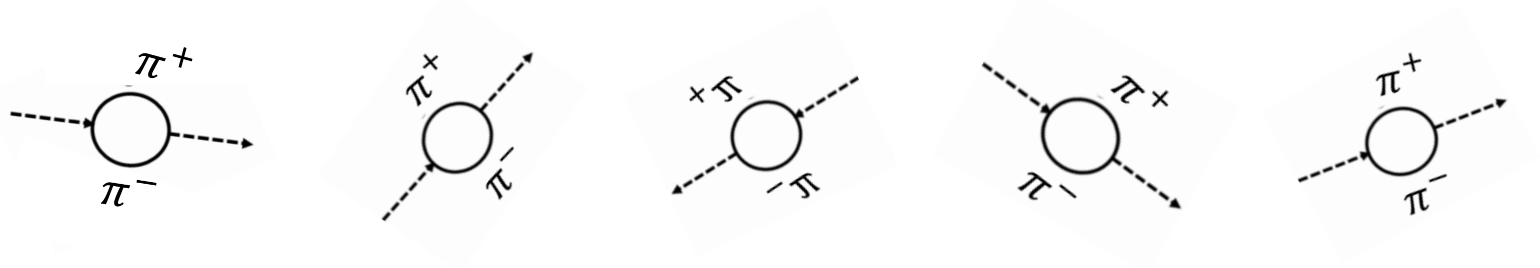
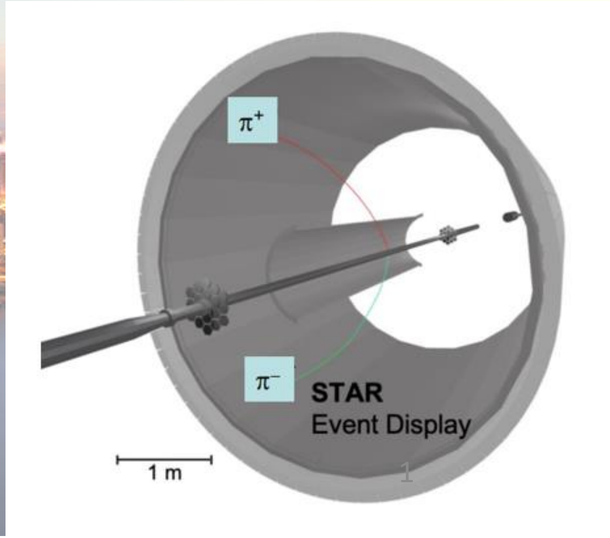


Measurement of the Drell-Söding process in UPC Au+Au 200 GeV collisions

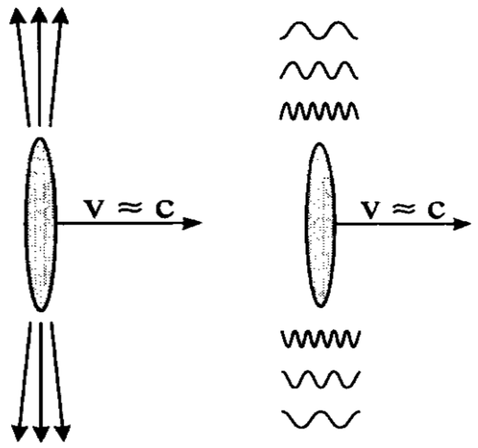
Xinbai Li (xinbai@mail.ustc.edu.cn)
University of Science and Technology of China



Photon nuclear interaction

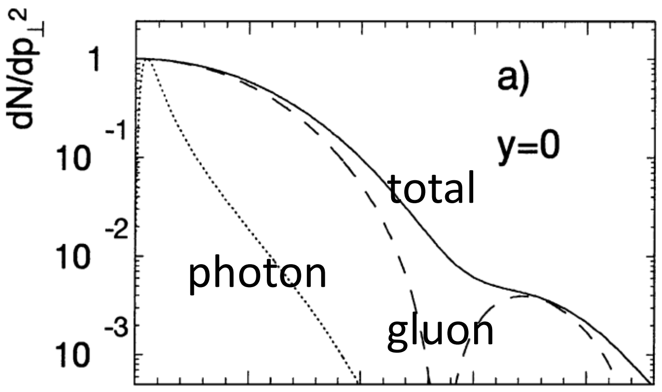
- Lorentz-contracted EM field

~ parallel-moving photon-cloud



F. Krauss, M. Greiner, G. Soff, Prog. Part. Nucl. Phys. 39 (1997) 503

- “TMDs” of photons ⊗ gluons

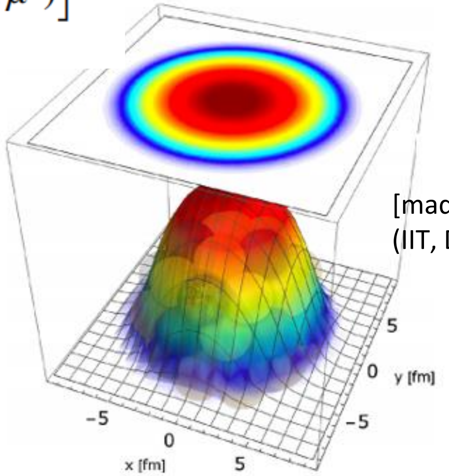


S. R. Klein and J. Nystrand, Phys. Rev. Lett. 84 (2000) 2330

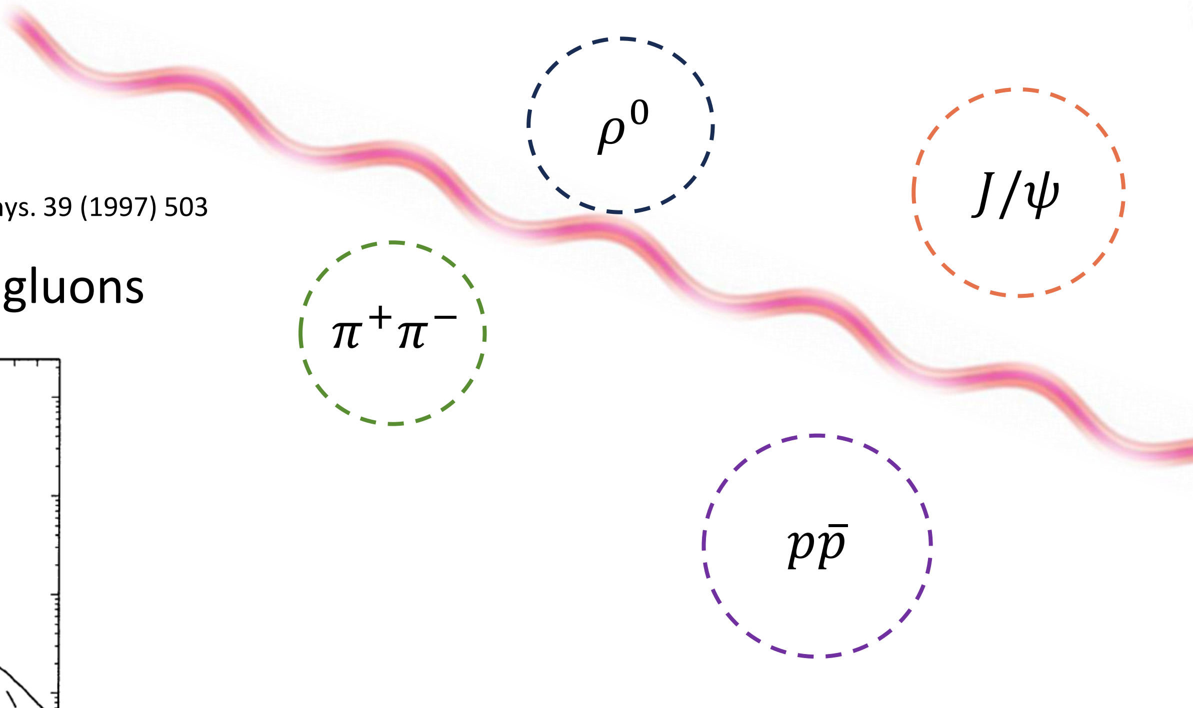
- Photon nuclear interaction

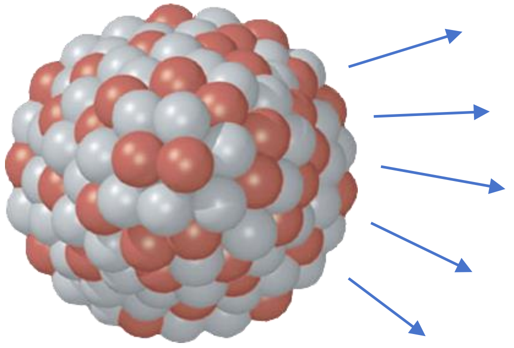
Partons inside a photon ⊗ Gluons

$$\left.\frac{d\sigma(\gamma A \to VA)}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^{\xi}} 16\pi^3 \left[x g_A(x,\mu^2) \right]^2$$

