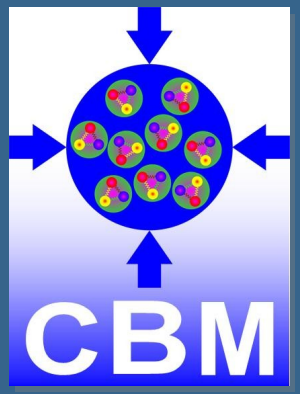
The Compressed Baryonic Matter Experiment at FAIR



Critical Point and the Onset of Deconfinement

Wrocław, Poland
May 30th – June 4th, 2016

Christoph Blume
University of Frankfurt

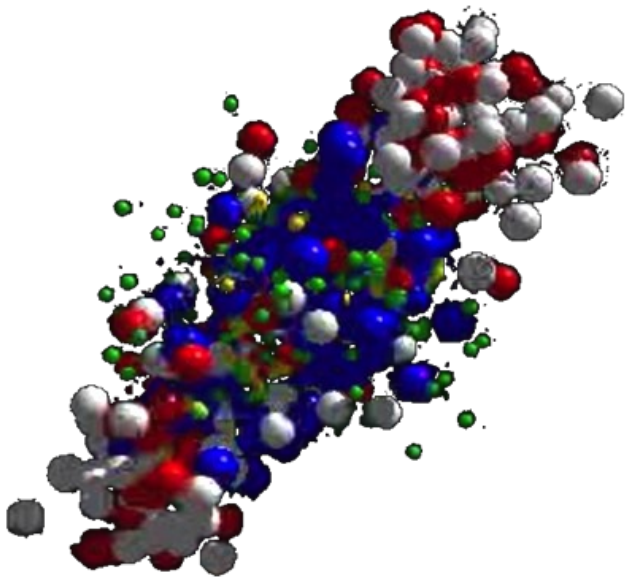
Outline

Physics program
QCD phase diagram
New phases and their properties
Chiral symmetry
Rare strange objects
Technological challenges

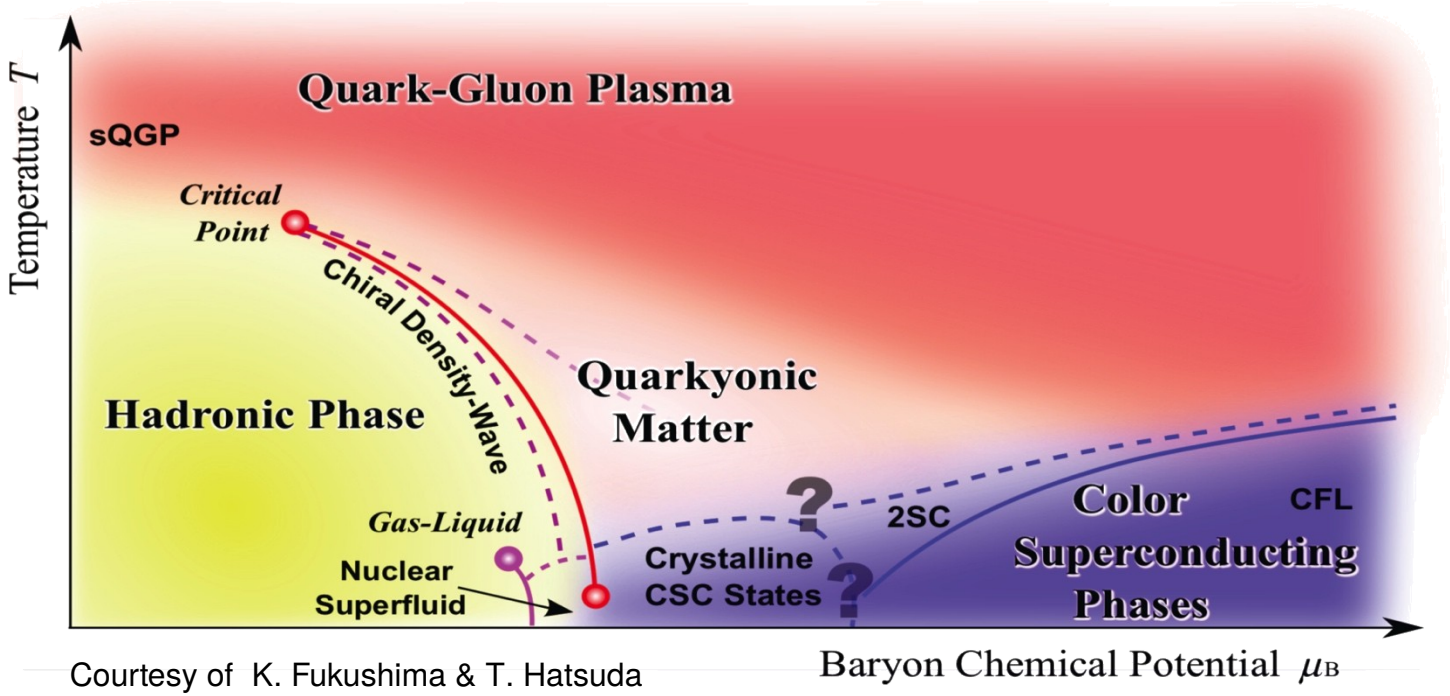
Experimental setup

Physics performance
Intermediate mass dileptons
Hyperons and hypernuclei
Heavy flavor

CBM status



Physics Program
QCD Phase Diagram



Courtesy of K. Fukushima & T. Hatsuda

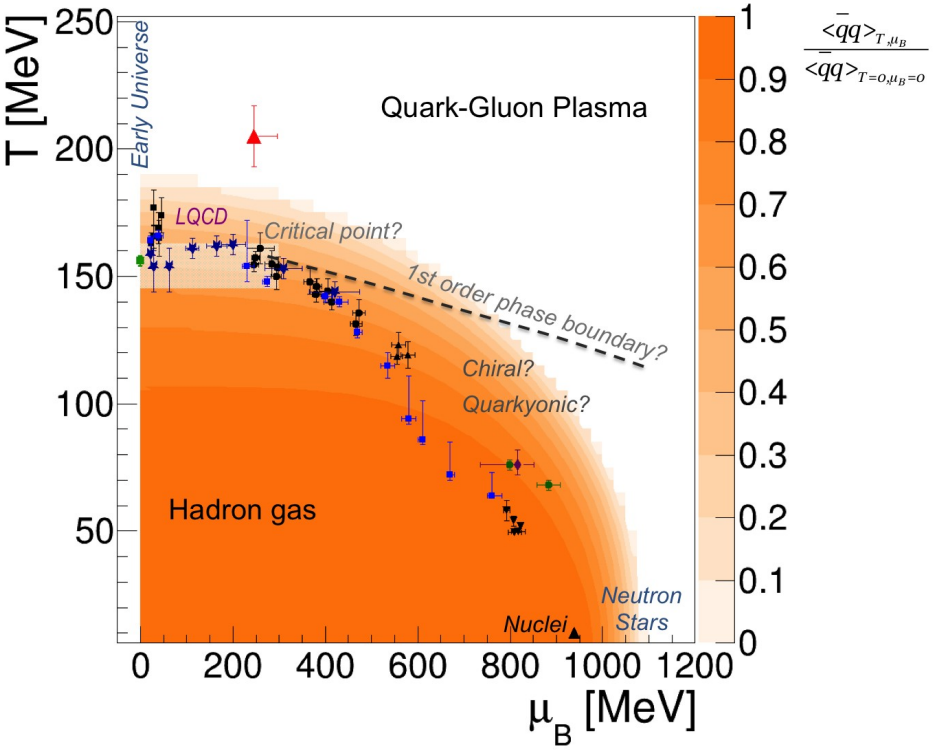
Probing the QCD phase diagram at high net-baryon densities

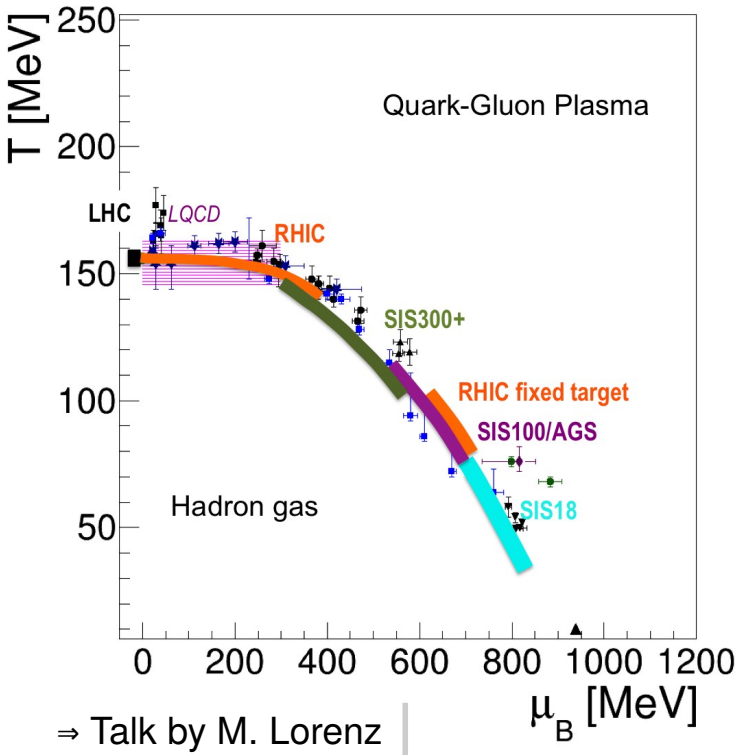
Phase transitions: deconfinement + chiral symmetry

Critical end point

New phases (quarkyonic matter, …)

Physics Program
QCD Phase Diagram





⇒ Talk by M. Lorenz

Experimental and theoretical access to the phase diagram

Chemical freeze-out points from statistical model analyses

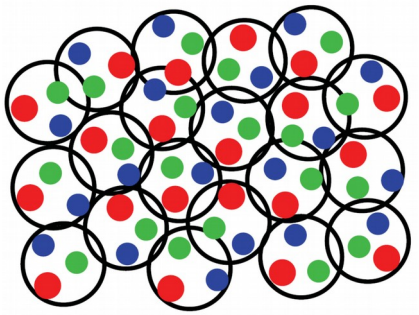
Lattice QCD: cross over transition at small μ_B

1st order at high μ_B and critical endpoint?

SHM : J. Cleymans: PRC 73 (2006) 034905, A. Andronic PLB 673 (2009) 142
ALICE : J. Stachel, arXiv:1311.4662
STAR : PRC 79 (2009) 034909
HADES : NPA 931 (2014)
FOPI : PRC 76 (2007) 052203
Lattice : $T_c(\mu_B) = 154(9)\ [1\text{-}0.0006(7)\ \mu_B^2]$ MeV

Physics Program
New Phases at High Densities

Net-baryon densities
More than 6×ρ_0 already at 5 AGeV

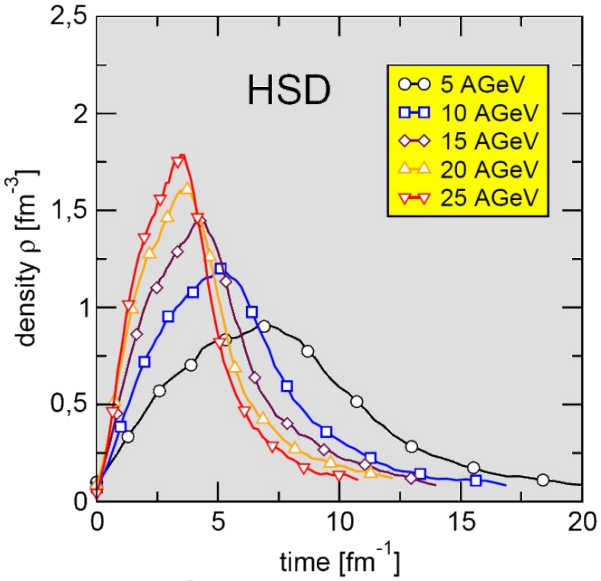


New phases of strongly interacting matter
E.g. Quarkyonic phase

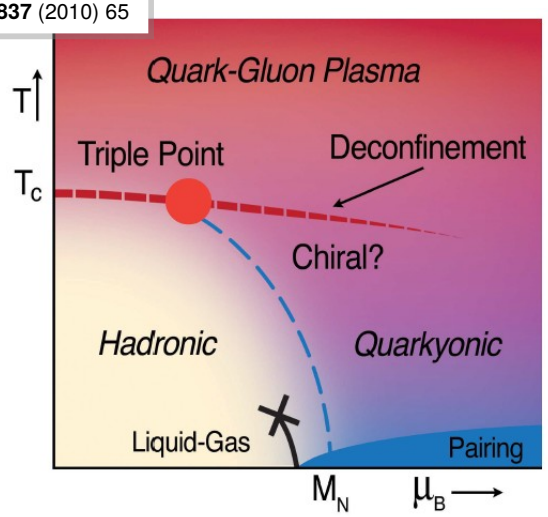
Observables
Di-lepton pairs

Strangeness (K, Λ, Ξ, Ω)

Excitation function and flow



A. Andronic et al.,
Nucl. Phys. **A837** (2010) 65



Physics Program
Matter Properties

Susceptibilities

Probing the medium response to external perturbations

Sensitive to matter properties

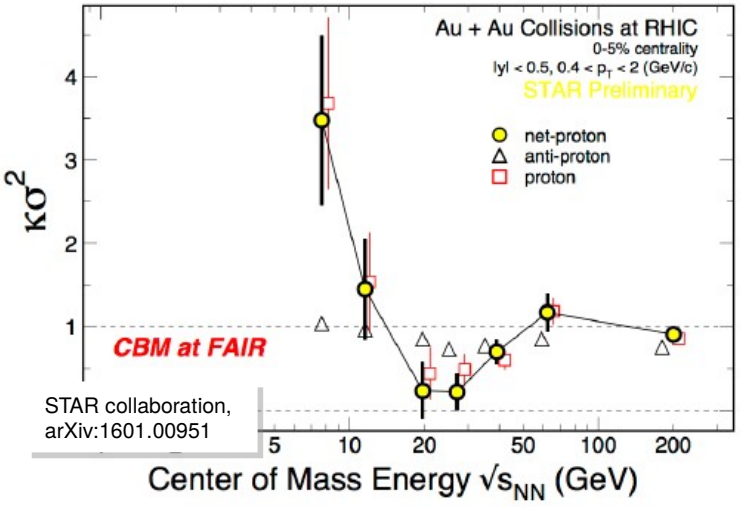
Related to phase structure of hot and dense matter

Search for the critical point

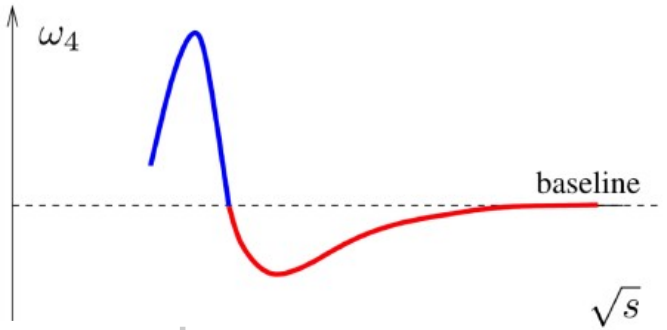
Observables

Event-by-event fluctuations of conserved quantities (e.g. *Q*, *S*, *B*)

