VACUUM AND HADRON STRUCTURES
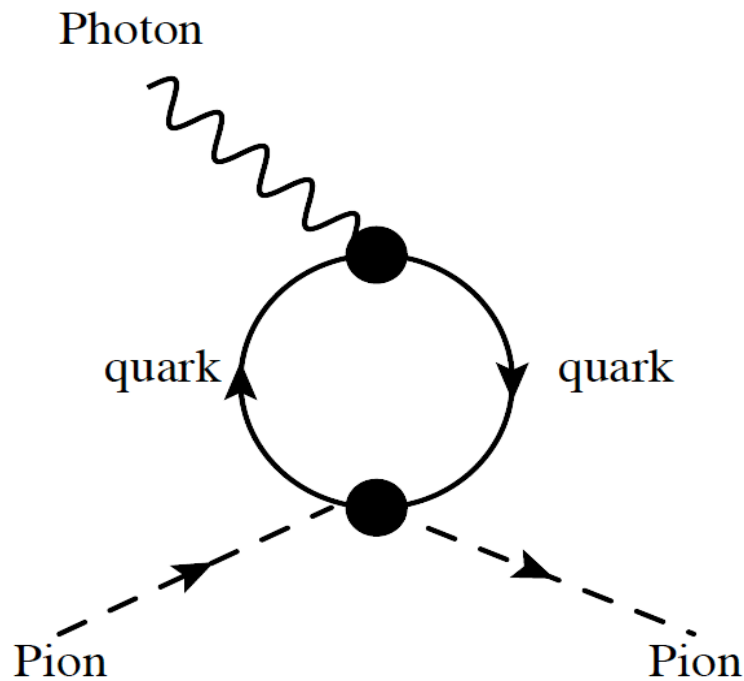
Investigations on hadron properties

EM & decay form factors, wave functions

Photon

quark   quark

Pion   Pion

Pion EM form factor

S.i.N. et al, PRD77 (2008)

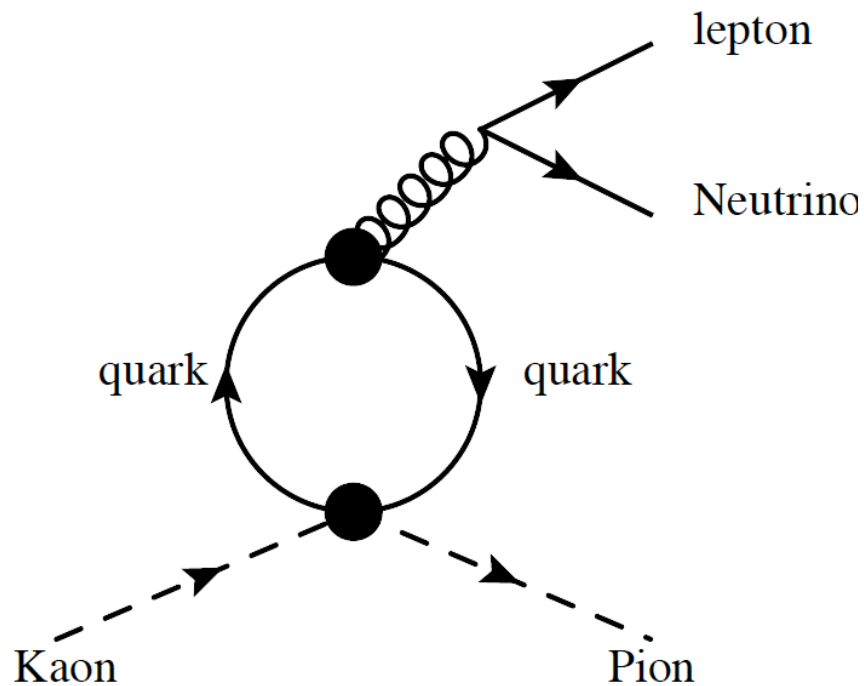|	Local	Nonlocal	Total	Exp. [56]
$\langle r^2 \rangle^{1/2}_{\pi^+}$ [fm]	0.594	0.319	0.675	0.672 ± 0.008

VACUUM AND HADRON STRUCTURES

Investigations on hadron properties

EM & decay form factors, wave functions

Kaon semileptonic decat form factor

S.i.N. et al, PRD75 (2007)

