Recent results with upgraded VES setup: $\pi^- 3\pi^0$ and other systems

Yu. Khokhlov
IHEP Protvino
for VES Group

12th International Workshop
on Meson Production, Properties and Interaction
KRAKÓW, POLAND
31 May - 5 June 2012

Outline

- **VES**
  - **Introductory remarks**
  - **Setup upgrade**
- **New data: First look**
- **Summary**

Experiment VES

- "Old player" in the field of light meson spectroscopy

Some selected topics:

→ **$\pi(1800)$ studies**

→ **$J^{PC} = 1^{-+}$ exotics**

→ **particular decays: DP in $\eta' \rightarrow \eta\pi^+\pi^-$**

ISB in $f_1(1285) \rightarrow \pi^+\pi^-\pi^0$ (EPJ A47 (2011) 68)

- Major approach: (quasy)exclusive forward production of meson systems in MA –collisions at moderate (25-40 GeV) energies
- Major tool: general purpose spectrometer **VES**

need for improvements

- **In parallel with analyses of previously collected data**

(lengthy**)** **VES Setup renovation** **undertaken**

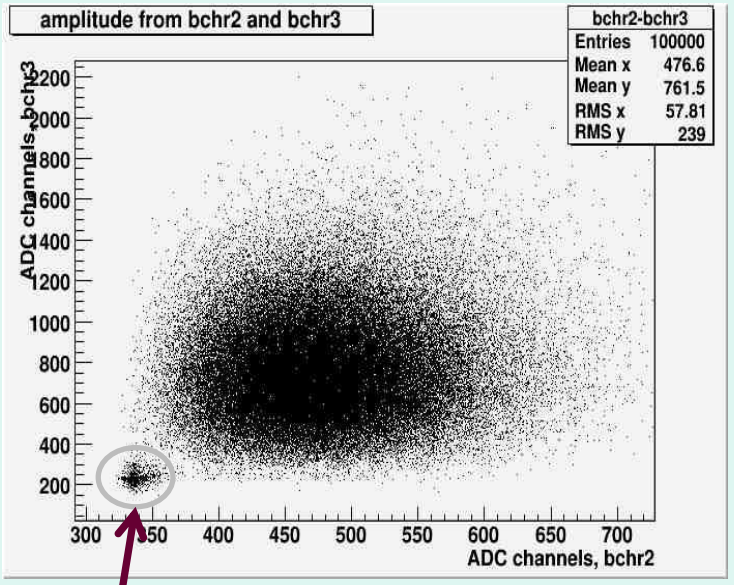
VES Setup

Operates with

- **secondary beam of U-70 PS:**
  $\sigma(\theta_x) \approx \sigma(\theta_y) \approx 0.7$ mrad, $\sigma(X) \sim \sigma(Y) \sim 1$cm
- **(typical)** momentum **p ~ 28 GeV/c;** spread (depending on setting) ~3%
- Composition: ~98% π^-, ~1.7% K^-

PID with beam Cherenkov counters

2D - distribution of amplitudes from two Beam Cherenkov Counters

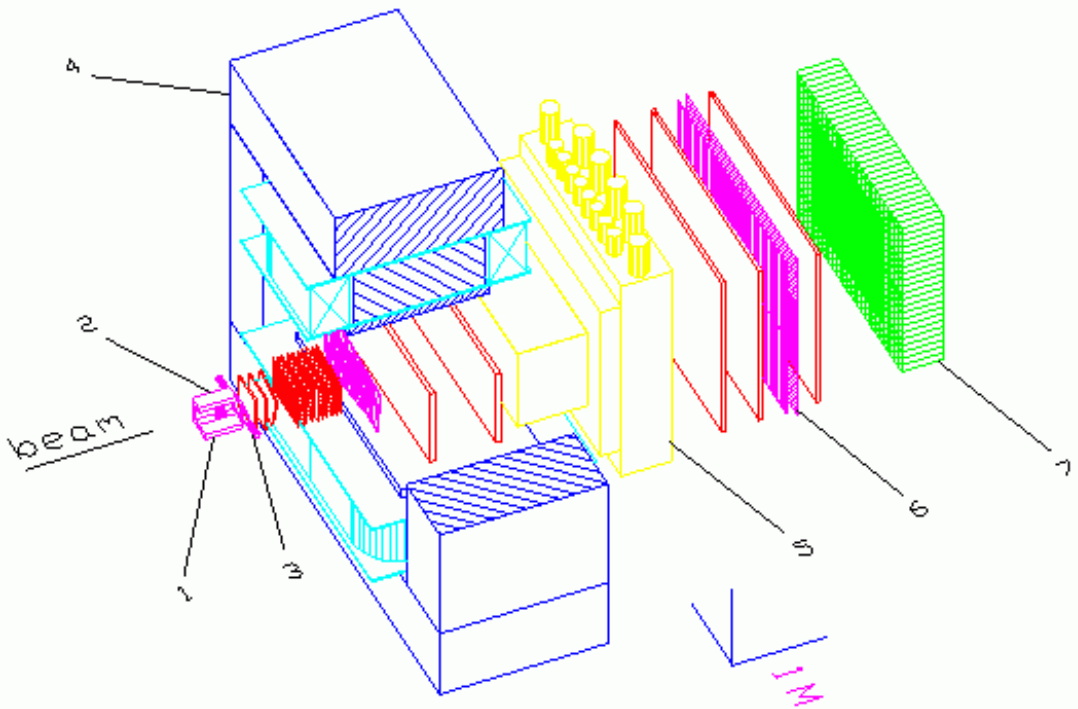


"Kaons corner"

VES Setup (cont'd)

- Nuclear target (Be) ~0.1 λ
- Magnetic spectrometer $p_{kick} = 0.56$ GeV/c
- Tracking system: (26 planes of) PCs and DCs
- ~ 0.150 x 0.200 mrad (V x H) acceptance
- EM – calorimetry
- PID for Secondaries: Multicell Cherenkov Counter (MCC) (28 cells)
- Fast DAQ ($4*10^4$ / 9 s-cycle)
- Minimum bias trigger

VES Setup (cont'd)



1 - target; 2 - veto counters; 3 - multiplicity discriminator (MD); 4 -magnet ; 5 – Čh counter; 6 –Sci –hodoscope; 7 - EMC

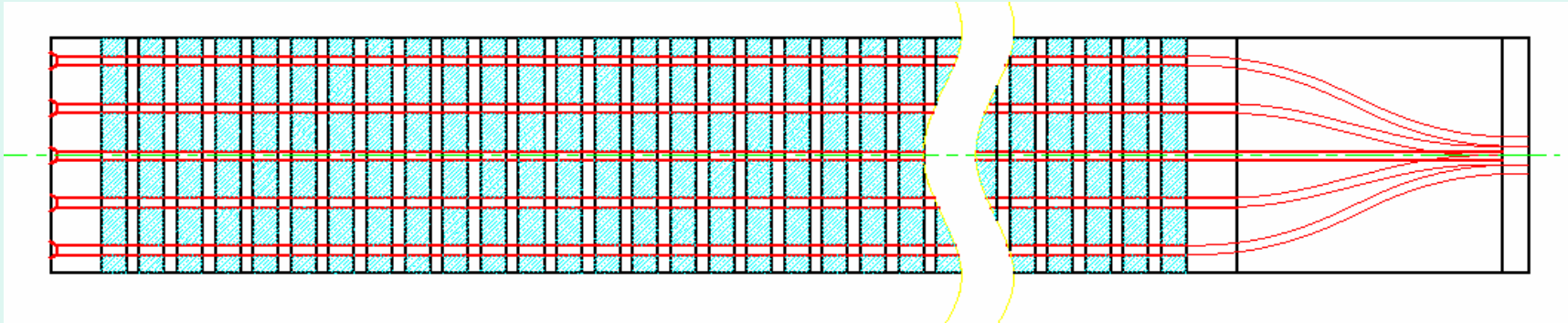
VES Setup: Upgrade

- **New DAQ**: fast (<Dead time> ~ 22 μs/event); reliable (<1% fault rate); flexible
- New triggering scheme: no “charged multiplicity” demand (MD & SciHod out)
- **Fully upgraded EMC**: finer granularity; radiation hardness; faster ADCs
- **New Large Area Trackers**: Drift Tubes (to be finished in October-2012)
- **New FE – electronics** for tracking detectors
- Improved performance of Multicell Cherenkov Counter
- Detector Control System
- Beam momentum spectrometer: 1% resolution
- New/improved software (on-line & off-line)

