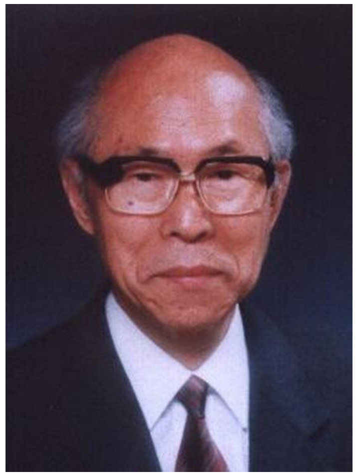
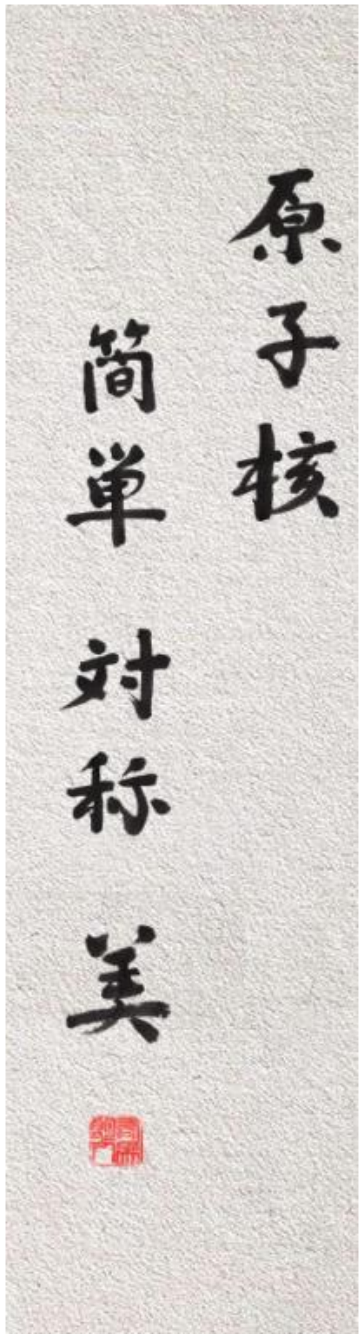
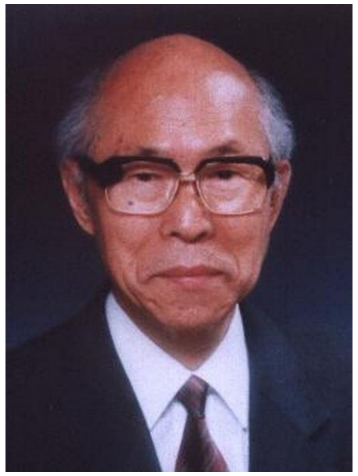
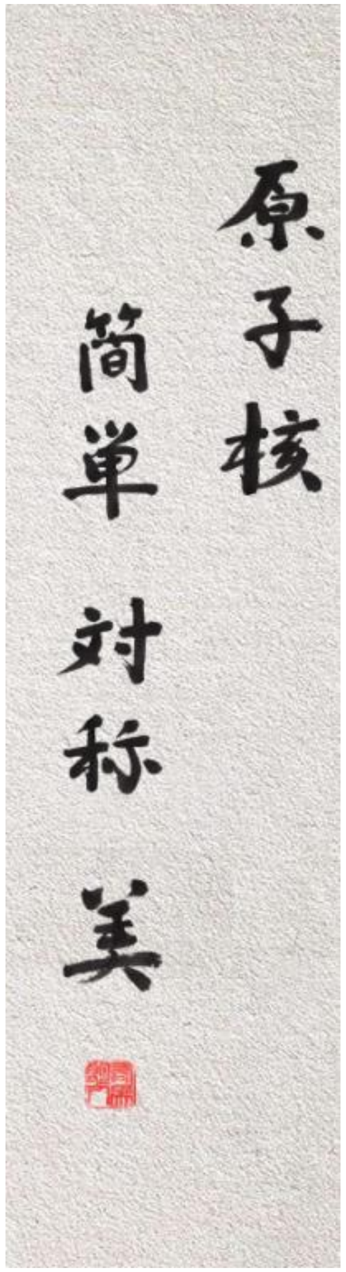
From p-p correlation to pbar-pbar interaction





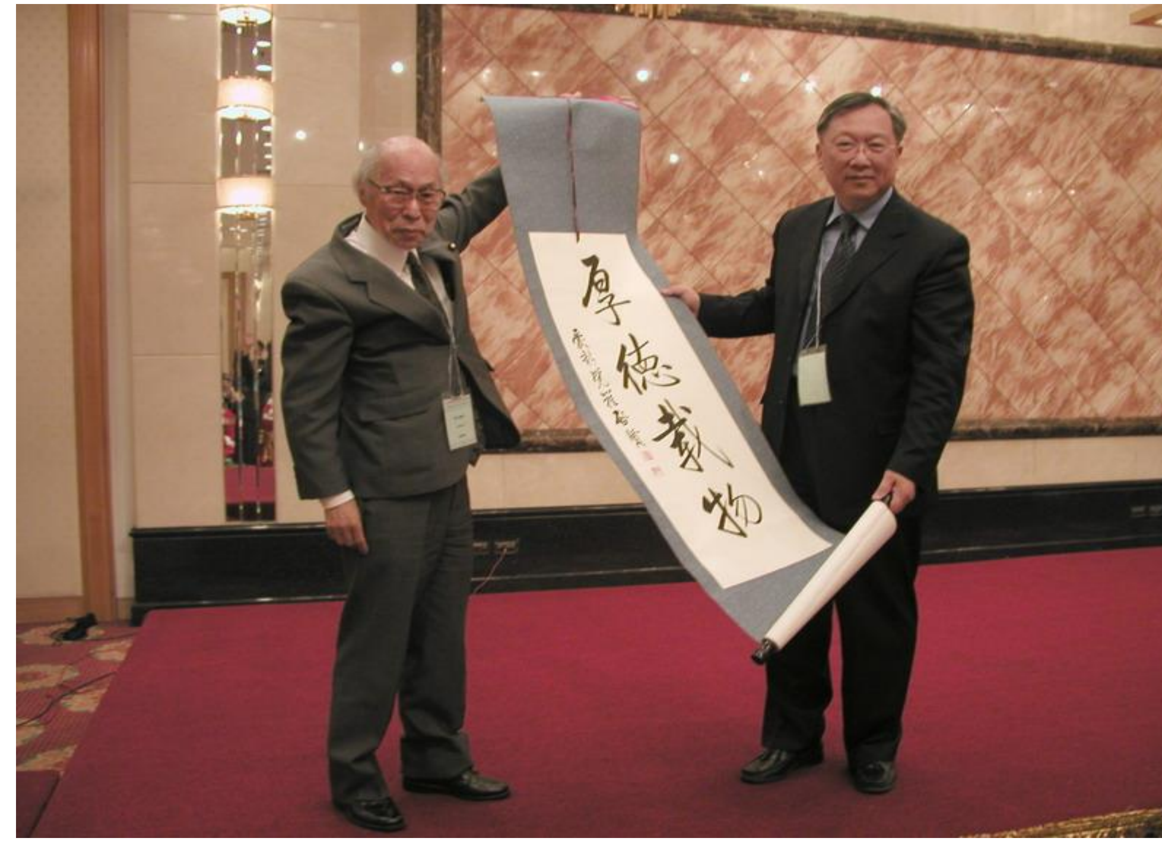




International Symposium of Nuclear Science:
Simplicity, Symmetry and Beauty
In honor of the Rice (米) Age of Professor Akito Arima
September 26th-28th, 2018, Shanghai

1996年8月27日周光召院长在院部会见有马先生

2002年7月路甬祥院长在中日科技与经济交流大会上
向有马先生赠送礼品



(1999年9月
李岚清在中
南海会见以
有马为团长
的日本重点
大学访华团)

With SSRF

● 有马郎人先生两次访问上海应用物理所，非常关心上海光源的建设和发展。

●积极推进上海光源和日本理化所（Spring-8 ）的合作。

2009年4月29日参加上海光源竣工典礼/关注上海光源的运行和发展

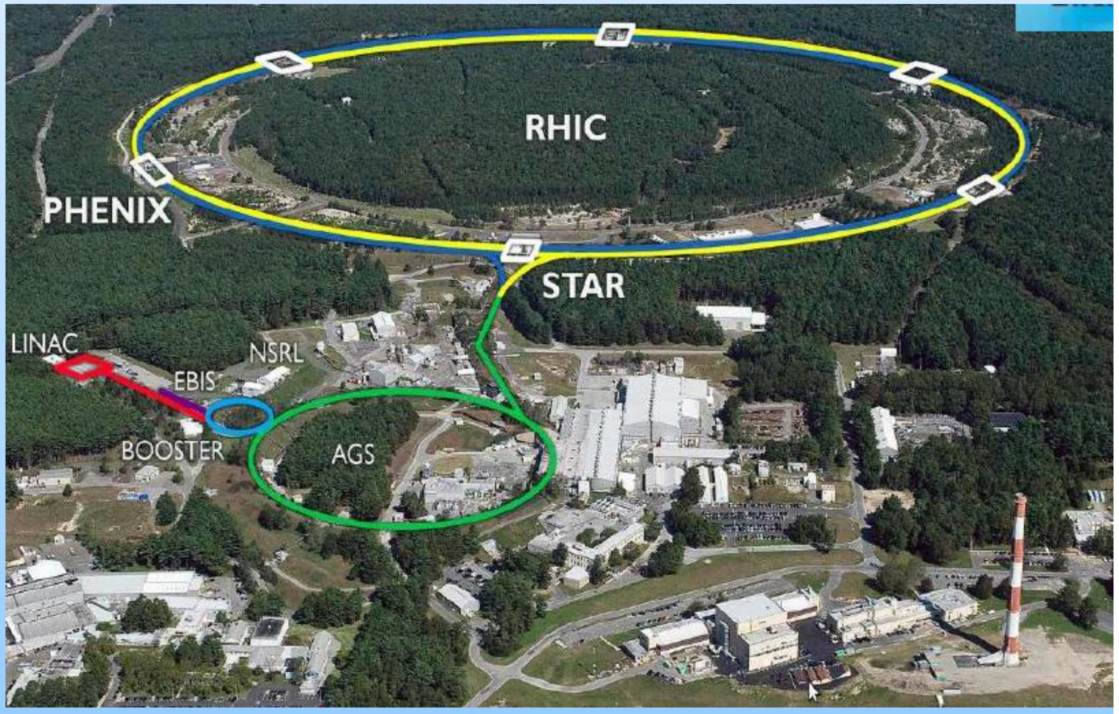
关注并促进中日大科学装置的交流和合作/**2008年中科院国际合作奖**

祝 有马郎人 先生88华诞快乐！

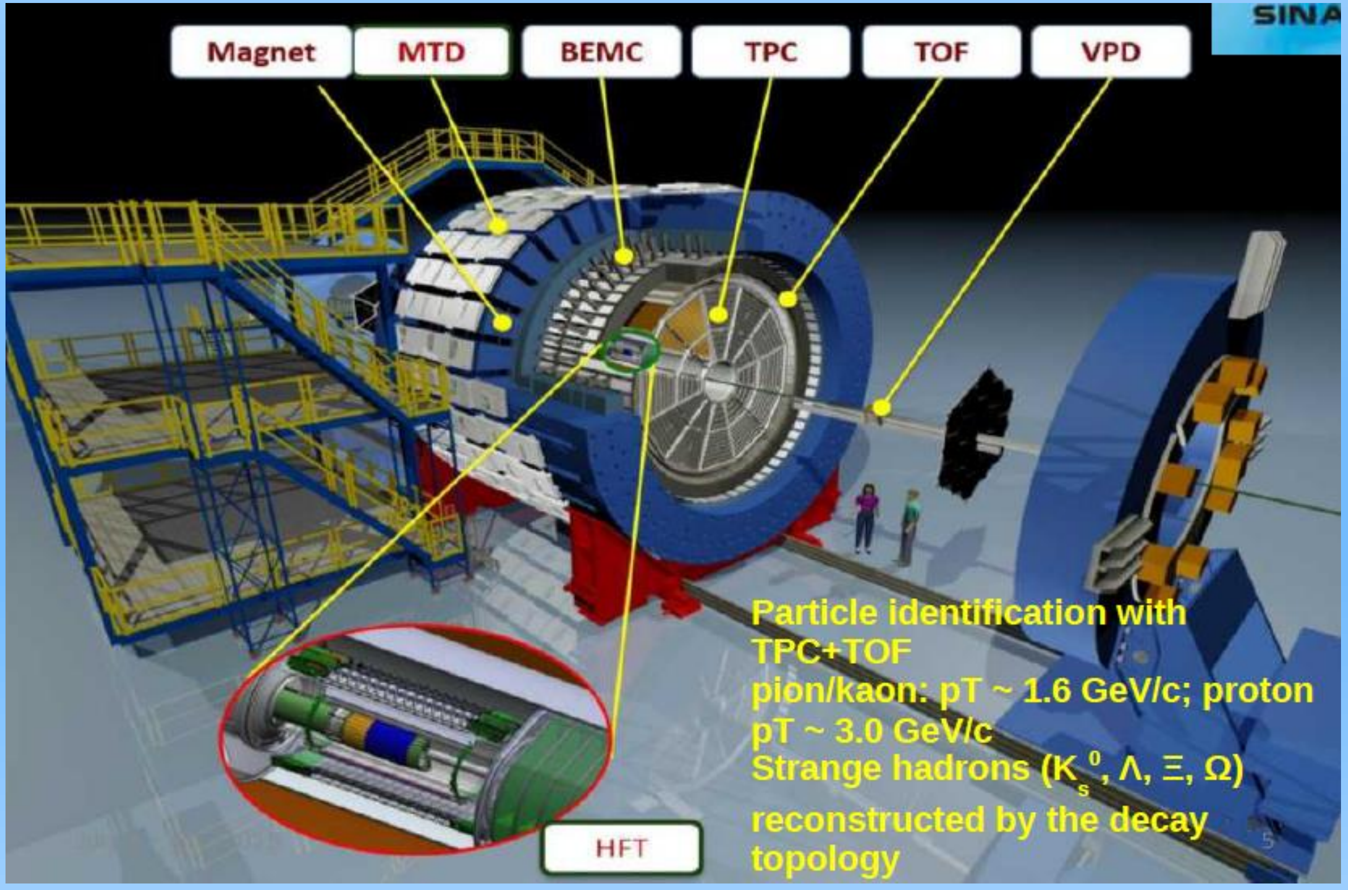
Happy Rice Birthday!

