Transition Form Factors of Light Mesons

New Frontiers in QCD 2018
May 28 - June 29, 2018
Yukawa Institute for Theoretical Physics, Kyoto University

Susan Schadmand

Thanks for workshop invitation YITP Kyoto and cross appointment with RCNP Osaka!

WASA-at-COSY physics and the fate of WASA

- meson production
- charge symmetry breaking

- dibaryons (ABC effect)

→ M.Bashkanov ... tbc at CLAS, JLab

- **light meson decays**

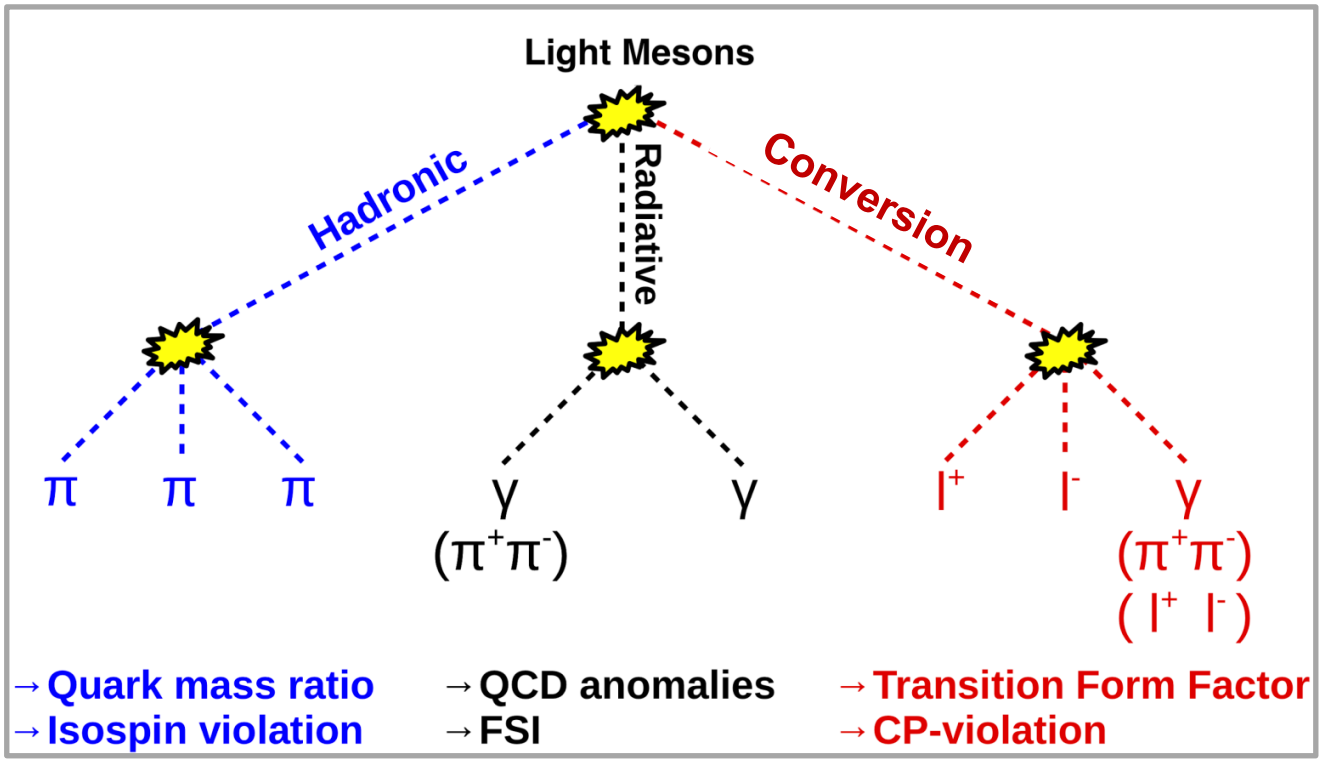
→ CAA-LMD and further at CLAS, JLab

- η-mesic nuclei

→ P.Moskal and K.Itahashi et al. ... tbc with η' nuclei at FRS, GSI/FAIR

WASA central detector is being moved to GSI (T. Saito)

light meson decays



WASA-at-COSY: π, η

the orginal proposal for bringing WASA to COSY :

Proposal for the wide angle shower apparatus (WASA) at COSY-Julich: WASA at COSY
WASA-at-COSY Collaboration, e-Print: **nucl-ex/0411038**

CLAS: π, η, ω, η'

the orginal proposal:
CAA Photoproduction and Decay of Light Mesons in CLAS
https://wiki.jlab.org/lmd/

light meson decay publications

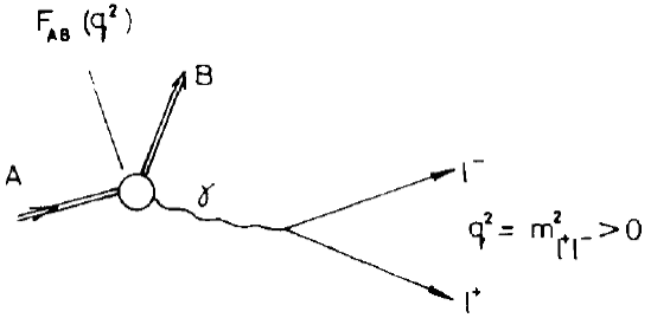
- **Search for C violation in the decay $\eta \rightarrow \pi^0 + e^+ + e^-$ with WASA-at-COSY**
  F.S. Bergmann, e-Print: arXiv:1802.08642*, submitted PLB*
- **Measurement of the $\omega \rightarrow \pi + \pi - \pi 0$ Dalitz plot distribution**
  L. Heijkenskjöld, S. Sawant, Phys.Lett. B770 (2017) 418
- **Measurements of branching ratios for η decays into charged particles**
  D. Coderre, P. Wurm, M. Hodana, Physical Review C, 94 (2016) 65206
- **Measurement of the $\eta \rightarrow \pi + \pi - \pi 0$ Dalitz plot distribution**
  P. Adlarson, Phys.Rev. C90 (2014) 4
- **Search for a dark photon in the pi0 --> e+e-gamma decay**
  C.-O. Gullström, Phys.Lett. B726 (2013) 187
- **Exclusive Measurement of the eta --> pi+ pi- gamma Decay**
  C.F. Redmer, Phys.Lett. B707 (2012) 243
- **Measurement of the eta->3pi0 Dalitz Plot Distribution with the WASA Detector at COSY**
  P. Vlasov, Phys.Lett. B677 (2009) 2

Stefan Leupold
Uppsala University

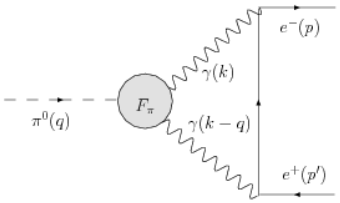
conversion decays

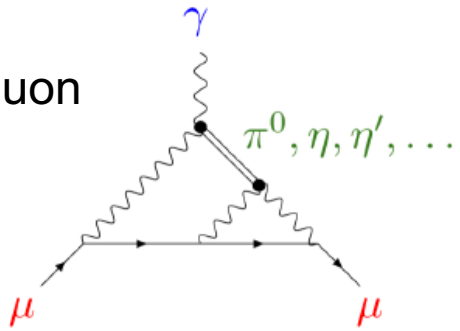
Reactions of hadrons with virtual photons

- intrinsic structure of hadrons
  - transition form factors
  - validity of vector meson dominance



- background for physics beyond the standard model
  - rare decays
    - eg $\pi \to ee$
  - g-2 anomalous magnetic moment of the muon
    - light-by-light scattering

