Binned angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ at LHCb
Rencontres de Moriond 2024

Young Scientist Forum

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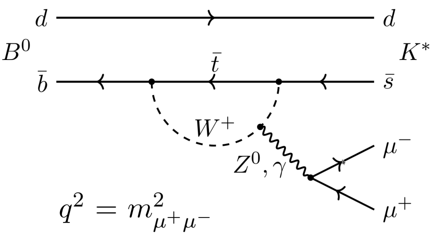
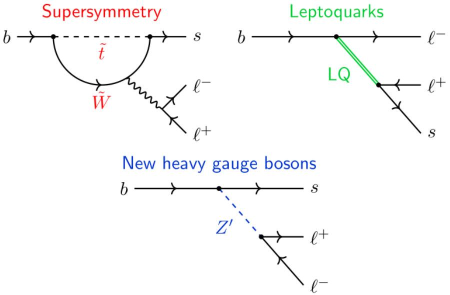
UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

LHCb

Emmy Noether-Programm
DFG Deutsche Forschungsgemeinschaft

Search for New Physics with $B^0 \to K^{*0}\mu^+\mu^-$

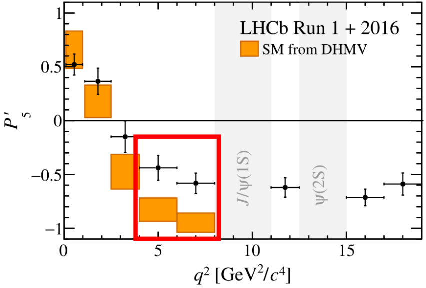




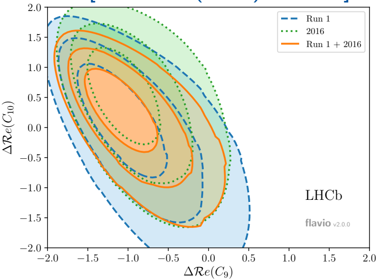
- B^0 decays via $b \to s$ flavour changing neutral current (FCNC)
- High sensitivity to New Physics due to high suppression in SM
- Angular analysis gives access to optimized observables [JHEP01(2013)048]
  - Less dependent on hadronic form factors than $\mathcal{B}$ measurements

Results of previous analysis: Run 1 + 2016

[PRL 125 (2020) 011802]

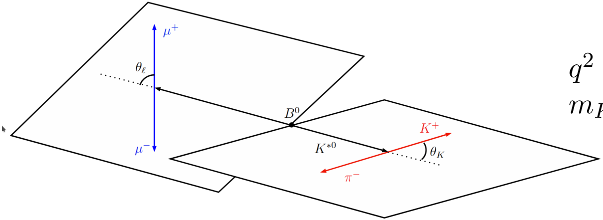


[PRL 125 (2020) 011802]



- Run1+2016 result published in 2020
- Global tension increased: $3.0\,\sigma$ (Run 1) $\rightarrow 3.3\,\sigma$ (Run 1 + 2016)
- This work: Improve analysis and include full Run2 dataset
- Integrated luminosities of 3.0 fb^{-1} (Run1) + 1.6 fb^{-1} (2016)
  1.7 fb^{-1} (2017) + 2.1 fb^{-1} (2018)

Angular description of the decay



$q^2 = (\text{inv. dimuon mass})^2$
$m_{K\pi} = \text{inv. } K\pi \text{ mass}$

- Decay fully described by three angles $\Omega = (\theta_l, \theta_K, \phi)$ + q^2 and $m_{K\pi}$
- $m_{K\pi}$ dependence now directly included into PDF as Breit-Wigners
- Previously: $m_{K\pi}$ shape fitted integrated over decay angles

$$\frac{1}{d(\Gamma+\overline{\Gamma})/dq^2}\frac{\overset{(-)}{\Gamma}}{d\vec{\Omega}\, dq^2\, dm_{K\pi}} = \frac{9}{64\pi}\sum_{i\in\mathcal{P}}(S_i \pm A_i) f_i(\theta_l,\theta_K,\phi)\, |\mathcal{BW}_\mathcal{P}(m_{K\pi})|^2 + \sum_{i\in\mathcal{S}}(S_i \pm A_i) f_i(\theta_l,\theta_K,\phi)\, |\mathcal{BW}_\mathcal{S}(m_{K\pi})|^2 + \sum_{i\in\mathcal{S}/\mathcal{P}}(S_i \pm A_i) f_i(\theta_l,\theta_K,\phi)\, g(\mathcal{BW}_\mathcal{S}(m_{K\pi})\mathcal{BW}^\star_\mathcal{P}(m_{K\pi}))$$

