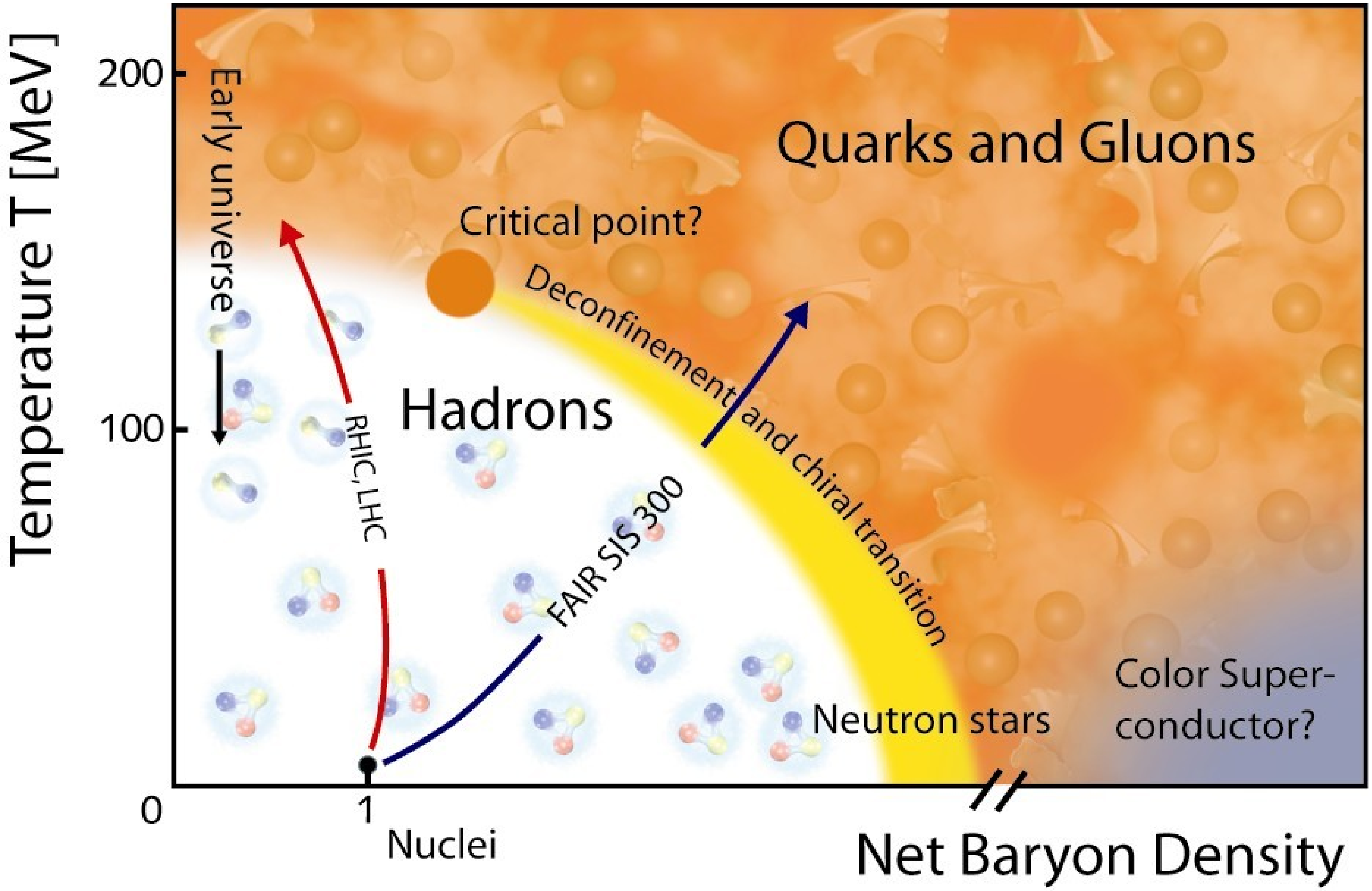
The CBM experiment

Radoslaw Karabowicz

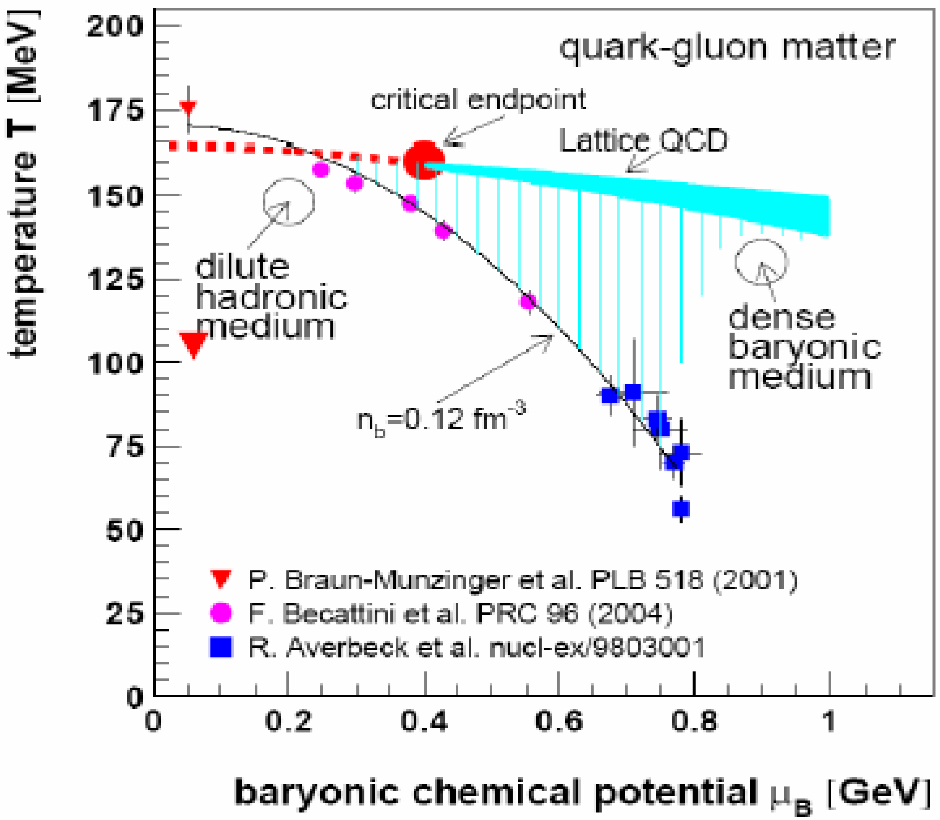
GSI, Germany

QCD phase diagram

Nice artistic picture:



Experimental status



Experimental results:

- Freeze-out curve (T, μ_B)
- T_{fo} = 161±4 MeV at (μ_B=0)
- new state of matter = perfect liquid?

L-QCD Predictions:

- T_C = 151 ± 7 ± 4 MeV (Z. Fodor, arXiv:0712.2930 hep-lat)
- T_C = 192 ± 7 ± 4 MeV (F. Karsch, arXiv:0711.0661 hep-lat)
- crossover transition at μ_B=0 (Z. Fodor, arXiv:0712.2930 hep-lat)
- 1. order phase transition with critical endpoint at $\mu_B > 0$

High-energy heavy-ion collision experiments:

RHIC, LHC: cross over transition, QGP at high T and low ρ
Low-energy RHIC: search for QCD-CP with bulk observables
NA61@SPS: search for QCD-CP with bulk observables
CBM@FAIR: scan of the phase diagram with bulk and rare observables

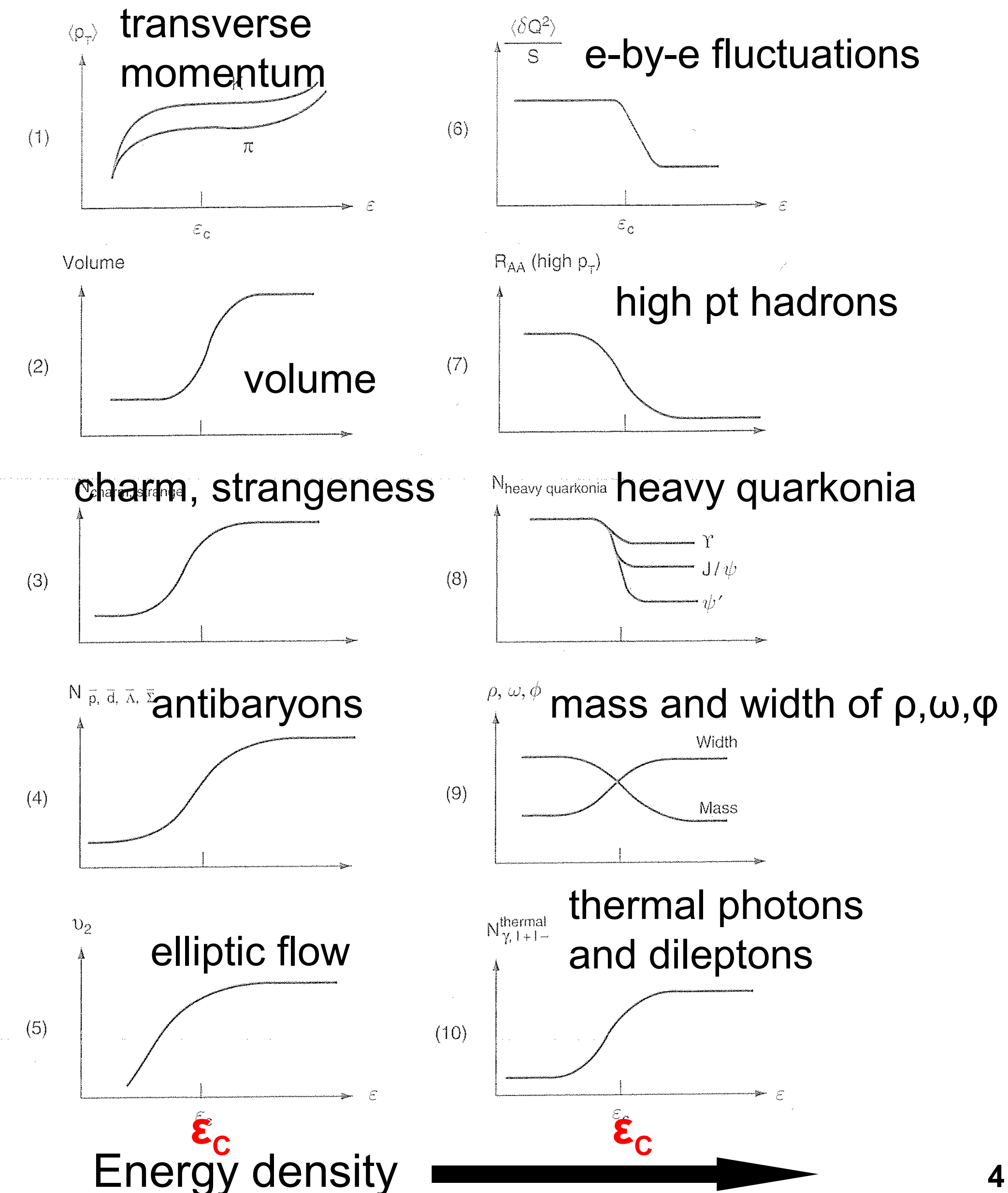
QGP signatures

taken from the book:
Quark-Gluon-Plasma:
from big bang to little bang
by
Kohsuke Yagi,
Tetsuo Hatsuda,
Yasuo Miake (2006)

adapted from an original
by Shoji Nagamiya

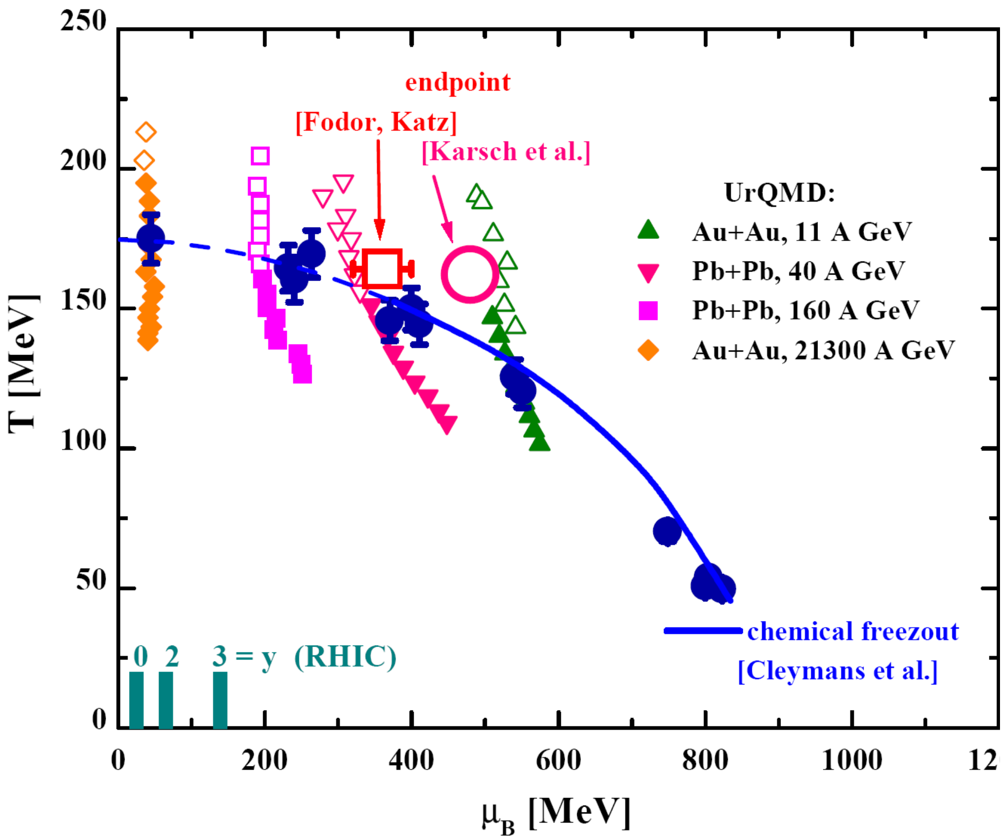
Seach for discontinuities
in excitation functions
of various observables !

How much are the signals
diluted by finite size,
short lifetimes,
and hadronization?

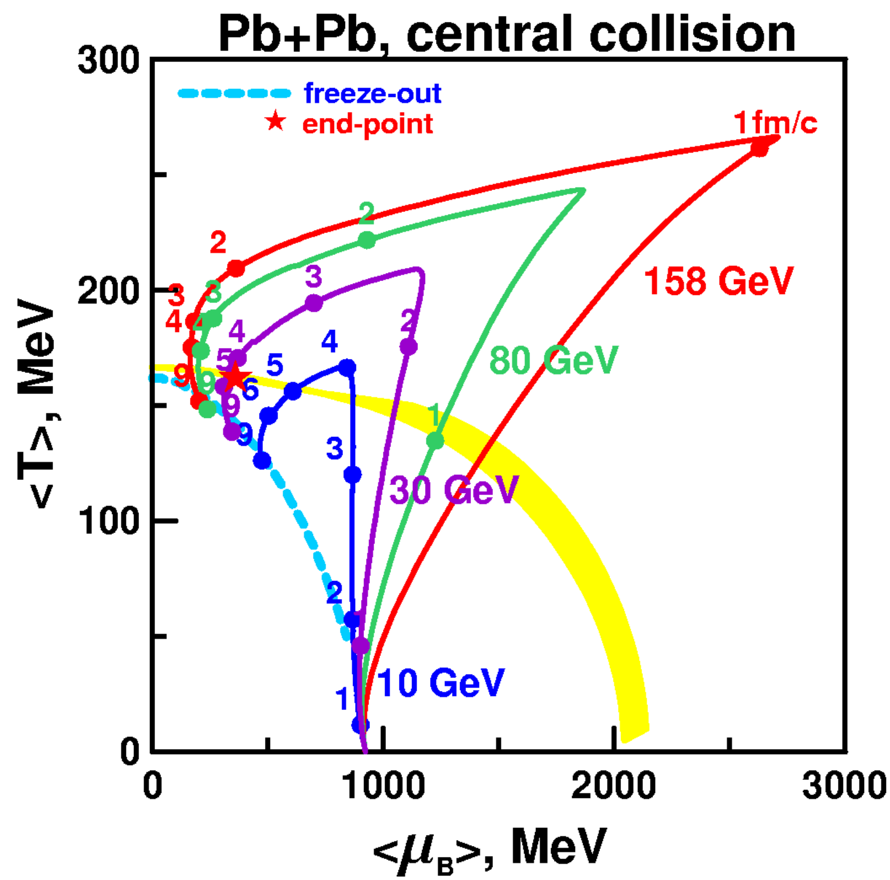


Trajectories from transport models

UrQMD: L.V. Bravina et al.,
Phys. Rev. C60 (1999) 044905



3-fluid hydro:
Y. Ivanov, V. Russkikh, V.Toneev,
Phys. Rev. C73 (2006) 044904



FAIR beam energies for CBM:
A+A collisions between 10 and 45 AGeV, Z/A=0.5 (0.4)
(p+p and p+A collisions up to 90 GeV)

