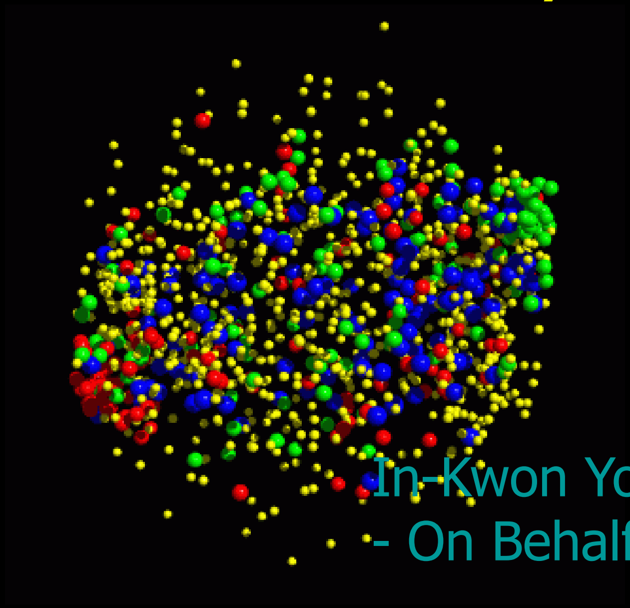
The Compressed Baryonic Matter experiment at the Facility for Antiproton and Ion Research



In-Kwon Yoo (Pusan Nat'l Univ.)
- On Behalf of Peter Senger (GSI) and B. Hong (Korea Univ.)

Outline:

- Introduction to FAIR
- The CBM experiment:
  - Physics case and observables
  - Simulations and technical challenges
  - Korean Contributions

WCU-Heavy Ion Meeting 2010-05, APCTP, Pohang, Korea, May 28-29, 2010

FAIR: the big challenge

FAIR is the largest fundamental science project worldwide for the next decade!

Forefront research in nuclear, hadron, atomic, anti-matter, plasma, and applied physics.

- **Construction until 2016**
- **Total cost 1.2 B€**
- **16 member states up to date**
- **Scientific users: 2500 - 3000 per year**

Observer

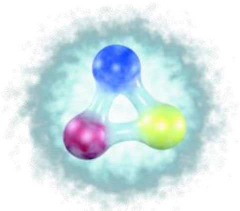
Financing:

- 65 % Federal Government of Germany
- 10 % State of Hessen
- 25 % Partner Countries

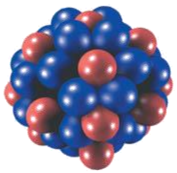
→FAIR GmbH with International Shareholders

Austria China Finnland France Germany Greece India Italy Poland Slovakia Slovenia Spain Sweden Romania Russia UK

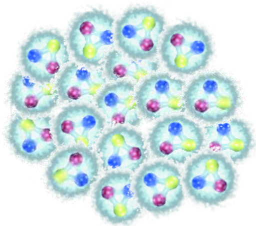
Research programmes at FAIR



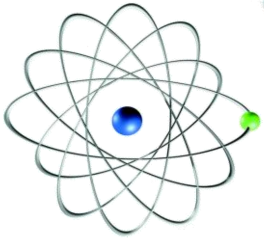
Beams of antiprotons: hadron physics
- quark-confinement potential
- search for gluonic matter and hybrids
- hypernuclei



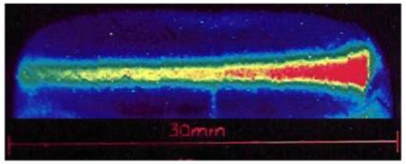
Rare isotope beams: nuclear structure and nuclear astrophysics
- nuclear structure far off stability
- nucleosynthesis in stars and supernovae



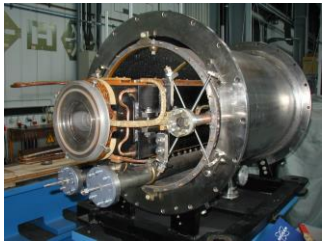
Nucleus-nucleus collisions: compressed baryonic matter
- baryonic matter at highest densities (neutron stars)
- phase transitions and critical endpoint
- in-medium properties of hadrons



Atomic physics and applied research
- highly charged atoms
- low energy antiprotons
- radiobiology

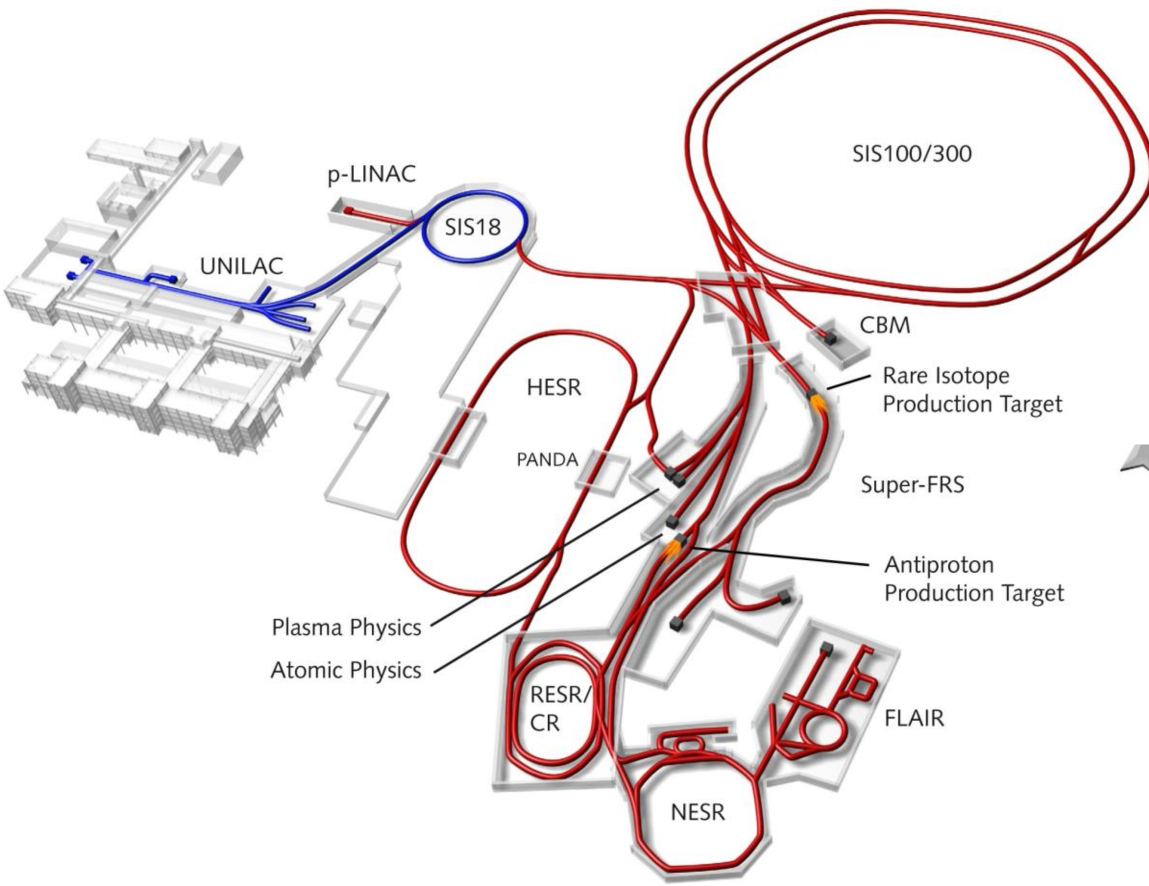


Short-pulse heavy ion beams: plasma physics
- matter at high pressure, densities, and temperature
- fundamentals of nuclear fusion



Accelerator physics
- high intensive heavy ion beams
- dynamical vacuum
- rapidly cycling superconducting magnets
- high energy electron cooling

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

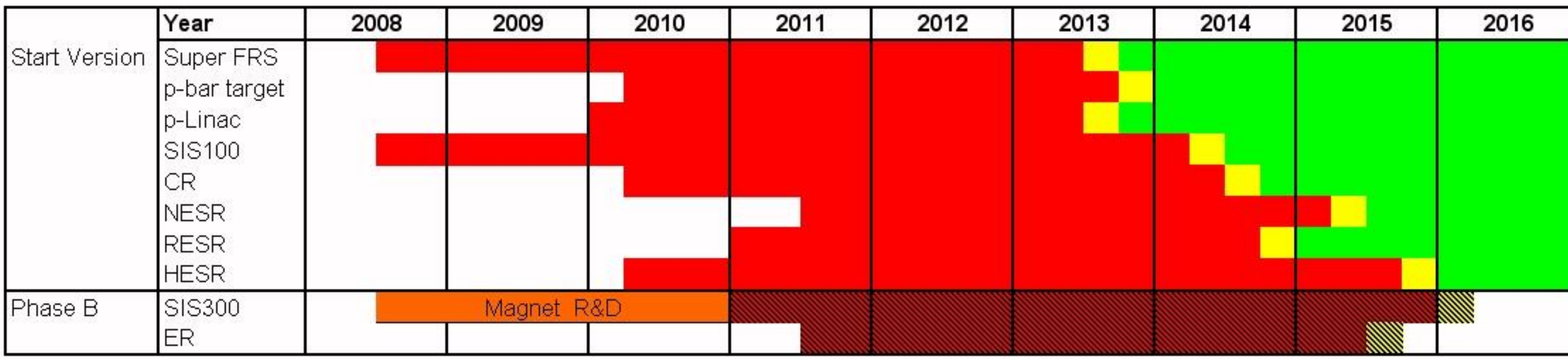
Overall schedule (FAIR accelerator sections)

2000: International Workshop at GSI (physics discussions, 300 participants)

2005: Evaluation of accelerators and experiments by international experts

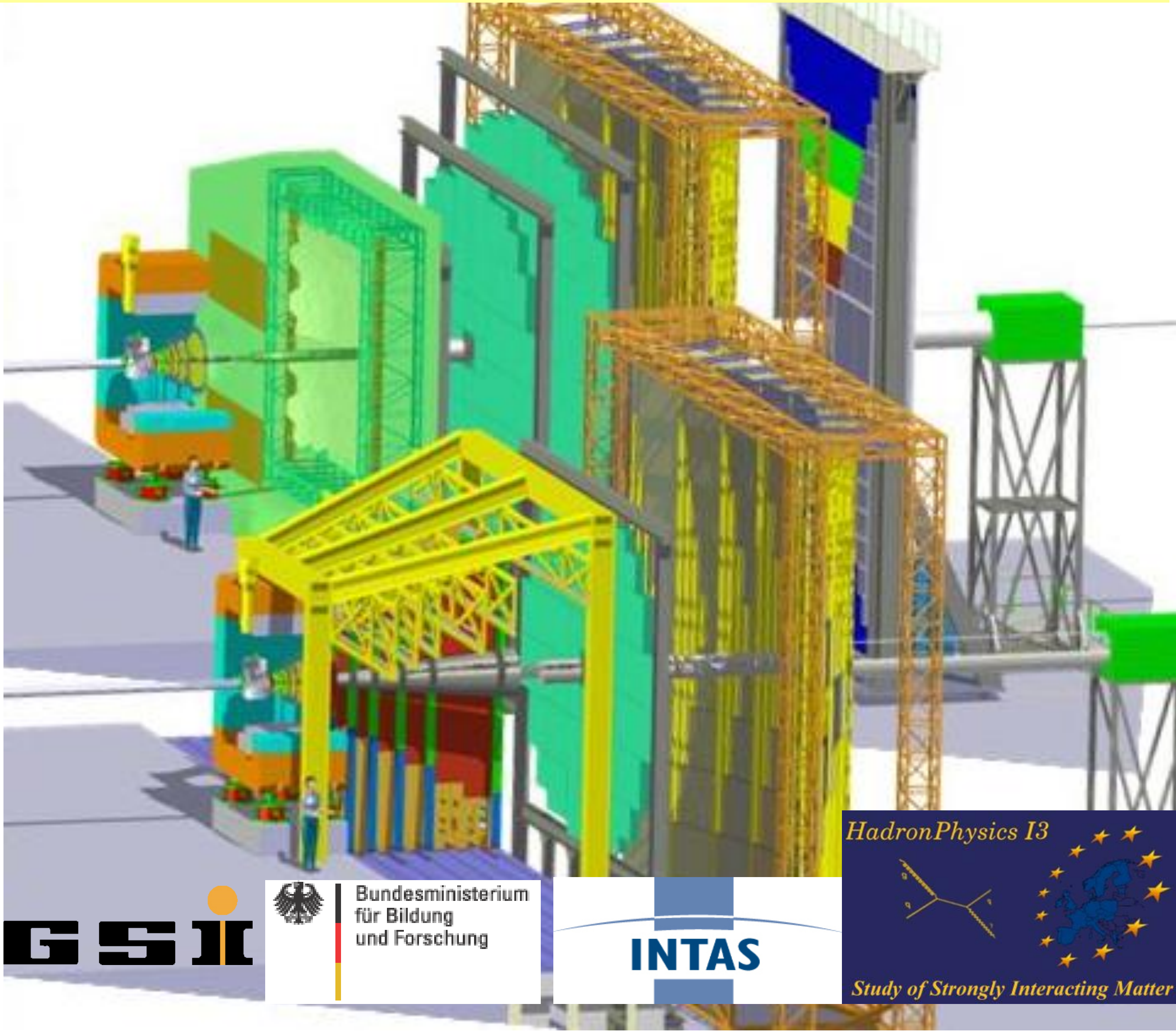
2006: FAIR Baseline Technical Report

(6 volumes with more than 3500 pages and more than 2600 authors

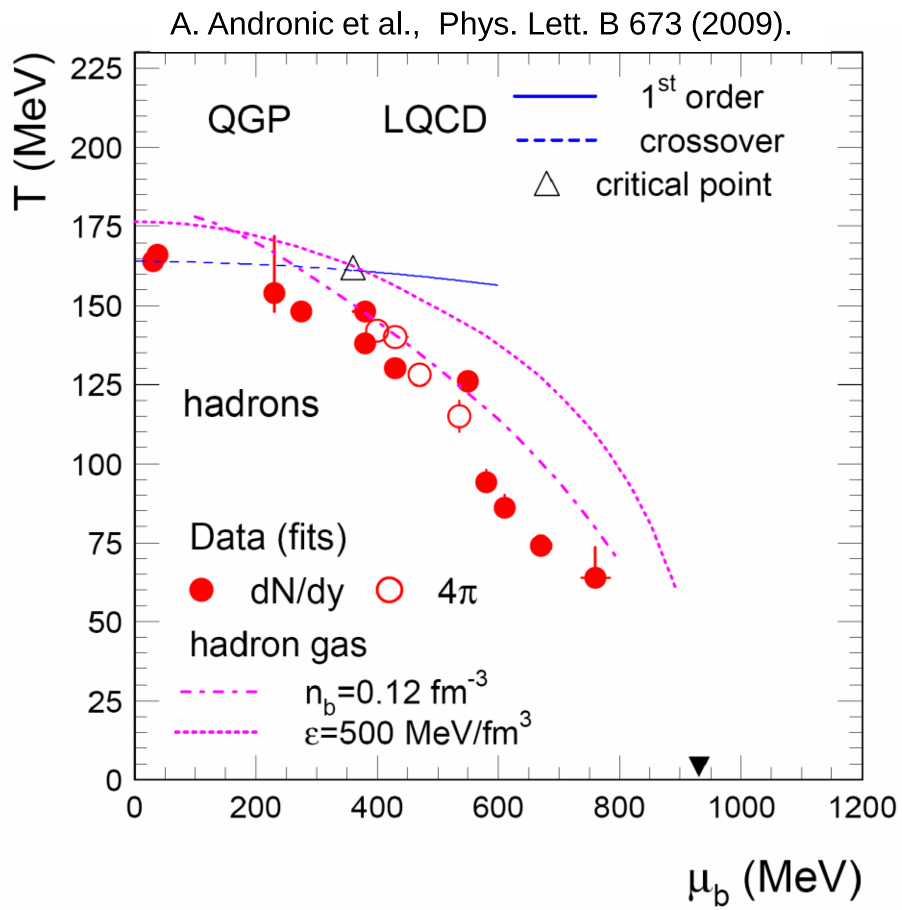


Project requires ~ 700 accelerator physicists and engineers

The Compressed Baryonic Matter experiment at FAIR



The QCD Phase diagram: facts and speculations



Experimental results:

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

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 μ_B > 0

Exploring the QCD phase diagram at large μ_B with heavy-ion collisions:

RHIC energy-scan: search for QCD-CP with bulk observables

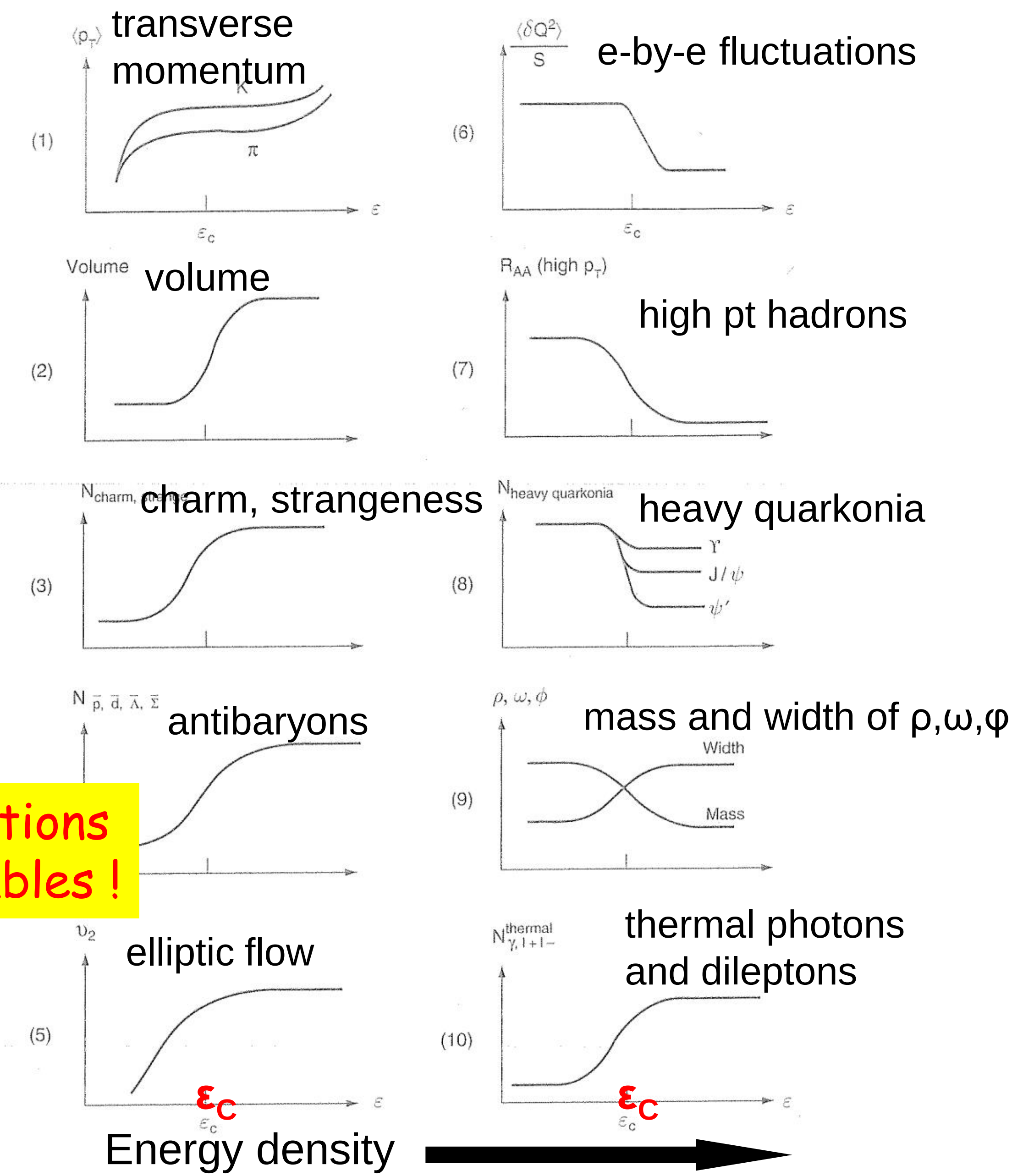
NA61@SPS: search for QCD-CP with bulk observables

MPD@NICA: search for the QCD mixed phase with bulk observables

CBM@FAIR: scan of the phase diagram with bulk and rare observables

Signatures for phase transitions in heavy-ion collisions

taken from the book:
Quark-Gluon-Plasma:
from big bang to little bang
by K. Yagi, T. Hatsuda, Y. Miake (2006)



Measure excitation functions of bulk and rare observables !

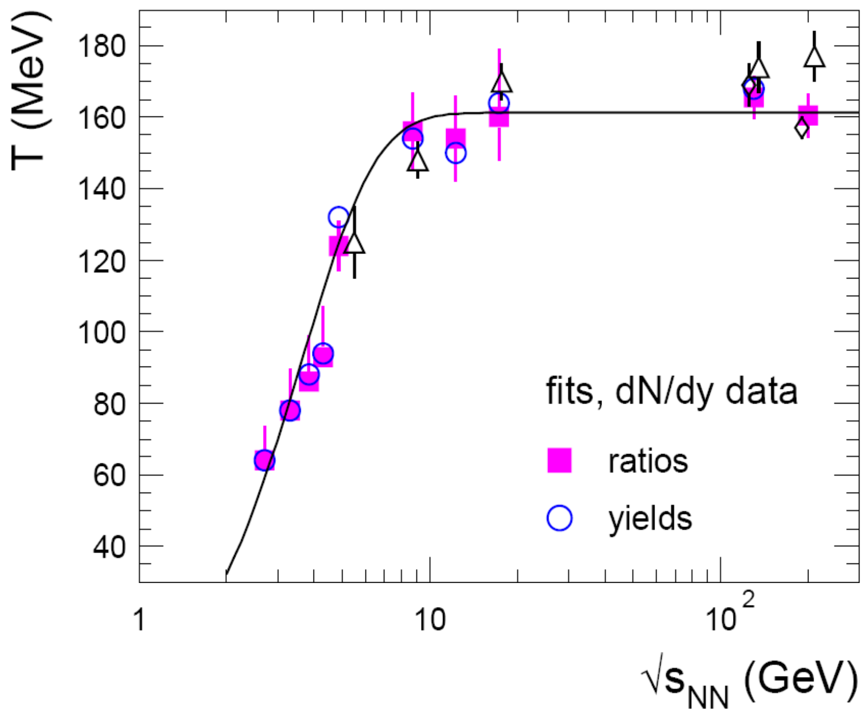
Signatures for phase transitions ?