EMC

Lead Glass 43x43 (86x86) mm² → "shashlyk" PbSci + WLS-Fi 38x38 (76x76) mm²

Design by V.Polyakov et al. (IHEP) similar to COMPASS's Ecal

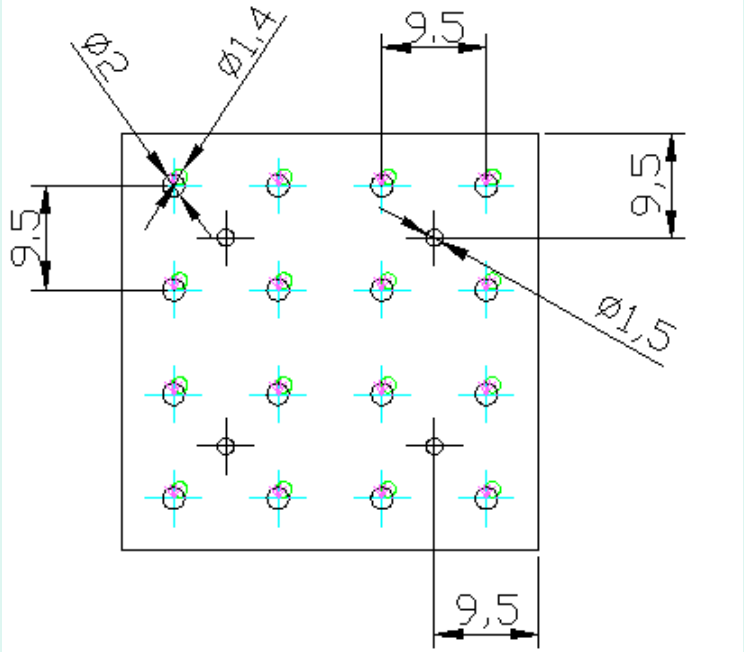


224 layers

Pb: Sci = 0.55 мм : 1.5 мм

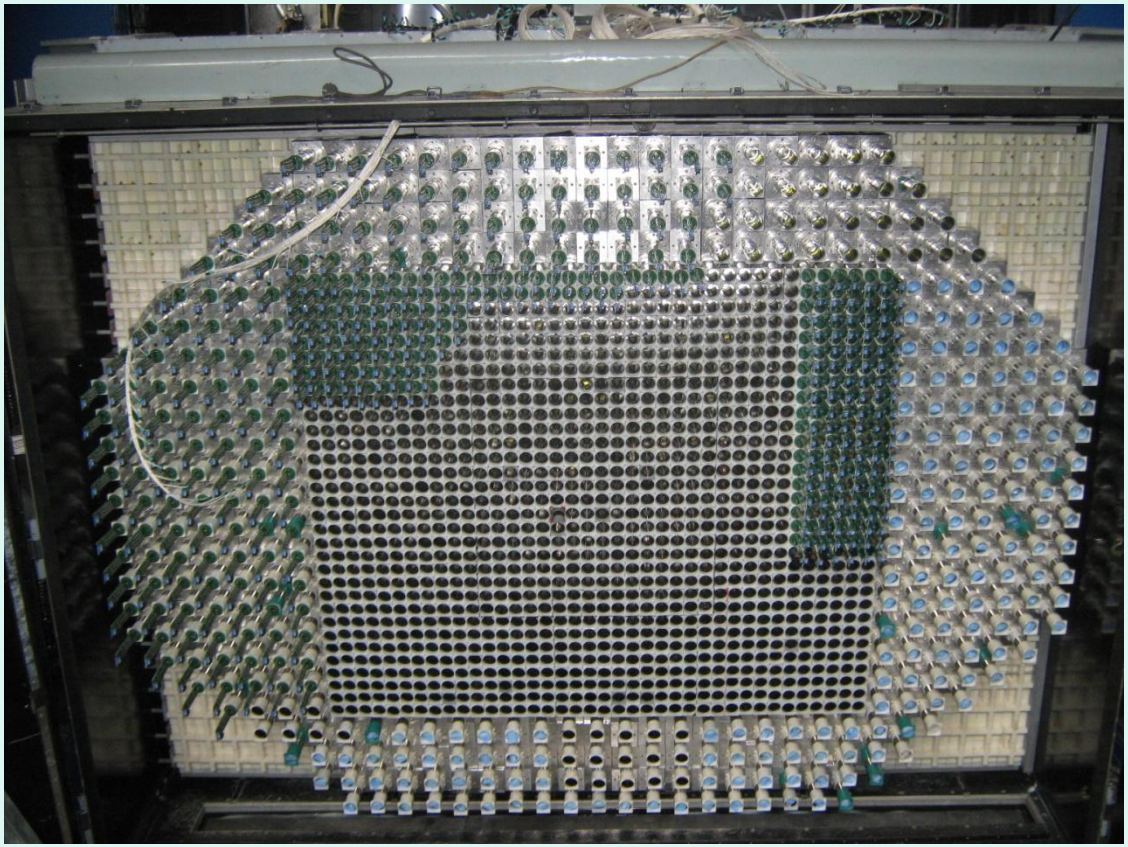
X_0 ≈ 19 мм → L = 24 X_0

RM ≈ 38 мм



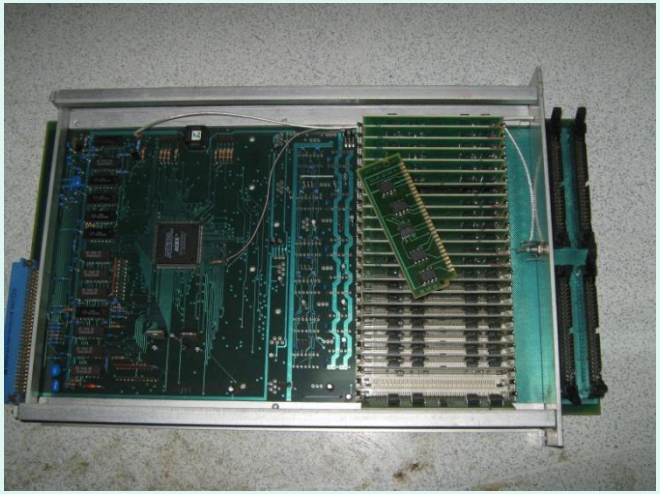
EMC

Pre-assembled modules



Cassette during assembly

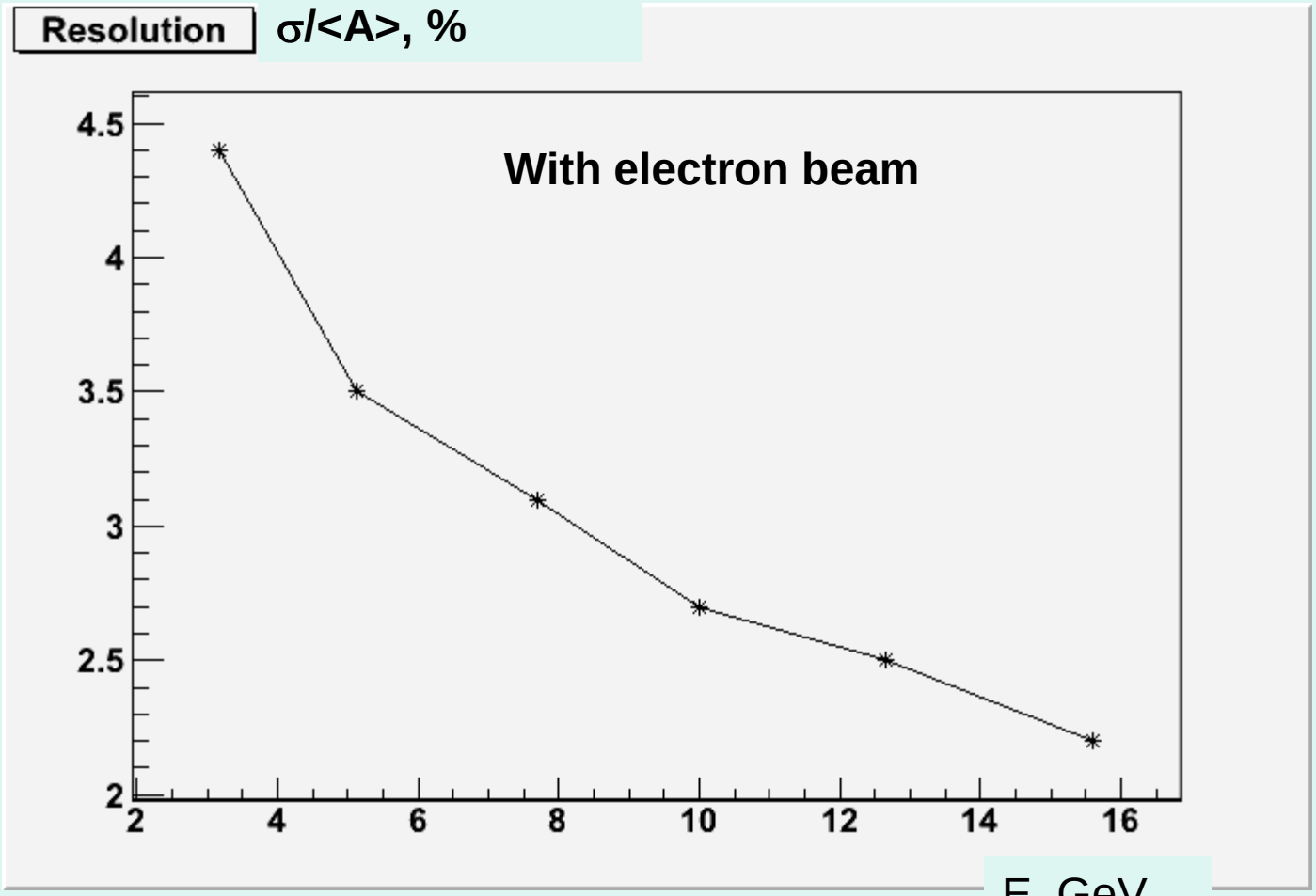
Irregular octagon (acceptance against Nb of channels)



