EXPERIMENT CBM – VESMÍRNÁ HMOTA V LABORATOŘI

Současná představa

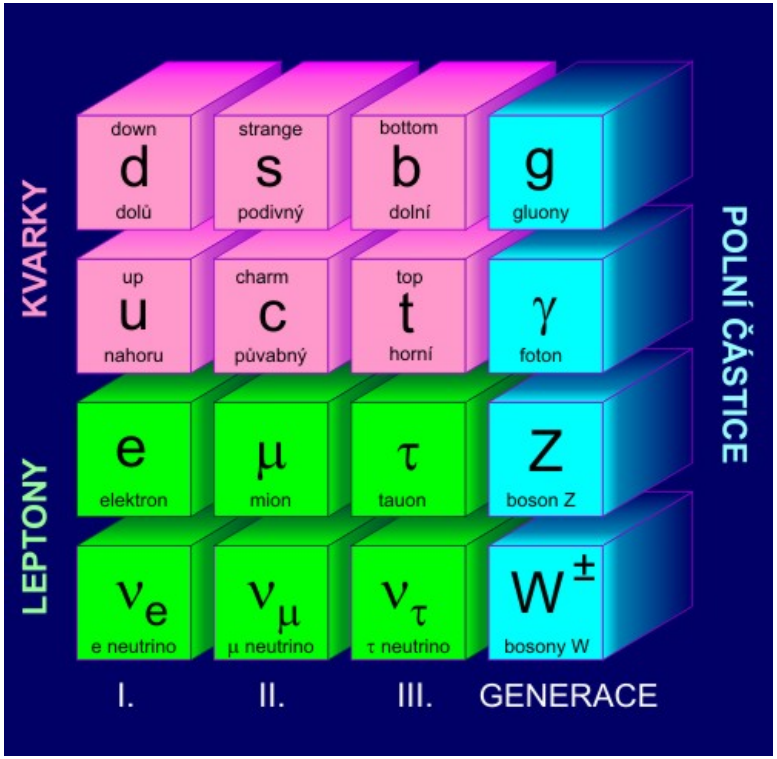
Standardní model

- 3 druhy částic: kvarky, leptony, nositelé sil
  ostatní částice s jsou složené:
  - baryony (proton): 3 kvarky
  - mezony (pion): 2 kvarky

- 3 druhy interakcí: silná, slabá, elektromag.
  Interakce vzniká výměnou nositelů:
  - elektromagnetická: foton,
  - slabá: Z a W částice
  - silná: gluon

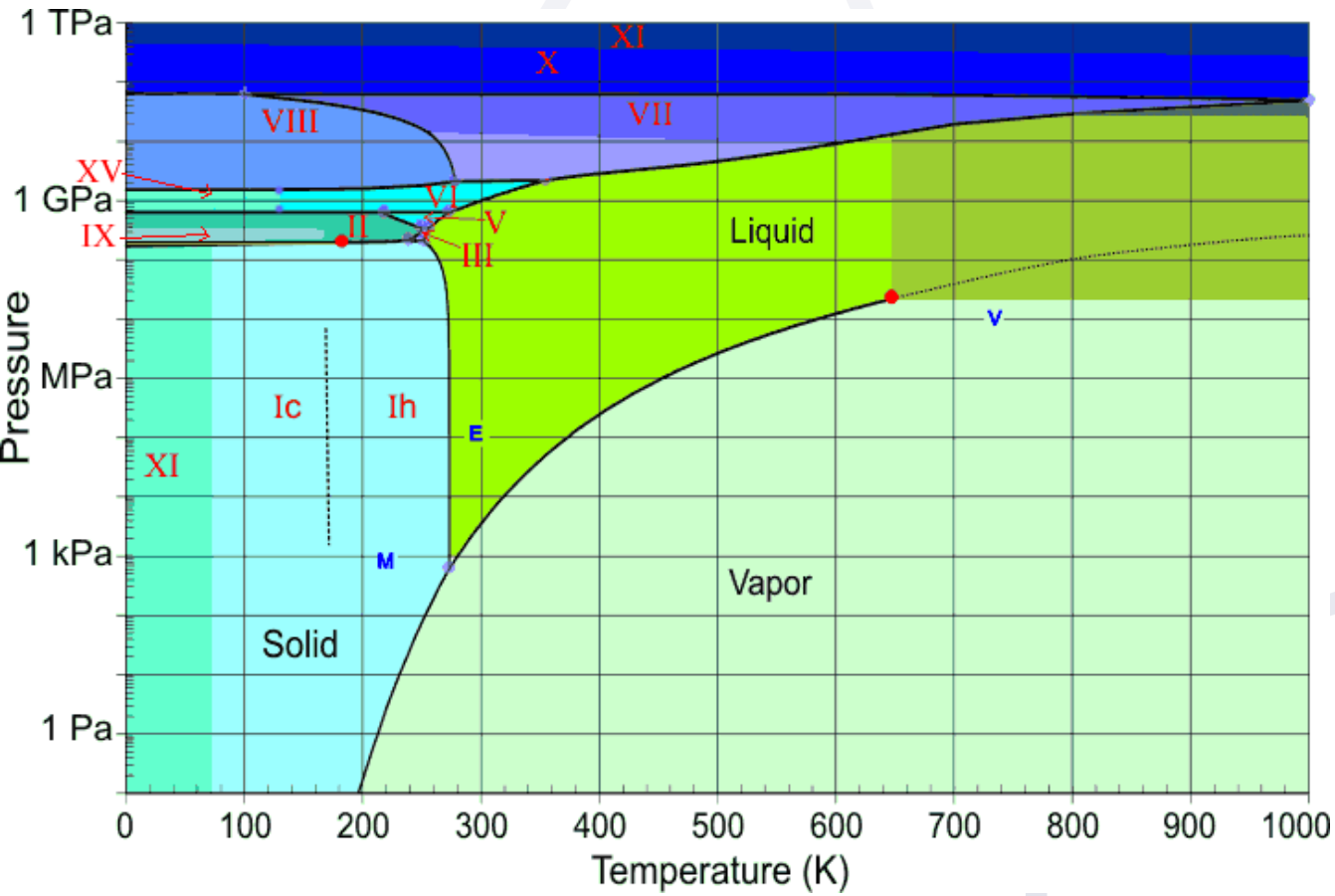
- Higgsův boson – dodává částicím hmotu
  předpovězen 1964, objeven 2012

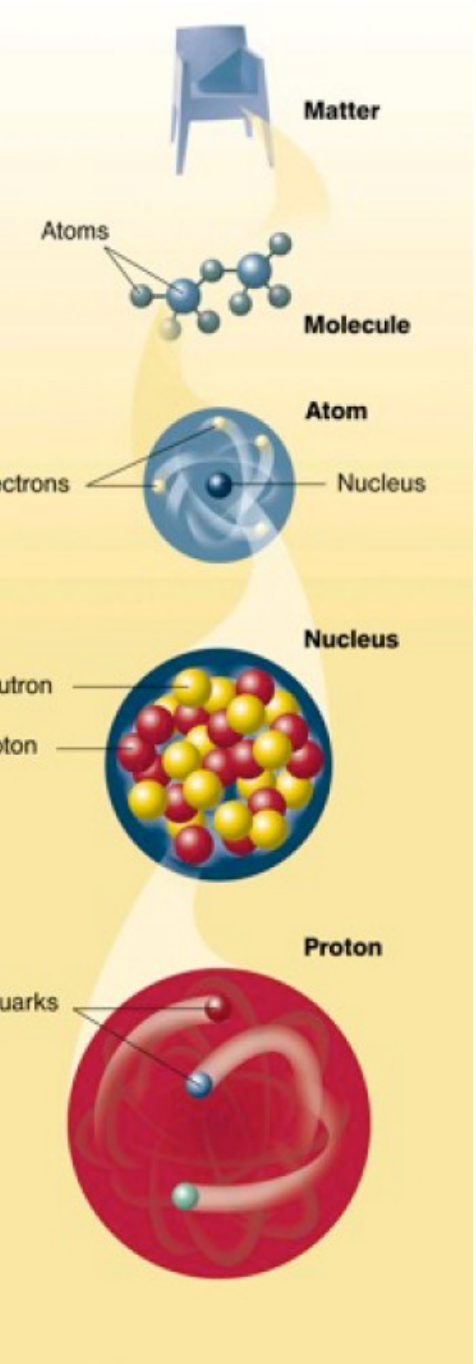
- Graviton – hypotetický nosič gravitace
  zatím neobjeven



Fázový diagram vody

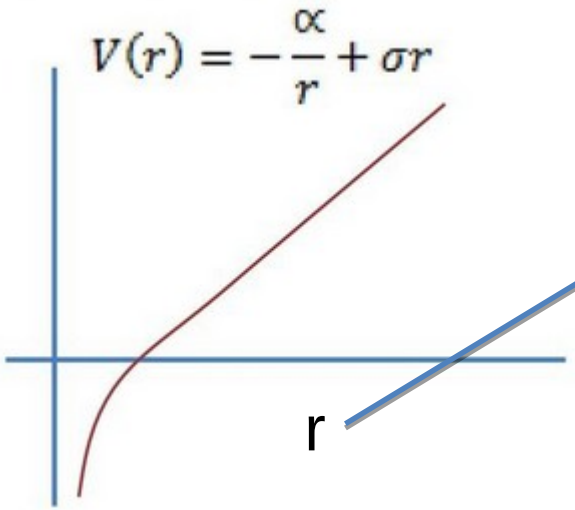
- Rozmanitá struktura generovaná elektromagnetickou interakcí
  - *15 fází, 16 trojných bodů,*
  - *2 kritické body*

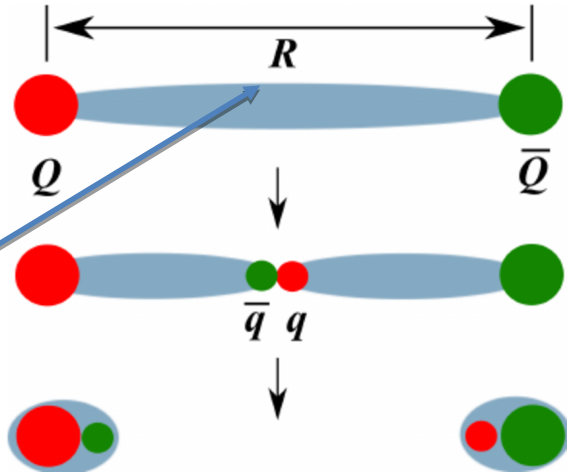




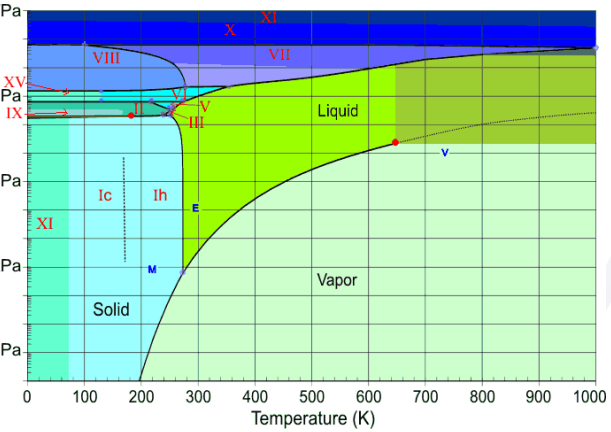
Silná interakce

- Matematický popis velmi podobný elektromagnetické interakci
  - kvarky ale mají silný náboj -interagují
- Potenciální energie mezi kvarky roste se vzdáleností
  - analogie s natahováním struny
  - důsledek – uvěznění kvarků v hadronech

