CBM 2028:
On the Verge of Extreme and Exotic QCD

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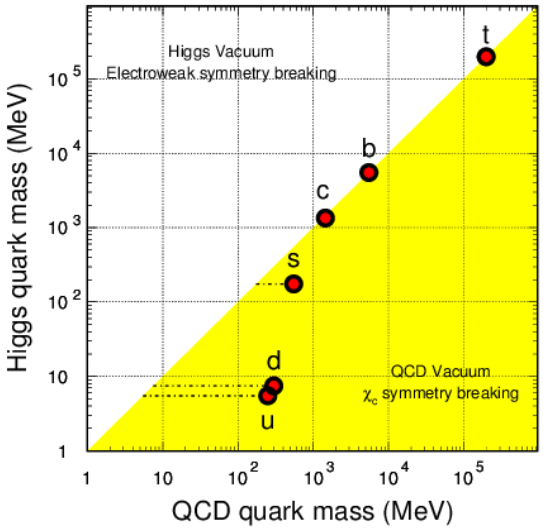
Physics First !

We want to understand what we observe: (→predictions!)

QCD is our description of the strong interaction

$$\mathcal{L} = \frac{1}{4g^2} G^a_{\mu\nu} G^a_{\mu\nu} + \sum_j \bar{q}_j (i\gamma^\mu D_\mu + m_j) q_j$$

Challenge is to connect observed phenomena to underlying theory

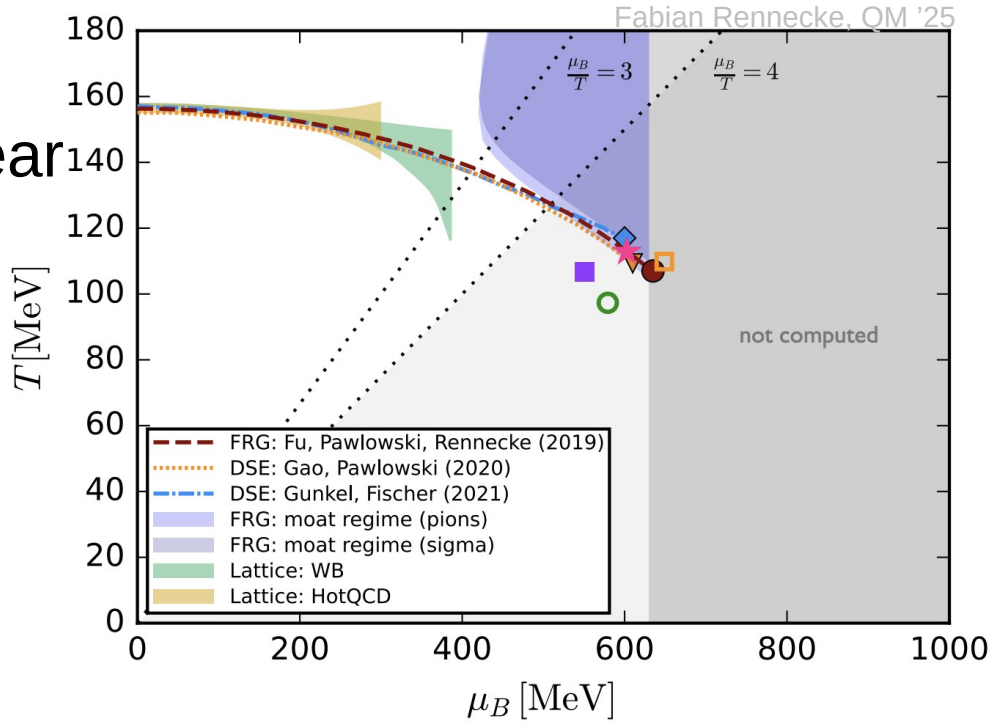


K. Schweda et al.

CBM will explore the QCD phase diagram in the region of high net baryon densities using high-energy A-A, p-A and p-p/n collisions

This includes:

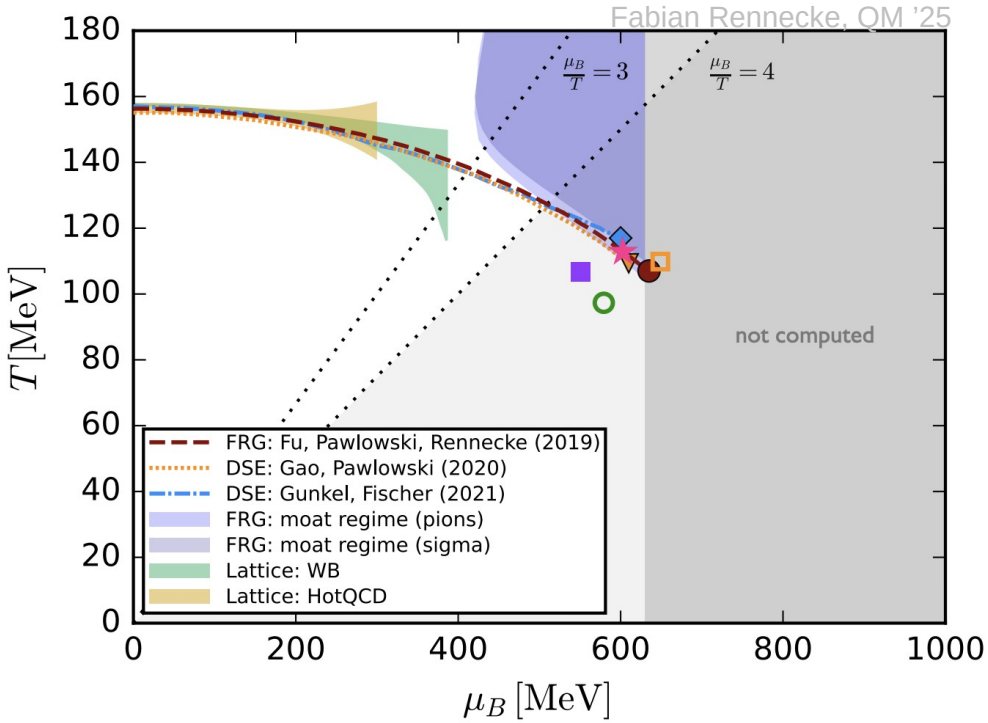
- study of the equation-of-state of nuclear matter at neutron star core densities
- Search for phase transitions search for critical point
- Chiral symmetry restoration
- Exotic forms of (strange) QCD matter
- Hadron-hadron interactions
- Composition of hadrons



