FSR Issues in 2010 $\pi^+\pi^-\gamma$ Analysis (off-peak, tagged γ_{ISR})

Paolo Beltrame (UCLA), Achim Denig (Mainz), Stefan Müller (KVI)

Up to which extent do we know the theoretical uncertainty of scalar QED as a model for FSR

Outline

- Summary 2010 ππγ result
- FSR effects in large-angle analysis
- How to subtract FSR and estimate the error
- Test model dependence for sQED model
  - SU(3) ChPT
  - RPT
- Model-independent approach using F-B-Asym.
- Conclusions

Disclaimer

- **Many contributions from those people:**

  H. Czyz (Katowice), S. Ivashyn (Kharkiv), S. Gorini (Mainz),
  S. Scherer (Mainz), O. Shekhovtsova (Valencia), ...

- **Presented today is the view of SM, PB, AD and Hernyk Czyz**

- **I will not discuss the theoretical models**

- **Work in progress**

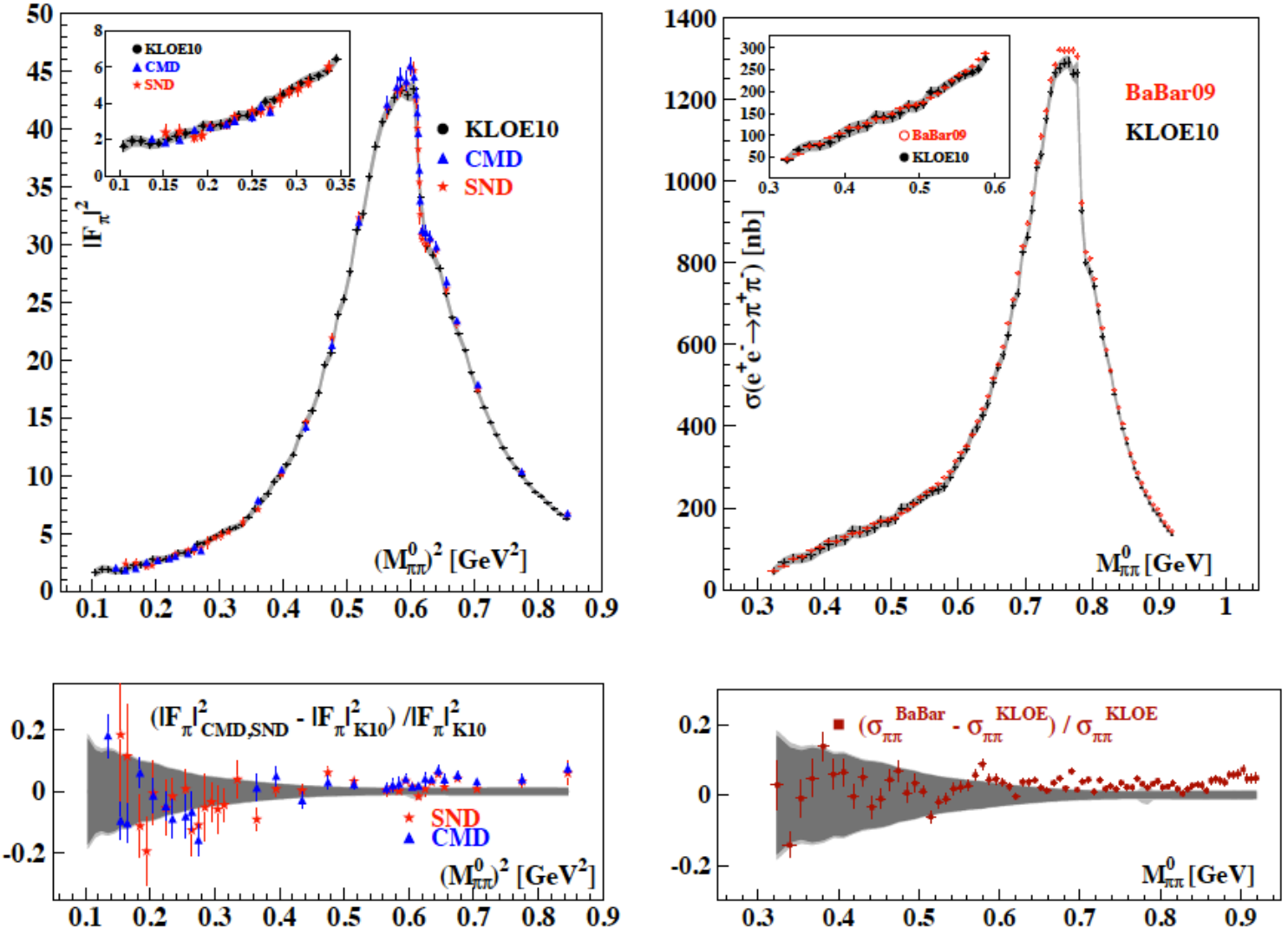
- **Conclusions and actions need to be discussed after this talk**

Warning: this is going to be a very technical talk – please ask questions immediately!

Summary 2010 ππγ result

‘Final’ Result 2010

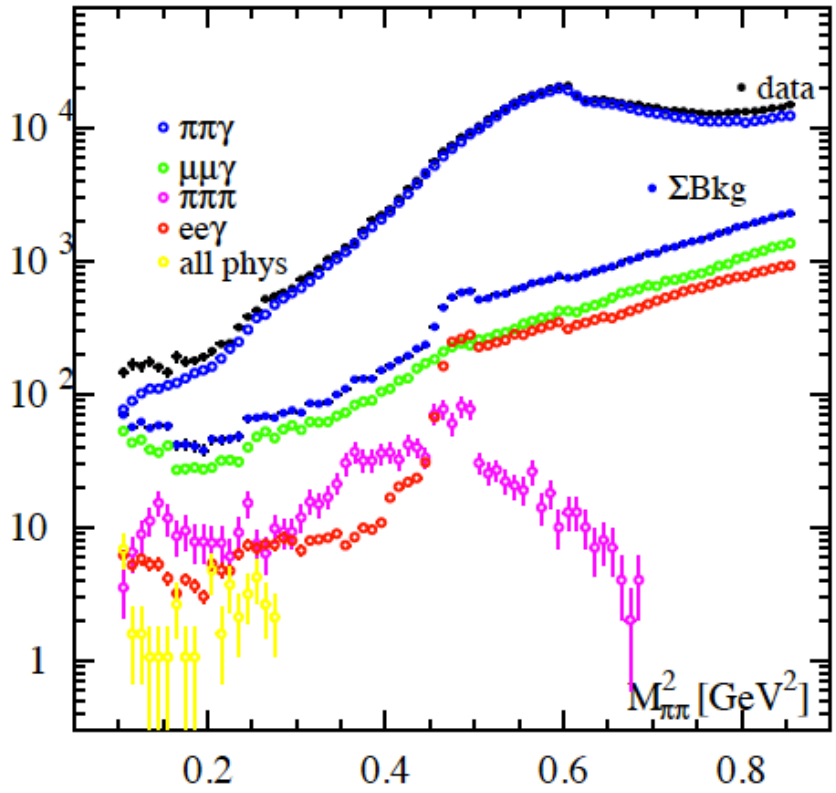
arXiv:1006.5313

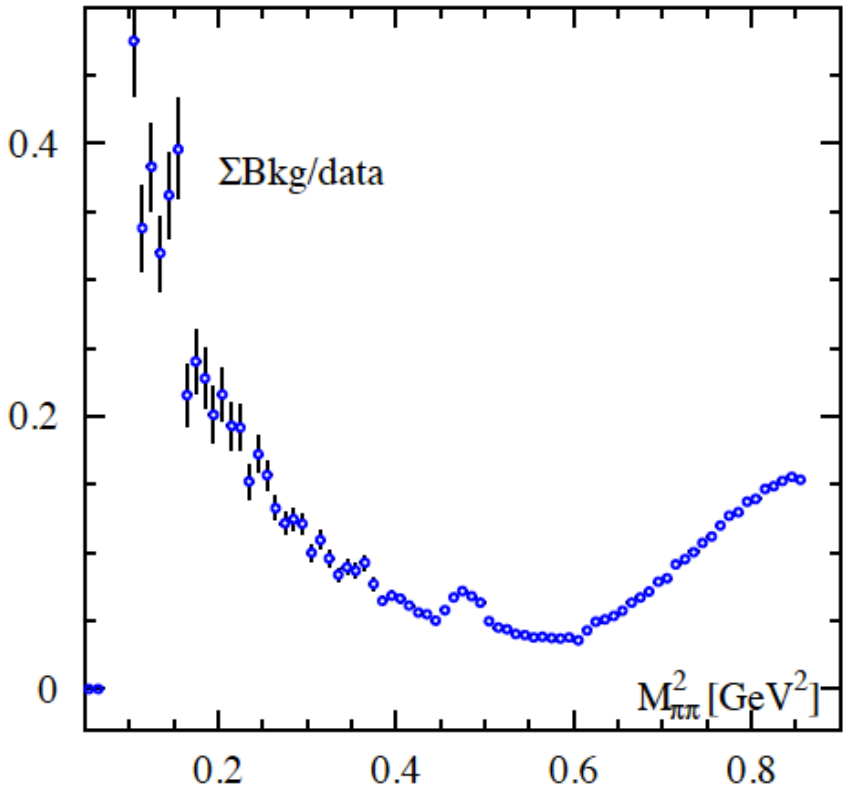


‘Final’ Result 2010

arXiv:1006.5313

‘Reducible’ Background is large in the LA kinematics even at $s = 1\ GeV^2$





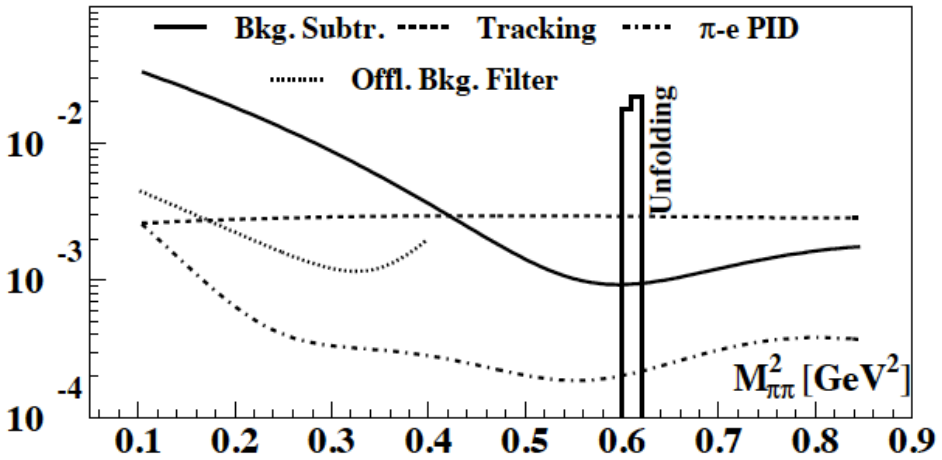
‘Final’ Result 2010

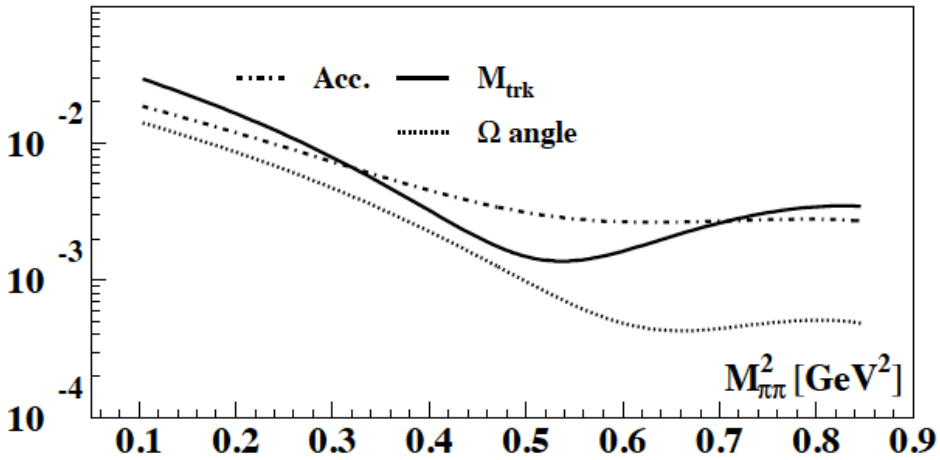
arXiv:1006.5313

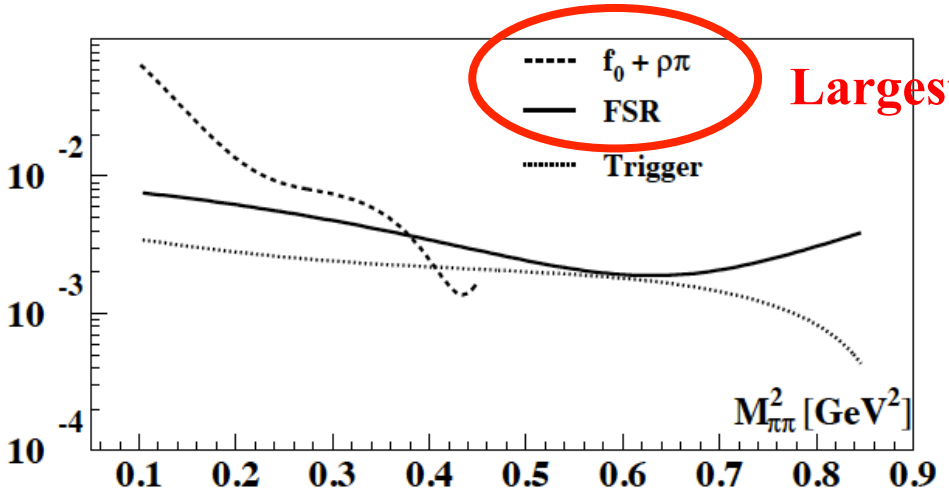
	$\sigma_{\pi\pi\gamma}$	$\sigma_{\pi\pi}^{\text{bare}}$	$\lvert F_\pi\rvert^2$	$\Delta a_\mu^{\pi\pi}$
Background Filter	Ref. [25]			negligible
Background subtraction				0.5%
$f_0 + \rho\pi$ bkg.				0.4%
Ω cut				0.2%
Trackmass cut				0.5%
π-e PID				negligible
Tracking				0.3%
Trigger				0.2%
Acceptance				0.5%
Unfolding				negligible
Software Trigger (L3)	0.1%			
Luminosity	0.3%			
Experimental syst.				1.0%
FSR treatment	-	Ref. [25]		0.3%
Radiator function H	-	0.5%		
Vacuum Polarization	-	Ref. [32]	-	0.1%
Theory syst.				0.6%

‘Final’ Result 2010

arXiv:1006.5313







Largest contributions!