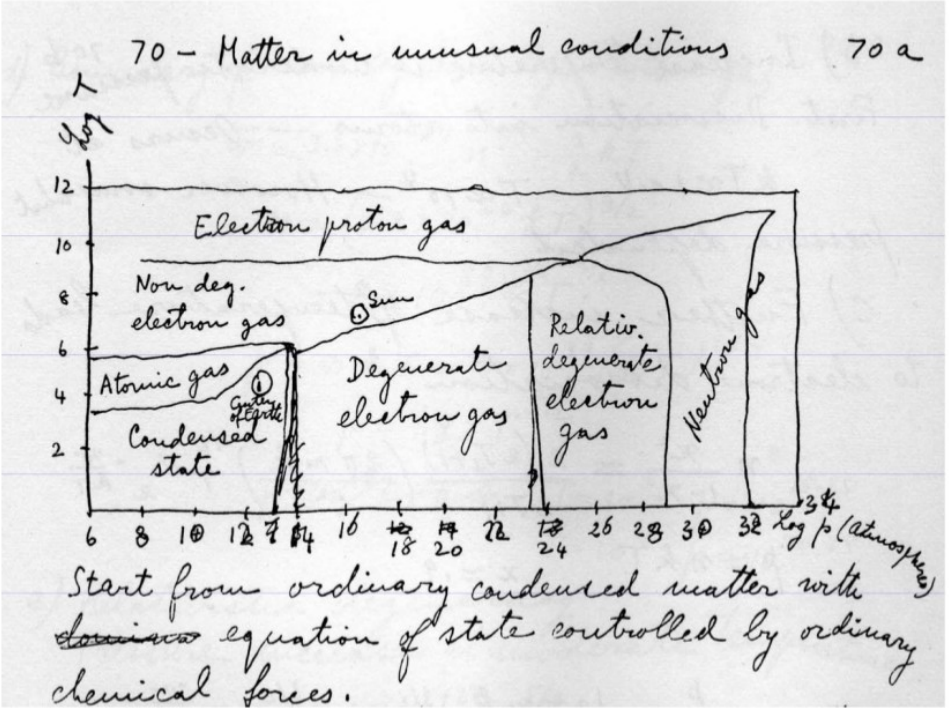


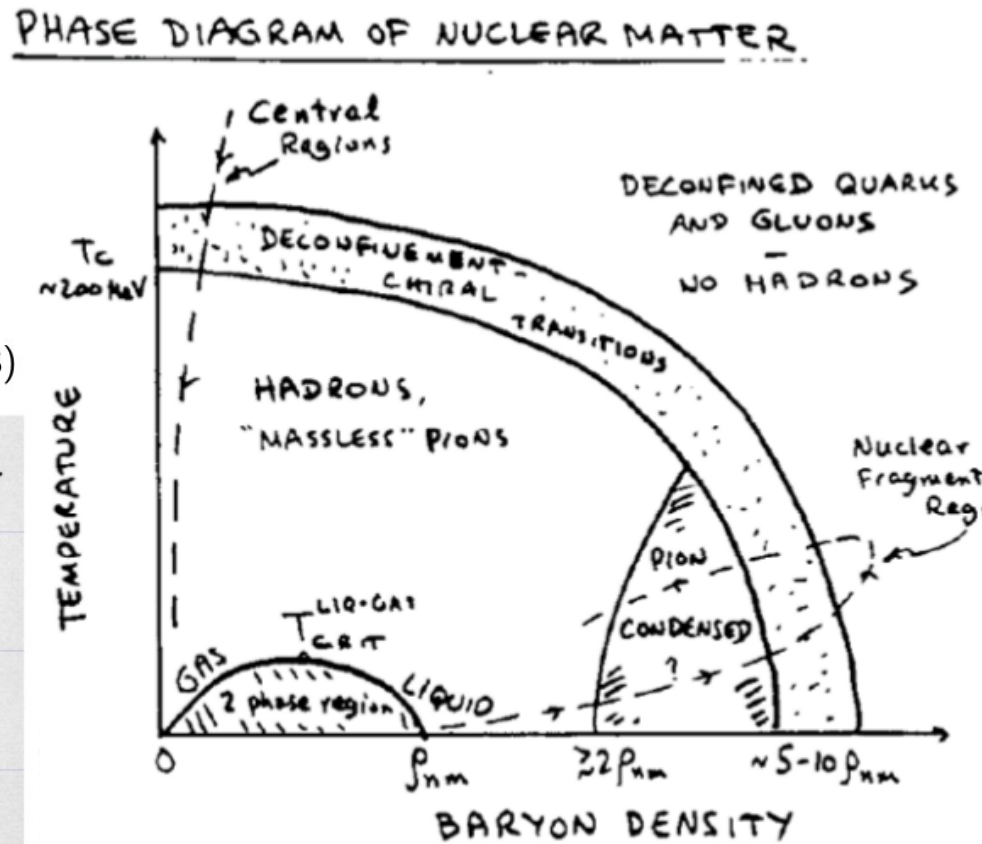


Fázový diagram jaderné hmoty?



E. Fermi: Notes on Thermodynamics and Statistics (1953)

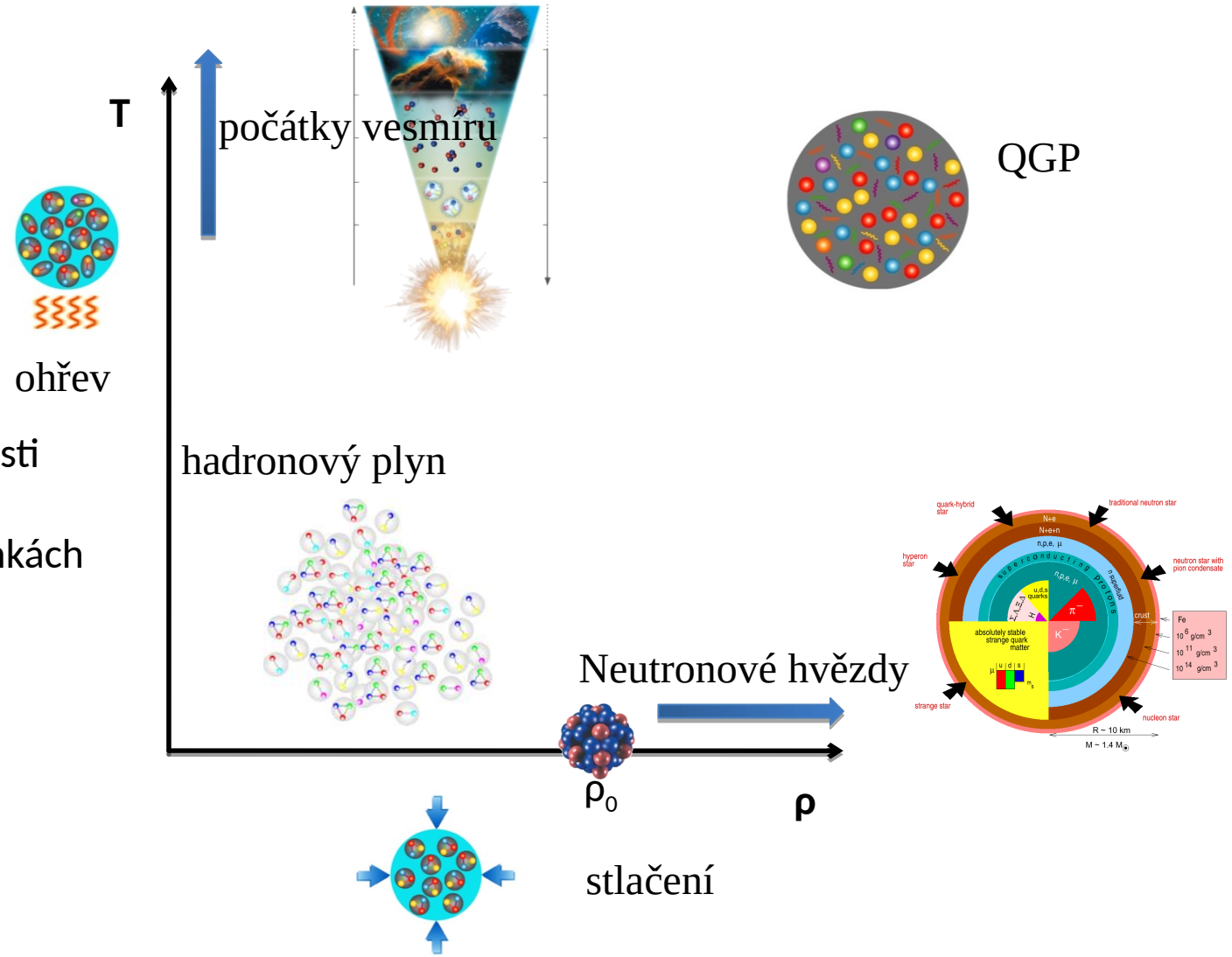




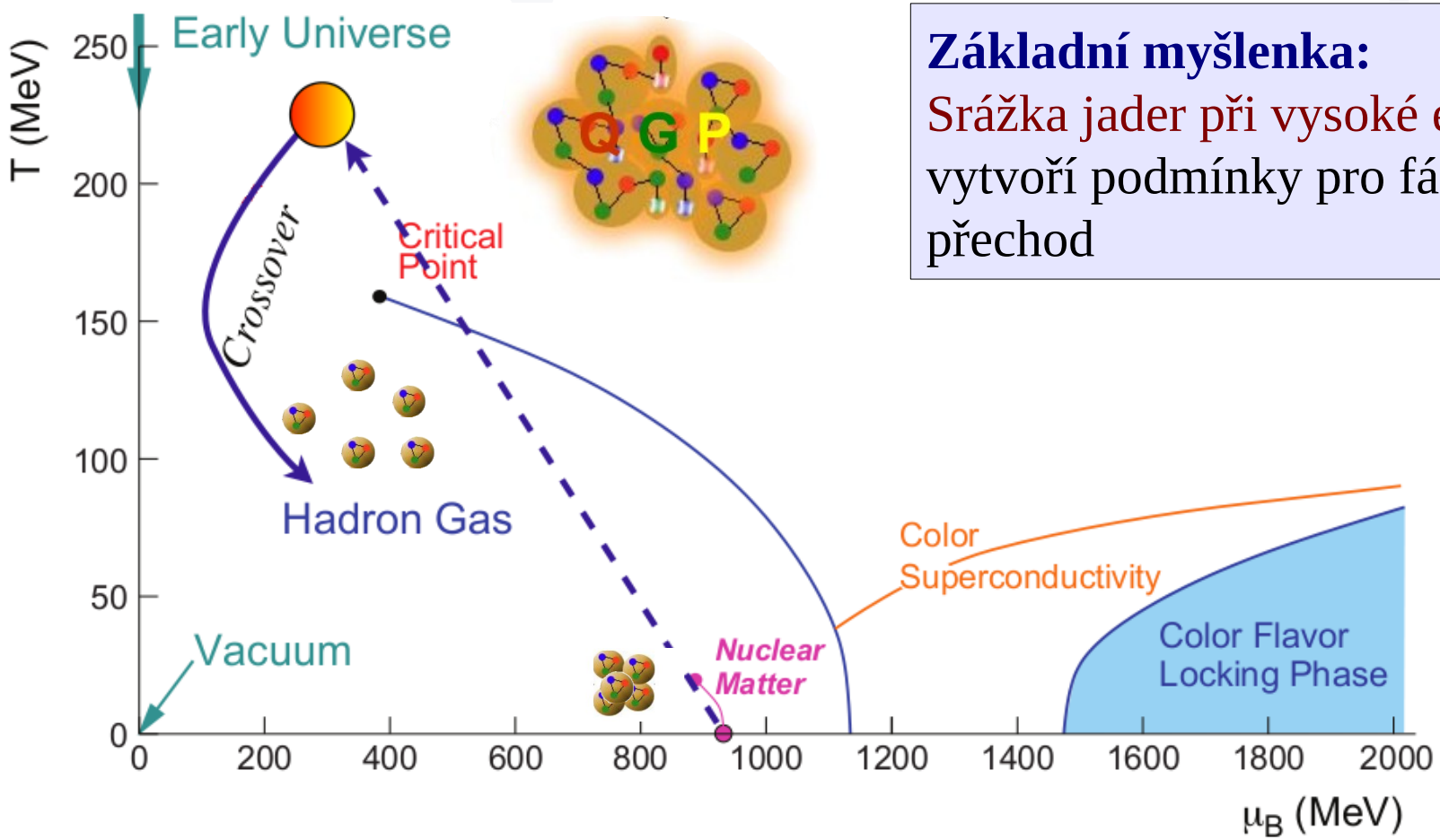
Phase diagram of nuclear matter in equilibrium, and how it can be explored in ultrarelativistic heavy ion collisions, from the 1983 NSAC Long Range Plan

