PRD 91 (2015) 057101

Pentaquark Θ^+ search at HERMES

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on behalf of the HERMES Collaboration

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Outline

- Significances of Θ^+ (if seen)
- HERMES experiment
- Previous and present results from deuterium target
- Results from hydrogen target
- Summary

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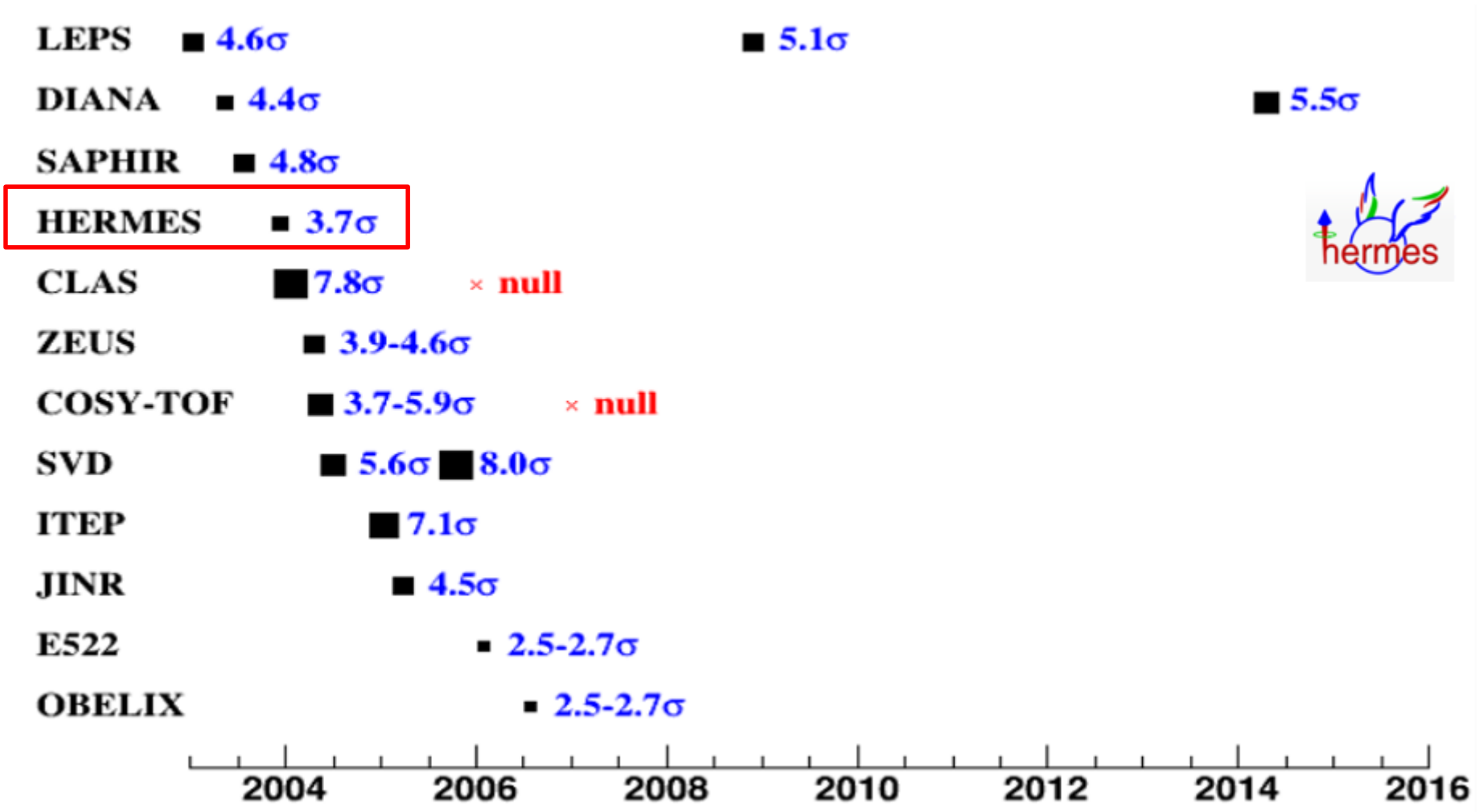
Significances of Θ^+(Groups ever announced positive results)



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Groups with Negative Results (now)

Group	Reaction	Mode	Upper limit	Confidence
CLAS	$\gamma d \to pK^-K^+n$	K^+n	$\sigma < 0.3$ nb	95%
	$\gamma d \to \Lambda K^+n$	K^+n	$\sigma < 5$ nb	95%
	$\gamma p \to \overline{K}^0K^+n$	K^+n	$\sigma < 0.8$ nb	95%
			$N(\Theta^+)/N(\Lambda(1520)) < 0.22\%$	95%
	$\gamma p \to \overline{K}^0K^0p$	K^0_Sp	$\sigma < 1.5$ nb	95%
COSY-TOF	$pp \to \Sigma^+K^0p$	K^0_Sp	$\sigma < 0.15$ μb	95%
FOCUS	γBeO $\to pK^0_SX$	K^0_Sp	$\sigma(\Theta^+)\mathcal{B}(pK^0_S)/\sigma(K(892)^+) < 0.13\%$	95%
			$\sigma(\Theta^+)\mathcal{B}(pK^0_S)/\sigma(\Sigma(1385)^\pm) < 2.3\%$	95%
NOMAD	$\nu_\mu A \to K^0_SpX$	K^0_Sp	$N(\Theta^+)/N_{\text{events}} < 2.13 \times 10^{-3}$	90%
BES	$\psi(2S), J/\psi$ decays	K^+n, K^0_Sp	see Eq.(2)	90%
BaBar	$e^+e^- \to \Upsilon(4S) \to pK^0_SX$	K^0_Sp	$N(\Theta^+)/N_{\text{events}} < 1.8 \times 10^{-4}$	95%
	$e^+e^- \to q\bar{q} \to pK^0_SX$	K^0_Sp	$N(\Theta^+)/N_{\text{events}} < 5.0 \times 10^{-5}$	95%
	$B^0 \to p\bar{p}K^0_S$	K^0_Sp	$\mathcal{B}(\Theta^+) \cdot \mathcal{B}(pK^0_S) < 0.5 \times 10^{-7}$	95%
Belle	$B^0 \to p\bar{p}K^0_S$	K^0_Sp	$\mathcal{B}(\Theta^+) \cdot \mathcal{B}(pK^0_S) < 2.3 \times 10^{-7}$	90%
	$KN \to pK^0_SX$	K^0_Sp	$N(\Theta^+)/N(\Lambda(1520)) < 2.5\%$	90%
	$K^+n \to pK^0_S$	K^0_Sp	$\Gamma < 0.64$ MeV	90%
ALEPH	$Z \to pK^0_SX$	K^0_Sp	$N(\Theta^+)/N_{\text{events}} < 2.5 \times 10^{-3}$	95%
DELPHI	$Z \to pK^0_SX$	K^0_Sp	$N(\Theta^+)/N_{\text{events}} < 2.0 \times 10^{-3}$	95%
L3	$\gamma\gamma \to p(\bar{p})K^0_SX$	K^0_Sp	$N(\Theta^+)/N_{\text{events}} < 4.7 \times 10^{-3}$	95%
H1	$ep \to ep(\bar{p})K^0_S$	K^0_Sp	$\sigma < 120 - 360$ pb	95%
COSY-Jülich	$pp \to pK^0\pi^+\Lambda$	K^0p	$\sigma < 58$ nb	95%
NA49	$pp \to pK^0_SX$	K^0_Sp	not observed	–
CDF	$p\bar{p} \to pK^0_SX$	K^0_Sp	$N(\Theta^+) < 89, 76$	90%
HERA-B	pC $\to pK^0_SX$	K^0_Sp	$N(\Theta^+)/N(\Lambda(1520)) < 2.7\%$	95%
SPHINX	$pN \to nK^+K^0_SN$	K^+n	$\sigma < 26$ nb	90%
	$pN \to pK^0_SK^0_LN$	K^0_Sp	$\sigma < 42$ nb	90%
	$pN \to pK^0_LK^0_SN$	K^0_Lp	$\sigma < 39$ nb	90%
	$pN \to pK^0_SK^0_SN$	K^0_Sp	$\sigma < 52$ nb	90%
PHENIX	dAu $\to K^-\bar{n}X$	$K^-\bar{n}$	not observed	–
HyperCP	$p(\pi^+, K^+)$Cu $\to p(\bar{p})K^0_SX$	K^0_Sp	$N(\Theta^+)/N_{\text{events}} < 0.3\%$	90%
LASS	$K^+p \to K^+n\pi^+$	K^+n	no narrow resonance	–
WA89	Σ^-C(Cu) $\to pK^0_S$	K^0_Sp	$\sigma < 7.2$ μb	99%
E559	$K^+p \to \pi^+X$	–	$d\sigma/d\Omega < 3.5$ μb/sr	90%
J-PARC	$\pi^-p \to K^-X$	–	$d\sigma/d\Omega < 0.26$ μb/sr	90%

