

# Hadron Physics from Heavy Ion Reactions in ALICE, CBM and HADES



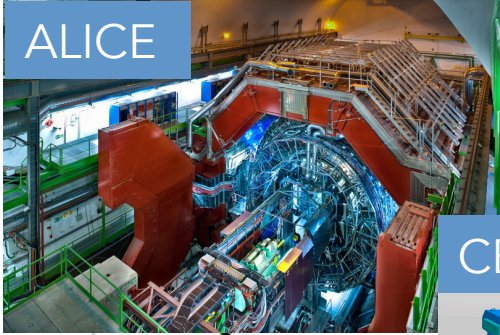
Manuel Lorenz

Goethe-University Frankfurt



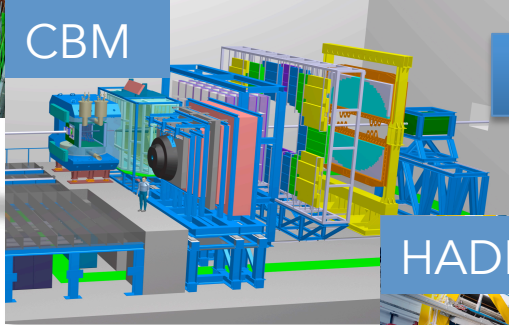
# Probing the Phase Diagram of Strongly Interacting Matter

ALICE



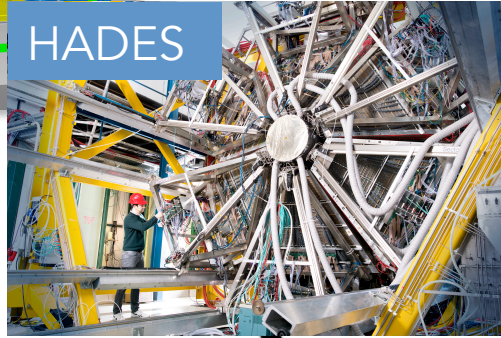
Systematic measurements from GeV to TeV energy regime.

CBM



All experiments have p/ $\pi$ +p/A programs.

HADES



$T_c$

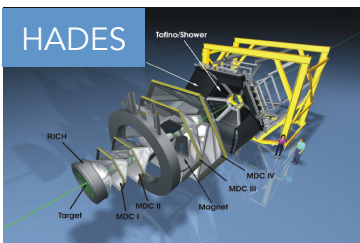
HADRON  
GAS

⊙  
NUCLEI

NEUTRON STARS  
 $\mu_B$



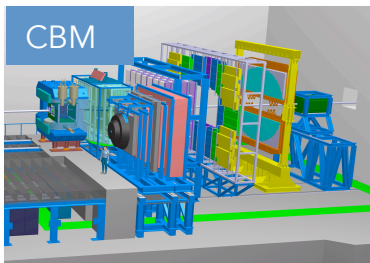
# Overview: Experiments and Selected Observables



Setup	$\sqrt{s_{NN}}$	Interaction rate	Status	Collision systems
-------	-----------------	------------------	--------	-------------------

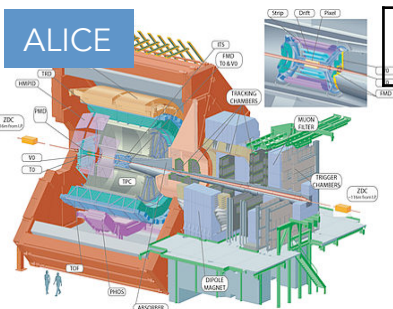
fixed target	2.2-3.5 GeV	2-200 kHz	running	$\pi/p/A + p/A$
--------------	-------------	-----------	---------	-----------------

Baryon resonance studies and in-medium vector mesons in  $\pi+p/A$



fixed target	3.3-7.7 GeV	0.1-10 MHz	in preparation	$p/A + p/A$
--------------	-------------	------------	----------------	-------------

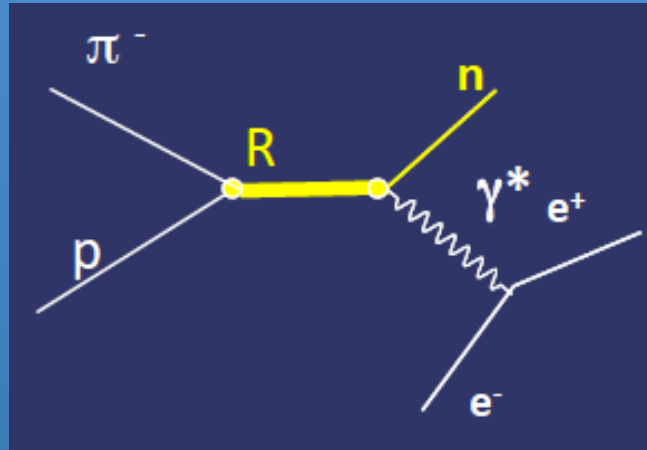
Hypernuclei production, open and hidden charm cross section

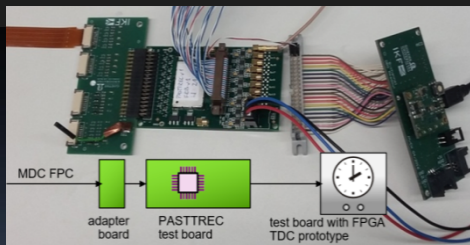


collider	0.9-13 TeV	1-50 kHz	running	$p/A + p/A$
----------	------------	----------	---------	-------------

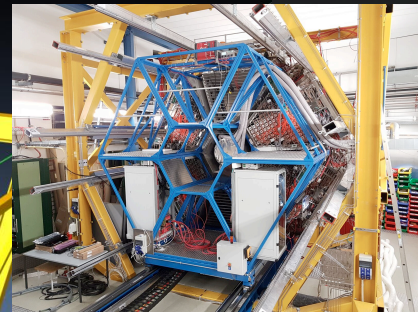
(Hyper)nuclei production, open and hidden charm cross section

# $\pi$ Beam Experiments with HADES

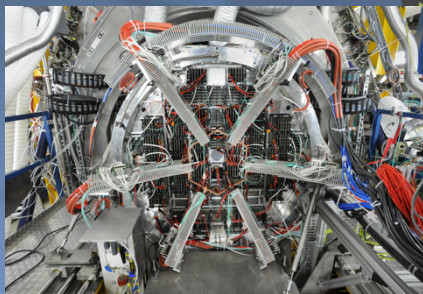




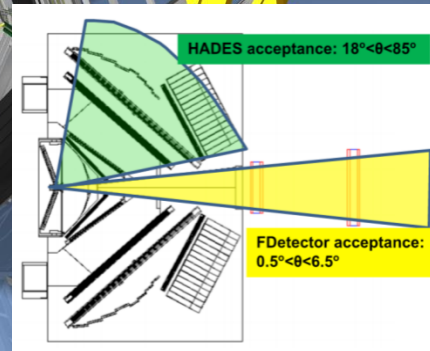
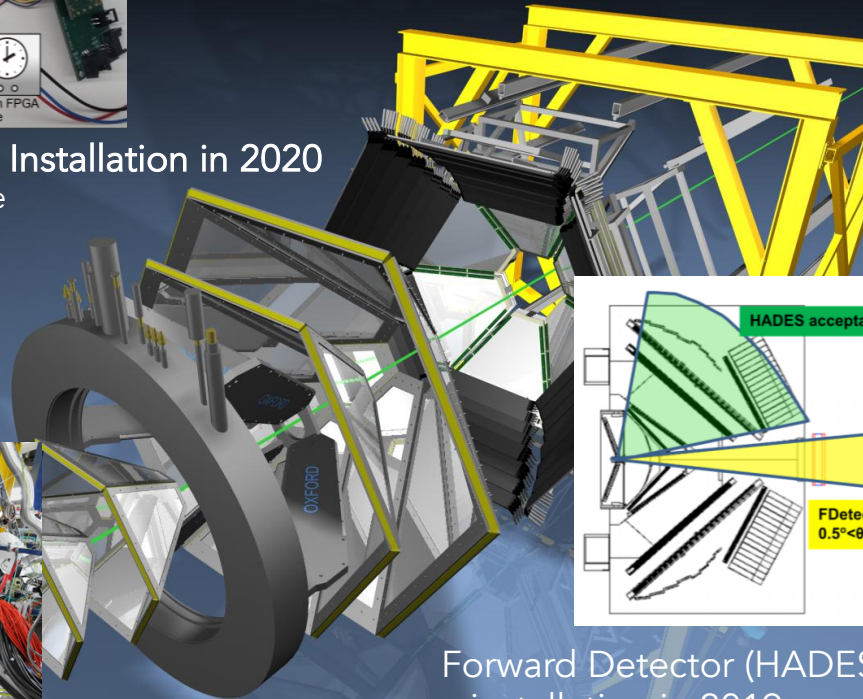
Electromagnetic Calorimeter – 4 sectors ready for beam  
Real photon measurements  
Electromagnetic decays of baryonic resonances



MDC readout upgrade – Installation in 2020  
Read-out trigger rate increase  
from 50 kHz to 200 kHz

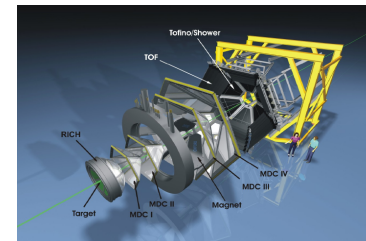
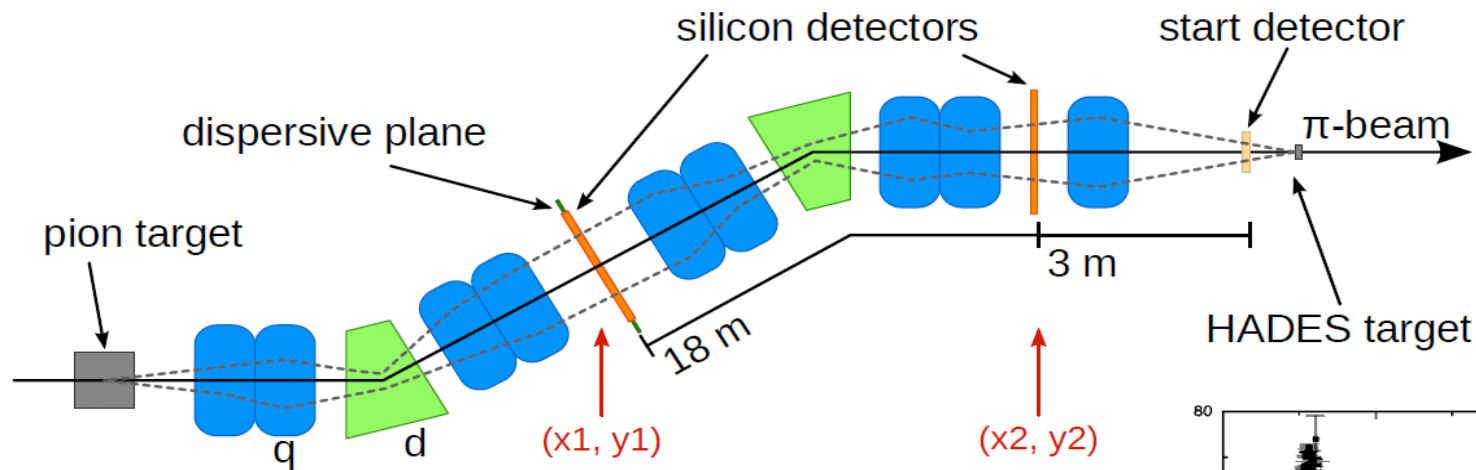


RICH (HADES/CBM project) – ready for beam  
Gain in lepton pair detection efficiency (x 3)  
Joint (CBM/PANDA/HADES) development of read-out system  
based on TRB3 platform.



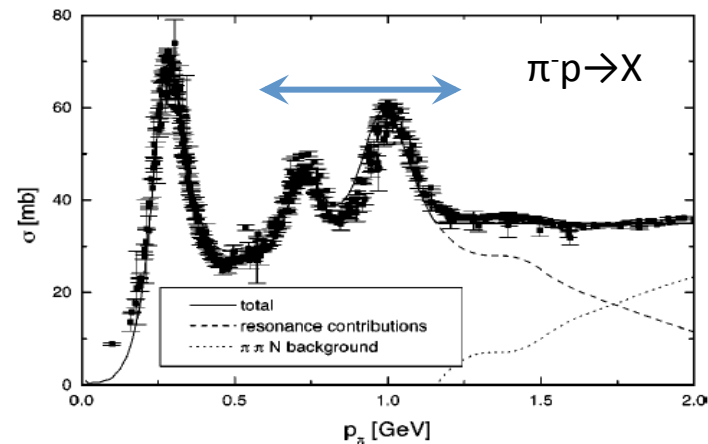
Forward Detector (HADES/PANDA project)  
– installation in 2019  
Enhance HADES capabilities for exclusive channels  
Hyperon production and EM decays

# $\pi$ Beam Experiments with HADES



HADES combines a pion beam with dielectron, hadron identification and secondary vertex reconstruction. Unique tool for [baryon resonance studies](#).