QCD fázový diagram

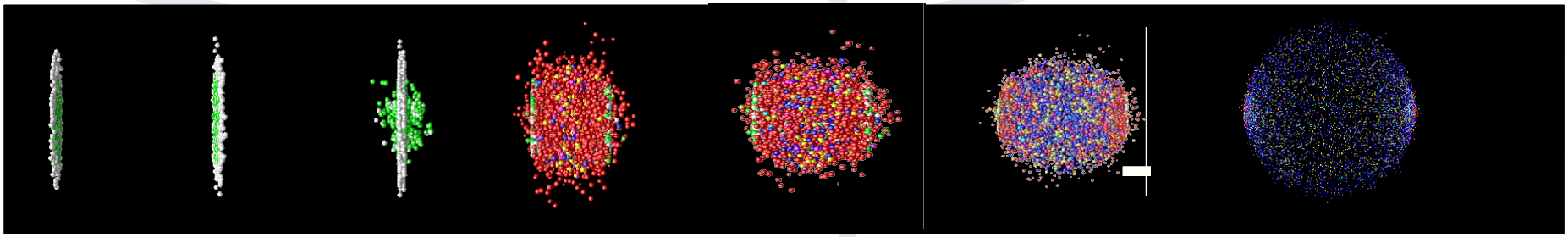
Jak se mění vlastnosti jaderné hmoty v extrémních podmínkách (tlak, teplota)?



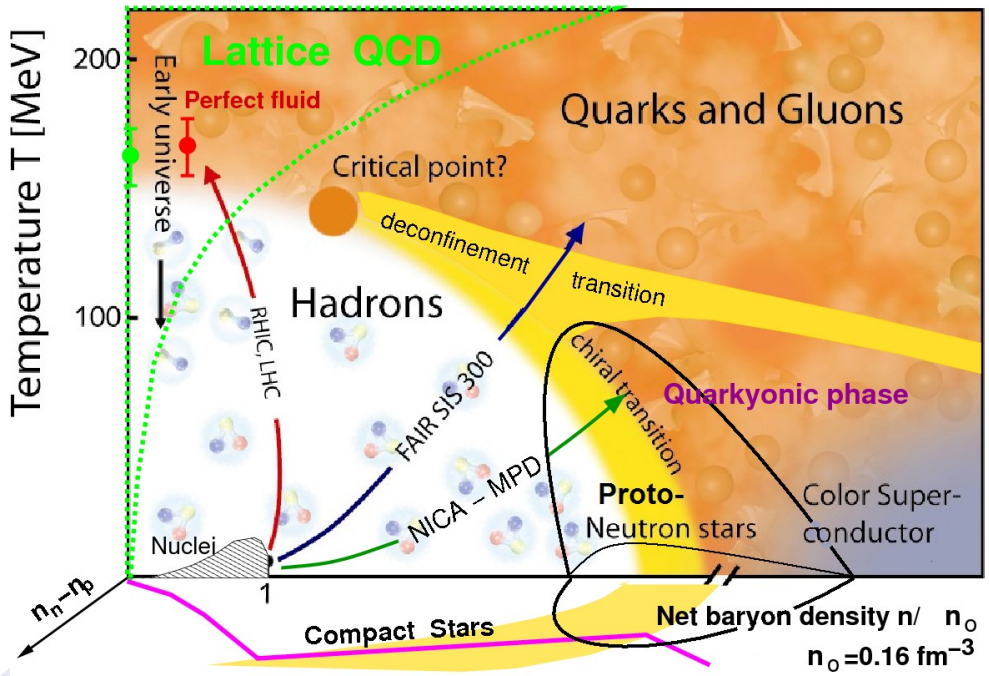
Experimentální zkoumání fázového diagram jaderné hmoty



Základní myšlenka:
Srážka jader při vysoké energii vytvoří podmínky pro fázový přechod



Experimentální zkoumání fázového diagram jaderné hmoty

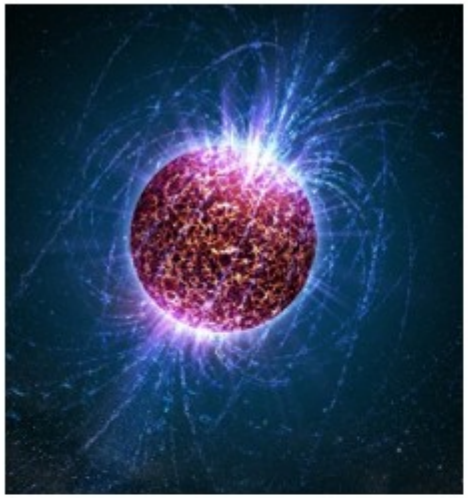


Potenciálně komplexní struktura!

- Při velké teplotě spojitý fázový přechod do QGP (LHC, RHIC),
- Při velké baryonové hustotě fázový přechod prvního druhu (RHIC BES, FAIR)
- Existuje kritický bod?
- Chirální fázový přechod/ kvarkyonová fáze?
- Exotické fáze při extrémních hustotách?

Tím, že měníme energii srážek, můžeme zkoumat různé části fázového diagramu. Při nízkých energiích oblast vysokých baryonových hustot – **stlačená baryonová hmota** …