Reviewed by Tianbo Liu, Yajun Mao, and Bo-Qiang Ma, *Int. J. Mod. Phys. A* **29** (2014) 1430020

HERA @ DESY

***H**adron-**E**lektron-**R**ing**a**nlage* @ **D**eutsches **E**lektronen-**Sy**nchrotron

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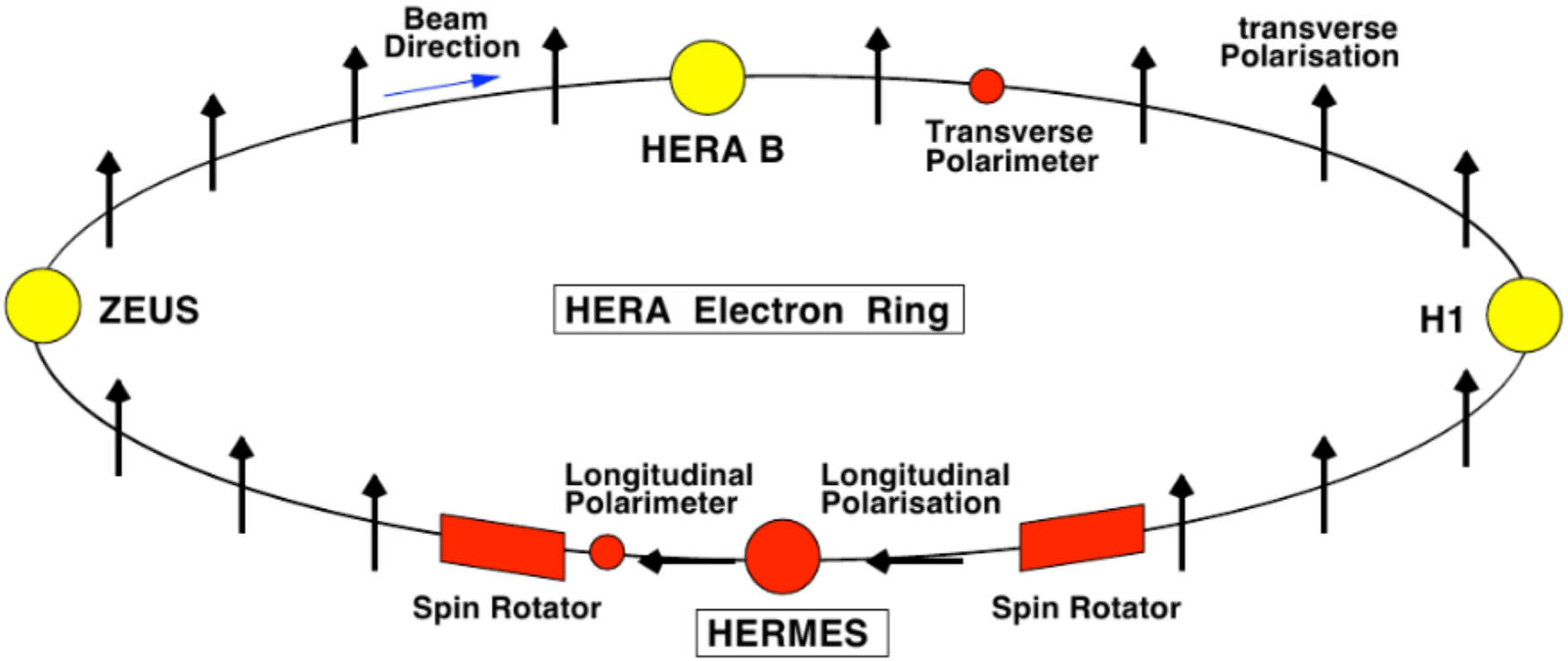
HERMES@HERA



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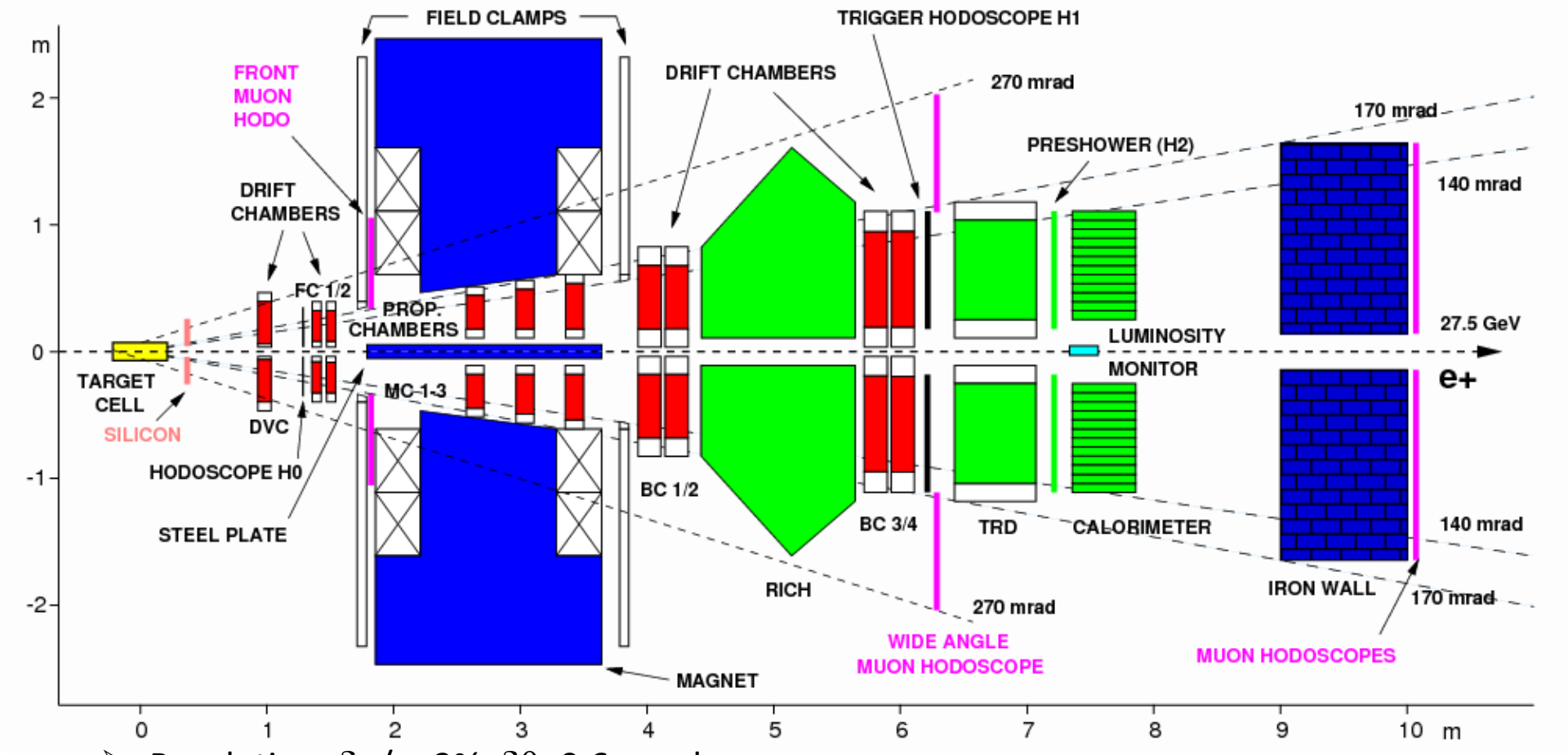
The HERMES Spectrometer