CBM program

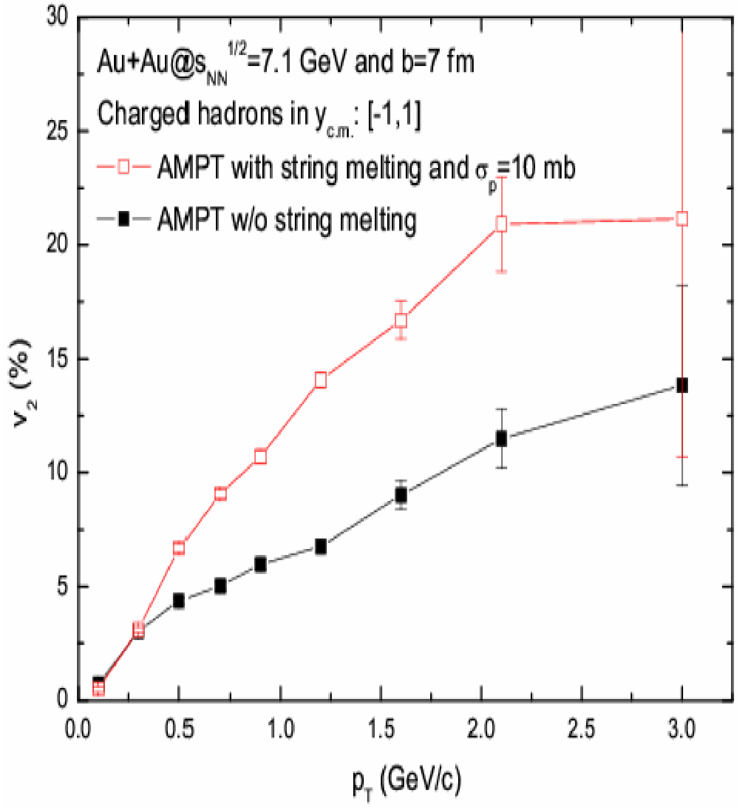
Measure heavy ion collisions at energies of 10-45 AGeV in order to:

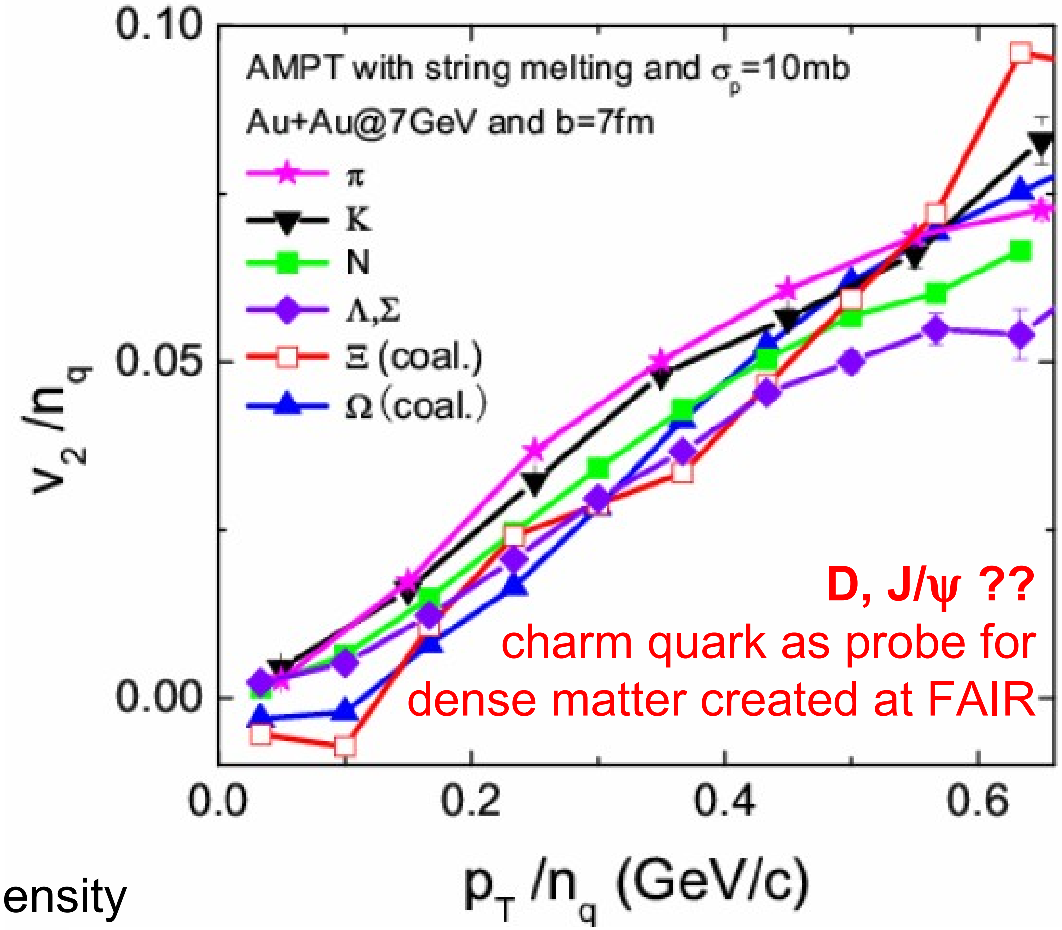
- study the properties of the equation of state at high ρ_B,
- tion
- high ρ_B,
- determine the existence and position of the critical endpoint.

hadrons' collective flow
threshold particle production

Elliptic flow

AMPT calculations: C.M. Ko at CPOD 2007





Strength of measured v_2 – initial density

Behavior of v_2 for different particle species – initial degrees of freedom

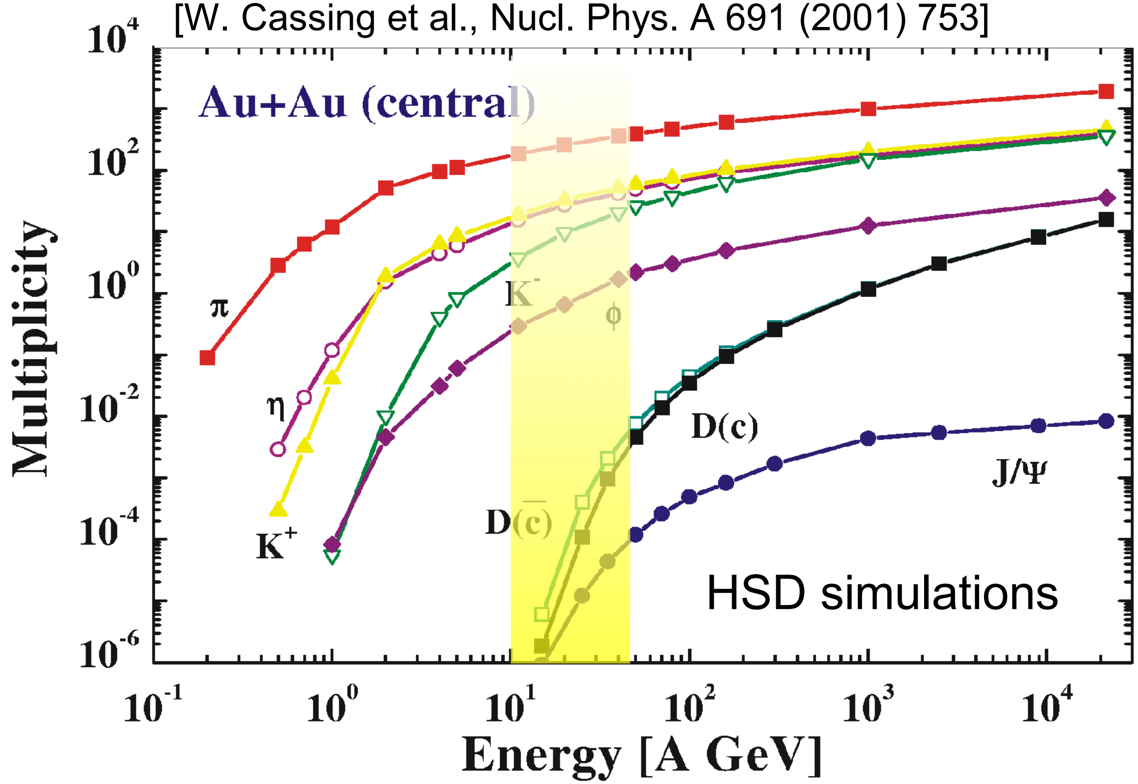
Measure flow for all particles over CBM energy range

Charm production at threshold

After primoridal production, the survival probability, momentum and distribution amongst different charm hadrons depends on the interactions with the dense and hot medium.

→ Charm is a direct probe of the medium

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



Measure production of charm at threshold

CBM program

Measure heavy ion collisions at energies of 10-45 AGeV in order to:

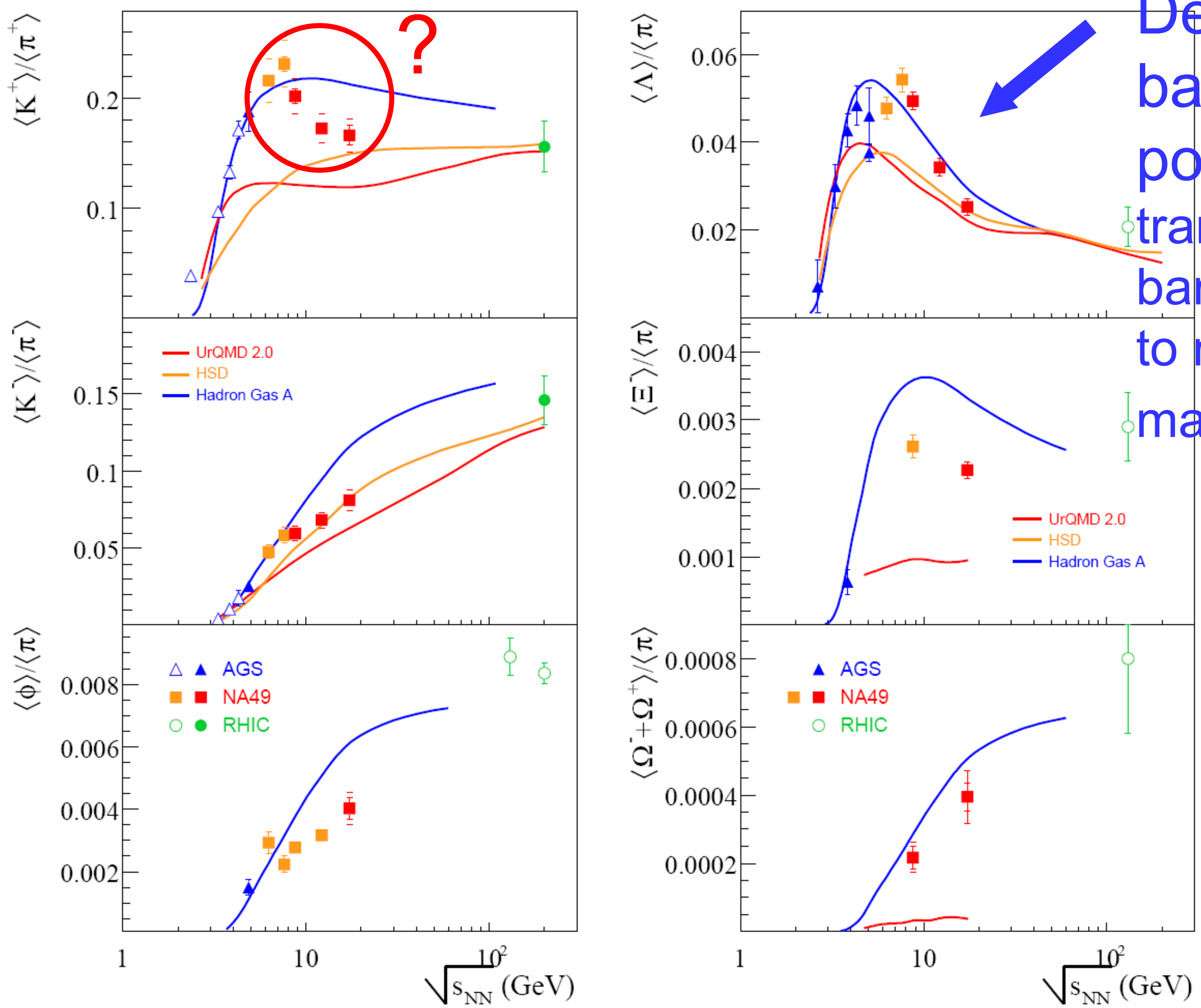
- study the properties of the equation of state at high ρ_B,
- observe the deconfinement phase transition

excitation function and flow of strangeness
excitation function and flow of charm
excitation function of low-mass lepton pairs

- high ρ_B,
- the critical endpoint.

Strangeness production

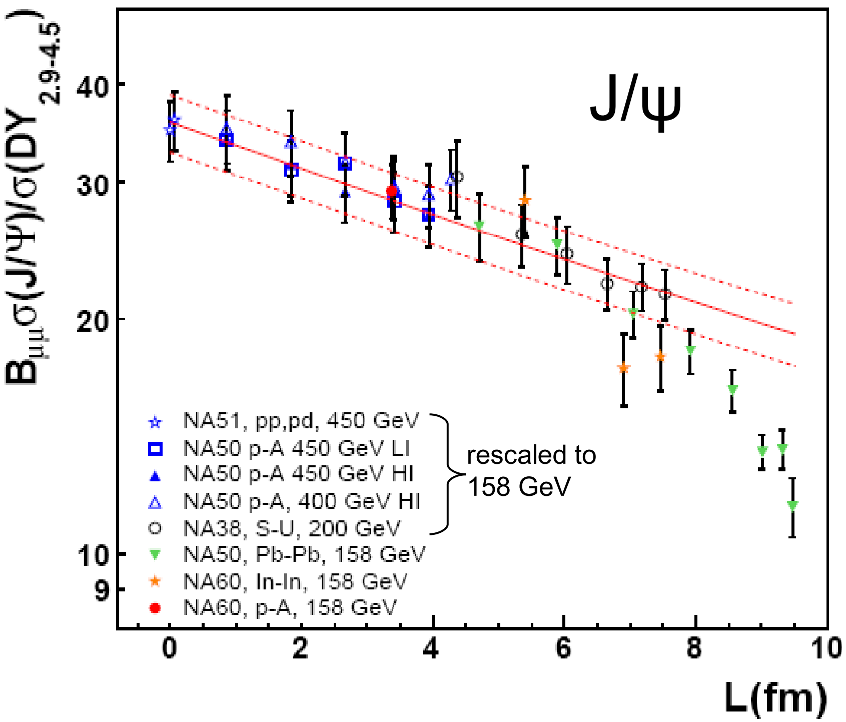
C. Blume et al. (NA49 at CERN-SPS), nucl-ex/0409008

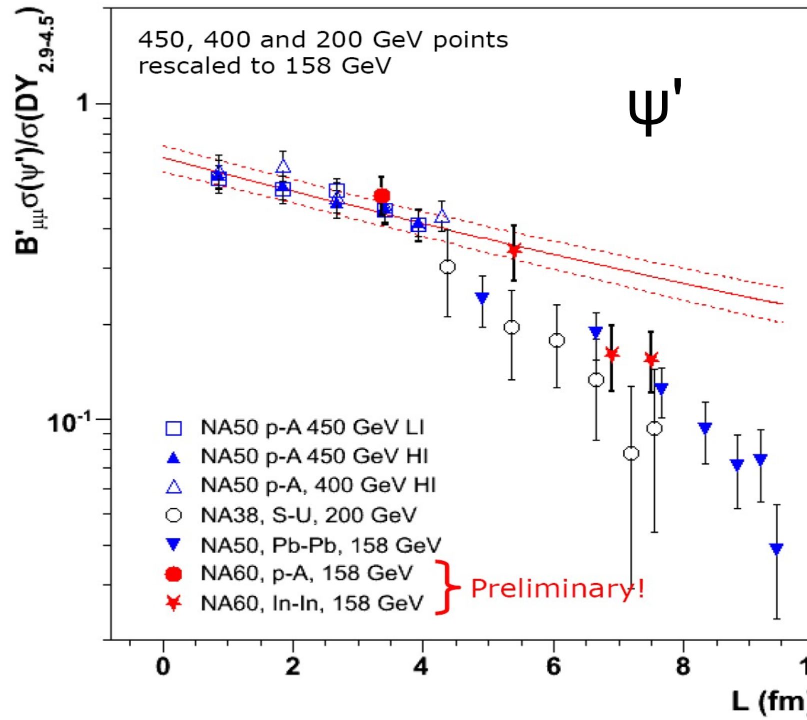


Decrease of baryon-chemical potential: transition from baryon-dominated to meson-dominated matter

Measure excitation function of multistrange particle production and flow

Charm production





Quarkonium dissociation temperatures:
(Digal, Karsch, Satz)

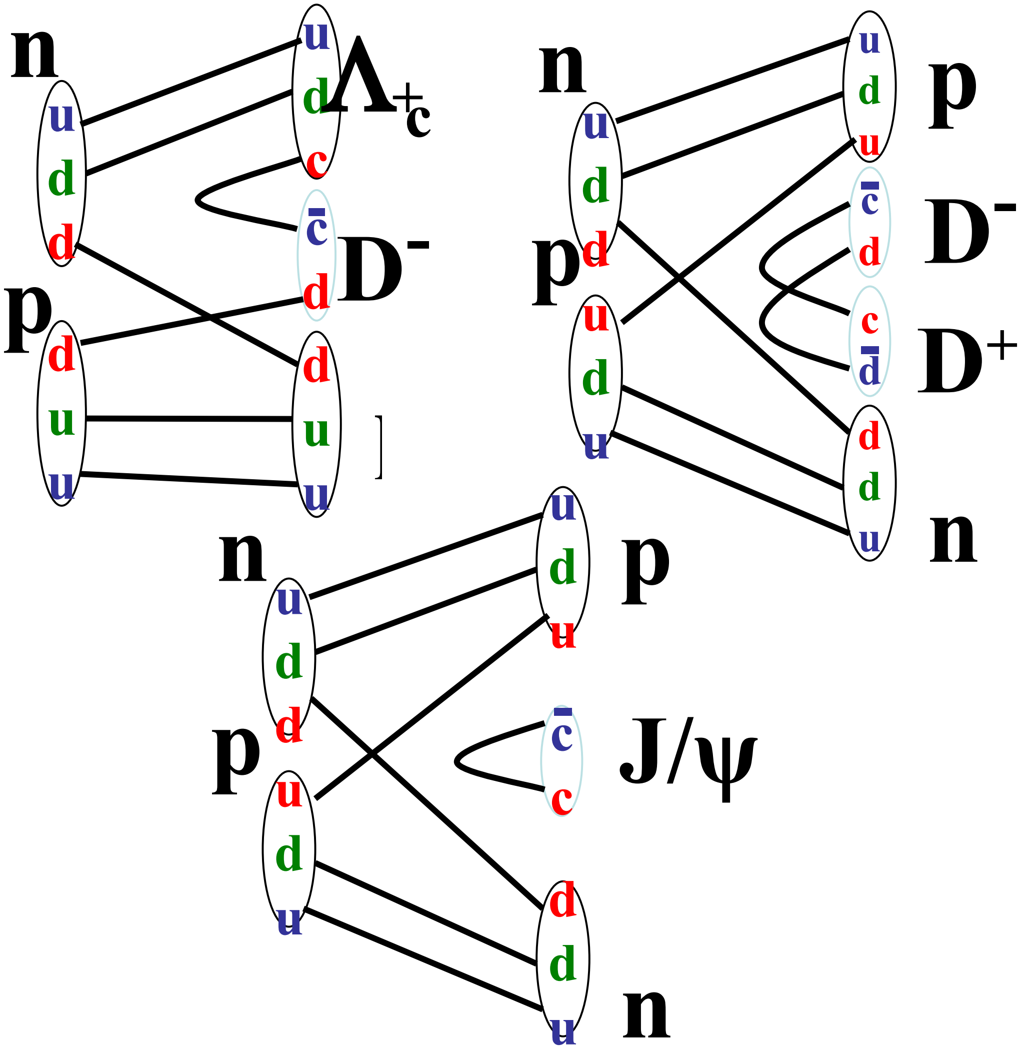
state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	>4.0	1.76	1.60	1.19	1.17

Could it be sign of sequential dissociation?