Stlačená jaderná hmota ve vesmíru



Neutron stars

Temperature
$T < 10$ MeV

Density
$\rho < 10\ \rho_0$

Lifetime
$T \sim$ infinity

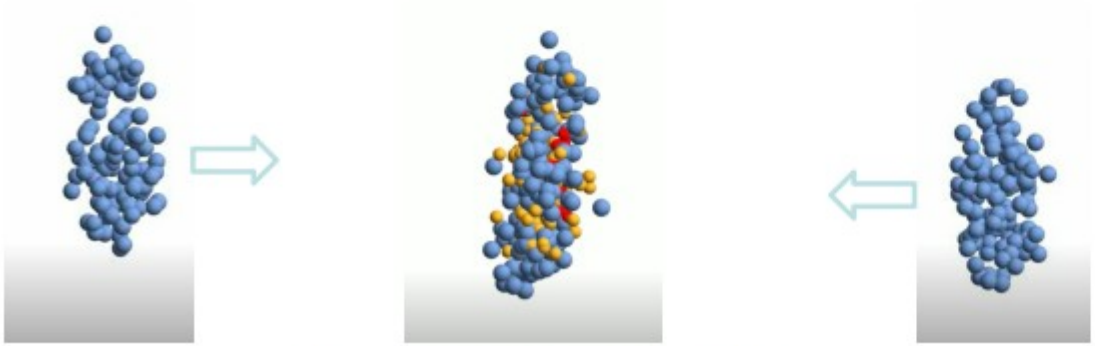
Neutron star merger

Temperature
$T < 50$ MeV

Density
$\rho < 2 - 6\ \rho_0$

Reaction time
(GW170817)
$T \sim 10$ ms

Heavy ion collisions at SIS100



Compressed Baryonic Matter

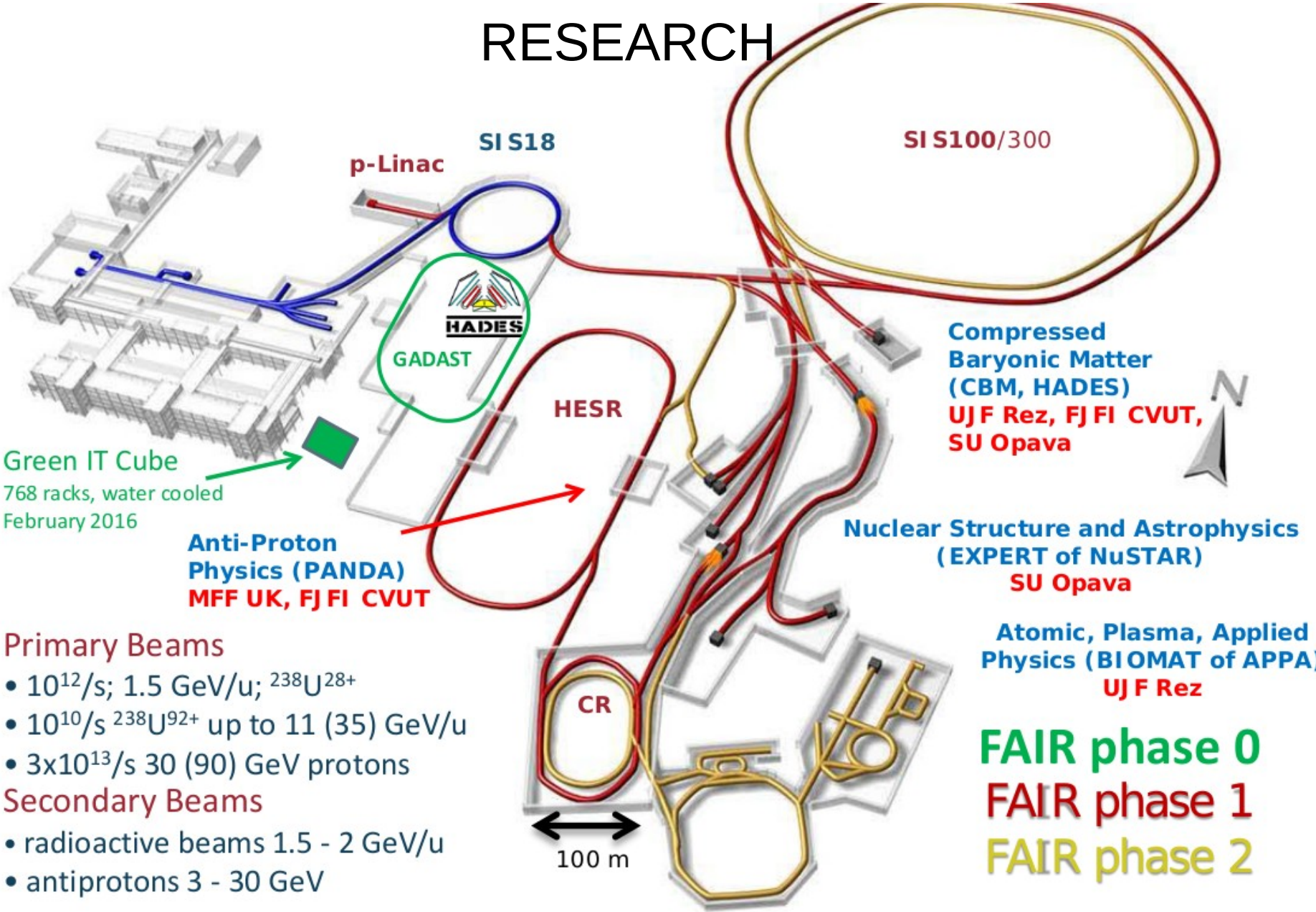
Temperature
$T < 120$ MeV

Density
$\rho < 8\rho_0$

Reaction time
$t \sim 10^{-23}$ s

Isospin symmetric matter

FACILITY FOR ANTIPROTON AND ION RESEARCH



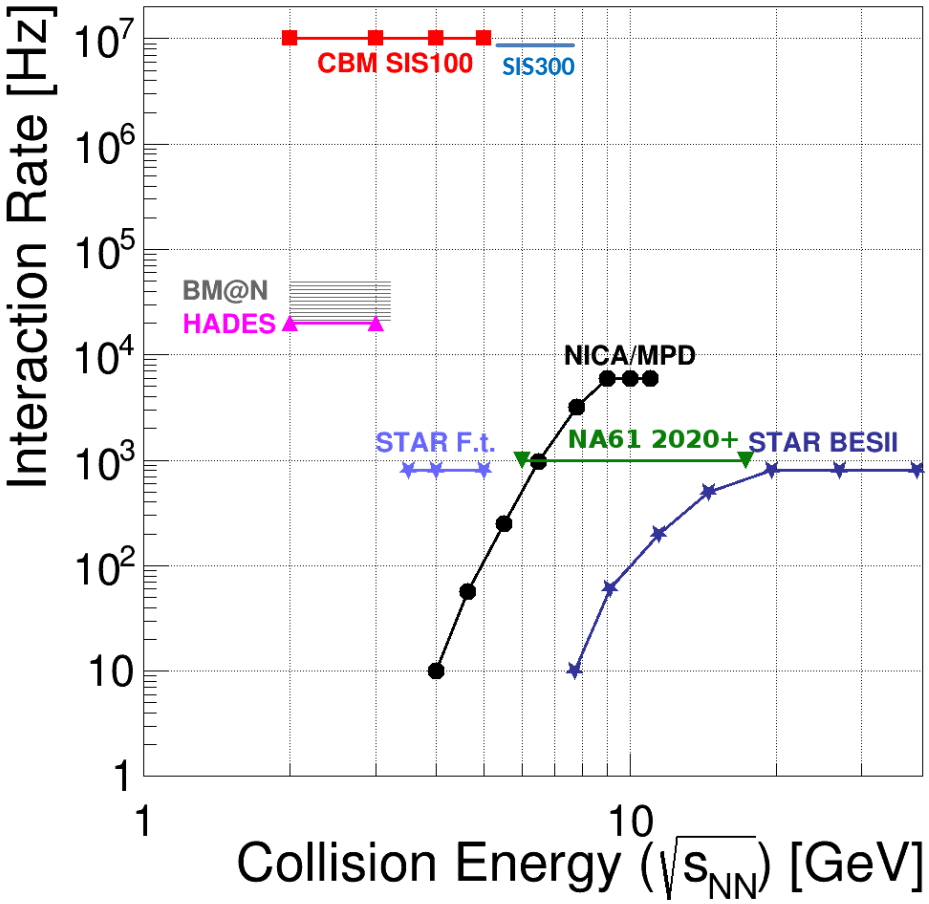
Primary Beams

- 10^{12}/s; 1.5 GeV/u; $^{238}U^{28+}$
- 10^{10}/s $^{238}U^{92+}$ up to 11 (35) GeV/u
- $3x10^{13}$/s 30 (90) GeV protons

Secondary Beams

- radioactive beams 1.5 - 2 GeV/u
- antiprotons 3 - 30 GeV

CBM a další experimenty



V čem je CBM unikátní:

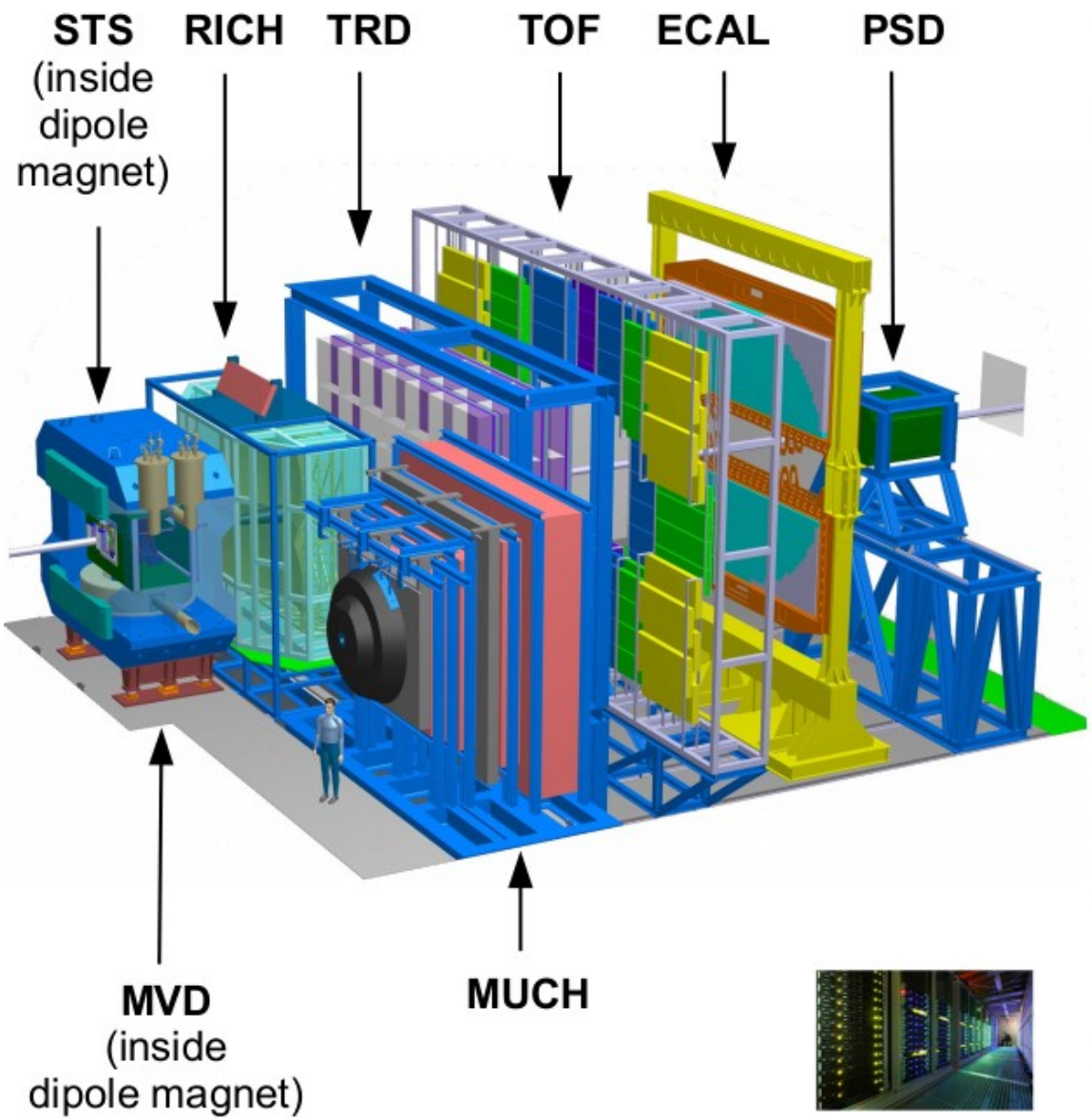
- Velmi vysoká frekvence : 10^5 - 10^7 Au+Au srážek/s
- flexibilní urychlovač schopný střídat různě nabité ionty
- Rychlost a radiační odolnost detektorů a elektroniky
- Kontinuální vyčítání a online zpracování dat - 1TB/s
- Měření tzv. „rare probes“ s vysokou přesností

Current schedule landmarks:

2017 Start of excavation
2018 Finished SIS18 tunnel upgrade
2022 CBM cave ready
2025 SIS100 commissioning with beams

CBM building
April 2021

CBM detector subsystems



Dipole Magnet
bends charged particle's trajectories

STS (Silicon Tracking System)
charged particle tracking

MVD (Micro-Vertex Detector)
secondary vertex reconstruction

RICH (Ring Imaging Cherenkov)

TRD (Transition Radiation Detector)
electron identification

TOF (Time of Flight detector)
hadron identification

MUCH (MUon CHambers)
muon tracking & identification

ECAL (Electromagnetic Calorimeter)
electron/photon identification

PSD (Projectile Spectator Detector)
collision centrality and
reaction plane determination

FLES (First-level Event Selector)
online reconstruction / event selectior

Fyzikální program

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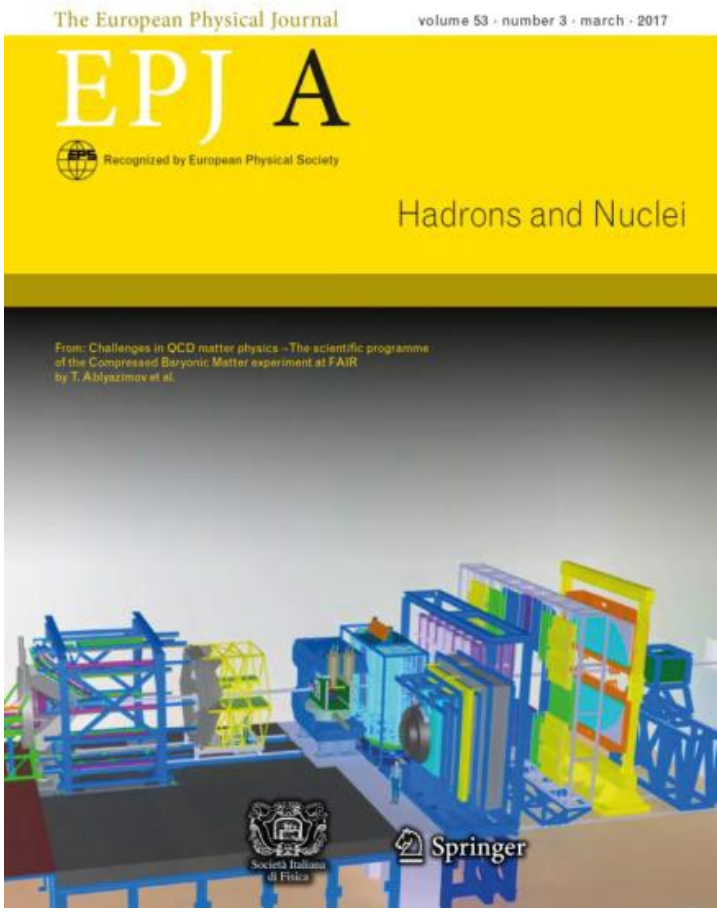


QCD equation-of-state

- collective flow of identified particles
- particle production at threshold energies

Phase transition

- excitation function of hyperons
- excitation function of LM lepton pairs

Critical point

- event-by-event fluctuations of conserved quantities

Chiral symmetry restoration at large $\hat{}_B$

- in-medium modifications of hadrons
- dileptons at intermediate invariant masses

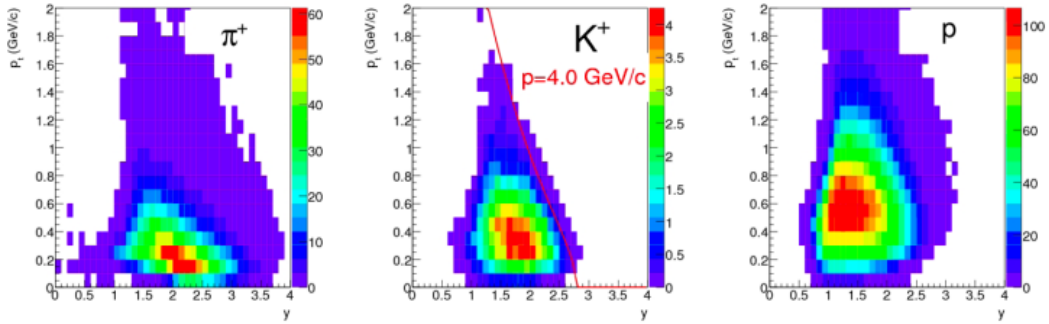
Strange matter

- (double-) lambda hypernuclei
- Search for meta-stable objects (e.g. strange dibaryons)