- Resolution: $\delta p/p<2\%$, $\delta\theta<0.6$ mrad
- **Internal Gas Target**: $\overrightarrow{He}$, $\vec{D}$, $\vec{H}$, $H^{\uparrow}$ unpol: H_2, D_2, He, N_2, Ne, Kr, Xe
- Particle Identification: **TRD, Preshower, Calorimeter,**
  →1997:Cherenkov; 1998→:RICH + Muon ID

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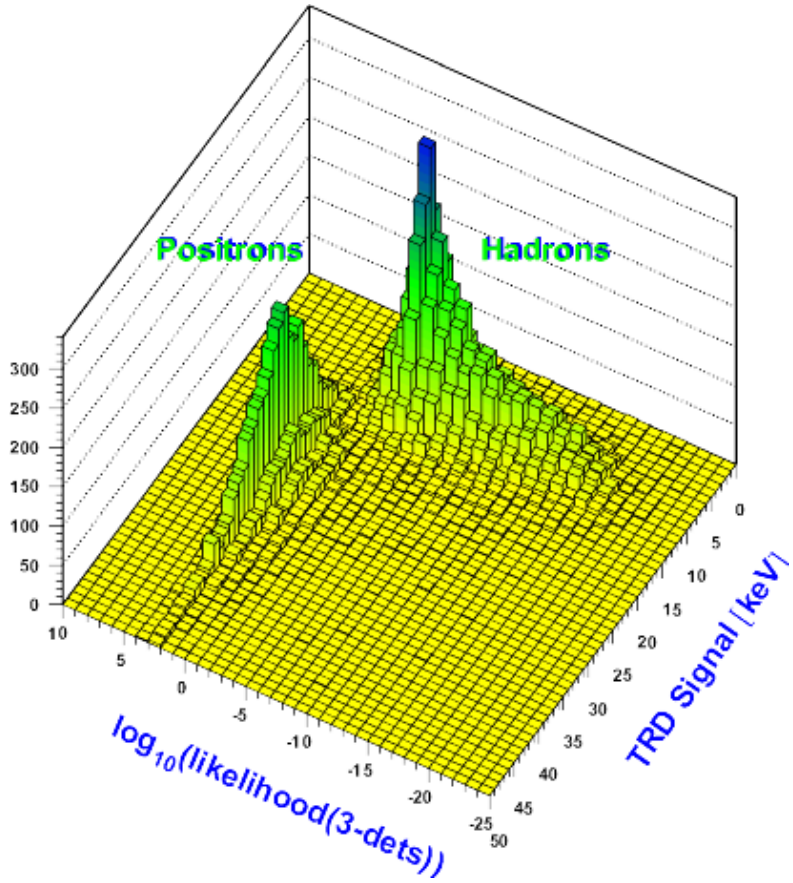
Particle Identification

Hadron/Positron separation:

Combining signals from:

TRD(Transition Radiation Detector),
Calorimeter, **Preshower**, **RICH**



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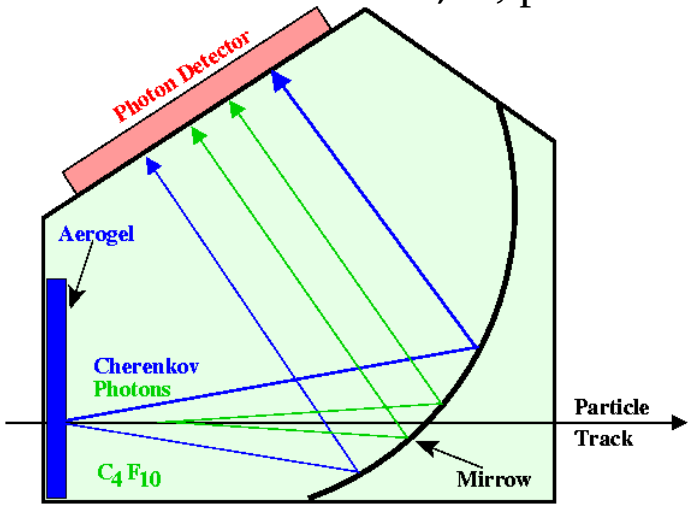
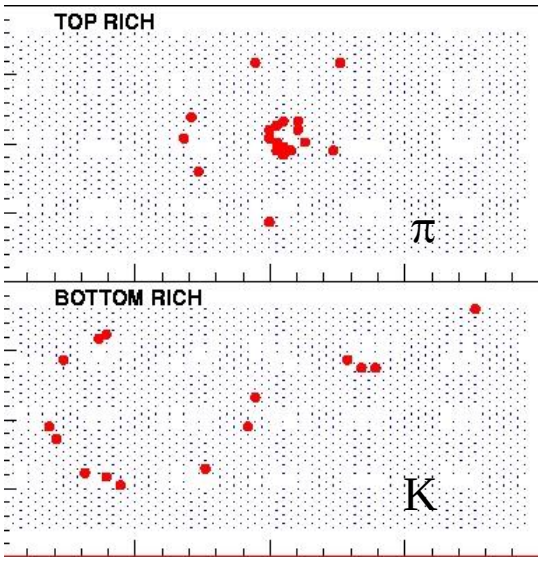
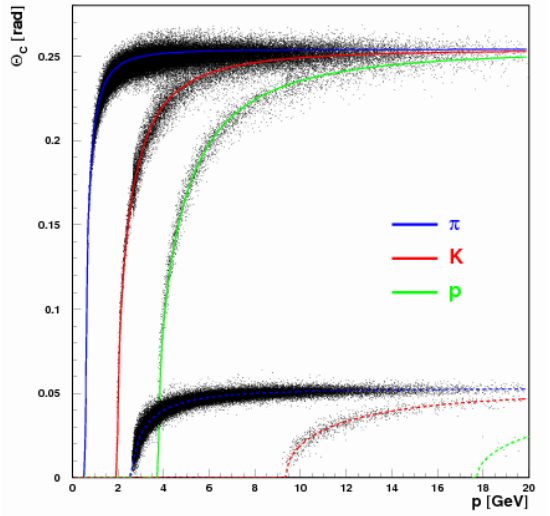
Particle Identification

Dual radiator RICH for π, K, p







Improvements in PID reconstruction:

Old (track level): Track-by-track reconstructed, separately

New(event level): Response pattern of all the tracks present in an event are reconstructed simultaneously, since with multiple tracks Cherenkov rings can overlap and lead to misidentification.