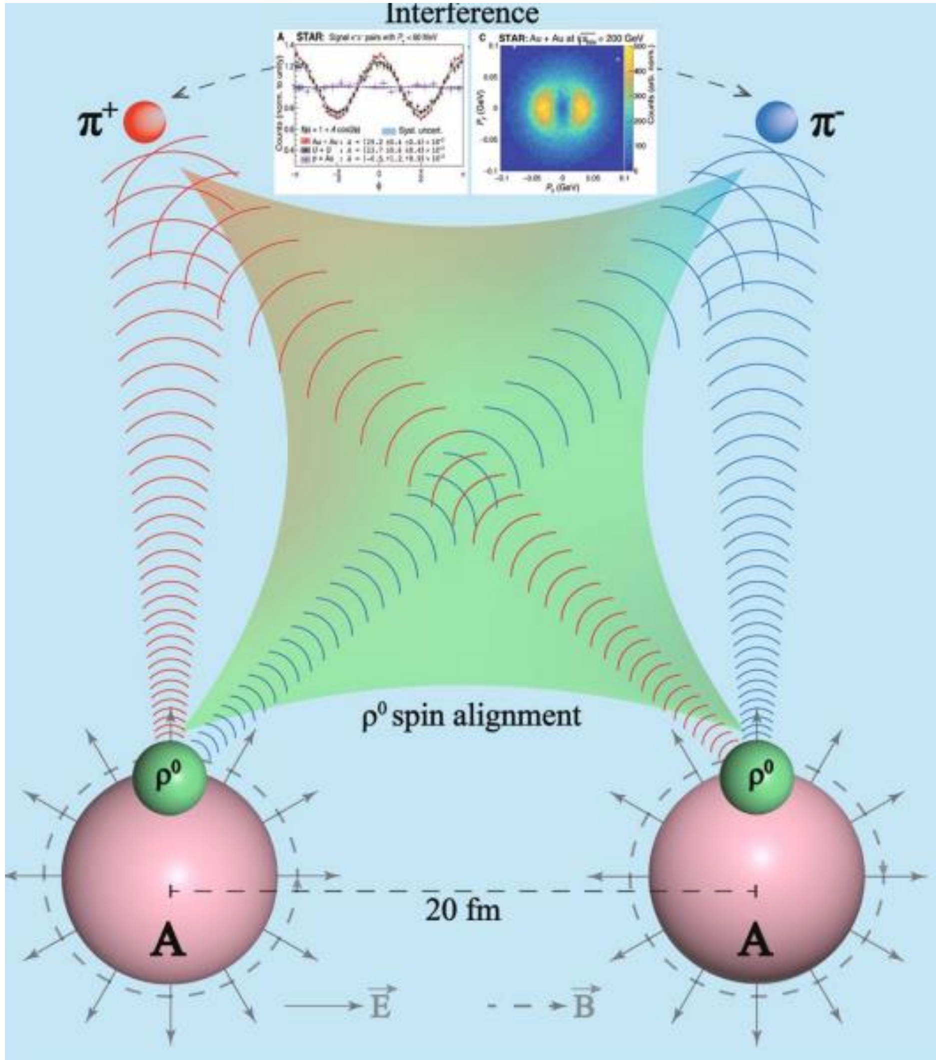


[made by A. Kumar (IIT, Delhi)]

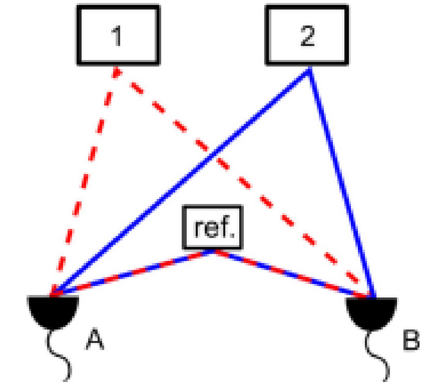


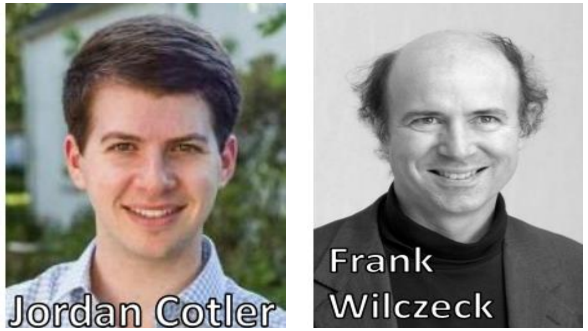


Entanglement-Enabled Spin Interference (EESI)

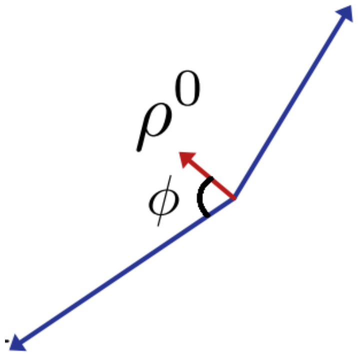


Y. Ma, Nucl. Sci. Tech. 34 (2023) 16



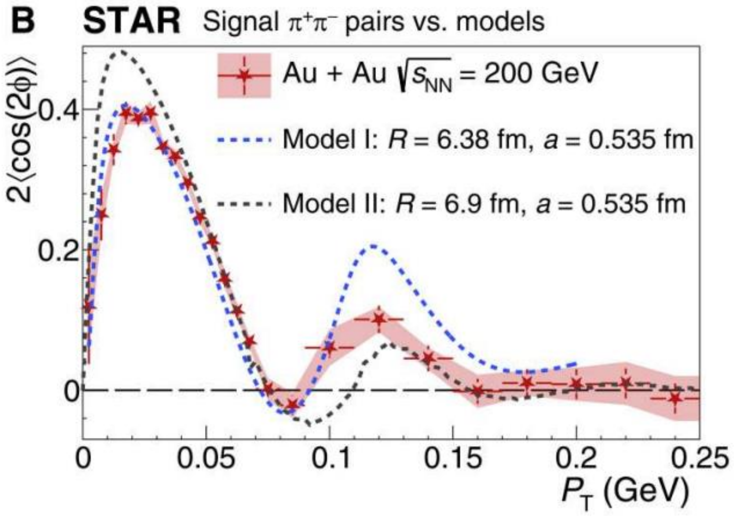


J. Cotler, F. Wilczek, V. Borish, Ann. Phys. 424 (2021) 168346



$$A_{2\phi} = 2\langle\cos(2\phi)\rangle$$

Oscillation amplitude

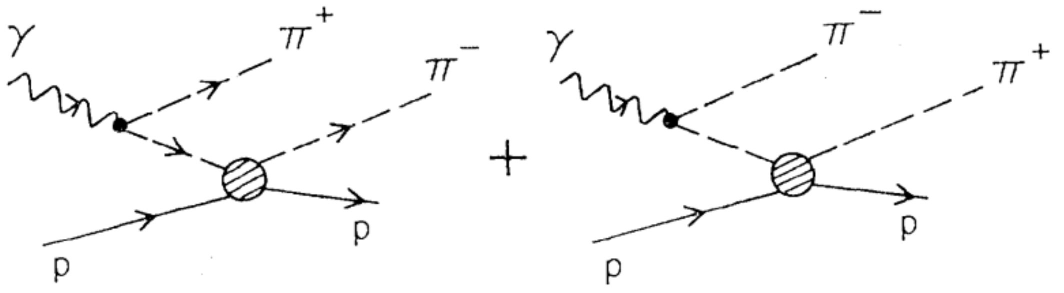


Sci. Adv. 9, eabq3903 (2023)

Drell-Söding process

Originally proposed to

- Produce charge π/K beam — S.D. Drell, Rev. Mod. Phys. 33 (1961) 458
- Peripheral cross section — S.D.Drell, Phys. Rev. Letters 5 (1960} 278
- Mass shift of ρ^0 — P. Soding Phys. Lett. 19 (1966) 702