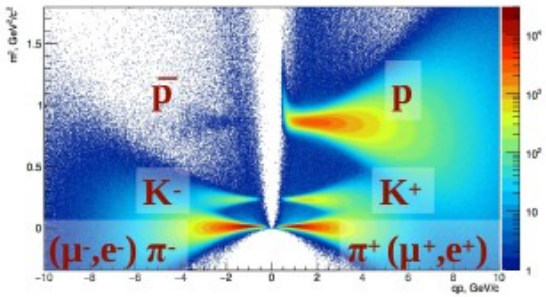
Heavy flavour in cold and dense matter

- excitation function of charm production

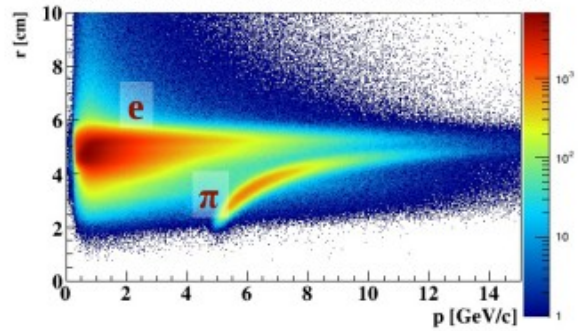
Identifikace částic



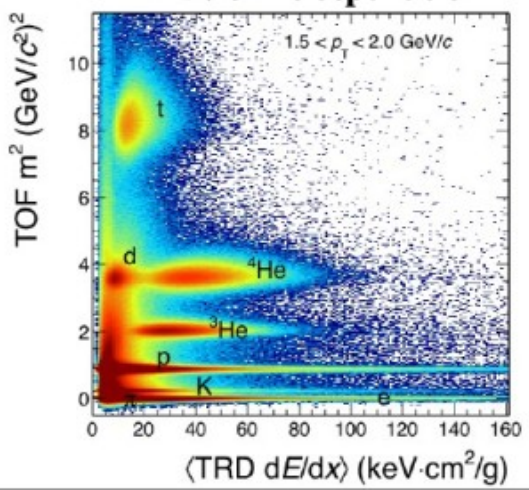
ToF: hadron identification



RICH: electron identification



TRD: d-He separation



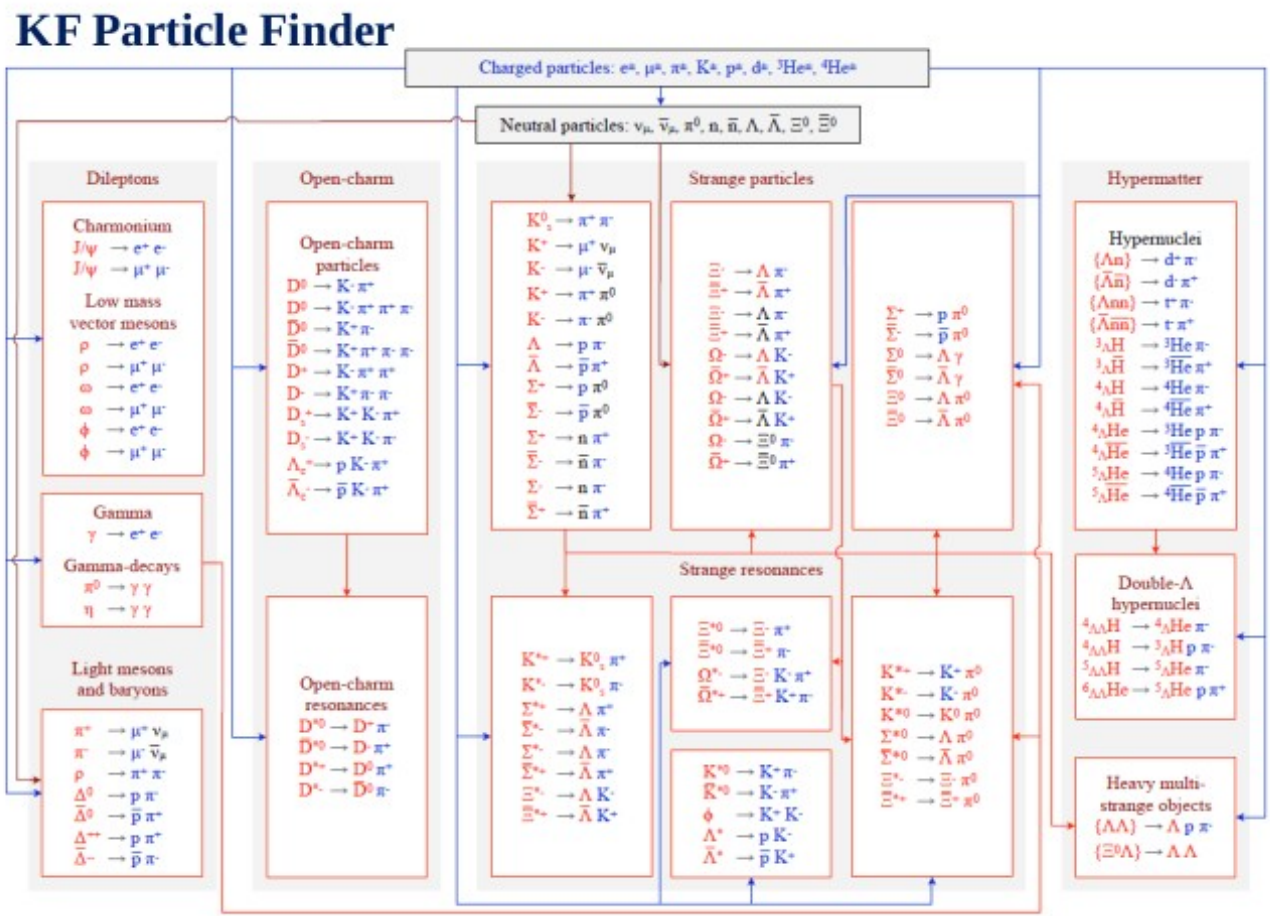
PID detectors:

- ToF (Time of Filght) — hadron identification;
- RICH (Ring Imaging CHerenkov detector) — electron identification;
- TRD (Transition Radiation detector) — electron and heavy fragments identification.

PID detectors of CBM will allow a clear identification of charged tracks.

Rekonstrukce rozpadů

- Rozlišení 50um pro sekundární rozpadové vrcholy
- KF ParticleFinder – více než 100 rozpadů rekonstruováno naráz



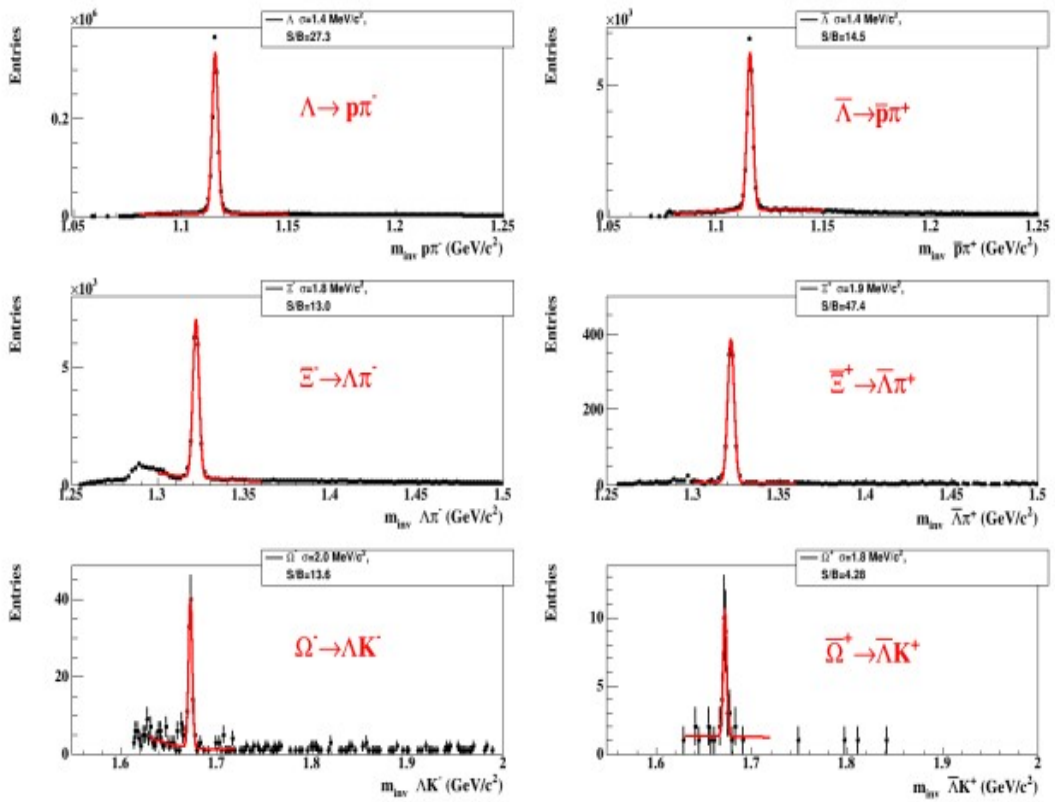
Podivnost

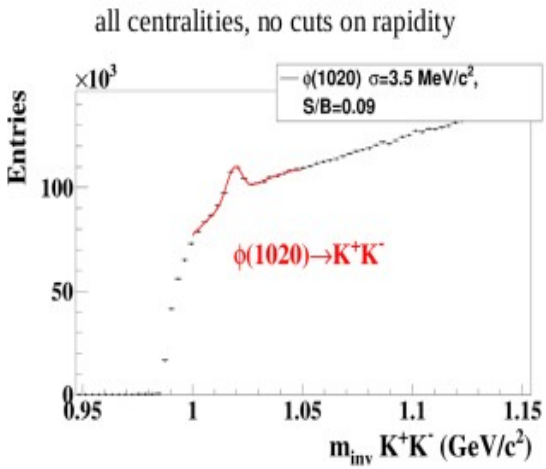
Není přítomna v počátečním stavu – produkována během reakce

V interakci hadronů (e. g. p+p -> KΛp): $m_K \approx 500$ MeV >> T_H
V interakci partonů (e.g. g + g -> s sbar): $m_s \approx 100$ MeV <= T_H
=> zvýšená produkce v QGP

Zatím žádná měření hyperonů při nízkých energiích.

Testing tools in real environment @ STAR 4.4M Au+Au events sqrt(s) = 7.7





- CBM KF Particle Finder is successfully applied to the STAR data in a wide energy range.

