The physics program of the CBM experiment

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Outline

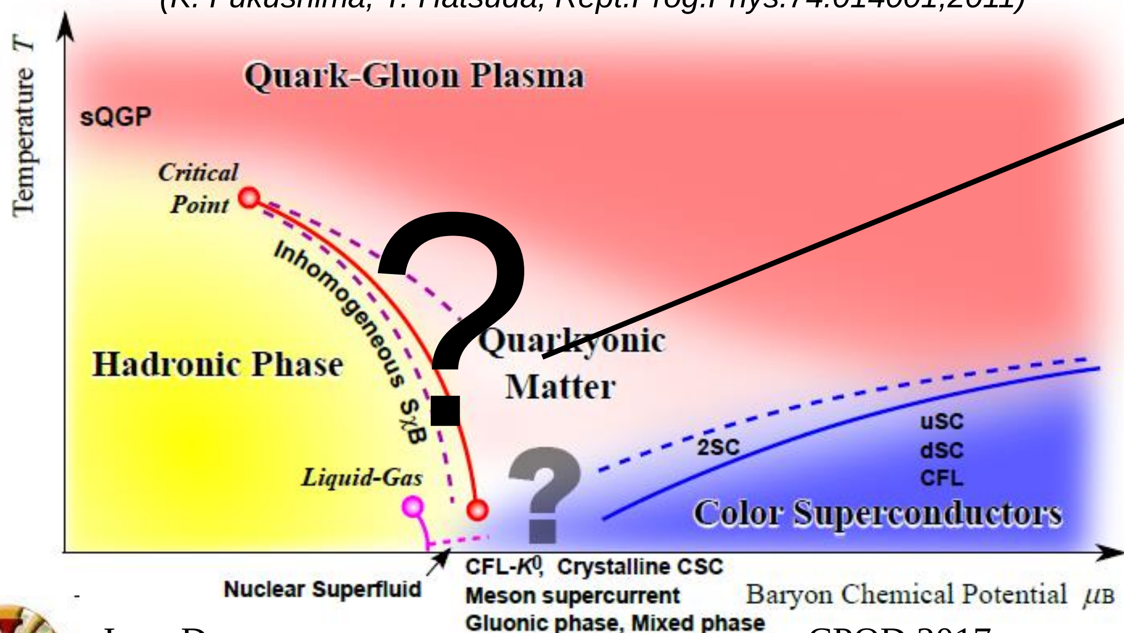
- Motivation - the QCD phase diagram
- Theoretically predicted observables probing the dense medium
- The FAIR facility and the CBM experiment
- Summary

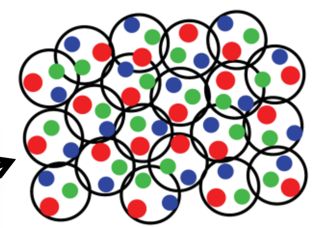
Motivation

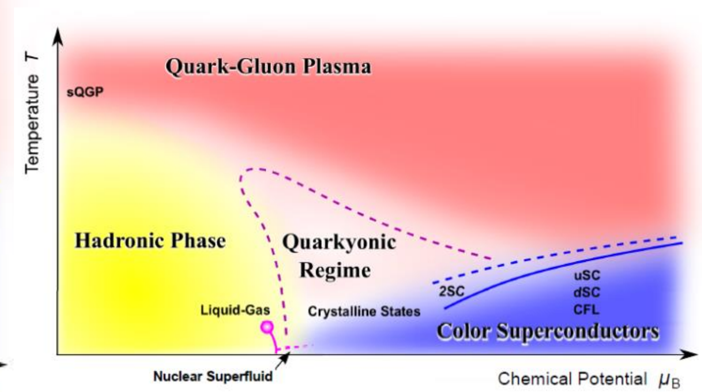
At large μ_b most of the phase structure is speculation

- Is there a first order phase transition?
- Is there a critical point?
- Does the deconfinement phase transition coincide with the chiral symmetry restoration phase transition at high μ_B?
- Quarkyonic phase?

(K. Fukushima, T. Hatsuda, Rept.Prog.Phys.74:014001,2011)

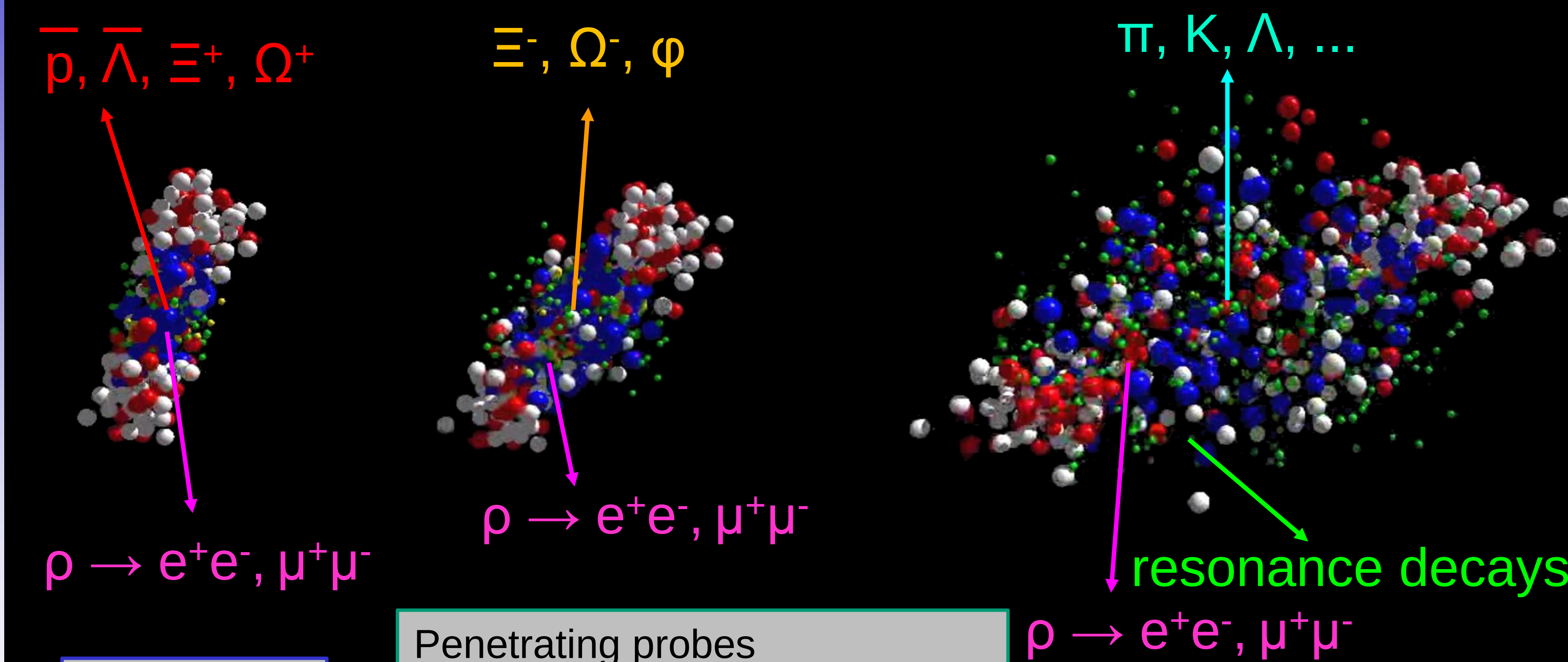






Motivation

UrQMD transport calculation Au+Au 10.7 A GeV



Hard probes
(initial state)

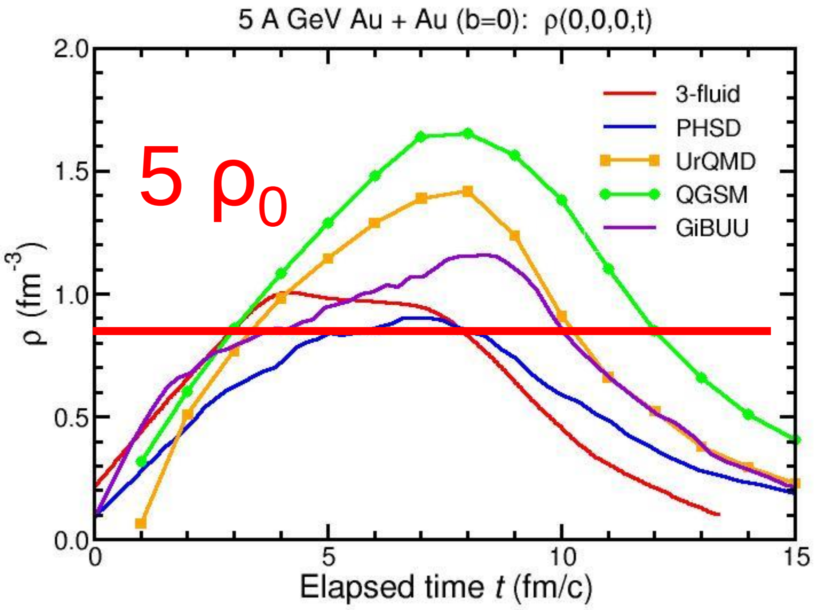
Penetrating probes
(integrate over collision history)
Relicts
(produced in dense phase)

Freeze-out
(final state particles)

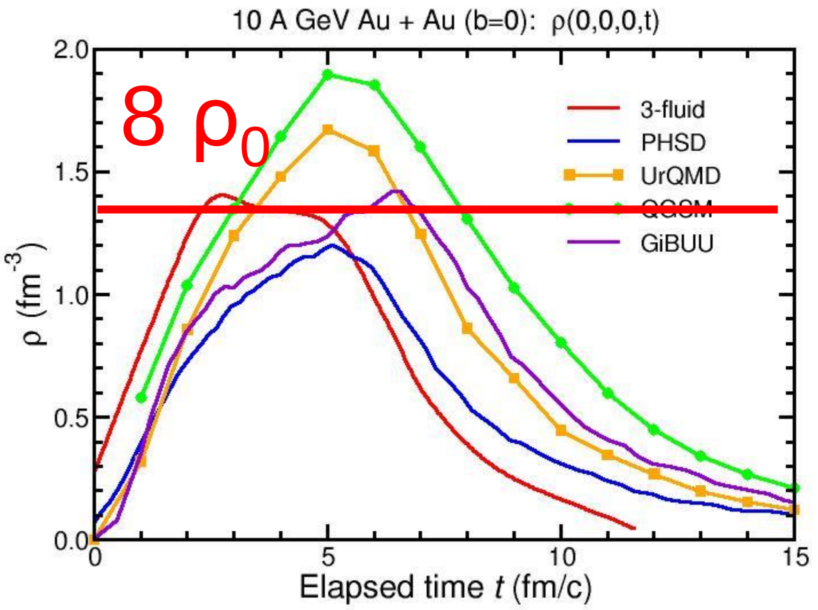
Thermalized (?) hadrons

Central Au + Au collision at beam energy of

5 A GeV



10 A GeV



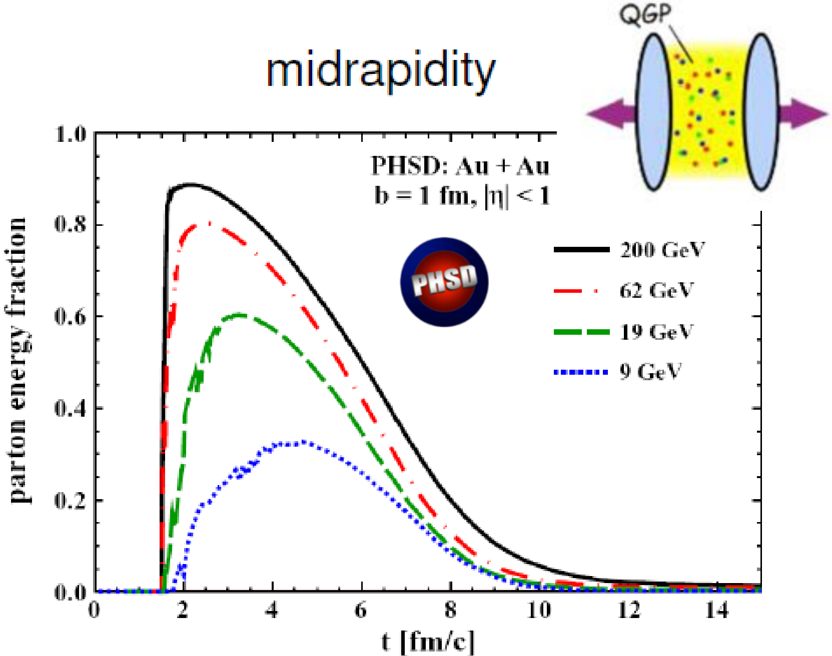
I.C. Arsene et al., Phys. Rev. C 75, 24902 (2007)