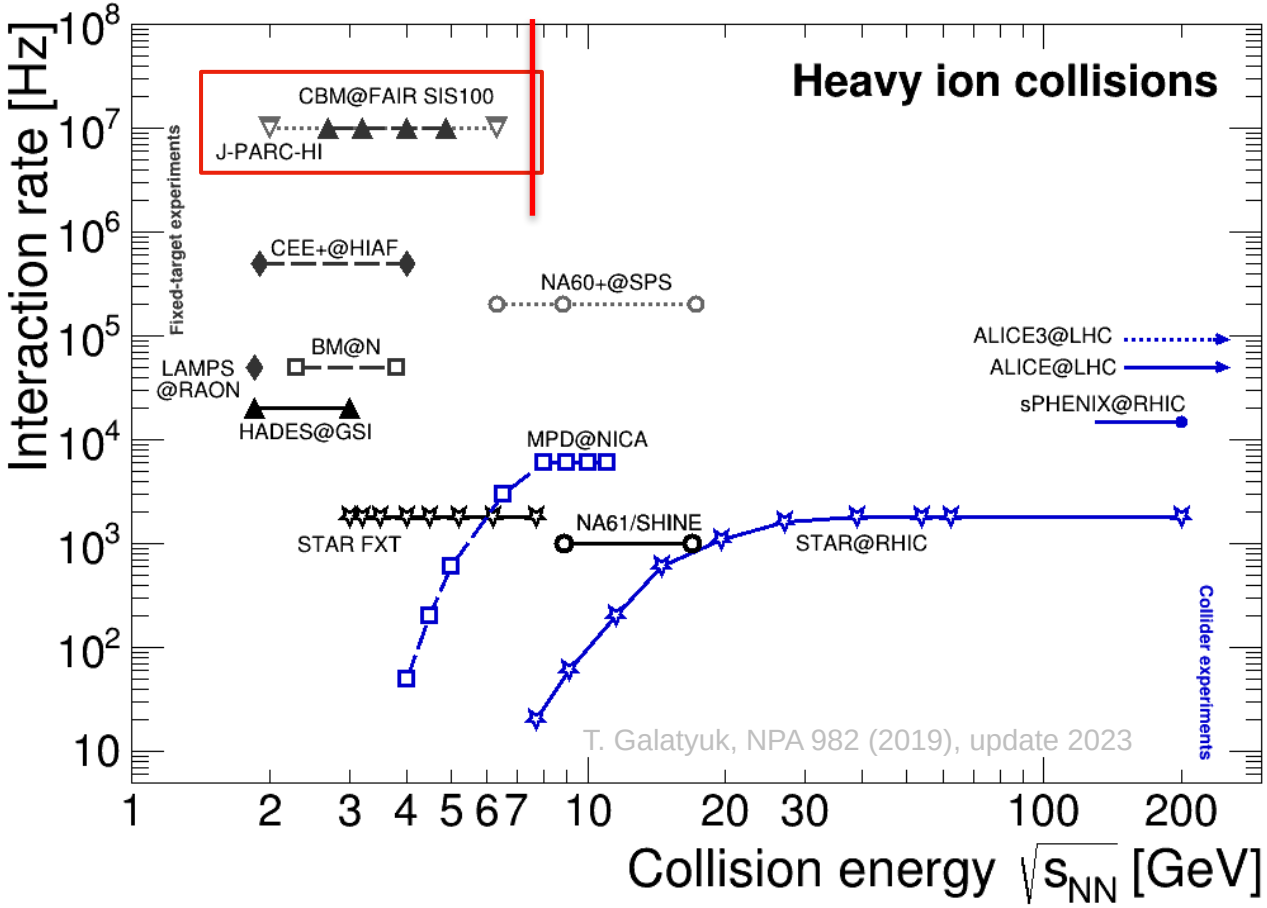
CBM will explore the QCD phase diagram in the region of
high net baryon densities using high-energy A-A, p-A and p-p/n collisions

Highest precision measurements of:

- Dileptons
- Collective flow
- Event-by-event fluctuations
- Strangeness
- Hypernuclei
- Charm



High Interaction Rate :



10 million reactions / s in CBM
→ rare (ppb) physics

FAIR is Rapidly Becoming Reality !

Mission of the CBM-Department at GSI

All activities of department must be subordinated to this goal

2025

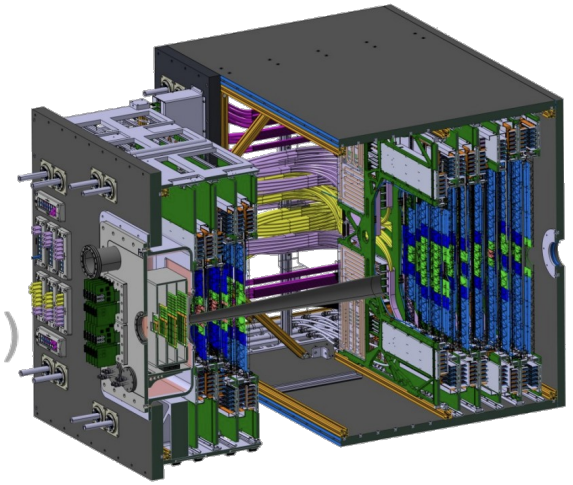
2028

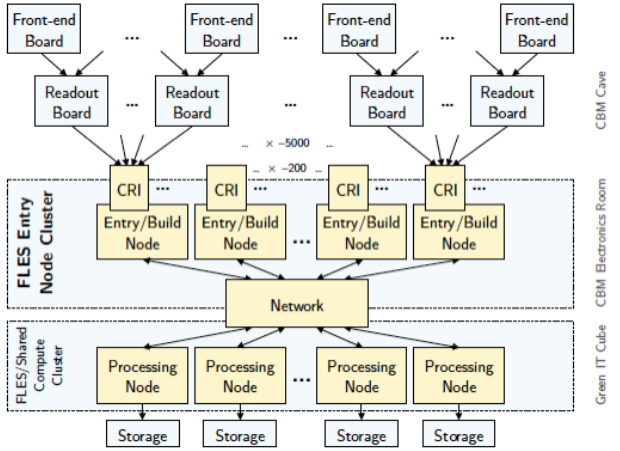
The Role of GSI as Host-Lab

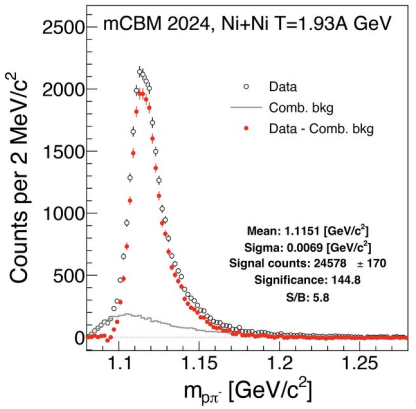
CBM Collaboration ↔ Host Lab

GSI/CBM major contributor for

- TC (P. Gasik)
- STS (C. Schmidt)
- DAQ (D. Emschermann)
- TOF (I. Deppner)
- EC (P.-A. Loizeau)
- Simu / comp (V. Frise)
- Engineering (M. Kis)
- mCBM (C. Sturm)
- …
- Physics (many…)