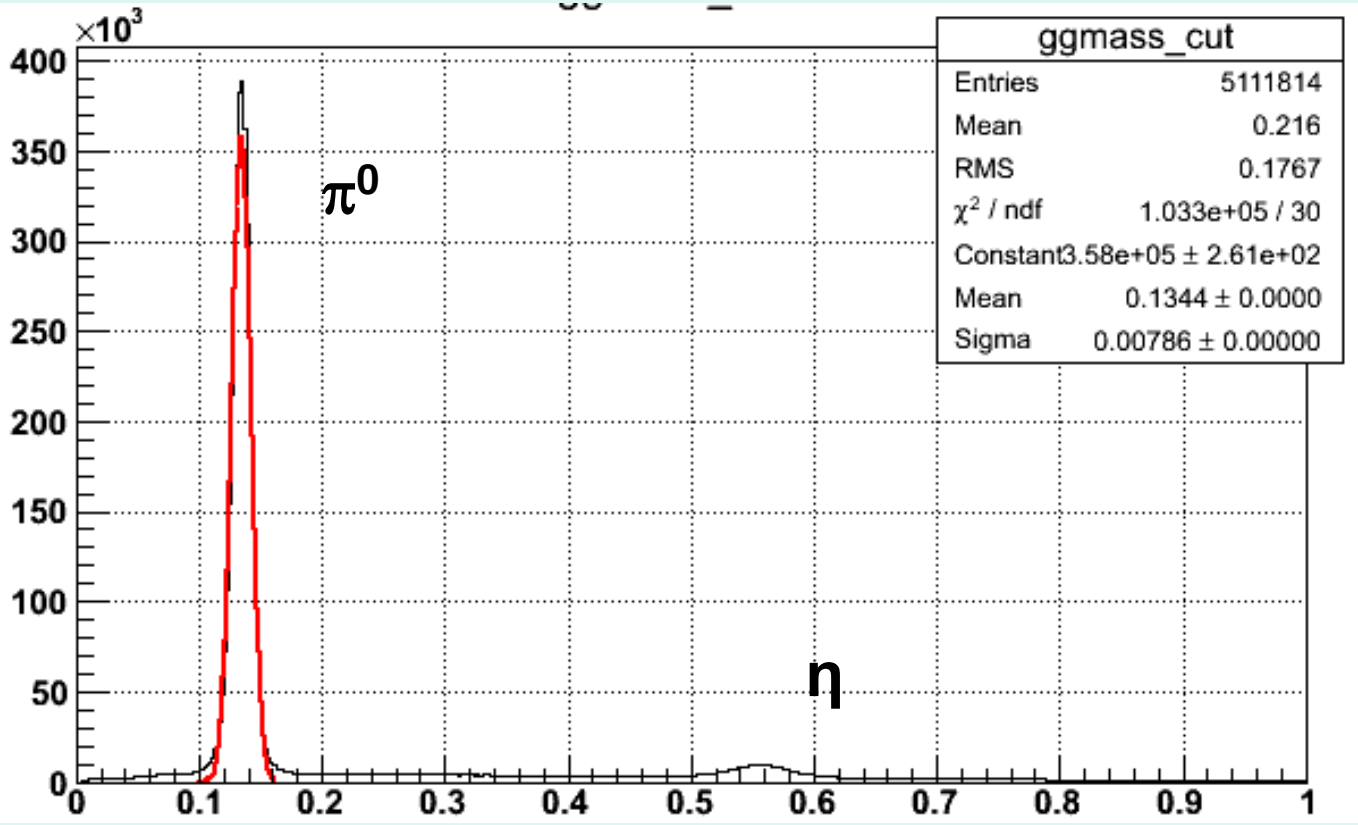
ADC module

1583 (= 1215 small + 368 big) counters

EMC resolution



EMC: M(γγ) in $\pi^-\gamma\gamma$ events

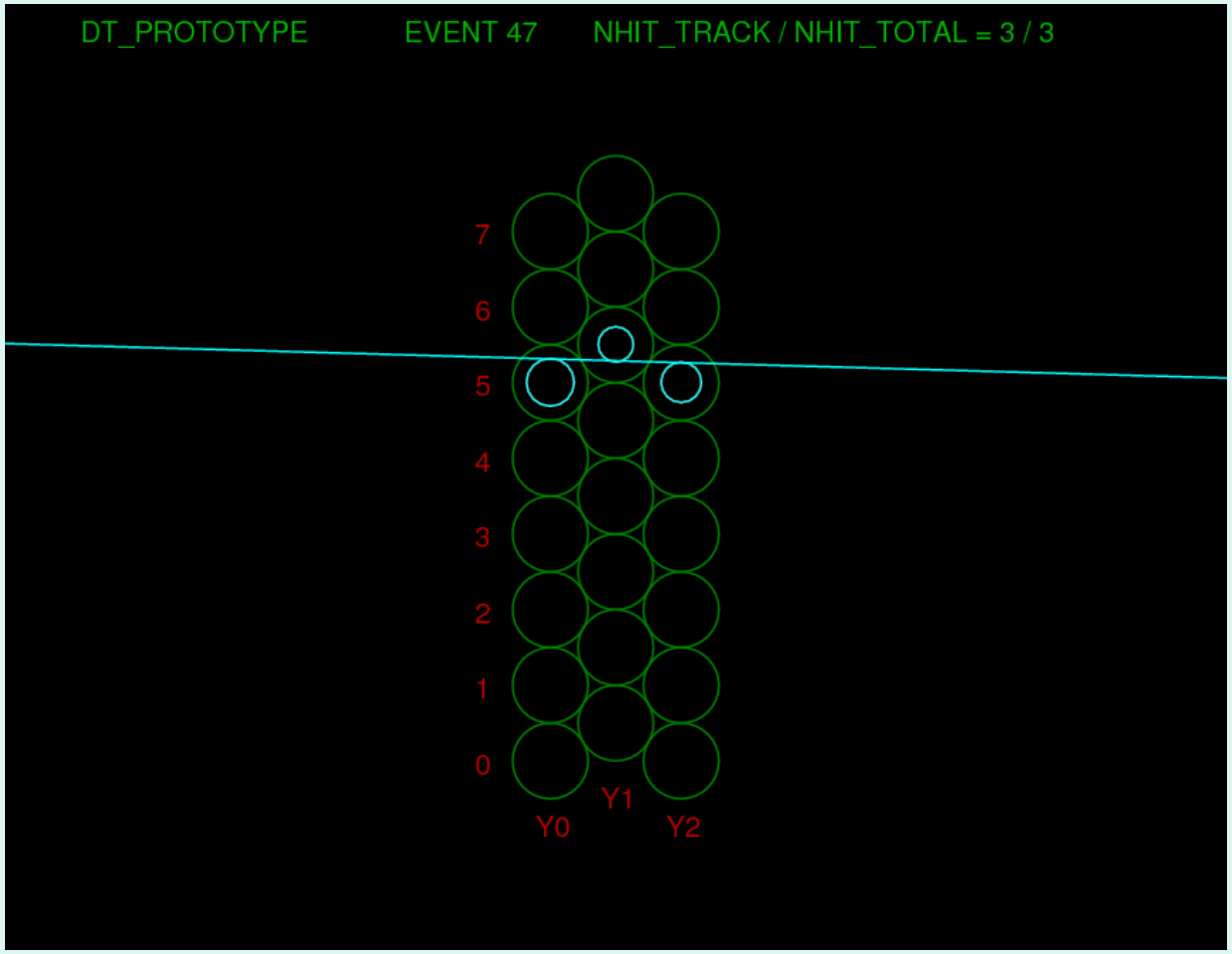


$\Delta M(FWHM) \approx 18.5\ MeV/c^2$

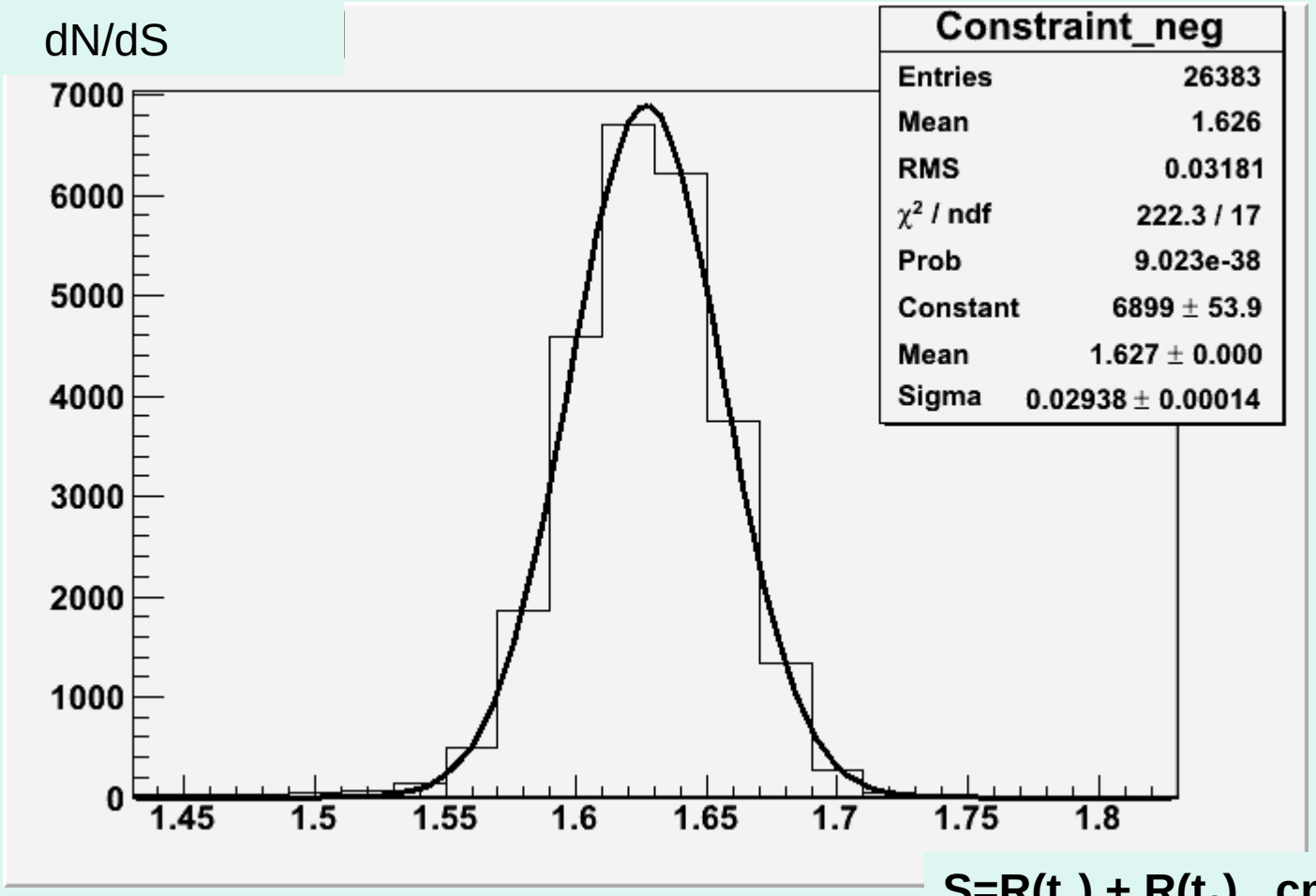
DT – chambers

- **6 planes (* 3-layer) of 3 types (X, Y, U/V coord.) planned**
- **Mylar tubes, D=30 mm**

  Design by R. Fakhrutdinov et al. (IHEP) similar to ATLAS MDTs



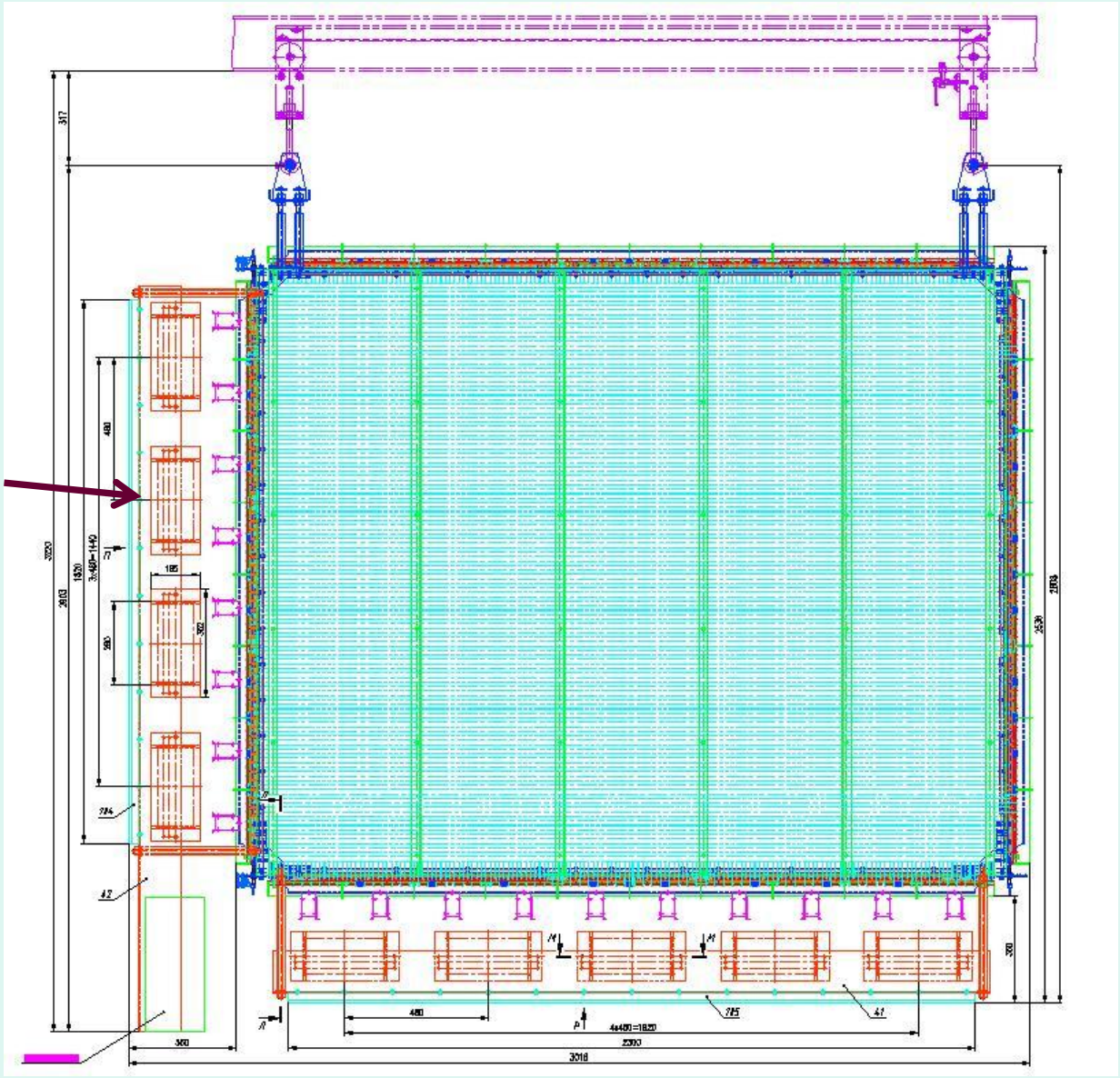
DT – chambers (cont'd)



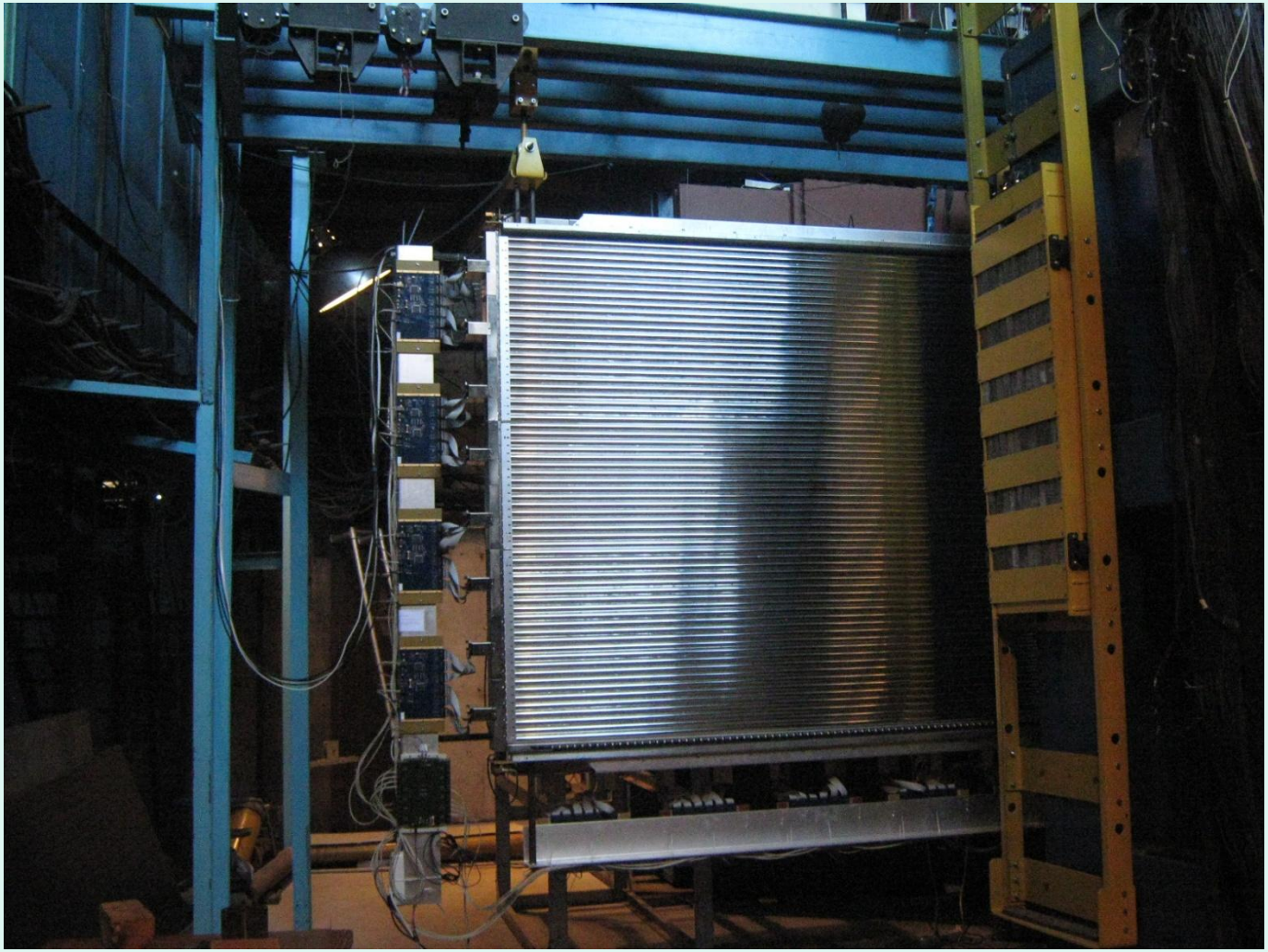
Distribution of sum of drift distances in adjacent layers with $\sigma \sim 300\ \mu m$