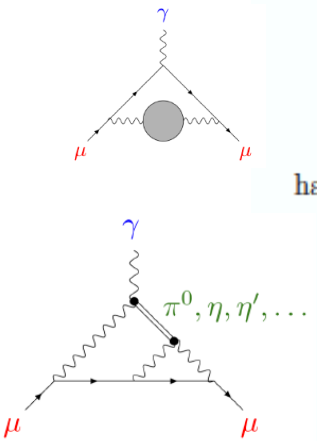


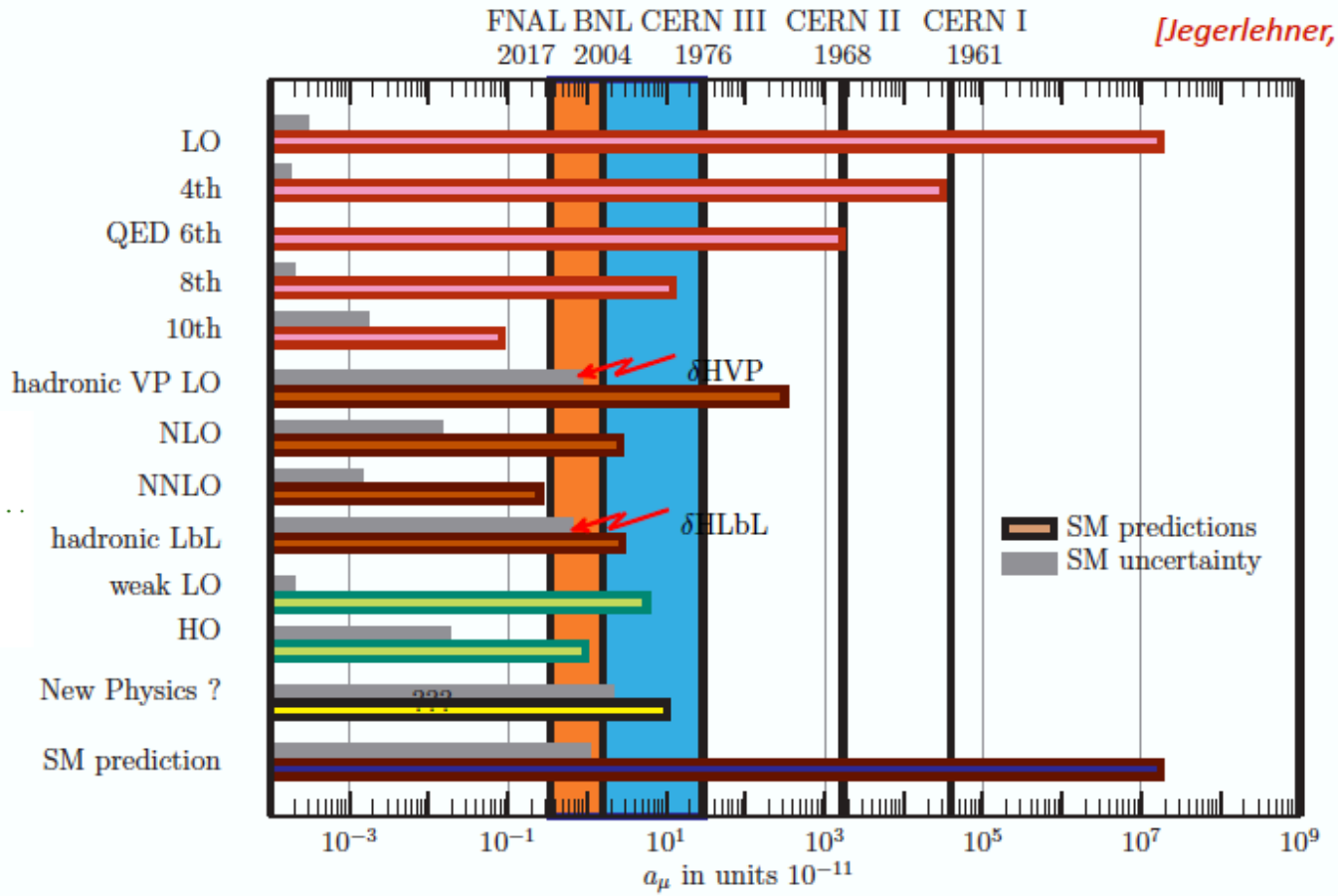


g-2 measurements: Fermilab and J-PARC

theory confronts experiment

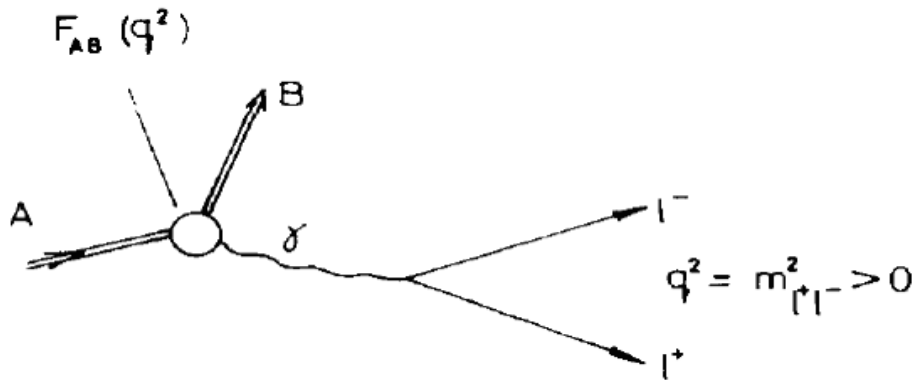
Role of hadronic decays for g-2





conversion decays

Transition Form Factors



$$\frac{d\Gamma(A \to B\, l^+ l^-)}{dq^2 \cdot \Gamma(A \to B\gamma)} = \left|F_{A\to B}(q^2)\right|^2 \cdot |\mathrm{QED}|$$

$$F_{AB}(q^2) = [1 - q^2/\Lambda^2]^{-1}$$ (single) pole approximation

$$\boxed{F_{AB}(q^2) \simeq 1 + q^2[\mathrm{d}F_{AB}/\mathrm{d}q^2]|_{q^2\simeq 0} = 1 + q^2 b_{AB} = 1 + \tfrac{1}{6}q^2\langle r^2_{AB}\rangle}$$

slope parameter

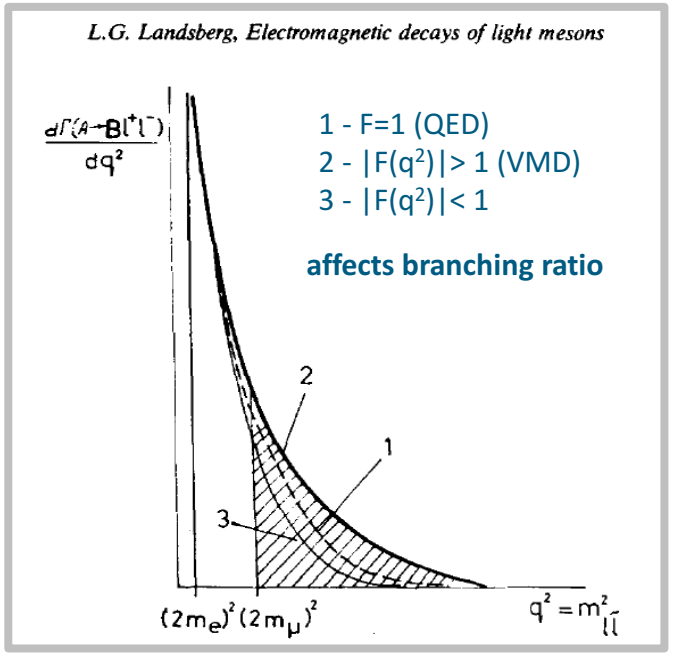
size (transition region)

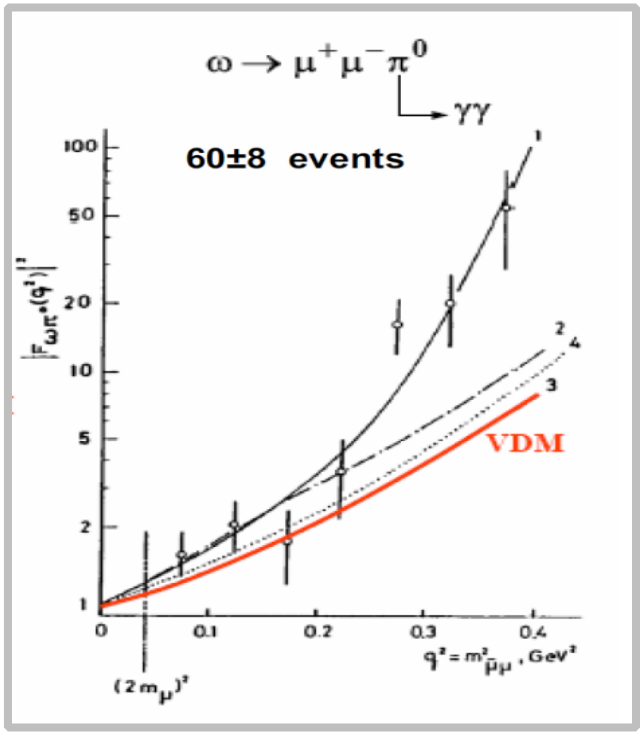
$$\Lambda \simeq m_\rho \; (\Lambda^{-2} = b_{AB})$$

'standard' VMD, b~1.69/GeV^2

conversion decays

Transition Form Factors





form factor: divide experimental q^2 distribution by QED

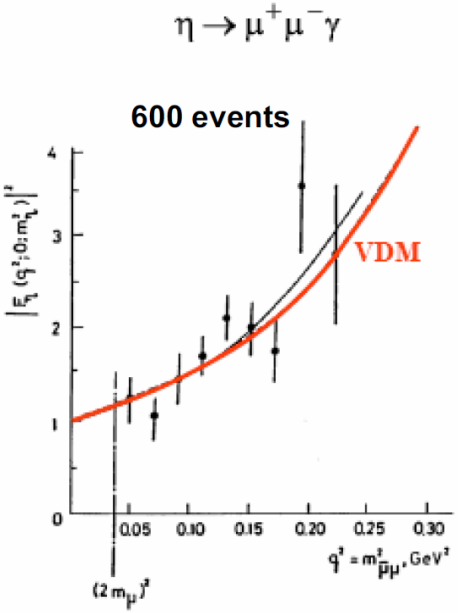
$$\Lambda \simeq m_\rho \; (\Lambda^{-2} = b_{AB})$$

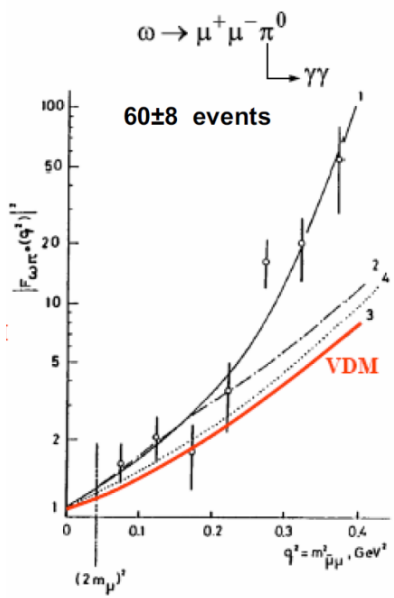
'standard' VMD, b~1.69/GeV^2

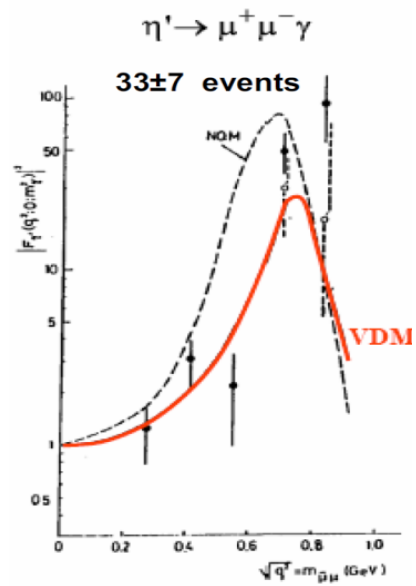
(old) world data set: conversion decays

L.G. Landsberg, Electromagnetic decays of light mesons

IHEP in 1978—1980 on the “Lepton-G” spectrometer







for ω meson, additional mechanisms apart from standard VMD ?