'Final' Result 2010

arXiv:1006.5313

Evaluating the dispersion integral for the dipion contribution to the muon magnetic moment anomaly, $\Delta a_\mu^{\pi\pi}$, in the range between 0.1 and 0.85 GeV^2 we have found

$$\Delta a_\mu^{\pi\pi}(0.1 - 0.85\ \mathrm{GeV}^2) = (478.5 \pm 2.0_{\mathrm{stat}} \pm 4.8_{\mathrm{exp}} \pm 2.9_{\mathrm{th}}) \times 10^{-10},$$ **1.2%**

confirming the discrepancy between the SM evaluation for a_μ and the experimental value measured by the Muon g-2 collaboration at BNL.

Combining our result with the previous KLOE results, we have calculated $\Delta a_\mu^{\pi\pi}$ in the range $0.1 < M_{\pi\pi}^2 < 0.95$ GeV^2 obtaining

$$\Delta a_\mu^{\pi\pi}(0.1 - 0.95\ \mathrm{GeV}^2) = (488.6 \pm 5.0) \times 10^{-10}.$$ **1.0%**

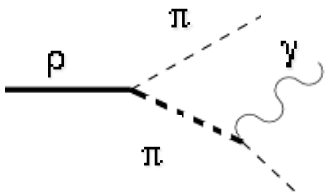
The KLOE experiment covers $\sim 70\%$ of the leading order hadronic contribution to the muon anomaly.

FSR effects in large-angle analysis

Final State Radiation FSR

There is often confusion when people/theoreticians speak about FSR, especially in KLOE FSR-analyses !

Our definition for today:



$$A_{FSR} = A_{Brems} + A_{Achasov}$$

Final State Radiation FSR

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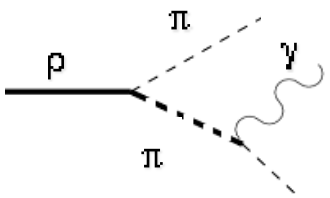
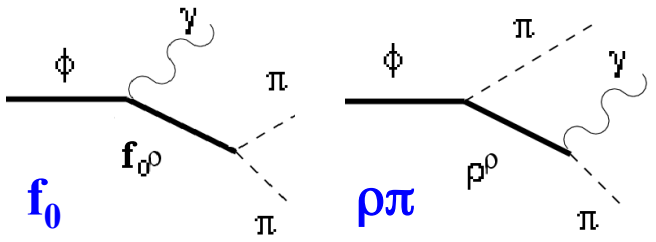


Main FSR issue of today!

$A_{sQED}=A_{brems}$???

$$A_{FSR} = A_{Brems} + A_{Achasov}$$



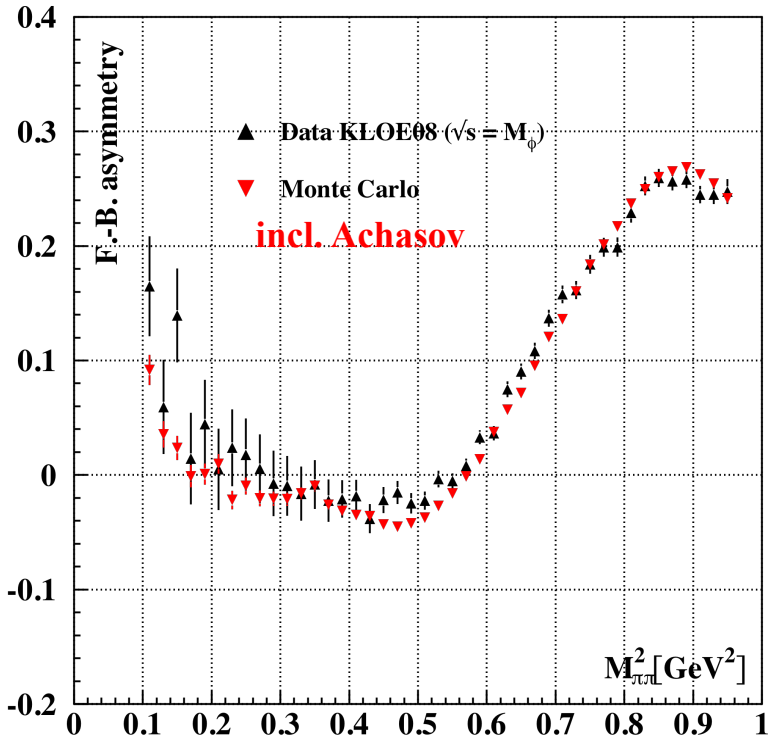
$$A_{achasov} = A_{\phi\to f0(980)+f0(600)} + A_{\phi\to\rho\pi} + A_{e+e-\to\rho\pi}$$

Achasov Model

We believe that Achasov's Model is a pretty good model for 2010 data!

Why? Phi meson contribution is suppressed – offpeak data!

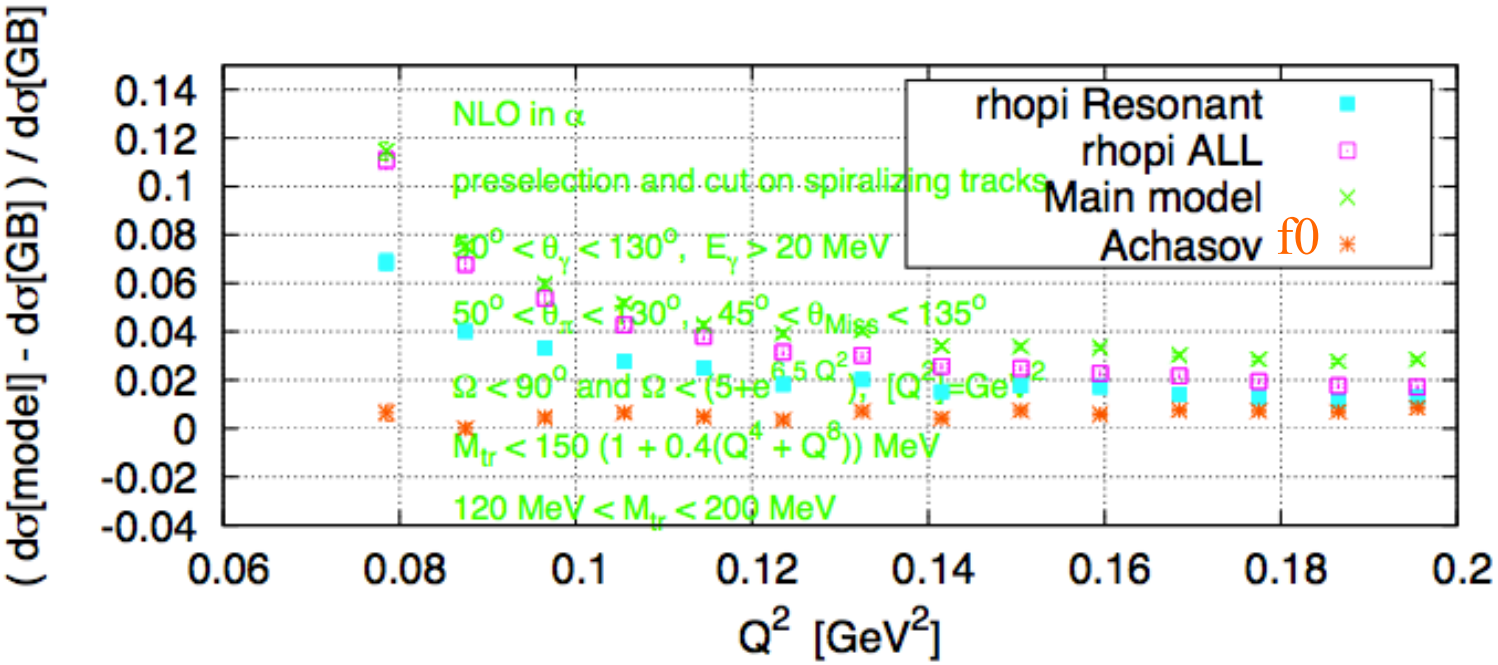
Why? Forward-Backward-Asymmetry for ONPEAK data looks already good!



Reminder: without Achasov's model the F-B-asymmetry is negative at low $M_{\pi\pi}$!

Achasov Model: Contributions at s=1 GeV^2

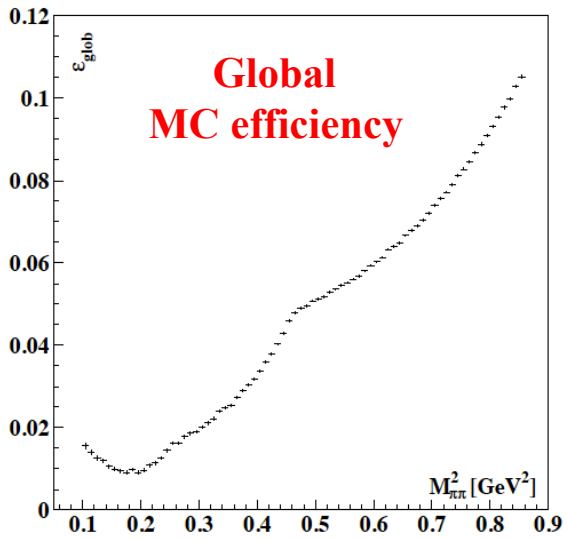
Plot done by Sergiy Ivashyn



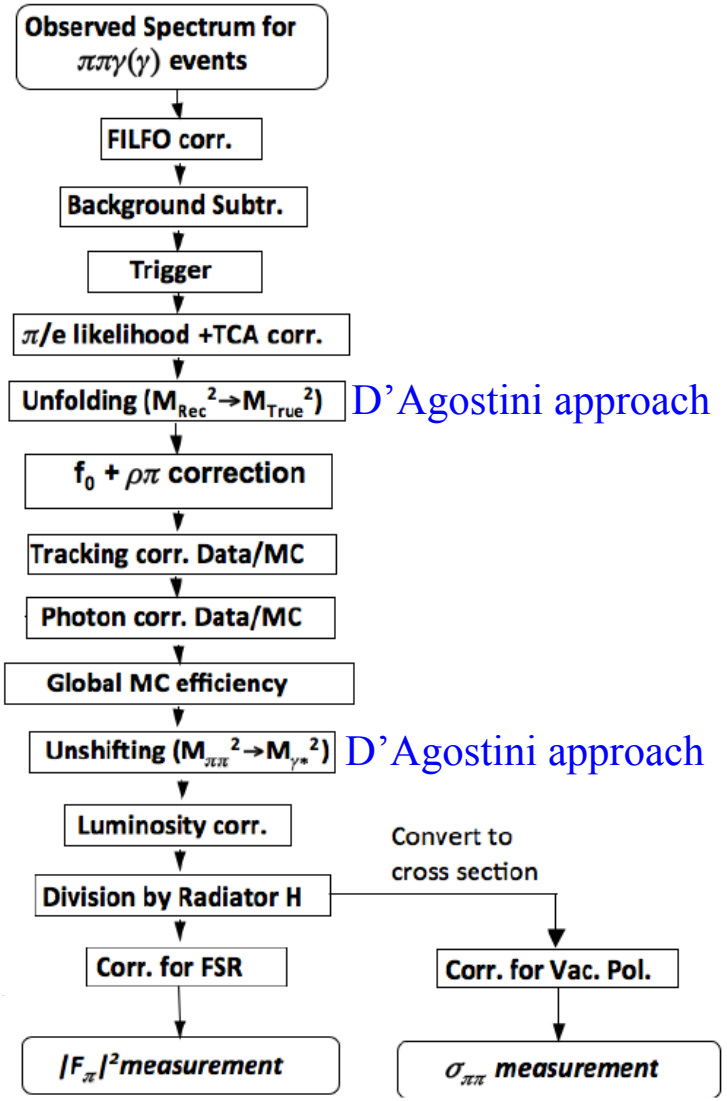
The leading terms at s=1GeV^2 are the resonant and non-resonant ρπ conributions!

How to subtract FSR and estimate the error ?

Analysis Flow in 2010 Result

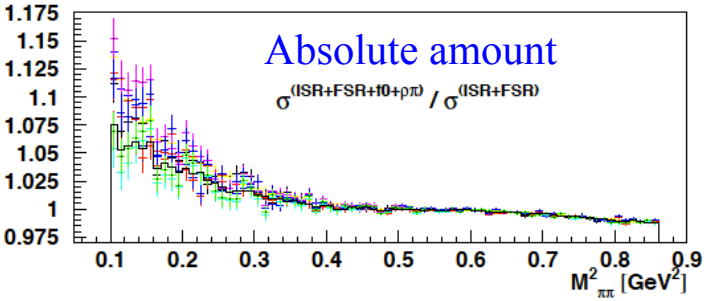


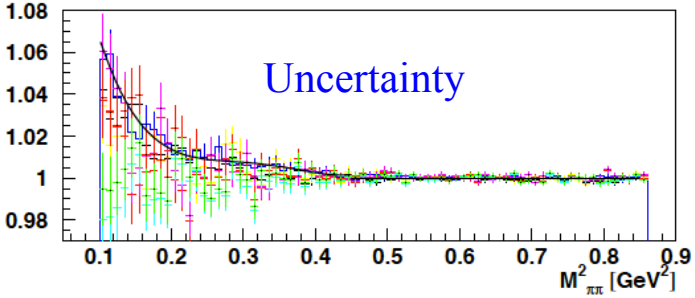
$$\frac{N(ISR\_nlo + FSR\_nlo)_{50\text{-}130^\circ}}{N(ISR\_nlo + FSR\_nlo)_{0\text{-}180^\circ}}$$