VACUUM AND HADRON STRUCTURES

Investigations on hadron properties
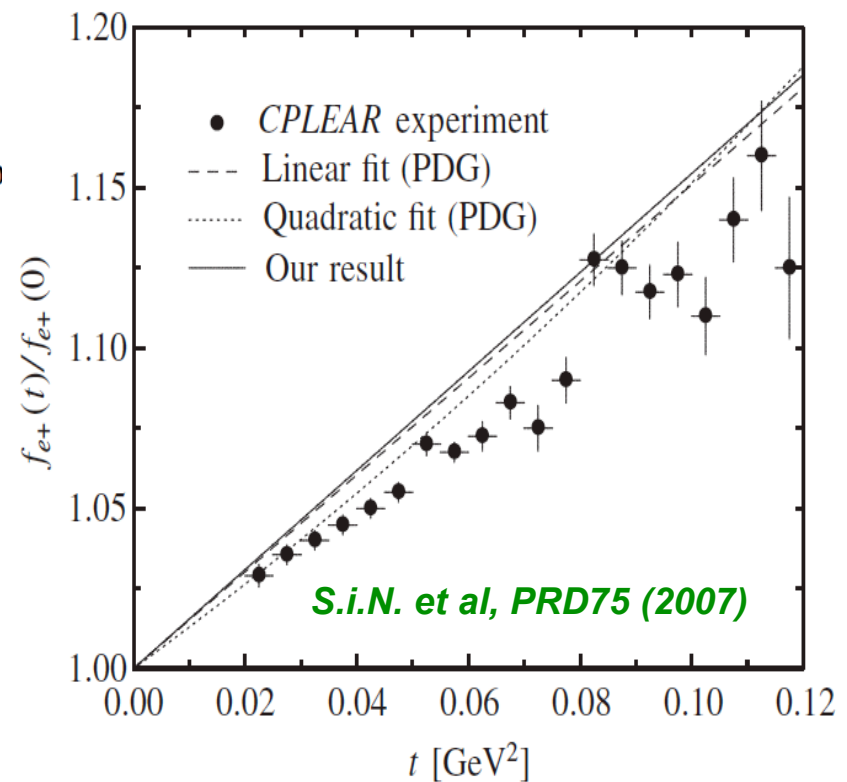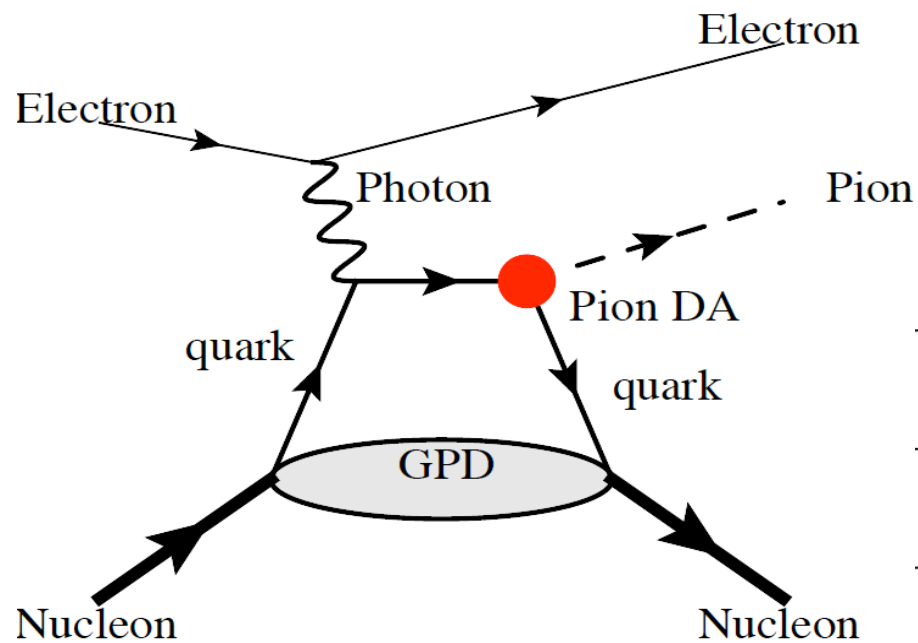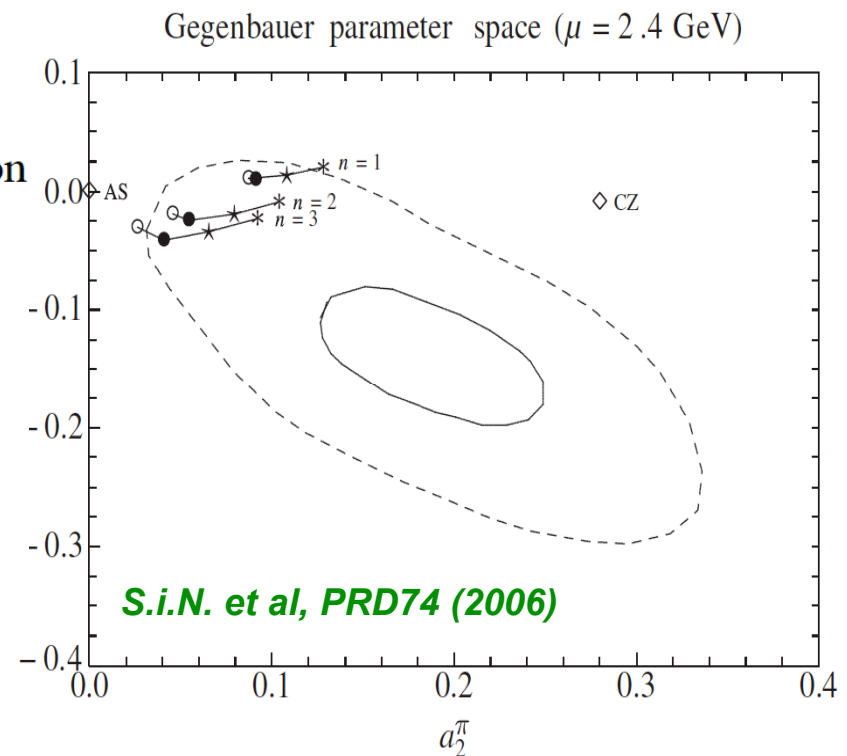
EM & decay form factors, wave functions

