Collective flow and long-range correlations in heavy-ion collisions

Matthew Luzum

based on: Phys.Lett.B**696** 499-504 (2011) (arXiv:1011.5773 [nucl-th])

Institut de physique théorique

Rencontre ions lourds
25 March, 2010

Outline

1. **Long-Range Two-Particle Correlations**
   - Azimuthal structure
   - Recent STAR data (arXiv:1010.0690)
2. **Fourier Decomposition**
   - Expected contribution from collective flow
   - $\langle \cos(n\Delta\phi) \rangle (\phi_s, p_t^{(a)})$
3. **Conclusions**

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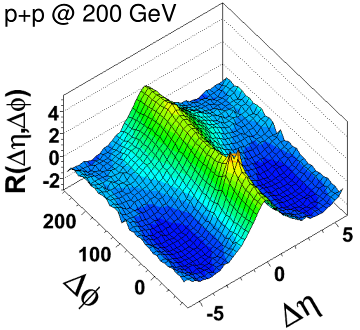
   - Azimuthal structure
   - Recent STAR data (arXiv:1010.0690)

2. FOURIER DECOMPOSITION
   - Expected contribution from collective flow
   - $\langle\cos(n\Delta\phi)\rangle(\phi_s, p_t^{(a)})$

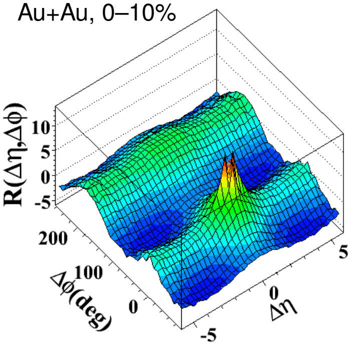
3. CONCLUSIONS

TWO-PARTICLE CORRELATION MEASUREMENTS

$\sim$ # of particle pairs with relative azimuth $\Delta\phi$ and pseudorapidity $\Delta\eta$:



(PHOBOS, Phys. Rev. C75(2007)054913)



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- Little azimuthal structure

- Long range in rapidity
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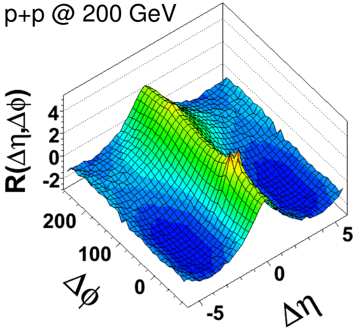

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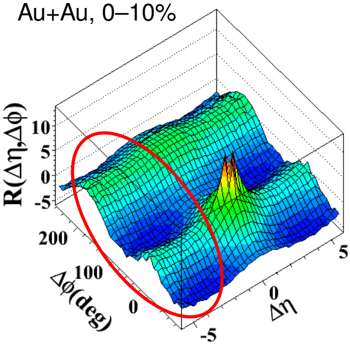

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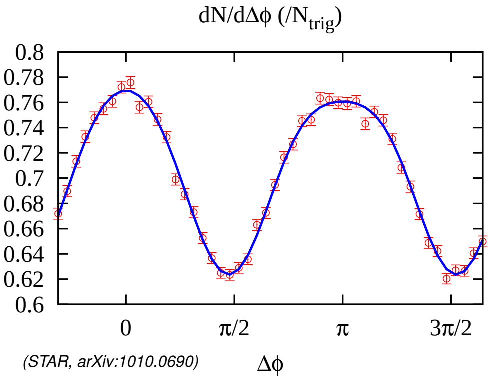
Long range azimuthal structure ($|\Delta\eta| > 0.7$)



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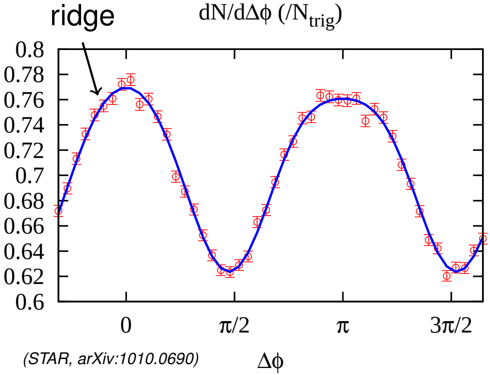
LONG RANGE AZIMUTHAL STRUCTURE ($|\Delta\eta| > 0.7$)



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- Narrow "ridge" at $\Delta\phi = 0$

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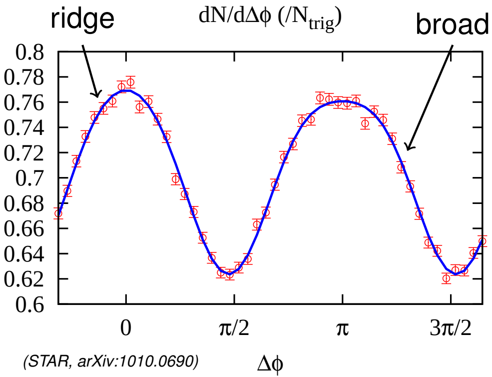

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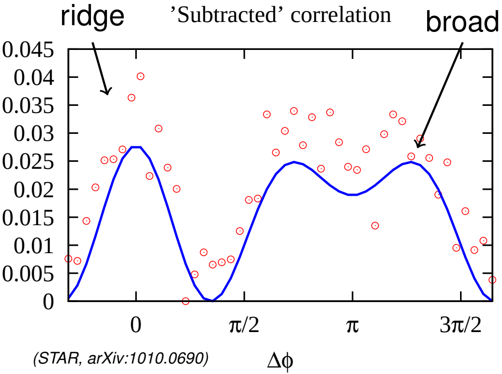

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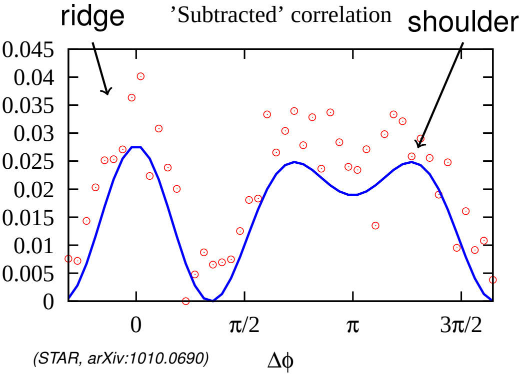

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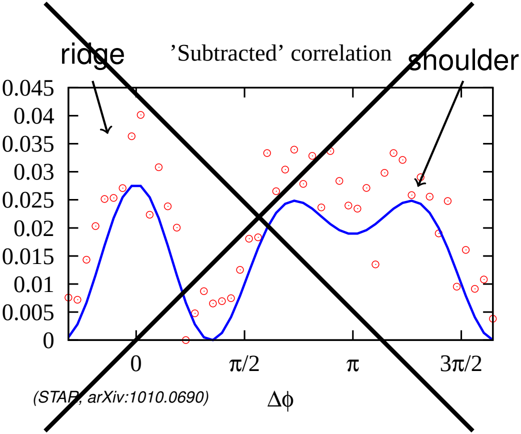

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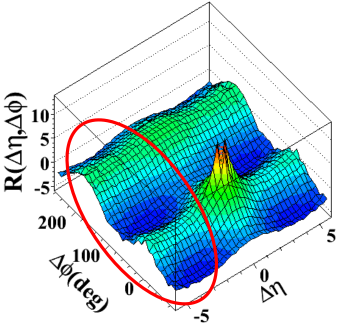
Long-range dihadron correlations

Question:

Can correlations at large $|\Delta\eta|$ be explained by collective flow alone?

- Can use new STAR data to test in detail.
- Idea: look at Fourier components of *unsubtracted* data



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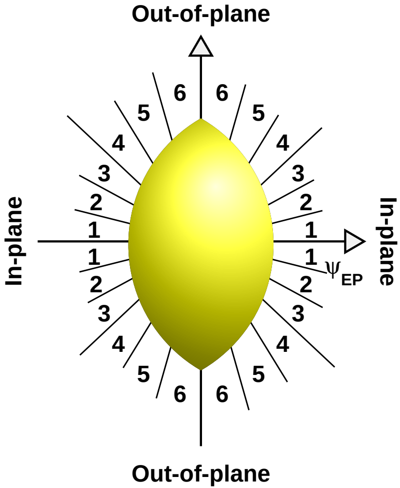

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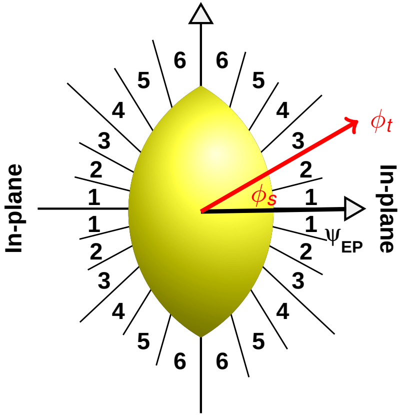

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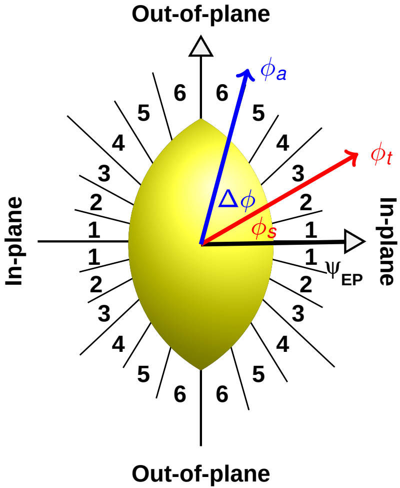

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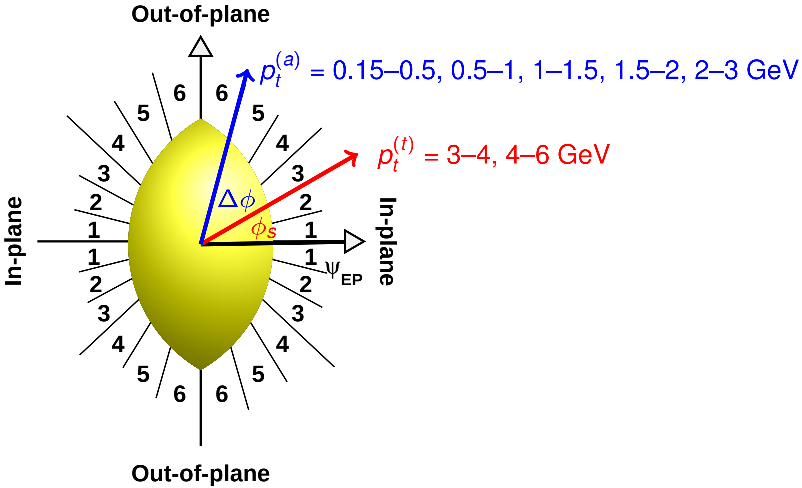

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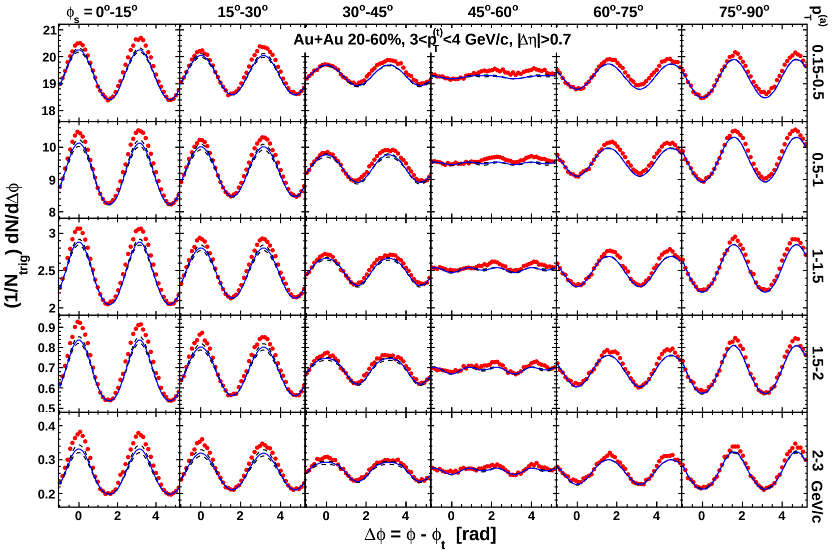