Successful pioneering run in 2014 in the N(1520) region.



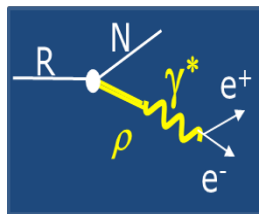


# $\pi$ Beam Experiments with HADES

Hadronic channels:  $\pi\pi N$  ..

Partial Wave Analysis for baryon spectroscopy  
(complementary to  $\gamma$  beam data)

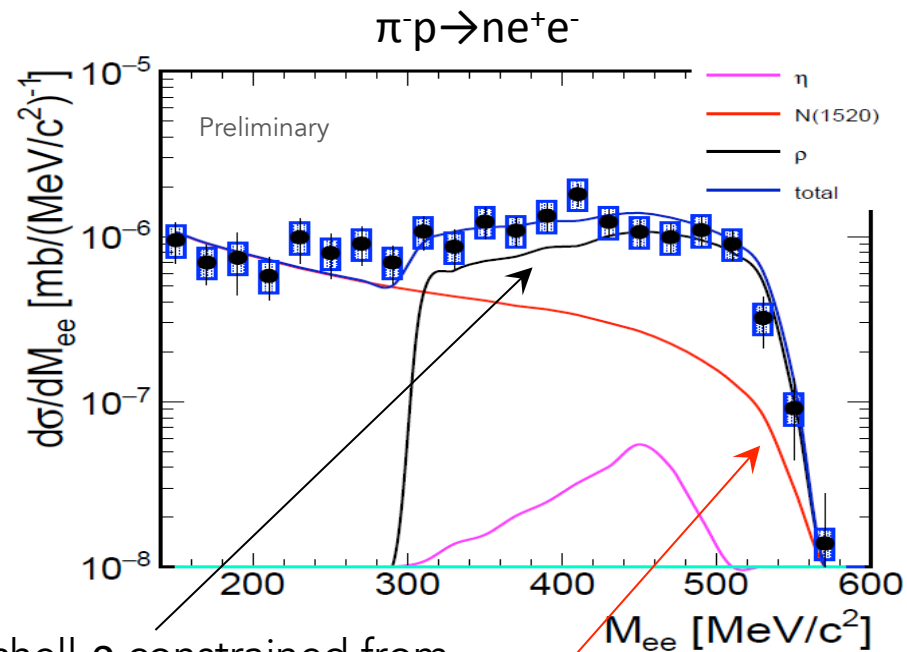
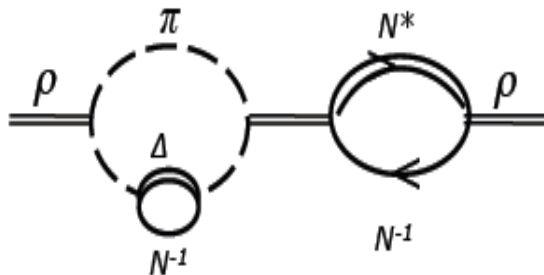
$e^+e^-$  : time-like baryon transitions



+ secondary vertex: hyperon transitions  
(terra incognita)

high intensity proton beam

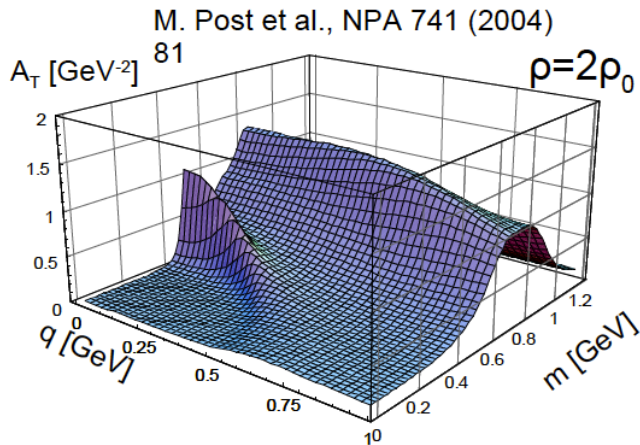
Vector mesons in cold nuclear matter:



Off-shell  $\rho$  constrained from  
PWA in hadronic channels

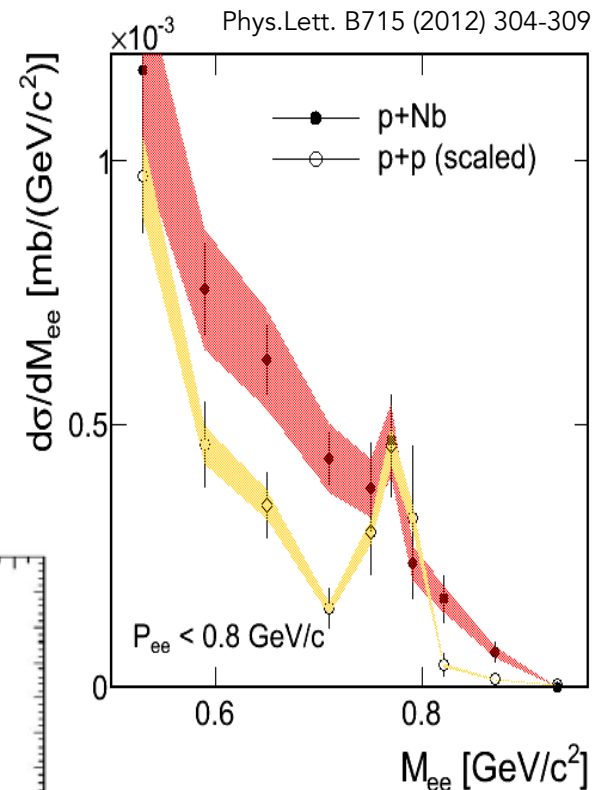
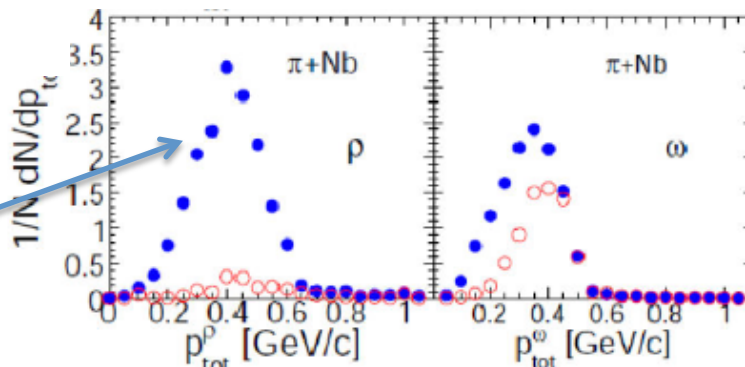
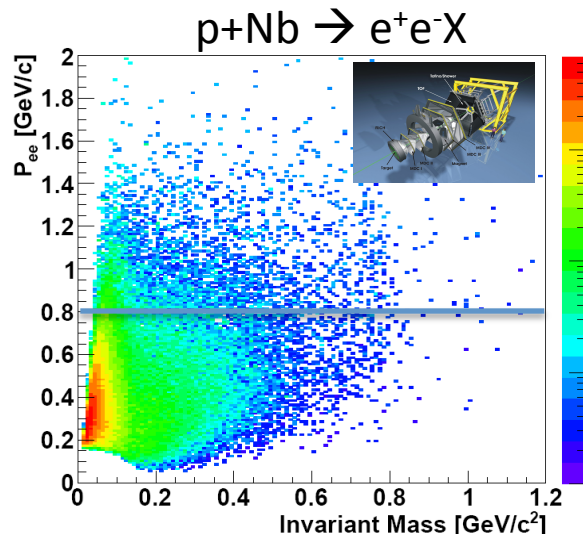
Point-like  $N(1520)$

# Vector-Mesons in Cold Nuclear Matter

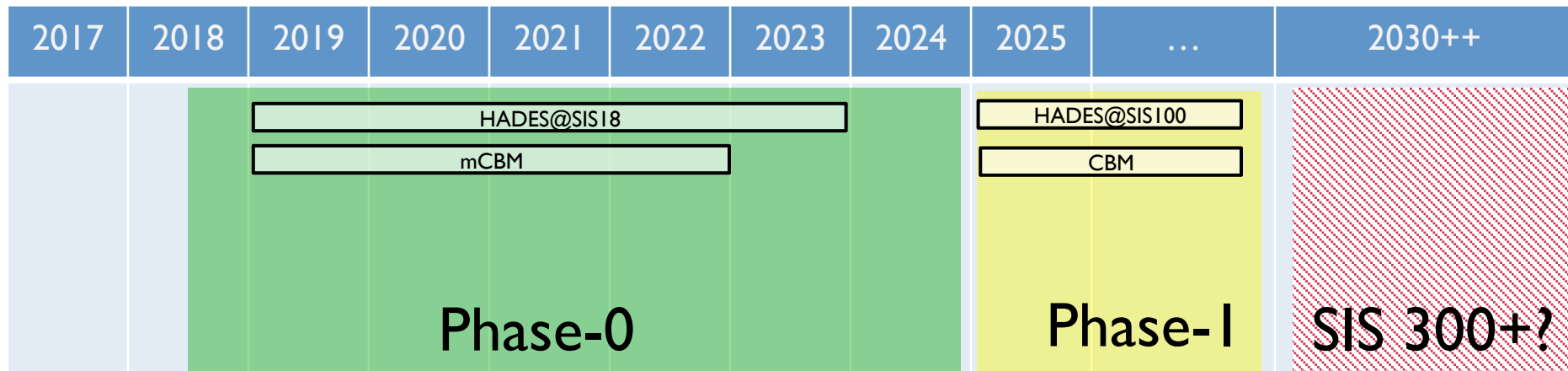



Effects restricted to momenta  
smaller 0.8 GeV  
→ ensure acceptance

$\pi$ -induced reactions:  
Low momenta  
vector mesons

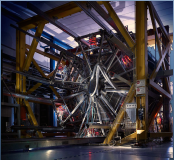


# Timeline FAIR


Proposal for experiments at SIS18 during FAIR Phase-0

The HADES Collaboration



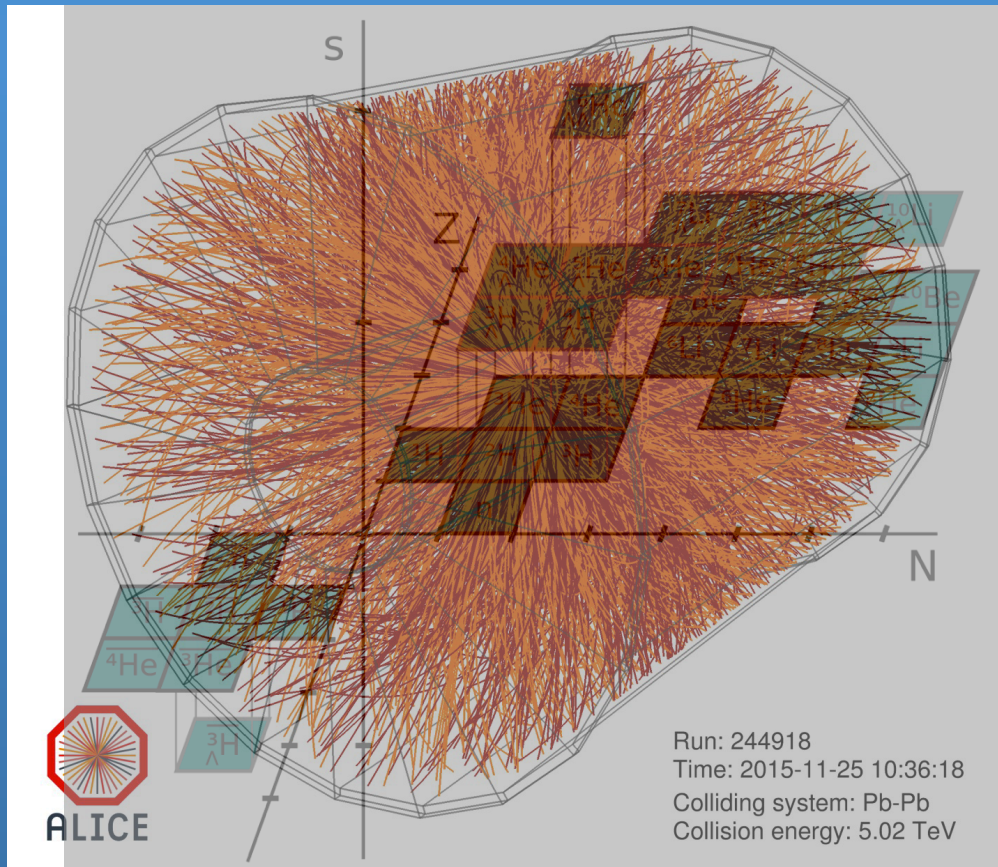
Properties of hadron resonances and baryon rich matter

