The ALICE experiment @ LHC

Philippe Crochet (LPC Clermont-Ferrand)
for the ALICE collaboration

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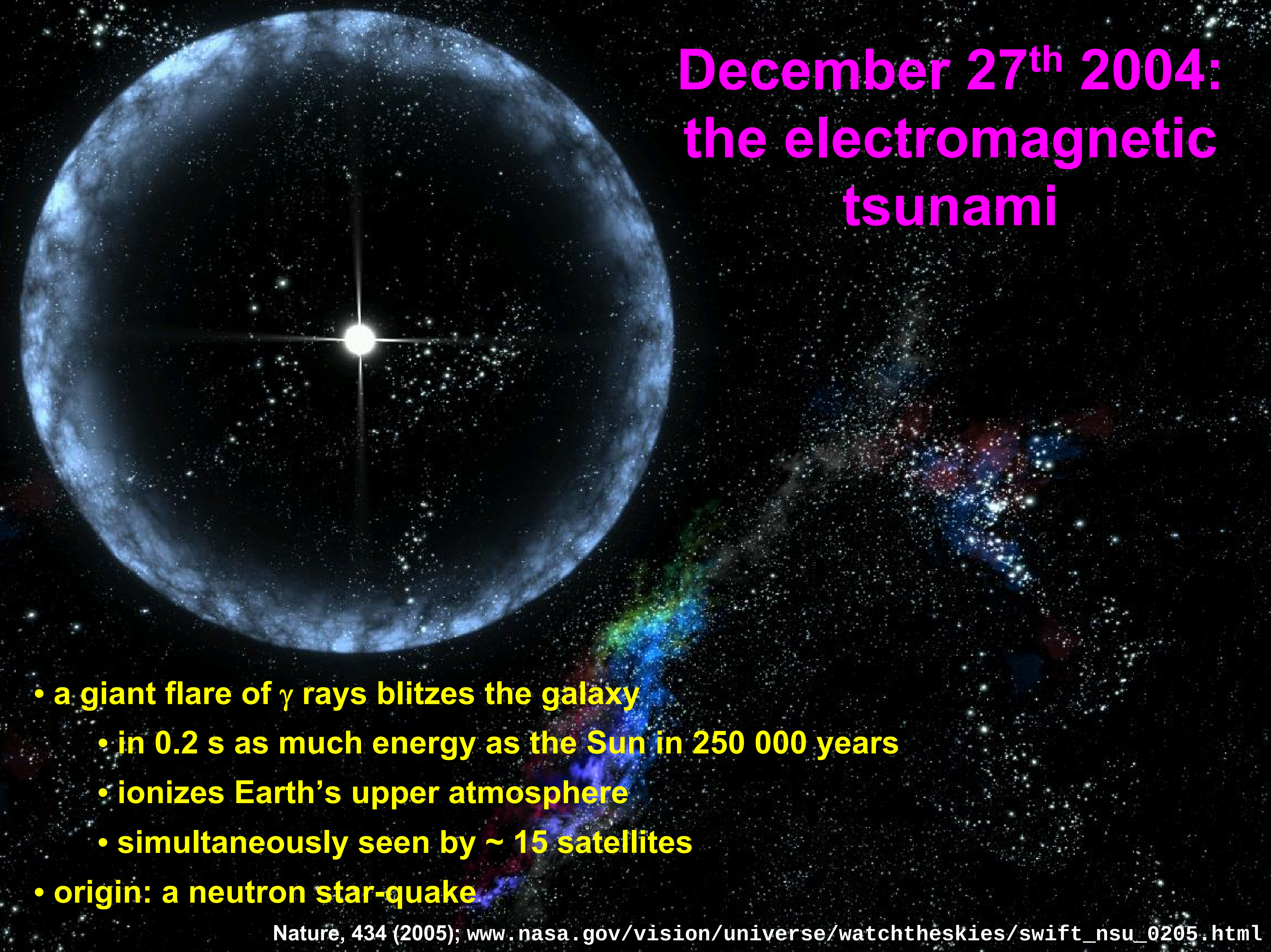
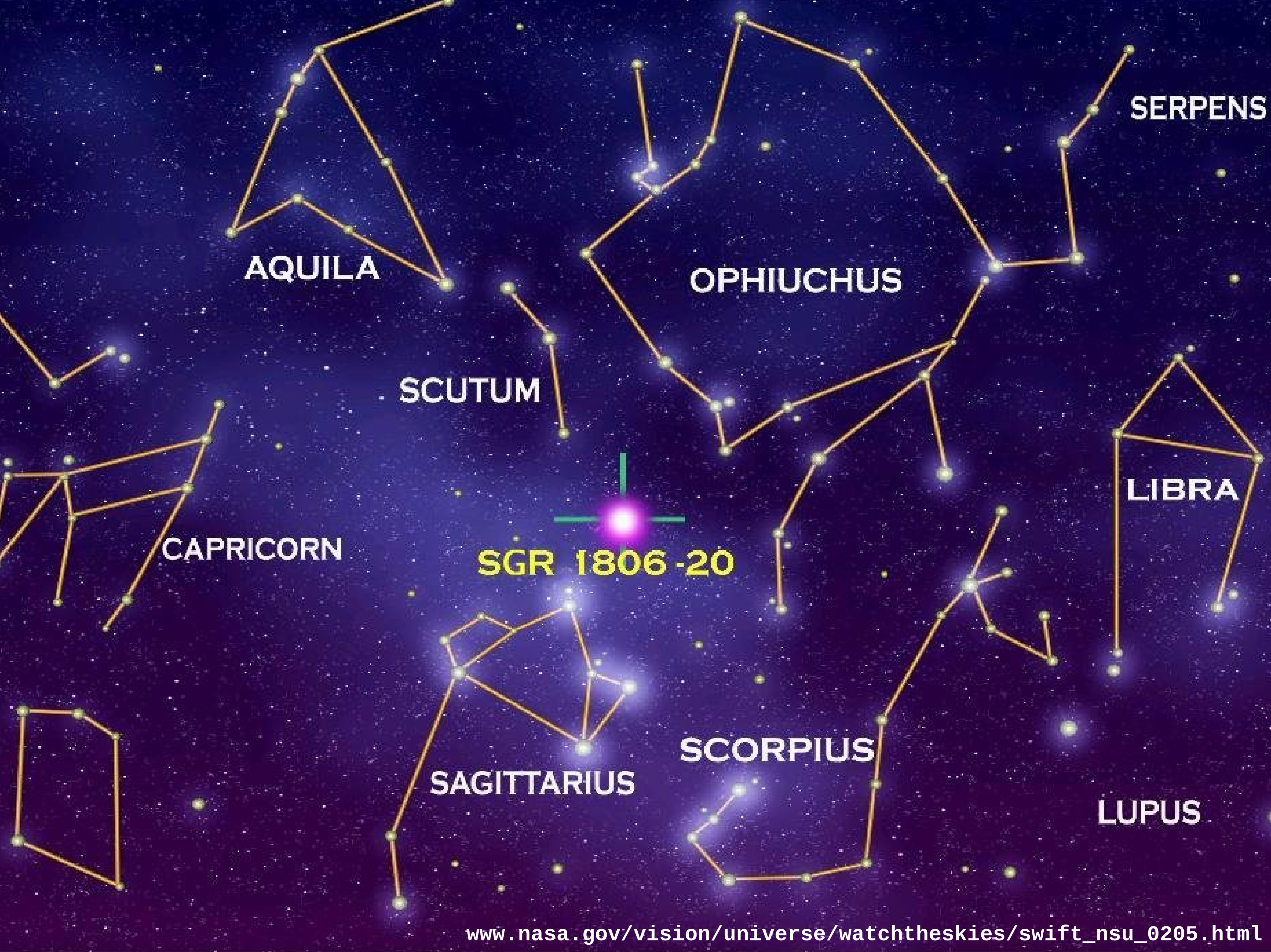


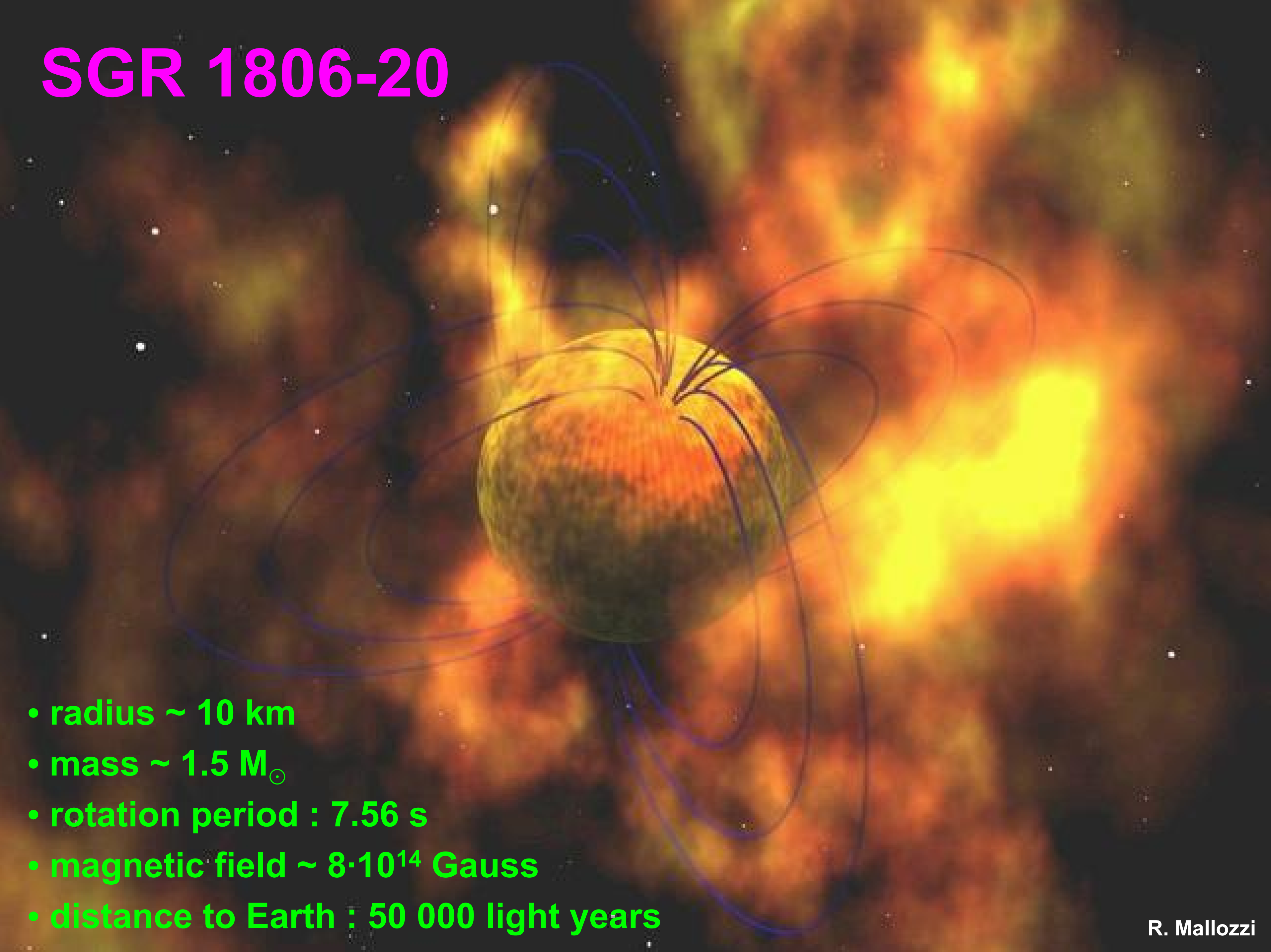
December 27th 2004: the electromagnetic tsunami

- a giant flare of γ rays blitzes the galaxy
  - in 0.2 s as much energy as the Sun in 250 000 years
  - ionizes Earth's upper atmosphere
  - simultaneously seen by ~ 15 satellites
- origin: a neutron star-quake

Nature, 434 (2005); www.nasa.gov/vision/universe/watchtheskies/swift_nsu_0205.html


AQUILA
SERPENS
OPHIUCHUS
SCUTUM
LIBRA
CAPRICORN
SGR 1806-20
SCORPIUS
SAGITTARIUS
LUPUS
www.nasa.gov/vision/universe/watchtheskies/swift_nsu_0205.html

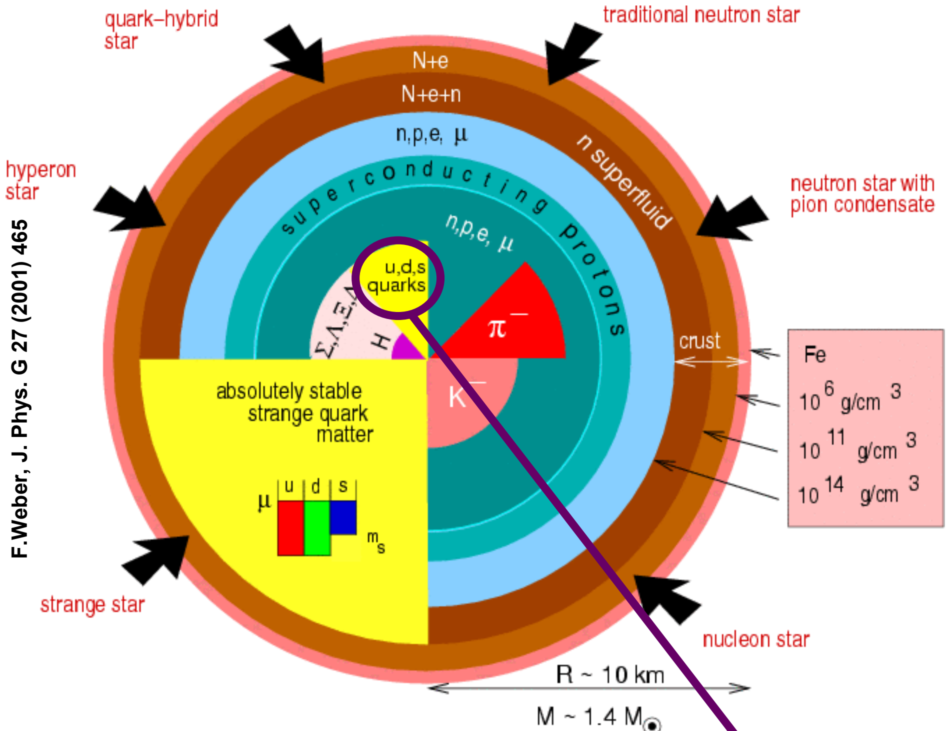
SGR 1806-20

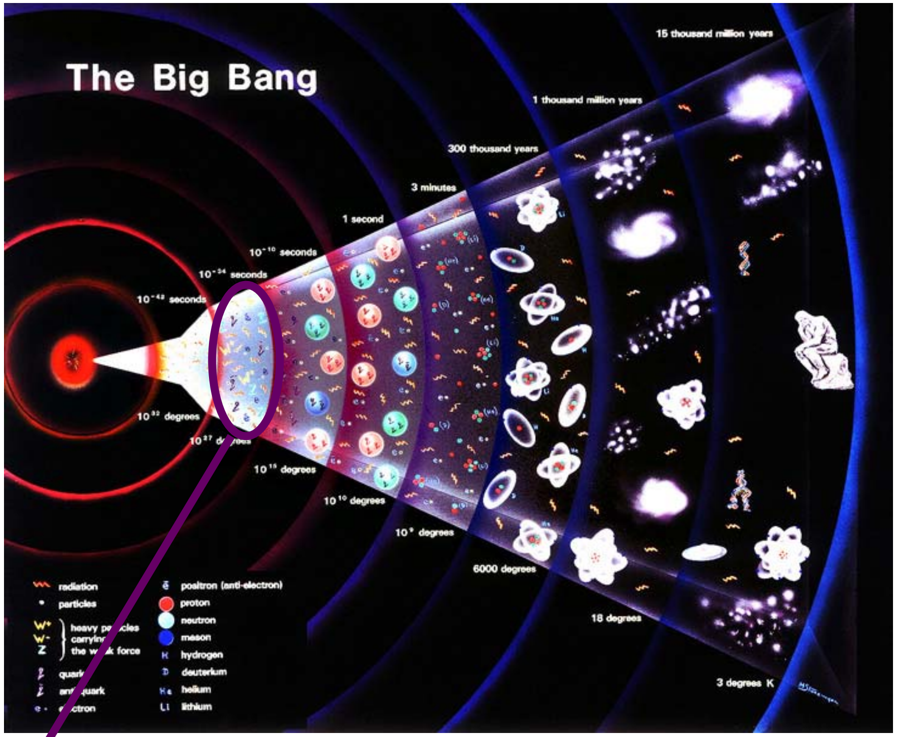


R. Mallozzi

- radius ~ 10 km
- mass ~ 1.5 $M_{\odot}$
- rotation period : 7.56 s
- magnetic field ~ $8 \cdot 10^{14}$ Gauss
- distance to Earth : 50 000 light years

Neutrons Stars, Big Bang, Quark Gluon Plasma & Heavy Ion Collisions





"When the energy density ε exceeds some typical hadronic value (~ 1 GeV/fm³), matter no longer exists of separate hadrons (protons, neutrons, etc), but as their fundamental constituents, quarks and gluons. Because of the apparent analogy with similar phenomena in atomic physics we may call this phase of matter the QCD (or Quark Gluon) plasma."

