FOR 5269 Charmonium and glueballs including light hadrons

FOR 5269

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FOR5269: Future methods for studying confined gluons in QCD

https://confluence.desy.de/display/for5269

Spokesperson: Francesco Knechtli

Main Goals:

- **Disconnected contributions in charmonium**
- String breaking in hybrid potentials
- **Glueballs in full dynamical QCD**
- Multilevel algorithms for glueballs
- Novel schemes for molecular dynamics
- Connection of distillation and multi-grid
- Multilevel Monte Carlo for trace estimation

Outline:

- Hadron spectroscopy and Distillation
- New ensembles for glueball measurements
- Charmonium spectrum and glueballs
- Hyperfine splitting of charmonium

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Hadron Spectroscopy and Distillation

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Hadron Spectroscopy on the lattice

- ensemble generation using openQCD
- average over configurations, error $\sim 1/\sqrt{N_{config}}$
- observables: correlation functions in terms of 'quark propagators'

Distillation: quark field smearing $\psi \rightarrow VV^{+}\psi$ using N_v eigenmodes of the

- 3D covariant lattice Laplace operator $\nabla^2 v_i = \lambda_i v_i,\ i = 1 \ldots N_v = O(10^2)$
- $4 \times N_v \times N_T$ inversions => 'quark perambulators' $\tau_{ij}^{\alpha\beta} = v_i^{+}(t_0) D_{\alpha\beta}^{-1} v_j(t_1)$
- meson operators via 'elementals' $\Phi(t) = \rho\, V(t)\, \Gamma\, V(t), \quad \Gamma = 1, \gamma_5, \gamma_i, \nabla_i, \ldots$
- solve generalized eigenvalue problem (GEVP) to access excited states
- optimal profiles from GEVP vectors, Gaussian profiles $\rho_k(\lambda) = e^{-\lambda^2/2\sigma_k^2}$

Glueballs: Laplacian eigenvalue correlator $\mathrm{C^{kl}(t)} = \sum_i \rho_k\, \lambda_i(t_0) \sum_i \rho_l\, \lambda_i(t_0 + t)$

- alternatively, 35 Wilson loop shapes and APE smearing

$N_f = 3 + 1$ Lattice Ensembles

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3 degenerate light quarks (up, down, strange)
1 physical charm quark => η_c ~ 3 GeV

light : m_π ~ 420 MeV, heavy: m_π ~ 1 GeV, glueball ~ 2 GeV!

Coarse lattices: a = 0.054 fm @ β = 3.24

- A0 - light : $16^3 \times 72$
- A1 - light : $32^3 \times 96$
- A2 - light : $48^3 \times 128$

} light quark mass at physical average
=> many decay channels for glueballs!

- A0 - heavy : $24^3 \times 72$
- A1 - heavy : $32^3 \times 96$
- A2 - heavy : $48^3 \times 128$

} - 4000 configurations each (16000 MDUs)
- eigenmodes on every 2nd/4th configuration
=> 2000/1000 charm + light perambulators
=> glueball can only decay into two pions!