Drawing of DT - chamber

TDC



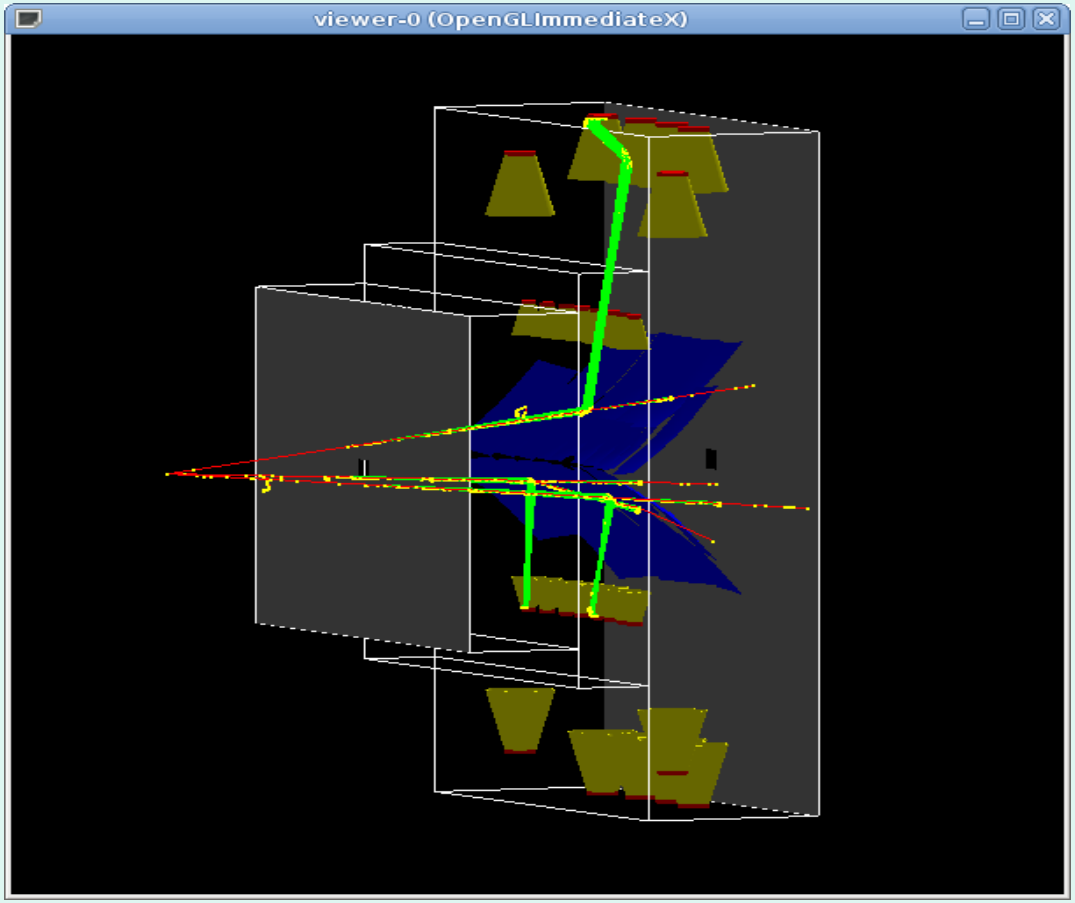
View of DT - chamber



On-detector TDC

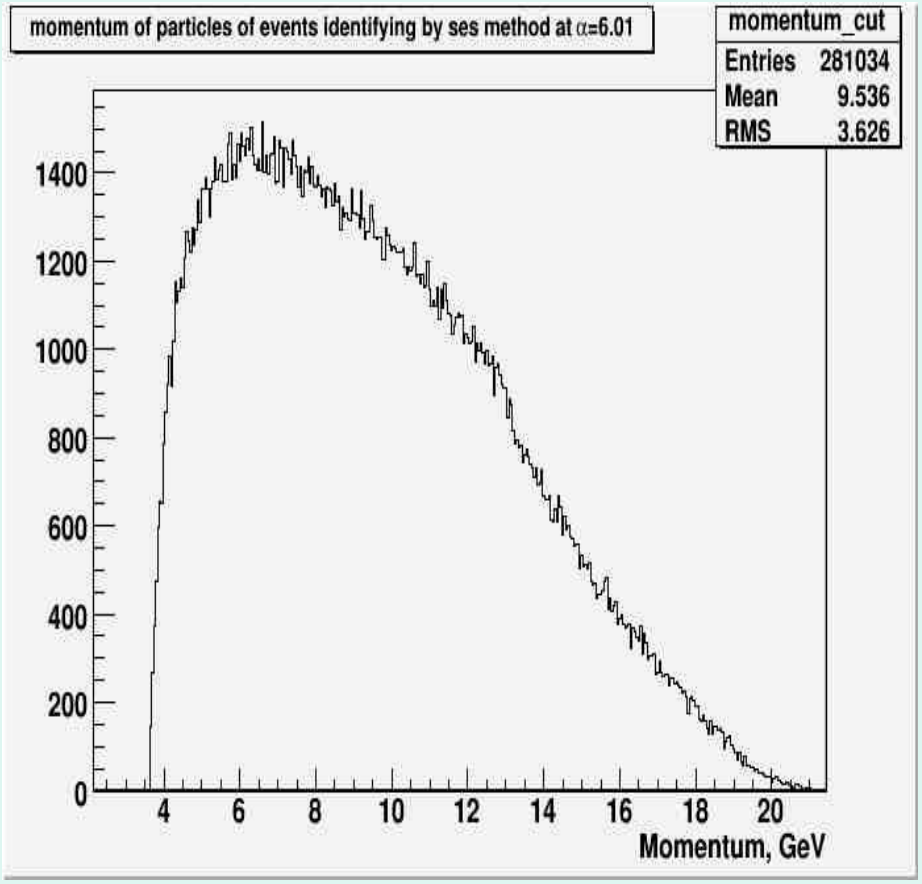
- Custom –design: 32- and 48- channel TDCs
- Full functionality
- FPGA – based digitizer
- μ-controller (+LINUX) based configuring/readout
- E-net → PC
- Time resolution (LSB) 2.5 ns
- Time window 500 ns
- Time for registering (Dead Time) 1.5 μs @ full occupancy
- Buffer memory 32 MB

Multicell Cherenkov Counter



GEANT model of MCC

Multicell Cherenkov Counter: momentum range for π/K ID



New data taking

- 1-month Run (Nov-Dec 2011)
- Fast DAQ

→ (Almost unselective) trigger on “beam fragmentation”

→ **Collect 1– prong events inaccessible @VES before**

- Good EM-calorimetry
- Unfinished LAT: 1 plane out of 6, not yet in Recon

→ weakened resolution and track finding for multiprong events

New data: First look

~2*10^{11} beam particles on target

Typical selection for

various (quasi)exclusive 1-prong systems:

- **Topology: 1 fast negatively charged particle,**

  N γ's (N=2, 4, 6,…)

- **Vertex within target**
- **γ pairing into neutral mesons (π^0, η) (w. control bands for bckg.)**
- **Sum of momenta (charged+neutrals) close to beam momentum**

Statistics estimate

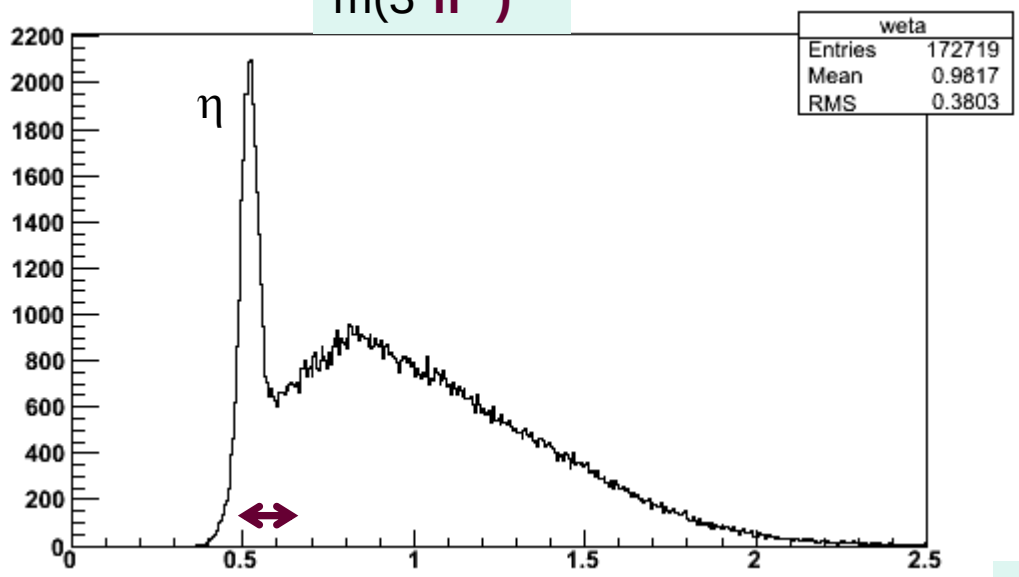
~30% accuracy; **55% of data** treated out of recorded

Nmb. of events:

- $\pi^- \pi^0$ $3.5 * 10^6$
- $\pi^- 2\pi^0$ $4*10^6$ diffractive (P- exchange), quite pure
- $\pi^- 3\pi^0$ $0.2*10^6$ R –ex; x-sect. ↓ w. √s↑ ; bckg+
- $\pi^- \eta(\rightarrow 3\pi^0)$ $2.6*10^4$
- $\pi^- \eta(\rightarrow 2\gamma)$ $0.2*10^6$
- Similar Br, but different efficiency (cuts, acceptance, absorption) 4 γ +
- $\pi^- \pi^0 \eta(\rightarrow 2\gamma)$ $0.2*10^6$ R- ex
- $\pi^- \eta(\rightarrow 2\gamma) \eta(\rightarrow 2\gamma)$ 10^4 P- ex; rather pure

$\pi^- 3\pi^0$ system

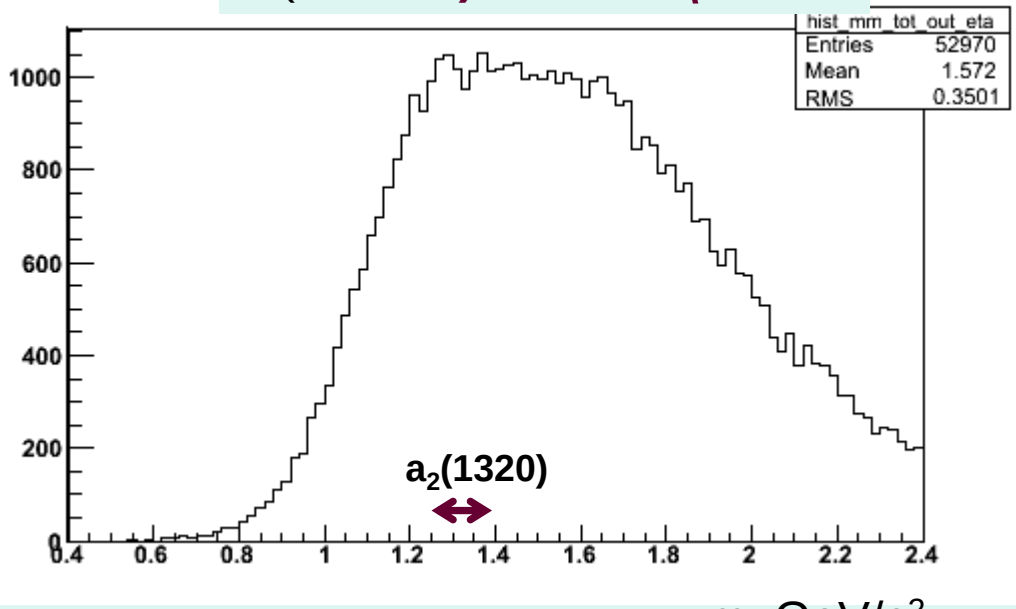
m($3\ \pi^0$)



no ρ's in neutral di-pion subsystem
access to f_0's ?