E.V. Shuryak, Phys. Rept. 61 (1980) 71

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Outline

- heavy ion collisions & QGP in short
- the QGP @ SPS & RHIC
- ALICE & the QGP @ LHC

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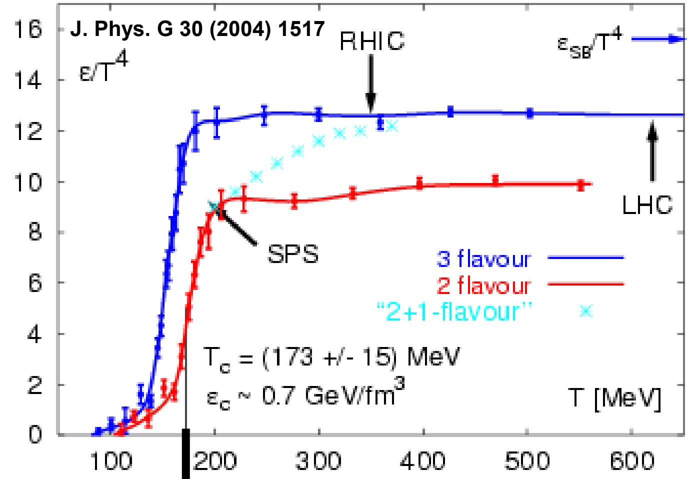
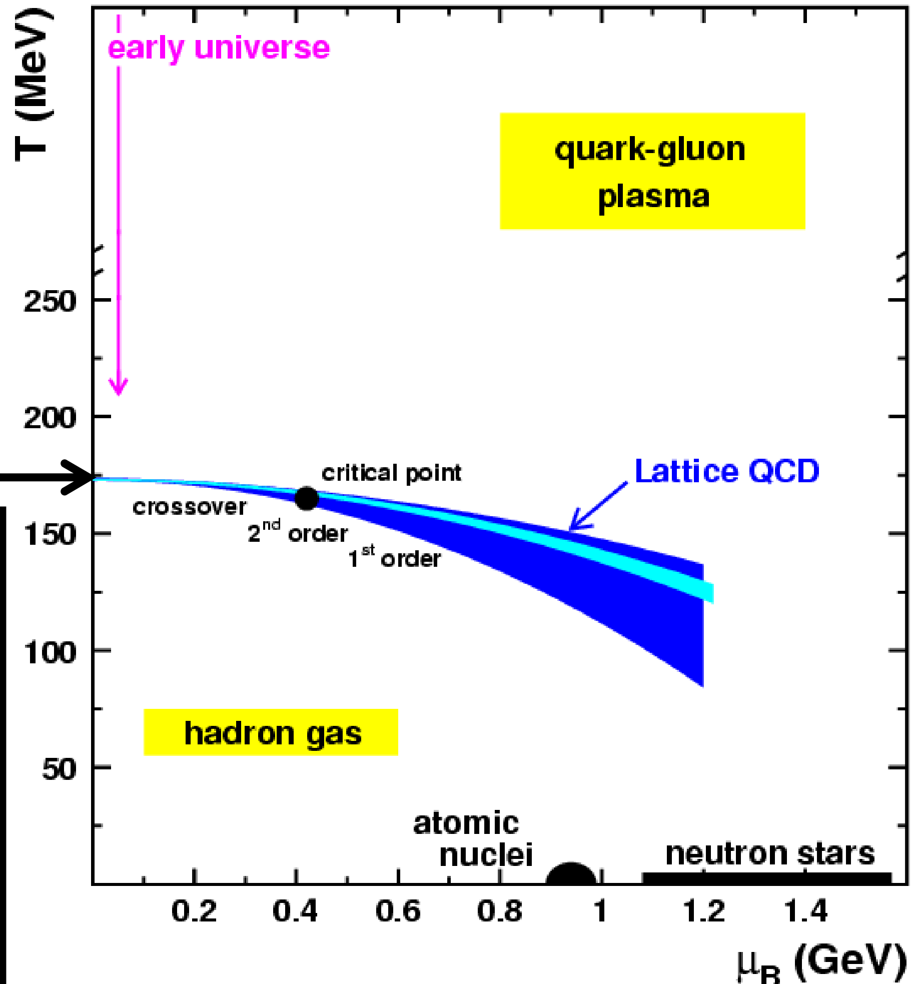
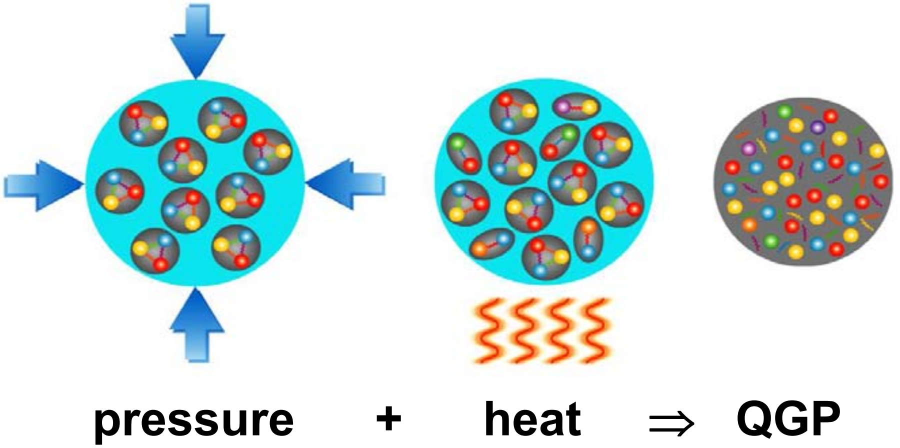
What QCD says

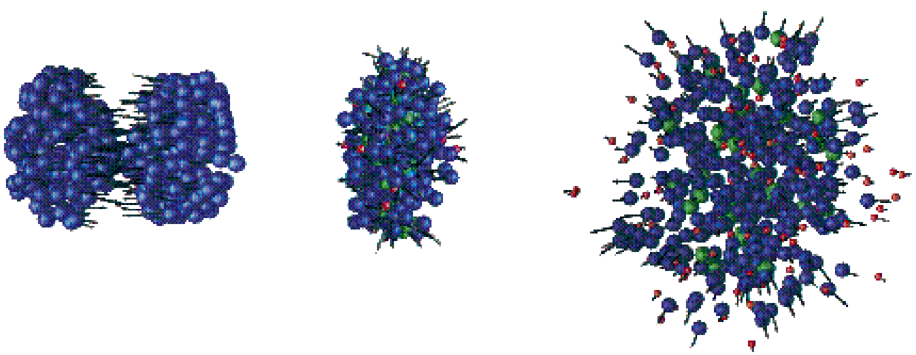


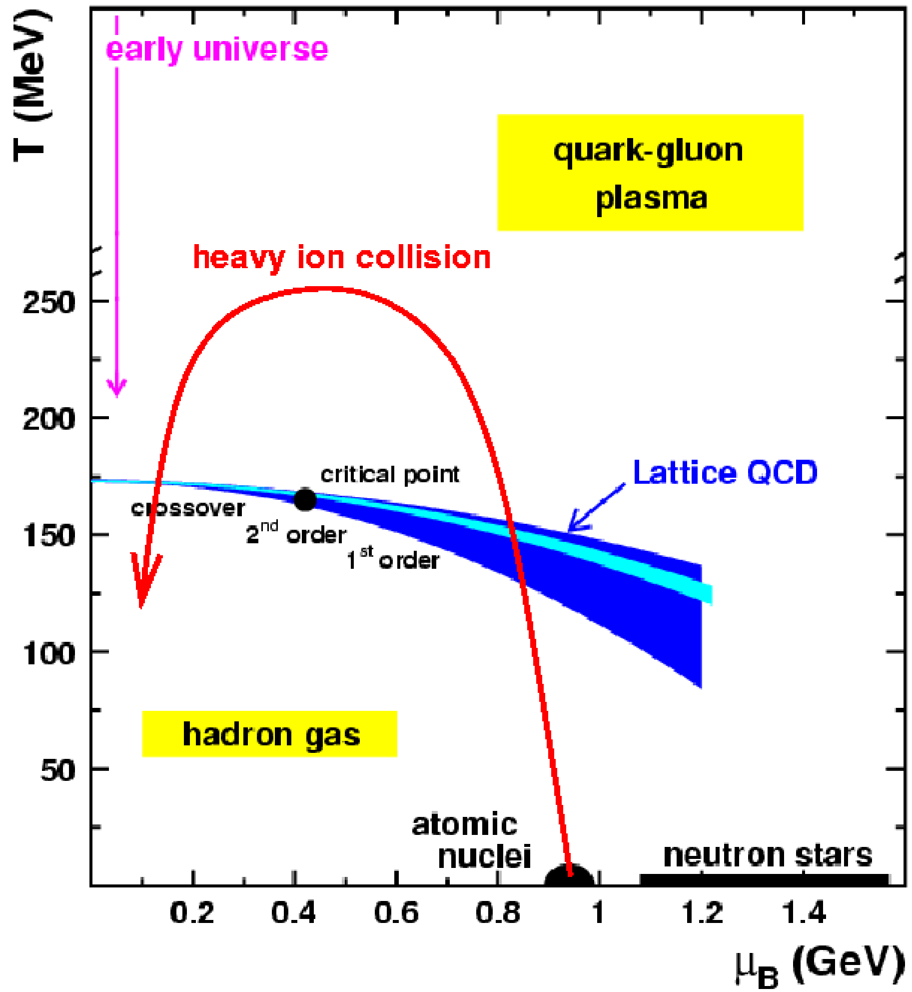


- $\mu_B = 0$:
  - T = 173 ± 15 MeV = 10^{12} K ($T_{sun} = 10^8$ K)
  - $\varepsilon = 0.7 \pm 0.3$ GeV/fm^3
  - "crossover"-like transition
- $\mu_B > 0$:
  - large uncertainties
  - order of transition unknown
  - existence of a critical point
- chiral sym. restoration coincides with deconf.
- the QGP is not an ideal gas

Recreating the QGP via heavy ion collisions







key parameters: bombarding energy, collision centrality, particle transverse momentum

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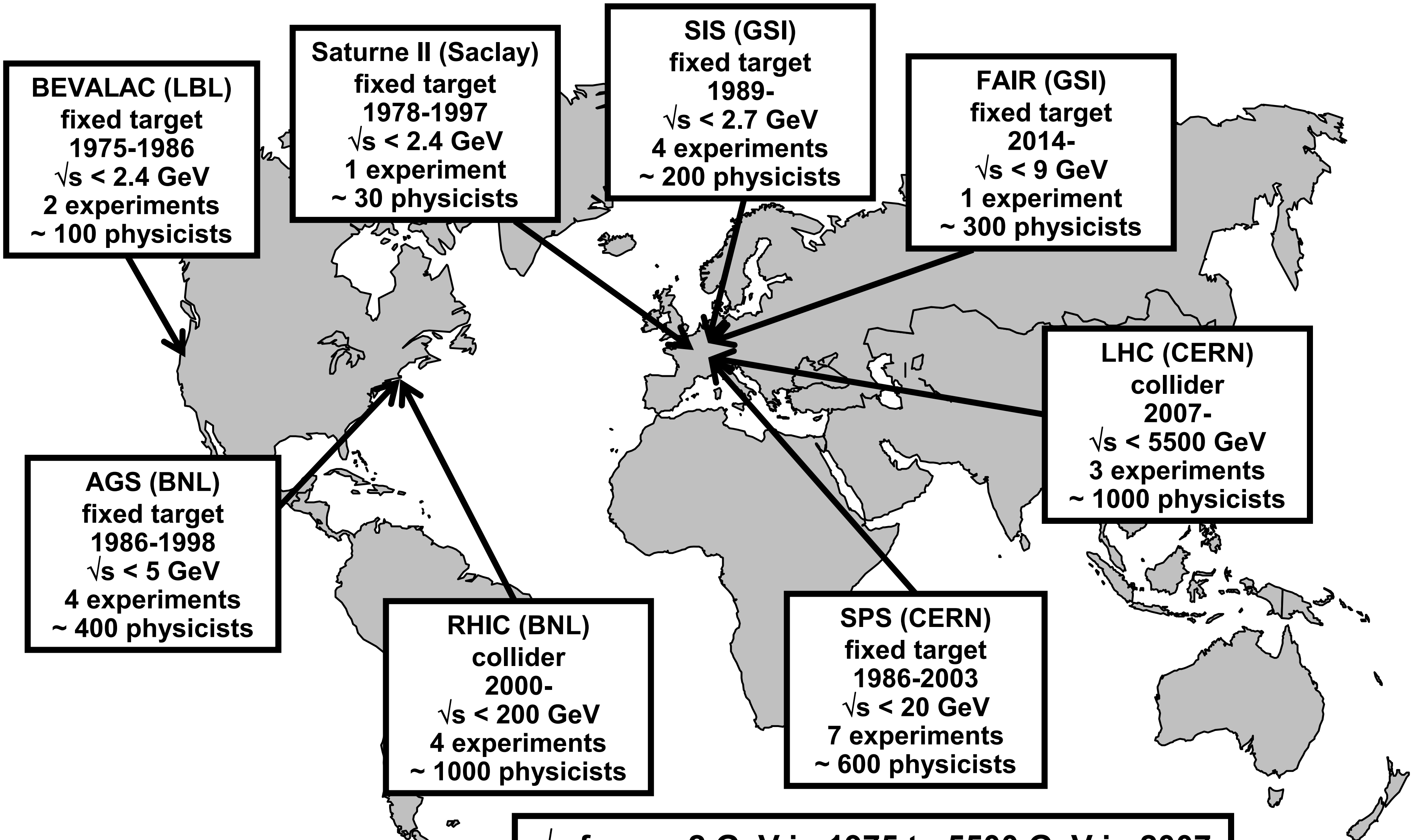
1975-2006: 30 years of heavy ion collisions



√s from ~ 2 GeV in 1975 to 5500 GeV in 2007

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Evolution of the QCD phase diagram in 30 years