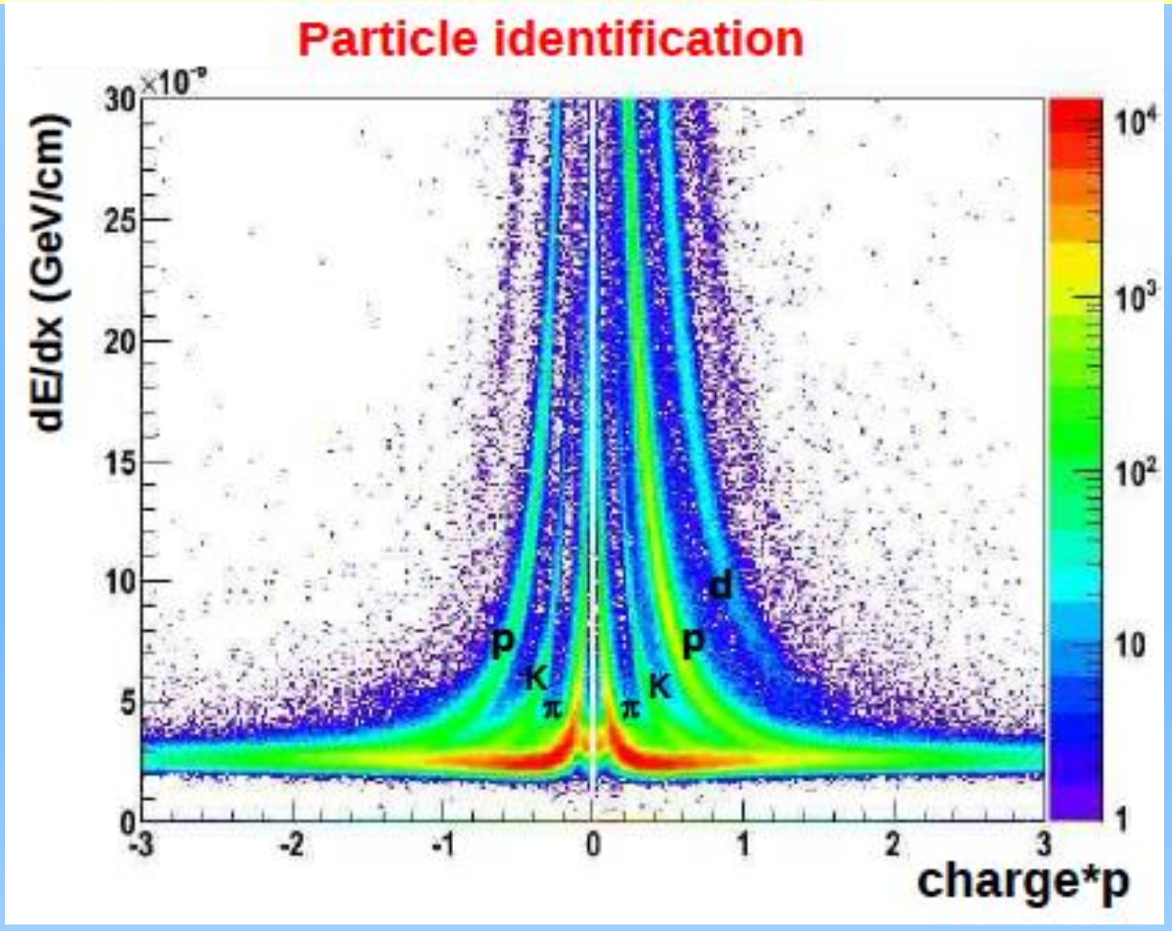
3 years ago
@ Osaka

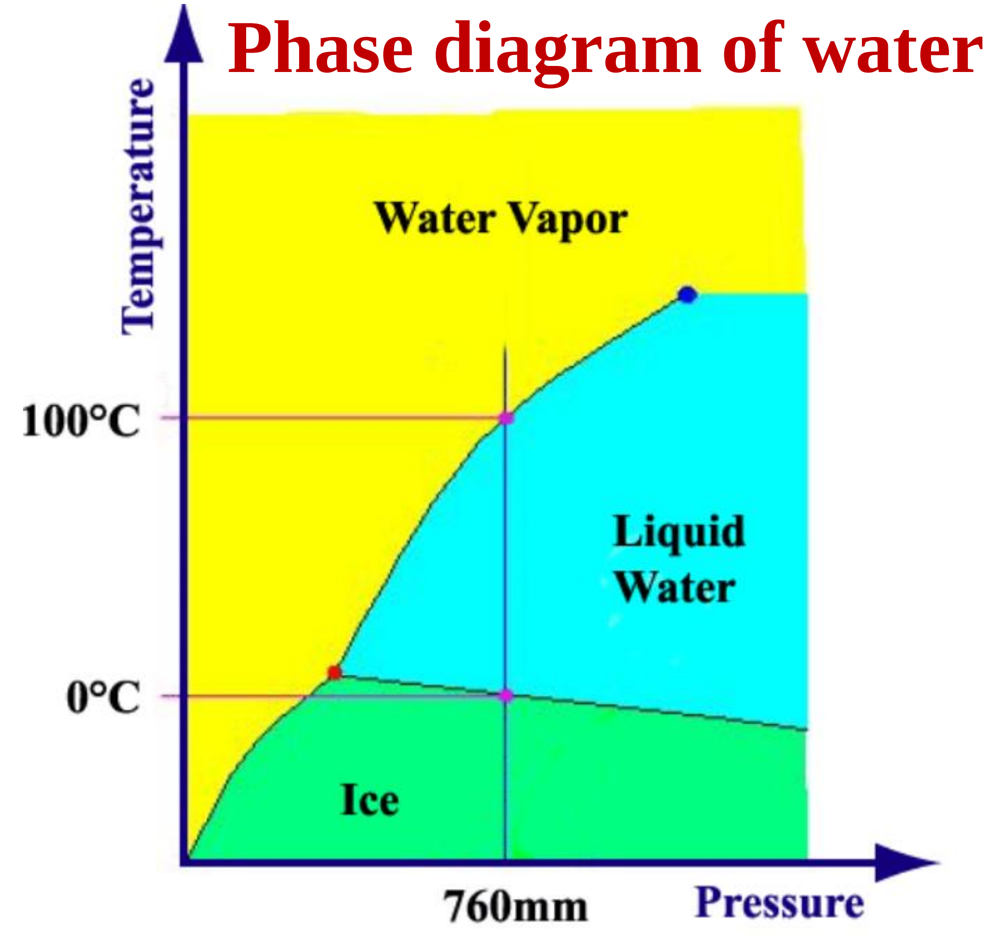
RHIC-STAR@BNL

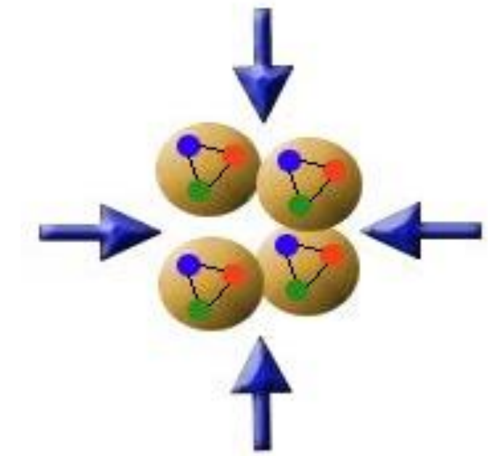


Collision species	C.M. Energy per nucleon pair (GeV)	Physics
Polarized p+p	510, 200, 150	Spin physics
Au+Au	200, 130, 62.4, 39, 27, 19.6, 14.5, 11, 7.7	Quark Gluon Plasma properties, QCD Critical point search
Cu+Cu, Cu+Au	200, 62.4, 19.6, 22.4	Study initial conditions
d+Au	200	Cold nuclear matter
U+U	193	Study initial conditions