Deep inelastic scattering (DIS)
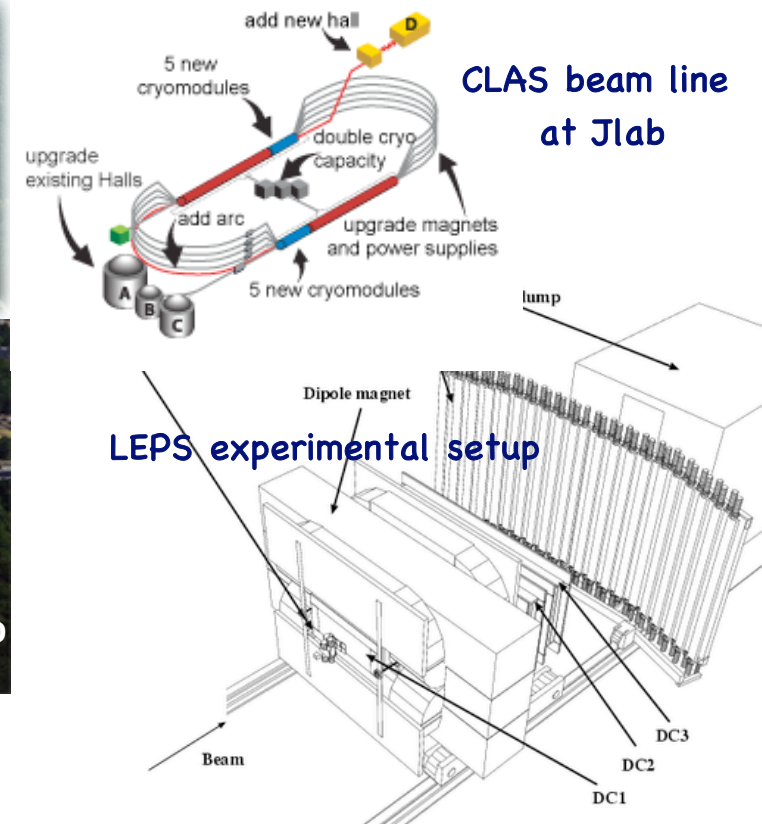
Gegenbauer parameter space ($\mu = 2.4$ GeV)

S.i.N. et al, PRD74 (2006)

HADRON REACTION

Hadron-production experiments

Energy scale ~ a few GeV

CLAS, LEPS, CB-ELSA, GRAAL, COSY..