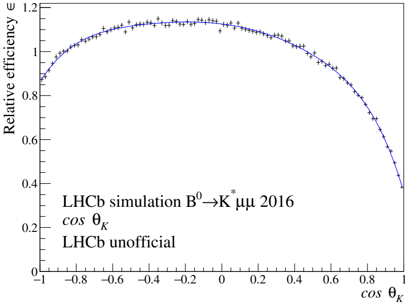
- S_i/A_i are CP-symmetries/asymmetries of angular observables
- Observables measured integrated over bins of q^2

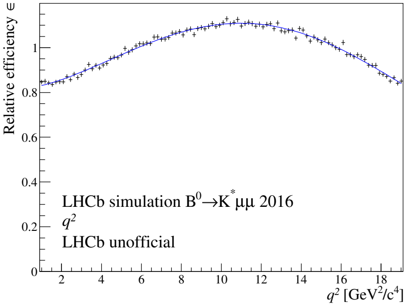
5D Acceptance correction

- Angles, q^2 and $m_{K\pi}$ distorted by reconstruction and selection
- Parameterize acceptance effect using 5D Legendre polynomials

$$\epsilon = \sum_{k,l,m,n,o} c_{klmno} P(cos(\theta_l),k)P(cos(\theta_K),l)P(\phi,m)P(q^2,n)P(m_{K\pi},o)$$

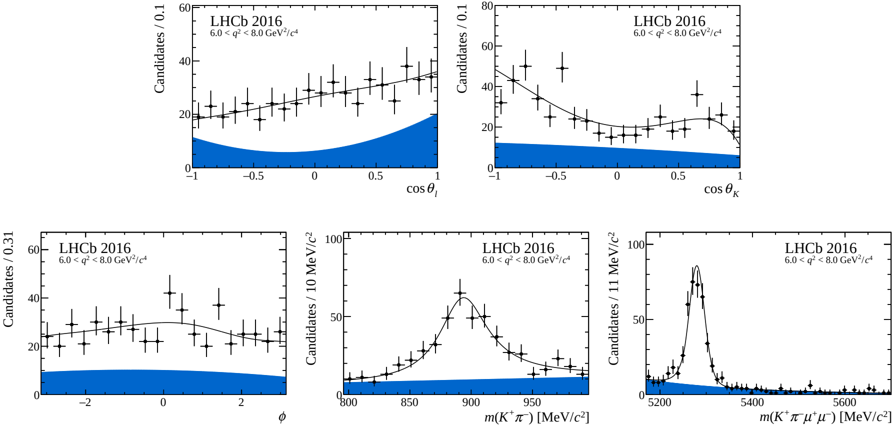
- c_{klmno} calculated with method of moments using LHCb simulation





5D maximum likelihood fit

- 5D maximum likelihood fit performed to extract angular observables
- Signal and background separated by fit to $m_{K\pi\mu\mu}$
- Separation between Spin-1 and Spin-0 contribution through $m_{K\pi}$



[PRL 125 (2020) 011802]

Improvements to analysis strategy

Event selection

- Selection retuned to improve signal efficiency / background rejection

CP-asymmetries

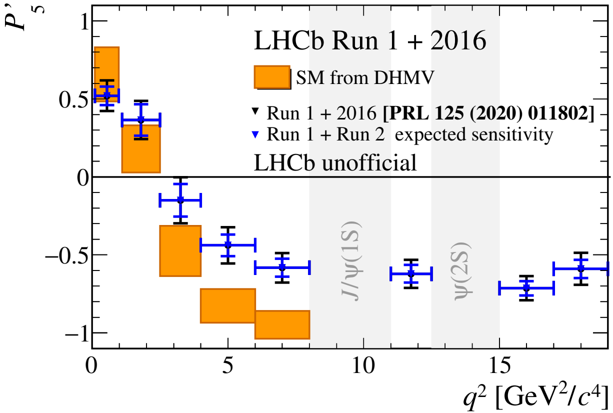
- Simultaneously extract angular CP-symmetries and asymmetries
- Preserve the correlations between them

S-wave observables and $\mathcal{B}$

- Extracting angular observables of Spin-0 $m_{K\pi}$ contributions
- Perform model independent measurement of $\mathcal{B}$

Expected sensitivity to P_5'

- Adding LHCb data from 2017/2018 roughly doubles the dataset



- Assuming the same central values from [PRL 125 (2020) 011802]
- Expected sensitivities using the full Run 1 + Run 2 dataset

Conclusions

- Binned angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ important test of the SM
- Previous analysis showed intriguing tensions with SM predictions
- Many improvements compared to previous analysis [PRL 125 (2020) 011802]
  - Added full Run 2 LHCb dataset
  - Retuned event selection to improve performance
  - Fit angular CP-asymmetries including A_{CP}
  - Will additionally publish Spin-0 observables and branching fraction

Stay tuned for an update very soon!

