Understanding charmonium production via polarization

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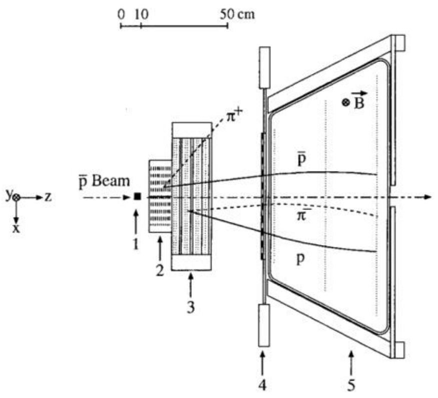
Outline

- The history of polarization studies at PS185@LEAR
- Production at intermediate energies in elementary systems in BESIII, BaBar and Belle experiments
- Complex systems and $q\bar{q}$ polarization at high energies, results of analysis done at RHIC for quarkonium
- Back to $p\bar{p}$, measurements of collisions at ultra high energies. CDF results obtained form Tevatron
- Beyond 1 TeV, „LHC era” what can we learn from the big experiments ?

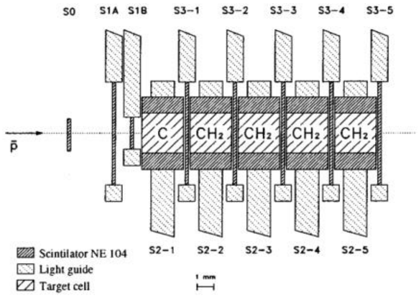
The beginning, PS185

10.1103/PhysRevC.54.1877

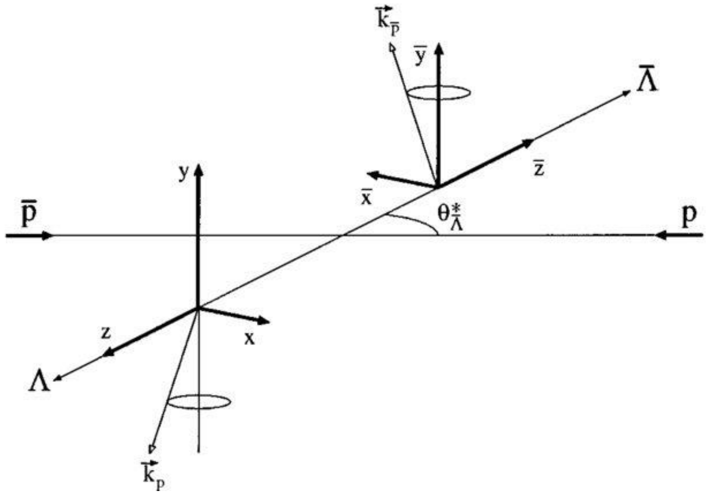
- Mesurment of $Y\bar{Y}$ for $p\bar{p}$ from 1.6 GeV to 1.9 GeV
- Fragmented target why C subtraction possibility (1)
- Multiwire proportional chamber (2)
- Multiwire drift chambers (3)
- Hodoscope (4)
- Solenoid (5)



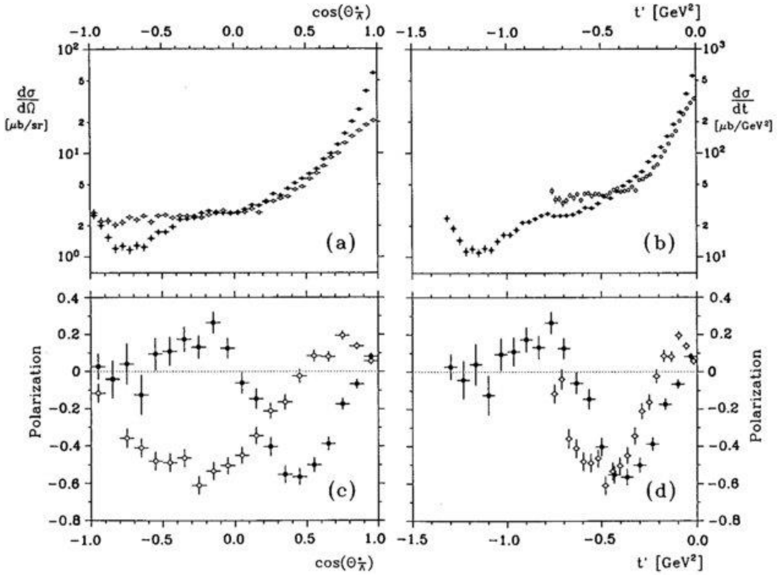
PS185



„proton” target



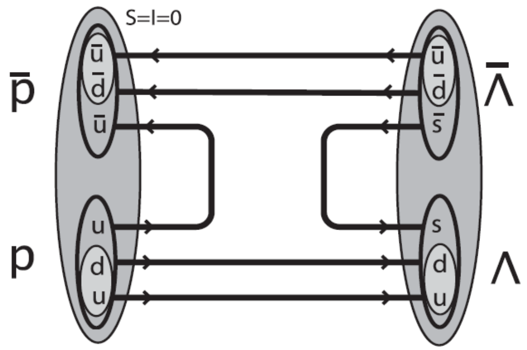
A sketch showing the reaction plane and topology of the $Y\bar{Y}$ in the canter of mass system

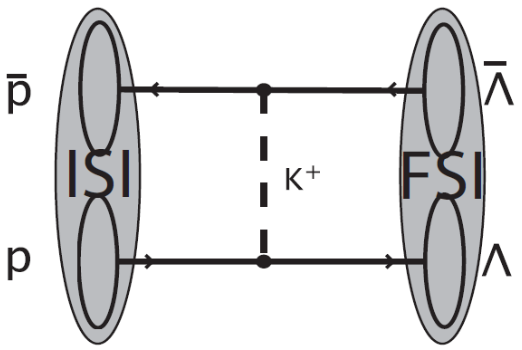


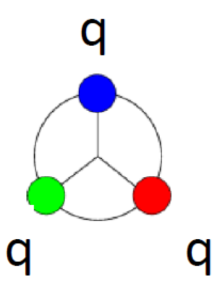
- Cross section (top) and polarization calculations for two energy points (bottom)
- Solid circle (1.6 GeV) open circle (1.9 GeV)

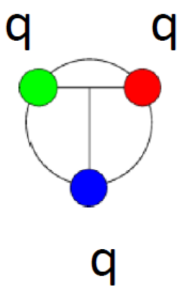
> - Clear sign of polarization flip at higher energy
> - Cross section is forward piked at 1.9 GeV

The beginning, PS185



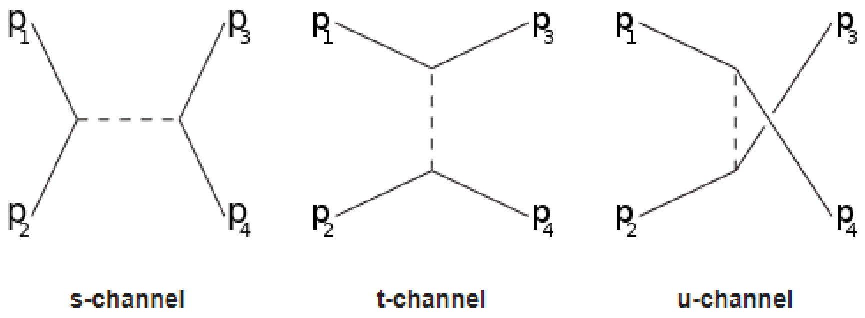






- Flavour changing process (s-quark production)
- s-channel gluon exchange (Left side) or a t-channel meson exchange (right)
- s-quark is the spin carrier in this process (spectator) (di-quark quark ?)

AIP Conference Proceedings **796**, 95 (2005)

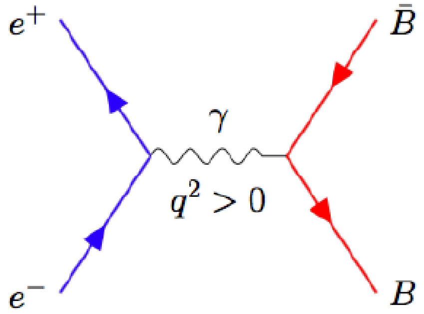


What do we know now ?

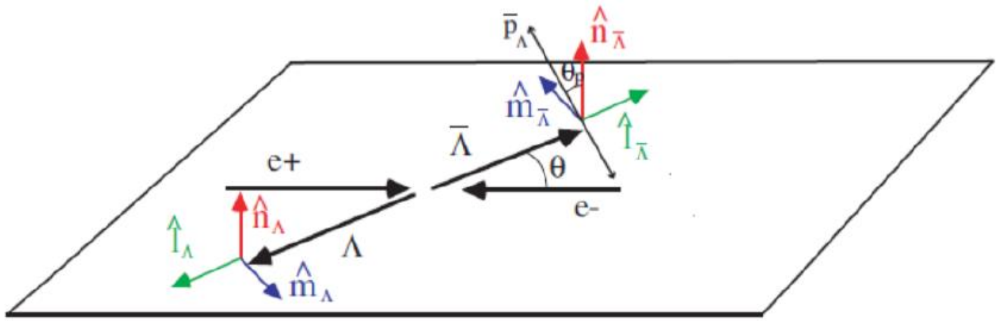
- Λ can be a quark di quark
- Forward spiked cross section can justify the assumption of the expected production diagrams
- The self analysing weak decay grants us the information abut the lambda polarization
- We experienced a flip in polarization between different energy points , different production mechanism ?

Electromagnetic form -factors

Electromagnetic form factors (EMFF`s) contain information abut hadron charge and current distributions.
For J = ½ one can get 2 types such as: **G_E, G_M**



$$\sigma_{Born}(q^2) = \frac{4\pi\alpha^2\beta}{3q^2}\left[\left|G_M(q^2)\right|^2 + \frac{1}{2\tau}\left|G_E(q^2)\right|^2\right]$$



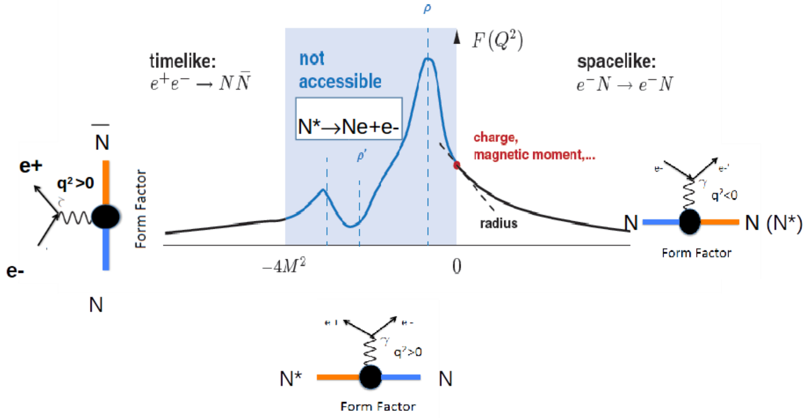
$$\cos\theta = \hat{\mathbf{p}} \cdot \hat{\mathbf{k}}.$$

$$\mathbf{p}_\Lambda = -\mathbf{p}_{\bar{\Lambda}} = \mathbf{p}$$

$$\mathbf{k}_{e^-} = -\mathbf{k}_{e^+} = \mathbf{k}.$$

In the time like region the EMFF`s are complex:

- $G_E(q^2) = |G_E(q^2)| * e^{i\Phi_E}$
- $G_M(q^2) = |G_M(q^2)| * e^{i\Phi_M}$



Have a relative phase:

- $\Delta\Phi = \Phi_M - \Phi_E$

The non zero relative phase induces polarization on the final state even if the initial state is unpolarized.

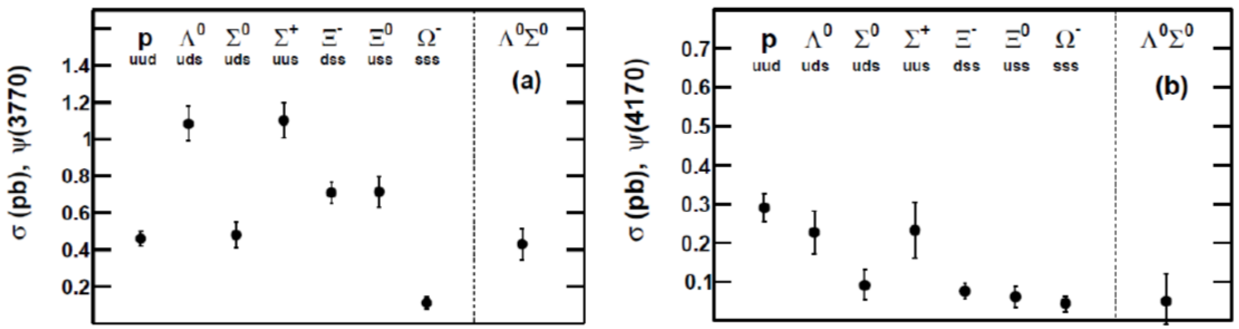
G. Eichmann **APhysPolSupp 7, 597** (2014)

L.G. LANDSBERG “Electromagnetic decays of light mesons” ***for*** **High Energy Physics, Serpukhov, U.S.S.R.**

Electromagnetic form -factors

- EMFF`s sensitive to hyperon structure (di-quark correlations)
- Are EMFF`s for hyperons equivalent to their counter partners in baryon sector – N*, Δ (SU(3)- symmetry)
- Measured EMFF`s (CLEO) are larger by factor 10 from early predictions based on VDM

The starting point ?
Baryons again ?
Where did the quarkonium go ?



