Direct photo-production of narrow pK resonance in CLAS

Moskov Amaryan

In collaboration with
Chandra Nepali and Gagik Gavalian

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Outline

Introduction

Review of current status

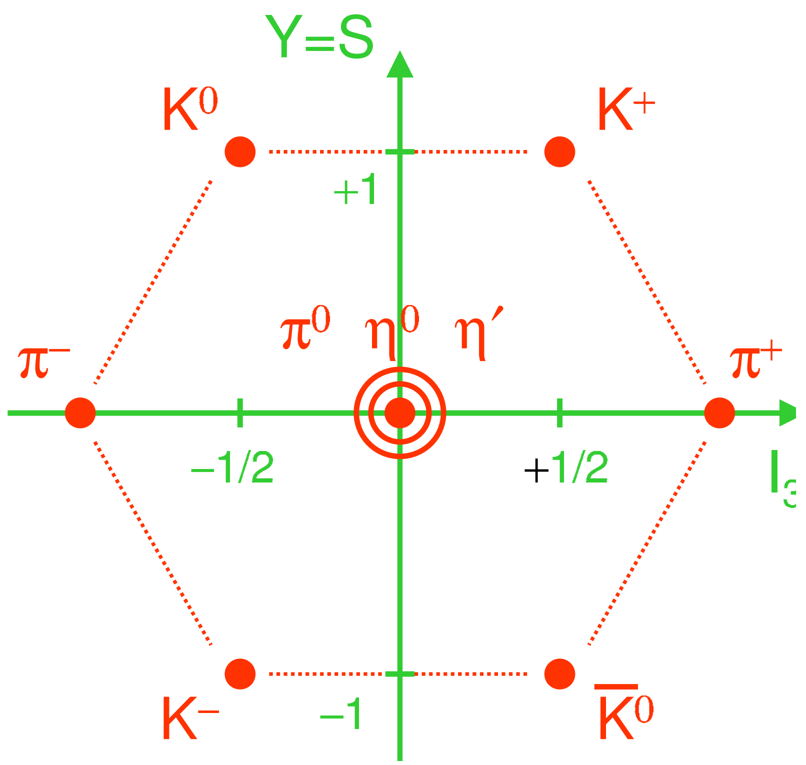
CLAS Data analysis

Direct production of a resonance in pK system

Conclusions

Constituent Quark Model

Light Mesons



$J^{PC} = 0^{-+}$

(pseudoscalar nonet)

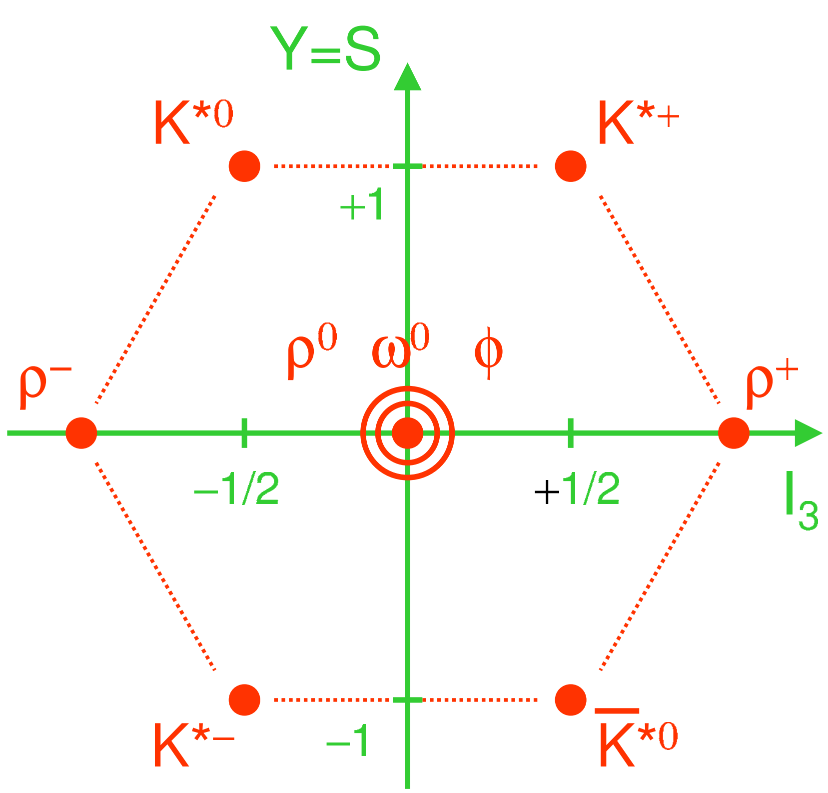
$$\pi^0 = \left(u\bar{u} - d\bar{d}\right)/\sqrt{2}$$
$$\eta^0 = \left(u\bar{u} + d\bar{d} - 2s\bar{s}\right)/\sqrt{6}$$
$$\eta' = \left(u\bar{u} + d\bar{d} + s\bar{s}\right)/\sqrt{3}$$

All are $q\bar{q}$ states

Why?

$Q = I_3 + (B+S)/2$

Gell-Mann-Nishijima



$J^{PC} = 1^{--}$

(vector nonet)

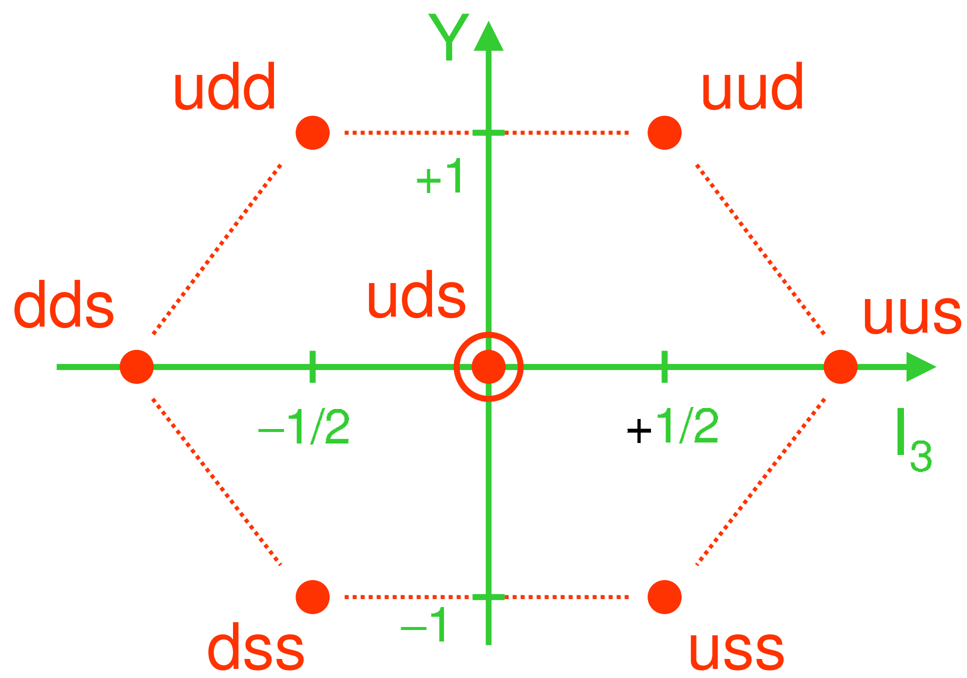
$$\rho^0 = \left(u\bar{u} - d\bar{d}\right)/\sqrt{2}$$
$$\omega^0 = \left(u\bar{u} + d\bar{d}\right)/\sqrt{2}$$
$$\phi = s\bar{s}$$

Y=B+S

B-baryon number

S-strangeness

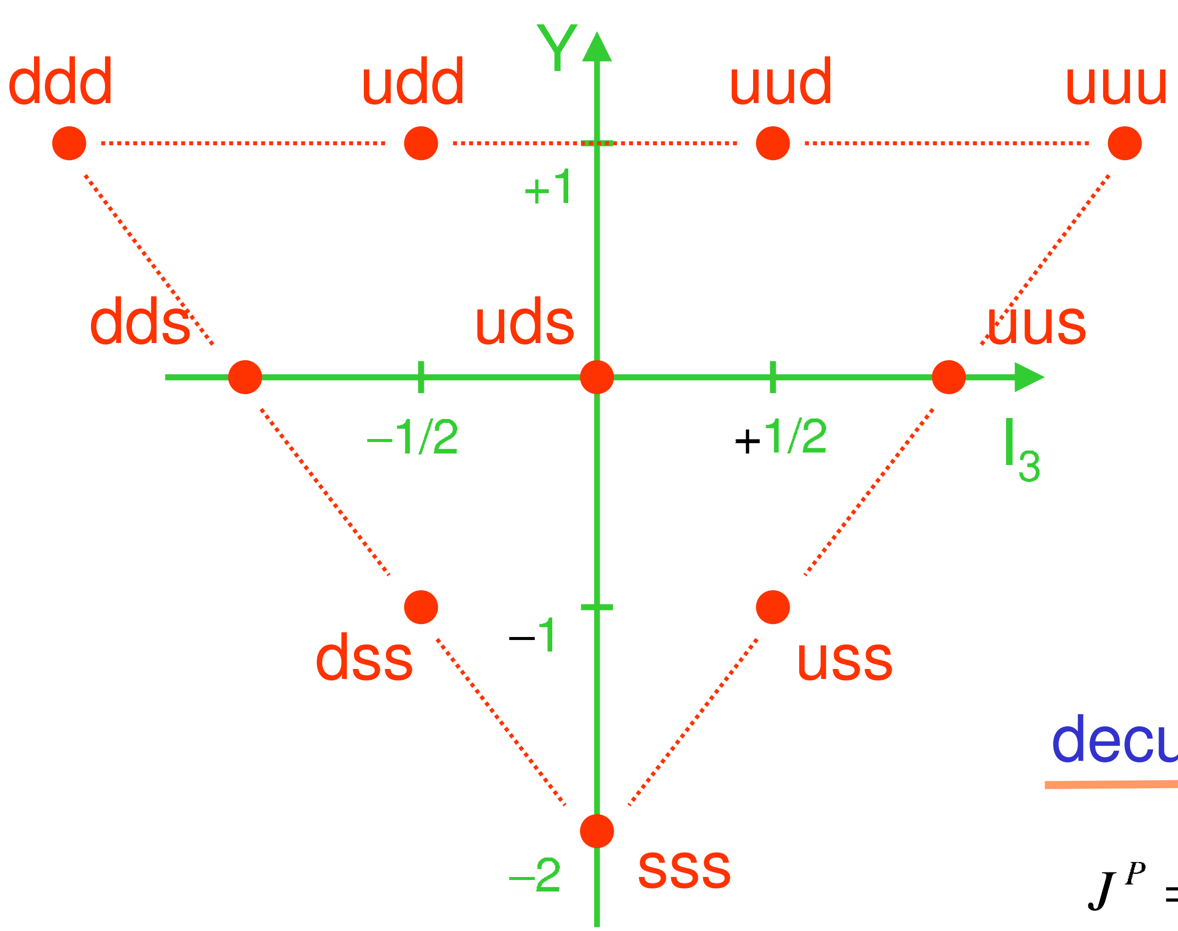
Light Baryons



octet

$J^P = \frac{1}{2}^+$

All are qqq states
Why?



decuplet

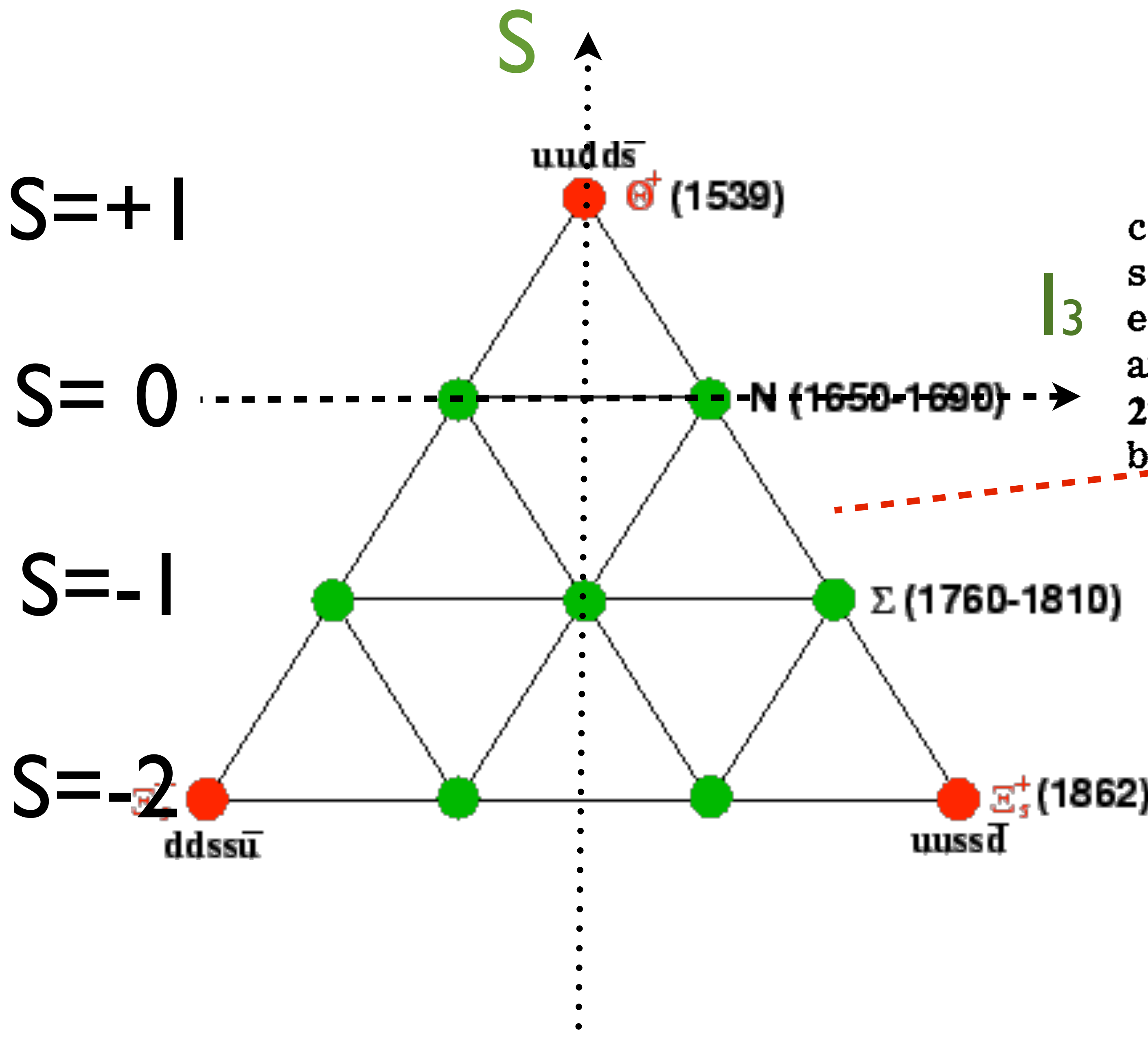
$J^P = \frac{3}{2}^+$

We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" 6) q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(q\,q\,q)$, $(q\,q\,q\,q\,\bar{q})$, etc., while mesons are made out of $(q\,\bar{q})$, $(q\,q\,\bar{q}\,\bar{q})$, etc. It is assuming that the lowest baryon configuration $(q\,q\,q)$ gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\,\bar{q})$ similarly gives just **1** and **8**.

M.Gell-Mann, Phys. Lett.V8, Num.3, 214 (1964)

But where are multiquark states?