**HADES upgrade 2019-2020:**  
DAQ upgrade - 200 kHz interaction rate  
( $p/\pi+p$ ,  $p/\pi+A$ )

**CBM:**  
Au+Au program  
Hadron physics ( $p+p/A$ )

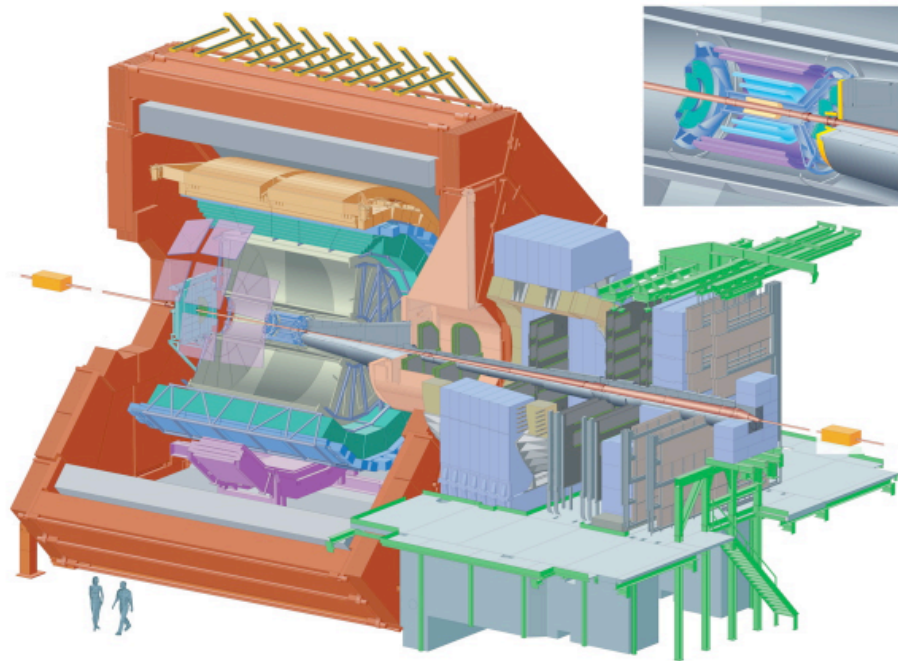
**HADES:**  
High intensity proton beam  
Cold matter physics ( $p+A$ )  
Exclusive measurements ( $p+p$ )

# (Hyper)nuclei at ALICE in Pb+Pb



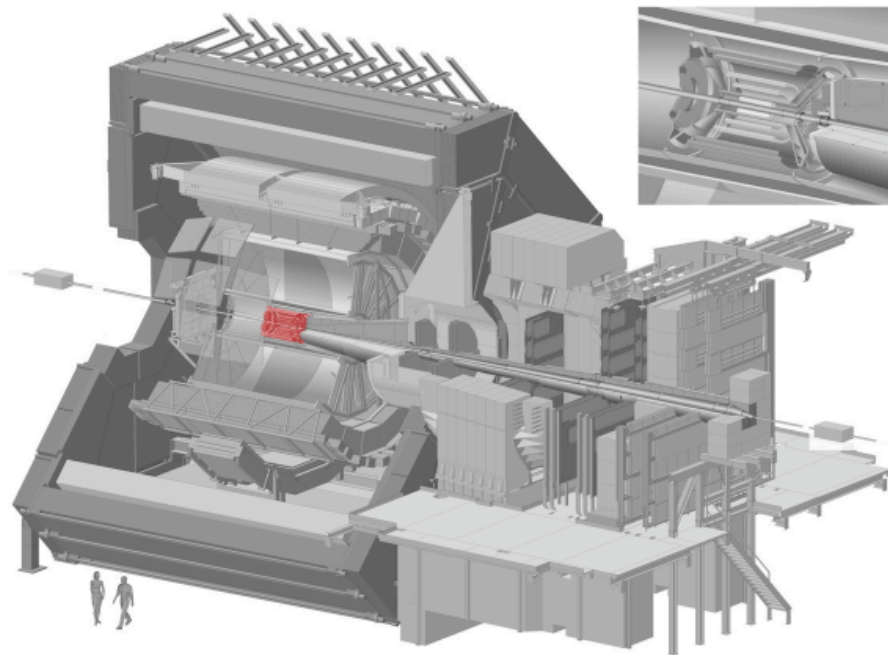


# ALICE Setup



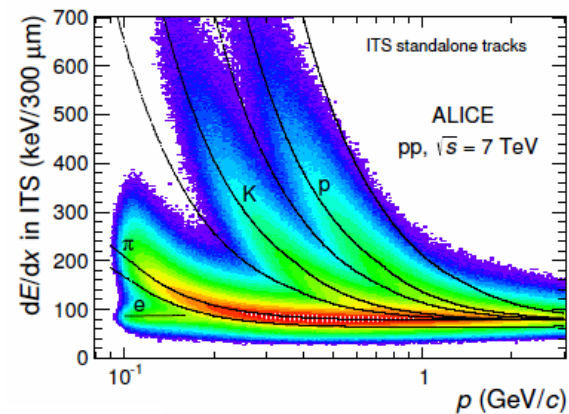
Unique feature:  
Low momentum coverage.

# ALICE Setup

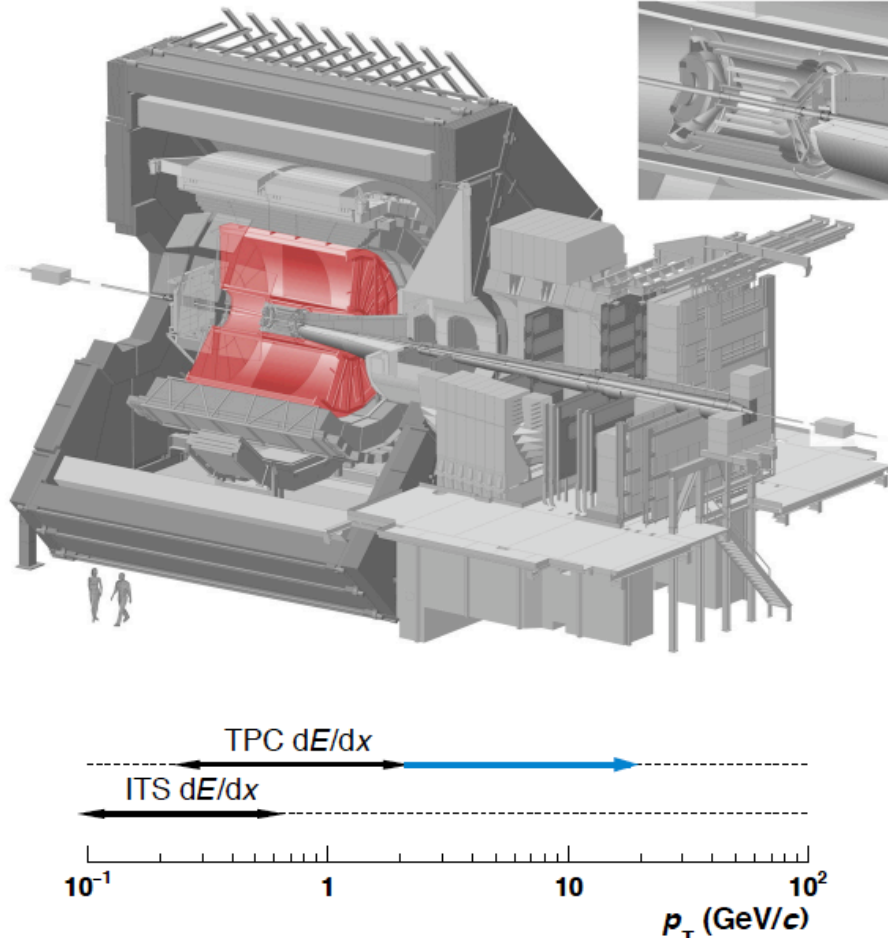


ITS ( $|\eta| < 0.9$ )

- 6 Layers of silicon detectors
- Trigger, tracking, vertex, PID ( $dE/dx$ )



# ALICE Setup

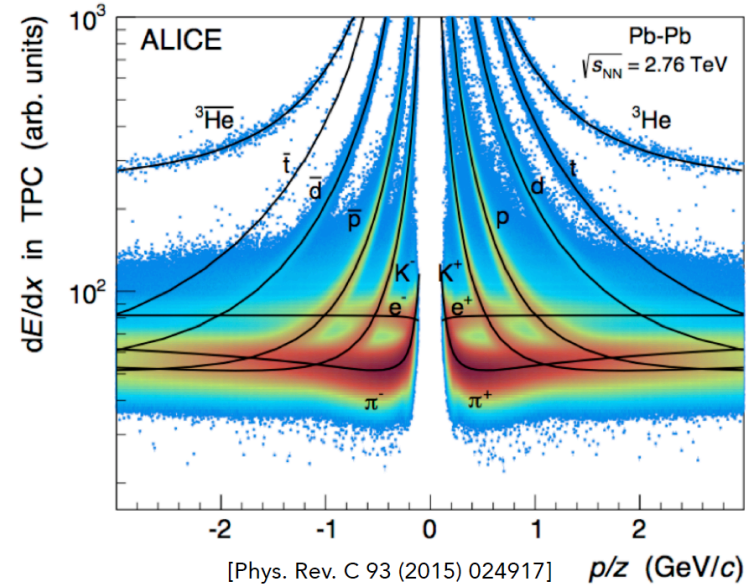


ITS ( $|\eta| < 0.9$ )

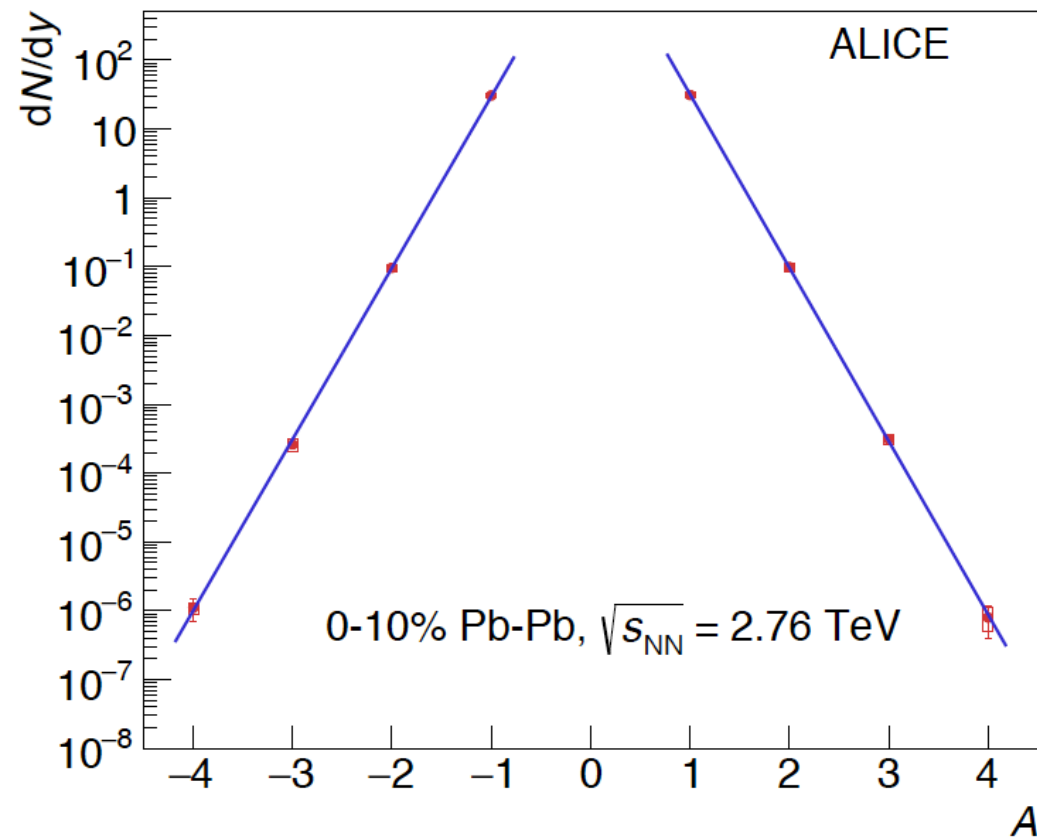
- 6 Layers of silicon detectors
- Trigger, tracking, vertex, PID ( $dE/dx$ )

