



J/ψ energy correlator measurement at RHIC-STAR

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50 years of J/ψ production mechanism study

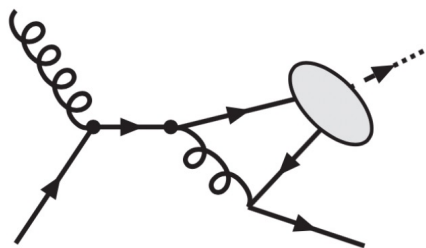
In 1974 November

$p + Be \rightarrow e^+ e^- + anything$ ➤ extreme narrowness in width ➡ (OZI)

$e^- + e^+ \rightarrow hadrons$ ➤ The large mass of 3097 MeV/c² ➡ charm quark

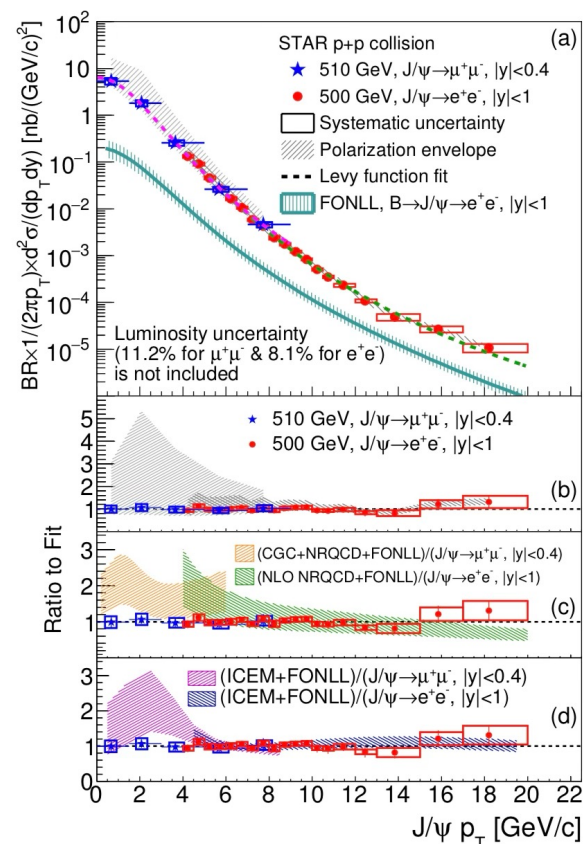
A non-relativistic approach in $c\bar{c}$ system (analogous to positronium)

How the J/Psi is produced in details?



Color-singlet:
the produced $c\bar{c}$ ($^3S_1^{[1]}$) has explicitly the same quantum number as the final state J/ψ

50 years of J/ψ production mechanism study



Color-octet status also contributes and very important at high- p_T range

$$^3S_1^{[8]} \quad ^1S_0^{[8]} \quad ^3p_J^{[8]}$$

J/Psi production: “ $c\bar{c}$ pair + evolution” intuitive picture

L.D.M.Es: the probability of C.O. status to J/Psi

- The NLO NRQCD calculation show a good describing of measurements from RHIC energies to LHC energies