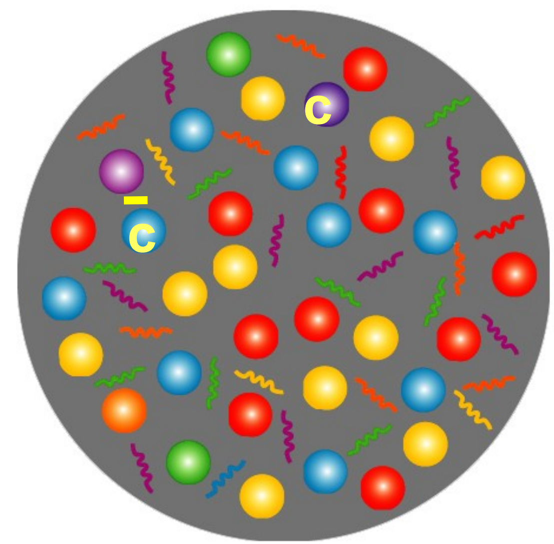
Measure excitation functions of J/ψ, ψ', D, Λ_c production

Charm production cont'd

Charm creation in hadronic transport models

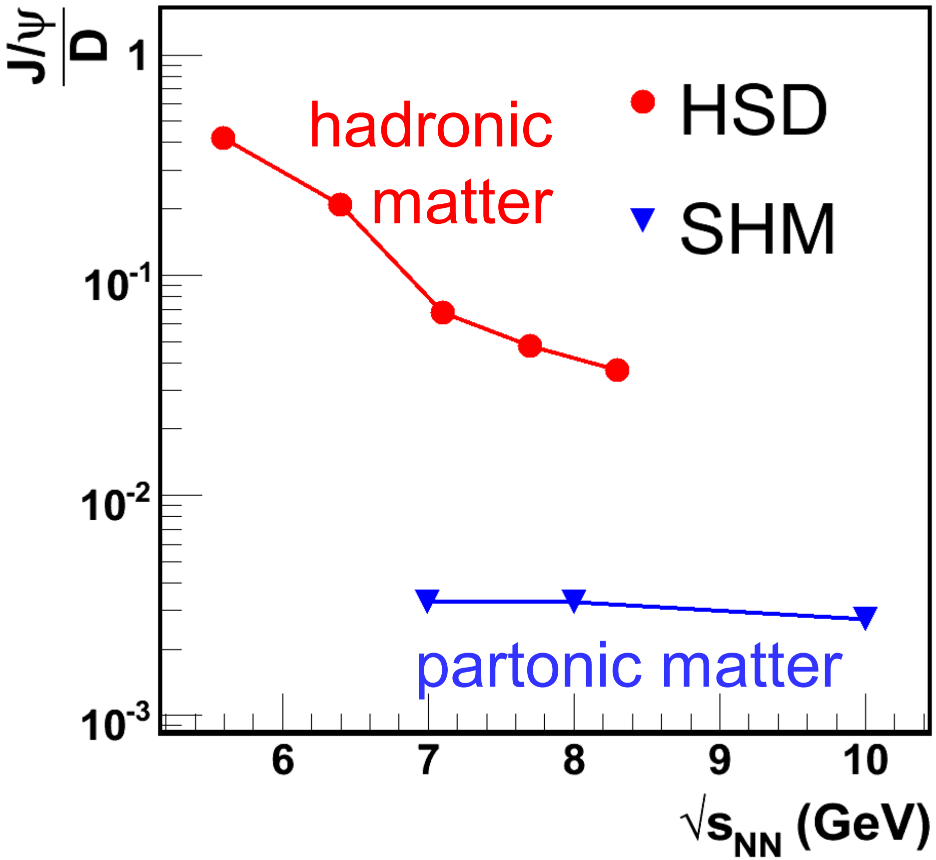


Charm creation in hard collisions (gg and qq) in partonic phase

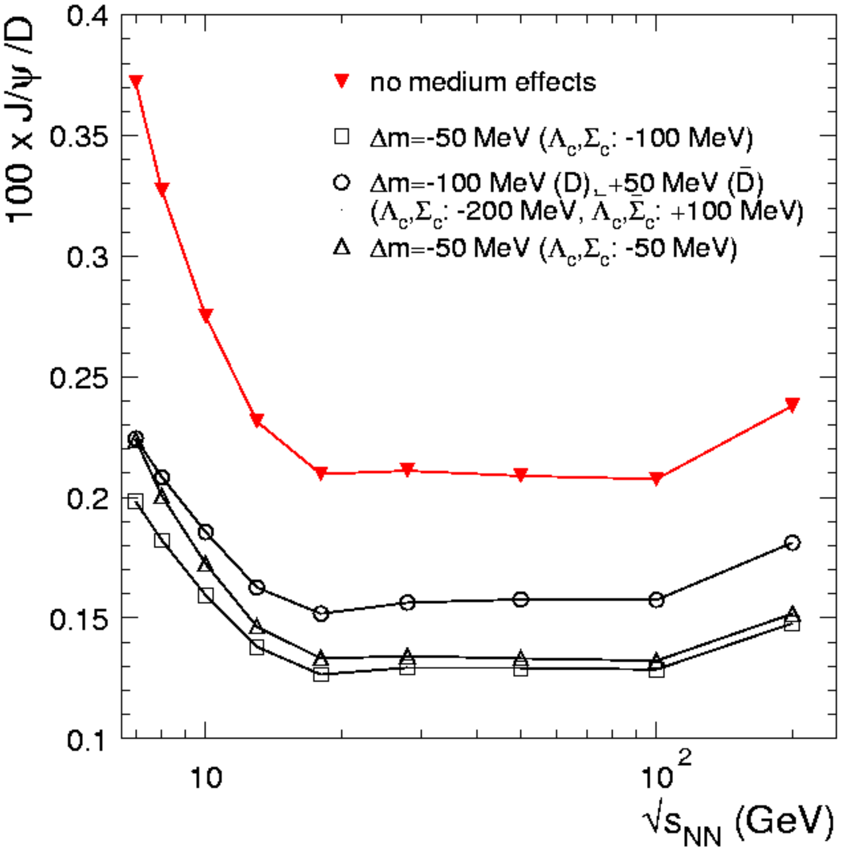


Charm particles created in hadronization process

Charmonium to open charm ratio



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



Charmed particle ratios (ψ/D, Λc/D, D/Ds, ...) sensitive to medium

CBM program

Measure heavy ion collisions at energies of 10-45 AGeV in order to:

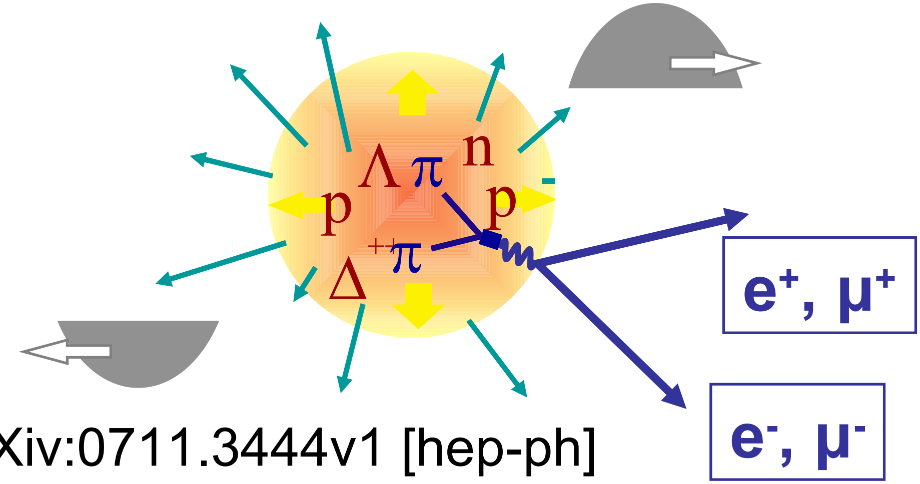
- study the properties of the equation of state at high ρ_B,
- observe the deconfinement phase transition
- and chiral symmetry restoration, both at high ρ_B,
- the

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

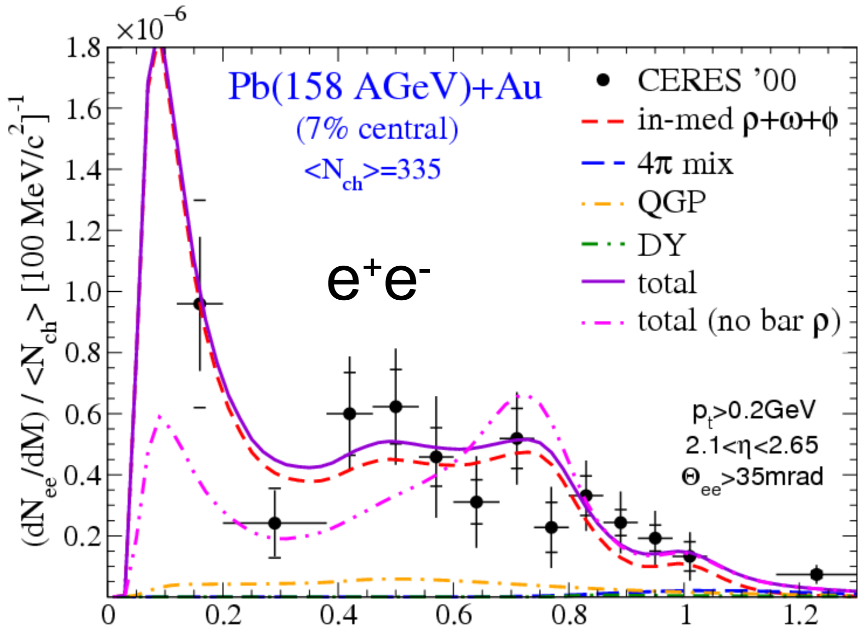
In-medium ρ meson modifications

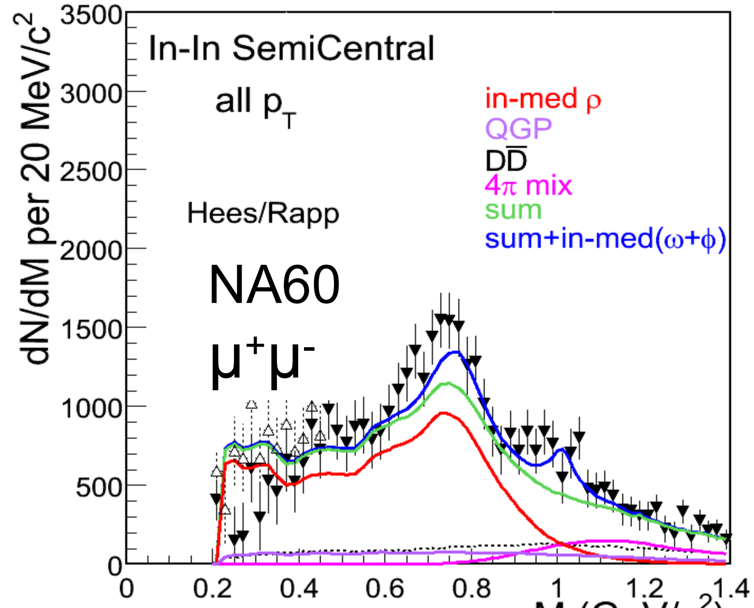
ρ-meson couples to the medium, direct radiation from the early phase

Vacuum lifetime τ_0 = 1.3 fm/c → dileptons = penetrating probe



Calculations: H. van Hees, R. Rapp, arXiv:0711.3444v1 [hep-ph]

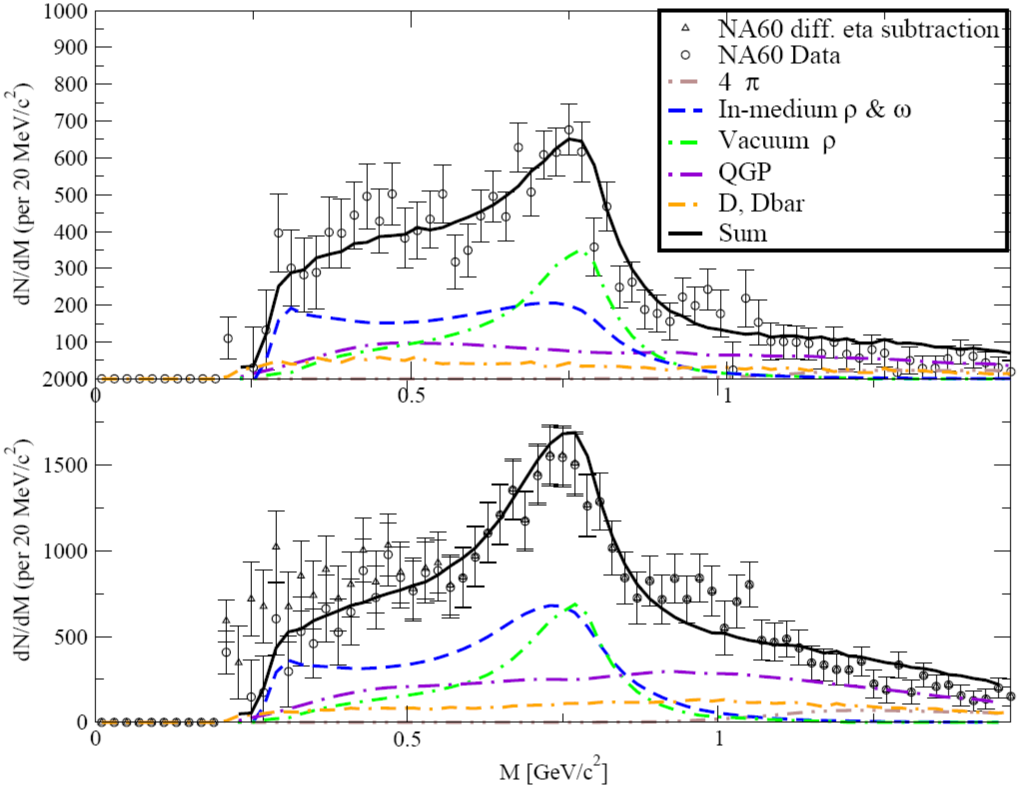




Electrons: access to M_{inv}<200MeV/c^2 Muons: better statistics

In-medium ρ meson modifications

Excess of di-muon yield at low invariant masses



Data: R. Arnaldi, et al. [NA60 Collaboration], Phys. Rev.Lett. 96, 162302 (2006);
Calculation: J.Ruppert, C. Gale, Th. Renk, P. Lichard, J. I. Kapusta, arXiv:0706.1934

no $\rho,\omega,\varphi \rightarrow e^+e^-$ ($\mu^+\mu^-$) data between 2 and 40 AGeV
no J/ψ, ψ' $\rightarrow e^+e^-$ ($\mu^+\mu^-$) data below 160 AGeV

Information needed in addition to dileptons from A+A:

- π, K, p, Λ, ... to constrain the fireball evolution
- $\rho \rightarrow \pi\,\pi$, $\varphi \rightarrow$ KK to measure the freeze-out contributions
- p+A collisions to determine the contribution of primordial ρ's