TPC ( $|\eta| < 0.9$ )

- Gas-filled ionization detection volume
- Tracking, vertex, PID ( $dE/dx$ )



# Light Nuclei

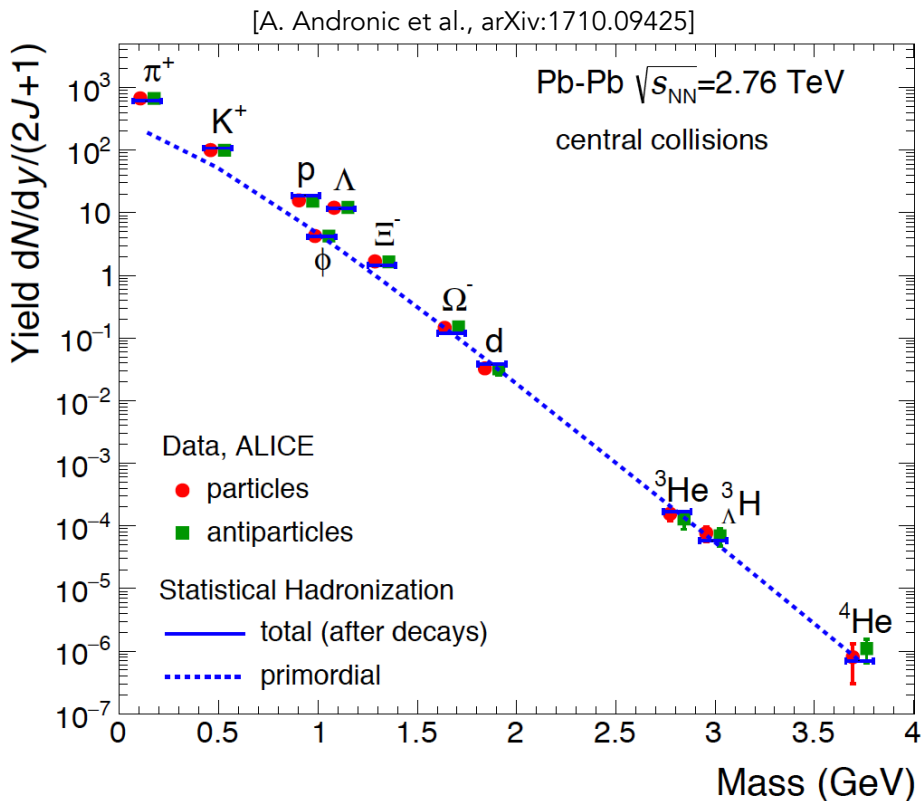


ALICE Collaboration, arXiv:1710.07531, NPA 971, 1 (2018)

- Similar amount of nuclei and anti-nuclei (after correction for interactions with the detector material)
- Nuclei yields follow an exponential decrease
- Penalty factor for adding one baryon  $\sim 300$
- Statistical description of hadron yields from chemically equilibrated fireball  $\sim \exp(-m/T)$

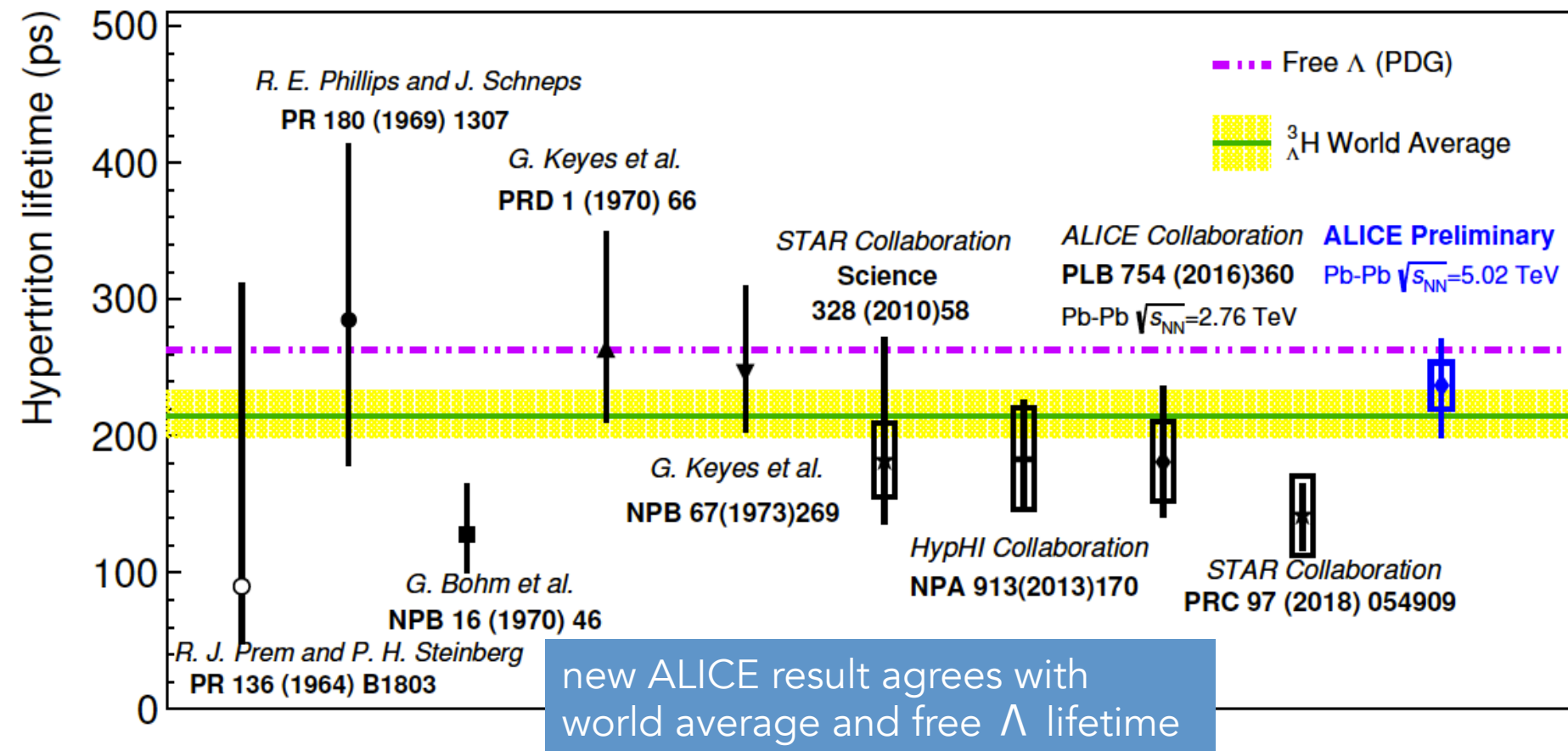


# The Hypertriton and the Statistical Model

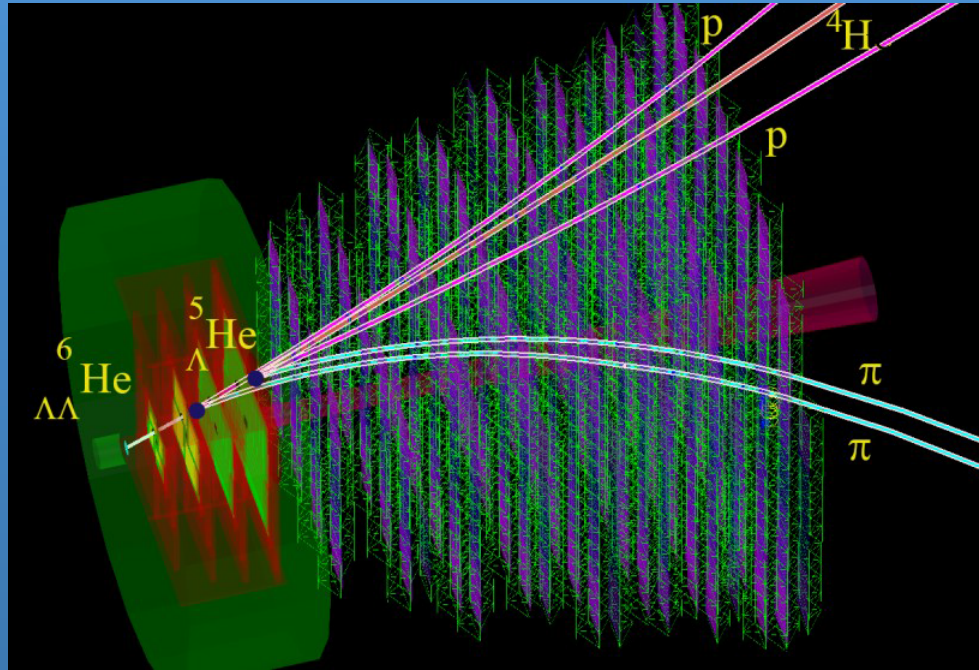


- Yields described over 7 orders of magnitude with a common chemical freeze-out temperature of  $T_{ch} \approx 156$  MeV.
- Despite the low binding energy of the 2.35 MeV also the hypertriton yield is described.

# The Hypertriton Lifetime Puzzle?



# Hypernuclei at CBM

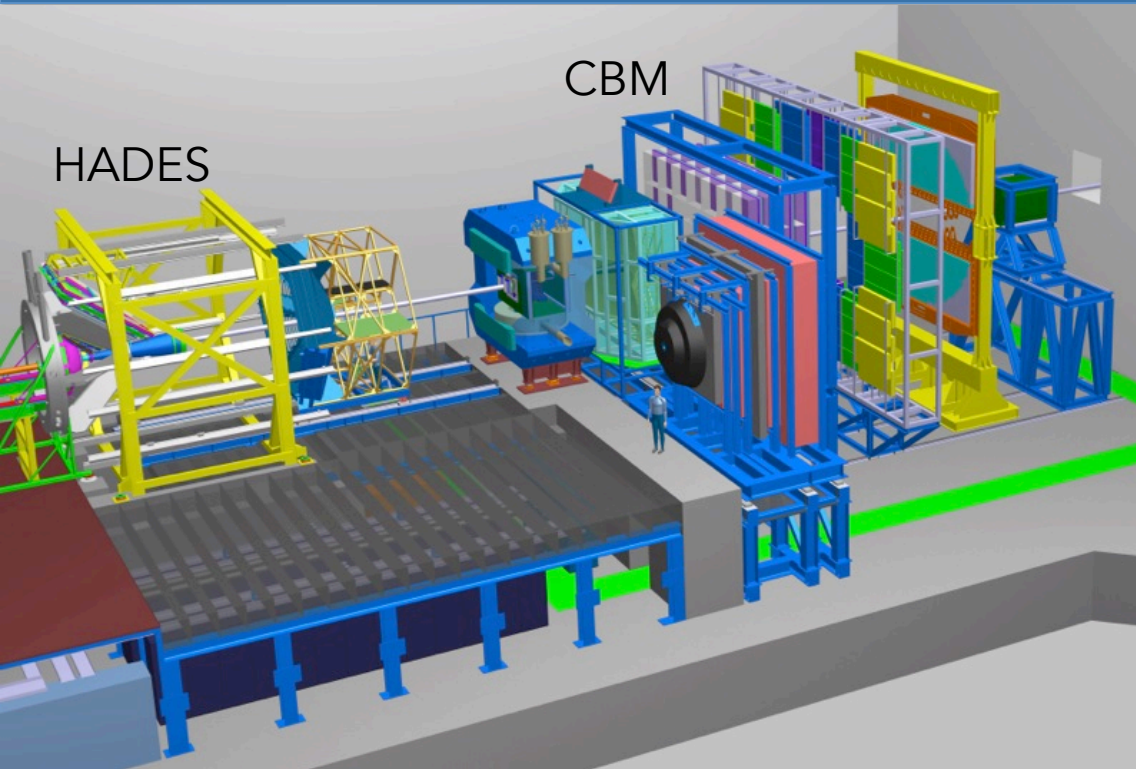


# Towards FAIR Phase I

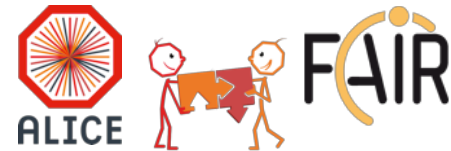




# CBM Setup

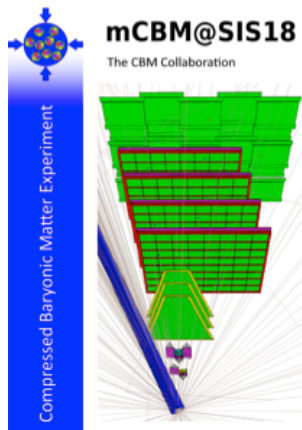


- Interaction rates of up to 10 MHz  
→ high statistic measurements of rare probes
- Free-streaming FEE  
→ nearly dead-time free data taking
- Tracking based entirely on silicon  
→ fast and precise track reconstruction  
→ 4D Tracking
- On-line event selection  
→ high-selective data reduction