Yue Hang Leung

My Path

- 1993 PhD Stony Brook FOPI & TAPS Peripheral heavy ion collisions Bi+Pb
- 93-96 PD GSI FOPI K^+ spectra, K^+ , K^0 & Λ directed flow
- 97-04 Assist. JLU Giessen HADES&DISTO Simu, PLUTO, strangeness prod.
- 04- Prof RU-Bochum 29 PhDs (7 ongoing)
- 04-20 Dir. FZ-Jülich Lead ~30 person dept.
  Physics coord. COSY
  Host lab WASA, TOF, KOALA
- 13-16 Spokesperson PANDA
- 21- Dept. head GSI / FFN TransFAIR (FZJ-IKP1&2 → FAIR)
  HADES: STT, iTOF, pp-physics
  CBM: NCAL,TRD, EC, p/n-beams

Experience: leading large technology driven departments at FZJ, FFN/GSI; strong physics credentials; administrative/management experience

Hadron – Hadron Interactions

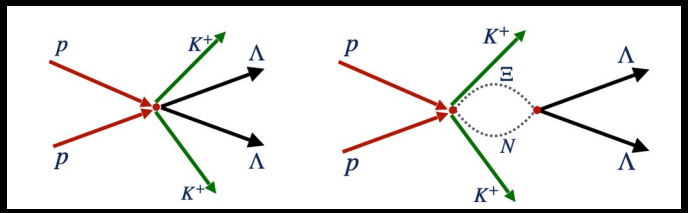
104 MeV/c²
-⅓
½ S
strange

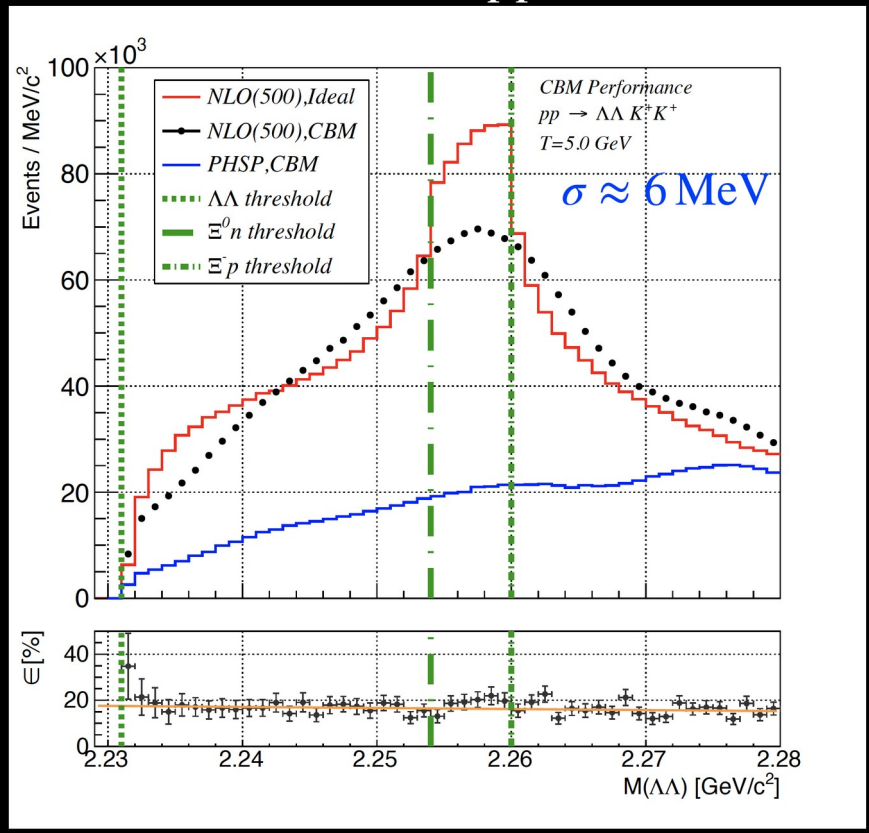
Baryonic $S = -2$ interaction studies

... scattering parameters from short-ranged production reactions

$pp \to K^+K^+\Lambda\Lambda$

- Systematic extraction of low-energy scattering parameters of two-baryon systems with strangeness $S = -2$
- $\Lambda\Lambda/\Xi N$: scattering lengths from thresholds cups within NREFT*
- $\Sigma^+\Sigma^+$: dispersive analysis of short ranged production reactions





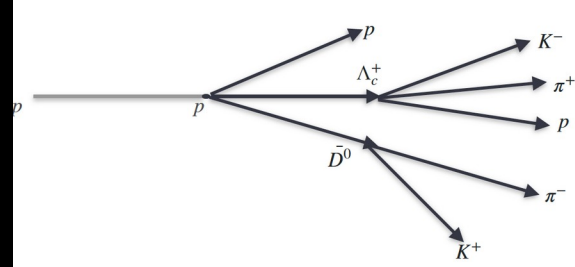
Gandharva Appagere (Stockholm Univ.)

*see *e.g.* scattering lengths in $\Lambda_b \to \pi^- p D^0$, [LHCb PLB 808 (2020) 135623]