Fireball properties

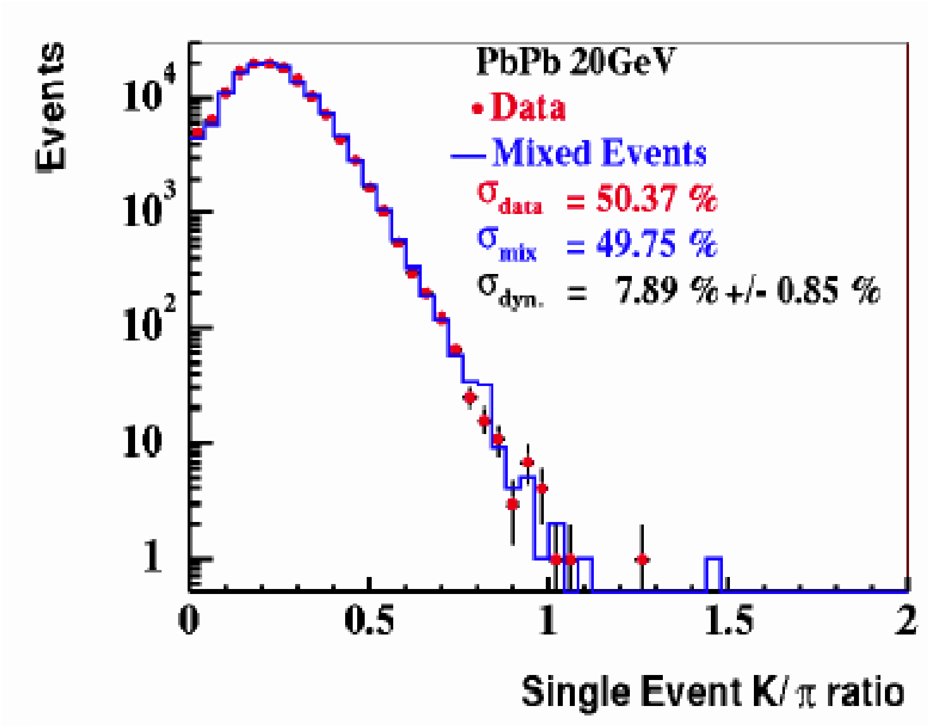
CBM program

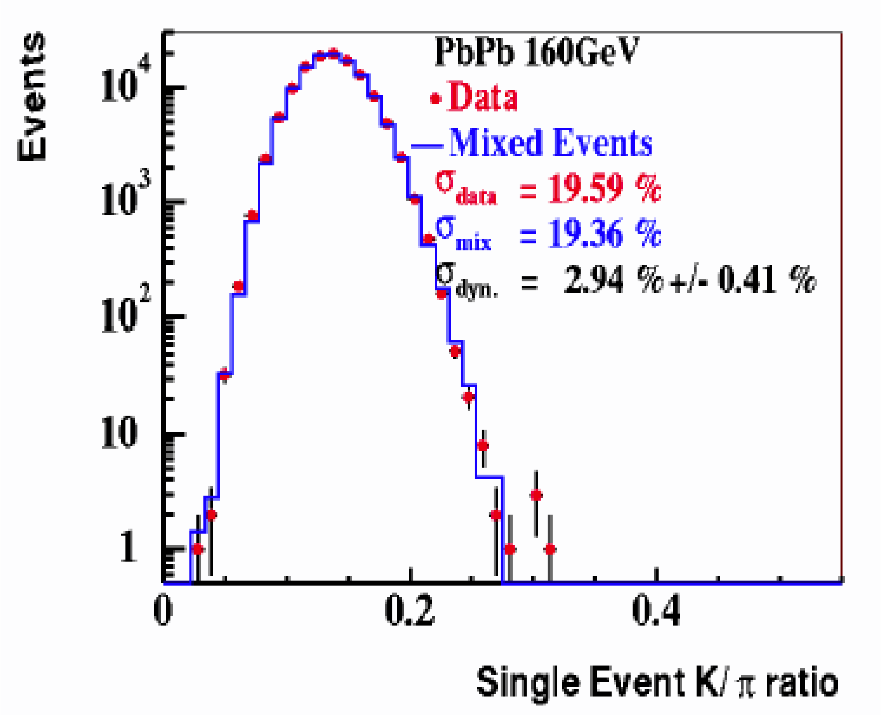
Measure heavy ion collisions at energies of 10-45 AGeV in order to:

- study the properties of the equation of state at high ρ_B,
- observe the deconfinement phase transition
- and chiral symmetry restoration, both at high ρ_B,
- determine the existence and position of the critical endpoint.

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

K/π event-by-event fluctuations





NA49 Preliminary

Definition

Measure the particle yields ratio in an event : K/π

Relative width of distribution : σ = RMS / MEAN

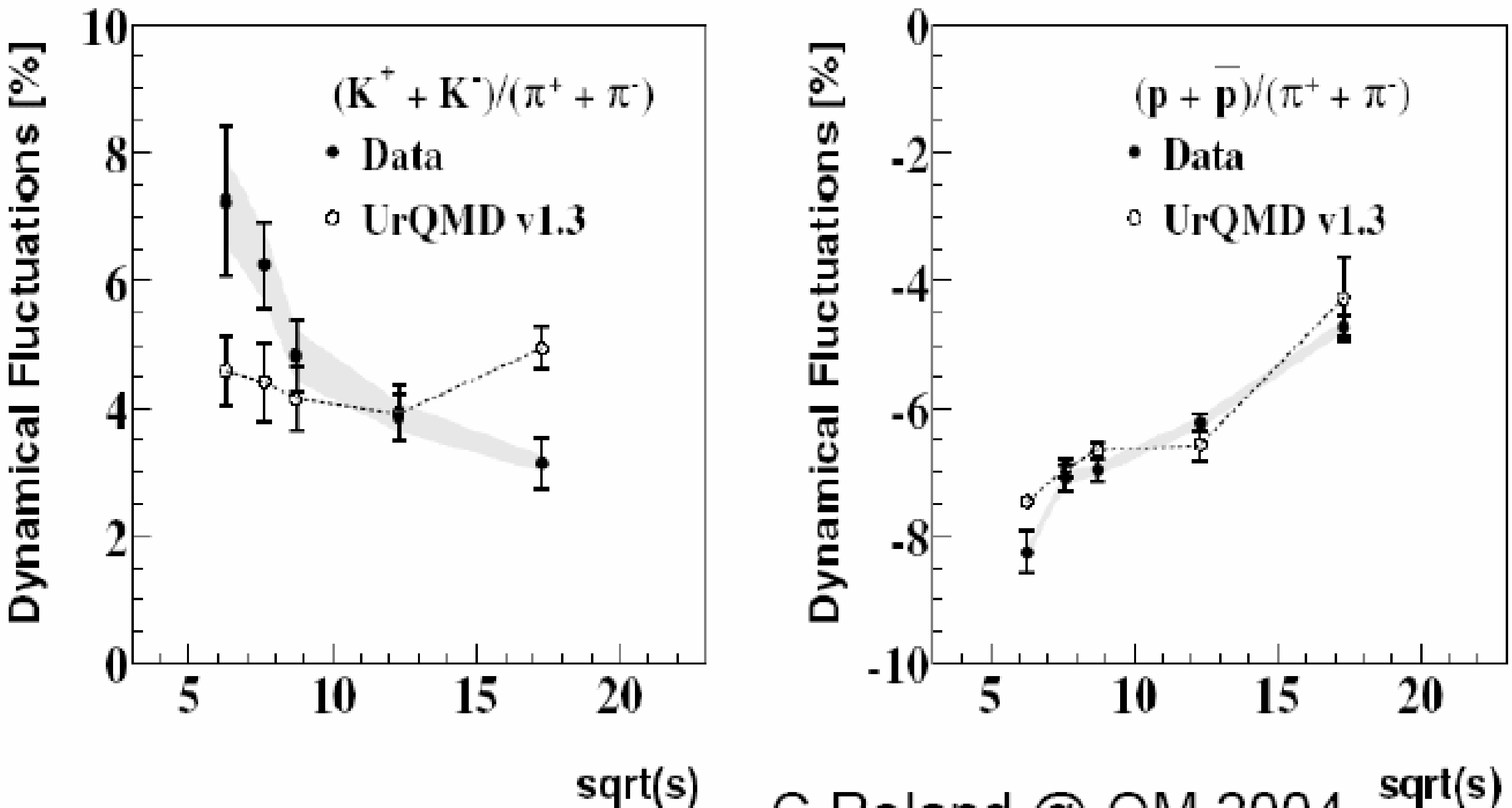
$$\sigma_{data}^2 = \underbrace{\sigma_{fin}^2 + \sigma_{exp}^2}_{\text{background}} + \sigma_{dyn}^2$$

Event mixing: no two tracks coming from one real event $\Rightarrow$ σ_{mixed}

$$\boxed{\sigma_{dyn}^2 = \sigma_{data}^2 - \sigma_{mixed}^2}$$

Fluctuations in NA49

- medium close to the critical point characterized by large fluctuations
- kaon fluctuations disagree with the UrQMD simulations



C.Roland @ QM 2004

Measure K/π event-by-event fluctuations in CBM

CBM measurements

hadrons' collective flow
threshold particle production

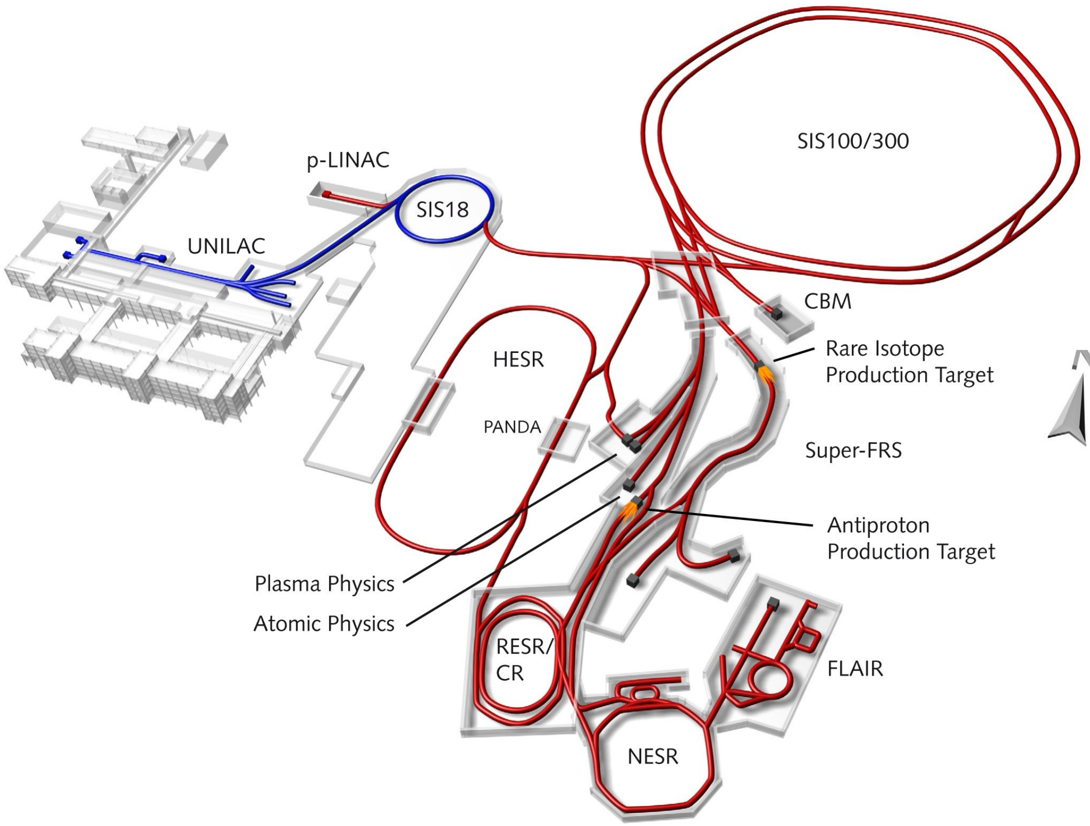
excitation function and flow of strangeness
excitation function and flow of charm
excitation function of low-mass lepton pairs

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

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

Measure everything! Large statistics, excellent quality essential!

Facility for Antiproton and Ion Research (FAIR)



primary beams

- $5x10^{11}$/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- factor 100-1000 increased intensity
- $4x10^{13}$/s 90 GeV protons
- 10^{10}/s ^{238}U 35 GeV/u (Ni 45 GeV/u)

secondary beams

- rare isotopes 1.5 - 2 GeV/u;
  factor 10 000 increased intensity
- antiprotons 3(0) - 30 GeV

storage and cooler rings

- beams of rare isotopes
- e – A Collider
- 10^{11} stored and cooled antiprotons
  0.8 - 14.5 GeV

accelerator technical challenges

- Rapidly cycling superconducting magnets
- high energy electron cooling
- dynamical vacuum, beam losses

CBM @ FAIR

the
Compressed
Baryonic
Matter
Experiment

SIS 100/300

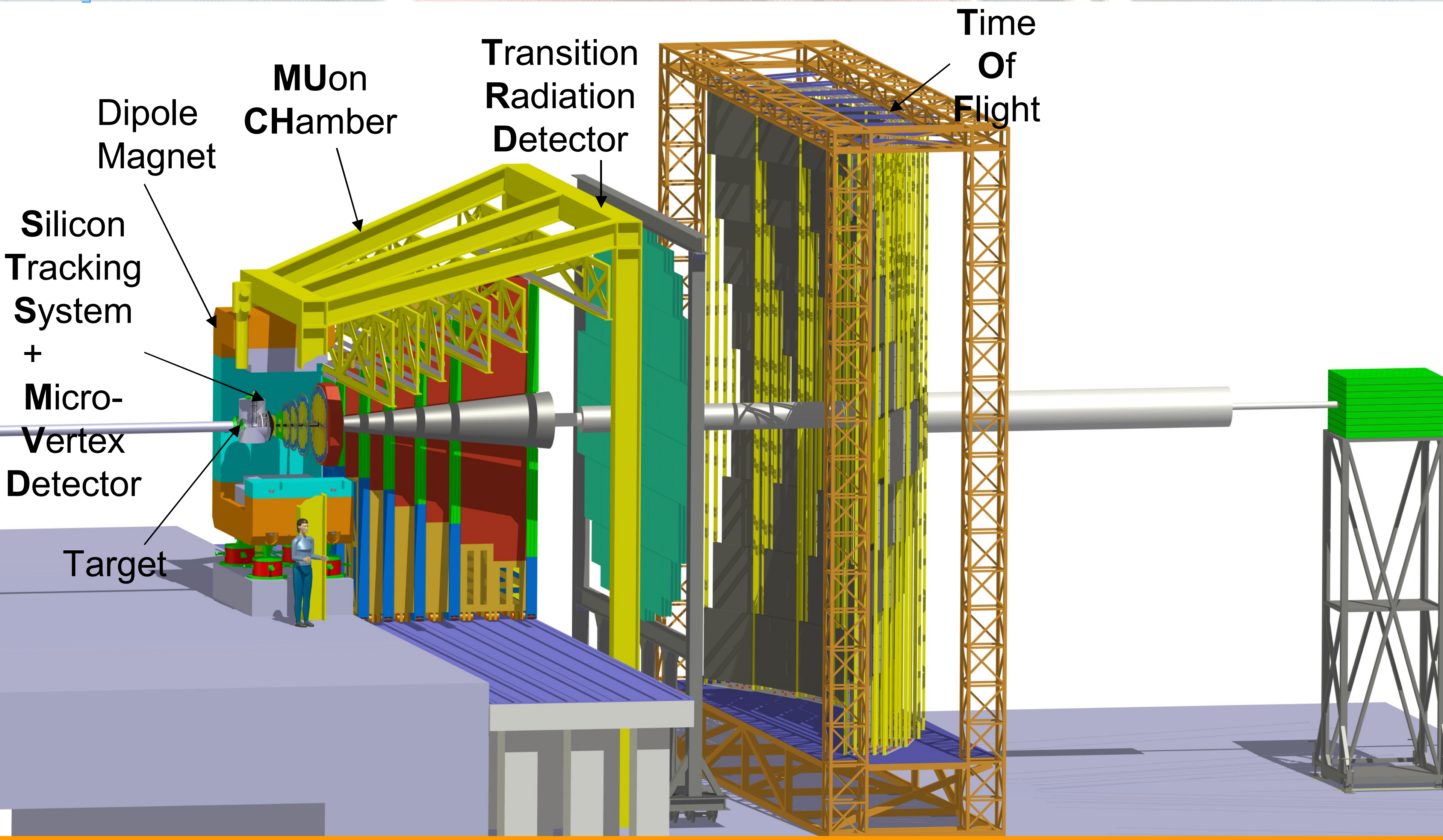
GSI as of 2008

Cost of the FAIR project: ~ 1.2 Billion € (25% from foreign partners)
German Federal Government has approved budget over 10 years
FAIR project started: Nov. 2007
First beams planned for 2014 – 2015

15 FAIR member states:

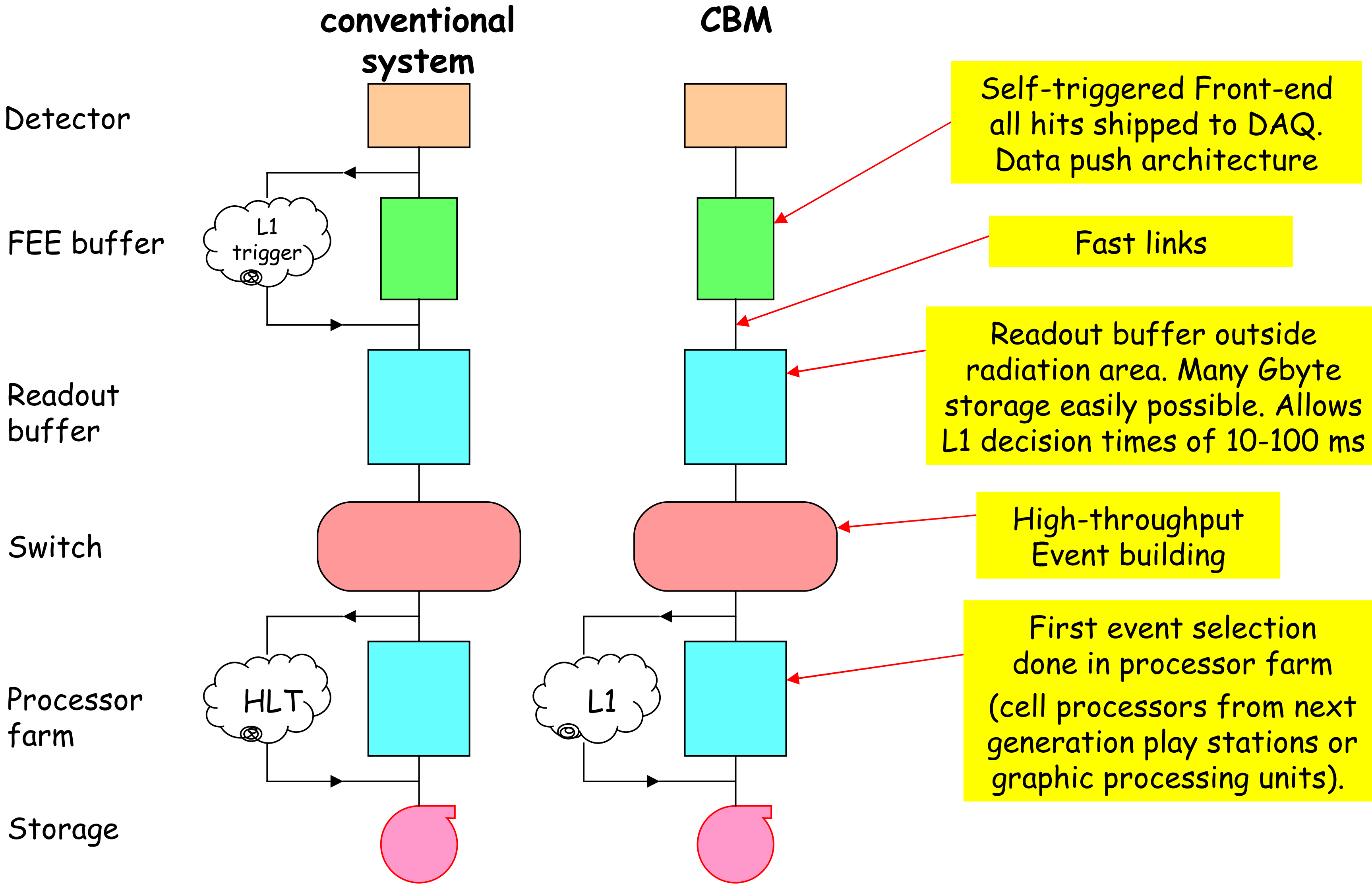
Austria China Finland France Germany Greece Hungary India Italy Poland Romiania Russia Spain Sweden UK

