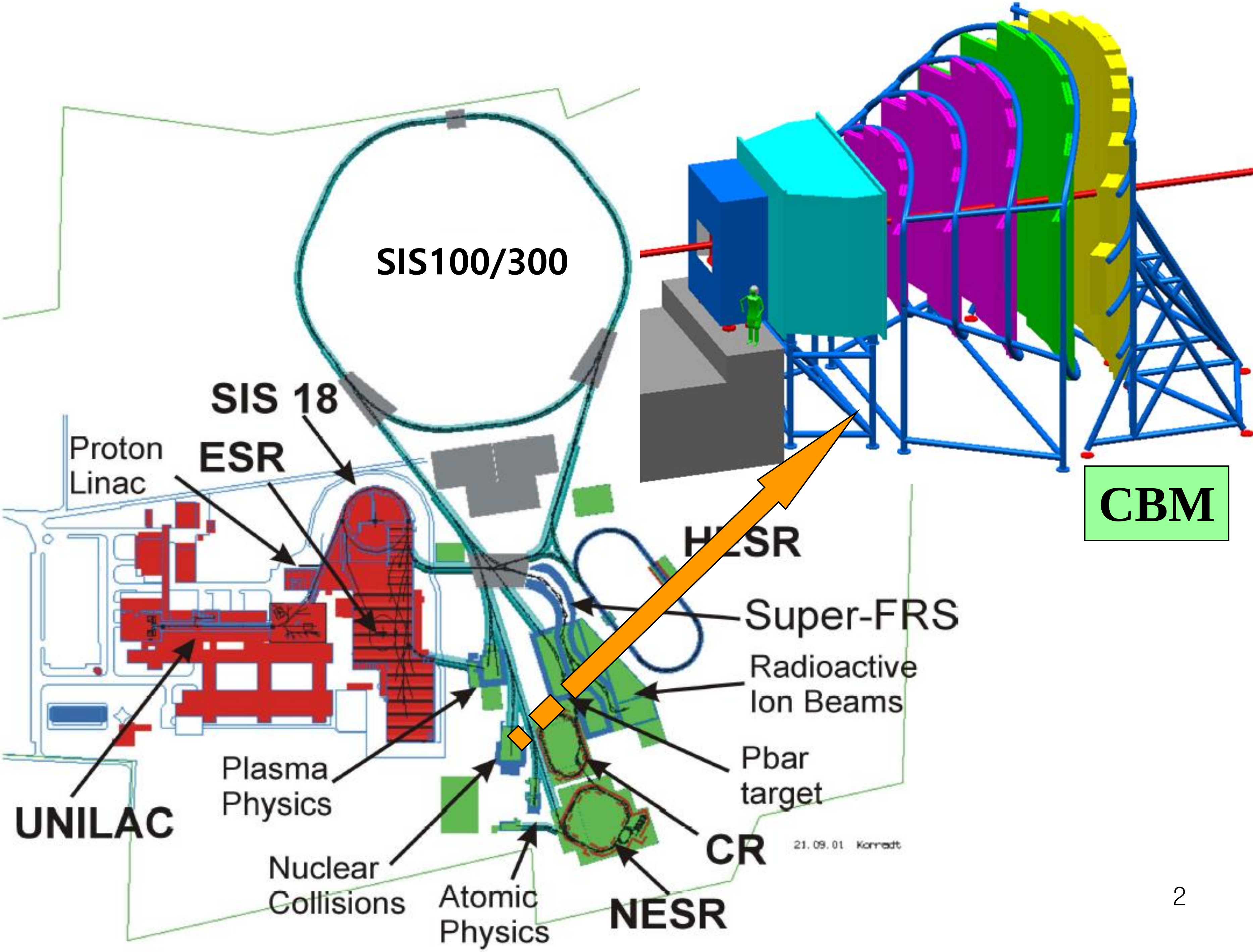
CBM Experiment: Opportunities for FAIR-GSI

Contents

- FAIR Project at GSI
- CBM at FAIR
  - ►Unique Opportunity for the dense matter study
- Discussion


SIS100/300
SIS 18
Proton
Linac
ESR
HESR
Super-FRS
Radioactive
Ion Beams
Pbar
target
CR
NESR
UNILAC
Plasma
Physics
Nuclear
Collisions
Atomic
Physics
21.09.01 Konradt
CBM

Facility for Antiproton and Ion Research

Primary beams:

$^{238}U^{28+}$ 1-2A GeV ~10^{12}/s

U 35A GeV ~10^{10}/s

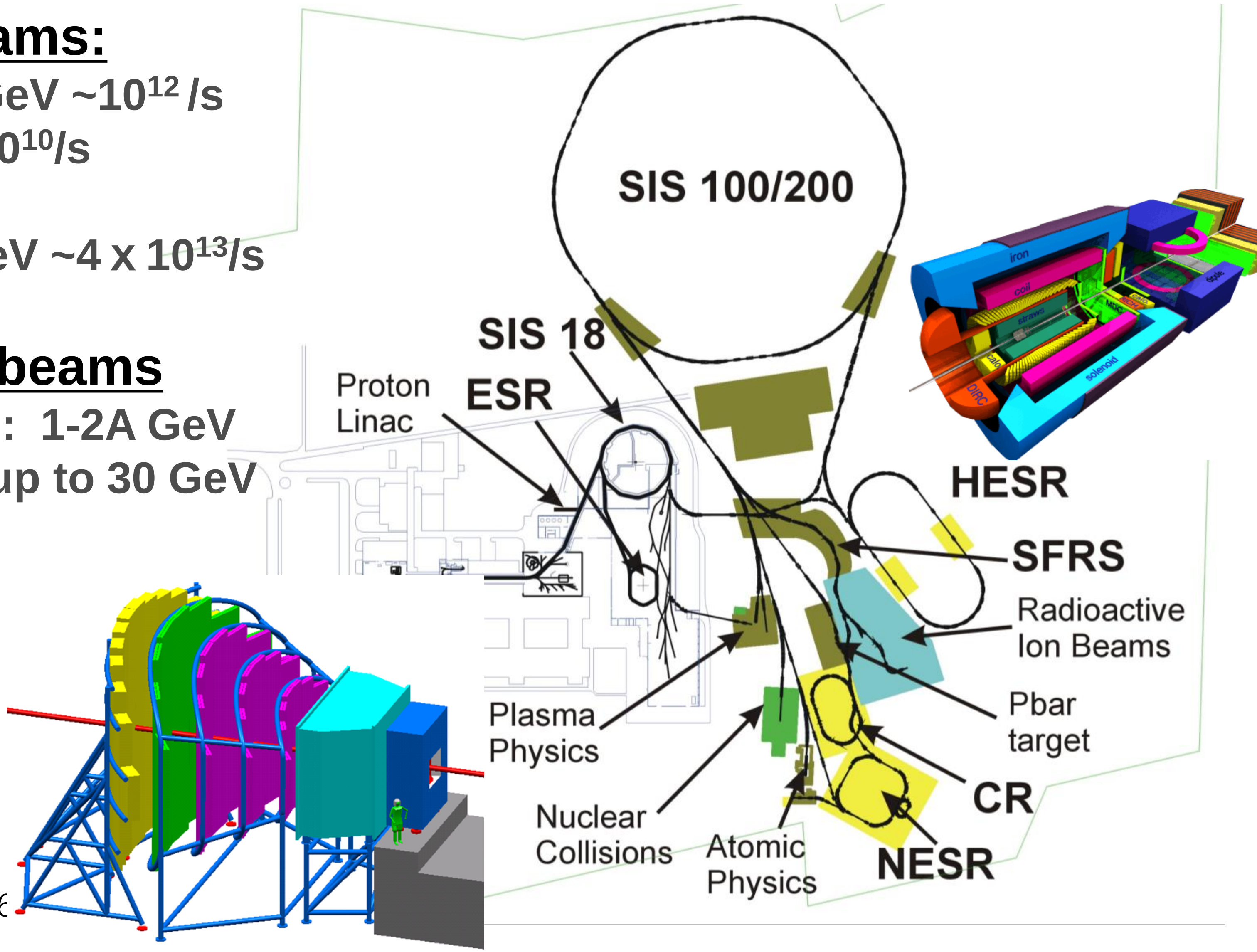
(Ni 45A GeV)

Protons 90 GeV ~4 x 10^{13}/s

Secondary beams

Rare Isotopes: 1-2A GeV

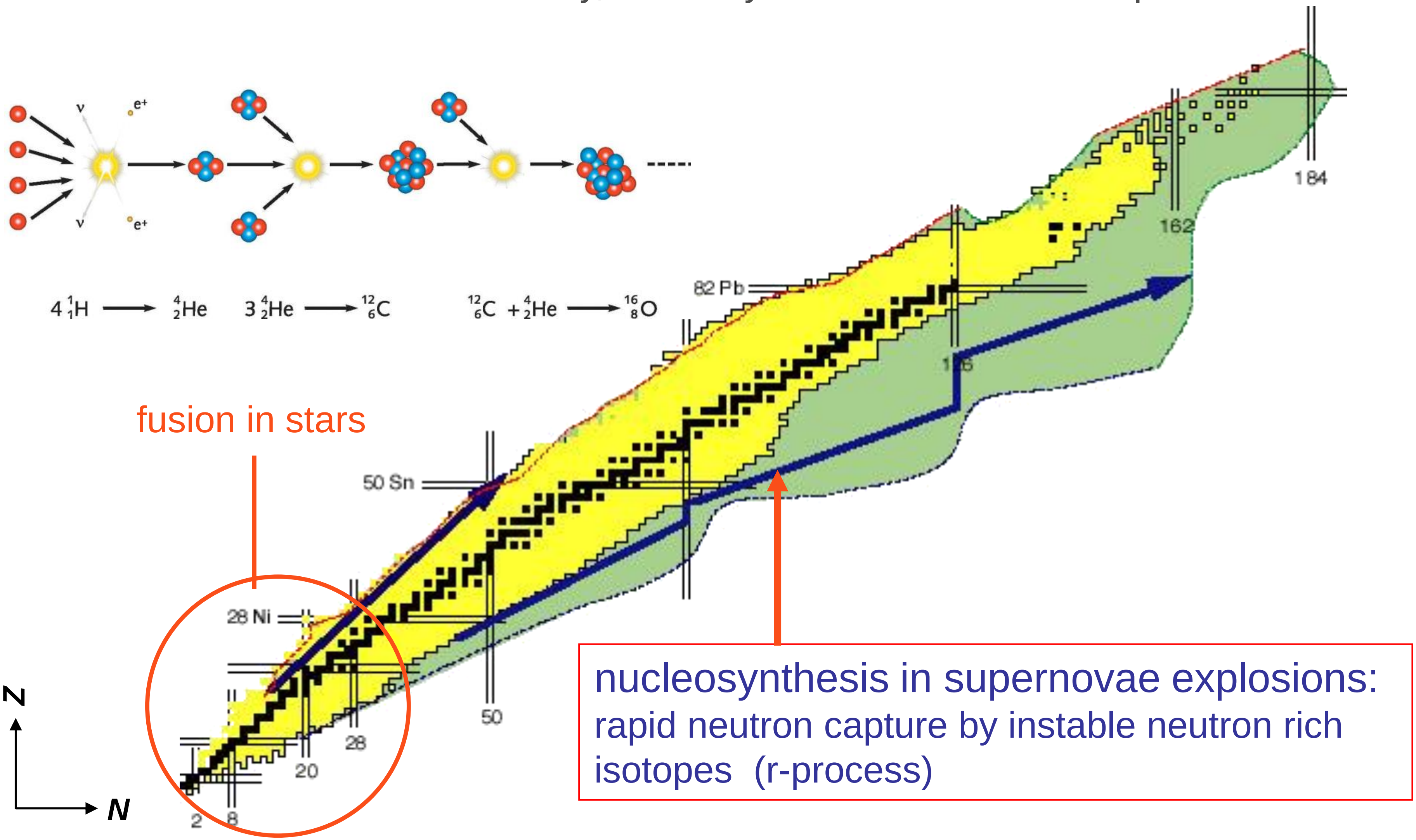
Antiprotons: up to 30 GeV



Research Programs at FAIR (SFRS)

Rare isotope beams: nuclear structure and nuclear astrophysics

nuclear structure far off stability, nucleosynthesis in stars and supernovae

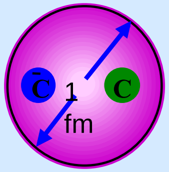


Research Programs at FAIR (PANDA)

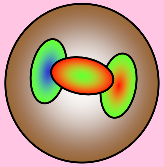
Beams of antiprotons: hadron physics

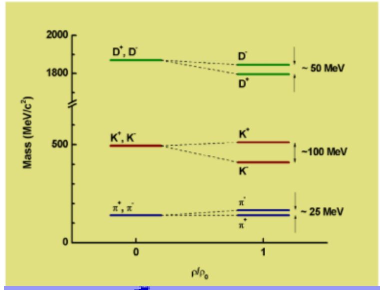
quark-confinement potential, search for gluonic matter and hypernuclei, ...

Charmonium ($c\bar{c}$) spectroscopy:
precision measurements of mass, width, and decay channels of charmonium states ($\rightarrow$ quark confinement)



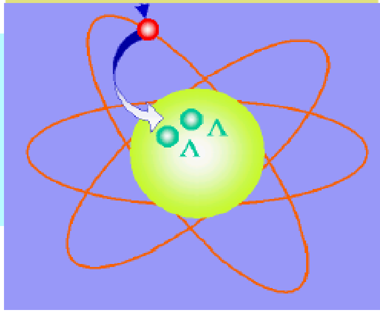
Search for gluonic excitations:
Charmed hybrids, glueballs
in the mass region of charmonia (3 – 5 GeV/c^2).





Search for in-medium modifications of hadron properties
Signal for onset of chiral symmetry restoration
at normal nuclear matter density

Precision γ-spectroscopy of single and double hyper nuclei
Information on nuclear structure and on hyperon-nucleon and hyperon-hyperon interaction.



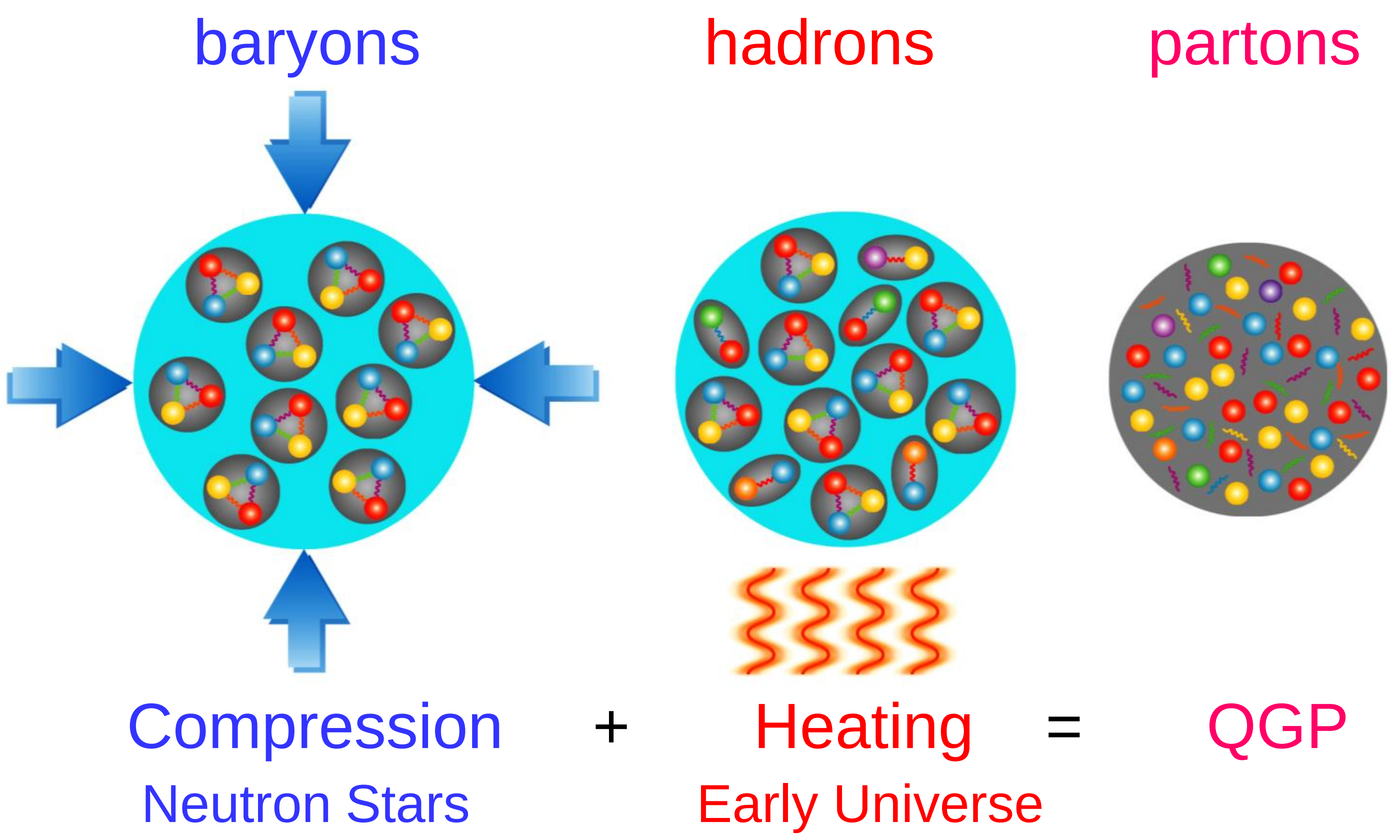
Research Programs at FAIR (CBM)

