

B_K and related matrix elements with unquenched, improved staggered fermions (Class B-GPU)

Chulwoo Jung (BNL), Weonjong Lee (SNU) & Stephen Sharpe (UW)

<http://www.phys.washington.edu/~sharpe/qcdoc/index.html>

AND

Non-perturbative renormalization with improved staggered fermions (Class B)

Andrew Lytle (Southampton) & Stephen Sharpe (UW)

<http://www.phys.washington.edu/~sharpe/usqcd/index.html>

B_k and related
matrix elements
with unquenched,
improved staggered
fermions

Overview

$$\frac{8}{3}m_k^2 f_K^2 B_K = \langle \bar{K} | \bar{s} \gamma_\mu (1 - \gamma_5) d \bar{s} \gamma_\mu (1 - \gamma_5) d | K \rangle$$

- * Aim: Calculate B_K and related matrix elements with percent-level precision
- * We use HYP-smearred valence quarks on asqtad sea
- * Staggered fermions provide relatively cheap alternative to DWF with complementary pros & cons

Allocation history

- * 2006-7: class B: 1.2 Mnode-hrs on the QCDOC
- * 2007-8: class B: 3.25 Mnode-hrs on the QCDOC
- * 2008-9: class B: 12 Mnode-hrs on the QCDOC
- * 2009-10: class A: 25 Mnode-hrs on the QCDOC
 - ➔ Results with 3 lattice spacings (now published)
- * 2010-11: class A: 20 Mnode-hrs on the QCDOC & 25+75K GPU-hrs
 - ➔ Results with 4 lattice spacings + improved statistics

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 - ➔ Results with 4 lattice spacings + improved statistics
- 🏆 2011-12 proposal: class B: 100K GPU-hrs

Status and Proposed Running

ID	a (fm)	am_l/am_s	Size	Configs.	status
C1	0.12	0.03/0.05	$20^3 \times 64$	564×1	old
C2	0.12	0.02/0.05	$20^3 \times 64$	486×9	update
C3	0.12	0.01/0.05	$20^3 \times 64$	671×9	old
C3-2	0.12	0.01/0.05	$28^3 \times 64$	275×8	old
C4	0.12	0.007/0.05	$20^3 \times 64$	651×10	old
C5	0.12	0.005/0.05	$24^3 \times 64$	509×9	update
F1	0.09	0.0062/0.031	$28^3 \times 96$	995×9	update
F2	0.09	0.0031/0.031	$40^3 \times 96$	853×1	update
S1	0.06	0.0036/0.018	$48^3 \times 144$	744×2	old
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U1	0.045	0.0030/0.015	$64^3 \times 192$	705×1	new
U1	0.045	0.0030/0.015	$64^3 \times 192$	300×1	rest of alloc

SNU

GPU

QCDOC

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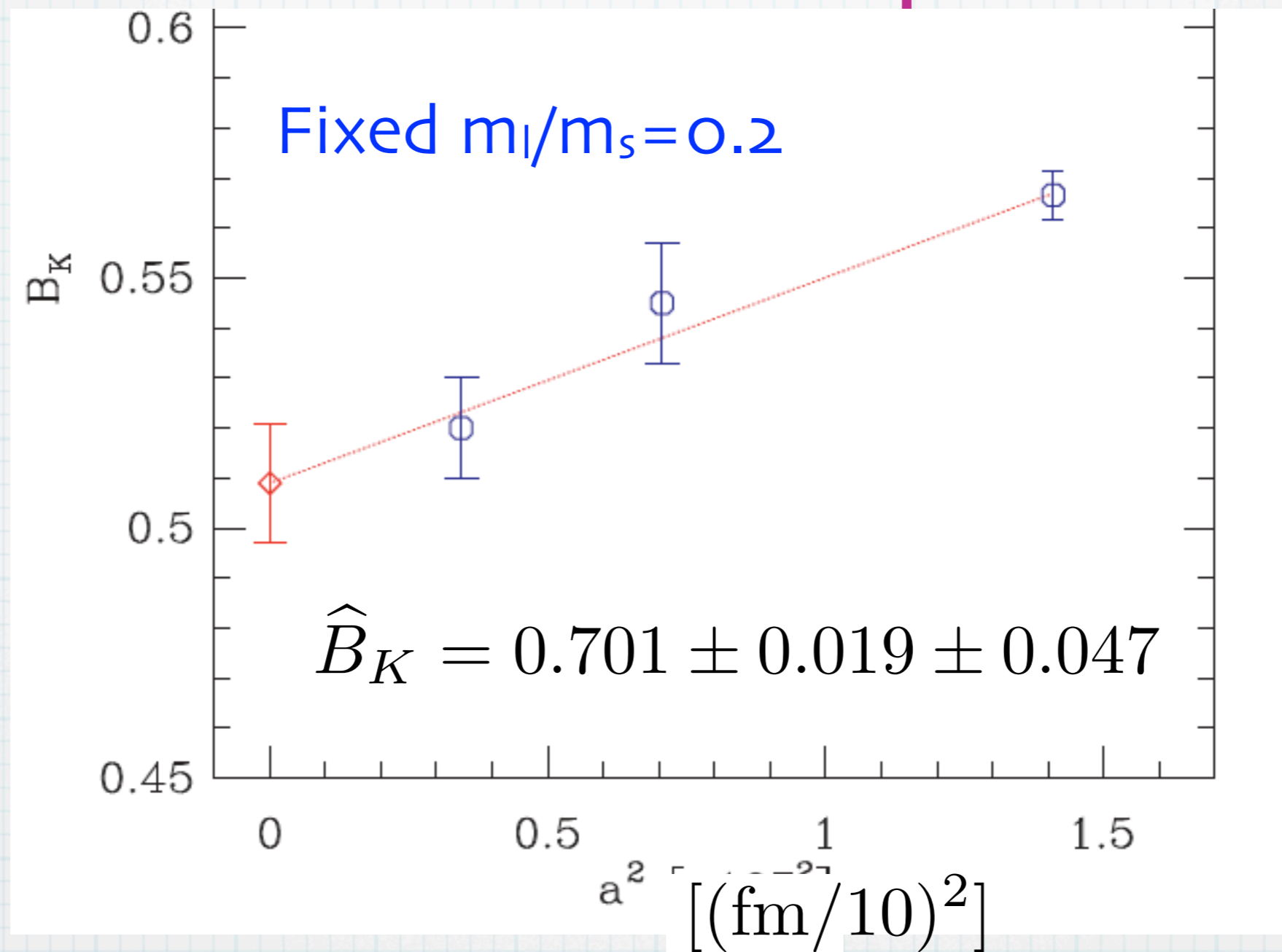
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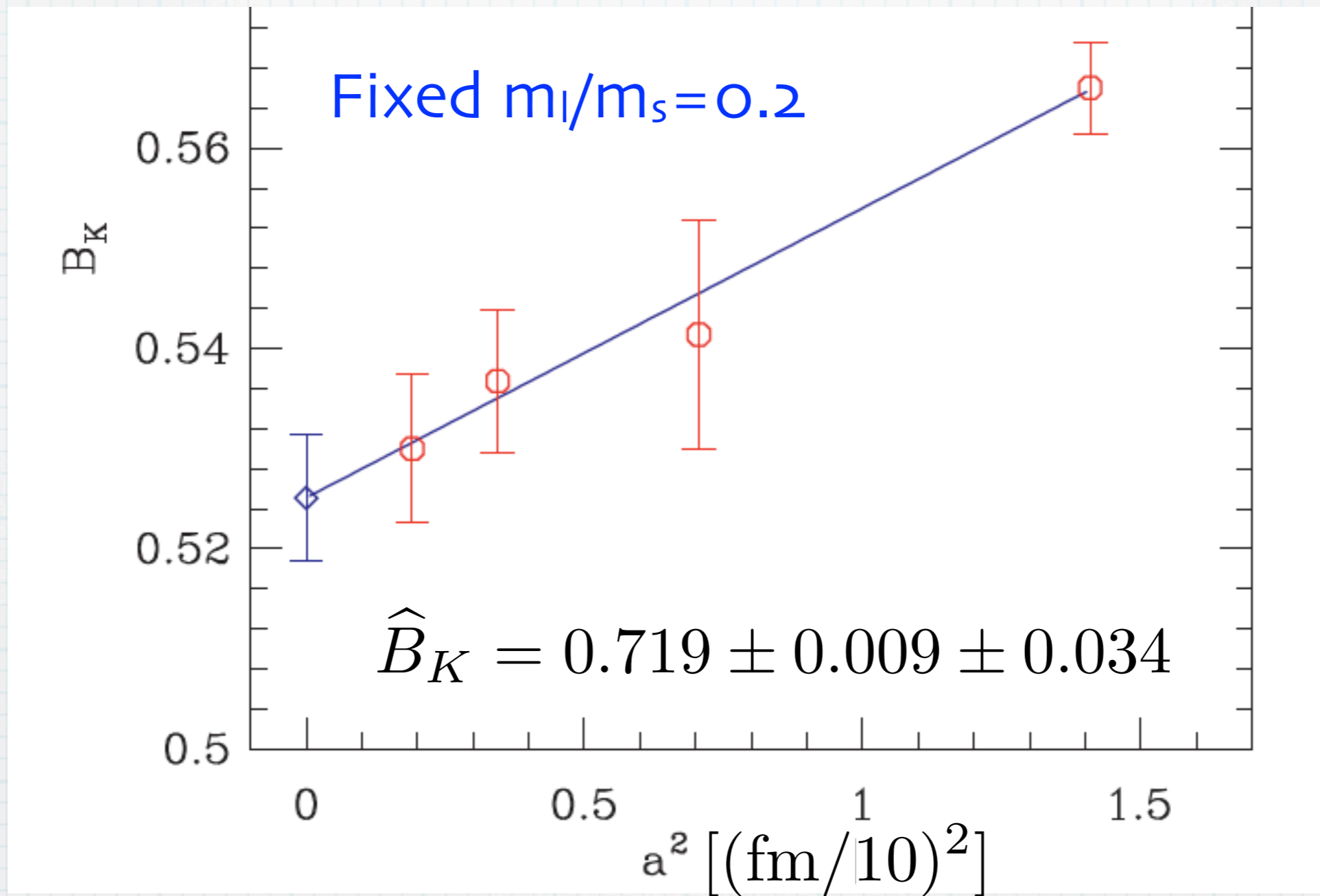
QCDOC