Fine lattice: a = 0.043 fm @ β = 3.43

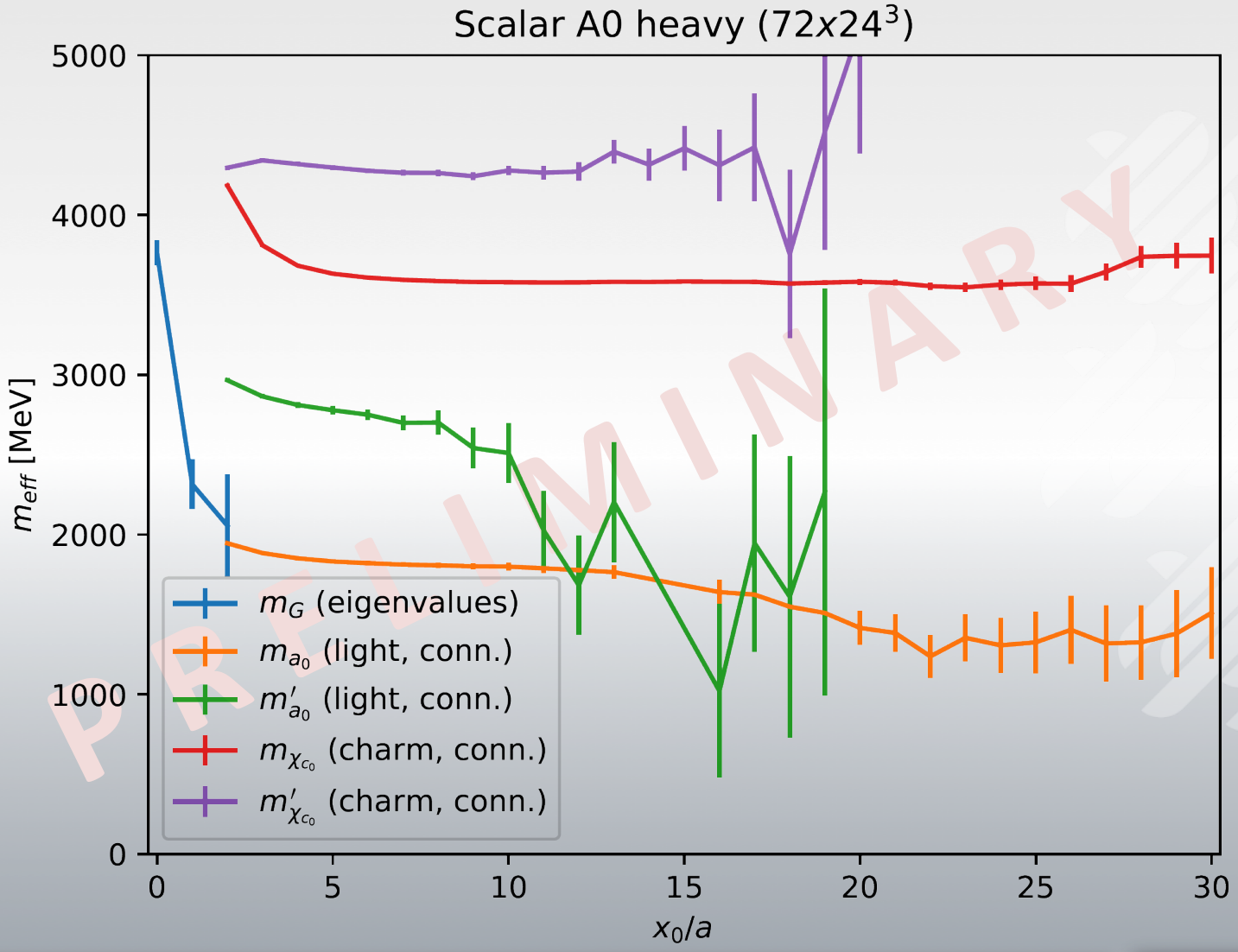
- B - light : $48^3 \times 144$

R. Hoellwieser et al.. Eur. Phys. J. C **80** (2020) no.4. 349

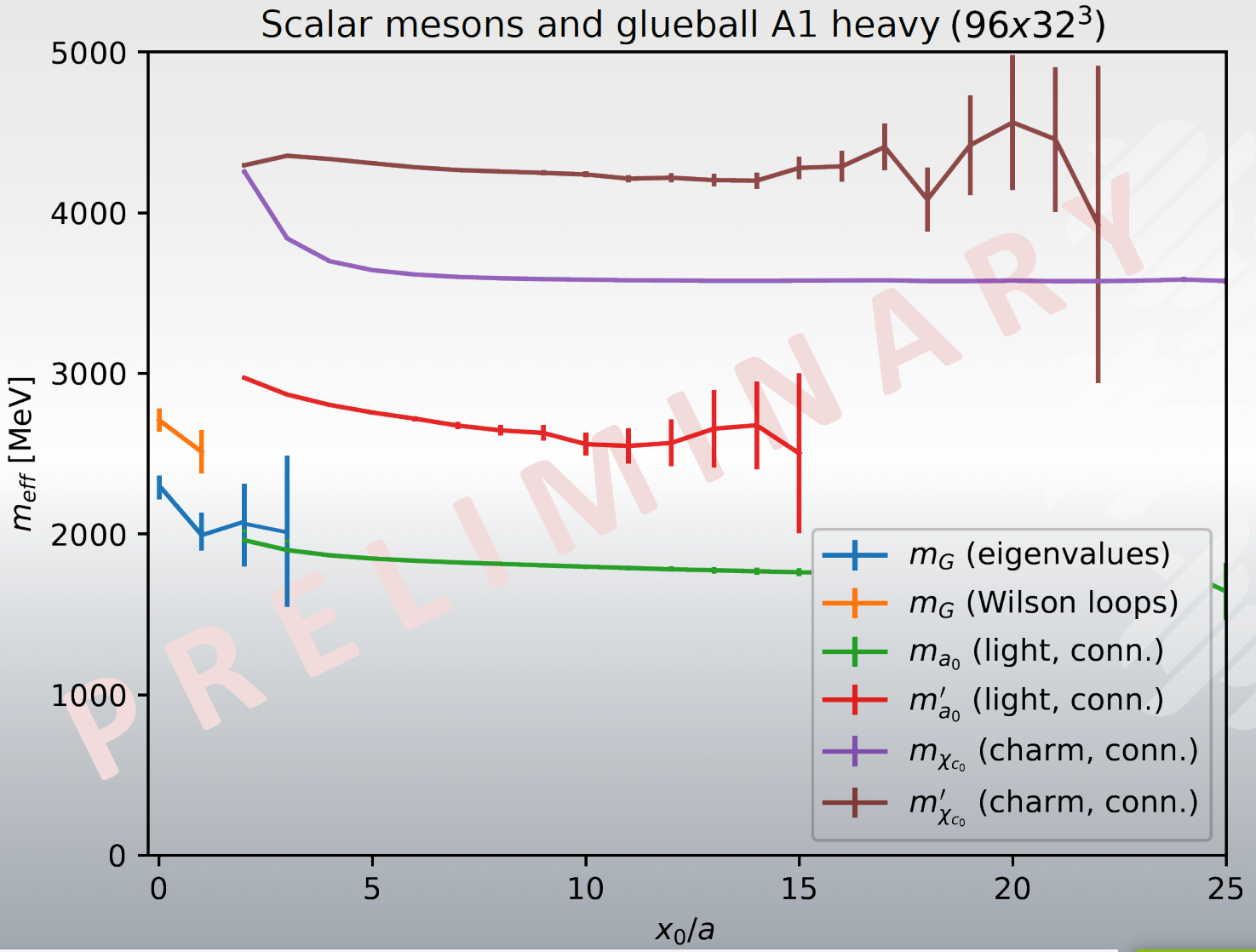
New „heavy pion“ ensembles, preliminary (connected only) results

name	A0 heavy	A1 heavy	A2 heavy
volume	$24^3 \times 72$	$32^3 \times 96$	$48^3 \times 144$
P_{acc}	0.971(1)	0.947(1)	0.924(2)
configs	2000+2000	2000+2000	1000+1000
#eigenvectors	100	200	400
per. T-range	20-52	24-72	30-114
# perc perl	2000/2000	1000/1000	15/5
t_0/a^2	5.115(30)	5.074(16)	5.1093(79)
$\chi^{1/4}$ [MeV]	146(1)	148(1)	147(1)
m_π [MeV]	**1002(4)**	**1000(2)**	**998(2)**
m_{η_c} [MeV]	**2979(3)**	**2980(1)**	**2982(1)**
$m_{J/\Psi}$ [MeV]	**3132(2)**	**3132(1)**	**3132(1)**
$\frac{m_{J/\Psi} - m_{\eta_c}}{m_{\eta_c}}$	**0.0512(13)**	**0.0510(8)**	**0.0503(4)**
m_{a_0} [MeV]	1786(41)	1795(25)	very preliminary
$m_{\chi_{c0}}$ [MeV]	3541.5(6.0)	3542.7(4.6)	glueball mass from
”glueball” 0^{++}	2090(310)	2120(140)	Laplacian eigenvalues

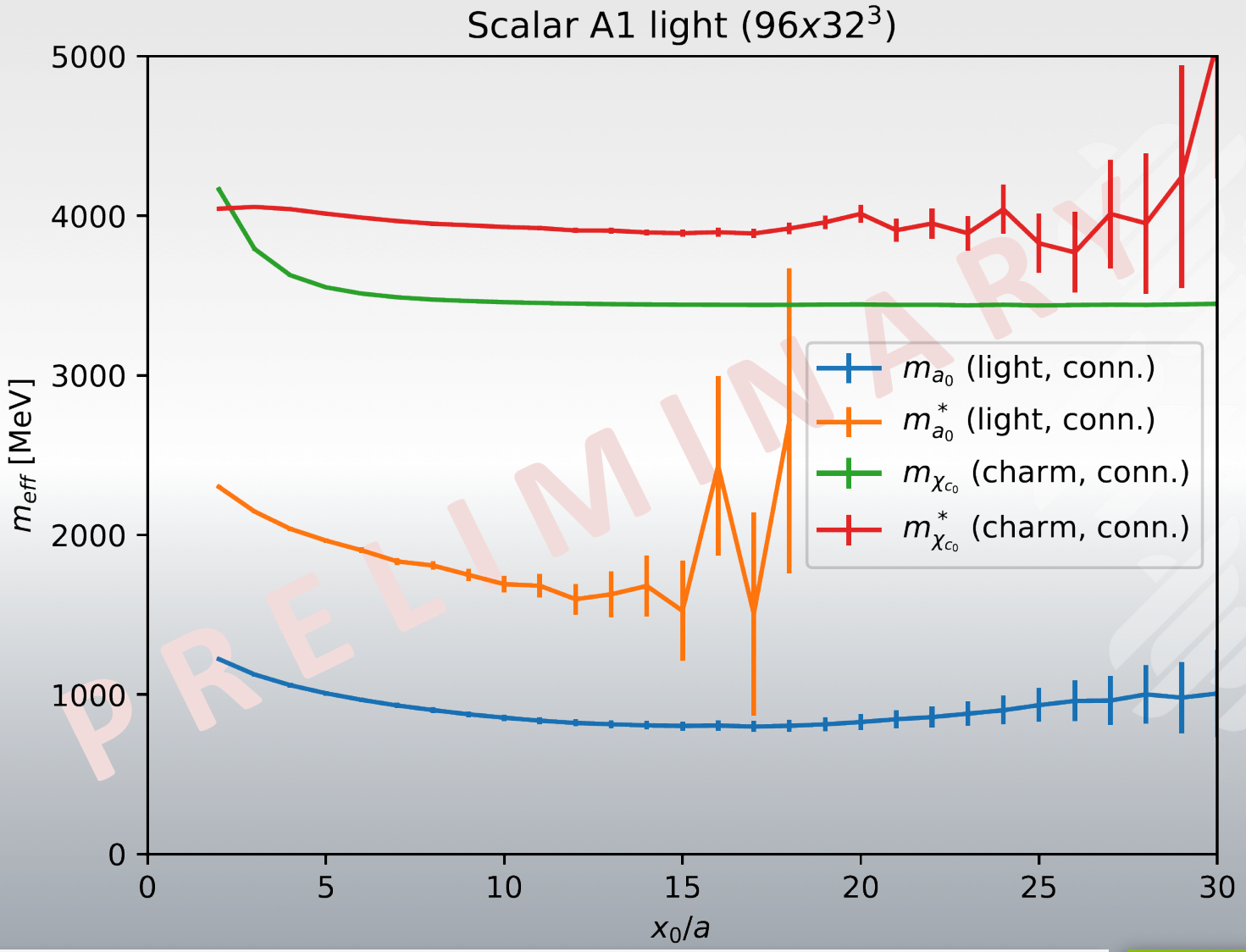
Light and charm scalar mesons and glueball on A0 heavy (72 x 24^3)