The polarization puzzle and the universality issue in NRQCD

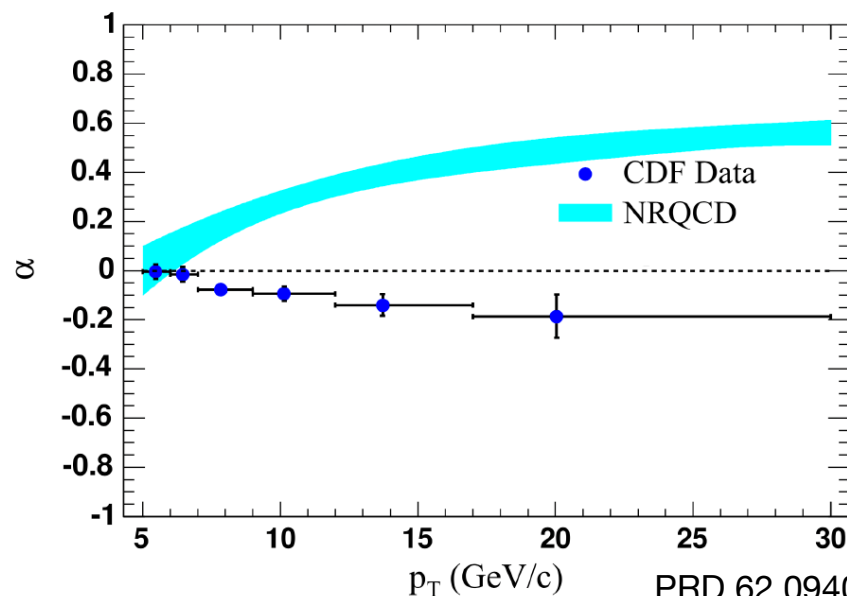


TABLE I. J/ψ NRQCD LDMEs from four different groups.

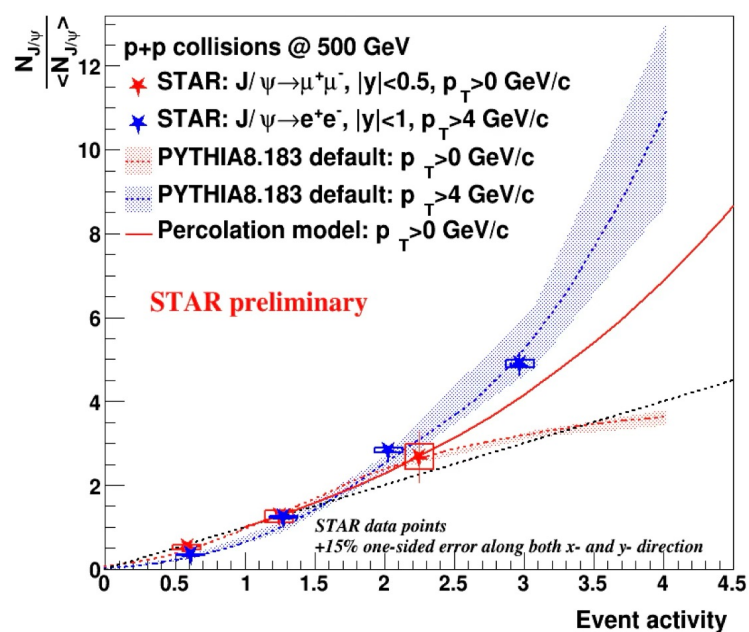
	$\langle \mathcal{O}(^3S_1^{[1]}) \rangle$ GeV ³	$\langle \mathcal{O}(^1S_0^{[8]}) \rangle$ 10 ⁻² GeV ³	$\langle \mathcal{O}(^3S_1^{[8]}) \rangle$ 10 ⁻² GeV ³	$\langle \mathcal{O}(^3P_0^{[8]}) \rangle$ 10 ⁻² GeV ⁵
Bodwin	0 ^a	9.9	1.1	1.1
Butenschoen	1.32	3.04	0.16	-0.91
Chao	1.16	8.9	0.30	1.26
Gong	1.16	9.7	-0.46	-2.14

PRL119,032001 (2017)

- Limited J/ψ polarization in data v.s. significant transverse polarization in model
- Significant different LDMEs from p+p system and e+e- collisions system

