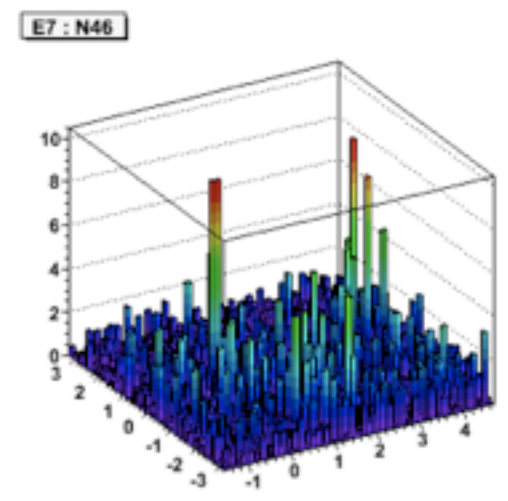
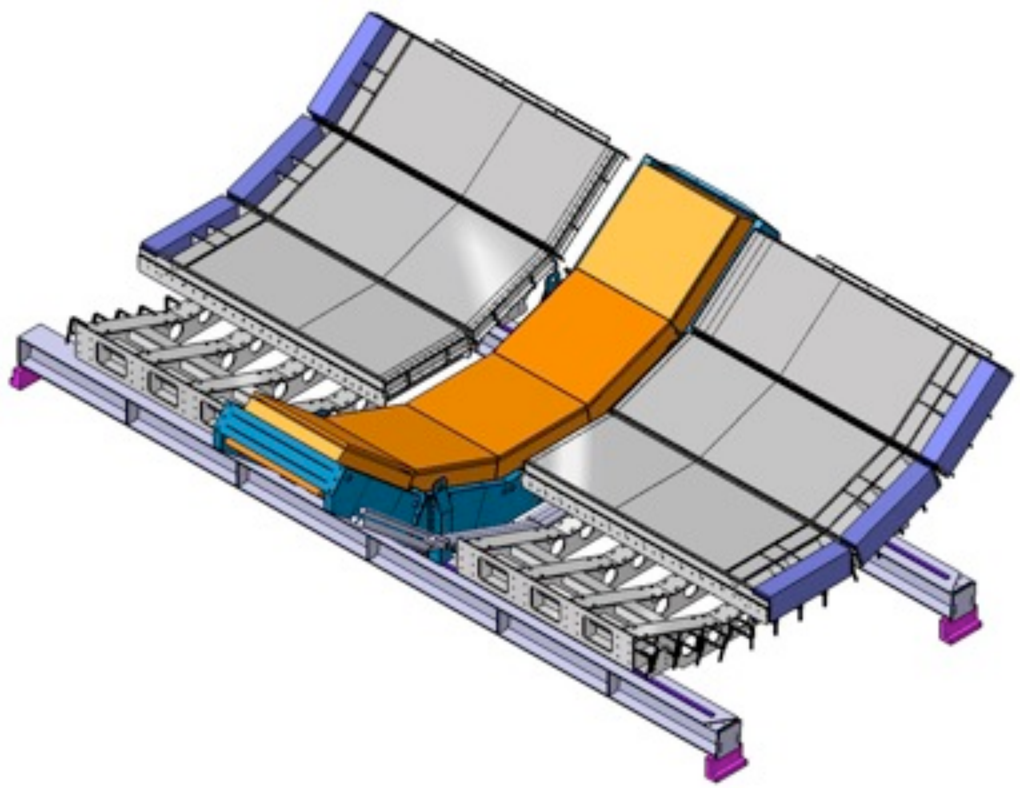
What we have learned at RHIC and homework to LHC

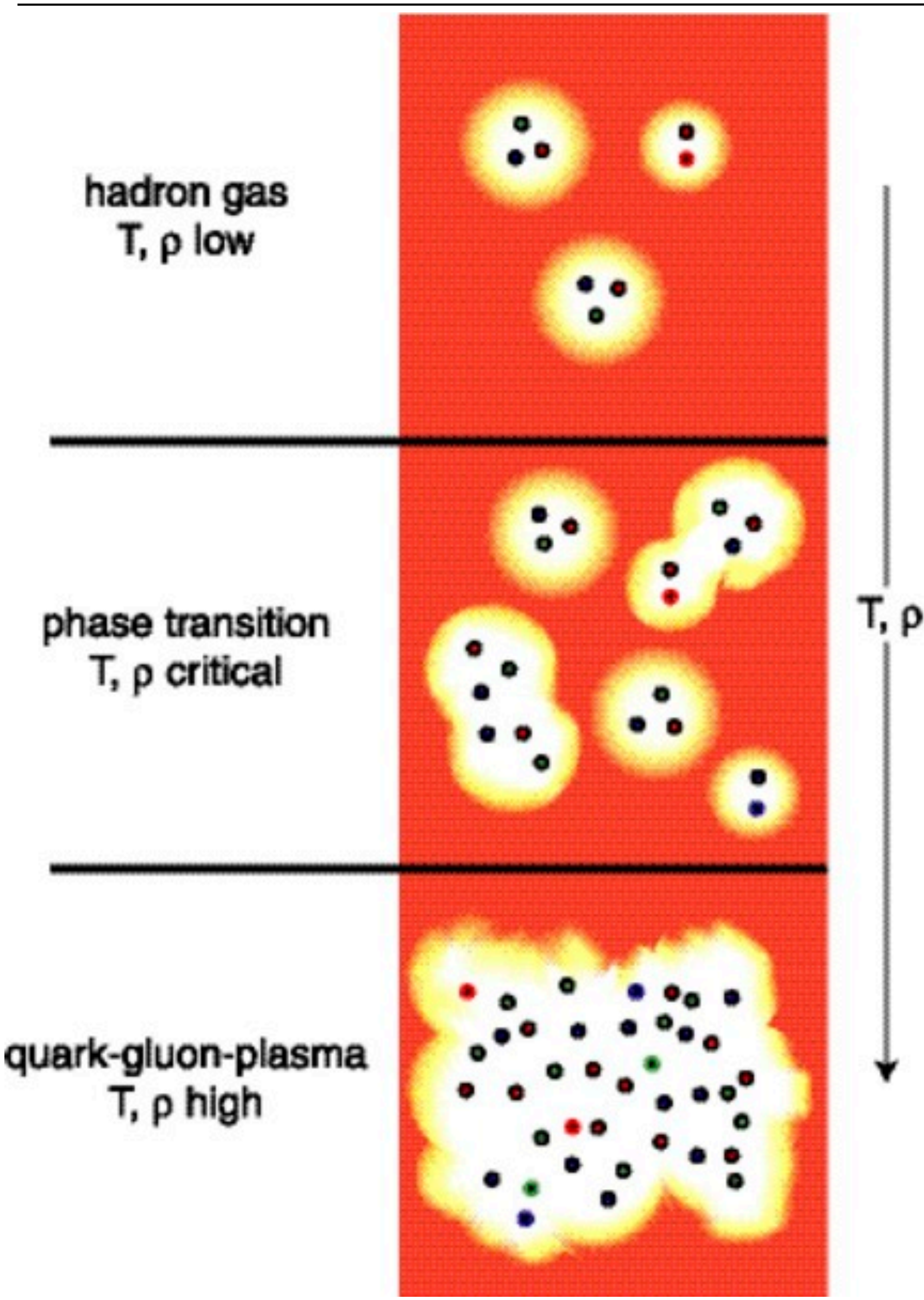


Success of soft physics and jet as a homework from RHIC to LHC

Yasuo MIAKE
Univ. of Tsukuba



Quark-Gluon Plasma

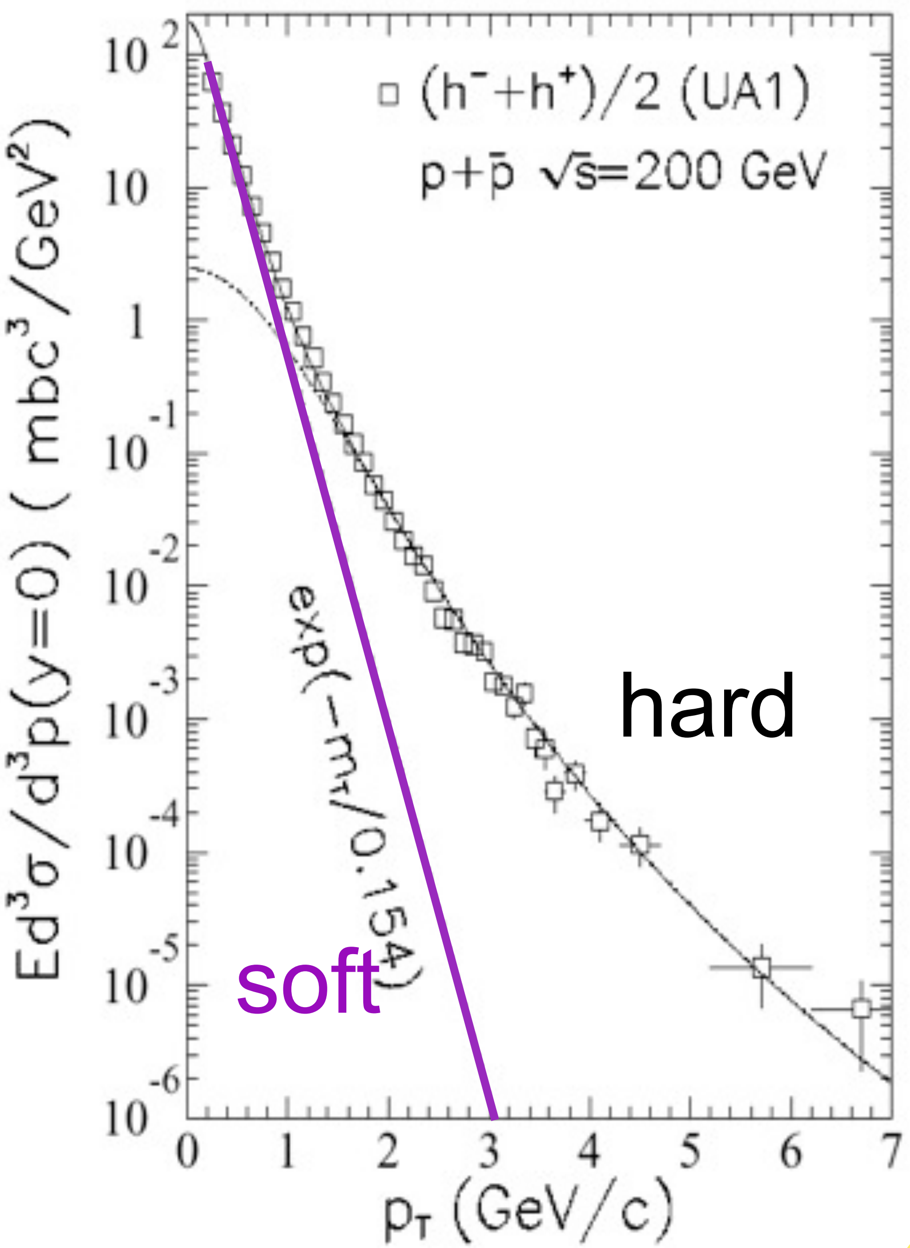


RHIC(200GeV)
since 2000

LHC(5.6TeV)
soon

- ✓ **Physics of QCD in extreme T, ρ and small x**
- ✓ **Nucleus-Nucleus collisions**
- ✓ **~ 10 years of RHIC running**

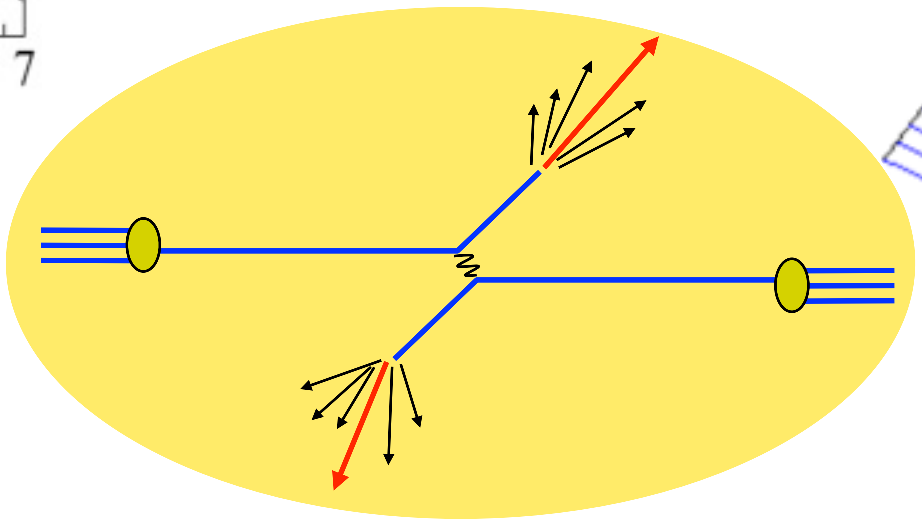
Soft & Hard comp. in pp

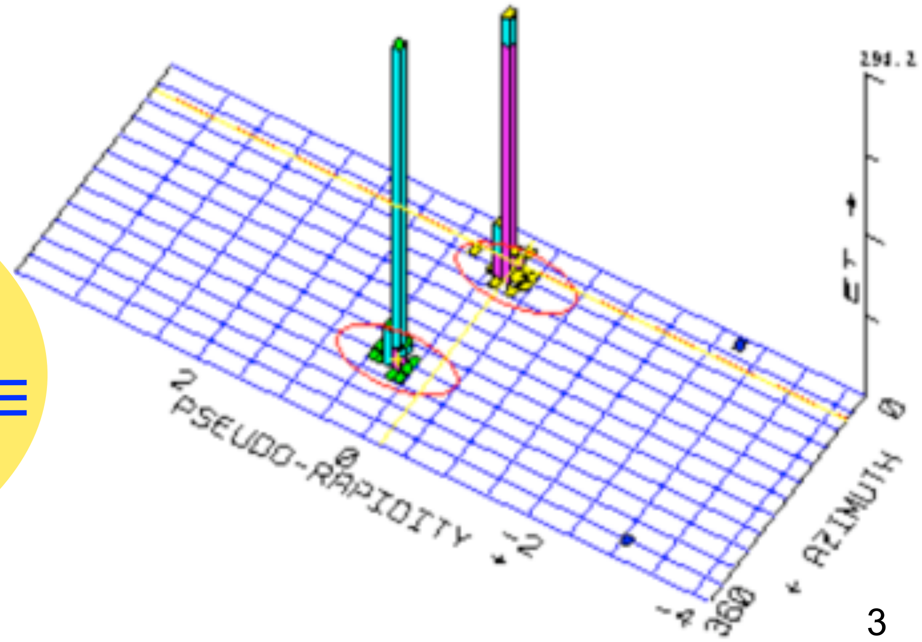


- ✓At ISR in 1972, deviation from the m_t scaling at high p_t region is observed as a first time.
- ✓Binary parton scattering followed by fragmentation produces back-to-back jet.
- ✓Main source of high pt particles.

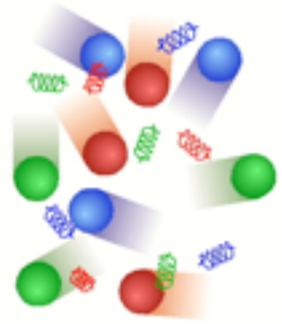
$$E\frac{d^3\sigma}{dp^3} = C_0 \exp(-\frac{m_t}{T_0}) + \frac{C_1}{(p_t + p_0)^n}$$

back-to-back jet



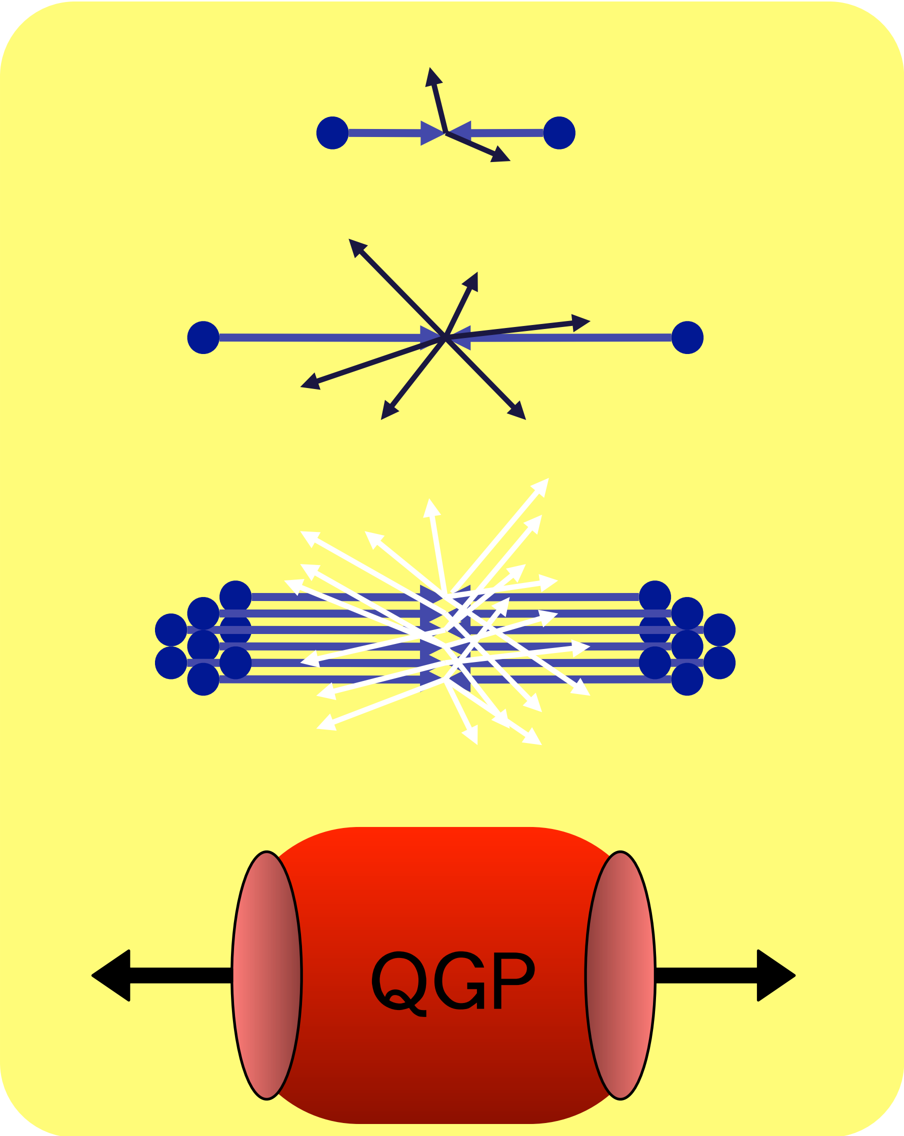


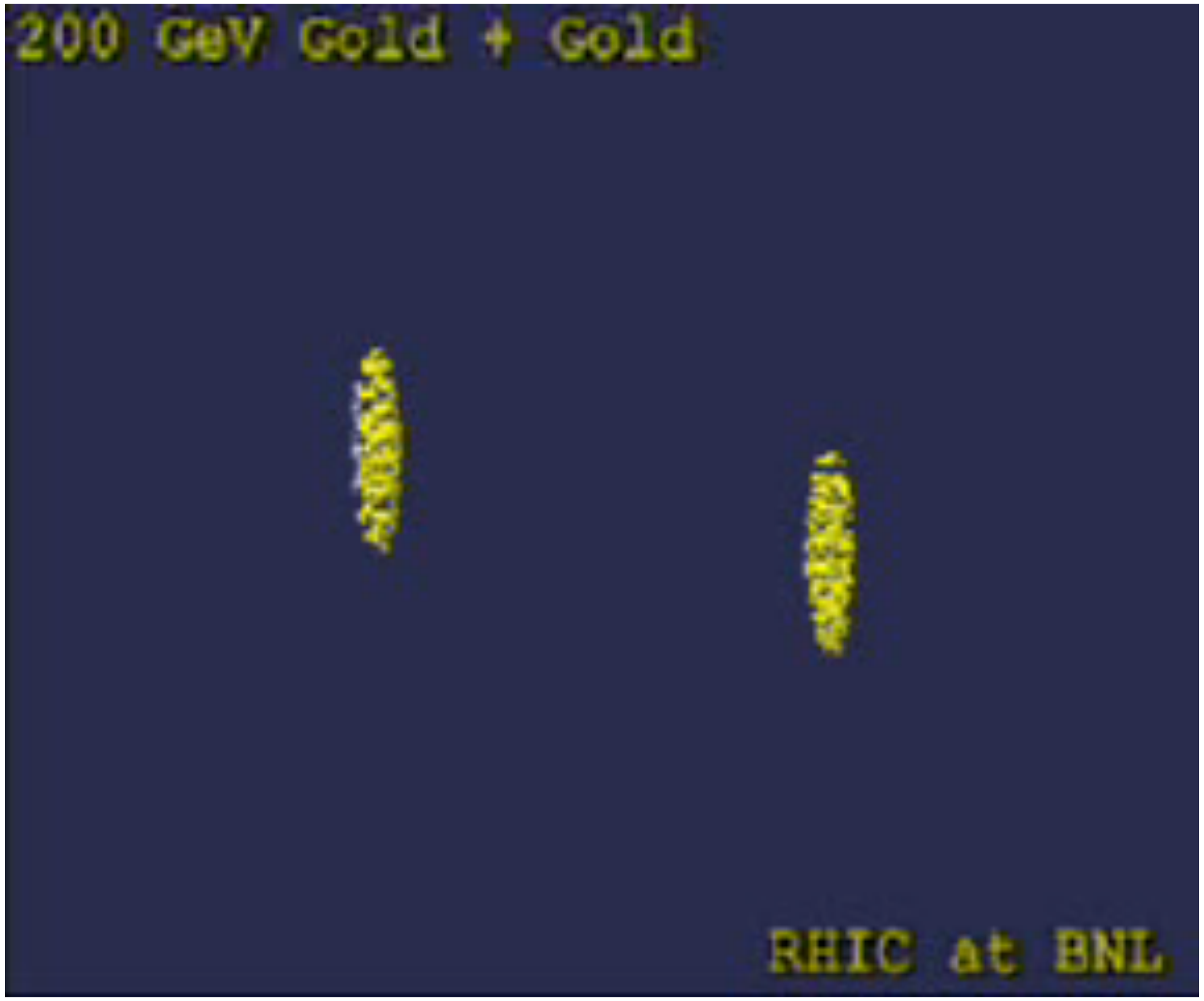
Outline



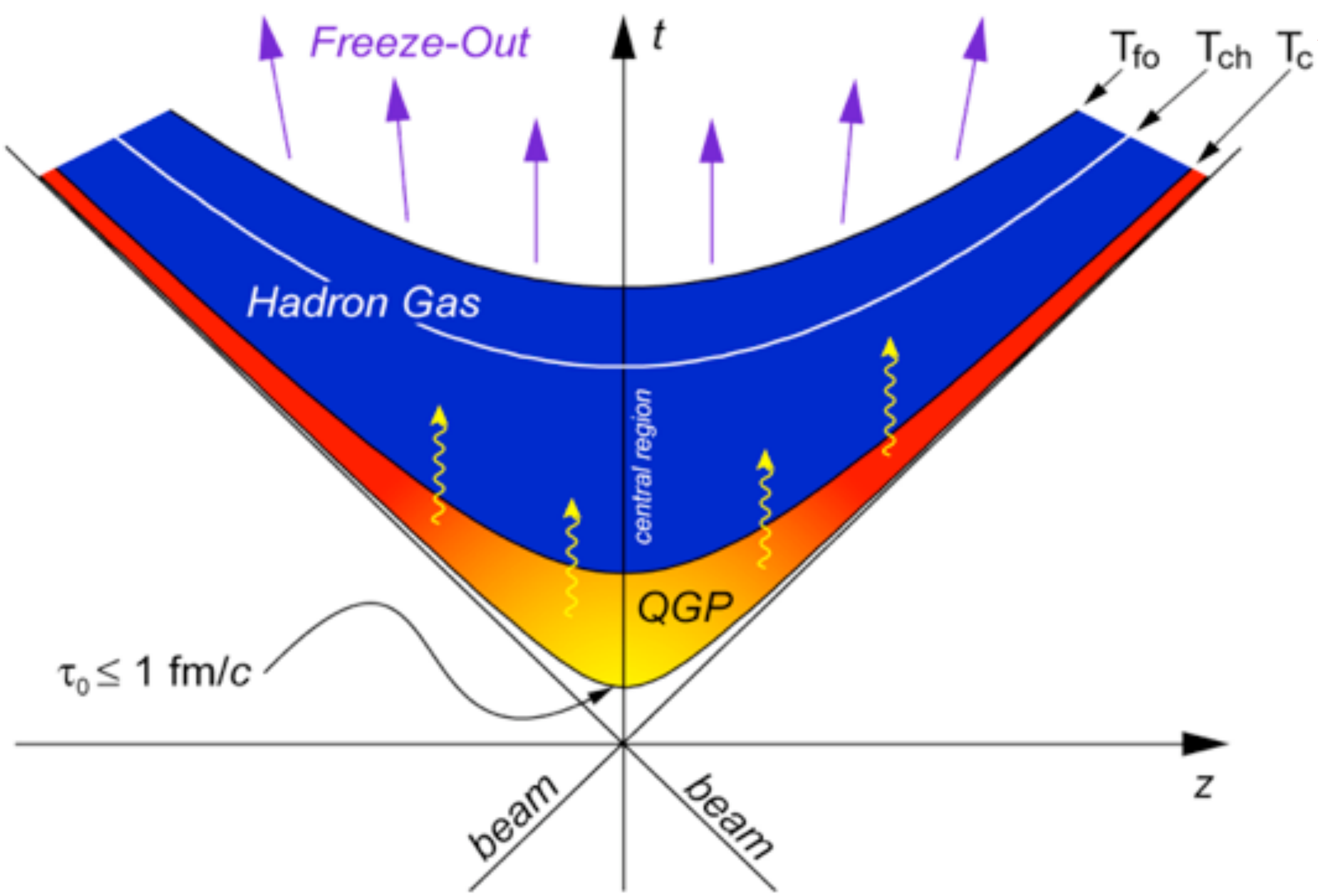
- ✓ Soft component and hard component
- ✓ RHIC
  - Soft physics
    - ➡well understood
  - Hard physics
    - ➡poor understanding
- ✓ RHIC vs. LHC
  - Expected property of QGP
  - Plenty of jets
- ✓ Physics of Jet quench
- ✓ Summary

Relativistic AA collision





Key 1; Time Evolution



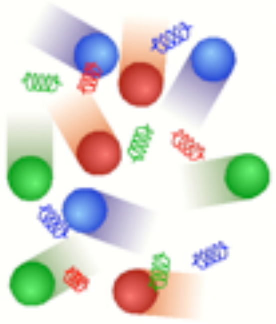
✓It is like Big Bang.

✓Time evolution in statistical nature

- Parton cascade followed by partonic thermalization (QGP)
- Hadron production
- Freezeout of v_2 ?
- Chemical freeze-out
- Kinematical freeze-out

Need consistent understanding of these epocs, in particular, aspects of statistical nature.

Key2 ; Statistical Nature



$$\epsilon_{\mathrm{QGP}} \sim 2\ [\mathrm{GeV/fm^3}]$$ ← **Ex. Lattice QCD**

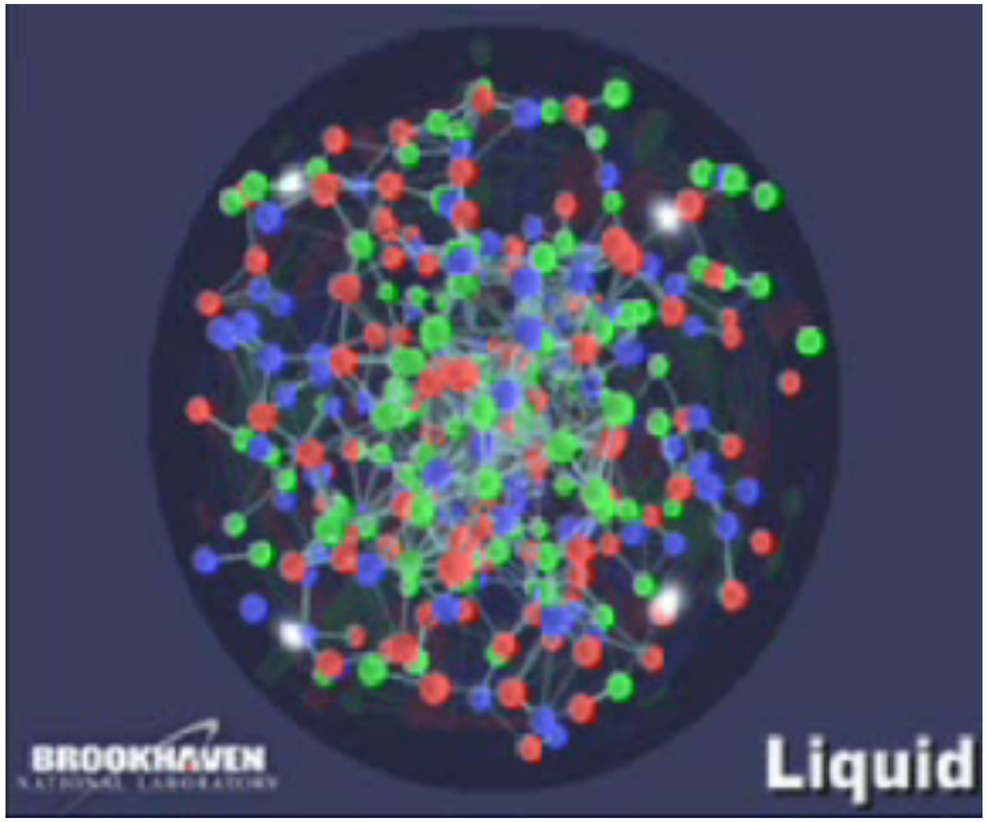
$$< n_{q,\bar{q}} > \sim \frac{\epsilon_{\mathrm{QGP}}}{< m_T >} \sim \frac{2\mathrm{GeV}}{1\mathrm{GeV}} \sim 5$$

$$\lambda_q = \frac{1}{n\sigma_{qq}}$$

$$\sim \frac{1}{5 \times 0.4} = 0.2\ [\mathrm{fm}]$$

$$\lambda_q \ll R_{\mathrm{system}}$$

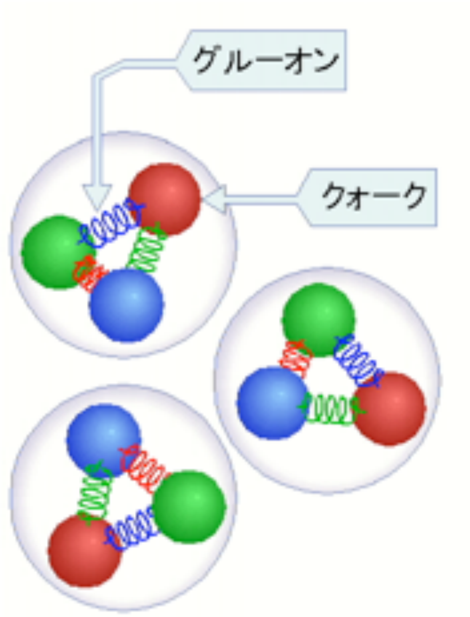
$$\because \sigma_{qq} \sim \frac{\sigma_{NN}}{n_{\mathrm{q}}} \sim \frac{4[\mathrm{fm}^2]}{3} \sim 1$$



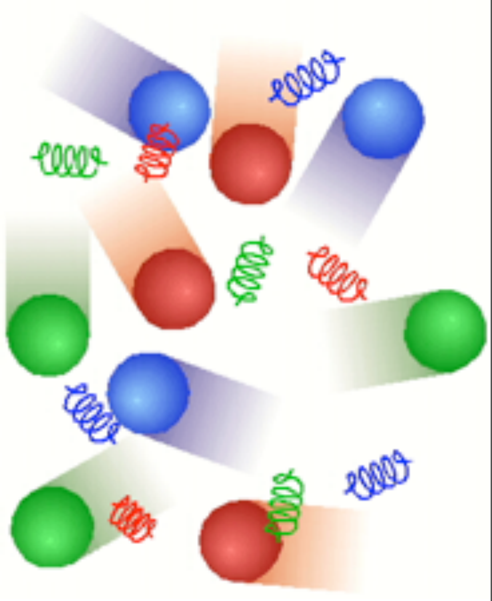
Animation by Jeffery Mitchell (Brookhaven National Laboratory). Simulation by the UrQMD Collaboration

✓ **What we expect,**

- **Statistical physics at quark level**
- **Hydrodynamical behavior at quark level**



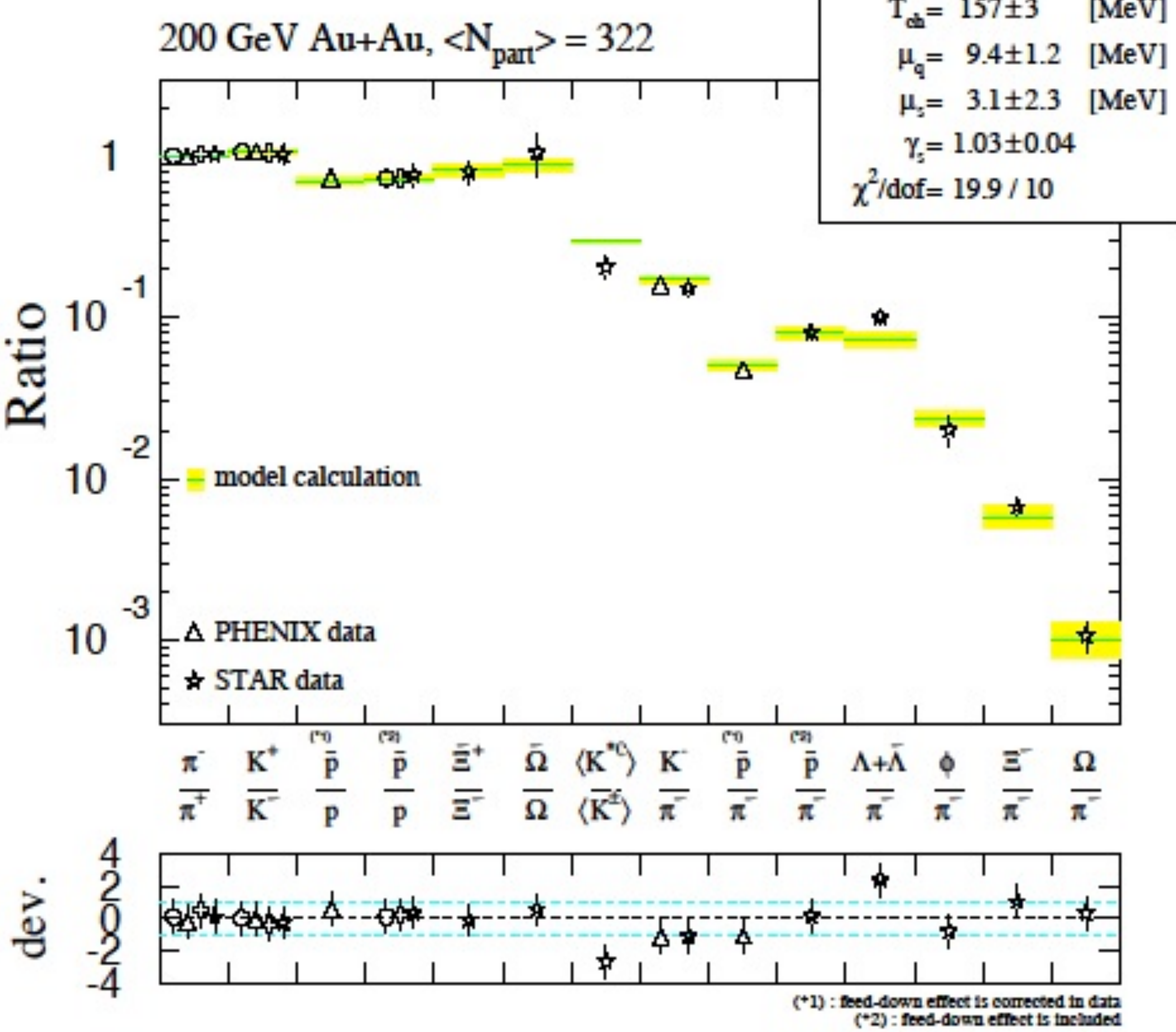
Soft comp.



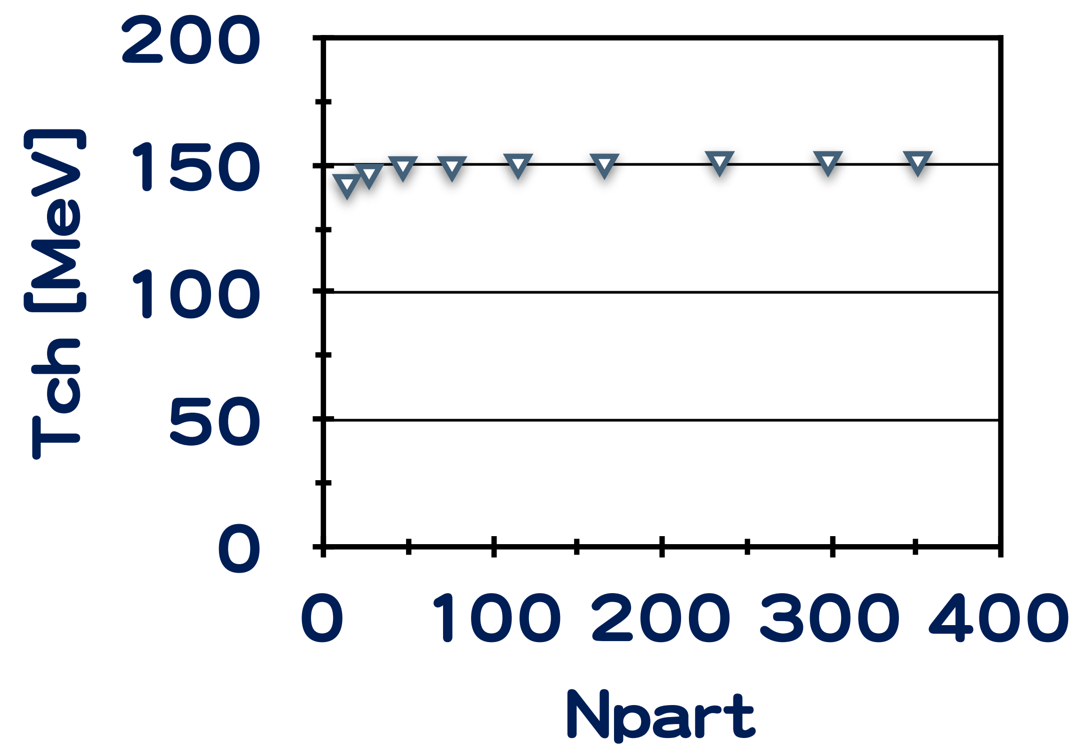
Statistical and Collective Nature characteristic to the QGP formation

Chemical Eq. from particle yield ratio

M.Kaneta, N.Xu, nucl-th/0405068



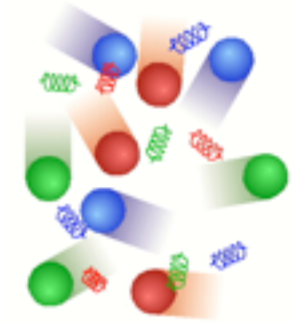
$$n_i = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 dp}{e^{(E_i-\mu_i)/T} \pm 1}$$



✓Only **few** parameters fit every ratio very well !