Particle Identification： $cos\Theta = \frac{1}{n}$

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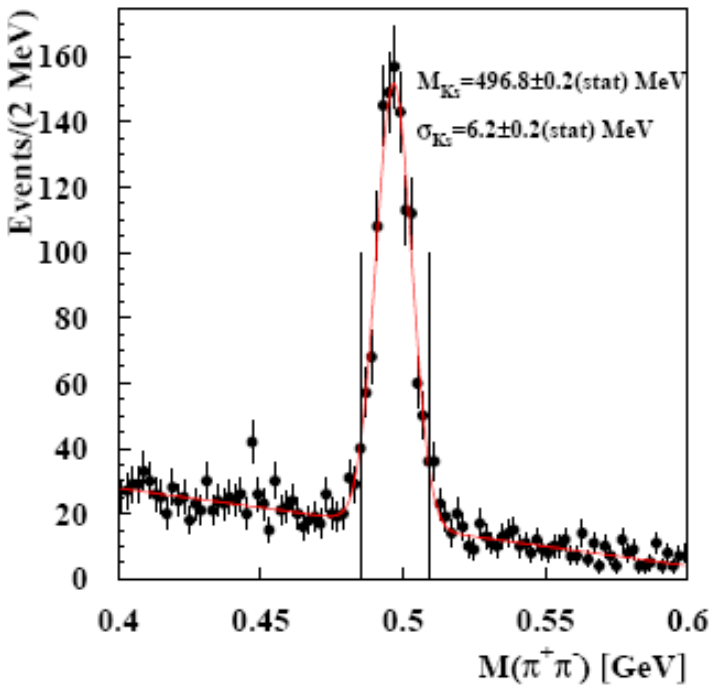
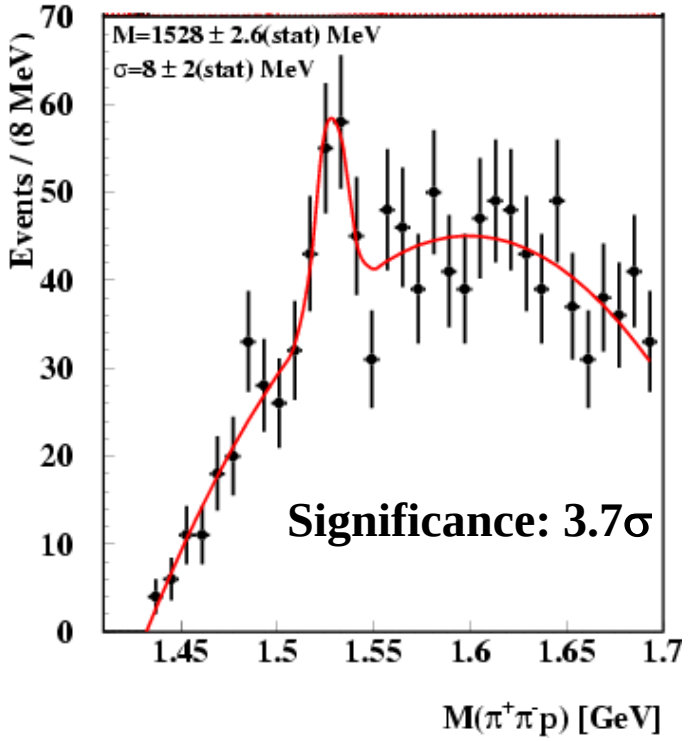
HERMES Result in 2004





1998-2000 D-target published in *Physics Letters B 585 (2004) 213*

How about the spectra with new (improved) data?

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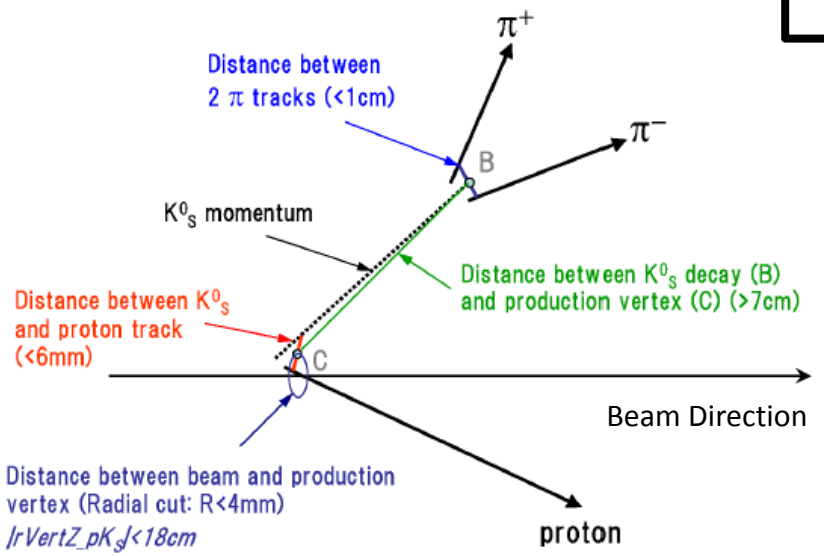
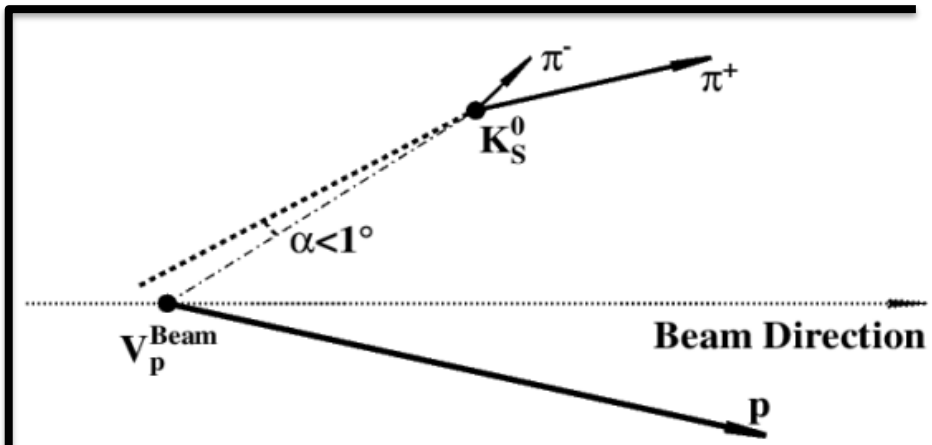
Old and New Topologies for Θ^+ Hunting

$$e^{+/-} + D \rightarrow \Theta^+ + X$$
$$\hookrightarrow pK_S^0 \rightarrow p\pi^+\pi^-$$



Topology in 2004



Topology in 2015

Main Improvements:

- Event-level RICH particle ID
- **Advanced tracking corrections for magnetic fields** and **detector material based on Kalman-filter algorithm** and **new alignment**