SPring-8

CEBAF

Jefferson lab

Photon-beam experimental facilities

add new hall

5 new cryomodules

upgrade existing Halls

add arc

double cryo capacity

upgrade magnets and power supplies

5 new cryomodules

CLAS beam line at Jlab

LEPS experimental setup

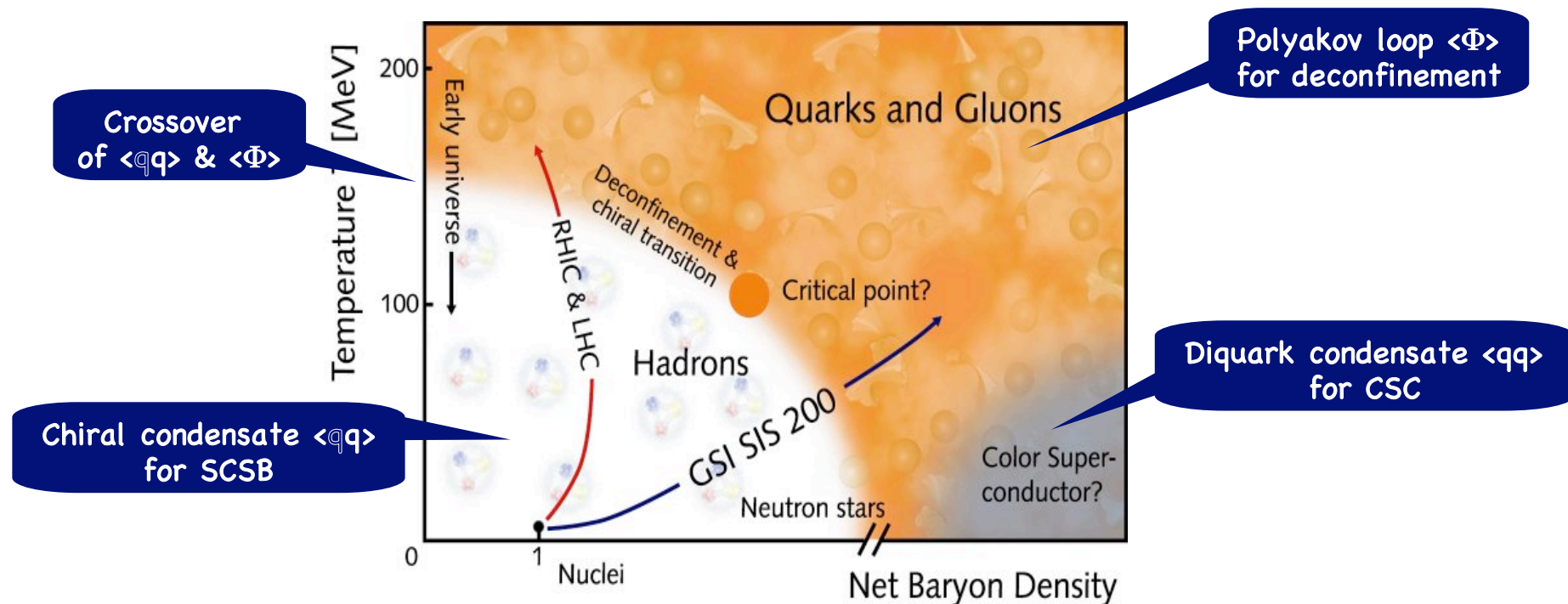Dipole magnet

lump

DC3

DC2

DC1

Beam

QCD at extreme conditions

QCD at extreme conditions (hot and/or dense)

Rich phase structures as function of T and ρ
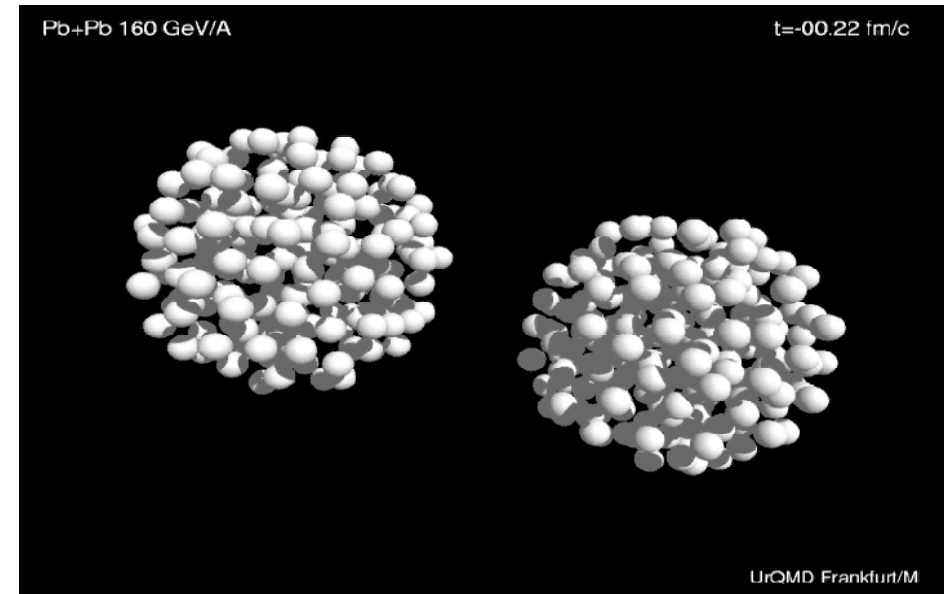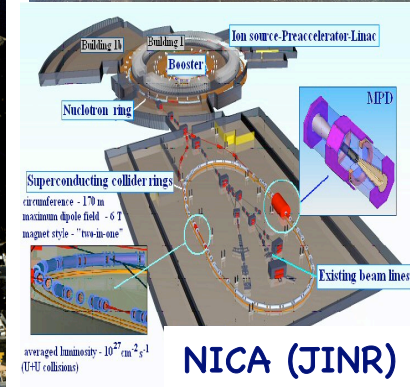
Behaviors of order parameters ~ Behaviors of symmetries