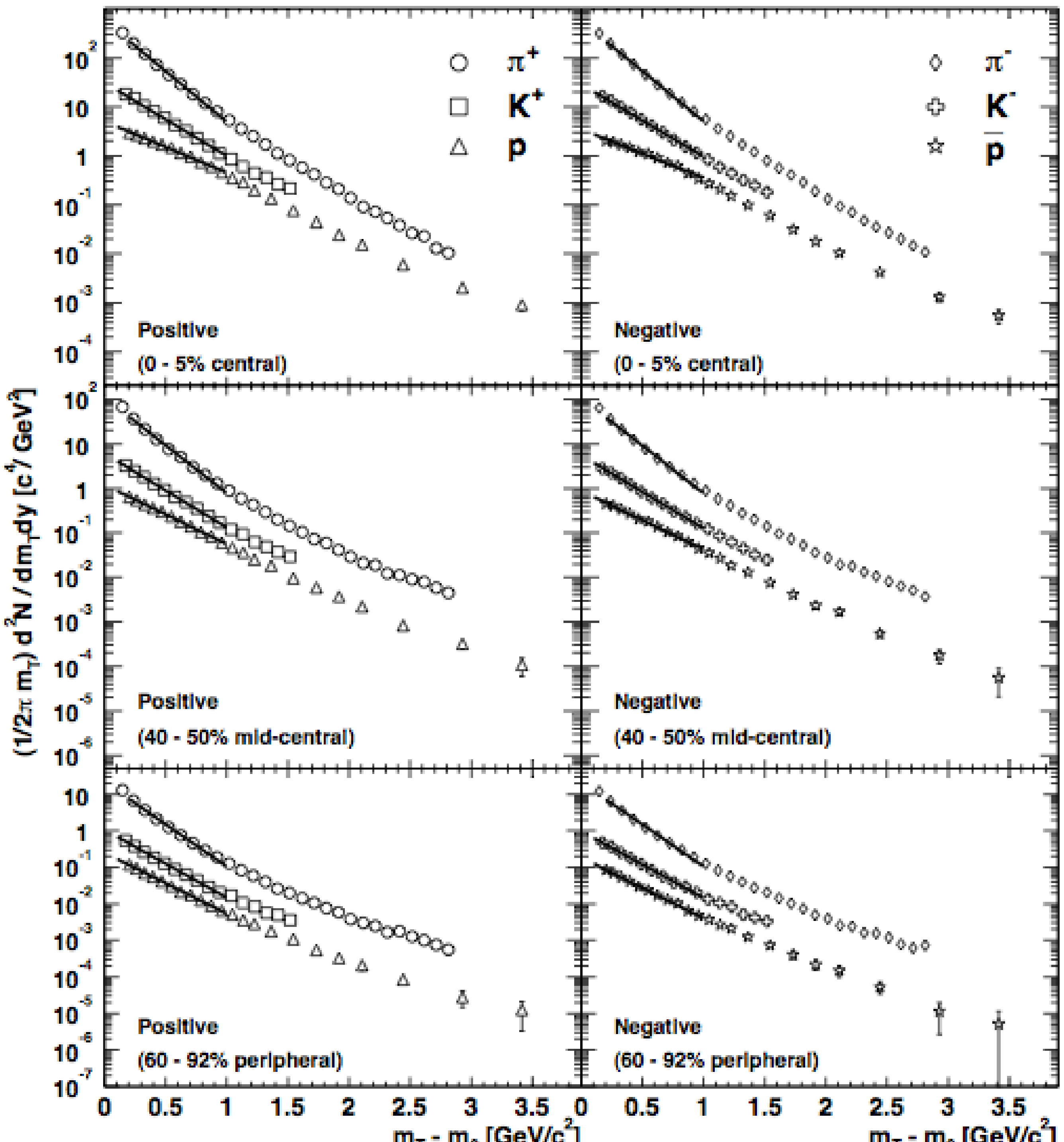
✓T_{ch} stays constant from peripheral to central collisions

Kinematical Distr.: Transverse mass distr.

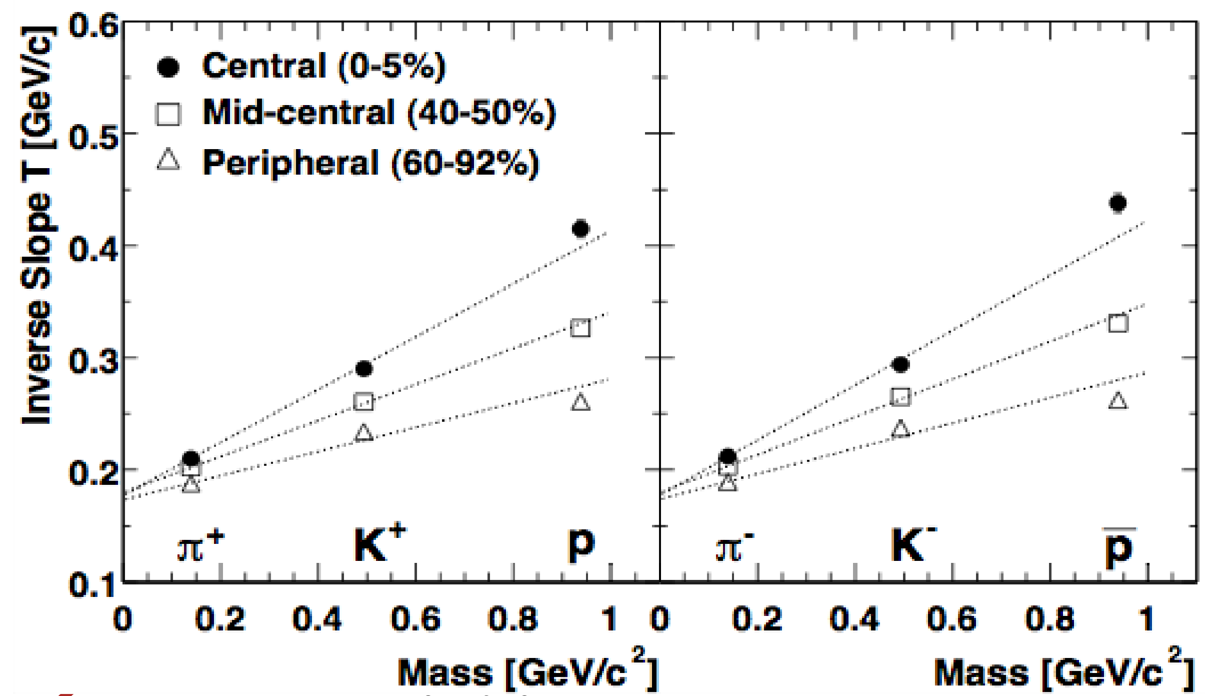


$$m_t = \sqrt{p_t^2 + m^2}$$

$$\frac{d^2N}{2\pi m_T dm_T dy} = \frac{1}{2\pi T(T+m_0)} A \exp\left(-\frac{m_T - m_0}{T}\right)$$



PHENIX, PRC69,034909(2004)

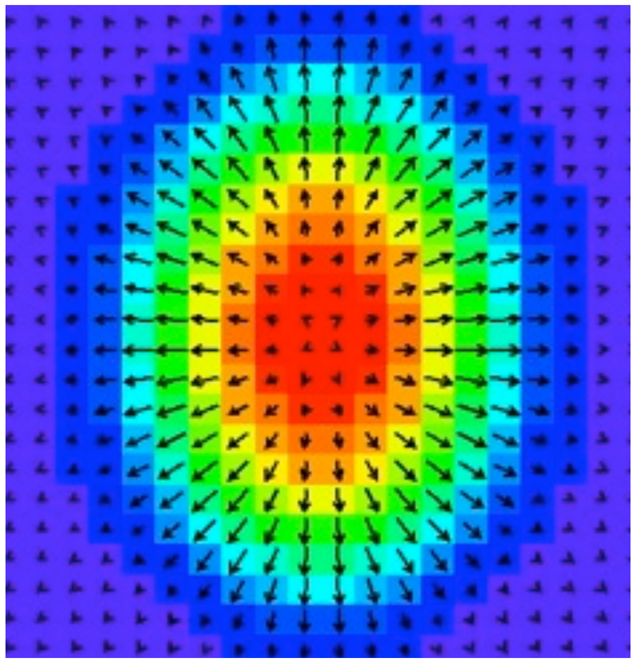


- ✓ Exponential in m_t
  - Known as m_t scaling
  - Thermal distr.
- ✓ Flatter m_t distr for heavier particle mass
  - Mass Ordering of Slope param.
  - Effect of Collective Flow

$$T \approx T_0 + \frac{1}{2} m \langle v_r \rangle^2$$

Collective Flow

Blast Wave Model



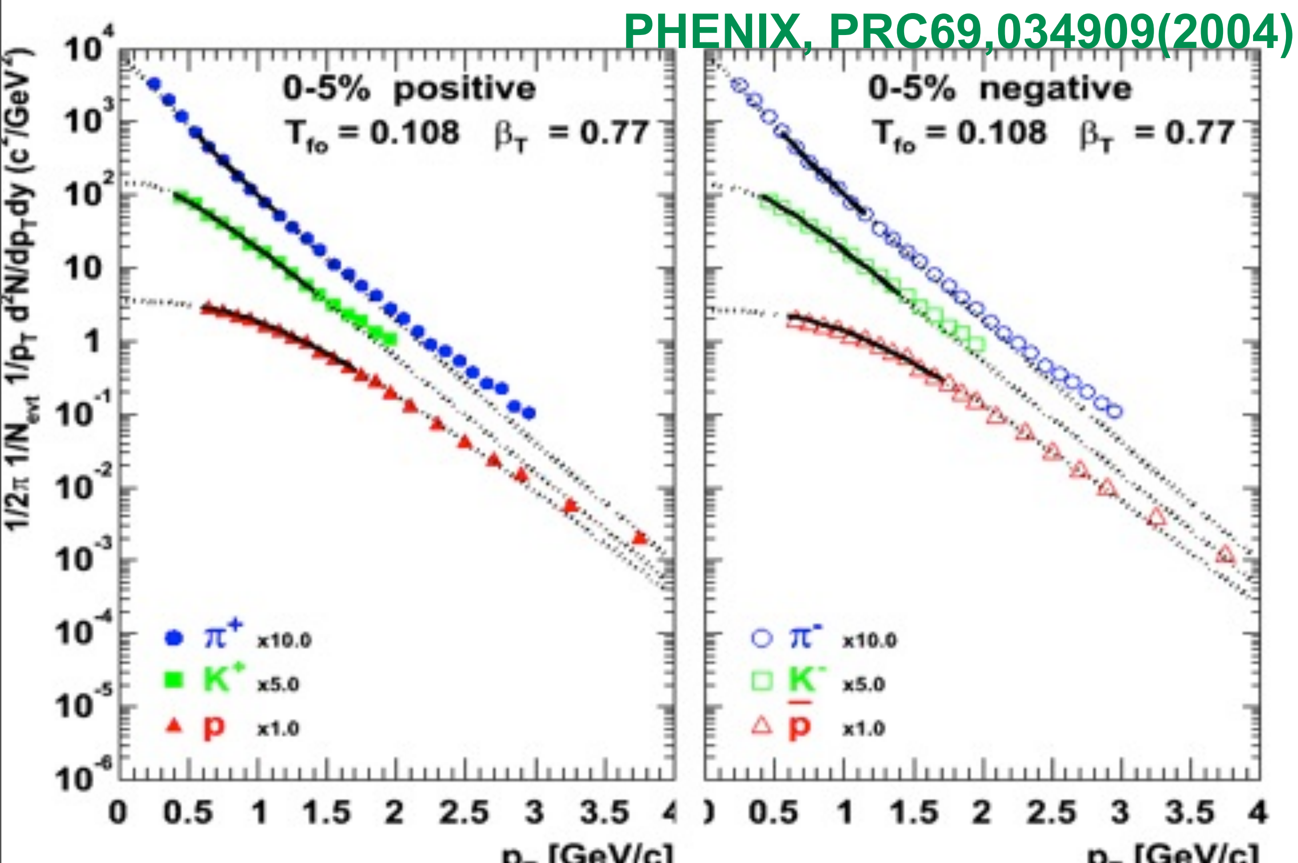
$$\frac{1}{m_T}\frac{dN}{dm_T} = A\int_0^R f(r)\,r\,dr\,m_T\,I_0\left(\frac{p_T \sinh\rho}{T_{fo}}\right)K_1\left(\frac{m_T\cosh\rho}{T_{fo}}\right)$$

PRC48(1993)2462.

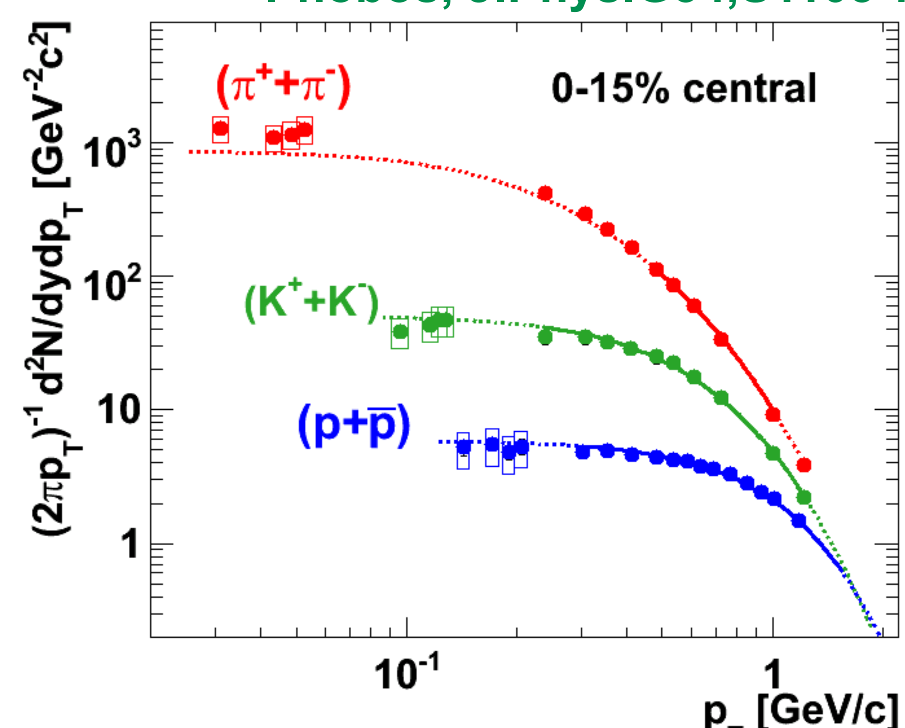
$$\rho(r) = \tanh^{-1}(\beta_T)\cdot r/R$$

I_0 , K_1: modified Bessel function

PHENIX, PRC69,034909(2004)



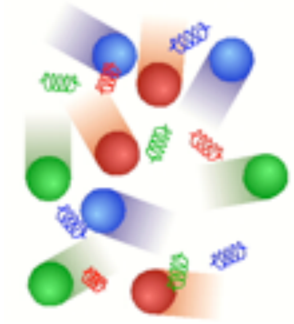
Phobos, J.Phys.G34,S1103-7(2007)

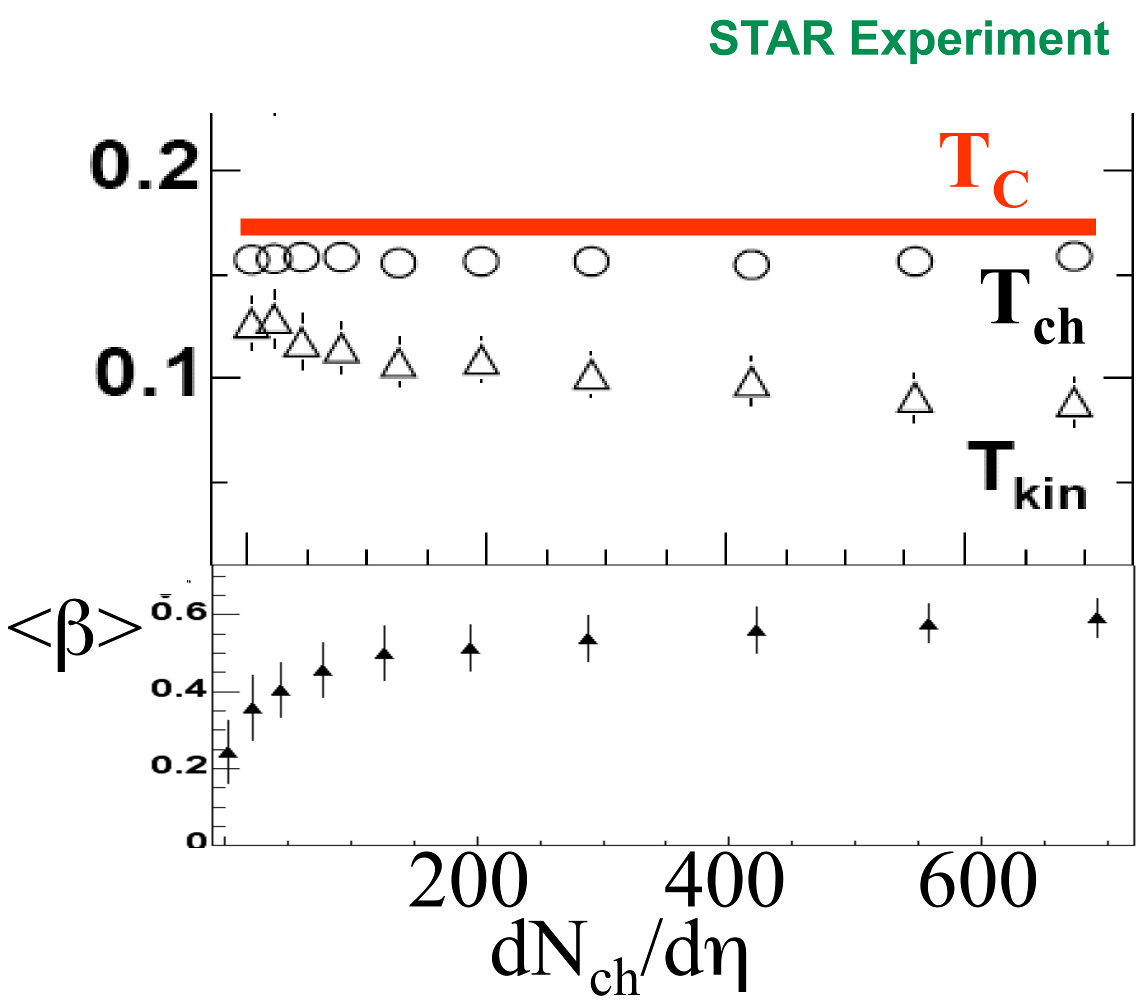


✓Good tool to separate thermal and collective

✓Well describe < 2 GeV/c

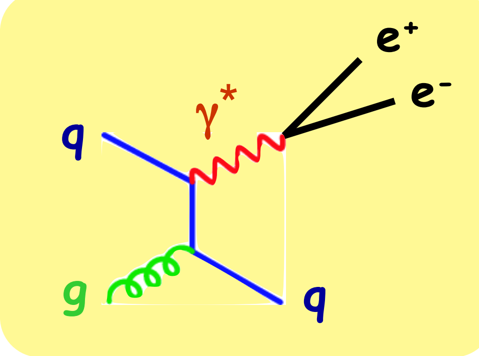
Time evolution & Freeze-out conditions



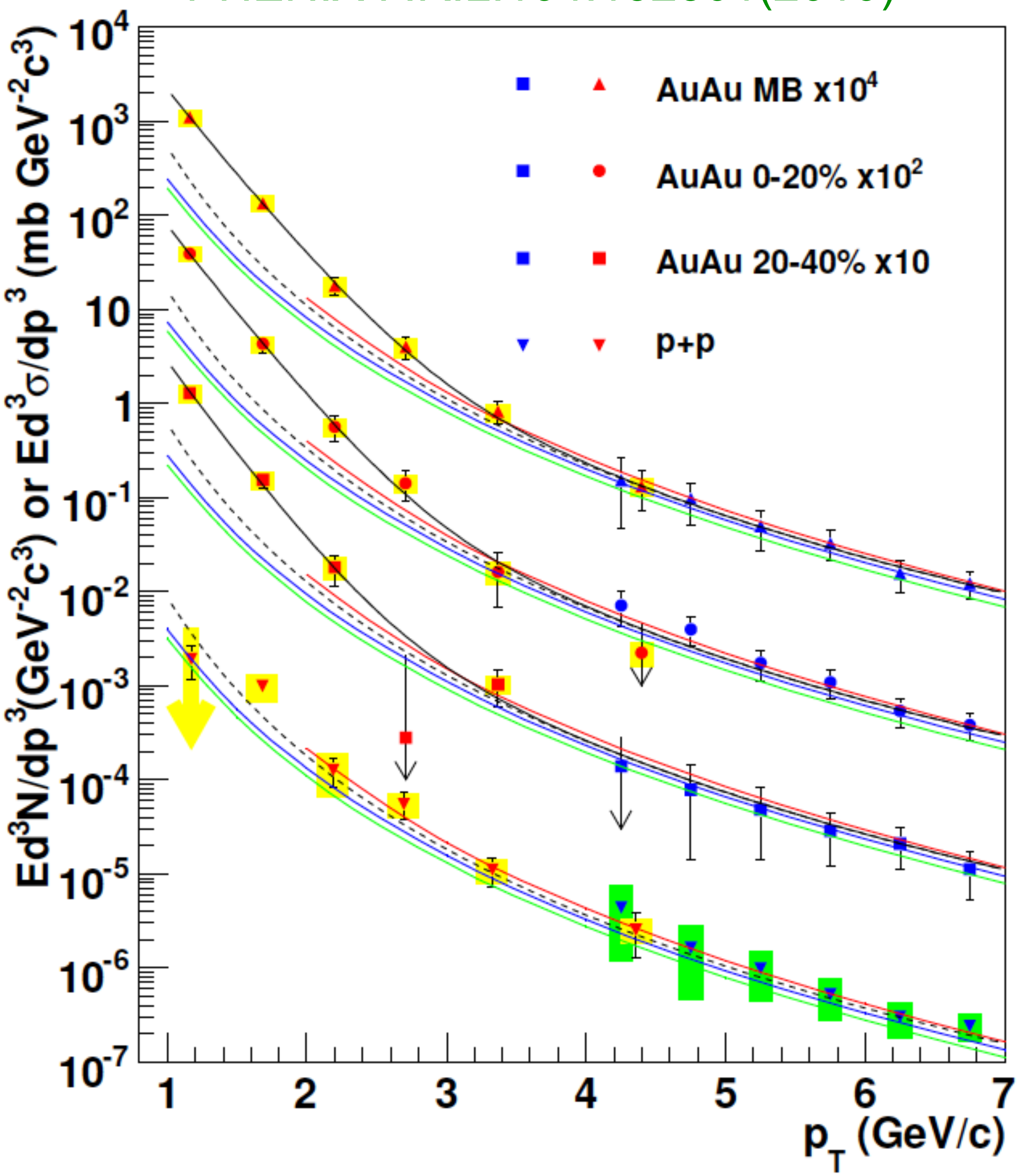


- ✓Difference of T_{ch} and T_{kin} corresponds to time evolution of the system.
- ✓Kinematical & Chemical freeze-out show difference in centrality dependence!
  - ➡Chem. freeze-out by T
  - ➡Kin. freeze-out by what?

Yet, another Temp.



PHENIX P.R.L.104:132301(2010)



- ✓ **Excess of electron pair at low pt in AA**

$$Ae^{-p_{\mathrm{T}}/T} + Bp_{\mathrm{T}}^{n}$$

centrality	$dN/dy(p_T > 1\mathrm{GeV}/c)$	T(MeV)	χ^2/DOF
0-20%	$1.50 \pm 0.23 \pm 0.35$	$221 \pm 19 \pm 19$	4.7/4
20-40%	$0.65 \pm 0.08 \pm 0.15$	$217 \pm 18 \pm 16$	5.0/3
Min. Bias	$0.49 \pm 0.05 \pm 0.11$	$233 \pm 14 \pm 19$	3.2/4

- ✓ **Imply initial high temperature !?**

Fun

EPJ C46, 451 (2006

Thermal photons: Au+Au → γ+X [0-10% central]

D.d'Enterria-D.Peressounko. T_0 = 590 MeV, τ_0=0.15 fm/c

S.Rasanen et al. T_0 = 580 MeV, τ_0=0.17 fm/c

D.K.Srivastava. T_0 = 450--600 MeV, τ_0=0.2 fm/c

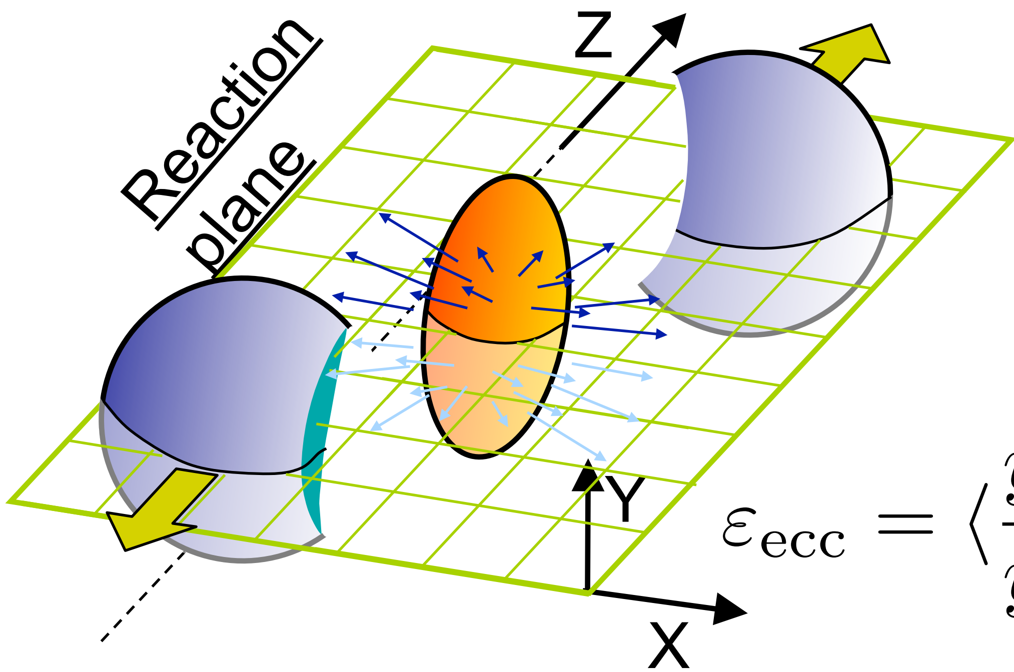
S.Turbide et al. T_0 = 370 MeV, τ_0=0.33 fm/c

J.Alam et al. T_0 = 300 MeV, τ_0=0.5 fm/c

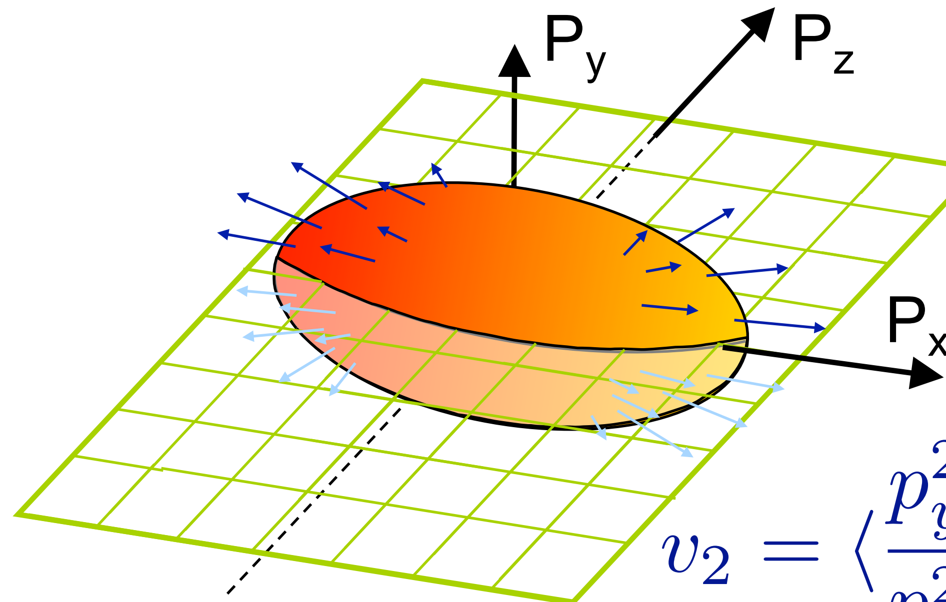
PHENIX Au+Au [0-10% central]

Prompt γ: NLO pQCD × T_{AA} [0-10%]

Large Elliptic Flow as a signature



$$\varepsilon_{ecc} = \langle \frac{y^2 - x^2}{y^2 + x^2} \rangle$$



$$v_2 = \langle \frac{p_y^2 - p_x^2}{p_y^2 + p_x^2} \rangle$$

✓ In non-central collisions, participant region has almond shape.

➡azimuthal anisotropy in coordinate space

✓ If $\lambda \ll R$, azimuthal anisotropy of the coordinate space is converted to that of the momentum space.

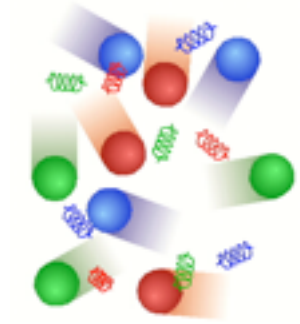
➡v_2 ; second Fourier harmonics of azimuthal distribution

✓ Goodies :

- Clear origin of the signal
- Collision geometry can be determined experimentally

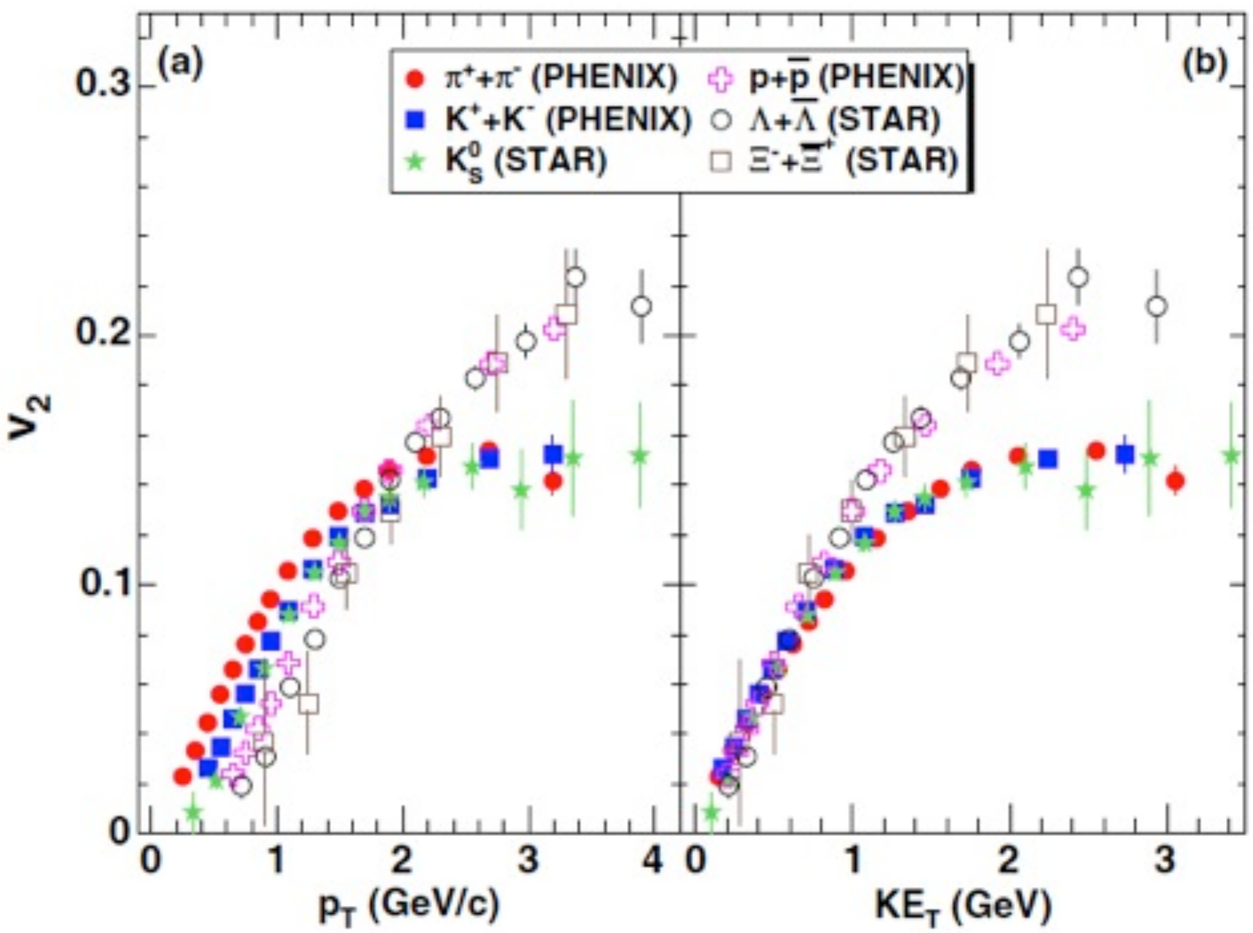
$$N(\phi) = N_0\{1 + 2v_1\cos(\phi - \Psi_0) + 2v_2\cos(2(\phi - \Psi_0))\}$$

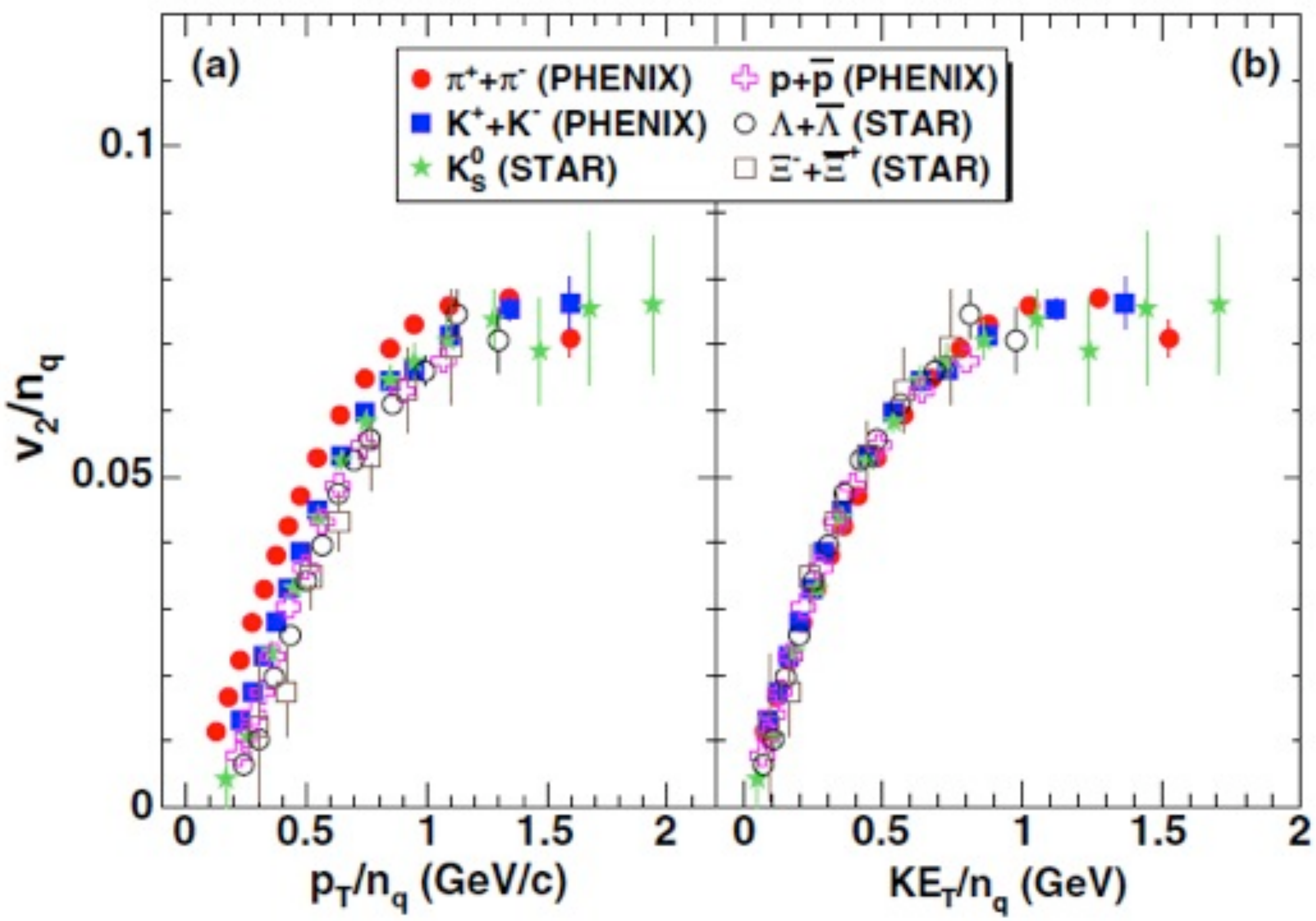
Beautiful scalings of v_2



PHENIX PRL 98(2007)162301

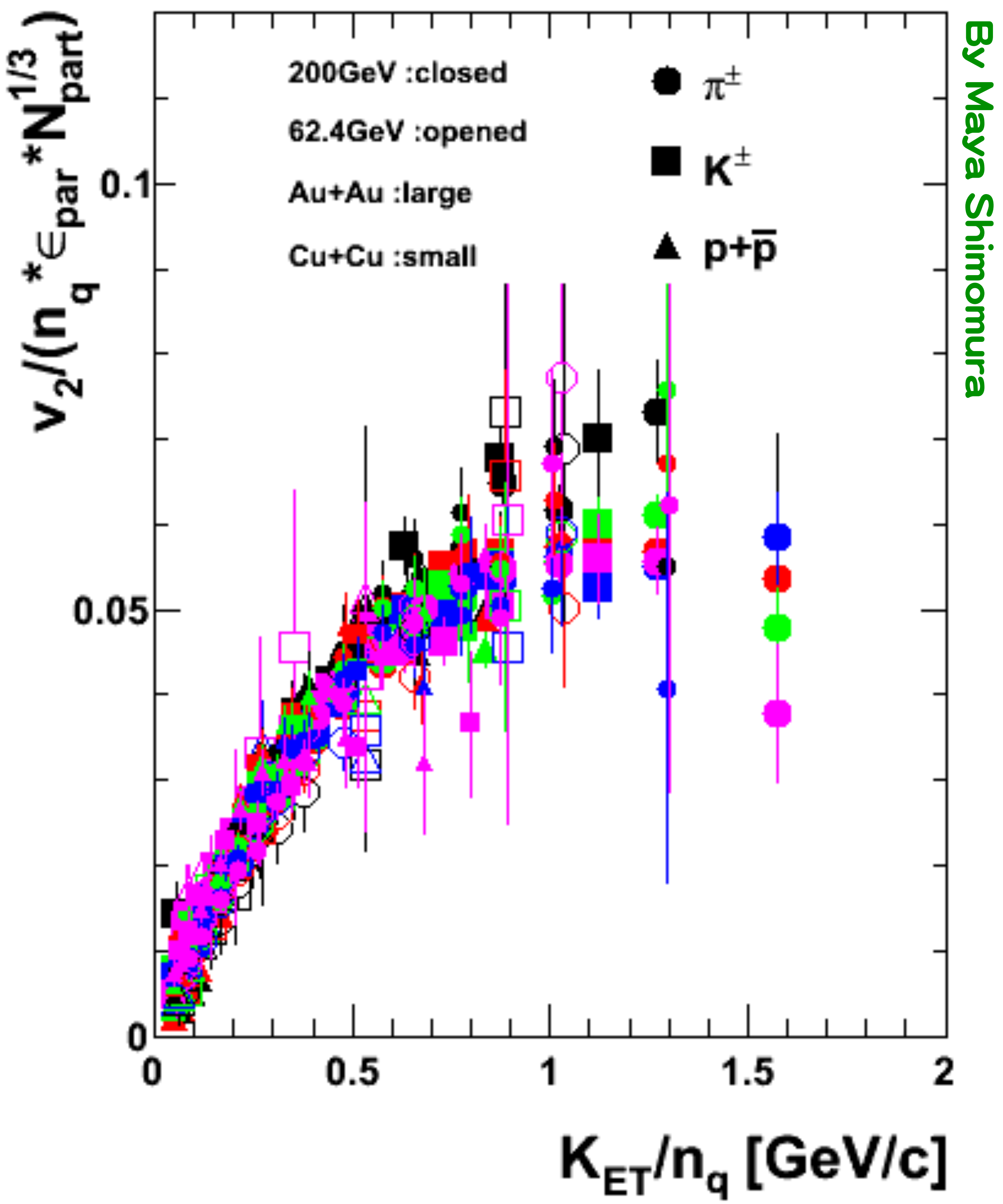
Au+Au 200 GeV





√ m_t scaling & quark number scaling hold!!

