In Pursuit of Knowledge and Wisdom

— My Story with Declan Keane

KENT STATE UNIVERSITY

Brookhaven National Laboratory

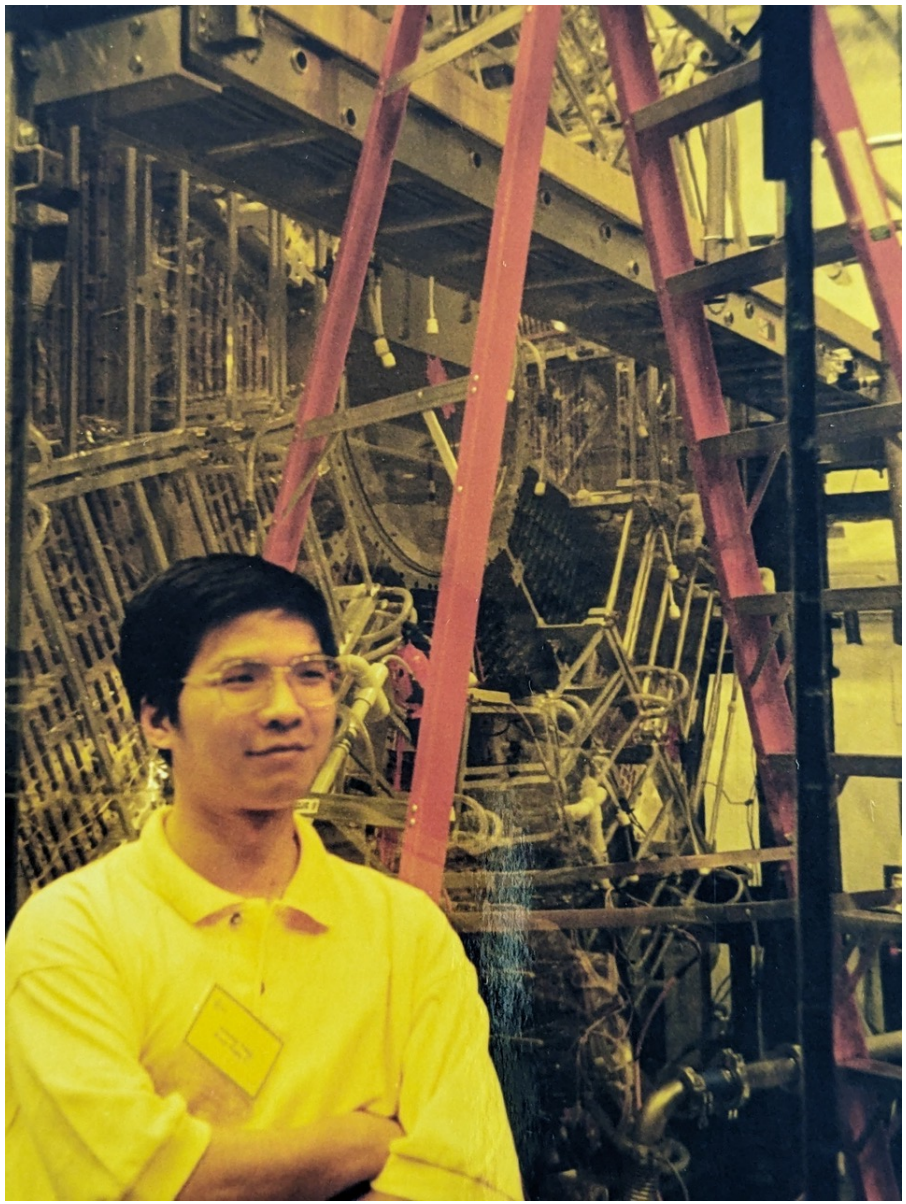
Back in the Day

When I knew little but thought
I was capable of anything …

Back in the Day

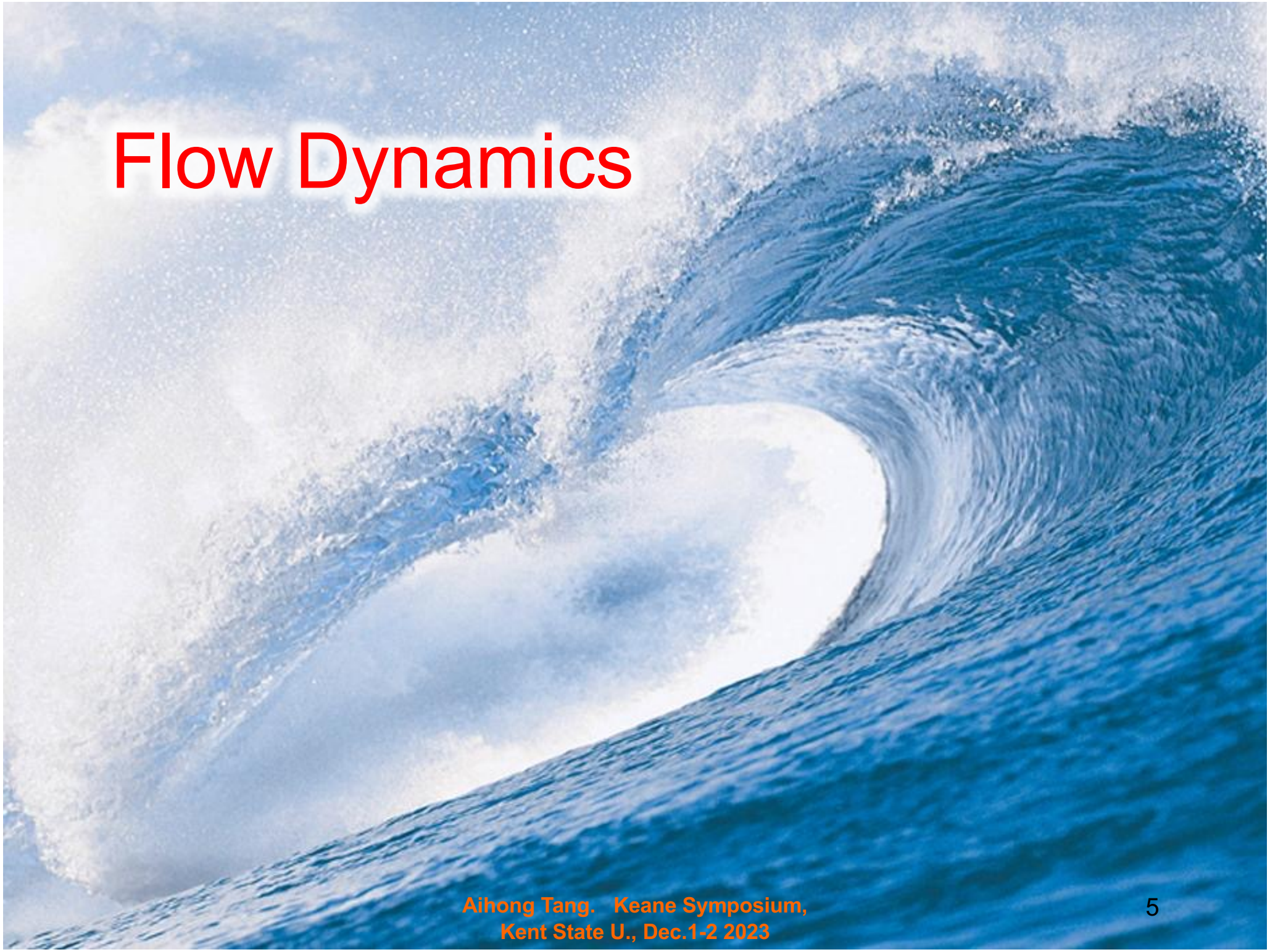
Lost and found in the RHIC tunnel …

Back in the Day

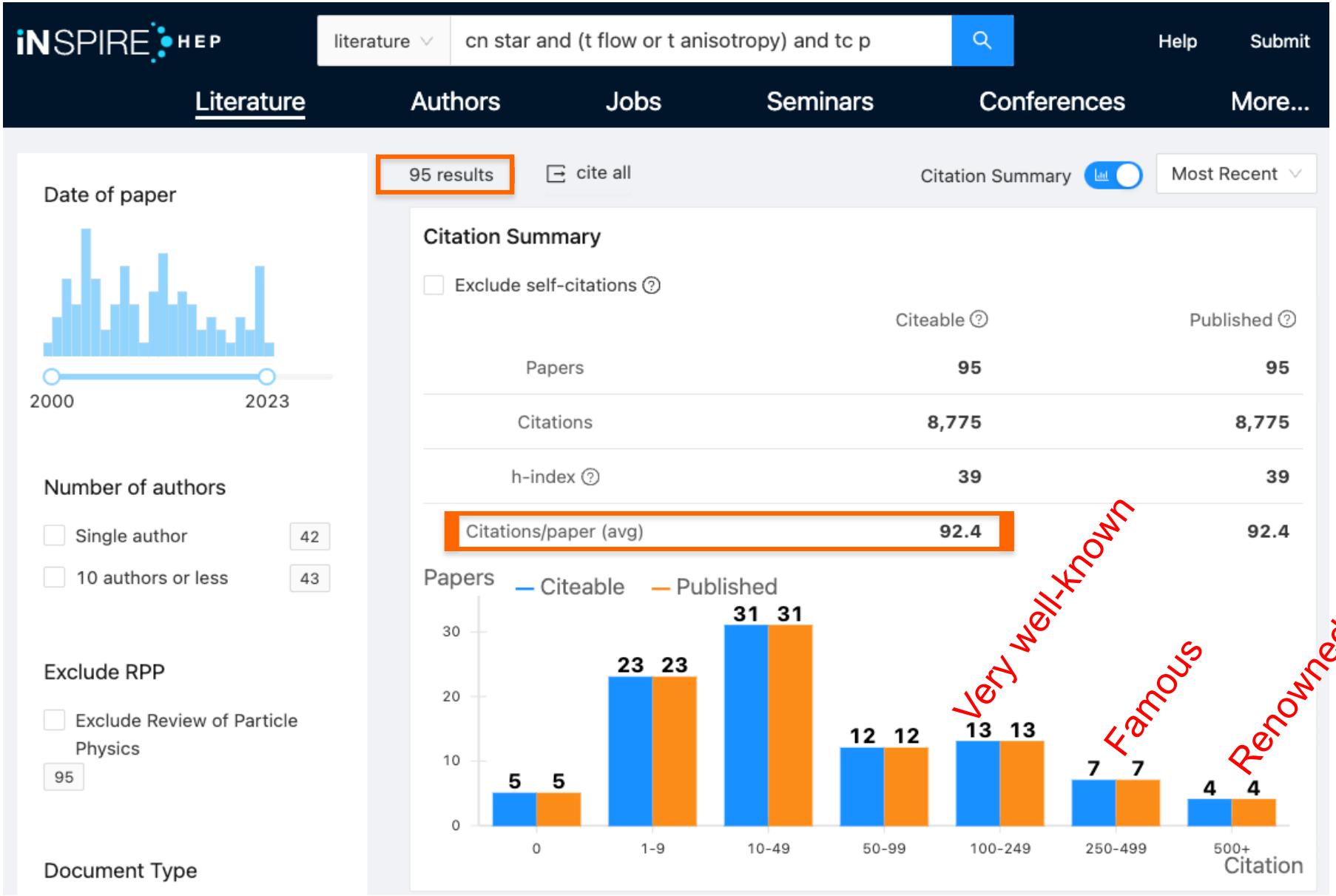


Decided to be powered by "STAR"-bucks !

