Apparent flow due to radiation
in heavy-ion collisions

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HAS Wigner RCP

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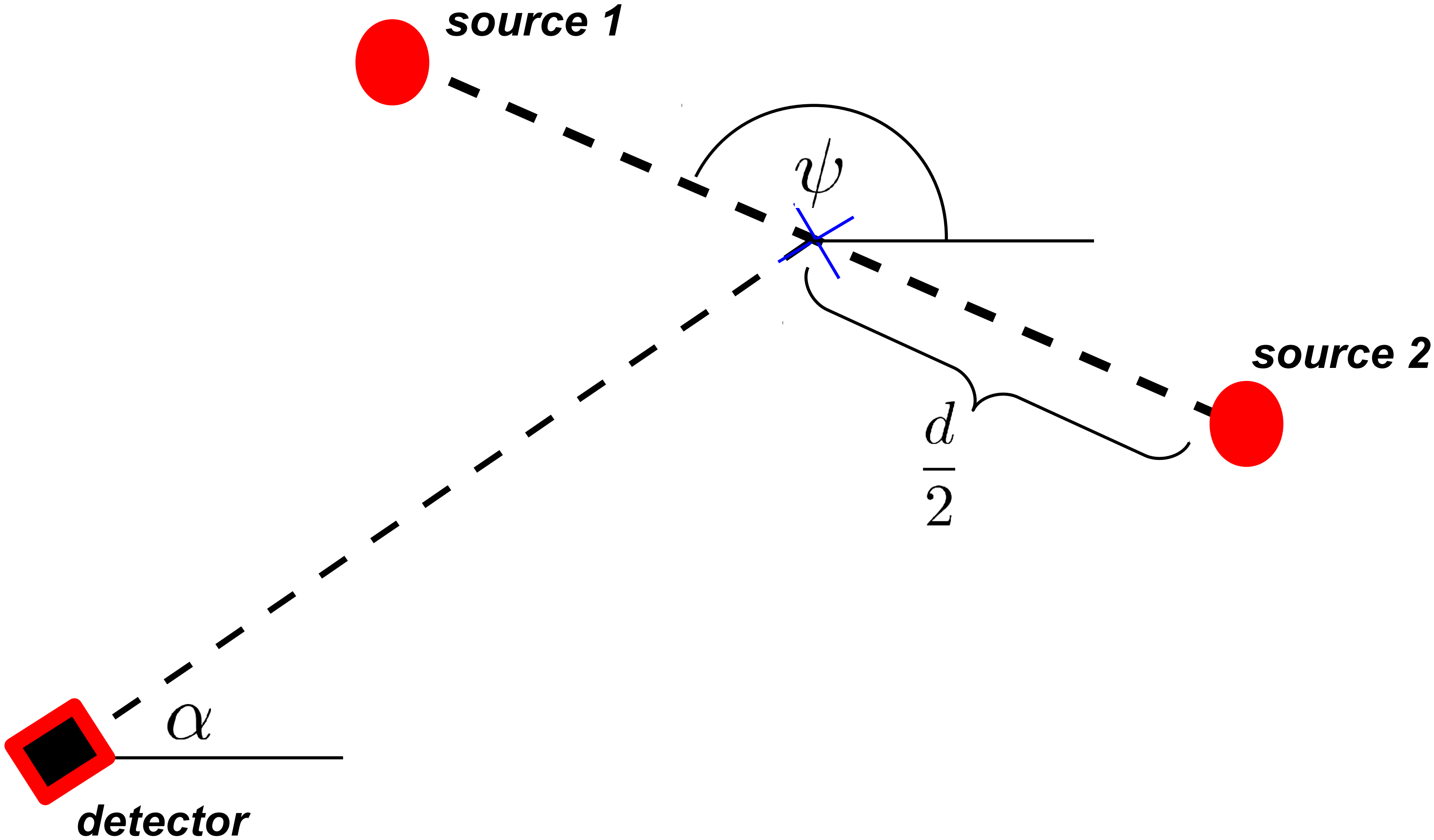
Outline

- Motivation
- Photon yield from classical radiation of decelerating charges
- Flow coefficients & fits

Motivations

- *photon yield ~ radiation of decelerating charge (Unruh-like, arXiv:1111.4817, 1401.1987)*
- *Color Scintillating Antenna arrays, remarkable scaling property of flow coeffs. (M. Gyulassy, arXiv:1405.7825)*
- *classical radiation fields ~ hydrodynamics (R. Jackiw)*

A pair of decelerating sources
(simplest set-up with elliptic asymmetry)



Flow coefficients

$$v_n = \langle \cos(n\theta) \rangle$$

Yield of two sources:

$$Y \propto \left| A_1 e^{ik_\perp \frac{d}{2}\cos(\alpha-\psi)} + A_2 e^{-ik_\perp \frac{d}{2}\cos(\alpha-\psi)} \right|^2$$

n^th Fourier-coefficient of the yield:

$$V_n = \frac{1}{2\pi}\int_{-\pi}^{\pi} \mathrm{d}\theta Y(\theta = \alpha - \psi)\cos(n\theta)$$

even ones: $V_{2n} = 4i^{2n}\mathrm{Re}(A_1 A_2^*) J_{2n}(k_\perp d)$

$$v_{2n} = \frac{V_{2n}}{V_0} = (-1)^n \frac{\cos\delta J_{2n}(k_\perp d)}{\frac{1+\gamma^2}{2\gamma} + \cos\delta J_0(k_\perp d)}$$

$$A_1 = Ae^{i\delta_0},\ A_2 = \gamma A e^{i(\delta+\delta_0)}$$

Flow coefficients

$$v_{2n} = \frac{V_{2n}}{V_0} = (-1)^n \frac{\cos\delta J_{2n}(k_\perp d)}{\frac{1+\gamma^2}{2\gamma} + \cos\delta J_0(k_\perp d)}$$

averaging respect to δ ⇓ if uniformly distributed

$$\langle v_{2n} \rangle = (-1)^n \frac{J_{2n}(k_\perp d)}{J_0(k_\perp d)} \left(1 - \frac{1}{\sqrt{1 - \frac{4\gamma^2}{(1+\gamma^2)^2} J_0^2(k_\perp d)}} \right)$$

