The **F**acility for **A**ntiproton and **I**on **R**esearch

Takeshi's
70th Birthday
April 6, 2013


e=mc2

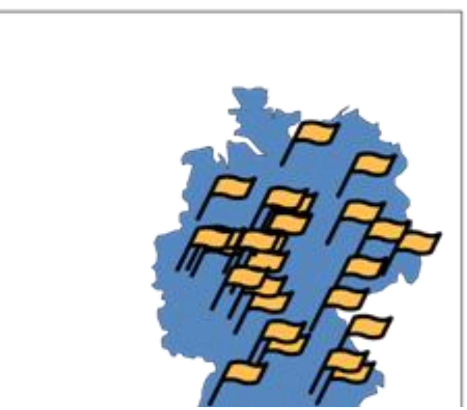
FAIR and GSI-Site @ Darmstadt

Dear Takeshi, HAPPY birthday from all Your friends at GSI and FAIR !!!

1500 x 60 m posts

International Cooperation : 2400 FAIR users at 100+ Labs

… from more than 40 countries, numbers rising - BRASIL now !
World's largest fundamental science project of this decade …
under construction



German University groups Max Planck Inst

4 Helmholtzcenters Juelich, KIT, HZDR, GSI


February 4-10, 2008
TAKESHI KODAMA

International Treaty

Signing of the **FAIR Convention** by representatives of
Finland, France, India, Poland, Romania, Russia, Slovenia and Sweden
in Wiesbaden on 4/10/2010

FAIR

Nuclear Structure & Astrophysics
(Rare-isotope beams)

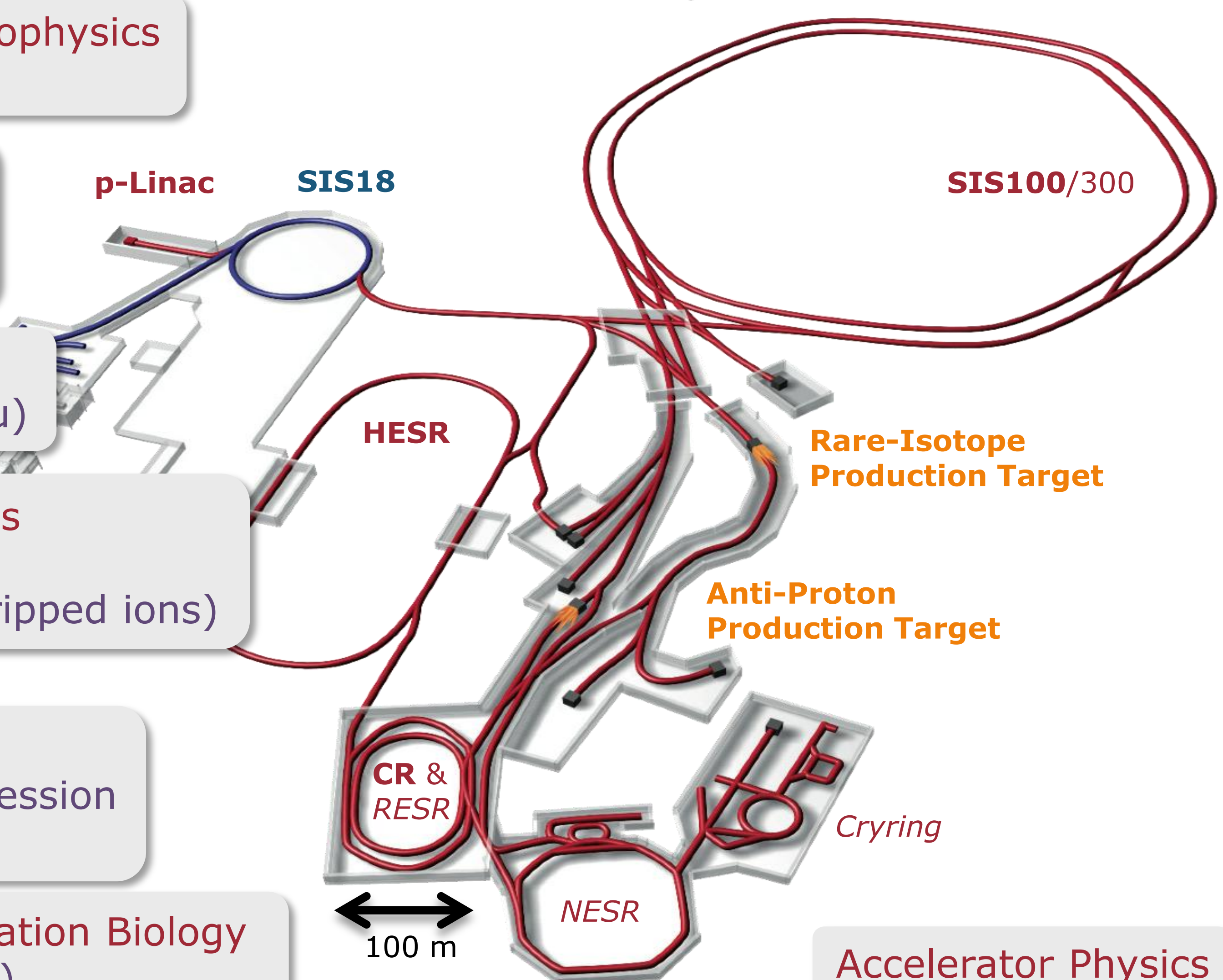
Hadron Physics
(Stored and cooled
14 GeV/c anti-protons)

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

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

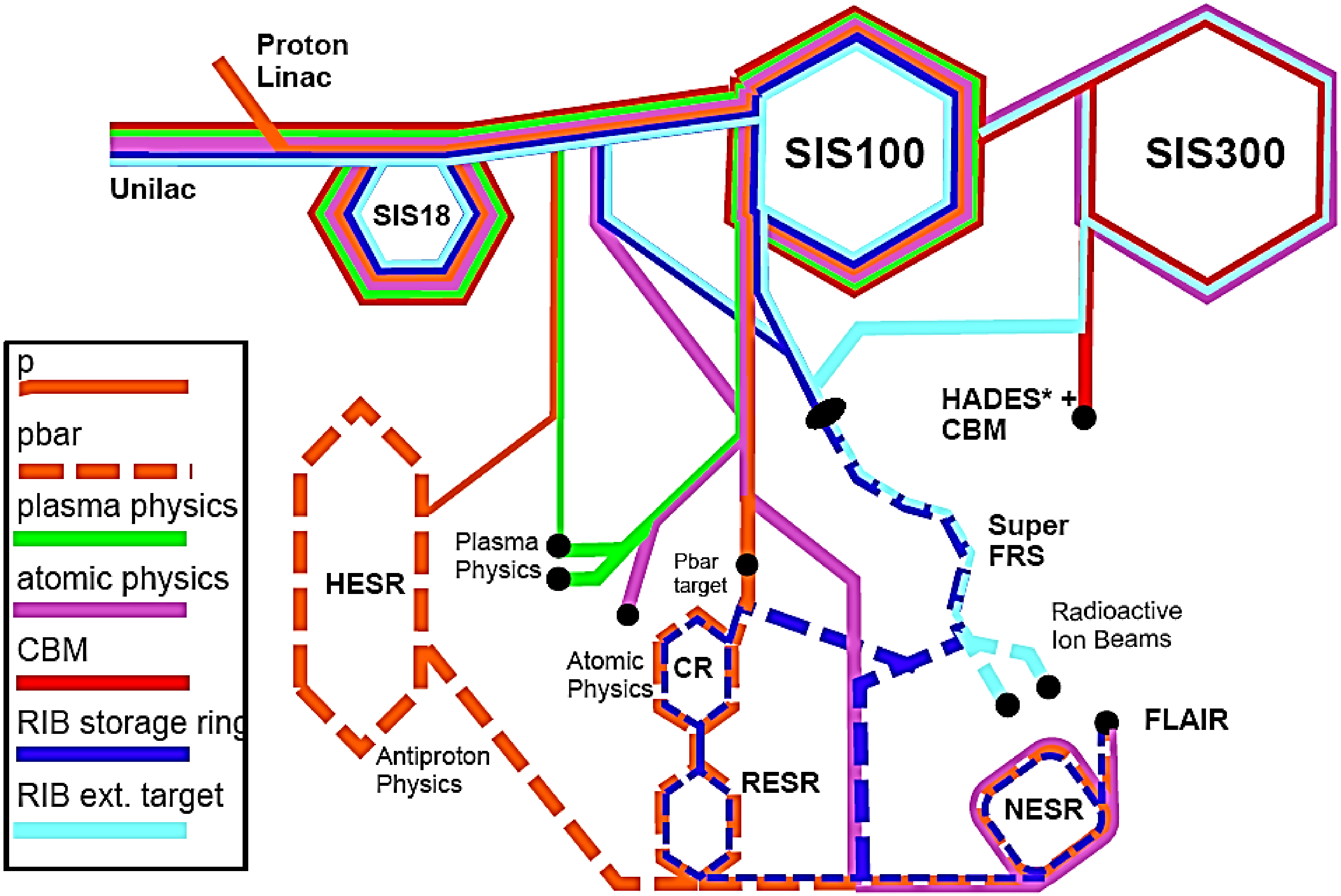
Dense Bulk Plasmas
(Ion-beam bunch compression
& petawatt-laser)

Materials Science & Radiation Biology
(Ion & antiproton beams)



Accelerator Physics

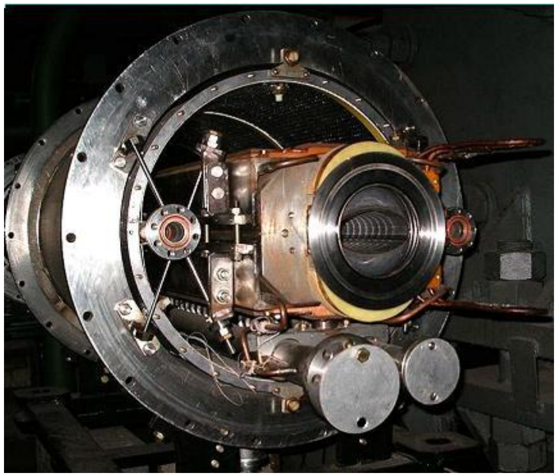
Parallel Operation



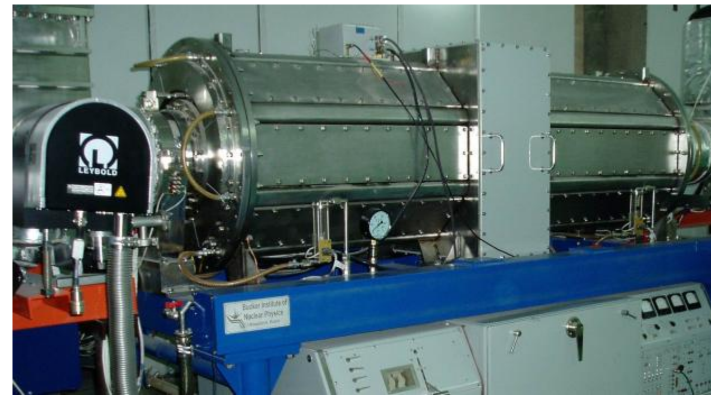

Oh my God !

FAIR Accelerator Challenges

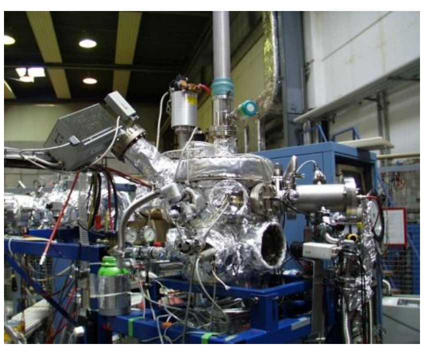
Compact & cost effective accelerators
Fast cycling superconducting magnets
dB/dt ~ 4T/s



Fast acceleration
High gradient, variable frequency
Ferrite & MA loaded cavities

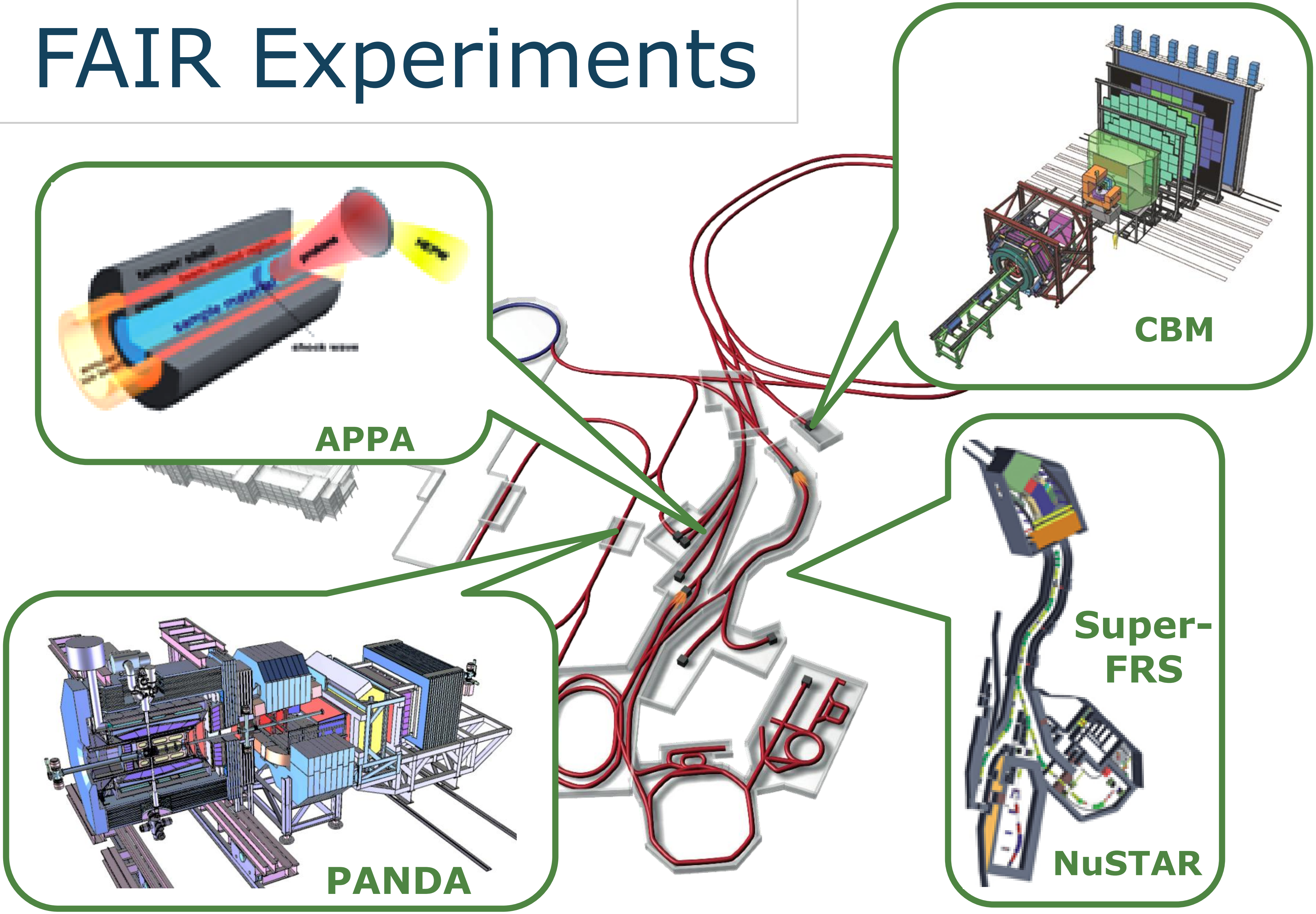


XHV @ high beam intensities
Extremely high vacuum ~10^{-13} mbar



Precision beams
Electron & stochastic cooling

FAIR Experiments

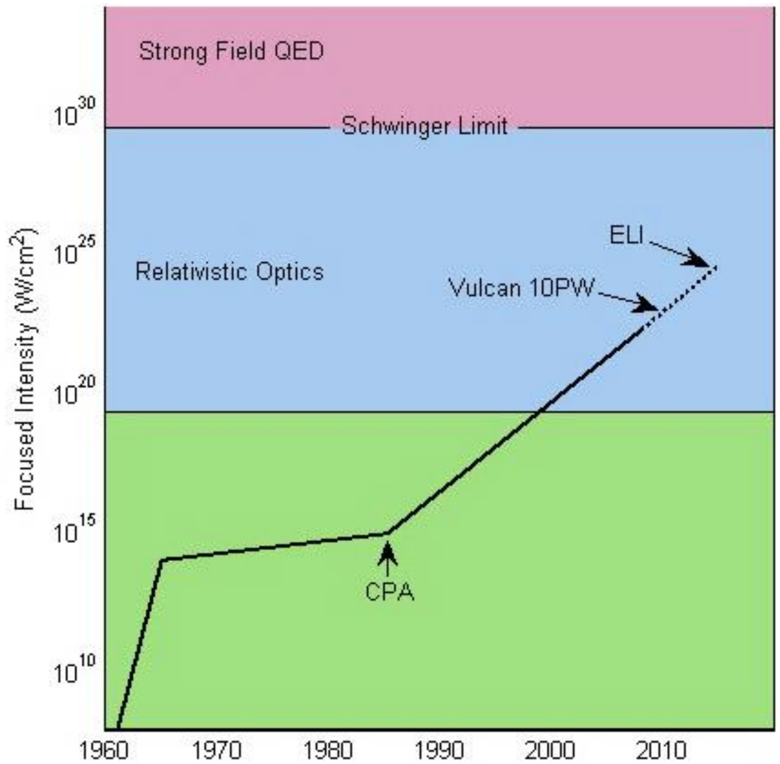


APPA

- **A**tomic Physics (SPARC)
  - Parity-violating atomic transitions
  - High-field QED in bound system
  - Particle-antiparticle pair production
- **P**lasma **P**hysics
  - Warm Dense Matter (WDM)
  - High Energy Density Matter (HEDgeHOB)
  - Planetary plasma-astrophysics
- **A**nti-matter Physics (FLAIR)
- Nuclear Physics
  - Measurement of nuclear moments
  - Nuclear excitation by laser excitation (NEET)
- Biophysics/medicine, Materials Science (BioMat)
- Accelerator Science
  - Laser-plasma acceleration

Large EM Fields

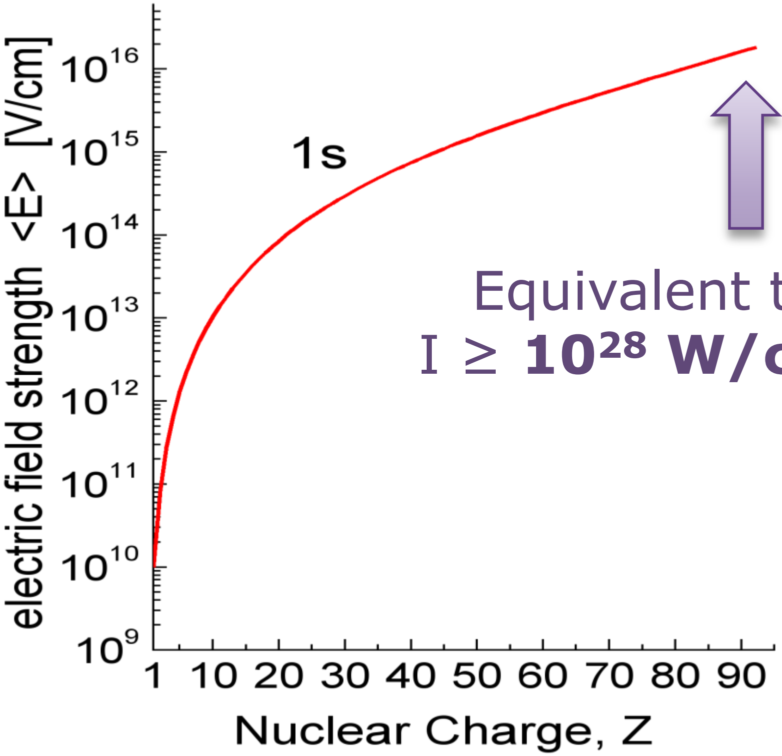
Lasers



(adapted from Mourou, Tajima, Bulanov, RMP **78**, 2006)