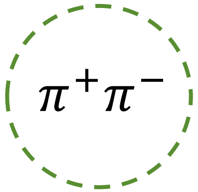


J. Pumplin, PRD. 2. 1859

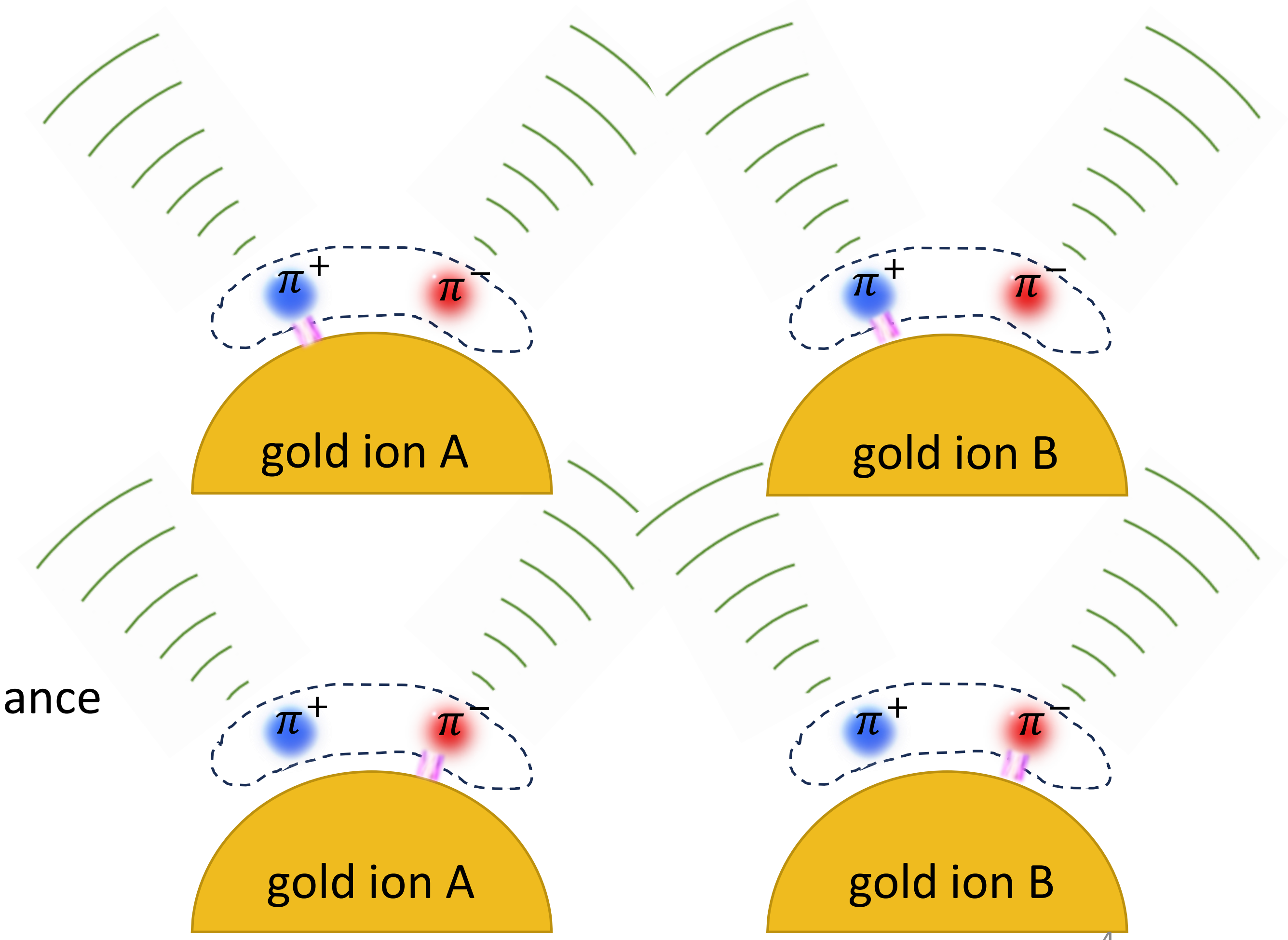
Appear as the protagonist (主角)

- ☐ Virtual pion nucleus scattering mechanism
- ☐ Additional diagram (no pion pole) for gauge invariance

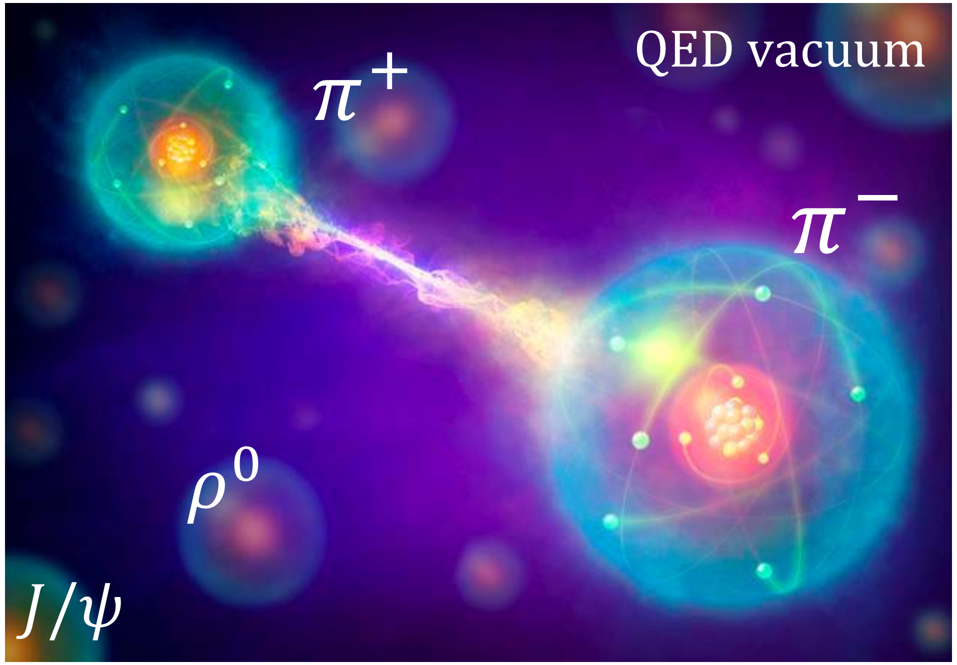
- ☐ 5% divergence in elastic scattering cross section of π^+p and π^-p

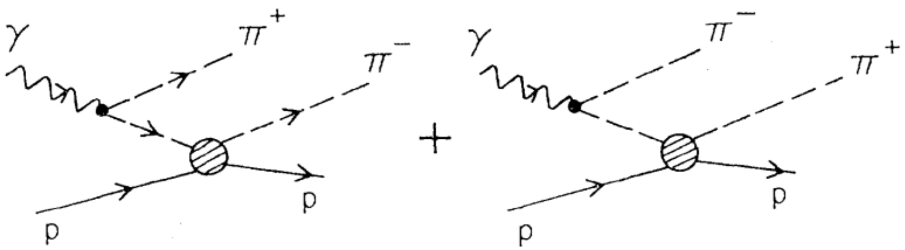


- ☐ An (Einstein-Podolski-Rosen) EPR pair
- ☐ Entangled nonlocal wave function



Comparison with ρ^0 photoproduction





- ✓ Exclusive $\pi^+\pi^-$ production via photon-nuclear interaction
- ✓ EESI tomography

- ☐ Intermediate ρ^0 (entanglement purity?)
- ☐ Decay angularity distribution (filter out higher order wave)
- ☐ Interference dynamics
- ☐ Interaction with the environment (giant dipole resonance(GDR), decoherence?)
- ☐ More Paths (four-slit interference? Diff. amp. Double-slit)

Data selection & Raw signal

Trigger Sets (upc main)	Number of Events
AuAu200_production	23,017,843
AuAu200_production_2011	15,288,719
AuAu_200_production_high_2014	43,911,754
AuAu_200_production_mid_2014	32,591,805
AuAu_200_production_low_2014	19,973,506