Flow coefficients

$$v_{2n} = \frac{V_{2n}}{V_0} = (-1)^n \frac{\cos\delta J_{2n}(k_\perp d)}{\frac{1+\gamma^2}{2\gamma} + \cos\delta J_0(k_\perp d)}$$

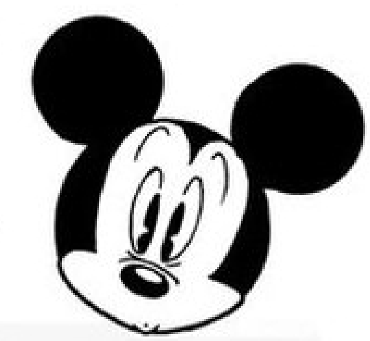
averaging respect to δ ⇩ if uniformly distributed

$$\langle v_2 \rangle_{\text{fit}} = A \frac{J_2(k_\perp d)}{J_0(k_\perp d)} \left(1 - \frac{1}{\sqrt{1 - \frac{4\gamma^2}{(1+\gamma^2)^2} J_0^2(k_\perp d)}} \right)$$

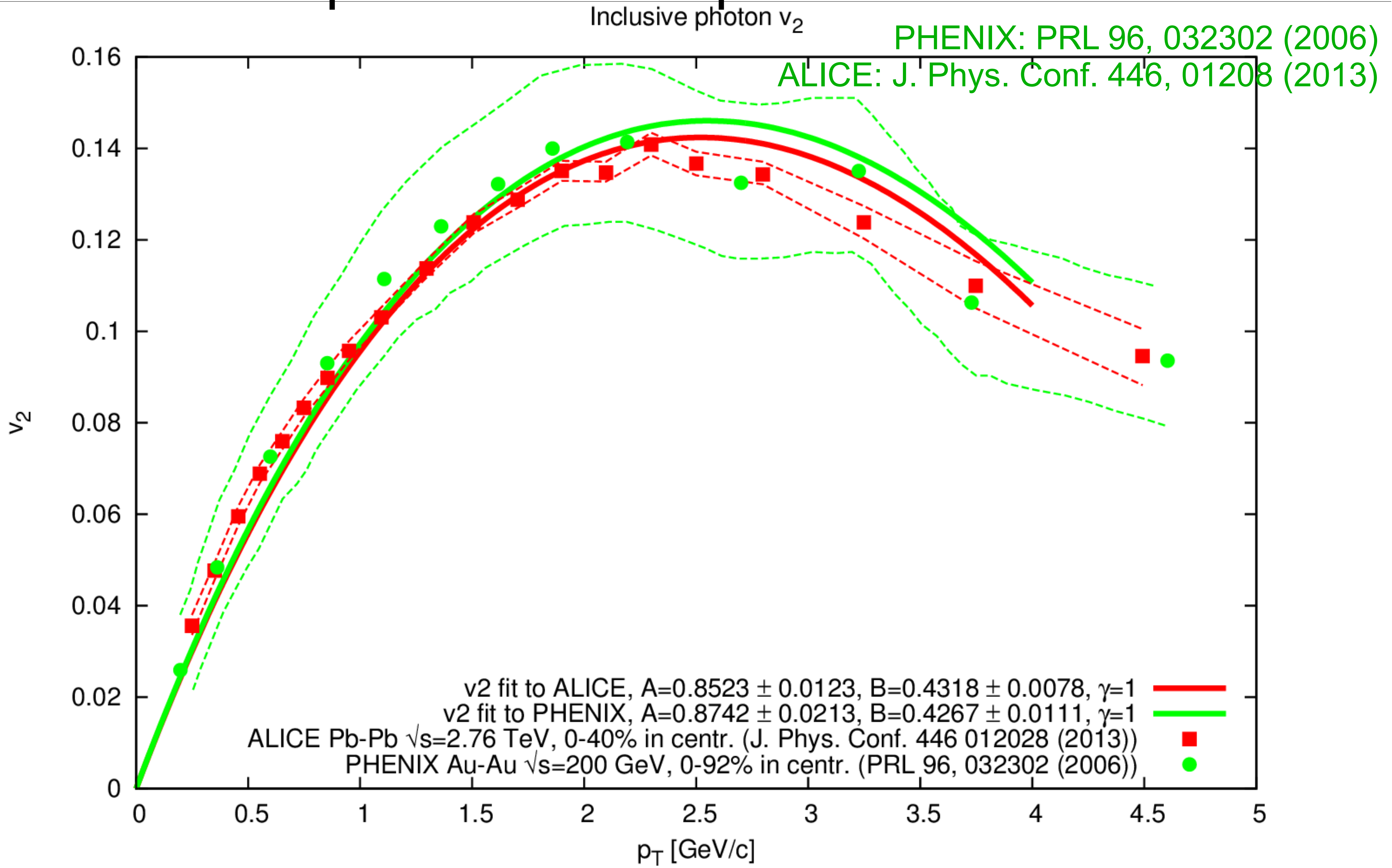
Assumptions for $\langle v_2 \rangle$

- interference effect of 2 sources gives the LO contribution

- averaging respect to the dipole ensemble
  - different phase shifts due to different deceleration times
  - random orientation of the dipoles