Energy dependence of higher moments



STAR collaboration, arXiv:1601.00951

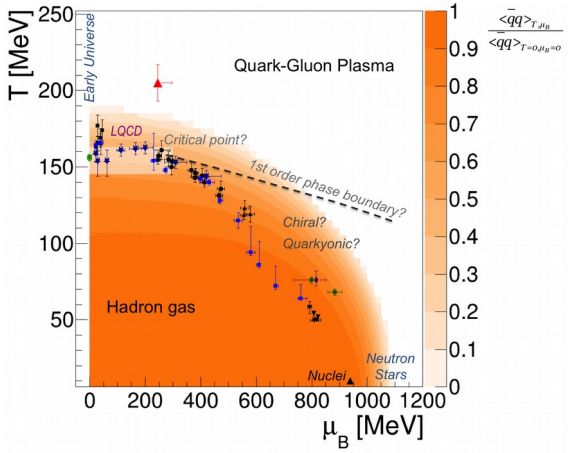


Curve based on: M. Stephanov, Phys. Rev. Lett. **107** (2011) 052301

Physics Program
Chiral Symmetry

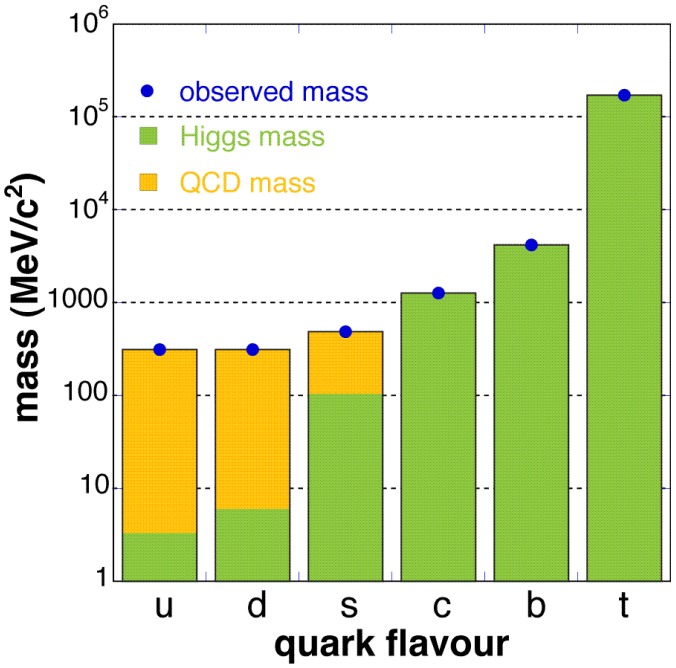
Origin of QCD mass
Medium modification of hadrons

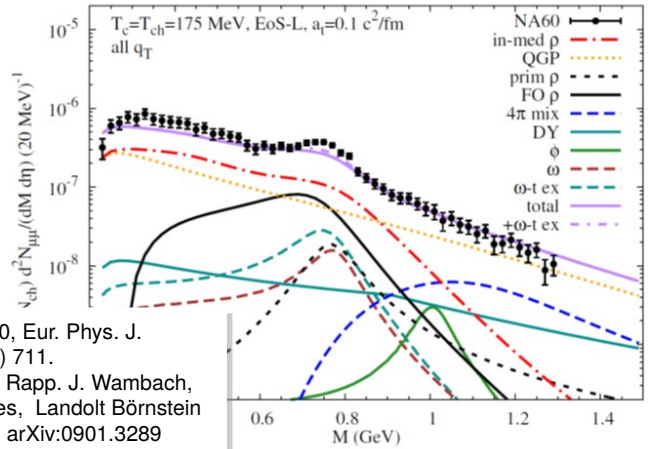
Restoration of chiral symmetry



Observables
Di-leptons: LMR (ρ), IMR (ρ-a_1-mixing)

Muon and electron decay channel

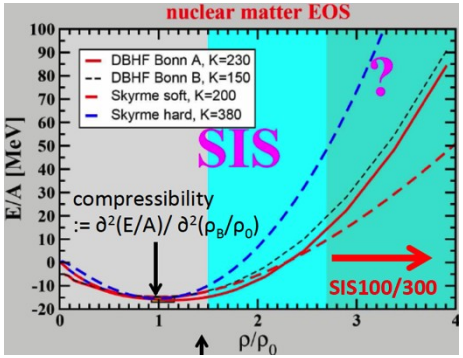




Data: NA60, Eur. Phys. J. **C61** (2009) 711.
Theory: R. Rapp. J. Wambach, H. van Hees, Landolt Börnstein (Springer), arXiv:0901.3289

Physics Program
Equation-of-State

Neutron star core densities
Compressibility of nuclear matter

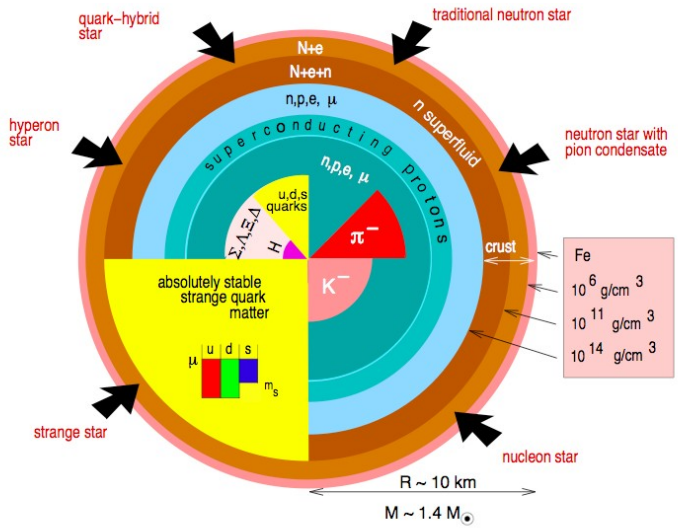


Interactions between strange baryons

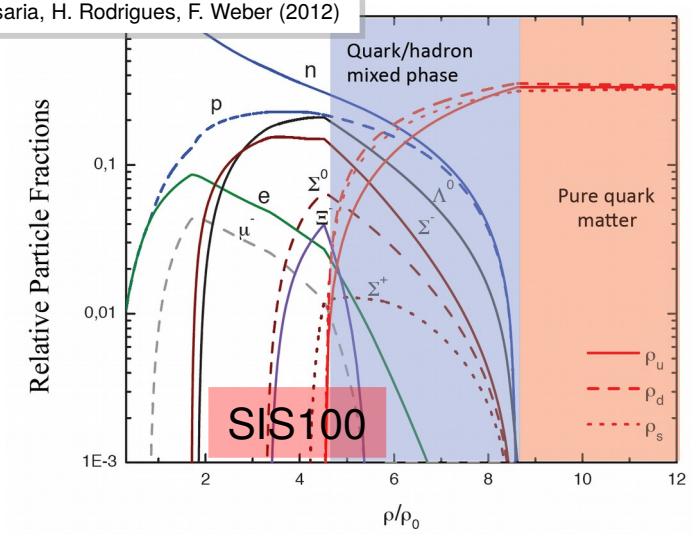
Observables
Collective flow of hadrons

Particle production at threshold (multi-strange hadrons)

Strange baryon correlations

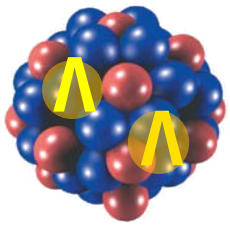


Equation-of-state:
Non-local SU(3) NJL with vector coupling
M. Orsaria, H. Rodrigues, F. Weber (2012)



Physics Program
Rare Strange Objects

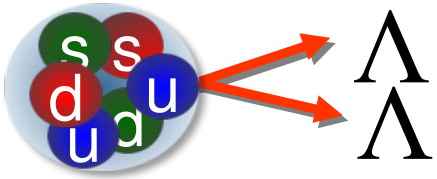
3rd axis of nuclide chart
(Double-) hypernuclei



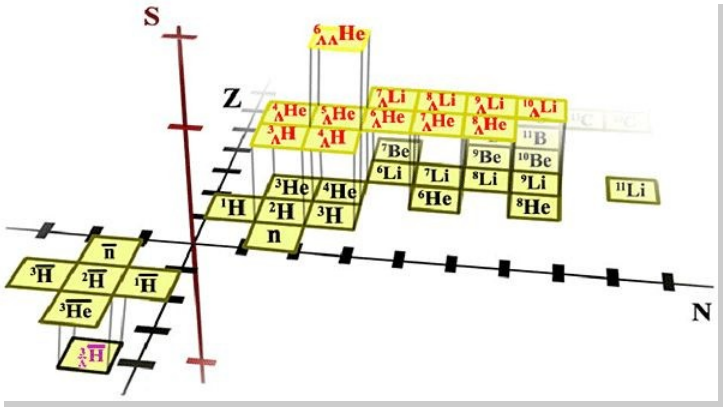
Information on ΛΛ interaction
(→ neutron stars)

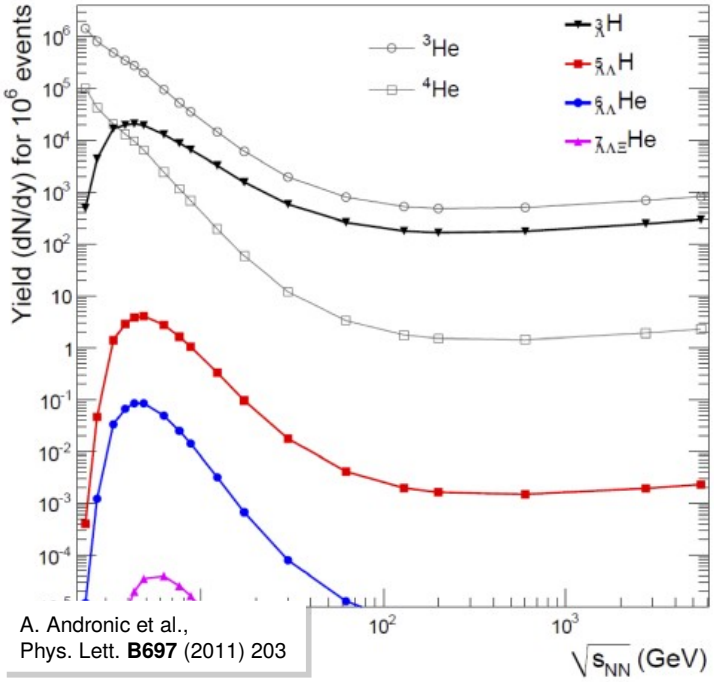
High event statistics needed
Production favored by high ρ_B

Strange matter
Di-baryons (e.g. H^0)



Meta-stable Exotic Multi-hypernuclear Objects (MEMOs)





A. Andronic et al.,
Phys. Lett. **B697** (2011) 203

Physics Program
Existing Measurements

Low data rates

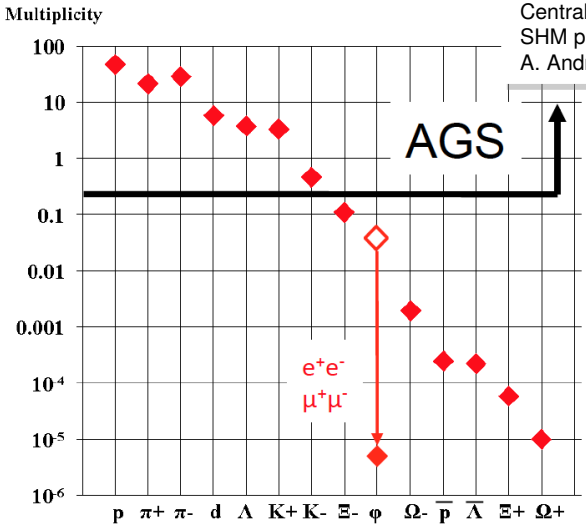
Mostly limited to bulk observables

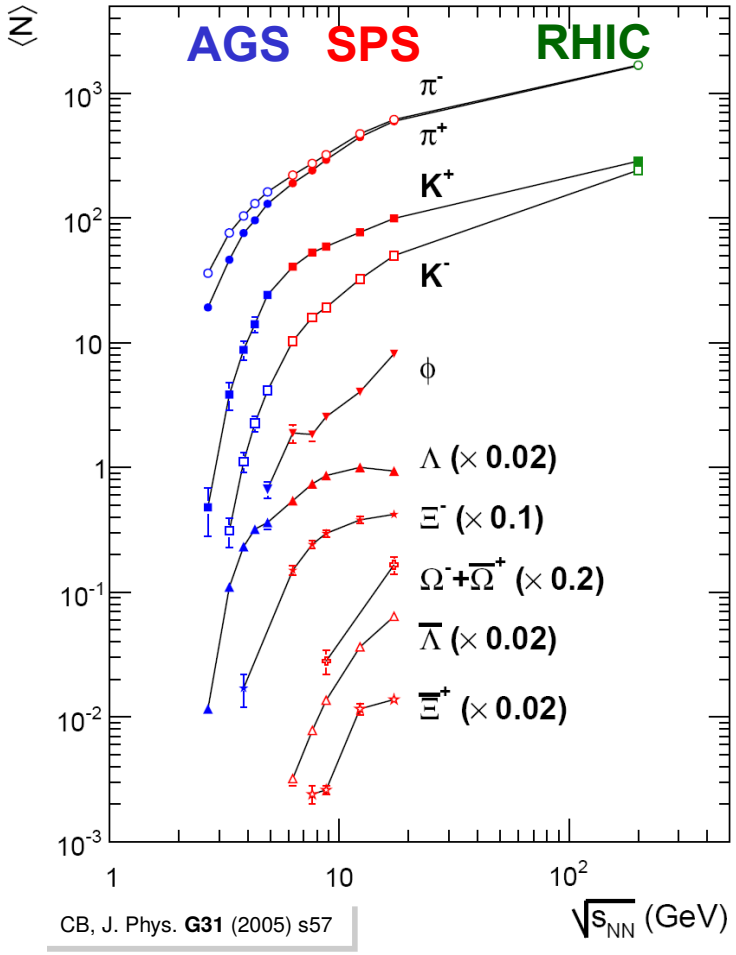
No rare (anti-)particles (Ξ^-, Ω^-)

