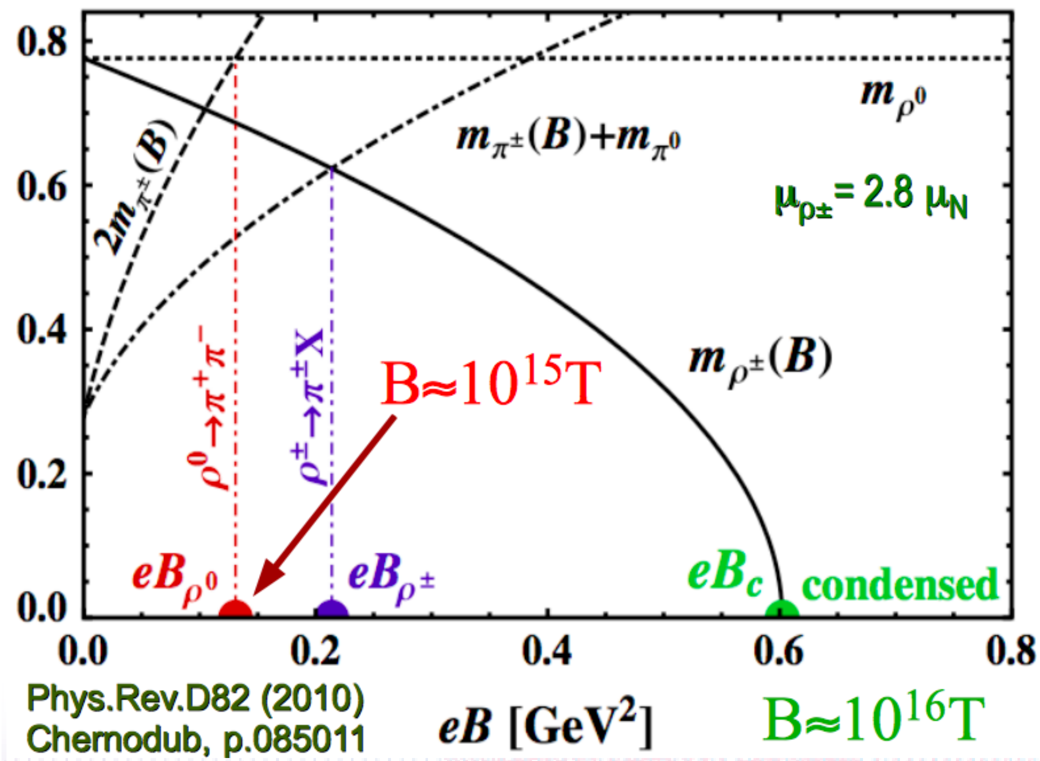
DECAY of RESONACES in Strong Magnetic Field

31^{st} WWND 2015 **P. Filip** Keystone, 29. January

Institute of Physics SAS, Bratislava

- $\rho \to \pi^+\pi^-$ [B]
- **K* → Kπ** decay [B]
- BR + isospin cons.
- $\Lambda^*(1520)$ in Au+Au/200GeV
- CP + P viol. $\eta \to \pi\pi$ [B]
- J/ψ ↔ η_c and Υ(ns) suppr.
- **Conclusions**

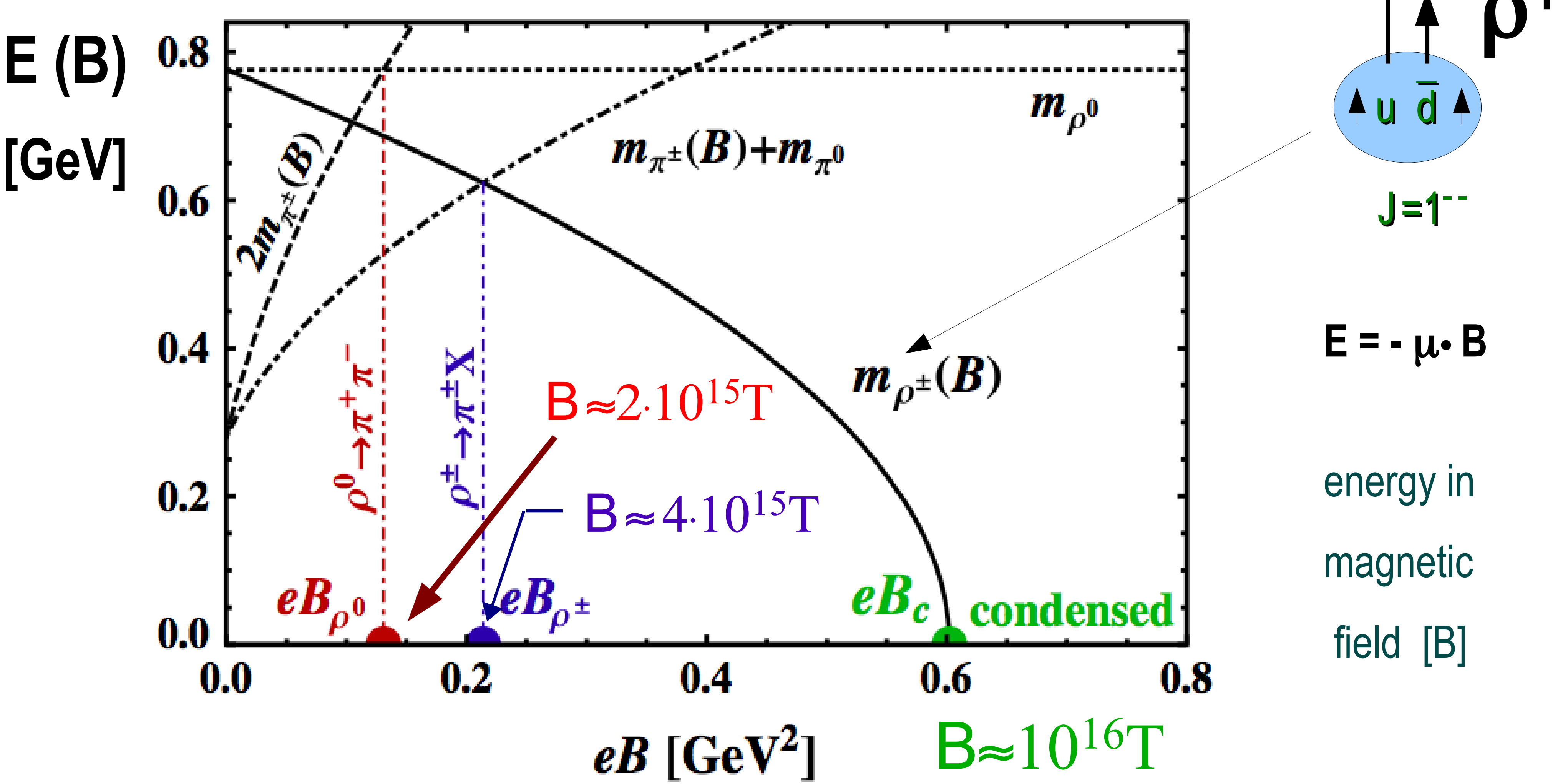


Phys.Rev.D82 (2010) Chernodub, p.085011

Predicted behavior for $\rho^{\pm 0}$ [B]

Chernodub: Physical Review D82 (2010) p.085011

Fig. 1



- $\rho^\pm$(770) and ρ^0 behave differently in external magnetic field

PHYSICAL REVIEW D **82**, 085011 (2010)

Superconductivity of QCD vacuum in strong magnetic field

M. N. Chernodub[1,2]

We show that in a sufficiently strong magnetic field the QCD vacuum may undergo a transition to a new phase where charged $\rho^{\pm}$ mesons are condensed.

Main idea: 1) $m^2_{\pi^\pm}(B_{\text{ext}}) = m^2_{\pi^\pm} + eB_{\text{ext}}$

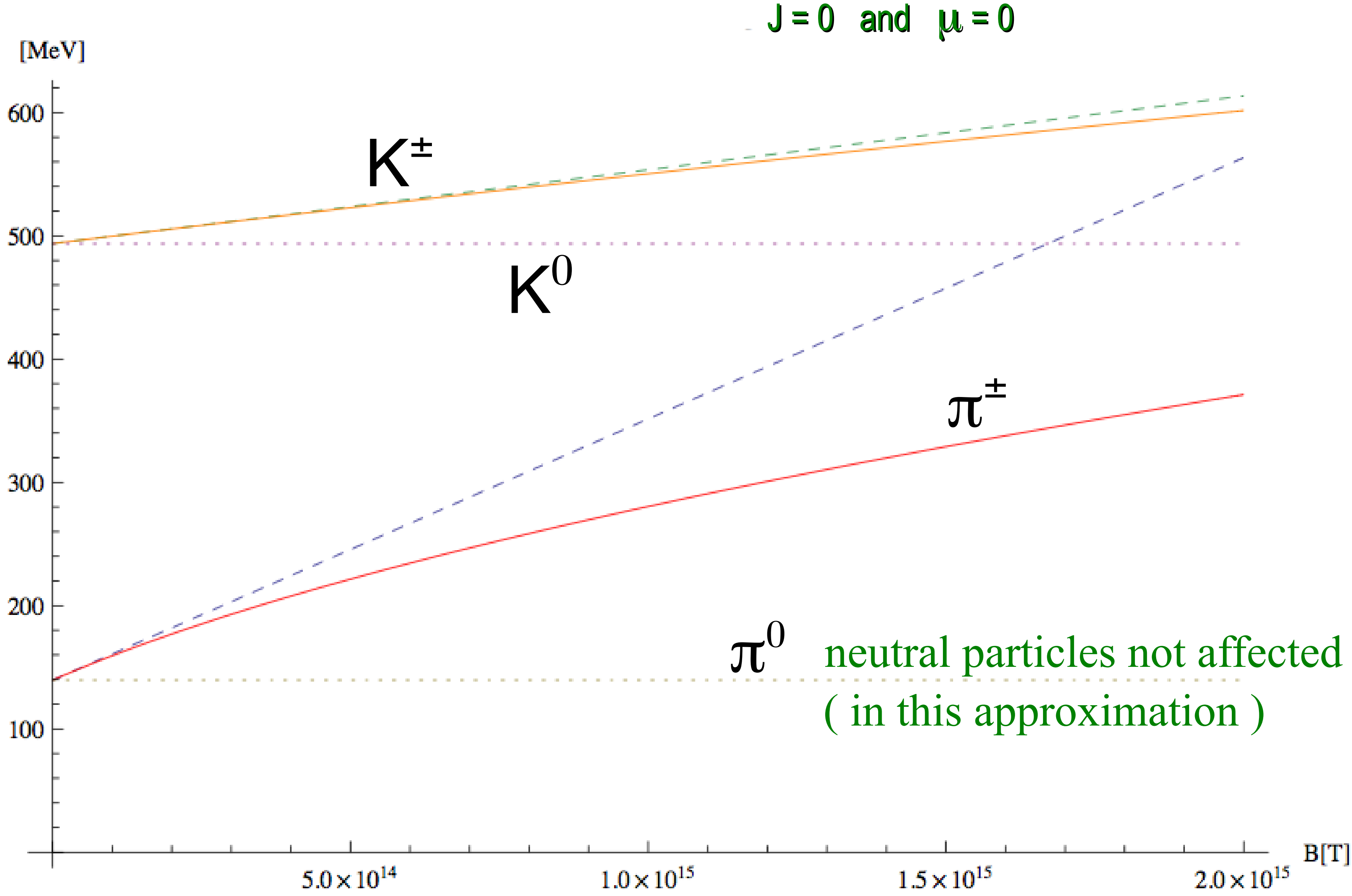
- Energy of n=0 Landau level of charged π± : $\Delta E_L = eB/2m$

2) for J > 0 particles: K*, D*, Λ*, ρ E = - μ·B

$$E[B] = \sqrt{m^2 + p_z^2 + eB(1 - 2s_z)}$$

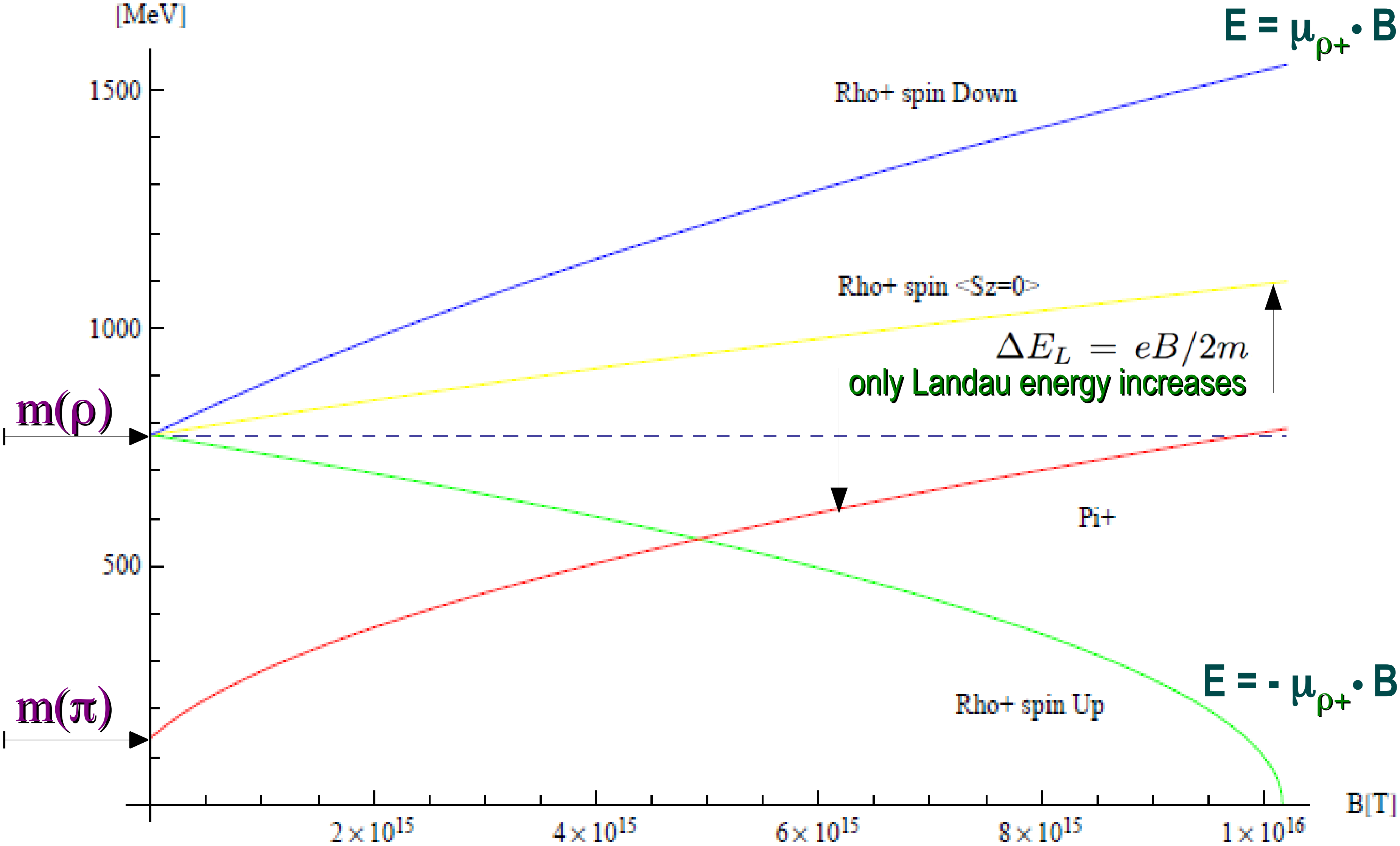
$$E[B] \approx m + (p_z^2 + eB)/2m - eBs_z/m$$

Landau energy of Kaon & Pion in [B]



