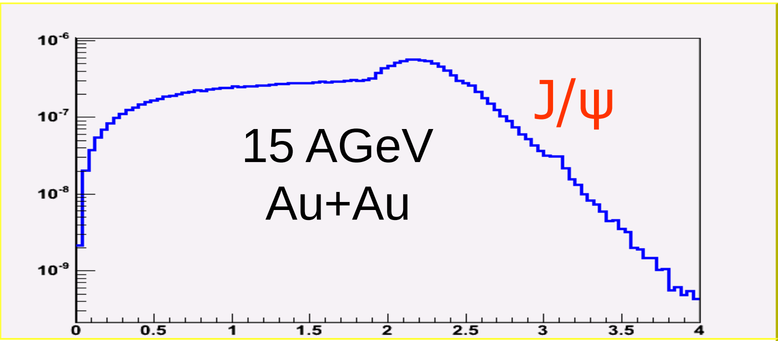
# Feasibility studies: charmonium measurements

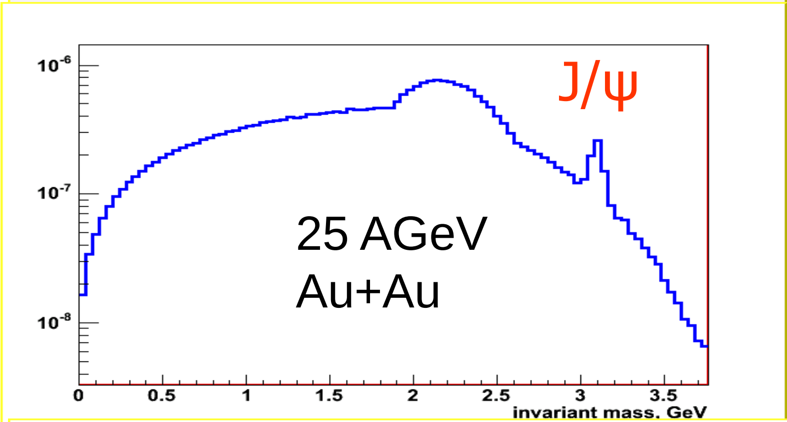
Assumptions:
no track reconstruction, momentum resolution 1%
Pion suppression $10^4$

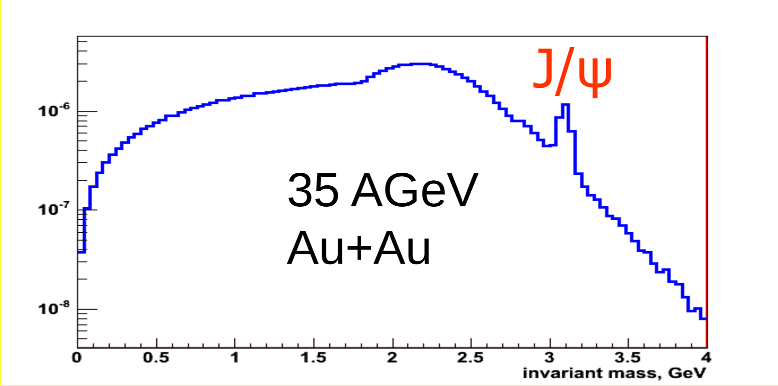
Background:
central Au + Au UrQMD + GEANT4
Cut $p_T > 1$ GeV/c