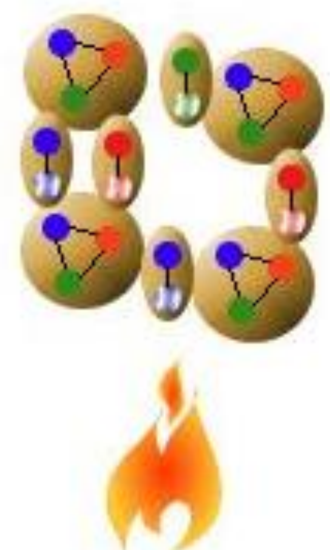




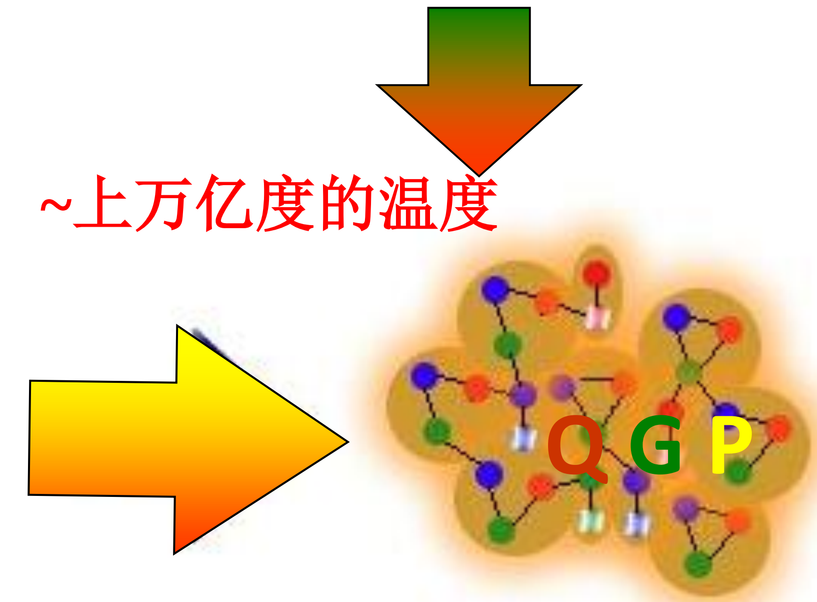




压缩（Compressing）

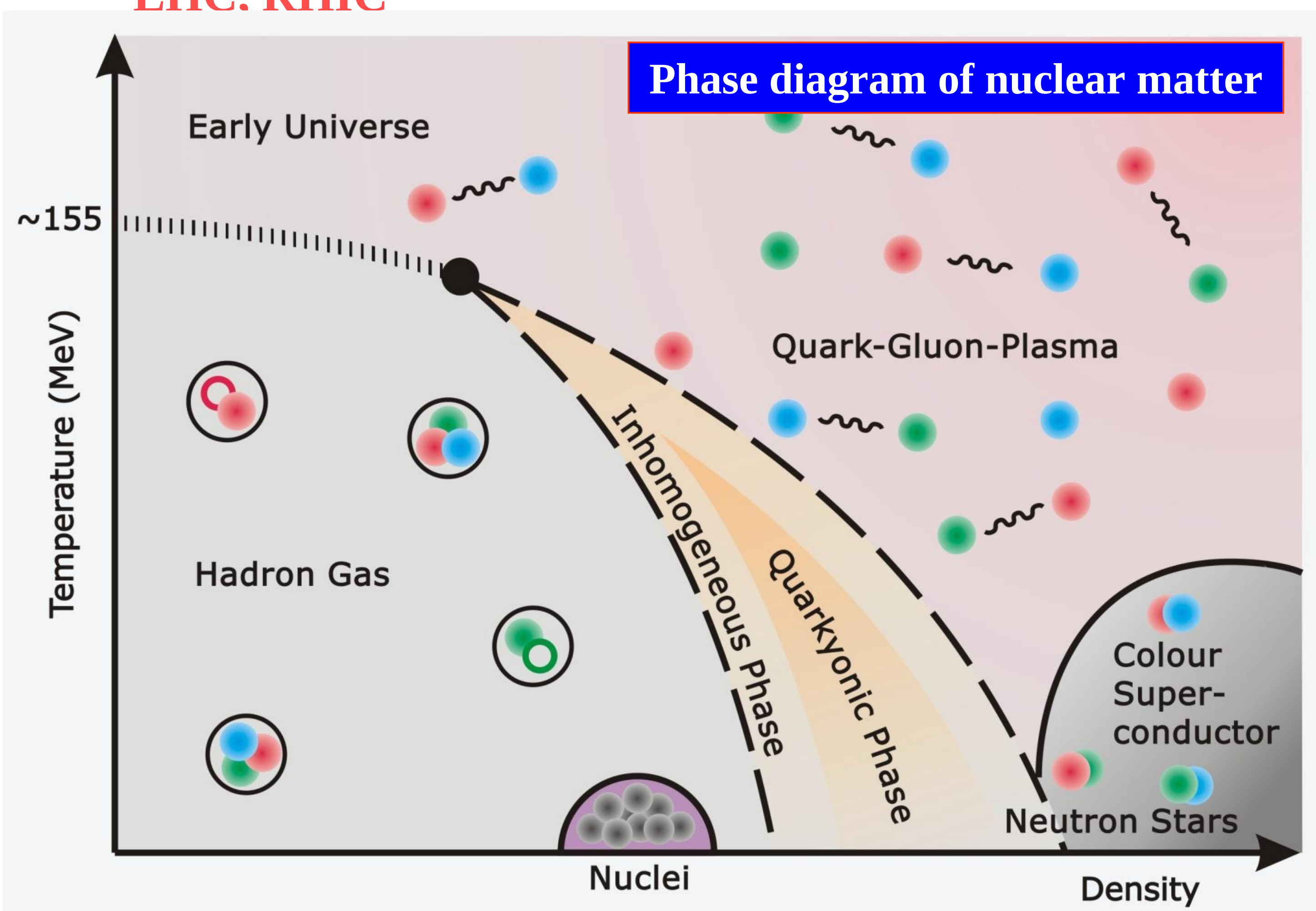


~上万亿度的温度

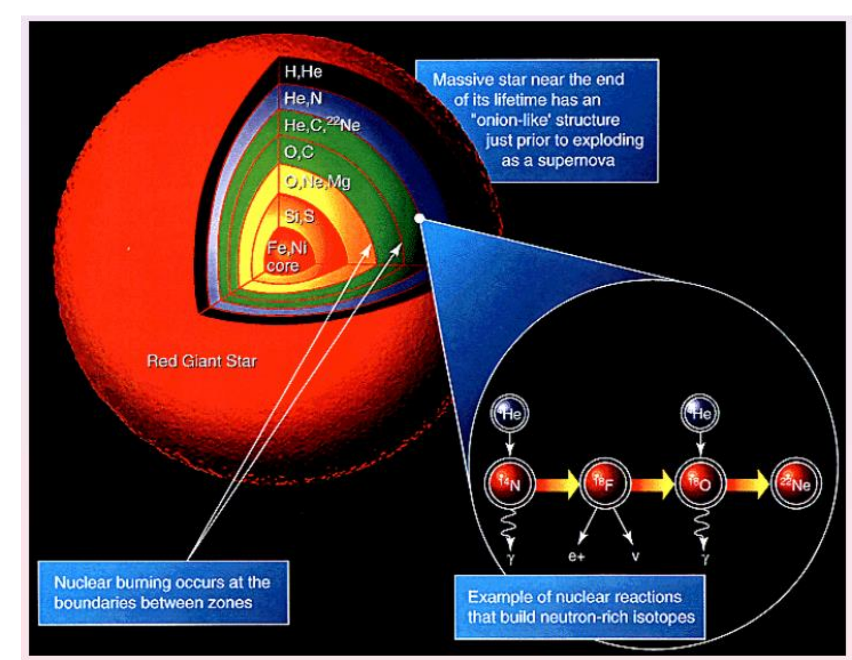


nucleon boundary irrelevant

LHC. RHIC

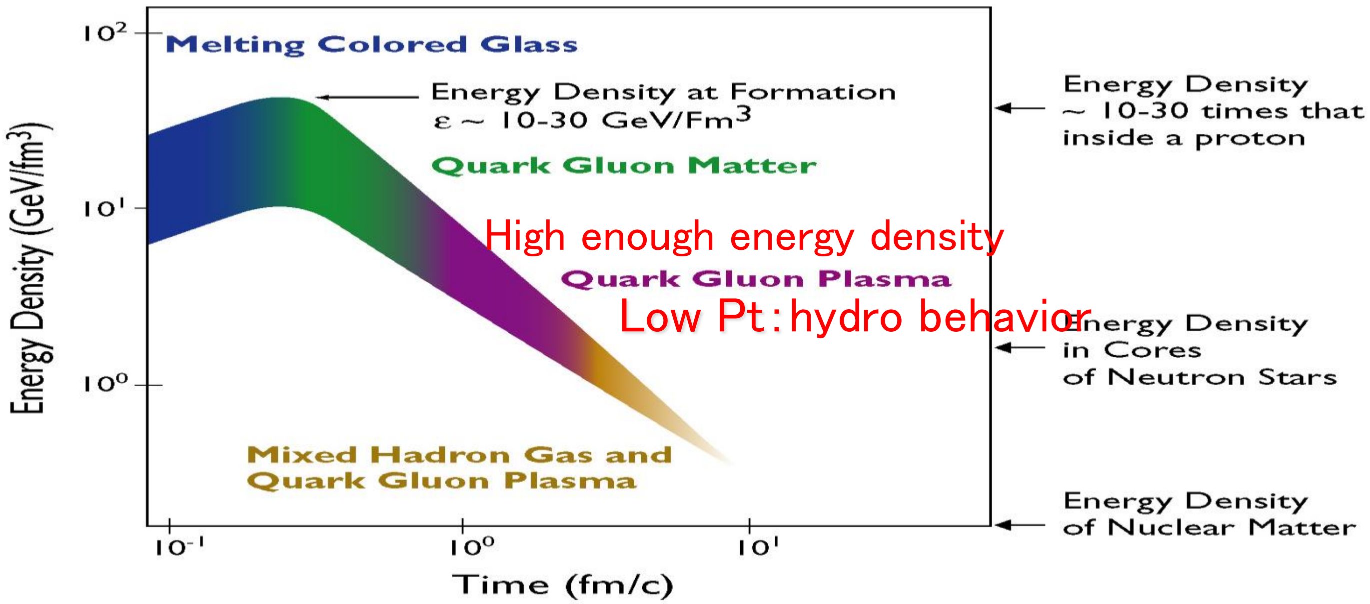


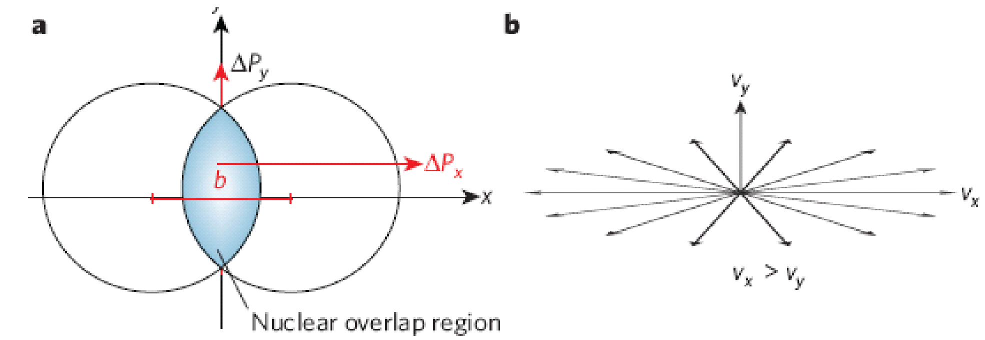
加热（Heating）



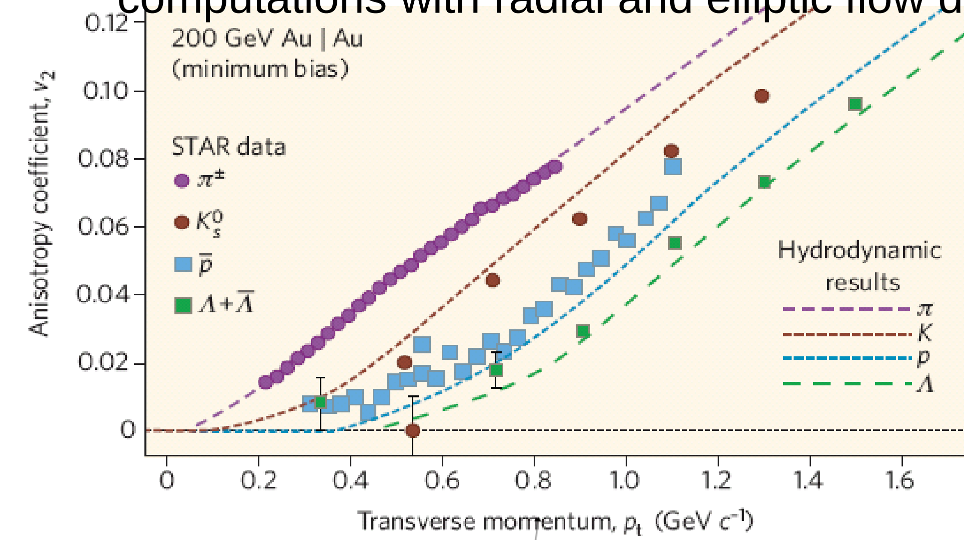
Quark Soup： strong coupling liquid

QGP高温达到了4万亿摄氏度，比太阳核心温度（2000万度）还高~20万倍

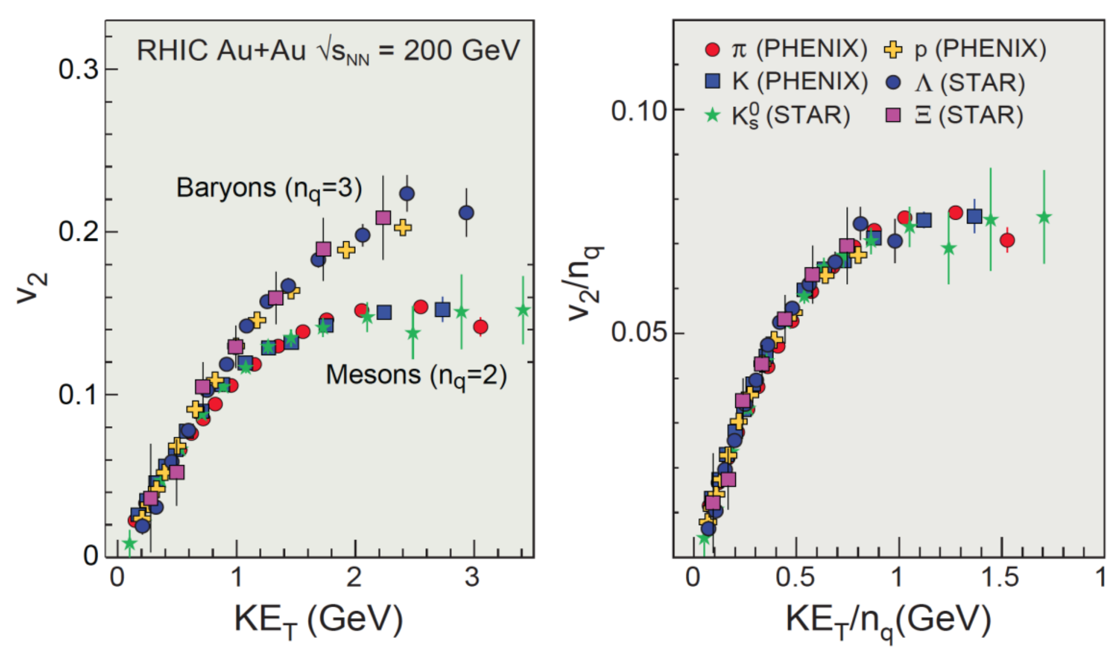


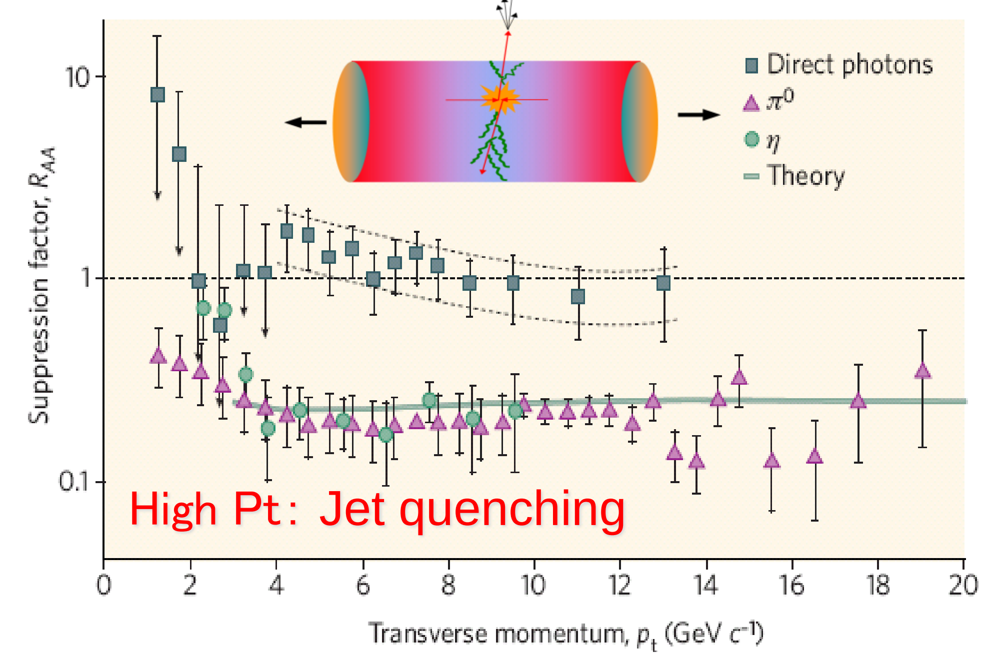


c Good agreement of “well thought out” hydro computations with radial and elliptic flow data



Middle Pt: Quark coalescence





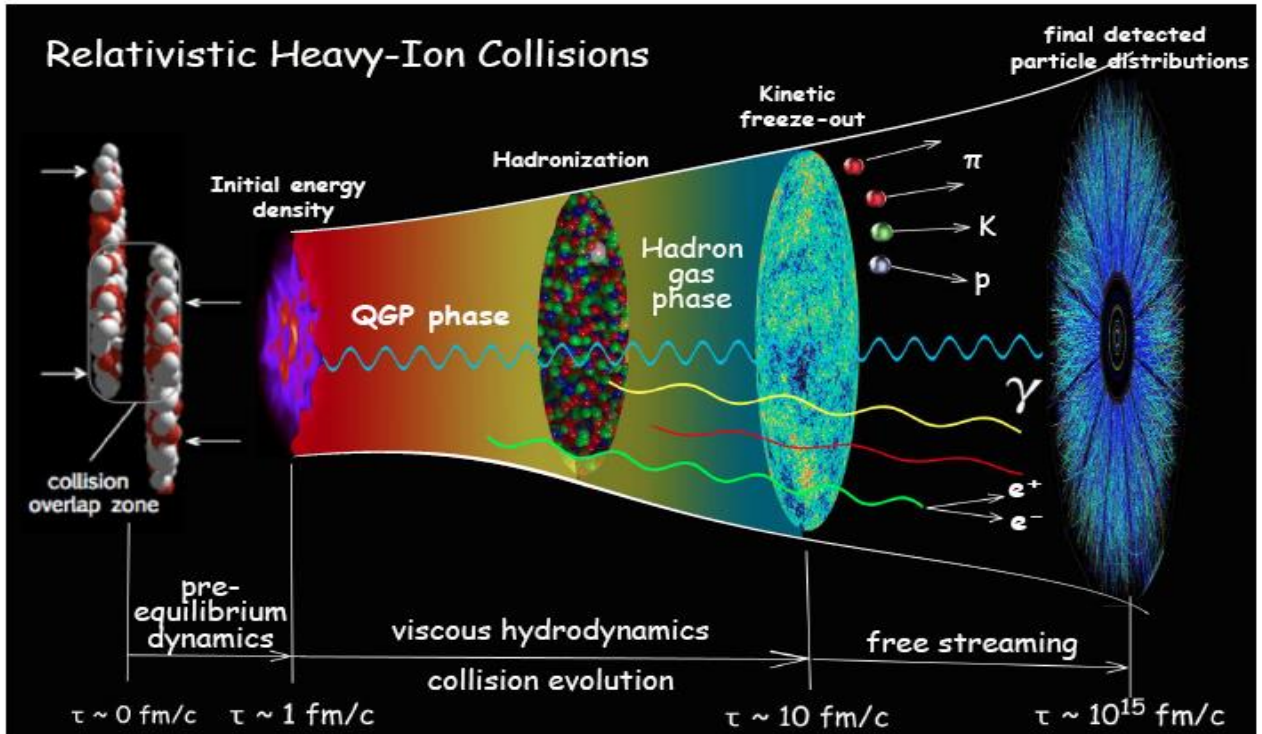
A system of quarks and gluons is to a good to fair approximation explained by a Quark Gluon Plasma:

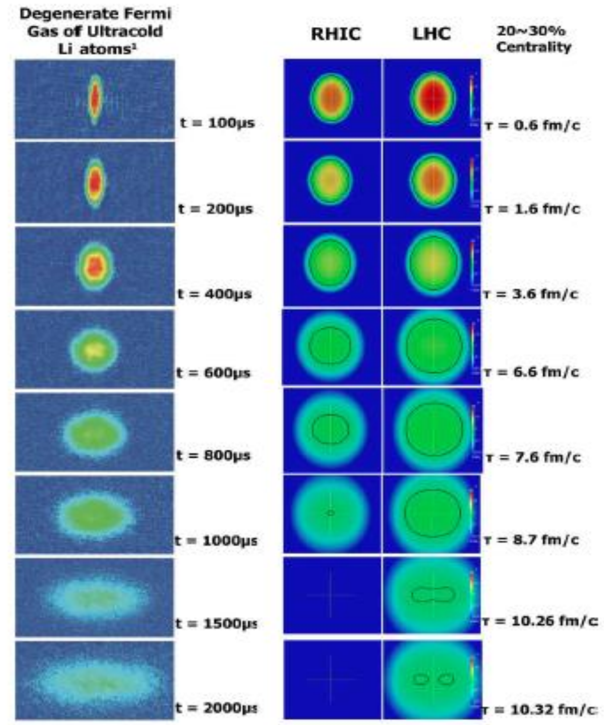
(1) Low Pt, hydrodynamical behavior: thermal

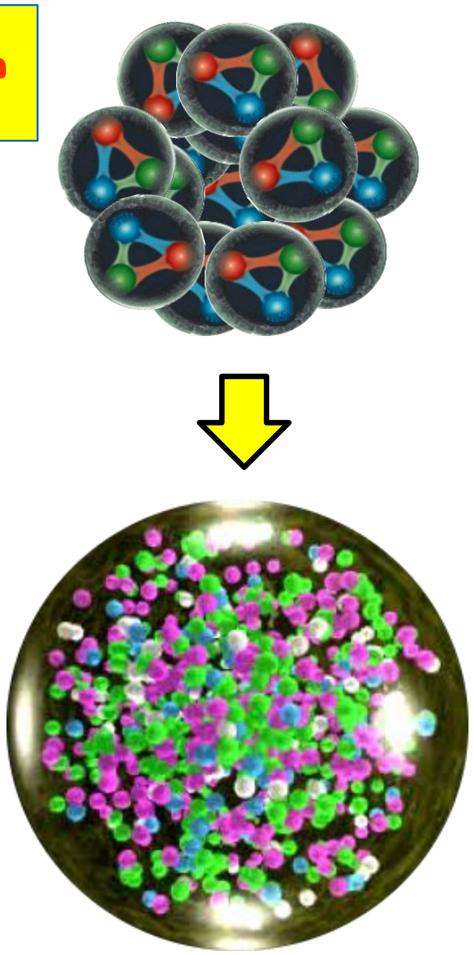
(2) Middle Pt, constituent quark number scaling: partonic flow

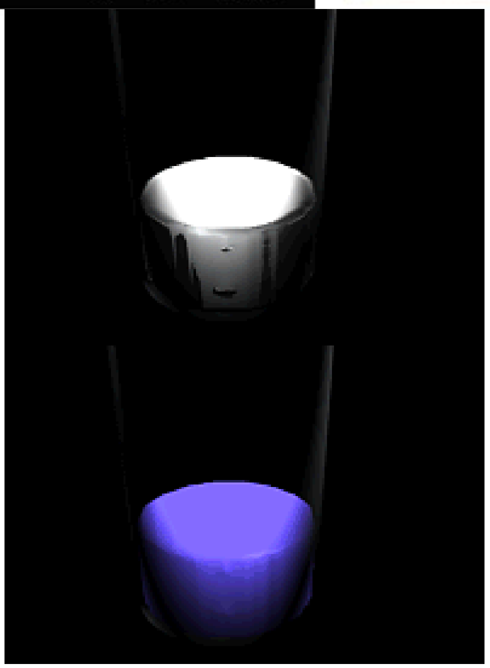
(3) High Pt, jet quenching: hot-dense matter