Continuum extrapolation



All-hands meeting 2010

Continuum extrapolation



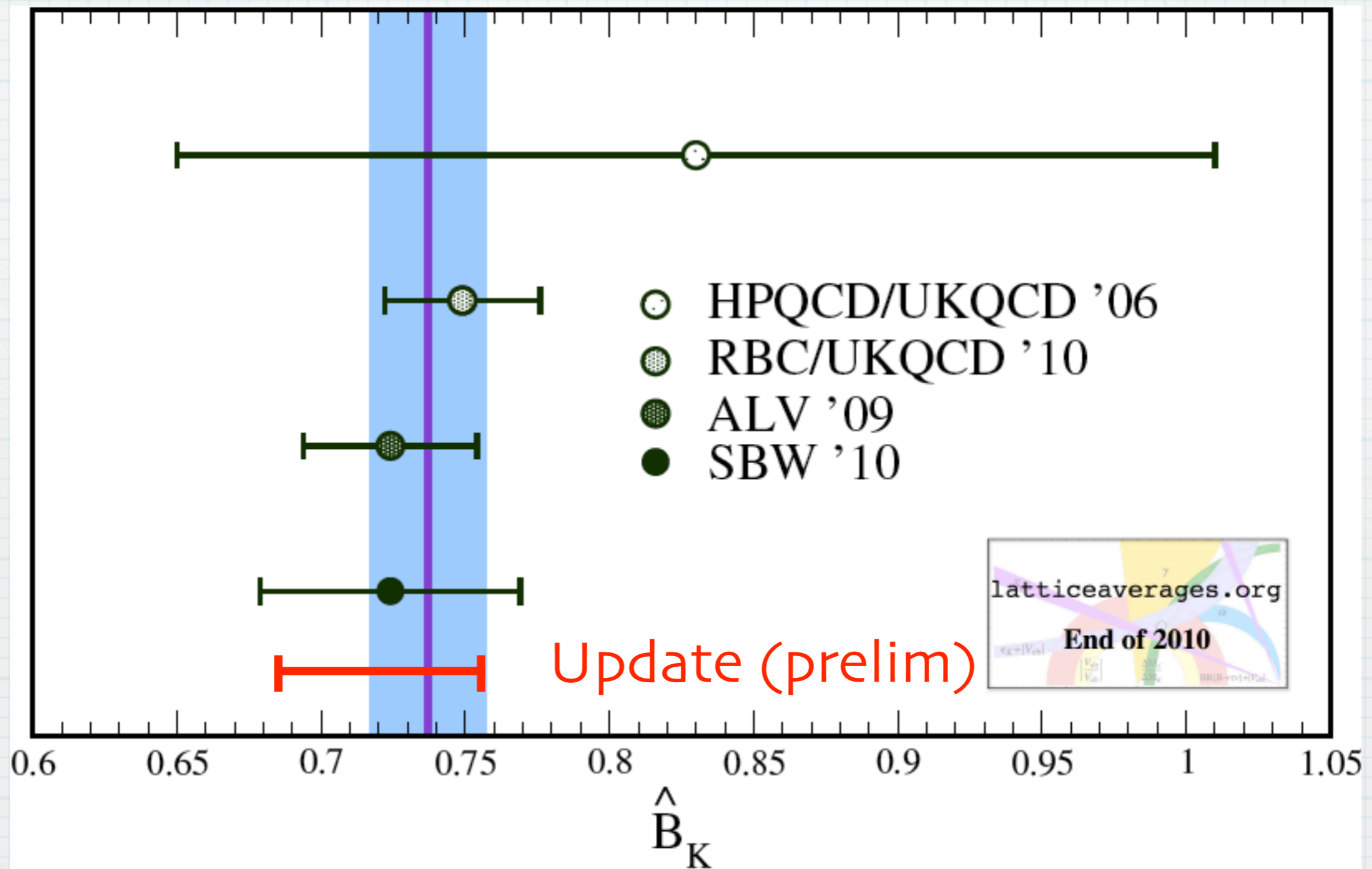
All-hands meeting 2011
(Vertical scale reduced by factor of 2)