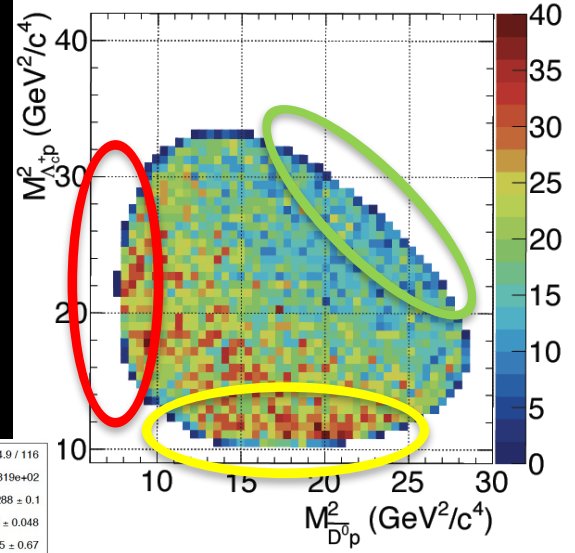
1.27 GeV/c²
⅔
½ C
charm

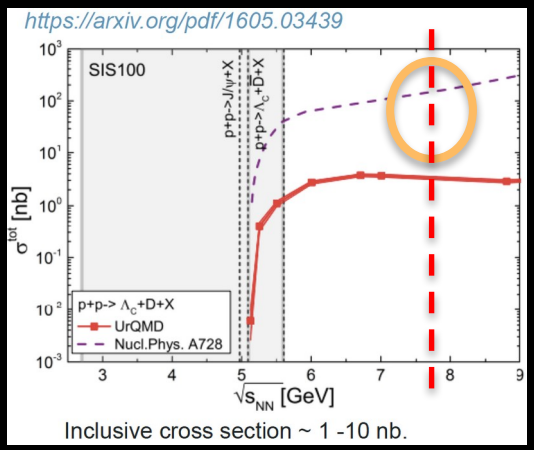
Open charm interaction studies

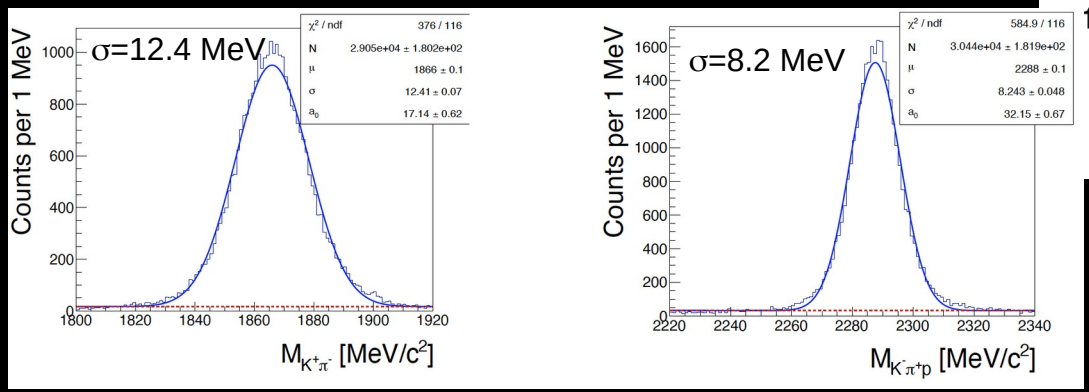
- Measure Λ_cp scattering lengths from Dalitz plot (Femtoscopy without source size uncertainty)
- ND interaction (attractive??) from pD⁰ spectrum, Near-threshold cusps (analogous to $\Lambda\Lambda$)
- Study Λ_cD interaction
- Intrinsic charm in proton (inclusive D yield/spectrum)



$pp \to \bar{D}^0 \Lambda_c^+ p \to (K^+\pi^-)(K^-\pi^+p)p$







0.1 μb x 10^9 p/s → up to 2000 exclusive reco evts / day

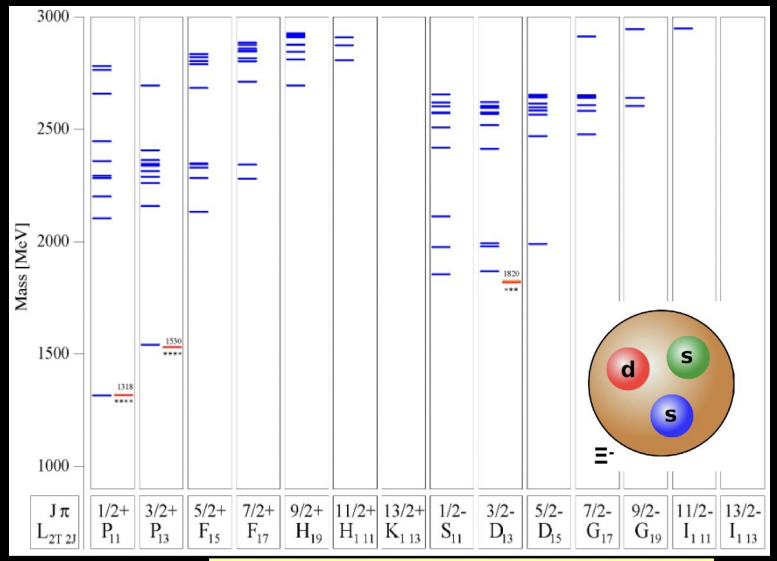
Pavish Subramani (BUW)

Composition of Hadrons

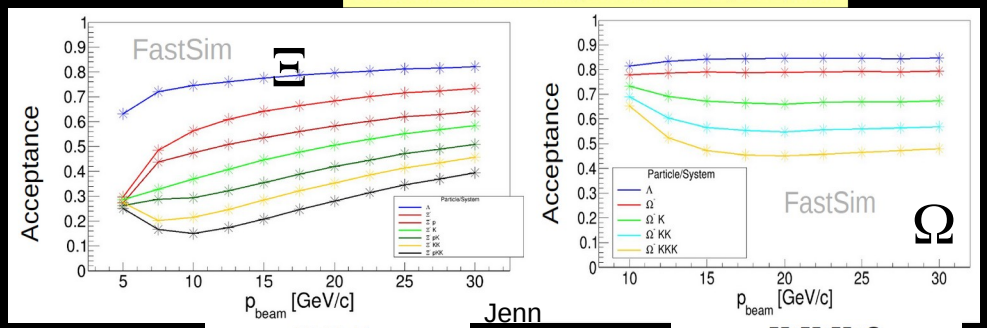
104 MeV/c²
-⅓
½ S
strange

|S| = 2, 3 hyperon spectroscopy

- Very little data exist for Ξ*, Ω*
- More complete spectra needed for thermal & transport model calculations
- Learn about structure and nature, i.e. molecules, pentaquarks…
- Focus on excited Ξ* and Ω* states
  - Sufficient c.m. energy for higher Y*
  - Resolve line shapes with ≈ 2 MeV (*e.g.* Flatte)
  - PWA for Spin-Parity assignment
- Access to production mechanism via N* → Ξ* KK in exclusive pp reactions ?