*PRD 96 (2017) 092004.

S. Dobbs et. al. PRD 96 (2017) 092004

Elementary systems e^+e^-

Spin correlation (quantum entanglement)

$$W(\xi)=1+\alpha_\psi\cos^2\theta_\Lambda+\alpha_-\alpha_+(\sin^2\theta_\Lambda\sin\theta_1\sin\theta_2\cos\phi_1\cos\phi_2+\cos^2\theta_\Lambda\cos\theta_1\cos\theta_2)$$
$$+\alpha_-\alpha_+\sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)\left[\sin\theta_\Lambda\cos\theta_\Lambda(\sin\theta_1\cos\theta_2\cos\phi_1+\cos\theta_1\sin\theta_2\cos\phi_2)\right]$$
$$+\alpha_-\alpha_+\alpha_\psi(\cos\theta_1\cos\theta_2-\sin^2\theta_\Lambda\sin\theta_1\sin\theta_2\sin\phi_1\sin\phi_2)$$
$$+\sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\sin\theta_\Lambda\cos\theta_\Lambda(\alpha_-\sin\theta_1\sin\phi_1+\alpha_+\sin\theta_2\sin\phi_2)$$

$$\xi=(\theta_\Lambda,\theta_1,\varphi_1,\theta_2,\varphi_2)$$

Spin polarization

$$G_E^\psi = \frac{\sqrt{s}}{2M_\Lambda}\sqrt{\frac{1-\boldsymbol{\alpha_\psi}}{1+\boldsymbol{\alpha_\psi}}}\,e^{i\boldsymbol{\Delta\Phi}}\,G_M^\psi$$

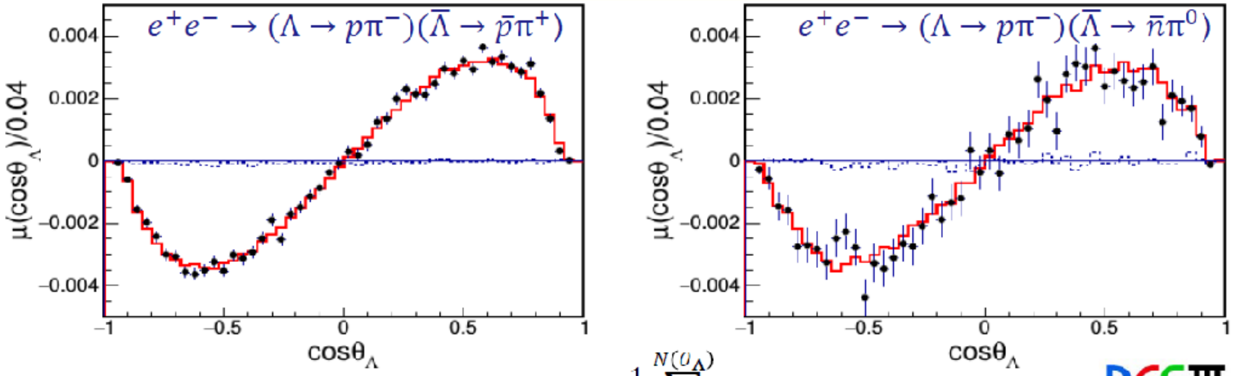
$$\alpha_-=\alpha(\Lambda\to p\pi^-)$$
$$\alpha_+=\alpha(\bar\Lambda\to\bar p\pi^+)$$

Fladt, Kupsc PLB 772 (2017) 16

Elementary systems e^+e^-

Fit results J/Ψ

$\Delta\Phi = 42.3° \pm 0.6° \pm 0.5°$



moment: $\mu(\cos\theta_\Lambda) = \frac{1}{N}\sum_{i=1}^{N(\theta_\Lambda)}\left(n_{1,y}^{(i)} - n_{2,y}^{(i)}\right)$

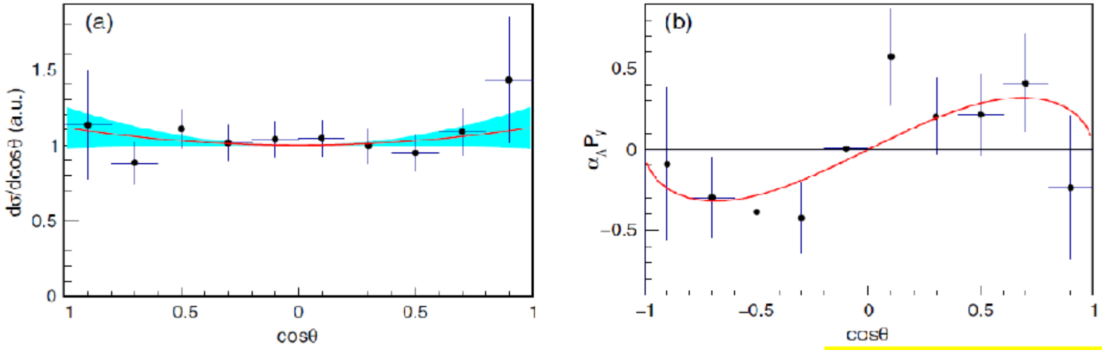
(uncorrected for acceptance)

Parameters	This work	Previous results	
α_ψ	$0.461 \pm 0.006 \pm 0.007$	0.469 ± 0.027 BESIII	
$\Delta\Phi$ (rad)	$0.740 \pm 0.010 \pm 0.008$	–	
α_-	$0.750 \pm 0.009 \pm 0.004$	0.642 ± 0.013	PDG
α_+	$-0.758 \pm 0.010 \pm 0.007$	-0.71 ± 0.08	PDG
$\bar{\alpha}_0$	$-0.692 \pm 0.016 \pm 0.006$	–	

BESIII Nature Phys. (2019)

$e^+e^- \to \gamma^* \to \Lambda\bar{\Lambda}$ (continuum: 2.396 GeV)

PHYSICAL REVIEW LETTERS 123, 122003 (2019)



555 events selected

$(\text{"}\alpha_\psi\text{"} = 0.13 \pm 0.16)$

$\Delta\Phi = 37° \pm 12° \pm 6°$

R = 0.94 ± 0.16(stat.) ± 0.03(sys.) ± 0.02(α_)

The same fit as for $J/\psi \to (\Lambda \to p\pi^-)(\bar{\Lambda} \to \bar{p}\pi^+)$ but $\alpha_- = \alpha_+$ and fixed

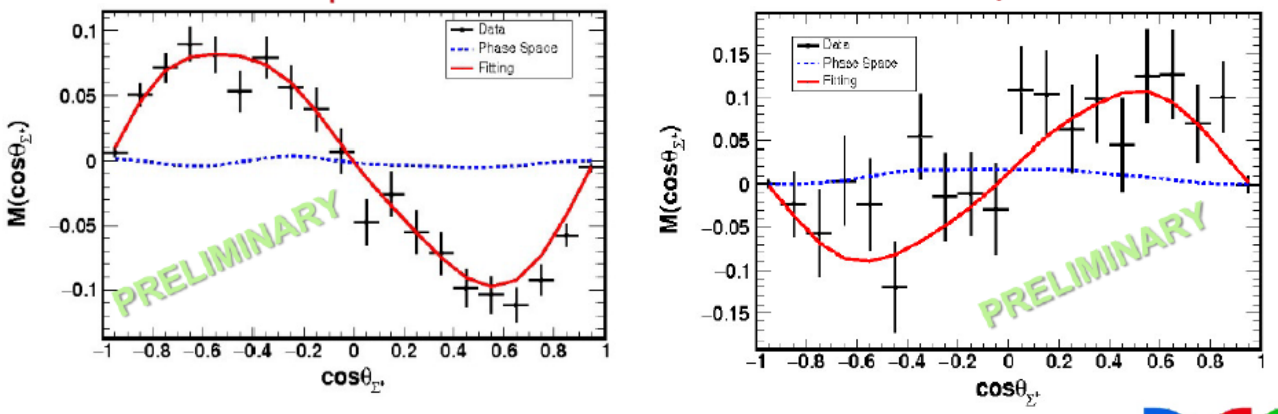
Similar results, J/Ψ to narrow to contribute to the production process ?

Elementary systems e^+e^-

$$e^+e^- \to J/\psi, \psi' \to \Sigma^+\bar{\Sigma}^- \to p\pi^-\bar{p}\pi^+$$

The same formalism as for $J/\psi \to \Lambda\bar{\Lambda}$

$J/\psi \to \Sigma^+ \Sigma^-$ $\qquad\qquad$ $\psi' \to \Sigma^+ \Sigma^-$



BESIII

$\alpha_{J/\psi}/\alpha_{\psi}$ = -0.507±0.006±0.002 / 0.676±0.030±0.006

$\Delta\Phi(J/\psi, \psi)$ = (-15.4±0.7±0.3)° / (21.5 ± 0.4 ± 0.5)°

α_0 = -0.999±0.037±0.010

$\bar{\alpha}_0$ = 0.992±0.037±0.008

A_{CP} = -0.015±0.037±0.008

Polarization flip ? So the width of the contribution vector meson plays a role ? ☺

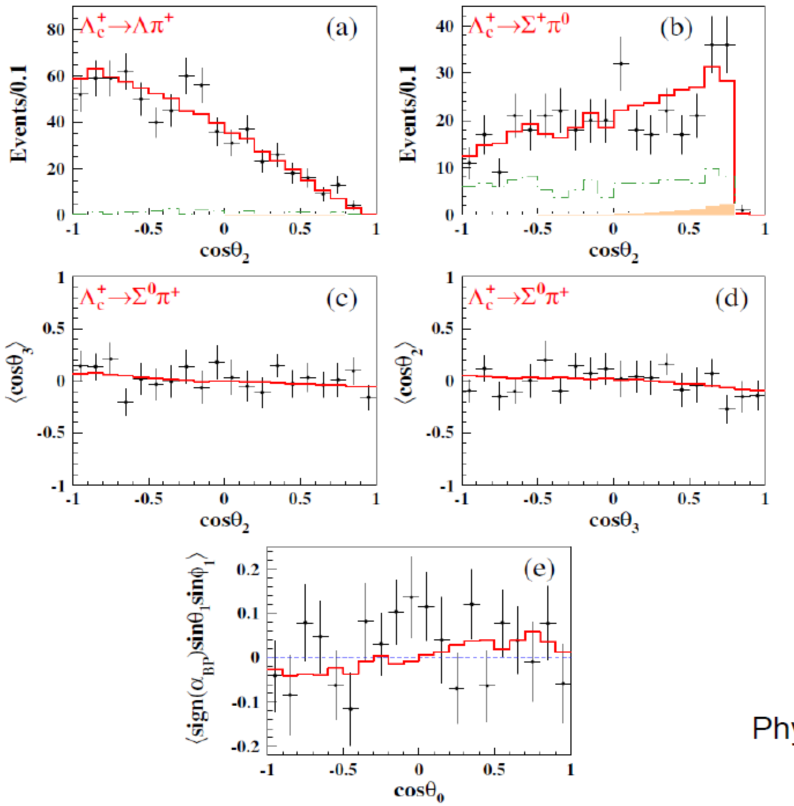
A talk by PACETTI, Simone (University of Perugia and INFN)

https://indico.ihep.ac.cn/event/9834/session/8/contribution/12/material/slides/0.pdf

Elementary systems e^+e^-

- Non zero relative phase does induce polarization
- Narrow resonances do not contribute to the production process
- Clear polarization flip visible for ψ` to $\Sigma\bar{\Sigma}$.
- What abut charmed baryons ?

$$e^+e^- \rightarrow (\Lambda_c^+ \rightarrow B\pi)(\bar{\Lambda}_c^- \rightarrow X)$$

