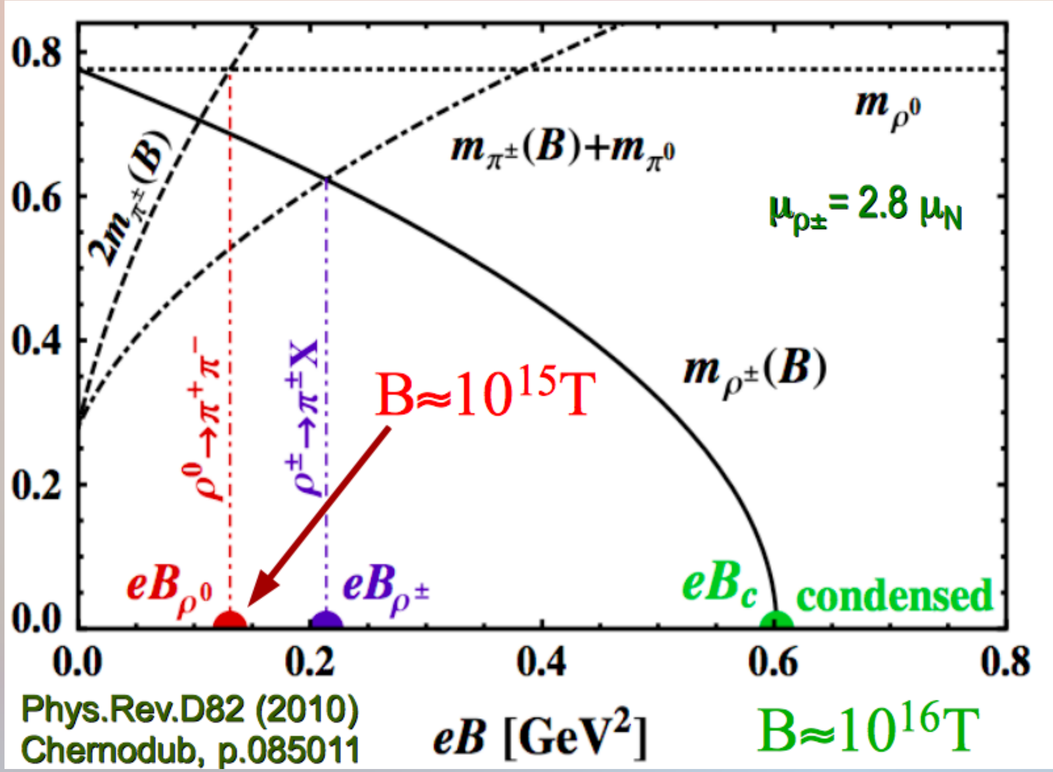
Decay of Hadronic Resonances in Strong Magnetic Field

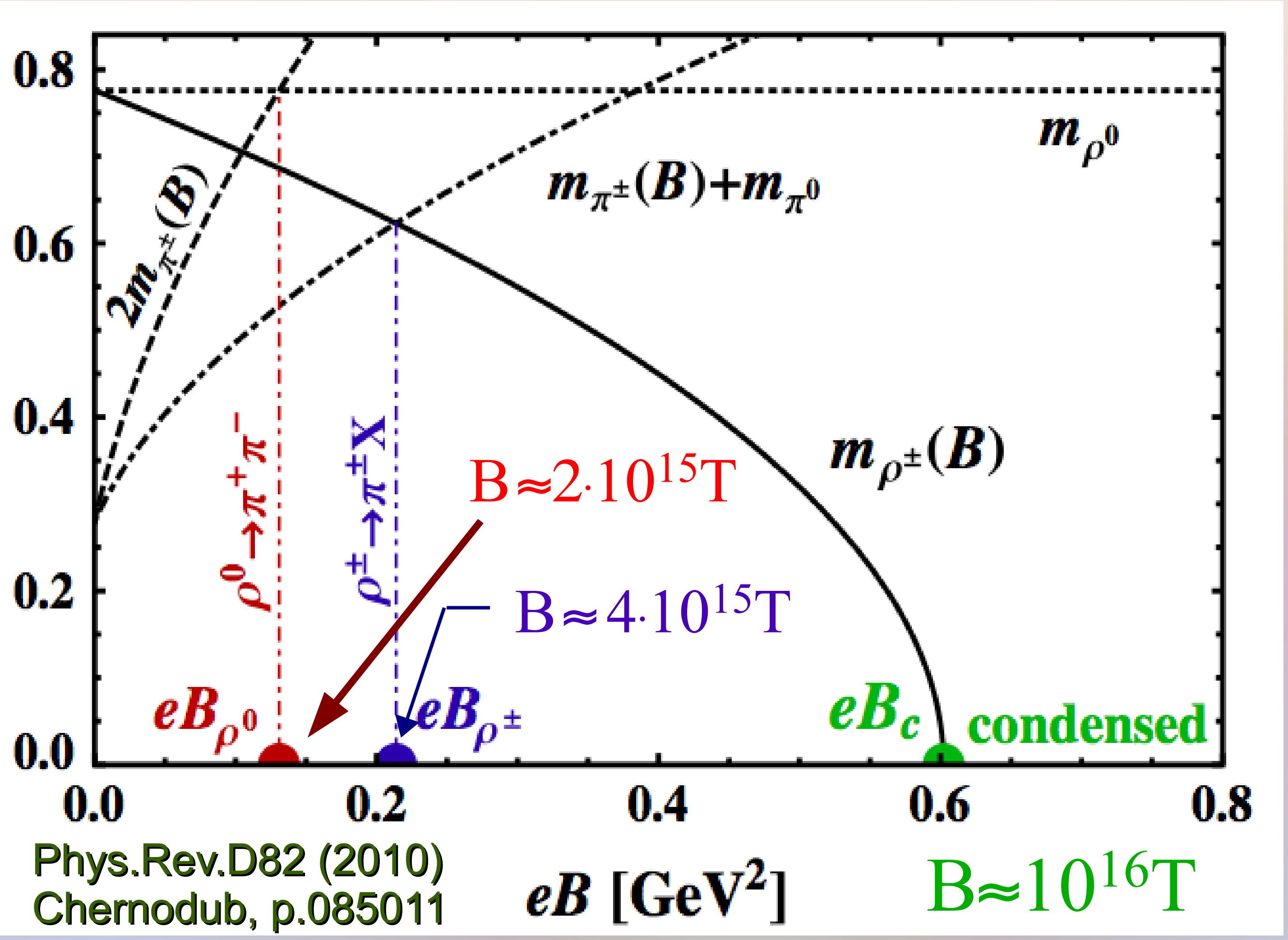
Baldin Seminar 2014 **P. Filip** *Dubna* 19.9. 2014

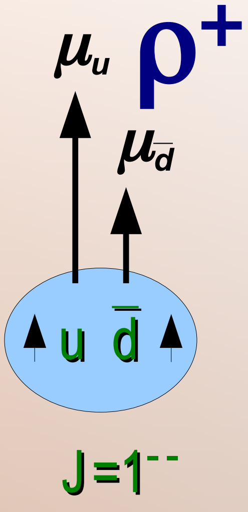
Institute of Physics SAV, Bratislava

- $\rho \to \pi\pi$ decay in [B] →
- Decay of K*, Λ* in HIC
- Decay of D*, Ξ^{0}* and Δ^{0}(1232)
- Summary (lifetimes, B_{crit})
- **Conclusions**



Behavior of ρ^0, $\rho^{\pm}$ mesons [B]



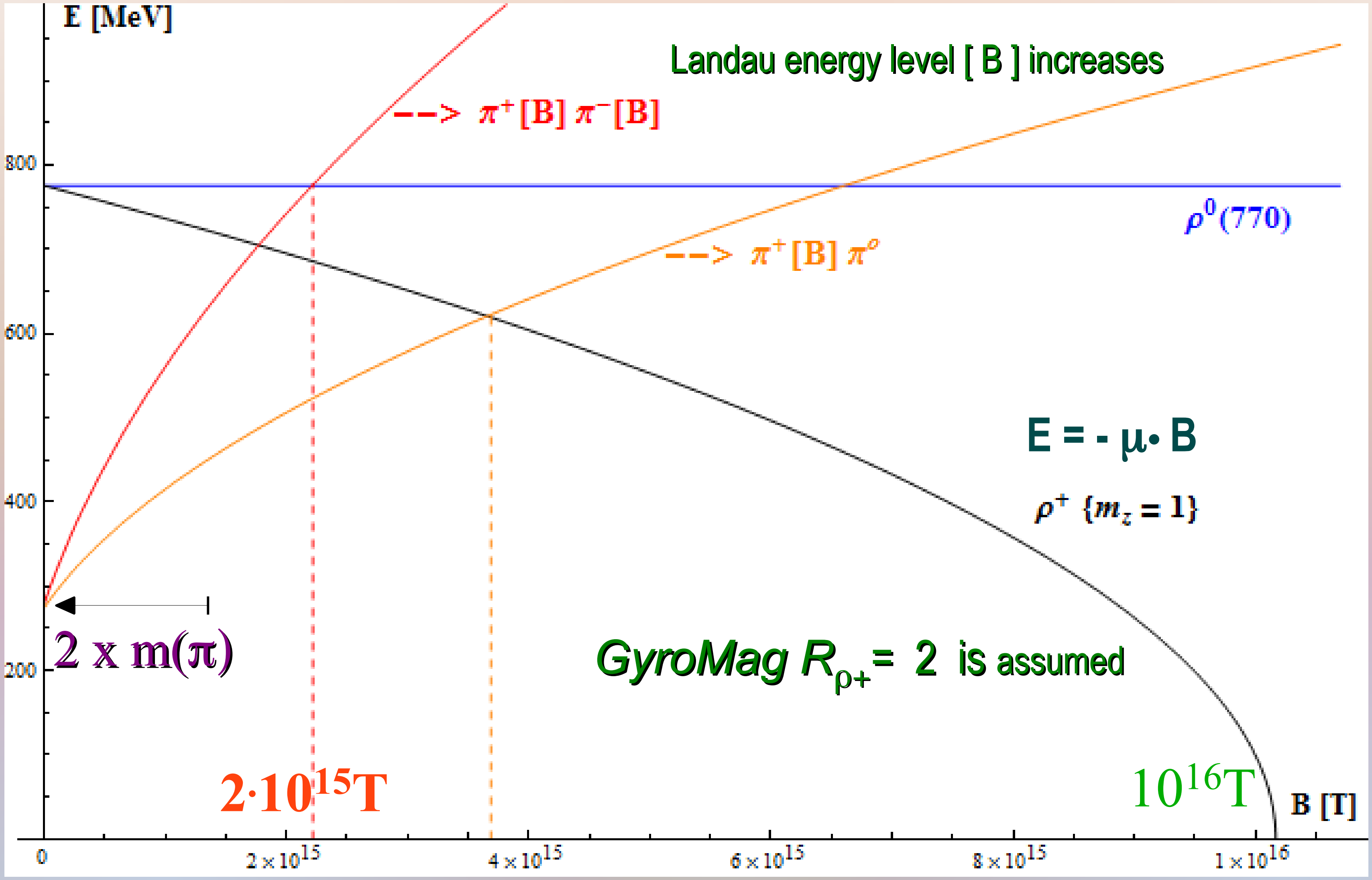


$E = -\mu \cdot B$

energy in magnetic field [B]

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

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



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

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) $m^2_{\pi^\pm}(B_{\rm ext}) = m^2_{\pi^\pm} + eB_{\rm ext}$

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

2) for s = 1/2, 1, 3/2 particles (J>0)