Quark Soup: The lowest viscosity matter





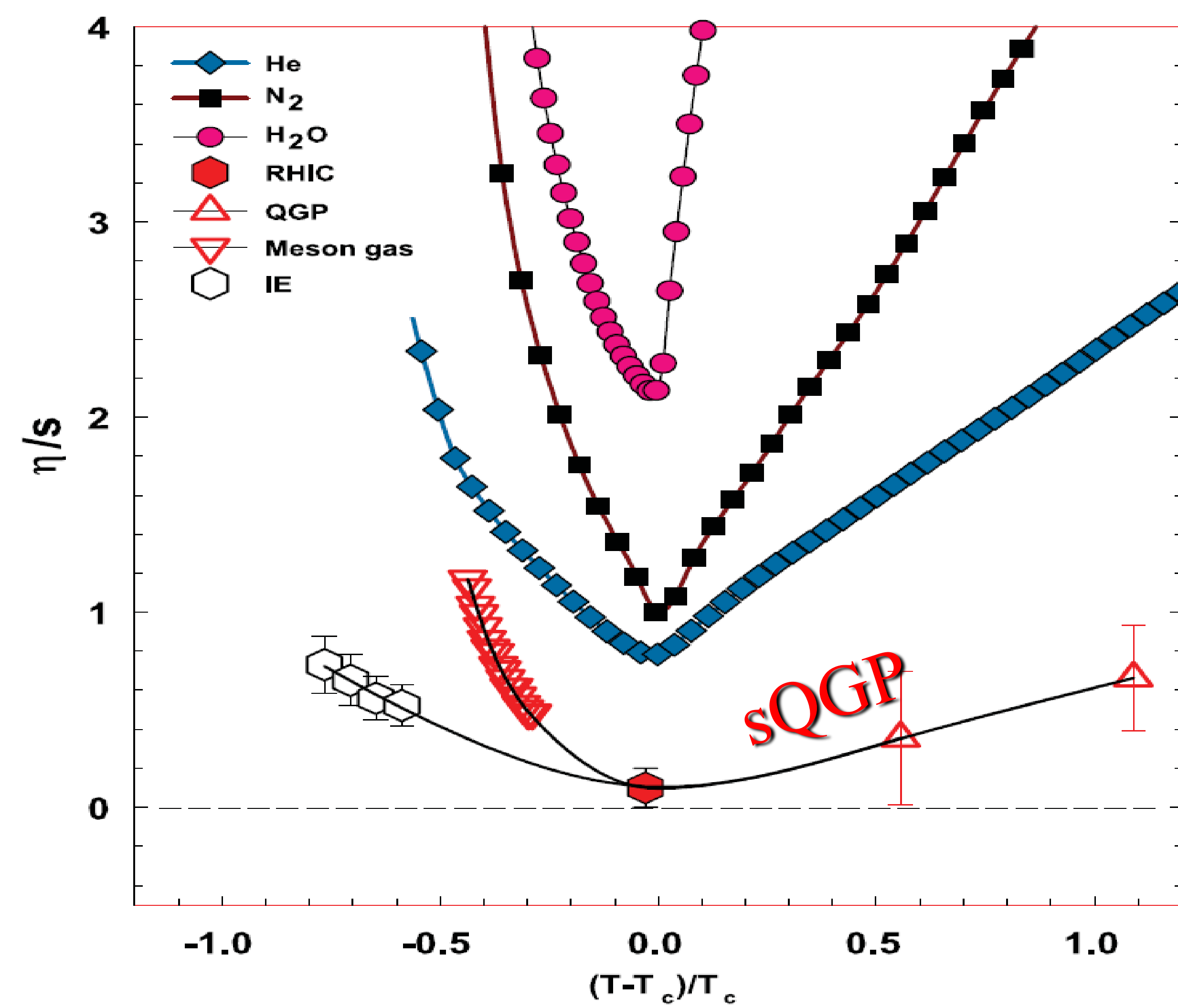




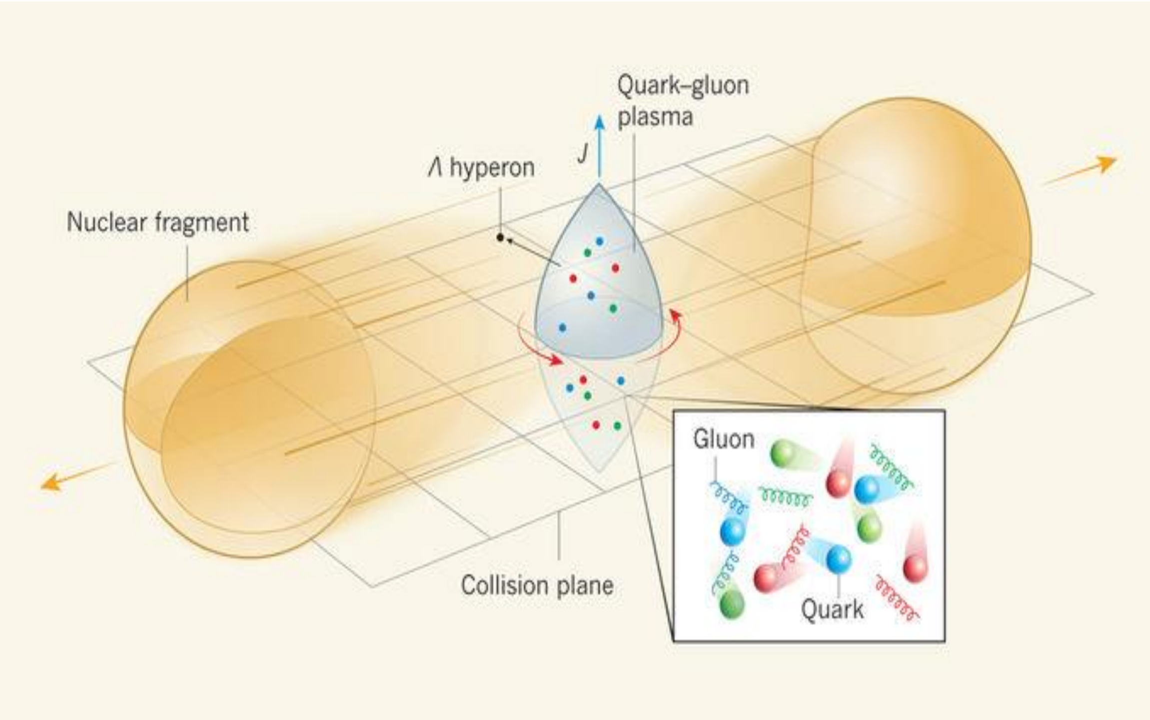
sQGP:

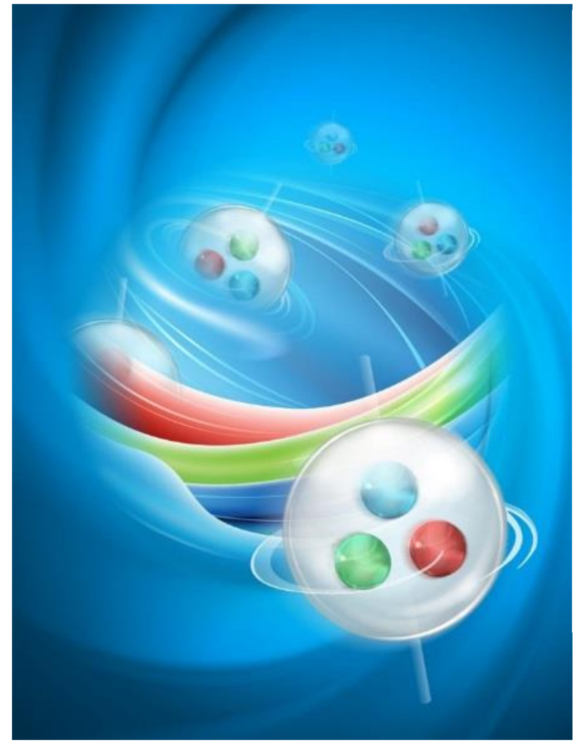
Perfect Liquid !

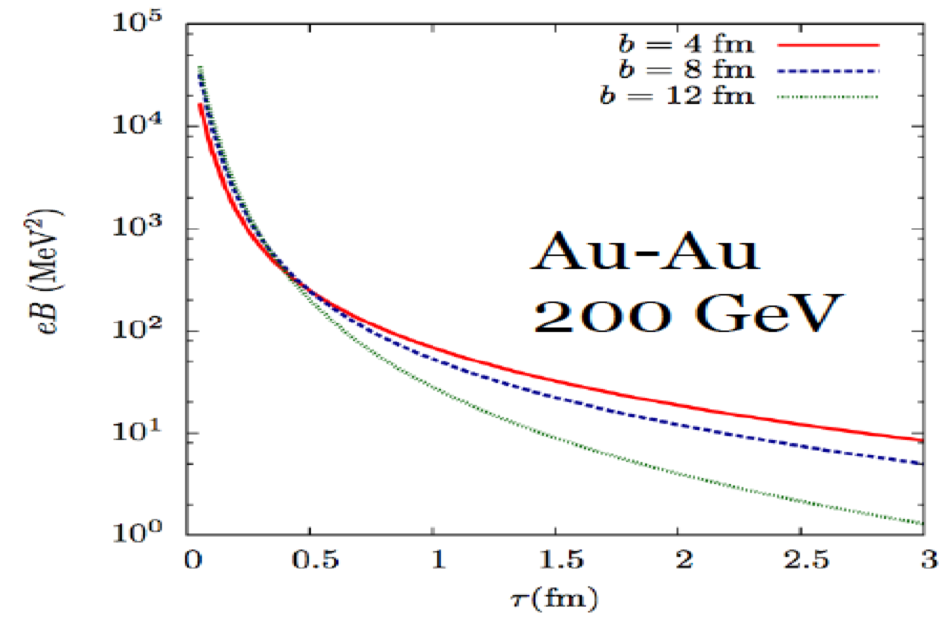
- Strong field condensed matter physics of QCD
- EOS of Neutron stars



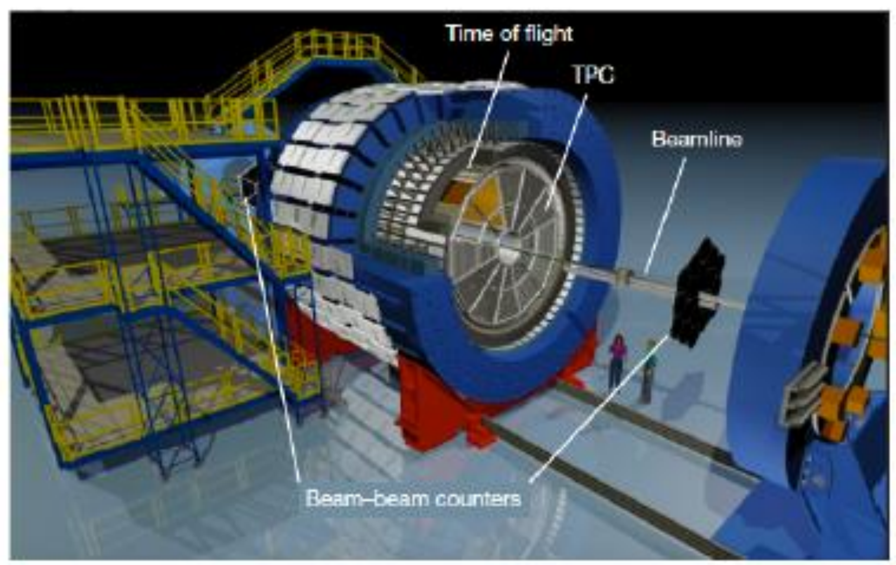
Quark soup: the most vortical matter!



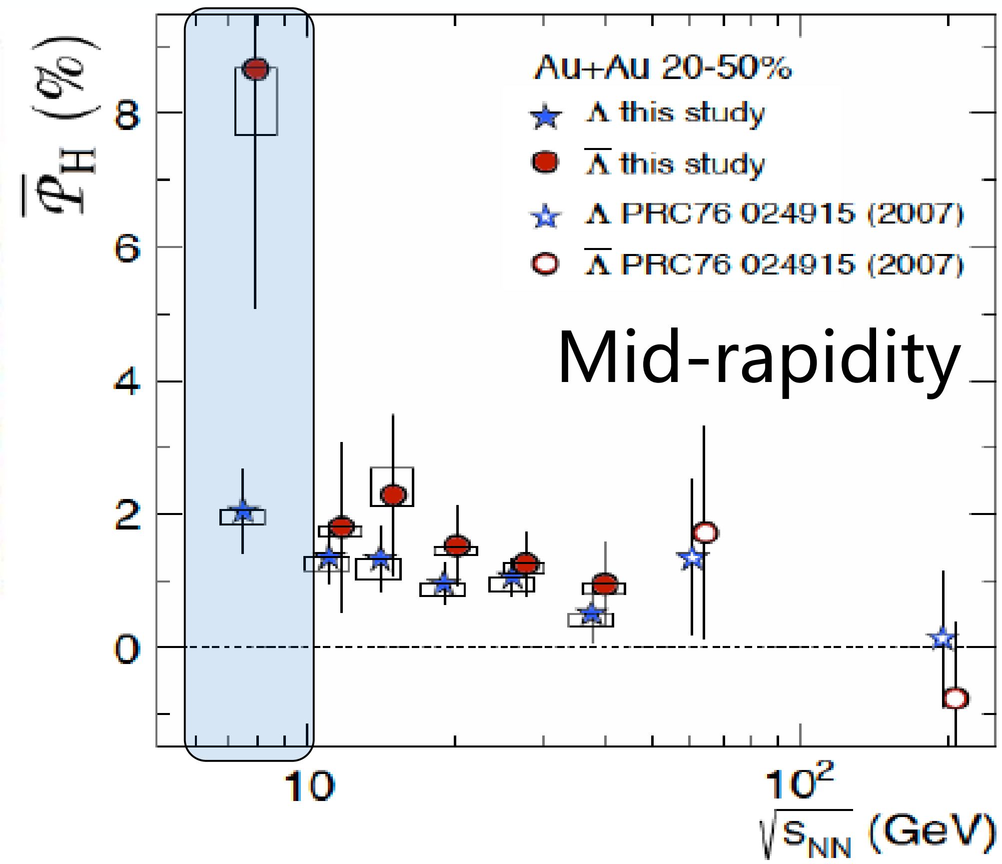




$eB(\tau=0.2\ \mathrm{fm/c}) \approx 10^3 \sim 10^4\,\mathrm{MeV}^2 \approx 10^{18}\mathrm{G}$



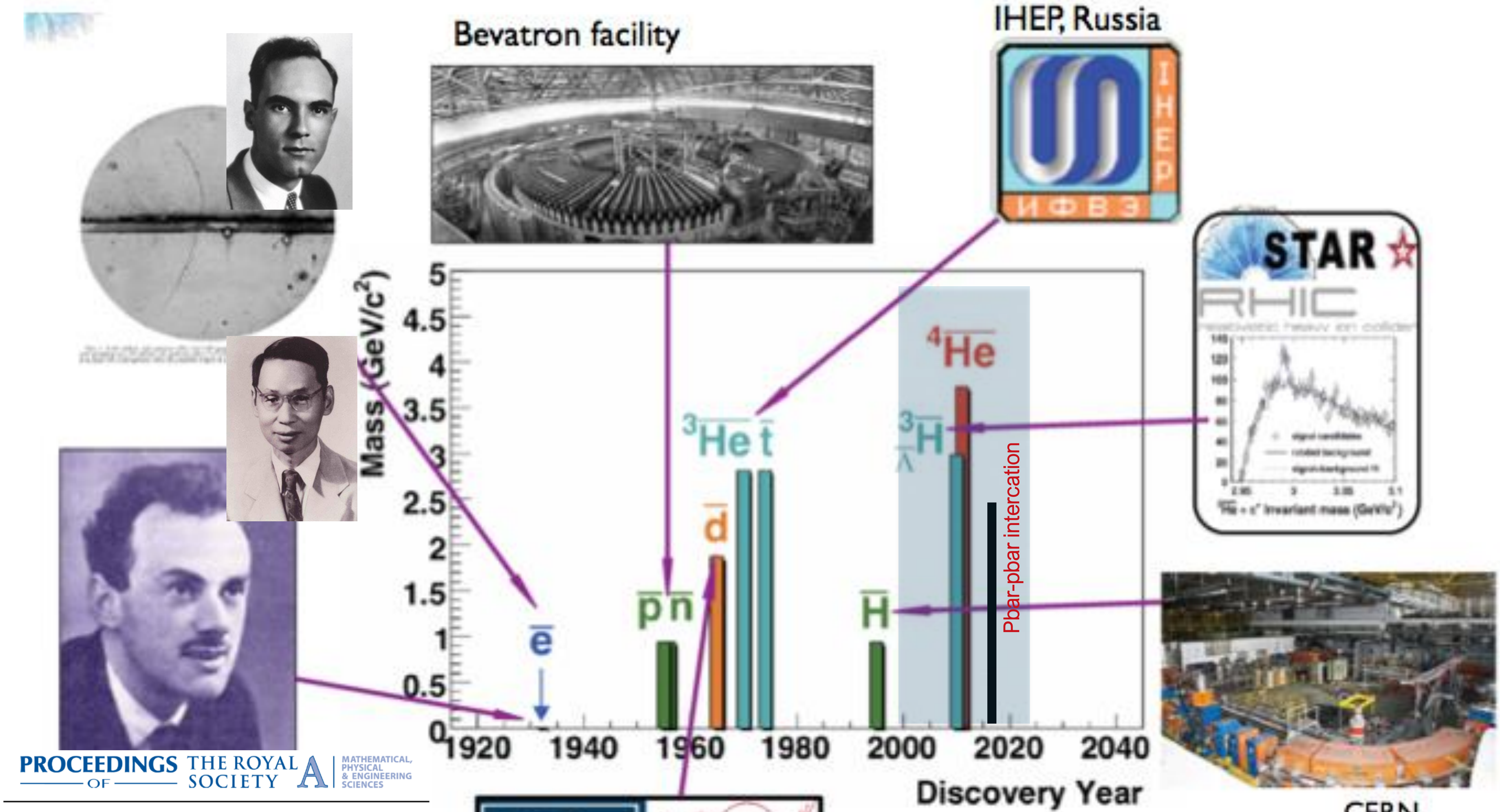
An exciting discovery from STAR Collaboration at RHIC:
The most vortical fluid!