Present Error Budget

cause	error (%)	description
matching factor (*)	4.4	α_s^2 on (U1)
statistics (*)	1.3	4X3Y-NNLO fit
discretization (*)	0.94	diff. of (U1) and $a = 0$
fitting (1)	0.92	X-fit
fitting (2)	0.08	Y-fit
am_ℓ extrap (*)	0.06	(C3) versus linear extrap
am_s extrap	0.5	constant vs. linear extrap
finite volume (*)	0.59	finite vol. vs. $V = \infty$ fit
r_1	0.14	r_1 error budget
f_π	0.38	132 MeV vs. 124.4 MeV

Table 2: Present status of error budget for B_K (preliminary). Estimates marked with an asterisk are updates from our published paper [2].

Global comparison



Proposals for 2011-12

- * Reduce errors on superfine lattices using GPUs
 - ➔ 100K GPU-hrs
- * Extract results for all other $\Delta S=2$ operators
 - ➔ 1-loop matching completed, ChPT underway
- * Use NPR to reduce dominant error (2nd proposal)

SPC questions (1)

- Given that the error in your current result are dominated by the 4.4% operator matching error, how much will be gained by working hard on further reducing statistical errors before more progress has been made on nonperturbative matching?

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- Given that the error in your current result are dominated by the 4.4% operator matching error, how much will be gained by working hard on further reducing statistical errors before more progress has been made on nonperturbative matching?
- ★ Better statistics can allow better understanding of systematics
- ★ Ultimately a 1% matching error is conceivable, and we would like to have a $< 1\%$ statistical error in hand
- ★ This class B allocation will allow us to improve our GPU codes for future work

SPC questions (2)

- The uncertainty in ε_K is affected more by errors in V_{cb} than in B_K . Given this, what are your long-term plans for having an impact on CKM-unitarity triangle physics? It would be useful if you could discuss in general how you see studies of kaon mixing on the lattice progressing in the future.

SPC questions (2)

- The uncertainty in ϵ_K is affected more by errors in V_{cb} than in B_K . Given this, what are your long-term plans for having an impact on CKM-unitarity triangle physics? It would be useful if you could discuss in general how you see studies of kaon mixing on the lattice progressing in the future.
- ★ Still worthwhile improving LQCD error in B_K since calculation of V_{cb} will gradually improve, and as a benchmark to compare different fermions and methodologies
- ★ Calculating beyond-the-SM matrix elements is our next priority
- ★ Longer term plans: move to HISQ valence, $K \rightarrow \pi l \nu$, $D \rightarrow (\pi, K) l \nu$, $K \rightarrow \pi \pi$ ($\Delta I = 3/2$ & $? 1/2?$)

Non-perturbative renormalization for improved staggered fermions

Aims of NPR project

- * Calculate Z_m for asqtad quarks

- ➔ check MILC 2-loop matching: $m_s(\overline{\text{MS}}, 2 \text{ GeV}) = 84 \pm 5 \text{ MeV}$

- ➔ and HPQCD (from m_s/m_c): $m_s(\overline{\text{MS}}, 2 \text{ GeV}) = 92.4 \pm 1.5 \text{ MeV}$

- ➔ Our preliminary result [Lytle, thesis]: $m_s(\overline{\text{MS}}, 2 \text{ GeV}) = 103 \pm 3 \text{ (stat)} \pm ?? \text{ MeV}$

- * Calculate Z-factors for bilinears and four-fermion operators with HYP valence fermions on asqtad sea

- ➔ Reduce dominant error in B_K

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● Calculate Z-factors for all hypercube bilinears

- ➔ Allows study of systematics & detailed comparison with PT

● Implement twisted BC & non-exceptional momenta

* Calculate Z-factors for bilinears and four-fermion operators with HYP valence fermions on asqtad sea

- ➔ Reduce dominant error in B_K

Allocation history

- * 2008-9: class B: 0.5 M 6n-hrs at FNAL
- * 2009-10: class B: 0.5 M 6n-hrs at FNAL
- * 2010-11: class B: 1.3 M J/ Ψ core-hrs at FNAL

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- * 2009-10: class B: 0.5 M $6n$ -hrs at FNAL
- * 2010-11: class B: 1.3 M J/Ψ core-hrs at FNAL
- 2011-12 proposal: class B: 2.36 M J/Ψ core-hrs

Status of 2010-11 running

lattices	size	$am_\ell : am_s$	valence masses
coarse	$20^3 \times 64$	0.01 : 0.05	<u>0.01</u>
coarse	$20^3 \times 64$	0.02 : 0.05	<u>0.02</u>
coarse	$20^3 \times 64$	0.03 : 0.05	<u>0.03</u>
fine	$28^3 \times 96$	0.0062 : 0.0310	0.0062
fine	$28^3 \times 96$	0.0093 : 0.0310	0.0093
fine	$28^3 \times 96$	0.0124 : 0.0310	0.0124