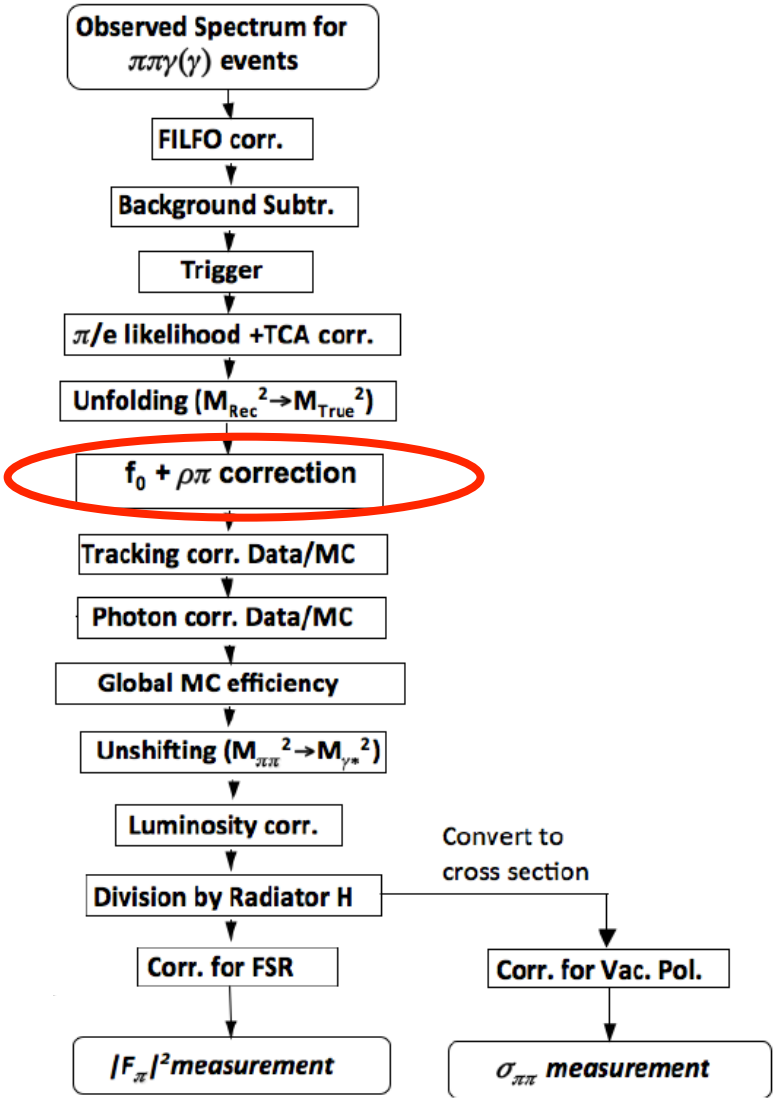


Analysis Flow in 2010 Result: f_0+ρπ

NOTA BENE:
- FSR effects are decoupled
→ first subtract f_0+ρπ







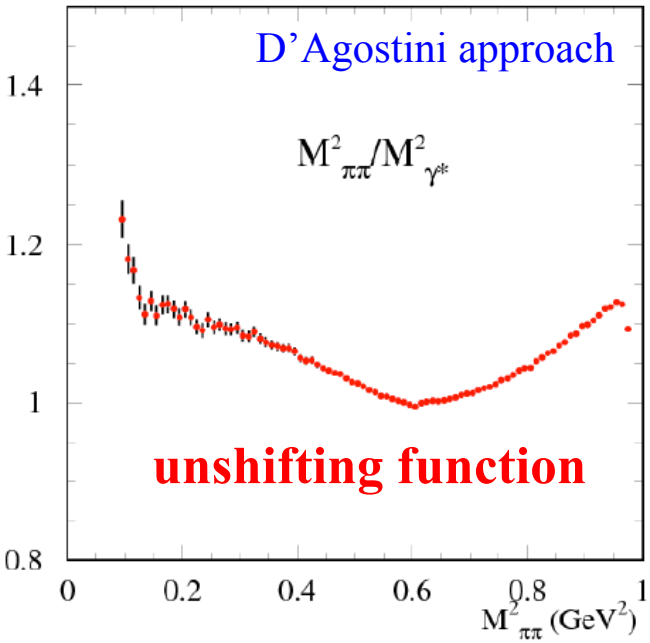
Analysis Flow in 2010 Result: Bremsstrahlung

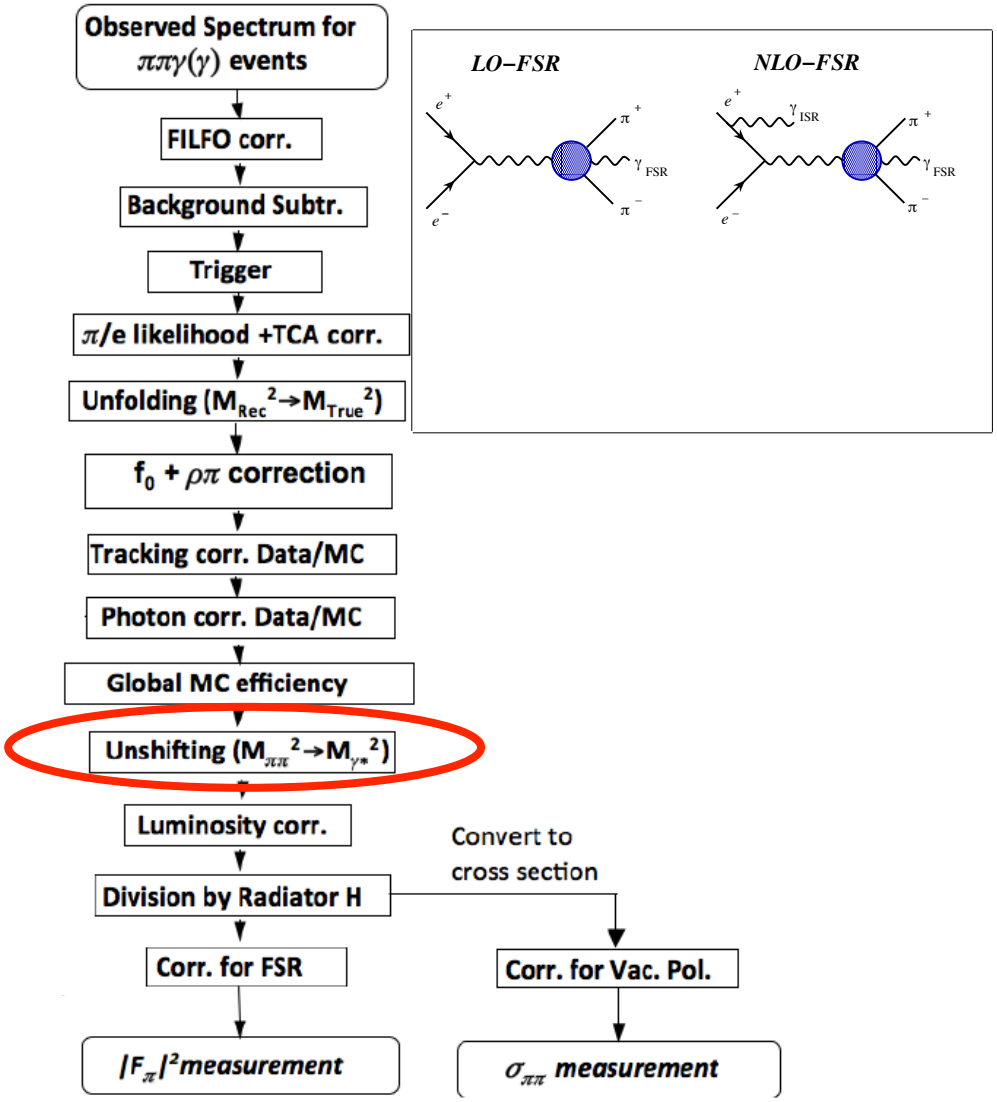
NOTA BENE:

- FSR effects are decoupled

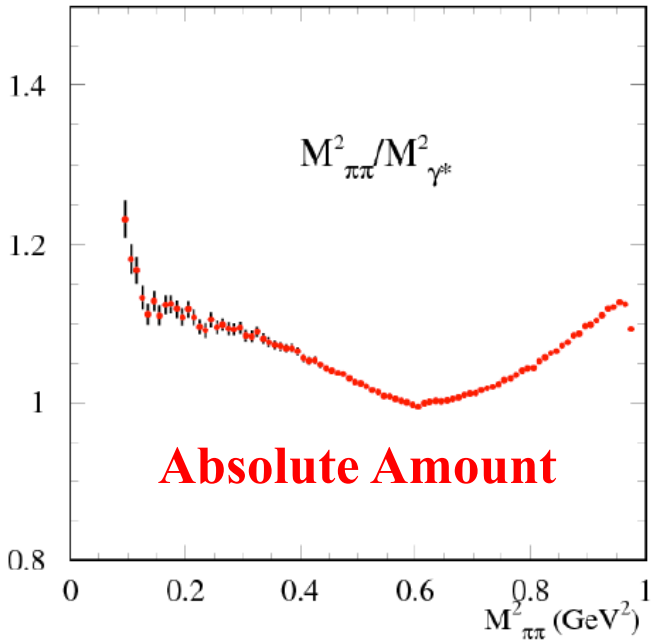
→ first subtract f_0+ρπ

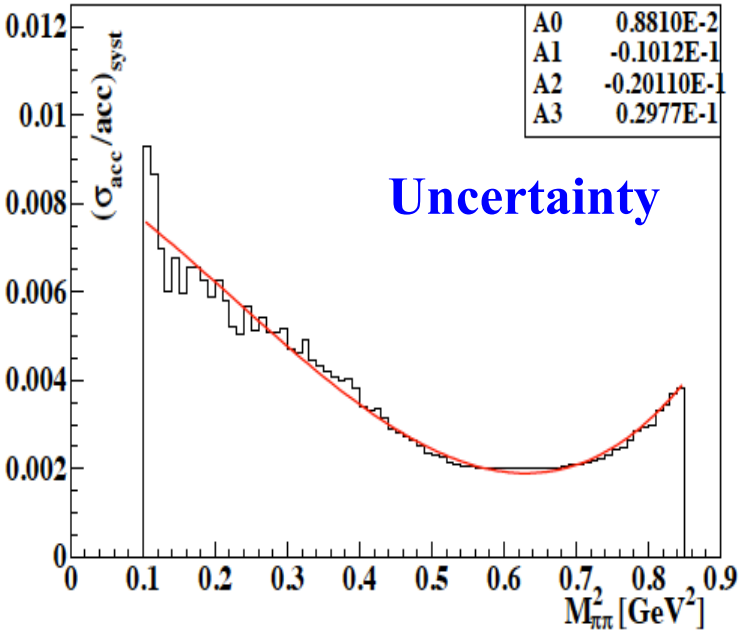
- then Bremsstrahlung contrib. from unshifting function!





2010 Result: Uncertainty Bremsstrahl. Contrib.





Absolute Amount • **5%** = Uncertainty of Bremsstrahl. contrib.

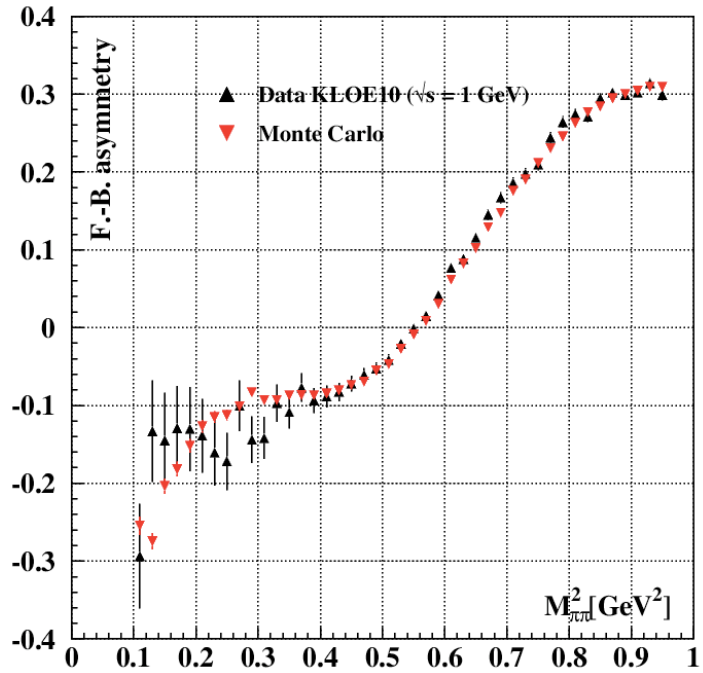
2010 Result: Uncertainty Bremsstrahl. Contrib.

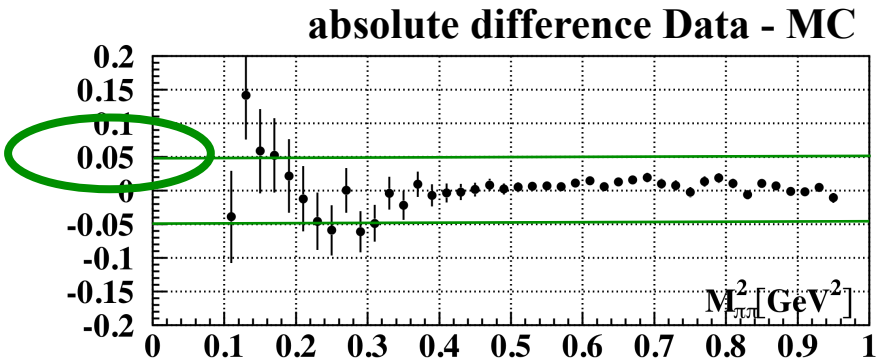
Absolute Amount • **5%** = Uncertainty of Bremsstrahl. contrib.

Where do these 5% come from?

→From comparison data – MC in F-B-asymmetry!

→ correct?! Not clear to me!





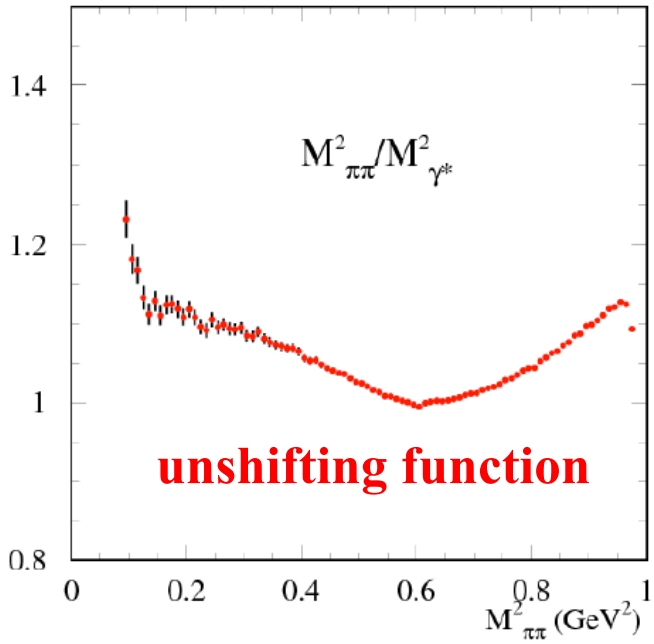
2010 Result: Mistake in Bremsstr. **Uncertainty**!

We considered only the amount of bremsstrahlung AFTER having applied acceptance cuts!!!

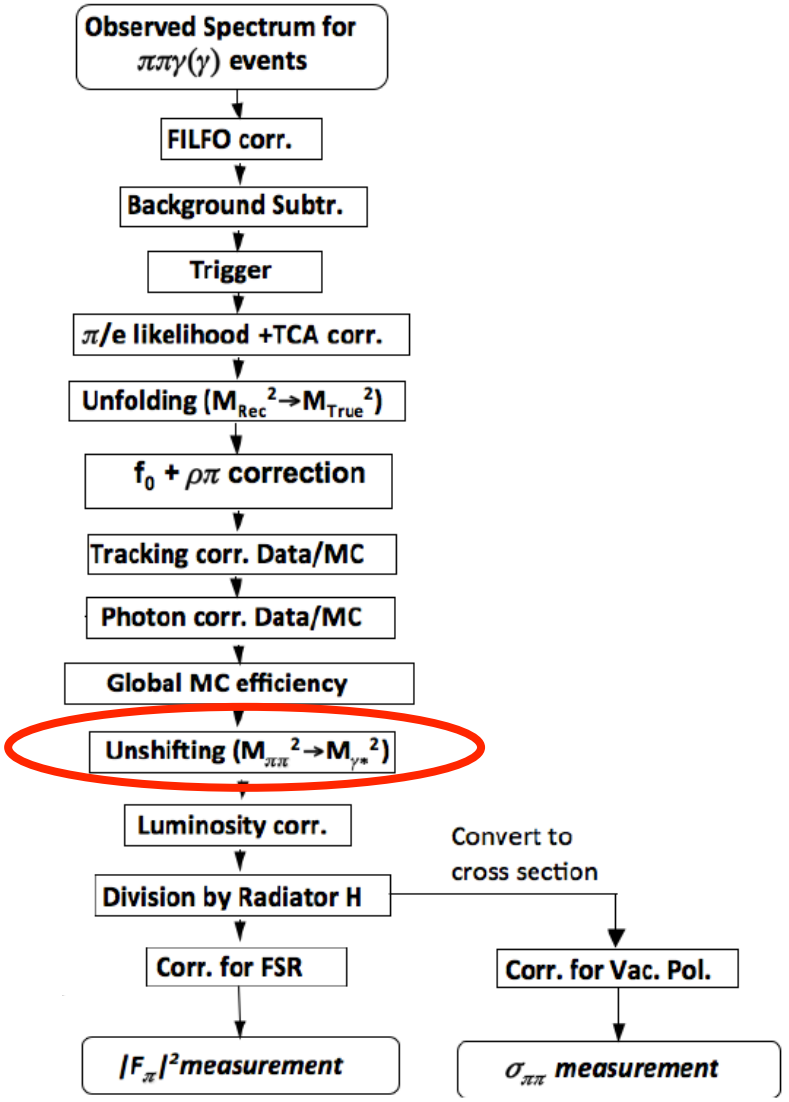
BUT:

Absolute amount of Bremsstrahlung is much larger for LA cuts!!!