Sub-fs pulses

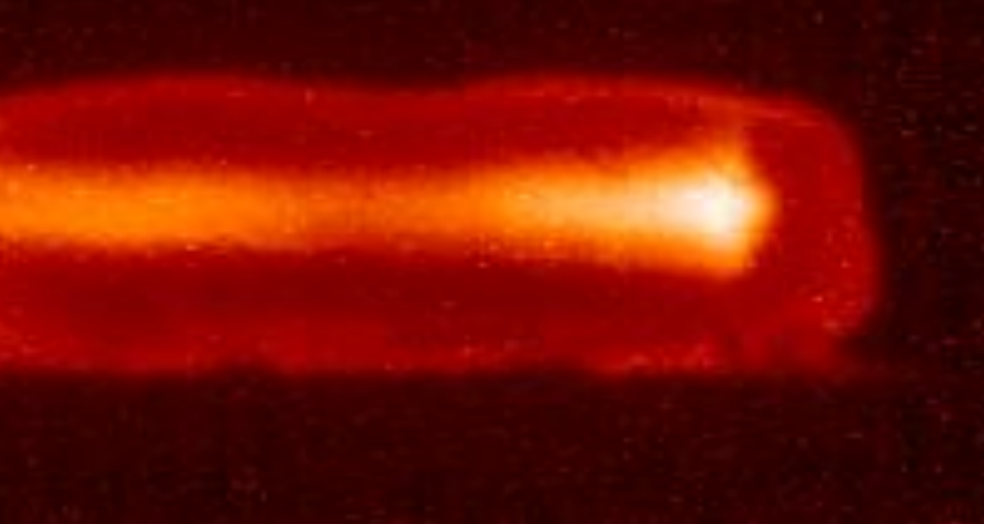
Heavy ions

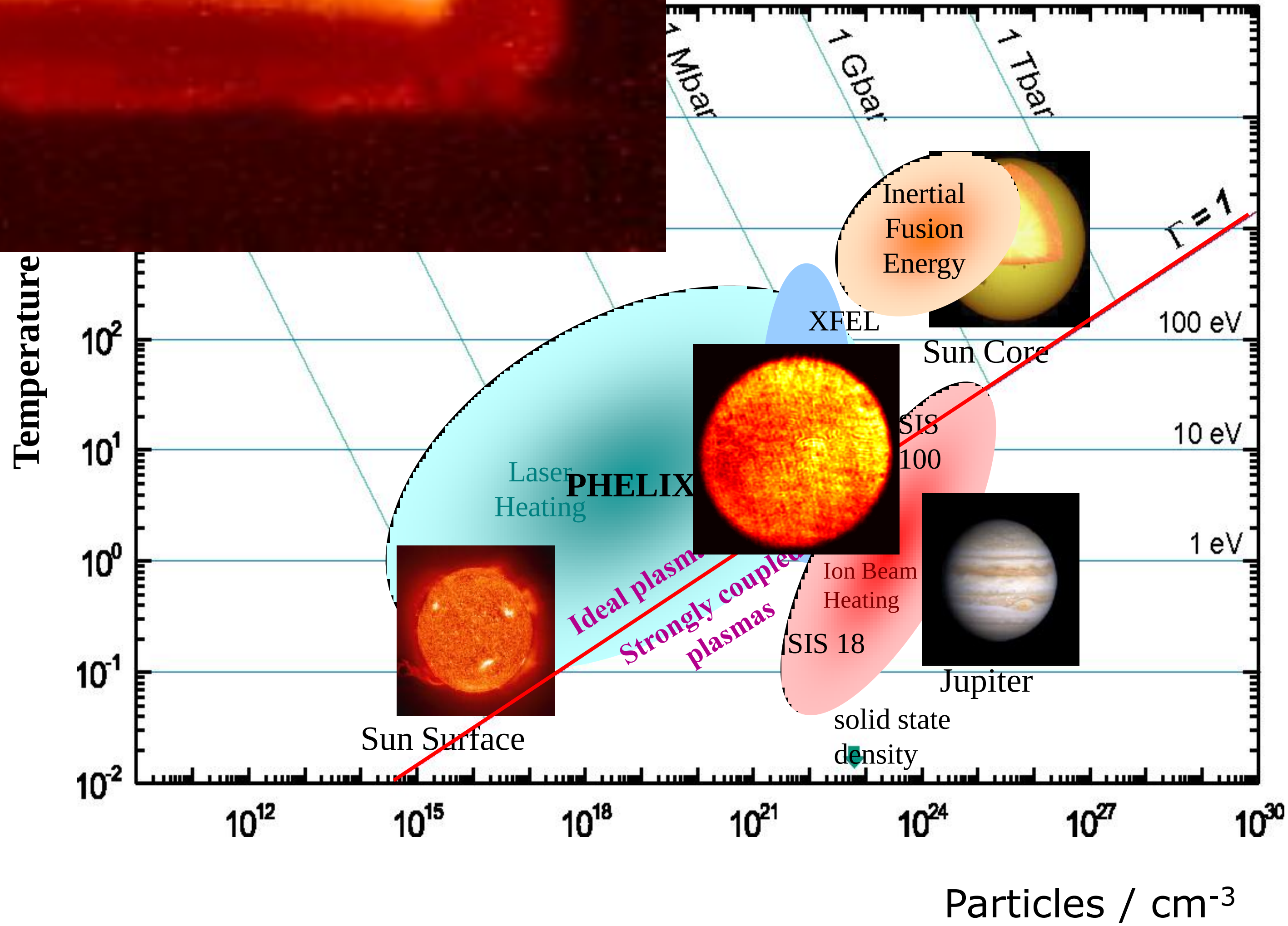


Equivalent to
$I \geq$ **10^{28} W/cm²**

Large EM fields, zs pulses

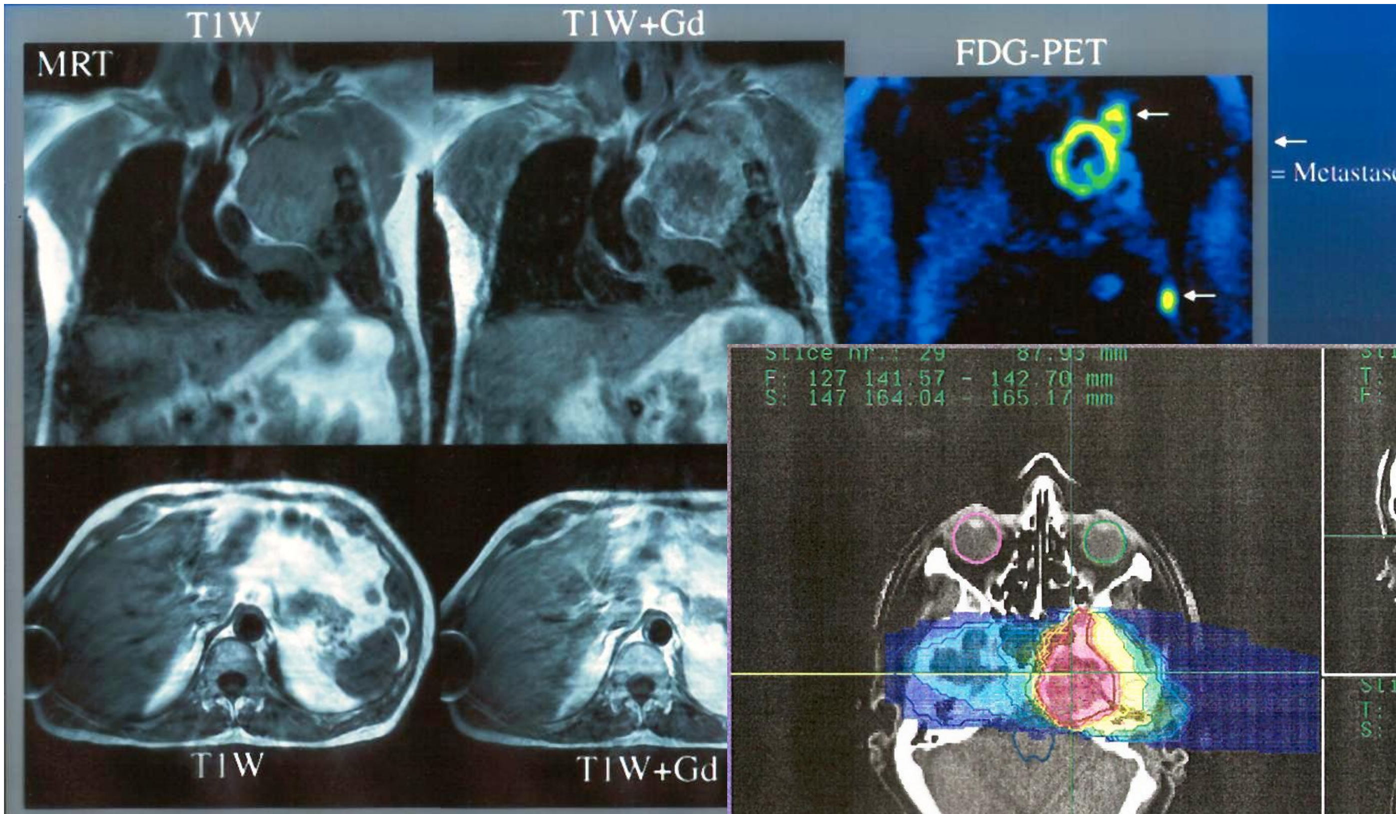
e Plasmas



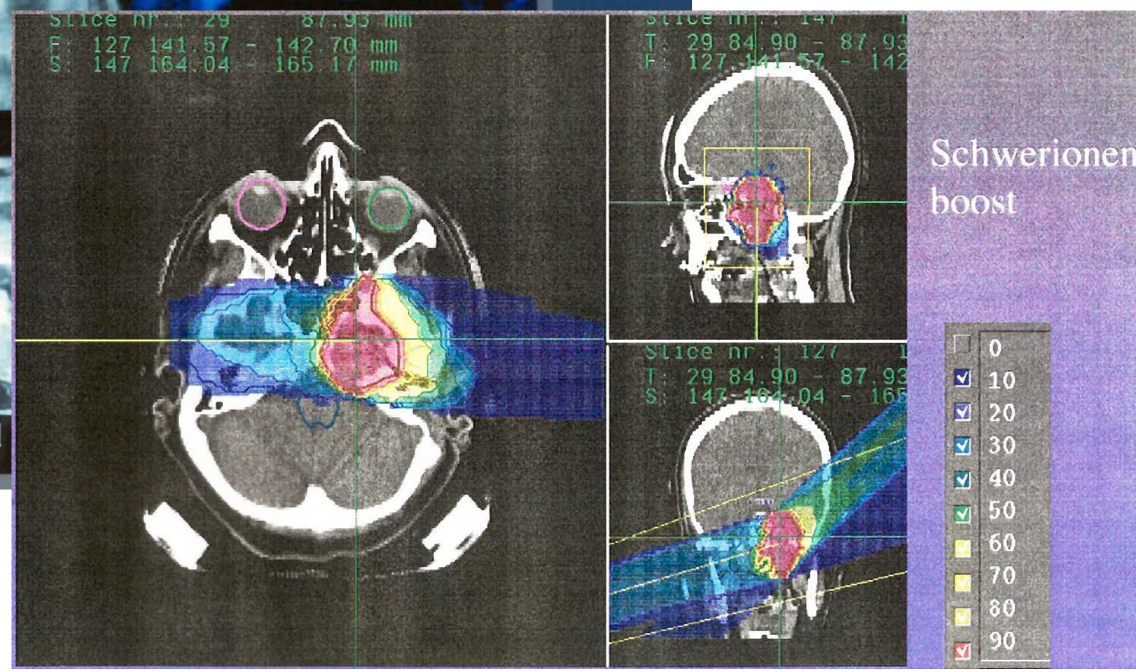

1 Mbar
1 Gbar
1 Tbar
Inertial
Fusion
Energy
Γ = 1
XFEL
100 eV
Sun Core
10 eV
SIS
100
Laser
Heating
PHELIX
1 eV
Temperature
10^2
10^1
10^0
10^{-1}
10^{-2}
Ideal plasm
Strongly couple
plasmas
Ion Beam
Heating
SIS 18
Jupiter
Sun Surface
solid state
density
10^{12}
10^{15}
10^{18}
10^{21}
10^{24}
10^{27}
10^{30}
Particles / cm^{-3}

Nuclear Medicine

Small cell lung carcinoma

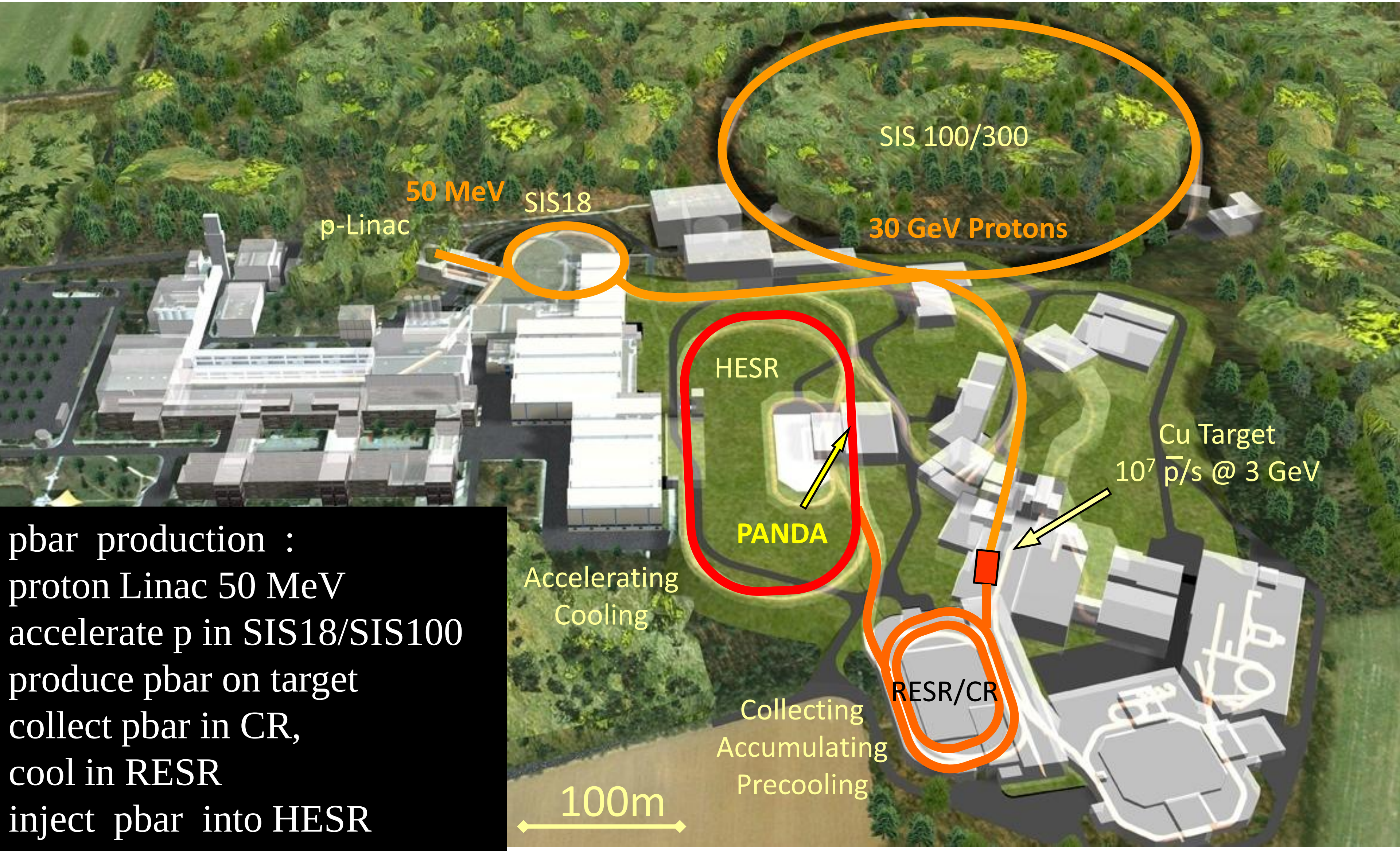


^{12}C Therapy
@ GSI



Adenoid cystic ca.

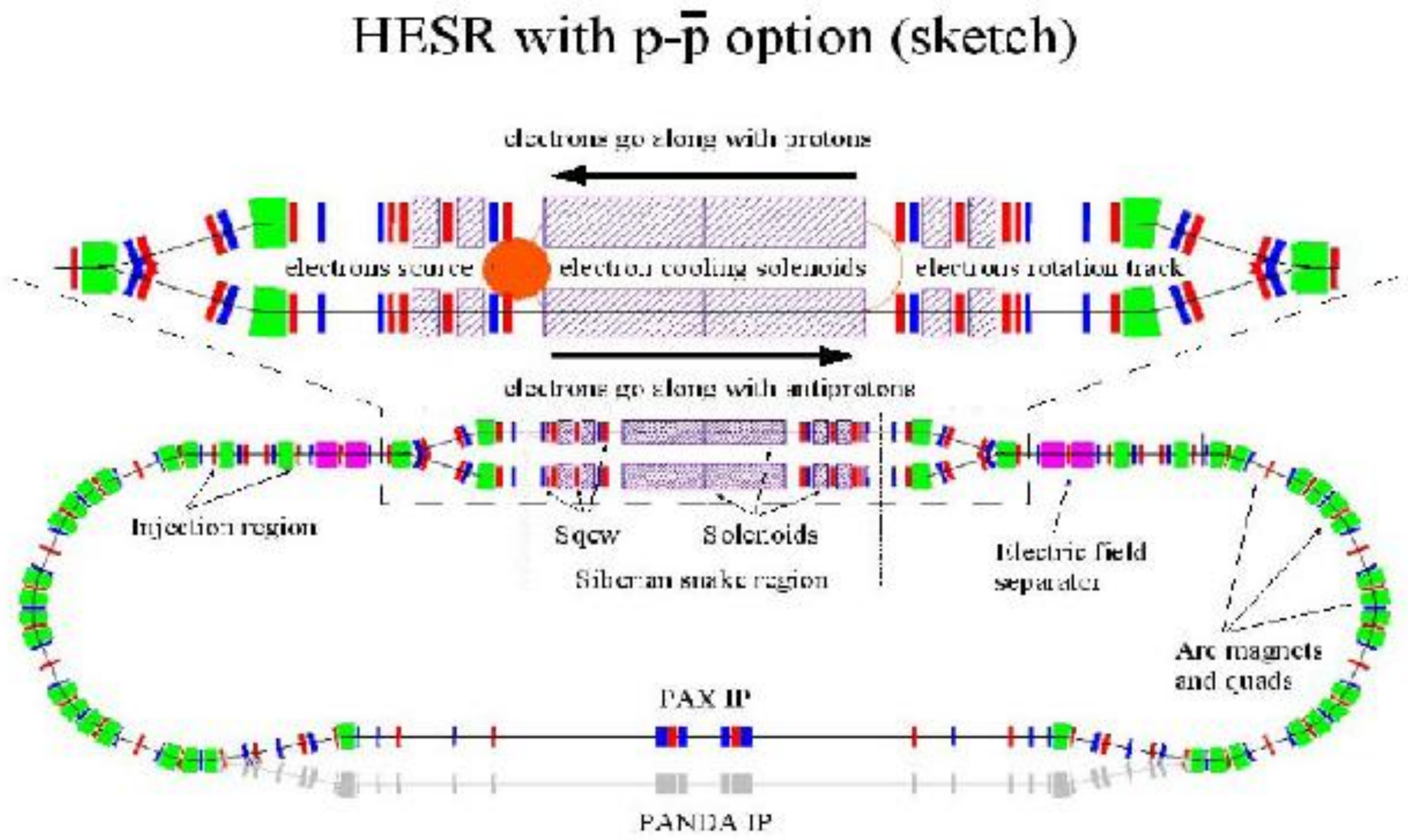
Brilliant Anti-proton beams
- Strange & Charm matter



pbar production :
proton Linac 50 MeV
accelerate p in SIS18/SIS100
produce pbar on target
collect pbar in CR,
cool in RESR
inject pbar into HESR

BEAUTY ? HESR collider mode : sqrt(s) = 30 GeV !