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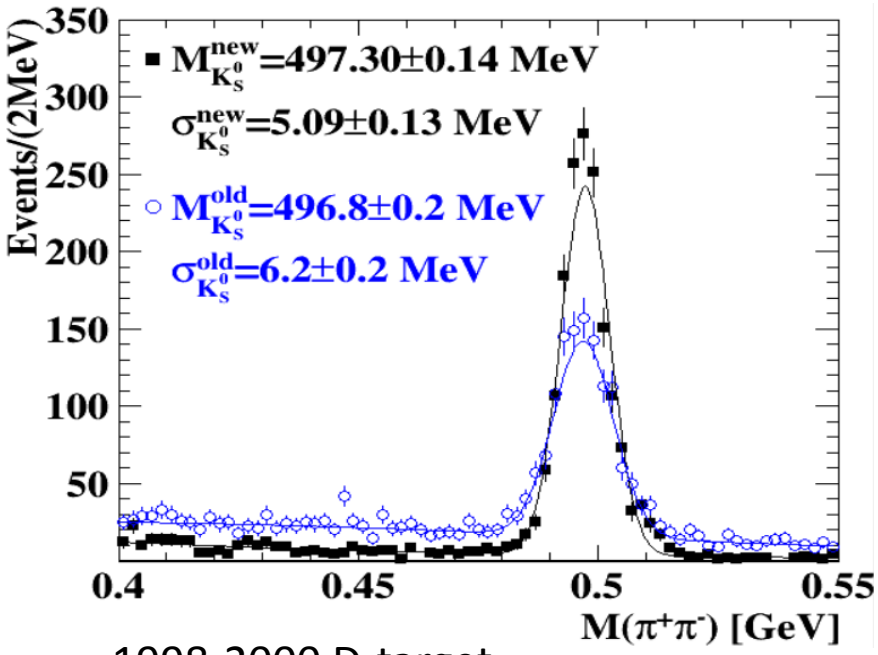
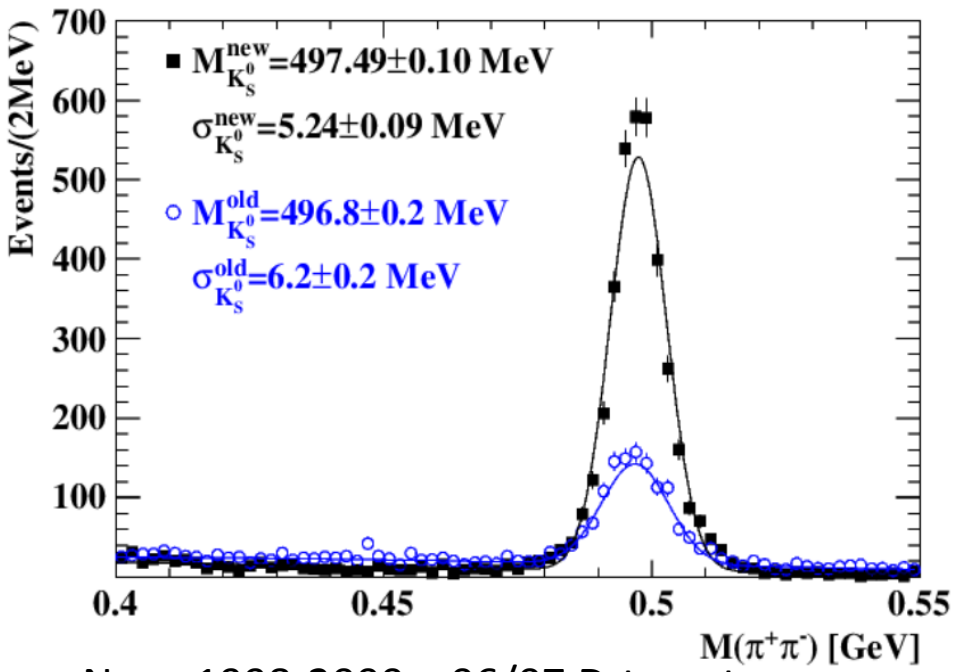
Improved K_S^0

PDG: M(Ks)=497.614±0.024MeV



1998-2000 D-target
With old and New analysis



New: 1998-2000 + 06/07 D-target
Old: 1998-2000 D-target

Analysis Periods	Number Ks S (±2σ)	Number Background B(±2σ)	Purity S/(S+B)
New Analysis(98-00+06/07)	3311±60	87±11	97.4±0.4%
Old Analysis(98-00)	963±38	180±15	84.3±1.3%

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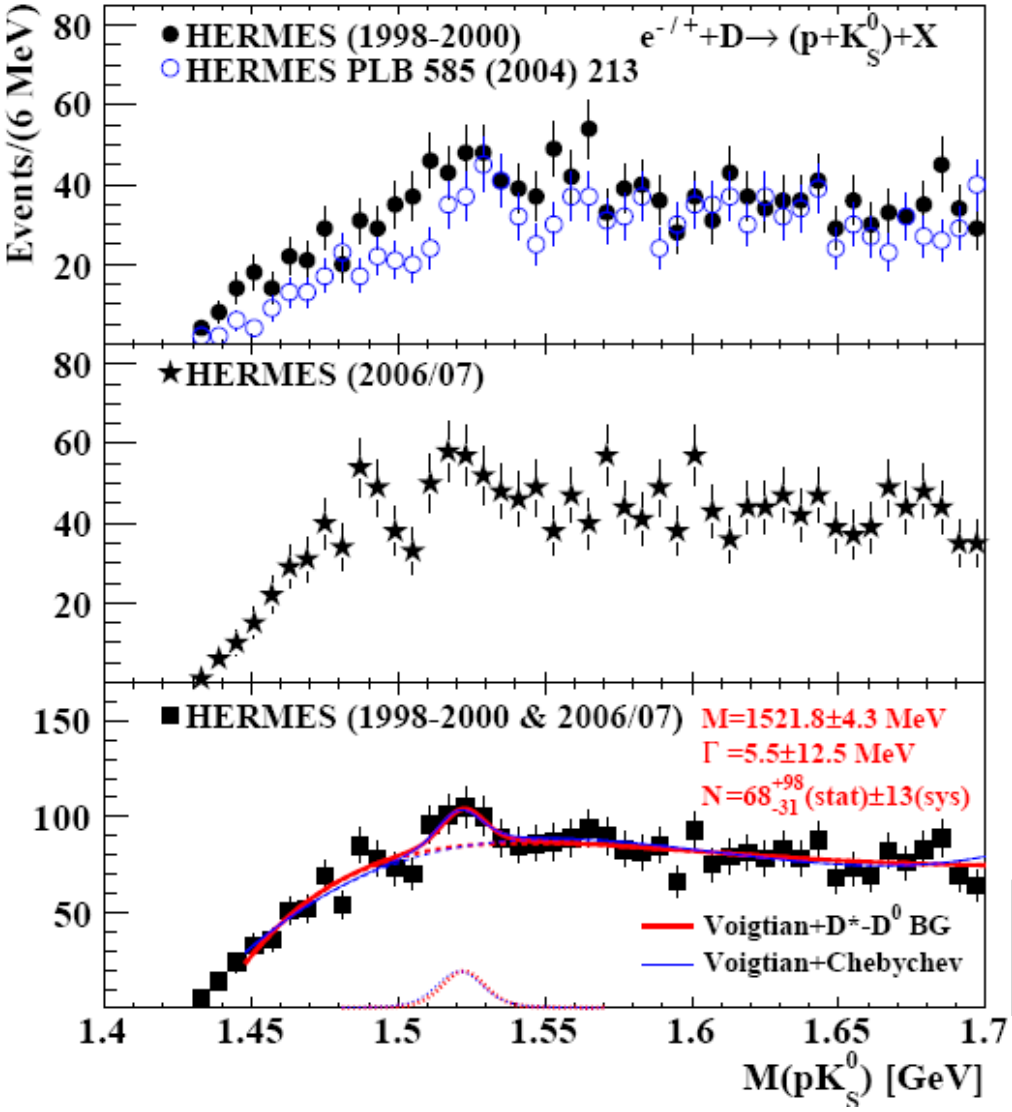
$M(pK_S^0)$ from D-target Data



Systematic uncertainty from:

① Different background shapes

② Fit ranges

③ Bias from the shape studied with Toy-MC to create and fit with Background+Peak functions

Significance: ~2σ

① Δ log-likelihood method gives 1.9σ(average value of different fit ranges)