Single electron (positron) spectra

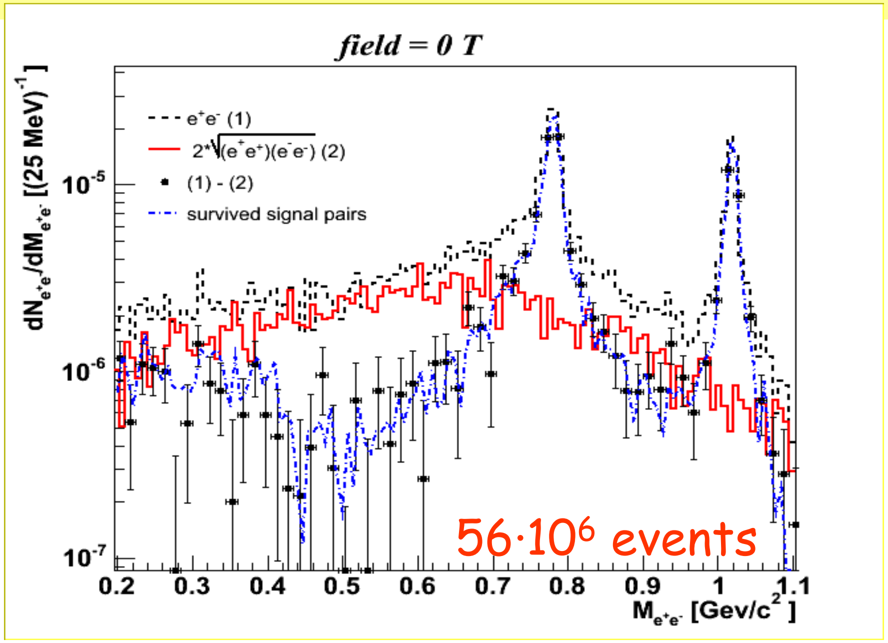


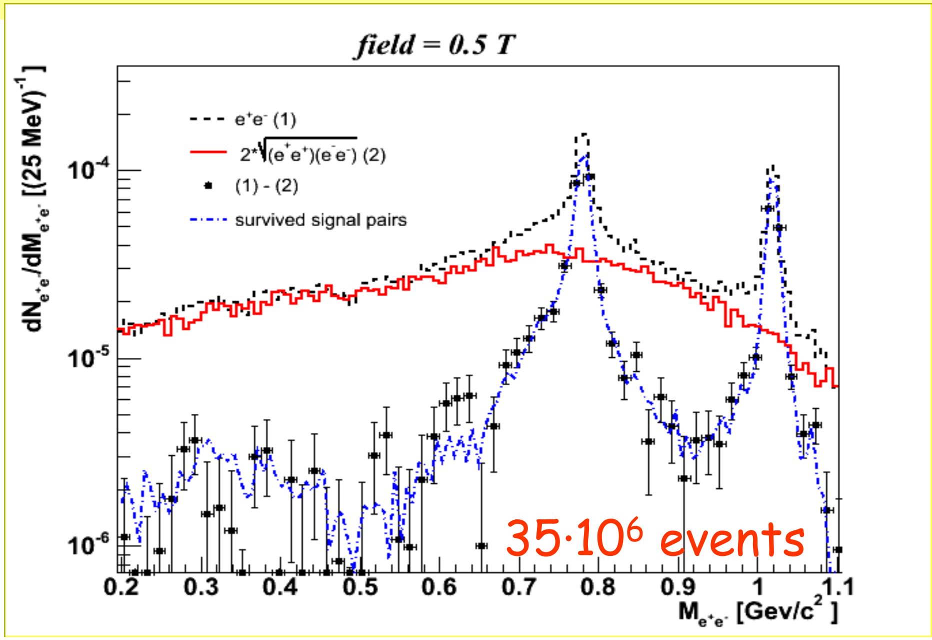



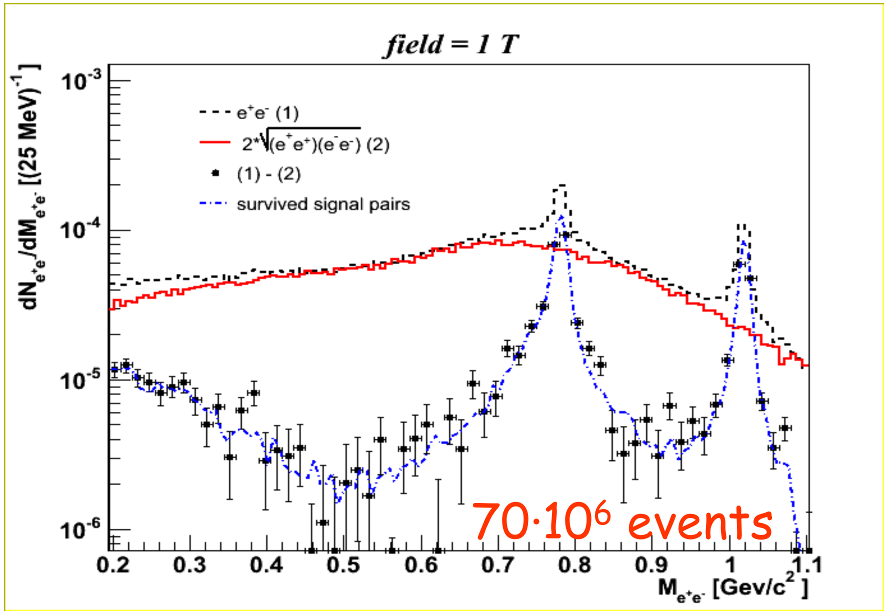



# Results




assumption:
soft electrons identified

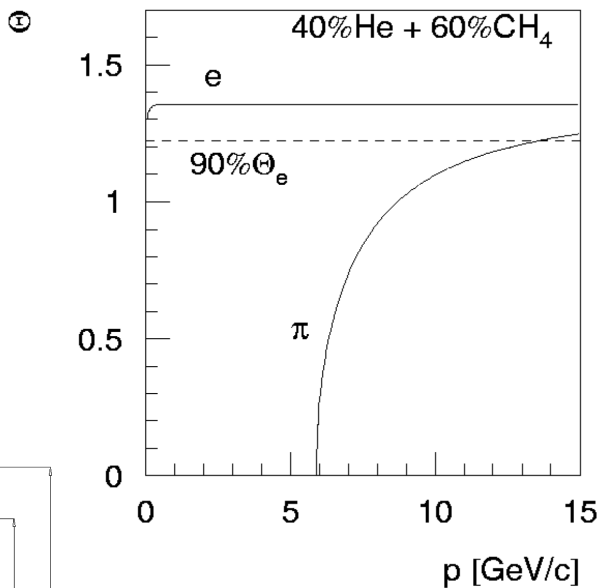
S/B in the peak:

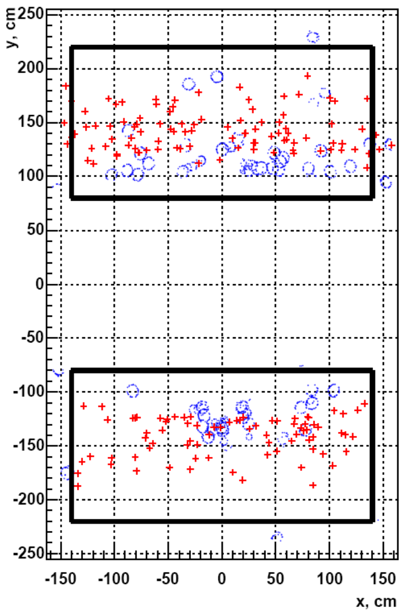
| | ρ+ω | φ |
|---|---|---|
| 0 T | 12.5 | 25 |
| 0.5T | 3.3 | 6 |
| 1.0T | 1.5 | 4 |

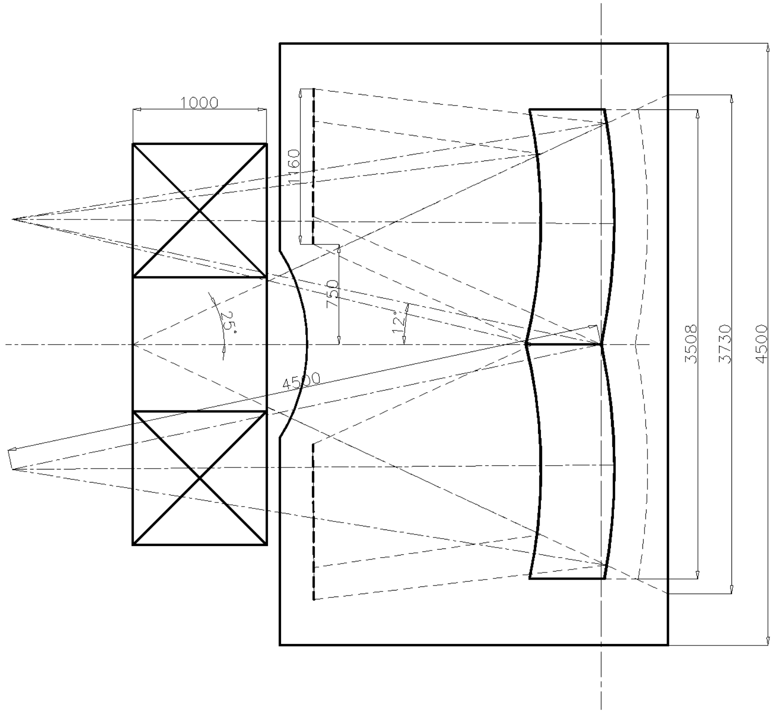
# Design of a fast RICH

## Design goals:

- electron ID for γ > 42
- e/π discrimination > 100
- hadron blind up to about 6 GeV/c
- low mass mirrors (Be-glass)
- fast UV detector




participating:
In-Kwon Yoo,
Pusan Nat. Univ.