Observables

- Chiral symmetry restoration
  - di-leptons
  - strange mesons and baryons
  - sub threshold charm production
- Onset of deconfinement
  - multi-strange (anti)-baryons
  - Hypernuclei
- Critical point
  - Fluctuations

    net proton cumulants

midrapidity

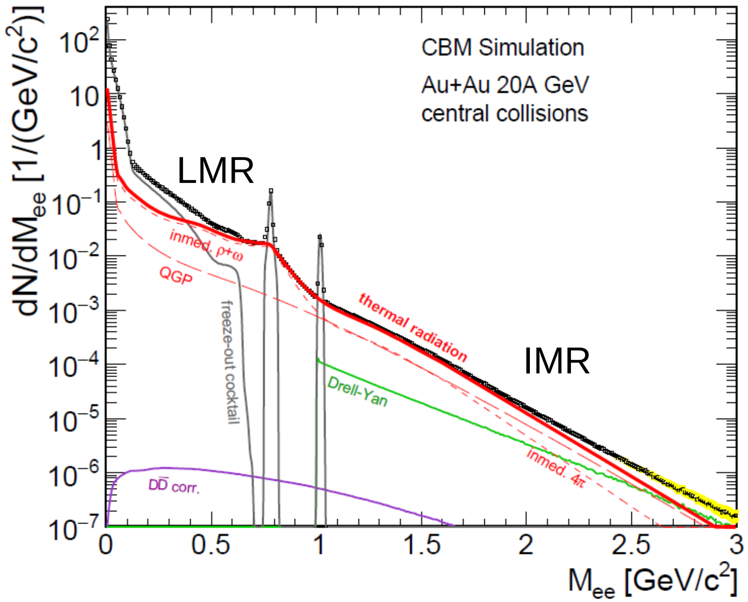


Central Au+Au

Cassing, CBM collaboration meeting, GSI 2016

"At AGS, only a small part of the initial energy is converted into the QGP phase"

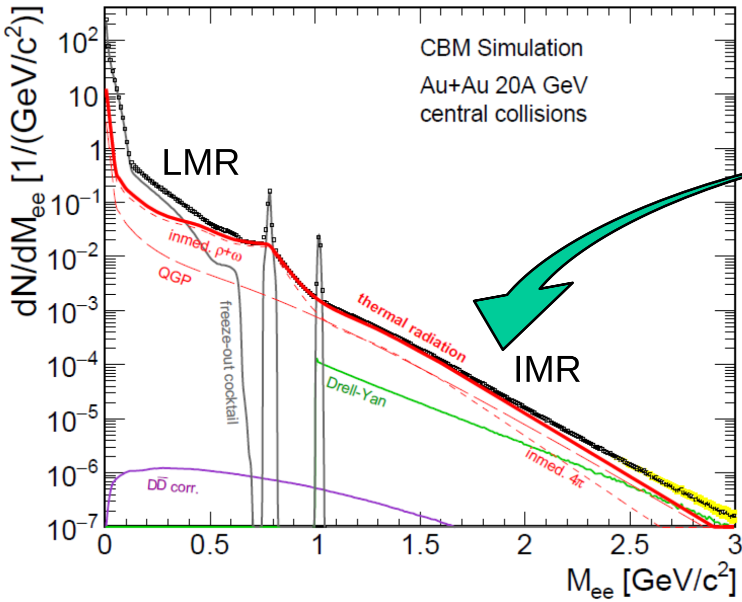
Di-leptons as a probe of dense matter



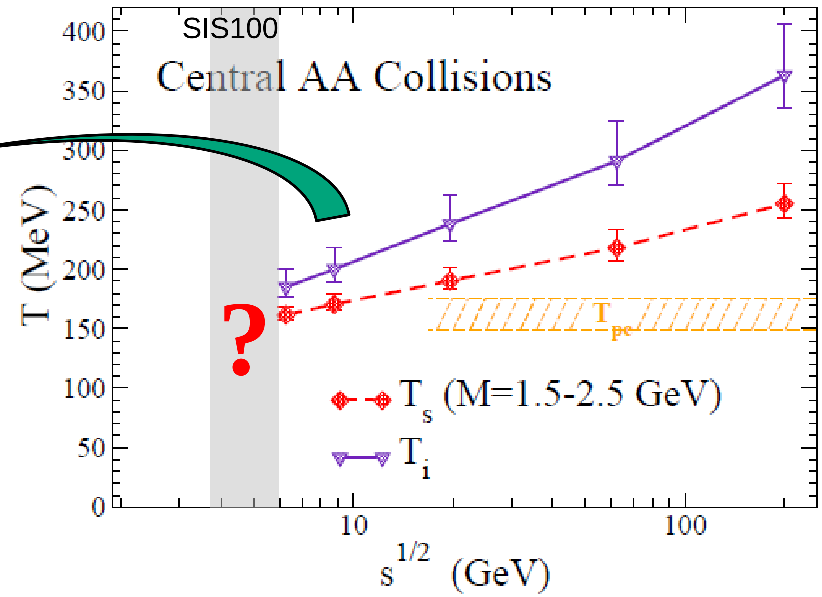
- Mass resolution: 13.6 MeV (ω)
- LMVM: about 10^6 ω per week
- IMR: S/B > 1/100
- Statistical accuracy of 10% requires ~1 week of CBM beamtime at 100 kHz IR

- Background sources strongly reduced with respect to SPS
  - (Drell Yan, open charm)
- Di-lepton measurement can provide
  - Temperature of fireball
  - Lifetime of fireball
  - Chiral symmetry restoration
- Large statistics needed to achieve sufficiently small errors !

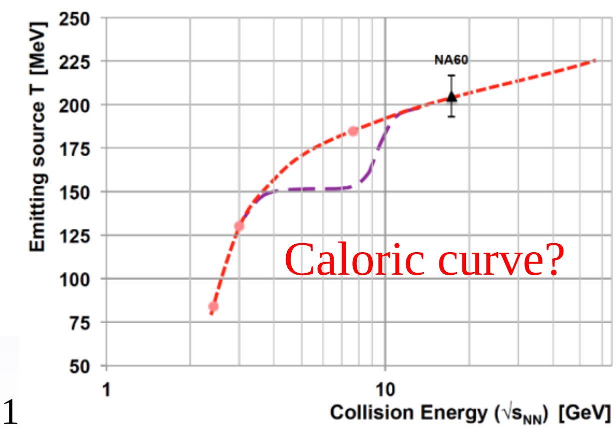
Di-leptons as a probe of dense matter



R. Rapp, H. v.Hees, PLB 753 (2016) 586



T. Galatyuk et al., Eur. Phys. J. A 52 (2016) 131

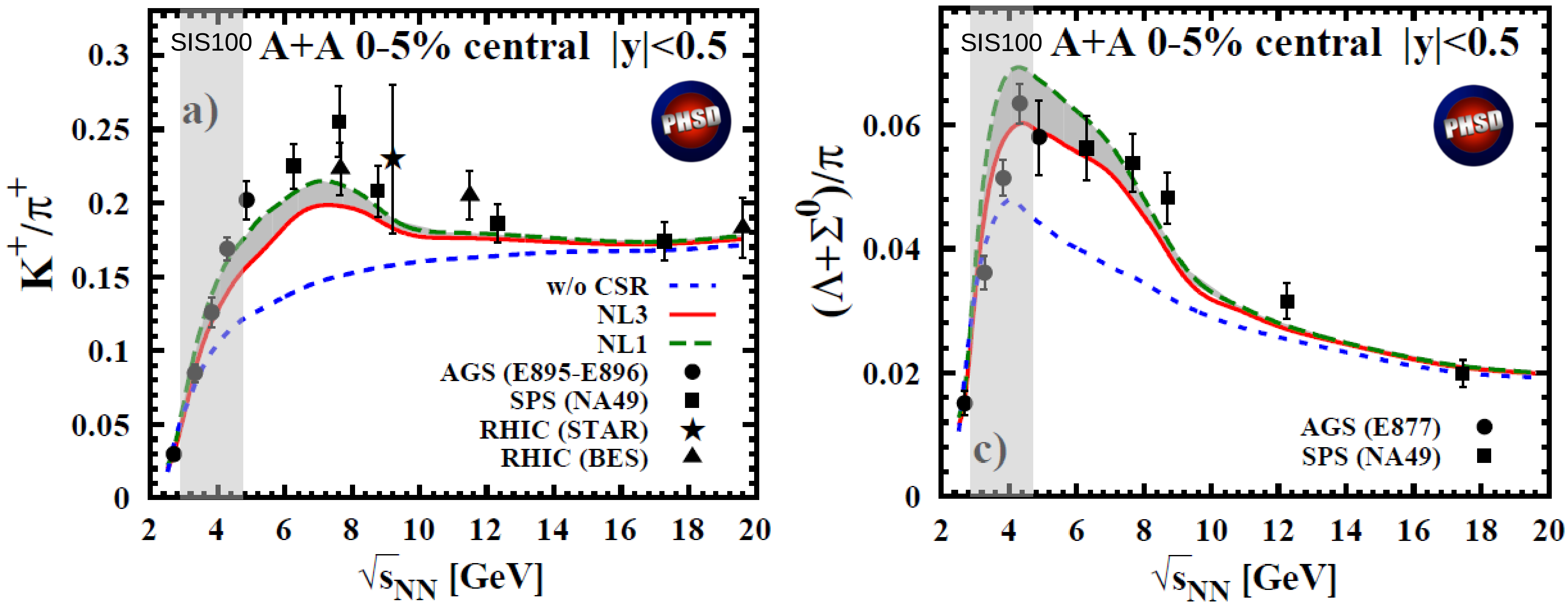


LMR: ρ – chiral symmetry restoration
fireball space – time extension
IMR: access to fireball temperature
ρ-a_1 chiral mixing
Kink in the caloric curve would be an indication of a 1st order phase transition

Light strange hadrons as a probe of dense matter

W. Cassing et al. Phys.Rev. C93 (2016) 014902

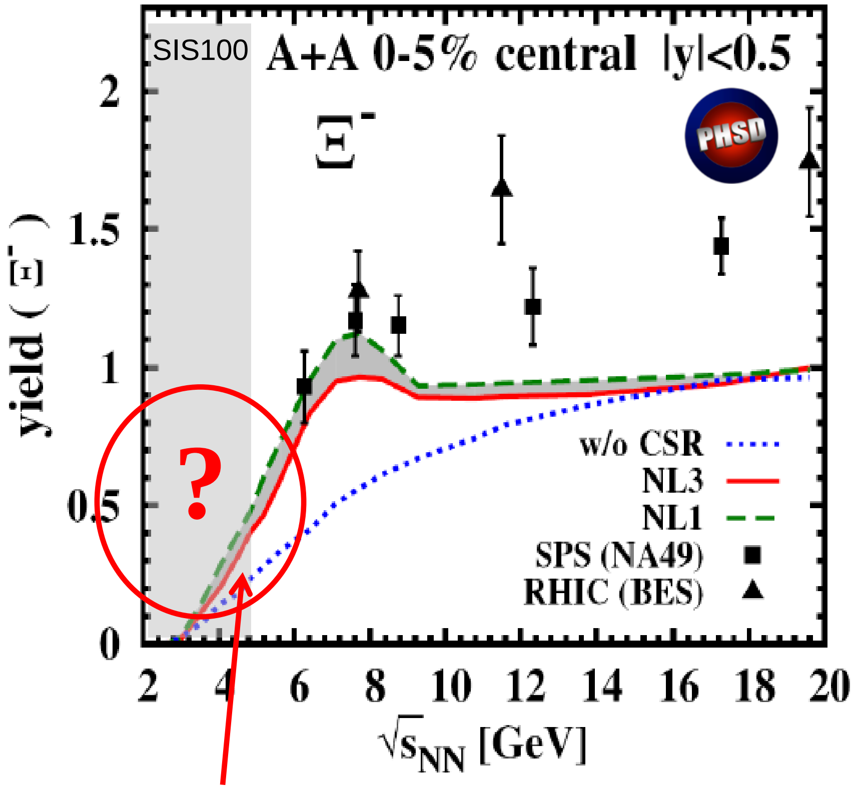
A. Palmese et al. Phys.Rev. C94 (2016) no.4, 044912



- "The microscopic PHSD studies support the idea that CSR occurs in hadronic systems with high temperatures and densities before the deconfinement phase transition takes over."