Anti-decuplet



Already anticipated by Gell-Mann
in the same 1964 paper

For any value of z and of triplet spin, we can construct baryon octets from a basic neutral baryon singlet b by taking combinations $(b t \bar{t})$, $(b t t \bar{t} \bar{t})$, etc. **. From $(b t \bar{t})$, we get the representations **1** and **8**, while from $(b t t \bar{t} \bar{t})$ we get **1**, **8**, **10**, $\overline{\mathbf{10}}$, and **27**. In a similar way, meson singlets and octets can be made out of $(t \bar{t})$, $(t t \bar{t} \bar{t})$, etc. The quantum num-

Revitalized in the paper

D.Diakonov, V.Petrov, and M.Polyakov
Z.Phys. A359, 305(1997)

Based on χQSM

Predicted narrow (Γ<15 MeV), Θ+ state at M~1530 MeV

Where Θ^{+} was searched for?

Since 2003 almost all particle and nuclear physics collaborations have been involved,
About few thousand physicists !
~1000 (or more) papers are published!

Japan: SPRING-8, BELLE

USA: CLAS, ? BABAR, D0, HyperCP, STAR, PHENIX

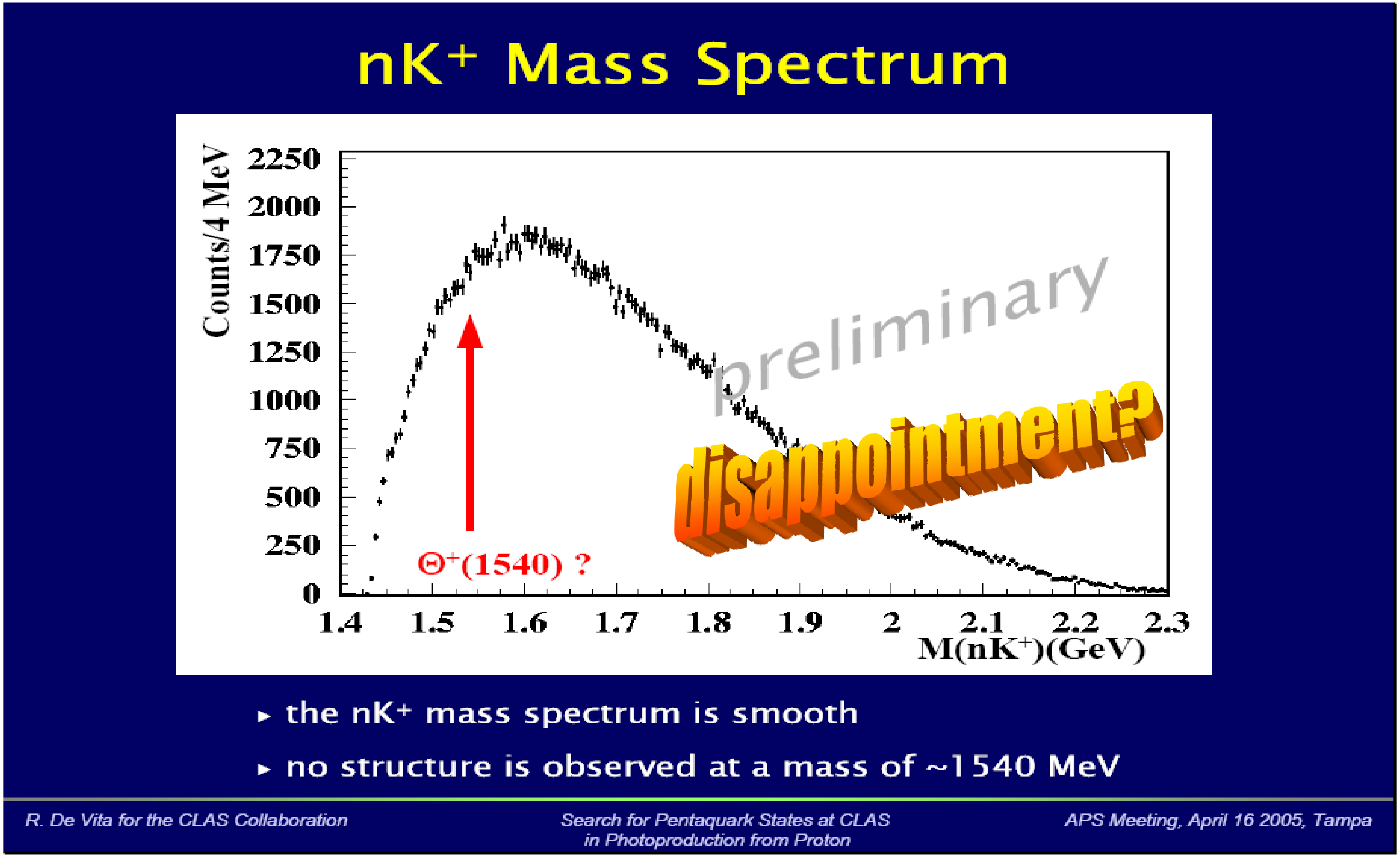
Europe: SAPHIR, COSY, HERMES, ZEUS, H1, HERA-B, NOMAD, ALEPH

Russia: DIANA, SVD, Dubna, SPHINX

China: BES

A lot of negative results: Pentaquark is really elusive!

CLAS at Tampa 2005



Since then the fate of Θ^+ was decided, but was it justified?

This is the question.

Where we stand?

- **The CLAS has set up an upper limit for the cross section**
- **Many experiments do not see a signal, but should they see it?**
- **Some previous positive results still hold**
- **Is the case closed?**
- **Can we increase sensitivity to the tiny cross section ?**
- **What must be done in order to convince ourselves in existence or in absence of the resonance ?**
- *We reported the signal via interference with ϕ* (arXiv:110.3325)
- ***Can we observe it in the direct production?***

Reanalysis of CLAS Data

Reaction of interest:

$\gamma + p = pK_S(\pi^+\pi^-)X(K_L)$

Experimental Strategy:

a) In final state detect $p\pi^+\pi^-$

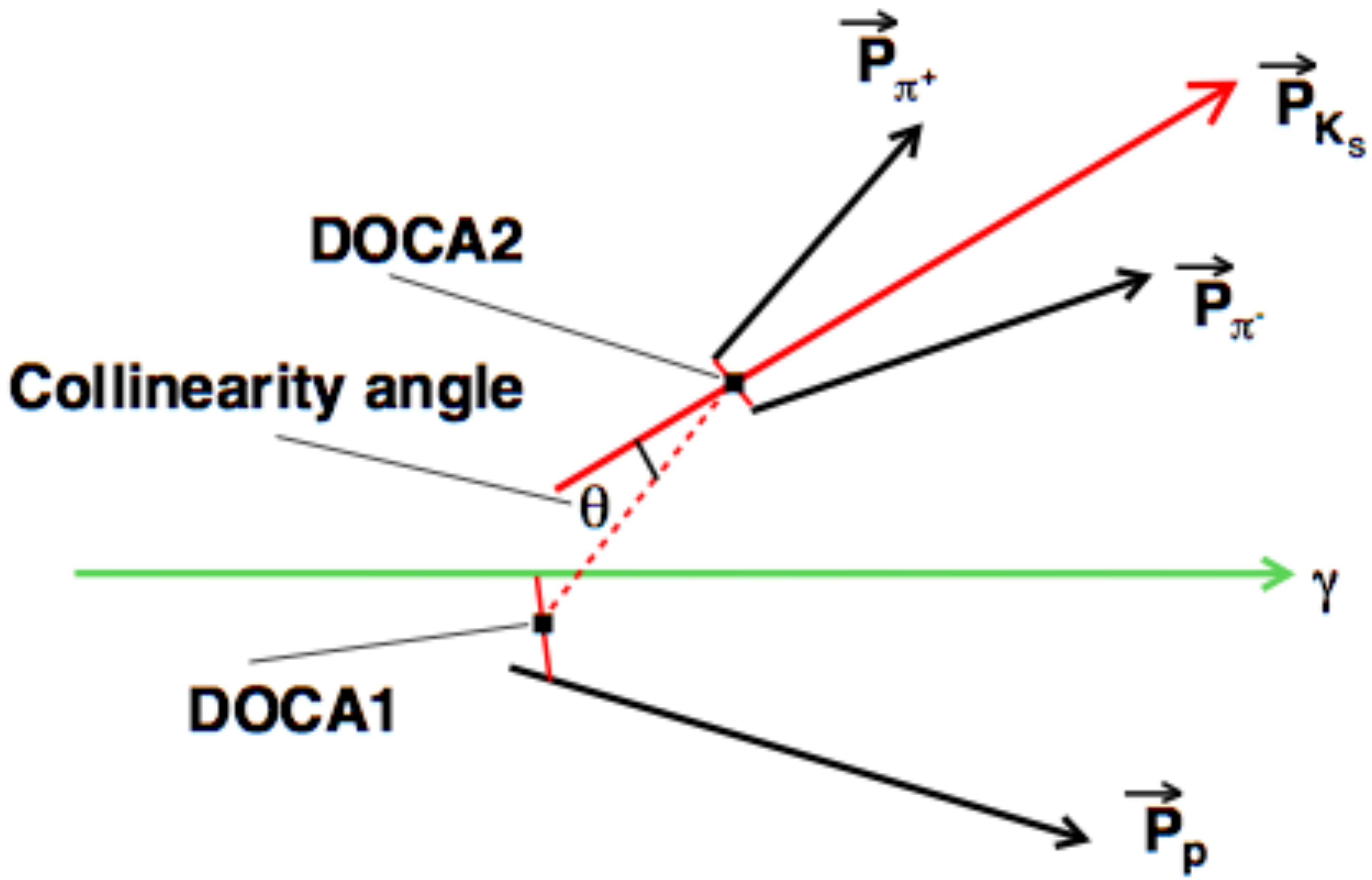
b) reconstruct K_S from $\pi^+\pi^-$

c) reconstruct K_L in missing mass of $p\pi^+\pi^-$

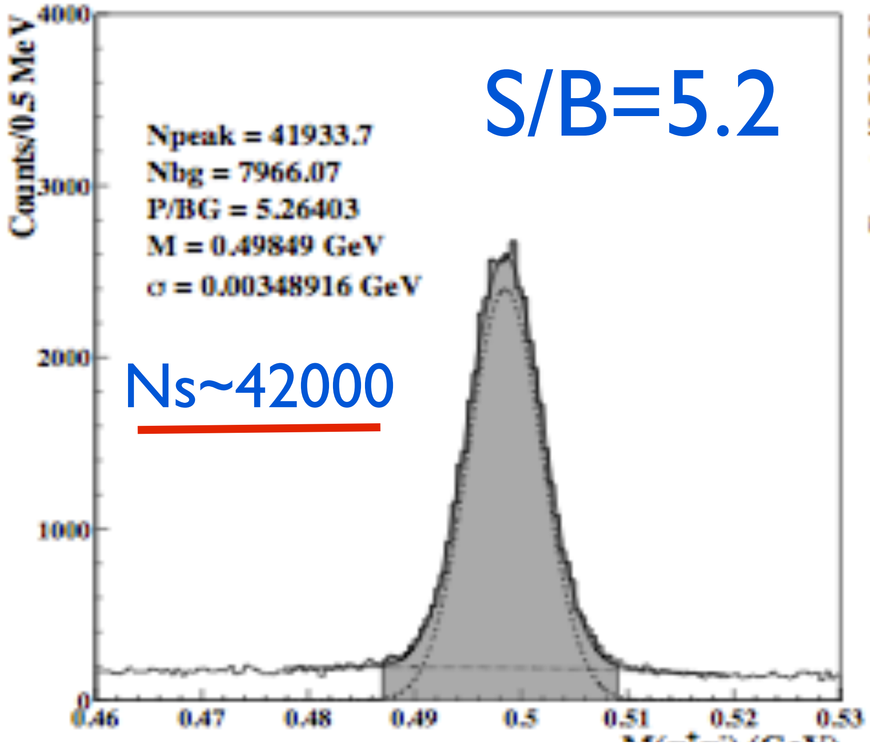
d) search for a resonance in pK system

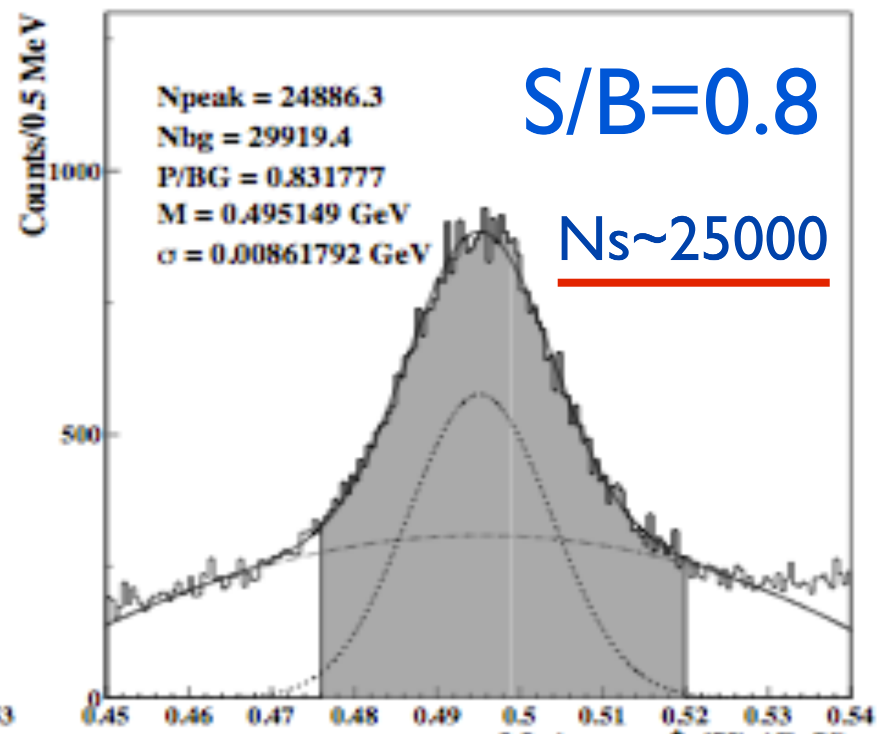
e) invoke Dalitz plot distribution

Reconstructing Ks



Reconstruction of Ks and KL



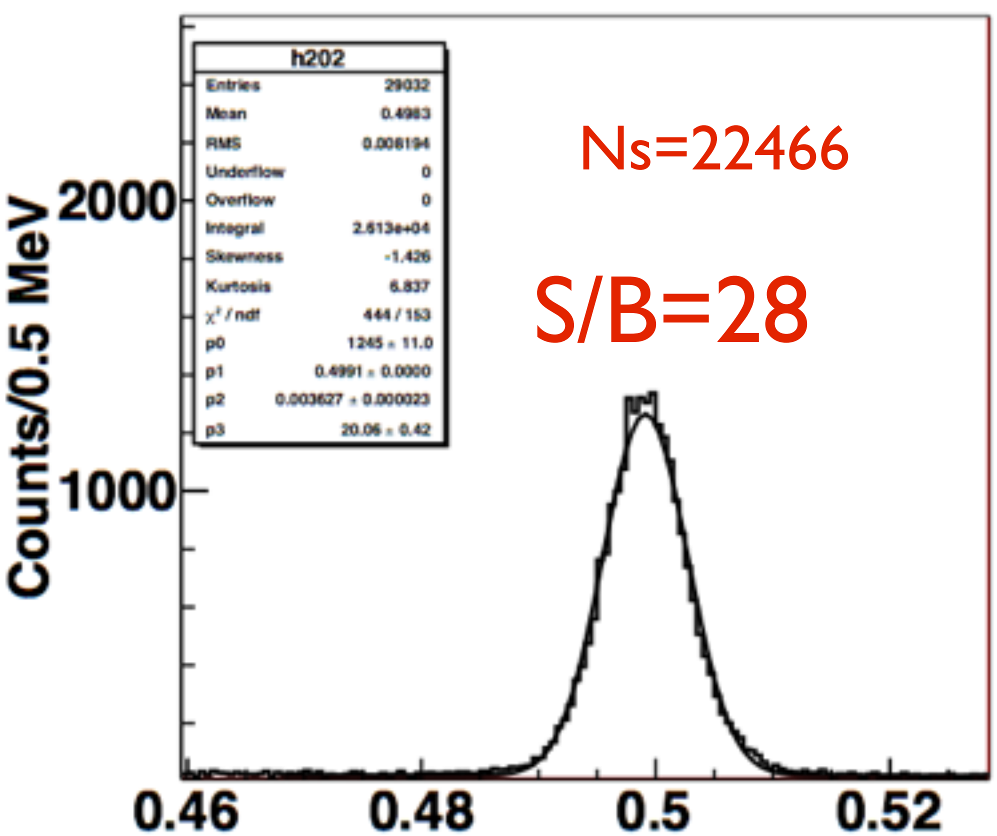


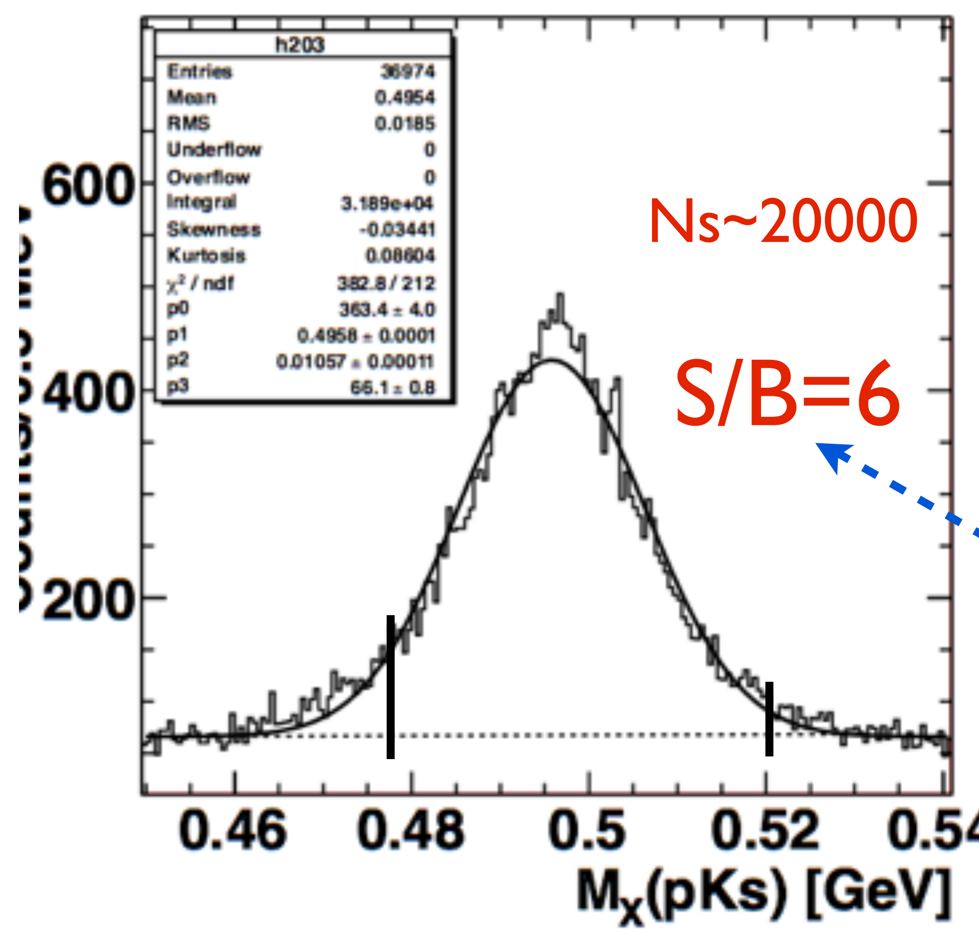
CLAS published paper

Phys. Rev. D74, 032001(2006)

Mx(p)>1.04 GeV

Doca1(Kp)<1cm
Doca2<1cm
d>3cm





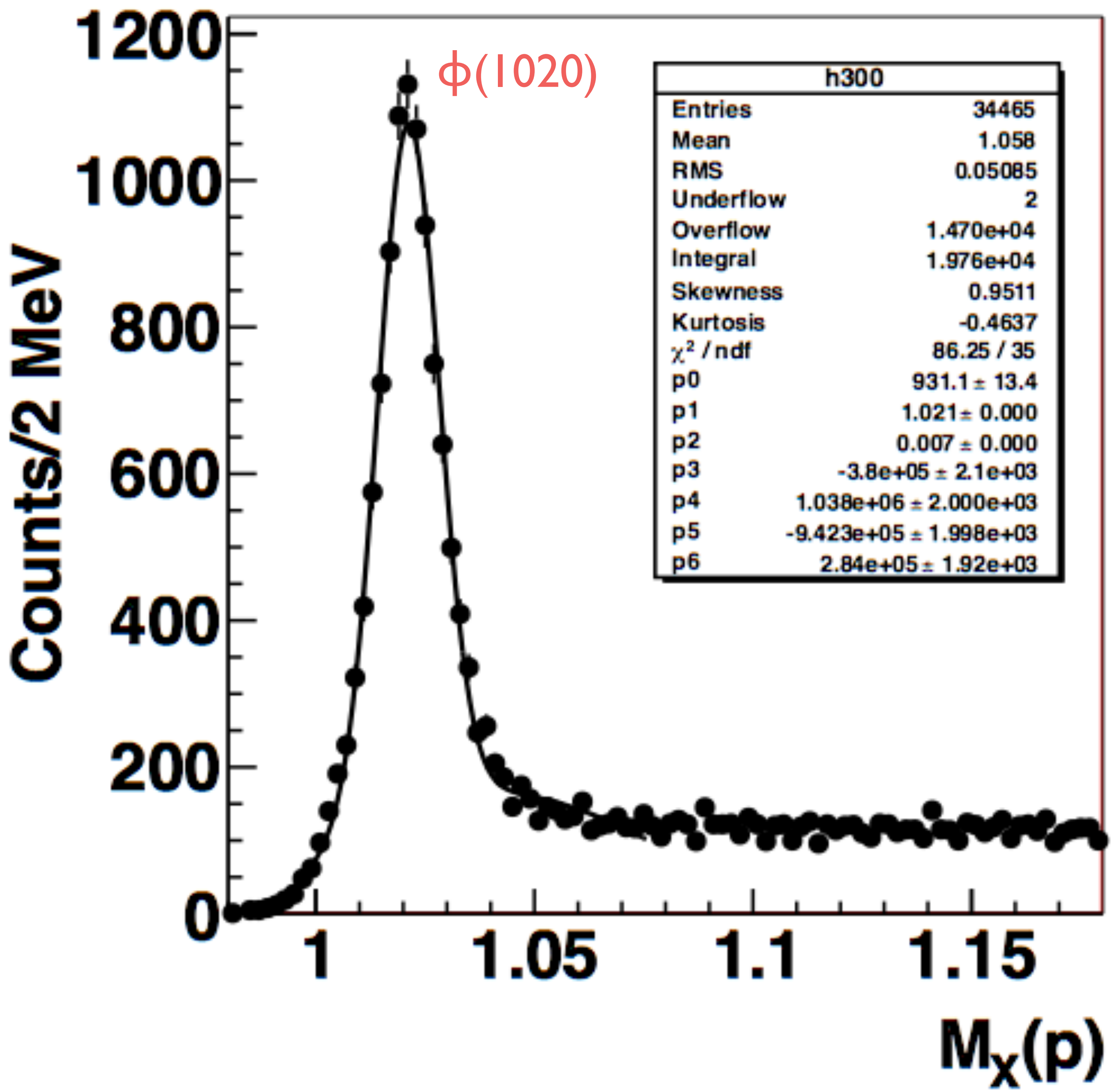
CLAS new analysis

Mx(p)>1.04 GeV

Doca1<1.0cm
Doca2<0.5cm
d>3cm
cosθ>0.98

Present Analysis:
close # of signal events.
But !