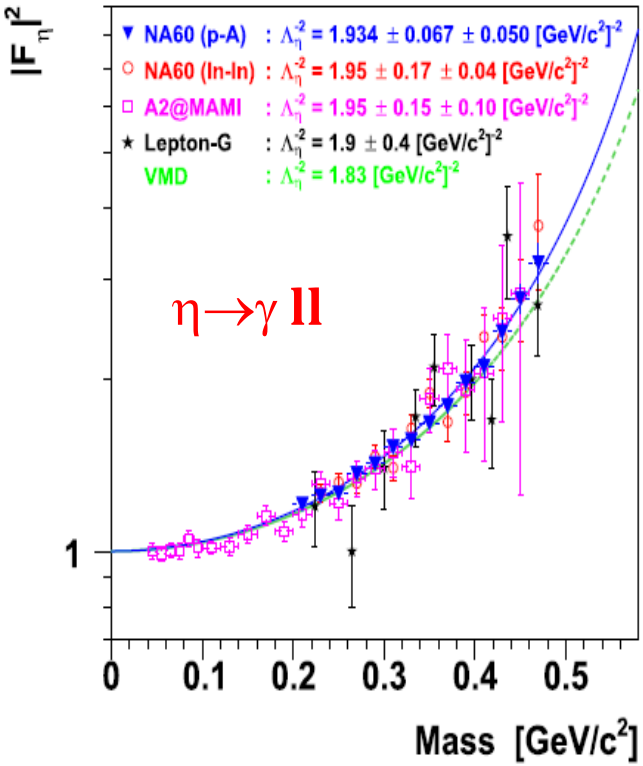
(black curves are fits to the data)

- confirmed by NA60 AA reactions, S. Damjanovic, PLB 677 (2009) 260
- confirmed by NA60 pA reactions, A.Uras, J.Phys. Conf.Ser.270(2011) 012038

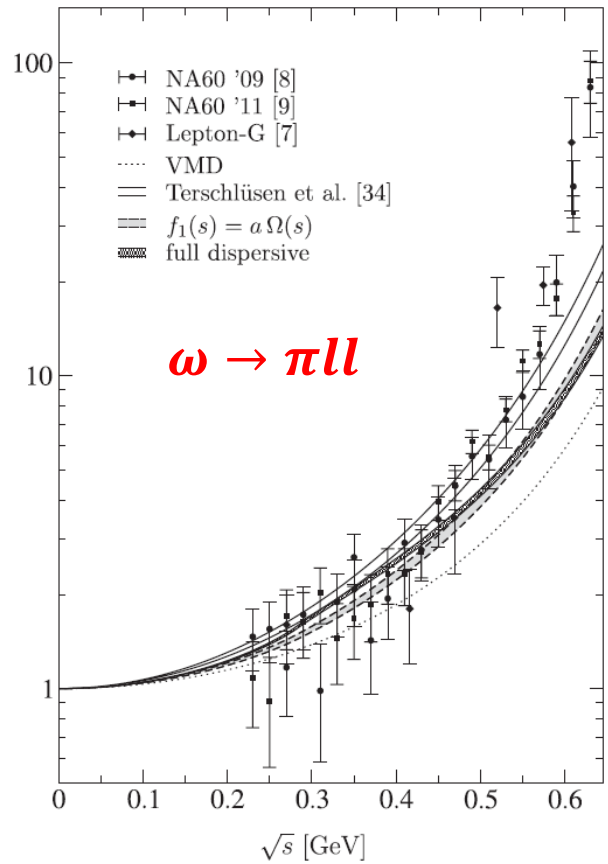
different experimental approach: elementary reactions, using di-electrons

new data sets: η transition form factor

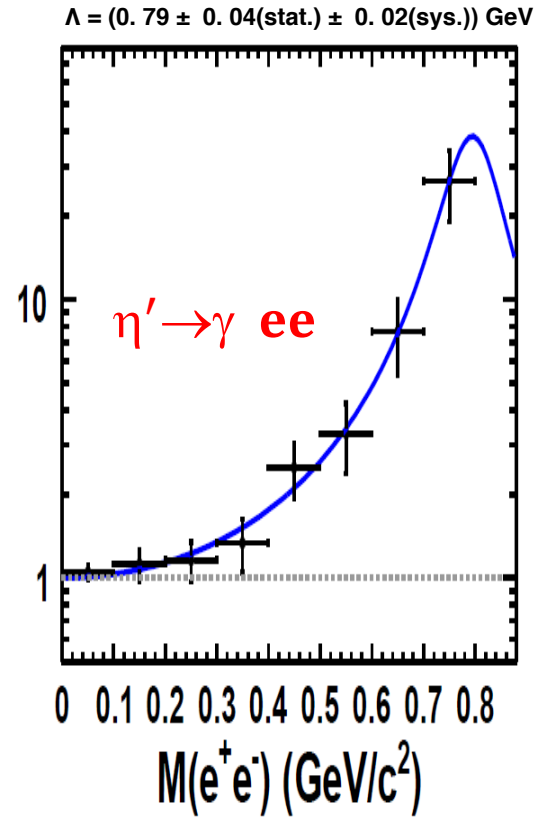
A2 **Phys.Rev. C89 (2014) 044608**
NA60 **Phys.Lett. B757 (2016) 437**



Schneider, Kubis, Niecknig
PRD 86 (2012) 054013



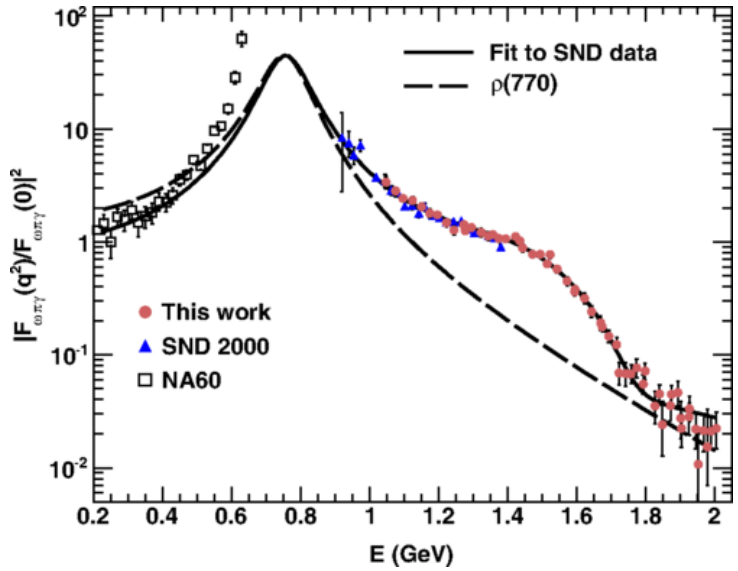
BESIII **PR D92 (2015) 012001**



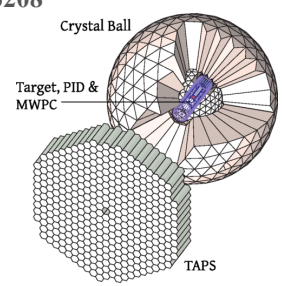
η and η′ improve data base and look for double conversion decays
ω meson, whats happening at the high mass end?

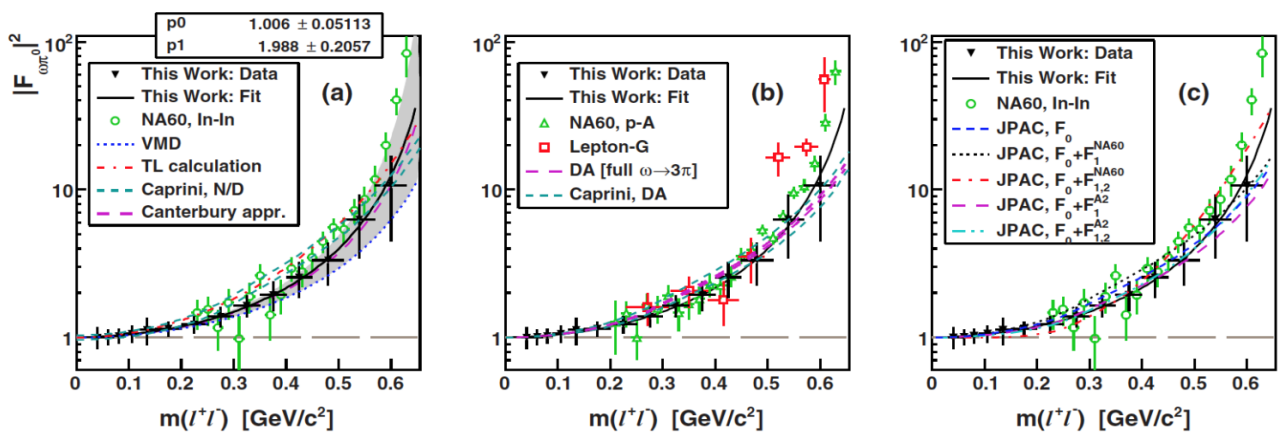
status of the ω-π transition form factor