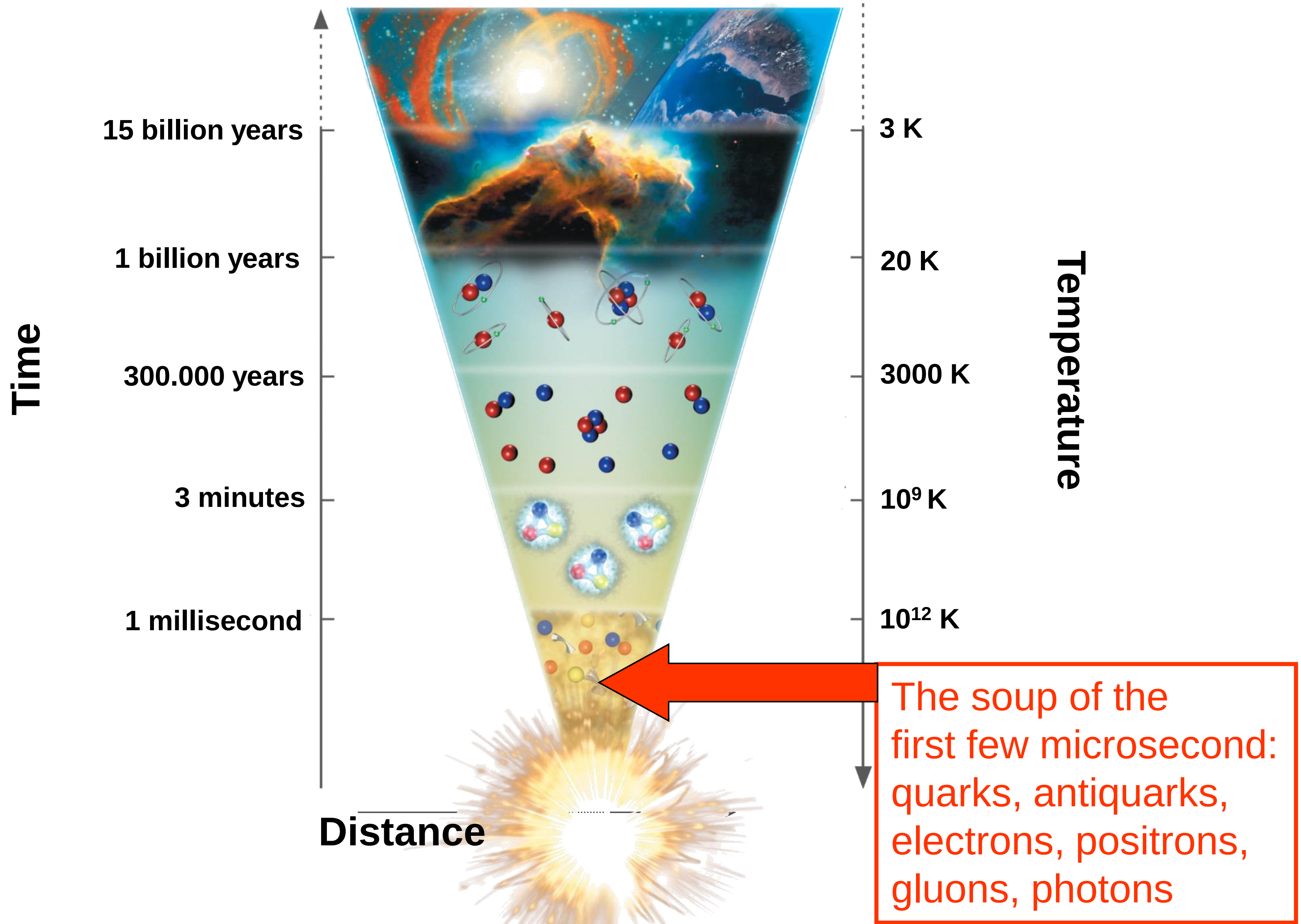
High-energy nucleus-nucleus collisions

Study compressed baryonic matter

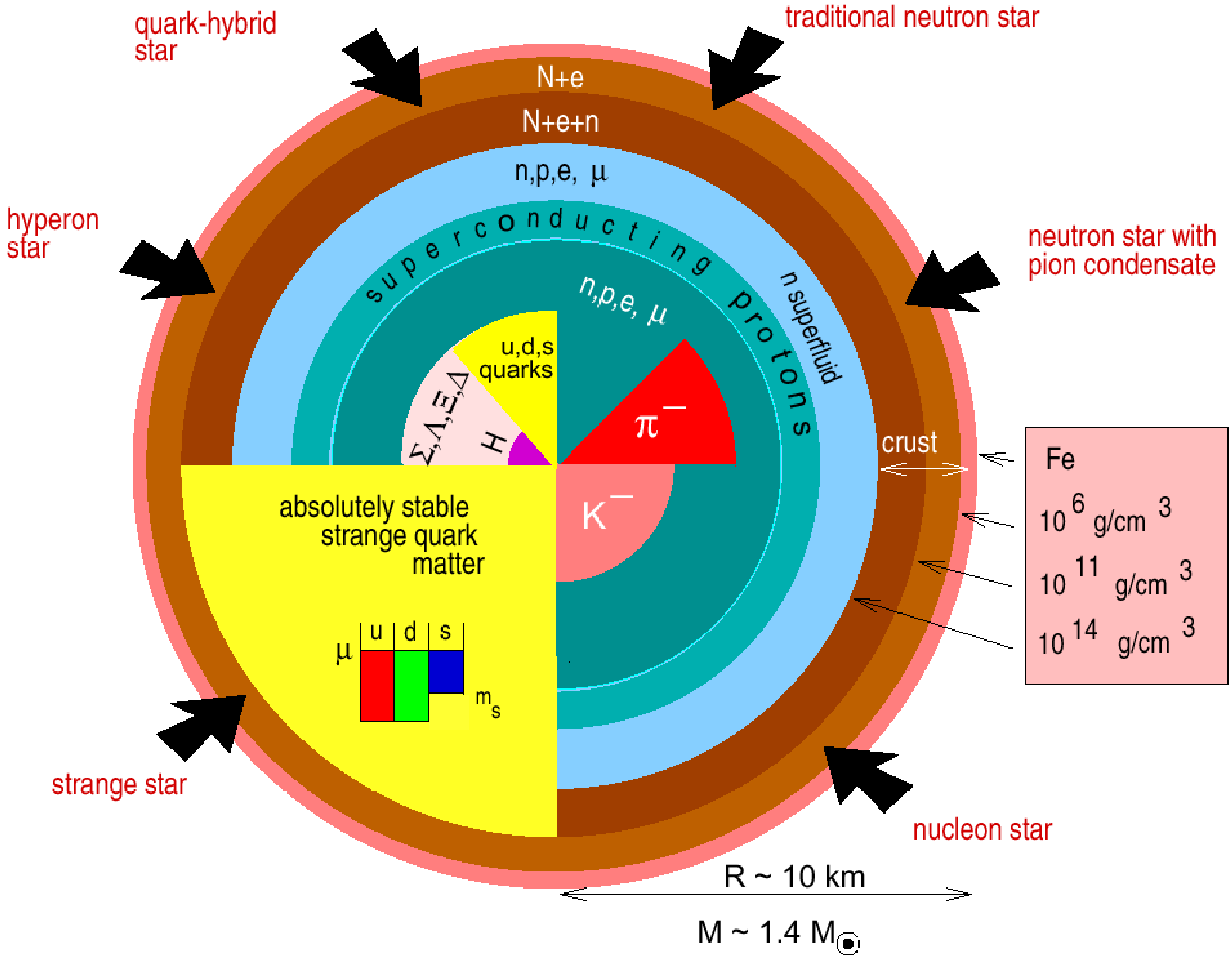
baryonic matter at highest densities (neutron stars)

phase transitions and in-medium properties of hadrons at extreme conditions

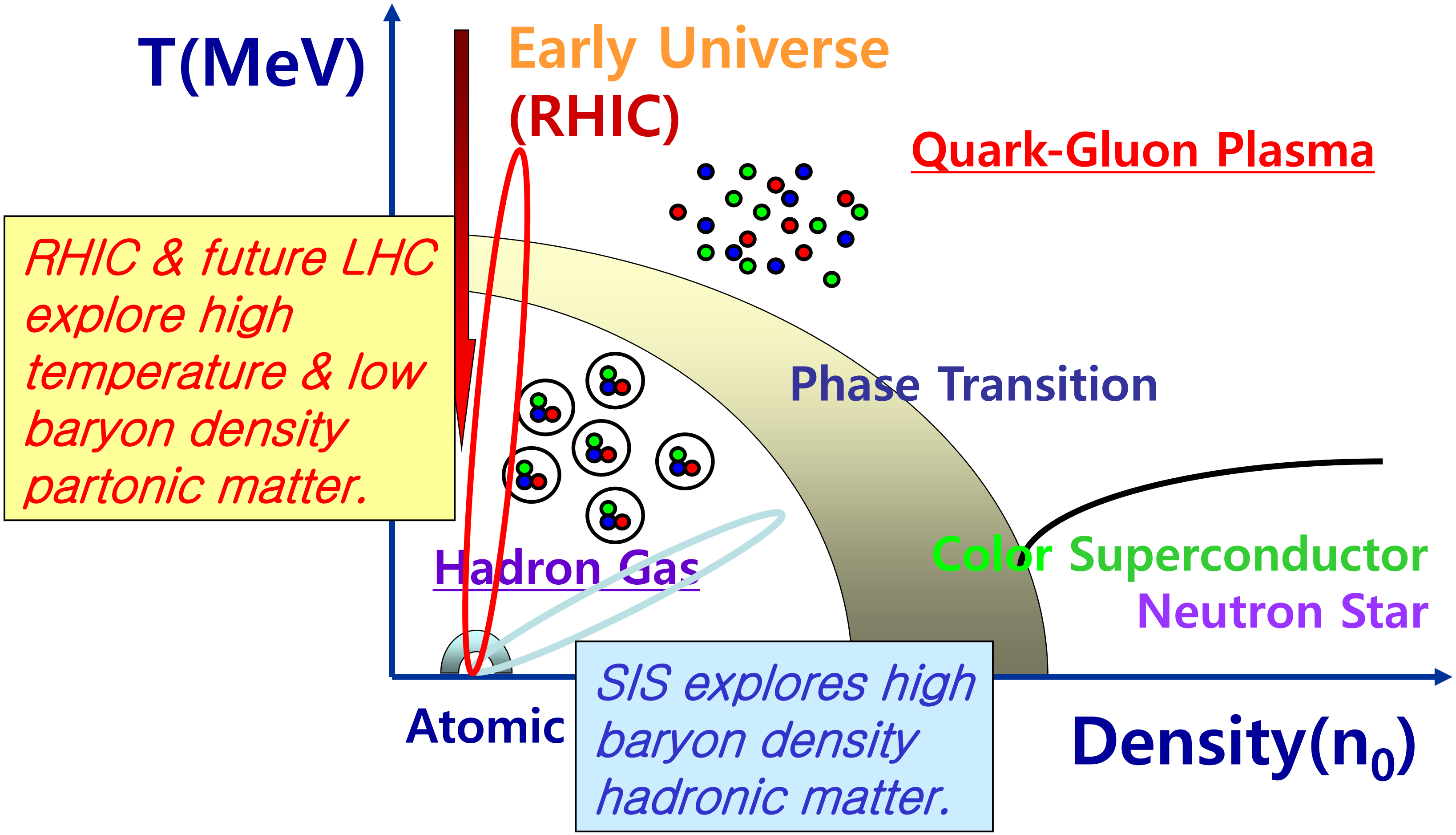



15 billion years
1 billion years
300.000 years
3 minutes
1 millisecond
Time
3 K
20 K
3000 K
10^9 K
10^{12} K
Temperature
Distance
The soup of the
first few microsecond:
quarks, antiquarks,
electrons, positrons,
gluons, photons

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

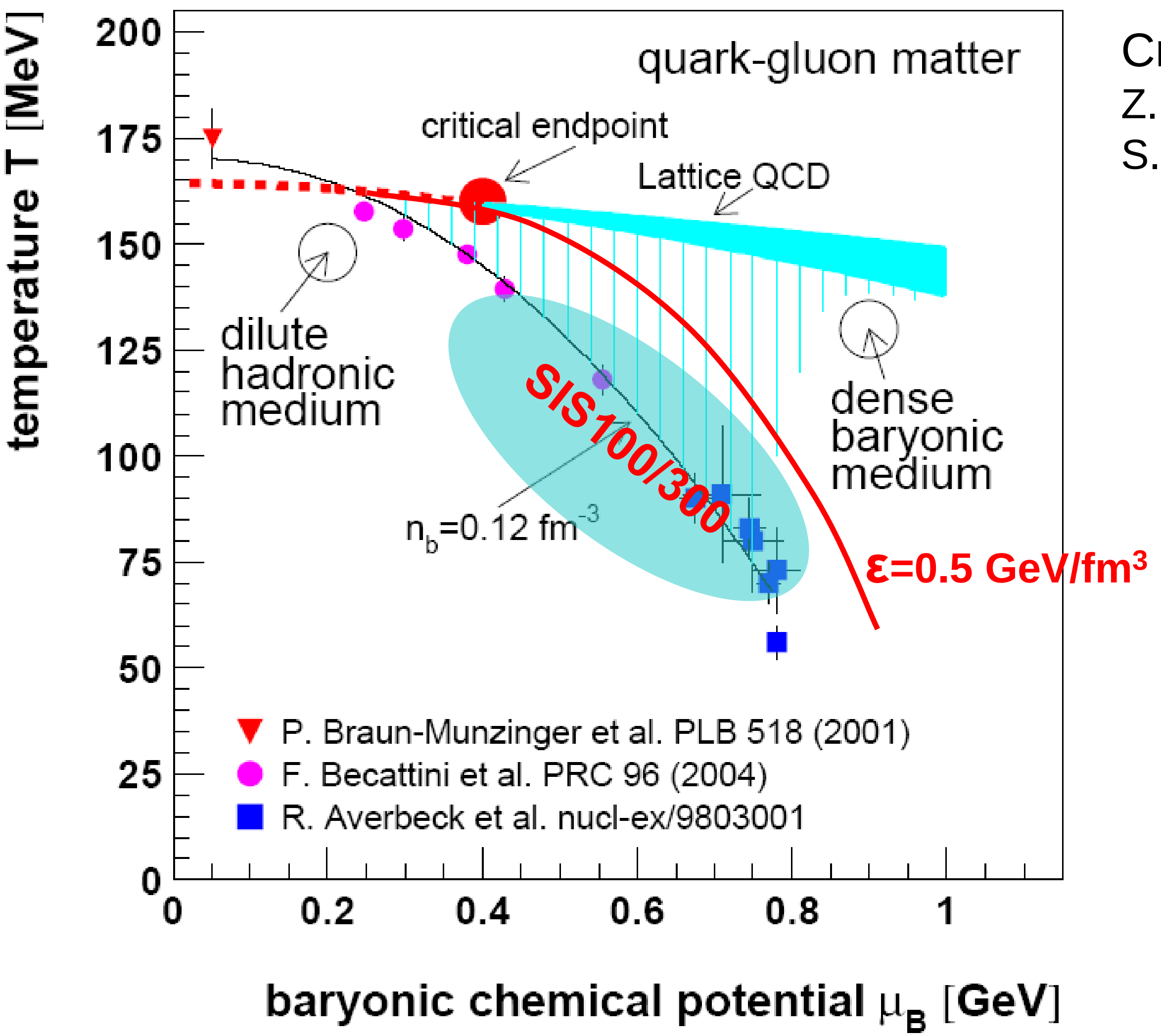


Nuclear Phase Diagram



Relativistic Heavy-Ion Accelerators

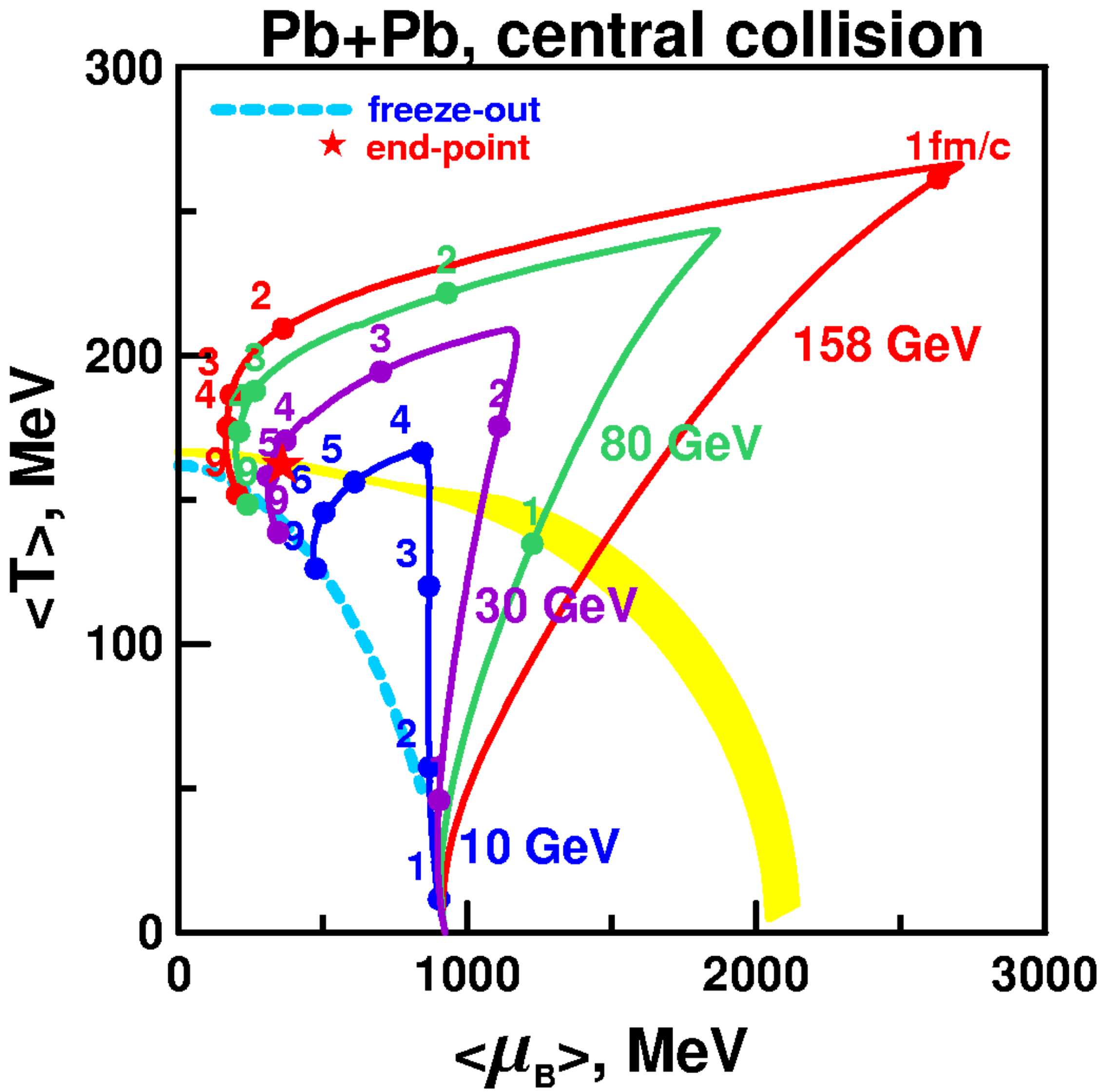
Accelerator	c.m. Energy (GeV)	Status
SIS18 (GSI, Germany)	**2A (A=mass number)**	Running
AGS (BNL, USA)	**5A**	Finished
SIS300 (GSI, Germany)	**8A**	Plan to run from ~2014
SPS (CERN, Switzerland)	**20A**	Finish soon
RHIC (BNL, USA)	**200A**	Running since 2000
LHC (CERN, Switzerland)	**5500A**	Plan to run from ~2007



Critical endpoint:

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

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



Ivanov & Toneev
Hadron gas EOS

Hydrodynamic calculations reproduce the freeze-out conditions

30A GeV trajectory is very close to the critical endpoint

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?

