CBM @ FAIR

Claudia Höhne for the CBM collaboration

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

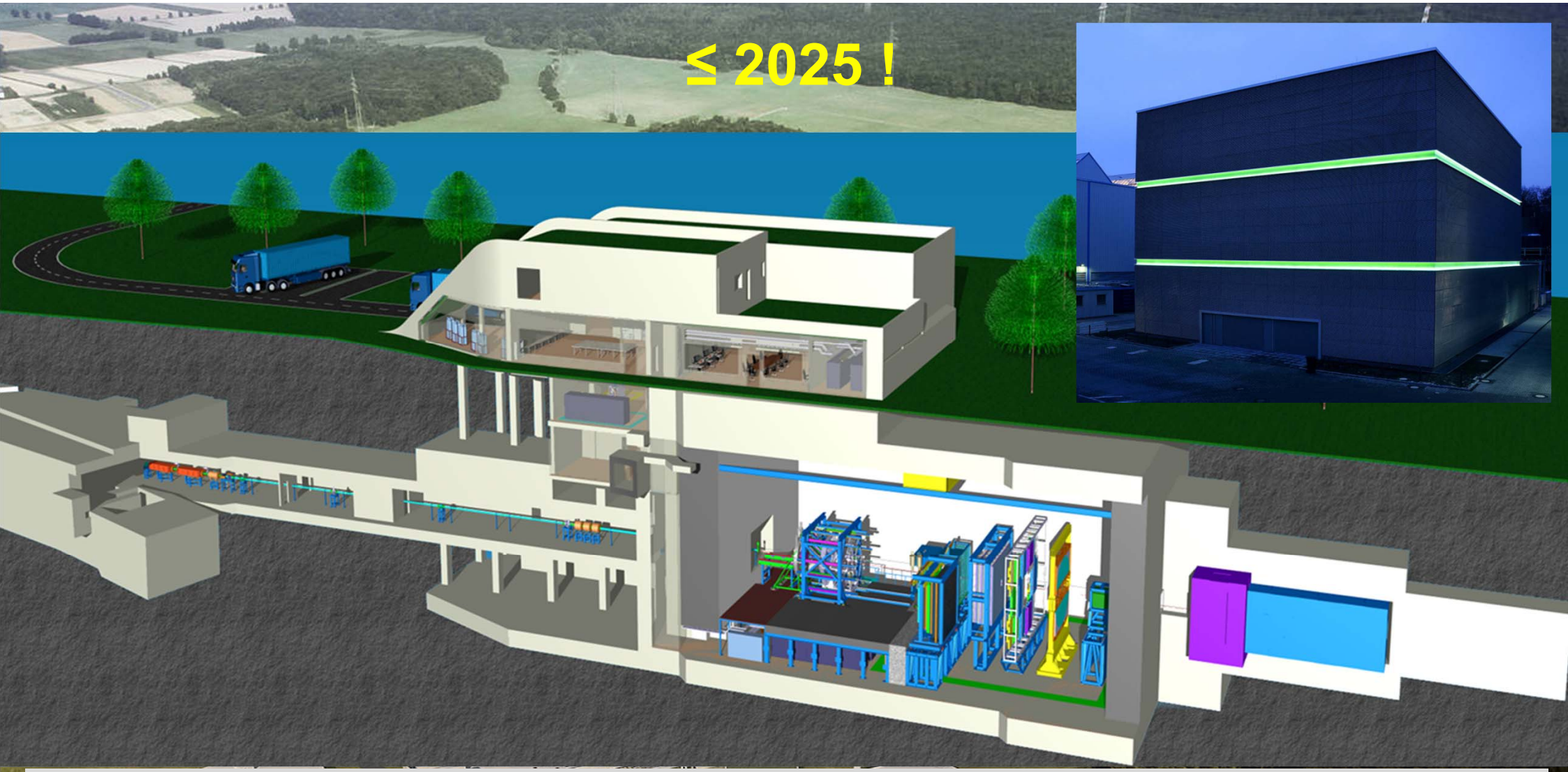
FAIR

GSI

FAIR Groundbreaking ceremony July 4th, 2017

- Civil construction of SIS 100 tunnel and CBM cave started
- CBM will get first SIS100 beams
- Detector installation/ commissioning 2021 – 2024
- FAIR MSV fully operational 2025 (FAIR phase 0 from 2018 on)


2017



CBM & HADES at SIS 100:

Systematic exploration of baryon dominated, high density matter in A+A collisions from 2-11 AGeV (Au+Au) beam energy with next generation experiments

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

High density range of QCD phase diagram

At large μ_b phase structure is uncharted territory

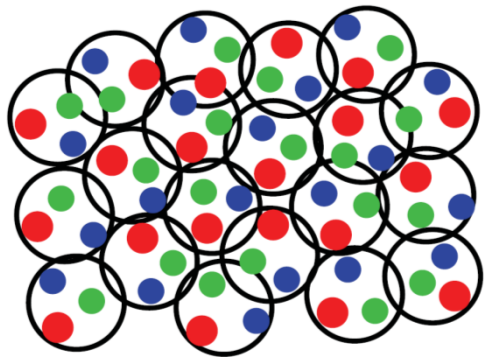
- first order phase transition at large μ_b ?

→ e.g. latent heat phase coexistence region ?

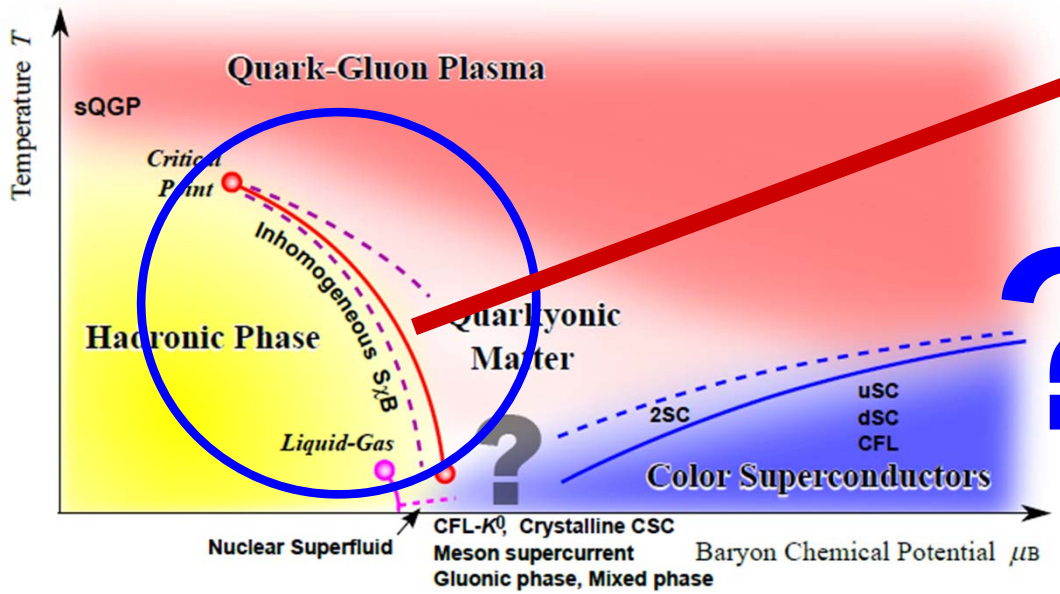
- critical point ?
- Deconfinement, chiral symmetry restoration
- different forms of matter? Quarkyonic phase?

Field driven by experimental data!

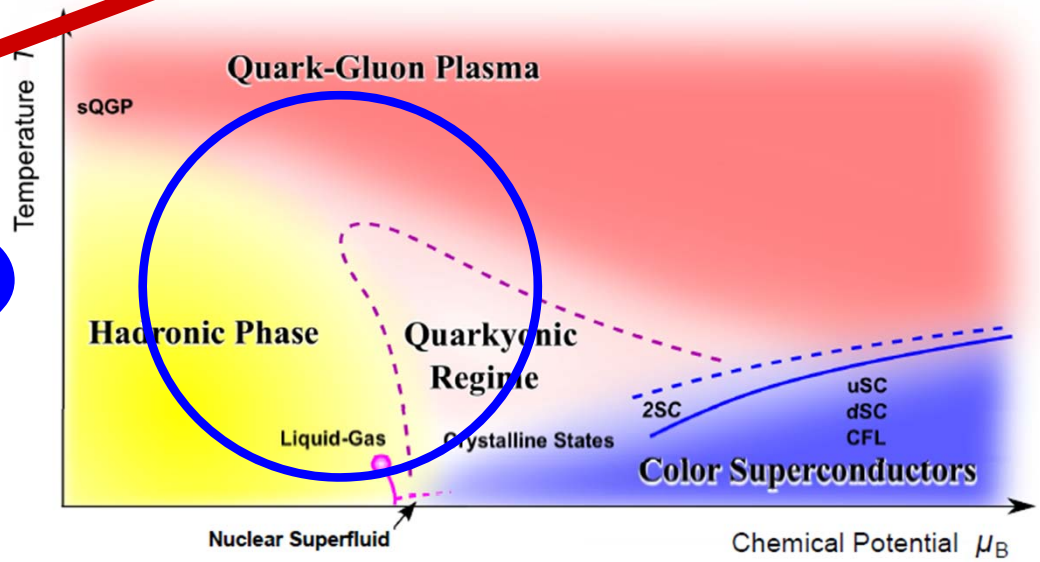
Need: ~ 2-40 AGeV beam energies



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



?



Outline

Introduction/ Motivation

- Energy and baryon density reach of CBM
- Physics questions & observables in CBM energy range

The CBM detector

- Novel readout and data taking concept
- Simulation results

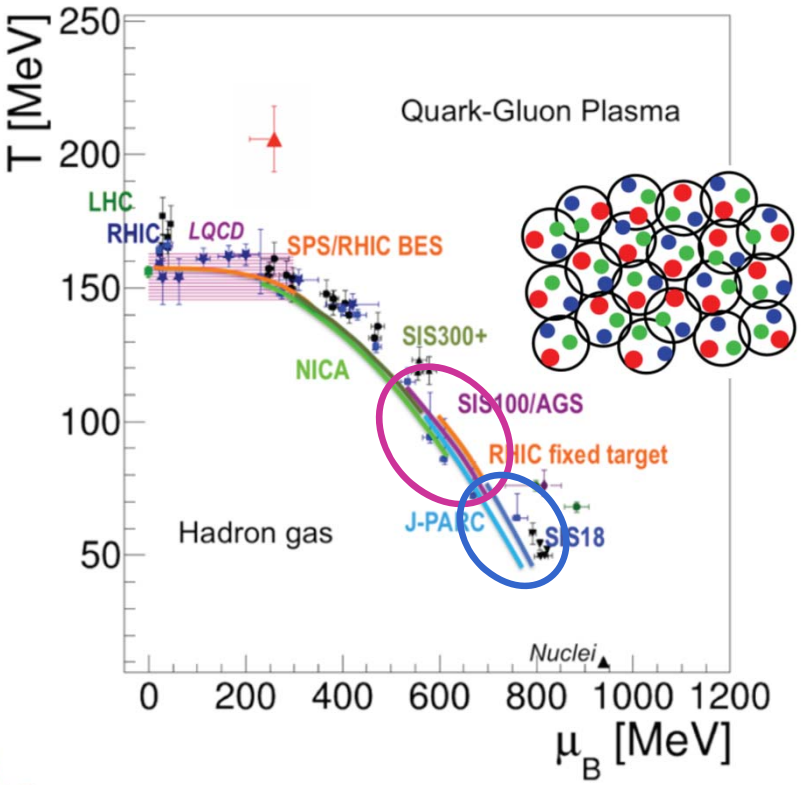
FAIR phase 0 activities

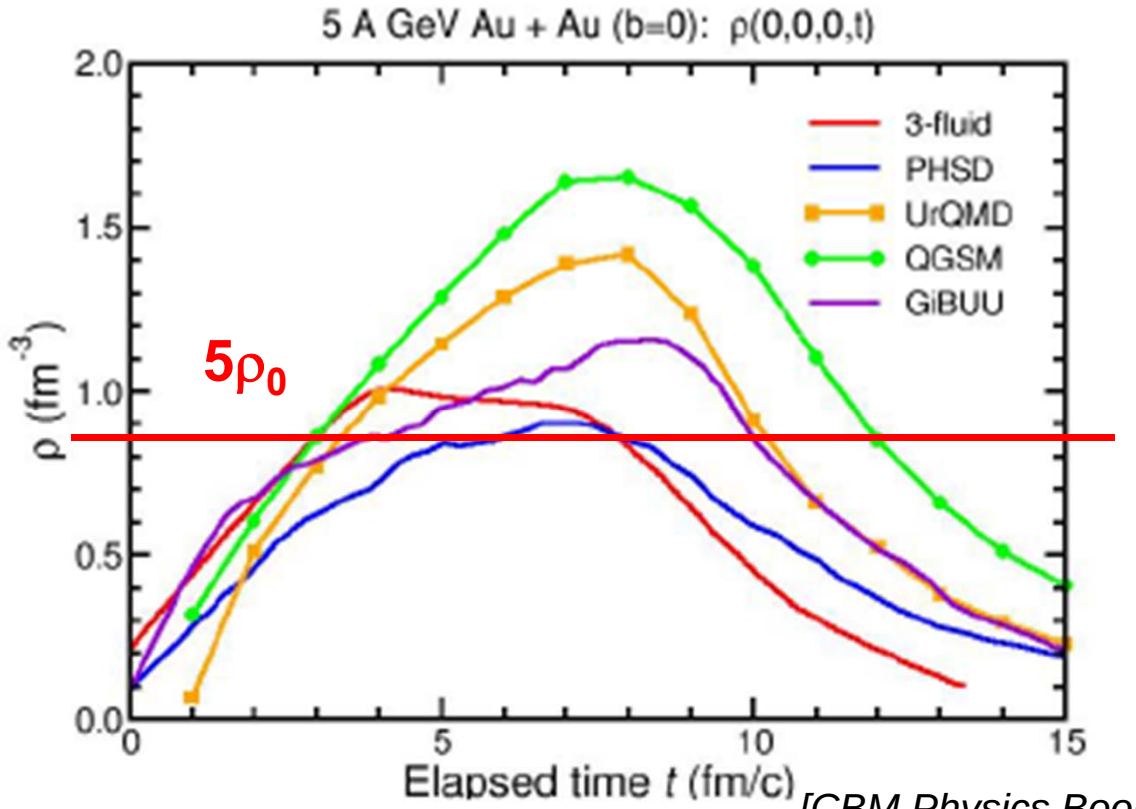
- Experimental preparations

Baryon density

- SIS 100 beam energy range
- High net-baryon densities to be probed
- Expected to persist for a few fm/c
- Characteristics of matter created?