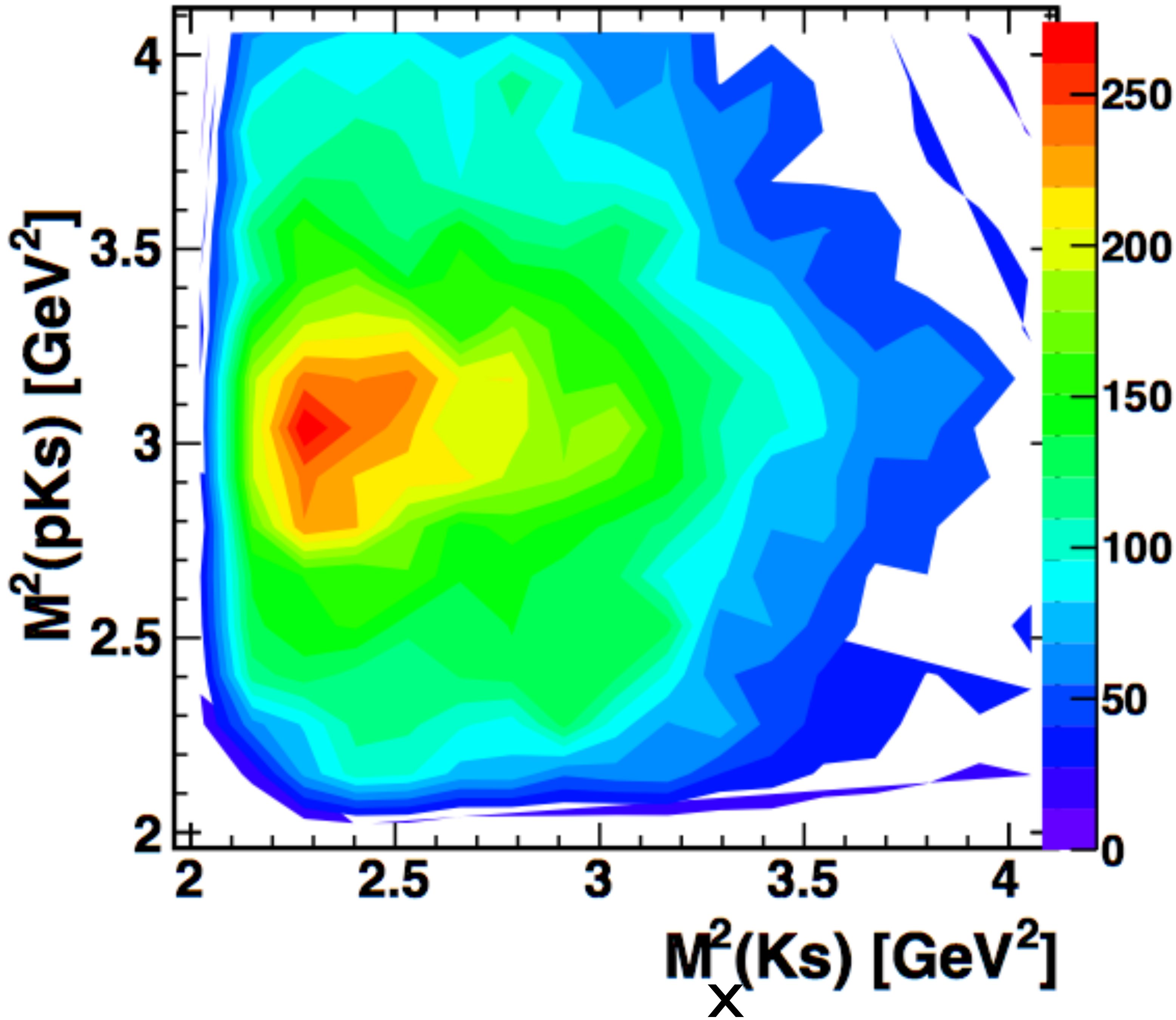
Missing Mass of Proton



M=1.021 GeV

σ=7 MeV

Dalitz Plot with no ϕ

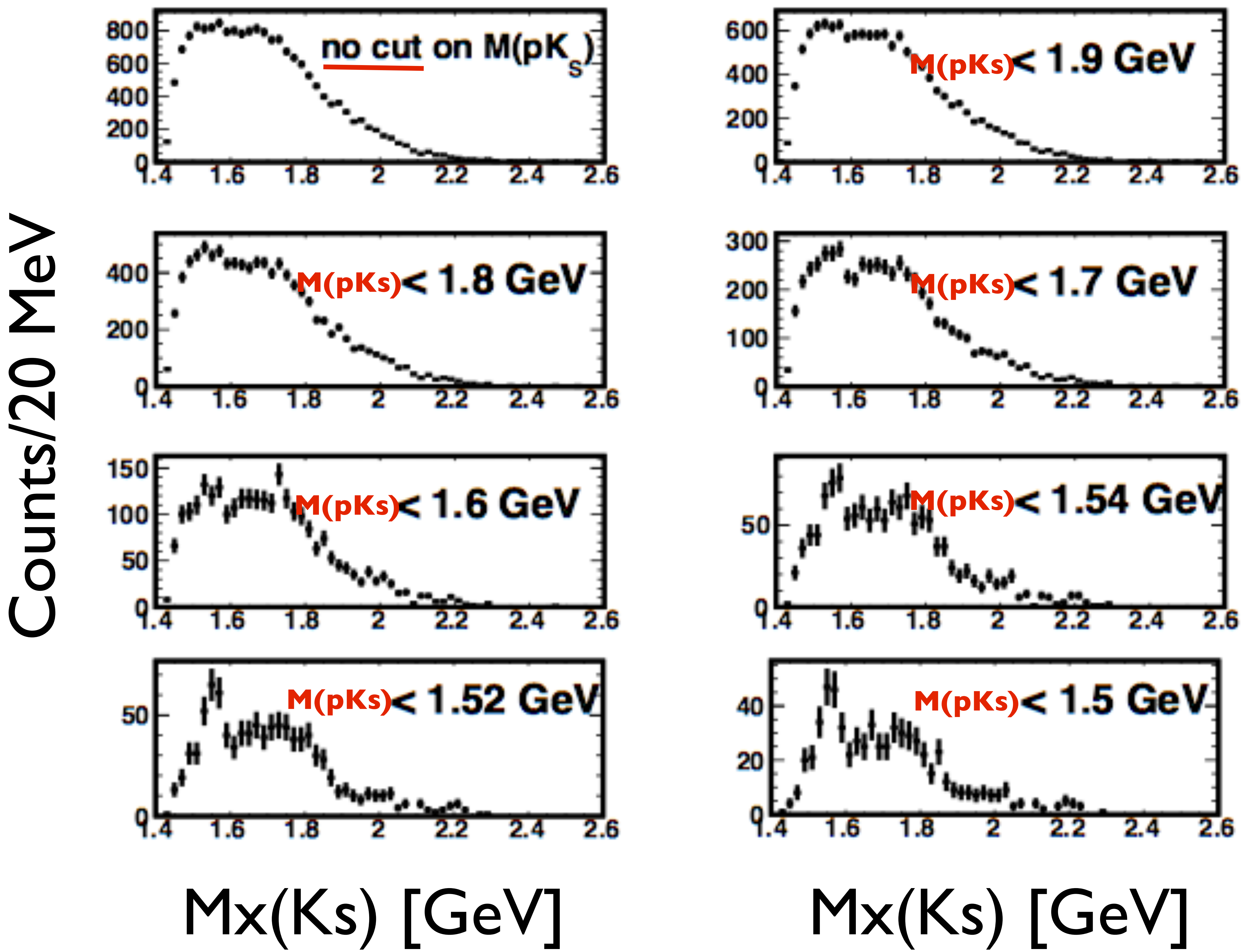


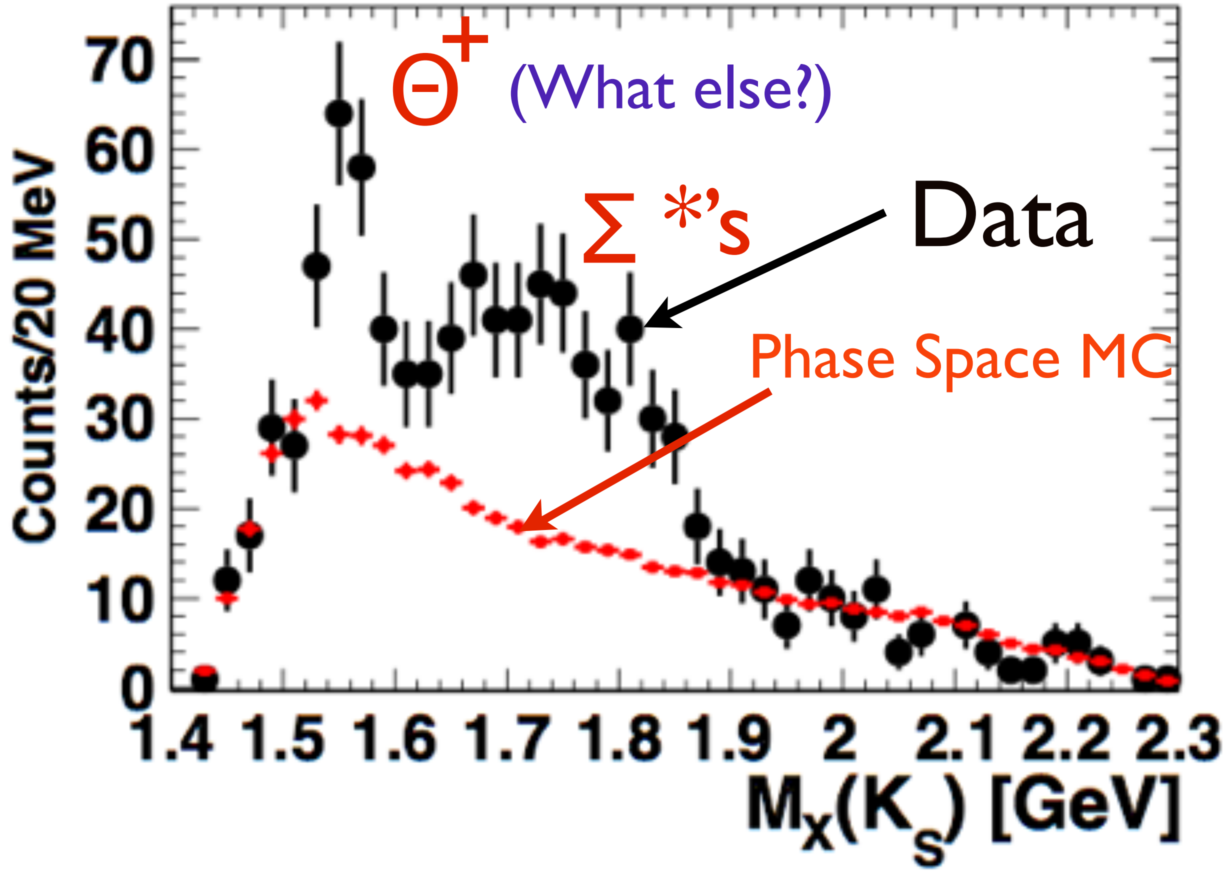
No ϕ

Mx(p)>1.035GeV

2σ cut

Missing Mass of Ks cutting out M(pKs)





Apply Vertex Cuts:

Doca1< 1.0 cm

Doca2< 0.5 cm

cosθ>0.98

d>3.0 cm

Select 2 kaons

M(π+π-)=0.497±0.004 GeV

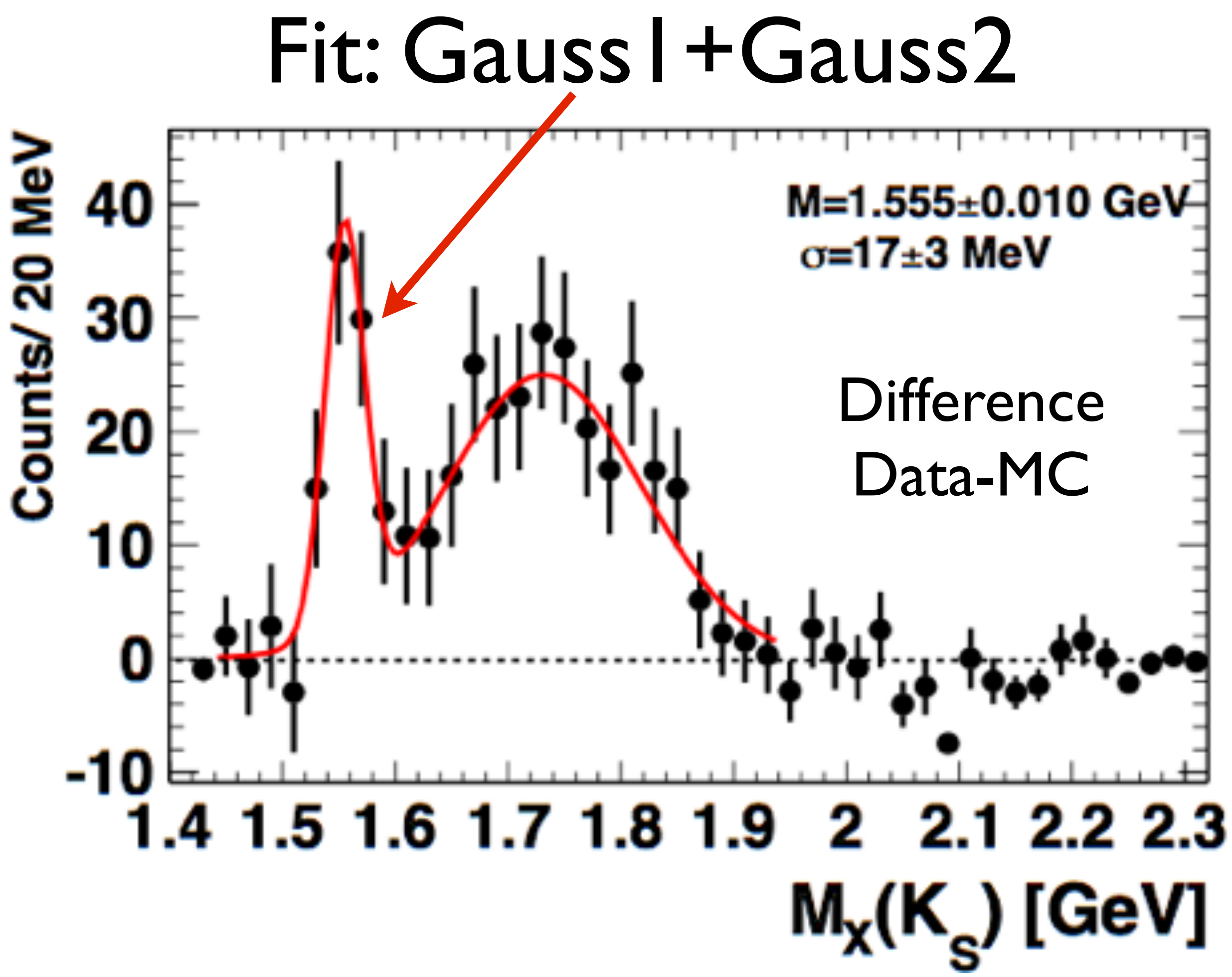
Mx(pKs)=0.497±0.020 GeV

Reject ϕ meson

Mx(p)> 1.035 GeV

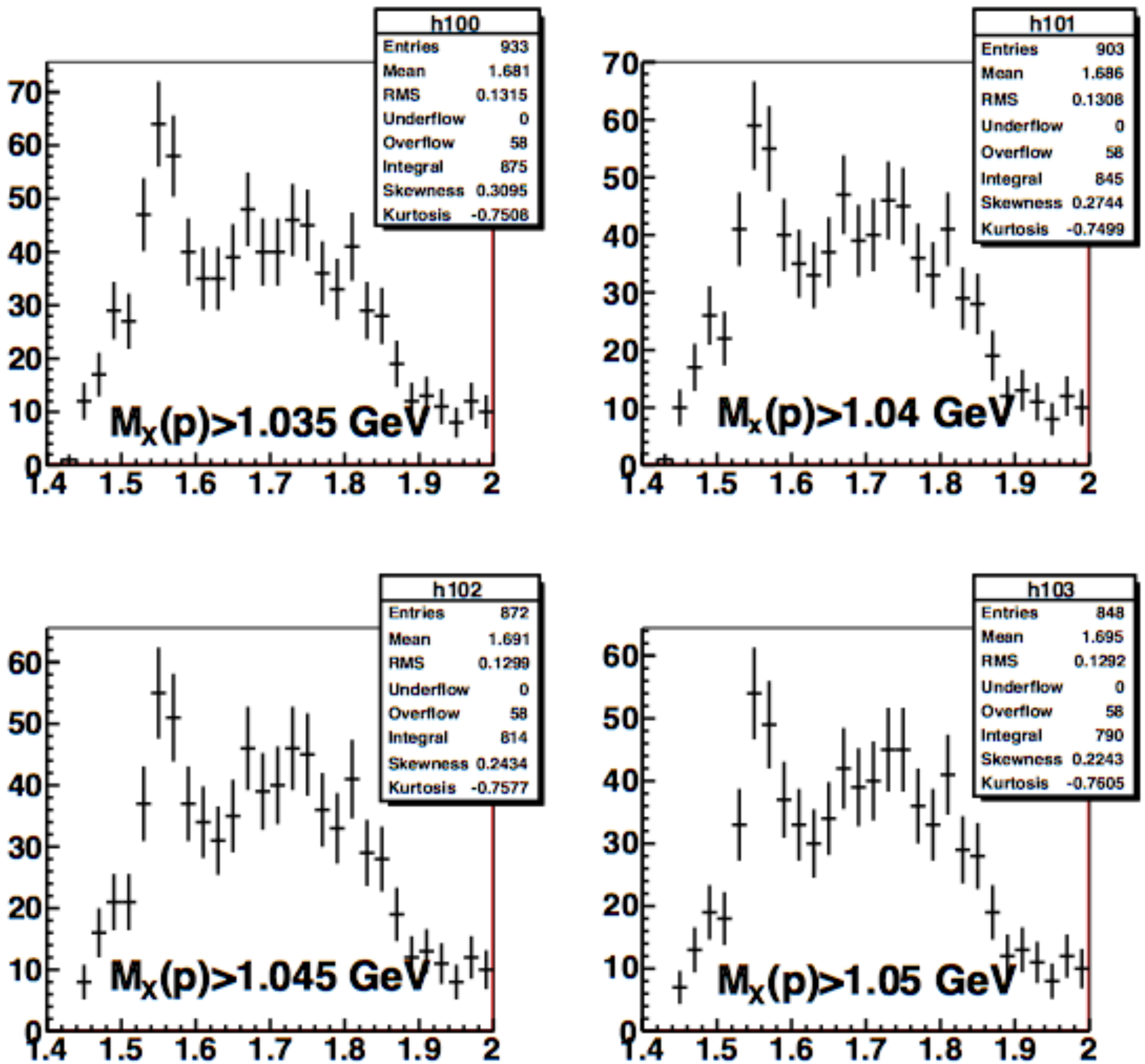
Apply Dalitz Cut

M(pKs)<1.52 GeV



And

How stable is a peak vs ϕ-cut ?



Mx(Ks) [GeV] Mx(Ks) [GeV]

very weak Mx(p) cut dependence

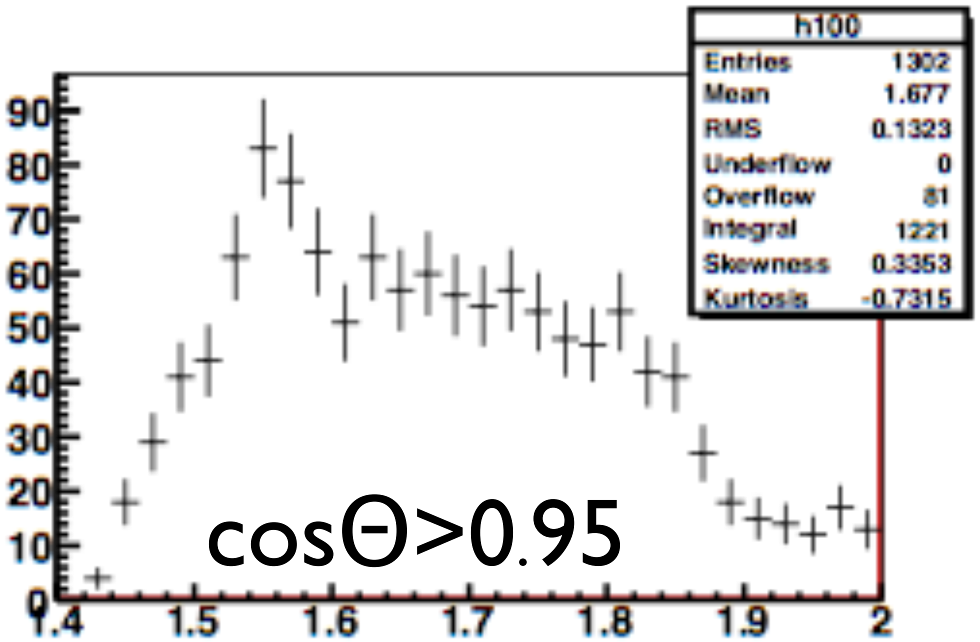
peek one

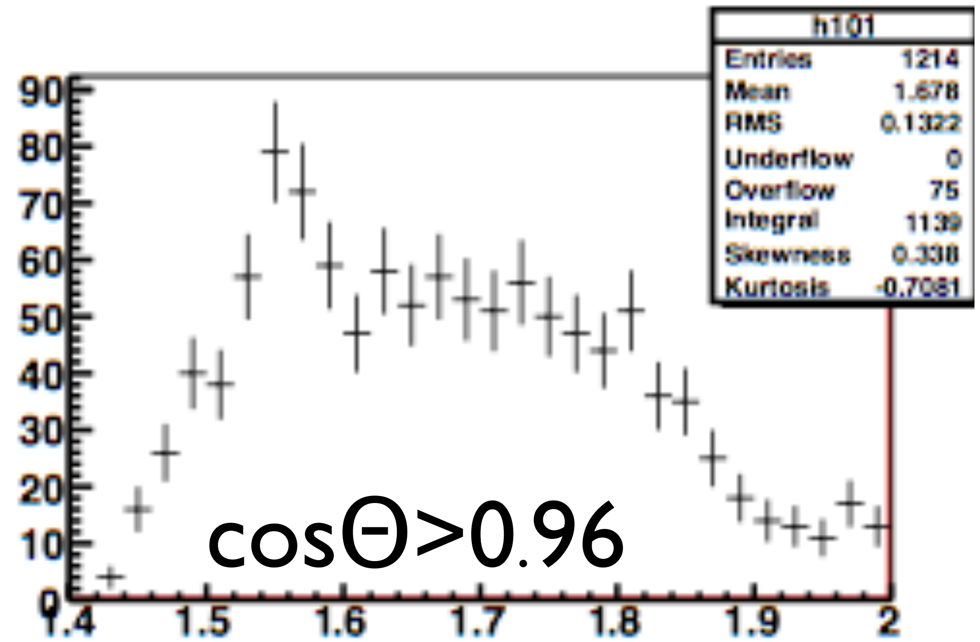
No tuning!