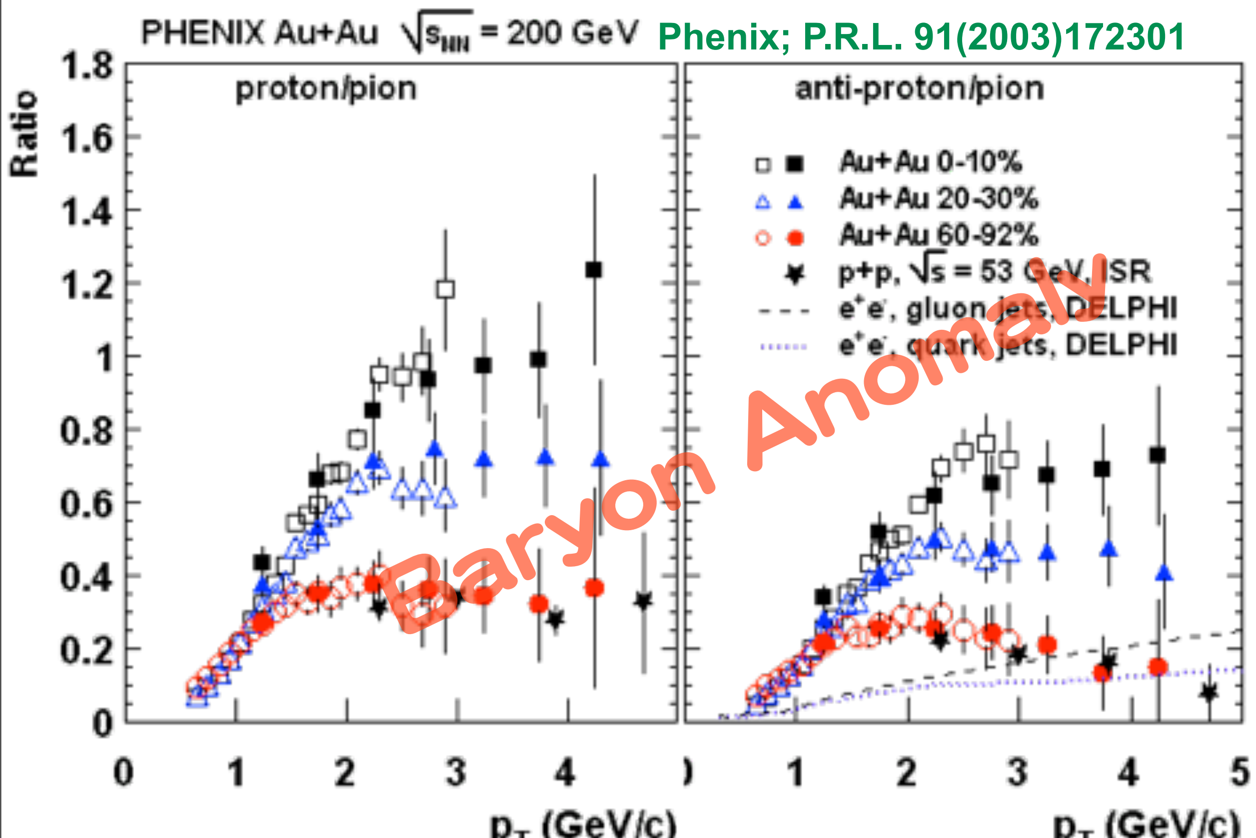
Universal scaling of v2?



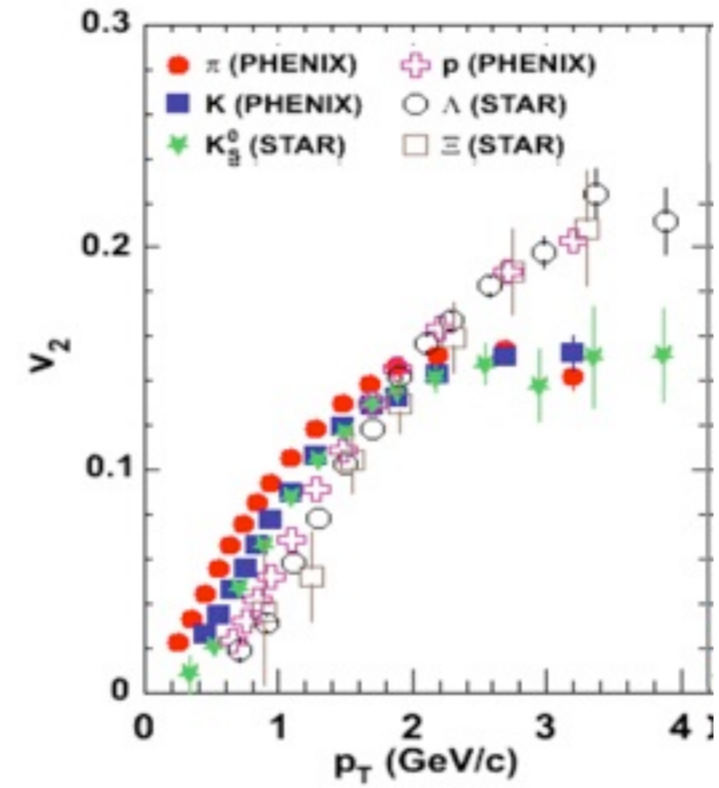
- ✓ Systematics
  - Au+Au, Cu+Cu
  - 200, 62 GeV
  - Centrality
  - Pions, Kaons, protons
- ✓ 45 curves scaled to be one curve!

Puzzles in the mid-p_t region

p/π enhances above 1.5 GeV/c



v_2 deviates from the mass ordering above 2 GeV/c

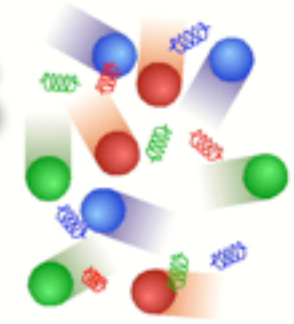


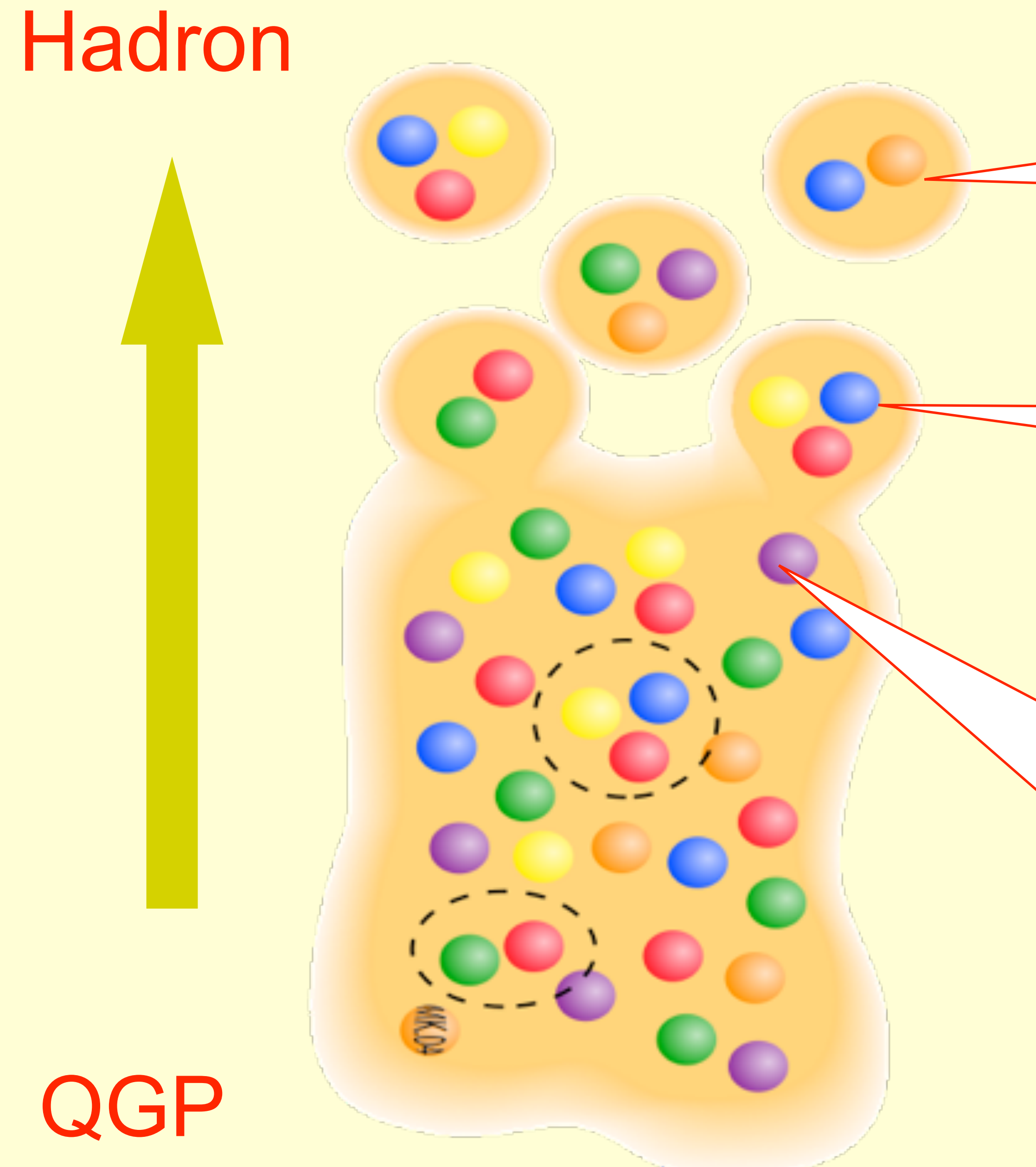
- ✓ In central col., p/π ratio is very large, while in peripheral, p/π ratio similar to those in ee/pp suggesting fragmentaton process.
  - Fragmentation process should show $n_p < n_\pi$ as seen in ee/pp.
- ✓ While mass ordering of v_2 seen at low pt region, clear departure observed.
- ✓ Suggesting other production mechanism.

↓

Quark Recombination Model (Quark Coalescence Model)

Quark Coalescence explains Baryon Anomaly, and ...





Because of the steep distr. of *w(pt), RECO* wins at high pt even w. small *Cx*.

✓ **Quarks, anti-quarks combine to form mesons and baryons from universal quark distribution, w(pt).**

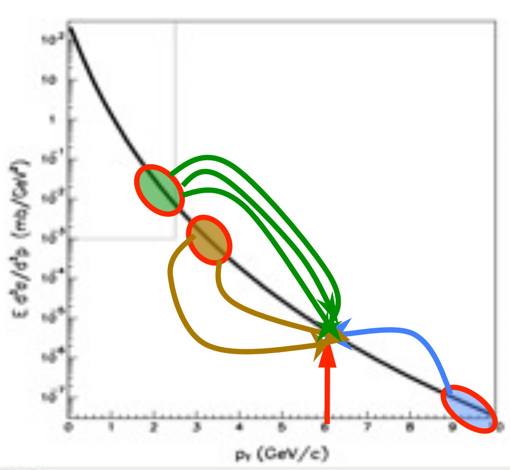
Mom. distr. of meson (2q);

$$W_M(p_t) \approx C_M \cdot w^2(p_t/2)$$

Mom. distr. of baryon (3q);

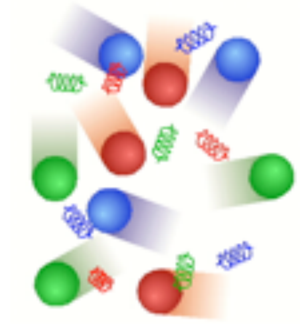
$$W_B(p_t) \approx C_B \cdot w^3(p_t/3)$$

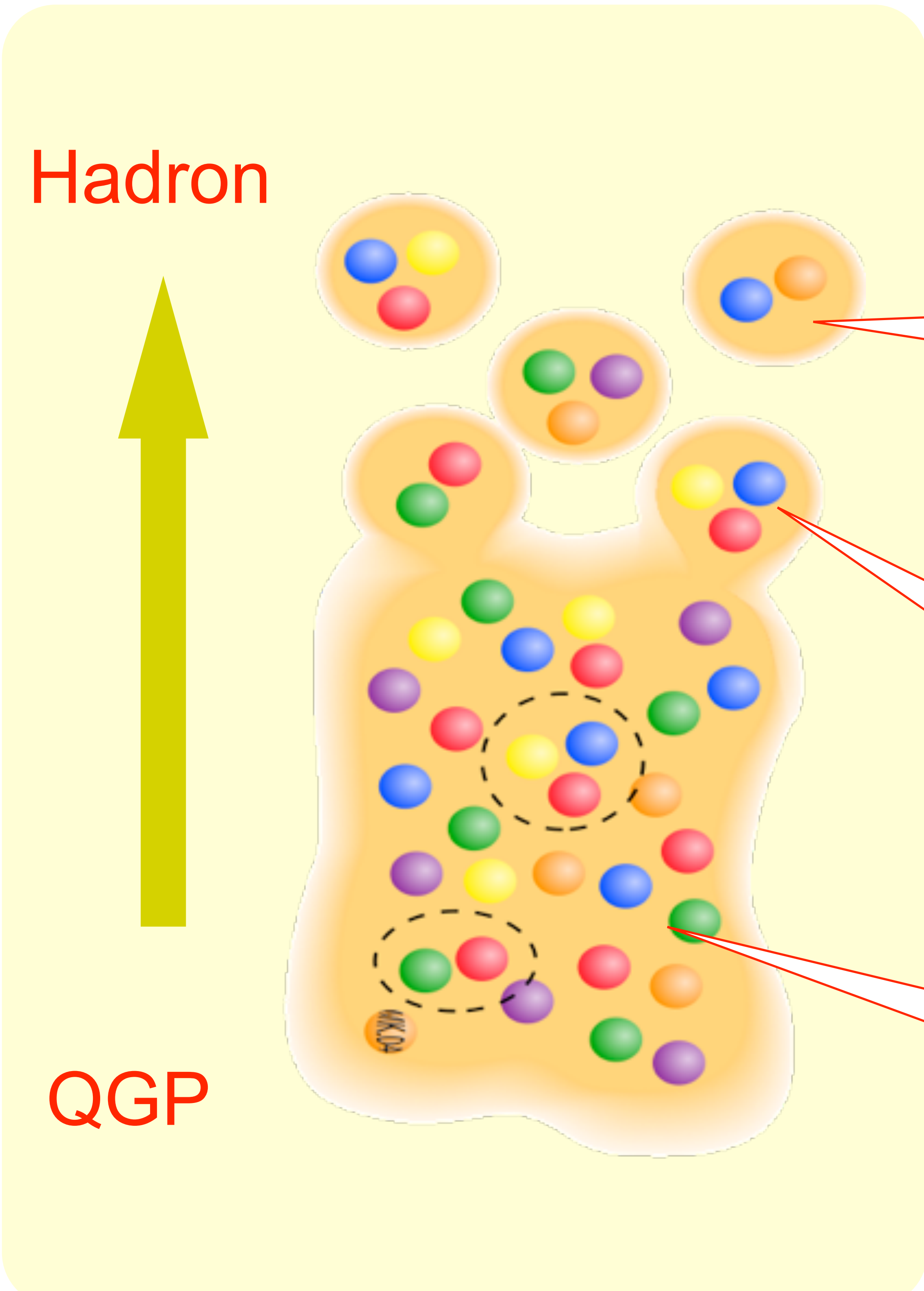
w(pt);
Universal mom. distr. of quarks
{*steep in pt*}



Characteristic scaling features expected.
➔Quark Number Scaling (QNS)

also explains n_q scaling !





✓ **Characteristic scaling behavior**

→**Quark Number Scaling**

Azimutal distr. of meson (2q);

$$\frac{dN_M}{d\phi} \propto w^2 = (1 + 2v_{2,q}\cos 2\phi)^2$$

$$\approx (1 + 4v_{2,q}\cos 2\phi)$$

Azimuthal distr. of baryon (3q);

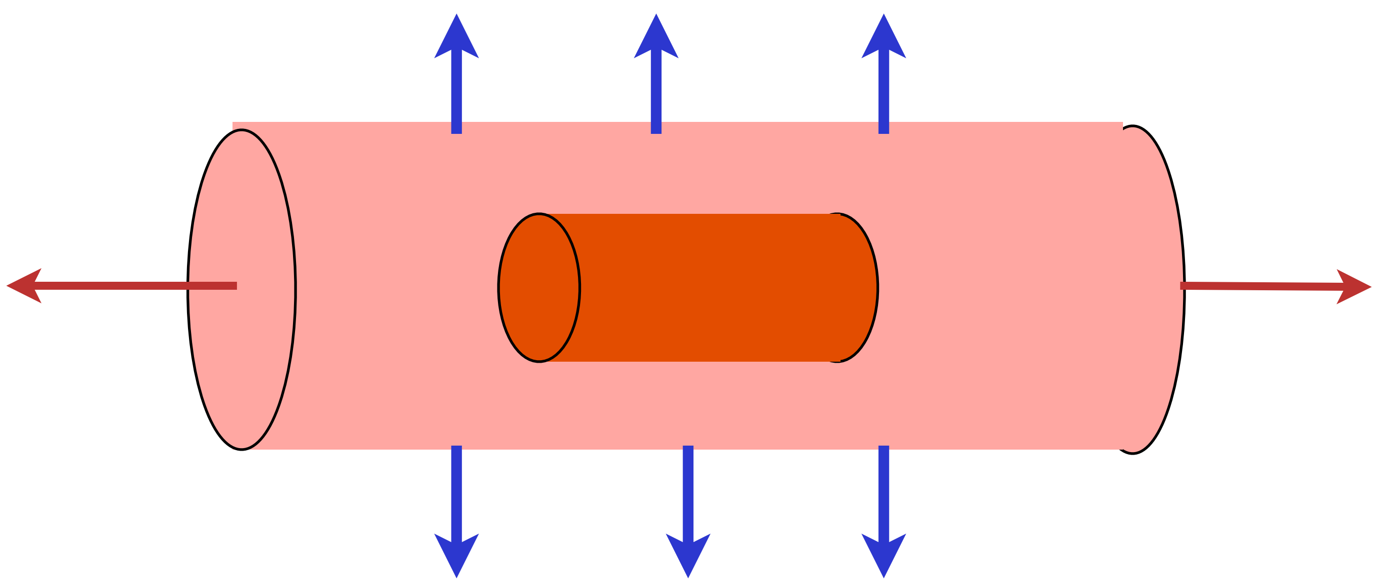
$$\frac{dN_B}{d\phi} \propto w^3 = (1 + 2v_{2,q}\cos 2\phi)^3$$

$$\approx (1 + 6v_{2,q}\cos 2\phi)$$

Azimuthal distr of quark; w

$$w \propto (1 + 2v_{2,q}\cos 2\phi)$$

Adiabatic Expansion Model



$$V(t) = ct\pi R(t)^2 = ct\pi(R_0 + \beta_{\rm T} t)^2$$

$$\frac{V(t_{\rm fo})}{kn_{\rm part}\sigma} \sim R(t_{\rm fo})$$

$$t_{\rm fo} = \frac{\sqrt{R_0^2 + 4\frac{k\sigma}{c\pi}\beta_{\rm T} n_{\rm part}} - R_0}{2\beta_{\rm T}}$$

$$T(t_{\rm fo}) = T_0(\frac{V_0}{t_{\rm fo}(R_0 + \beta_{\rm T} t_{\rm fo})^2})^{1/3}$$

✓ Intuitive Model

✓ Assuming,

- Cylindrical expansion
- Freeze-out condition

$$\lambda = \frac{1}{n\sigma} \sim R$$

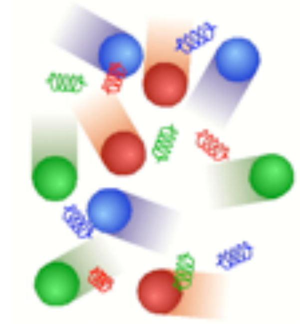
- Adiabatic expansion

$$T^3(t)V(t) = \mathrm{Const.}$$

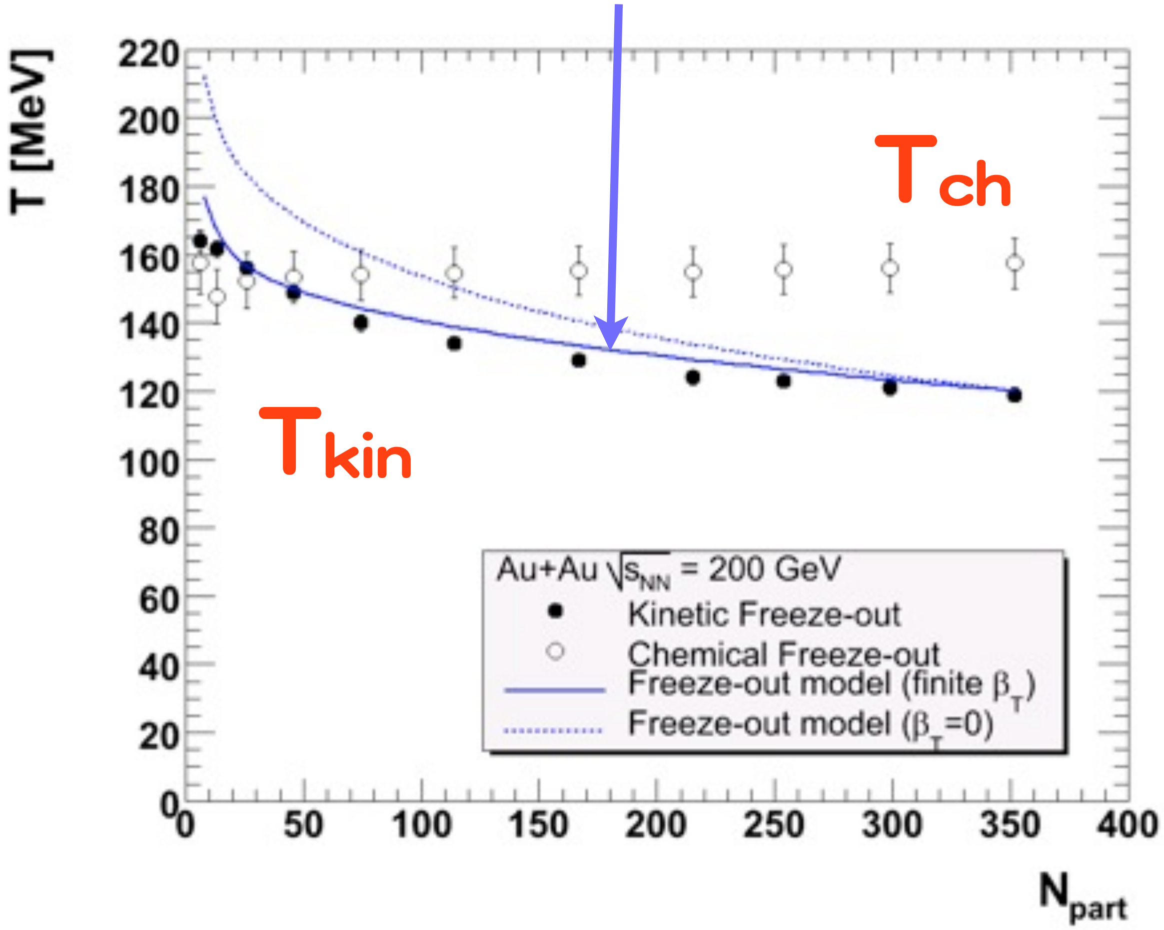
$$(\because s \propto T^3)$$

✓ Larger fireball freezees out later in time

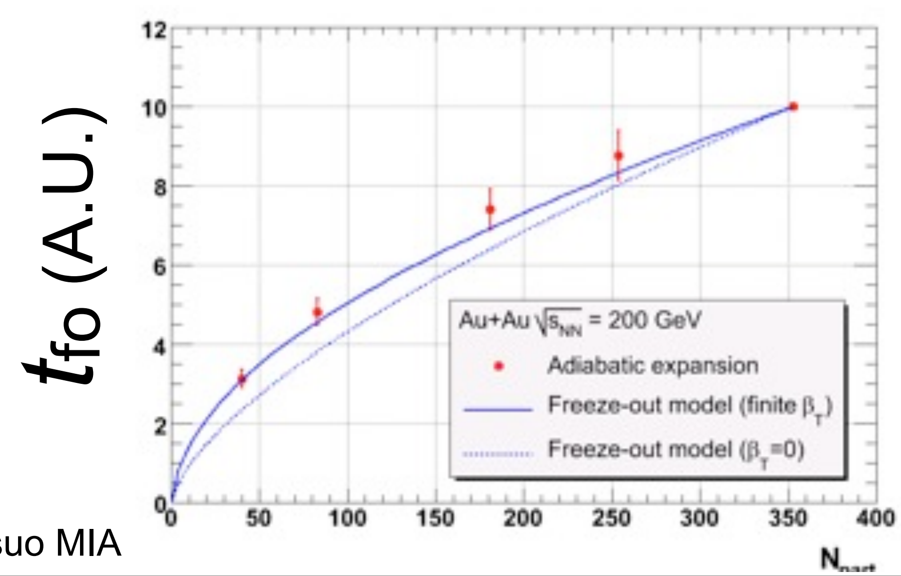
Kinematical Freeze-out w. Adiabatic Expansion



Adiabatic Expansion Model (M.Konno,Y.M. 2008)



Central collisions freeze-out late.



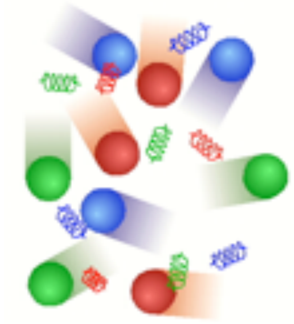
✓Adiabatic Expansion Model explains centrality dependence very well.

- Freeze-out conditions ; λ~R

✓In central collsions, the F.B. is so large that F.O. occurs later than peripheral.

➡Kinematical freeze-out is collisional, while chemical is not.

Blast Wave Fitting of v2 and spectra



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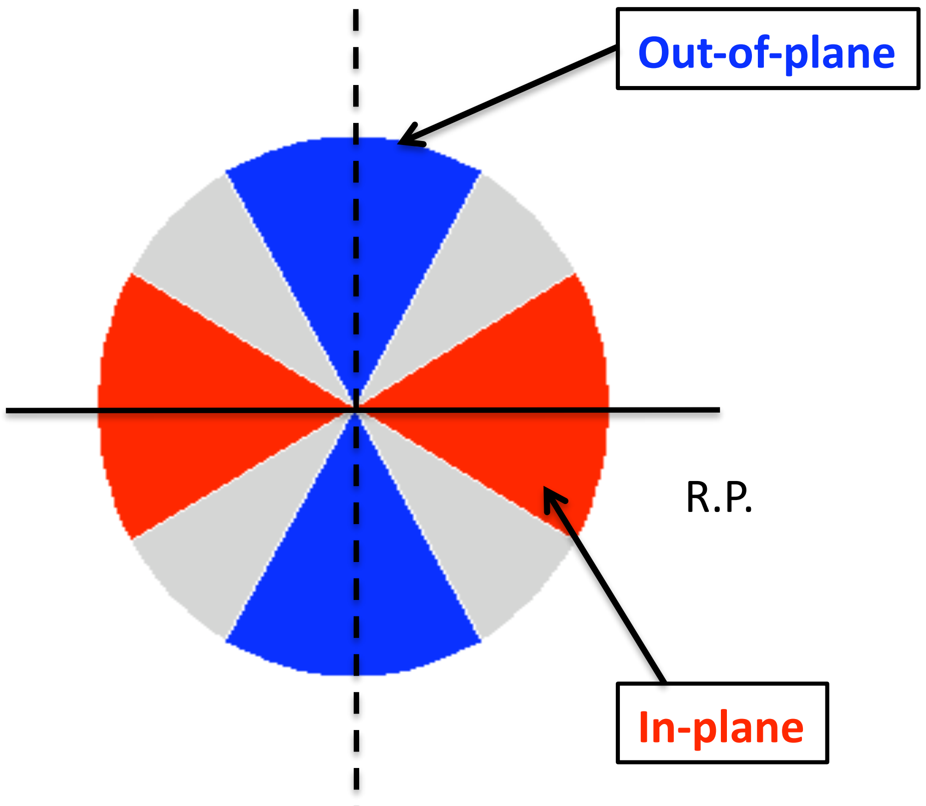
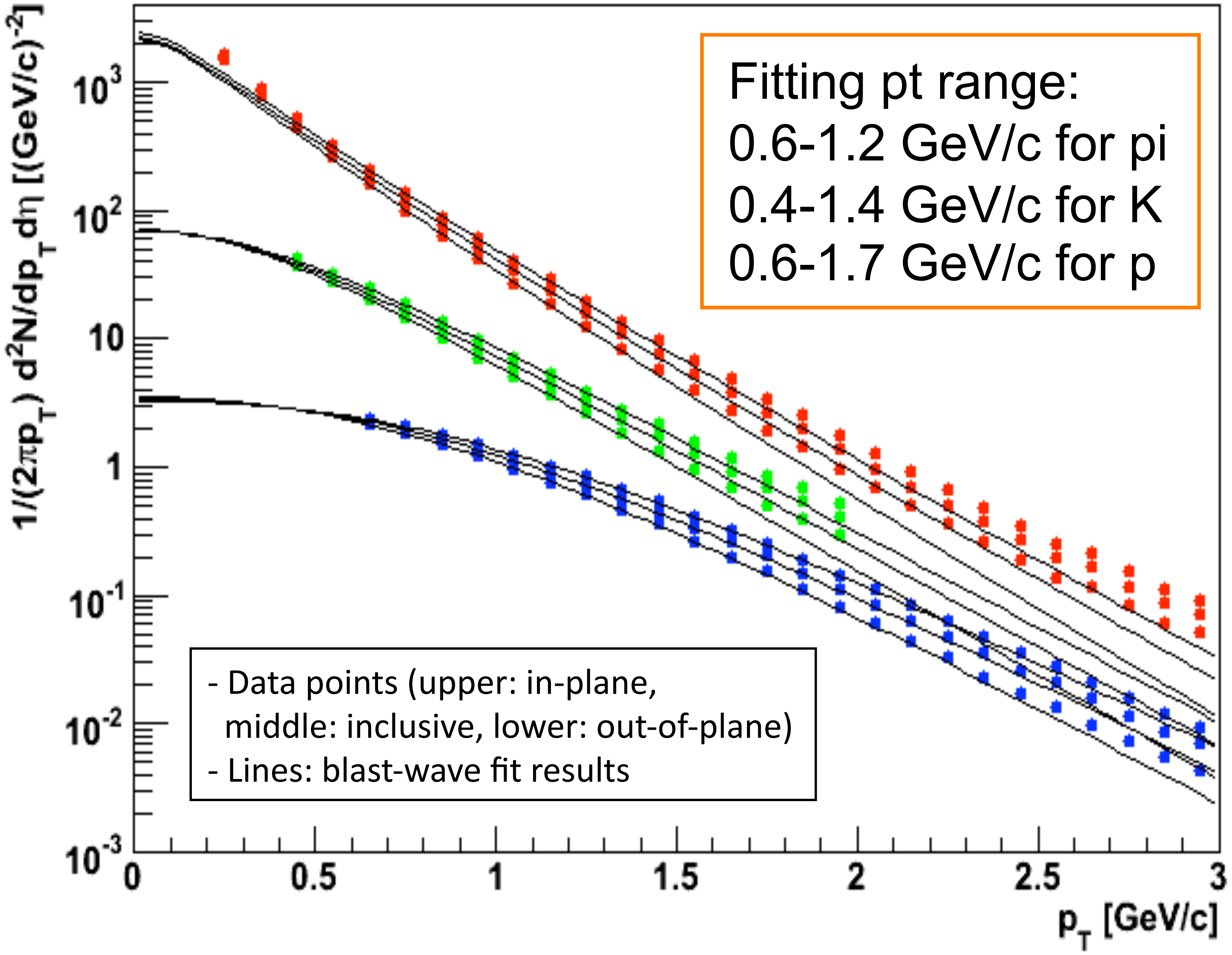
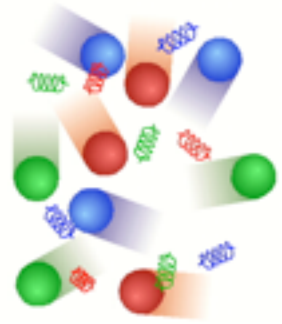




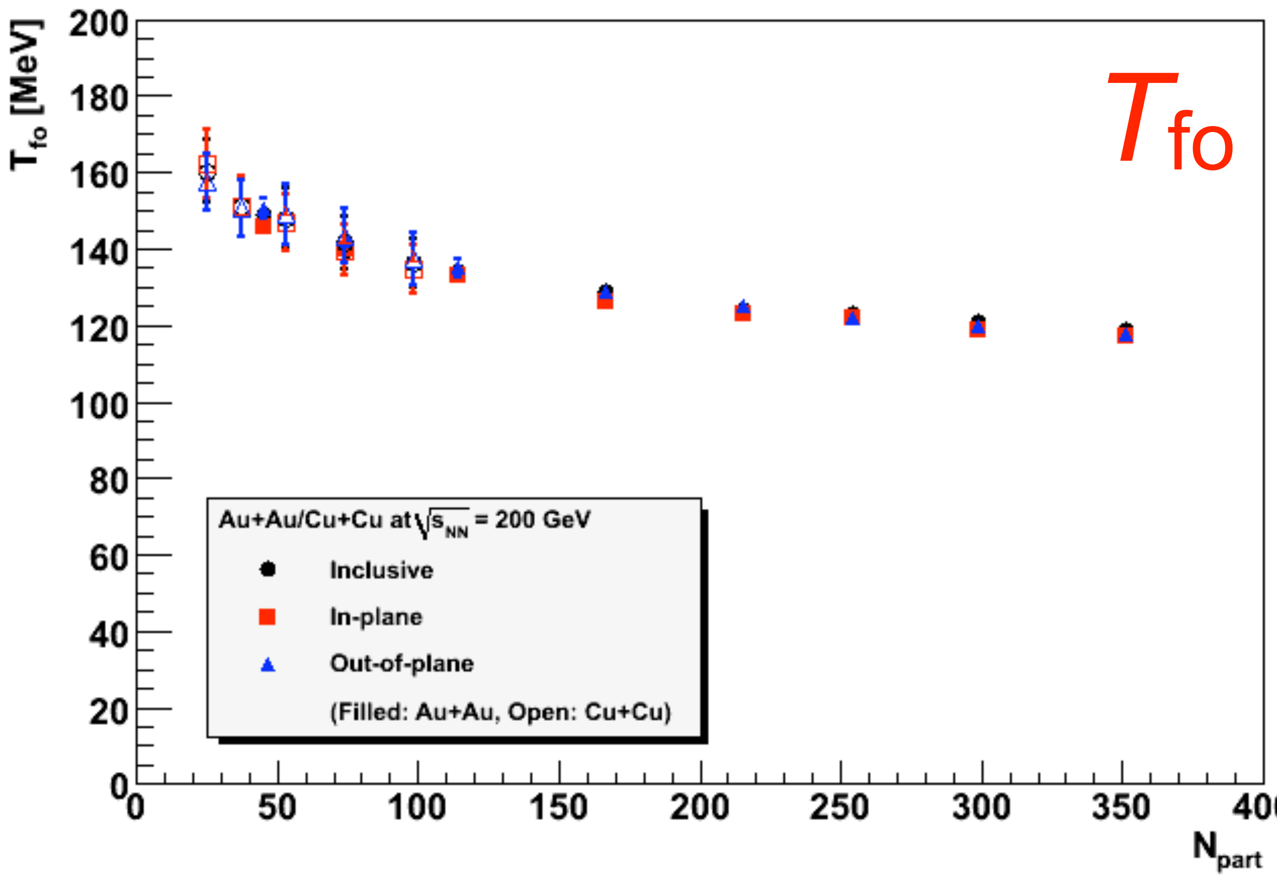
By Masahiro Konno

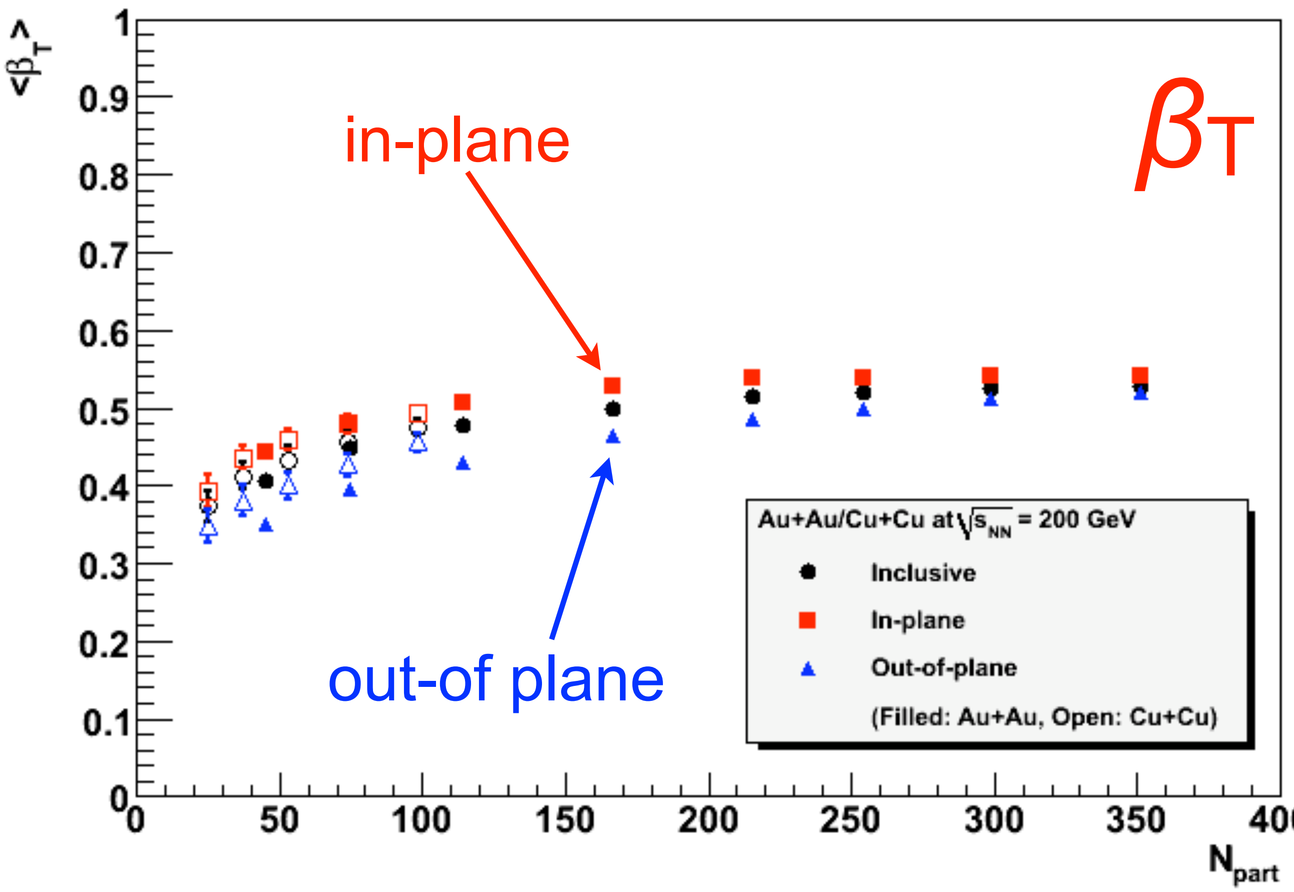
- ✓ pt distributions measured in plane and out-of plane are B.W. fitted independently

B.W. Fitting Results



Adiabatic Expansion Model (M.Konno,Y.M. 2008)



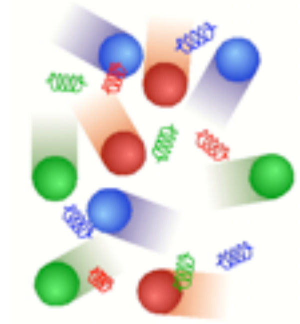


By Masahiro Konno

√ T are the same in plane and out-of plane, while

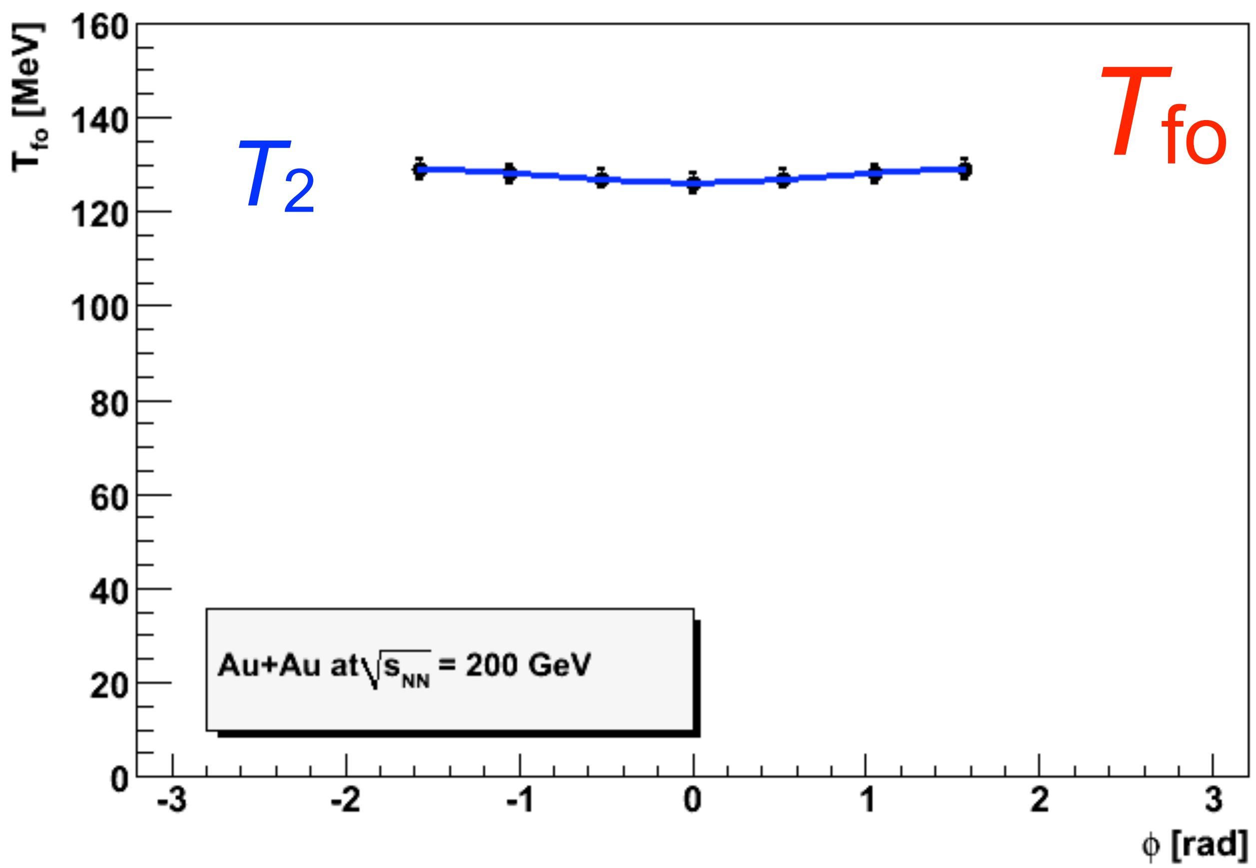
β_T(in-plane) > β_T(out-of plane) !