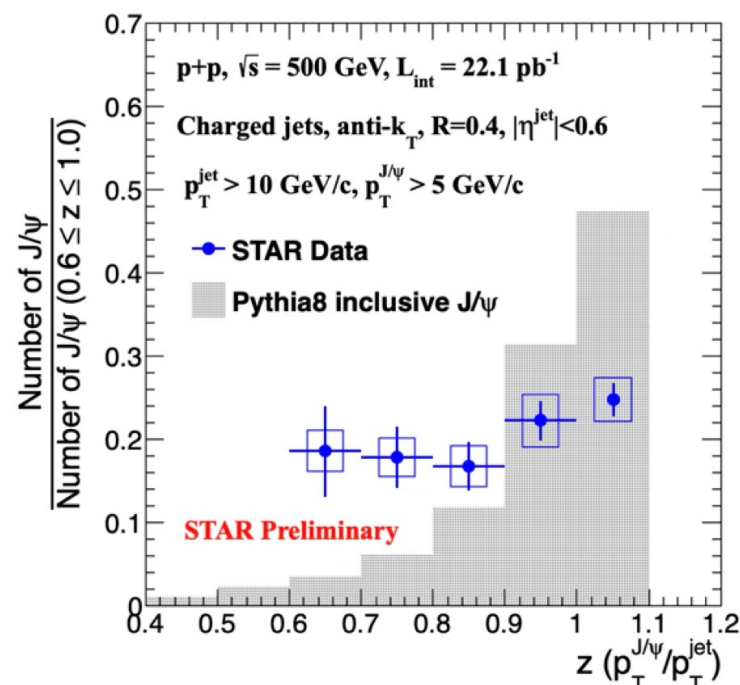
Many attempts since then

J/Psi production vs event-activity



Scattering, M.P.I. or fragmentation?

J/Psi production within a jet



Hadronization information contained in Jet structure

Breaking-down the polarization puzzle in NRQCD

$$\sigma(AB \rightarrow J/\psi + X) = \sum_n \sigma(AB \rightarrow c\bar{c}[n] + x) \langle \mathcal{O}^{J/\psi}[n] \rangle$$

Color-octet status transition to J/Psi:

$^3S_1^{[8]} \rightarrow J/\psi (^3S_1) + \text{gluon}$ 4π uniform radiative of gluon

$^1S_0^{[8]} \rightarrow J/\psi (^3S_1) + \text{gluon}$ $\cos^2\theta$ distribution of gluon

Main source of J/Psi transverse polarization in NRQCD

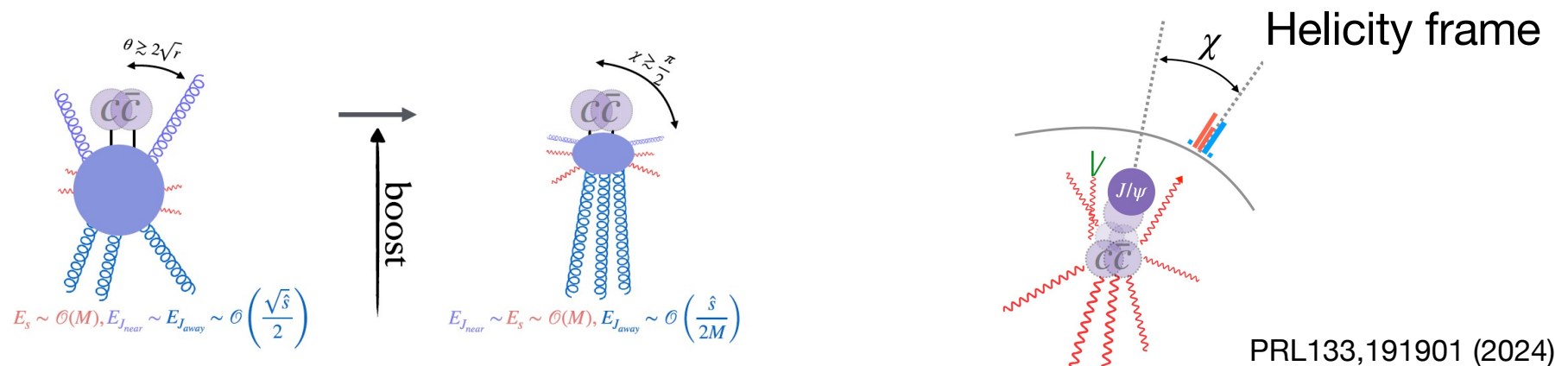
$^3p_J^{[8]} \rightarrow J/\psi (^3S_1) + \text{gluon}$ More complex distribution of gluon

➤ Measuring gluon angle distribution can provide information of hadronization

J/ψ energy correlator

- How much energy are emitted during N.P. process and its distribution?