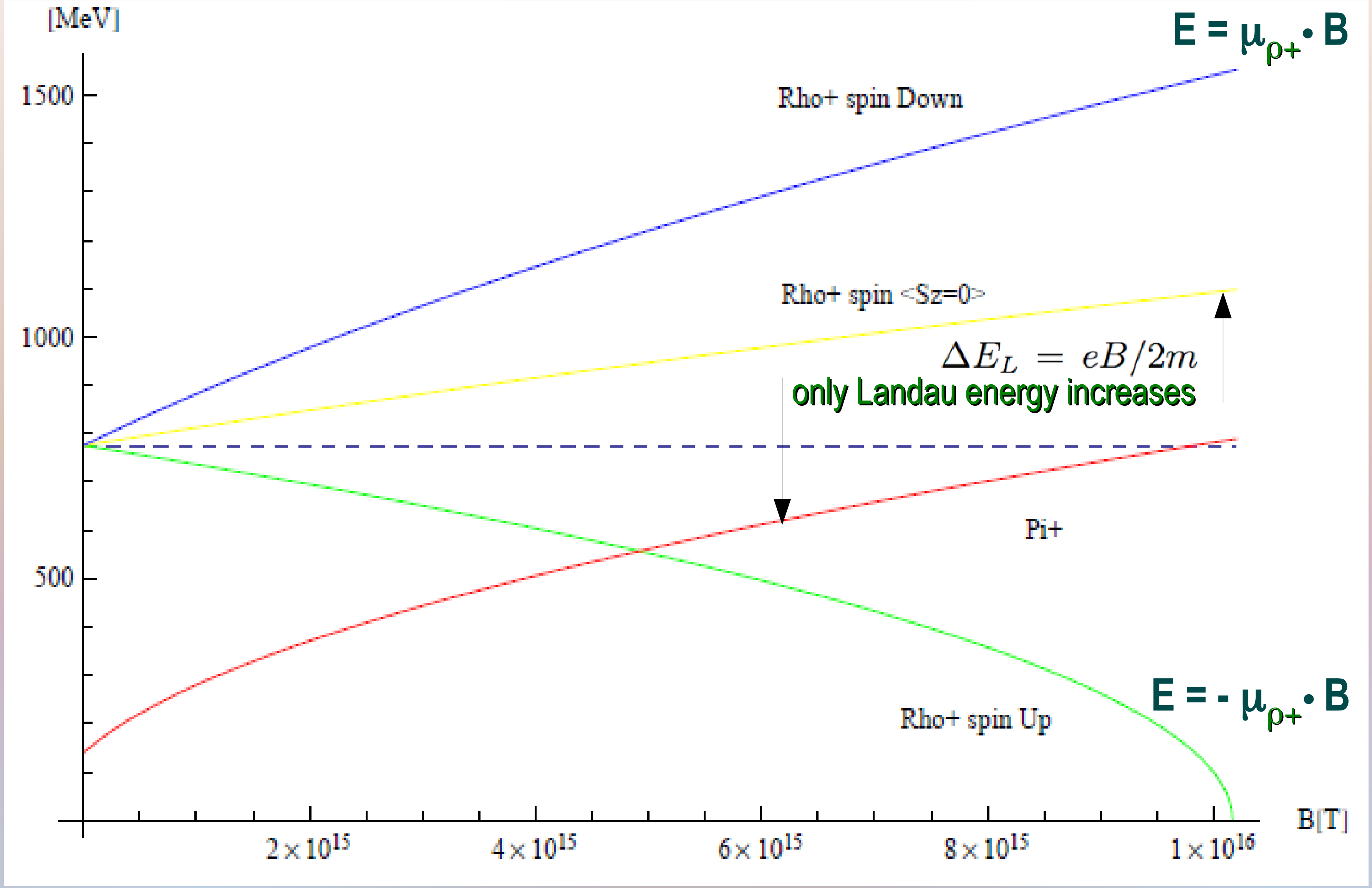
$$E[B] = \sqrt{m^2 + p_z^2 + eB(1-2s_z)}$$

$$\mu = \frac{\hbar Q}{2m}$$

$$E = -\bar{\mu}\cdot B$$

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

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



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

OBSERVATION

1) Rho(770) decay modified in B ~ 10^{15} T

- Phys.Rev.D82: $\rho \to \pi\pi$ (closed) in $B = [4 * 10^{15} T]$
  (2010) p.085011 $\tau = 1.2$ fm/c

2) RHIC: Au+Au [10^{14} T], LHC [$B \approx 10^{15}$ T]
   duration of extremal B field: $\tau \approx 2\text{-}3$ fm/c possible

3) K*(892) $\tau \approx 4$ fm/c, Λ*(1520) $\tau \approx 13$ fm/c

⇒ resonances produced in HIC may be influenced by [B]

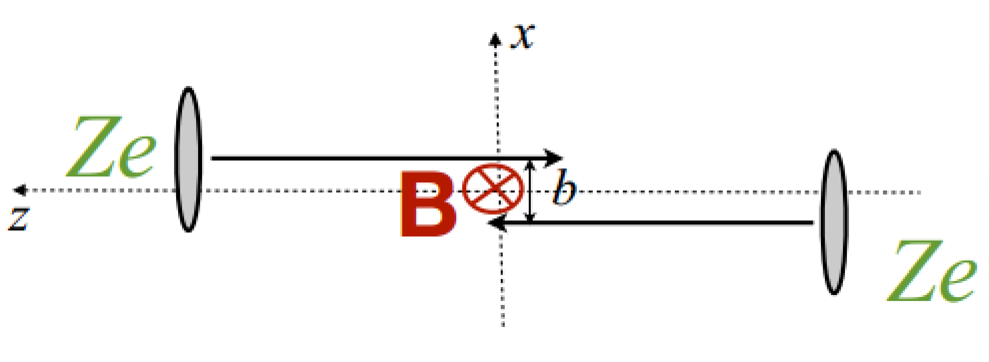
Magnetic Fields in Au+Au / Pb+Pb

LHC: $\mathbf{B = 4.10^{15} T}$

RHIC: $\mathbf{B = 3.10^{14} T}$

$\mathbf{eB = 3 m_\pi^2}$

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



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

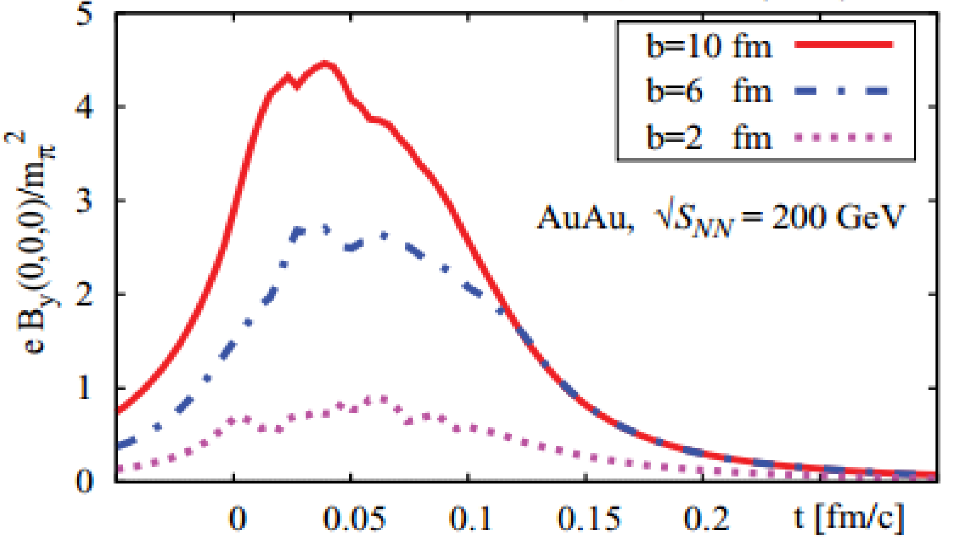
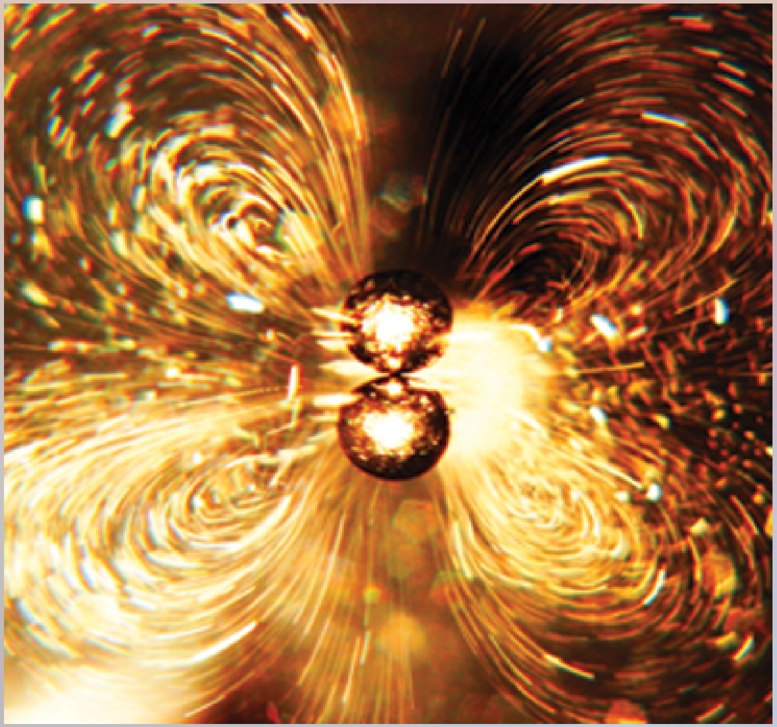


FIG. 13. Impact parameter dependence of the magnetic field. Au + Au collisions $\sqrt{s_{NN}} = 200$ GeV.



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

Kirill Tuchin

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

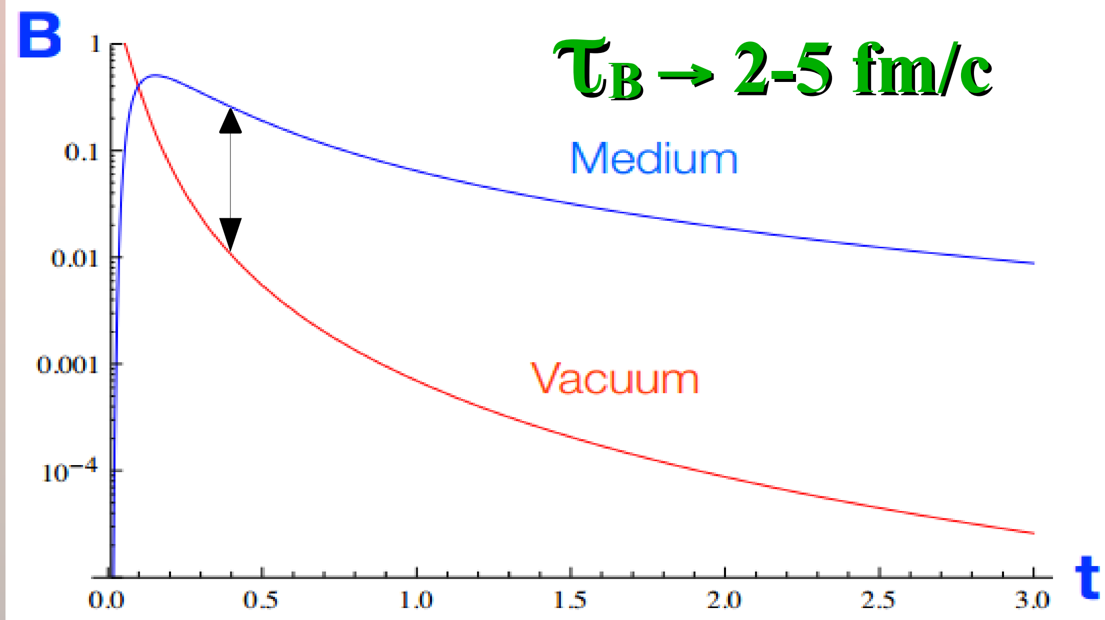
We study the synchrotron radiation of gluons by fast quarks in strong magnetic field produced by colliding relativistic heavy ions. We argue that due to high electric conductivity of plasma, the magnetic field is almost constant during the entire plasma lifetime. We calculate the energy loss due to synchrotron 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