*ALFA - a common framework for  
ALICE and FAIR experiments*

# mCBM at SIS18 FAIR Phase0



Demonstrator for full CBM data taking and analysis chain under full load (Au-Au,  $10^7$  interactions/s)

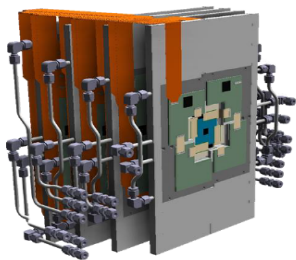
mFLES racks @ Green IT Cube



mCBM will focus on:

- Free streaming data transport to a computer farm
- Online reconstruction and event selection
- Offline data analysis

Requested beam time was fully granted by G-PAC



mMVD<sub>2020</sub> Frankfurt



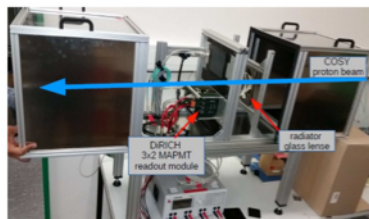
mSTS GSI



mMUCH VECC



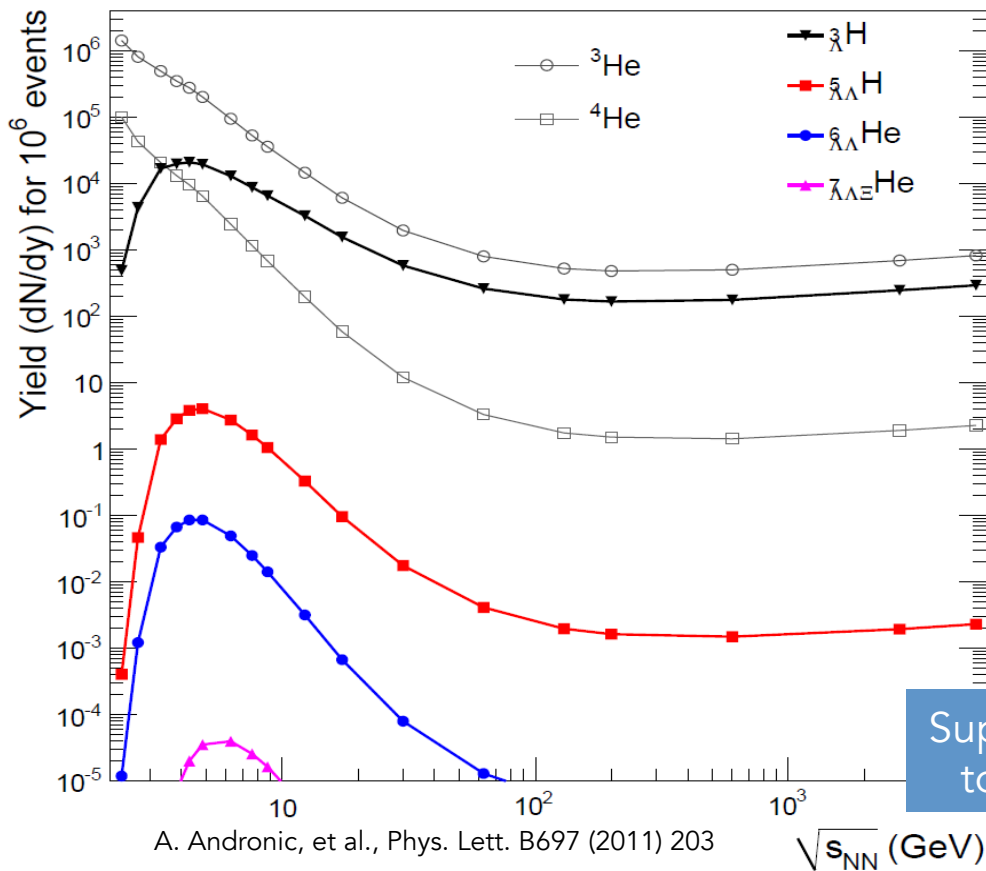
mTRD Münster, Frankfurt



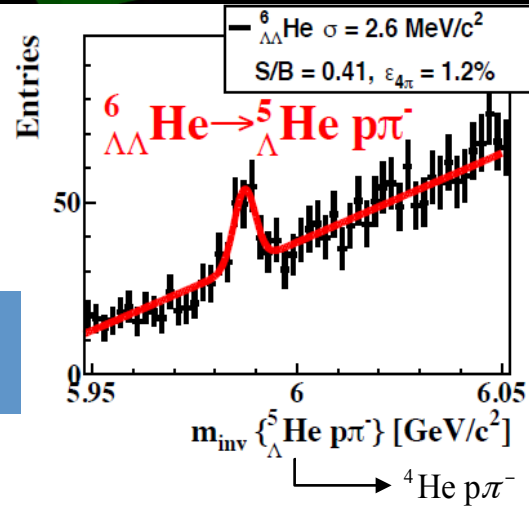
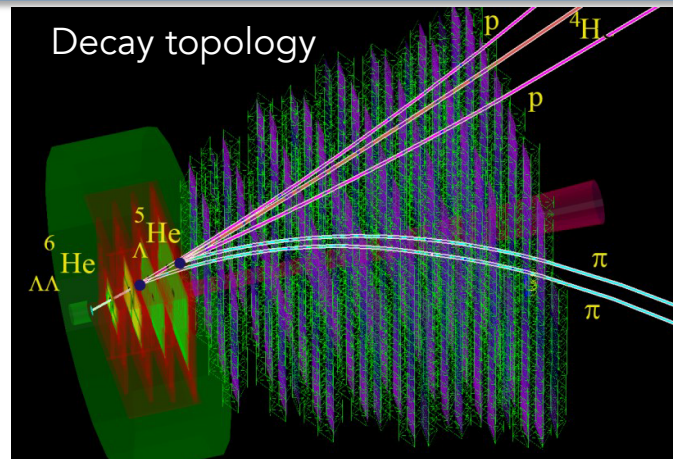
mRICH Giessen, Wuppertal

# Hypernuclei at CBM: $\Lambda\Lambda$ – Hypernuclei

Thermal model prediction for Au+Au



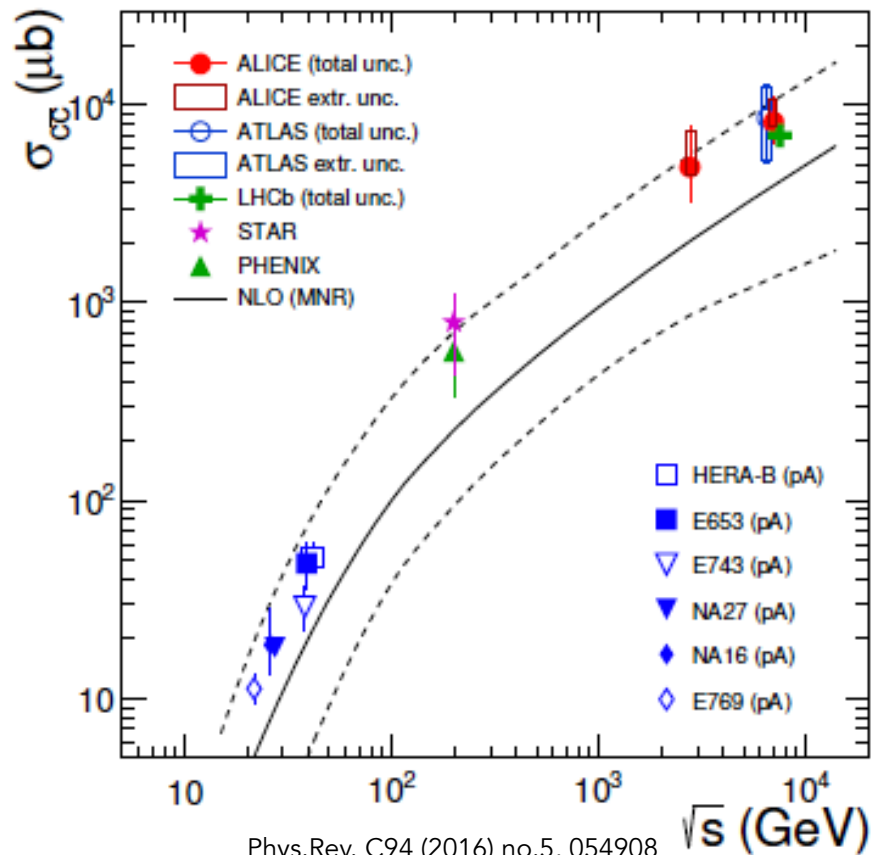
Supplemental  
to PANDA



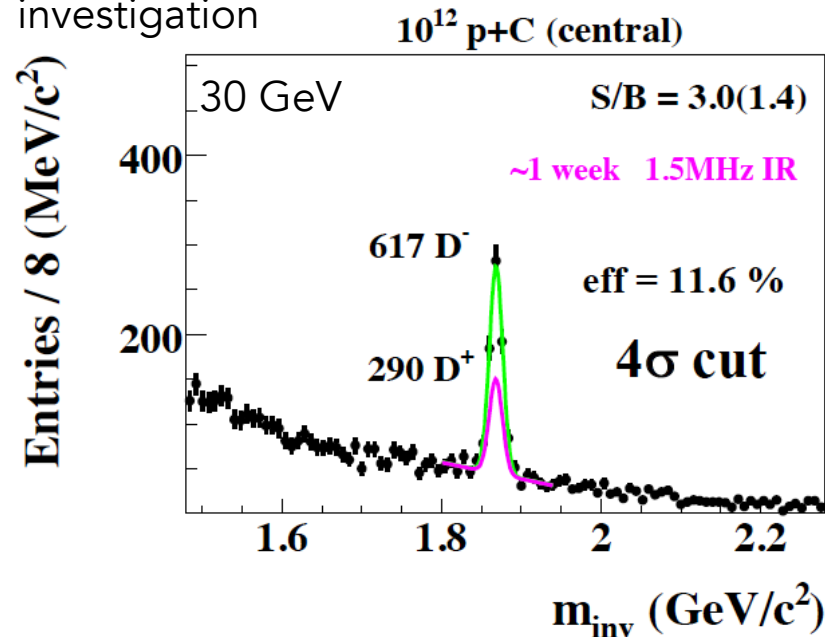
Charm in p+A with CBM

# Charm at CBM

Total charm cross-section

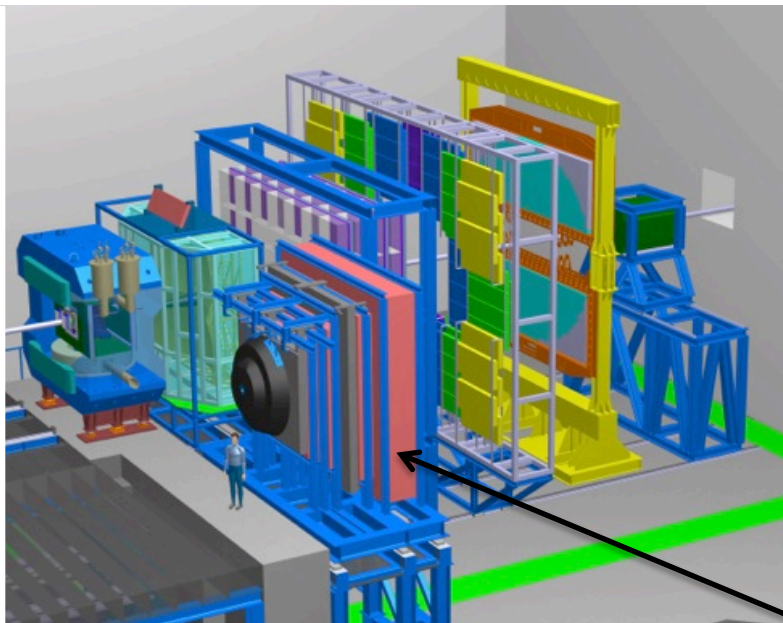


- Lack of data close to threshold.
- Study of charm production mechanism and propagation in cold nuclear matter in proton induced reactions.
- $D^{0+}$ -reconstruction feasible,  $\Lambda_c$  under investigation