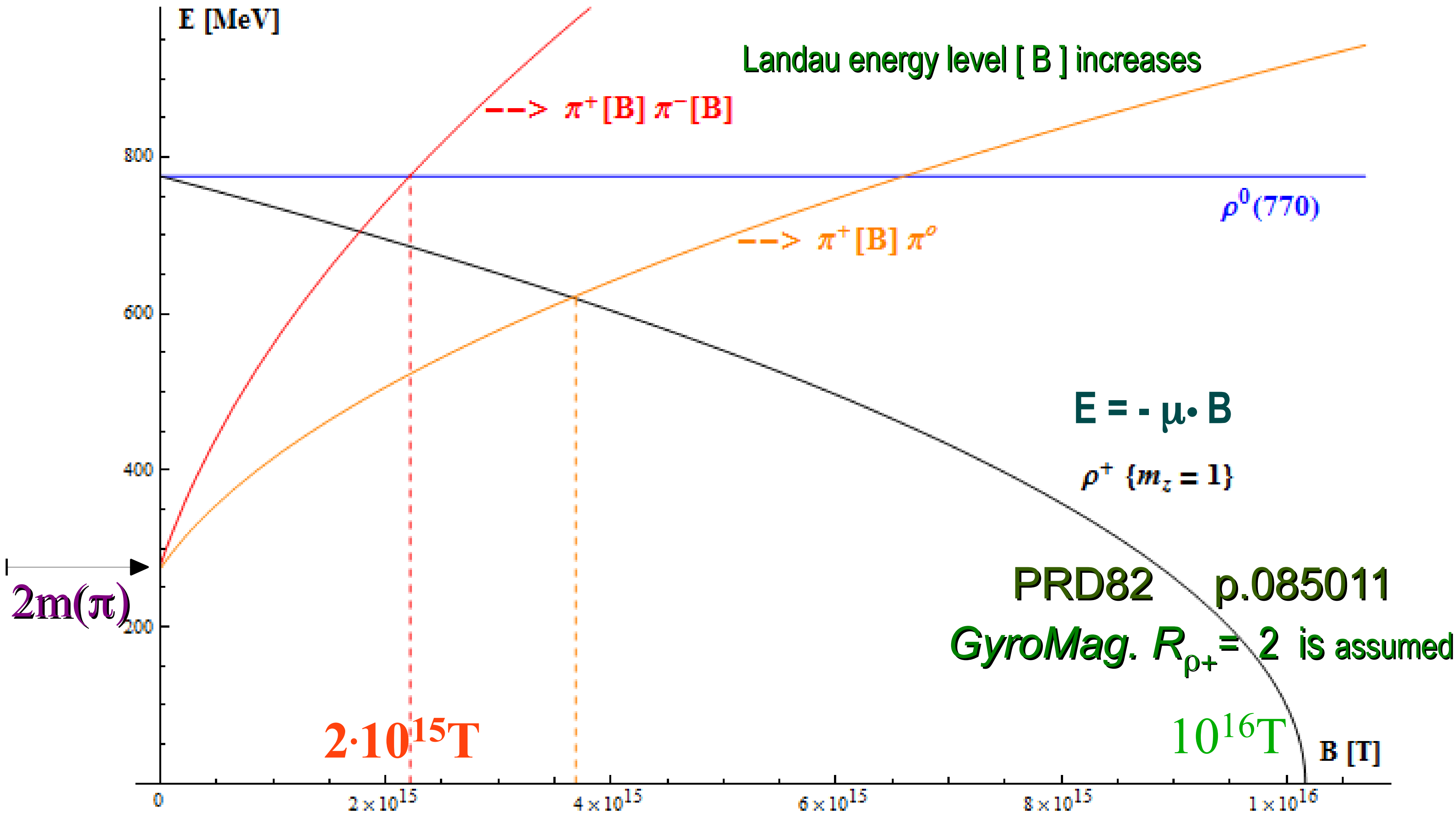
- $K^{\pm}$ energy increases less than $\pi^{\pm}$ due to mass: $M_K > M_\pi$.

$\rho^{\pm}$ meson Energy levels ($s_z = +1,0,-1$) in [B]



- **Energy of $\rho^{\pm}$(770) in [B] depends on spin projection +1, 0, -1**

ρ^0 and $\rho^{\pm}$ meson decay influenced by [B]



- **Energy of $\rho^{\pm}(770)$ [B] , mass($\pi^{\pm}$)** modified: $\rho \rightarrow \pi\pi$ influenced

Magnetic field effect on ρ^0 decay

$\rho(770)$ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\pi^+\pi^-$		$\sim$ 100 %		363
$\pi^0\pi^0$		→ 0 % • C – parity + isospin conservation		
		$\rho(770)^0$ decays		
$\pi^+\pi^-\gamma$		$(9.9 \pm 1.6) \times 10^{-3}$		362
$\pi^0\gamma$		$(6.0 \pm 0.8) \times 10^{-4}$		376
$\eta\gamma$		$(3.00 \pm 0.21) \times 10^{-4}$		194
$\pi^0\pi^0\gamma$		$(4.5 \pm 0.8) \times 10^{-5}$		363
$\mu^+\mu^-$	[k]	$(4.55 \pm 0.28) \times 10^{-5}$		373
e^+e^-	[k]	$(4.71 \pm 0.05) \times 10^{-5}$		388
$\pi^+\pi^-\pi^0$		$(1.01^{+0.54}_{-0.36} \pm 0.34) \times 10^{-4}$		323
$\pi^+\pi^-\pi^+\pi^-$		$(1.8 \pm 0.9) \times 10^{-5}$		251
$\pi^+\pi^-\pi^0\pi^0$		$< 4 \times 10^{-5}$	CL=90%	257

- $\rho^0 \Rightarrow \pi^+ + \pi^-$ phase space decreases in the Magnetic field.

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- $\rho^0 \Rightarrow \pi^+ + \pi^-$ phase space decreases → closed: $B > 2 \cdot 10^{15}$T

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dileptons

- $\rho^0 \Rightarrow \pi^+ + \pi^-$ phase space decreases $\rightarrow$ closed: $B=2 \cdot 10^{15}$T

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photons

- $\rho^0 \Rightarrow \pi^+ + \pi^-$ phase space decreases → closed: $B = 2 \cdot 10^{15}$T

Summary I

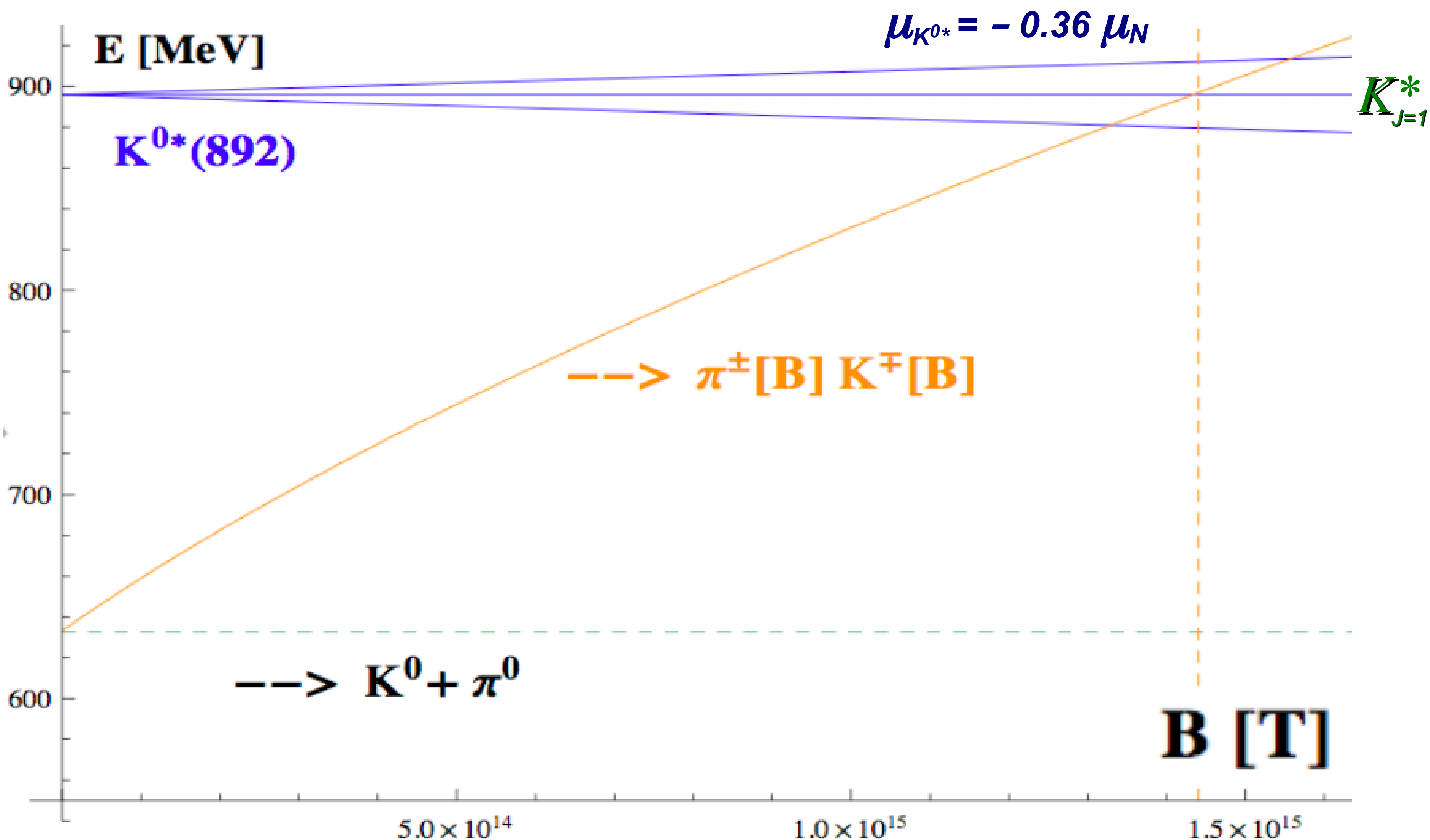
1) $\rho(770)$ decay is modified in B ~ 10^{15} T

- Phys.Rev.D82: $\rho \to \pi\pi$ (closed) in $B = [2 * 10^{15} \mathrm{T}]$
  (2010) p.085011 $\tau = 1.2$ fm/c

$\Rightarrow$ **excess of photons and dilepton pairs may be generated in HIC:**
if $\rho \to \pi^+\pi^-$ decay is closed for some reason

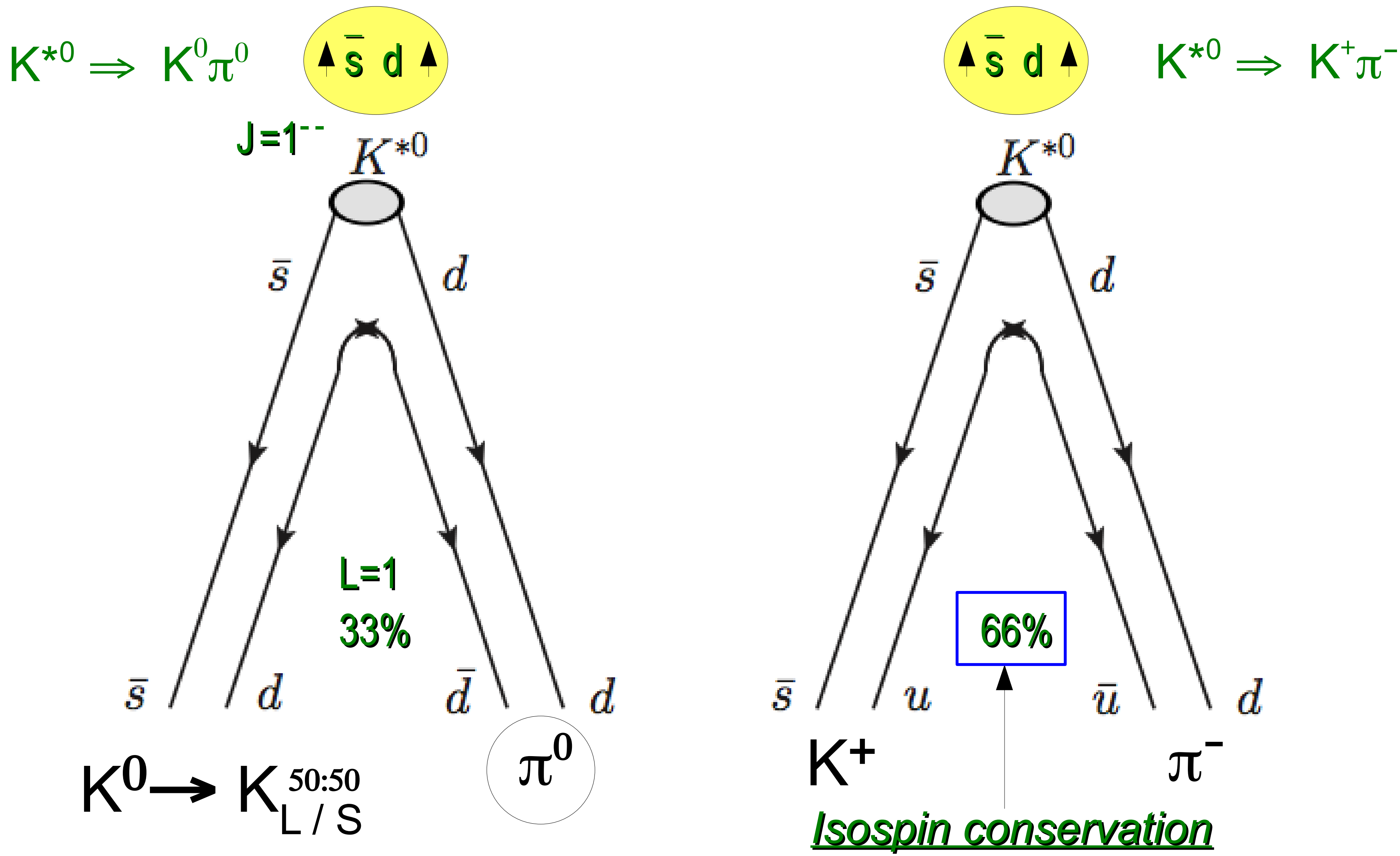
2) case of $K^{+*}, K^{0*} \to \pi^{\pm} + K^{0\pm}$ and $\Lambda^*(1520)$??

Magnetic field effect on K^{0*} decays



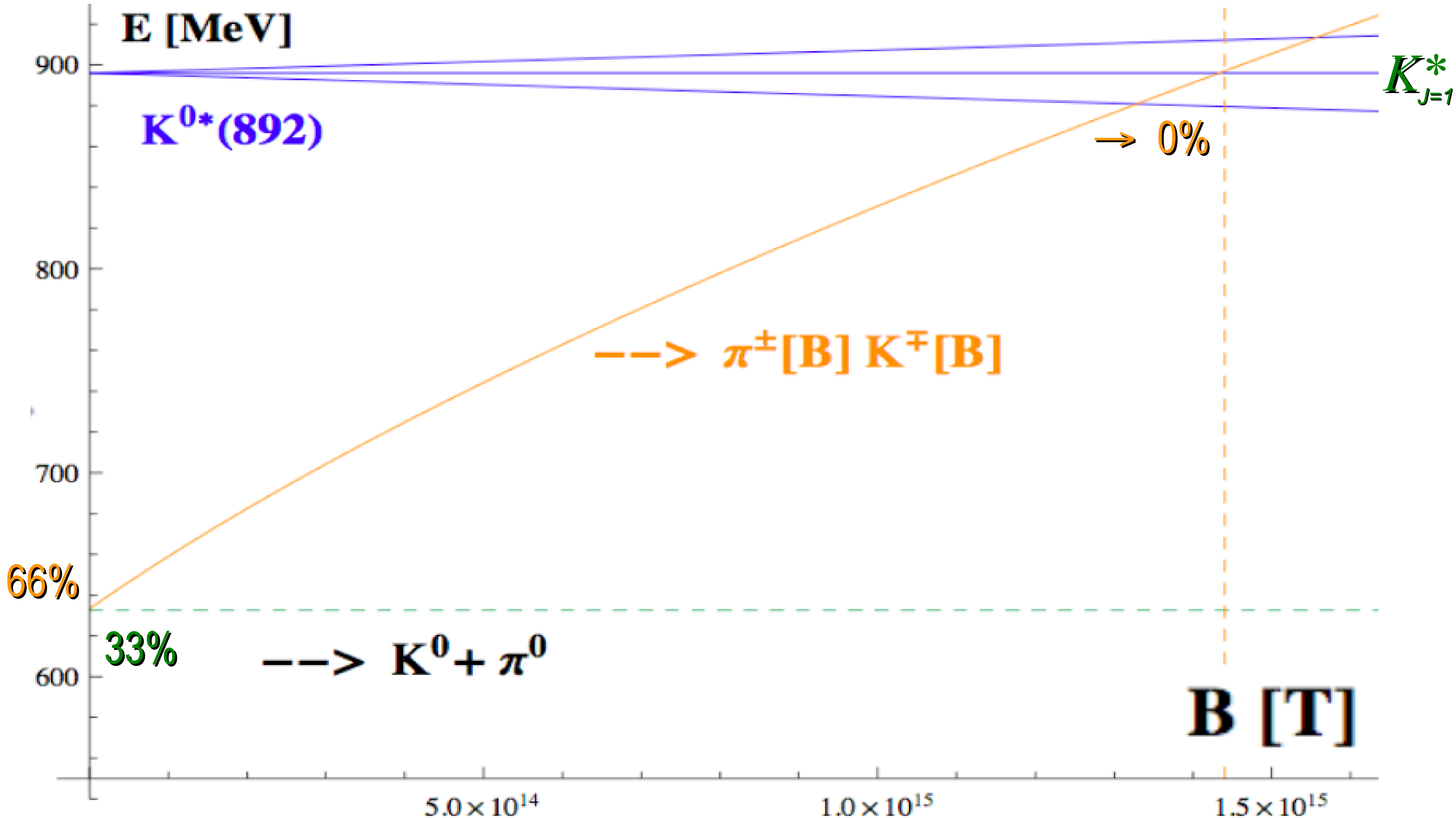
- $K^{0*} \Rightarrow \pi^{\pm}+K^{\pm}$ phase space decreases→closed: $B=1.5 \cdot 10^{15}$T

Strong decays of neutral K^{0*}



- Gluonic string breaking via $q\bar{q}$ (0^{++}) pair creation...