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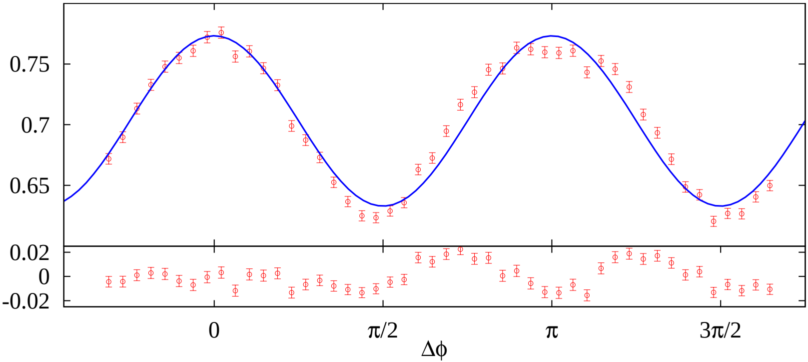
Fourier Decomposition



$$\frac{dN^{pairs}}{d\Delta\phi} \simeq \frac{N^{pairs}}{2\pi}[1 \qquad + 2V_{2\Delta}\cos(2\Delta\phi) \qquad]$$

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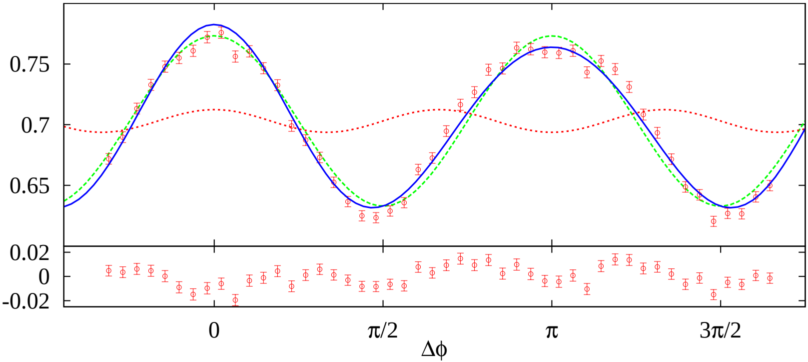

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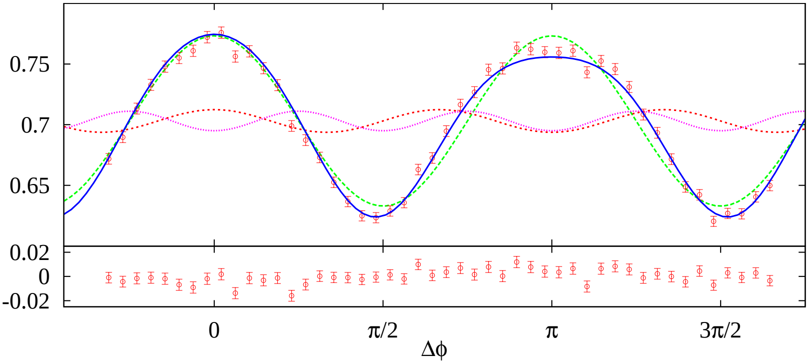
FOURIER DECOMPOSITION



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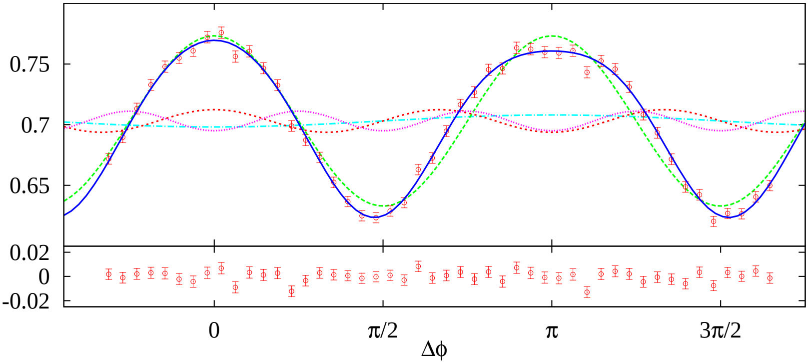

$$\frac{dN^{pairs}}{d\Delta\phi} \simeq \frac{N^{pairs}}{2\pi}[1 + 2V_{1\Delta}\cos(\Delta\phi) + 2V_{2\Delta}\cos(2\Delta\phi) + 2V_{3\Delta}\cos(3\Delta\phi) + 2V_{4\Delta}\cos(4\Delta\phi)]$$

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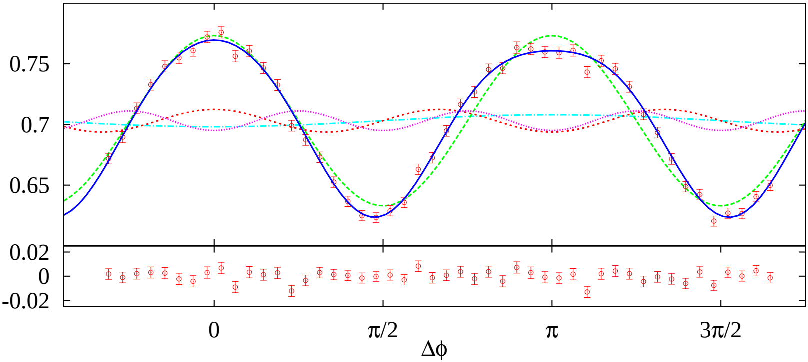

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Data well described by first 4 Fourier harmonics in all cases.

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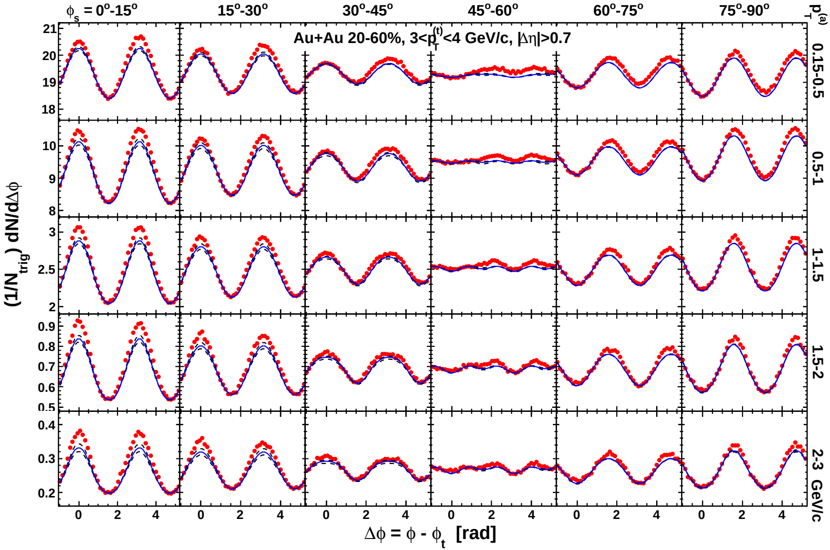

Collective flow contribution

Collective flow: particles emitted according to 1-particle distribution

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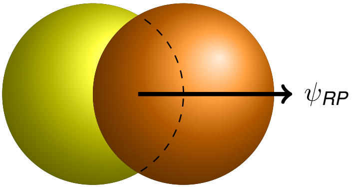
$$\frac{dN}{dY\, d^2p_t} \propto 1 + 2v_2 \cos 2(\phi - \psi_{RP}) + 2v_4 \cos 4(\phi - \psi_{RP}) + \ldots$$



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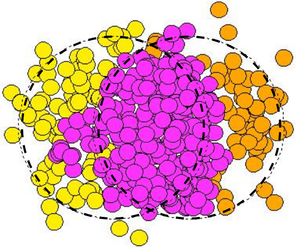

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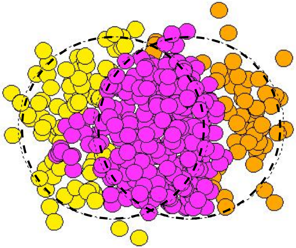

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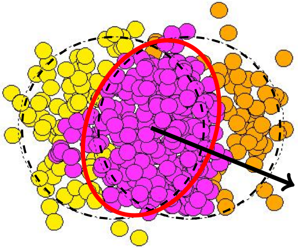

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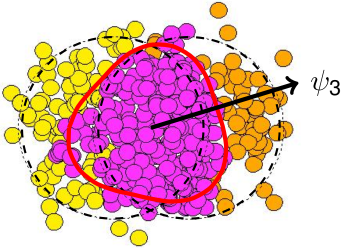

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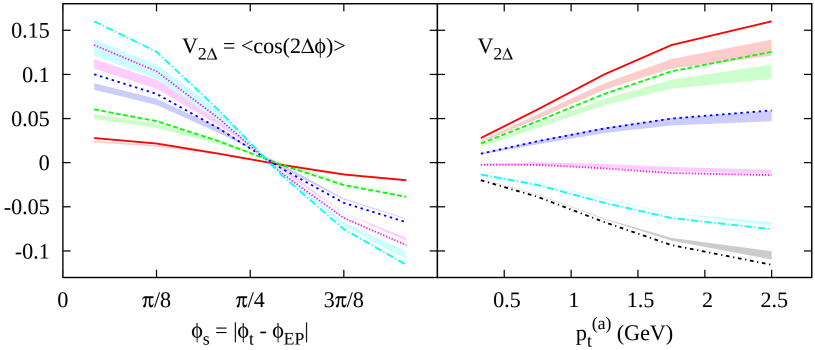
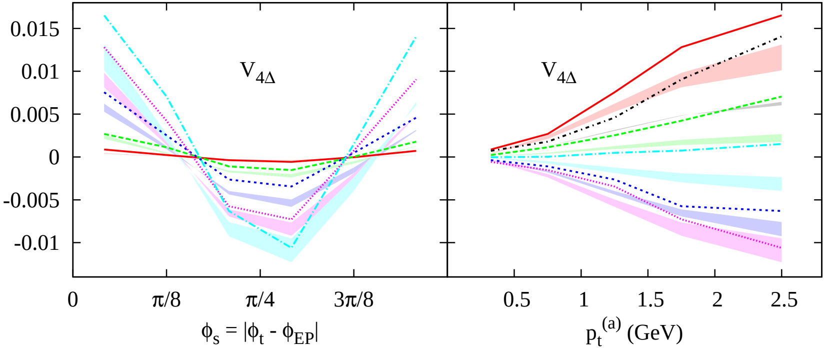
$\langle \cos(2\Delta\phi)\rangle$ — ELLIPTIC FLOW



Flow contribution to second harmonic:

- $V_{2\Delta} \equiv \langle \cos(2\Delta\phi)\rangle = v_2^{(a)} v_2^{(t,R)}$
- $v_2^{(a)} = \langle \cos(2\phi_a - 2\psi_{EP})\rangle$ = Standard elliptic flow
- $v_2^{(t,R)} \sim \cos(2\phi_s) = \cos(2\phi_t - 2\psi_{EP})$

