U.S. DEPARTMENT OF ENERGY | Office of Science

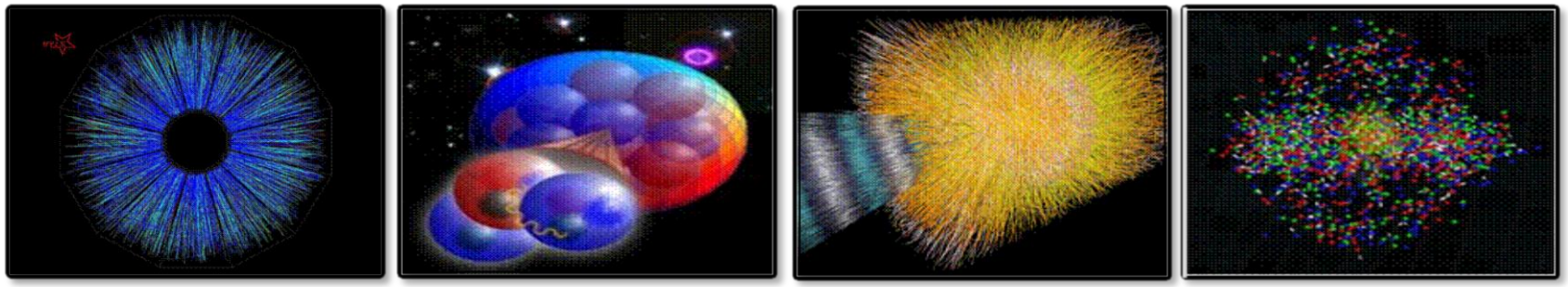
Perspectives from DOE Nuclear Science

Users Meeting

Brookhaven National Laboratory

June 11, 2015

Dr. Timothy J. Hallman
Associate Director for Nuclear Physics
DOE Office of Science



Three Broad Scientific Thrusts of Nuclear Science

Quantum Chromodynamics (QCD) seeks to develop a complete understanding of how quarks and gluons assemble themselves into protons and neutrons, how nuclear forces arise, and what forms of bulk strongly interacting matter can exist in nature, such as the quark-gluon plasma.

Nuclei and Nuclear Astrophysics seeks to understand how protons and neutrons combine to form atomic nuclei, including some now being observed for the first time, and how these nuclei have arisen during the 13.8 billion years since the birth of the cosmos.

Fundamental Symmetries of neutrons and nuclei seeks to develop a better understanding of fundamental interactions by studying the properties of neutrons and targeted, single focus experiments using nuclei to study whether the neutrino is its own anti-particle.

DOE NP Supported Research and Operations in the U.S. Nuclear Physics Program

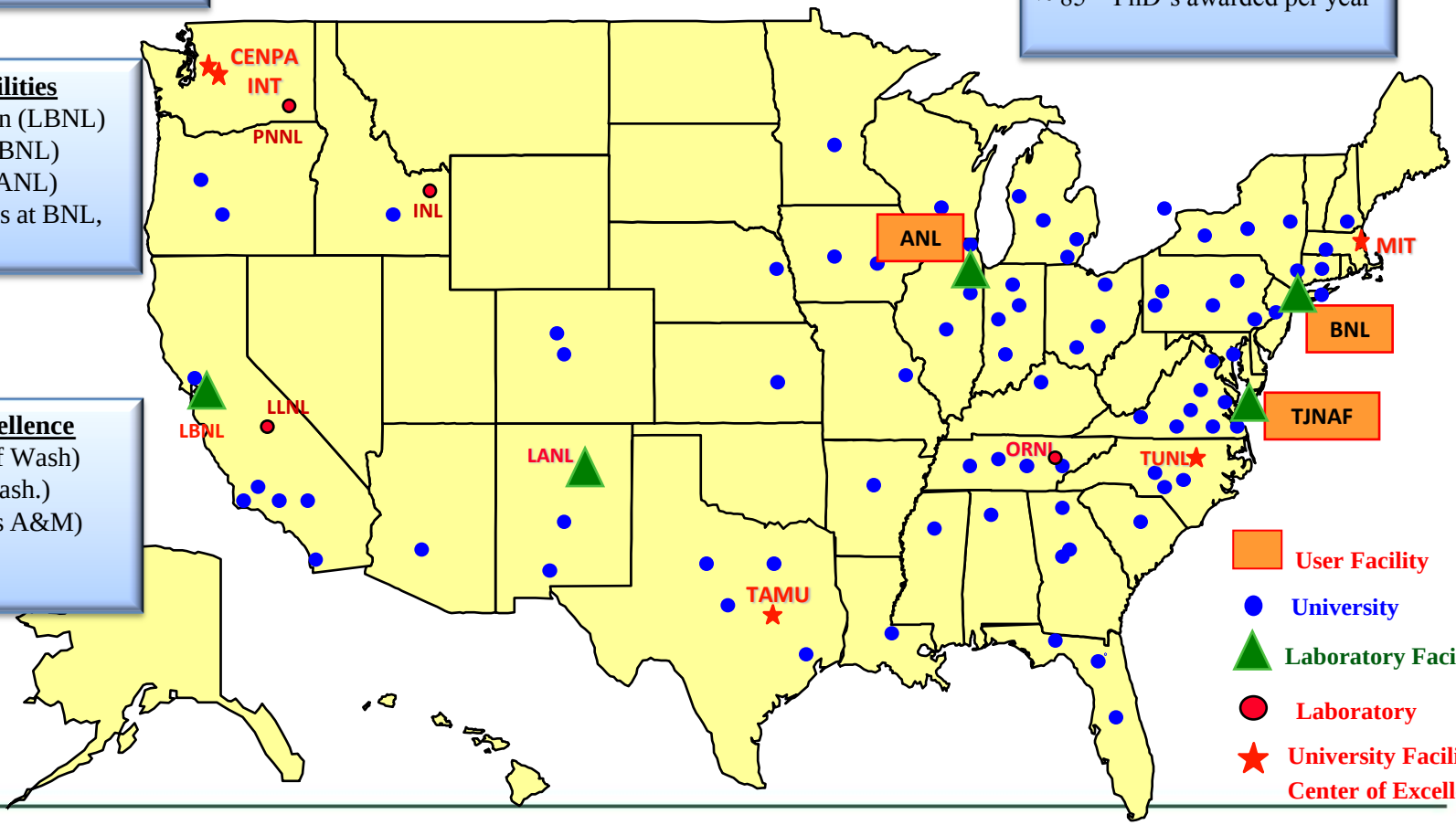
National User Facilities
- RHIC (BNL)
- CEBAF (TJNAF)
- ATLAS (ANL)
- ~2,900 users

Research Groups
- 9 National Laboratories
- 85 Universities

NP Research Workforce
~700 Faculty & Lab Res Staff
~345 Post-docs
~515 Graduate Students
~1000 Technical/admin
~100 Undergraduate Students
~ 85 PhD's awarded per year

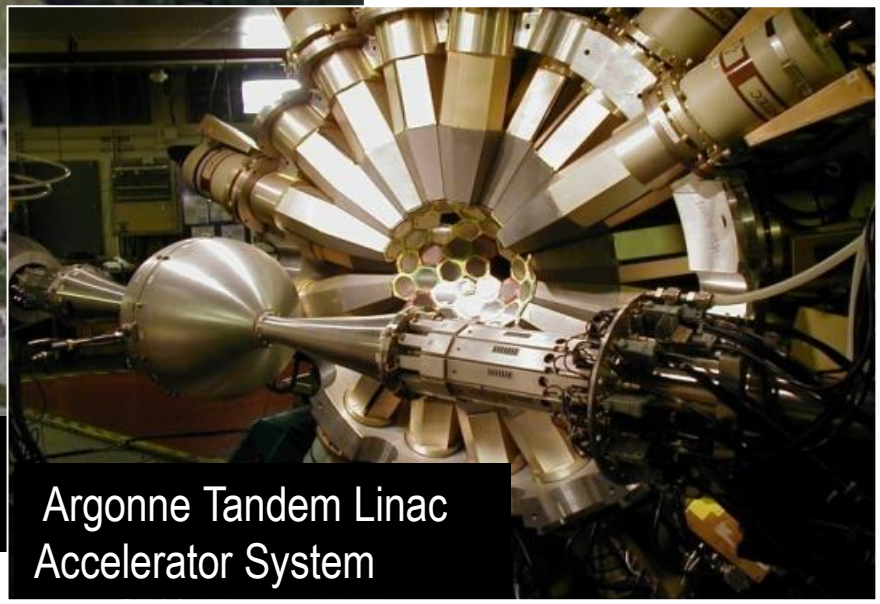
Other Lab. Facilities
- 88-Inch Cyclotron (LBNL)
- 200 MeV BLIP (BNL)
- 100 MeV IPF (LANL)
- Hot Cell Facilities at BNL, LANL, ORNL

Centers of Excellence
- CENPA (U. of Wash)
- INT (U. of Wash.)
- TAMU (Texas A&M)
- TUNL (Duke)
- REC (MIT)



NP National User Facilities

"Microscopes" pursuing groundbreaking research



Nuclear Physics
FY 2016 President's Request – Summary

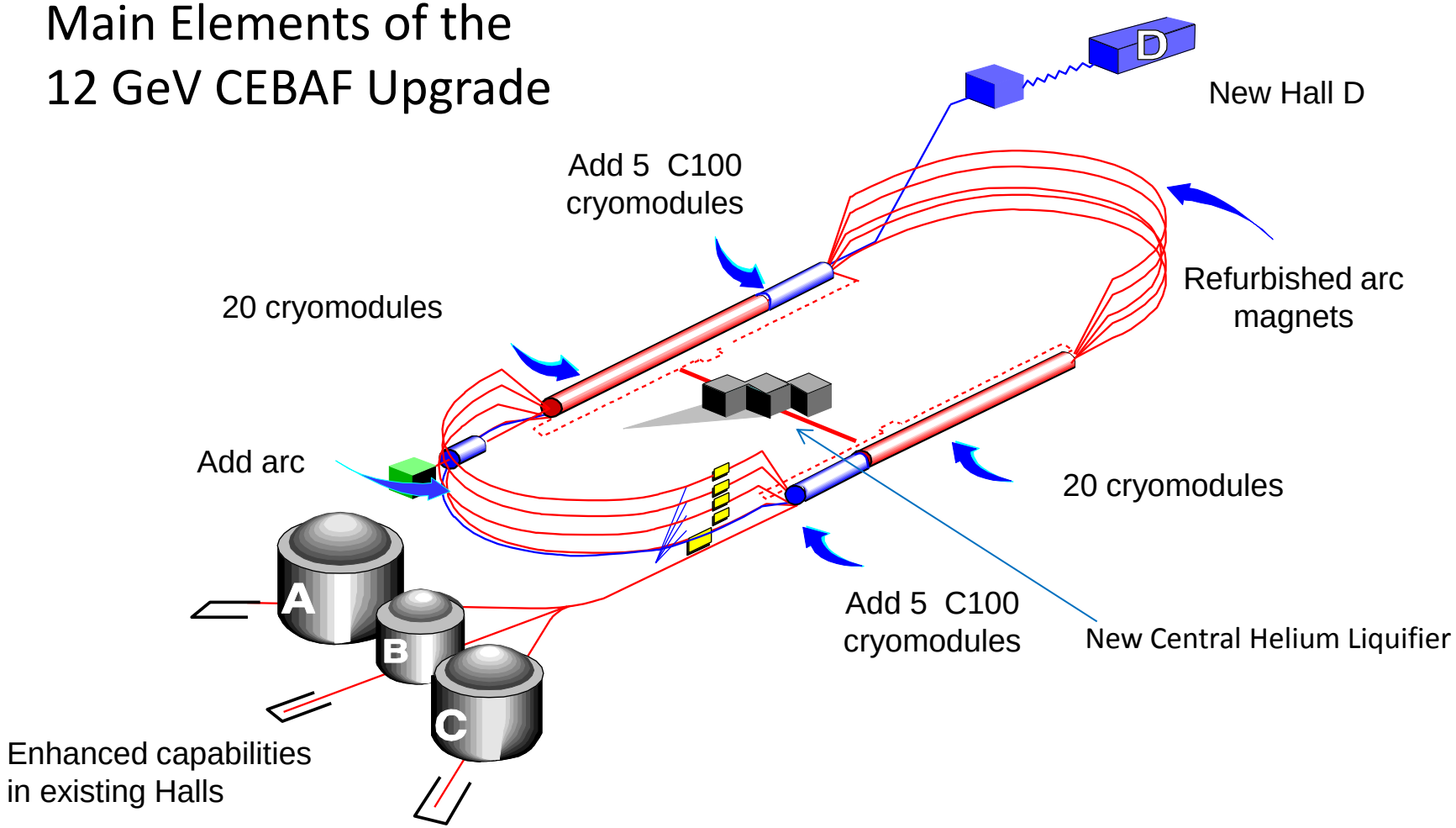
($ in 000s)	FY 2014 Enacted	FY 2015 Enacted	FY 2016 Request	FY 2016 vs. FY 2015
Research	170,668	165,828	179,311	+13,483
User Facility Operations	276,887	280,663	293,304	+12,641
Other Operations	24,120	24,313	24,995	+682
Projects	80,500	106,500	107,500	+1,000
Other	16,963	18,196	19,490	+1,294
TOTAL NP	**569,138**	**595,500**	**624,600**	**+29,100**

Explanation of Requested Increases

- **Research** – Support for university and lab research increases across the program to address important opportunities identified by the research community, and to enhance high priority research that will foster significant advances in nuclear structure, nuclear astrophysics, the study of matter at extreme conditions, hadronic physics, fundamental properties of the neutron, and neutrinoless double beta decay.
- **User Facility Operations** – Operations of RHIC are maintained at the FY 2015 level with increases provided for critical staff, equipment, and materials required for reliable operations and support research focused on characterizing the perfect quark-gluon liquid discovered in collisions of relativistic heavy nuclei. Beam development and commissioning activities continue at CEBAF as the 12 GeV CEBAF Upgrade project approaches completion, and scientific instrumentation is implemented in the experimental halls in preparation for the full start of the physics program in FY 2017. Operations of ATLAS are optimized, exploiting the new capabilities of CARIBU and completing the campaign with the GRETINA gamma ray spectrometer.
- **Other Operations** – Requested funding for the Isotope Program maintains mission readiness for the production of radioisotopes.
- **Projects** –12 GeV CEBAF Upgrade and FRIB construction are supported according to baselined profiles.
- **Other** – Increased funding is provided for the SBIR/STTR programs consistent with the legislative mandate.