Backup

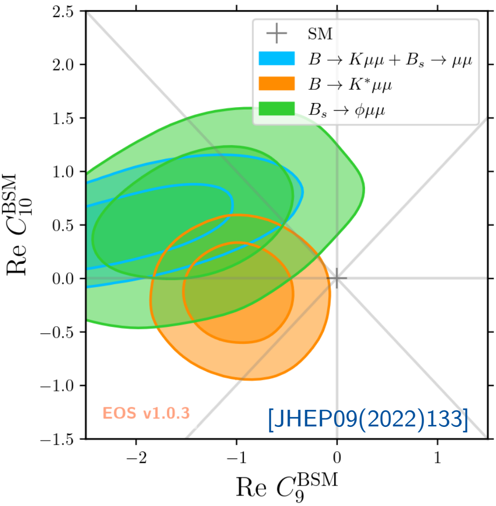
Angular coefficients I_i' and corresponding $f_i(\vec{\Omega})$

i	I_i'	f_i
$1s$	$\left(\frac{(2+\beta_\mu^2)}{4}(\lvert A_\perp^L\rvert^2+\lvert A_\parallel^L\rvert^2+\lvert A_\perp^R\rvert^2+\lvert A_\parallel^R\rvert^2)+\frac{4m_\mu^2}{q^2}\,\mathrm{Re}\left[A_\perp^L A_\perp^{R*}+A_\parallel^L A_\parallel^{R*}\right]\right)\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin^2\theta_K$
$1c$	$\left((\lvert A_0^L\rvert^2+\lvert A_0^R\rvert^2)+\frac{4m_\mu^2}{q^2}(\lvert A_t\rvert^2+2\,\mathrm{Re}\left[A_0^L A_0^{R*}\right])+\beta_\mu^2\lvert A_\text{scalar}\rvert^2\right)\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\cos^2\theta_K$
$2s$	$\frac{\beta_\mu^2}{4}(\lvert A_\perp^L\rvert^2+\lvert A_\parallel^L\rvert^2+\lvert A_\perp^R\rvert^2+\lvert A_\parallel^R\rvert^2)\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin^2\theta_K\cos 2\theta_\ell$
$2c$	$-\beta_\mu^2(\lvert A_0^L\rvert^2+\lvert A_0^R\rvert^2)\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\cos^2\theta_K\cos 2\theta_\ell$
3	$\frac{1}{2}\beta_\mu^2(\lvert A_\perp^L\rvert^2-\lvert A_\parallel^L\rvert^2+\lvert A_\perp^R\rvert^2-\lvert A_\parallel^R\rvert^2)\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$
4	$\frac{1}{\sqrt{2}}\beta_\mu^2\,\mathrm{Re}\left[A_0^L A_\parallel^{L*}+A_0^R A_\parallel^{R*}\right]\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin 2\theta_K\sin 2\theta_\ell\cos\phi$
5	$\sqrt{2}\beta_\mu\left(\mathrm{Re}\left[A_0^L A_\perp^{L*}-A_0^R A_\perp^{R*}\right]-\frac{m_\mu}{\sqrt{q^2}}\mathrm{Re}\left[A_\parallel^L A_\text{scalar}^*+A_\parallel^R A_\text{scalar}^*\right]\right)\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin 2\theta_K\sin\theta_\ell\cos\phi$
$6s$	$2\beta_\mu\,\mathrm{Re}\left[A_\parallel^L A_\perp^{L*}-A_\parallel^R A_\perp^{R*}\right]\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin^2\theta_K\cos\theta_\ell$
$6c$	$4\beta_\mu\frac{m_\mu}{\sqrt{q^2}}\,\mathrm{Re}\left[A_0^L A_\text{scalar}^*+A_0^R A_\text{scalar}^*\right]\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\cos^2\theta_K\cos\theta_\ell$