Partonic gas ⇒ **“elmag”** Plasma ⇒ frozen B field

B field lifetime τ_B

is enhanced

by factor 10x-50x



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

Wei-Tian Deng[1,*] and Xu-Guang Huang[1]

Event-by-event generation of electromagnetic fields in heavy-ion collisions

Motivation: Au+Au 200GeV/n

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

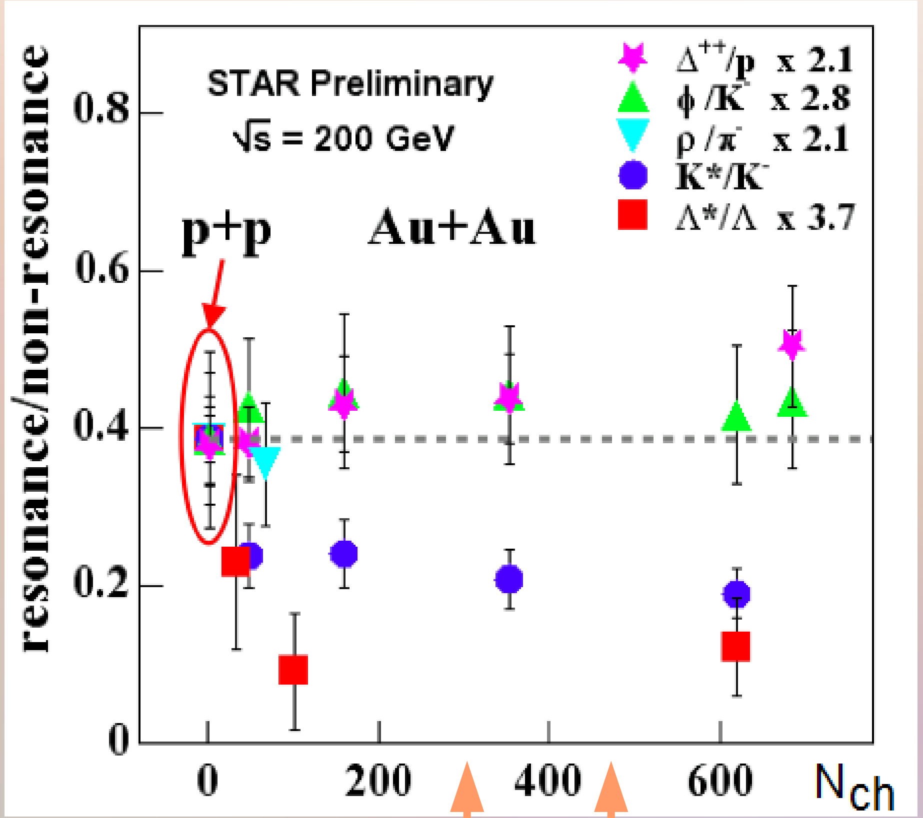
observed in peripheral Au+Au

disappears in non-central

seen again in "central" Au+Au

(magnetic field or statistics?)

Quark Matter 2004



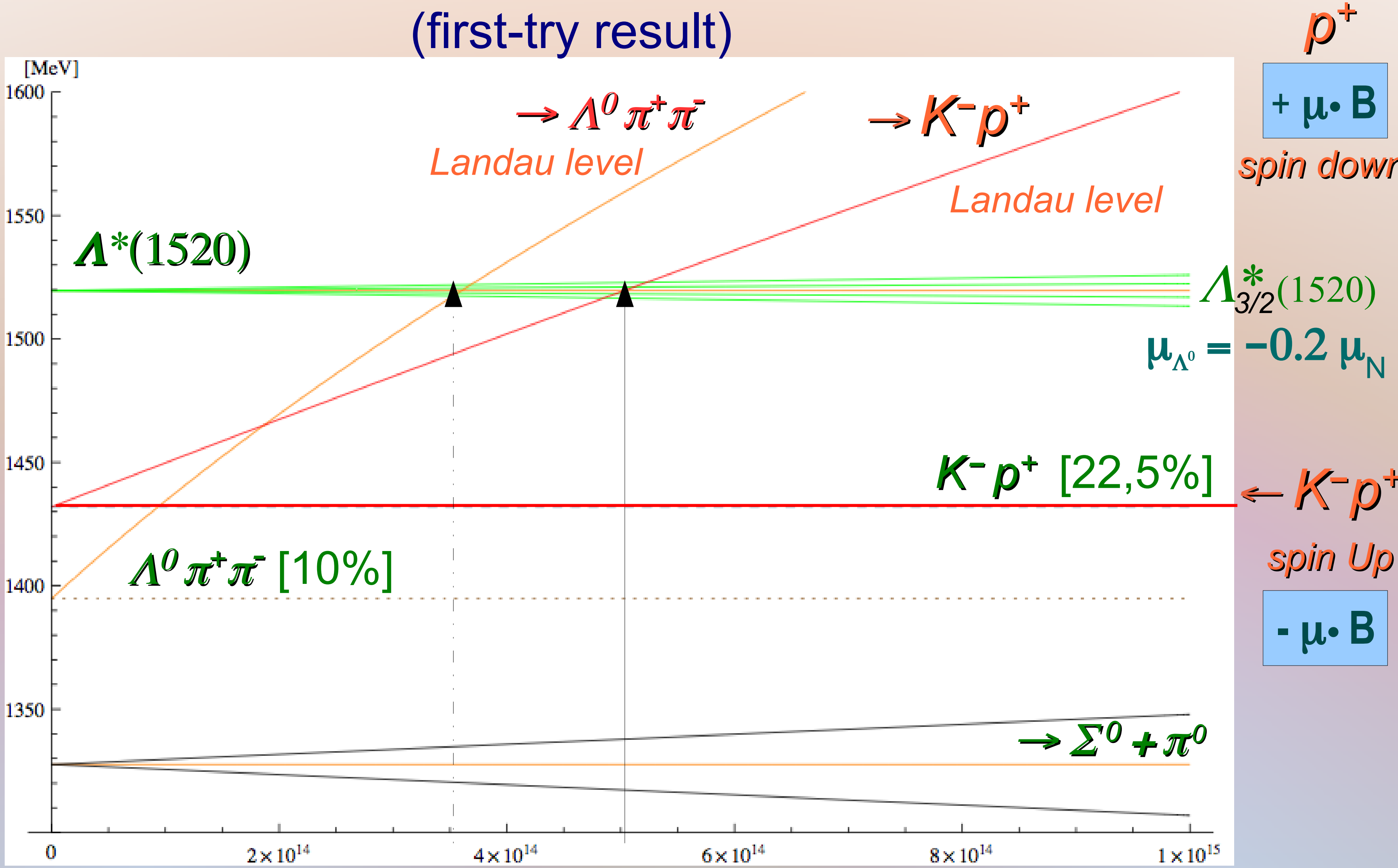
Note: Magnetic field [B]

a) is large in non-central collisions

b) should decrease in very central Au+Au coll.

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

(first-try result)