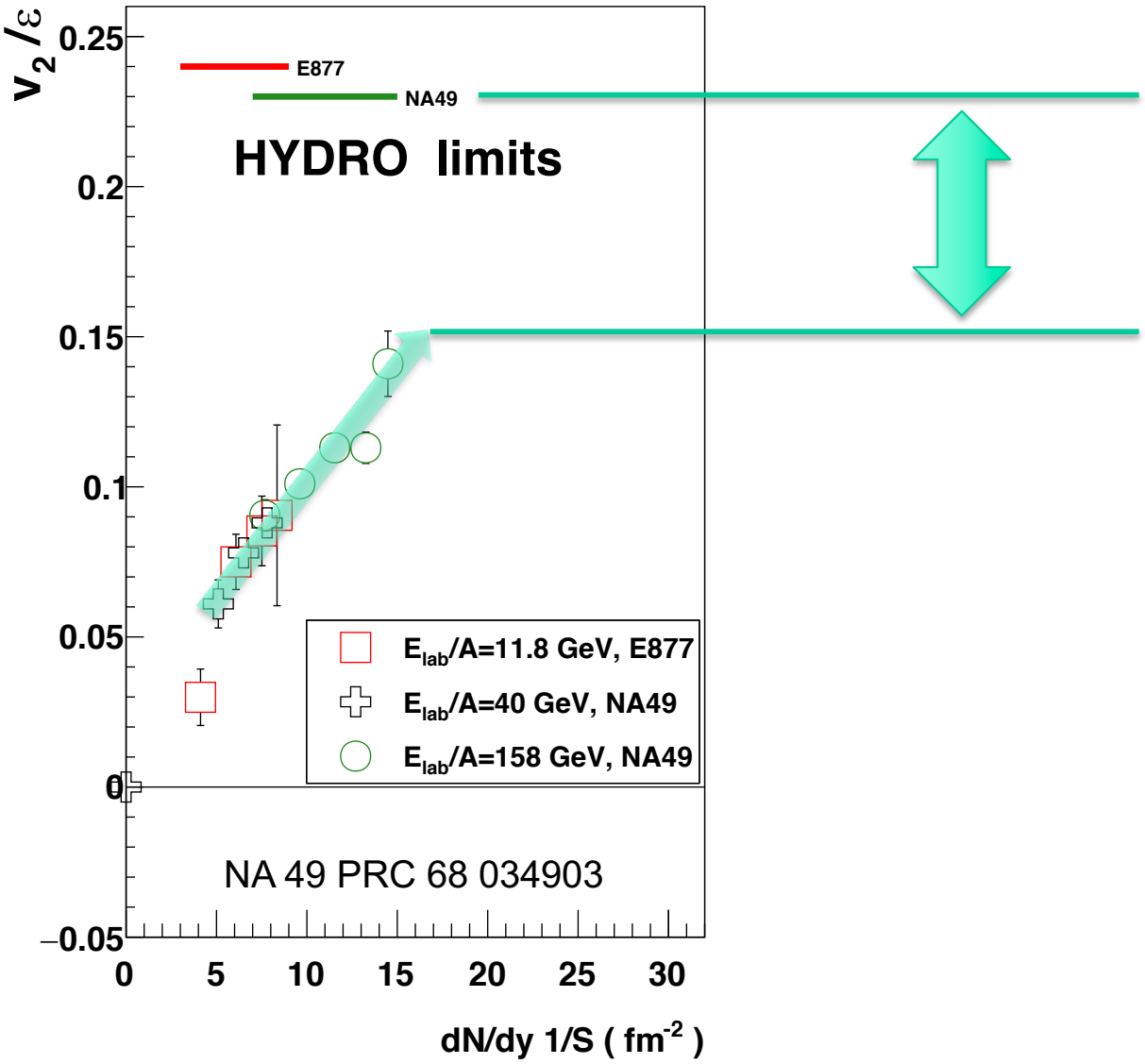
Flow Dynamics



STAR Flow Publications

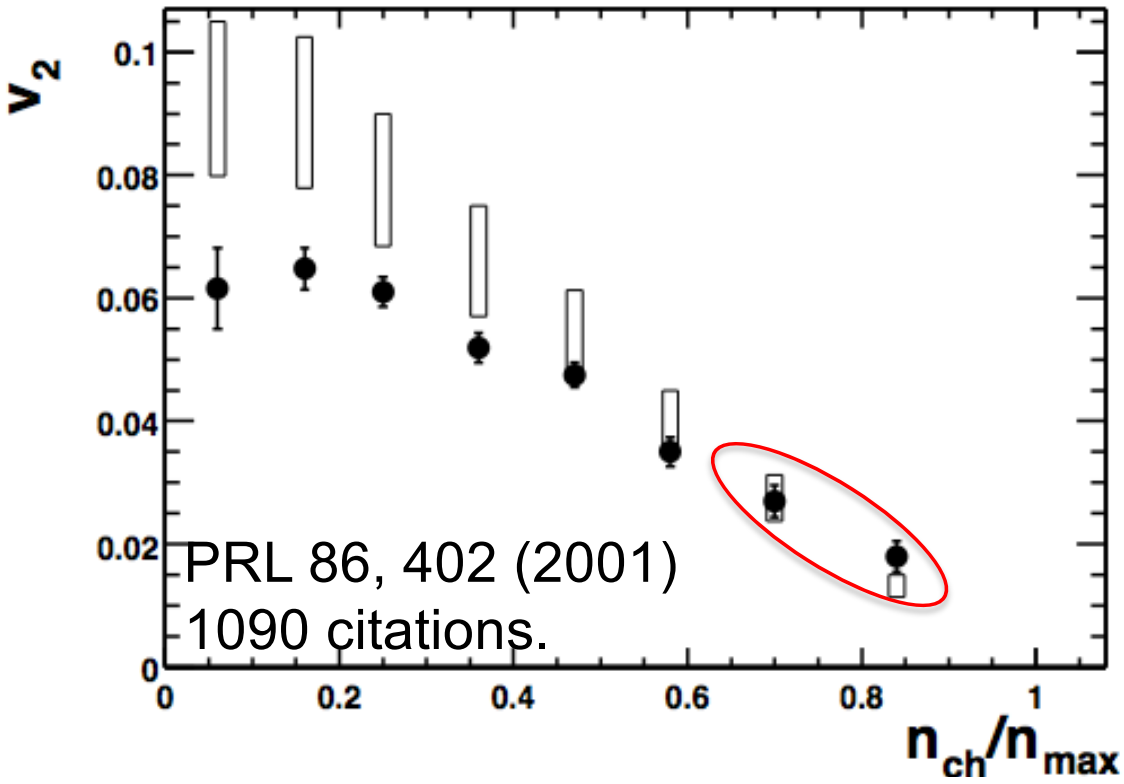


The March to Hydro



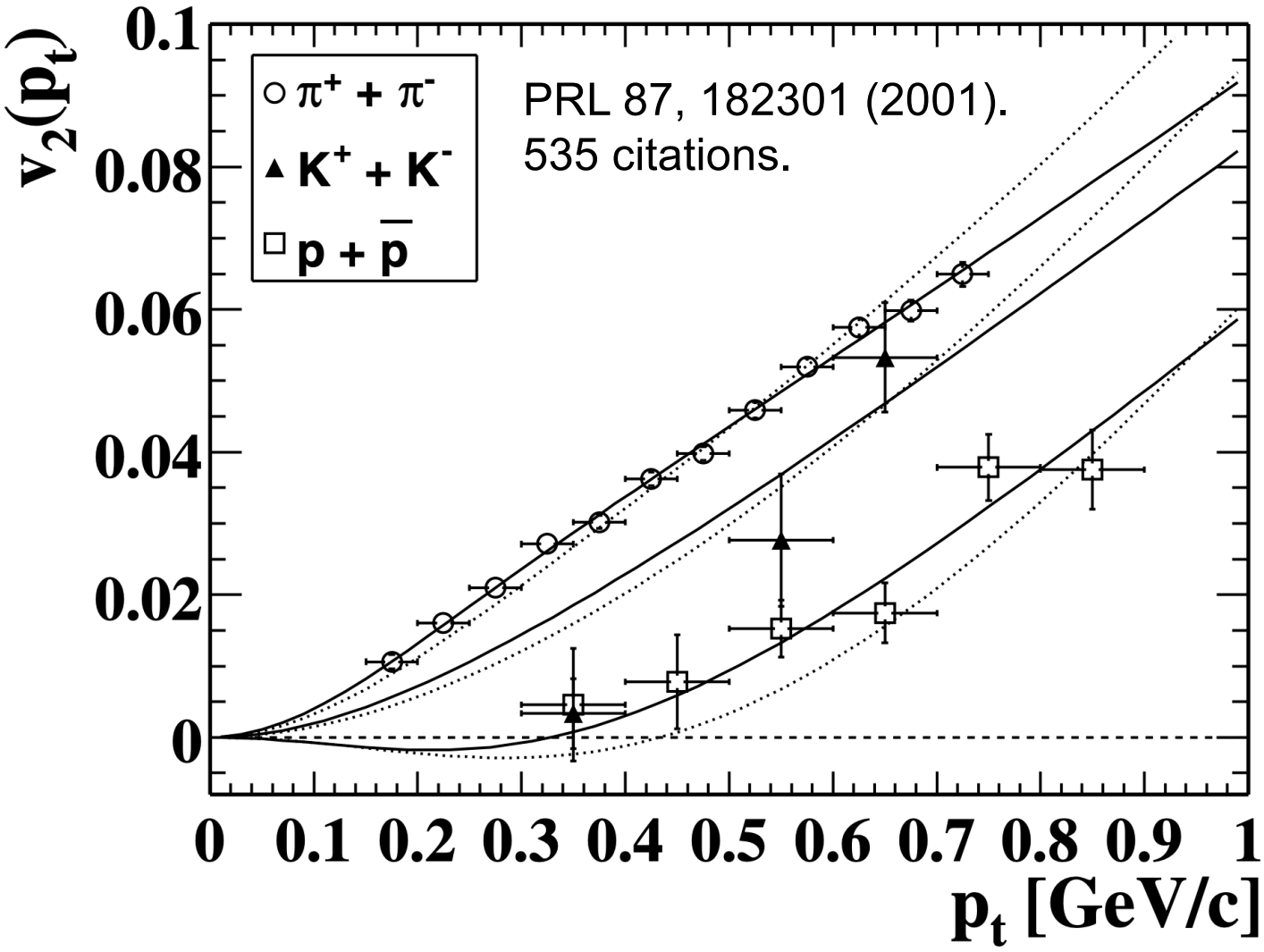
The March to Hydro

The first sign of Hydro flow



Approaching Hydro for central collisions.

Hydro flow in differential view



Mass splitting consistent with collective flow

The nearly perfect liquid

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More Science :: News :: April 18, 2005 :: Email :: Print

New State of Matter Is 'Nearly Perfect' Liquid

By Sarah Graham

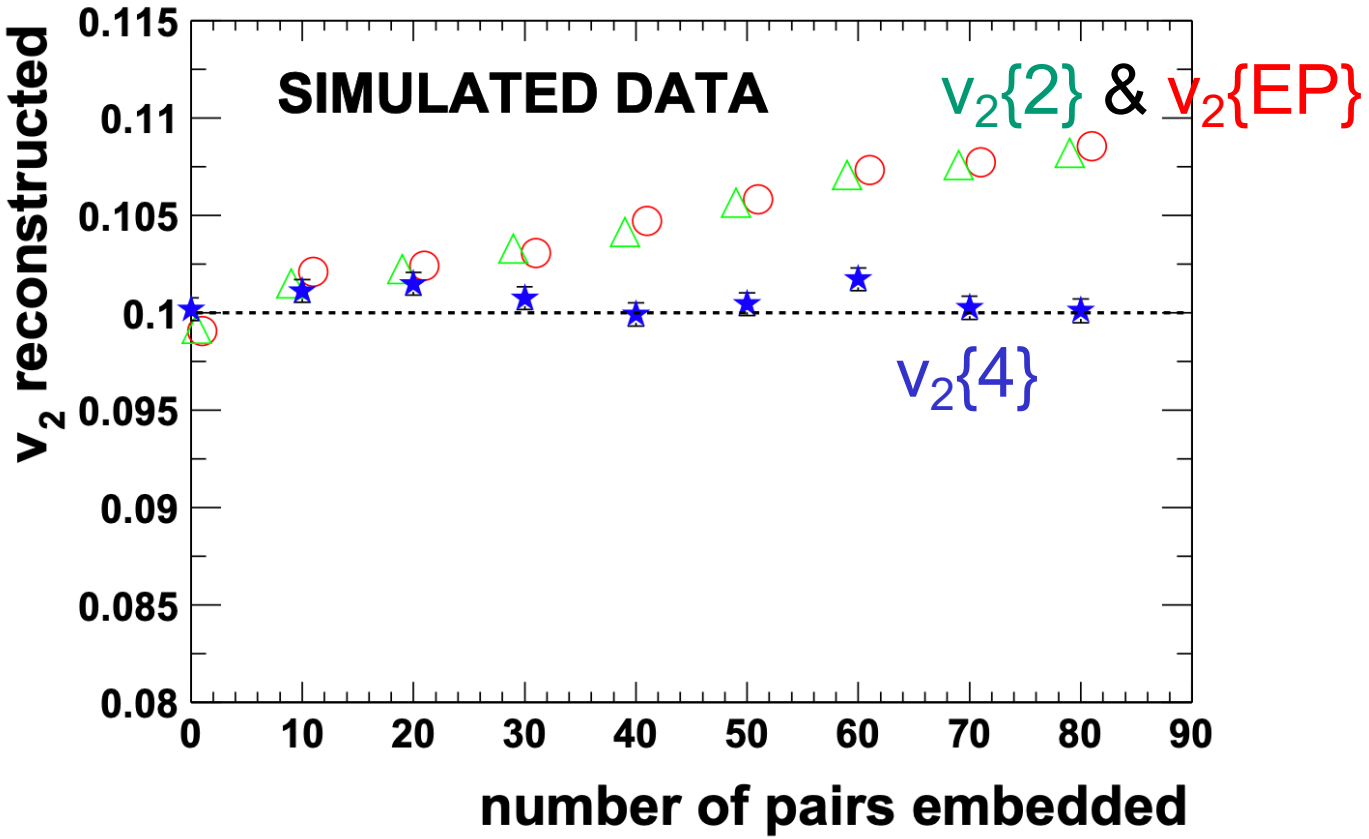
Physicists working at Brookhaven National Laboratory announced today that they have created what appears to be a new state of matter out of the building blocks of atomic nuclei, quarks and gluons. The researchers unveiled their findings--which could provide new insight into the composition of the universe just moments after the big bang--today in Florida at a meeting of the American Physical Society.

Pin it

Image: BNL

Not Everything Flows

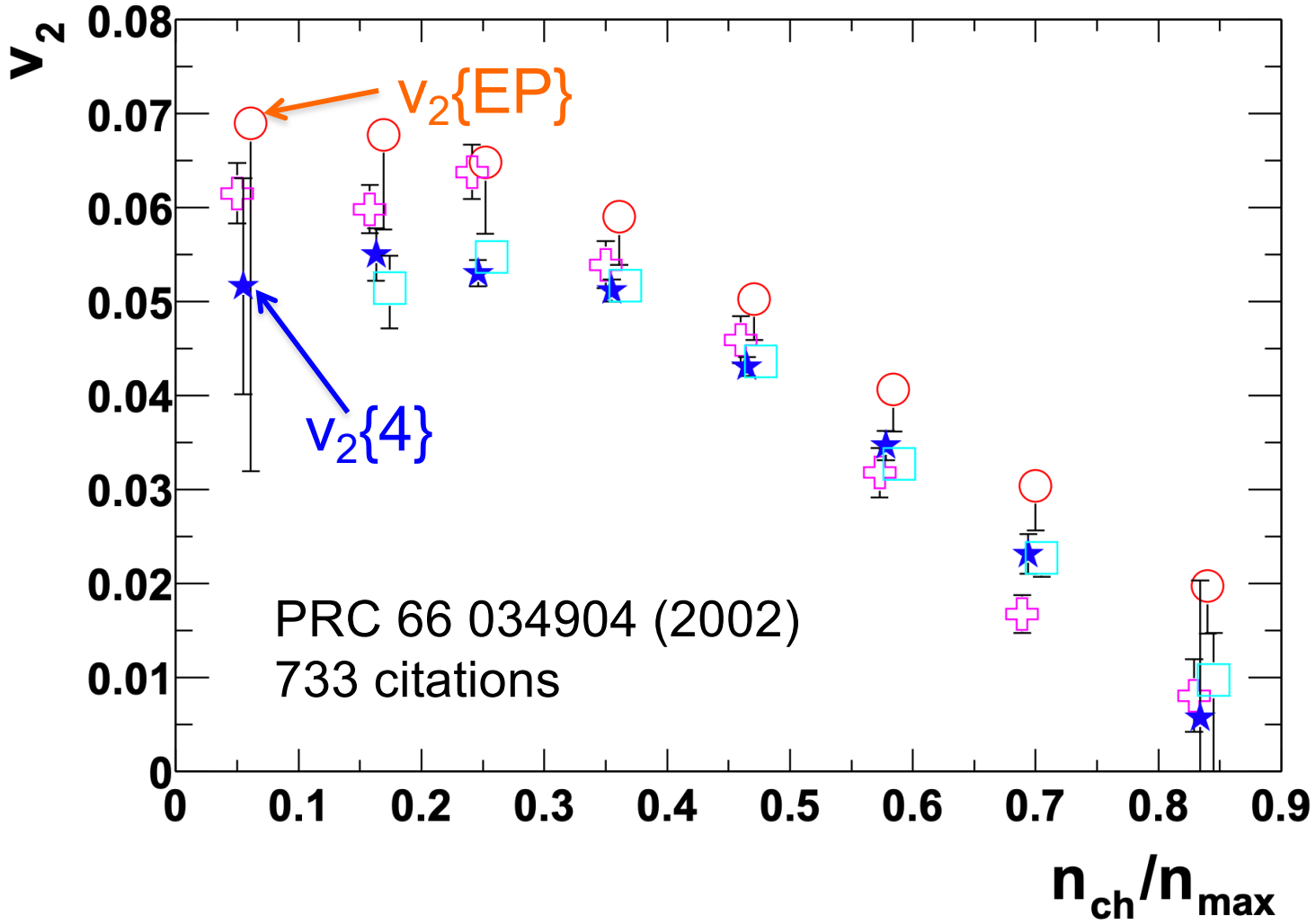
Nonflow and Cumulants



Borghini, Dinh and Ollitrault, PRC 63 054906 (2001) …
STAR PRC 66 034904 (2002)

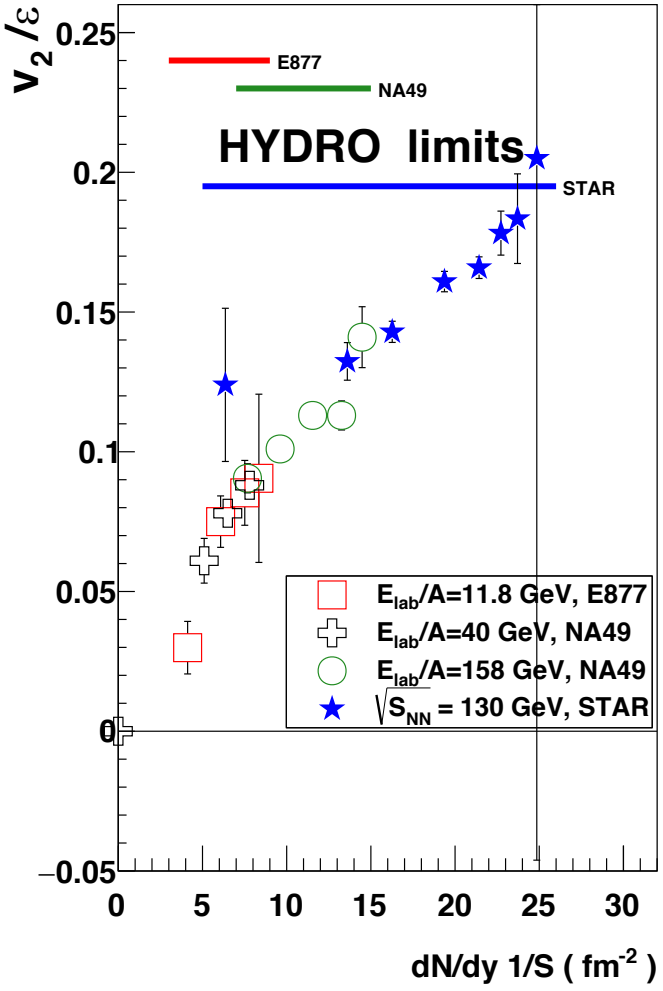
Considerable nonflow in conventional flow method.
Going for 4th order cumulants !

Sharpen the flow probe



Considerable nonflow in conventional flow method.
Going for 4th order cumulants !

How close to Hydro ?