URQMD + GEANT4: Au+Au 25 AGeV
radiator (40% He + 60% $CH_4$), ≈ 50 rings per event, 30-40 photons per ring

# Experimental conditions

Hit rates for $10^7$ minimum bias Au+Au collisions at 25 AGeV:

| Θ mrad | TRD 1 distance 4 m | | | TRD 2 distance 6 m | | | TRD 3 distance 8 m | | | TOF-RPC distance 10 m | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | rates kHz/ $cm^2$ | area $m^2$ | N $cm^{-2}$ x $10^{-2}$ | rates kHz/ $cm^2$ | area $m^2$ | N $cm^{-2}$ x $10^{-2}$ | rates kHz/ $cm^2$ | area $m^2$ | N $cm^{-2}$ x $10^{-3}$ | rates kHz/ $cm^2$ | area $m^2$ | N $cm^{-2}$ x $10^{-3}$ |
| 50 – 100 | 100 | 0.5 | 4.5 | 50 | 1.2 | 2.2 | 32 | 2.1 | 14.0 | 20 | 3.2 | 8.9 |
| 100 – 150 | 53 | 1.0 | 2.6 | 25 | 2.2 | 1.3 | 15 | 3.9 | 7.0 | 13 | 5.8 | 6.5 |
| 150 – 200 | 26 | 1.4 | 1.4 | 13 | 3.1 | 0.66 | 7.9 | 5.5 | 3.9 | 6.6 | 8.1 | 3.2 |
| 200 – 250 | 17 | 1.8 | 0.78 | 7.5 | 4.1 | 0.36 | 4.8 | 7.3 | 2.3 | 4.5 | 10.2 | 2.0 |
| 250 – 300 | 9.6 | 2.3 | 0.46 | 5.0 | 5.2 | 0.24 | 2.7 | 9.2 | 1.4 | 2.6 | 12.3 | 1.4 |
| 300 – 350 | 7.1 | 2.8 | 0.34 | 3.3 | 6.4 | 0.17 | 2.0 | 11.3 | 0.95 | 2.1 | 14.3 | 1.0 |
| 350 – 400 | 4.4 | 3.4 | 0.21 | 2.1 | 7.7 | 0.1 | 1.3 | 13.7 | 0.65 | 1.8 | 16.1 | 0.69 |
| 400 – 450 | 2.0 | 4.1 | 0.09 | 1.0 | 9.3 | 0.05 | 0.6 | 16.5 | 0.29 | 0.8 | 17.7 | 0.31 |
| 450 – 500 | 0.9 | 4.9 | 0.04 | 0.4 | 11 | 0.02 | 0.3 | 19.6 | 0.13 | 0.4 | 19.2 | 0.14 |
| sum | | 22.2 | | | 50.2 | | | 89.1 | | | 106.8 | |

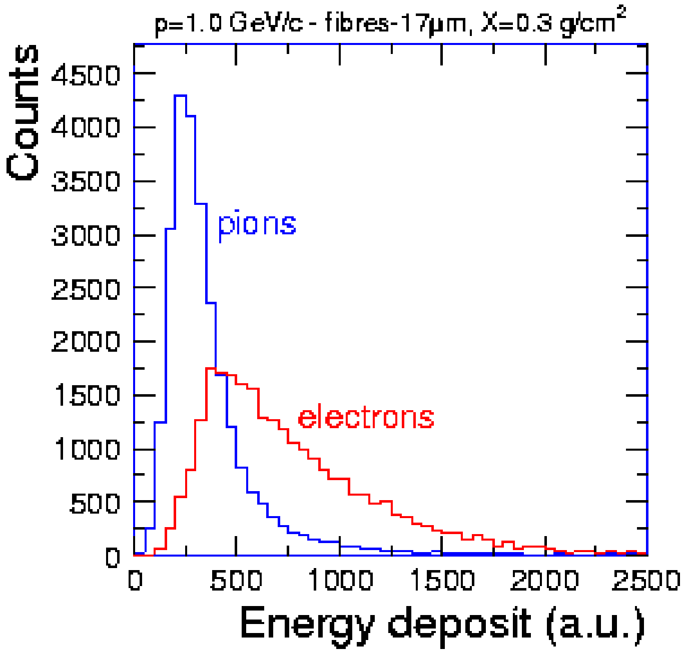
Rates of > 5 kHz/$cm^2$ ⇨ detector R&D

# Design of a fast TRD

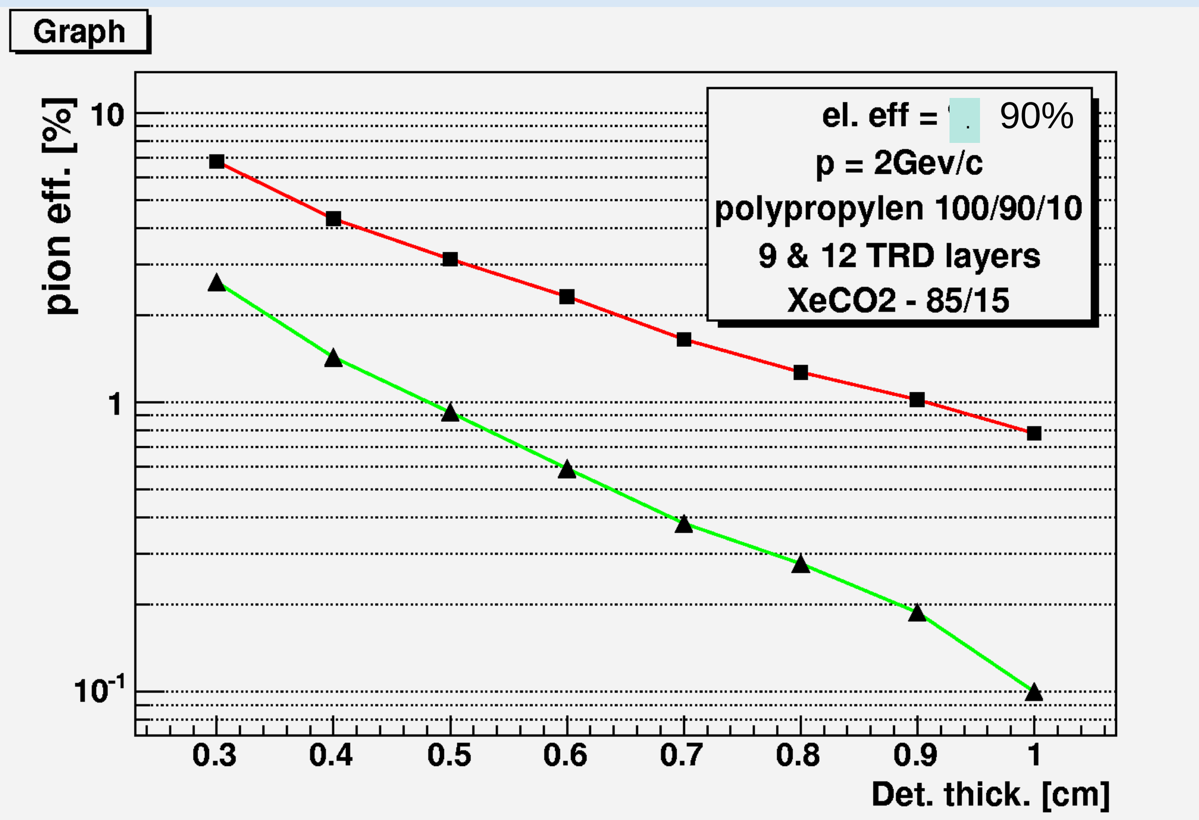
## Design goals:

e/π discrimination of > 100 (p > 1 GeV/c)