Heavy flavor (J/ψ, D) not addressed

Systematic di-lepton measurements missing

Lack of multi-dimensional studies



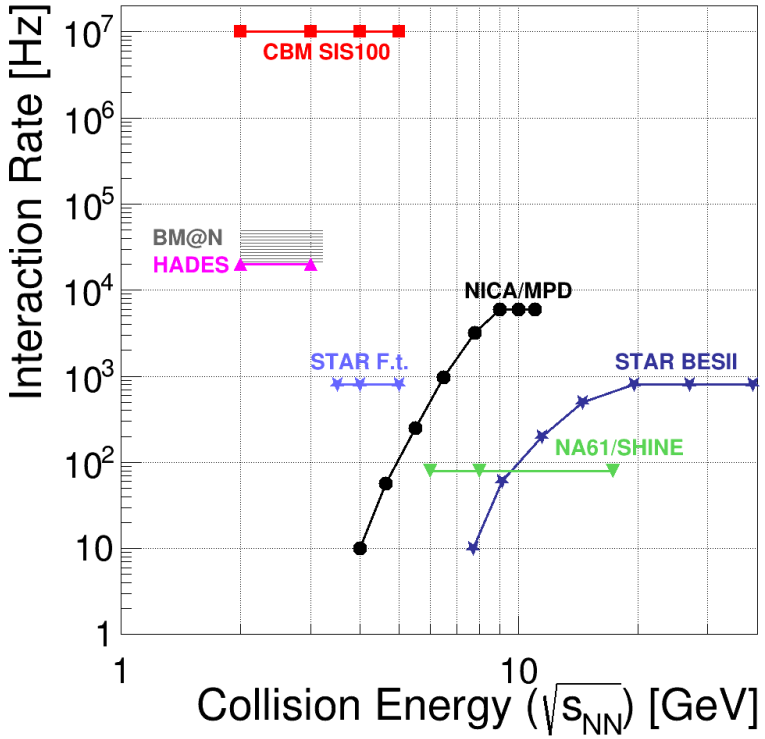


Physics Program
Data Rates

Highest data rates
Independent of centre-of-mass energies

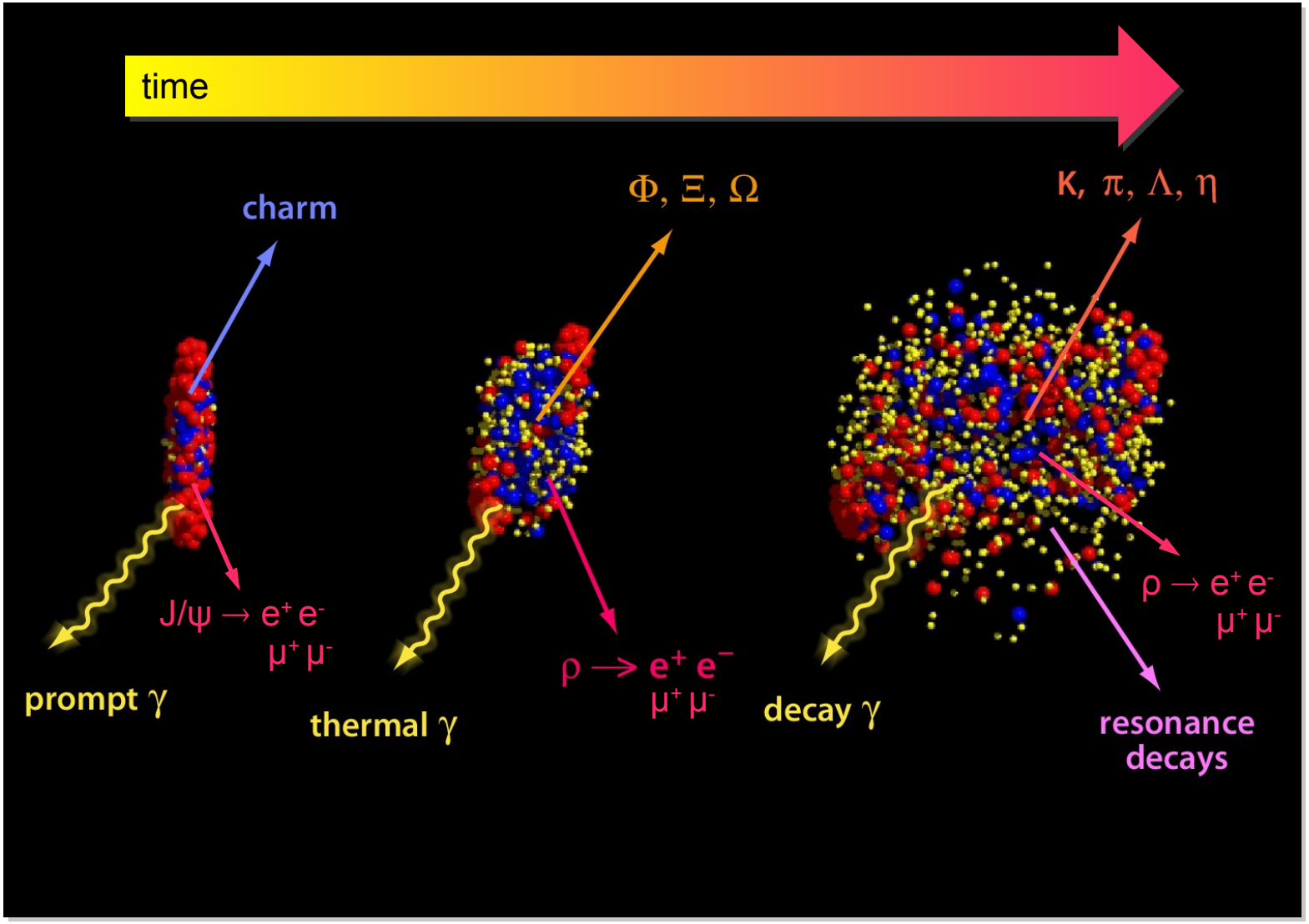
Systematic studies with rare probes possible at SIS100

Colliders experiments not competitive to fixed target in terms of interaction rates



Numbers taken from:
NICA: A. Sorin, CPOD 2014
RHIC: C. Montag, D. Cebra, CPOD 2014
STAR-FT: G. Odyniec, CPOD 2013
SPS: G. Usai, TPD workshop 2014
NA61: M Gazdzicki, CBM Symposium 2014
HADES: J. Michel et al.,
IEEE Trans Nucl. Sci. **58** (2011)

Physics Program
Observables



Physics Program
Technological Challenges

High interaction rates
10^5 – 10^7 Au+Au collisions/sec.

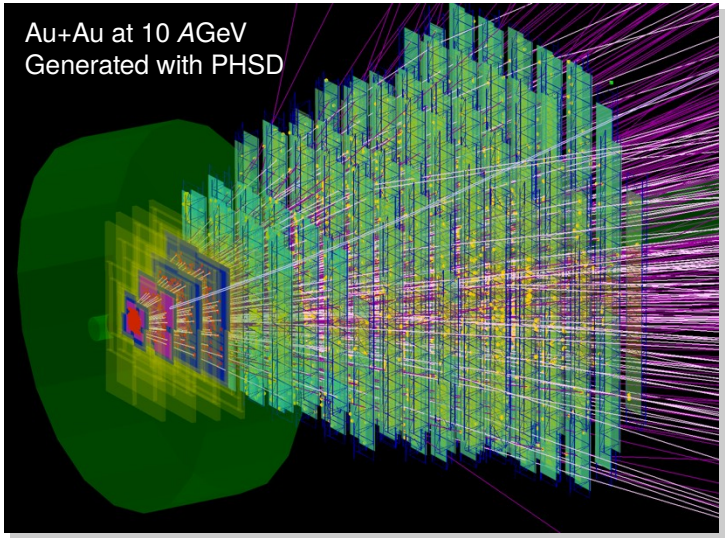
Fast and radiation hard detectors

Free streaming read-out electronics

High speed data acquisition

Computing farm for online event selection

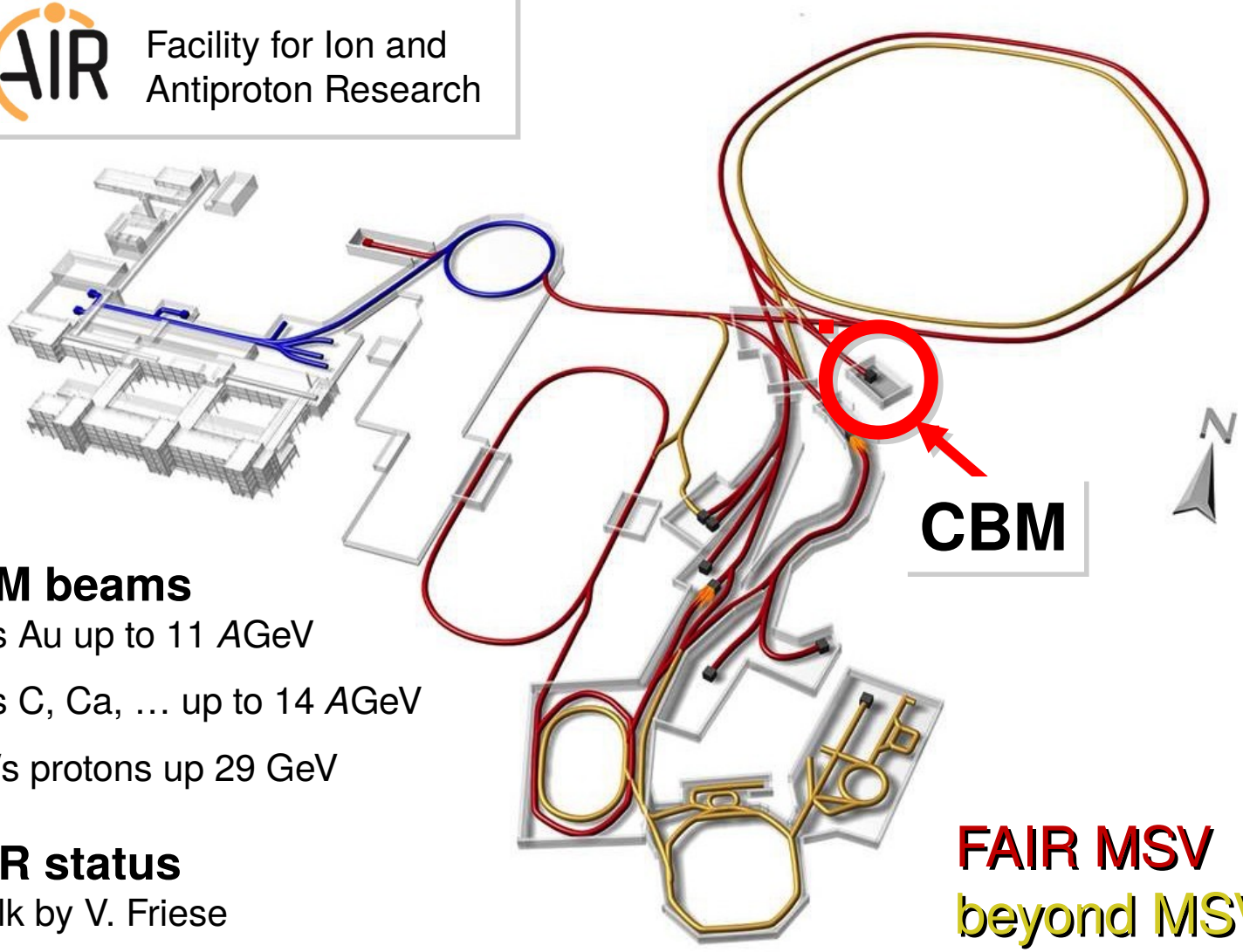
4D reconstruction



Particle identification
Hadrons (π, K, p, fragments) and leptons ($e^{\pm}$, $\mu^{\pm}$)

Vertexing for open charm
Resolution for (main and secondary) vertices $\sigma \approx 50\mu m$