Structures in excitation functions of observables at low SPS energies:

- limiting chemical freeze-out temperature
- limiting collective flow
- limiting radial flow and kinetic freeze-out temperature
- maximum in the strangeness/entropy ratio
- enhanced dynamical event-by-event fluctuations

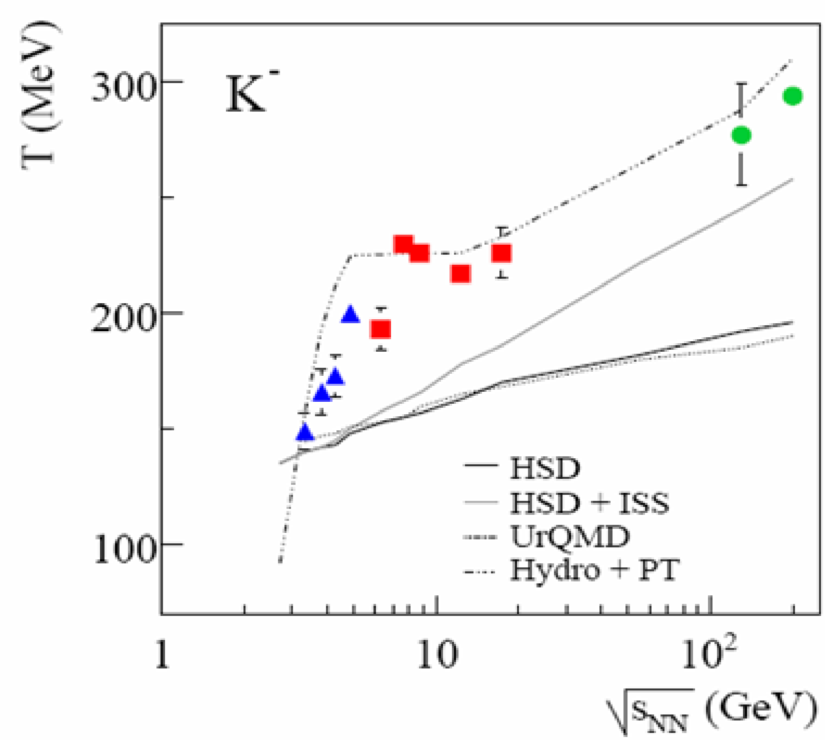
chemical freeze-out temperature

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



inverse slope parameter

[NA49, PRC 77, 024903 (2008)]



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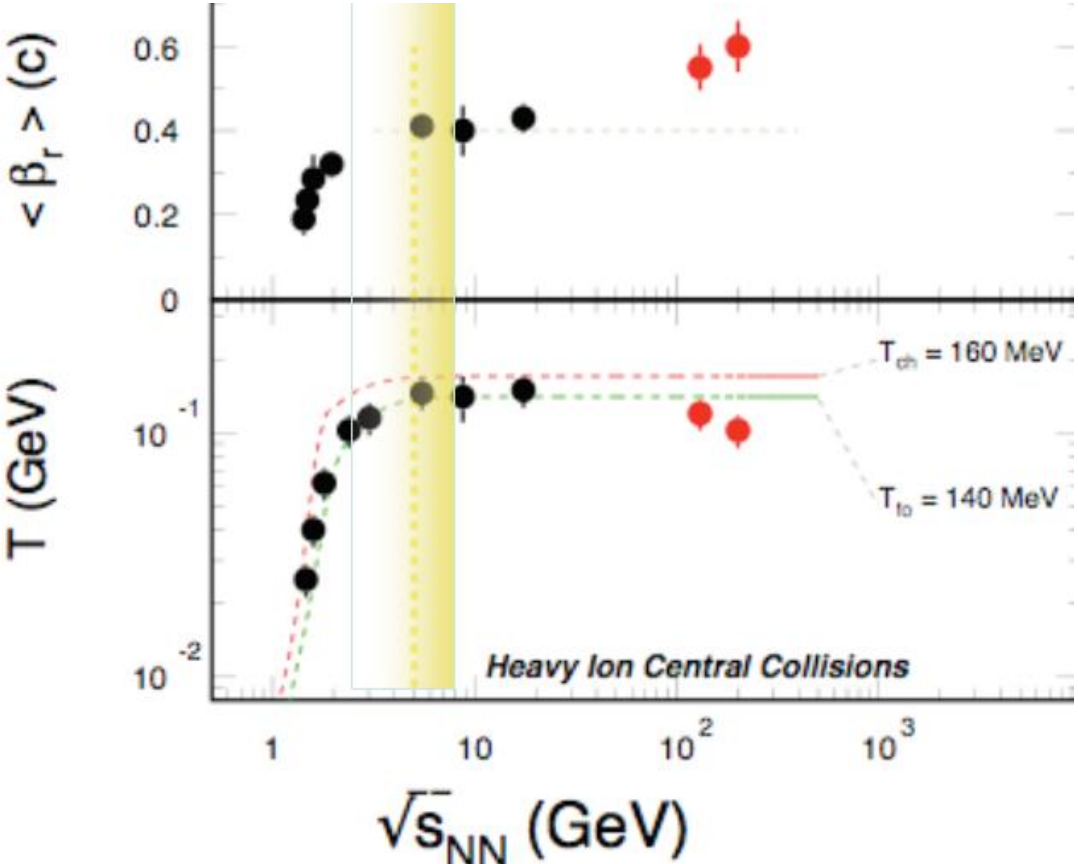

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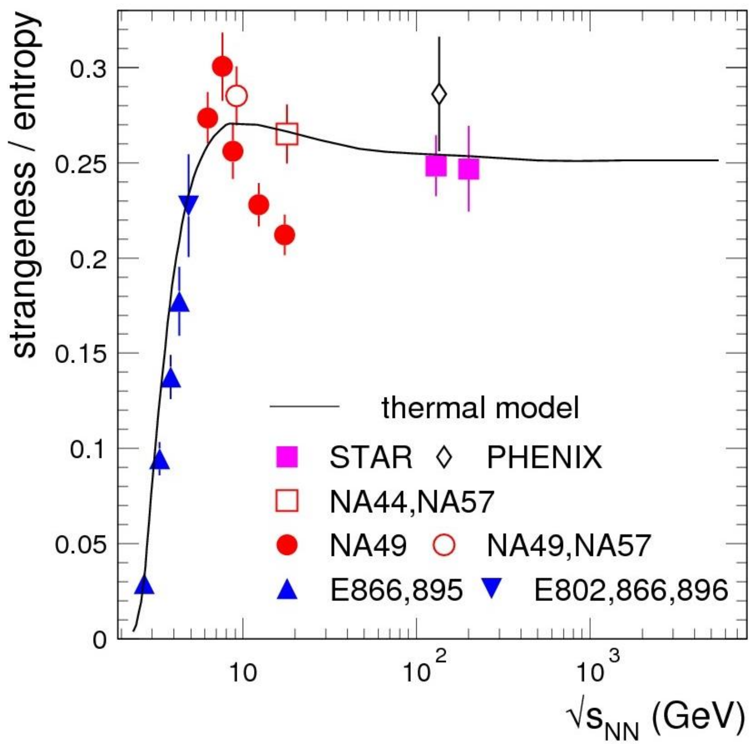
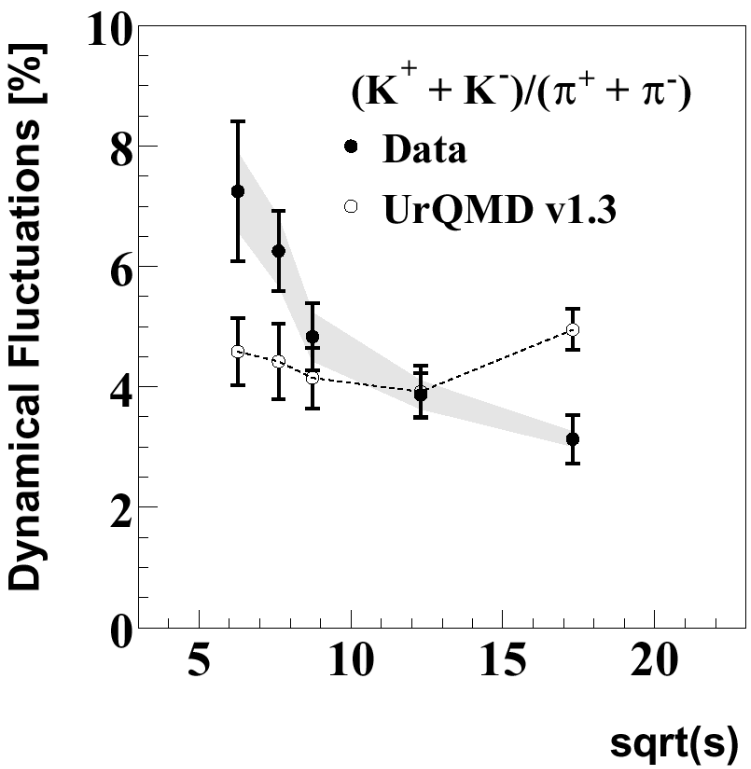
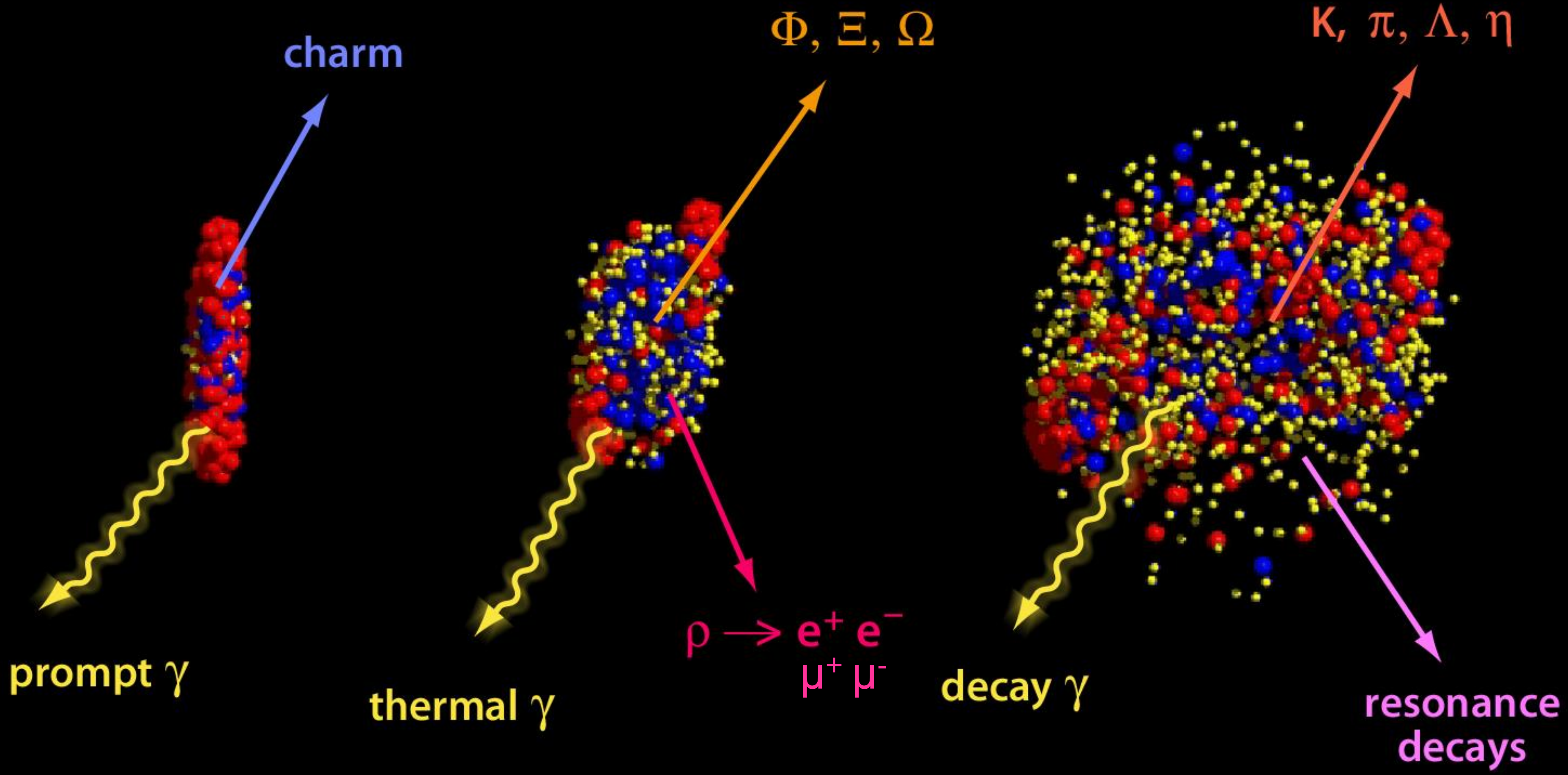


NA49 arXiv:0808.1237



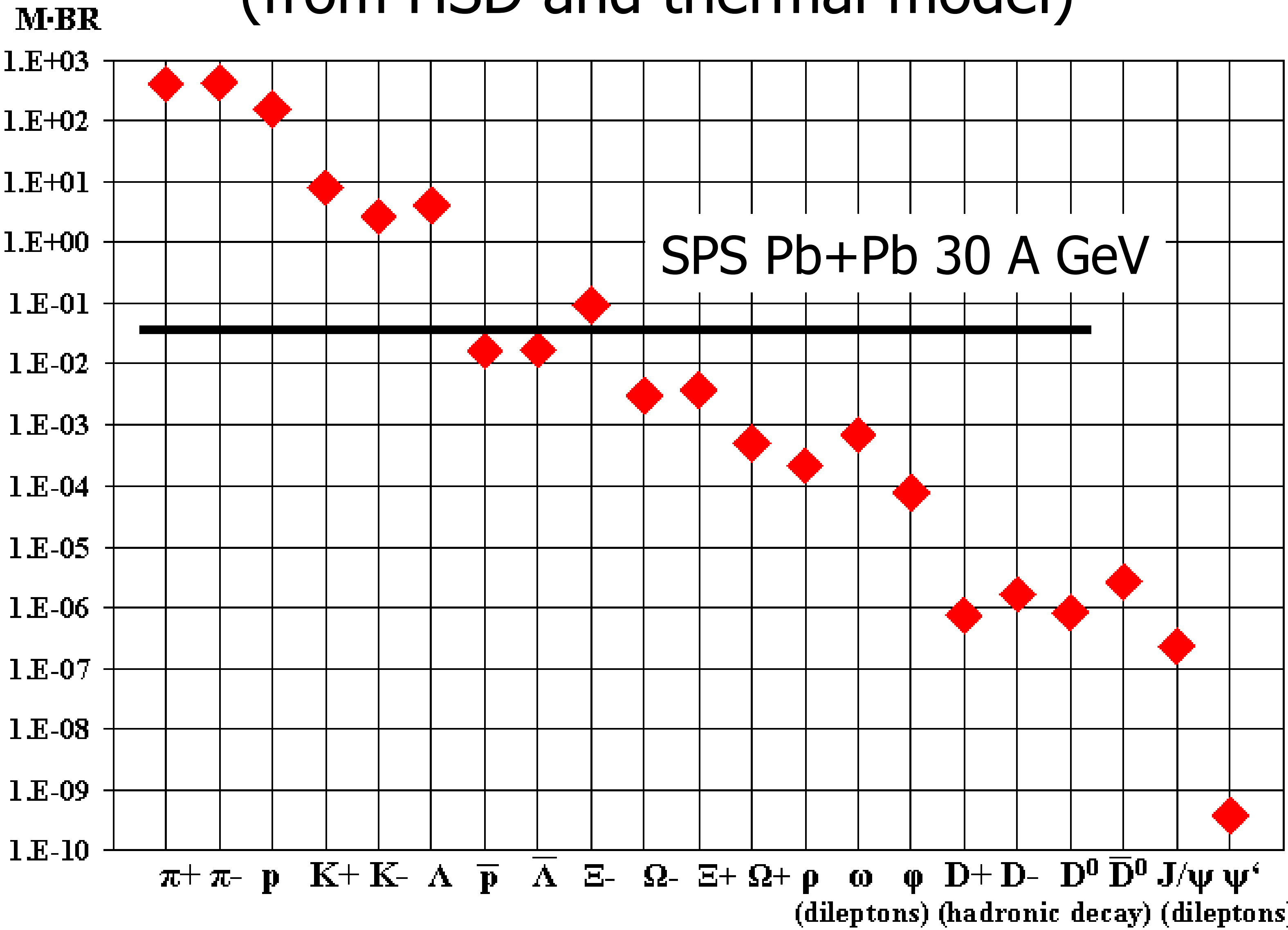
Messengers from the dense fireball ?

UrQMD transport calculation U+U 23 AGeV



Up to date only freeze-out probes have been measured in A+A collisions at 2 - 40 AGeV

Particle multiplicity x branching ratio for min. bias Au+Au collisions at 25 GeV (from HSD and thermal model)



CBM physics topics and observables

The equation-of-state at high ρ_B

- collective flow of hadrons
- particle production at threshold energies (multistrange hyperons, 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) (e.g. melting of J/ψ and ψ')
- excitation function of low-mass lepton pairs

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 ($\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$)

The equation-of-state of (symmetric) nuclear matter

Equation of state:

$P = \delta E/\delta V \,|_{T=const}$

$V = A/\rho$

$\delta V/ \delta\rho = - A/\rho^2$

$P = \rho^2 \; \delta(E/A)/\delta\rho \,|_{T=const}$

T=0: $E/A = 1/\rho \int U(\rho)d\rho$

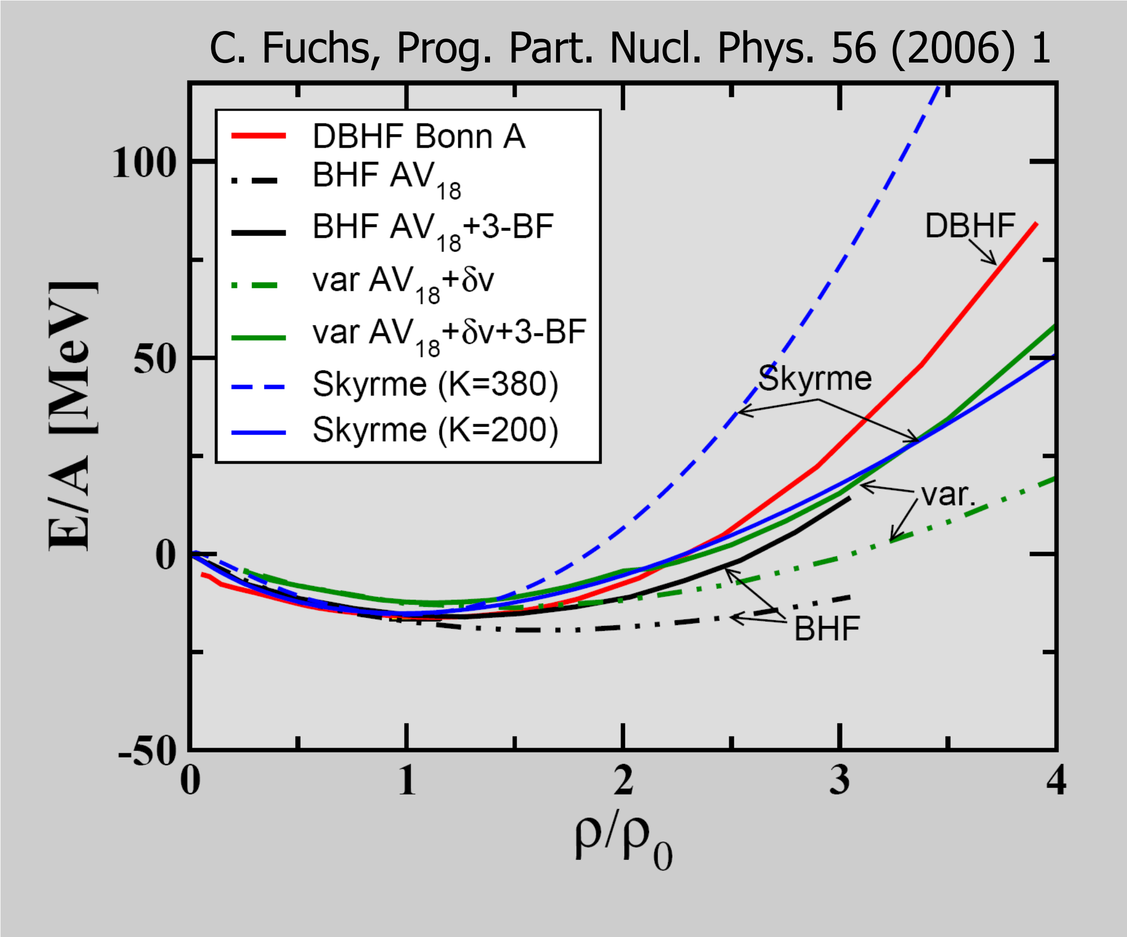
Effective NN-potential:

$U(\rho)=\alpha\rho+\beta\rho^\gamma$

$E/A(\rho_o) = -16$ MeV

- $\delta(E/A)(\rho_o)/\delta\rho = 0$
- Compressibility:

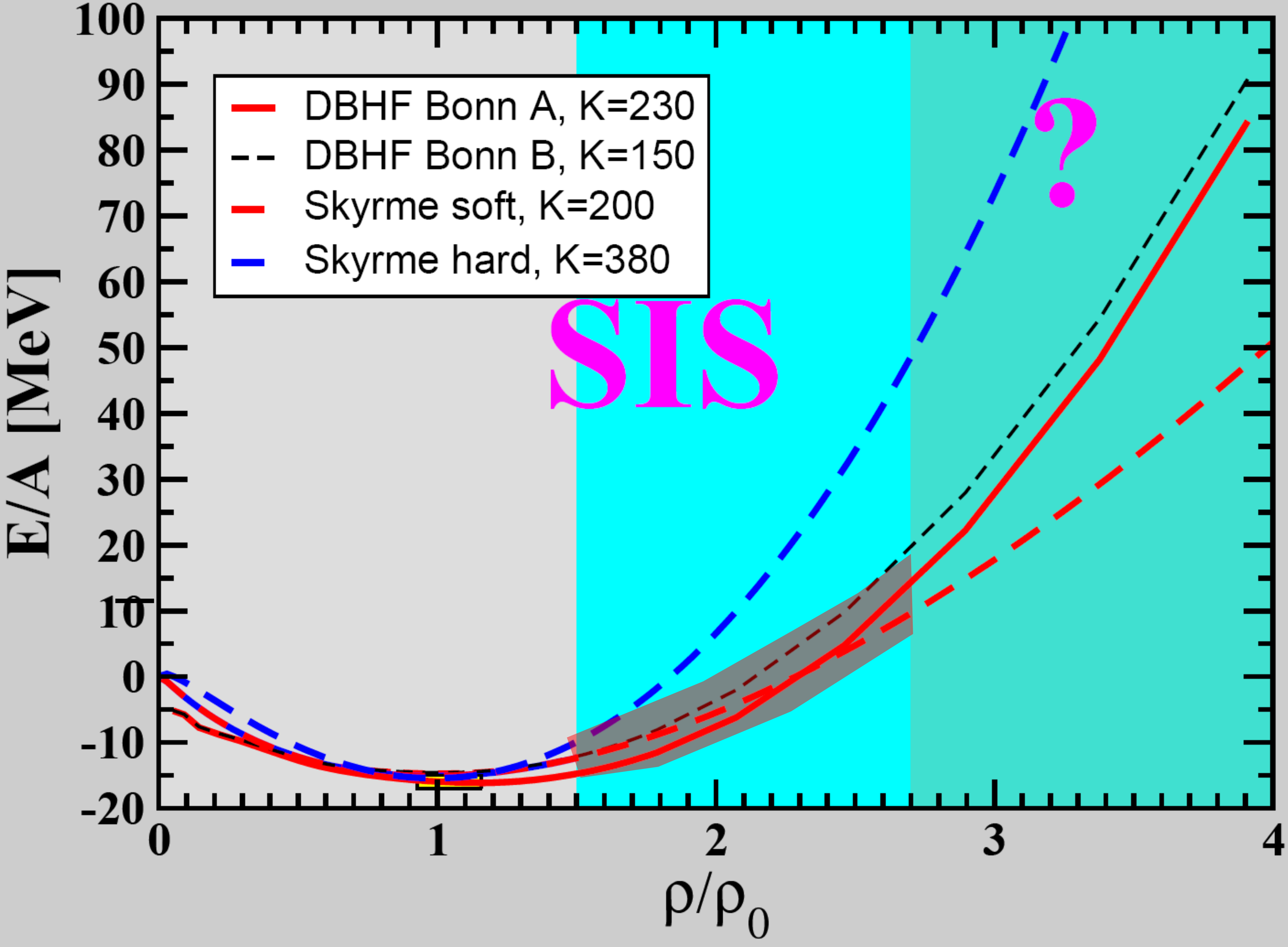
$\kappa = 9\rho^2 \; \delta^2 (E/A)/ \delta\rho^2$



κ = 200 MeV: "soft" EOS

κ = 380 MeV: "stiff" EOS

nuclear matter EOS



Exploring the "nuclear" EOS at $3\rho_0 < \rho < 7\rho_0$ with (sub)threshold production of multistrange hyperons

Direct production:

$NN \rightarrow \Lambda^0\overline{\Lambda}^0 NN$ (E_{thr} = 7.1 GeV)
$NN \rightarrow \Xi^+ \Xi^- NN$ (E_{thr} = 9.0 GeV)
$NN \rightarrow \Omega^+ \Omega^- NN$ (E_{thr} = 12.7 GeV)

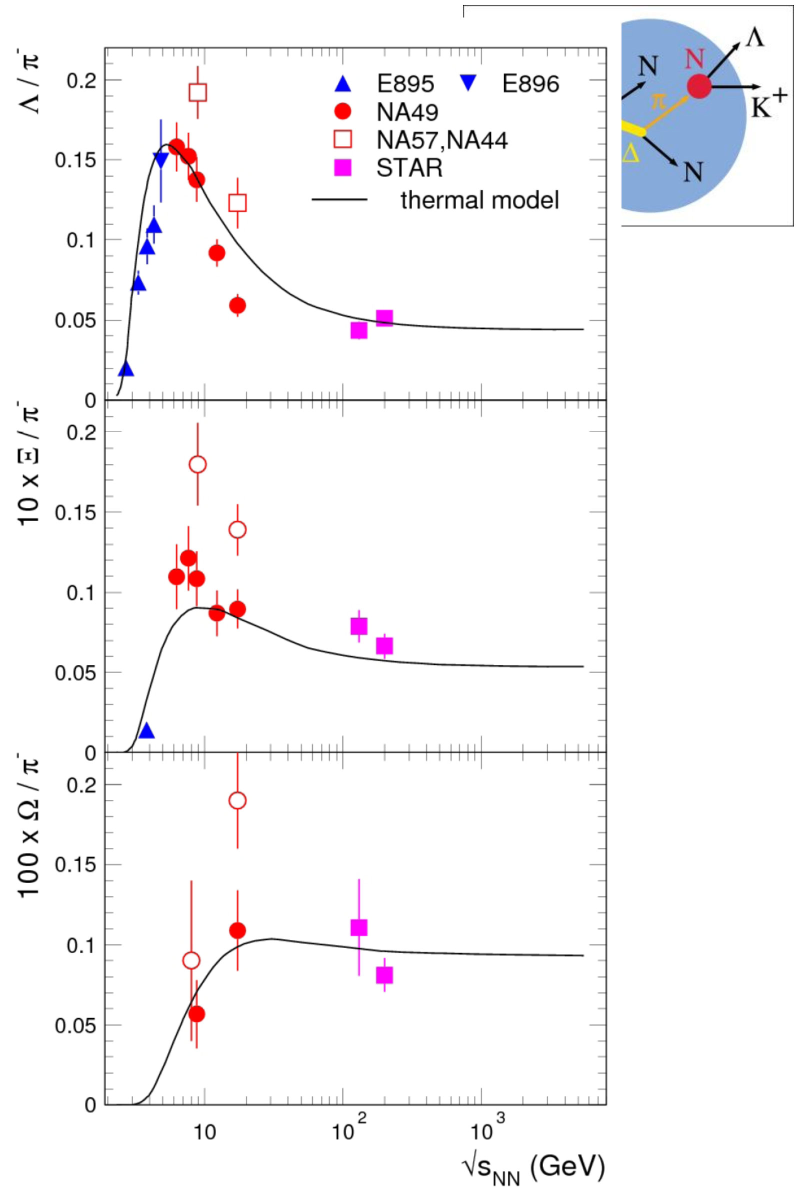
Production via multiple collisions:

Hyperons (s quarks):

1. $NN \rightarrow K^+\Lambda^0 N$, $NN \rightarrow K^+K^-NN$,
2. $\Lambda^0\Lambda^0 \rightarrow \Xi^- p$, $\Lambda^0 K^- \rightarrow \Xi^- \pi^0$
3. $\Lambda^0 \Xi^- \rightarrow \Omega^- n$, $\Xi^- K^- \rightarrow \Omega^- \pi^-$

Antihyperons (anti-s quarks):

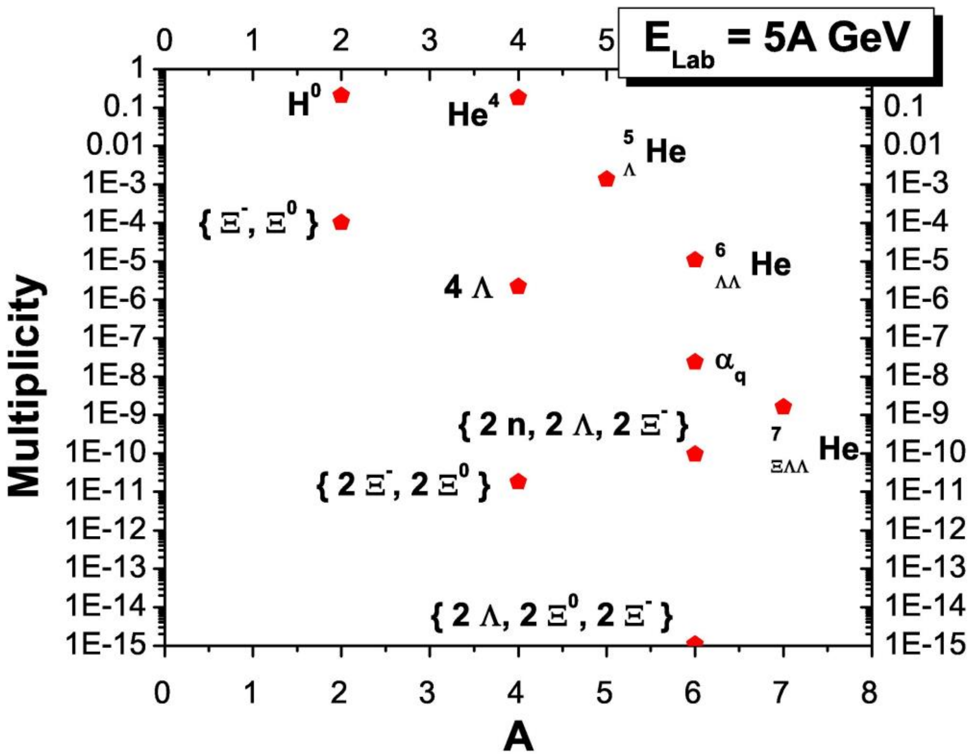
1. $\overline{\Lambda}^0 K^+ \rightarrow \Xi^+ \pi^0$,
2. $\Xi^+ K^+ \rightarrow \Omega^+ \pi^+$.



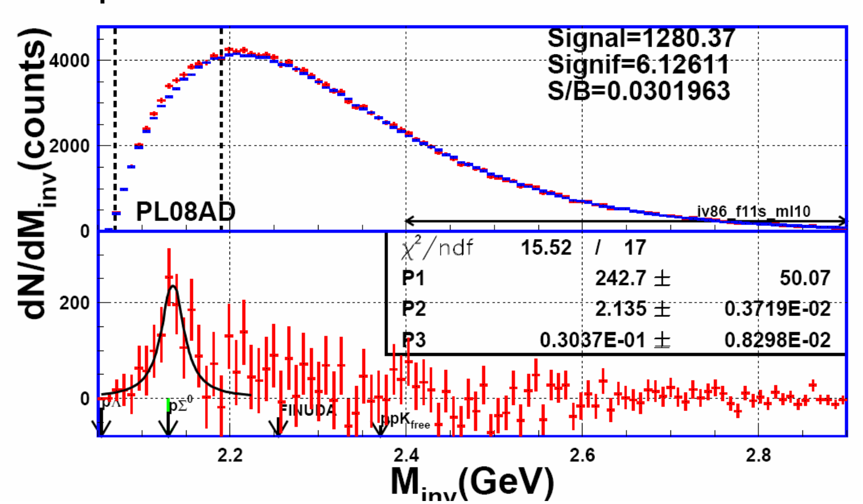
Measure excitation function for multi-strange hyperons in light and heavy collision systems

Search for metastable strange objects: experimental reconstruction of (multi)strange dibaryons

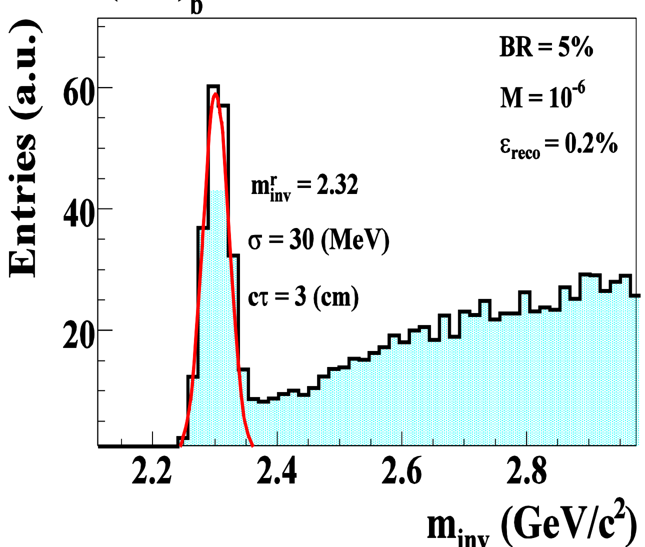
H. Stöcker et al., Nucl. Phys. A 827 (2009) 624c



FOPI: strange dibaryon
Λp–invariant mass in Ni+Ni at 1.91AGeV



$(\Xi^0\Lambda)_b \to \Lambda\Lambda$



Simulation for CBM:

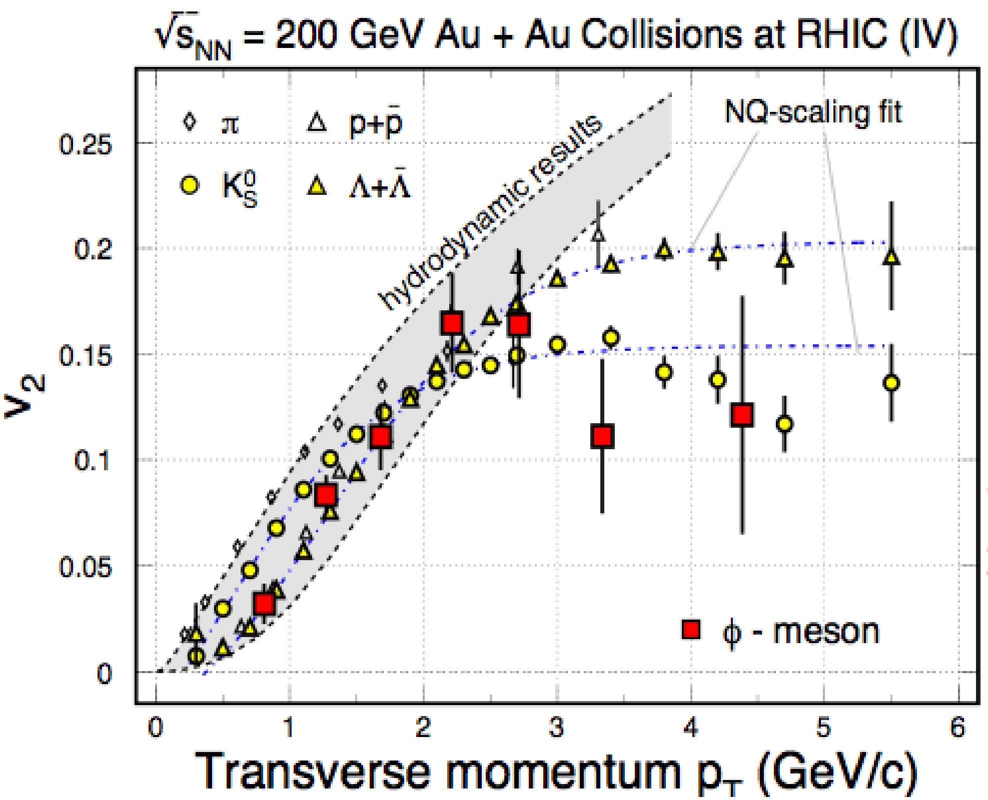
$(\Xi^0\Lambda)_b \to \Lambda\Lambda$ (cτ=3cm)

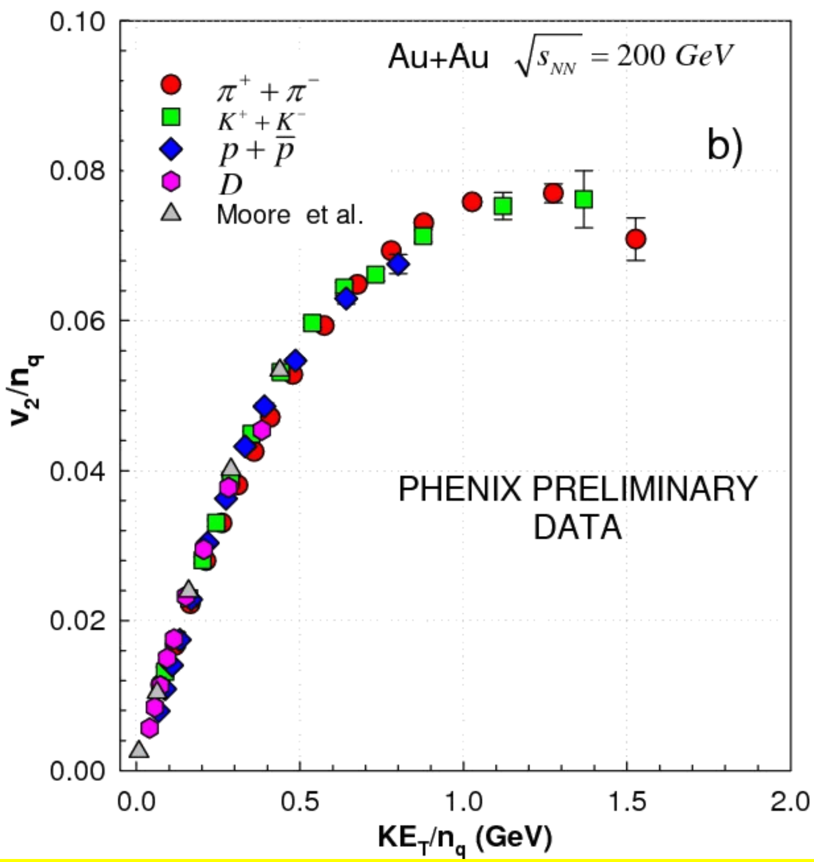
M= 10^{-6}, BR = 5%

Background:
Au+Au @ 25 AGeV
32 Λ per central event
11 Λ reconstructable

Signatures for partonic collectivity at RHIC

- Large elliptic flow
- elliptic flow scales with number of participant quarks
- suppression of high momentum hadrons (jet quenching)





Measure excitation function of elliptic flow for φ, Ω, D, and J/ψ.