CEBAF is in the Final Phases of a Major Upgrade in Energy to 12 GeV From 6 GeV

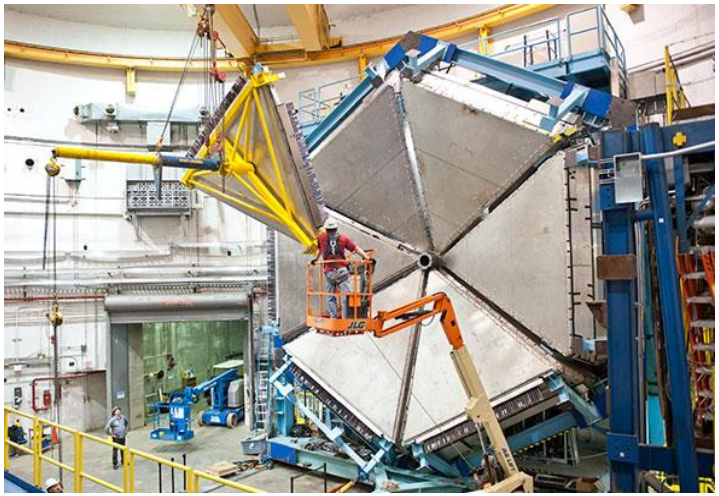
Main Elements of the 12 GeV CEBAF Upgrade



The 12 GeV CEBAF Upgrade is More Than 94% Complete

With the completion of the 12 GeV CEBAF Upgrade, researchers will address:

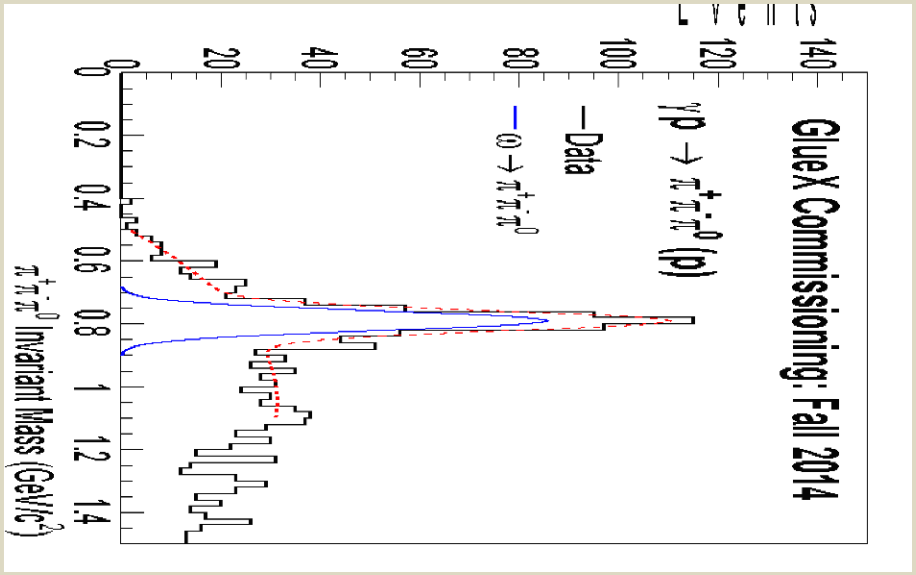
- The search for exotic new quark anti-quark particles to advance our understanding of the strong force
- Evidence of new physics from sensitive searches for violations of nature's fundamental symmetries
- A detailed microscopic understanding of the internal structure of the proton, including the origin of its spin, and how this structure is modified when the proton is inside a nucleus



Mounting of the Forward Time-of-Flight detector arrays onto the forward carriage in Hall B

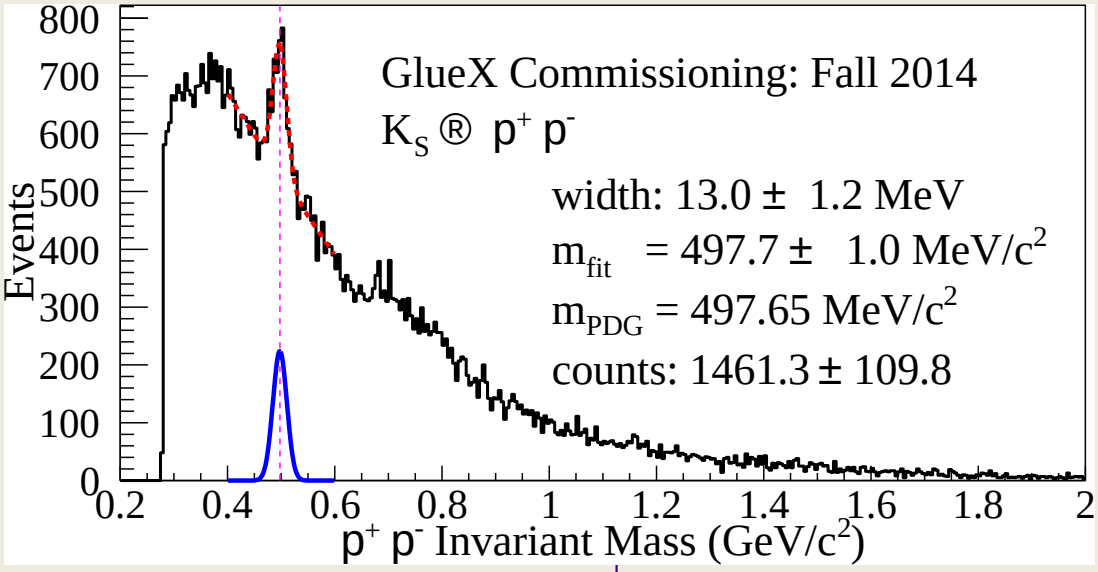
Project was re-baselined in September 2013 with a Total Project Cost of $338M and completion in September 2017

February 2015

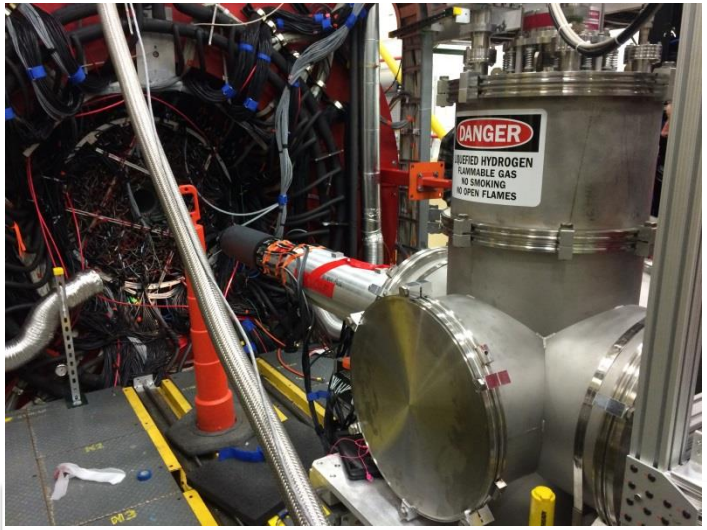


$\omega \to \pi^+\pi^-\pi^0$

Select detached vertices

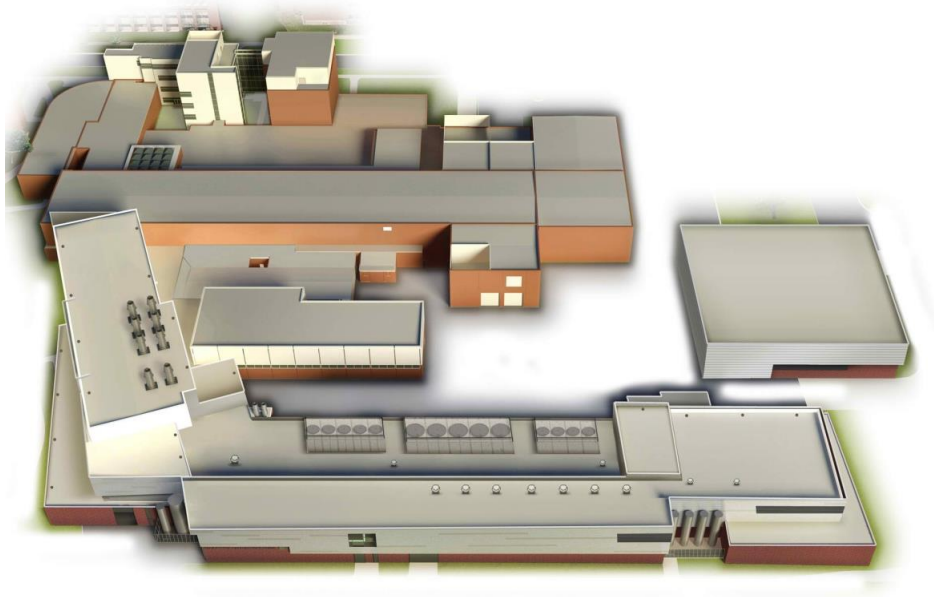


$K_S \to \pi^+\pi^-$



Start Counter mounted to LH2 target prior to installation in GlueX, February 2015

Facility for Rare Isotope Beams

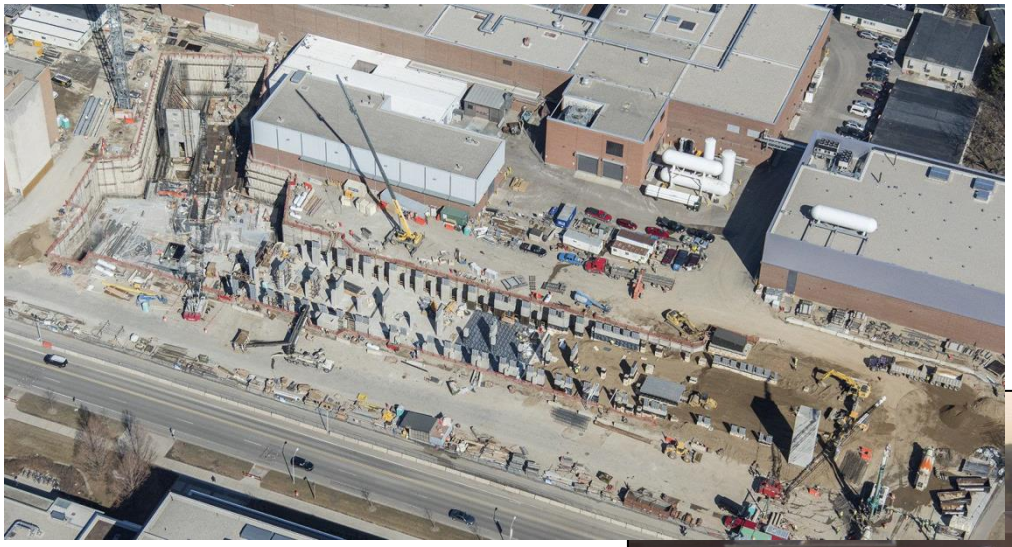


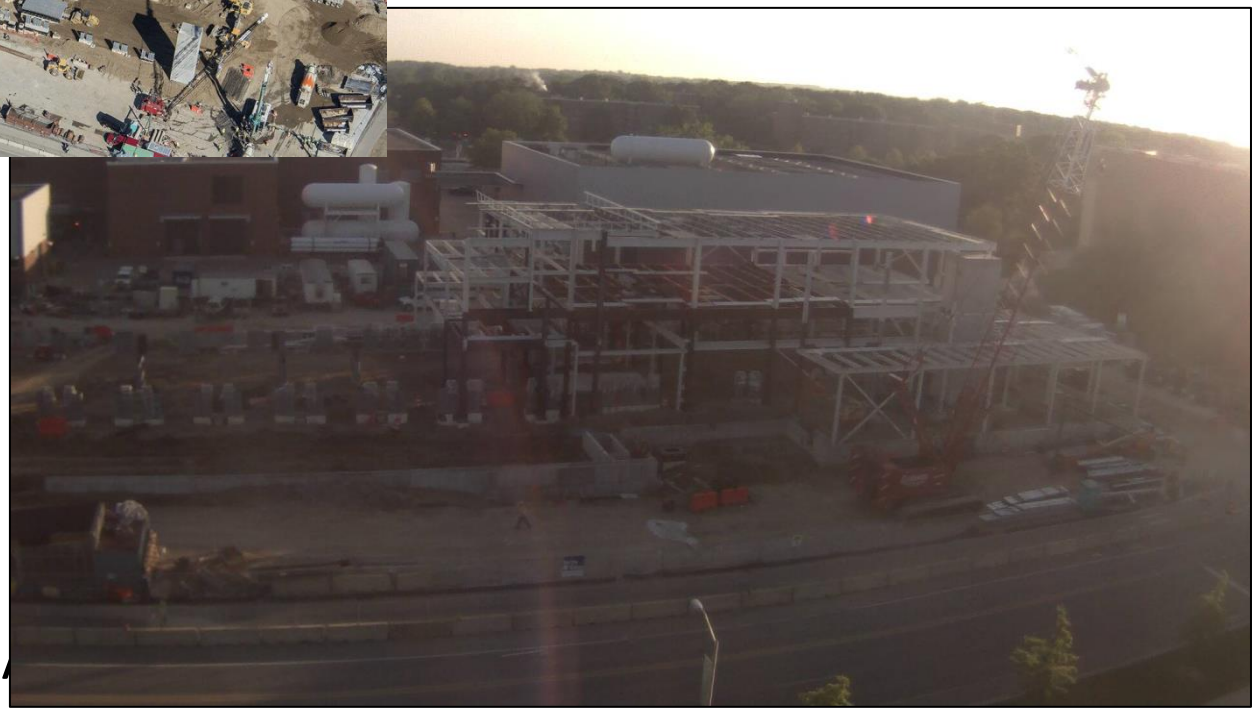
Ground breaking ceremony with participation by DOE officials and Senate and House representatives was held on March 17, 2014.

FRIB Construction is Now Like a Speeding Train

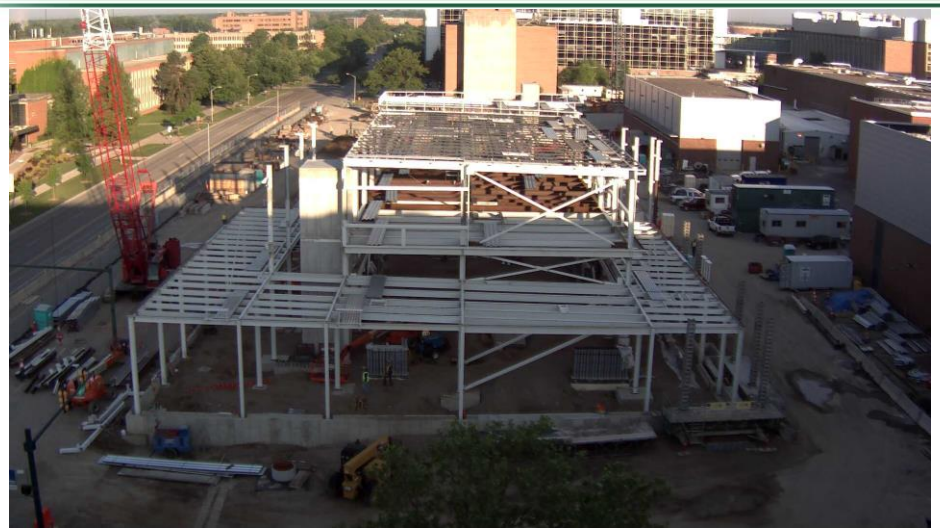
TPC $000s	PYs	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	TOTAL
FRIB	51,000	22,000	55,000	90,000	100,000	100,000	97,200	75,000	40,000	5,300	635,500

Progress on the Facility for Rare Isotope Beams





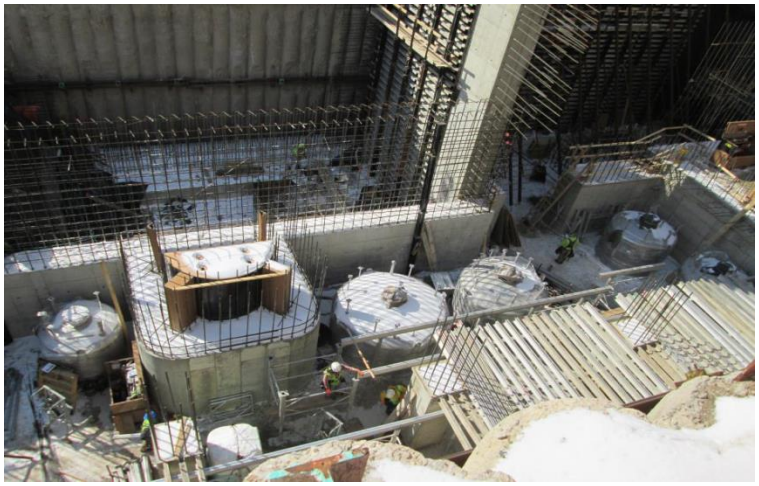
Progress on the Facility for Rare Isotope Beams



Structural steel for surface buildings being erected

Tunnel warm and painted

Pour for the tunnel foundation slab



First technical installation: NCU Low-level liquid waste tanks in target area

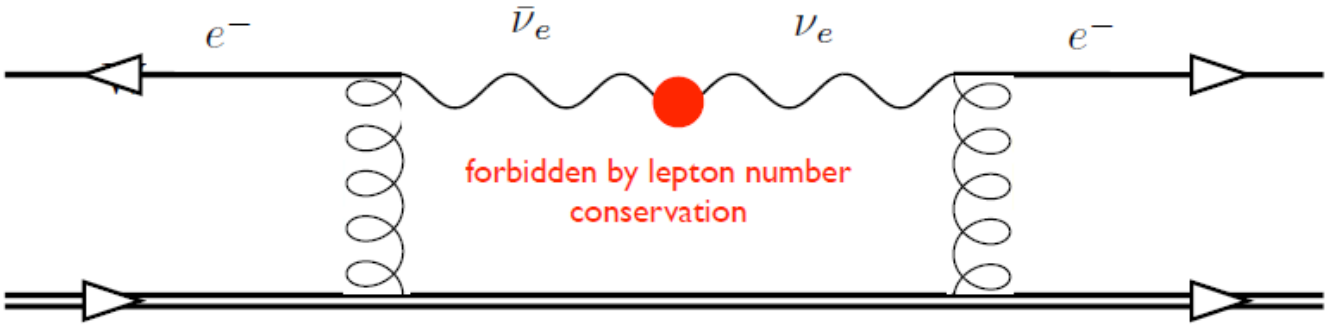
A High Priority NP Frontier: Neutrino-less Double Beta Decay

Three Light Neutrinos: What Do We Know ?