Facility for Ion and Antiproton Research



CBM beams

10^9/s Au up to 11 *A*GeV

10^9/s C, Ca, … up to 14 *A*GeV

11^{11}/s protons up 29 GeV

FAIR status

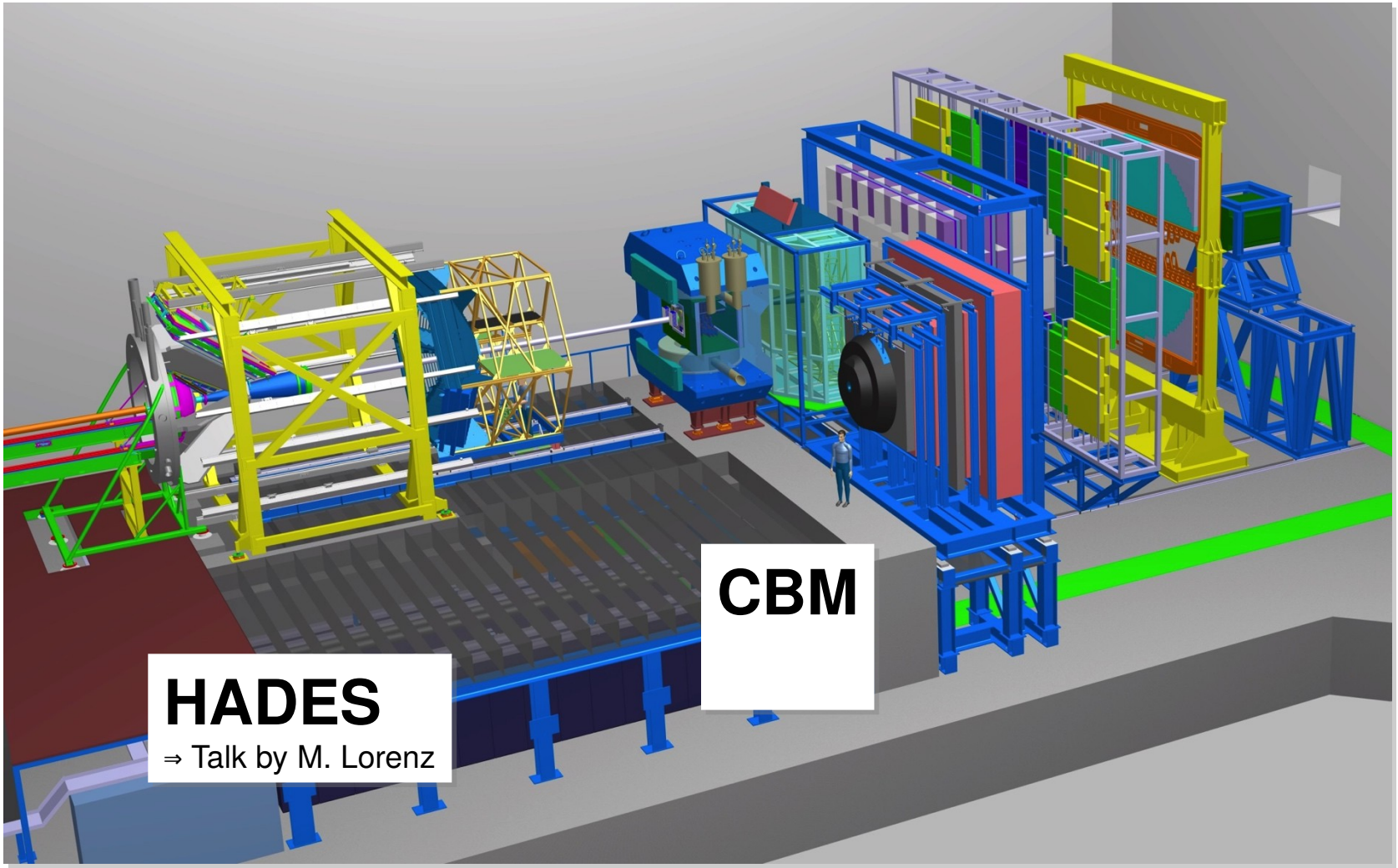
⇒ Talk by V. Friese

FAIR MSV

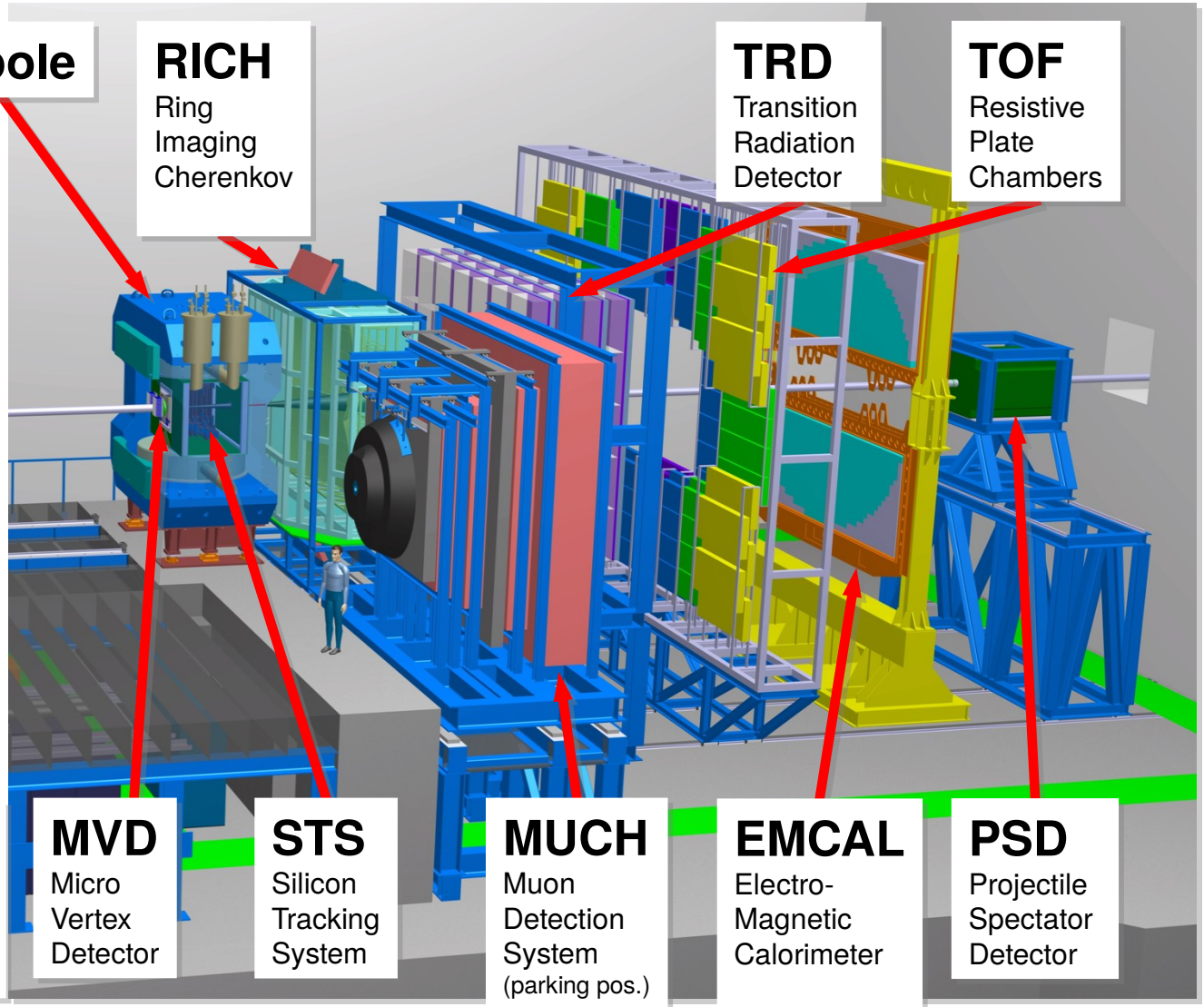
beyond MSV

Experimental Setup
HADES + CBM in Cave

Experimental Setup
HADES + CBM



Experimental Setup
CBM Detector Components



Acceptance

$p_t > 0$

Forward rapidities

Experimental Setup
Particle Identification

Hadrons
$\pi^{\pm}$, $K^{\pm}$, p

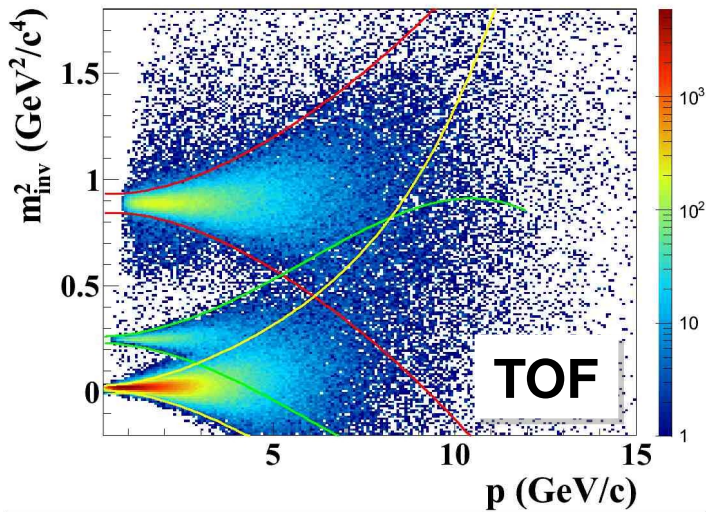
Fragments
TOF + TRD

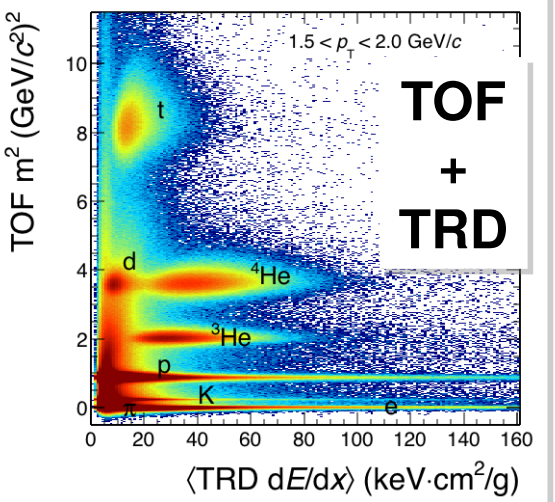
Electrons
RICH + TRD

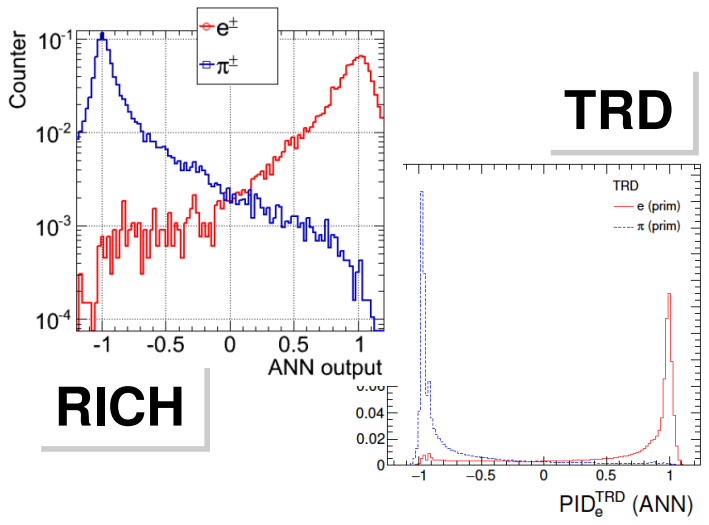
Muons
MUCH
with hadron absorber

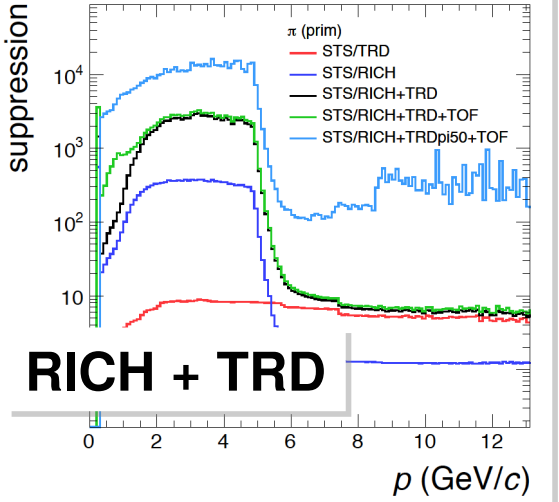
Photons
EMCAL

Conversion









Physics Performance
Intermediate Mass Dileptons

Dilepton spectra
Space-time integral of EM radiation

Different collision stages accessible in different mass regions

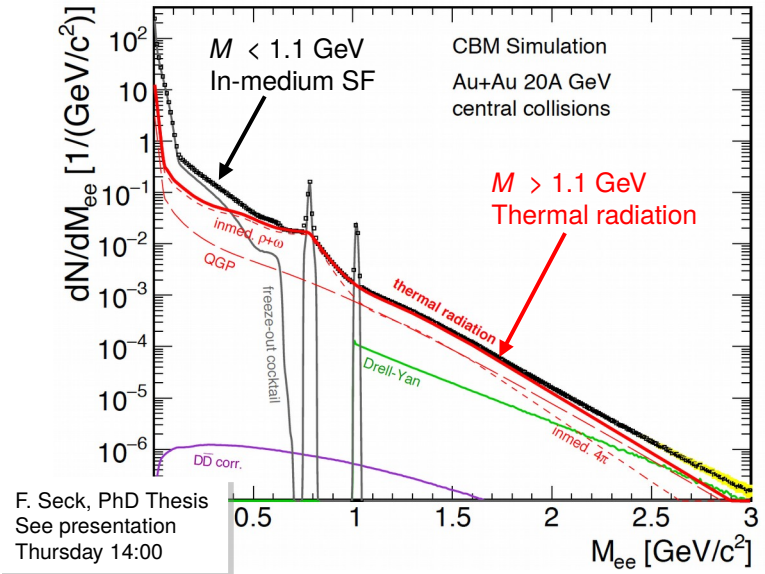
Low mass region (M < 1.1 GeV)
Access to in-medium spectral functions

Intermediate mass region (M > 1.1 GeV)
Access to thermal medium radiation

Excitation function of IMR
Extract T_{slope} from mass spectra

Monotonous decrease or possible indications for 1st order phase transition?

Challenging measurement!



F. Seck, PhD Thesis
See presentation
Thursday 14:00

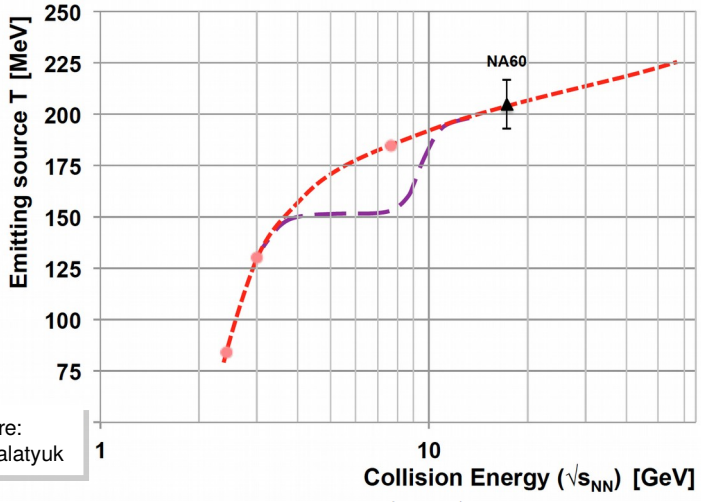
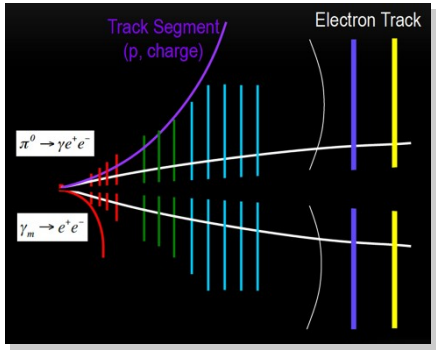


Figure:
T. Galatyuk

Physics Performance
Intermediate Mass Dileptons

Dilepton spectra
Signal/background ratio essential

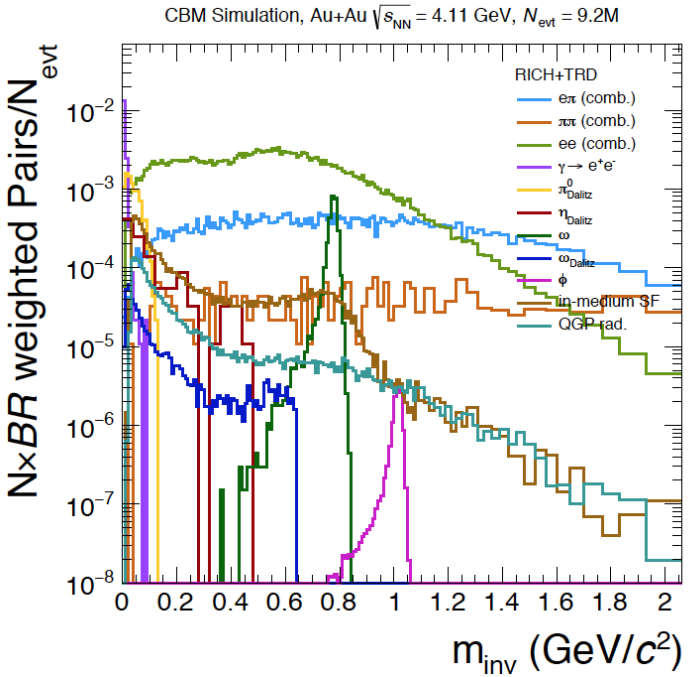
Physical sources: conversion, π^0-Dalitz
Rejection via topological cuts (MVD)



Mass Range [GeV/c^2]	S/B	S/√(S+B)
0.0-0.15	7.51 ± 0.53	39.1 ± 0.55
0.15-0.6	0.28 ± 0.02	9.34 ± 0.43
0.6-1.2	0.30 ± 0.02	8.37 ± 0.44
ω	0.88 ± 0.11	7.86 ± 0.55
φ	0.23 ± 0.09	1.24 ± 0.40