7	$\sqrt{2}\beta_\mu\left(\mathrm{Im}\left[A_0^L A_\parallel^{L*}-A_0^R A_\parallel^{R*}\right]+\frac{m_\mu}{\sqrt{q^2}}\mathrm{Im}\left[A_\perp^L A_\text{scalar}^*+A_\perp^R A_\text{scalar}^*\right]\right)\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin 2\theta_K\sin\theta_\ell\sin\phi$
8	$\frac{1}{\sqrt{2}}\beta_\mu^2\,\mathrm{Im}\left[A_0^L A_\perp^{L*}+A_0^R A_\perp^{R*}\right]\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin 2\theta_K\sin 2\theta_\ell\sin\phi$
9	$\beta_\mu^2\,\mathrm{Im}\left[A_\parallel^L A_\perp^{L*}+A_\parallel^R A_\perp^{R*}\right]\times\lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi$
10	$\frac{1}{2}\left(\lvert A_\mathrm{S}^L\rvert^2+\lvert A_\mathrm{S}^R\rvert^2+\frac{4m_\mu^2}{q^2}(\lvert A_t\rvert^2+2\mathrm{Re}\left[A_\mathrm{S}^L A_\mathrm{S}^{R*}\right])\right)\times\lvert\mathcal{BW}_\mathrm{S}\rvert^2$	1
11	$\sqrt{3}\left(\mathrm{Re}\left[(A_\mathrm{S}^L A_0^{L*}+A_\mathrm{S}^R A_0^{R*}+\frac{4m_\mu^2}{q^2}(A_\mathrm{S}^L A_0^{R*}+A_{\text{scalar},t}A_t^*))\times\mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]+\mathrm{Re}\left[\frac{4m_\mu^2}{q^2}A_0^L A_\mathrm{S}^{R*}\times\mathcal{BW}_\mathrm{P}\mathcal{BW}_\mathrm{S}^*\right]\right)$	$\cos\theta_K$
12	$-\frac{1}{2}\beta_\mu^2\,(\lvert A_\mathrm{S}^L\rvert^2+\lvert A_\mathrm{S}^R\rvert^2)\times\lvert\mathcal{BW}_\mathrm{S}\rvert^2$	$\cos 2\theta_\ell$
13	$-\sqrt{3}\beta_\mu^2\,\mathrm{Re}\left[(A_\mathrm{S}^L A_0^{L*}+A_\mathrm{S}^R A_0^{R*})\times\mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\cos\theta_K\cos 2\theta_\ell$
14	$\sqrt{\frac{3}{2}}\beta_\mu^2\,\mathrm{Re}\left[(A_\mathrm{S}^L A_\parallel^{L*}+A_\mathrm{S}^R A_\parallel^{R*})\times\mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\sin\theta_K\sin 2\theta_\ell\cos\phi$
15	$2\sqrt{\frac{3}{2}}\beta_\mu\,\mathrm{Re}\left[(A_\mathrm{S}^L A_\perp^{L*}-A_\mathrm{S}^R A_\perp^{R*})\times\mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\sin\theta_K\sin\theta_\ell\cos\phi$
16	$2\sqrt{\frac{3}{2}}\beta_\mu\,\mathrm{Im}\left[(A_\mathrm{S}^L A_\parallel^{L*}-A_\mathrm{S}^R A_\parallel^{R*})\times\mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\sin\theta_K\sin\theta_\ell\sin\phi$
17	$\sqrt{\frac{3}{2}}\beta_\mu^2\,\mathrm{Im}\left[(A_\mathrm{S}^L A_\perp^{L*}+A_\mathrm{S}^R A_\perp^{R*})\times\mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\sin\theta_K\sin 2\theta_\ell\sin\phi$