② Toy-MC to create smooth shape and fit with Background+Peak, gives 2.2σ

Note:
"D^*-D^0 BG" is a function name of RooFit

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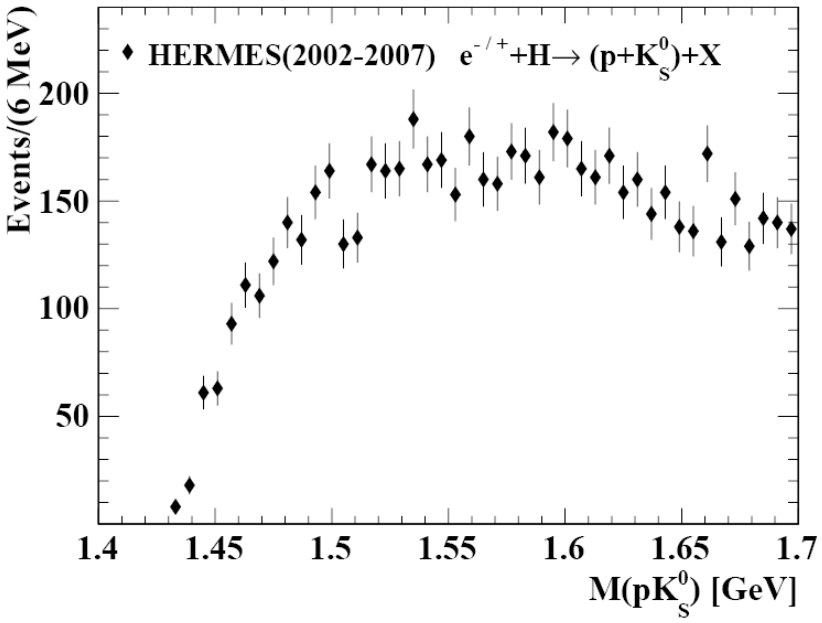
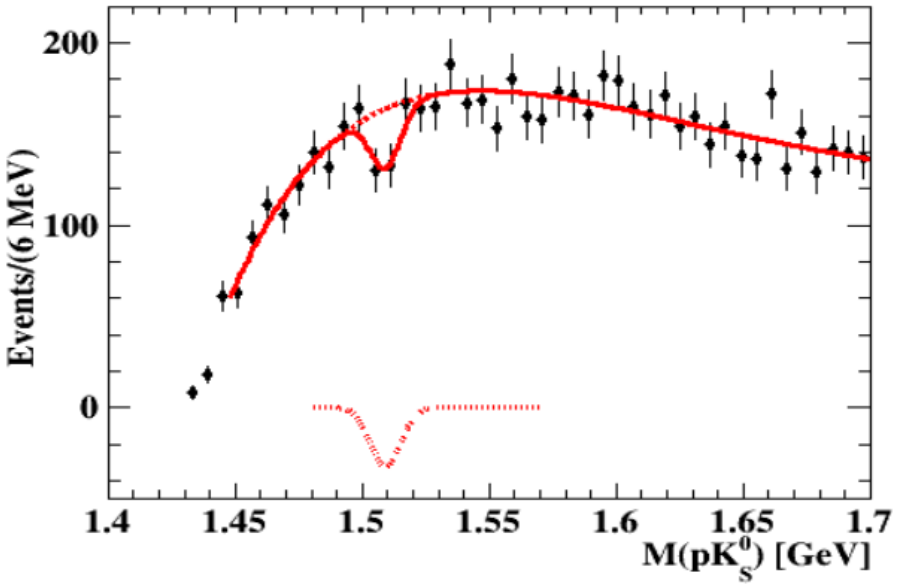
$M(pK_S^0)$ from H-target Data





no structure found in hydrogen data

an attempt to fit gives "negative peak"

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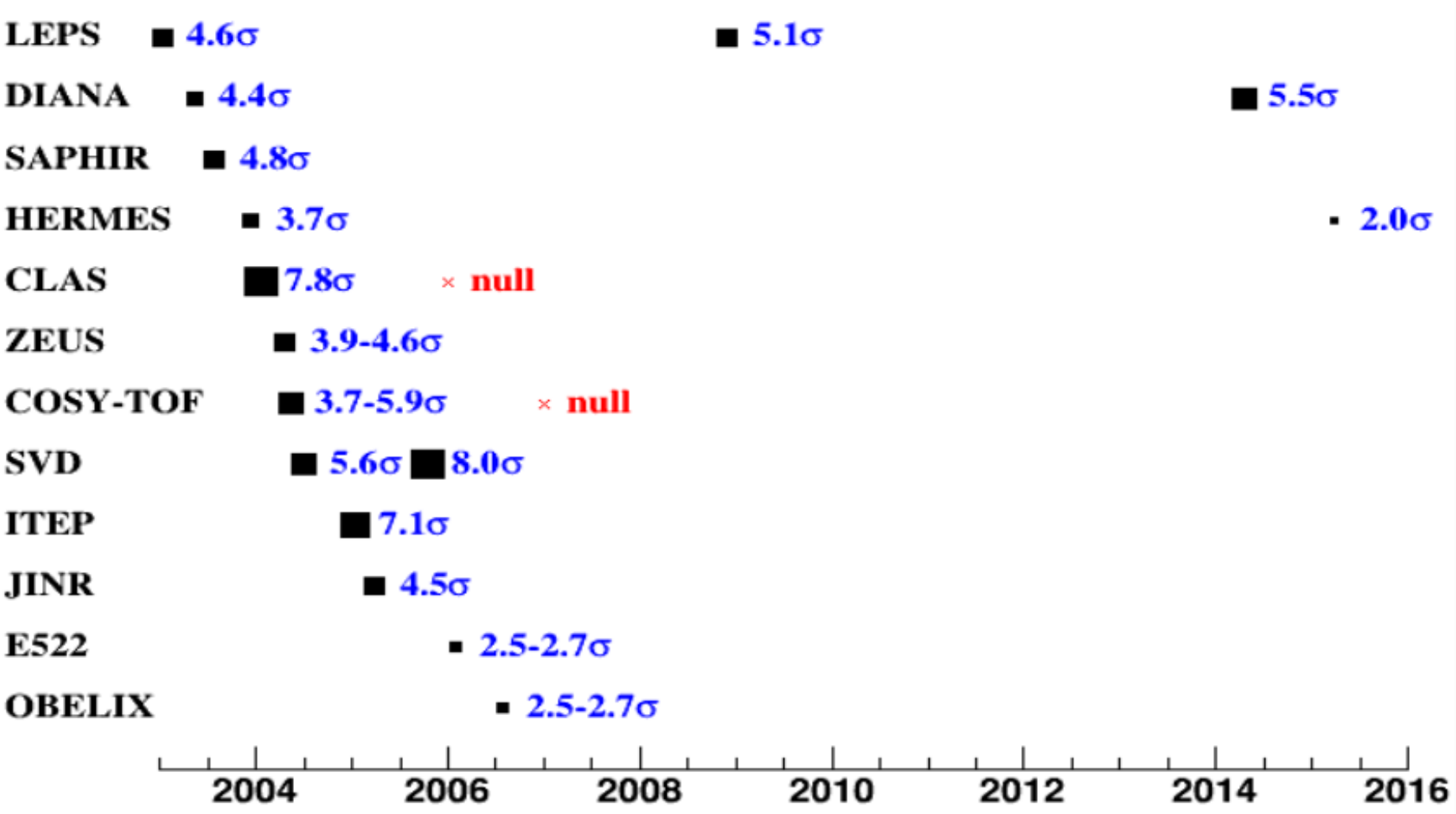
Significances of Θ^+(Groups ever announced positive results)



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Summary

- With the improved HERMES original data set taken in 1998-2000 and also the additional 2006-2007 data on deuterium target, the K_S^0 is obtained with significantly less background and better mass resolution.
- The potential resonance structure in the $M(pK_S^0)$ spectrum near the 1521.8±4.3MeV has a significance ~2σ while it was 3.7 σ at 1528.0±2.6MeV in the old analysis.
- Drop in significance in spite of twice the number of events for the data from a deuterium target does not support the presence of a positive Θ^+ signal at HERMES.
- For the hydrogen data, there is no indication of the existence of an enhancement in the region of interest.