1975

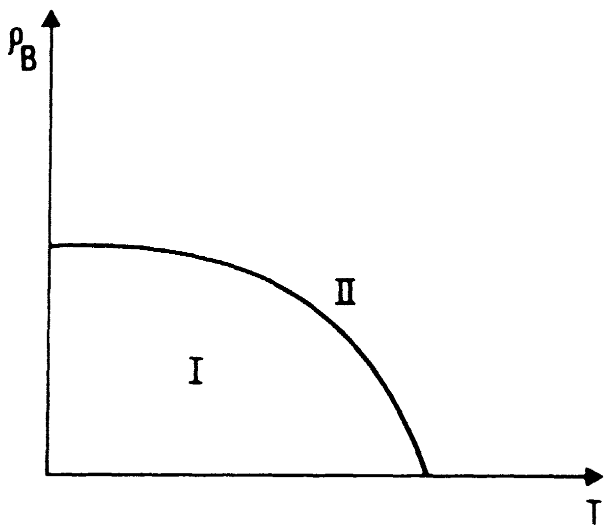
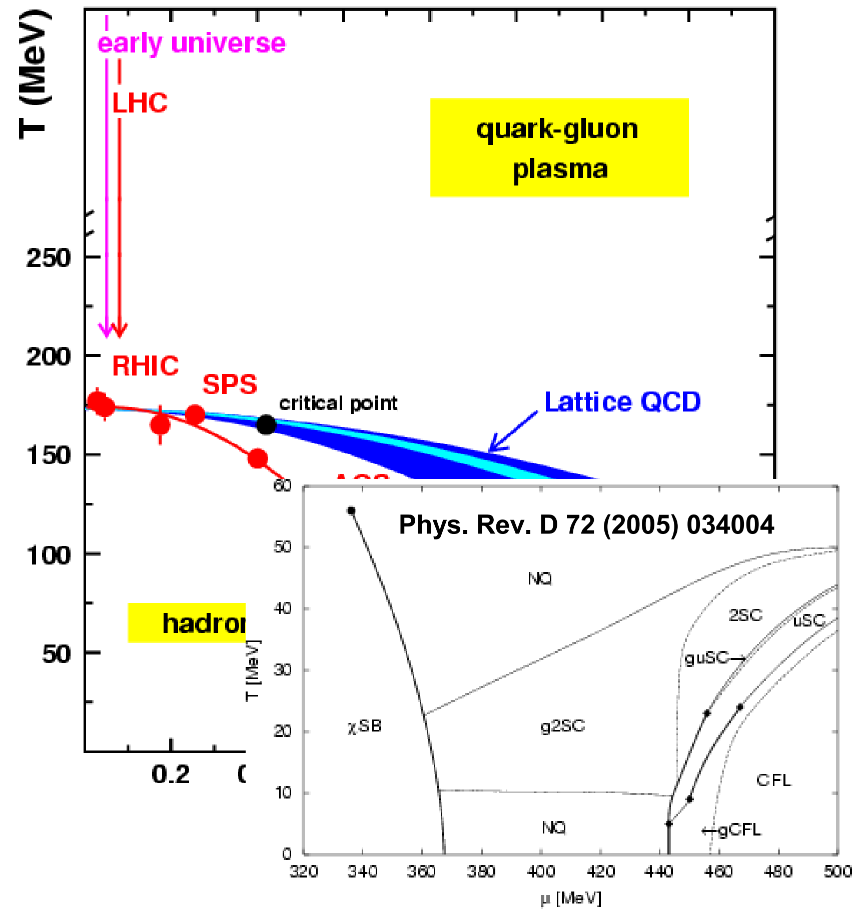


Fig. 1. Schematic phase diagram of hadronic matter. ρ_B is the density of baryonic number. Quarks are confined in phase I and unconfined in phase II.

"…we expect a phase diagram of the kind indicated in Fig.1. The true phase diagram may actually be substantially more complex…"
N. Cabibbo & G. Parisi (1975)

2006



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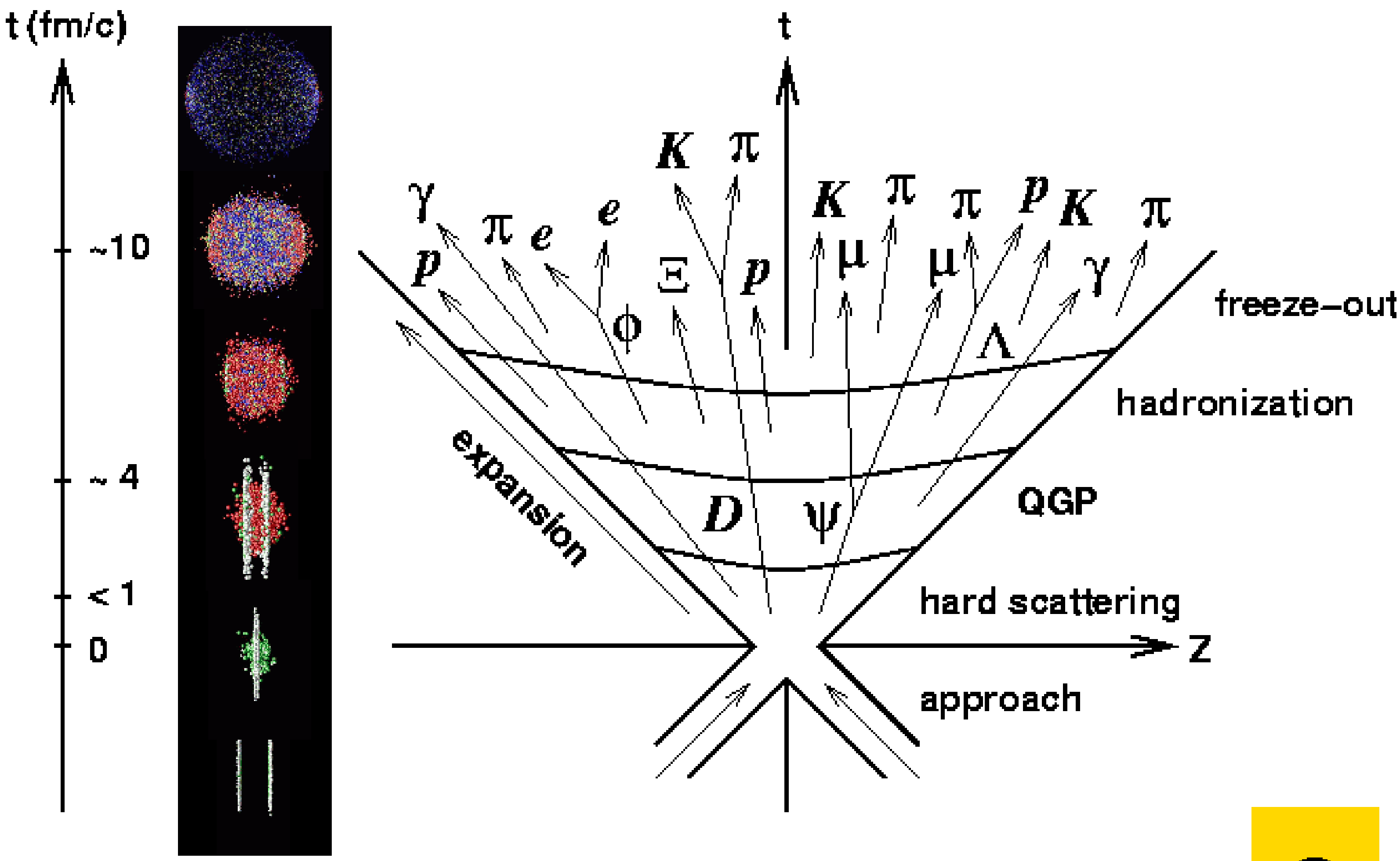
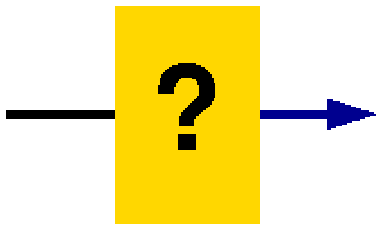
Schematic space-time evolution of a heavy ion collision



strategy: use produced particles
as probes of the medium



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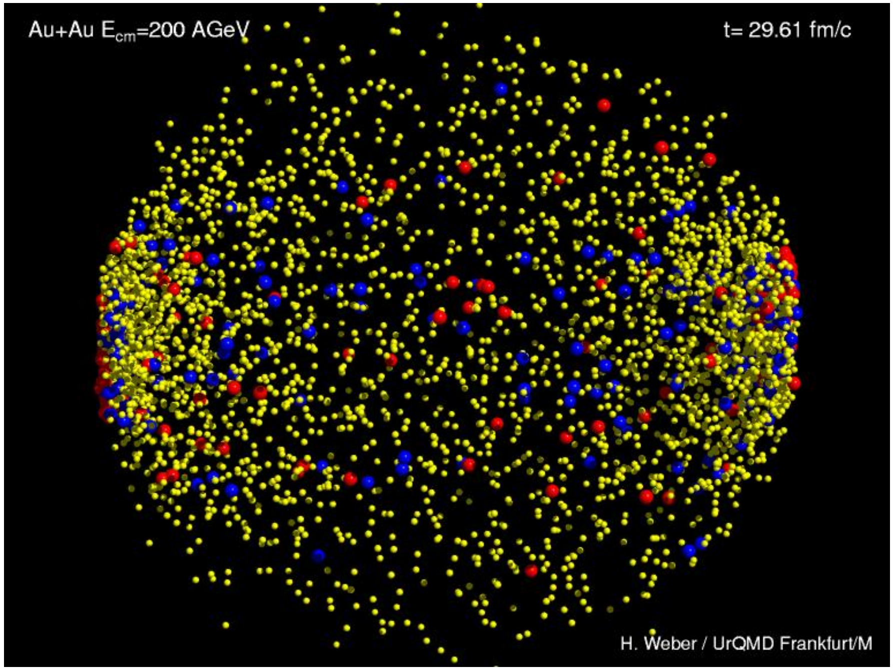
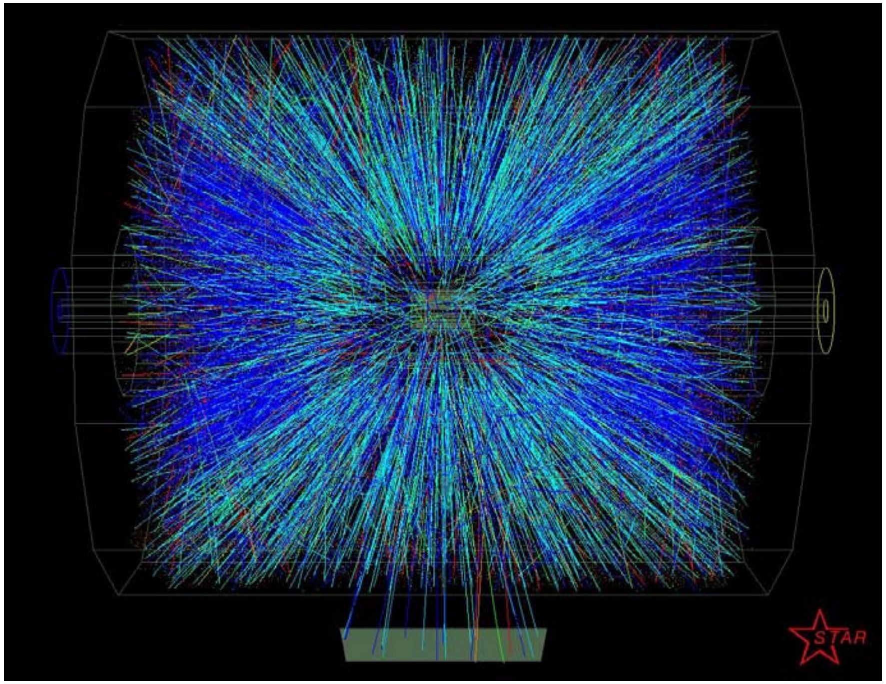
Not that simple…



a simulated heavy ion collision



the same collision in real life

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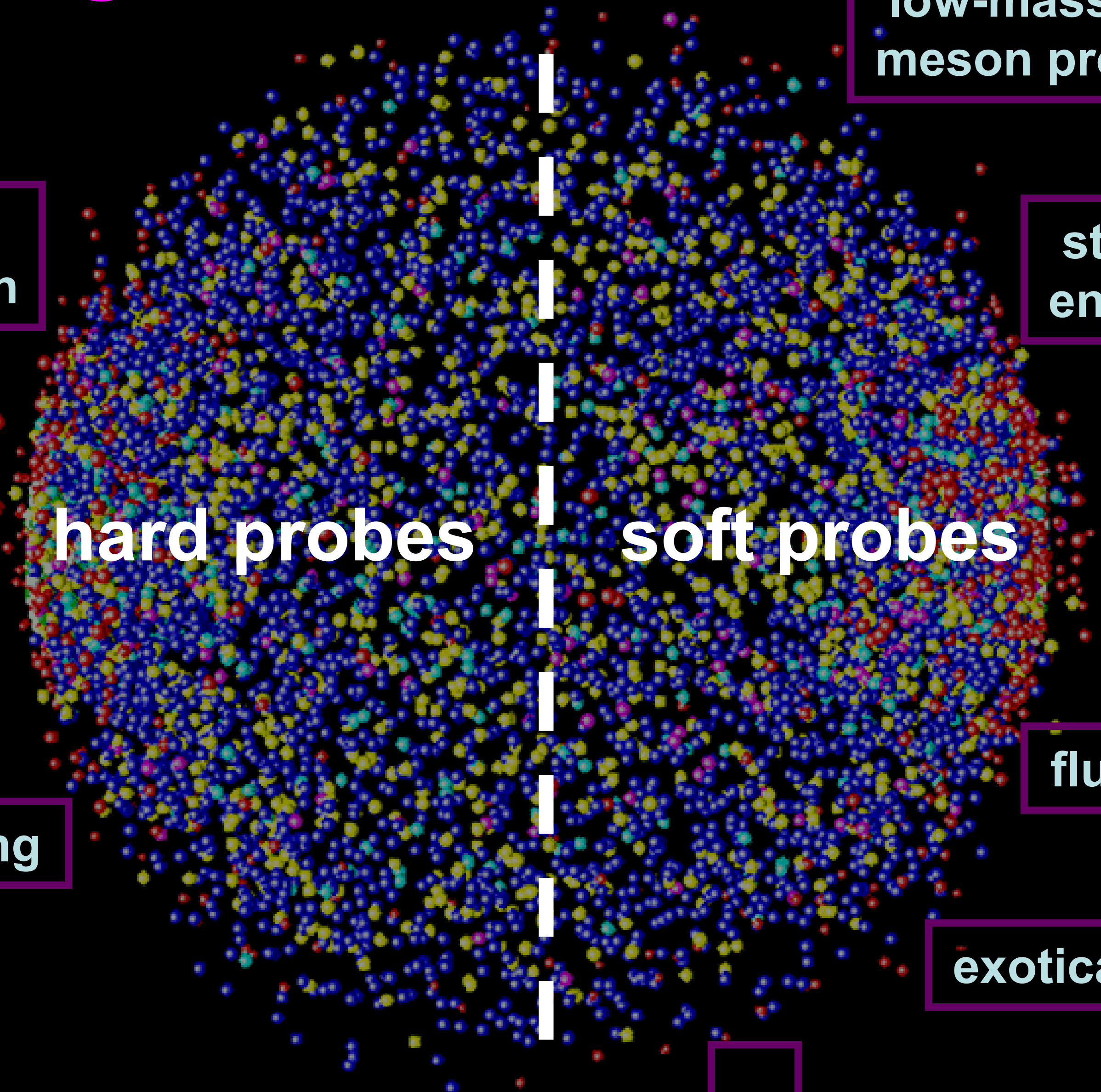
Strategy for studying the QGP