PRC 66 034904 (2002)
733 citations

Eccentricity scaled v_2 reveals important information on how data approaching Hydro limit

The Strangelet

The Strangelet

Review of Speculative "Disaster Scenarios" at RHIC

R.L. Jaffe[a], W. Busza[a], J. Sandweiss[b], and F. Wilczek[c]

a) Laboratory for Nuclear Science and Department of Physics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

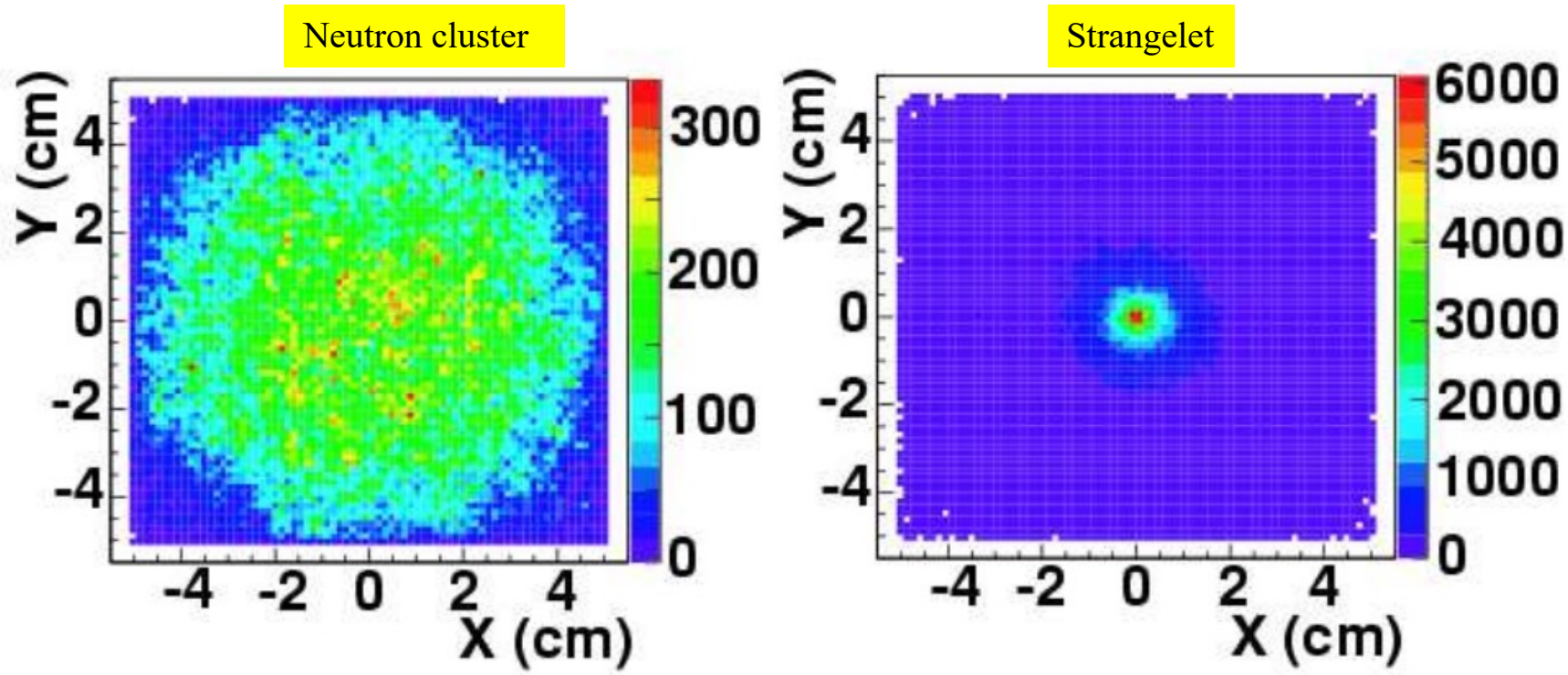
b) Yale University
New Haven, Connecticut 06520

c) School of Natural Sciences, Institute for Advanced Study
Princeton, New Jersey 08540

14 Jul 2000

ZDCSMD and Strangelet Search

Geant simulation of a normal event and a strangelet event



With position sensitive ZDC, we can distinguish a strangelet event from neutron cluster ⇒ ZDC upgrade !

A Shower Max Detector at ZDC for STAR

version 2.5, November 4, 2003
Revised December 2, 2003

Proposed Addition of a Shower Max Detector to the STAR Zero Degree Calorimeters

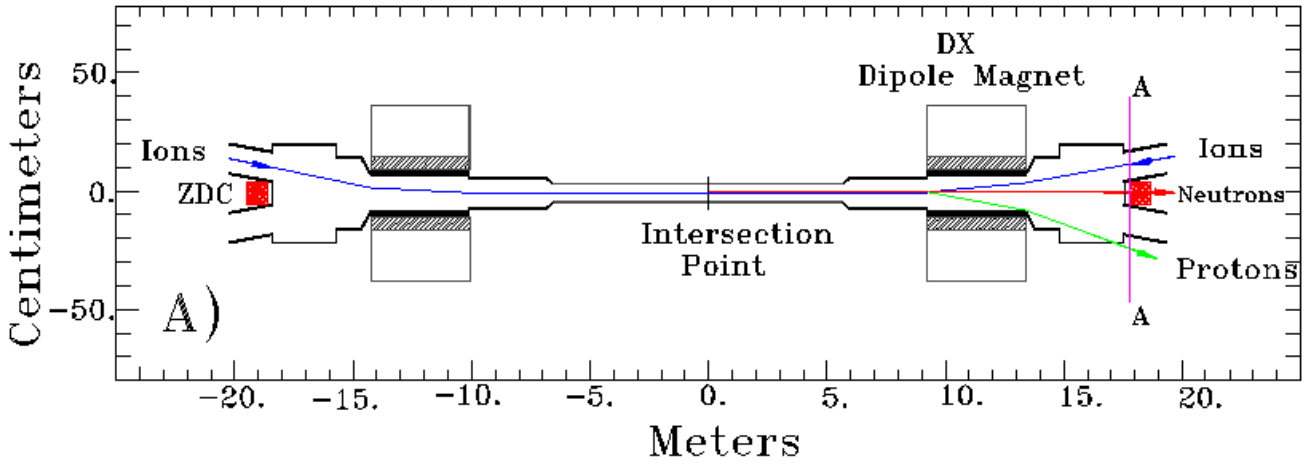
Hank Crawford[1], Declan Keane[2], Spencer Klein[3], Mikhail Kopytine[2],
Bernd Surrow[4], Aihong Tang[4,5], Sergei Voloshin[6], Gang Wang[2], Zhangbu Xu[4]

[1] *UC Berkeley Space Sciences Laboratory*
[2] *Kent State University*
[3] *Lawrence Berkeley National Laboratory*
[4] *Brookhaven National Laboratory*
[5] *NIKHEF*
[6] *Wayne State University*

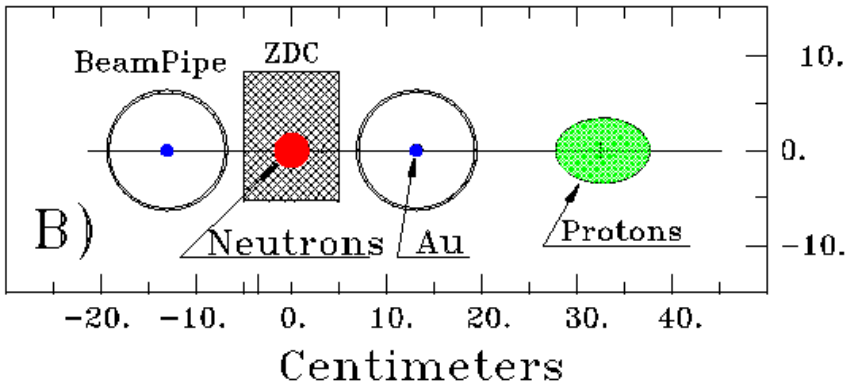
I. EXECUTIVE SUMMARY

We propose the addition of a Shower Maximum Detector (one plane of 7 vertical slats and another of 8 horizontal slats) to the STAR Zero Degree Calorimeters, closely resembling the ZDC-SMD already used by PHENIX in RHIC run III. The SMD would add significant capability to STAR in four areas of physics: anisotropic flow, strangelet searching, ultra-peripheral collisions, and spin physics. The modest funding needed to implement this upgrade has been identified, and an ample manpower effort is available to complete the installation in time for RHIC run IV.

A Shower Max Detector at ZDC for STAR

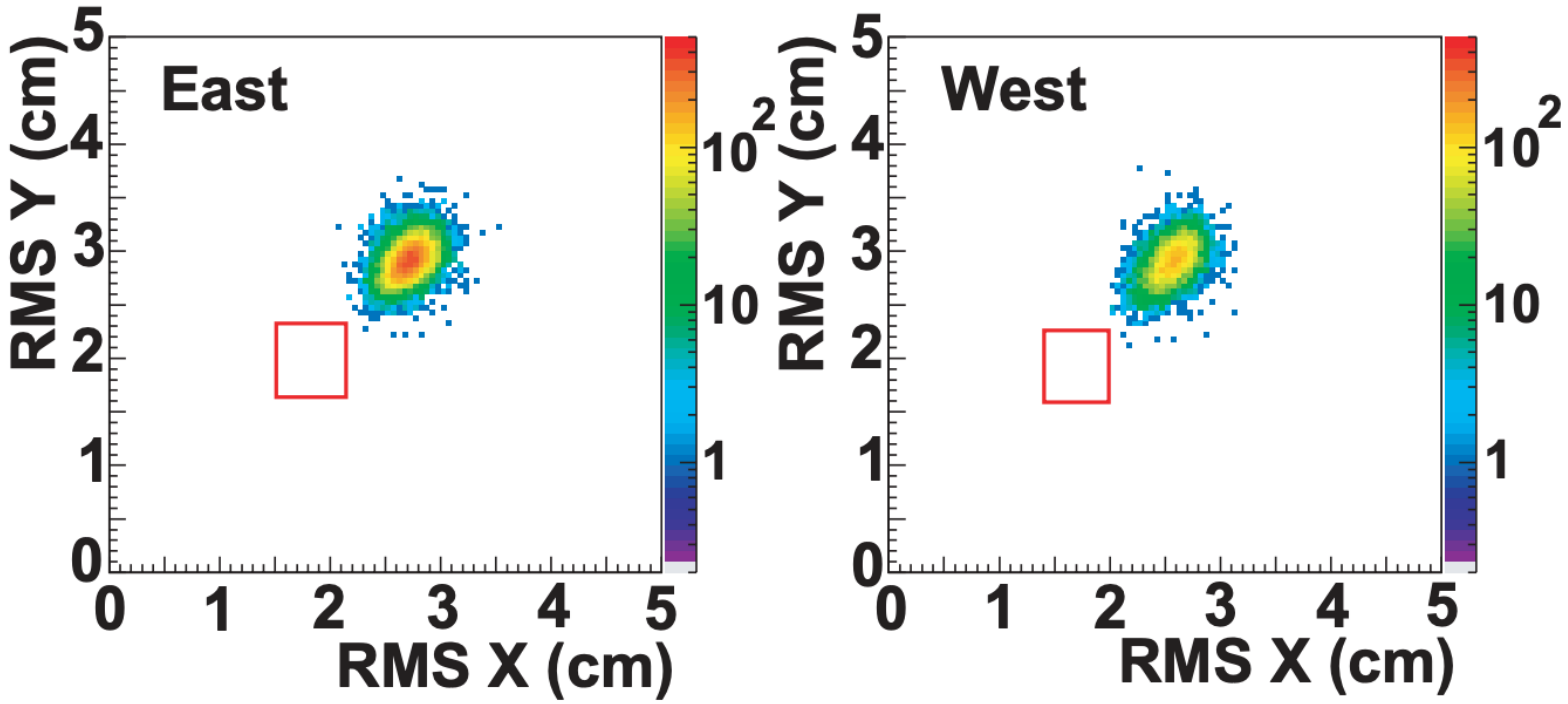


- STAR installed a shower max detector (SMD) between the first and second elements of the ZDCs at STAR during early run 2004.
- The SMDs measure the angular distribution of neutrons on the face of the ZDCs



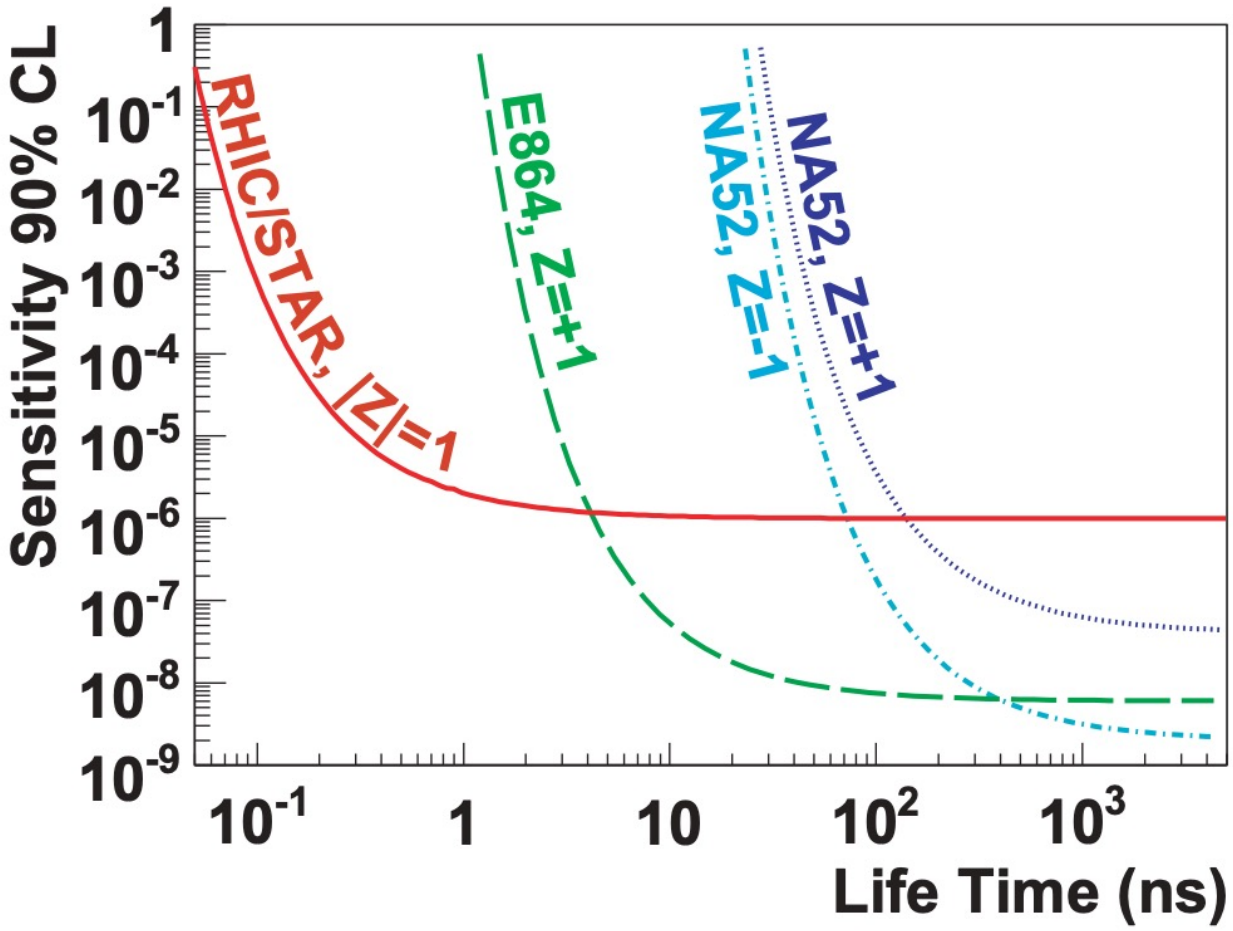
- It is a segmented scintillator detector lying in the path of the beam but coming after the DX magnets. 24 horizontal strips and 21 vertical strips.
- The SMD measures the shower profile inside the ZDC

Strangelet Search



STAR, PRC 76, 011901 (R) (2007)

Strangelet Search



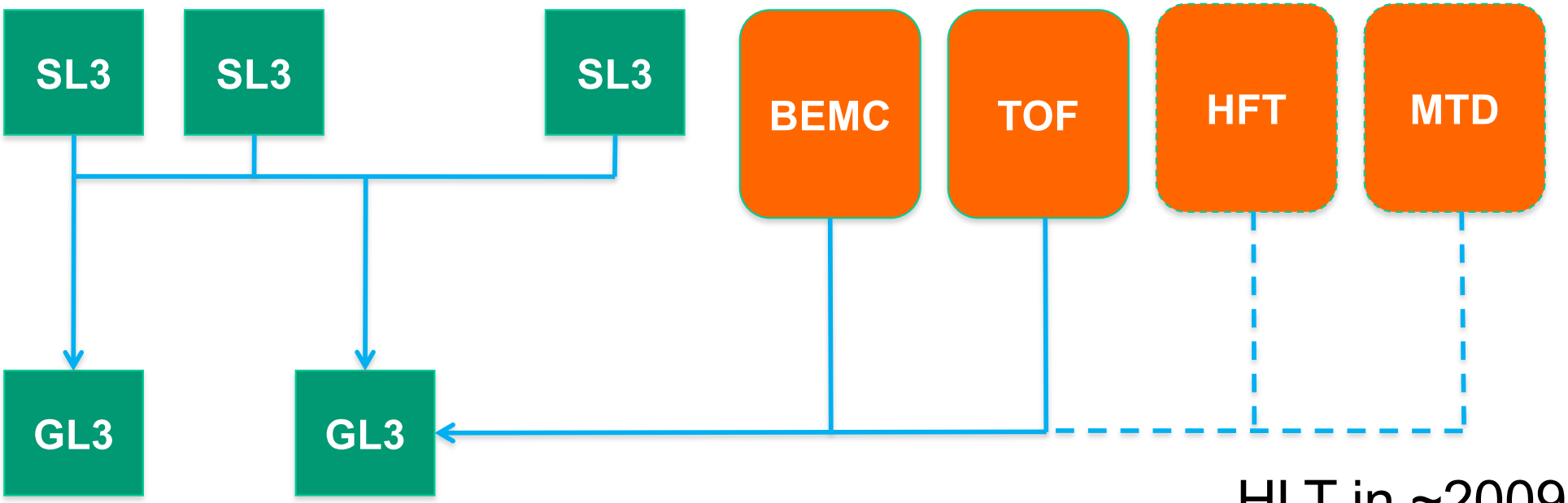
STAR, PRC 76, 011901 (R) (2007)