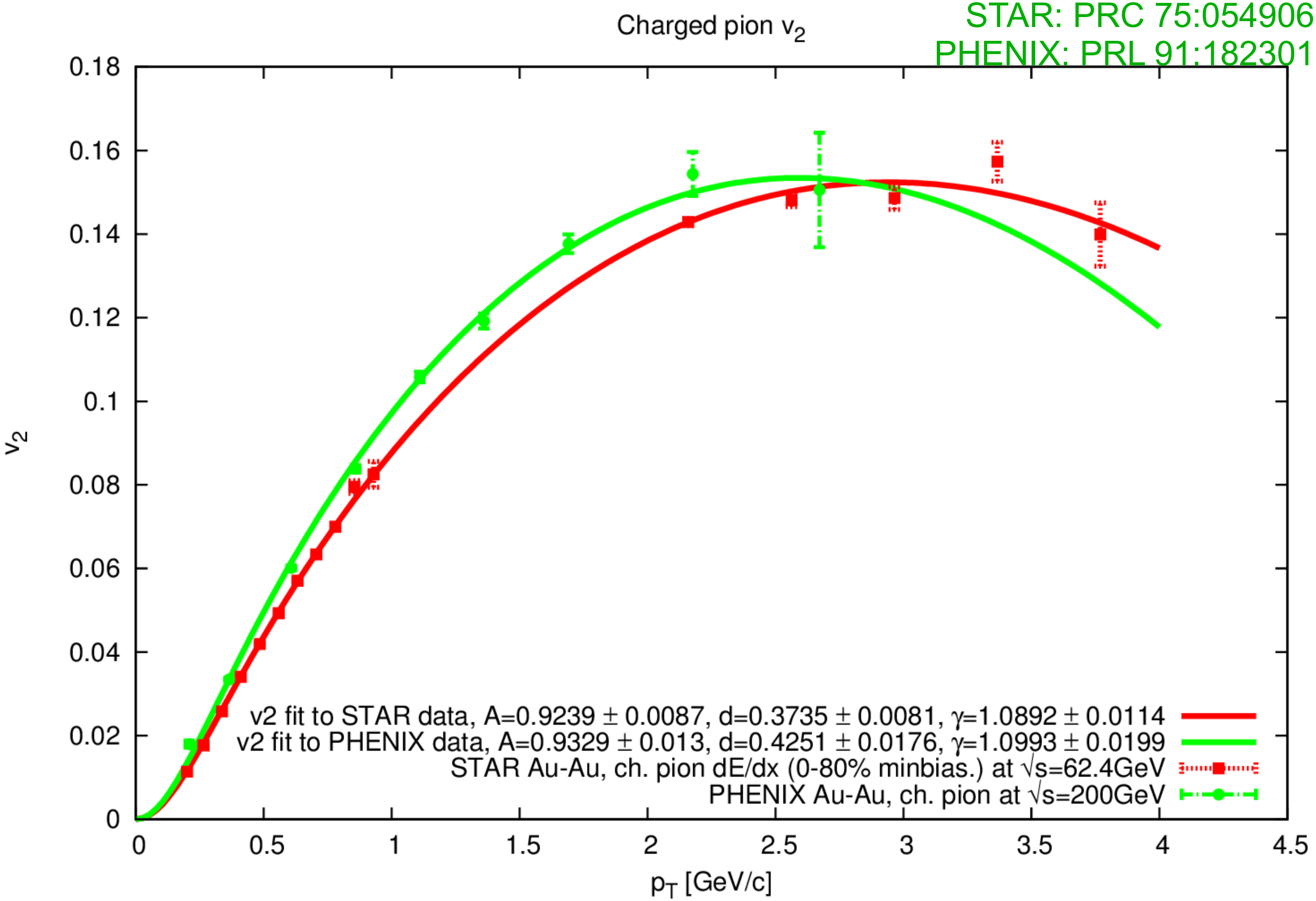


Inclusive photon elliptic flow



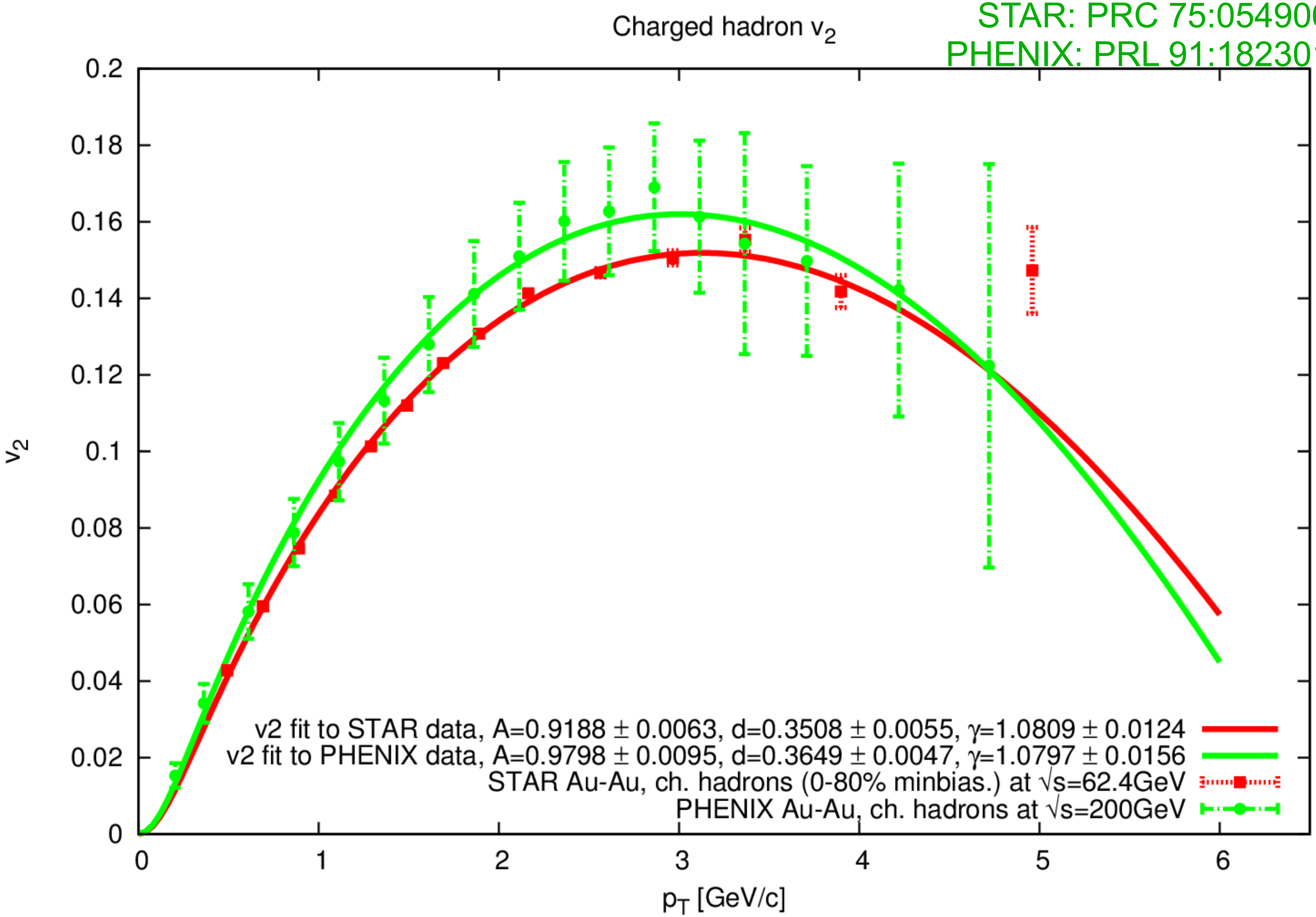
Elliptic flow of charged pions

STAR: PRC 75:054906 (2007)
PHENIX: PRL 91:182301 (2003)