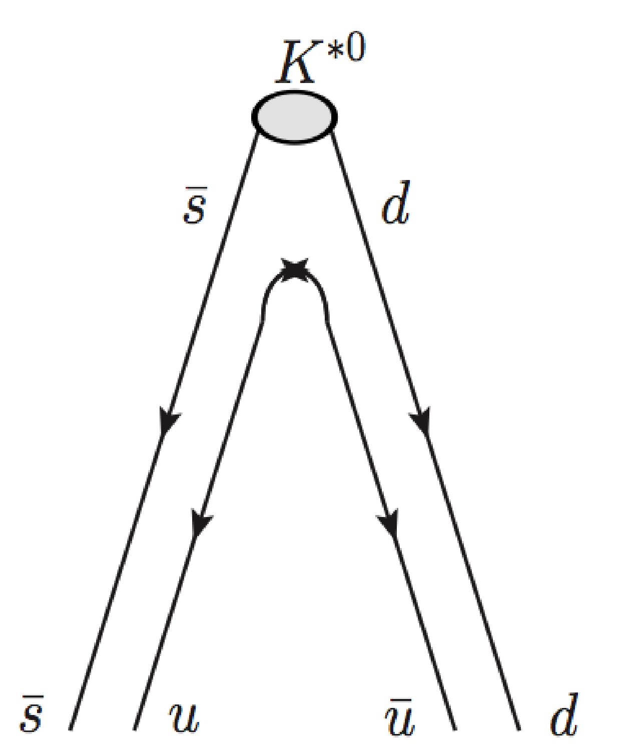


50% decays $\Lambda^* \rightarrow K^- p^+$ **closed** at B=$5 \cdot 10^{14}$ T

K*(892) strong 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^+ π^-

Isospin conservation

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

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

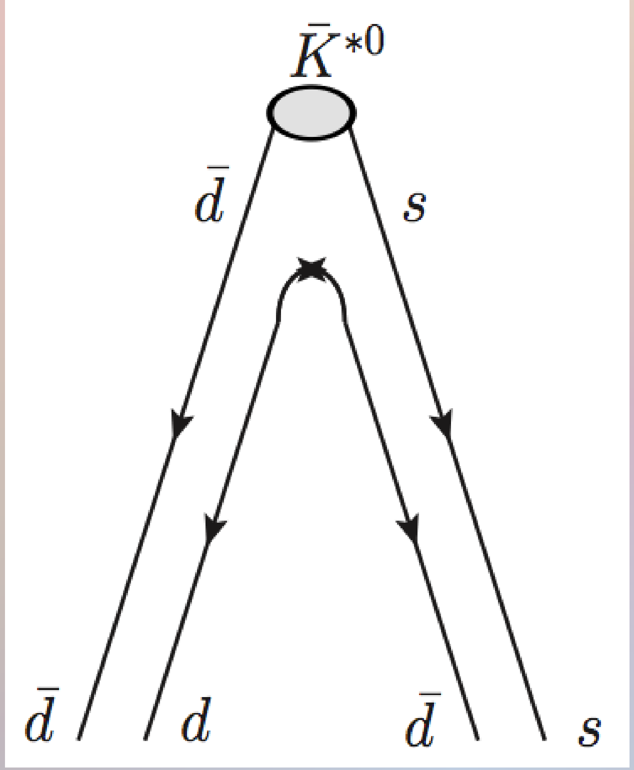
Clebsch-Gordan coefficients

$\bar{K}^* \to \bar{K}^0\pi^0$

2 : 1

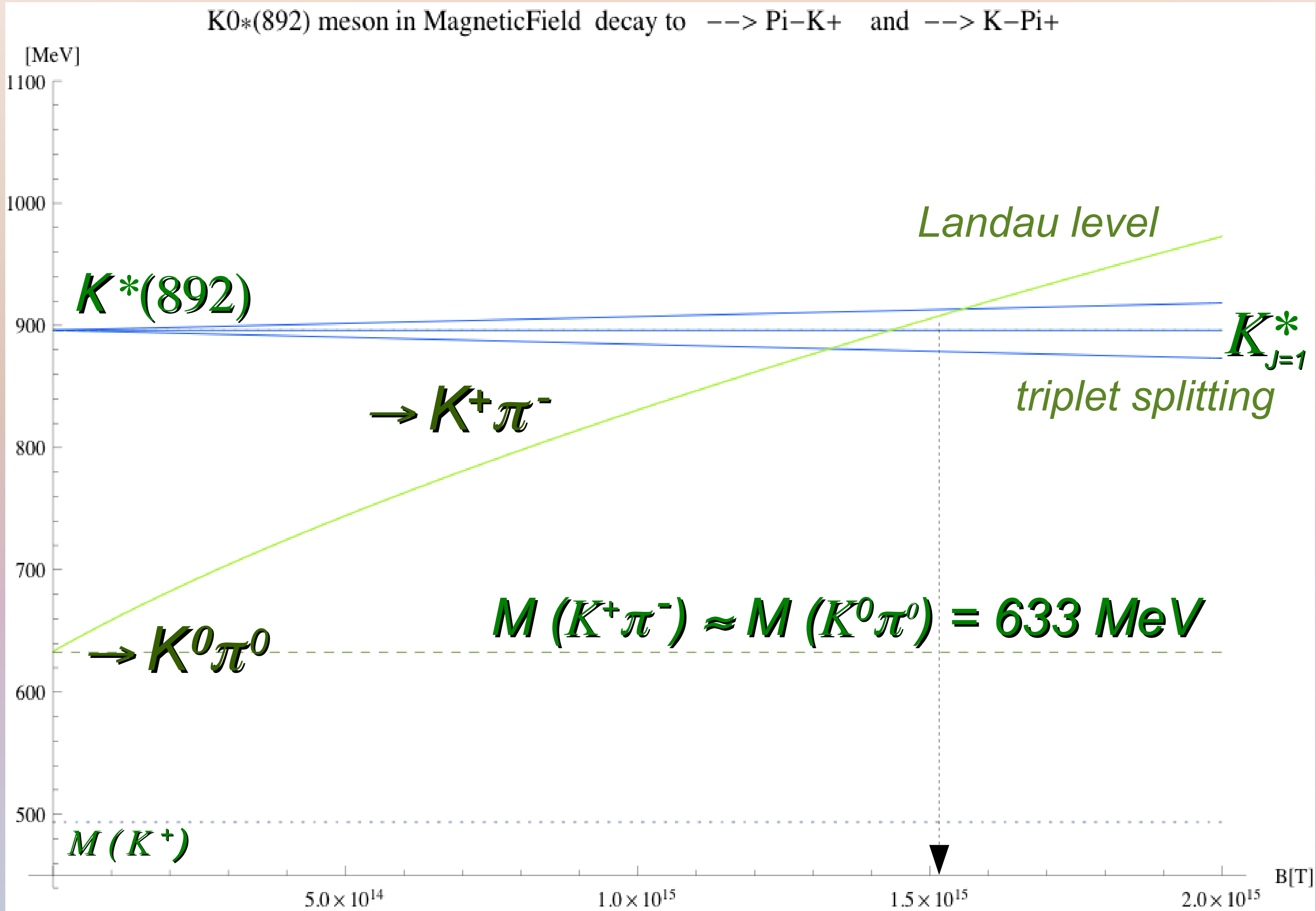
$K^* \to K^+\pi^-$

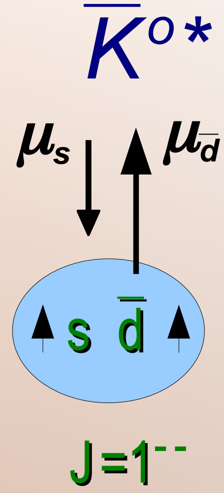
[B = 0]



π^0 $\bar{K}^0$

K*(892) in B = 10^{15} T





$\mu_{\overline{K}^{0*}} = 0.3\mu_N$

$K^* \rightarrow K^+\pi^-$ **closed** at B=$1.5\cdot10^{15}$ [T] $\Rightarrow$ Pb+Pb/LHC

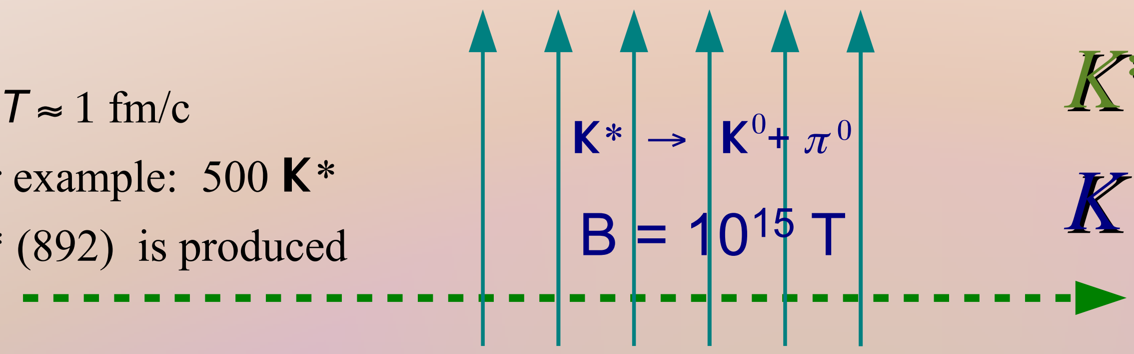
K* reconstructed Yield Depletion

1) "production" in Pb+Pb

at $T \approx 1$ fm/c

for example: 500 **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) In [*B*] field $K^{*0} \rightarrow K^{\pm}\pi^{\pm}$ is closed

and 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 $K^* \rightarrow K^{\pm} + \pi^{\pm}$

SUMMARY for K^{0*} mesons

[$K^{*0}(896) = d\bar{s}$ $\bar{K}^{*0}(896) = s\bar{d}$]

Isospin rule becomes gradually violated as $B \rightarrow 10^{15} T$

$K^{*0} \rightarrow K^{\pm}\pi^{\pm}$ [BR → 66%] reduced → 0% in $B > 1.5 \cdot 10^{15} T$

-> systematically biased K^{*0} yields (assuming BR = 66%)

$K^{*0} \rightarrow K^{0}\pi^{0}$ *is main decay channel in field* $B = 1.5 \cdot 10^{15} T$

-> increases K^{*0} lifetime by factor 3

Overall: possibly significant at LHC/RHIC

(may lead to under-estimated K^{*0} extracted yields)

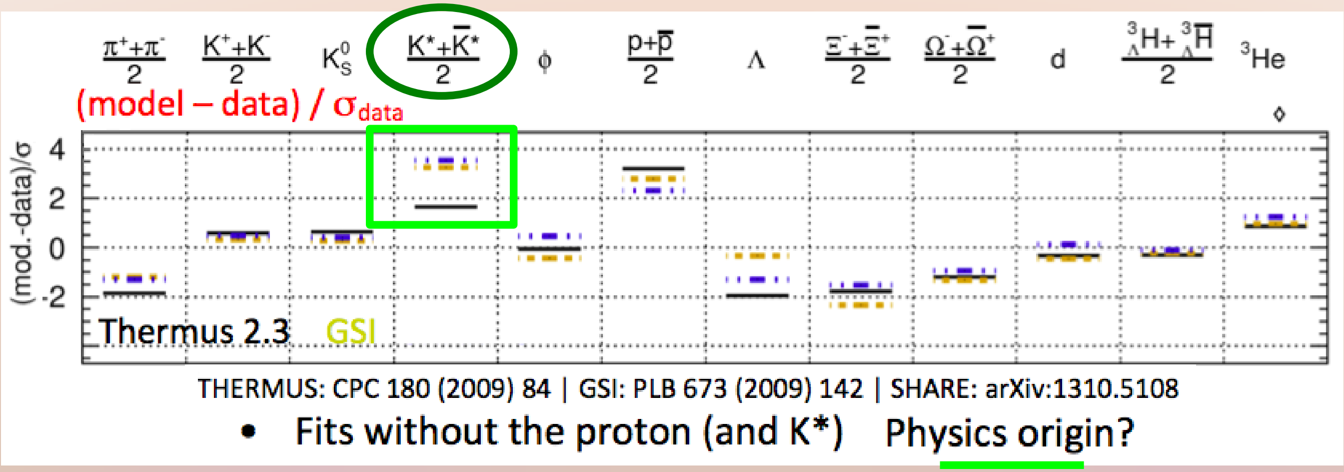
LHC: p+p (7TeV), p+Pb (5TeV), Pb+Pb (2.7TeV)

MC models

DISAGREE

with

Exp. DATA



MESON 2014

ALICE talk

3. June 2014

M.Ploskon

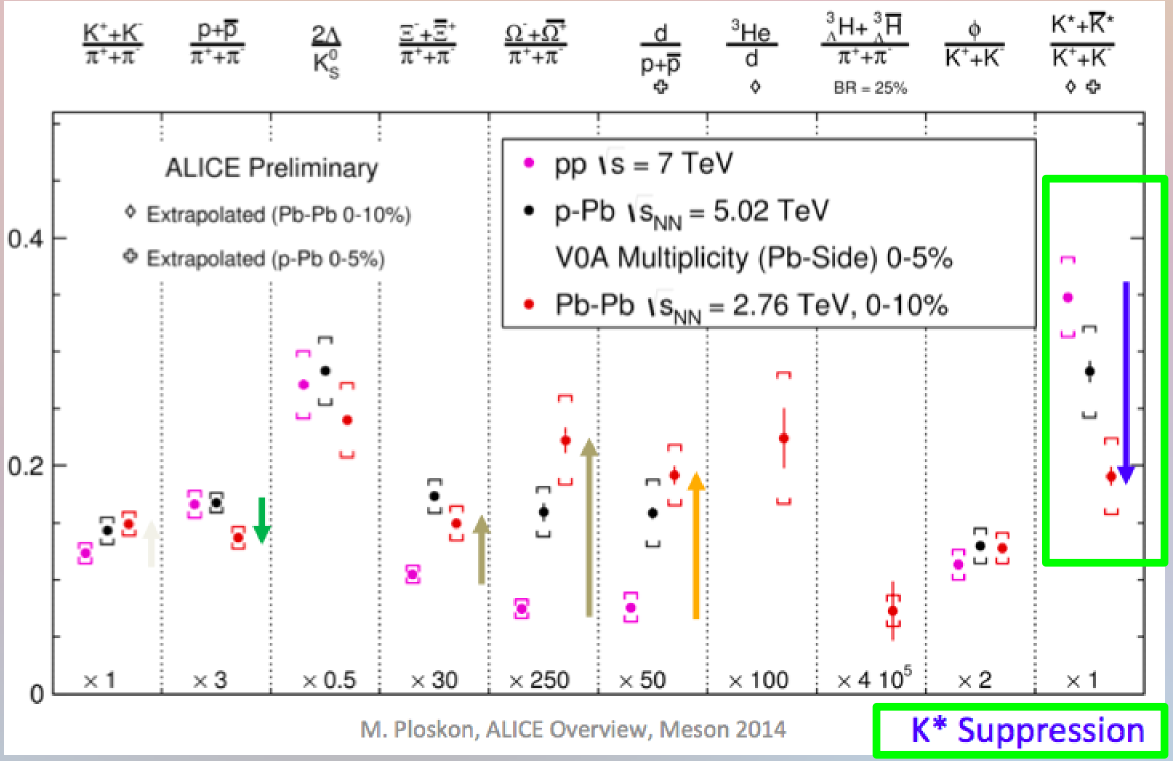
K* suppression:

- observed at LHC

origin is “not clarified”
(rescattering not enough)
to explain exp. data

RHIC data ?