Angular coefficients I_i' and corresponding $f_i(\vec{\Omega})$

i	I_i'	f_i
$1s$	$\frac{3}{4}(\lvert A_\parallel^L\rvert^2 + \lvert A_\perp^L\rvert^2 + \lvert A_\parallel^R\rvert^2 + \lvert A_\perp^R\rvert^2) \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin^2\theta_K$
$1c$	$(\lvert A_0^L\rvert^2 + \lvert A_0^R\rvert^2) \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\cos^2\theta_K$
$2s$	$\frac{1}{4}(\lvert A_\parallel^L\rvert^2 + \lvert A_\perp^L\rvert^2 + \lvert A_\parallel^R\rvert^2 + \lvert A_\perp^R\rvert^2) \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin^2\theta_K \cos 2\theta_\ell$
$2c$	$(-\lvert A_0^L\rvert^2 - \lvert A_0^R\rvert^2) \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\cos^2\theta_K \cos 2\theta_\ell$
3	$\frac{1}{2}(\lvert A_\perp^L\rvert^2 - \lvert A_\parallel^L\rvert^2 + \lvert A_\perp^R\rvert^2 - \lvert A_\parallel^R\rvert^2) \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin^2\theta_K \sin^2\theta_\ell \cos 2\phi$
4	$\sqrt{\frac{1}{2}}\,\mathrm{Re}\left[A_0^L A_\parallel^{L*} + A_0^R A_\parallel^{R*}\right] \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin 2\theta_K \sin 2\theta_\ell \cos\phi$
5	$\sqrt{2}\,\mathrm{Re}\left[A_0^L A_\perp^{L*} - A_0^R A_\perp^{R*}\right] \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin 2\theta_K \sin\theta_\ell \cos\phi$
$6s$	$2\,\mathrm{Re}\left[A_\parallel^L A_\perp^{L*} - A_\parallel^R A_\perp^{R*}\right] \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin^2\theta_K \cos\theta_\ell$
$6c$	0	$\cos^2\theta_K \cos\theta_\ell$
7	$\sqrt{2}\,\mathrm{Im}\left[A_0^L A_\parallel^{L*} - A_0^R A_\parallel^{R*}\right] \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin 2\theta_K \sin\theta_\ell \sin\phi$
8	$\sqrt{\frac{1}{2}}\,\mathrm{Re}\left[A_0^L A_\perp^{L*} + A_0^R A_\perp^{R*}\right] \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin 2\theta_K \sin 2\theta_\ell \sin\phi$
9	$\mathrm{Im}\left[A_\parallel^L A_\perp^{L*} + A_\parallel^R A_\perp^{R*}\right] \times \lvert\mathcal{BW}_\mathrm{P}\rvert^2$	$\sin^2\theta_K \sin^2\theta_\ell \sin 2\phi$
10	$\frac{1}{2}(\lvert A_\mathrm{S}^L\rvert^2 + \lvert A_\mathrm{S}^R\rvert^2) \times \lvert\mathcal{BW}_\mathrm{S}\rvert^2$	1
11	$\sqrt{3}\,\mathrm{Re}\left[(A_\mathrm{S}^L A_0^{L*} + A_\mathrm{S}^R A_0^{R*}) \times \mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\cos\theta_K$
12	$-\frac{1}{2}(\lvert A_\mathrm{S}^L\rvert^2 + \lvert A_\mathrm{S}^R\rvert^2) \times \lvert\mathcal{BW}_\mathrm{S}\rvert^2$	$\cos 2\theta_\ell$
13	$-\sqrt{3}\,\mathrm{Re}\left[(A_\mathrm{S}^L A_0^{L*} + A_\mathrm{S}^R A_0^{R*}) \times \mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\cos\theta_K \cos 2\theta_\ell$
14	$\sqrt{\frac{3}{2}}\,\mathrm{Re}\left[(A_\mathrm{S}^L A_\parallel^{L*} + A_\mathrm{S}^{\prime R} A_\parallel^{\prime R*}) \times \mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\sin\theta_K \sin 2\theta_\ell \cos\phi$
15	$2\sqrt{\frac{3}{2}}\,\mathrm{Re}\left[(A_\mathrm{S}^L A_\perp^{L*} - A_\mathrm{S}^R A_\perp^{R*}) \times \mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\sin\theta_K \sin\theta_\ell \cos\phi$
16	$2\sqrt{\frac{3}{2}}\,\mathrm{Im}\left[(A_\mathrm{S}^L A_\parallel^{L*} - A_\mathrm{S}^R A_\parallel^{R*}) \times \mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\sin\theta_K \sin\theta_\ell \sin\phi$
17	$\sqrt{\frac{3}{2}}\,\mathrm{Im}\left[(A_\mathrm{S}^L A_\perp^{L*} + A_\mathrm{S}^R A_\perp^{R*}) \times \mathcal{BW}_\mathrm{S}\mathcal{BW}_\mathrm{P}^*\right]$	$\sin\theta_K \sin 2\theta_\ell \sin\phi$

Global fits


SM
$B \to K\mu\mu + B_s \to \mu\mu$
$B \to K^*\mu\mu$
$B_s \to \phi\mu\mu$
EOS v1.0.3
[JHEP09(2022)133]
Re C_{10}^{BSM}
Re C_9^{BSM}
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2
−1
0
1

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