CBM Experimental Setup



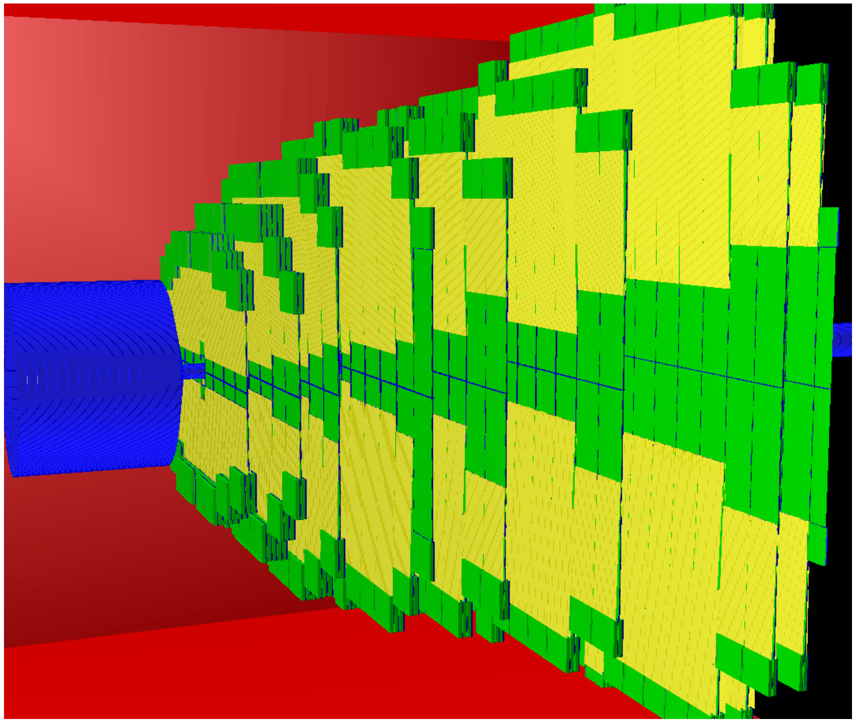
Maximum event rate: 10^7 events/s, data flow: 1TByte/s

DAQ architecture



STS – fast and accurate tracking

STS geometry as present in the MC simulations



Silicon Tracking System:

-8 double-sided micro-strip silicon stations

-detector length: 100cm

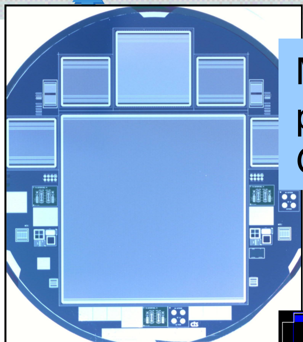
-acceptance of about 2.5 to 25 degrees

-sensor thickness: 300μm

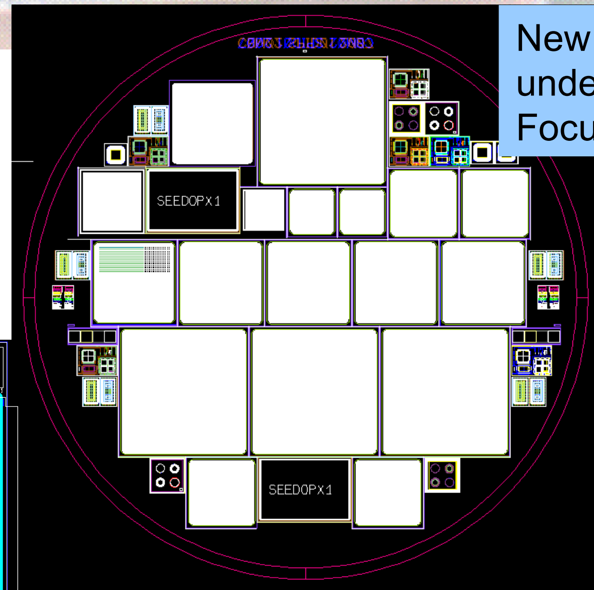
-1.3 million channels

-readout electronics, support structures, cables implemented

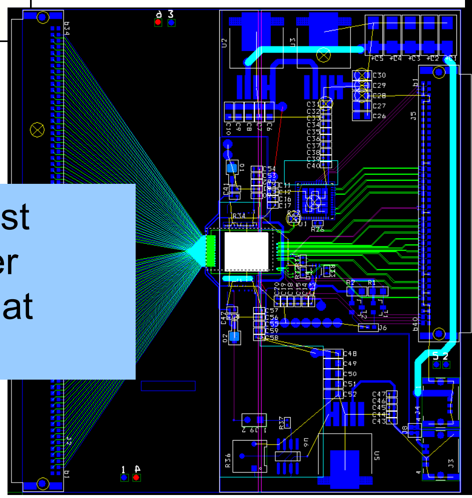
STS – fast and accurate tracking



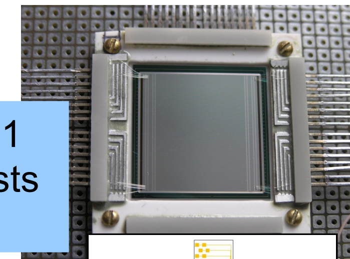
Micro-strip detector prototype CBM01, GSI-CIS (2007).



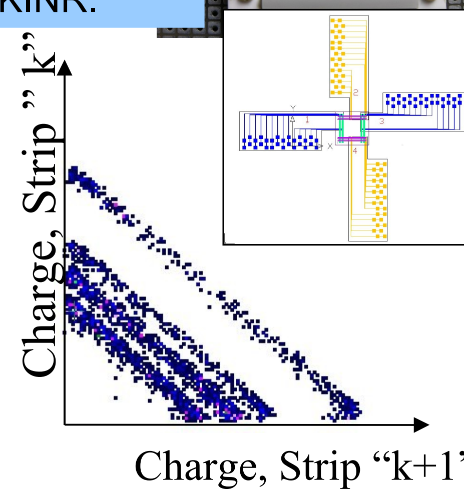
New "Technology wafer" under production at CIS: Focus on radiation hardness.

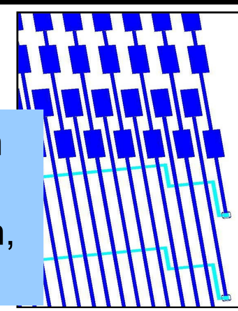


Detector test board under production at GSI.

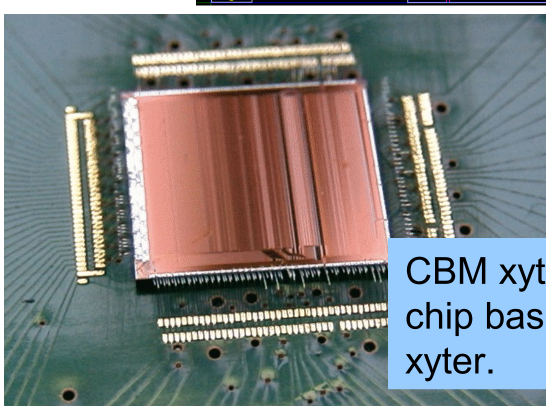


First CBM01 detector tests @ KINR.





Detector design & technology characterization, MSU Moscow.



CBM xyter FE chip based on n-xyter.

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

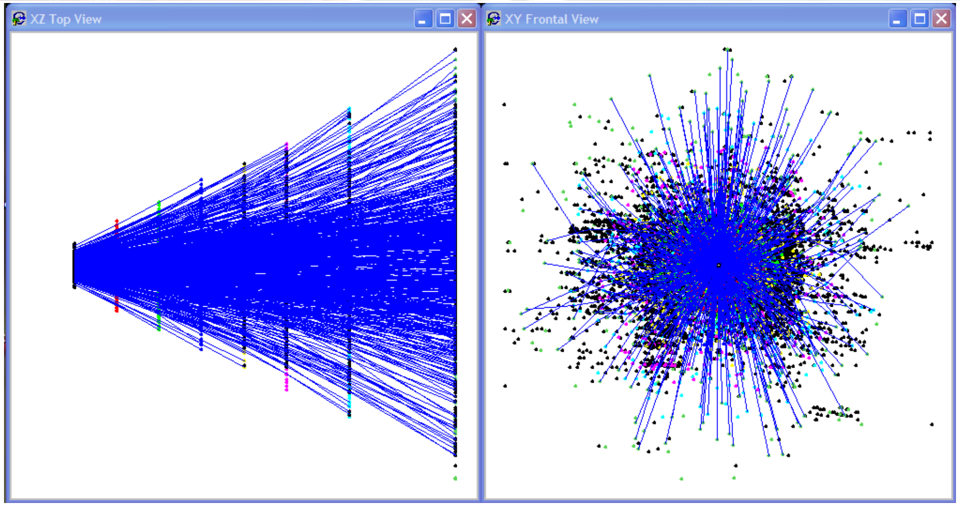
Track reconstruction

• up to ~10^9 tracks/s in the silicon tracker (10 MHz, ~100 tracks/event) to analyze ***<u>ONLINE</u>***

→ **fast track reconstruction!**

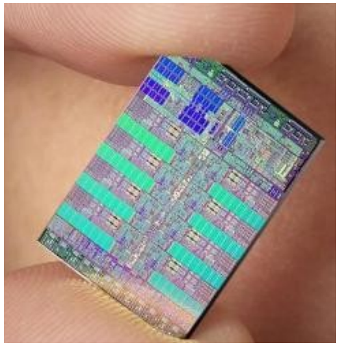
→ **with high efficiency**

→ **and good momentum resolution**



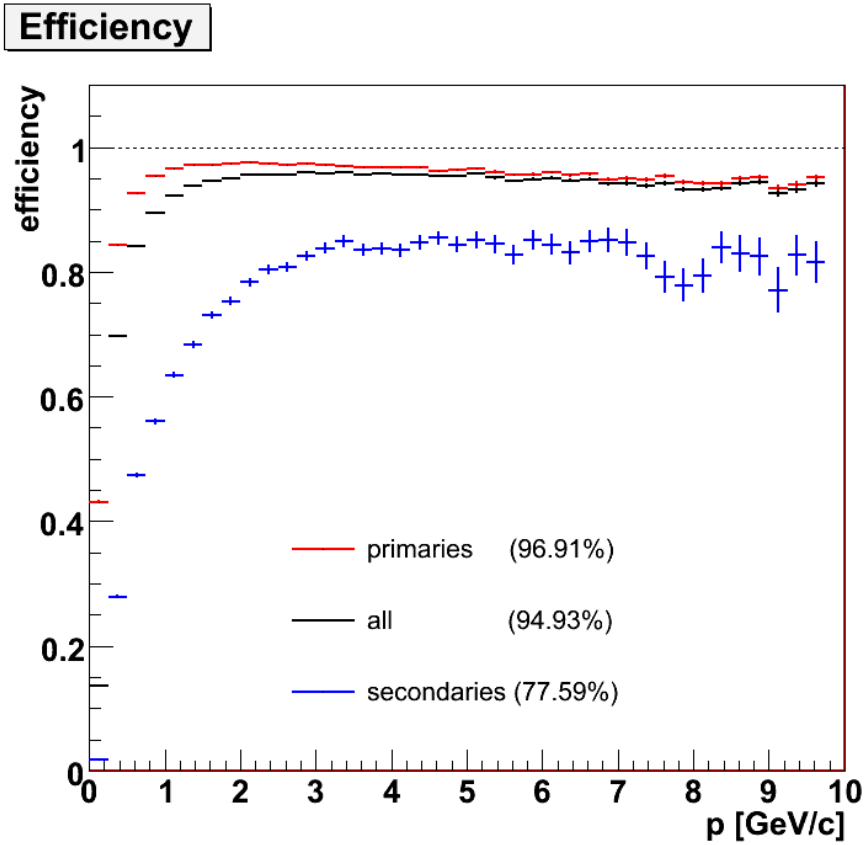
Work on: code optimization, porting to cell processor, parallel processing