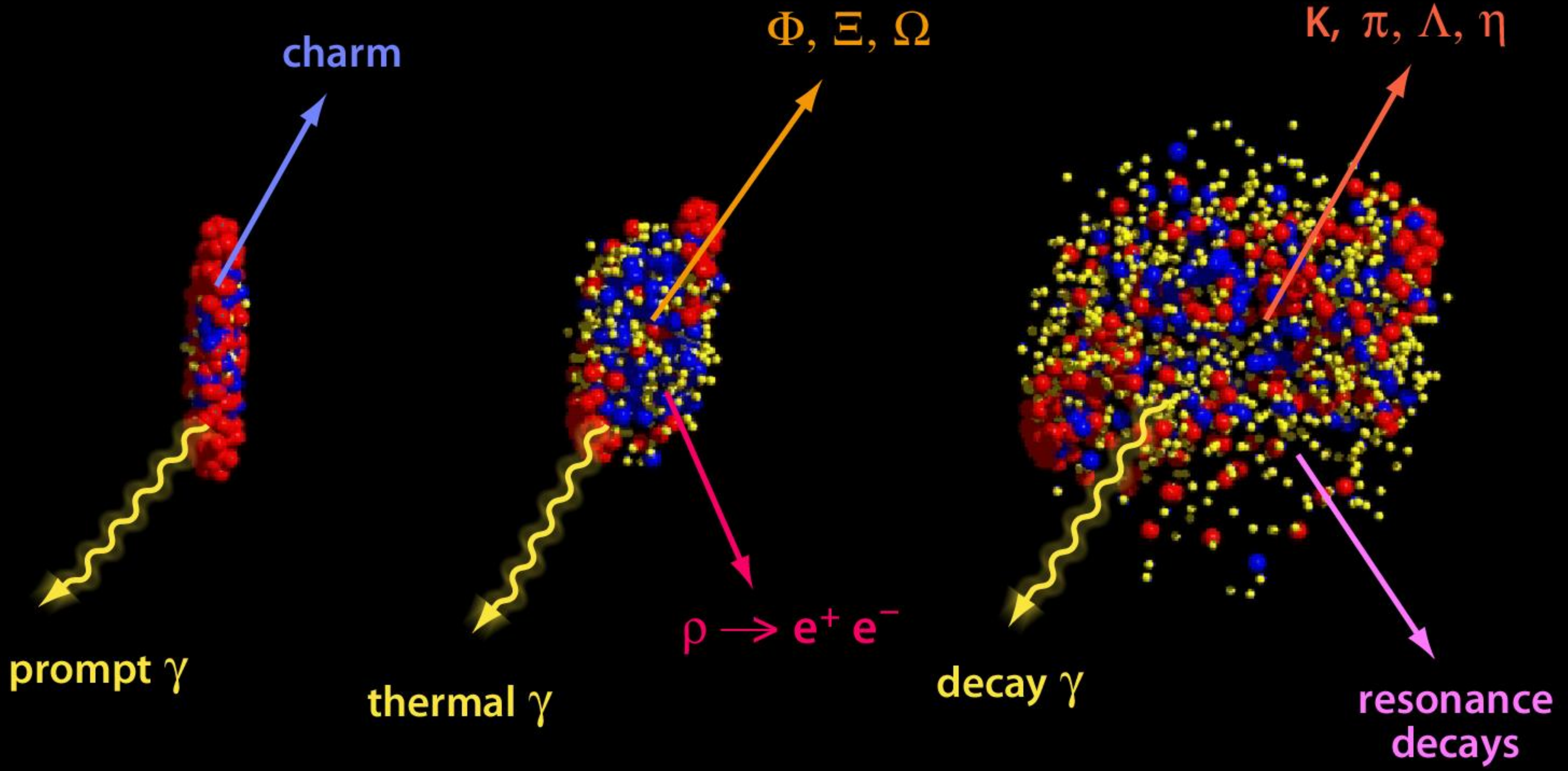
observables: J/ψ, D

excitation function of flow (softening of EOS)

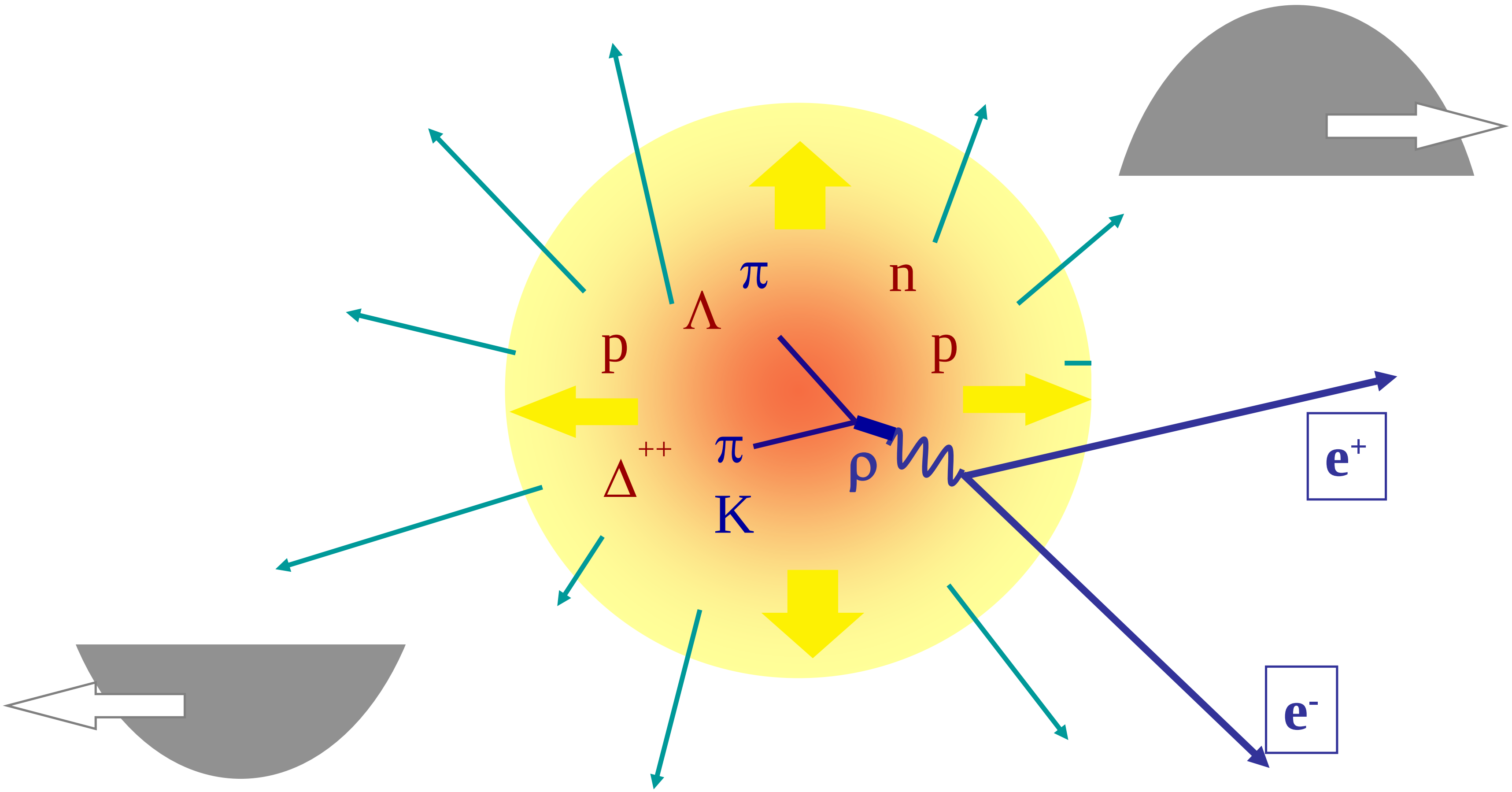
4. Critical point

observables: event-by-event fluctuations

Diagnostic Signals at Various Stages



Looking into the fireball,

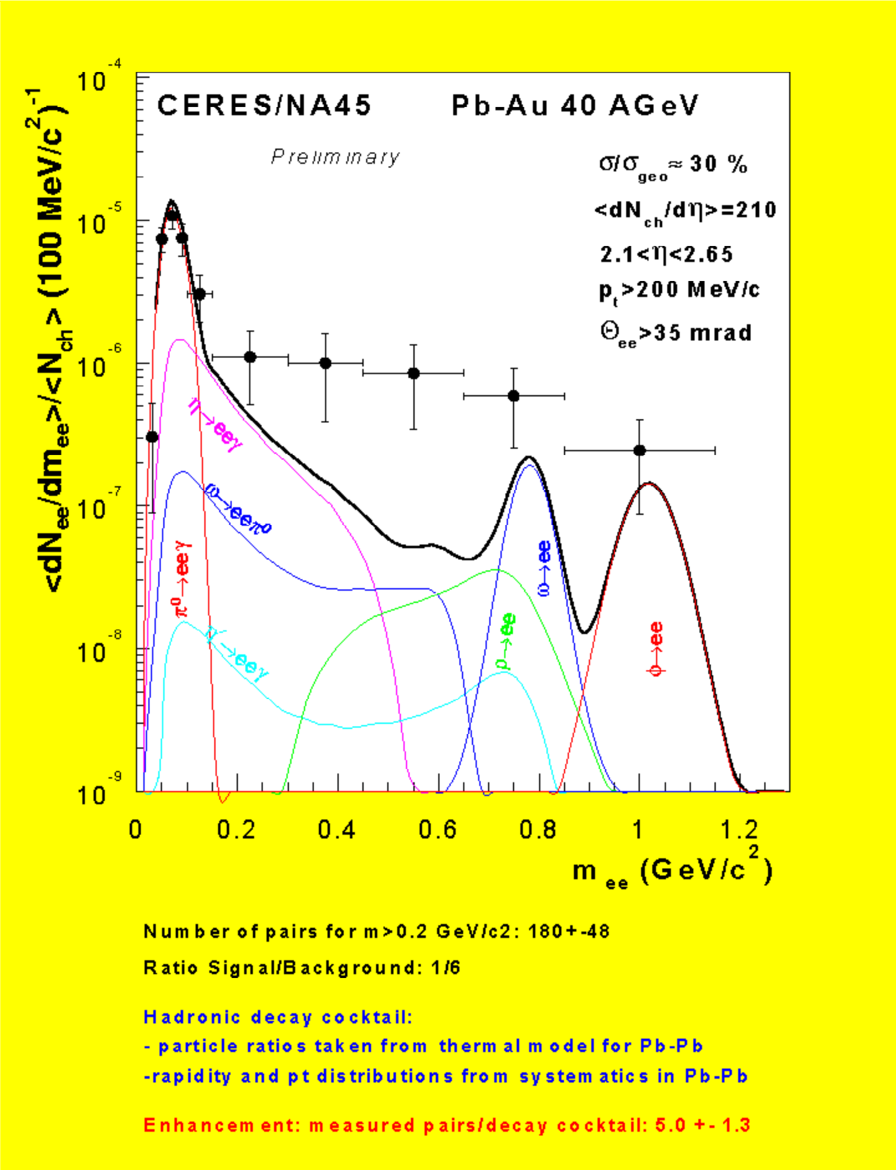


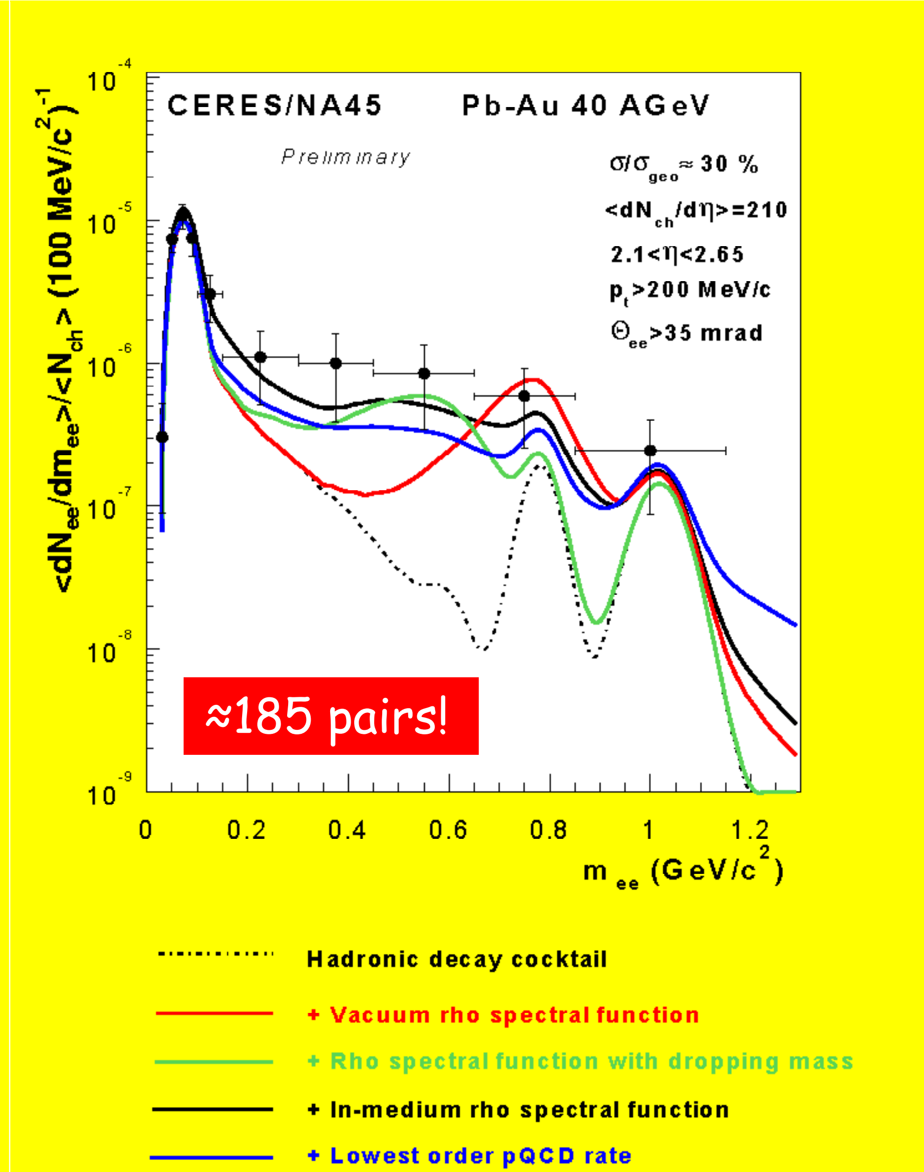
… using the penetrating probes:

short-lived vector mesons decaying into electron-positron pairs

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

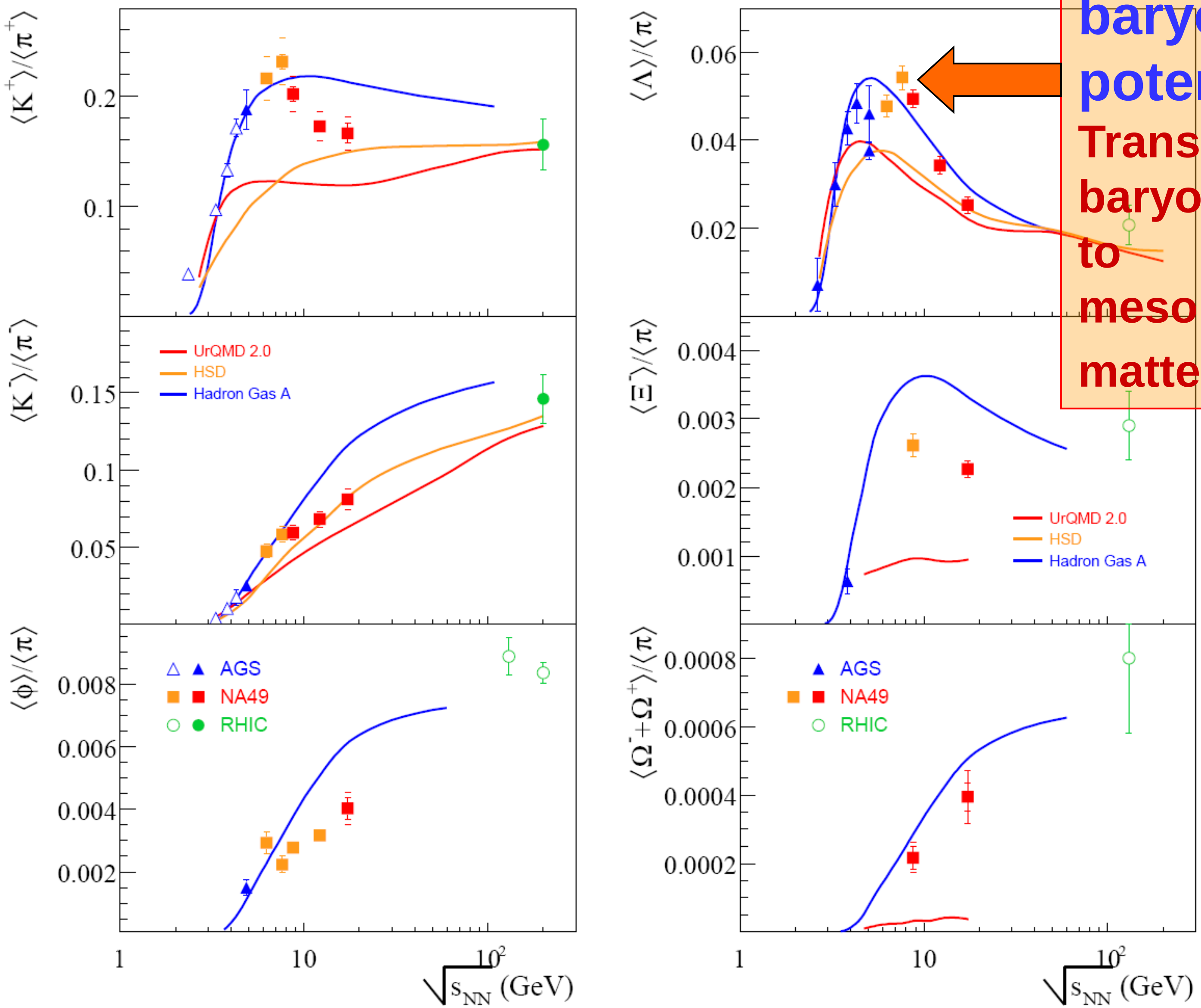
CERES Collaboration: D.Adamova et al., Phys. Rev. Lett. 91 (2003) 042301





Strangeness Production

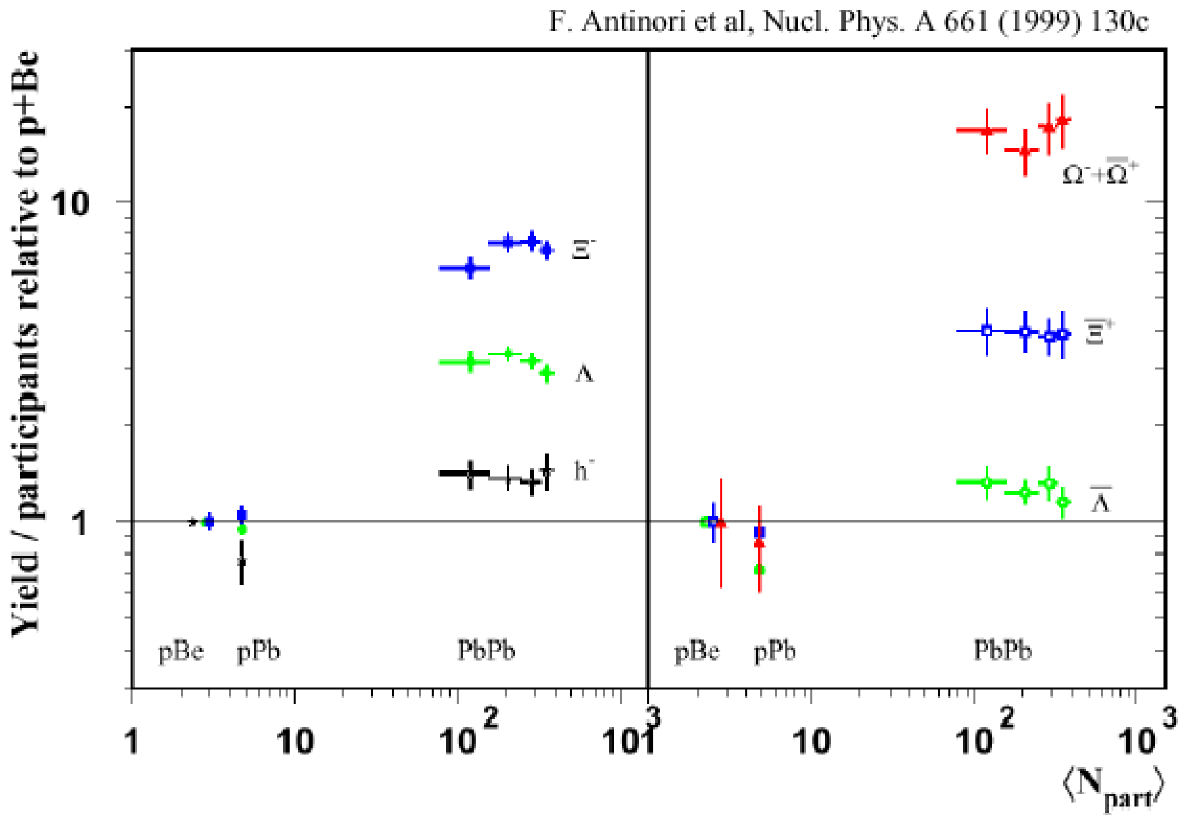
C. Blume et al., nucl-ex/0409008



Decrease of baryon-chemical potential:

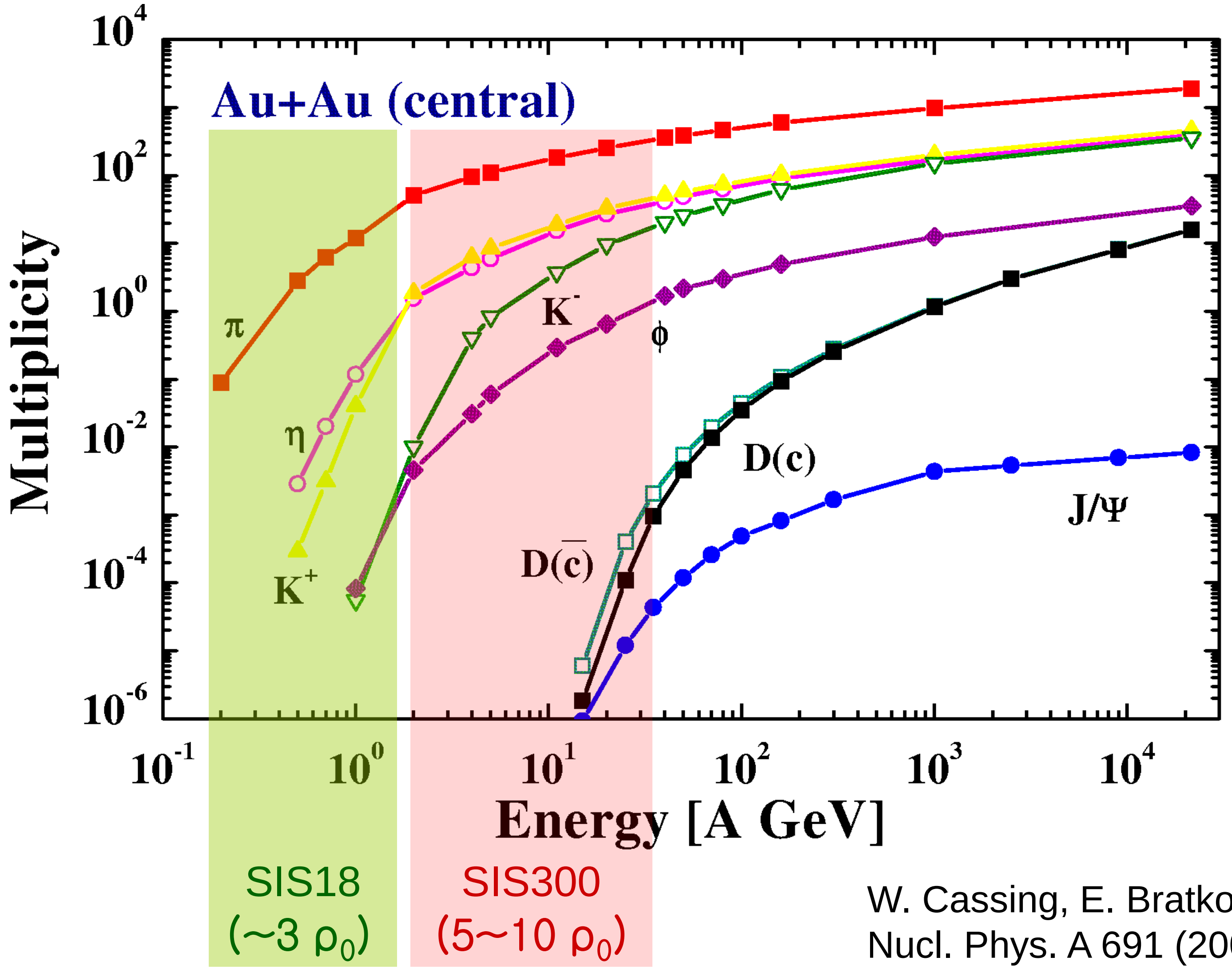
Transition from baryon-dominated to meson-dominated matter

Strangeness Production



When the enhancement of hyperons starts?