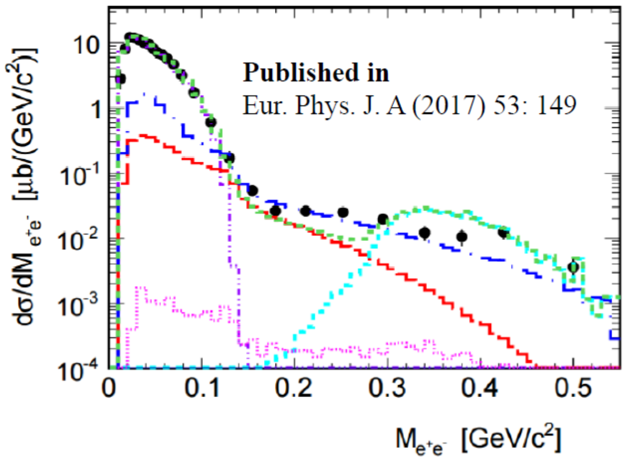


Phys.Rev. D100 (2019) 072004

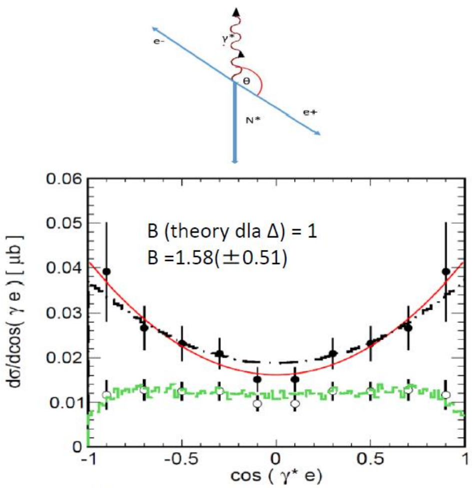
Model I :
- π^0 Dalitz (----)
- Δ Dalitz (----)
- η Dalitz (----)
- ρ (----):

Model II :
- bremsstrahlung

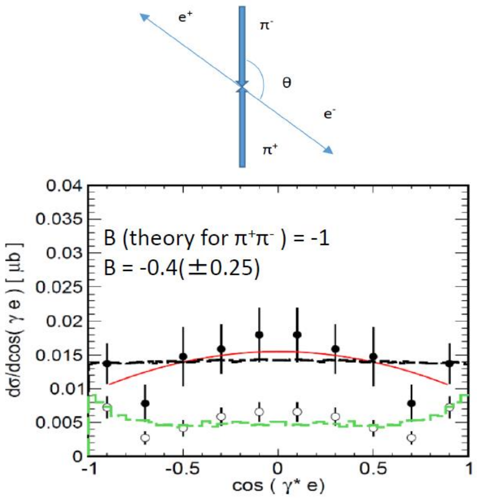
1. $np \rightarrow \Delta\Delta \rightarrow np\rho$	$\sigma = 170\ \mu b$
2. $np \rightarrow d^* \rightarrow np\rho$	$\sigma = 40\ \mu b$



140 < $M_{inv}(e^+e^-)$ < 280 MeV/c^2



$M_{inv}(e^+e^-)$ > 280 MeV/c^2



FIT: $\frac{dN}{d\alpha} = A(1 + B\cos^2\alpha)$

E. Batkovskaya et.al, PLB348 (1995) 283

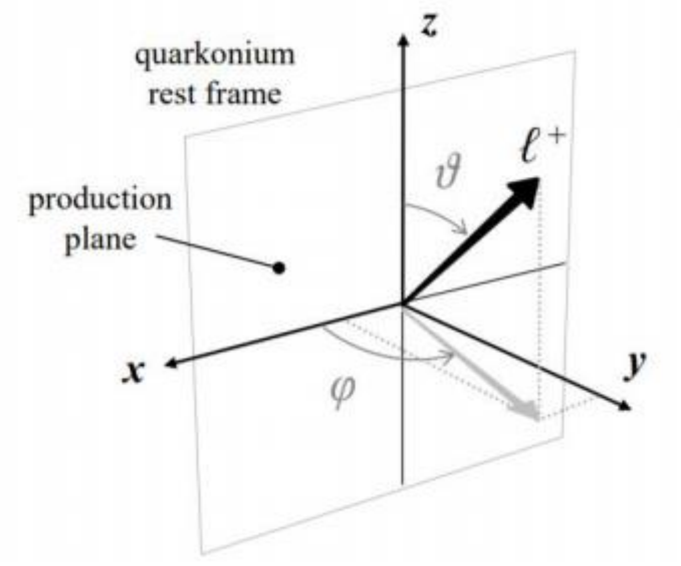
Polarisation measurements at high energies

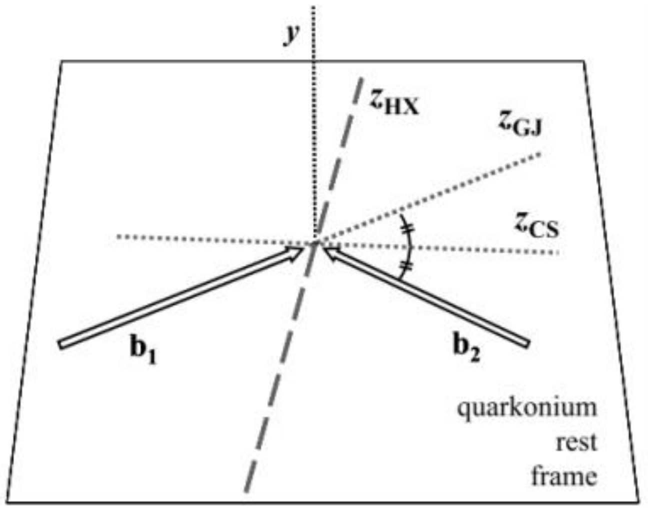
- $(c\bar{c}$ & $b\bar{b}) \rightarrow \mu\mu$
- There is no model describing the polarisation !

$$W(\theta,\phi) \propto \frac{1}{3+\lambda_\theta}\left(1+\lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi\right),$$

Two body decay angular parametrization where:

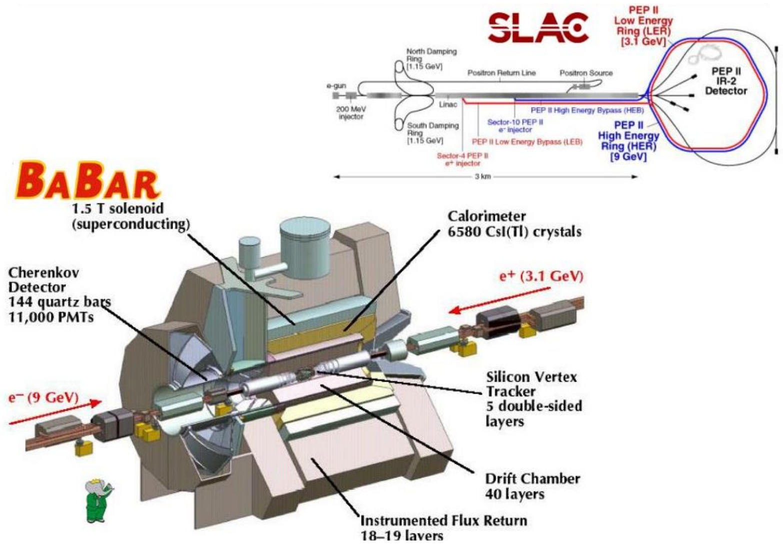
θ – polar production angle in the quarkonium rest frame
Φ – azimuthal production angle in the quarkonium rest frame
λ – represents various polarization parameters depended on the quarkonium production spin density matrix elements





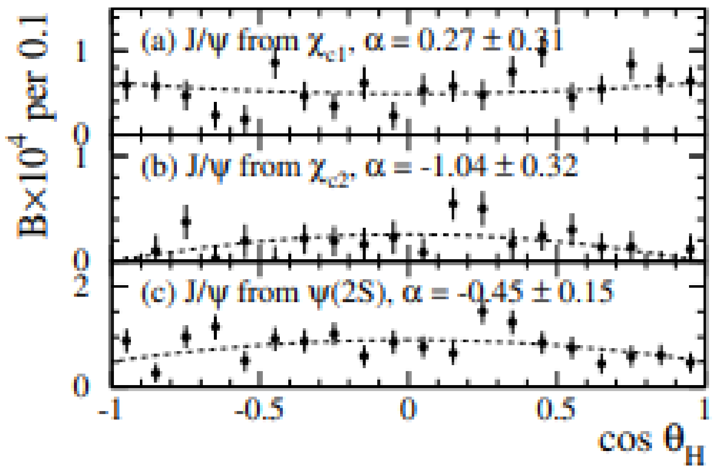
$\lambda_\Theta, \lambda_\varphi, \lambda_{\theta\varphi} \rightarrow (0,0,0)$ no polarisation ☹
$\lambda_\Theta, \lambda_\varphi, \lambda_{\theta\varphi} \rightarrow (-1,0,0)$ longitudinal polarisation
$\lambda_\Theta, \lambda_\varphi, \lambda_{\theta\varphi} \rightarrow (+1,0,0)$ Transvers polarisation

Charmonium production at higher energies in BaBar

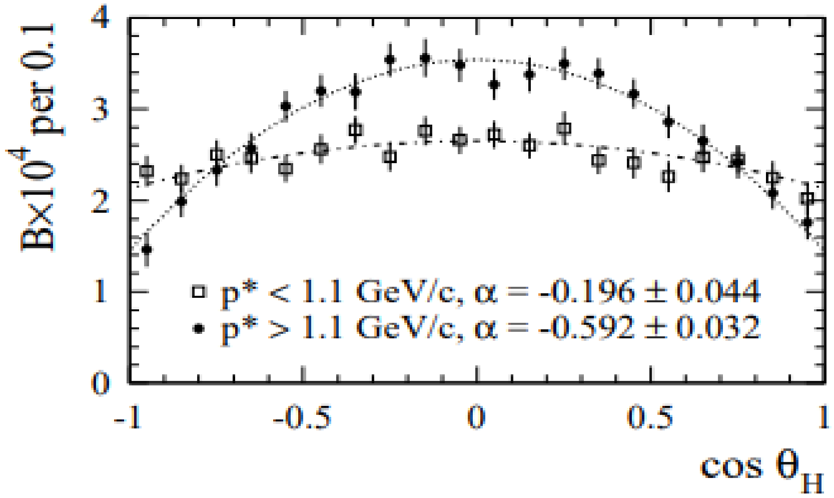


- Clear sign of helicity distribution (anisotropy) sensitivity to the origin of quarkonium
- What would be the signature of in medium effect such as quark gluon plasma formation ?

J/ψ coming for different heavier charmonium

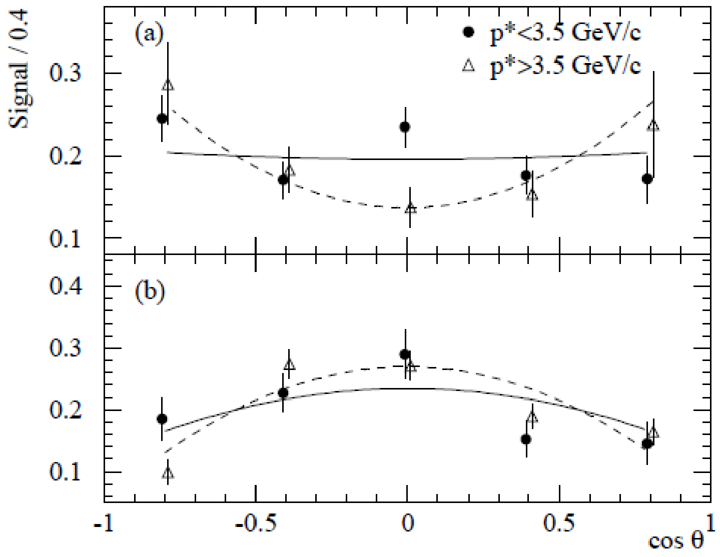


J/ψ coming for different B decays



-0.46 ± 0.21 for p< 3.5GeV/c and
$\alpha = -0.80 \pm 0.09$ for p> 3.5GeV/c.

J/ψ production in continuum



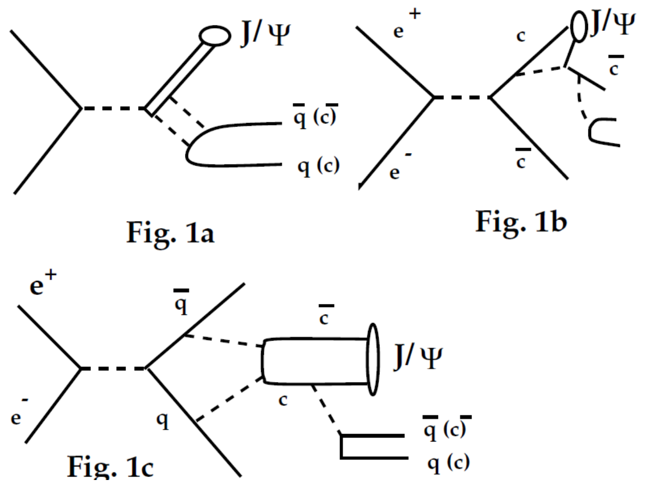
Phys. Rev. D, 67:032002, Feb 2003.