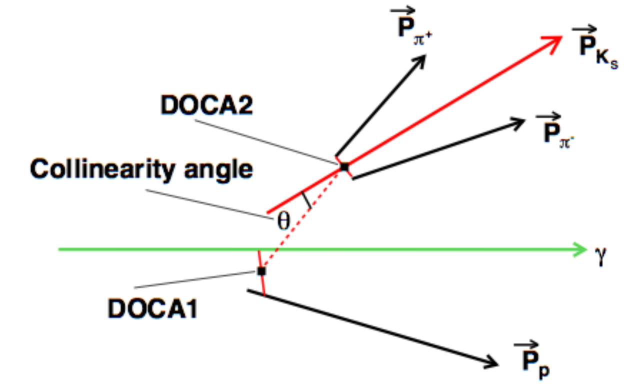
Doca1< 1.0 cm
Doca2< 0.5 cm
cosθ>0.98
d>3.0 cm

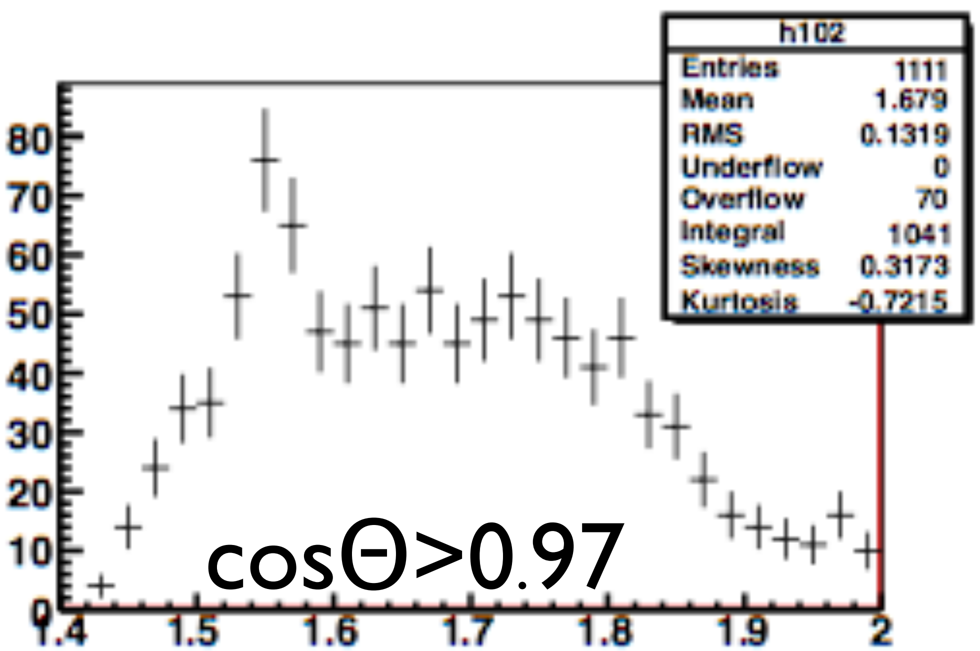
M(pKs)<1.52 GeV

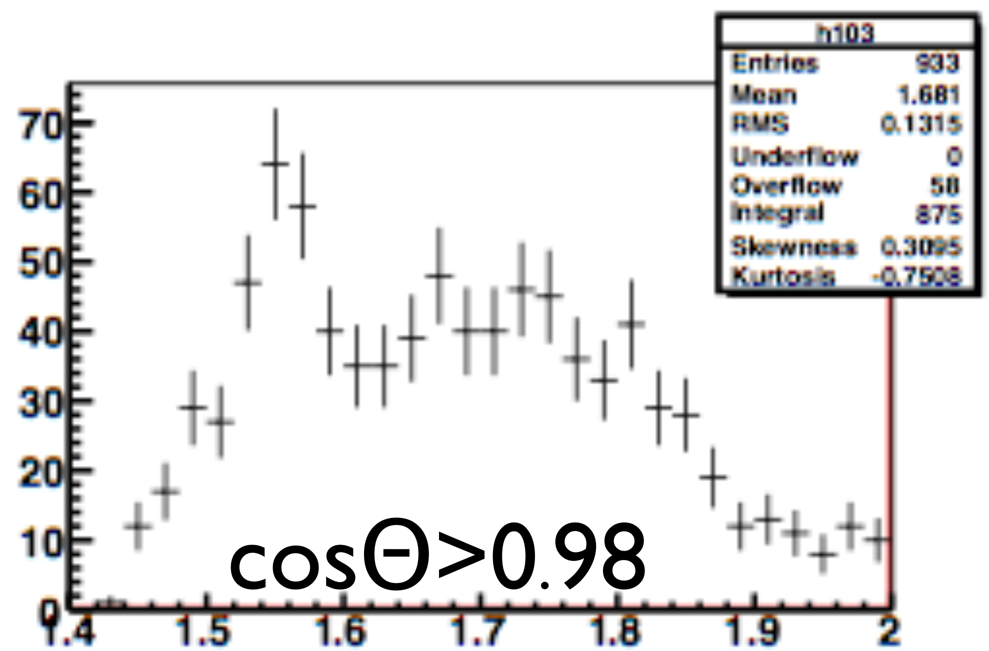
How stable is a peak vs cosΘ-cut?











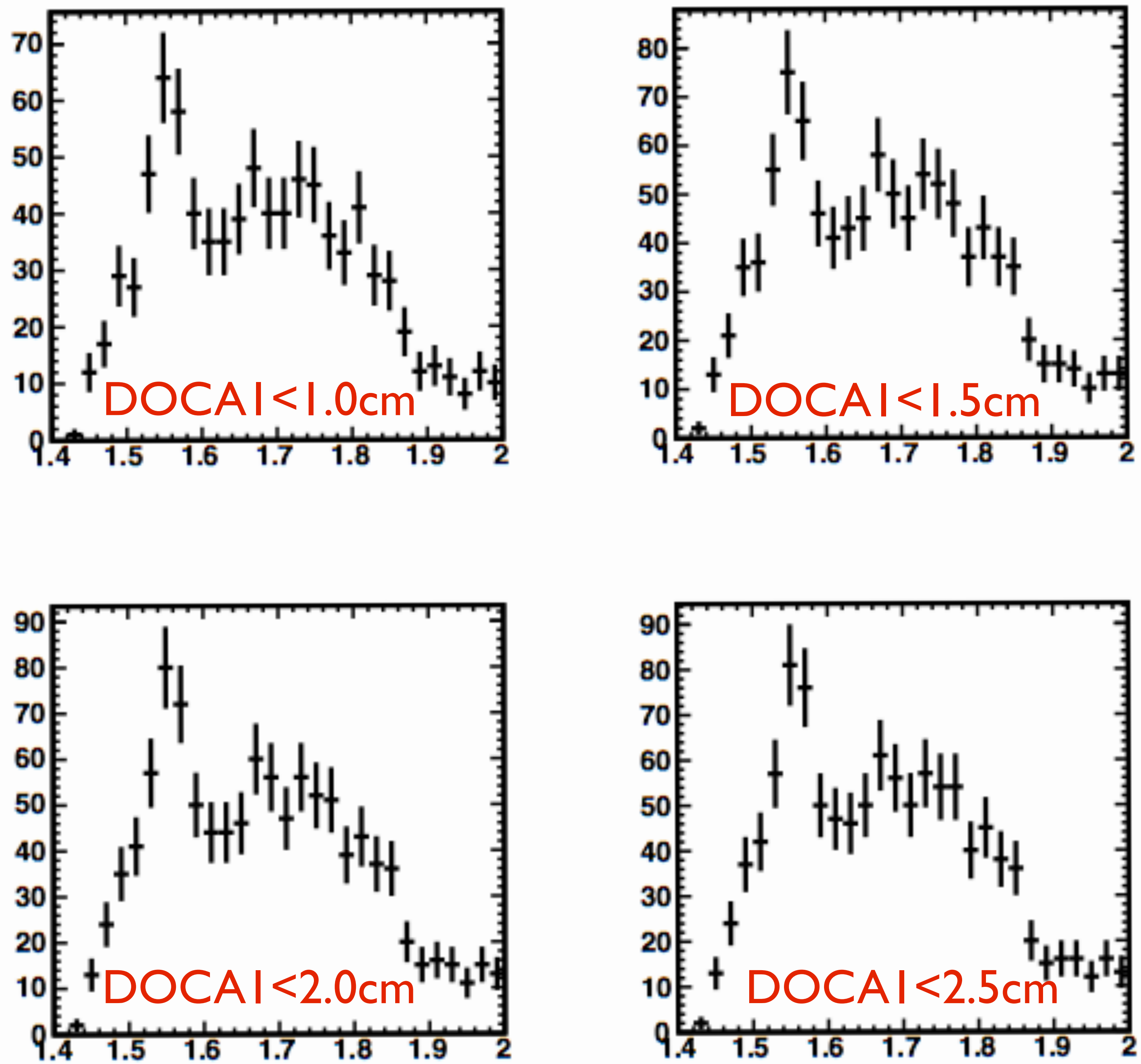
Doca1<1.0cm
Doca2<0.5cm
d>3cm

M(pKs)<1.52GeV

Mx(p)> 1.035 GeV

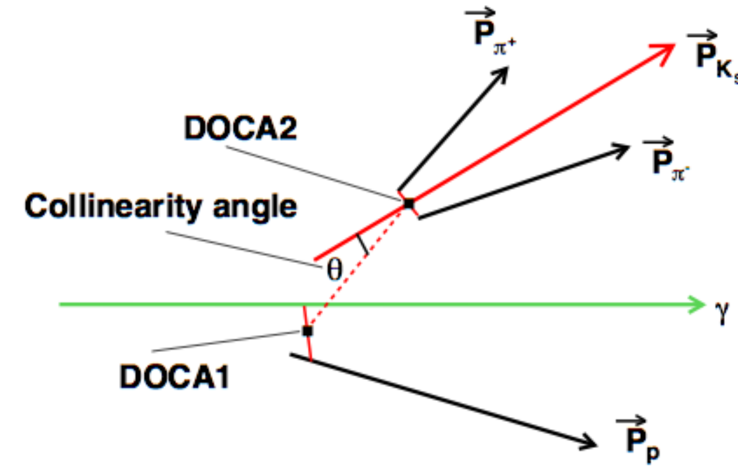
Mx(Ks) [GeV] Mx(Ks) [GeV]

How stable is a peak vs DOCA1-cut?



Mx(Ks) [GeV]

Mx(Ks) [GeV]



DOCA2<0.5cm

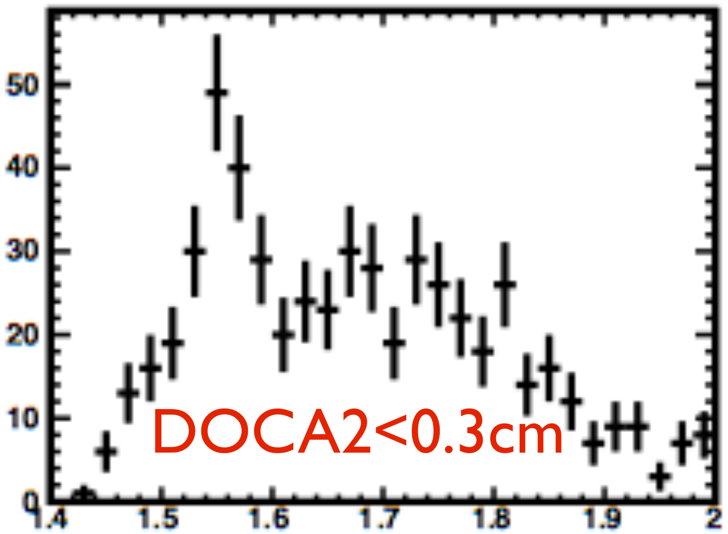
d>3cm

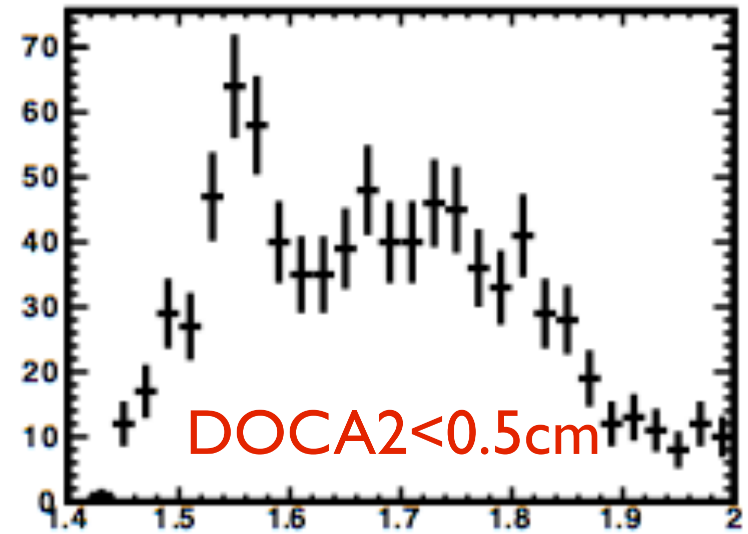
cosΘ>0.98

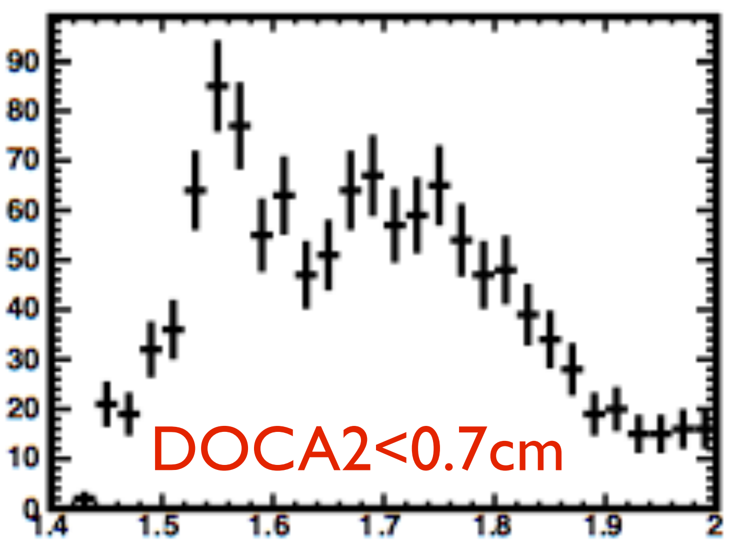
Mx(p)> 1.035GeV

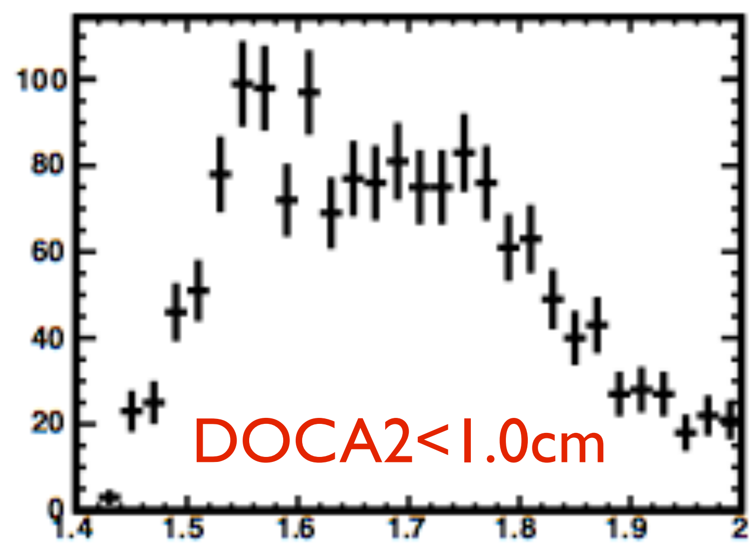
M(pKs)<1.52GeV

How stable is a peak vs DOCA2-cut?

