Elliptic flow of the ϕ -meson in Au+Au collisions at 62.4 GeV

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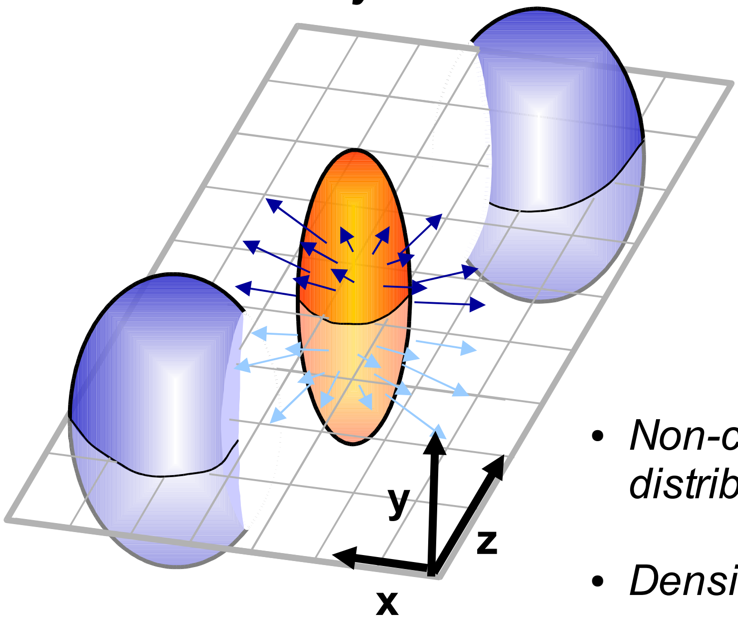
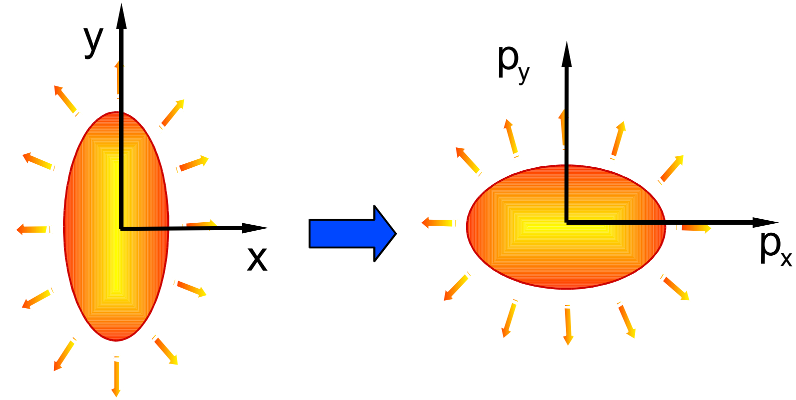
Overview

- Physics motivation
- Method discussion
  - ➔ Event plane method
  - ➔ v_2 vs. m_{inv} method
- Results
- Summary and Outlook

Elliptic Flow (v_2)

Elliptic flow can provide early time information on the collectivity of particles from heavy-ion collisions:





- *Non-central AA collisions result in an azimuthally anisotropic distribution of particles in **coordinate-space***
- *Density gradients and i**nteractions** between the particles lead to an asymmetry in momentum-space*
- *Signal is **self-quenching** with time – **EARLY TIME OBSERVABLE!***

- *Expanding in a Fourier series:*

$$E\frac{d^3N}{d^3p}=\frac{1}{\pi}d^2\frac{N}{dp_T^2\,dy}[1+2v_1\cos(\phi)+2v_2\cos(2\phi)+...]$$

$$v_2=\langle\cos(2\phi)\rangle$$

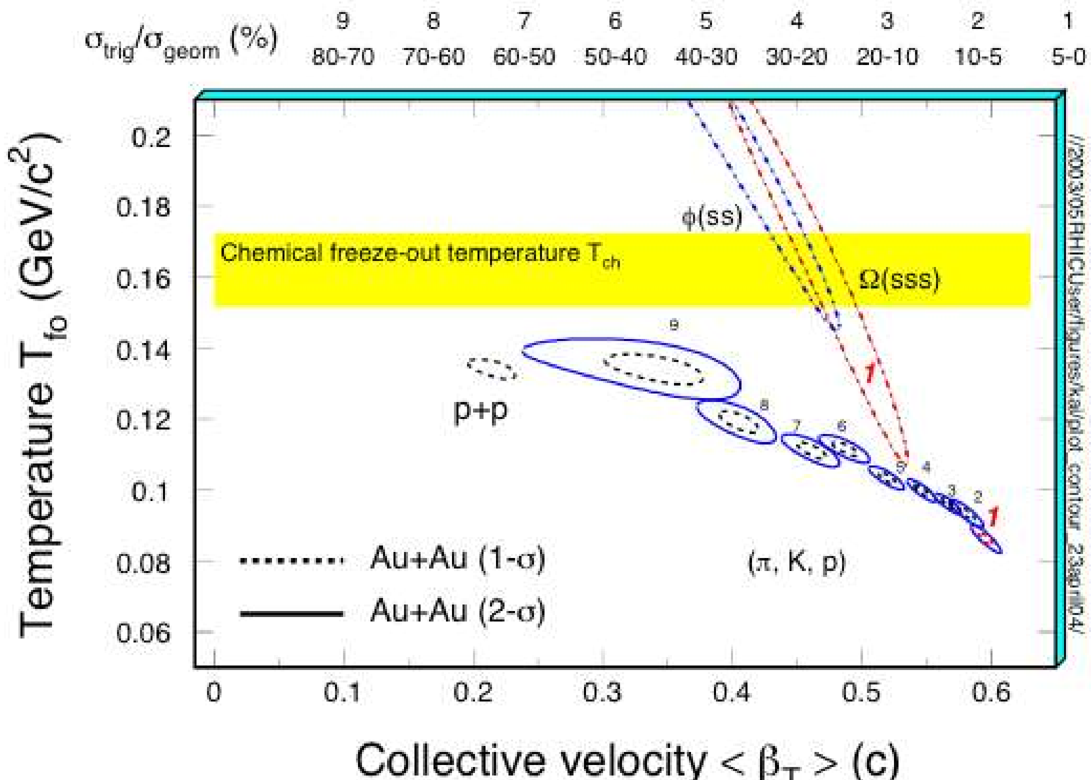
Motivation

The elliptic flow of the ϕ -meson is interesting because:

Why the ϕ -meson v_2?