Multi-strange baryons as a probe of dense matter

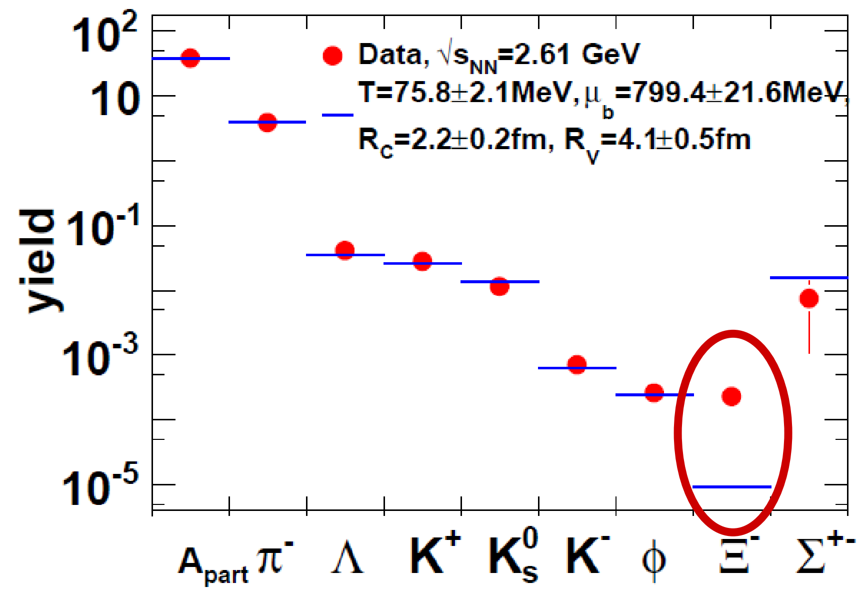
A. Palmese et al. Phys.Rev. C94 (2016) no.4, 044912



No data available

Ar+KCl reactions at 1.76A GeV

- Ξ^- yield by appr. factor 25 higher than thermal yield



- A possible explanation for the deep sub-threshold Ξ^- production yield - via resonance excitation and decay $N^* \rightarrow \Xi + K + K$

J. Steinheimer and M. Bleicher J.Phys. G43 (2016) no.1, 015104

Charm as a probe of dense matter

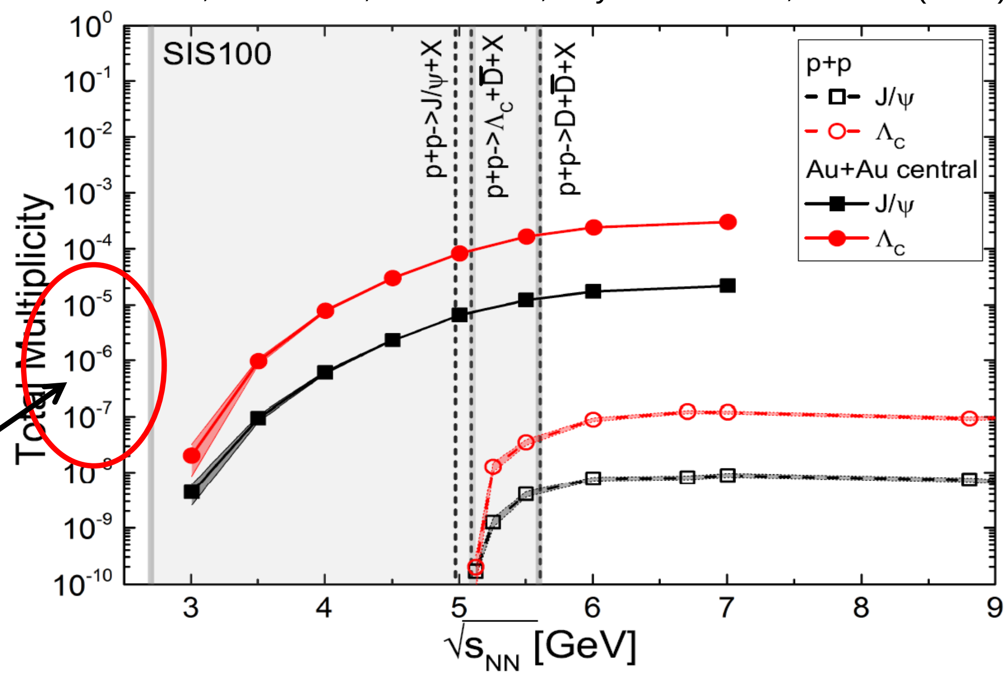
UrQMD prediction of subthreshold charm production via

N* → Λ_c + D and N* → N +J/ψ

J. Steinheimer, A. Botvina, M. Bleicher, Phys. Rev. C 95, 014911 (2017)

“It opens the possibility to study charm production and propagation in very dense hadronic environment

⇒ possible effects of chiral symmetry restoration could become visible”

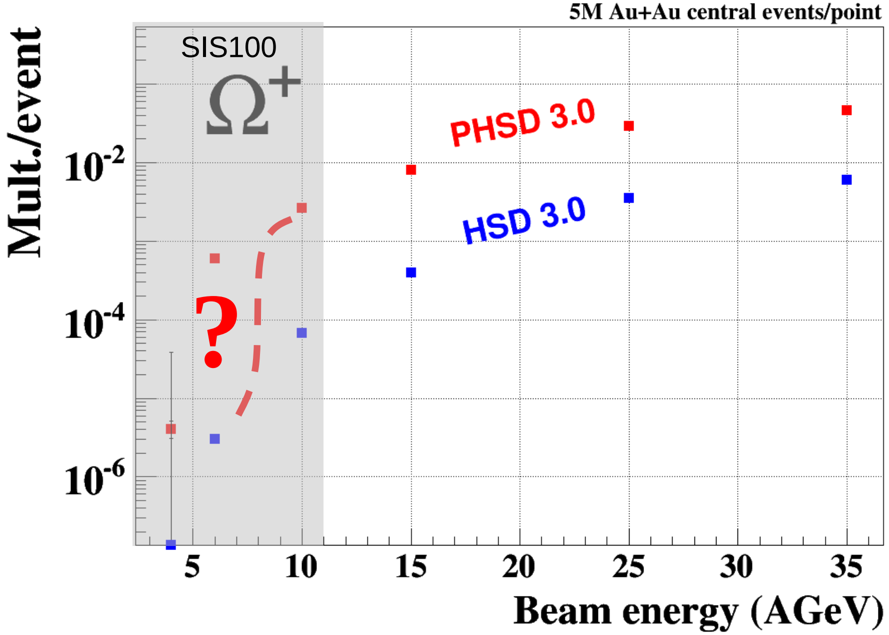


production mechanism?

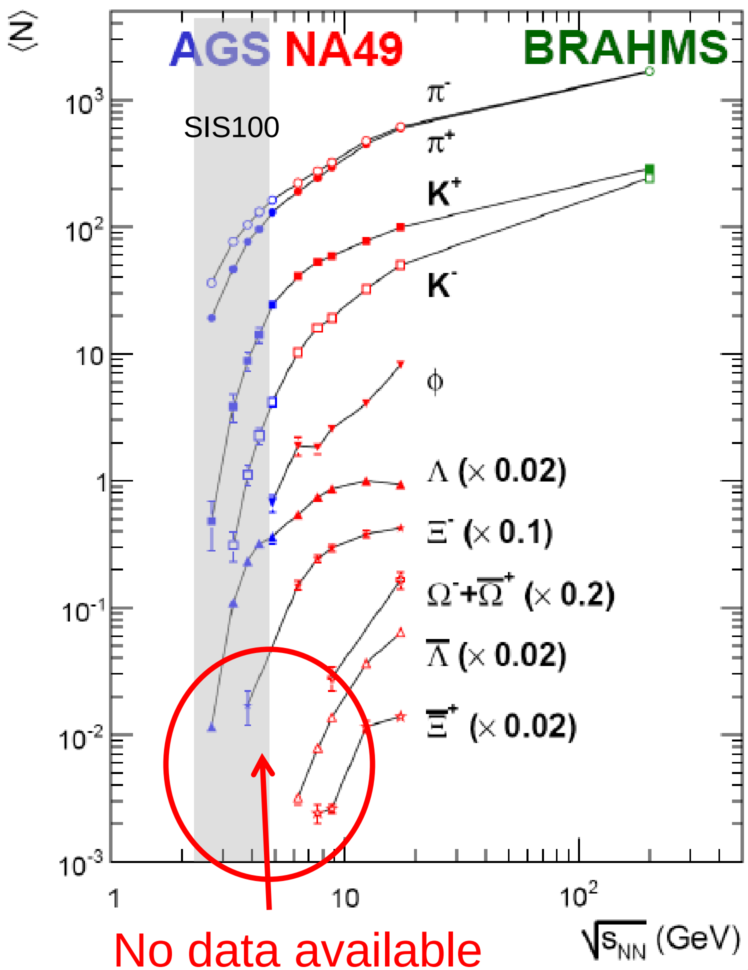
Extreamly rare probe (10^{-5} – 10^{-7})

Anti multi-strange hyperons as a probe of deconfinement

I. Vassiliev, CBM, private communication



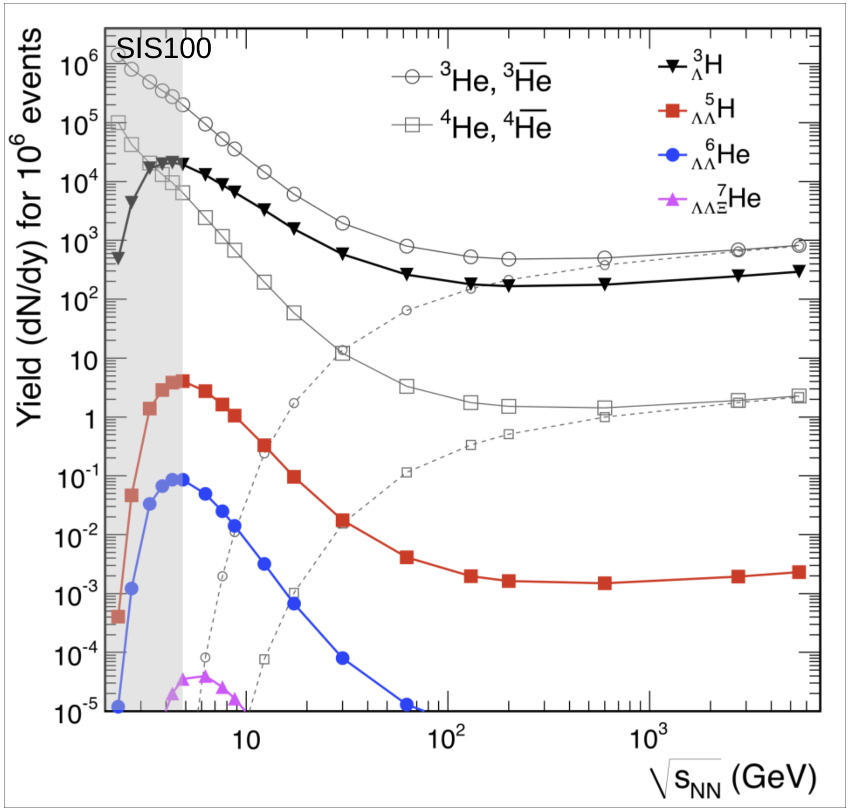
[C. Blume, JP 31 (2005) S57]



- An sudden increase in Ω^{+} yield could indicate an onset of deconfinement
- Ω^{+} is a rare probe

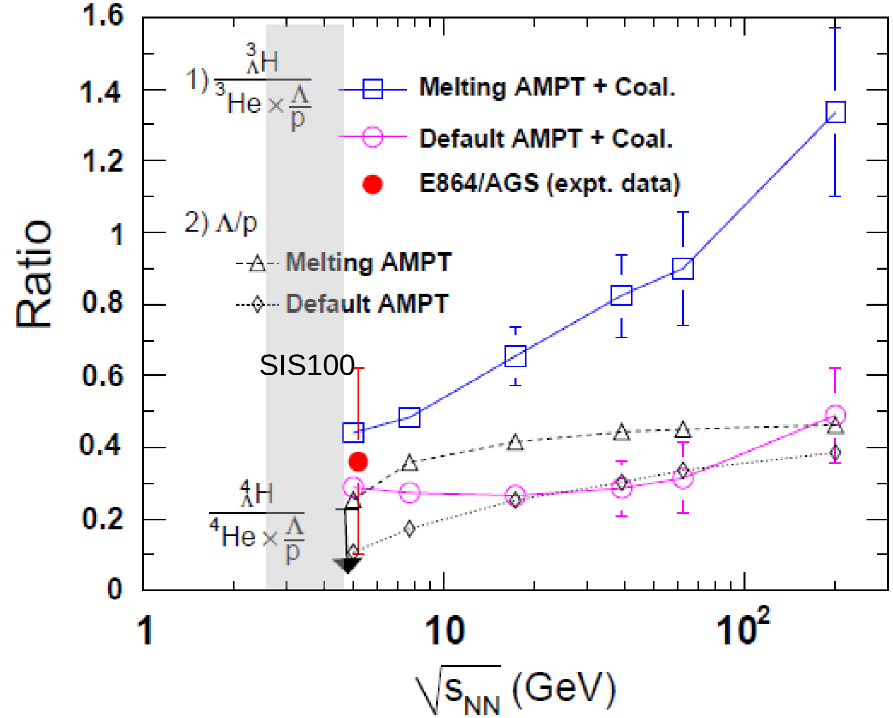
Hypernuclei as a probe of deconfinement

A. Andronic, P. Braun-Munzinger, J. Stachel, and H. Stocker, Phys. Lett. B697, 203 (2011), arXiv:1010.2995 [nucl-th]



- Thermal model predicts a maximal yield at top SIS100 energies

S. Zhang et al., Phys.Lett. B684, 224 (2010)

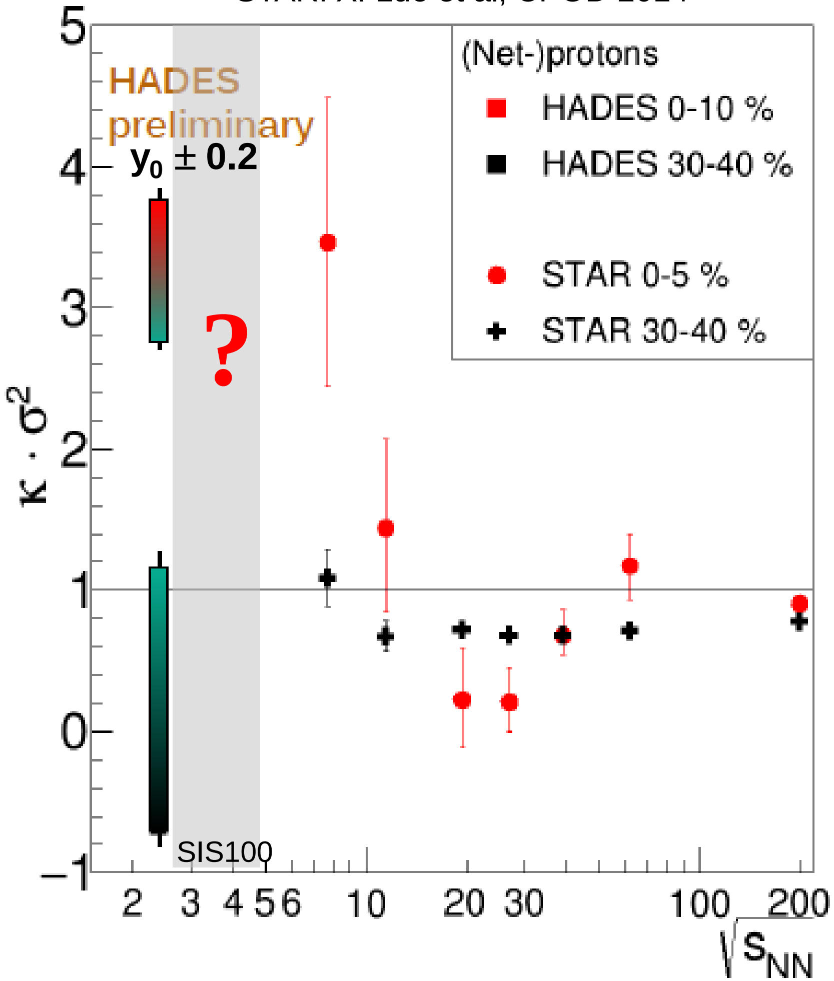


- Local correlation between baryon number and strangeness => sensitivity to deconfinement!
- Strangeness Population Factor