→ **K***(896) in Au+Au



Au+Au at 200GeV/n

Quark Matter 2004

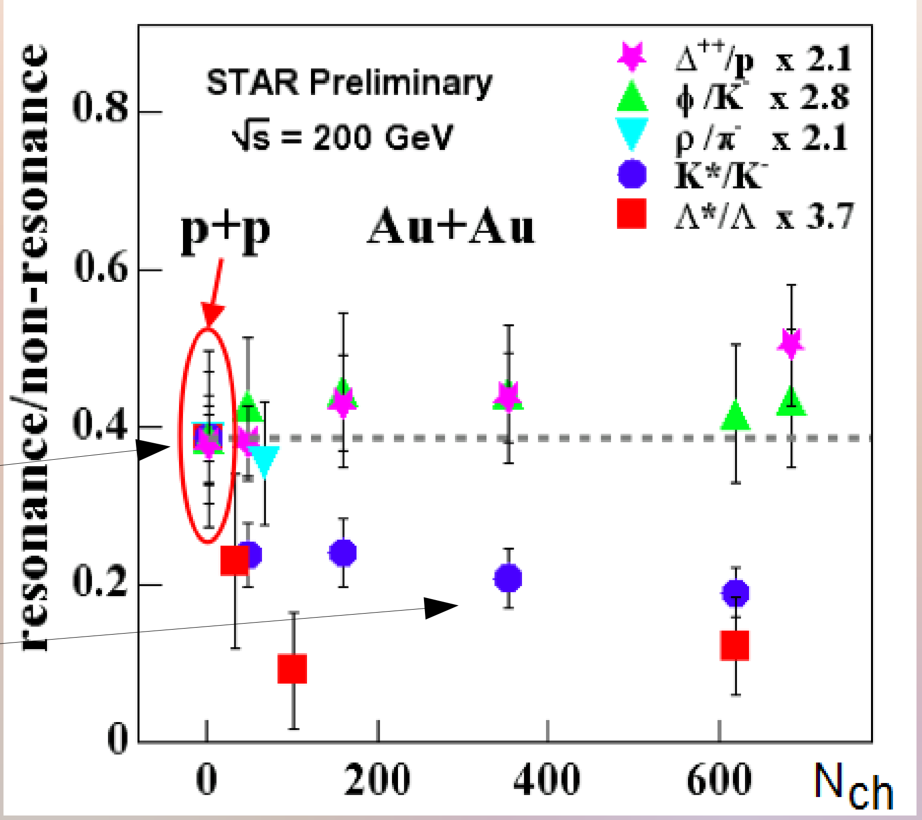
$K^*(896) \rightarrow K^{\pm} + \pi^{\pm}$

observed yield in Au+Au

P+P value

sudden drop for Au+Au

weak decrease with N_{ch}



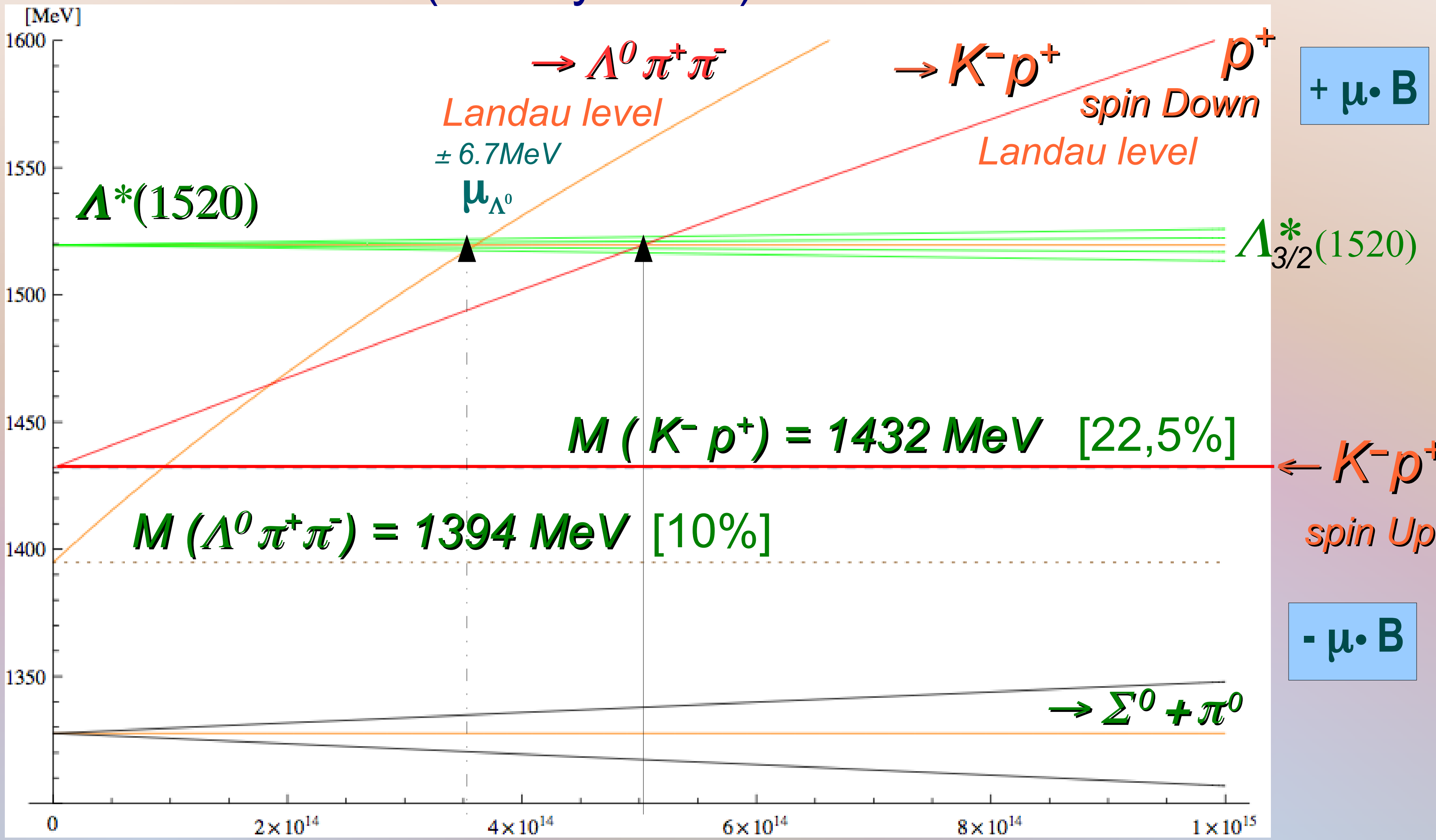
Magnetic field [B] in Au+Au

a) strong enough to influence K* decays ?

b) effect should depend on Beam Energy = BEScan

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

(first-try result)



50% decays $\Lambda^* \to K^- p^+$ **closed** at $B=5\cdot10^{14}$[T]

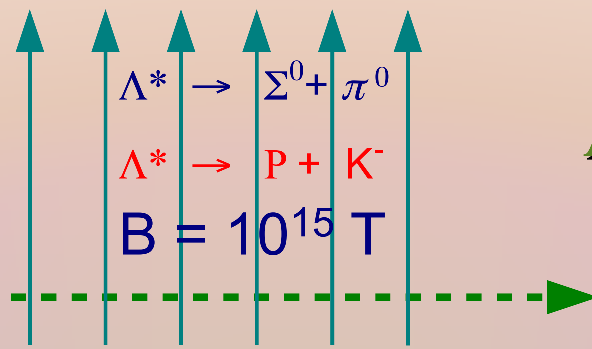
Λ^* reconstructed Yield Depletion:

1) production in Au+Au:

at $T \approx 1$ fm/c

for example: 100 Λ^*

Λ^* (1520) is produced



22.5 %

$\Lambda^* \rightarrow K^- + P$

$B=0$

2) In mag. Field ½ = 11.2 % $\Lambda^* \rightarrow K^- + P$

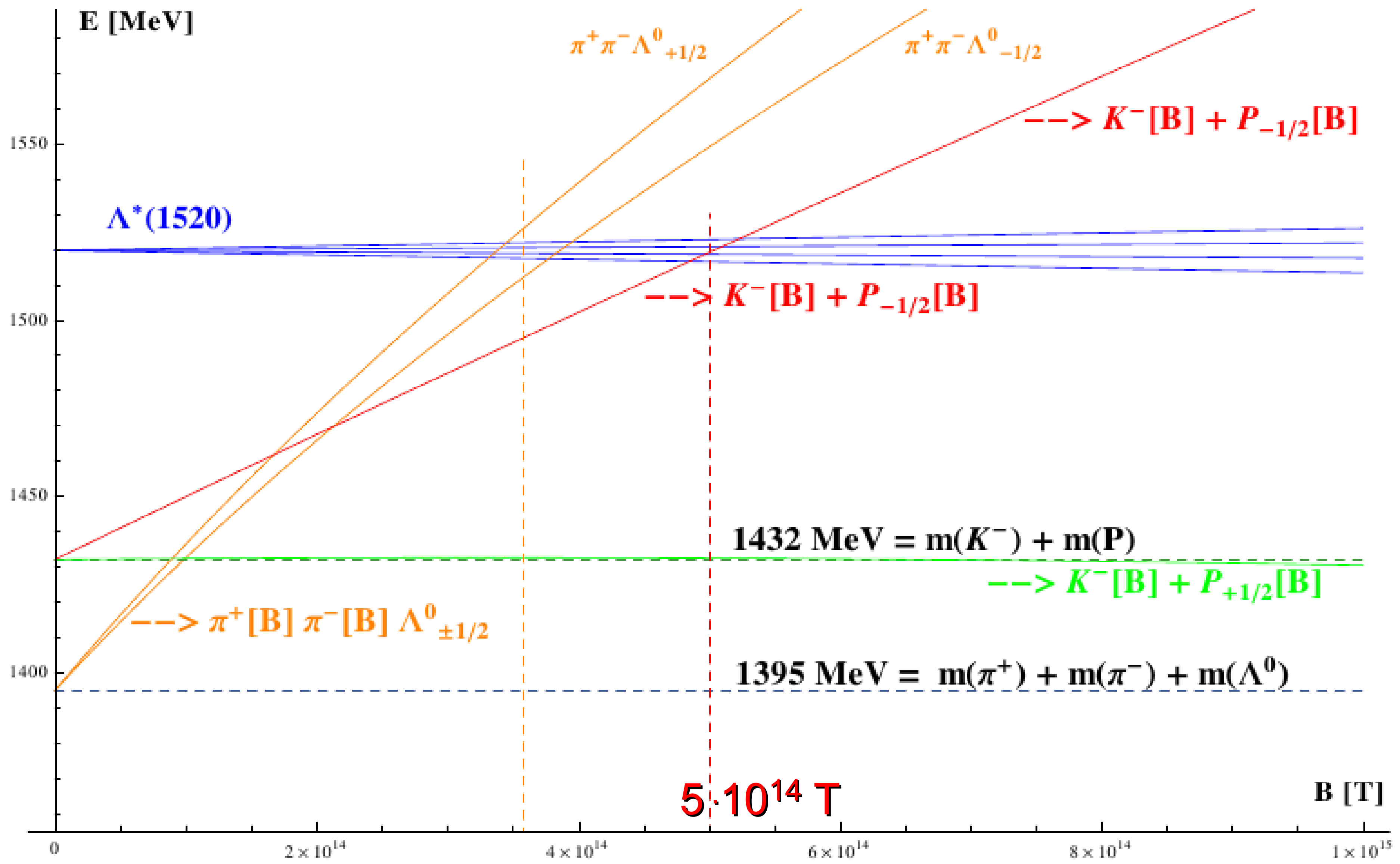
$\Lambda^*(1520)$ can decay via other channels, e.g. $\Lambda^* \rightarrow \Sigma^0 + \pi^0$

3) Later, B=0: remaining $\Lambda^* \rightarrow K^- + P$ *reconstructed*

$\Rightarrow$ Yield underestimated: assuming 22.5% for $\Lambda^* \rightarrow K^- + P$

$\Rightarrow$ Λ^* *signal / background decreases* *(Λ^* becomes invisible ?)*

Λ*(1520) in static B < 10^{15} T



SUMMARY: Λ^* (1520) baryon

$\Lambda^* \rightarrow \Lambda^0 \pi^- \pi^+$ becomes closed in $B \approx 3.10^{14} T$ (BR=10%)

$\Lambda^* \rightarrow K^- p^+$ [50% of decays closed] in $B > 5 \cdot 10^{14} T$

-> syst. lower Λ^* yield (if assumed BR = 22,5%)