- High rate capability up to 100 kHz/cm²
- Position resolution of about 200 µm
- Large area (≈ 450 - 650 m², 9 – 12 layers)

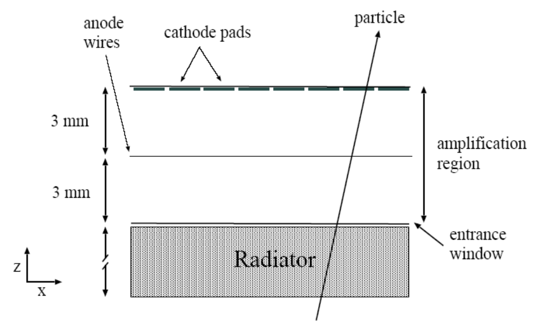



**Simulation of pion suppression: MWPC-based TRD**

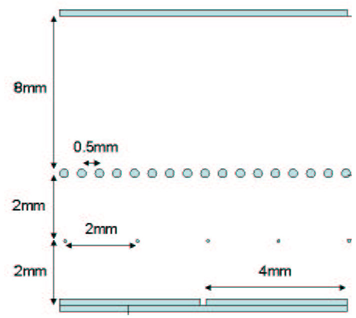


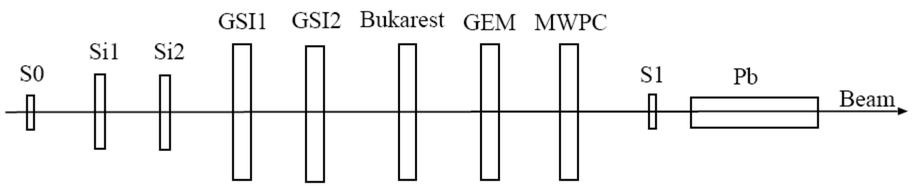
# Rate performance of TRD prototypes (ALICE type): beam test measurements (p and π)