Polyakov loop $\langle\Phi\rangle$ for deconfinement

Crossover of $\langle\bar{q}q\rangle$ & $\langle\Phi\rangle$

Diquark condensate $\langle qq\rangle$ for CSC

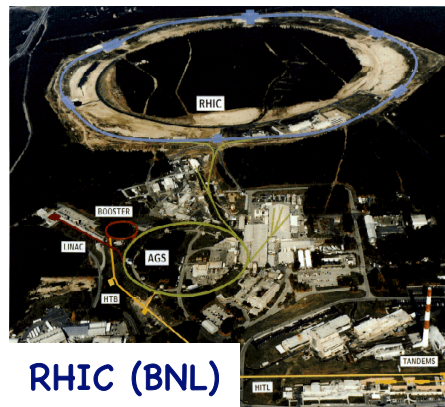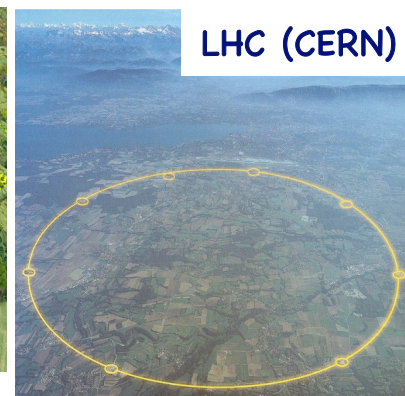Chiral condensate $\langle\bar{q}q\rangle$ for SCSB

QCD phase diagram as function of T and ρ

QCD at extreme conditions

Hot and/or dense **QCD** achieved in **H**eavy-**I**on **C**ollision (**HIC**)

RHIC, FAIR, LHC, NICA, KoRIA, etc

QGP, CGC, Jet quenching, Higgs, and more

FAIR (GSI)

LHC (CERN)

Pb+Pb 160 GeV/A   t=-0.22 fm/c

UrQMD Frankfurt/M

RHIC (BNL)

NICA (JINR)

Pb-Pb peripheral scattering animation (RHIC)
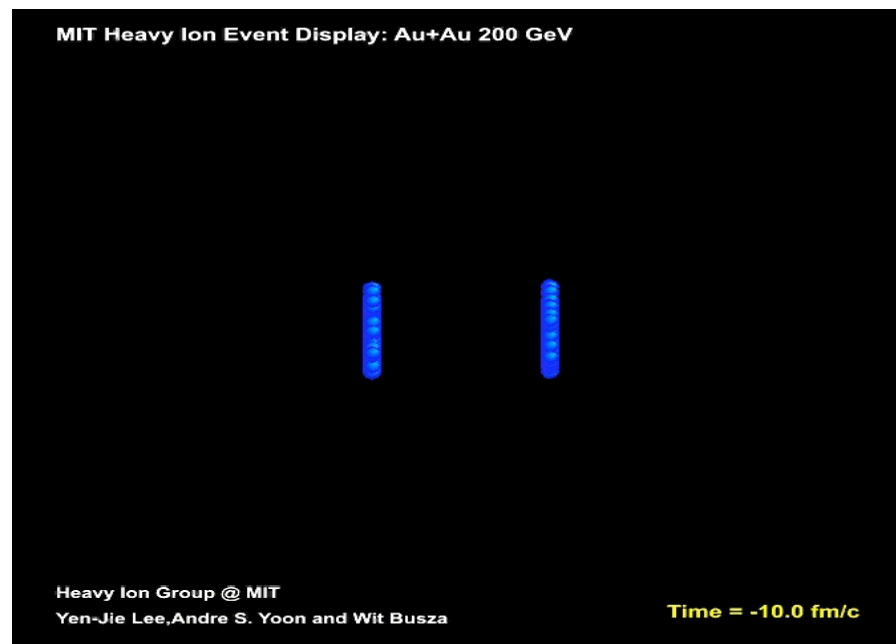
White: Hadron, Red/Green/Blue: Quarks