- from Ypsilons to X_b, Y_b, Z_b with M >12 GeV



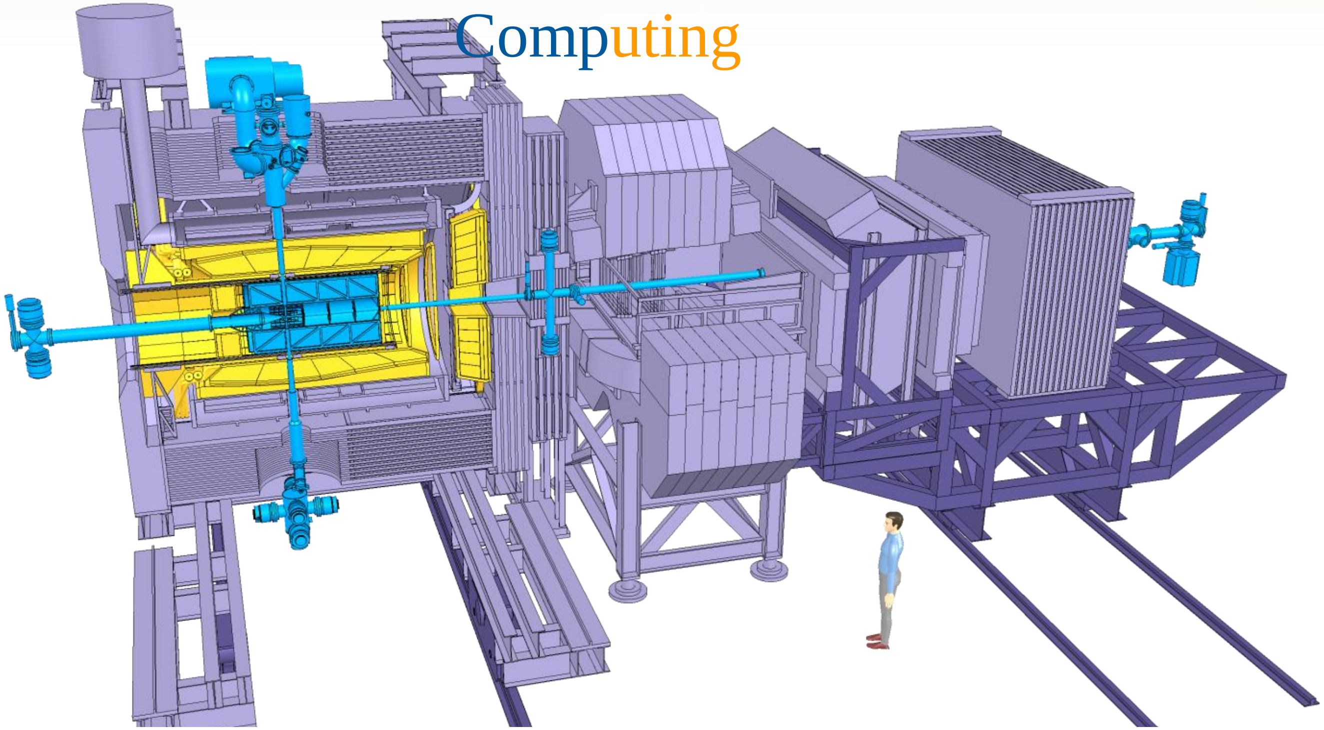
R&D and Construction of panda

700 tons

Pellet Target
Micro Vertex Detector
Central Tracker
Luminosity Monitor

Electronics
Simulation
Physics
Infrastructure
Computing

DIRC Detector
EM Calorimeter
Planar GEMs



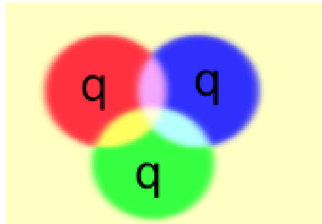
FAIR

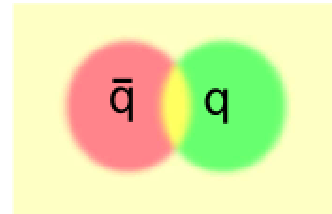
Physics Book, Technical Design Reports: EMC, Magnets, Targets, Tracking

Beyond standard quark configurations

- QCD allows much more than what we have observed to date:

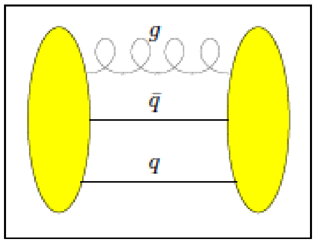
Baryons



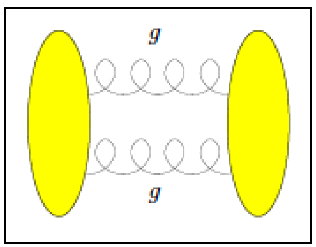


Mesons

Exotica:

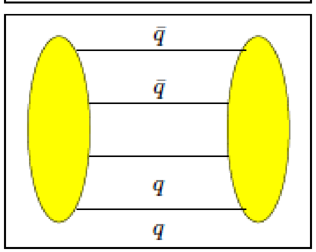


hybrid:
with gluon excitation

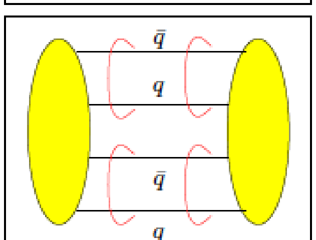


glueball:
pure gluon state

} may have J^{PC} not allowed for $q\bar{q}$



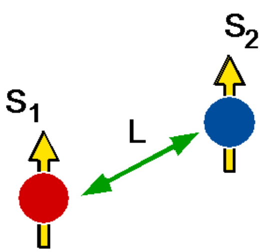
4 quark state:
compact 4–quark state



hadronic molecule:
bound state of two mesons

Courtesy C. Hanhart

Gluonic excitations



$S = S_1 + S_2$

$J = L + S$

$P = (-1)^{L+1}$

$C = (-1)^{L+S}$

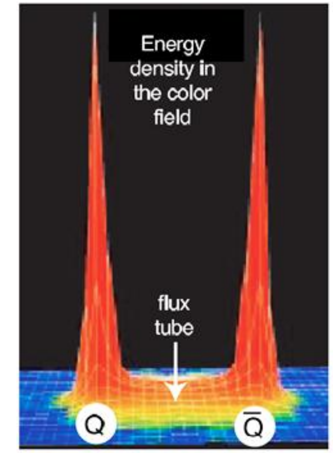
Quantum number rules for quark-antiquark pair:-

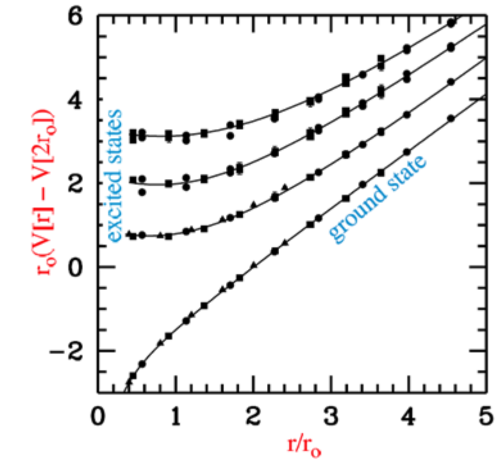
$J^{PC} = 0^{-+}\ \ 0^{++}\ \ 1^{--}\ \ 1^{+-}\ \ 2^{++} \ldots$

Allowed combinations

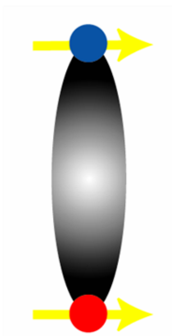
$J^{PC} = 0^{--}\ \ 0^{+-}\ \ 1^{-+}\ \ 2^{+-} \ldots$

Not-allowed





Flux tube model: 1st excited state of flux tube has J=1



Combine with S=1 for quarks to get:

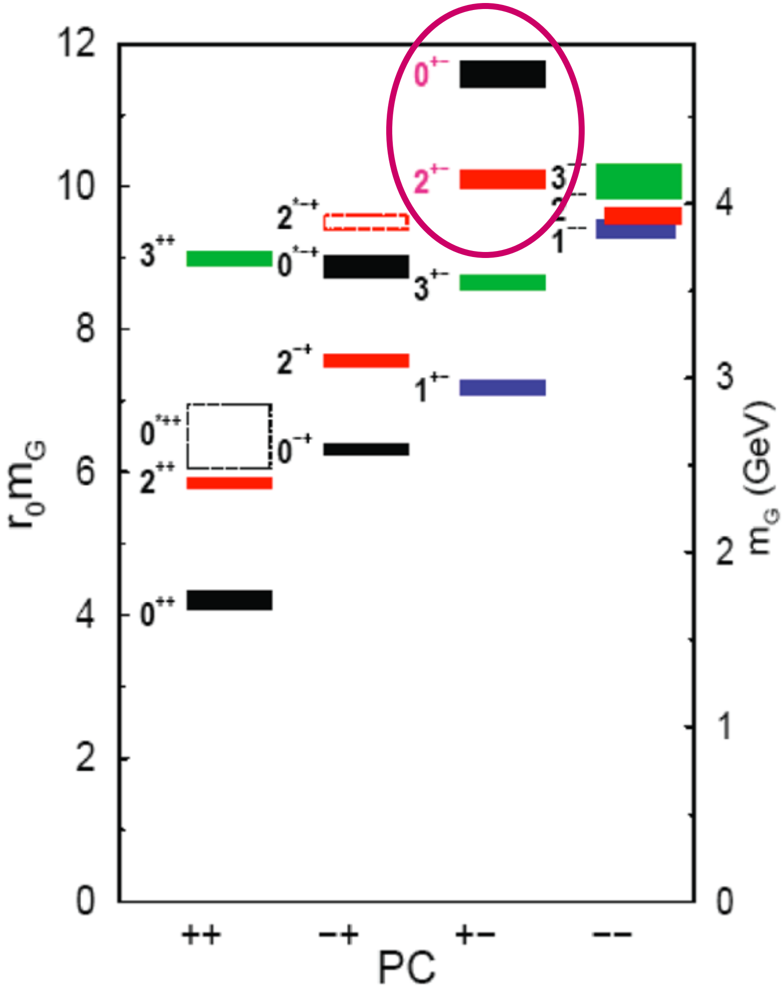
$J^{PC} = 0^{-+}\ \ 0^{+-}\ \ 1^{+-}\ \ 1^{-+}\ \ 2^{-+}\ \ 2^{+-}$

exotic

Exotic mesons are not generated when S=0

PANDA @ FAIR

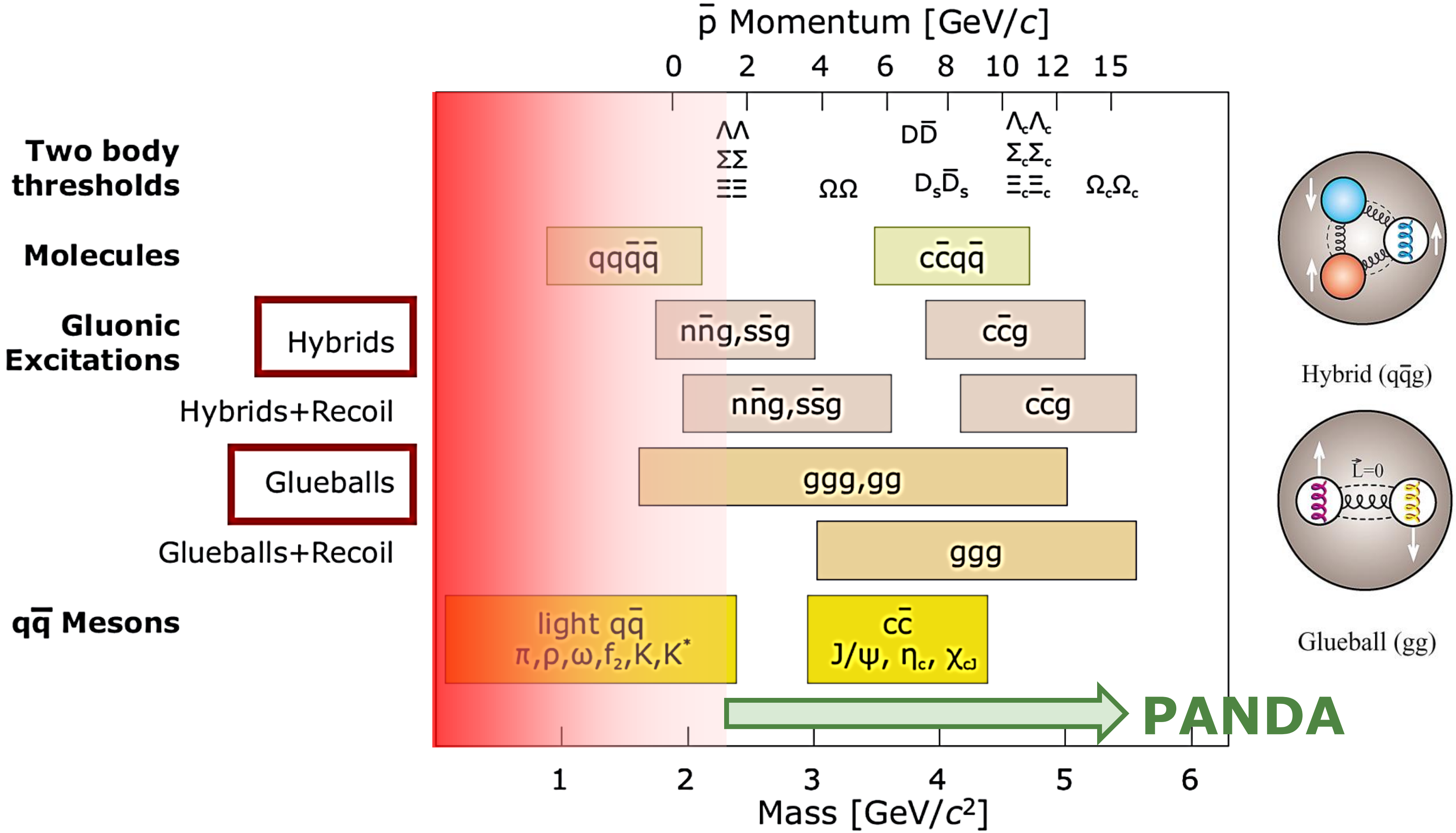
Search for Heavy Glueballs



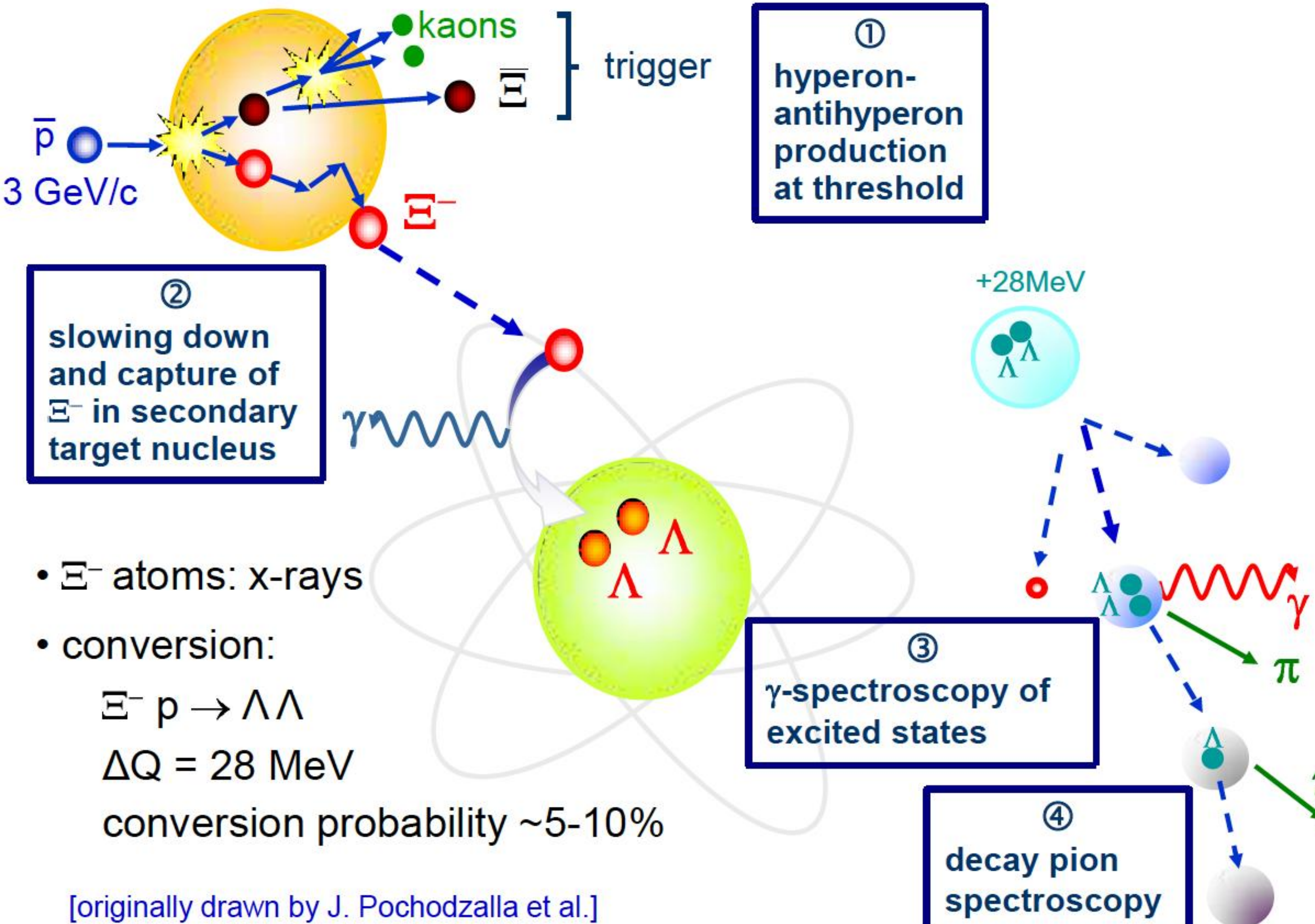
Morningstar & Peardon, PRD60(1999)34509
Morningstar & Peardon, PRD56(1997)4043

- Charmed glueballs
  - flavour blind decays
    - charmed final states
  - only a few charmed mesons around 3 - 4 MeV/c^2
    - less mixing
- Exotic glueballs (oddballs), no mixing!
  - $m(2^{+-})$ = 4140(50)(200) MeV
  - $m(0^{+-})$ = 4740(70)(230) MeV
  - decay modes $\phi\phi$, $\phi\eta$, $J/\psi\eta$, $J/\psi\phi$
  - Narrow widths predicted

Anti-Proton Annihilation @ DA



Multi-Hypernuclear Production and Detection



- Ξ^- atoms: x-rays
- conversion:

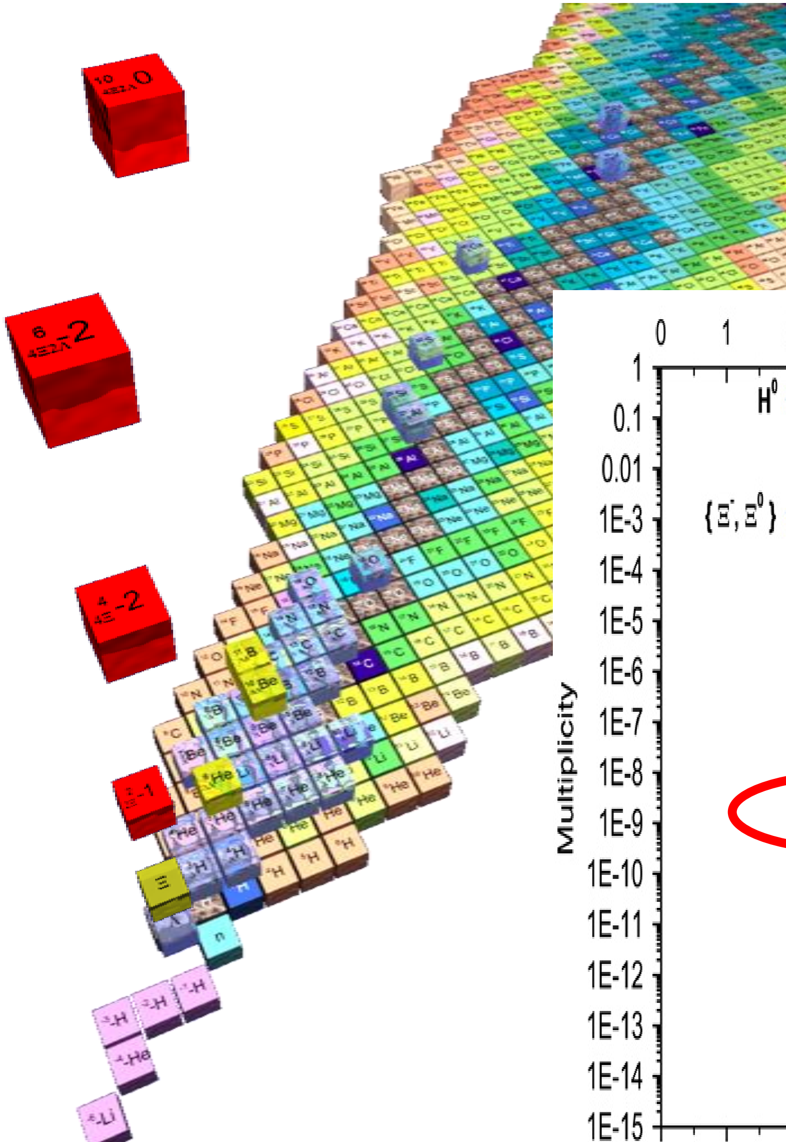
  $\Xi^- p \rightarrow \Lambda\Lambda$

  $\Delta Q = 28$ MeV

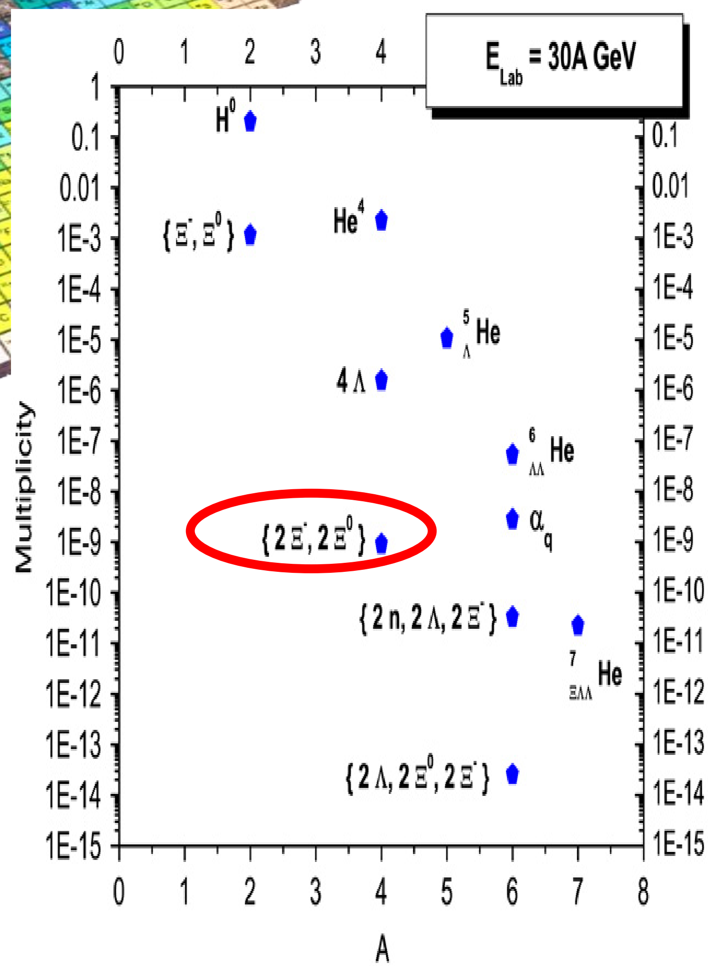
  conversion probability ~5-10%

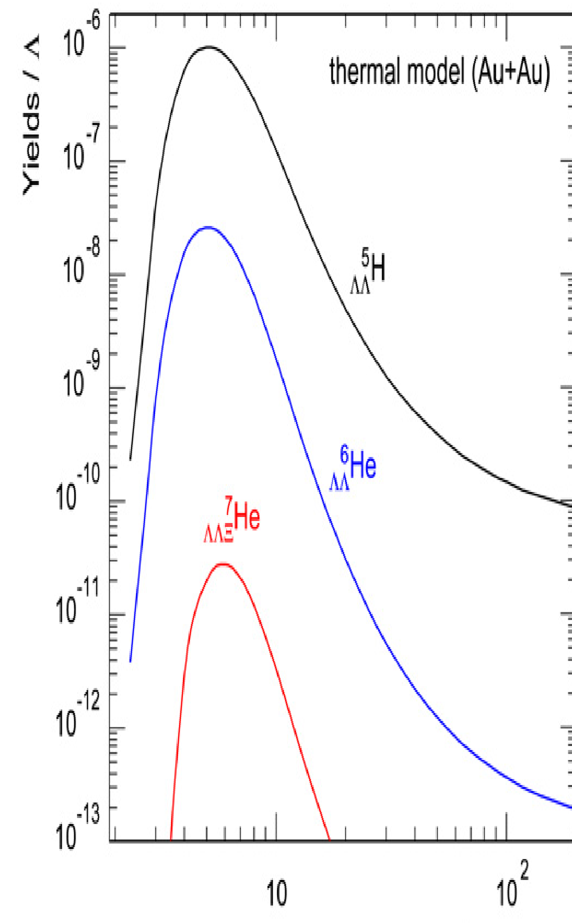
[originally drawn by J. Pochodzalla et al.]

Hypernuclei and metastable multistrange matter



J. Steinheimer, P. Senger, H. Stöcker et. al.
Progress in Particles and Nuclear Physics
62 (2009)313-317

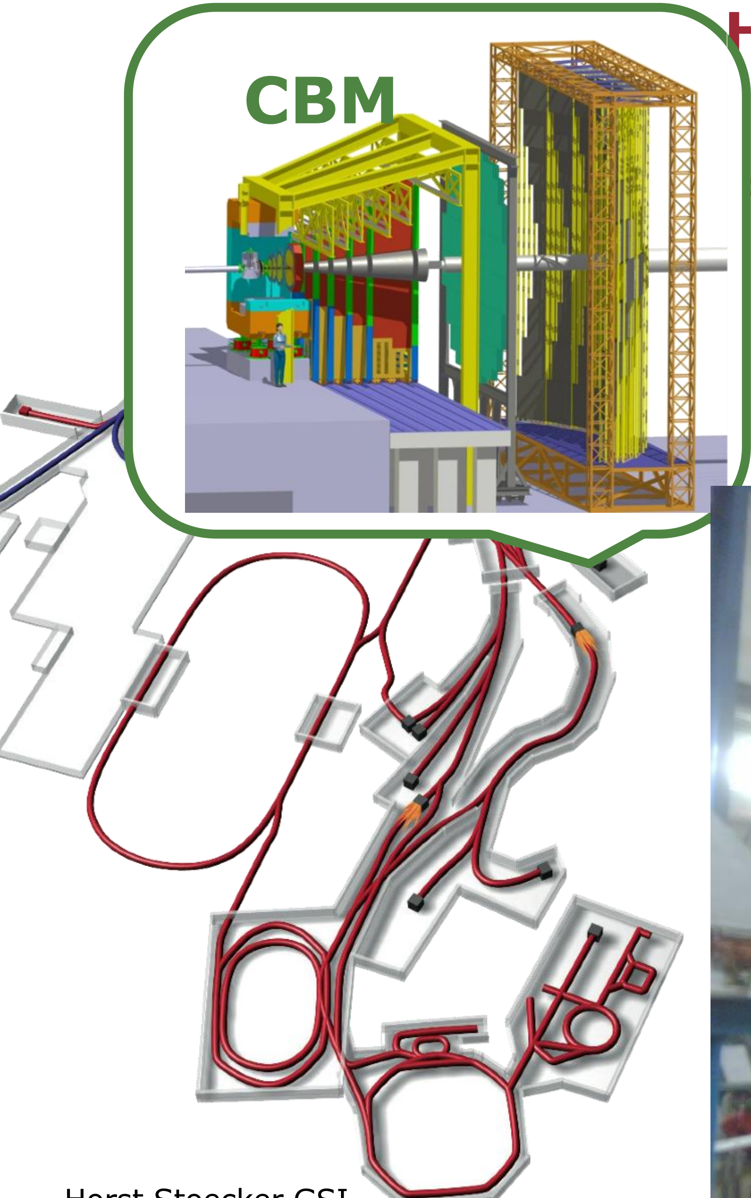




From Panda to CBM

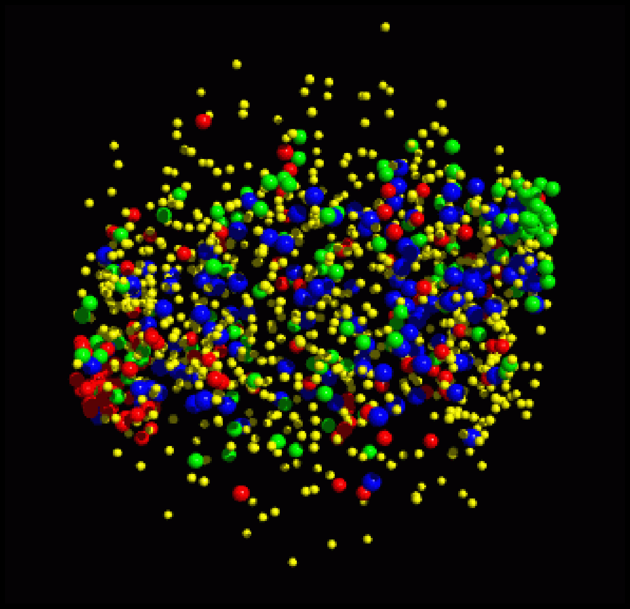
Highest Baryon densities in the universe
- probing the center of neutron stars

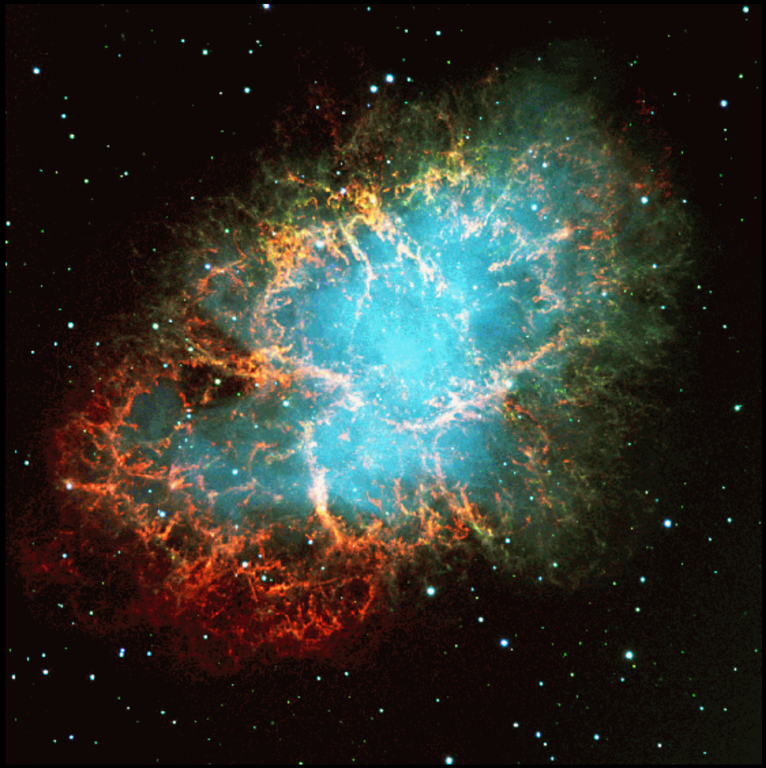
HADES high multiplicity upgrade
Au+Au@SIS18 => Ag+Ag@SIS100



Horst Stoecker GSI

CBM: The Compressed Baryonic Matter Experiment



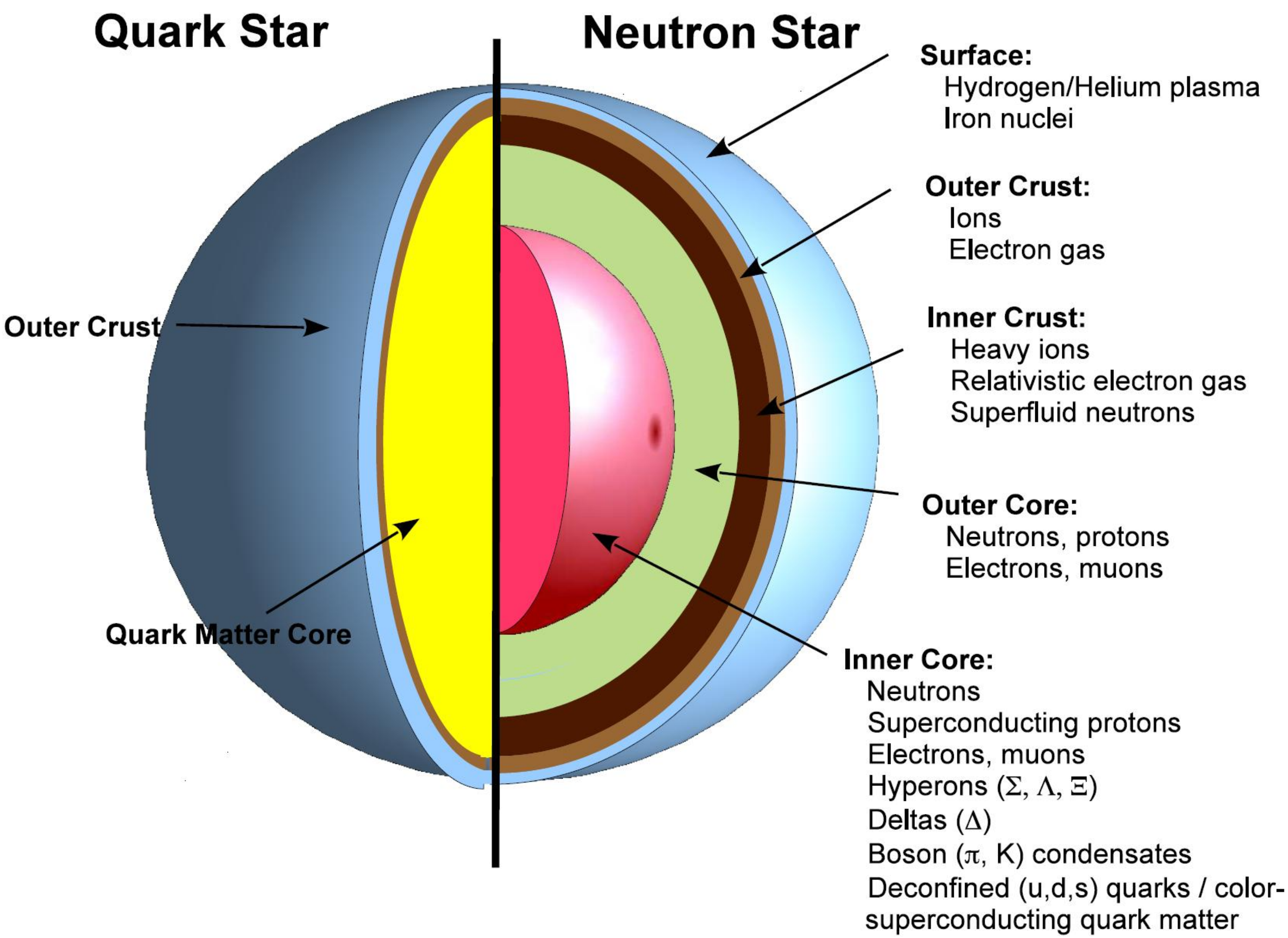


- Science case
- Status experiment preparation

Courtesy of Peter Senger (GSI)

Fundamental Questions of (QCD-) Physics

- What is the structure of compact stars?



Fundamental Questions of (QCD-) Physics

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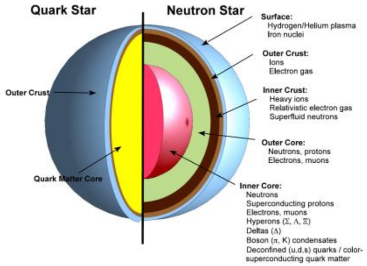
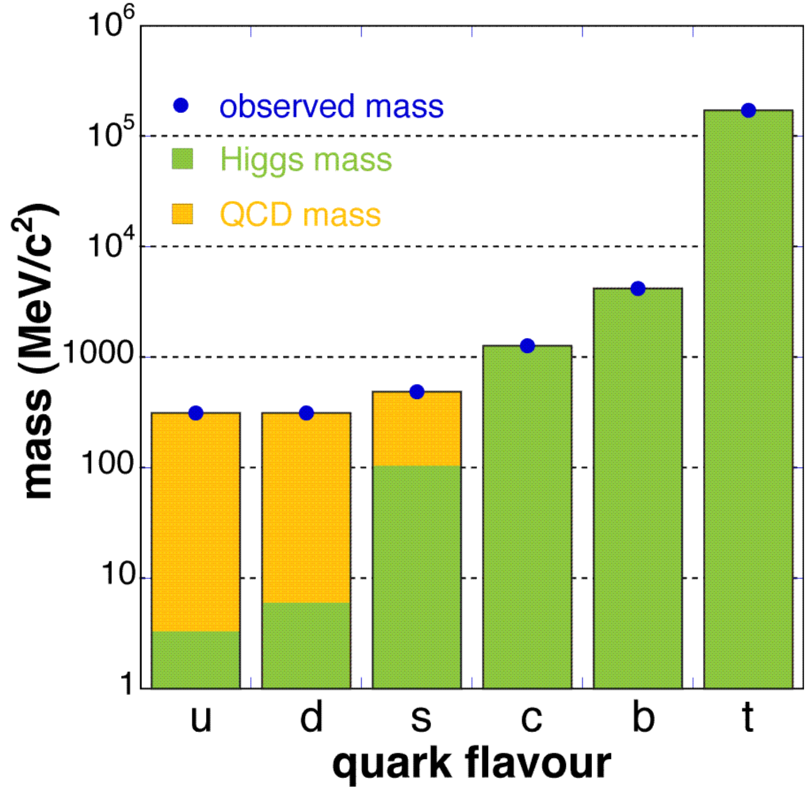
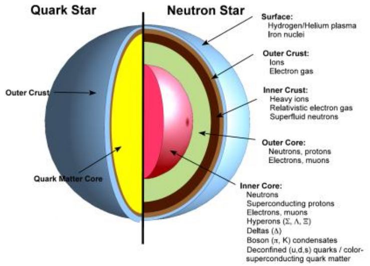


- What is the origin of the mass of the hadrons which determine the visible mass of the universe?



Fundamental Questions of (QCD-) Physics



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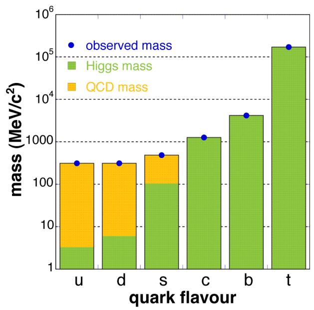
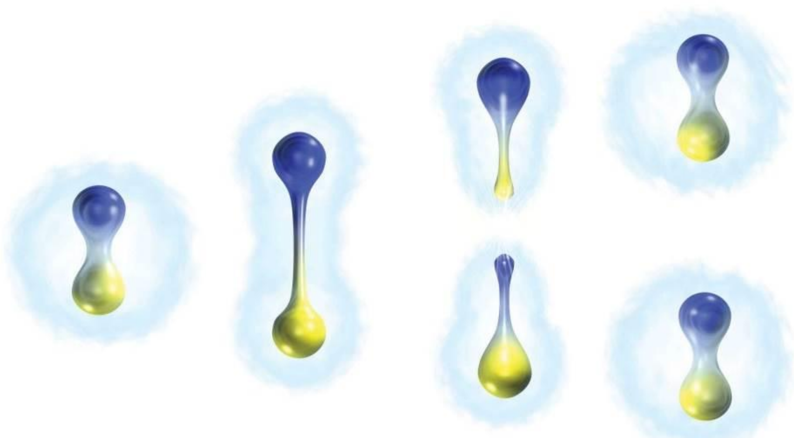


- What is the origin of the mass of the hadrons which determine the visible mass of the universe?

- Why do we not observe individual quarks, the elementary building blocks of matter?



Fundamental Questions of (QCD-) Physics

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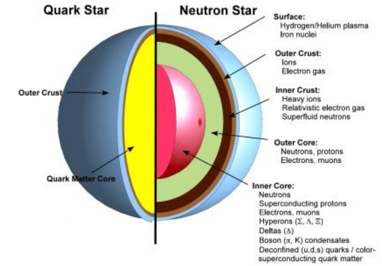

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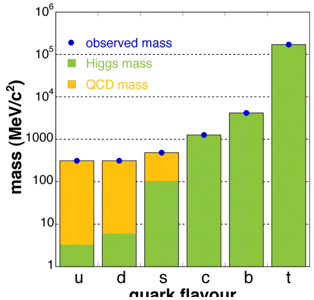
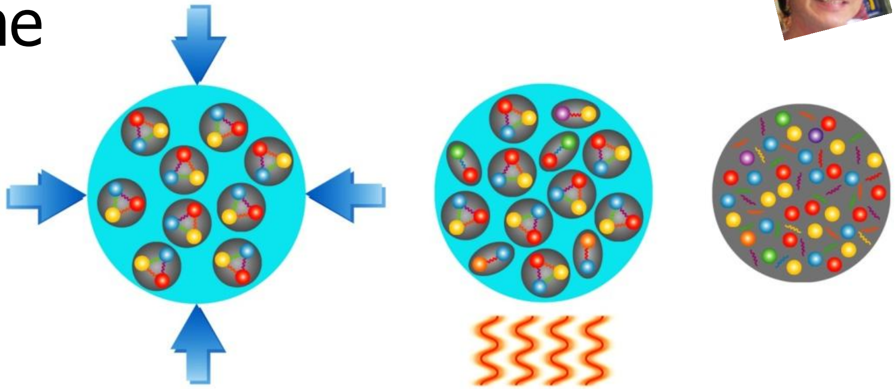


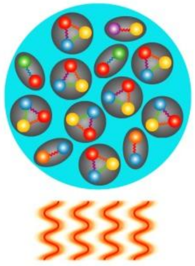
- Why do we not observe individual quarks, the elementary building blocks of matter?