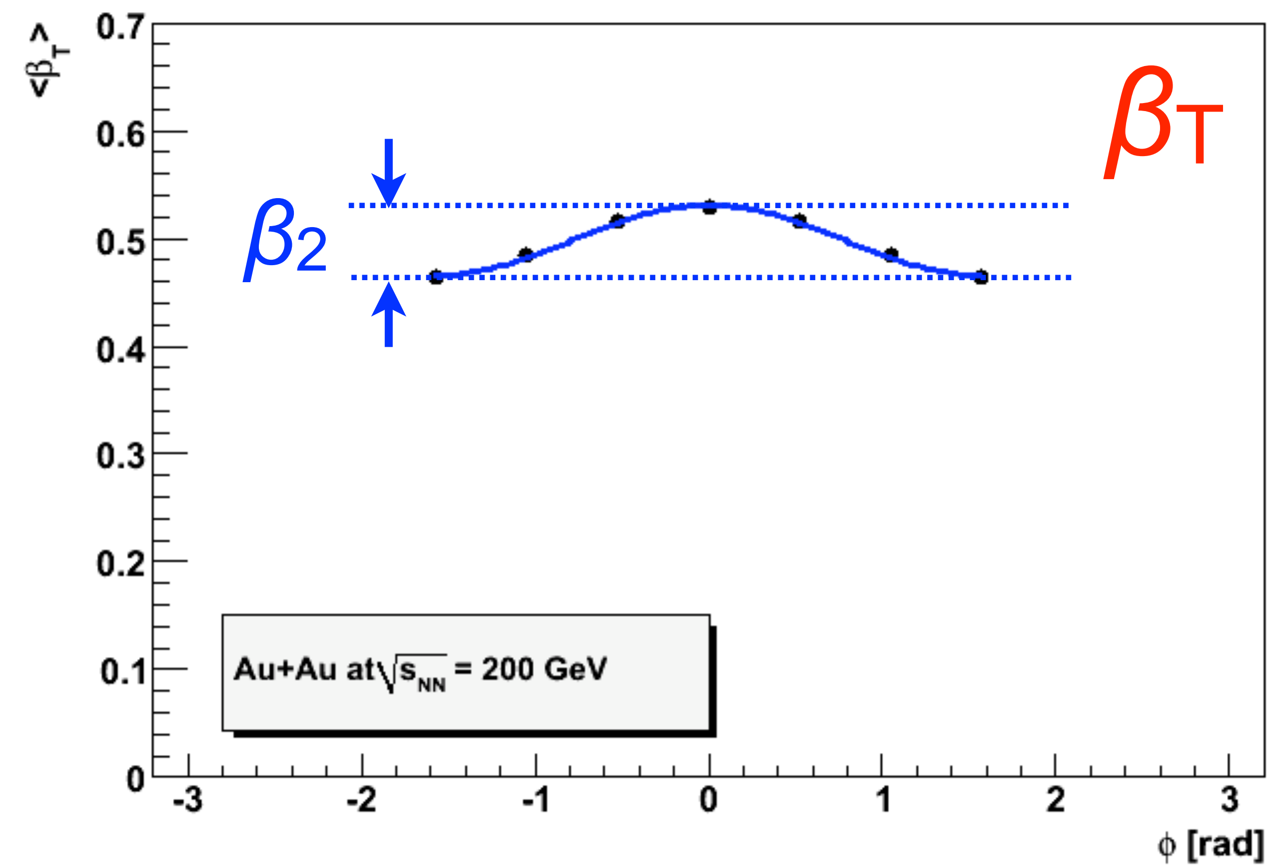
Modulations wrt. the ϕ_{RP}



Adiabatic Expansion Model (M.Konno,Y.M. 2008)

Au+Au 200 GeV 20-30 %





By Masahiro Konno

$$T_{\rm fo}(\phi) = 1 + 2T_2\cos(\phi - \phi_{\rm RP})$$

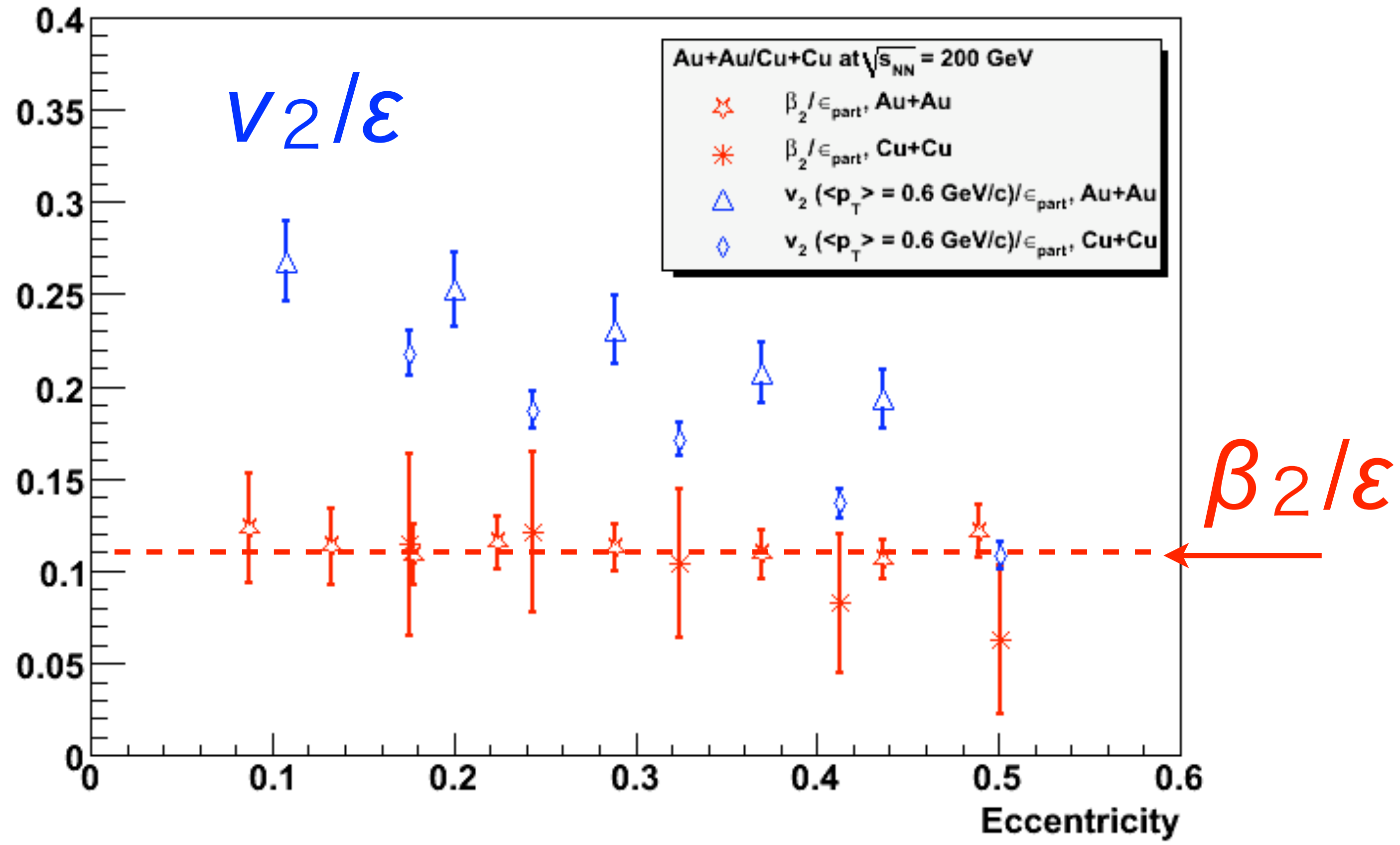
T_2 = (-5.4 +/- 4.0) x 10^{-3}

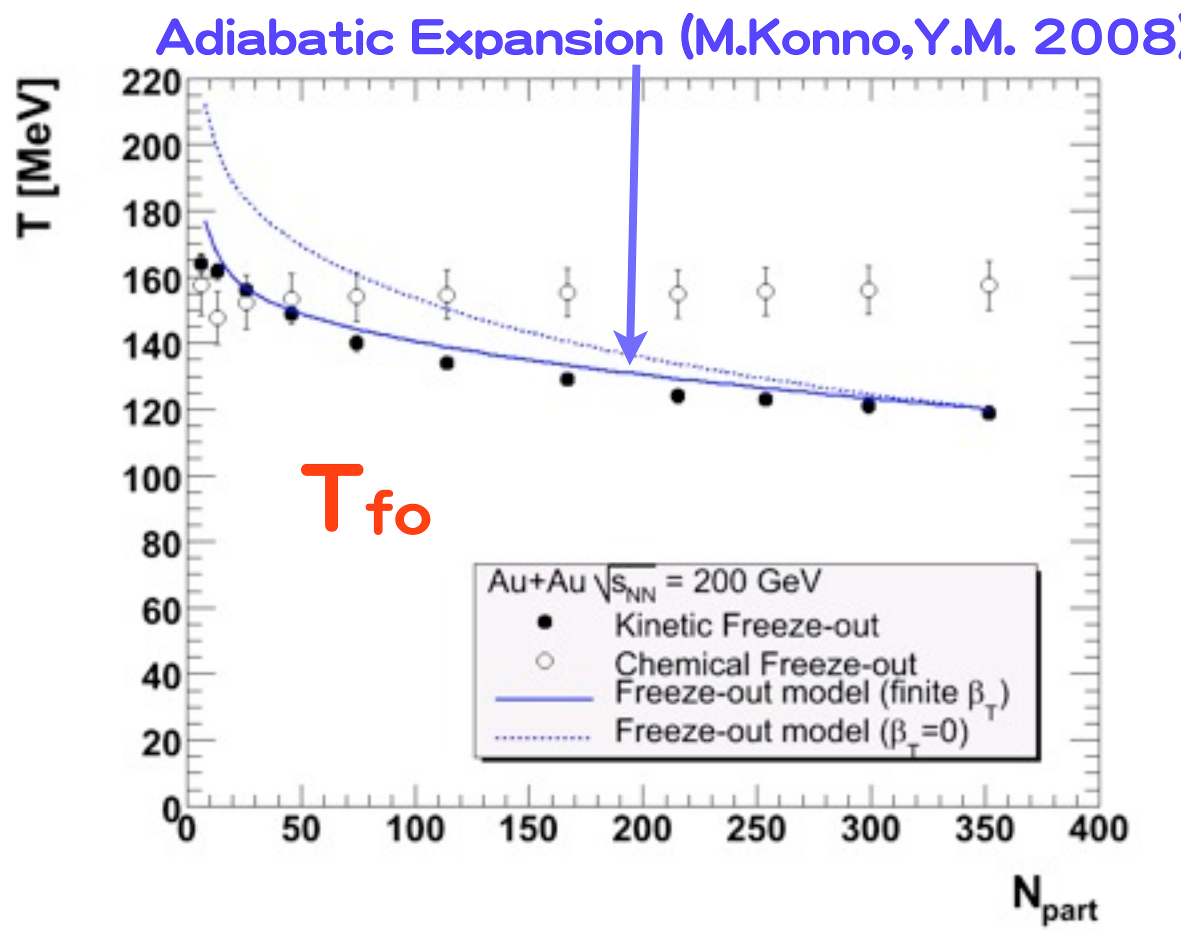
$$\beta_{\rm T}(\phi) = 1 + 2\beta_2\cos(\phi - \phi_{\rm RP})$$

β_2 = (3.3 +/- 0.2) x 10^{-2}

- ✓ $T_2 \simeq 0$, while clear modulation in β.
- ✓ Reaction Plane is determined independently.

β_2/ε is the constant !

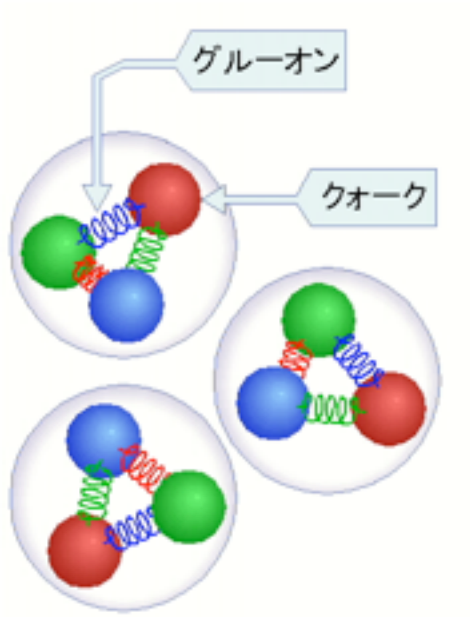




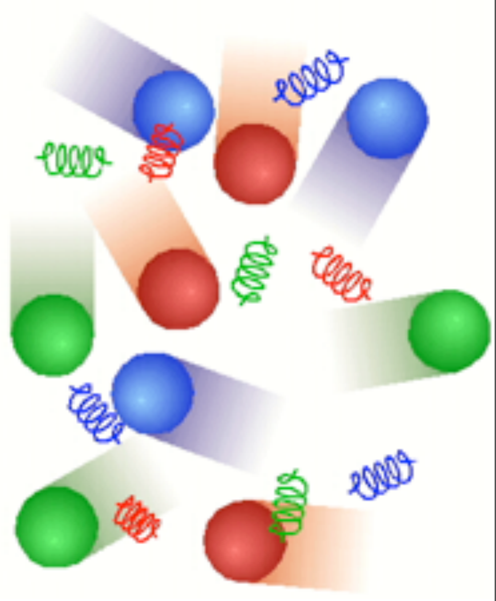
✓ β_2/ε is the constant in Au+Au and Cu+Cu, while v_2/ε shows ~ $N_{part}^{1/3}$.

➡Difference comes from the fact that v2 is sensitive to T_{fo} as well. Strength of v2 is diluted if the T_{fo} is high.

➡Central collision shows lower T_{fo} because of the late freeze-out.



Soft



Statistical and
Collective Nature
characteristic to the
QGP formation

well understood

Refer to the textbook !

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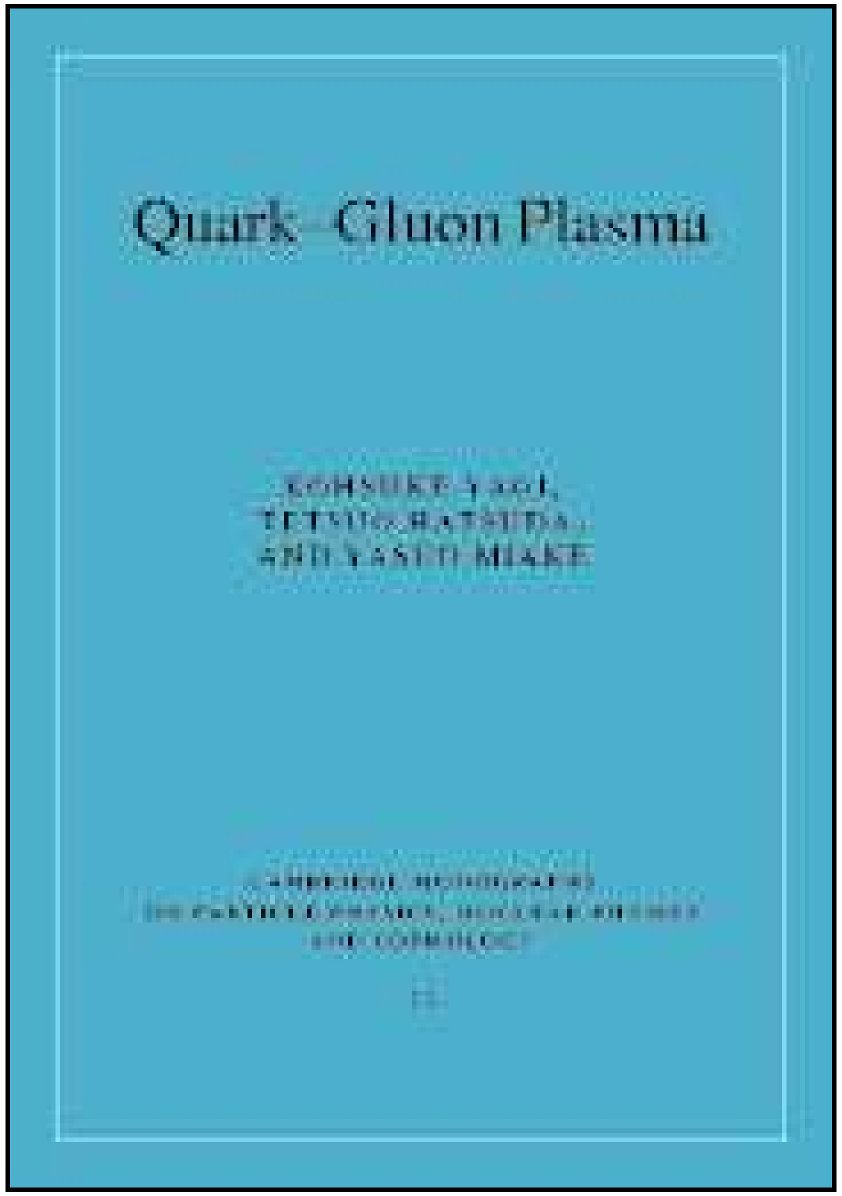

Quark-Gluon Plasma

Series: Cambridge Monographs on Particle Physics, Nucle

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Urawa University, Japan

Tetsuo Hatsuda
University of Tokyo

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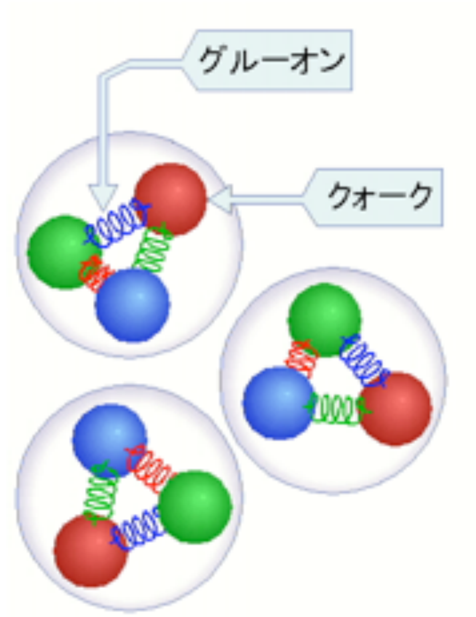
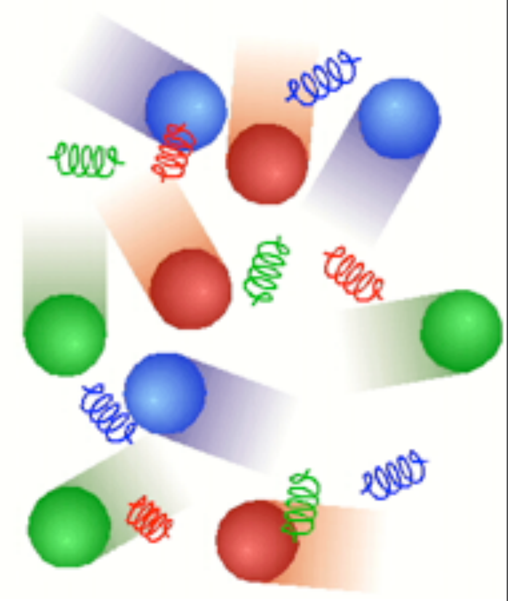
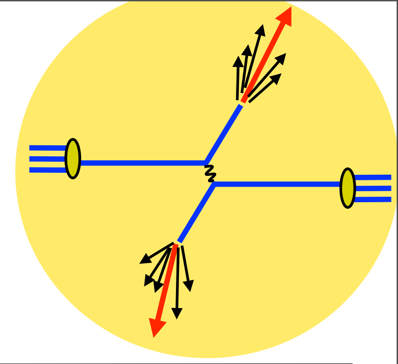


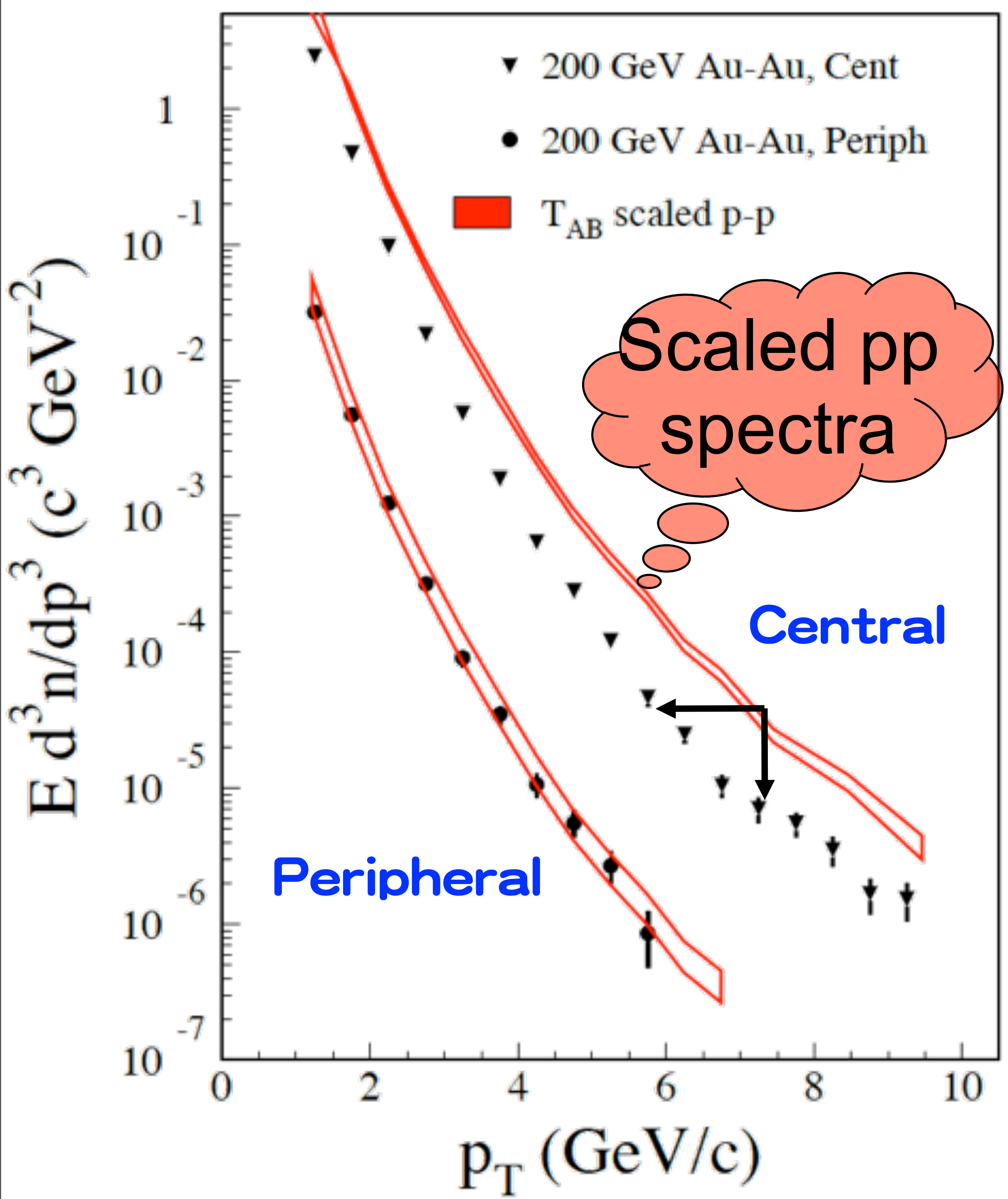
Hard comp.



Partonic energy loss
Medium response
Tomography

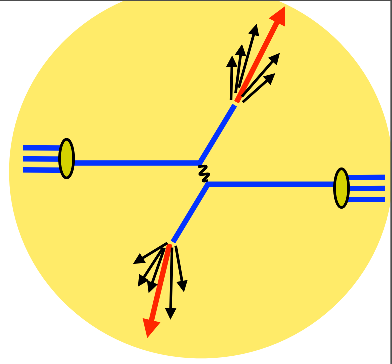
Effects in Hard comp. observed immediately



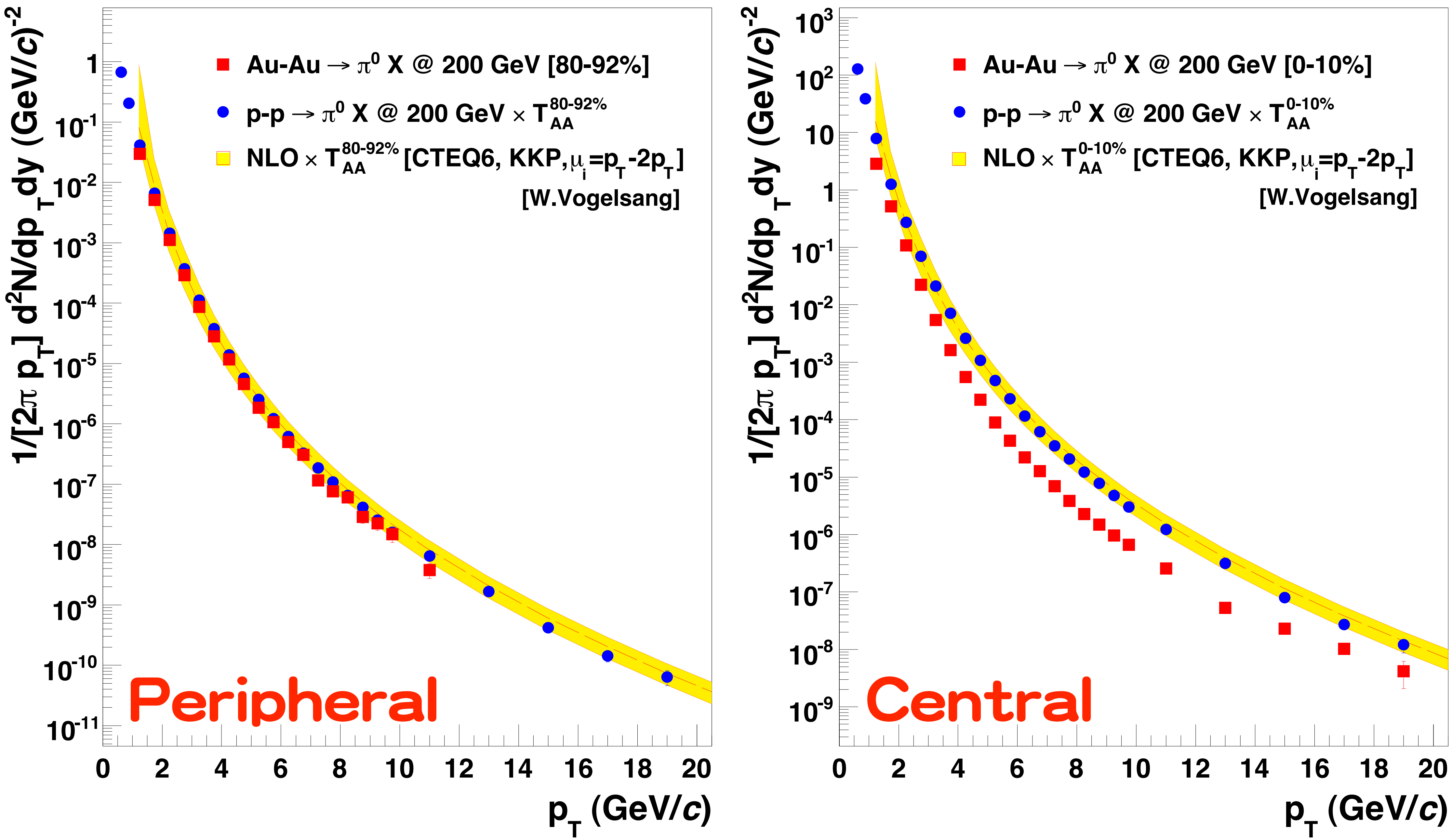


- ✓ For comparison, Au+Au & pp spectra scaled by N_{binary}.
- ✓ In peripheral collisions, Au+Au ~ pp
- ✓ In central collisions, Au+Au < pp
  - Suppression of yield ?
  - Loss of p_T ?

High pt suppression in AA

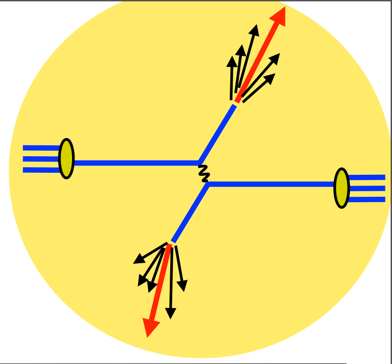


Phenix; P.R.L. 91, 232301 (2008), PRD76,051106(2007)



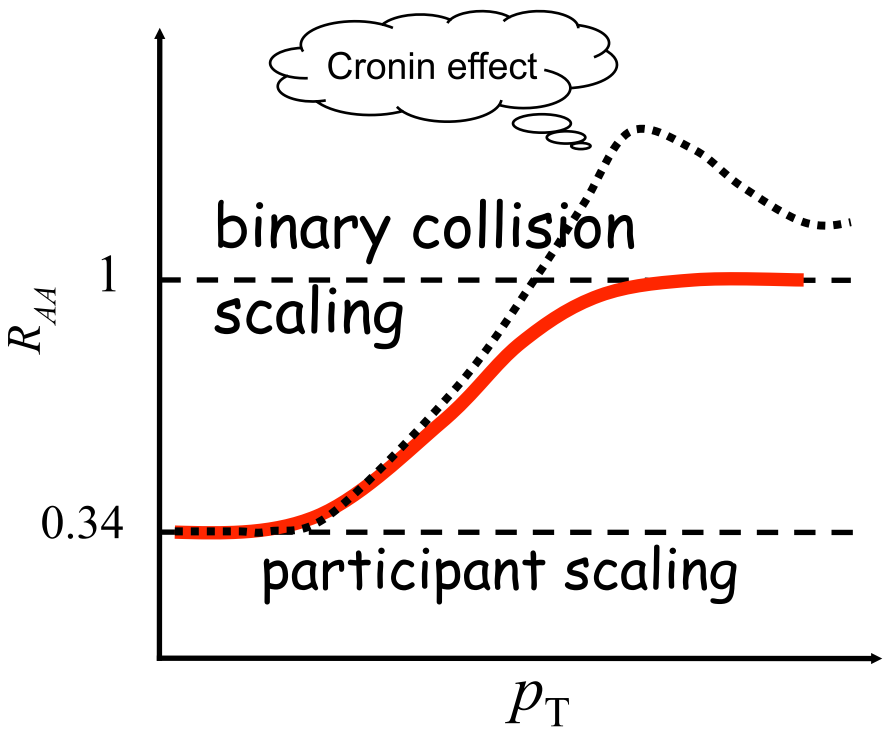
✓Clear and similar suppression up to ~20 GeV/c

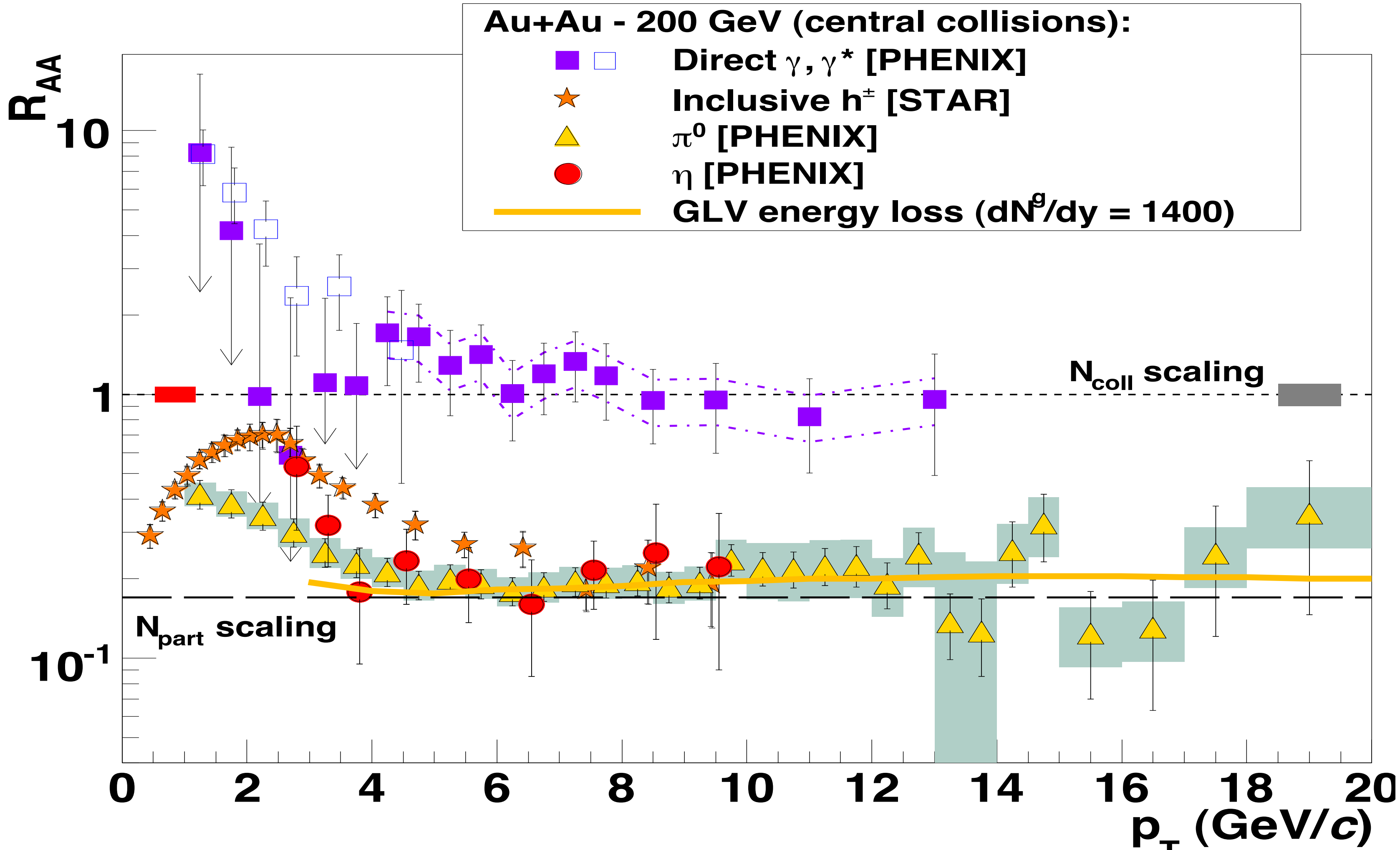
Suppression of high p_t particles



Nuclear Modification Factor

$$R_{AA} = \frac{\text{"hot/dense QCDmedium"}}{\text{"QCD vacuum"}} = \frac{dn_{AA}/dp_T dy}{\langle N_{binary} \rangle \cdot dn_{pp}/dp_T dy}$$

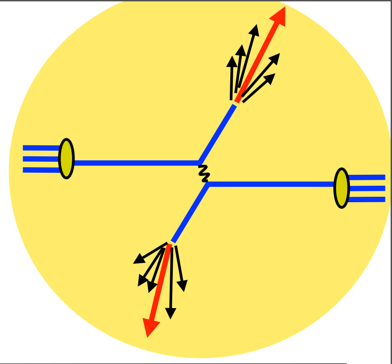




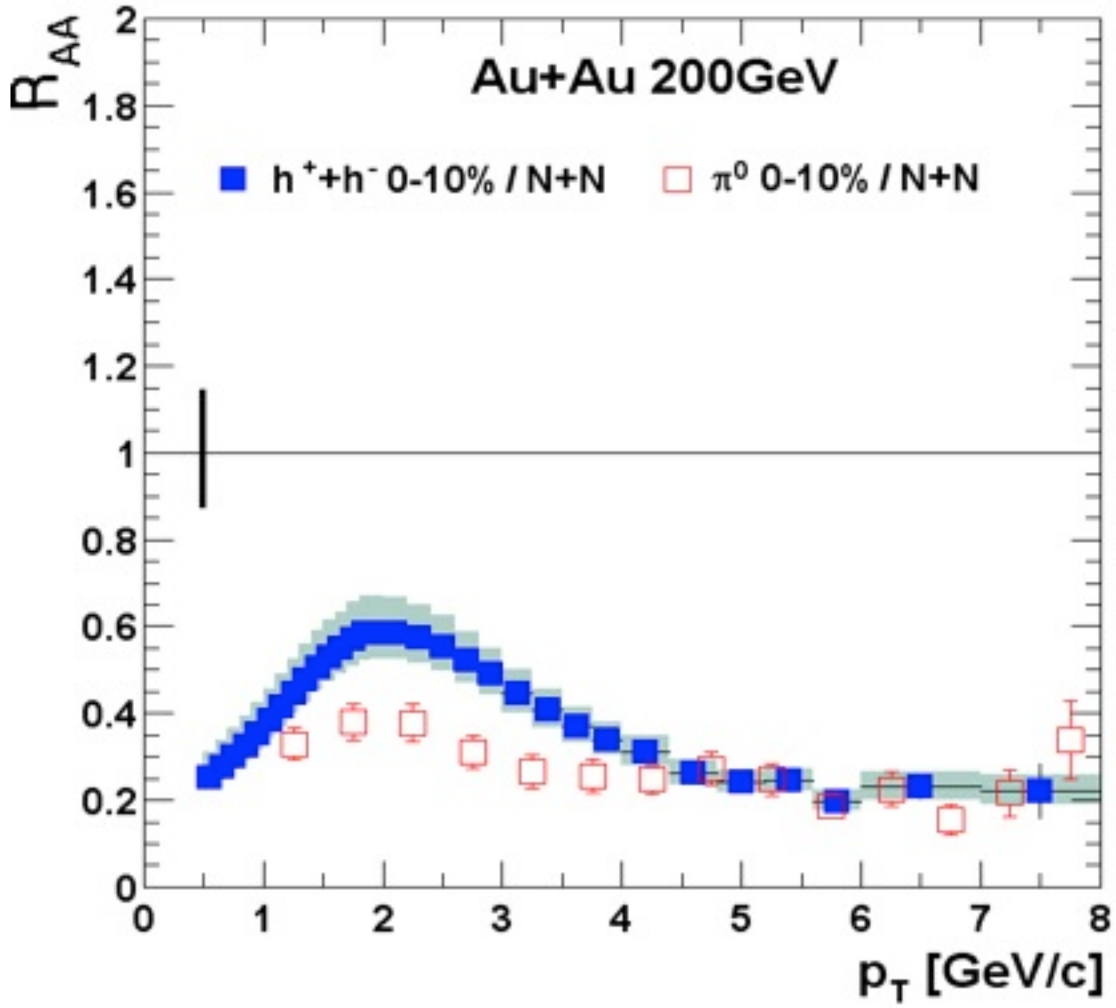
✓ **Pions are suppressed, direct photons are not**

