Prospects of the FAIR project at GSI

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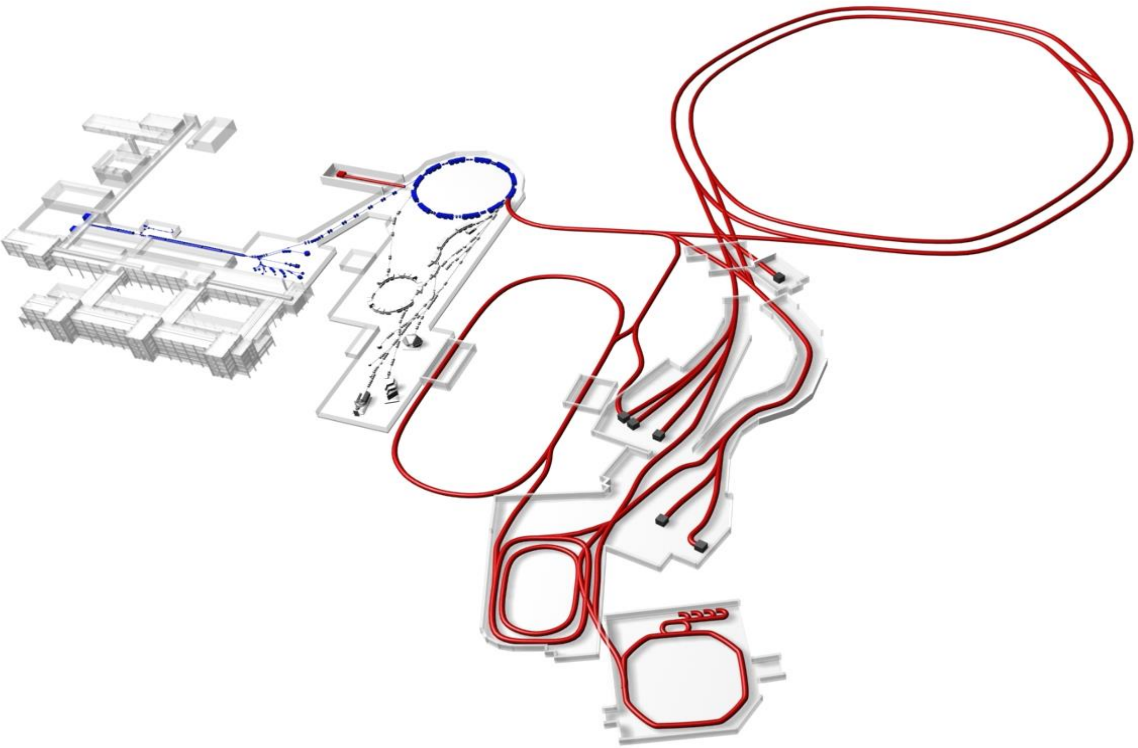
Korea University

Contents

- Introduction to FAIR at GSI
- CBM Experiment at FAIR
  - ►Unique Opportunity for the dense matter study
- Summary

Facility for Antiproton and Ion Research



primary beams

- 5×10^{11}/s; 1.5 - 2 GeV/u; $^{238}U^{28+}$
- ~100 - 1,000 increased intensity
- 4×10^{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
- ~10,000 increased intensity
- antiprotons; up to 30 GeV

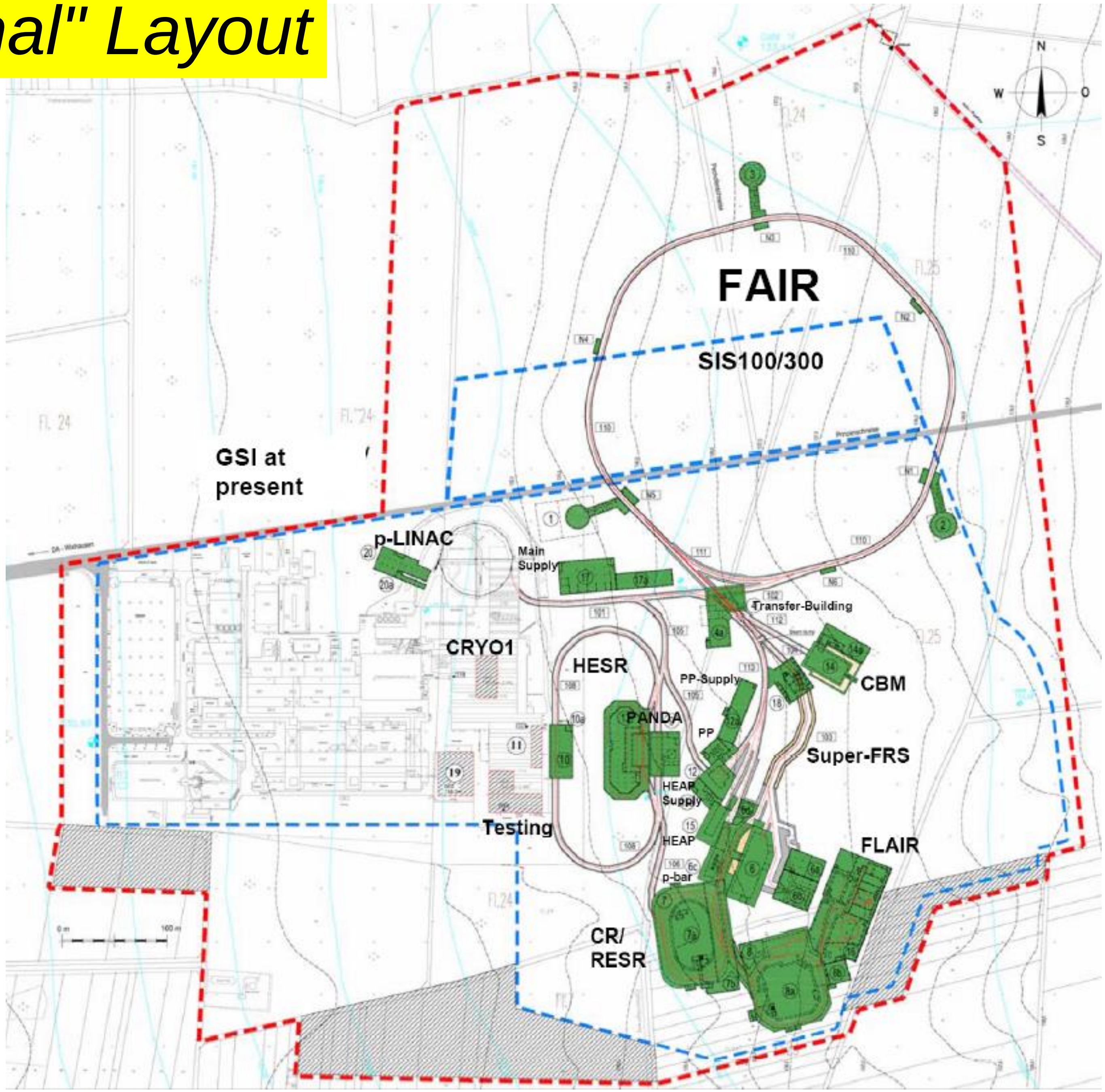
storage and cooler rings

- beams of rare isotopes
- eA collider
- 10^{11} stored & cooled antiprotons; 0.8 - 14.5 GeV

accelerator technical challenges

- rapidly cycling superconducting magnets
- high energy electron cooling

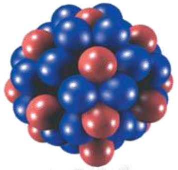
"Final" Layout



Research Programs at FAIR

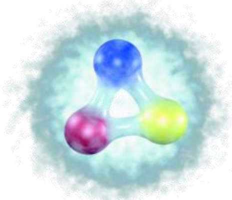
Rare isotope beams; nuclear structure and nuclear astrophysics

- nuclear structure far off stability
- nucleosynthesis in stars and supernovae



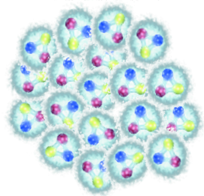
Beams of antiprotons: hadron physics

- quark-confinement potential
- search for gluonic matter and hybrids
- hypernuclei



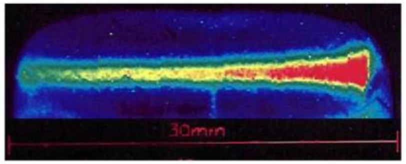
High-energy nucleus-nucleus collisions: compressed baryonic matter

- baryonic matter at the highest densities (neutron stars)
- phase transitions and critical endpoint
- in-medium properties of hadrons



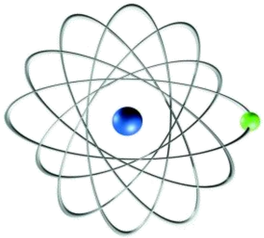
Pulsed heavy ion beams: plasma physics

- matter at high pressure, density and temperature
- fundamentals of nuclear fusion



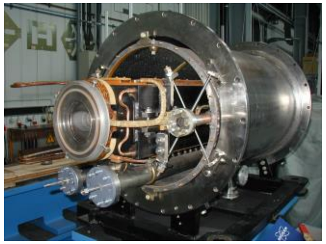
Atomic physics and applied research

- highly charged atoms
- low energy antiprotons
- radiobiology



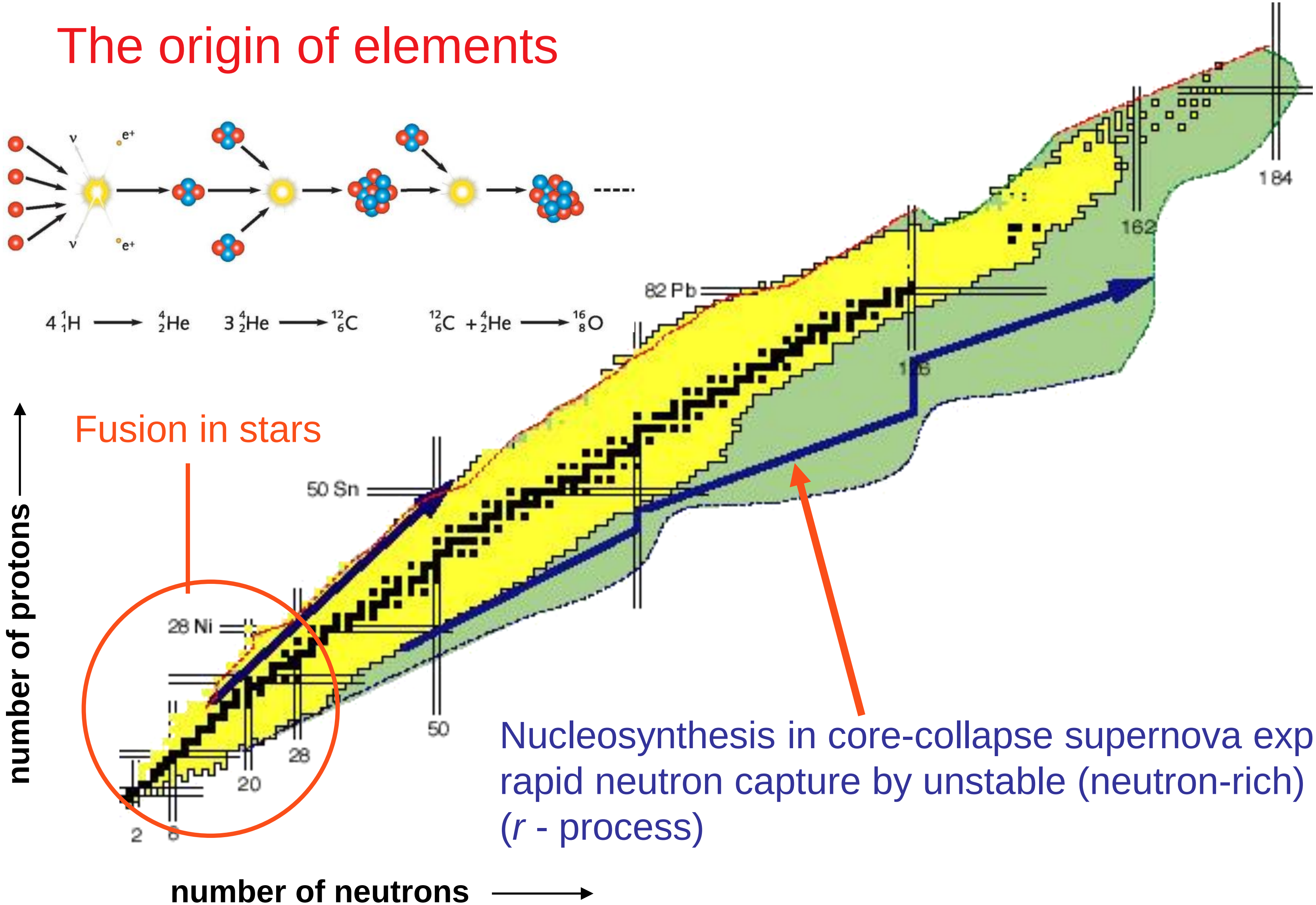
Accelerator physics

- high intensive heavy ion beams
- rapidly cycling superconducting magnets
- high energy electron cooling



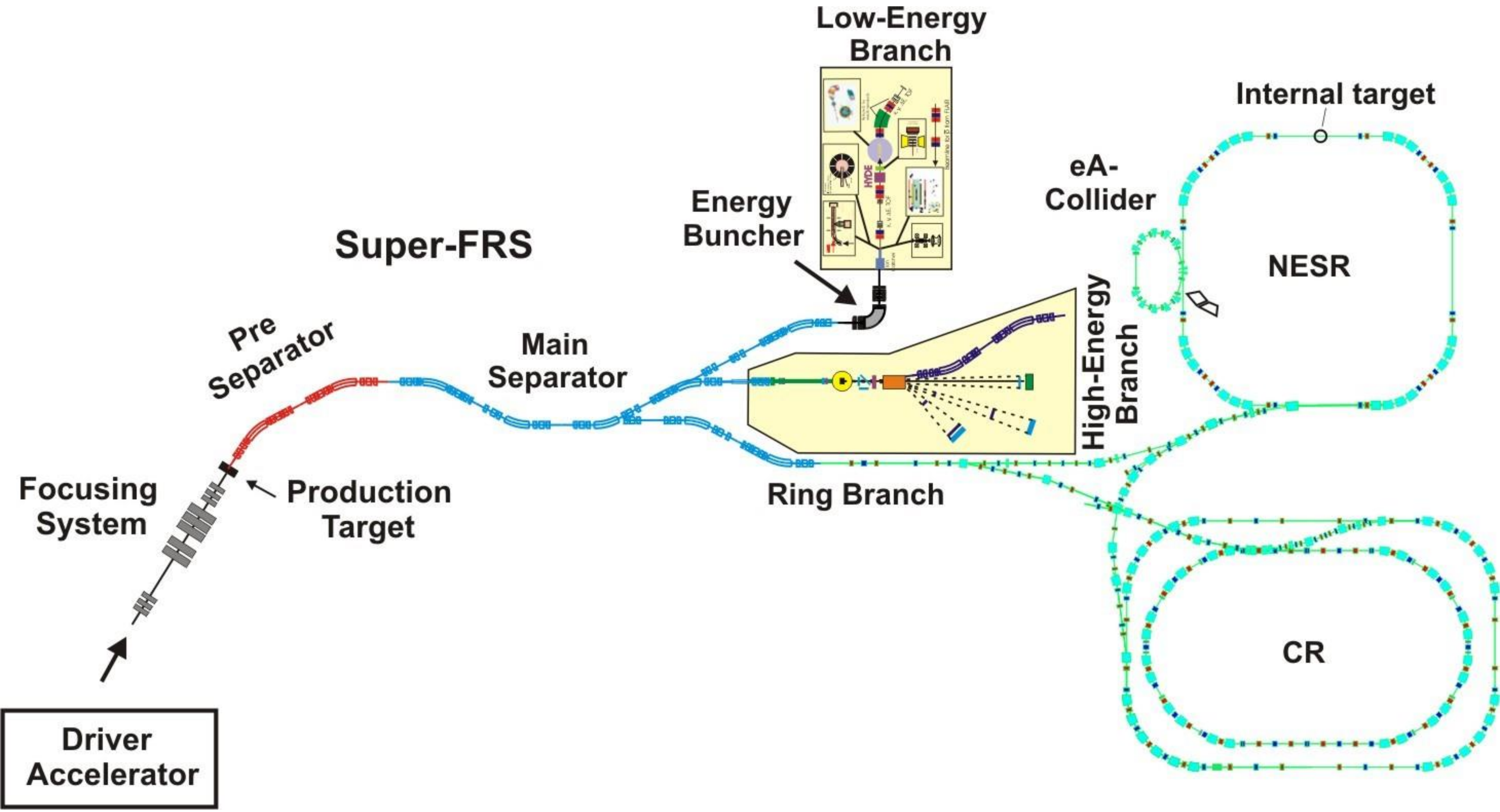
Nuclear Structure, Astrophysics, Reactions - NuSTAR