Current year, for both
asqtad & HYP

Proposed

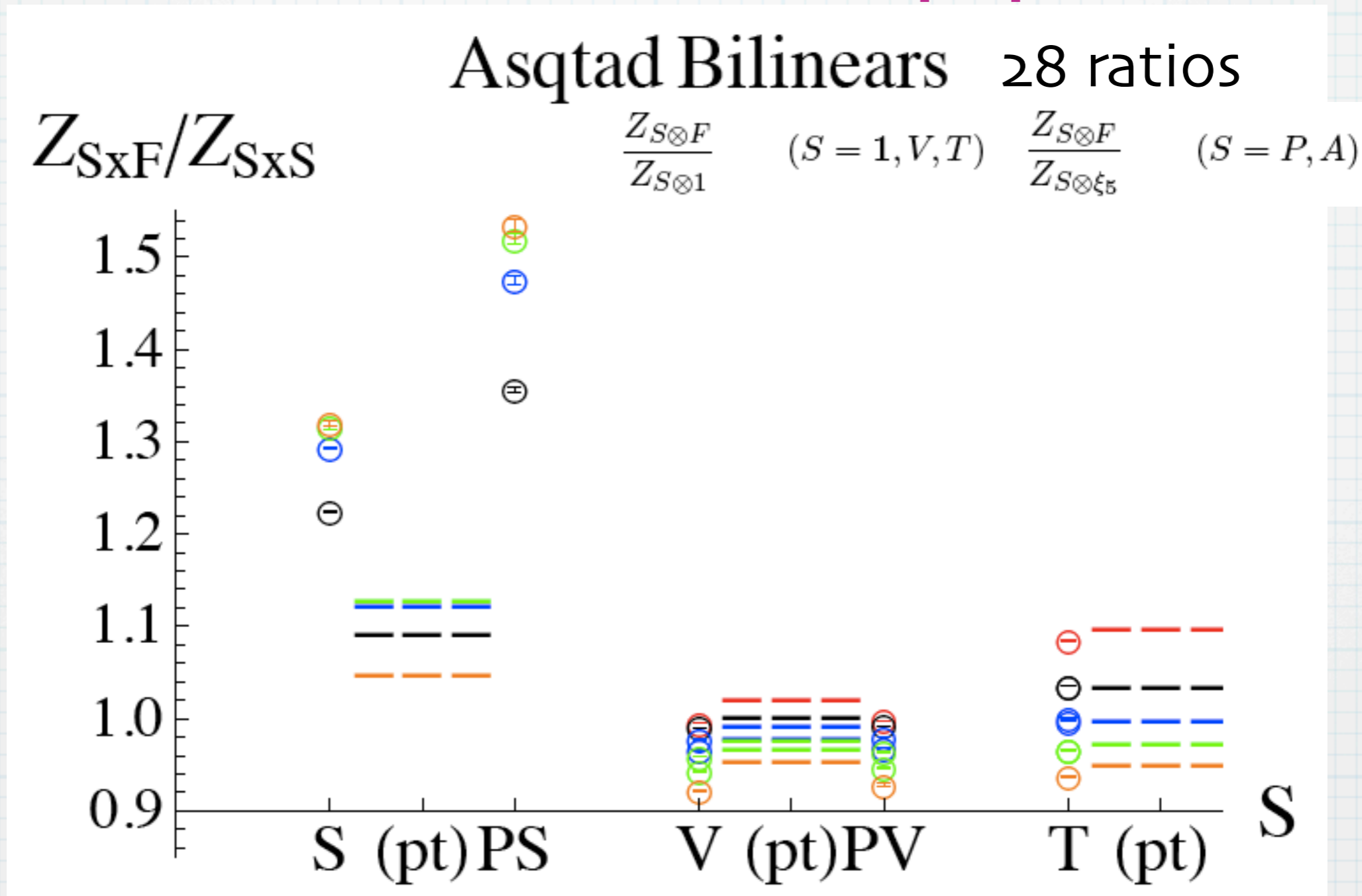
- * Expect to use full allocation
- * Dominant time is calculation of bilinear correlators (& not propagators)---due to gauge-connectors

$$\mathcal{O}_{S \otimes F}^{cov} = \frac{1}{N_x} \sum_x \frac{1}{16} \sum_{A,B} \bar{\chi}(x) \overline{(\gamma_S \otimes \gamma_F)_{x,x+B-A}} \mathcal{U}_{x,x+B-A} \chi(x+B-A)$$

S, P, V, A & T

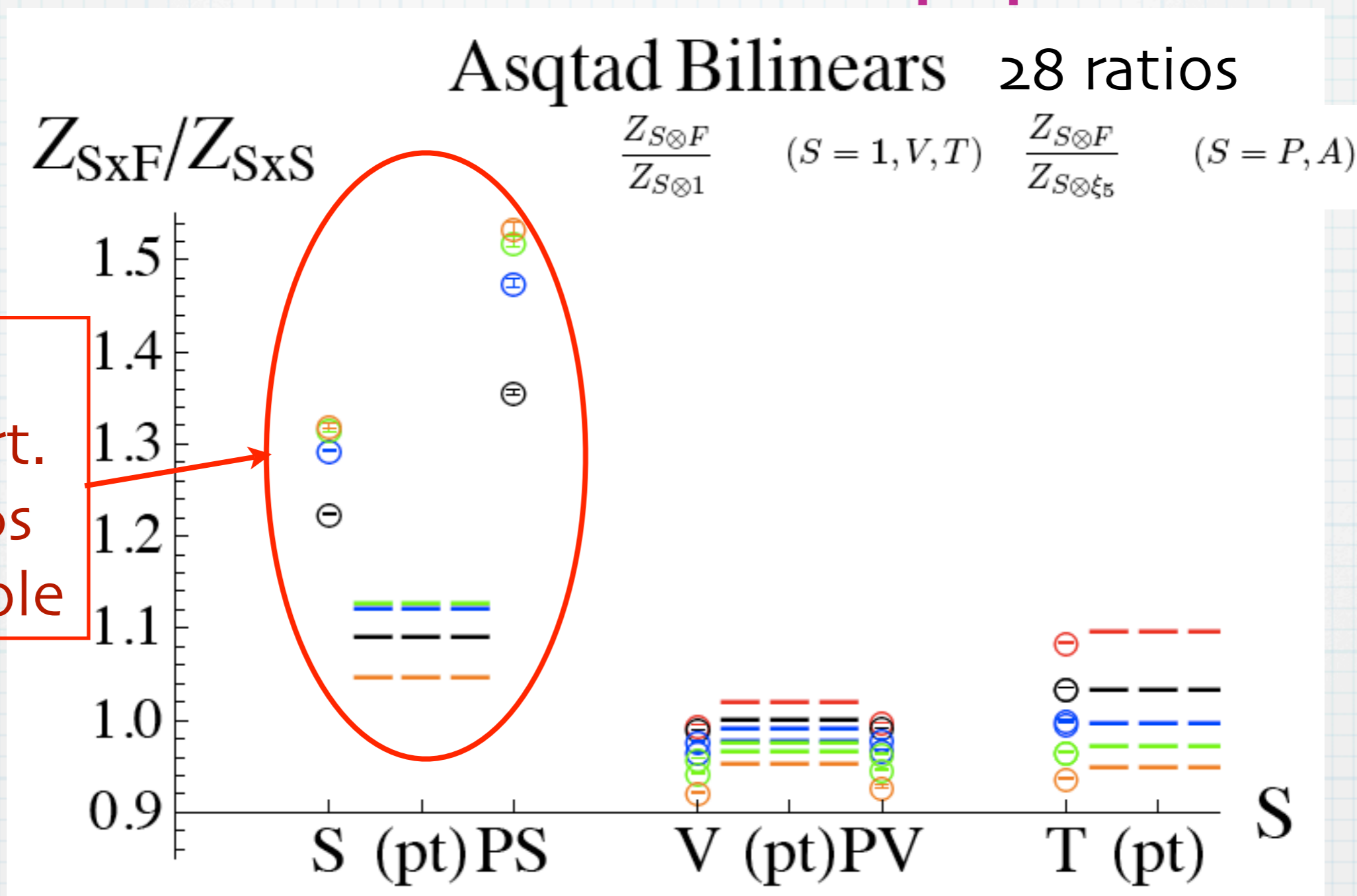
16 tastes

Ratios of Z's vs. 1-loop pert. th.