T. Galatyuk, ECT*-Dilepton Workshop, Trento 2015

Extraction of T_{slope}
Residual background via event mixing



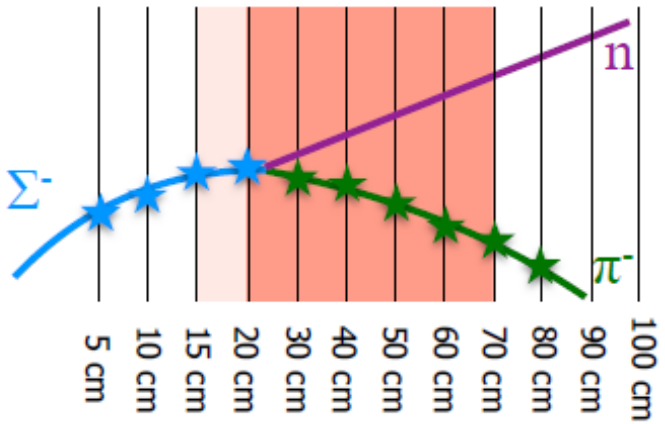
Physics Performance
Hyperons

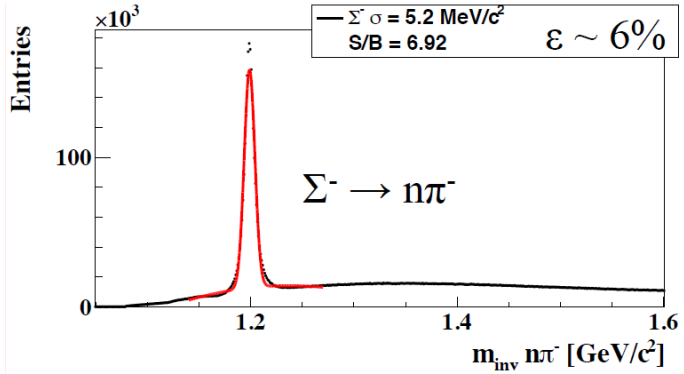
Σ-Hyperons in heavy-ions

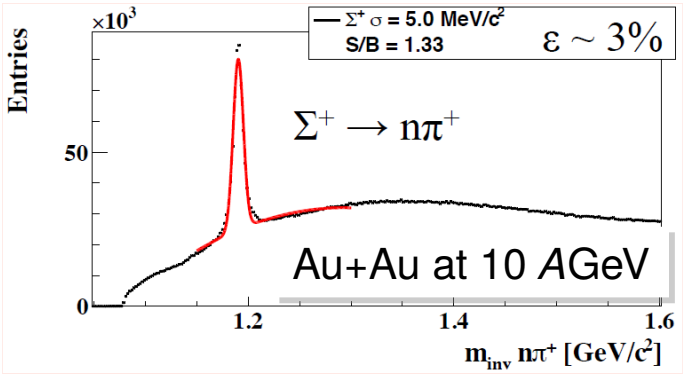
Neutral decay partner
via missing mass analysis

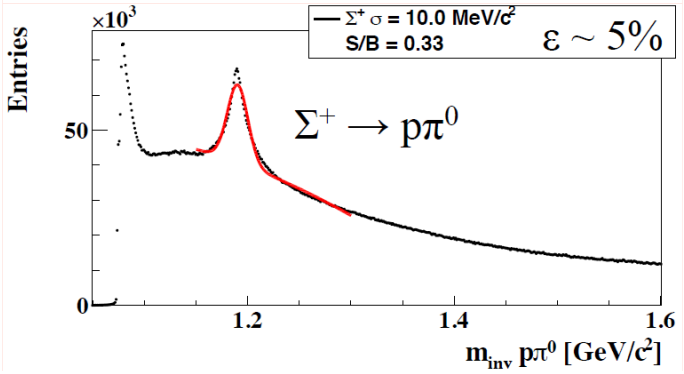
STS + MVD

KFParticleFinder Algorithm







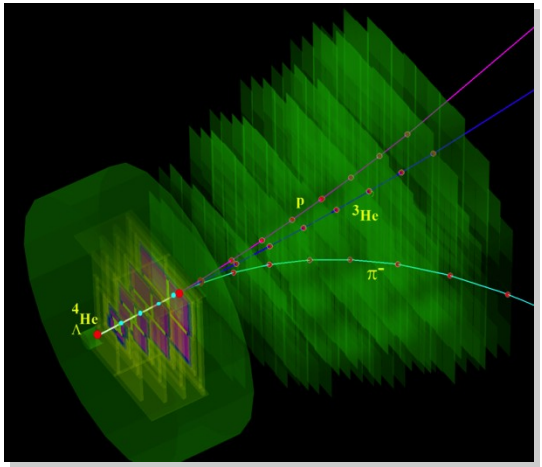


Physics Performance
Hypernuclei

Hypernuclei in heavy-ions

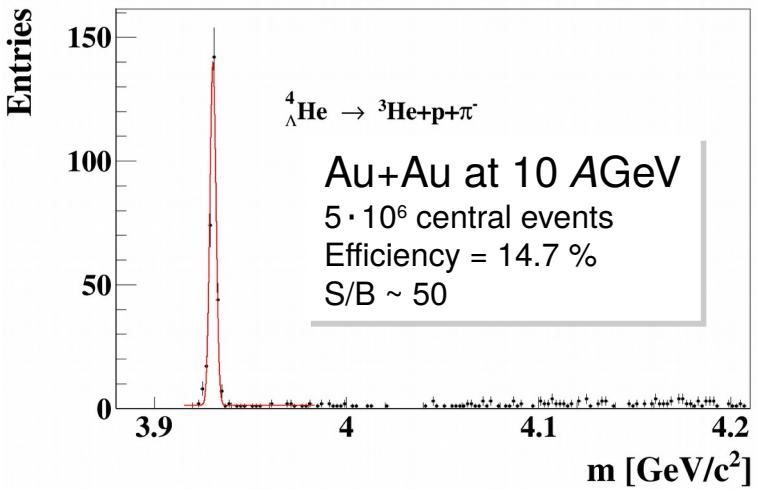
$^{4}_{\Lambda}He \rightarrow {}^{3}He + p + \pi^-$

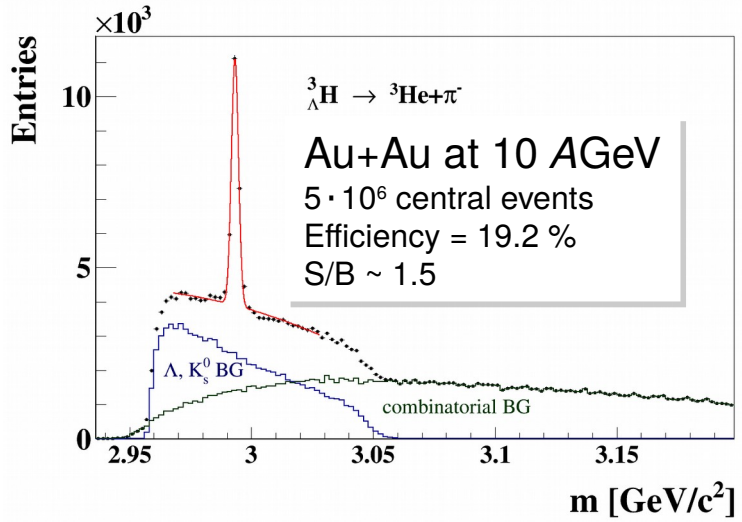
3-prong decay from detached vertex



$^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^-$

Input to simulations:
J. Steinheimer et al., Phys. Lett. **B714** (2012) 85
H. Kameda et al., Phys. Rev. **C57** (1998) 1595
A. Andronic et al., Phys. Lett. **B697** (2011) 203
H. Stöcker et al., Nucl. Phys. **A827** (2009) 624c





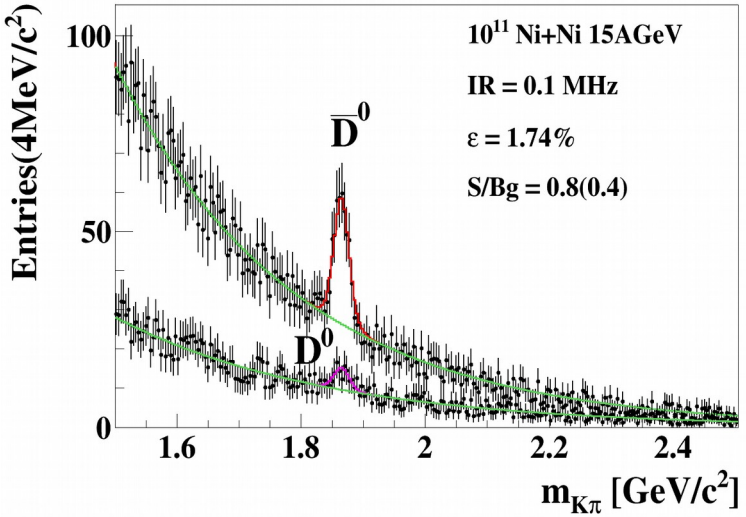
Physics Performance
Heavy-Flavour

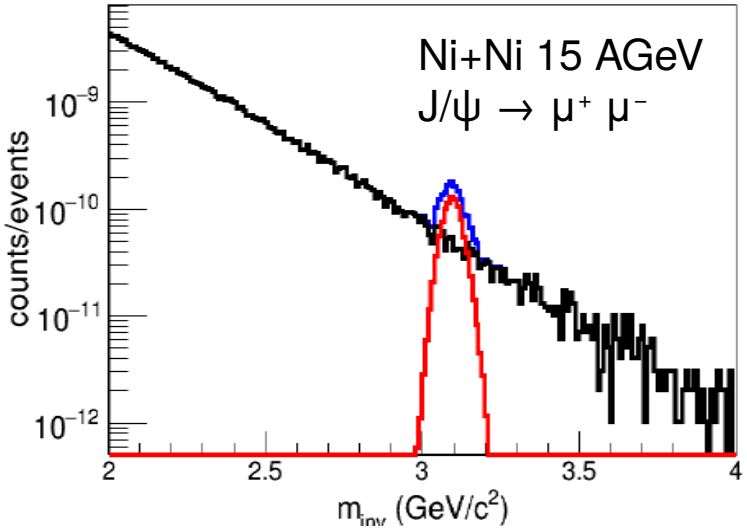
Ni+Ni collisions at 15 *A*GeV

D^0-mesons
Interaction rate = 0.1 MHz
260 $\overline{D}^0$ and 45 D^0 in ~ 2 weeks

J/ψ via di-muons
Interaction rate = 1 MHz
3300 J/ψ in ~ 2 weeks

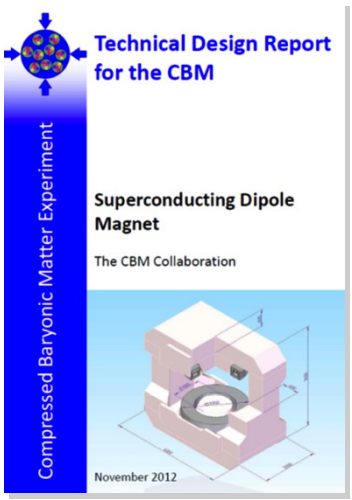
Objectives
Ratio open to hidden charm
Cold nuclear matter effects (p+A)

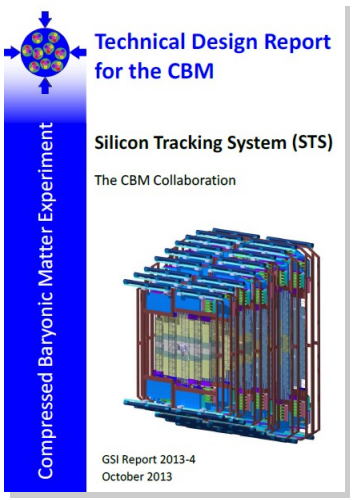


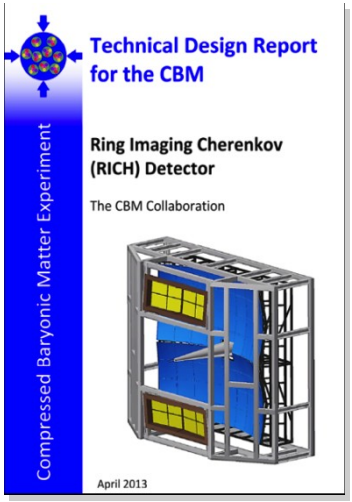


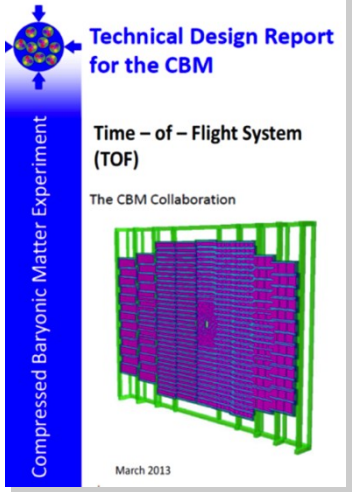
CBM Status
Technical Design Reports

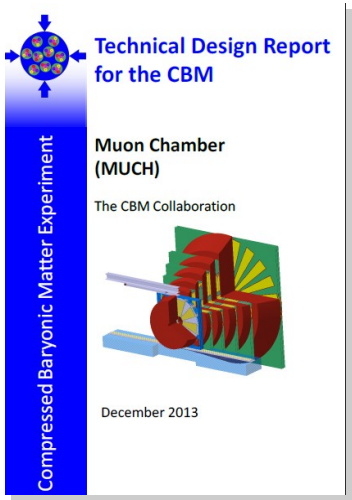
Project	TDR Status
Magnet	approved
STS	approved
RICH	approved
TOF	approved
MUCH	approved
HADES ECAL	approved
PSD	approved
MVD	submission 2016
DAQ/FLES	submission 2017
TRD	submission 2016
ECAL	submission 2016











CBM Status
Detector R&D

Recent R&D results

60ps time resolution (MIPS) for MRPCs with adjustable granularity

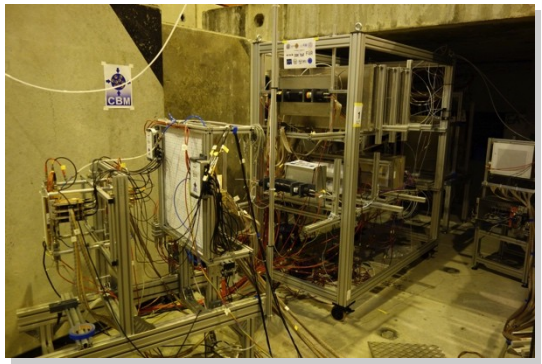
Low-mass, vacuum-compatible pixel sensor integration