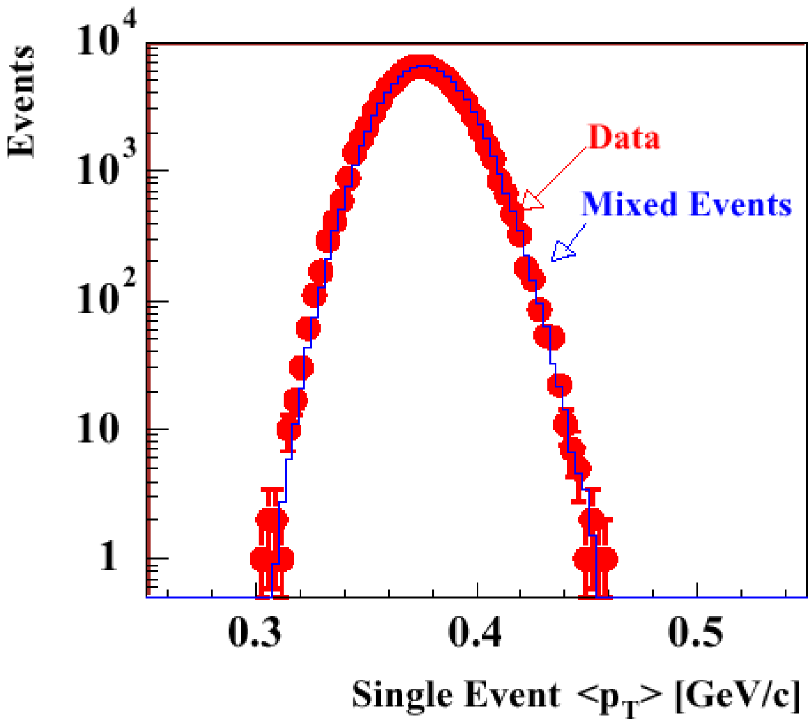
Charm Production

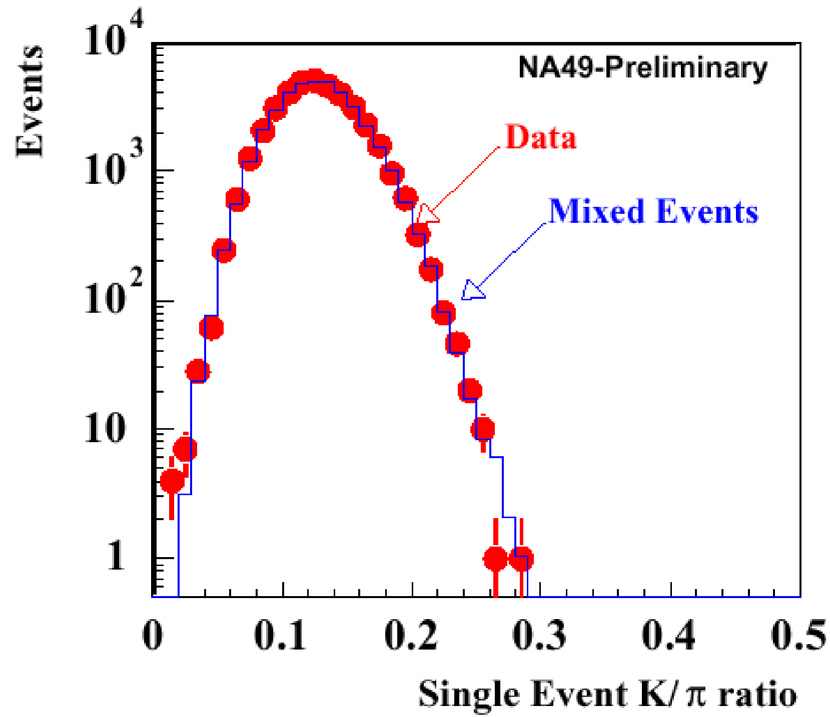


W. Cassing, E. Bratkovskaya, A. Sibirtsev
Nucl. Phys. A 691 (2001) 745

Event-by-Event Fluctuations

NA49: 5% most central Pb+Pb collisions at 158A GeV

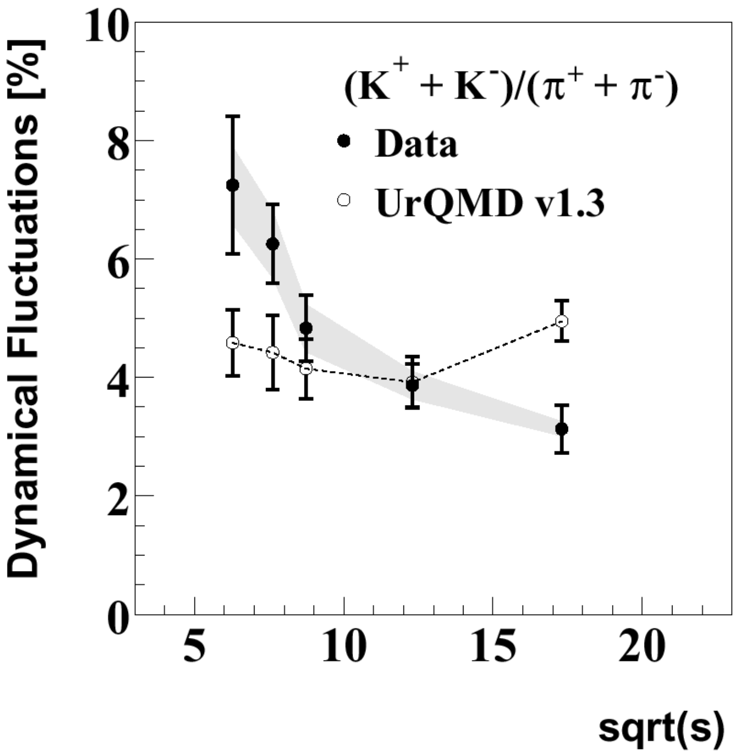


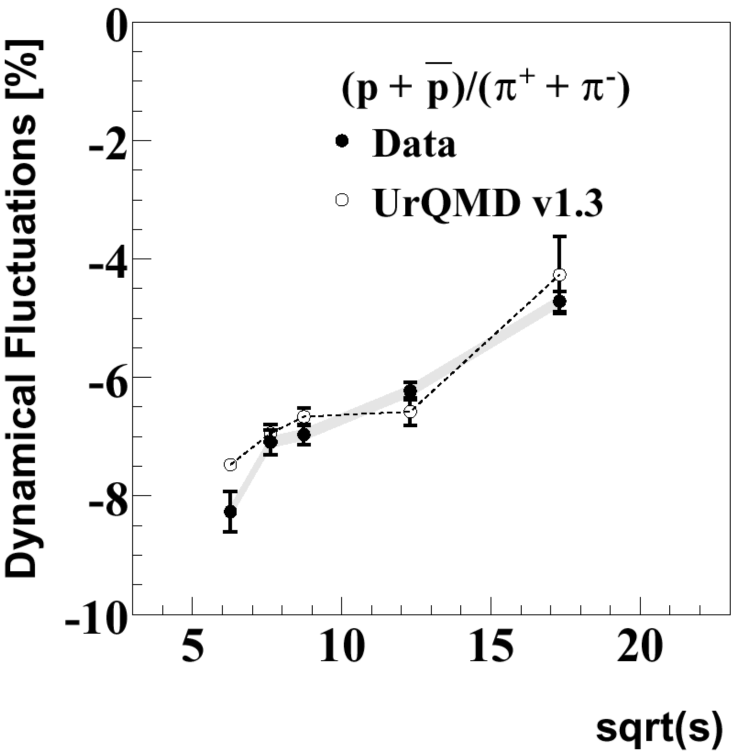


At the critical point:
Large density fluctuations,
critical opalescence

Fluctuations from NA49

nucl-ex/0403035

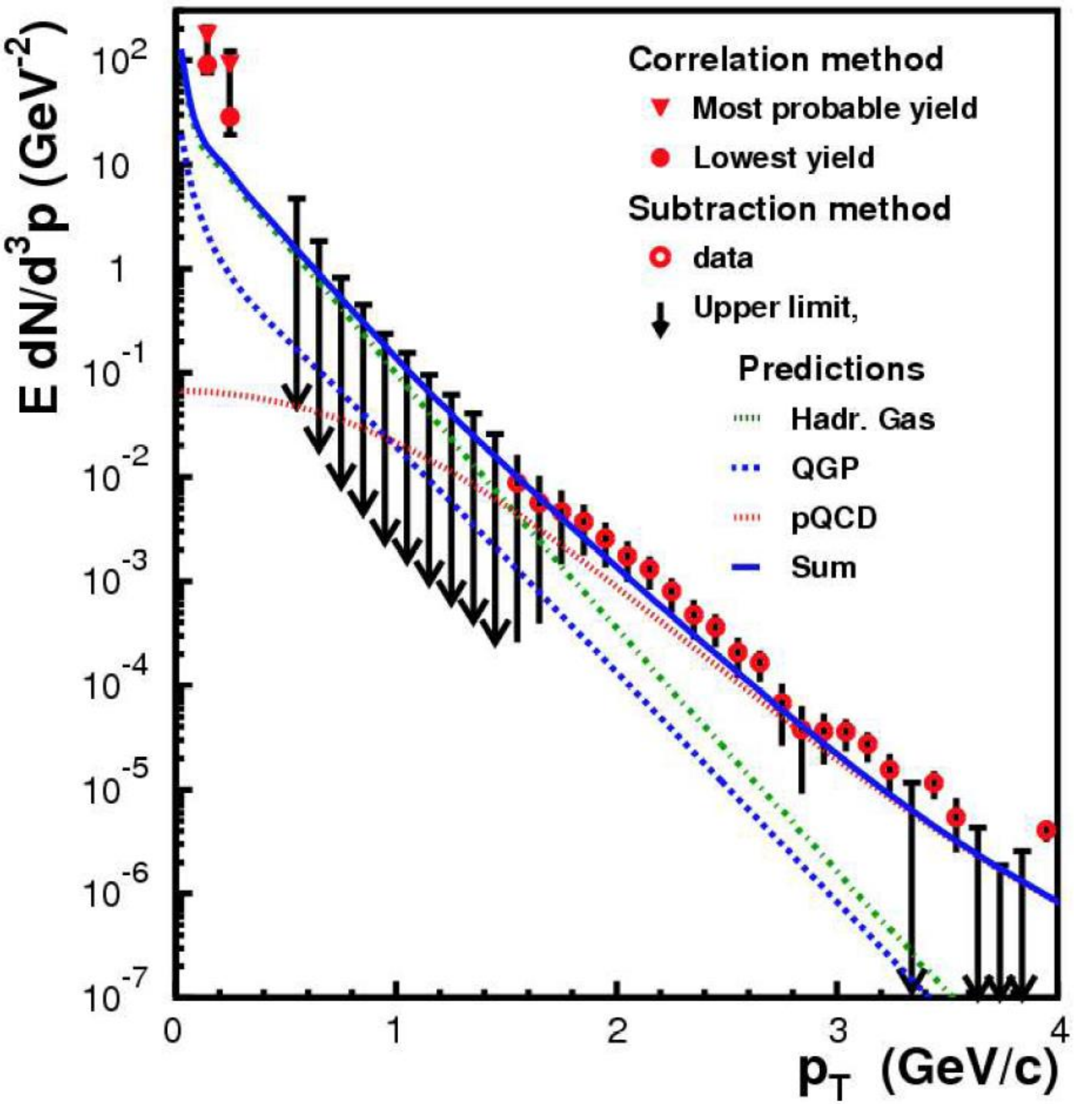




- dynamical fluctuations reported by NA49
- increase towards low energies
- K/π : not reproduced by UrQMD
- p/π : correlation due to resonance decays

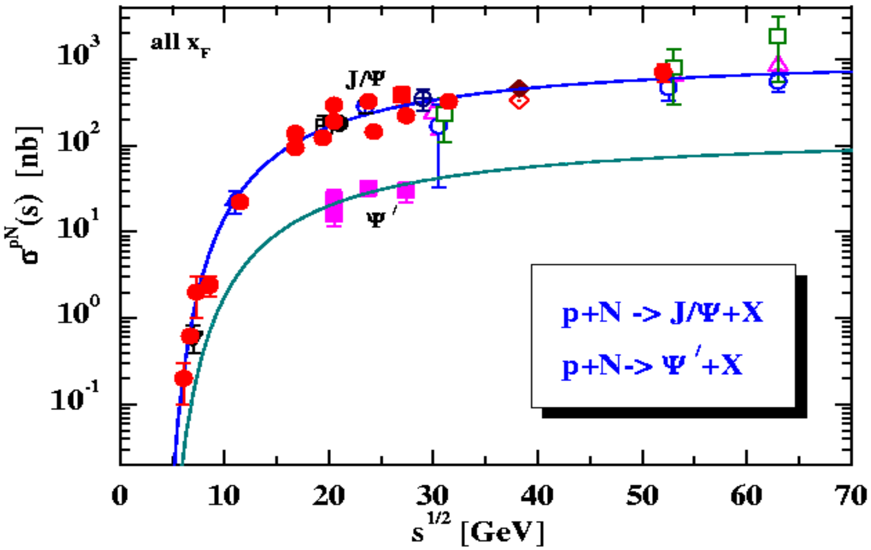
Photons

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



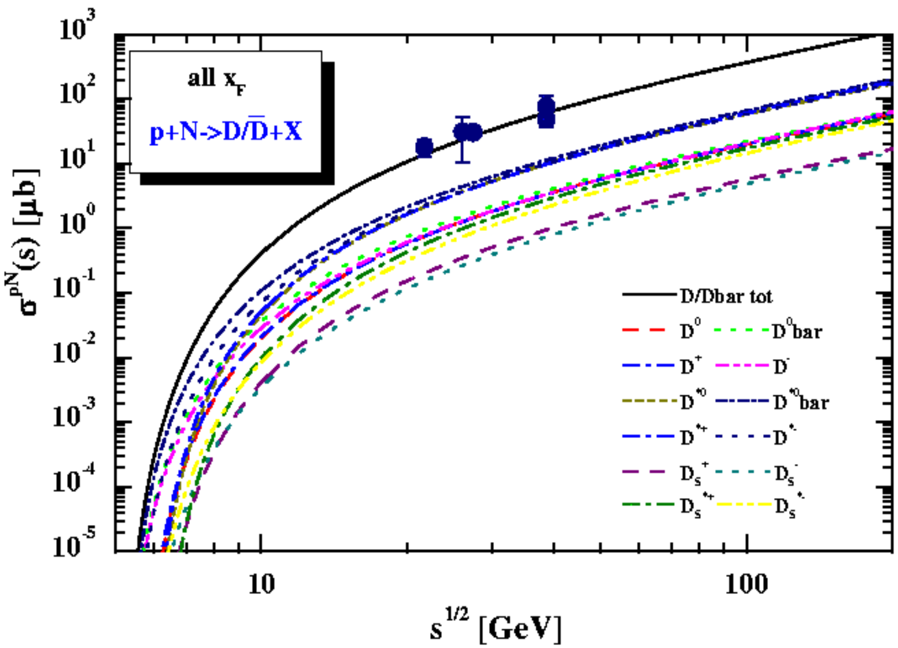
Requirements

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 $J/\psi \to e^+e^-$ ($\mu^+\mu^-$)	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):

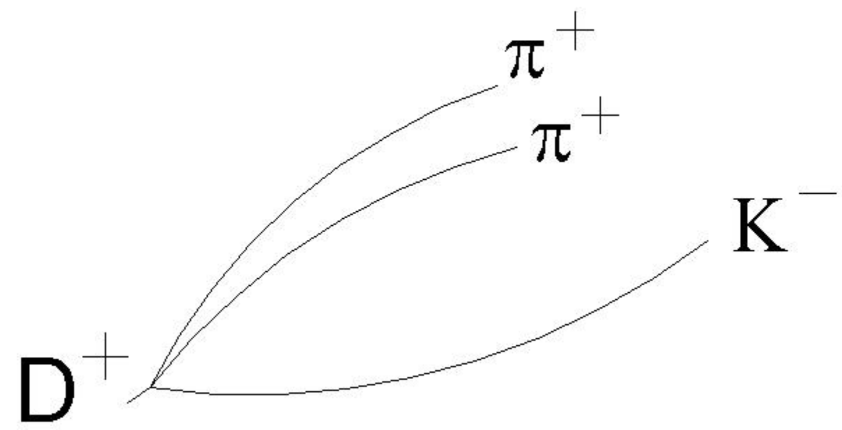
$D^+ \to K^0\pi^+$ (2.9±0.26%)

$D^+ \to K^-\pi^+\pi^+$ (9 ± 0.6%)

D^0 ($c\tau$ = 124.4 μm):

$D^0 \to K^-\pi^+$ (3.9 ± 0.09%)

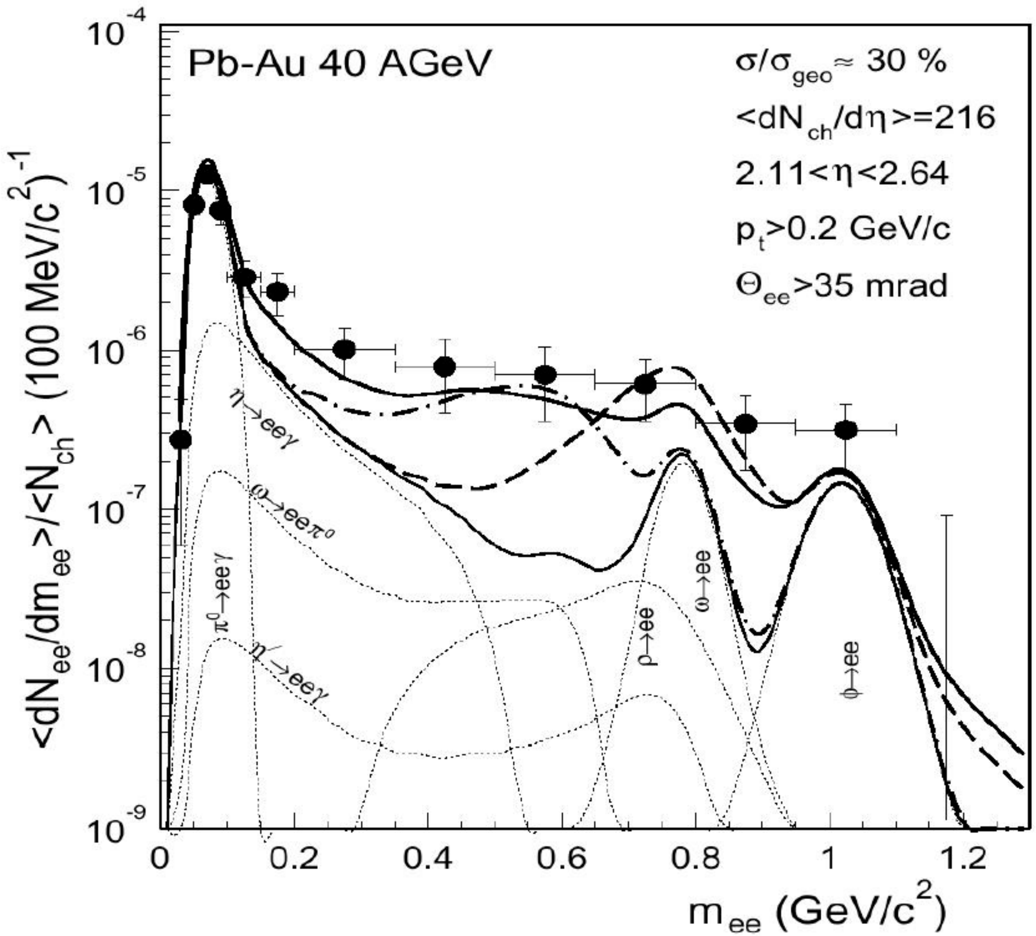
$D^0 \to K^-\pi^+\pi^+\pi^-$ (7.6 ± 0.4%)



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

High Precision on Tracking !

Requirements



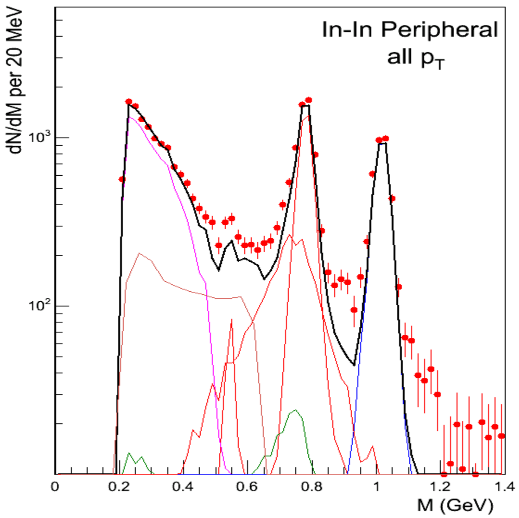
Dominant background in e^+e^- invariant mass spectrum:
π^0-Dalitz decay and gamma conversion

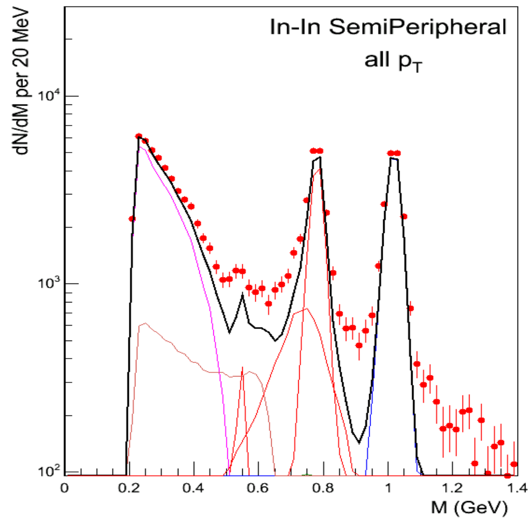
Good identification of soft electrons and positrons !

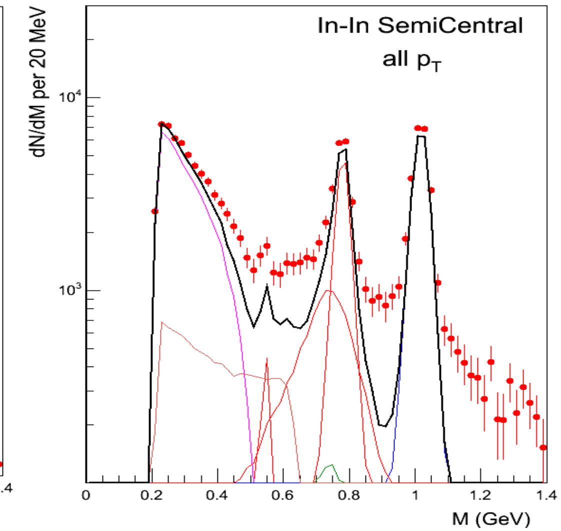
Requirements

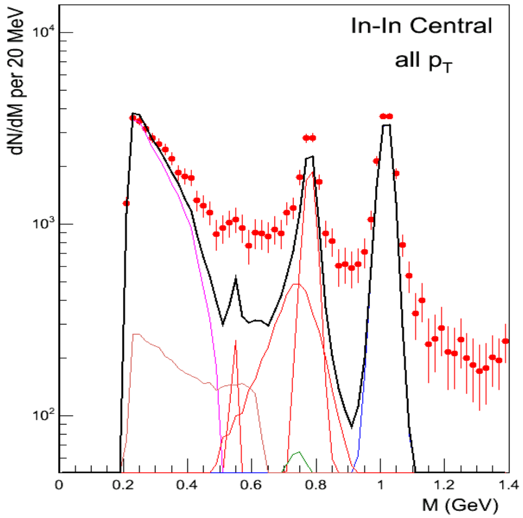
- data (NA60 presented at QM05)

—— sum of cocktail sources including the ρ contribution





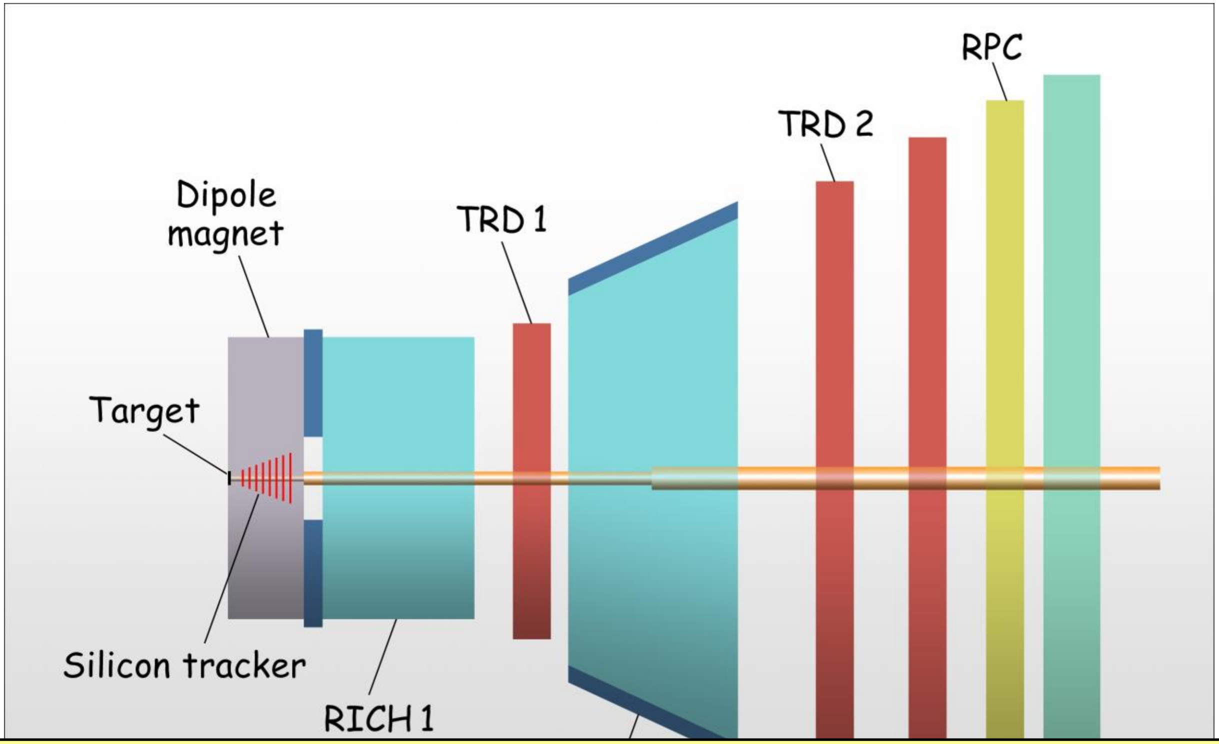




Muon channels usually show a much better mass resolution with smaller background.