Quark models: U. Löring *et al.*, EPJA 10 (2001) 447



Jenn

$pp \rightarrow pK^+K^+\Xi^-$
$\Xi^- \rightarrow \Lambda\pi^-$ (BR ~ 100%)
$\Lambda \rightarrow p\pi^-$ (BR = 64%)

10^9 / day

$pp \rightarrow nK^+K^+K^+\Omega^-$
$\Omega^- \rightarrow \Lambda K^-$ (BR = 68%)
$\Lambda \rightarrow p\pi^-$ (BR = 64%)

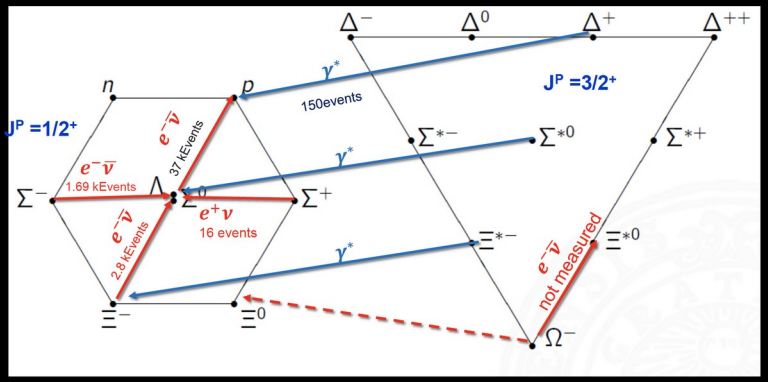
10^7 / day

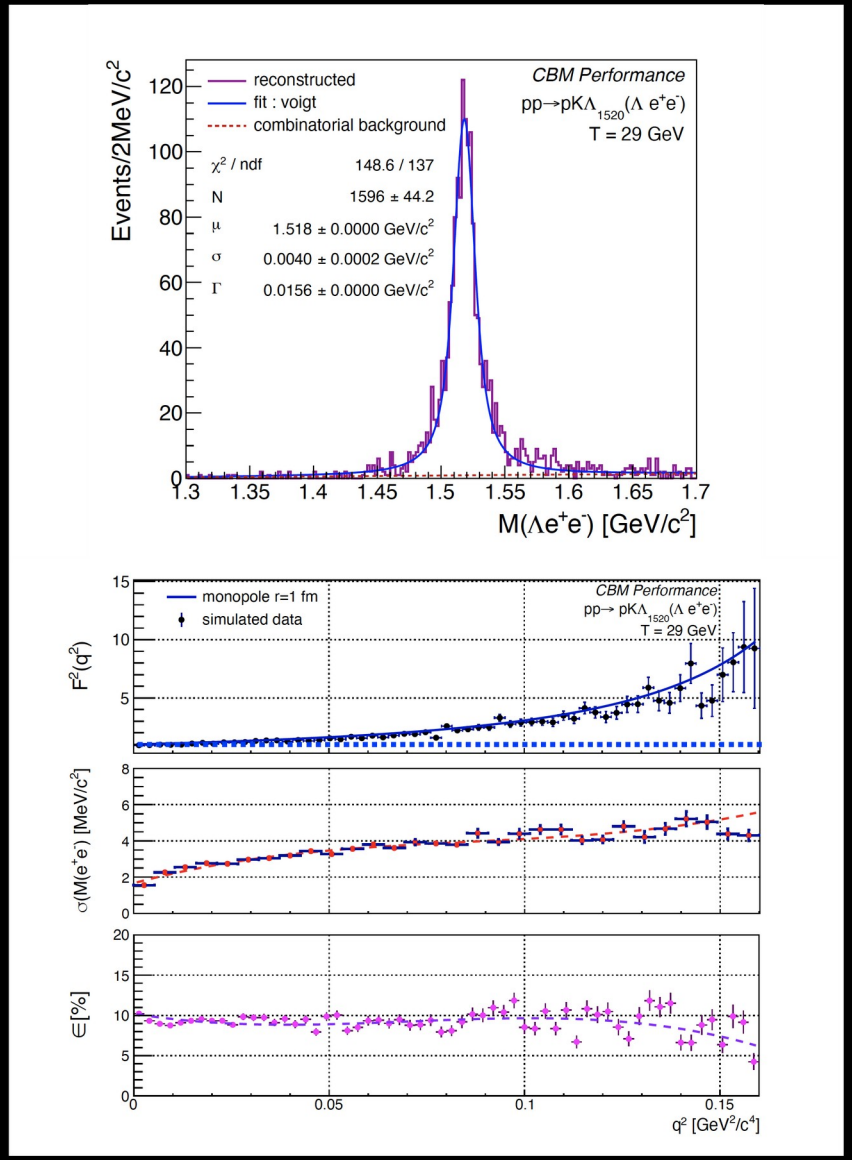
104 MeV/c²
-⅓ S
½ strange

Hyperon structure

… *e.m. & weak transition form factors*

- Expand extraction of transition form factors in SU(3) baryon domain
- Measure decay rates towards low-q^2 in $h_2 \rightarrow h_1 e^+ e^-$ reactions, e.g. $pp \rightarrow pK^+\Lambda(1520)(\rightarrow \Lambda e^+ e^-)$
- Excellent acceptances, resolutions with high production rates allow precision measurements with CBM
- Measurements of weak transition form factors in $h_2 \rightarrow h_1 e^- \bar{\nu}$ evaluated: vector and axial form factors!





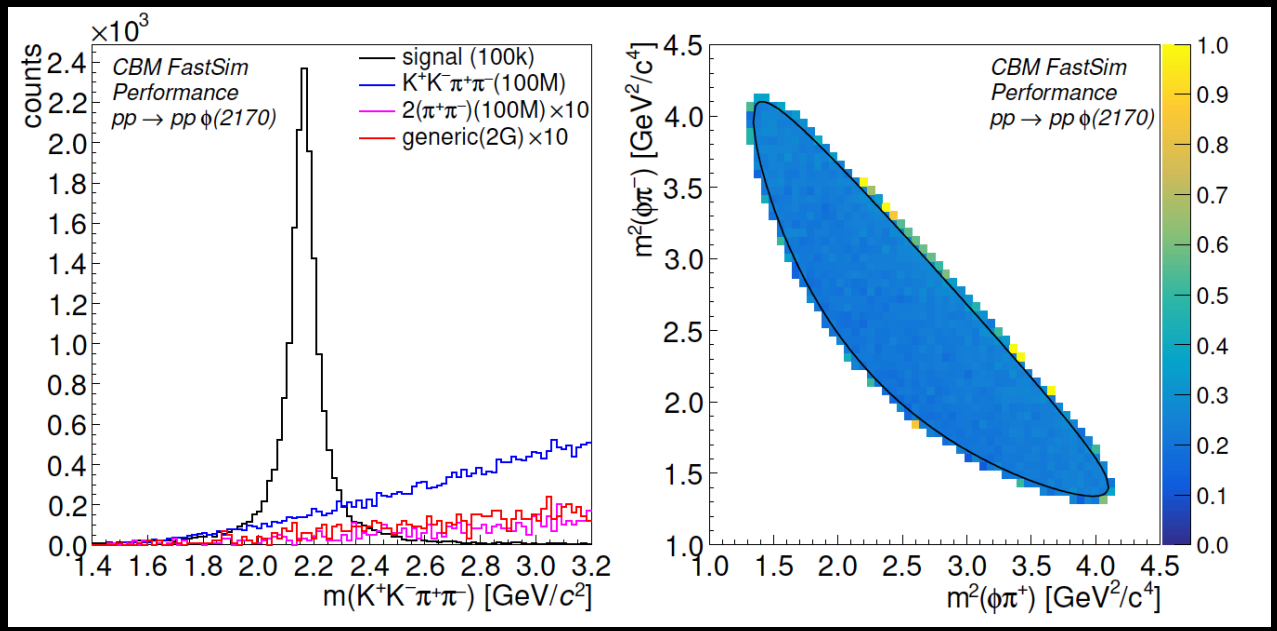
S. Roy (GSI)