Enhanced UV photon efficiency with wavelength shifting film

High-rate modular muon detection system

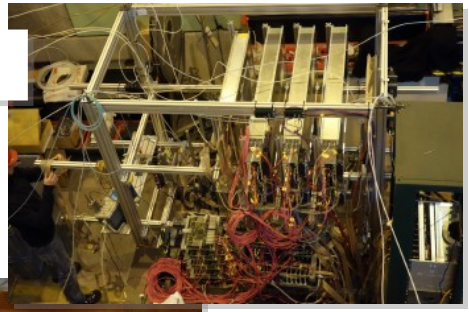
Test-beam activities

PS, SPS, COSY, …



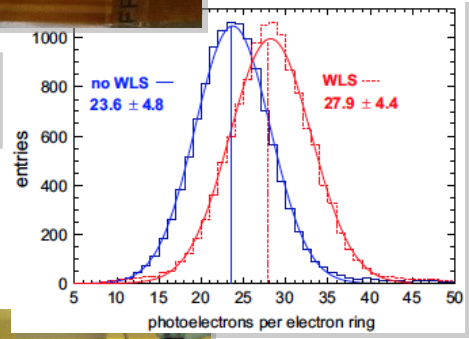
High-rate test at CERN-SPS with TOF and TRD

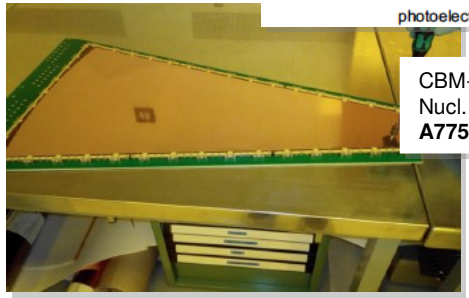
CBM-TOF collaboration:
J. Instrum. **7** (2012) R10008



CBM-MVD collaboration:
Nucl. Instrum. Meth.
A732 (2013) 515

CBM-RICH collaboration:
Nucl. Instrum. Meth.
A783 (2015) 543





CBM-MUCH collaboration:
Nucl. Instrum. Meth.
A775 (2014) 139

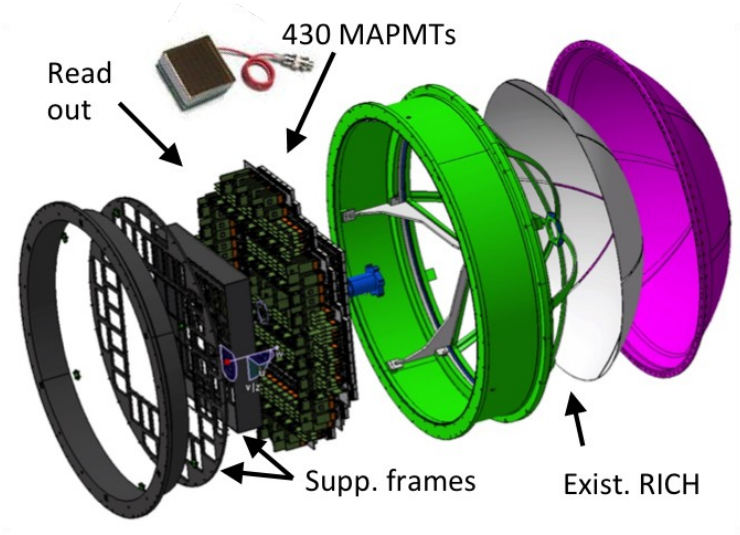
CBM Status
FAIR Phase-0 Experiments

MAPMTs for HADES-RICH
Joint CBM and HADES activity

430 out of 1100 Multi-Anode-PMTs for CBM-RICH installed in HADES-RICH

Provides experience in detector setup, calibration and data analysis

GSI research program 2018–2020

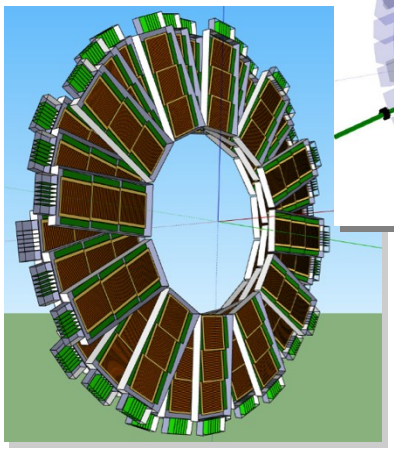


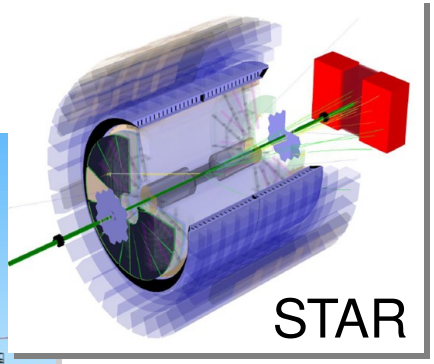
CBM-TOF modules in STAR
10% of total number of TOF modules

Participation in STAR-BES-II 2019/2020

Extends PID coverage to large rapidities

Large scale integration test and provides experience in MRPC operation



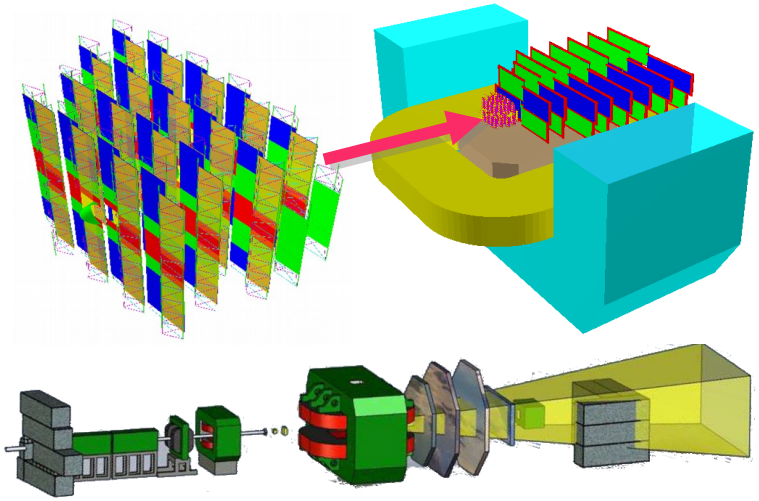


CBM Status
FAIR Phase-0 Experiments

STS layers for BM@N
Fixed target experiment
at the Nuclotron in JINR/Dubna

Four layers STS in front of tracker

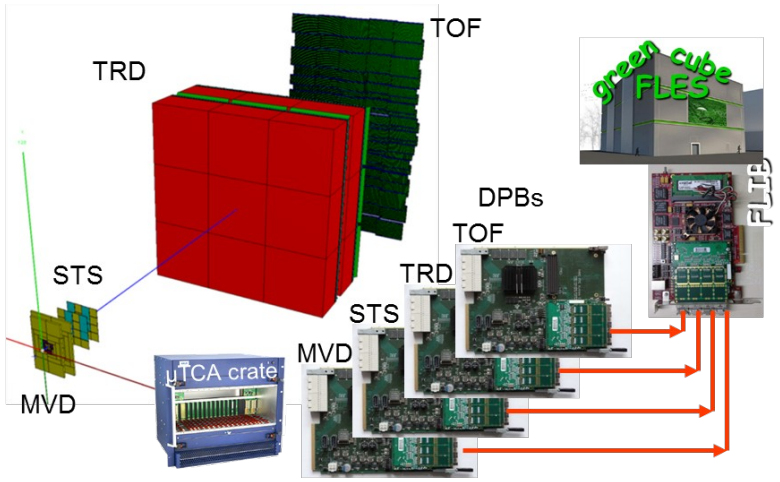
Au-beams up to 4.5 *A*GeV in 2018–2019



CBM commissioning setup
High rate A+A collisions at SIS18/GSI

Full size detector modules
and read-out chain

Testing environment for:
Detector performance
Free streaming data transport
Online reconstruction

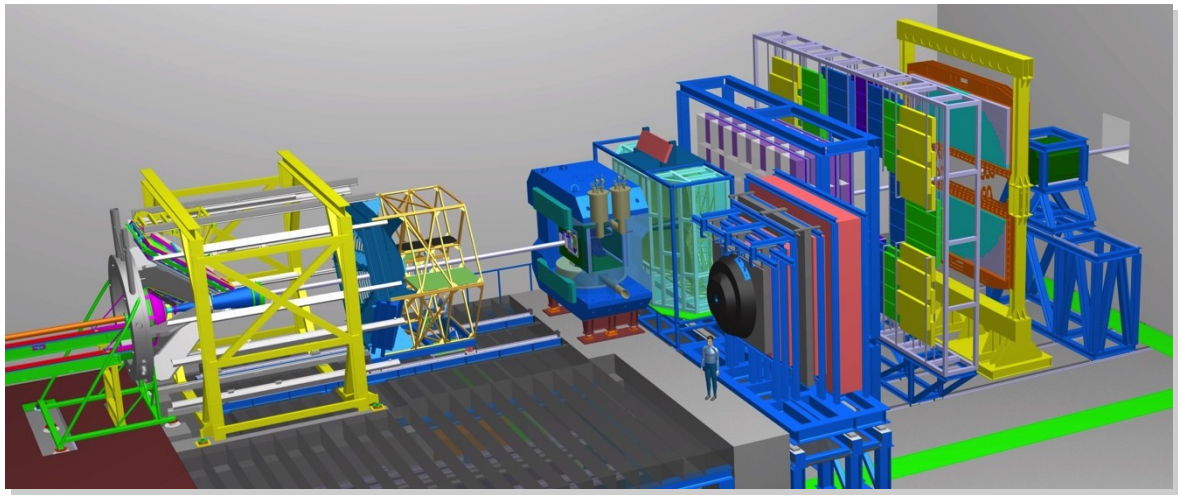


Conclusions

Diverse and exciting physics program
QCD phase diagram
Exotic matter and particles

Many new observables accessible due to highest rates
E.g. dileptons, heavy flavor, …
Systematic, multi-dimensional studies

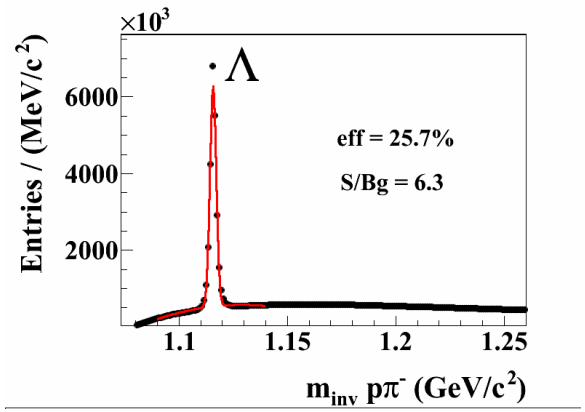
Experiment will be ready for day-1 physics at the SIS100

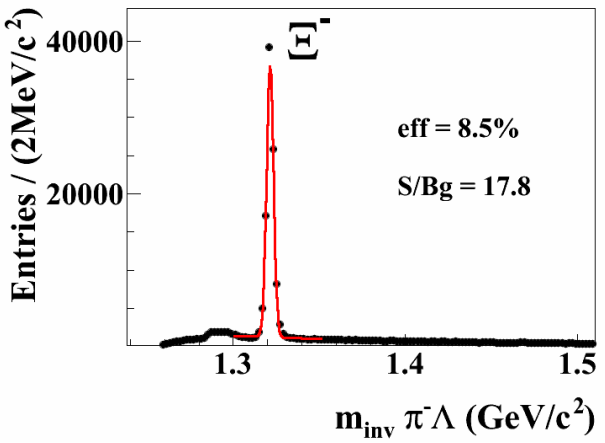


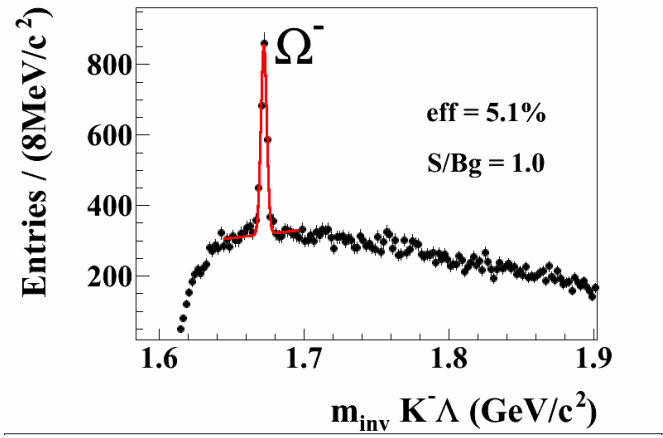
Many Thanks!