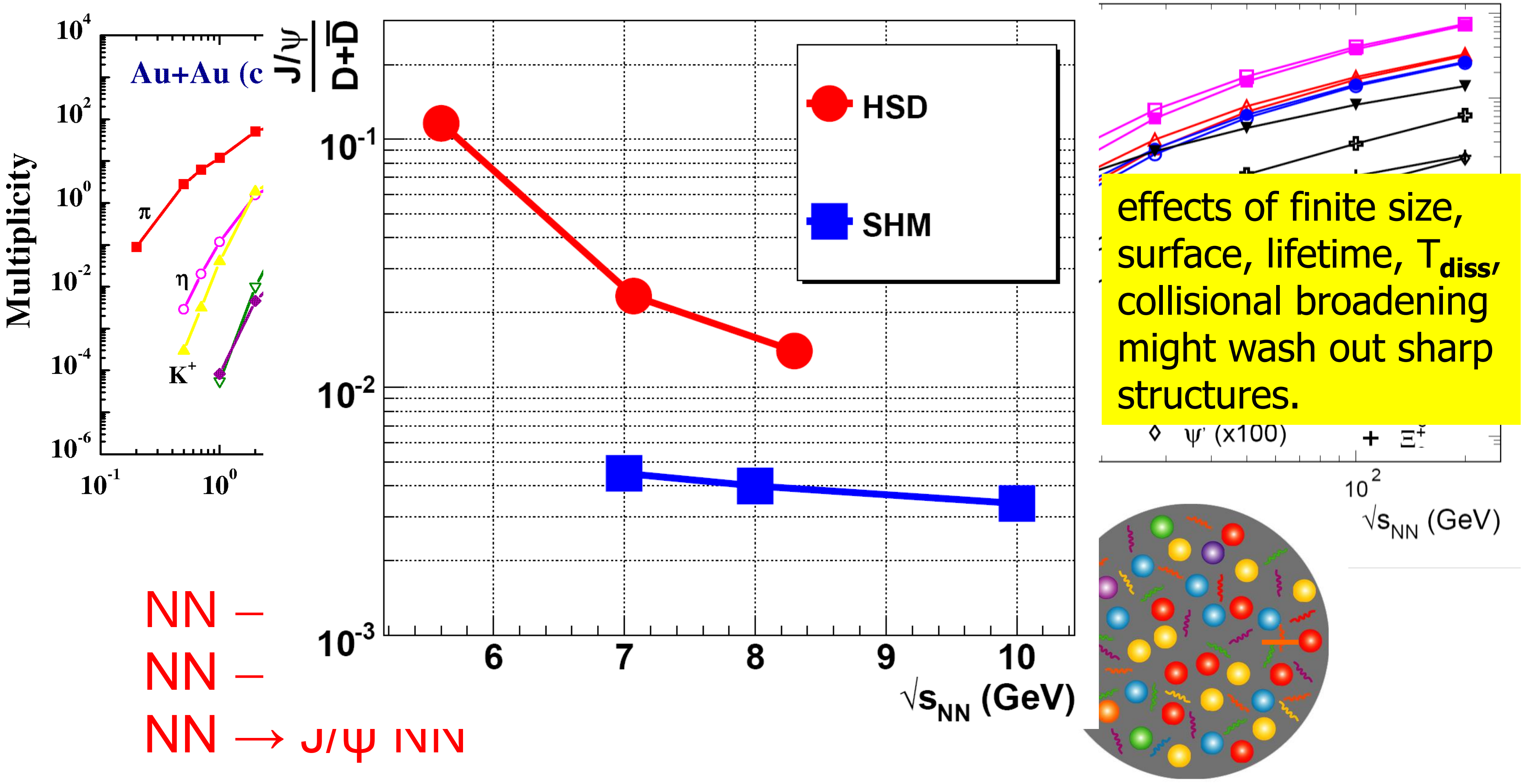
Searching for the deconfinement phase transition: Charm production in hadronic and partonic matter

Hadronic model (HSD)

O. Linnyk, E.L. Bratkovskaya, W. Cassing, H. Stöcker, Nucl.Phys.A786:183-200,2007

Statistical hadronization model (SHM)
(c-cbar production in partonic phase)

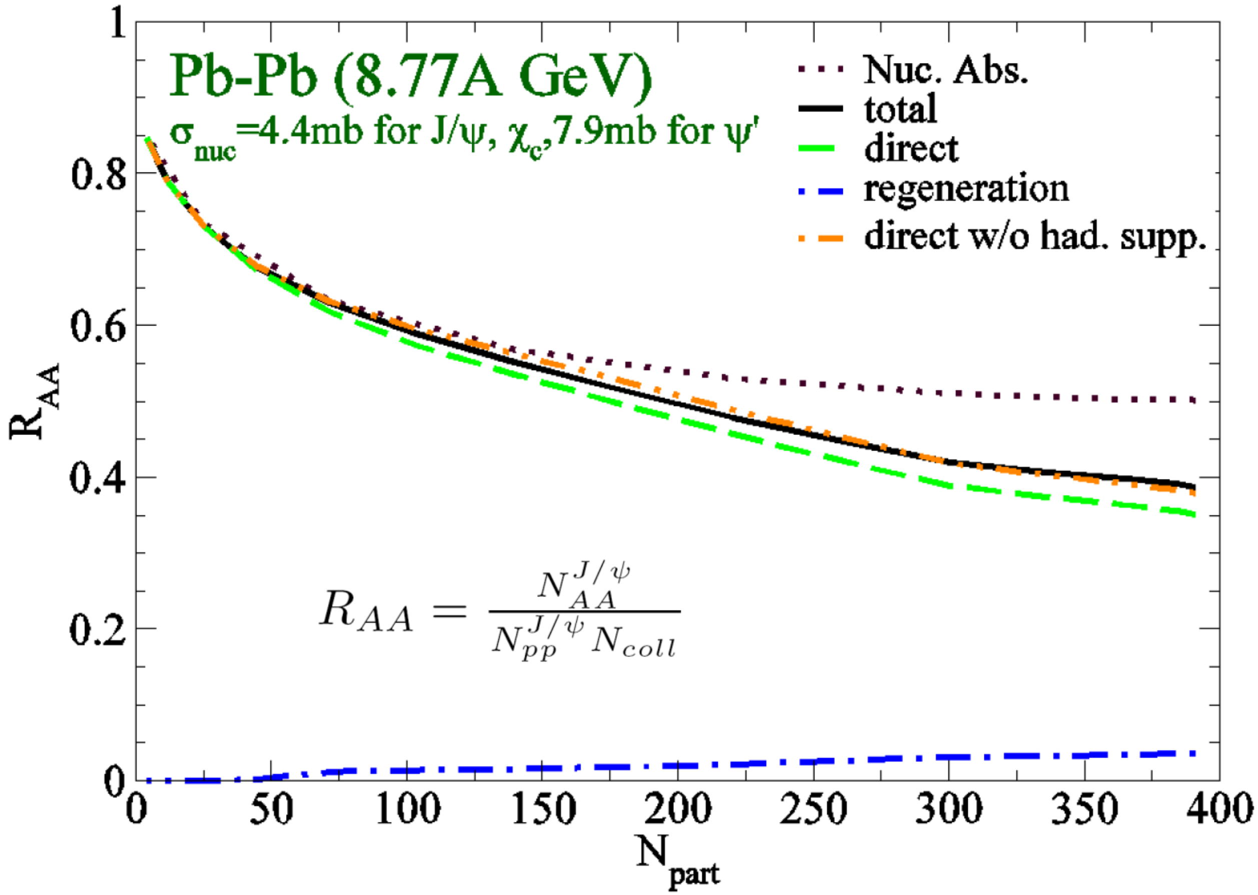
A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, arXiv:0708.1488



effects of finite size, surface, lifetime, T_{diss}, collisional broadening might wash out sharp structures.

NN →
NN →
NN → J/ψ NN

Charmonium suppression at FAIR energies



Xingbo Zhao, Ralf Rapp

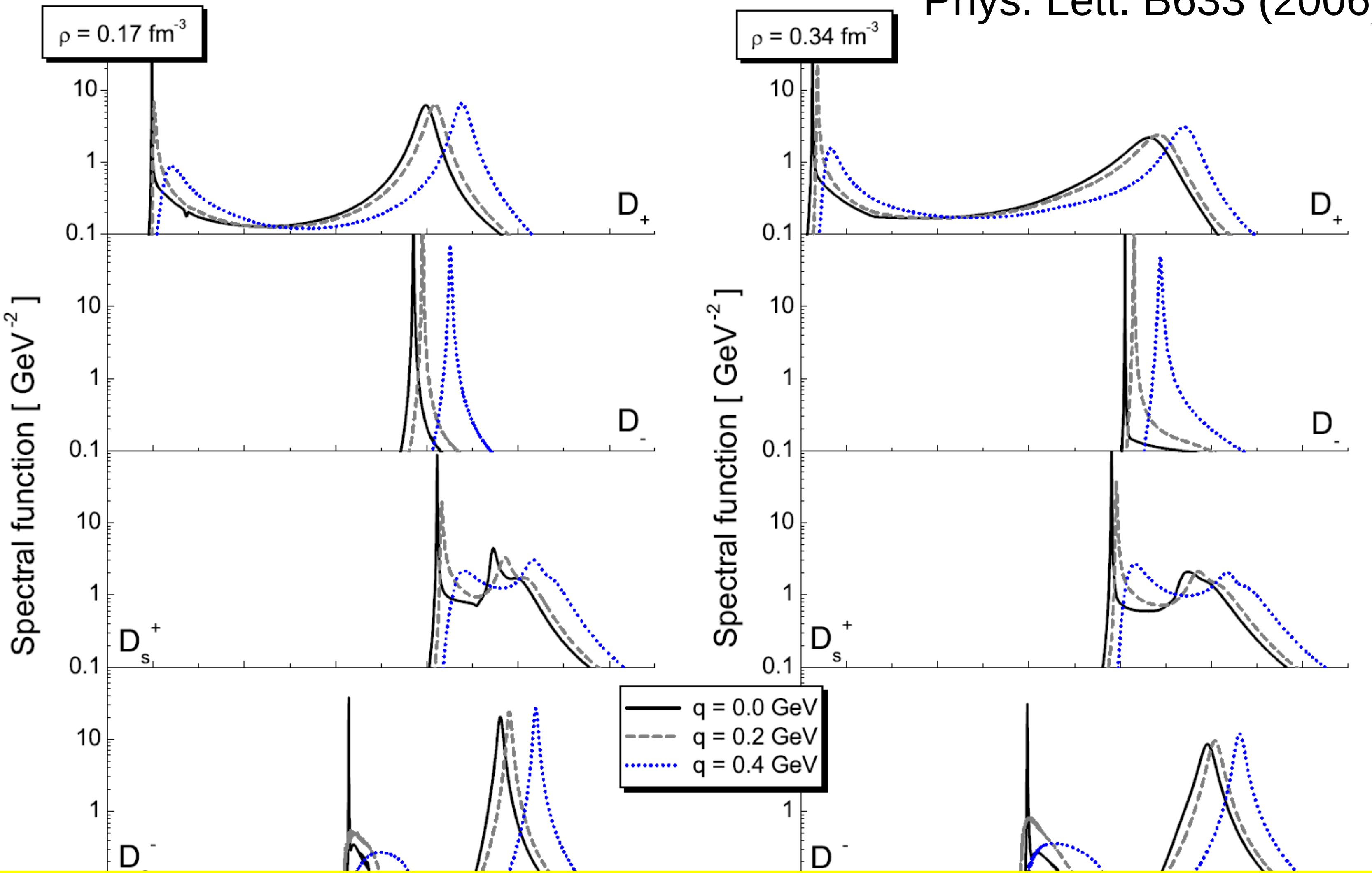
new NA60 data: 158 GeV p+A
E. Scomparin, QM2009

$\sigma_{abs}^{J/\psi}$ (158 GeV) = 7.6 ± 0.7 ± 0.6 mb
$\sigma_{abs}^{J/\psi}$ (400 GeV) = 4.3 ± 0.8 ± 0.6 mb

Measure excitation function of R_{AA},
i.e. p+p → J/ψ+X, p+A → J/ψ+X, A+A → J/ψ+X

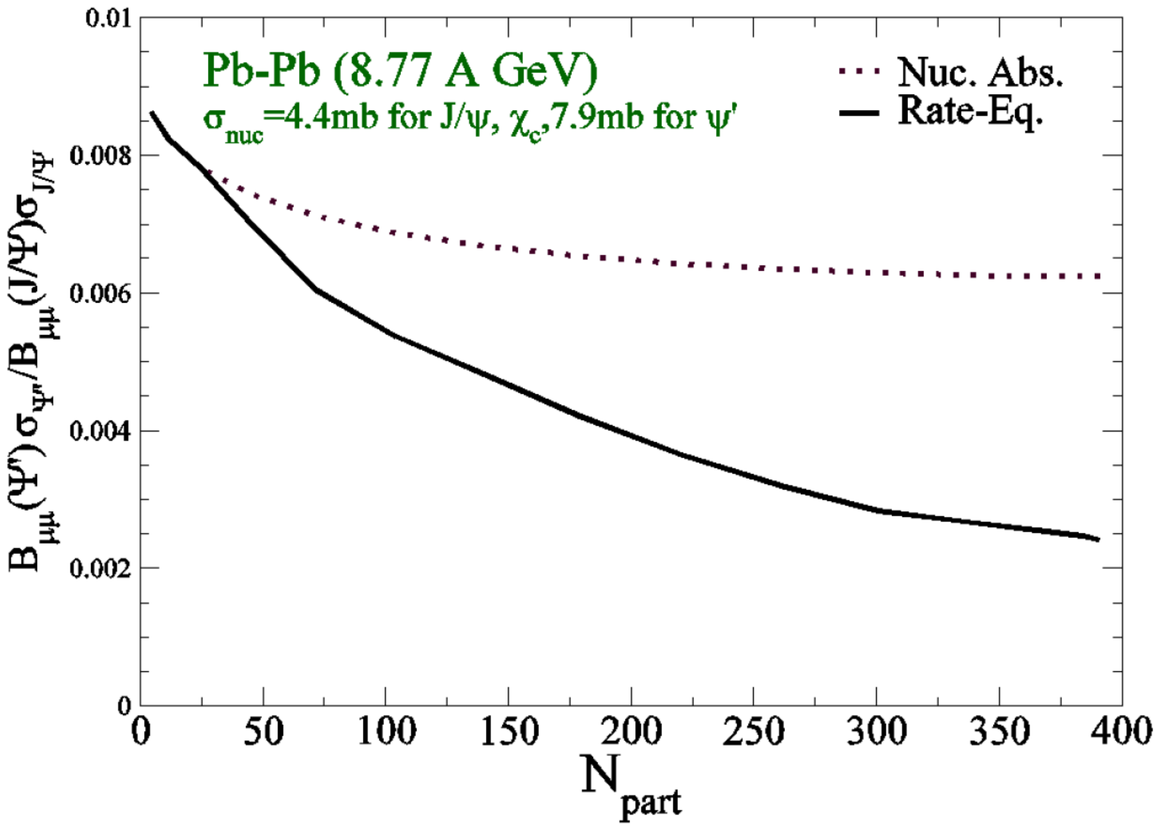
In-medium properties of D-mesons

M.F.M. Lutz and C.L. Korpa, Phys. Lett. B633 (2006) 43



Measure collective flow (v_1, v_2) of D^+ and D^- mesons

In-medium properties of D-mesons



Xingbo Zhao and Ralf Rapp

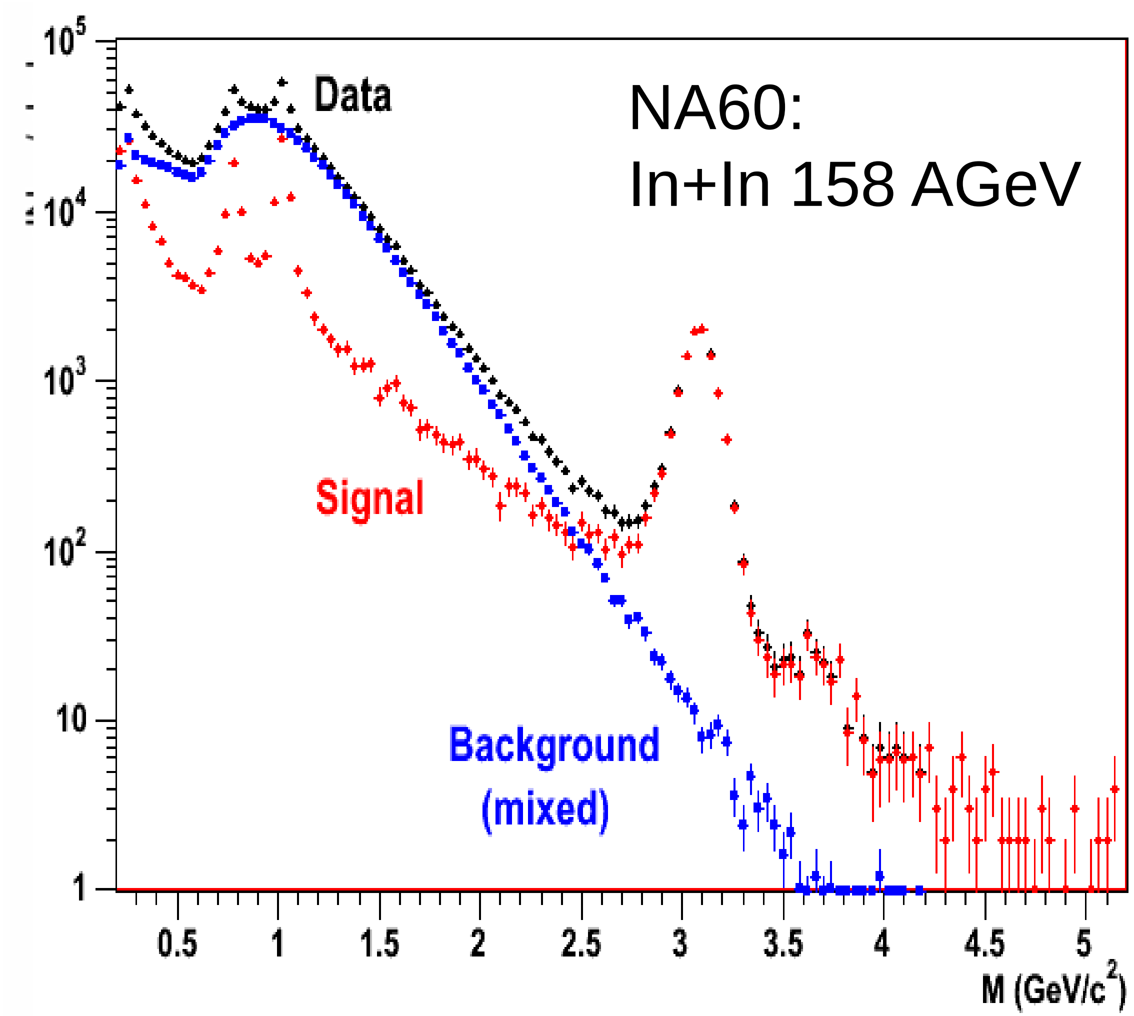
D meson mass modification affects the ψ'/(J/ψ) ratio

New absorption mechanism in nuclear medium
if D meson mass reduced: $\psi' \rightarrow D^+D^-$

Not possible in vacuum: ψ'(3686 MeV) < D^+D^-(3738 MeV)

Measure: $p + A \rightarrow J/\psi,\ \psi'$ $A + A \rightarrow J/\psi,\ \psi'$

Dilepton production in heavy-ion collisions



mass [GeV/c^2]

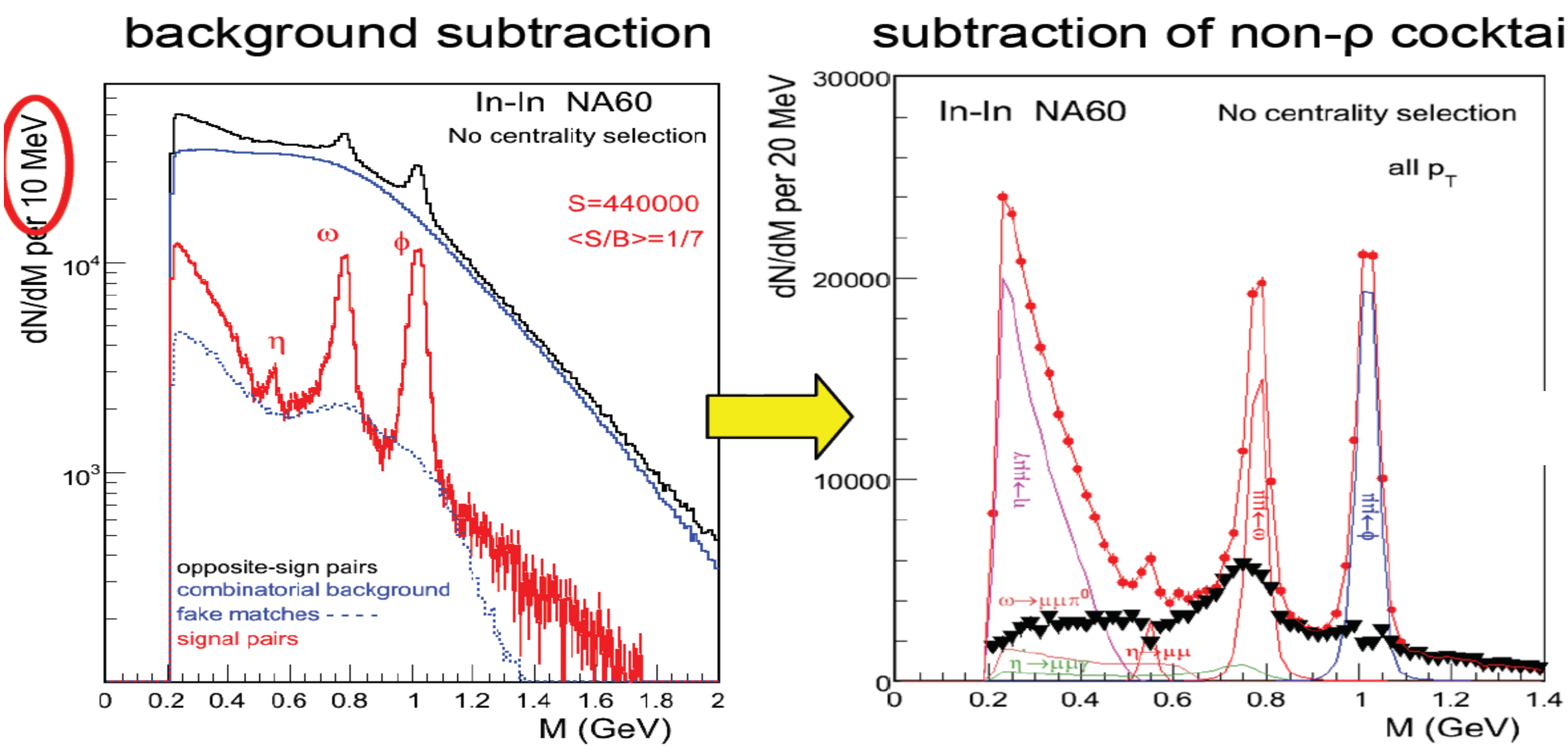
5-week-long run in Oct.–Nov. 2003

courtesy of Axel Drees

~ 4 × 10^{12} ions delivered in total

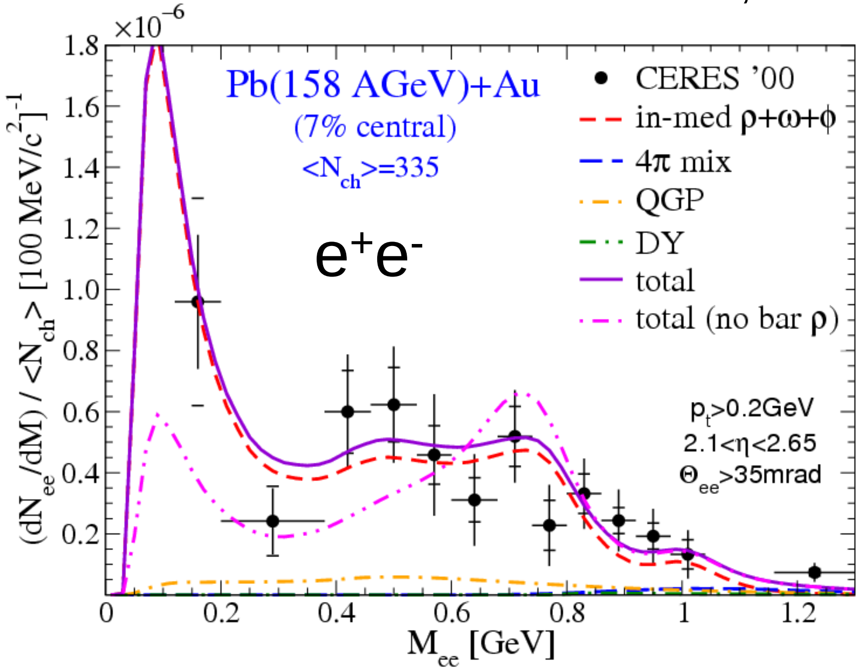
Digging out the signal

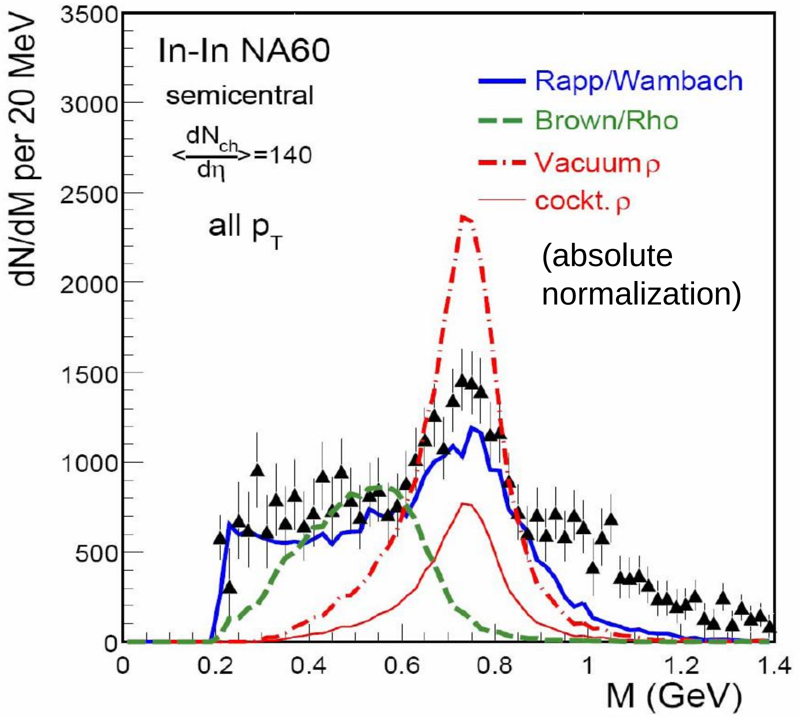
Substraction of combinatorial background and known sources of $\mu^+\mu^-$ pairs in the region of low invariant masses:



Searching for the modification of hadron properties via dilepton measurements

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





Electrons: access to $M_{inv} < 200\ MeV/c^2$ Muons: better statistics (trigger)

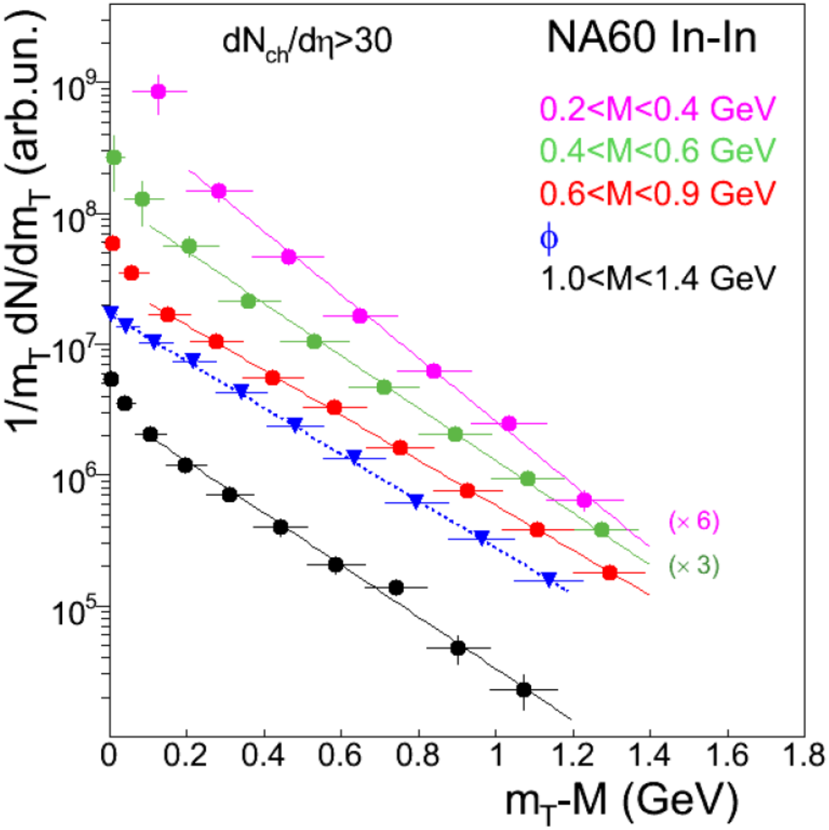
no ρ,ω,φ → e^+e^- ($\mu^+\mu^-$) data between 2 and 40 AGeV

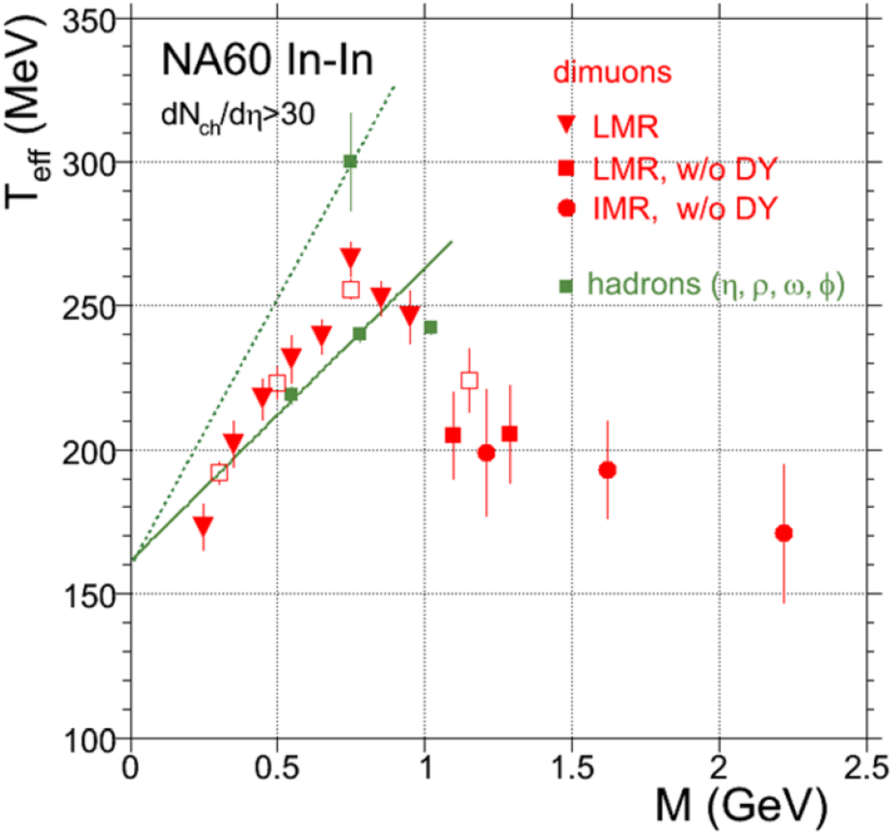
no J/ψ, ψ' → e^+e^- ($\mu^+\mu^-$) data below 160 AGeV

More information: the spectral slope as function of invariant mass

parameterisation $\frac{1}{m_T}\frac{dN}{dm_T} \sim \exp\left(-m_T/T_{eff}\right)$

NA60: PRL 100,022302(2008)

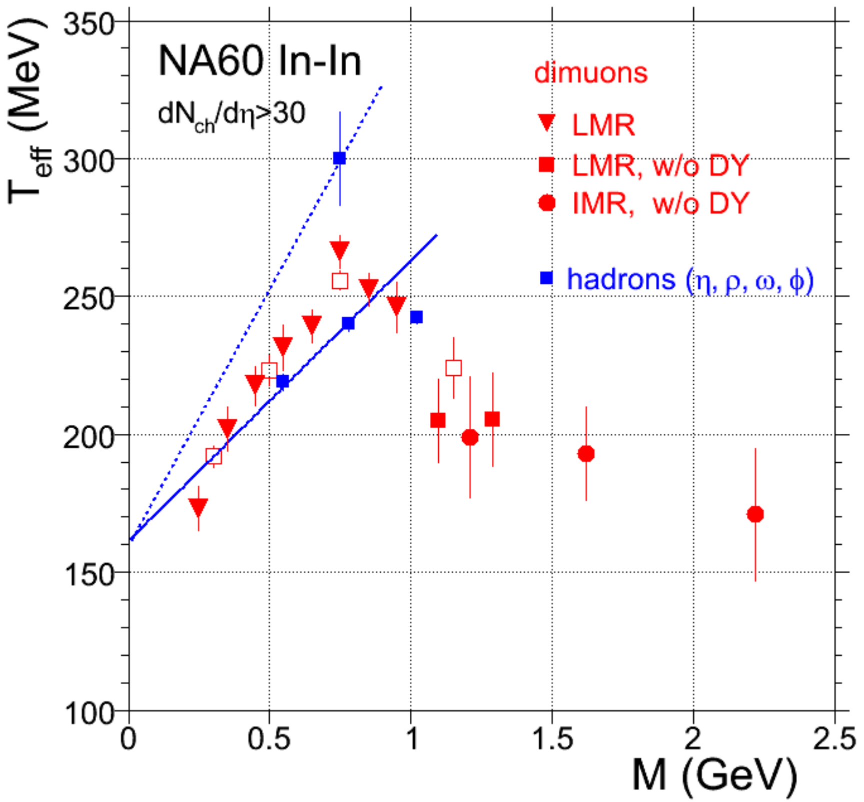


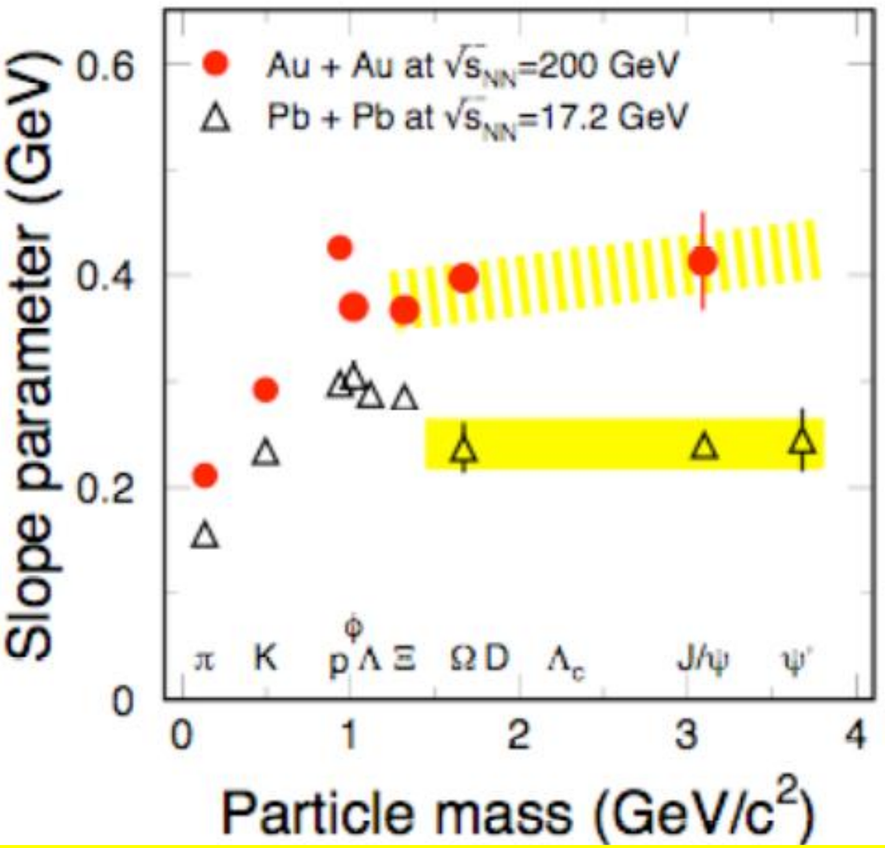


Radial flow as function of particle mass: probing the early phase of the fireball evolution

R. Arnaldi et al., (NA60), PRL 100 (2008) 022302

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





Measure excitation function of dilepton and hadron yields and slope parameters (e^+e^-, $\mu^+\mu^-$, Ω, D, J/ψ, ψ')

CBM Physics Book

Content:

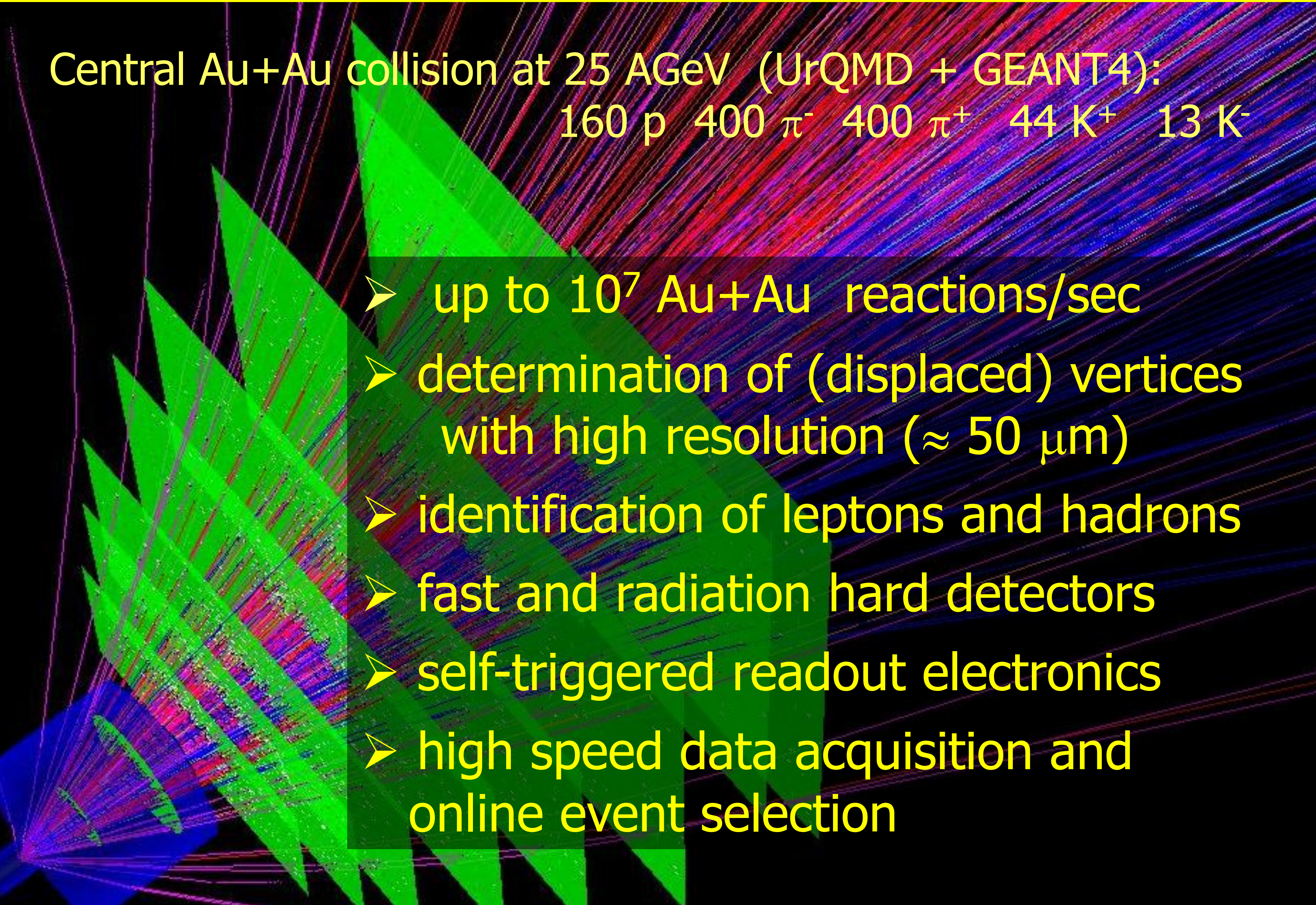
- Bulk Properties of Strongly Interacting Matter
- In-Medium Excitations
- Collision Dynamics
- Observables and Predictions
- The CBM Experiment
- Appendix: Overview on heavy-ion experiments

1000 pages, about 60 authors,

Submitted Sept. 2009 to Springer as "Lecture Notes in Physics"

Electronic version will be available on document servers once an official version is approved by Springer.

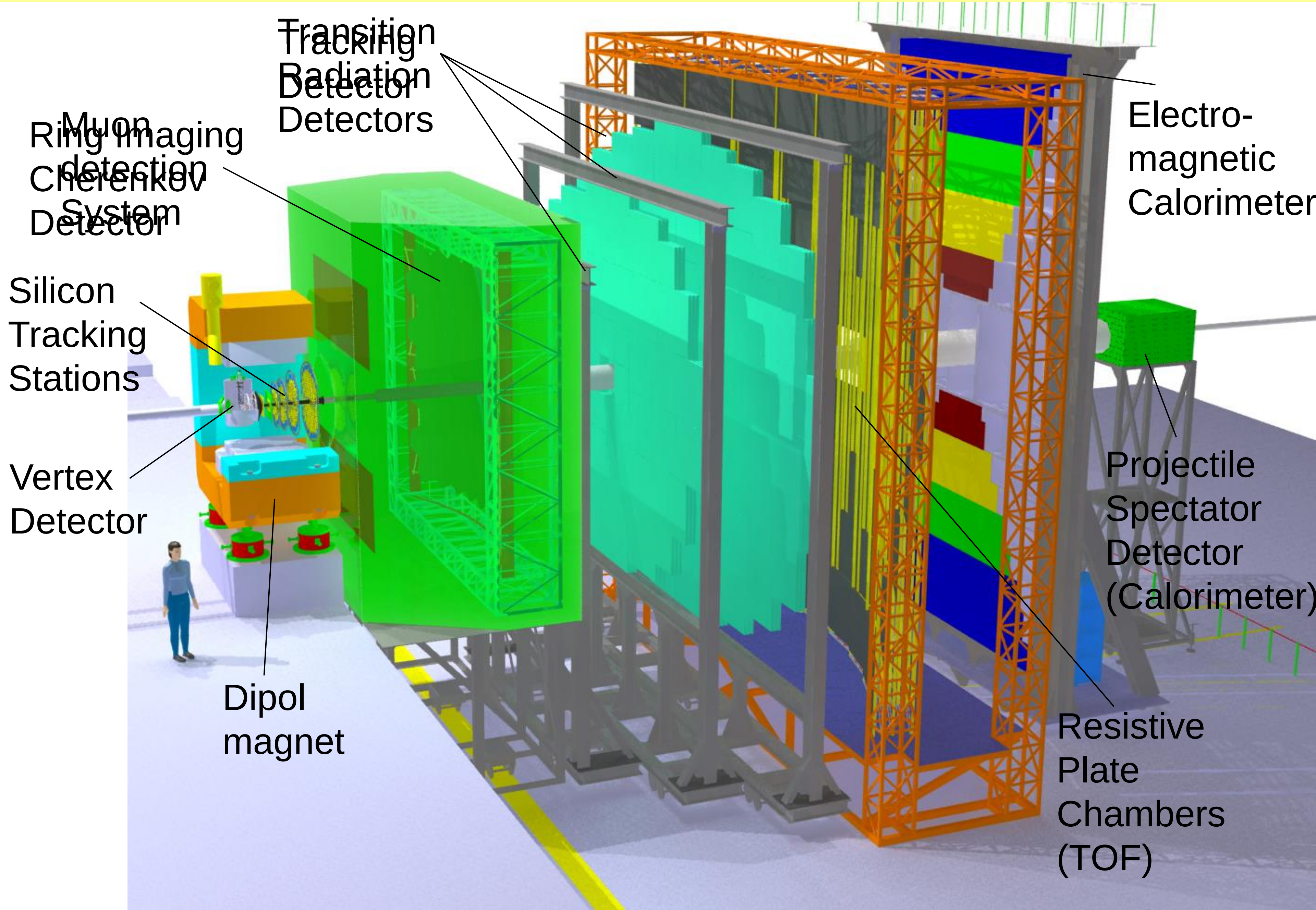
Experimental challenges



Central Au+Au collision at 25 AGeV (UrQMD + GEANT4):
160 p 400 π^- 400 π^+ 44 K^+ 13 K^-

- up to 10^7 Au+Au reactions/sec
- determination of (displaced) vertices with high resolution ($\approx$ 50 μm)
- identification of leptons and hadrons
- fast and radiation hard detectors
- self-triggered readout electronics
- high speed data acquisition and online event selection

The Compressed Baryonic Matter Experiment



The CBM Collaboration: 55 institutions, 450 members

Croatia:
RBI, Zagreb
Split Univ.

China:
CCNU Wuhan
Tsinghua Univ.
USTC Hefei

Czech Republic:
CAS, Rez
Techn. Univ.Prague

France:
IPHC Strasbourg

Hungaria:
KFKI Budapest
Budapest Univ.

Norway:
Univ. Bergen

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
Gauhati Univ.

Korea:
Korea Univ. Seoul
Pusan Nat. Univ.

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

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
LHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg P. Univ.