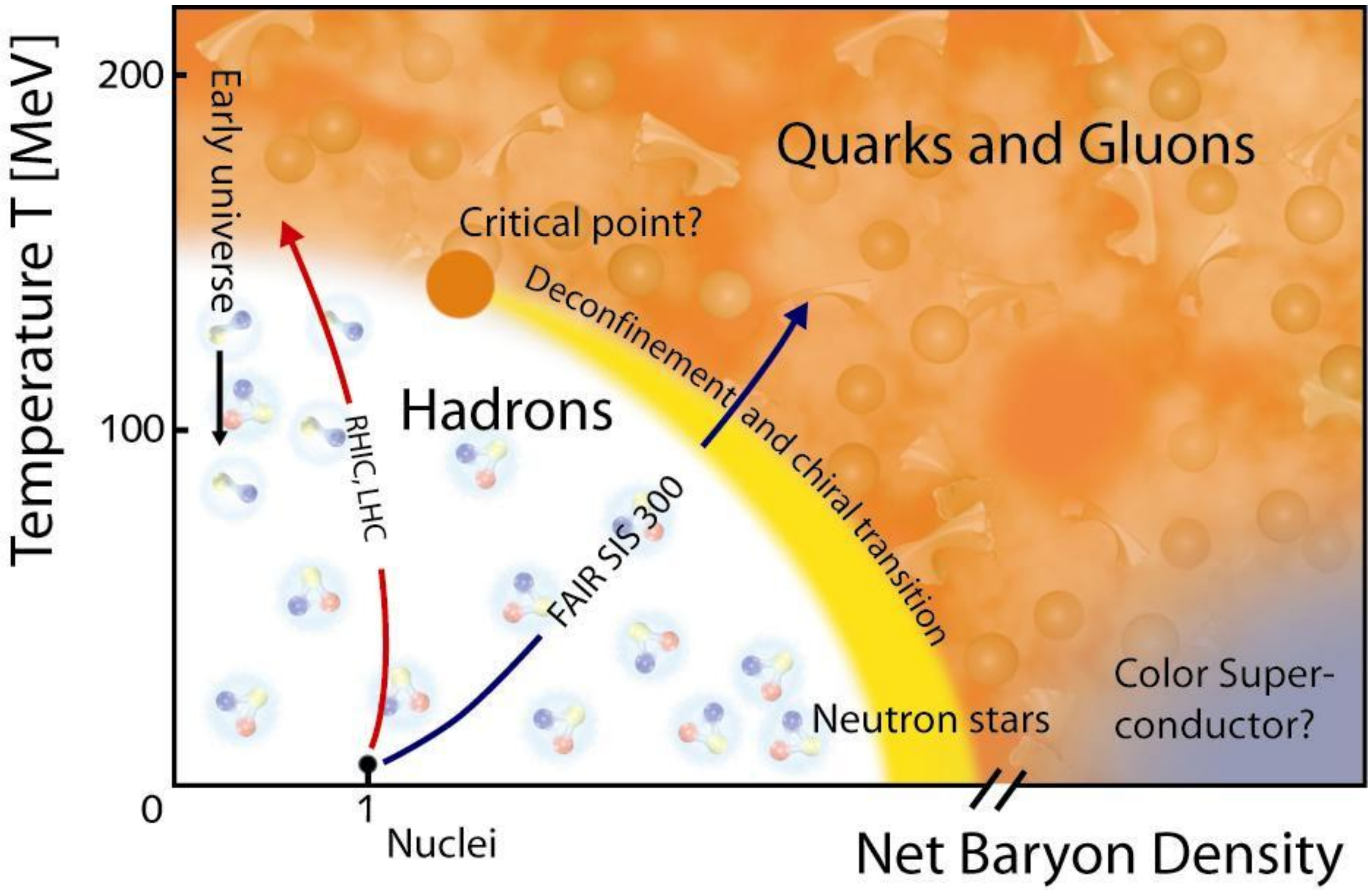
- What are the properties and the degrees-of-freedom of nuclear matter under extreme conditions (high temperature and/or high density)?

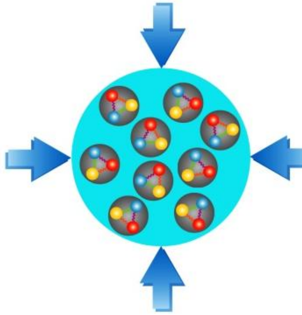



Quark Matter 2008
February 4-10, 2008
Jaipur, India
KESHI KODAMA

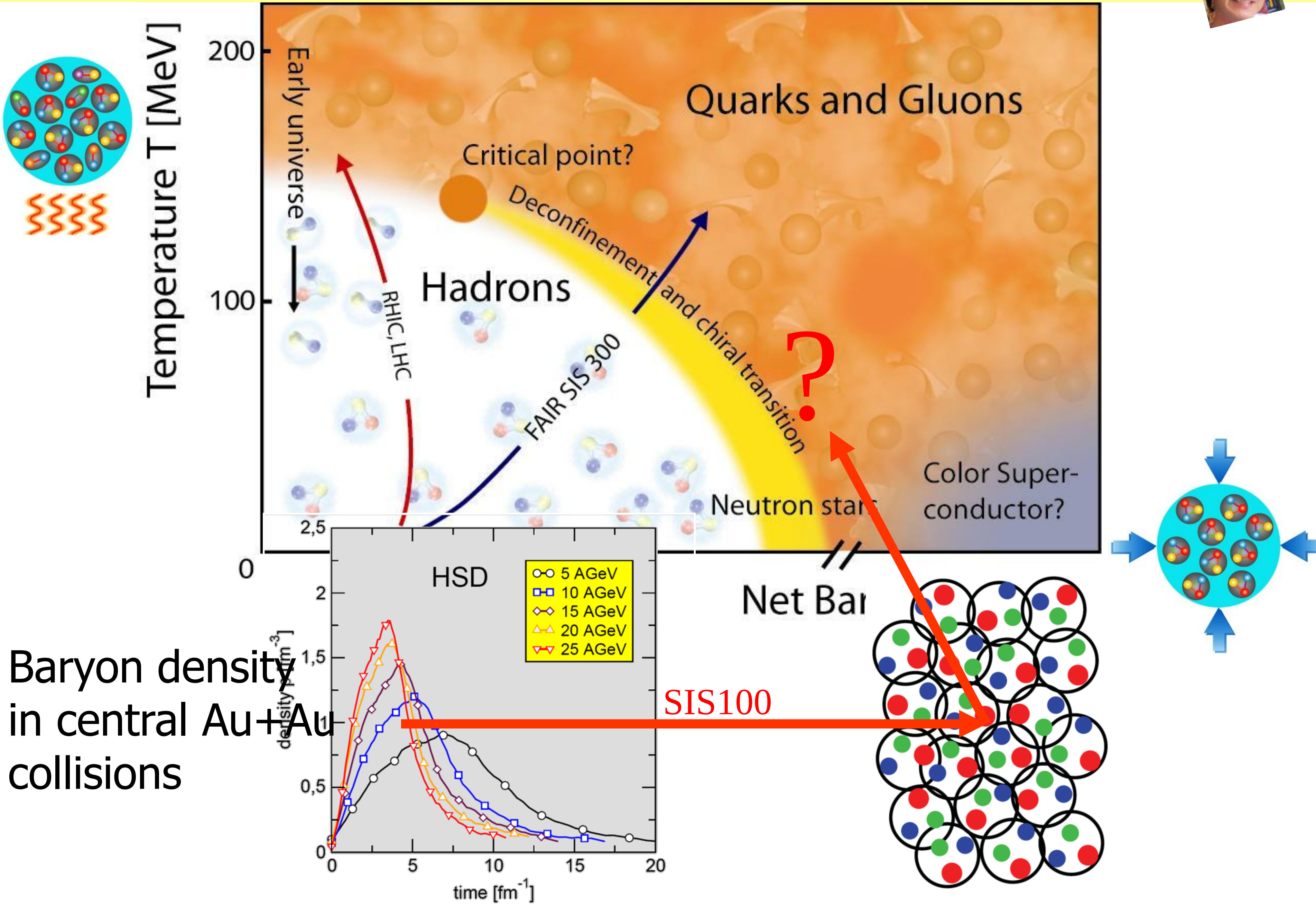
Exploring the QCD phase diagram





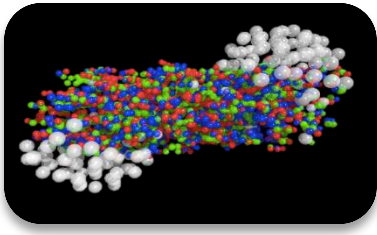


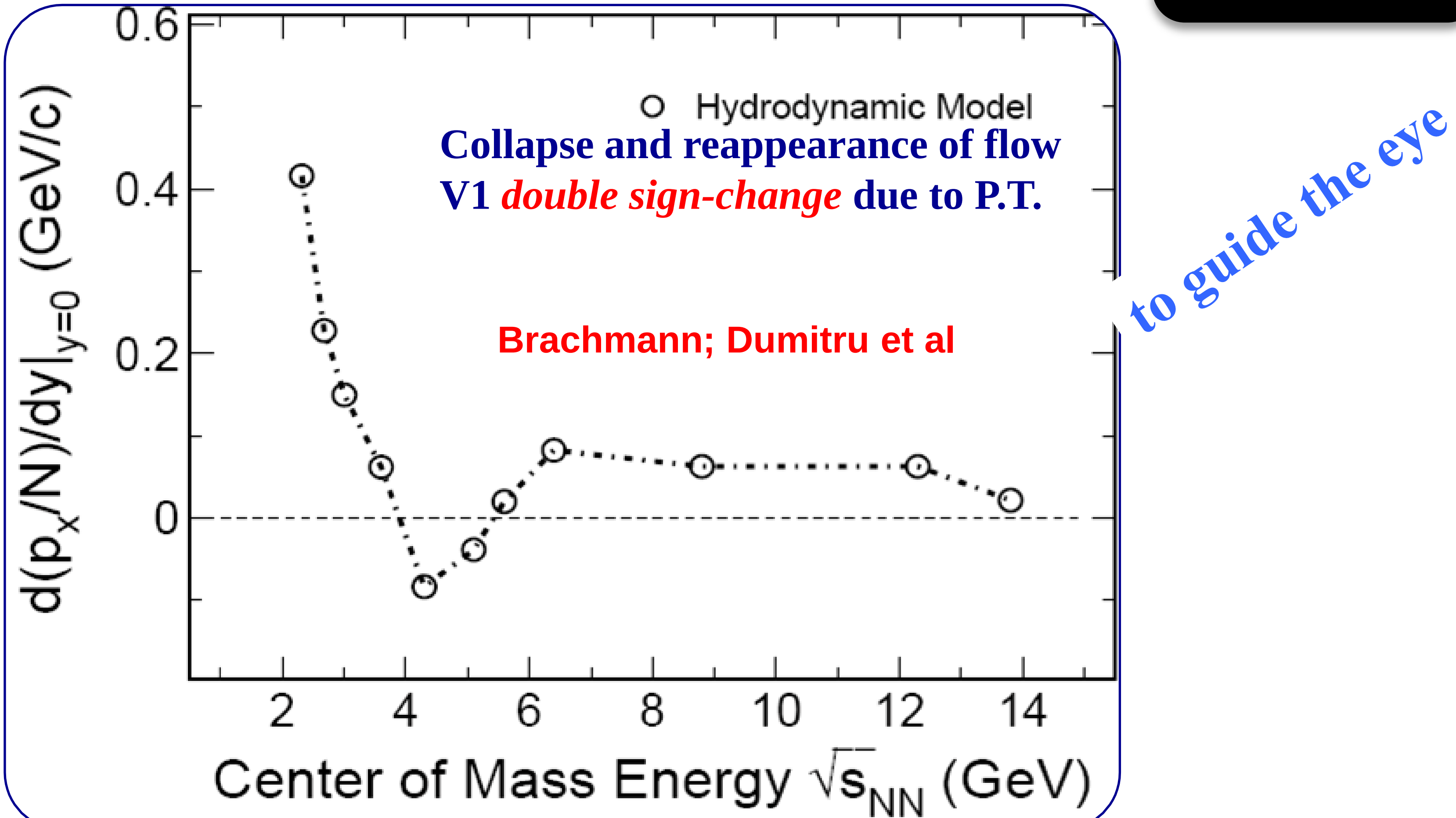
Exploring the QCD phase diagram



Baryon density in central Au+Au collisions

Directed flow – early pressure probe
“Bounce off as a Barometer for RHIC”
H. St., B. Mueller, W.Greiner 1979

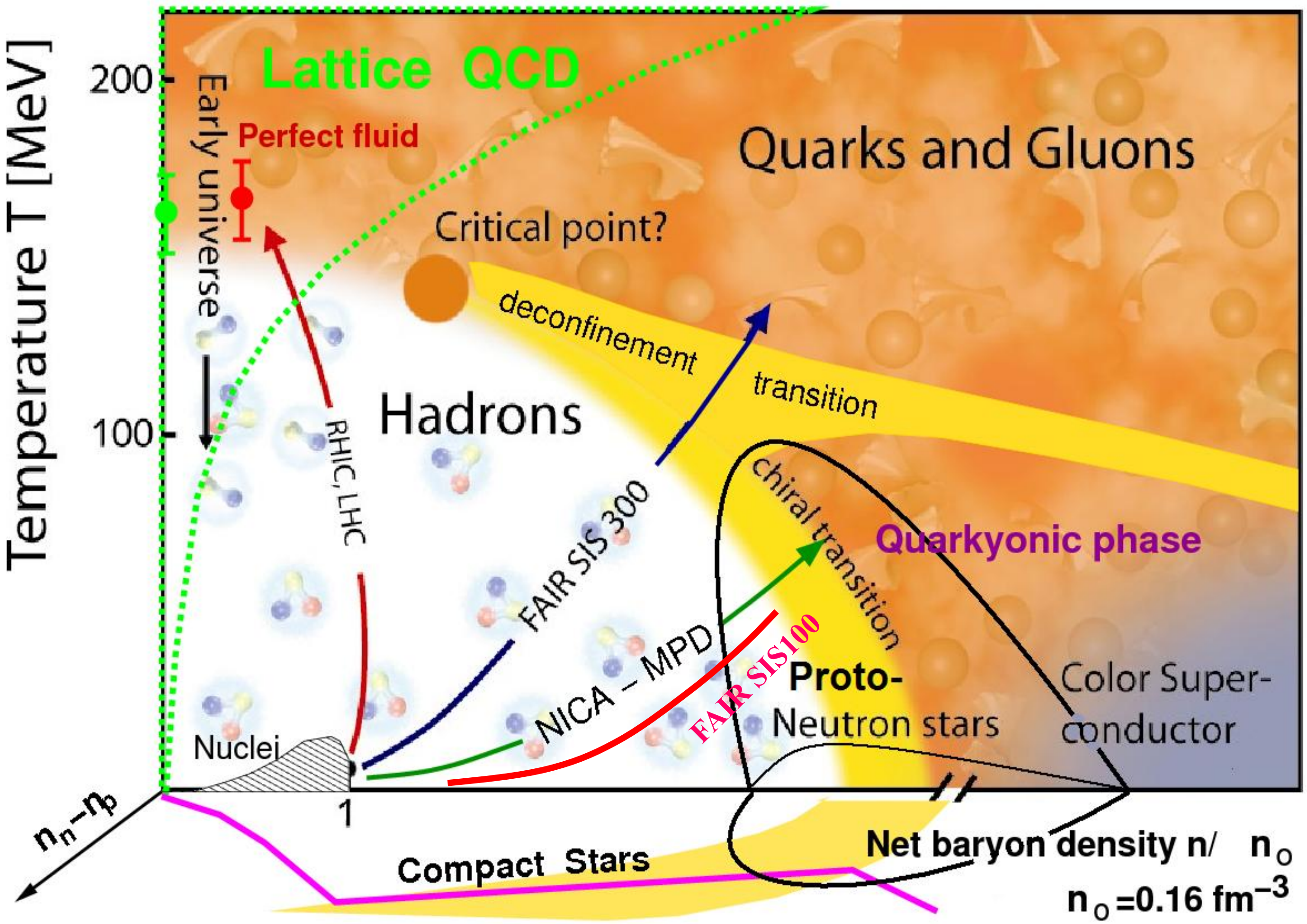




First-order anisotropy imprints itself on momentum space in first instants

- Promising soft-spot probe, due to rapid dynamics
- **Long-standing probe for 1st-order transition neglected in v2 @RHI**

CBM : Big Bang and Neutron Star matter
- in the laboratory

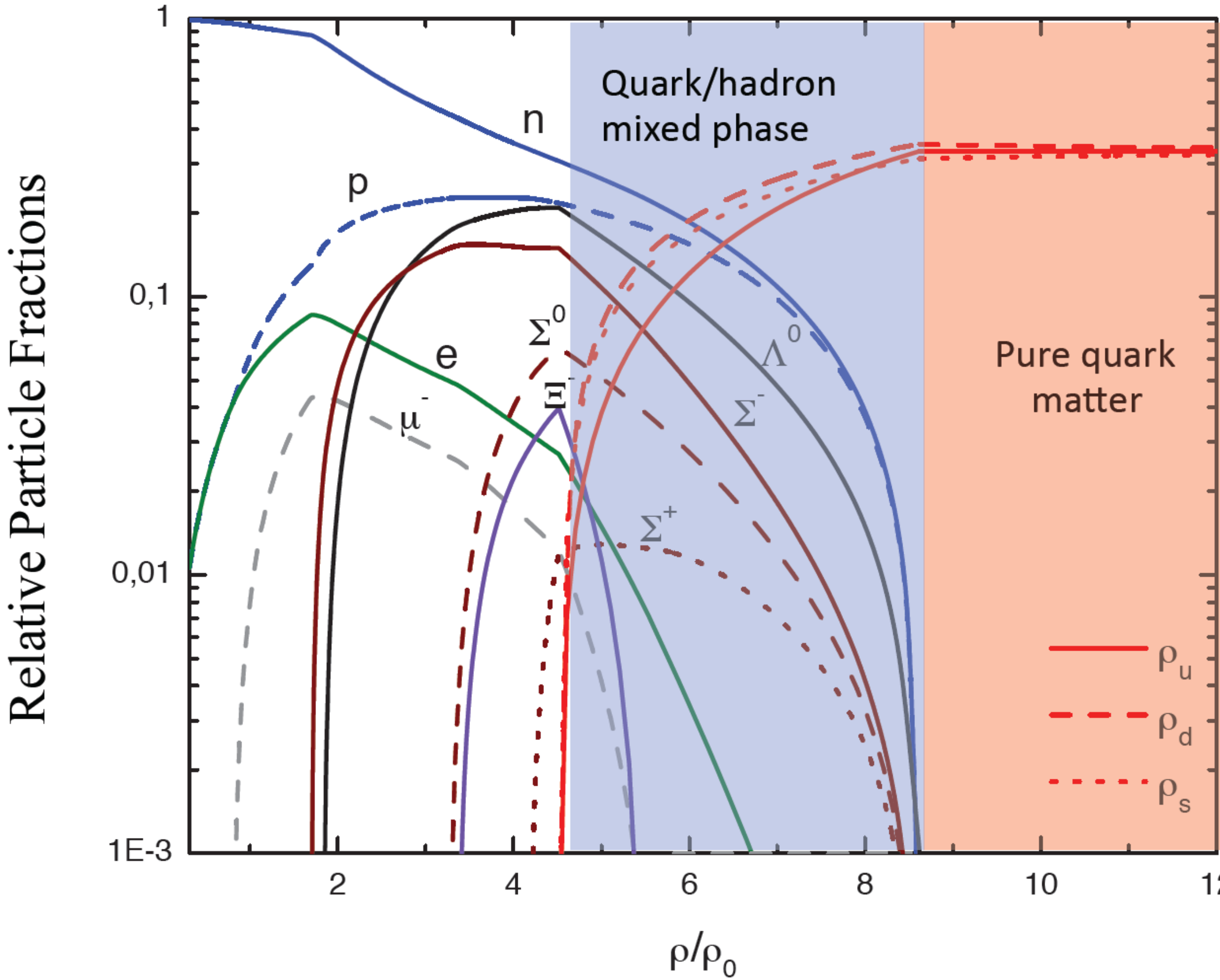


- deconfinement phase transition Quarks=> Proton
- Equation-of-state at neutron star densities, Multi-Strange Quarks
- in-medium properties of hadrons, hadron mass generation

Highest Proton Densities in the Universe !