- **Accidental with N_{part} scaling !?**

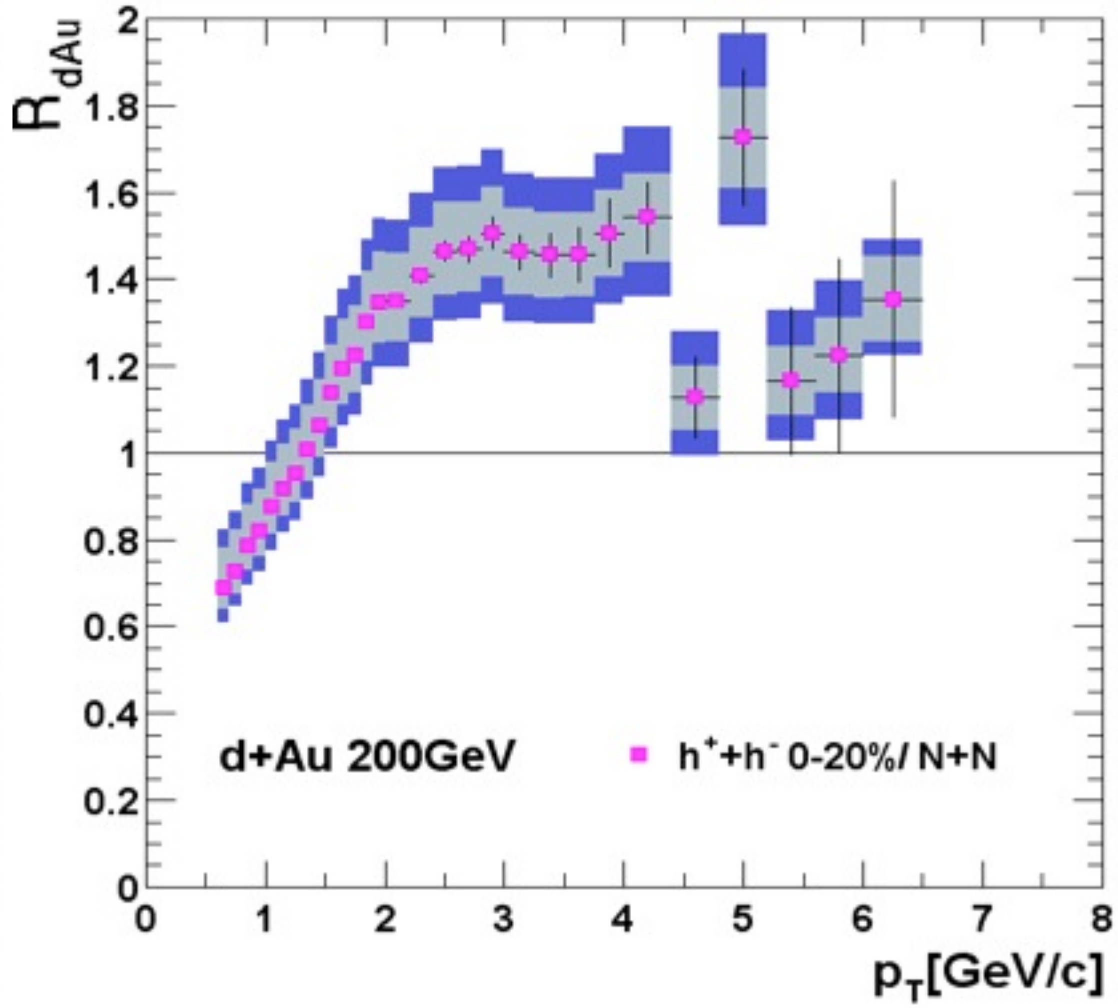
Au+Au vs d+Au



Phenix; P.R.L. 91, 072303 (2003)



Au+Au at $\sqrt{s_{NN}}$ = 200 GeV

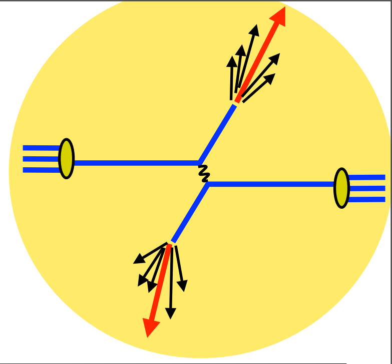


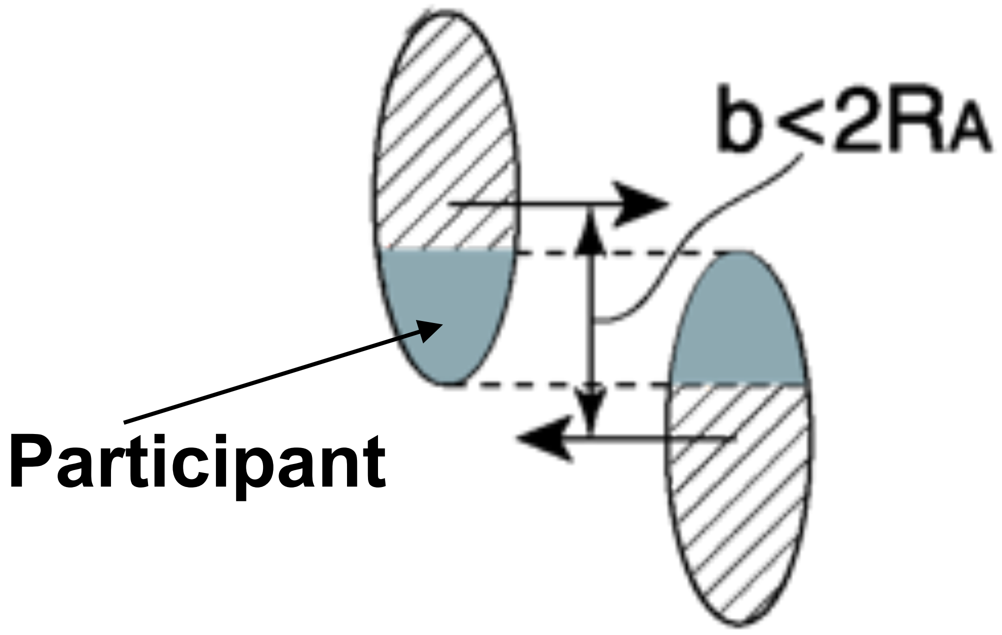
d+Au→h±+X at $\sqrt{s_{NN}}$ = 200 GeV

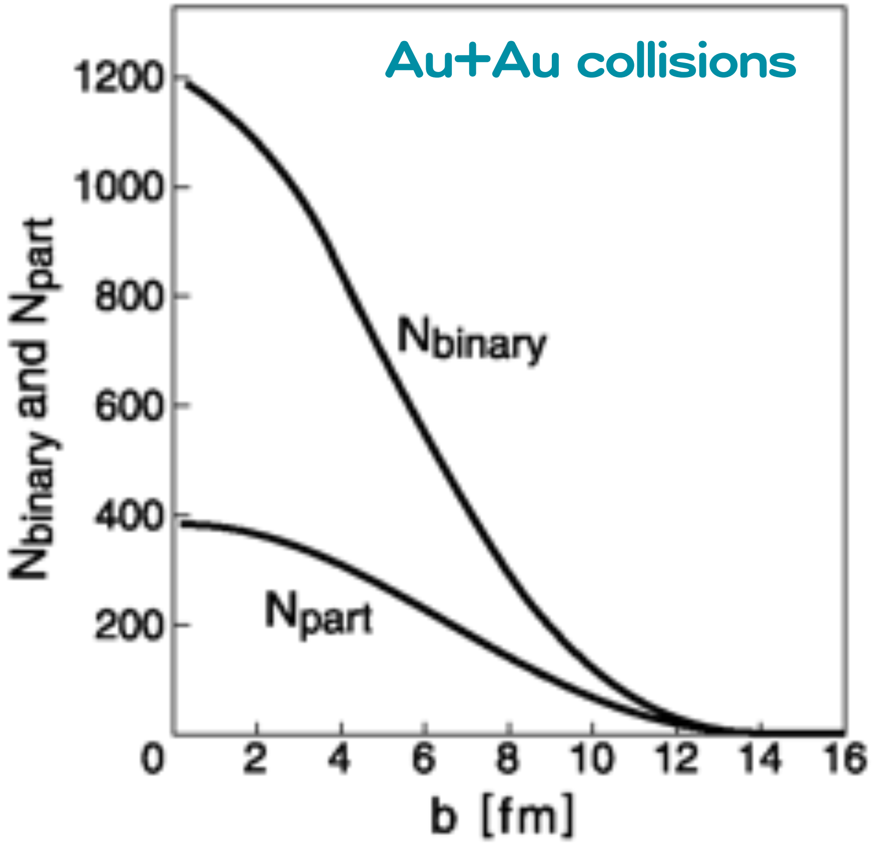
✓High pt suppression in Au+Au, while not observed in d+Au.

➡Effect is not due to initial state, but final state.

N_{part} & N_{binary}

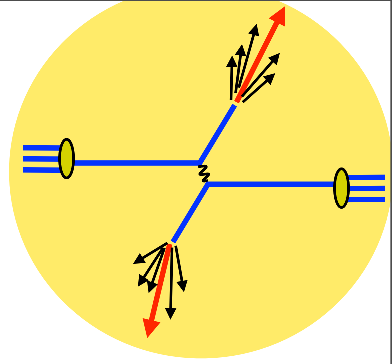




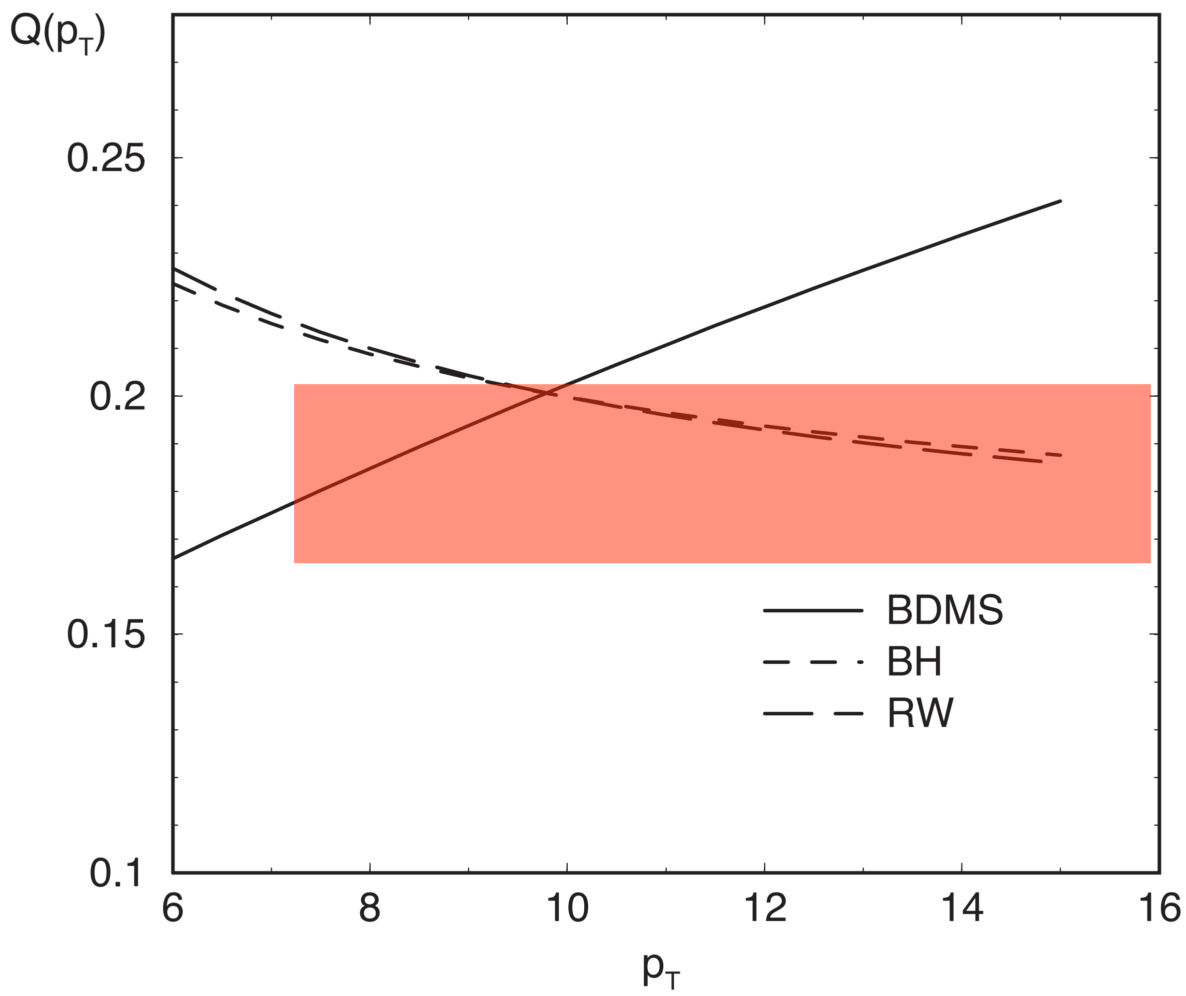


- ✓ N_{part};
  - # of participant nucleons
  - Particle production in hA is prop. to N_{part}, (Wounded-Nucleon Model)
- ✓ N_{binary};
  - # of binary nucleon-nucleon collisions
  - Pass through at high energy.
  - Evaluation of N_{part} & N_{binary} by Glauber Model.

N_{part} scaling?

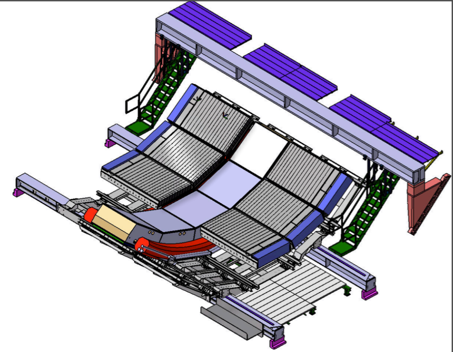


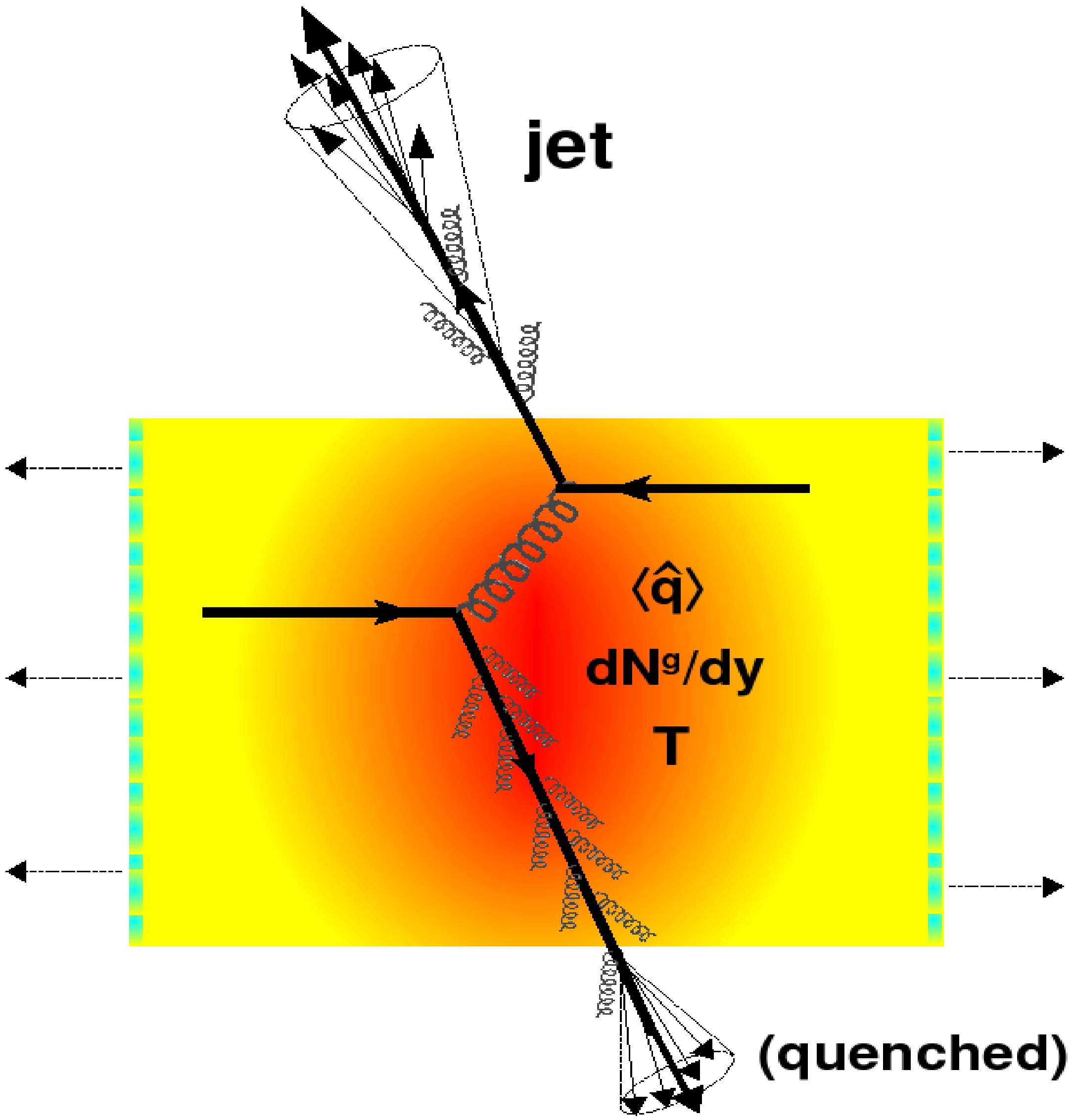
Phys. Rev. C 67,061902(2003)



- ✓Rate of initial hard scattering should be prop. to N_{binary}.
- ✓N_{part} scaling may be due to surface emission of particles;
  - ➡strong quenching limit
- ✓Need LHC data !!

"Jet Quench"





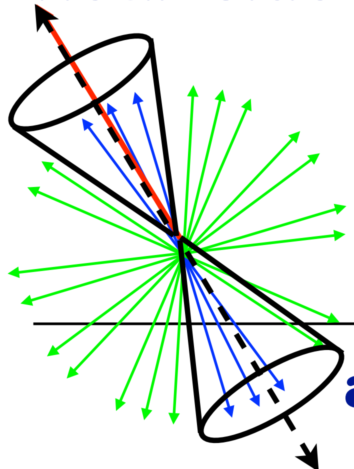
"Jet quenching" in nucleus-nucleus collision.

✓ Two quarks suffer a hard scattering in AA collision
- One goes out to vacuum creating jet,
- but the other goes through the QGP suffering energy loss due to gluon

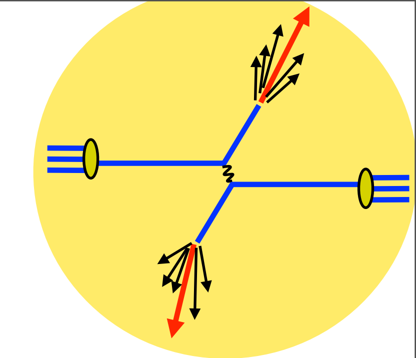
✓ Manifestation:
- attenuation/ disappearance of jet
- suppression of high pt hadrons
- modification of jet frag.

Modification of back-to-back corr.

near side

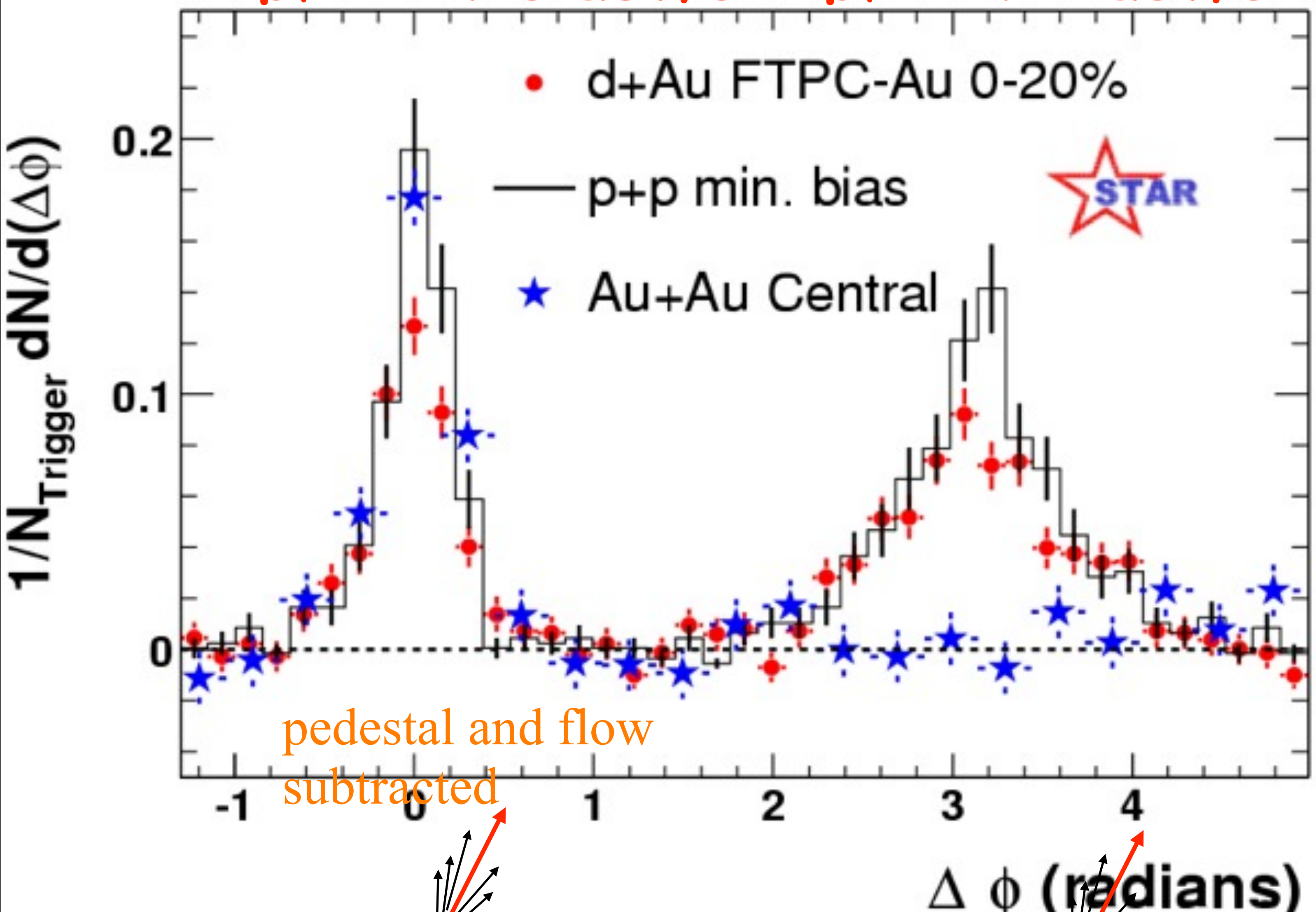


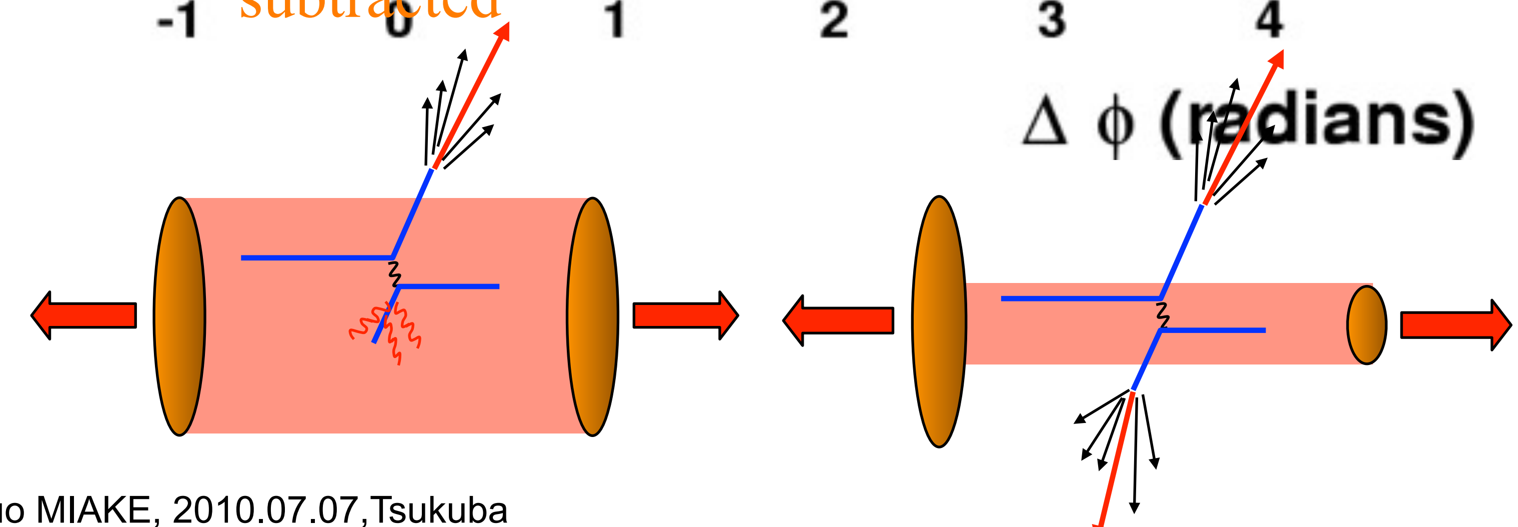
away side



Star; P.R.L. 91, 72304 (2003)

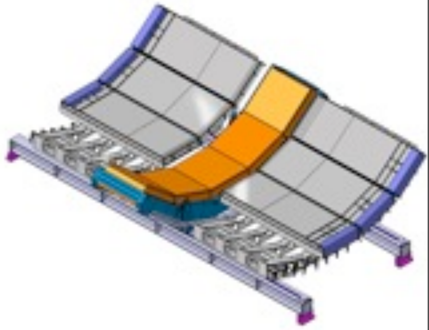
p_T^{trig} = 4~6 GeV/c × p_T^{assoc} > 2 GeV/c



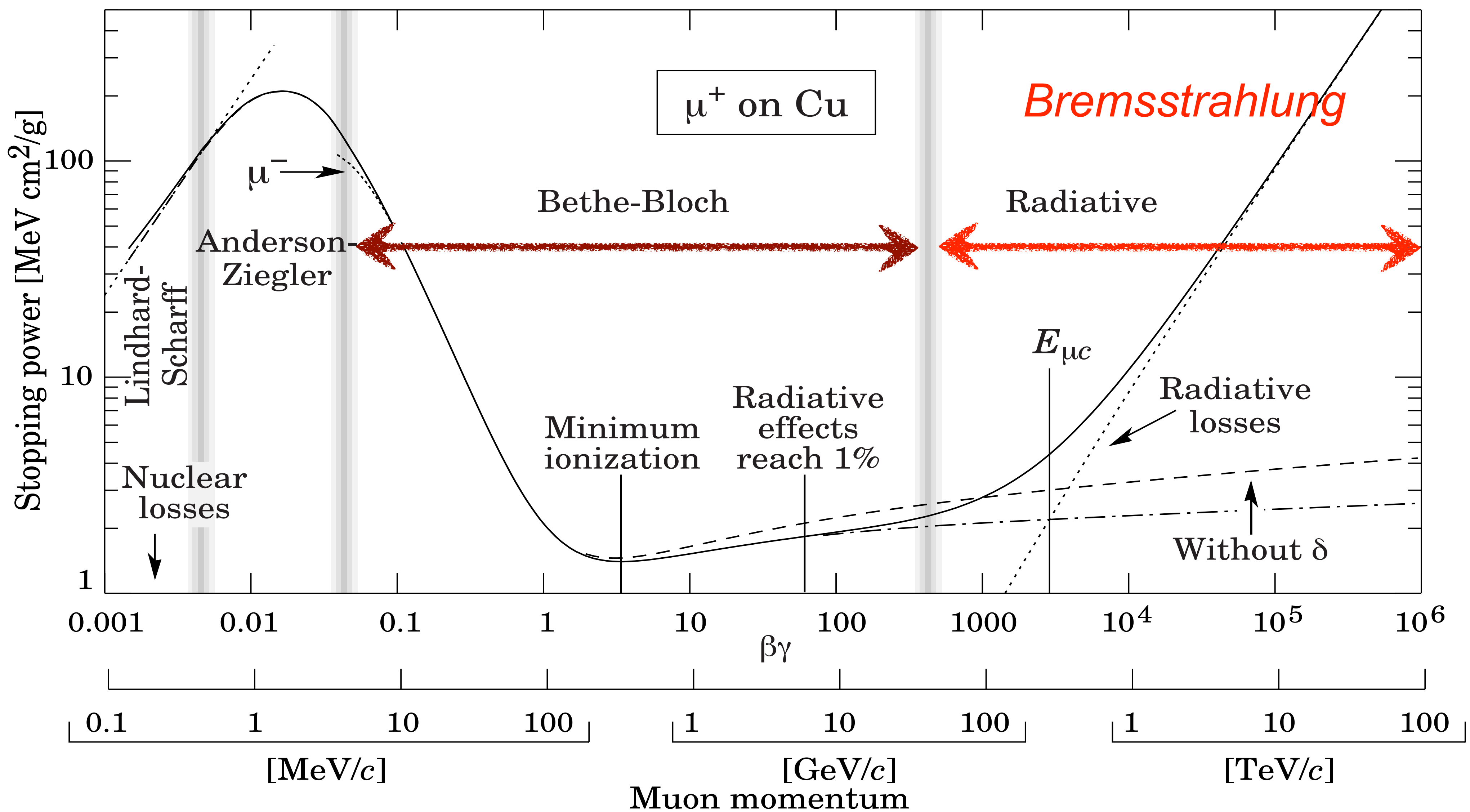


- ✓ Direct evidence of loss of 'jet'
- ✓ Azimuthal correlation w.r.t. high pt leading particle (trigger).
  - pp ; clean di-jet
  - dAu; similar to pp
  - Au+Au; Similar on the same side (suggesting jet-like mechanism), but b-to-b disappeared
    - Effect is not in initial but in final stage
    - Energy loss of partons in dense matter created in Au+Au

Energy loss in QED



Energy loss of charged particle in a matter



Collisional

- √Bethe-Bloch

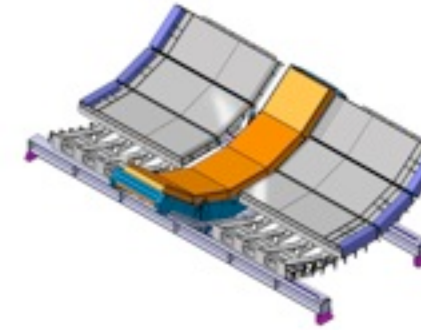
Radiative

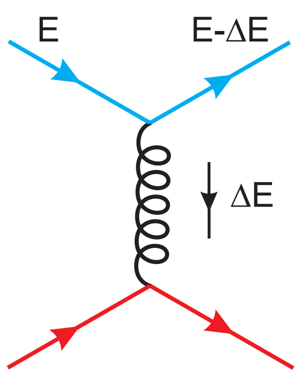
- √Bethe-Heitler (thin; L<<λ)
- √Landau-Pomeranchuk-Migdal (thick; L>>λ)

√**Measurements of dE/dx gives prop. of matter**

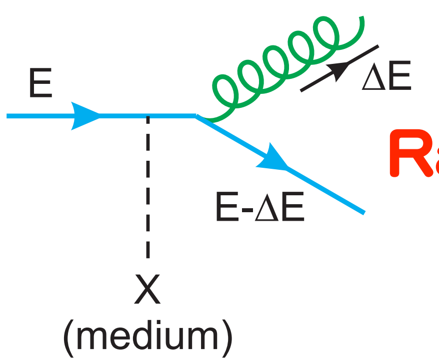
- **Energy loss in QED plasma gives T & m_D info.**

Energy Loss in QCD





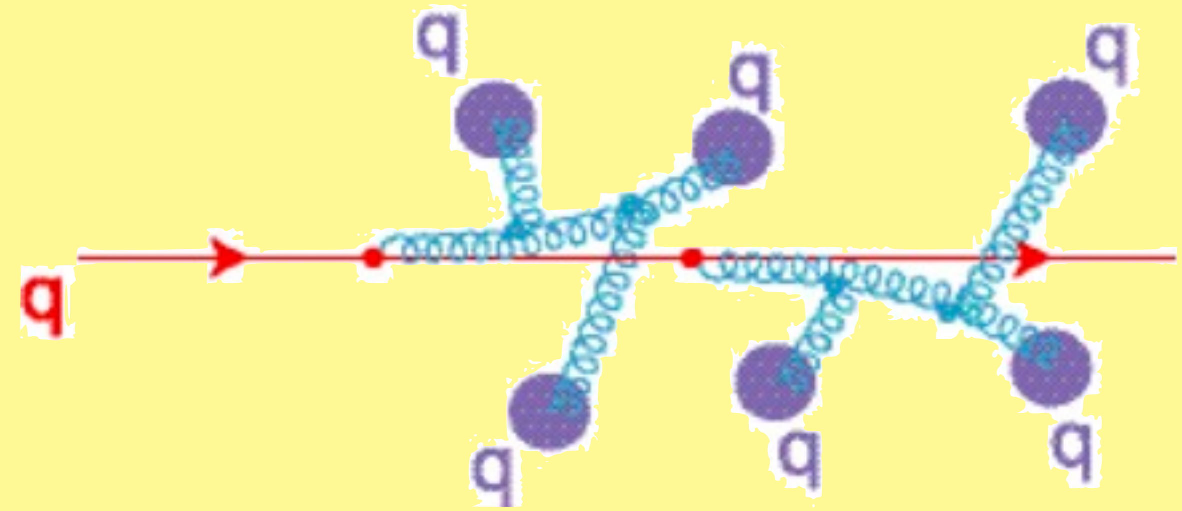
Collisional



Radiative

✓ **Many theories on**

- **Collisional loss**
- **Radiative loss**
  - ➡Bethe-Heitler regime
  - ➡LPM regime
  - ➡ "dead-cone" effect



$$\Delta E \propto \alpha_S C_R \langle \hat{q} \rangle L^2$$

(Executive) Summary

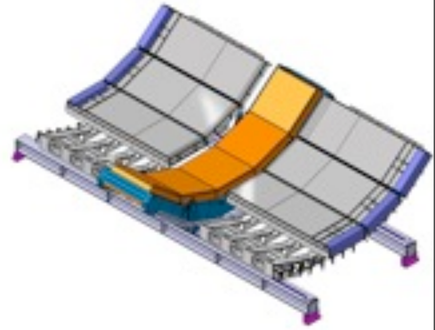
Radiative loss is dominant

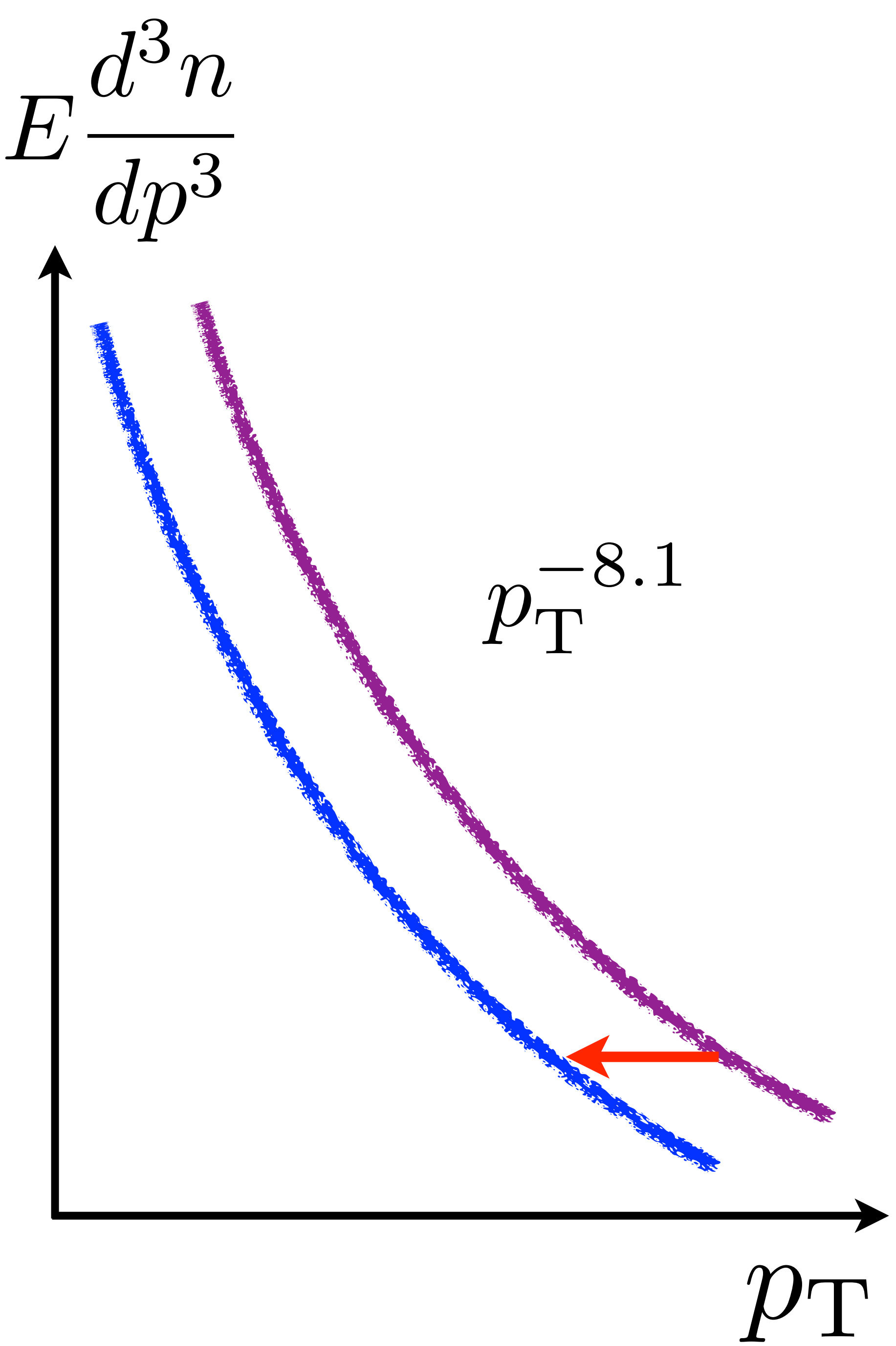
Effects are;

- suppression of high pt hadron
- unbalanced back-to back
- modification of jet fragmentation
  softer, larger multiplicity, angular broadening

$$\Delta E_{\text{gluon}} > \Delta E_{\text{quark}} > \Delta E_{\text{charm}} > \Delta E_{\text{bottom}}$$

Intuitive analysis of energy loss of parton





In pp collisions,

$$E\frac{d^3n}{dp^3} = \frac{dn}{2\pi p_T dp_T dy} = \frac{A}{p_T^n} \text{ with } n = 8.1$$

In Au + Au collisions, fraction of p_T loss; S_{loss}

$$p'_T = (1 - S_{loss})p_T$$

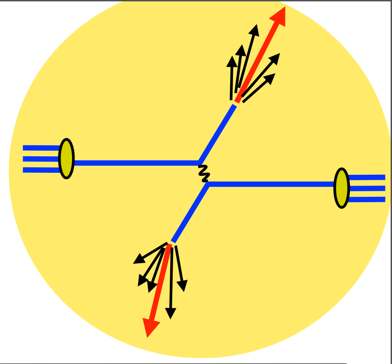
$$\frac{dn}{dp'_T} = \frac{dn}{dp_T}\frac{dp_T}{dp'_T} = \frac{A}{p_T^{n-1}}\frac{1}{(1-S_{loss})} = \frac{A(1-S_{loss})^{n-2}}{p'^{n-1}_T}$$

$$R_{AA} = \frac{A(1-S_{loss})^{n-2}/p'^{n-1}_T}{A/p_T^n} = (1-S_{loss})^{n-2}$$

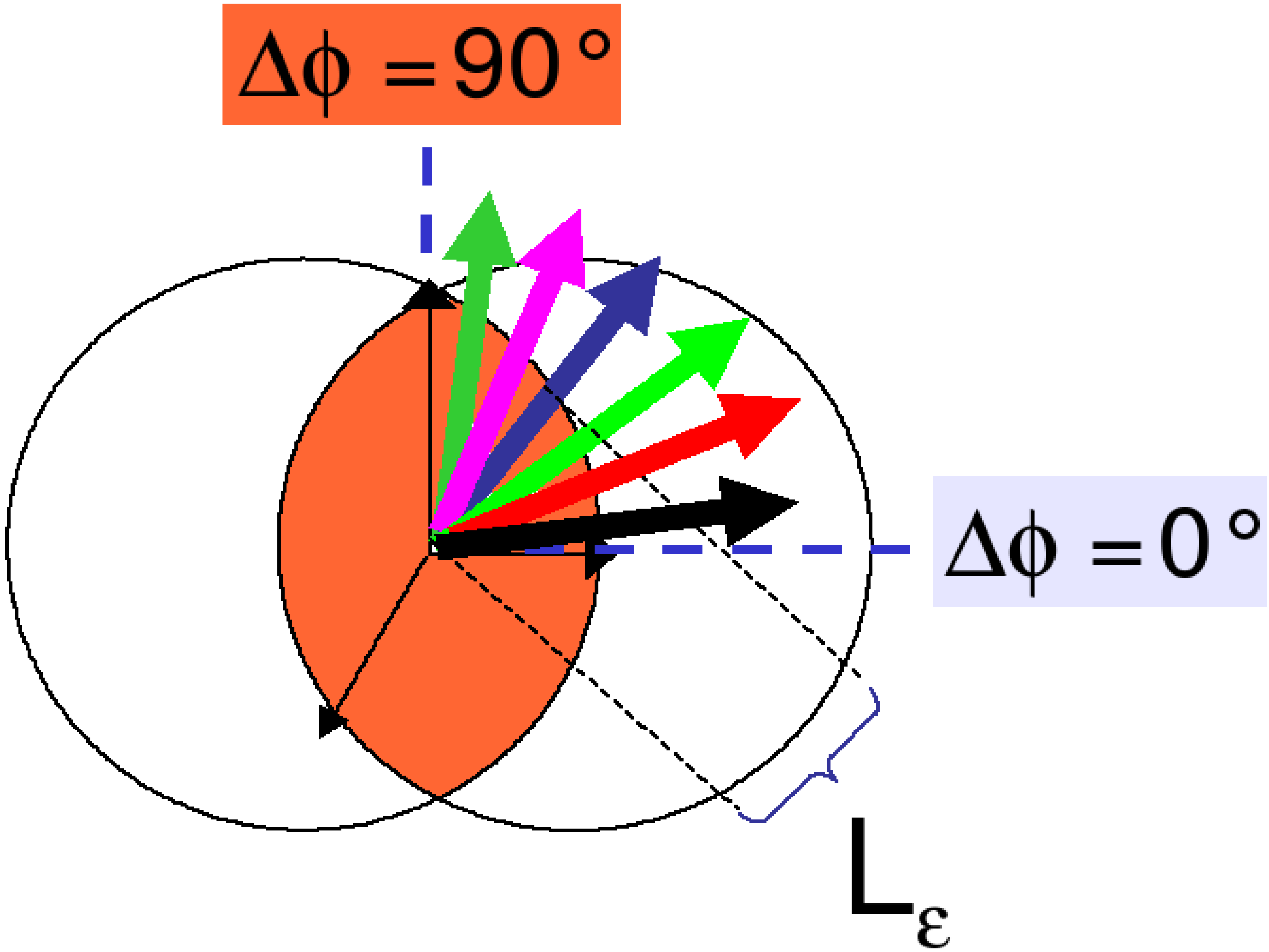
$$\rightarrow S_{loss} = 1 - R_{AA}^{1/(n-2)}$$