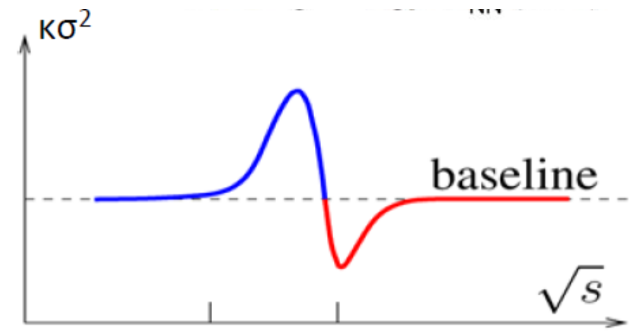
$$S_3 = {}^3_\Lambda\mathrm{H}/({}^3\mathrm{He} \times \frac{\Lambda}{p})$$

Fluctuations as a probe of the critical point

HADES: M. Lorenz, QM 2017
STAR: X. Luo et al, CPOD 2014



in the vicinity of the critical point



M. Stephanov. J. Physics G.: Nucl. Part. Phys. ***38*** (2011) 124147

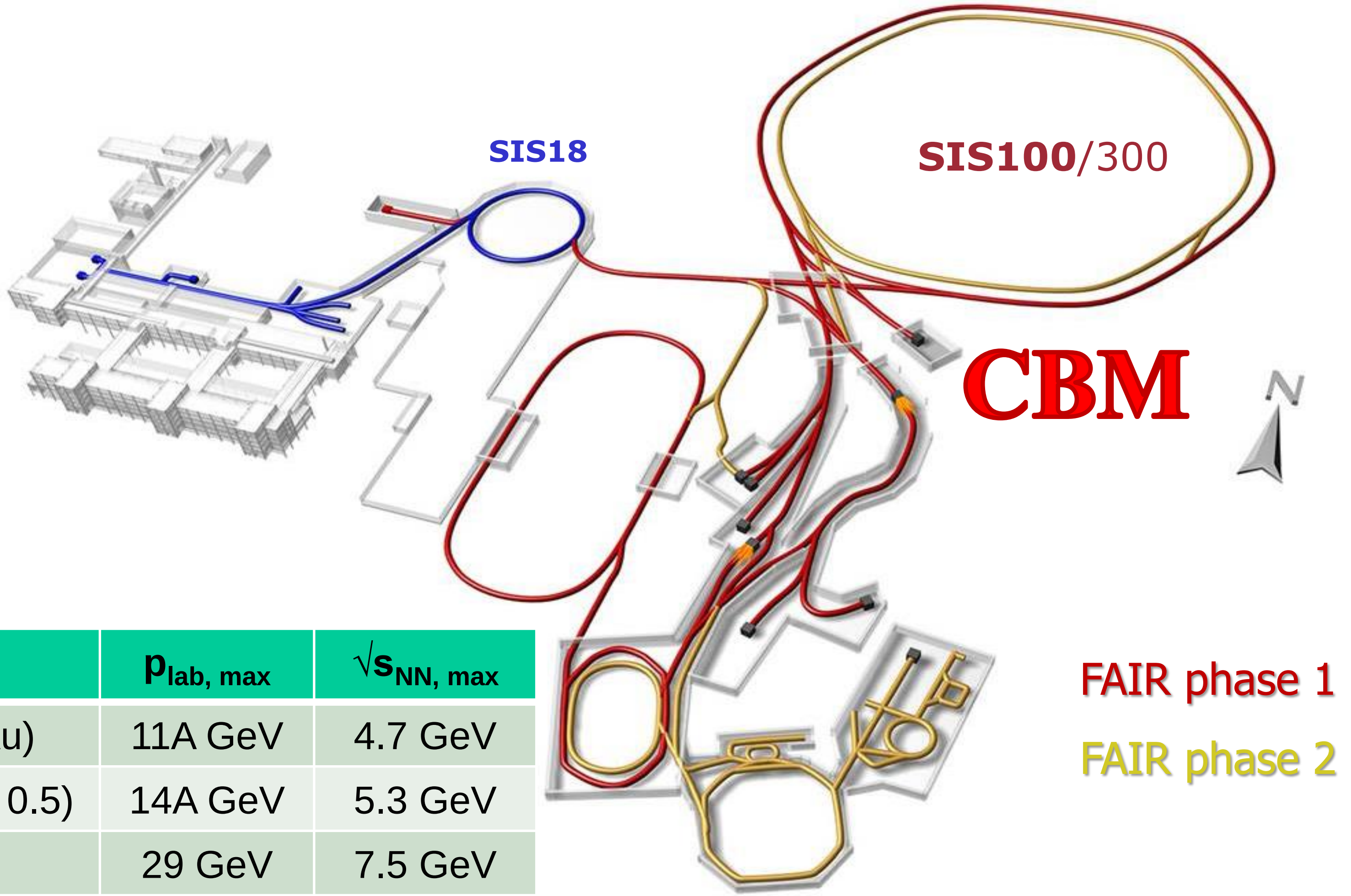
$$\delta N = N - \langle N \rangle$$

$$C_2 = \langle (\delta N)^2 \rangle \,,$$

$$C_4 = \langle (\delta N)^4 \rangle - 3 \langle (\delta N)^2 \rangle^2$$

$$\kappa\sigma^2 = \frac{C_4}{C_2} \qquad C_4 \propto \xi^7$$

Facility for Antiproton & Ion Research



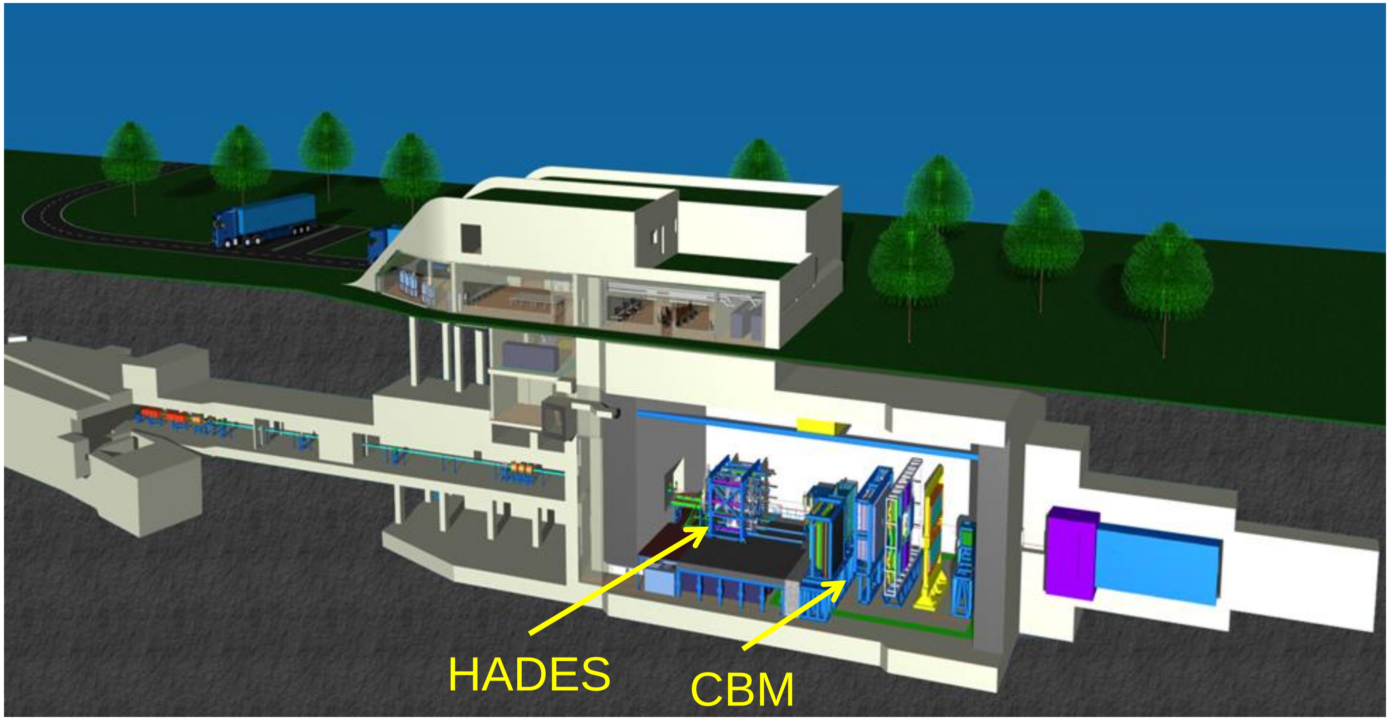
Beam	$p_{lab, max}$	$\sqrt{s}_{NN, max}$
heavy ions (Au)	11A GeV	4.7 GeV
light ions (Z/A = 0.5)	14A GeV	5.3 GeV
protons	29 GeV	7.5 GeV

Facility for Antiproton & Ion Research

Facility for Antiproton & Ion Research

- Civil construction of SIS 100 tunnel and CBM cave started
- Detector installation/ commissioning 2021 – 2024
- FAIR delivers 1st beam 2024 (FAIR phase 0 from 2018 on)

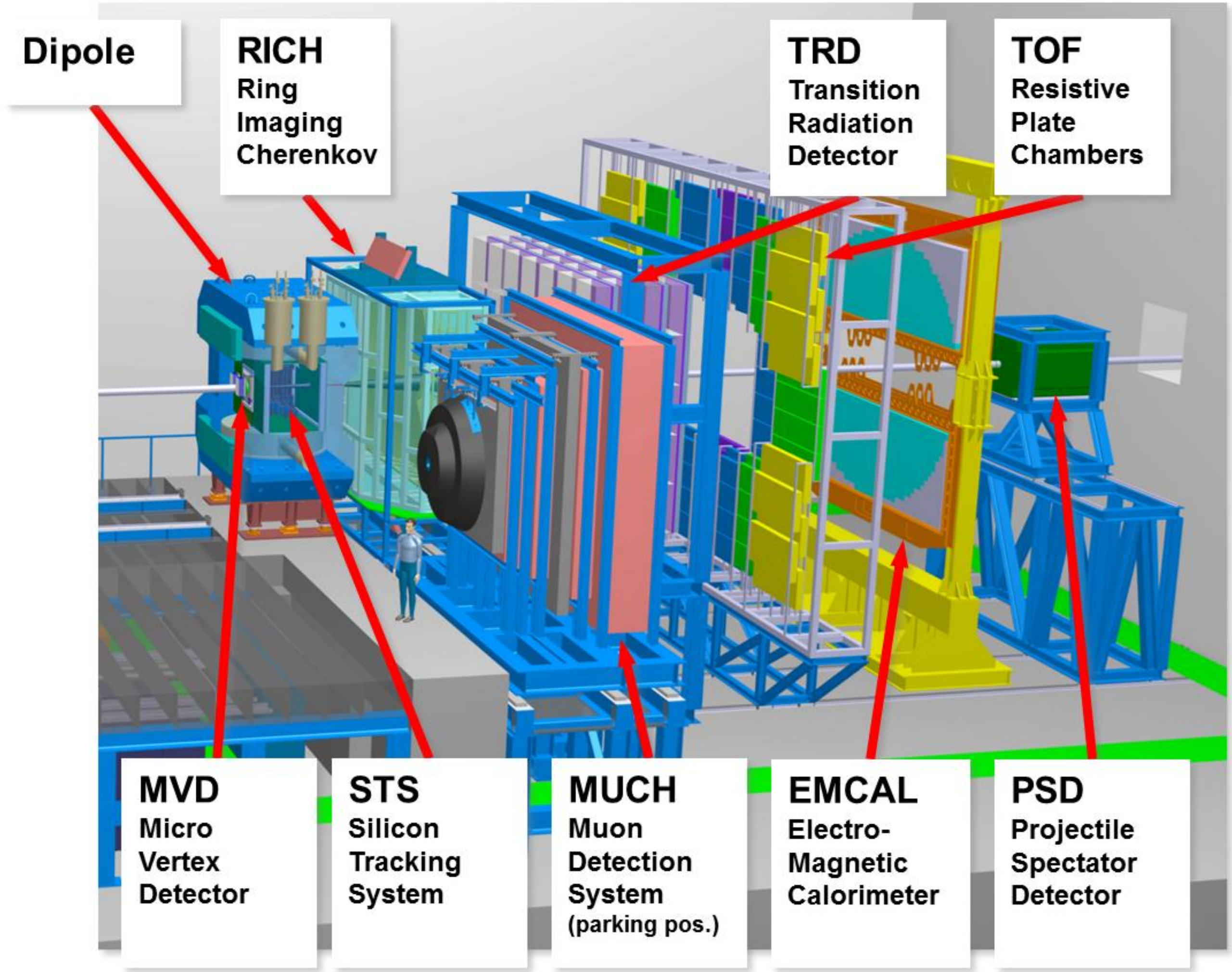
The HADES and CBM cave



HADES: mainly p+p, p+A, low material budget, 20°-85° polar angle, 20 kHz

CBM: p+A, A+A, larger material budget, 2.5°-25° polar angle, max. 10 MHz

CBM apparatus



- **Tracking acceptance:** $2° < \theta_{lab} < 25°$
- **Free streaming DAQ**

  R_{int} = 10 MHz (Au+Au)