M. N. Achasov *et al.*, Phys. Rev. D 94, (2016) 112001



S. Prakhov (A2 Collaboration at MAMI)
Phys. Rev. C 95, 035208



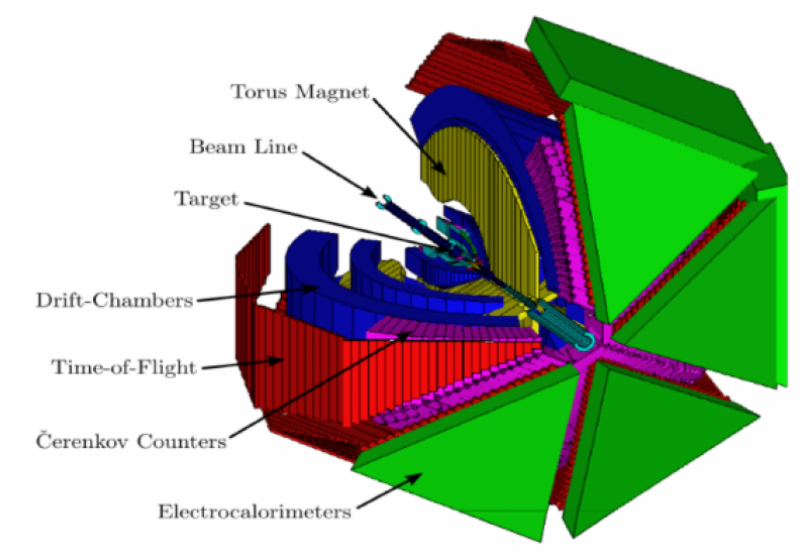


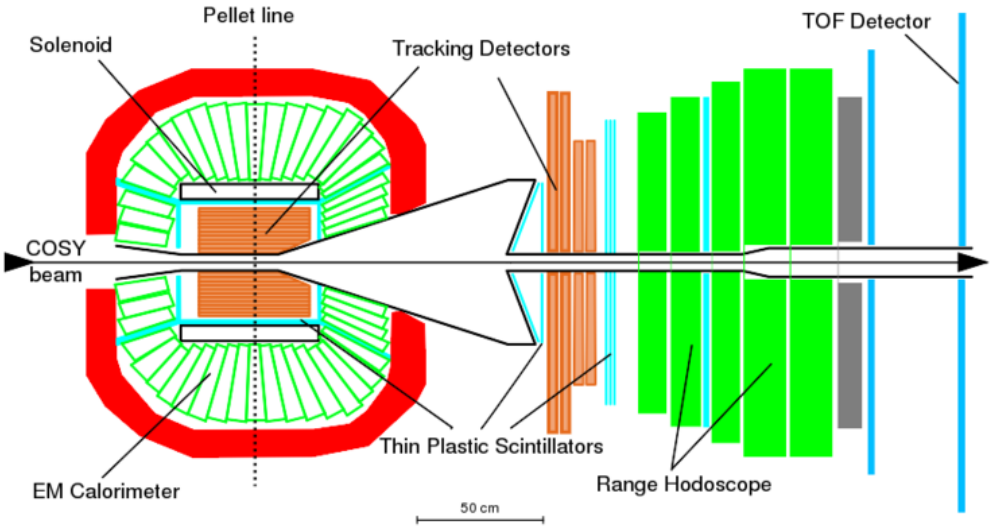
$\Lambda^{-2}=(1.99\pm0.21_{tot})$ GeV^{-2}
1100 overall statistics

conclusion:

- A2 results are in better agreement with theoretical calculations, compared to earlier experiments
- statistical accuracy of the present data points at large m (ee) masses does not allow a final conclusion