- *ϕ -meson has a **long lifetime** (41 fm/c)*
  - ➔ *Most likely decays **outside** the fireball created in nucleus-nucleus collisions*

- *ϕ -meson has **low cross-section** for hadronic interactions[1]*
  - ➔ *Clean probe of **v_2 signal** from early partonic time **inside** the fireball*



*Data: STAR: NP**A715**, 458c(03);*
*PRL **92**, 112301(04);*
*PRL **92**, 182301(04)*
Plot: Nu Xu, private communication

*[1] A. Shor, PRL **54,** 11 (1985)*

Motivation

The elliptic flow of the ϕ -meson is interesting because:

Why the ϕ -meson v_2?

- ϕ -meson has a ***long lifetime*** *(41 fm/c)*
  - *Most likely decays* ***outside*** *the fireball created in nucleus-nucleus collisions*
- ϕ -meson has ***low cross-section*** *for hadronic interactions[1]*
  - *Clean probe of* ***v_2 signal*** *from early partonic time* ***inside*** *the fireball*

If the ϕ -meson (ss(bar)) v_2 is non-zero → ***Partonic collectivity!***

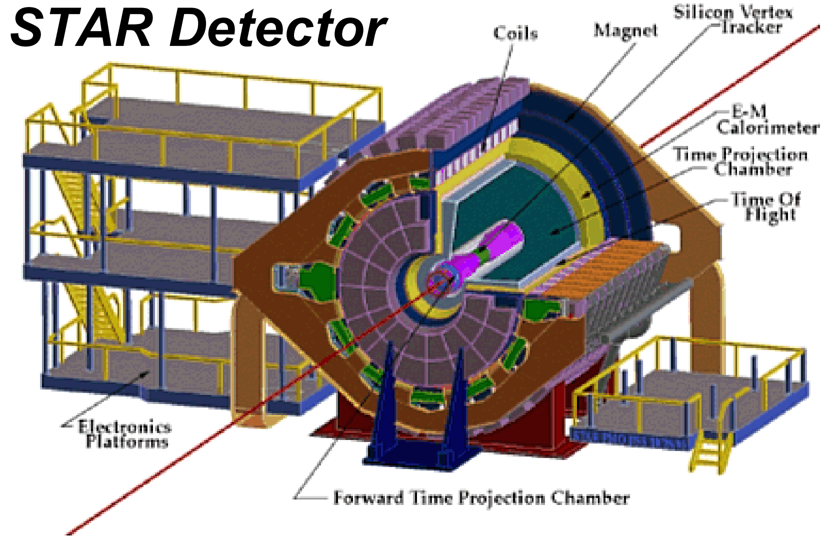
Partonic collectivity is an expected attribute of a QGP!

[1] A. Shor, PRL ***54,*** *11 (1985)*

Data Selection

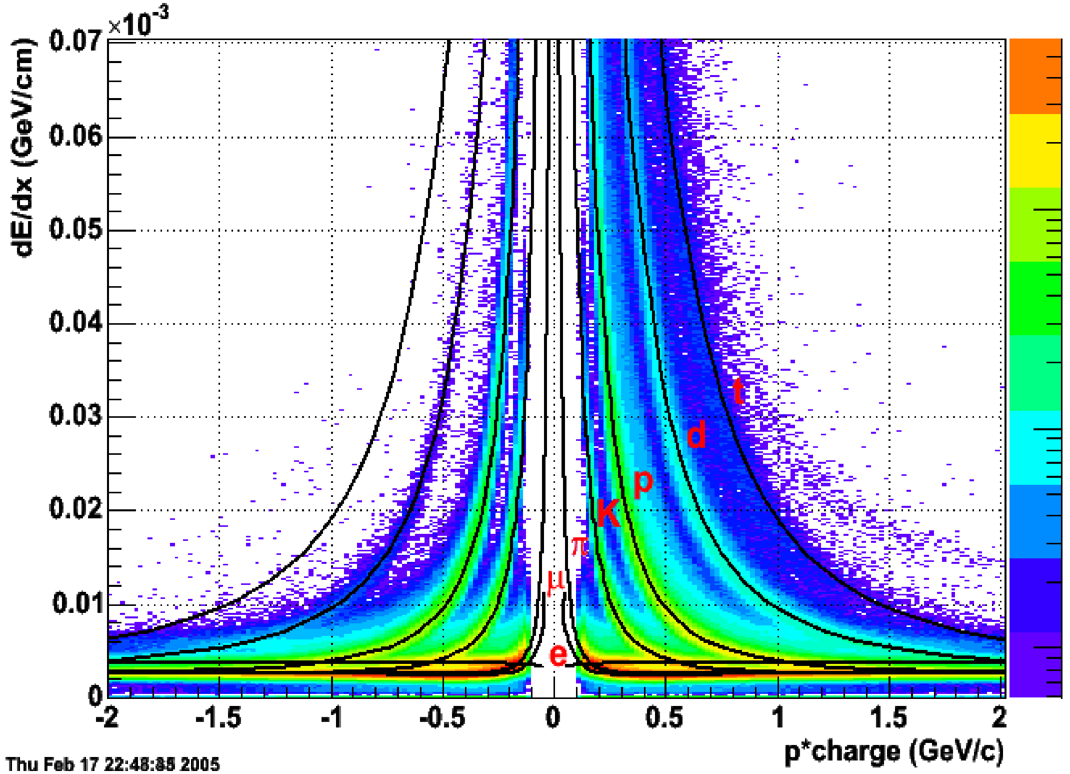
Data were taken using the STAR detector at RHIC for Au+Au collisions at sqrt(s) = 62.4 GeV

STAR Detector



- *STAR TPC to ID Kaons from their energy loss in the TPC gas:*
  - $|\eta| < 1$
  - $0.1 < p_T < 4.0$ GeV/c
  - *DipAngle > 0.04 rad*
- *Event-mixing method used to estimate background from uncorrelated pairs*

- ϕ *was reconstructed via* $\phi \rightarrow K^+K^-$ *(49.1 %) decay channel*



Method

Find event plane angle

The event plane is an estimation of the true reaction plane and therefore resolution effects need to be taken into account:

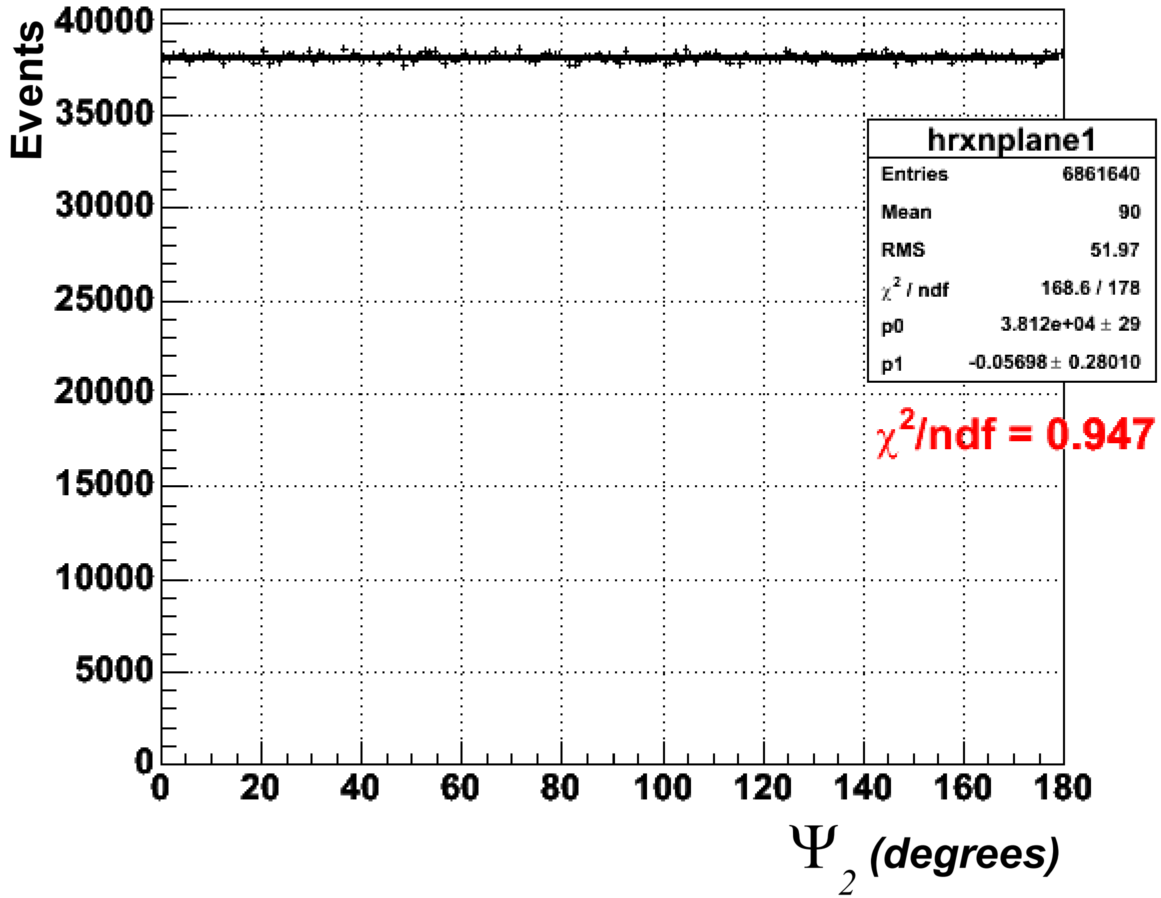
2nd Order reaction plane angle:

$$\Psi_2 = \left(\arctan \left(\frac{\sum_i w_i \sin(2\phi_i)}{\sum_i w_i \cos(2\phi_i)} \right) \right) / 2$$

The measured v_2 signal has to be corrected for the event plane resolution:

$$v_{2\,Real} = \frac{v_{2\,Obs}}{Res_{EP}}$$

Following [2], ***Res_{EP} = 0.62***



[2] A.M Poskanzer, S.A. Voloshin, Phys. Rev C58, 1671 (1998)

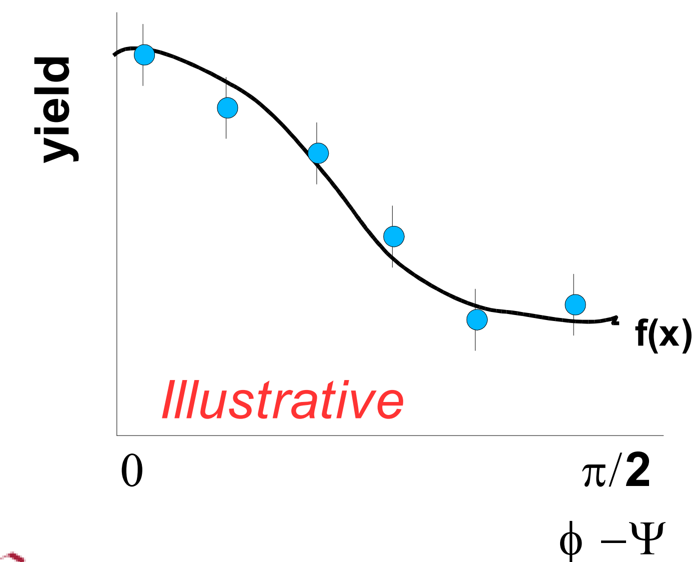
Extracting v_2

Two methods were used to extract the v2 signal:

Method 1:

$$E\frac{d^3N}{d^3p}=\frac{1}{\pi}d^2\frac{N}{dp_T^2\,dy}\left[1+2v_1\cos(\phi)+2v_2\cos(2\phi)+\ldots\right]$$

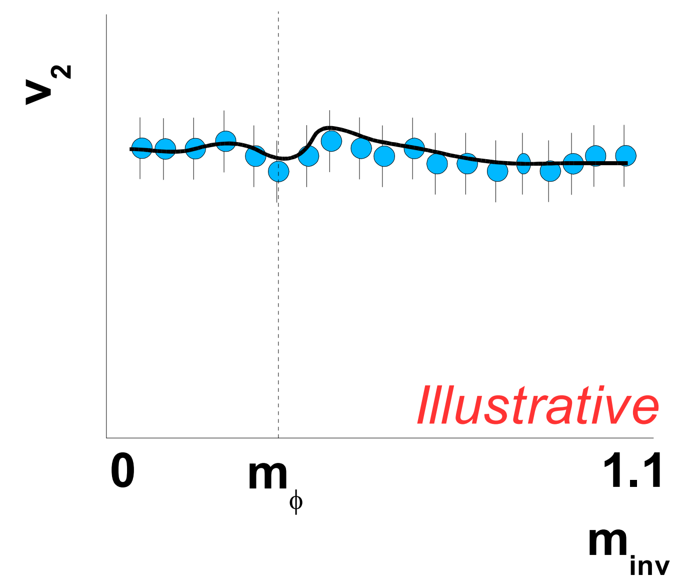
- *Extract the ϕ-meson yield as a function of $\phi-\Psi$*
- *Fit the distribution with:*
  $f(x) = P_0(1+2v_2\cos(2x))$