The origin of elements



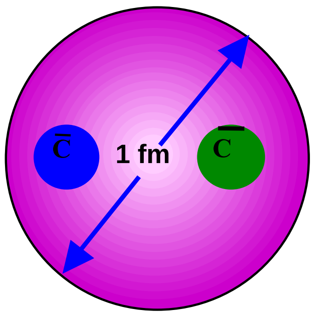
Nucleosynthesis in core-collapse supernova explosions: rapid neutron capture by unstable (neutron-rich) isotopes (*r* - process)

Intensive Rare Isotope Beams Produced by In-Flight Projectile Fragmentation/Fission

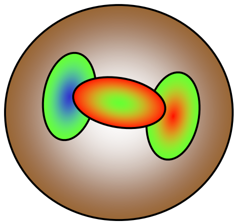


Hadron Physics with High Energy Antiprotons

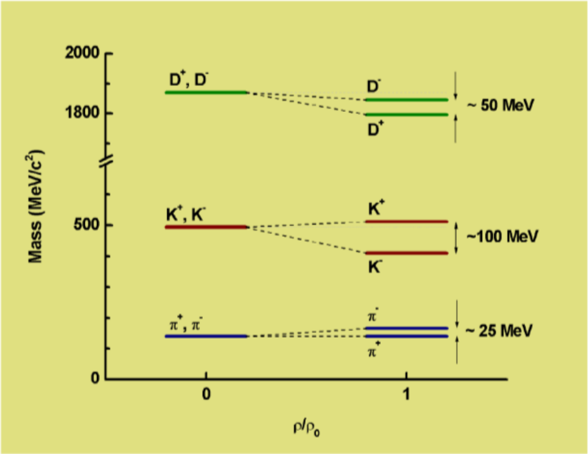
Study of the confinement potential with charmonium spectroscopy



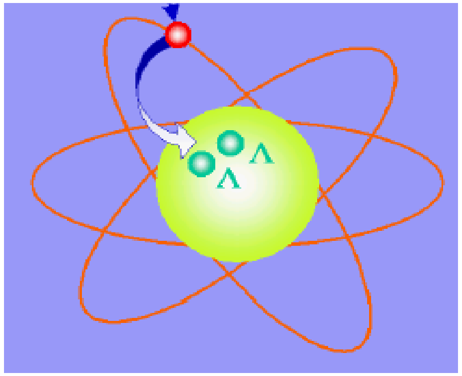
Search for gluonic excitations



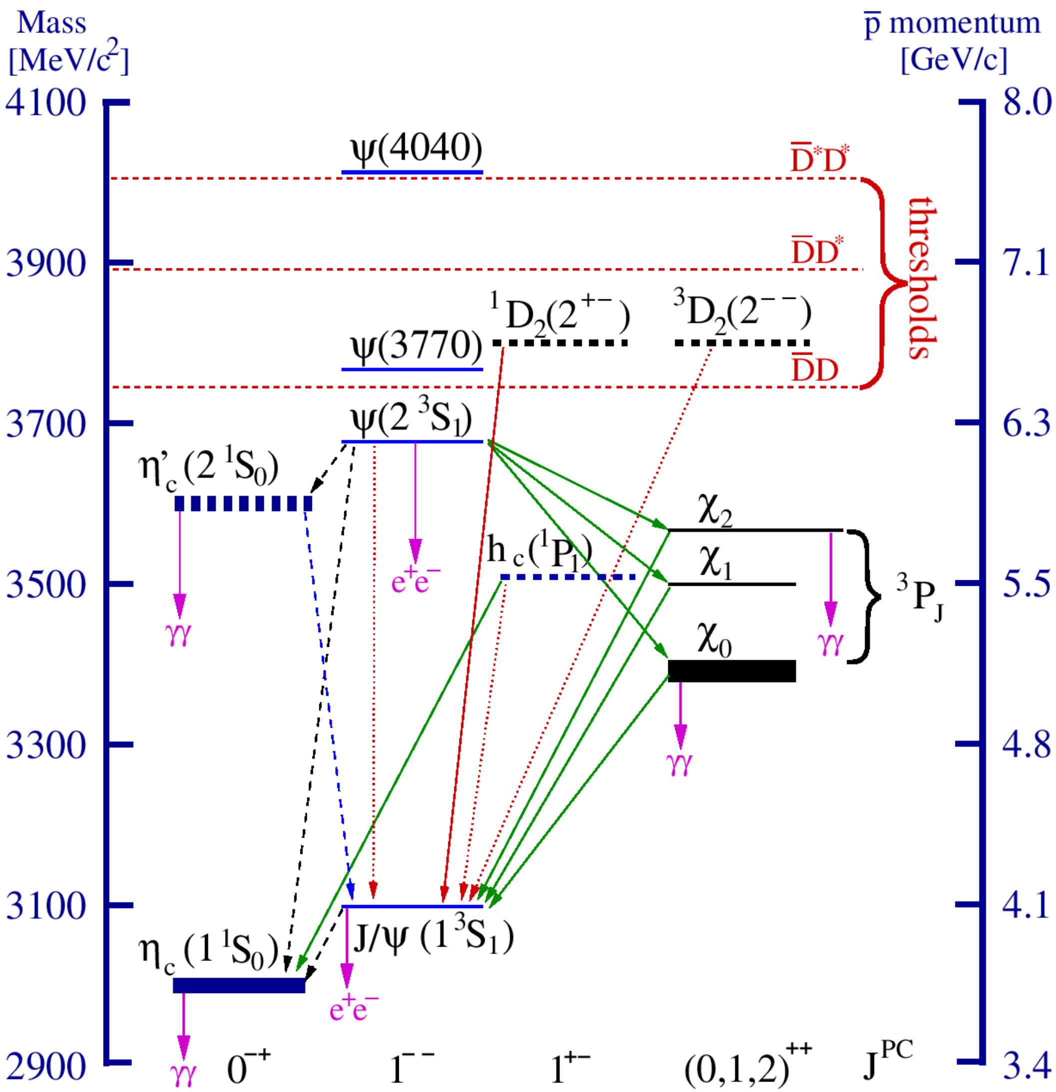
Search for in-medium modifications of hadron properties