We may need the muon detectors !

CBM Detector Proposal



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

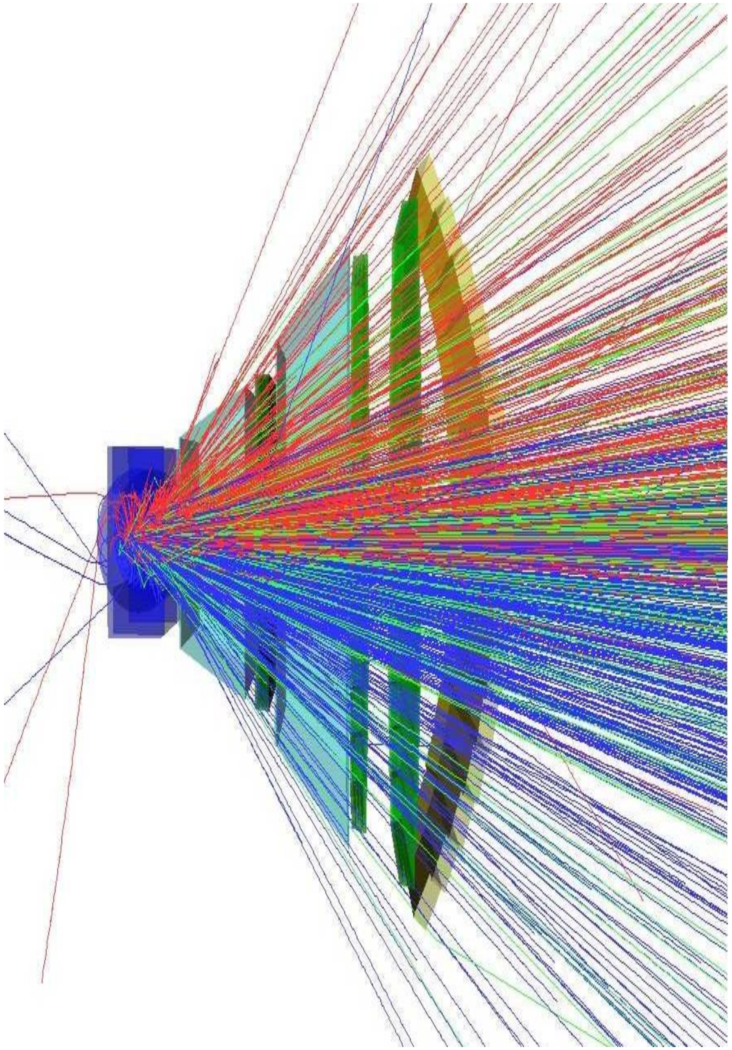
Electron identification: RICH & TRD & ECAL for the pion suppression up to 10^5

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°

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)

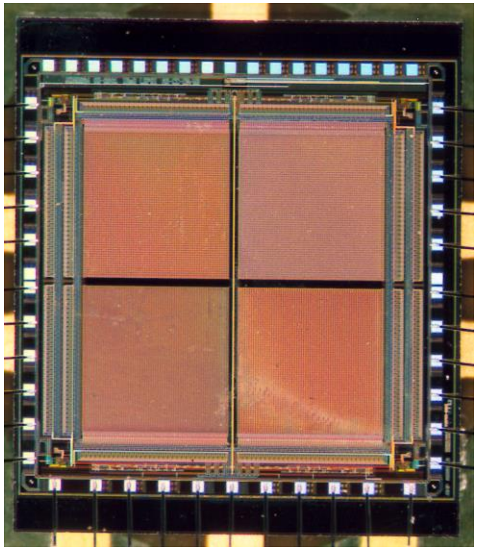
Design goals:

- 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

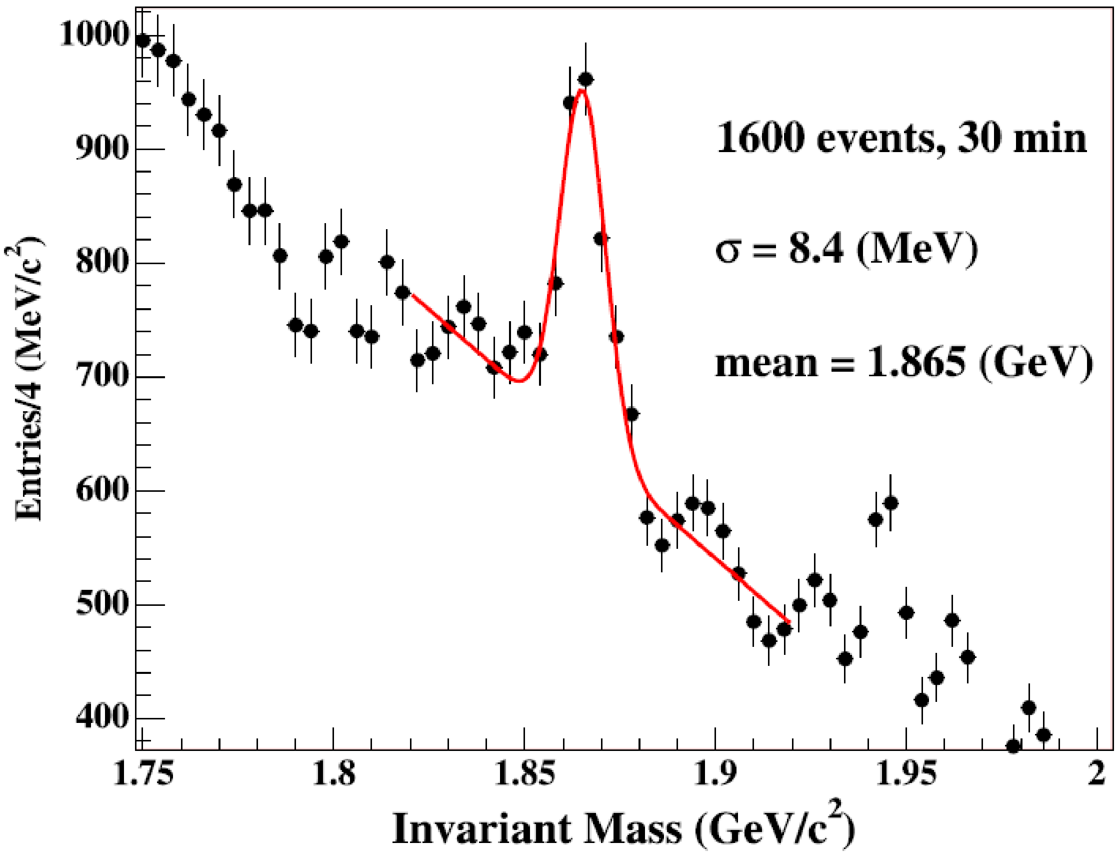


MIMOSA IV
IReS / LEPSI Strasbourg

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

D-meson Reconstruction

Track reconstruction (Kalman filter) without magnetic field, dp/p = 1%
using track information from MAPS Silicon Tracker only (no particle ID)

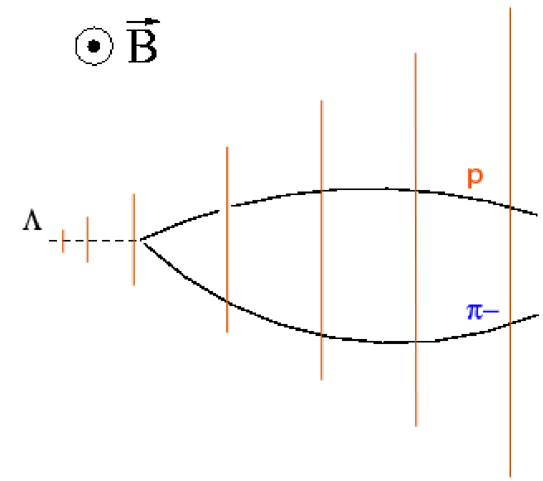


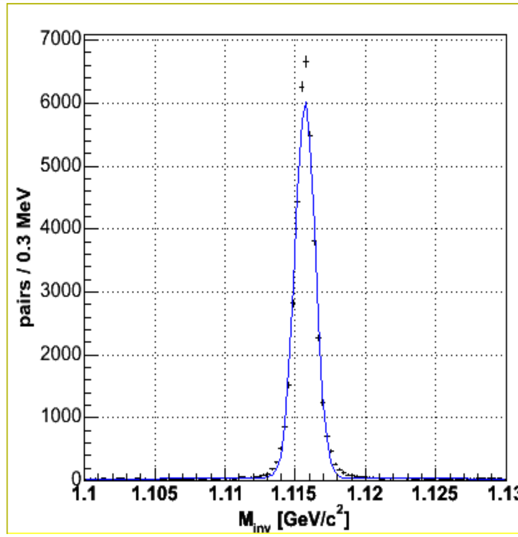
cut	optimised value	signal efficiency [%]
track IP cuts	80 <IP< 500 μm	28
p-cut	1.0 *GeV/c*	72
pt-cut	0.5 *GeV/c*	61
z-vertex cut	250 μm	54
D^0 *pointing cut*	30 μm	99
vertex χ^2 *cut*	≤5	91
all cuts	-	5.3

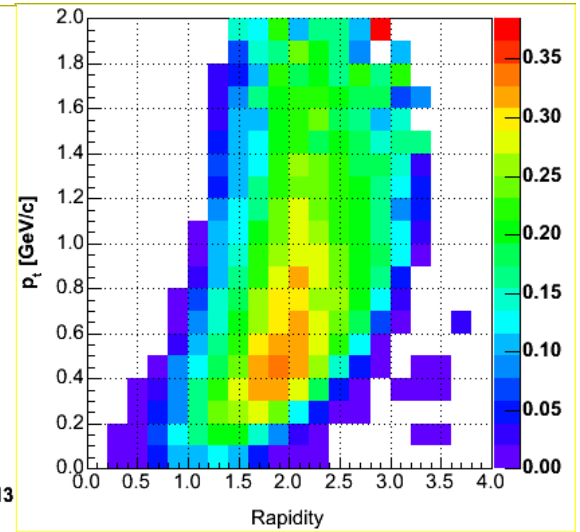
Event reduction factor: 1000

Vertex trigger with MAPS:
~ 1 MHz reaction rate
~ 300 D mesons per hour

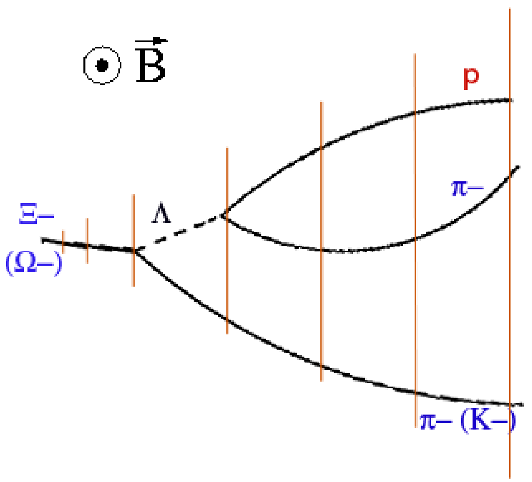
Hyperon with STS only

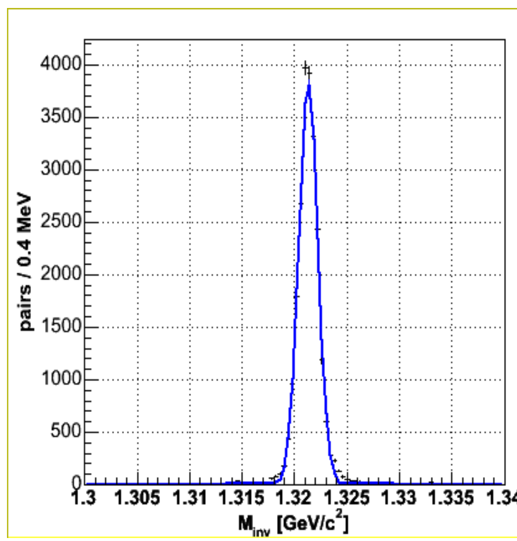


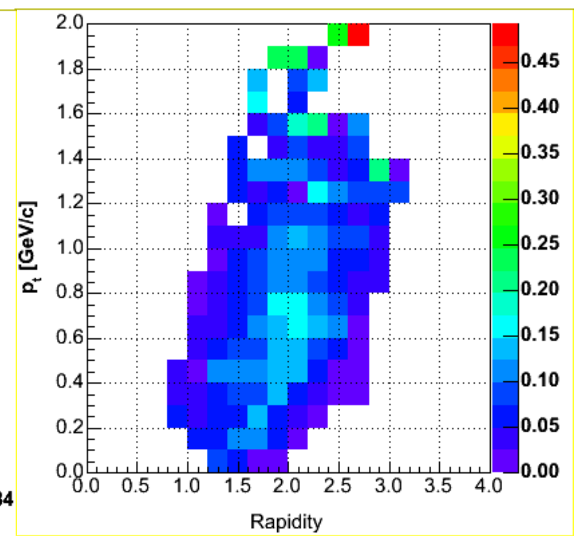




efficiency 15.8%







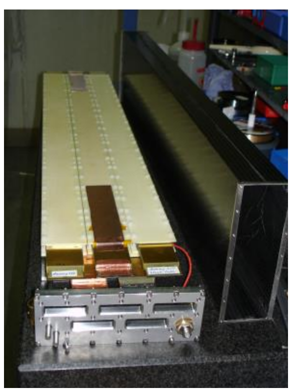
6.7%

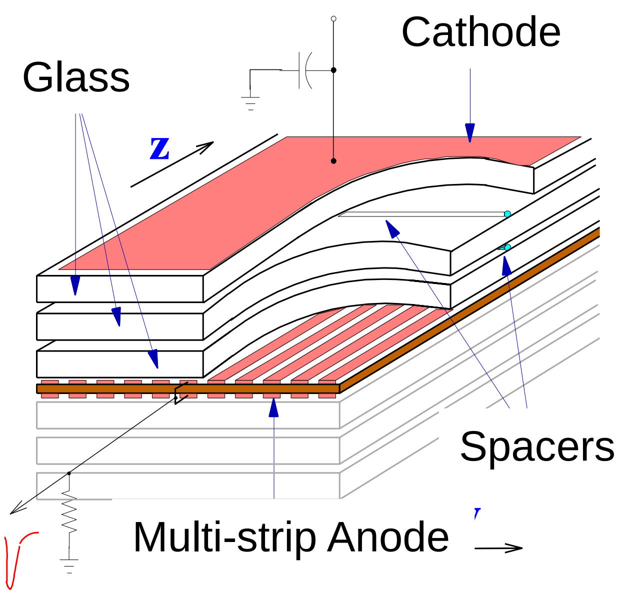
TOF Resistive Plate Chamber

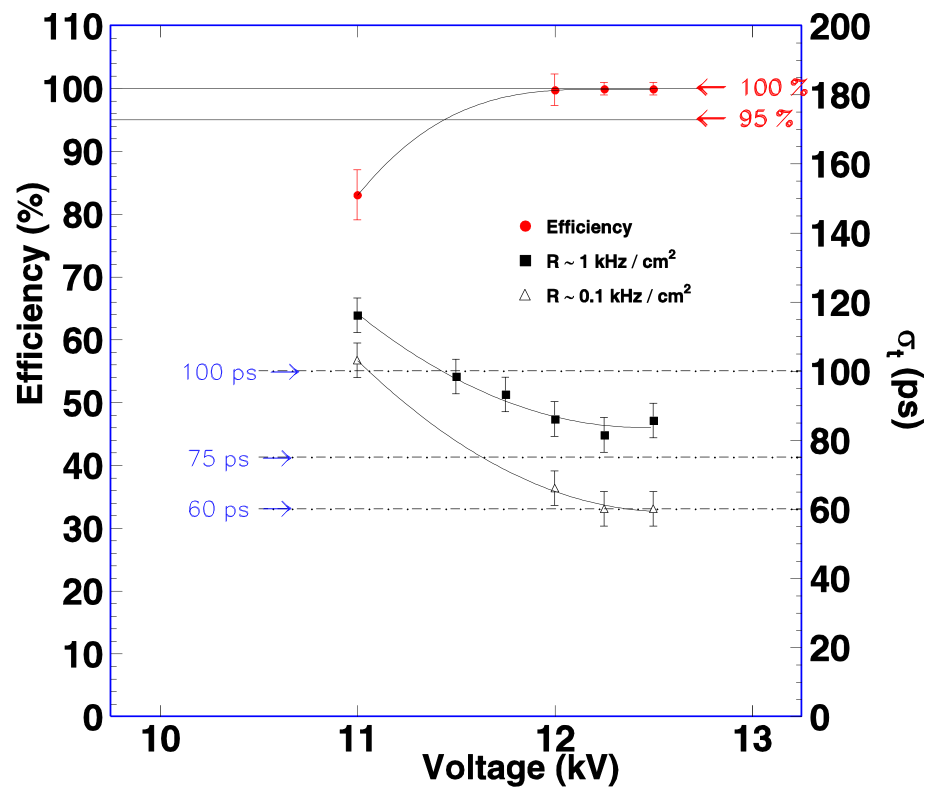
Design goals:
- Time resolution ≤ 80 ps
- Rate capability up to 20 kHz/cm²
- Efficiency > 95 %
- Large area ≈ 100 m²
- Long term stability