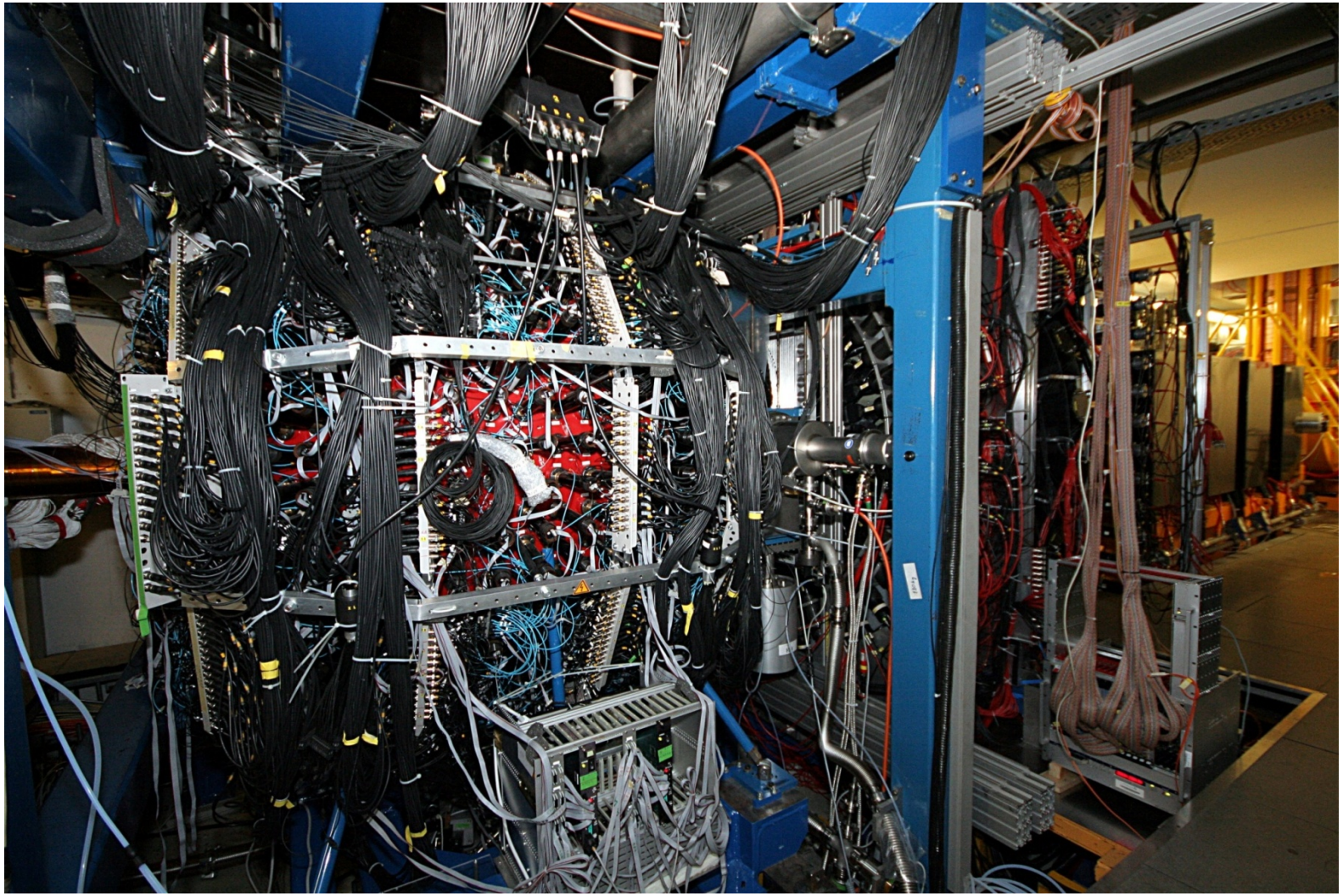
a tale of two experiments



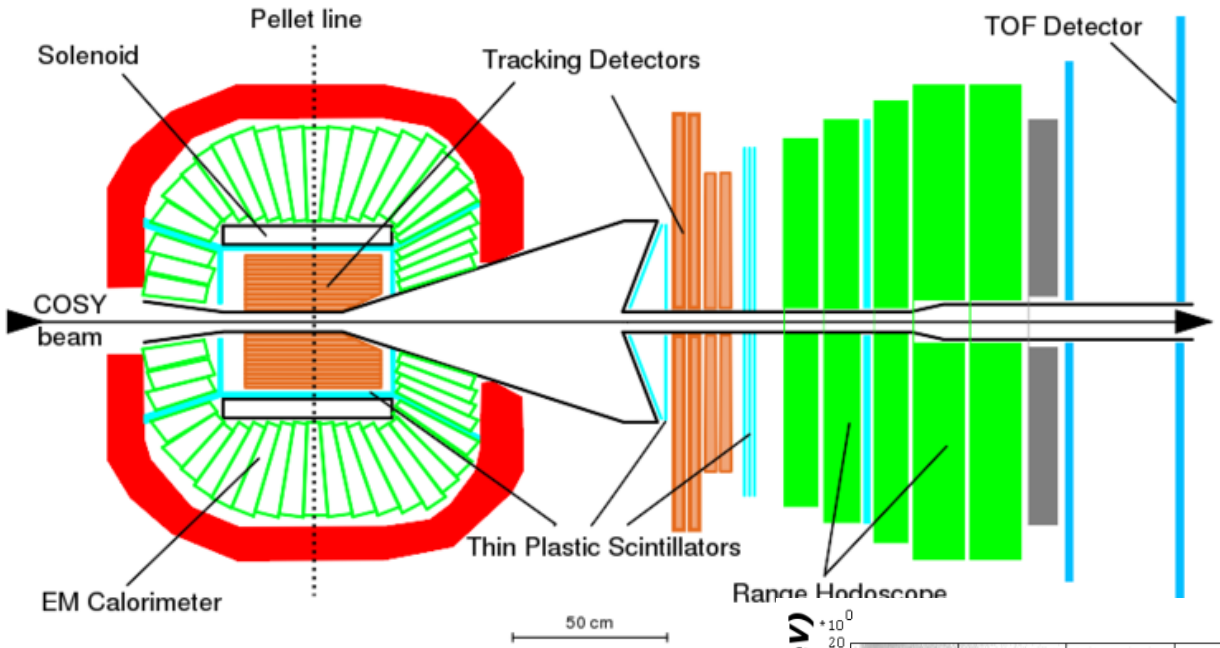


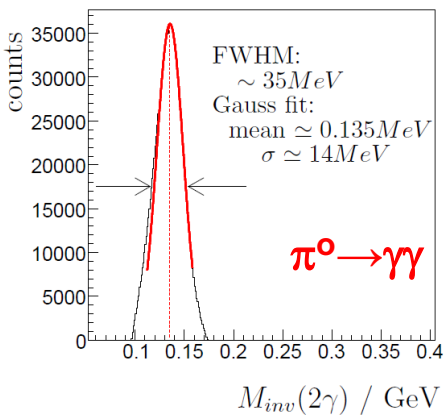
CLAS Jefferson Lab	experimental issue	WASA COSY-Jülich
$\gamma + p$ (g12 experiment)	• cross section • multipion background	$p + p$ (2010)
LH_2 target	external γ conversion	pellet target + beam pipe
Cerenkov Counters	dilepton identification	
EM calorimeter	photon detection	CsI EM Colrimeter

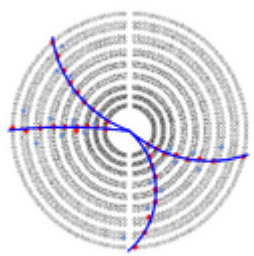
experimental approach WASA-at-COSY



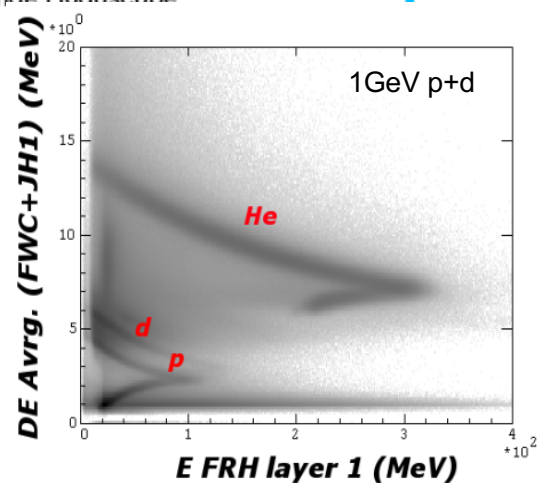
experimental approach WASA-at-COSY







$\eta \rightarrow e^+ e^- e^+ e^-$

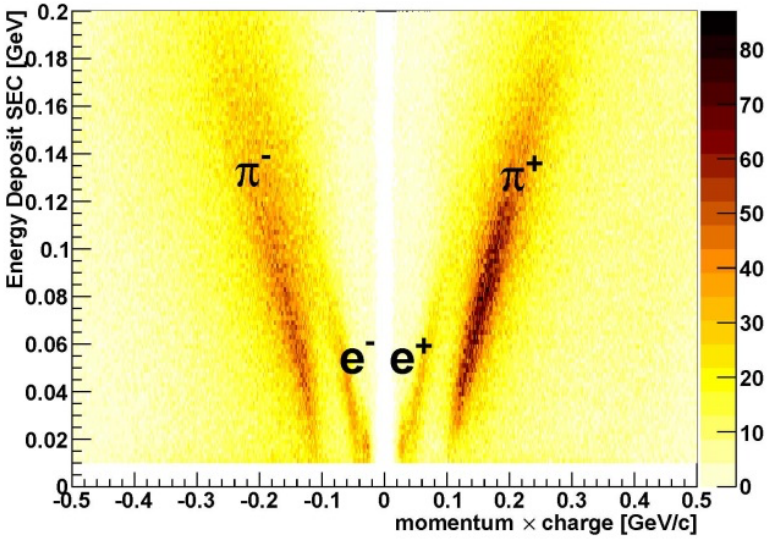


particle identification WASA central detector

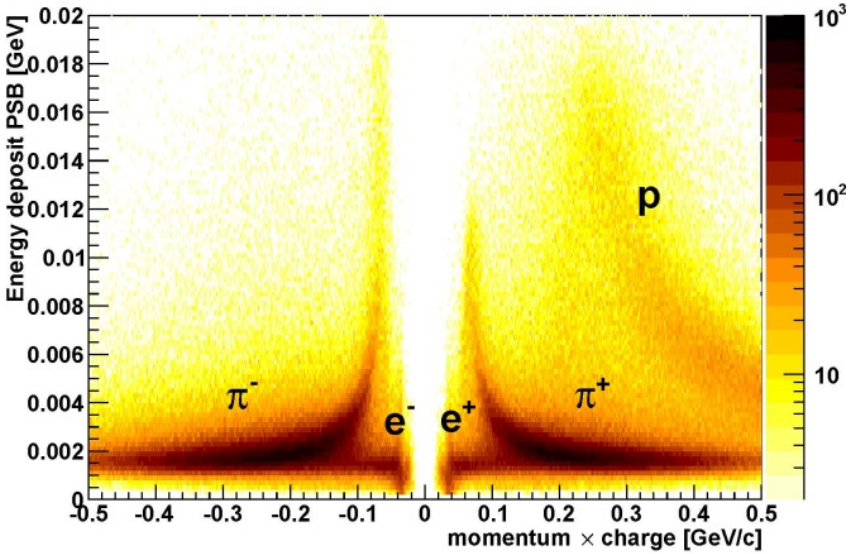
example PID:
analysis of p + d → ^{3}He + η

- ^{3}He selected in WASA forward detector
- low-energy proton background visible (in thin plastic scintillator)

calorimeter vs signed momentum



plastic scintillator vs signed momentum



Measurements of branching ratios for η decays into charged particles
Physical Review C, 94(6), 65206

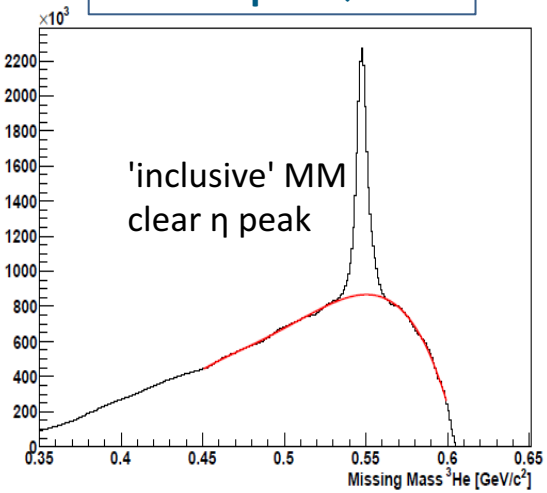
η meson tagging with forward detector

pd →^{3}He η and pp→ppη

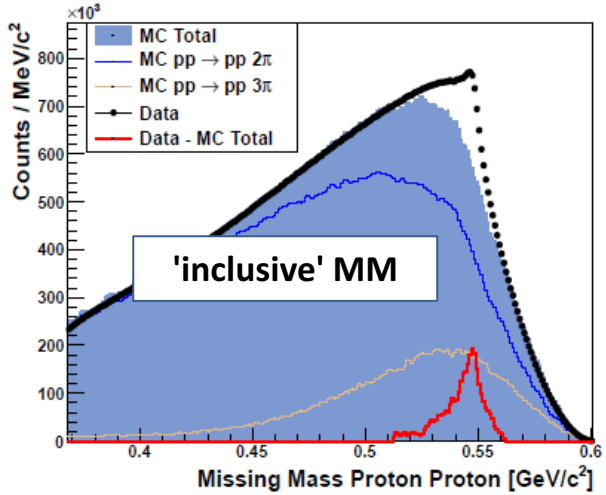
- missing mass method: meson tagging
- detection of all decay products

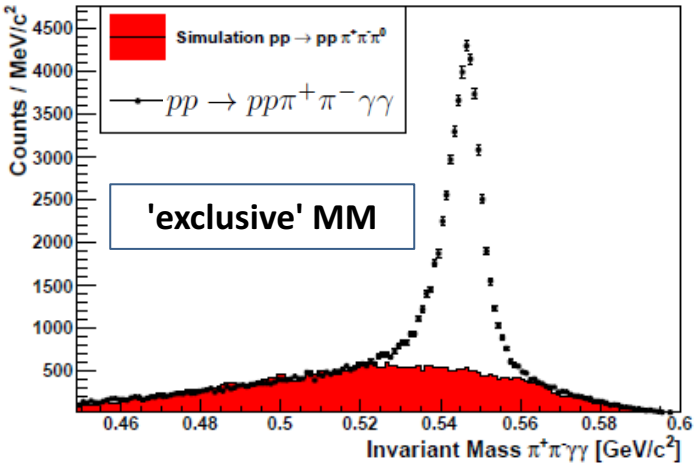
$$MM = \sqrt{(E_{initial} - E_{recoil})^2 - (\vec{P}_{initial} - \vec{P}_{recoil})^2}$$