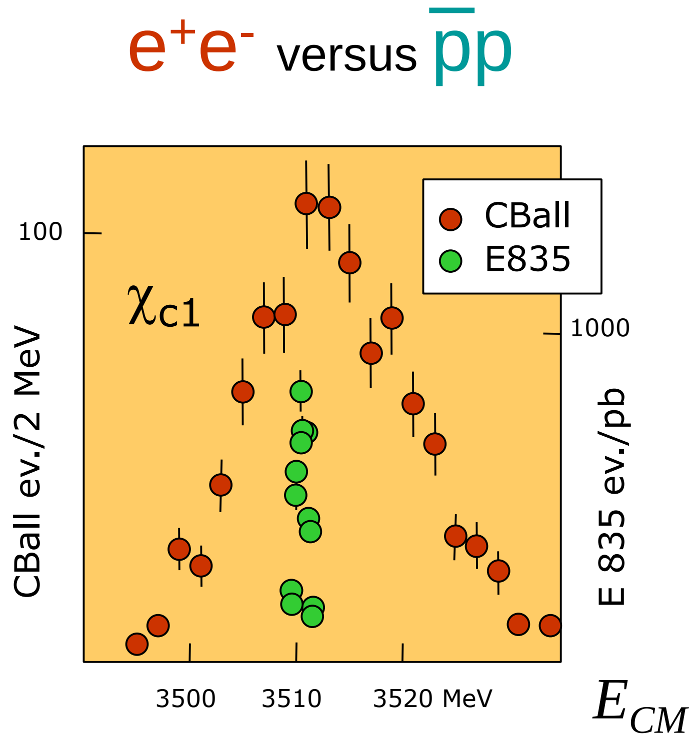


Precision γ-spectroscopy of single and double hypernuclei

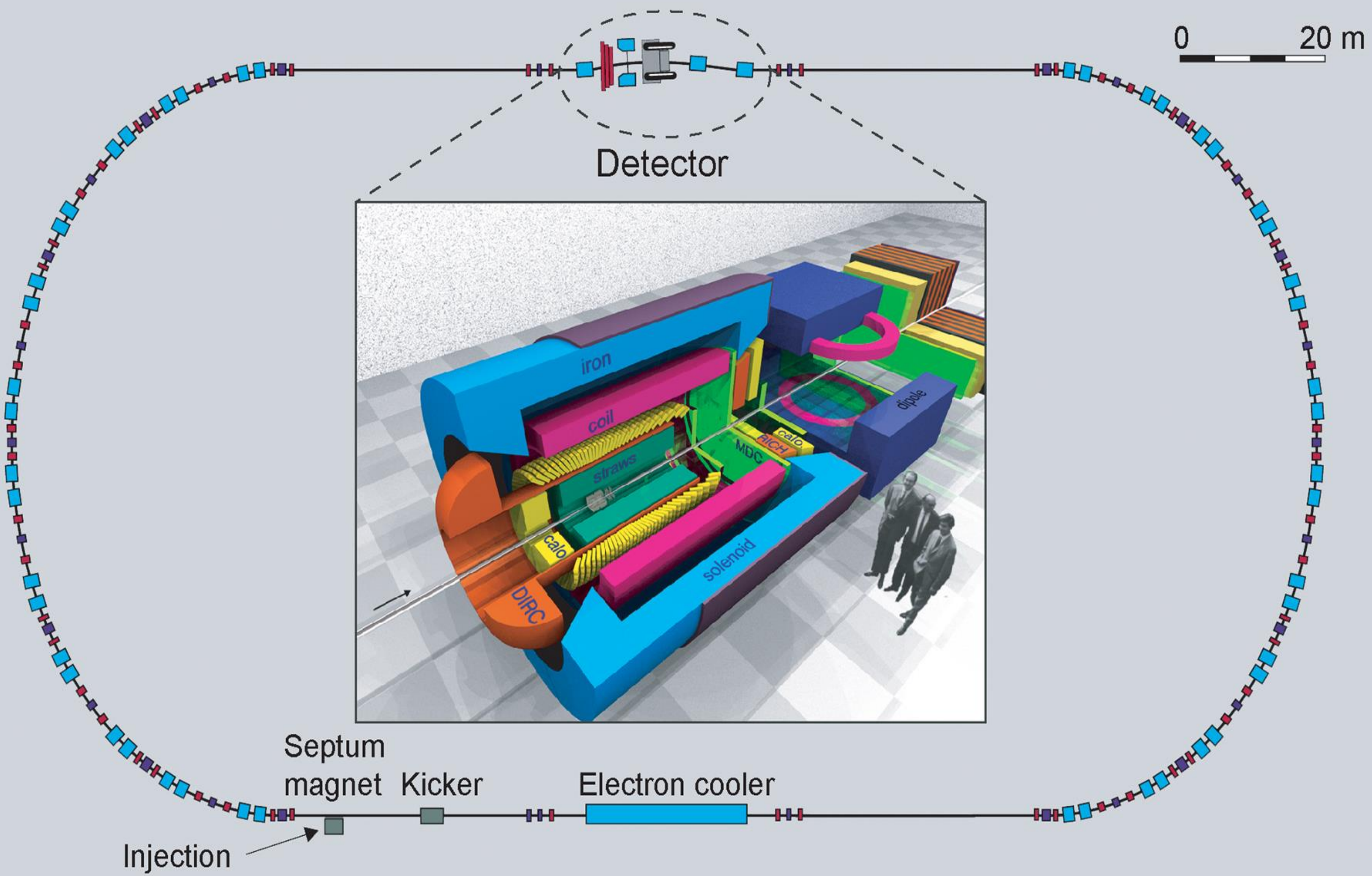


Charmonium Spectroscopy





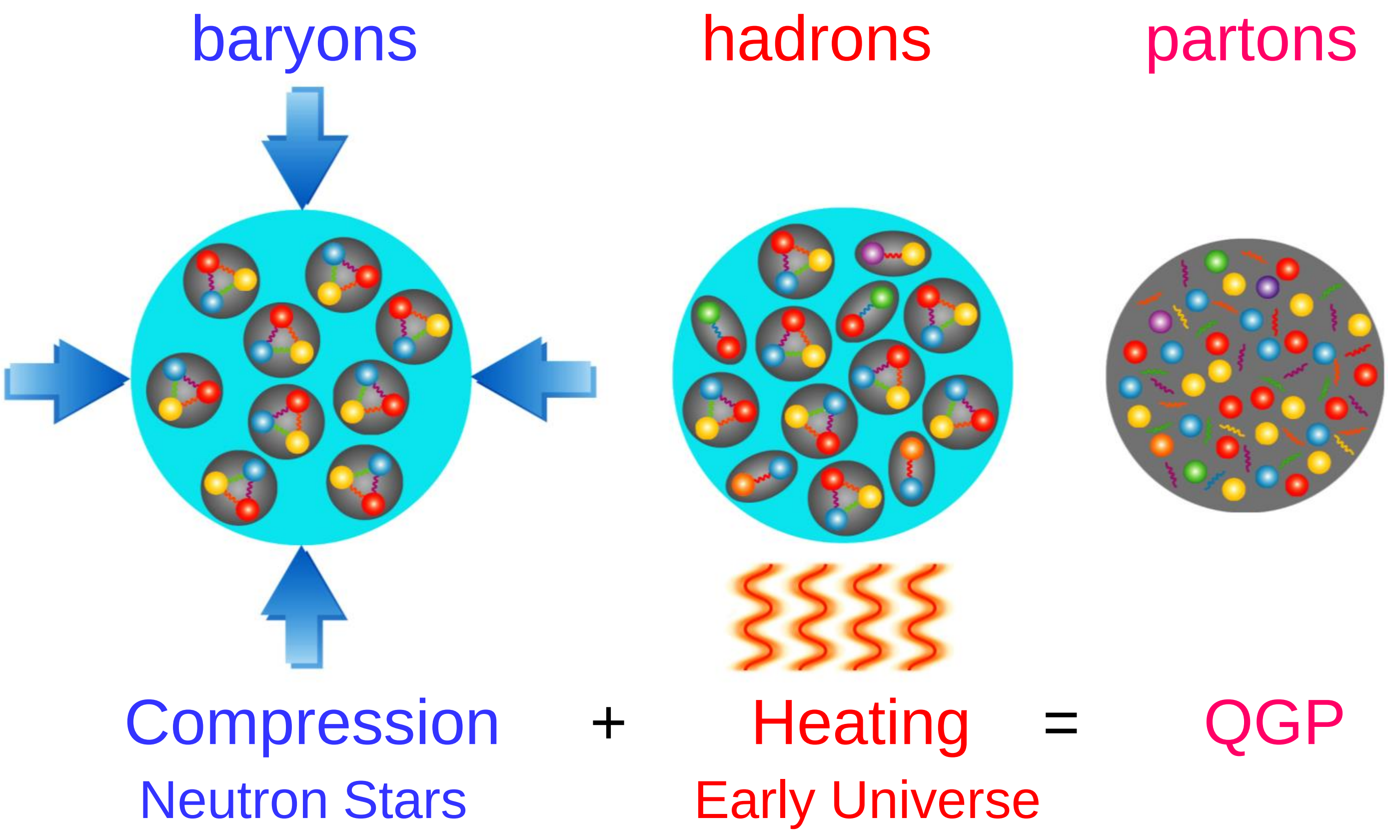
The PANDA Detector

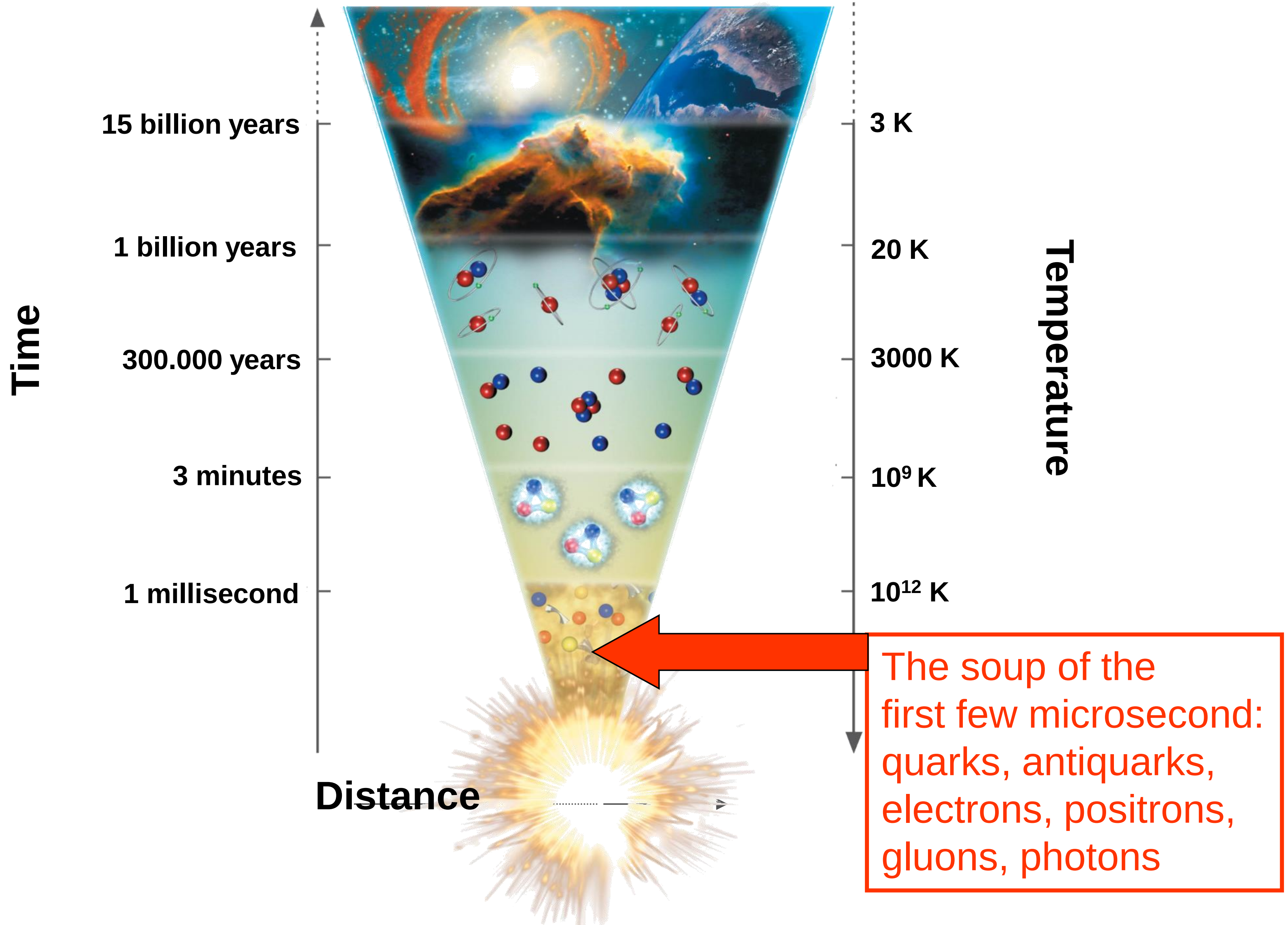


Research Program of CBM

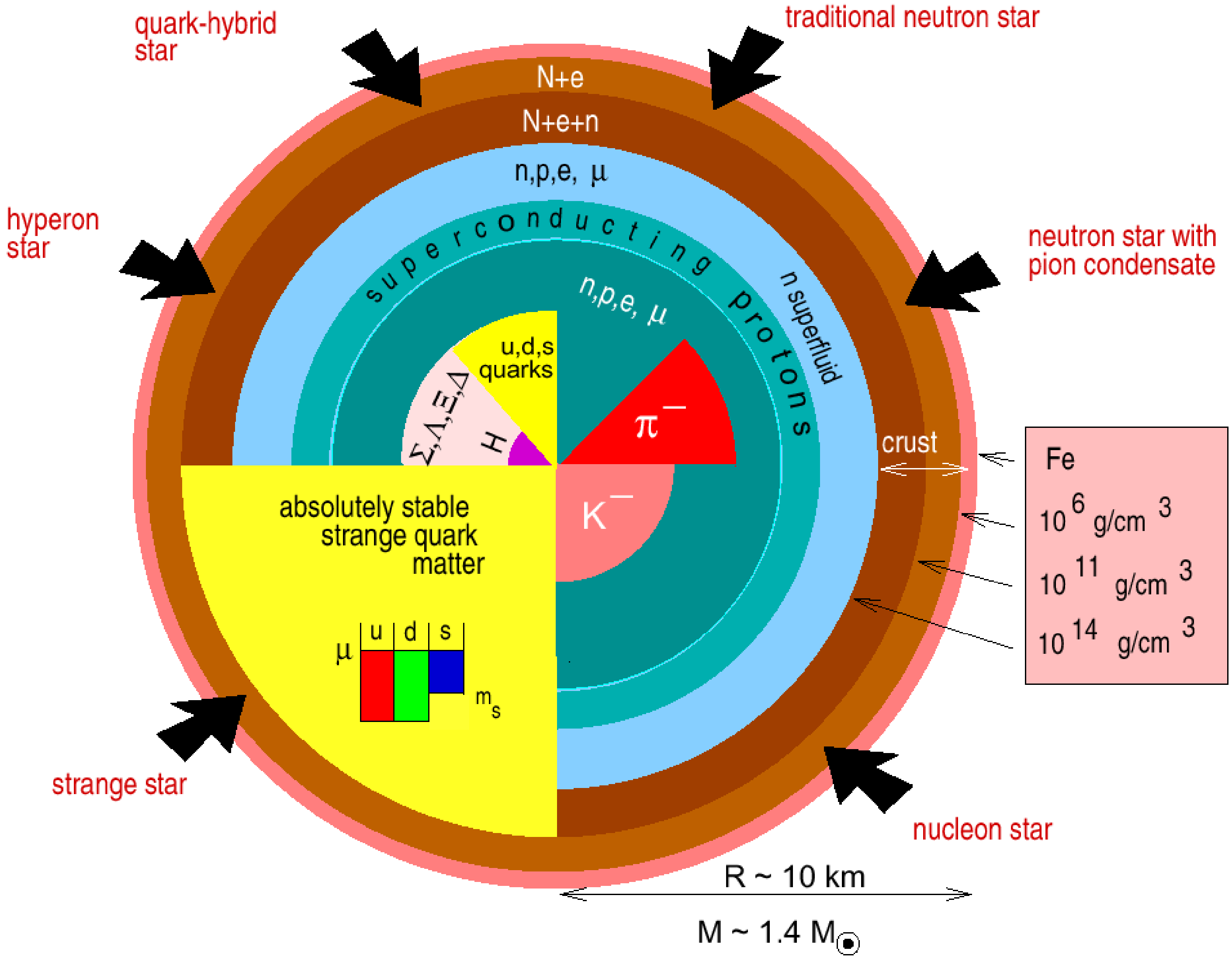
High-energy nucleus-nucleus collisions
Study compressed baryonic matter

baryonic matter at the highest densities (neutron stars)
phase transitions and in-medium properties of hadrons at extreme conditions

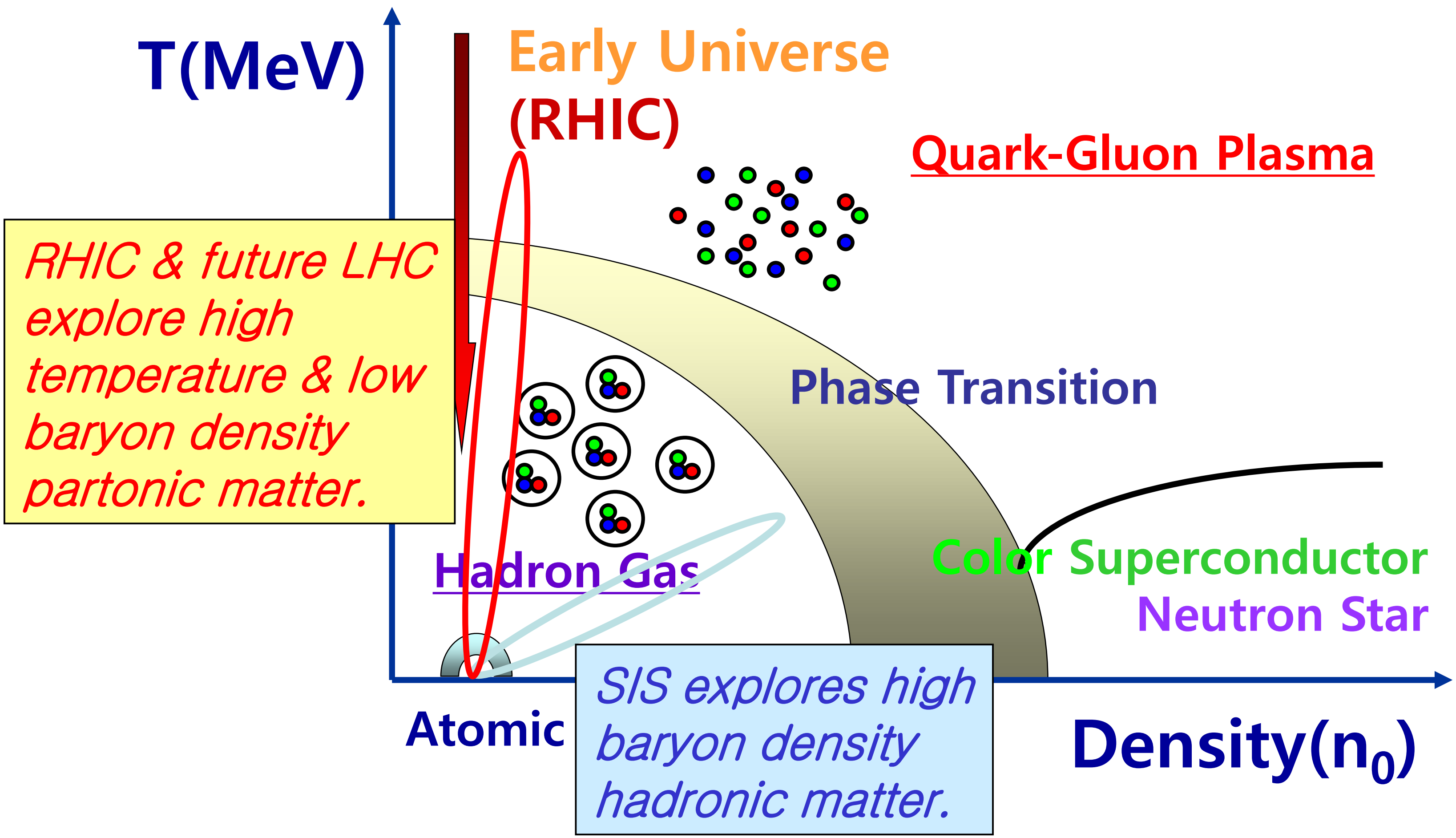


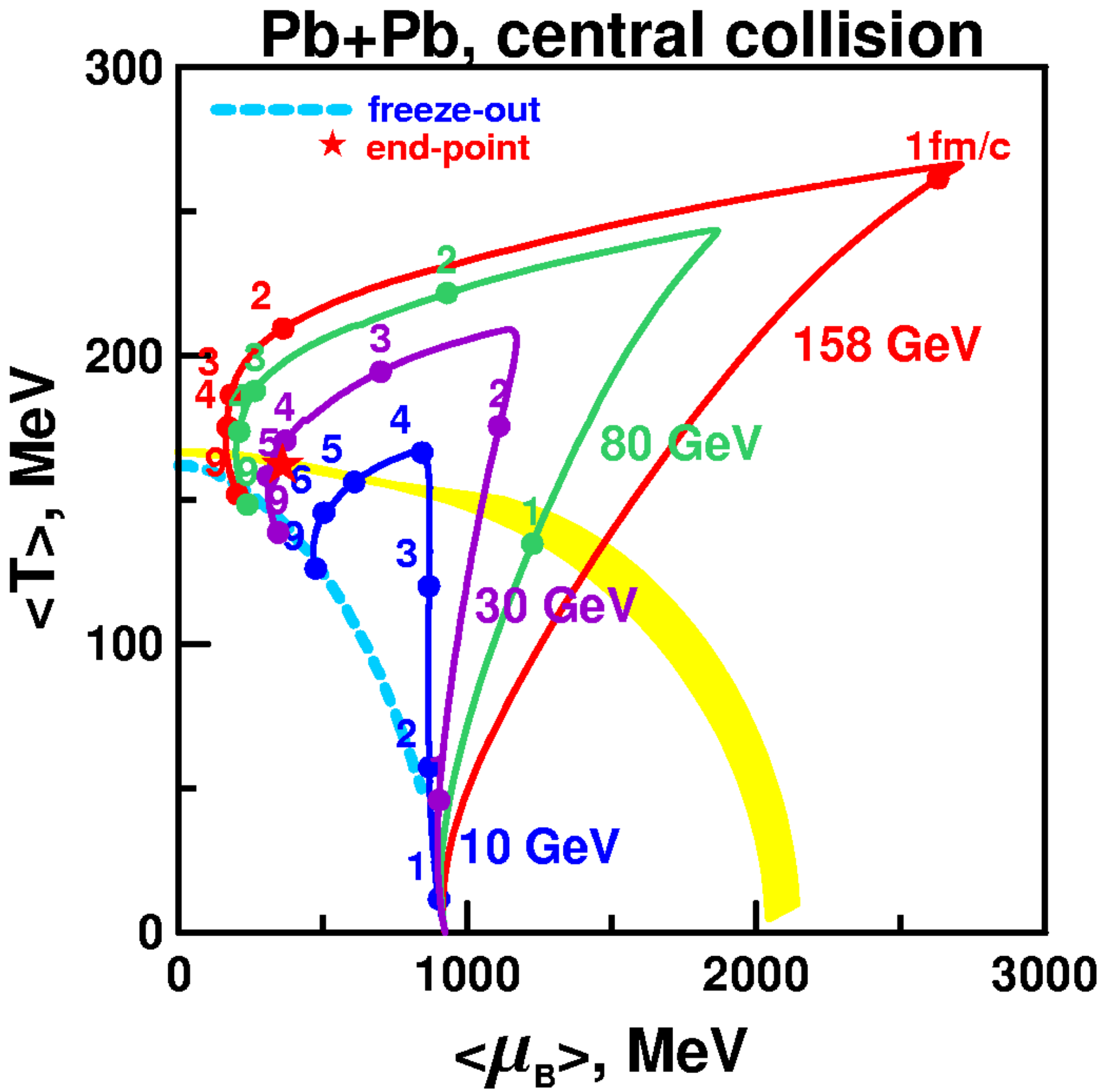

15 billion years
1 billion years
300.000 years
3 minutes
1 millisecond
Time
3 K
20 K
3000 K
10^9 K
10^{12} K
Temperature
Distance
The soup of the
first few microsecond:
quarks, antiquarks,
electrons, positrons,
gluons, photons