Coarse Lattices, 4 configs, $am = 0.03$, $ap = "2,2,2,7"$

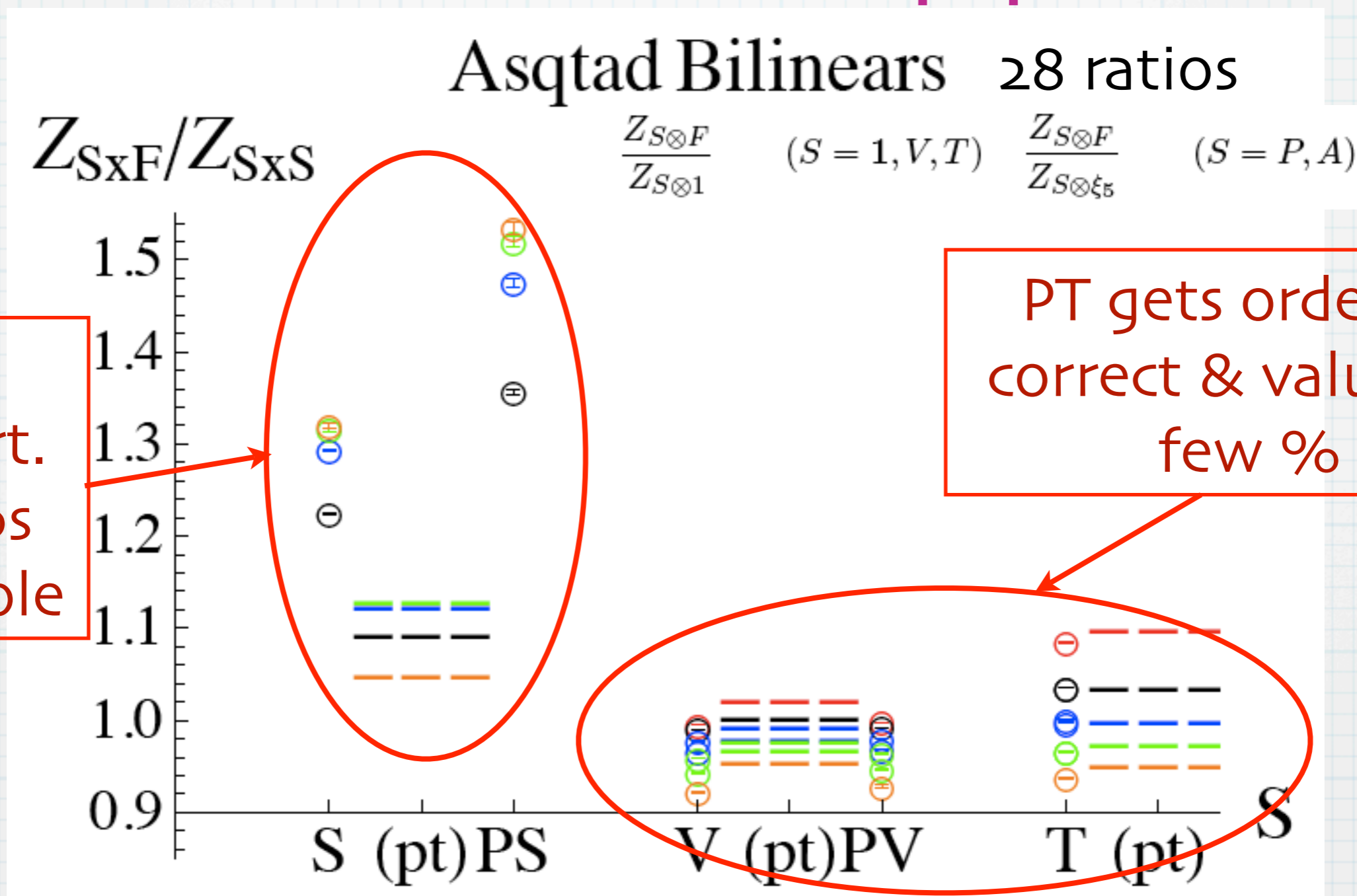
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Large
Nonpert.
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e.g. π pole

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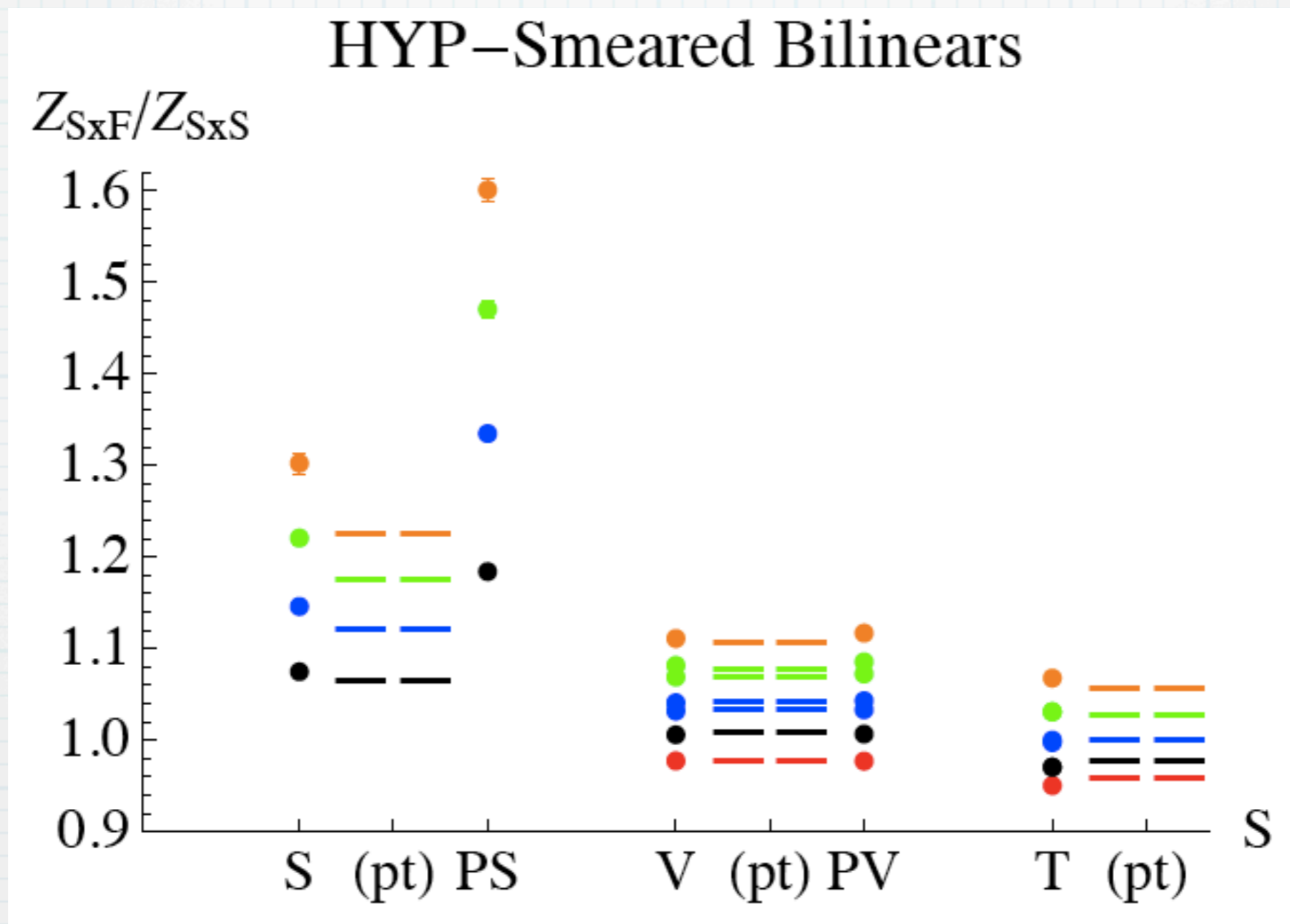