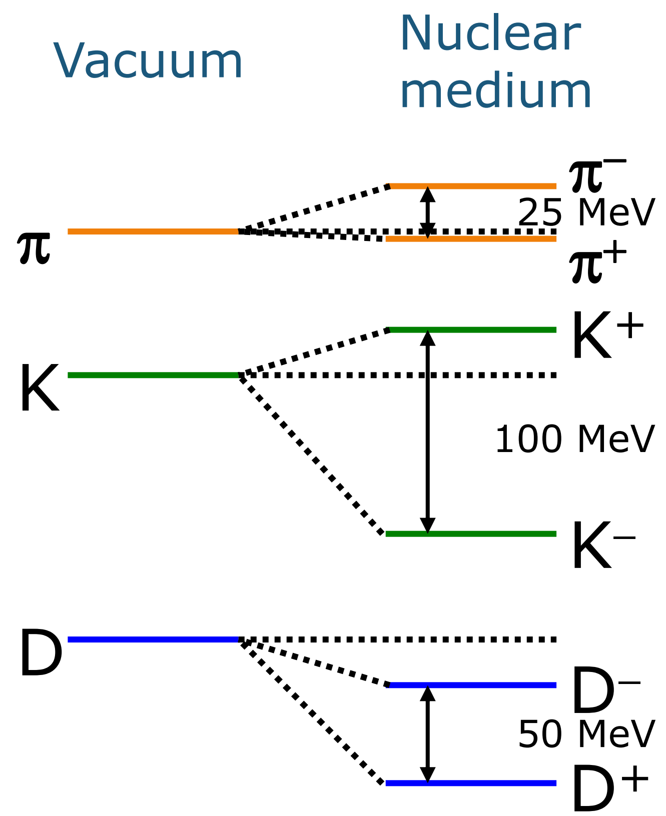
Quark/hadron mixed phase in neutron stars

M. Orsaria, H. Rodrigues, F. Weber (August 2012)



Hadrons in Nuclear Matter

- Partial restoration of chiral symmetry in nuclear matter
  - Light quarks sensitive to quark condensate
- ($c\bar{c}$) states sensitive to gluon condensate
  - Small (5-10 MeV/c^2) in medium modifications for low-lying ($c\bar{c}$) (J/ψ, η_c)
  - Significant mass shifts expected for excited states: 40, 100, 140 MeV/c^2 for χ_{cJ}, ψ', $\psi(3770)$ resp.
- D mesons - QCD analogue of H-atom
  - Chiral symmetry to be studied on a single light quark
  - Theoretical calculations disagree in size and sign of mass shift (50 MeV/c^2 attractive – 160 MeV/c^2 repulsive)



Hayaski, PLB 487 (2000) 96
Morath, Lee, Weise, priv. Comm.

CBM = Look into neutron stars !

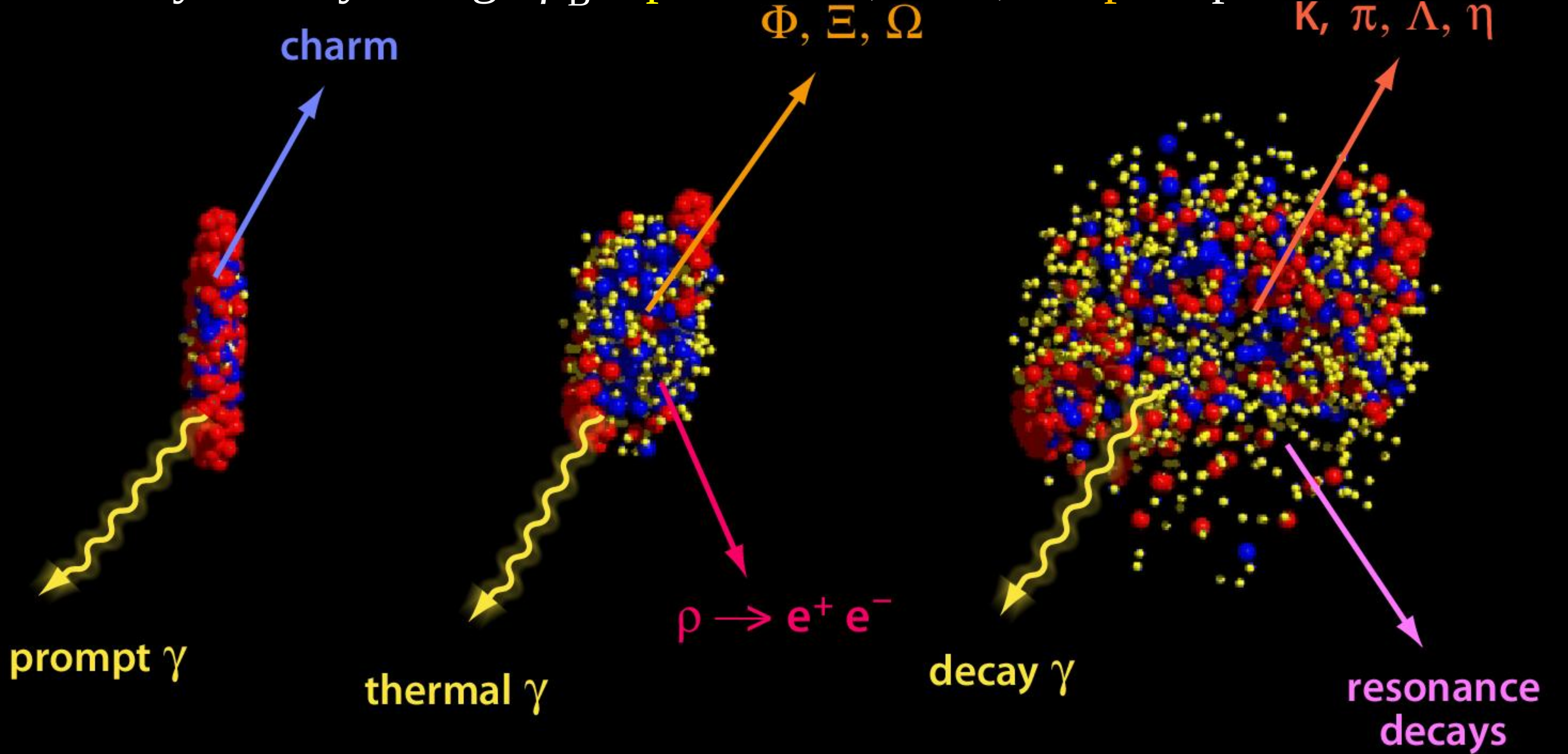
High density matter - EoS: collective explosive flow of protons

Quark-Hadron phase boundary @ high baryon density ρ_B:

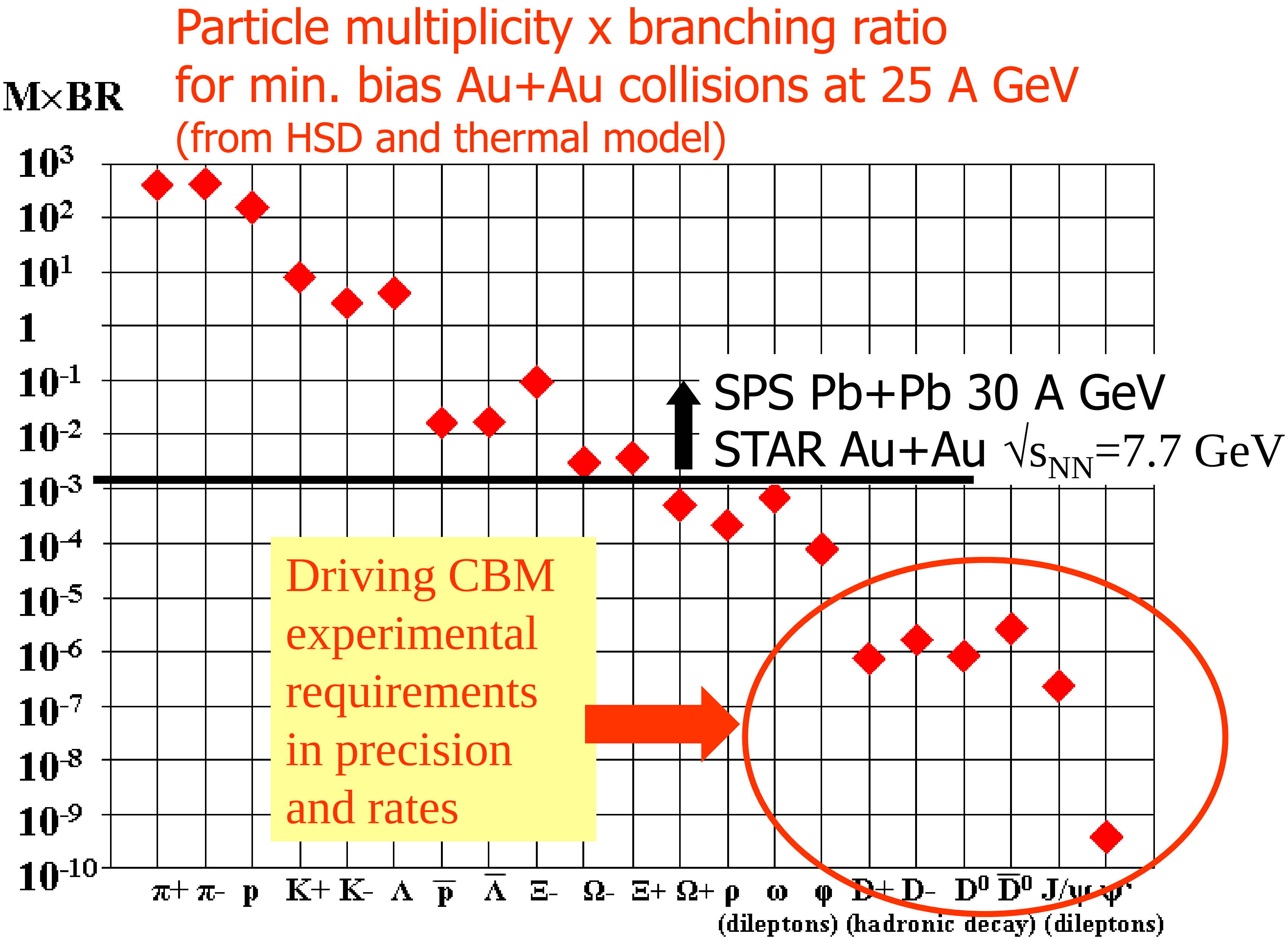
- multi-strange + charm production

QCD critical point

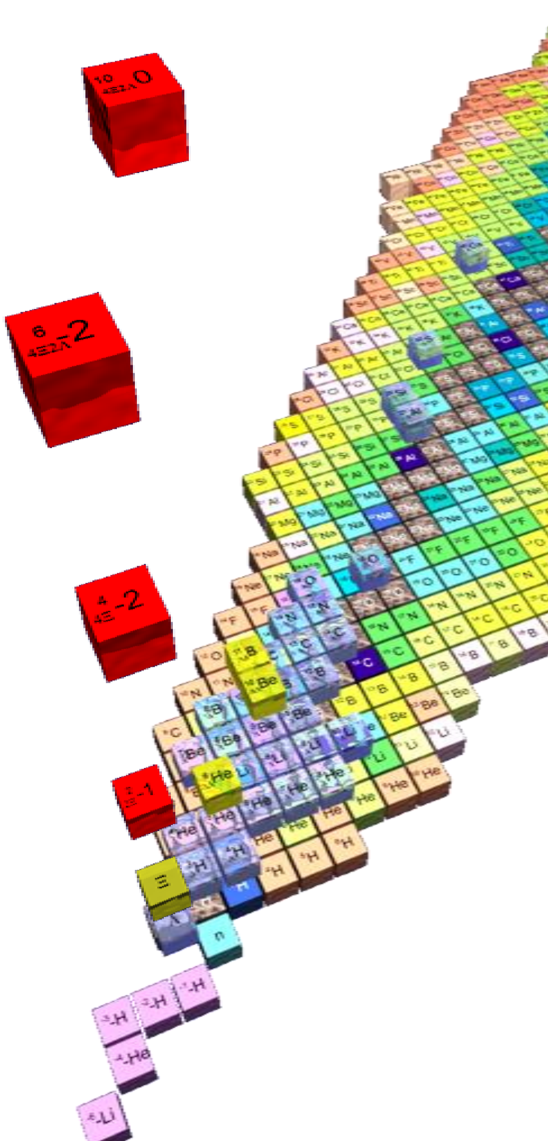
Chiral symmetry at high ρ_B: open charm, J/Psi, dilepton production

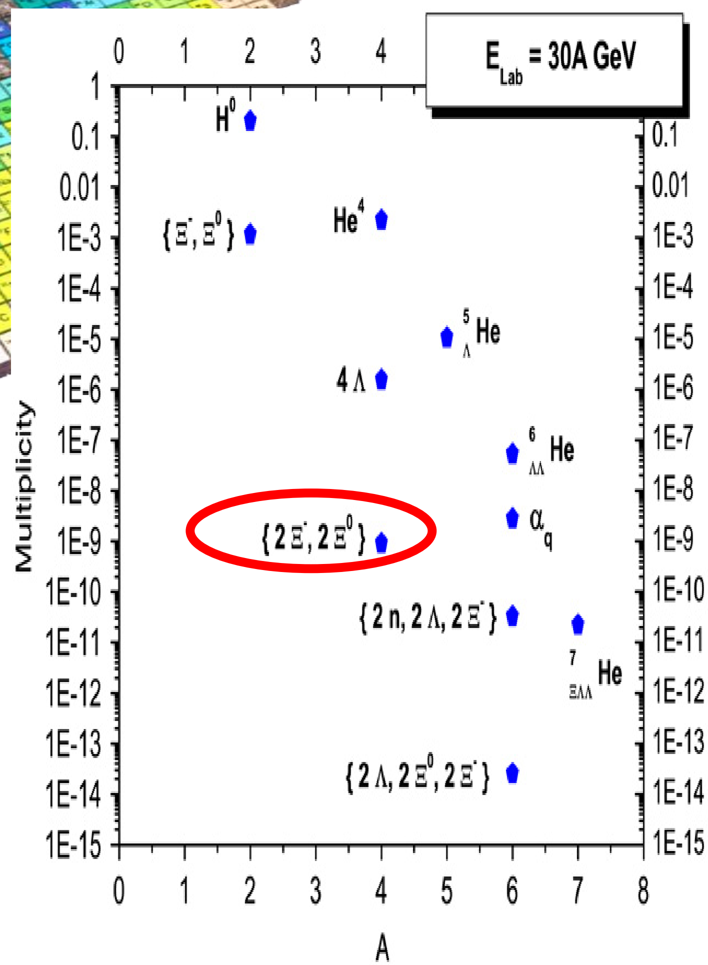


Experimental challenges

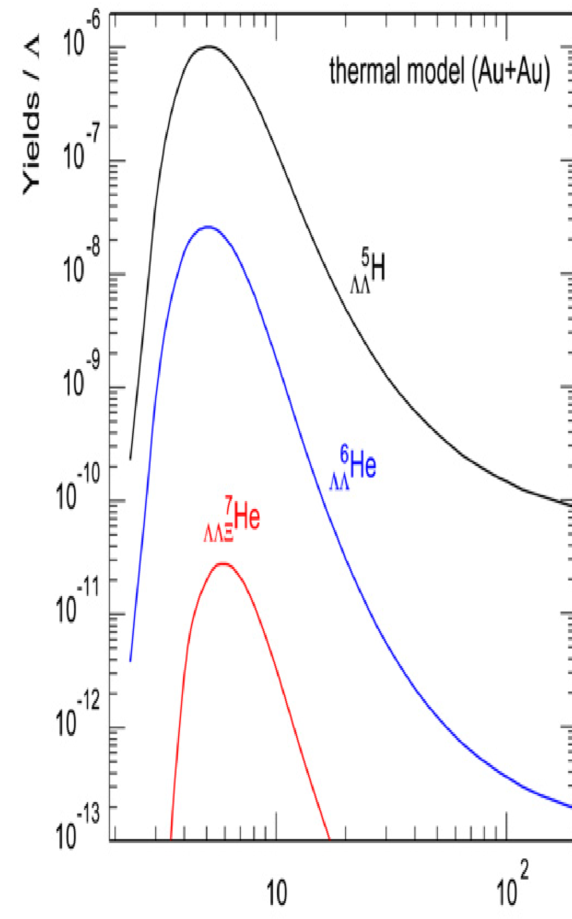


Hypernuclei and metastable multistrange objects





J. Steinheimer, P. Senger, H. Stöcker et. al.
Progress in Particles and Nuclear Physics
62 (2009)313-317



Subhasis Chattopadhyay,
CBM Collaboration

Experiments on superdense nuclear matter

Experiment	Energy range (Au/Pb beams)	Reaction rates Hz
STAR@RHIC BNL	$\sqrt{s_{NN}}$ = 7 – 200 GeV	1 – 800 (limitation by luminosity)
NA61@SPS CERN	E_{kin}= 20 – 160 A GeV $\sqrt{s_{NN}}$= 6.4 – 17.4 GeV	80 (limitation by detector)
MPD@NICA Dubna	$\sqrt{s_{NN}}$= 4.0 – 11.0 GeV	~1000 (design luminosity of 10^{27} $cm^{-2}s^{-1}$ for heavy ions)
HADES@SIS100	1.5 A GeV Au+Au 8 A GeV Ni+Ni	$5 \cdot 10^4$
CBM@FAIR Darmstadt	E_{kin}= 2.0 – 35 A GeV $\sqrt{s_{NN}}$= 2.7 – 8.3 GeV	10^5 – 10^7 (limitation by detector)

CBM technological challenges

Central Au+Au collision at 25 AGeV (UrQMD + GEANT4):

160 p 400 π^- 400 π^+ 44 K^+ 13 K^-

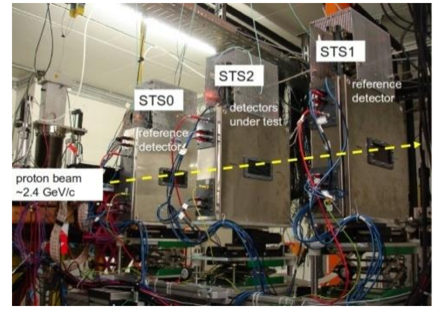
- 10^5 - 10^7 Au+Au reactions/sec
- determination of (displaced) vertices ($\sigma \approx 50$ μm)
- identification of leptons and hadrons
- fast and radiation hard detectors
- free-streaming readout electronics
- high speed data acquisition and high performance computer farm for online event selection
- 4-D event reconstruction

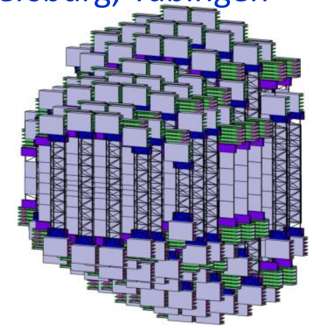
CBM technical developments

SC Magnet: JINR Dubna

Micro-Vertex Detector: Frankfurt, Strasbourg

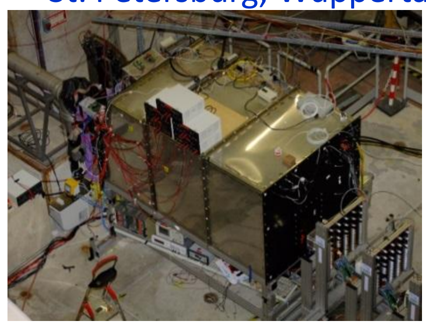
Silicon Tracking System: Darmstadt, Dubna, Krakow, Kiev, Kharkov, Moscow, St. Petersburg, Tübingen



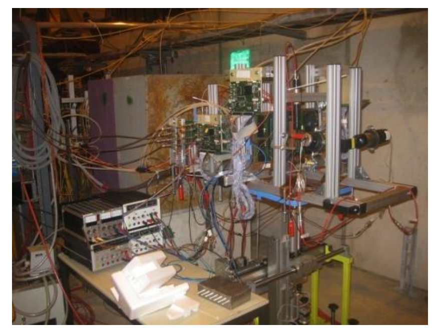


MRPC ToF Wall: Beijing, Bucharest, Darmstadt, Frankfurt, Hefei, Heidelberg, Moscow, Rossendorf, Wuhan, Zagreb

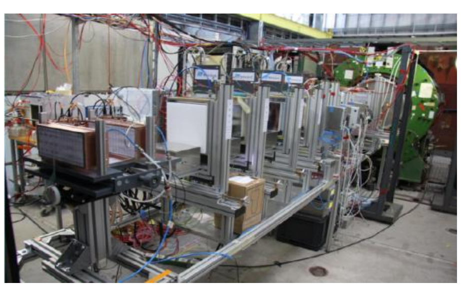
RICH Detector: Darmstadt, Giessen, Pusan, St. Petersburg, Wuppertal



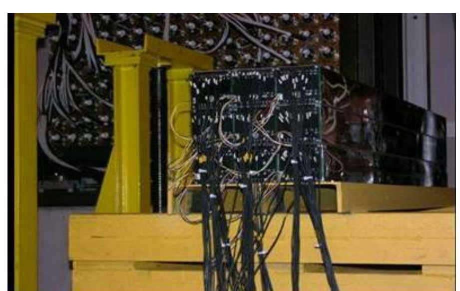
Muon detector: Kolkata + 13 Indian Inst., Gatchina, Dubna