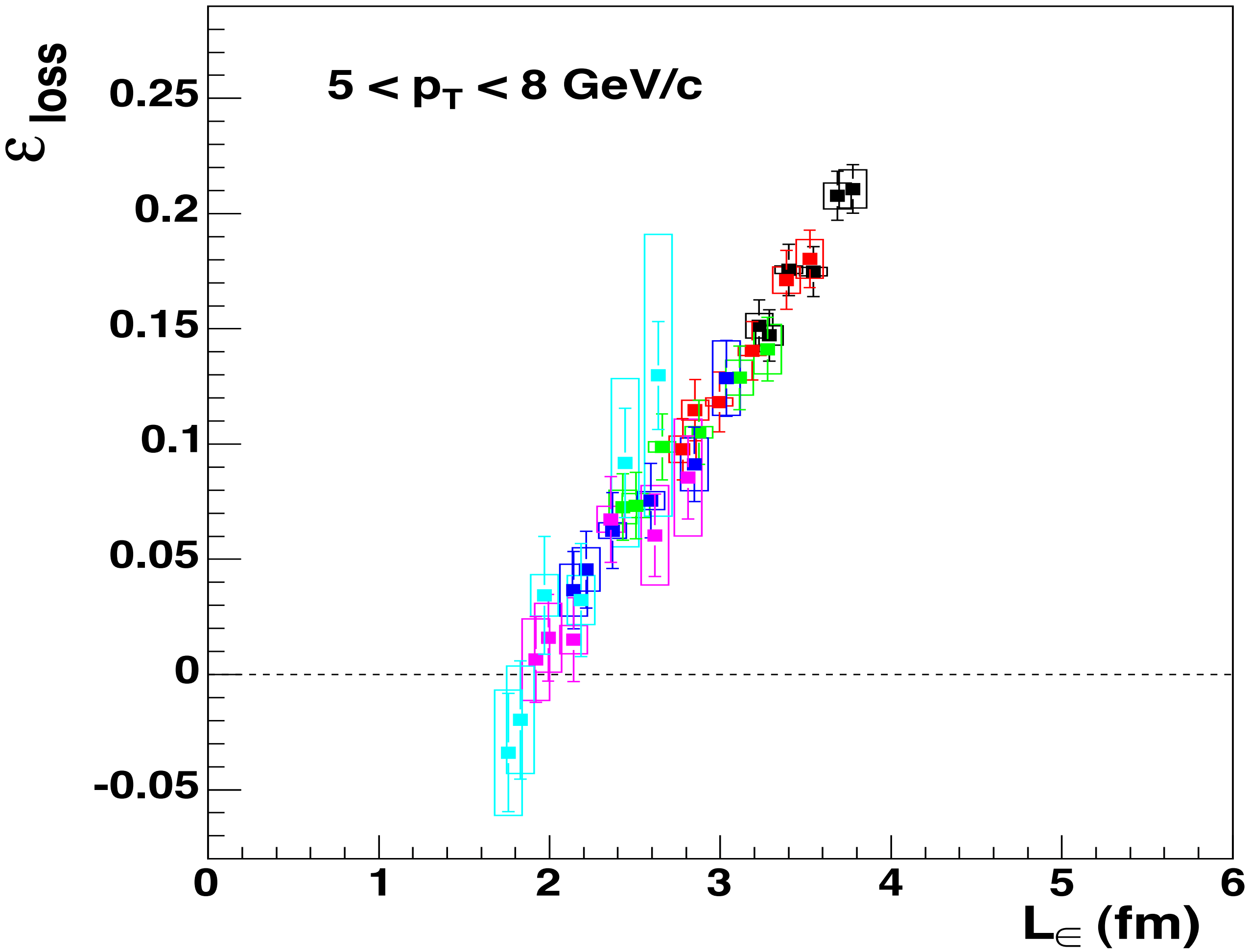
✓**Energy loss ~ 0.2 @ RHIC**

L-dependence of suppression



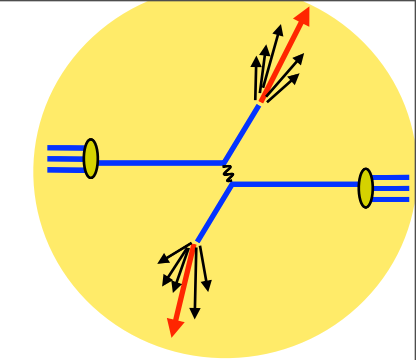
Phenix; P.R.L. 76, 034904 (2007)



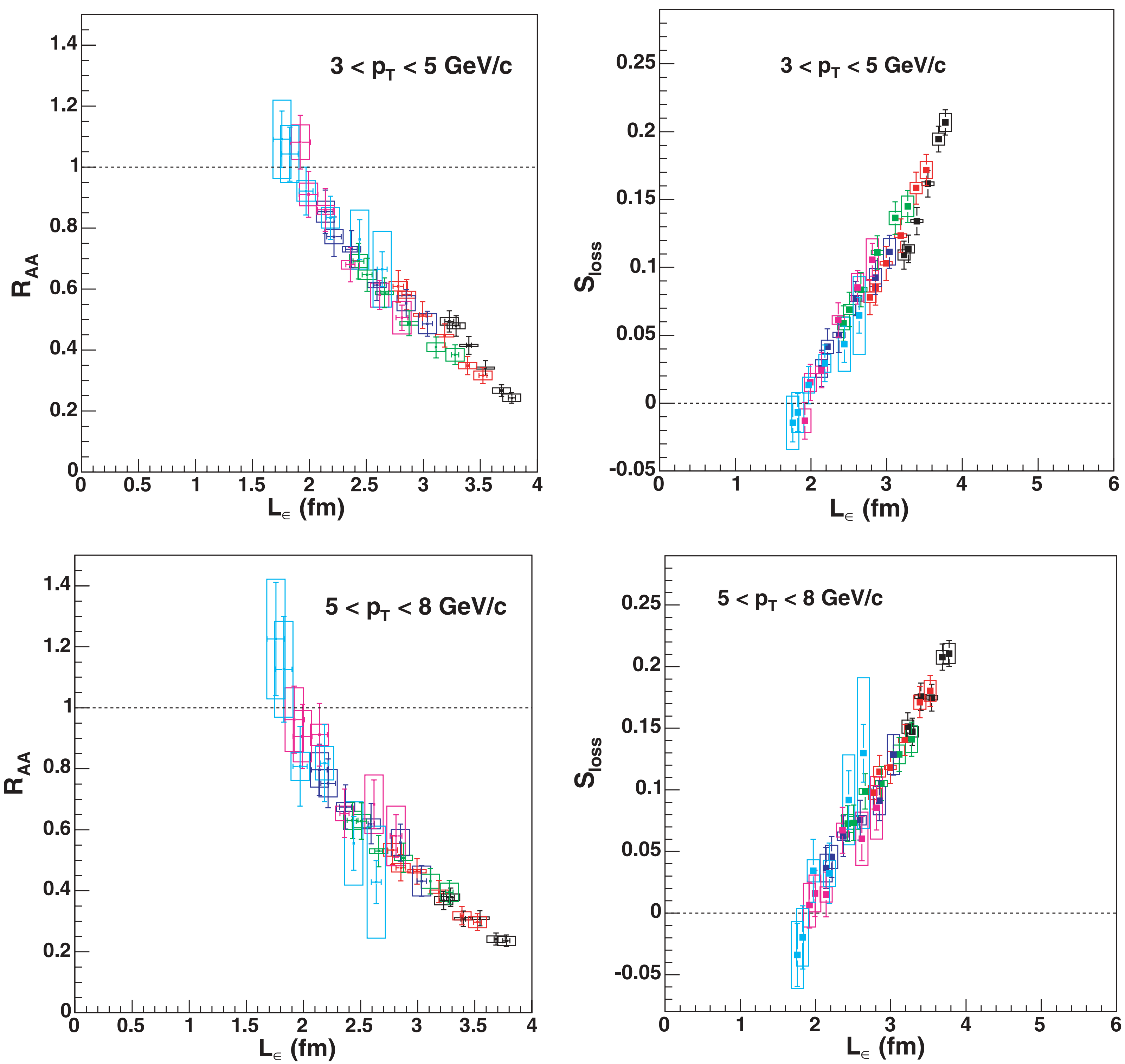


- ✓ Dependence of suppression on reaction plane angle
- ✓ Assume Glauber Model w. Wood-saxon

Universal Behavior

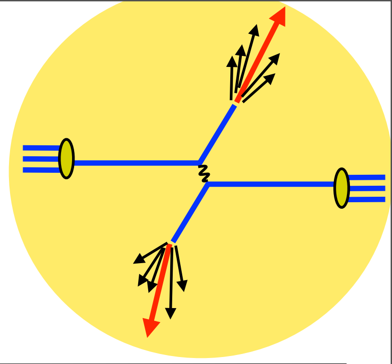


Phenix; P.R.L. 76, 034904 (2007)

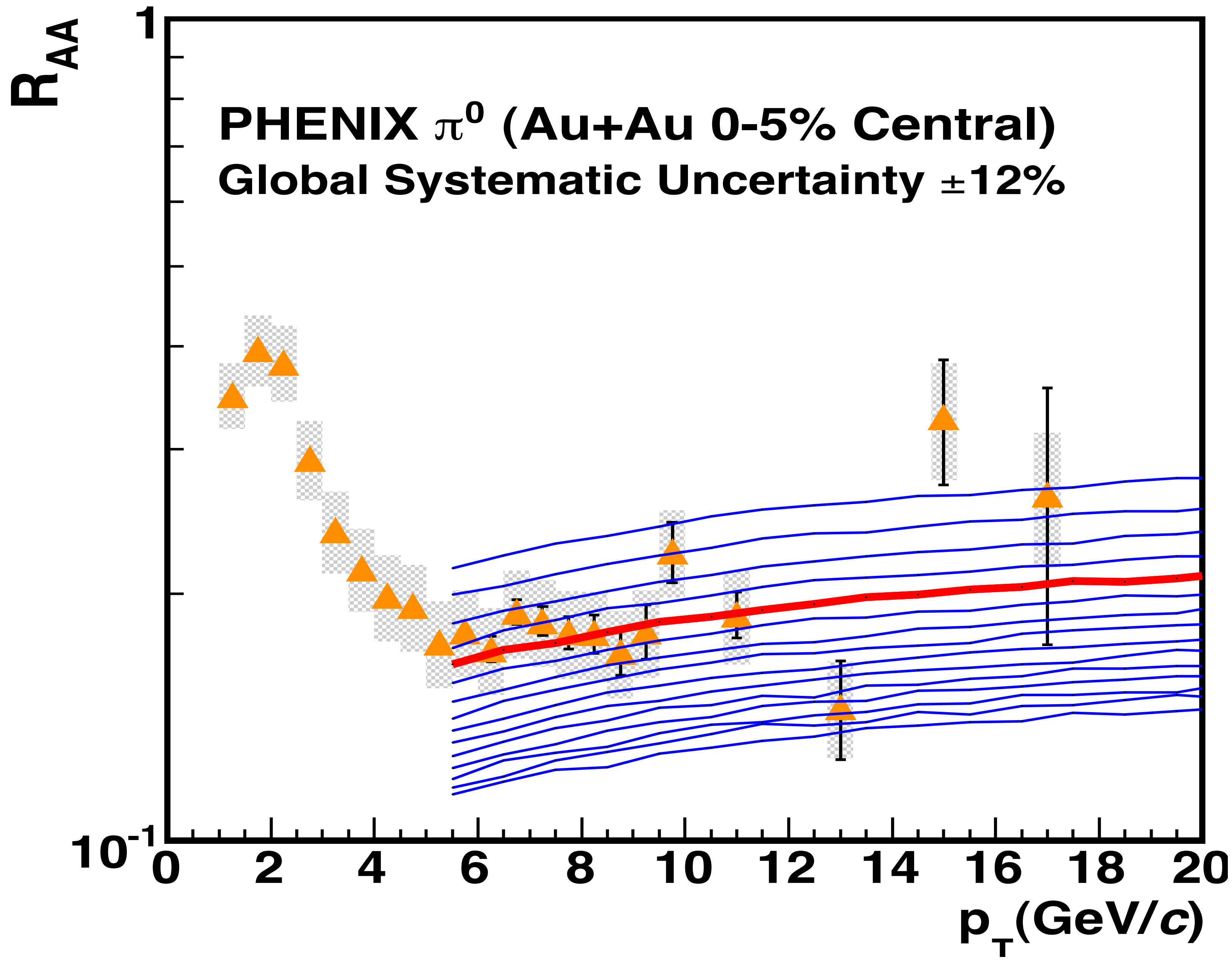


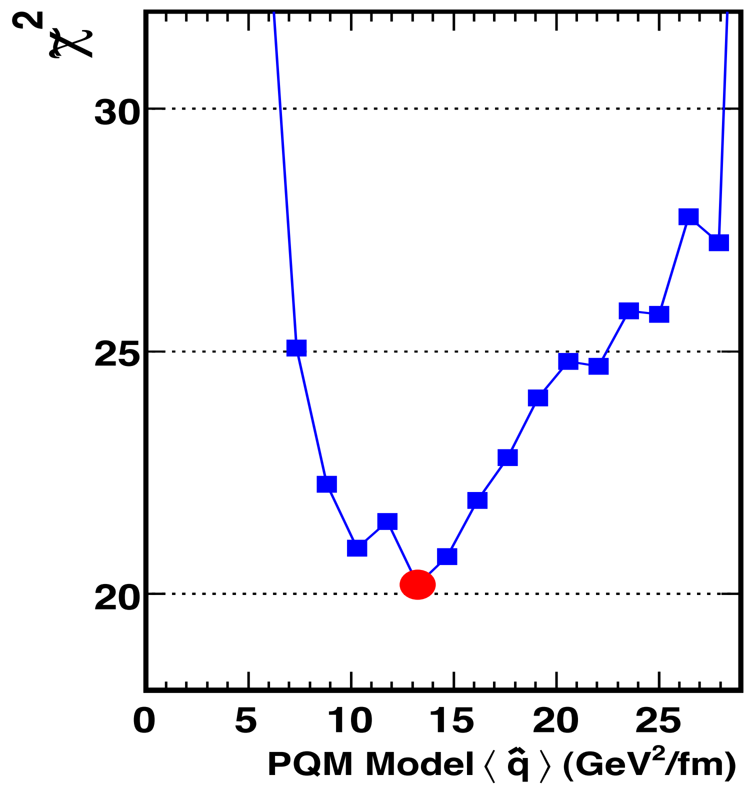
- ✓ R_{AA} and S_{loss} are universal as a function of path length L
  - all centrality
  - all p_T range
- ✓ No suppresion for L < 2 fm

High pt supp. w PQM model

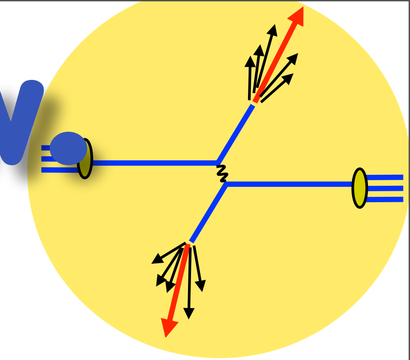


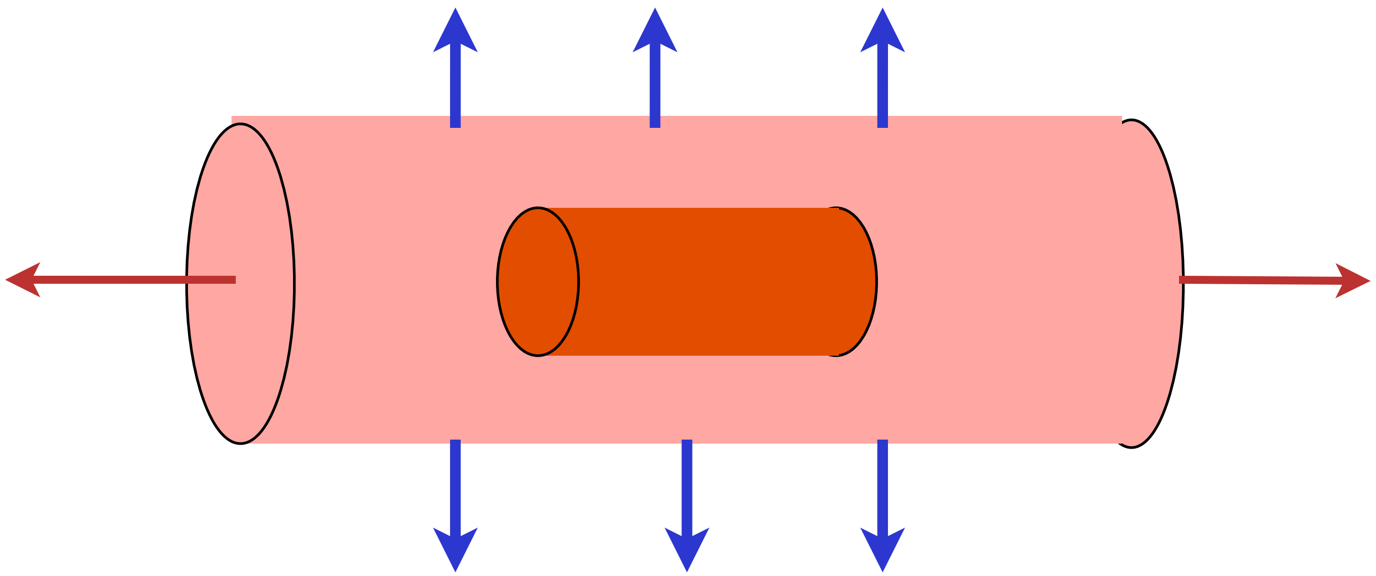
$$\hat{q} = 13.2^{+2.1}_{-3.2} \text{ and } {}^{6.3}_{-5.2}\text{GeV}^2/\text{fm}$$





Phenomenological quench w. hydrodynamical expansion





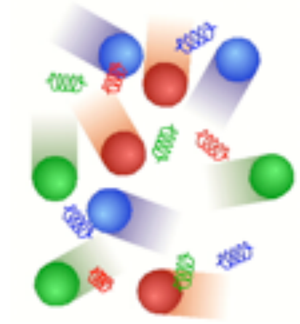
+ $\Delta E \propto \alpha_S C_R \langle \hat{q} \rangle L^2$

See arXiv:0902.2011 for references

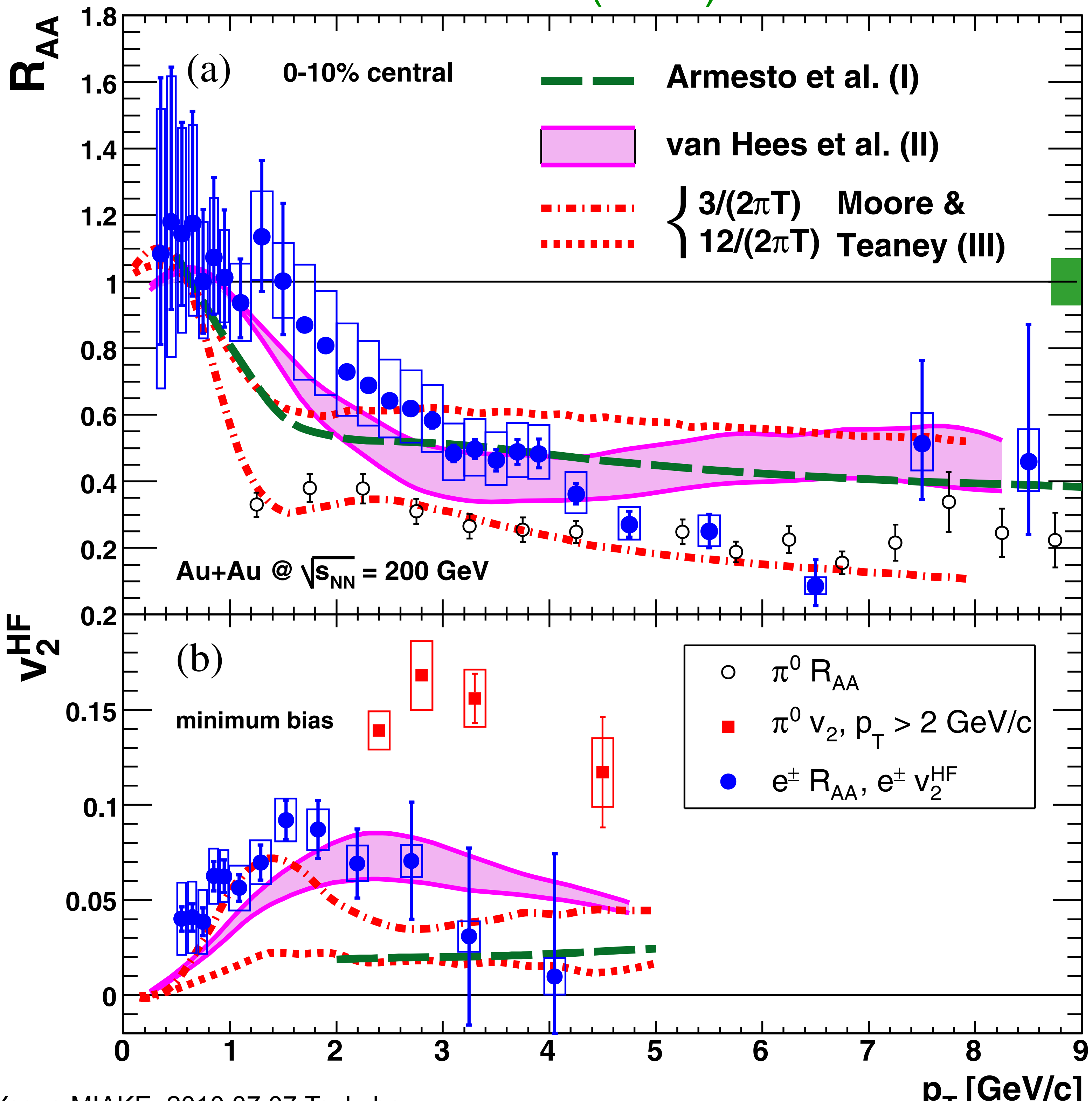
Table 1. Transport coefficients $\hat{q}$ derived in a 3-D hydro simulation of an expanding QGP with initial temperature T_0 = 0.4 GeV (at τ_0 = 0.6 fm/c) [145] with different parton energy loss implementations (ASW, HT and AMY schemes) that reproduce the high-p_T π^0 suppression observed in central *AuAu* at RHIC [89]. The a, b exponents indicate two choices of scaling of $\hat{q}(\mathbf{r},\tau)$ with the initial plasma temperature or energy-density: (a) $\hat{q}_0 \propto T_0^3(\mathbf{r},\tau)$, and ($b$) $\hat{q}_0 \propto \varepsilon_0^{3/4}(\mathbf{r},\tau)$. The PQM/ASW result (Fig. 17, $\langle \hat{q} \rangle$ for a *static* plasma) is also listed for comparison.

	ASW	HT	AMY
$\hat{q}$ (GeV^2/fm)	$10^{(a)} - 18.5^{(b)}, 13.2^{(PQM)}$	$2.3^{(a)} - 4.3^{(b)}$	$4.1^{(a)}$

Heavy Flavor, c & b

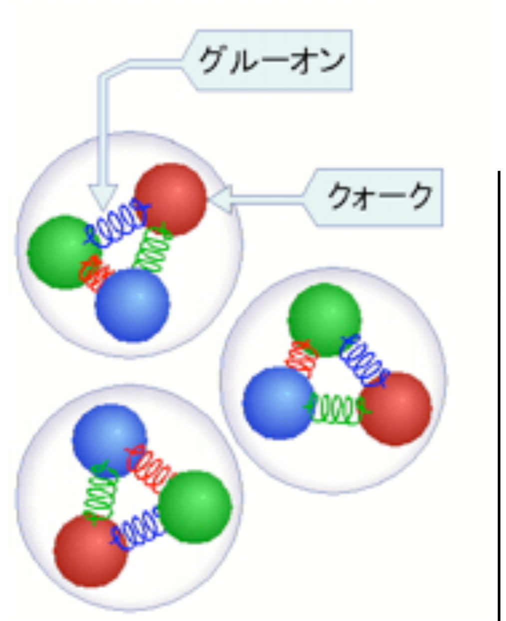


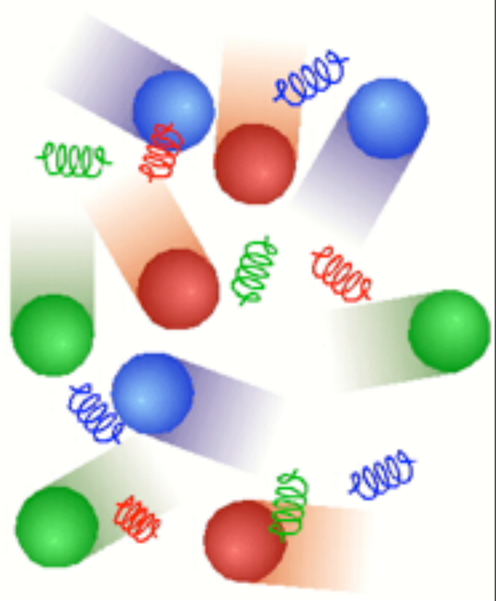
PHENIX PRL 98(2007)172301



- ✓Electrons from Heavy Flavor decay (charm, bottom)
- ✓HF suffers similar energy loss
  (I) $\hat{q} = 14\ \mathrm{GeV}^2/\mathrm{fm}$
- ✓Large v_2^{HF} indicates charm flows

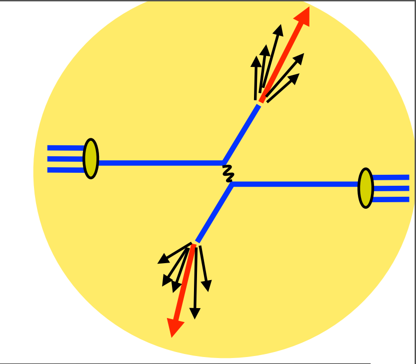
➡Heavy quarks are coupled to the medium



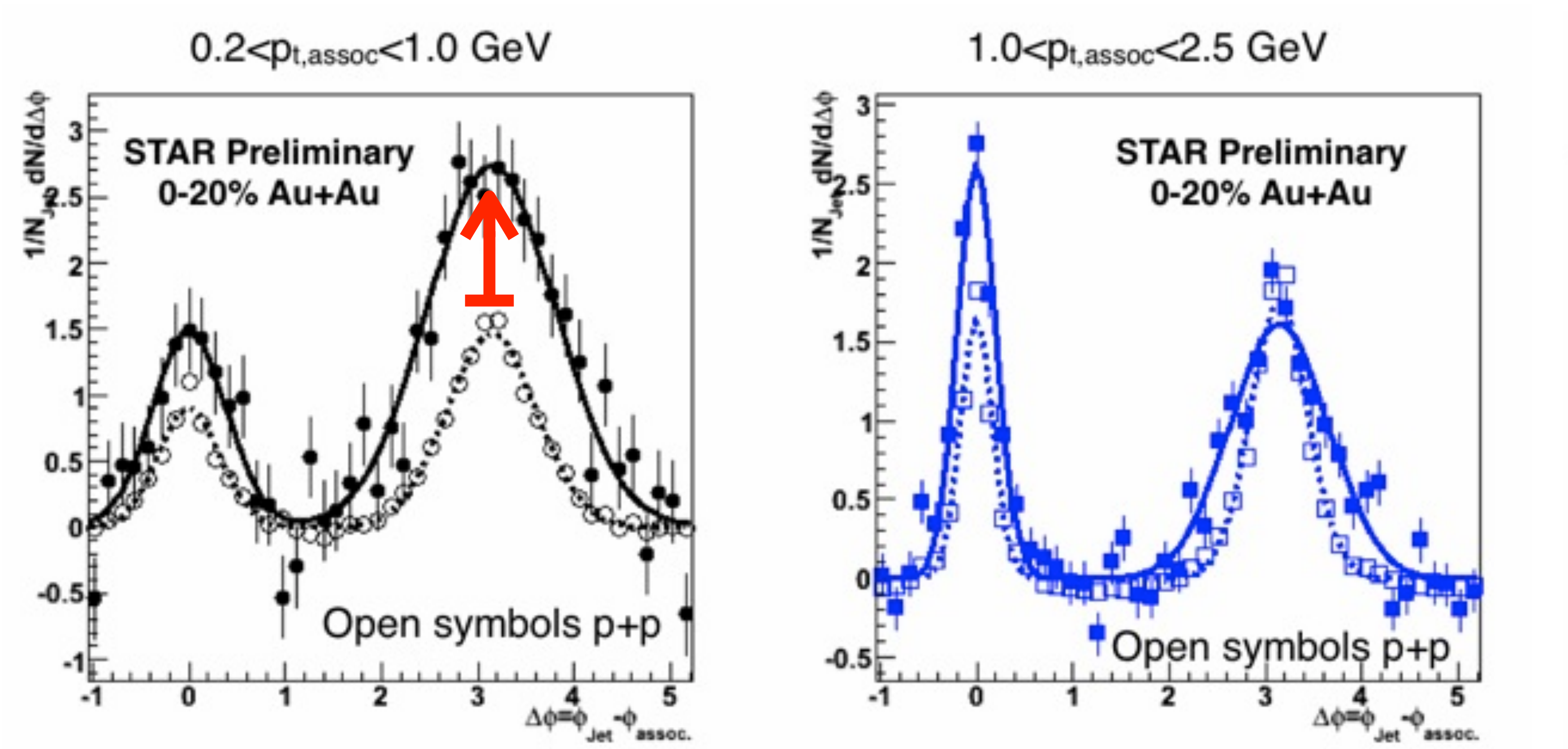


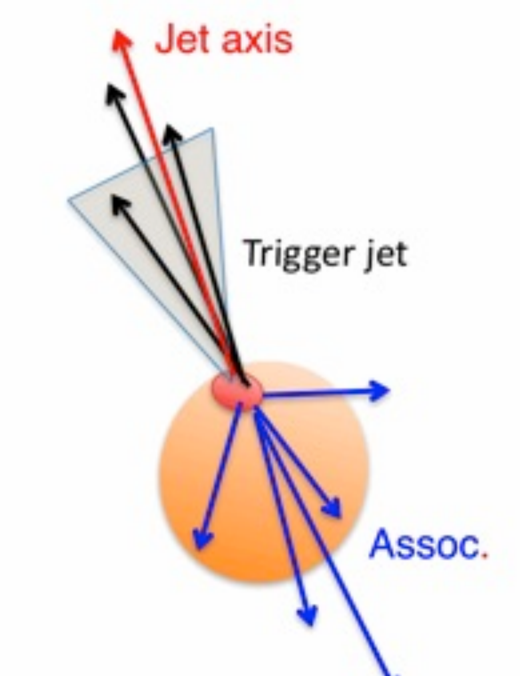
Should we study Jet Quench in Jets?

Jet - hadron correlation



High Tower Trigger (HT) : $(\eta\times\phi)$=(0.05x0.05) ET>5.4GeV



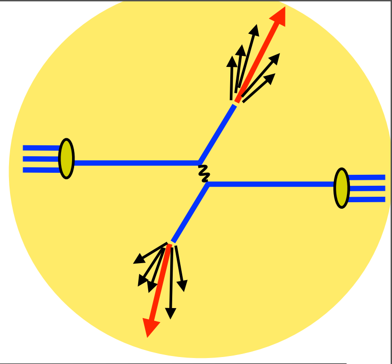


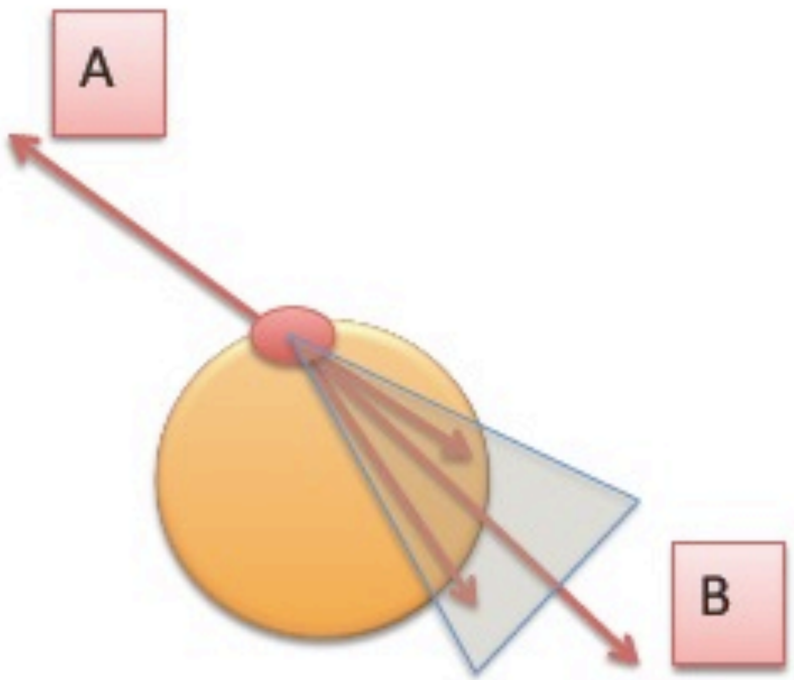
RHIC-AGS' 09, J. Putschke

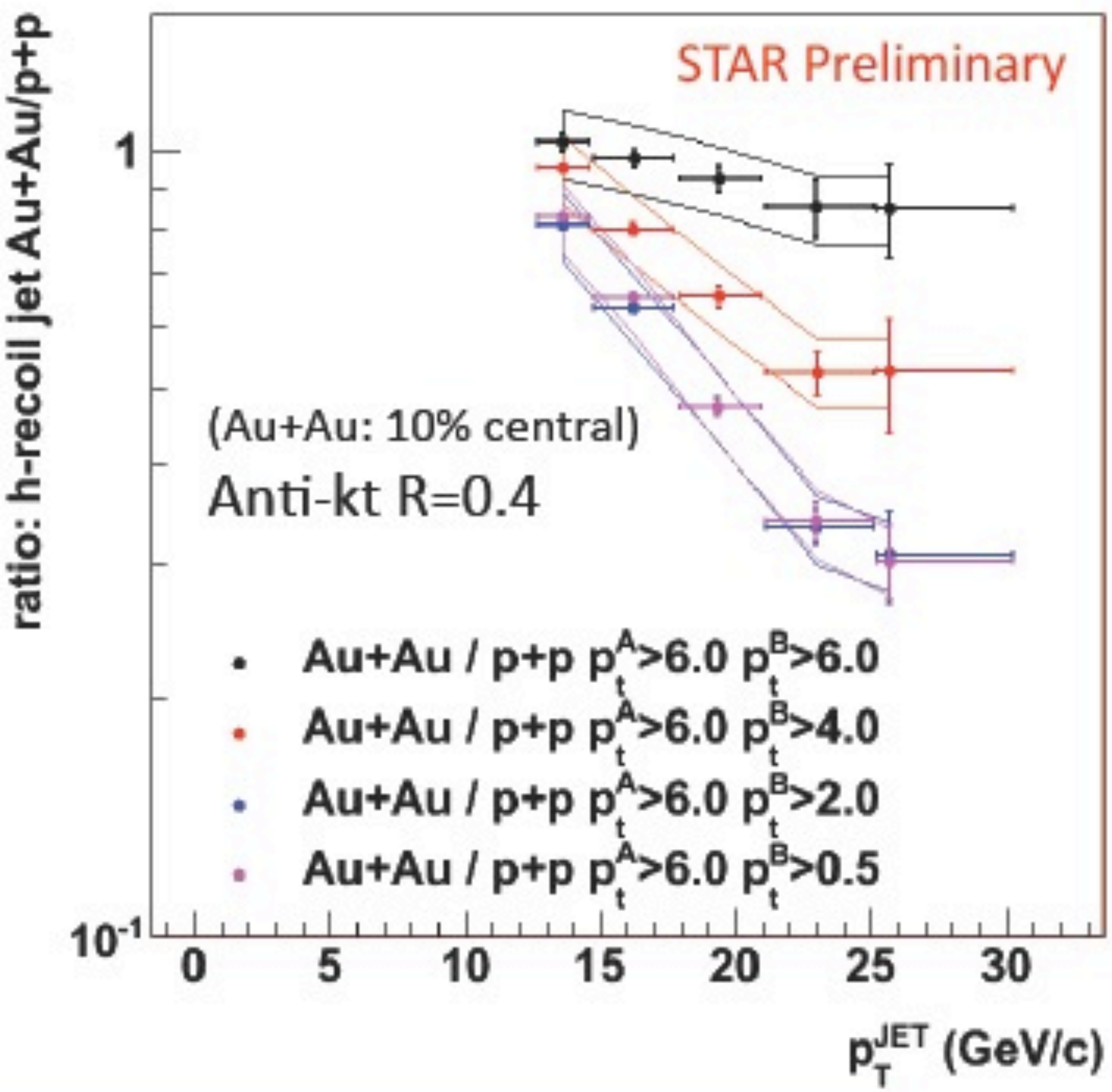
✓On away side, less high p_t particles, while more low p_t particles

✓No mach cone structure !?

Jet - hadron corr.