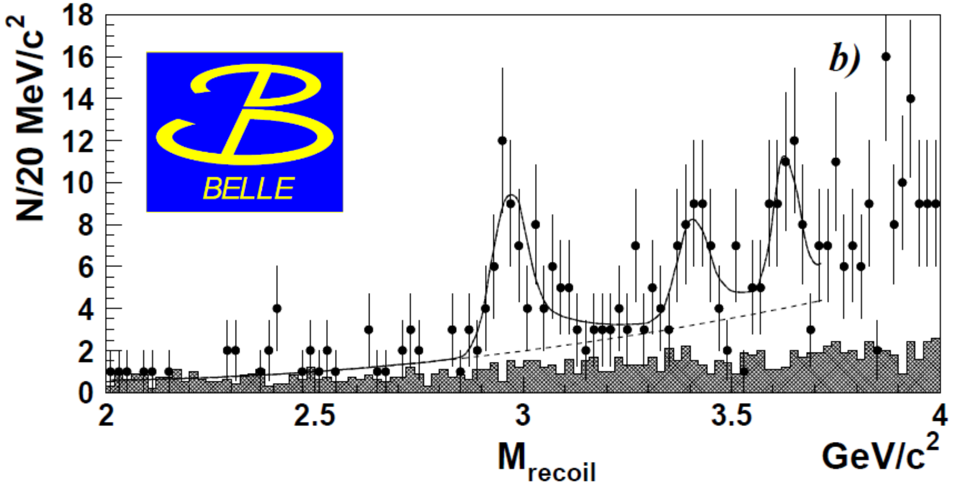
Phys.Rev.Lett.87:162002,2001

Charmonium production at higher energies in BaBar

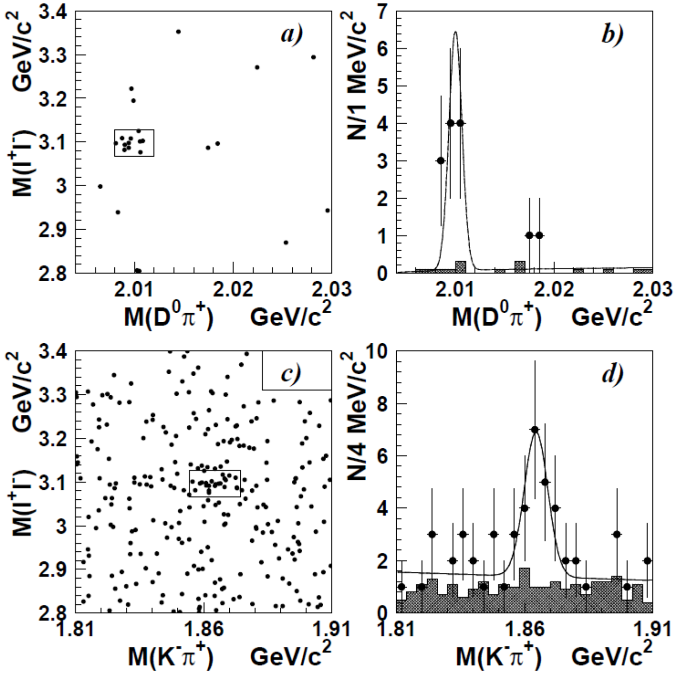
Phys.Part.Nucl.35:S98-S101,2004

- J/Ψ can be produced with an associated $\bar{c}c$ pair
- First type of production (a) considers a fusion of a $\bar{c}c$ pair the momentum conservation is assured by radiating gluons witch can produce a additional $\bar{c}c$
- Second type (b) assumes c quark fragmentation in to J/Ψ with the production of an additional gluon
- Third type (c) the virtual photon produces a pair of $\bar{c}c$ forming the J/Ψ via gluon exchange (suppressed channel by $\alpha(m_c)$)





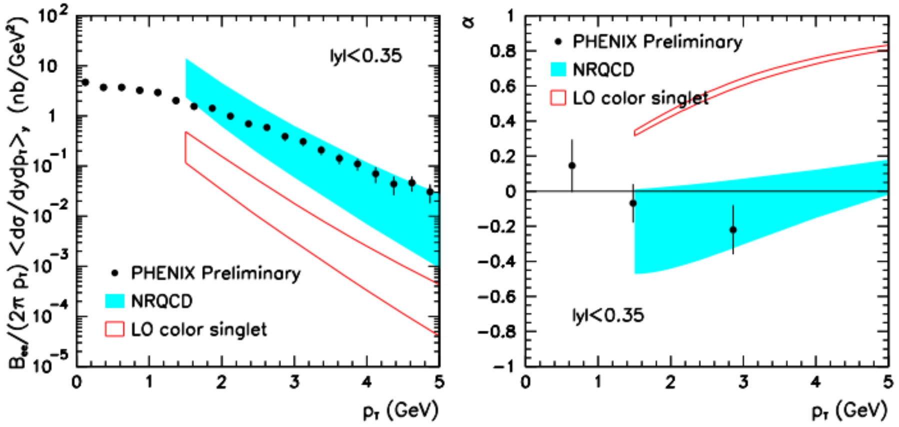
- Recoil mass measured at 10 GeV for e^+e^-
- η_c shape reproduced by MC simulation of $e^+e^- \to J/\psi\eta_c(\gamma)$
- $N_{\eta c\,(2S)} = 67(12)$ were found



Phys.Rev.Lett.89:142001,2002

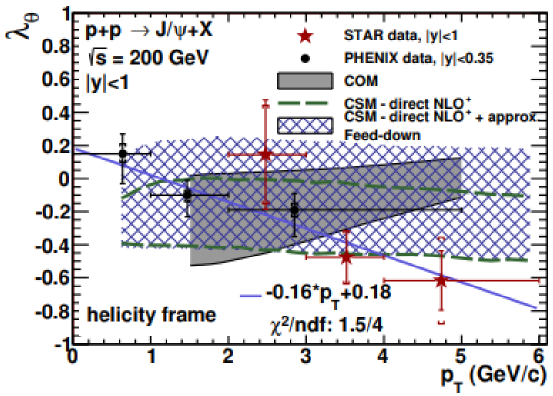
RHIC quarkonium polarization in complex systems

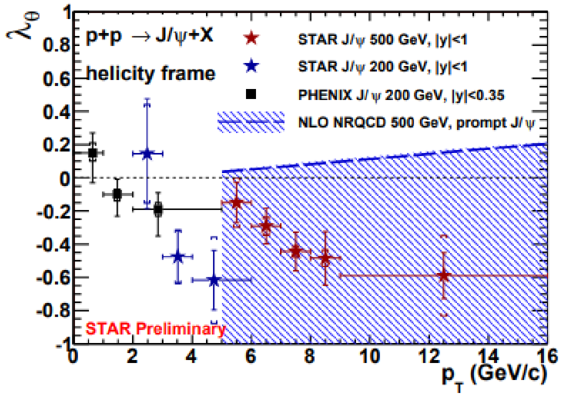
$\sqrt{s} = 200\ GeV\ for\ pp$ **Phys.Rev.D81:014020,2010**

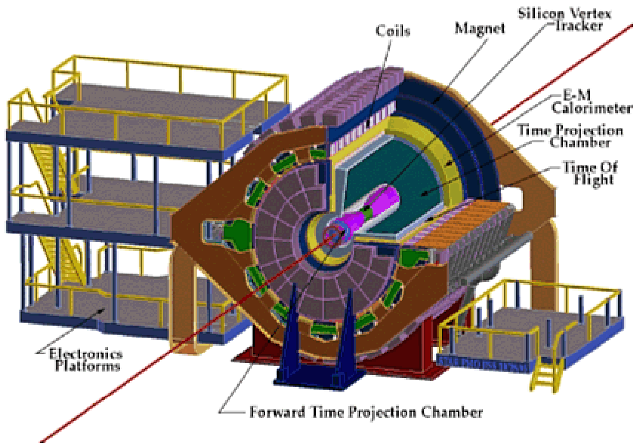


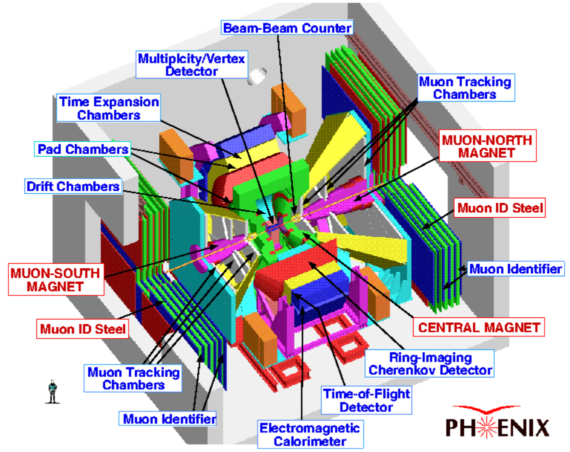
- Prompt production within the medium
- Very narrow acceptance
- Model description for higher p_t values, less sensitive for in-medium effects
- Colour singlet model does not describe the data and gives different trends (α)

arXiv:1512.07405 **[hep-ex]**





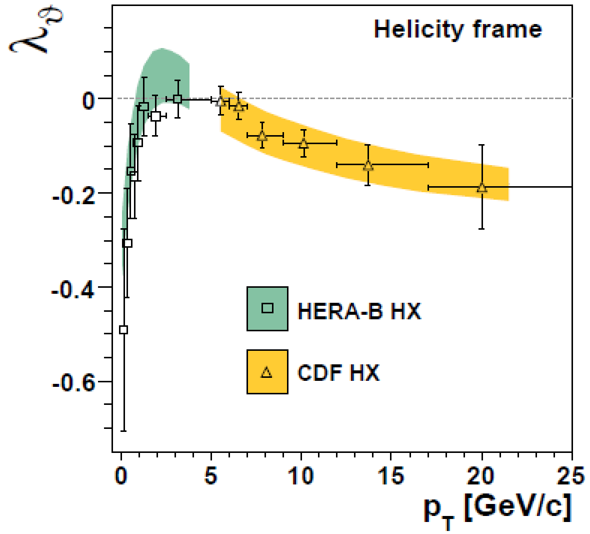




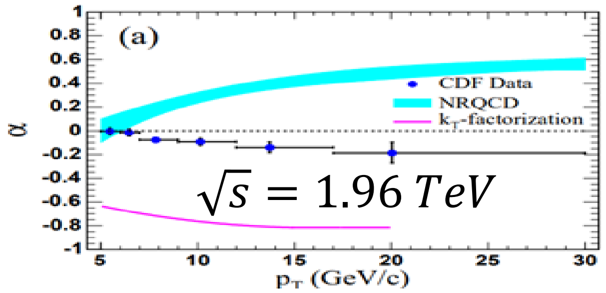
- STAR data in a wide acceptance in comparison to PHENIX
- The trend in alpha stays the same but one can deduce a flip in the alpha anisotropy for higher pt values for 500 GeV in respect to 500 GeV
- I think we „can/do" see a similar pattern at LHC ☺

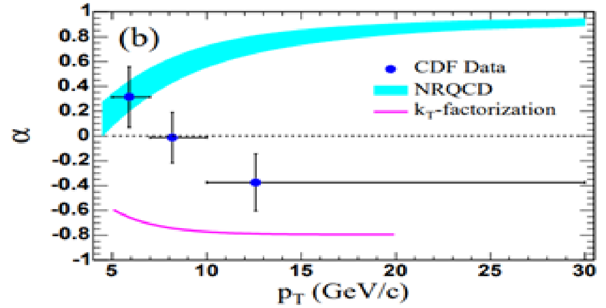
Complex systems at TeV energy

Phys.Rev.Lett. 102 (2009) 151802

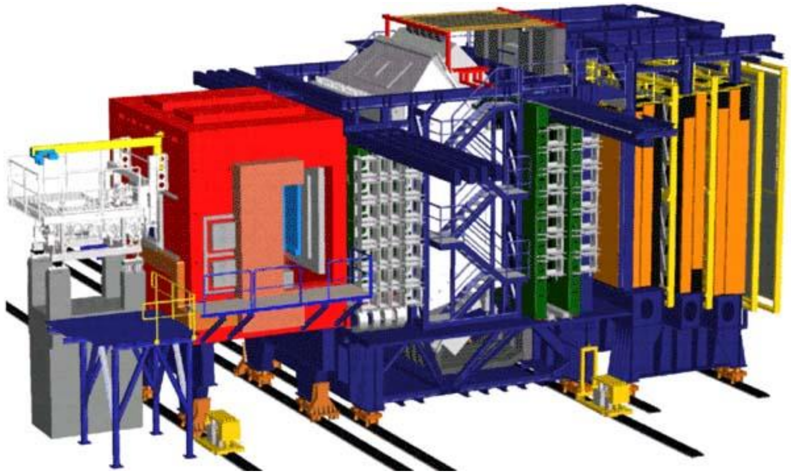


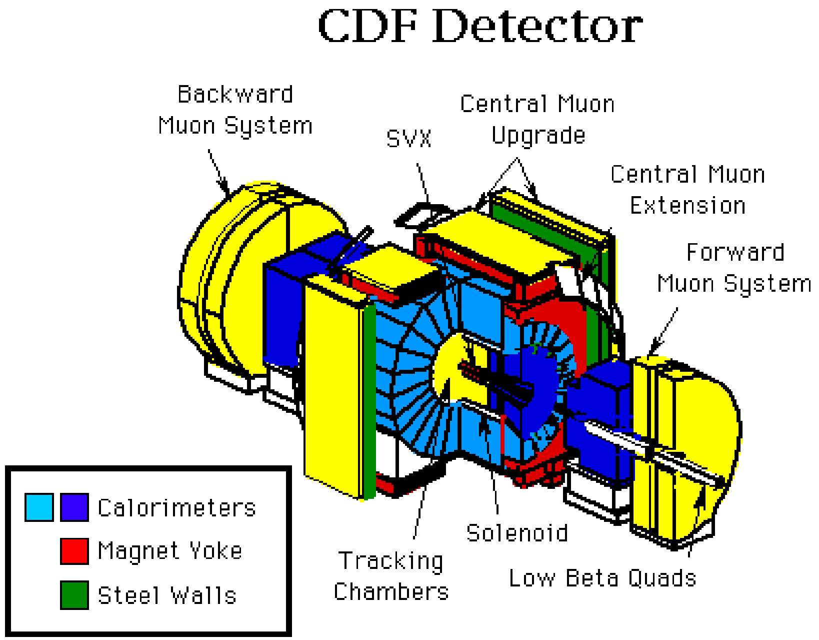
Phys. Rev. Lett., 99:132001, Sep 2007.