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





[CBM Physics Book]

Energy dependence of strangeness production

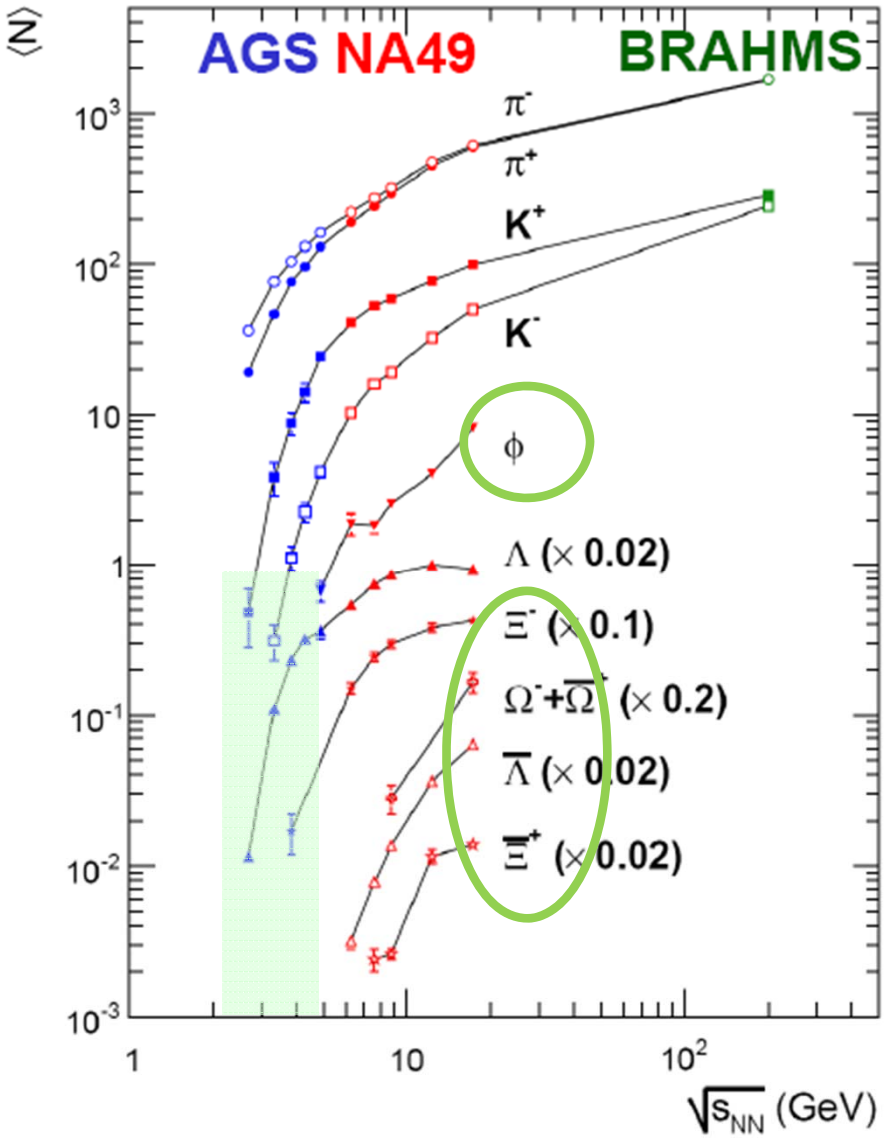
Physics Questions

→ thermal equilibrium also for multi-s hadrons?
→ equilibrium as signature for phase transition?
→ EOS?
→ production mechanism, in particular for multi-s hadrons??

CBM

→ yields and phase space distributions of strange particles including Ω, Ξ, ϕ and antiparticles
→ flow, fluctuations
→ systematic scan of energies and system size
→ (sub)threshold production of multi-s hadrons: sensitivity to EOS, μ_B?

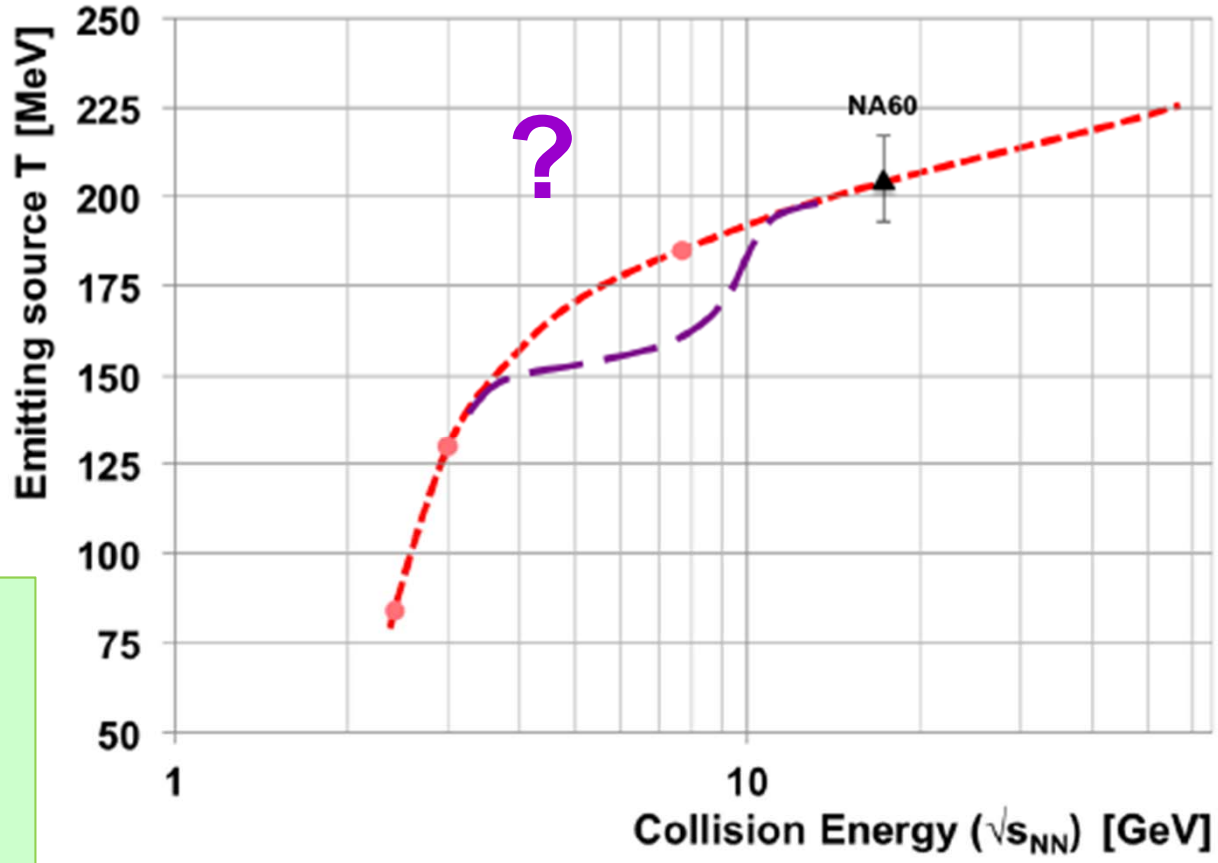
[C. Blume, JP 31 (2005) S57]



Dileptons at CBM

Physics Questions
→ phase transition
→ quarkyonic matter?
→ lifetime of dense hadonic fireball
→ in-medium properties of vector mesons

[T. Galatyuk et al., EPJA 52 (2016) 131]



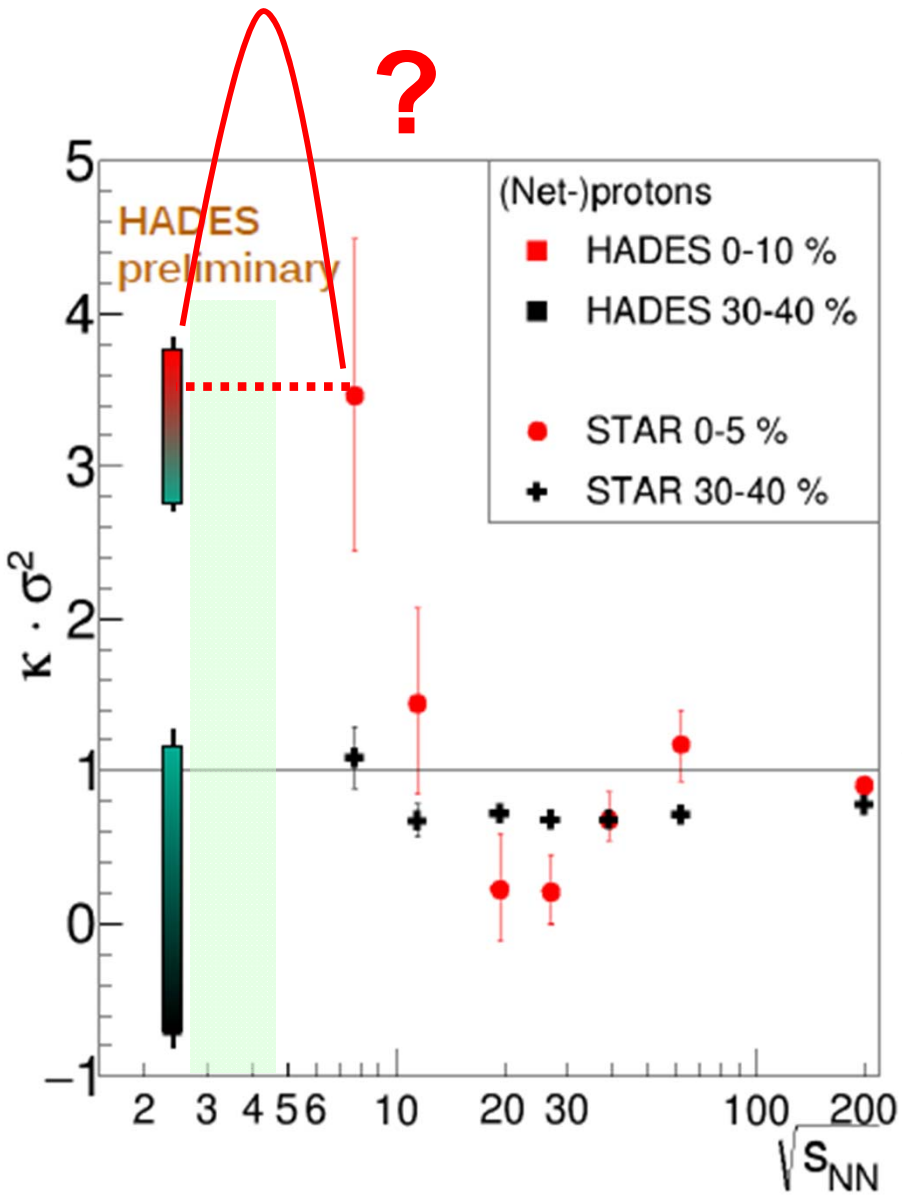
CBM
→ yields and phase space distributions of dileptons
→ mass range > 1 GeV to extract thermal fireball radiation

(Net-) proton number fluctuations

Physics Questions
→ phase transition?
→ order of phase transition?
→ mixed phase?

CBM
→ net-proton number fluctuations
→ fluctuations of conserved quantities including strangeness

$$S\sigma \approx \frac{\chi_B^3}{\chi_B^2}, \qquad \kappa\sigma^2 \approx \frac{\chi_B^4}{\chi_B^2}$$



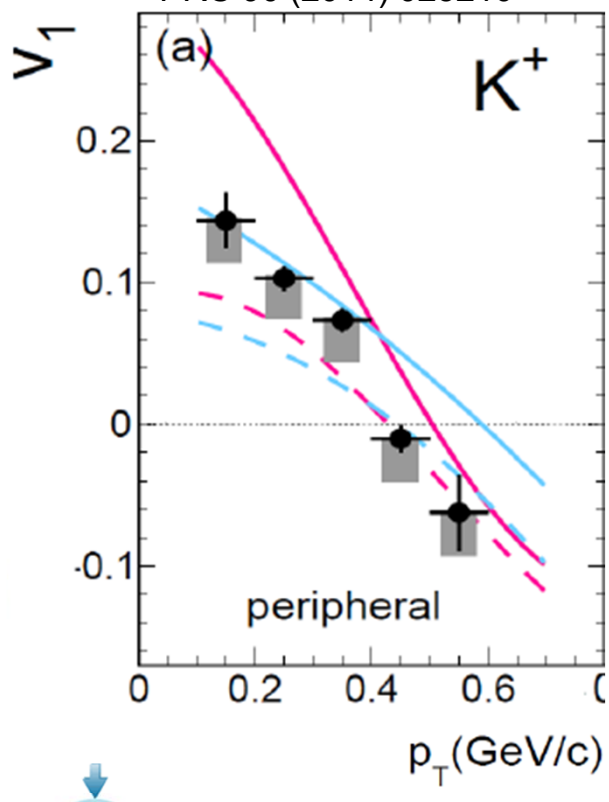
HADES: M. Lorenz, QM 2017
STAR: X. Luo et al, CPOD 2014

Directed and elliptic flow

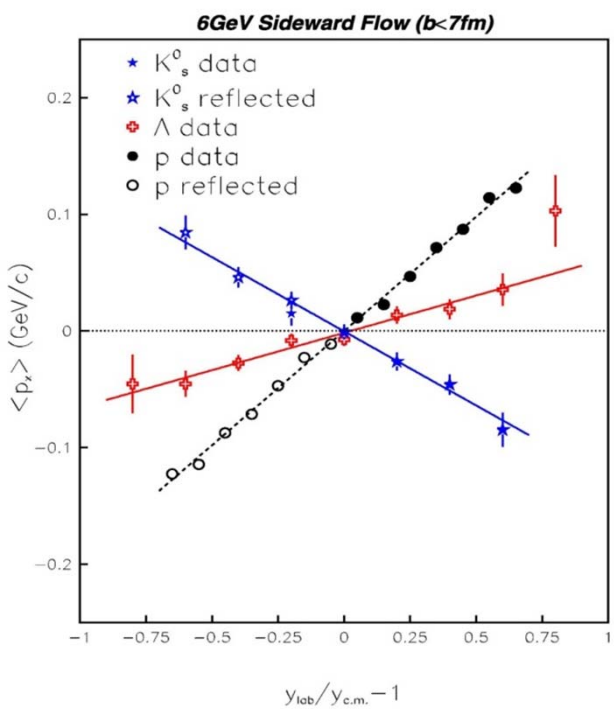
Physics Questions
→ equation of state of dense matter?
→ production mechanism?
→ in-medium properties?

CBM
→ directed and elliptic flow of all particles
→ (kaon) flow as barometer?

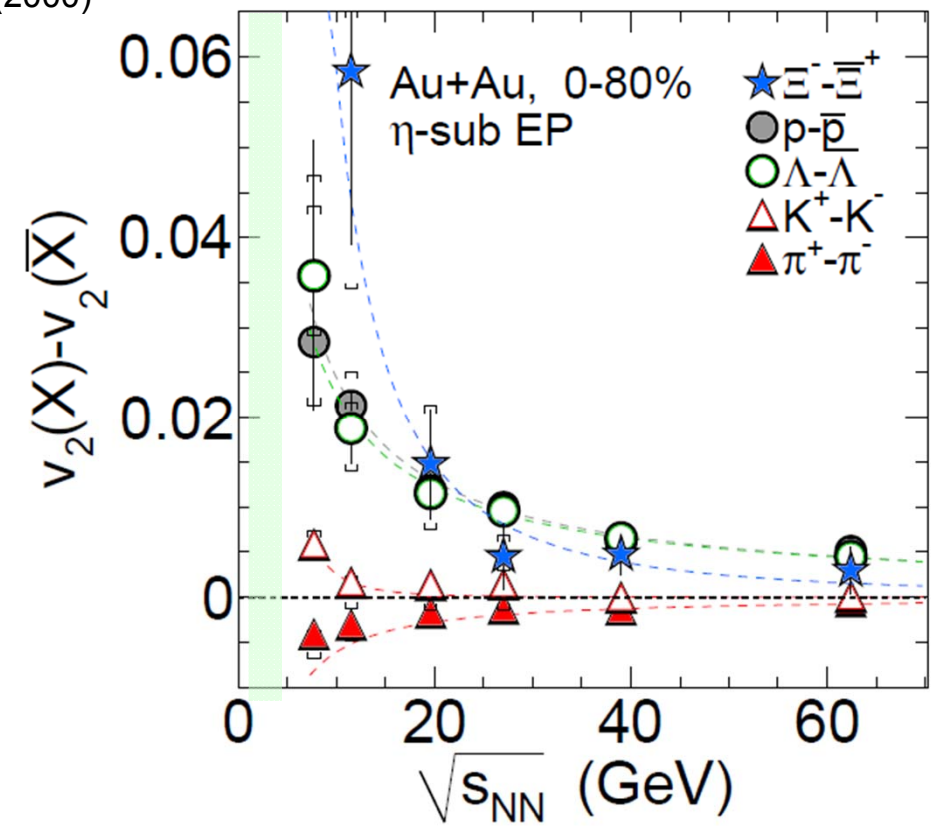
V.Zinyuk et al. (FOPI)
PRC 90 (2014) 025210



P. Chung et al. (E895), PRL85, 940 (2000)



[STAR, PRL 110 (2013) 142301]



Strange baryonic bound states

Physics Questions

→ existence and yield of (exotic) strange objects?