QGP is the most vortical matter
Rotation frequency=(9±1)10^{21}/s

Z. T. Liang & X. N. Wang, PRL94, 102301 (2005)

History of antimatter particles



The Quantum Theory of the Electron

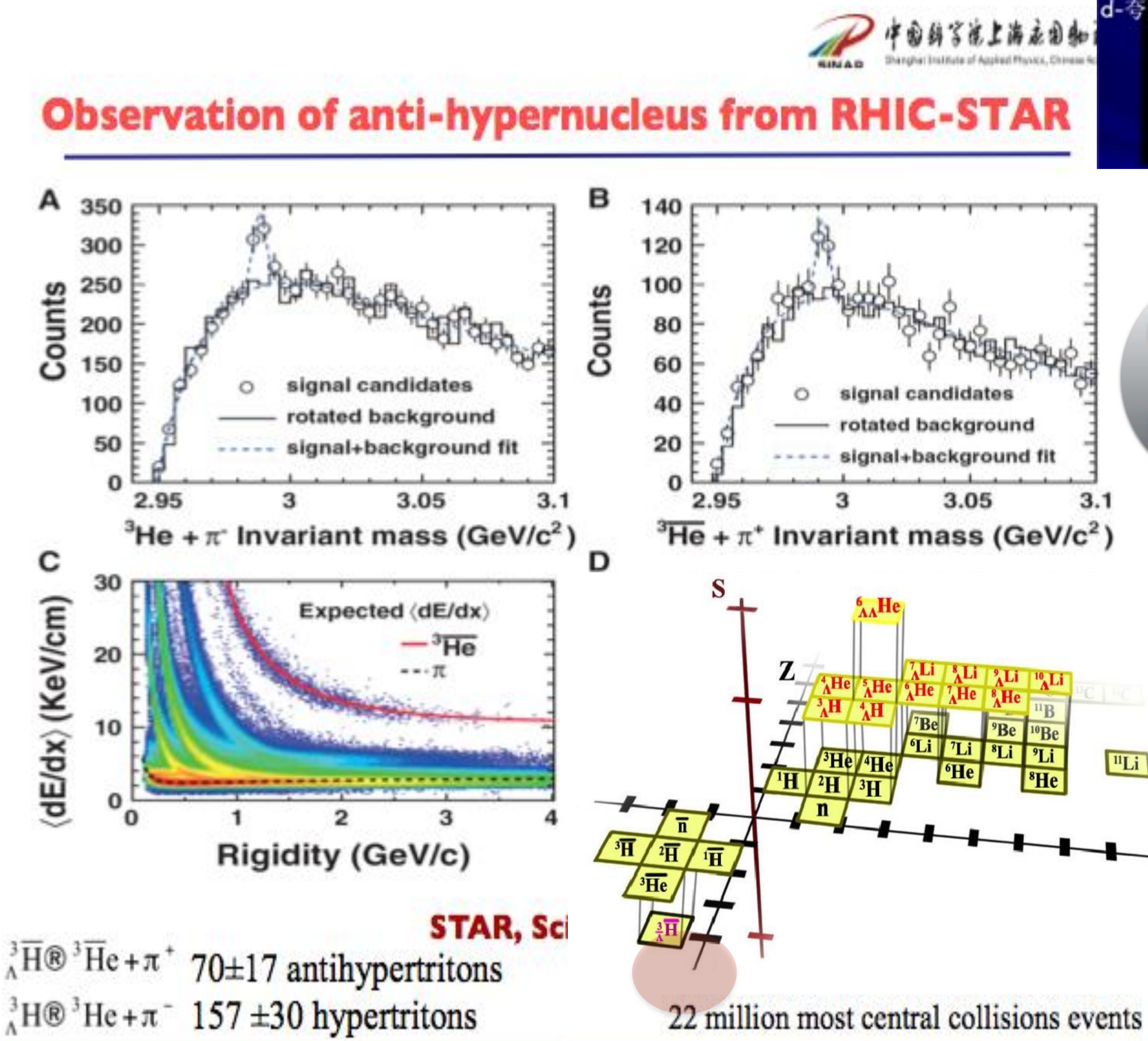
P. A. M. Dirac

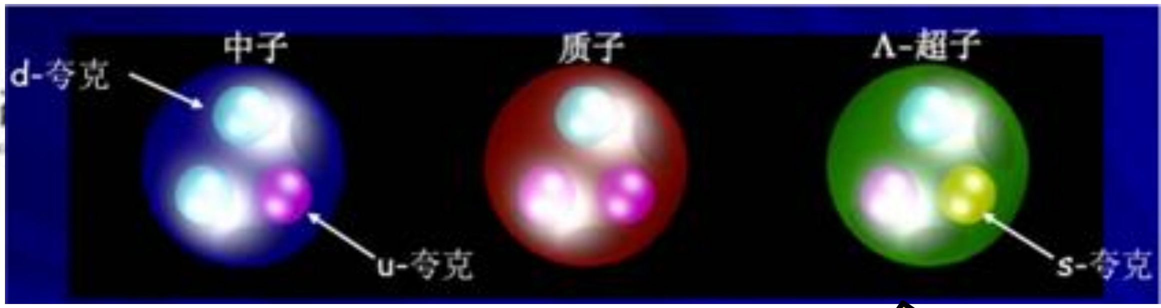
Proc. R. Soc. Lond. A 1928 **117**, doi: 10.1098/rspa.1928.0023, published 1 February 1928

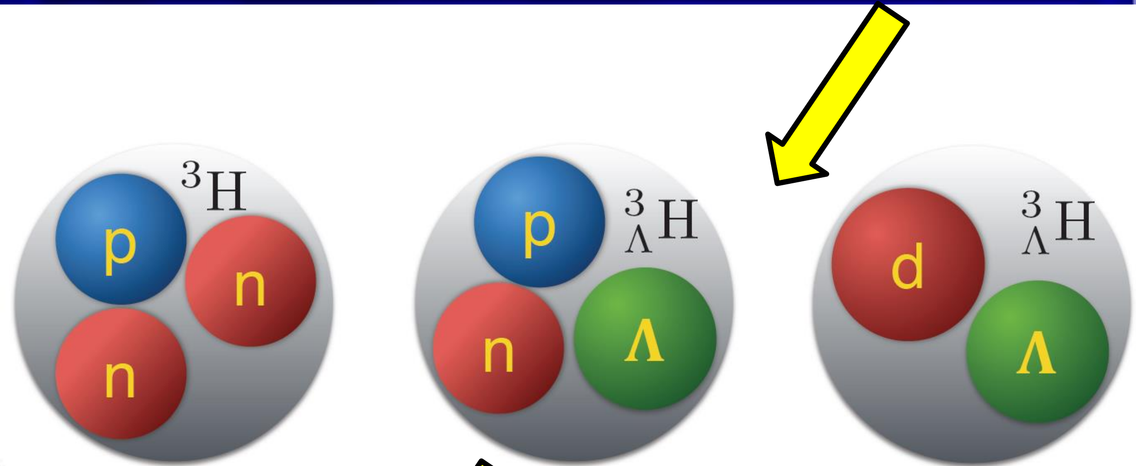
Anderson, C. D. Phys. Rev. 43, 491-494 (1933).
Chamberlain, O. etal. Phys. Rev. 100, 947 (1955).
Dorfan, D.E. etal. Phys. Rev. Lett. 14, 1003 (1965).
Antipov, Y. M. et al.. Yad. Fiz. 12, 311 (1970).
Abelev, B. I. et al., STAR Collaboration. Science 328, 58 (2010).
Abelev, B. I. et al., STAR Collaboration. Nature 473, 353 (2011).
...een. et al., The ALPHA Collaboration. Nature Physics 7, 558 (2...

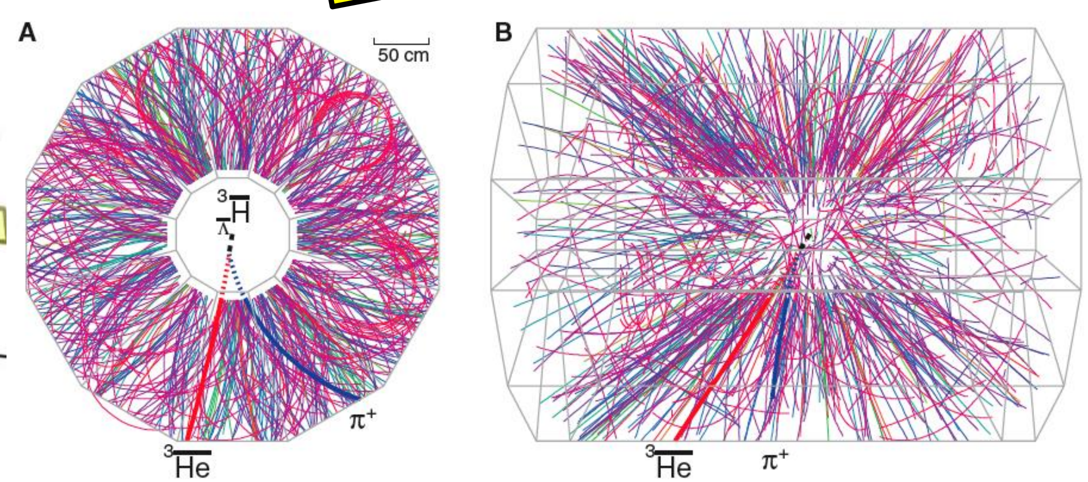
Y. G. Ma, J. Chen, L. Xue, *Front Phys.* 7 (2012) 637–646
J. Chen, D. Kean, Y.G.Ma, A. Tang, Z. Xu, *Phys. Rep*. (2018) in press

STAR@2010: From hyperon to hypernuceus, to Antihypernucleus



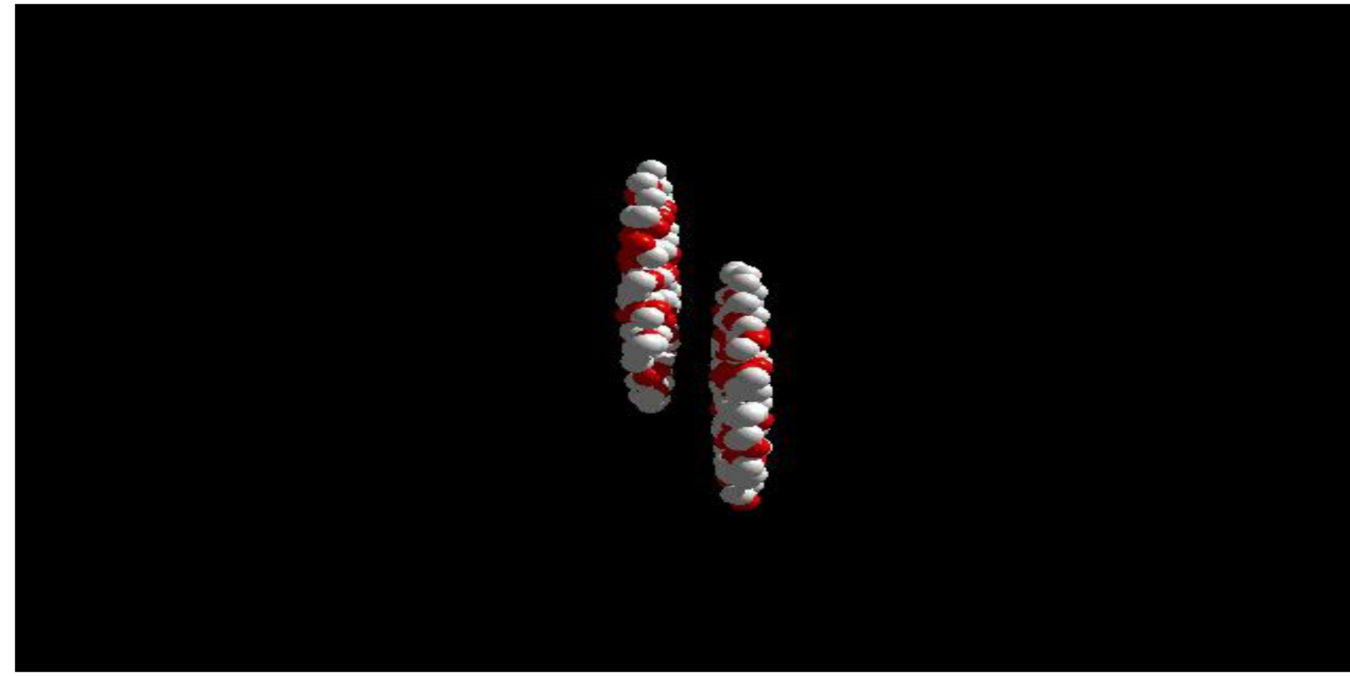


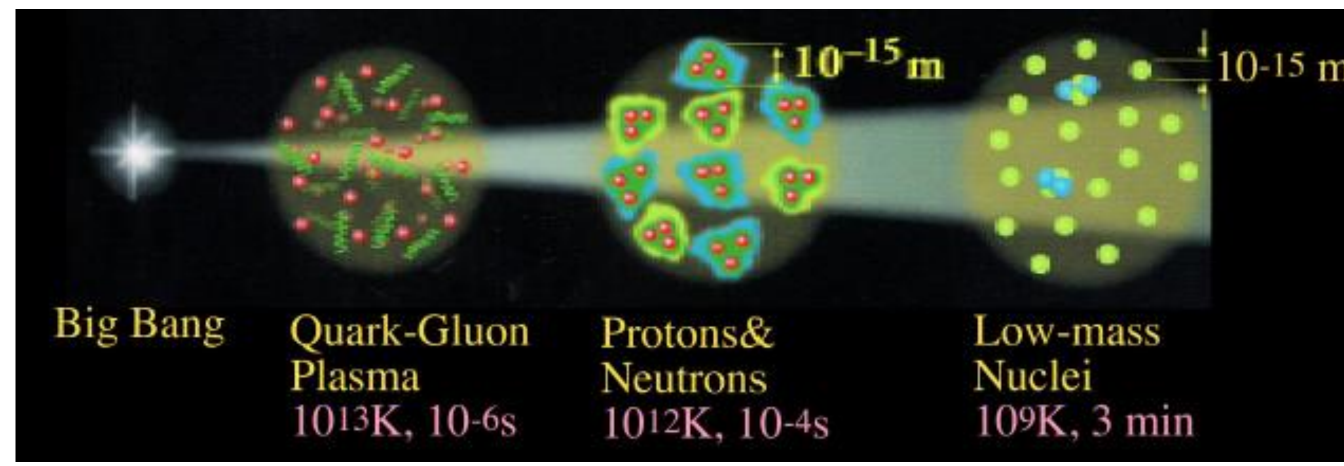




Science 328(2010)58

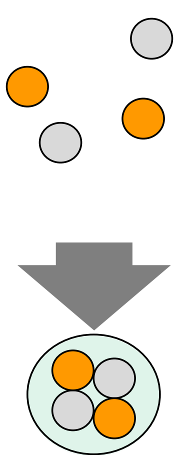
STAR@2011: From AMS to RHIC: Helium4 to Anti-helium 4



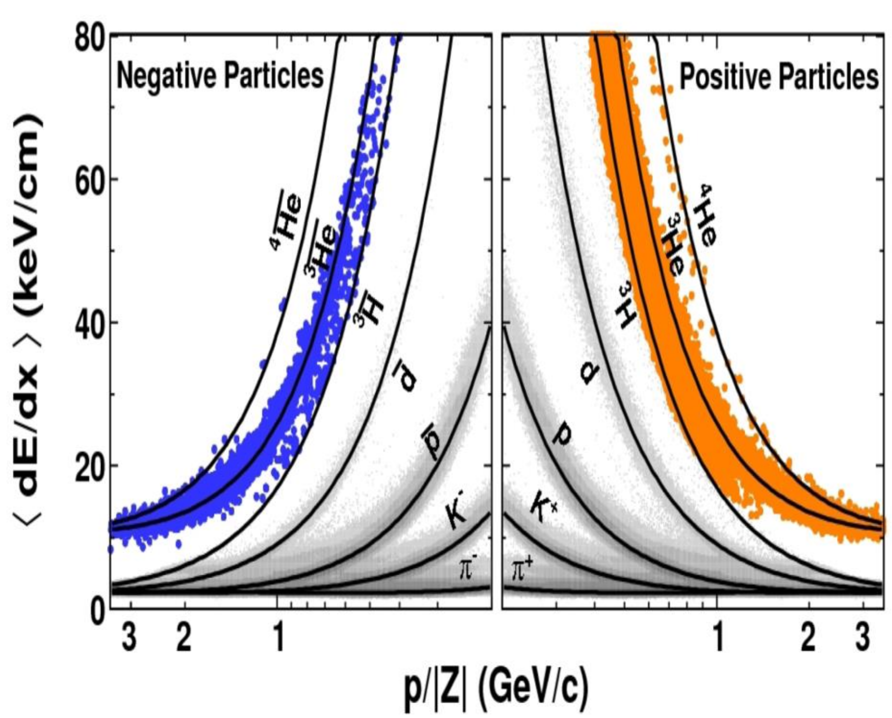


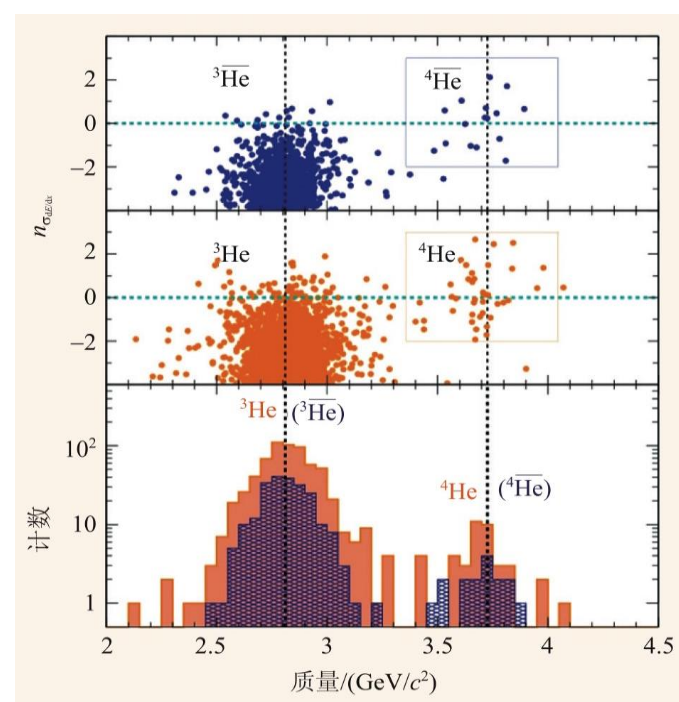
STAR Experiment: ***Nature*** **(2011)**