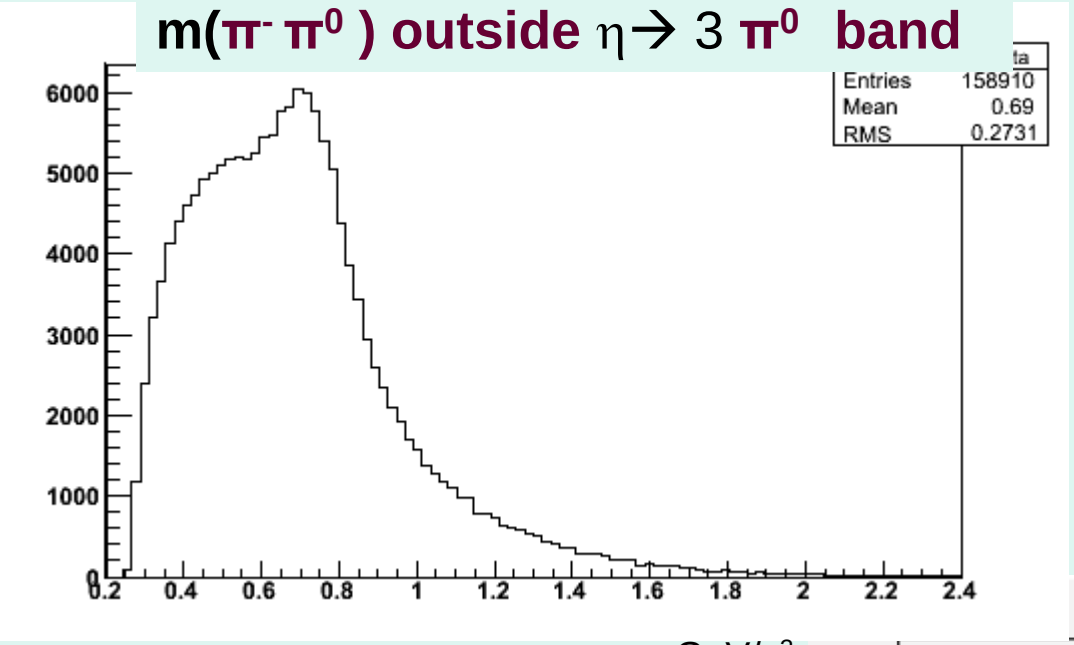
(residual)
$a_2(1320) \rightarrow \pi^- \eta$

m(π^- 3 π^0) **outside η band**



$\pi^- 3\pi^0$ system

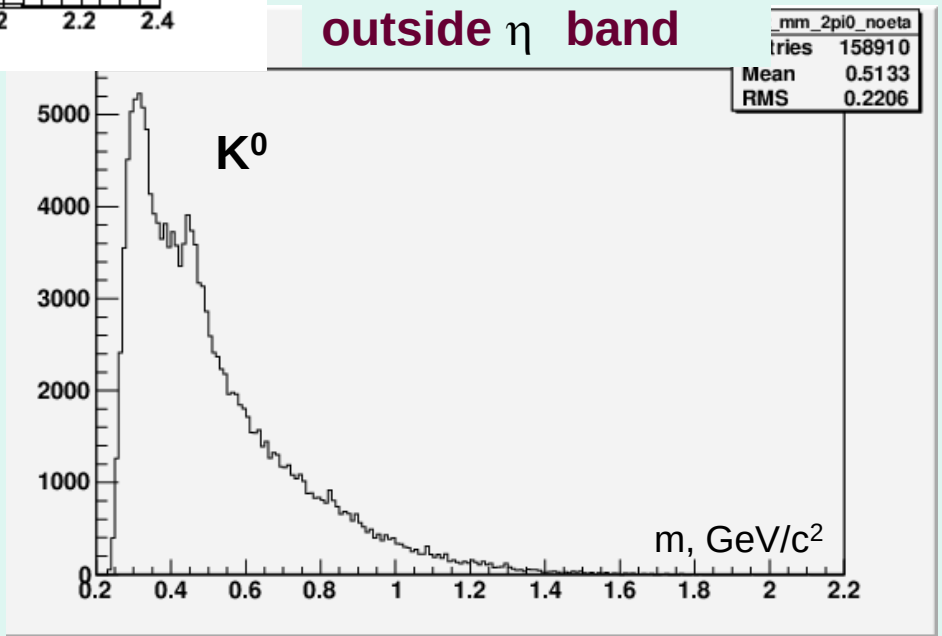
m($\pi^- \pi^0$) outside $\eta \rightarrow 3\,\pi^0$ band



(unusually) weak $\rho(770)$
No evident f_0's signals

So… turn to
$\pi^- 2\pi^0$ system

m($\pi^0 \pi^0$)
outside η band



$\pi^- \pi^0 \pi^0$ system

- Good "exclusivity" → clean sample
- **stat. ~4 x COMPASS (F.Nerling, MESON2012)**

  ~ 1 x E852 (A.R.Dzierba e.a. PR D73, 072001(2006))

→ **γ - effective (transparent) setup**

→ **Low- $|t'|$ region included** **compared w. COMPASS & E852**

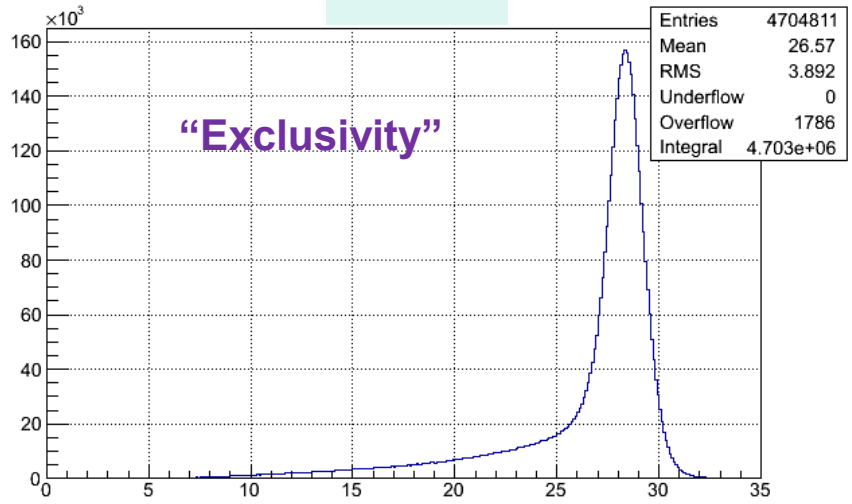
particularly important for $\pi(1300)$ & $\pi(1800)$

- Counterpart of well studied $\pi^- \pi^- \pi^+$

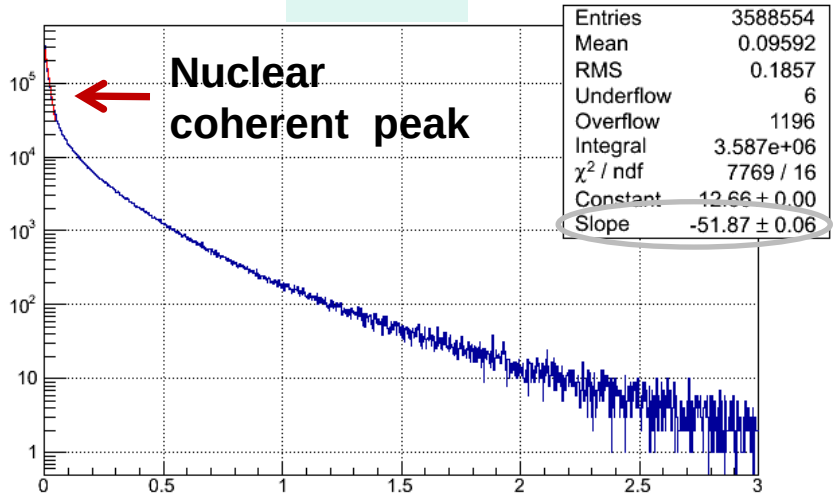
→ **no neutral ρ's → easier access to f_0's (?)**

- **Promising for PWA →**
- **preliminary evaluation of data**

$\pi^- \pi^0 \pi^0$ system (cont'd)