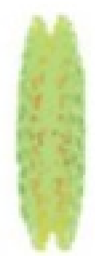
Isospin *violation*: K^{0*} decays [B]



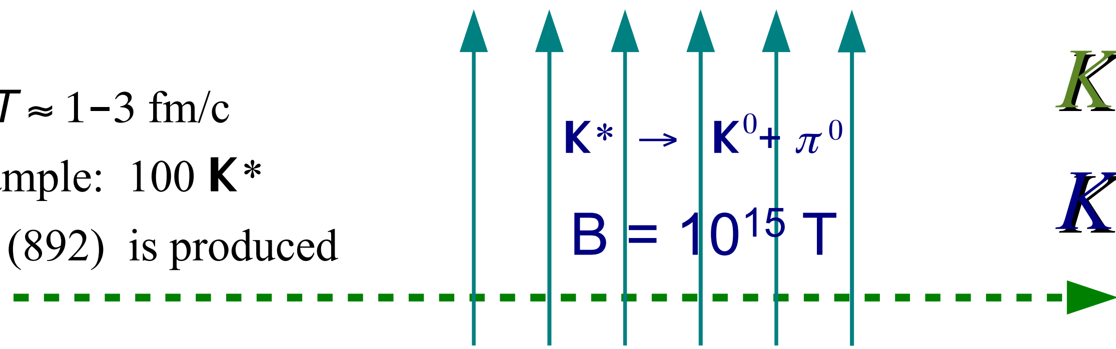
- due to phase space decrease $K^{0*} \Rightarrow \pi^{\pm}+K^{\pm}$ at $B \approx 10^{15}$ T

K^{0*} reconstructed Yield Depletion

1) K^{*0} "production" in Pb+Pb



at $T \approx$ 1−3 fm/c
example: 100 **K***
K* (892) is produced



$K^{*0} \rightarrow K^{\pm}\pi^{\pm}$ [66%]
$K^{*0} \rightarrow K^{0}\pi^{0}$ [33%]
in B=0

2) if $K^{*0} \rightarrow K^{\pm}\pi^{\pm}$ is [*B*] closed/suppressed

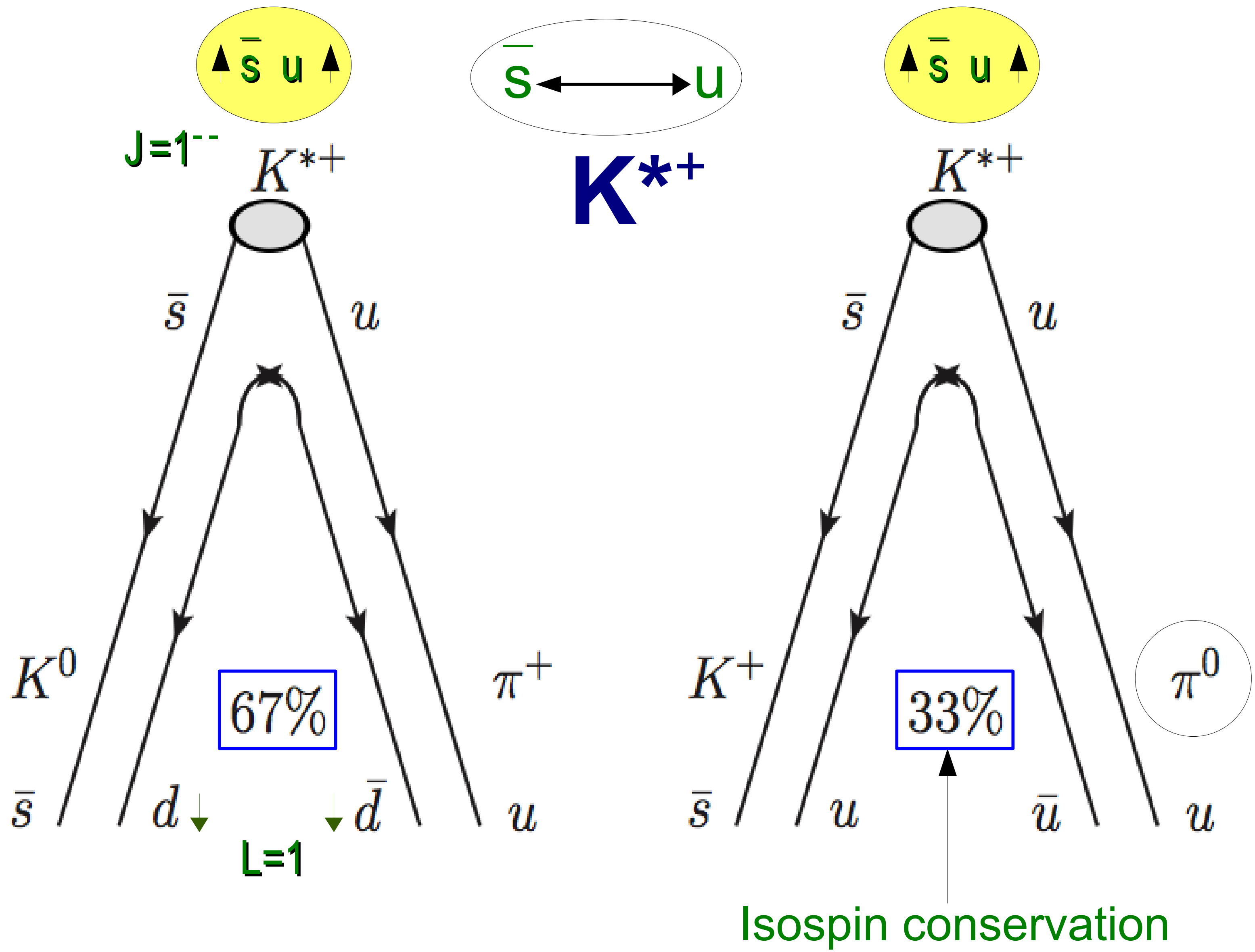
K^{*0}(892) still decays via $\rightarrow K^{0}+\pi^{0}$ [100%] $\tau \neq 4$ fm/c

$\Rightarrow$ in [B] field: changed branching ratio and Lifetime

3) Later, in *B=0* remaining $K^* \rightarrow K^{\pm}\pi^{\pm}$ *reconstructed*

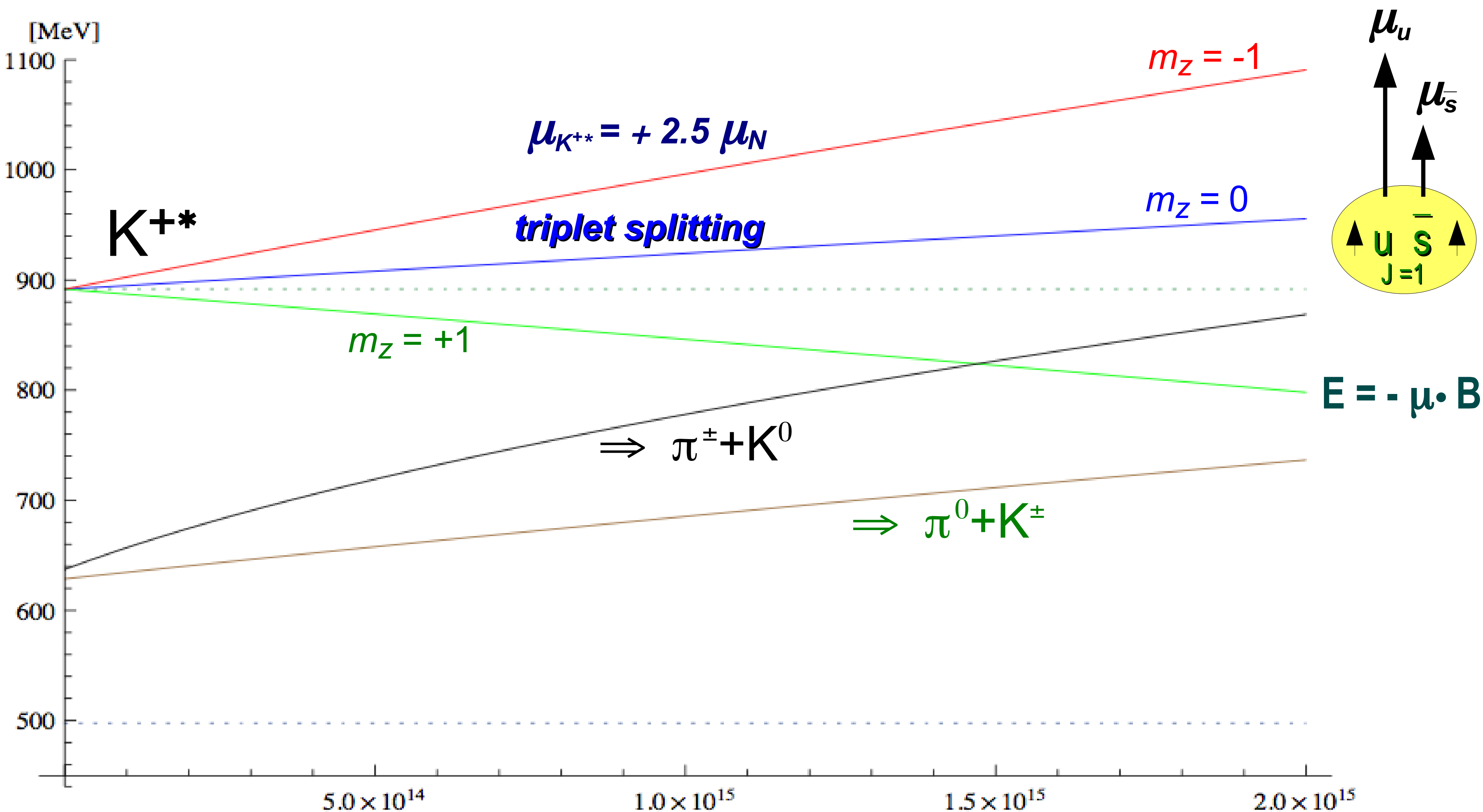
$\Rightarrow$ Yield is <u>underestimated</u>: assuming 66% for $K^* \rightarrow K^{\pm} + \pi^{\pm}$

Strong decays of charged $K^{\pm *}$



- Gluonic string breaking via $q\bar{q}$ (0^{++}) pair creation...

K^{+*} in strong Magnetic Field



- $K^{+*} \Rightarrow \pi^{\pm}+K^0$ $(\pi^0+K^{\pm})$ phase space → remains open @10^{15}T.

SUMMARY II

$\pi^0 + K^0$ unaffected, unobserved

1) $K^{0*}(896)$ $\tau \approx 4$ fm/c → $\pi^- + K^+$ is sensitive to [B]

BR can be different than assumed (isospin rule violated in [B])

→ reconstructed yield in HIC can be underestimated

$\pi^0 + K^{\pm}$ usually unobserved

2) $K^{+*}(892)$ $\tau \approx 4$ fm/c → $\pi^+ + K^0$ less sensitive [B]

⇒ different yields of $K^{0*}(d\bar{s})$ ↔ $K^{+*}(u\bar{s})$ in HIC ?

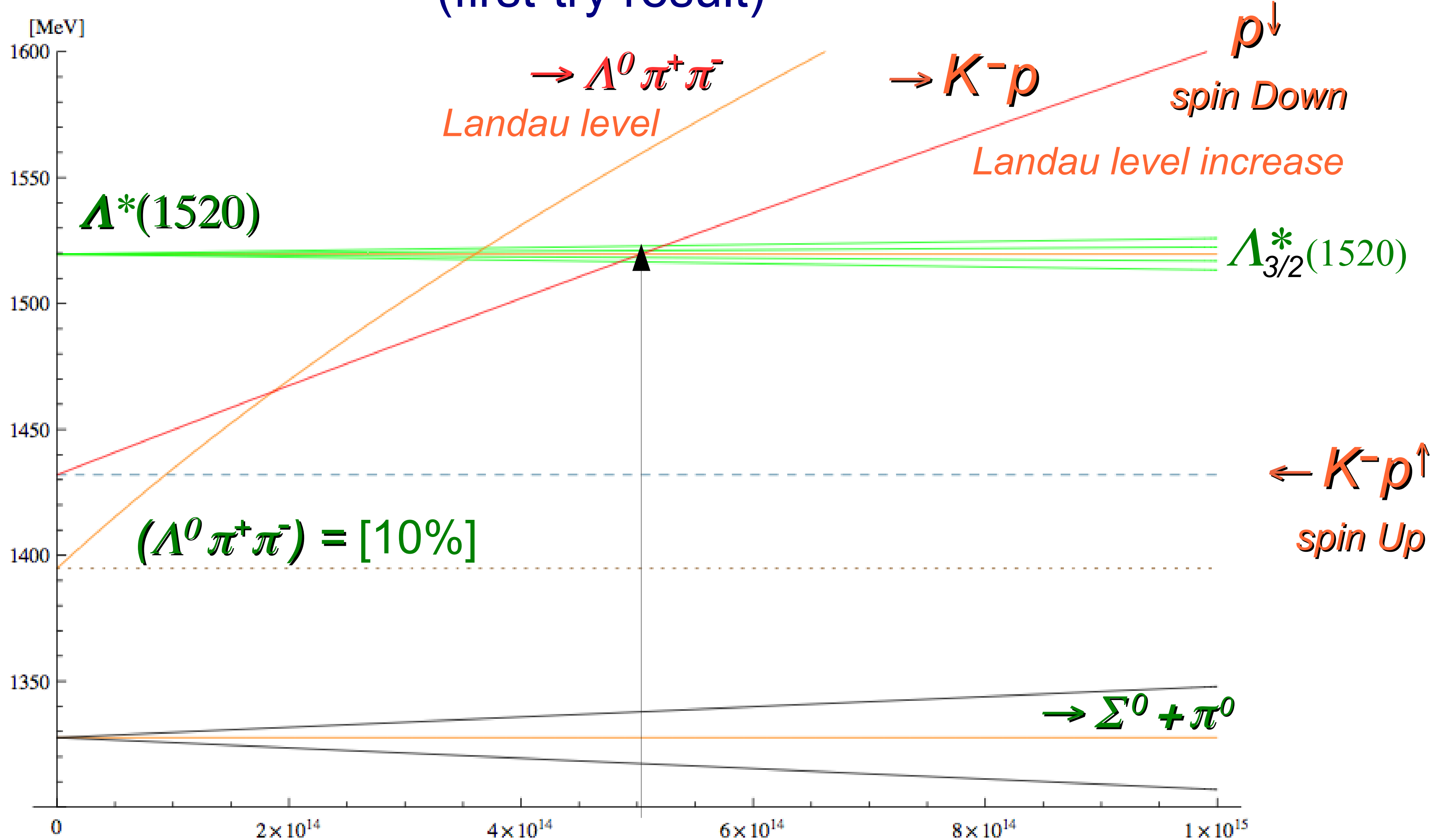
3) K^{+*} could be tensor-polarized in HIC

COMPARISON
Lifetime vs Critical Field

	Width [MeV]	Lifetime [fm/c]	B critical [10^{14} T]	Channel
ρ^o(770)	150	1.3	20	$\pi^+\pi^-$
Δ^o(1232)	117	1.7	5	$P^+\pi^-$
→ K^{o*}(896)	50	4	15	$K^{\pm}\pi^{\pm}$ ←
$K^{\pm*}$(892)	50	4	—	$K^0\pi^{\pm}$
→ Λ^*(1520)	16	13	5	P^+K^- ←
Ξ^{o*}(1532)	9	21	4	$\Xi^{\pm}\pi^{\pm}$
$D^{\pm*}$(2010)	0.1	2040	0.3	$D^o\pi^{\pm}$
D^{o*}(2007)	0.04*	4560*	1.5	$D^o\pi^o$