1. **Measure a quantity**
   - whose value (from theoretical predictions) is expected to be different with or w/o a QGP. Most appropriate: central AA collisions
2. **Validate the measurement**
   - by comparing the quantity to theoretical predictions with & w/o QGP
   - by comparing the quantity to the same quantity measured in pp, pA & peripheral AA (no QGP) & then extrapolated to central AA
3. **Validate the result**
   - repeat 1. et 2. with as many quantities as possible
4. **Extract QGP properties**
   - tune theoretical models & repeat comparisons

QGP signatures



quarkonia suppression

thermal radiation

jet quenching

modification of low-mass vector meson properties

strangeness enhancement

flow strength

fluctuations

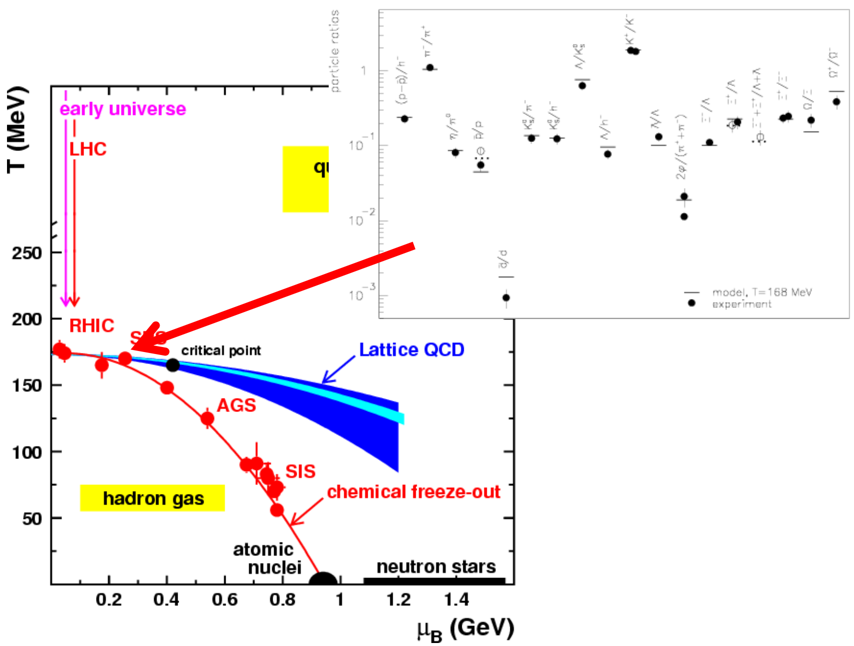
exotica

...

Do we reach the thermodynamical conditions of the QGP in HIC?

- **freeze-out temperature**

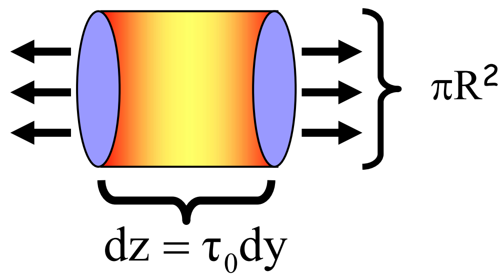
$$n_i = \frac{g}{2\pi^2}\int_0^\infty \frac{p^2 dp}{e^{(E_i(p)-\mu_i)/T} \pm 1}$$

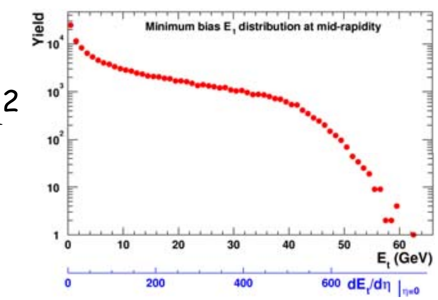


…coincides with critical value

- **energy density**

$$\varepsilon_{Bj} = \frac{1}{\pi R^2}\frac{1}{\tau_0}\frac{dE_T}{dy}$$





system	$\sqrt{s}$ (GeV)	ε (GeV/fm^3)
Pb+Pb	17	2.5
Au+Au	200	4.6

…larger than critical value

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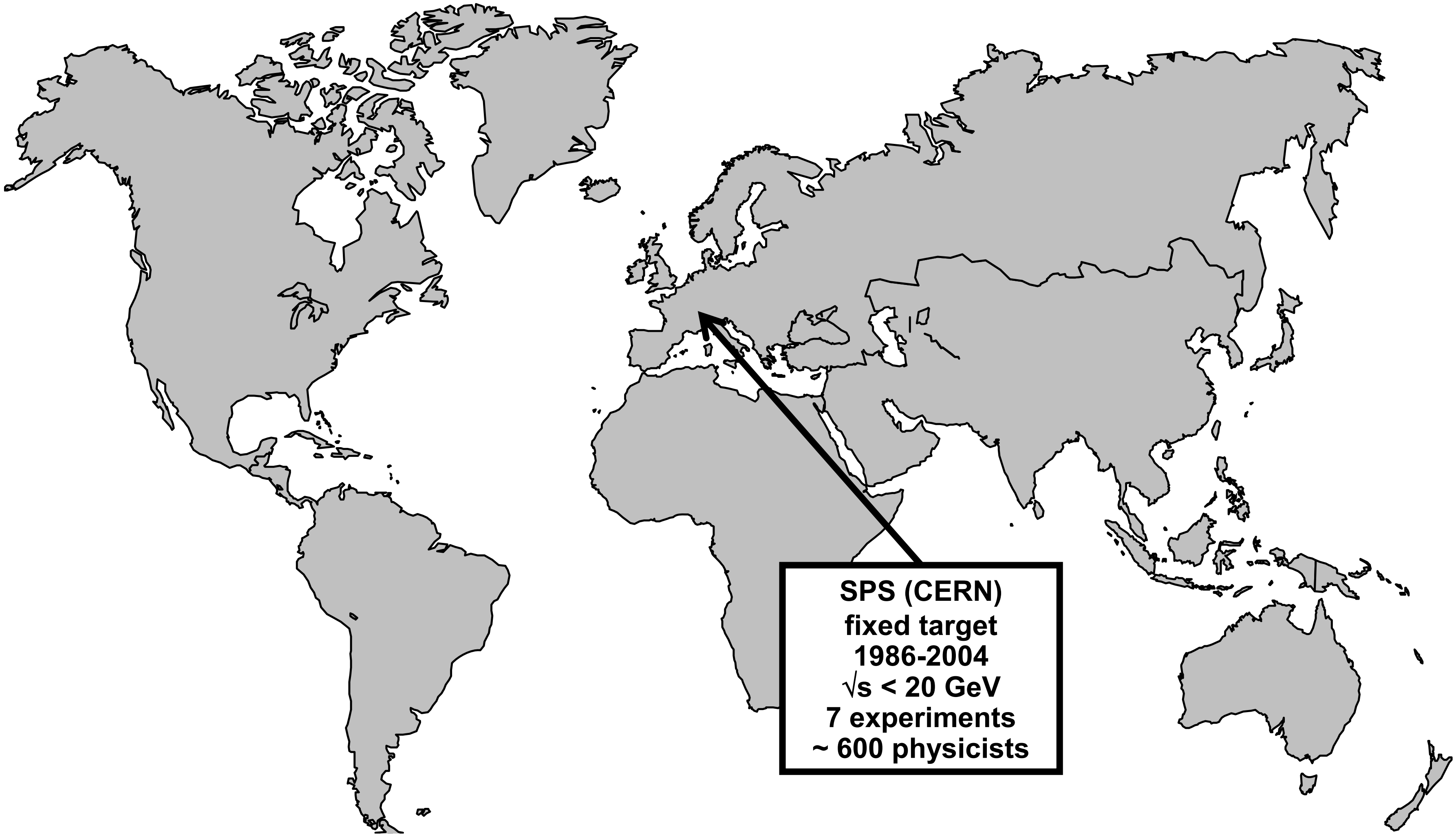
The QGP @ SPS



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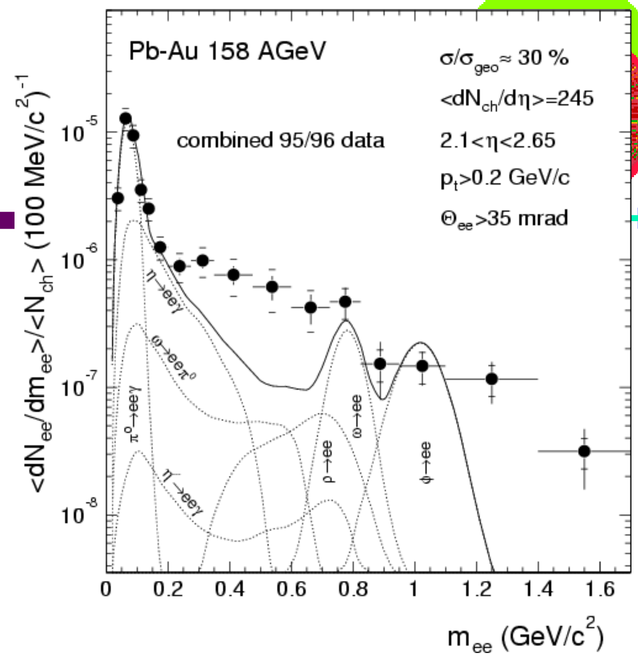
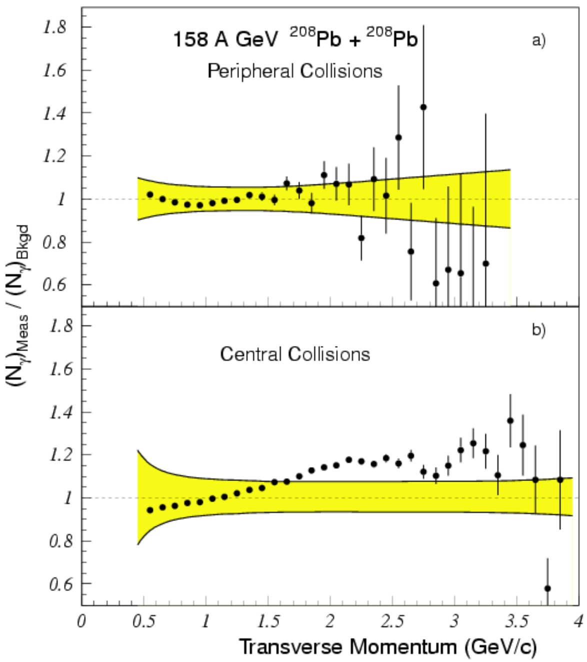
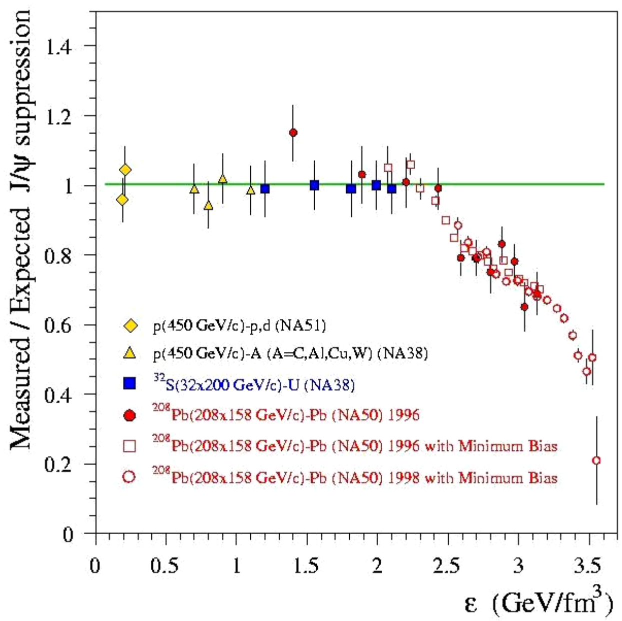
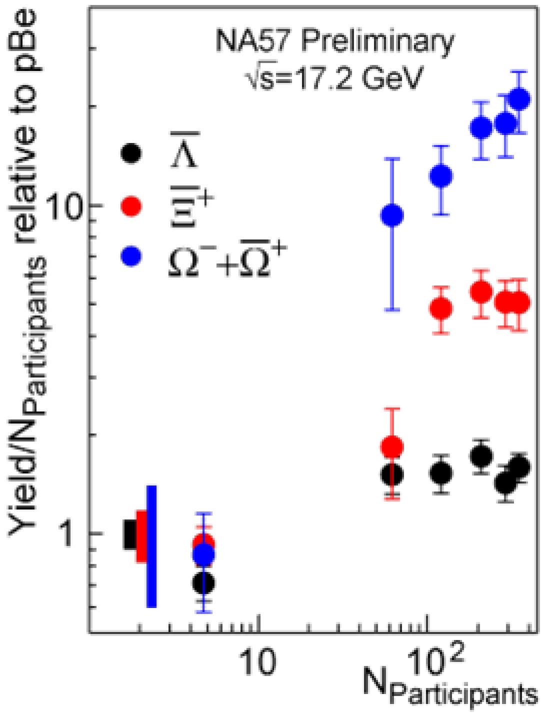
SPS results in 4 plots

- **low-mass dilepton excess**
  chiral symmetry rest. modifies vector meson properties
- **strangeness enhancement**
  strange quark mass decreases in QGP
- **charmonium suppression**
  J/ψ melts in QGP due to debye screening
- **thermal radiation**
  beyond radiation from hadron gaz









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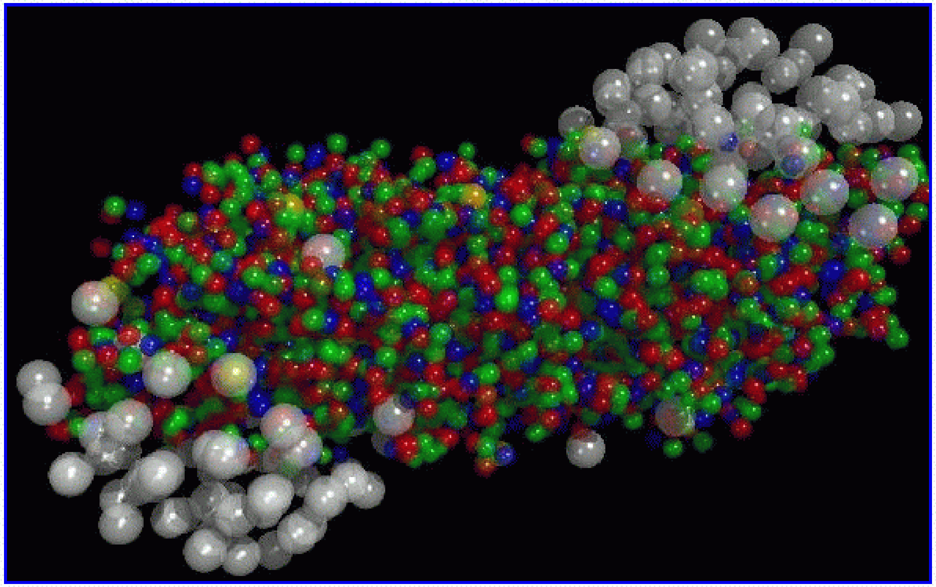
CERN press release (Feb. 10th 2000), 15 years of QGP studies @ the SPS

CERN

PRESS RELEASE

Organisation Européenne pour la Recherche Nucléaire
European Organization for Nuclear Research

New State of Matter created at CERN



At a special seminar on 10 February, spokespersons from the experiments on CERN* 's Heavy Ion programme presented compelling evidence for the existence of a new state of matter in which quarks, instead of being bound up into more complex particles such as protons and neutrons, are liberated to roam freely.