Large Nonpert. contribs e.g. π pole

PT gets ordering correct & values to few %

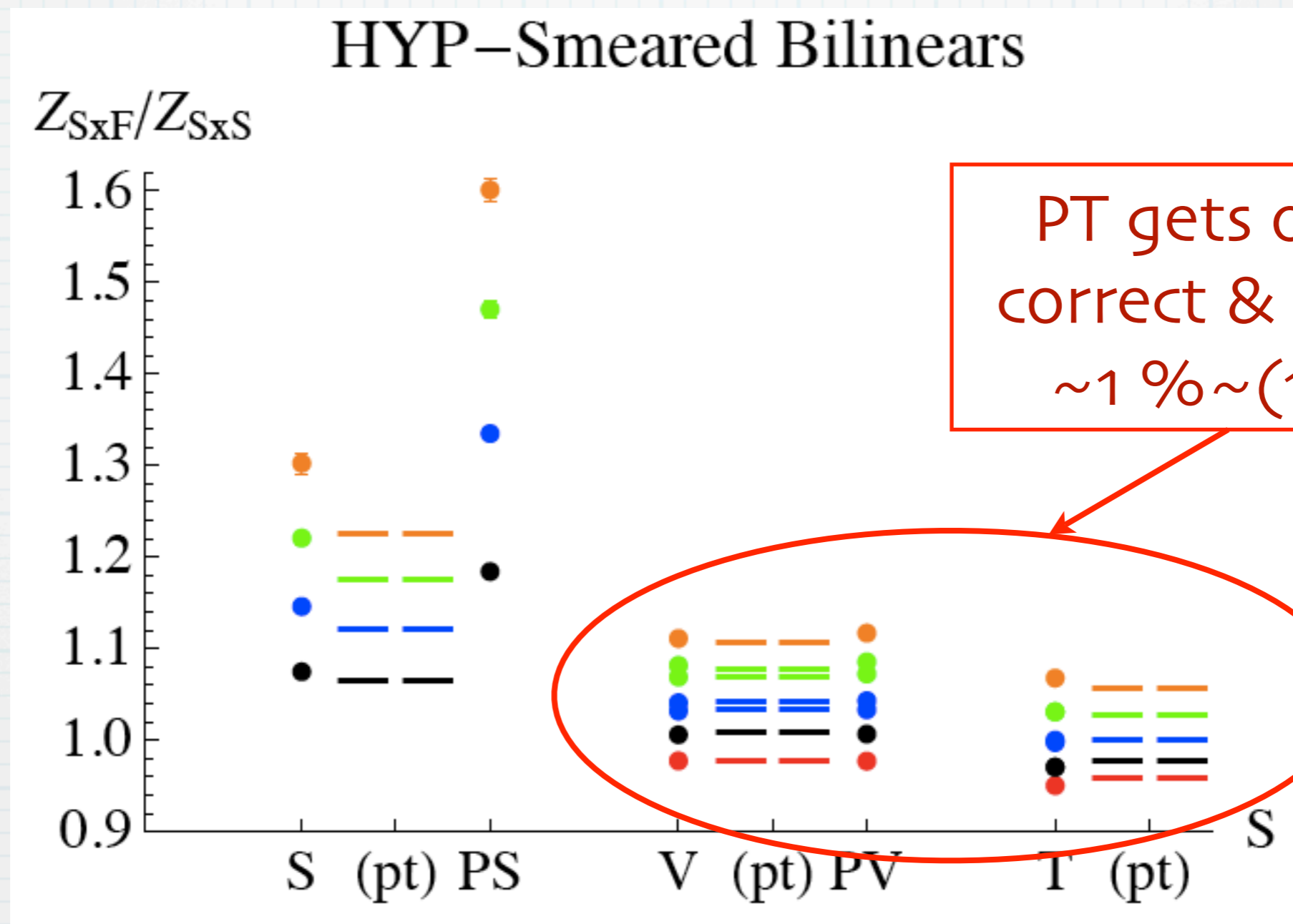
Coarse Lattices, 4 configs, $am = 0.03$, $ap = "2,2,2,7"$

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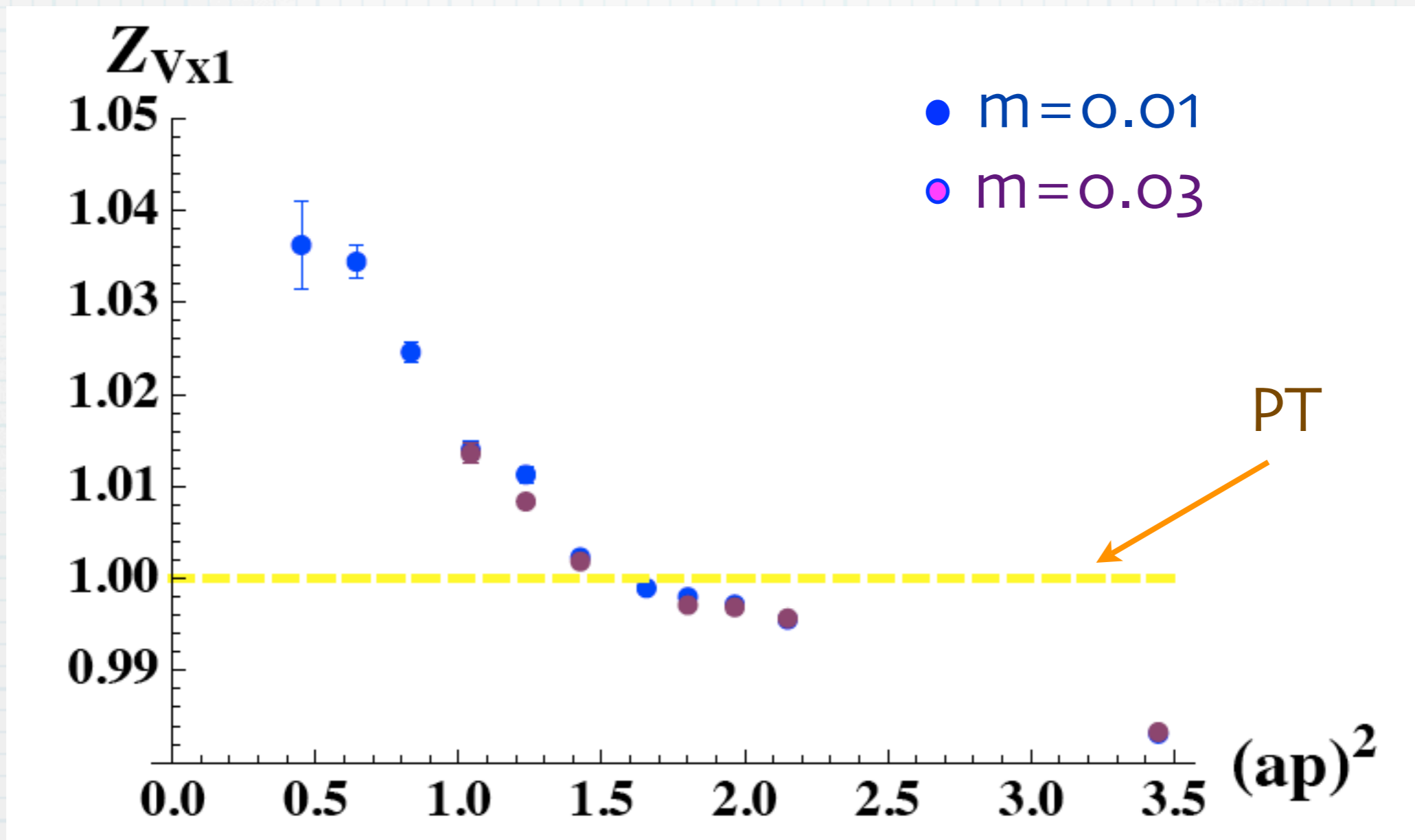
Coarse Lattices, 8 configs, $am=0.01$, $ap="2,2,2,7"$