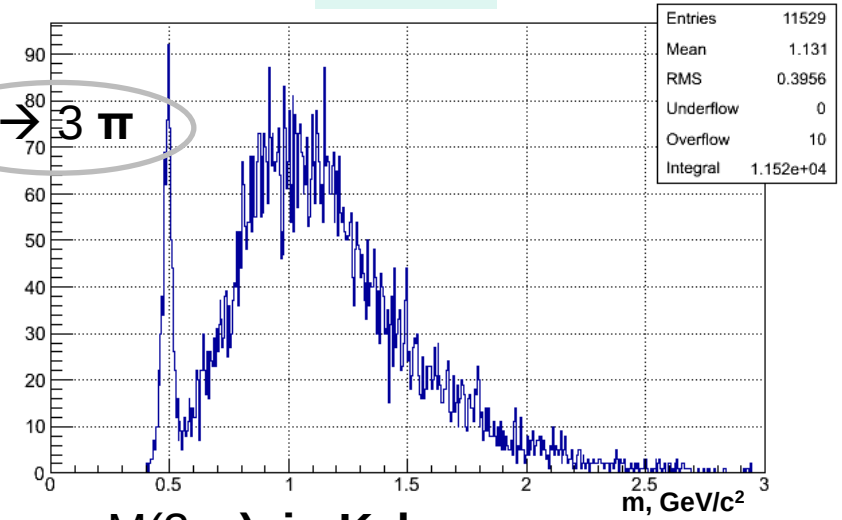


P_{tot}, GeV/c

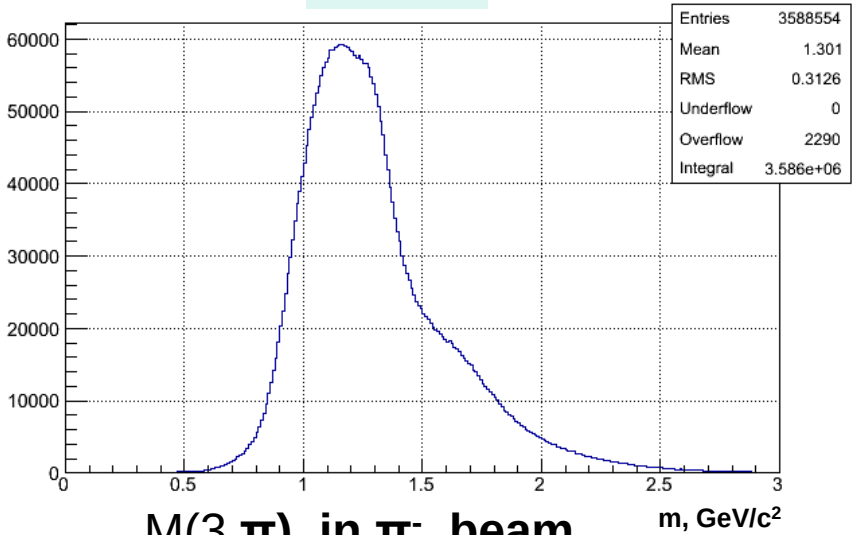


$|t'|$, $(GeV/c)^2$

$K^- \rightarrow 3\ \pi$

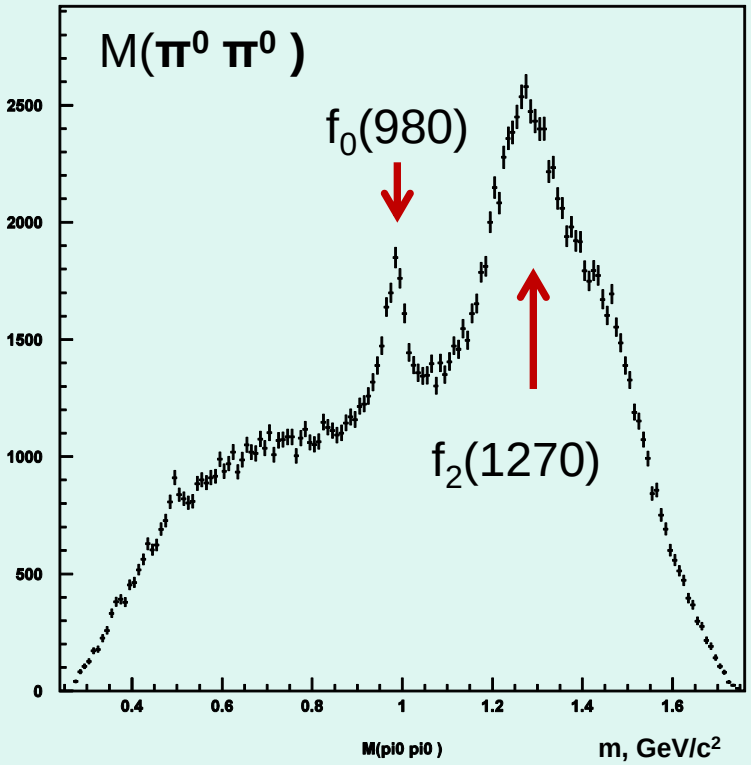


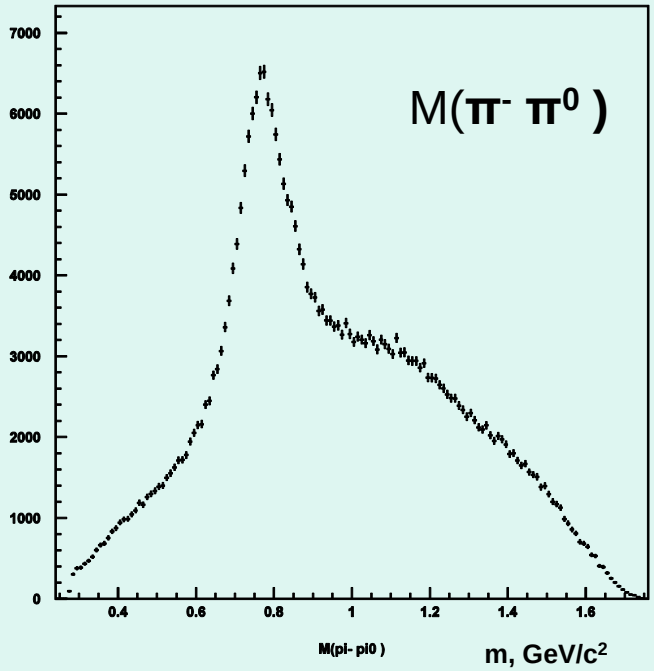
M(3 **π**) in K^- beam



M(3 **π**) in π^- beam

$\pi^- \pi^0 \pi^0$ system: mass spectra





π (1800) region: 1.7 GeV/c^2 < M($\pi^- \pi^0 \pi^0$) < 1.9 GeV/c^2

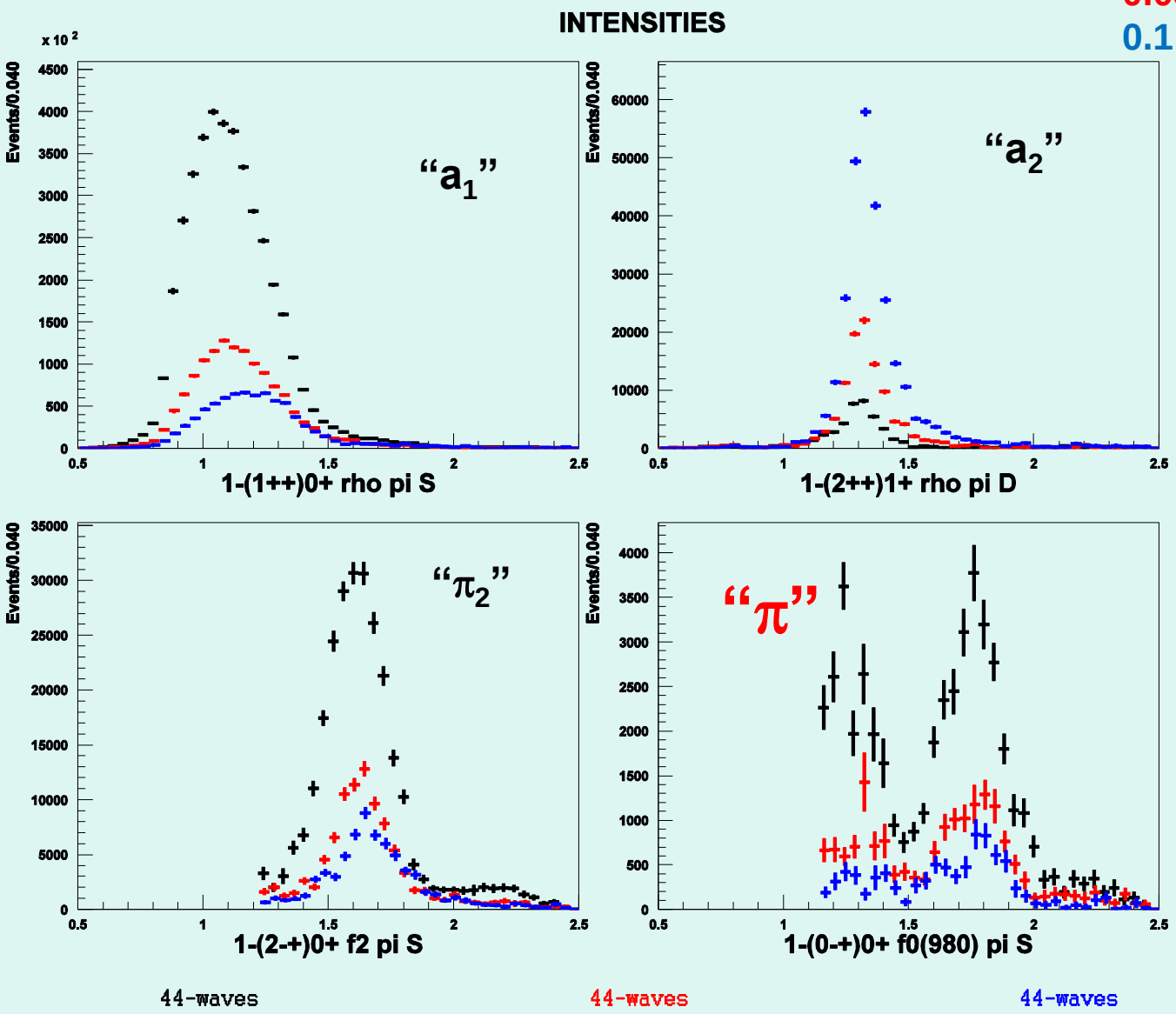
$\pi^- \pi^0 \pi^0$ system: PWA

- State-of-art PWA framework (used further in COMPASS, F.Nerling report)
- Large set (44) of waves
- Density matrix of rank-2
- Simplified model for setup (geometrical acceptance only)

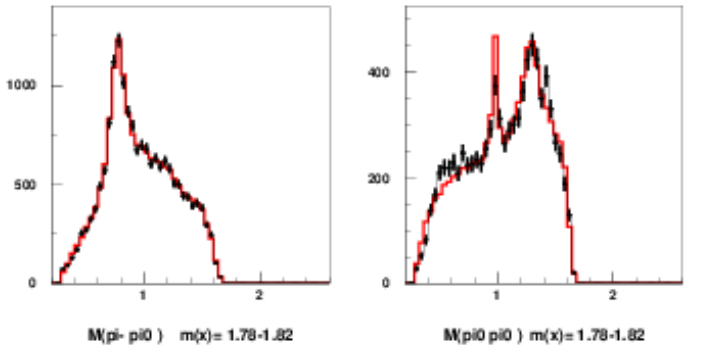
- Demonstration of analyses feasibility

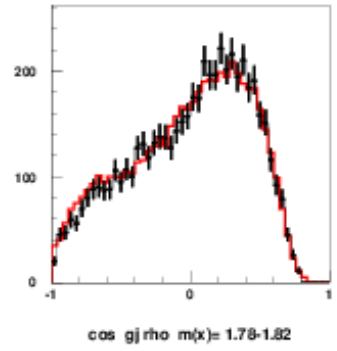
$\pi^- \pi^0 \pi^0$ system: major waves (J^{PC} Mη X_1X_2 L)

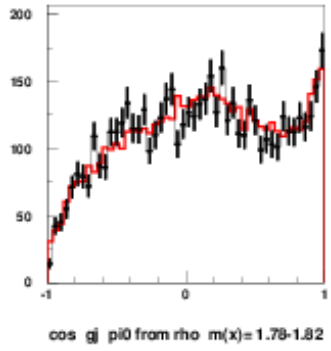
$|t| < 0.03$ GeV^2
$0.03 < |t| < 0.1$ GeV^2
$0.1 < |t| < 1.$ GeV^2

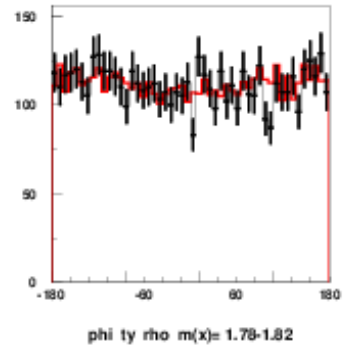


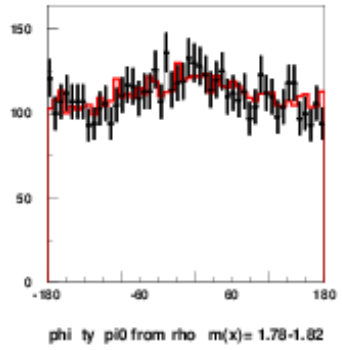
$\pi^- \pi^0 \pi^0$ system: MC(PWA) vs. RD

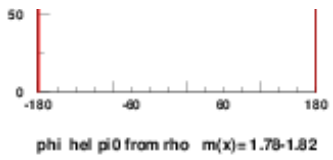


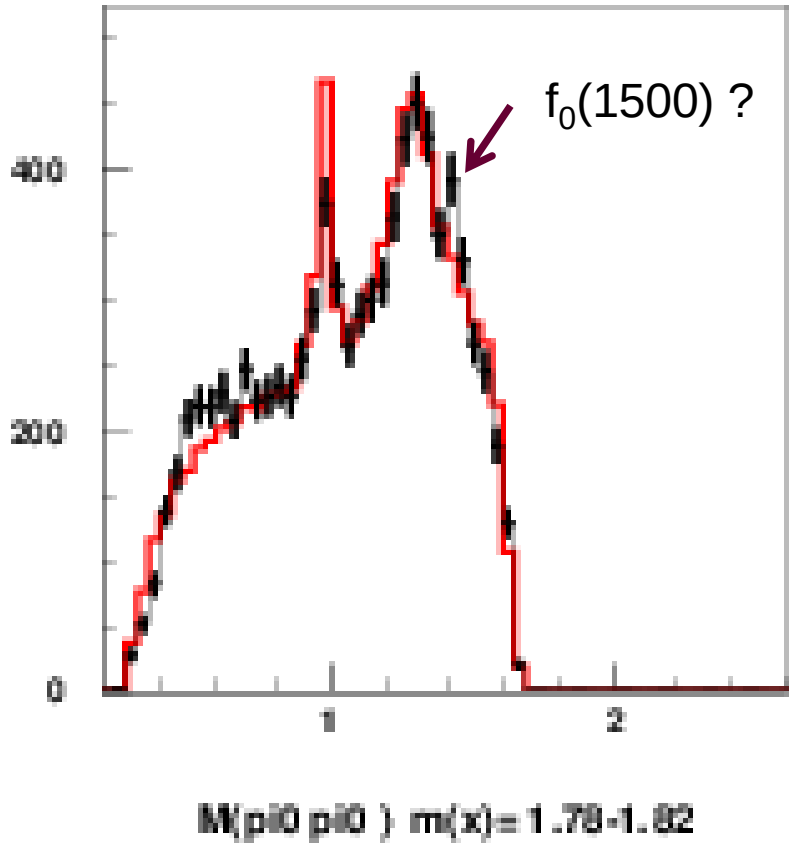






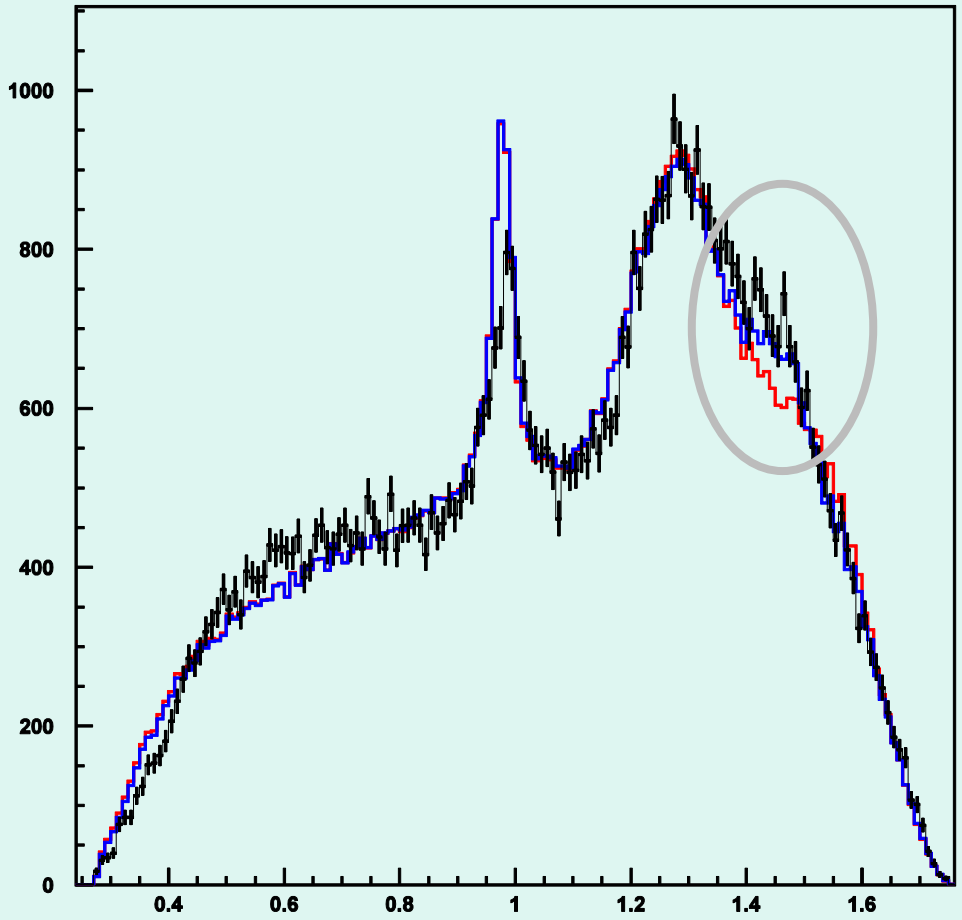






$\pi^- \pi^0 \pi^0$ system: more MC vs. RD

$f_0(1500)$ case



RD
MC PWA w/o $f_0(1500)$
MC PWA w. $f_0(1500)$

m($\pi^0 \pi^0$), GeV/c^2
for m(3 π) = 1.74-1.9 GeV/c^2, low |t‘|

First look on $\pi^- \pi^0 \pi^0$ system: Summary

2 production mechanisms:

i. (first) Coherent diffraction ($|t'|$=0-0.03 GeV$^2/c^2$) on Be nucleus

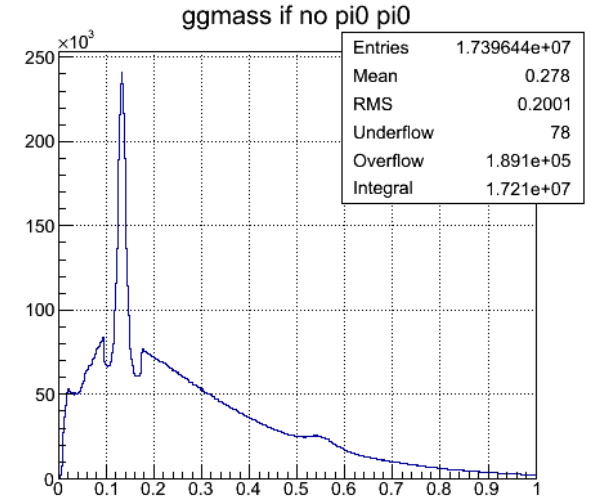
- high intensities of $J^{PC}=0^{-+} \rightarrow (\pi^0 \pi^0)_S \pi^-$
  study of $\pi(1300)$, $\pi(1800)$ and f_0's
- high coherence of amplitudes 0^{-+}, 1^{++}, 2^{-+} , ... with spin projection M=0
  study of resonances in comparison with $\pi^- \pi^- \pi^+$ case