<ins>Event level:</ins>

|Vz|<100 cm, nPrimTrks = 2,   Both match TOF

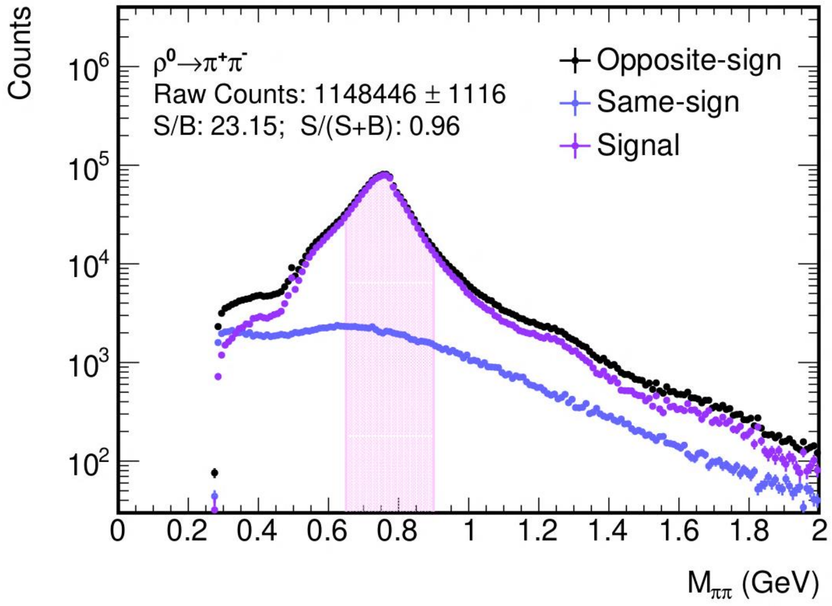
<ins>Track level:</ins>

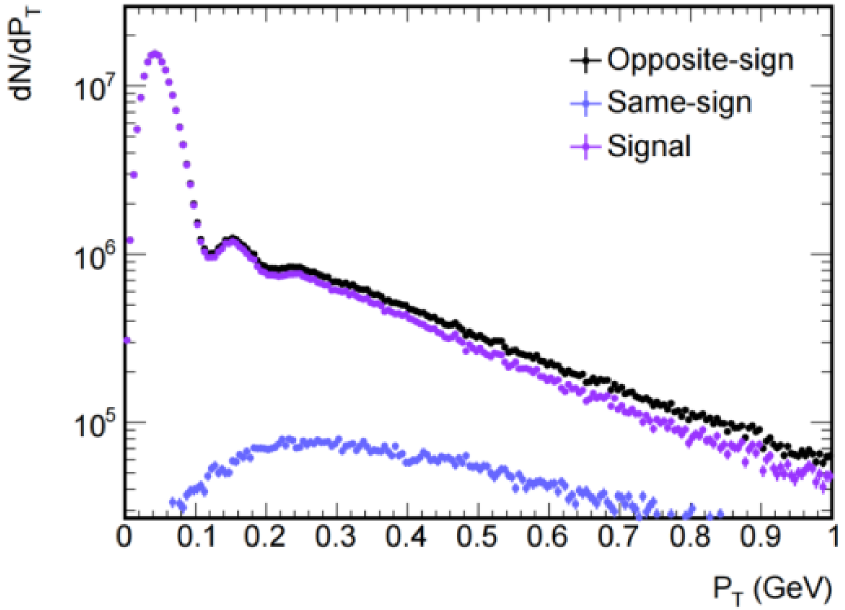
nHitFits ≥ 15,   nHitDedx ≥ 10

$(nSigmaPion\_1)^2 + (nSigmaPion\_2)^2 < 8$,

dca_1 < 1.5 cm, dca_2 < 1.5 cm, |eta| < 1,

pt > 0.2 GeV/c, $|y_{pair}| < 0.9$, $M_{pair}\ in\ [0.5, 1.3]$





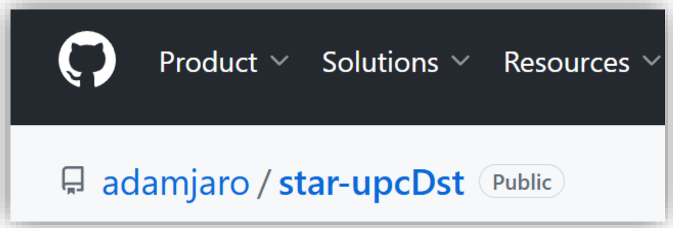
Technology solution — TOF eff.

- ☐ TOF match efficiency for upc-main

a) Unfeasible — data-driven by upc-main

b) Extract from mini-bias data

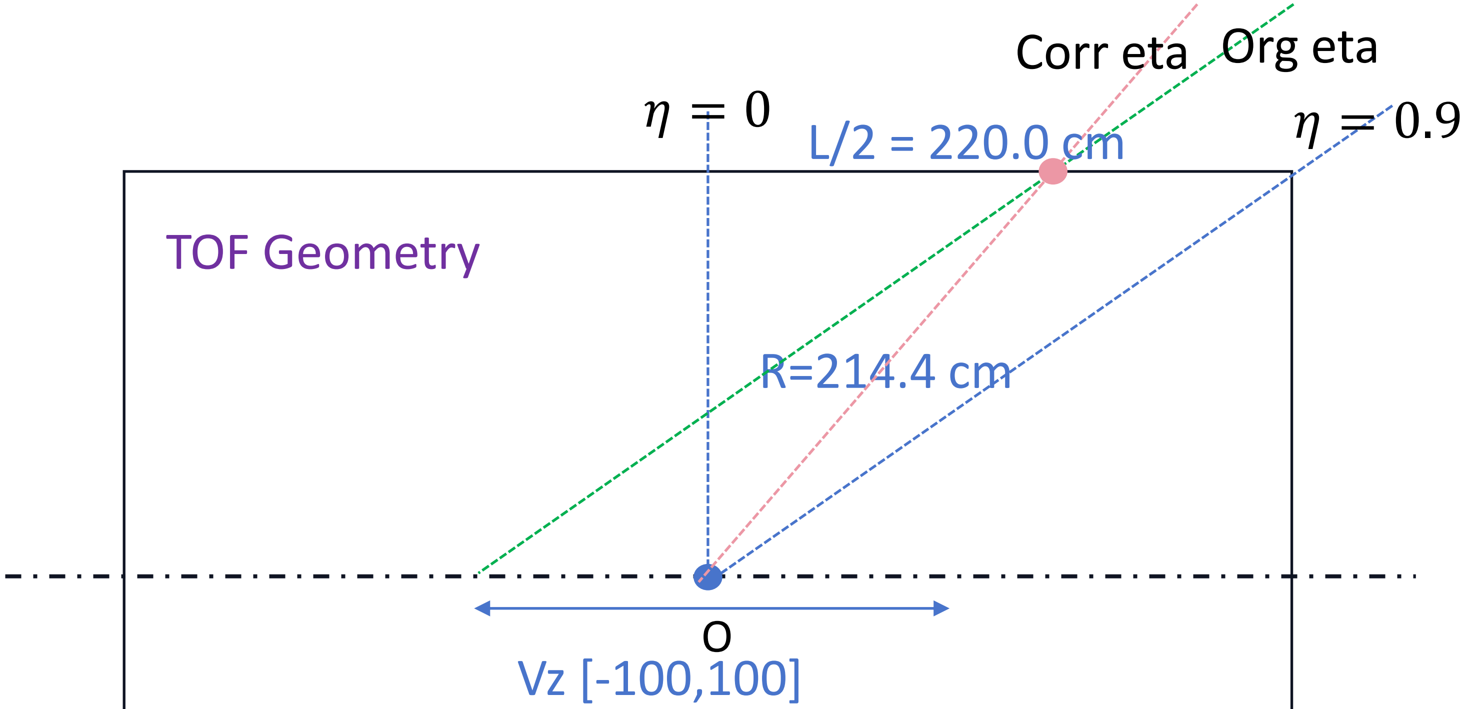
c) Correct η for the wide Vz



The standard STAR upc pico framework

skips the tracks failing recalibration.

— comment out



At Vz = -100 cm

Org eta: 0.9 (θ_1)

Corr eta: $\theta_2 = \arctan(R/(\frac{R}{\tan(\theta_1)} - 100)$

Technology solution — Fitting algorithm

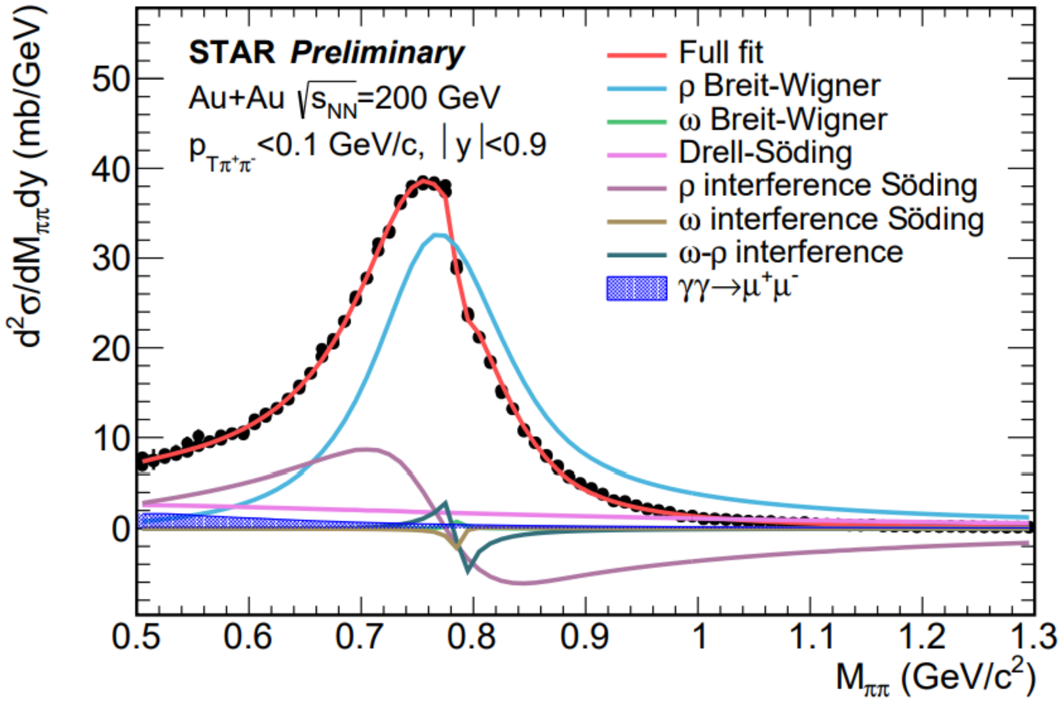
$$\frac{d\sigma}{dM_{\pi^+\pi^-}} = \left| A_\rho \frac{\sqrt{M_{\pi\pi}M_\rho\Gamma_\rho}}{M_{\pi\pi}^2 - M_\rho^2 + iM_\rho\Gamma_\rho} f_{fluxcorr}(M_{\pi\pi}) + B f_{Söding}(M_{\pi\pi}) + C_\omega e^{i\phi_\omega} \frac{\sqrt{M_{\pi\pi}M_\omega\Gamma_{\omega\to\pi\pi}}}{M_{\pi\pi}^2 - M_\omega^2 + iM_\omega\Gamma_\omega} \right|^2 + f_{dimuon} + f_{background}$$