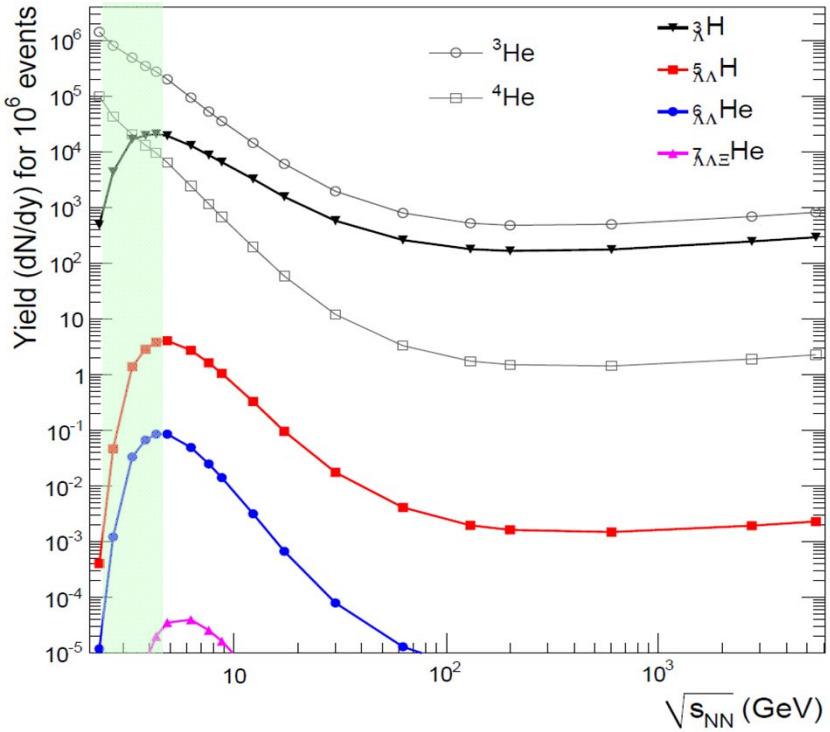
→ ΛΛ, NΛ interactions?

→ remnants of dense (chirally restored? strange?) matter?

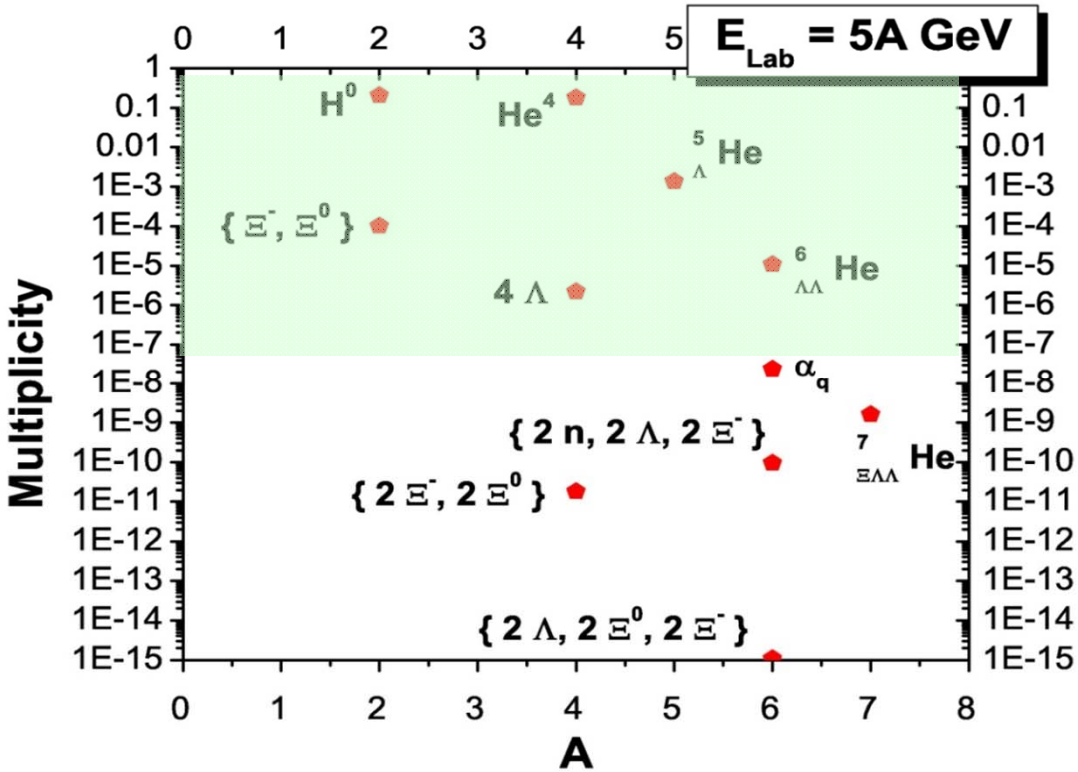
CBM

→ search for and measure strange hypernuclei and (all) other kinds of exotic strange baryons

A. Andronic, P. Braun-Munzinger, J. Stachel, H. Stöcker, Phys. Lett. B697 (2011) 203

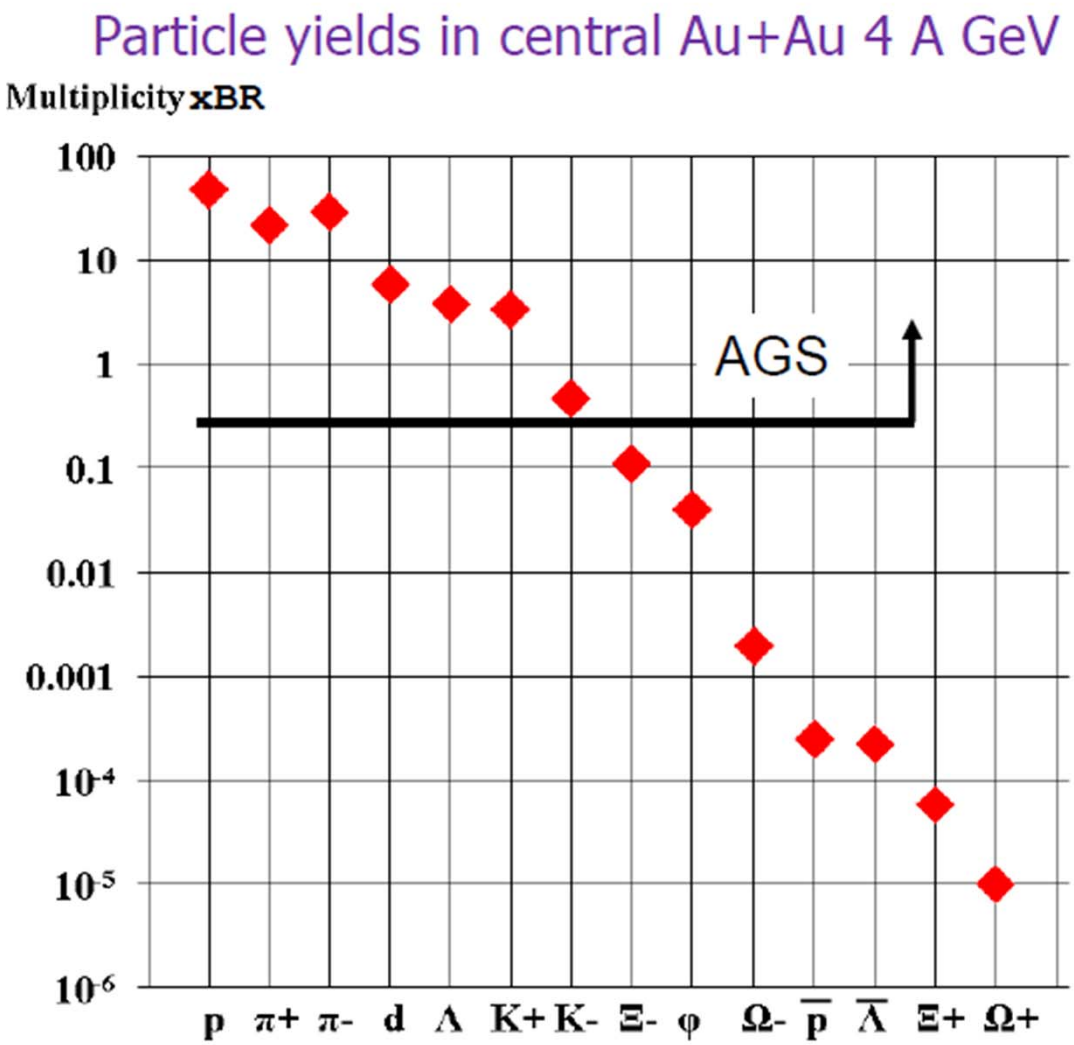


H. Stöcker et al., Nucl. Phys. A 827 (2009) 624c



Experimental challenge

All multistrange particles are rare, not to speak of dileptons or charm ….



Yields: A. Andronic private communication, statistical model

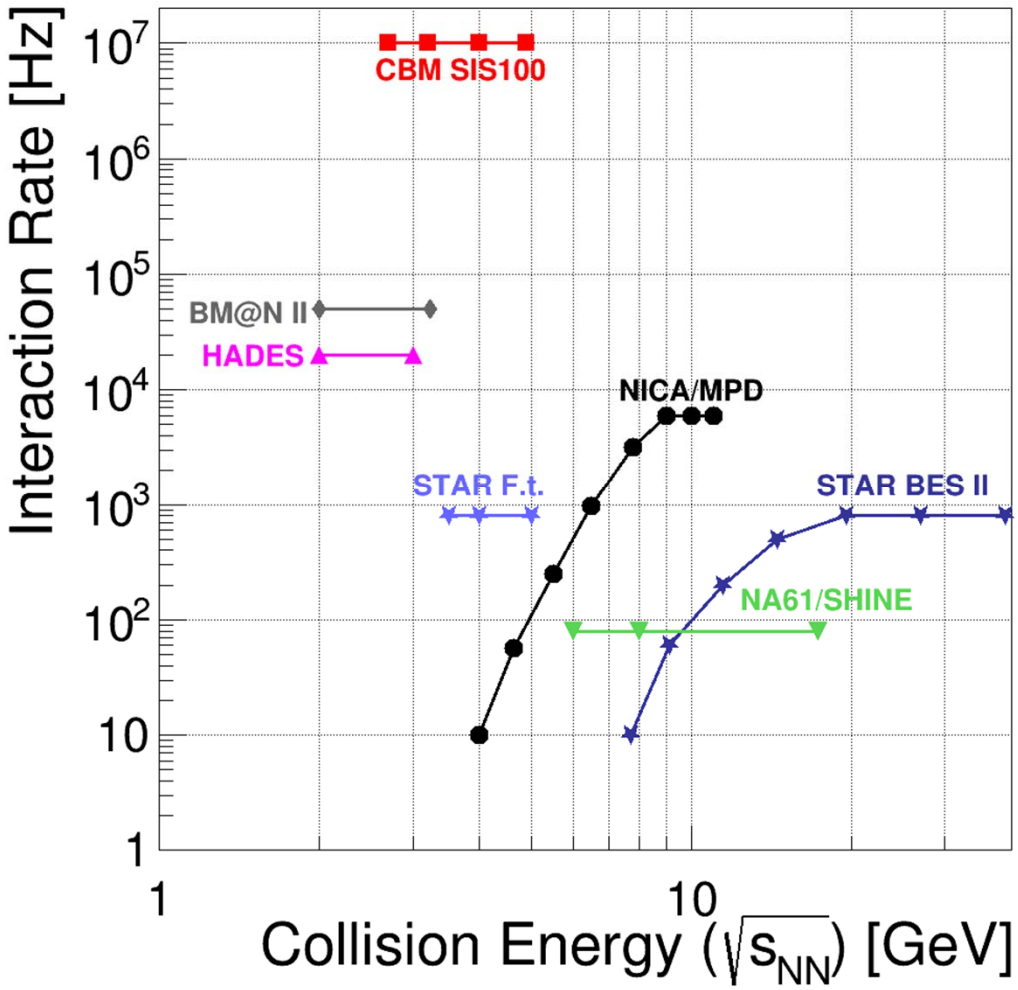
CBM – interaction rates

CBM:
high rate experiment!

→ Opens up new possibilities!

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

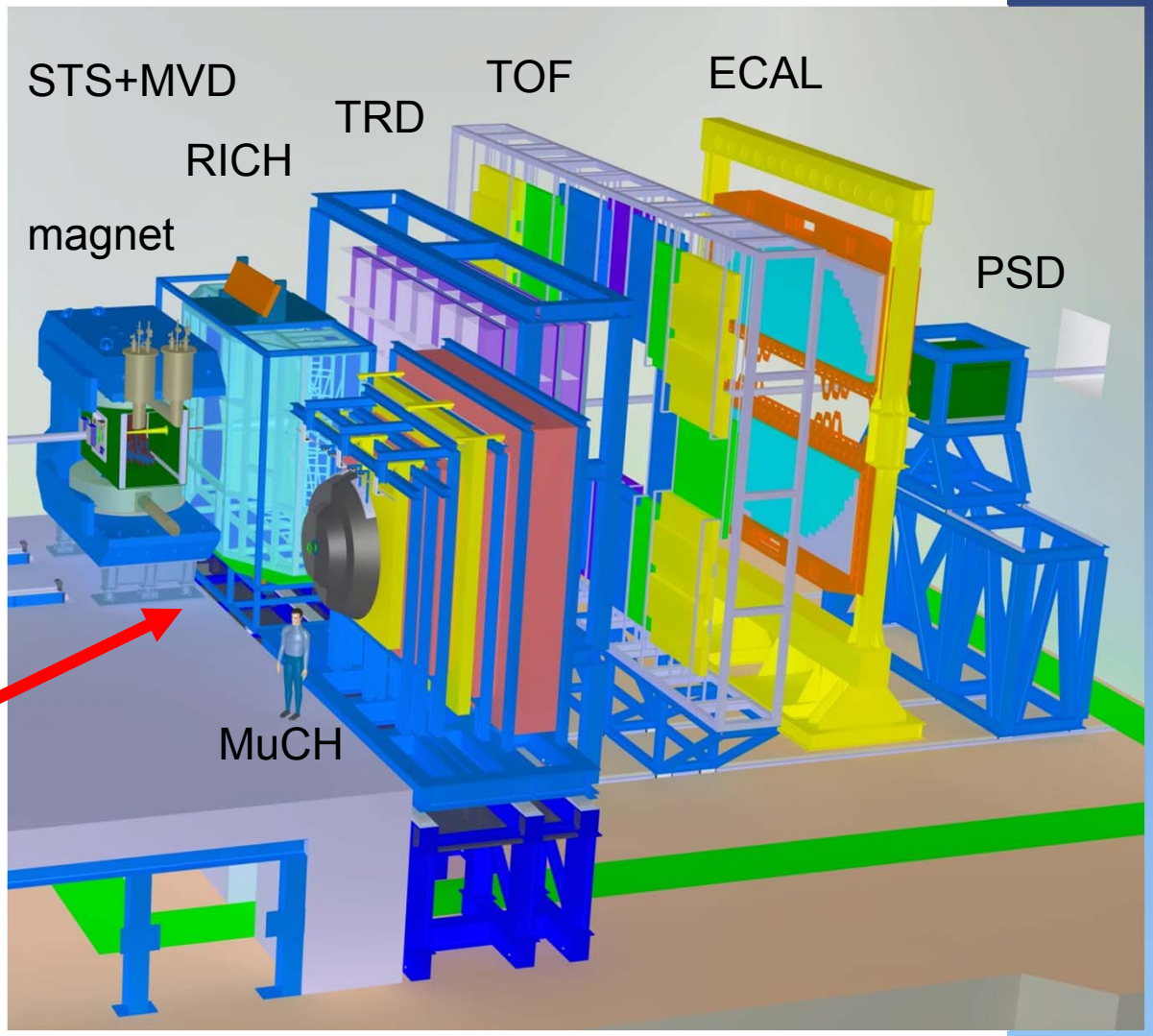
CBM, Eur. Phys. J. A (2017) 53: 60.