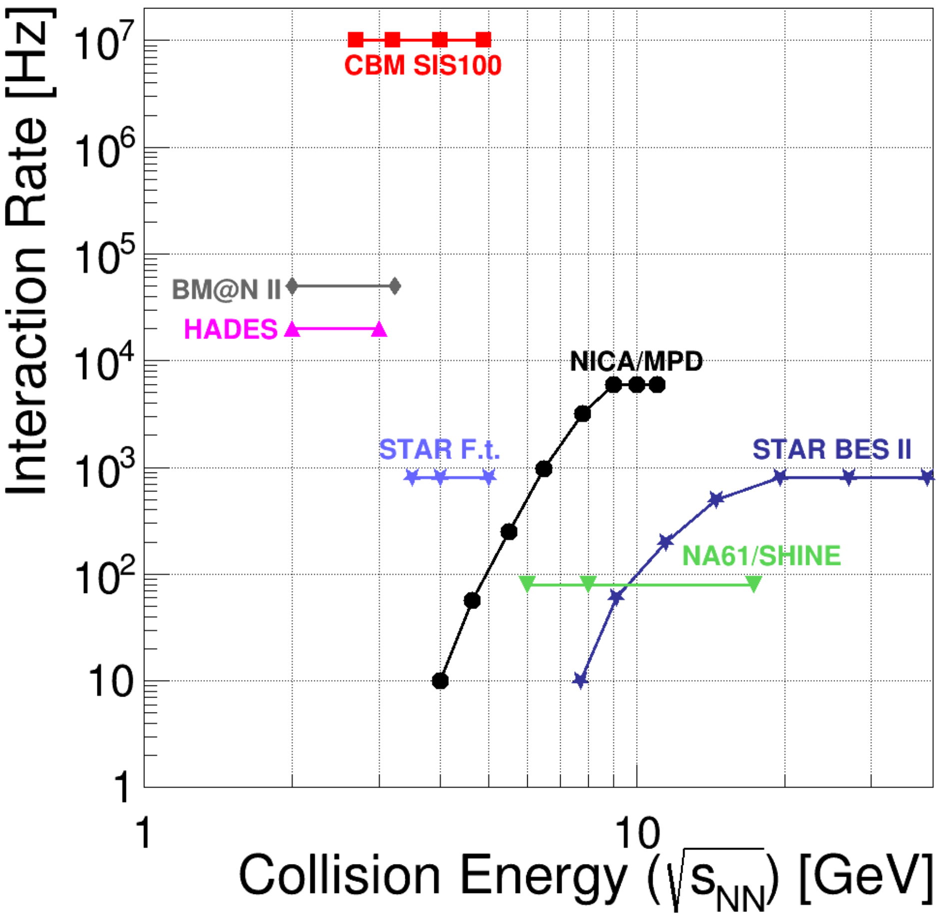
  except:
  R_{int} (MVD)=0.1 MHz
- **Software based event selection**

CBM experiment

CBM:
is a high rate experiment!

→ Opens up new possibilities!

- Electromagnetic observables, charm production
- High statistics and good systematics on hadronic observables: multi-strange baryons, flow, fluctuations
- New (exotic) observables: kaonic clusters, hypernuclei

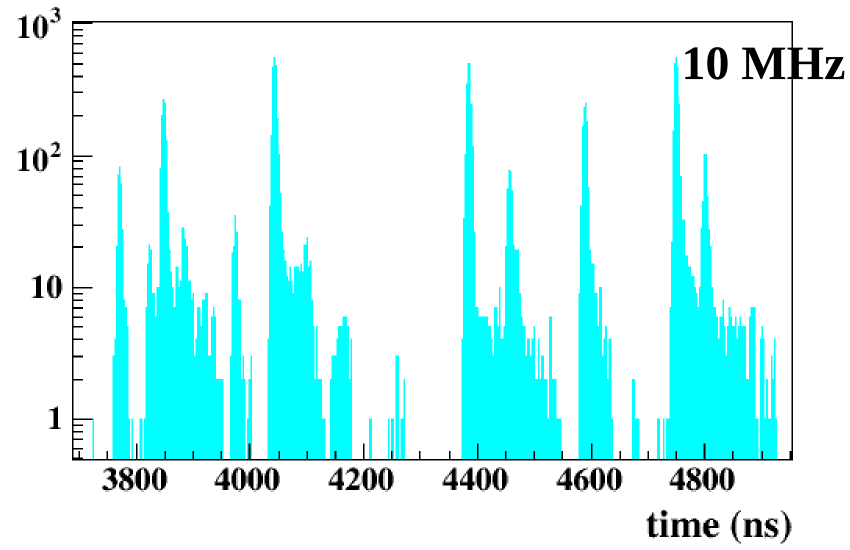


CBM readout and online system

Novel readout system

- no hardware trigger on events, free streaming trigger-less data
- detector hits with time stamps,

High rate scenario: STS hits vs time



CBM readout and online system

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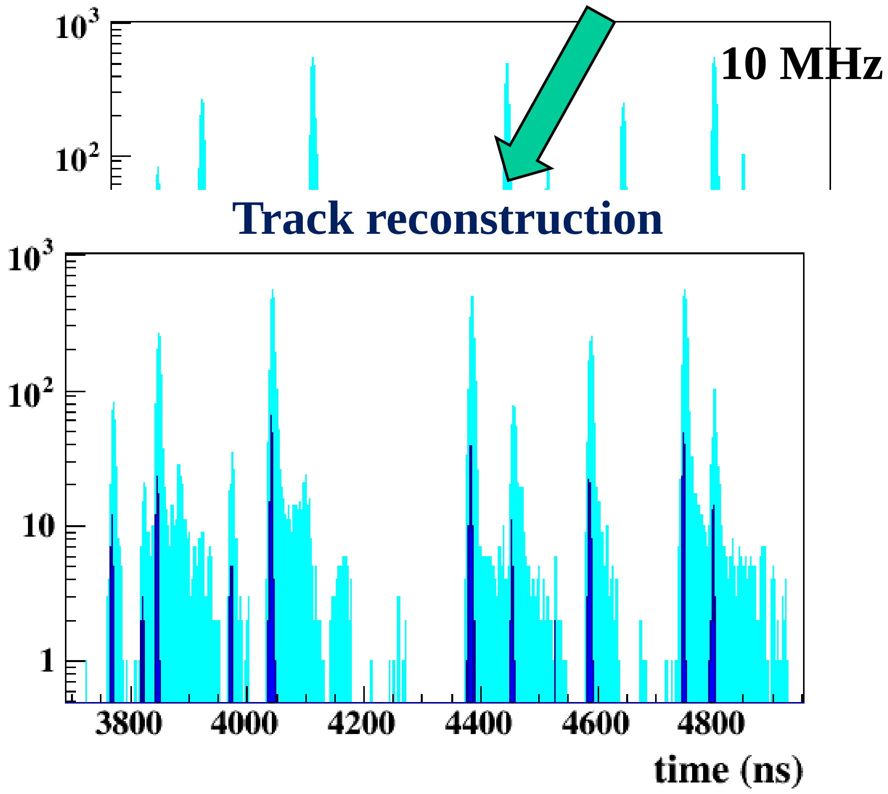
- full online 4-D track and event reconstruction

  - Requirement: online calibration

- Full analysis of 10 MHz event rate implemented, only very moderate losses in efficiency

High rate scenario: STS hits vs time



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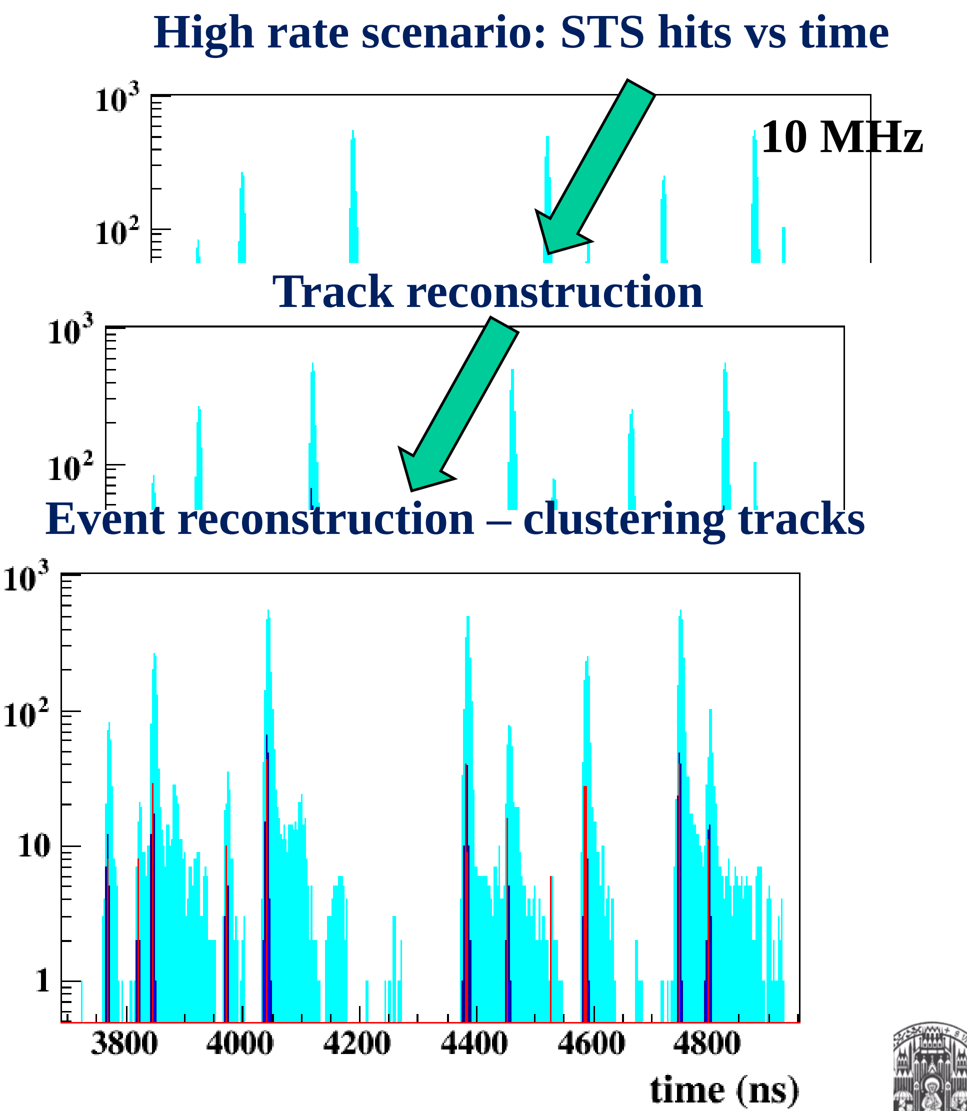
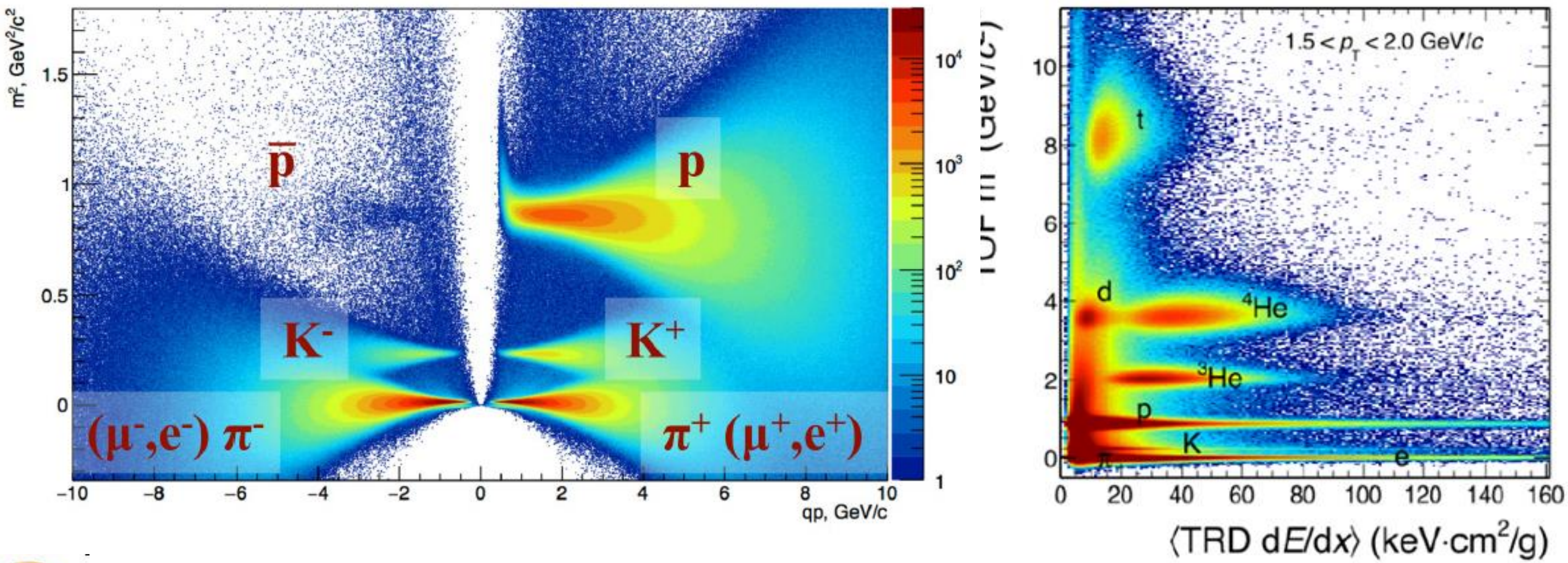