-> signal/backgr. is affected, Λ^* peak may disappear

It may be related to LHC Pb+Pb / RHIC Au+Au

Au+Au at 200GeV/n

Quark Matter 2004

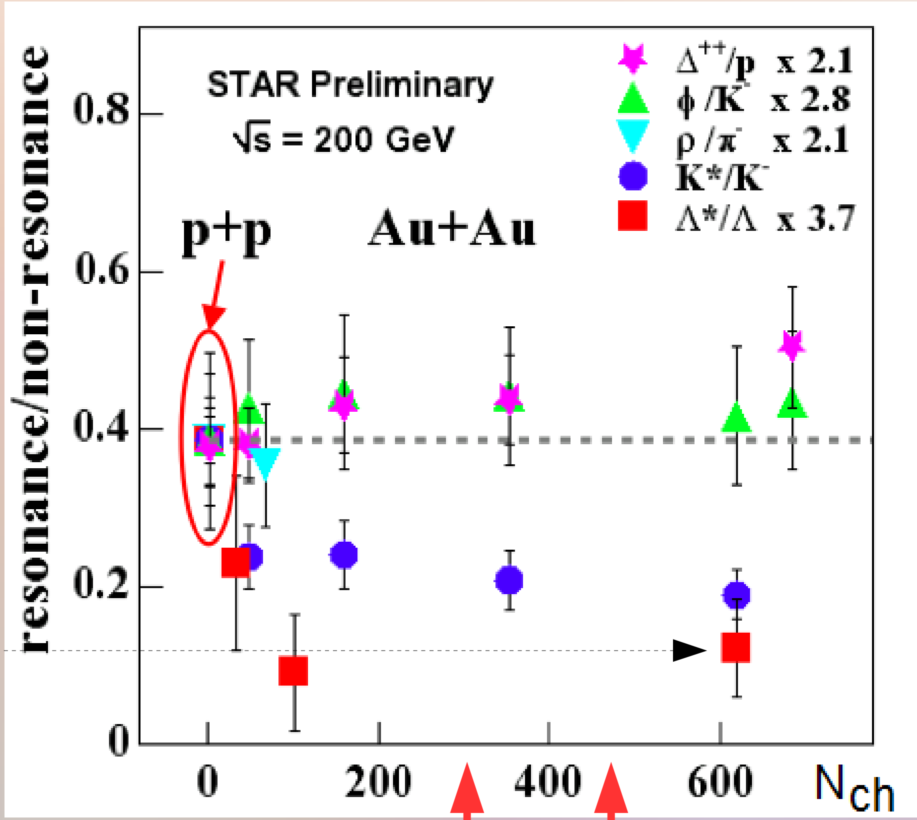
$\Lambda^*(1520) \rightarrow K^- + Proton$

observed in peripheral Au+Au
(yield decreases with centrality)

disappears in non-central

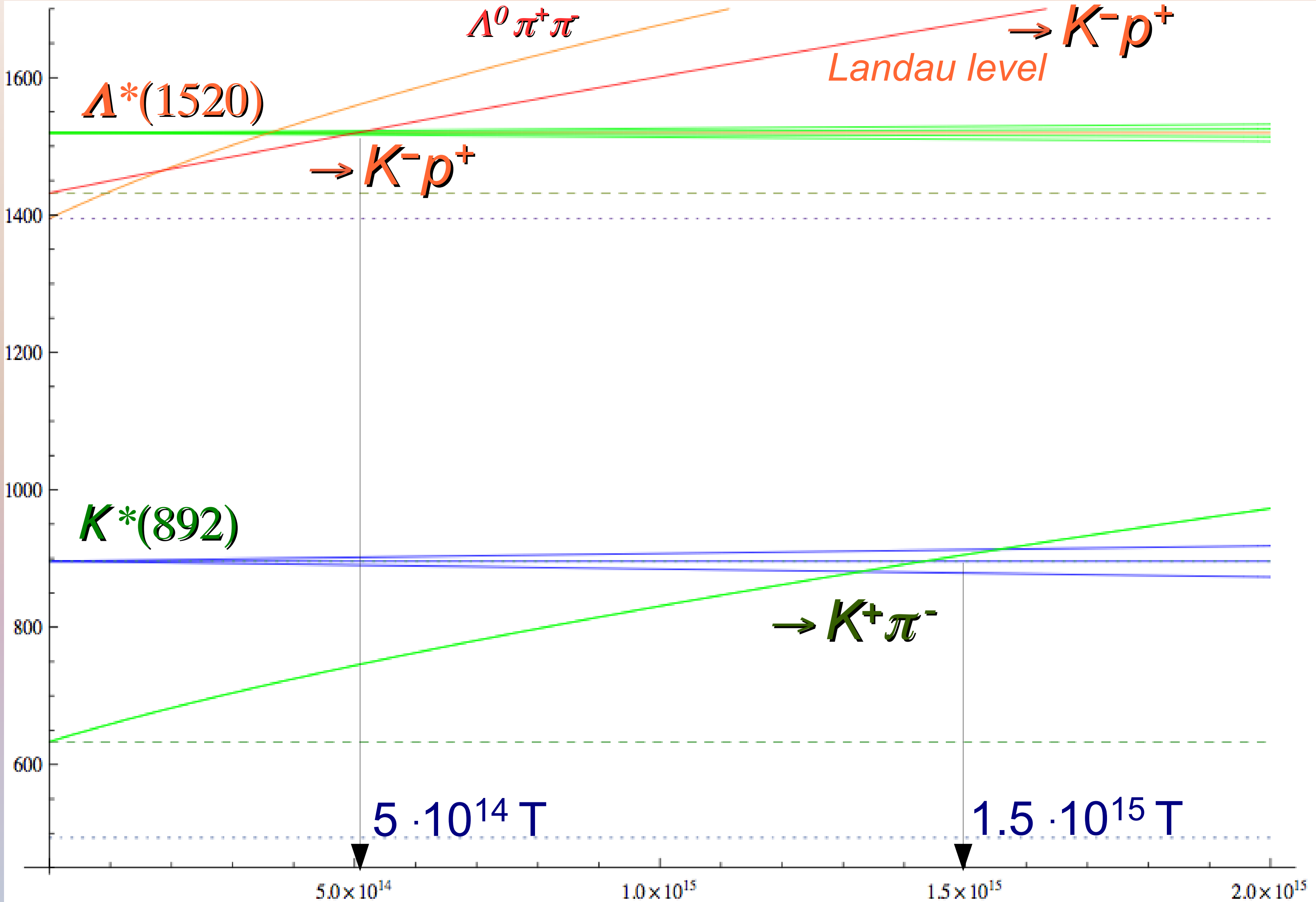
seen again: “central” Au+Au

(statistics of B-field effect ?)



Note: Magnetic field [B]
a) is maximal for non-central collisions
b) should decrease in ultra-central Au+Au coll.

K*(892), Λ*(1520) in B=10^{15}T



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

$D^{\pm *}$ meson strong decays

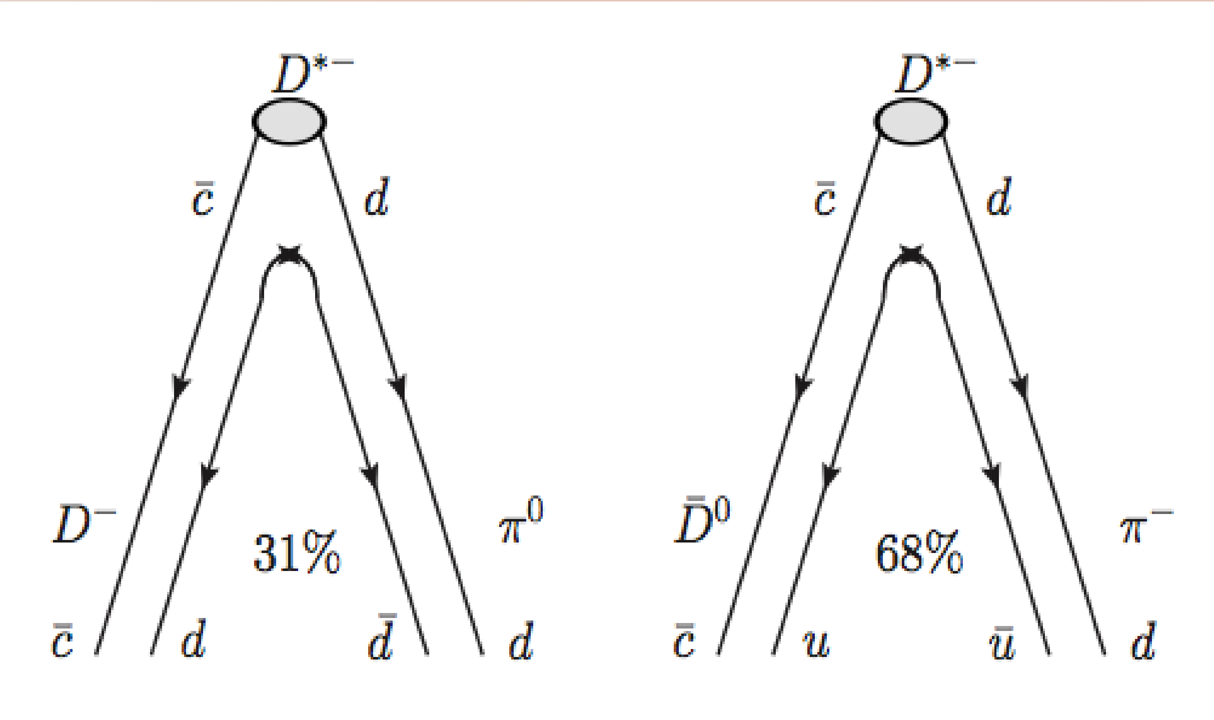
$D^{*\pm} \to D^{\pm}\pi^{0}$ (30.7%) $D^{*\pm} \to D^{0}\pi^{\pm}$ (67.7%) $D^{*\pm} \to D^{\pm}\gamma$ (1.6%)

isospin conservation

Clebsch-Gordan coefficients

Radiative decay is here

(phase-space reason)



$D^{*0} \to D^{0}\gamma$ (38%)

$D^{*0} \to D^{0}\pi^{0}$ (61.9%)