$$\Gamma_\rho = \Gamma_0 \frac{M_\rho}{M_{\pi\pi}} \left(\frac{M_{\pi\pi}^2 - 4m_\pi^2}{M_\rho^2 - 4m_\pi^2} \right)^{3/2}, \quad \Gamma_\omega = \Gamma_0 \frac{M_\omega}{M_{\pi\pi}} \left(\frac{M_{\pi\pi}^2 - 9m_\pi^2}{M_\omega^2 - 9m_\pi^2} \right)^{3/2}, \quad \Gamma_{\omega\to\pi\pi} = \mathrm{Br}(\omega\to\pi\pi)\Gamma_0 \frac{M_\omega}{M_{\pi\pi}} \left(\frac{M_{\pi\pi}^2 - 4m_\pi^2}{M_\omega^2 - 4m_\pi^2} \right)^{3/2}$$

Parameters:

A_ρ : amplitude for ρ
M_ρ : mass of ρ
B : scale for Söding
C_ω/A_ρ: ratio of amp.
M_ω : mass of ω
$\Gamma_{0\omega}$: mass width of ω
ϕ_ω : mixing phase angle
b_1 : polynomial $b_2(M_{\pi\pi} - b_1)$
b_1 : (remain background slope (negligible))

Fix to reduce the parameter dimensions



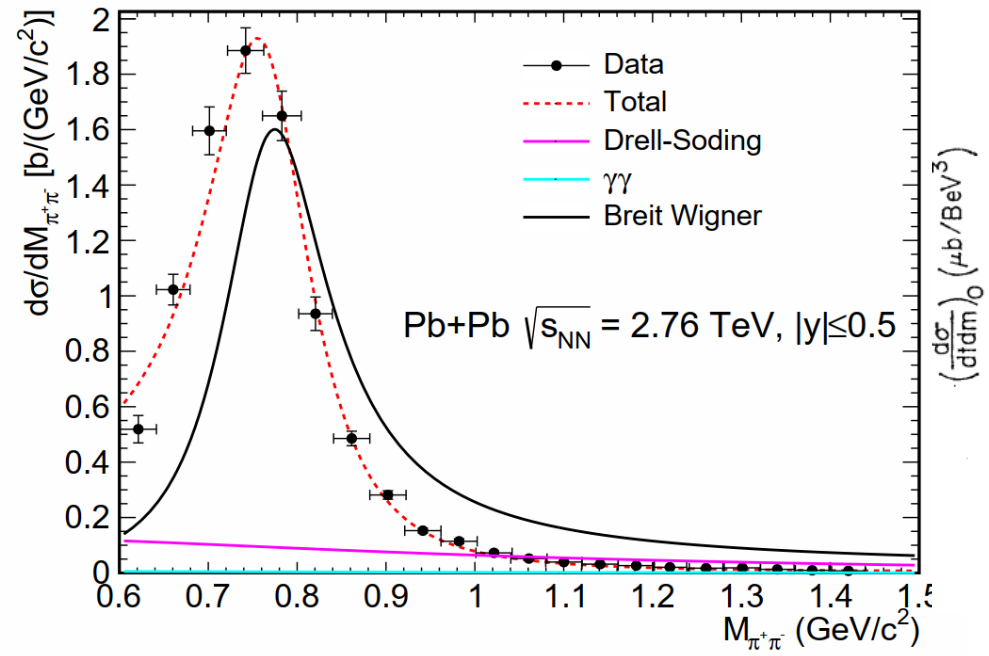
Technology solution — Model input

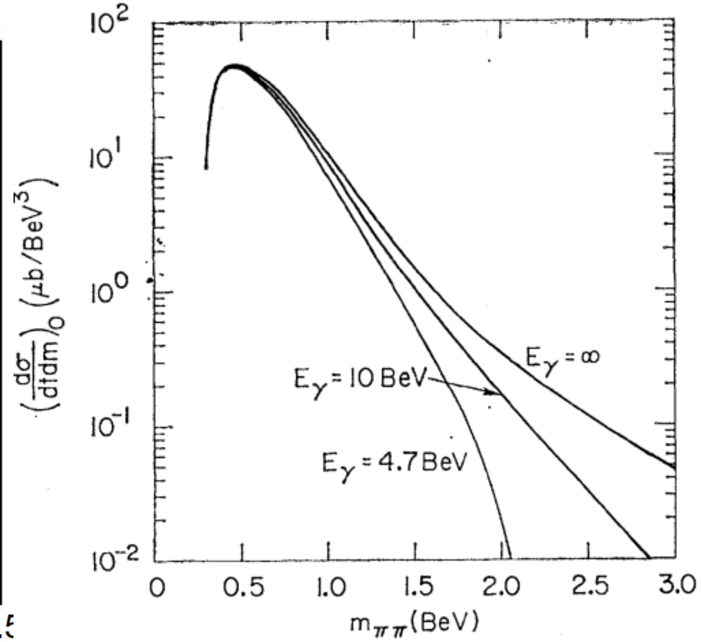
STAR: Flat mass — constant

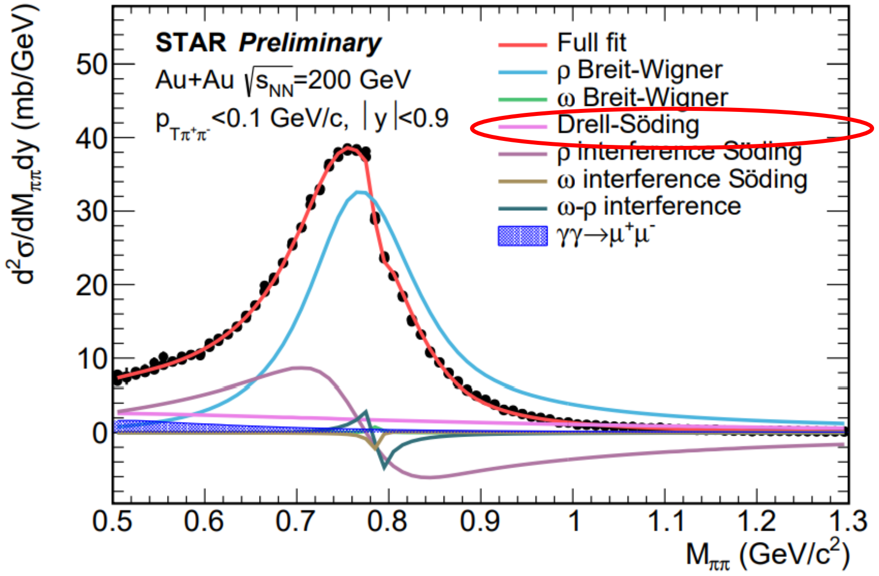
HERA: Parametrised by function (the unknown non-resonant amplitude): $A_{nr} = \dfrac{f_{nr}}{(m_{\pi\pi}^2 - 4m_\pi^2 + \Lambda_{nr}^2)^{\delta_{nr}}}$

[Incorporate model calculation for Drell-Söding process]()

Pion nucleon elastic scattering amplitude: $$T_\pm = 2i\sigma_{\pi p}\left[\left(q_\pm \cdot p'\right)^2 - m_\pi^2 m_p^2\right]^{1/2} e^{B_\pm t/2},$$







J. Pumplin, PRD. 2. 1859

Technology solution — QED dimuon

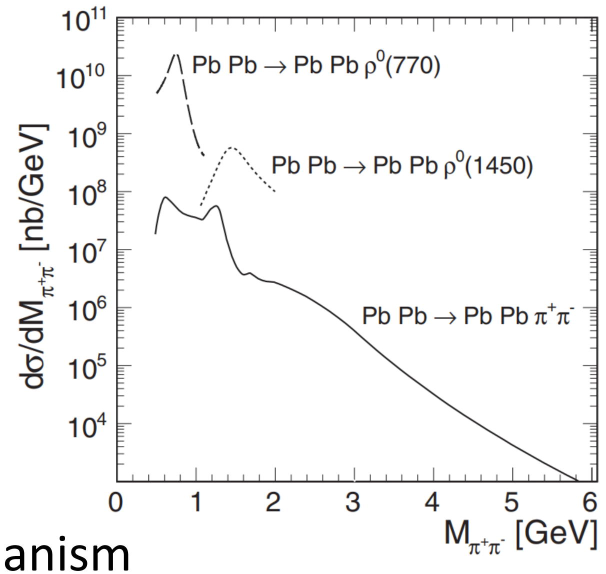
Contamination from $\gamma\gamma$ fusion: mainly $\gamma\gamma \to \mu^+\mu^-$