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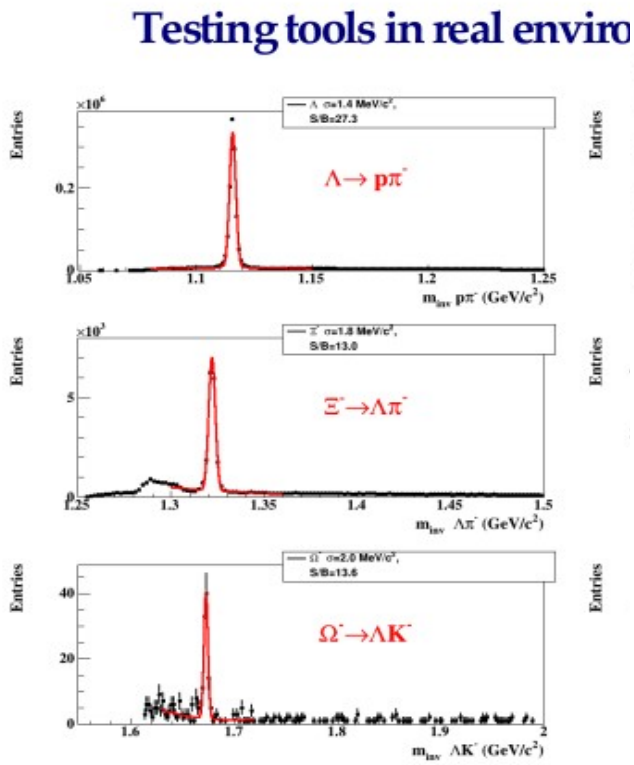
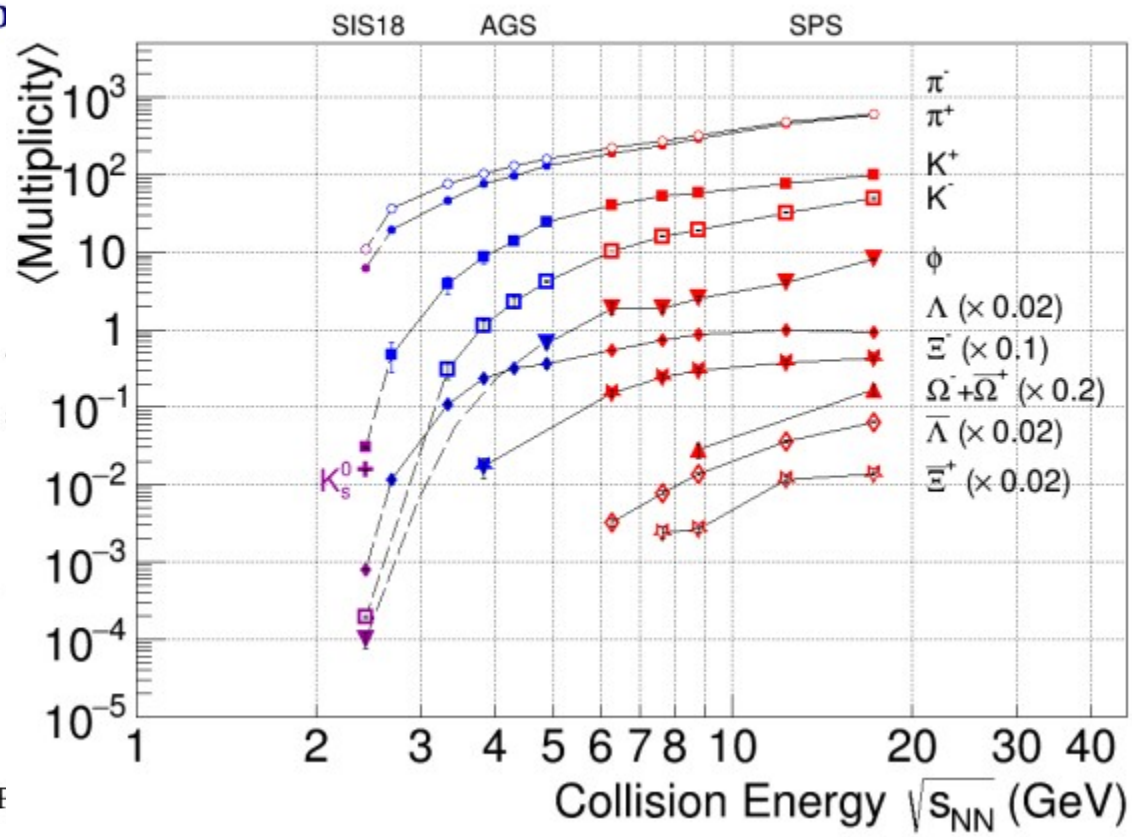
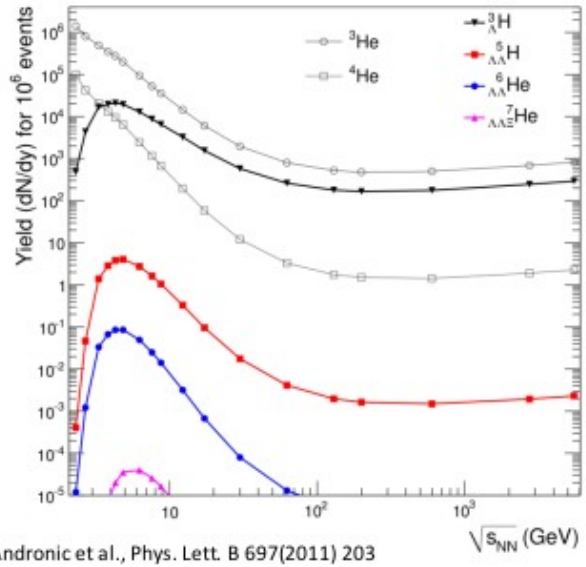
Blume/Markert PPNP66 (2011)
HADES PLB778 (2018); PLB793 (2019)



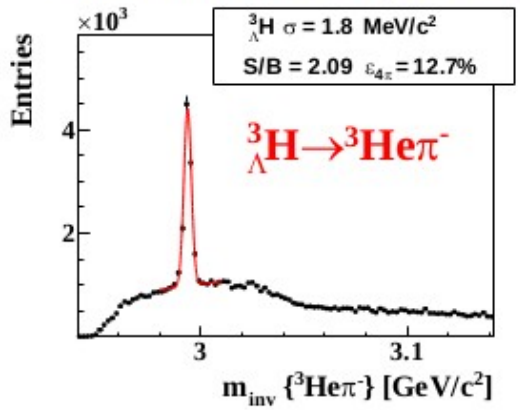


Studium produkce hyperjader

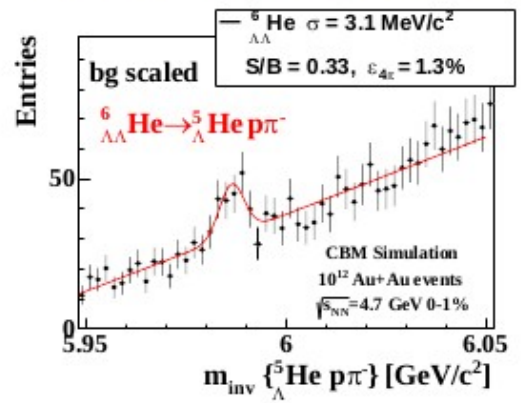


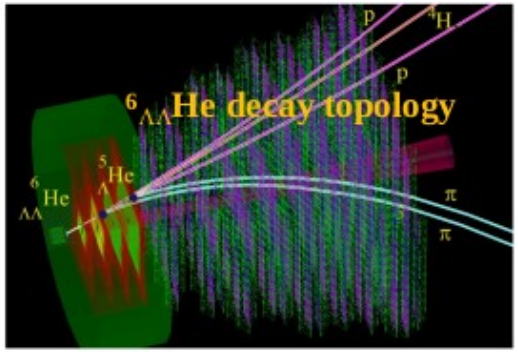
A,Andronic et al., Phys. Lett. B 697(2011) 203

5M mbias events Au+Au at 10AGeV/c
50 sec at 0.1MHz IR (1.8 k/sec)



Expected collection rate: ~60 $^6_{\Lambda\Lambda}$He
in 1 week at **10MHz IR** (not day-1)

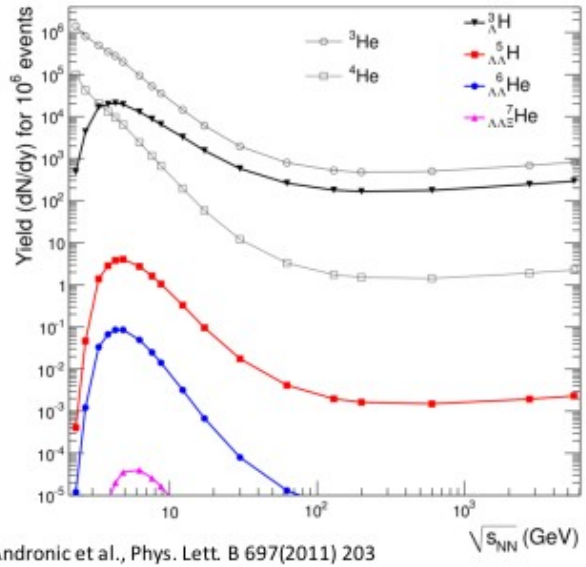




Produkovány zachycením lambda baryonu na lehkých jádrech

- CBM v oblasti maximální produkce (termální model)
- Citlivé na na vlastnosti hmoty (transportní modely)
- Měření: toku, excitační funkce, doby života, vazebné energie

Studium produkce hyperjader



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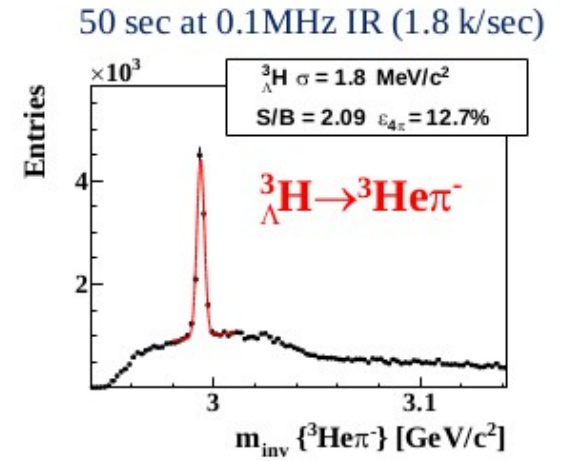
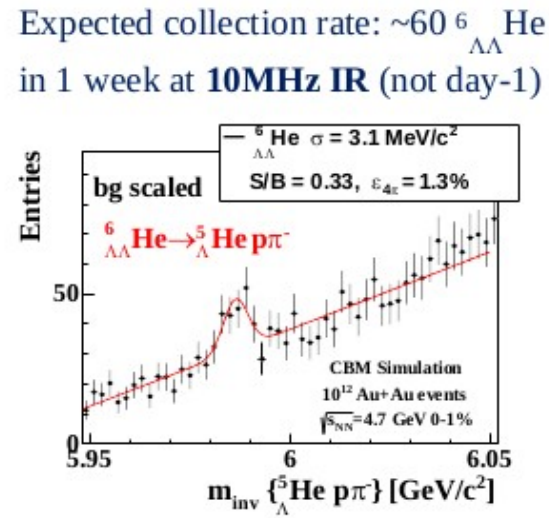
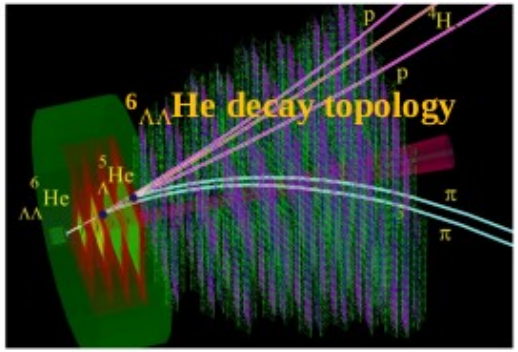