Error underestimated !!!

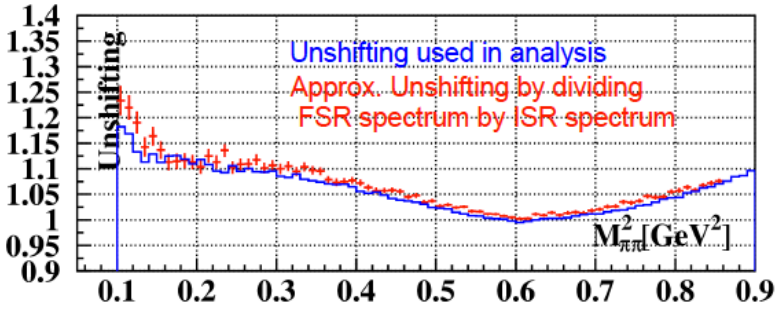


unshifting function



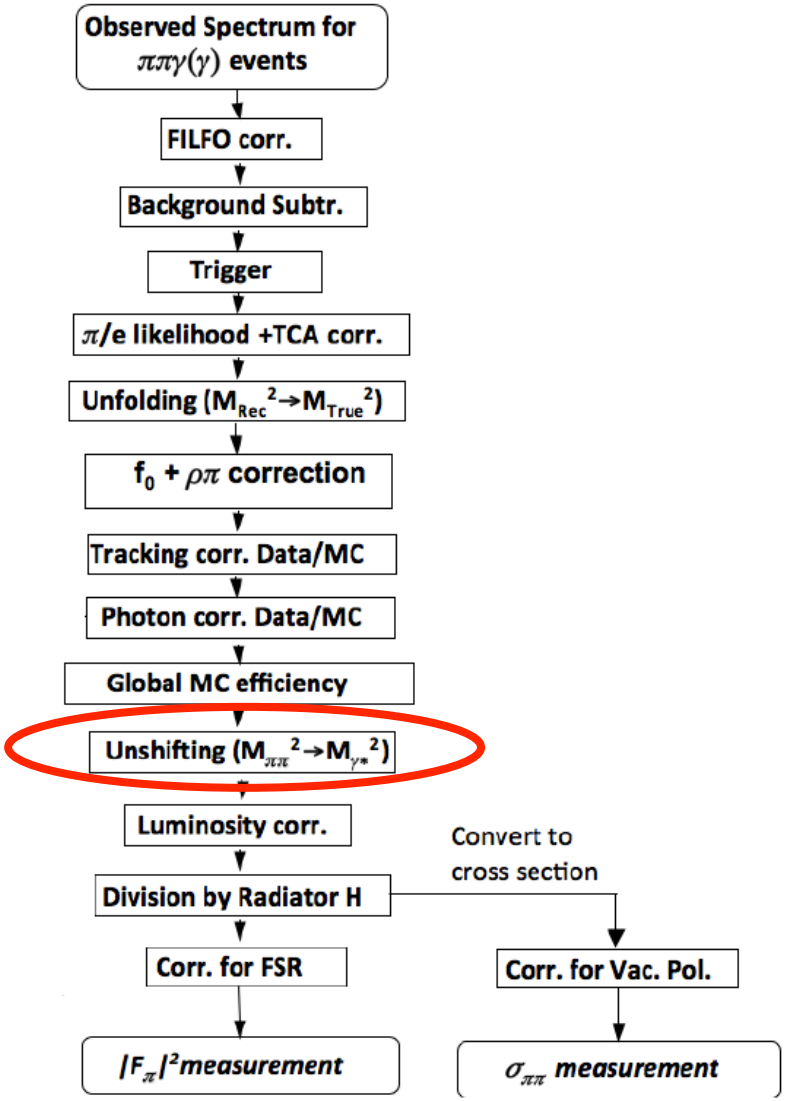
How estimate Bremsstr. Uncertainty correctly ?

Discovery 1: "approx." unshifting works pretty well !



"approx." unshifting =

$$\frac{N(ISR\_nlo + FSR\_nlo)}{N(ISR\_nlo)}$$



How estimate Bremsstr. Uncertainty correctly ?

Discovery 1: "approx." unshifting works pretty well !

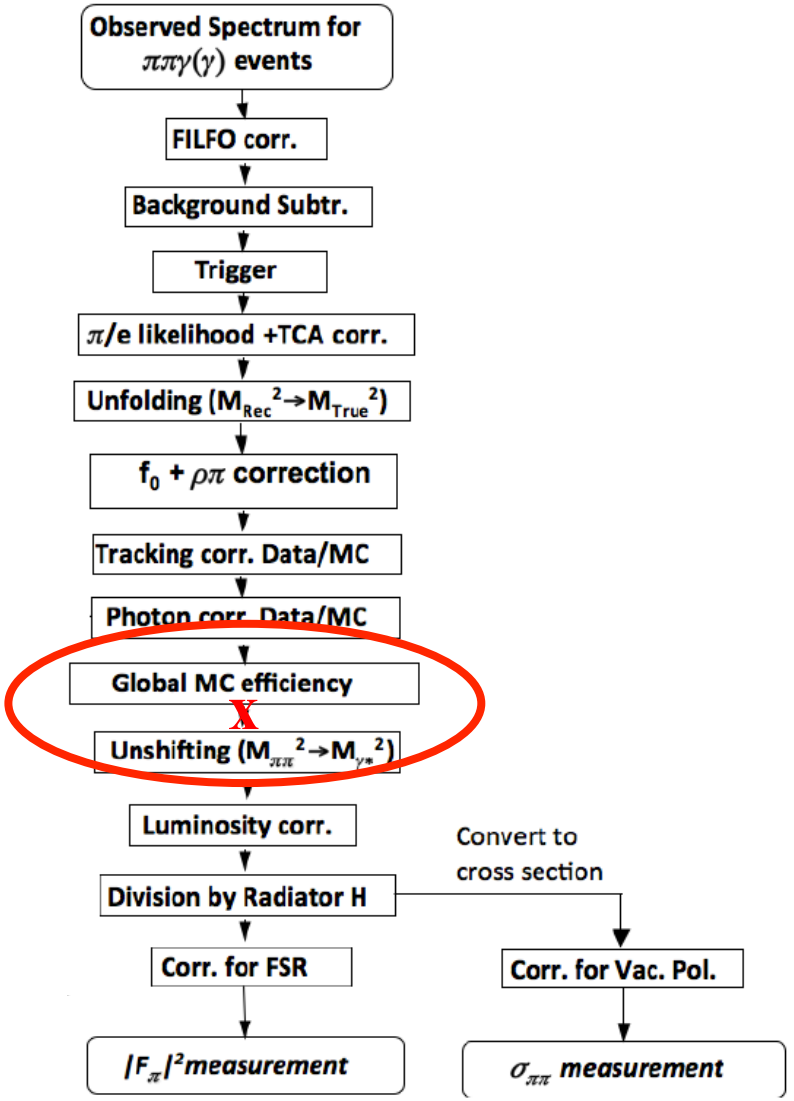
"approx." unshifting =

$$\frac{N(ISR\_nlo + FSR\_nlo)}{N(ISR\_nlo)}$$

Discovery 2: The product Global efficiency x approx. unshifting gives the ratio:

$$\frac{N(ISR\_nlo + FSR\_nlo)_{50\text{-}130^\circ}}{N(ISR\_nlo)_{0\text{-}180^\circ}}$$

→What remains to be estimated is the Bremsstr. uncertainty for LA cuts!

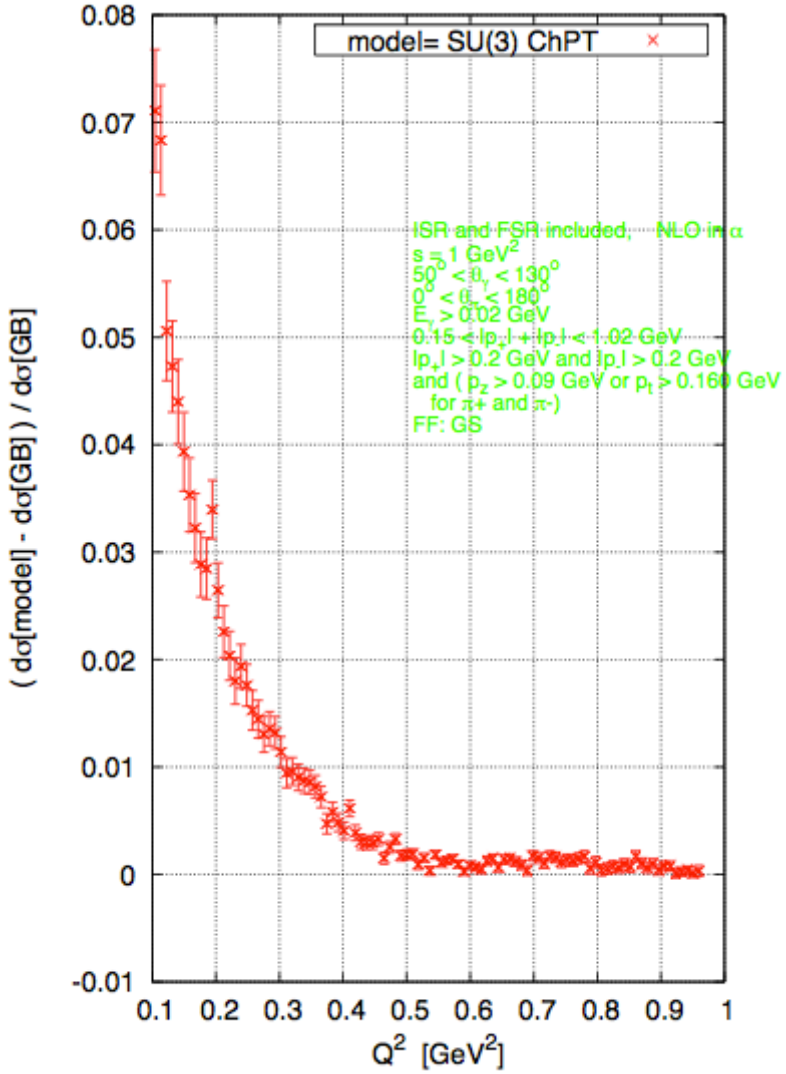


What remains to be esitmated is the model dependence of sQED for description of Bresmsstrahlung for LA cuts!

→ Comparison with models

1) SU(3) ChPT
2) RPT

1) SU(3) ChPT vs. sQED



Plot done by Sergiy Ivashyn
Work with Czyz, Scherer

Plotted is here the fractional difference btw. a production with ChPT as model for bremsstrahlung vs. sQED

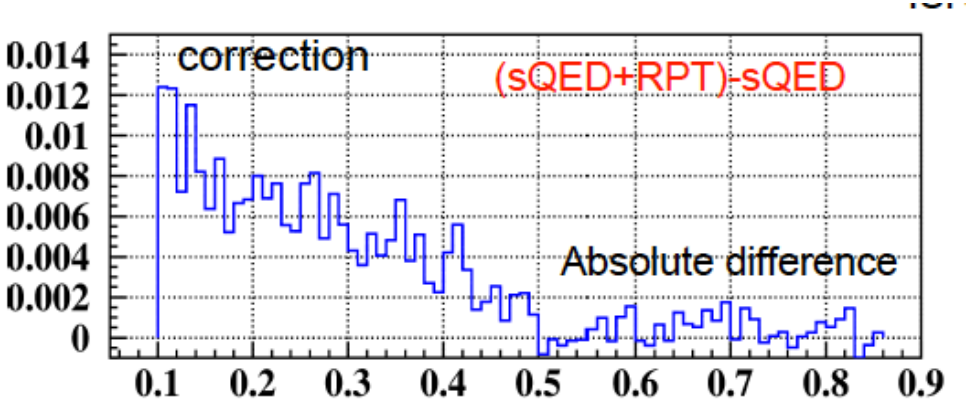
- NLO-effects included
- for realistic LA acceptance cuts

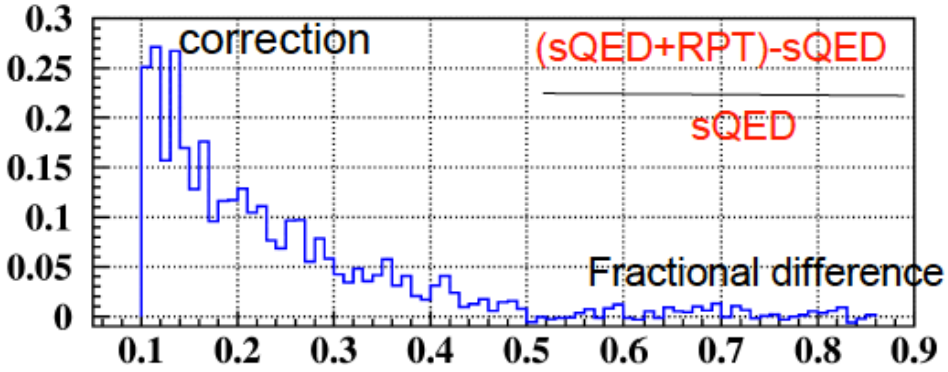
up to 7% effect!

Issue with ChPT model: low energy constants contain (partly?) contrib. from $\rho\pi$,f_0, … !