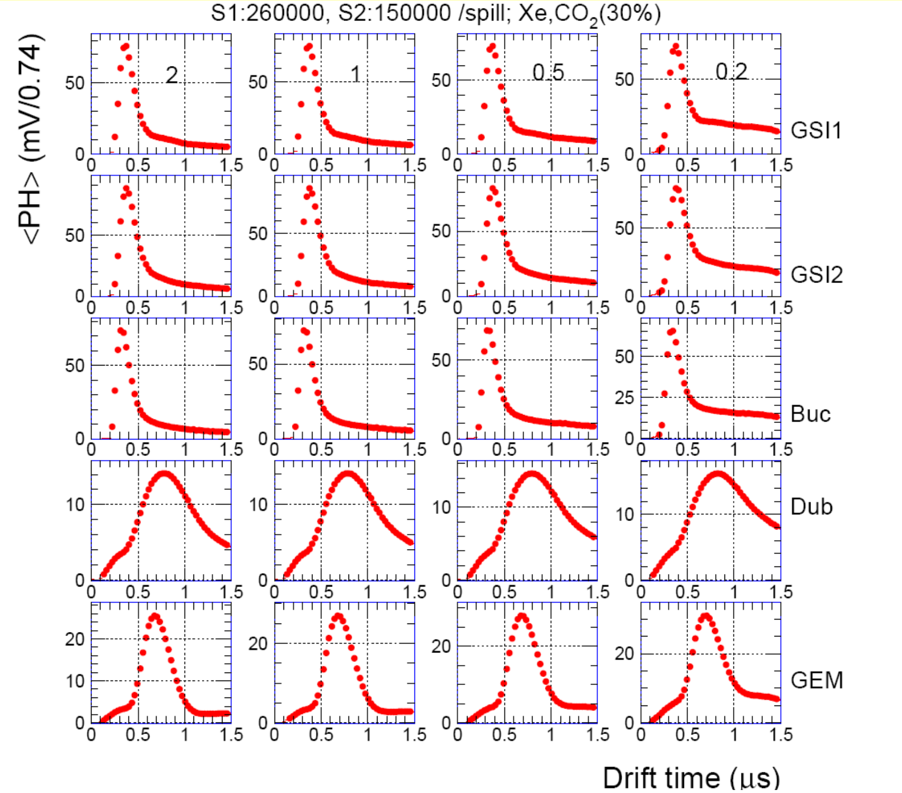
## MWPC GSI, Bucharest

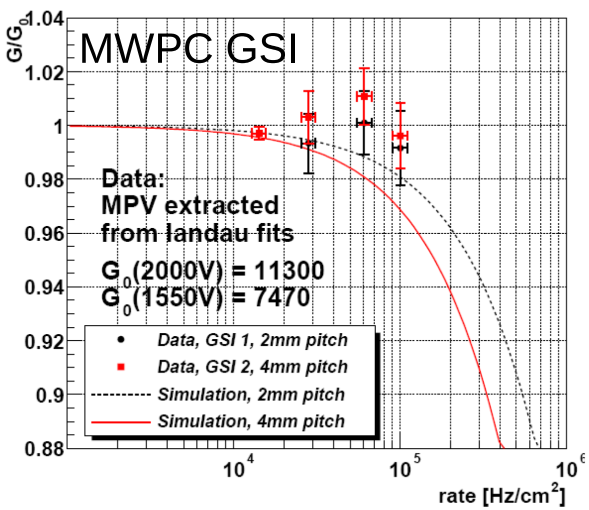


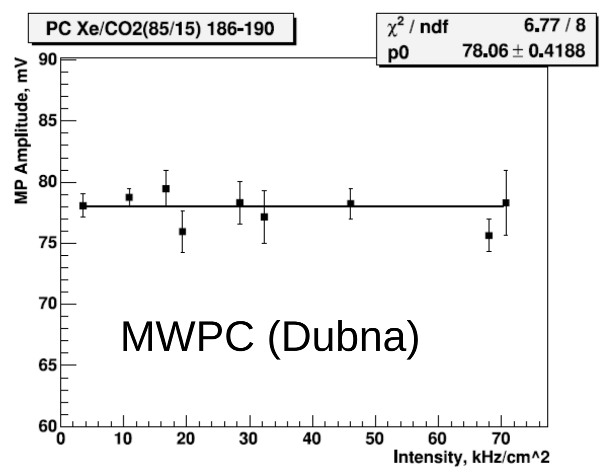

## MWPC Dubna

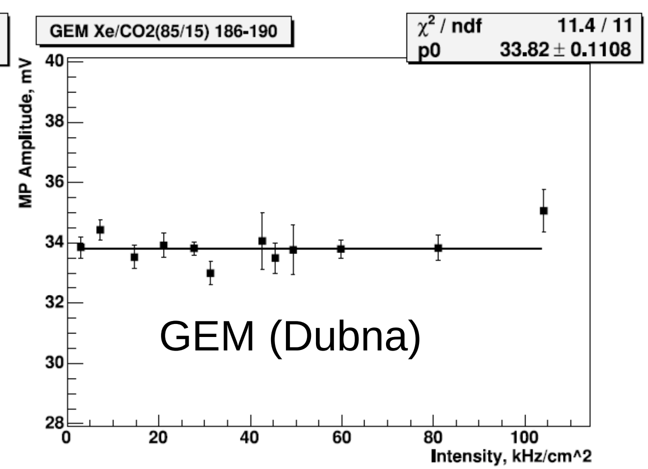


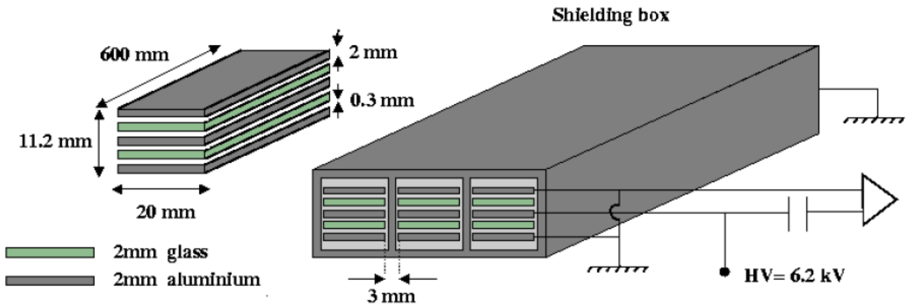



# Development of a large-area high-rate timing RPC

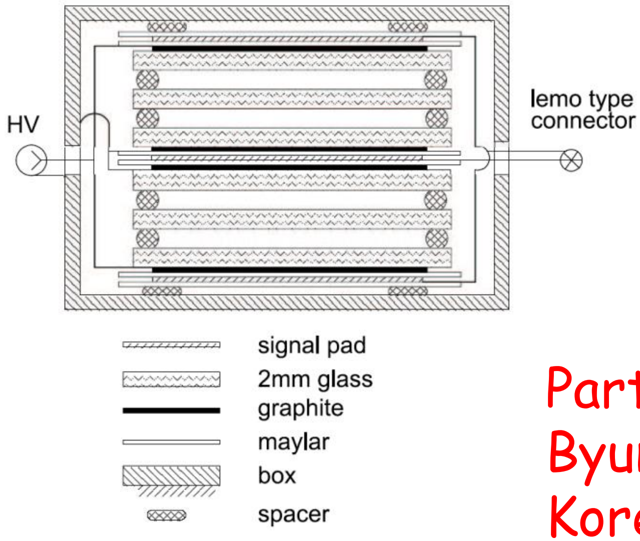
## Design goals:
- Time resolution ≤ 80 ps
- Rate capability up to 20 kHz/cm$^2$
- Efficiency > 95 %
- Large area ≈ 100 m$^2$
- Long term stability

## shielded RPC prototype

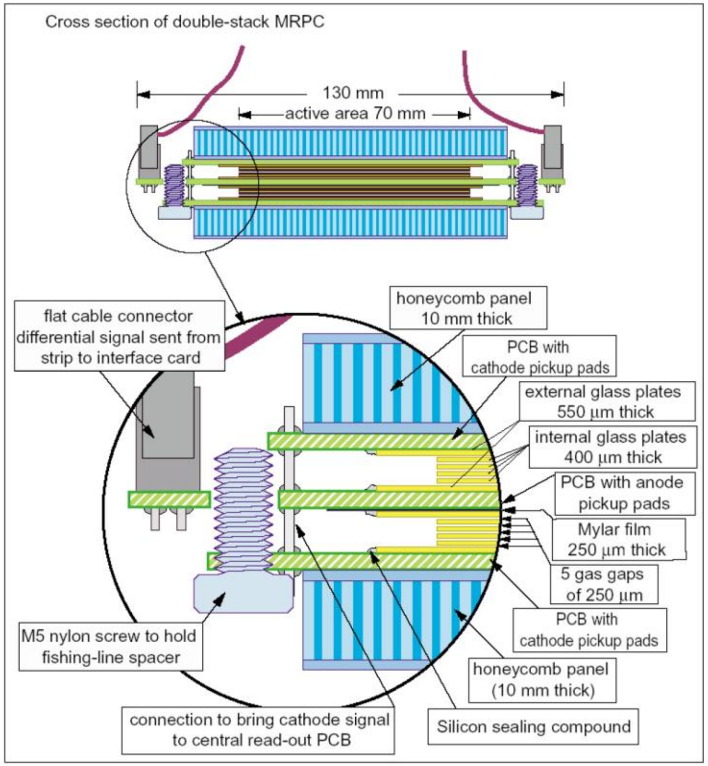



## Layout options

## single cell RPC

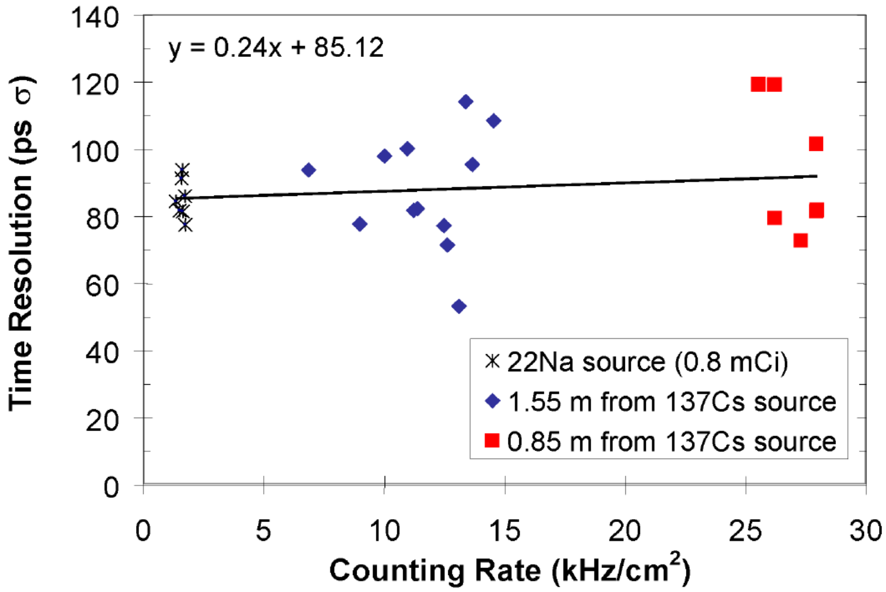



## Multigap RPC (ALICE )




Participating:
Byungsik Hong,
Korea Univ.