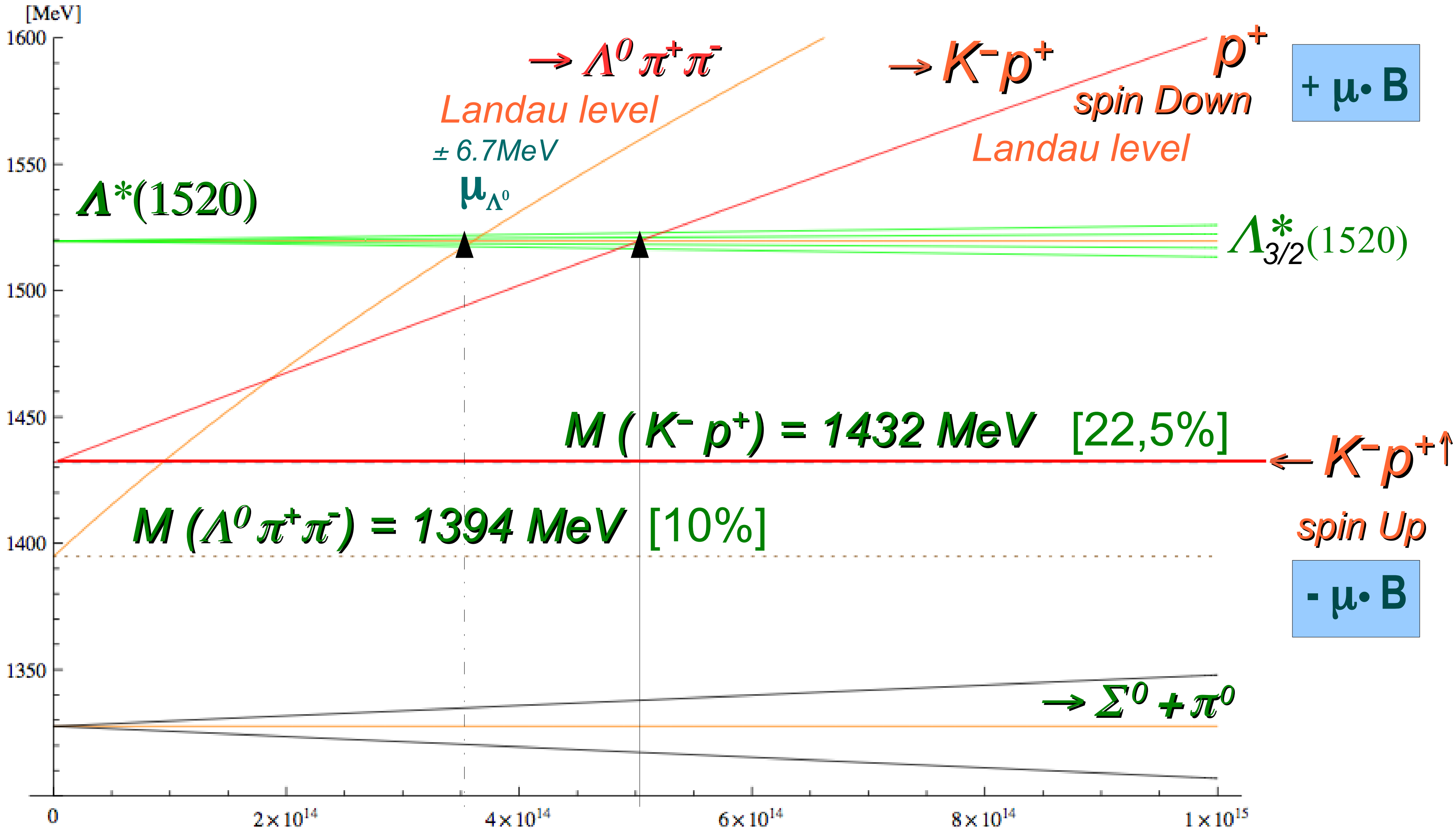
$\Lambda^*(1520)$ in static B < 10^{15} T

(first-try result)



50% decays $\Lambda^* \to K^- p^+$ **closed** at B=5·10^{14}[T]

$\Lambda^*(1520)$ in static B < 10^{15} T



50% decays $\Lambda^* \to K^-p^+$ **closed** at $B=5\cdot 10^{14}$[T]

Au+Au at RHIC 200GeV/n

Quark Matter 2004

$\Lambda^*(1520) \rightarrow K^- + Proton$

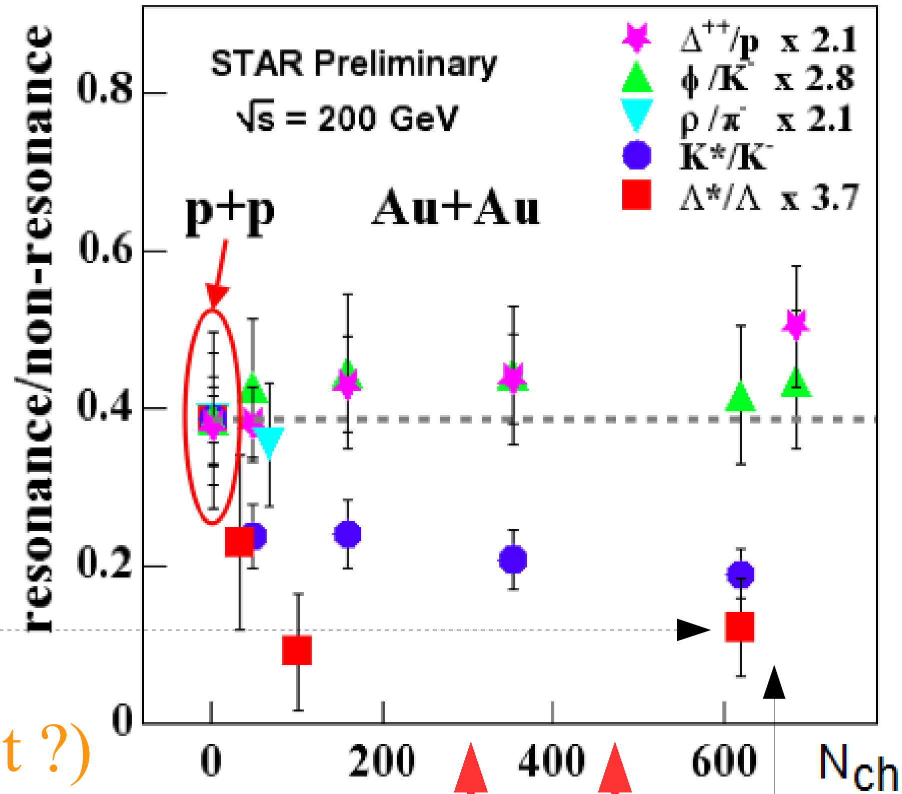
observed in peripheral Au+Au

(yield decreases with centrality ?)

disappears in non-central

seen again: “central” Au+Au

(statistics, B-field or other effect ?)



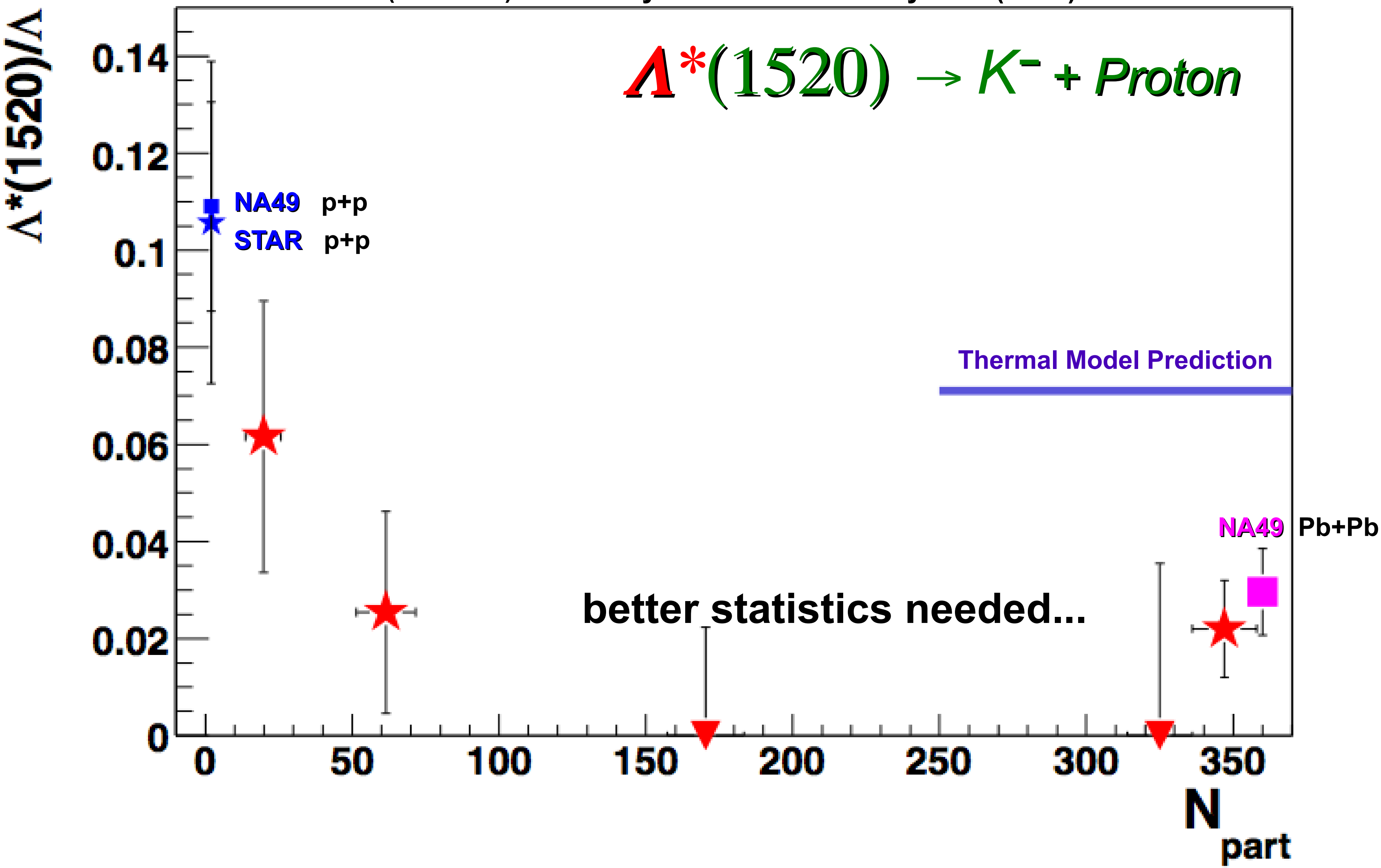
Note: Magnetic field [B]

a) is maximal for non-central collisions

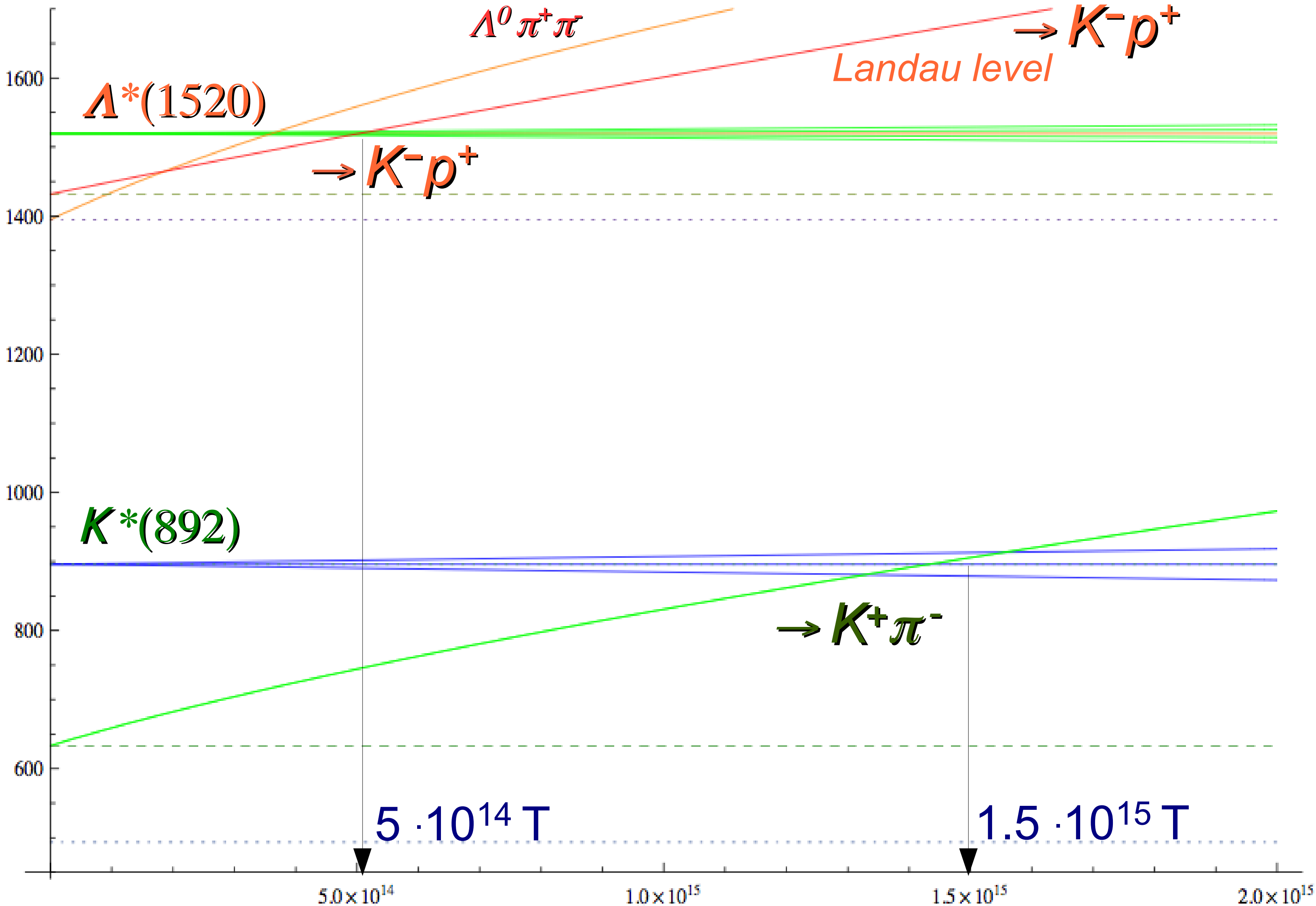
b) QGP medium keeps B field up to 5 fm/c

Λ*(1520) at RHIC and SPS

L Gaudichet (for STAR) Jour. Phys. G Nucl. Part. Phys. 30 (2004) S549-S555.



K*(892), Λ*(1520) in B=10^{15}T



$K^*\rightarrow K^+\pi^-$ **affected** in Pb+Pb/LHC, $\Lambda^*\rightarrow K^-p^+$ *in* Au+Au?

SUMMARY III

1) K^{0*}, Λ^* affected by Magnetic Fields

⇒ reconstructed K^0* yields may be underestimated
$K^{\pm}*$ and K^0* yields may differ more than expected

⇒ missing $\Lambda*$ peak in non-central Au+Au @ RHIC
to be clarified → Au+Au data available
waiting for LHC data → Pb+Pb, p+Pb

2) D^* and J/ψ ? *too long lifetimes: >1000fm/c*

COMPARISON
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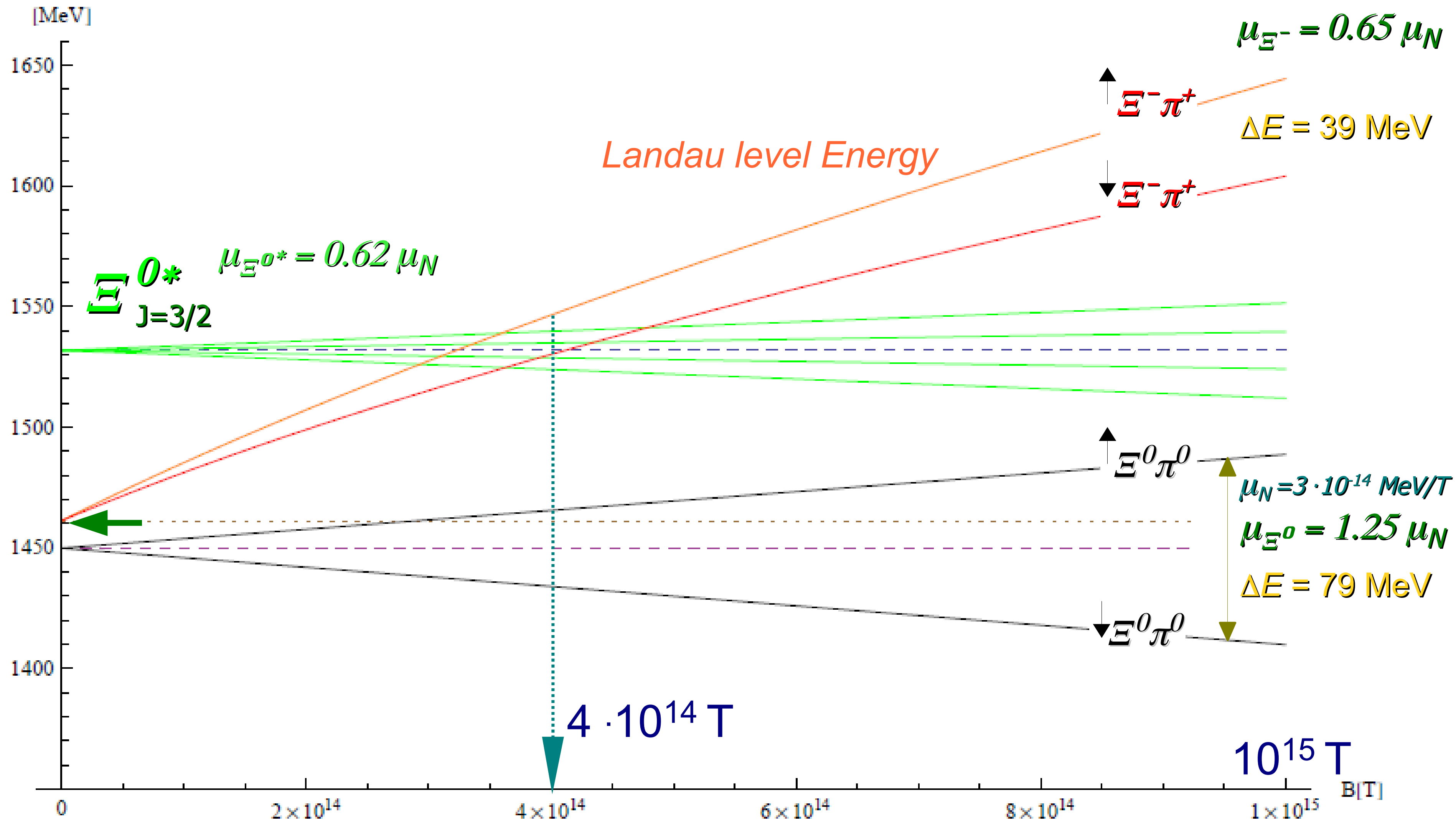
Ξ^{0*} baryon in field $B \to 10^{15}$T