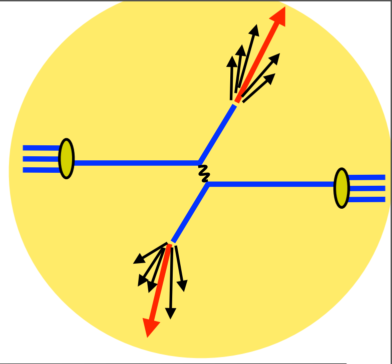


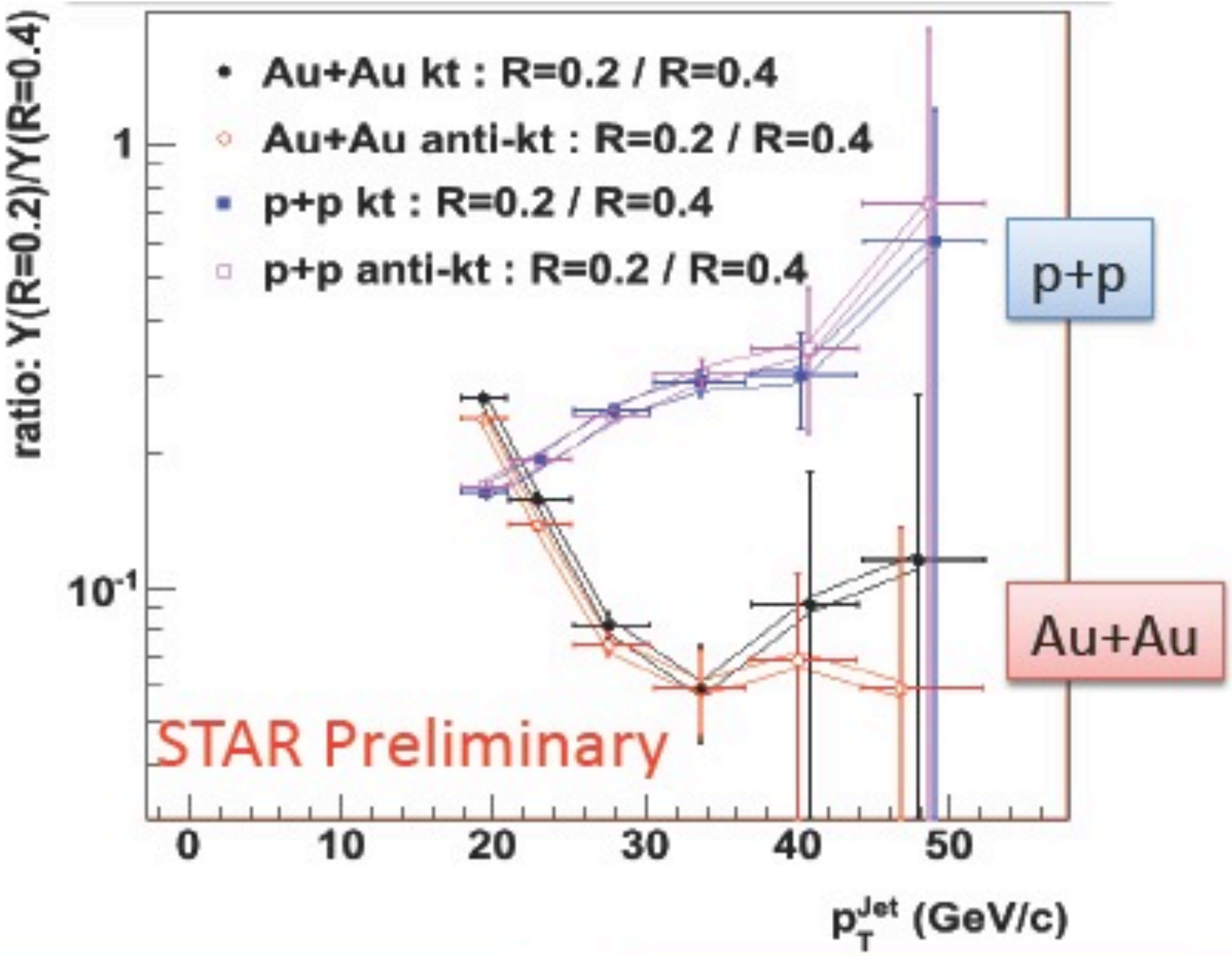
Significant suppression of the bias free recoil jet spectrum

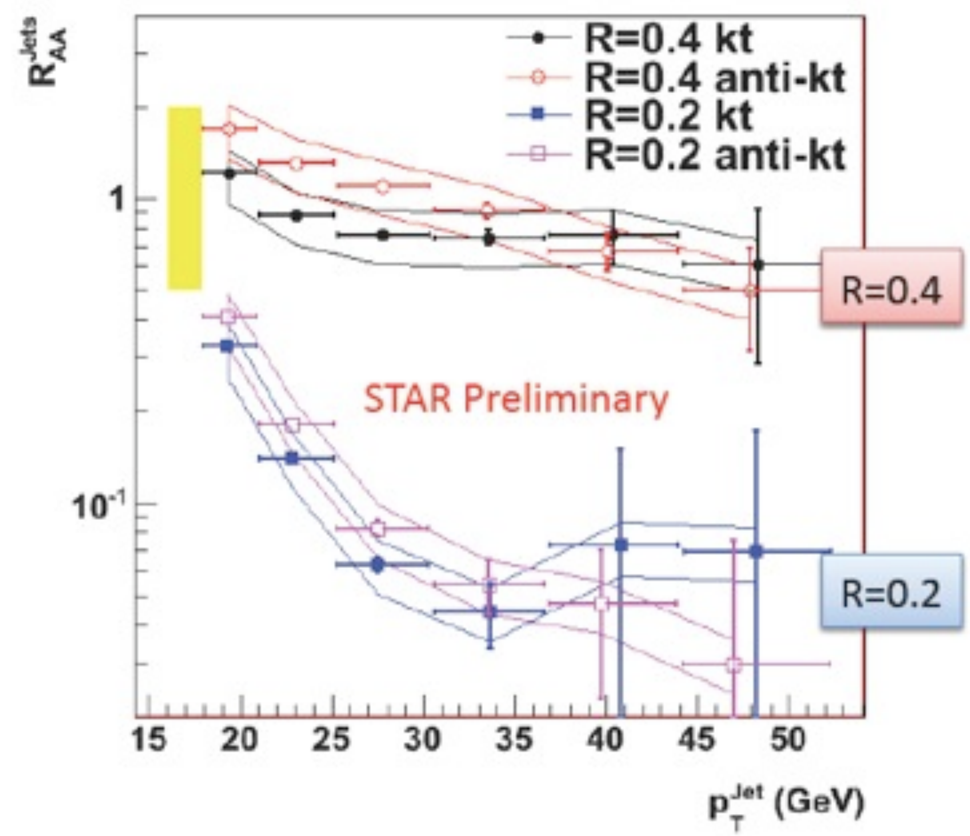
Mateusz Ploskon (LBNL), STAR, QM'09

✓ **Study of "jet quenching" in terms of the energy flow**

Jet analysis ~ cone radius





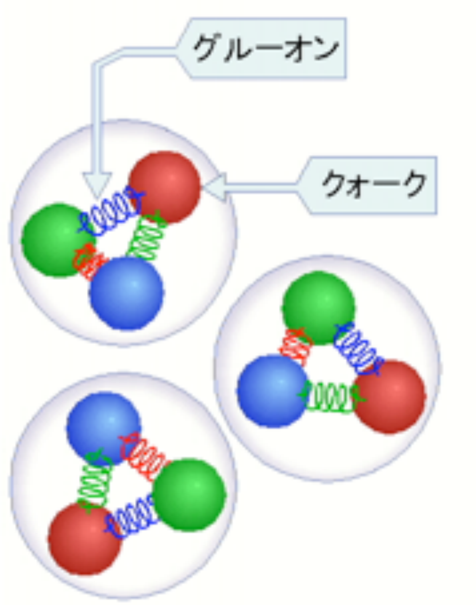


p+p: "Narrowing" of the jet structure with increasing jet energy

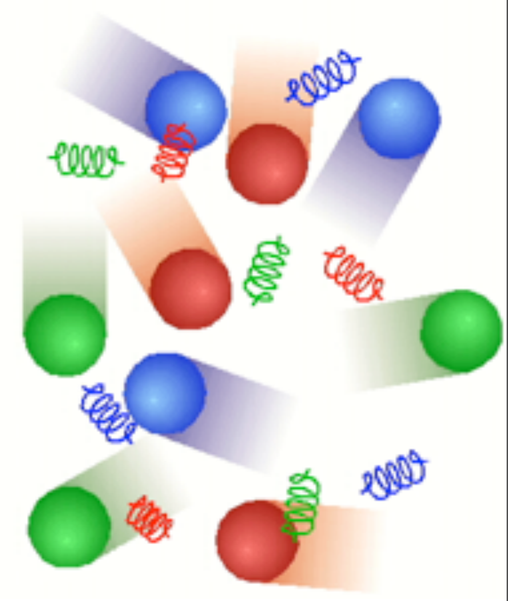
Au+Au: Strong broadening of the jet energy profile

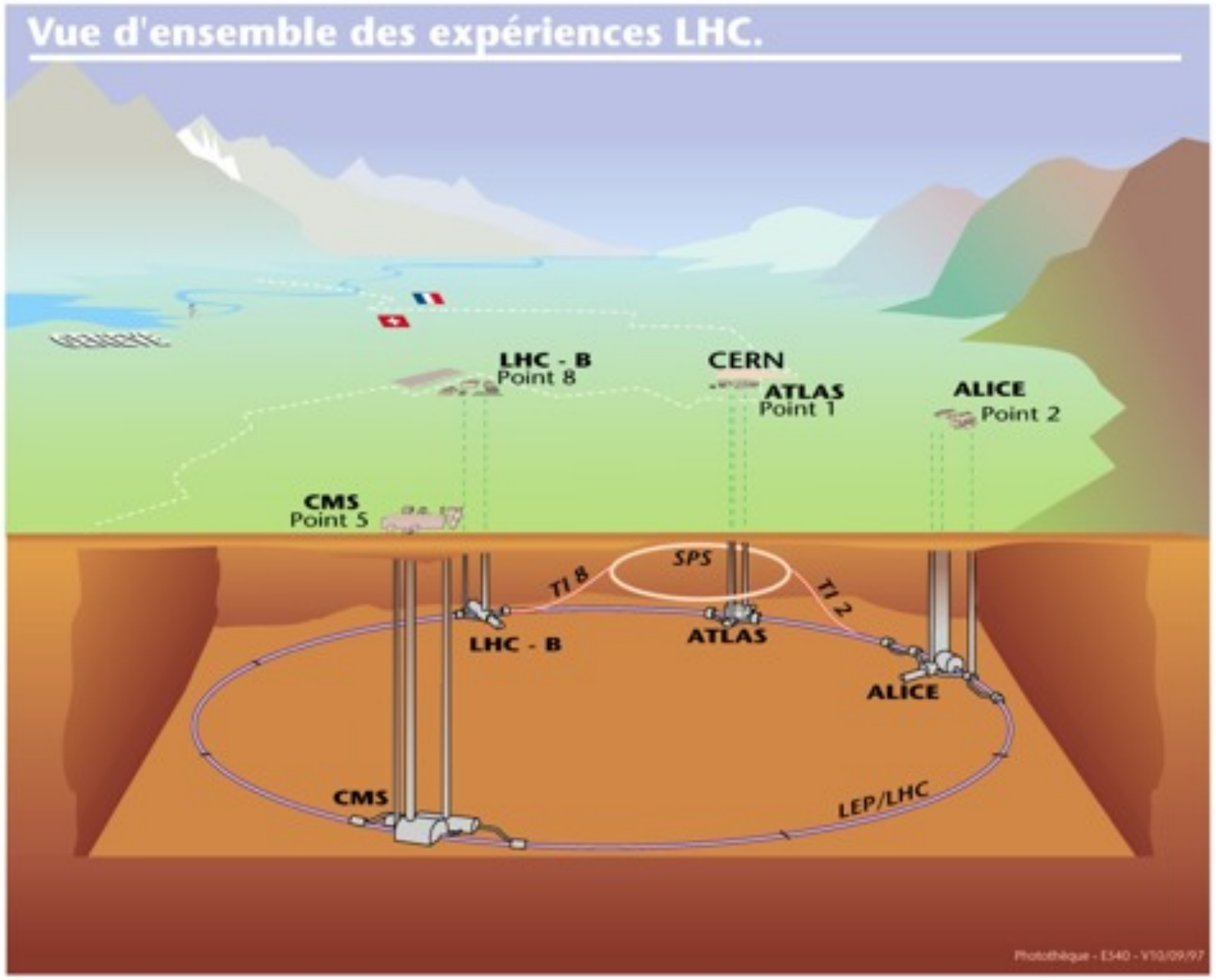
Mateusz Ploskon (LBNL), STAR, QM'09 22

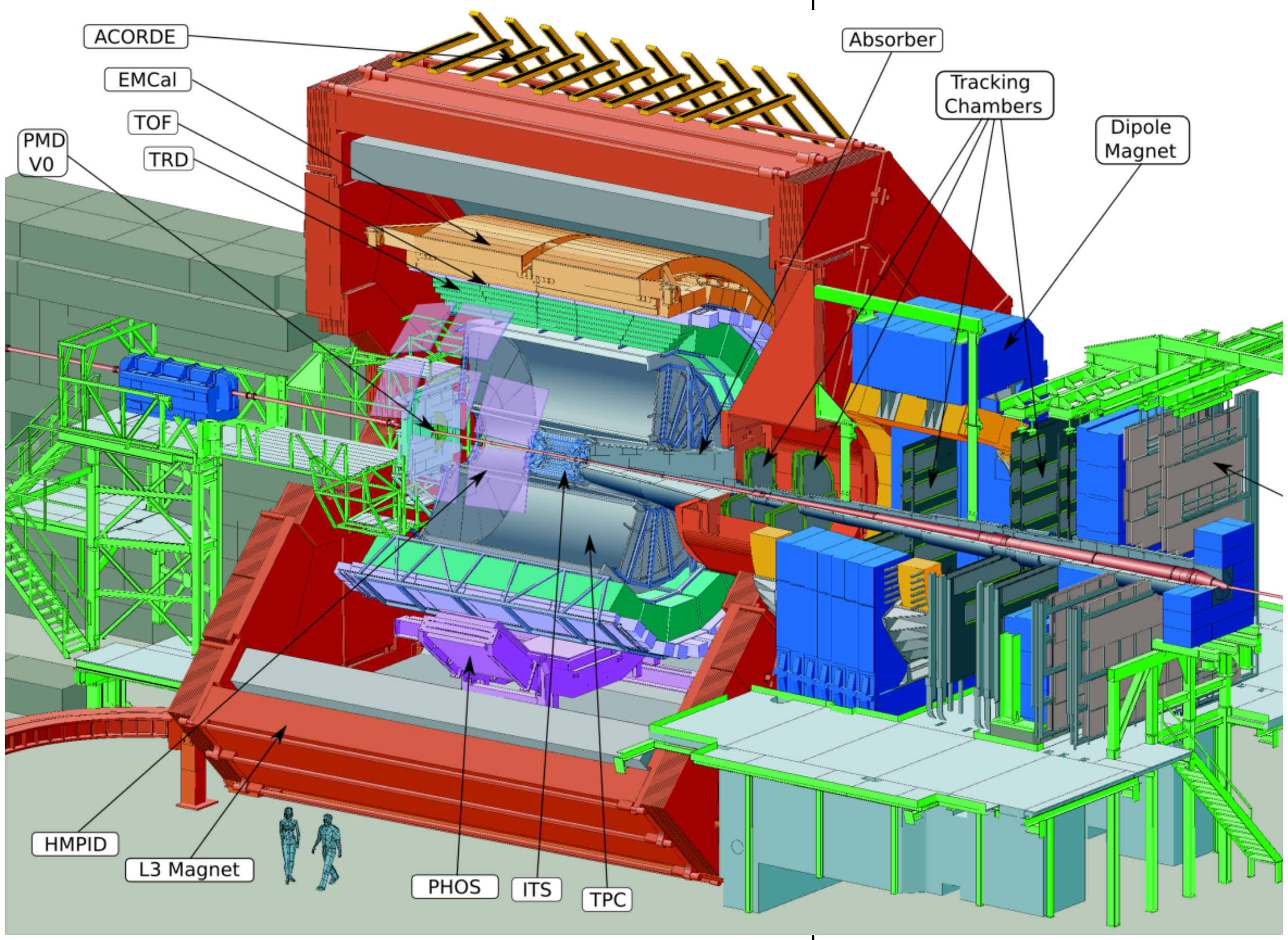
- √ Effects are energy loss and broadening !!
- √ Narrow cone may be another control variable
  - ➡ We like to extend and bring up to a precision meas.


グルーオン
クォーク

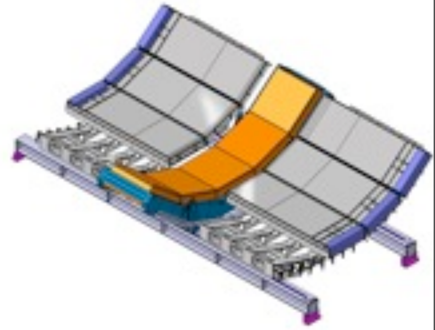
Now, LHC




Vue d'ensemble des expériences LHC.
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC


ACORDE
EMCal
TOF
TRD
PMD
V0
Absorber
Tracking Chambers
Dipole Magnet
HMPID
L3 Magnet
PHOS
ITS
TPC

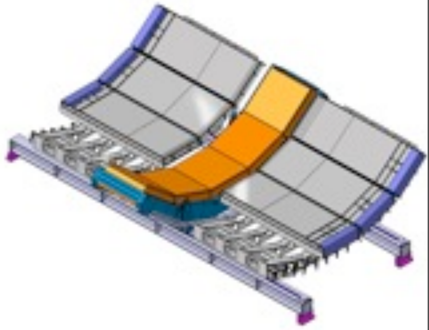
View from RHICians

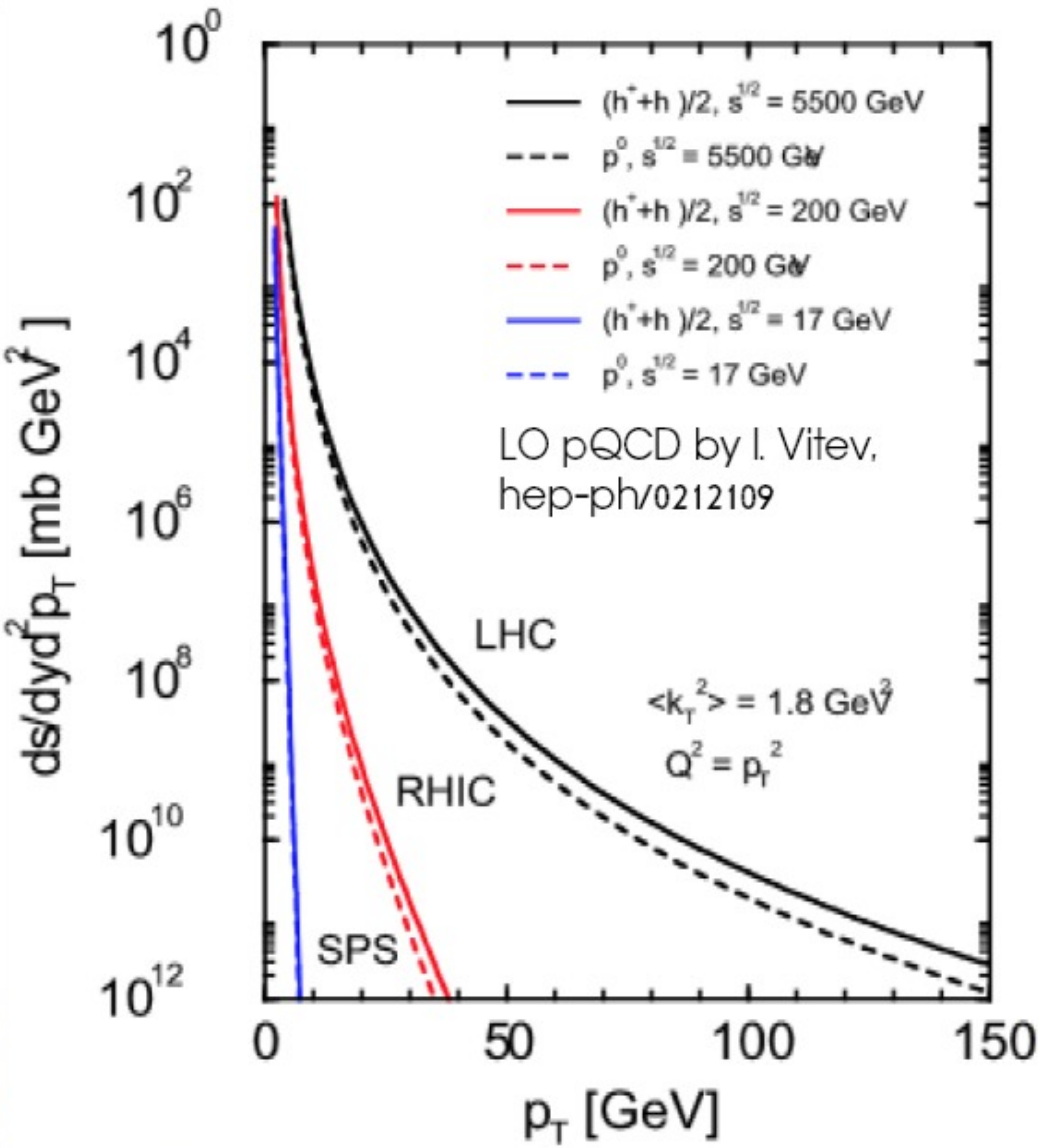


	RHIC	LHC
$\sqrt{s_{NN}}$ (GeV)	200	5500
T/T_c	1.9	3.0-4.2
ε (GeV/fm^3)	5	15-60
τ_{QGP} (fm/c)	2-4	>10

- ✓ Nothing much changes from RHIC to LHC.
  - Nevertheless,
    - ➡Larger/longer QGP
    - ➡Nice to confirm RHIC results
- ✓ Moreover, higher energy jets become available!

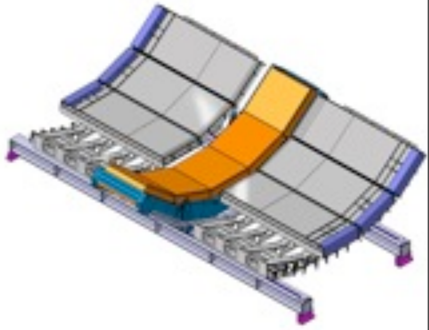
Chances are at LHC

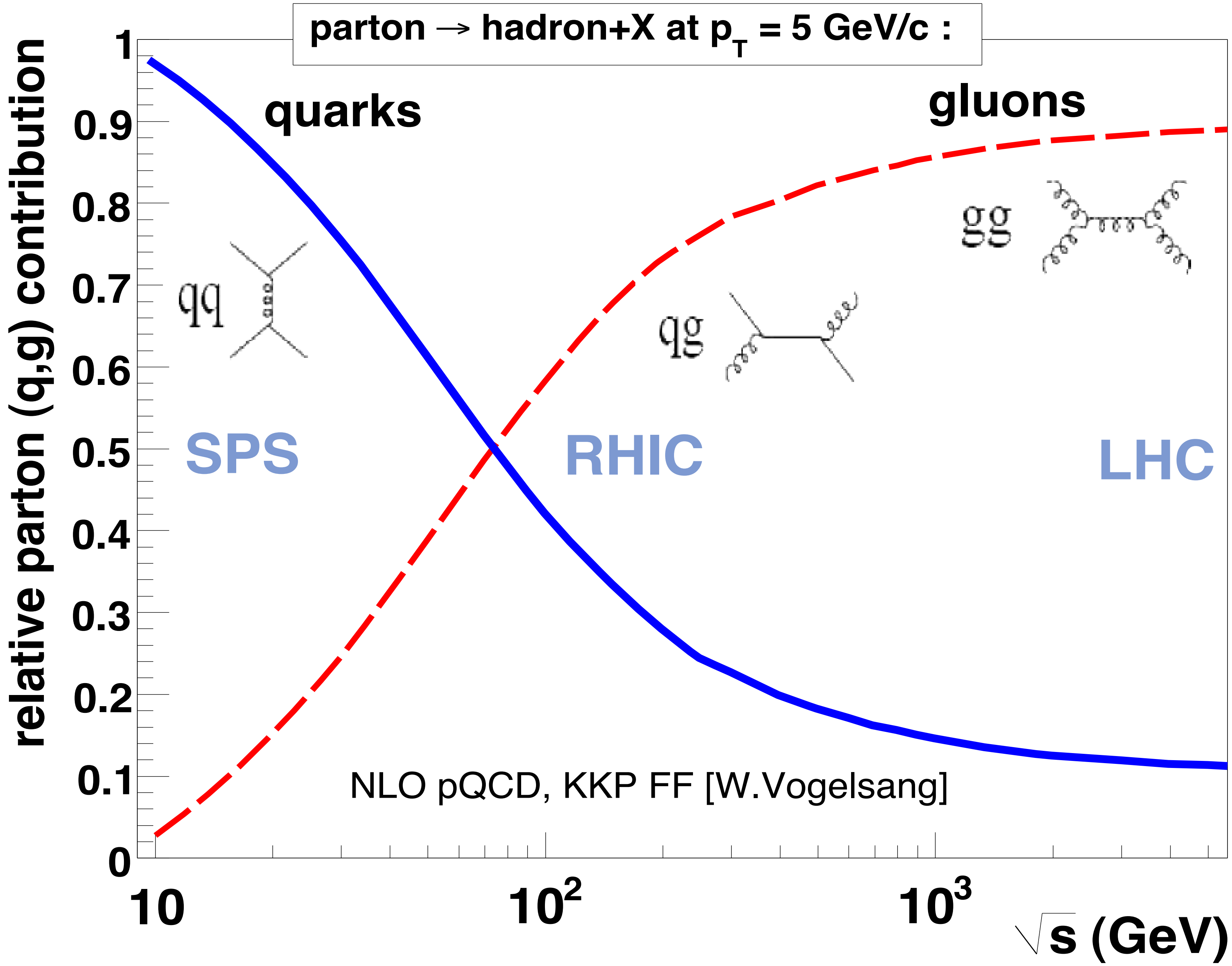


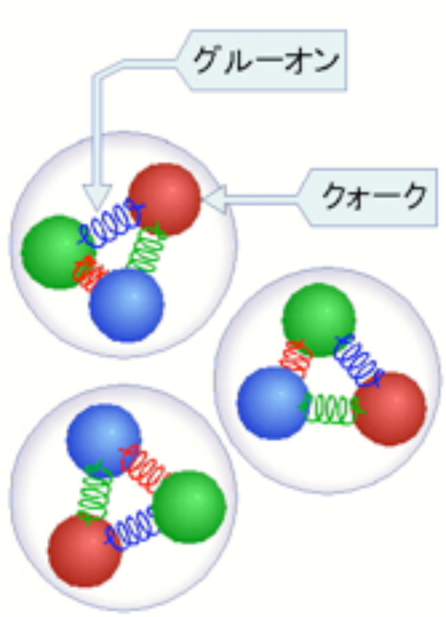


- ✓ Many orders of magnitude!
- ✓ Jet Quench as a function of,
  - jet energy
  - path length, reaction plane angle
  - quark/gluon diff.
- ✓ From particle ID to parton ID !!

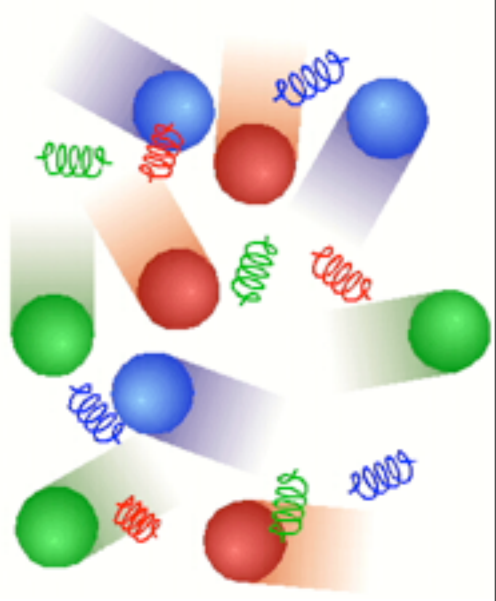
More gluons !!




parton → hadron+X at p_T = 5 GeV/c :
quarks
gluons
qq
qg
gg
SPS
RHIC
LHC
NLO pQCD, KKP FF [W.Vogelsang]
relative parton (q,g) contribution
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
10^2
10^3
$\sqrt{s}$ (GeV)



How we study Jet quench at LHC



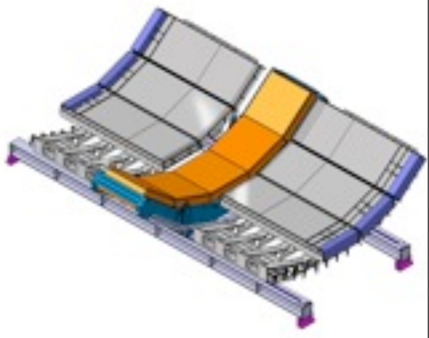
Meas. of high pt suppression/

Hadron corr.

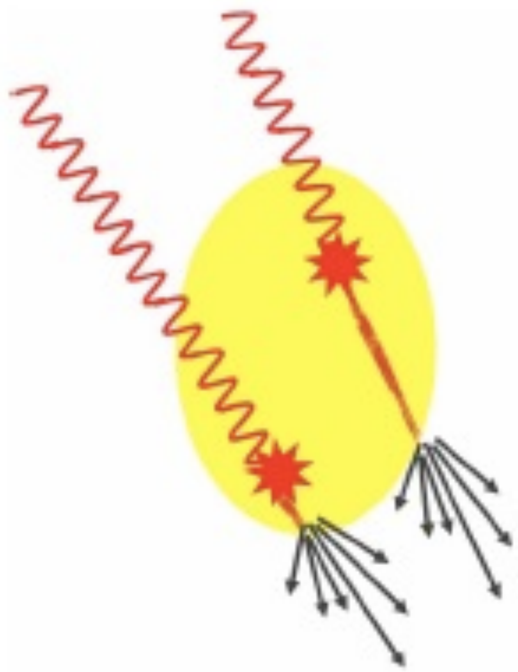
↓

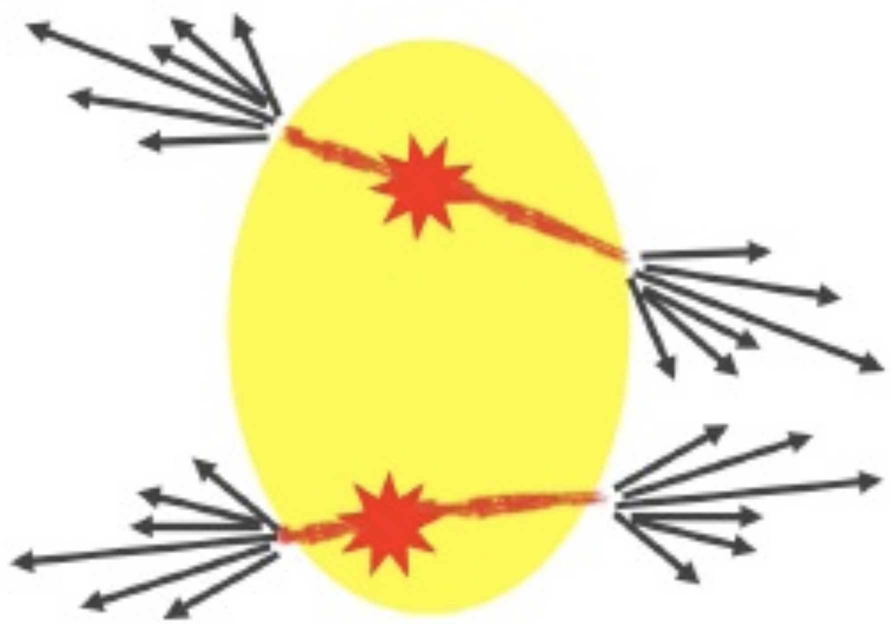
Full back-to back jet analysis of higher energy jets

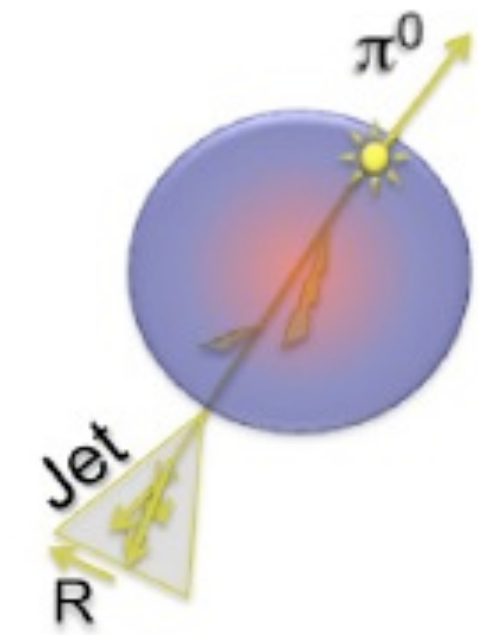
Probes for the study



γ-Jet	Di-jet	π^0-Jet
✓Quark Jet	✓Mostly Gluon Jet	✓Clean π^0 trig
✓Small Xsection	✓Larger Xsection	✓Large Xsection
✓Experimentally challenging	✓Interpretation is complicated	✓Important for DCal

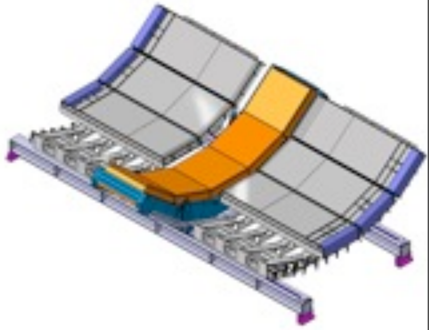


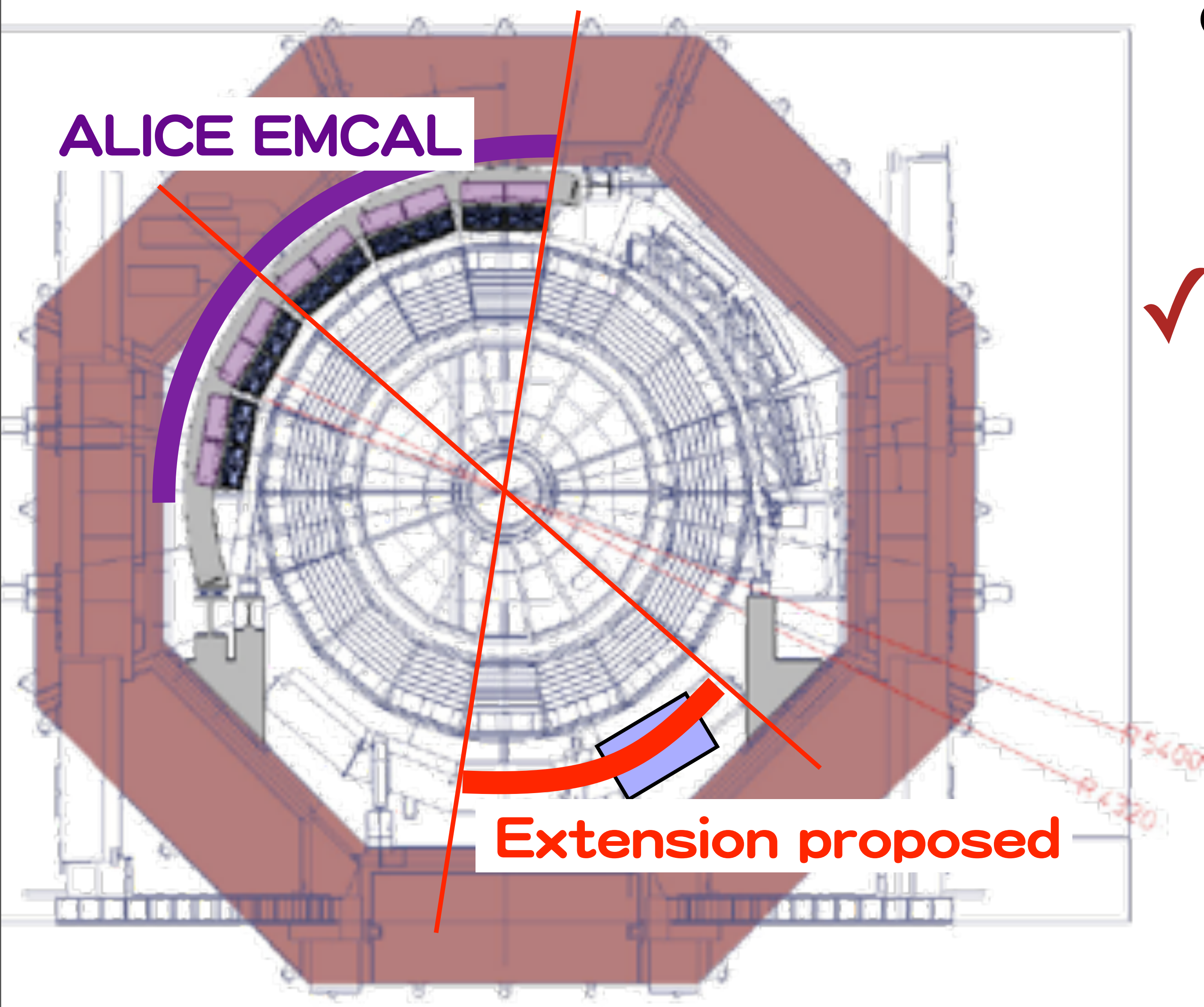




Systematic meas. of these processes for model comparison provides at high precision level.

DCal as an extension of EM-Cal

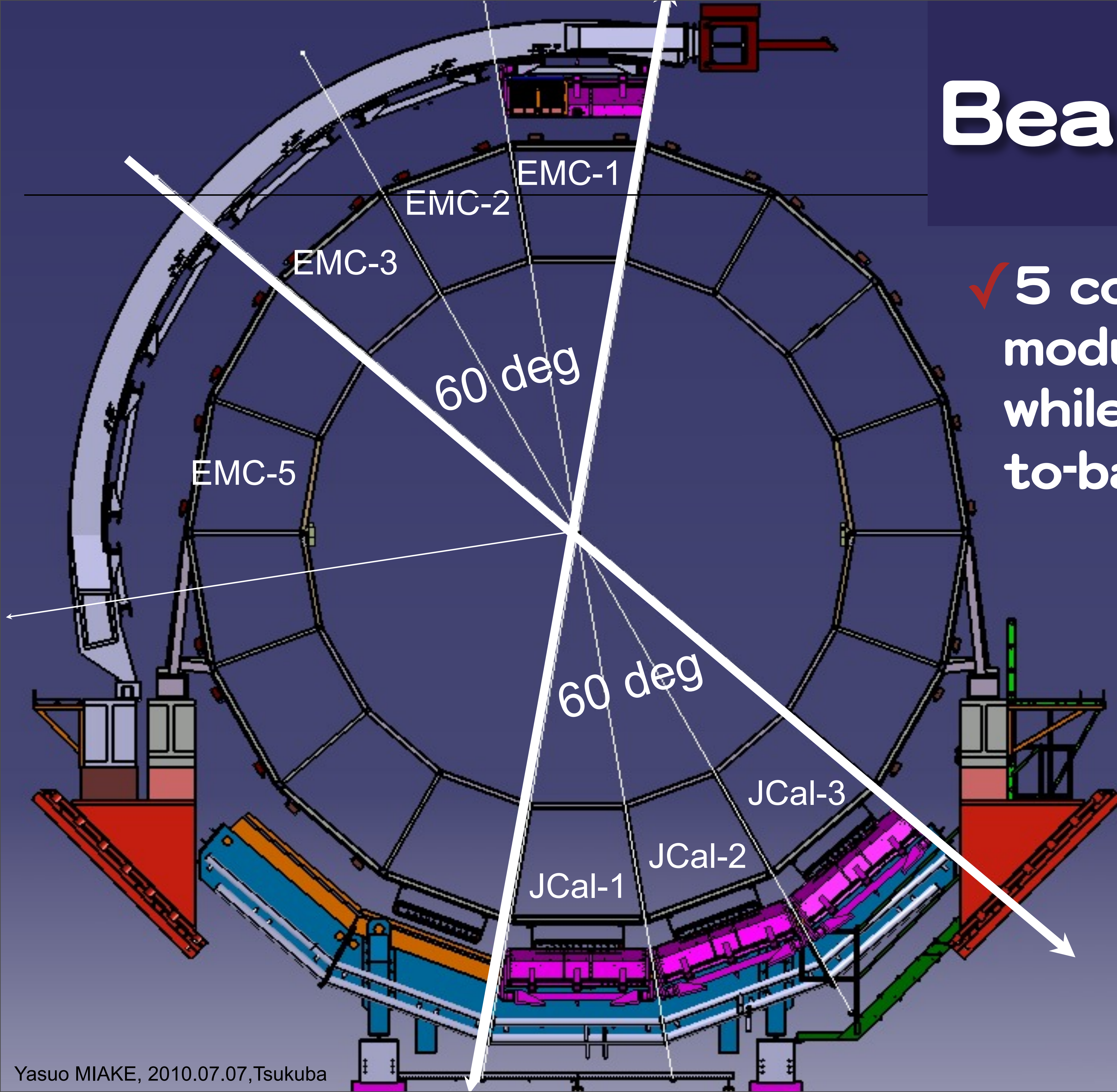




DiJet Calorimeter

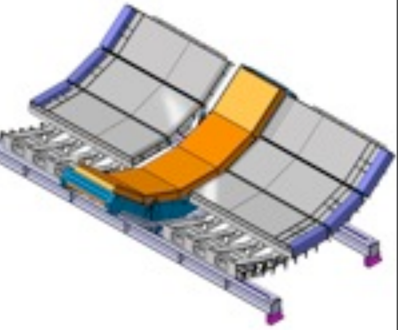
- ✓ For better performance of back-to back capability
  - ➡Define back-to back jets
  - ➡Trigger back-to back jets
- ✓ Progress
  - Proposed in Feb.,09
  - Discussed w. IN2P3 in May, 09
  - Discussed in March,09
  - Proposal in May, 09
  - Partial approval in July, 09
  - Full approval by ALICE in Oct. 09
- ✓ Construction started !