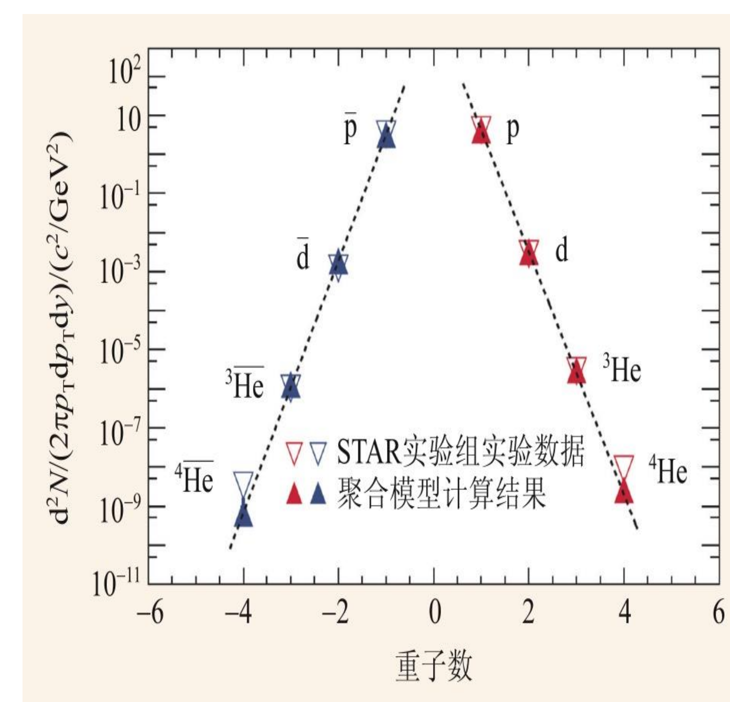
Liang Xue@SINAP, PhD Thesis @ 2012



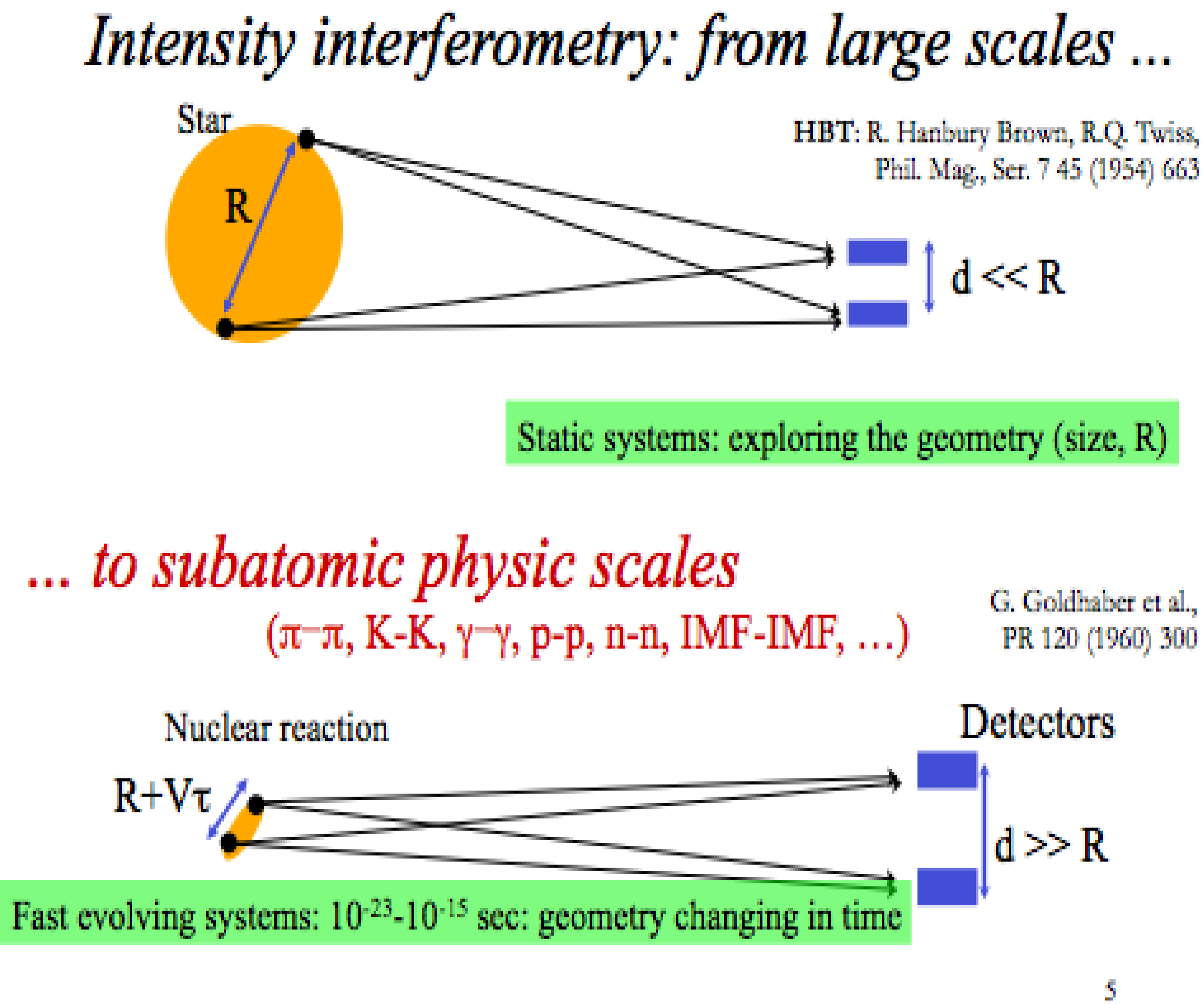
13

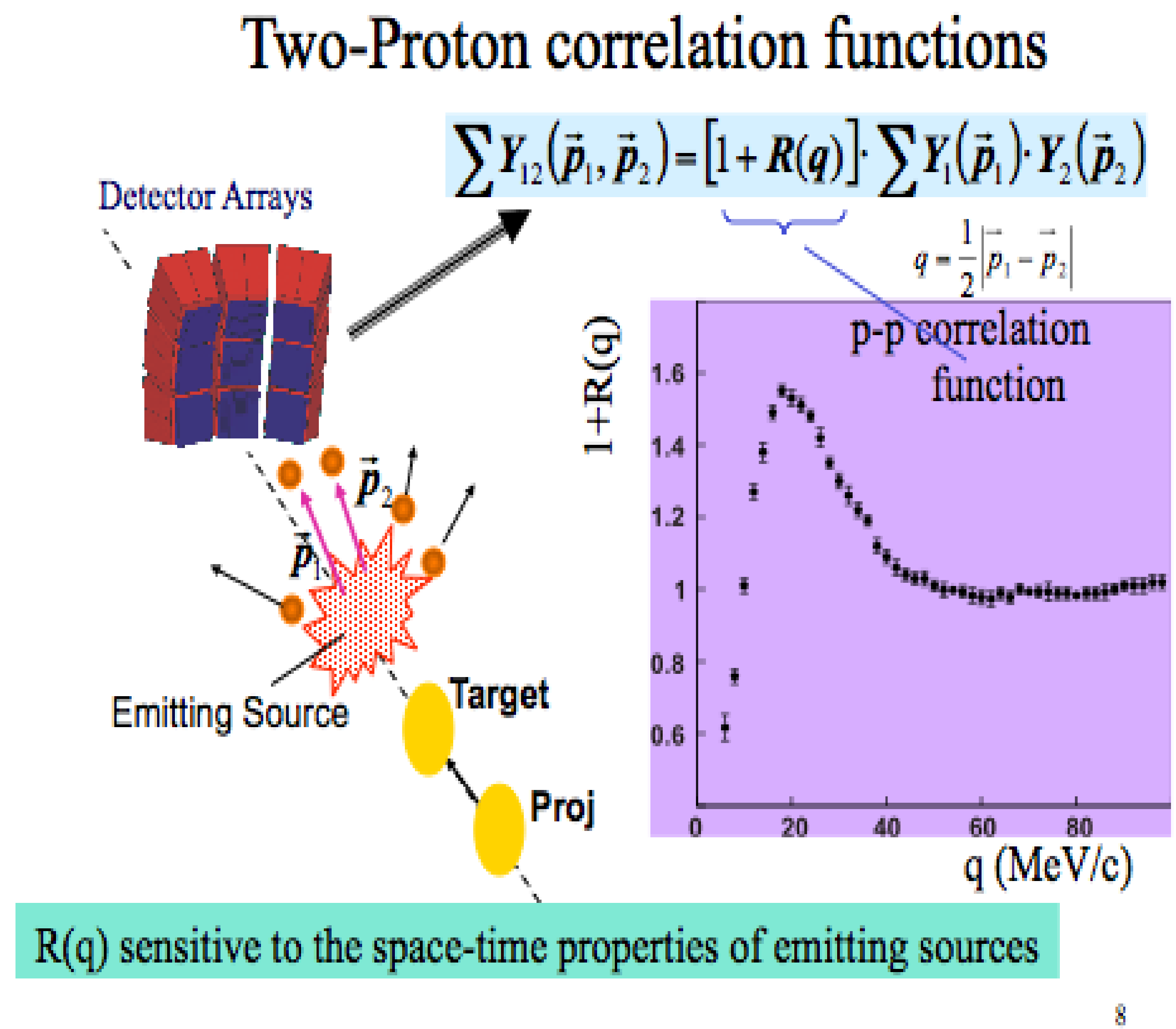






An intensity interferometry method:
From HBT to pp correlation





Many works have been done at low-E HIC. eg. B. Lynch, Pochldzalla, C. Gelbke, Pratt et al.

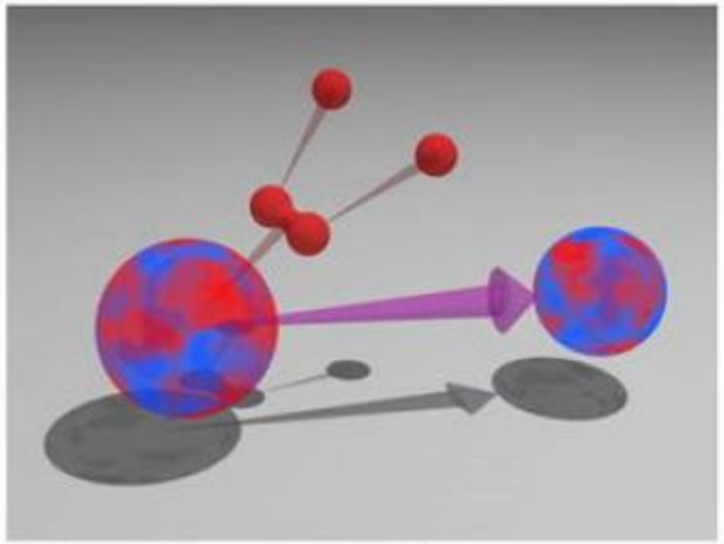
However, there is no any antiproton-antiproton measurement so far.

If so , antiproton interaction parameters could be extracted.

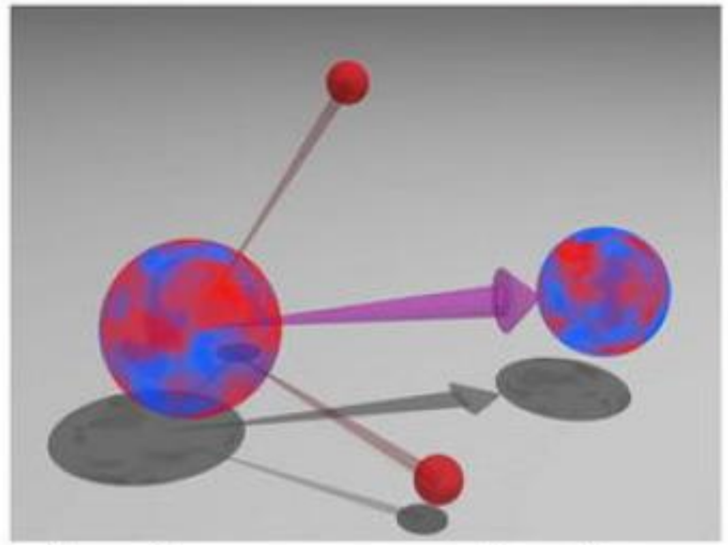
Different mechanism of two-proton emission

B. Blank et al.

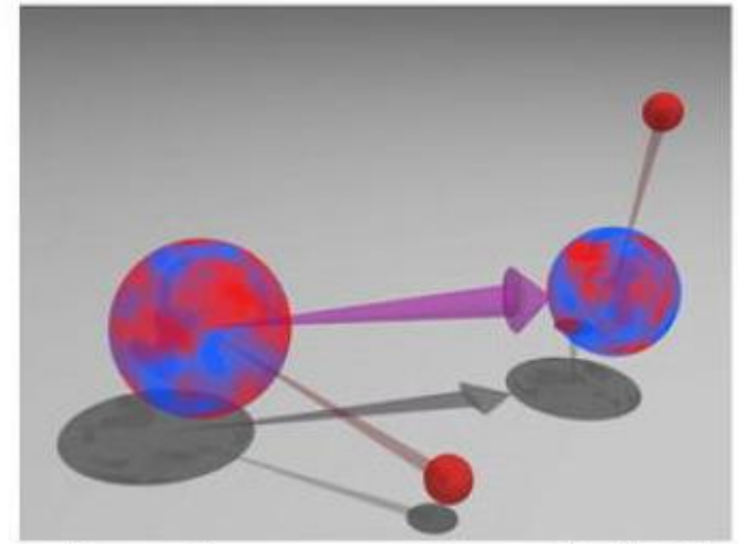
Three extreme decay modes



^{2}He cluster decay



3-body democratic decay



2-body sequential decay

Two types of 2p emission

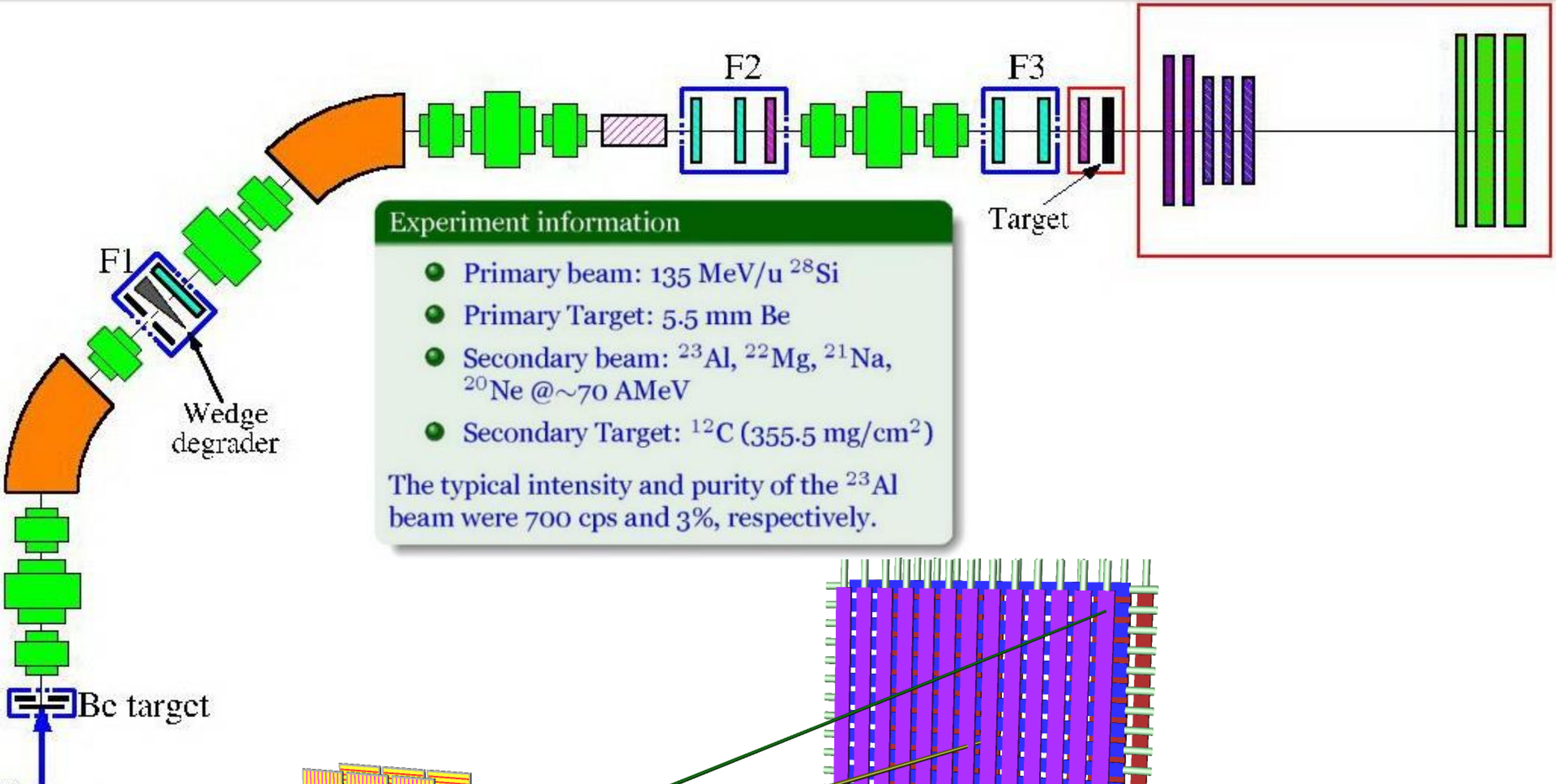
– emission from ground-state
- long lived: ^{45}Fe, ^{48}Ni, ^{54}Zn
- short lived: ^{6}Be, ^{12}O, ^{16}Ne, ^{19}Mg