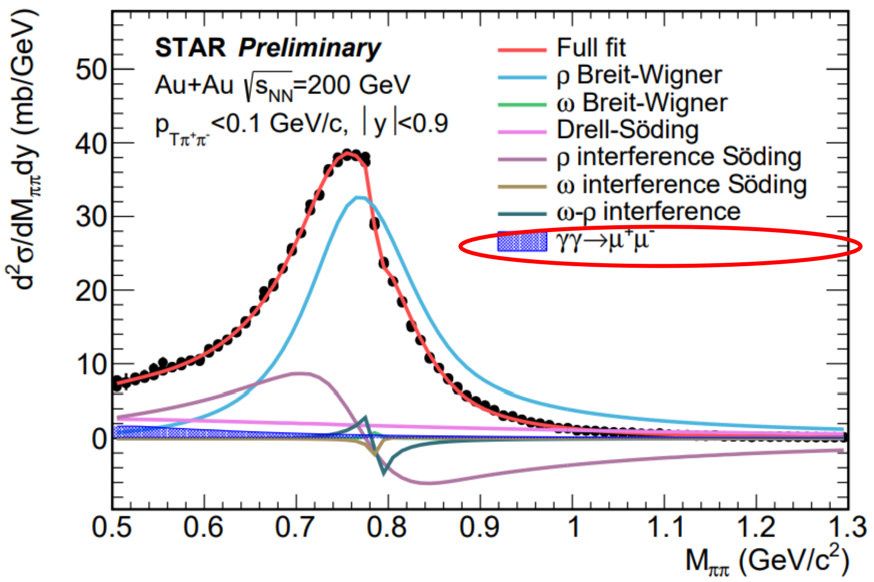
meson	mass [GeV]	$\gamma = 108$, $Z = 79$	
		σ^{tot} [μb]	σ^{red} [μb]
$\pi^\pm$	0.140	14762	12159

fermion	mass [GeV]	$\gamma = 108$, $Z = 79$	
		σ^{tot} [μb]	σ^{red} [μb]
$\mu^\pm$	0.1057	208329	177789

$$\hat{M} = -ie^2 \int \frac{d^4q_1}{(2\pi)^4} \not{A}^{(1)}(q_1) \frac{\not{p}_- - \not{q}_1 + m}{(p_- - q_1)^2 - m^2} \not{A}^{(2)}(p_+ + p_- - q_1)$$
$$- ie^2 \int \frac{d^4q_1}{(2\pi)^4} \not{A}^{(2)}(p_+ + p_- - q_1) \frac{\not{q}_1 - \not{p}_+ + m}{(q_1 - p_+)^2 - m^2} \not{A}^{(1)}(q_1)$$
$$= -i(\frac{Ze^2}{2\pi})^2 \frac{1}{2\beta} \int d^2q_{1\perp} \frac{1}{q_1^2} \frac{1}{(p_+ + p_- - q_1)^2} \exp(iq_{1\perp}b)$$
$$\{\frac{\not{\psi}^{(1)}(\not{p}_- - \not{q}_1 + m)\not{\psi}^{(2)}}{[(p_- - q_1)^2 - m^2]} + \frac{\not{\psi}^{(2)}(\not{q}_1 - \not{p}_+ + m)\not{\psi}^{(1)}}{[(q_1 - p_+)^2 - m^2]}\},$$

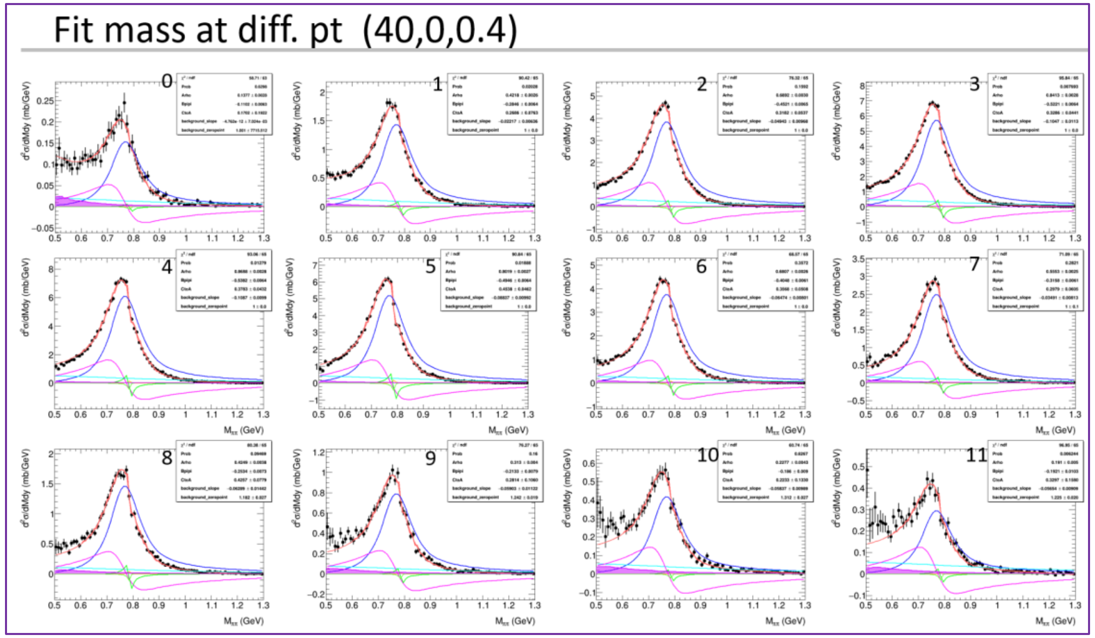
$$P(p_+, p_-, b) = \sum_s |M|^2$$

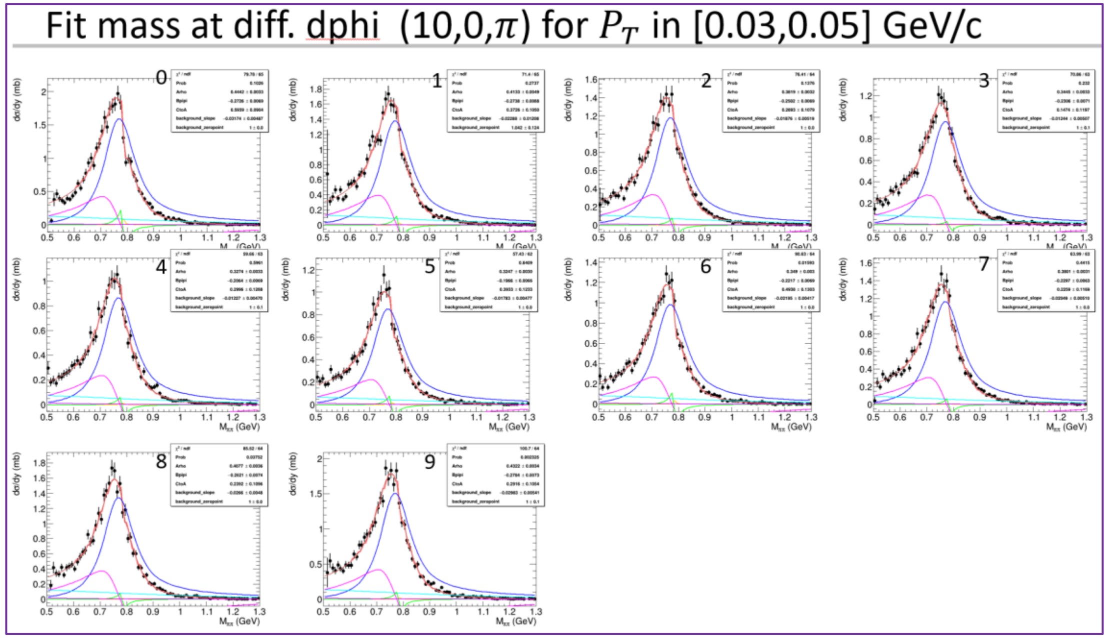




- ☐ $\gamma\gamma \to \pi^+\pi^-$ is small ~ 1/15 of Söding
- ☐ $\gamma\gamma \to \mu^+\mu^-$ is comparable to Söding mechanism

Differential fitting





- Fit mass to separate components per p_T, $\Delta\phi$
- Low mass (0.4-0.55 GeV/c^2) contaminated by $K_s \rightarrow \pi^+\pi^-$, ($\omega \rightarrow \pi^+\pi^-\pi^0$)
- High mass (>1.3 GeV/c^2) obvious twist due to extra form factor? (A.Donohoe Wed. 9:00 HP2024),