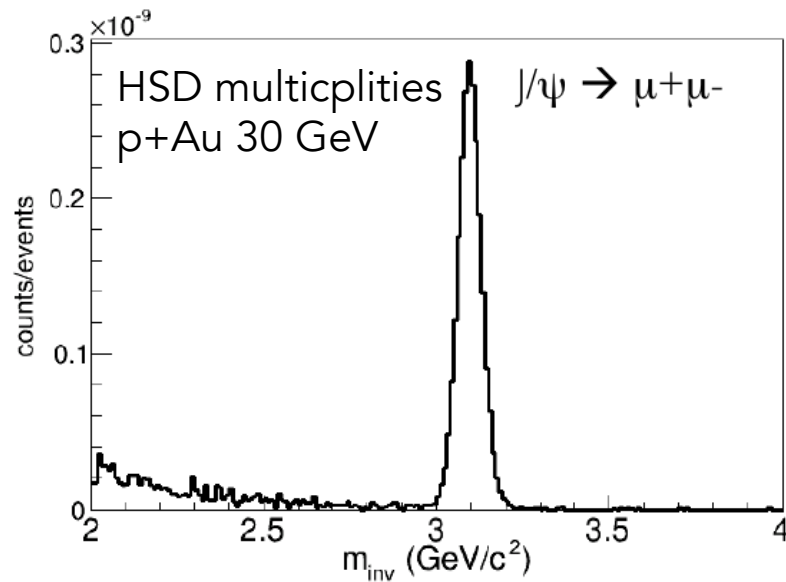




# Charm at CBM: Myon Setup



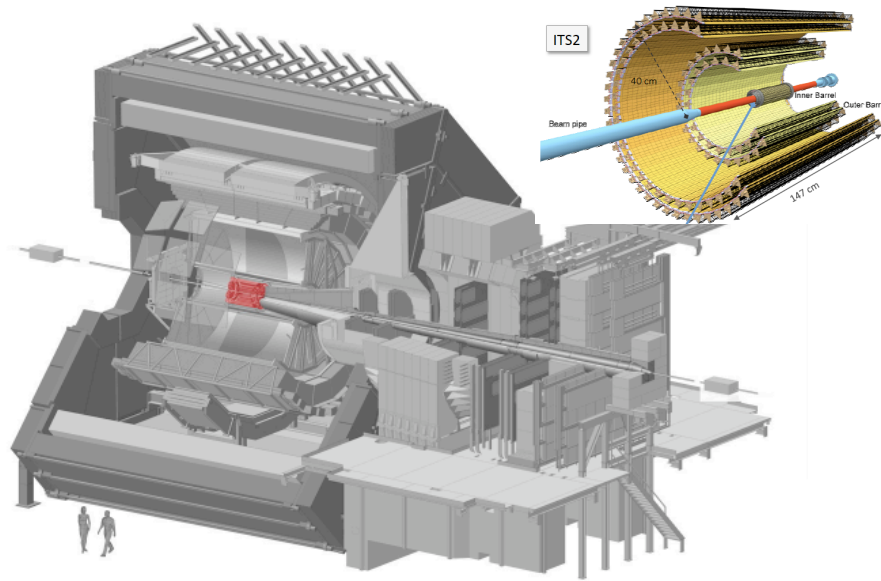
$J/\Psi$  reconstructions feasible with Myon (MUCH) setup



Absorber Layers

Charm in p+p with ALICE in the Future

# ALICE Upgrade: ITS2 2019



ITS ( $|\eta| < 0.9$ )

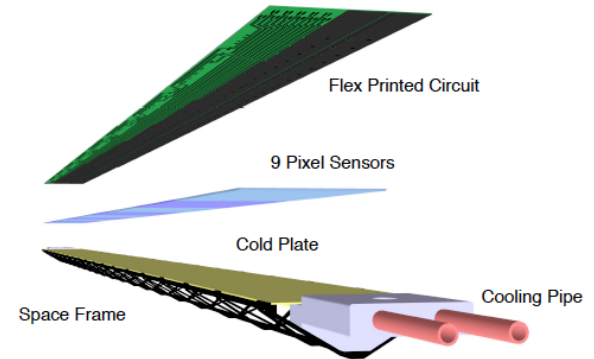
- 6 Layers of silicon detectors
- Trigger, tracking, vertex

Motivation, goals and technology

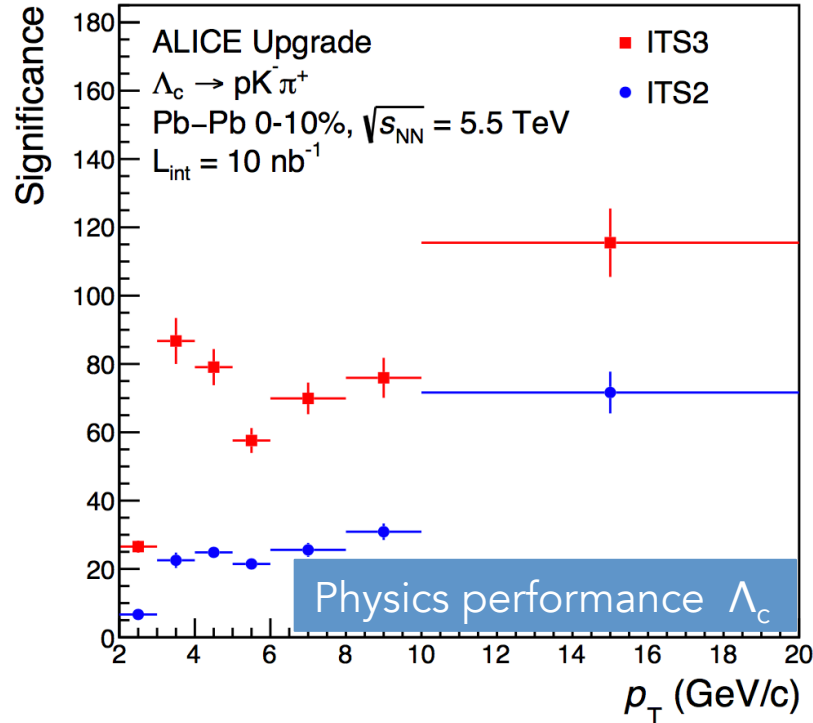
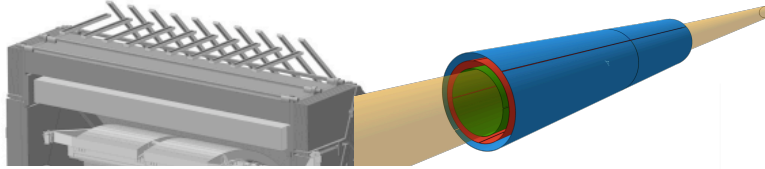
- Improved tracking precision  
smaller pixels, closer to IP, less material
- Faster readout
- CMOS Pixel Sensor (ALPIDE)

ITS  $dE/dx$

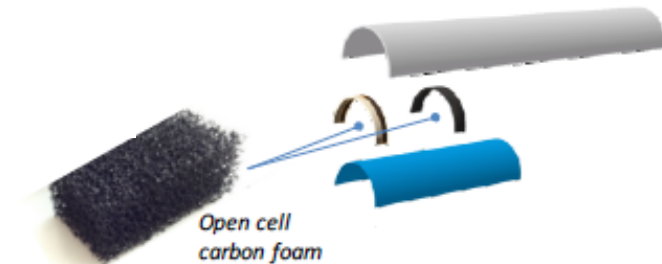
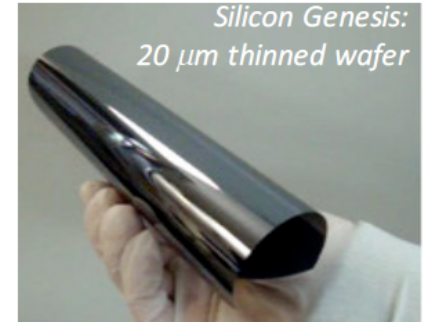
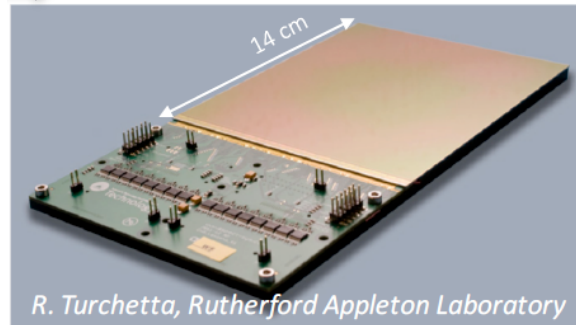
Only 15% silicon!  
Further reduction:  
Frame, cooling and readout



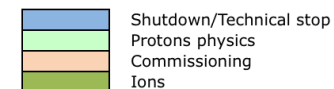
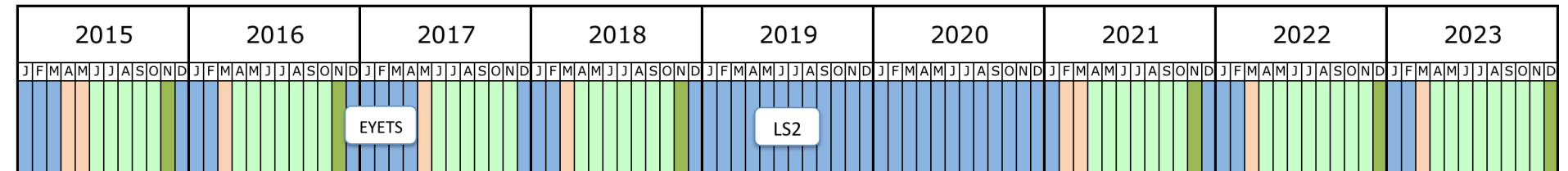
# ALICE Upgrade: ITS3 2024



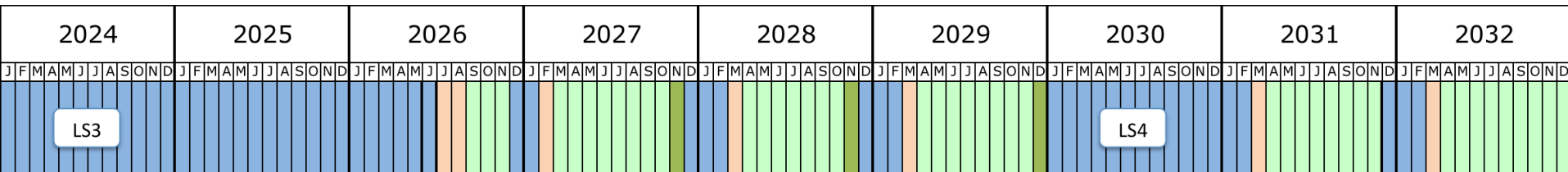
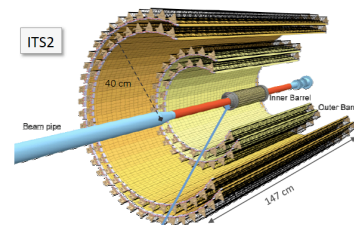
- Cooling with forced air flow:  
Reduce power densities (below 20mW/cm<sup>2</sup>)
- Reduce supporting structure:  
Large area pixels, self-supported  
New technology and procedures