PID

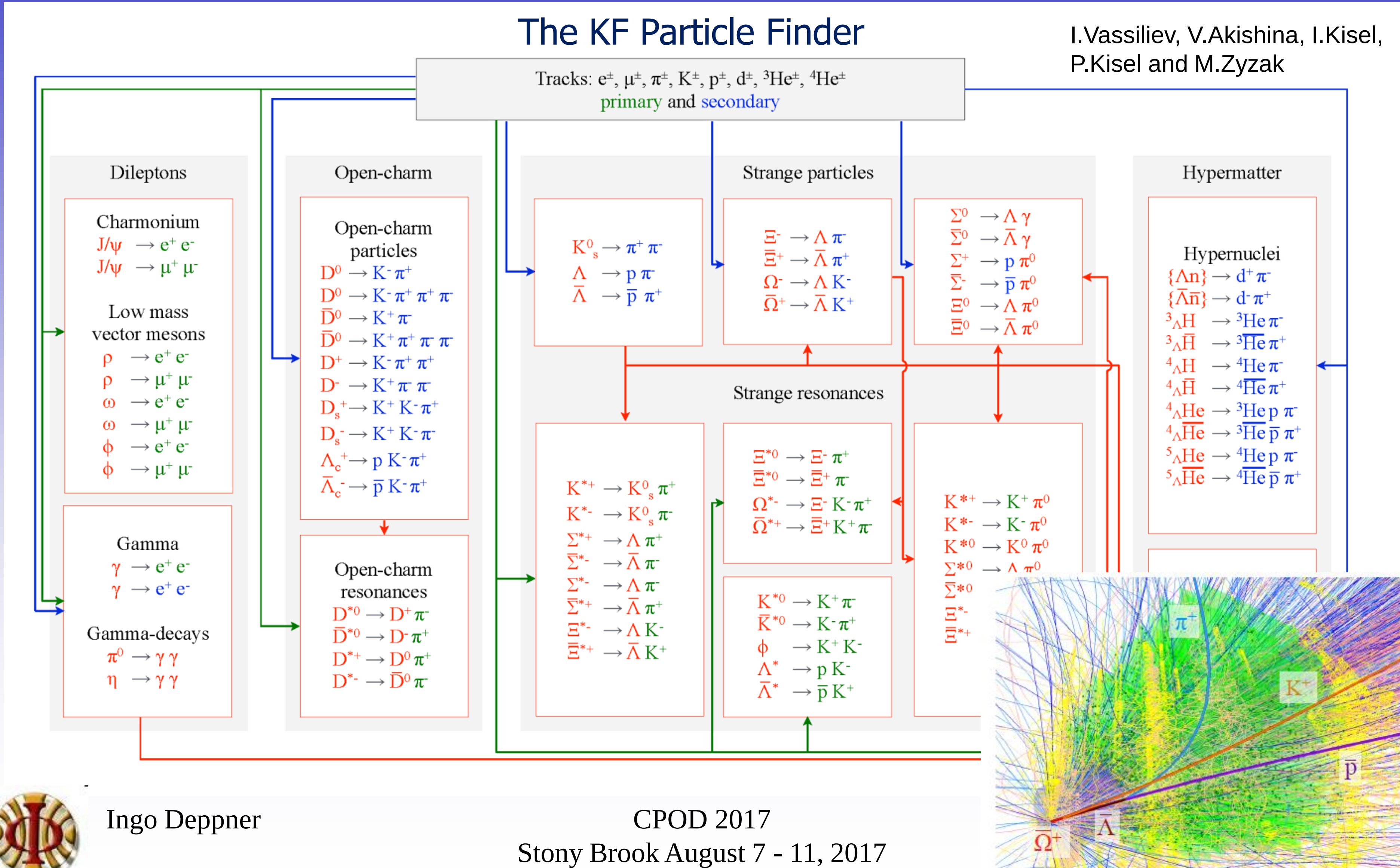
- Hadron id: TOF (+TRD)
- Lepton id: RICH+TRD or MUCH
- γ, π^0: EMC (or RICH)

TOF

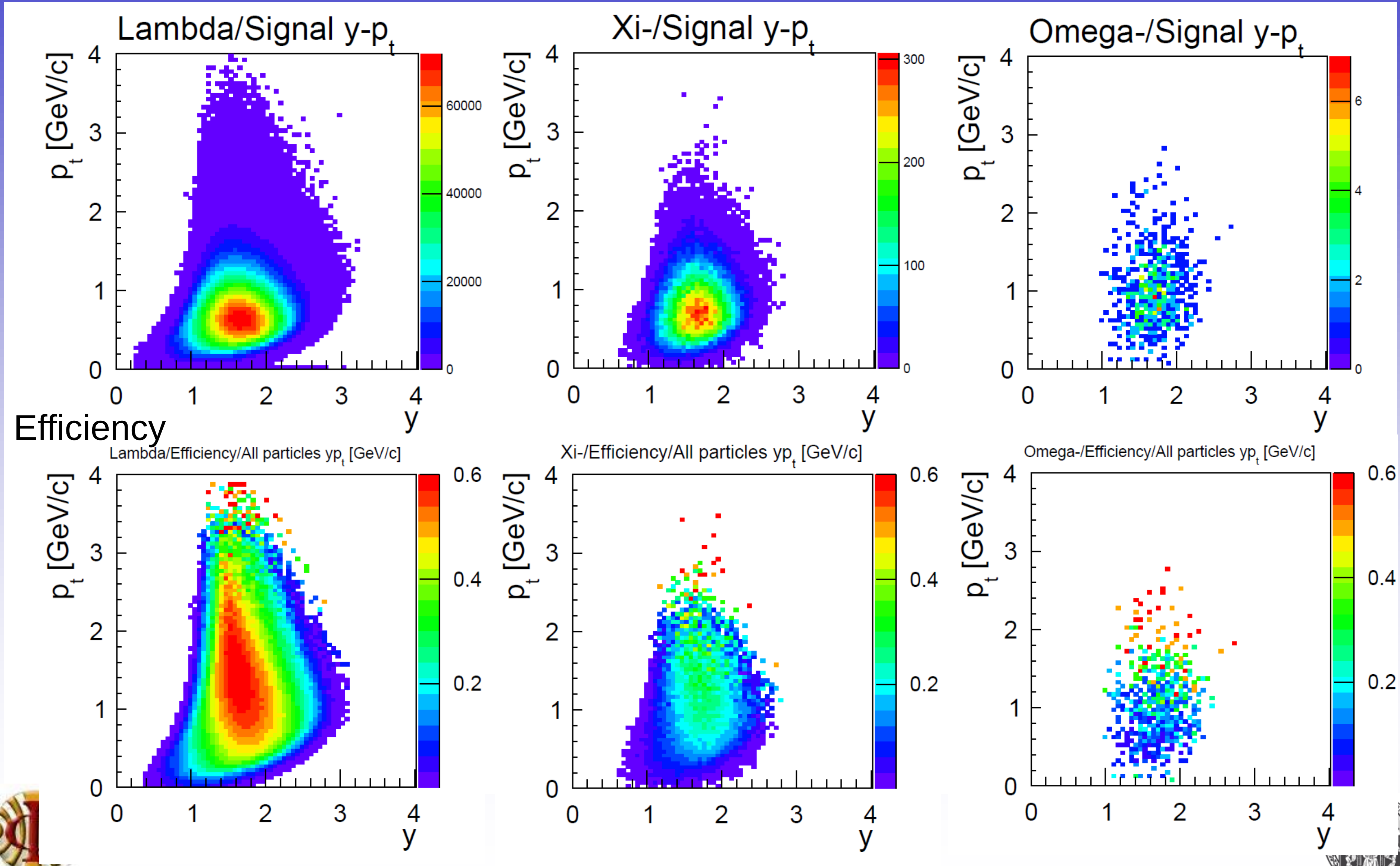
TOF + TRD



Online particle identification

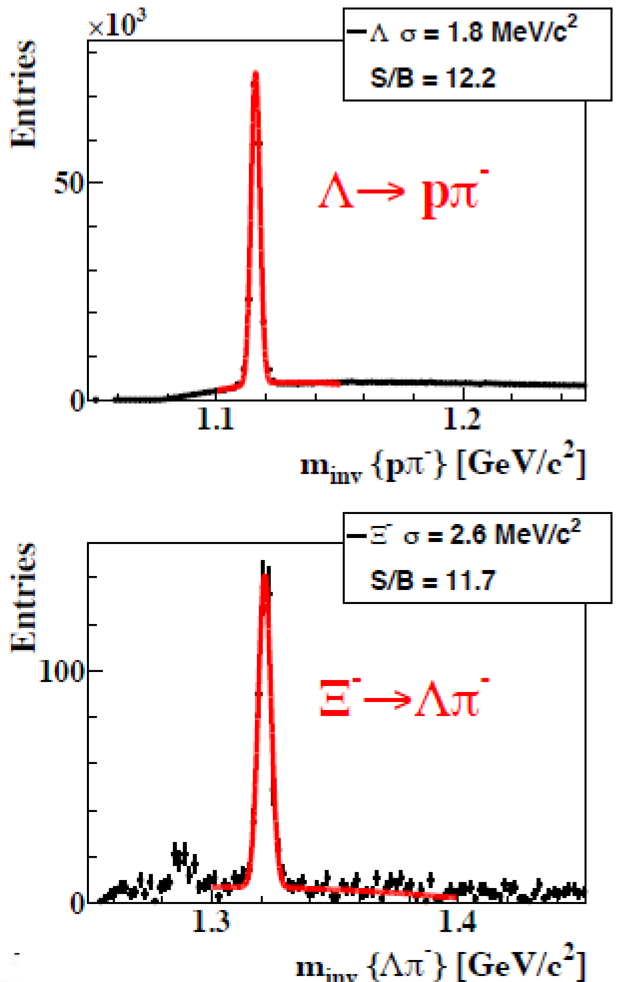


Acceptance and Efficiency



Acceptance and Efficiency

10 MHz, AuAu, 10 AGeV, 300k mbias UrQMD events, ideal PID



		K0s	Λ	$\bar{\Lambda}$	Ξ^-
3D	ε_{method}, %	68.6	61.2	67	46.7
	$\varepsilon_{4\pi}$, %	20.7	19.4	28	10.5
	S/B	10.6	23.7	12.7	21.8
0.1 MHz	ε_{method}, %	68.5	62.0	62	45.2
	$\varepsilon_{4\pi}$, %	21.1	20.6	32	11.7
	S/B	9.8	12.9	10	14.2
1 MHz	ε_{method}, %	67.5	60.9	59	46.0
	$\varepsilon_{4\pi}$, %	19.4	18.7	26	10.6
	S/B	9.3	12.5	10	12.3
10 MHz	ε_{method}, %	66.8	60.0	64	41.8
	$\varepsilon_{4\pi}$, %	17.6	16.7	28	8.2
	S/B	9.2	12.2	8	11.7