2) RPT vs. sQED

RPT in Phokhara provided by Olga





Plotted is here the fractional difference btw. a production with RPT as model for bremsstrahlung vs. sQED

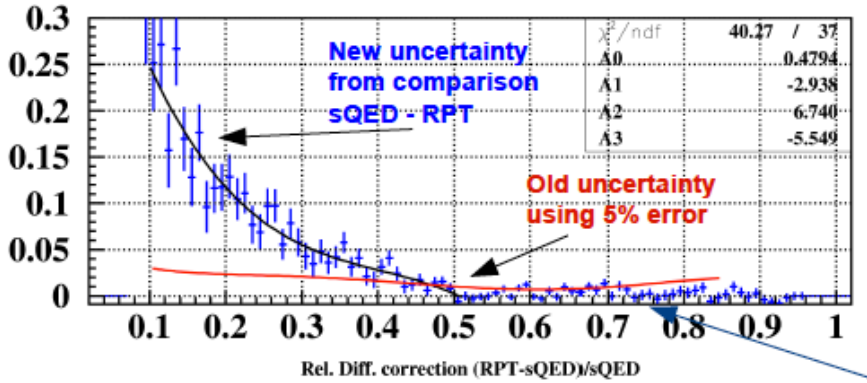
- NLO-effects included
- for realistic LA acceptance cuts

up to 20% effect!

Issue with RPT model: ????
None????

2) What if RPT is right? Impact on $(g-2)_\mu$

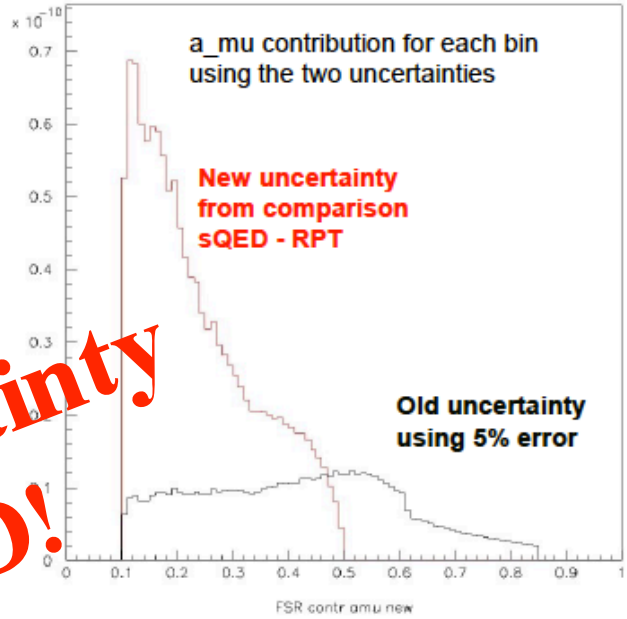
a_mu contribution between 0.1 and 0.85 GeV^2:



New uncertainty is negligible above 0.5 GeV^2!

Δa_mu(FSR)/a_mu = 1.3% for old uncertainty

Δa_mu(FSR)/a_mu = 2.7% for new uncertainty



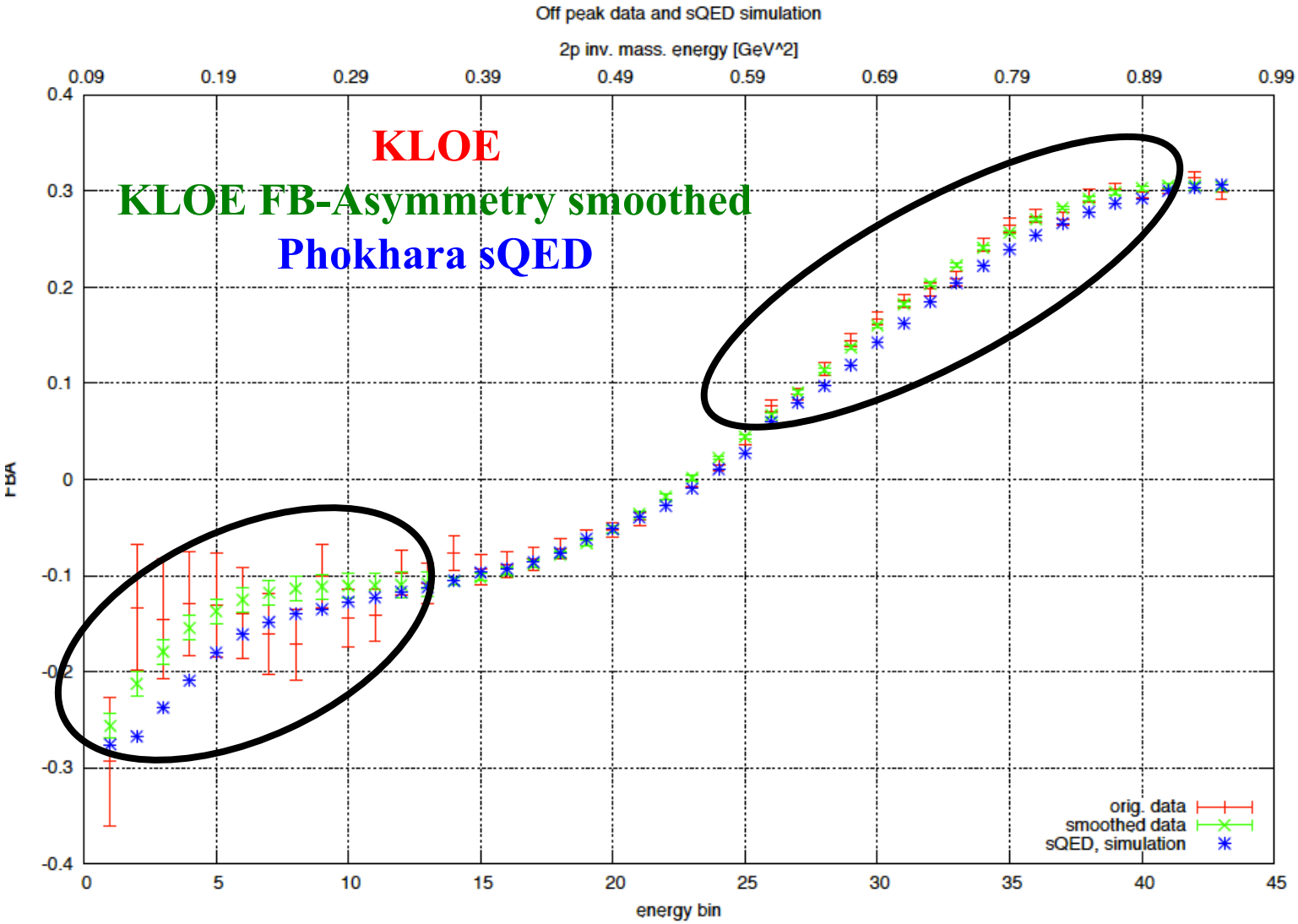
assumed: 20% uncertainty on sQED!

What remains to be esitmated is the model dependence of sQED for description of Bresmsstrahlung for LA cuts!

→Aiming for a model-independent approach

All plots from now on
from Sandro Gorini (Mainz)

Idea 1: Exploit F-B-Asymmetry



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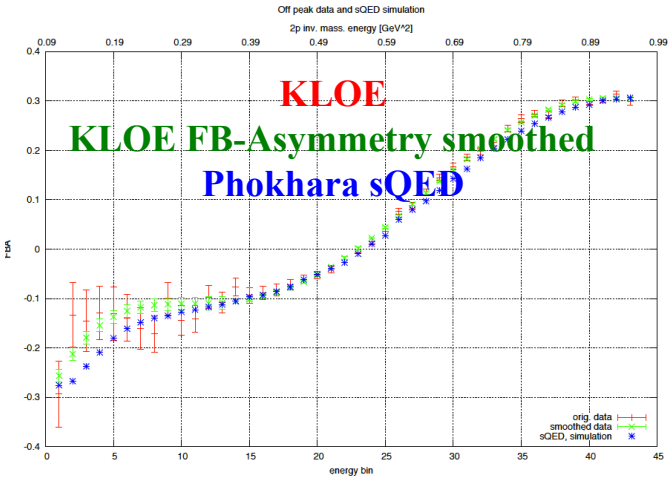


$$A_{FSR} = A_{sQED} + A_{complex}$$

$$|A_{complex}| \cdot e^{i\phi}$$

- Scan parameter space for complex amplitude
- Look for agreement with data in F-B-asymmetry → A'
- Look at effect of this complex number A' on cross section

→ model-independent estimate for beyond-sQED-effects!
Bin-by-bin!

But, there is an Issue: $F_\pi(1\ GeV^2)$

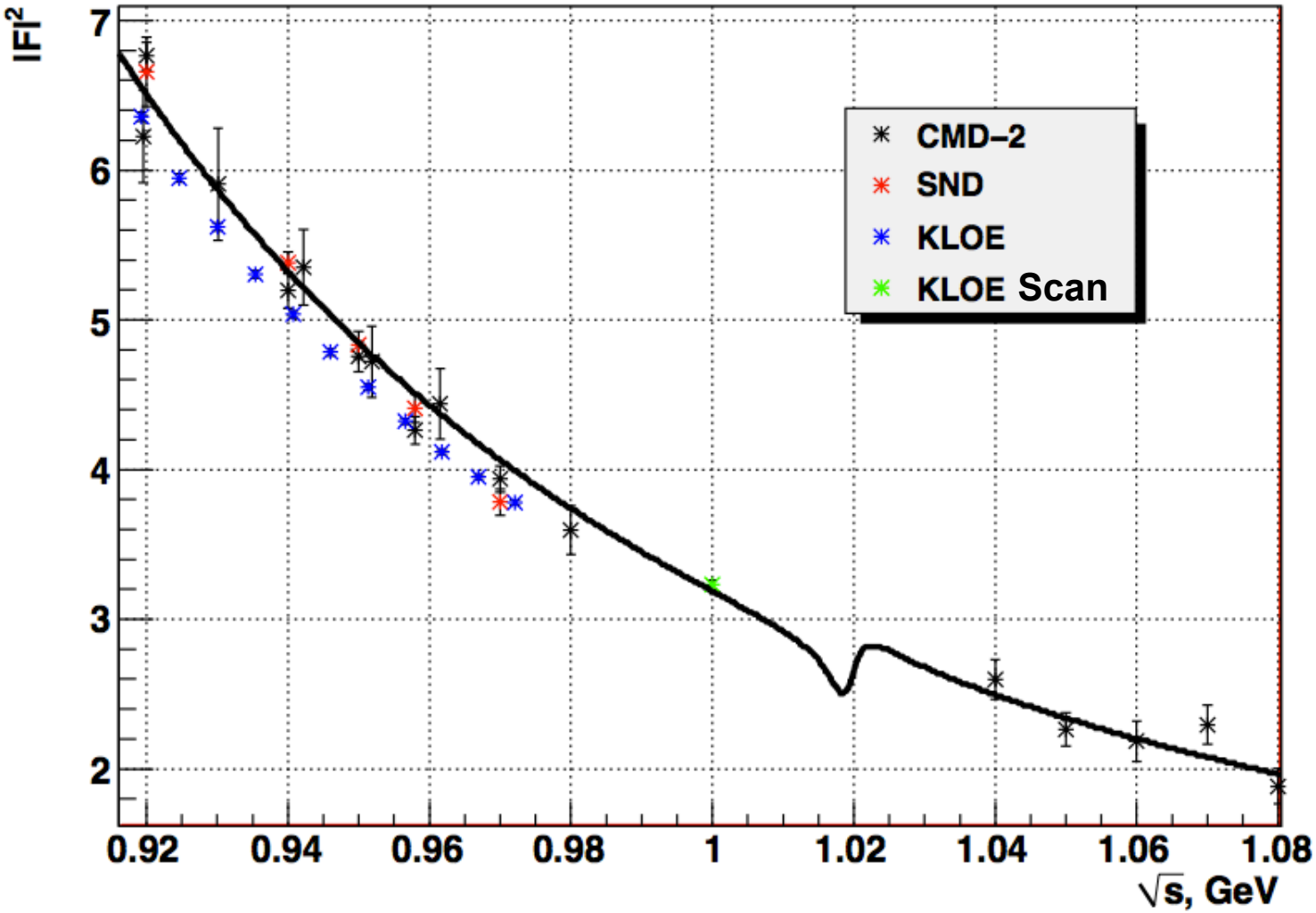
Warning!
The asymmetry is proportional to $F_\pi(1GeV^2)$

Value $F_\pi(1GeV^2)$ not precisely known !

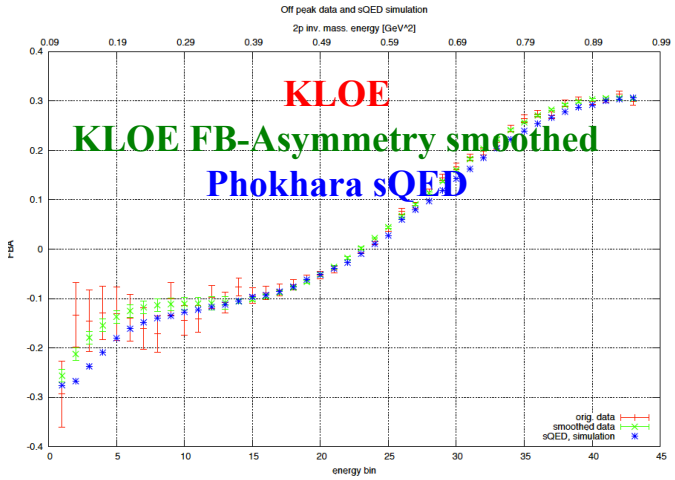
Deviations of up to 5%!