1.0GeV p+d →^{3}HeX



1.4GeV p+p →ppX$_{trig}$ triggered on charged decay products





pd →^{3}He η *$3 \cdot 10^7$ ^{3}Heη tagged*
abundant decays, analysis training

pp→ppη *5×10^8 η produced*
rare decays

experimental challenge p+p reactions

method:
reconstruct meson mass peak, use full final state information

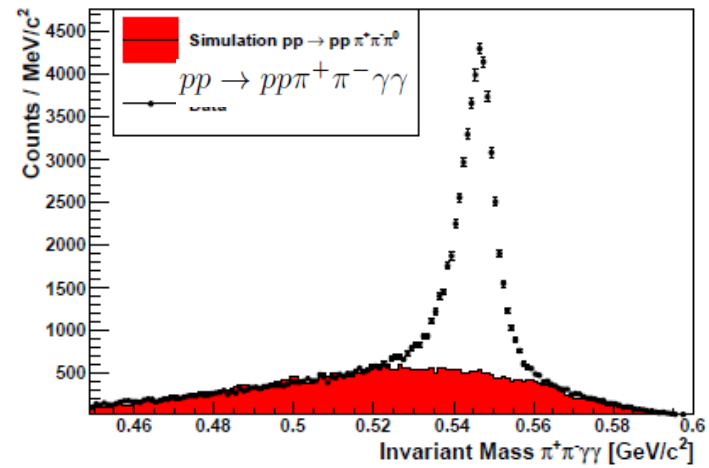
2 types of background:

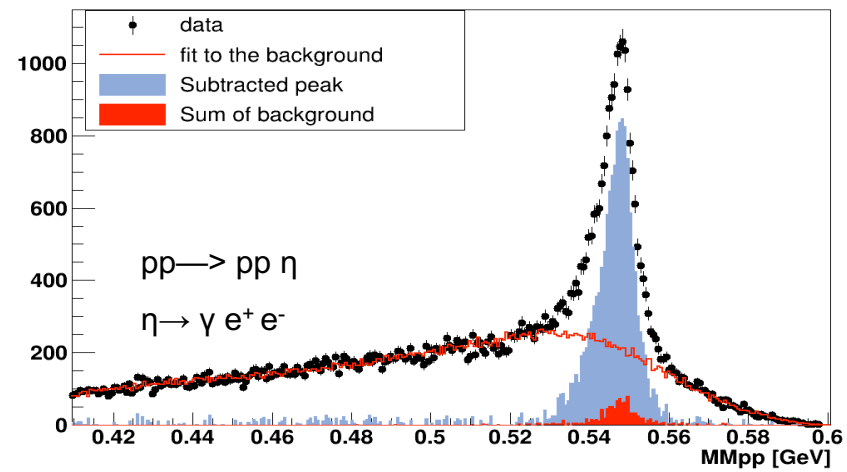
1. multi-pion background
   meson production cross sections

→ smooth background under meson mass peak
example:
- signal $\eta \to \pi^+\pi^-\pi^0$ decay
- background direct $\pi^+\pi^-\pi^0$ production

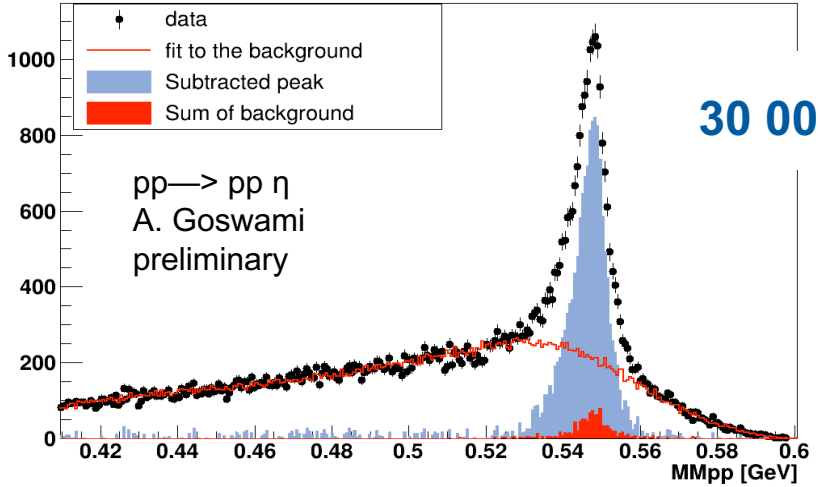
2.) competing meson decays
relative branching ratios

→ peaked background at the meson mass peal
subtract via simulations
example:
- signal $\eta \to e^+e^-\gamma$ decay
- background (eg) from $\eta \to \gamma\gamma$ decay

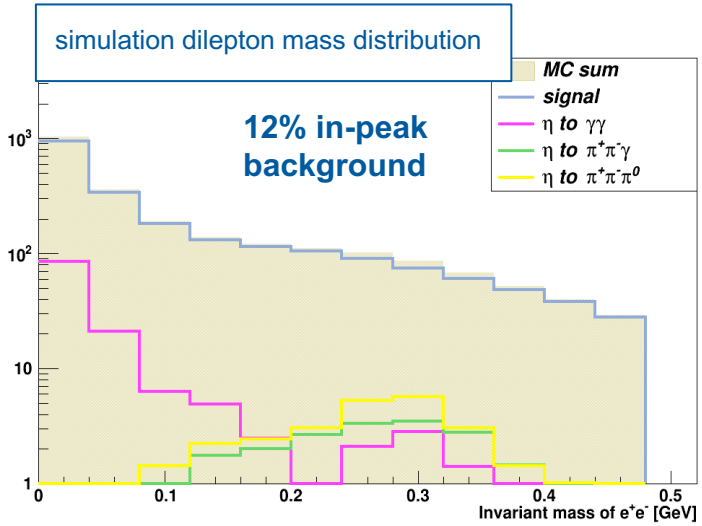




conversion decay η→ γ $e^+ e^-$



30 000 η→ γ $e^+ e^-$



'benchmark decay'

analysis: new base class for pp eta analyses

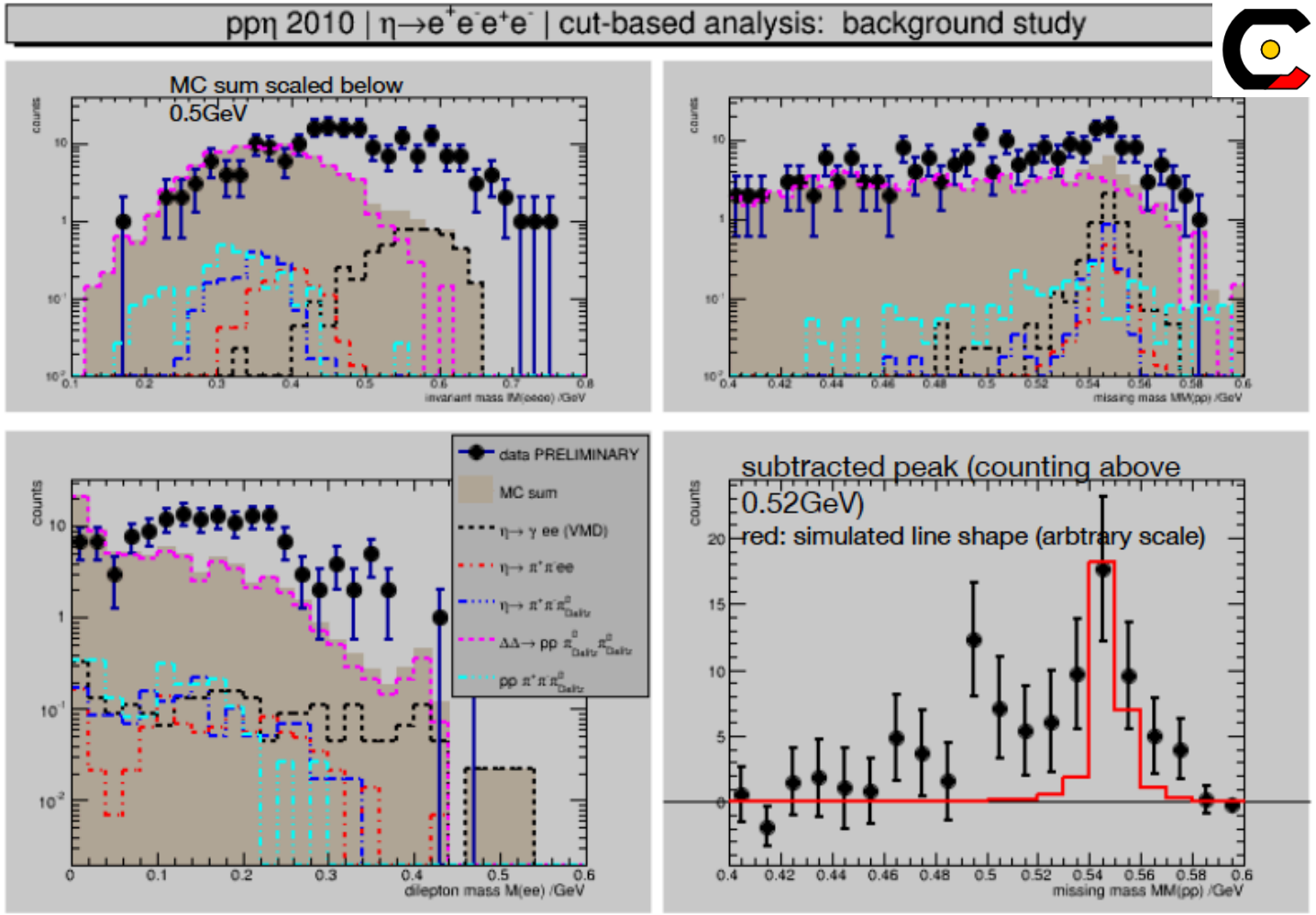
- full particle multiplicities
- improved particle id (neural networks)
- kinematic fit

→ can improve the efficiency and signal/background

- in parallel, look at **η→ eeee**

further: *study in γ p—> p η(') and ω with CLAS/JLab*

η→eeee



preliminary analysis:
only 50 counts
new analysis:
improve statistics
look at pp pi0 data

integral 51.9013 error 7.20426 eff 0.0098225
BR rel to eta2gee 0.00328246 +- 0.000455628
→ BR 2.2649e-005 +- 3.14383e-006
PDG 2.4e-005 +- 2.2e-006
WASA-at-COSY p+d→3He+eta: (3:2 +-0:9stat +-0:5sys) *1e5

the decay η→eeee

double virtual photon decay, branching ratio, 2 dimensional transition form factor?