- CDF and HERA-B (~40 GeV p-W and p-C) results provide a interesting picture
- At low pt one can see very strong negative anisotropy





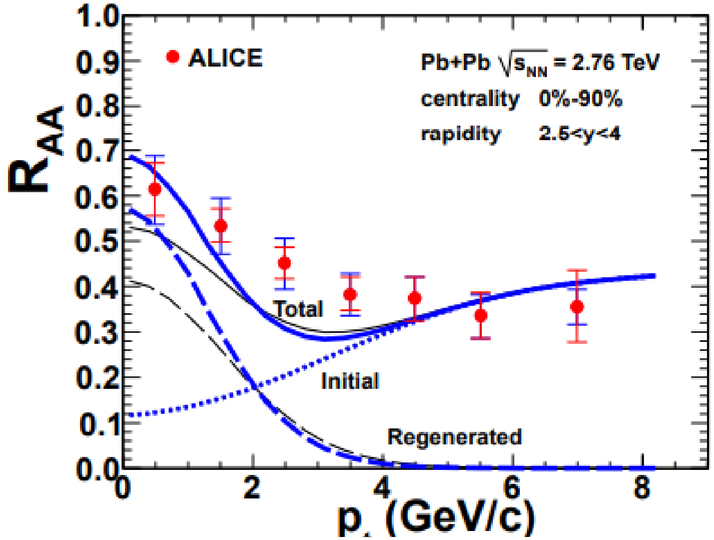
- Similar patterns for bout data sets
- Strange anisotropy flip for low pt between two data sets ?
- Different trends for J/ψ and ψ (2S)

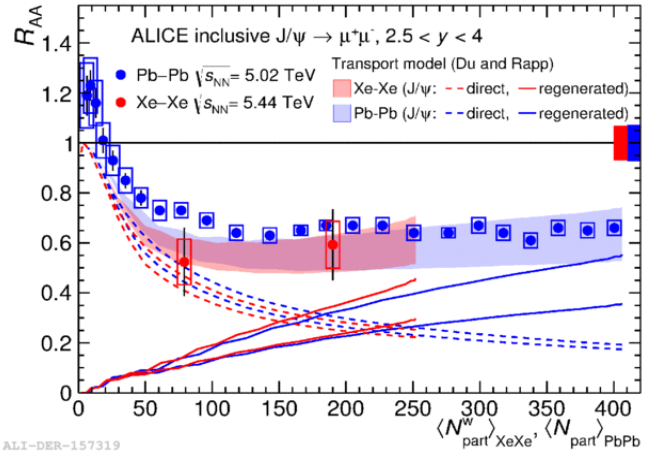
Charmonium production in heavy ion collisions

- In HI collisions charmonium production can be modified by regeneration (*) and dissociation (@) processes
- Shadowing reduces the regeneration process
- The initial production is not affected by the QGP formation in contrast to the regeneration process (?)
- High p_t region is mostly unaffected and dominated by non prompt J/Ψ

The initial production, the regeneration, and the total are shown by dotted, dashed and solid lines, and the thick and thin lines are the calculations with and without considering the mean field effect

Phys.Rev.C 86 (2012) 034906





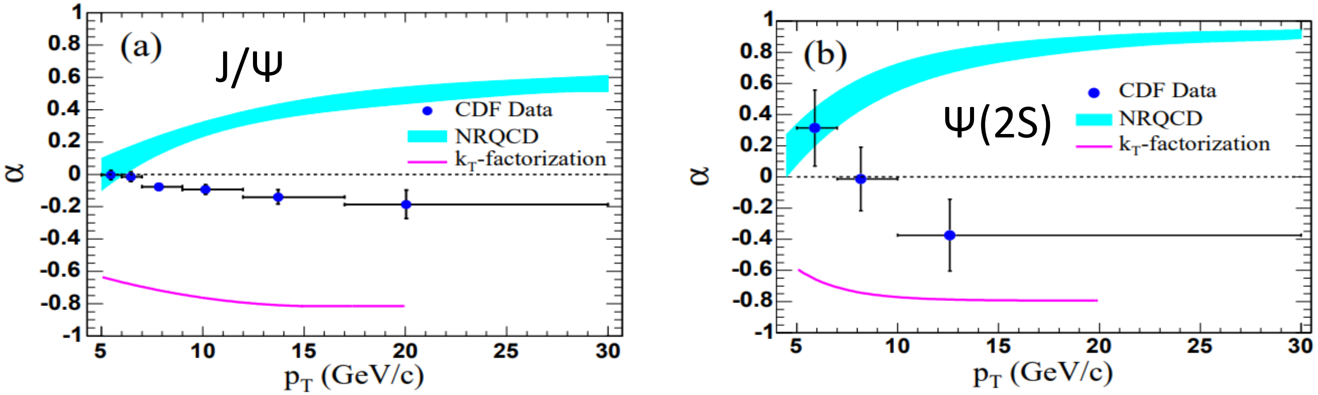
@T. Matsui and H. Satz, "J/ψ Suppression by Quark-Gluon Plasma Formation" Phys. Lett. B168 (1986) 415

*P. Braun-Munzinger and J. Stachel, "(Non)Thermal Aspects of Charmonium Production and a New Look at J/ψ Suppression", Phys. Lett. B490 (2000) 196

Polarisation measurements at high energies

- J/Ψ Inclusive polarisation measurements in pp collisions in the forward rapidity bins
- Calculations done in two reference frames, Colin Soper and Helicity
- LHCb and ALICE follow the same trend in CS frame
- Discrepancies can bee observed in HX frame, the polarization is non zero in high p_t bins (dominated by non-prompt J/Ψ)
- Measurements obtained by CDF form $p\bar{p}$ show a different pattern
- High p_t J/Ψ may come form jets ?

Prompt



$$I(\cos\theta^*) = \frac{3}{2(\alpha+3)}(1+\alpha\ \cos^2\theta^*)$$

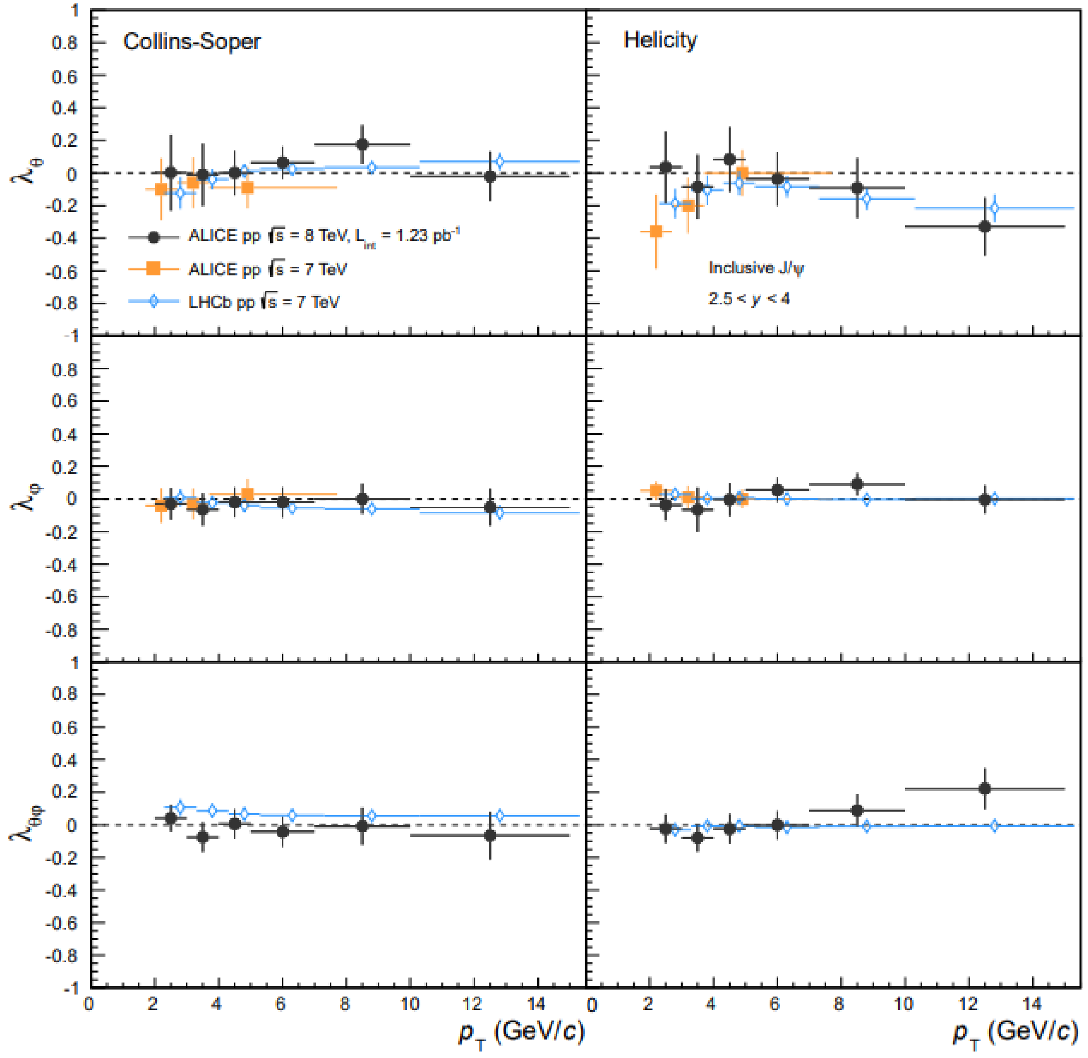
Phys. Rev. Lett., 99:132001, Sep 2007.