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



Nuclear Phase Diagram





Ivanov & Toneev
Hadron gas EOS

Hydrodynamic calculations reproduce the freeze-out conditions

30*A* GeV trajectory is very close to the critical endpoint

CBM Physics Topics

1. In-medium modifications of hadrons

   onset of chiral symmetry restoration at high ρ_B

   observables: ρ, ω, ϕ $\rightarrow$ e^+e^-

   open charm production

2. Strangeness in matter (strange matter)

   enhanced strangeness production

   observables: K, Λ, Σ, Ξ, Ω

3. Indications for deconfinement at high ρ_B

   anomalous charmonium suppression?

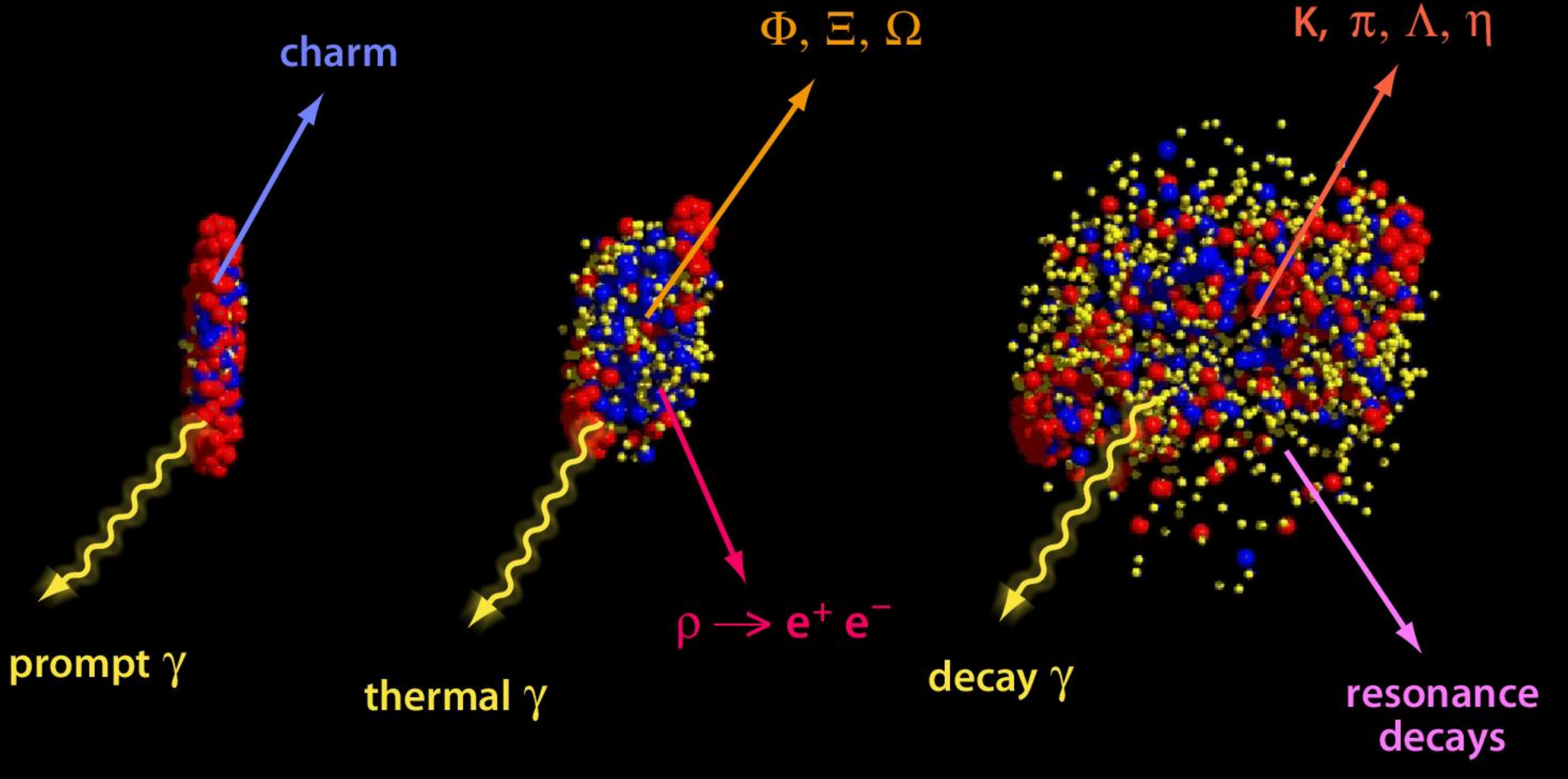
   observables: J/ψ, D

   excitation function of flow (softening of EOS)

4. Critical point

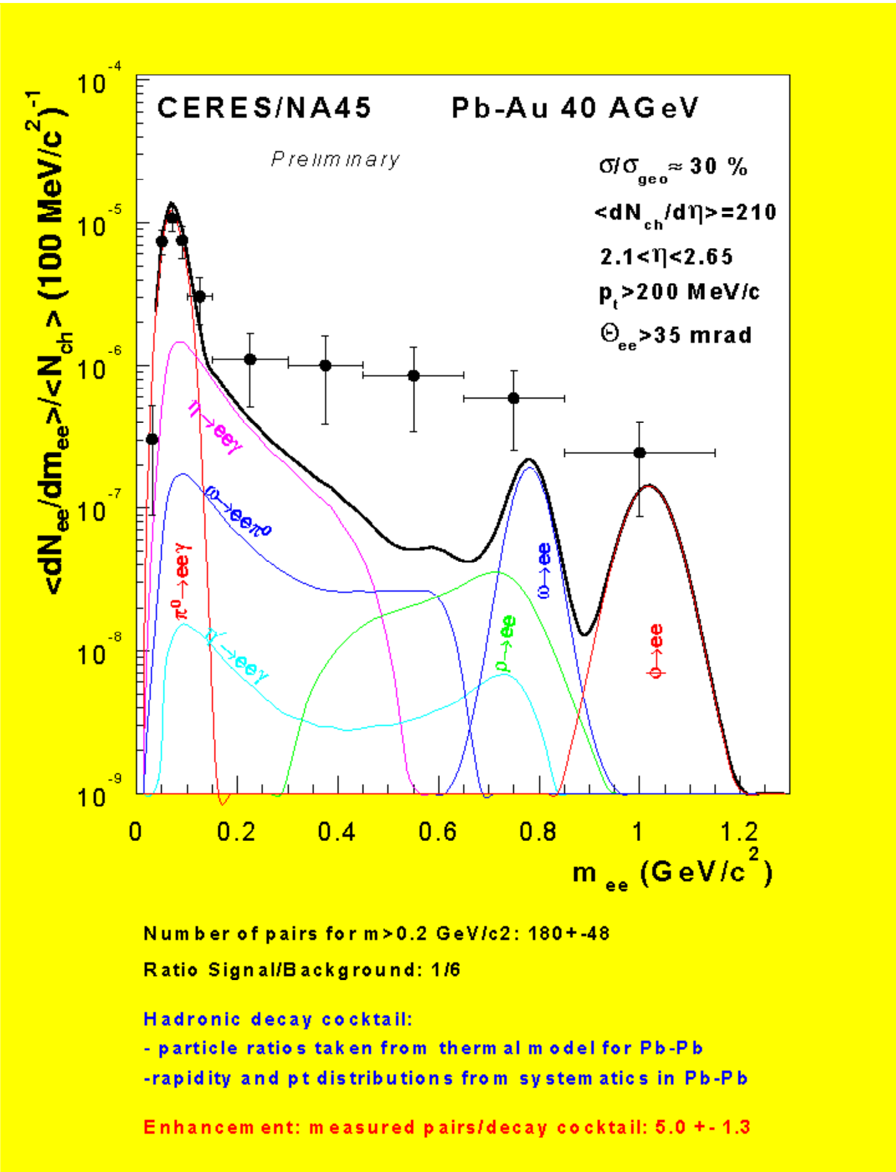
   observables: event-by-event fluctuations

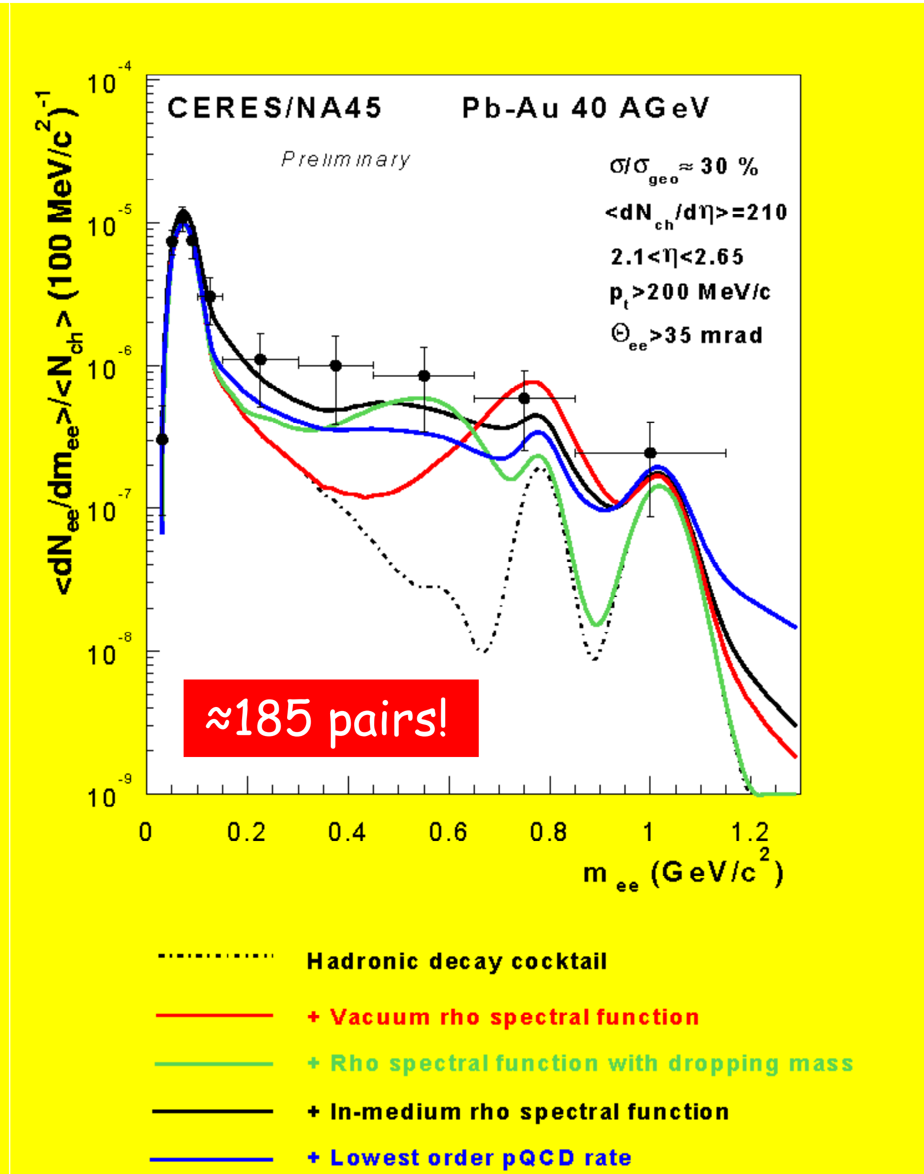
Diagnostic Signals at Various Stages



Low Mass Vector Mesons to e^+e^- pair

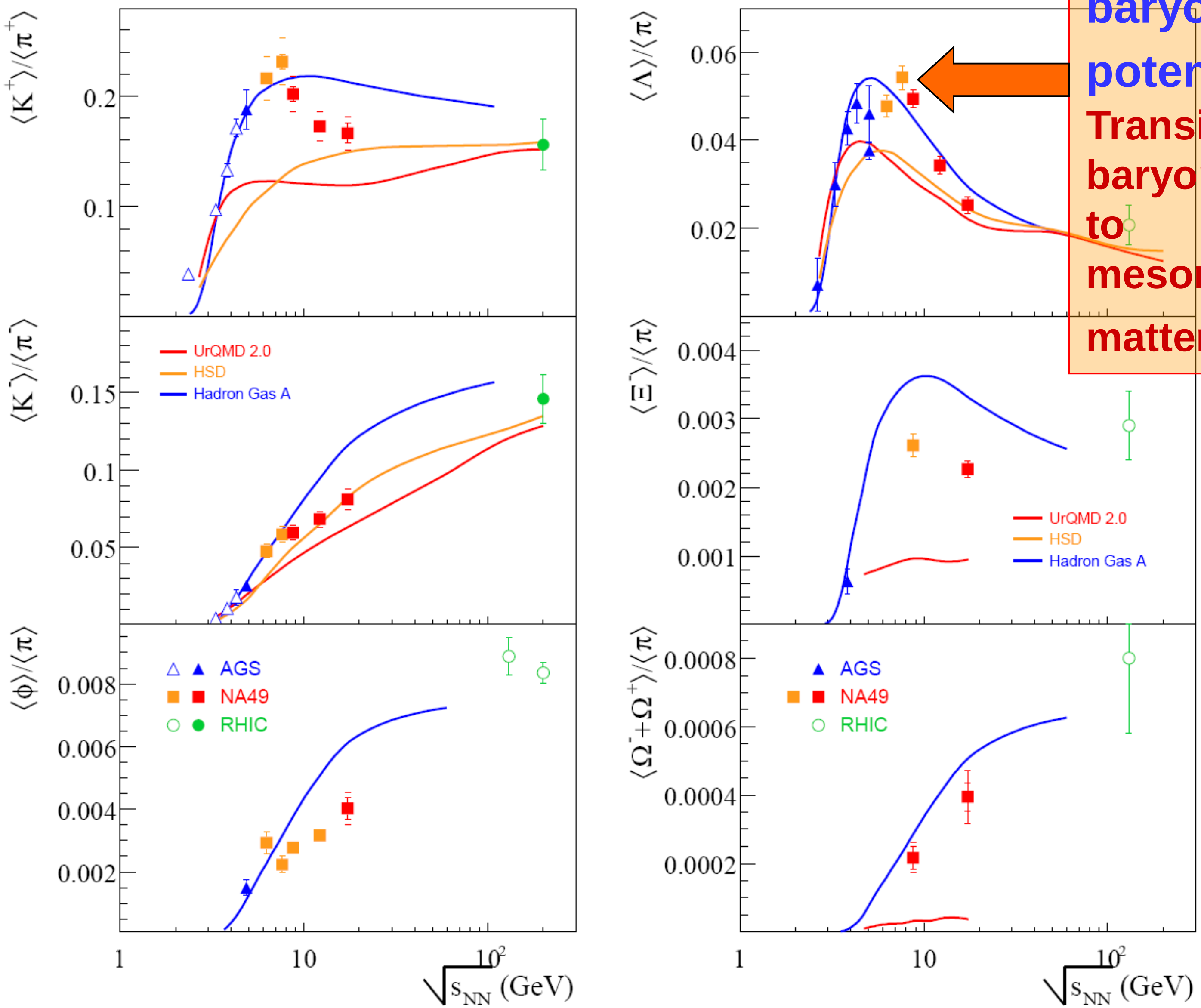
CERES Collaboration: D.Adamova et al., Phys. Rev. Lett. 91 (2003) 042301