Ratios of Z's vs. 1-loop pert. th.



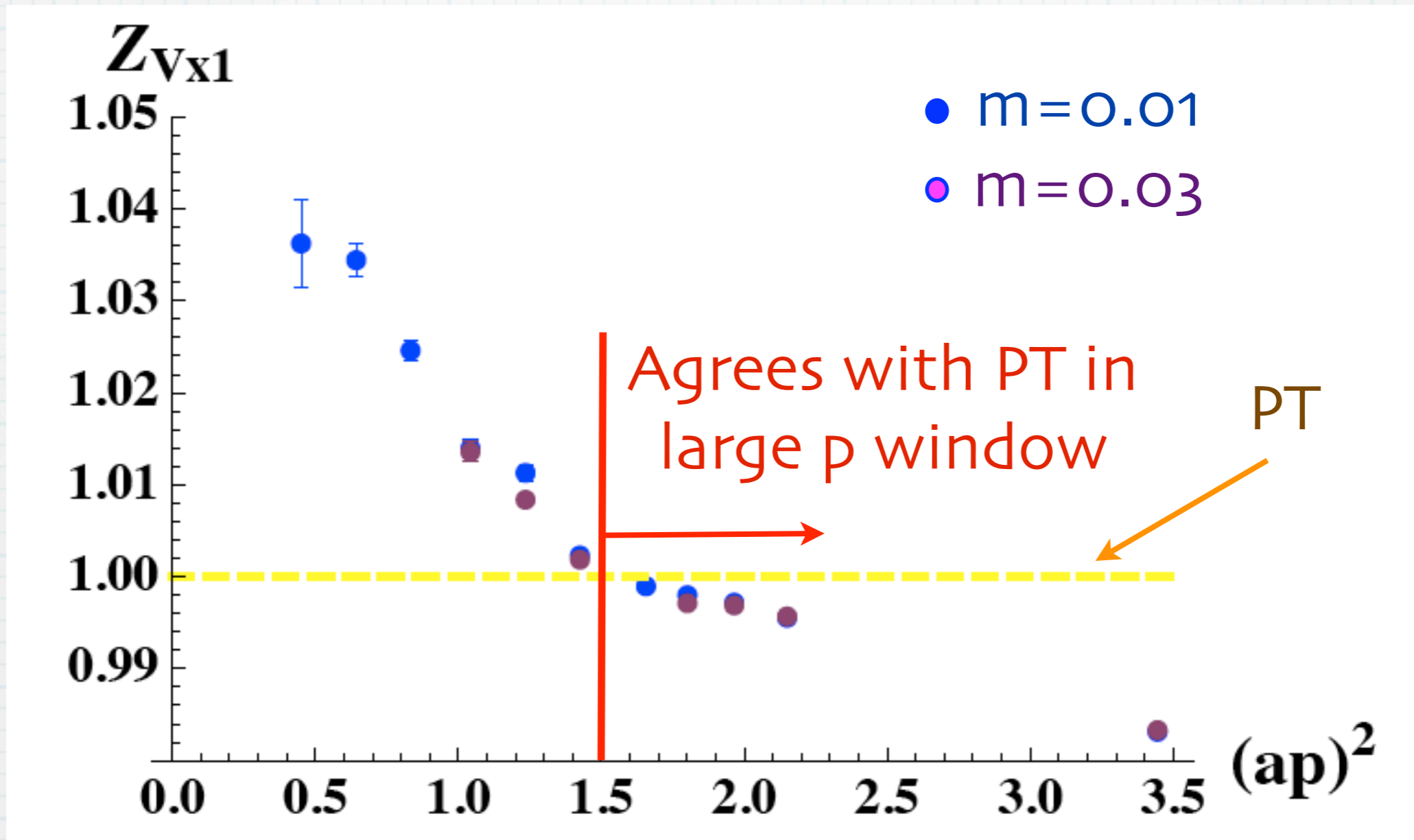
Coarse Lattices, 8 configs, $am=0.01$, $ap="2,2,2,7"$

$Z_{V \times 1}$ vs. 1-loop pert. th.