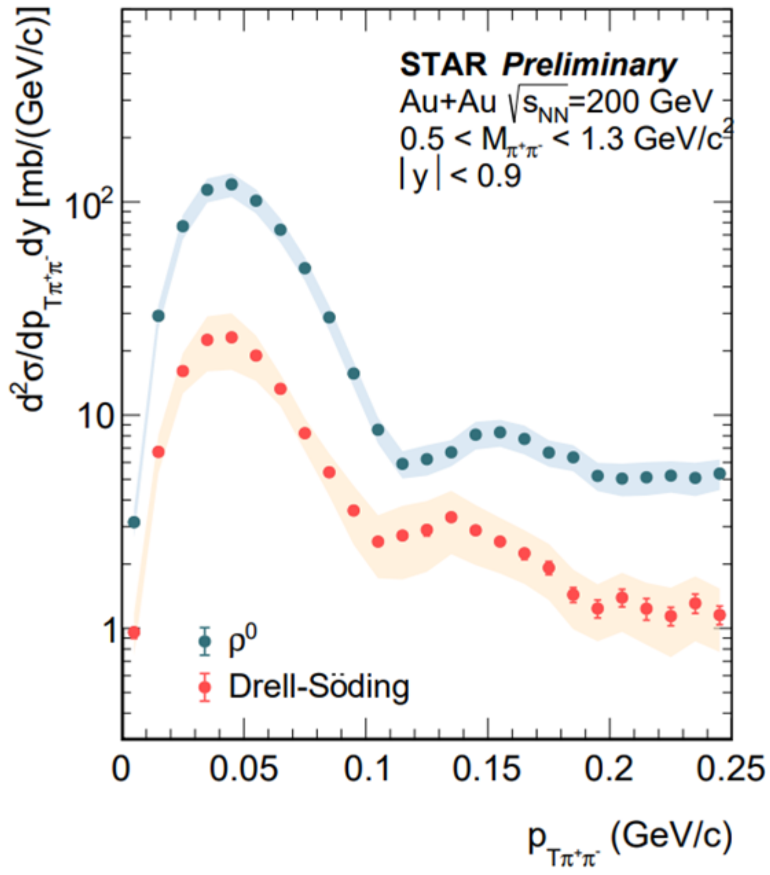
ρ^0 ρ' ρ'' Söding $\gamma\gamma \rightarrow \pi^+\pi^-$

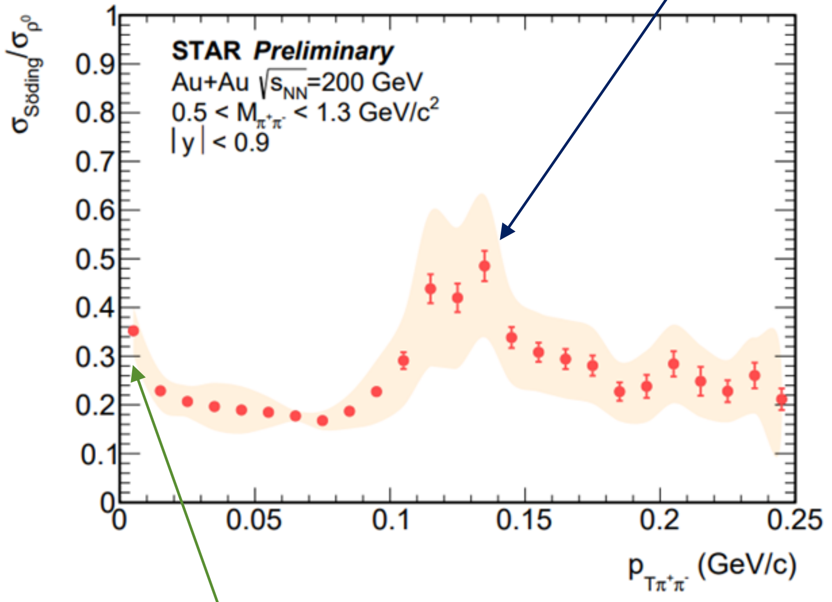
interference between each of them.

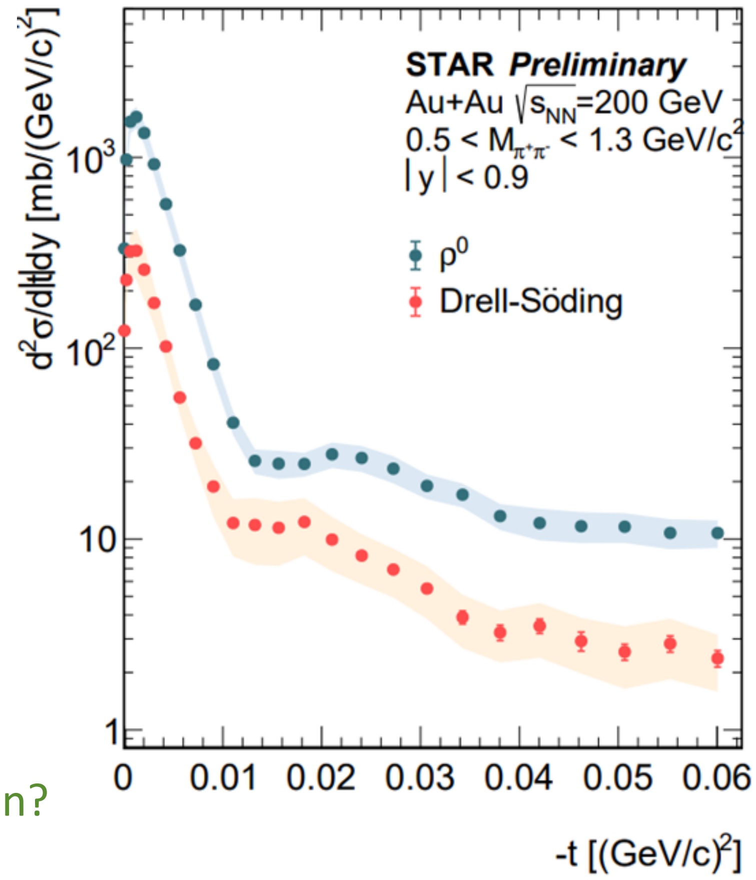
Diffractive p_T spectrum

Reveal the photon transverse momentum parton distribution and interference dynamics.

Photon parton distributions and scattering dynamics







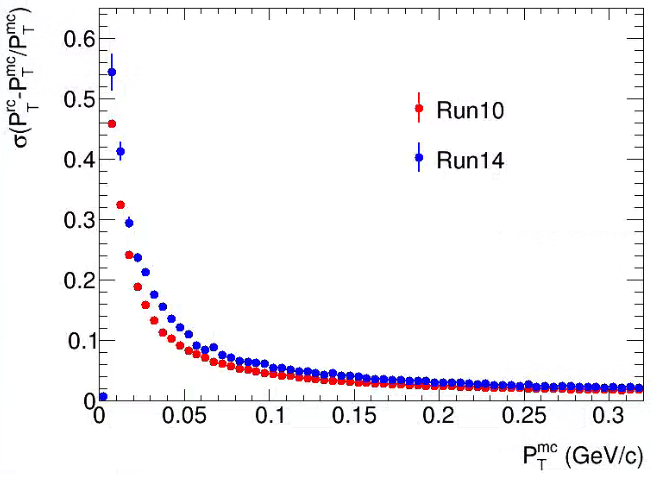
Interference dominate? diphoton fusion?

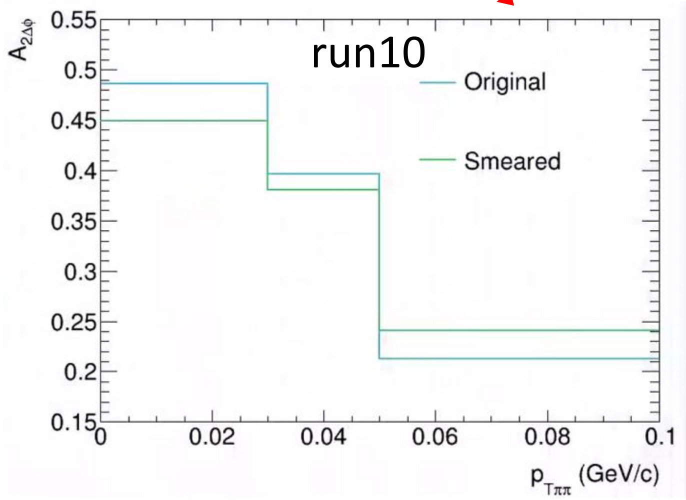
Multiplicative noise on A_2

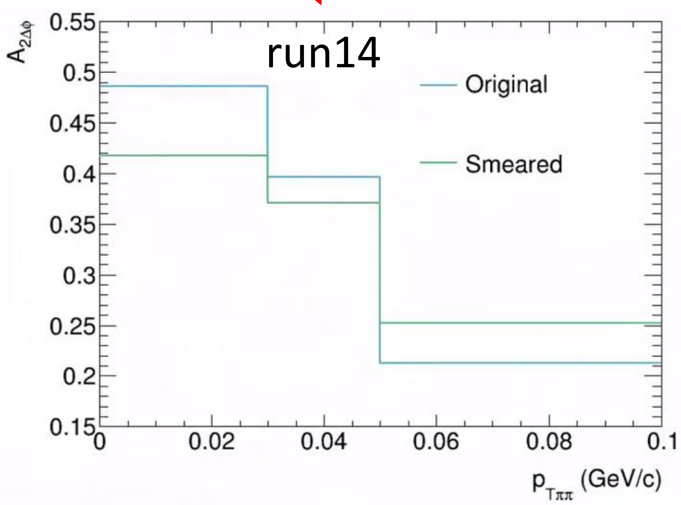
Have you heard of the concepts of multiplicative noise and additive noise?