Strangeness Production

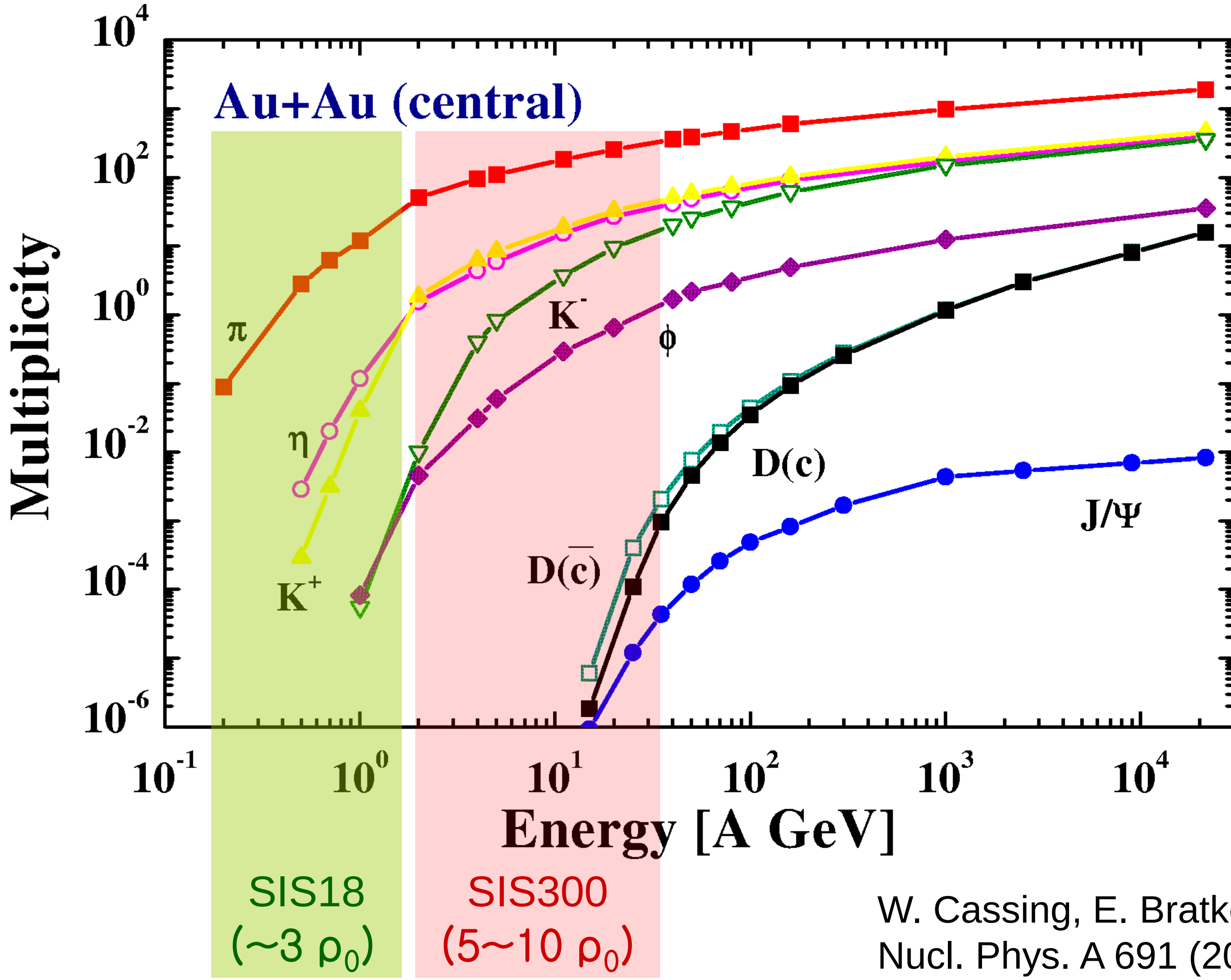
C. Blume et al., nucl-ex/0409008



Decrease of baryon-chemical potential:

Transition from baryon-dominated to meson-dominated matter

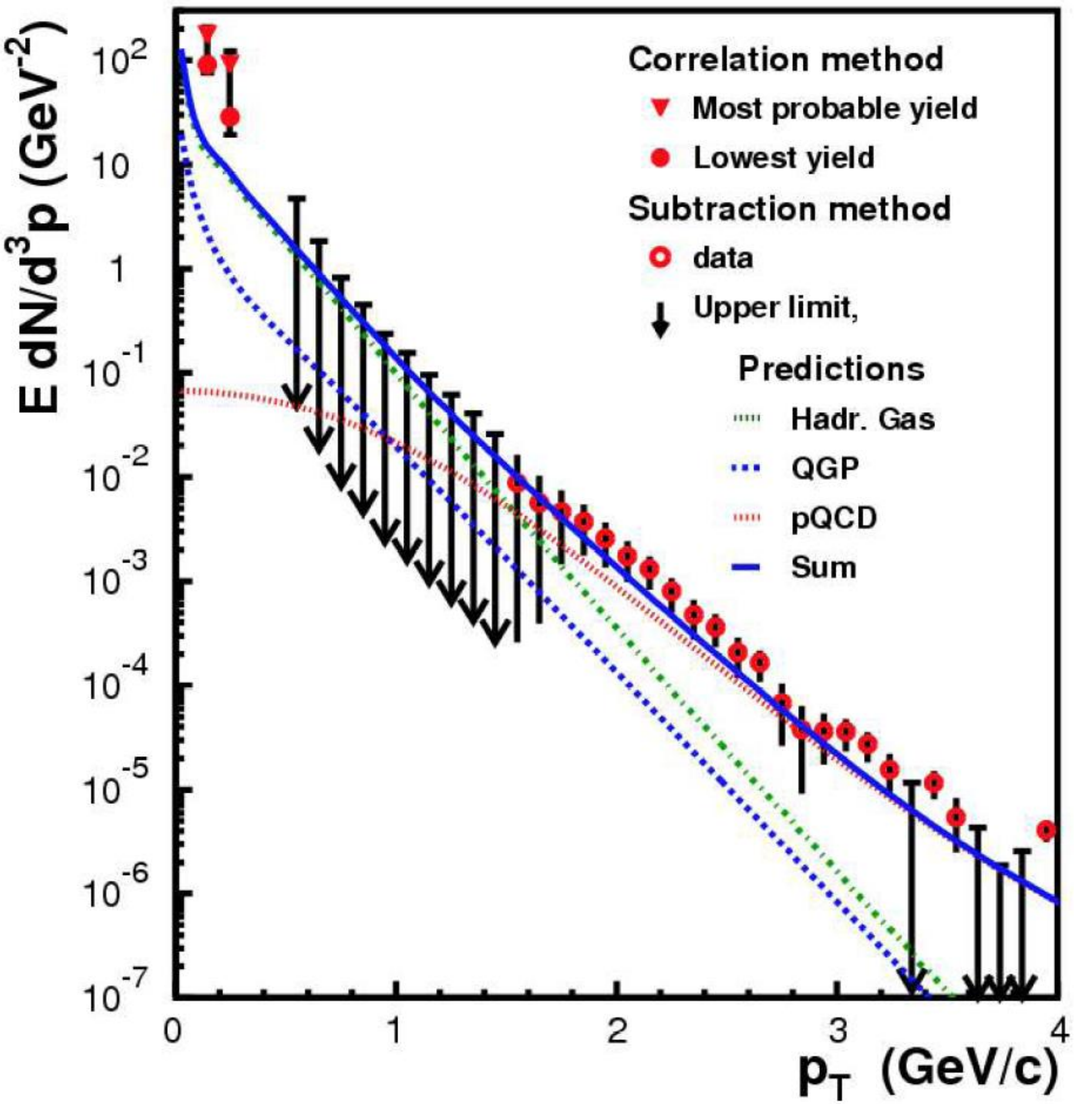
Charm Production



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

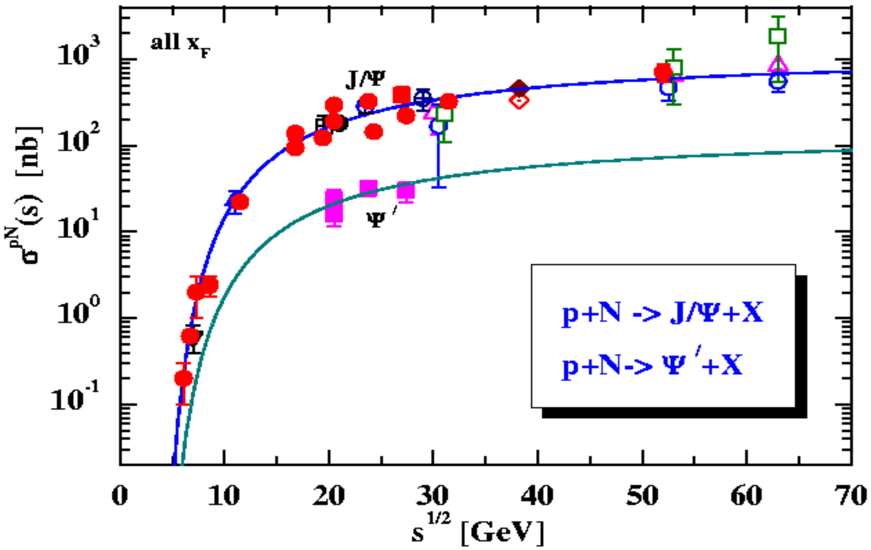
Photons

WA98, Phys. Rev. Lett. 93 (022301), 2004



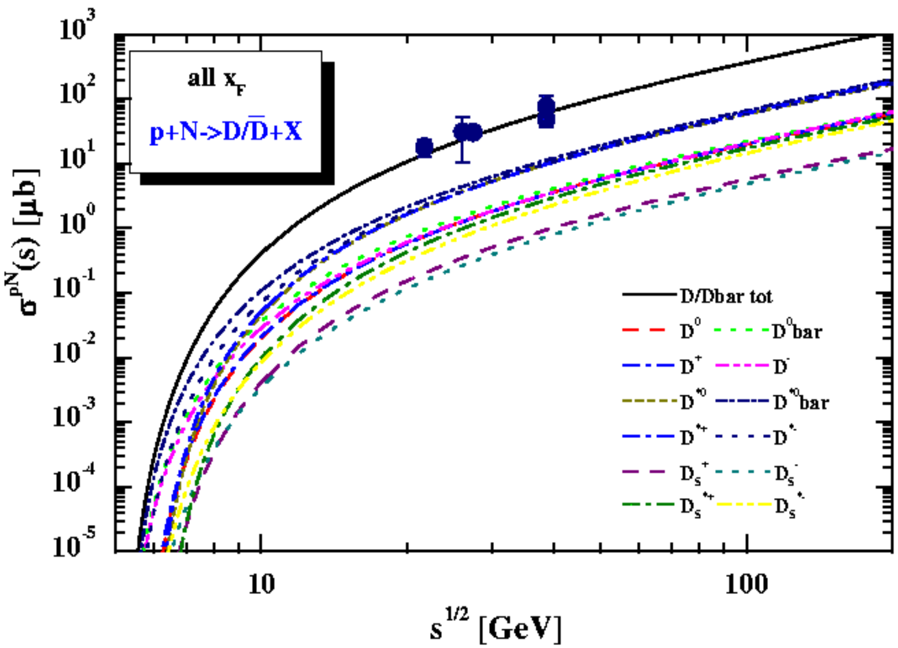
Requirements

Very High Beam Intensity !
Large Acceptance !
Large Spill Fraction !