Thanks! 谢谢！

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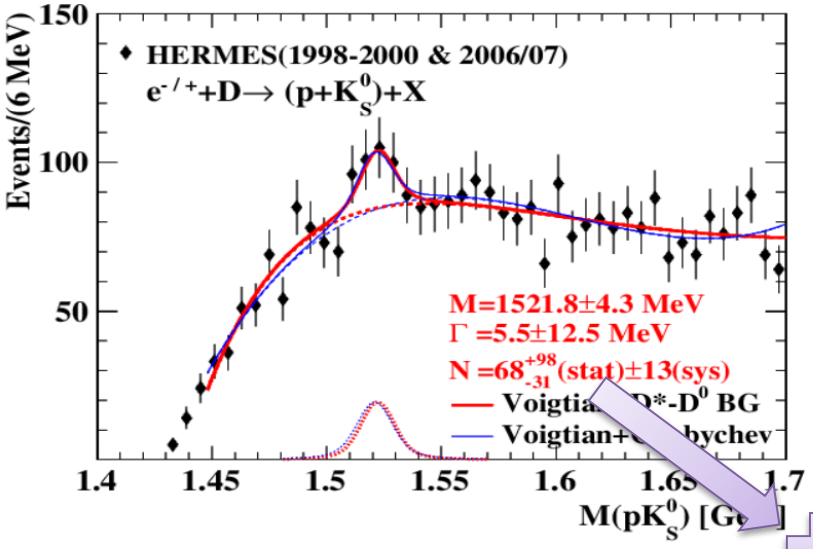
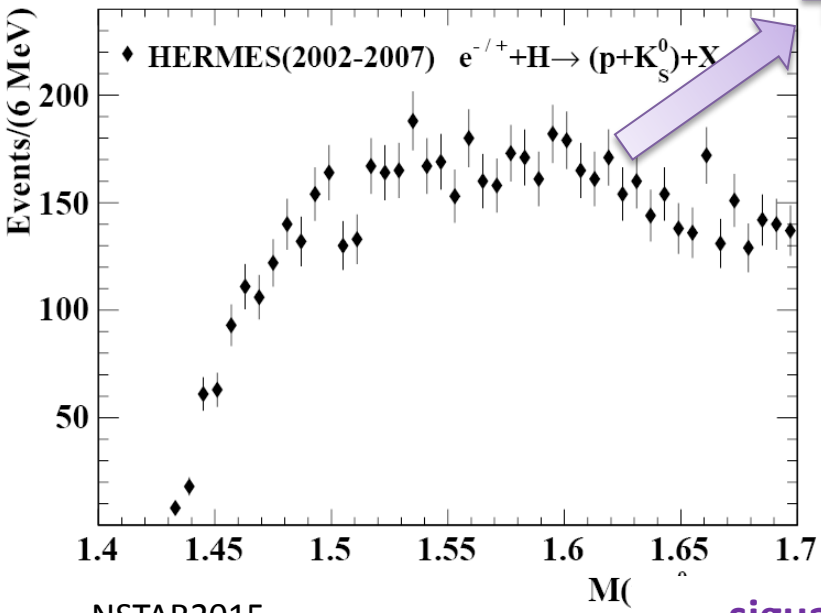
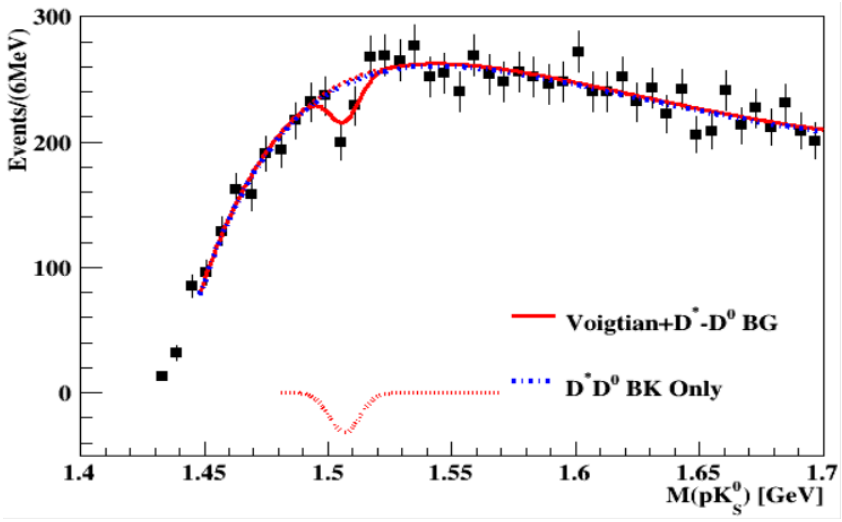
Backup

$M(pK_S^0)$ from D- & H-target Data







to fit the D-target and H-target combined data gives a "negative peak“ again

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CLAS and COSY-TOF Results

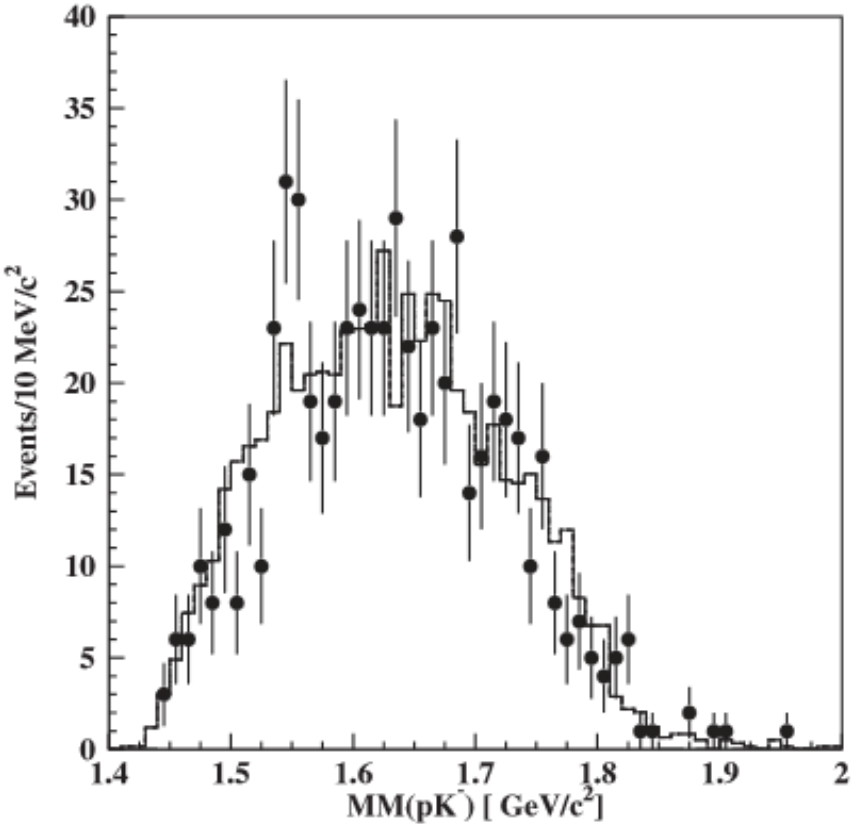

FIG. 5. Comparison of the previously published [8] result (points) with the current result (histogram) normalized (by a factor of 1/5.92) to get the same total number of counts.