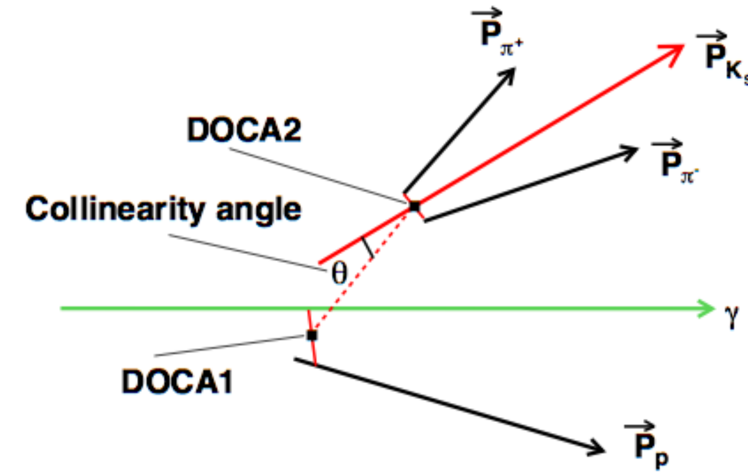








Mx(Ks) [GeV] Mx(Ks) [GeV]



DOCA1<1.0cm

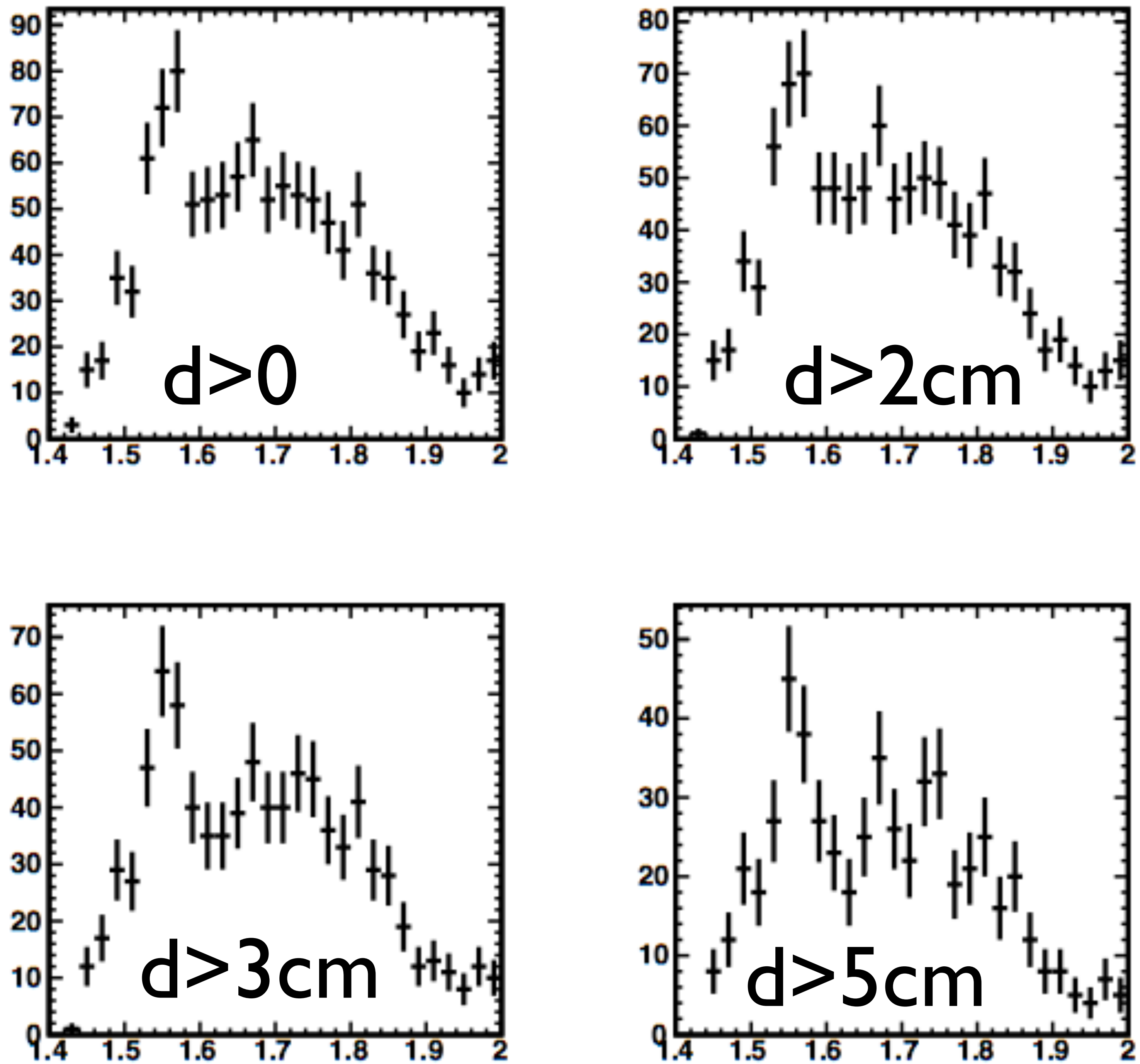
d>3cm

cosΘ>0.98

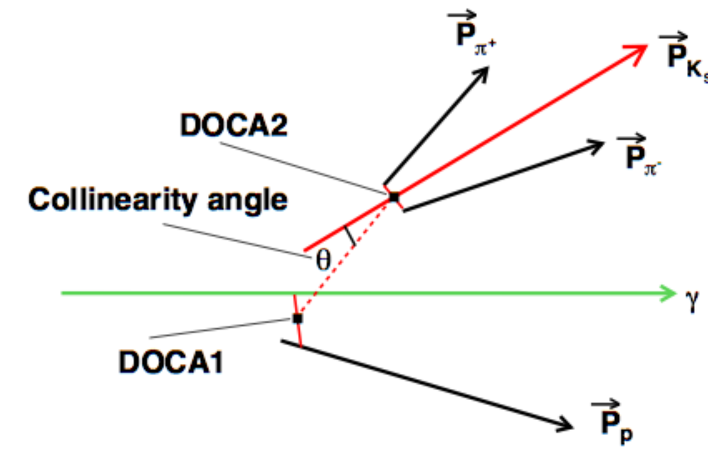
Mx(p)> 1.035GeV

M(pKs)<1.52GeV

How stable is a peak vs Decay distance-cut?



Mx(Ks) [GeV]   Mx(Ks) [GeV]

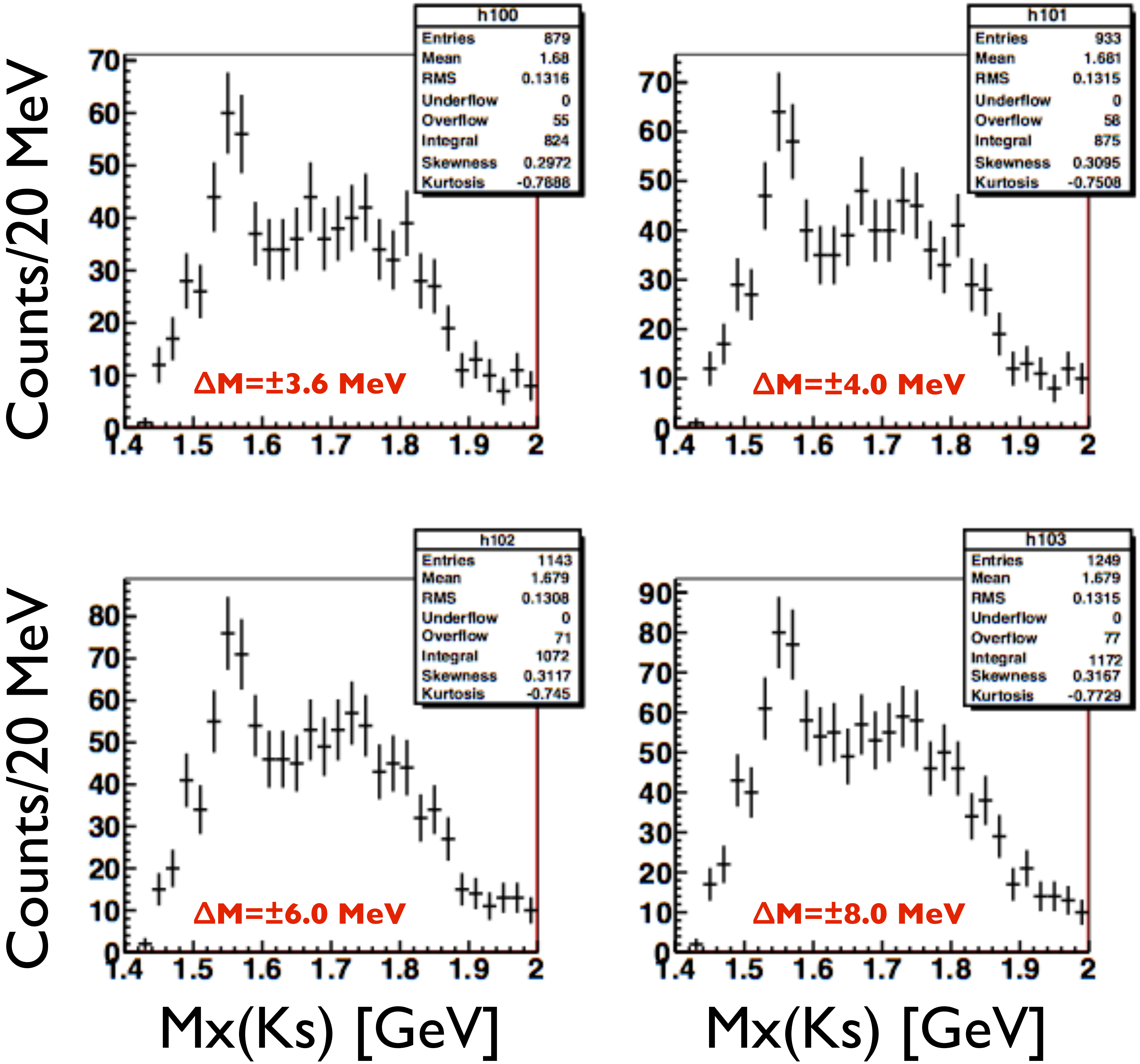


DOCA1<1.0cm
DOCA2<0.5cm
cosΘ>0.98

Mx(p)> 1.035GeV

M(pKs)<1.52GeV

How stable is a peak vs ΔM(π+π-) cut around Ks?



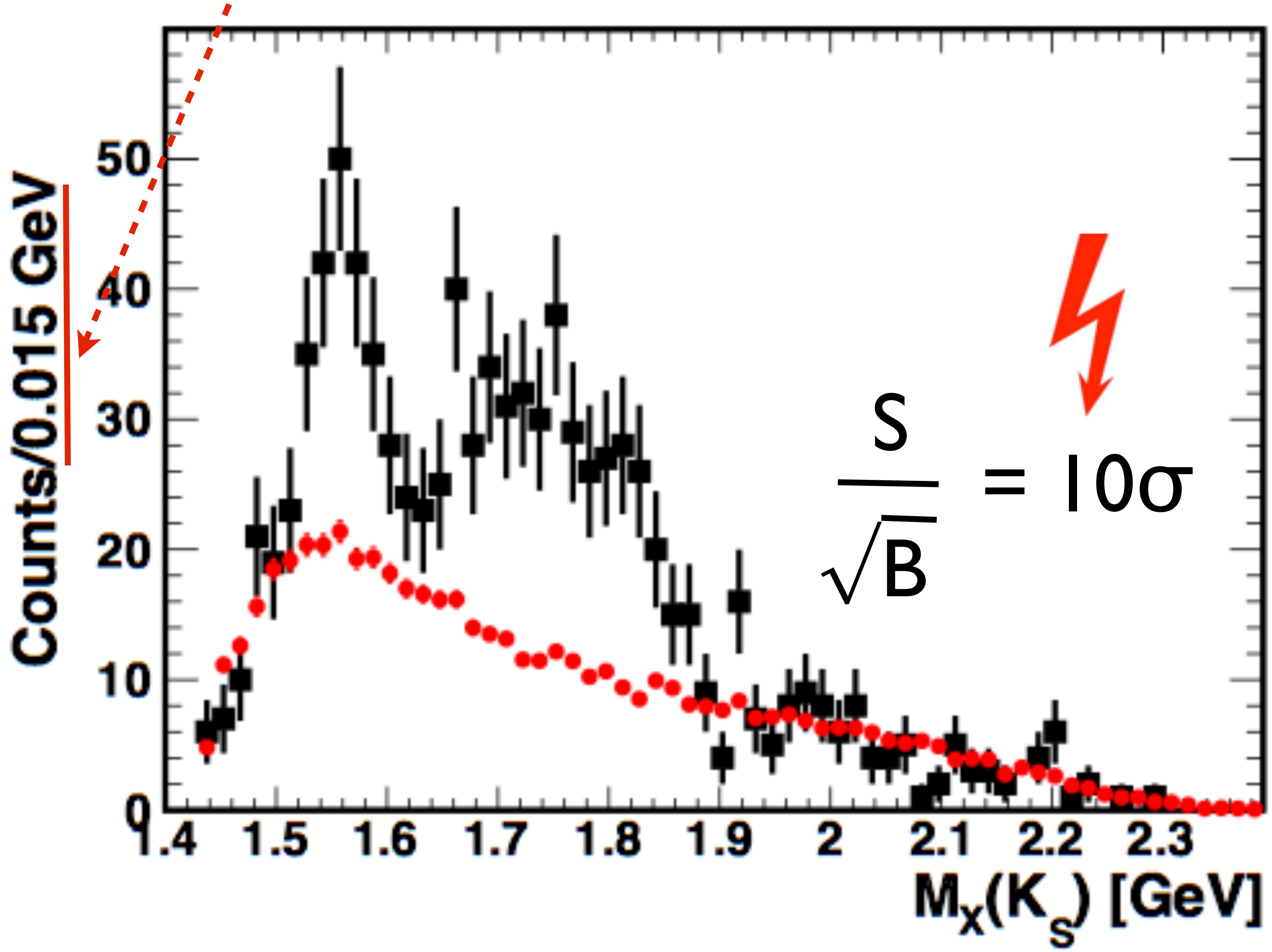
Don’t panic!