A question of N.P. that never been answered by any measurements due to its N.P. nature



Dead-cone effect + Lorentz boost

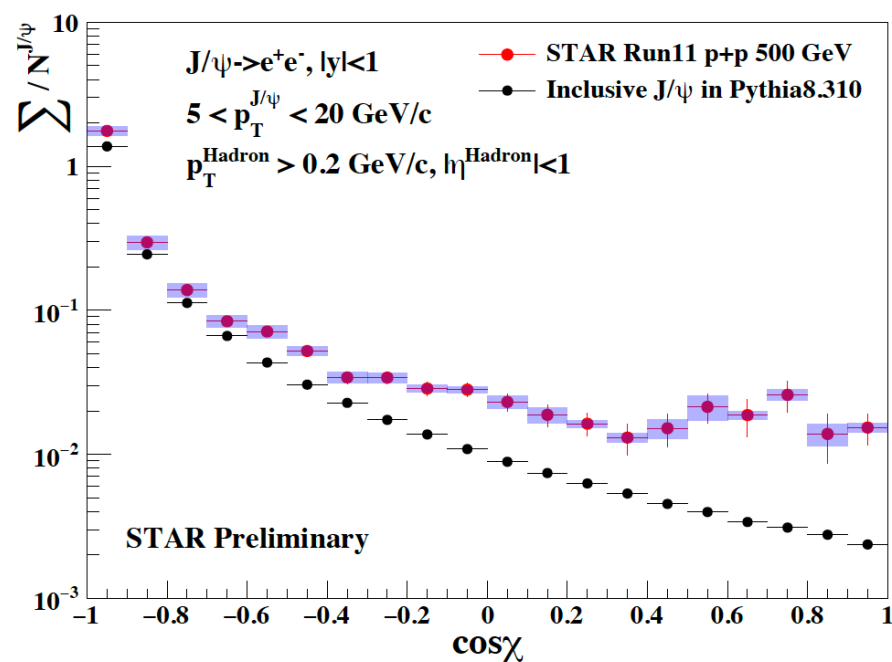
$$\sum (\cos\chi) = \int d\sigma \sum_i \frac{E_i}{M} \delta(\cos\chi - \cos\theta_i)$$

- Separation of N.P.T process from P.T process in $\cos\chi$

$(\cos\chi > 0)$

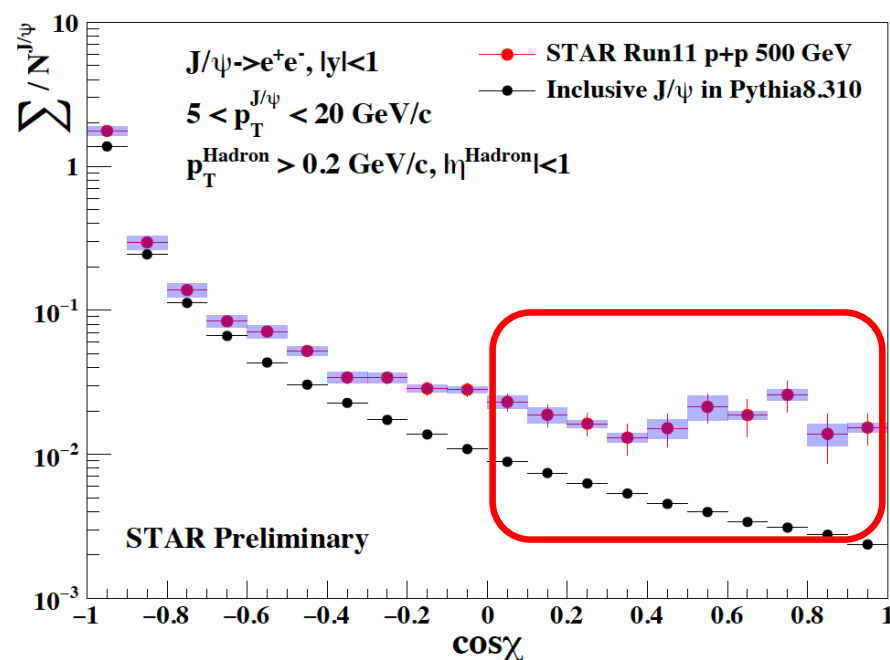
$(\cos\chi < 0)$

J/Psi-charged hadron energy correlator at p+p 500 GeV



$$\sum (\cos\chi) = \int d\sigma \sum_i \frac{p_T^i}{M} \delta(\cos\chi - \cos\theta_i)$$