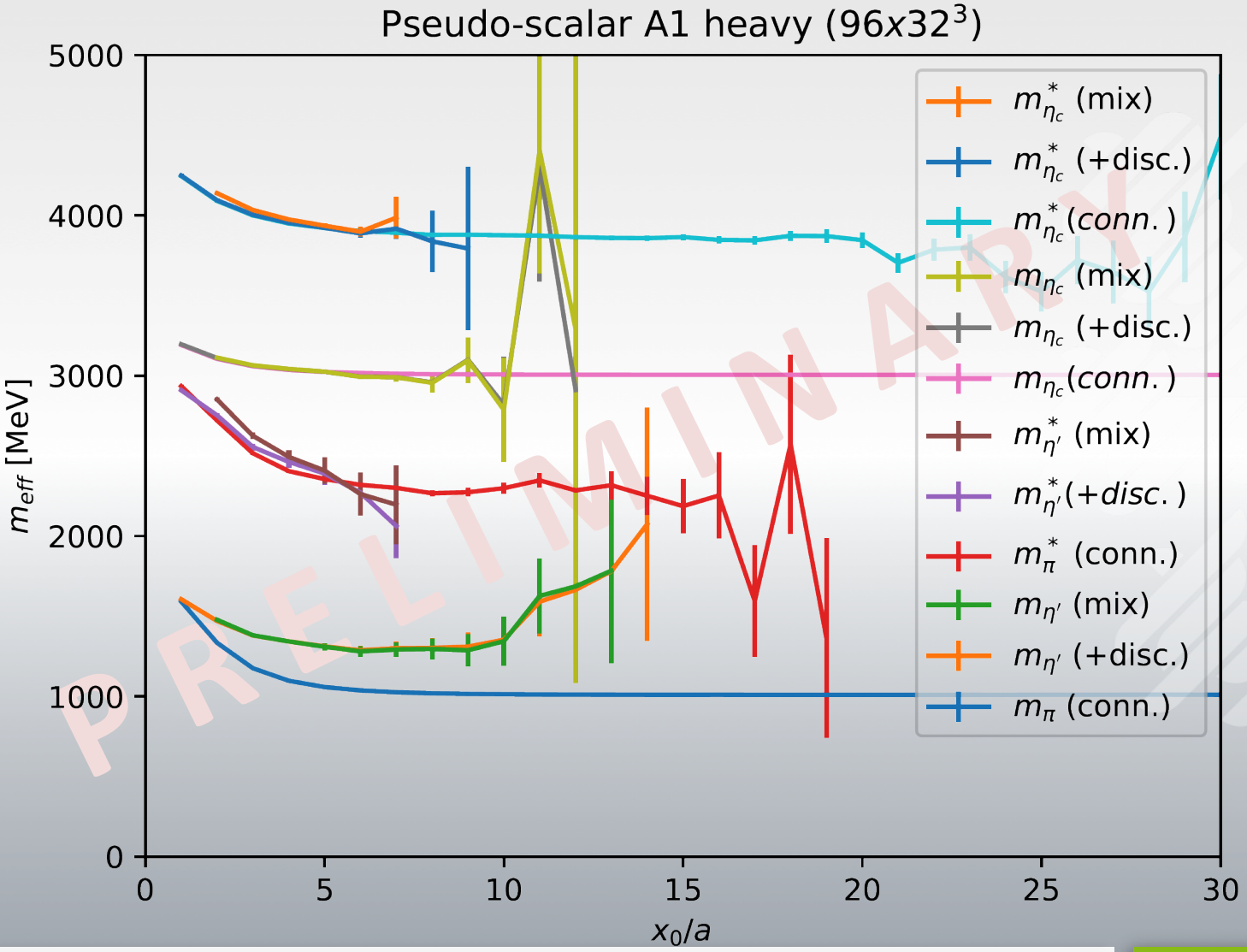
Light and charm scalar mesons and glueball on A1 heavy (96 x 32^3)



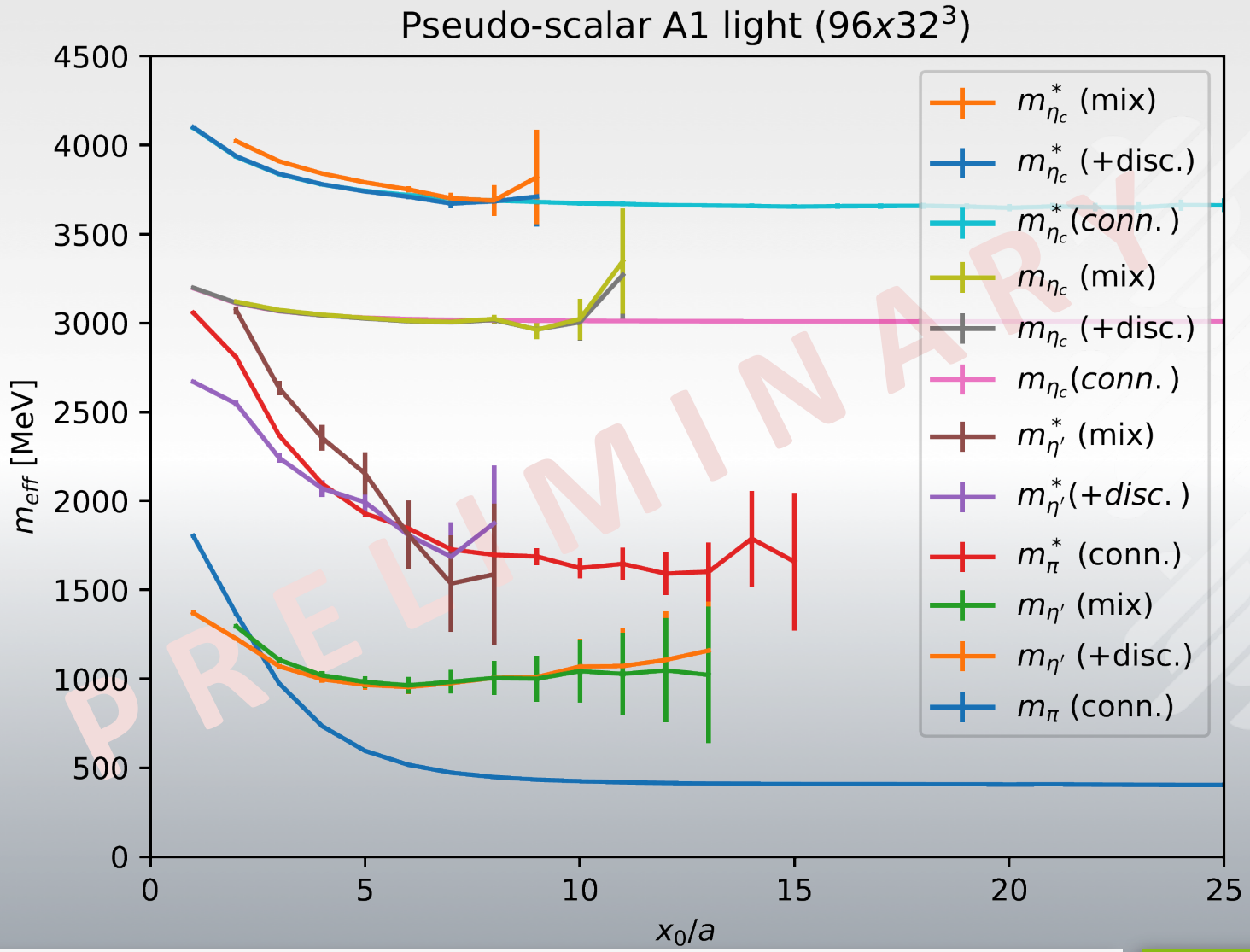
Light and charm scalar mesons and glueball on A1 light (96 x 32^3)