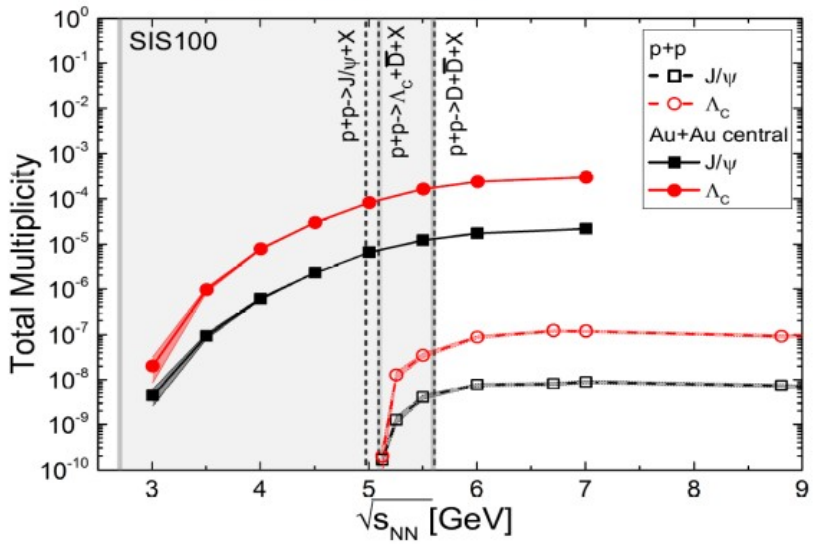


Particle (mass MeV/c^2)	Multiplicity central ev. 6 AGeV	Multiplicity central ev. 10 AGeV	decay mode	BR	ε (%)	yield in 90 days 6AGeV	yield in 90 days 10 AGeV	IR MHz
$\bar{\Lambda}$ (1115)	$4.6\cdot10^{-4}$	0.034	$\bar{p}\pi^+$	0.64	19.7	$1.1\cdot10^7$	$8.3\cdot10^8$	**0.1**
Ξ^- (1321)	0.054	0.222	$\Lambda\pi^-$	1	9.9	$1.0\cdot10^9$	$4.3\cdot10^9$	**0.1**
Ξ^+ (1321)	$3.0\cdot10^{-5}$	$5.4\cdot10^{-4}$	$\bar{\Lambda}\pi^+$	1	8.7	$5.0\cdot10^5$	$9.1\cdot10^6$	**0.1**
Ω^- (1672)	$5.8\cdot10^{-4}$	$5.6\cdot10^{-3}$	ΛK^-	0.68	4.4	$3.4\cdot10^6$	$3.3\cdot10^7$	**0.1**
Ω^+ (1672)	-	$7\cdot10^{-5}$	$\bar{\Lambda}K^+$	0.68	3.9	0 (QGP?)	$3.8\cdot10^5$	**0.1**
$^3_\Lambda$H (2993)	$4.2\cdot10^{-2}$	$3.8\cdot10^{-2}$	^{3}Heπ^-	0.25	12.7	$2.7\cdot10^8$	$2.5\cdot10^8$	**0.1**
$^4_\Lambda$He (3930)	$2.4\cdot10^{-3}$	$1.9\cdot10^{-3}$	^{3}He$p\pi^-$	0.32	11.4	$1.7\cdot10^7$	$1.4\cdot10^7$	**0.1**
$^5_{\Lambda\Lambda}$He(5047)		$5.0\cdot10^{-6}$	^{3}He2p2π	0.01	3	15	250	**0.1**
$^6_{\Lambda\Lambda}$He(5986)		$1.0\cdot10^{-7}$	^{4}He2p2π	0.01	1.2			**0.1**

Půvab (c-kvark)

- Důležitý zdroj informací o vytvořeném médiu
  - Propagace c-kvarku jadernou hmotou
  - Potlačení produkce J/psi v QGP
- Výhoda nízkých energií (below top SPS):
  - $N_{ccbar} << 1$ -> neexistuje regenerace
  - Dlouhožijící systém
- Statisticky náročné

J. Steinheimer et al., PRC 95 (2017) 014911



Sub-threshold production through heavy baryonic resonances:
$N^* \rightarrow \Lambda_c + D$ and $N^* \rightarrow N + J/\psi$

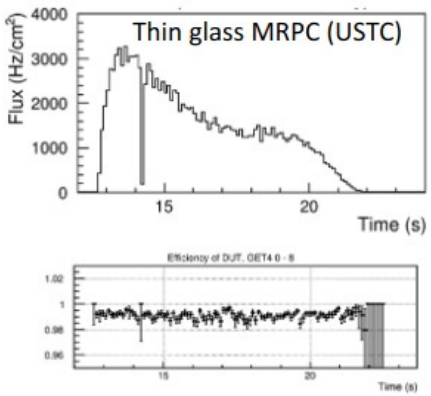
mCBM - data campaign 2021

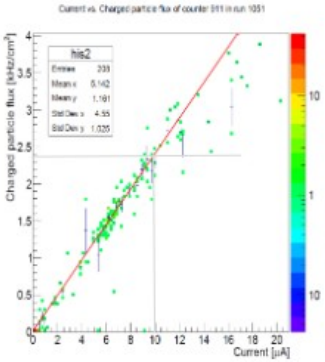
CBM Progress Report 2020 (2021) [10.15120/GSI-2021-00421]

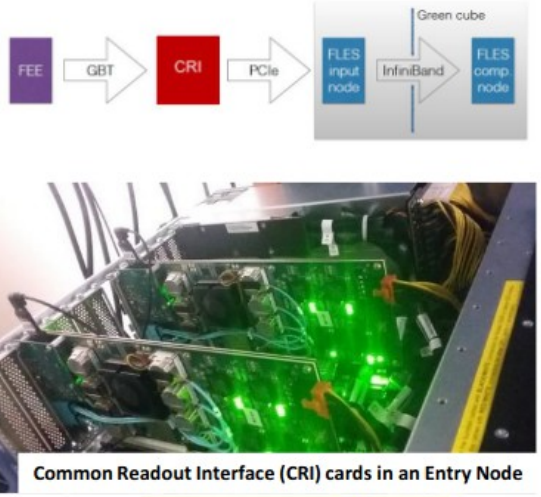
Beam time schedule and goals 2021

(1) Commissioning of upgraded data transport and detector subsystems & high-rate det. tests
^{208}Pb beam, March 2021 and ^{78}Kr beam, May 2021

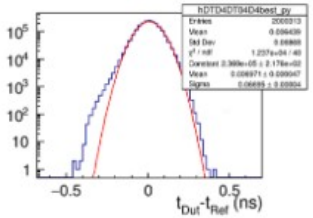
(2) Commissioning of benchmark runs (Λ production) incl. online reconstruction & selection
^{16}O beam, June/July 2021

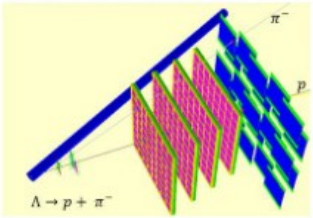




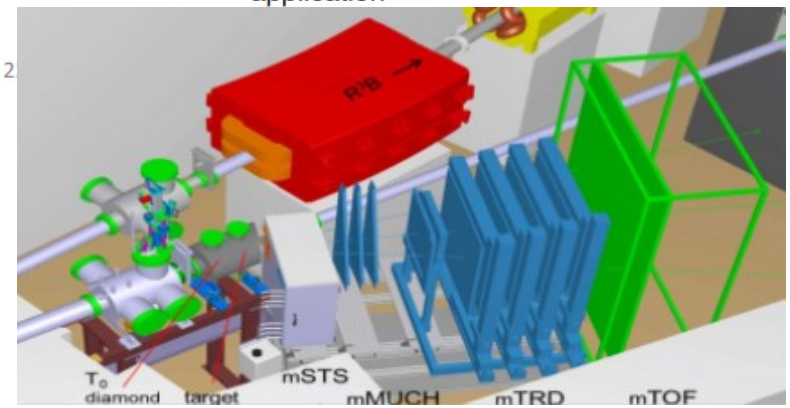


Timing resolution at efficiency 99%:
σ_t = 47 ps
(preliminary)





beam time application



Momentálně probíhá testování prototypů (modulů) detektorů a vyčítací elektroniky na urychlovači SIS-18.

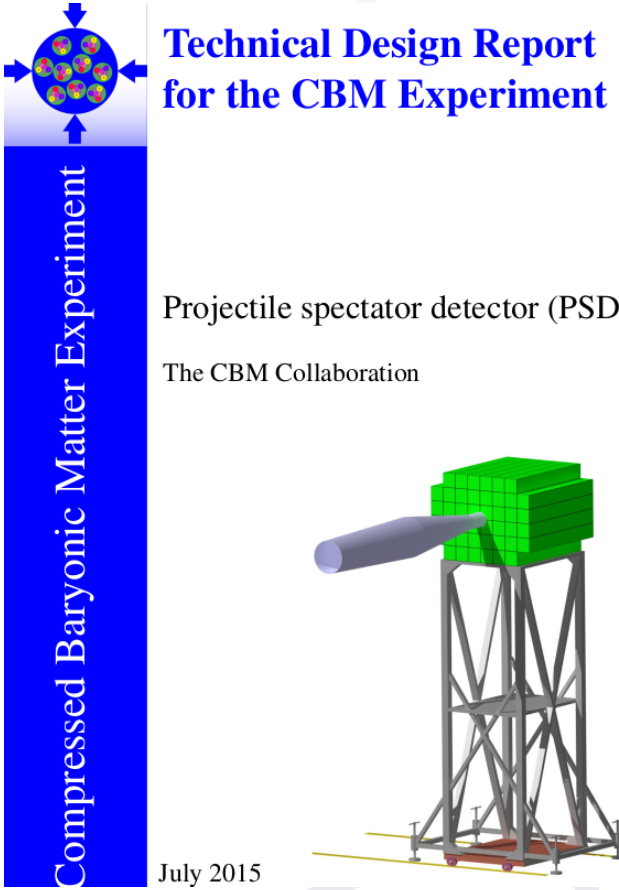
ČVUT @ CBM

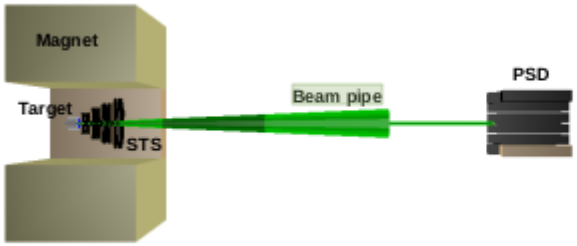
Detektor PSD – *Projectile spectator detector*

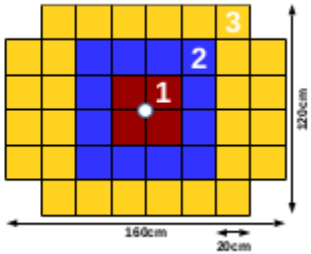
- Spolupráce s ÚJF
- Fakulta strojní – vyrobila a dodala nosnou strukturu
- FJFI – optimalizace simulátoru odezvy (Lukáš Chlad)
  - - simulace optimální geometrie beam-pipu

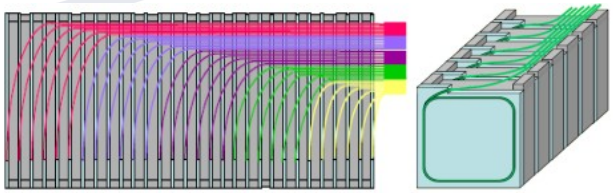
The support structure of the PSD at GSI

The CBM cave (September 2020)





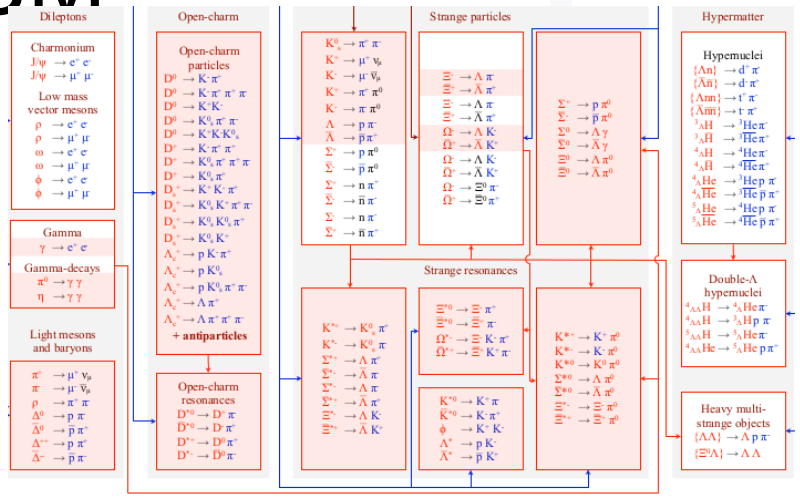




ČVUT @ CBM

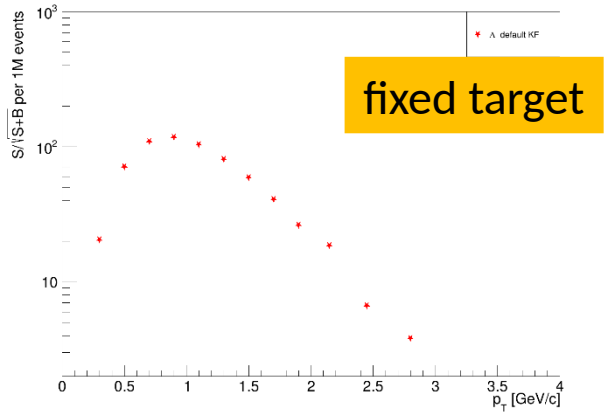
KF Particle Finder

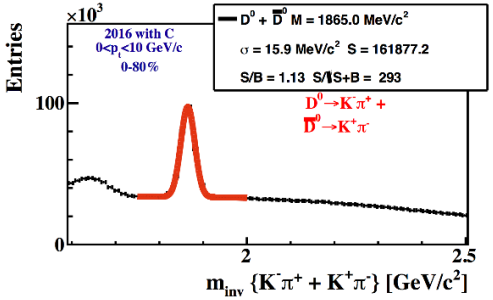
- Implementace a testování na experimetnu STAR
- “CBM-like” fixed target
- Otimalizace rekonstrukce podivných a půvabných částic