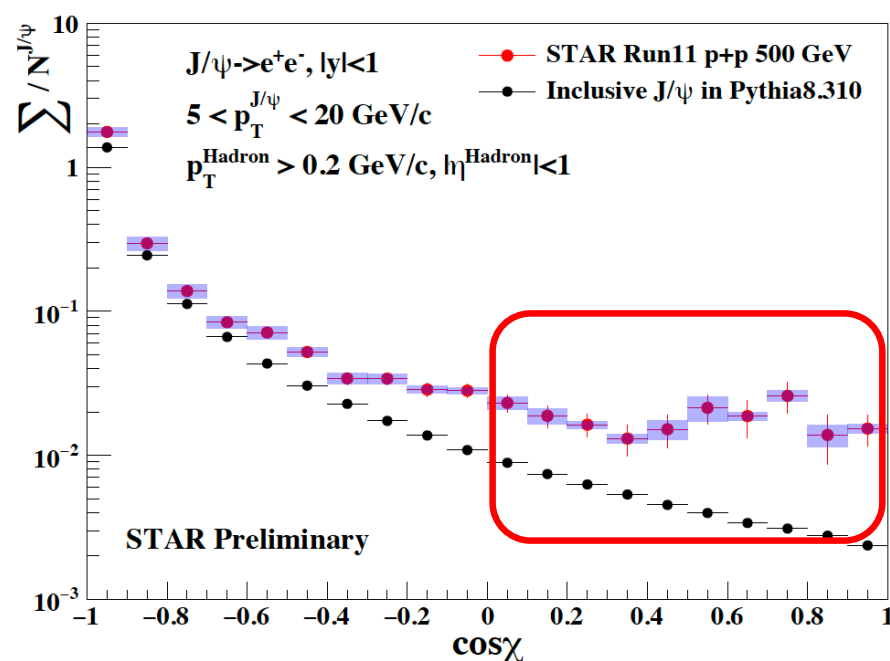
J/Psi-charged hadron energy correlator at p+p 500 GeV



$$\Sigma(\cos\chi) = \int d\sigma \sum_i \frac{p_T^i}{M} \delta(\cos\chi - \cos\theta_i)$$

➤ No significant dependence of correlator on $\cos\chi$ for $\cos\chi > 0$

J/Psi-charged hadron energy correlator at p+p 500 GeV



$$\sum (\cos\chi) = \int d\sigma \sum_i \frac{p_T^i}{M} \delta(\cos\chi - \cos\theta_i)$$

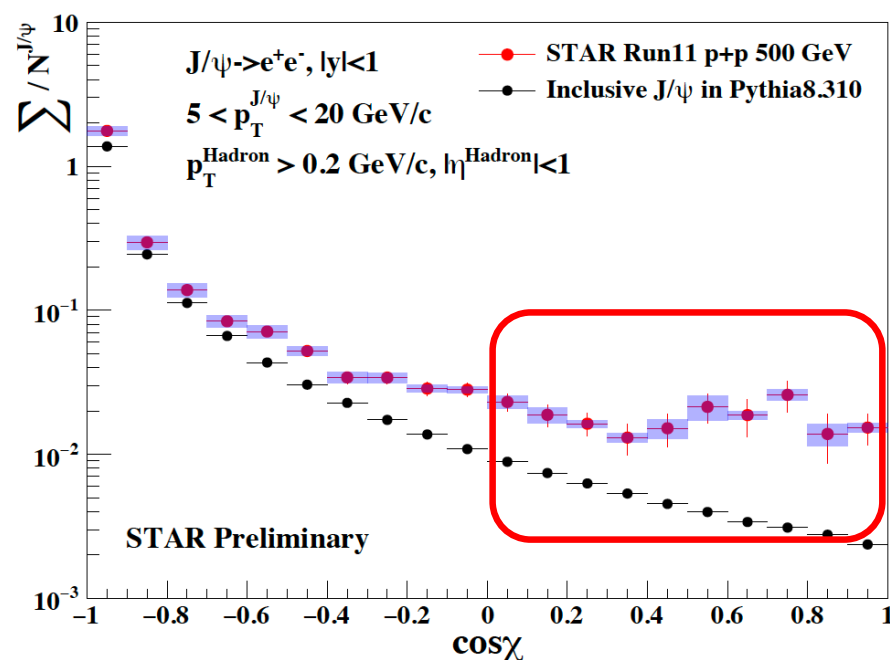
➤ No significant dependence of correlator on $\cos\chi$ for $\cos\chi > 0$