Professor Luciano Maiani, CERN Director General, said *"The combined data coming from the seven experiments on CERN's Heavy Ion programme have given a clear picture of a new state of matter. This result verifies an important prediction of the present theory of fundemental forces between quarks. It is also an important step forward in the understanding of the early evolution of the universe. We now have evidence of a new state of matter where quarks and gluons are not confined. There is still an entirely new territory to be explored concerning the physical properties of quark-gluon matter. The challenge now passes to the Relativistic Heavy Ion Collider at the Brookhaven National Laboratory and later to CERN's Large Hadron Collider."*

http://info.web.cern.ch/Press/PressReleases/Releases2000/PR01.00FQuarkGluonMatter.html

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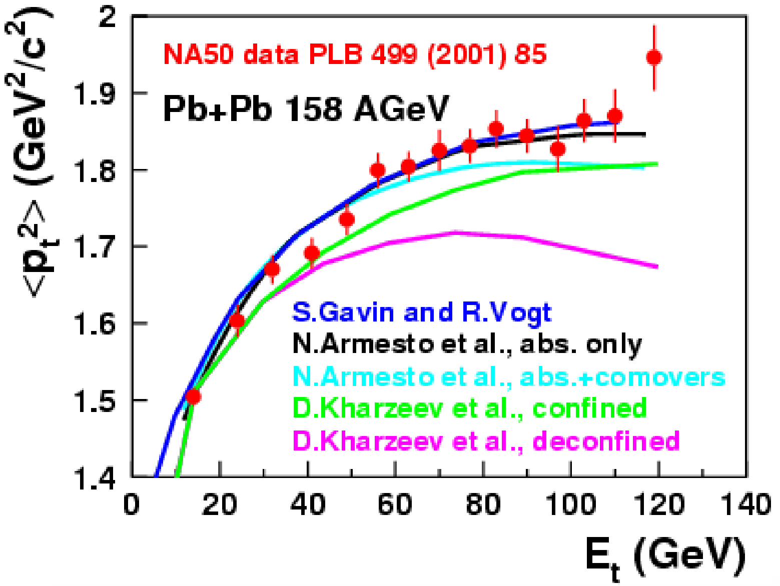
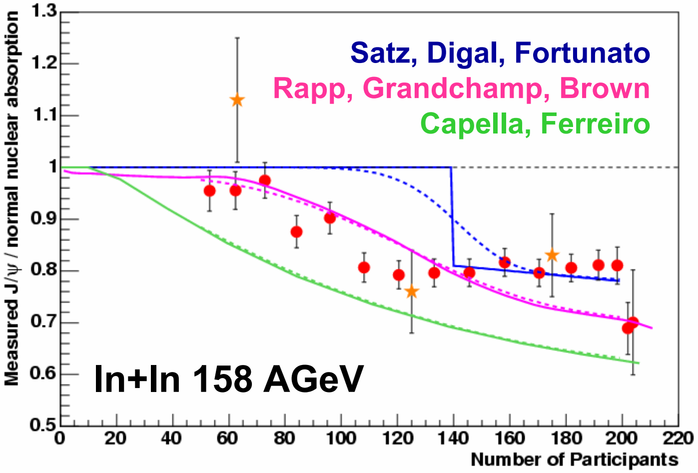
However…

no unambiguous evidence for the formation of the QGP

- some features are not understood yet
  - J/ψ $<p^2_t>$ is missed only by the QGP model in Pb+Pb collisions
  - none of the model gets (J/ψ)/(DY) right in In+In collisions
  - …
- small effects w.r.t. hadronic scenario
- one single observable/experiment

(the word "discovery" is never used in the press release[#])





E. Scomparin for NA60, Quark Matter (2005),
O. Drapier, HDR (1998), [#]M. Gonin, La Recherche 357 (2002) 22

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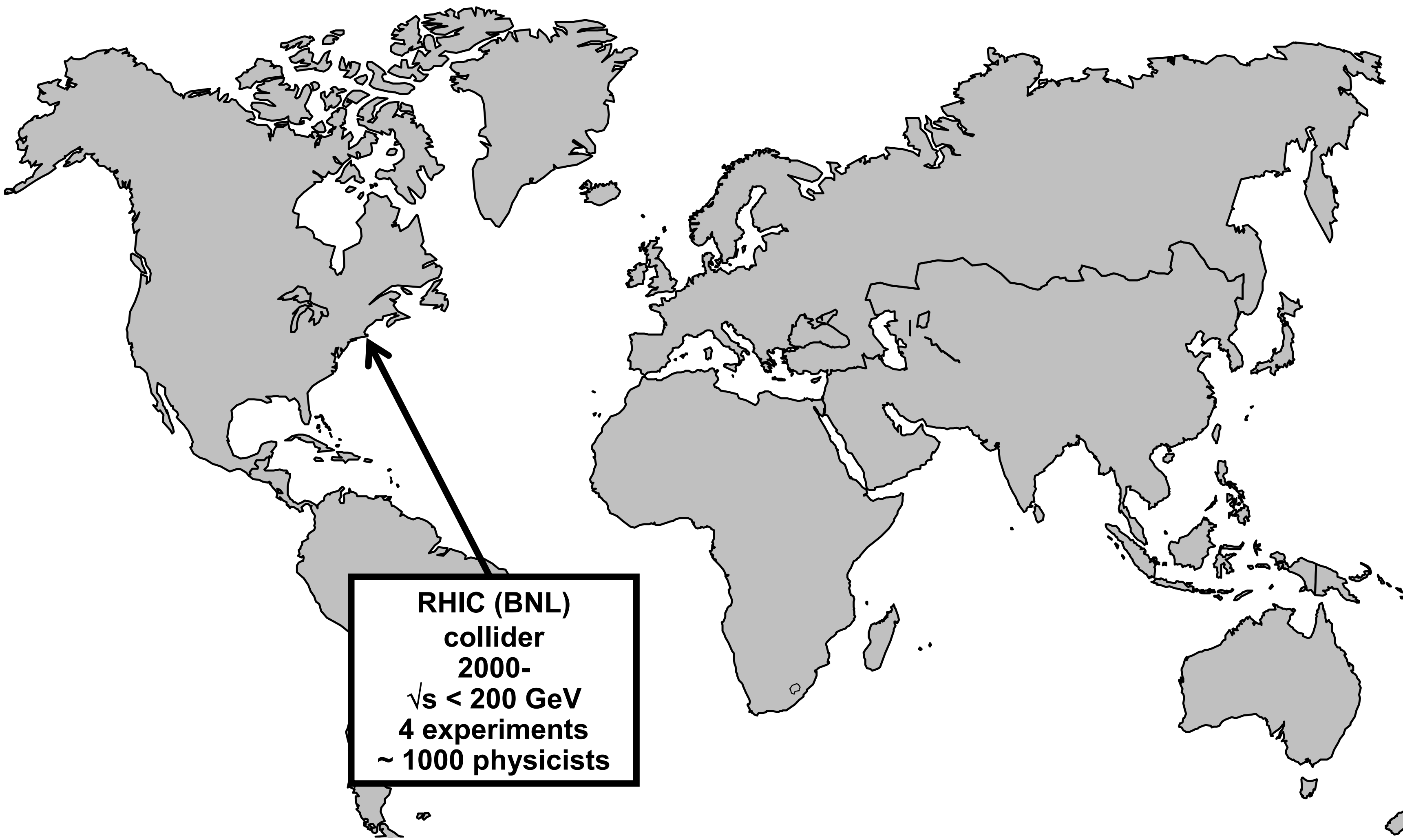
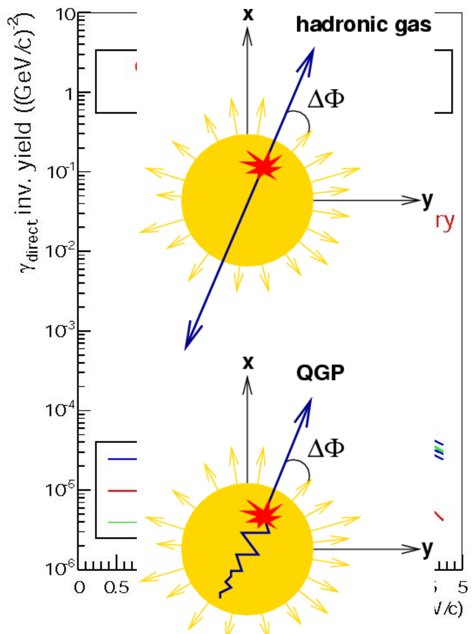
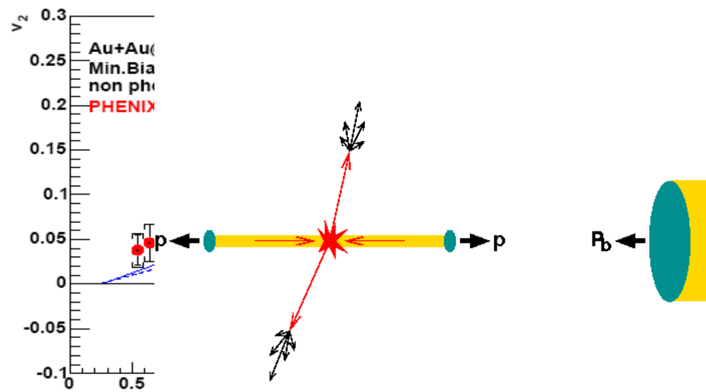
The QGP @ RHIC

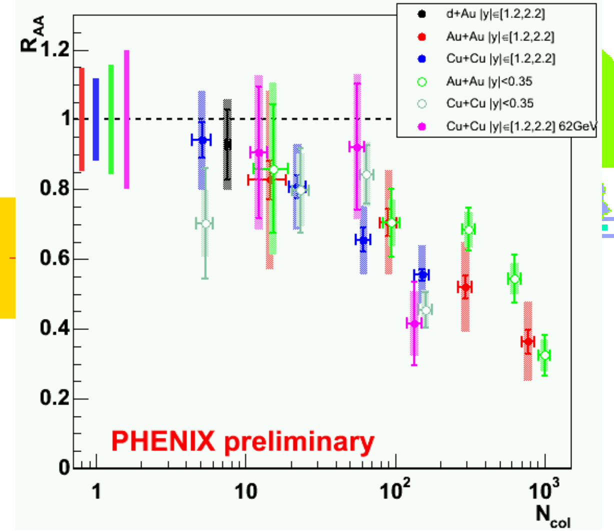


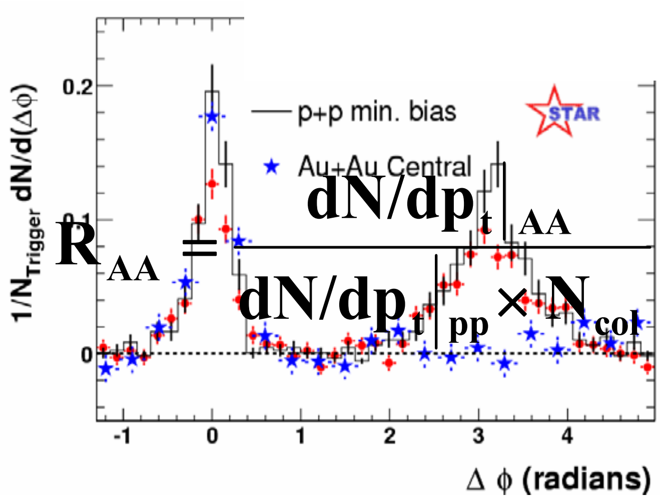
RHIC (BNL)
collider
2000-
√s < 200 GeV
4 experiments
~ 1000 physicists

RHIC results in 7 plots

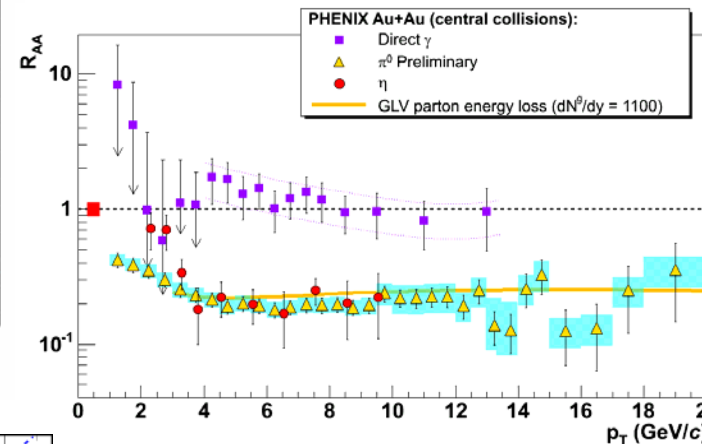


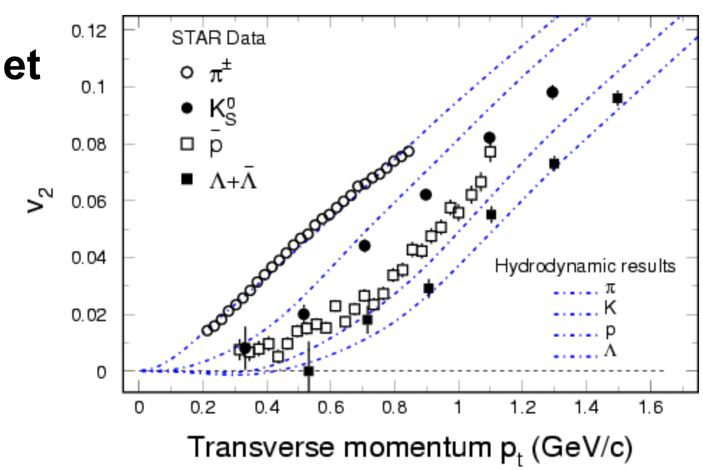


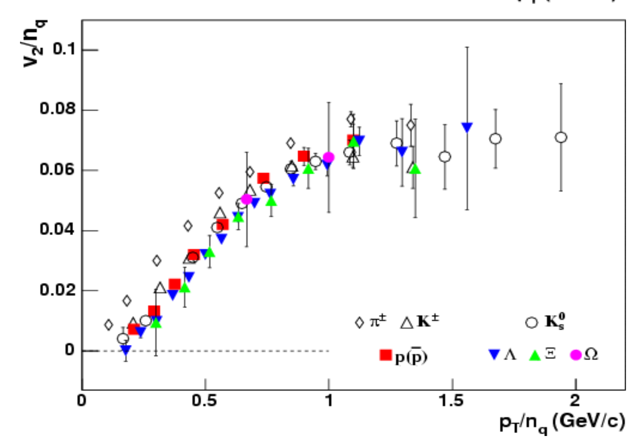




$$R_{AA} = \frac{dN/dp_t|_{AA}}{dN/dp_t|_{pp} \times N_{col}}$$







- hadron suppression
- vanishing away-side jet
- hydro. elliptic flow
- partonic elliptic flow
- charm elliptic flow
- J/ψ suppression
- thermal radiation