Antimatter

$\bar{d}$

Aihong Tang. Keane Symposium,
Kent State U., Dec.1-2 2023

STAR's High Level online tracking Trigger (HLT)

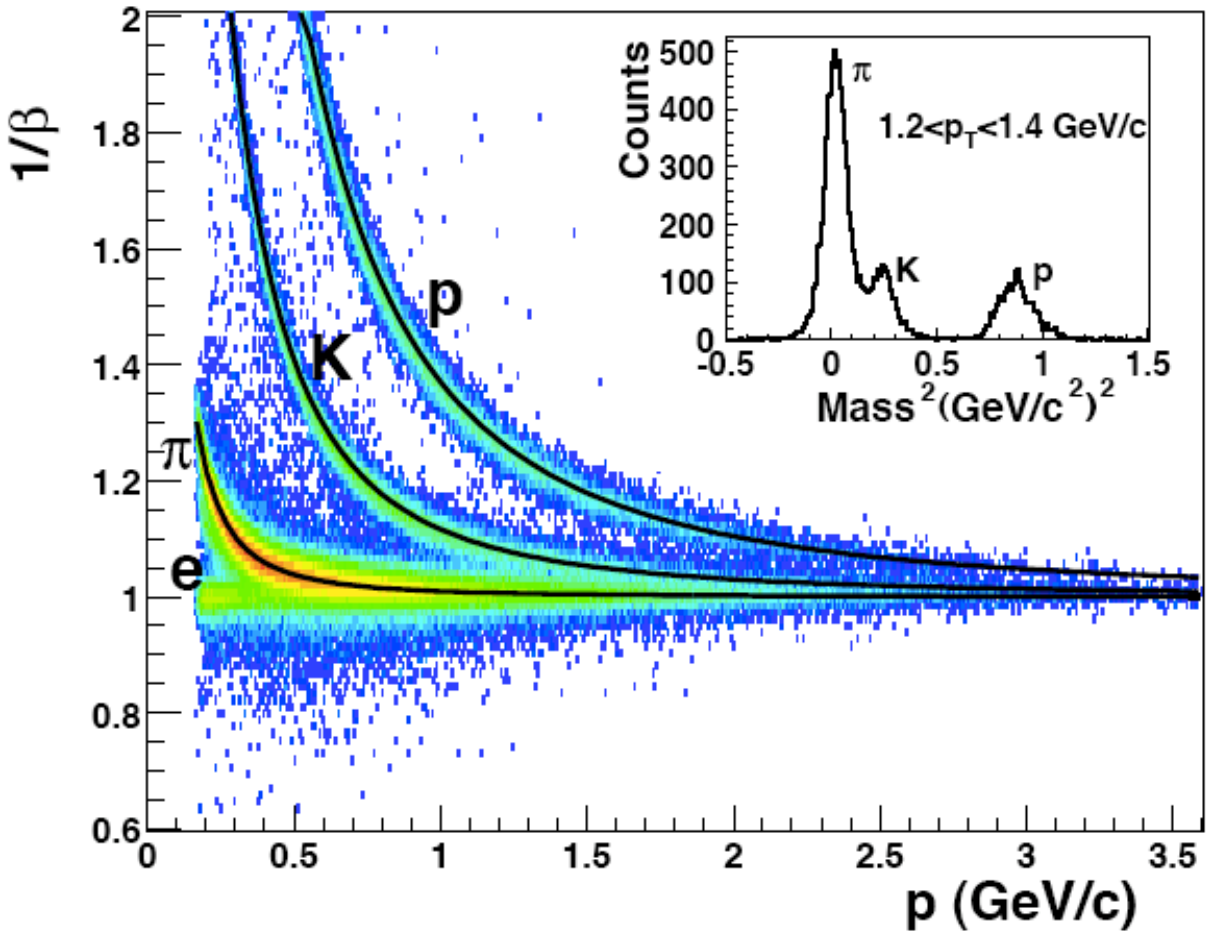


HLT in ~2009

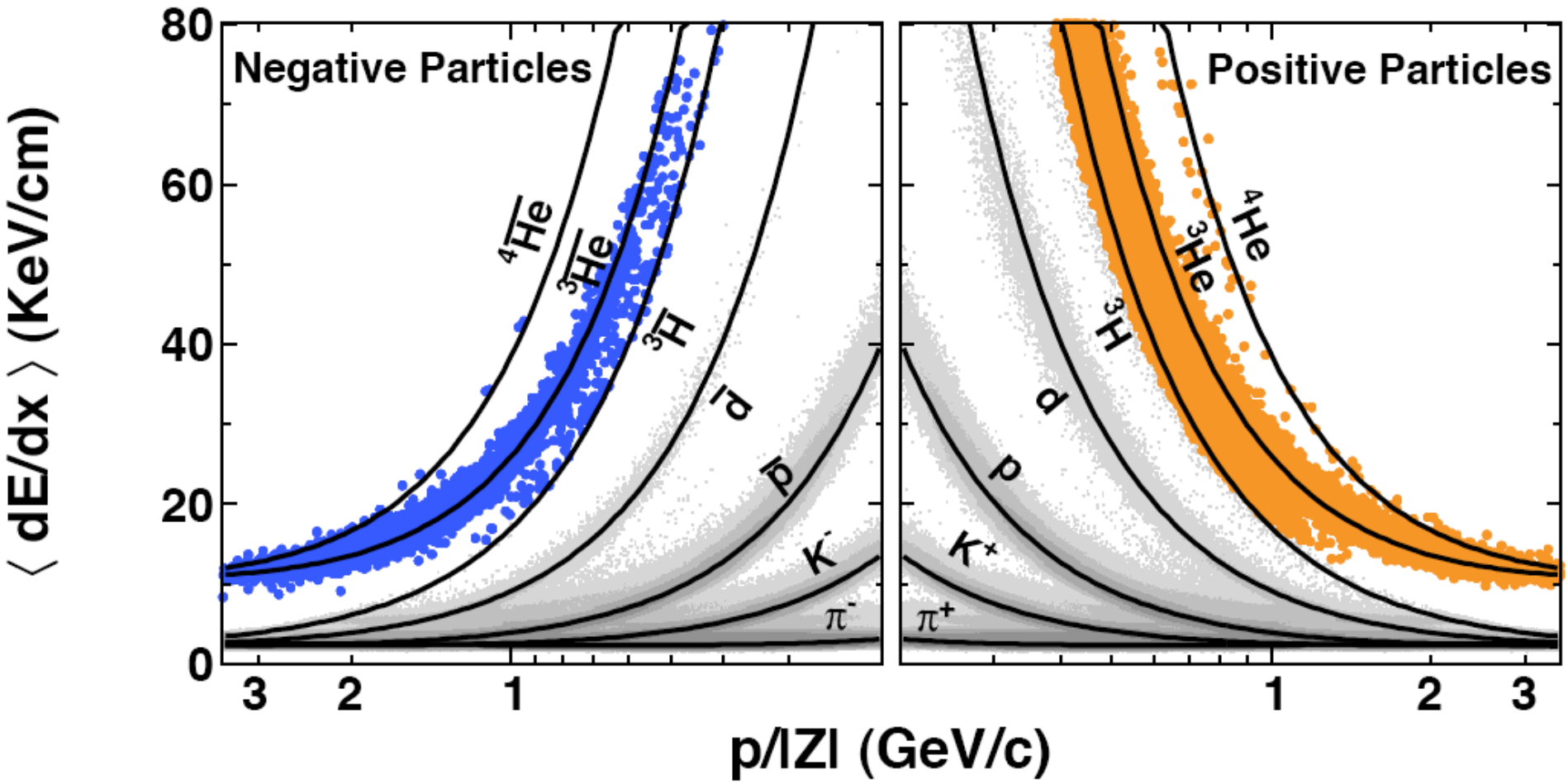
- Sector tracking (SL3) in DAQ machines (24 in total, each for a TPC sector).
- Information from subsystems (SL3 and others) are sent to Global L3 machines (GL3) where an event is assembled and a trigger decision is made.

Fast physics output with HLT

PID : TPC + TOF

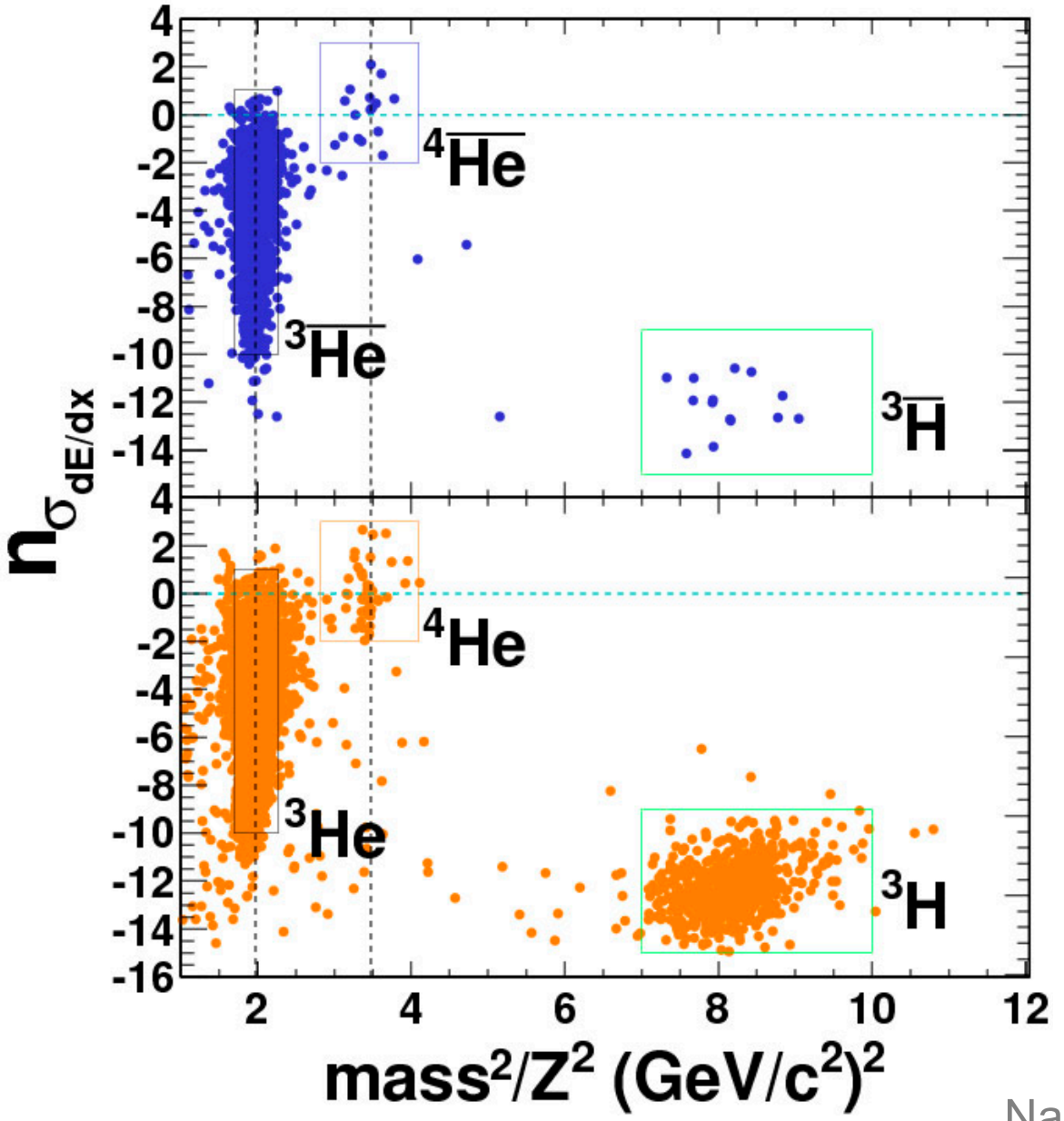


dE/dx vs Rigidity



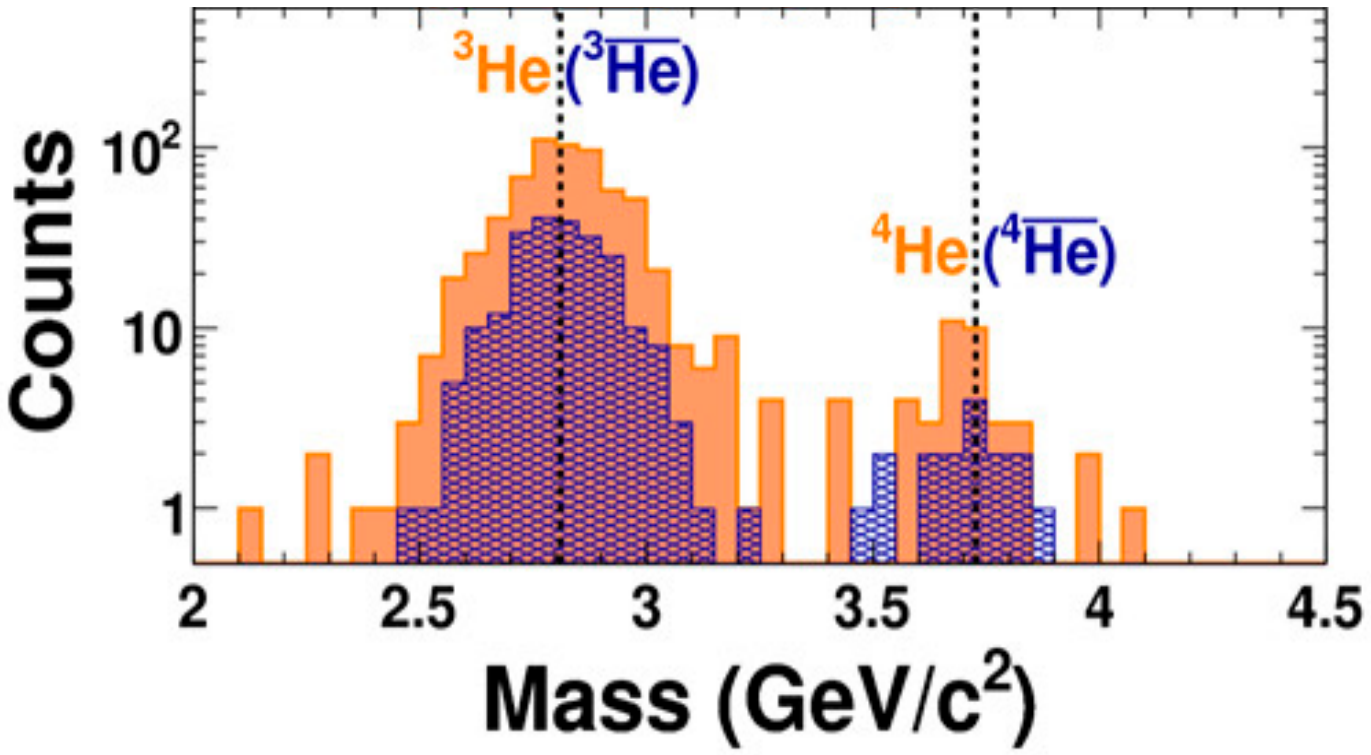
HLT has processing power to do rudimentary event reconstruction in real time, allowing events with a $|Z| = 2$ track to be tagged and fast-tracked via the normal offline calibration & reconstruction chain.