α = 1 Transvers polarization

α = 0 No polarization ☹

α = -1 Longitudinal polarization

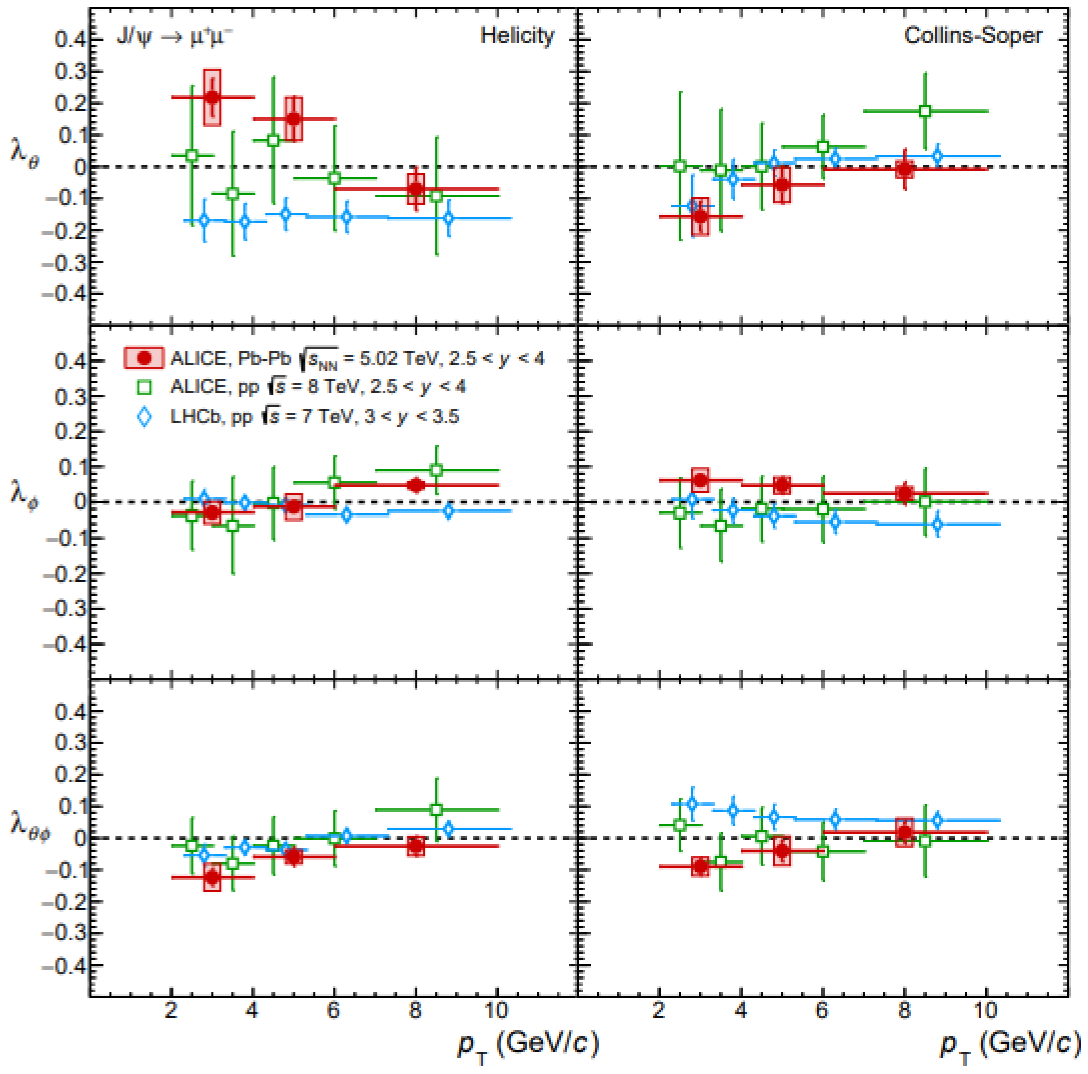
J/Ψ -> μ μ



arXiv:1805.04374v2 [hep-ex]

Polarisation measurements at high energies

- First polarization measurement of inclusive J/Ψ in Heavy Ion Collisions (PbPb)
- Parameter values are close to zero both in the HX and CS frames except λ_θ both in CS and HX frames
- It is expected that HI collisions have a different prompt / non prompt ratio in comparison to pp or $p\bar{p}$ data sets



Spin density matrix elements in NRQCD

$$\lambda_\theta = \frac{d\sigma_{11} - d\sigma_{00}}{d\sigma_{11} + d\sigma_{00}}, \qquad \lambda_\phi = \frac{d\sigma_{1,-1}}{d\sigma_{11} + d\sigma_{00}}, \qquad \lambda_{\theta\phi} = \frac{\sqrt{2}\,\mathrm{Re}(d\sigma_{10})}{d\sigma_{11} + d\sigma_{00}}.$$

$$d\sigma_{ij} = \sum_\kappa d\hat{\sigma}^\kappa_{ij} \langle \mathcal{O}_\kappa \rangle$$

$\langle O_k \rangle$ - long distance NRQCD matrix elements (hadronization of a $\bar{q}q$), usually derived form experimental data

$$\kappa = {}^{2S+1}L_J^{[C]},$$

$d\hat{\sigma}^\kappa_{ij}$- producing with given quantum state κ

[C] – denotes the singlet or octet states

JHEP 12 (2018) 057

$${}^3S_1^{[1]},\ {}^1S_0^{[8]},\ {}^3S_1^{[8]},\ {}^3P_J^{[8]} \text{ with } J = 0, 1, 2.$$

Leading contribution in the equation. The outline contributions will produce J/Ψ with the same spin as a $\bar{c}c$ intermediate state

$$d\sigma_{ij}^{{}^1S_0^{[8]}} = \begin{cases} \frac{1}{3} d\sigma^{{}^1S_0^{[8]}} & \text{if } ij = 00, ++, \text{ or } --, \\ 0 & \text{in other cases}, \end{cases}$$

Polarisation measurements at high energies

- First polarization measurement of inclusive J/Ψ in Heavy Ion Collisions (PbPb)
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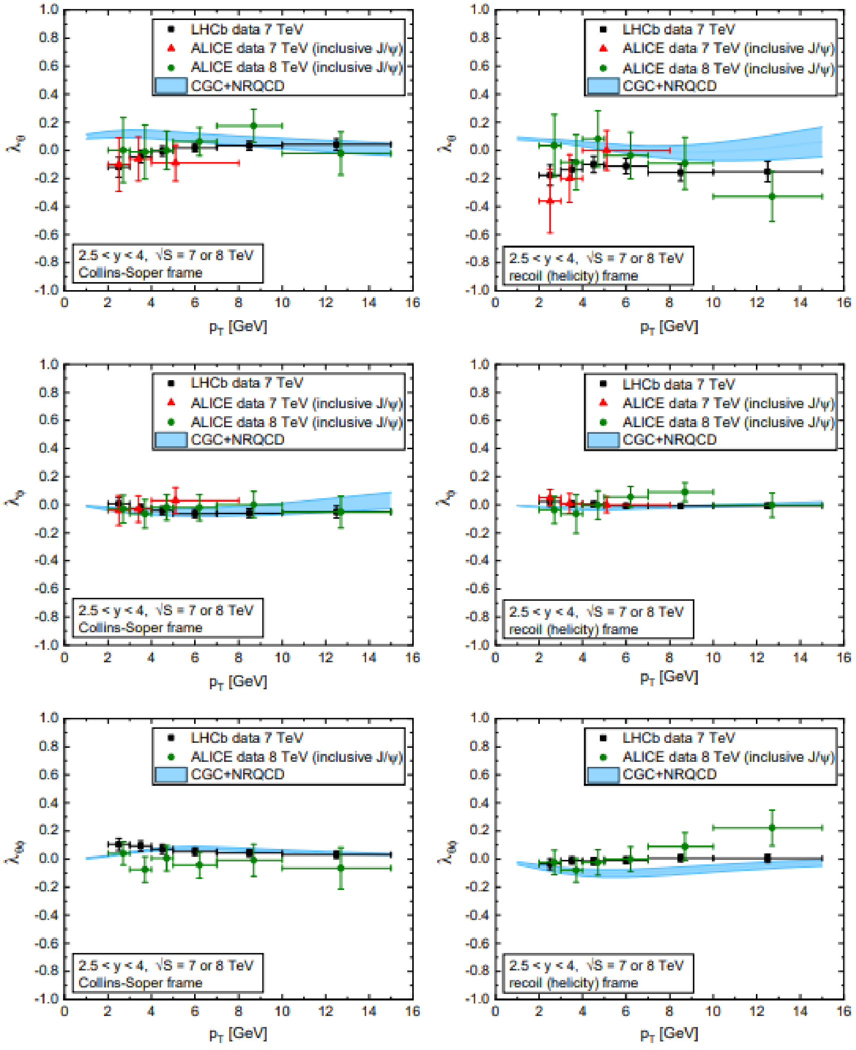
- It is expected that HI collisions have a different prompt / non prompt ratio in comparison to pp or $p\bar{p}$ data sets
- The model fails to provide a satisfying description of the data (blue band)



JHEP 12 (2018) 057

Polarisation measurements at high energies

- The polarization is somewhat sensitive to the production mechanism when one compares pp, PbPb and $p\bar{p}$?
- Is there a difference between prompt and non prompt J/Ψ polarisation ?
- What abut the data for low p_t ex. J/Ψ -> $e^+ e^-$?
- Is there a magnetic filed influence ?

System	Magnetic Field in Tesla
Human brain	10^{-12}
Earth's magnetic field	10^{-5}
Refrigerator magnet	10^{-3}
Loudspeaker magnet	1
Strongest field in lab	10^{3}
Neutron star	10^{6}
Heavy-ion collisions	$\mathbf{10^{15} - 10^{16}}$

Spin alignment of vector mesons measured in Pb-Pb collisions with ALICE

Bedanga Mohanty

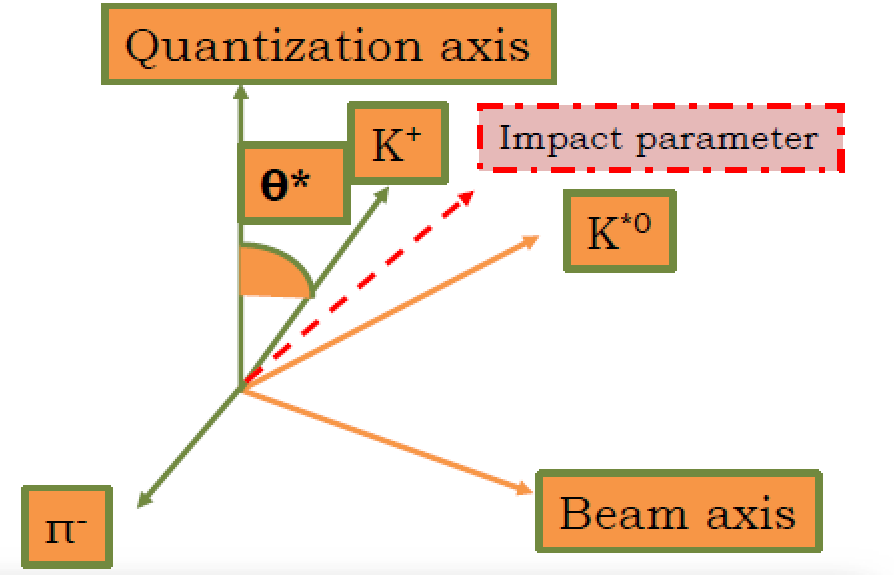
Polarisation measurements at high energies (Angular momentum)

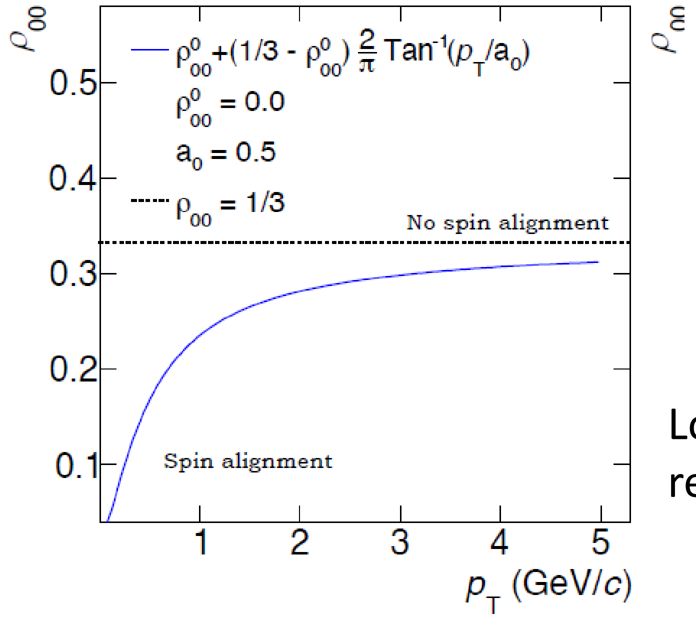
K. Schilling et al., Nucl. Phys. B 15 (1970) 397

$$\frac{dN}{d\cos\theta d\phi} = \langle \theta, \phi, \lambda_1, \lambda_2 | M \rho M^{\dagger} | \theta, \phi, \lambda_1, \lambda_2 \rangle$$

$$= \sum_{\lambda_V} \sum_{\lambda_{V'}} \langle \theta, \phi, \lambda_1, \lambda_2 | M | \lambda_V \rangle \langle \lambda_V | \rho | \lambda_{V'} \rangle \langle \lambda_{V'} | M^{\dagger} | \theta, \phi, \lambda_1, \lambda_2 \rangle$$

λ = Helicities
ρ = spin density matrix
M = Decay amplitude





Z. Liang et. al., Phys. Lett. B629, 20 (2005)

Low p_t dominated by recombination effects

Spin Alignment

- Presence of large spin angular momentum in HI collisions
- “directed flow” comes form hadrons produced in the hadronization phase from polarized quarks
- Difficult to disentangle because of the interaction with mater and spectator nucleus

Z. Liang et. al., Phys. Lett. B629, 20 (2005)

Spin Alignment

$$P_q = -\frac{\pi}{4}\frac{\mu\, p}{E(E+m_q)}\,,$$

Where:
E and p - intimal energy and momentum of the quark in the cm frame of the parton scattering
μ- specific to average interaction range (Debey screening quark mass in medium)

- Global quark polarization via elastic scattering (hyperon polarization but also spin alignment of vector mesons)

$$W(\theta) = \frac{3}{4}[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta].$$

$$W(\phi) = \frac{1}{2\pi}[1 - 2\cos(2\phi)\mathrm{Re}\rho_{1-1} + 2\sin(2\phi)\mathrm{Im}\rho_{1-1}].$$