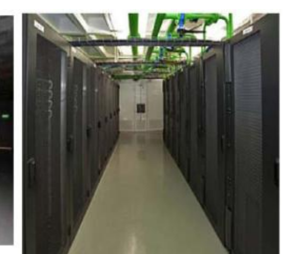
Transition Radiation Detector: Bucharest, Dubna, Frankfurt, Heidelberg, Münster



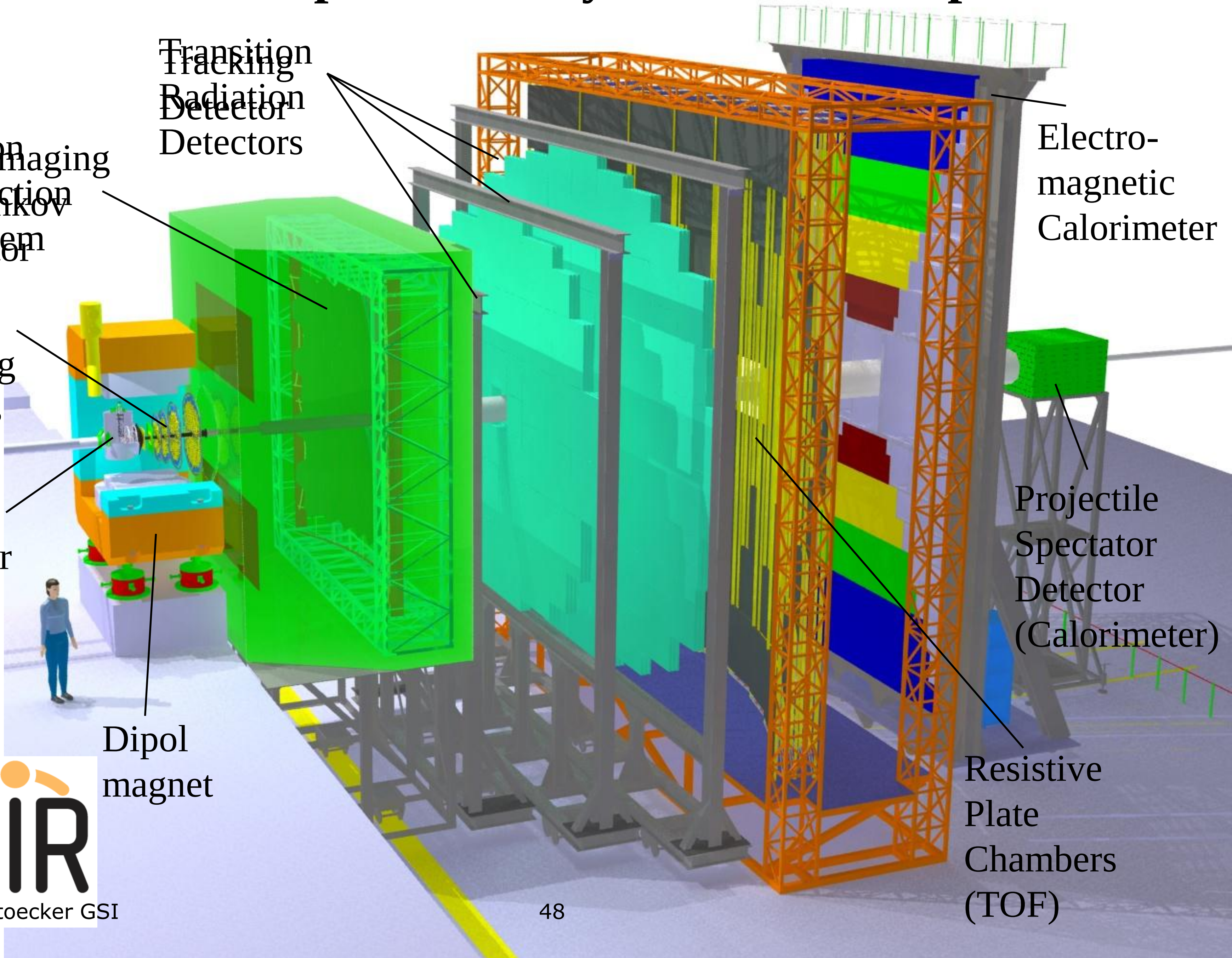
Forward calorimeter: Moscow, Prague, Rez



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



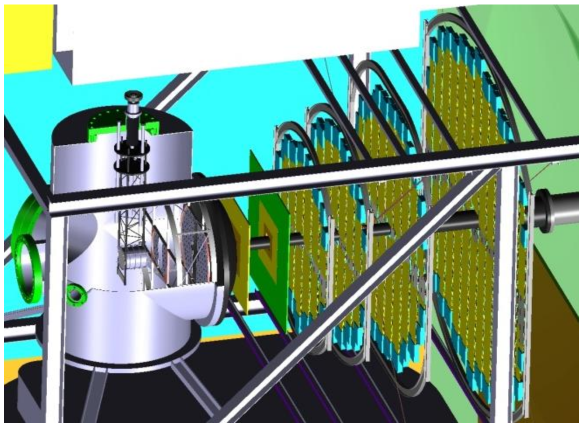
CBM: The Compressed Baryonic Matter Experiment



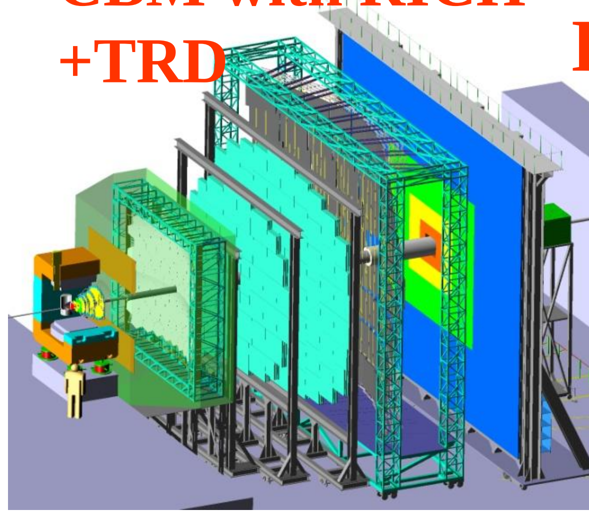
CBM- India & Brasil -Collaboration

CBM: Dileptons central Au+Au 25 AGeV simulations

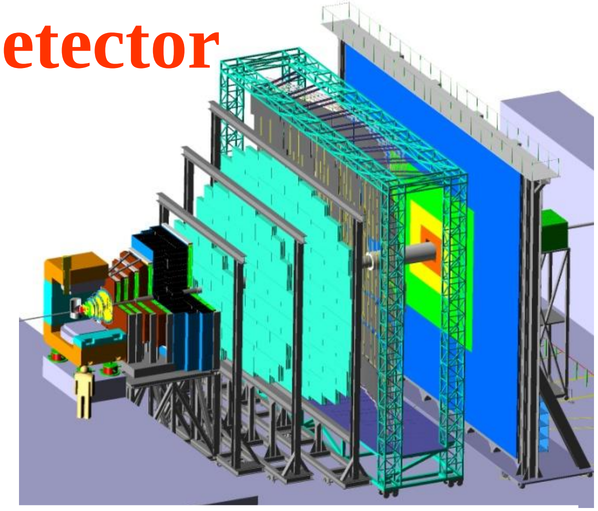
Micro-Vertex detector (MAPS)
+ Silicon-Microstrip System



CBM with RICH +TRD

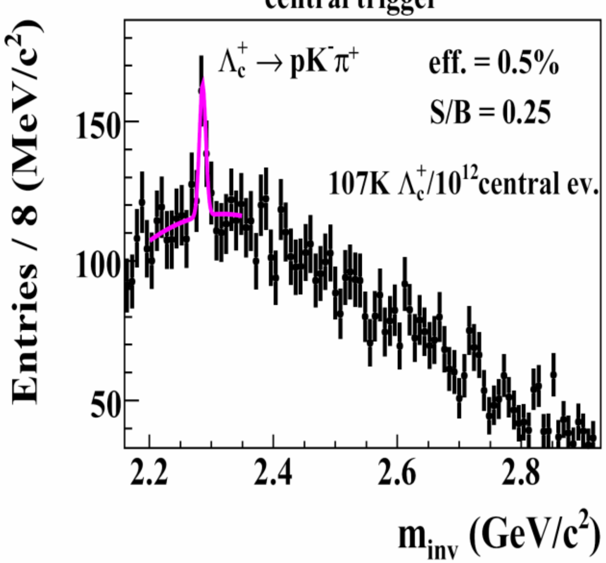


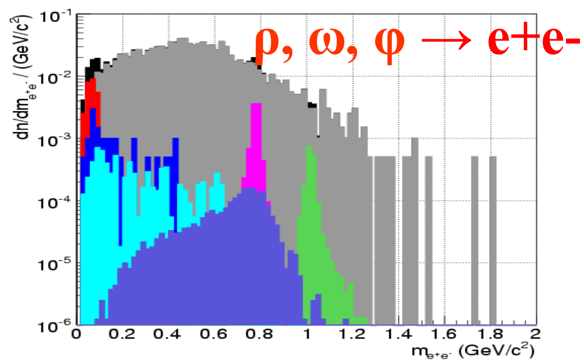
CBM with Muon Detector

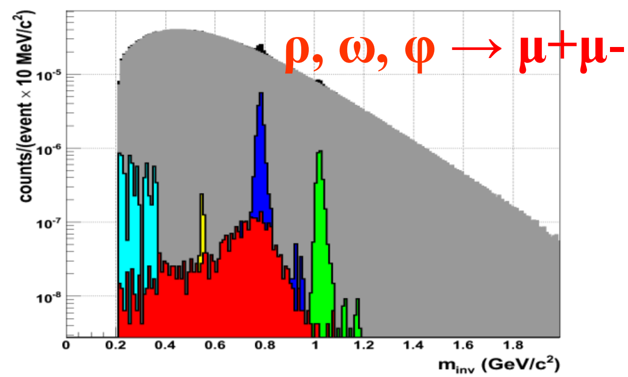


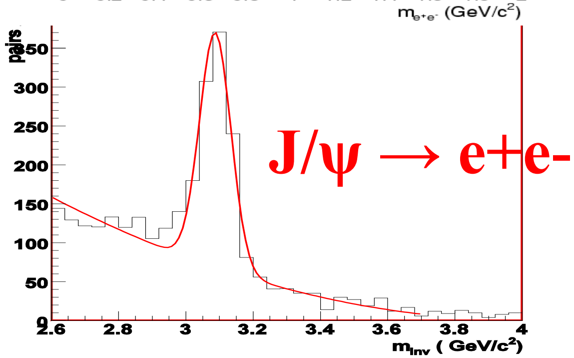
Λ_C: $\tau = 60$ μm/c

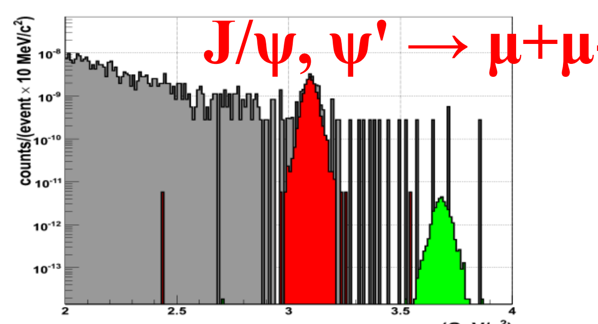
central trigger





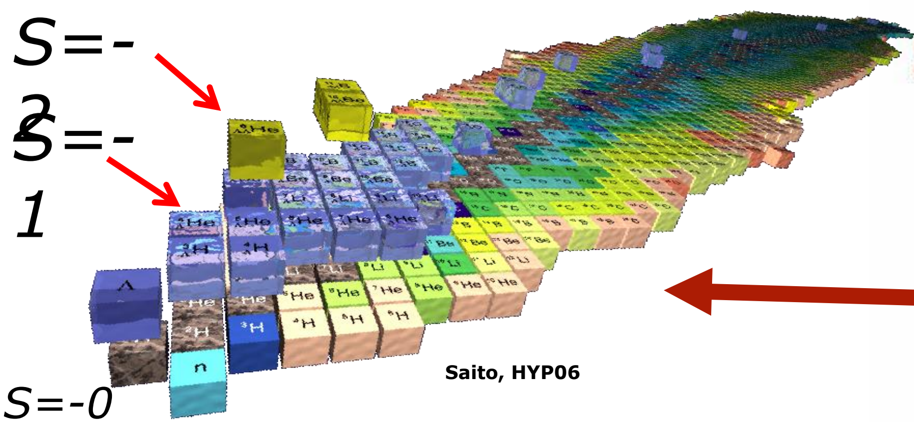


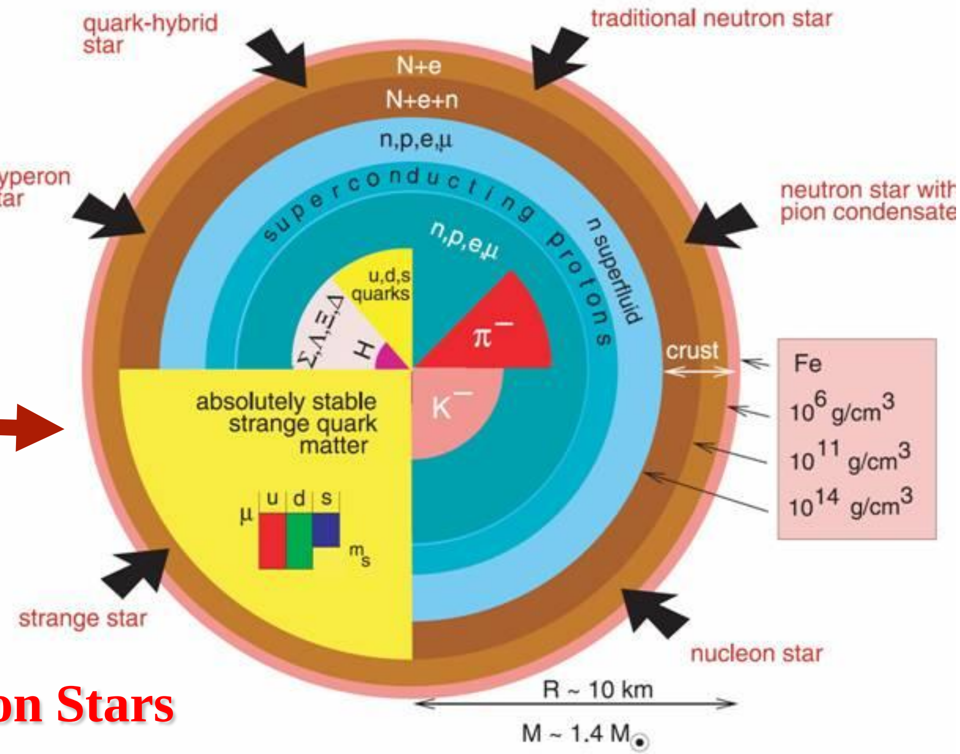




From CBM to NuSTAR – of Hypernuclei and Neutron Stars

hypernuclei ← Λ-B Interaction → Neutron Stars





Several possible configurations of Neutron Stars

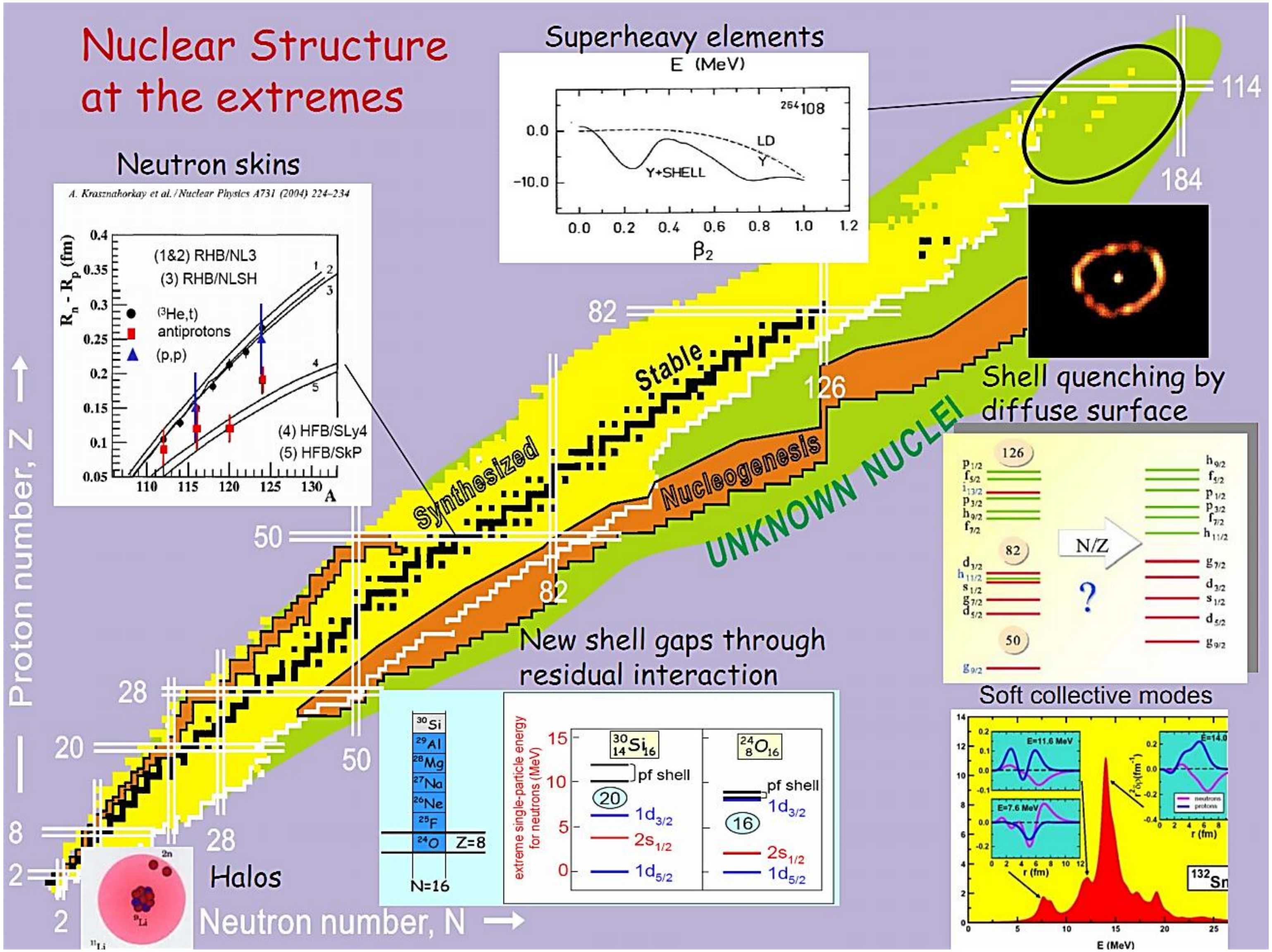
- **Kaon condensate, hyperons, strange quark matter**

J.M. Lattimer and M. Prakash, "The Physics of Neutron Stars", Science 304, 536 (2004)
J. Schaffner and I. Mishustin, *Phys. Rev. C* 53 (1996): Hyperon-rich matter in neutron stars

Single **and** ***double*** **hypernuclei in the laboratory:**

- **study the strange sector of the baryon-baryon interaction**
- **provide info on EOS of neutron stars**

NuSTAR



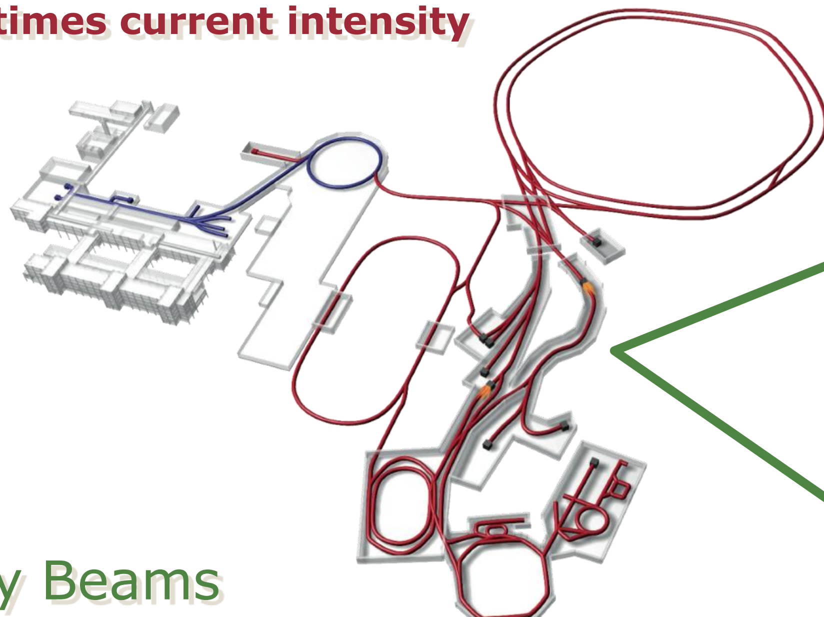
Nuclear Structure at the extremes
Neutron skins
A. Krasznahorkay et al. / Nuclear Physics A731 (2004) 224–234
(1&2) RHB/NL3
(3) RHB/NLSH
(³He,t)
antiprotons
(p,p)
(4) HFB/SLy4
(5) HFB/SkP
Superheavy elements
E (MeV)
²⁶⁴108
LD
Y
Y+SHELL
β2
114
184
82
126
50
28
20
8
2
Stable
Synthesized
Nucleogenesis
UNKNOWN NUCLEI
Shell quenching by diffuse surface
N/Z
New shell gaps through residual interaction
pf shell
1d3/2
2s1/2
1d5/2
N=16
Z=8
Soft collective modes
132Sn
E (MeV)
Halos
Proton number, Z
Neutron number, N