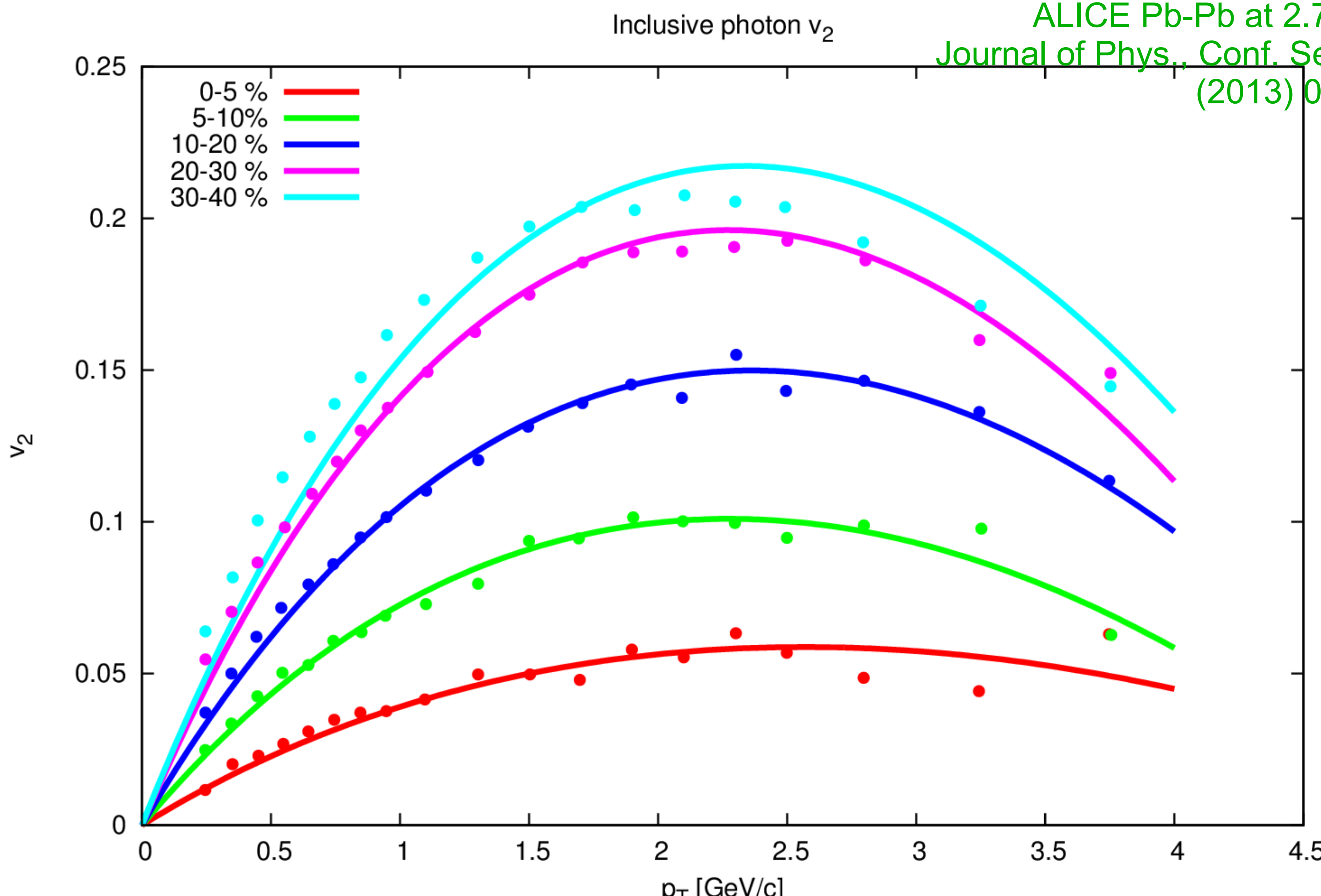
Elliptic flow of charged hadrons

STAR: PRC 75:054906 (2007)
PHENIX: PRL 91:182301 (2003)



Elliptic flow of photons

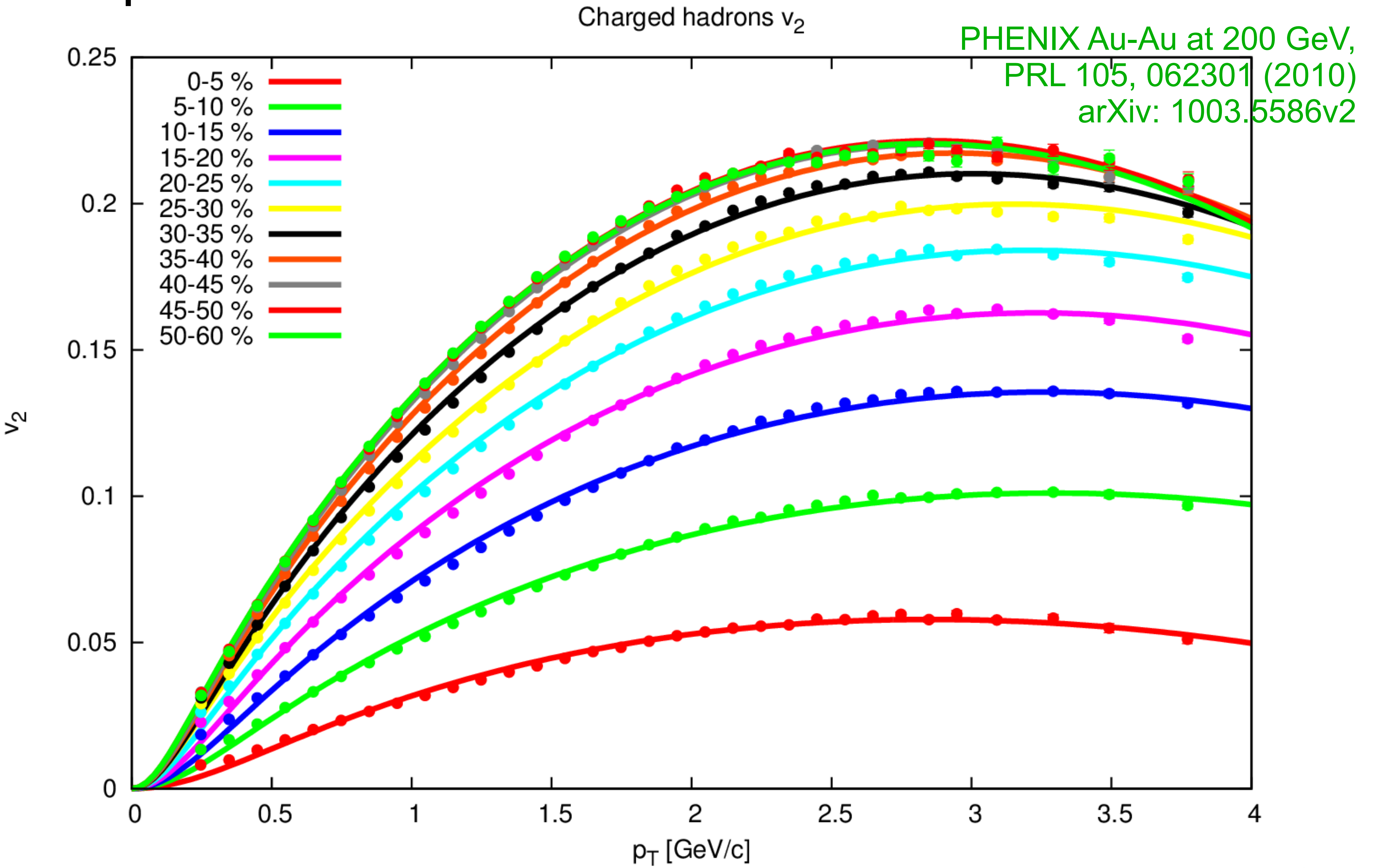
ALICE Pb-Pb at 2.76 TeV
Journal of Phys., Conf. Ser. 446 (2013) 012028