* Important part of CBM program, but not covered in this talk

The CBM experiment at SIS 100

- Tracking, momentum, V^0: MVD+STS+dipole magnet
- Event characterization: PSD
- Hadron id: TOF (+TRD)
- Lepton id: RICH+TRD or MUCH
- γ, π^0: EMC (or RICH)
- High speed DAQ
- Online event selection

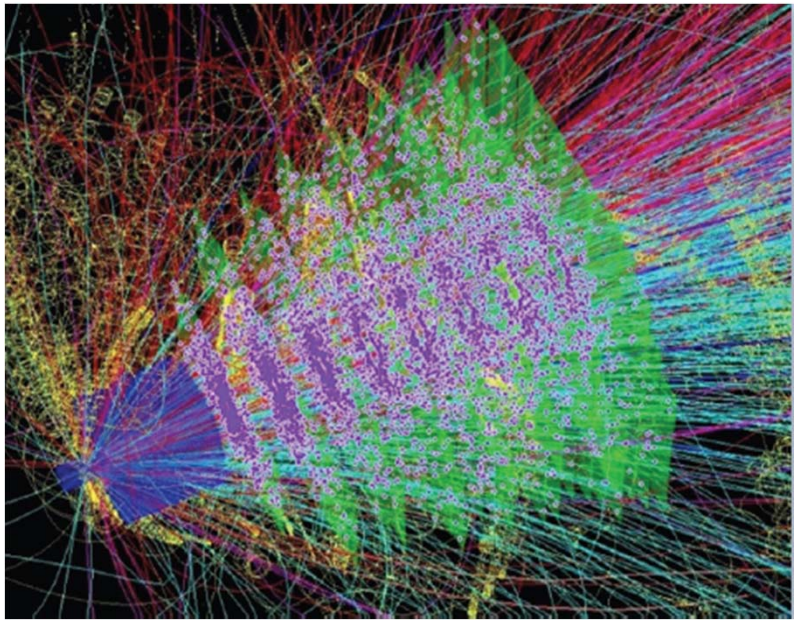


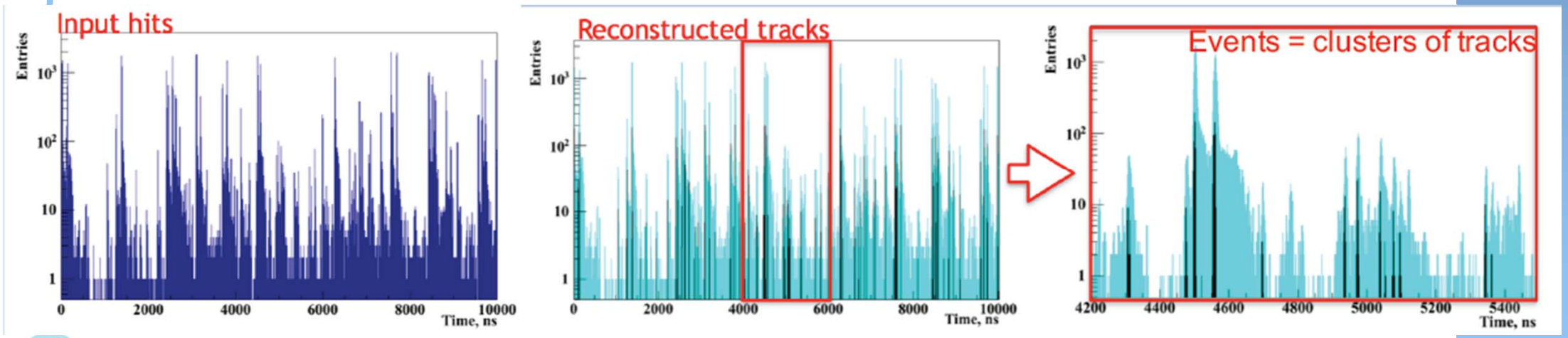
350 m
Linear
distance

CBM readout and online systems

Novel readout system

- no hardware trigger on events, free streaming triggerless data
- detector hits with time stamps,
- full online 4-D track and event reconstruction
- Full analysis of 10 MHz event rate implemented, only very moderate losses in efficiency



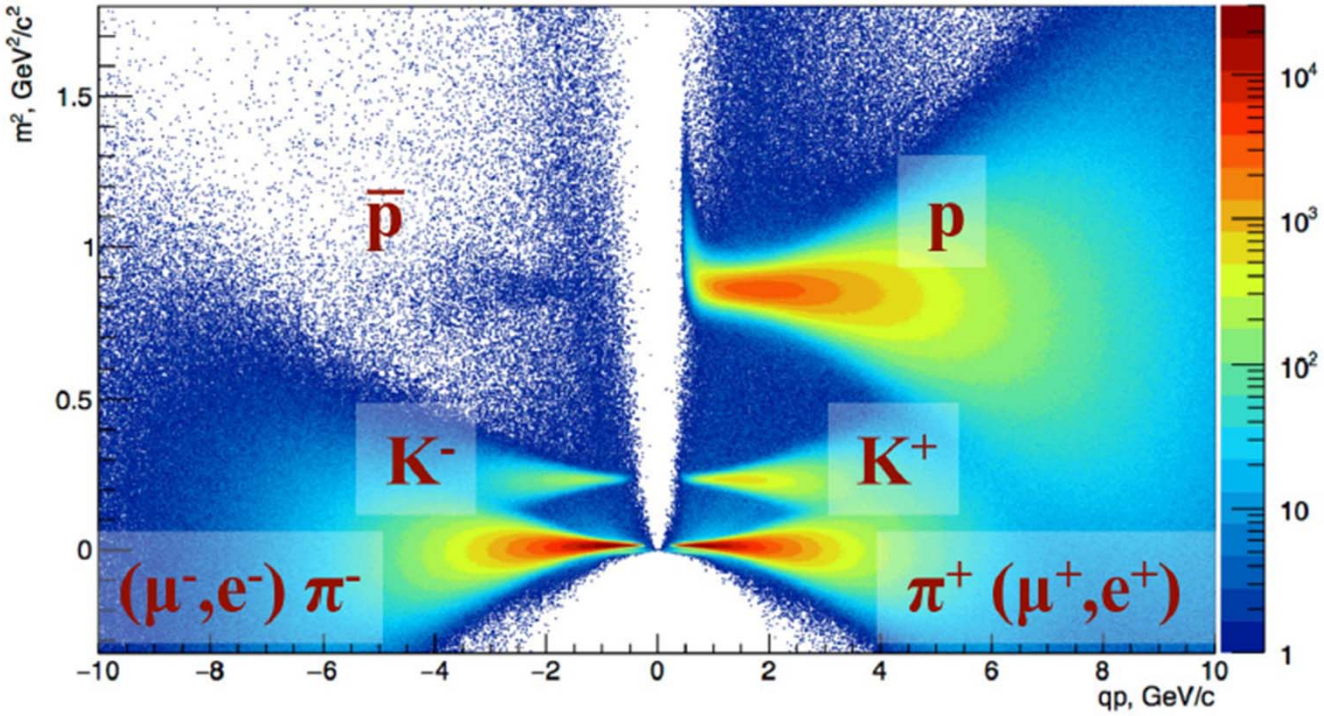


Hadron identification

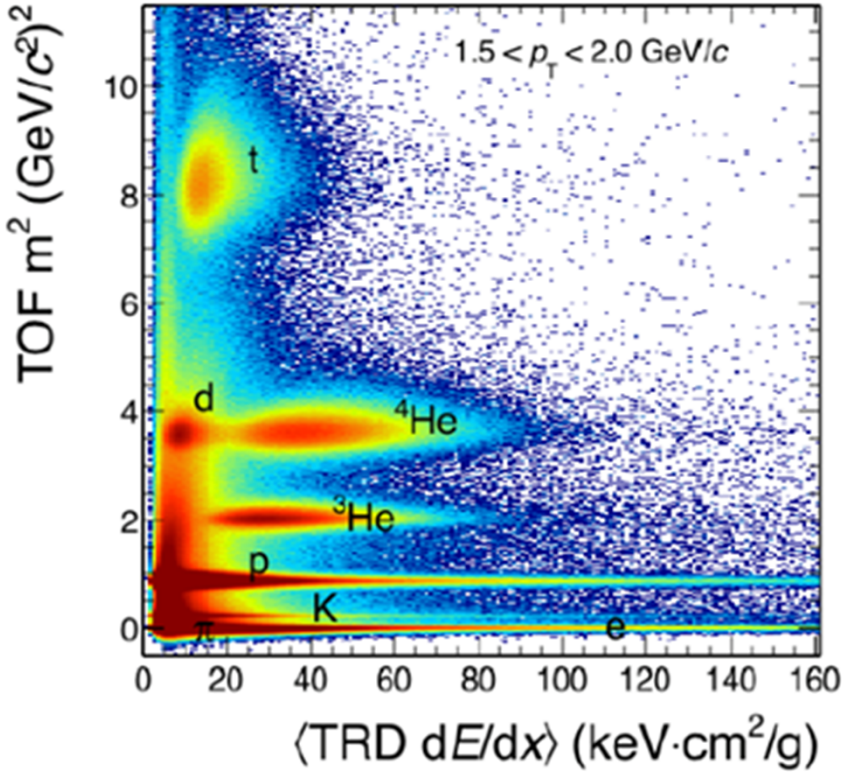
Hadron identification in TOF & TRD

- Add energy loss information from TRD to identify heavier fragments!

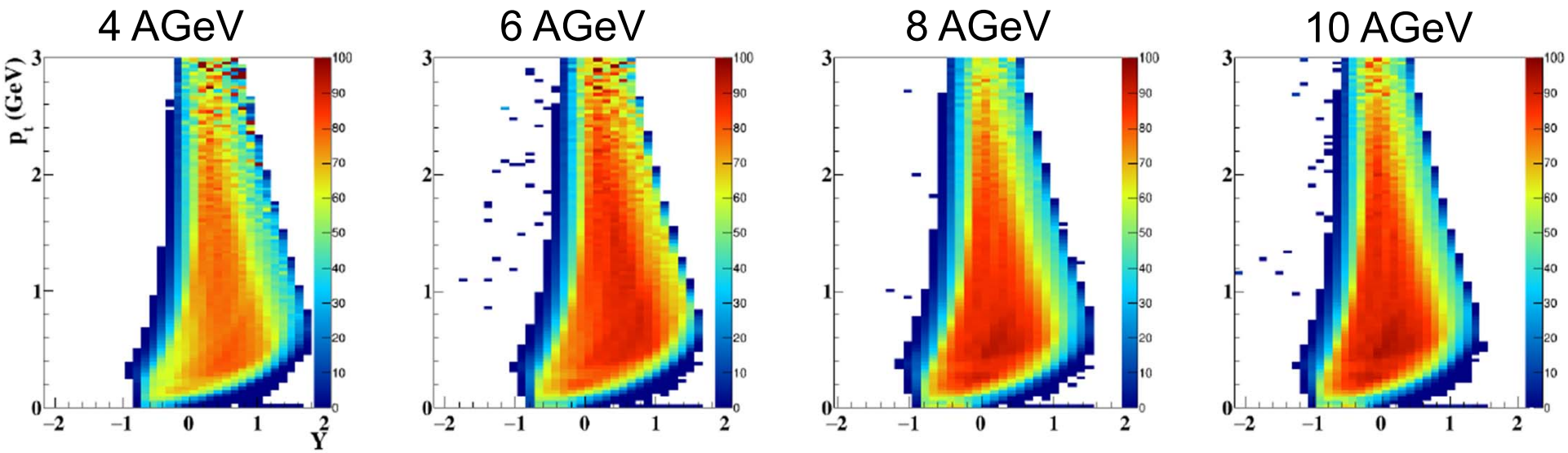
TOF



TOF + TRD

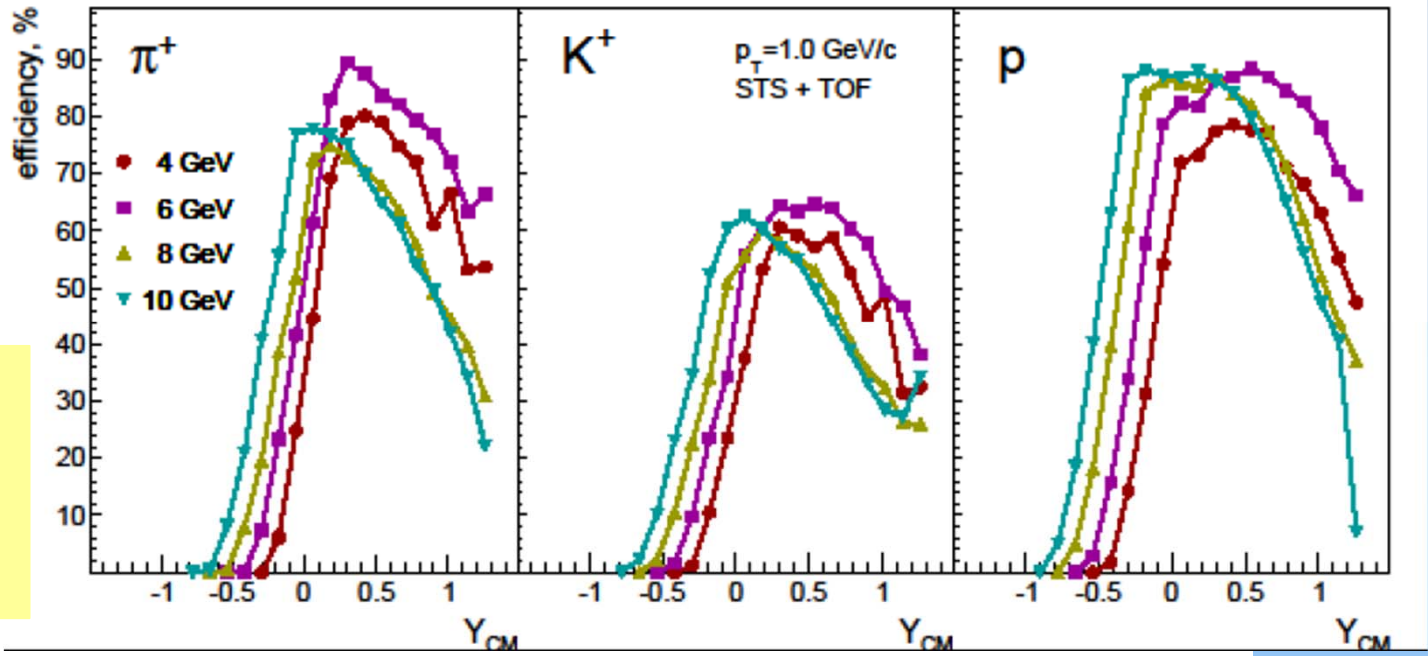


Hadron acceptance (STS + TOF)



Acceptance (STS + TOF) for

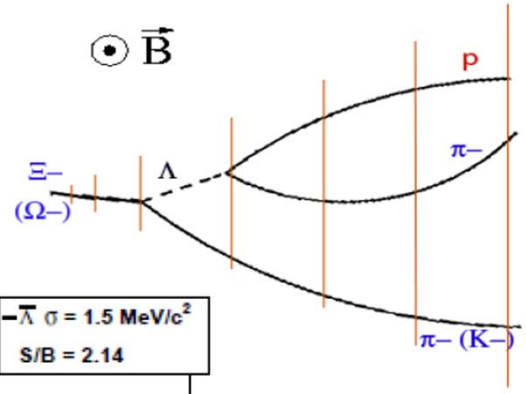
- protons in (y,pt)
- π, K, p projected onto y