Combined PID (TPC+TOF)



Nature 473 353 (2011)

Combined PID (TPC+TOF)



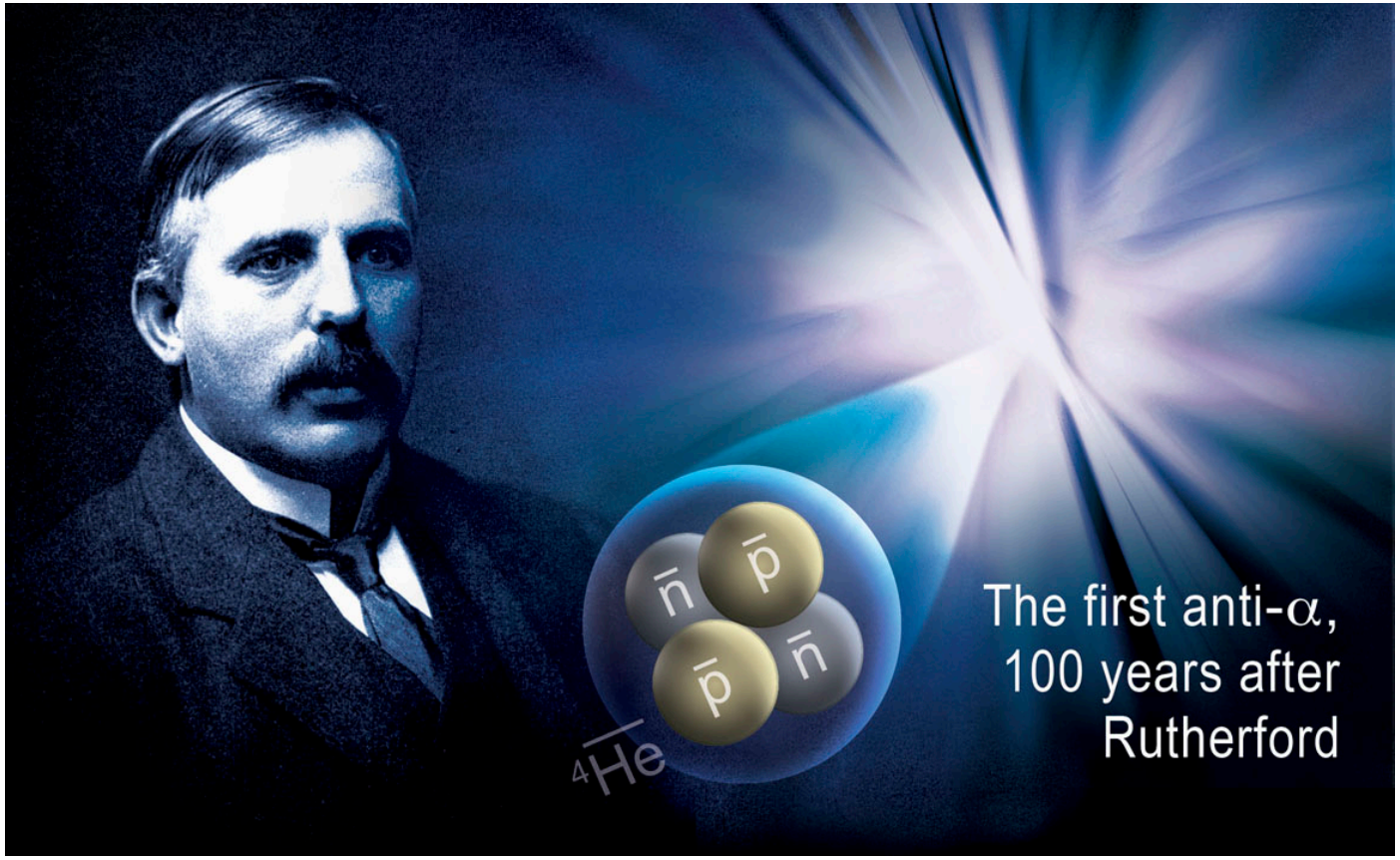
Very clean identification after search of > half-trillion tracks from almost one billion gold-gold collisions.

In total 18 counts observed. Nature 473 353 (2011)

News Coverage

3 story by DISCOVERY magazine for the year 2011 under physics and math

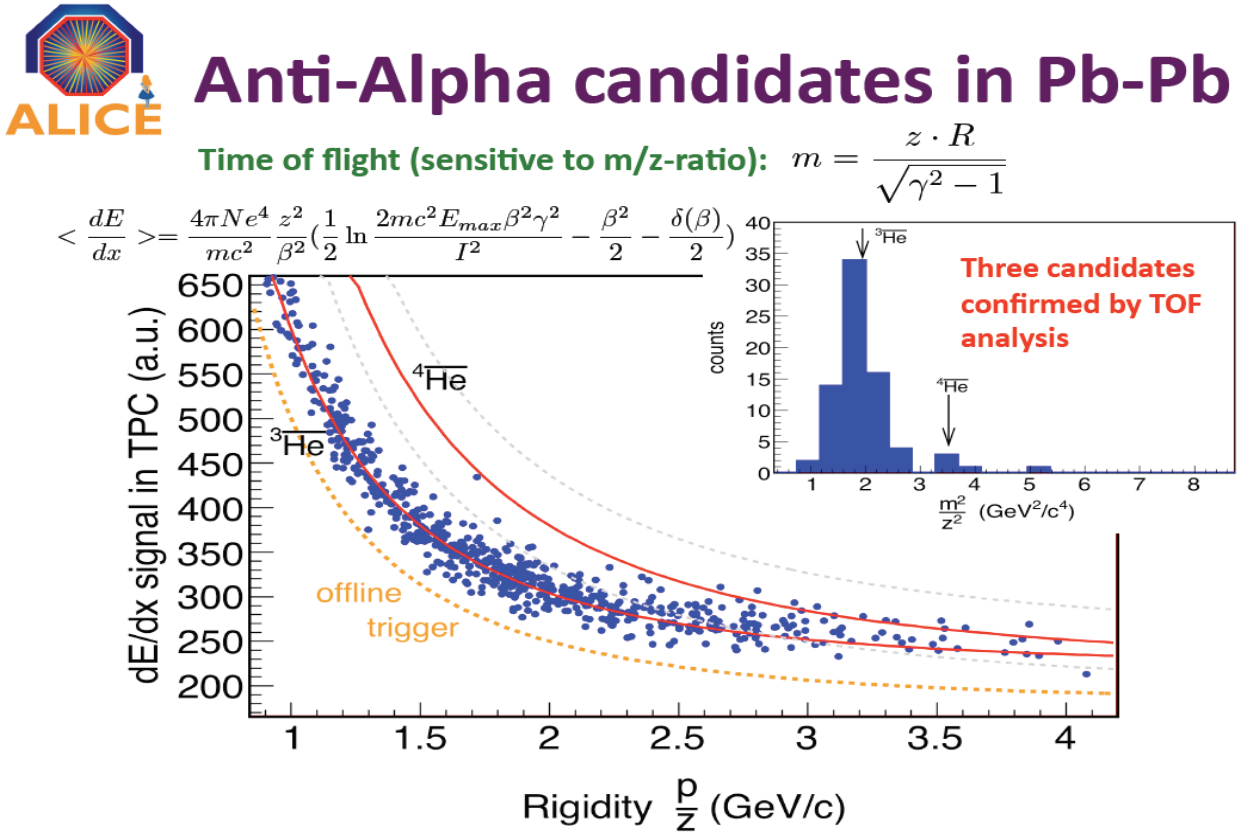
Synergy with Major Scientific Anniversary



Year 2011 : the 100th anniversary of Rutherford's α particle scattering experiments which marked the dawn of modern sub-atomic physics.

1911 : Rutherford used α + gold to discover the nucleus;
2011 : RHIC used gold + gold to discover the anti-α.

The Competition



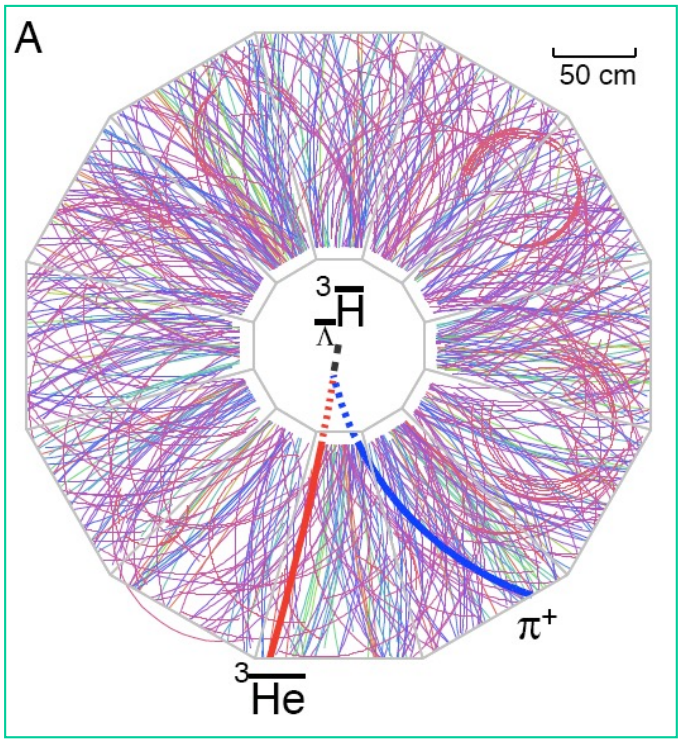
STAR :
Paper submitted to Nature on March 14th, 2011

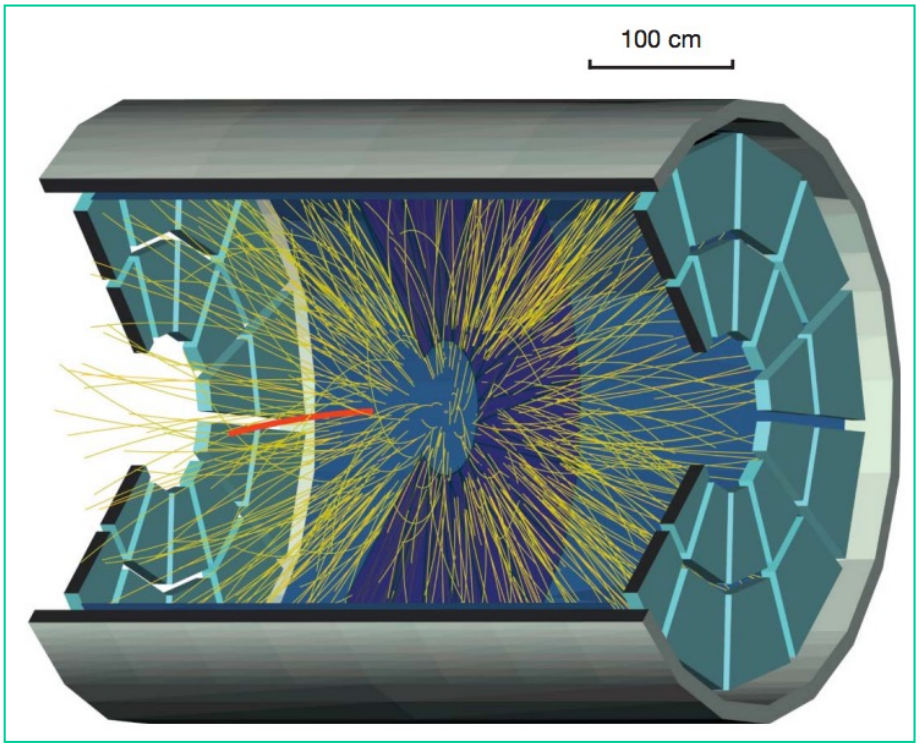
Posted on arXiv on March 16th

Alice :
Candidates presented to public on March 23rd

Without STAR's High Level Trigger, anti-helium 4 would be eventually observed at RHIC, but LHC would claim the prize for sure.

RHIC : an ideal environment for antimatter production





Science

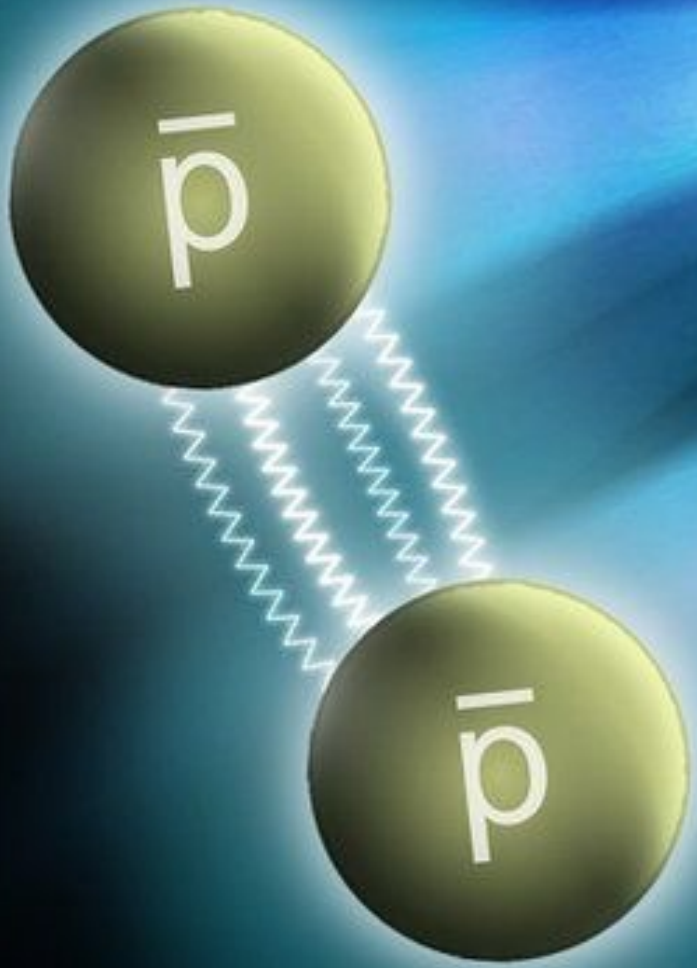
nature

STAR ☆ ***Science* 328,** 58 (2010)

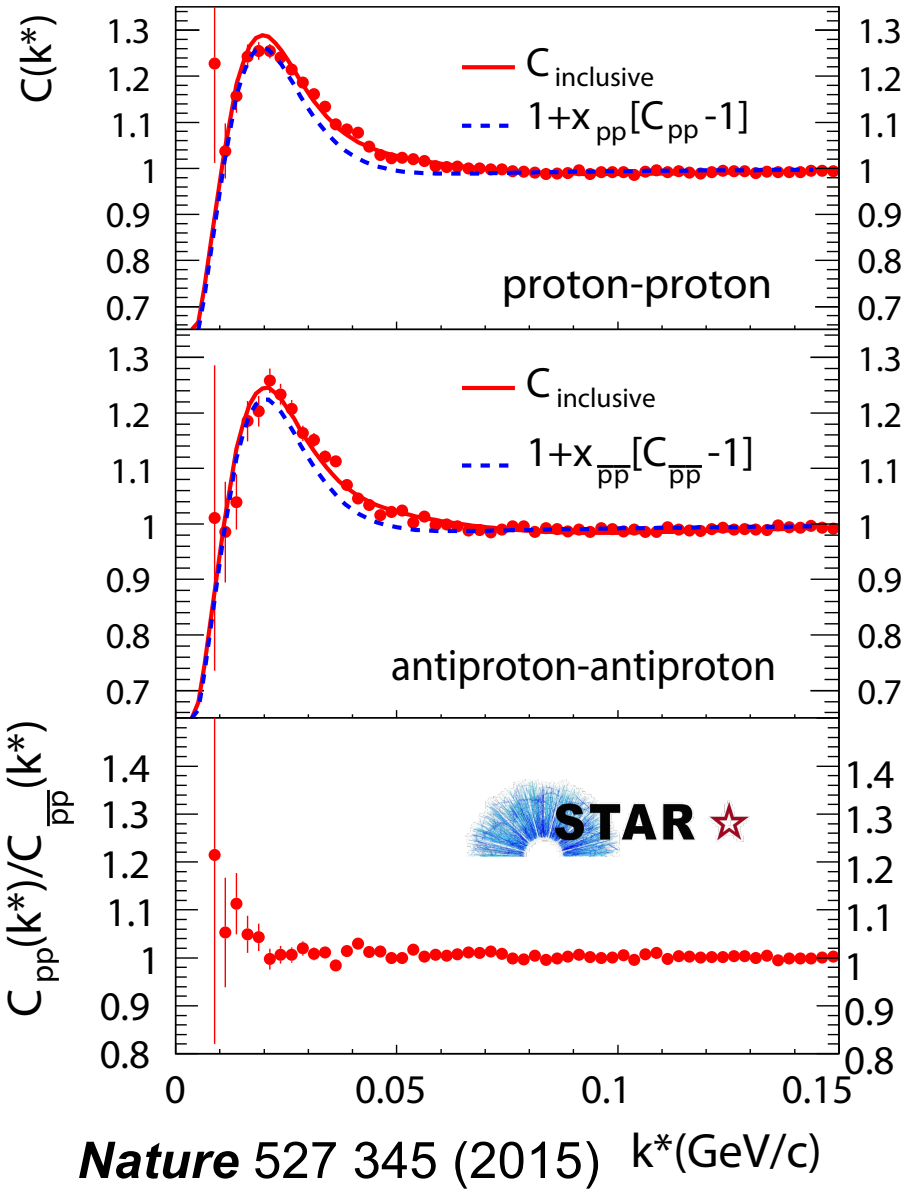
STAR ☆ ***Nature* 473,** 353 (2011)

- With abundantly produced antinucleons, RHIC (and LHC too) has the excellent capability of conducting this study.