→ Gounaris-Sakurai fit to CMD-2 data
→ Fit to KLOE-SA data
→ Preliminary value of direct KLOE measurement (P. Lukin, A.D.) → 1% precision

But, there is an Issue: $F_\pi(1\ GeV^2)$



Idea 2: Extract $F_\pi(1\ GeV^2)$ from F-B-Asymmetry

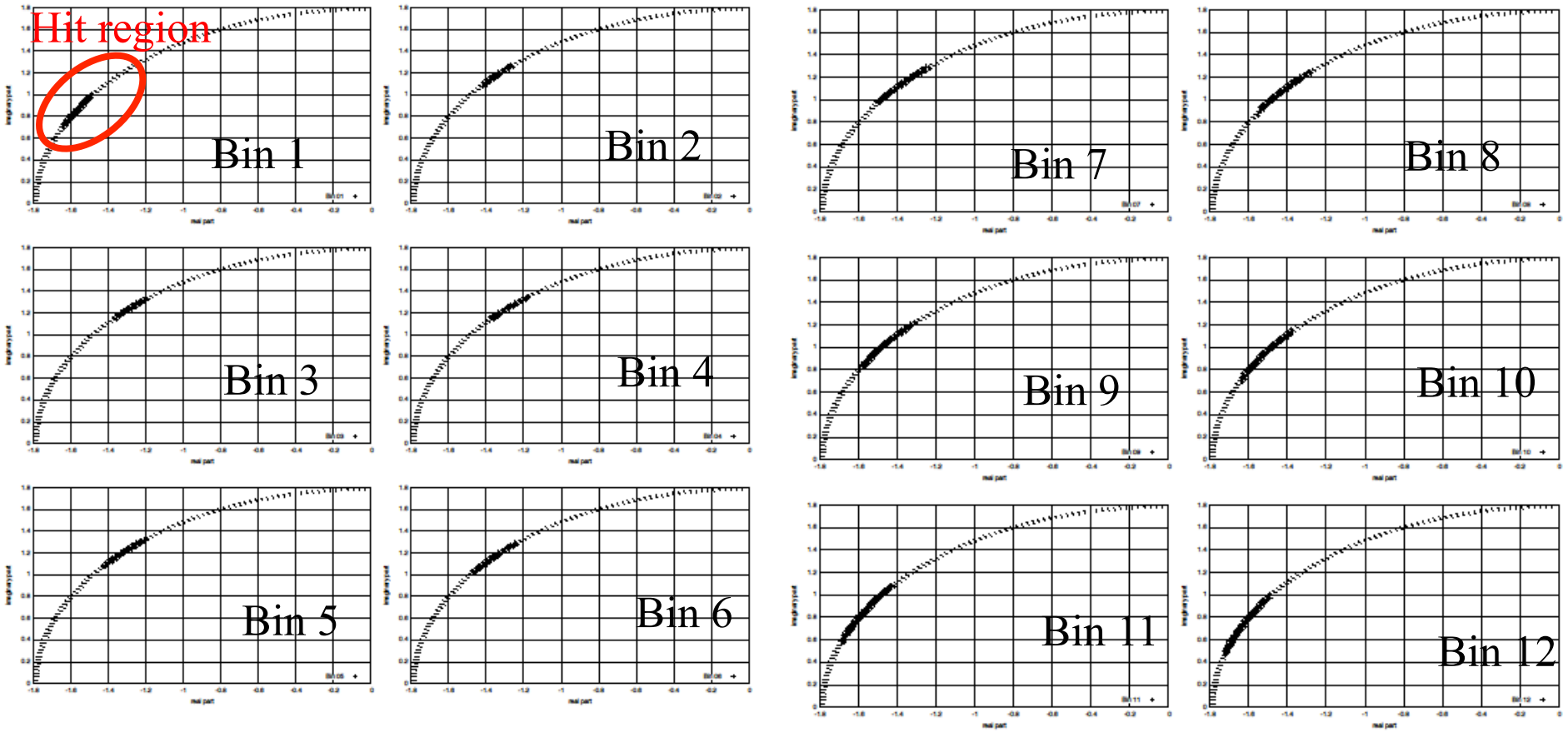


$$A_{FSR} = A_{sQED} + \cancel{A_{complex}}$$

- no complex number A_{compl} added
- vary $F_\pi(1\ GeV^2)$ modulus and/or phase and try to reproduce F-B-asymmetry!
- every bin in $M_{\pi\pi}$ allows in principle an independent extraction of $F_\pi(1GeV^2)$

Idea 2: Extract $F_\pi(1\ GeV^2)$ from F-B-Asymmetry

1st attempt: modulus $|F_\pi(1GeV^2)|$ fixed to KLOE scan value
phase ϕ extracted



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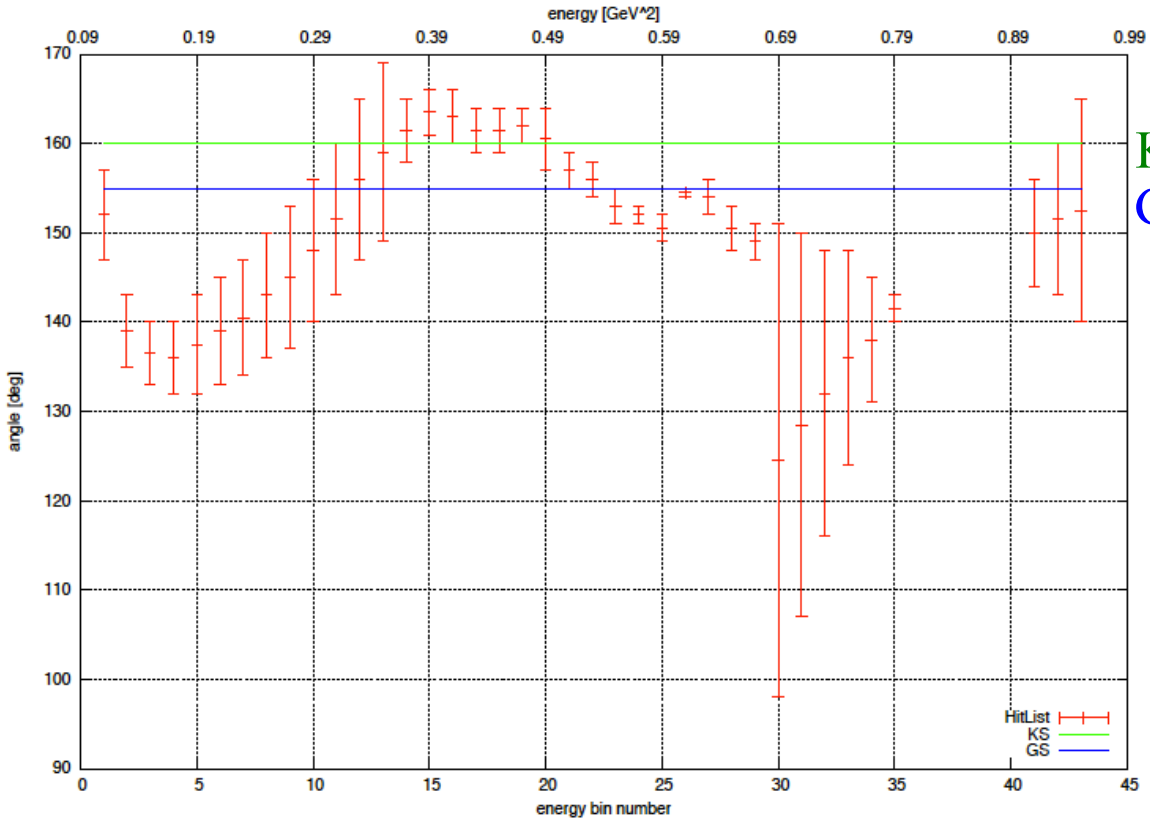
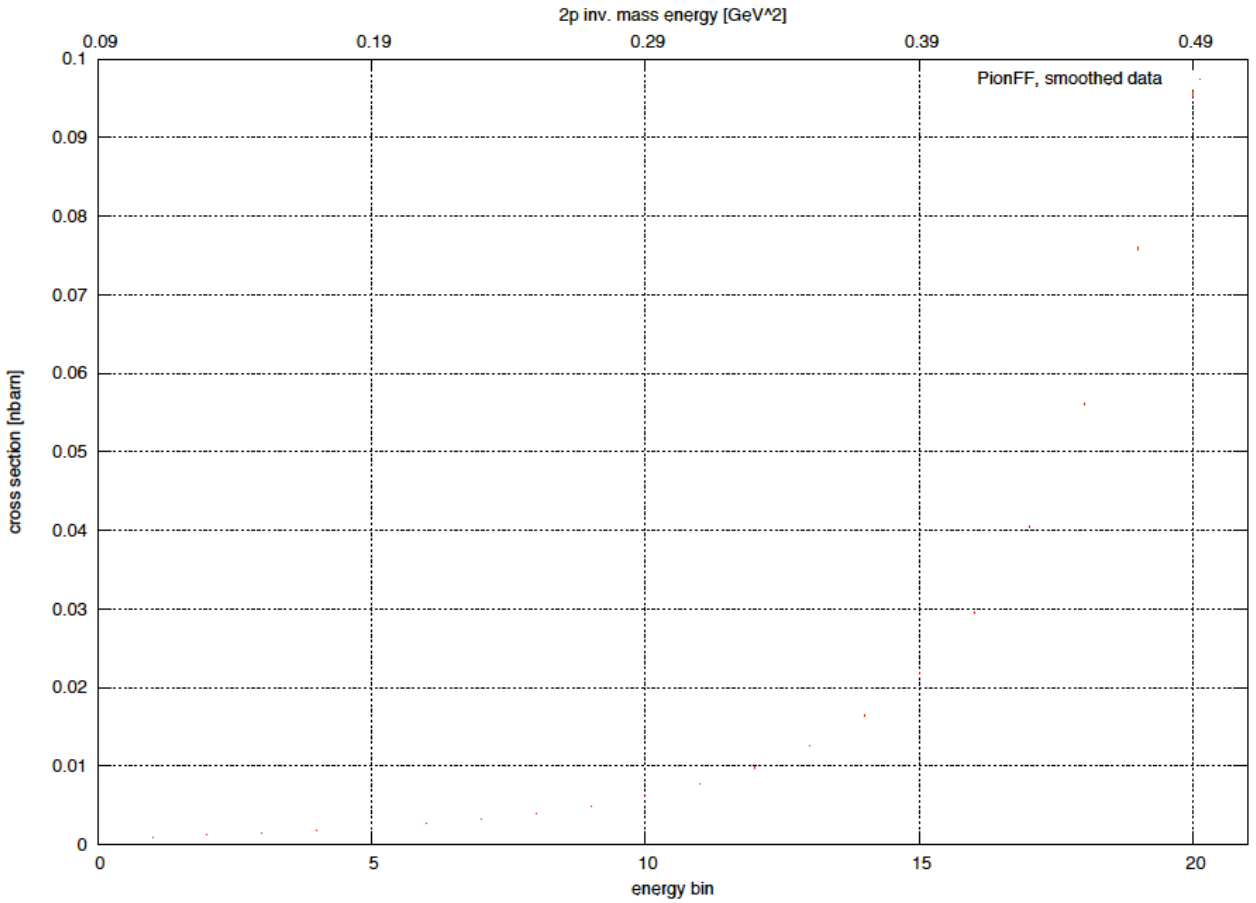


Kühn-Santamaria
Gounaris-Sakurai

Phase variation → insenstive to pion formfactor! Good!

Idea 2: Extract $F_\pi(1\ GeV^2)$ from F-B-Asymmetry

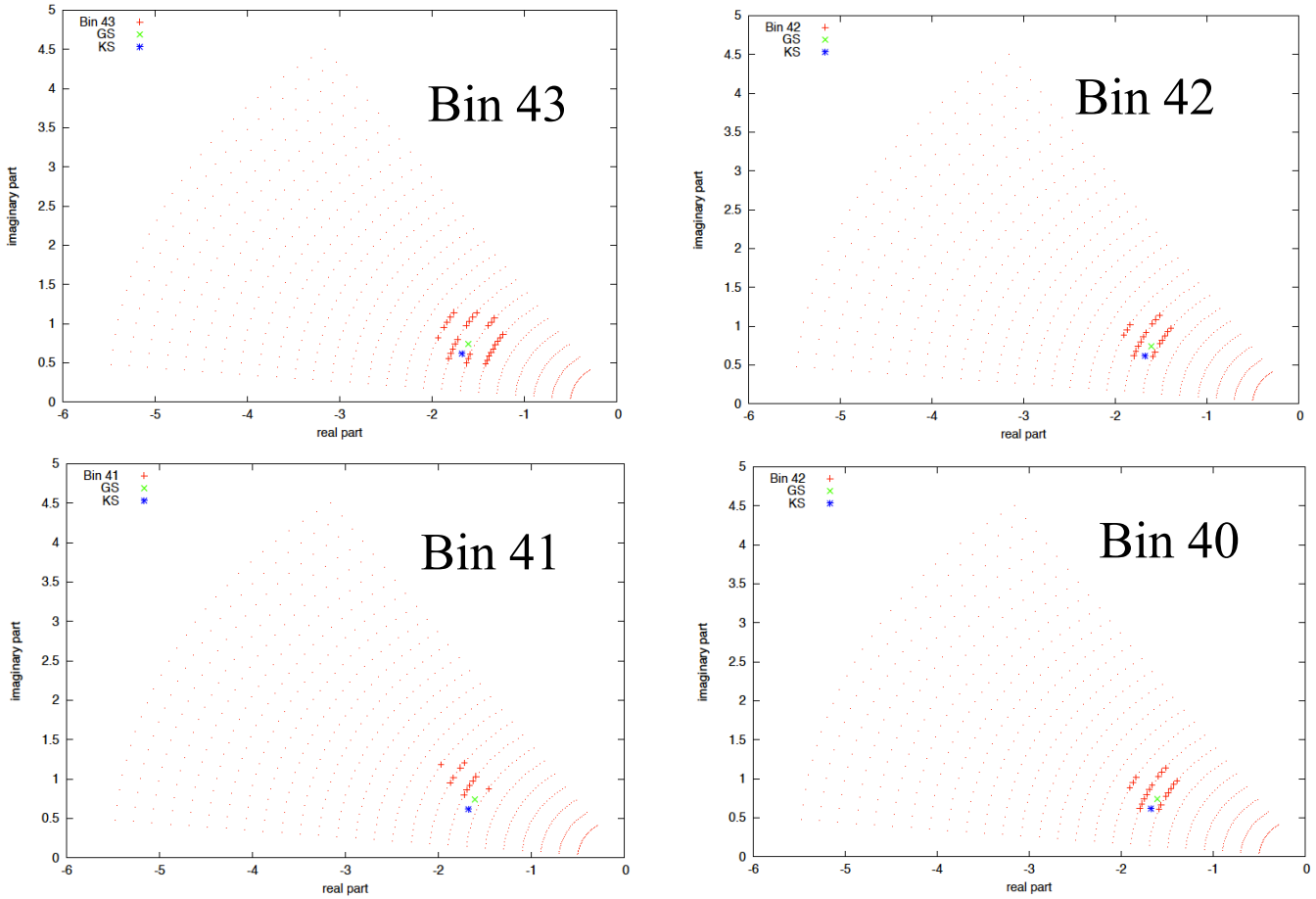
Phase variation → insenstive to cross section! → Good!