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
BR $J/\psi \rightarrow e^+e^-$ ($\mu^+\mu^-$)	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

Requirements



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%)

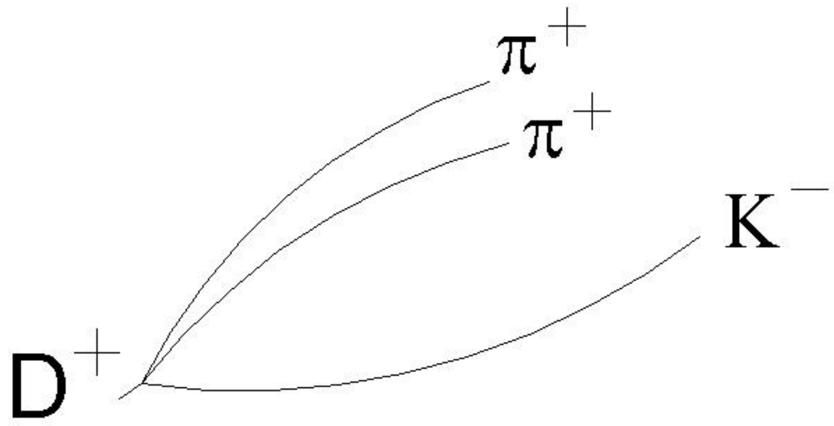
D^0 ($c\tau$ = 124.4 μm):

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

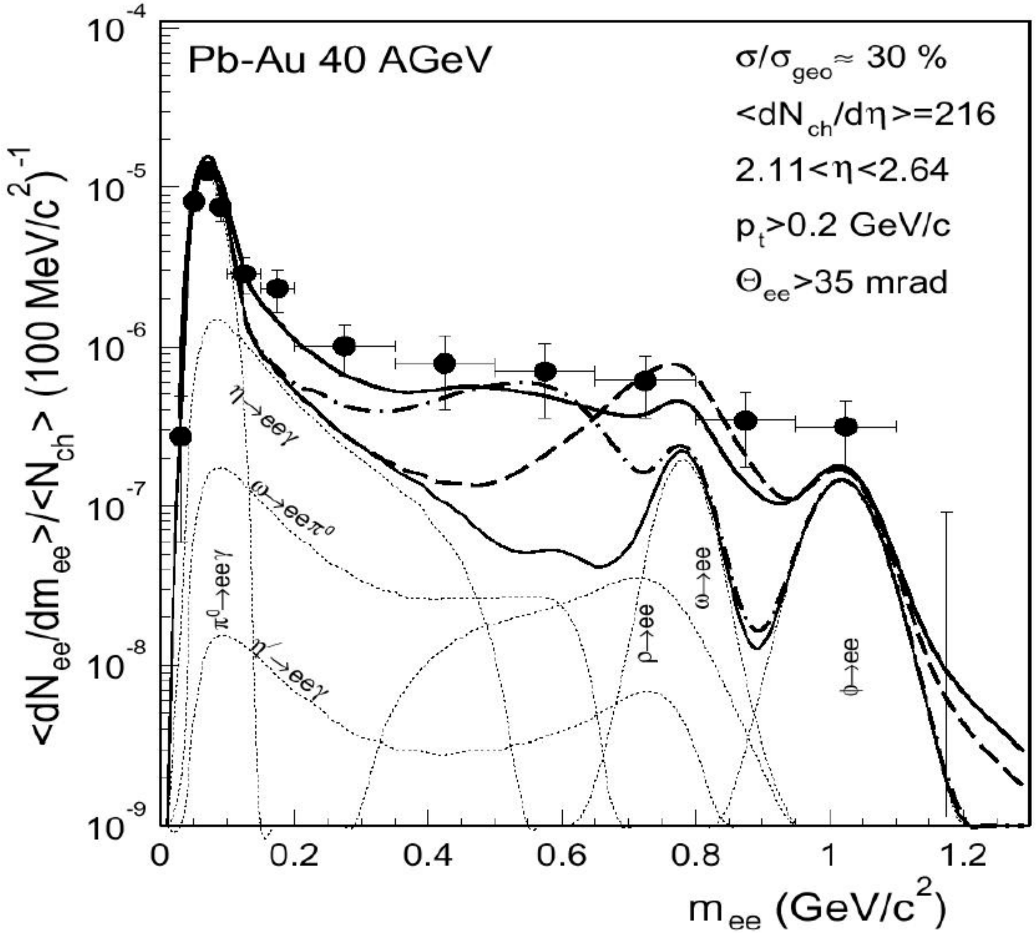
$D^0 \rightarrow K^-\pi^+\ \pi^+\ \pi^-$ (7.6 ± 0.4%)

Have to measure the displaced vertex with resolution of ≤ 50 μm

High Precision on Tracking !



Requirements



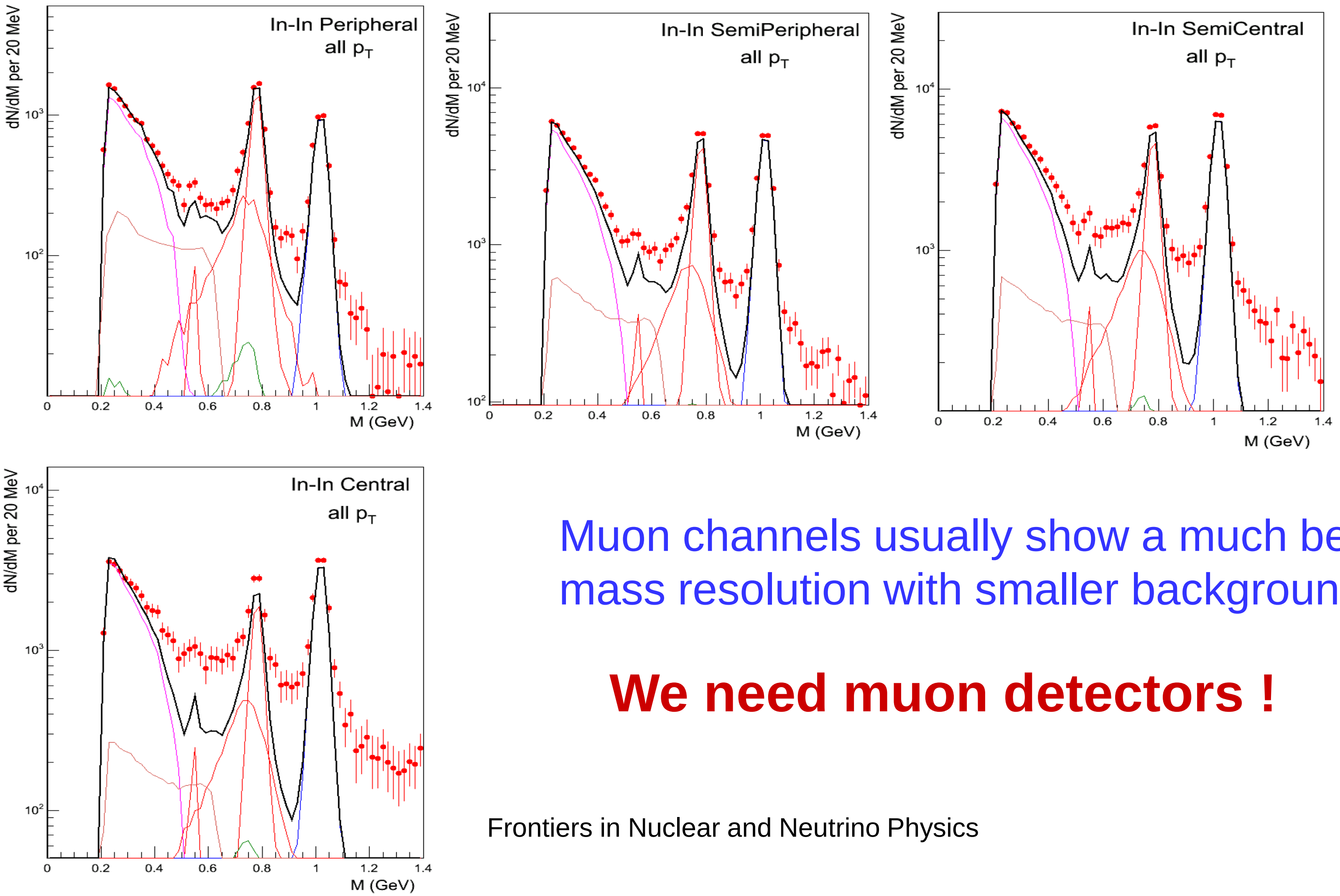
Dominant background in e^+e^- invariant mass spectrum:
π^0-Dalitz decay and gamma conversion

Good identification of soft electrons and positrons !

Requirements

- data (NA60 presented at QM05)

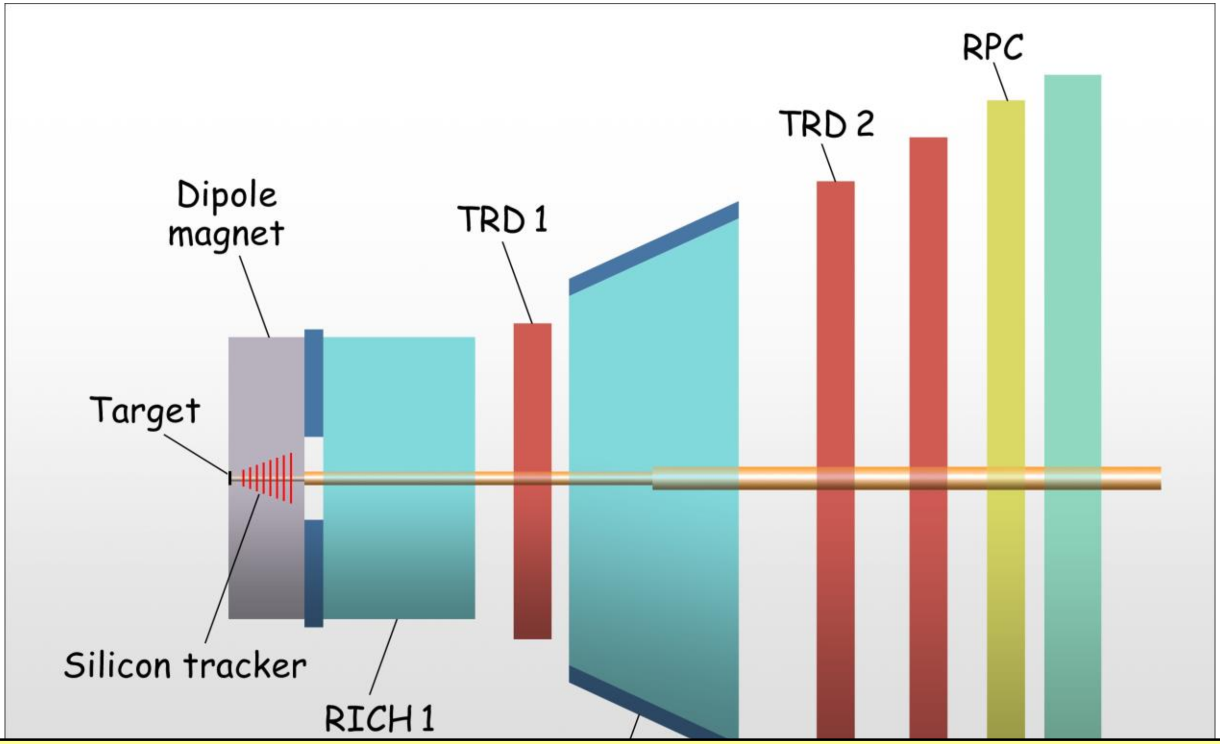
—— sum of cocktail sources including the ρ contribution



Muon channels usually show a much better mass resolution with smaller background.

We need muon detectors !

CBM Detector Proposal



Radiation hard silicon pixel/strip detectors in a magnetic dipole field

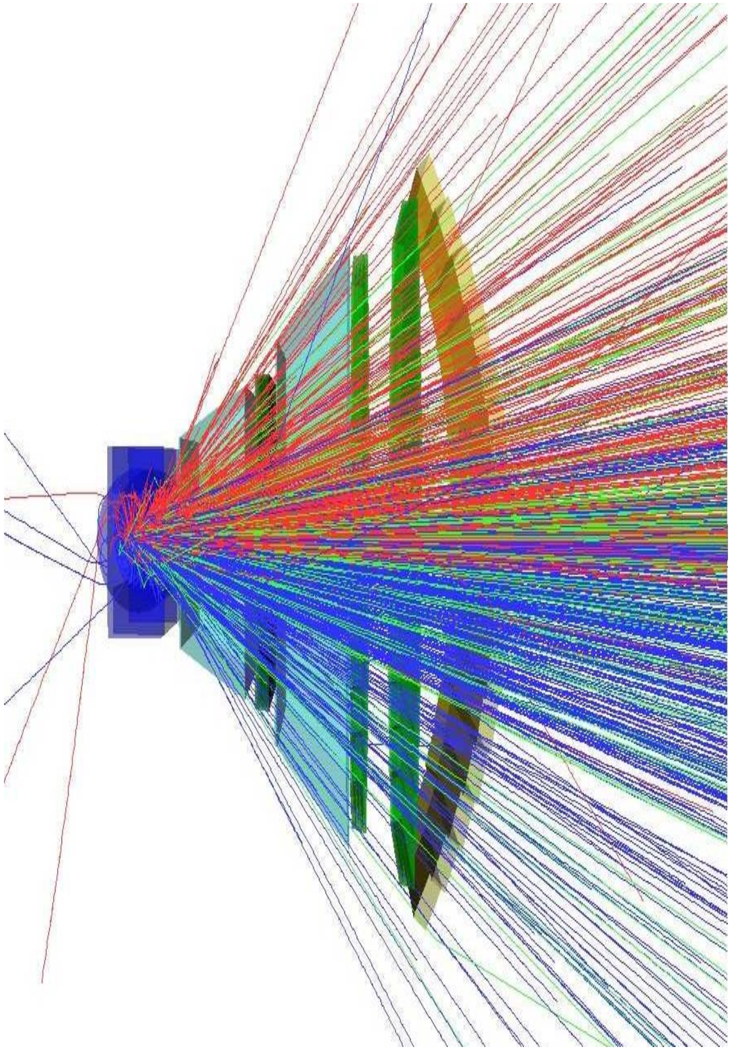
Electron identification: RICH & TRD & ECAL for the pion suppression up to 10^5

Hadron identification: RPC, RICH

Measurements of photons, π^0, and η: EM calorimeter (ECAL)

High speed data acquisition and trigger system (Muon option is under investigation)

Simulation



Central Au+Au at 25A GeV:
URQMD + GEANT4

160 p/400 π^-/400 π^+/44 K^+/13 K^-

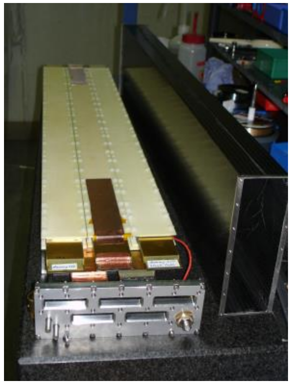
~600 charged particles in $\pm$ 25°

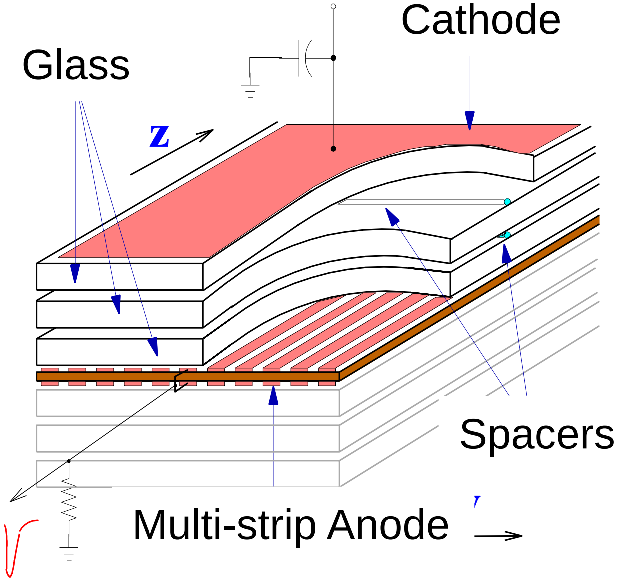
TOF Resistive Plate Chamber

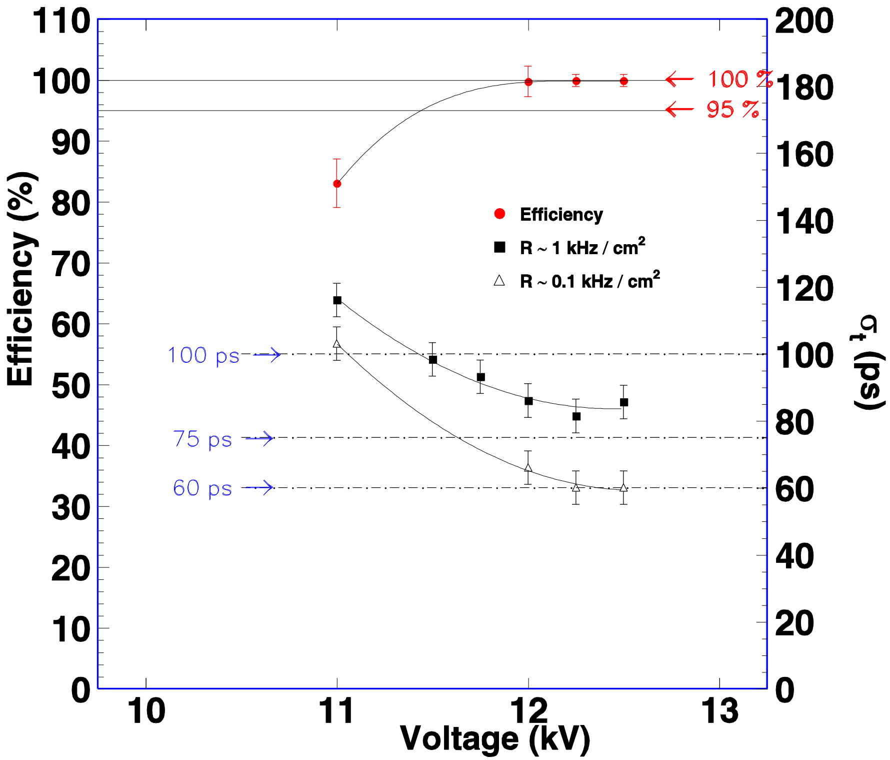
Design goals:
- Time resolution ≤ 80 ps
- Rate capability up to 20 kHz/cm^2
- Efficiency > 95 %
- Large area ≈ 100 m^2
- Long term stability