- consistent with a uniform radiative of gluons in NRQCD model

- $^3S_1^{[8]}$ status dominated J/Psi production at RHIC

- Zero polarization of final J/Psi

J/Psi-charged hadron energy correlator at p+p 500 GeV



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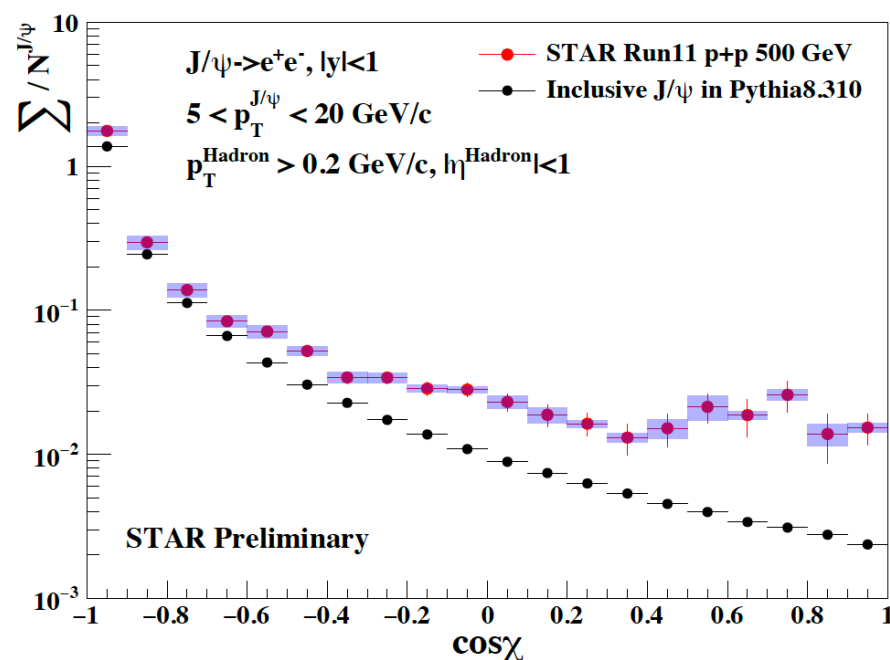
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J/Psi-charged hadron energy correlator at p+p 500 GeV



$$\sum (\cos\chi) = \int d\sigma \sum_i \frac{p_T^i}{M} \delta(\cos\chi - \cos\theta_i)$$

- No significant dependence of correlator on $\cos\chi$ for $\cos\chi > 0$
- The averaged energy (pT) is around 150 MeV/c

How do we understand the energy here?

Not yet a direct connection

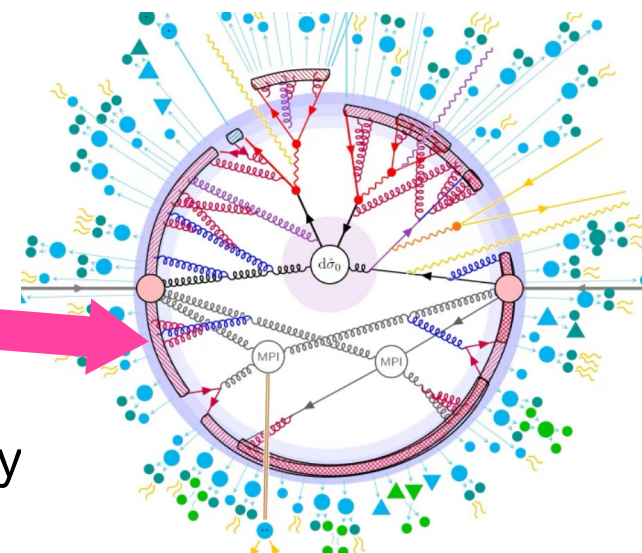
Of interested: J/Ψ - parton energy correlator