2ν DBD: $A(Z,N) \rightarrow A(Z+2, N-2) + e^- e^- \; \nu\,\nu$

If own antiparticle, can be emitted then absorbed during decay

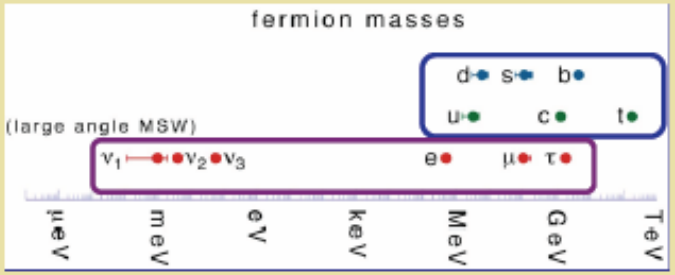
0ν DBD: $A(Z,N) \rightarrow A(Z+2, N-2) + e^- e^-$



Why Is $0\nu\beta\beta$ a Science "Must Do" Experiment

What Questions Does It Address ?

- *Is the neutrino its own antiparticle ?*
- *Why is there more matter than antimatter in the present universe?*
- *Why are neutrino masses so much smaller than those of other elementary fermions ?*



Partners

Partners

Experimental searches for 0νββ-decay

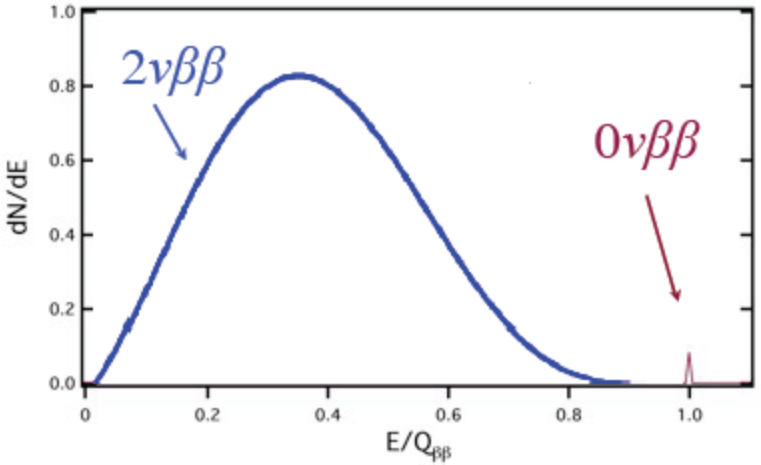
Most sensitive experiments to date using ^{76}Ge, ^{130}Te, and ^{136}Xe have attained results for $T_{1/2} > 10^{25}$ years

(source mass) × (exposure times) of 30 - 100 kg-years

To reach IH region requires sensitivities of

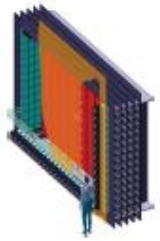
$0\nu\beta\beta$ $T_{1/2} \sim 10^{27}$ - 10^{28} years

($2\nu\beta\beta$ $T_{1/2} \sim 10^{19}$ - 10^{21} years)

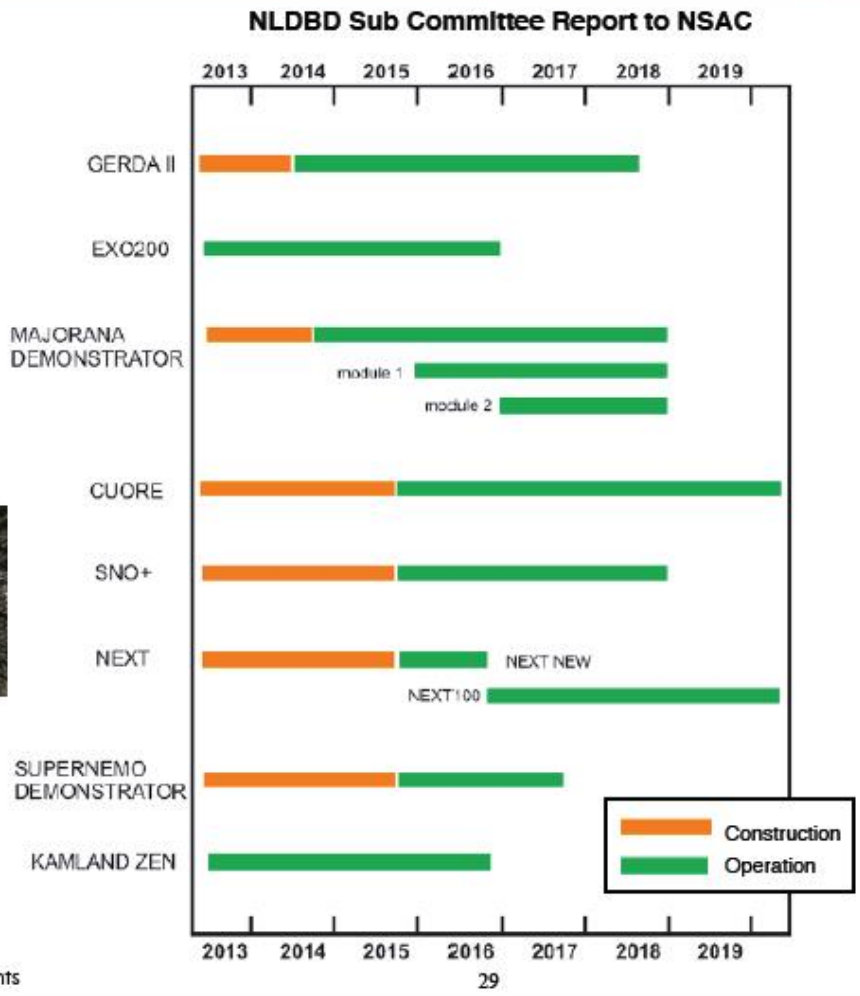


International Efforts Underway

0νββ decay Experiments - Efforts Underway



0νββ-decay — experiments



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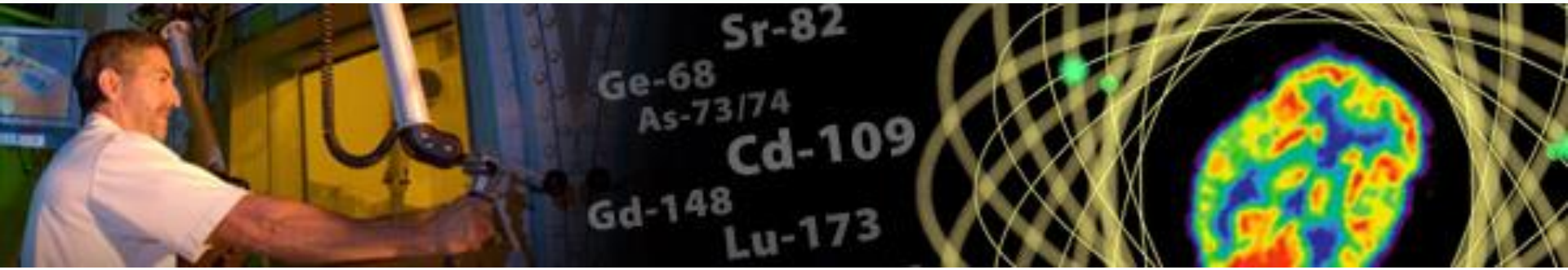
Isotope Program Mission



The mission of the DOE Isotope Program is threefold

- Produce and/or distribute radioactive and stable isotopes that are in short supply, associated byproducts, surplus materials and related isotope services.
- Maintain the infrastructure required to produce and supply isotope products and related services.
- Conduct R&D on new and improved isotope production and processing techniques which can make available new isotopes for research and applications.

Produce isotopes that are in short supply only –
the Isotope Program does not compete with industry

RHIC had been trying to make collisions for many days; many people “hanging out” in the control room for days; it was a Monday night, the collider was having troubles, the STAR DAQ was broken, Tonko Ljubicic was about to reboot, and then…….the room exploded in cheers and applause

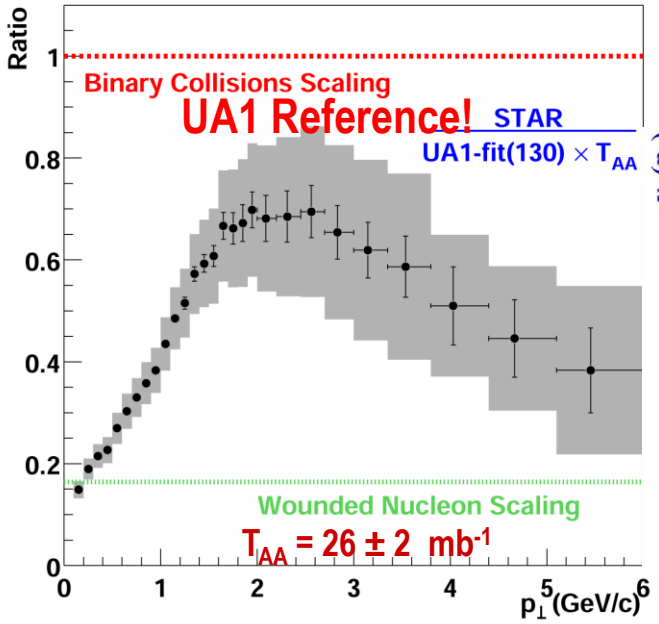
Six months later at the time of QM2001(15-20, Jan):
(which had been delayed by 6 months waiting for the arrival of data)

Despite the relative crudeness of these data by today's standard the new results from RHIC dominated this meeting (no one even noticed the terrible lunches) and RHIC took over leadership of the field

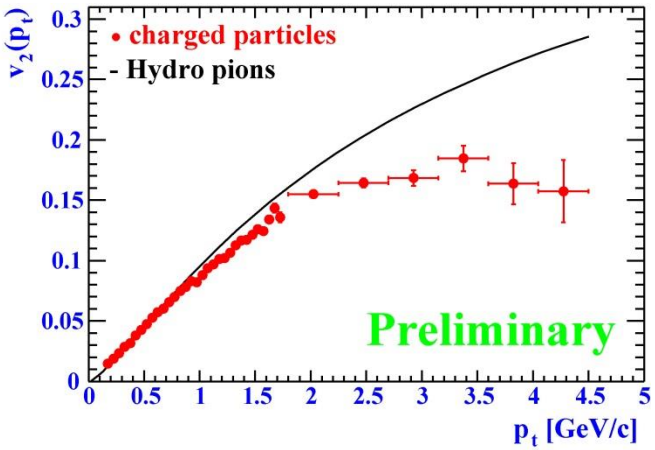
"High p_T" particle suppression & flow

m_T spectra and inverse slopes $\pi^{\pm}$, $K^{\pm}$, p, pbar

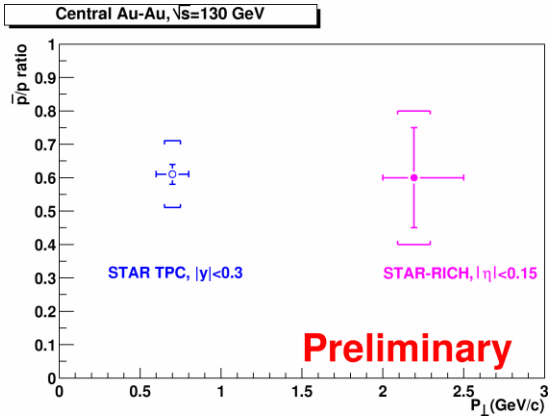
p_T integrated yield ratios, HBT vs $\sqrt{s}$ for $\pi^{\pm}$, ρ^0 photoproduction



STAR min-bias $\sqrt{s_{NN}}$ = 130 GeV



Identified pbar/p ratio



Elliptic flow in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV

K.H. Ackermann[19], N. Adams[28], C. Adler[12], Z. Ahammed[27], S. Ahmad[28], C. Allgower[13], J. Amsbaugh[34], M. Anderson[6], E. Anderssen[17], H. Arnesen[3], L. Arnold[14], G.S. Averichev[10], A. Baldwin[16], J. Balewski[13], O. Barannikova[10,27], L.S. Barnby[16], J. Baudot[14], M. Beddo[1], S. Bekele[24], V.V. Belaga[10], R. Bellwied[35], S. Bennett[35], J. Bercovitz[17], J. Berger[12], W. Betts[24], H. Bichsel[34], F. Bieser[17], L.C. Bland[13], M. Bloomer[17], C.O. Blyth[4], J. Boehm[17], B.E. Bonner[28], D. Bonnet[14], R. Bossingham[17], M. Botlo[3], A. Boucham[30], N. Bouillo[30], S. Bouvier[30], K. Bradley[17], F.P. Brady[6], E.S. Braithwaite[2], W. Braithwaite[2], A. Brandin[21], R. L. Brown[3], G. Brugalette[34], C. Byrd[2], H. Caines[24], M. Calderón de la Barca Sánchez[36], A. Cardenas[27], L. Carr[34], J. Carroll[17], J. Castillo[30], B. Caylor[17], D. Cebra[6], S. Chatopadhyay[35], M.L. Chen[3], W. Chen[3], Y. Chen[7], S.P. Chernenko[10], M. Cherney[9], A. 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Submitted September 12, 2000 Published January 8, 2001

R. Stone[17], M. Strikhanov[21], B. Stringfellow[27], H. Stroebele[12], C. Struck[12], A.A.P. Suaide[29], E. Sugarbaker[24], C. Suire[14], T.J.M. Symons[17], J. Takahashi[29], A.H. Tang[16], A. Tarchini[14], J. Tarzian[17], J.H. Thomas[17], V. Tikhomirov[21], A. Szanto de Toledo[29], S. Tonse[17], T. Trainor[34], S. Trentalange[7], M. Tokarev[10], M.B. Tonjes[20], V. Trofimov[21], O. Tsai[7], K. Turner[3], T. Ullrich[36], D.G. Underwood[1], I. Vakula[7], G. Van Buren[3], A.M. VanderMolen[20], A. Vanyashin[17], I.M. Vasilevski[11], A.N. Vasiliev[26], S.E. Vigdor[13], G. Visser[5], S.A. Voloshin[35], C. Vu[17], F. Wang[27], H. Ward[31], D. Weerasundara[34], R. Weidenbach[17], R. Wells[17], R. Wells[24], T. Wenaus[3], G.D. Westfall[20], J.P. Whitfield[8], C. Whitten Jr. [7], H. Wieman[17], R. Willson[24], K.Wilson[35], J. Wirth[17], J. Wisdom[7], S.W. Wissink[13], R. Witt[16], J. Wolf[17], L. Wood[6], N. Xu[17], Z. Xu[36], A.E. Yakutin[26], E. Yamamoto[7], J. Yang[7], P. Yepes[28], A. Yokosawa[1], V.I. Yurevich[10], Y.V. Zanevski[10], J. Zhang[17], W.M. Zhang[16], J. Zhu[34], D. Zimmerman[17], R. Zoulkarneev[11], A.N. Zubarev[10]
(STAR Collaboration)

At the time of QM2002 (July 18-24)

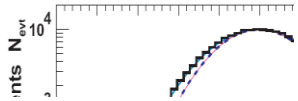
- The Collaboration gave 3 plenary talks and a "late breaking news" talk