Antimatter Interaction

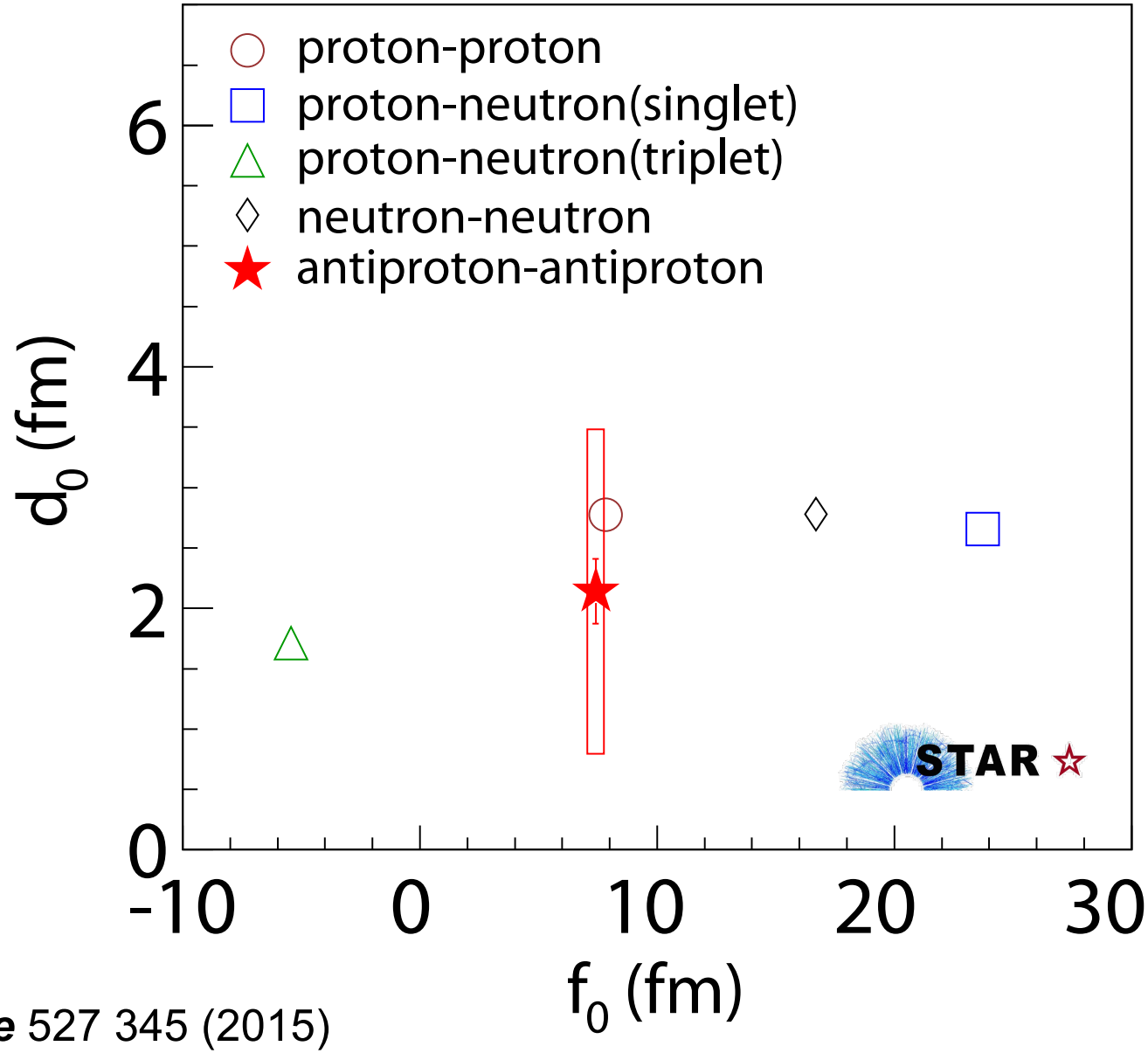


Antiproton-antiproton correlation



Nature 527 345 (2015)

Antiproton-antiproton correlation



Nature 527 345 (2015)

Antiproton-antiproton correlation

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Strong forces make antimatter s

Physicists have shed new light on one of the greatest mysteries in science: Why the Universe consists primarily of matter and not antimatter.

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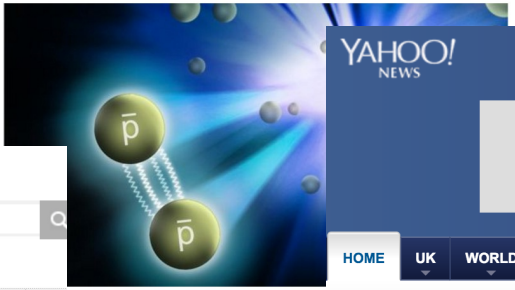

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Physicists Probe Antimatter For Clues To How It All Began

NOVEMBER 04, 2015 4:06 PM ET

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Spin in Heavy Ion Collisions

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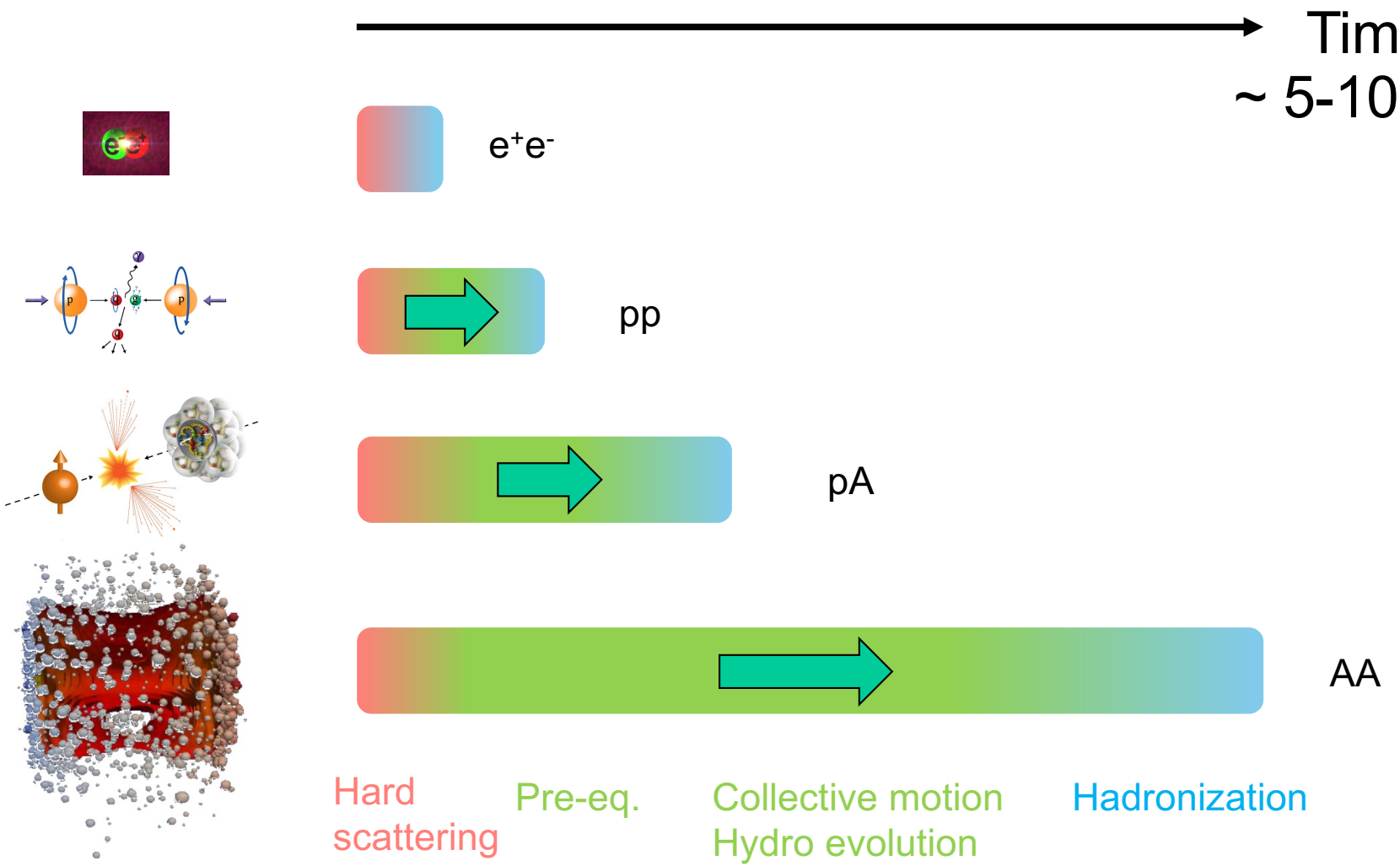
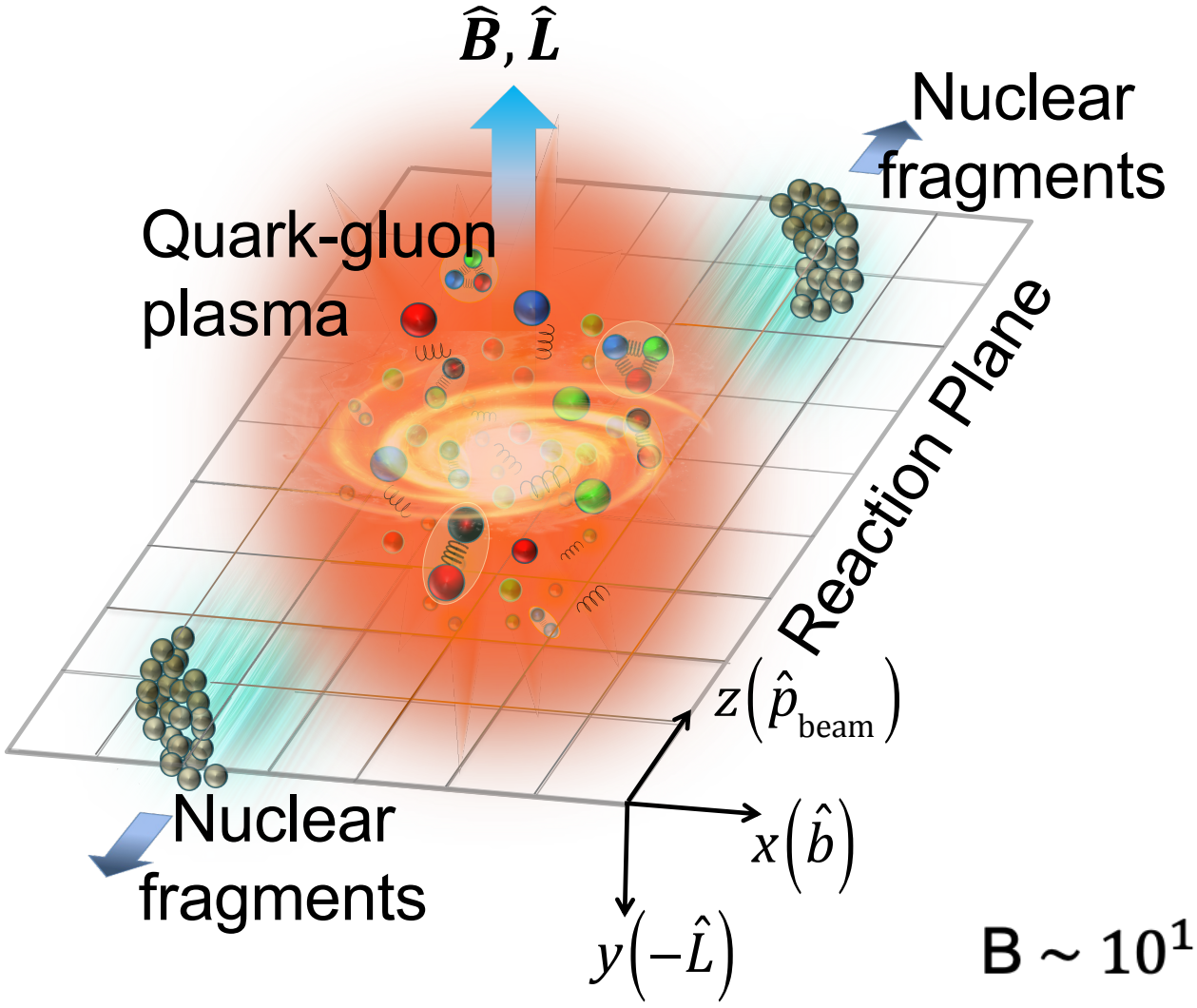


Strongly Interacting QGP under Rotation



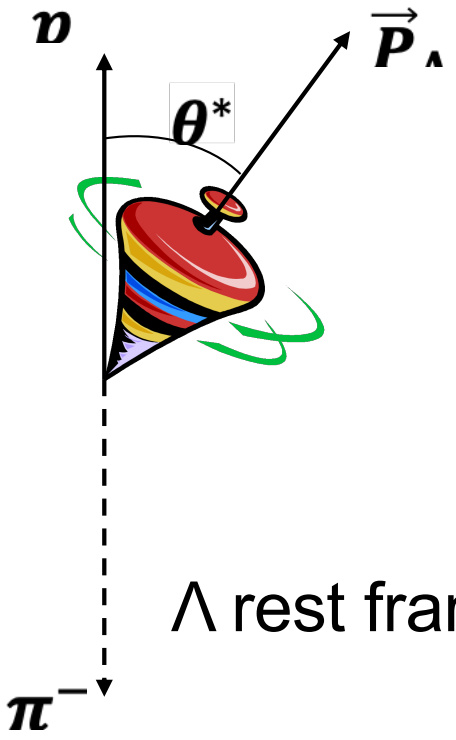
$B \sim 10^{18}$ Gauss

$L \sim 10^3 - 10^7 \hbar$

Λ Global Polarization

Parity-violating weak decay of hyperons ("self-analyzing")

Daughter baryon is preferentially emitted in the direction of hyperon's spin (opposite for anti-particle)



Λ rest frame

$$\Lambda \rightarrow p + \pi^-$$

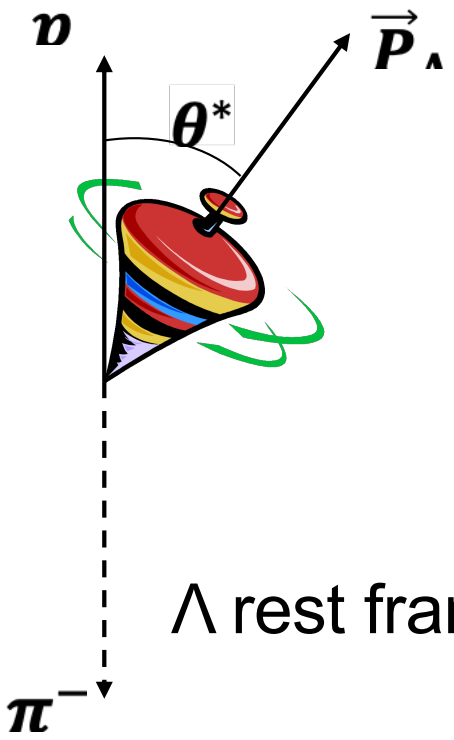
$$\frac{dN}{d\Omega^*} = \frac{1}{4\pi}(1 + \alpha_H P_H \cos\theta^*)$$