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

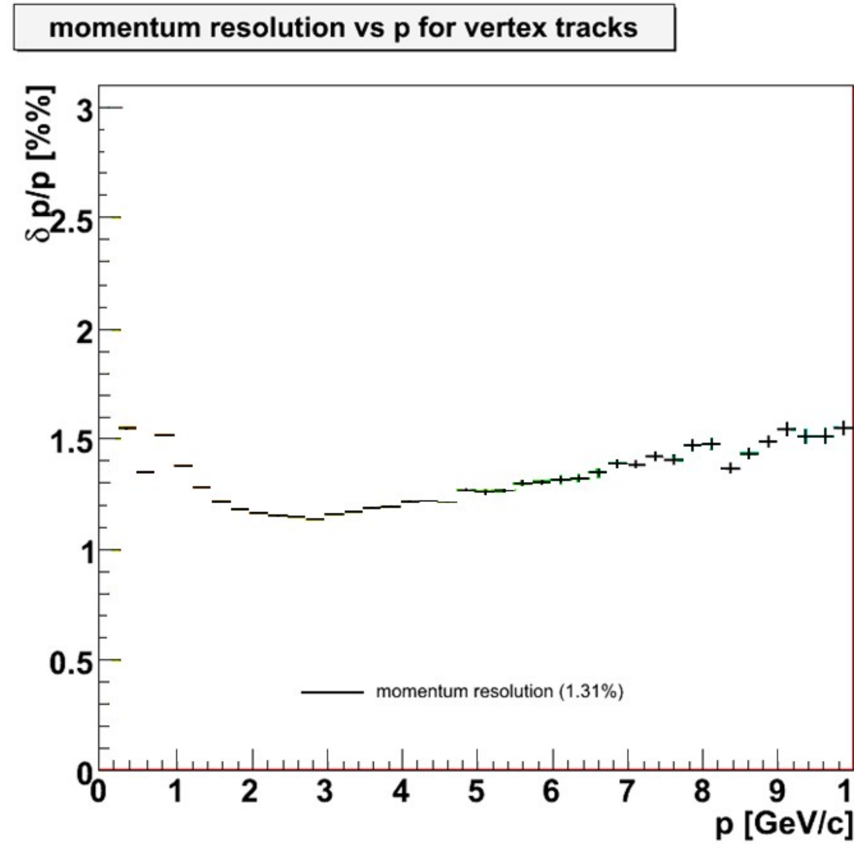


Track reconstruction results

Efficiency 97%

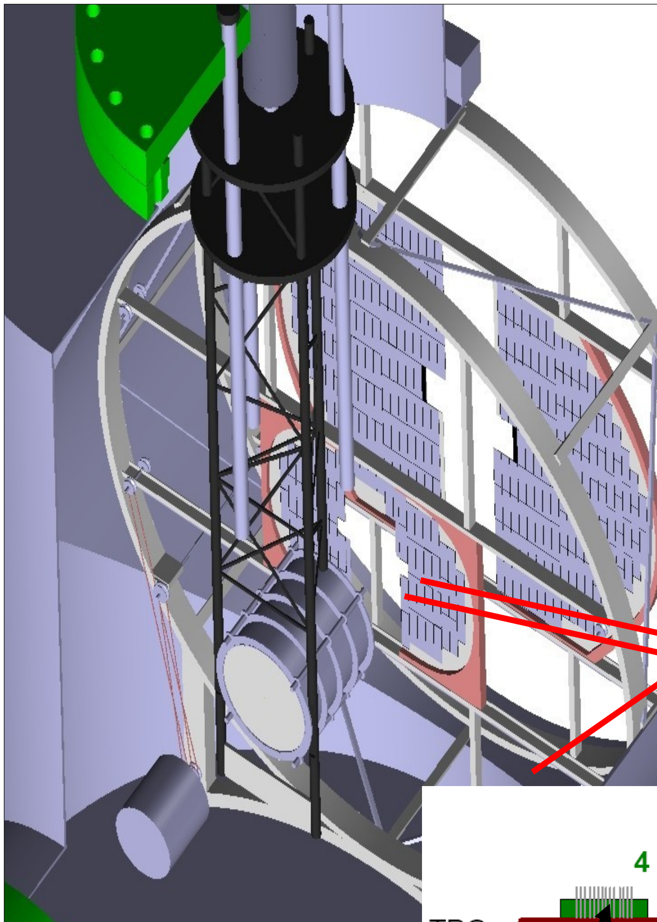


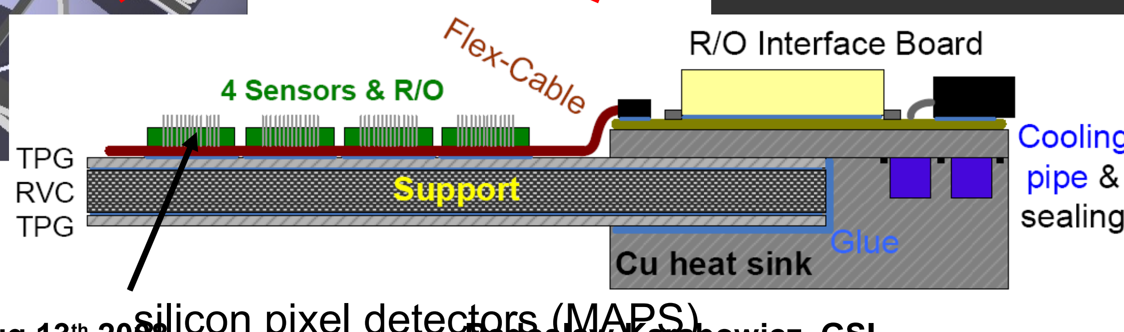
Momentum resolution 1.3%



MVD – precise vertexing

Artistic view of the MVD



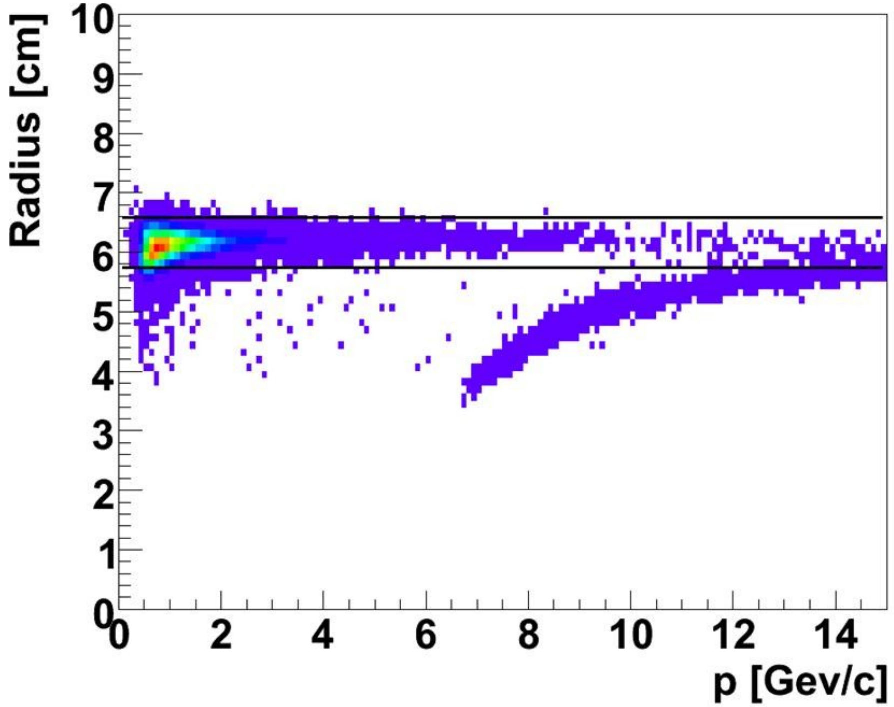


Micro Vertex Detector:

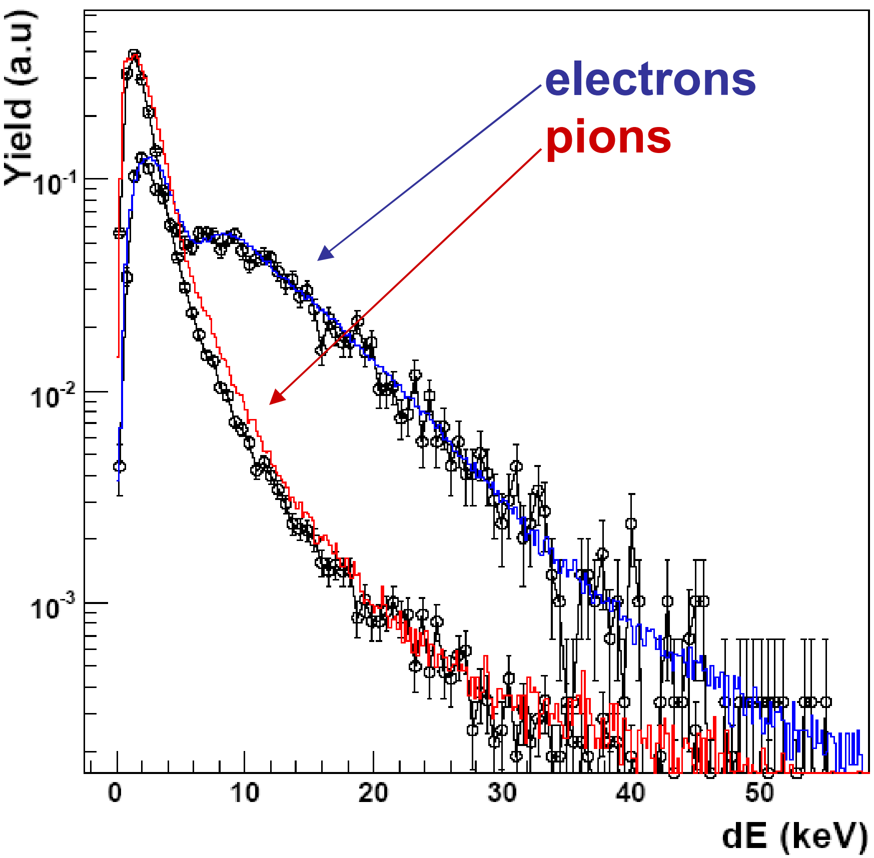
- **M**onolithic **A**citive **P**ixel **S**ensors (MAPS) in commercial CMOS process
- $10\times10\ \mu m^2$ pixels fabricated
- efficiency > 99%
- $\Delta x \sim 1.5 - 2.5\ \mu m$

RICH and TRD – e identification

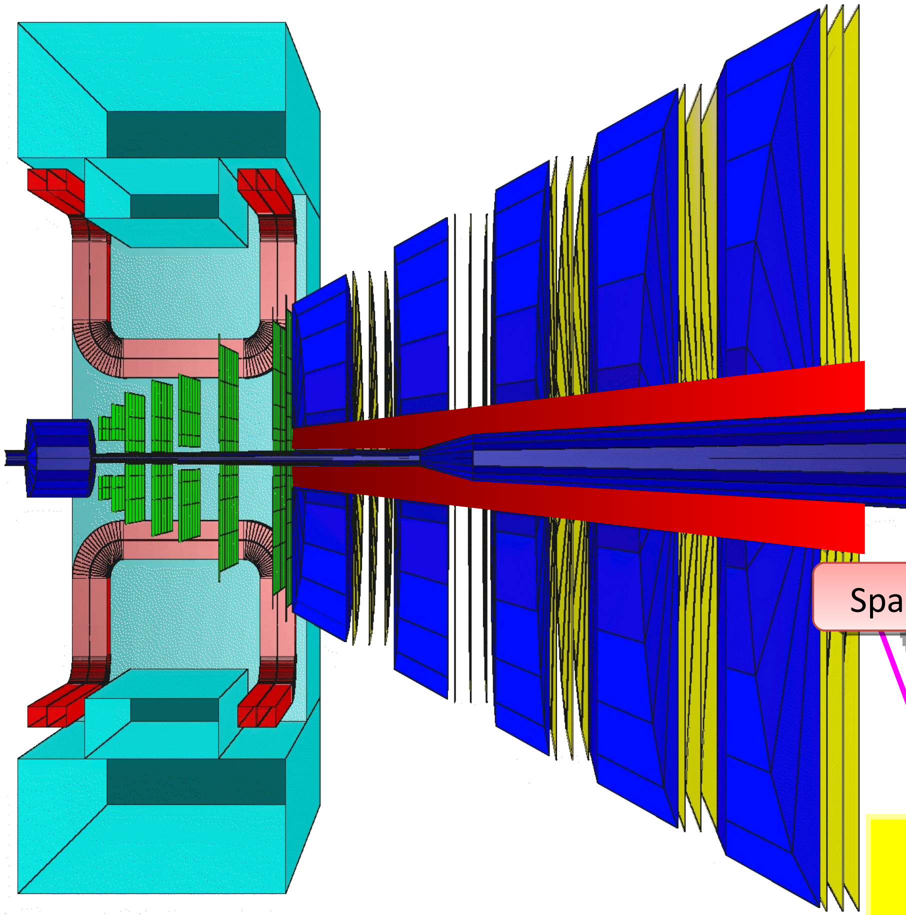
Ring Imaging CHerenkov (RICH) detector, ring radius vs momentum



Transition Radiation Detector (TRD) energy loss simulations



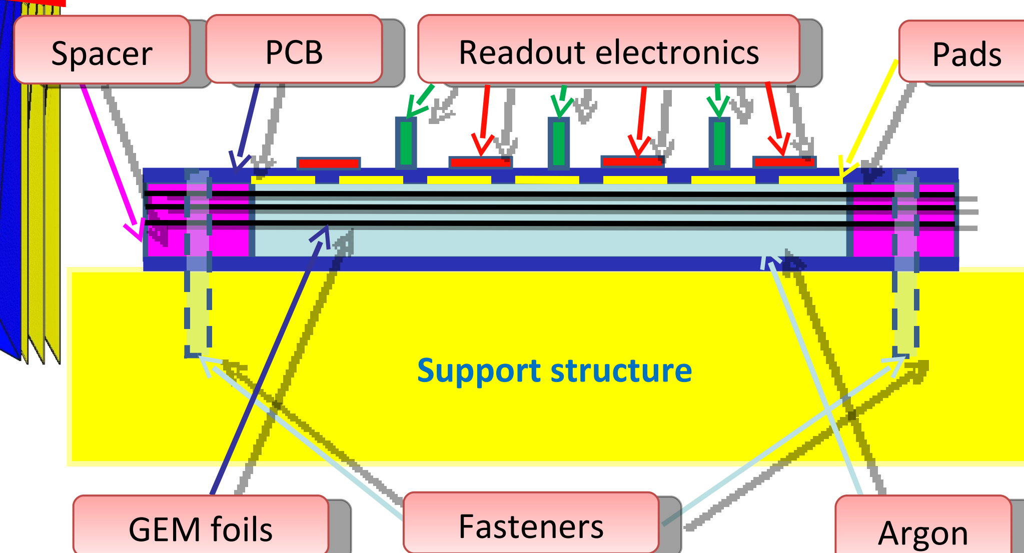
MUCH – muon identification



event suppression factor
for 1 cm position resolution:

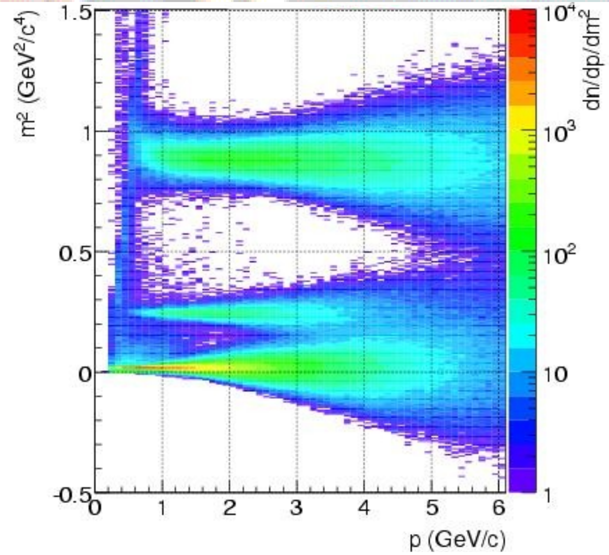
min. 2 tracks in last 6 detector layers from target region	
central	300
mbias	1600
J/ψ	ε ≈ 6%

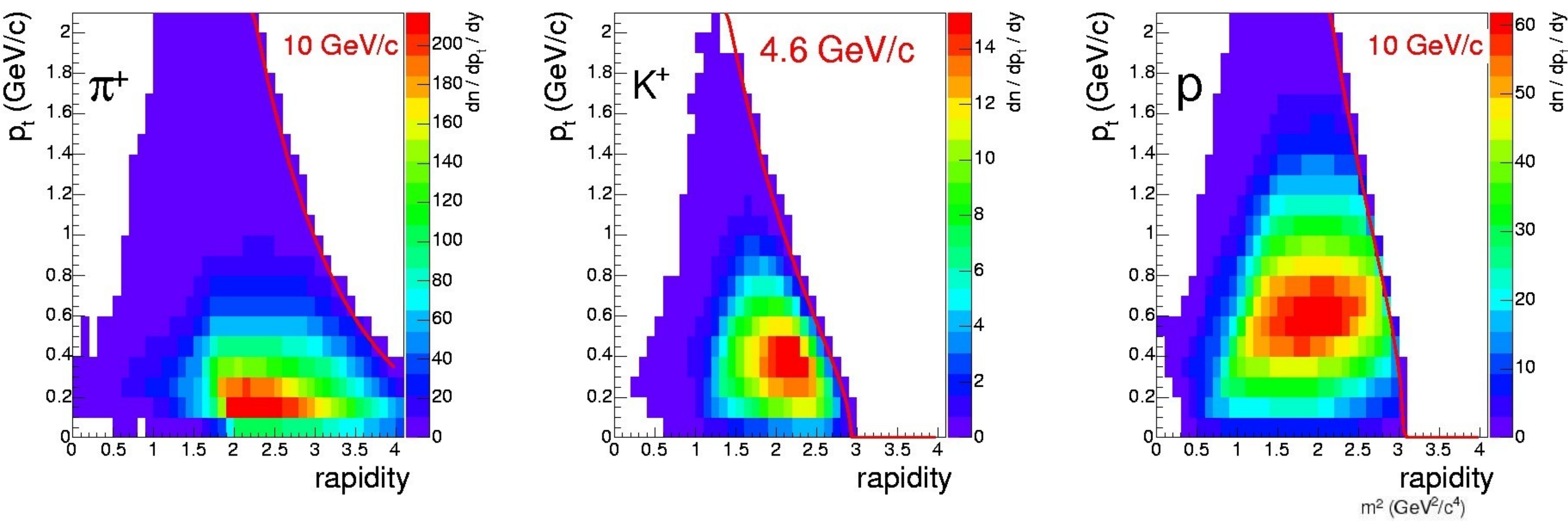
GEM detectors



TOF detector

Large detector acceptance with good particle identification needed for physical studies, especially the event-by-event fluctuations measurement

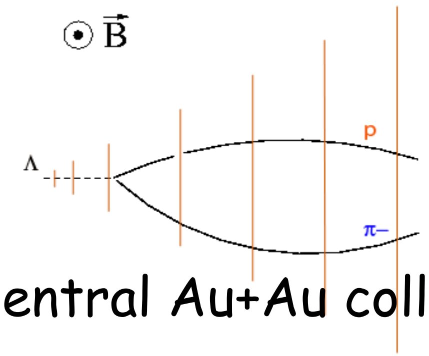


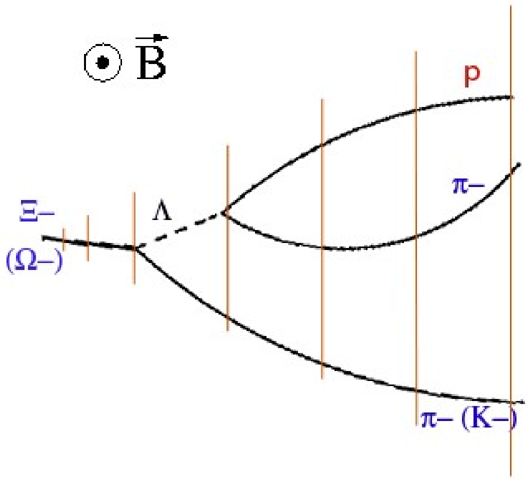


Simulations

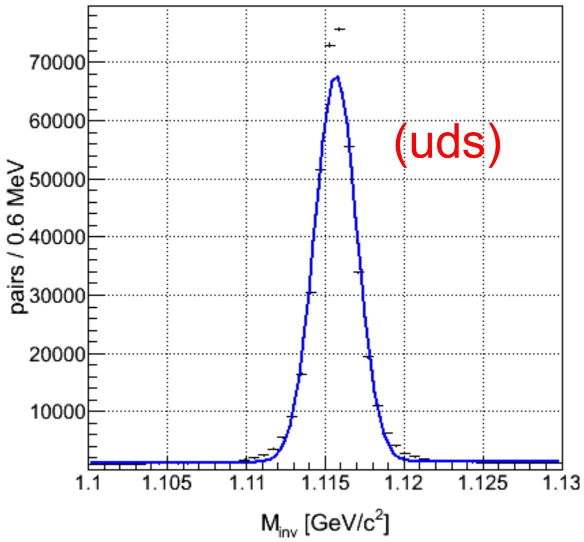
- Software tools:
  - framework: FairRoot
  - event generators: UrQMD, HSD, Pluto
  - transport codes: Geant3, Geant4, Fluka
- Reference system: central Au+Au events at 25 AGeV