Lanny Ray — Fluctuations and Correlations

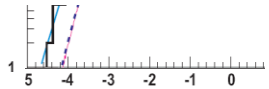
Van Buren — Soft Physics

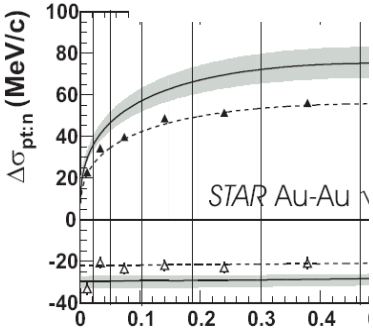
Gerd Kunde — High P_T results

Hardtke — Jets and di-jets

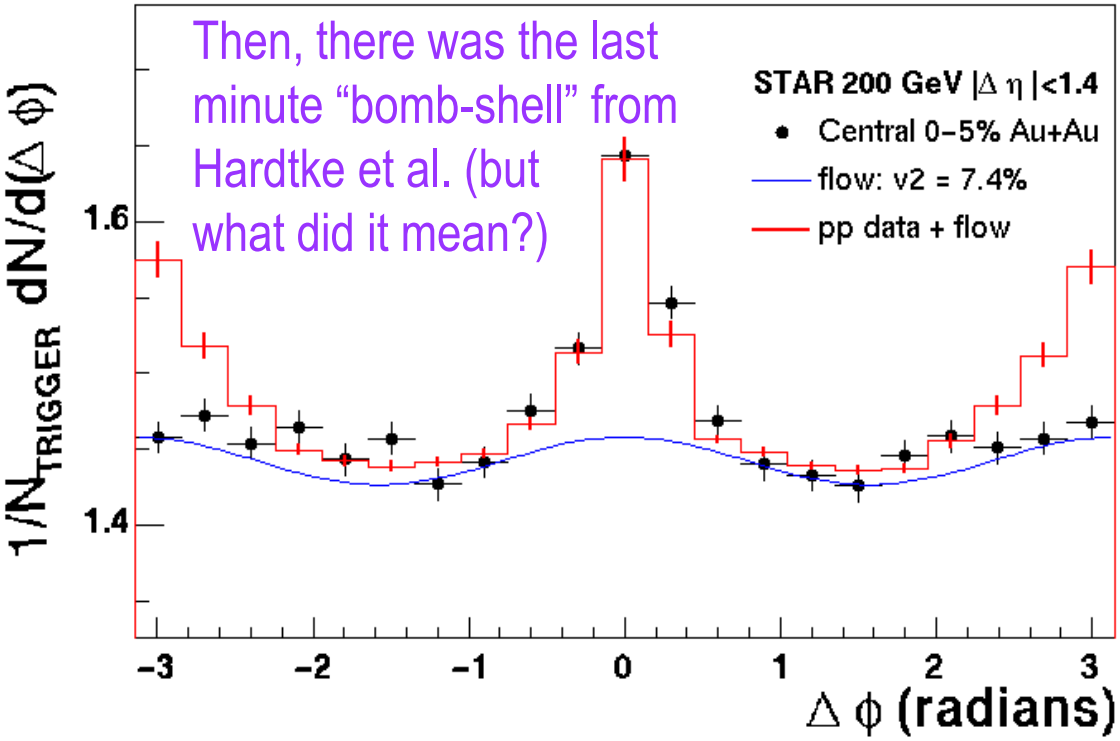


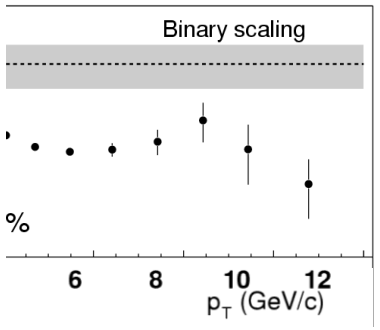
In addition to v_2 usi cumulant, and first plots,

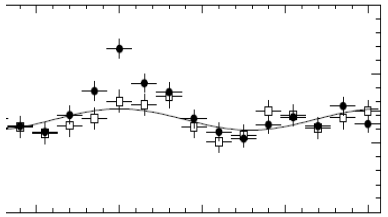


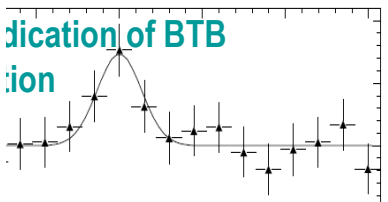


Then, there was the last minute "bomb-shell" from Hardtke et al. (but what did it mean?)









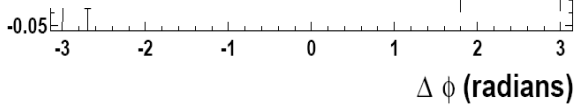
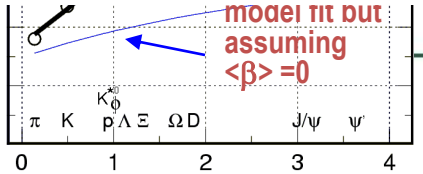


FIG. 2: Mean-p_t difference factors $\Delta\sigma_{p_t:n}^{(CI)}$ and $\Delta\sigma_{p_t:n}^{(CD)}$ for 205k minimum-bias Au-Au events at $\sqrt{s_{NN}} = 130$ GeV versus relative multiplicity N/N_0 [14], which is approximately $N_{part}/N_{part,max}$, the relative fraction of participant nucle-



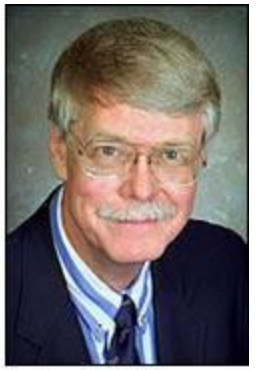
Off to the races in early 2003

- After QM2002, there was a lot of excitement about the observed high p_T and back-to-back suppression, but no conclusion about the underlying cause
- At its meeting in Nantes, the Collaboration decided to push for d+Au to (not a popular decision internally at the time) to allow confirmation this was a final state effect
- STAR was determined not to be second with this result, and began analyzing the d+Au data before the run was finished.
- This generated a race towards the finish (about May of that year) ultimately resulting in a special colloquium (controversial within STAR) to announce the discovery of jet quenching
- This turned out to be a very important and exciting moment for the RHIC program and the STAR Collaboration

Exciting First Results from Deuteron-Gold Collisions at Brookhaven

Findings intensify search for new form of matter

UPTON, NY — The latest results from the Relativistic Heavy Ion Collider (RHIC), the world's most powerful facility for nuclear physics research, strengthen scientists' confidence that RHIC collisions of gold ions have created unusual conditions and that they are on the right path to discover a form of matter called the quark-gluon plasma, believed to have existed in the first microseconds after the birth of the universe. The results will be presented at a special colloquium at the U.S. Department of Energy's Brookhaven National Laboratory on June 18 at 11 a.m., to coincide with the submission of scientific papers on the results to *Physical Review Letters* by three of RHIC's international collaborations. The scientists are not yet ready to claim the discovery of the quark-gluon plasma, however. That must await corroborating experiments, now under way at RHIC, that seek other signatures of quark-gluon plasma and explore alternative ideas for the Kind of matter produced in these violent collisions.


Thomas Kirk

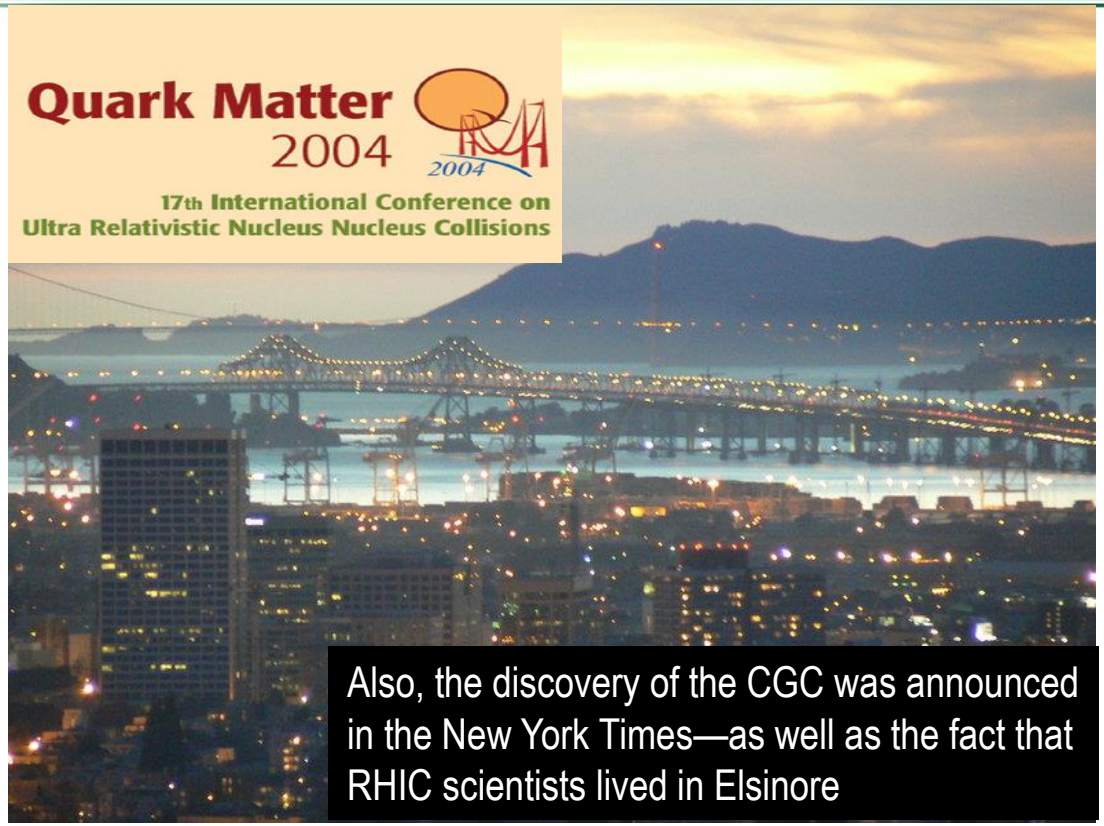
"This is a very exciting result that clearly indicates we are on the right track to an important scientific discovery," said Thomas Kirk, Brookhaven's Associate Laboratory Director for High Energy and Nuclear Physics. "But the case for having created quark-gluon plasma is not yet closed. We have four experiments looking for a number of different 'signatures' of this elusive form of extremely hot, dense nuclear matter."

"These results from RHIC are profoundly important," said Raymond L. Orbach, Director of the Department of Energy's Office of Science, the primary funding agency for research at RHIC. "They go to a fundamental question in science: how did the universe look at the beginning of time? People have always been fascinated by the question of how our world began. And every time something fundamental is learned, society eventually benefits, either directly from that knowledge or from the technology developed to obtain it."

This success had importance beyond what anyone imagined at the time, not only scientifically

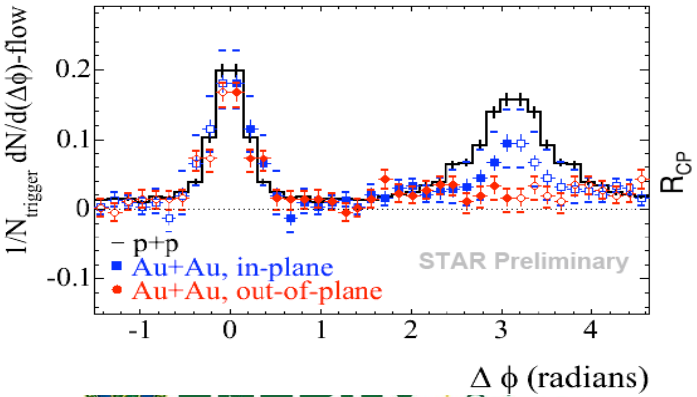
- Barnes Panel in 2004, prioritization in HI in constant dollar budget scenario
- Tribble Panel in 2005, prioritization in NP for worse than constant dollar scenario.

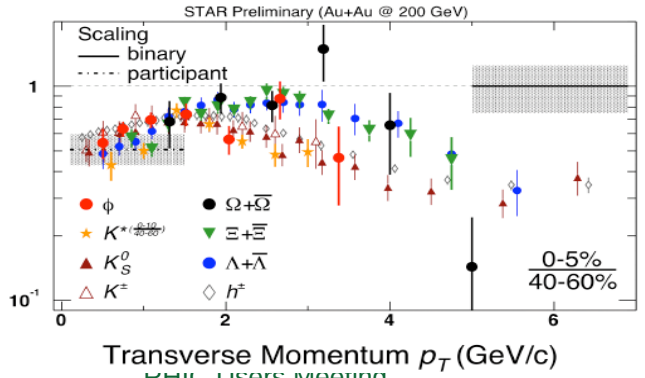
Quark Matter 2004

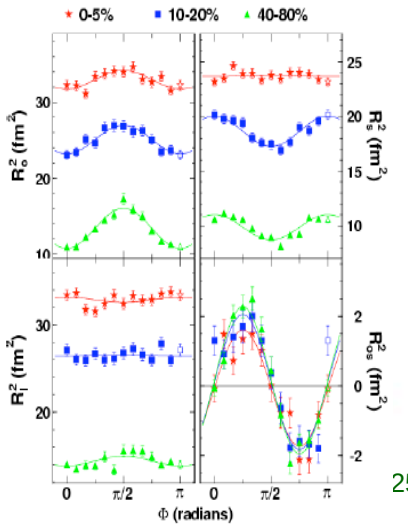


STAR Plenary talks:

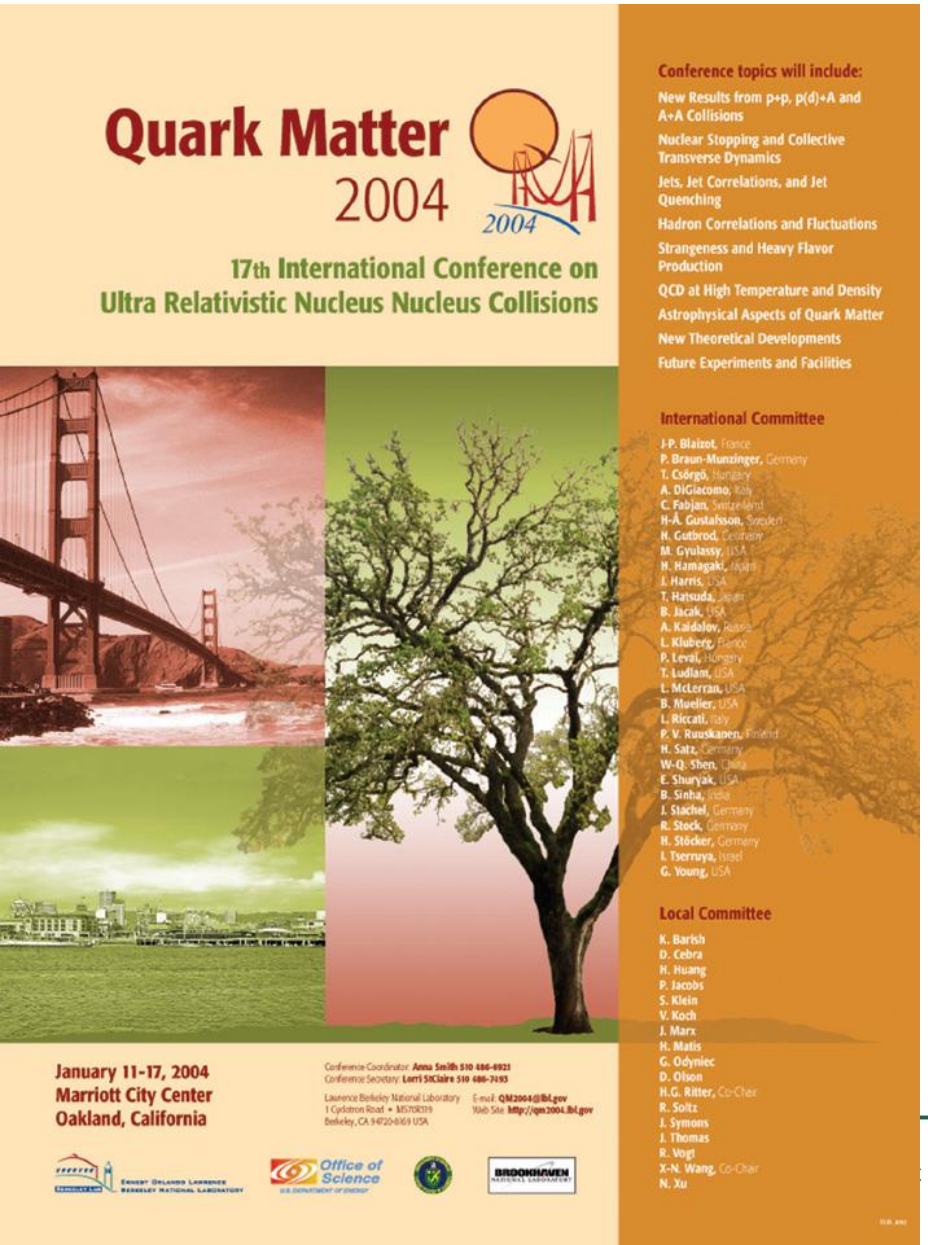
- 2 particle correlations wrt reaction plane
- NCQ scaling
- Meson-baryon anomaly
- $\langle p_T \rangle$ away side vs minbias
- ρ^0 photoproduction
- $\rightarrow K\pi$, $D \rightarrow e^{\pm}$+ X in p+p and d+Au







Too Much Data, Too Few Discovery Claims?