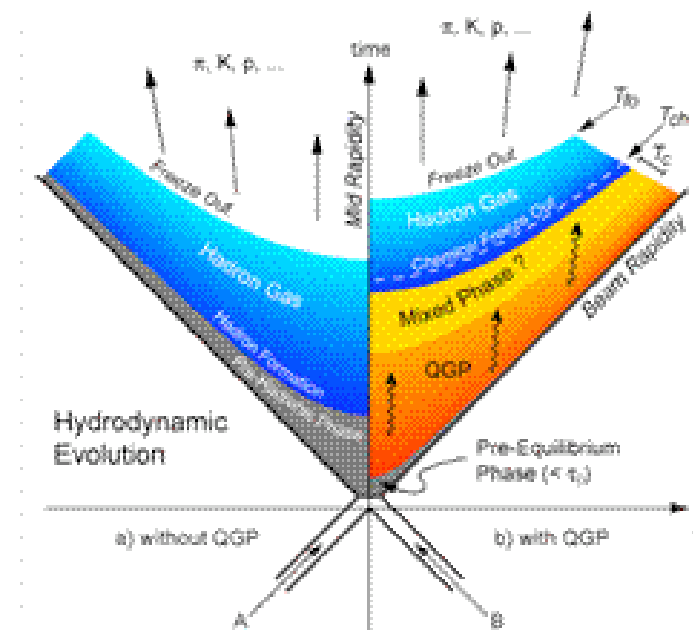**Heavy-ion collider in the world**

QCD at extreme conditions

Quark-Gluon Plasma (QGP): Deconfined quarks and gluons

A good place to study QCD

Chiral Magnetic Effect (CME) ~ QCD vacuum
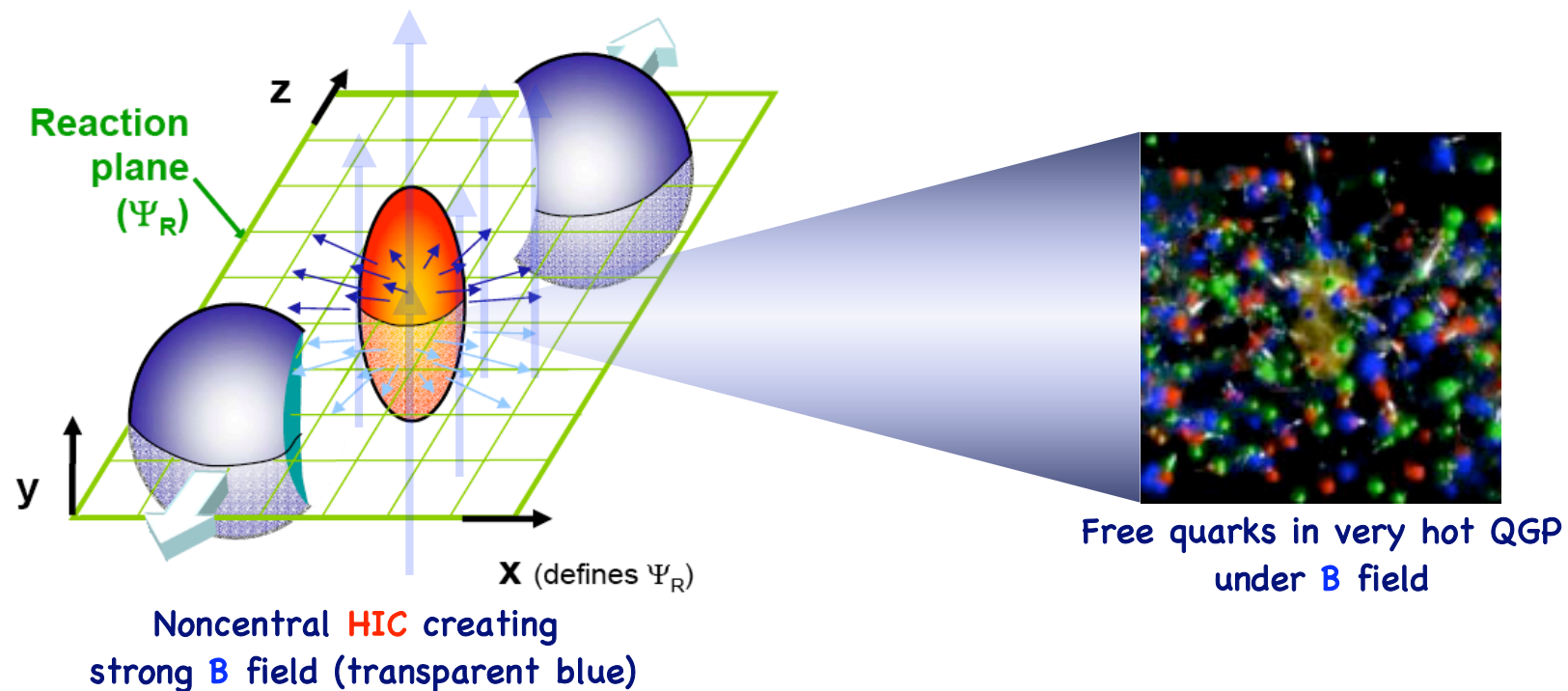