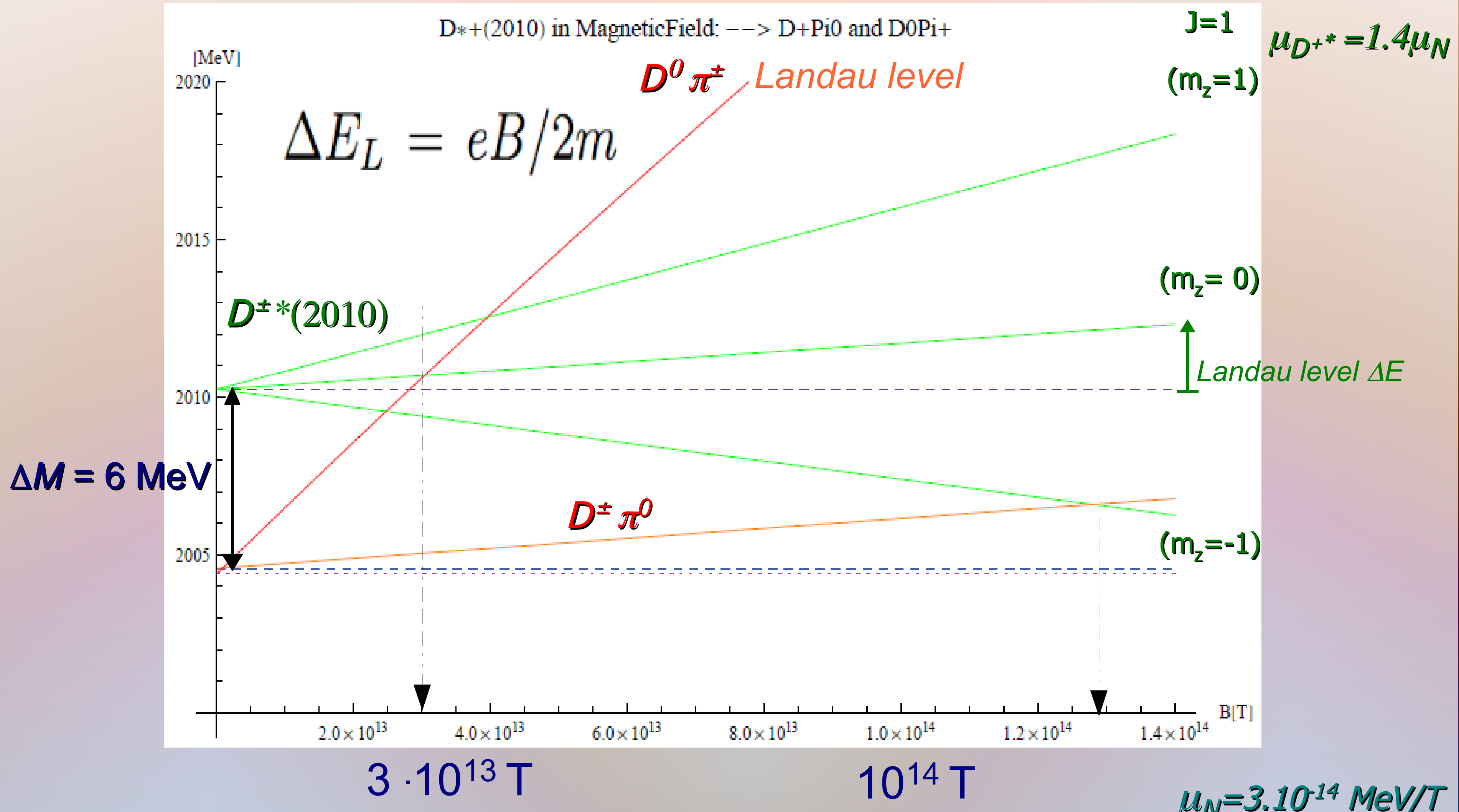
$D^{*0} \not\to D^{\pm} + \pi^{\pm}$

$m(D^{*0}) < m(D^{\pm}) + m(\pi^{\pm})$

decay is forbidden

What shall happen in the magnetic field $B = 10^{13} - 10^{15}$ T ?

$D^{\pm *}(2010)$ in field $B=10^{14}$T



$D^{\pm *}\rightarrow D^0\pi^\pm$ **affected** at 3.10^{13}T, ($D^{+*}\rightarrow D^+\pi^o\approx$ unaffected)

SUMMARY: $D^{*\pm}$ mesons:

*D**(2010)

$D^{*\pm} \to D^0 \pi^\pm$ is closed in $B > 3 * 10^{13}$ T !

→ relatively small B fields

→ due to small ΔM = 6 MeV energy difference

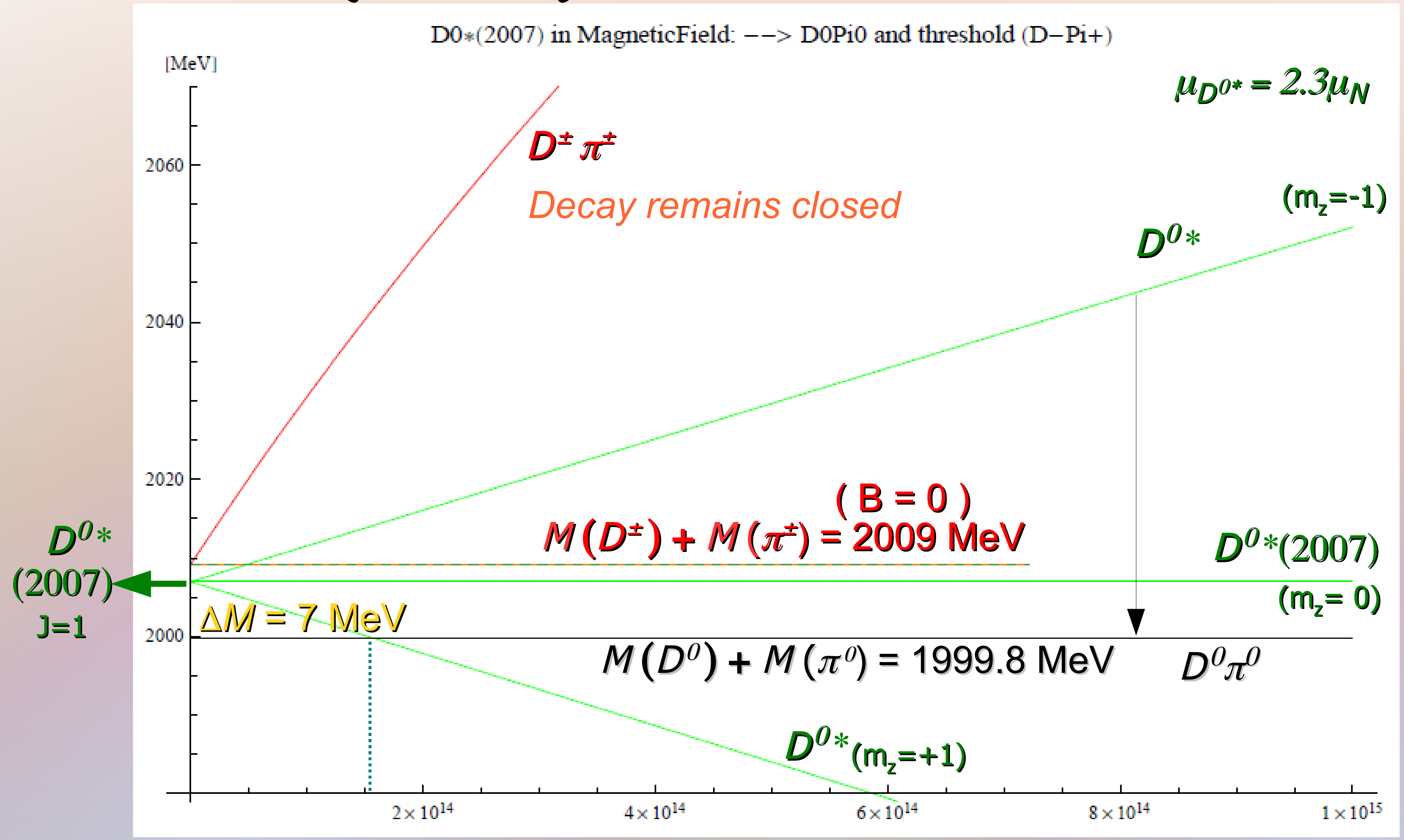
$D^{*\pm} \to D^\pm \pi^0$ *becomes main decay channel in* $B > 3 * 10^{13}$ *T*

→ isospin rule violated for $D^{*\pm}$ decays in B field

→ longer $D^{*\pm}$ lifetime in [B]

→ $D^{*\pm} \to D^\pm \gamma$ *BR increases ⇒ 5%*

$D^{0*}(2007)$ in field B → 10^{15}T



$1.5 \cdot 10^{14}$ T

$D^{*0} \to D^0\pi^0 \quad (61.9\%)$ → **52 %**

48% ← $D^{*0} \to D^0\gamma \quad (38\%)$

SUMMARY II: D^{*o}-mesons:

D^*(2007)

D^{*0} decays in [B]

$D^{*0} \rightarrow D^{\pm}\pi^{\pm}$ remains closed in any $B = 0 \leftrightarrow 10^{15} T$

$D^{*0} \rightarrow D^0\pi^0$ in $B > 1.5 \cdot 10^{15} T$ [BR → 52%] reduced width

-> systematic bias of D^{*0} yield (if assumed BR=61.9%)

$D^{*0} \rightarrow D^0\gamma$ 38% = BR → 48% in $B = 1.5 \cdot 10^{15} T$

-> only small change in D^{*0} lifetime

Overall: not a significant effect in strong B field

Ξ^{0*} baryon resonance decays

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

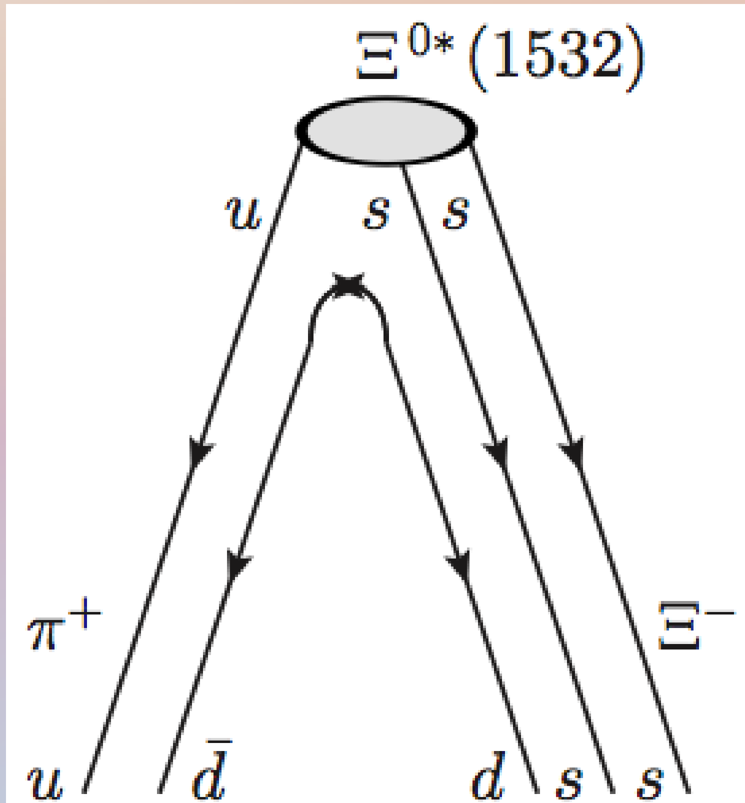
Radiative decay ~ 1%
(assumed here)

isospin conservation

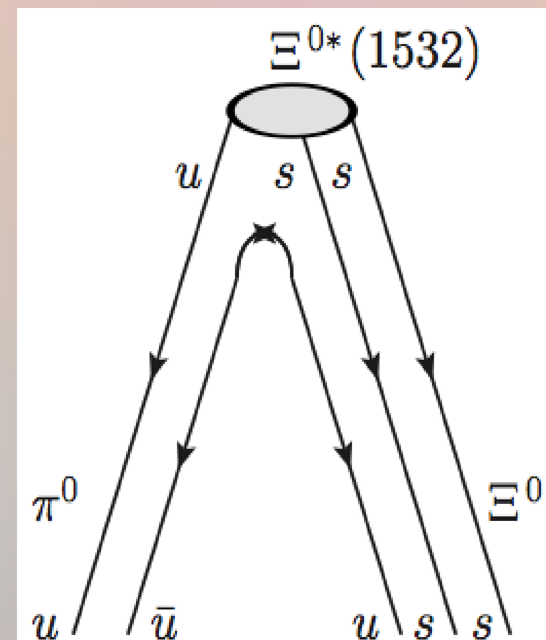
$$\Xi^{*0}_{|\frac{1}{2},\frac{1}{2}\rangle} \to \sqrt{\frac{2}{3}}\, \Xi^-_{|\frac{1}{2},-\frac{1}{2}\rangle} \pi^+_{|1,+1\rangle} - \sqrt{\frac{1}{3}}\, \Xi^0_{|\frac{1}{2},-\frac{1}{2}\rangle} \pi^0_{|1,0\rangle}$$