The New York Times

Like Particles, 2 Houses of Physics Collide

By JAMES GLANZ Published: January 20, 2004

A bland and bulky conference center in this city's fogbound downtown was transformed in recent days into the Elsinore of particle physics. The ghost that continually appeared, disappeared and appeared again during a scientific meeting was not the shade of a murdered king but a puff of primordial matter with an otherworldly name: the quark-gluon plasma. This drama, like the original, involved not only a clash of great forces but also what some saw as betrayal and a measure of revenge. It drew in a pair of renowned laboratories -- two great houses of physics -- that have avidly pursued what may be among the most important discoveries in science. Most of all, the meeting was a forum for one of those institutions, Brookhaven National Laboratory, to play Hamlet, earnestly raising doubt after doubt about the meaning of its own data: the laboratory's scientists refused to acknowledge that they had created the plasma, even though it would be hard to find a physicist anywhere who seriously argued that the lab had blundered and failed in its quest.

More Hamlet By The Bay …

More from the Glanz NYT article:

"The evidence for the quark-gluon plasma is overwhelming," …

To announce a discovery now, … "the very same people who were very critical [of a CERN announcement in 2000] have to eat their words."

Others wonder if modern collaborations, run democratically rather than led by the famously headstrong leaders of earlier decades -- the Nobel Prize winners Leon M. Lederman and Carlo Rubbia are routinely mentioned -- may breed indecision.

"In my younger days, we didn't vote,"… "Leon -- vote? Carlo -- vote?" …"I think I would have been a bit stronger."

The caution of the RHIC experimentalists was attributed to many things but not possibly justified scientific skepticism…

What to do?

- The idea of a white paper had arisen at the time of QM04, but initially had some resistance from the other collaborations
- After QM04, there was a pitched debate and the whitepaper became the accepted vehicle for the Collaborations to state their position
- Later in 2004 the Collaboration were invited to write an article in an RBRC proceedings, but they decided to stick with the plan as it stood
- The collected whitepapers were published in April 2005 by BNL and May 2005 by NPA. But getting to that point was a lot of work…

An Invitation to Publish

February 26, 2004

To The Spokespeople for the
Four RHIC Collaborations:

This letter is to cordially invite you to contribute a short paper (about fifteen pages) to a special volume in the RBRC Scientific Articles Proceedings Series. The purpose of this special volume is to **highlight and summarize the published experimental discoveries from RHIC so far, and to pinpoint their physics implications from our present theoretical understanding…**

We propose to assemble your and others' summary reports under the title

"New Discoveries at RHIC
--The Strongly Interactive QGP"

The deadline for all contributions is April 5, 2004. The report will be immediately made public and posted on the LASL server as an official RBRC special report.

Sincerely yours,

T. D. Lee Nicholas P. Samios

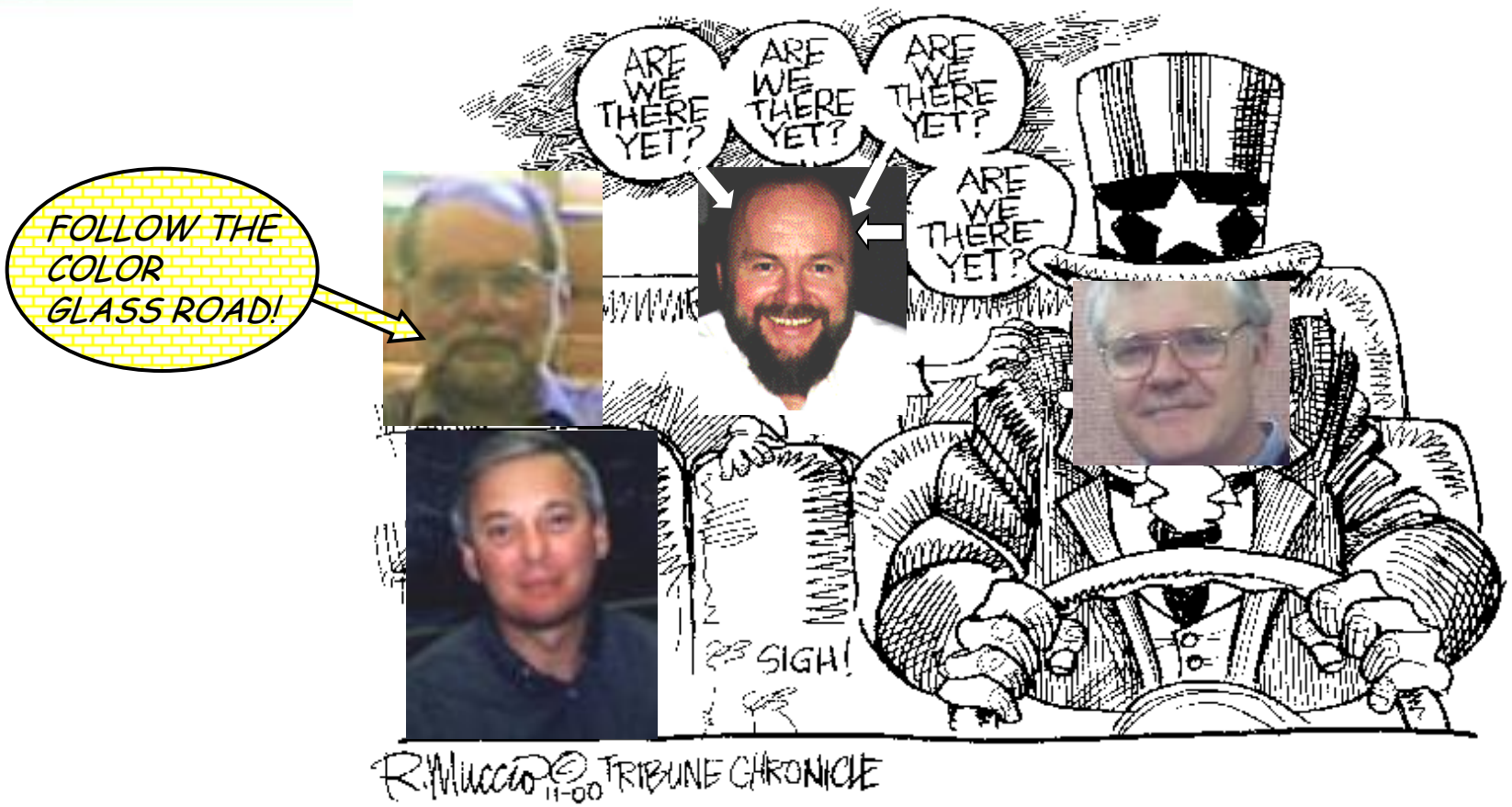
Experimentalists "Huddle in Elsinore"

Charge from Tim Hallman (March 18, 2004) to STAR White Paper Drafting Team: Dunlop, Huang, Jacobs, Lisa, Snellings, Vigdor (Chair), N. Xu, Z. Xu

The charge to this panel is to make a *critical assessment* of the presently available evidence to judge whether it warrants a discovery announcement for the QGP, using any and all experimental and theoretical results that address this question. The white paper should pay particular attention to identifying the most crucial features of the QGP that need to be demonstrated experimentally for a compelling claim to be made. It should summarize those data that may already convincingly demonstrate some features, as well as other data that may be suggestive but with possible model-dependence, and still other results that raise questions about a QGP interpretation. If the conclusion is that a discovery announcement is at present premature, the paper should outline critical additional measurements and analyses, as well as theoretical developments, that would make the case stronger, and the timeline anticipated to produce those new results.

⇒ *Collaboration discussion of first draft on June 12, 2004*

Are We There Yet?



The STAR Collaboration's Critical Evaluation of the Evidence Regarding Formation of a Quark Gluon Plasma in RHIC Collisions

Steve Vigdor for the White Paper Drafting Team

White Paper Abstract Says it All…

Experimental and Theoretical Challenges in the Search for the Quark Gluon Plasma:

The STAR Collaboration's Critical Assessment of the Evidence from RHIC Collisions

Many of the observations are consistent with models incorporating QGP formation in the early collision stages, and have not found ready explanation in a hadronic framework. However, the measurements themselves do not yet establish unequivocal evidence for a transition to this new form of matter. The theoretical treatment of the collision evolution, despite impressive successes, invokes a suite of distinct models, degrees of freedom and assumptions of as yet unknown quantitative consequence. We pose a set of important open questions, and suggest additional measurements…

A sampling of opinion on the Preliminary STAR White Paper

They hated it in Peoria

the star paper does such a very terrible job … it makes star look like a disillusioned bunch of resentful folks and sends absolutely the wrong message to the outside community.
--

shocking and very surprising …a frontal attack on the whole RHIC program
--

It needs major re-THINKING and re-VISION … Getting a compelling and relatively unambiguous message out of that white paper is essential.
--

We sincerely urge you to… prevent this imminent disaster. --

But they loved it in Des Moines

a remarkable, fantastic job! … nothing short of brilliant … it sets new standards for the scientific culture of our field.
--

this is beautifully done. a very impressive, and very thoughtful, look at the landscape.
--

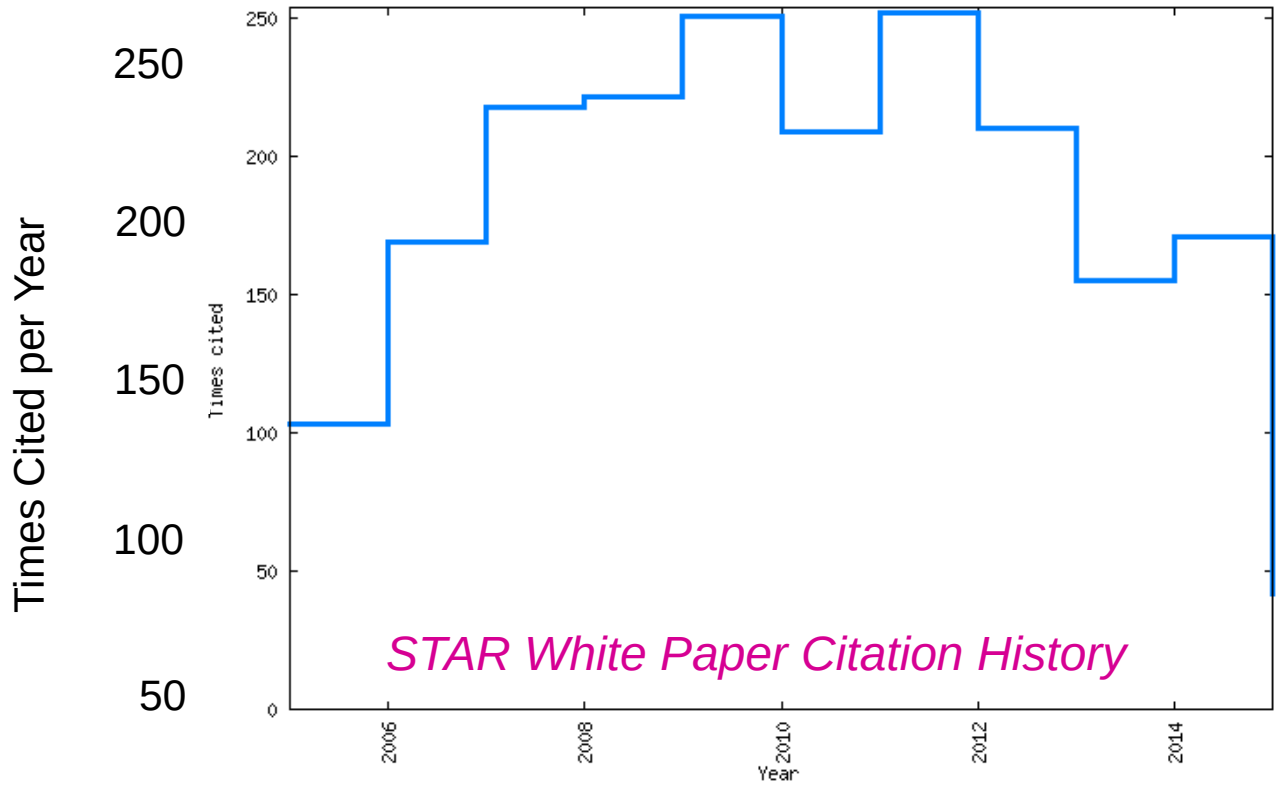
a very impressive and thoughtful review on the state of RHIC physics.
--

a solid and mostly well-written document … it marks a very important milestone in our quest.
–

a very impressive document in scope and detail

NOW, 2015:

10 years and >2000 citations later



And then—just like that—the narrative changed

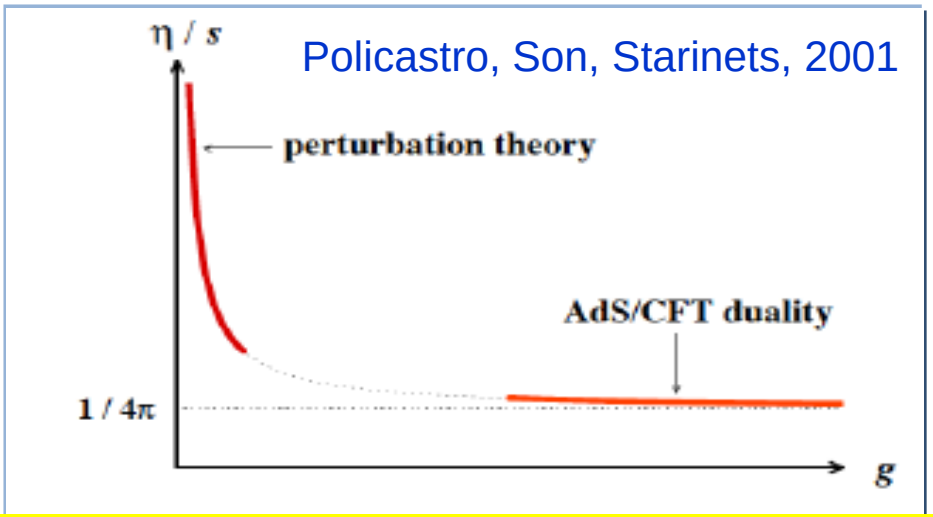
- In April 2005, the focus of all this debate shifted to the announcement of the Perfect Liquid (April 2005, APS meeting in Tampa)

- This became AIP 2005 Science Story of the year

Publication of 4 RHIC White Papers ⇒ April 2005 Press Release

"The truly stunning finding at RHIC that the new state of matter created in the collisions of gold ions is more like a liquid than a gas gives us a profound insight into the earliest moments of the universe," said Dr. Raymond L. Orbach, Director of the DOE Office of Science. "The possibility of a connection between string theory and RHIC collisions is unexpected and exhilarating."

"In fact, the degree of collective interaction, rapid thermal-ization, and extremely low viscosity of the matter being formed at RHIC make this the most nearly perfect liquid ever observed," Aronson said.