Fire ball (QGP) created in head-on HIC

HIC without (left) and with (right) QGP

QCD at extreme conditions

Strong B field created in noncentral HIC ~ 10^{17} Gauss

Emergence of free quarks in hot QGP with B field
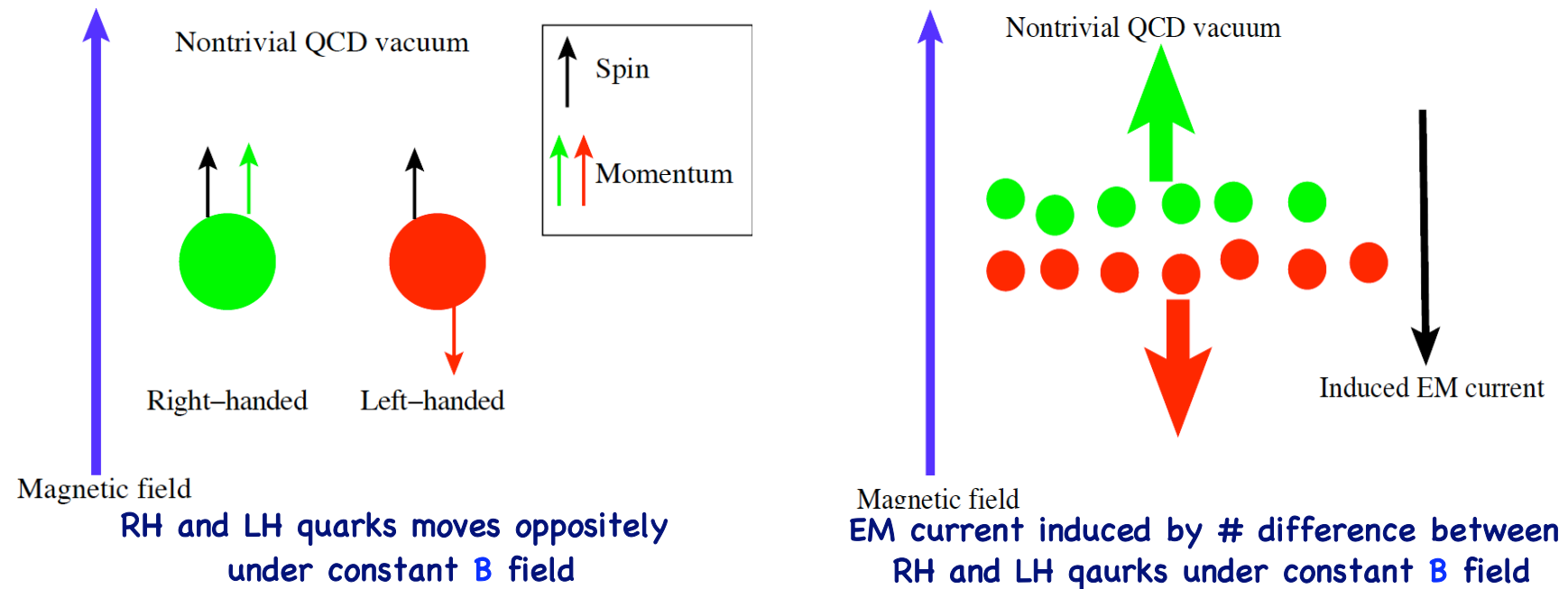
Event-by-event phenomena: very instantaneous!!

Reaction plane (Ψ_R)

z

y

X (defines Ψ_R)

Noncentral HIC creating
strong B field (transparent blue)

Free quarks in very hot QGP
under B field

QCD at extreme conditions

Free-quark spins aligned to B field (σ // B)

According to Helicity (Chirality at m ≈ 0), Left-handed and Right-handed quarks in opposite directions

What if numbers of LH and RH are different?: EM current induced

RH and LH quarks moves oppositely under constant B field

EM current induced by # difference between RH and LH qaurks under constant B field