More details on
Professor Wenchao Zhang' talk
at 15:05-15:25

parton color reconnection

String hadronization

Primary hadron decay



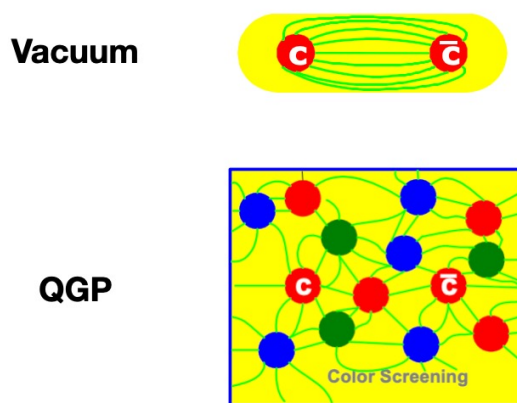
Of measured: J/Ψ - charged hadron energy correlator

Also needs underlying event subtraction

The average energy emitted is at the order of 150 MeV. A really N.P. process!

What we can learn from the measurement?

Deby screening

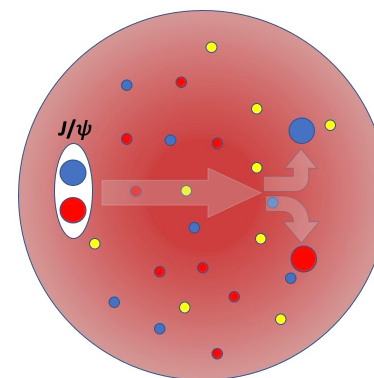


$$V(r) = -\frac{\alpha}{r} e^{-r/\lambda_D(T)}$$

$\lambda_D \propto T^{-1}$

Deby length

Dynamical dissociation



J/ψ binding energy:
~ 400 MeV/c²



Keep in mind:

it is a N.P. process – open quantum system!

J/ψ spin evolution in HIC

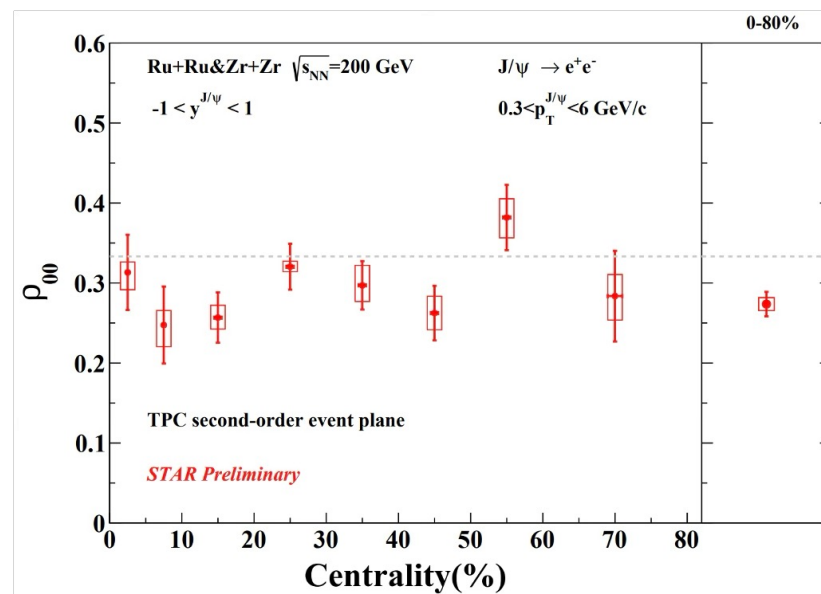
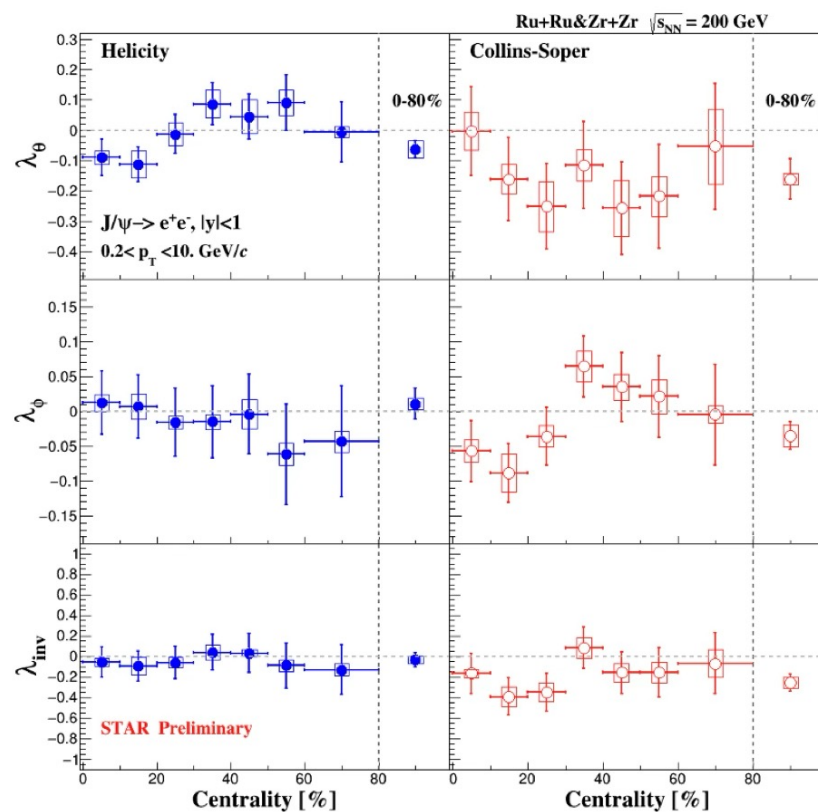
$$\text{gluon} + \text{J}/\psi \rightarrow c\bar{c} \rightarrow \text{J}/\psi + \text{gluon}$$