No tuning!

all other cuts the same

“Le doute n'est pas une condition agréable, mais la certitude est absurde.” Voltaire

What if we change the binning?



$$\frac{S}{\sqrt{B}} = 10\sigma$$

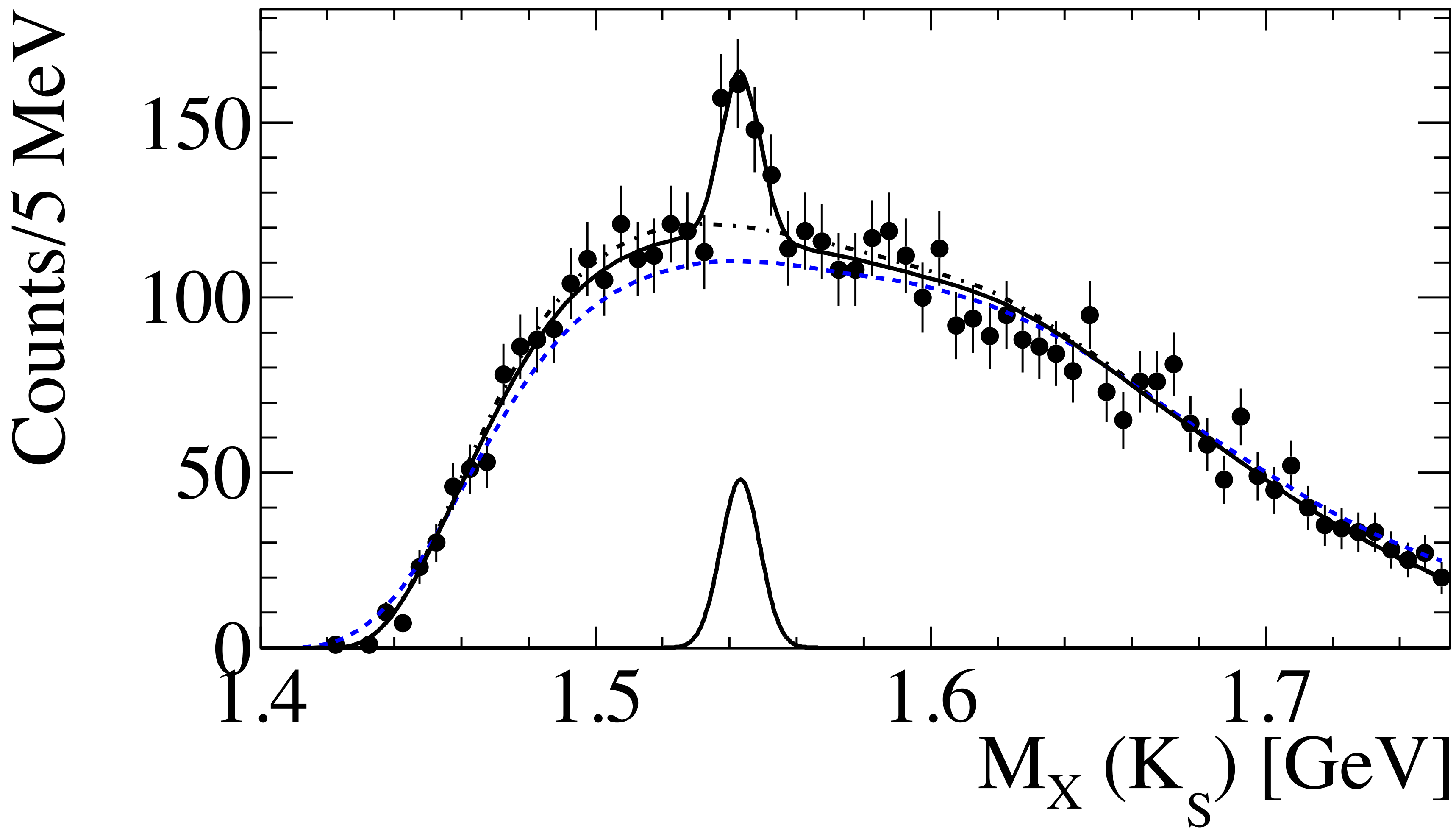
And Finally:

10σ !

From our previous paper

arXiv: 1110.3325v1

PHYSICAL REVIEW C 85, 035209 (2012)

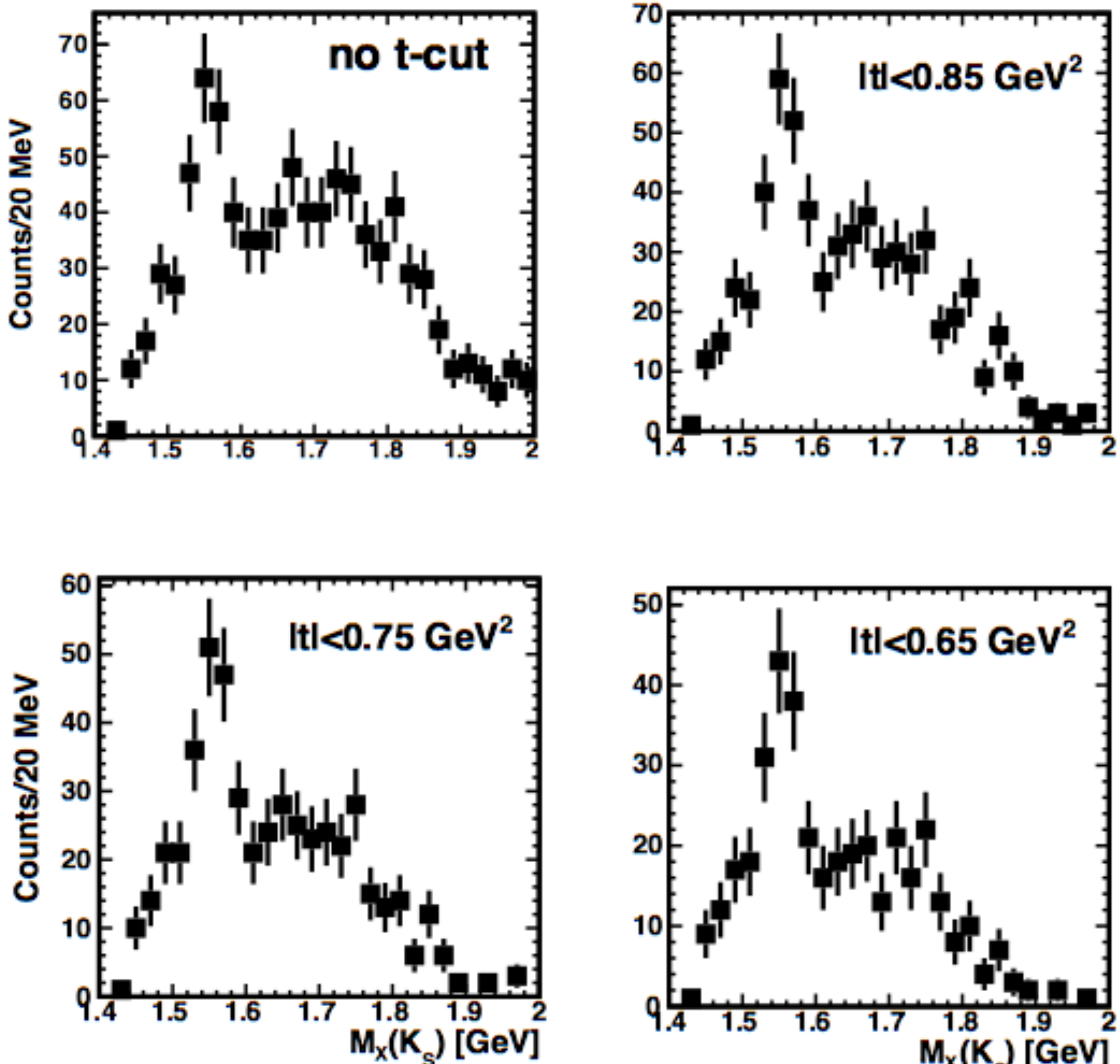


Interference with ϕ at low $t<0.45$ GeV^2

We hypothesized strong t dependence

Can we see it now?

How peak changes vs t-cut?



For illustration purposes only:

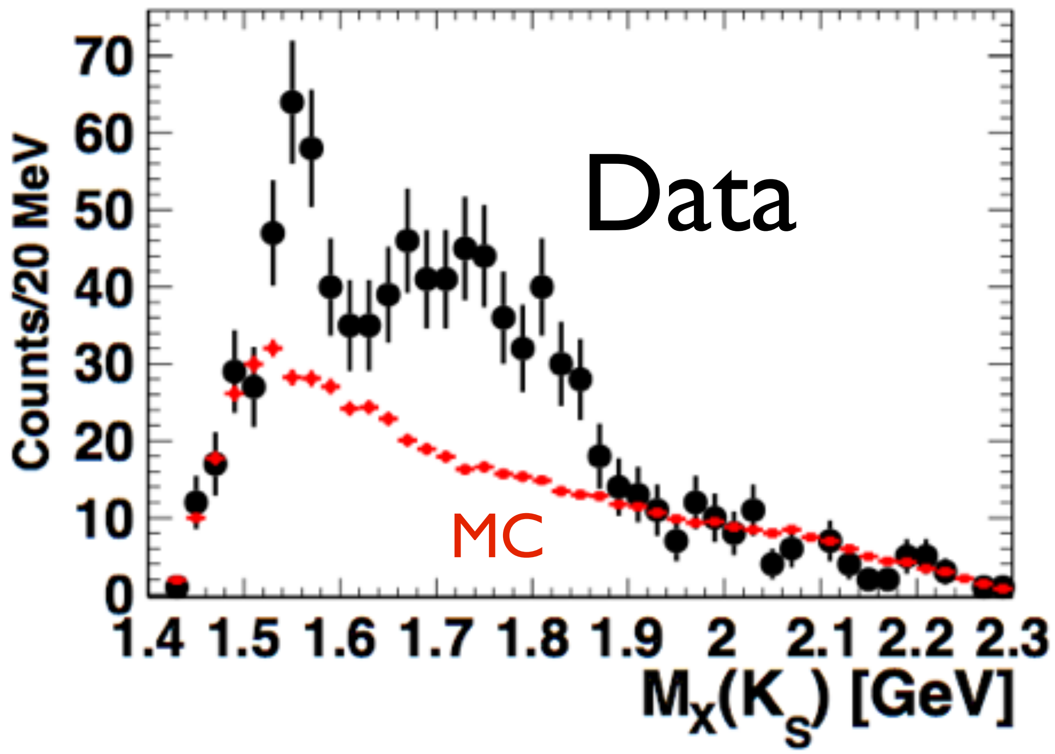
now we do not need this cut

However:

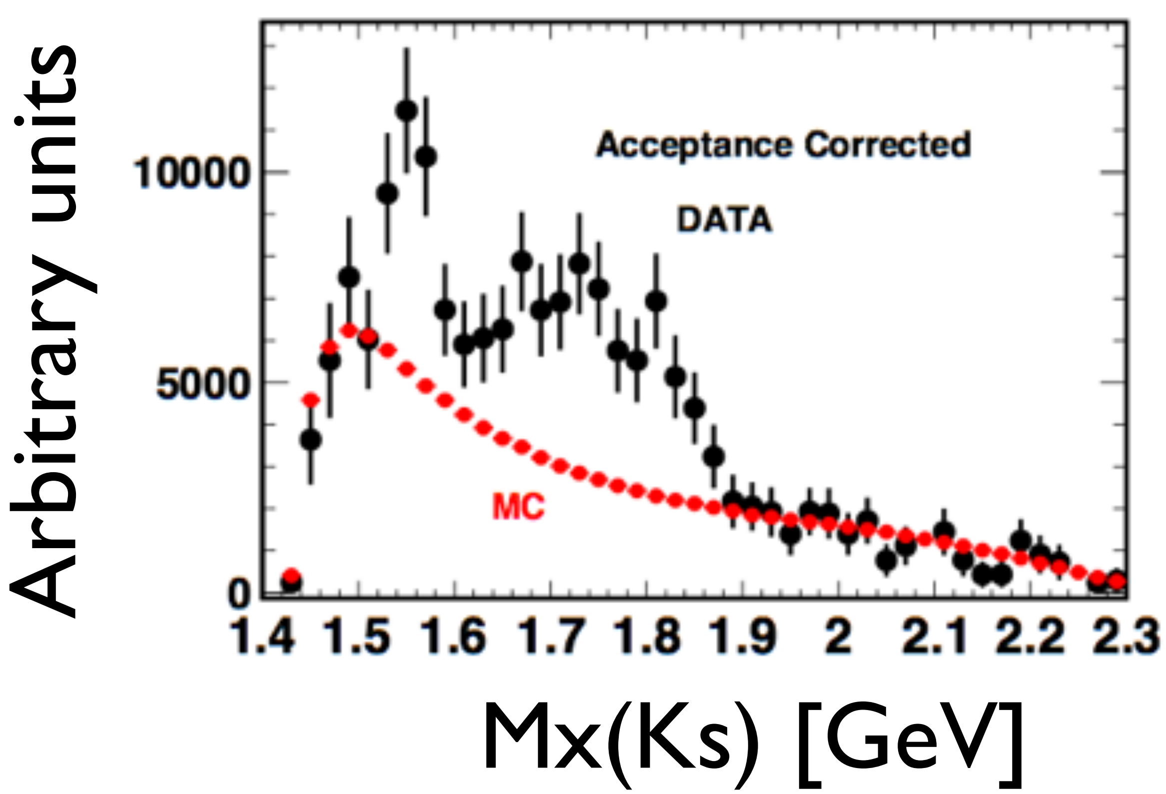
We see **sharper t-dependence** for the peak at ~1.55 GeV (it is less affected by the t-cut)

compared to (higher mass region) of Σ^*'s **with shallower t-dependence**

The Effect of the CLAS Acceptance



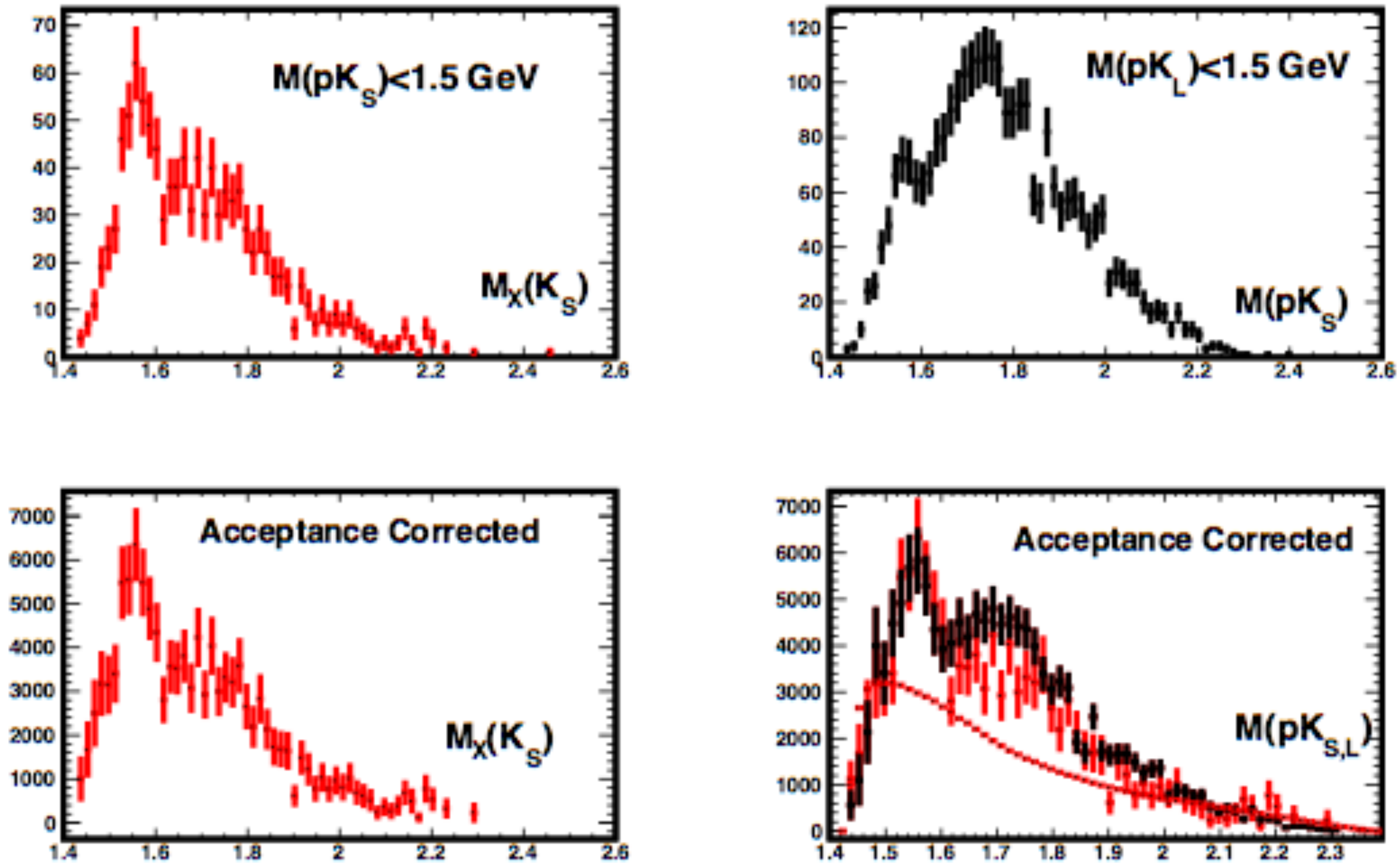
No acc. correction: sharp decrease near threshold