Spin alignment can be described via spin density matrix elements ρ

$\cos^2\theta$ dependence makes spin alignment (ρ_{00}) not sensitive to the reaction plane

Z. Liang et. al., Phys. Lett. B629, 20 (2005)

Spin Alignment

1. recombination of the polarized quarks and anti-quarks (low p_t and central rapidity)
2. recombination of the polarized quarks (anti-quarks) with unpolarized anti-quarks (quarks)
3. fragmentation of polarized quarks (or antiquarks) (forward direction)

Scenario 1.

$$\rho^V = \begin{pmatrix} \frac{(1+P_q)(1+P_{\bar{q}})}{3+P_qP_{\bar{q}}} & 0 & 0 \\ 0 & \frac{1-P_qP_{\bar{q}}}{3+P_qP_{\bar{q}}} & 0 \\ 0 & 0 & \frac{(1-P_q)(1-P_{\bar{q}})}{3+P_qP_{\bar{q}}} \end{pmatrix}$$

For ρ and K we get

$$\rho_{00}^{\rho(\text{rec})} = \frac{1-P_q^2}{3+P_q^2},$$

$$\rho_{00}^{K^*(\text{rec})} = \frac{1-P_qP_s}{3+P_qP_s},$$

$$p_0 = \mu L_0$$

"momentum scale" L_0 is the relative angular momentum between two colliding partons

This would yield in a non polarized $\bar{q}q$ (quarks with similar polarization) system but thanks to **Scenario 2** the quark (quark p_t>> p_0) can form a system with a low p_t polarized quark

Scenario 3. (fragmentation of polarized quarks)

- quark that was created via fragmentation may carry information regarding the initial quark

$$\rho_{00}^{V(frag)} = \frac{1+\beta P_q^2}{3-\beta P_q^2}.$$

β – form fit (0.5)

$$\rho_{00}^{\rho\,(\text{frag})} = \frac{1+\beta P_q^2}{3-\beta P_q^2},$$

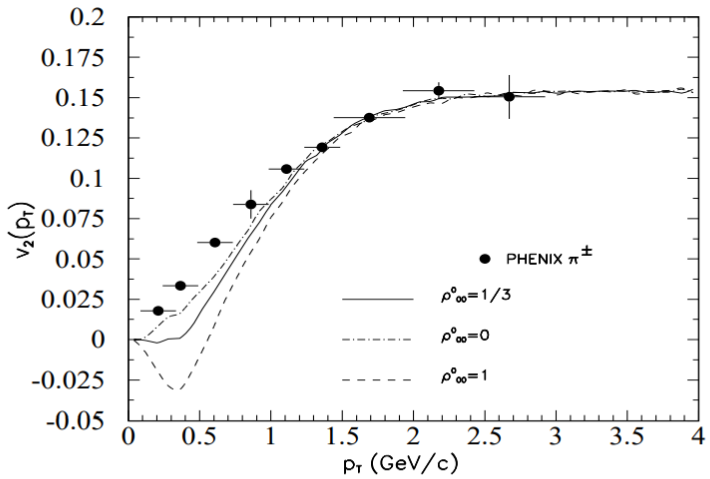
$$\rho_{00}^{K^*(\text{frag})} = \frac{f_s}{n_s+f_s}\frac{1+\beta P_q^2}{3-\beta P_q^2} + \frac{n_s}{n_s+f_s}\frac{1+\beta P_s^2}{3-\beta P_s^2},$$

Taking in to account the fragmentation of different quark flavours; n and f are strange quark abundance

$$\rho_{00}(p_T) = \rho_{00}^0 + (\frac{1}{3} - \rho_{00}^0)\frac{2}{\pi}\tan^{-1}(\frac{p_T}{a_0}),$$

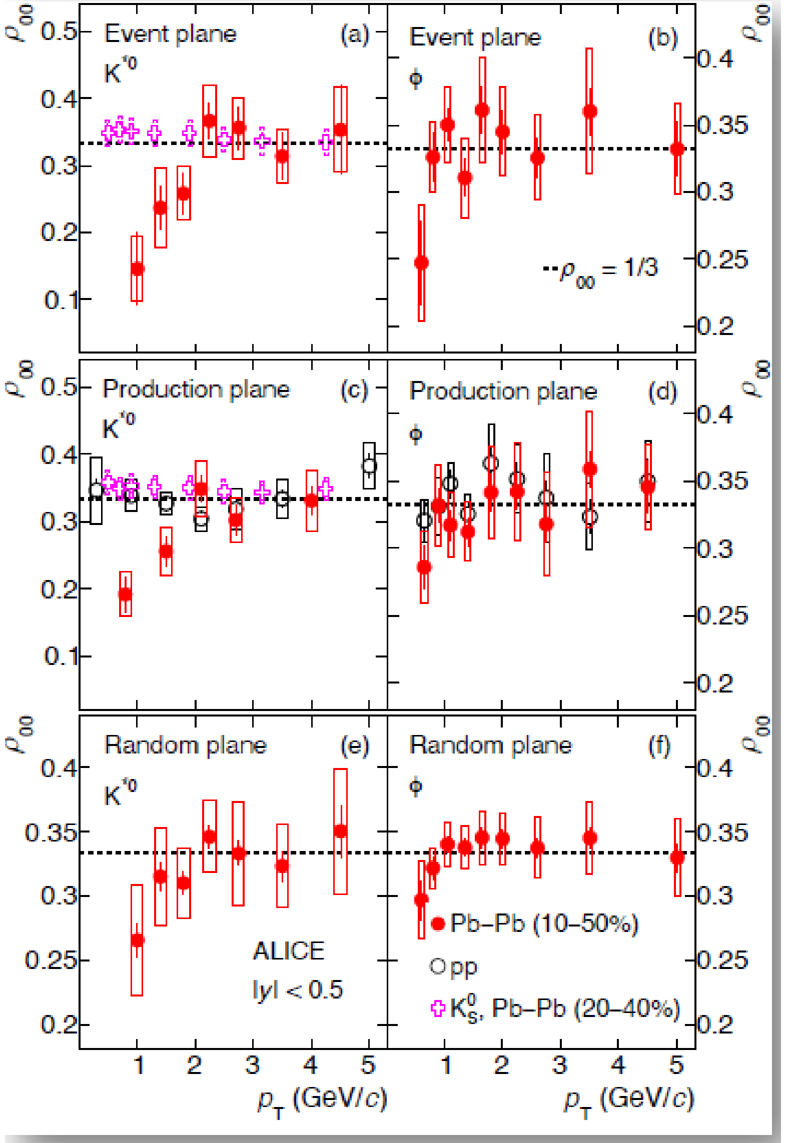
ρ_{00} at p_t = 0 and a_0 sec the scale for vanishing of spin alignment

$$v_2^\rho = \frac{0.22}{1.0 + e^{-(p_T/2.0-0.35)/0.2}} - 0.06.$$



Z. Liang et. al., Phys. Lett. B629, 20 (2005)

Polarisation measurements at high energies (Spin alignment of vector mesons)



Spin alignment for vector mesons (spin 1) in PbPb

arXiv:1910.14408 (ALICE)

Conclusions a proposal for the future

- Polarization is a good tool to study the structure and production mechanism of a given object
- Elementary quarkonium production suggests that there is a influence of vector meson width on the production mechanism (BESIII and HADES possibly CDF?)
- Results form higher energies suggest direct influence of E_{cm} on the anisotropy flip
- LHC already collected interesting data sets for pp and PbPb, how precise can we be how low with pt can we get ?
- A lot has been done in the sense of quarkonium production, BUT we can do more! (see next page)

What can we measure ?

Branching ratios (form PDG)

Resonance	ppbar	e^+e^-	$\Lambda\bar{\Lambda}$	D*Dbar*
j/psi	$1.2 * 10^{-3}$	6%	$1.9*10^{-3}$	X
Psi(2S)	$3*10^{-4}$	$8*10^{-3}$	$3.8*10^{-4}$	X
Psi(4040)	No info in PDG	$1*10^{-5}$	?	seen
Eta_c	$1.45*10^{-3}$	?	$1.07*10^{-3}$	X
X(3872)	Not seen	?	?	Lighter Ds

What abut Λ_c ? The decay modes of pKπ (6.3%) or Bπ (3 x 1.3%) are interesting candidates !

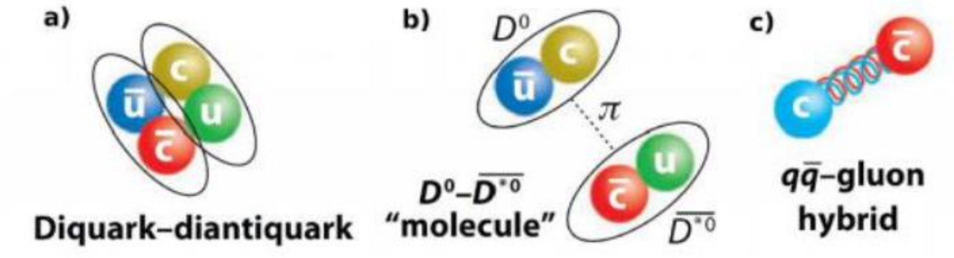


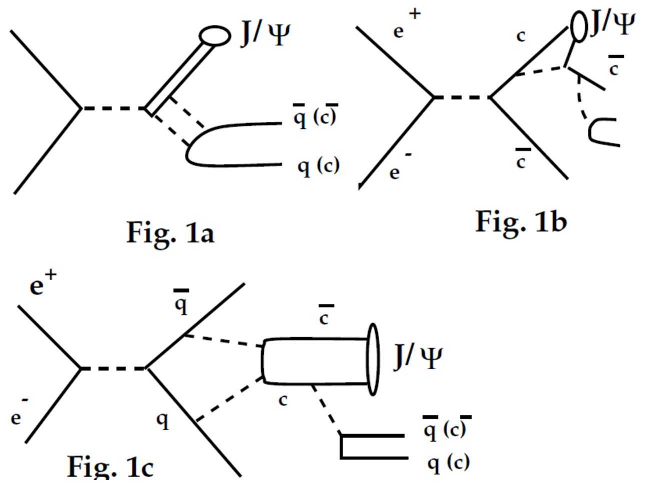
Fig 4.3 XYZ possible states: a) schematic of a tetra quark state, b) molecular $D\bar{D}$ sate and c) gluon hybrid state [60].

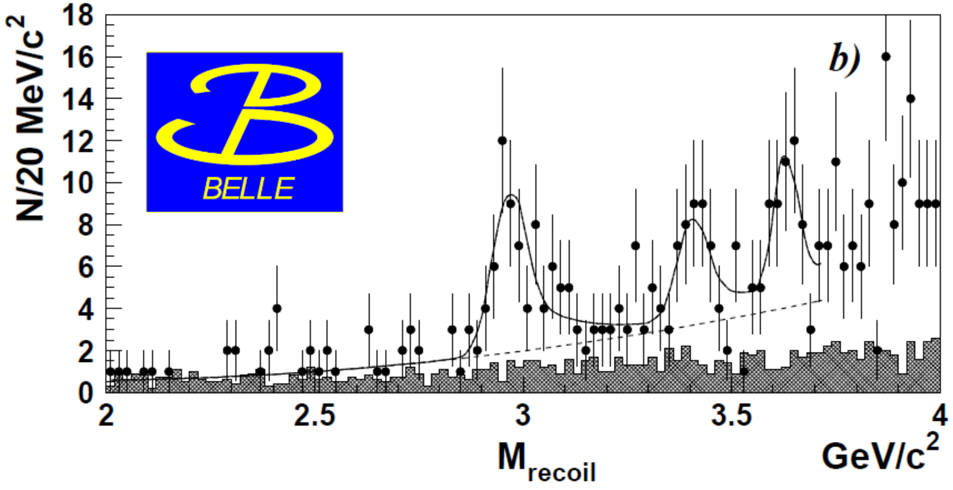
Backup

Charmonium production at higher energies in BaBar

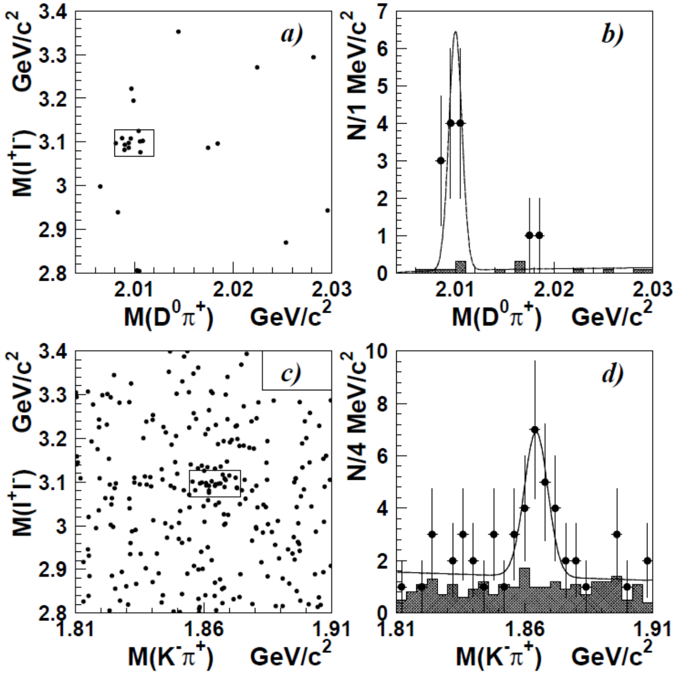
Phys.Part.Nucl.35:S98-S101,2004

- J/Ψ can be produced with an associated $\bar{c}c$ pair
- First type of production (a) considers a fusion of a $\bar{c}c$ pair the momentum conservation is assured by radiating gluons witch can produce a additional $\bar{c}c$
- Second type (b) assumes c quark fragmentation in to J/Ψ with the production of an additional gluon
- Third type (c) the virtual photon produces a pair of $\bar{c}c$ forming the J/Ψ via gluon exchange (suppressed channel by $\alpha(m_c)$)