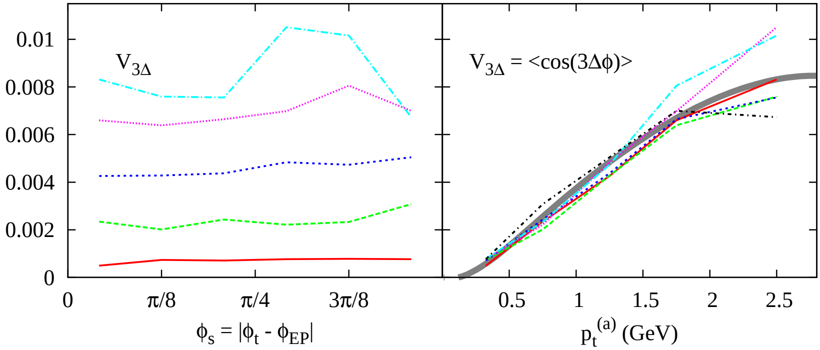
$\langle\cos(4\Delta\phi)\rangle$ — Quadrangular flow



Flow contribution to fourth harmonic:

- $V_{4\Delta} \equiv \langle\cos(4\Delta\phi)\rangle = v_4^{(a)}\{EP\} v_4^{(t,R)}\{EP\}$ + fluctuations
- $v_4^{(a)}\{EP\} = \langle\cos(2\phi_a - 2\psi_{EP})\rangle$ = Quadrangular flow with respect to v_2 event plane
- $v_4^{(t,R)}\{EP\} \simeq \cos(4\phi_s)$

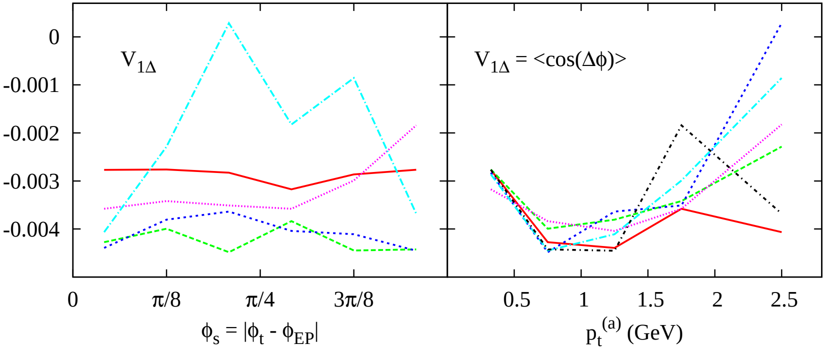
$\langle\cos(3\Delta\phi)\rangle$ — Triangular flow



Flow contribution to third harmonic:

- $V_{3\Delta} \equiv \langle\cos(3\Delta\phi)\rangle = v_3^{(a)} v_3^{(t)}$
- $v_3 = \langle\cos(3\phi_a - 3\psi_3)\rangle$ = Triangular flow
- No dependence on ϕ_s

$\langle\cos(\Delta\phi)\rangle$ — MOMENTUM CONSERVATION AND v_1



Flow contribution to first harmonic (plus p_t conservation):

- $V_{1\Delta} \equiv \langle\cos(1\Delta\phi)\rangle$ = (p_t cons.) + $v_1^{(a)} v_1^{(t)}$
- (p_t cons.) = $\frac{-p_t^{(a)} p_t^{(t)}}{\langle\sum p_t^2\rangle}$
- $v_1 = \langle\cos(\phi_a - \psi_1)\rangle$ = Directed flow

Summary

To be consistent with data, a non-flow signal must have:

1. Odd harmonics with no dependence on ϕ_s
2. A second harmonic with monotonically decreasing dependence on ϕ_s
3. A fourth harmonic that decreases and then increases with ϕ_s
4. p_t dependence that is identical to flow

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More likely: there are only collective flow correlations at large $\Delta\eta$

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   - Azimuthal structure
   - Recent STAR data (arXiv:1010.0690)

2. Fourier Decomposition
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3. Conclusions

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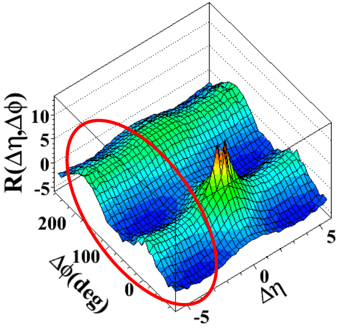
- Entire long-range dihadron correlation can be explained by collective flow
- No compelling evidence of non-flow correlation
- ⇒ Previous signals (mach-cones, etc.) are products of flawed background "subtraction" (flow fluctuations are important!)

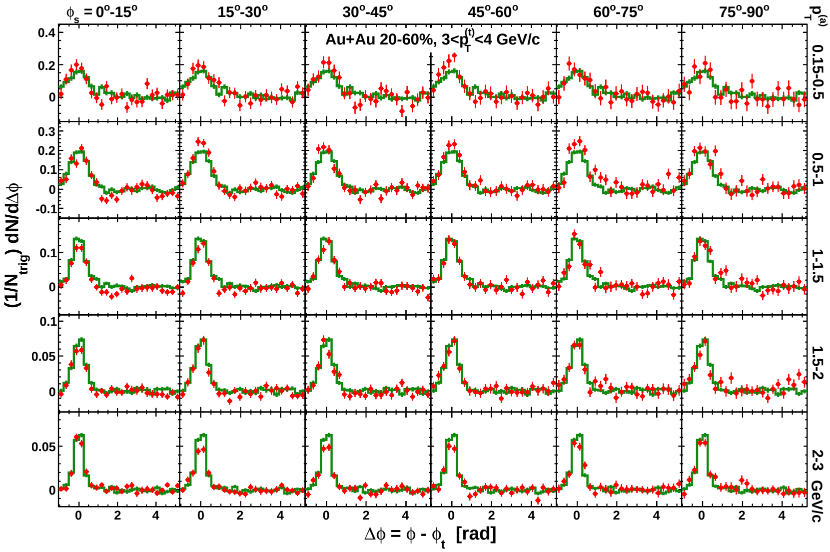


(PHOBOS, Phys. Rev. C75(2007)054913)

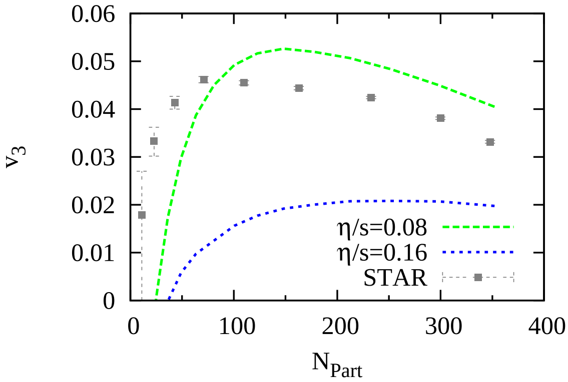
EXTRA SLIDES

Extra Slides:

SHORT-RANGE "JET-LIKE" CORRELATION



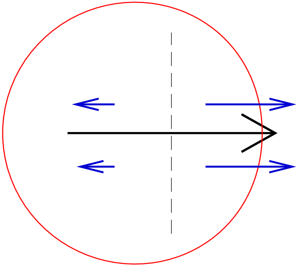
$\langle\cos(3\Delta\phi)\rangle$ — Triangular flow



(Recall that centrality dependence also follows hydro calculation)

v_1 AT MIDRAPIDITY

Event-by-event fluctuations generate a dipole asymmetry which causes directed flow that is (roughly) independent of rapidity:



(arXiv:1010.1876)

$v_1 = \langle \cos(\phi_p) \rangle$

v_1 at midrapidity

By estimating momentum conservation term

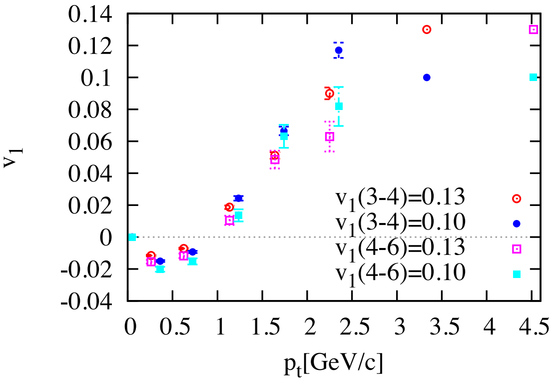
$$(p_t \text{ cons.}) = \frac{-p_t^{(a)} p_t^{(t)}}{\langle \sum p_t^2 \rangle},$$

can extract $v_1^{(a)} v_1^{(t)}$ from dihadron correlation:

$$v_1^{(a)} v_1^{(t)} = \langle \cos(\Delta\phi) \rangle + \frac{p_t^{(a)} p_t^{(t)}}{\langle \sum p_t^2 \rangle}$$

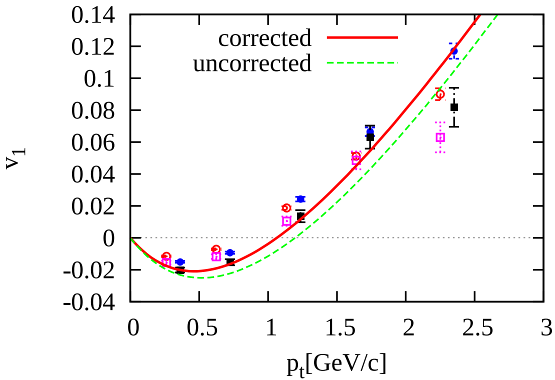
v_1 at midrapidity

Choosing a value for $v_1(p_t^{(t)})$ then gives a curve for $v_1(p_t)$:



v_1 AT MIDRAPIDITY

Which agrees with hydrodynamic calculations!



v_1 at midrapidity

Can remove large uncertainties with a dedicated measurement:

$$Q\cos\psi_{EP,1} \equiv \sum w_j \cos\phi_j$$
$$Q\sin\psi_{EP,1} \equiv \sum w_j \sin\phi_j$$

Usual choice $w = y$ gives v_1 that is odd in rapidity y.
To measure v_1 from fluctuations, choose w independent of y:

$$w = p_t - \frac{\langle p_t^2 \rangle}{\langle p_t \rangle}$$

Because $\langle w\, p_t \rangle = 0$, momentum conservation correlation is removed.

ZERO YIELD AT MINIMUM (ZYAM) PRESCRIPTION

2-particle correlations often analyzed using ZYAM:

$$\frac{dN^{pairs}}{d\Delta\phi} = B\,[\mathrm{F}(\Delta\phi)] + \mathrm{NF}(\Delta\phi)$$

ZERO YIELD AT MINIMUM (ZYAM) PRESCRIPTION

2-particle correlations often analyzed using ZYAM:

$$\begin{aligned}\frac{dN^{pairs}}{d\Delta\phi} =& B\,[\mathrm{F}(\Delta\phi)] + \mathrm{NF}(\Delta\phi) \\ =& B\left[1 + 2v_2^{(a)}v_2^{(t,R)}\cos(2\Delta\phi) + 2v_4^{(a)}v_4^{(t,R)}\cos(4\Delta\phi)\right] + \mathrm{NF}(\Delta\phi)\end{aligned}$$

Zero Yield at Minimum (ZYAM) prescription

2-particle correlations often analyzed using ZYAM:

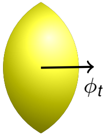
$$\frac{dN^{pairs}}{d\Delta\phi} = B\left[\mathrm{F}(\Delta\phi)\right] + \mathrm{NF}(\Delta\phi)$$
$$= B\left[1 + 2v_2^{(a)}v_2^{(t,R)}\cos(2\Delta\phi) + 2v_4^{(a)}v_4^{(t,R)}\cos(4\Delta\phi)\right] + \mathrm{NF}(\Delta\phi)$$

Fix *B* by assuming zero yield at minimum:

$$\mathrm{NF}(\Delta\phi_{\mathrm{min}}) = \mathrm{NF}'(\Delta\phi_{\mathrm{min}}) = 0$$

Zero Yield at Minimum (ZYAM) prescription

Subtracted data from STAR:



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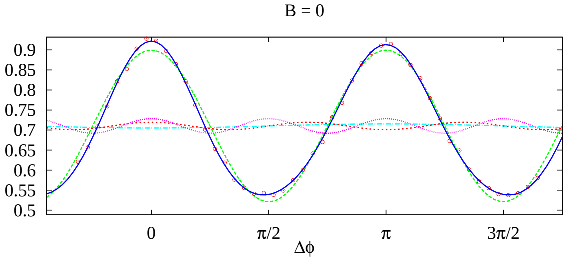

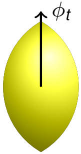

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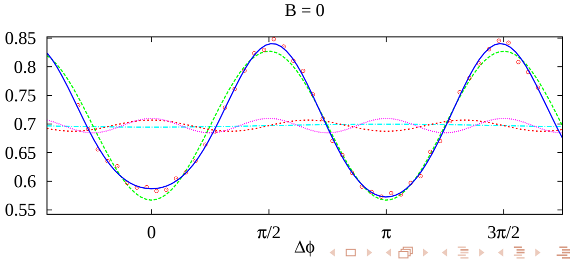

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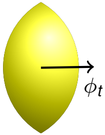

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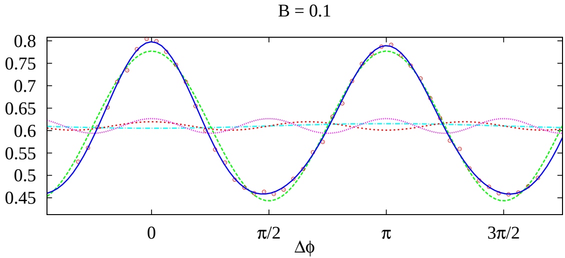

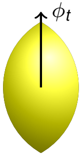

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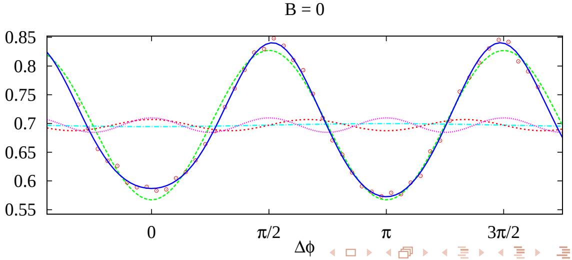

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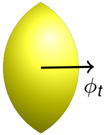

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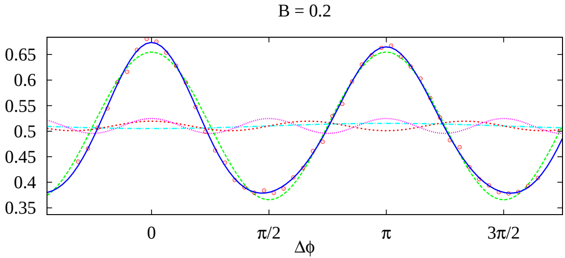

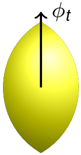

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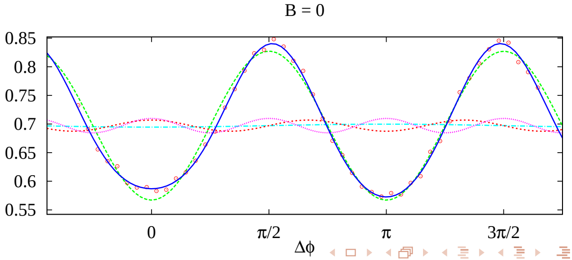

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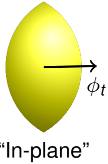

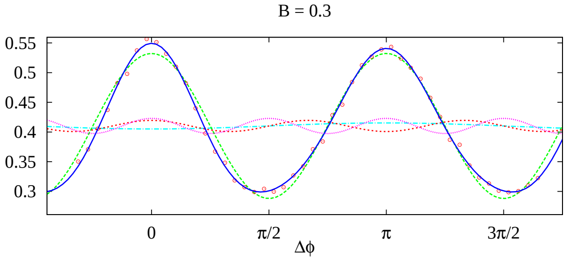

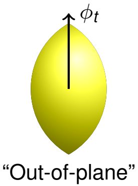

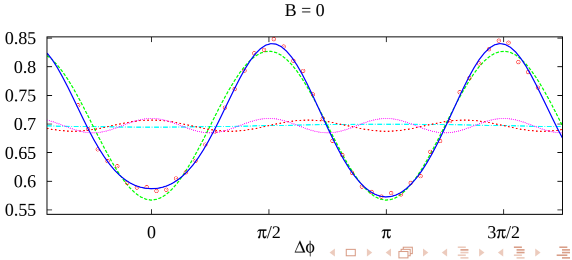

Zero Yield at Minimum (ZYAM) prescription

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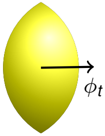

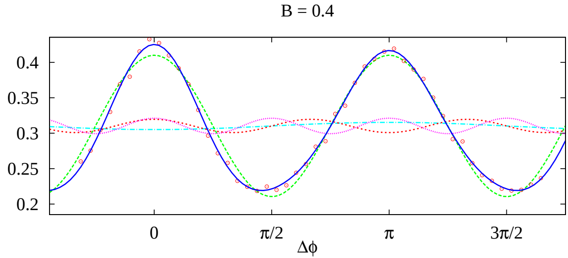

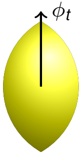

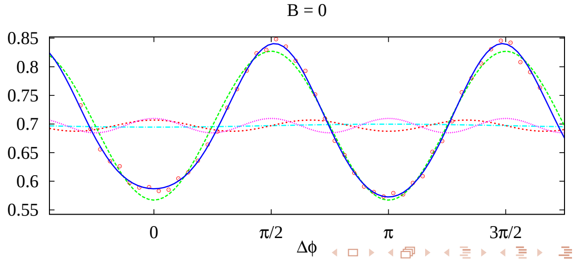

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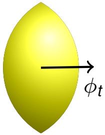

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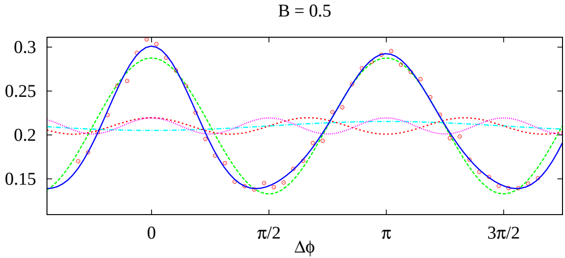

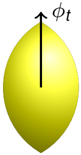

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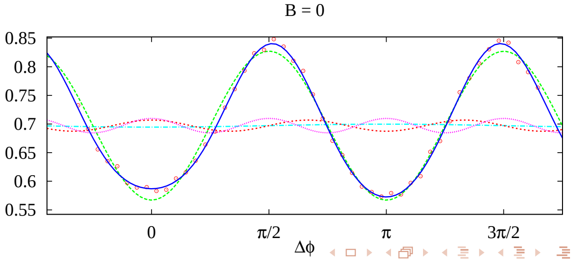

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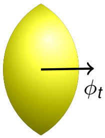

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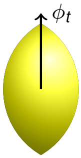

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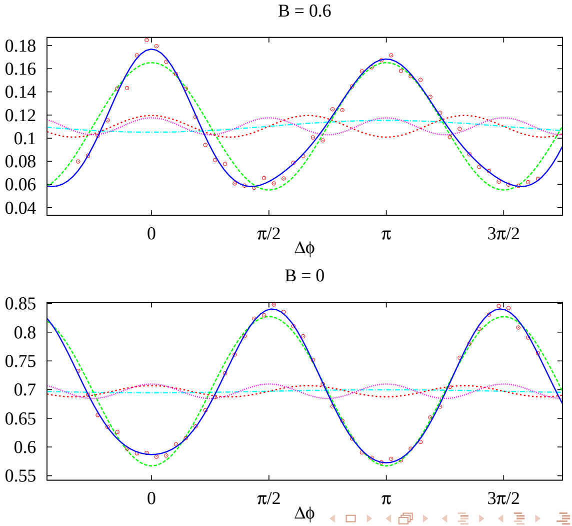

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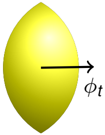

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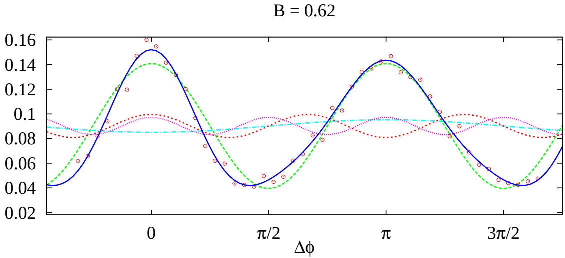

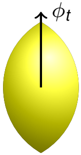

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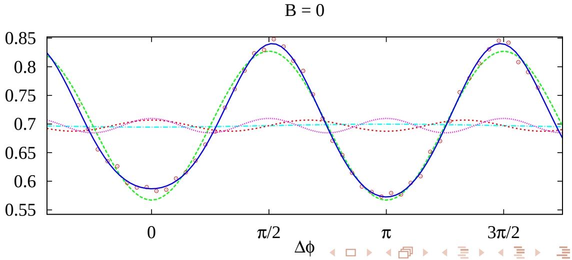

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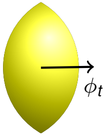

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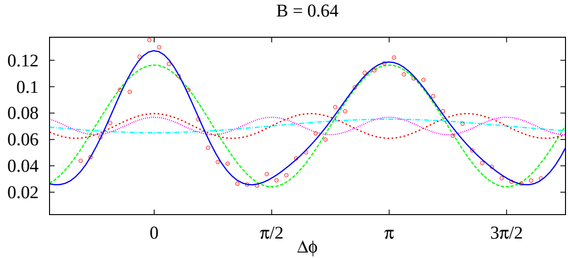

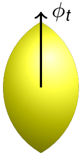

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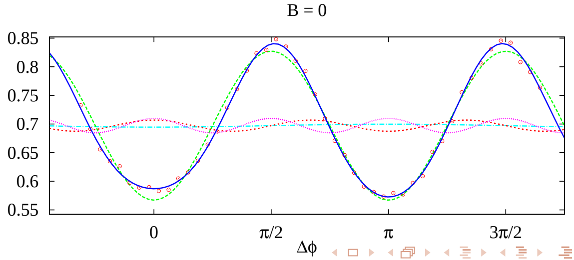

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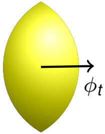

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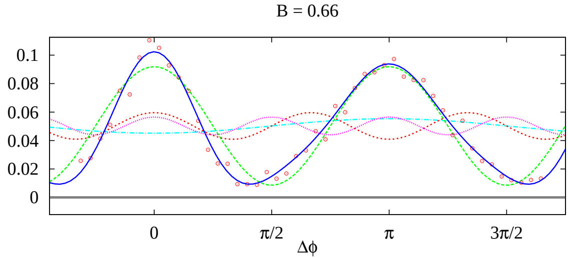

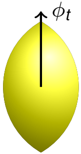

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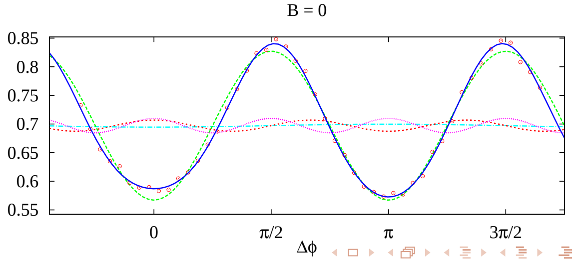

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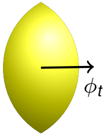

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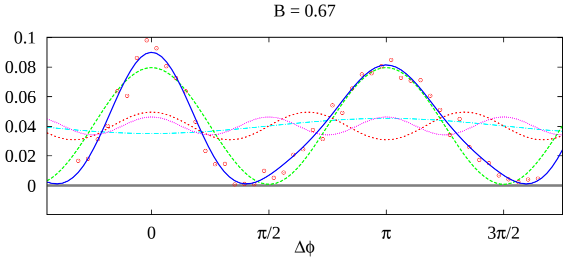