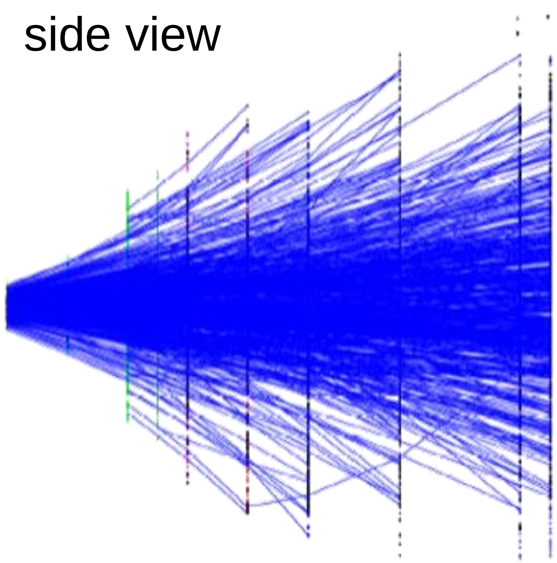
Ukraine:
T. Shevchenko Univ. Kiev
Kiev Inst. Nucl. Research

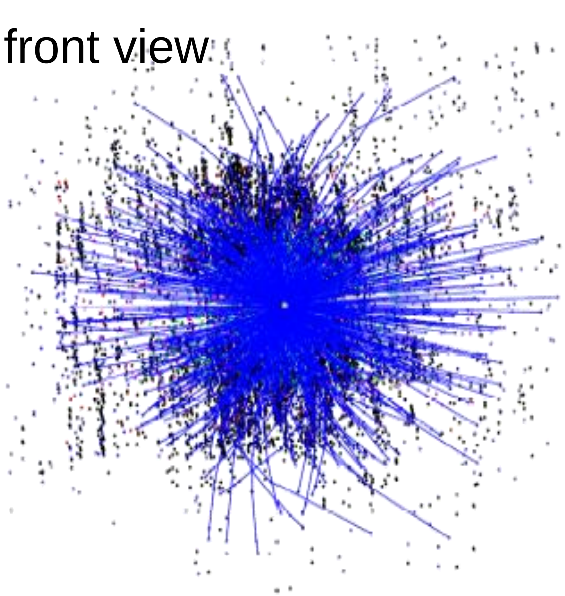
Conceptual design and feasibility studies

- Framework FAIRroot: Root + Virtual Monte Carlo
  Transport codes GEANT 3 & 4, FLUKA
  Event generators UrQMD, HSD, PLUTO
- Fast ("SIMDized") track reconstruction algorithms for online event selection using many-core architectures
- Realistic detector layouts and response functions

Example: Silicon Tracking System

Central Au+Au collision 25 AGeV (UrQMD): 770 reconstructed tracks

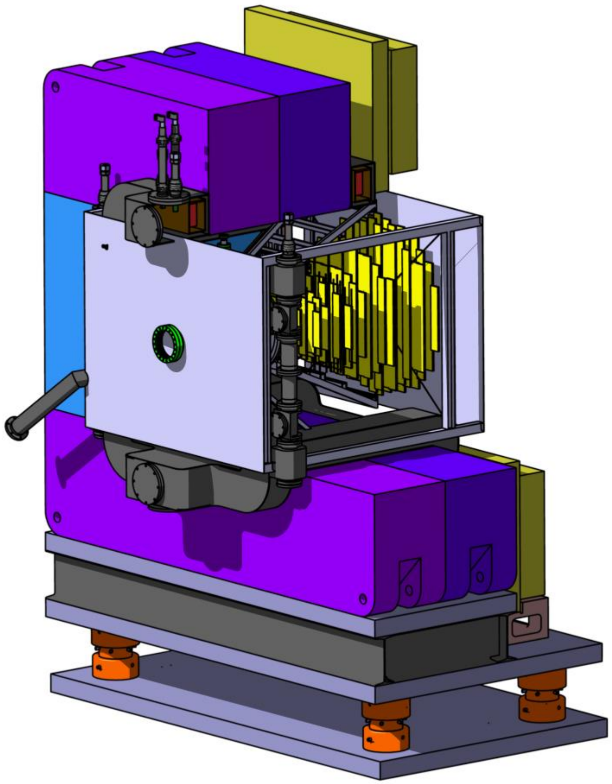




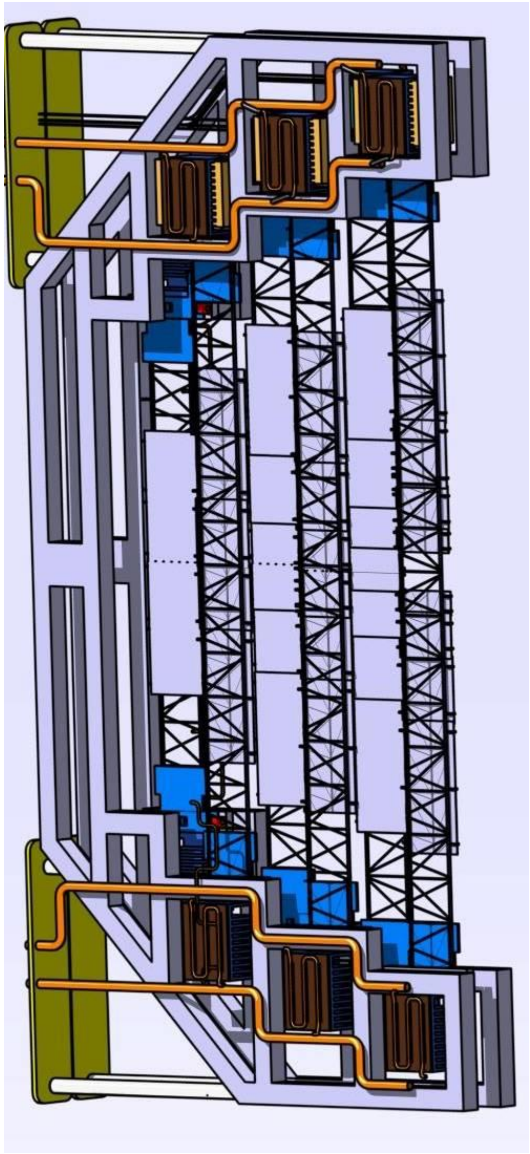
Fast track reconstruction algorithms running graphic processing units:

- fitting: 22 million tracks/s
- track reconstruction efficiency > 96 %
- momentum resolution $\Delta p/p < 1.5$ %

Development of the Silicon Tracking System (STS)



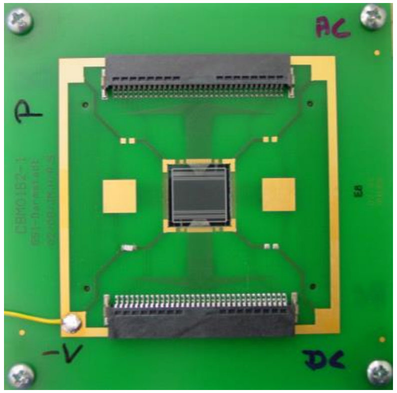
STS in thermal enclosure

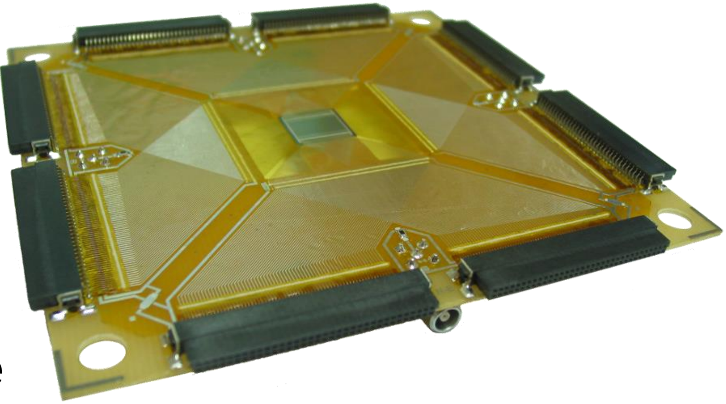


Detector planes:
ultra-light weight ladder structure

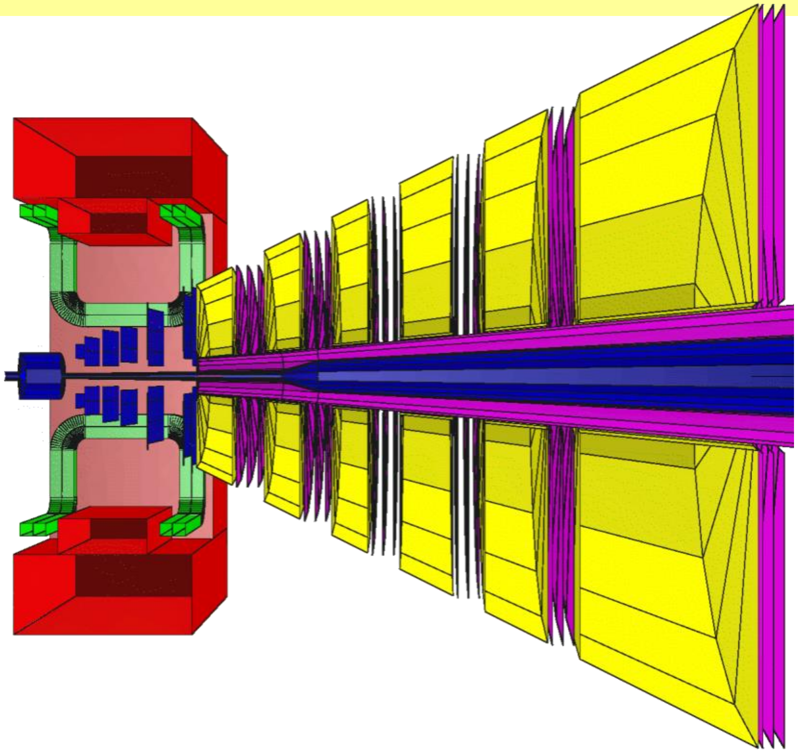
<u>Sensor development:</u>
double-sided micro-strips,
stereo angle 15°, pitch 60 µm
300 µm thick, bonded to
ultra-thin micro-cables

Prototypes for beam tests:





The CBM Muon Detection system

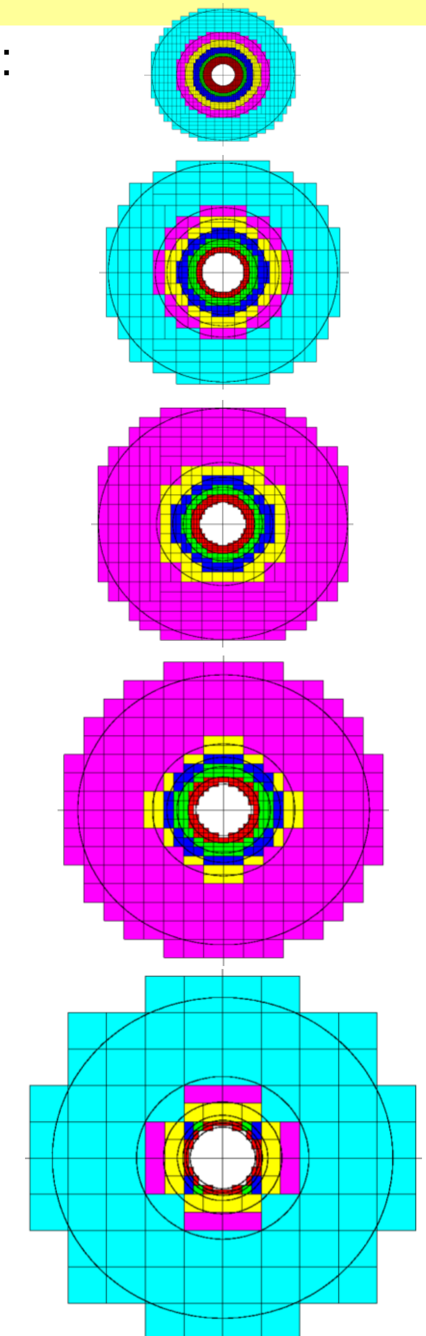


6 segmented absorber layers:
225 cm Fe: 13.5 λ_I
18 tracking detector layers

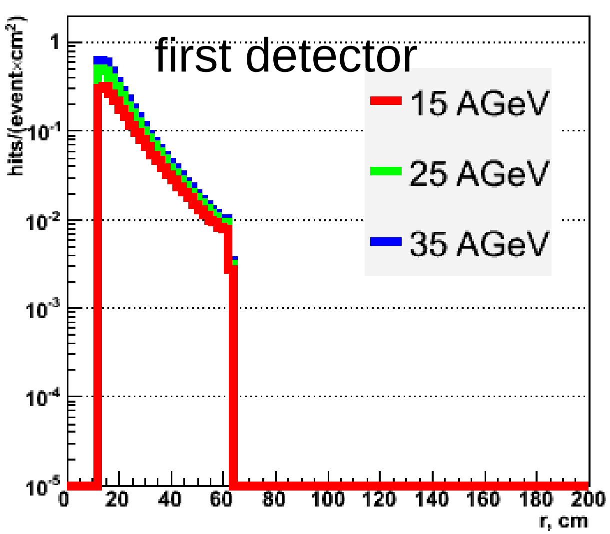
Detector segmentation:
5% occupancy

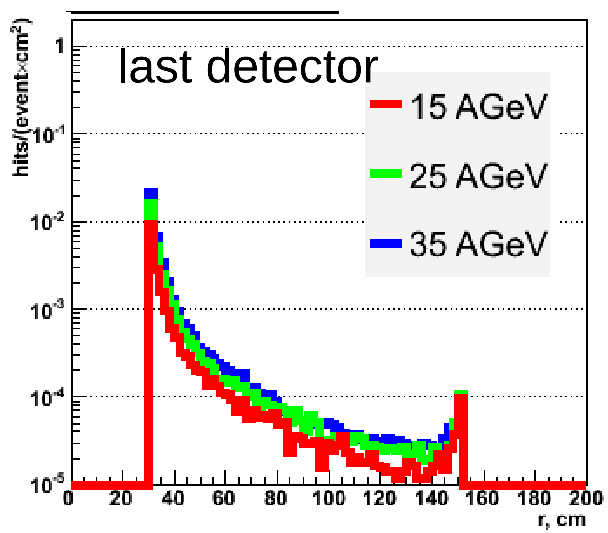
min pad 1.4 × 2.8 mm²
space resolution:
x – 400 µm, y – 800 µm

max pad 44.8 × 44.8 mm²
space resolution:
x – 12.8 mm, y – 12.8 mm

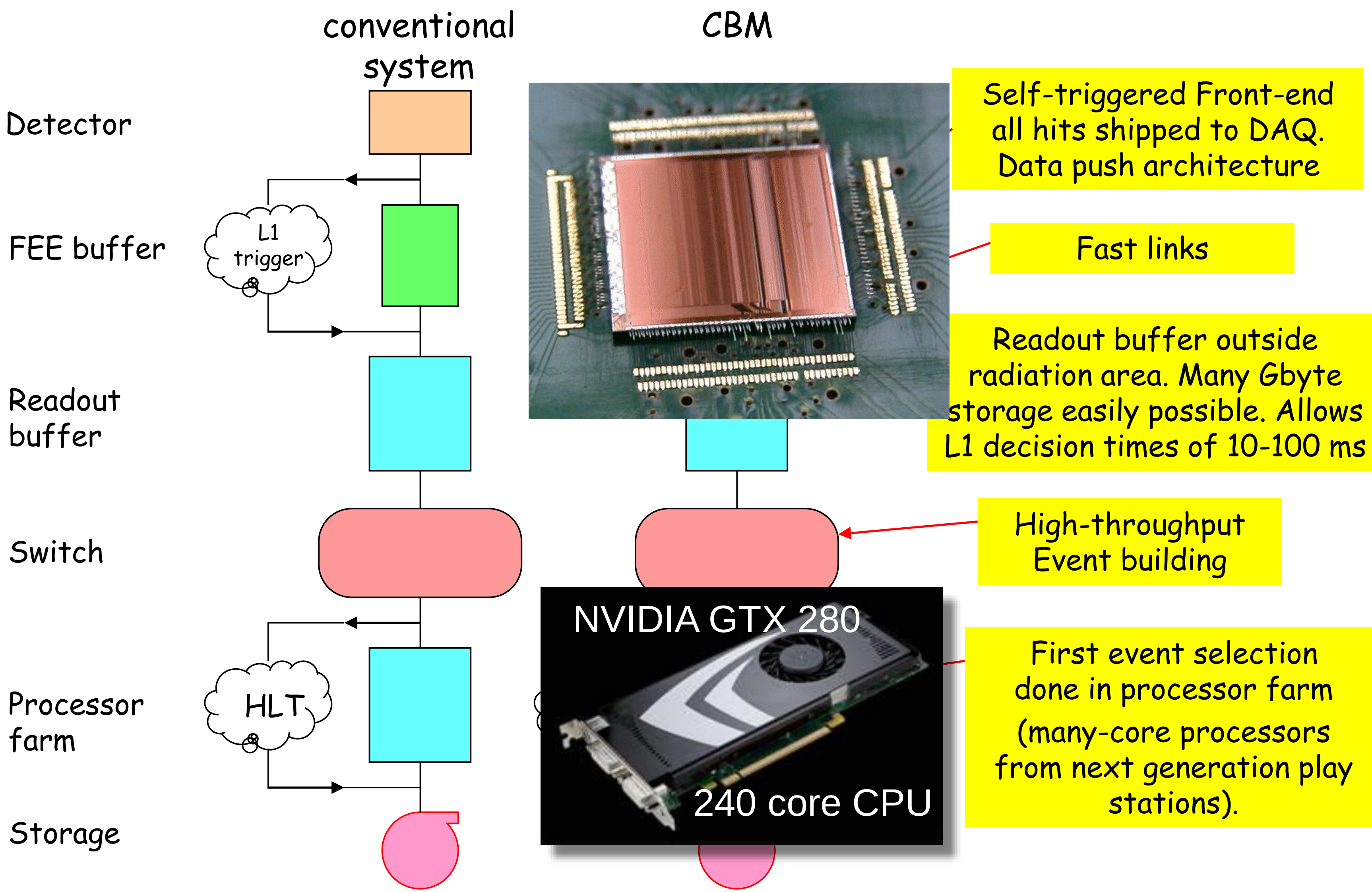


Simulations Au+Au central collisions at 25 AGeV :





CBM DAQ architecture: free-streaming data flow



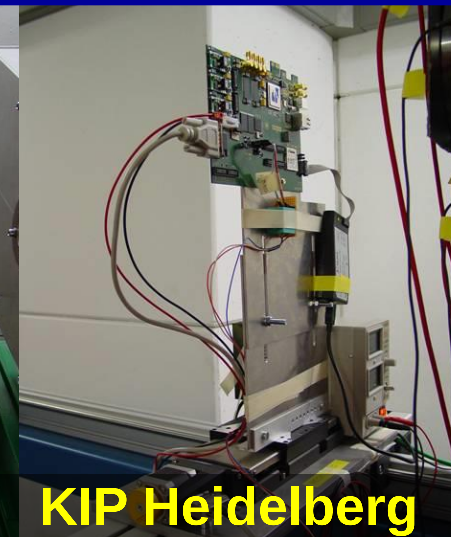
Successful test of CBM prototype detector systems with free-streaming read-out electronics using proton beams at GSI, September 28-30, 2008

GSI and AGH Krakow

2 Double-sided silicon microstrip detectors

VECC Kolkata

Double and triple GEM detectors



KIP Heidelberg

Radiation tolerance studies for readout electronics

Full readout and analysis chain:

Detector signals →

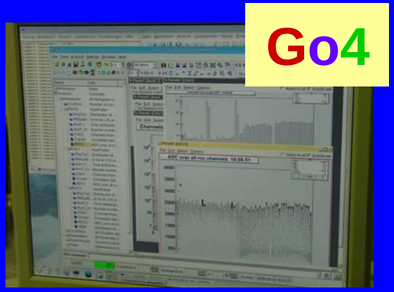
Front-end board with self-triggering *n-XYTER* chip →