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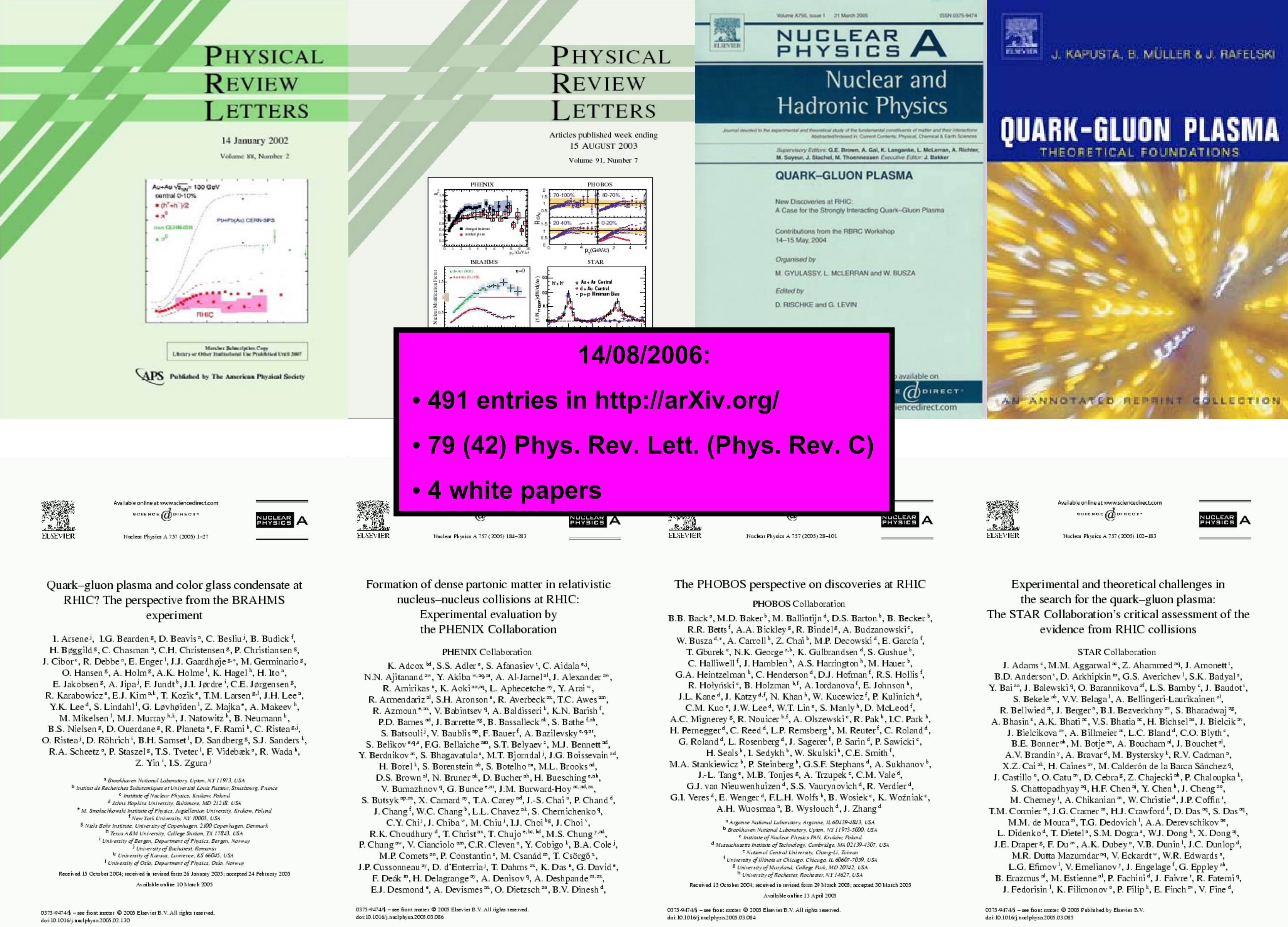


14/08/2006:
• 491 entries in http://arXiv.org/
• 79 (42) Phys. Rev. Lett. (Phys. Rev. C)
• 4 white papers
PHYSICAL REVIEW LETTERS
14 January 2002
Volume 88, Number 2
PHYSICAL REVIEW LETTERS
Articles published week ending 15 AUGUST 2003
Volume 91, Number 7
NUCLEAR PHYSICS A
Nuclear and Hadronic Physics
QUARK–GLUON PLASMA
New Discoveries at RHIC: A Case for the Strongly Interacting Quark–Gluon Plasma
Contributions from the RBRC Workshop 14–15 May, 2004
Organised by M. GYULASSY, L. MCLERRAN and W. BUSZA
Edited by D. RISCHKE and G. LEVIN
J. KAPUSTA, B. MÜLLER & J. RAFELSKI
QUARK-GLUON PLASMA
THEORETICAL FOUNDATIONS
AN ANNOTATED REPRINT COLLECTION
Quark–gluon plasma and color glass condensate at RHIC? The perspective from the BRAHMS experiment
Formation of dense partonic matter in relativistic nucleus–nucleus collisions at RHIC: Experimental evaluation by the PHENIX Collaboration
The PHOBOS perspective on discoveries at RHIC
Experimental and theoretical challenges in the search for the quark–gluon plasma: The STAR Collaboration's critical assessment of the evidence from RHIC collisions

RHIC press release (April 18th 2005), 4 years of QGP studies @ RHIC

RHIC Scientists Serve Up "Perfect" Liquid

New state of matter more remarkable than predicted -- raising many new questions

April 18, 2005

TAMPA, FL -- The four detector groups conducting research at the Relativistic Heavy Ion Collider (RHIC) -- a giant atom "smasher" located at the U.S. Department of Energy's Brookhaven National Laboratory -- say they've created a new state of hot, dense matter out of the quarks and gluons that are the basic particles of atomic nuclei, but it is a state quite different and even more remarkable than had been predicted. In peer-reviewed papers summarizing the first three years of RHIC findings, the scientists say that instead of behaving like a gas of free quarks and gluons, as was expected, the matter created in RHIC's heavy ion collisions appears to be more like a *liquid*. ⇒ **sQGP**

"Once again, the physics research sponsored by the Department of Energy is producing historic results," said Secretary of Energy Samuel Bodman, a trained chemical engineer. "The DOE is the principal federal funder of basic research in the physical sciences, including nuclear and high-energy physics. With today's announcement we see that investment paying off."

Secretary of Energy Samuel Bodman

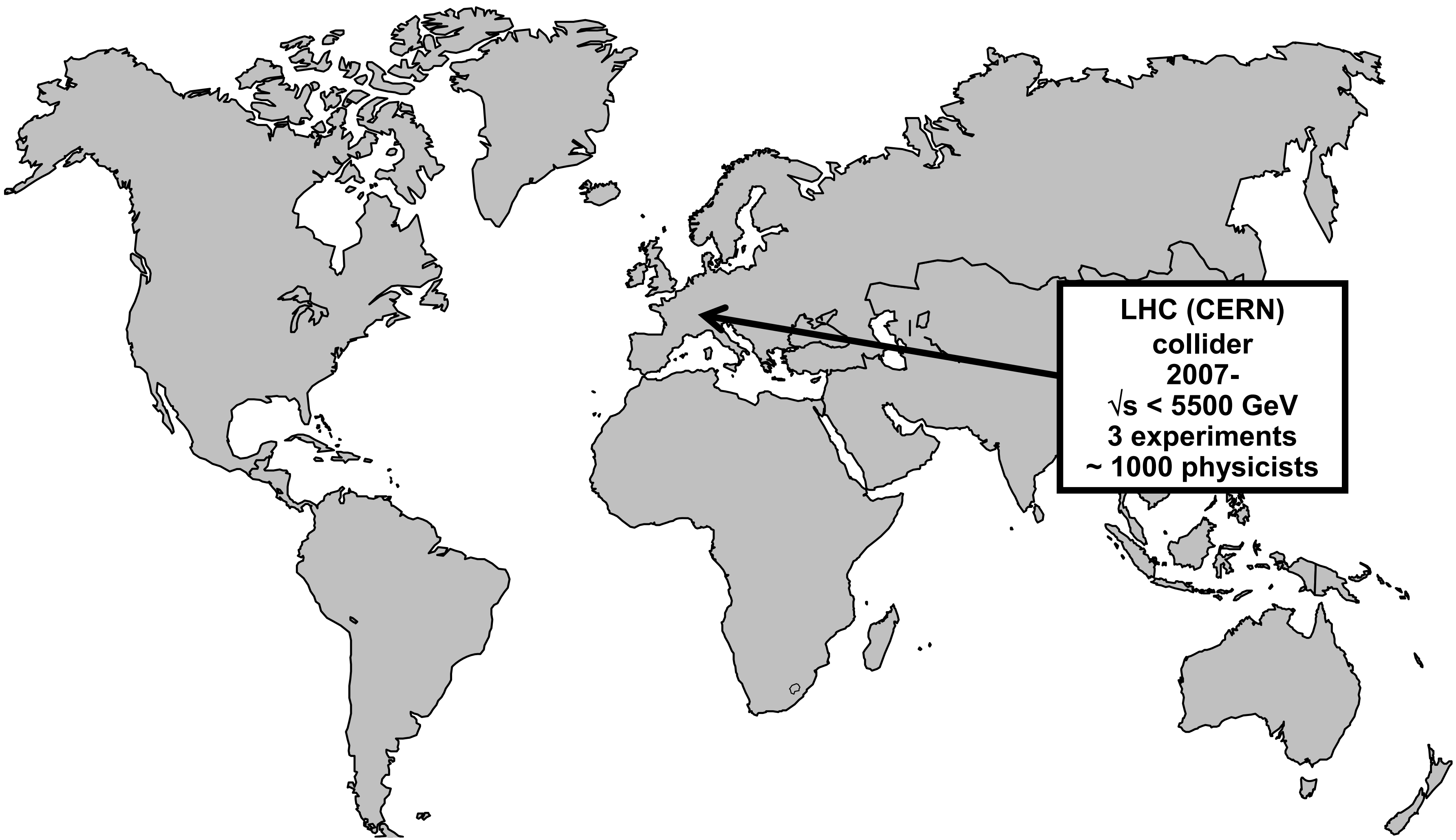
"The truly stunning finding at RHIC that the new state of matter created in the collisions of gold ions is more like a liquid than a gas gives us a profound insight into the earliest moments of the universe," said Dr. Raymond L. Orbach, Director of the DOE Office of Science.

Also of great interest to many following progress at RHIC is the emerging connection between the collider's results and calculations using the methods of string theory, an approach that attempts to explain fundamental properties of the universe using 10 dimensions instead of the usual three spatial dimensions plus time.

"The finding of a nearly perfect liquid in a laboratory experiment recreating the conditions believed to have existed a few microseconds after the birth of the universe is truly astonishing," said Praveen Chaudhari, Director of Brookhaven Lab. "The four RHIC collaborations are now collecting and analyzing very large new data sets from the fourth and fifth years of operation, and I expect more exciting and intriguing revelations in the near future."

http://www.bnl.gov/rhic

The QGP @ LHC


LHC (CERN)
collider
2007-
√s < 5500 GeV
3 experiments
~ 1000 physicists

Heavy ion collisions & QGP @ LHC

machine	SPS	RHIC	LHC
$\sqrt{s}$ (GeV)	17	200	5500
N_{ch}	1000	4000	50 000
τ^0_{QGP} (fm/c)	1	0.2	0.1
T/T_c (τ^0_{QGP})	1.1	1.9	3.0-4.2
ε[1 fm/c] (GeV/fm^3)	3	5	16-64
τ_{QGP} (fm/c)	$\leq$ 2	2-4	$\geq$ 10
τ_f (fm/c)	~ 10	20-30	30-40
V_f (fm^3)	~ 10^3	~ 10^4	~ 10^5
baryo-chemical	baryon-rich	→	baryon-free
processes	soft →	semi-hard →	hard

= 0.18 mJ

$\Rightarrow$ faster

$\Rightarrow$ hotter

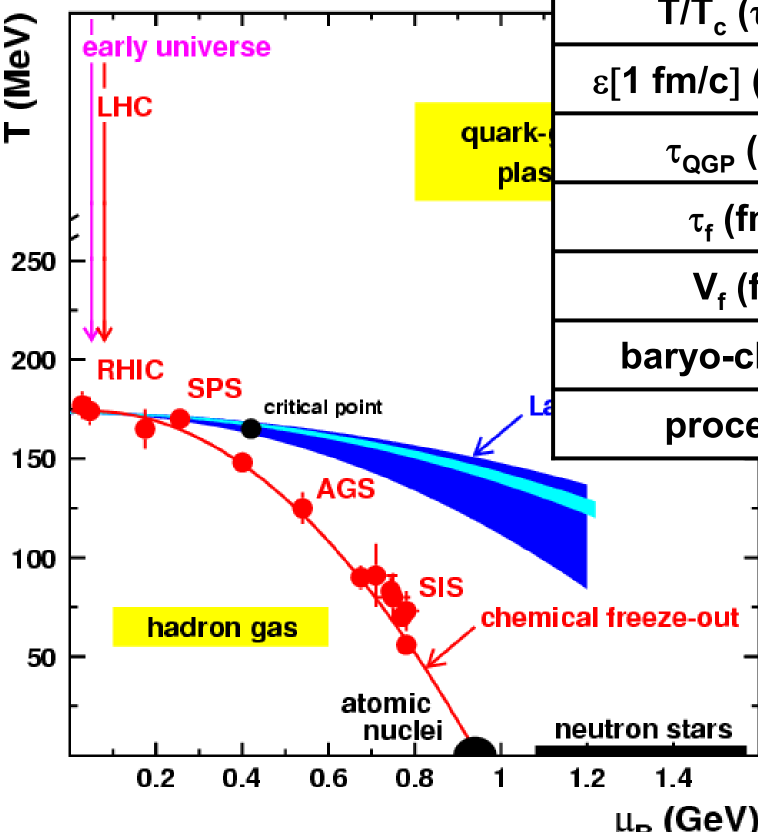
$\Rightarrow$ denser

$\Rightarrow$ longer

$\Rightarrow$ bigger

$\Rightarrow$ cleaner

$\Rightarrow$ harder



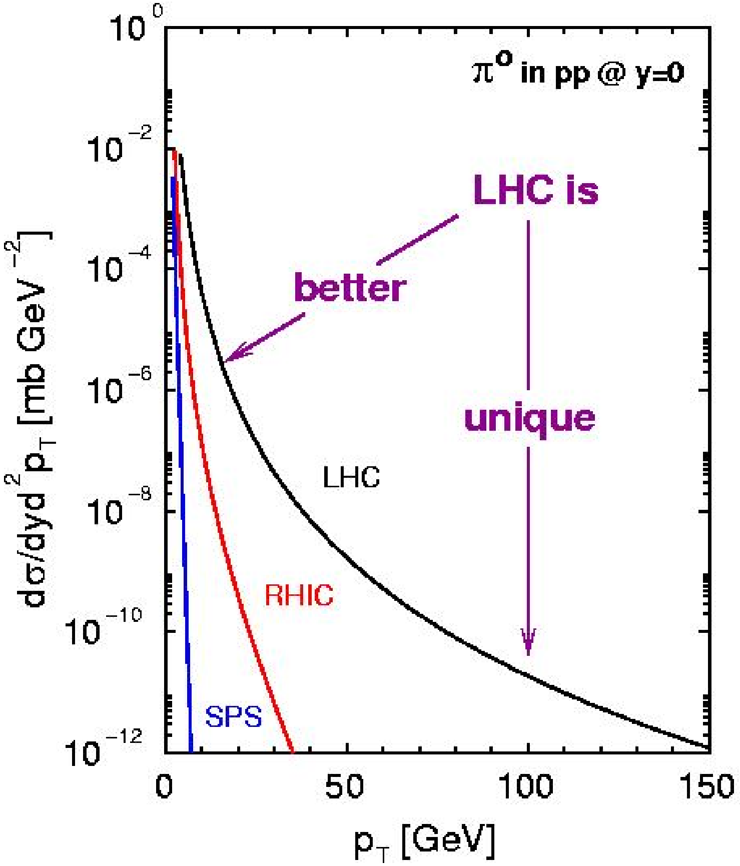
"...the LHC will become the ideal facility for a systematic exploration and quantitative confirmation of the insights obtained at RHIC, aided by the plentiful abundance of hard probes."