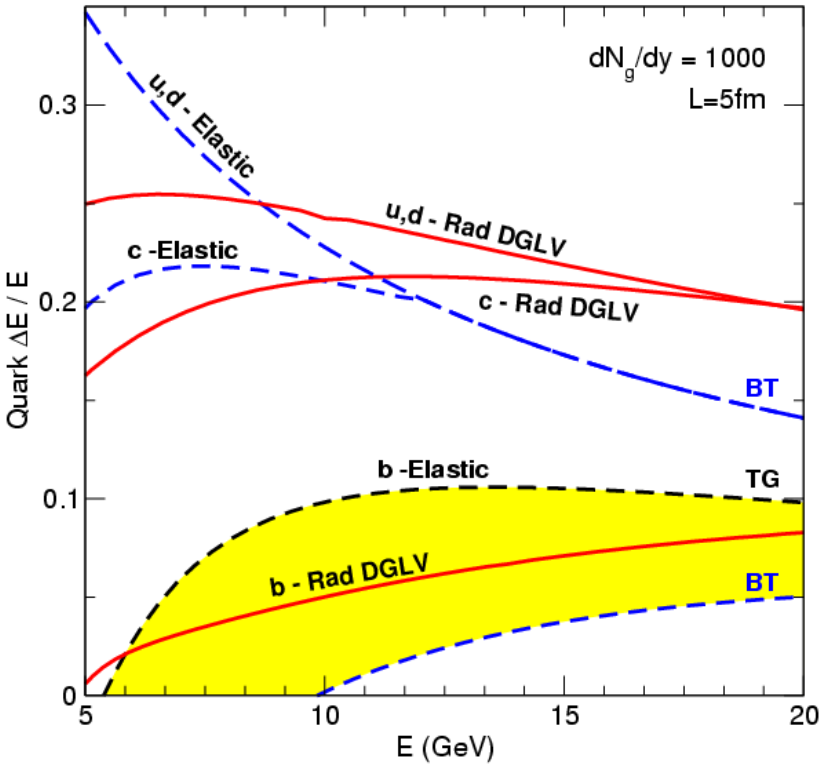


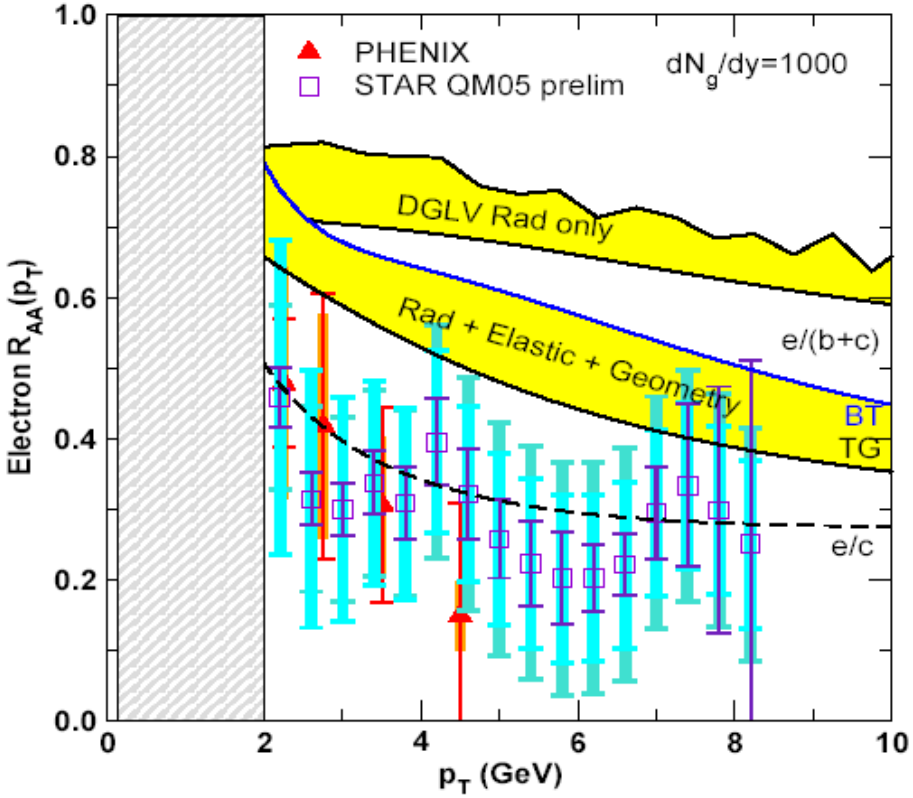
The "perfect liquid" announcement was very timely (followed shortly by Tribble I), of lasting value (still a dominant theme in 2015 LRP), and made important connections to the String Theory community!

Then, there was Budapest- Aug 4-9, 2005

Elastic (collisional) energy loss revisited

S.Wicks et al., nucl-th/0512076





Elastic ΔE comparable to Radiative ΔE – not negligible

Elastic ΔE important even for light quarks

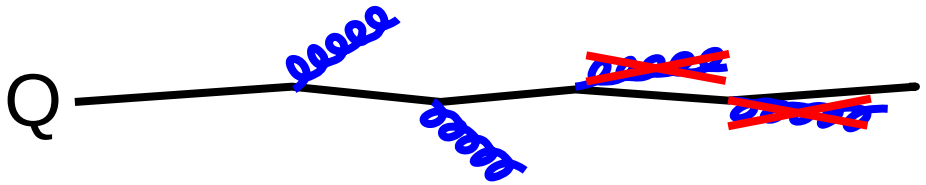
⇒ revisit energy density estimates?

A new puzzle emerges:

Up to 2005, a reasonably strong consensus that the suppression was basically understood: radiative energy loss in a medium 50-100 times normal nuclear matter density

Then these measurements were extended to the heavy quark sector (c, b) by studying suppression of electrons from their semi-leptonic decays

Heavy quark energy loss



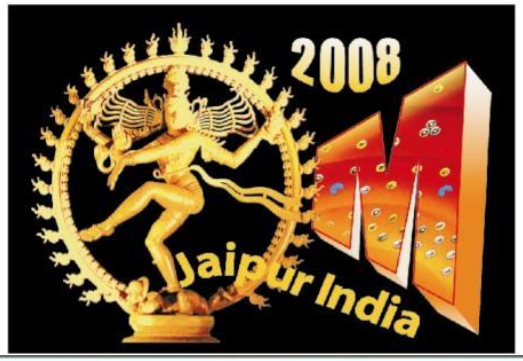
Dokshitzer, Khoze, Troyan, JPG 17 (1991) 1602.
Dokshitzer and Kharzeev, PLB 519 (2001) 199.

- In vacuum, gluon radiation suppressed at $\theta < m_Q/E_Q$
- "dead cone" effect: heavy quarks fragment hard into heavy mesons

Dead cone also implies lower heavy quark energy loss in matter: (Dokshitzer-Kharzeev, 2001)

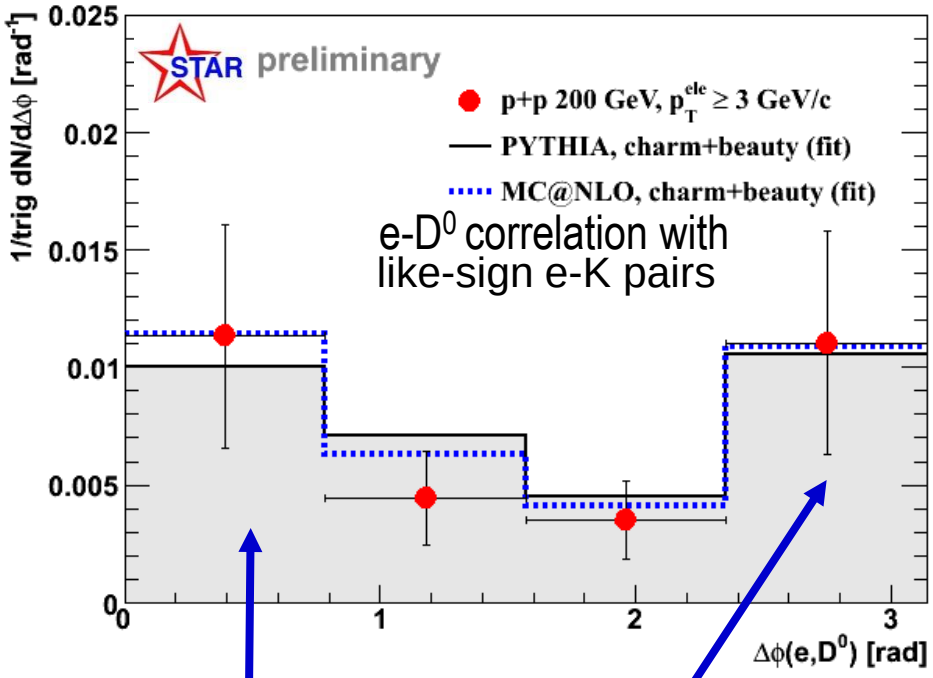
$$\left.\omega \frac{\mathrm{d}I}{\mathrm{d}\omega}\right|_{HEAVY} = \frac{\left.\omega \frac{\mathrm{d}I}{\mathrm{d}\omega}\right|_{LIGHT}}{\left(1+\left(\frac{m_Q}{E_Q}\right)^2 \frac{1}{\theta^2}\right)^2}$$

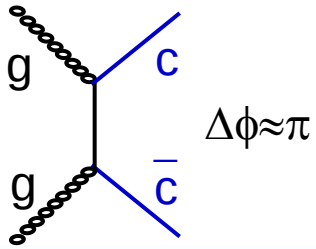
Coming to QM08

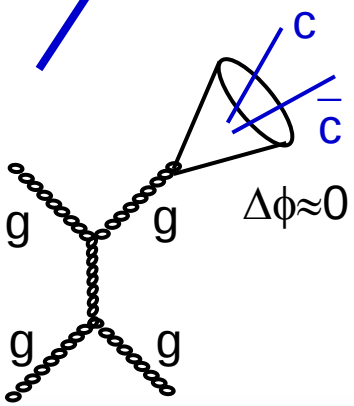


- High p_T J/Ψ and R_{AA} of J/Ψ
- First glimpse of Υ in AuAu
- v_2/ε vs centrality and v_2/n_q vs p_T/n_q
- γ + jet
- σ_{ccbar}
- v_2 fluctuations
- pairwise correlations
- K/π fluct and DCC search
- future CP search

QM08: insight possible using electron tagged correlations

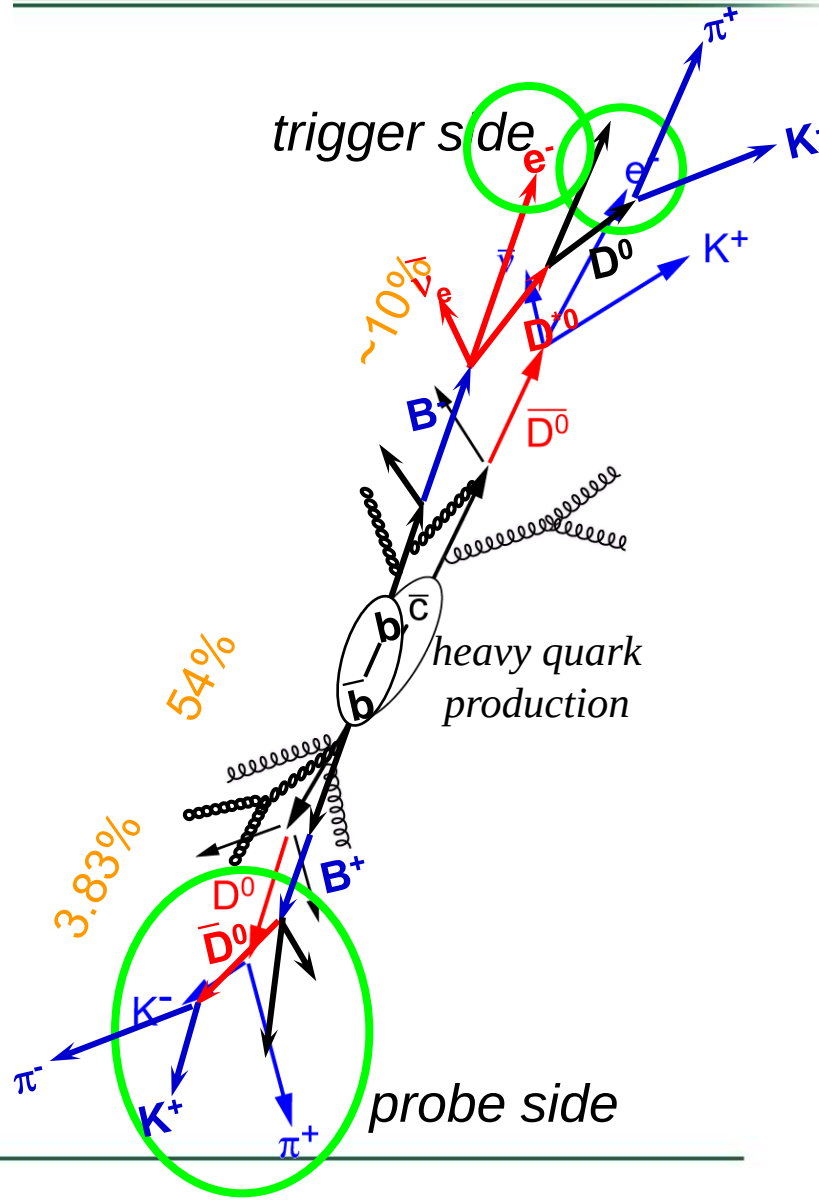






flavor creation

gluon splitting/fragmentation



Enormous Advances Since 2005, Fueled By…

Experiment:

- expansion of energy range (÷ 26 @ RHIC, × 14 @ LHC)
- dramatic increases in luminosity ⇒ greater statistics, extended p_T range, higher flow harmonics, more sophisticated correlations, rarer events, …
- greater variety of colliding beam species (e.g., U+U, ^{3}He+A)
- detector upgrades (vertexing, PID, heavy flavor sensitivity, improved forward coverage)

Theory coherence:

- 2nd-order 3+1-D relativistic viscous hydro, incorporating…
- Precision LQCD Equation of State
- Initial-state quantum fluctuations at both nucleonic and gluonic (CGC) scales
- Multi-variate analyses to constrain parameters by fitting to wide array of data
- Benchmarking of jet quenching approaches
- New incorporation of chiral anomaly and chiral magnetic effect in hydro calcs.

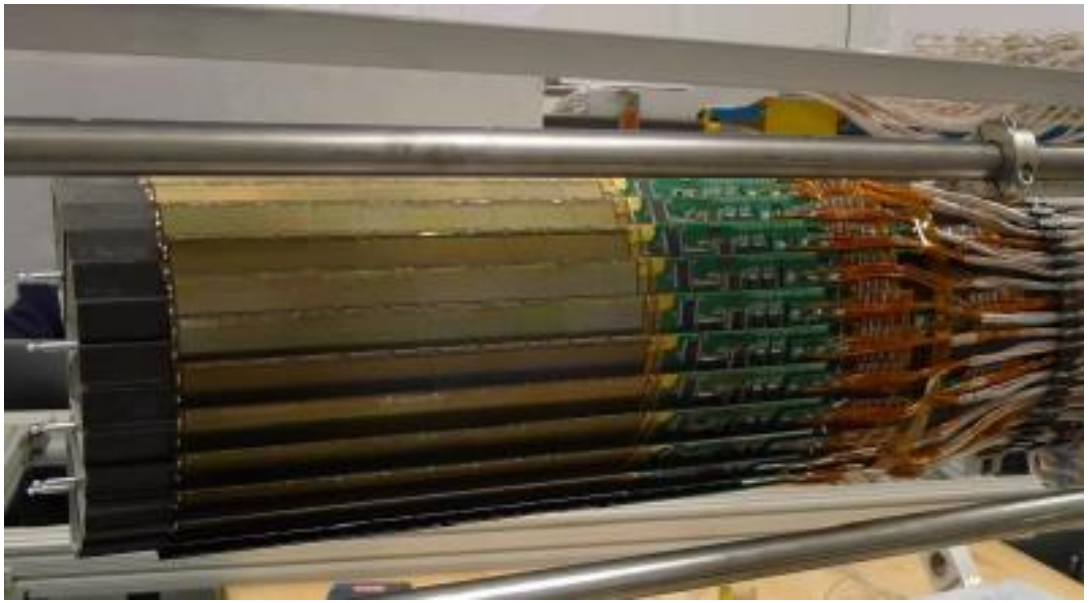
⇒ Definitive case for QGP, quantification of properties, new questions

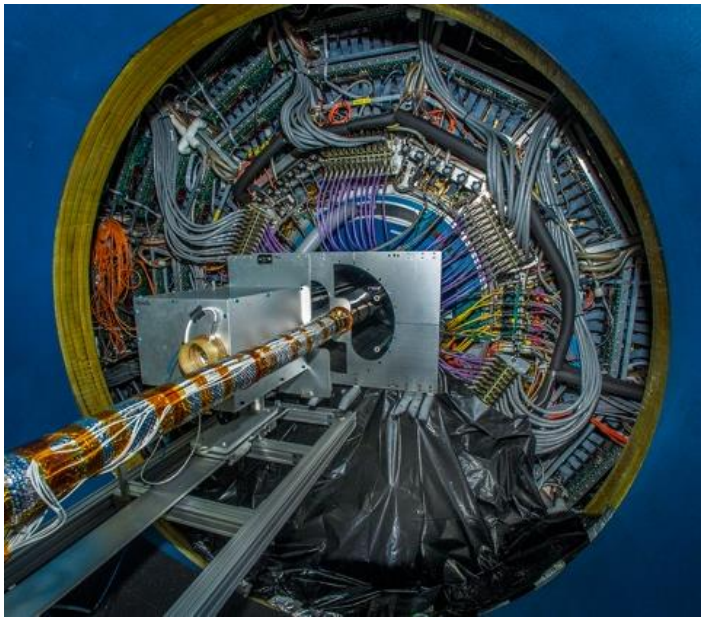
Conclusion: You've Come a Long Way, Baby!