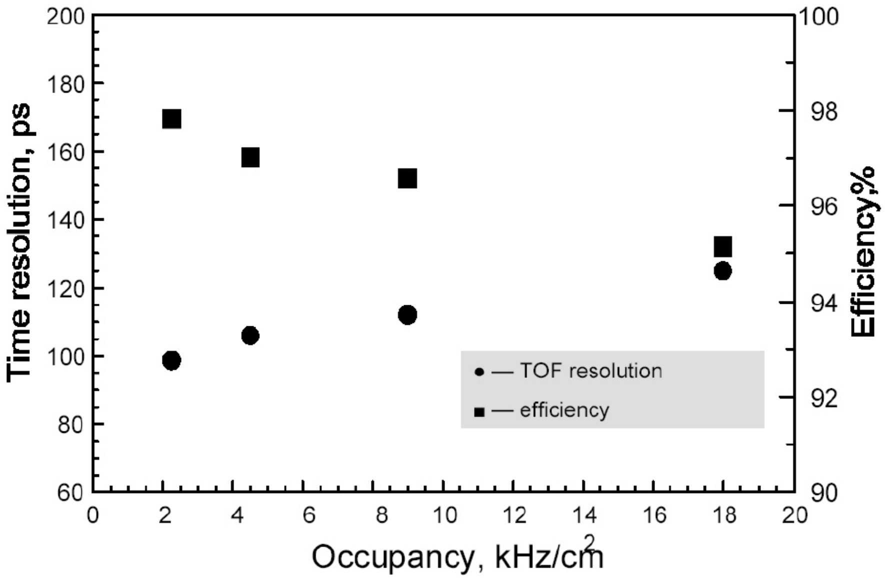
# RPC prototype tests: time resolution vs. rate



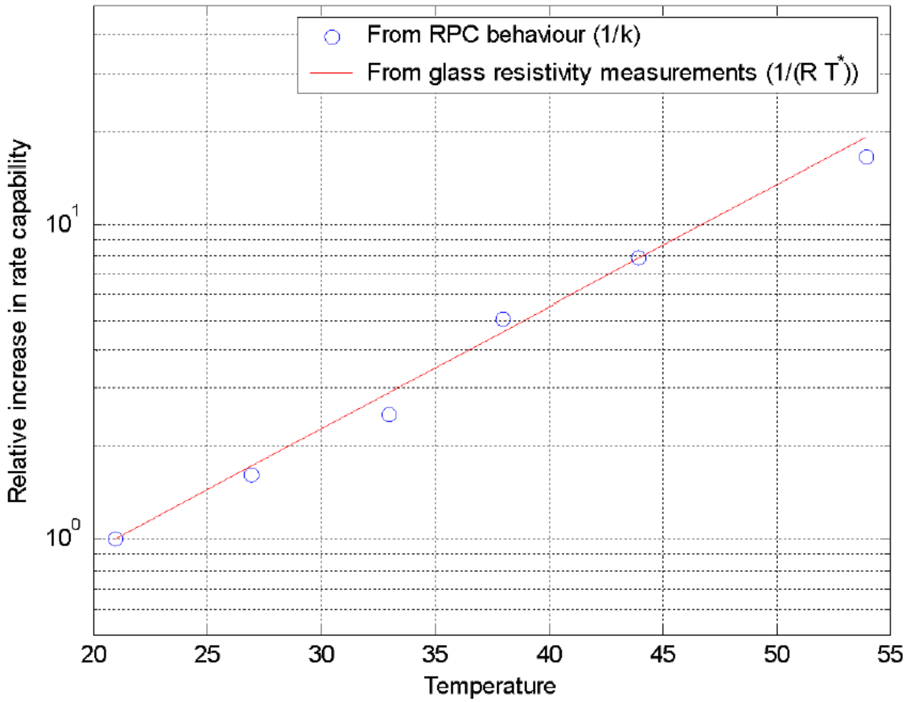

Detector with plastic electrodes (resistivity $10^9$ Ohm cm.)

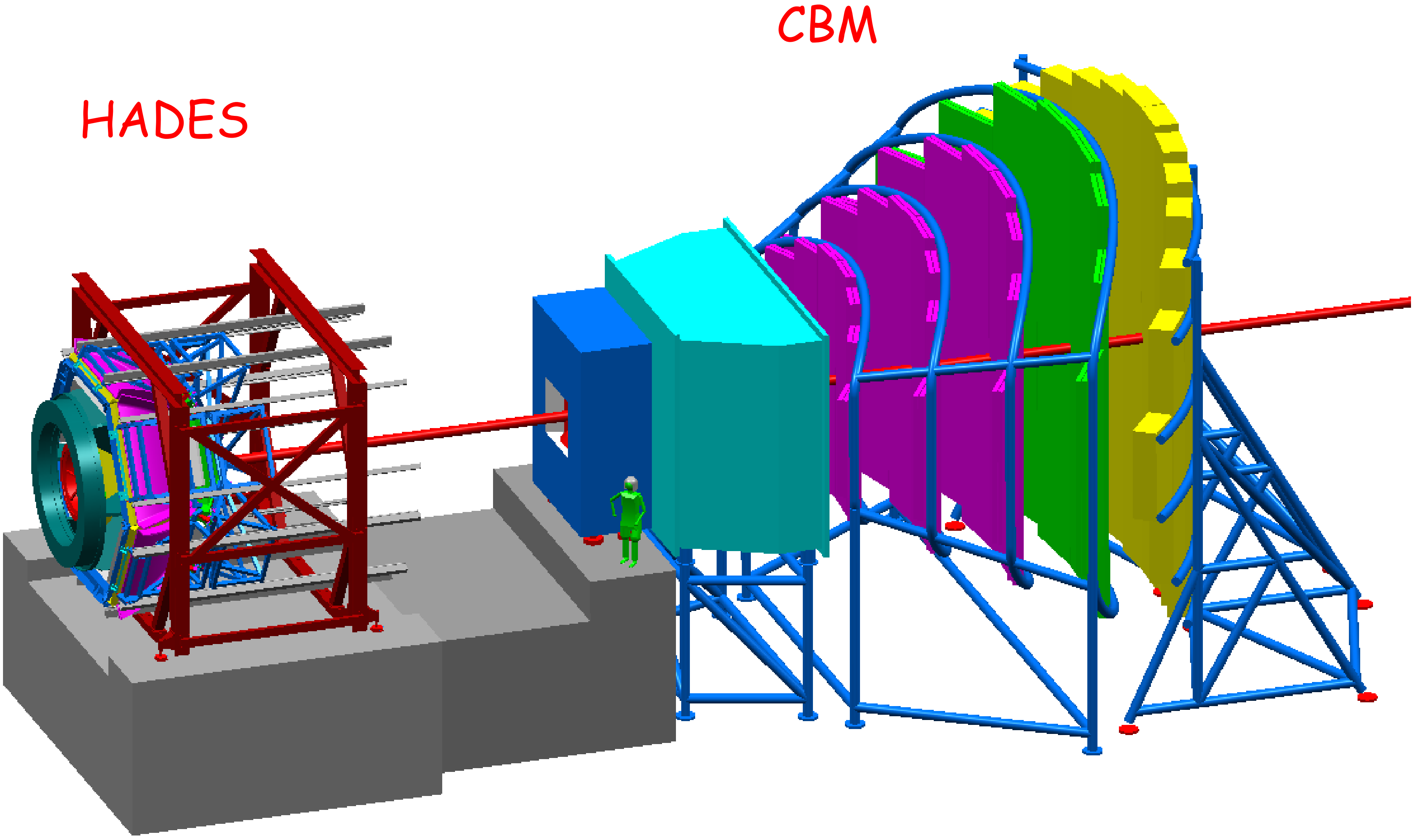
New: encouraging results with ceramic electrodes !