B. Müller, hep-ph/0410115

J. Schukraft, Nucl. Phys. A 698 (2002) 287

Hard processes:
what is different @ LHC

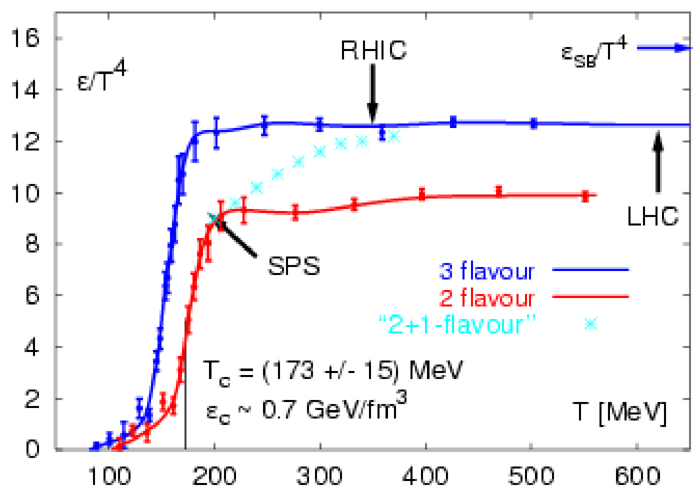
huge cross-section



$\sigma^{hard}/\sigma^{tot}$ = 2/50/98% @ SPS/RHIC/LHC

K. Kajantie, Nucl. Phys. A 715 (2003) 432

pQCD under better control



$$\sigma_{pp}^{hard} = O(\alpha_s) + O(\alpha_s^2) + O(\alpha_s^3) + \ldots$$

$$\alpha_s(T) \propto \frac{4\pi}{18\log(5T/T_c)} = \begin{matrix} 0.43 @ T = T_c \\ 0.23 @ T = 4T_c \end{matrix}$$

3/4/5th order terms are ~ 7/12/23 times smaller @ LHC than @ SPS

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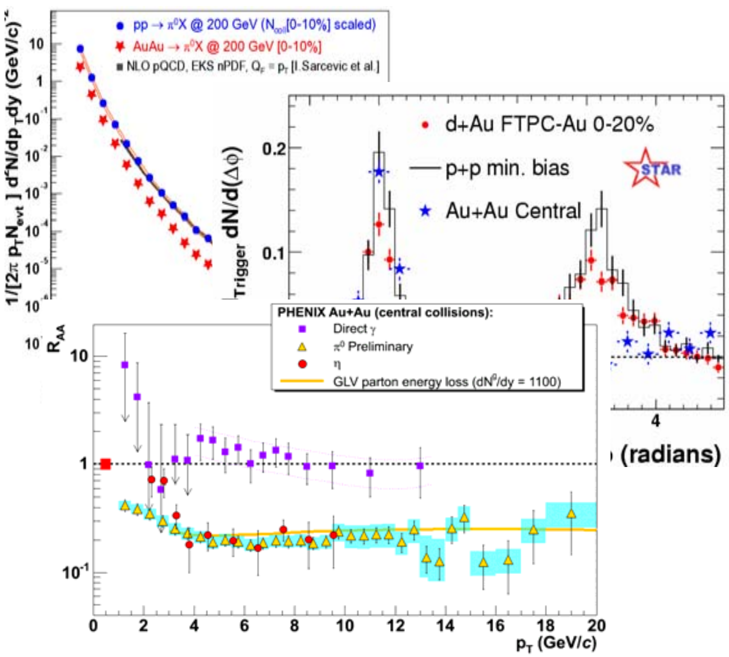
Jets:
what is different @ LHC

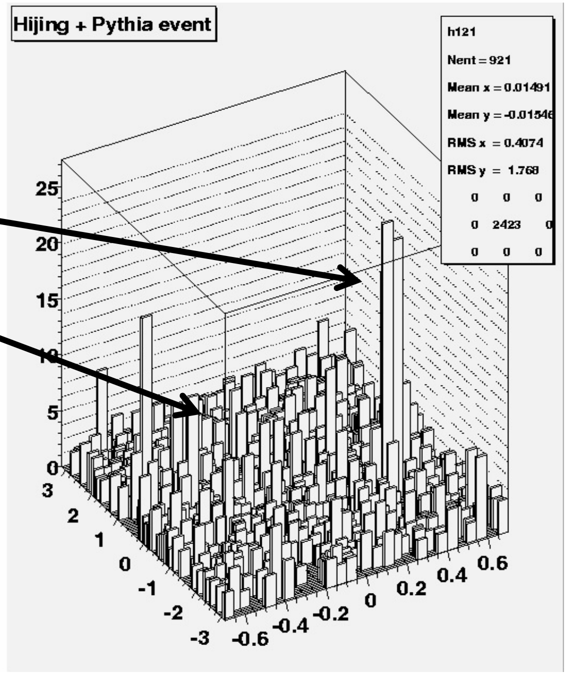
RHIC-like analyses — **20** — **Tevatron-like analyses** — **200** — E_t (GeV)

inclusive distributions

evt-by-evt reconstruction



100 GeV/c jet (PYTHIA)
Pb+Pb (HIJING)



dN/dp_t, R_{AA}, R_{cp}, $\Delta\Phi$ with unlimited statistics

- jet energy
- parallel & perpendicular momentum dist.
- tagging with photons
- fragmentation functions

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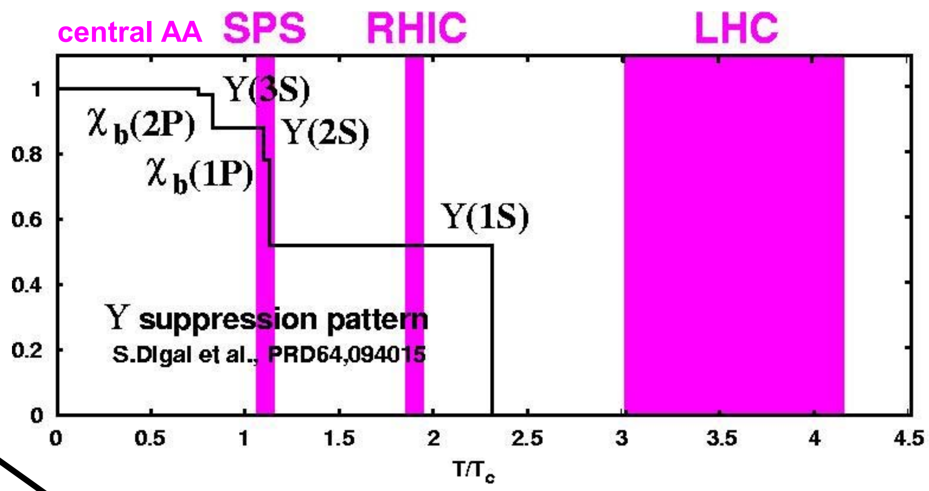
Heavy flavors:
what is different @ LHC

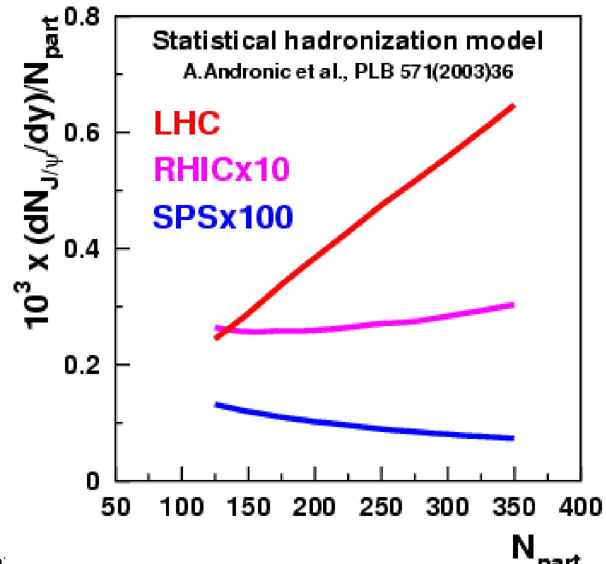
N($q\bar{q}$) per central AA (b=0)

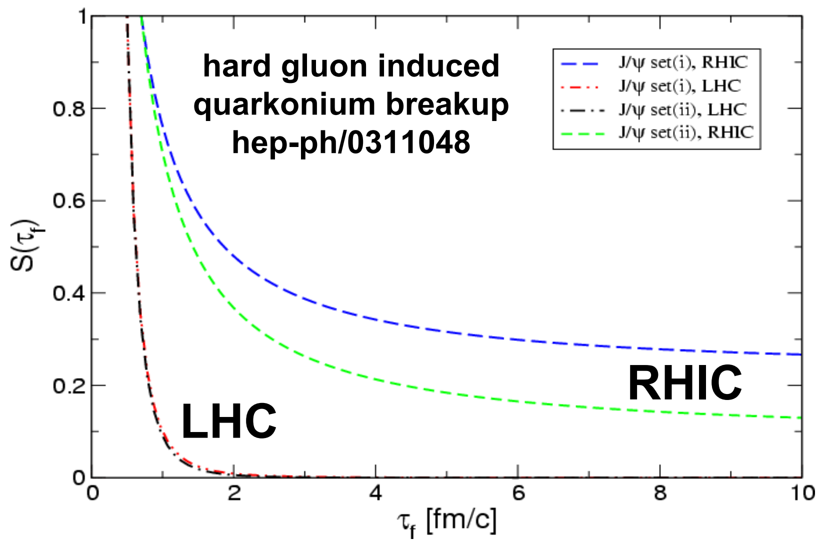
	SPS	RHIC	LHC
charm	0.2	10	130
bottom	---	0.05	5



- large primary production
- melting of $\Upsilon(1S)$ by color screening
- none of the primary J/ψ survives the (PbPb)QGP
- a lot of charmonia from b hadron decay
- large secondary production of charmonia

statistical hadronization, kinetic recombination, DD annihilation





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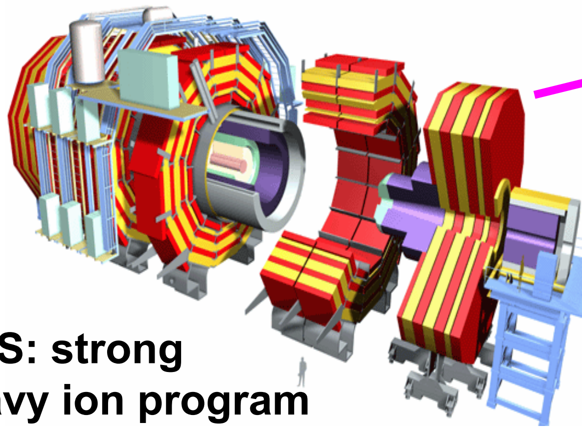
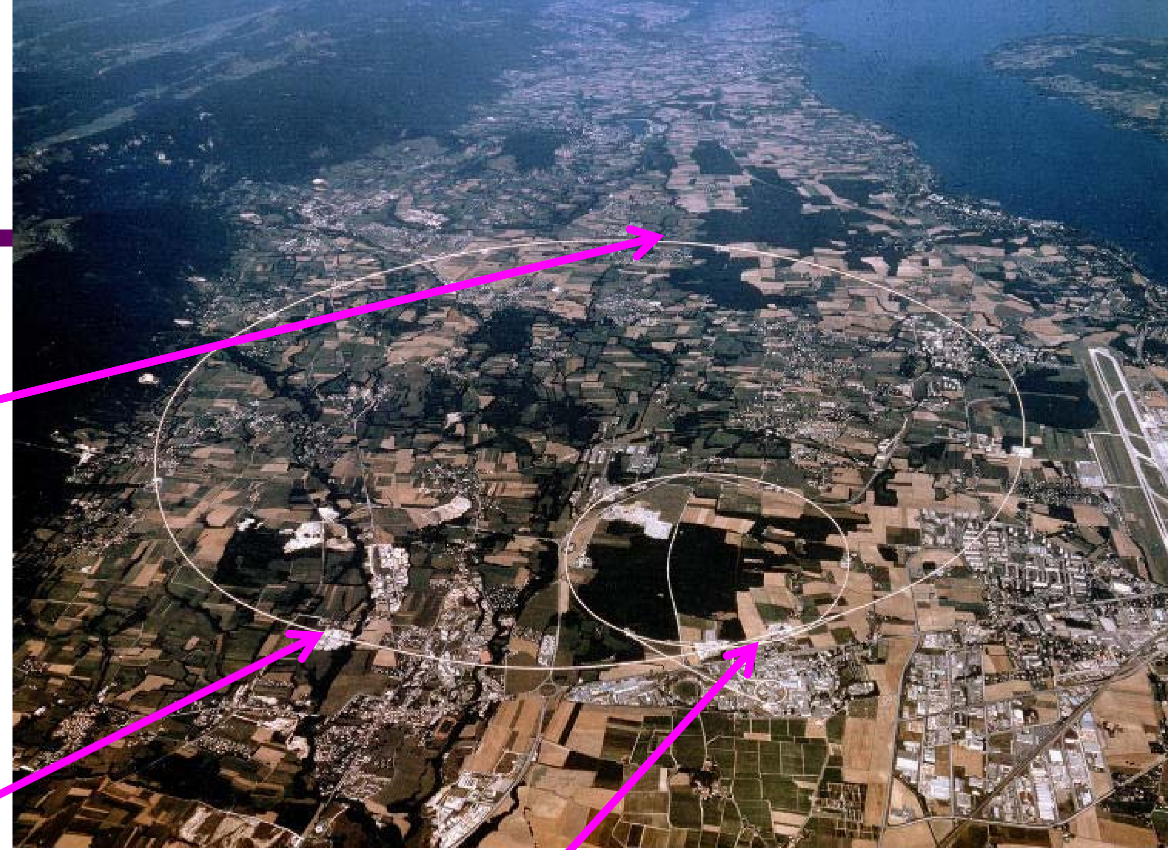
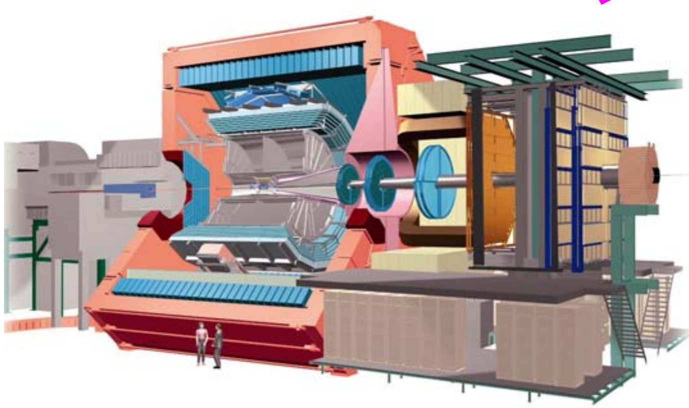
Heavy ions @ the LHC

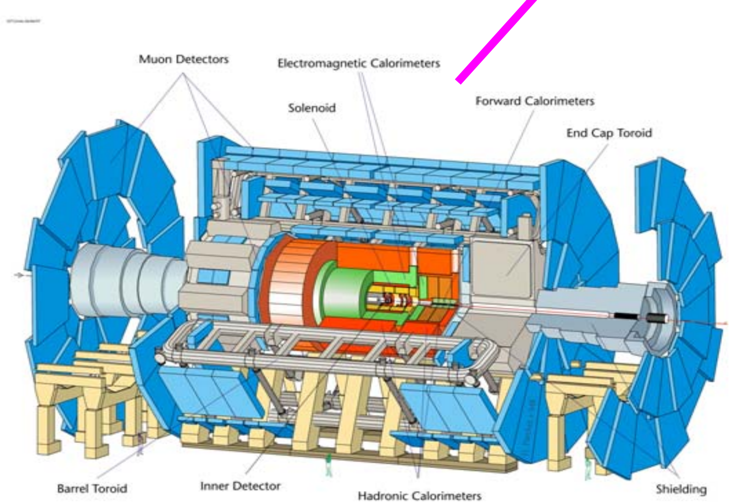


CMS: strong heavy ion program





ALICE: the dedicated heavy ion experiment



ATLAS: heavy ion LOI (2004)