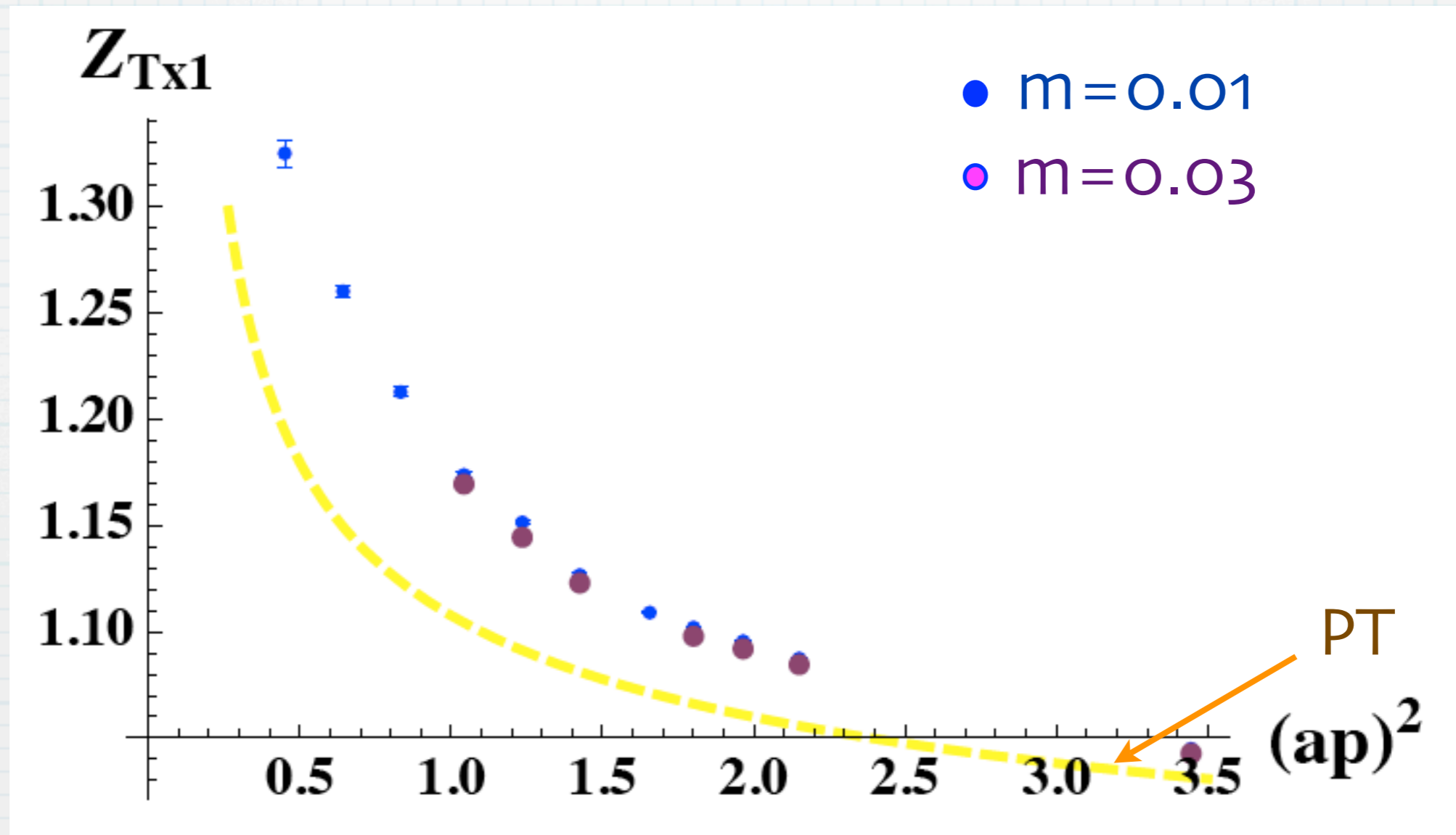
Coarse Lattices, 8 configs

$Z_{V \times 1}$ vs. 1-loop pert. th.



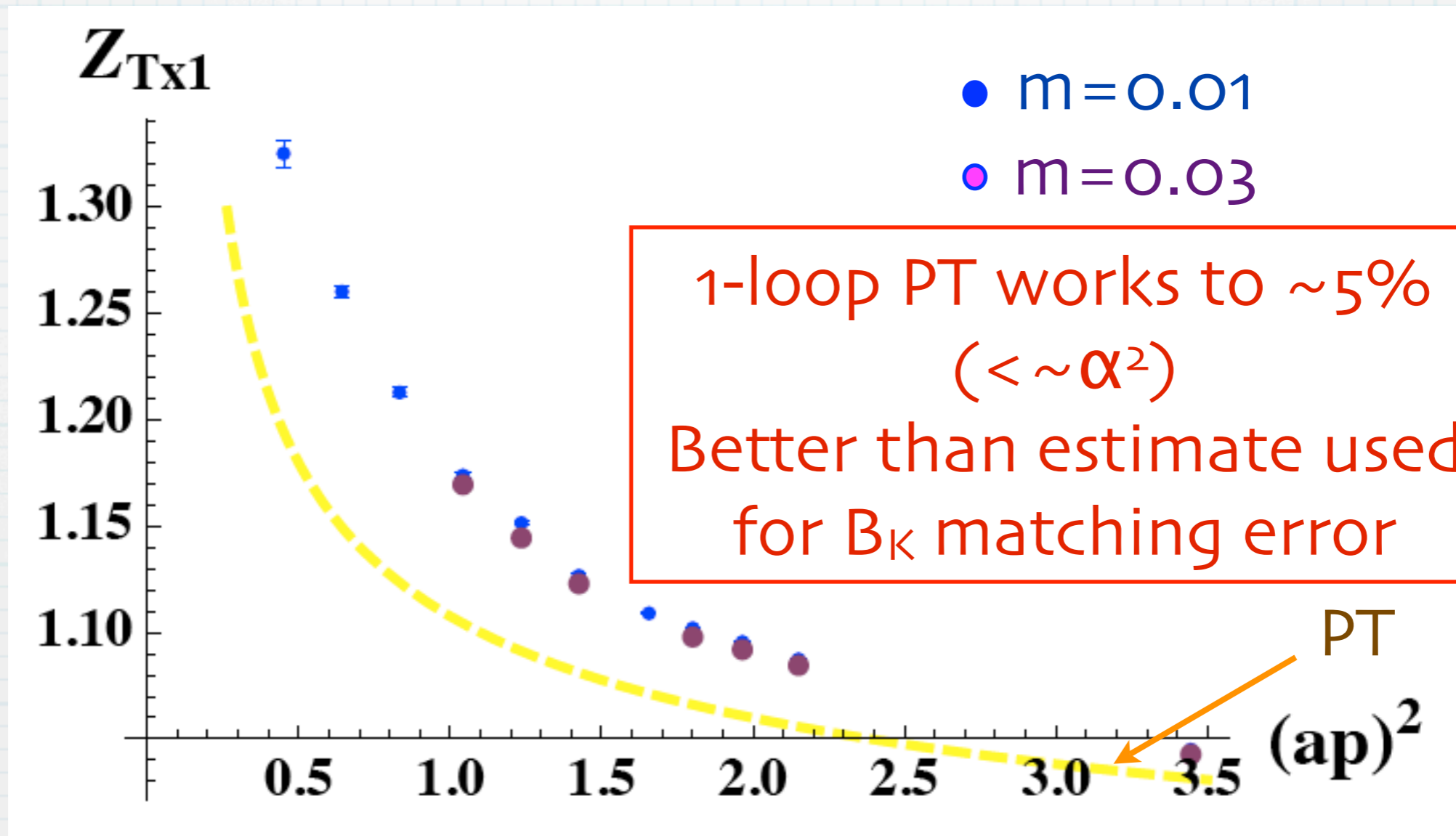
Coarse Lattices, 8 configs

$Z_{T \times 1}$ vs. 1-loop pert. th.



Coarse Lattices, 8 configs

$Z_{T \times 1}$ vs. 1-loop pert. th.



Coarse Lattices, 8 configs

Proposal for 2011-12

- * Extend full bilinear NPR for valence asqtad & HYP fermions to fine lattices
 - ➔ 3 masses, 8 configurations, 11 momenta: 1.5 M J/Ψ core hours
- * Implement twisted BC & non-exceptional momenta
 - ➔ Exploratory: 0.875 M J/Ψ core hours