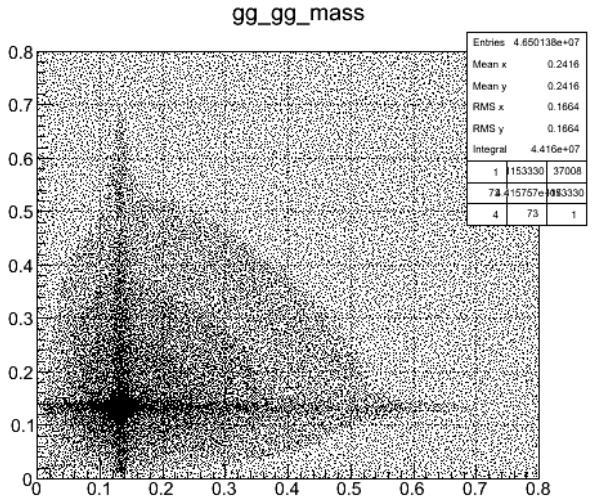
ii. Incoherent production ($|t'|$>0.1 GeV$^2/c^2$)

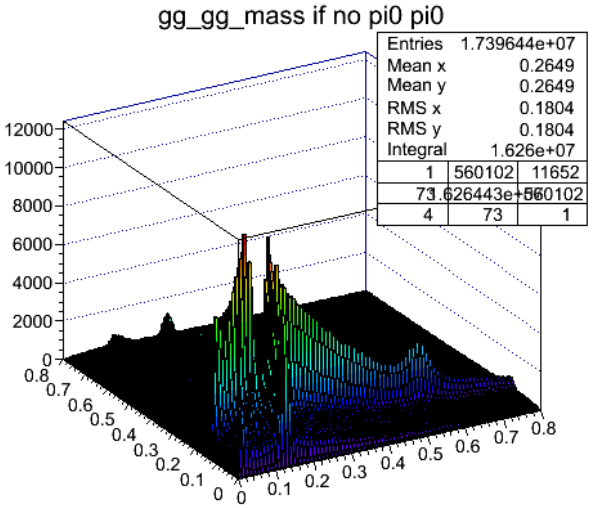
- stat. compatible with COMPASS -2008 on proton
- 2^{++}, 4^{++}, ... w. M=1 enhanced
- exotic $\pi_1(1600)$ ($J^{PC}=1^{-+}$ with M=1) still highly disputed

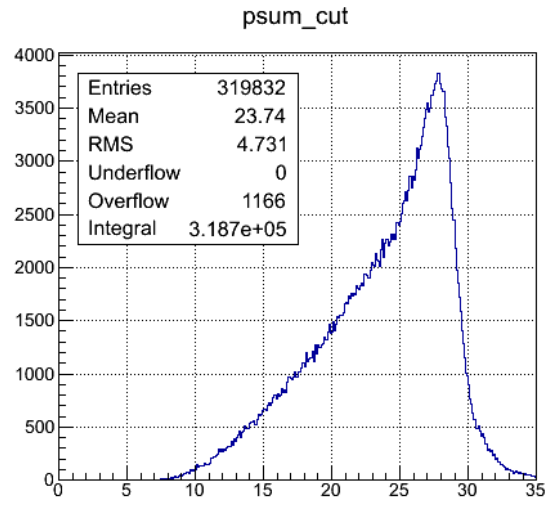
$\pi^- \pi^0 \eta$ system

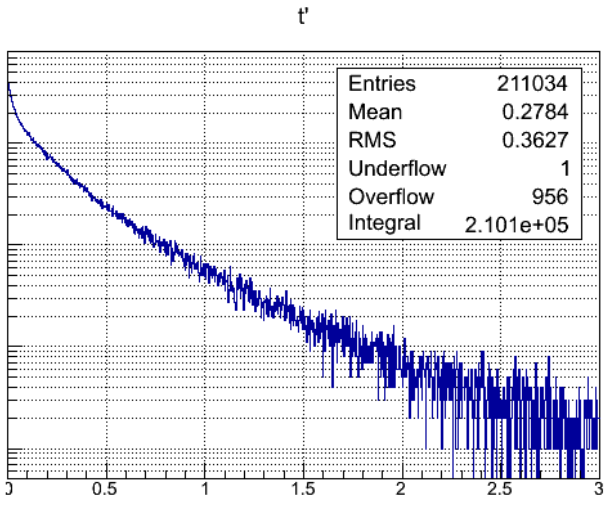
search for ISB-decay $\pi^-(1800) \rightarrow \pi^- f_0(980) \rightarrow \pi^- a_0(980)$