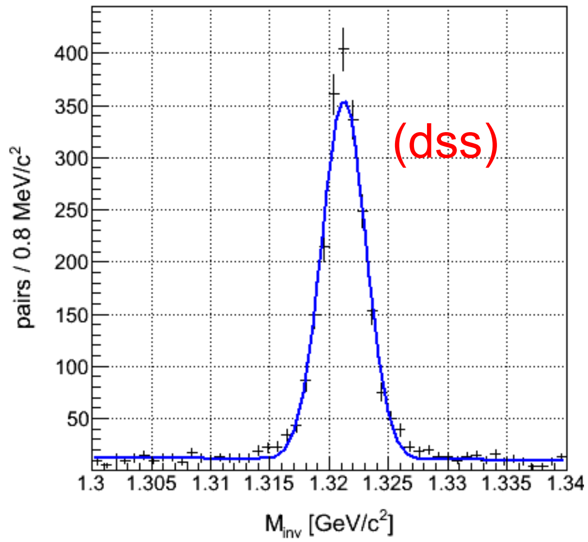
Hyperon detection with STS

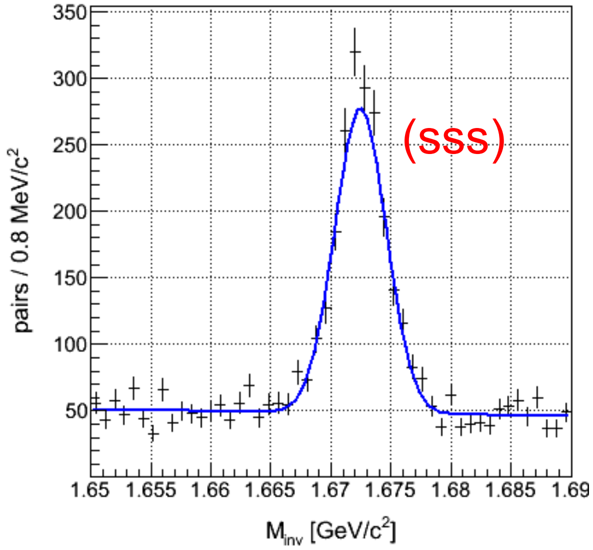




central Au+Au collisions at 25 AGeV:







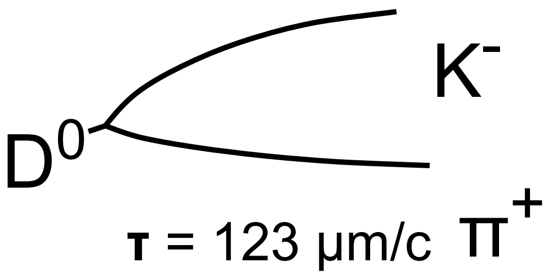
total efficiency 10.6% 2.1% 1.0%

D meson simulations

•full event reconstruction: track reconstruction, particle-ID (RICH, TRD, TOF), secondary vertex finder

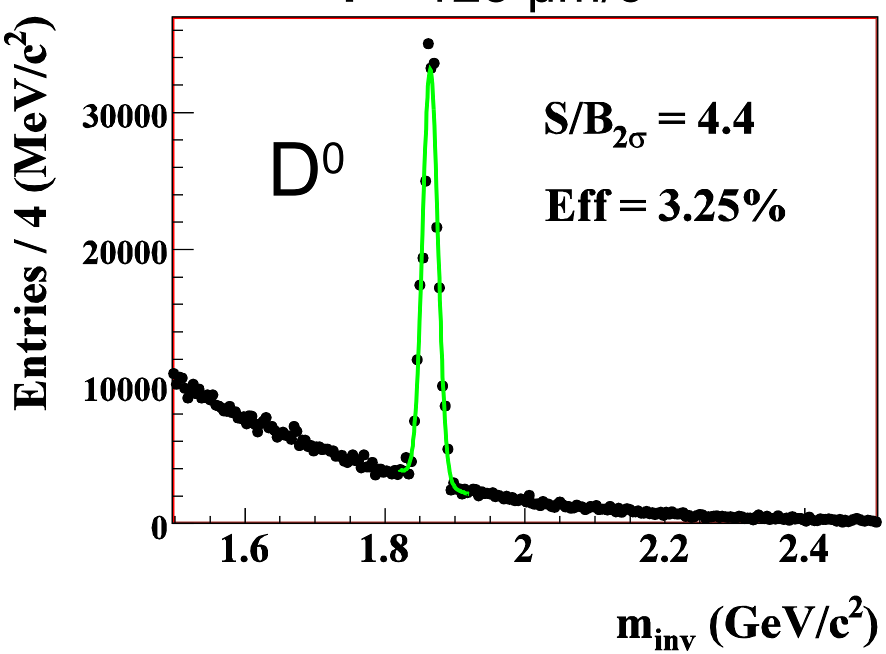
•several channels studied: D^0, $D^{\pm}$, D_s, Λ_c

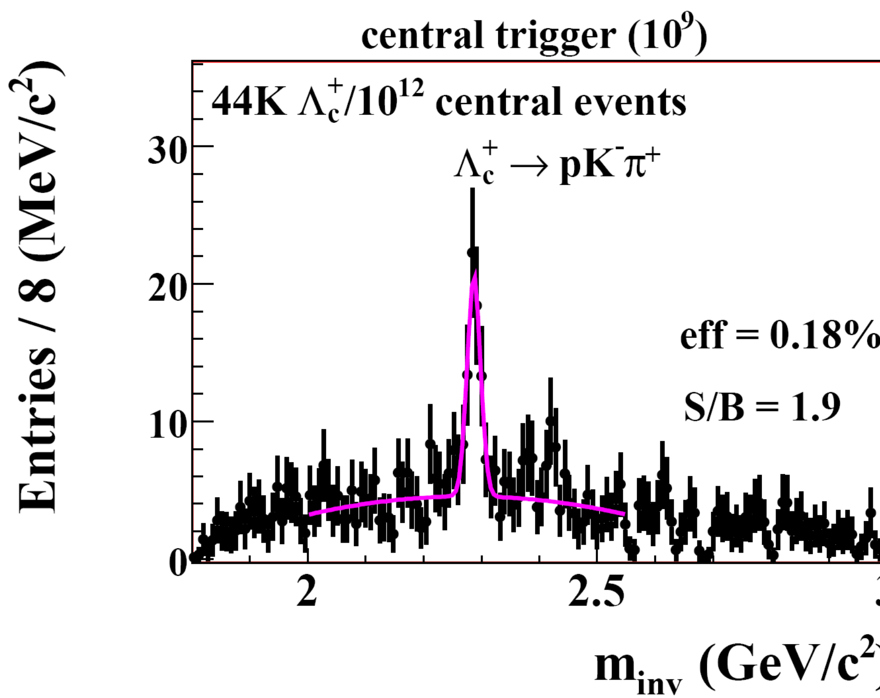
D and Λ_C multiplicity from HSD
Hadronic background from UrQMD



τ = 123 μm/c

$\Lambda_C \rightarrow \pi^+ K^- p$
τ = 60 μm/c

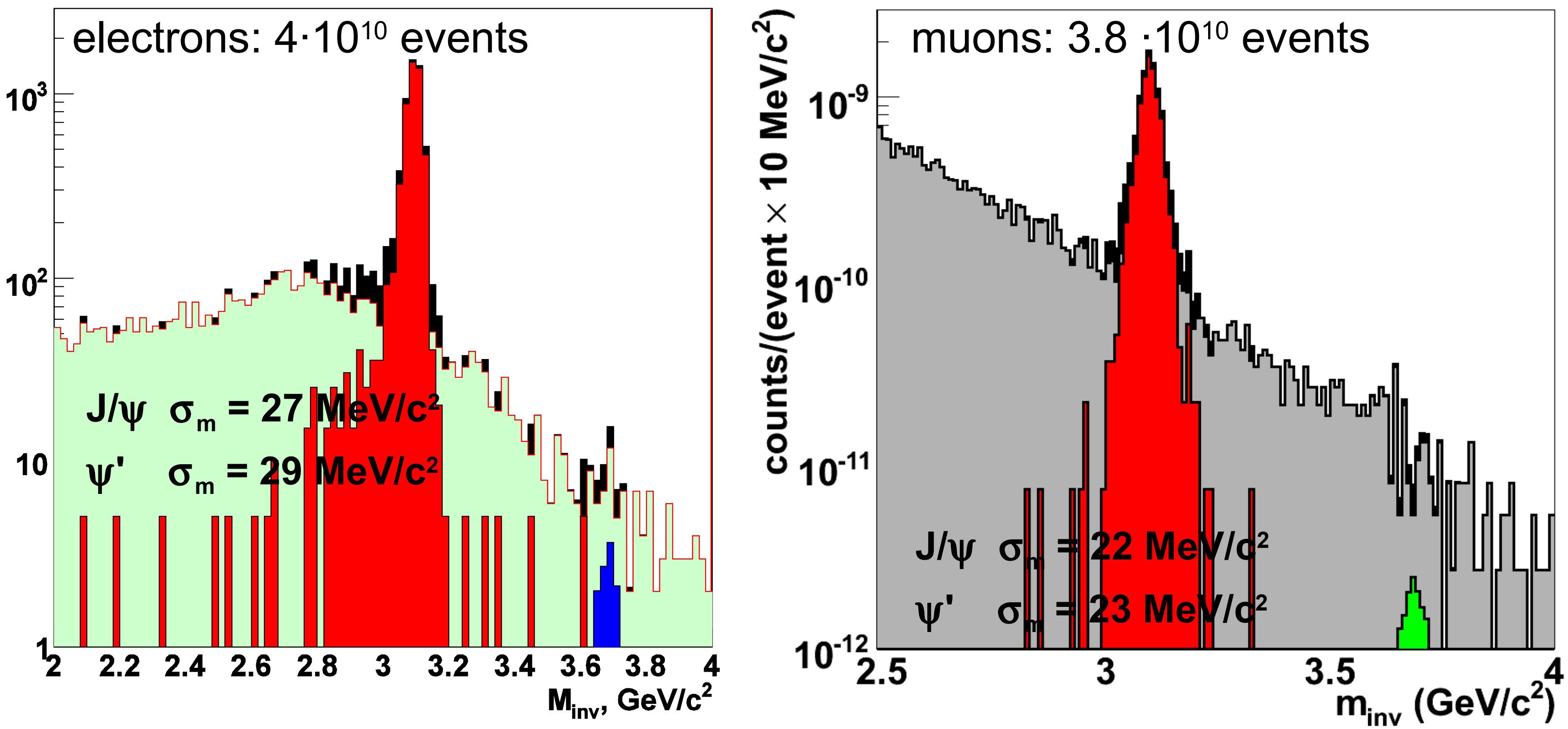




J/ψ and ψ'

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

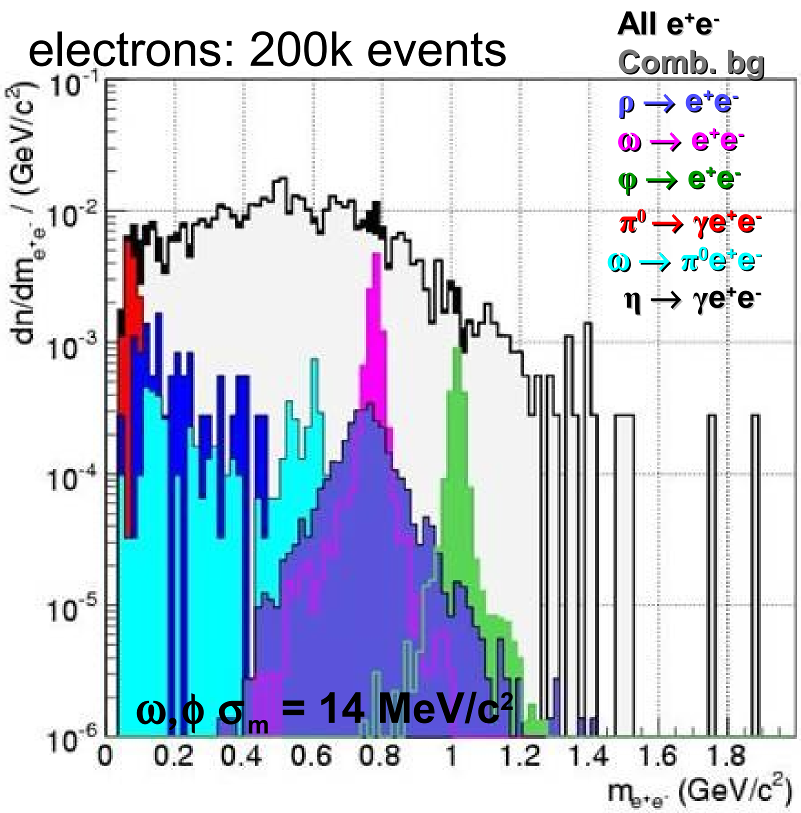


Low mass vector mesons

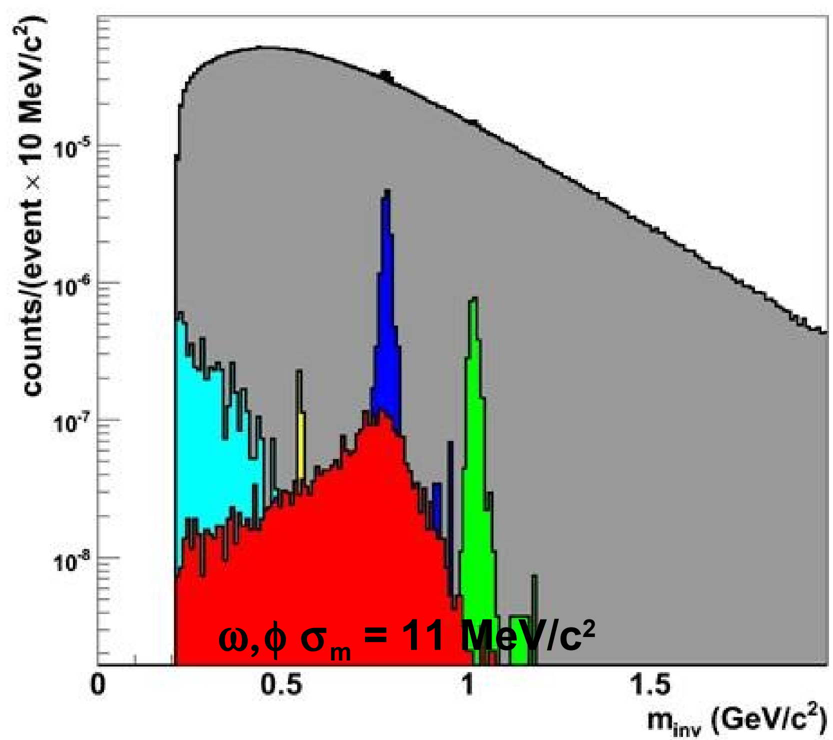
invariant mass spectra

- 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

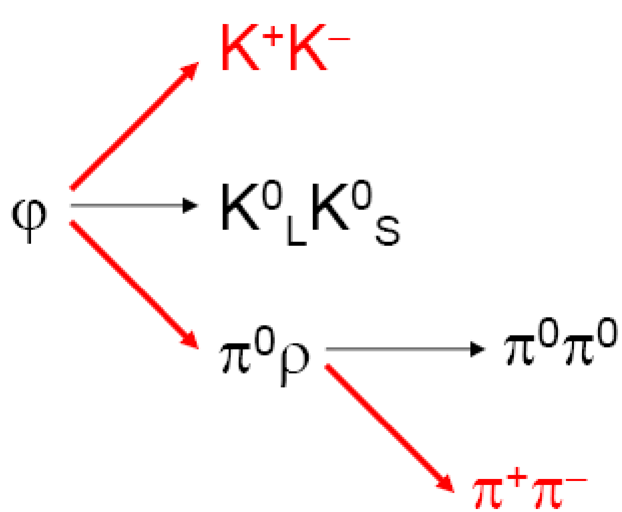


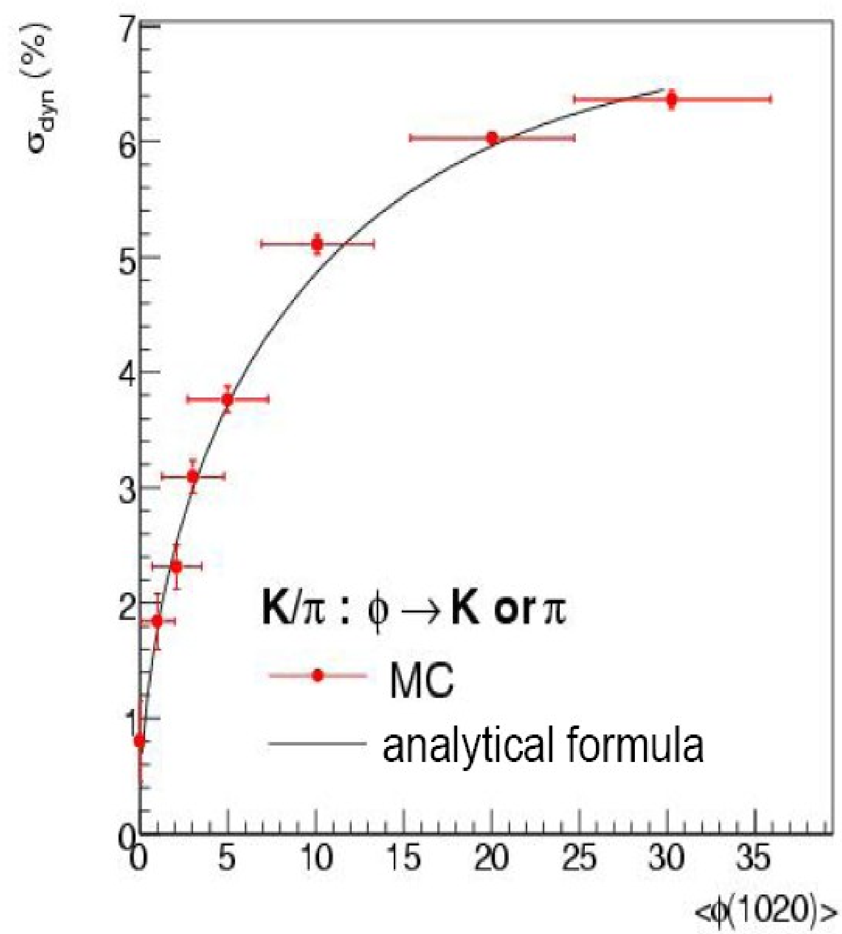
Resonances in toy model – ϕ

K/π fluctuations

Toy model:

Into UrQMD events with normally produced kaons (41) and pions (363) a number of ϕ has been injected.