Idea 2: Extract $F_\pi(1\ GeV^2)$ from F-B-Asymmetry

2nd attempt: phase ϕ fixed to 125-175°

modulus $|F_\pi(1GeV^2)|$ extracted



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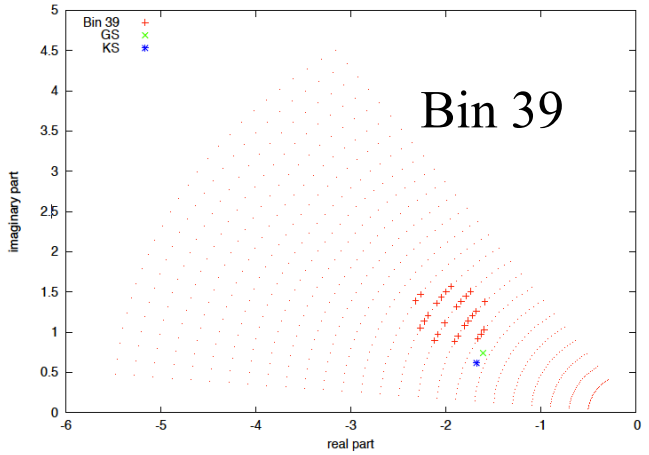
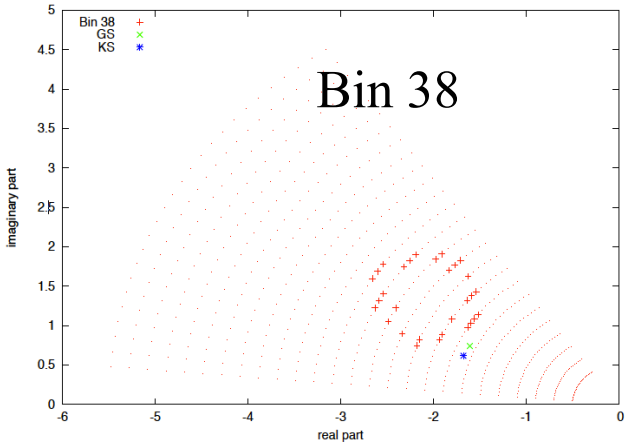
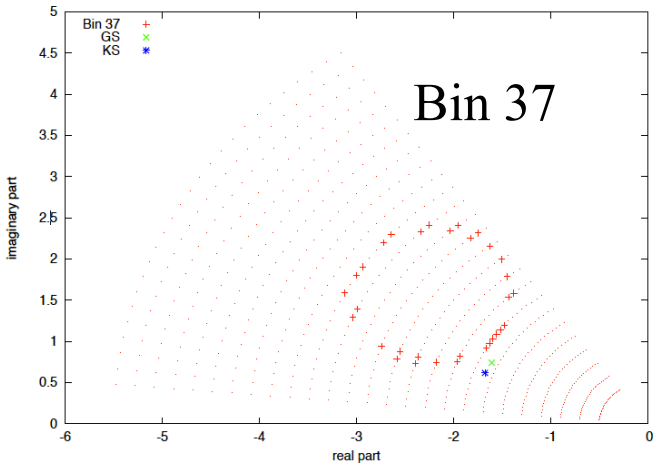
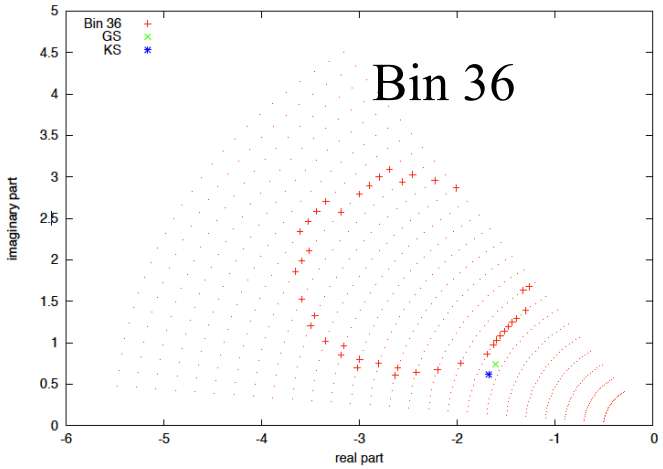
2nd attempt: phase ϕ fixed to 125-175°

modulus $|F_\pi(1GeV^2)|$ extracted





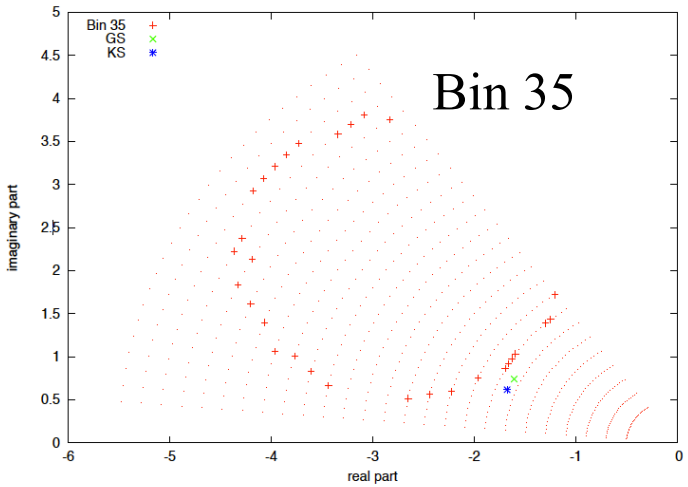


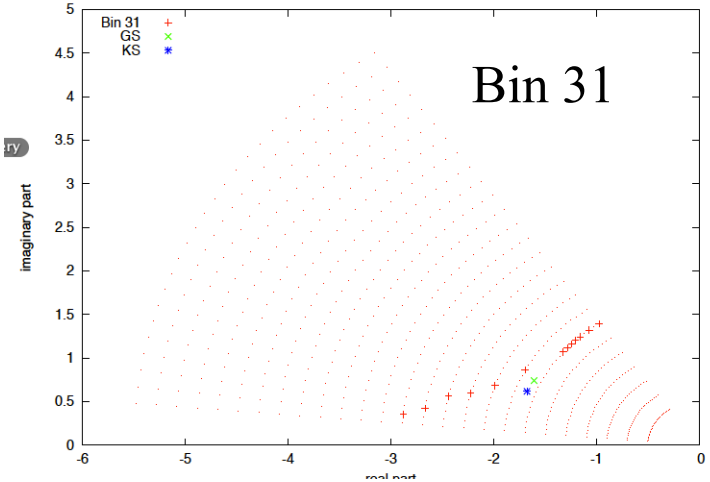


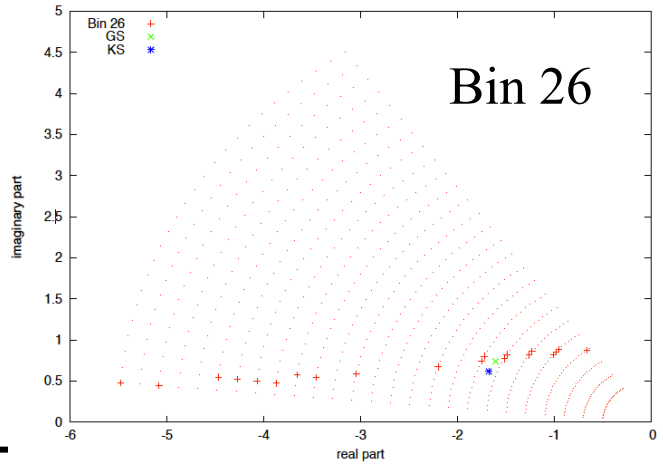
Idea 2: Extract $F_\pi(1\ GeV^2)$ from F-B-Asymmetry

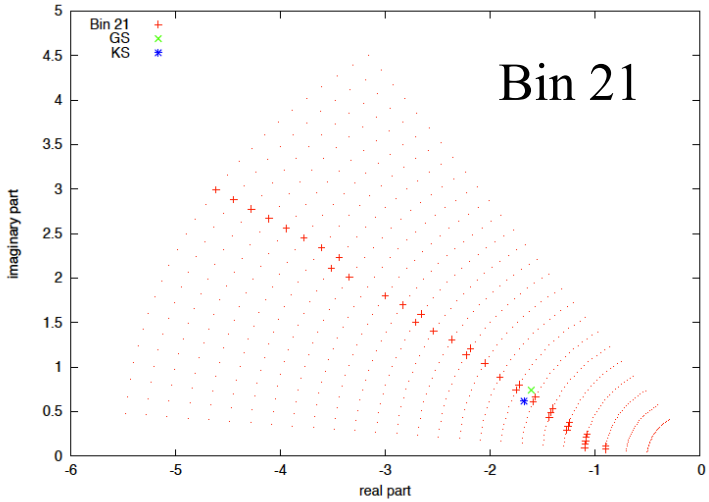
2nd attempt: phase ϕ fixed to 125-175°

modulus $|F_\pi(1GeV^2)|$ extracted









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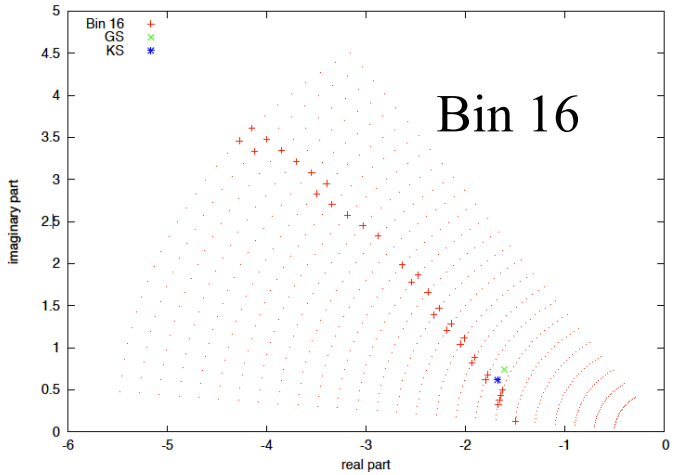
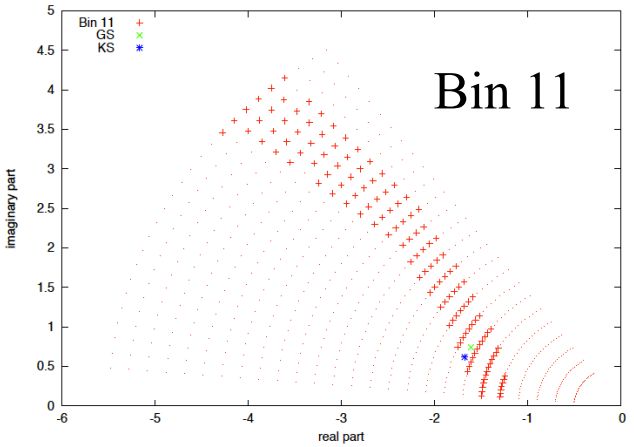
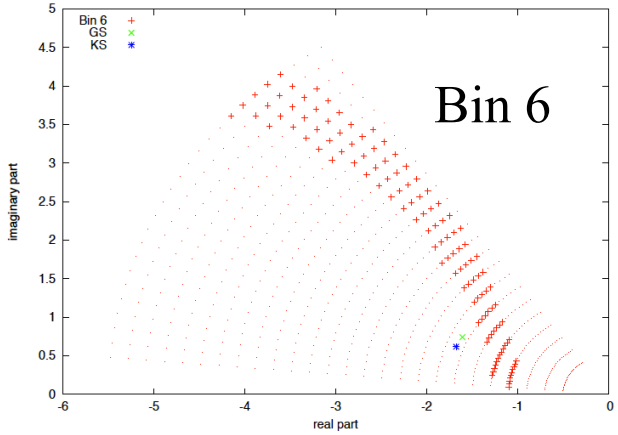
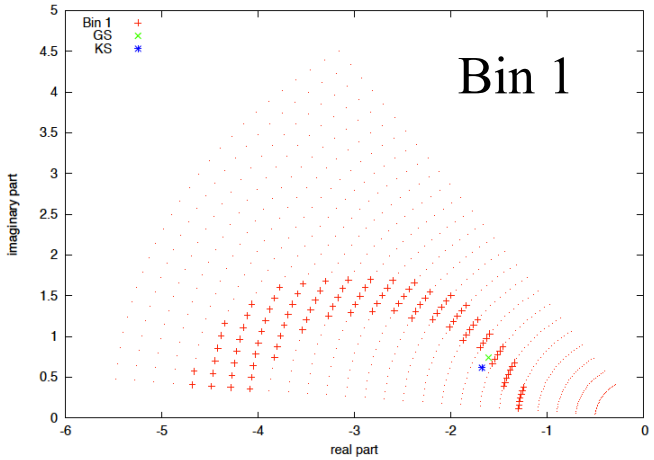