Exotic Hadrons

104 MeV/c²
-⅓
½ S
strange

Nature of light quark exotics

- $\phi(2170)$ described as:
  - traditional $s\bar{s}$ state
  - $s\bar{s}$ gluon hybrid
  - tetraquark
  - $\Lambda\bar{\Lambda}$ bound state
  - $\phi K K$ resonance



Mass is at least 200 MeV too high,
→ search for $K\bar{K}$ and KK* decay modes

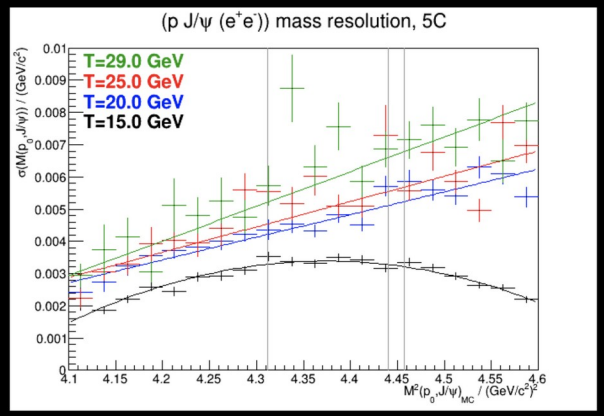
K. Goetzen(GSI)
F. Nerling(GSI,GUF)

1.27 GeV/c²
⅔
½ C
charm

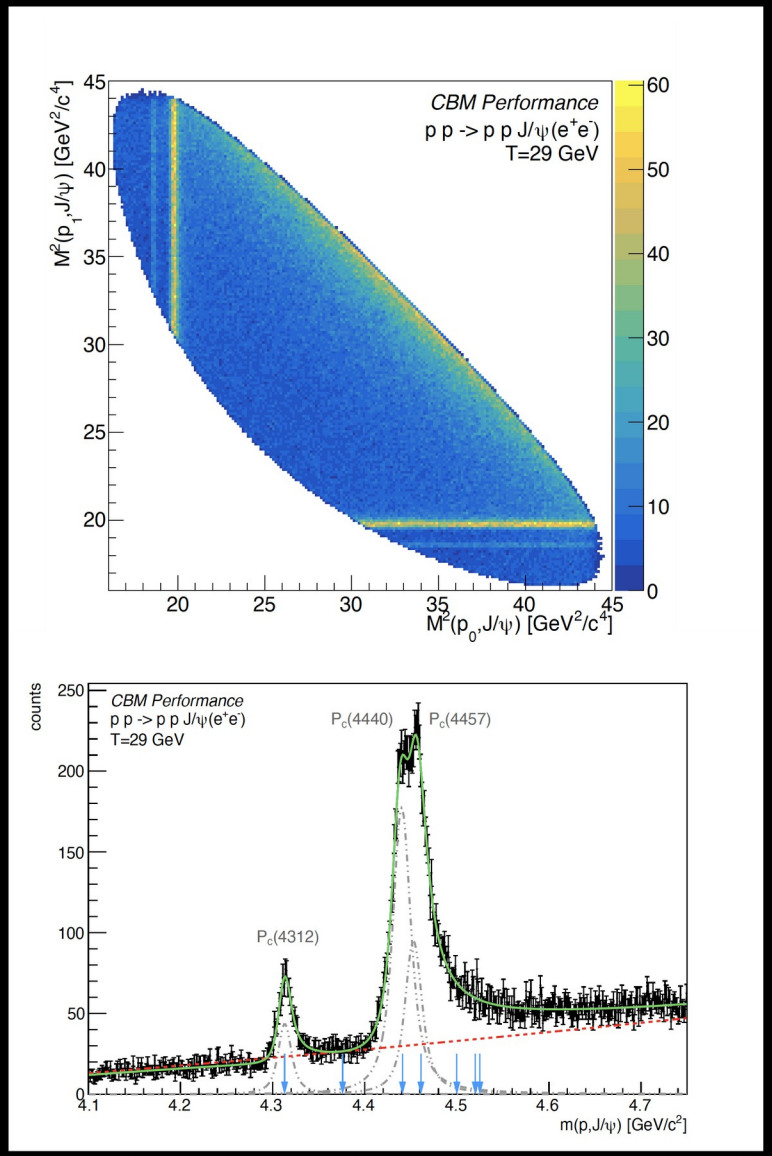
Charming baryons

… *hidden-charm pentaquarks and more*

- Study of open and hidden-charm processes, e.g. $pp \to ppJ/\psi, p\Lambda_c\bar{D}^{(*)}, p\Sigma_c^{(*)}\bar{D}^{(*)}, \ldots$
- Wide physics opportunities: from interaction studies to baryon spectroscopy (exotics)
- Case feasibility study: “LHCb” $P_{c\bar{c}}$ production in pp
- Promising perspectives with CBM at SIS100 energies: good resolution and acceptances for exclusive studies