- **RHIC White Papers set high "discovery" standards**
- **STAR White Paper outlined decade-long program of follow-up measurements that has been largely realized**

- **RHIC + LHC + Theory have met the high standards, delivered on promises and laid claim to an extraordinary QGP phase**
- **Well-posed open questions remain, with clear plans to address them**
- **3 Bonner Prizes (Poskanzer 2008, Zajc 2014, Gyulassy & Wieman 2015) + 1 Feshbach Prize (McLerran 2015) to date, still counting…**
  - **No evidence of harm from White Paper philosophy**

RHIC is Perfectly Positioned to Make Additional Major Discoveries



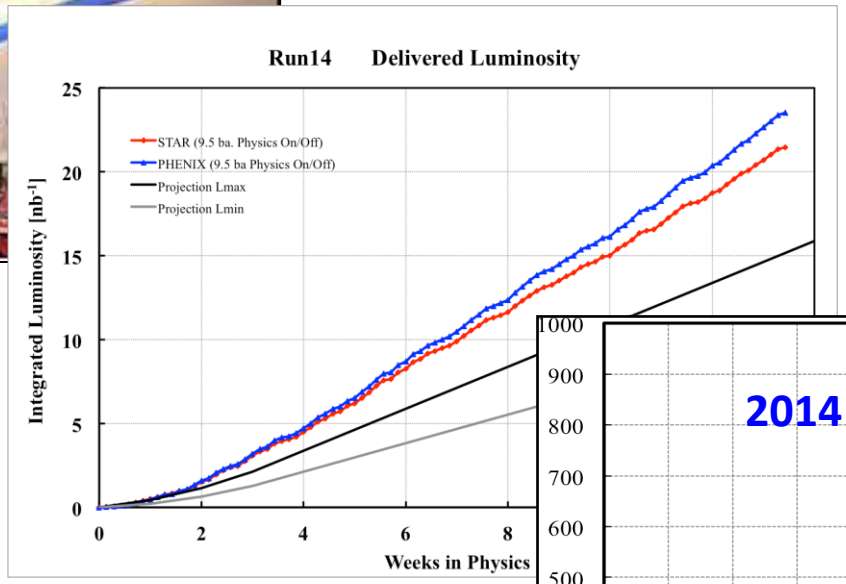


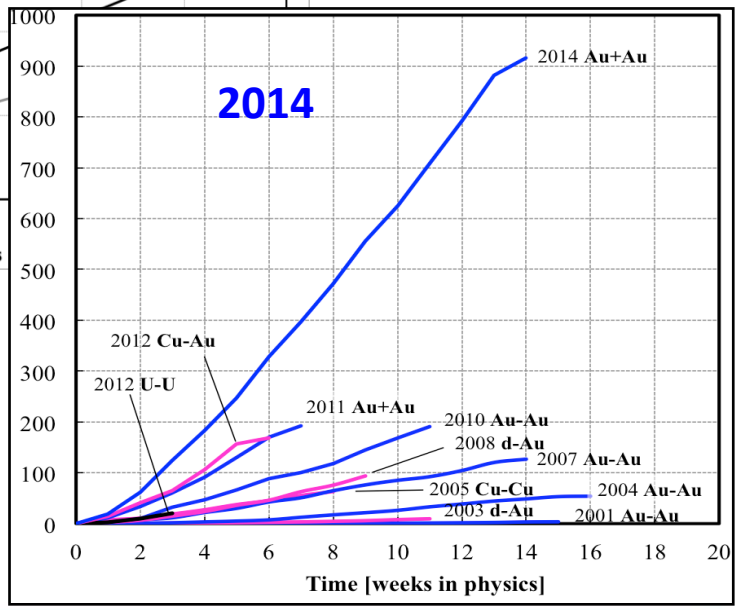
Recently completed new, innovative micro-vertex capability installed in both large detectors (STAR, and PHENIX) completed STAR Heavy Flavor Tracker to enable measurement of heavy quarks

Innovative, forefront machine accelerator R&D which increased the RHIC luminosity by more than an order of magnitude and novel microvertex detector upgrades (now being copied at the LHC) place RHIC in the perfect position to definitively answer compelling scientific questions about the nature and properties of the new state of matter it discovered.

RHIC Machine Performance Sets New Records in FY 2014

Heavy ion runs

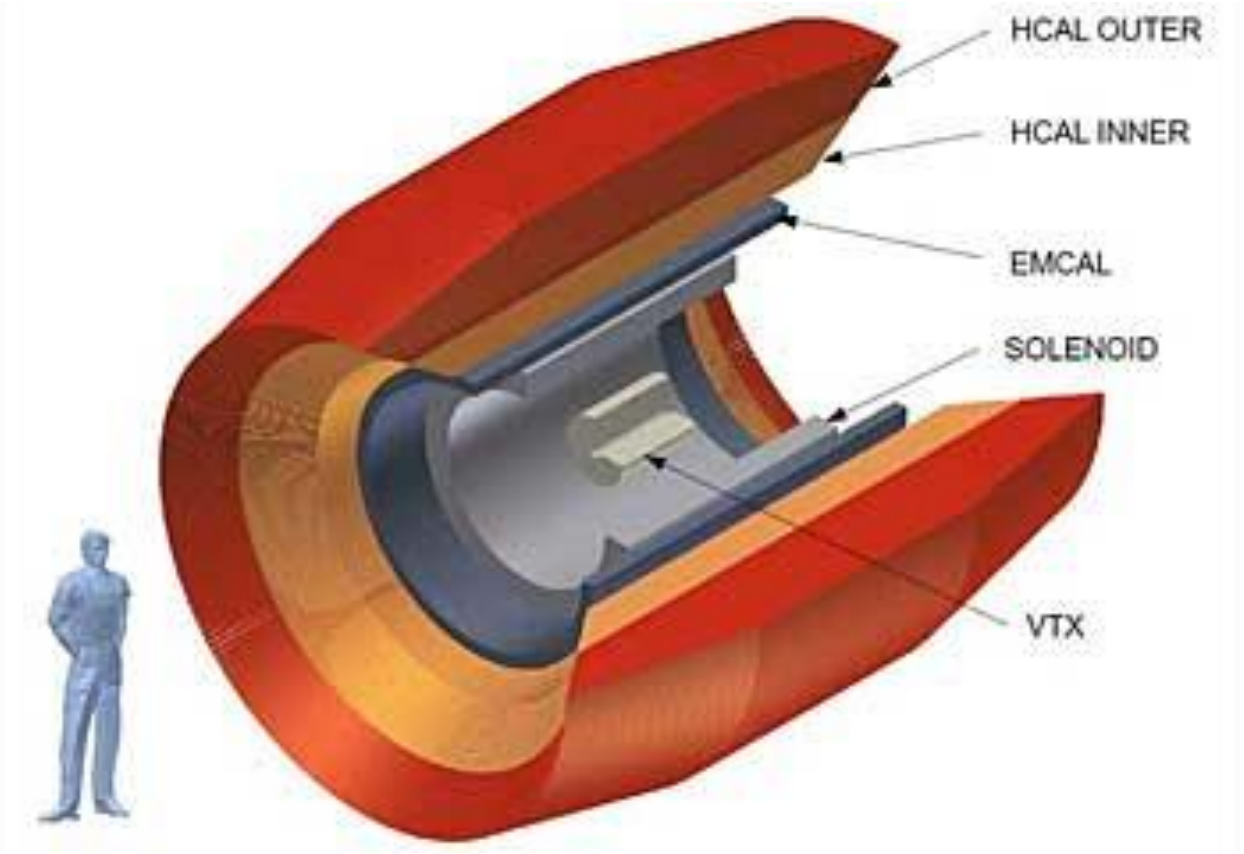




Au + Au integrated luminosity from Run 14 exceeded all previous Au+ Au runs combined

No other facility worldwide, existing or planned, can rival RHIC in range and versatility as a heavy ion collider. It is the only polarized proton collider in the world.

Looking Forward: Advanced Instrumentation to Help Complete the Mission



A rendering of the proposed upgrade showing the inner silicon tracker (VTX), the solenoid, and the calorimeters. The solenoid has a diameter of 1.4 m

Main Remaining RHIC Questions

- What do we need to know about the initial state? Is it a weakly coupled color glass condensate? How does it thermalize?
- What do the data tell us about the initial conditions for the hydro-dynamic expansion? Can we determine it unambiguously?
- What is the smallest collision system that behaves collectively?
- What does the QCD phase diagram look like? Does it contain a critical point in the HG-QGP transition region? Does the HG-QGP transition become a first-order phase transition for large μ_B?
- What can jets and heavy flavors tell us about the structure of the strongly coupled QGP?
- What do the quarkonium (and other) data tell us about quark deconfinement and hadronization?
- Can we find unambiguous proof for chiral symmetry restoration?

Let’s get it done

Parallels with the voyages of a great explorer, Christopher Columbus

- Columbus started with a proposal: "Enterprise of the Indies". It took 8 years to be approved
- Submitted to King John II of Portugal who passed it on to the Council of Geographical Affairs
  - Too expensive
  - Wrong on distance and measurements
  - Only worthless rocky land to the west
  - Contrary to Portugal's national priorities (eastern route to Asia)
- Lukewarm interest in France and England (aware of the proposal but no or slow invitation)
- Submitted to Ferdinand and Isabella who passed it on to the Wise Men of Salamanca
  - Ocean sea simply too large to cross
  - Several more attempts; had given up; called back after fall of Muslim Grenada & approved
- Expert committees were right on the detail: calculation of distance grossly in error
- Columbus was right on the concept—way off on detail: existing landmass constituted 235º leaving only 180º of water; read map distances in Italian miles (1,238 m vs 1,830m); thought 1º = 56.67 miles, calculating earth's circumference = 25,255 km (vs 40,000 km). If the new continents hadn't been there, they probably would have perished on the voyage

Additional Interesting Parallels

- The Vikings (& others) probably landed in North America first–

  but they didn't know where they were and left no record; history accords the important discovery to Columbus

- Columbus had an impact not because he was first, but because he kept going back to explore the territory further. He was the one that put this new land "on the European map"

  "A great experimenter is one who keeps asking the same question over and over in a deeper and more meaningful way" — Gene Sprouse, Neutrino Helicity at 50

- He tried to make annual runs to the new land at first, but was hindered by funding & politics

- He died thinking he had reached Asia; he thought Cuba was an isthmus of Cathay and made his crew take a solemn oath to swear to that, even though there was no proof

  Columbus was victim to being trapped by his own paradigm, which he would not give up

- About a year later, Vespucci spent 2 months going through Brasil and northern South America; he new immediately this was not China but a new previously unknown continent.

  He is the one with his name on today's maps

On the other hand…

- Columbus may not have known exactly where he was, but he knew he had made a real discovery –which he had
- The analogy: there is no question we have made a real discovery at RHIC: but like Columbus's voyages, the real significance likely will not be fully understood we finish the exploration
- To accomplish that, we need more voyages (running and luminosity), some better navigational tools, and (maybe) to think a bit "outside the traditional QCD box
- One other point from Thomas Tirado (Prof. History, Millersville University):

"It was more than a coincidence that the Age of Discovery occurred at the same time as the appearance of the first truly national governments in Western Europe…indispensible […] was the support of the bourgeoisie'— outreach was important even back then!

The Breadth of the Horizon for Discovery in Nuclear Science

Neutron-rich Nuclei;
Structure Of Nuclei;

Reactions in Core Collapse Super Novae;

Super Heavy Element 117
Heavy Nuclei Formation;
Density Effects in Nuclei;
Neutron Skins;

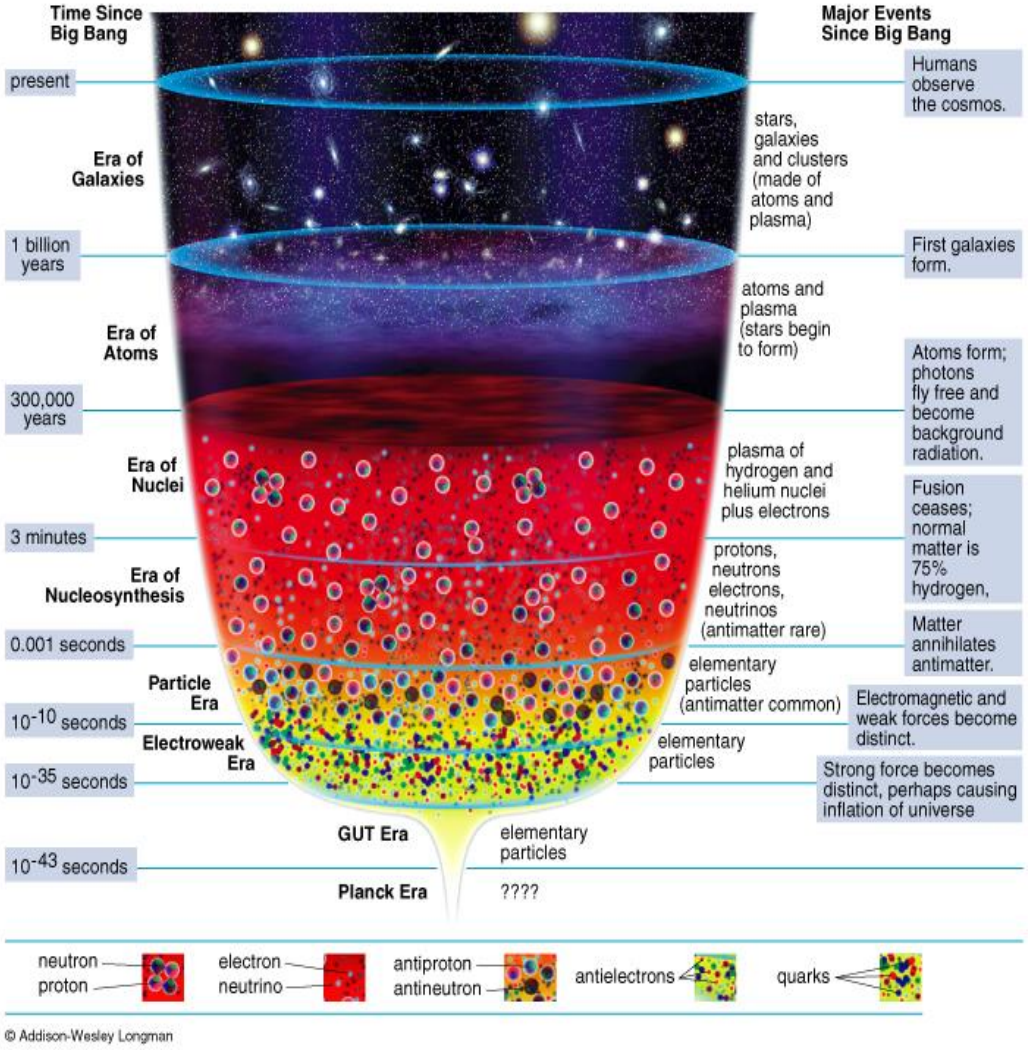
Nuclear-Reactions;

NP Discovery Horizon

Anti-Helium 4;
Proton Spin
Majorana/DIRAC Neutrino;
Perfect QGP Liquid

Neutron Beta Decay;
Neutron EDM;
Parity Violation
Searches;

Evolution of the Universe

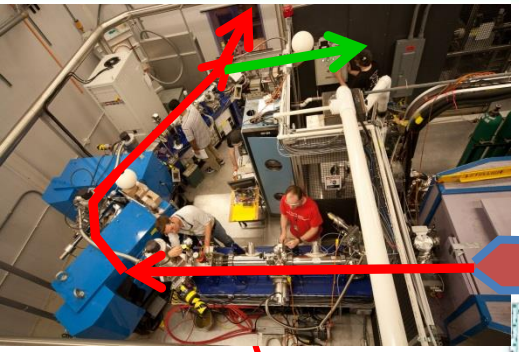


Status and Outlook

- The CEBAF and RHIC programs are both unique and at the “top of their game” with compelling “must-do” science in progress or about to start.
- Long term, an electron-ion collider is envisioned to be the facility which provides exciting opportunities fort the entire experimental QCD research community. An important challenge is charting and being able to follow a course to this future which realizes expected scientific return on existing investment and does not leave important science discoveries “on the table” –forever, perhaps.
- A very high priority for the NP community is not losing U.S. leadership in the science of neutrino-less double beta decay.
  - A specific challenge will be ensuring essential R&D for candidate technologies is completed in the next 2-3 years prior to a down-select for a ton-scale experiment
  - A concomitant challenge will be ensuring inclusiveness and fairness for all demonstration efforts in progress and completing the down-select in a timely way so as not to endanger US leadership in this science.
- An equally high priority for the NP community is increasing investment in research and projects as a percentage of the total NP budget. This will have to be accomplished while still respecting the unitarily limit.