$\Xi^{*0} \to \Xi^-\pi^+\ (66\%)$ → **0 %**

99% ← $\Xi^{*0} \to \Xi^0\pi^0$

Ξ^{0*} baryon ($s^{\uparrow}s^{\uparrow}u^{\uparrow}$) decays

$\Xi^{*0} \to \Xi^- \pi^+$ (66%) $\Xi^{*0} \to \Xi^0 \pi^0$ (33%)

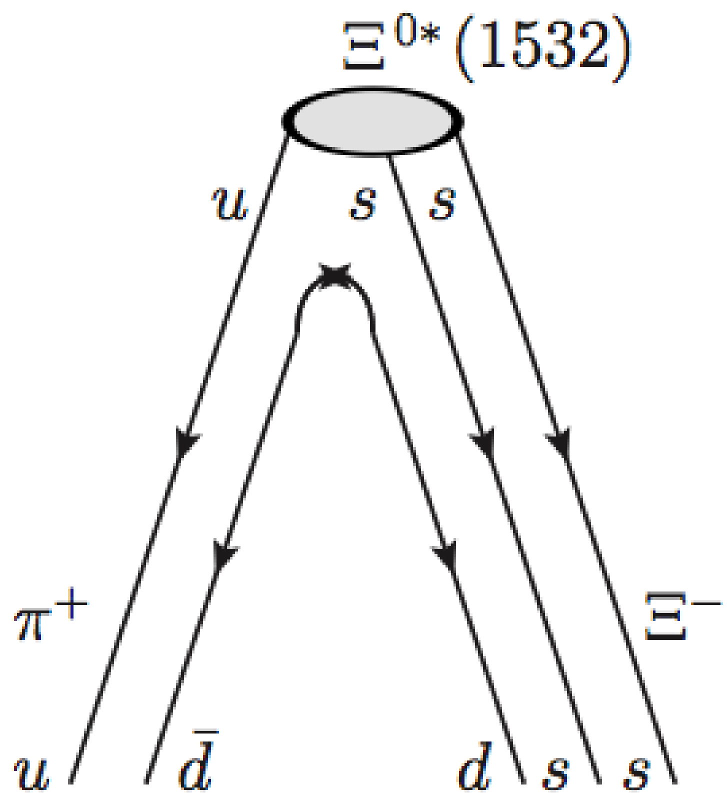
Radiative decay ~ 1%
(assumed here)

isospin conservation

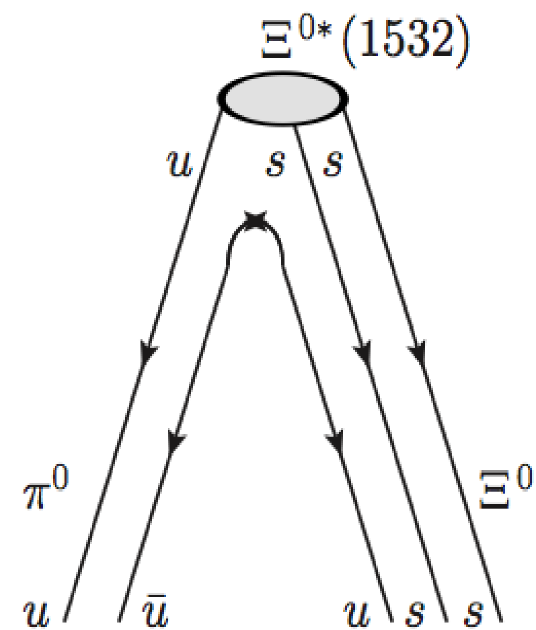
$$\Xi^{*0}_{|\frac{1}{2},\frac{1}{2}\rangle} \to \sqrt{\frac{2}{3}}\,\Xi^-_{|\frac{1}{2},-\frac{1}{2}\rangle}\pi^+_{|1,+1\rangle} - \sqrt{\frac{1}{3}}\,\Xi^0_{|\frac{1}{2},-\frac{1}{2}\rangle}\pi^0_{|1,0\rangle}$$

Clebsch-Gordan coefficients

66%



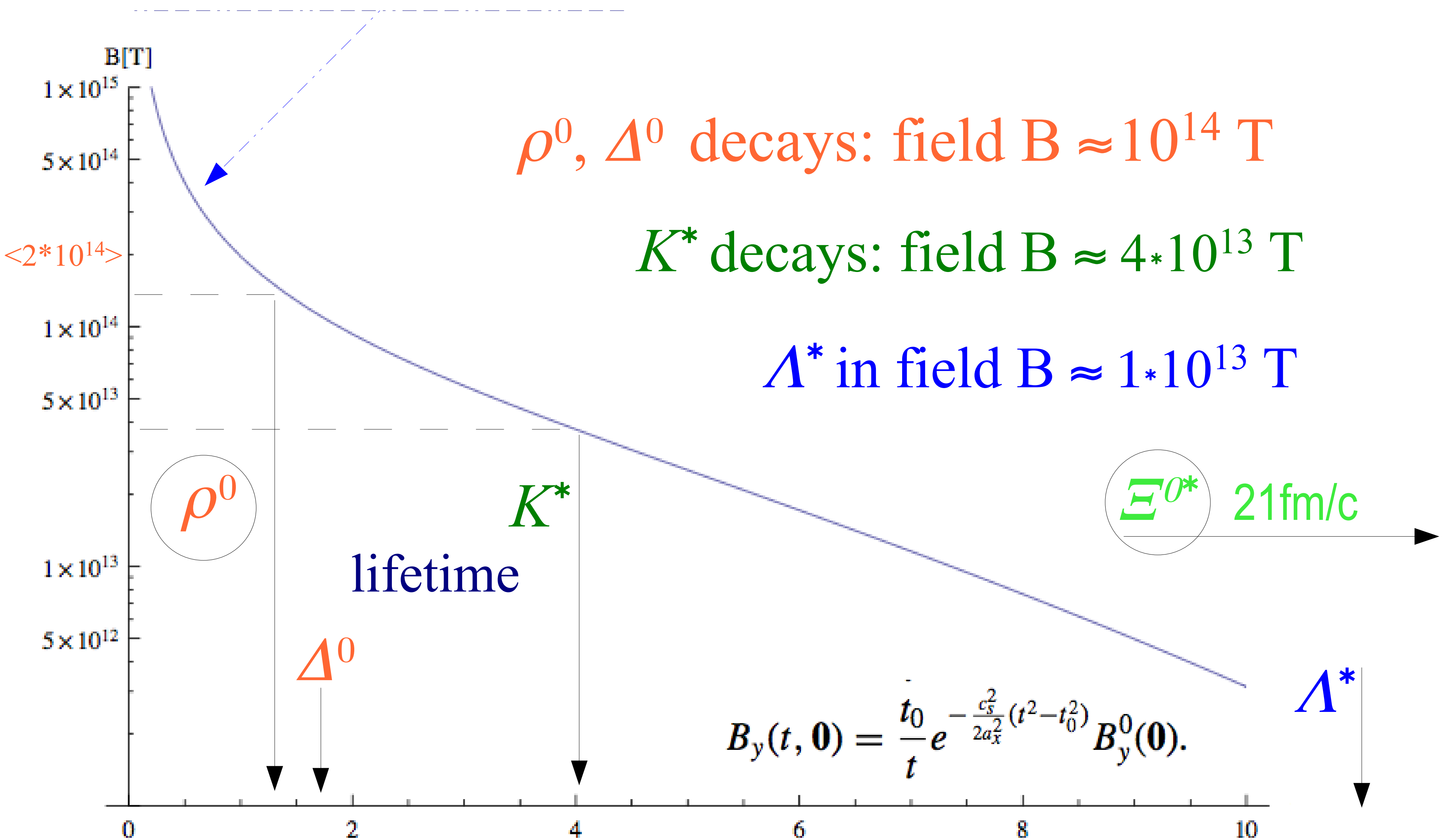
33%



in magnetic field $B = 4 \cdot 10^{14}$ T $\Rightarrow$ isospin violation

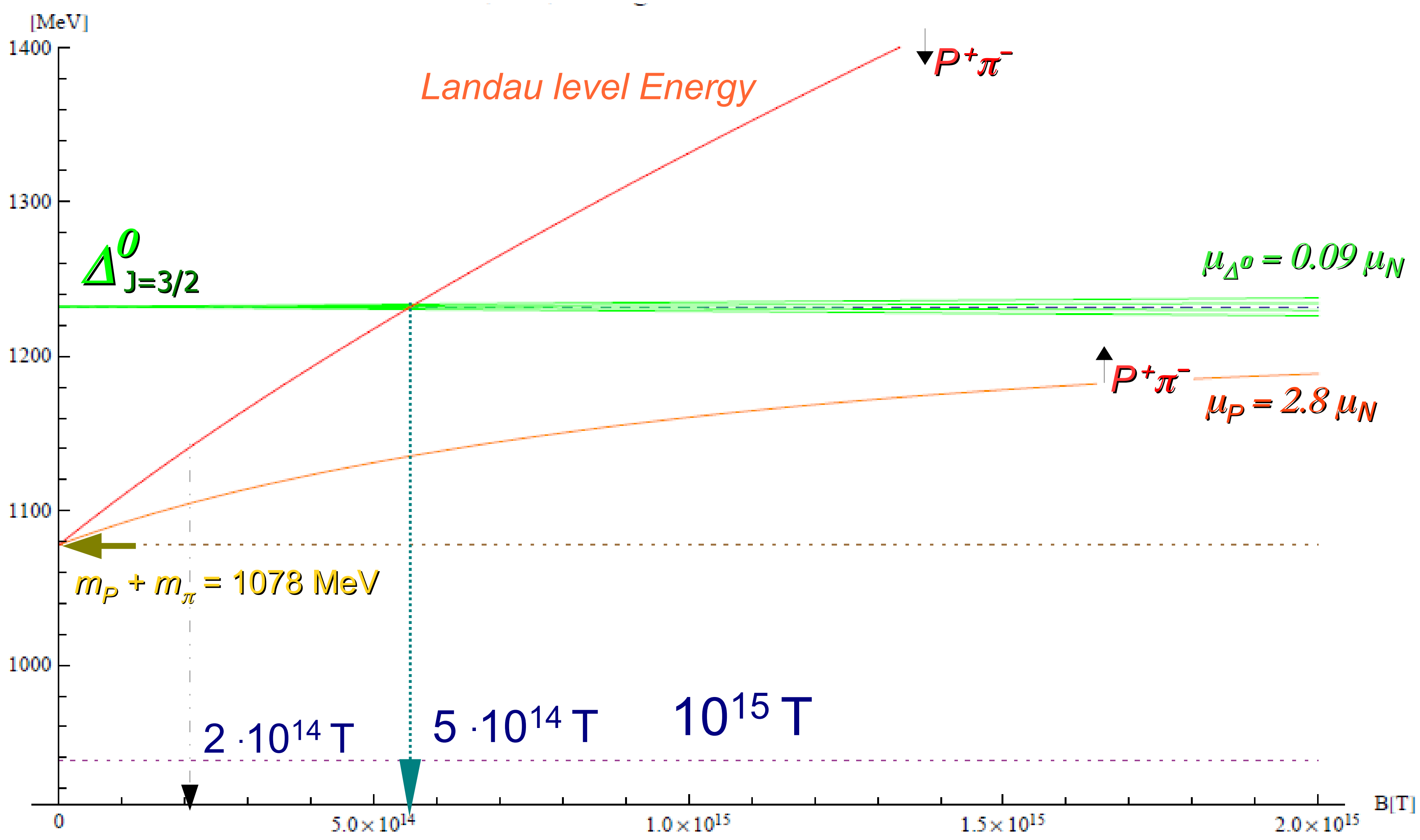
B field evolution and ρ^0, Δ^0, K^*, Λ^* decays

PRC85 (2012) 044907, for Pb+Pb at **LHC**



If QGP keeps B(t) and resonances are created at t=0.

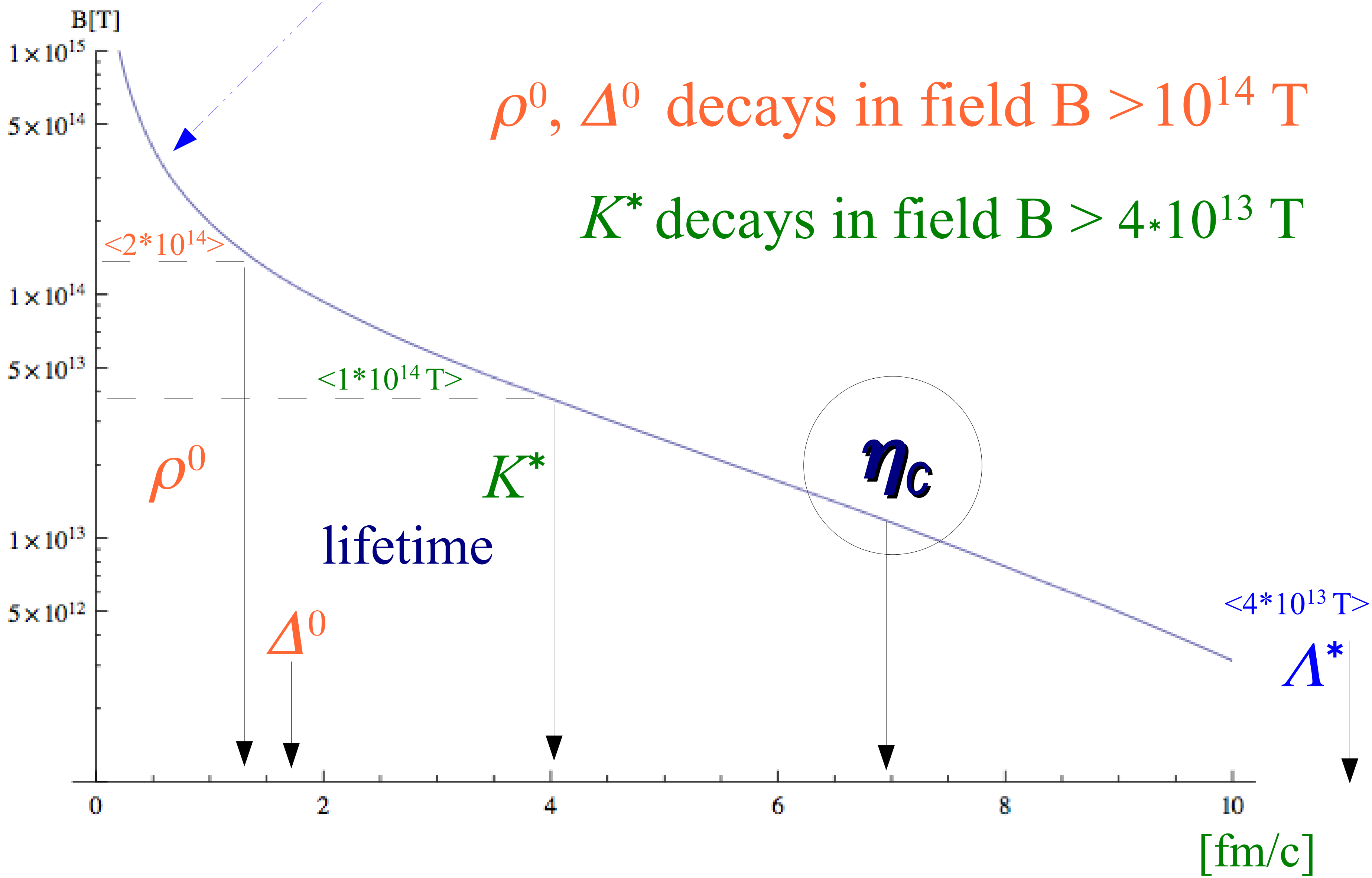
Δ^0 baryon in field $B \to 10^{15}$T



$\Delta^0 \to \pi^- p^+$ width **affected** at $B > 2{\cdot}10^{14}$T (50% closed at $5{\cdot}10^{14}$ T)