$pp \to ppJ/\psi$

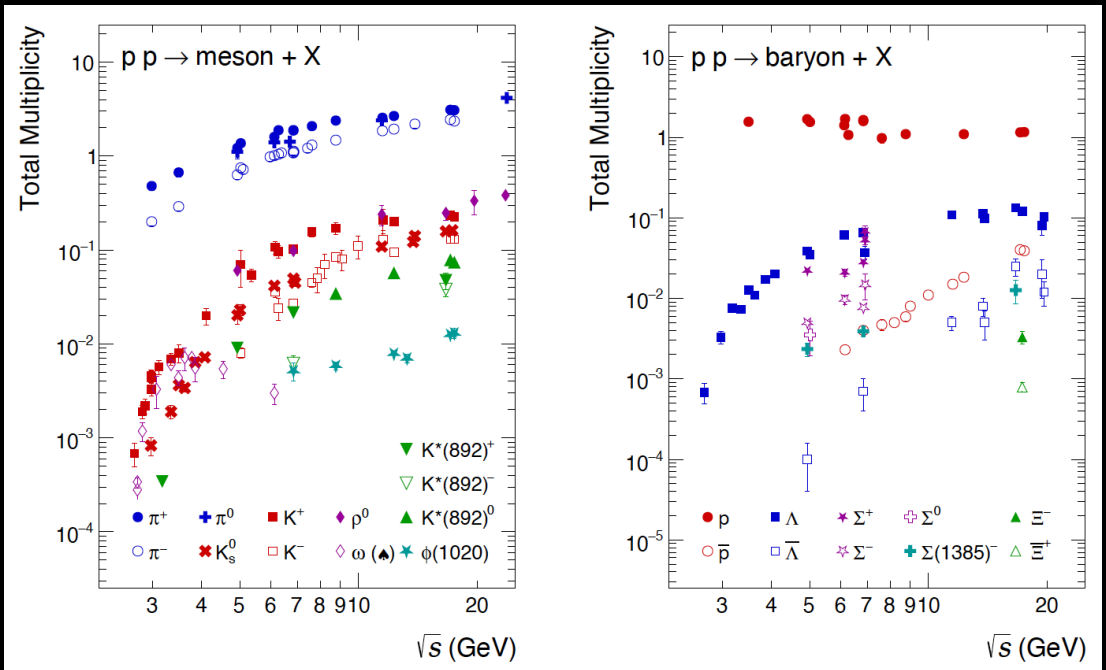


R. Kliemt (RUB), S. Roy (GSI)

Probing matter: from baselines to medium modifications

p+p and n+p cross sections

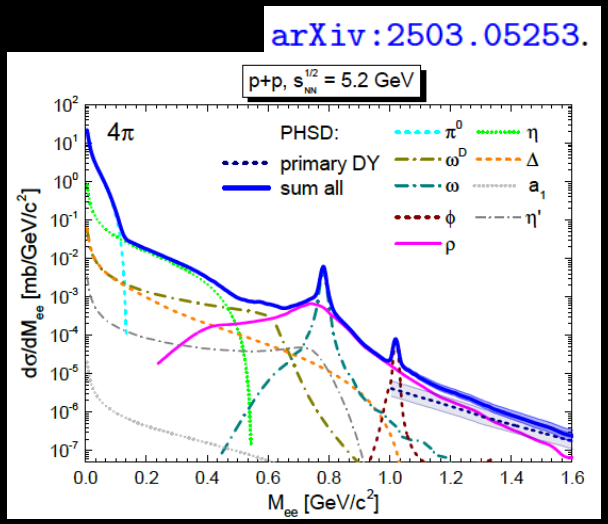
- Transition from hadron to parton dominated reactions
  fully occupied phase space → longitudinal phase space
- Isospin effects: deuteron beam for quasi-free neutron beam
- SIS100→ heavier strange baryons, production mechanisms
  role of secondary interactions

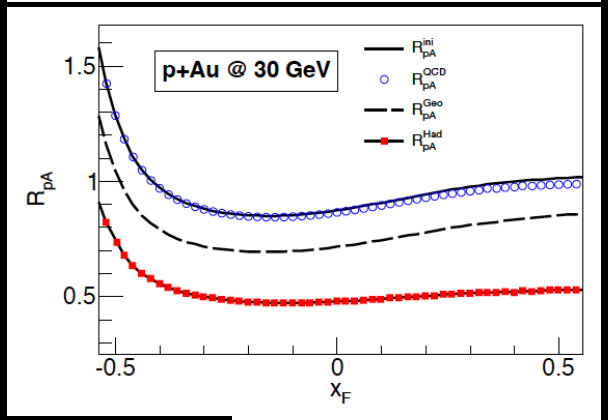


p + A reactions

- Cold-matter, in-medium properties
- SRC - Short Range Correlations (recoil neutron…) role in subthreshold (multi-step) production
- In-medium properties of vector mesons
- Drell-Yan needed for VM spectral function in CoMa PDFs poorly known at large x at this √s
- Dimuons ideal to study initial state quark energy loss → shadowing (different A)

- In-medium strange-hadron properties
- Isospin sym. violation in kaon production ±/00
- EoS → cosmos
- Constraining open charm in nuclear matter