– emission from excited states
- β delayed: ^{22}Al, ^{31}Ar, ...
- others: ^{14}O, ^{17}Ne, ^{18}Ne, ^{94}Ag

Objectives of studying 2p emission

- masses of nuclei beyond drip line
- p-p pair correlation inside nuclei
- nuclear structure information for proton-rich nuclei (single-particle levels, deformation)
- tunneling process

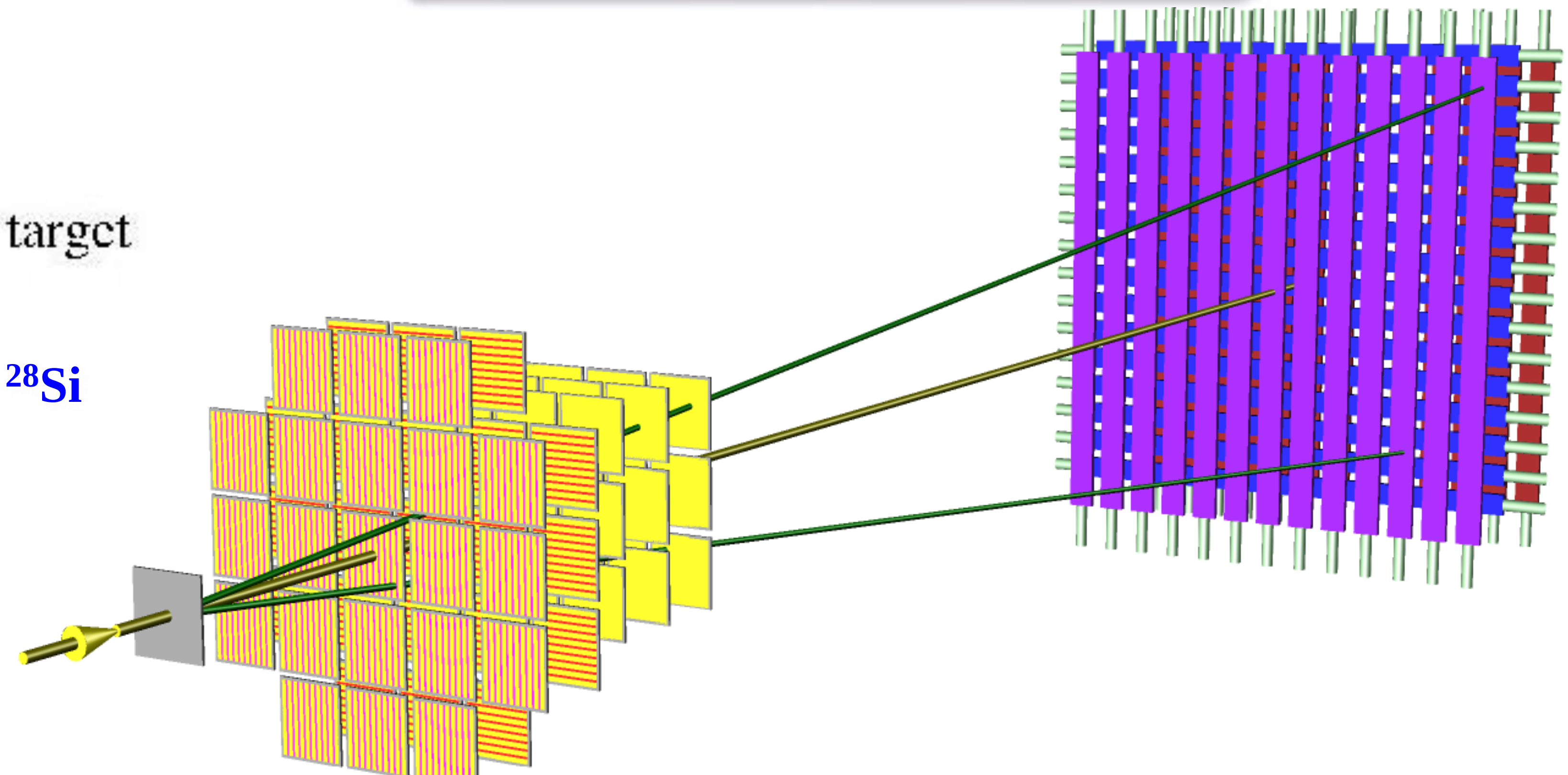
Experimental description @ RIPS



Experiment information

- Primary beam: 135 MeV/u ^{28}Si
- Primary Target: 5.5 mm Be
- Secondary beam: ^{23}Al, ^{22}Mg, ^{21}Na, ^{20}Ne @~70 AMeV
- Secondary Target: ^{12}C (355.5 mg/cm^2)

The typical intensity and purity of the ^{23}Al beam were 700 cps and 3%, respectively.

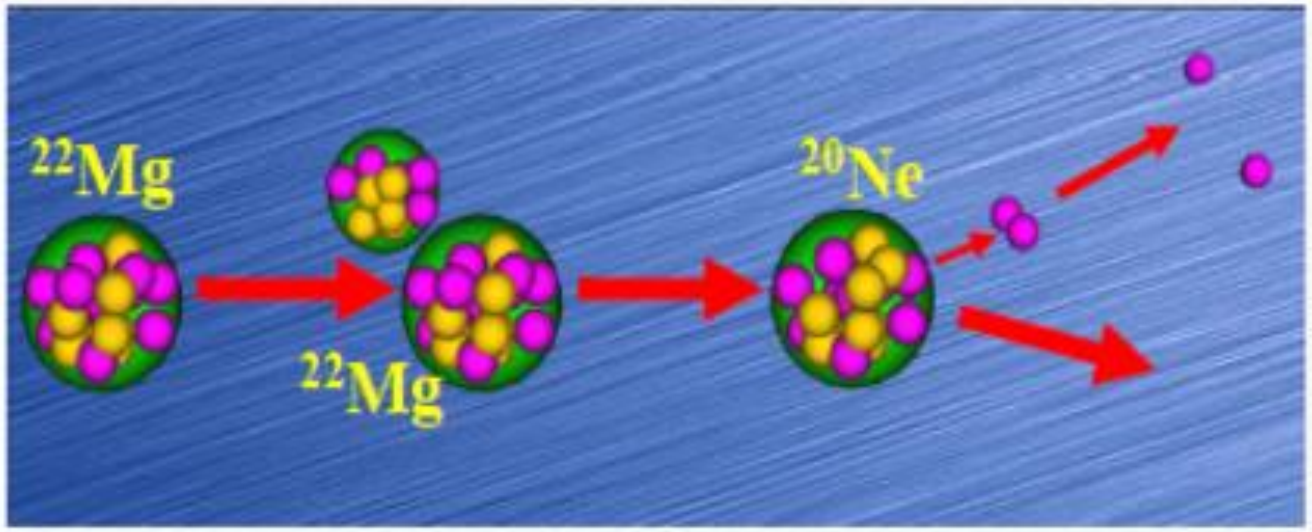


HODO:
dE: 1000×100×5mm
E1: 1000×75×60mm
E2: 1000×75×60mm

Si telescope:
Si-strip: 0.5 mm (5×5−4) ×2
Si: 0.5 mm (3×3) ×3

Collaboration with Y. Tagano, Sakurai, T. Matobayshi et al.@2008

Our p-p correlation measurement for 22Mg



Q_pp~20MeV/c & theta_pp ~ 30deg, indicating a strong 2p emission component for 22Mg

Physics Letters B 743 (2015) 306–309

Contents lists available at ScienceDirect

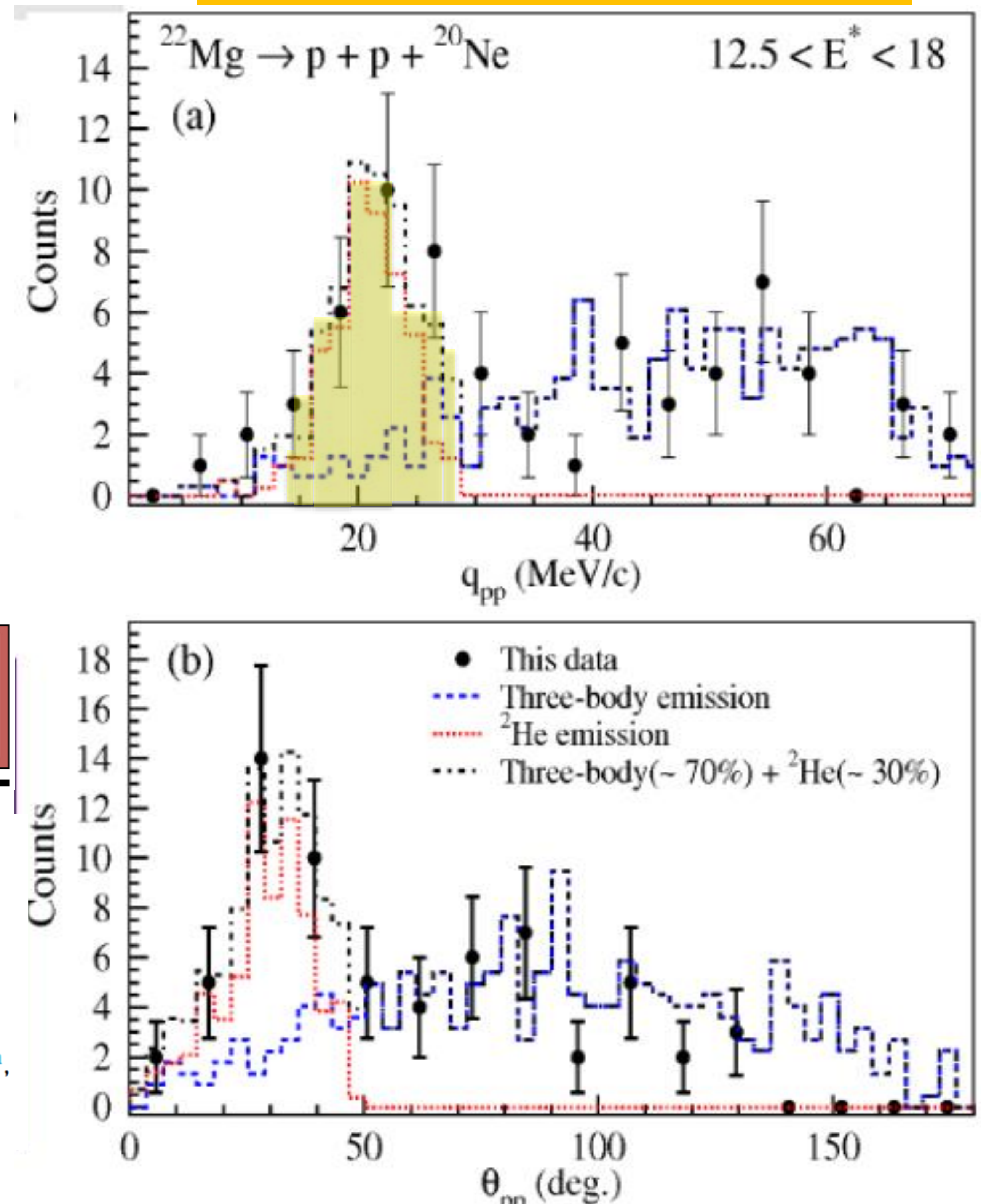
Physics Letters B

www.elsevier.com/locate/physletb

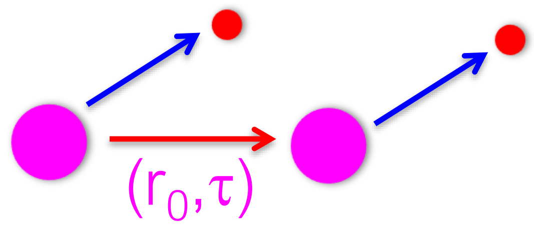
Different mechanism of two-proton emission from proton-rich nuclei ^{23}Al and ^{22}Mg

Y.G. Ma [a], D.Q. Fang [a], X.Y. Sun [a], P. Zhou [a], Y. Togano [b], N. Aoi [b], H. Baba [b], X.Z. Cai [a], X.G. Cao [a], J.G. Chen [a], Y. Fu [a], W. Guo [a], Y. Hara [c], T. Honda [c], Z.G. Hu [d], K. Ieki [c], Y. Ishibashi [e], Y. Ito [e], N. Iwasa [f], S. Kanno [b], T. Kawabata [g], H. Kimura [h], Y. Kondo [b], K. Kurita [c], M. Kurokawa [b], T. Moriguchi [e], H. Murakami [b], H. Ooishi [e], K. Okada [c], S. Ota [g], A. Ozawa [e], H. Sakurai [b], S. Shimoura [g], R. Shioda [c], E. Takeshita [b], S. Takeuchi [b], W.D. Tian [a], H.W. Wang [a], J.S. Wang [d], M. Wang [d], K. Yamada [b], Y. Yamada [c], Y. Yasuda [e], K. Yoneda [b], G.Q. Zhang [a], T. Motobayashi [b]

^{22}Mg → ^{20}Ne + 2p

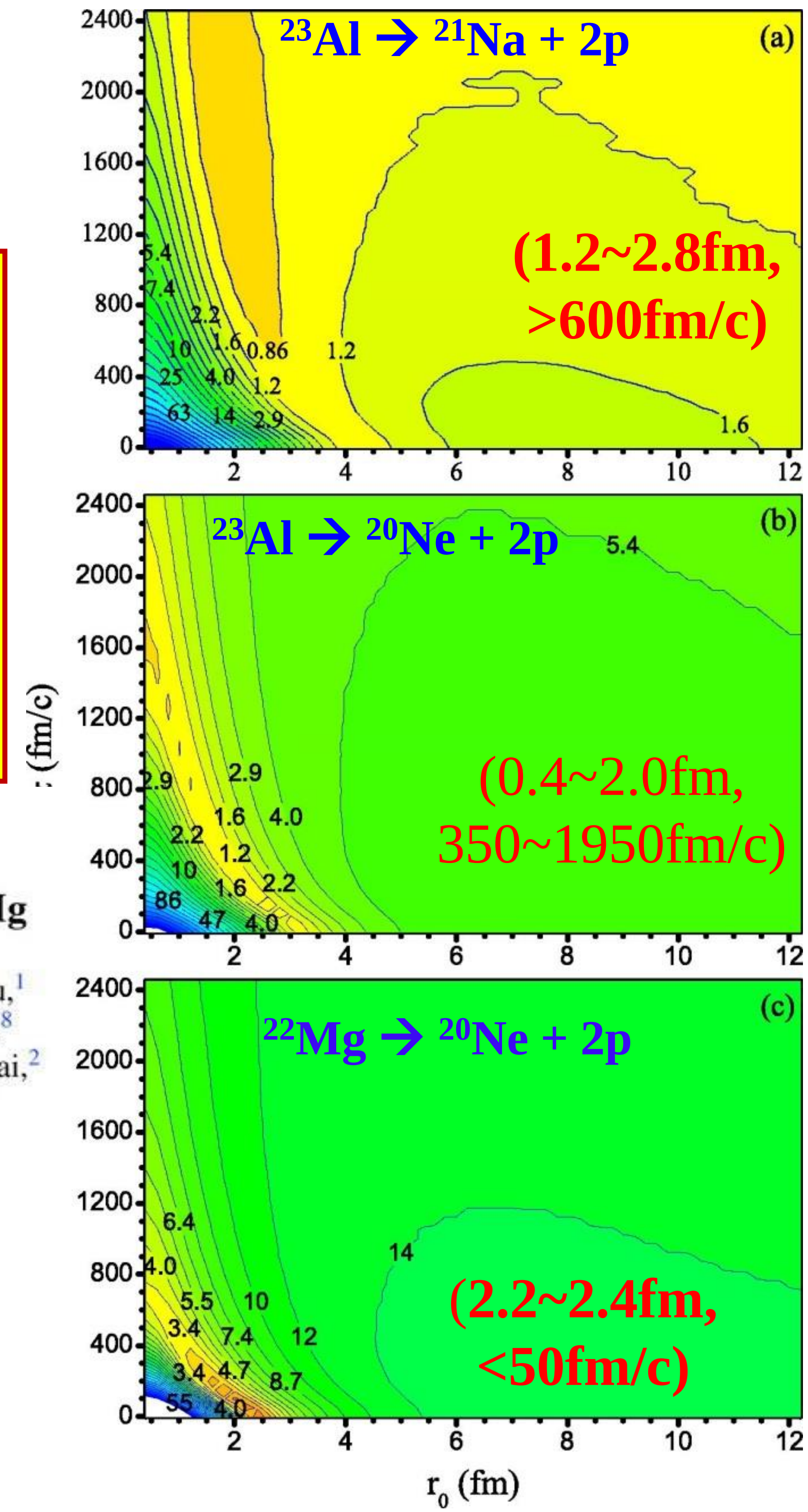


Source size + emission time:



$$S(r) \sim \exp\left(-r^2/2r_0^2 - t/\tau\right)$$

The results indicate that the emission time difference between two protons for ^{22}Mg is shorter than that for ^{23}Al. The mechanism of 2p emission from ^{23}Al was dominately sequential, while that for ^{22}Mg was mainly three-body simultaneous emission.