Method 2:

- *Borghini et al. [nucl-th/0407041] proposed finding v_2 as a function of m_{inv}*
- *Fit using:*

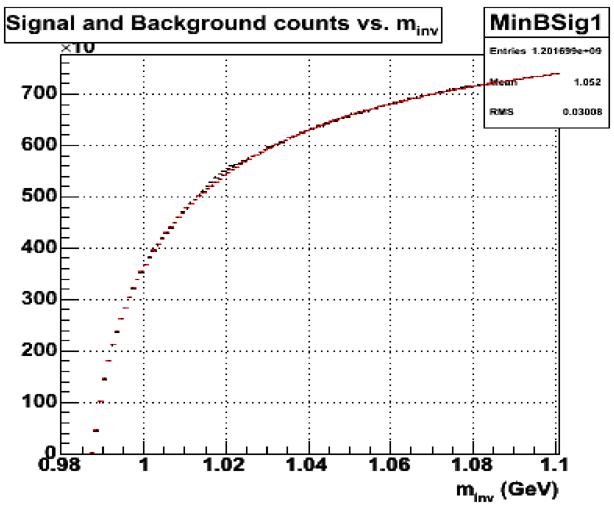
$$v_{2TOT}(m)=v_{2Sig}(m)\left(\frac{Sig}{Sig+BG}\right)+v_{2BG}(m)\left(\frac{BG}{Sig+BG}\right)$$

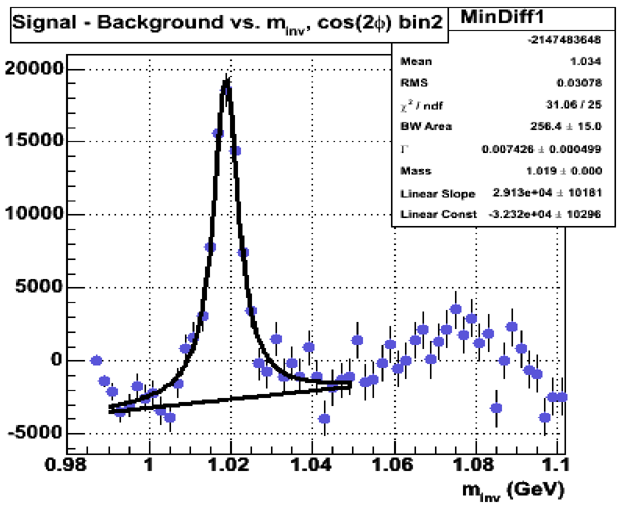


Method 1

In the first method, v_2 is found by measuring the raw yield of ϕ -mesons in bins of p_T and ($\phi - \Psi$) angle:

Fit <cos2($\phi - \Psi$)> method



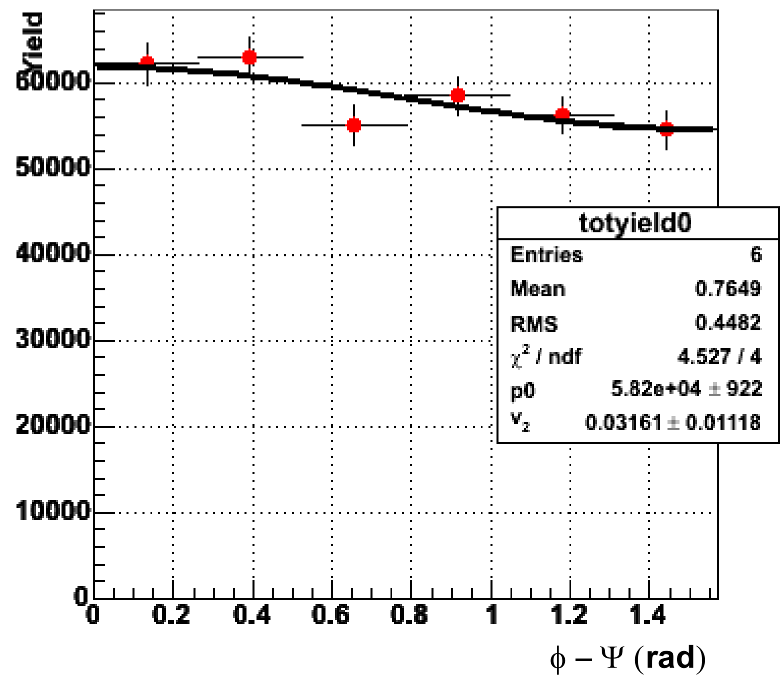


For each bin in ϕ angle and p_T:

- *Scale mixed event background (red) to signal (black) and subtract*
- *Fit with Breit-Wigner plus straight line to extract yield*

For each p_T bin:

- *Fit the distribution with:* ***$f(x) = P_0(1+2v_2\cos(2x))$***



Method 2

v_2 vs. m_{inv} Method

The 2nd method is based on the fact that the single particle probability distribution can be generalised for pairs of particles [3] as follows:

$$p(\phi_{pair}-\Phi_R)=\frac{1}{2\pi}\sum v_n^{pair}\, e^{in(\phi_{pair}-\Phi_R)}$$

- *For resonances, $\phi_{pair} = \phi$ of parent particle*

- ***Pair flow coefficients:*** $v_{c,n}^{pair}=\langle\cos n(\phi_{pair}-\Phi_R)\rangle$ *and* $v_{s,n}^{pair}=\langle\sin n(\phi_{pair}-\Phi_R)\rangle$

$$N_{pairs}(m)v_{c,n}(m)=N_b(m)v_{c,n}^{(b)}(m)+N_\phi(m)v_{c,n}^{\phi}$$

$$\boxed{v_{2TOT}(m)=v_{2Sig}(m)\left(\frac{Sig}{Sig+BG}\right)+v_{2BG}(m)\left(\frac{BG}{Sig+BG}\right)}$$