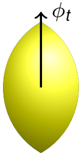

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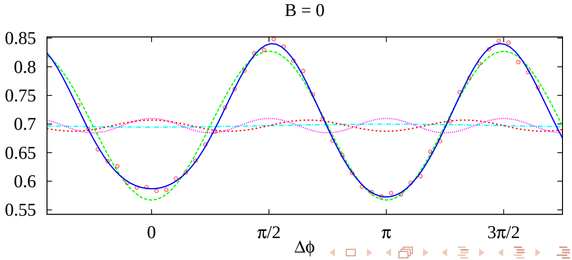

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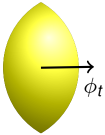

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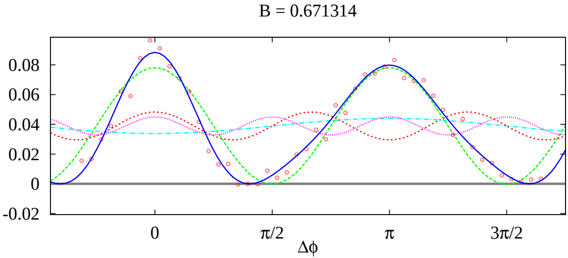

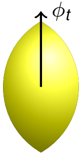

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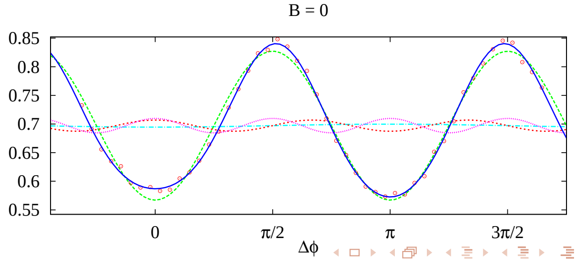

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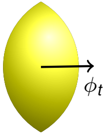

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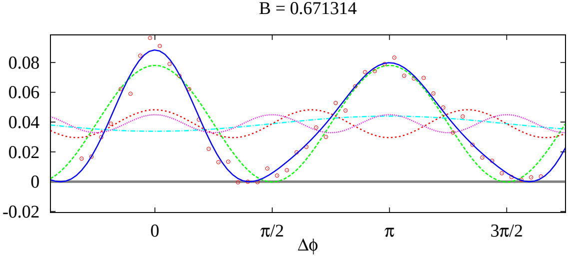

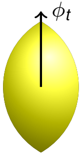

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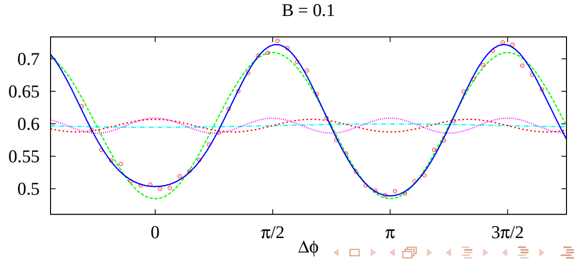

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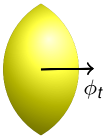

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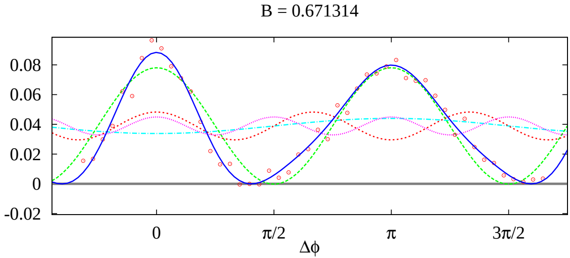

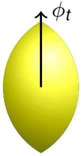

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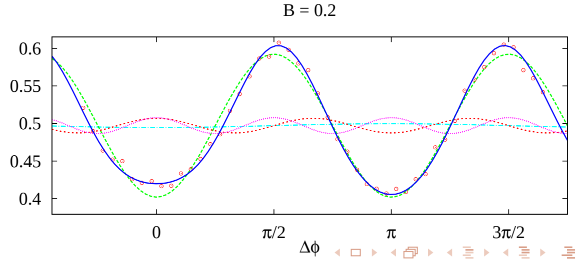

Zero Yield at Minimum (ZYAM) prescription

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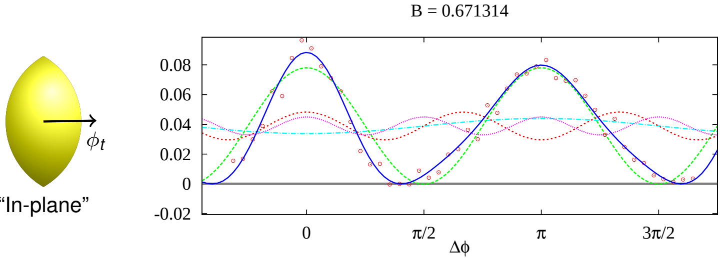

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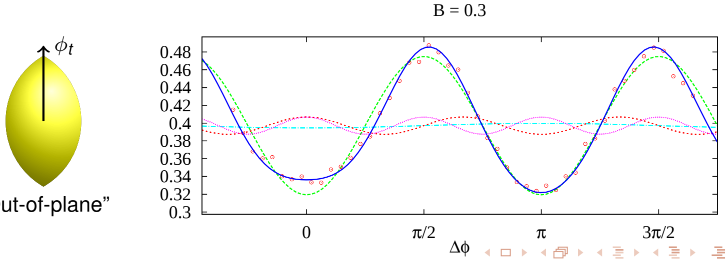

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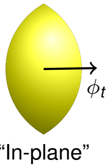

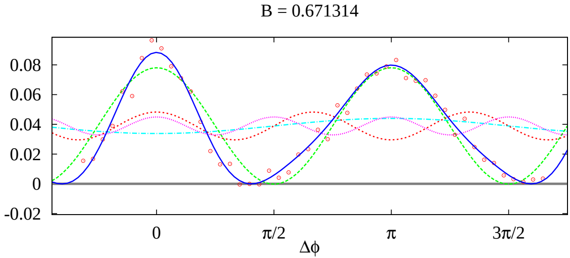

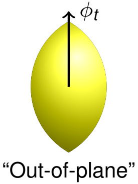

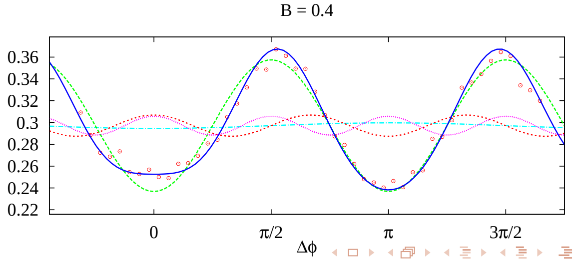

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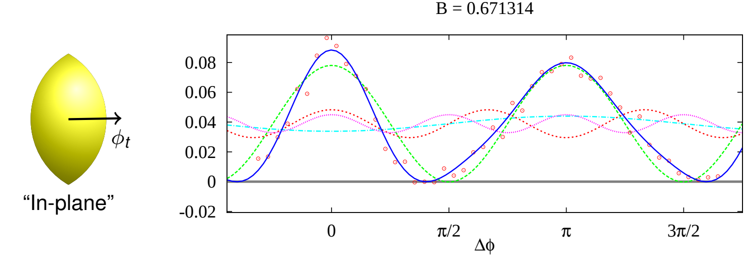

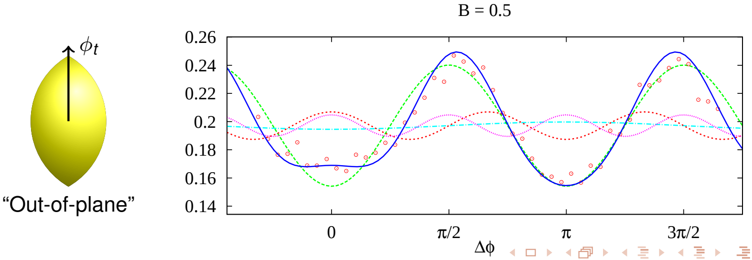

ZERO YIELD AT MINIMUM (ZYAM) PRESCRIPTION

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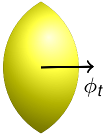
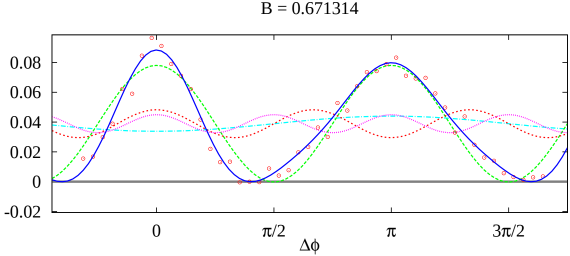
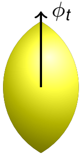


"In-plane"





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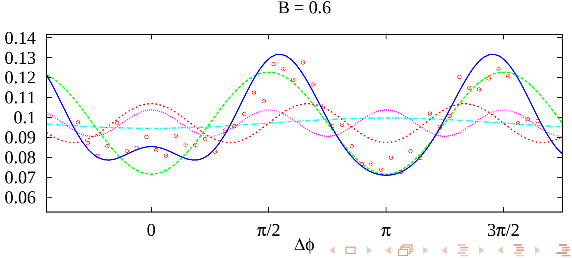

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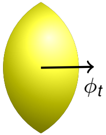
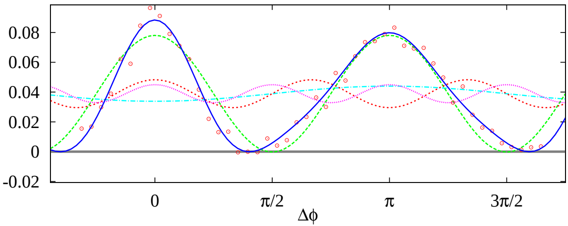


“In-plane”



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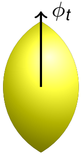
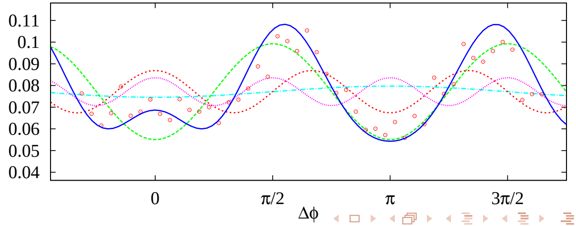


“Out-of-plane”



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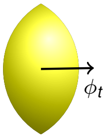

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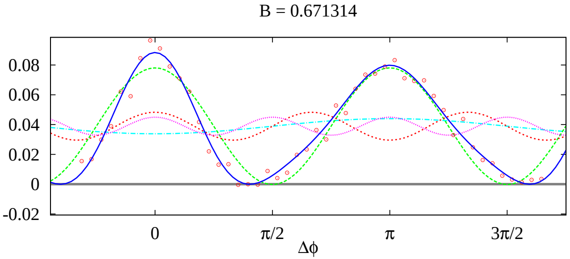
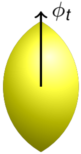
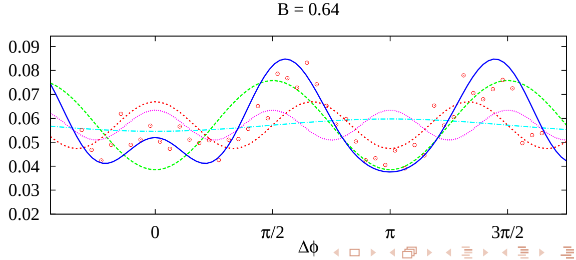




"Out-of-plane"