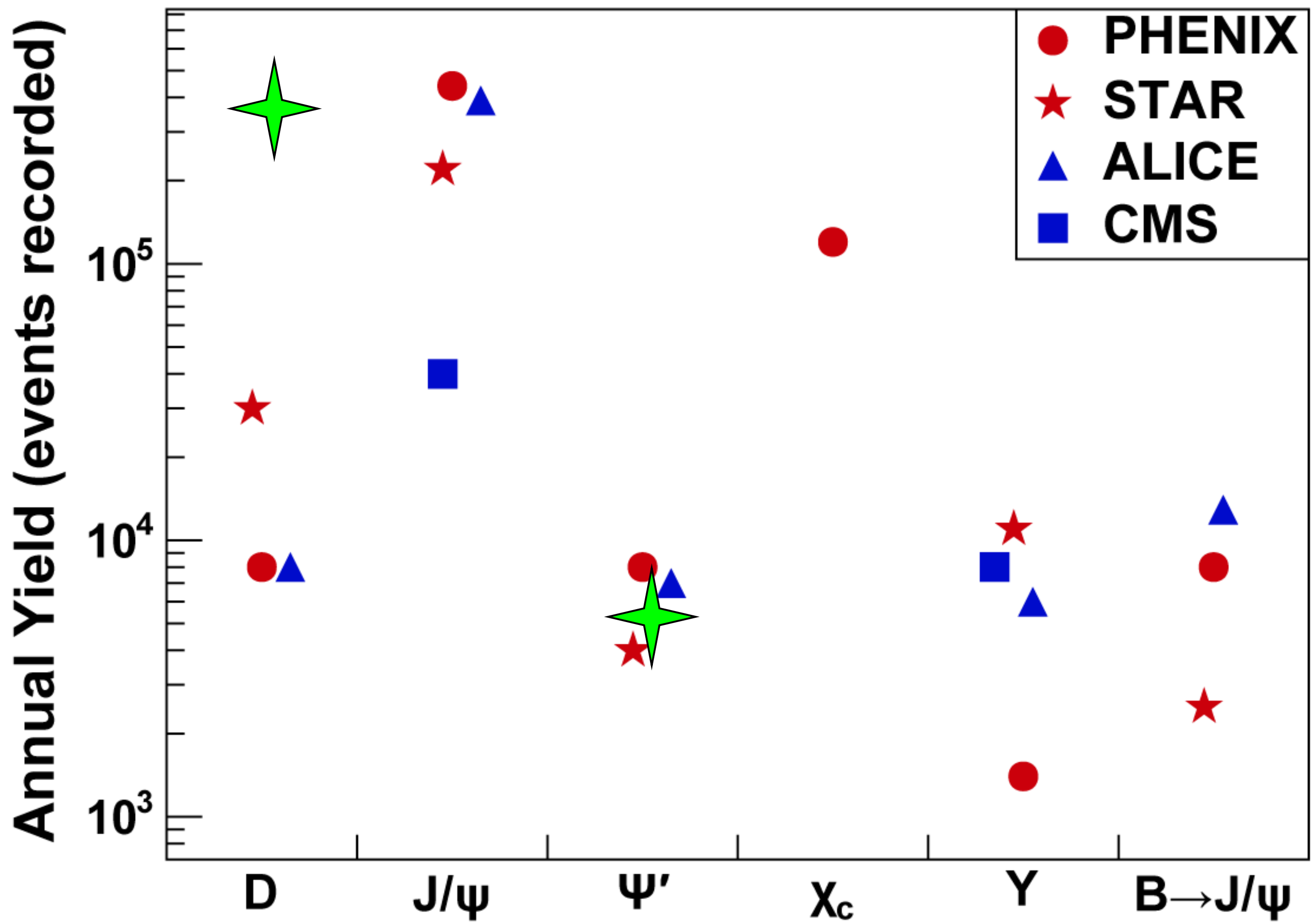


Fluctuations influenced by resonance decays

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 L 25% running time

Summary

CBM: heavy ion experiment in energy domain of 10-45 AGeV with high event rates:

- explore QCD phase diagram at moderate temperatures and high baryon chemical potential
- systematic measurements of bulk properties
- large statistics for rare probes
- high tracking reconstruction efficiency, excellent momentum resolution and particle identification

CBM Collaboration – 52 institutions, ~400 members

Croatia:
RBI, Zagreb
Split Univ.

China:
CCNU Wuhan
USTC Hefei

Cyprus:
Nikosia Univ.

Czech Republic:
CAS, Rez
Techn.Univ.Prague

France:
IPHC Strasbourg

Hungary:
KFKI Budapest
Budapest Univ.

India:
Aligarh Muslim Univ.
Panjab Univ.
Rajasthan Univ.
Univ. of Jammu
Univ. of Kashmir
Univ. of Calcutta
B.H. Univ. Varanasi
VECC Kolkata
SAHA Kolkata
IOP Bhubaneswar
IIT Kharagpur

Korea:
Korea Univ. Seoul
Pusan National Univ.

Norway:
Univ. Bergen

Germany:
Univ. Heidelberg, P.I.
Univ. Heidelberg, KIP
Univ. Heidelberg, ZITI
Univ. Frankfurt
Univ. Münster
FZ Dresden
GSI Darmstadt

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

Portugal:
LIP Coimbra

Romania:
NIPNE Bucharest
Univ. Bucharest

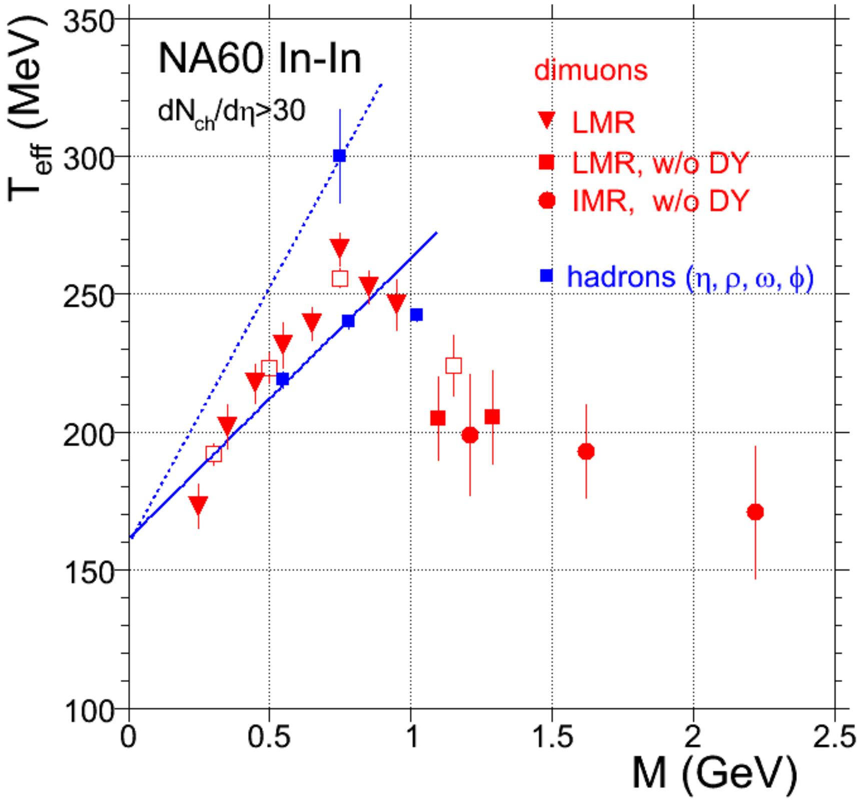
Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg
Kurchatov Inst., Moscow
LHE, JINR Dubna
LPP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg P. Univ.

Ukraine:
T. Shevchenko Univ. Kiev

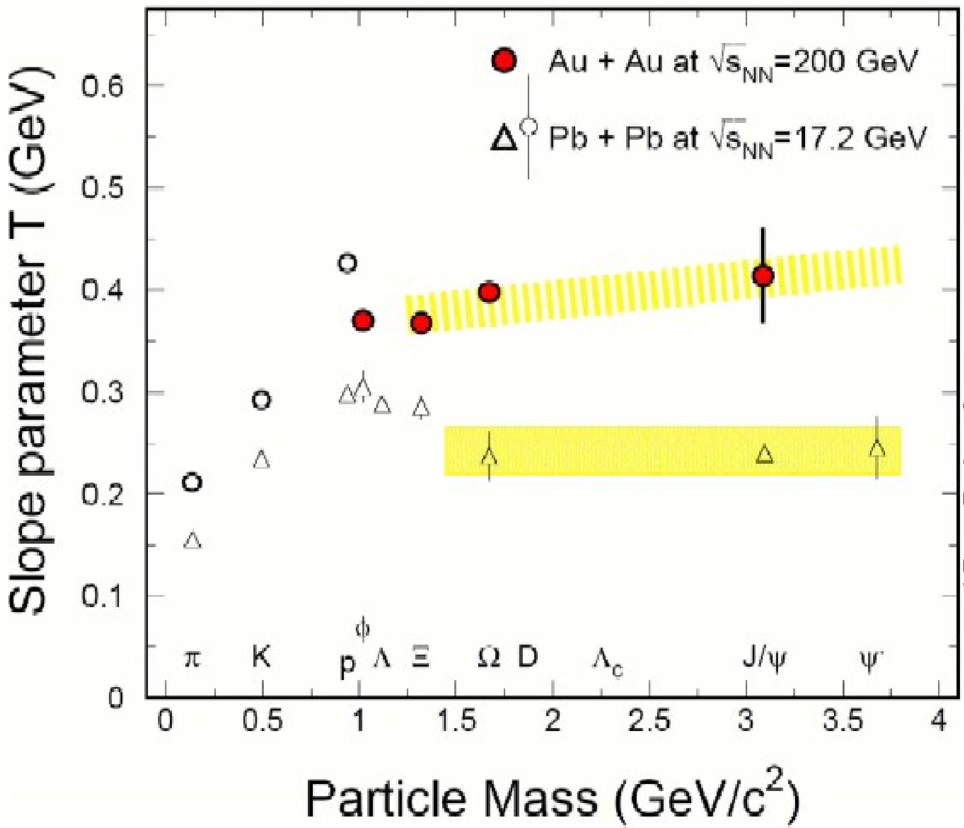
Backup

Temperature as function of mass

R. Arnaldi et al., (NA60),
arXiv: 0711.1816v1 [nucl-ex]
to appear in PRL



N. Xu, Int. J. Mod. Phys. E16 (2007) 715

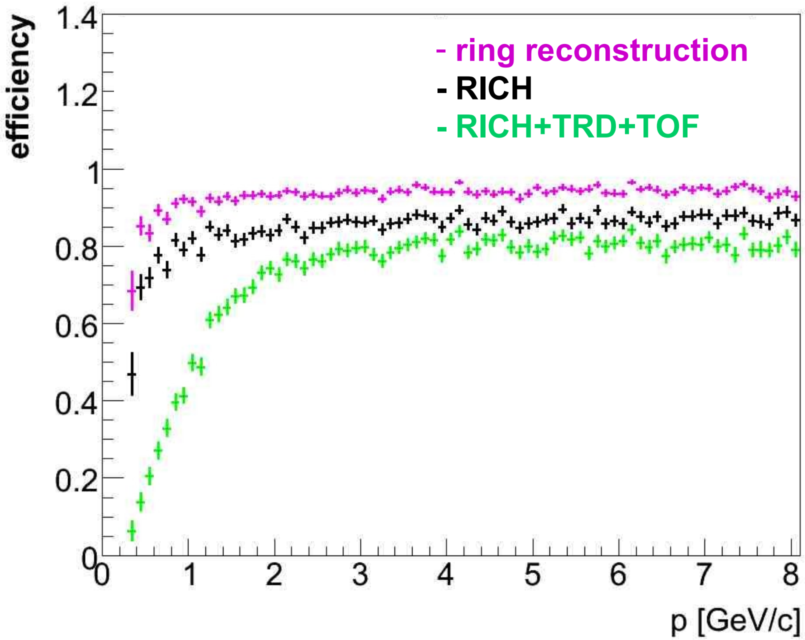


M < 1 GeV/c^2: radial flow generated in the late hadronic phase

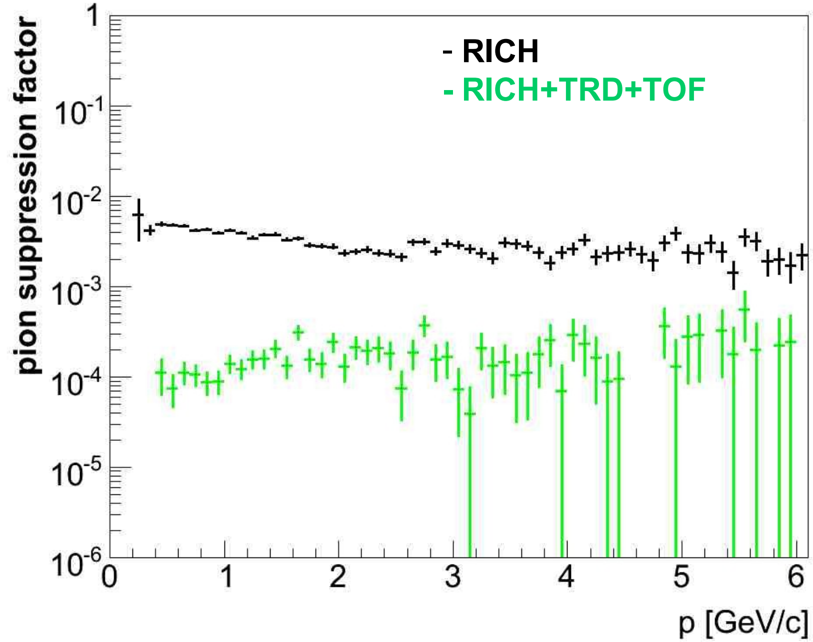
M > 1 GeV/c^2: messengers from the early partonic phase ?

e^- id effiiciency, π rejection factor

Electron id efficiency



π suppression factor



Particle yields at Au+Au, 25AGeV

particle, mass (MeV)	N	decay mode	BR	R/s (MHz)	T	ε (%)	Y/s	Y/10 w
η (547)	6.6	$\mu^+\mu^-$	$5.8\cdot10^{-6}$	0.25	y	3	0.28	$1.7\cdot10^{6}$
K^+ (494)	8	-	-	0.025	n	20	$4\cdot10^{4}$	$2.4\cdot10^{11}$
K^- (494)	2.6	-	-	0.025	n	20	$1.3\cdot10^{4}$	$7.8\cdot10^{10}$
K_s^0 (497)	5.4	$\pi^+\pi^-$	0.69	0.025	n	10	$9.3\cdot10^{3}$	$5.6\cdot10^{10}$
ρ (770)	4.6	e^+e^-	$4.7\cdot10^{-5}$	0.025	n	5.4	0.29	$1.8\cdot10^{6}$
ρ (770)	4.6	$\mu^+\mu^-$	$4.6\cdot10^{-5}$	0.25	y	2.7	1.4	$8.6\cdot10^{6}$
ω (782)	7.6	e^+e^-	$7.1\cdot10^{-5}$	0.025	n	7.2	1	$6\cdot10^{6}$
ω (782)	7.6	$\mu^+\mu^-$	$9\cdot10^{-5}$	0.25	y	3.7	6.3	$38\cdot10^{6}$
ϕ (1020)	0.256	e^+e^-	$3\cdot10^{-4}$	0.025	n	9.6	0.18	$1\cdot10^{6}$
ϕ (1020)	0.256	$\mu^+\mu^-$	$2.9\cdot10^{-4}$	0.25	y	6	1.	$6.7\cdot10^{6}$
Λ (1115)	6.4	$p\,\pi^-$	0.64	0.025	n	10.6	$1.1\cdot10^{4}$	$6.5\cdot10^{10}$
Ξ^- (1321)	0.096	$\Lambda\,\pi^-$	0.999	0.025	n	2.1	50.4	$3\cdot10^{8}$
Ω^- (1672)	0.0044	$\Lambda\,K^-$	0.68	0.025	n	1	0.75	$4.5\cdot10^{6}$
D^0 (1864)	$7.5\cdot10^{-6}$	$K^-\pi^+$	0.038	0.1	y	3.25	$8.5\cdot10^{-4}$	$5.1\cdot10^{3}$
D^0 (1864)	$7.5\cdot10^{-6}$	$K^-\pi^+\pi^+\pi^-$	0.075	0.1	y	0.37	$2.1\cdot10^{-4}$	$1.3\cdot10^{3}$
$\bar{D}^0$ (1864)	$2.3\cdot10^{-5}$	$K^+\pi^-$	0.038	0.1	y	3.25	$2.6\cdot10^{-3}$	$1.6\cdot10^{4}$
D^+ (1869)	$8\cdot10^{-6}$	$K^-\pi^+\pi^+$	0.092	0.1	y	4.2	$3.1\cdot10^{-3}$	$1.9\cdot10^{4}$
D^- (1869)	$1.8\cdot10^{-5}$	$K^+\pi^-\pi^-$	0.092	0.1	y	4.2	$7\cdot10^{-3}$	$4.2\cdot10^{4}$
Λ_c(2285)	$4.9\cdot10^{-4}$	$pK^-\pi^+$	0.05	0.1	y	0.5	$1.2\cdot10^{-2}$	$7.4\cdot10^{4}$
J/ψ (3097)	$3.8\cdot10^{-6}$	e^+e^-	0.06	1-10	y	14	0.032 - 0.32	$1.9\cdot10^{5-6}$
ψ′ (3686)	$5.1\cdot10^{-8}$	e^+e^-	$7.3\cdot10^{-3}$	1-10	y	15	$5.6\cdot10^{-(5-4)}$	$3.4\cdot10^{2-3}$
J/ψ (3097)	$3.8\cdot10^{-6}$	$\mu^+\mu^-$	0.06	10	y	16	0.36	$2.2\cdot10^{6}$
ψ′ (3686)	$5.1\cdot10^{-8}$	$\mu^+\mu^-$	$7.3\cdot10^{-3}$	10	y	19	$7.1\cdot10^{-4}$	$4.3\cdot10^{3}$

Acceptance