- ***Plot v_2 as a function of m_{inv} and fit to find $v_{2\phi}$***
- ***Plot <sin2($\phi - \Psi$)> as a function of m_{inv} and fit***

- ***Symmetry w.r.t. the reaction plane implies:*** $v_{s.2}^{\phi}(m)=0$
- ***If the background consists of uncorrelated particles:*** $v_{s,2}^{(b)}(m)=0$

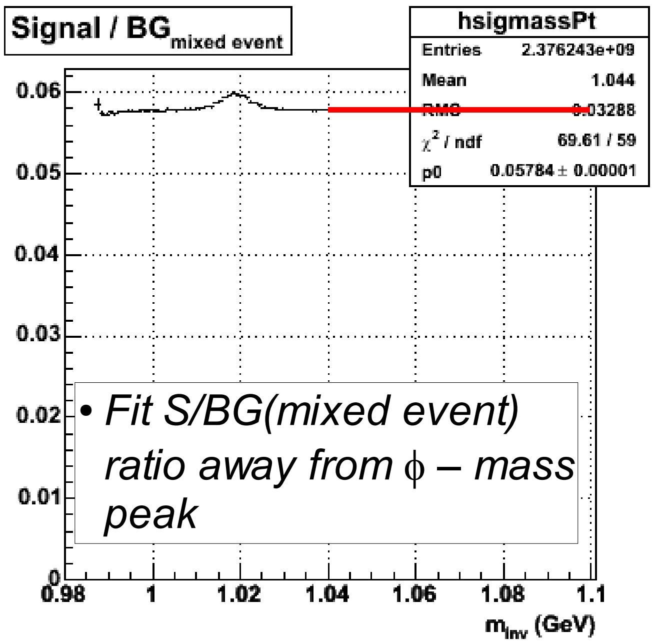
- ***Can use these identities to check the accuracy of experimental procedure***

[3] N. Borghini & J-Y Ollitrault, nucl-th/0407041

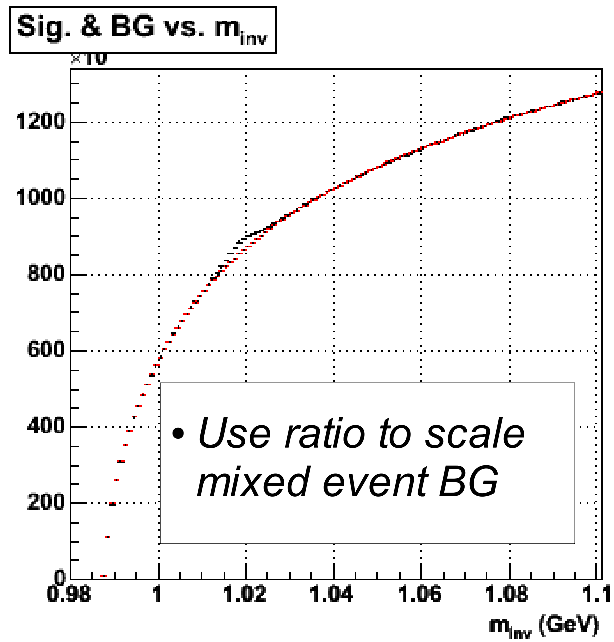
Method 2

To calculate the S/(S+BG) and BG/(S+BG) ratios, the residual background needs to subtracted after the mixed event background:

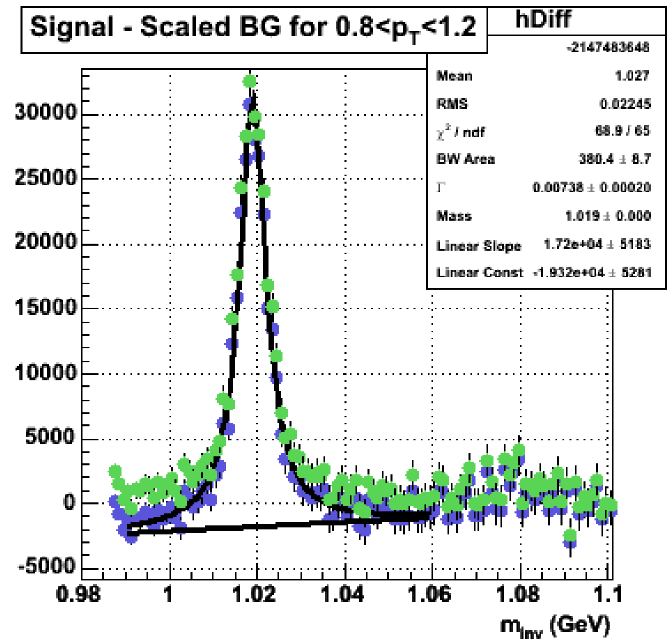
Extracting the ratios

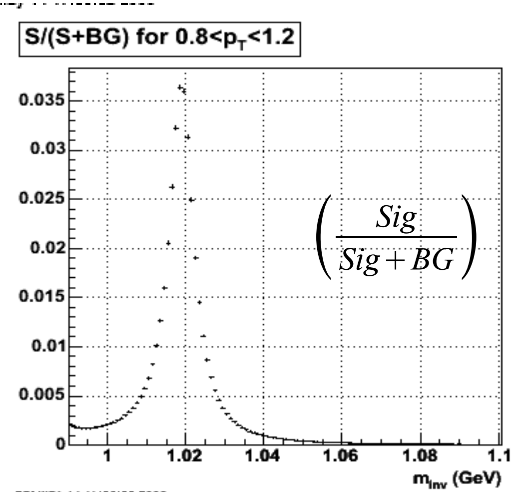


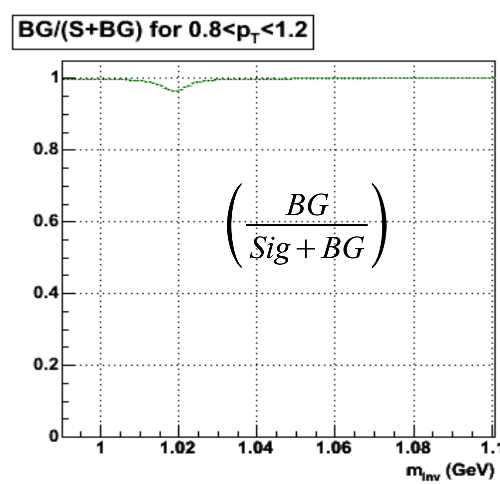
- *Fit S/BG(mixed event) ratio away from ϕ – mass peak*