Various options are under investigation:
- Strip vs. pad readout
- Single cell vs. multichannel RPC
- Glass vs. plastic electrodes

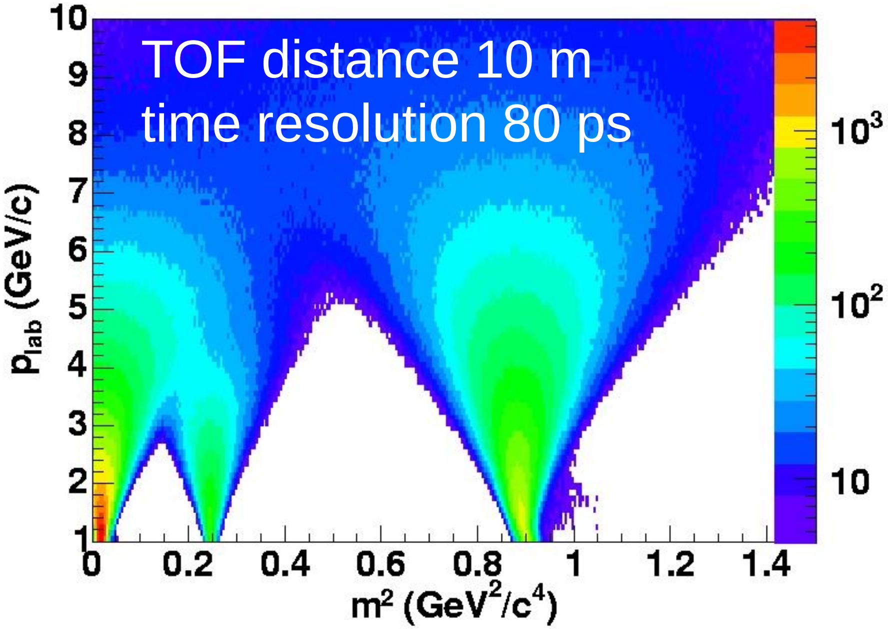
FOPI MMRPC project

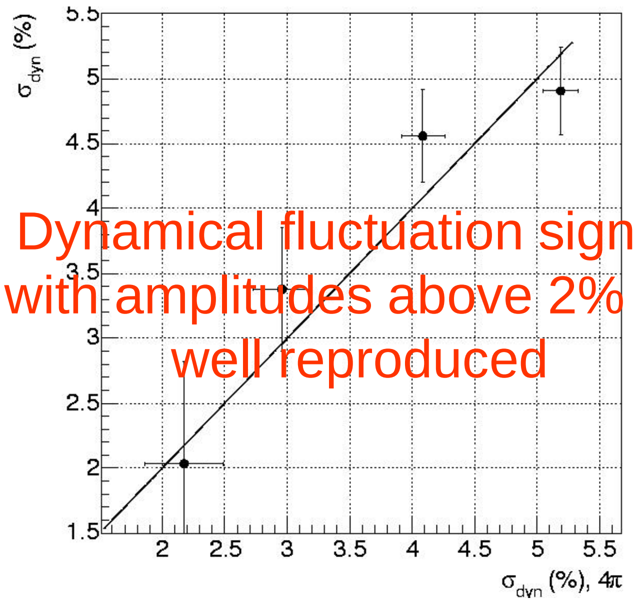




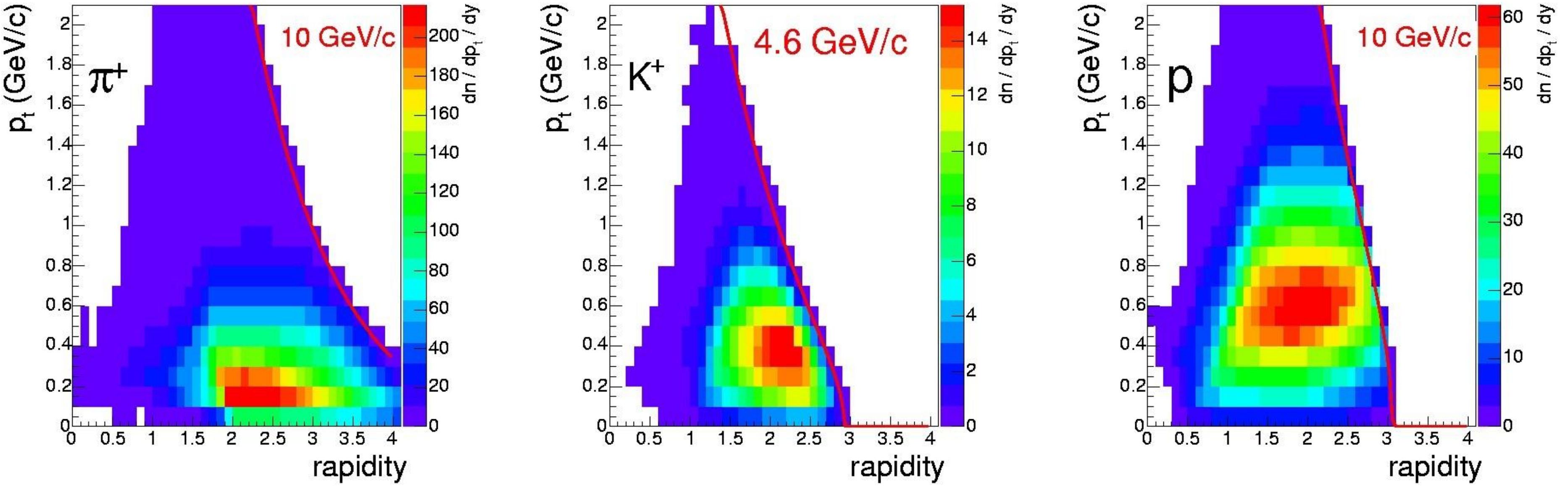


Particle Identification with TOF





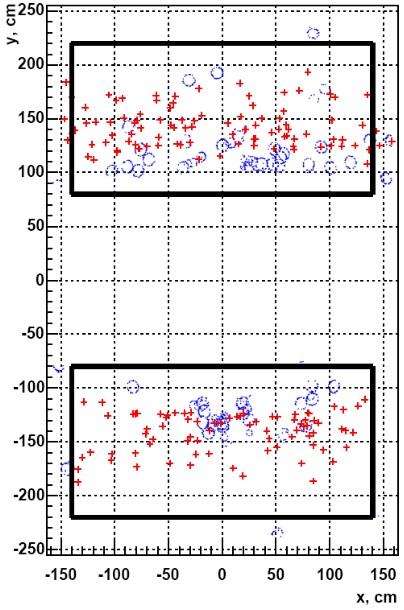
Dynamical fluctuation signals with amplitudes above 2% are well reproduced

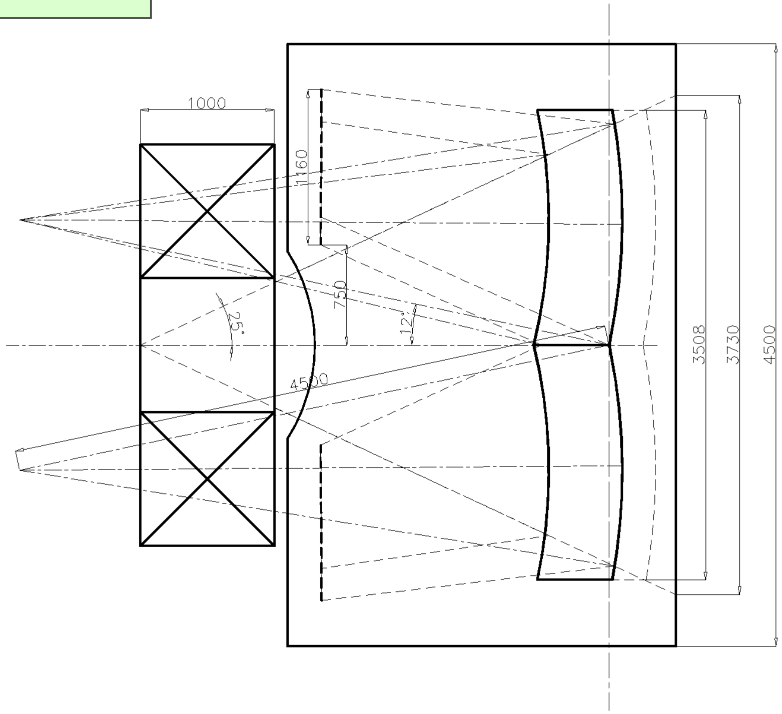


Fast RICH

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

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

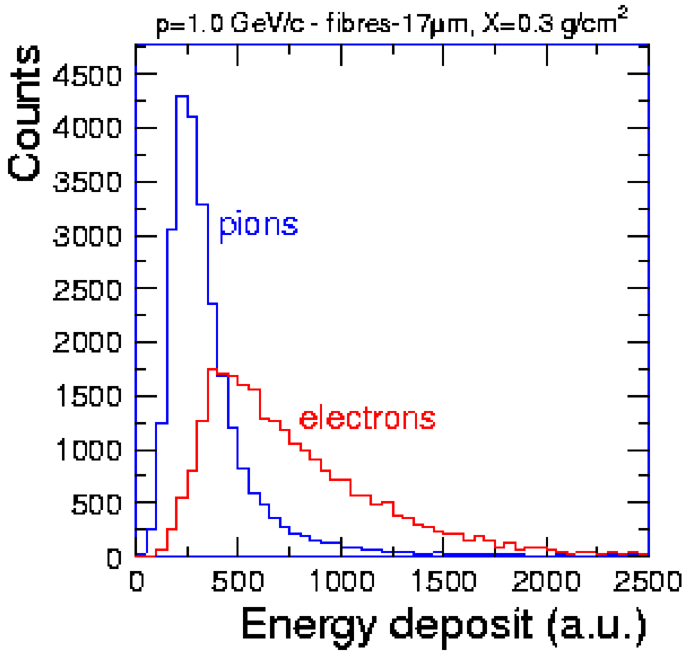




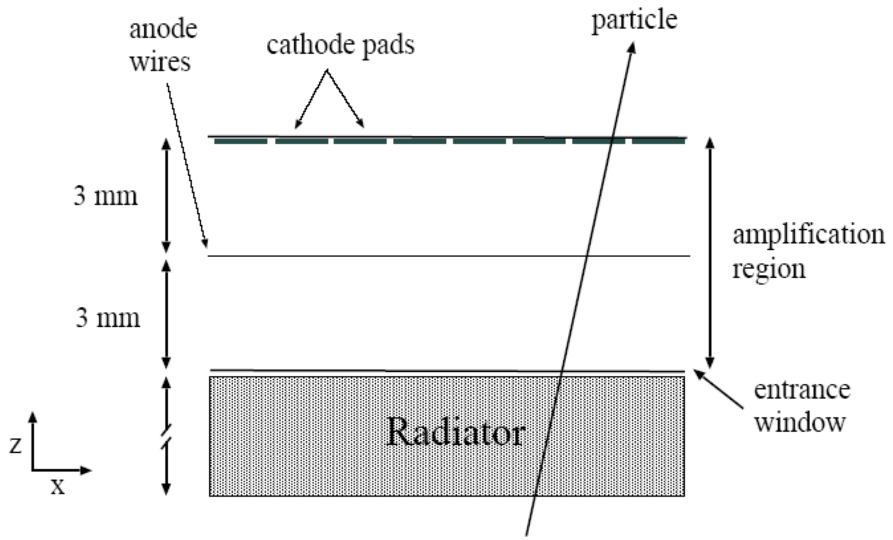
Fast TRD

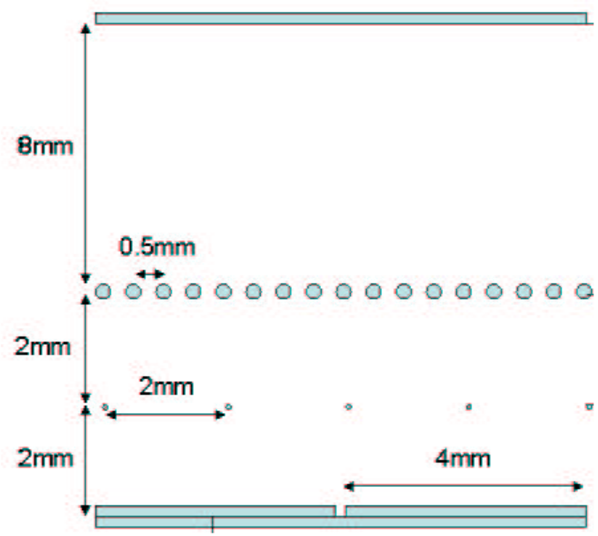
Design goals:

- 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





Low Mass e^+e^- pairs

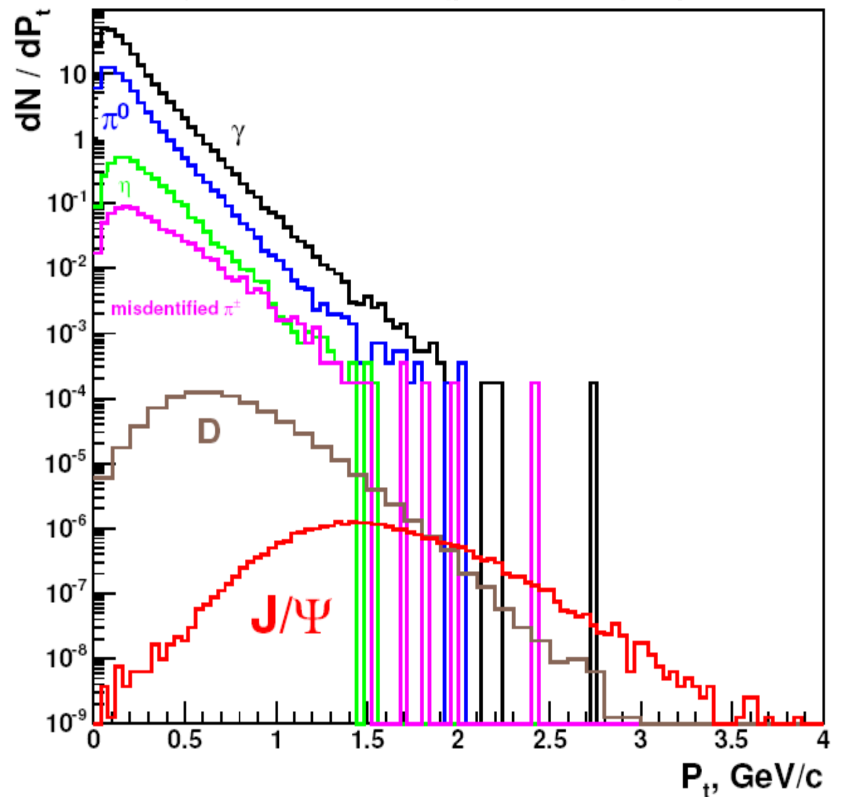
Generic study assuming ideal tracking
Background: URQMD Au+Au 25 AGeV + GEANT4
Magnetic fields: 0T, 0.5 T (constant), 1 T (constant)

Dominant background:

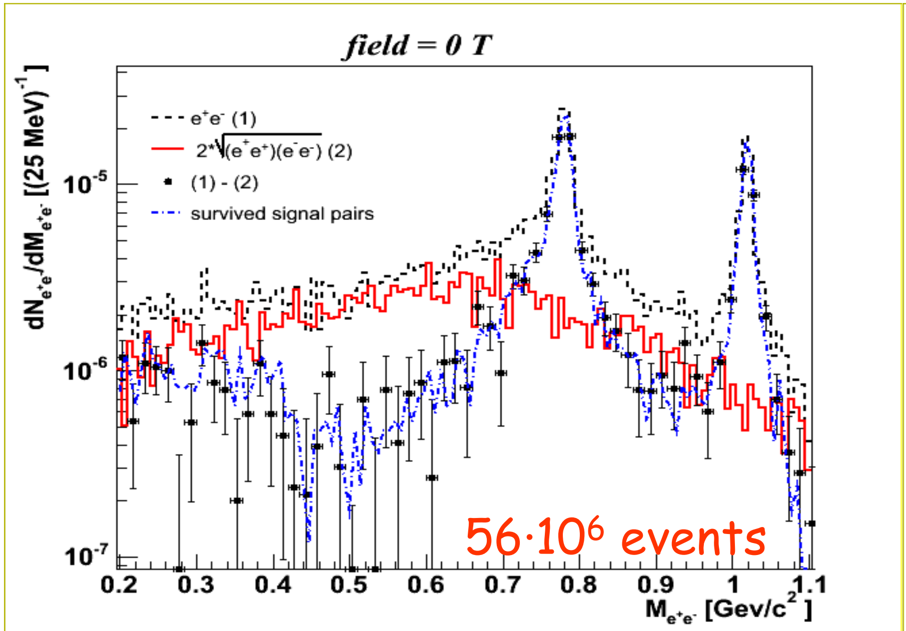
$\gamma \rightarrow e^+e^-$, $\pi^0 \rightarrow \gamma\, e^+e^-$