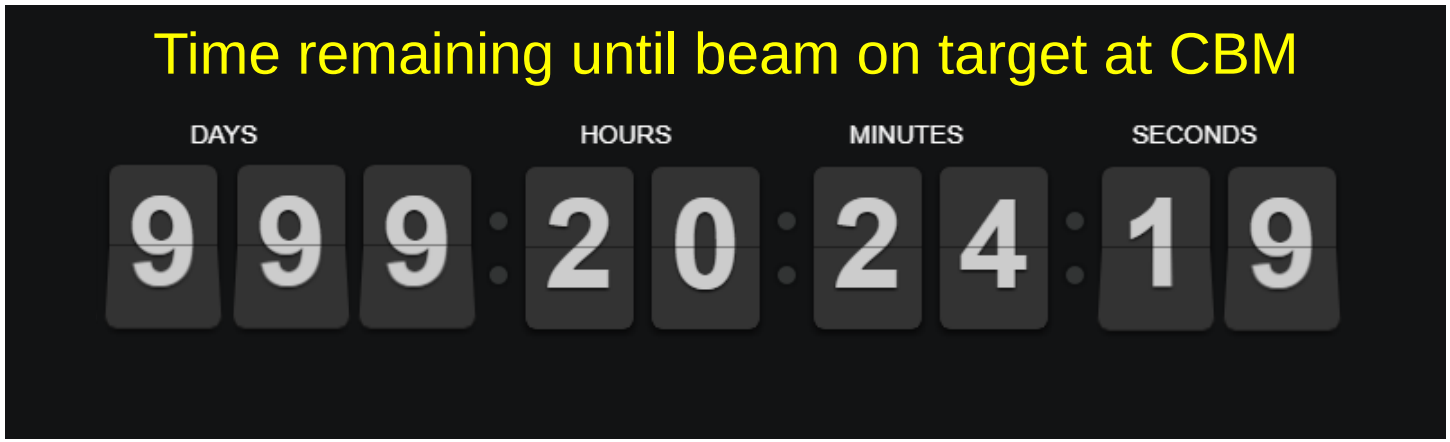


J. Phys. G 45 (2018)

Summary

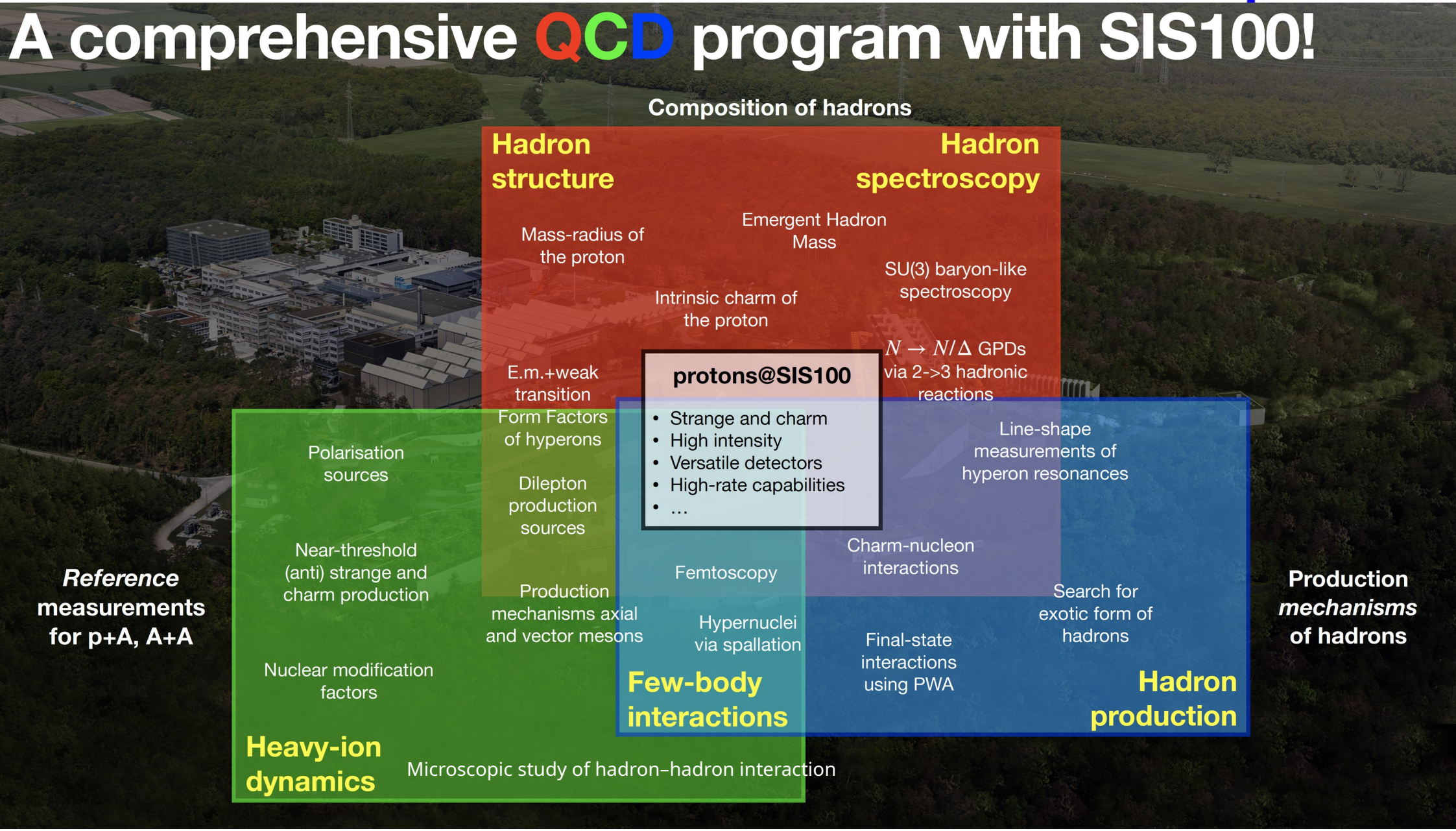
- CBM is a worldwide leading experiment that will soon provide crucial input to our understanding of the universe
- GSI as host lab has a special responsibility to make this reality
- Project is well advanced but we must remain focused

- Time is fleeting, so let‘s roll up our sleeves together !
- PhD students who begin today will see first data at SIS100 !



Thank you very much

A comprehensive QCD program with SIS100!



International Comparison

Topic	BESIII	LHCb	ALICE	AMBER	INSIGHT	HADES (π)	CBM	WASA@SFRS	HIAF	Halls A/B/C	GlueX	KLF	J-PARC K1.8	J-PARC K1.8BR	J-PARC high-p/π20	J-PARC HIHR	J-PARC K10	BelleII	NICA
N^*, Δ^* spectroscopy	■		■		■	■	■			■	■	■	■	■	■				
$\|S\| = 1$ spectroscopy	■		■		■	■	■				■	■	■	■	■		■		
$\|S\| = 2, 3$ spectroscopy	■		■				■					■	■		■		■		
$C \neq 0$ spectroscopy	■	■	■	■			■								■			■	
Meson-Meson interactions			■	■	■	■	■												
Meson-Baryon interactions			■	■	■	■	■			■	■	■		■	■		■		
Baryon-Baryon interactions			■			■	■		■				■	■	■	■	■		
Dibaryons			■				■						■		■		■		
Hypernuclei			■			■	■	■	■			■	■	■		■	■		
Mesic atoms								■						■					
Baryon Transition Form Factors	■			■		■	■			■	■				■			■	
Semileptonic Baryonic transitions	■						■											■	
Intrinsic Charm of Nucleon				■			■			■					■			■	
Exotic hadrons with charm	■		■	■			■								■			■	
Charmed hadron–Nucleon FSI		■	■				■												
Light–quark exotics	■	■		■	■		■			■	■	■	■					■	
Particle multiplicities in pp reactions						■	■												
Resonance production with π beam				■		■							■	■	■				
In-medium hadron properties						■	■		■						■		■		■
In-medium strange hadron properties						■	■						■	■	■	■	■		
Short Range Correlations						■	■		■	■			■						■
Drell–Yan in π/p + A reactions				■			■								■				
Isospin effects in dense matter						■	■		■				■	■		■			■
Dark matter searches		■	■	■			■				■							■	