- *Use ratio to scale mixed event BG*







- *Subtract BG(mixed event) to get signal (still includes residual BG)*
- *Fit signal with BW + straight line (blue histogram)*
- ***Subtract** residual (str. Line) to get true signal (green histogram)*
- ***Add** residual to scaled background*

Method 2

v_2 vs. m_{inv} Method

To extract v_2 for each p_T bin, fit the function

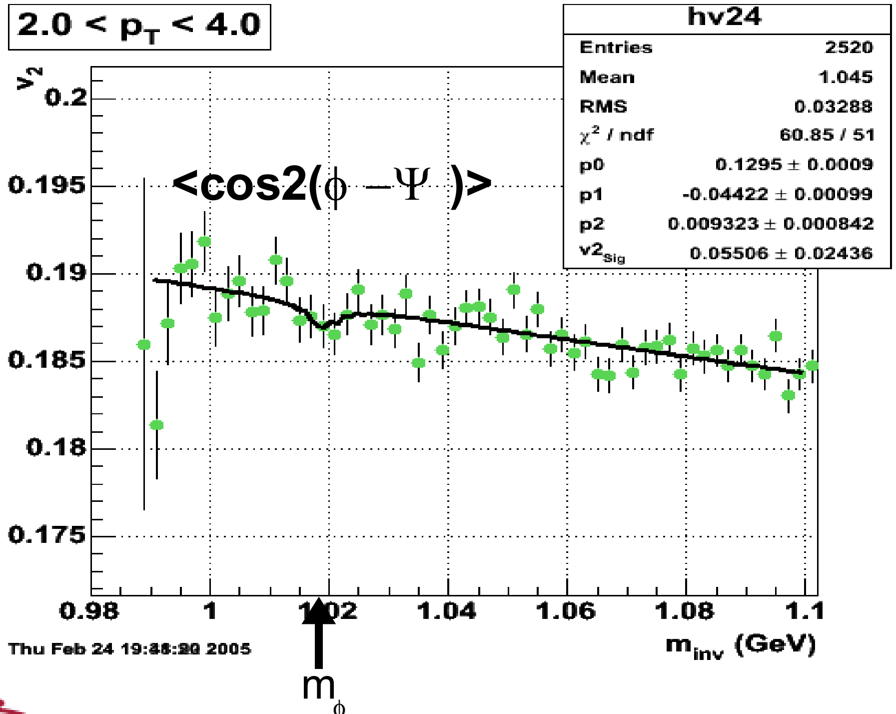
$$v_{2TOT}(m) = v_{2Sig}(m)\left(\frac{Sig}{Sig+BG}\right) + v_{2BG}(m)\left(\frac{BG}{Sig+BG}\right)$$

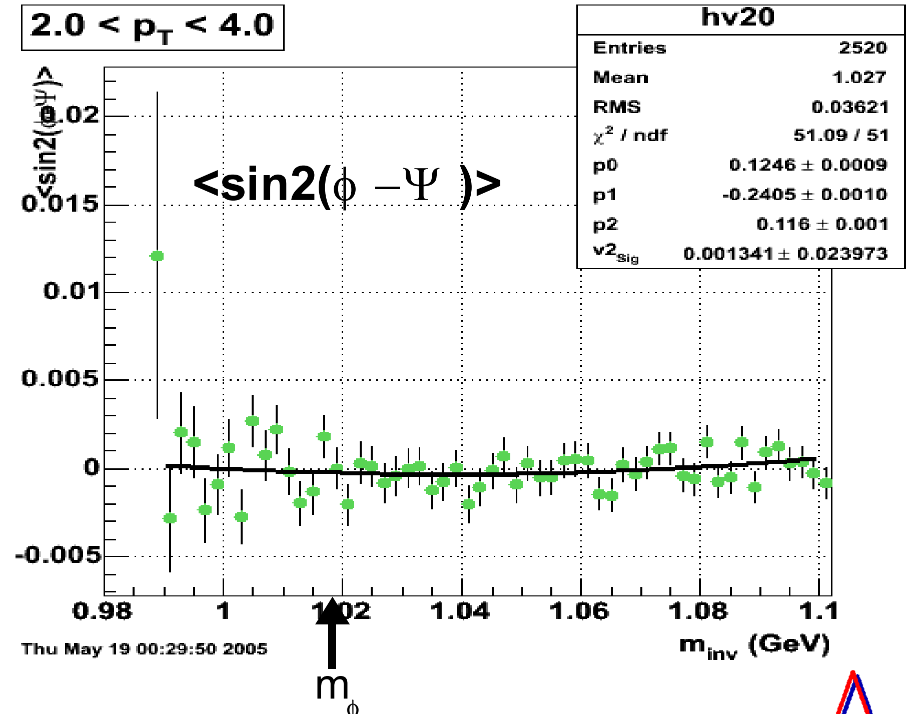
to the v_2 vs. m_{inv} plot:

1st fit parameter

$$V_{2BG} = p_0 + p_1 m_{inv} + p_2 m_{inv}^2$$

(Quadratic function in m_{inv})