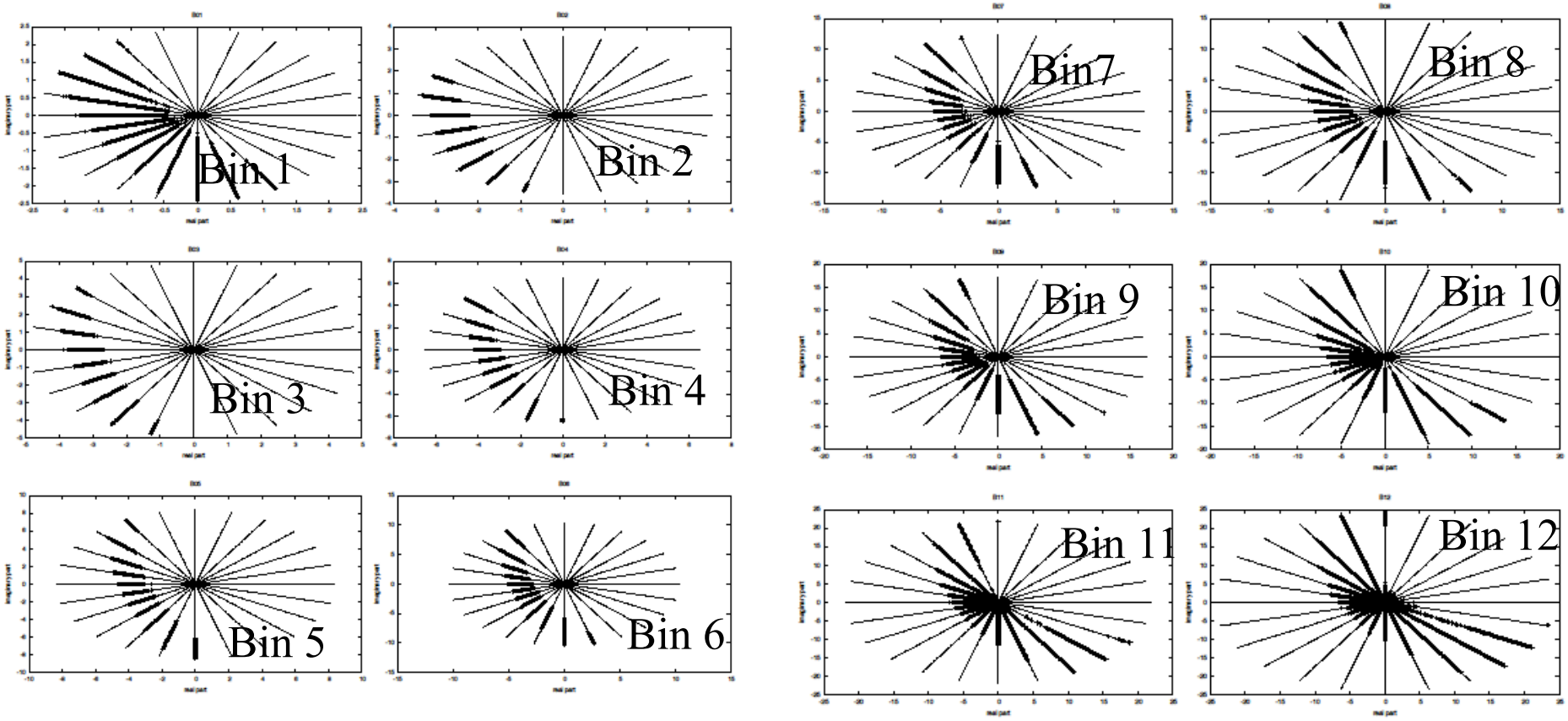






Idea 1: Extract $F_{complex}$ from F-B-Asymmetry

Pion FF sticks to KS-parametrization



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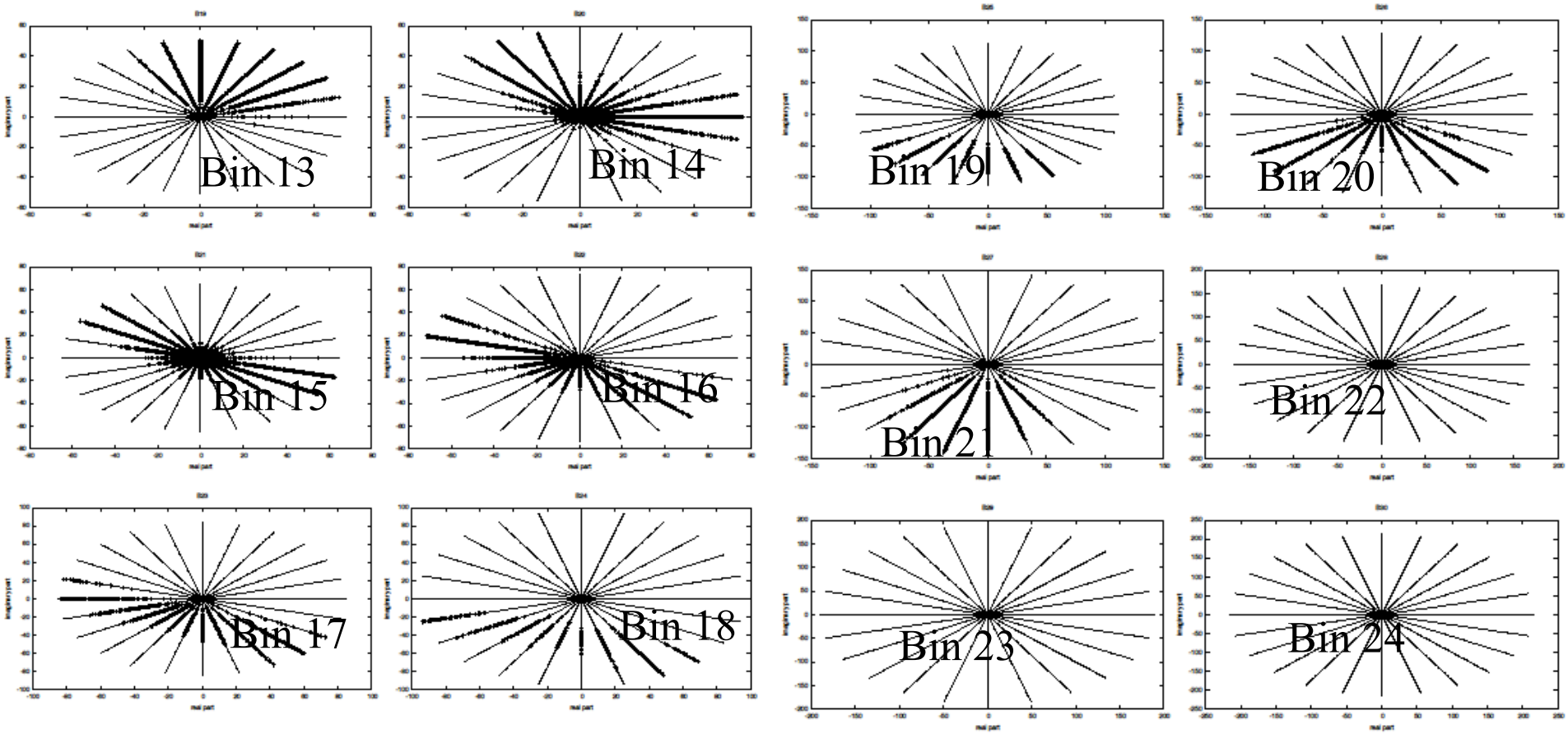

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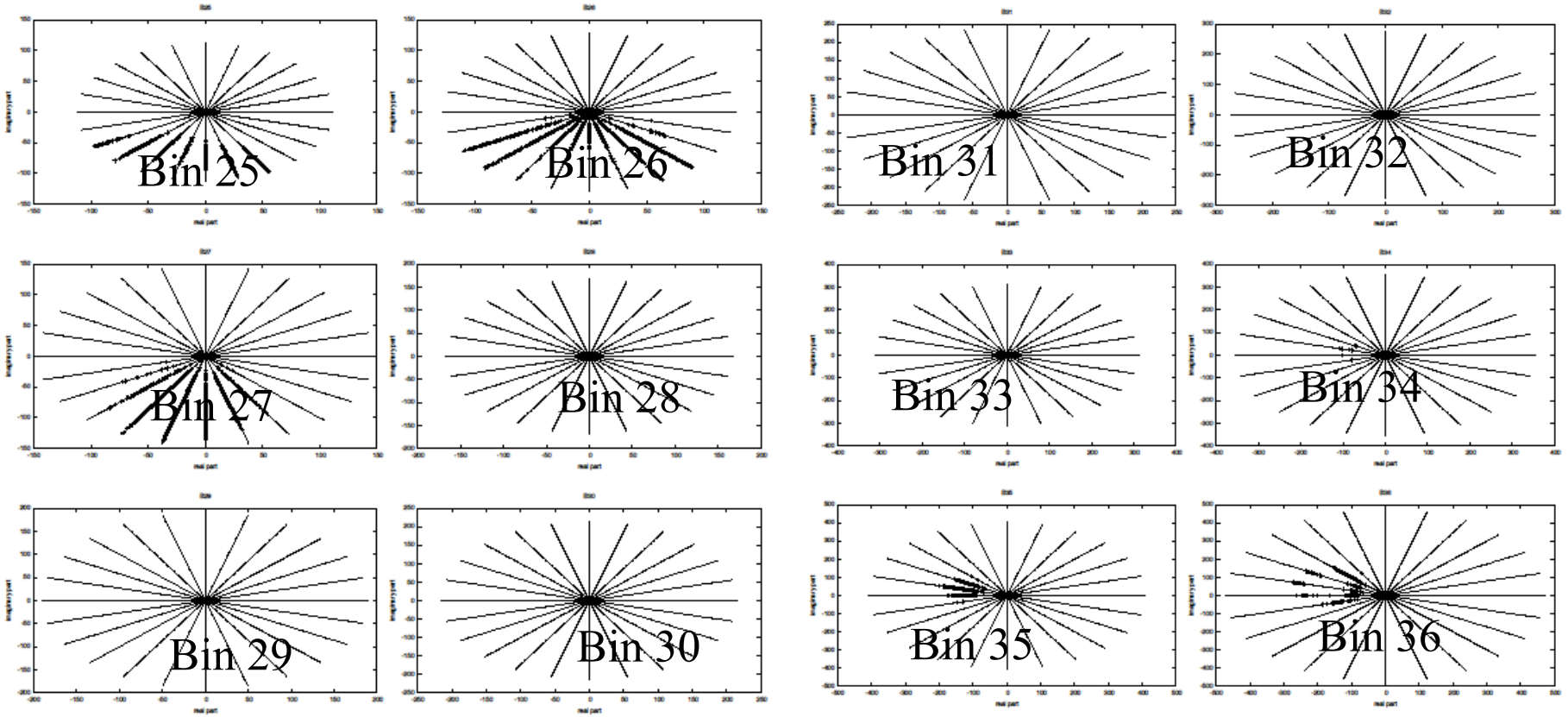

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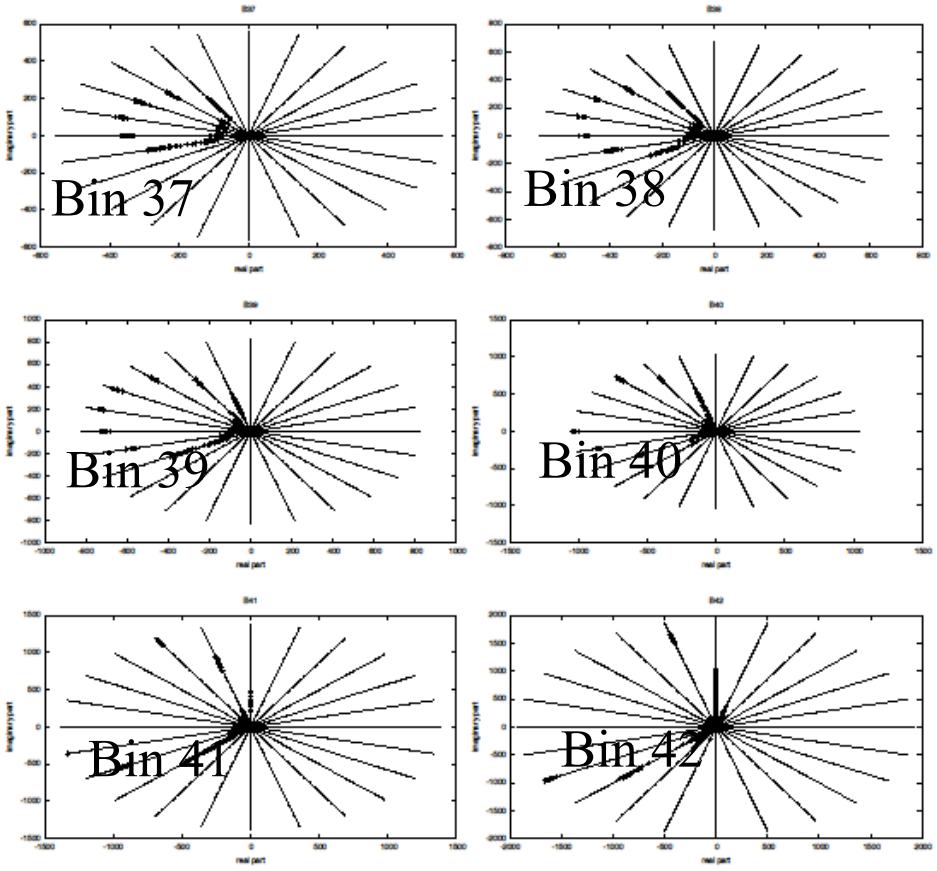
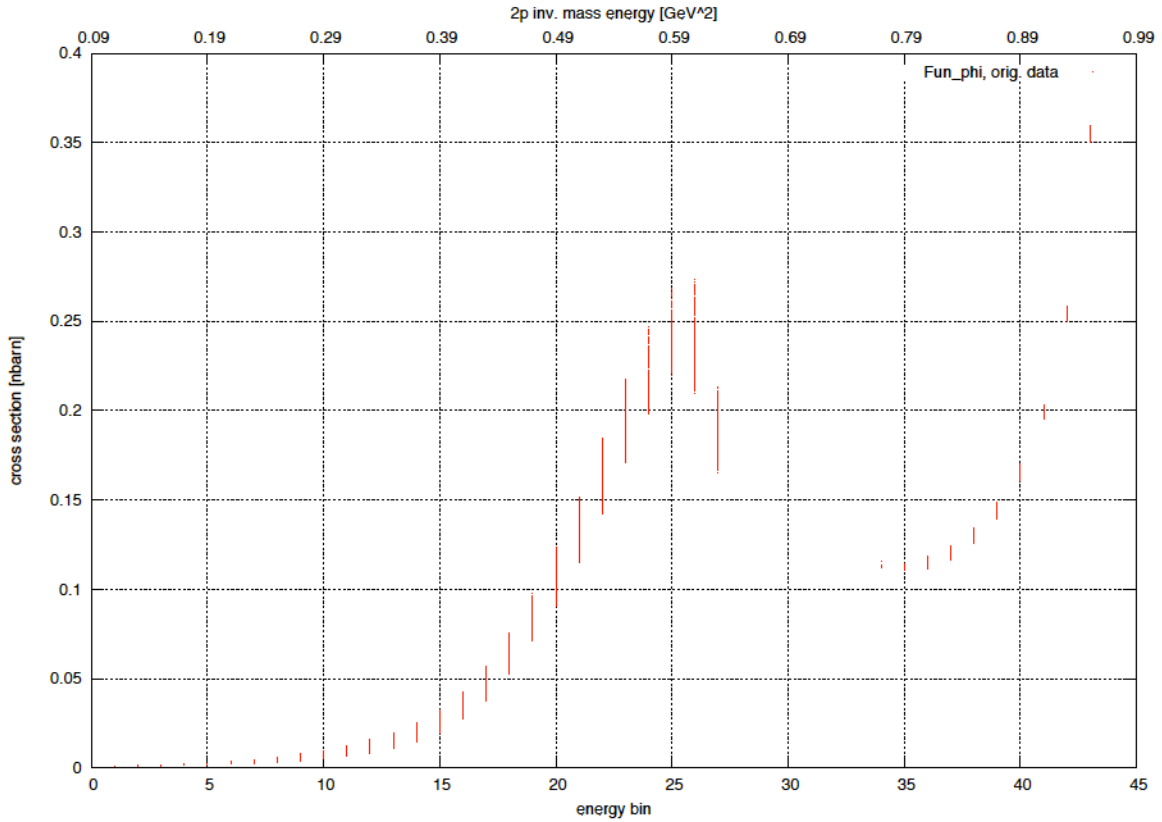


Idea 1: Extract $F_{complex}$ from F-B-Asymmetry

Effect of fitted complex phase on cross section?



Large uncertainties → use smoothed KLOE F-B-Asymmetry curve
→ restrict further phase and modulus of $F_\pi(1\text{GeV}^2)$

Conclusions ?!

Summary

- We have factorized FSR in FSR-Bremsstrahlung effects and effects beyond beyond Bremsstrahlung, like $f_0(980)$,$f_0(600)$,ρπ

- We believe that the main issue for the off-peak LA analysis is the model dependence in the description of Bremsstrahlung; i.e. How reliable is sQED ?

- Two models have been compared to sQED, which include beyond-sQED pion structure effects;

  both models show deviations only at low $M_{\pi\pi}$

  → SU(3) ChPT up to 7% in cross section at threshold

  → RPT up to 20% in cross section at threshold

Summary

- We have worked out an approach for a model-dependent test of the reliability of sQED using the F-B-asymmetry; at present not sensitive enough for our analysis; precision limited by exptl. statistics!

- This approach still needs some refinements
  - → Some cross checks are still missing
  - → There are still some technical details to be checked
  - → Issue of $F_\pi(1\ GeV^2)$: modulus, phase
  - → Smoothing of F-B-asymmetry will increase precision
  - →Try to add phase on top of Achasov model?

Publication

- Option 1:
  Use RPT uncertainty as sQED model dependence estimate
  → relative FSR-uncertainty on $(g\text{-}2)_\mu$ increases to 2.7%
  (in old version 1.2% overall uncertainty)
  → Using ChPT would yield a significant smaller uncertainty

- Option 2:
  Wait 2 more weeks to see whether the model-independent approach converges to a reliable estimate

- Option 3:
  Try to extract $F_\pi(1\text{GeV}^2)$ from F-B-asymmetry;
  Use difference Data-MC in F-B-asymmetry as model error

Finally ….

- Main authors of the LA 2010 paper are available for finishing the publication!

- FSR is a serious issue in our LA analysis
  BUT:
  → It contains interesting meson structure aspects
  → KLOE has a unique opportunity with present data set
  → Is it possible to run over full KLOE sample to have a high statistics F-B-asymmetry?
  → We should in any case publish F-B-asymmetry and possibly the investigations we are performing at present