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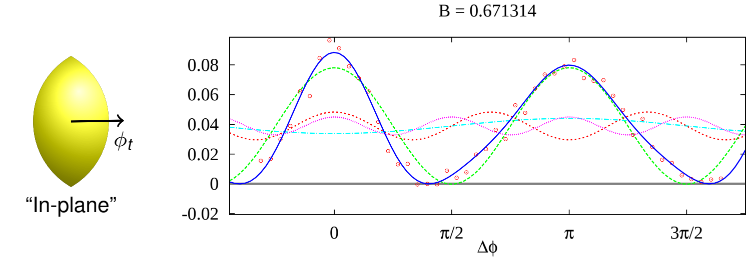

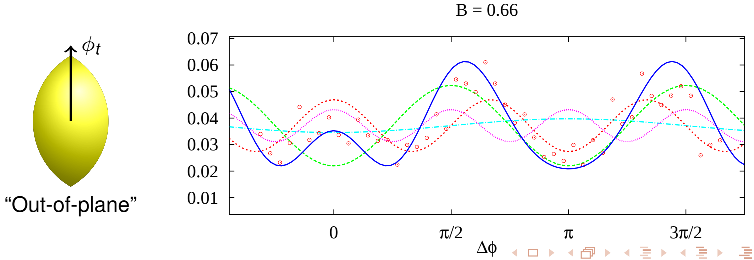

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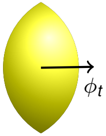

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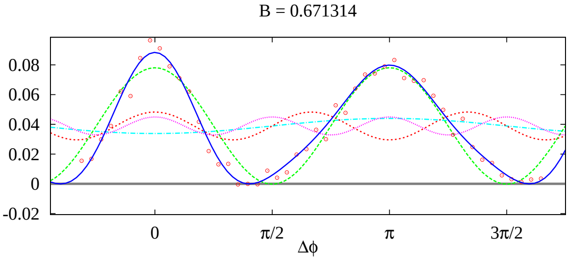

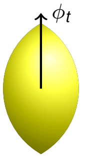

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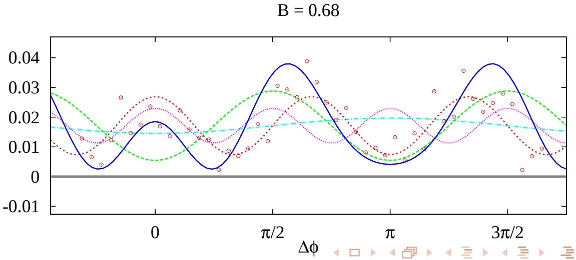

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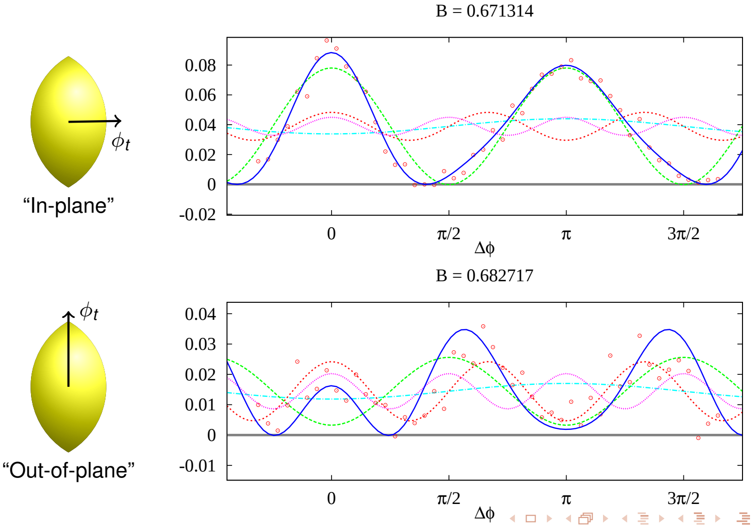

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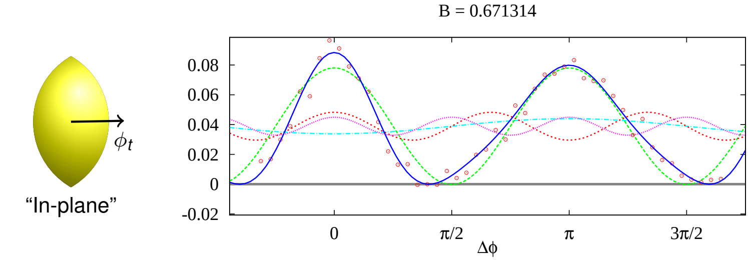

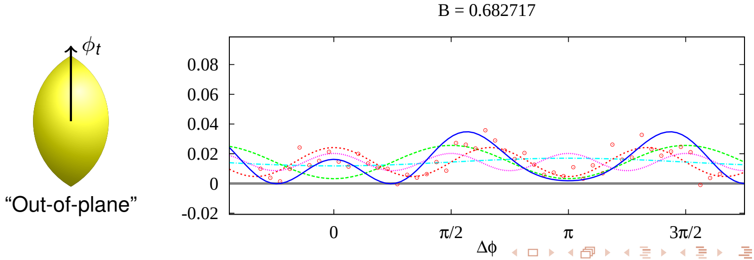

Zero Yield at Minimum (ZYAM) prescription

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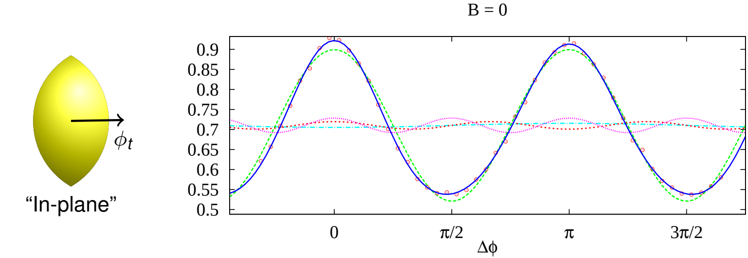
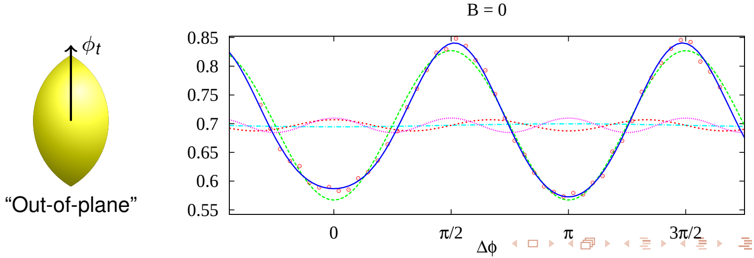
ϕ_s dependence comes from even harmonics that aren't fully subtracted
This is because of ZYAM prescription, not just because v_2 underestimated:

ZERO YIELD AT MINIMUM (ZYAM) PRESCRIPTION

Instead use $v_2^{(a)} v_2^{(t,R)} \equiv V_{2\Delta}$, $v_4^{(a)} v_4^{(t,R)} \equiv V_{4\Delta}$ — still depends on ϕ_s:





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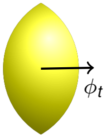
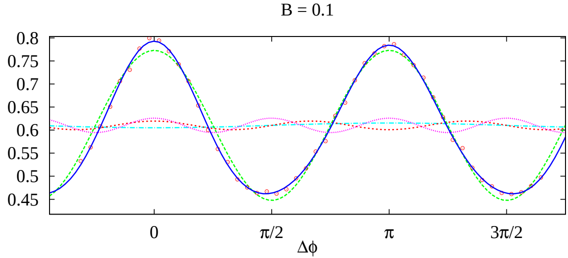
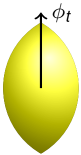
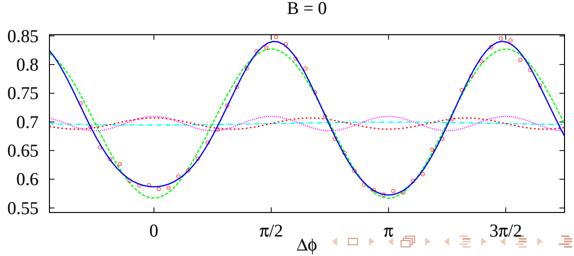


“In-plane”





“Out-of-plane”



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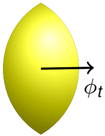

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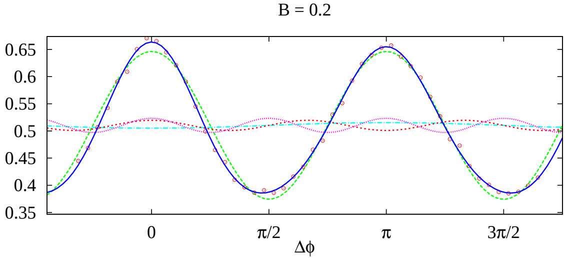

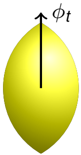

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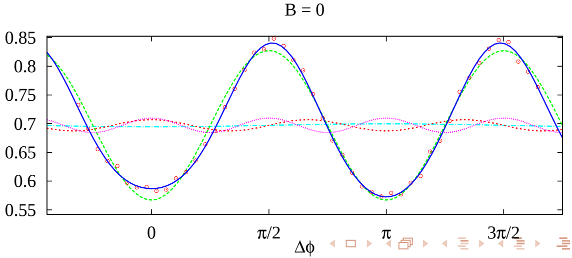

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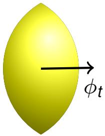

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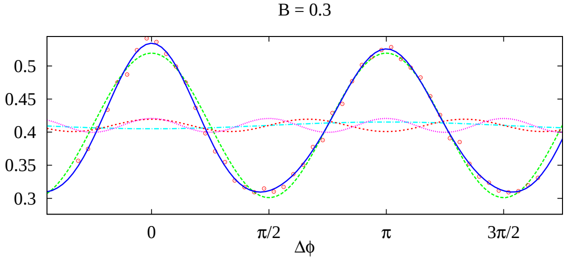

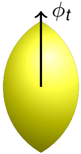

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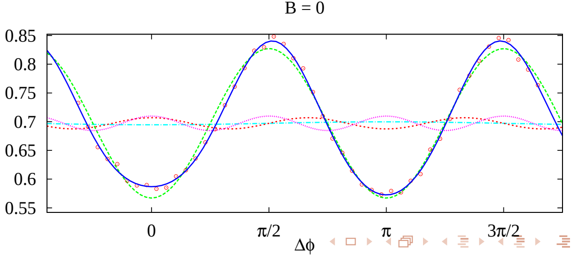

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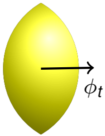

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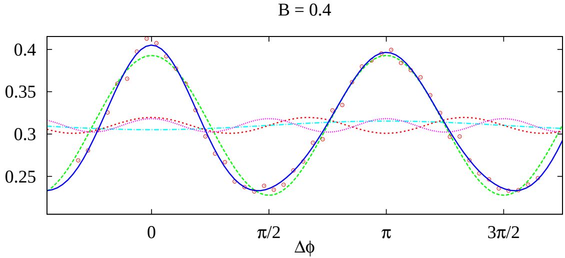

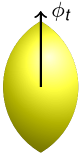

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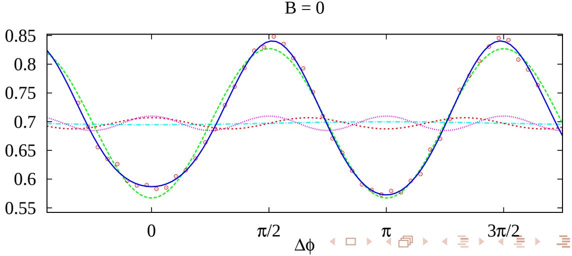

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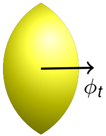