B field evolution and ρ^0, Δ^0, K^*, Λ^* decays

PRC85 (2012) 044907, for Pb+Pb at LHC

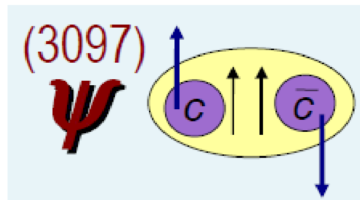


Quarkonium ⇔ Leptonium

J/ψ   ϒ(9460)   φ(1020) e^+e^- , $\mu^+\mu^-$, $\tau^+\tau^-$ HPS JLab 2015

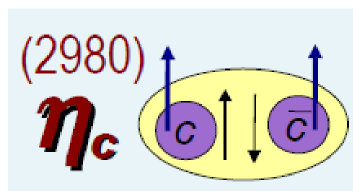
$(c\bar{c})$ $(b\bar{b})$

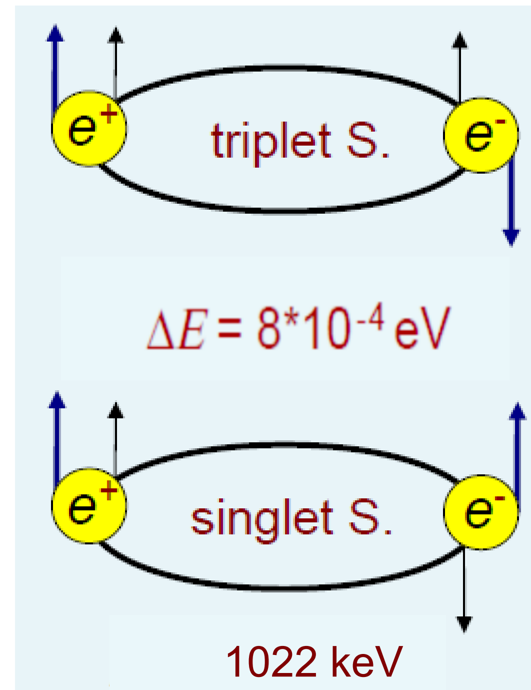
ortho-($c\bar{c}$) = J/ψ
($J^{PC}=1^{--}$)



ΔE =117 MeV

para-($c\bar{c}$) = η_c
($J^{PC}=0^{-+}$)





142ns

0.12ns

Decay: $J/\psi \rightarrow 3g, \gamma gg$ $\eta_c \rightarrow gg, \gamma\gamma$

- lifetimes: **2100fm/c** (J=1) and **7fm/c** (J=0)

States of Quarkonium

ϒ and **J/ψ**

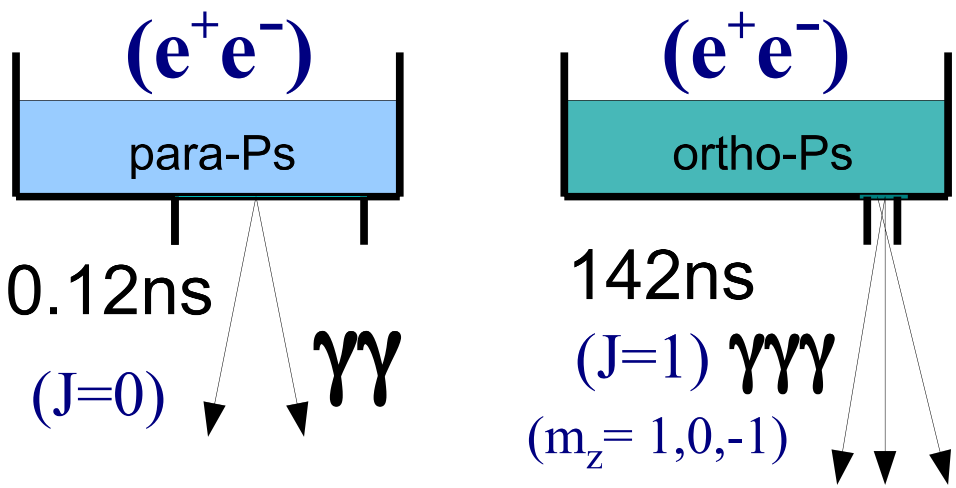
correspond to Positronium

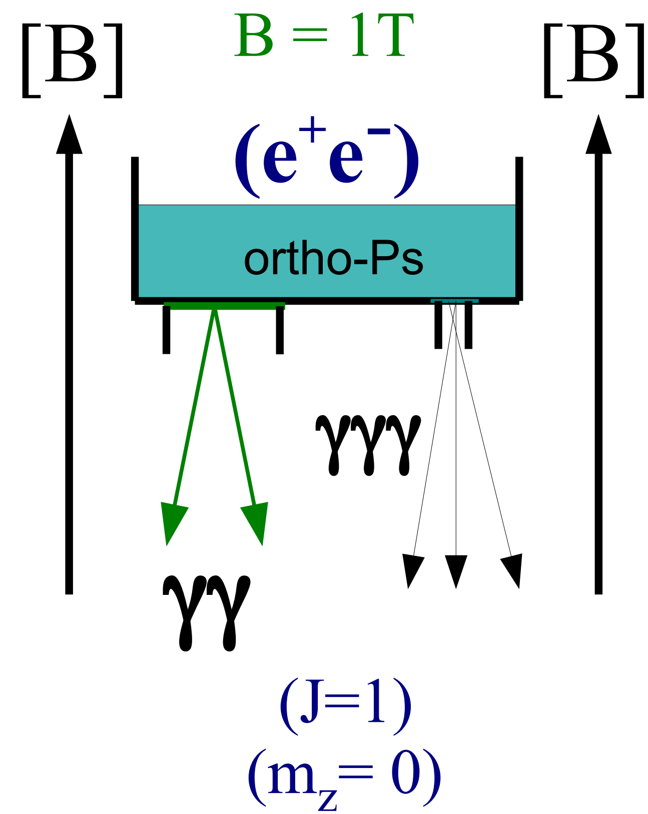
What happens in [B] ?

PHYSICAL REVIEW VOLUME 98, NUMBER 6 JUNE 15, 1955

Static Magnetic Field Quenching of the Orthopositronium Decay

V. W. Hughes, S. Marder, and C. S. Wu
Columbia University, New York, New York





In the presence of a magnetic field the $M=\pm1$ magnetic substates of orthopositronium are still pure ortho-states, and will decay by the three quantum annihilation characteristic of orthopositronium decay. On the other hand, the $M=0$ state of orthopositronium has a small admixture of para-state due to the interaction with the magnetic field, and hence can decay either by three-quantum annihilation or by two-quantum annihilation. The relative probabilities of these two modes of decay depend of course, on the

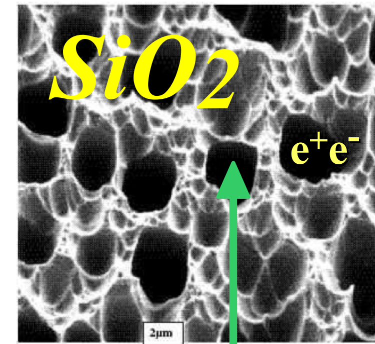
$$X = 2|\mu_e|B/\Delta E_{hf}$$

- Max. ≈ 33% decays γγγ affected.

Main parameter

Positronium (e^+e^-) discovered: 1951@MIT

ortho-Ps → γγγ (10^{-7}s) para-Ps → γγ (10^{-10}s)

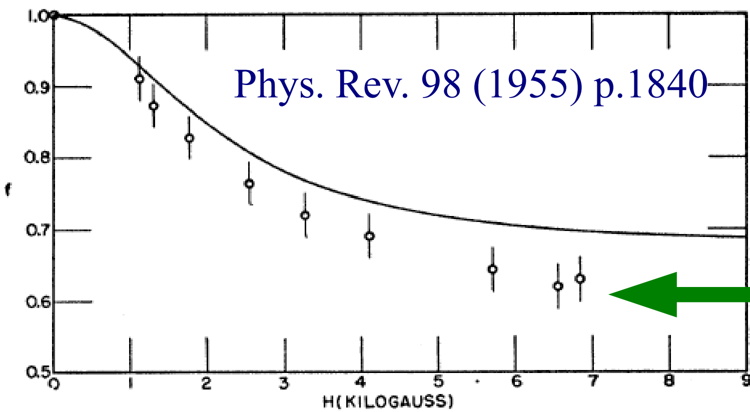


SiO_2 target used to form positronium

e^+ Ne^{22} ← Na^{22}

ν_e

1955: Magnetic Quenching observed



fraction, *f*, of orthopositronium which decays by three-q annihilation as function of magnetic field.

30% of γγγ decays

in magnetic field ≈ 1 Tesla

decays disappear

(replaced by γγ)

ortho-Positronium J=1: -> γγγ

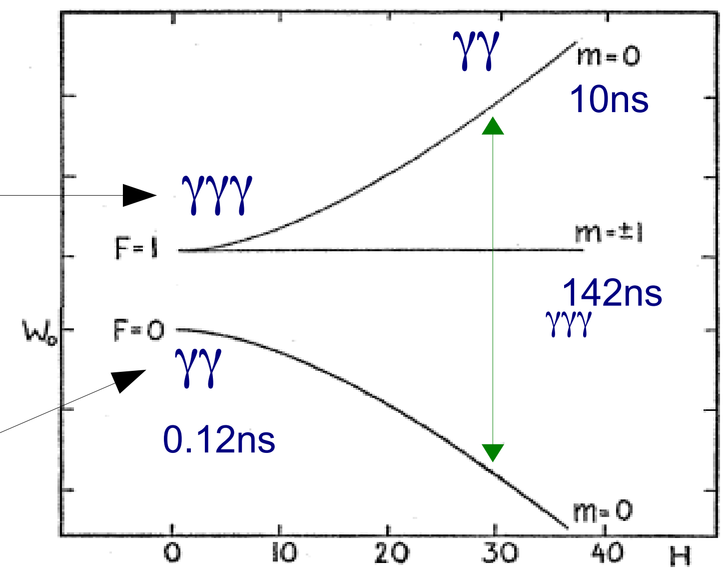
$|1,1\rangle = \uparrow\uparrow \quad |1,-1\rangle = \downarrow\downarrow$ $m_z = \pm 1$

$|1,0\rangle = (\uparrow\downarrow + \downarrow\uparrow)/\sqrt{2}$ $m_z = 0$

mixing

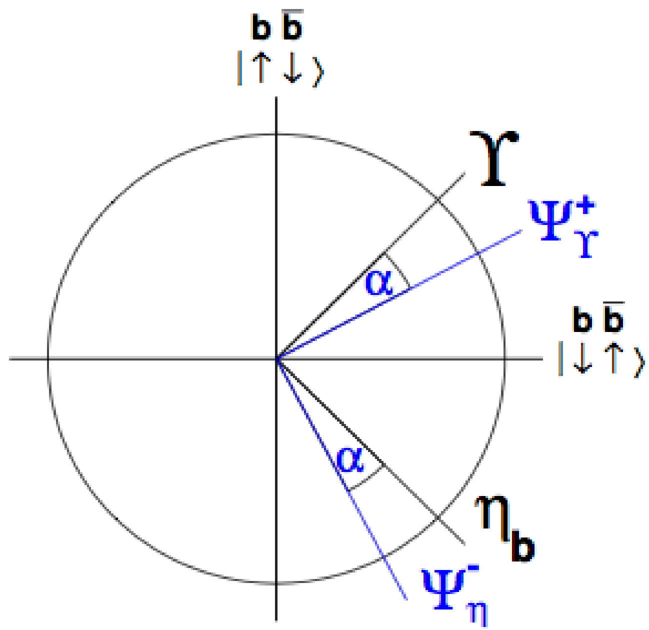
para-Positronium J=0: -> γγ

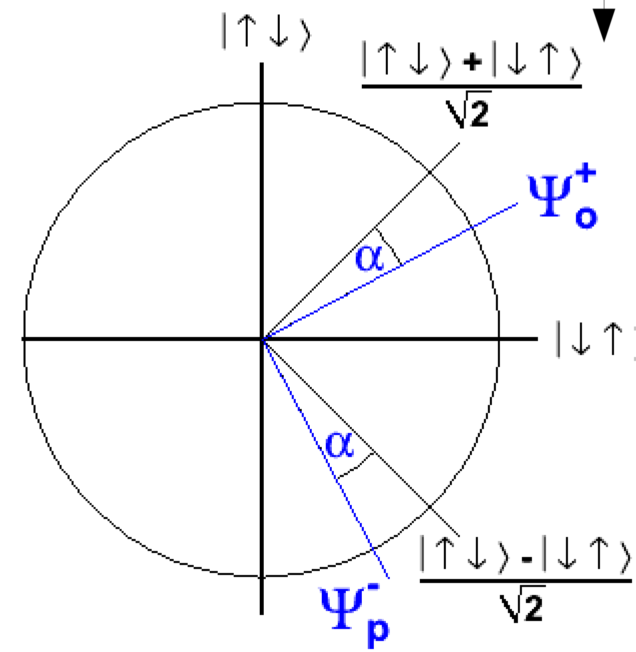
$|0,0\rangle = (\uparrow\downarrow - \downarrow\uparrow)/\sqrt{2}$ $m_z = 0$



Bottomium (ϒ) and Positronium

superposition of ortho/para-states in ***B***.





$$\Psi^+_\Upsilon = \cos(\alpha)\Upsilon + \sin(\alpha)\eta_b$$

(82%)

(2.4%) e^+e^- ggg gg

In static field B= 5*10^15 Tesla

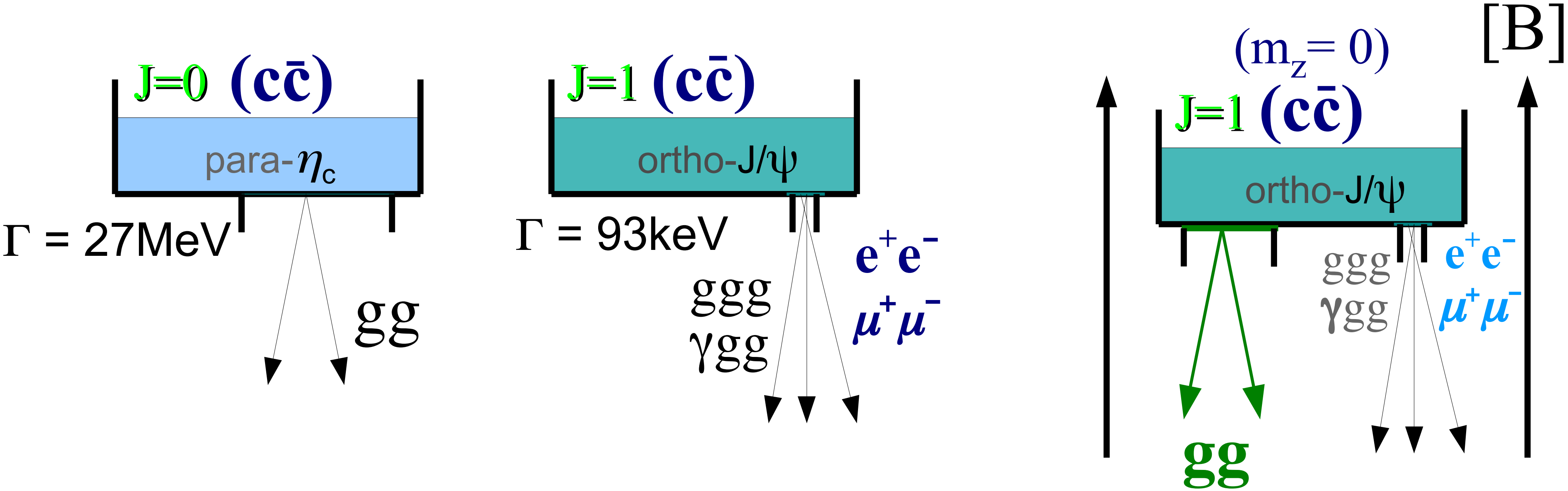
$$\Psi^+_o = \cos(\alpha)\Psi_o + \sin(\alpha)\Psi_p$$