Fit to experimental data

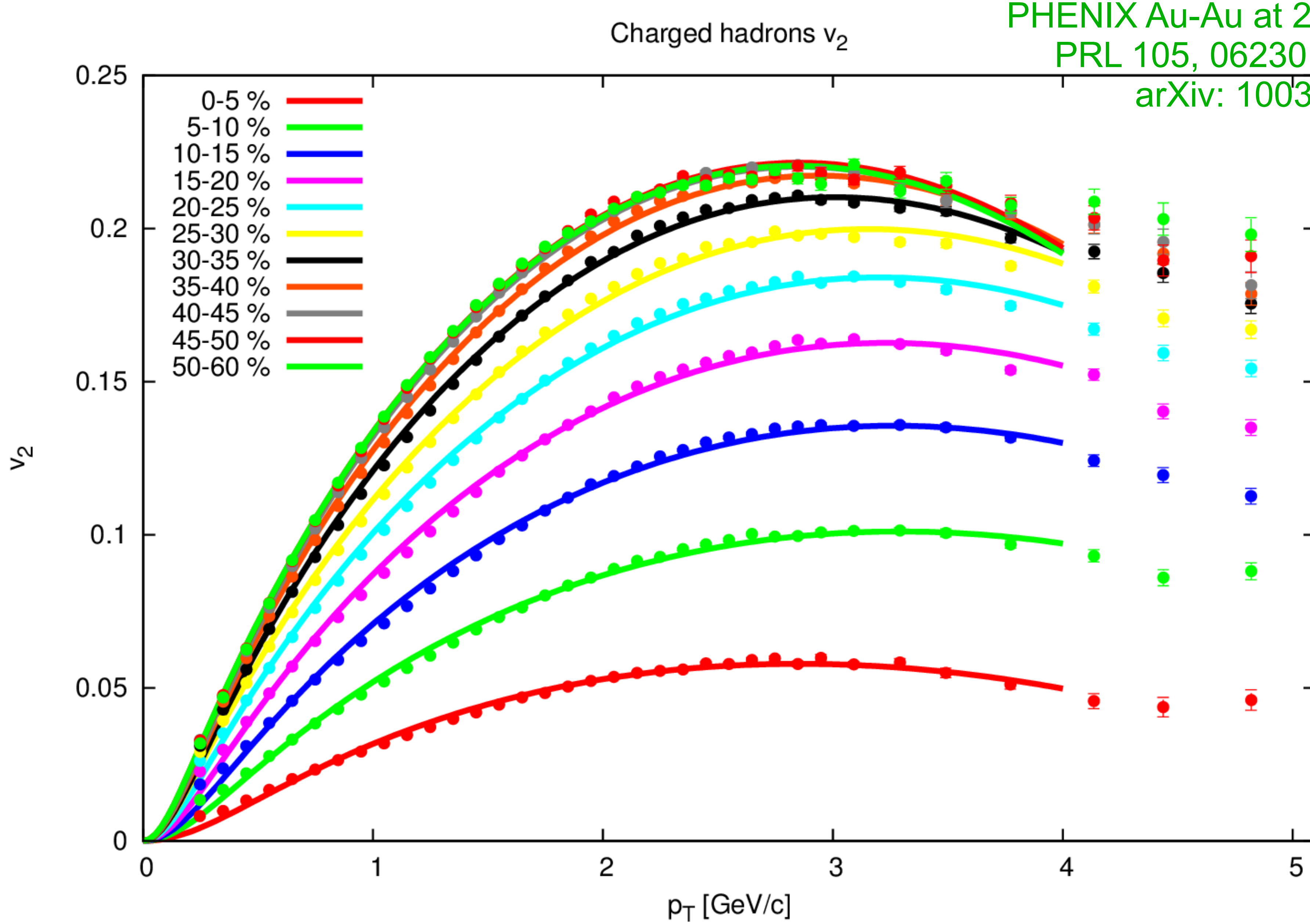
Centr. (%)	A	ΔA	d	Δd	γ	Δγ
0-5	0.34871	0.01027	0.43754	0.01551	1	0
5-10	0.60427	0.00785	0.47850	0.00899	1	0
10-20	0.89707	0.00743	0.46046	0.00601	1	0
20-30	1.17399	0.01242	0.47852	0.00734	1	0
30-40	1.30055	0.03011	0.46576	0.01123	1	0