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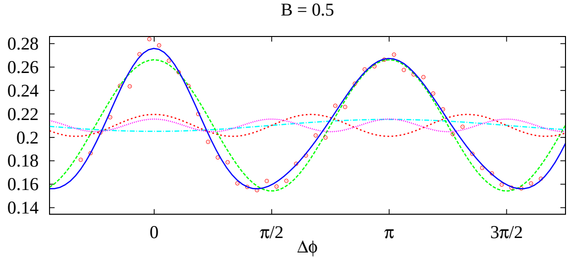

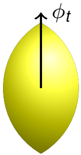

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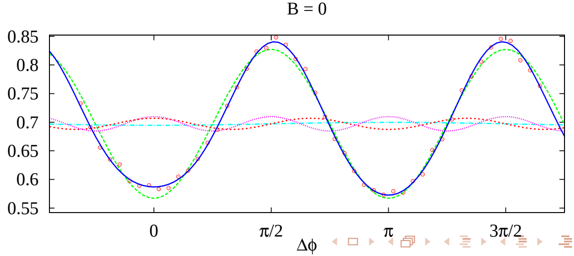

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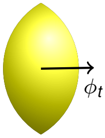

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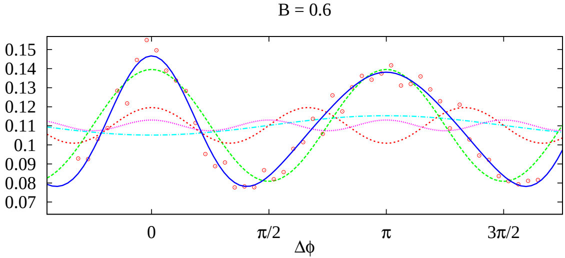

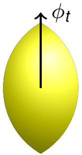

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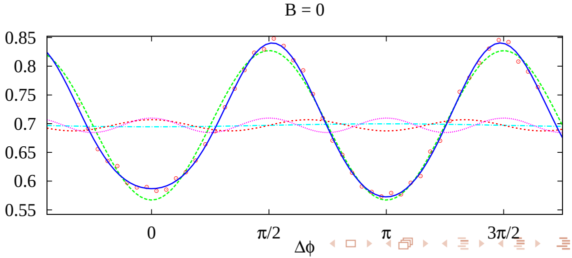

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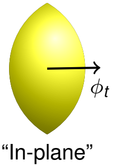

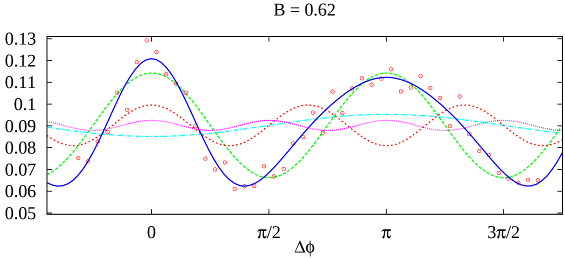

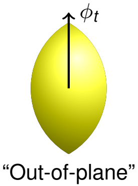

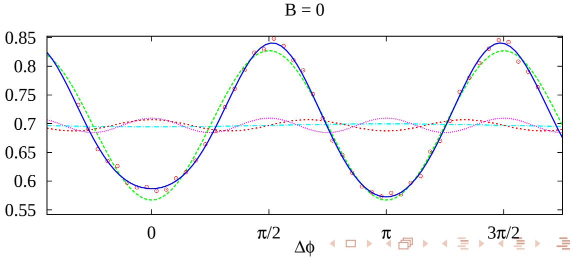

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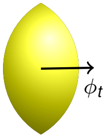

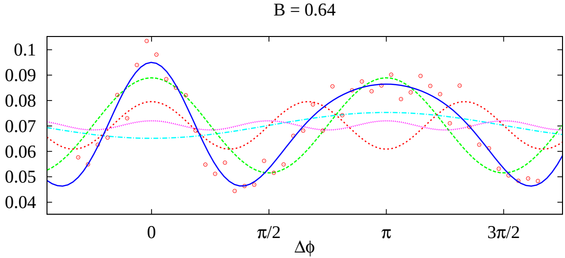

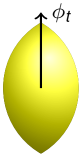

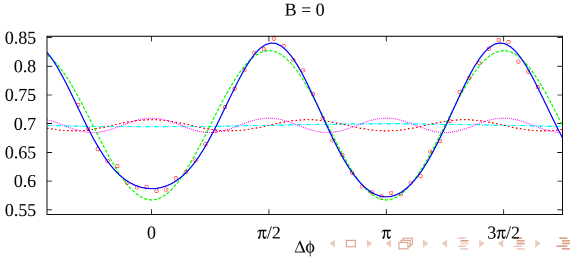

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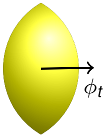

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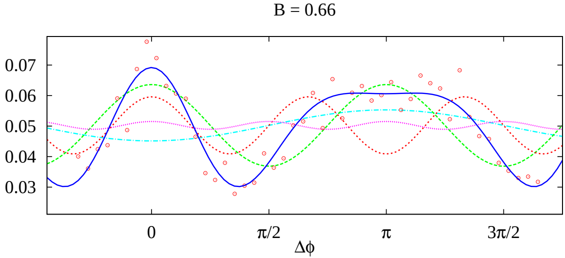

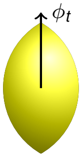

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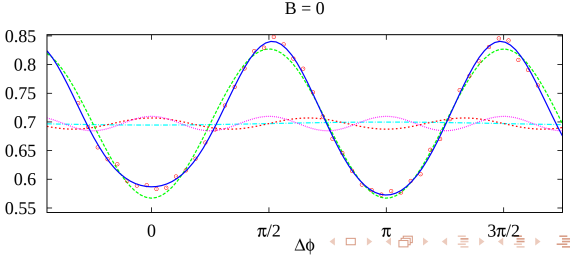

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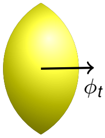

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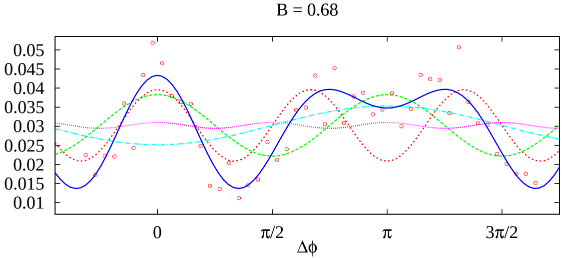

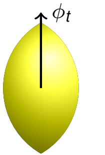

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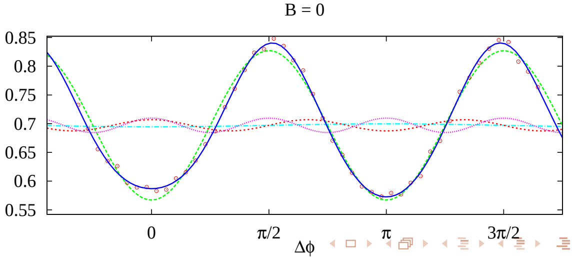

ZERO YIELD AT MINIMUM (ZYAM) PRESCRIPTION

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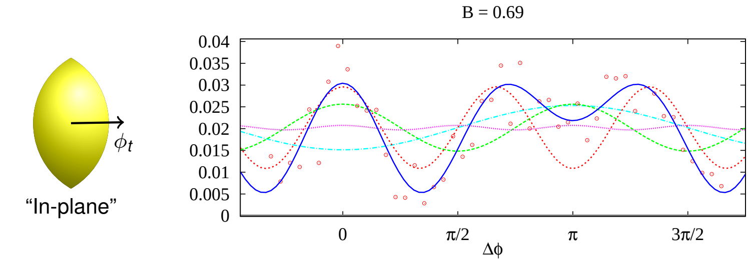

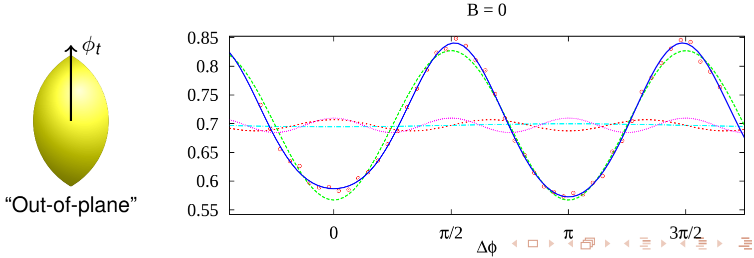

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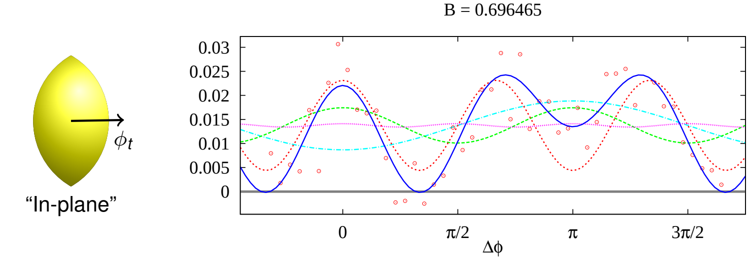

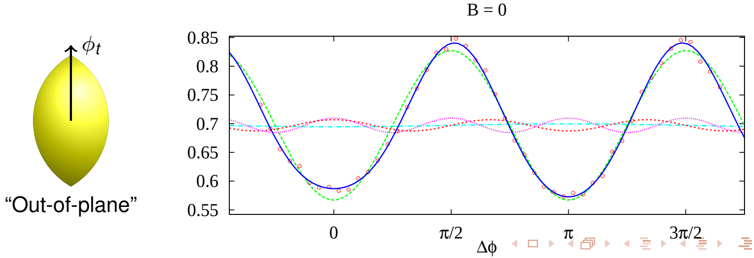

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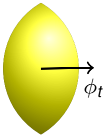

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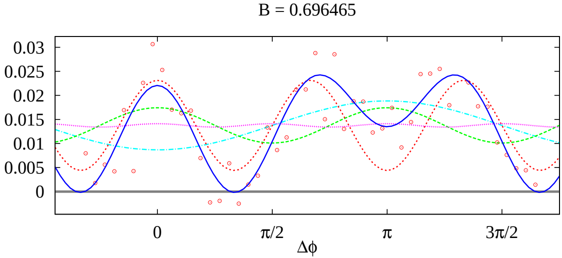

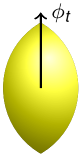

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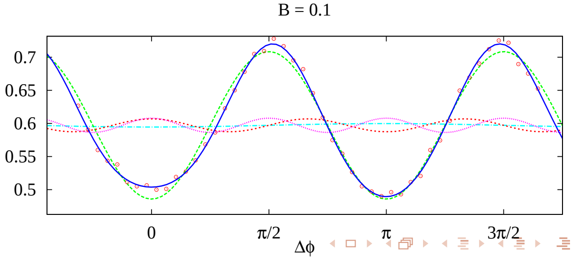

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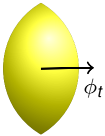

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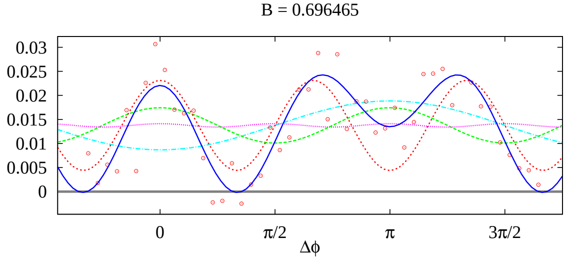

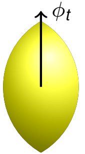

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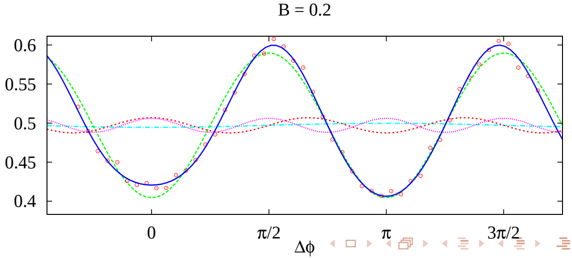