$\gamma\gamma\gamma$ $\gamma\gamma$

in field B = 1 Tesla

Magnetic Field Quenching: J/Ψ decay

- Quark magnetic moments → behavior similar to Positronium
- Superposition of Quantum states J=0 and J=1, $m_z = 0$



- DSPIN 2012 conf.: Phys.Part.Nucl. 45, p.7
- CPOD conference: PoS (CPOD 2013) 035.
- Phys. Rev. D88 (2013) 105017
- Phys. Rev. Lett. 113 (2014) 172301.

$$X = 2|\mu_q| B / \Delta E_{hf}$$

$\Delta E_{hf} = 116\text{MeV}$

$\tau = 2100\text{fm/c} \rightarrow 300\text{ fm/c}$

- *J/ψ* lifetime in magnetic field decreases... but still too long

C-parity Quarkonium & Positronium

$\Psi_p = (\uparrow\downarrow - \downarrow\uparrow)/\sqrt{2}$ J=0, parity C= +1 → 2γ, 4γ

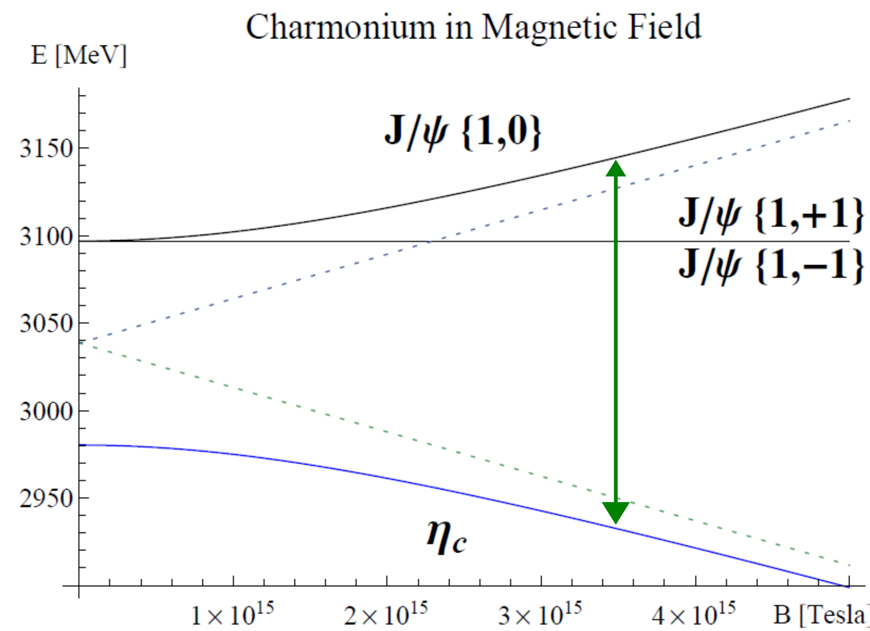
$\Psi_o = (\uparrow\downarrow + \downarrow\uparrow)/\sqrt{2}$ J=1, parity C= −1 → 3γ, 5γ

$m_z = 0$

- In magnetic field ⇒ superposition:

$$\Psi_o^+ = \cos(\alpha)\Psi_o + \sin(\alpha)\Psi_p$$

$$\Psi_p^- = \cos(\alpha)\Psi_p - \sin(\alpha)\Psi_o$$



Superposition of C-parity eigenstates:

- Gell-Mann & A.Pais

allowed in ext. fields:

We are effectively dealing here with the "charge conjugation quantum number" *C*, which is the eigenvalue of the operator ℭ, and which is rigorously conserved in the absence of external fields. If only an odd (even) number of photons is present, we have $C = -1 (+1)$; if only

Phys.Rev.97(1955) p.1387: Behavior of Neutral Particles under Charge Conjugation

Quantum superpositions:

(in magnetic field)

$\omega_{\{1,0\}}$ <----> $\eta_{\{0,0\}}$

$J/\Psi_{\{1,0\}}$ <----> η_c

J/Ψ J/Ψ η_c

1) ω [B] $\rightarrow$ $\omega + \varepsilon . \eta$

$BR\ (\omega \rightarrow \pi^+\pi^-) = 1.5\%$

$BR\ (J/\psi \rightarrow \pi^+\pi^-) = 1.47\times10^{-4}$

J/Ψ

2) η [B] $\rightarrow$ $\eta + \varepsilon . \omega$

admixture of ω in η meson

J/Ψ c

CP violation in Hadronic state → affected by [B]

due to Mixing

$\eta \rightarrow \pi^+\pi^-$ is CP violating

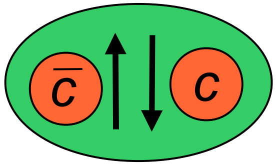
SM predicts: $BR(\eta \rightarrow \pi\pi) \leq 2\times10^{-27}$

MESON 2014

13th International Workshop on Meson Production, Properties and Interaction

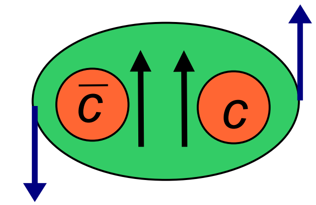
29th May - 3rd June 2014, Kraków, Poland

enhanced in [B] → Proceedings of MESON 2014, EPJ WoC 81, 05013.



η_c

MECHANISM to influence CP violation in hadronic decays



J/ψ

J/ψ , $\varphi(1020) \rightarrow \pi^+\pi^-$ (BR $\approx 10^{-4}$) ← (Experimental Data)

$\omega(782) \rightarrow \pi^+\pi^-$ (BR $\approx 10^{-2}$) [G-parity violation]

η_c , $\eta \rightarrow \pi\pi$ (BR $\leq 10^{-27}$) ⇐ Standard Model Prediction

[CP-violation]

Superposition of (J=1, m_z= 0) and (J=0) mesons

(in Magnetic field)

allows for η (J=0) $\rightarrow \pi\pi$ *decay*

→ indirect CP violation (via mixing) [B]

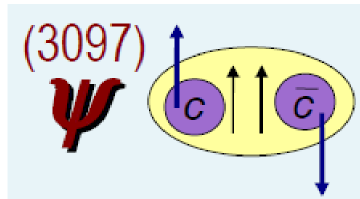
Quarkonium ⇔ Leptonium

J/ψ Υ(9460) φ(1020) e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$ → **JLab** 2015

$(c\bar{c})$ $(b\bar{b})$

ortho-$(\mathbf{c\bar{c}})$ = J/ψ

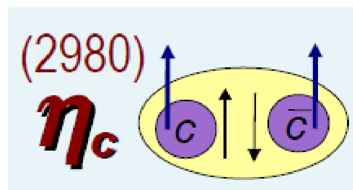
($J^{PC}=1^{--}$)

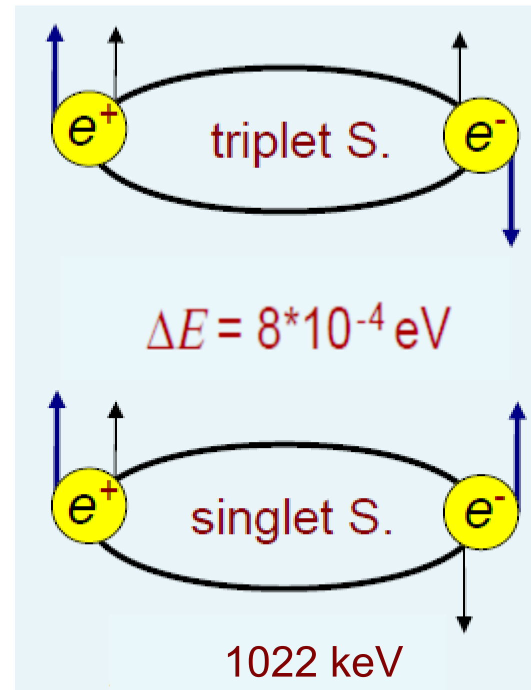


ΔE =117 MeV

para-$(\mathbf{c\bar{c}})$ = η_c

($J^{PC}=0^{-+}$)





142ns

0.12ns

Decay: **J/ψ** → 3g,γgg **η_c** → gg,γγ

- lifetimes: **2100fm/c** (J=1) and **7fm/c** (J=0)

What happens in [ExB] ?

States of Quarkonium

Υ and **J/ψ**

correspond to Positronium

STARK + ZEEMAN effect in Ps

Perturbative analysis of simultaneous Stark and Zeeman effects on $n = 1 \leftrightarrow n = 2$ radiative transitions in positronium

C. D. Dermer
Physics Department, Lawrence Livermore National Laboratory, Livermore, California 94550

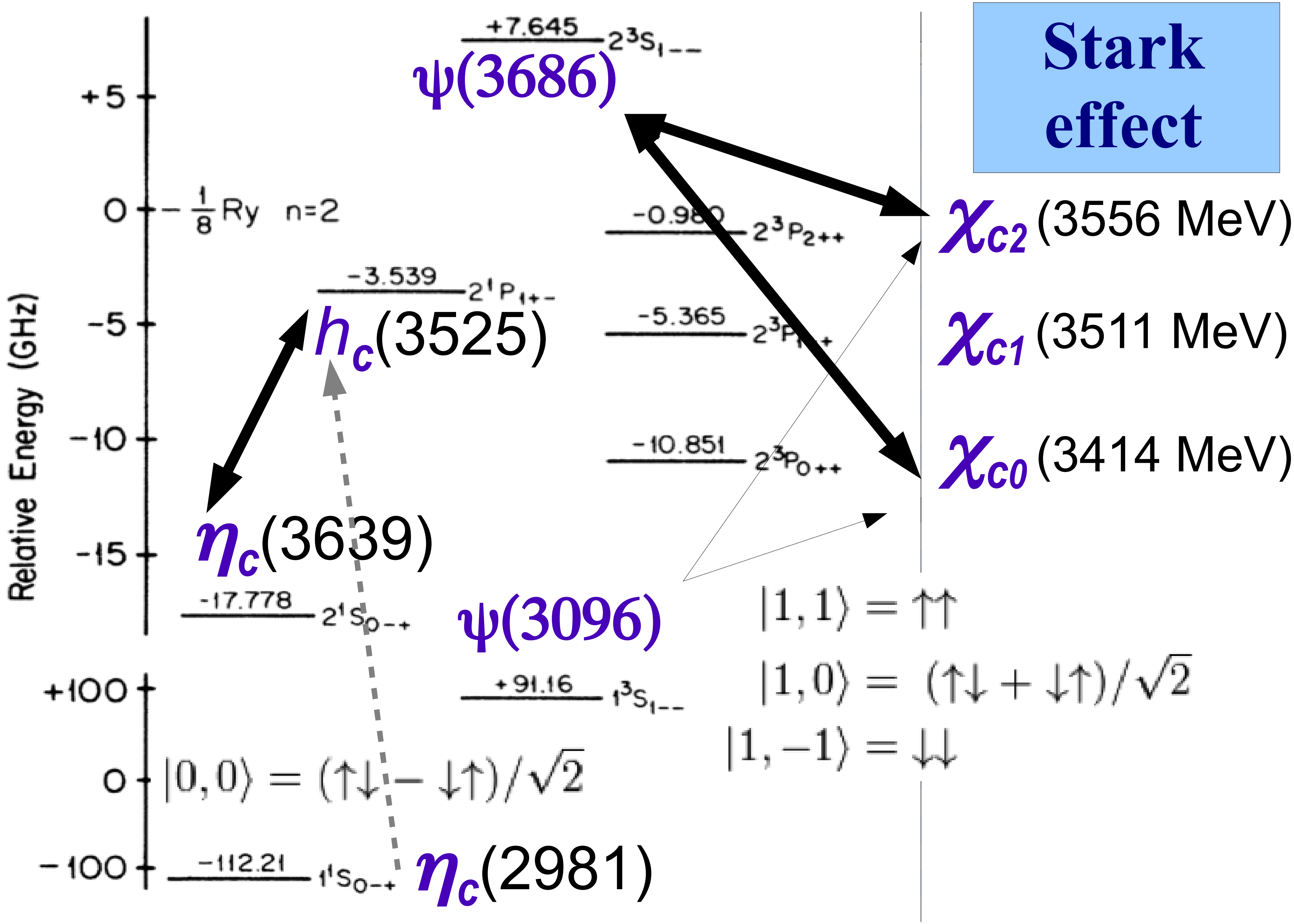
The Stark Hamiltonian $\mathcal{H}_S$ couples $2\,^3S$ and $2\,^3P$, and $2\,^1S$ and $2\,^1P$, states with $\Delta m = \pm 1$. The maximum Stark matrix elements for the $n=2$ state in

$$\varepsilon_{\gamma'\gamma} = 3 \cdot 2^{1/2} e a_0 \mathcal{E}_\perp / \Delta E_{\gamma'\gamma}$$

$$\varepsilon_{\gamma'\gamma} = 2\mu_B B / \Delta E_{\gamma'\gamma}$$

effects. The Zeeman effect couples ^3S and ^1S states, and ^3P and ^1P states. For any S state with

Charmonium & Positronium in “E”



Effect depends on ΔE ($\chi_b \leftrightarrow \Upsilon$)

		Upsilon(1s)	Upsilon(2s)	Upsilon(3s)
	[MeV] →	9460.3	10023.3	10355.3
[MeV]	(1p)	Γ = 0.054 MeV	Γ = 0.032 MeV	Γ = 0.020 MeV
9859.4	Chi_0b	399.1	163.9	495.9
9892.8	Chi_1b	432.5	130.5	462.5
9912.2	Chi_2b	451.9	111.1	443.1
	(2p)	ΔE	ΔE	ΔE
10232.5	Chi_0b	772.2	209.2	122.8
10255.4	Chi_1b	795.1	232.1	99.9
10268.6	Chi_2b	808.3	245.3	86.7
	(3p)	ΔE	ΔE	ΔE
10530.0	Chi_0b	1069.7	506.7	174.7
10544.0	Chi_1b	1083.7	520.7	188.7
10551.0	Chi_2b	1090.7	527.7	195.7
	(LHC 2012)			

Υ(2s),Υ(3s) affected more than Υ(1s)

CONCLUSIONS.

1) $\rho(770)$, $K^*(892)$, $\Lambda^*(1520)$ in $B \approx 10^{15}$ T

-> **reduced widths, changed BR, isospin violation**

K^{0*} **yields may be underestimated,** $K^{\pm *}$ **different ?**

Λ^* behavior should be understood (Au+Au & Pb+Pb)

ρ^0 **enhanced** e^+e^-, $\gamma\gamma$ yields (v2) if $\rightarrow \pi^+\pi^-$ is closed

2) **Suppression of Υ(2s,3s) in [ExB] fields**

- *due to Stark + Zeeman effect*

3) **CP - violation in decay of η mesons**

enhanced $\eta \rightarrow \pi^+\pi^-$ due to Q.-mixing in B

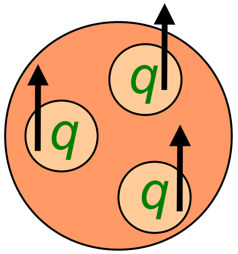
THANK YOU

For ATTENTION

Magnetic moments for ***parallel spins***:

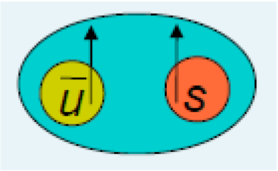
Observe: spin **3/2** baryons

			μ_{exp}	δ_μ	μ
Ω^-	1672	sss	-2.02	9 %	-1.84
Δ^{++}	1232	uuu	6.14	(9%)	5.56
Δ^+	1232	uud	2.7	(1%)	2.73



$\mu^* = \sum \mu_q$

Vector mesons: spin 1 (L=0)



K^{*-}

charged open-flavor $\mu^* = \sum \mu_q$

	ρ^-	K^{*+}	D^{*-}	D_s^{*-}	B^{*-}
m [MeV]	770	892	2010	2112	5325
$q\bar{q}$	$d\bar{u}$	$u\bar{s}$	$d\bar{c}$	$s\bar{c}$	$b\bar{u}$
μ [μ_N]	-2.82	2.46	-1.37	-1.02	-1.92

Agrees with L-QCD: Lee et al. PoS (LATTICE 2007) 151.

$$\mu_q = \frac{\hbar Q}{2m^*}$$

m^*_b=4730

m^*_c=1510

quark	Q	μ_q [μ_N]
u	2/3	1.852
d	-1/3	-0.972
s	-1/3	-0.613
c	2/3	0.404
b	-1/3	-0.066