$$\int F(\phi)d\phi = \int f(\phi)\omega(\phi)\mathcal{R}(\phi_{true} - \phi)d\phi d\phi_{true}$$

$$a_2^{true} = \frac{2 \times (a_2^{measure} R_2 - 2\omega_2)}{4 + a_2^{measure} R_2\omega_2} = \frac{2(a_2^{smear} - \omega_2)}{2 + a_2^{smear} \times \omega_2}, \qquad a_2^{smear} = \frac{a_2^{measure} R_2}{2}$$



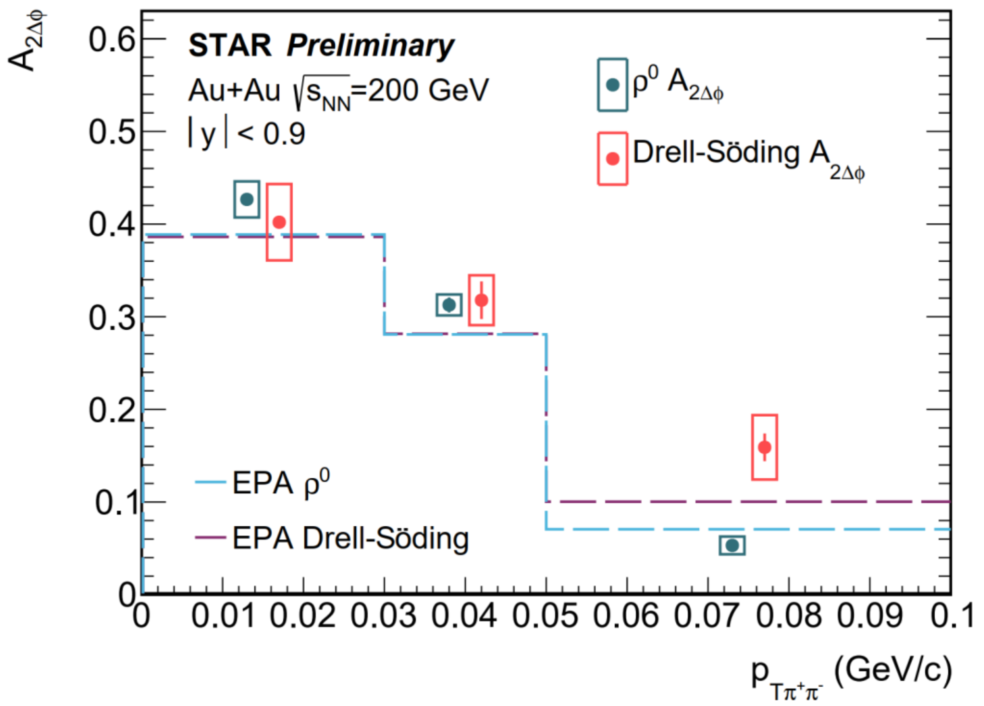


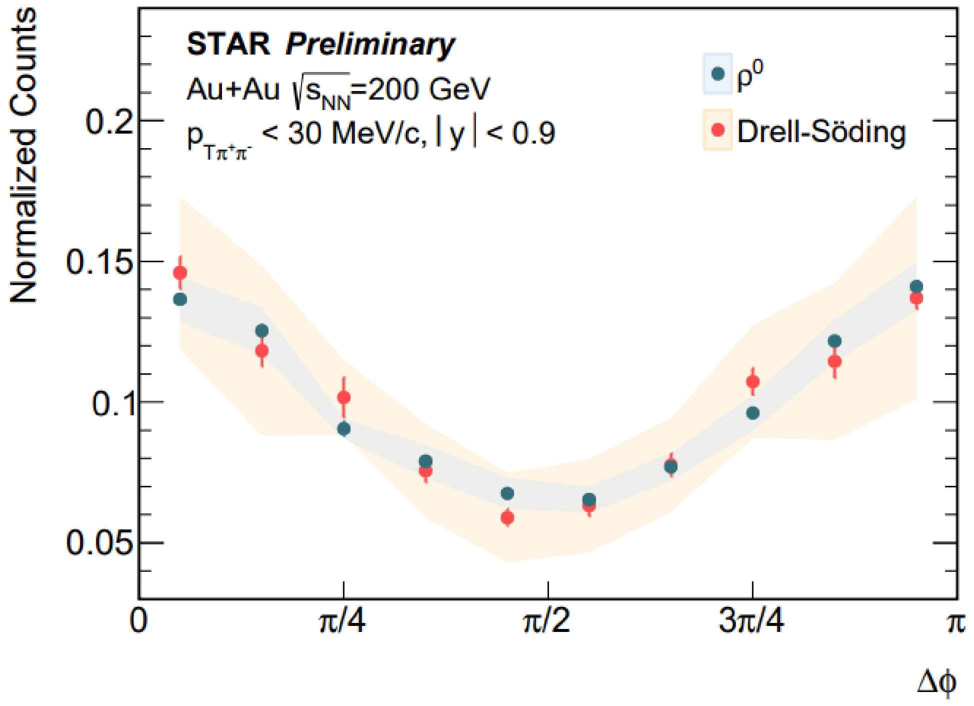


Simple MC to get R_2 for run10, run11, run14 for ρ^0 and Söding respectively

Interference measurement

- Spin interference enabled between π^+Au and π^-Au with different amplitude.
- Similar interference p_T dependence at low p_T, different interference dynamics.
- Obvious stronger interference for Drell-Söding process on mass dependence (not shown)





Summary

- First measurement of diffractive p_T and interference pattern for Drell-Söding process
- A rich environment to explore quantum interference:
  - Interference dynamics
  - Decay effect
  - Amplitude divergence in interference ...
- Photon transverse momentum parton distributions?
- Extend the discussion to ϕ and direct K^+K^- (future EIC)
- Hadronic structure of vacuum (proton-antiproton excitation)

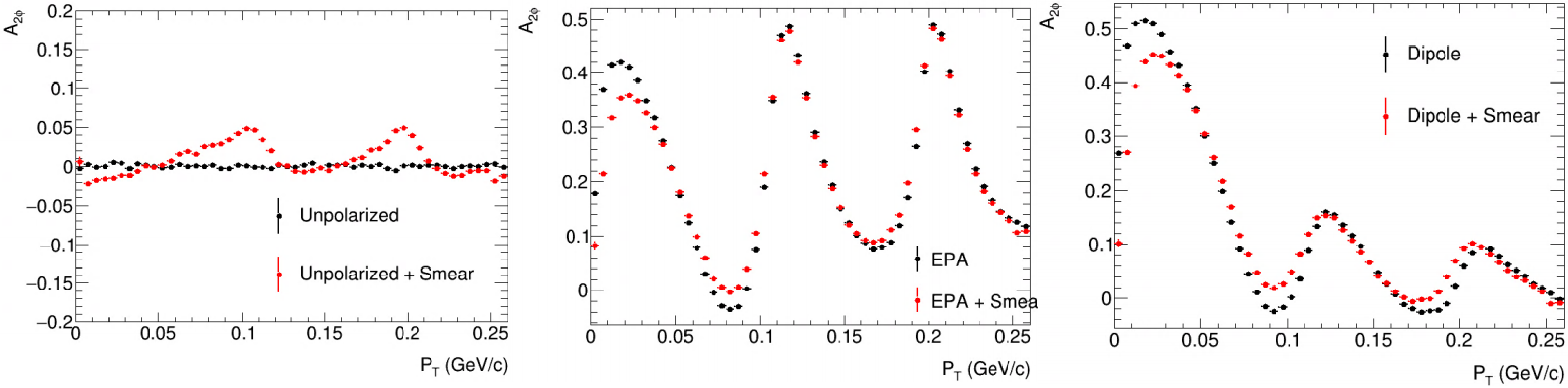
Backup

Any questions and suggestions are welcome

In the meeting or after
By email – xinbai@mail.ustc.edu.cn

pt detection resolution effect

From embedding (single pion)



$$\int F(\phi)d\phi = \int f(\phi)\omega(\phi)\mathcal{R}(\phi_{true} - \phi)d\phi d\phi_{true}$$

$$a_2^{true} = \frac{2 \times (a_2^{measure} R_2 - 2\omega_2)}{4 + a_2^{measure} R_2\omega_2} = \frac{2(a_2^{smear} - \omega_2)}{2 + a_2^{smear} \times \omega_2}, \qquad a_2^{smear} = \frac{a_2^{measure} R_2}{2}$$