Light and charm pseudo-scalar mesons on A1 heavy (96 x 32^3)

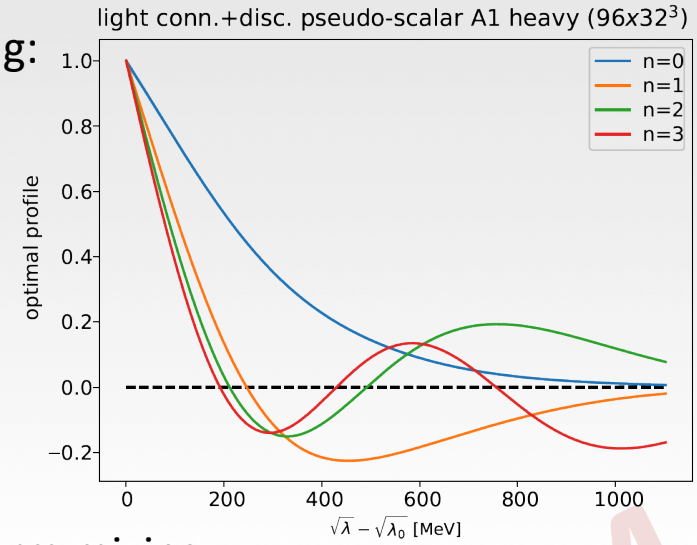


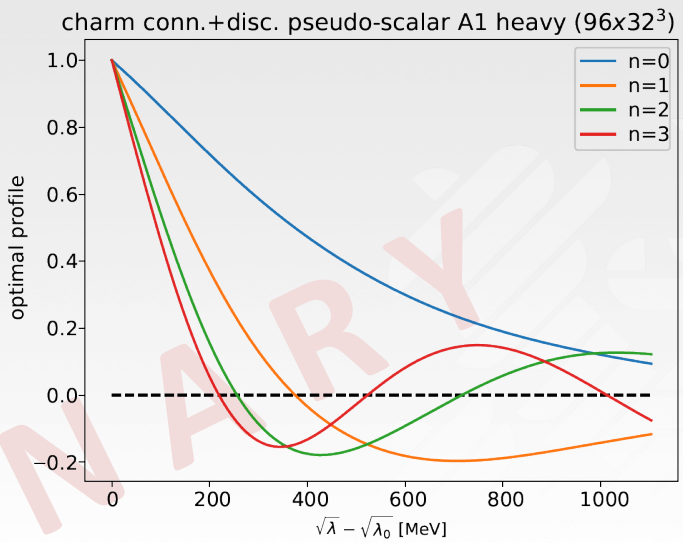
Light and charm pseudo-scalar mesons on A1 light (96 x 32^3)



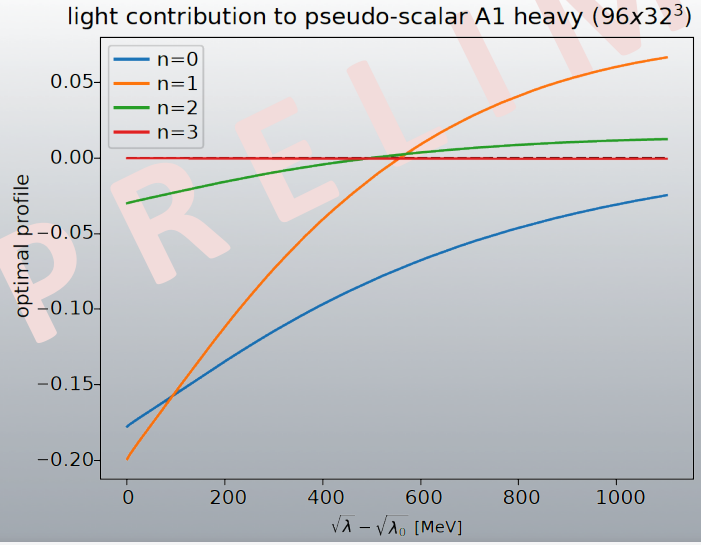
Optimal distillation profiles for pseudo-scalar mesons on A1 heavy

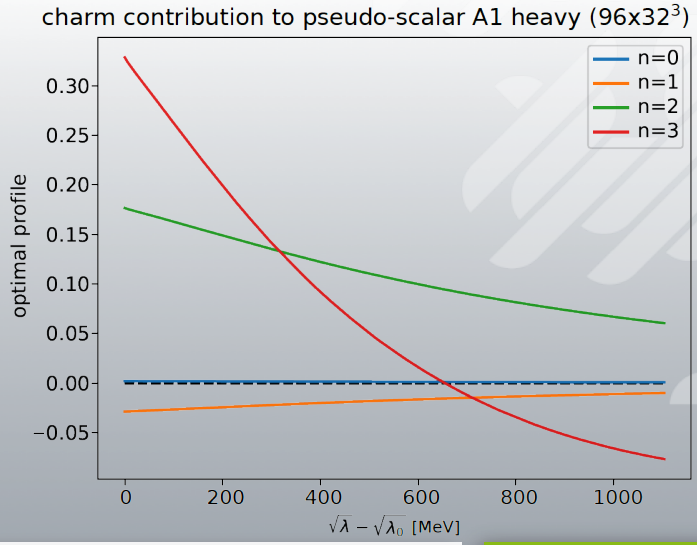
no mixing:





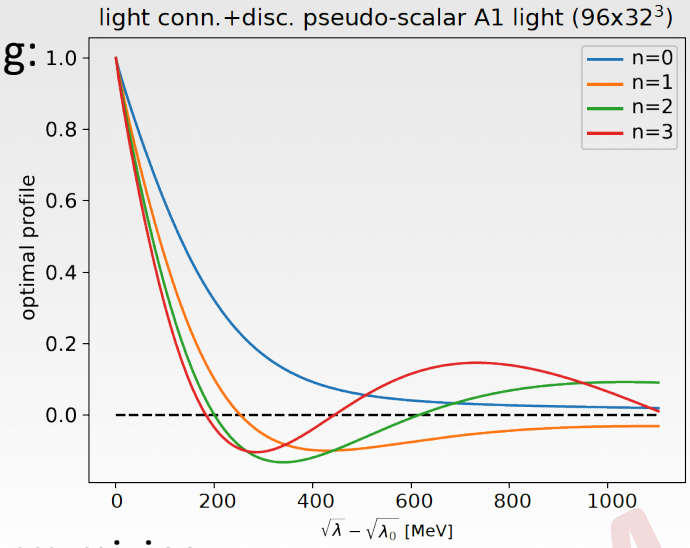
light/charm mixing:

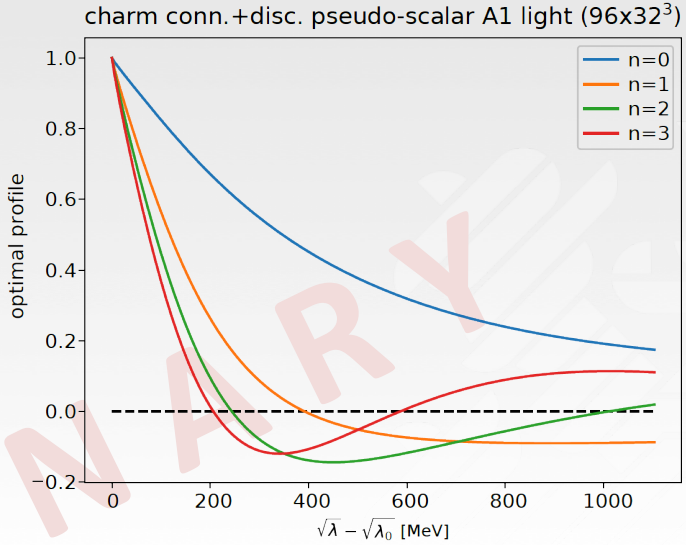




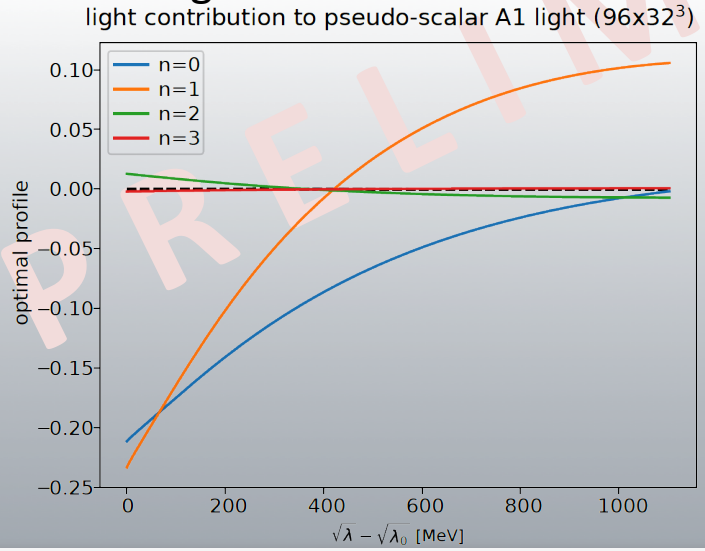
Optimal distillation profiles for pseudo-scalar mesons on A1 light

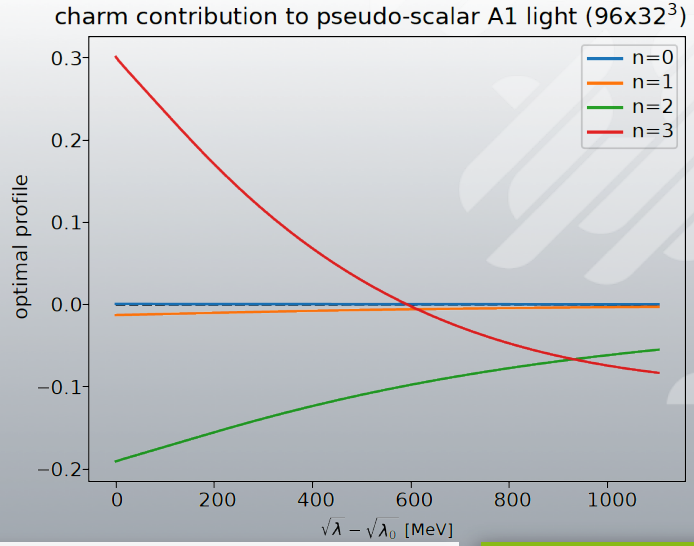
no mixing:



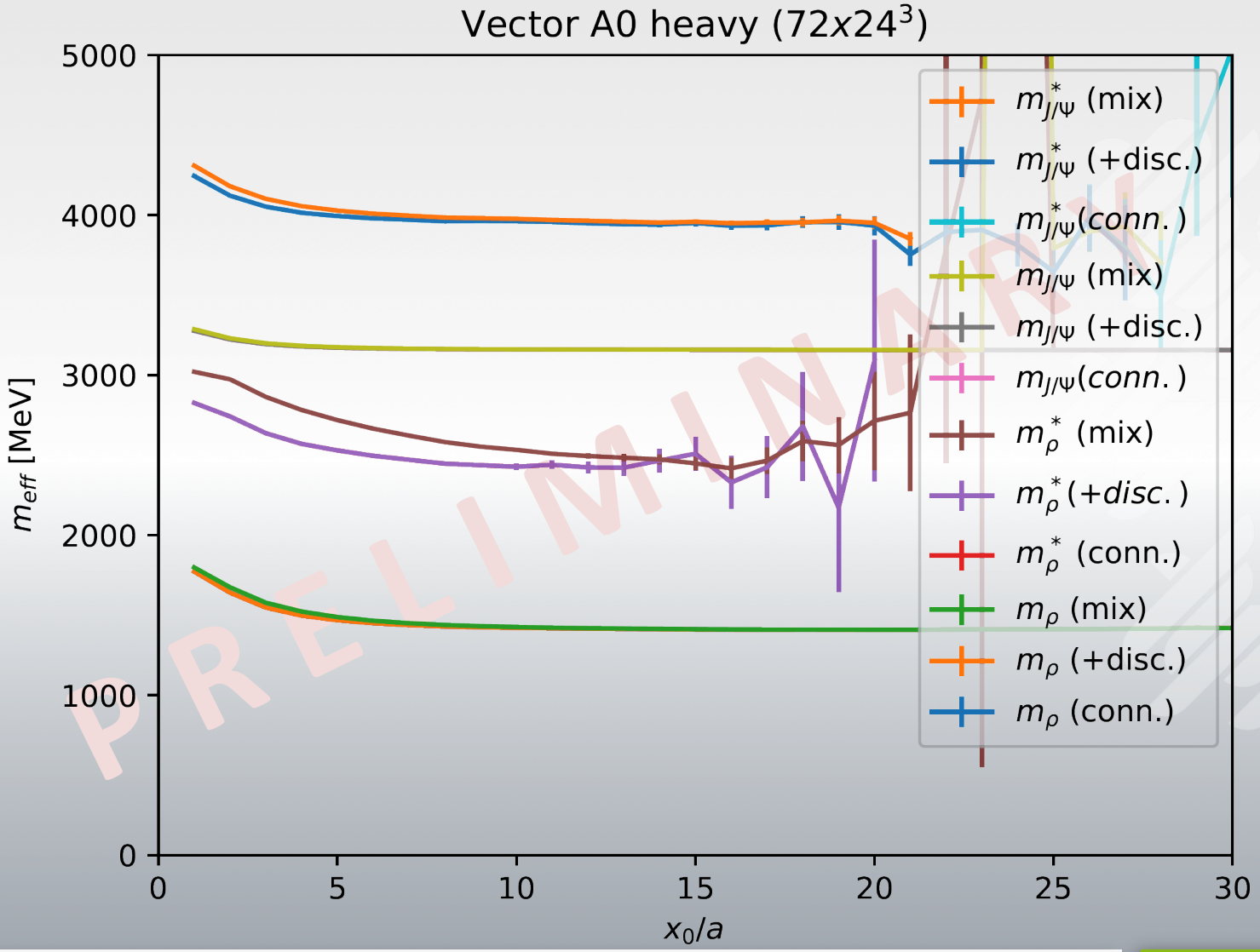


light/charm mixing:

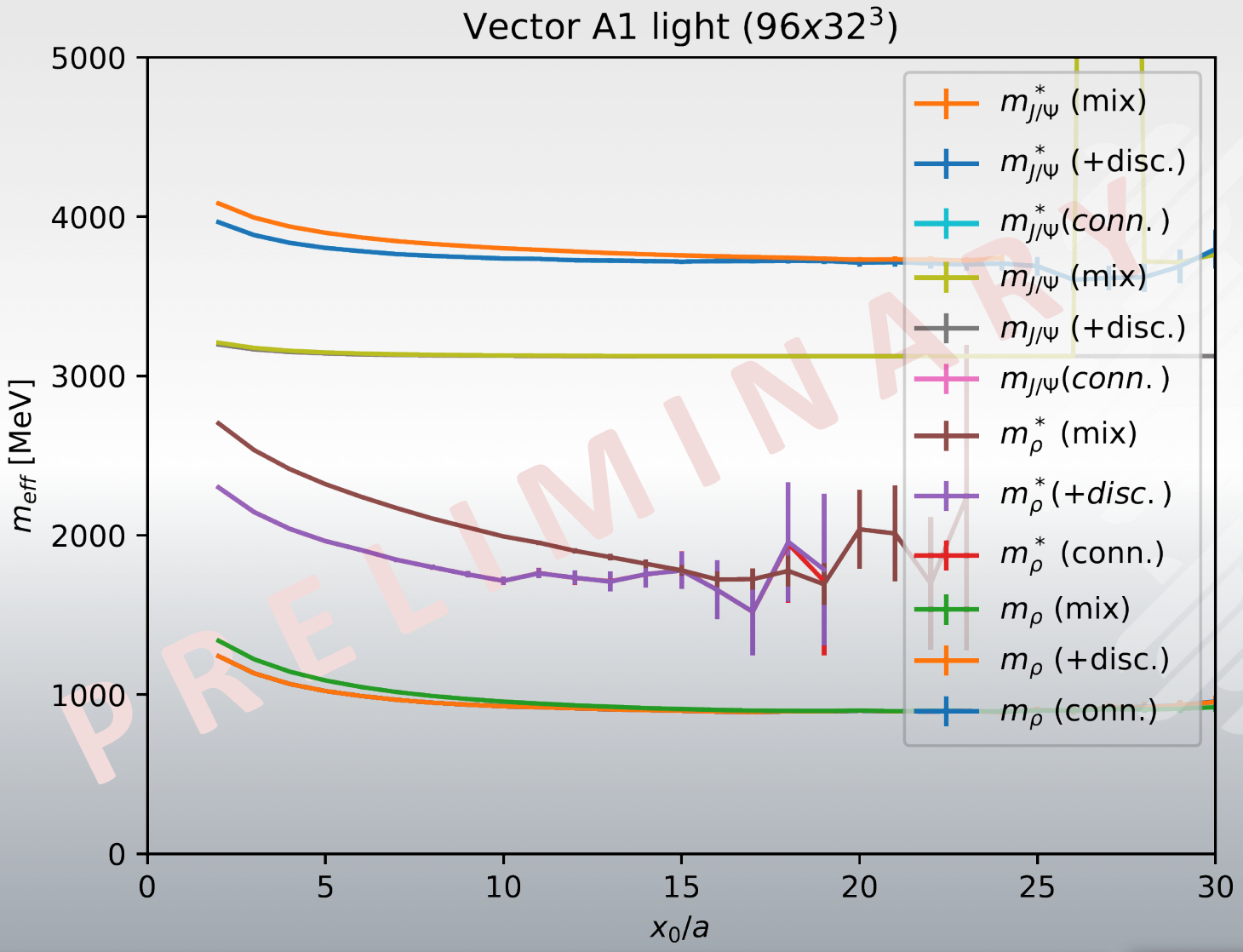




Light and charm vector mesons on A0 heavy (72 x 24^3)

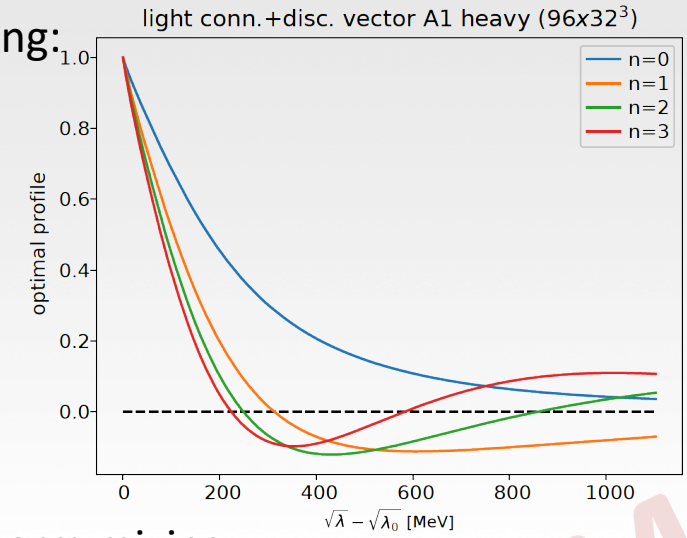


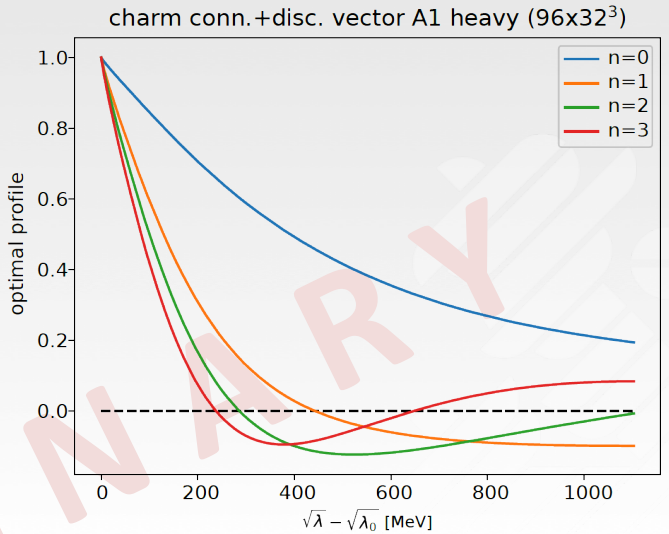
Light and charm vector mesons on A1 light (96 x 32^3)