CLAS, PRL 96, 212001 (2006)

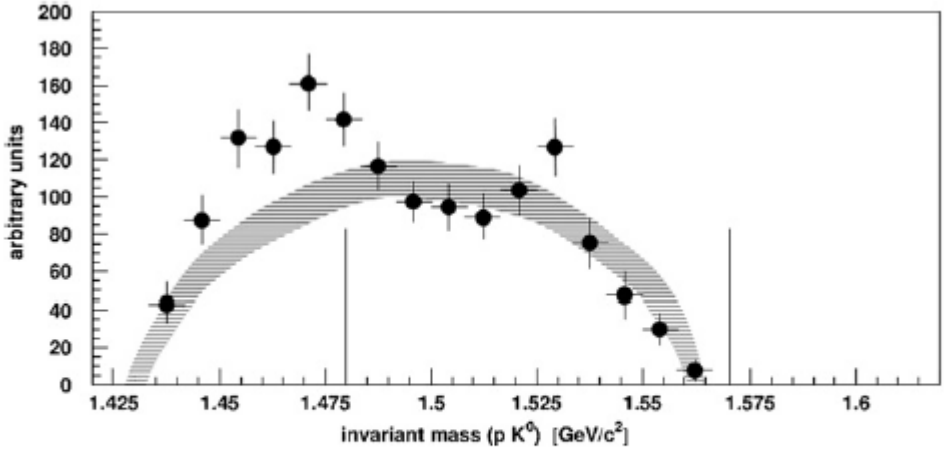

Fig. 5. Invariant mass of the pK^0 spectrum of the previous measurement together with a band representing the shape of the new measurement. The height of the band is adjusted in the mass range indicated by the two vertical lines.

COSY-TOF, Physics Letters B 649(2007) 252-257

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LEPS (2009)

Evidence for the Θ^+ in the $\gamma d \to K^+K^- pn$ reaction by detecting K^+K^- pairs

T. NAKANO *et al.*

PHYSICAL REVIEW C 79, 025210 (2009)

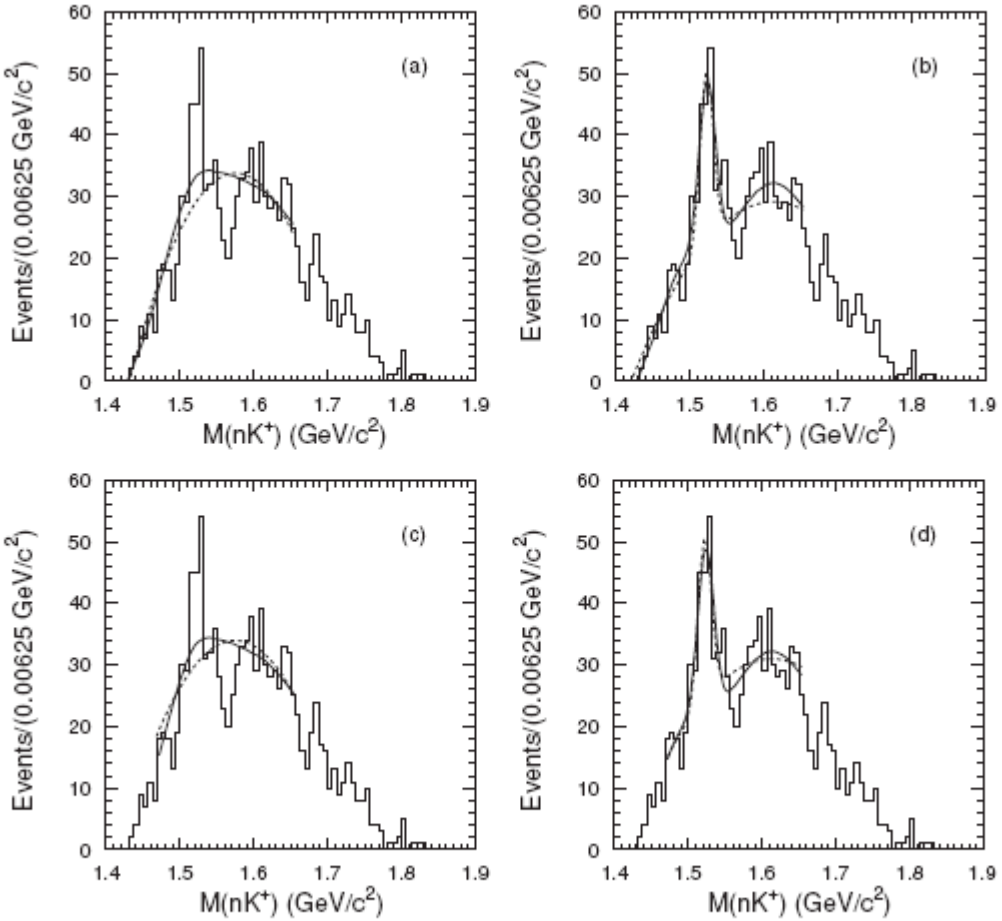

FIG. 14. Comparison of the fits with the RMM distributions (solid line) and a second-order polynomial functions (dashed line): (a) in the region of 1.43 GeV/c^2 < $M(nK^+)$ < 1.65 GeV/c^2 without the Θ^+ contribution; (b) with the Θ^+ contribution; (c) in the region of 1.47 GeV/c^2 < $M(nK^+)$ < 1.65 GeV/c^2 without the Θ^+ contribution; (d) with the Θ^+ contribution.

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DIANA Collaboration (2014)

Observation of a narrow baryon resonance with positive strangeness formed in K^+Xe collisions

arXiv:1307.1653v3 [nucl-ex] 18 Apr 2014

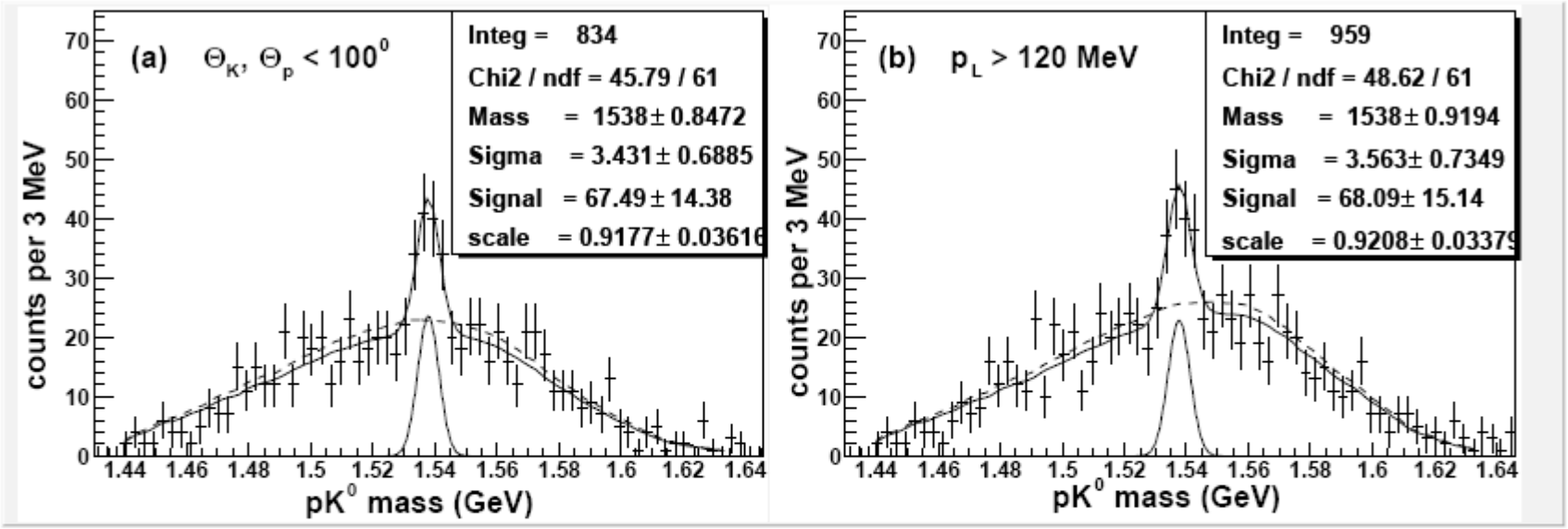

Figure 7: Shown in (a) and (b) are the pK^0 effective-mass spectra under the selections $\Theta_K, \Theta_p < 100^0$ and $p_L > 120$ MeV plus the common selections $p_T < 300$ MeV and $445 < p(K^+) < 535$ MeV. The signal and null fits are shown by the solid and dashed lines, respectively.

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