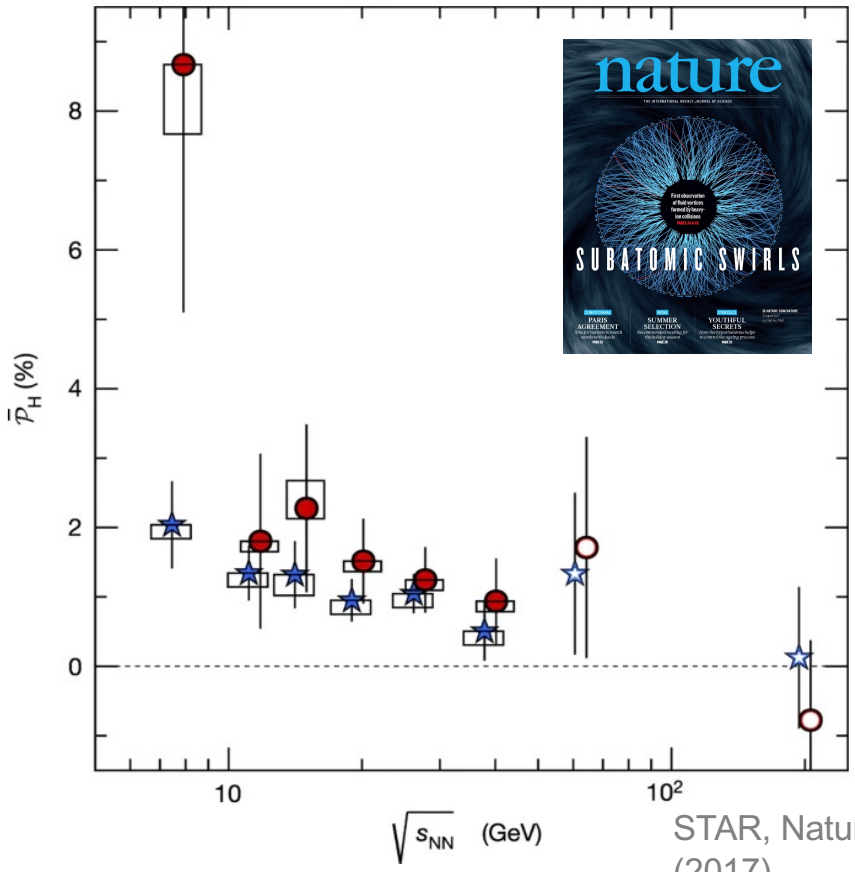
P_H : Λ polarization
θ^* : polar angle of daughter w.r.t. polarization direction
α_H : Λ decay parameter (0.732 ±0.014)

Λ Global Polarization

Parity-violating weak decay of hyperons (“self-analyzing”)

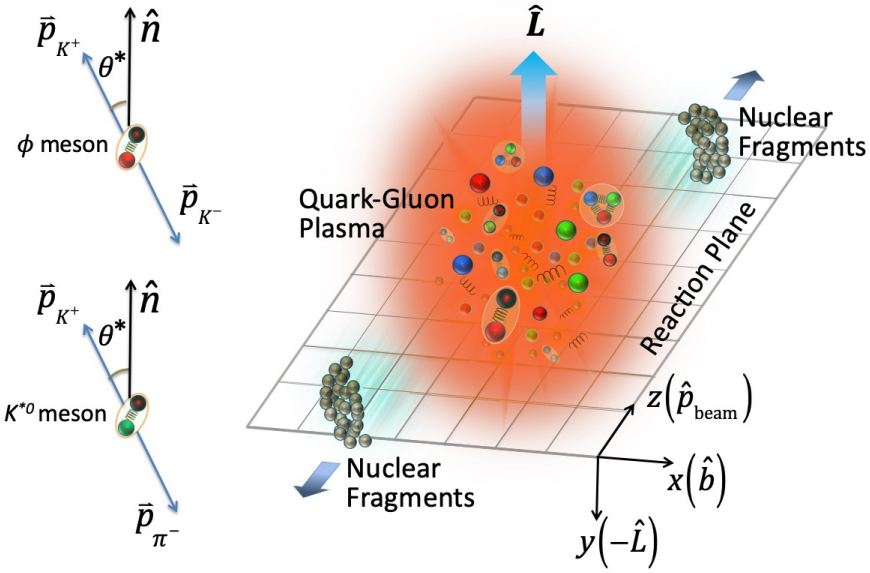
Daughter baryon is preferentially emitted in the direction of hyperon’s spin (opposite for anti-particle)



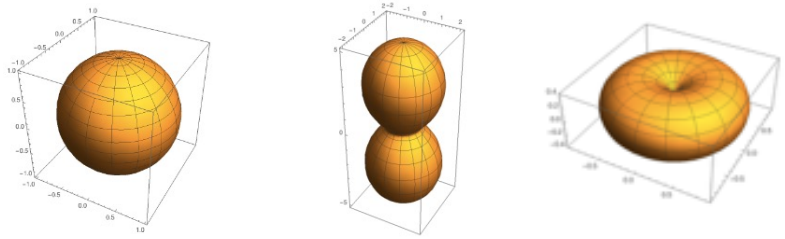


STAR, Nature 548 62 (2017)

Global Spin Alignment



$$\frac{dN}{d(\cos\theta^*)} = N_0 \times \left[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*\right]$$



$\rho_{00} = \frac{1}{3}$ $\rho_{00} > \frac{1}{3}$ $\rho_{00} < \frac{1}{3}$

The spin state of a vector meson can be described by a 3x3 spin density matrix.

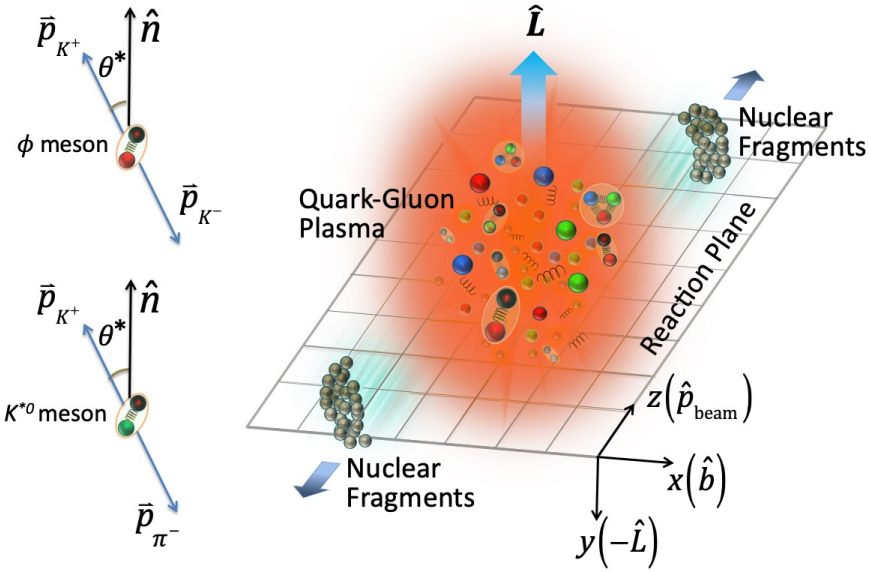
The diagonal element ρ_{00} corresponds to the probability of finding a vector meson in spin state 0 out of 3 possible spin states of -1, 0 and 1.

A deviation of ρ_{00} from 1/3 would indicate a non-zero spin alignment.

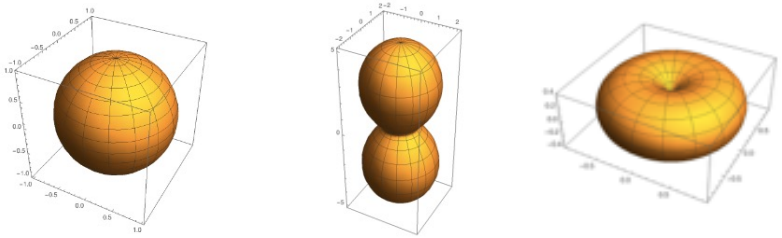
From quark combination :

$$\rho_{00}^{V} = \frac{1-\langle P_q P_{\bar{q}} \rangle}{3+\langle P_q P_{\bar{q}} \rangle} \approx \frac{1}{3} - \frac{4}{9}\langle P_q P_{\bar{q}} \rangle$$

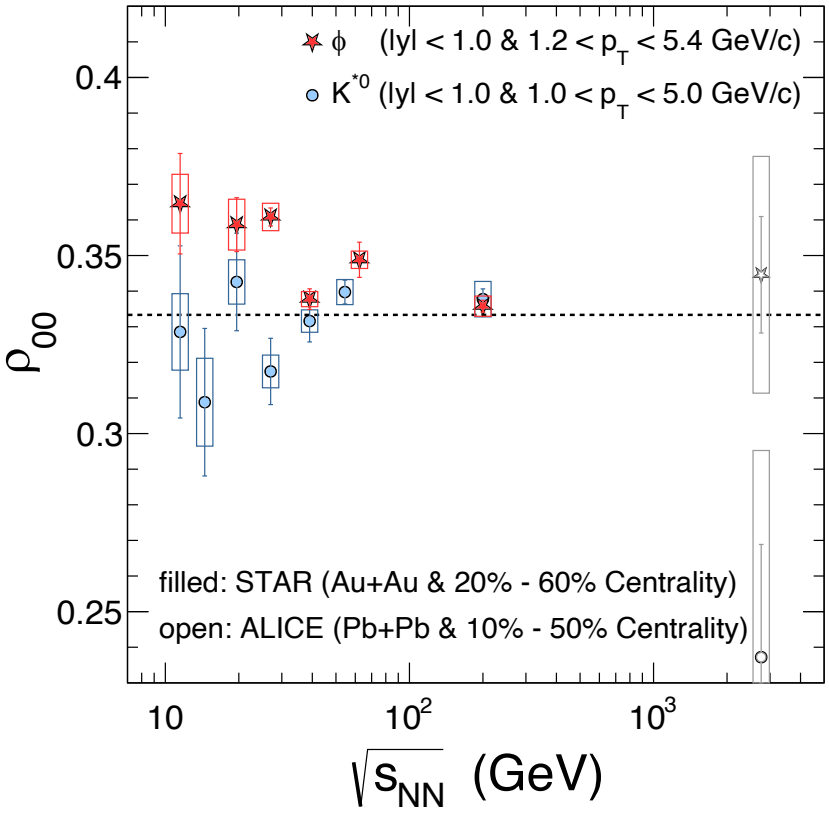
Global Spin Alignment



$$\frac{dN}{d(\cos\theta^*)} = N_0 \times \left[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*\right]$$



$\rho_{00} = \frac{1}{3}$ $\rho_{00} > \frac{1}{3}$ $\rho_{00} < \frac{1}{3}$



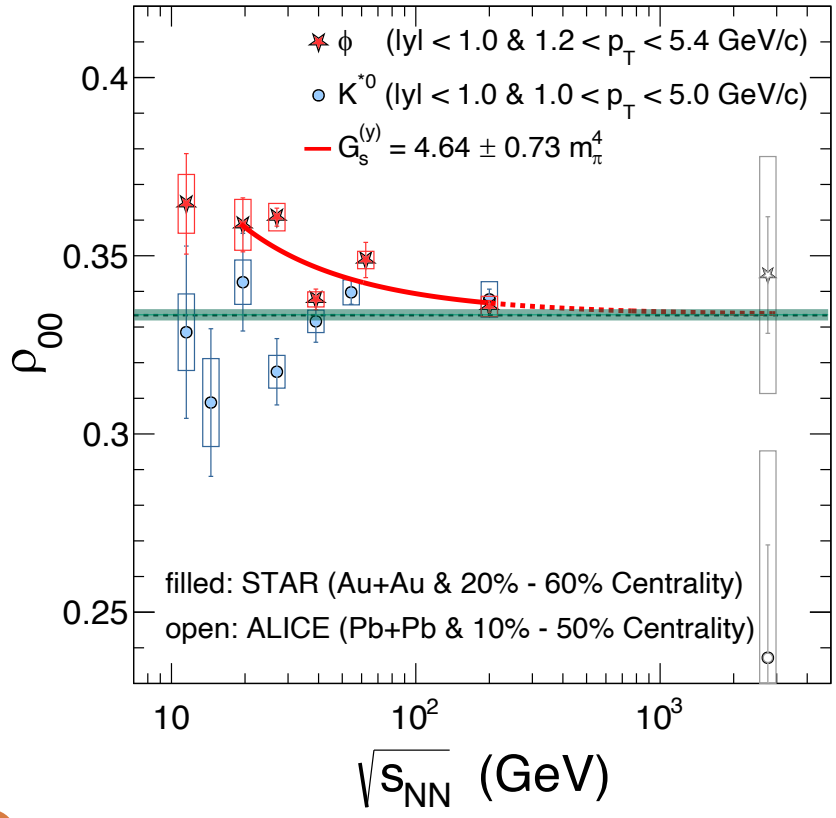
STAR, Nature 614 244 (2023)

ϕ exhibits surprisingly large global spin alignment while K* displays little.

Global Spin Alignment

$$\rho_{00} \approx \frac{1}{3} + C_\Lambda + C_\varepsilon + C_E + C_F + C_L + C$$

Physics Mechanisms	(ρ_{00})
c_Λ: Quark coalescence vorticity & magnetic field[1]	< 1/3 (Negative ~ 10^{-5})
c_ε: E-comp. of Vorticity tensor[1]	< 1/3 (Negative ~ 10^{-4})
c_E: Electric field[2]	> 1/3 (Positive ~ 10^{-5})
c_F: Fragmentation[3]	> or, < 1/3 (~ 10^{-5})
c_L: Local spin alignments[4]	< 1/3
c_A: Turbulent color field[5]	< 1/3
c_ϕ: Vector meson strong force field[6]	> 1/3 (Can accommodate large positive signal)
c_g: Glasma fields + effective potential	could be significant



STAR, Nature 614 244 (2023)

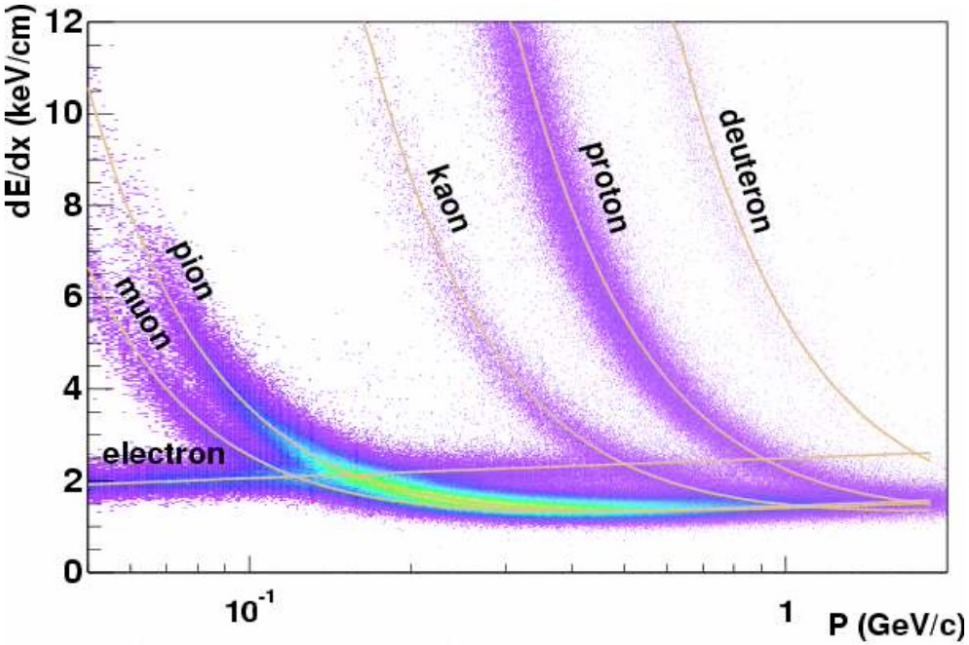
strong force

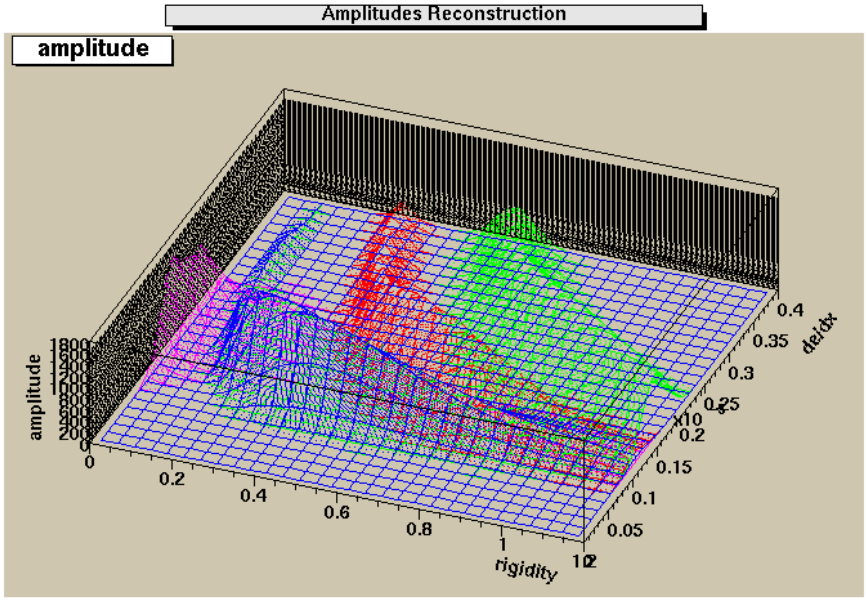
ϕ exhibits surprisingly large global spin alignment while K* displays little.