Various options are under investigation:
- Strip vs. pad readout
- Different materials for electrodes

FOPI MMRPC project

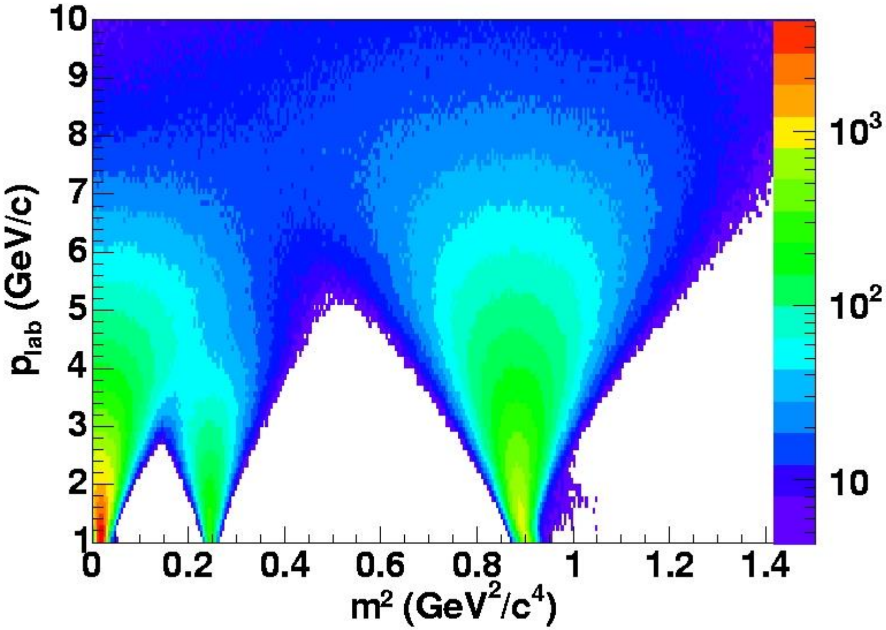


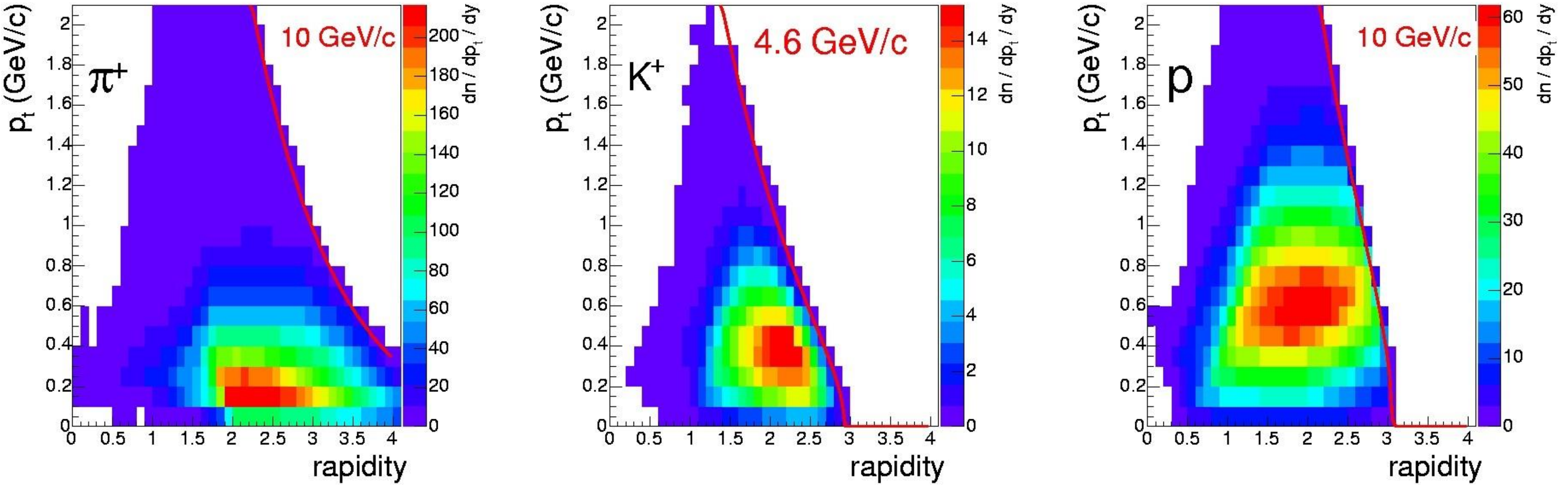




Particle Identification with TOF

Assuming that
TOF distance = 10 m
and
time resolution = 80 ps

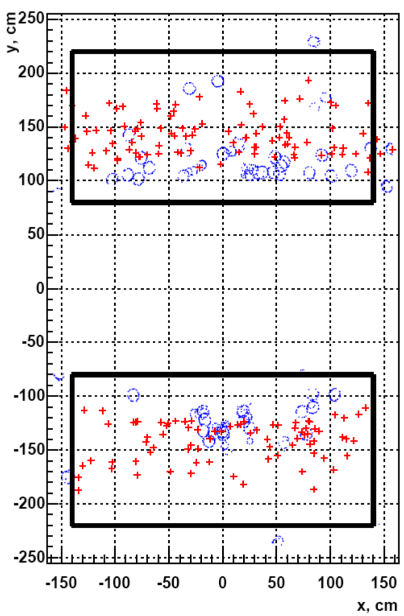


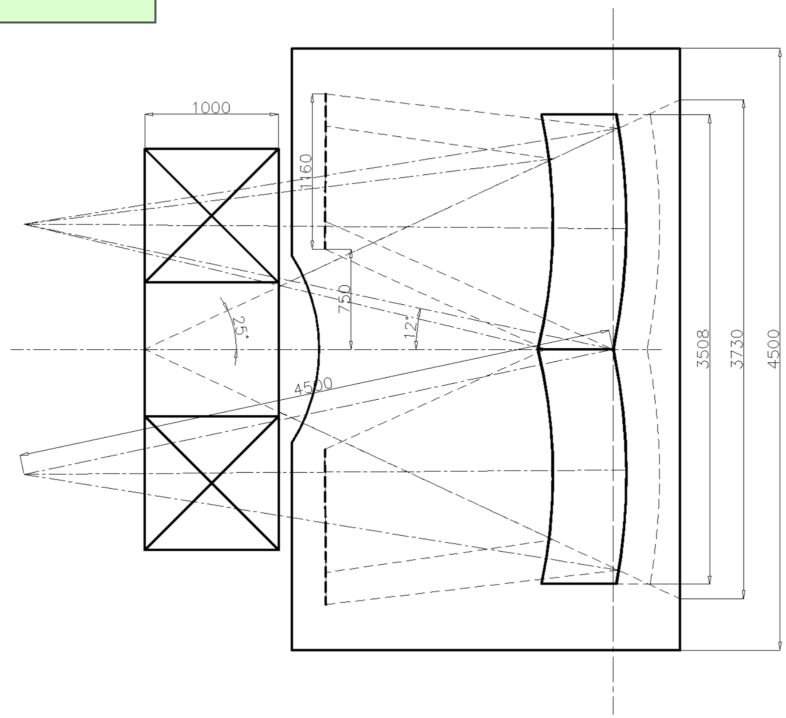


Fast RICH

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 response detector

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 25A GeV:

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 ⇨ major detector R&D required

CBM Collaboration

41 institutions, 15 countries

Croatia:
RBI, Zagreb

China:
Wuhan Univ.

Cyprus:
Nikosia Univ.

Czech Republic:
Czech Acad. Science, Rez
Tech. Univ. Prague

France:
IReS Strasbourg

Hungary:
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. 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.

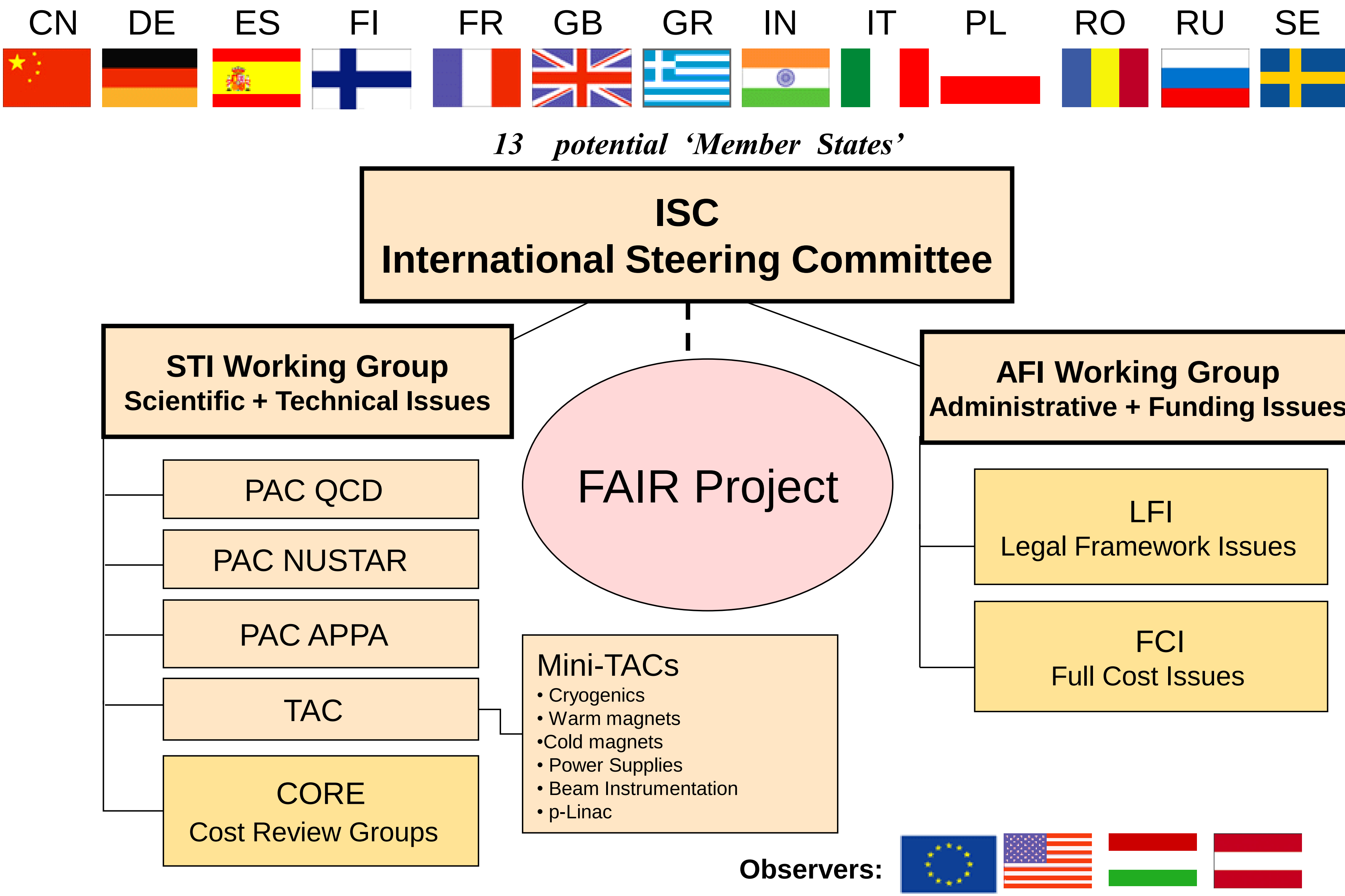
Ukraine:
Shevshenko Univ. , Kiev

Working Groups

R&D on fast gaseous detectors for TRD	JINR-LHE Dubna, GSI Darmstadt, Univ. Münster, PNPI St. Petersburg, NIPNE Bucharest
R&D on straw tube tracker (TRD)	JINR-LPP Dubna, FZR Rossendorf
R&D on Ring Imaging Cherenkov Detector (RICH)	IHEP Protvino, GSI Darmstadt, Pusan Nat. Univ., PNPI St. Petersburg
Design and construction of an electromagnetic calorimeter (ECAL)	ITEP Moscow, Univ. Krakow, Univ. Frankfurt
Diamond microstrip detector	GSI, Univ. Mannheim
Trigger and Data Acquisition	KIP Univ. Heidelberg, Univ. Mannheim, JINR LIT Dubna, GSI Darmstadt, Univ. Bergen, KFKI Budapest, Silesia Univ. Katowice, PNPI St. Petersburg, Univ. Warsaw
Design of a superconducting dipole magnet	JINR-LHE Dubna, GSI Darmstadt
Calculation of radiation doses	Kiev Univ.
Modification of HADES for 8 AGeV	Czech Acad. Science Rez
Delta electrons	GSI Darmstadt

Task	
Feasibility study D-Meson identification	
Feasibility study low-mass vector mesc identification via electron-positron pairs	
Feasibility study charmonium identificat via electron-positron pairs	
Feasibility study charmonium identificat via muon pairs	
Simulations hadron identification via TC	
Simulation tools	
Tracking	KIP Univ. Heidelberg, Univ. Mannheim, JINR-LHE Dubna, JINR-LIT Dubna
Silicon Pixel Detector	IReS Strasbourg, Frankfurt Univ., GSI Darmstadt, RBI Zagreb, Krakow Univ.,
Silicon Strip Detector	Obninsk Univ., SINP Moscow State Univ., CKBM St. Petersburg, KRI St. Petersburg
R&D on RPC TOF detector system with read-out electronics	LIP Coimbra, Univ. Santiago de Compostela, Univ. Heidelberg, GSI Darmstadt, NIPNE Bucharest, INR Moscow, FZR Rossendorf, IHEP Protvino, ITEP Moscow, Korea Univ. Seoul, RBI Zagreb, Univ. Krakow, Univ. Marburg

Present Committee Structure of the International Project FAIR



FAIR Baseline Cost

	CORE Evaluation and TAC recommendation (M€)
Accelerators	533
Baseline Experiments **	180
Buildings & Supply Systems	289
Total Investments	1002
Manpower (2400 MY)	185
Total Project Construction Cost	**1187**

75% of construction cost from Germany, 25% from member states
Operation costs shared among member states

** additional funding expected from 30 non-member states already involved in FAIR experiments

Summary of CBM

1. Systematic investigations of dense matter
   - A+A collisions from 8 to 45A GeV (for Z/A=0.5)
   - p+p and p+A collisions from 8 to 90 GeV
   - Beam energies up to 8A GeV by HADES
2. Detector and machine requirements
   - High beam intensity and duty cycle
   - Large geometrical acceptance
   - Good hadron, electron, and muon identification
   - Excellent vertex resolution
   - High rate capability of detectors, FEE and DAQ
3. Observables
   - Penetrating probes: ρ, ω, φ, J/ψ (light and heavy vector mesons)
   - Strangeness: K, Λ, Σ, Ξ, Ω
   - Open charm: D^o, $D^{\pm}$
   - Hadrons (p, π), exotica, etc.
4. It will be a unique opportunity for the study of dense nuclear matter.