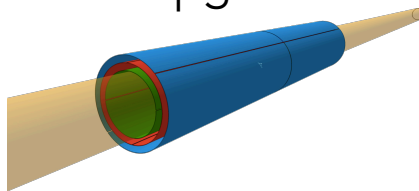
# ALICE Upgrades: Timeline



TPC upgrade  
ITS 2 upgrade  
50 kHz



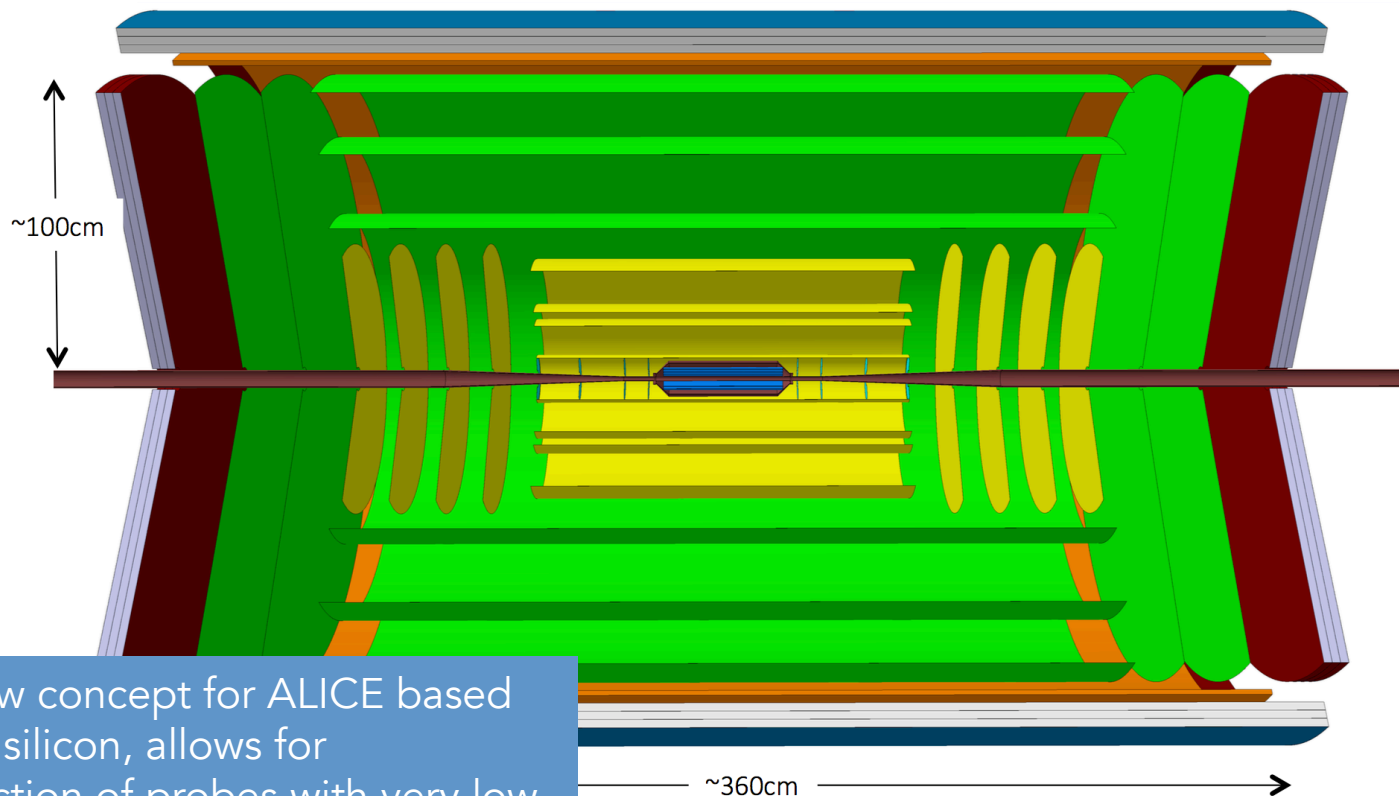
## ITS 3 upgrade



## Upgrade concept for LS4 MHz

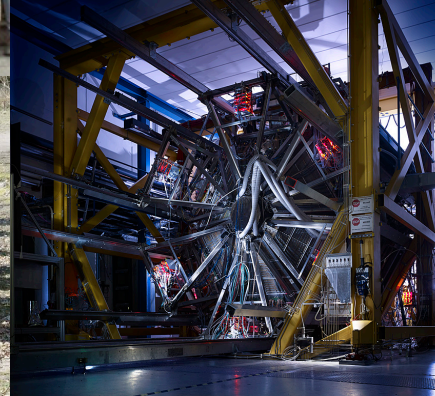
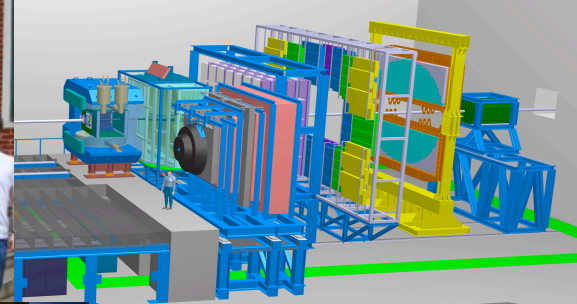
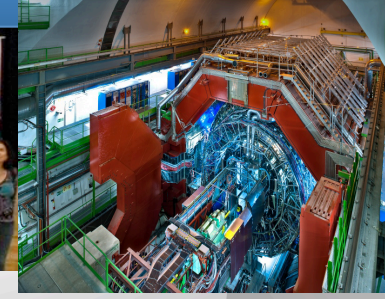


# ALICE Upgrade concept for 2030



Totally new concept for ALICE based purely on silicon, allows for reconstruction of probes with very low momentum (photons, dileptons ..).

# The Collaborations

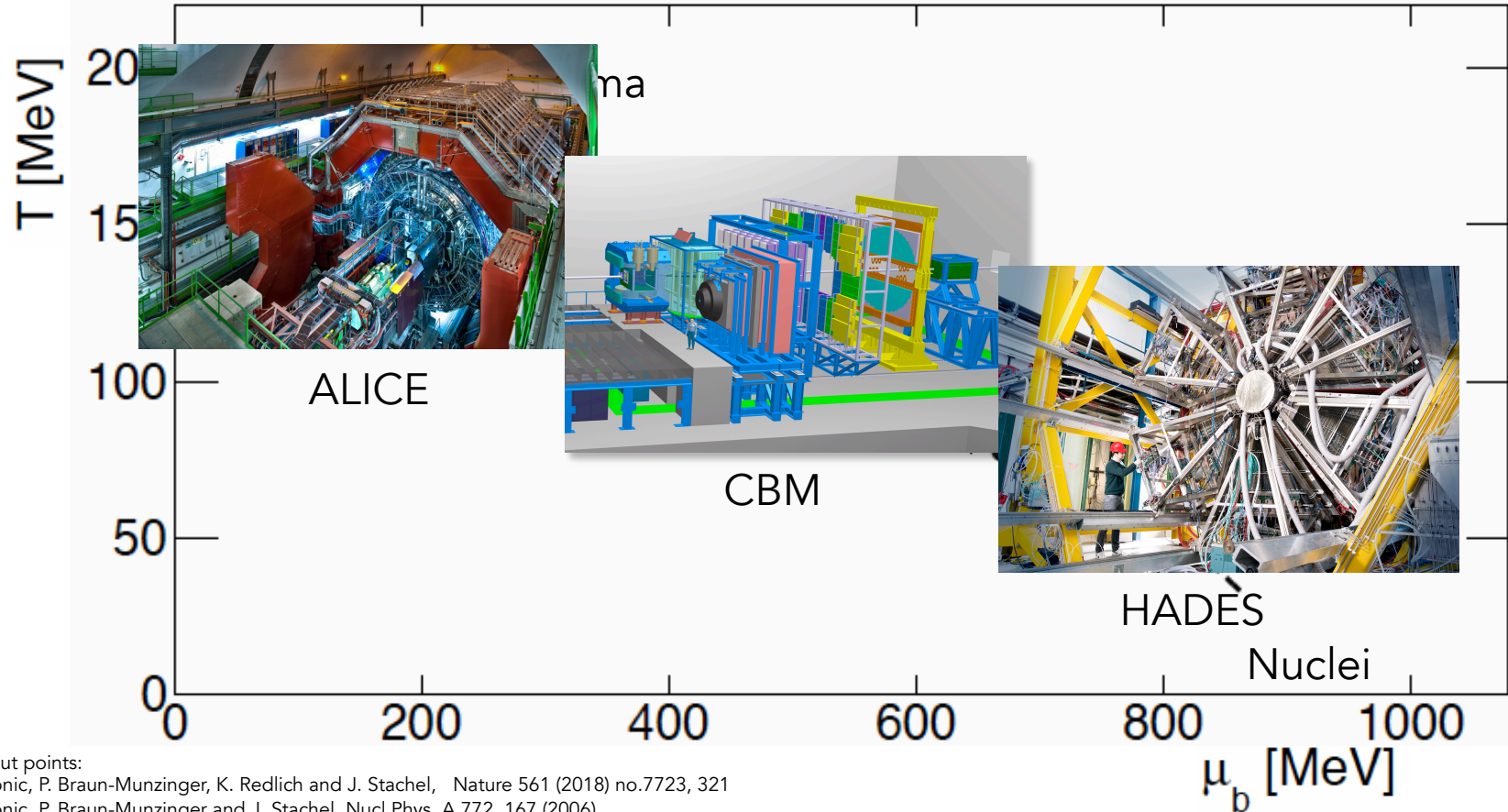


Many thanks to  
C.Blume, P.Braun-  
Munzinger, M.Deveaux,  
B.Doenigus, T.Galatyuk,  
N.Herrmann, S.Masciocchi,  
C.Muentz, P.Salabura,  
J.Stroth, J.Wirth.

Thank you!



# Probing the Phase Diagram of Strongly Interacting Matter

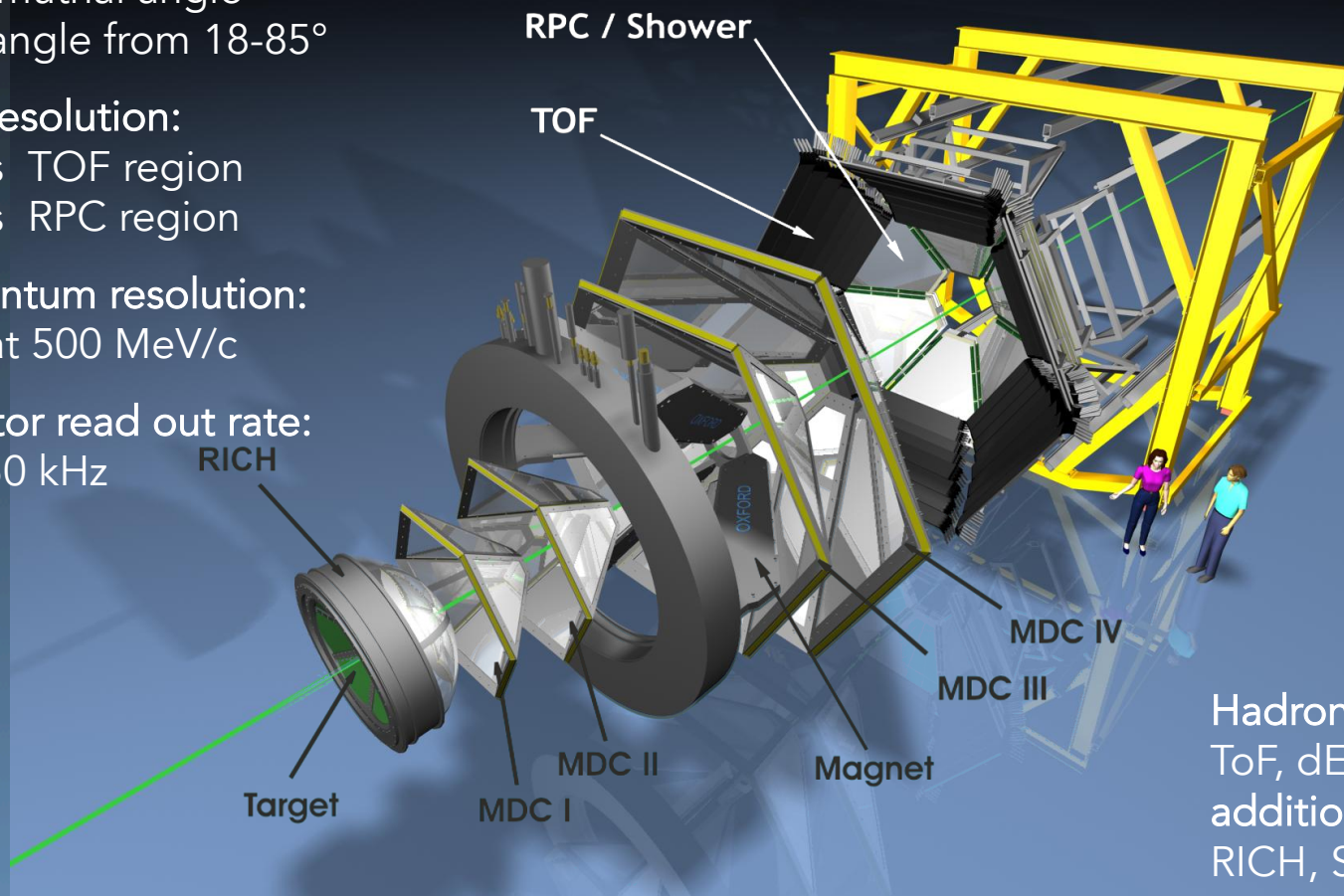


Acceptance:  
full azimuthal angle  
polar angle from 18-85°

Time resolution:  
150 ps TOF region  
90 ps RPC region

Momentum resolution:  
1.5% at 500 MeV/c

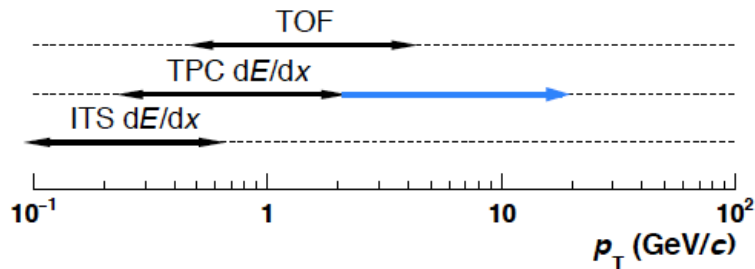
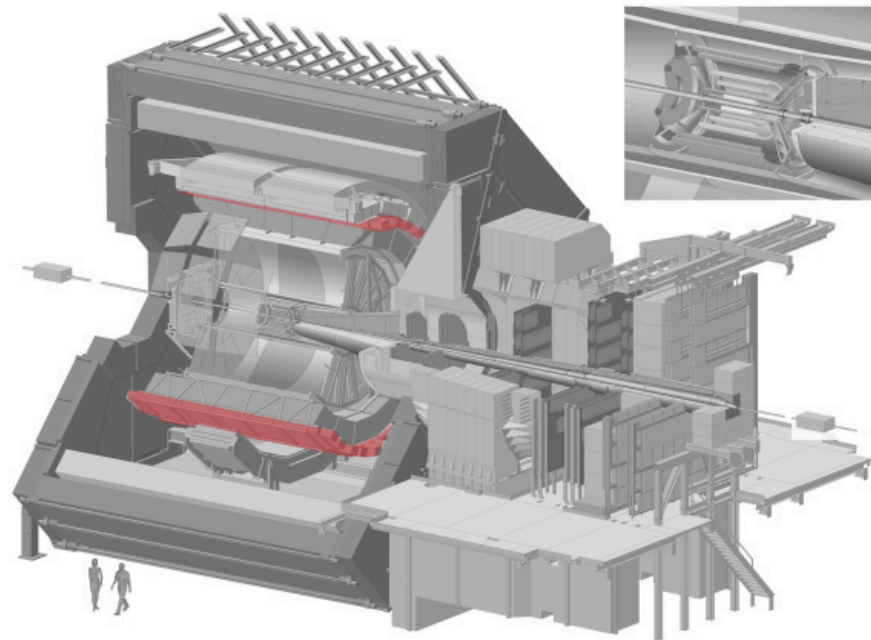
Detector read out rate:  
max. 50 kHz