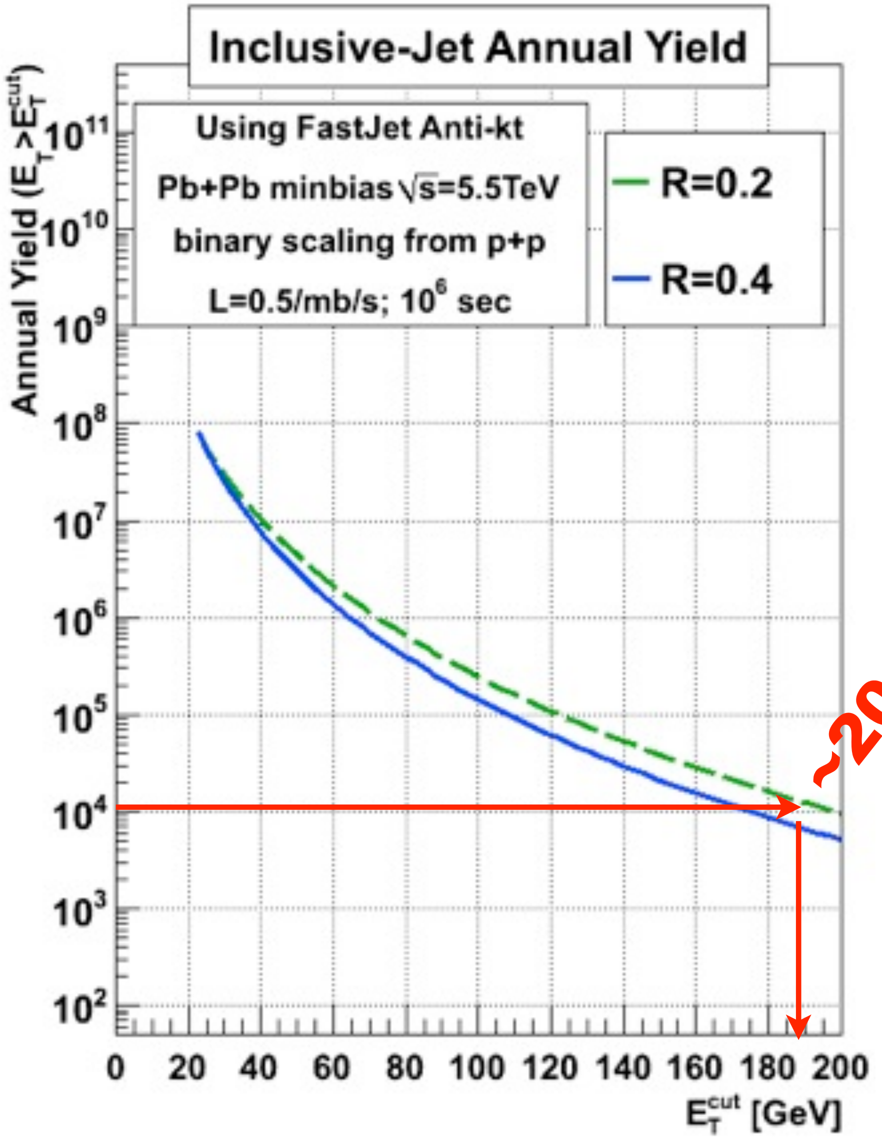
Beam View

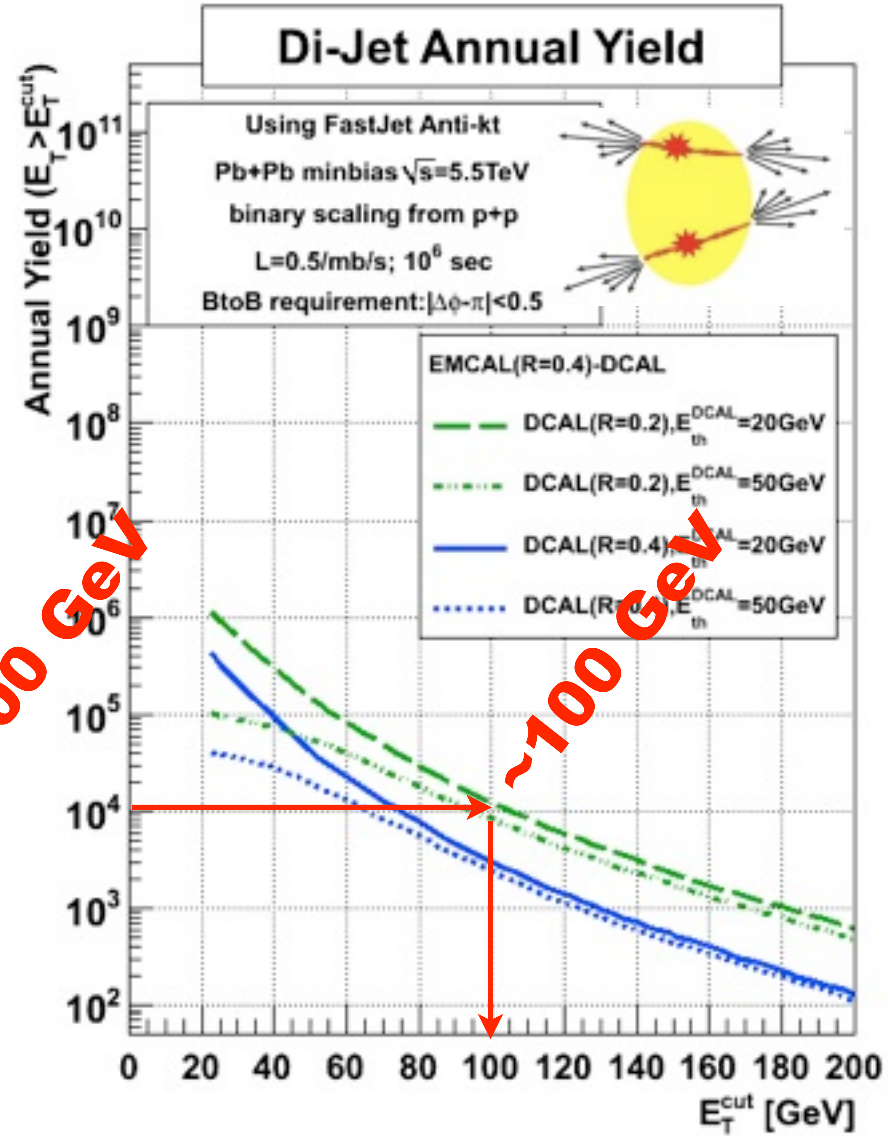


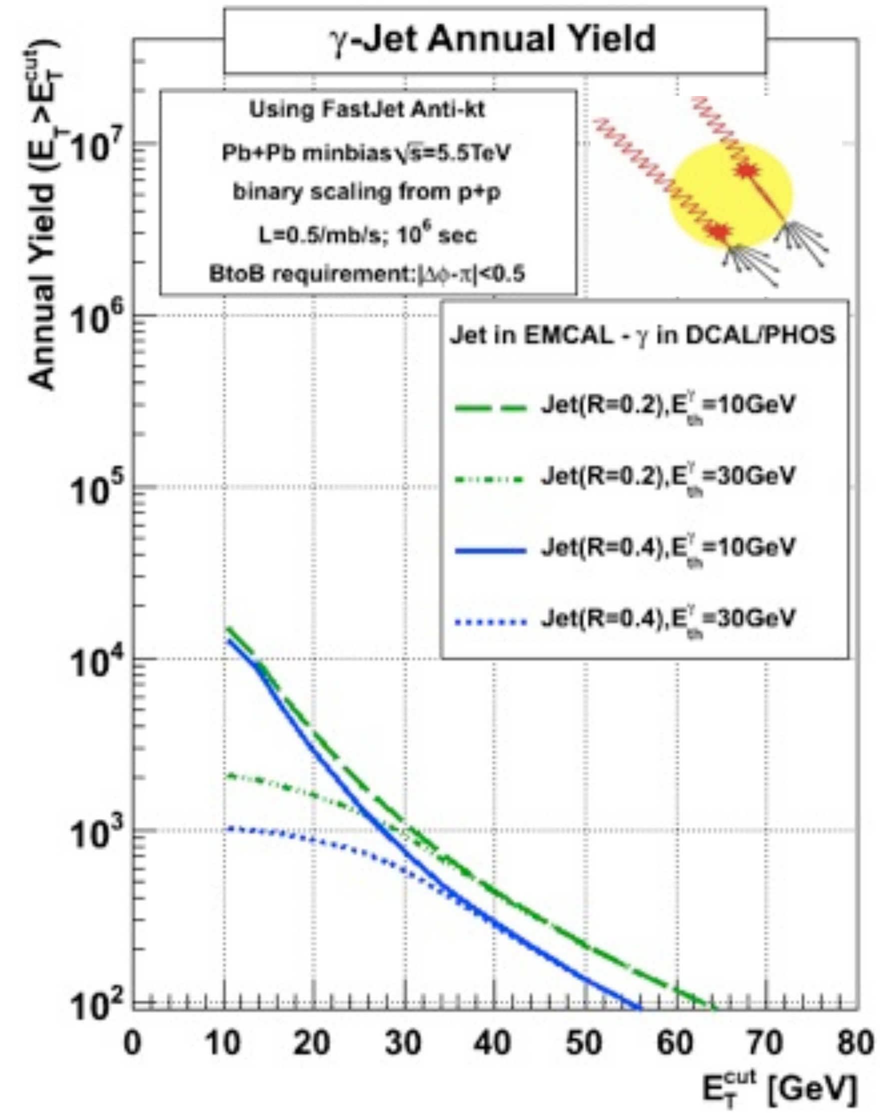
- ✓ 5 contiguous modules possible, while exact back-to-back is 3

What we expect; Reach of Jet Energy





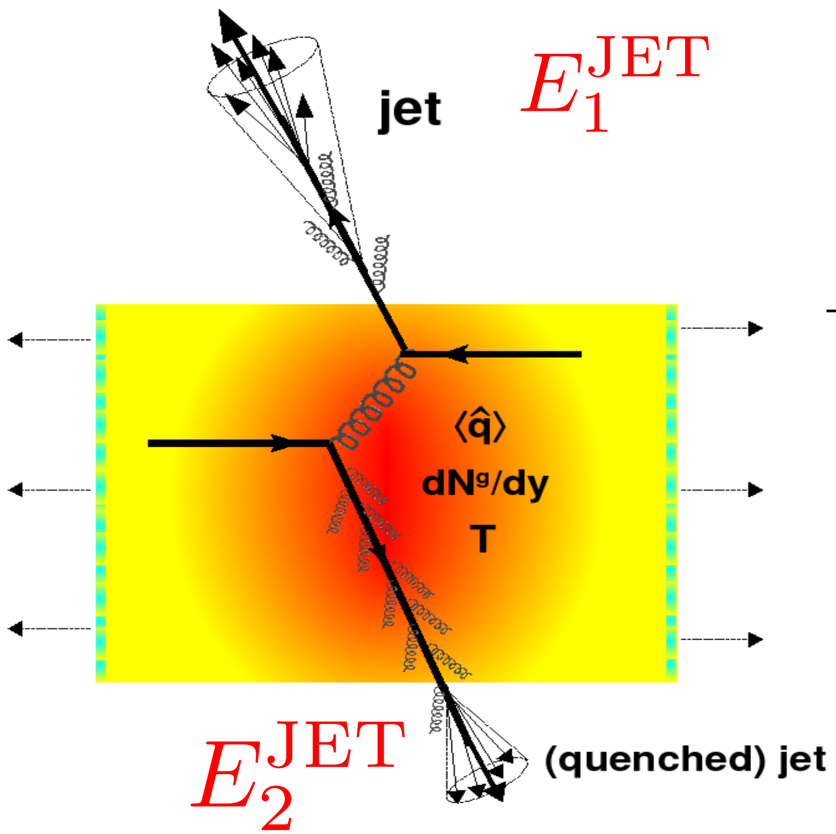


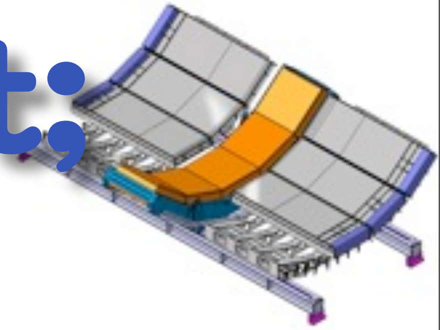


✓ For 10^4 events/year in Pb+Pb@5.5TeV,

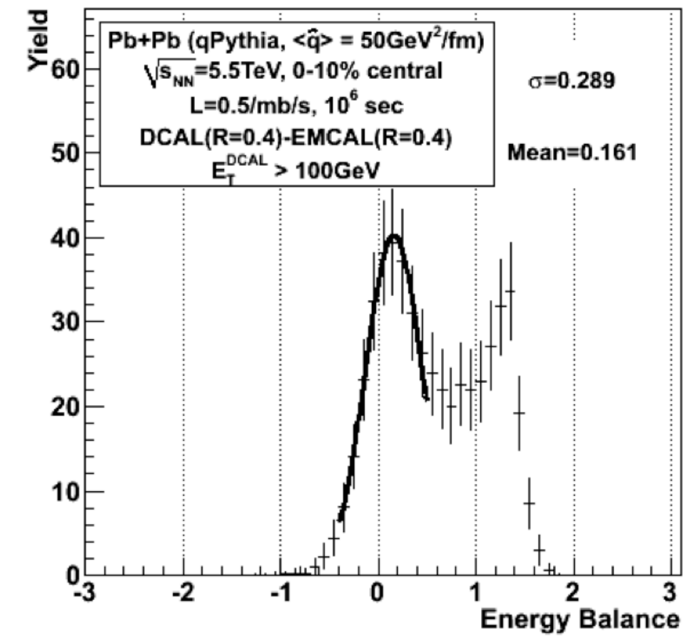
- Inclusive jet up to 200 GeV
- Di-Jet to 100 GeV

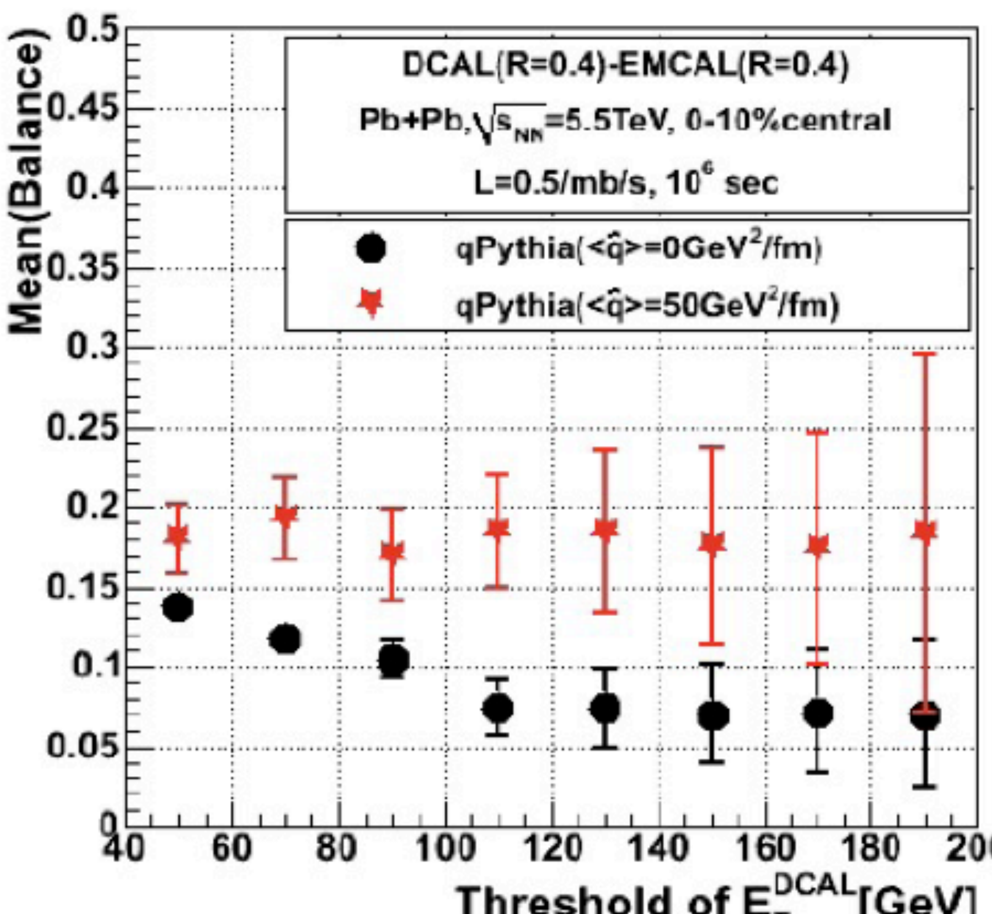
What we expect; sensitivity

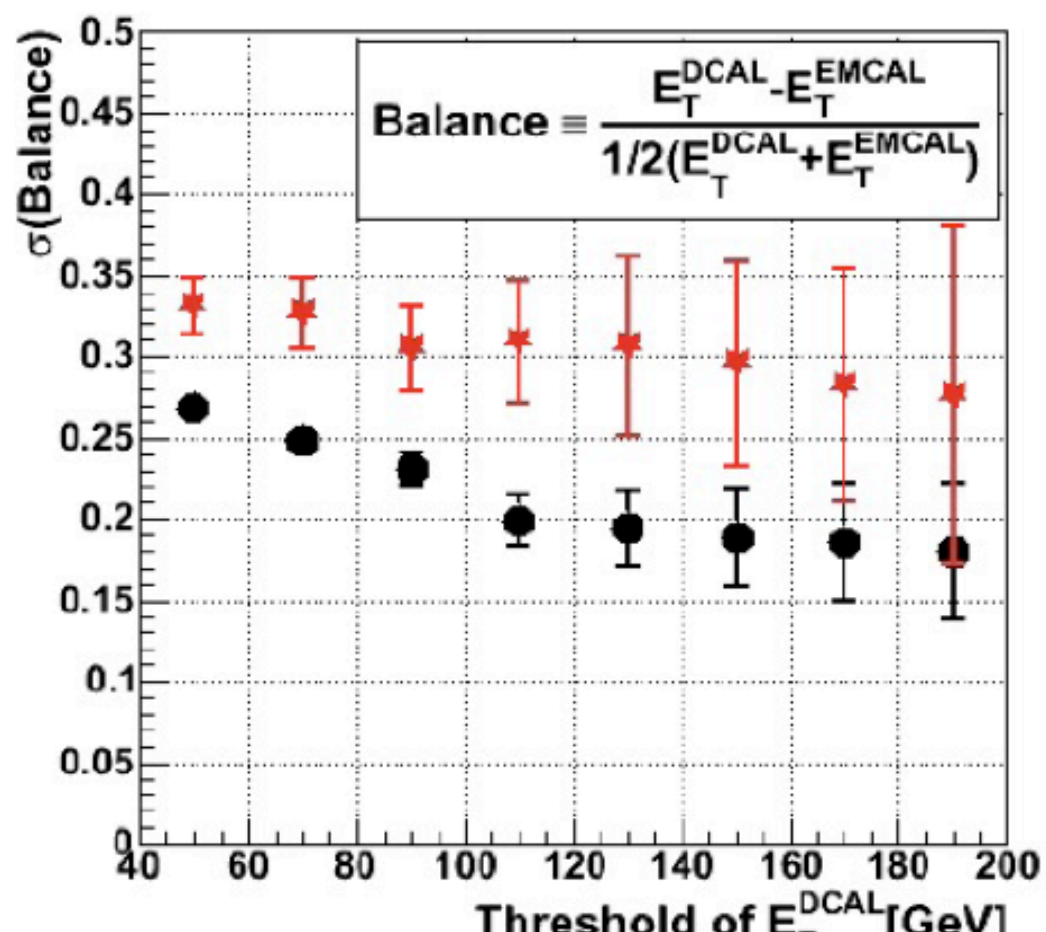




$$\text{Balance} \equiv \frac{E_1^{\rm JET} - E_2^{\rm JET}}{1/2(E_1^{\rm JET} + E_2^{\rm JET})}$$

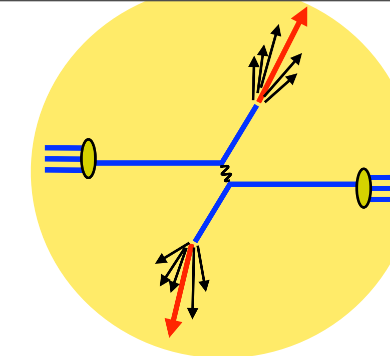


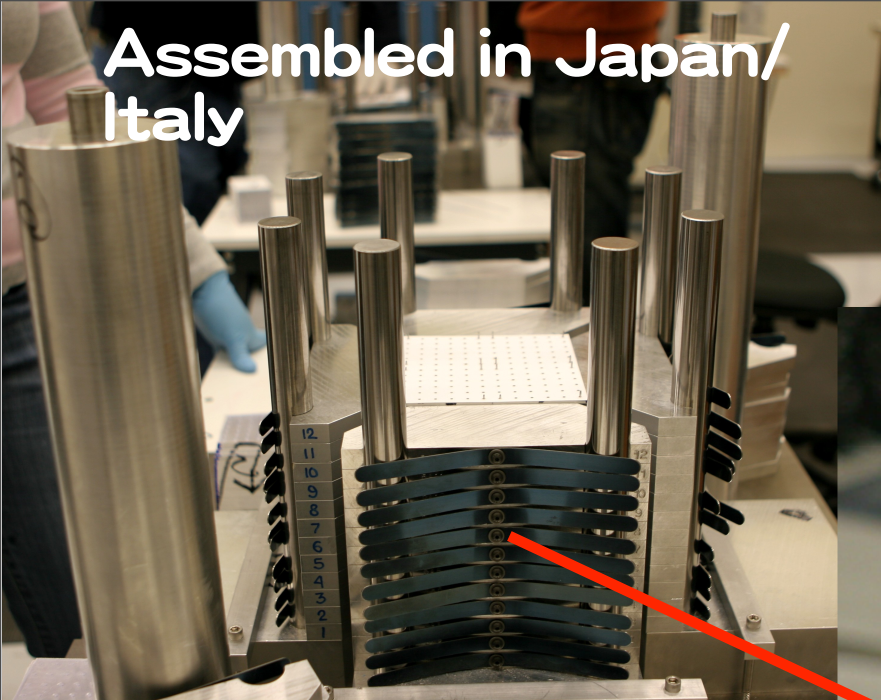




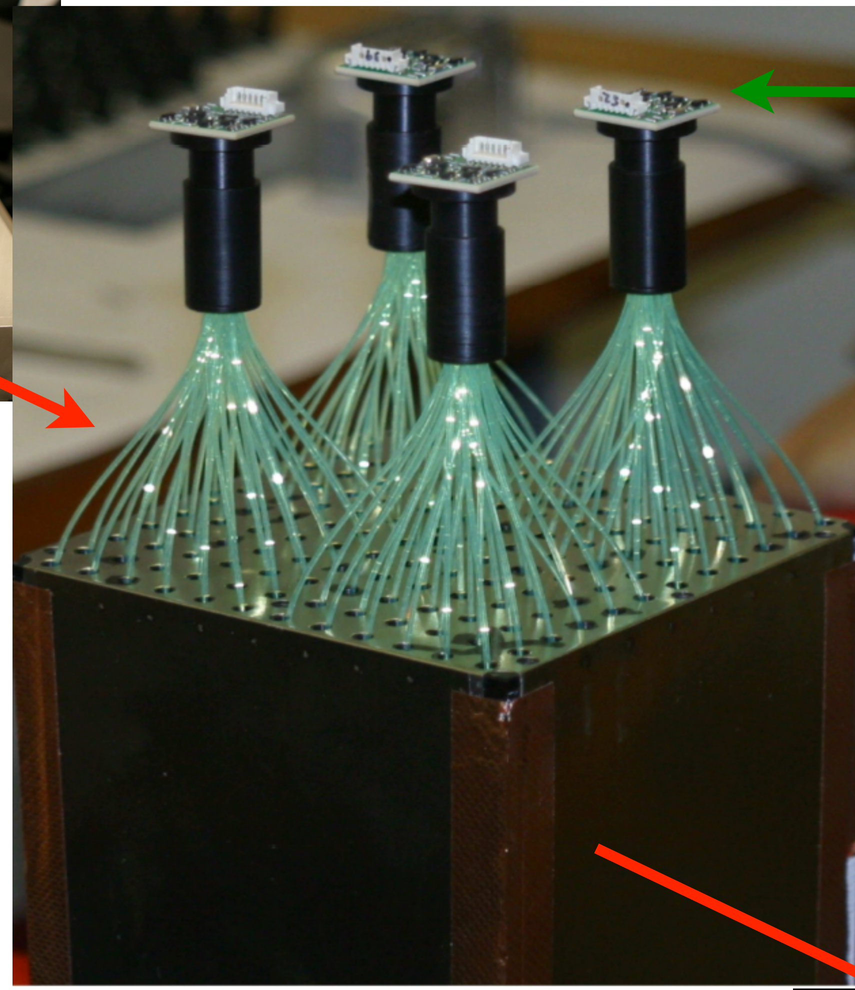
✓ Sensitivity in data of 1 year

DCal assembly

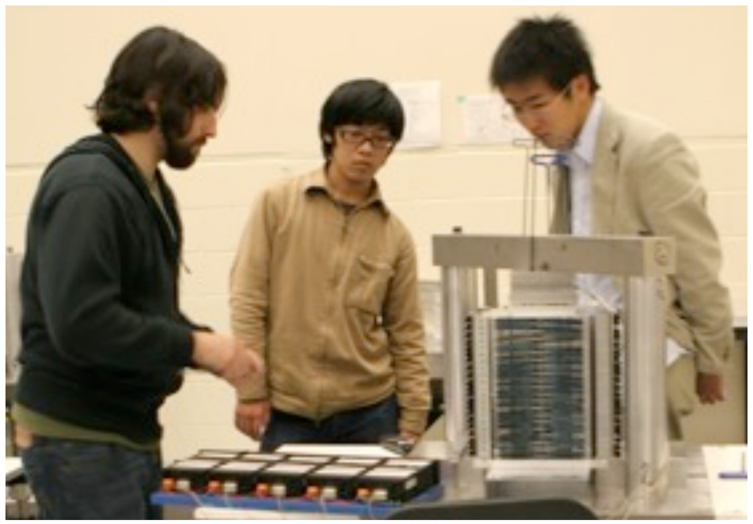




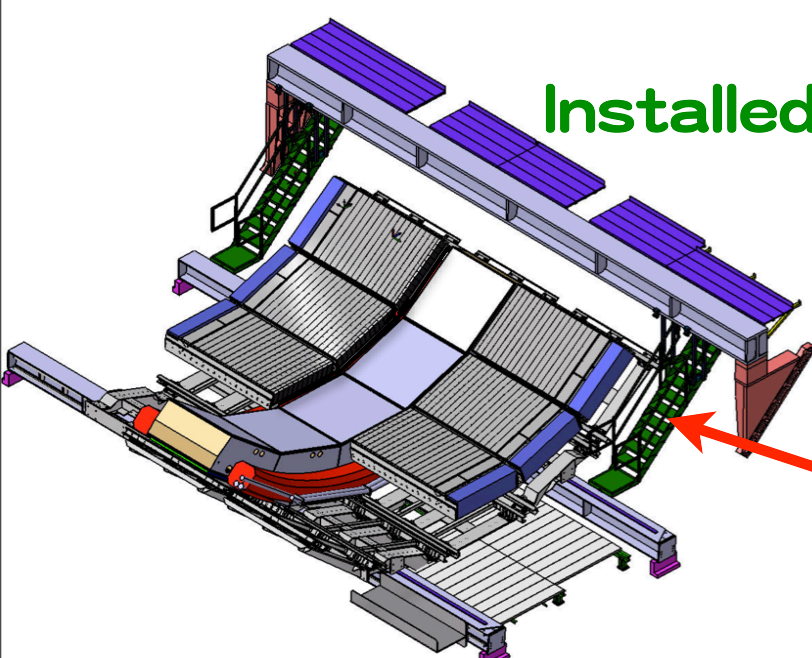
Assembled in Japan/ Italy



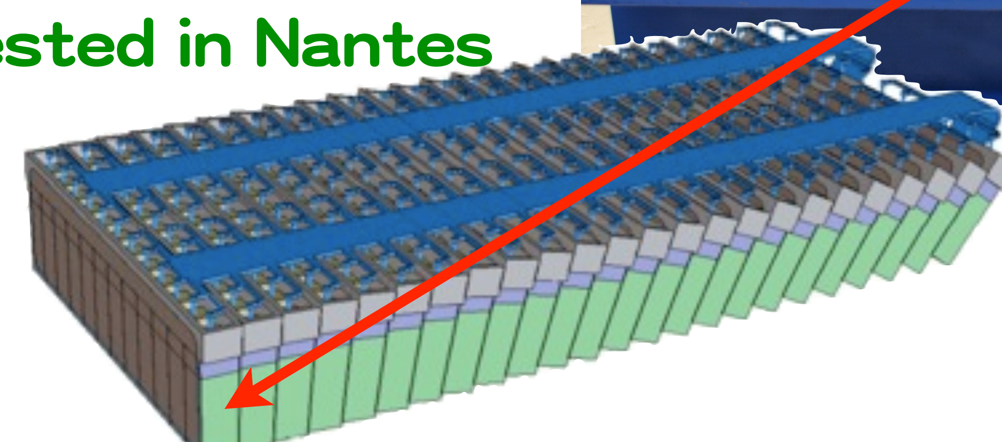
APD tested in Italy



Assembled in Grenoble/ Nantes

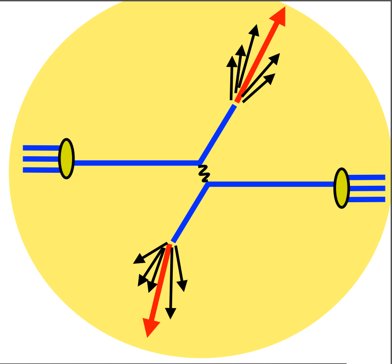


Installed at CERN

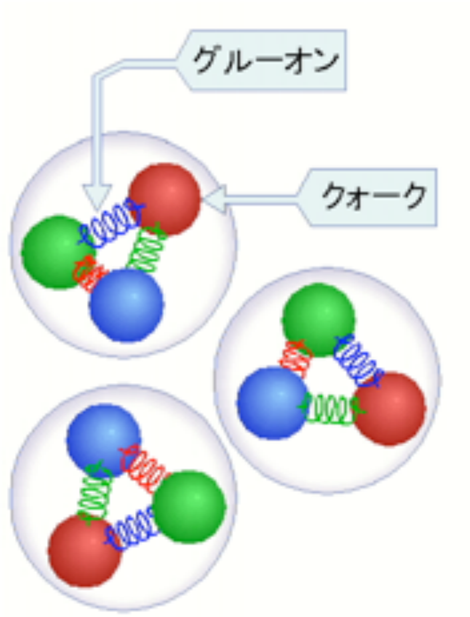


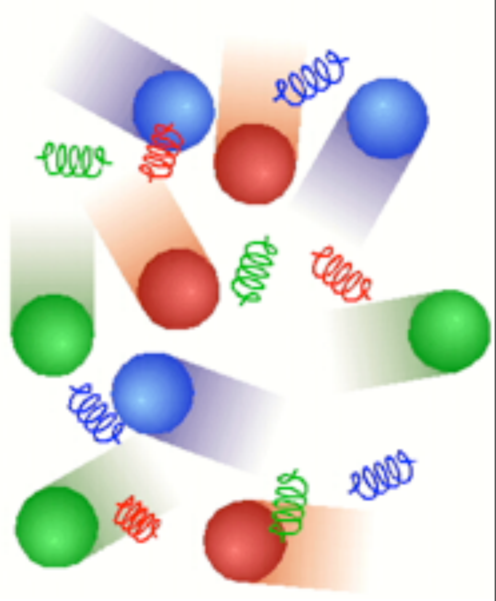
Tested in Nantes

Summary



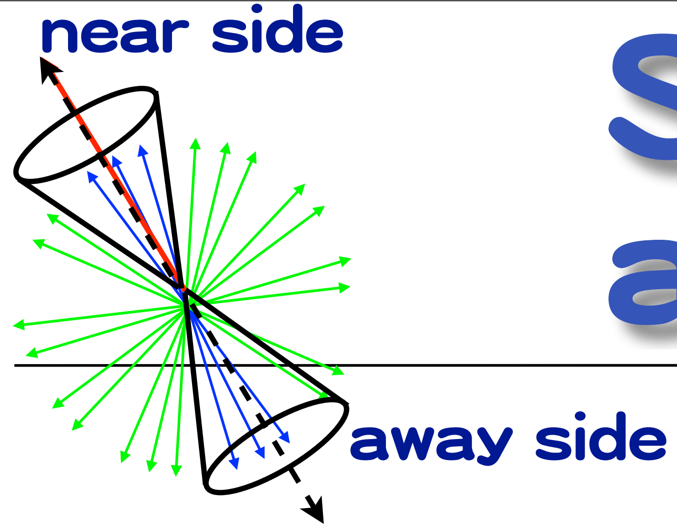
- ✓ 10 years of RHIC running was very successful
- ✓ QGP formation and time evolution of the reaction well understood (personal bias!)
  - Need quantitative understanding of QGP phase
- ✓ Next steps are,
  - Discover phase transition point by lower energy scanning at RHIC
  - Quantitative study of QGP property using jet as a probe at LHC

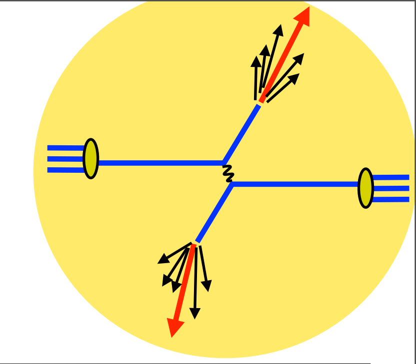




Backups

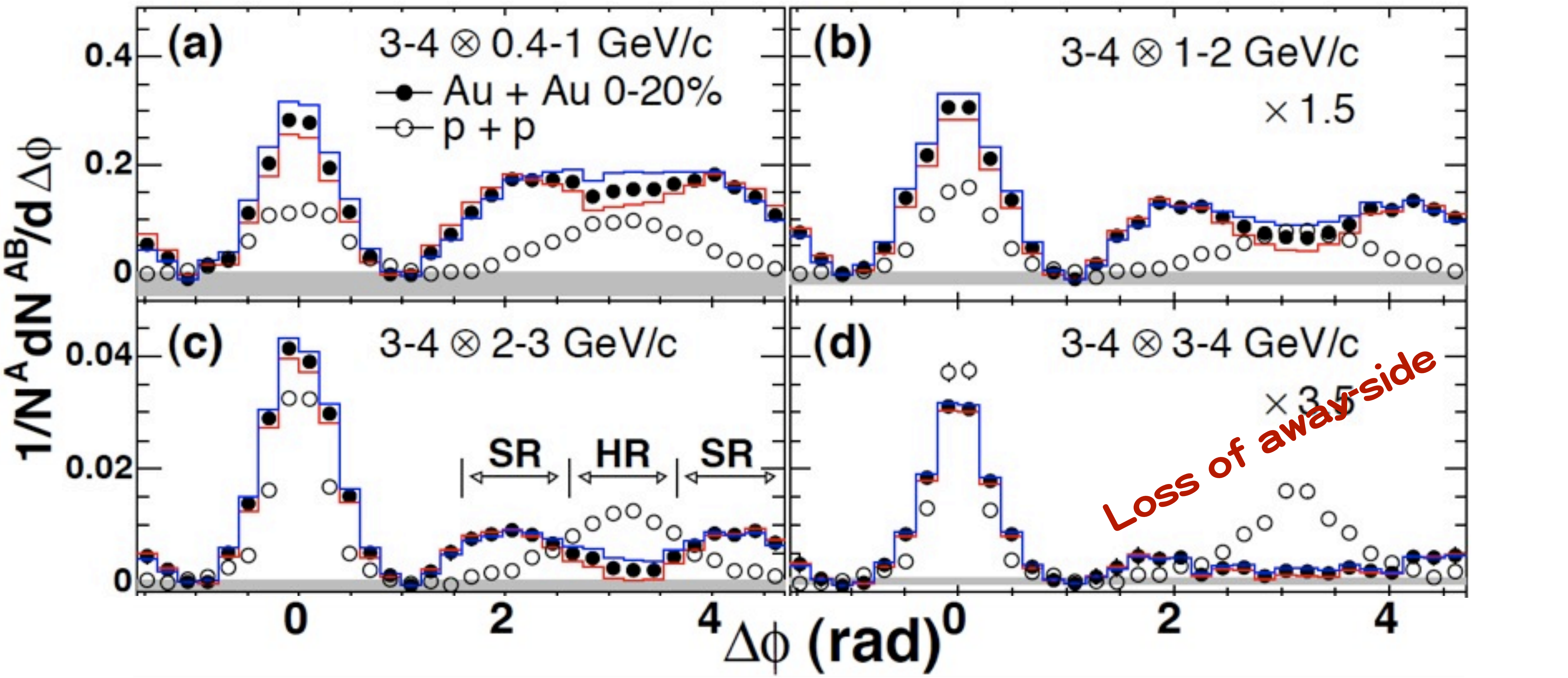
Shape change of away-side





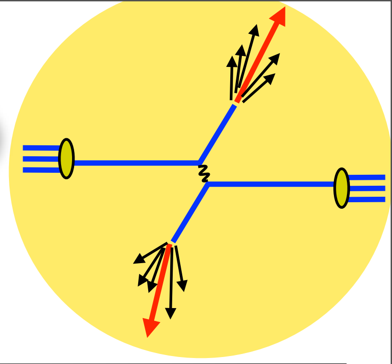
p_T^{trig} = 3~4 GeV/c × p_T^{assoc}

PHENIX, arXiv:0705.3238 [nucl-ex]

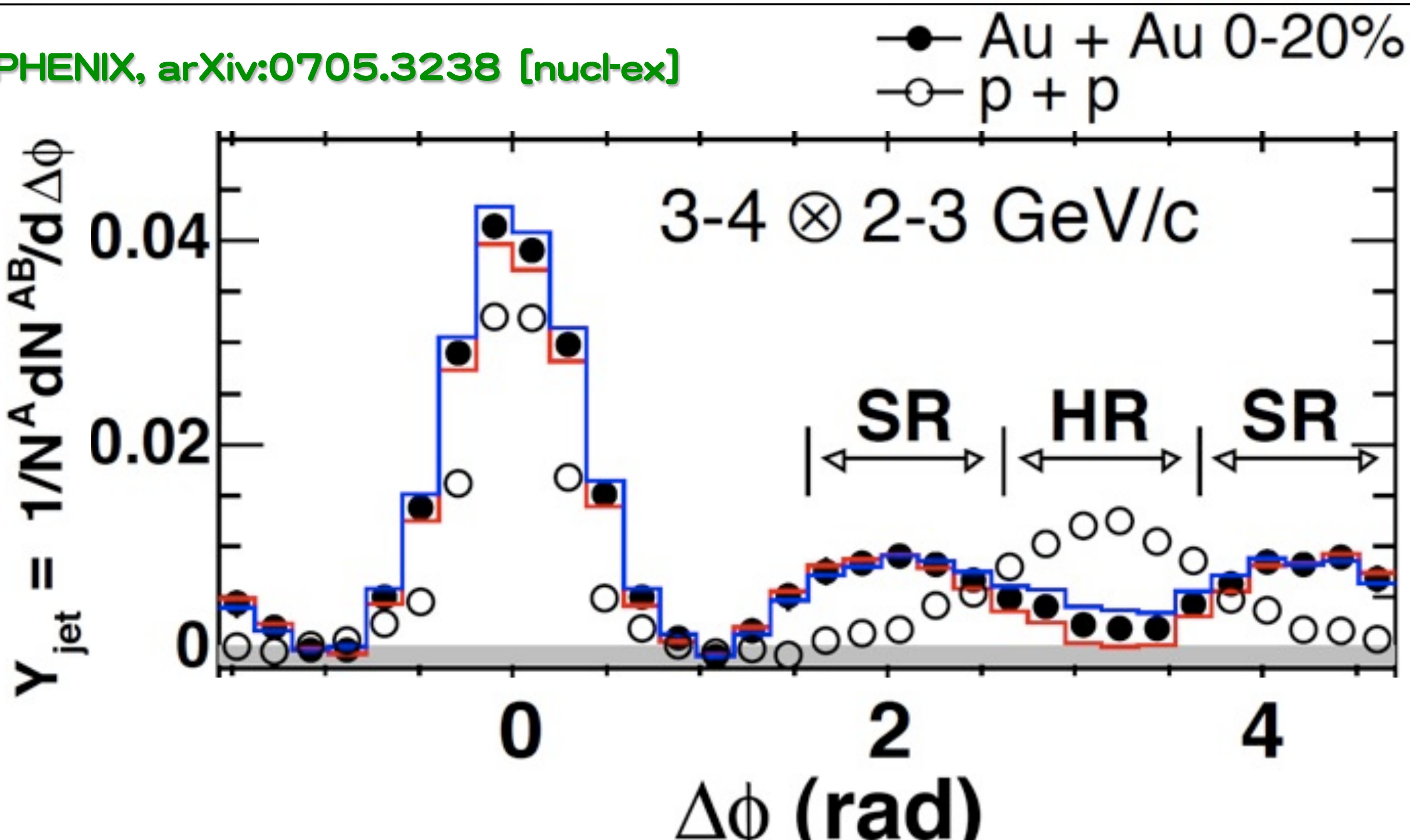


✓From broad/none to distinct two shoulders at $\Delta\Phi = \pi \pm 1$ with decreasing momentum.

Shoulders at ΔΦ = π ± 1 !?



PHENIX, arXiv:0705.3238 [nucl-ex]



- ✓ Location & <pt> of shoulder seem to be independent of centrality and pt.
  - ➡If confirmed, Shock Wave / Mach Cone !
- ✓ Effect is very fragile, sensitive to mom. range and ZYAM correction