QCD at extreme conditions

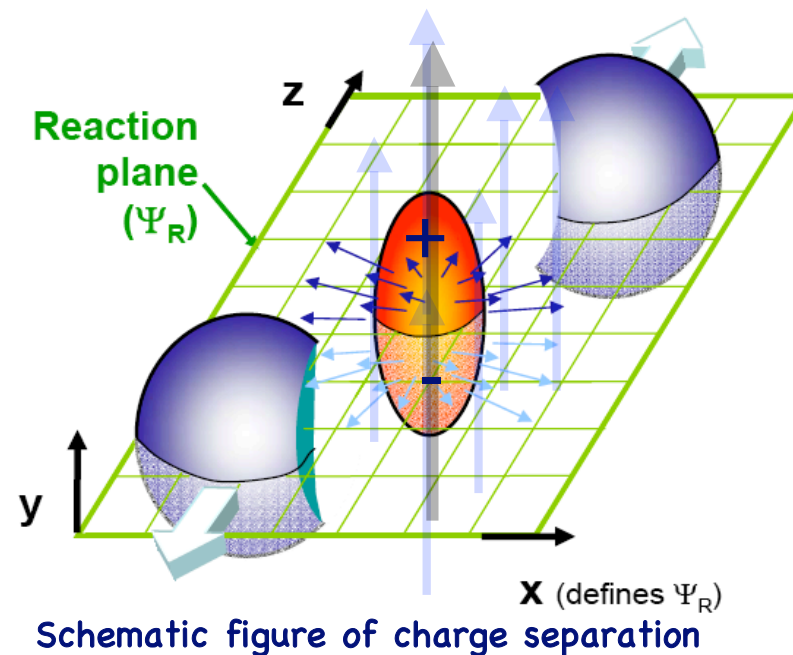Axial identity $Q_t \propto N_R - N_L$ relates to P- & CP- violations

Nonzero Q_t indicates Redundant RH (LH) quarks

Q_t can be tested under strong B field in HIC

Chiral Magnetic Effect (CME)
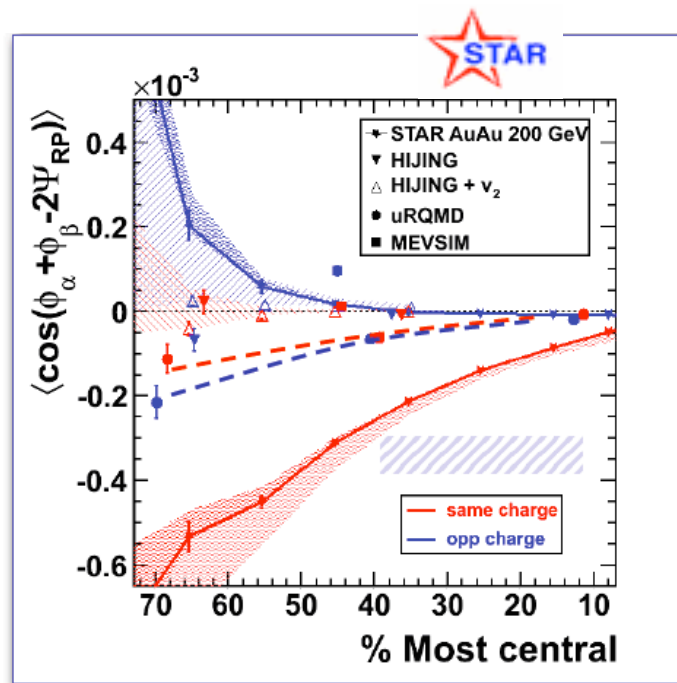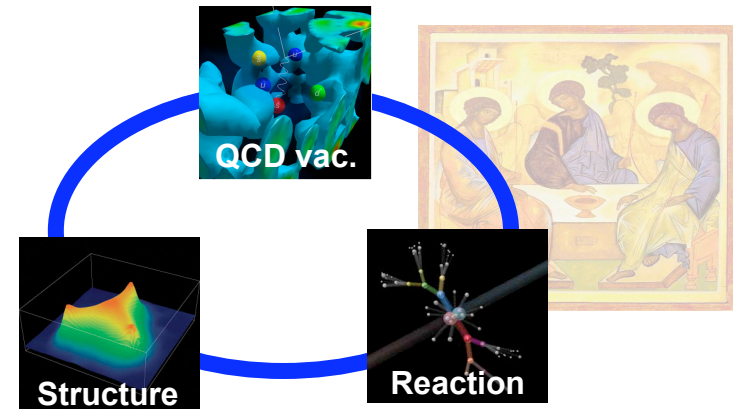

Charge separation
due to induced EM current

Schematic figure of charge separation

QCD at extreme conditions

Instanton-Antiinstanton number difference ~ $\Delta^{I\bar{I}}$

$\Delta^{I\bar{I}} \sim$ Chirality flip $\sim \Delta^{RL} \sim Q_t$

Final remarks

In **QCD** we trust: the holy grail

Trinity of strongly interacting systems

i) **Vacuum** ii) **Structure** iii) **Reaction**

QCD vac.

Structure

Reaction

Finally..

Thank you very much for your attention!!