Readout controller →

GSI DABC

Data Acquisition System

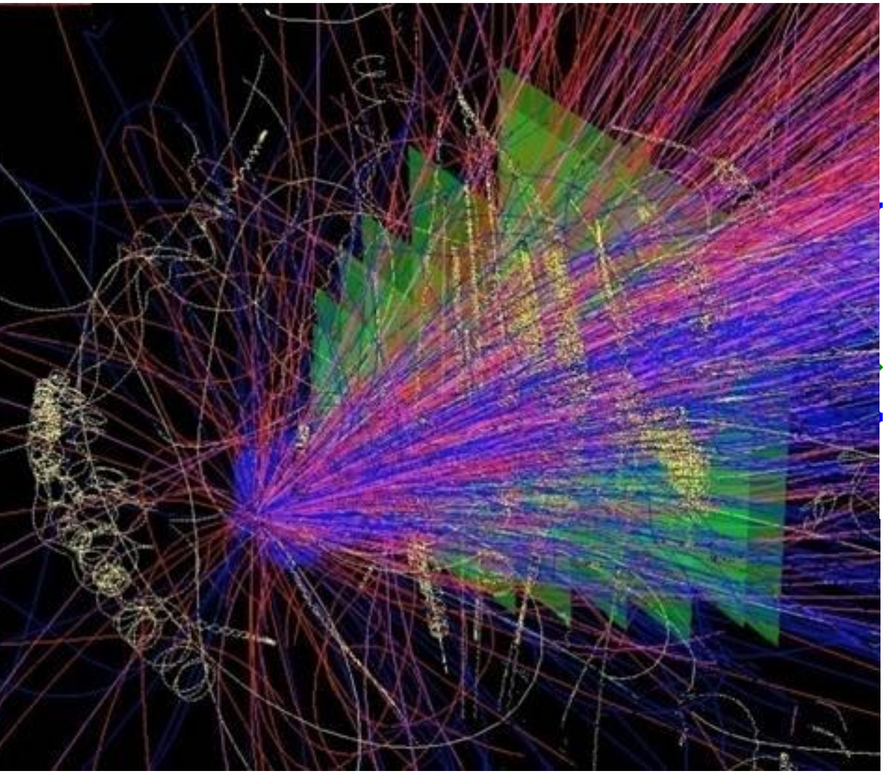
→ online / Analysis / offline →



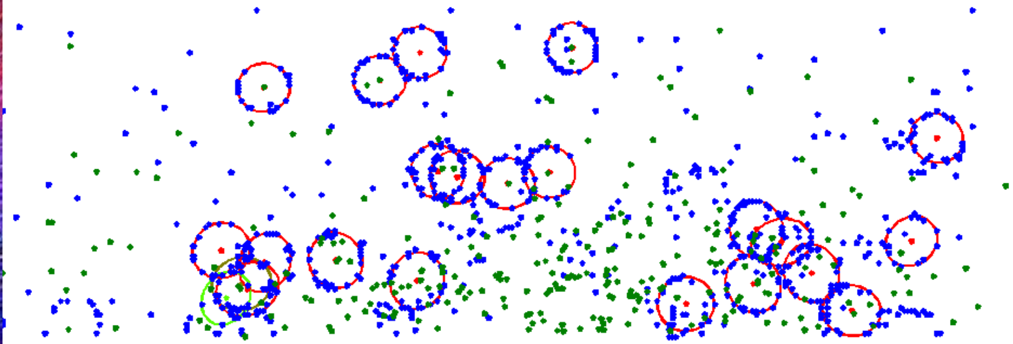
FairRoot

CBM-RICH R&D

- RICH behind material budget of STS: 2ndary $e^{\pm}$! → high ring density!
- high track densities → problem of ring-track mismatches
- interaction rates up to 10 MHz



event display of part of photodetector plane



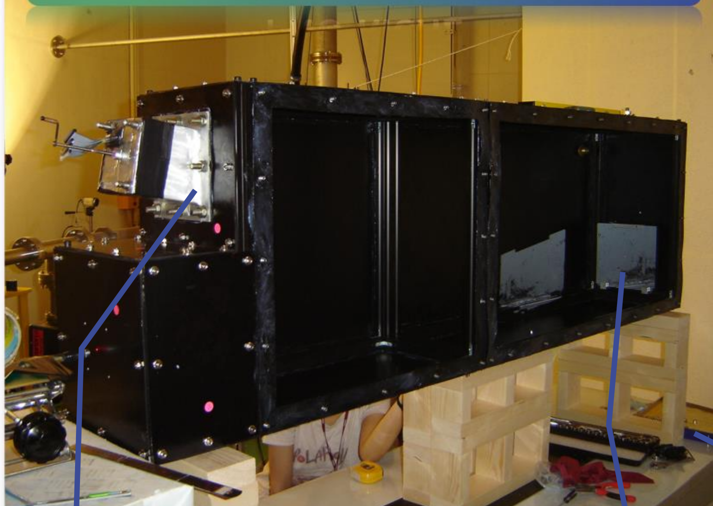
green – track projections

blue – hits

red – found rings

Development of a CBM-RICH prototype in Pusan

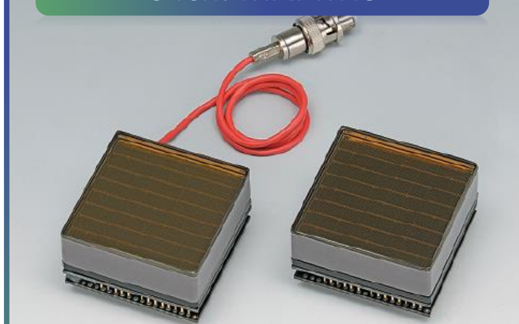
PNU-RICH2



Specifications	
*Radiator length (L[m])	*1.76
Photo Detector	4 × 64ch MAPMT
Mirror Curvature (R[m])	3.2
Mirror Reflectivity	≥80%, λ≥200nm
Radiators	N_2, CO_2 & mixed gas
Calculated Ring Dia. [mm]	73.21(N_2),91.91(CO_2)

* *Same dimension as the CBM-RICH detector proposal*

64ch. MAPMTs



HAMAMATSU Multi-Anode PMT

- **H8500 (Borosilicate glass window)**
  : Q.E.> 10% @300~500nm
- **H8500-03 (UV extended window)**
  : Q.E.> 10% @185~500nm

Enhanced UV reflectivity Mirror

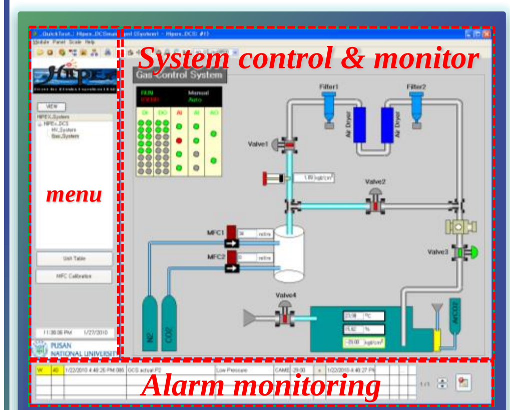
CBM mirror prototype

- Reflectivity > 80 in UV

- R= 3.2m, 20 × 20cm^2

by Dr. M.Dürr @Esslingen University

Gas Control System with PLC, PVSSII



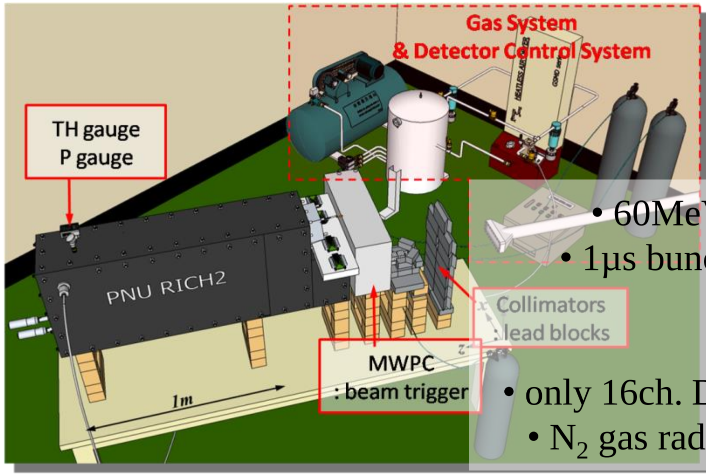
↳ gas flow control & Pressure monitor

↳ Humidity & Temperature monitor

PVSSII

: SCADA (Supervisory Control And Data Acquisition) tool adapted by CERN

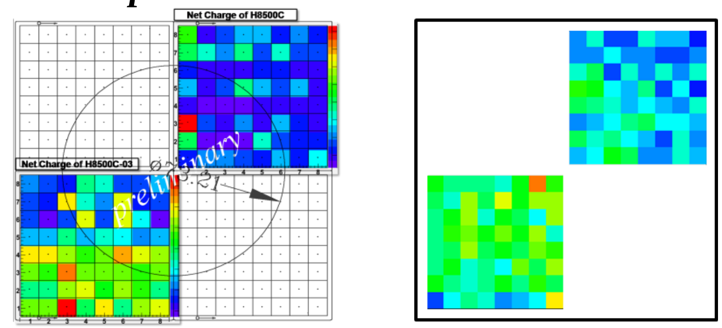
Test Experiment @ 60MeV LINAC, PAL, Pohang



- 60MeV electron
- 1μs bunch size, 1nA
- only 16ch. DAQ electronics
- N_2 gas radiator (γ_{th} = 41)

Comparison Test Result with Simulation

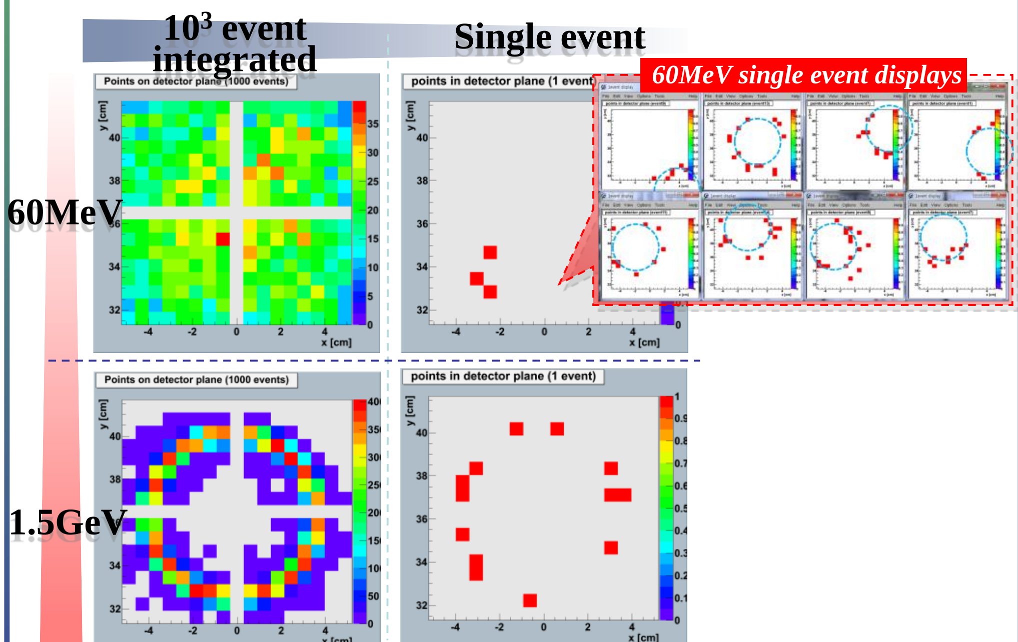
Experiment ***CbmRoot + GEANT3***



- All events are integrated
- Enhanced Cherenkov photons in H8500-03
- Ring Image?

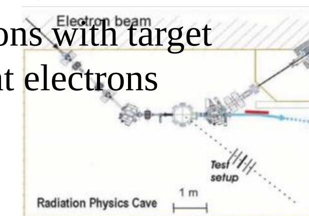
→ ***Neither Experiment result Nor Simulation result***

Simulations : Energy & Current dependency

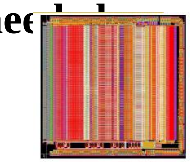


Conclusion & Outlook

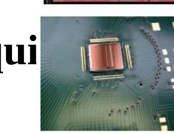
- **Measurement of single event essential**
  - → use secondary electrons with target
  - → trigger the incident electrons



- **256 ch. Coincidence DAQ needed**
  - → CBM –XYTER



- **Higher e- beam energy required**



TOF Resistive Plate Chamber

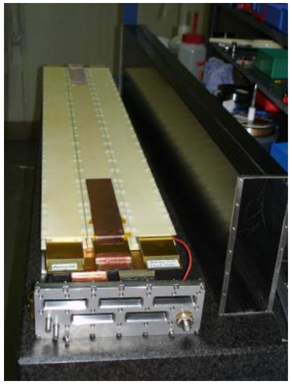
Design goals:

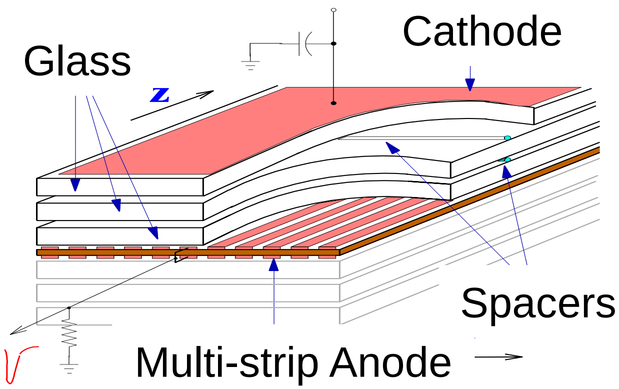
- Time resolution ≤ 80 ps
- Rate capability up to 20 kHz/cm^2
- Efficiency > 95 %
- Large area ≈ 100 m^2
- Long term stability

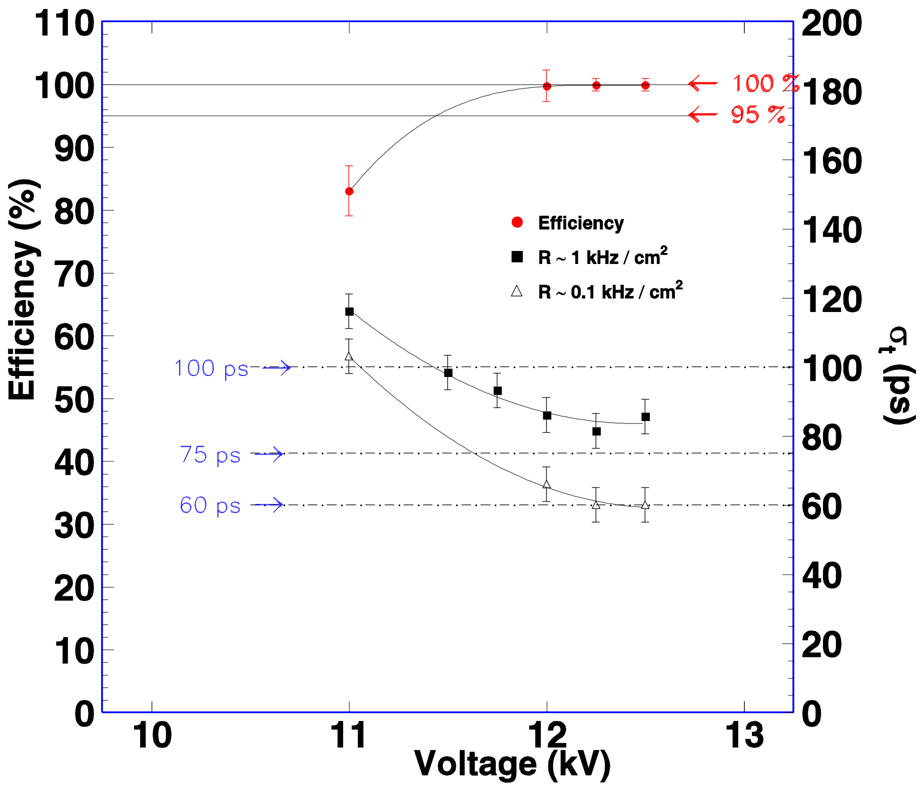
Various options are under investigation:

- Strip vs. pad readout
- Single cell vs. multichannel RPC
- Glass vs. plastic electrodes