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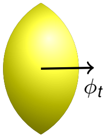

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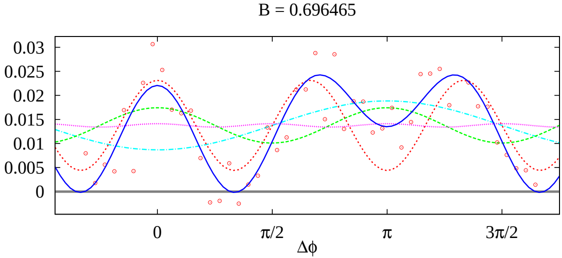

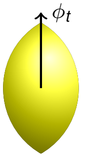

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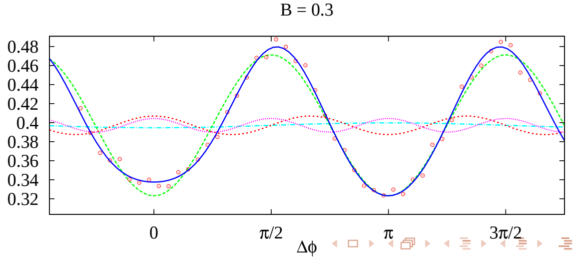

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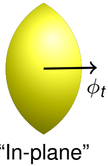

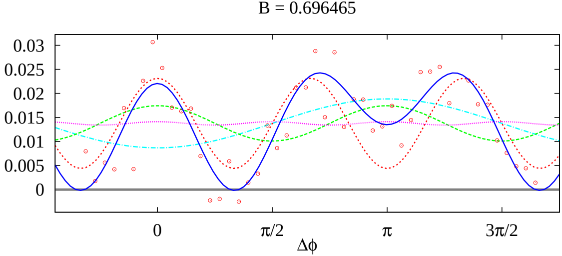

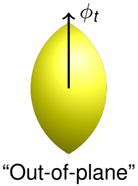

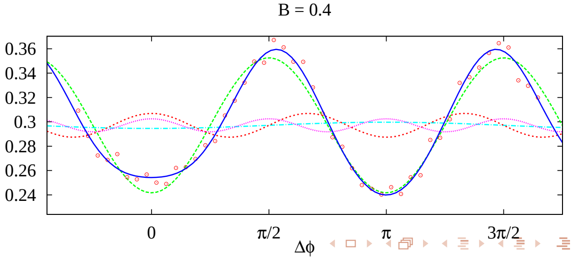

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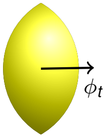

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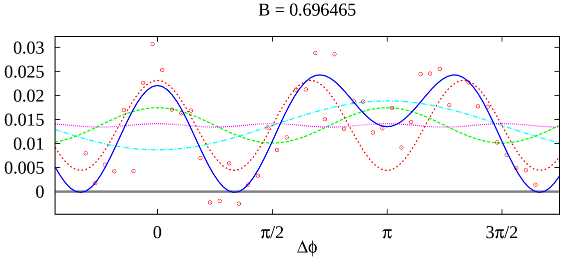

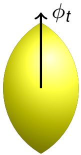

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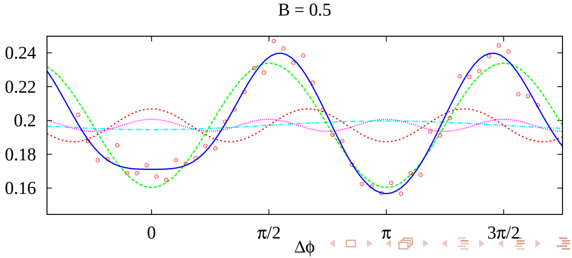

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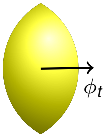

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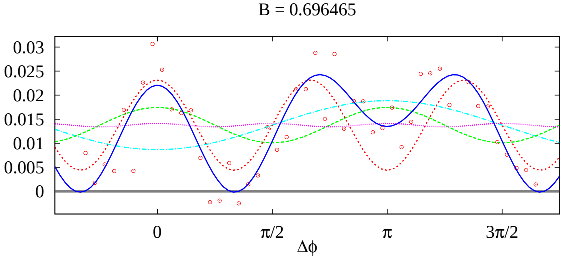

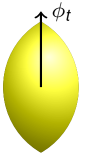

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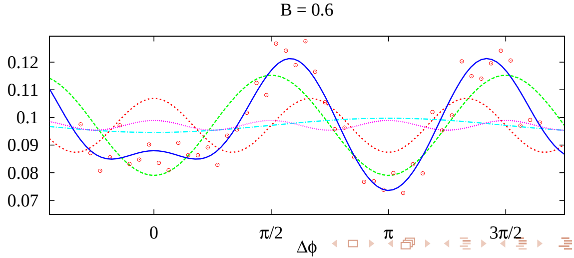

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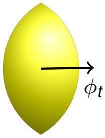

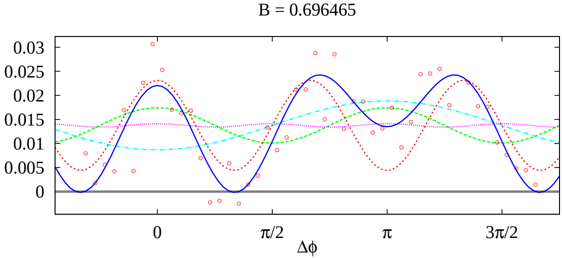

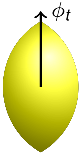

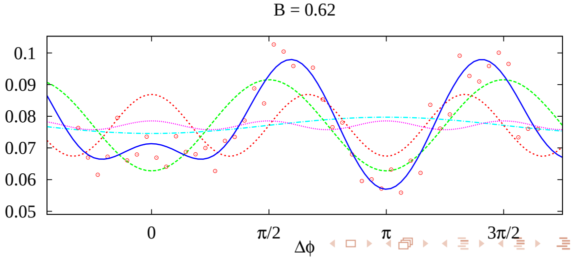

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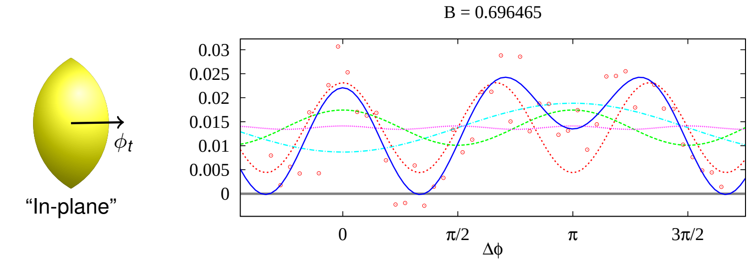

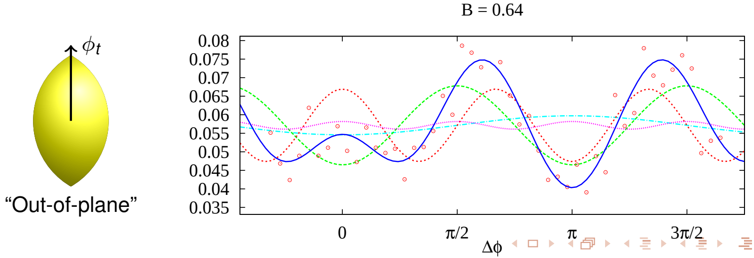

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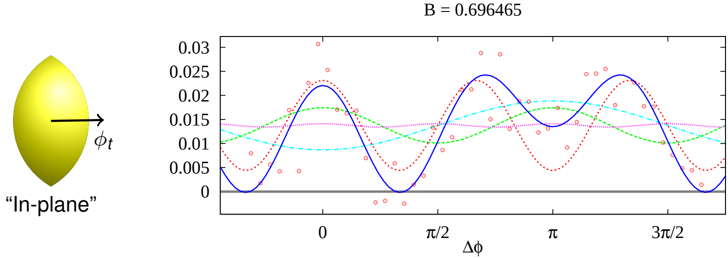

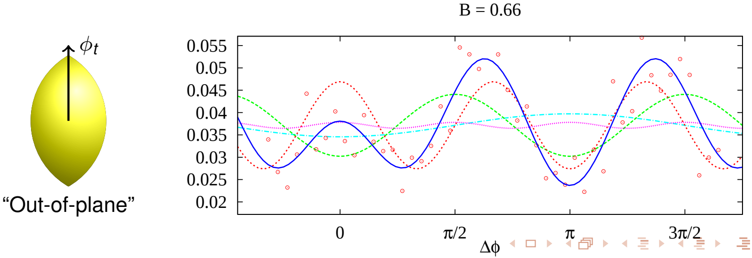

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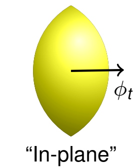

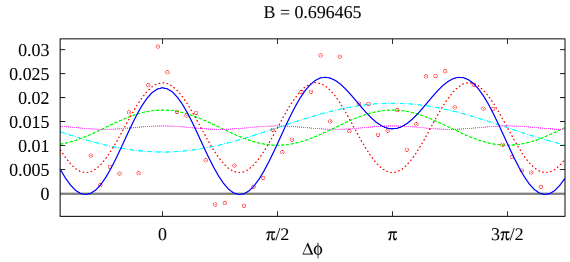

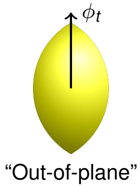

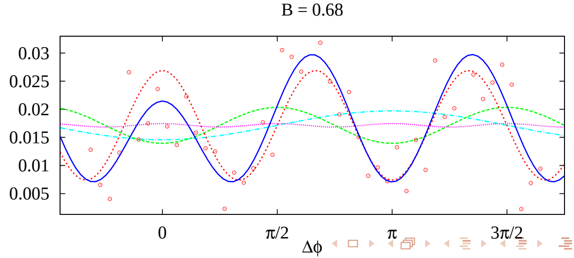

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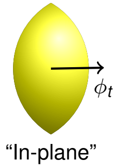

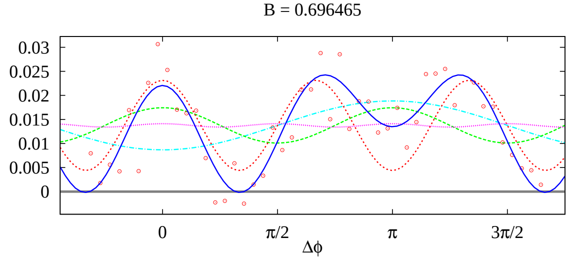

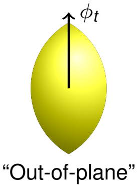

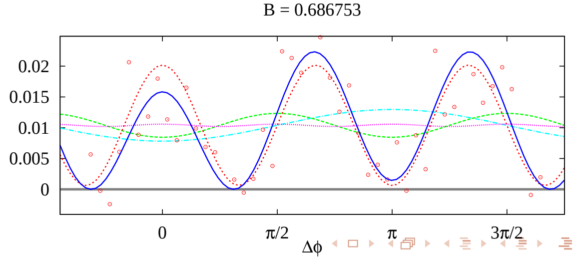

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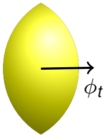

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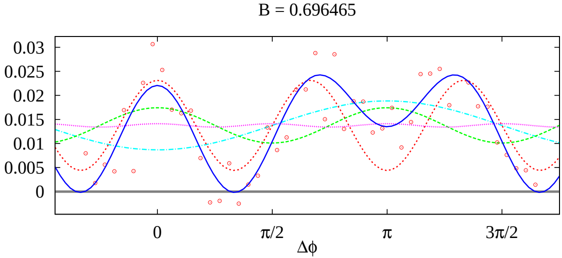

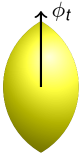

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