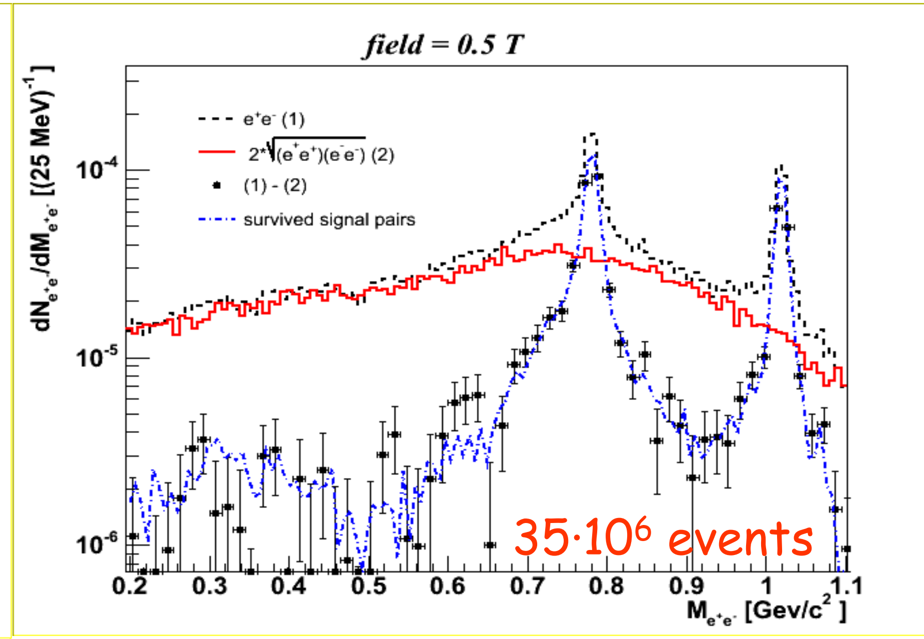
parameter	0T	0.5T	1T
M_{ee} (MeV)	130	137	130
p_t (MeV)	242	314	305
d (mm)	116	72	70
α (deg)	8.1	7	7

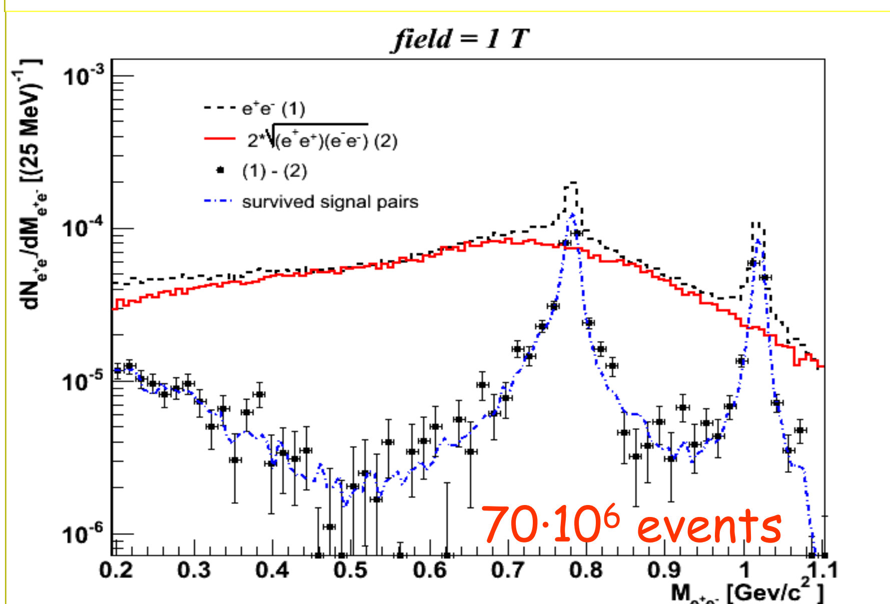
Single electron (positron) spectra



Low Mass e^+e^- pairs







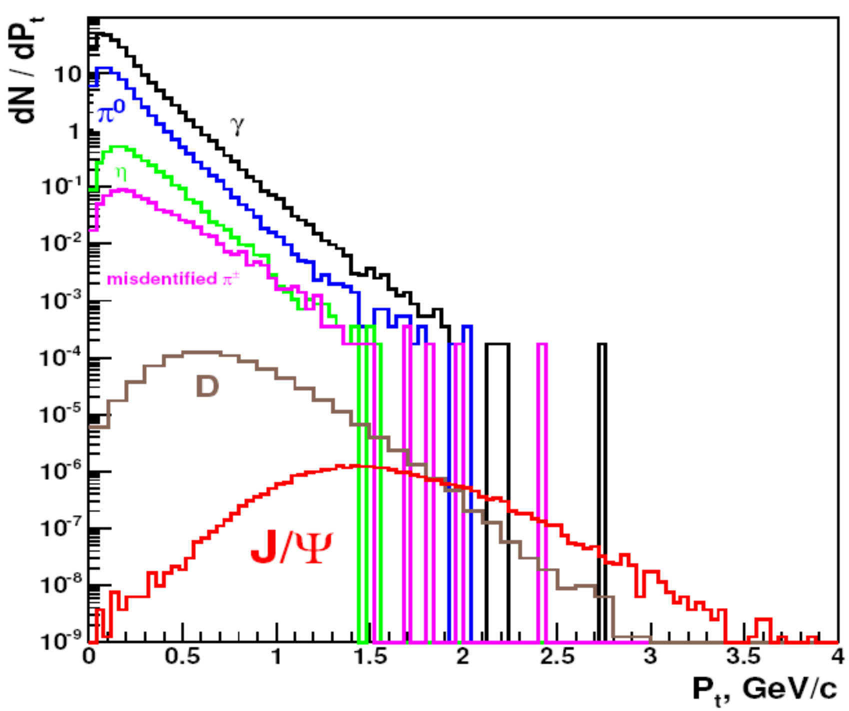
Providing soft electrons are identified,

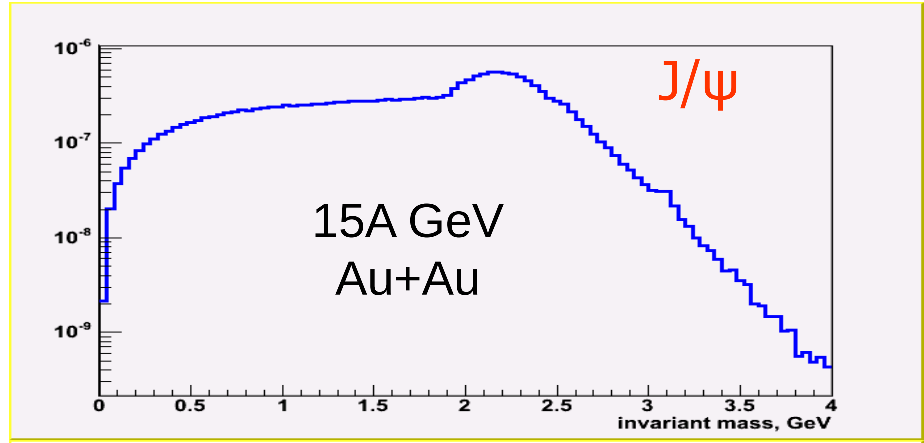
S/B in the peak:

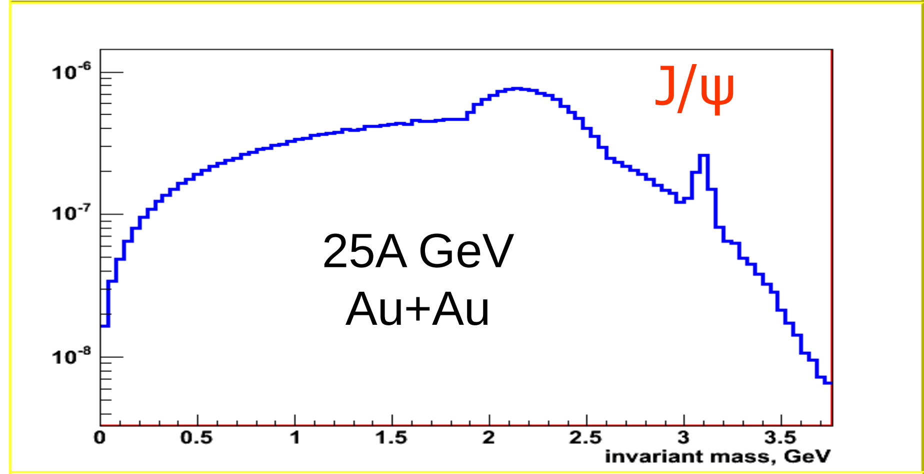
B (T)	ρ+ω	φ
0.0	12.5	25
0.5	3.3	6
1.0	1.5	4

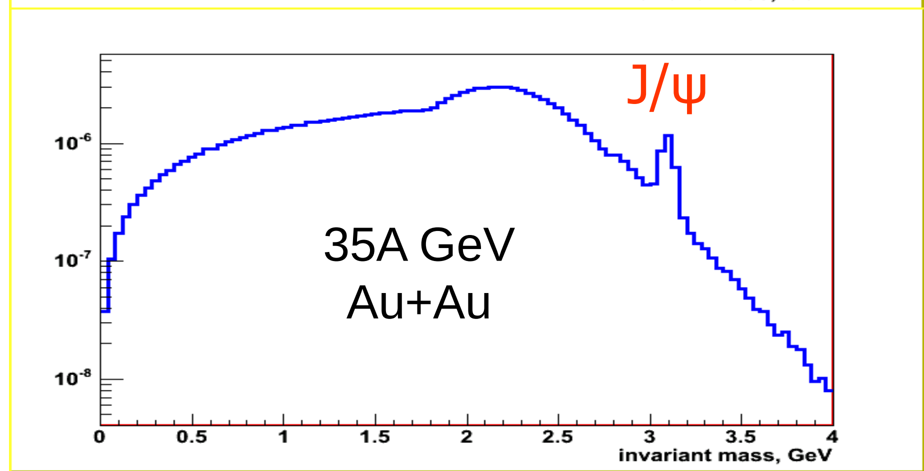
Charmonium

Assumptions:
no track reconstruction
momentum resolution 1%
Pion suppression 10^4
Background:
central Au + Au UrQMD + GEANT4
Cut $p_T > 1$ GeV/c









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

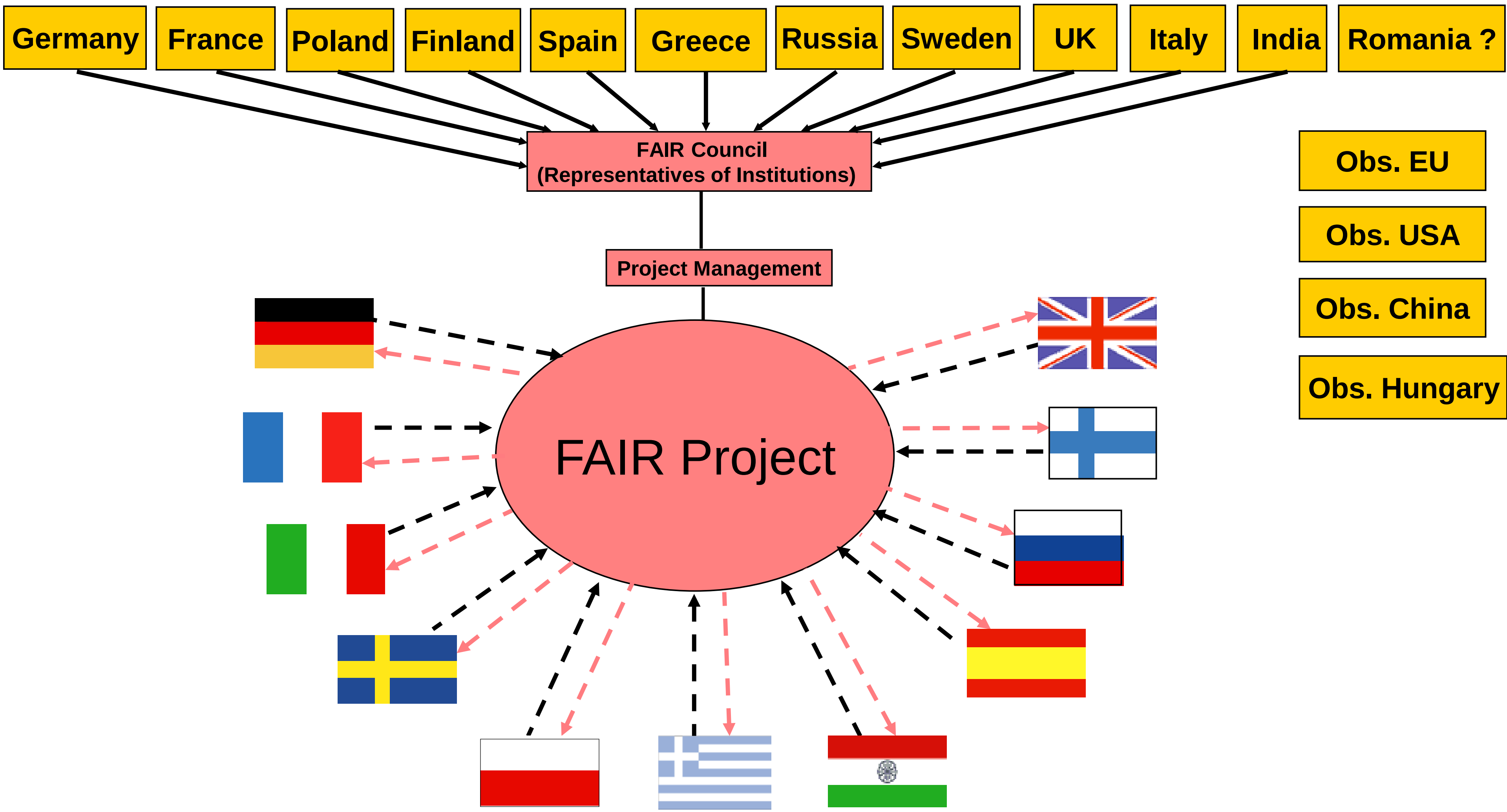
Russia:
CKBM, St. Petersburg
IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg
Kurchatov Inst., Moscow
LHE, JINR Dubna
LPP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP, Moscow State Univ.
St. Petersburg Polytec. U.
Spain:
Santiago de Compostela Univ.
Ukraine:
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 meso 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

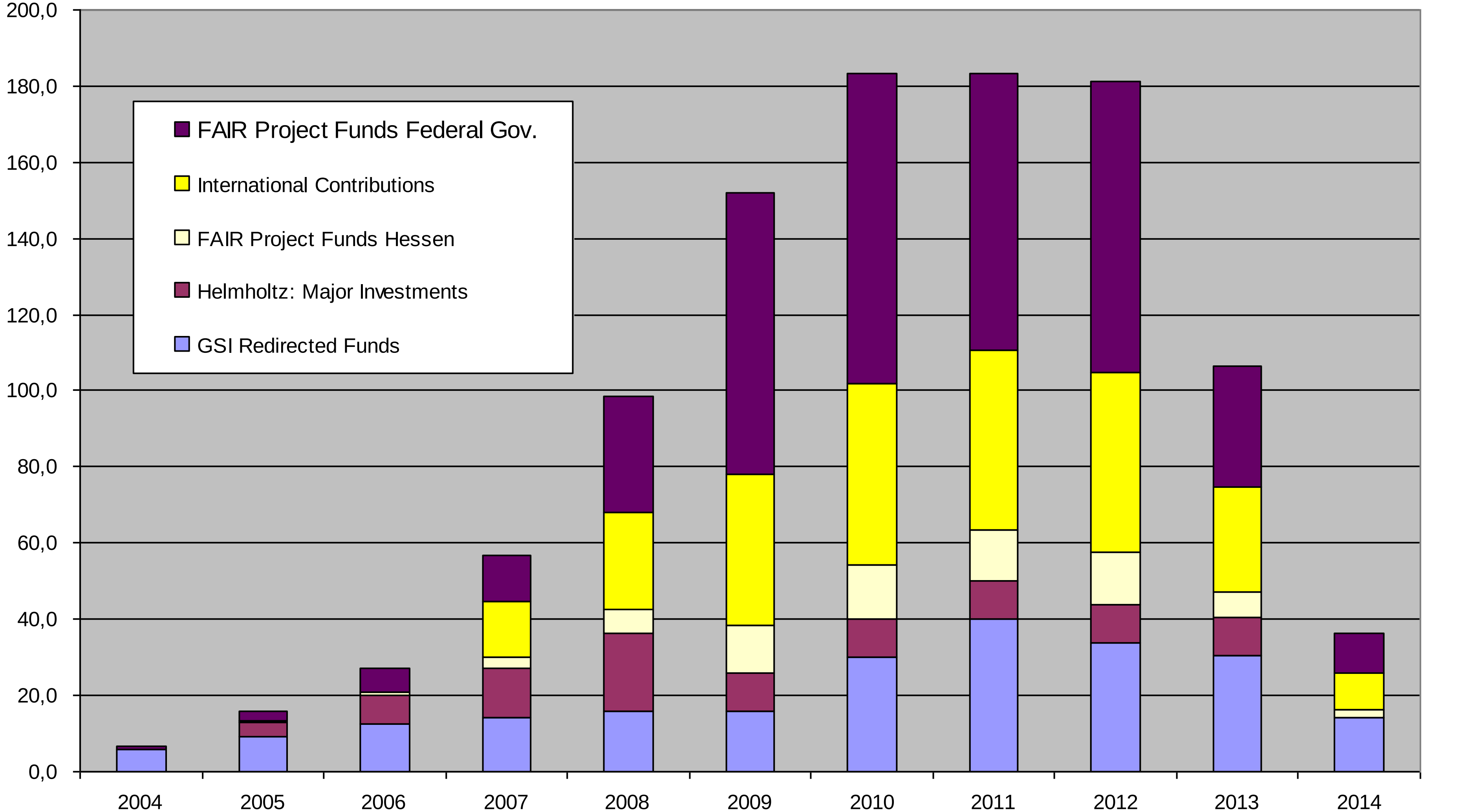
The FAIR member states (March 2005)



Funding profile

Total: 675 M€

Finance Plan Accumulated



Summary

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 and electron 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.