Grateful for standing on your shoulders in this wonderful journey, Declan !

Backup Slides

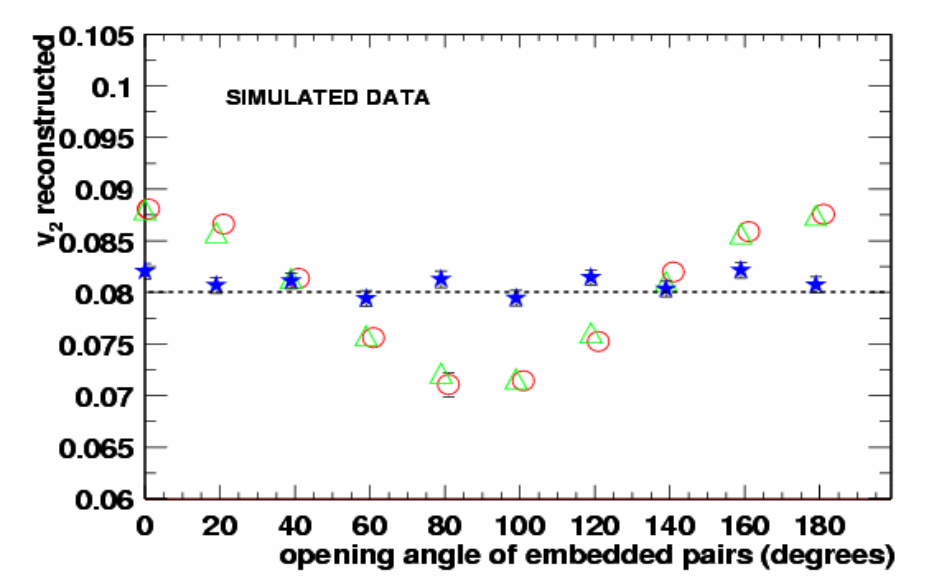
First Task @ STAR

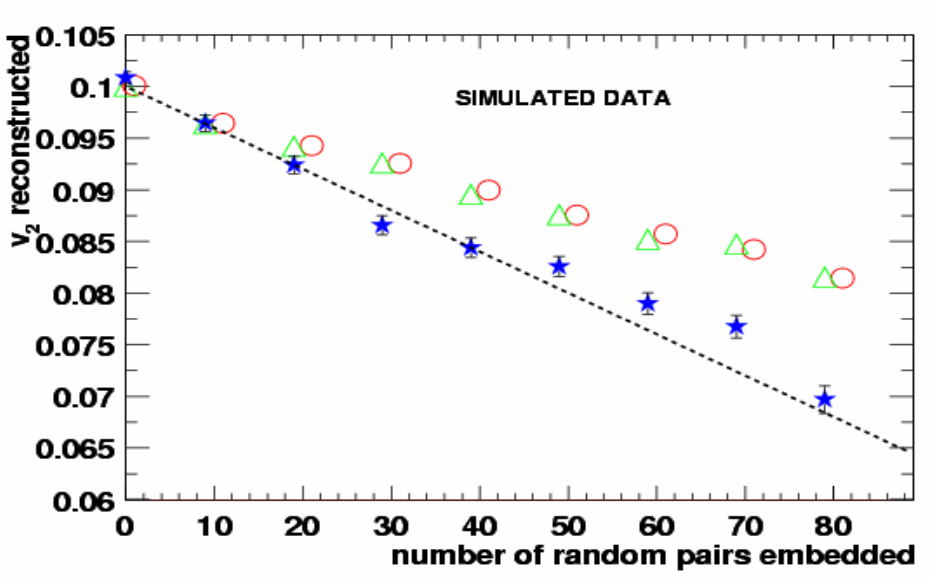




Probability PID, used in first PID flow paper.
Was hoping to use it for extended spectra, but it did not happen.

Nonflow and Cumulants





Borghini, Dinh and Ollitrault, PRC 63 054906 (2001) …
STAR PRC 66 034904 (2002)

Considerable nonflow in conventional flow method.
Going for 4th order cumulants !

Nuclear force between antimatter

• So far the large body of knowledge on nuclear force was derived from studies made on nucleons or nuclei, little is known directly about the nuclear force between antinucleons.

• The knowledge of interaction among two anti-protons, one of the simplest system of antinucleons(nuclei), is a fundamental ingredient for understanding the structure of more-complex antinuclei and their properties.

Nuclear force : scattering length (f_0) and effective range (d_0)

f_0 is related to the cross section.

At low energy limit, the scattering cross section is given by

$$\sigma = 4\pi f_0^2$$

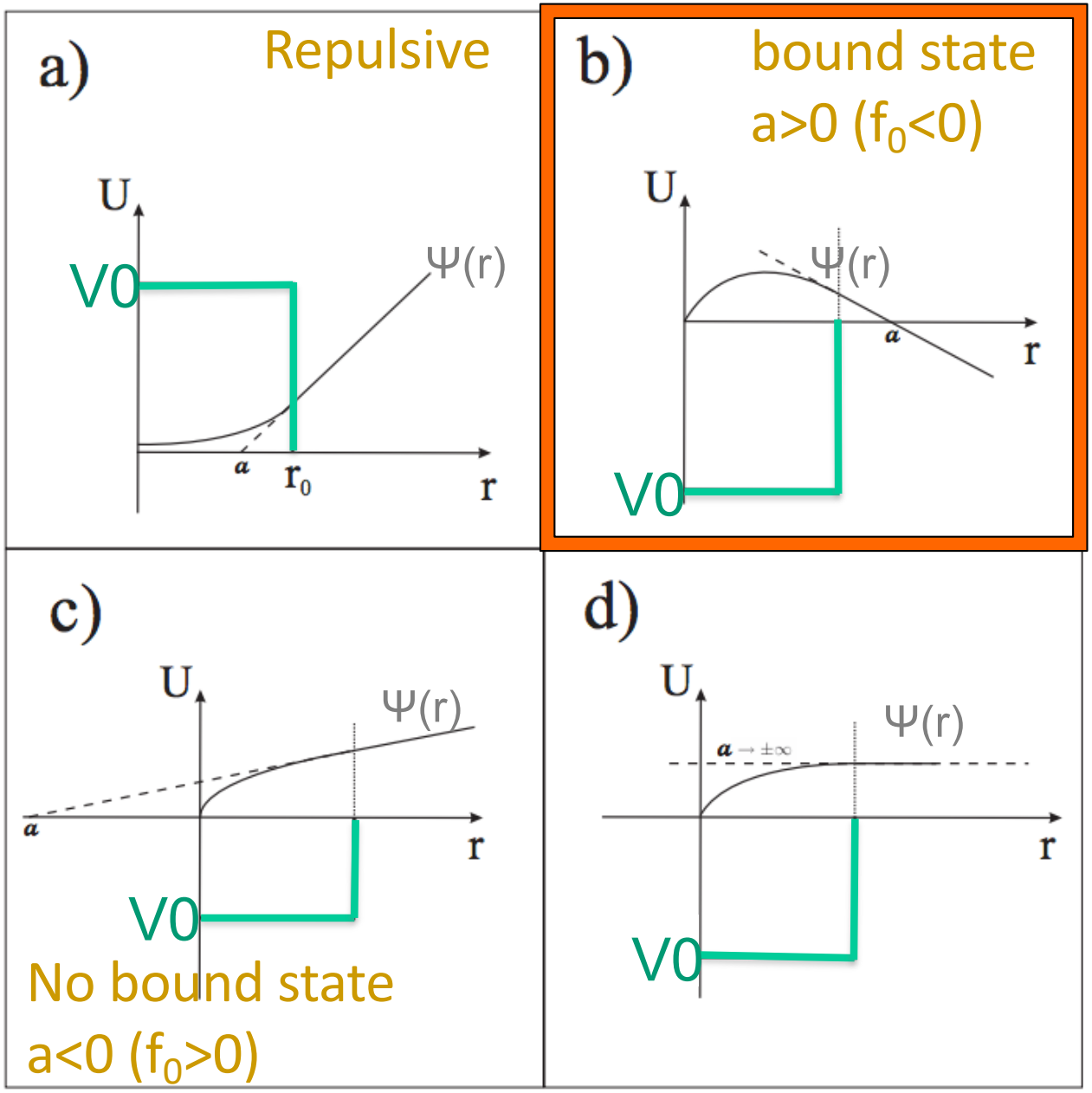
d_0 is related to the range of the potential.

In the case of square well potential, d_0 is the range (radius) of the potential.

For a short range potential, f_0 and d_0 are related to the s-wave scattering phase shift δ_0 and the collision momentum k by :

$$k\cot(\delta_0) \approx \frac{1}{f_0} + \frac{1}{2} d_0 k^2$$

f_0 and d_0 : characterizing the nuclear force



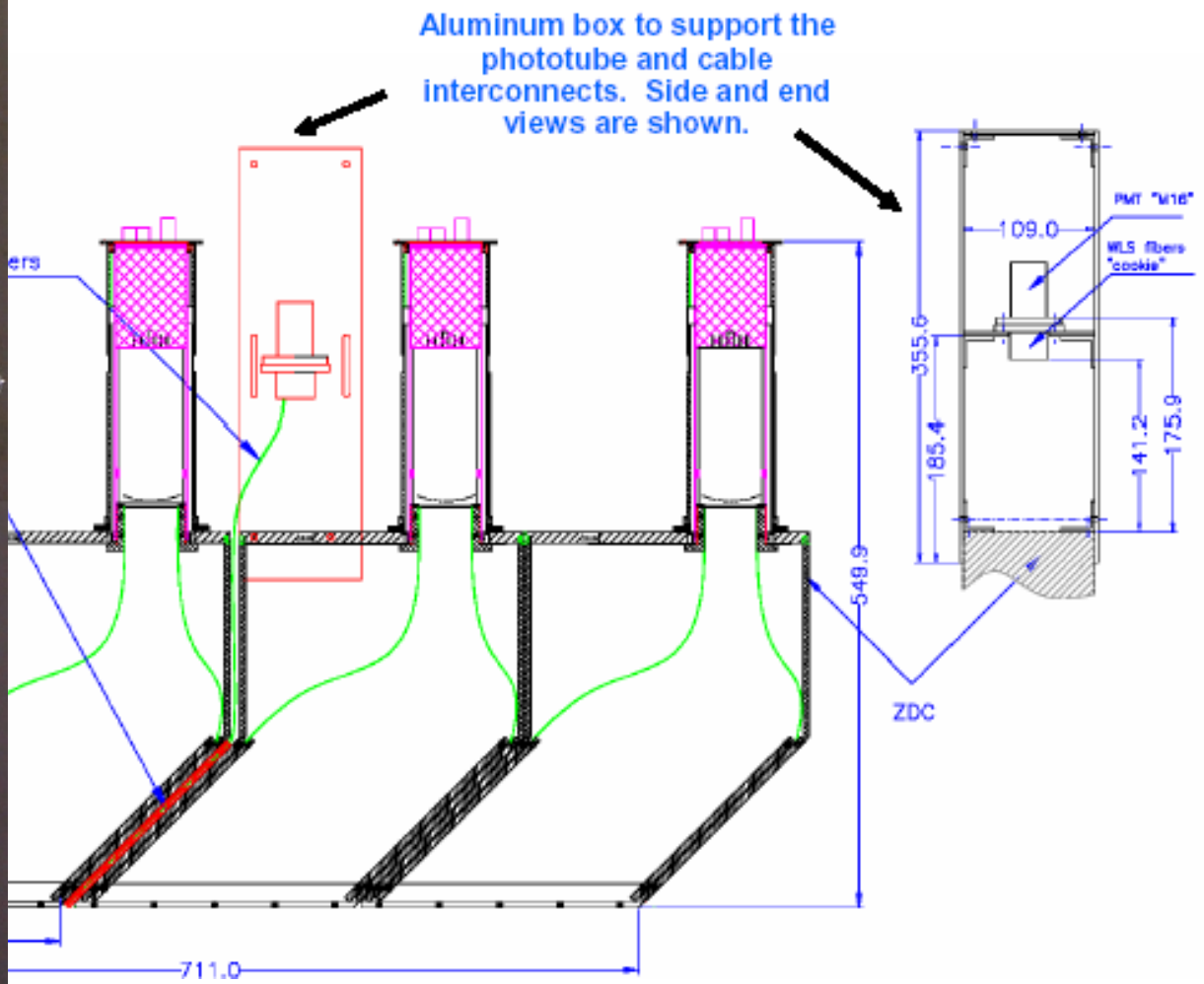
$kr << 1$

$k \to 0$

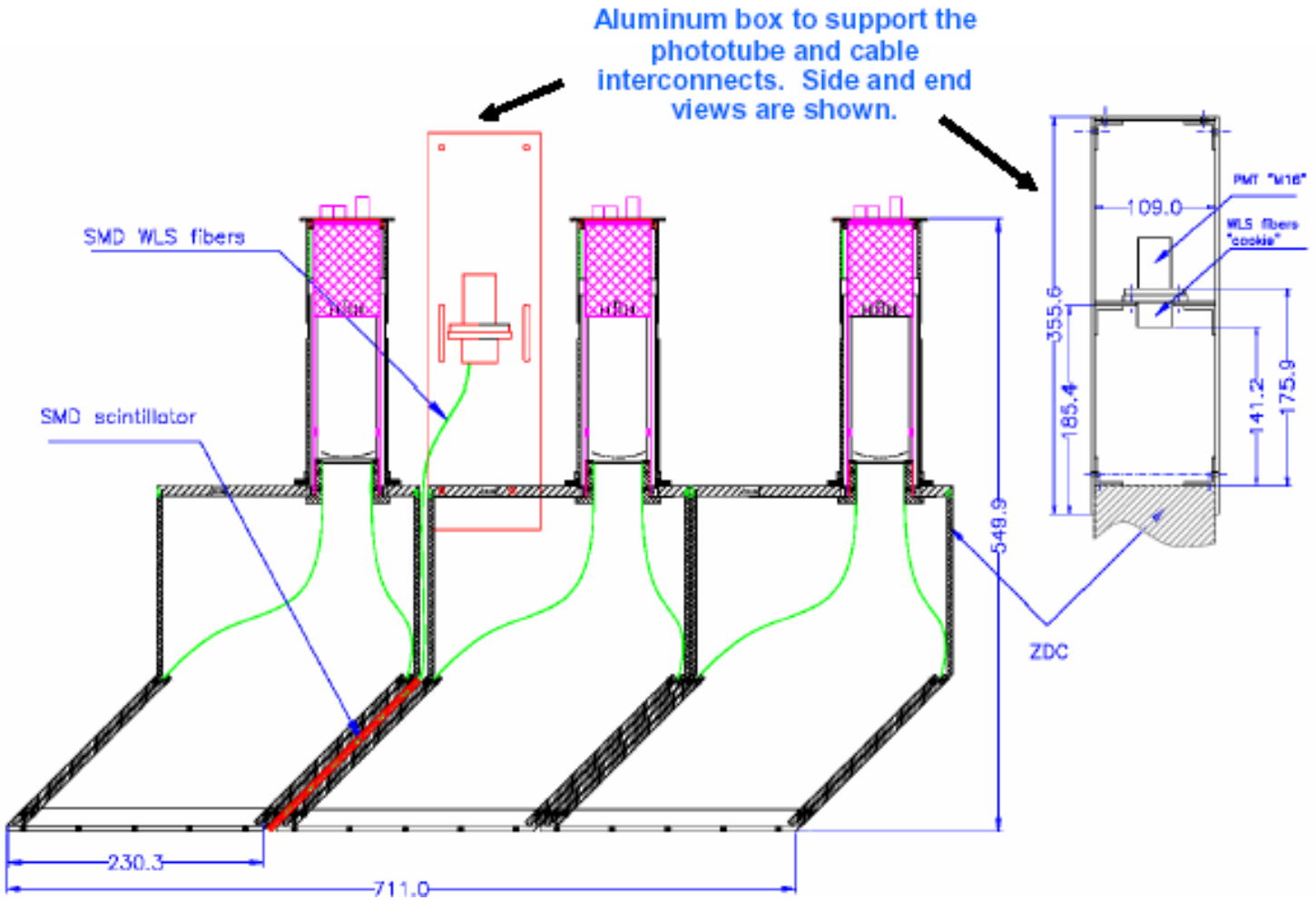
$f_0 \equiv -a$

$d_0 \equiv r_0$

A Shower Max Detector at ZDC for STAR



A Shower Max Detector at ZDC for STAR



A Shower Max Detector at ZDC for STAR