Clebsch-Gordan coefficients

66%

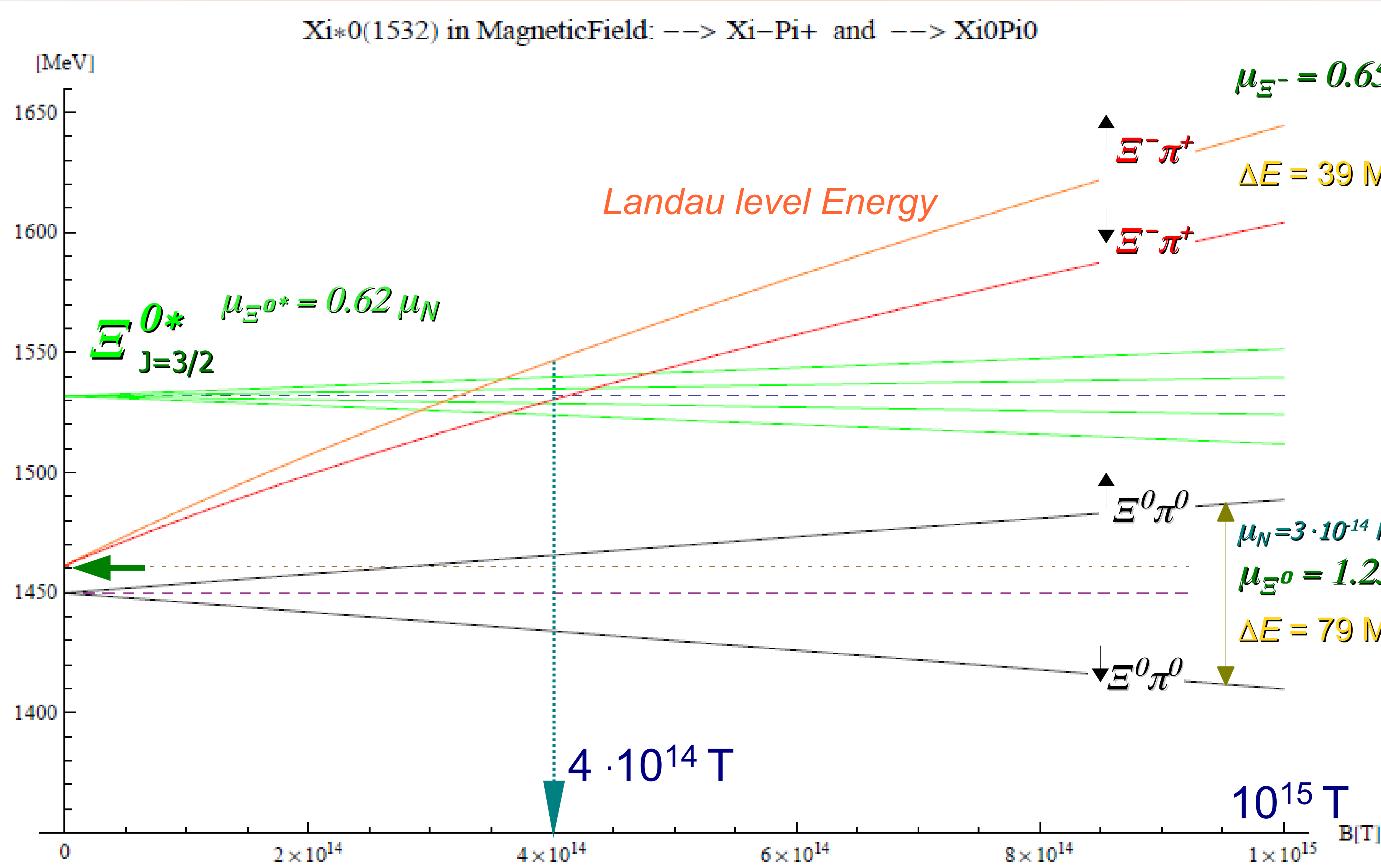


33%



What shall happen in the magnetic field $B = 10^{13} – 10^{15}$ T ?

Ξ^{0*} baryon in field B → 10^{15}T



$\Xi^{*0} \to \Xi^-\pi^+ \; (66\%)$ | **→ 0 %** | **99% ←** | $\Xi^{*0} \to \Xi^0\pi^0$

SUMMARY ON Ξ^{0*}

1) Suppression of $\Xi^{*0} \rightarrow \Xi^{\pm}\pi^{\pm}$ decay in [B]

$\Xi^{*0} \rightarrow \Xi^{\pm}\pi^{\pm}$ (closed) in static $B > 4{*}10^{14}$ Tesla

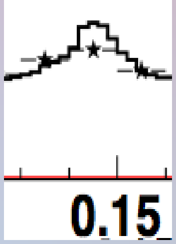
$\Xi^{*0} \rightarrow \Xi^{0}\pi^{0}$ enhanced [33% $\rightarrow$ 100%] main channel

-> increased lifetime τ by factor 3x [for $B > 4{*}10^{14}$ T]

-> isospin (BR) not conserved: Ξ^{*0} decays $B > 5{*}10^{13}$ T

2) In A+A collisions (RHIC, LHC)

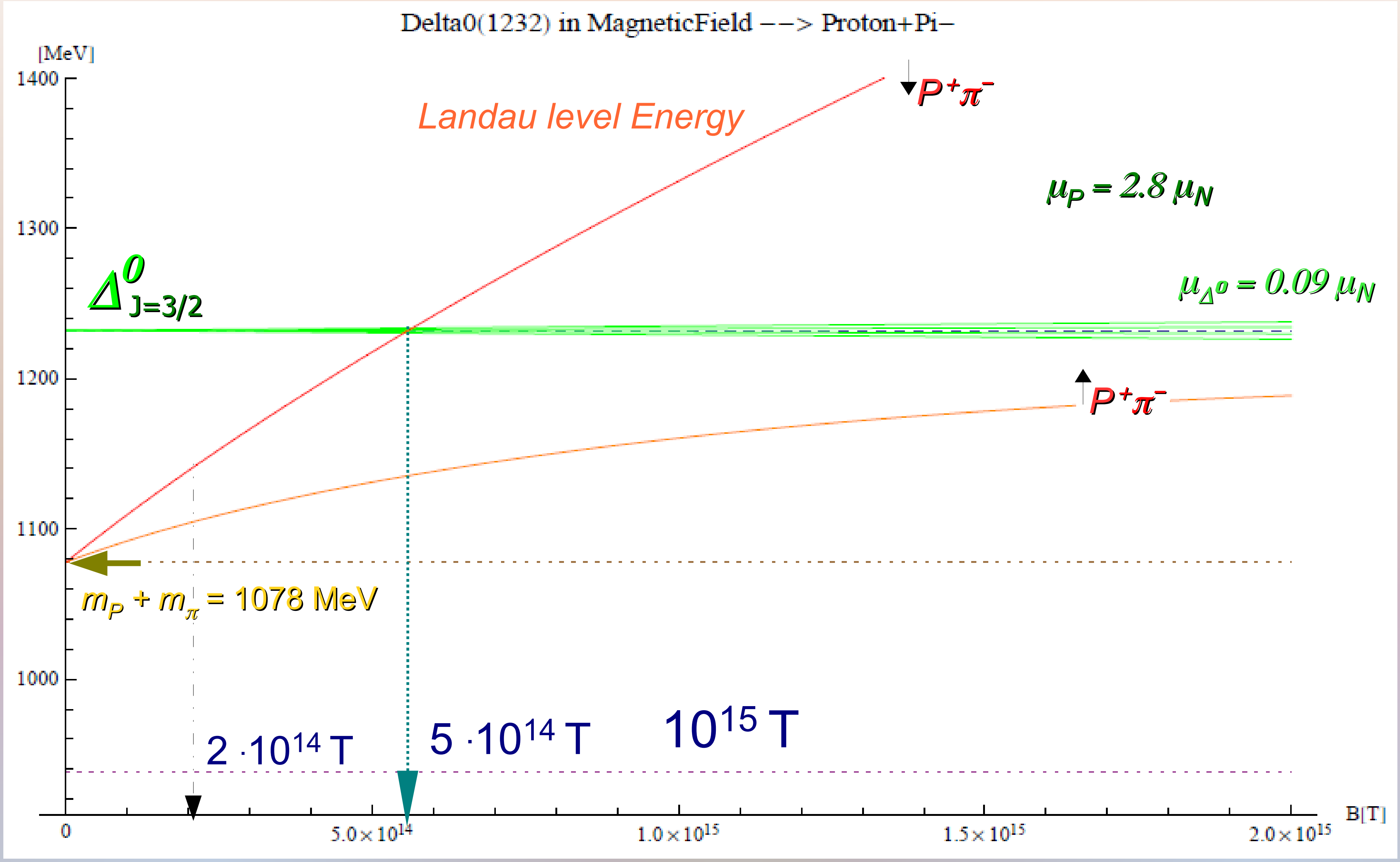
-> reconstructed Ξ^{*0} yield lower than expected



arXiv: **0907.0617**

3) possibly related to Ξ^{*0} RHIC puzzle (Phys. Rev. C81, 034901)

Δ^0 baryon in field B → 10^{15}T



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

COMPARISON
Lifetime vs Critical Field

	Width [MeV]	Lifetime [fm/c]	B critical [10^{14} T]	Channel
$\rho^o(770)$	150	1.3	20	$\pi^+\pi^-$
$\Delta^o(1232)$	117	1.7	5	$P^+\pi^-$
$K^{o*}(892)$	50	4	15	$K^\pm\pi^\pm$
$\Lambda^*(1520)$	16	13	5	P^+K^-
$\Xi^{o*}(1532)$	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	$D^o\pi^o$

CONCLUSIONS.

1) $\rho(770)$, $\Delta(1232)$, $K^{*}(892)$ decays

- can be influenced by magnetic fields $B=10^{14}$-10^{15} T in HIC
  - -> reduced widths, closed decay channels
  - -> isospin conservation (BR) becomes violated

2) Strong decays of Λ^*, Ξ^* resonances

sensitive to moderate fields $B \approx 10^{14}$ T

→ but: lifetimes are 5-10x longer than B-field

3) Decay of D* mesons ? (static B needed)

→ they live 1000x longer than B fields in HIC

THANK YOU

***For* ATTENTION**

BACKUP: Magnetic moments

baryon	m [MeV]	quarks	μ_{exp}	δ_μ	μ
p	938.3	du-u	2.79	0	2.79
n	939.6	du-d	-1.91	0	-1.91
Λ	1115	du-s	-0.613	0	0.613
Σ^+	1189	us-u	2.46	9 %	2.67
Σ^-	1197	ds-d	-1.16	6 %	-1.09
Ξ^o	1315	us-s	-1.25	13%	-1.43
Ξ^-	1322	ds-s	-0.65	24%	-0.49
Ω^-	1672	sss	-2.02	9 %	-1.84
Δ^{++}	1232	uuu	6.14	(9%)	5.56
Δ^+	1232	uud	2.7	(1%)	2.73

SU(6)

$\mu^* = (4\mu_a - \mu_b)/3$

$\mu^* = \mu_s$

$\mu^* = (4\mu_a - \mu_b)/3$

$\mu^* = (4\mu_a - \mu_b)/3$

spin **3/2**

$\mu^* = \sum \mu_q$

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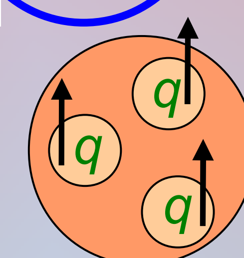


Quark magnetic moments:

quark	Q	μ_q [μ_N]	m^* [MeV]
u	2/3	1.852	338
d	-1/3	-0.972	322
s	-1/3	-0.613	510

Agreement:

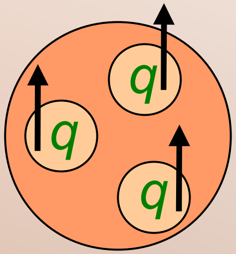
$$\mu_q = \frac{\hbar Q}{2m^*}$$

constituent quark mass

Magnetic moments for *parallel spins*:

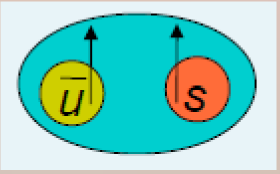
Observe: spin **3/2** baryons

			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

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

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

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

-> $\mu_c = -2\mu_s / 3$

-> $\mu_b = \mu_s / 9$