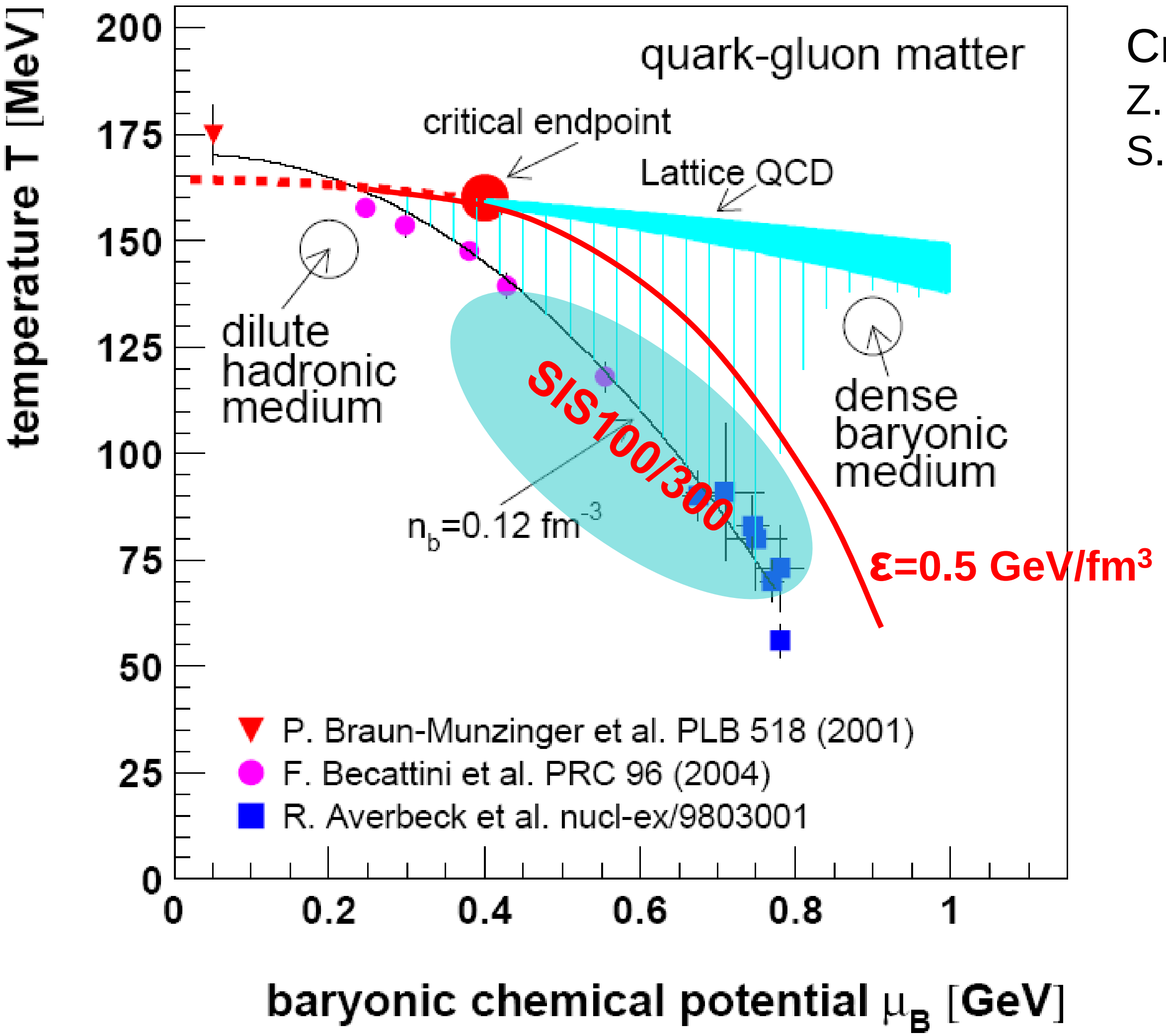
Summary of FAIR

1. Wide Physics Coverage
   - Nuclear structure and nuclear astrophysics **(LENS)**
   - Hadron physics **(HaPhy)**
   - Compressed baryonic matter **(HIM)**
   - Plasma physics
   - Atomic physics
   - Biophysics
   - Accelerator and detector R & D
   - Applications
2. Present developments
   - Actively progressing
   - 13 member states and 4 observer states **(Korea?)**
   - Total budget: € 1187 M
   - Expected completion: 2015
3. FAIR could be a model of the National Institute of Nuclear Science in Korea

Backups

Relativistic Heavy-Ion Accelerators

Accelerator	c.m. Energy (GeV)	Status
SIS18 (GSI, Germany)	2A (A=mass number)	Running
AGS (BNL, USA)	5A	Finished
SIS300 (GSI, Germany)	8A	Plan to run in ~2015
SPS (CERN, Switzerland)	20A	Finish soon
RHIC (BNL, USA)	200A	Run since 2000
LHC (CERN, Switzerland)	5500A	Plan to run in ~2008

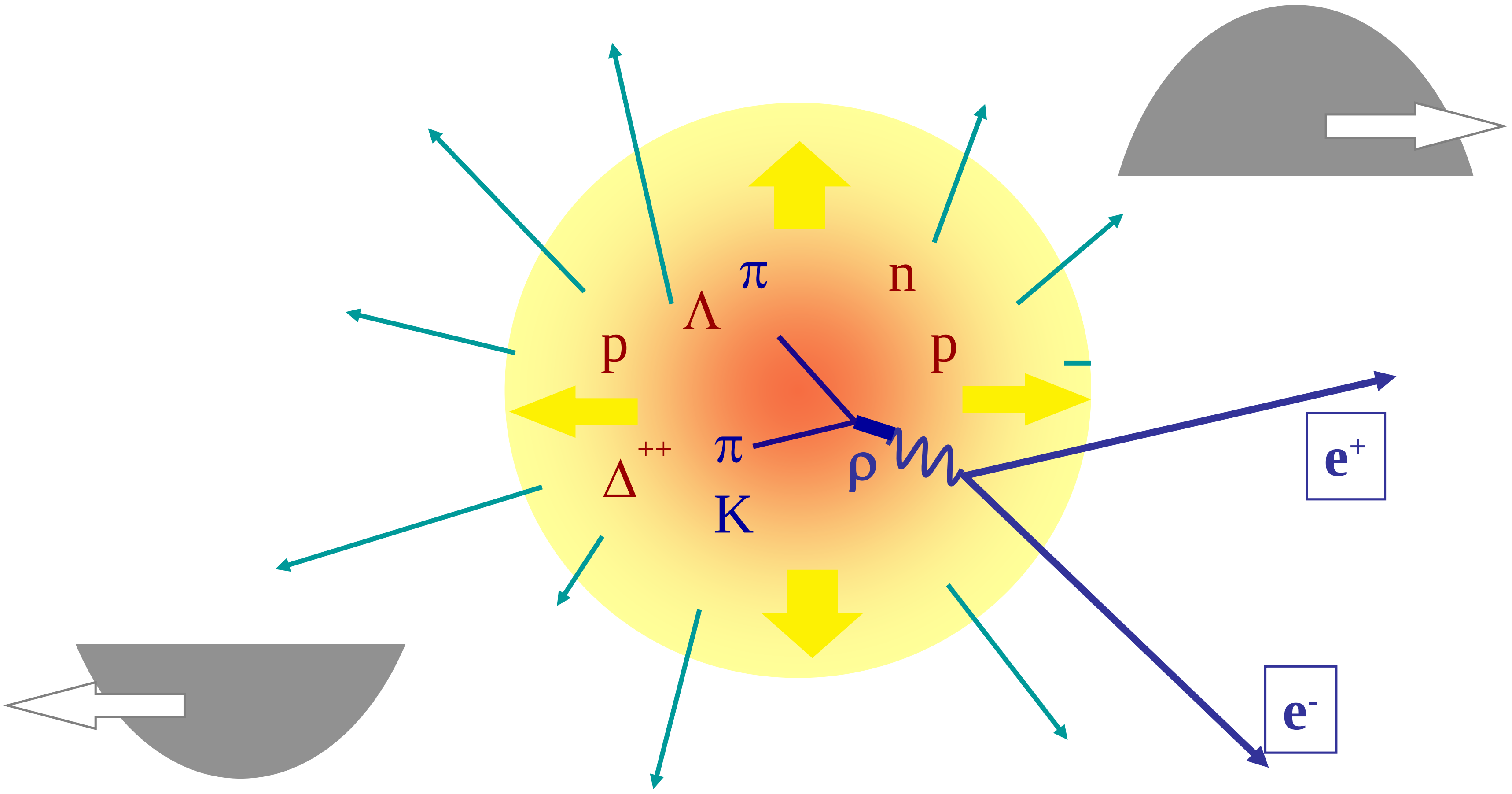


Critical endpoint:

Z. Fodor, S. Katz, hep-lat/0402006

S. Ejiri et al., hep-lat/0312006

Looking into the fireball,

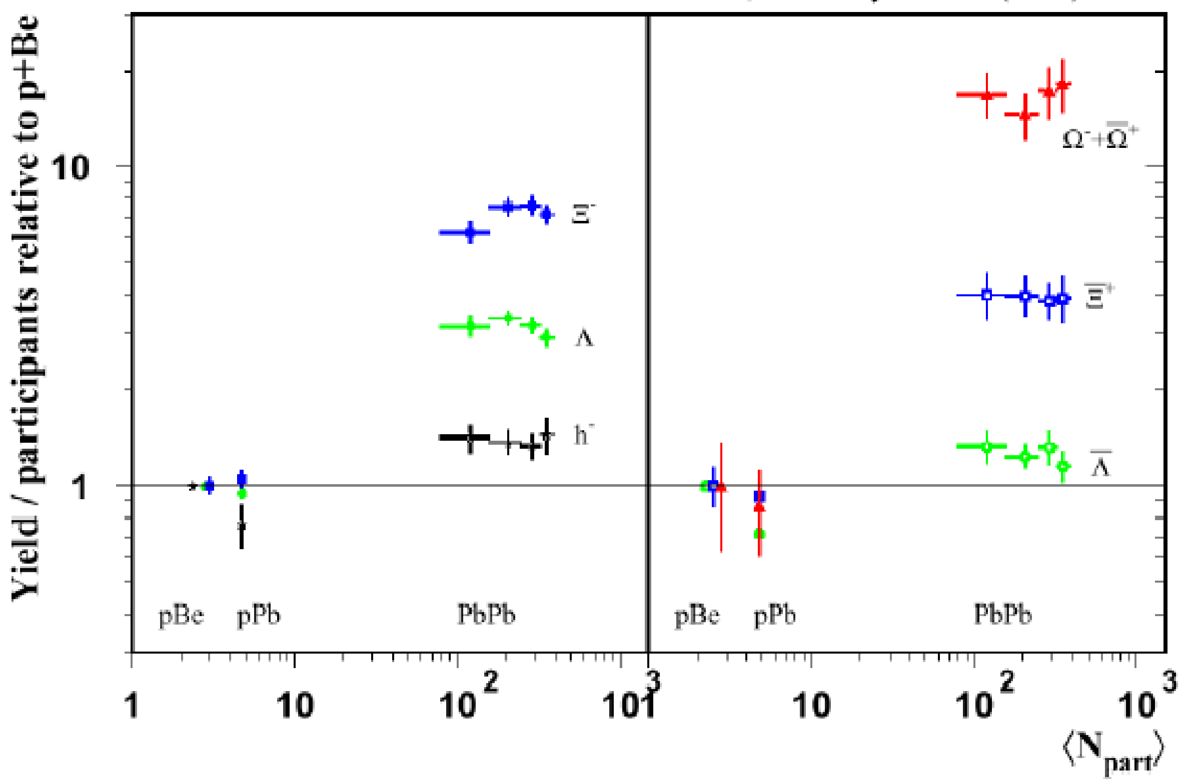


… using the penetrating probes:

short-lived vector mesons decaying into electron-positron pairs

Strangeness Production

F. Antinori et al, Nucl. Phys. A 661 (1999) 130c



When the enhancement of hyperons starts?

Silicon 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)

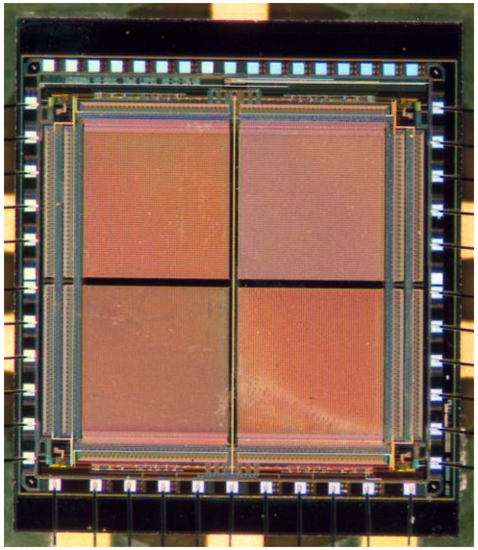
Design goals:

- 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

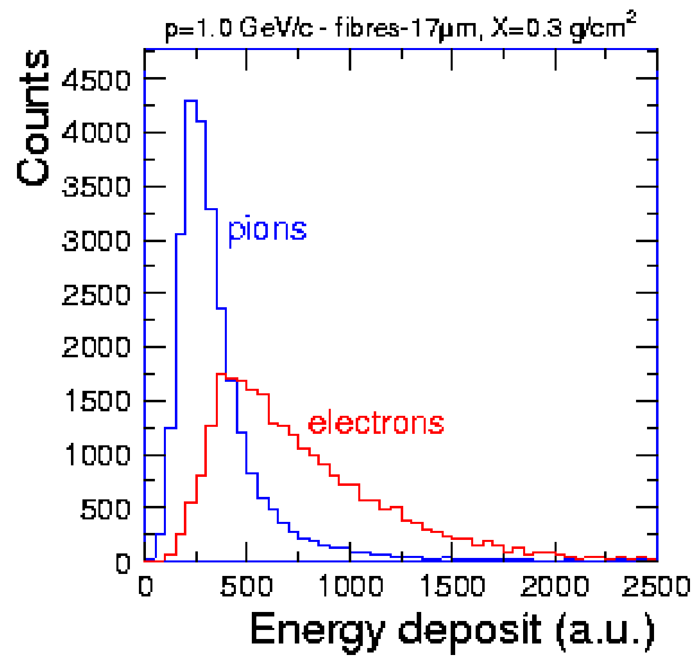


MIMOSA IV
IReS / LEPSI Strasbourg

Alternative: next generation of thin, radiation hard, and fast hybrid detectors

Fast TRD

Design goals:
- 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)



MWPC GSI, Bucharest