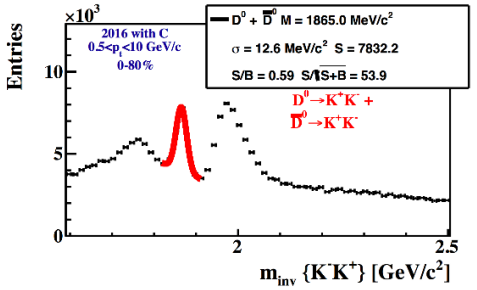


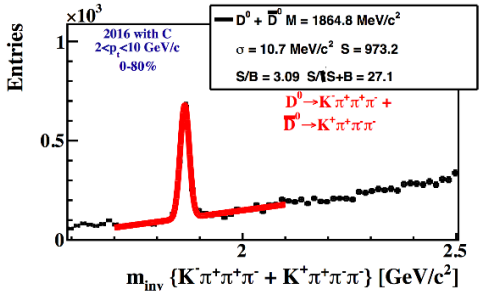
Marked decay channels are currently being tuned in STAR

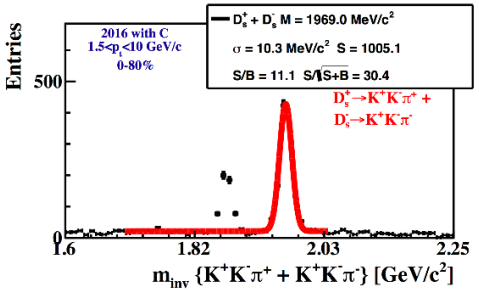
Λ signal significance, Fixed target, 7.3 GeV



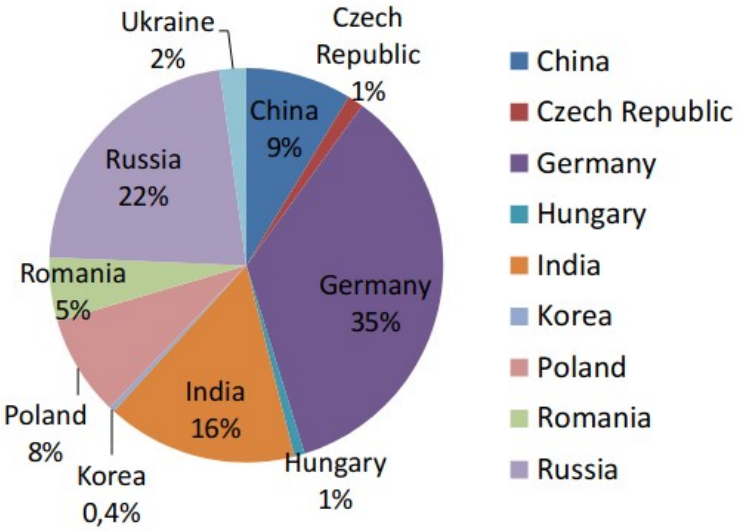








CBM collaboration



- 66 institutes
- 493 members

Můžete se připojit i vy ...

The FAIR Project

Nuclear Structure & Astrophysics
(Rare-isotope beams)

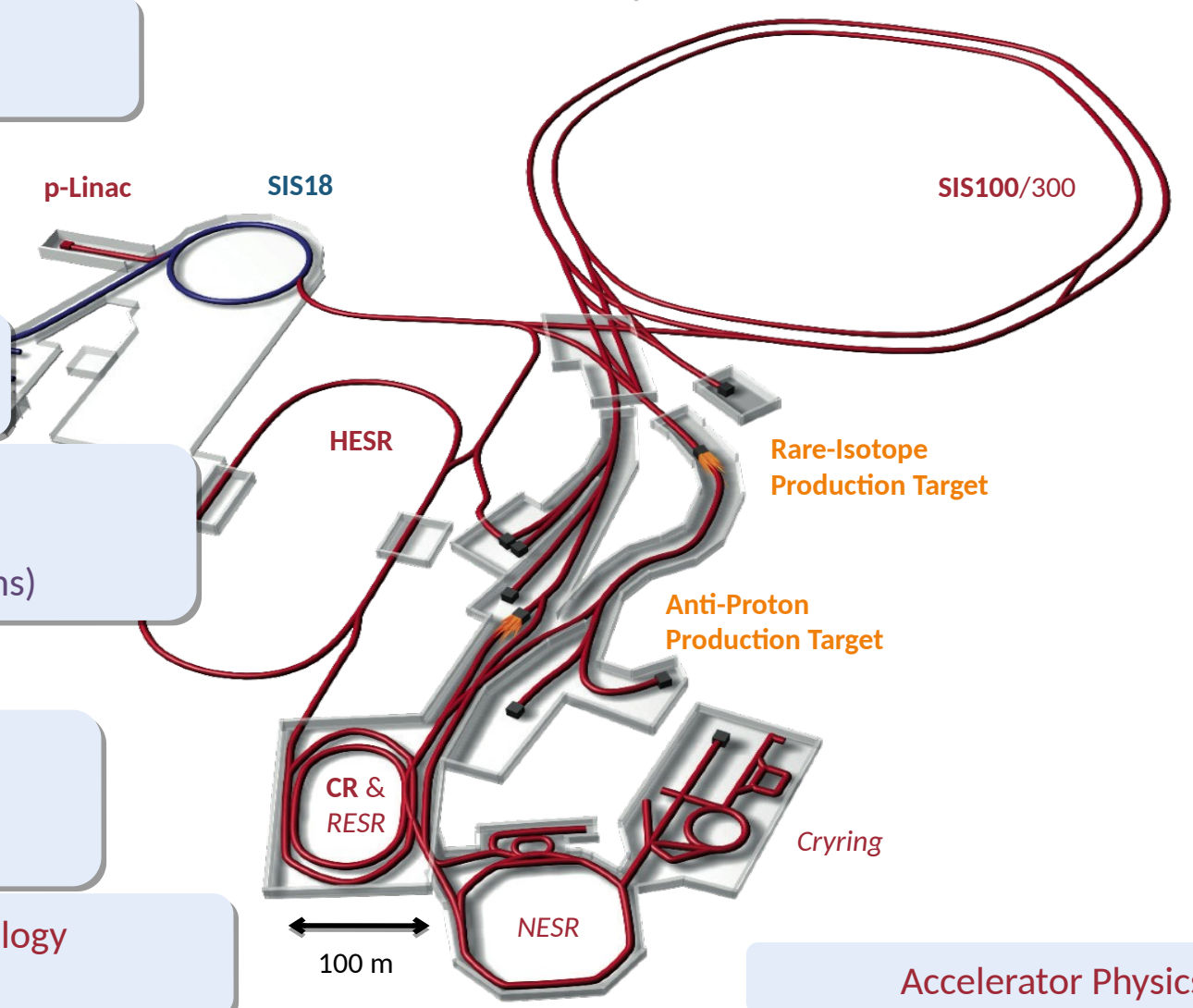
Hadron Physics
(Stored and cooled
14 GeV/c anti-protons)

QCD-Phase Diagram
(HI beams 2 to 45 GeV/u)

Fundamental Symmetries
& Ultra-High EM Fields
(Antiprotons & highly stripped ions)

Dense Bulk Plasmas
(Ion-beam bunch compression
& petawatt-laser)

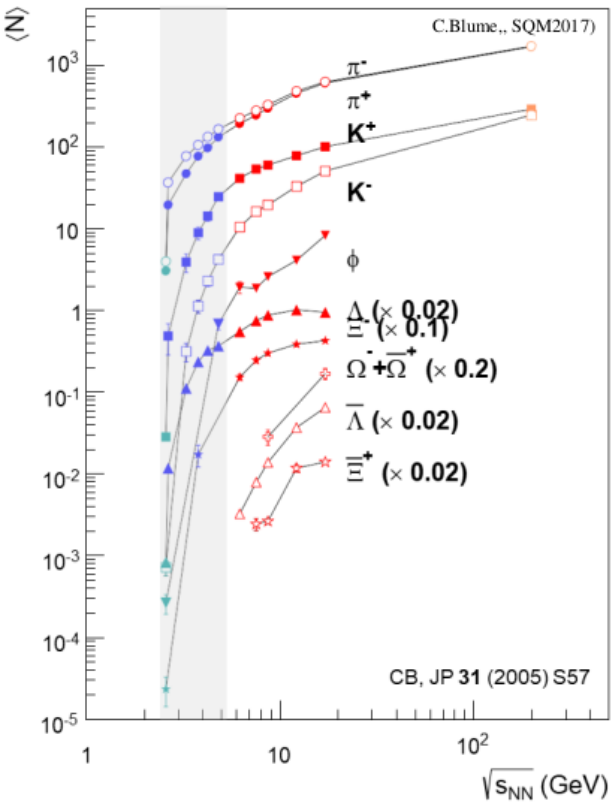
Materials Science & Radiation Biology
(Ion & antiproton beams)



Accelerator Physics

Final state particle abundance

World data, central Au + Au collisions

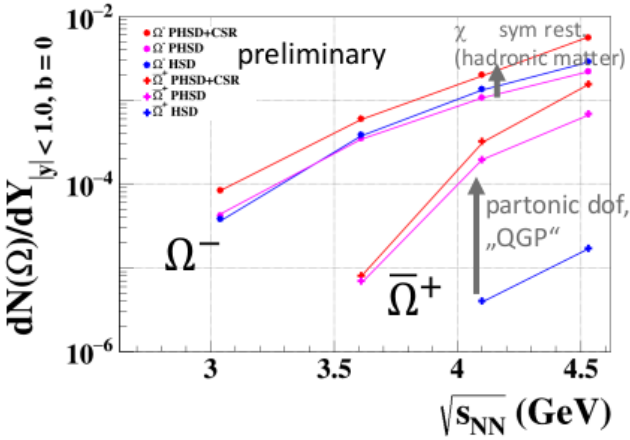


Strange and charmed particle production thresholds in pp - collisions

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
$pp \to \Lambda\Lambda pp$	4.108	7.1
$pp \to \Xi^-\Xi^+pp$	4.520	9.0
$pp \to \Omega^-\Omega^+pp$	5.222	12.7
$pp \to J/\Psi\, pp$	4.973	12.2

Transport Model Predictions

PHSD W. Cassing, E. Bratkovskaya et al., Phys.Rev. C93 (2016), 014902
I. Vassiliev, CBM Prog.Report 2019



Sensitivities of subthreshold particle production

- Equation-of-state
- In-medium properties of hadrons
- Contributions from partonic degrees of freedom („QGP“)