Elliptic flow of hadrons



Elliptic flow of hadrons

PHENIX Au-Au at 200 GeV,
PRL 105, 062301 (2010)
arXiv: 1003.5586v2



Fit to experimental data

Centr. (%)	A	ΔA	d	Δd	γ	Δγ
0-5	0.3605	0.0039	0.3930	0.0060	0.8577	0.0117
5-10	0.6154	0.0042	0.3354	0.0039	1.1040	0.0106
10-15	0.8234	0.0043	0.3369	0.0030	0.9135	0.0068
15-20	0.9842	0.0047	0.3396	0.0028	1.0815	0.0077
20-25	1.1103	0.0047	0.3417	0.0025	0.9362	0.0063
25-30	1.2030	0.0050	0.3464	0.0025	0.9450	0.0067
30-35	1.2679	0.0037	0.3638	0.0029	1.0677	0.0053
35-40	1.3099	0.0031	0.3726	0.0023	1.0655	0.0044
40-45	1.3280	0.0030	0.3831	0.0021	1.0667	0.0043
45-50	1.3338	0.0036	0.3832	0.0025	1.0601	0.0052
50-60	1.3280	0.0043	0.3853	0.0031	0.9434	0.0057

Observations

- simple dipole picture with centrality dependent form-factors reaches the data well
- **good fits to charged hadron elliptic flows, too (even better than to inclusive photon v2)**
- higher harmonics fail... (at least not dominant, e.g. v4 lowers)

Thank you for the attention!

Questions? Comments?

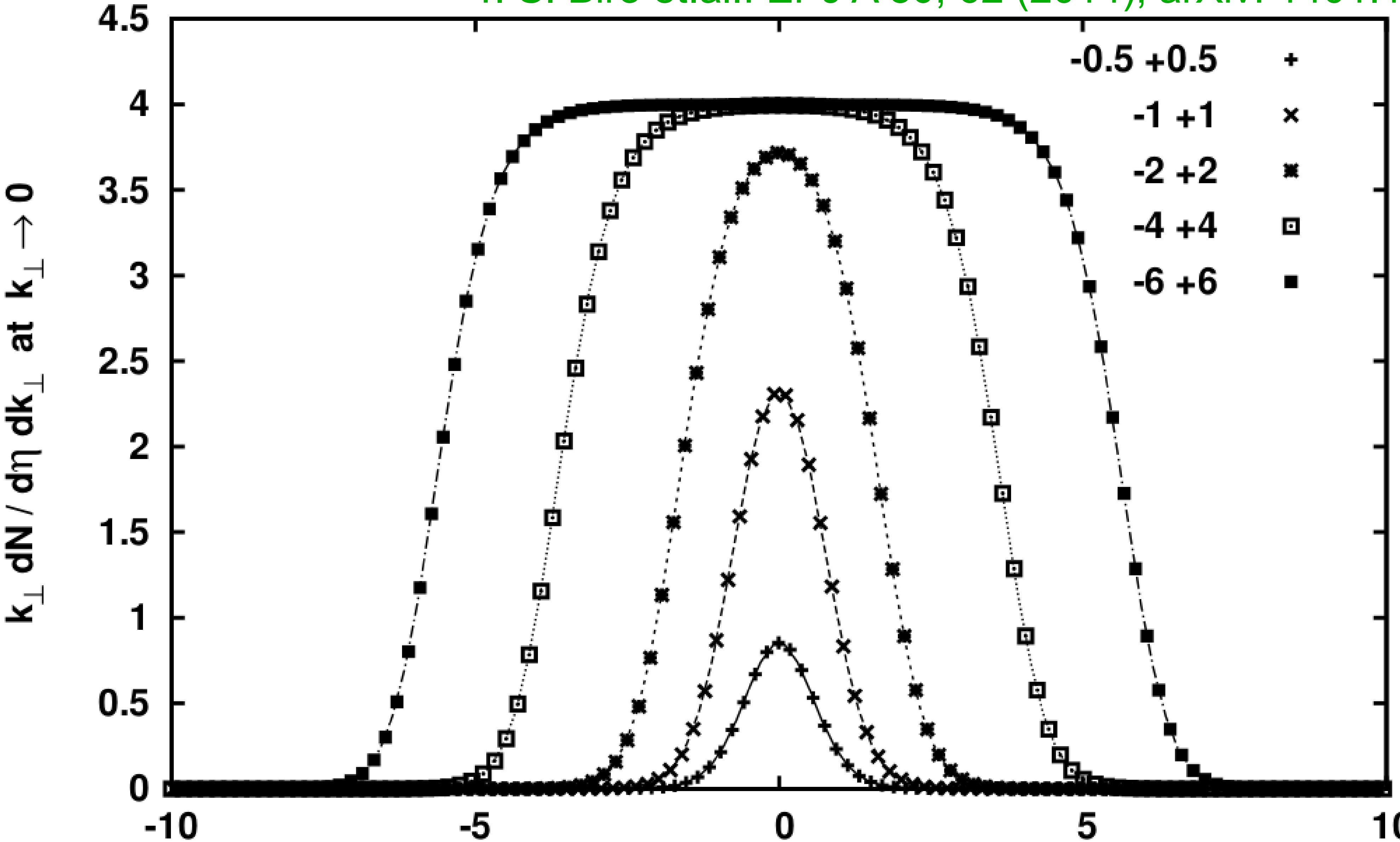
T.S. Biró & M. Gyulassy: PLB **708**, 276 (2012), arXiv: 1111.4817
T.S. Biró et.al.: EPJ A **50**, 62 (2014), arXiv: 1401.1987
M. Gyulassy: arXiv:1405.7825

1409.????
stay tuned!