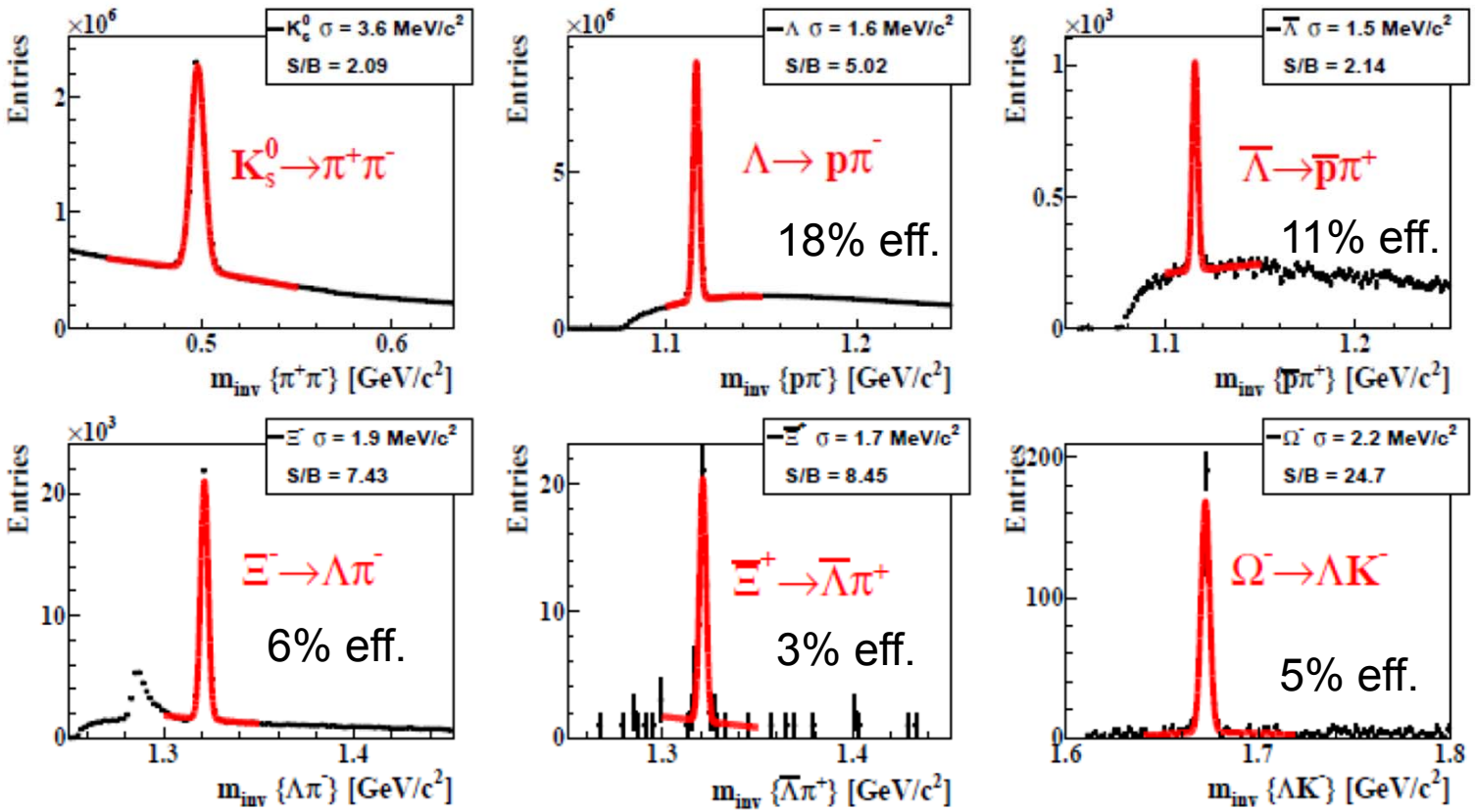


→ yields; also of resonances (ϕ-meson!)
→ flow
→ fluctuations

Strange baryons

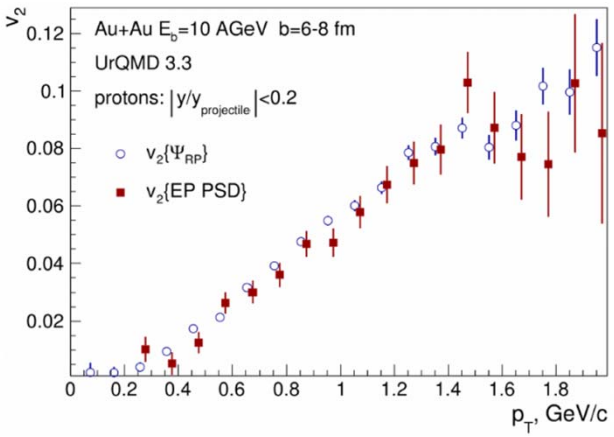
- Simulation: central (b=0fm) Au+Au collisions at 10 AGeV, 3.5M events
- Massively parallel data reconstruction and selection in real-time
- 1MHz interaction rate, 10% central Au+Au collisions, 10 weeks beamtime
  - → 10^7 Ω at 6 AGeV
  - → 10^8 Ω at 10 AGeV

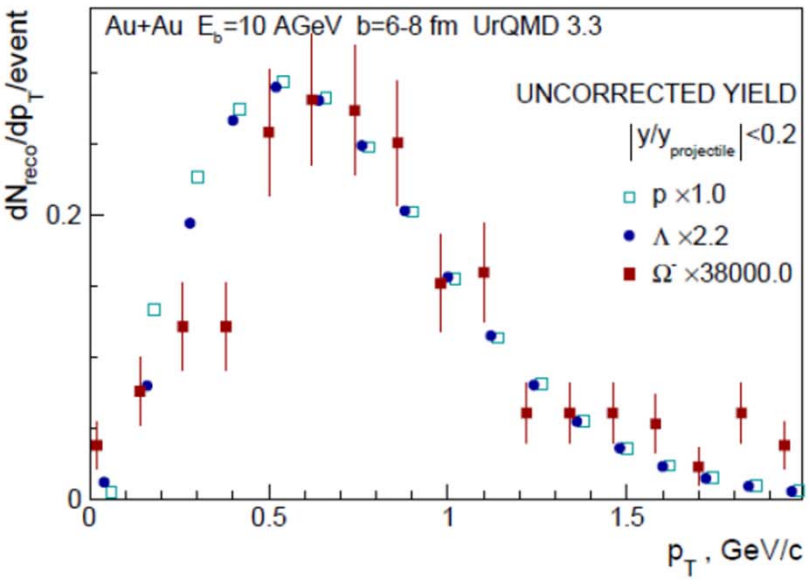




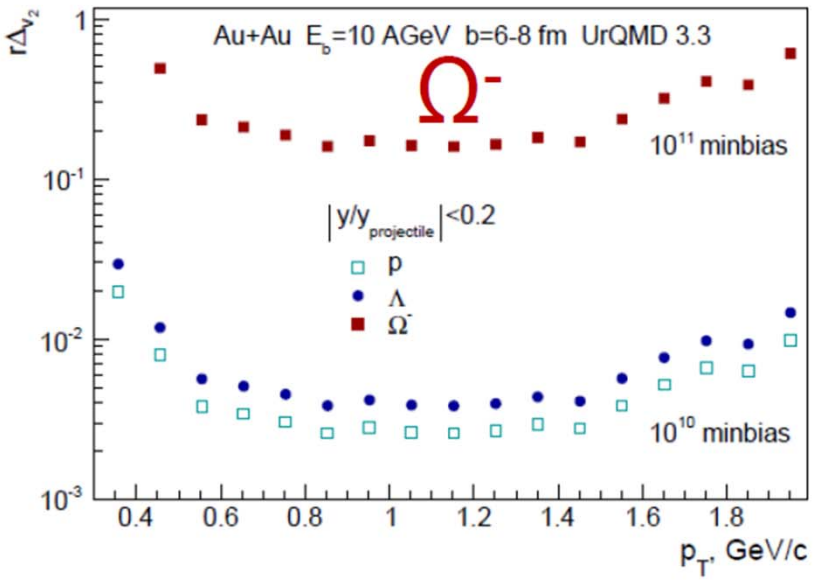
Elliptic flow v_2

- Reaction plane resolution (PSD) ~30-40 degrees for mid-central Au+Au coll.
- UrQMD simulation: 1M mid-central (b=6-8 fm) Au+Au collisions: succesfully reconstruct input proton flow
- Use this and yields/ event for estimate of relative statistical errors for p, Λ, Ω flow in 10^{10} (10^{11}) minbias Au+Au events
- 250 kHz minbias Au+Au → $2 \cdot 10^{10}$ ev/day





Yield of p, Λ, and Ω^- vs. p_T



Relative statistical error of v_2 for p, Λ, and Ω^-

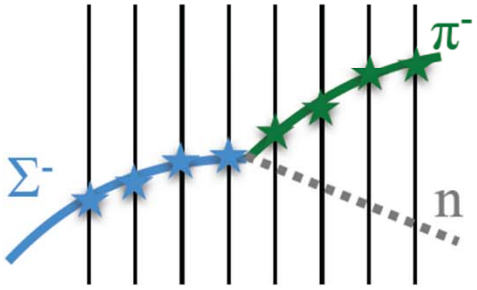
Strange particle production: Σ^+ & Σ^-

- **NEW: Identification of Σ^+ and Σ^- via their decay topology**

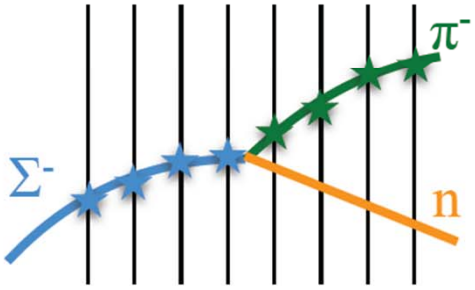
$\Sigma^+ \rightarrow p\pi^0$	$\bar{\Sigma}^+ \rightarrow \bar{p}\pi^0$	BR = 51.6%
$\Sigma^+ \rightarrow n\pi^+$	$\bar{\Sigma}^+ \rightarrow \bar{n}\pi^-$	BR = 48.3%
$\Sigma^- \rightarrow n\pi^-$	$\bar{\Sigma}^- \rightarrow \bar{n}\pi^-$	BR = 99.8%

- Method:
  - Find all primary and secondary tracks, use TOF PID for secondary track
  - Search whether two would fit together with a kink
  - From momentum conservation get momentum of neutral particle
  - Assume e.g. Σ^- decay, calculate (missing) mass of neutral particle
  - Select neutron candidates, recalculate Σ mass

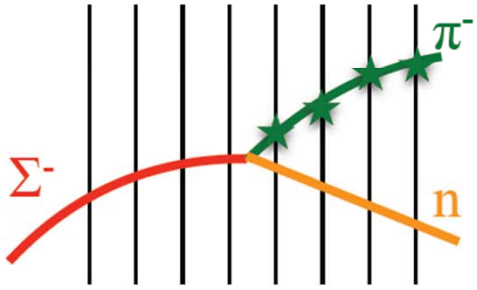
Find tracks of Σ and its charged daughter in STS and MVD



Reconstruct a neutral daughter from the mother and the charged daughter



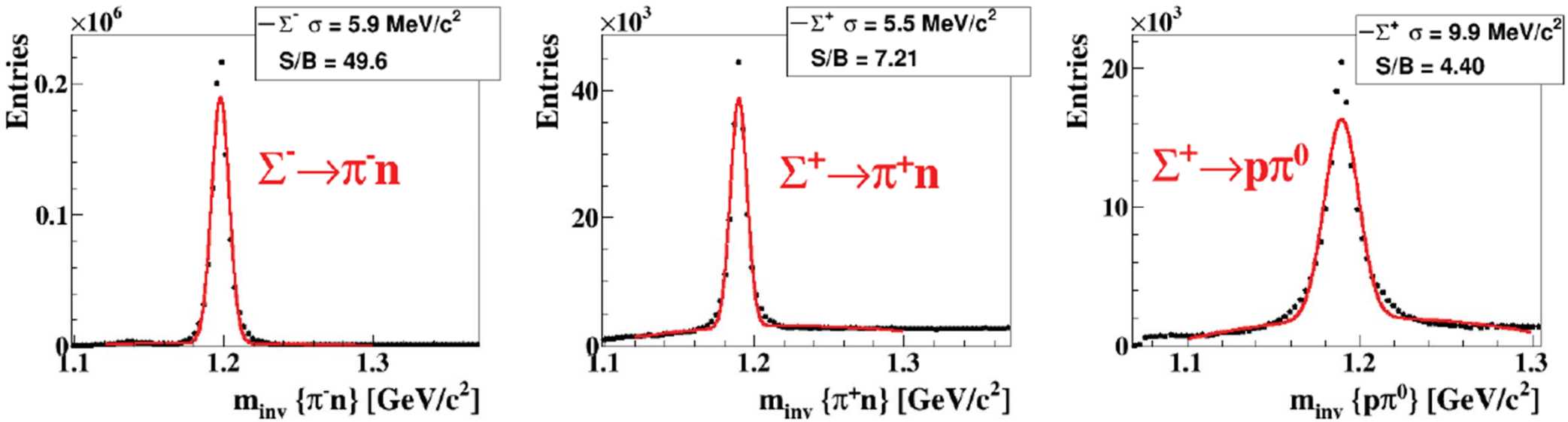
Reconstruct Σ mass spectrum from the charged and obtained neutral daughters



Strange particle production: Σ^+ & Σ^-

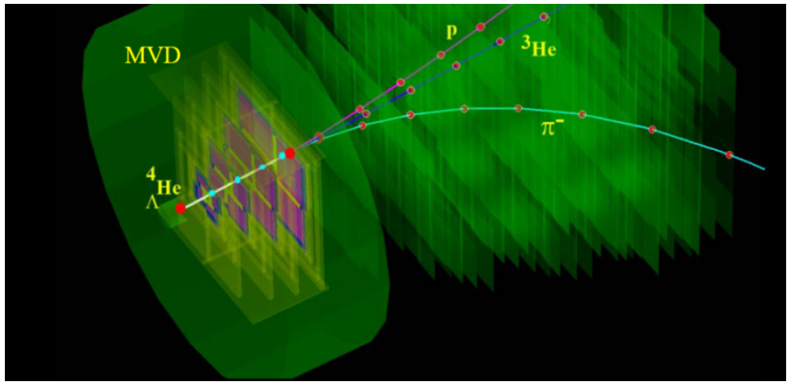
- Simulations: UrQMD, 5M central collisions Au+Au, 10 AGeV beam energy
- Method also applicable for
  - Anti-Σ
  - $K^{\pm} \rightarrow \pi^0 + \pi^{\pm}$
- Total (4π) efficiency ~(1-3)%