Reconstruction of hyperons and hypernuclei

Expected particle yields Au+Au @ 6, 10 AGeV

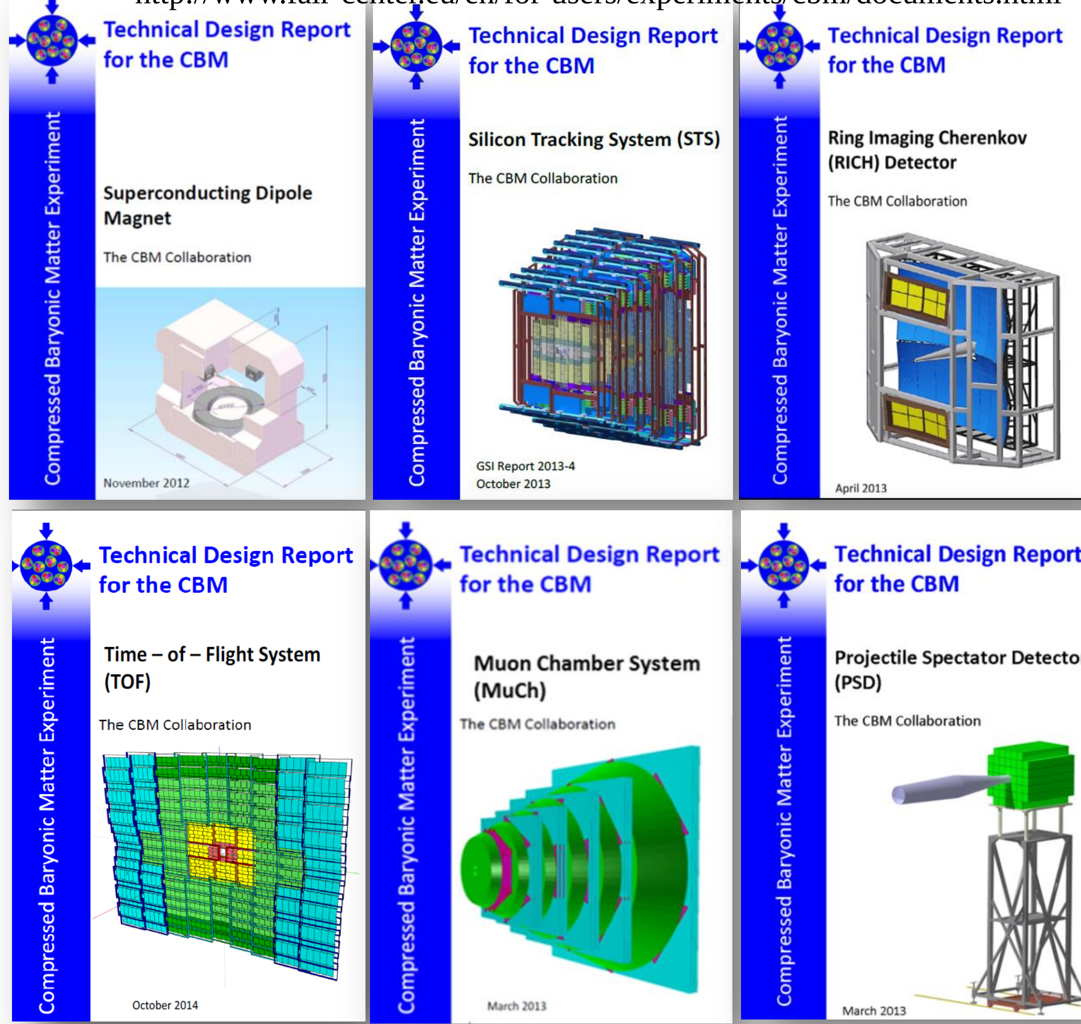
Particle (mass MeV/c^2)	Multi-plicity 6 AGeV	Multi-plicity 10 AGeV	decay mode	BR	ε (%)	yield (s^{-1}) 6AGeV	yield (s^{-1}) 10AGeV	yield in 10 weeks 6AGeV	yield in 10 weeks 10 AGeV	IR MHz
Λ (1115)	$4.6\cdot10^{-4}$	0.034	$p\pi^+$	0.64	11	1.1	81.3	$6.6\cdot10^{6}$	$2.2\cdot10^{8}$	**10**
Ξ^- (1321)	0.054	0.222	$\Lambda\pi^-$	1	6	$3.2\cdot10^{3}$	$1.3\cdot10^{4}$	$1.9\cdot10^{10}$	$7.8\cdot10^{10}$	**10**
Ξ^+ (1321)	$3.0\cdot10^{-5}$	$5.4\cdot10^{-4}$	$\Lambda\pi^+$	1	3.3	$9.9\cdot10^{-1}$	17.8	$5.9\cdot10^{6}$	$1.1\cdot10^{8}$	**10**
Ω^- (1672)	$5.8\cdot10^{-4}$	$5.6\cdot10^{-3}$	ΛK^-	0.68	5	17	164	$1.0\cdot10^{8}$	$9.6\cdot10^{8}$	**10**
Ω^+ (1672)	-	$7\cdot10^{-5}$	ΛK^+	0.68	3	-	0.86	0	$5.2\cdot10^{6}$	**10**
$^{3}_{\Lambda}H$ (2993)	$4.2\cdot10^{-2}$	$3.8\cdot10^{-2}$	$^{3}He\pi^-$	0.25	19.2	$2\cdot10^{3}$	$1.8\cdot10^{3}$	$1.2\cdot10^{10}$	$1.1\cdot10^{10}$	**10**
$^{4}_{\Lambda}He$ (3930)	$2.4\cdot10^{-3}$	$1.9\cdot10^{-3}$	$^{3}Hep\pi^-$	0.32	14.7	110	87	$6.6\cdot10^{8}$	$5.2\cdot10^{8}$	**10**

- systematic measurement of multi-dimensional observables of rare probes become possible

CBM technical design report status

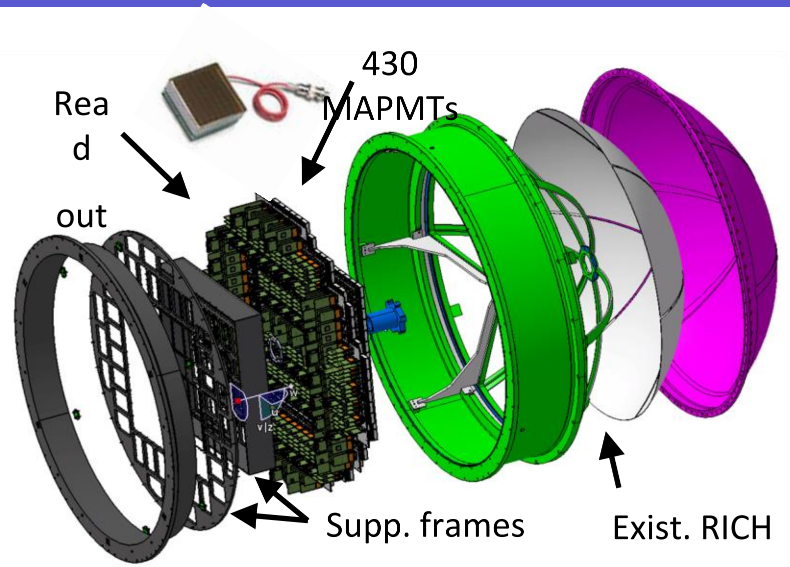
#	Project	TDR Status
1	Magnet	approved
2	STS	approved
3	RICH	approved
4	TOF	approved
5	MuCh	approved
6	HADES ECAL	approved
7	PSD	approved
8	MVD	submission 2018
9	DAQ/FLES*	submission 2018
10	TRD	submission 2017
11	ECAL	submission 2017
12	Computing*	submission ~2020

http://www.fair-center.eu/en/for-users/experiments/cbm/documents.html

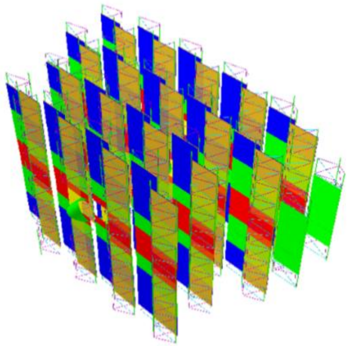


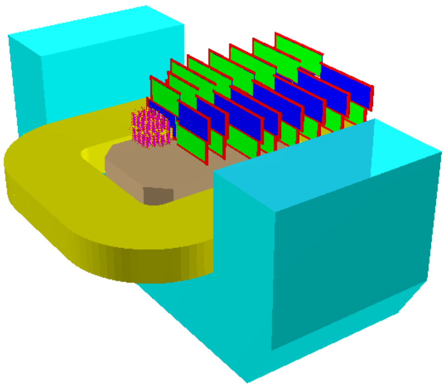
FAIR phase 0 program

1. Install, commission and use 430 out of 1100 CBM RICH multi-anode photomultipliers (MAPMT) in HADES RICH photon detector



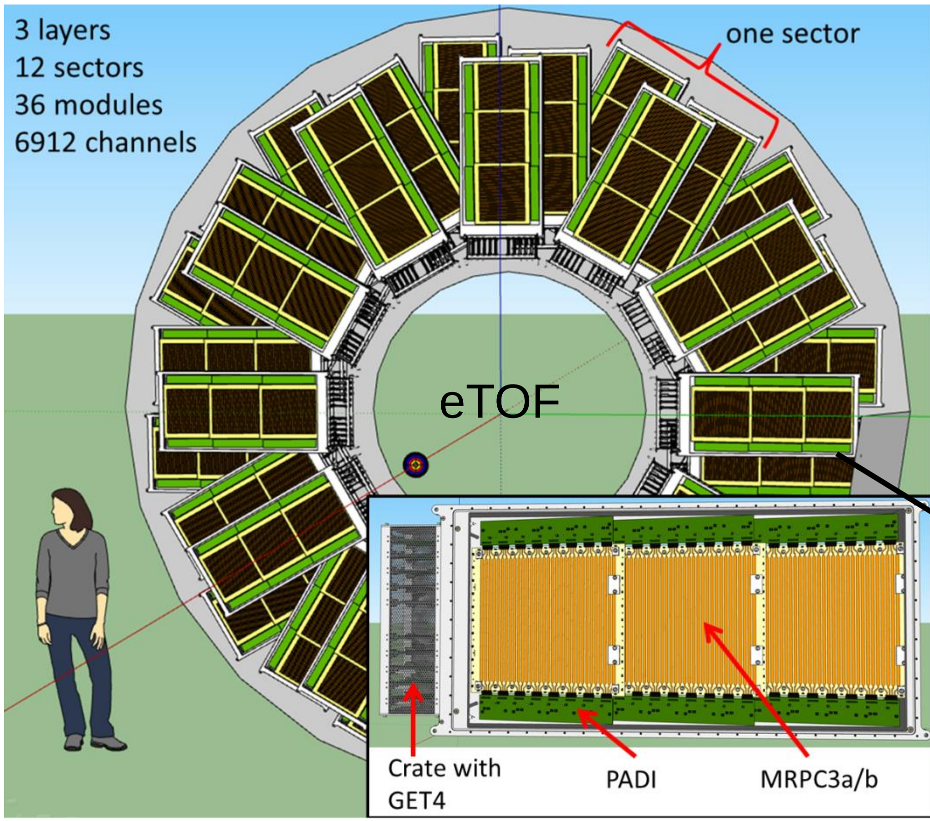
2. Install, commission and use 4 STS layers and the PSD at the BM@N experiment at the Nuclotron in JINR/Dubna (Au-beams up to 4.5 A GeV in 2018/19)



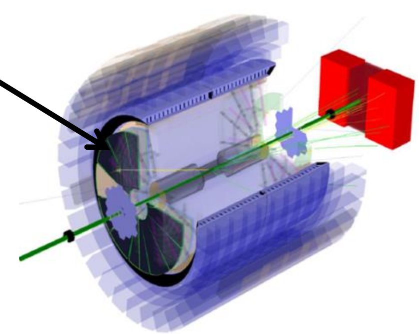


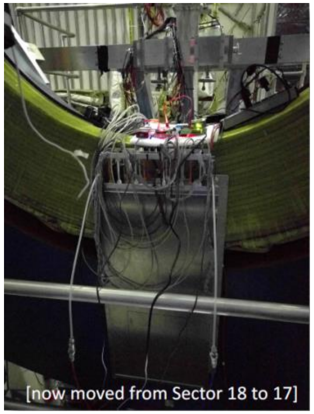
FAIR phase 0 - program

3. Install, commission and use 10% of the CBM TOF modules including CBM read-out chain at STAR/RHIC (BES II 2019/2020)



02/2018	2nd system integration test with one sector by participating in the Run18 beam time in STAR
09/2018	Installation and commissioning
2019/2020	Start of the BES II campaign
2021	Decommissioning and shipping of all modules including infrastructure to FAIR





4. A CBM full system test-setup for high-rate nucleus-nucleus collisions at GSI/FAIR

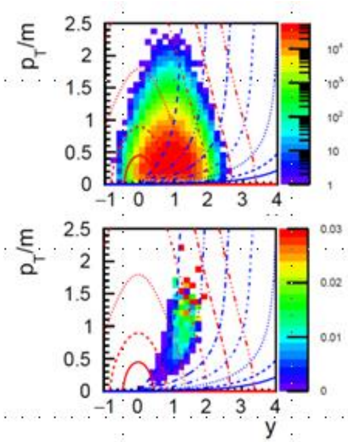
the mCBM test-setup ("mini-CBM") will focus on the

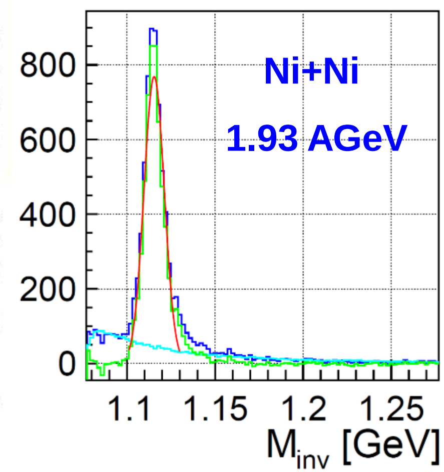
- test of final detector prototypes
- free streaming data transport to a computer farm
- online reconstruction and event selection
- offline data analysis

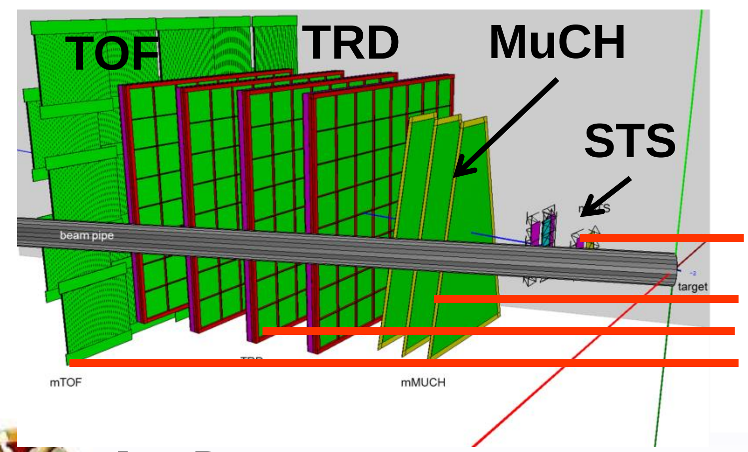
02/2018	mFLES cluster in Green IT Cube operational
03/2018	ready for installation of detector subsystems
09/2018	start commissioning with beam
2020	1st benchmark run

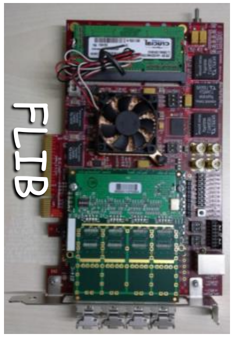
(Sub)threshold Λ – baryon reconstruction.