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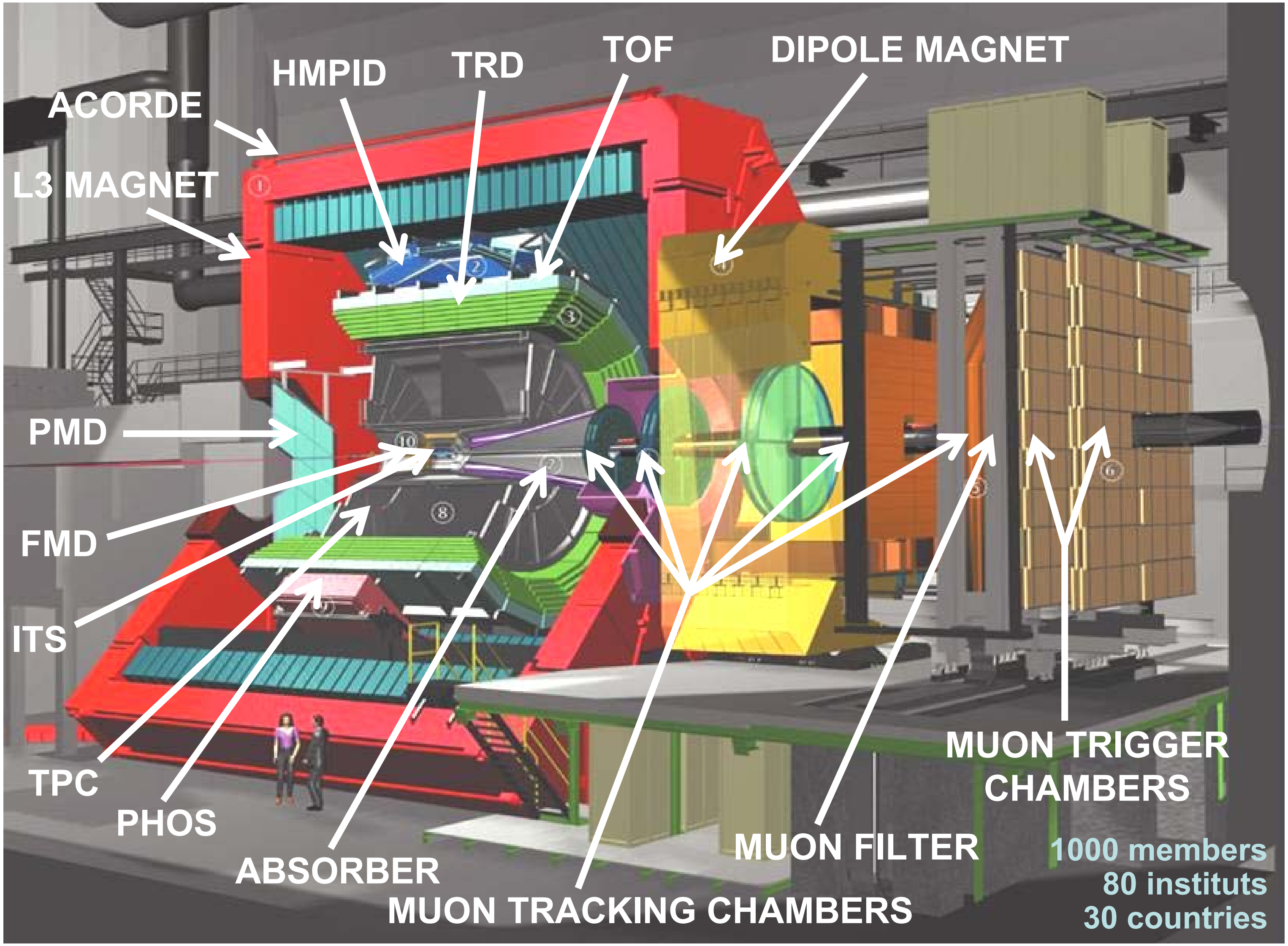
ALICE (A Large Ion Collider Experiment):
7(4) SPS(RHIC) experiments in one



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ALICE shopping list

time →

hard scattering

- hard photons
  ⇨ pQCD
- heavy flavors
  ⇨ pQCD
- jets
  ⇨ pQCD

deconfinement

- thermal photons
  ⇨ QGP temperature
- heavy flavors
  ⇨ QGP properties
- jet quenching
  ⇨ QGP density

hadronization

- EbyE fluctuations
  ⇨ critical behavior
- l.m. dilepton, DCC
  ⇨ chiral symmetry
- exotica
  ⇨ QGP condens.

freeze-out

- particle yields, spectra, flow & HBT
  ⇨ thermal & chemical conditions
  ⇨ dynamical evol.
  ⇨ indirect info from the early stage

← p_t

ALICE is designed to explore a broad p_t range and to correlate most of the signals

large acceptance, excellent granularity, selective triggers, good tracking capabilities, wide momentum coverage, good secondary vertex reconstruction, hadron, lepton & photon identification

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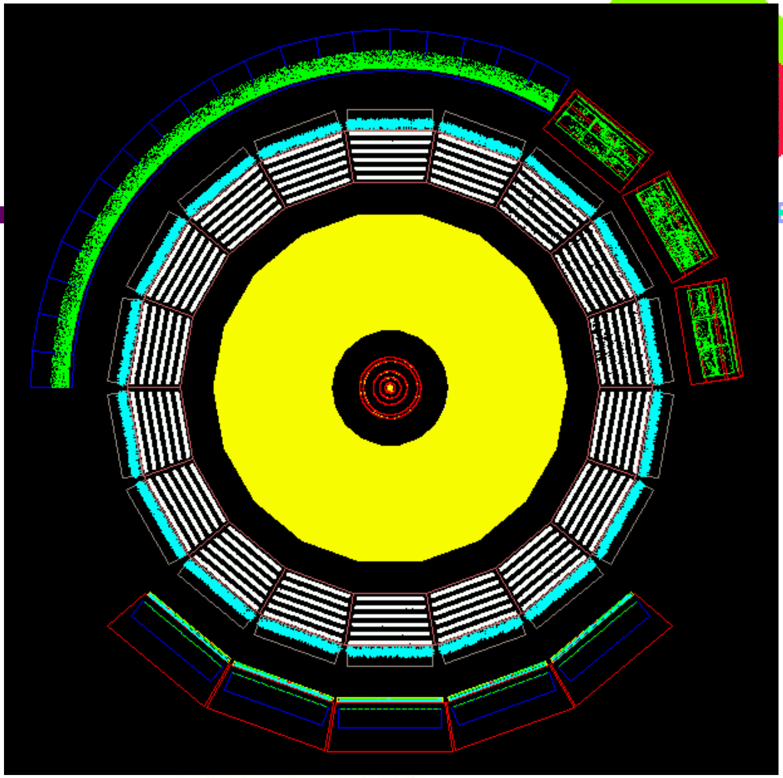
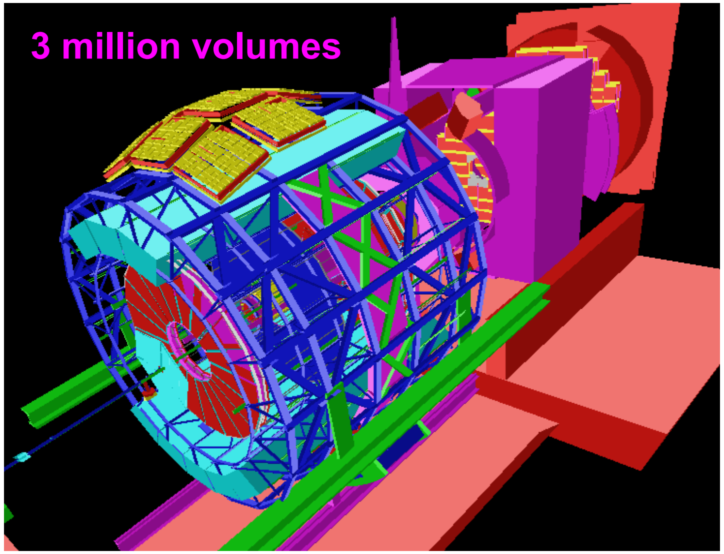
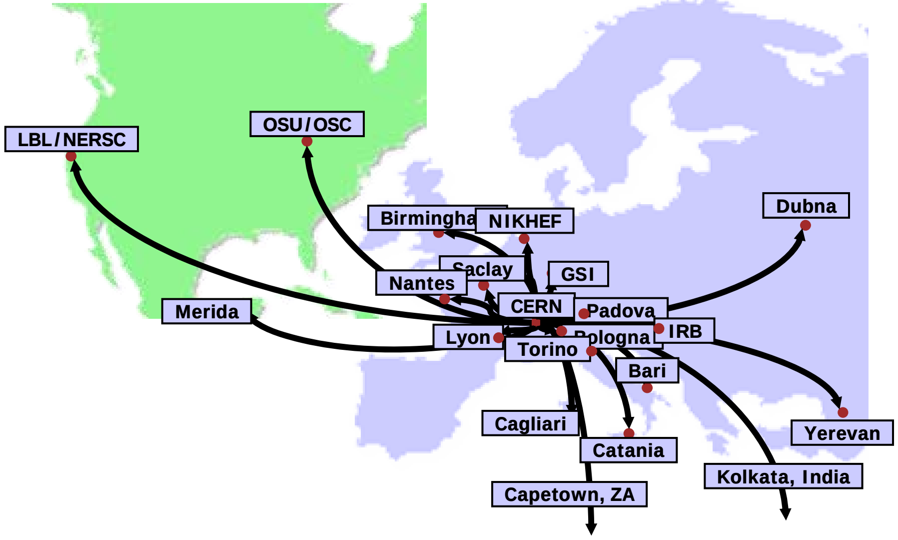
ALICE in facts

- ALICE uses (almost) all known particle detection techniques
- largest TPC, TRD & warm dipole ever built
- up to 10 000 particles per central Pb+Pb event in the central part
- data taking rate: 1.2 GB/s (~ 1 PB/month)
- software: 600 kLoC
- data analysis & storage is world distributed







ALICE collaboration, J. Phys. G 30 (2004) 1517

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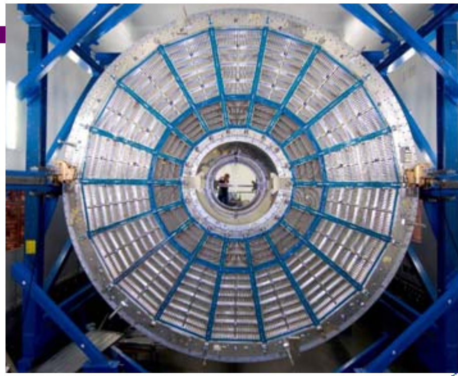
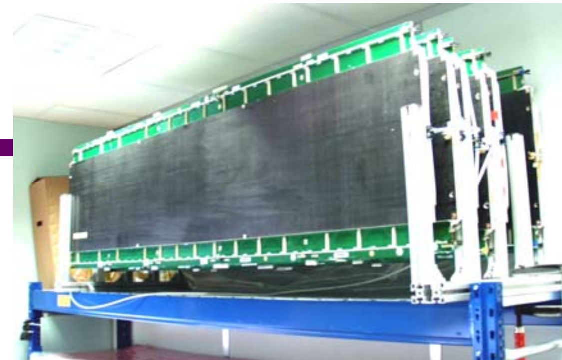
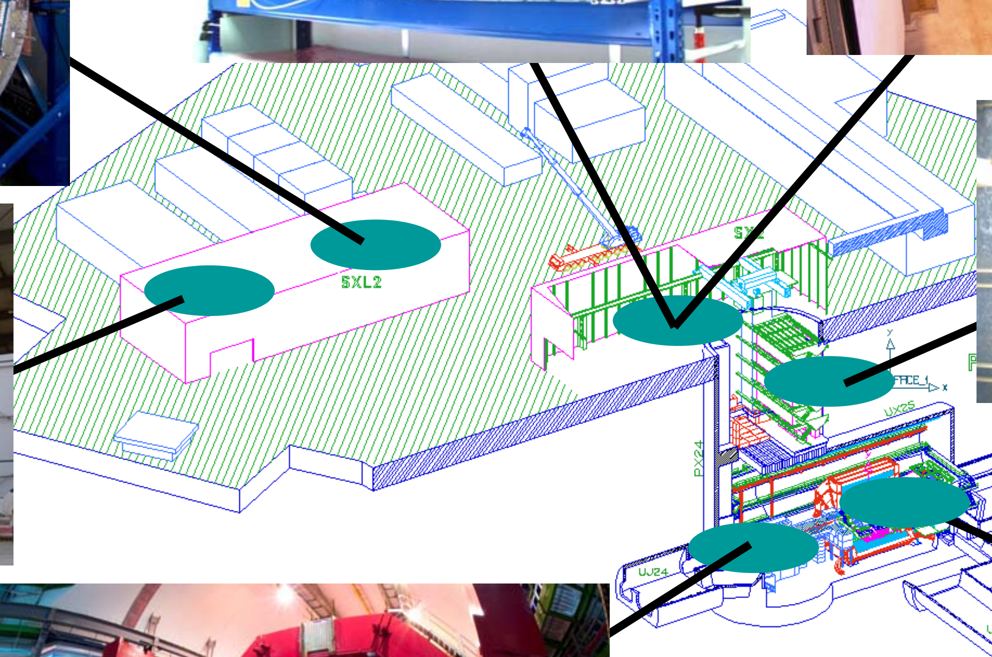
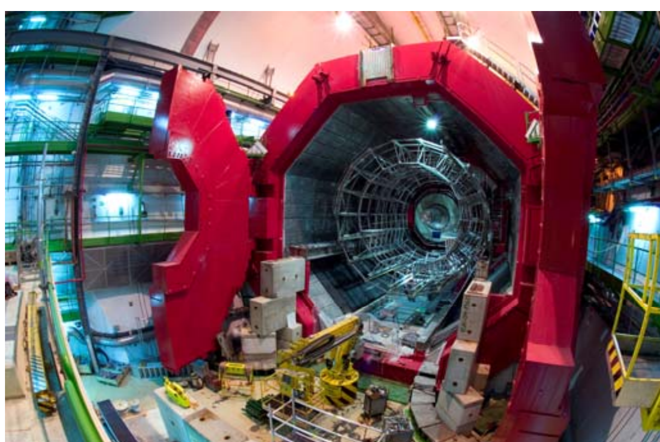
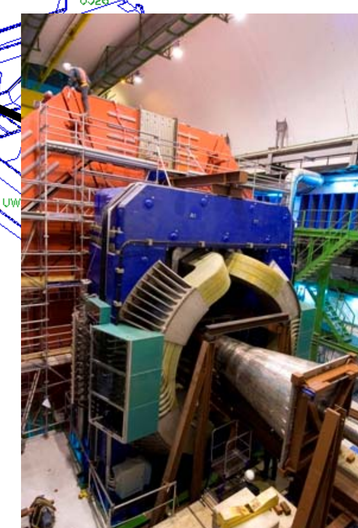
ALICE today











L. Leistam, IR3, updated

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Instead of a summary, what will happen next year

2007					2008						
Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	July
	10 weeks pp				shut-down			pp high L, 1^{st} PbPb…			

machine closure
set-up, injection

first physics run!

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