Remark:
Che-Ming Ko (Tuesday):
Symmetry energy effect on Σ^-/Σ^+ ratio

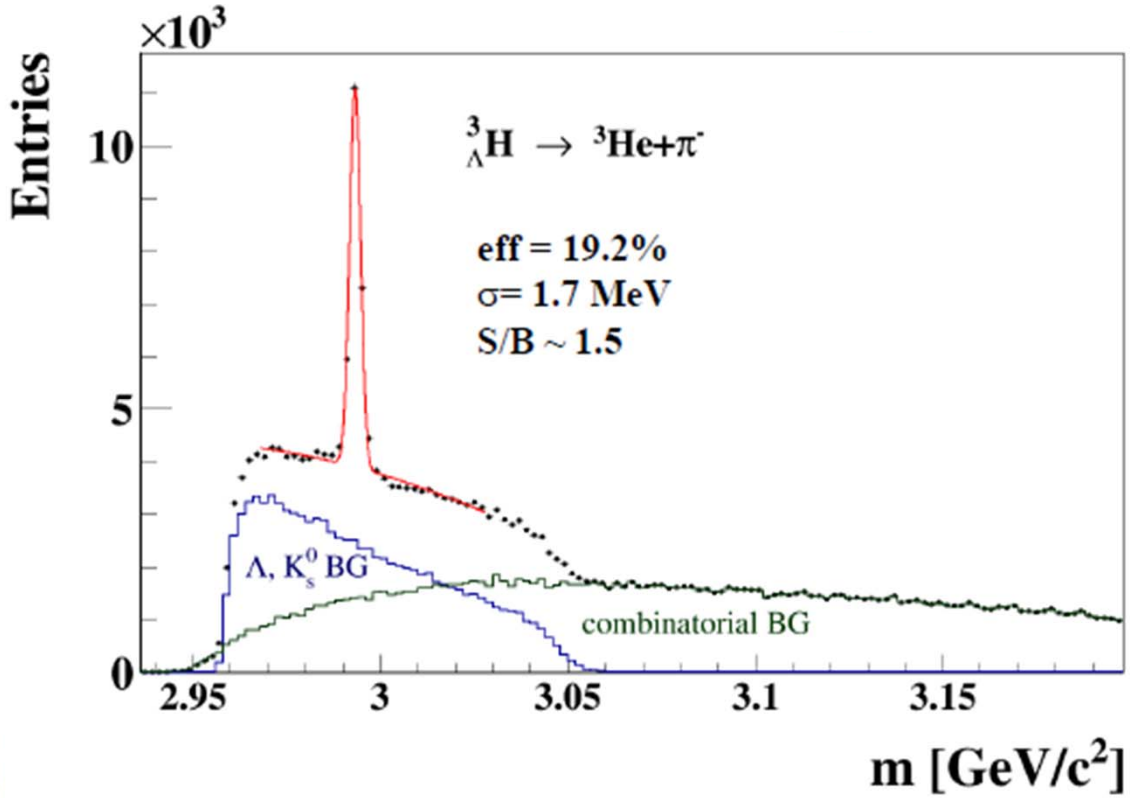


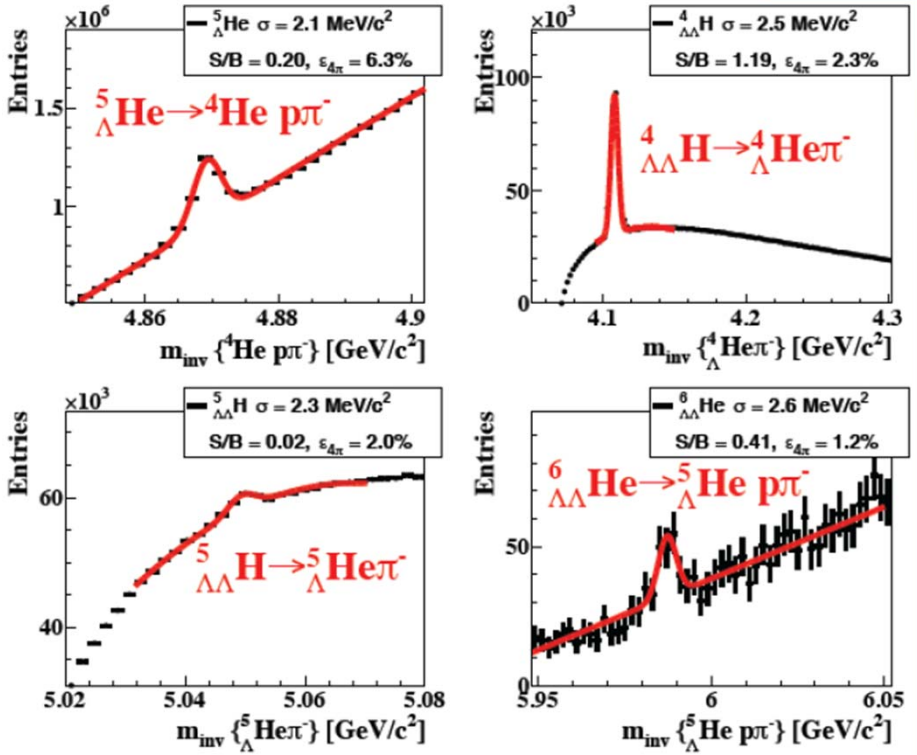
Hypernuclei

Simulations: UrQMD, 5M central collisions Au+Au, 10 AGeV beam energy



Simulations: UrQMD, 10^{12} events, central collisions Au+Au, 10 AGeV beam energy



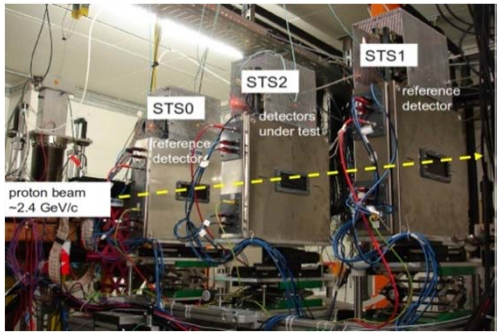


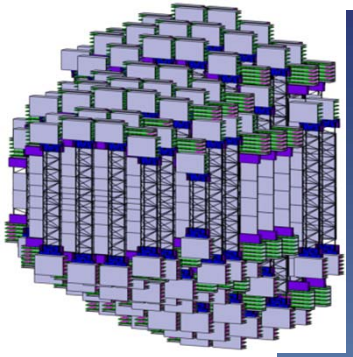
CBM Technical Developments

SC Magnet: JINR Dubna

Micro-Vertex Detector: Frankfurt, Strasbourg

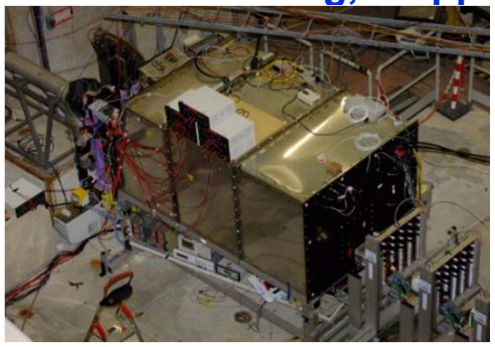
Silicon Tracking System: Darmstadt, Dubna, Krakow, Kiev, Kharkov, Moscow, St. Petersburg, Tübingen



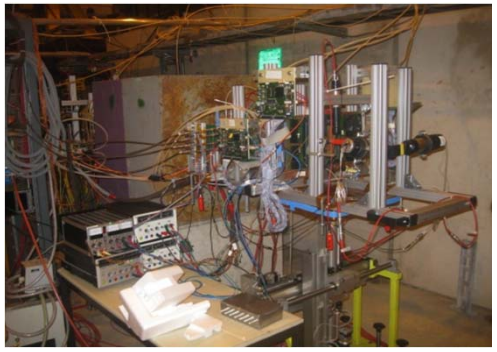


MRPC ToF Wall: Beijing, Bucharest, Darmstadt, Frankfurt, Hefei, Heidelberg, Moscow, Rossendorf, Wuhan, Zagreb

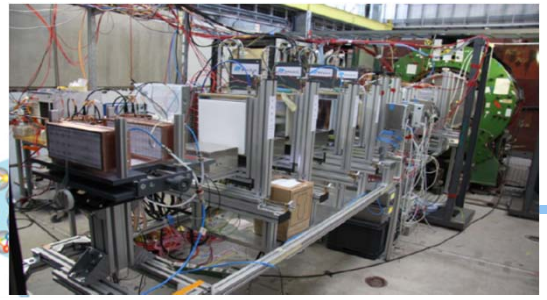
RICH Detector: Darmstadt, Giessen, St. Petersburg, Wuppertal



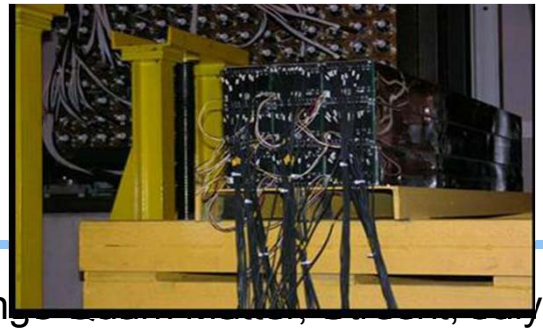
Muon detector: Kolkata + 13 Indian Inst., Gatchina, Dubna



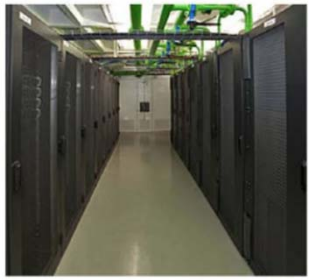
Transition Radiation Detector: Bucharest, Frankfurt, Heidelberg, Münster



Forward calorimeter: Moscow, Prague, Rez



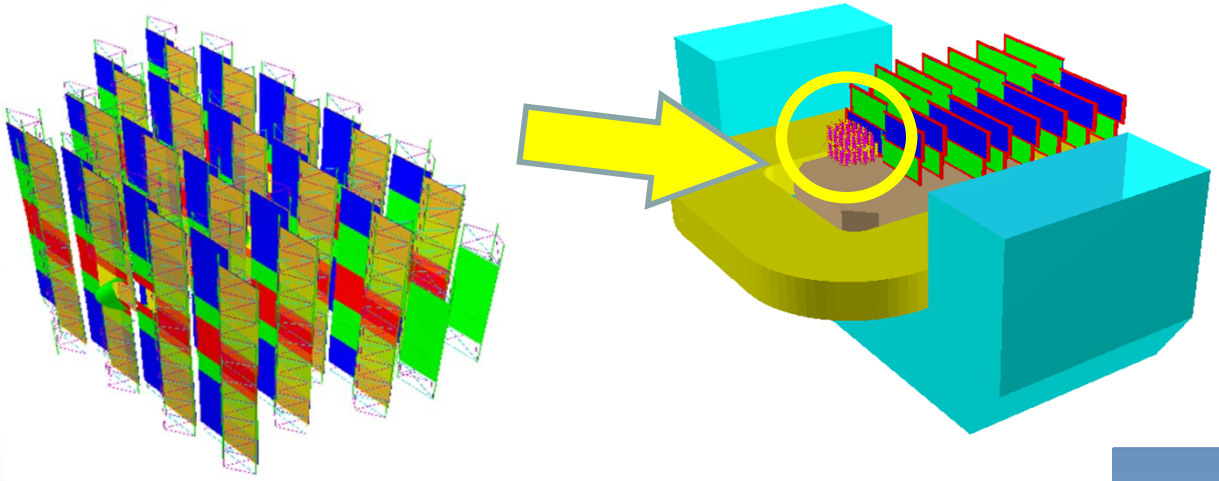
DAQ and online event selection: Darmstadt, Frankfurt, Kharagpur, Warsaw

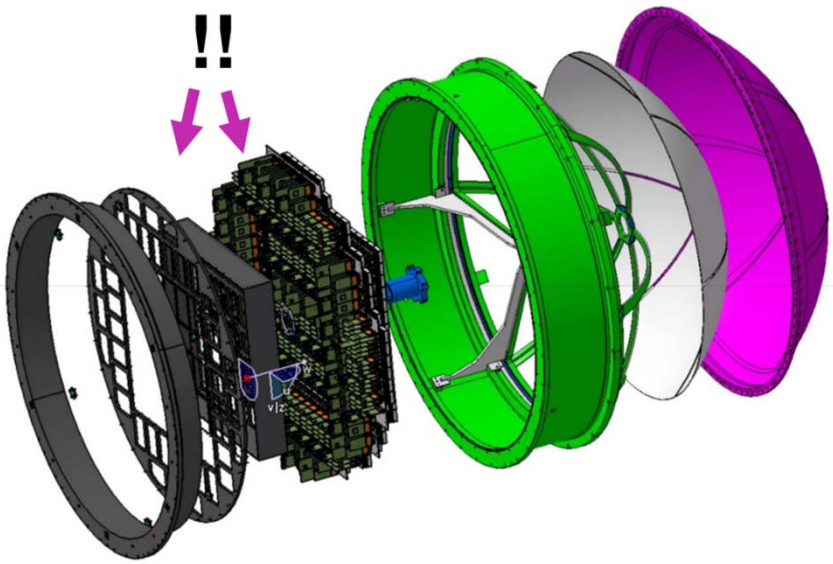


FAIR phase 0 experiments

Install, commission and use CBM detector components in ongoing (starting) physics campaigns

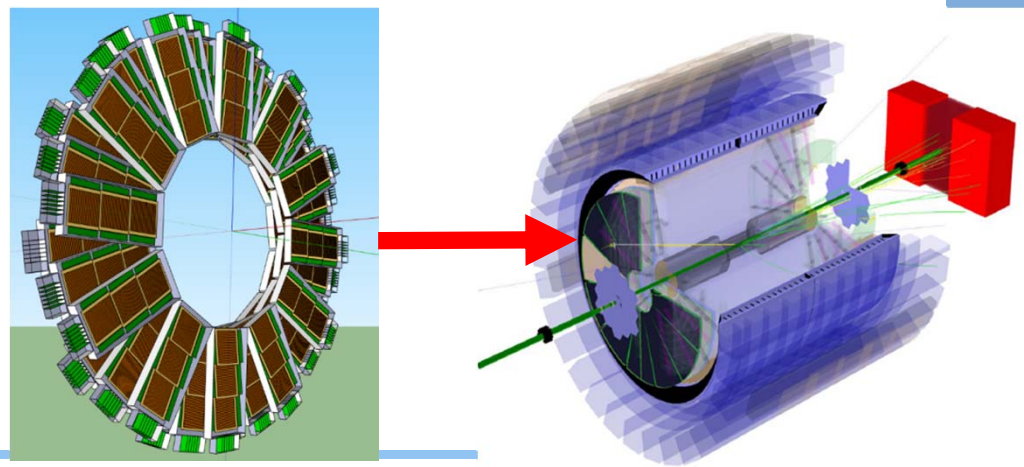
- 4 STS stations in BM@N experiment at Dubna





- 40% of the RICH MAPMTs and electronics in HADES RICH for SIS 18

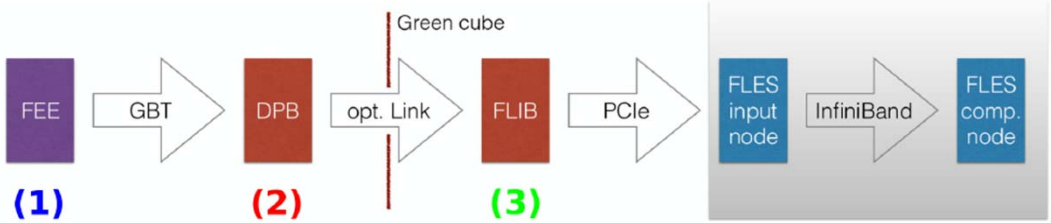
- 10% of the TOF detector moduls including readout in STAR at RHIC for BESII



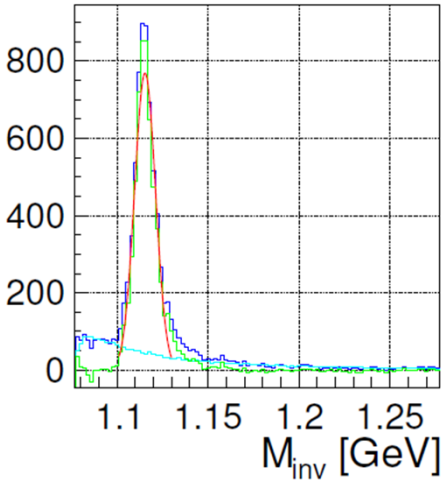
mCBM

Beamtime proposal for „miniCBM“ at GSI handed in:

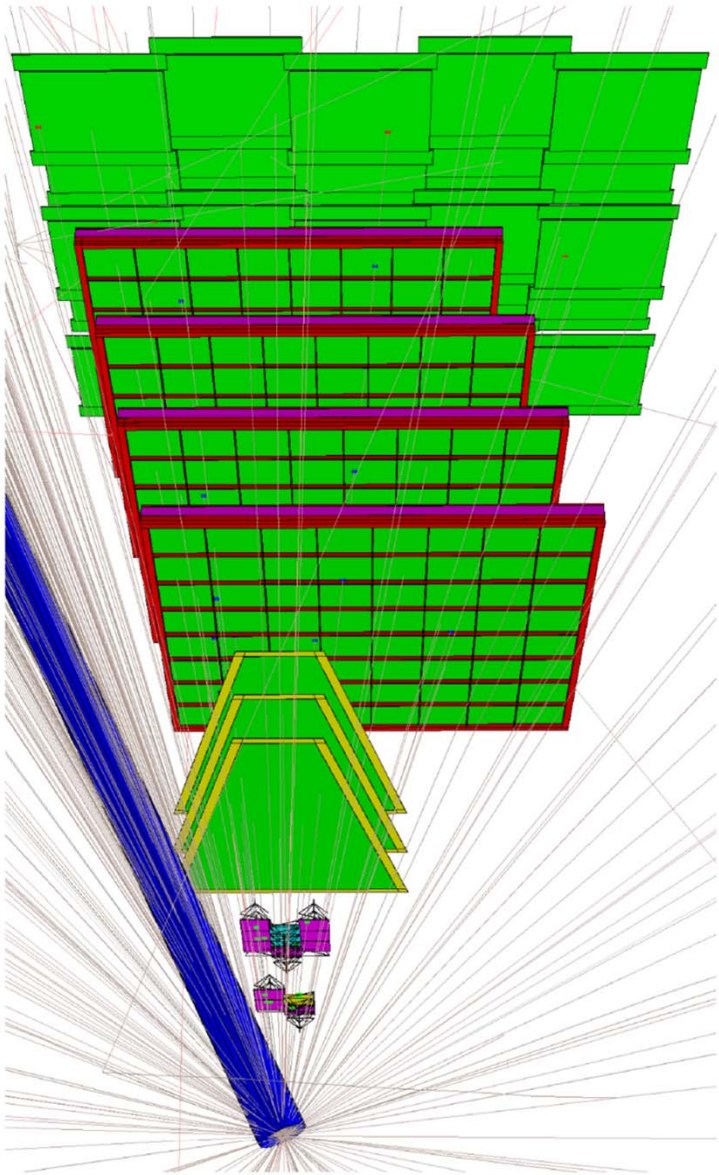
- using prototype detectors of CBM in order to test/ establish self-triggered read-out, data transfer to FLES, event building, online analysis



CBM readout chain, start-up phase



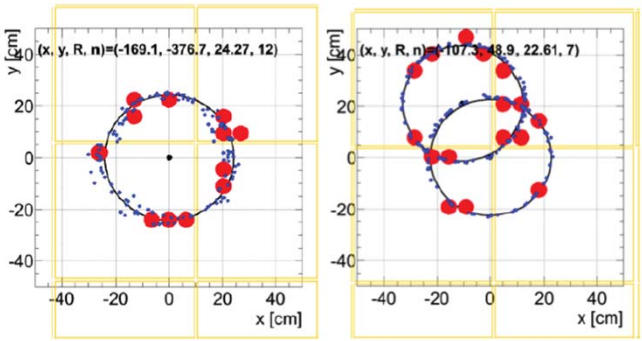
10^8 minbias UrQMD collisions, 1,93 AGeV Ni+Ni
Technical goal: 10 s data taking



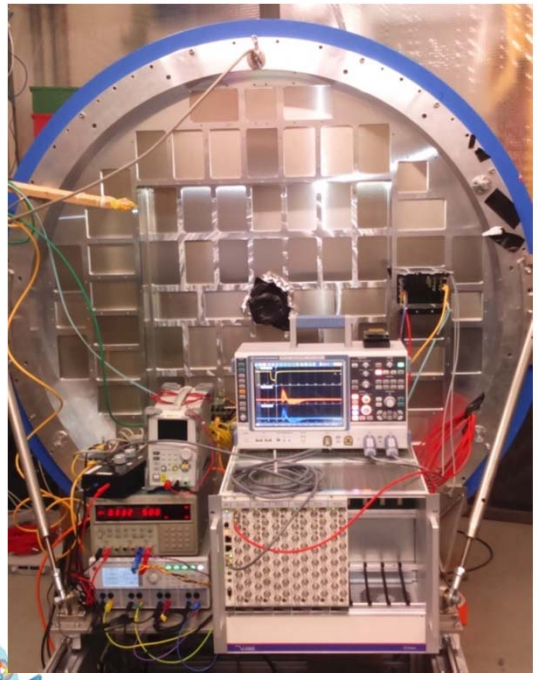
HADES RICH upgrade

- HADES RICH detector in operation since more than 10 years
- Reduced performance over years

→ replace by CBM-RICH MAPMTs and gain a huge factor in e-PID

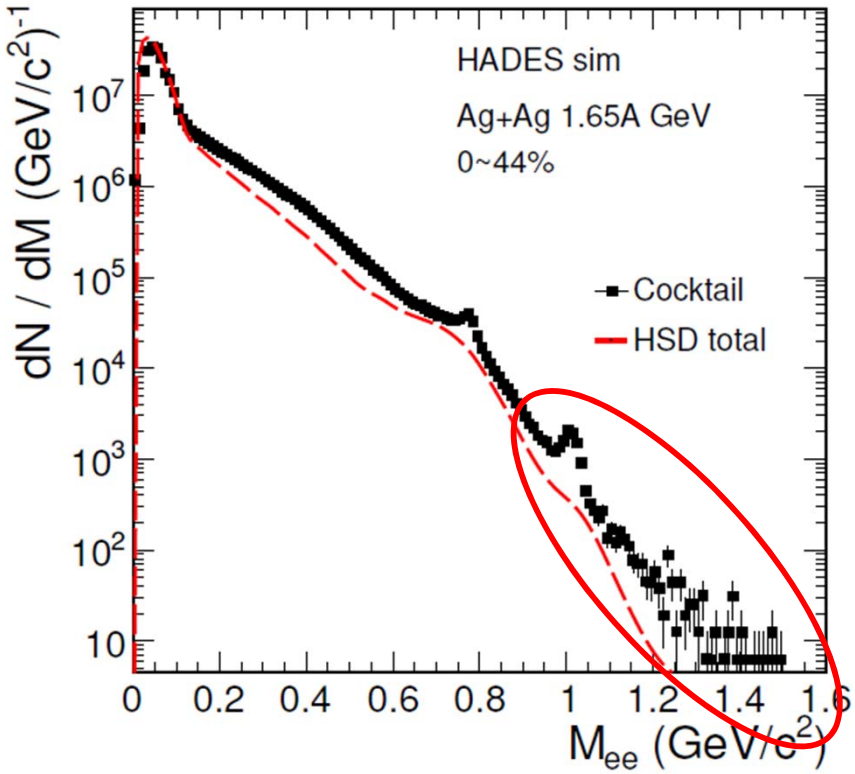


Simulation and reconstruction of single/ double rings



Preparation of new photondetector plane

HADES beamtime proposal:
CB subtracted e^+e^- mass spectrum for $5 \cdot 10^9$ events (4 weeks beamtime)

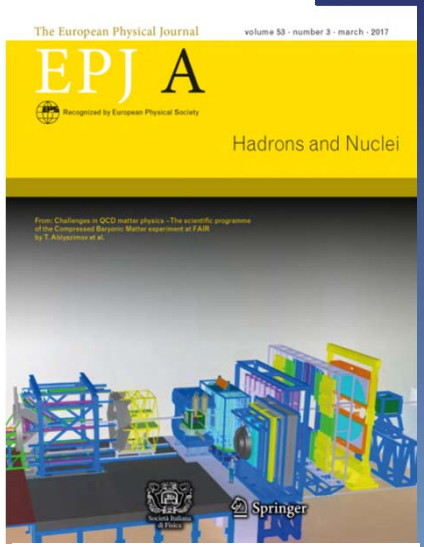


Conclusion/ Summary

Daniel Cebra, Tuesday morning:

The ***Open Questions*** fall is four broad categories:

1. The energy dependence of strangeness production ✓
2. The system size dependence of strangeness production ✓
3. Strange hadron cross-sections and potentials ✓
4. Hyperon interactions and Hyper-nuclei ✓



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

CBM

→ phase structure will not be revealed by a single measurement – need systematic studies!

→ systematic studies with sufficient statistics: strangeness, em probes, charm

→ CBM well advanced with respect to FAIR timeline, 7 out of 11 TDRs accepted, start version 90% financed

→ exciting FAIR phase-0 activities!

The CBM collaboration

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.

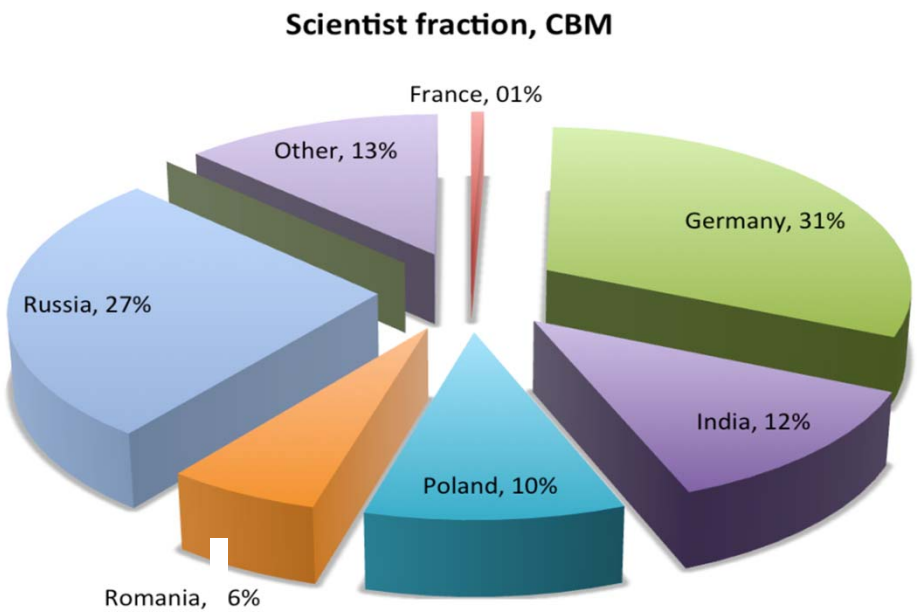
Korea:
Pusan Nat. Univ.

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



Particle yields based on HSD calculations

10 % most central Au+Au collisions at 6 and 10 A GeV

Particle (mass MeV/c^2)	Multi-plicity 6 A GeV	Multi-plicity 10 A GeV	decay mode	BR	ε (%)	yield (s^{-1}) 6 A GeV	yield (s^{-1}) 10 A GeV	yield in 10 weeks 6 A GeV	yield in 10 weeks 10 A GeV	IR MHz
K^+ (494)	12.5	20	-	-	31	$3.9\cdot10^{5}$	$6.2\cdot10^{5}$	$2.4\cdot10^{12}$	$3.7\cdot10^{12}$	1
K^- (494)	1.4	3	-	-	27	$3.8\cdot10^{4}$	$8.1\cdot10^{4}$	$2.3\cdot10^{11}$	$4.8\cdot10^{11}$	1
ρ (770)	5	9	L^+L^-	$4.7\cdot10^{-5}$	4.6	1.1	2.0	$6.5\cdot10^{6}$	$1.2\cdot10^{7}$	1
ω (782)	3.3	6	L^+L^-	$7.1\cdot10^{-5}$	5.2	1.2	2.2	$7.4\cdot10^{6}$	$1.3\cdot10^{7}$	1
φ (1020)	0.07	0.12	L^+L^-	$3\cdot10^{-4}$	6.0	$1.3\cdot10^{-1}$	$2.2\cdot10^{-1}$	$7.6\cdot10^{5}$	$1.3\cdot10^{6}$	1
Λ (1115)	10.4	17.4	$p\pi^-$	0.64	18	$1.2\cdot10^{5}$	$2.0\cdot10^{5}$	$7.2\cdot10^{11}$	$1.2\cdot10^{12}$	1
$\bar{\Lambda}$ (1115)	$4.6\cdot10^{-4}$	0.034	$\bar{p}\pi^+$	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	-	$5.2\cdot10^{6}$	10
J/ψ (3097)	-	$1.74\cdot10^{-7}$	L^+L^-	0.06	5	-	$5.2\cdot10^{-4}$	-	3100	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

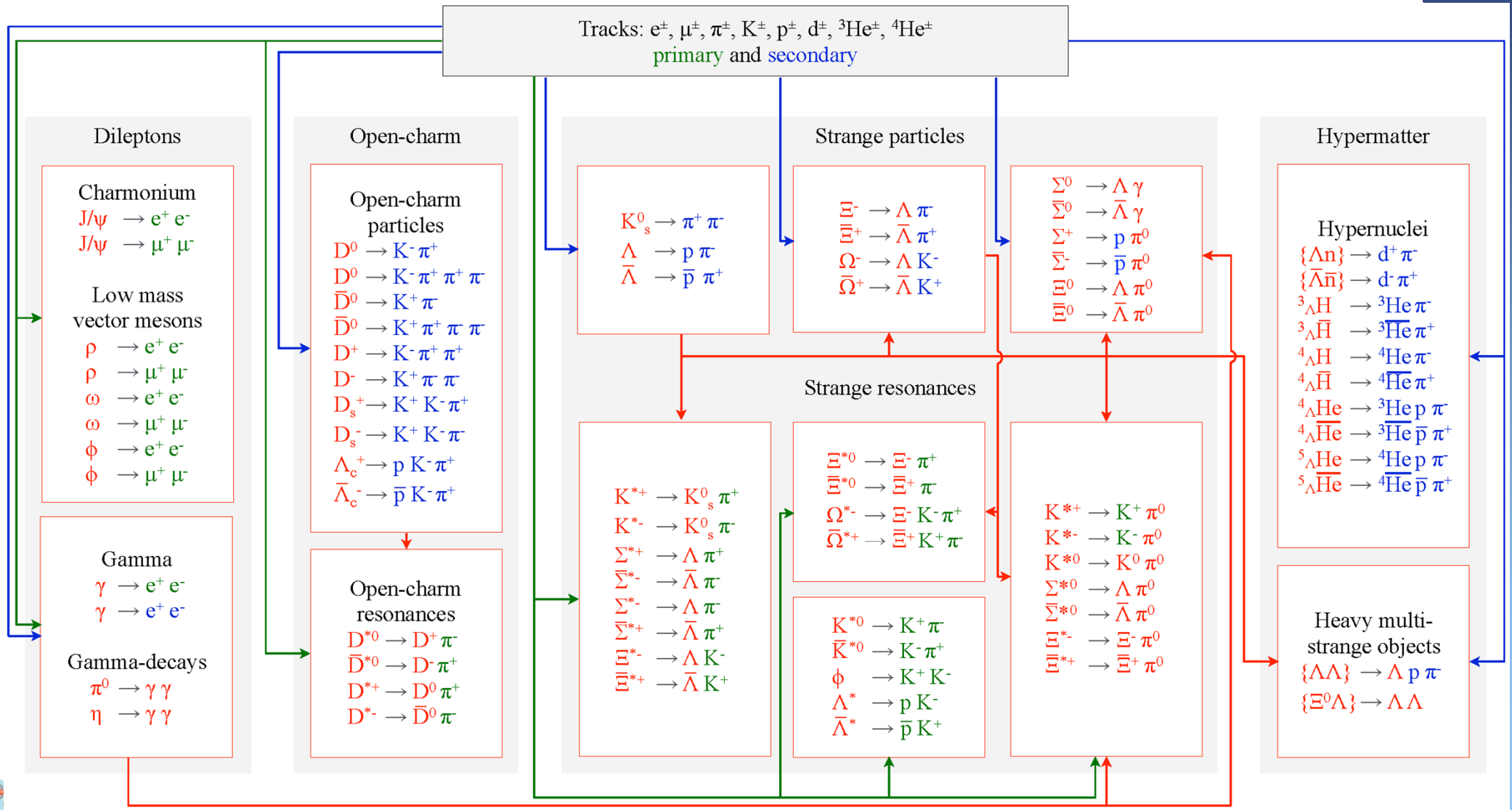
p + A collisions at 20 and 30 GeV

Particle (mass MeV/c^2)	Multi-plicity 20 GeV	Multi-plicity 30 GeV	decay mode	BR	ε (%)	yield (s^{-1}) 20 GeV	yield (s^{-1}) 30 GeV	yield in 10 weeks 20 GeV	yield in 10 weeks 30 GeV	IR MHz
$D^{\pm}$ (1869)	$3.4\cdot10^{-7}$	$1.3\cdot10^{-6}$	$K^+\pi^-\pi^-$	0.09	13	$4.0\cdot10^{-2}$	$1.5\cdot10^{-1}$	$2.4\cdot10^{5}$	$9.2\cdot10^{5}$	10
D^0 (1865)	$5.1\cdot10^{-7}$	$2.0\cdot10^{-6}$	$K^+\pi^-\pi^-\pi^+$	0.08	2	$8.2\cdot10^{-3}$	$3.2\cdot10^{-2}$	$4.9\cdot10^{4}$	$1.9\cdot10^{5}$	10
J/ψ (3097)	$7.5\cdot10^{-8}$	$2.9\cdot10^{-6}$	L^+L^-	0.06	5	$2.3\cdot10^{-3}$	$8.7\cdot10^{-2}$	$1.4\cdot10^{4}$	$5.2\cdot10^{5}$	10