Hadron PID:  
ToF, dE/dx  
additional PID for leptons:  
RICH, SHOWER



# ALICE setup



ITS ( $|\eta| < 0.9$ )

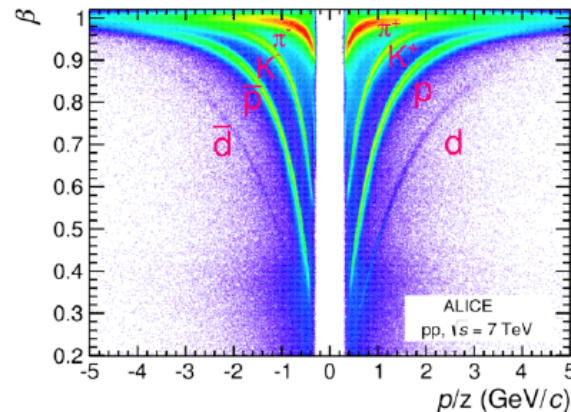
- 6 Layers of silicon detectors!
- Trigger, tracking, vertex, PID (dE/dx)

TPC ( $|\eta| < 0.9$ )

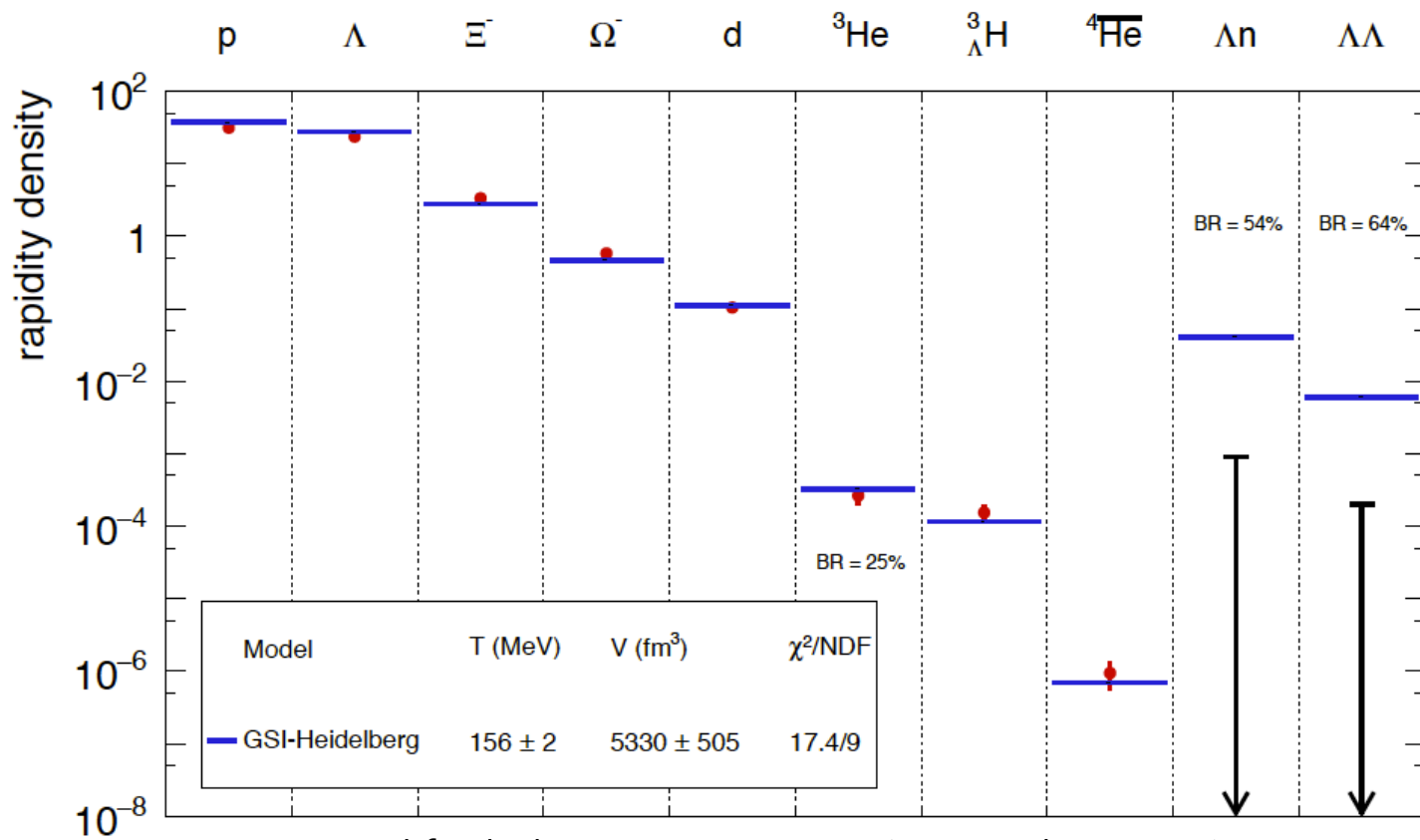
- Gas-filled ionization detection volume!
- Tracking, vertex, PID (dE/dx)!
- Weak decay reconstruction (topological)

TOF ( $|\eta| < 0.9$ )

- Multi-gap resistive plate chambers!
- PID via velocity determination



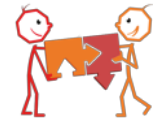
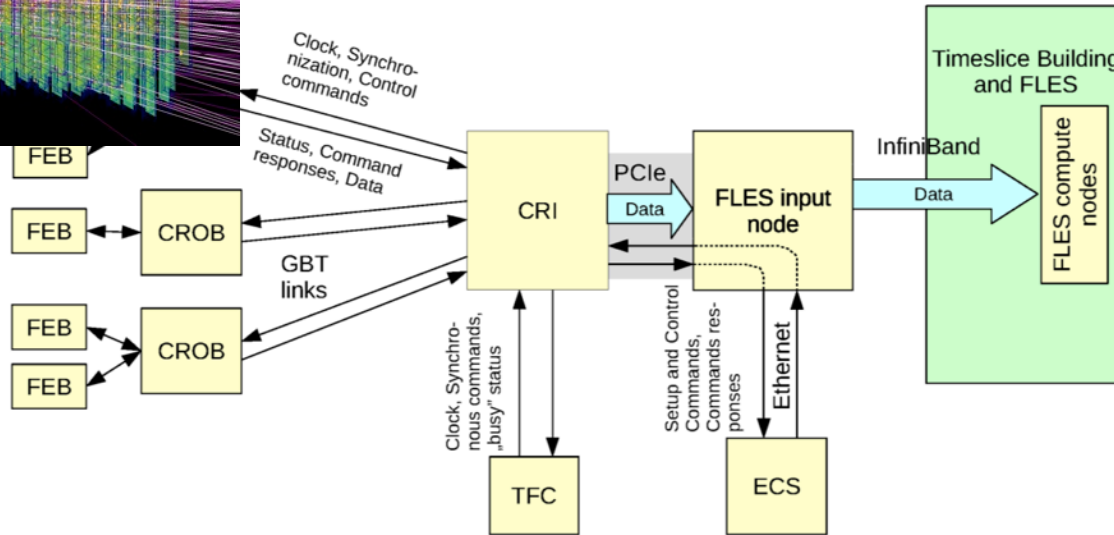
# Exotica search with ALICE



Simplified plot, CERN Courier (September 2015)

# CBM data processing system

- Reaction rate Au+Au:  $10^7$  collisions / s
- Data rate:  $\sim 1$  TB / s
- Archived data volume 10 - 20 PB/year

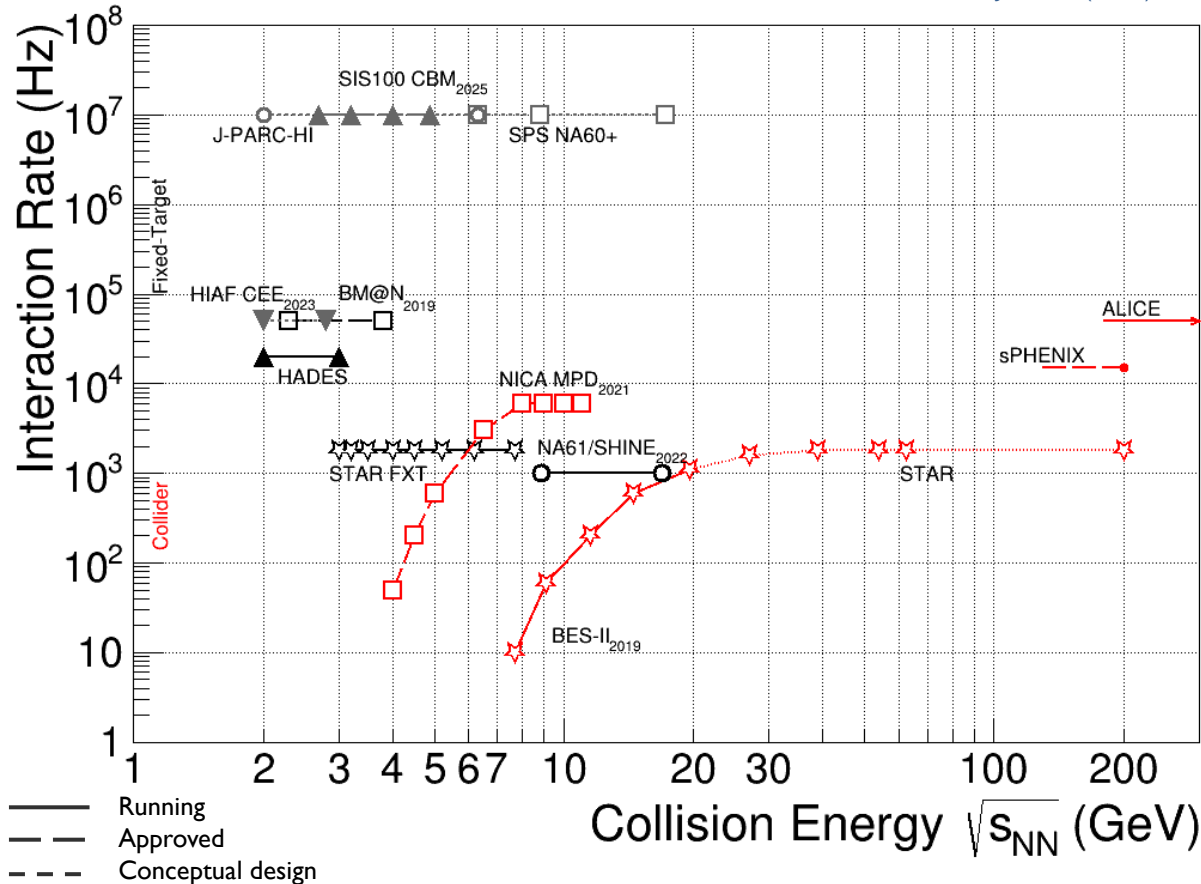


*ALFA - a common framework for  
ALICE and FAIR experiments*

- Radiation tolerant detectors and front-end electronics
- Software based event selection, 4D tracking

# Interaction Rate

CBM Collab., EPJA 53 3 (2017) 60



CBM's unique feature –  
high statistics measurement  
of rare probes