Event based MC simulation of 10^8 events









The CBM collaboration
60 institutions, ~530 members

Croatia:
Split Univ.

China:
CCNU Wuhan
Tsinghua Univ.
USTC Hefei
CTGU Yichang

Czech Republic:
CAS, Rez
Techn. Univ.Prague

France:
IPHC Strasbourg

Hungary:
KFKI Budapest
Budapest Univ.

Germany:
Darmstadt TU
FAIR
Frankfurt Univ. IKF
Frankfurt Univ. FIAS Frankfurt Univ. ICS
GSI Darmstadt
Giessen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
KIT Karlsruhe
Münster Univ.
Tübingen Univ.
Wuppertal Univ.
ZIB Berlin

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
IOP Bhubaneswar
IIT Kharagpur
IIT Indore
Gauhati Univ.

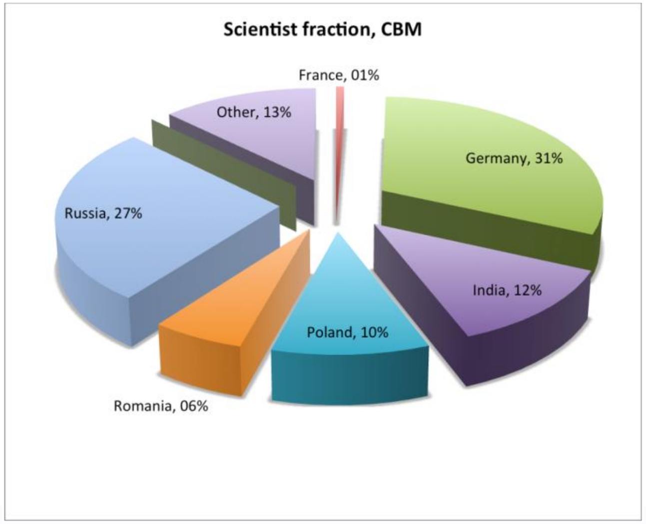
Korea:
Pusan Nat. Univ.

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

Romania:
NIPNE Bucharest
Univ. Bucharest

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
Kurchatov Inst., Moscow
LHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg P. Univ.
Ioffe Phys.-Tech. Inst. St. Pb.

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



Summary

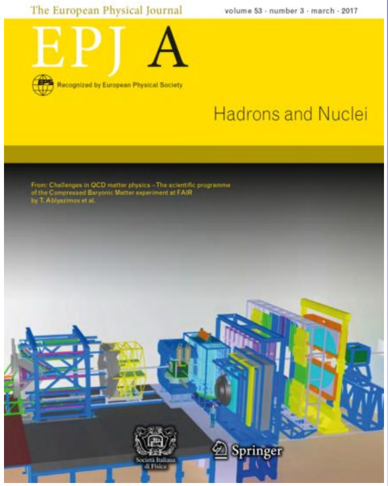
- Phase structure of QCD will not be revealed by a single measurement.
- QCD matter physics needs a facility for systematic studies and a 3rd generation experiment -> CBM

  rate capability: 10 MHz interaction rate
- CBM physics program

  many open physics questions
  substantial discovery potential at SIS100
- CBM strategy

  systematic measurement of multi-dimensional observables of (rare) probes
  use detector components as tool kit.
- CBM status

  well advanced with respect to overall FAIR timeline



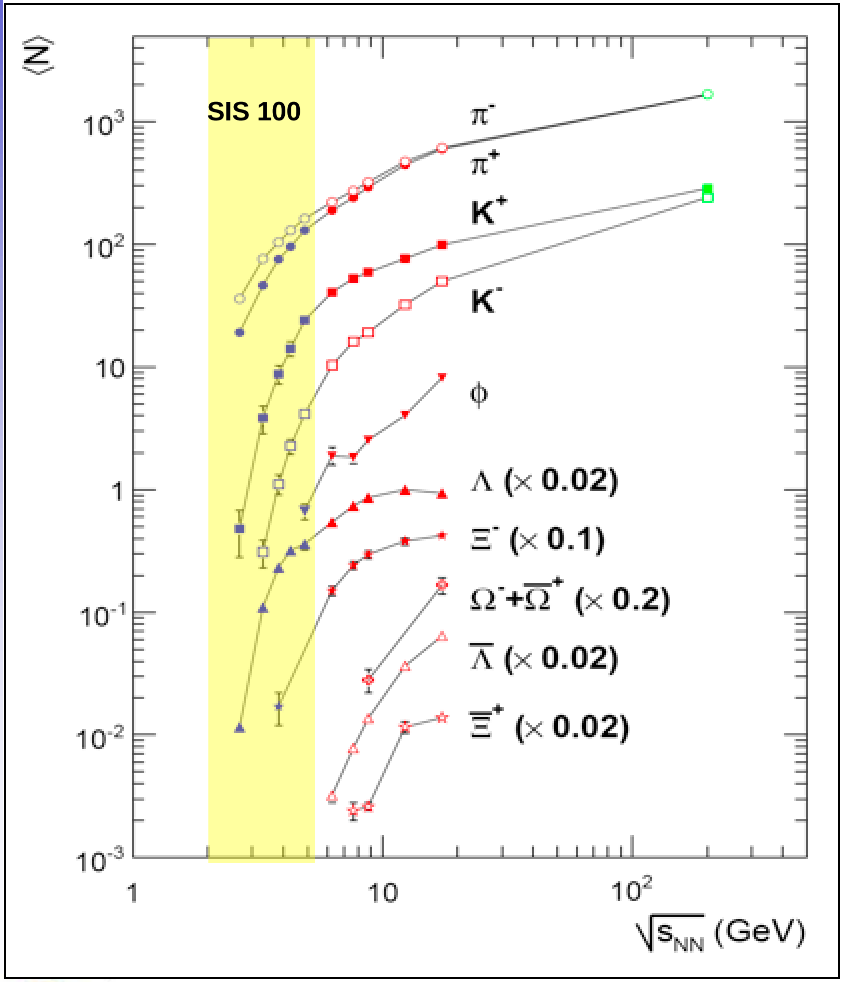
CBM, Eur. Phys. J. A (2017) 53: 60.

Thank you for your attention

Backup Slides

Particle production threshold

C. Blume, J. Phys. G31, S57 (2005)



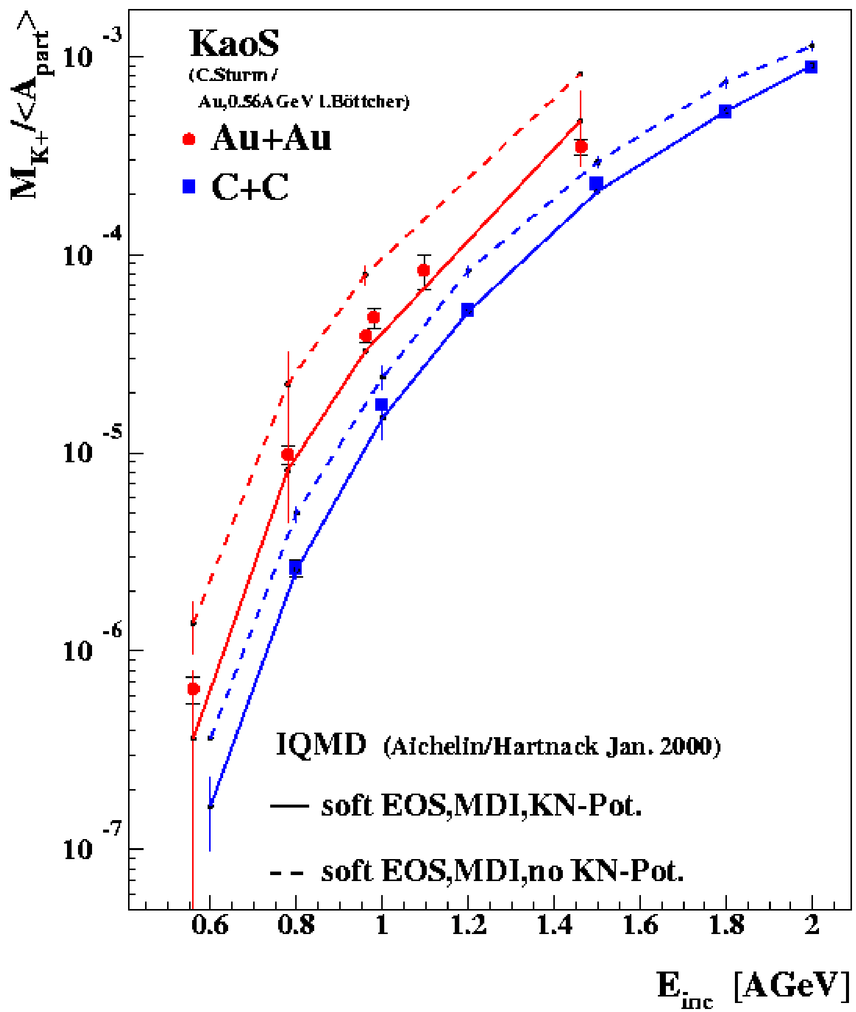
Strange and charmed particle production thresholds in pp - collisions

reaction	$\sqrt{s}$ (GeV)	T_{lab}(GeV)
$pp \to K^+\Lambda p$	2.548	1.6
$pp \to K^+K^-pp$	2.864	2.5
$pp \to K^+K^+\Xi^-p$	3.247	3.7
$pp \to K^+K^+K^+\Omega^-n$	4.092	7.0
$pp \to \Lambda\bar{\Lambda}pp$	4.108	7.1
$pp \to \Xi^-\bar{\Xi}^+pp$	4.520	9.0
$pp \to \Omega^-\bar{\Omega}^+pp$	5.222	12.7
$pp \to J/\Psi\, pp$	4.973	12.2

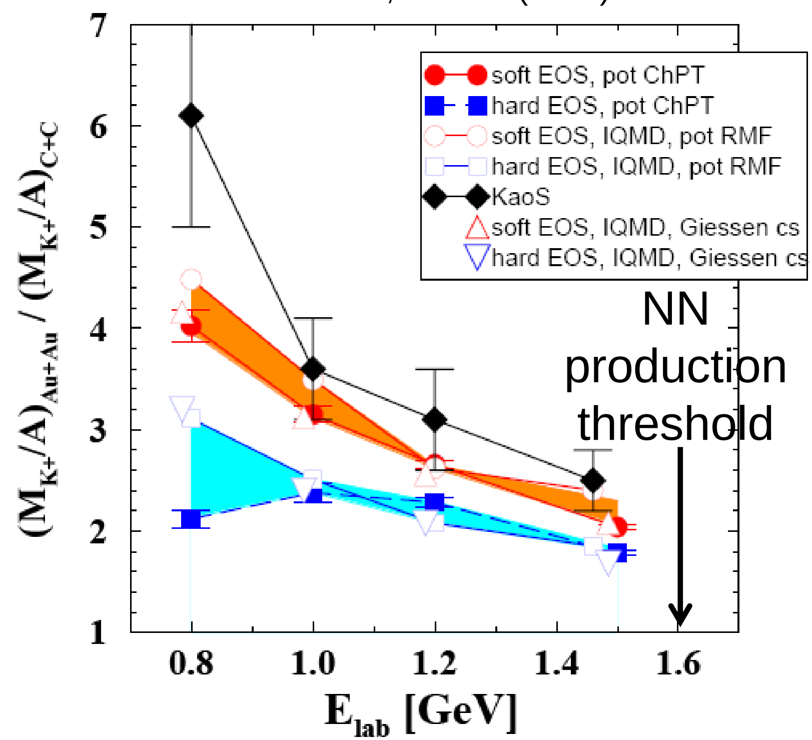
- Yield of sub-threshold produced hyperons is sensitive to the medium density (multi step processes)
- In the SIS100 energy regime very few data available

Kaon production at SIS 18

C.Sturm et al. (KaoS), PRL 86 (2001) 39



C. Fuchs et al., PRL 86 (2001) 1974



- Strong sensitivity to Equation Of State due to multistep production (formation of nucleon resonances)

=> soft EOS (K=200 MeV)

Particle acceptance
central Au+Au collisions at 10 A GeV