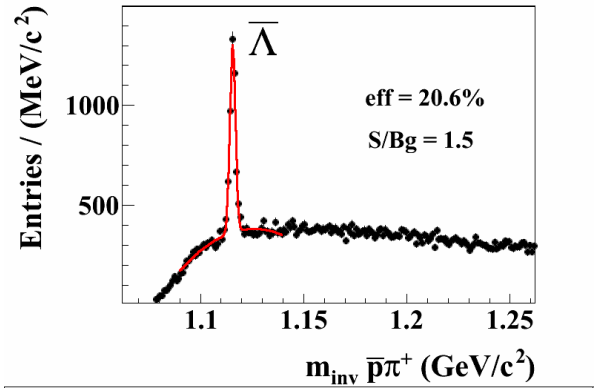
Backup

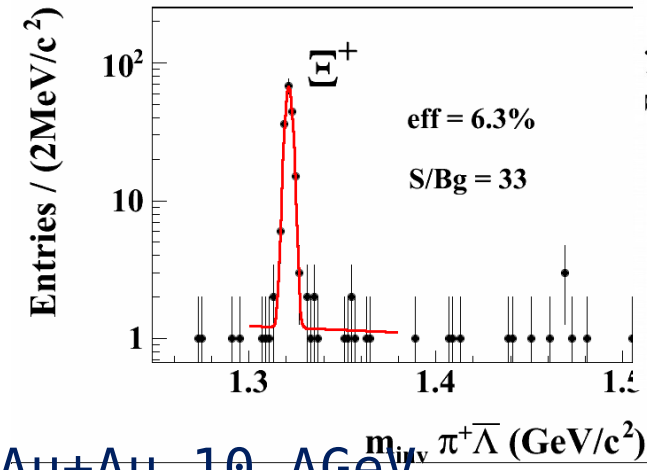
UrQMD

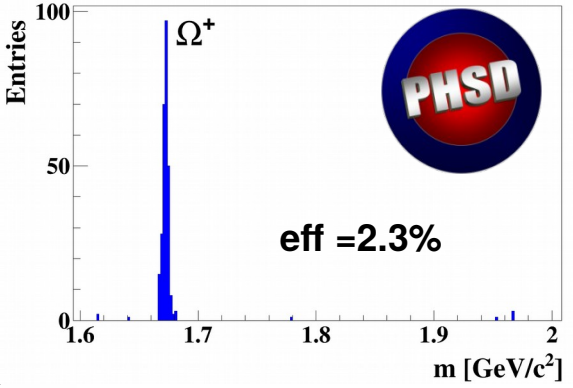




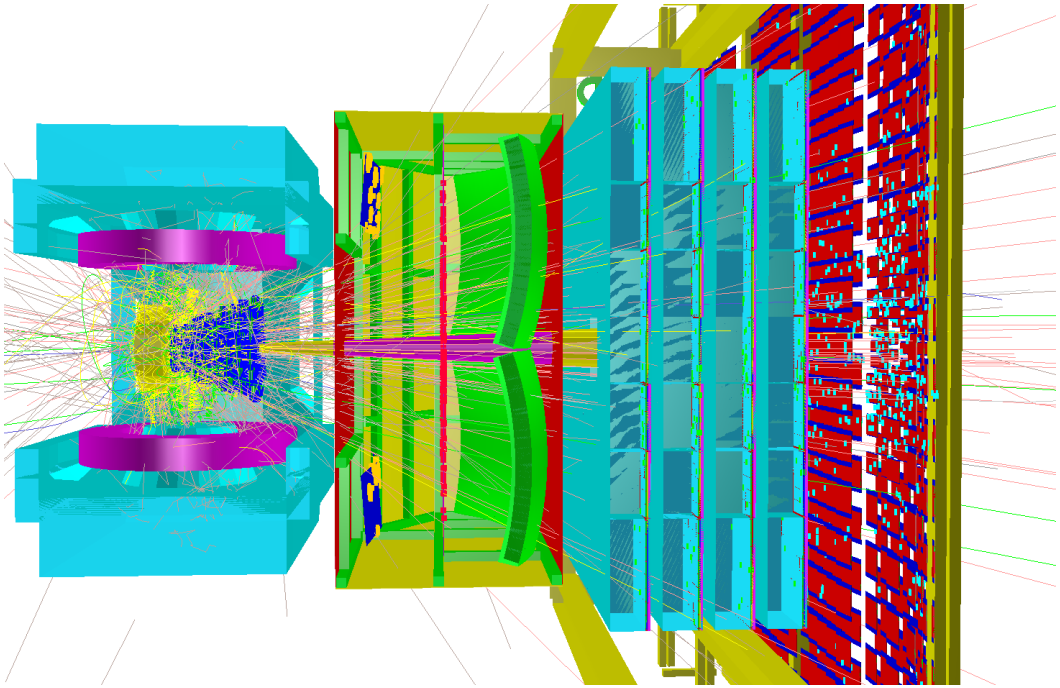


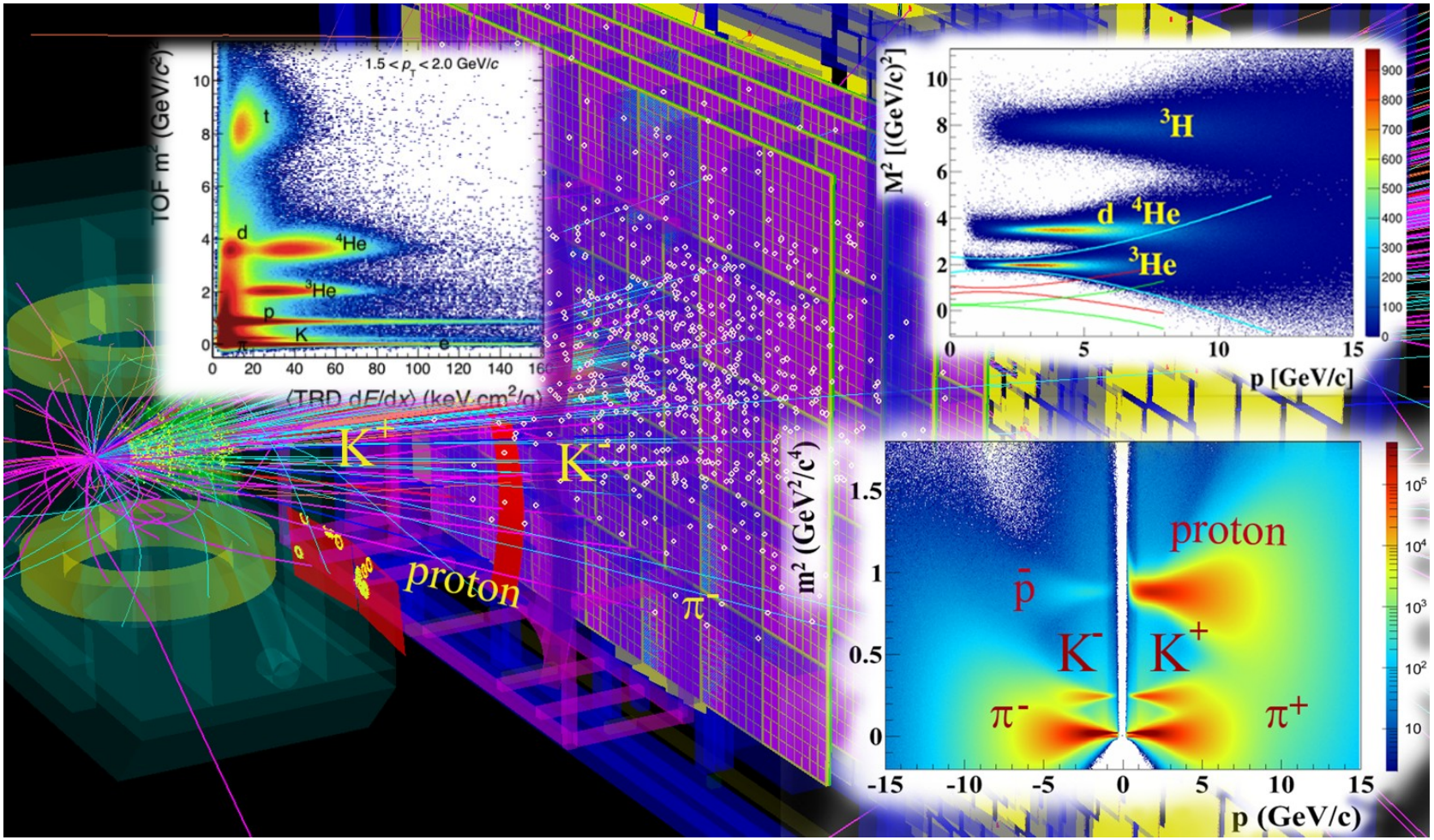


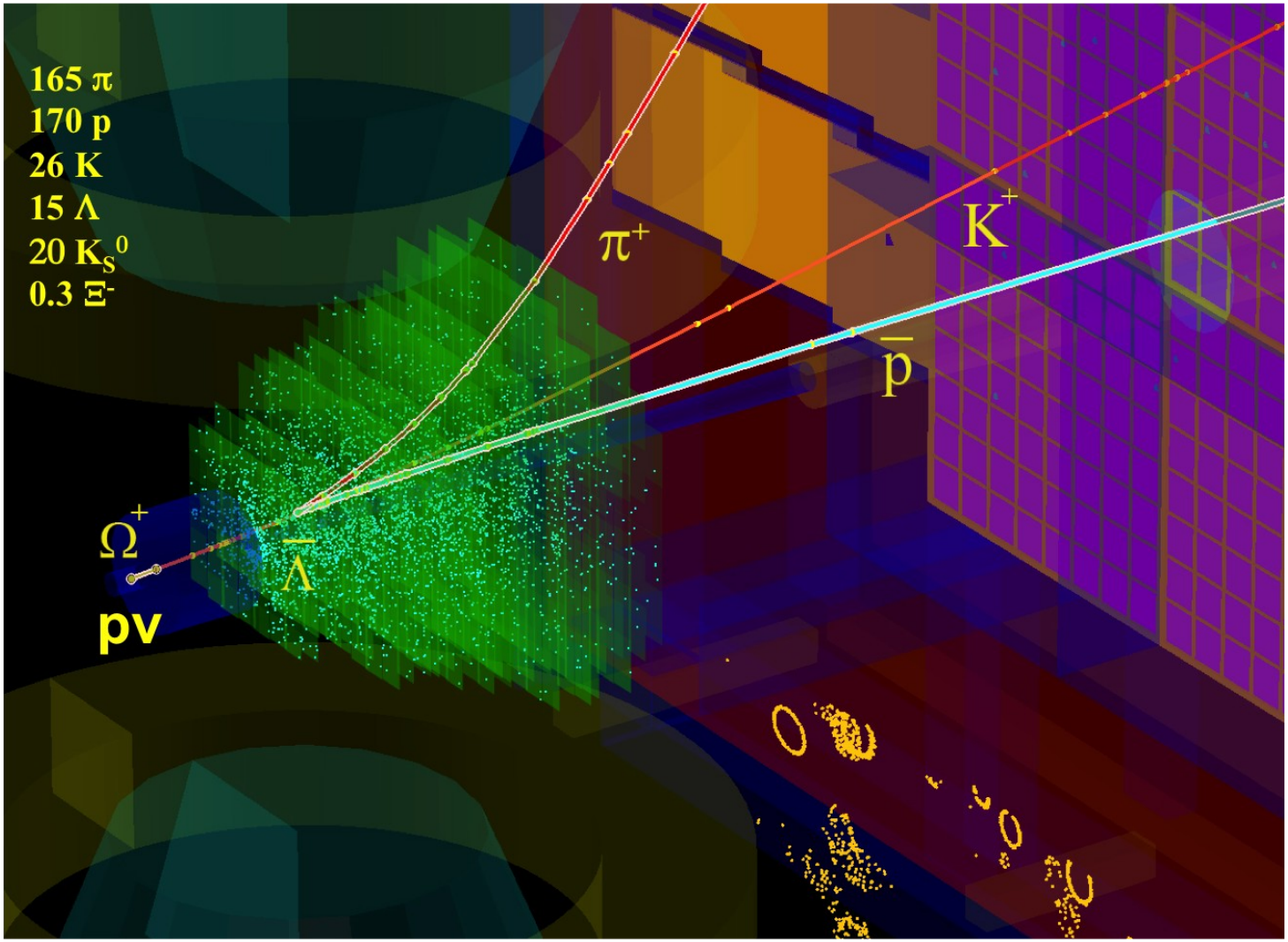


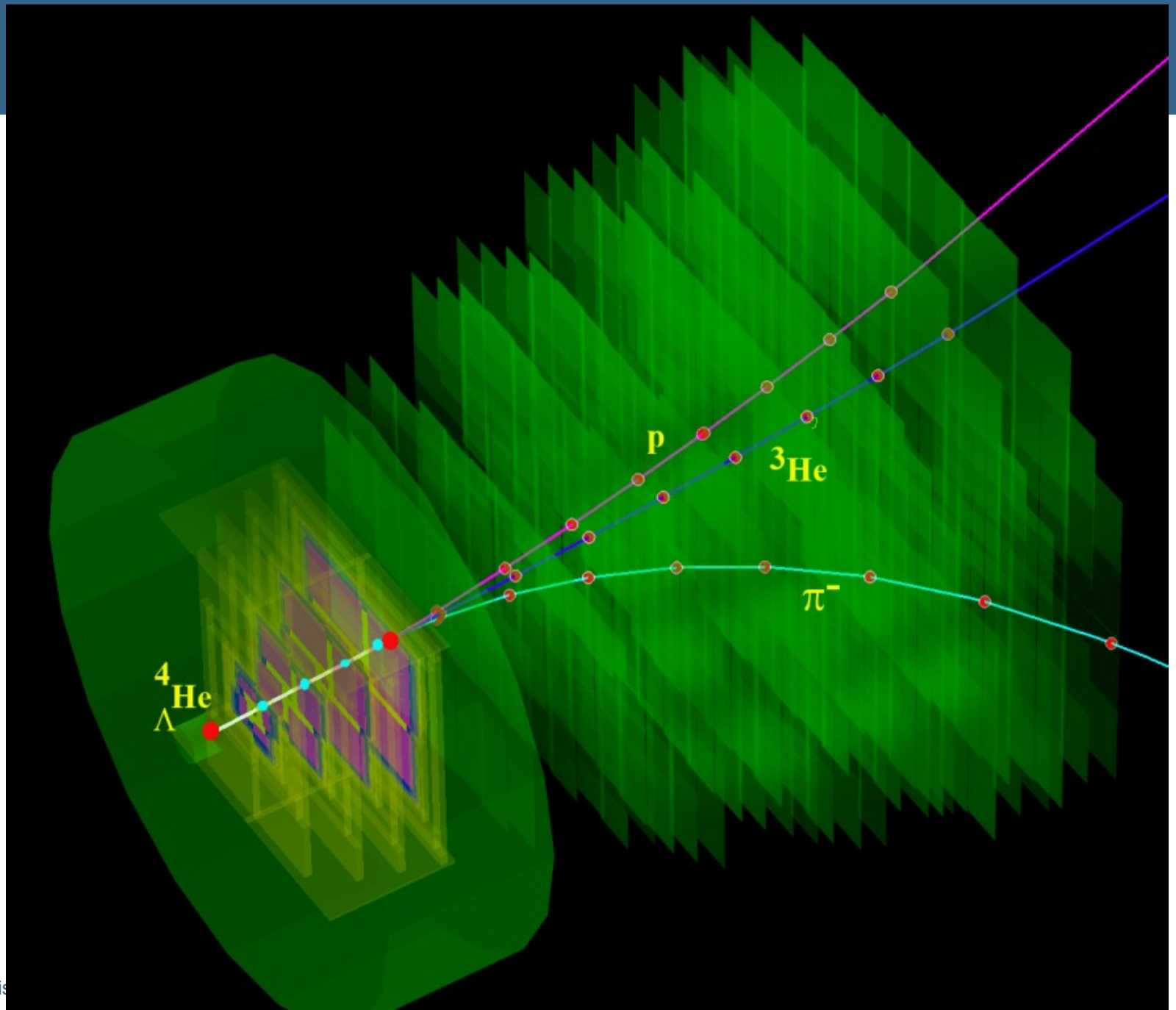


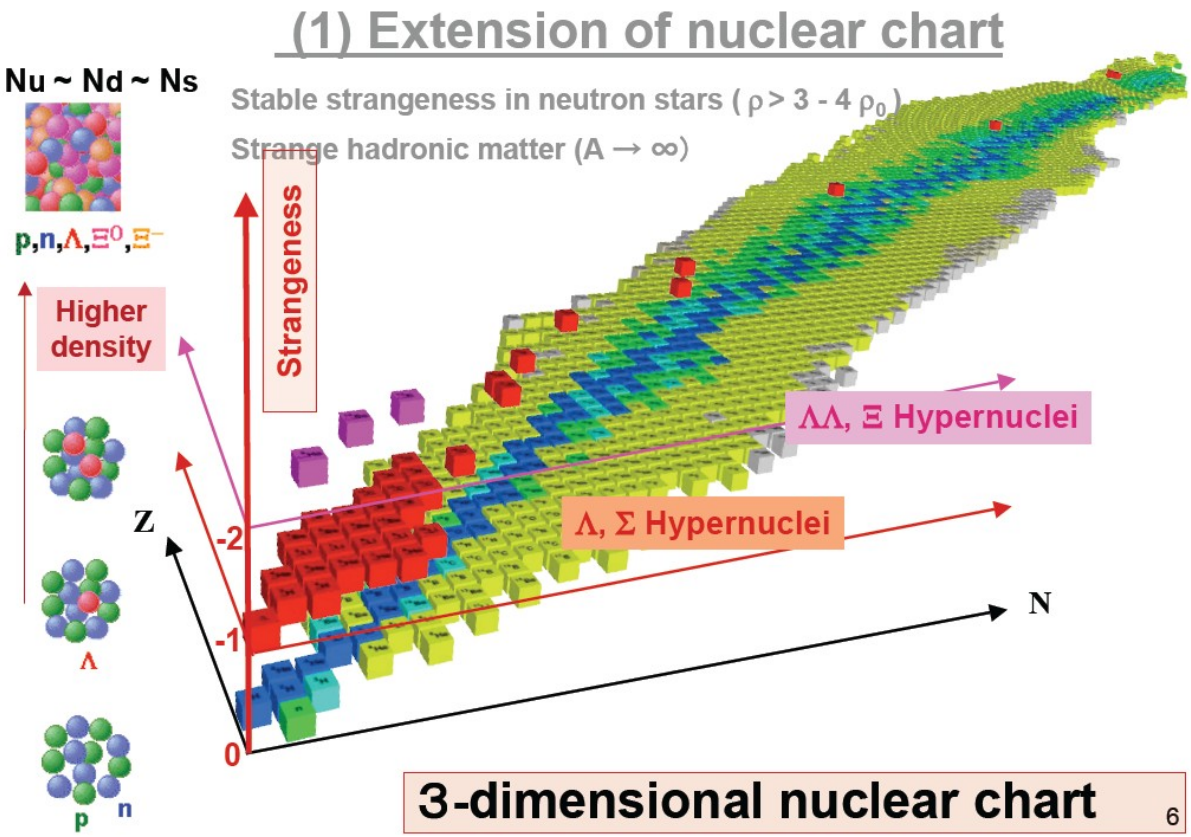
Hyperons in Au+Au 10 AGeV




TOF m² (GeV/c²)
1.5 < p_T < 2.0 GeV/c
t
d
⁴He
³He
p
K
π
e
⟨TRD dE/dx⟩ (keV·cm²/g)
K⁺
K⁻
π⁻
proton
m² (GeV²/c⁴)
M² [(GeV/c)²]
³H
d ⁴He
³He
p [GeV/c]
proton
p̄
K⁻
K⁺
π⁻
π⁺
p (GeV/c)


165 π
170 p
26 K
15 Λ
20 K_S^0
0.3 Ξ⁻
π^+
K^+
$\bar{p}$
Ω^+
$\bar{\Lambda}$
pv


p
^{3}He
π^{-}
$^{4}_{\Lambda}$He

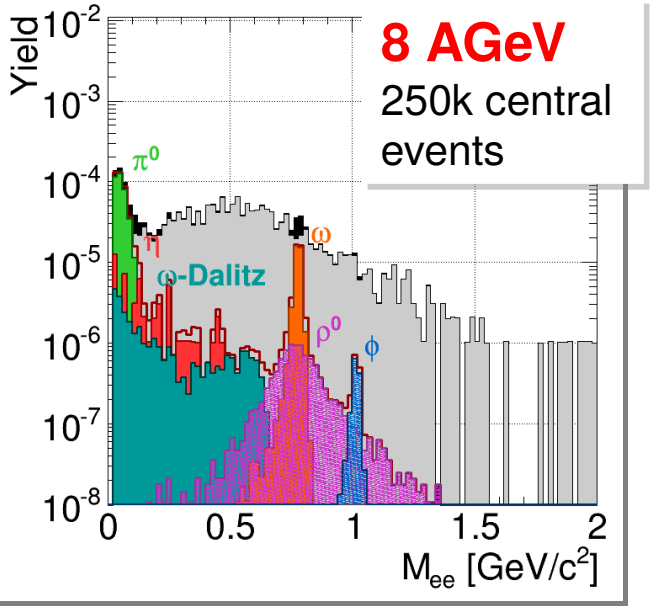

(1) Extension of nuclear chart
Nu ~ Nd ~ Ns
Stable strangeness in neutron stars (ρ > 3 - 4 ρ0)
Strange hadronic matter (A → ∞)
p,n,Λ,Ξ0,Ξ−
Higher density
Strangeness
ΛΛ, Ξ Hypernuclei
Λ, Σ Hypernuclei
Z
N
-2
-1
0
Λ
p
n
3-dimensional nuclear chart
6

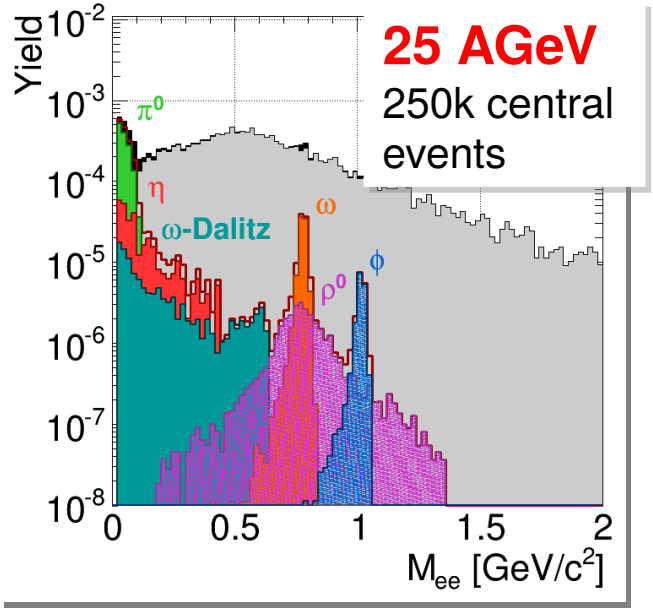
Physics Performance
Low Mass Vector Mesons via e^+e^- and $\mu^+\mu^-$

STS+ RICH+ TRD

$J/\psi \rightarrow e^+e^-$

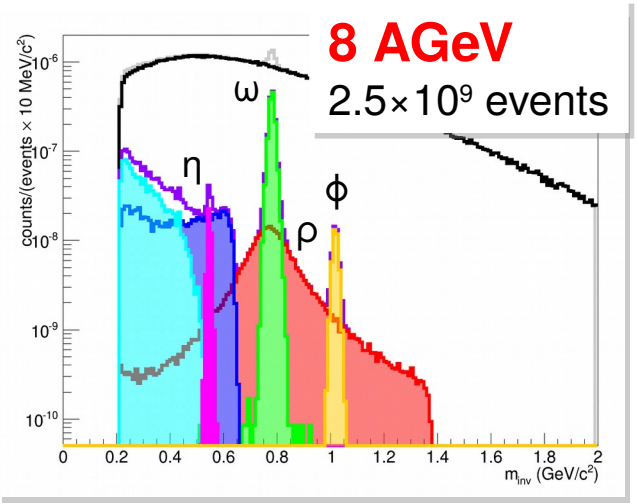
8 AGeV: 4-layer TRD
25 AGeV: 10-layer TRD

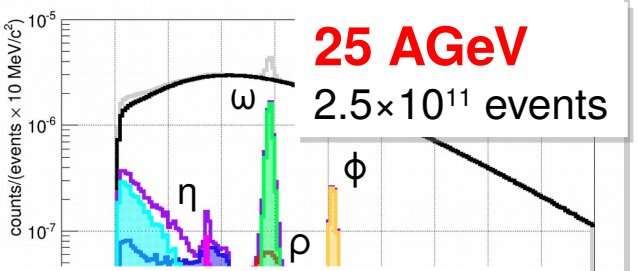




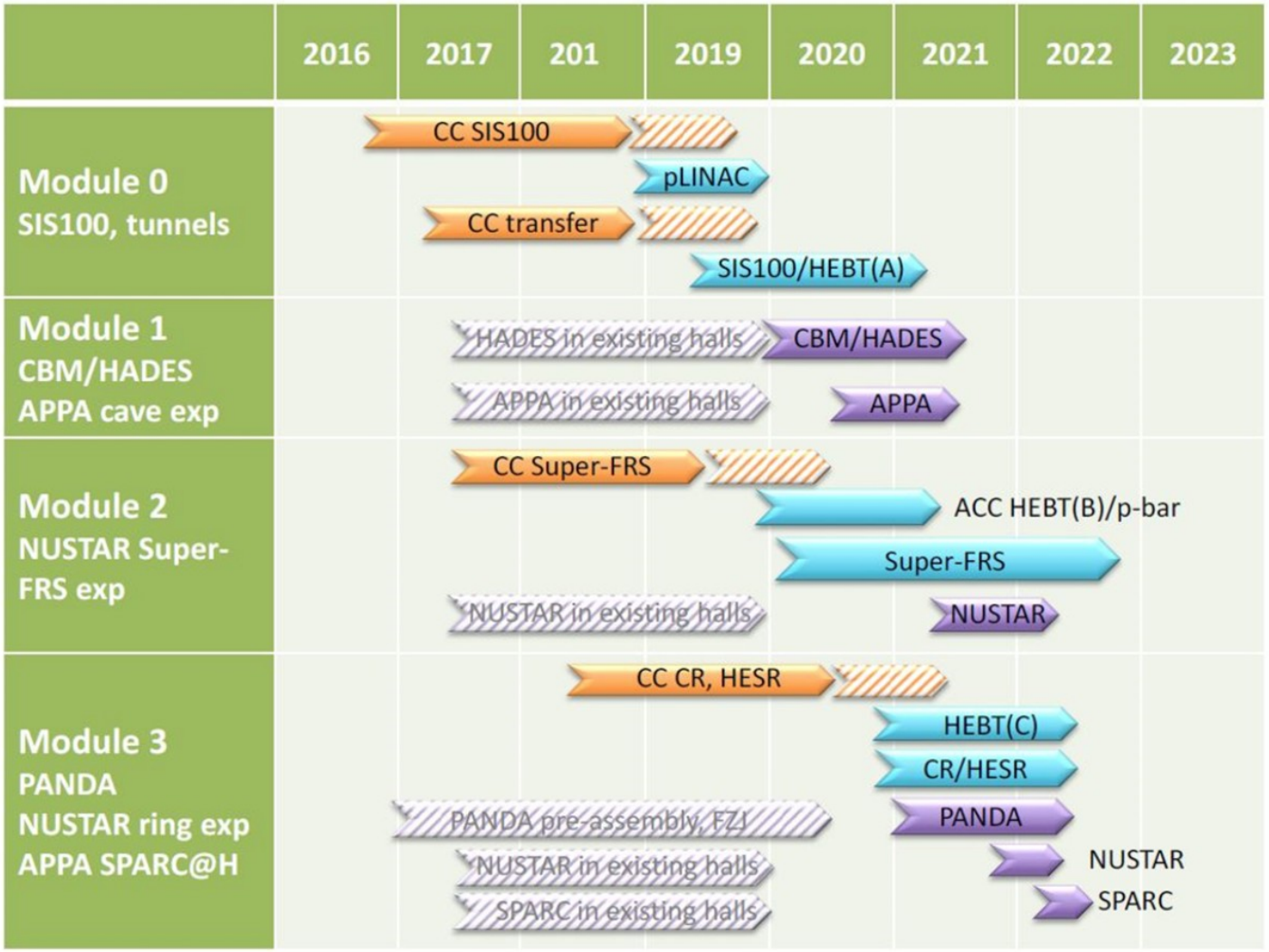
STS+ MUCH+ TOF

$J/\psi \rightarrow \mu^+\mu^-$

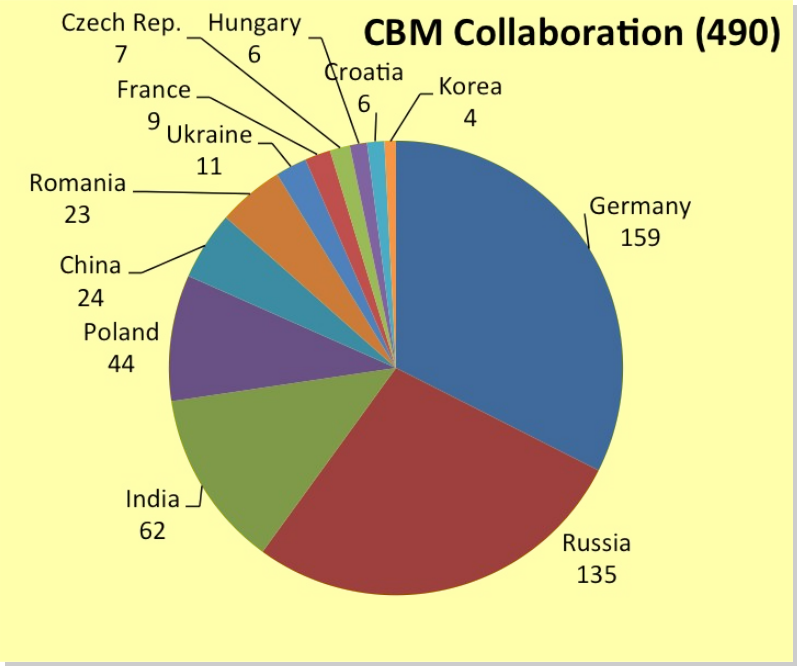




⇒ HK33.7: *E. Lebedeva*
⇒ HK64.2: *E. Krebs*