$$v_2^{\text{J}/\psi} \sim 0, \rho_{00}^{\text{J}/\psi} \neq 0, \text{ polarization in HX and CS frame can be 0}$$

$$\text{gluon} + c + \bar{c} \rightarrow \text{J}/\psi + X$$

$$v_2^{\text{J}/\psi} \neq 0, \rho_{00}^{\text{J}/\psi} \neq 0, \text{ polarization in HX and CS frame can be non-zero}$$

J/ψ spin measurement at RHIC-STAR



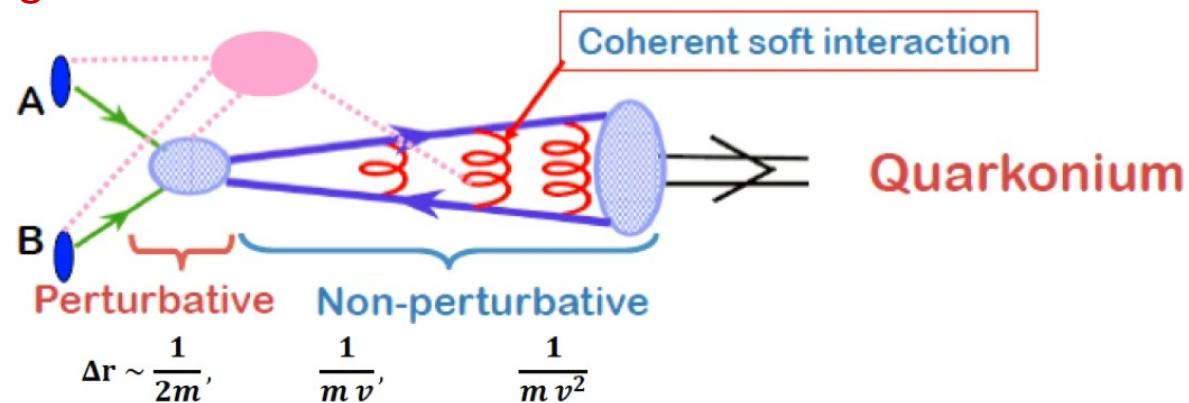
Take home messages

- J/Psi as a multi-scale system is ideal for QCD study
- J/Psi-energy correlator is a promising observable which can directly provide the information of J/Psi hadronization details
- The J/Psi-energy correlator measurement also help to understand the J/Psi behavior in HIC

Stay tuned and Thank you!

Study of QCD with J/ψ

Color-singlet/Color-octet



➤ J/ψ is a multiscale system: Perturbative QCD + Phenomenological model (N.P.)

NRQCD, CSM, CEM, ICEM et.al