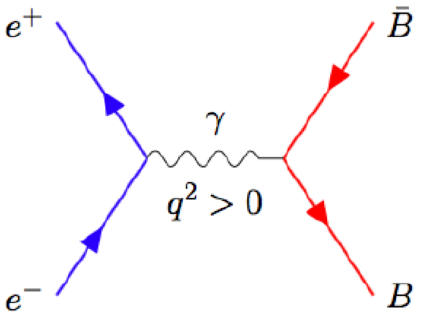
- Recoil mass measured at 10 GeV for e^+e^-
- η_c shape reproduced by MC simulation of $e^+e^- \to J/\psi\eta_c(\gamma)$
- $N_{\eta c\,(2S)} = 67(12)$ were found



Phys.Rev.Lett.89:142001,2002

Form Factors

- Electromagnetic form factors (EMFF`s) contain information abut hadron charge and current distributions.
- For J = ½ one can get 2 types such as: **G_E, G_M**



Assuming one photon exchange:
- neutral baryons

$$\sigma_{Born}(q^2) = \frac{4\pi\alpha^2\beta}{3q^2}\left[\left|G_M(q^2)\right|^2 + \frac{1}{2\tau}\left|G_E(q^2)\right|^2\right]$$

$$\alpha = \frac{1}{137} \qquad \beta = \sqrt{1-\frac{1}{\tau}} \qquad \tau = \frac{q^2}{4m_B^2}$$

Effective form factor →

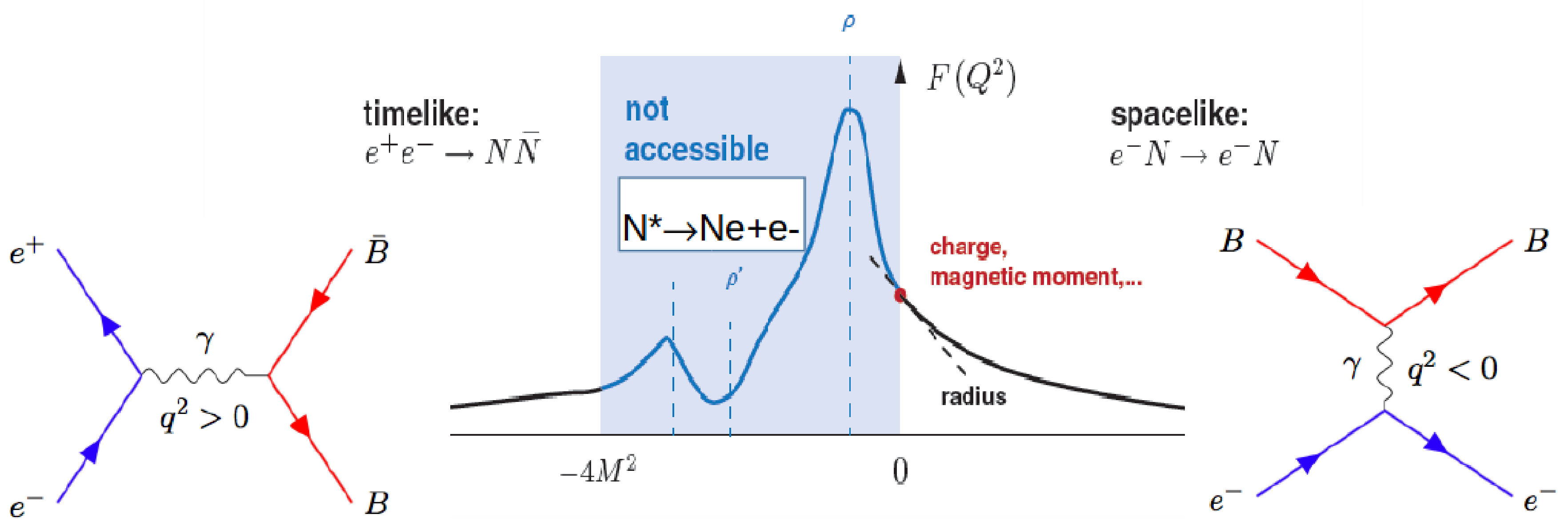
$$\left|G(q^2)\right|^2 = \frac{2\tau\left|G_M(q^2)\right|^2 + \left|G_E(q^2)\right|^2}{2\tau+1}$$

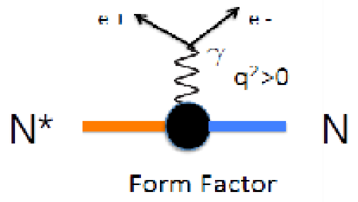
$$R = \frac{G_E}{G_M}$$

Electromagnetic form -factors

Form factors depend on $\mathbf{q^2}$ and can be probed in the space- like region (scattering experiments) and time-like region, by annihilation experiments (**focus of this talk**) and Dalitz decays

$Q^2 = -q^2$

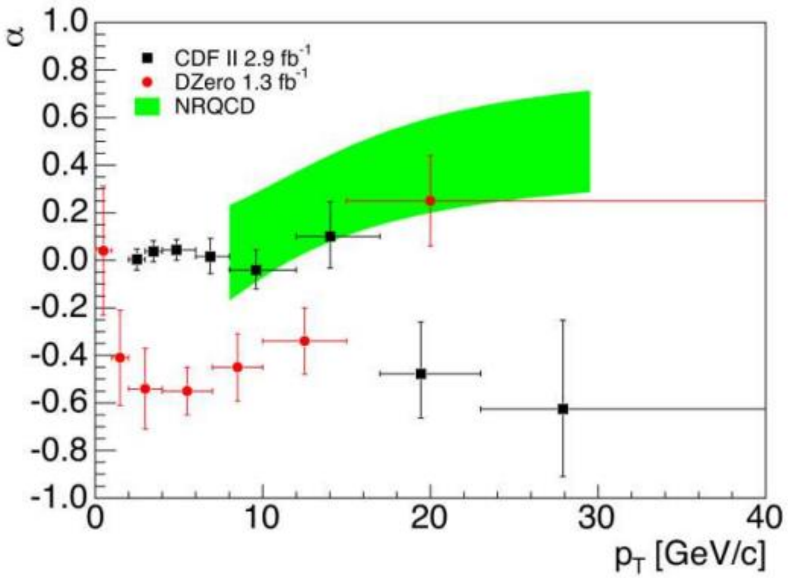




G. Eichmann **APhysPolSupp 7, 597** (2014)

L.G. LANDSBERG "Electromagnetic decays of light mesons" ***for* High Energy Physics, Serpukhov, U.S.S.R.**

$\bar{b}b$ production at CDF and D0

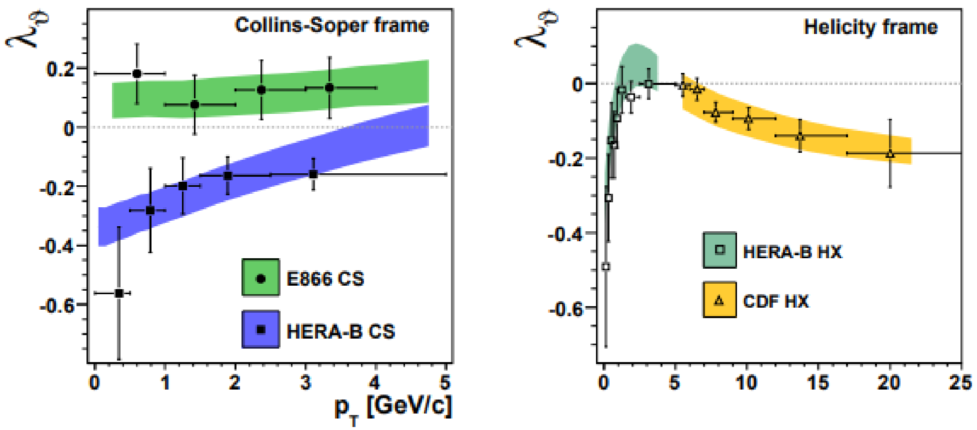


Phys. Rev. Lett., 88:161802, Apr 2002.

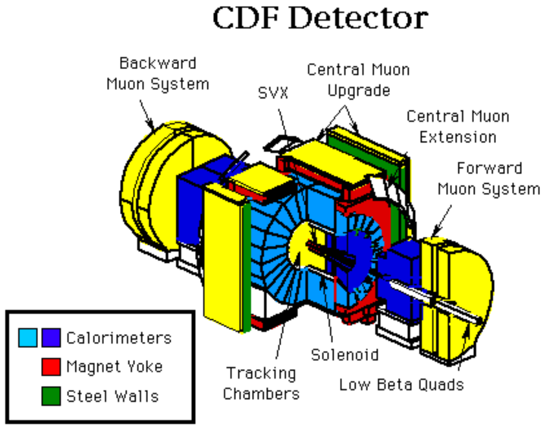
Phys. Rev. Lett., 101:182004, Oct 2008

Complex systems at TeV energy

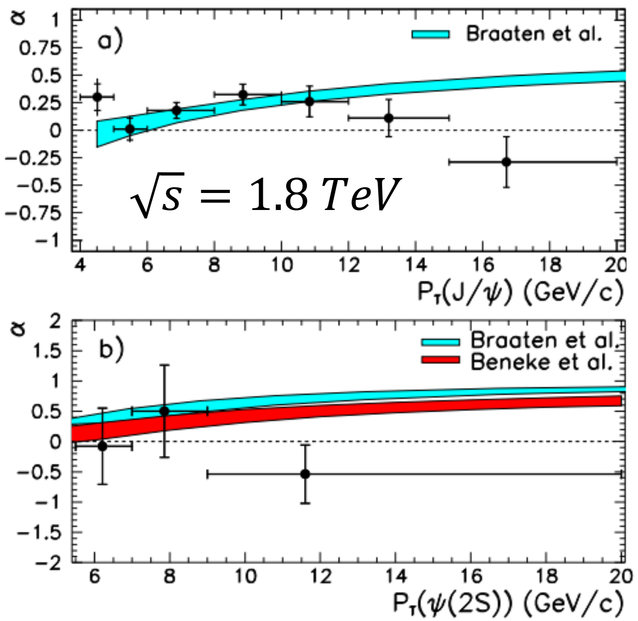
Phys.Rev.Lett. 102 (2009) 151802



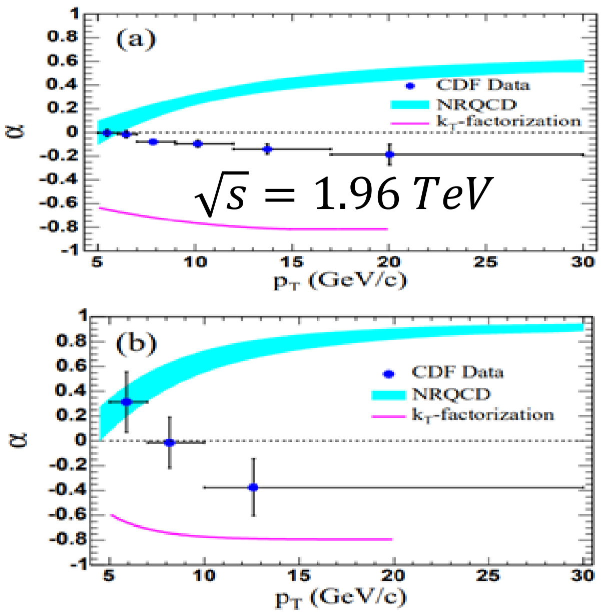
- CDF and HERA-B (~40 GeV p-W and p-C) results provide a interesting picture
- At low pt one can see very strong negative anisotropy



Phys. Rev. Lett., 85:2886–2891, Oct 2000.



Phys. Rev. Lett., 99:132001, Sep 2007.



- Similar patterns for bout data sets
- Strange anisotropy flip for low pt between two data sets ?
- Different trends for J/ψ and ψ (2S)