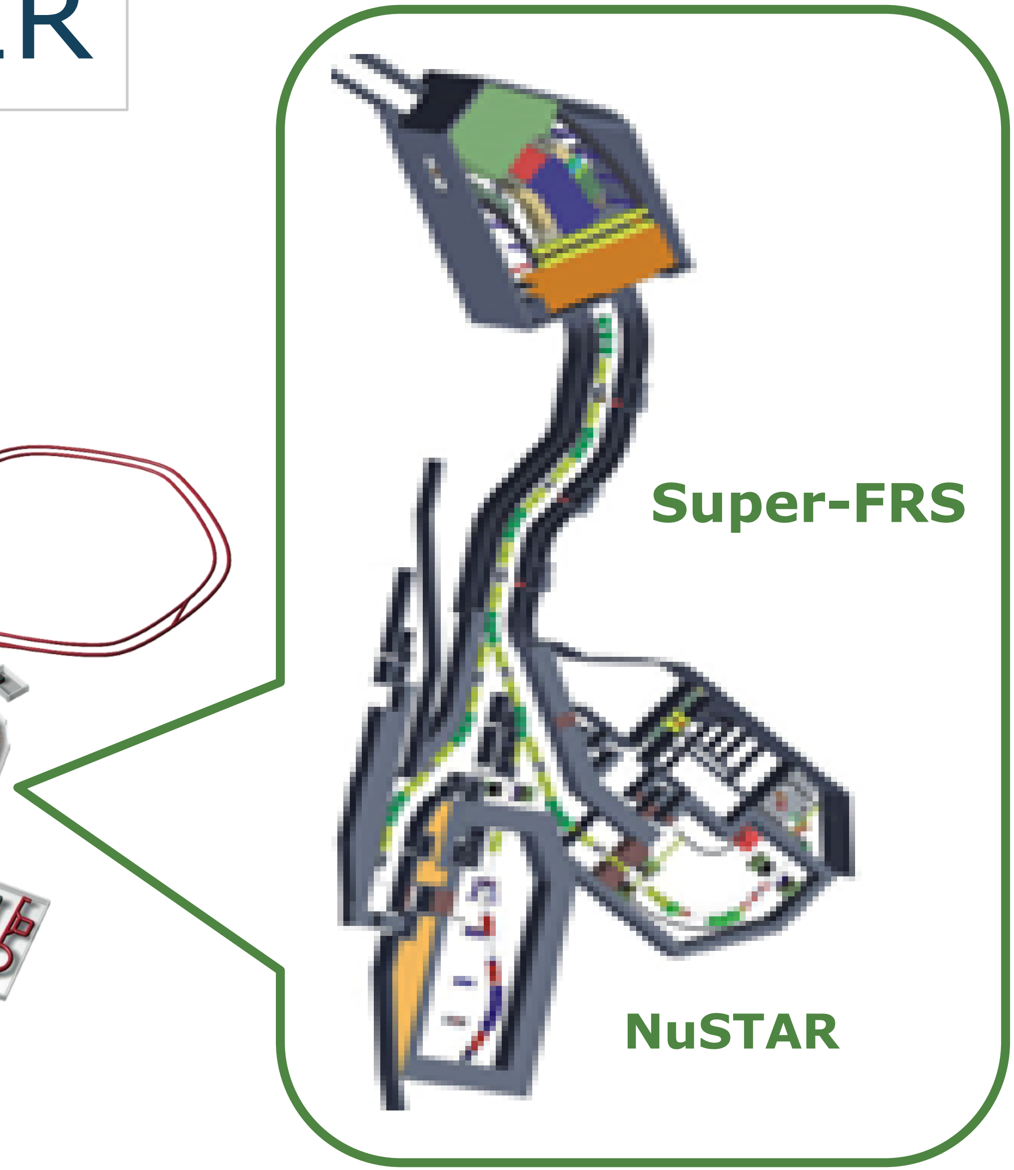
NuSTAR @ FAIR

Primary HI Beams

- $^{40}Ar^{18+}$ $2x10^{12}/s$ @ 1 – 2 GeV/u
- $^{238}U^{28+}$: $5x10^{11}/s$ @ 1 – 2 GeV/u
- $^{40}Ar^{18+}$ $2x10^{10}/s$ @ 1 – 45 GeV/u
- $^{238}U^{92+}$: $1x10^{10}/s$ @ 1 – 35 GeV/u

100 x 1000 times current intensity

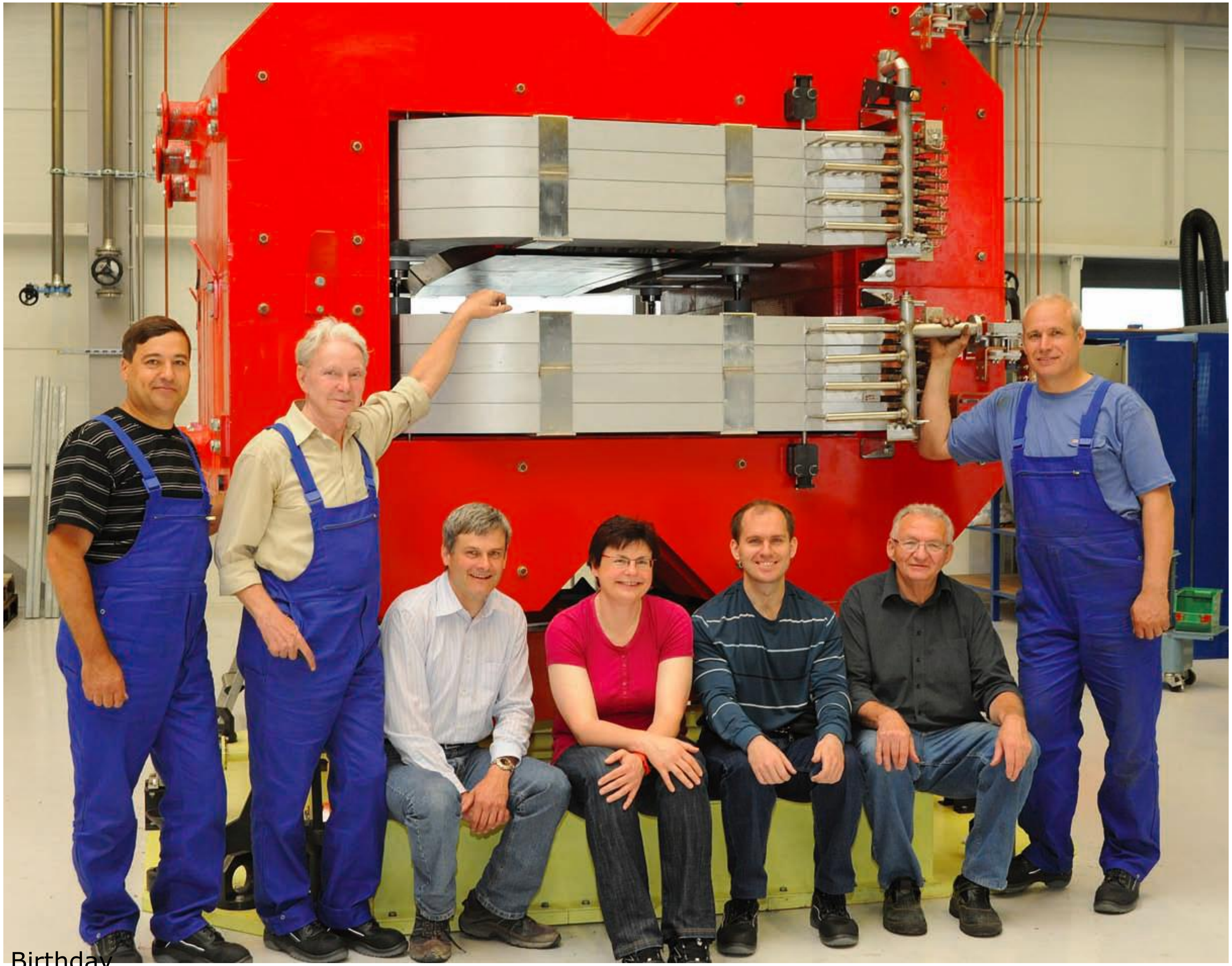




Secondary Beams

- Broad range of radioactive ion beams up to 1 – 2 GeV/u
- **RI- Intensities up to 10 000 over present**

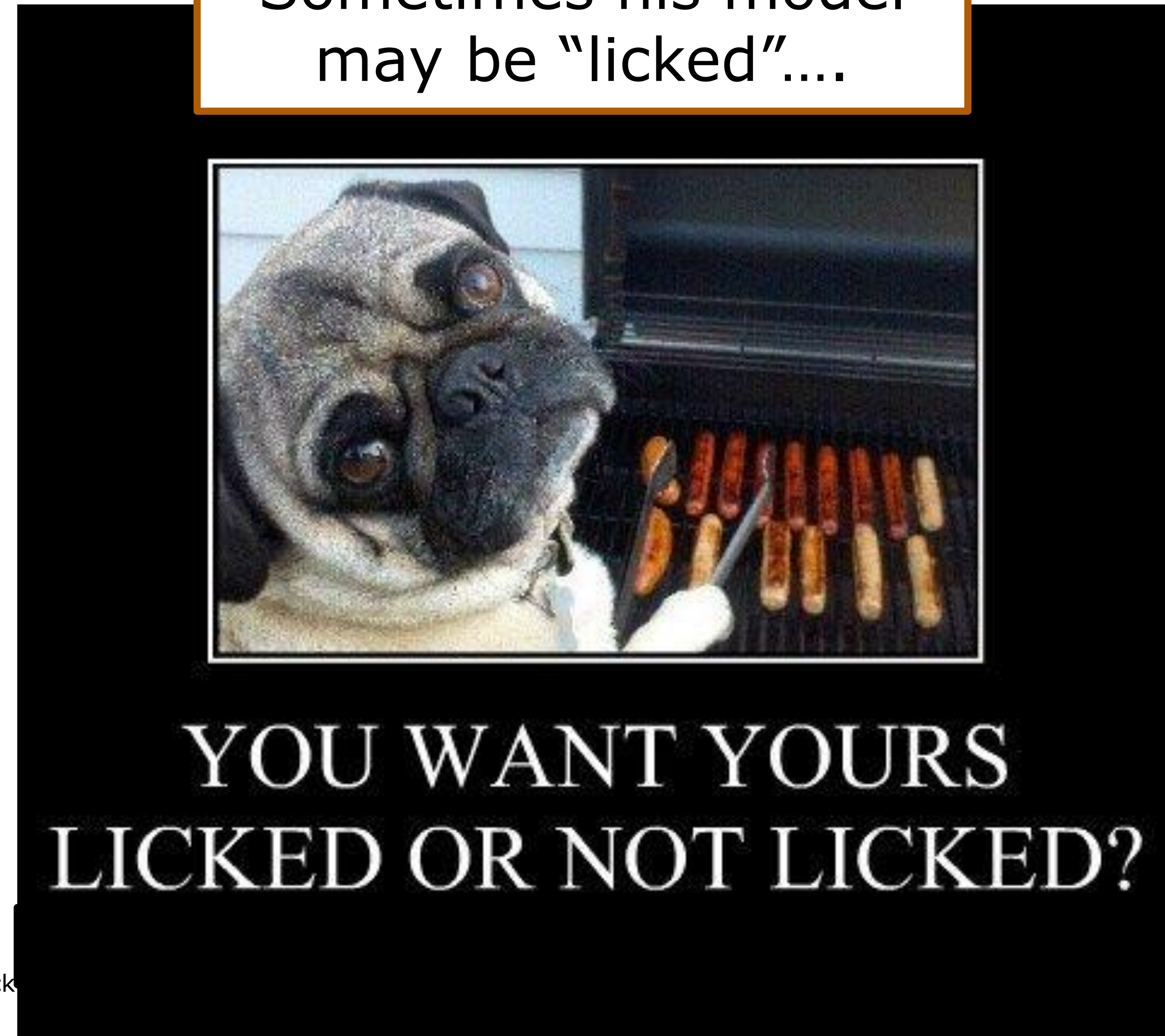
First warm **radiation-hard** SuperFRS Magnet Budger Inst.



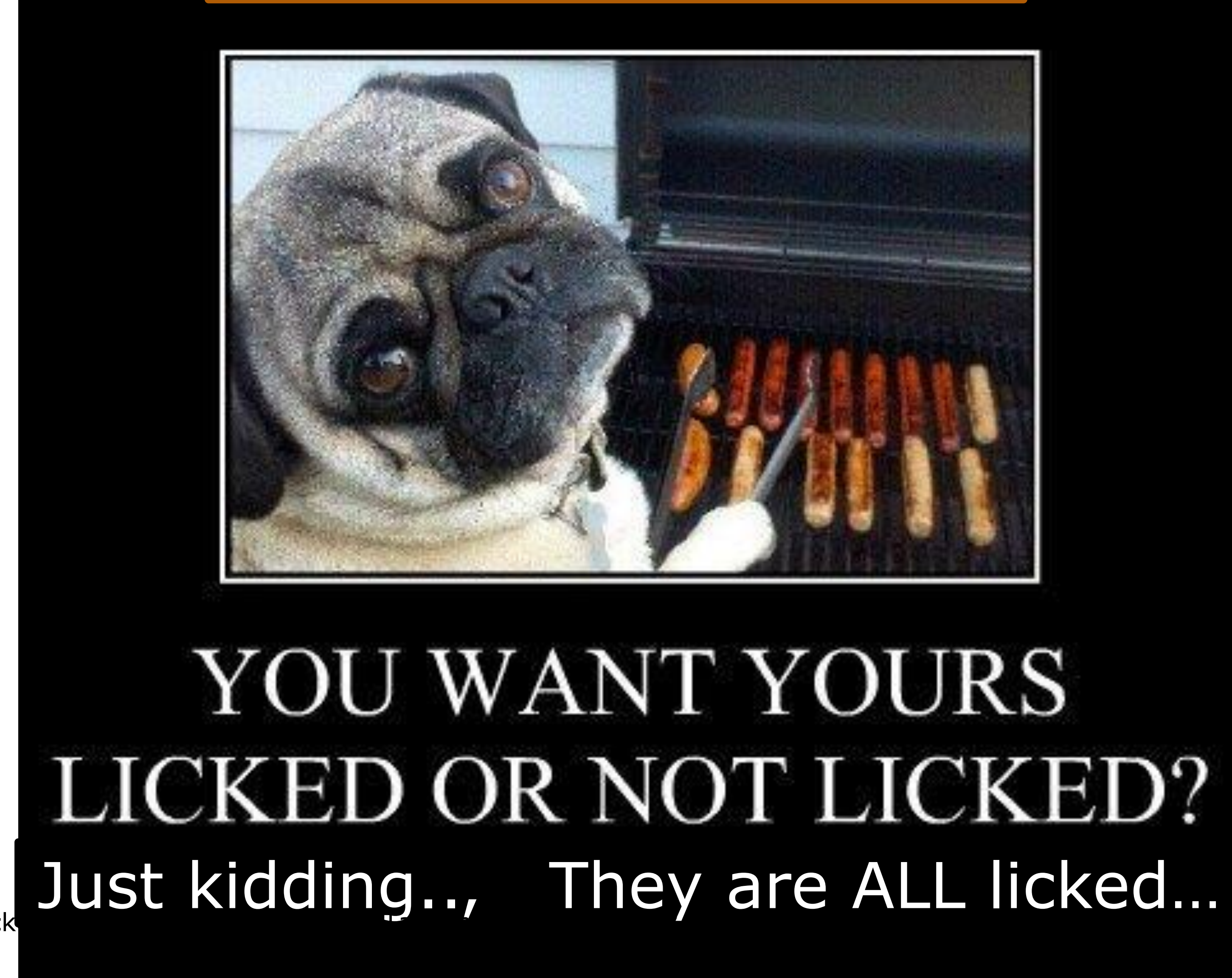
Ei guude, Wie?

When a theorist cooks his model,..

Sometimes his model may be “licked”….

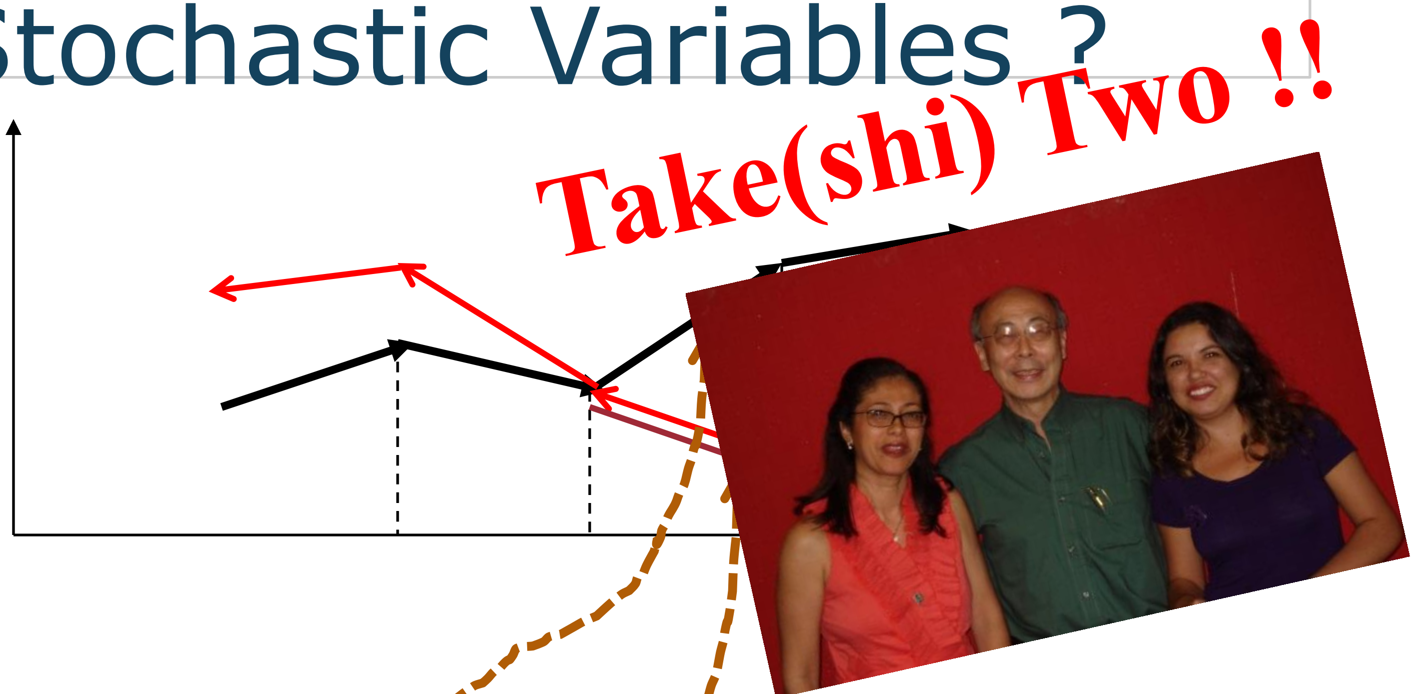


Sometimes his model may be "licked"….



Just kidding.., They are ALL licked…

How to define velocity for Stochastic Variables ?



$$\vec{v} = \lim_{dt \to 0+} \frac{\vec{r}(\vec{R}, t+dt) - \vec{r}(\vec{R}, t)}{dt}$$

Forward SDE

$$\tilde{\vec{v}} = \lim_{dt \to 0+} \frac{\vec{r}(\vec{R}, t) - \vec{r}(\vec{R}, t-dt)}{dt}$$

Backward SDE

Or take these two?

Or ….. Take Three ?


You‘ve got Your three girls already!

Actually : Seven girls!