Acceptance corrected

Peak at ~1.55GeV is very robust

How about invariant mass M(pKs) ?



Same cuts:

DOCA1<1.0cm

DOCA2<0.7cm

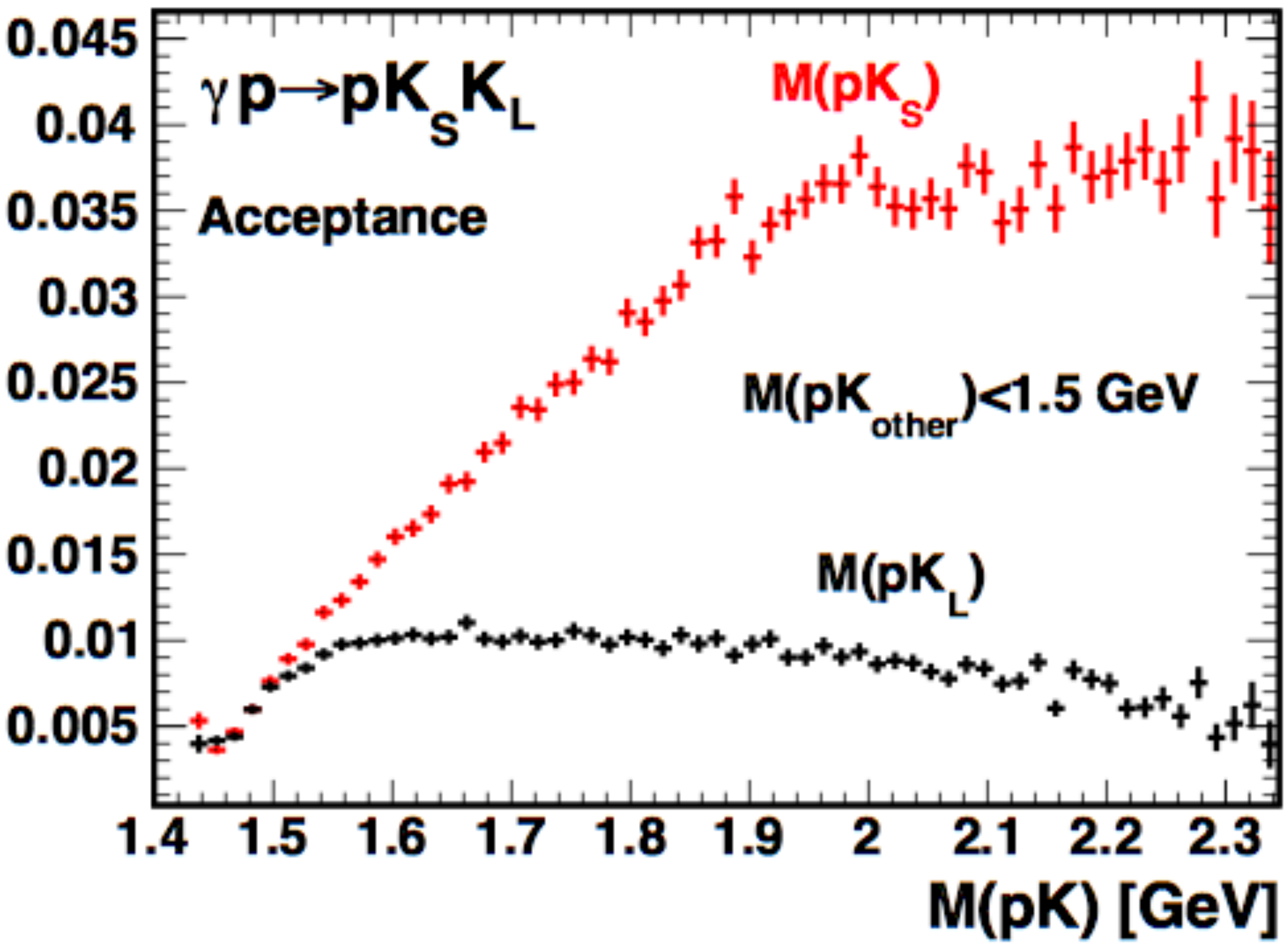
$\cos\theta>0.95$

d>3cm

Mx(p)>1.035GeV

We see a signal in both channels

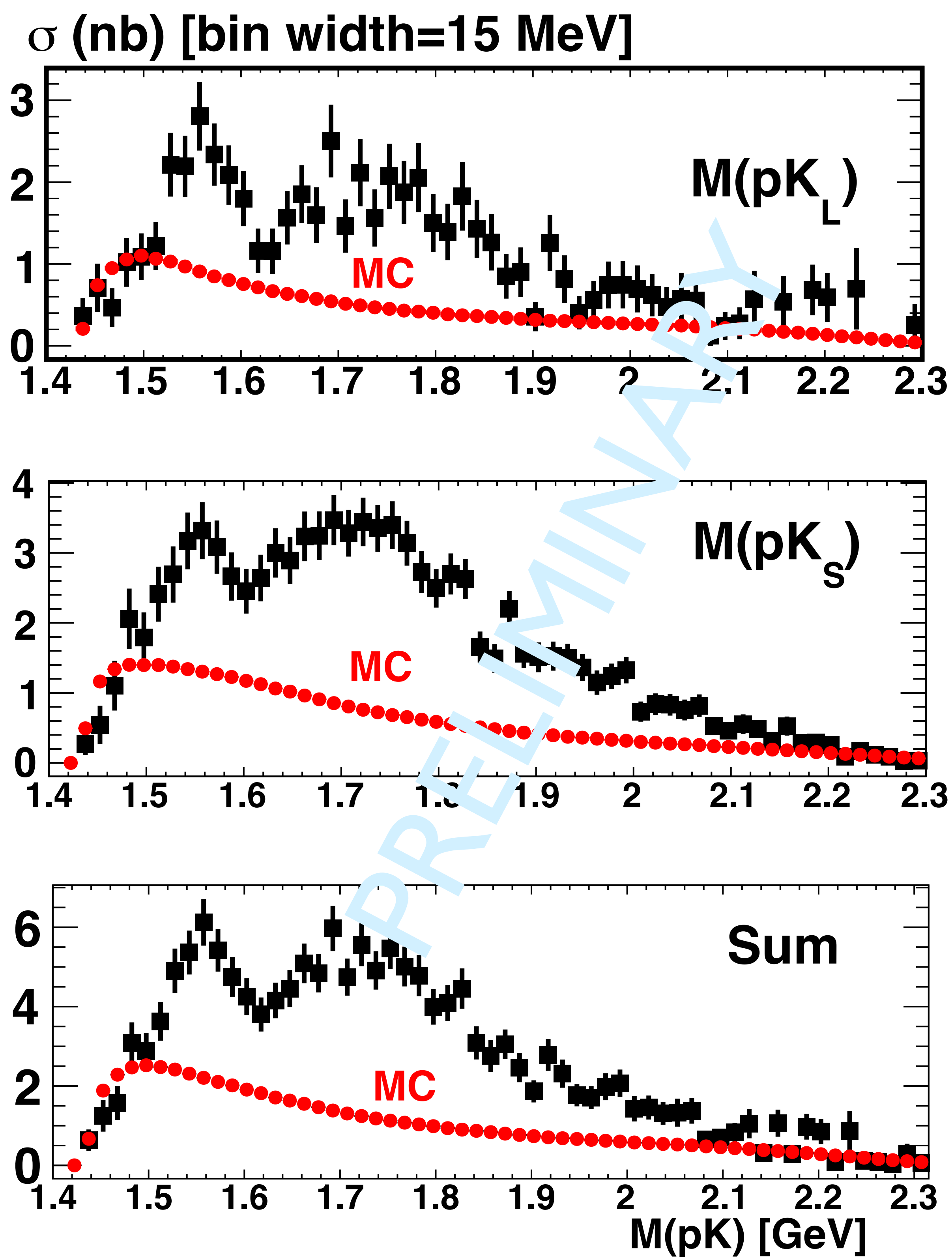
CLAS Acceptance for observed signals



It is very different for pK_S and pK_L

Therefore huge peak at higher masses (see previous slide)

Cross Section



in a 4MeV bin CLAS upper limit was 2nb (for Eγ~2GeV)

now per 4MeV we have (if calculated similarly) σ_{max}=1nb

Br[Ks(π+π-)]=69%

Br[Ks(K°)]=50%

Br[Θ+(pK°)]=50%

total cross section over Θ peak:

σ=20 ± 7 nb

Conclusions

- Narrow resonance in pK system is observed for the first time in a direct photo-production in CLAS
- Statistical significance of the peak is $\sim 10\sigma$
- Strangeness of the state is not fixed
- Observed peak could be either due to pentaquark Θ^+
- Or previously unobserved excited hyperon state
- Observation of narrow peak at M(pK)~1.545 GeV

via interference with ϕ

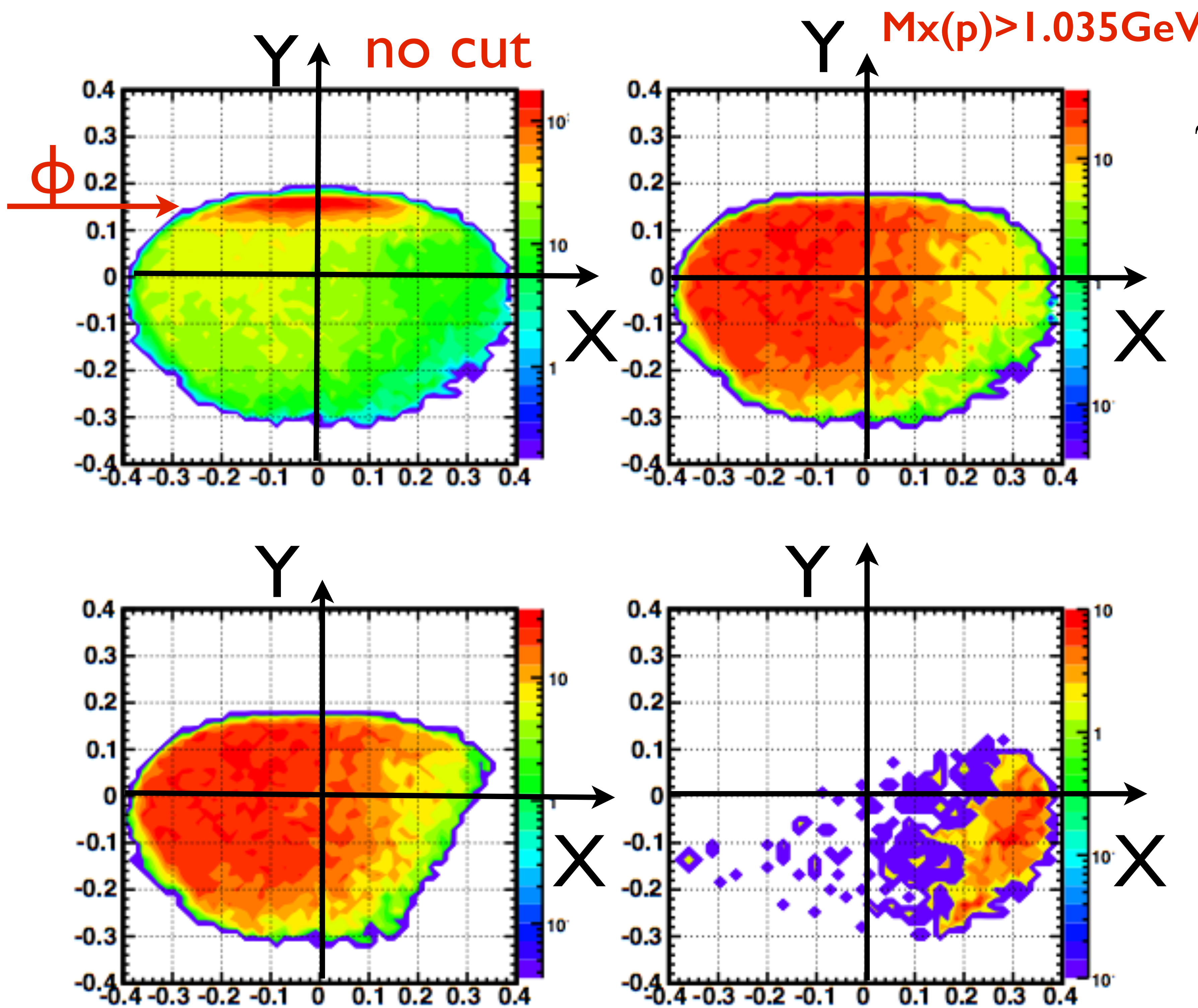
and in a direct production in both pKs and pKL channels

Provides very strong confidence that the observed signal is real

- Preliminary estimation of the cross section is consistent with CLAS upper limit and integrated over the peak is

σ=20+-7nb

Backup: Classic Dalitz Plots



M(pKs)>1.52GeV

M(pKs)<1.52GeV

$\gamma p \rightarrow 1+2+3 \rightarrow K_S K_L p$

$Q = T_1 + T_2 + T_3$

T_i - KE in CM

$$Y = \frac{T_3}{Q} - \frac{1}{3}$$

$$X = \frac{T_2 - T_1}{\sqrt{3}\,Q}$$

it is insufficient
to cut out ϕ only