Backup slides

Photon yield from decelerating charge

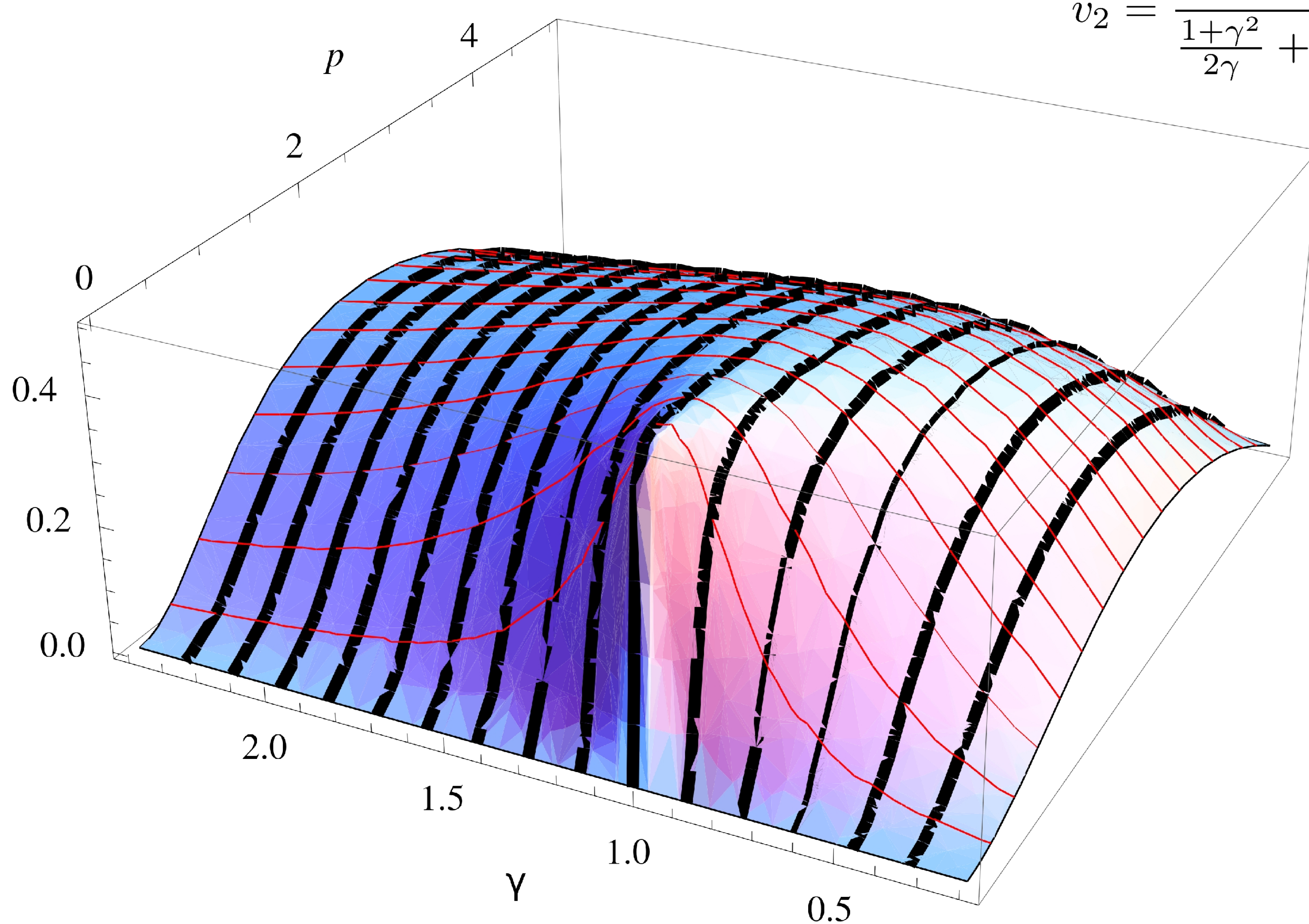
T. S. Biró et.al.: EPJ A **50**, 62 (2014), arXiv: 1401.1987



"Raw" v2 of *p*, γ

$$v_2 = \frac{\cos\delta J_{2n}(k_\perp d)}{\frac{1+\gamma^2}{2\gamma} + \cos\delta J_0(k_\perp d)}$$