–> $\mu_c = -2\mu_s / 3$

–> $\mu_b = \mu_s / 9$

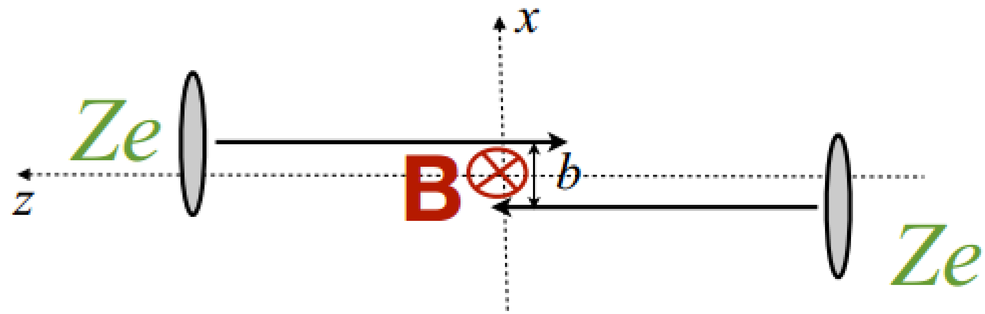
Magnetic Field in Heavy Ion Collisions

LHC: B = 4.10^{15}T

RHIC: B = 3.10^{14}T

Present for a very short time

PHYSICAL REVIEW C **85**, 044907 (2012)



PHYSICAL REVIEW C **83**, 054911 (2011)

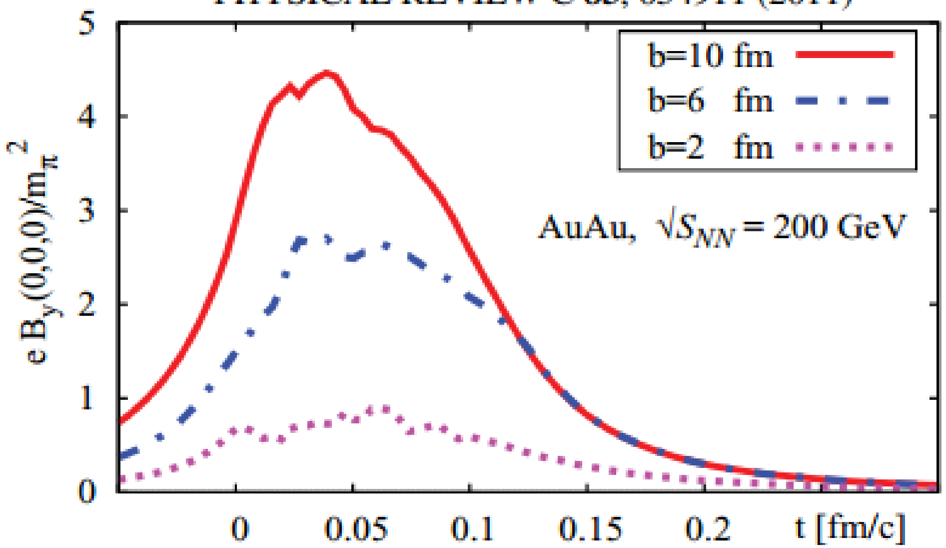
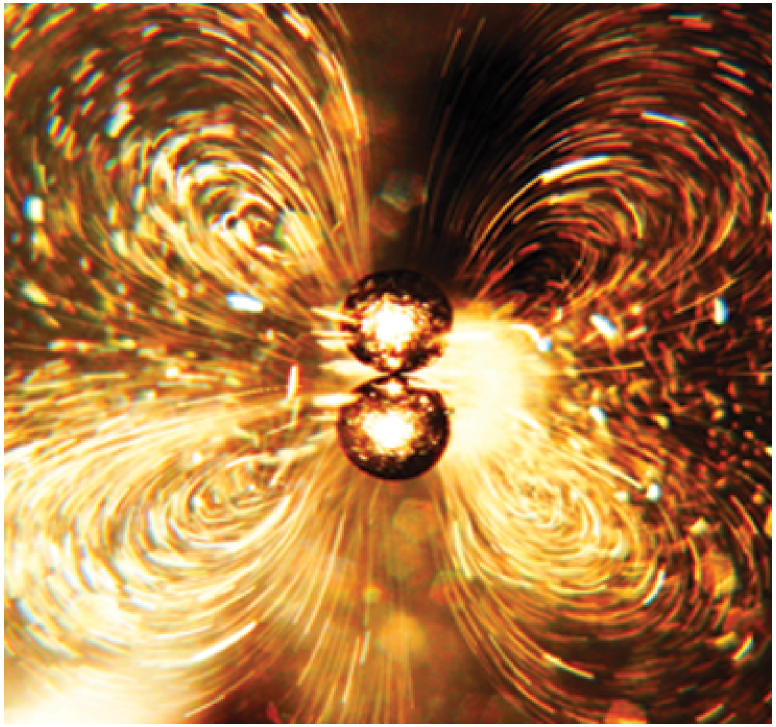


FIG. 13. Impact parameter dependence of the magnetic field. Au + Au collisions $\sqrt{s_{NN}}$ = 200 GeV.



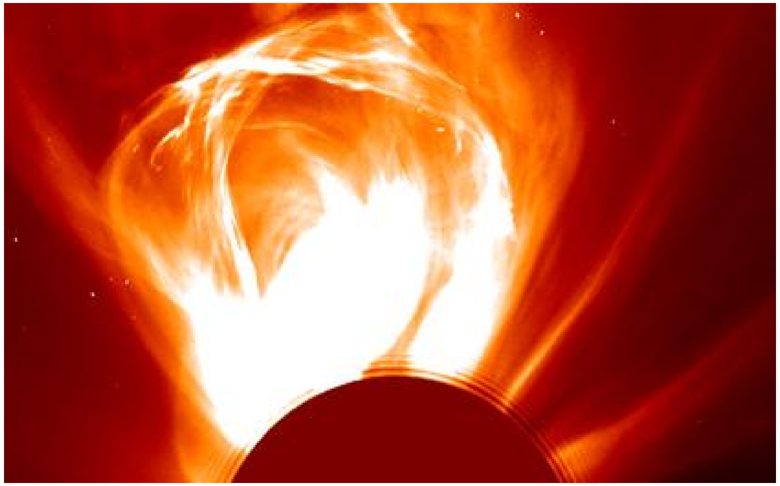
PHYSICAL REVIEW C **82**, 034904 (2010)

Kirill Tuchin

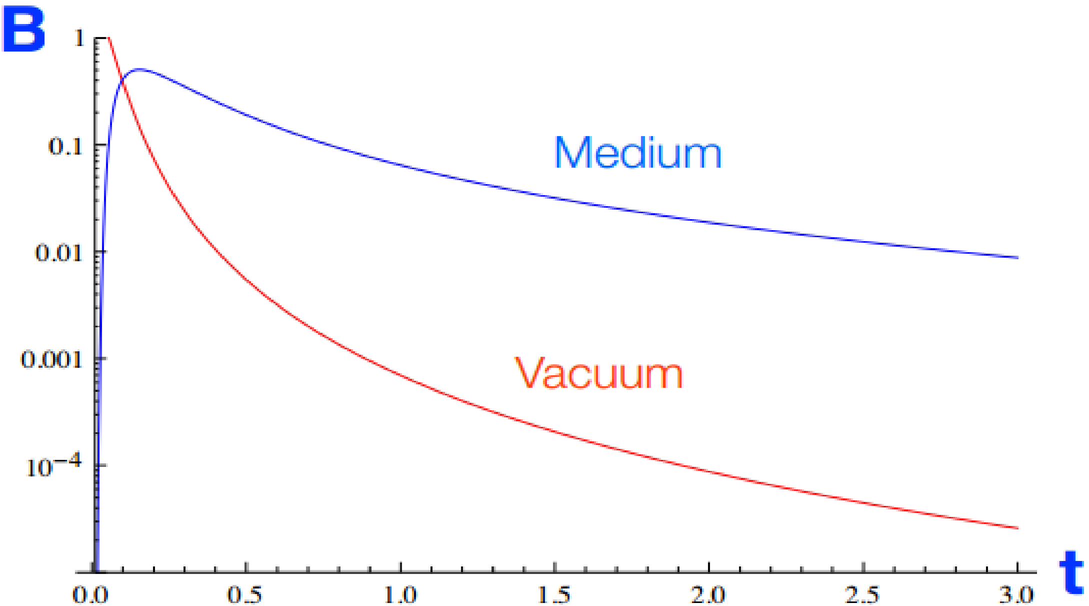
Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA and

We study the synchrotron radiation of gluons by fast quarks in strong magnetic field produced by colliding relativistic heavy ions. We argue that due to high electric conductivity of plasma, the magnetic field is almost constant during the entire plasma lifetime. We calculate the energy loss due to synchrotron radiation of gluons by fast quarks. We find that the typical energy loss per unit length for a light quark at the Large Hadron Collider

-> Plasma keeps [B] fields: QGP is elmag. Plasma too



Solar + Tokamak physics



QED plasma $\Rightarrow$ able to stabilize decaying B field.

Isospin <u>conservation</u> in K* decays

$$K^{*0} \to K^+\pi^- \quad (66.5\%) \qquad K^{*0} \to K^0\pi^0 \quad (33.3\%)$$
$$\bar{K}^{*0} \to K^-\pi^+ \quad (66.5\%) \qquad \bar{K}^{*0} \to \bar{K}^0\pi^0 \quad (33.3\%)$$
$$K^{*\pm} \to K^0\pi^\pm \quad (66.6\%) \qquad K^{*\pm} \to K^\pm\pi^0 \quad (33.3\%)$$

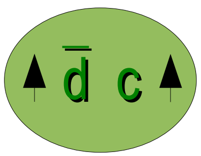
- from Clebsch-Gordan coefficients: ½ → (½ x 1)

$$K^{*0}_{|\frac{1}{2},-\frac{1}{2}\rangle} \to -\sqrt{\frac{2}{3}}\,K^+_{|\frac{1}{2},+\frac{1}{2}\rangle}\pi^-_{|1,-1\rangle} + \sqrt{\frac{1}{3}}\,K^0_{|\frac{1}{2},-\frac{1}{2}\rangle}\pi^0_{|1,0\rangle}$$
$$\bar{K}^{*0}_{|\frac{1}{2},+\frac{1}{2}\rangle} \to +\sqrt{\frac{2}{3}}\,K^-_{|\frac{1}{2},-\frac{1}{2}\rangle}\pi^+_{|1,+1\rangle} - \sqrt{\frac{1}{3}}\,\bar{K}^0_{|\frac{1}{2},+\frac{1}{2}\rangle}\pi^0_{|1,0\rangle}$$
$$K^{*+}_{|\frac{1}{2},+\frac{1}{2}\rangle} \to +\sqrt{\frac{2}{3}}\,K^0_{|\frac{1}{2},-\frac{1}{2}\rangle}\pi^+_{|1,+1\rangle} - \sqrt{\frac{1}{3}}\,K^+_{|\frac{1}{2},+\frac{1}{2}\rangle}\pi^0_{|1,0\rangle}$$
$$K^{*-}_{|\frac{1}{2},-\frac{1}{2}\rangle} \to -\sqrt{\frac{2}{3}}\,\bar{K}^0_{|\frac{1}{2},+\frac{1}{2}\rangle}\pi^-_{|1,-1\rangle} + \sqrt{\frac{1}{3}}\,K^-_{|\frac{1}{2},-\frac{1}{2}\rangle}\pi^0_{|1,0\rangle}$$

- there is penalty factor (½) whenever π^0 is being created.

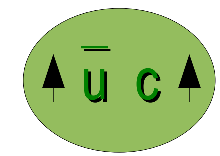
Isospin *violation* in D^{0*} decays

D*+



$$D^{*0} \to D^{+}\pi^{-} \ (0\%), \qquad D^{*0} \to D^{0}\pi^{0} \quad (61.9\%)$$
$$\bar{D}^{*0} \to D^{-}\pi^{+} \ (0\%), \qquad \bar{D}^{*0} \to \bar{D}^{0}\pi^{0} \quad (61.9\%)$$
$$D^{*\pm} \to D^{0}\pi^{\pm} \ \underline{(67.7\%)}, \qquad D^{*\pm} \to D^{\pm}\pi^{0} \ \underline{(30.7\%)},$$

D*0



- same Clebsch-Gordan coefficients ½ → (½ x 1)
- <u>however</u>: phase space is very restricted

$$D^{*0} \to D^{+}\pi^{-} \ \underline{\text{is energetically forbidden}}$$

$\Delta M(D^{*0} \Rightarrow \pi^{\pm}+D^{\pm})$ = -2,2 MeV $\quad$ $\Delta M(D^{*0} \Rightarrow \pi^{0}+D^{0})$ = +7.1 MeV

$\Delta M(D^{*\pm} \Rightarrow \pi^{\pm}+D^{0})$ = <u>+5,85</u> MeV $\quad$ $\Delta M(D^{*\pm} \Rightarrow \pi^{0}+D^{\pm})$ = <u>+5.68</u> MeV

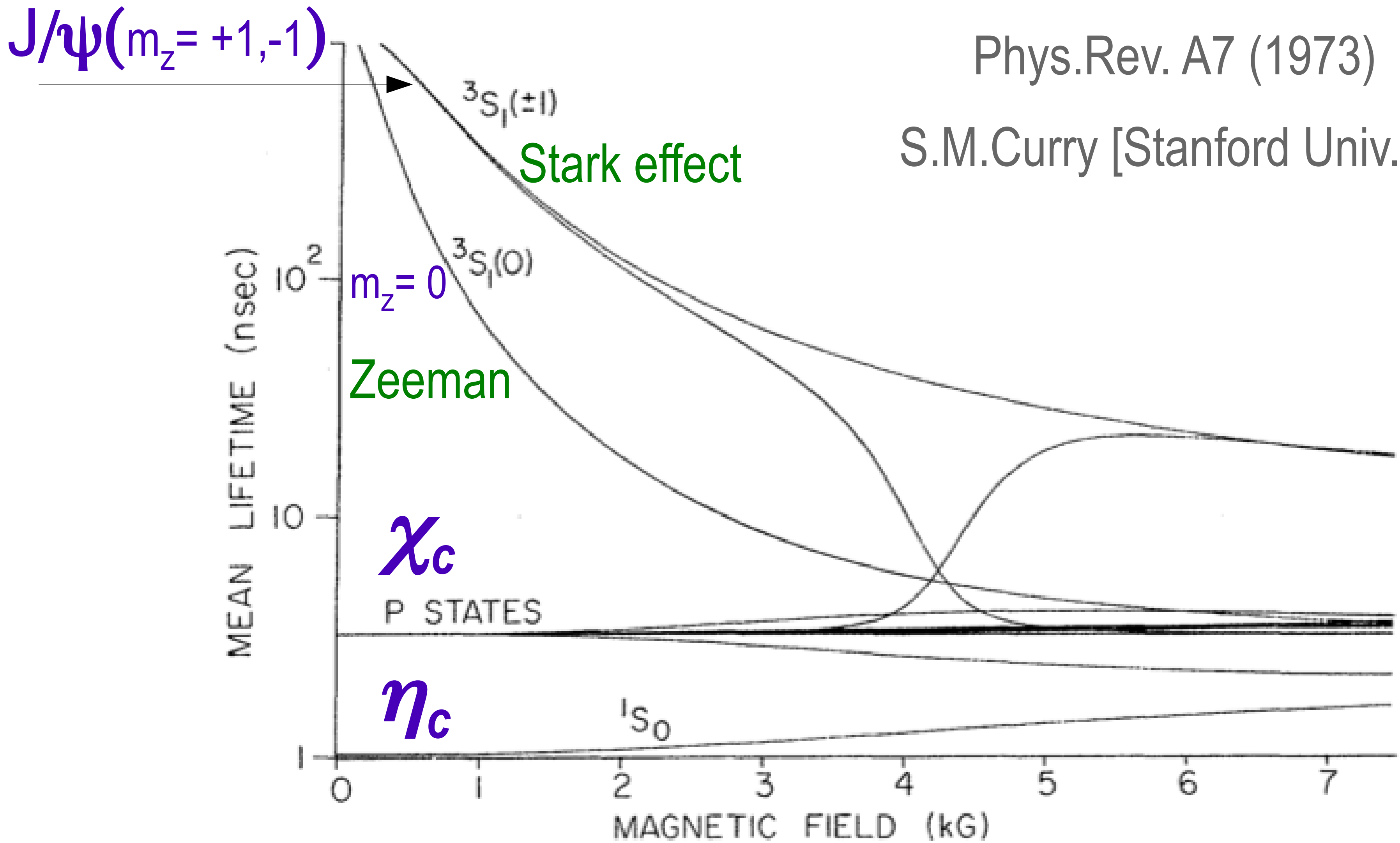
Compare to Kaon*: $\Delta M(K^{*} \Rightarrow \pi+K)$ = 256 MeV

- Penalty factor (½) again, if π^{0} is created in $D^{*\pm}$ decay.

ortho-Positronium (J=1) lifetime in [ExB]
all three (m_z) states affected

Phys.Rev. A7 (1973)

S.M.Curry [Stanford Univ.]



Stark+Zeeman affect: J/ψ(m_z= +1,-1, 0)