Thanks to Liz Mogavero and Steve Vigdor for help in the preparation of this talk

ATLAS at ANL Uniquely Provides Low Energy SC Research Opportunities



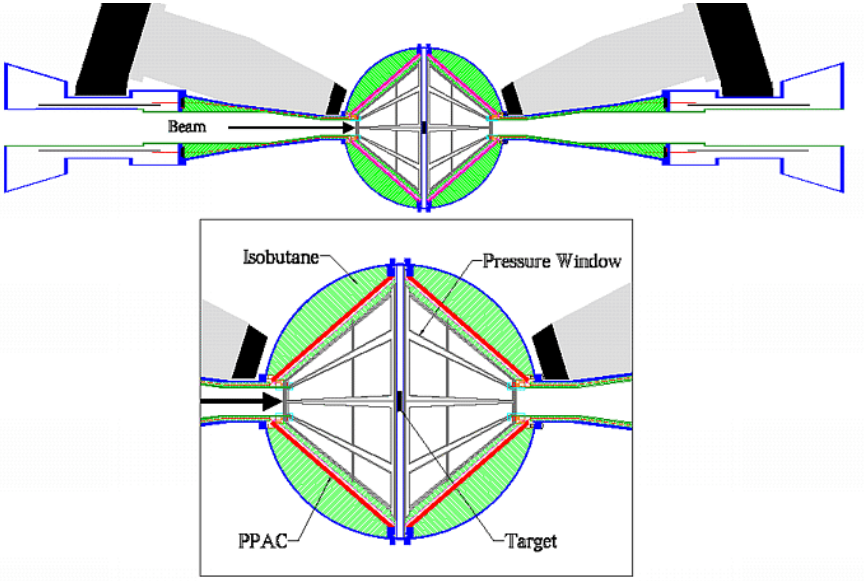
ATLAS

ATLAS is a unique premier Stable Beam Facility for research on Nuclear Structure & Nuclear Astrophysics

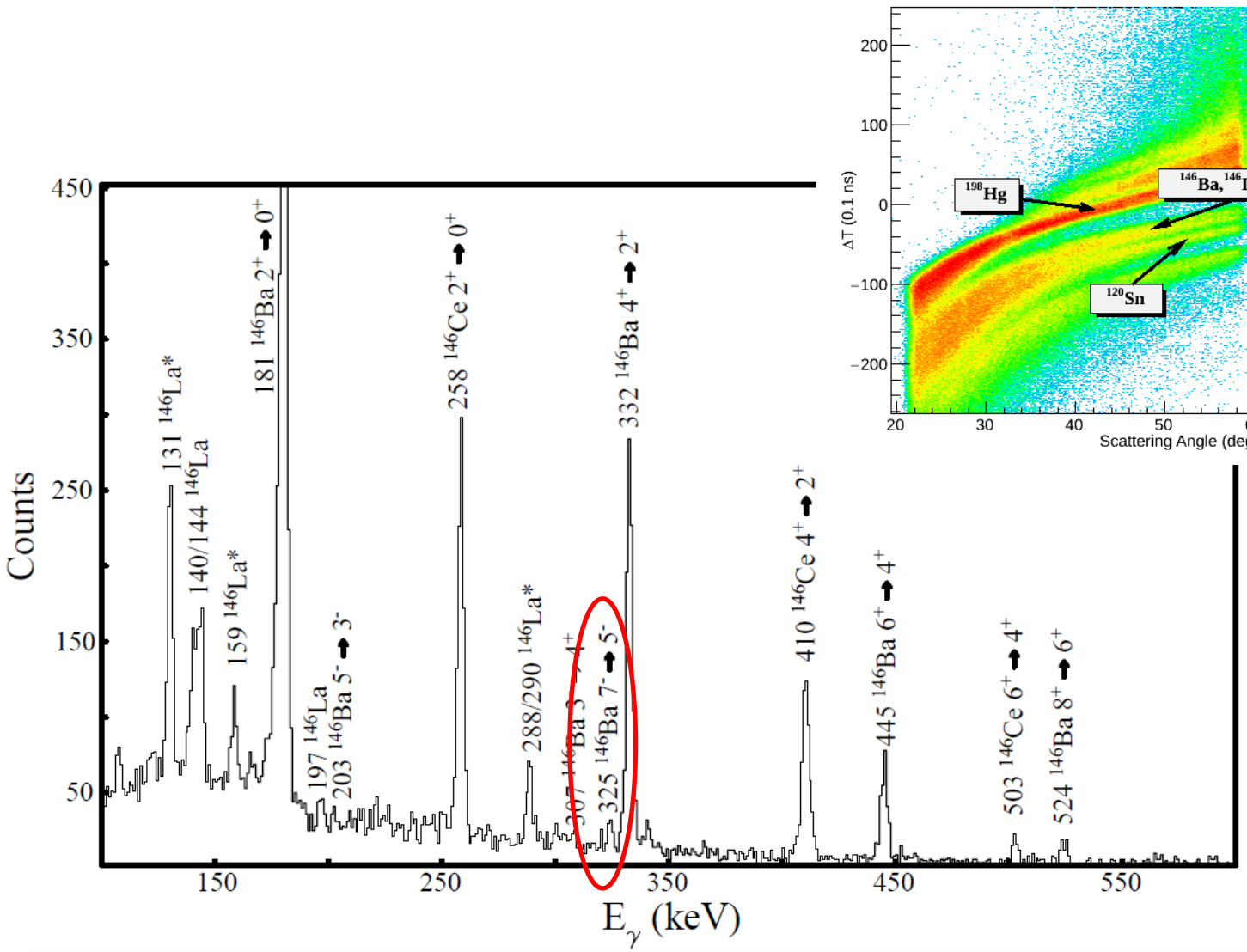
CHICO-II and GRETINA at ATLAS

Programs:

- Coulomb Excitation of stable and CARIBU beams;
- Structure studies of neutron-rich nuclei using deep-inelastic reactions;
- CHICO-II: high segmentation for both θ (1°) and φ (1.4°)
- GRETINA: about 3.50(2)% absolute efficiency at 1332.5 keV



^{146}Ba Coulomb Excitation



146Ba is predicted to octupole deformed. The observed coincidence γ spectra allow extraction of an E3 transition probability to verify the theory.

Nuclear Theory

Maintaining adequate support for a robust nuclear theory effort is essential to the productivity and vitality of nuclear science

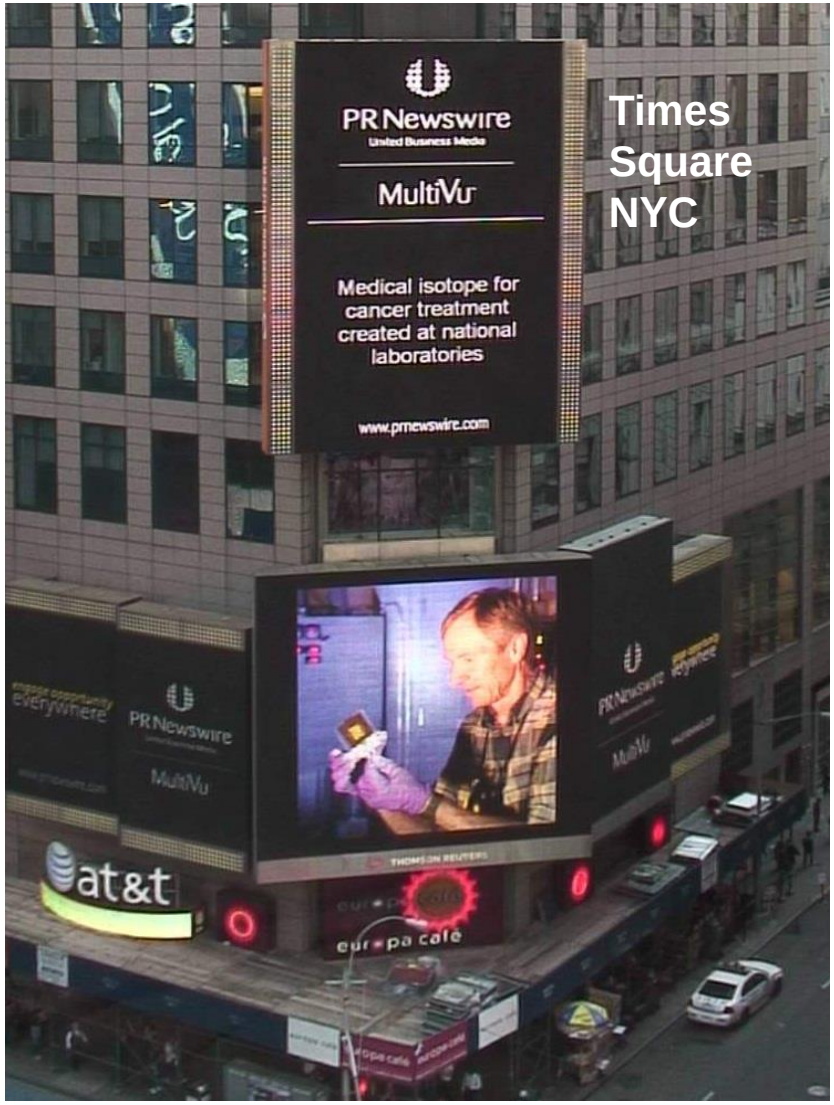
A strong Nuclear Theory effort:

- Poses scientific questions and presents new ideas that potentially lead to discoveries and the construction of facilities
- Helps make the case for, and guide the design of new facilities, their research programs, and their strategic operations plan
- Provides a framework for understanding measurements made at facilities and interprets the results

A successful new approach for NP—Theory Topical Collaborations are fixed-term, multi-institution collaborations established to investigate a specific topic

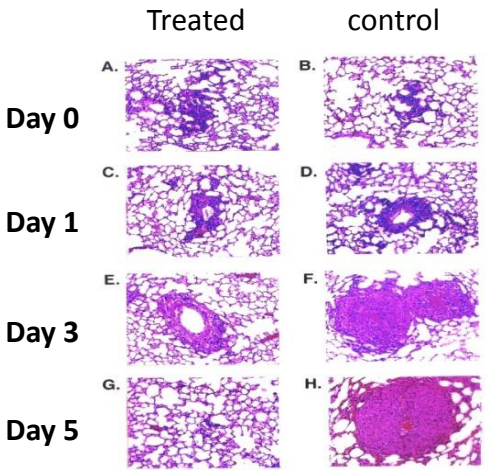
- "A new direction to enhance the research effort by bundling scientific strength and expertise located at different institutions to reach a broader scientific goal for the benefit of the entire nuclear science community… an extremely promising approach for funding programmatic and specific science goal oriented research efforts." Processing of the proposals received in response to the new FOA is under way.

R&D Creates New Production Method for Actinium-225



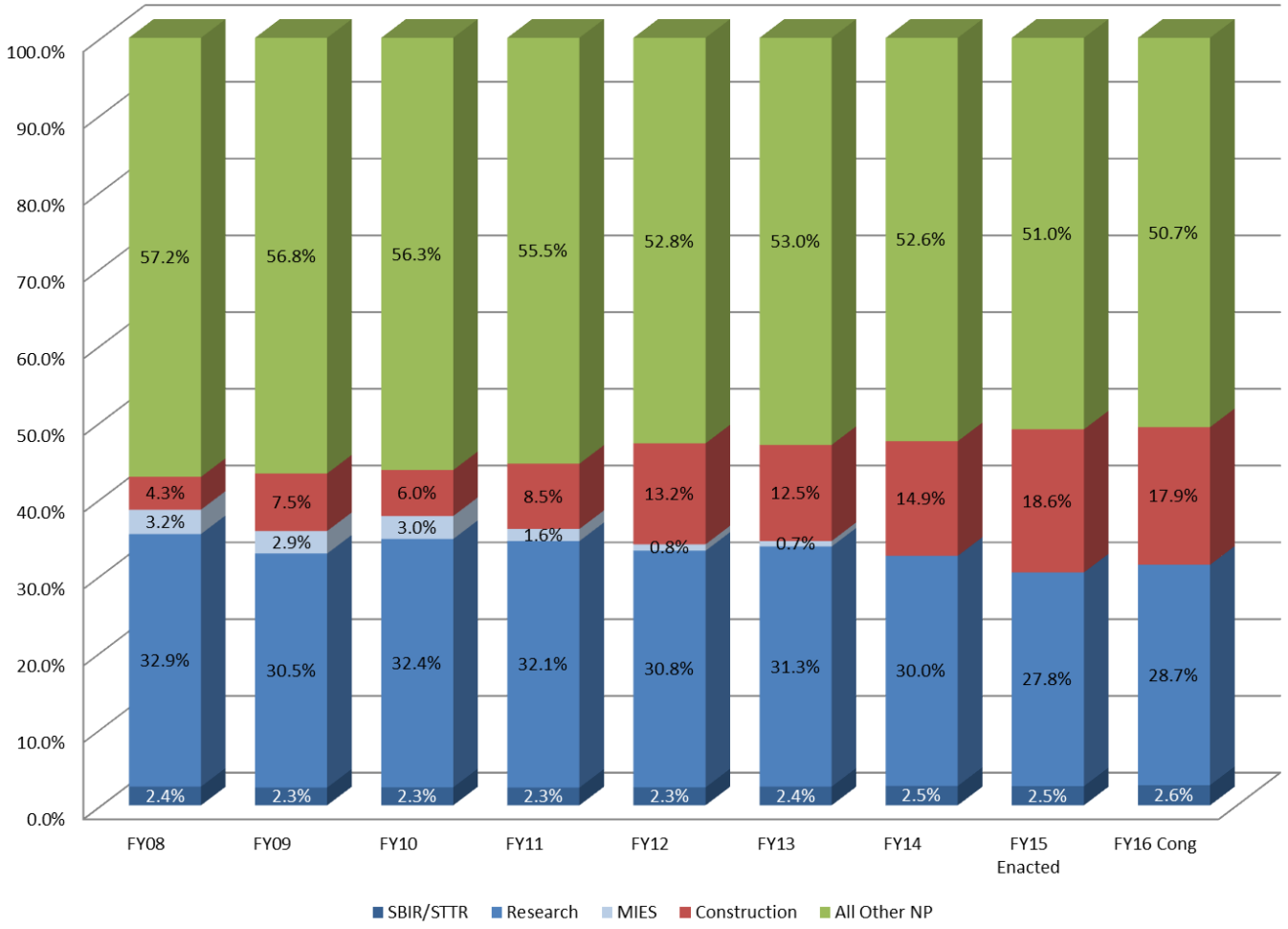
- Using proton beams, LANL and BNL could match current annual worldwide production of the actinium-22 in just a few days.
- Ac-225 emits alpha radiation. Alpha particles are energetic enough to destroy cancer cells but are unlikely to move beyond a tightly controlled target region and destroy healthy cells. Alpha particles are stopped in their tracks by a layer of skin—or even an inch or two of air.

Cancer-cell culture experiment: Tumor cells treated with Ac-225 radiopharmaceutical were "cured" while untreated control cells proliferated



Research as a Percentage of the NP Budget
FY 2008-FY2015

Construction has stressed all aspects of the NP program – not just Research



The NP Isotope Program Continues to Provide Isotopes and Radioisotopes in Short Supply

Some key isotopes and radioisotopes and the companies that use them

Strontium-82, Rubidium-82	Imaging / Diagnostic cardiology
Germanium-68, Gallium-68	Calibration / PET scan imaging
Californium-252	Oil and gas exploration and manufacturingcontrols
Selenium-75	Radiography / Quality control
Actinium-225, Yttrium-90, Rhenium 188	Cancer / Infectious disease treatment
Nickel-63	Explosives detection at airports
Gadolinium-160, Neodymium-160	Tracers and contrast agents for biological agents
Iron-57, Barium-135	Standard sources for mass spectroscopy
Sulfur-34	Environmental monitoring
Rubidium-87	Atomic frequency / GPS applications
Lithium-6, Helium-3	Detection of Special Nuclear Materials
Samarium-154	Solar energy /transportation applications