Online particle identification

Fast (online) reconstruction of all resonances available

- use excellent tracking of STS + MVD: secondary vertex finding

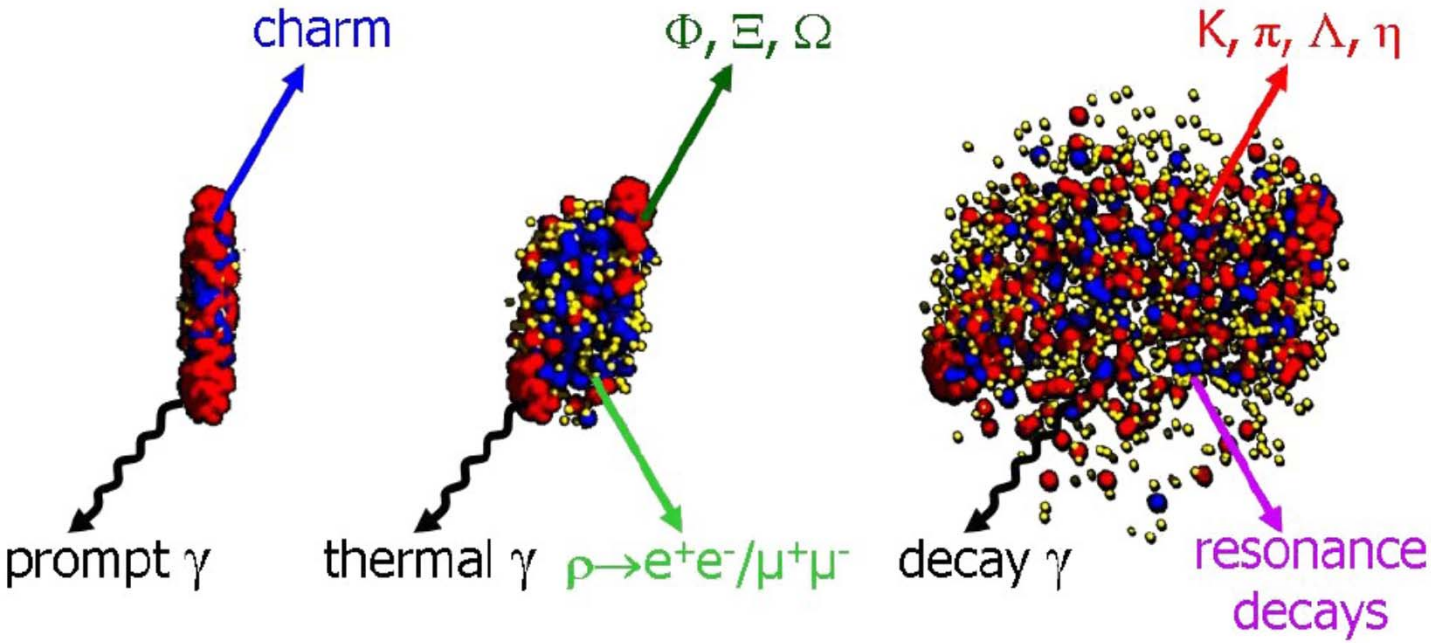


Heavy – Ion Collisions

Hadrons:

- In final state: thermalized?
- From „before“:
  relicts from high density phase still carrying information on this phase?

Penetrating probes: *… not this talk …*



Hard probes
(initial state)

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

Freeze-out
(final state particles)

Thermalized (?) hadrons

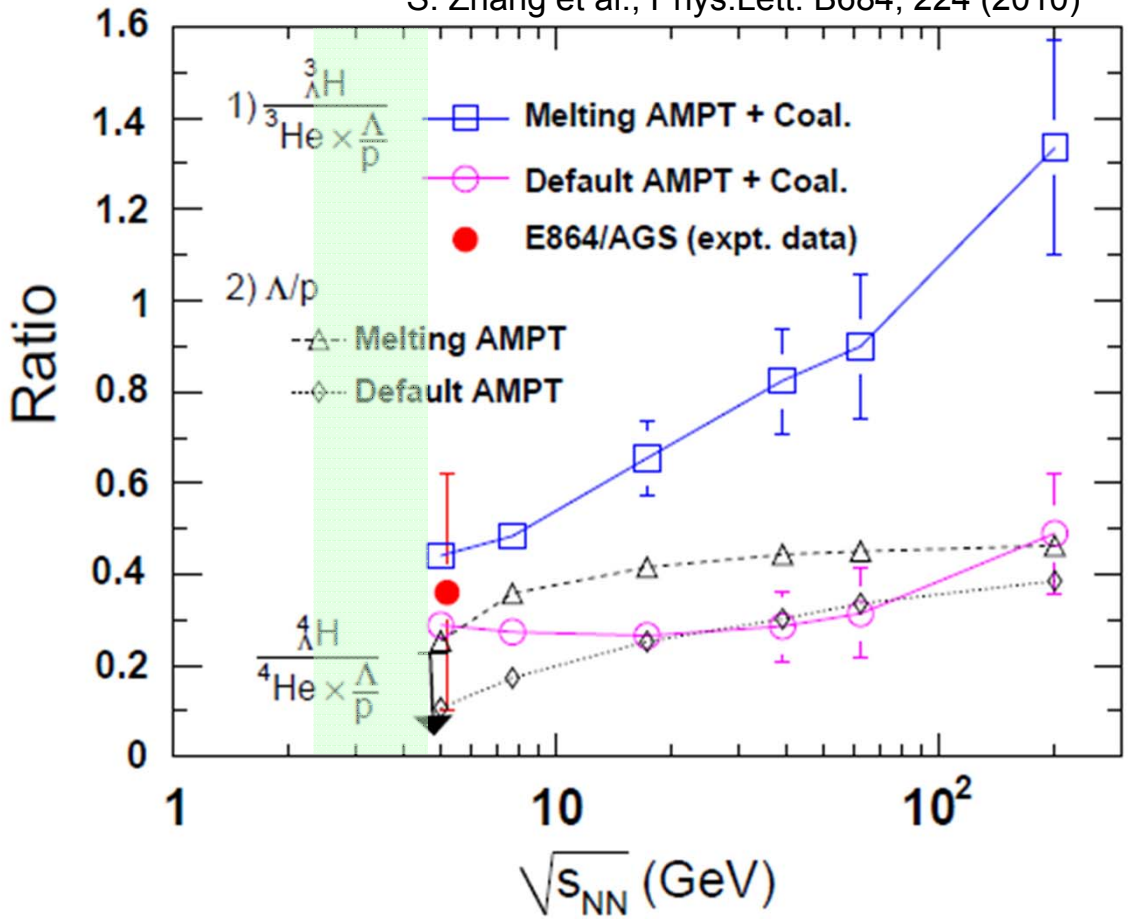
Baryon – Strangeness – Correlation

CBM

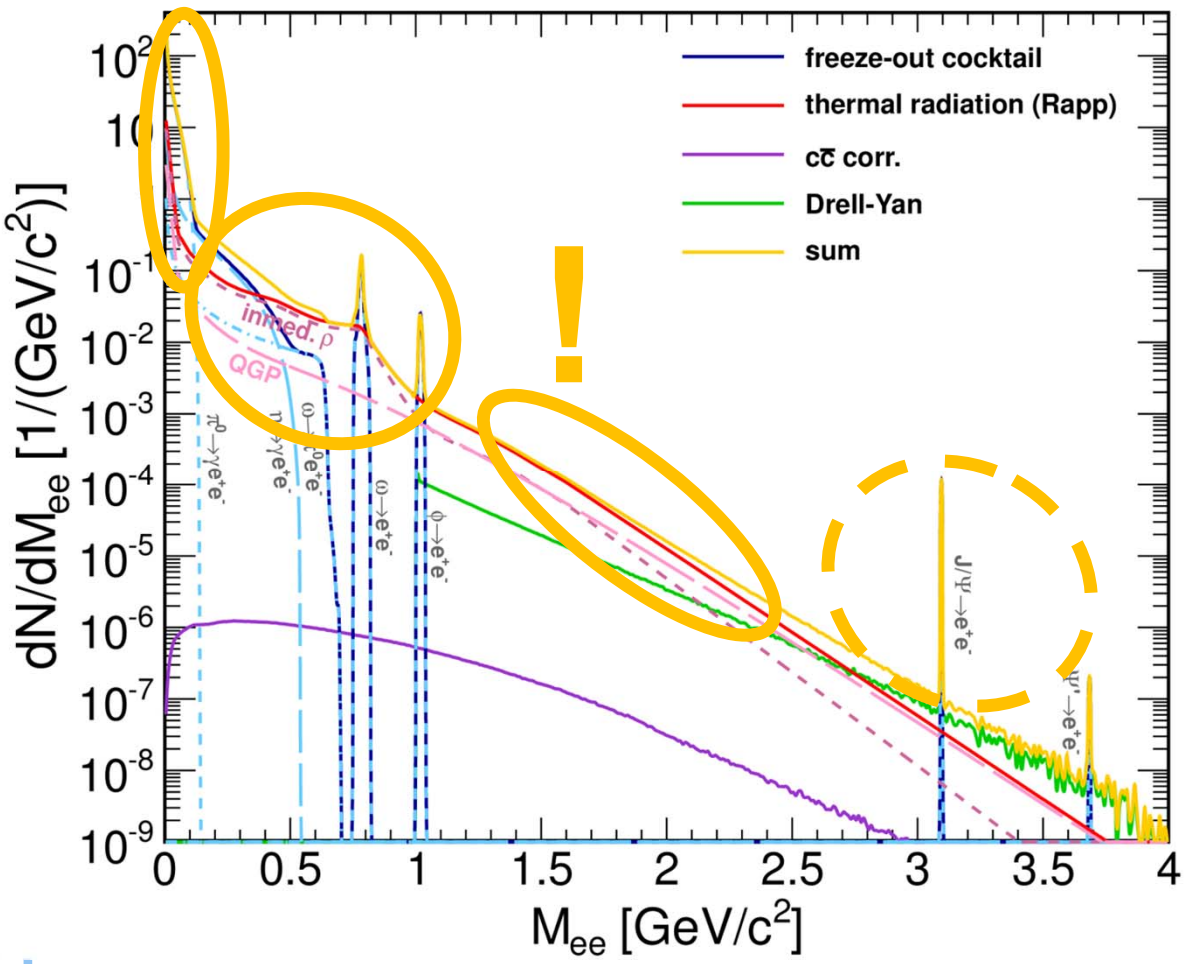
→ Compare $_{\Lambda}t/^{3}He$ production to Λ/p:
Local correlation between baryon number and strangeness

→ sensitivity to deconfinement!

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



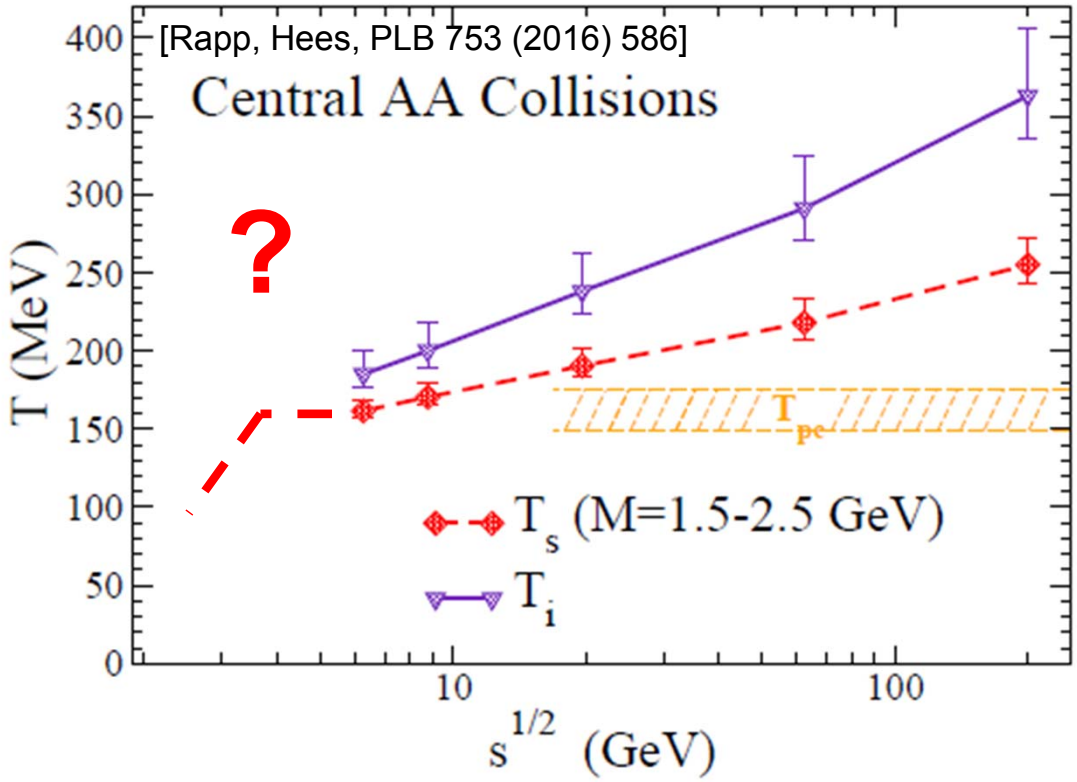
Dileptons at CBM



- Photons: access to early temperatures
  → excitation function?
- Low-mass vector mesons: in-medium properties of ρ
  → strength due to coupling to baryons (see HADES)
  → go to real dense matter!
- Intermediate range: access to thermal fireball radiation: QGP, 4π- or ρ-a$_1$ chiral mixing
  → quarkyonic phase?
- J/ψ: charm as a probe for dense baryonic / partonic matter
  → propagation of charm?
  → distribution amongst hadrons?

Central Au+Au collisions, 25 AGeV

Dileptons at CBM



Caloric curve?

- Photons: access to early temperatures
  → excitation function?
- Low-mass vector mesons: in-medium properties of ρ
  → strength due to coupling to baryons (see HADES)
  → go to real dense matter!
- Intermediate range: acces to fireball radiation (see NA60): QGP, 4π- or ρ-a_1 chiral mixing
  → quarkyonic phase?
- J/ψ: charm as a probe for dense baryonic / partonic matter
  → propagation of charm?
  → distribution amongst hadrons?