KLOE 2011	362 ± 29	BR $\eta \to e^+e^-e^+e^-(\gamma) = (2.4 \pm 0.2_{stat+bckg} \pm 0.1_{syst}) \times 10^{-5}$
WASA 2016	$18.4 \pm 4.9_{(stat)}$	BR $\eta \to e^+e^-e^+e^- = (3.2 \pm 0.9_{stat} \pm 0.5_{sys}) \times 10^{-5}$

WASA pd → ^{3}He η 3 x10^7 η mesons produced
(14 040 ± 120) η → γee events (12% efficiency)
(18 ± 5) η → eeee events (3% efficiency)

WASA 2010 pp → pp η indeed, **< 50 η → eeee to be expected?? ***

** meanwhile: more statistics possible by improved tracking (nuclear interactions of protons in detector)*

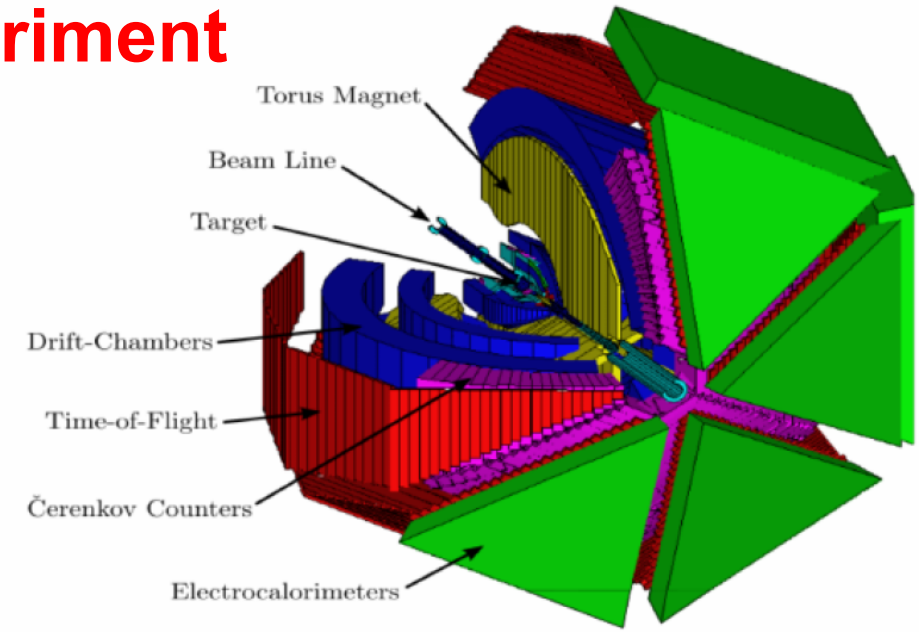
CLAS approved analysis CAA-LMD

hadronic decays: Dalitz plot analysis			
$\eta \to \pi^0 \pi^+\pi^-$	g12	Daniel Lersch	• analysis report in progress
$\omega \to \pi^0 \pi^+\pi^-$	g12	Chris Zeoli	• PhD 2016 FSU
$\eta' \to \eta \pi^+\pi^-$	g12,(g11)	Sudeep Ghosh	• analysis report submitted
f.s. $\eta \pi^+\pi^-$	g12	Cathrina Sowa	• PhD 2016 Bochum
radiative decays: box anomaly, branching ratio			
$\eta' \to \pi^+\pi^-\gamma$	g11	Georgie Mbianda Njencheu	• analysis report submitted • PhD 2017 ODU
$\eta \to \pi^+\pi^-\gamma$	g11	Torri Roark	
$\rho \to \pi^+\pi^-\gamma$	g11	Tyler Viducic	
conversion decays: electromagnetic transition form factor			
$\pi \to \gamma e^+e^-$	g12	Michael Kunkel	• paper draft on π^0 cross section • PhD 2014 ODU
$\omega \to \pi^0 e^+e^-$	g12	Susan Schadmand	
$\eta' \to \gamma e^+e^-$	g12	(Michaela Schever, Master 2015)	• Jülich proposal for CLAS12 (M.Kunkel and D.Lersch),

CLAS6 experiment

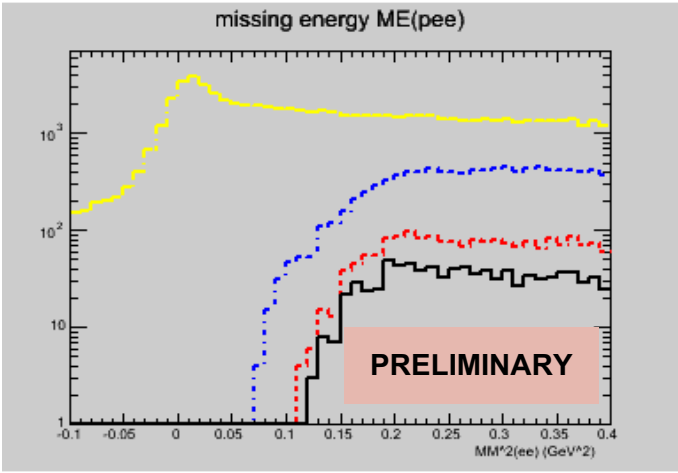
g12 experiment

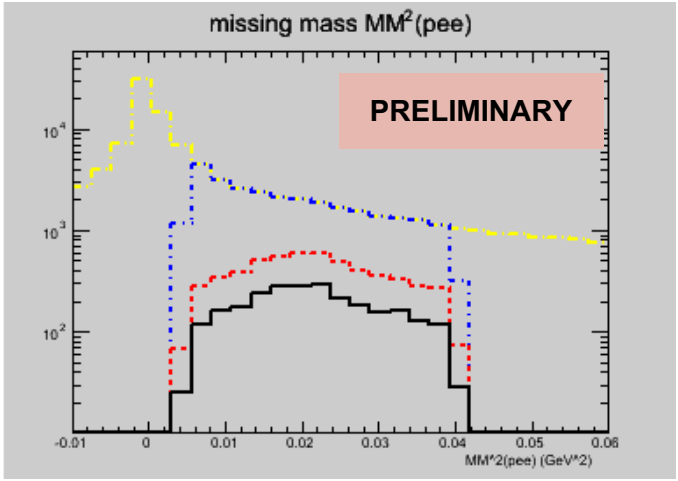
$\gamma + p \rightarrow p\,X$



fixed target experiment with energy-tagged Bremsstrahlung photon beam from 6GeV CEBAF	
LH_2 target	main source for *external γ conversion*
magnetic field	charged particle tracking momenta and *charge state*
Cerenkov Counters	excellent *electron-positron identification*
EM calorimeter	particle identification (limited acceptance photon detection)

analysis strategy cut-based analysis





e^+e^- detection
and missing particle

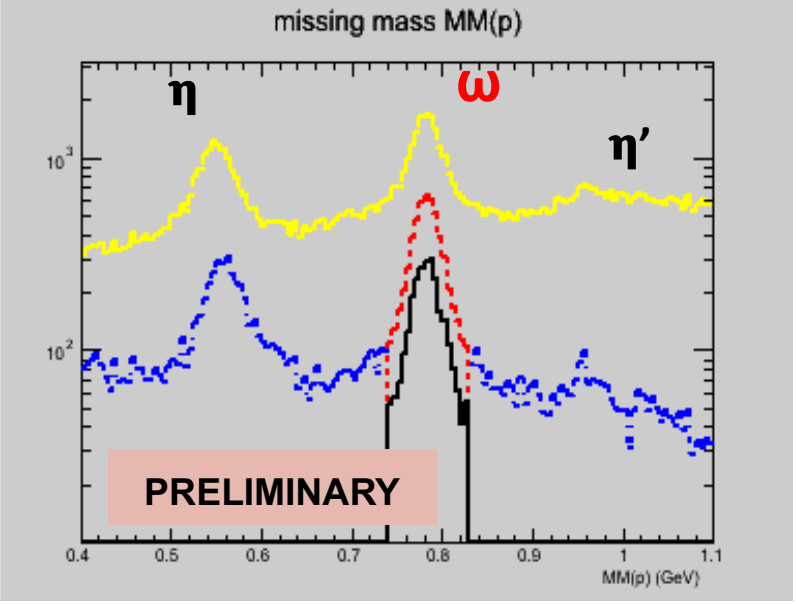
missing pion: **ω→πee**
- missing mass is pion mass
- missing energy finite