RPC prototype with phosphate glass




Window glass: improved rate capability with increased temperature




HADES
CBM

# Experimental program of CBM:

## Observables:

Penetrating probes: $\rho$, $\omega$, $\varphi$, $J/\psi$ (vector mesons)
Strangeness: K, $\Lambda$, $\Sigma$, $\Xi$, $\Omega$,
Open charm: $D^o$, $D^\pm$
Hadrons ( p, $\pi$), exotica

## Detector requirements

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

## 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

## Large integrated luminosity:

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

# CBM Collaboration : 41 institutions, > 300 Members

**Croatia:**
RBI, Zagreb

**China:**
Wuhan Univ.

**Cyprus:**
Nikosia Univ.

**Czech Republic:**
CAS, Rez
Techn. Univ. Prague

**France:**
IReS Strasbourg

**Hungaria:**
KFKI Budapest
Eötvös Univ. Budapest

**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. Marburg
Univ. Münster
FZ Rossendorf
GSI Darmstadt

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

**Portugal:**
LIP Coimbra

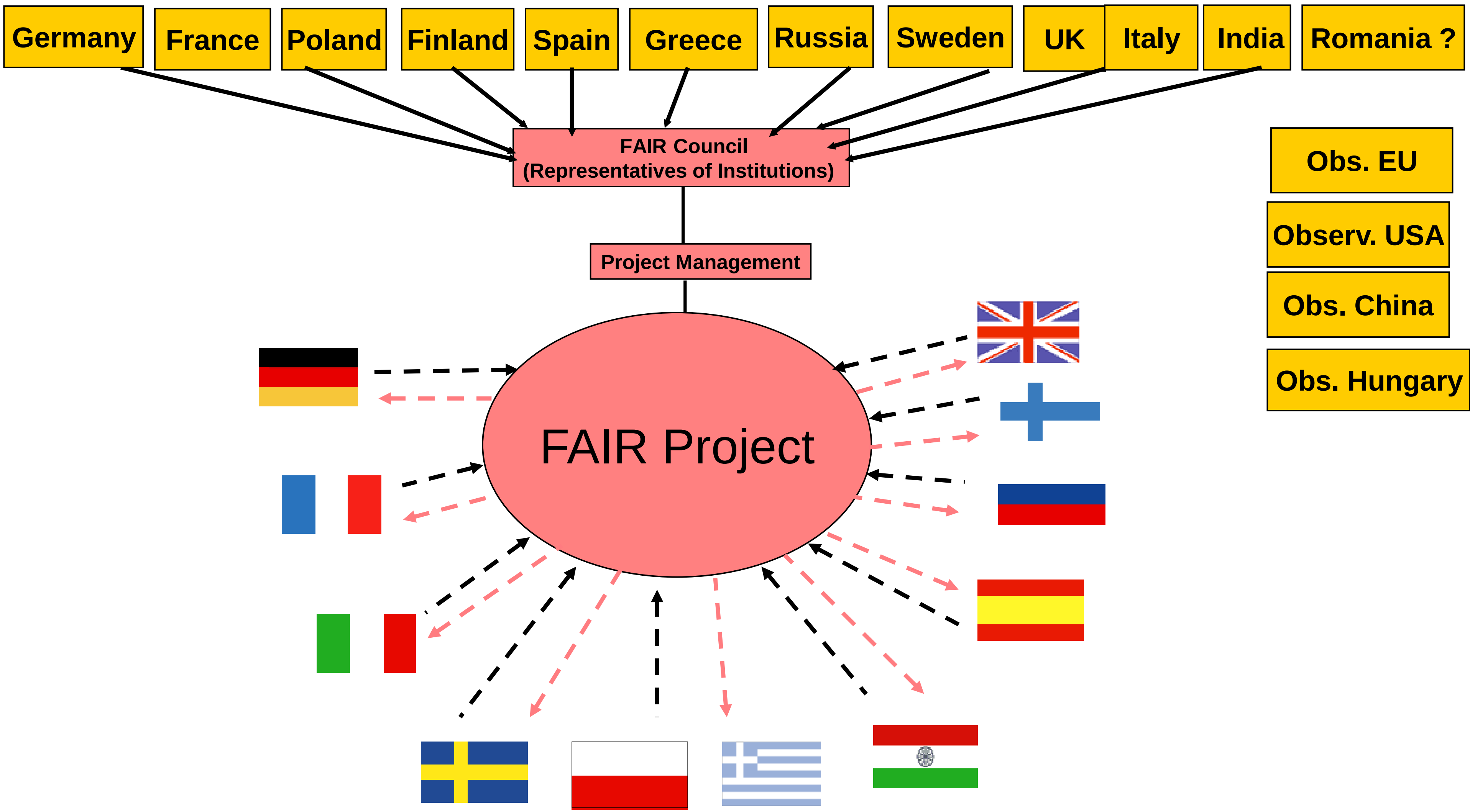
**Romania:**
NIPNE Bucharest

**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.

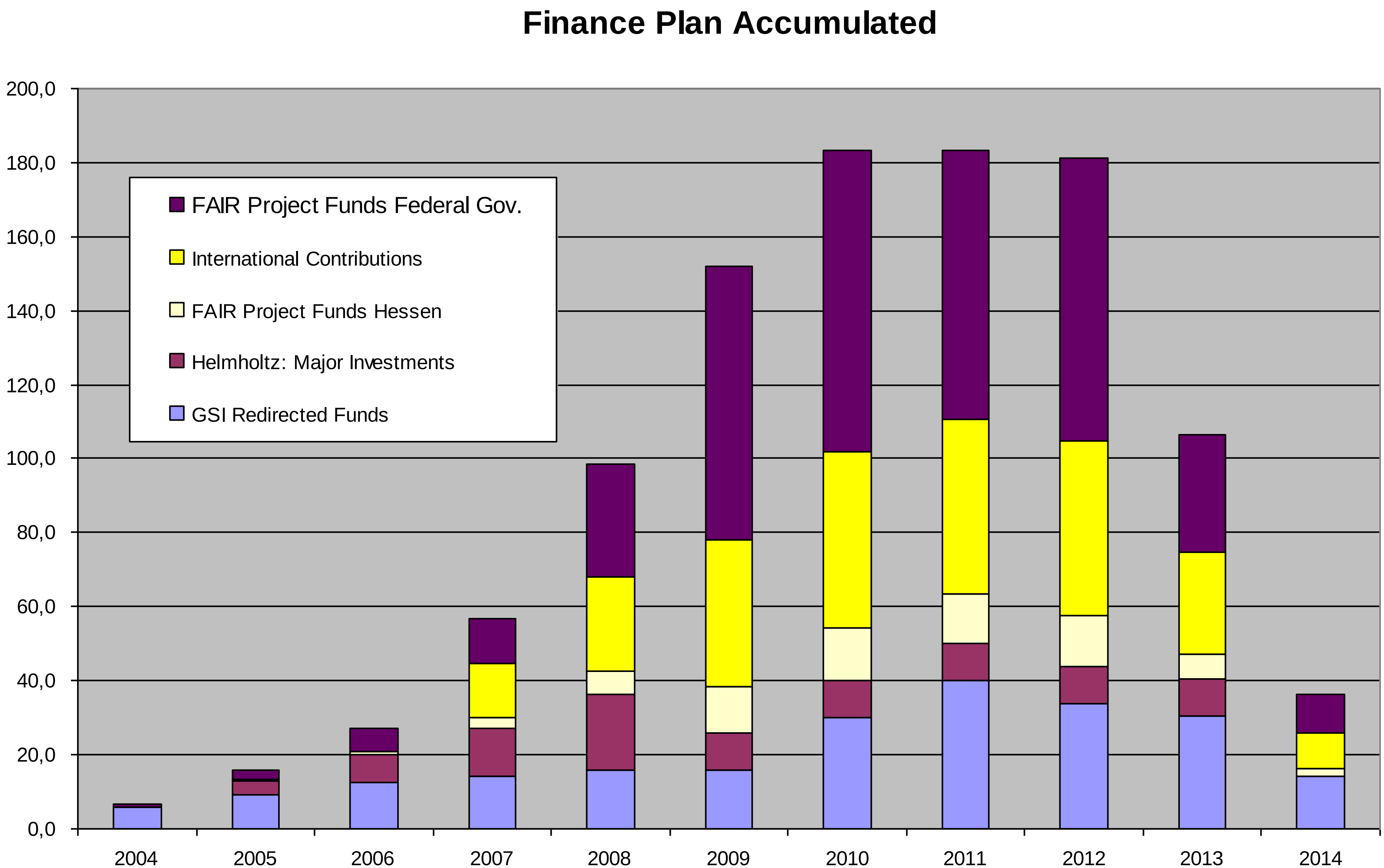
**Spain:**
Santiago de Compostela Univ.

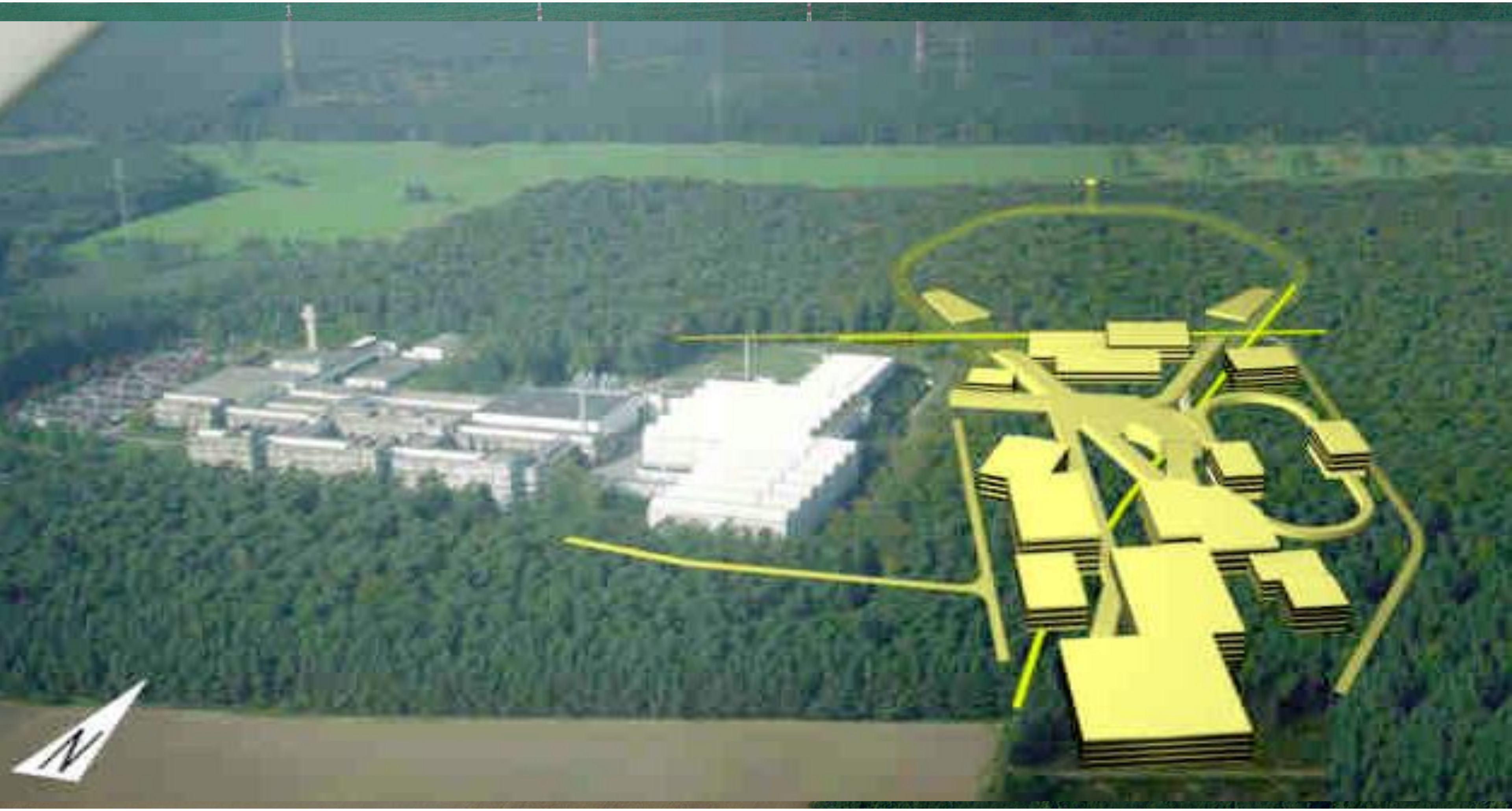
**Ukraine:**
Shevshenko Univ. , Kiev

# The FAIR member states  (March 2005)



# Funding profile

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