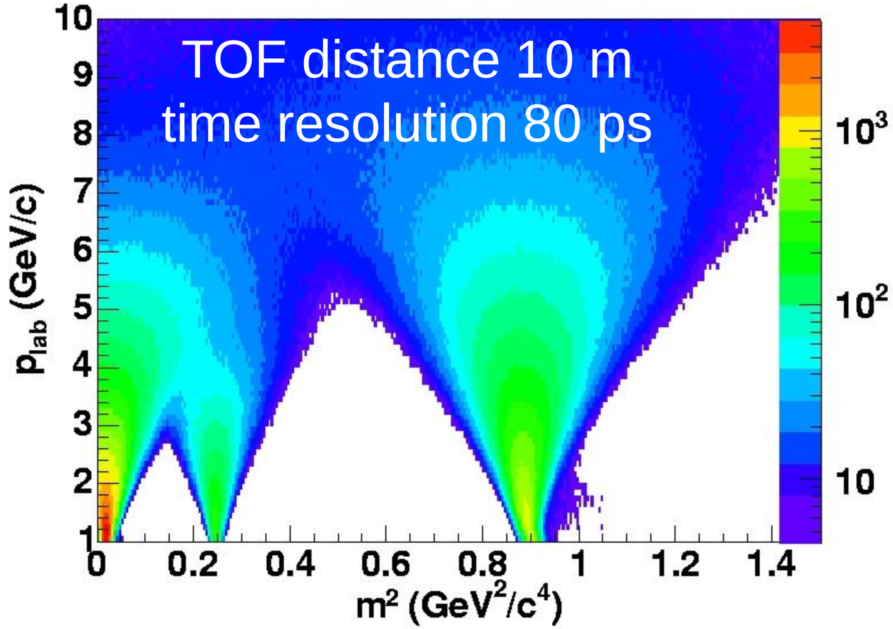
FOPI MMRPC project

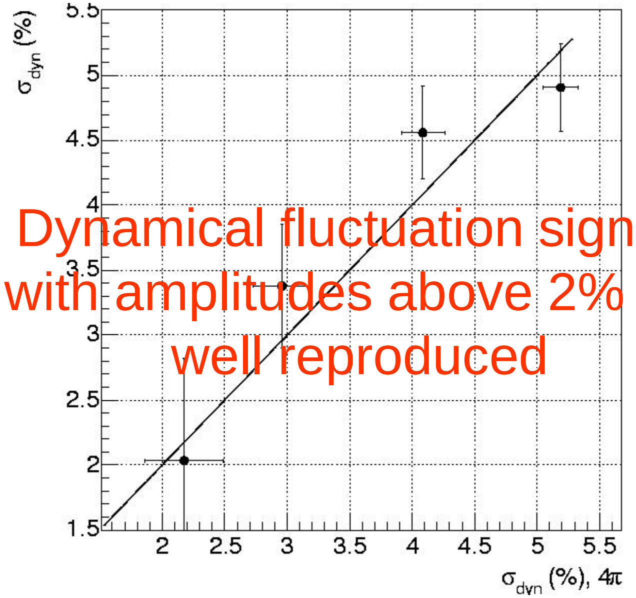




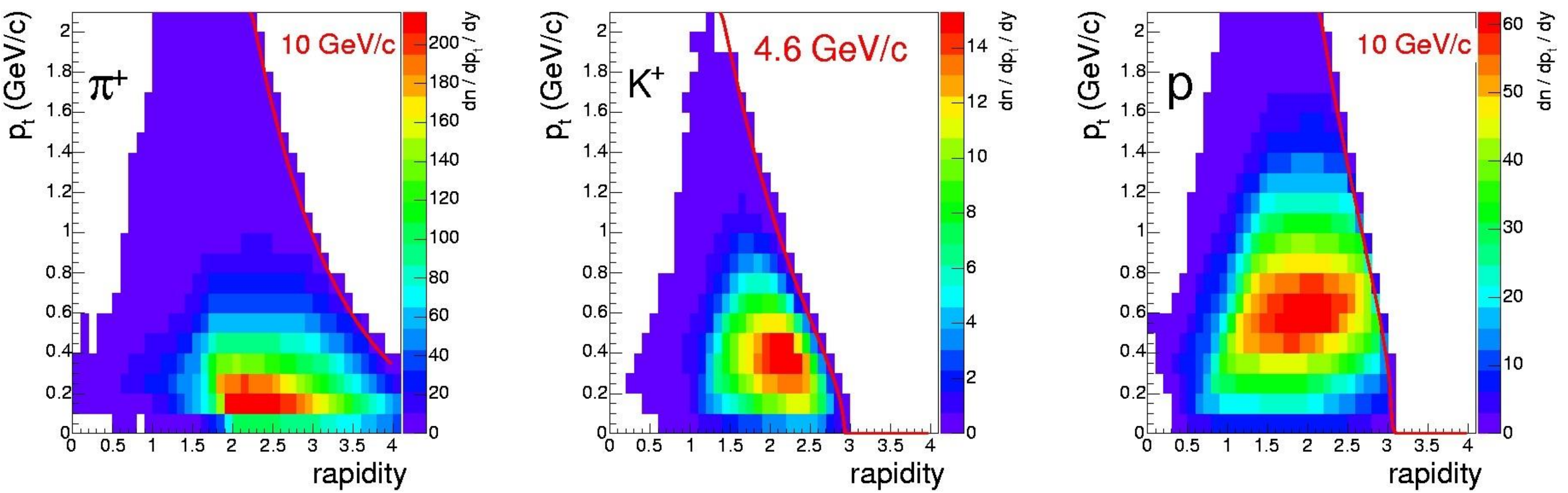


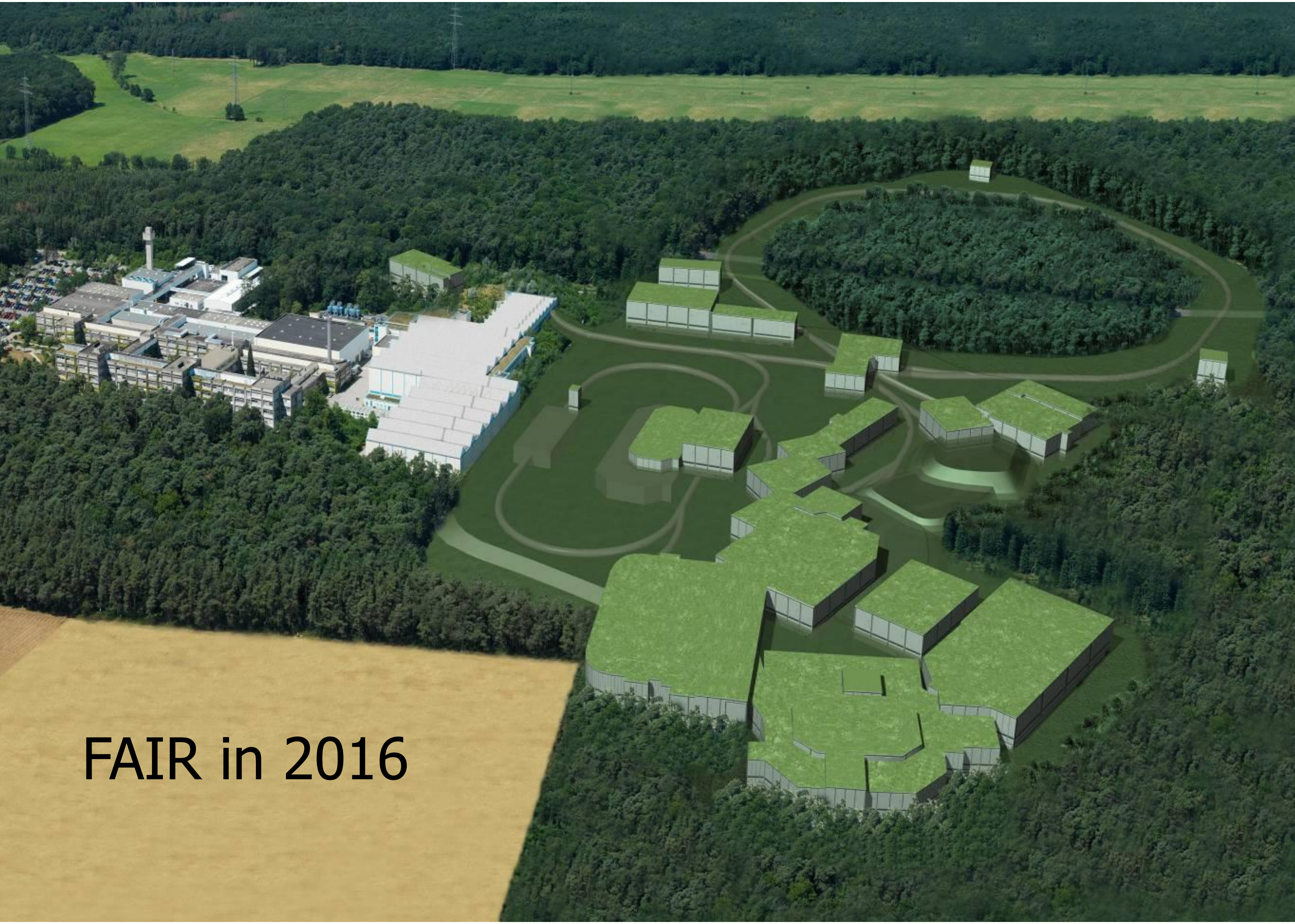
Particle Identification with TOF





Dynamical fluctuation signals with amplitudes above 2% are well reproduced



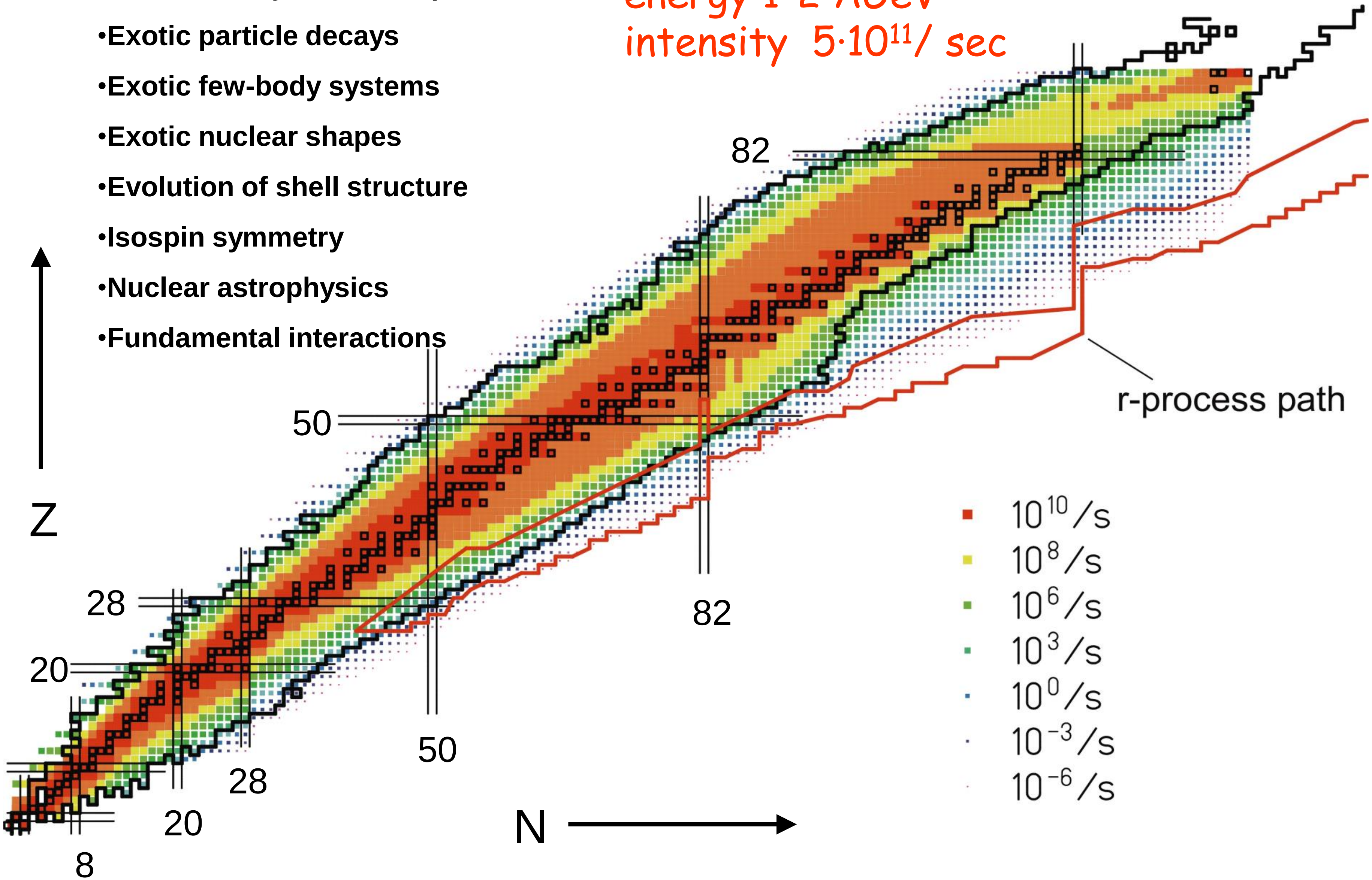

FAIR in 2016

NuSTAR: Nuclear Structure, Astrophysics, Reactions

Physics topics:

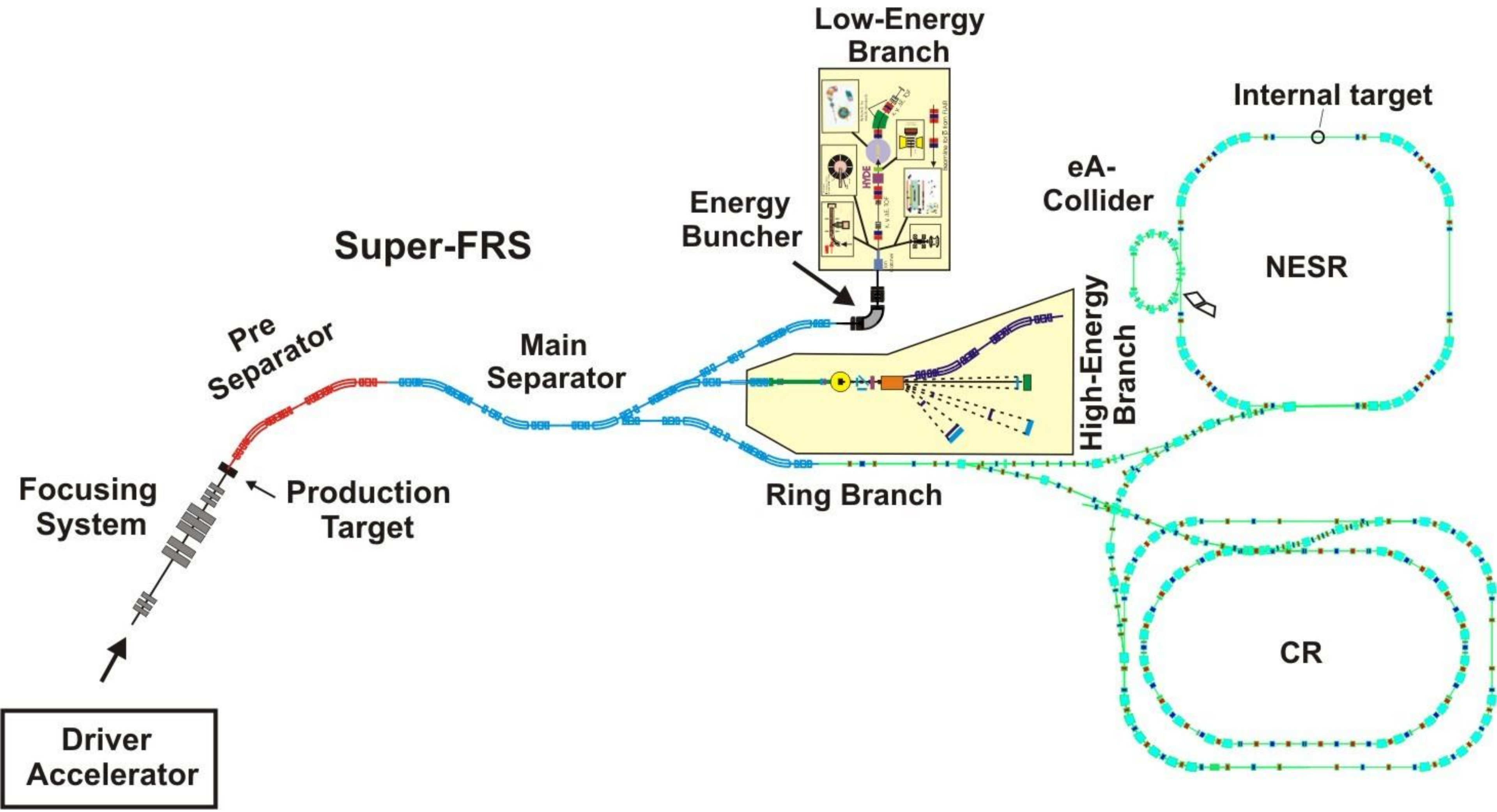
- **Structure beyond the driplines**
- **Exotic particle decays**
- **Exotic few-body systems**
- **Exotic nuclear shapes**
- **Evolution of shell structure**
- **Isospin symmetry**
- **Nuclear astrophysics**
- **Fundamental interactions**

Uranium beam at SIS100:
energy 1-2 AGeV
intensity $5 \cdot 10^{11}$/ sec



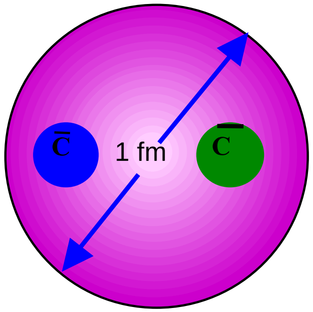
The NUSTAR experimental facility:

- Production of intensive rare isotope beams by in-flight projectile fragmentation/fission (access to short-lived isotopes)
- Detailed investigations, large variety of experimental techniques

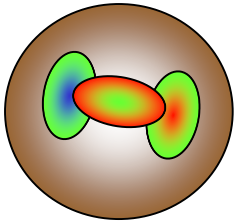


Hadron physics with high energy antiprotons

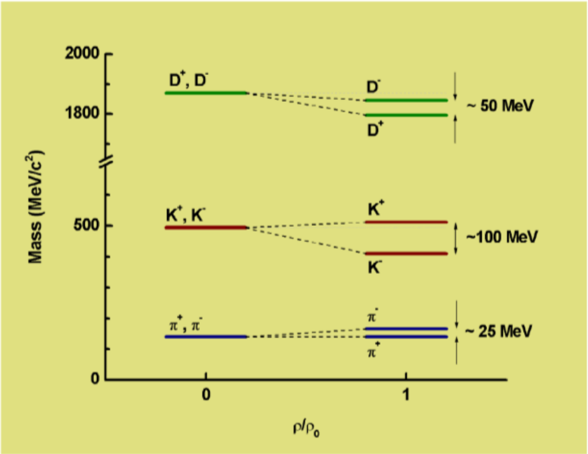
Study of the confinement potential with charmonium spectroscopy:



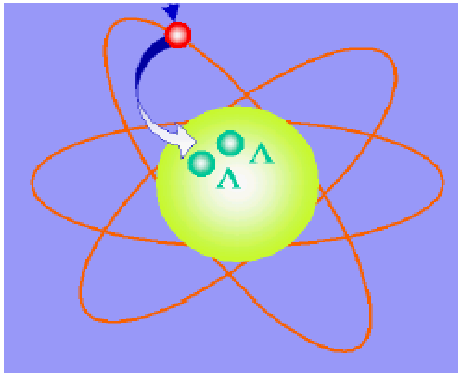
Search for gluonic excitations:



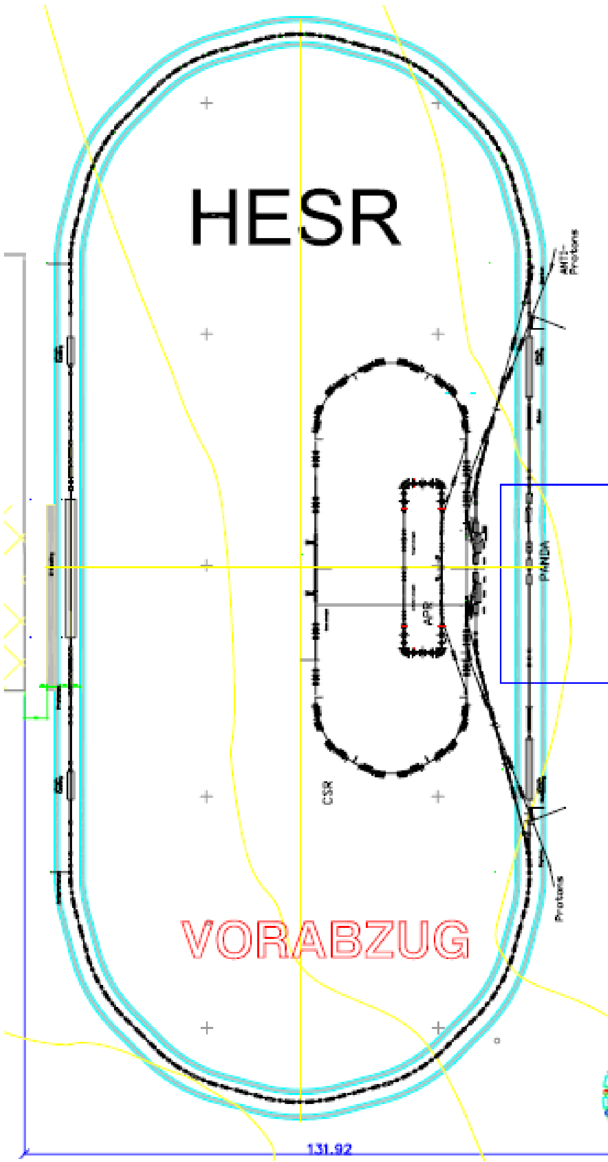
Search for in-medium modifications of hadron properties

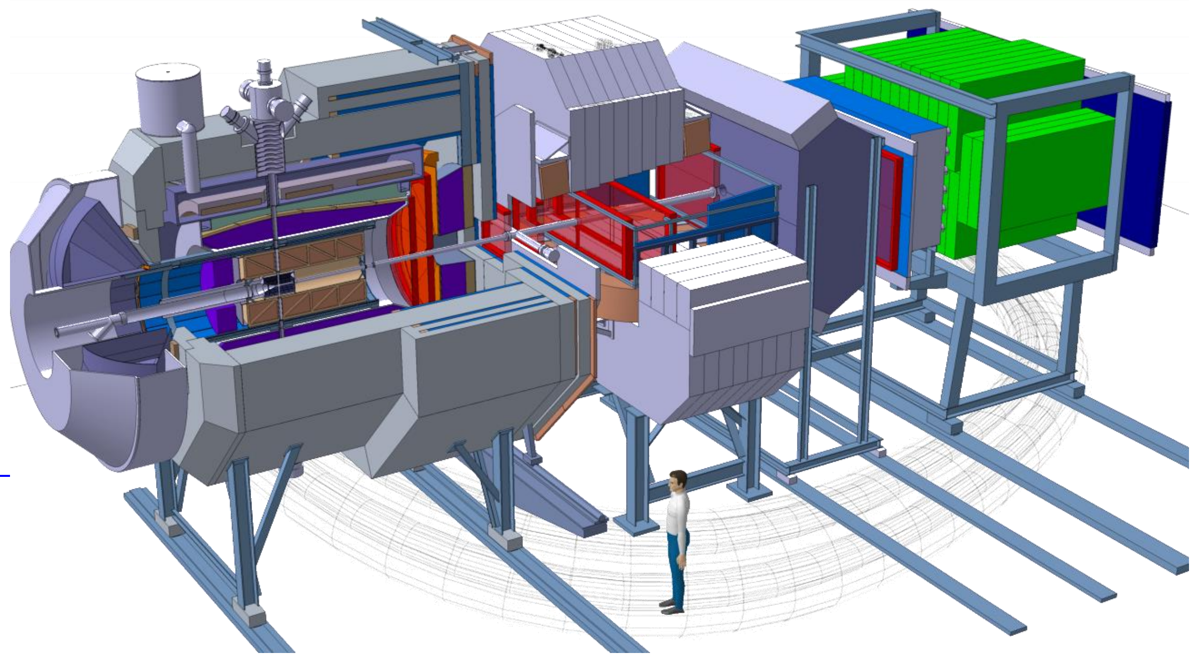


Precision γ-spectroscopy of single and double hypernuclei



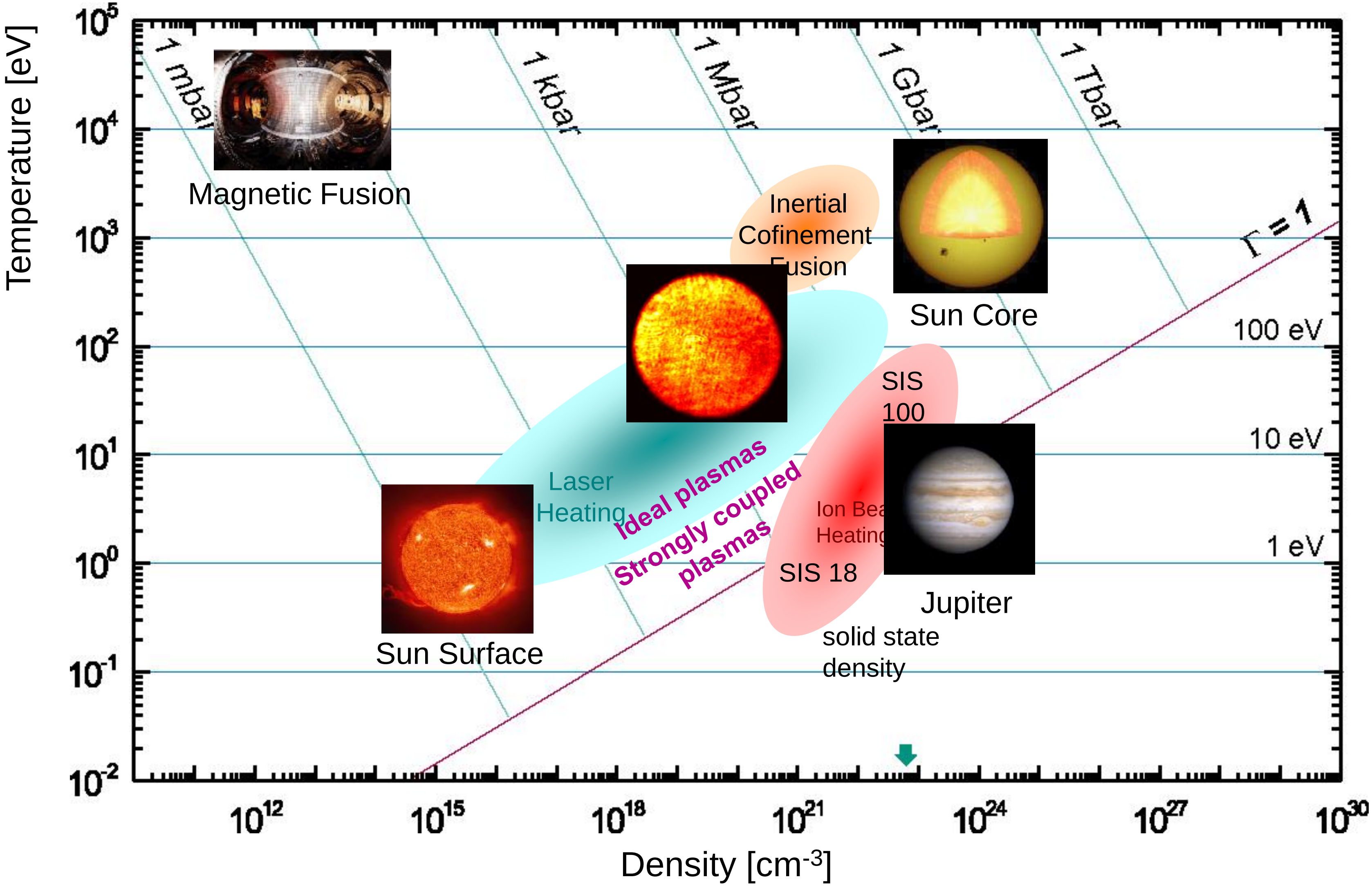
Antiproton-Proton-Annihilation in Darmstadt





- High luminosity mode
  - Luminosity = 2×10^{32} $cm^{-2}s^{-1}$
  - $\delta p/p \sim 10^{-4}$ (stochastic cooling)
- High resolution mode
  - $\delta p/p \sim$ few 10^{-5} (+electron cooling)
  - Luminosity $> 10^{31}$ $cm^{-2}s^{-1}$
- Gas-Jet/Pellet/Wire Target

Hot electro-magnetic plasmas:
high intensity ion bunches hitting petawatt laser pulses (PHELIX and heavy-ion beams)



Radiobiology:
Radiation dose during long-term space missions ?

Cosmic radiation in space