⇒ HK51.5: *A. Senger*


2016
2017
201
2019
2020
2021
2022
2023
Module 0
SIS100, tunnels
CC SIS100
pLINAC
CC transfer
SIS100/HEBT(A)
Module 1
CBM/HADES
APPA cave exp
HADES in existing halls
CBM/HADES
APPA in existing halls
APPA
Module 2
NUSTAR Super-
FRS exp
CC Super-FRS
ACC HEBT(B)/p-bar
Super-FRS
NUSTAR in existing halls
NUSTAR
Module 3
PANDA
NUSTAR ring exp
APPA SPARC@H
CC CR, HESR
HEBT(C)
CR/HESR
PANDA pre-assembly, FZJ
PANDA
NUSTAR
NUSTAR in existing halls
SPARC
SPARC in existing halls

The CBM Experiment
Collaboration



Germany:
Darmstadt TU
FAIR
Frankfurt Univ. IKF
Frankfurt FIAS
GSI Darmstadt
Gießen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
Münster Univ.
Tübingen Univ.
Wuppertal Univ.

India:
Aligarh Muslim Univ.
Bose Inst. Kolkata
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.

Romania:
NIPNE Bucharest
Univ. Bucharest

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

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
Joffe Inst., St. Petersburg
Kurchatov Inst., Moscow
LHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP MSU, Moscow
SPbSPU, St. Petersburg

Ukraine:
T. Shevchenko Univ. Kiev
Kiev Inst. Nucl. Research
LTU, Kharkov (industrial partner)

Croatia:
RBI Zagreb
Split Univ.

China:
CCNU Wuhan
Tsinghua Univ. Beijing
USTC Hefei

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

France:
IPHC Strasbourg

Hungary:
KFKI Budapest
Budapest Univ.

Korea:
Korea Univ. Seoul
Pusan Nat. Univ.