PHYSICAL REVIEW C **94**, 044621 (2016)

Proton-proton correlations in distinguishing the two-proton emission mechanism of ^{23}Al and ^{22}Mg

D. Q. Fang,[1,*] Y. G. Ma,[1,†] X. Y. Sun,[1] P. Zhou,[1] Y. Togano,[2] N. Aoi,[2] H. Baba,[2] X. Z. Cai,[1] X. G. Cao,[1] J. G. Chen,[1] Y. Fu,[1] W. Guo,[1] Y. Hara,[3] T. Honda,[3] Z. G. Hu,[4] K. Ieki,[3] Y. Ishibashi,[5] Y. Ito,[5] N. Iwasa,[6] S. Kanno,[2] T. Kawabata,[7] H. Kimura,[8] Y. Kondo,[2] K. Kurita,[3] M. Kurokawa,[2] T. Moriguchi,[5] H. Murakami,[2] H. Ooishi,[5] K. Okada,[3] S. Ota,[7] A. Ozawa,[5] H. Sakurai,[2] S. Shimoura,[7] R. Shioda,[3] E. Takeshita,[2] S. Takeuchi,[2] W. D. Tian,[1] H. W. Wang,[1] J. S. Wang,[4] M. Wang,[4] K. Yamada,[2] Y. Yamada,[3] Y. Yasuda,[5] K. Yoneda,[2] G. Q. Zhang,[1] and T. Motobayashi[2]

[1] *Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China*
[2] *Institute of Physical and Chemical Research (RIKEN), Wako, Saitama 351-0198, Japan*
[3] *Department of Physics, Rikkyo University, Tokyo 171-8501, Japan*
[4] *Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[5] *Institute of Physics, University of Tsukuba, Ibaraki 305-8571, Japan*
[6] *Department of Physics, Tohoku University, Miyagi 980-8578, Japan*
[7] *Center for Nuclear Study (CNS), University of Tokyo, Saitama 351-0198, Japan*
[8] *Department of Physics, University of Tokyo, Tokyo 113-0033, Japan*

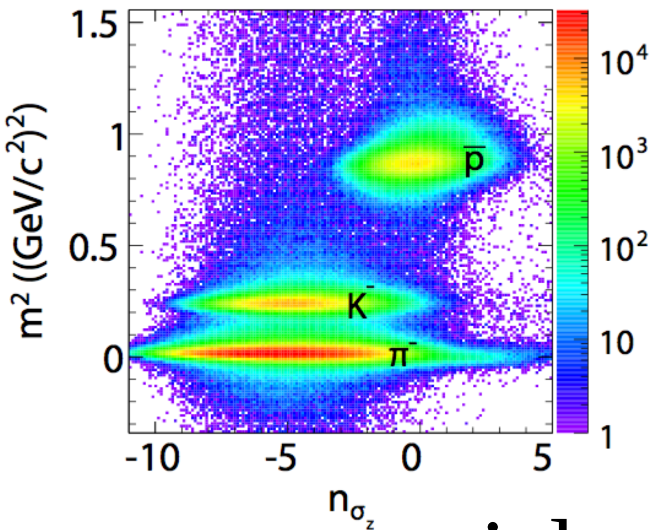
(Received 6 August 2016; revised manuscript received 11 September 2016; published 28 October 2016)

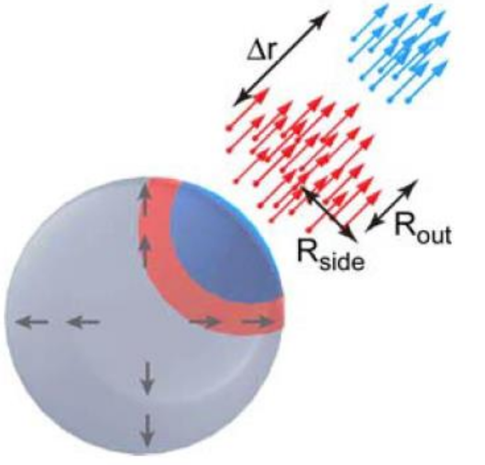
It is possible to distinguish clearly the mechanism of 2p emission by investigating on the p-p momentum correlation function, the 2p relative momentum and opening angle distributions.

From p-p to Pbar-pbar Femtoscopy

Correlation Function(CF):

$$C_{measure}(k^*) = \frac{A(k^*)}{B(k^*)}$$





A(k*) - real pair,

B(k*) - pair from mixed events

k* - half of relative momentum between two particles

Residual correlation

Inside our (anti)proton sample, there are secondary (anti)protons that are indistinguishable from primordial ones. Taking the case for proton as an example, two main weak decay channels give the most contribution :

$$\Lambda \rightarrow p + \pi^- \qquad \sim 26\%$$

$$\Sigma^+ \rightarrow p + \pi^0 \qquad \sim 5\%$$

As the Lambda decay contribute the most secondary (anti)protons, in our analysis we only consider the contribution from Lambda decay.

Formula to fit our data

Inside our (anti)proton samples, there are secondary (anti)protons that are indistinguishable from primordial ones. In the residual protons, the Lambda decay channel gives the most contribution. We fit the data by the following equation

$$C_{meas}(k^*_{pp}) = 1 + x_{pp}[C_{pp}(k^*; R_{pp}) - 1] + x_{p\Lambda}[\widetilde{C}_{p\Lambda}(k^*_{pp}; R_{p\Lambda}) - 1] + x_{\Lambda\Lambda}[\widetilde{C}_{\Lambda\Lambda}(k^*_{pp}; R_{\Lambda\Lambda}) - 1]$$

Measured correl. **Primary correl.** **Residual Correl.**

where

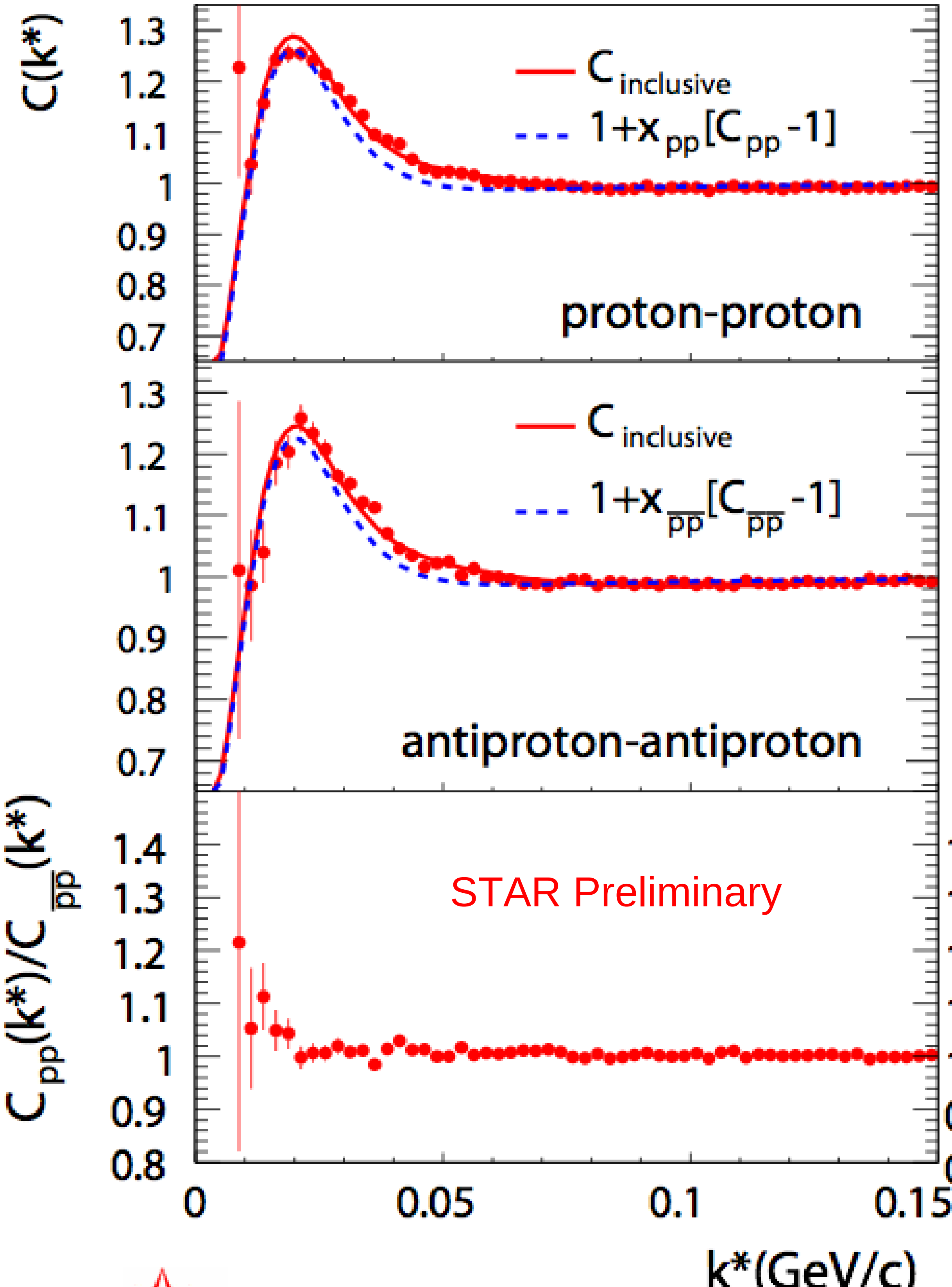
$$\widetilde{C}_{\Lambda\Lambda}(k^*_{pp}) = \sum_{k^*_{\Lambda\Lambda}} C_{\Lambda\Lambda}(k^*_{\Lambda\Lambda}) T(k^*_{\Lambda\Lambda}, k^*_{pp})$$ and $$\widetilde{C}_{p\Lambda}(k^*_{pp}) = \sum_{k^*_{p\Lambda}} C_{p\Lambda}(k^*_{p\Lambda}) T(k^*_{p\Lambda}, k^*_{pp})$$

$C_{pp}(k^*)$ and $C_{p\Lambda}(k^*_{p\Lambda})$ are calculated by the Lednicky and Lyuboshitz model.

$C_{\Lambda\Lambda}(k^*_{\Lambda\Lambda})$ is from STAR published paper (Phys. Rev. Lett. 114 (2015) 22301).

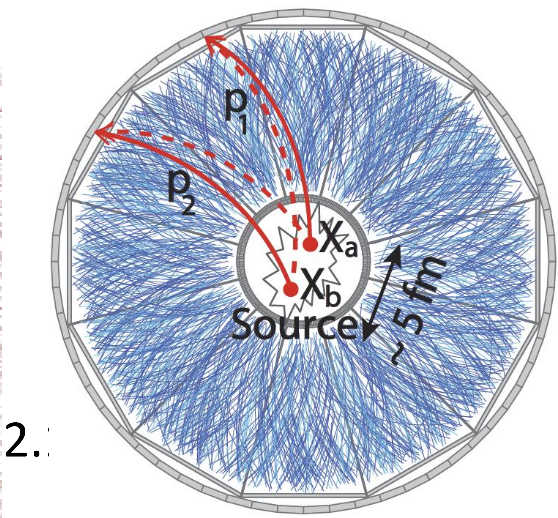
T is the corresponding transform matrices generated by THERMINATOR2 model to transform the $k^*_{p\Lambda}$ to k^*_{pp} or $k^*_{\Lambda\Lambda}$ to k^*_{pp}.

STAR@2015: From p-p to pbar-pbar HBT, 1st measurement of pbar-pbar interaction parameters

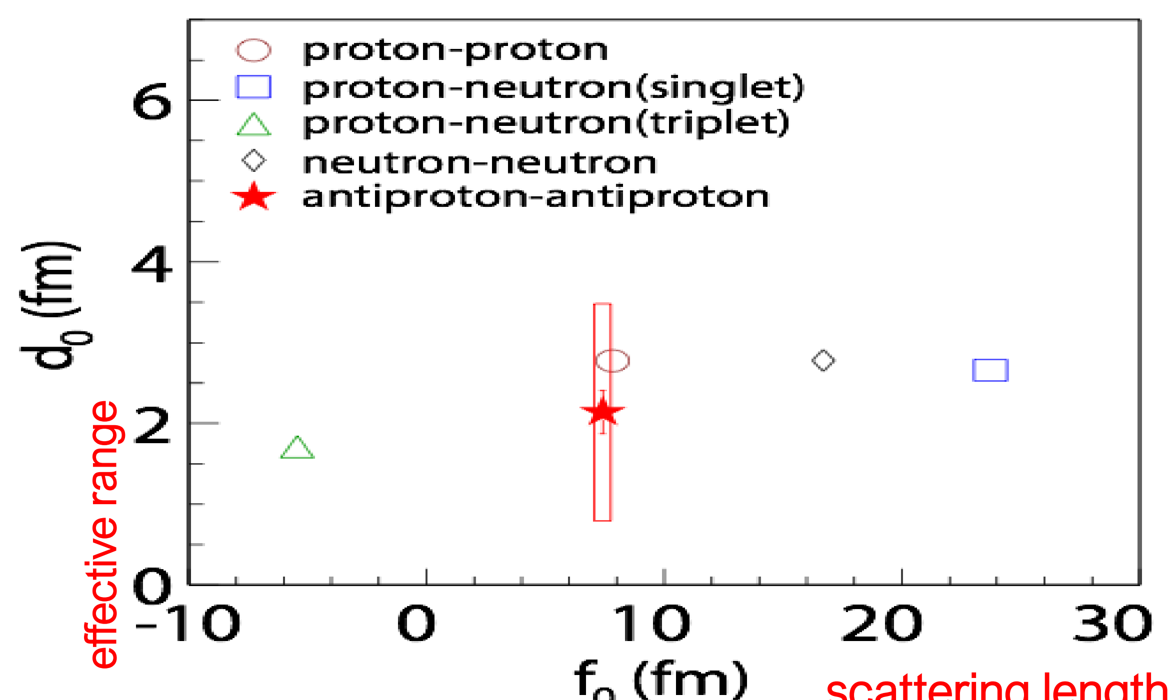


Fit results:
For proton-proton CF,
R=2.75±0.01fm; χ^2/NDF = 1.66;

For pbar-pbar CF,
R=2.80±0.02fm , f_0=7.41±0.19fm, d_0=2.
χ^2/NDF=1.61



nature 527, 325 (2015)



Zhengqiao Zhang@SINAP, PhD Thesis @ 2017

Summary

- At RHIC, a so-called strong coupling Quark-Gluon Plasma is discovered, it has almost the smallest viscosity and the most vortical motion under the strongest magnetic field.
- At RHIC, the 1st anti-hypernucleus (anti-hypertriton) and the heaviest anti-nuclei (anti-helium-4) were observed so far.
- At RHIC, the pbar-pbar interaction was measured, for the 1st time, its scattering length f_0 & effective range d_0 are extracted. It is symmetric to pp interaction, satisfy a CPT symmetry.
- **Nuclear Physics has Simplicity, Symmetry and Beauty!**

STAR

Major collaborators:

Jinhui Chen, Liang Xue, Zhengqiao Zhang, Qiye Shou, Aihong Tang, Zhangbu Xu et al. and STAR Collaboration

Ref: **Antinuclei in heavy-ion collisions,**
Jinhui Chen, Declan Keane, Yu-Gang Ma, Aihong Tang, Zhangbu Xu,
Phys. Rep. **(2018) in press**

Arima-san, 生日快乐!

Thanks for your attention!