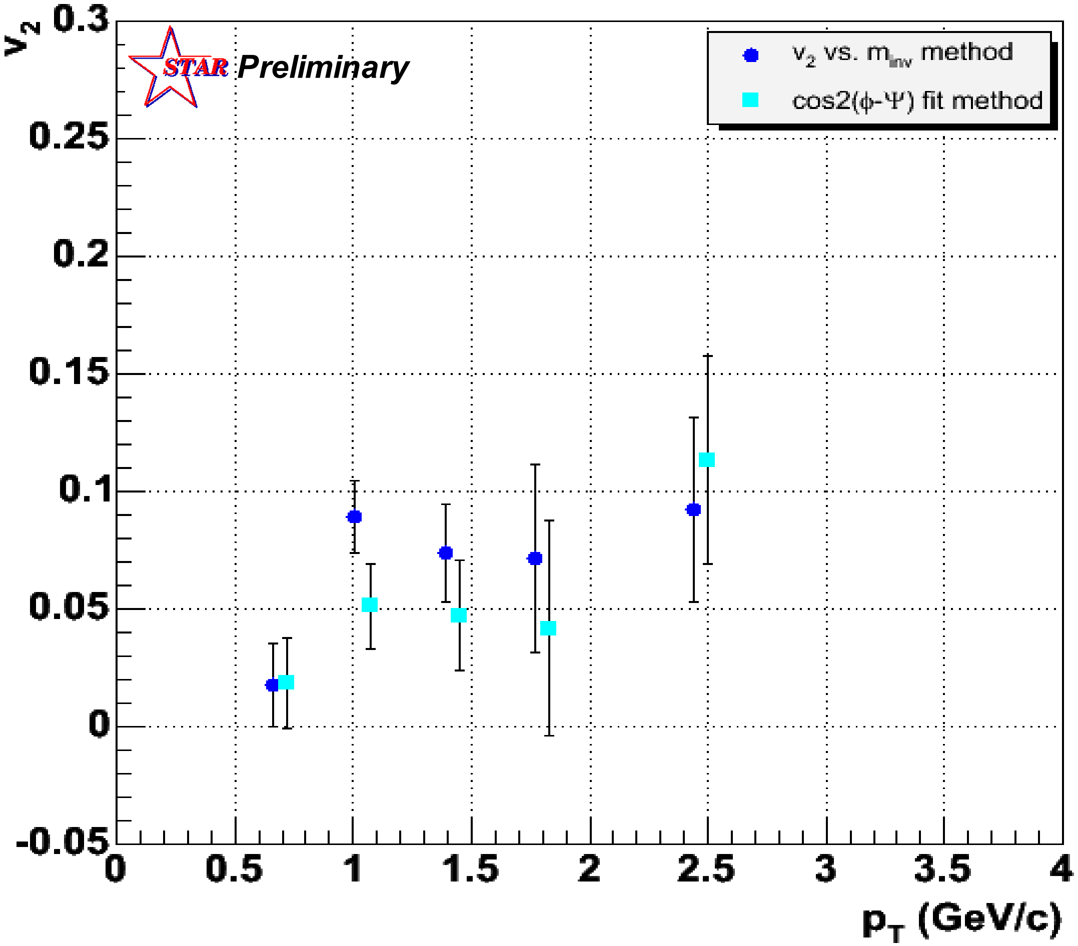




Results

Method Comparison

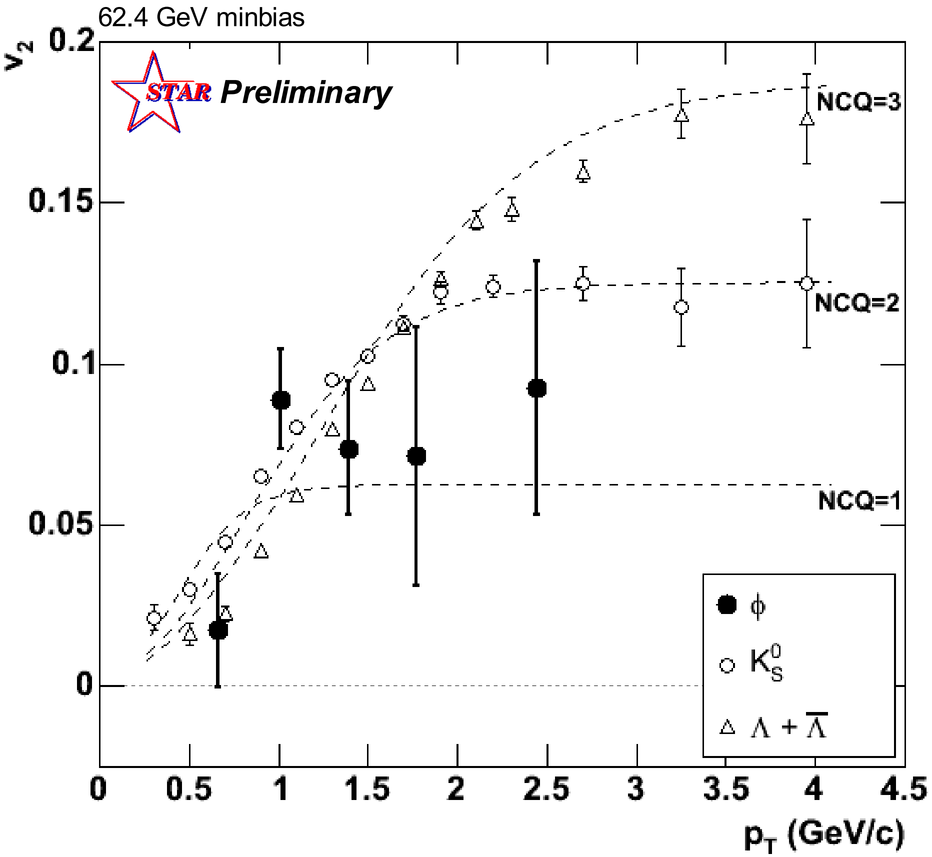
For minimum bias, Au+Au collisions at sqrt(s)=62.4 GeV, the 2 methods produce consistent results:



- ϕ ***-meson has non-zero flow!***

Model Comparison

Due to limited statistics, it is not yet possible to make a definite conclusion on how much the ϕ flows:

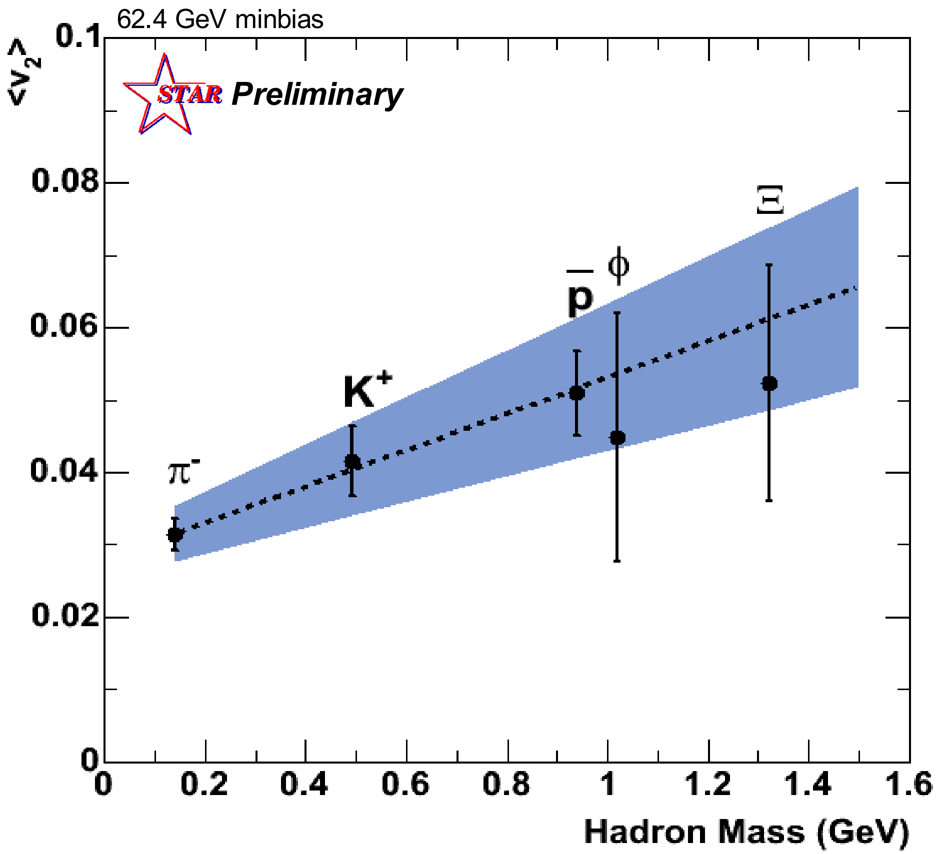


- *Dashed lines represent parameterization based on Number of Constituent Quark (NCQ) scaling [4]*

*[4] X. Dong et al. Phys. Lett. **B** 597, 328 (2004)*

Other Particle Comparison

Comparing integrated v_2 of identified particles from 62.4 GeV Au+Au collisions...



- *Integrated v_2 increases with hadron mass for π , K, p*
- *ϕ v_2 does not seem to be > p v_2 – less hadronic contributions?*

Summary and Outlook

Summary:

- ϕ -meson has non-zero elliptic flow in 62.4 GeV Au+Au collisions!
  - We may be seeing direct evidence of partonic collectivity in 63.4 GeV Au+Au collisions at RHIC!

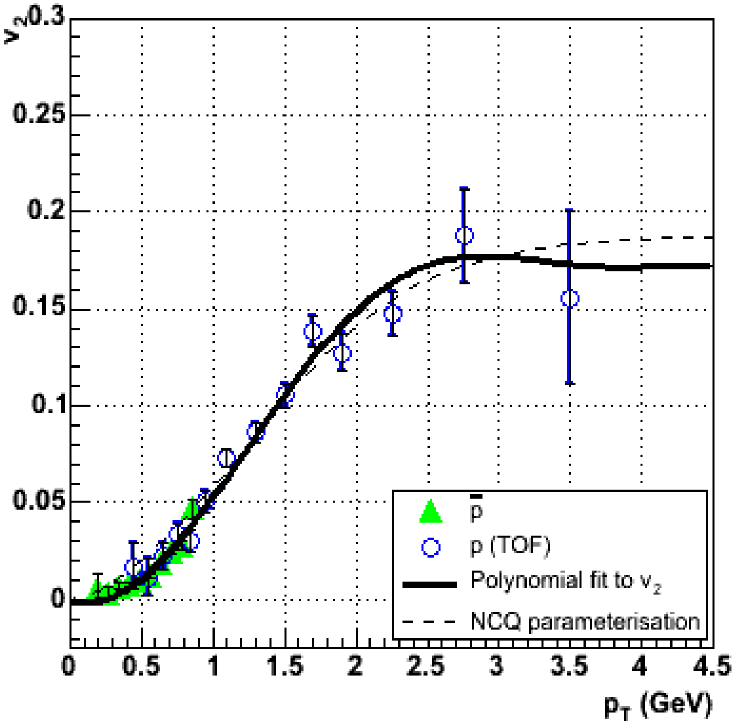
Outlook:

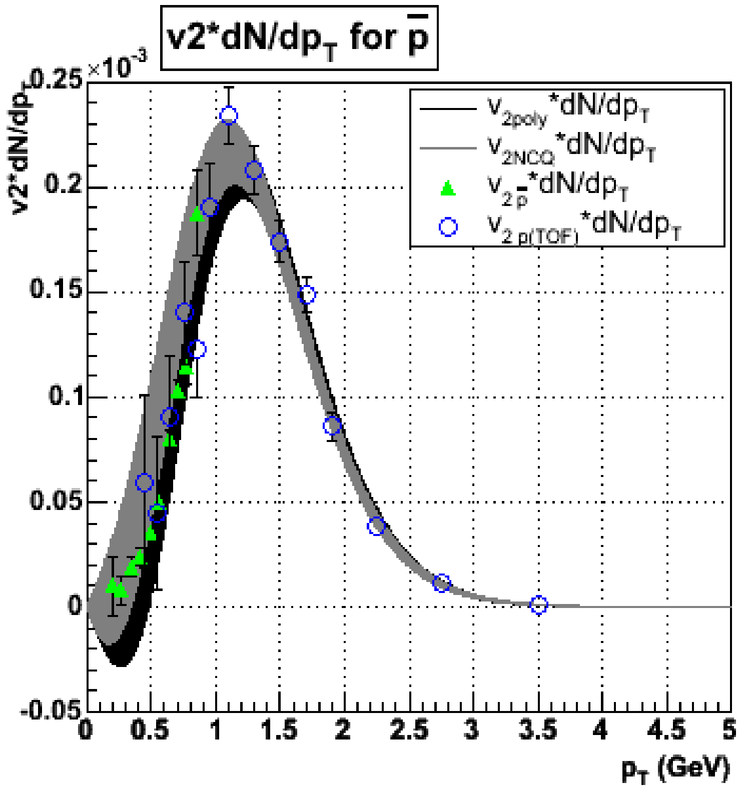
- Analyze the high statistics 2004 Run IV 200 GeV Au+Au data
  - ϕ -meson v_2 with high statistics will allow to test the NCQ model ($v_2^s = v_2^{u,d}$?)
  - Measure ϕ (ss(bar)) + Ω (sss) elliptic flow $\rightarrow$ Measure s-quark elliptic flow!

Extra Slides

Method Details

$$\langle v_2\rangle = \frac{\int \frac{dN}{dp_T} v_2(p_T)\,dp_T}{\int \frac{dN}{dp_T}\,dp_T}$$





Extrapolations on $\langle v_2\rangle$:

- π = 15.9%
- *K* = 11.6%
- *p(bar)* = 0.2%
- ϕ = 23.6%
- Ξ = 15.8%

<sin2(ϕ – Ψ)>

Method Details

- ***Consistent with zero:***