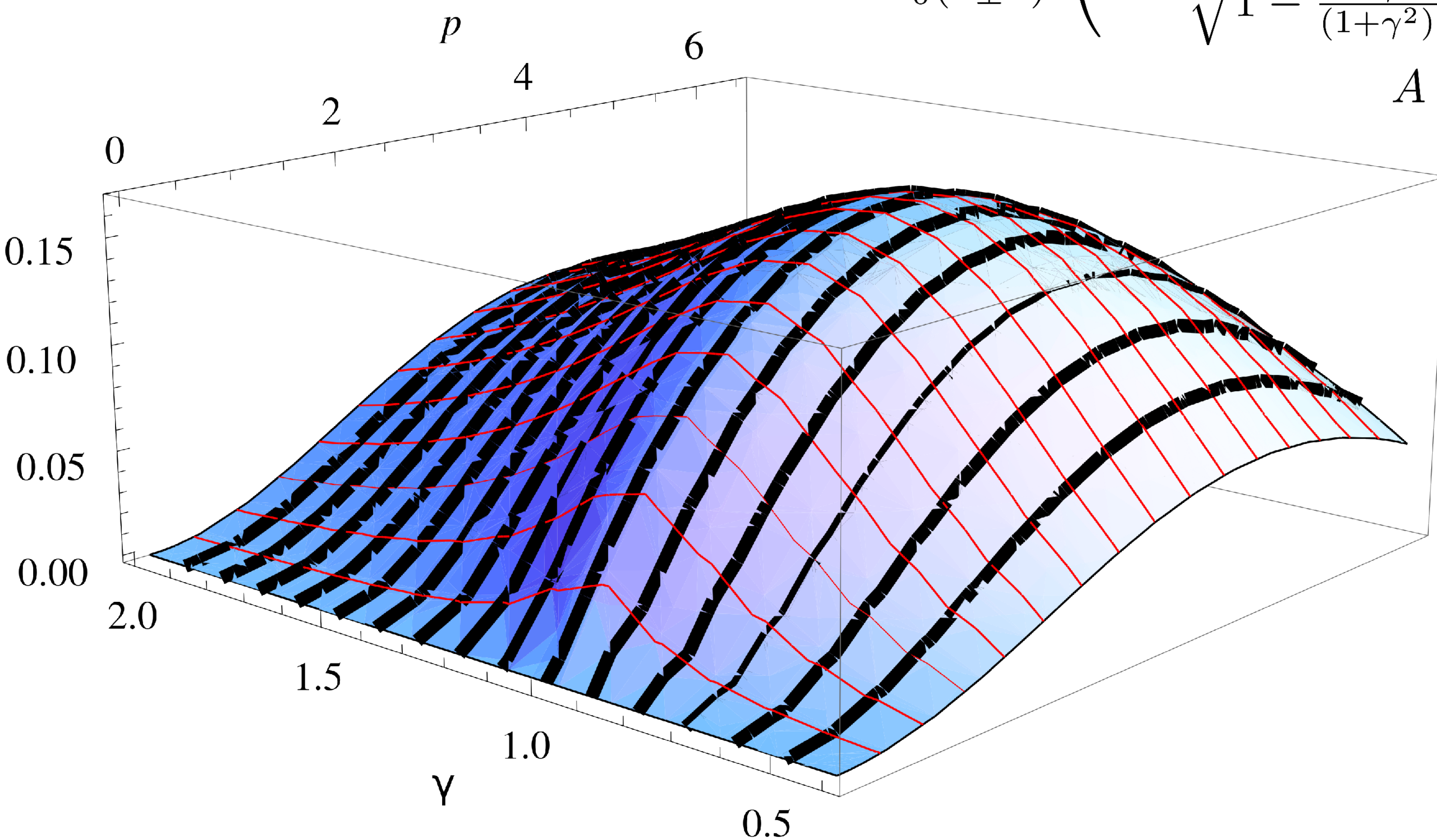
$$\delta = \pi$$



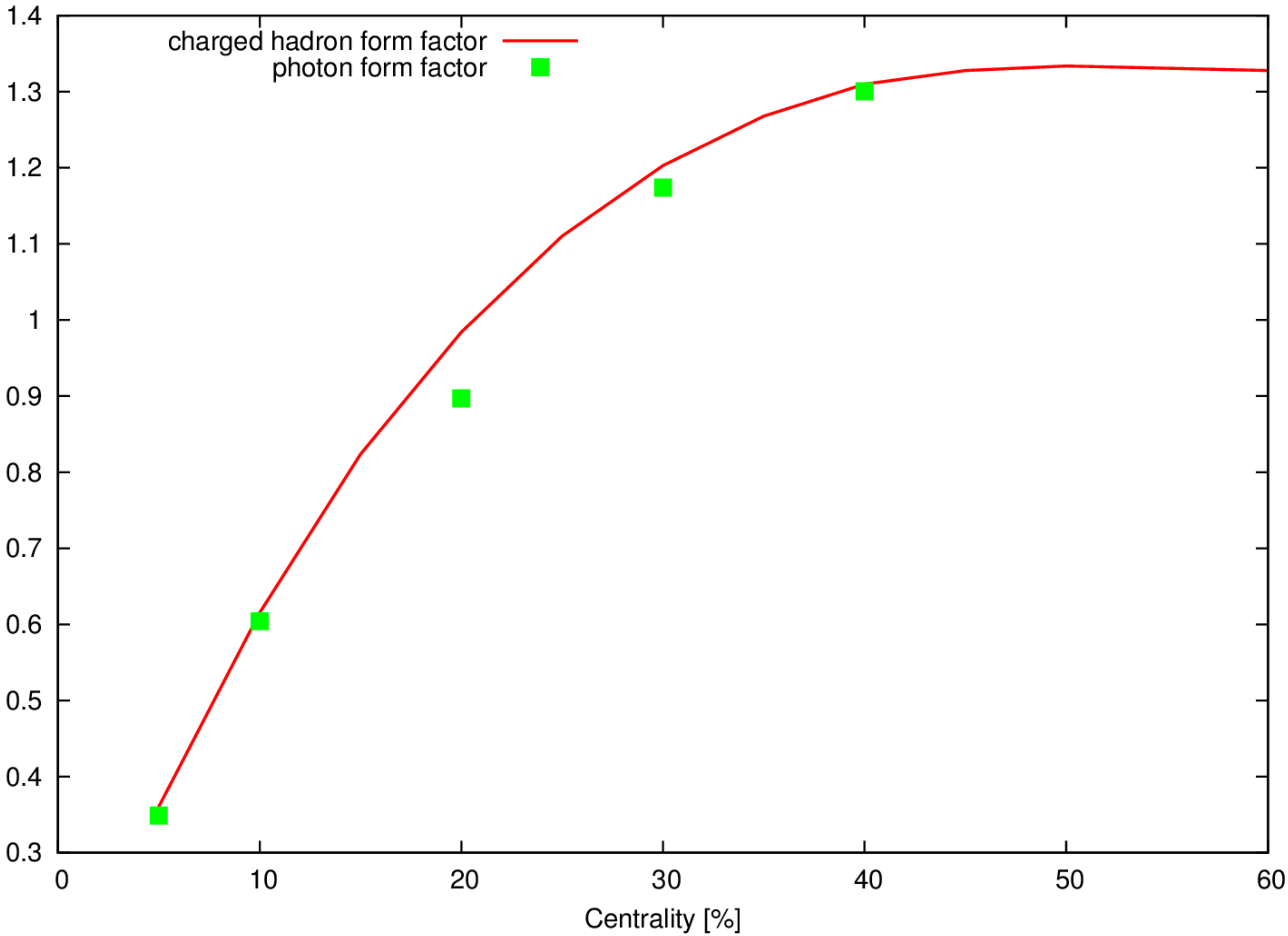
Averaged v2 of *p*, γ

$$\langle v_2 \rangle_{\text{fit}} = A \frac{J_2(k_\perp d)}{J_0(k_\perp d)} \left(1 - \frac{1}{\sqrt{1 - \frac{4\gamma^2}{(1+\gamma^2)^2} J_0^2(k_\perp d)}} \right)$$

$$A = 1, \ d = 1$$



Fit to experimental data



Flow coefficients

$$v_n = \langle \cos(n\theta) \rangle$$

Jacobi-Anger:

$$e^{ix\cos\theta} = J_0(x) + \sum_{l=1}^{\infty} i^l J_l(x) \cos(n\theta)$$

$$Y \propto |A_1 e^{ik_\perp \frac{d}{2}\cos(\alpha-\psi)} + A_2 e^{-ik_\perp \frac{d}{2}\cos(\alpha-\psi)}|^2 =$$

$$= |A_1|^2 + |A_2|^2 + 2J_0(k_\perp d)\mathrm{Re}(A_1 A_2^*) +$$

$$+4\sum_{n=1}^{\infty} i^{2n}\mathrm{Im}(A_1 A_2^*) J_{2n-1}(k_\perp d)\cos((2n-1)\theta) +$$

$$+4\sum_{n=1}^{\infty} i^{2n}\mathrm{Re}(A_1 A_2^*) J_{2n}(k_\perp d)\cos(2n\theta)$$