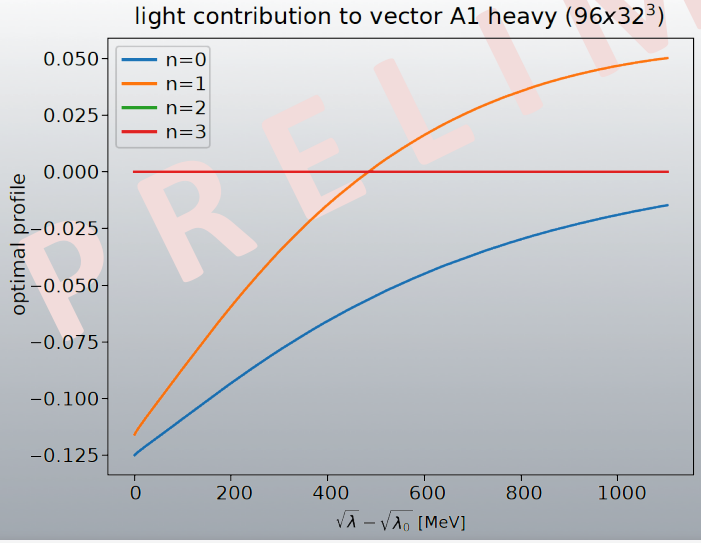
Optimal distillation profiles for vector mesons on A1 heavy

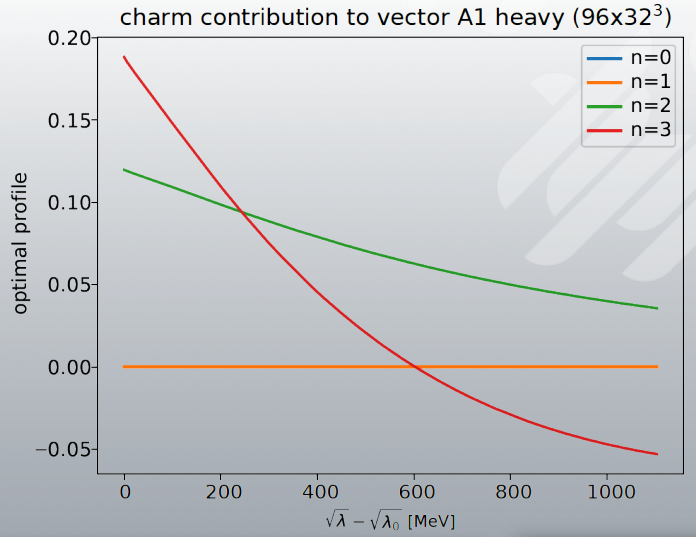
no mixing:





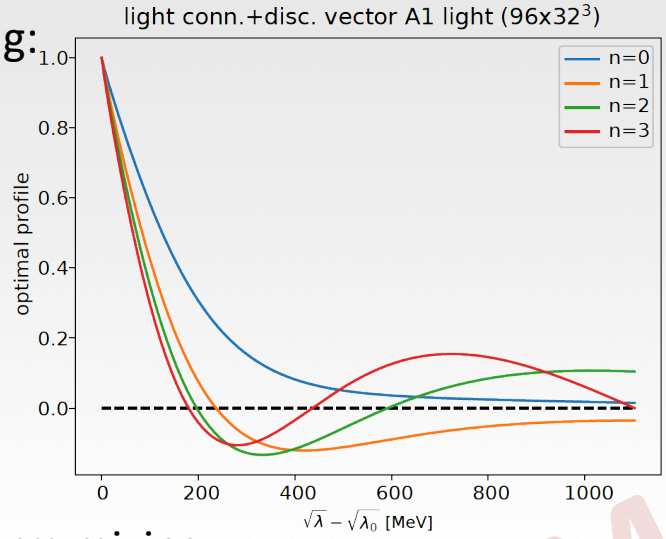
light/charm mixing:

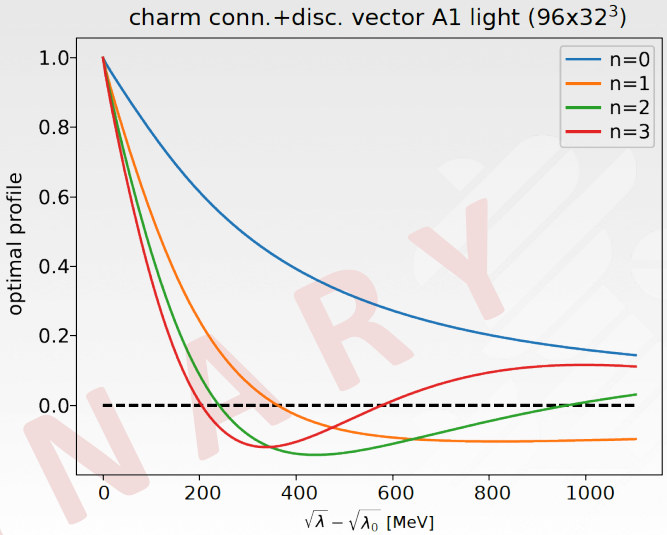




Optimal distillation profiles for vector mesons on A1 light

no mixing:





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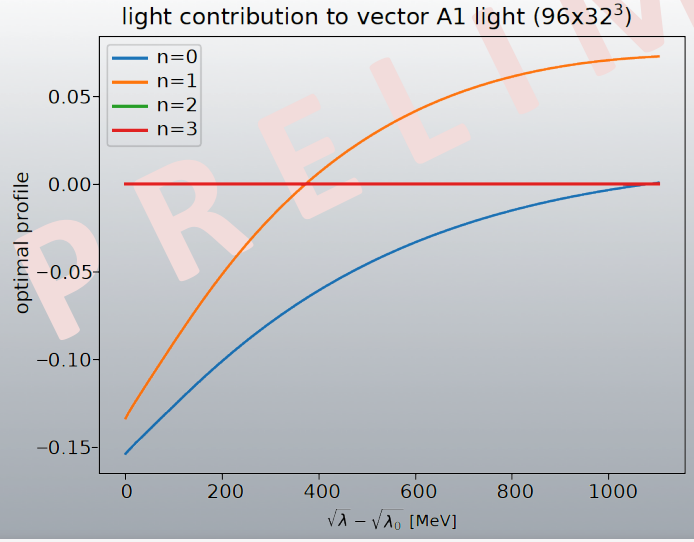
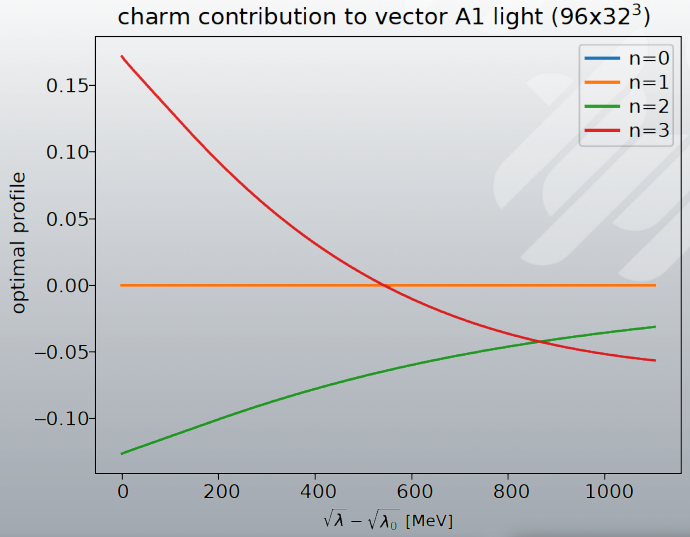
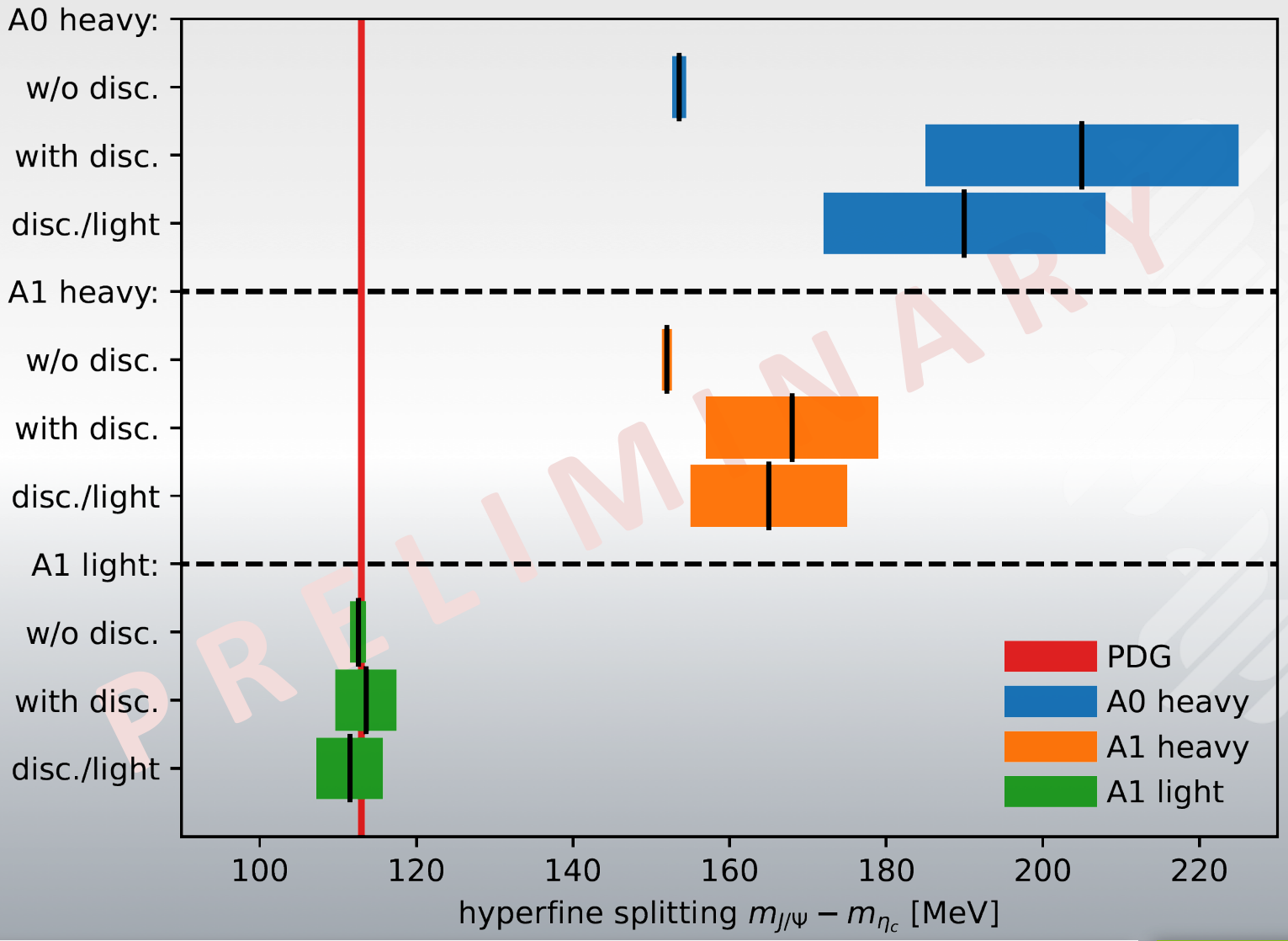




Overview of meson masses on light and heavy ensembles

ensemble	A0 heavy	A1 heavy	A1 light
volume	$24^3 \times 72$	$32^3 \times 96$	$32^3 \times 96$
measurements	2000	1000	2000
m_π	1008(4)	1009(3)	418(3)
$m_{\eta'}$	1317(22)	1295(35)	972(40)
	1324(21)	1287(37)	982(48)
m_{η_c}	3006(7)	3005(7)	3011(7)
	2954(21)	2989(13)	3010(8)
	2970(20)	2992(13)	3012(8)
m_ρ	1425(9)	1411(6)	898(11)
$m_{J/\Psi}$	3160(8)	3157(8)	3124(8)
$m_{J/\Psi} - m_{\eta_c}$	154(1)	152(1)	113(1)
	205(20)	168(11)	114(4)
	190(18)	165(10)	112(4)
m_{a_0}	1802(18)	1761(34)	894(12)
$m_{\chi_{c0}}$	3579(10)	3578(9)	3442(9)
"glueball" 0^{++}	2090(310)	2120(140)	(Laplacian eigenvalues!)

Hyperfine splitting of charmonium on light and heavy ensembles



Conclusions & Outlook

New $N_f = 3 + 1$ lattice ensembles

- a=0.054fm, 24^3 x 72, 32^3 x 96 and 48^3 x 128
- m_π ~ 1 GeV, physical charm $m_{\eta c}$ ~ 3 GeV
- 4000 configurations each (16000 MDUs)
- eigenmodes on every 2nd/4th configuration
- 2000/1000 charm and light perambulators
- glueball can only decay into two pions
- mixing of charmonium with light hadrons and glueballs

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Outlook

- study glueballs / scattering via Lüscher analysis
- including two pion states in the correlation matrix
- working on multilevel glueball operators in full QCD

Thank you for your attention!

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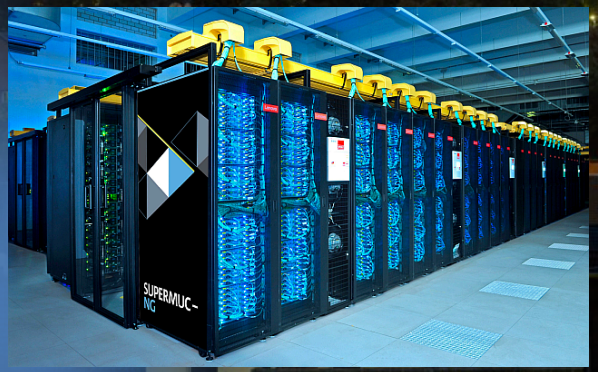
Questions?

NHR FAU

superMUC



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