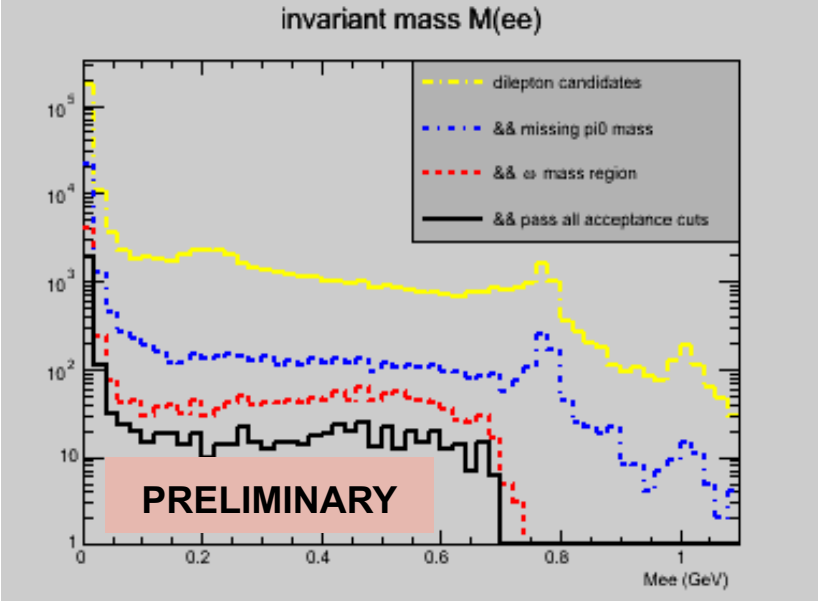
missing photon: **η(´)→γee**
- missing mass zero
- missing energy finite

missing nothing: **ρ/ω→ee**
- missing mass zero
  missing energy zero

missing mass cut is crucial

analysis strategy cut-based analysis



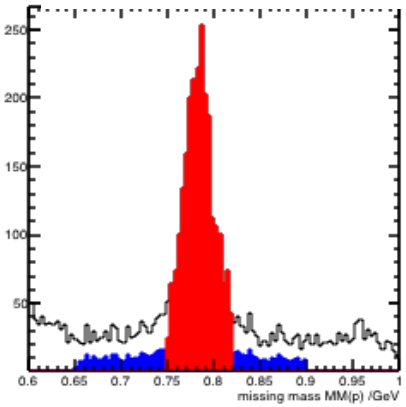


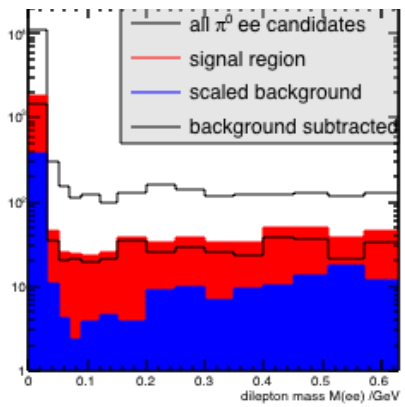
- smooth background ← fit and subtract
- in-peak background (competing decays) ← simulations
- photon conversion from $\pi \rightarrow \gamma\gamma$ ← simulations, small ee masses

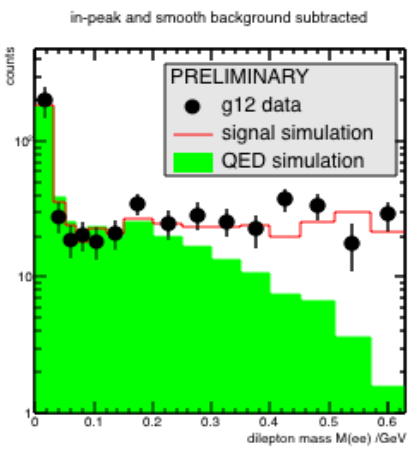
* based on dilepton analysis of M.C.Kunkel

towards the ω-π^0 transition form factor

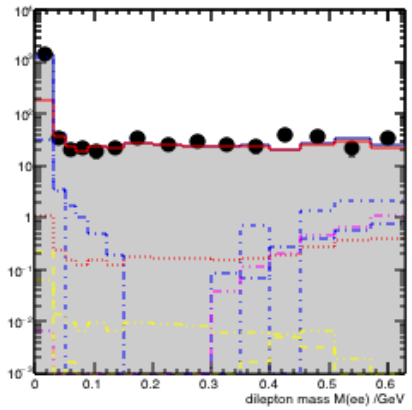
smooth background subtraction







in-peak background



simulations for
in-peak background reveal:

- **external conversion** at small masses
- **combinatorics** at large masses
- influence of rho/omega diletpon decay

- effect of (strict) cut-based analysis
- **new analysis -> more statistics** ?!

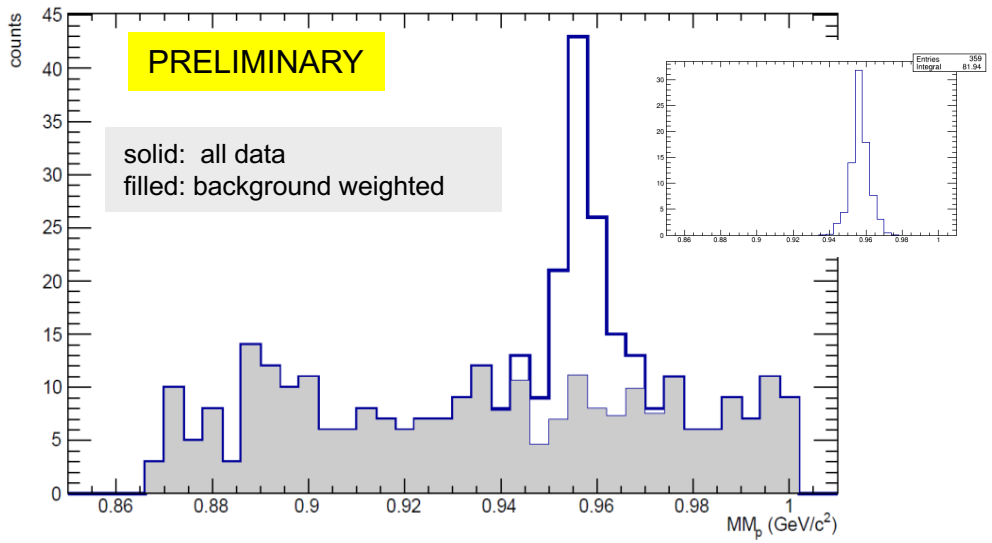
preliminary analysis:
so far, consistent with A2 result (and VMD?)

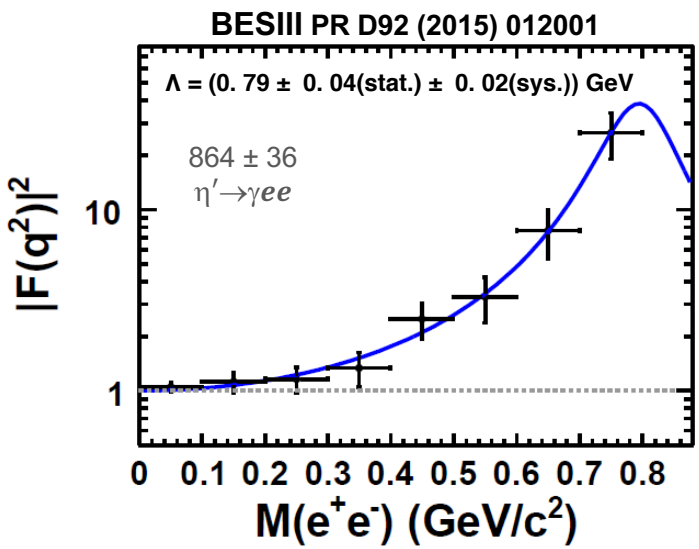
$\eta' \to \gamma ee$: cut-based analysis

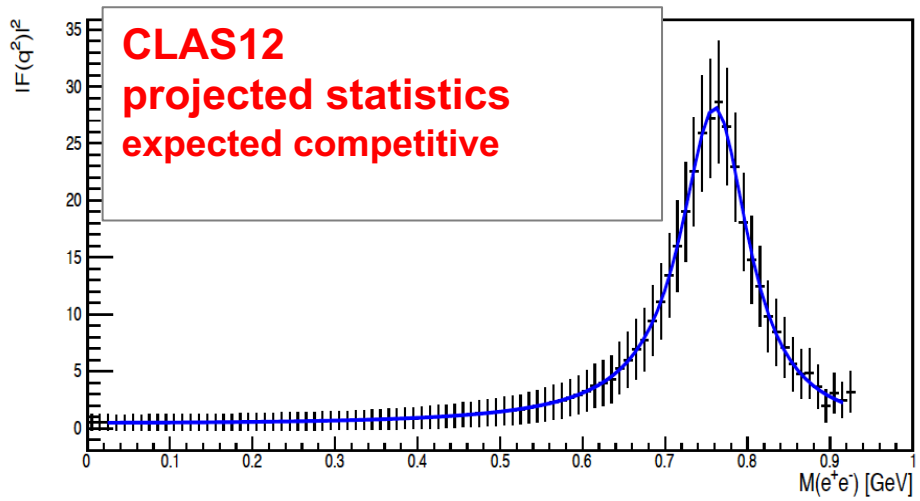
- CLAS g12 experiment
- data analysis: g12 procedures
- q-factor signal extraction:
  evaluate <u>smooth background</u>
  event-by-event

➢ 359 event candidates
➢ **82 events (signal weight)**

CLAS6 not competitive with BESIII







summary

electromagnetic transition form factors of light mesons

- WASA-at-COSY
  - π^0, η single and double conversion decays
    - planning new analysis (statistics)

- CLAS g12 experiment
  - π^0, η, η', and ω decays
  - planning new analysis
    - use of kinematic fit
    - statistics
    - combinatorics

- CLAS12 campaigns:
  - η' decays proposed
  - other proposals to come