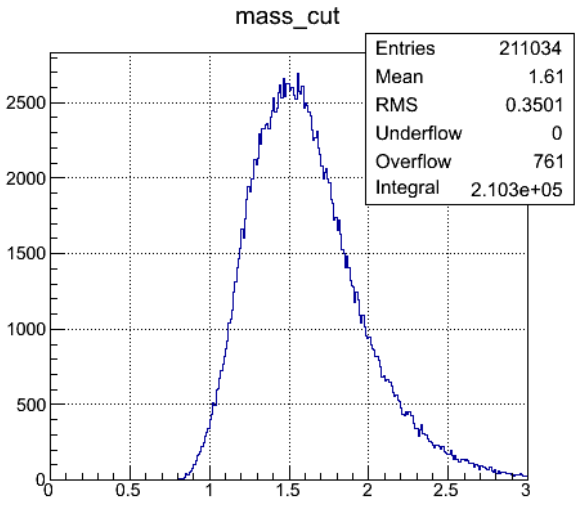




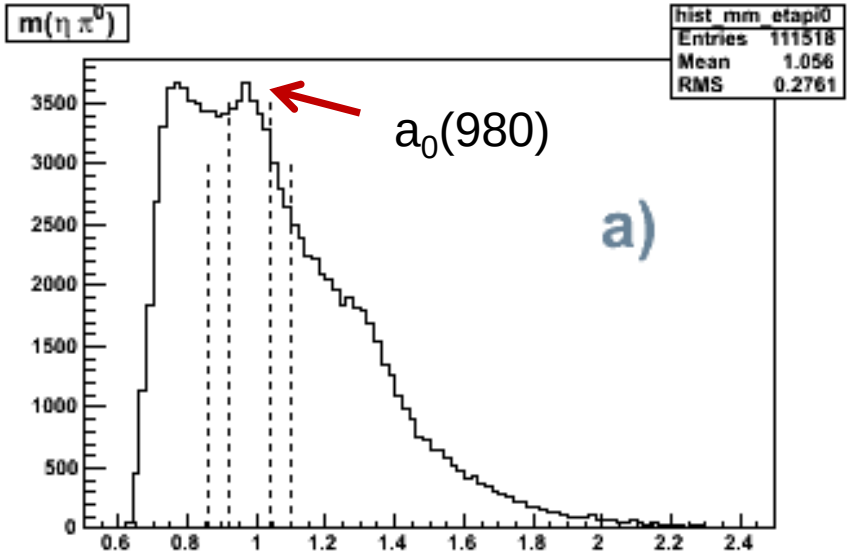


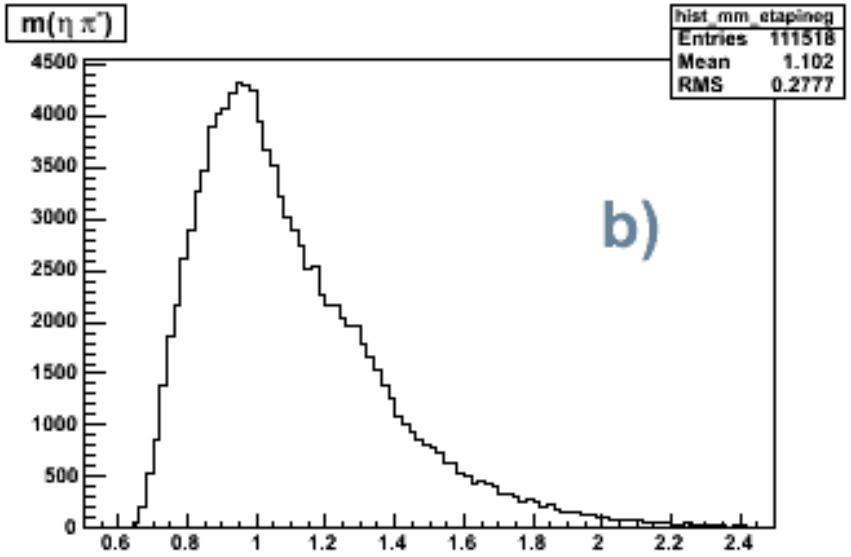


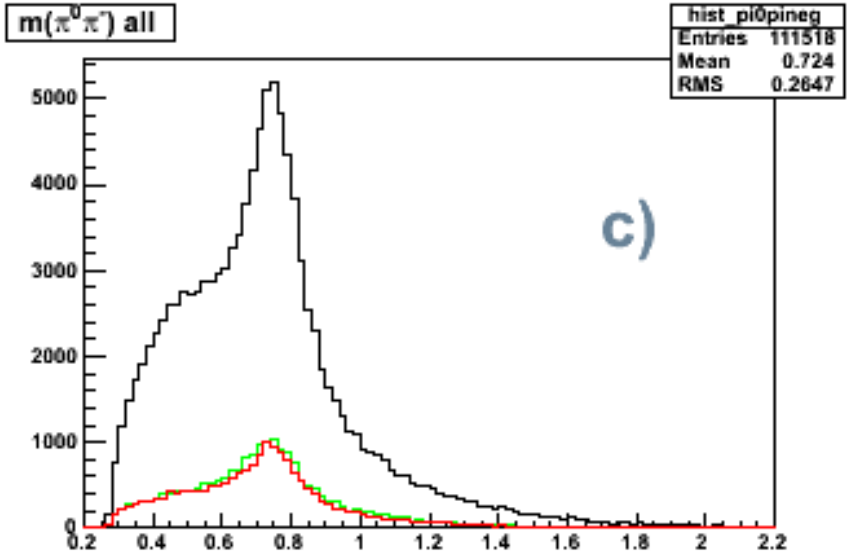


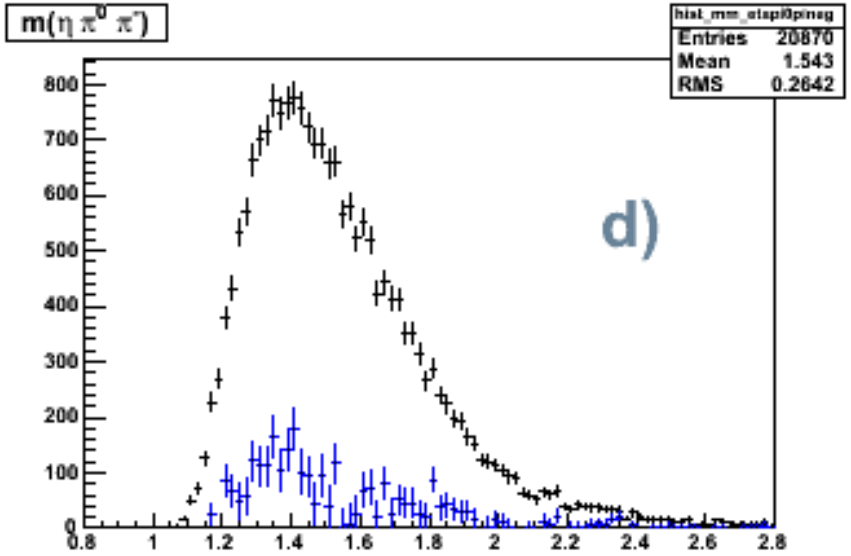


$\pi^- \pi^0 \eta$ system





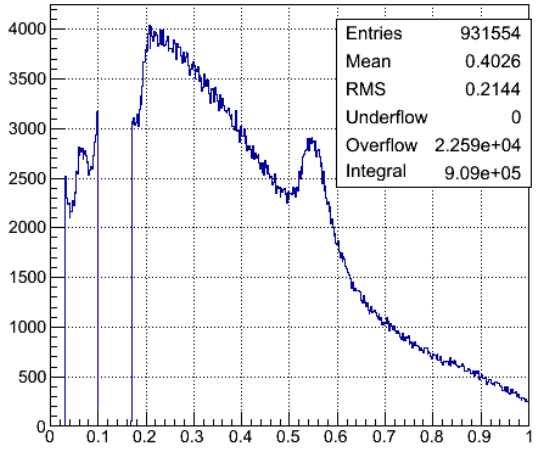


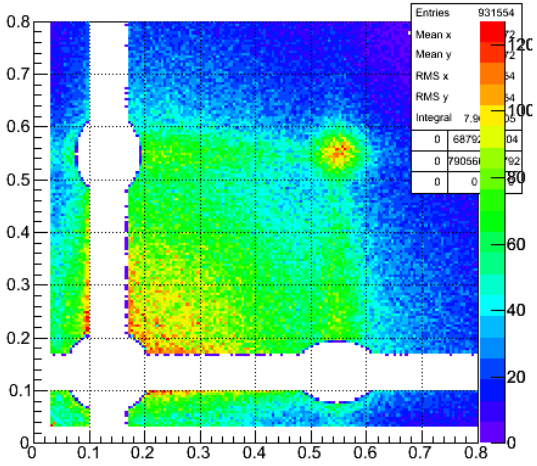


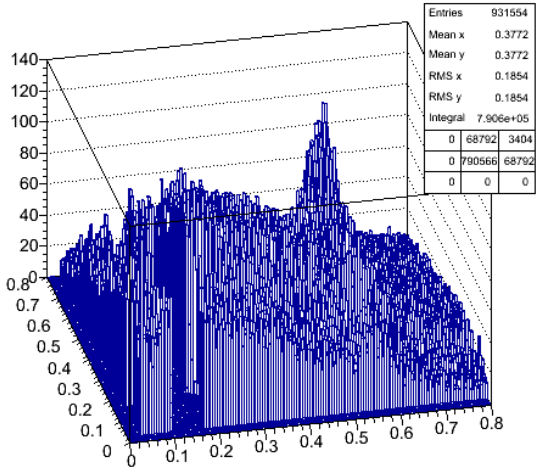
$m(\pi^- \pi^0 \eta)$ for a_0^0 band

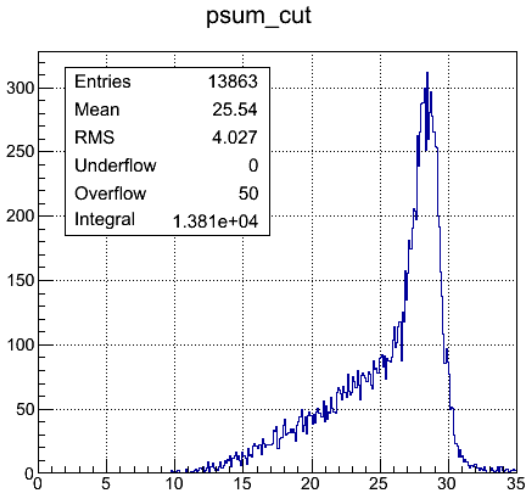
$\pi^- \eta \eta$ system

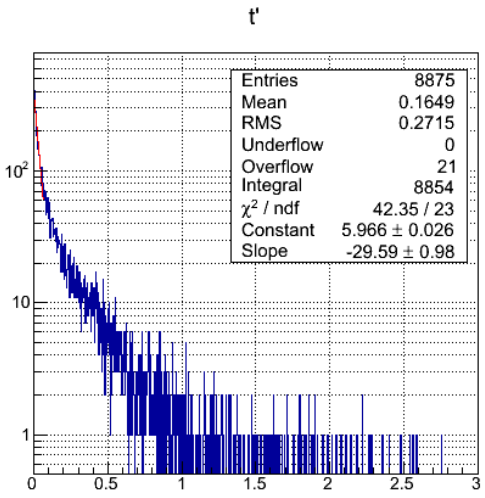
Stat.: 8x "old" VES (PAN 59 (1996) 976), 2x E852 (PLB 660 (2008) 466)

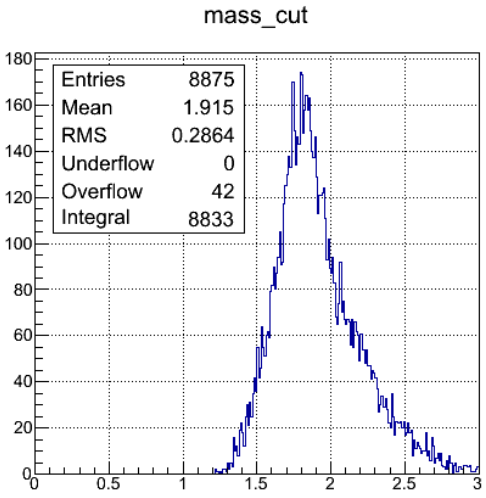












Summary

- The VES upgrade to be finished soon
- The first new data available, processing ongoing, more data expected this year
  - ➢ good performance of EMC
  - ➢ one-prong systems feasible
  - ➢ room for strong improvement of tracking
- **Competitive for non- P- ex and/or multi-gamma modes**
- **1-st candidate: $\pi^- 2\pi^0$** prospective for PWA

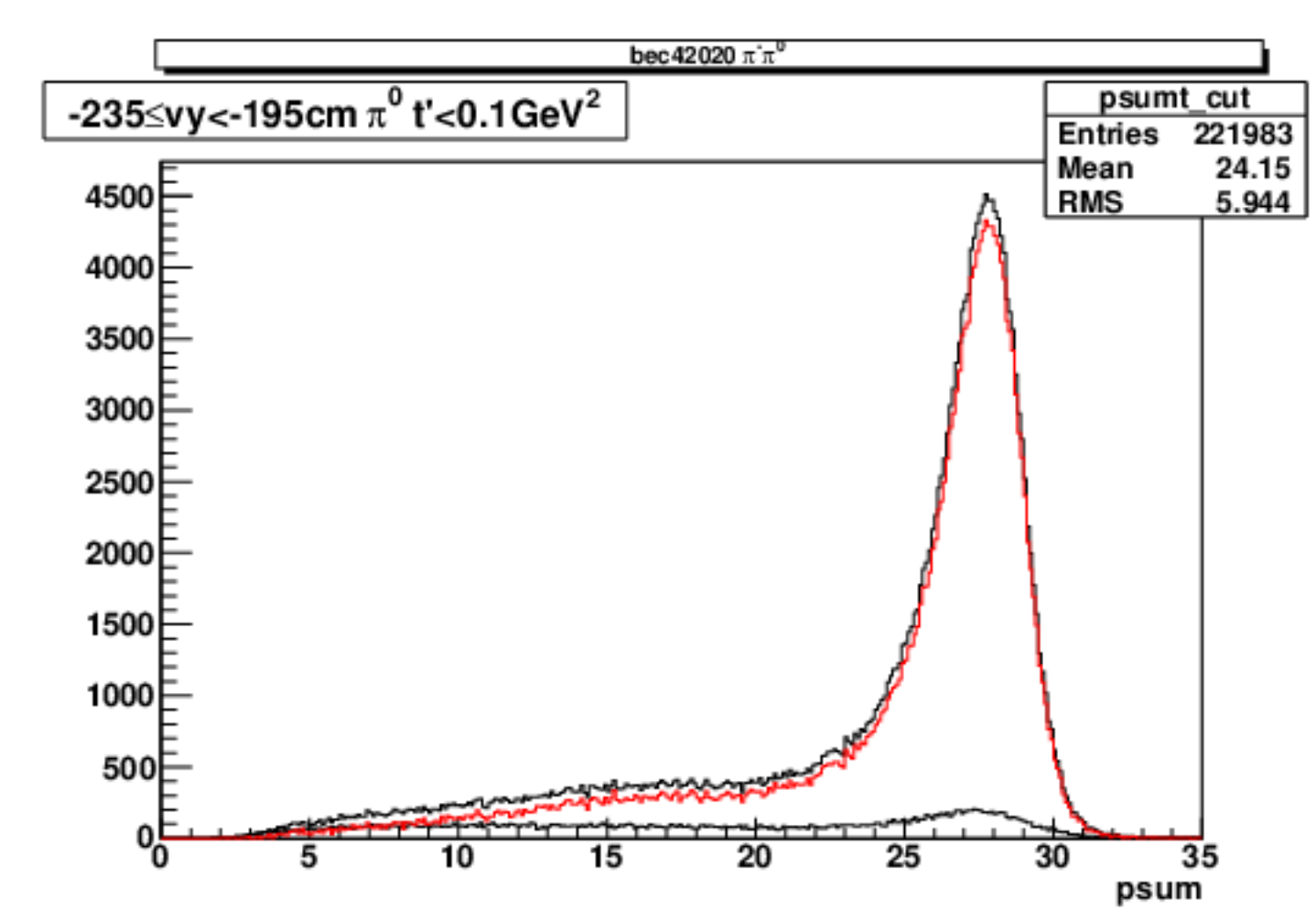
  → first in coherent production

  → access to $J^{PC}=0^{-+}$ -> $(\pi^0 \pi^0)_S \pi^-$

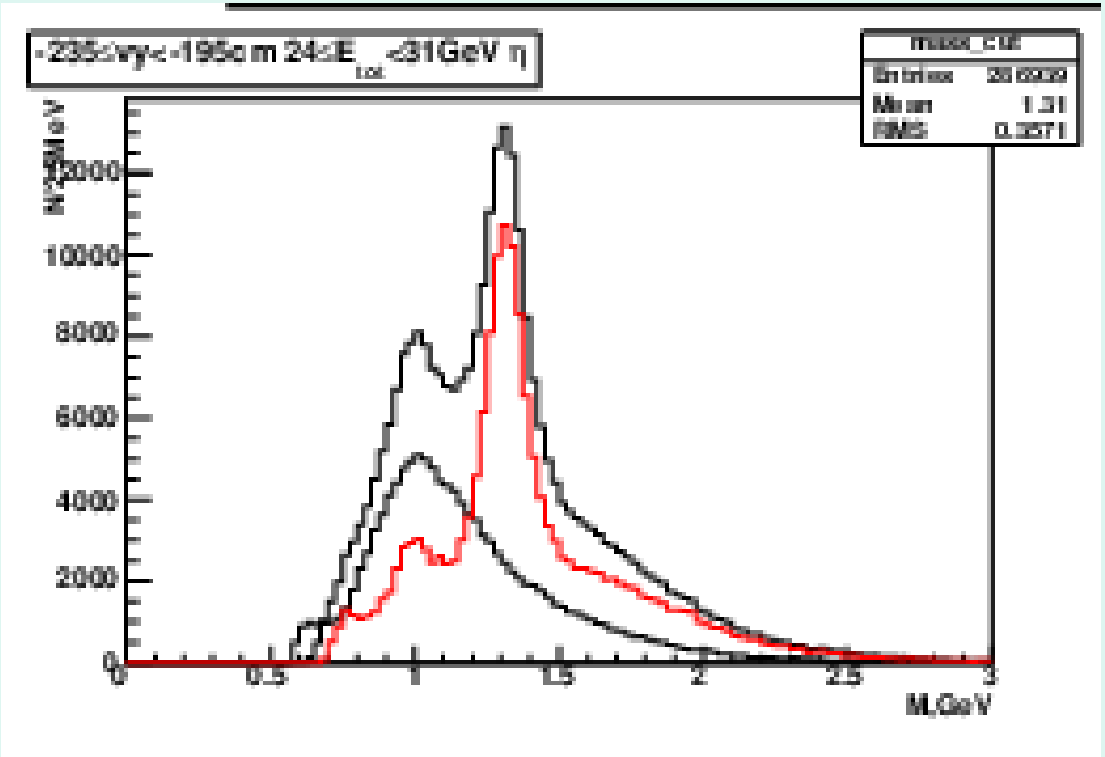
  → Clear $f_0(980)$ in **π(1800) region**
- **Next: $\pi^- 3\pi^0$ and $\pi^- \pi^0 \eta$**: large statistics ready for analyses
- **More systems to come soon**

Thank you for attention

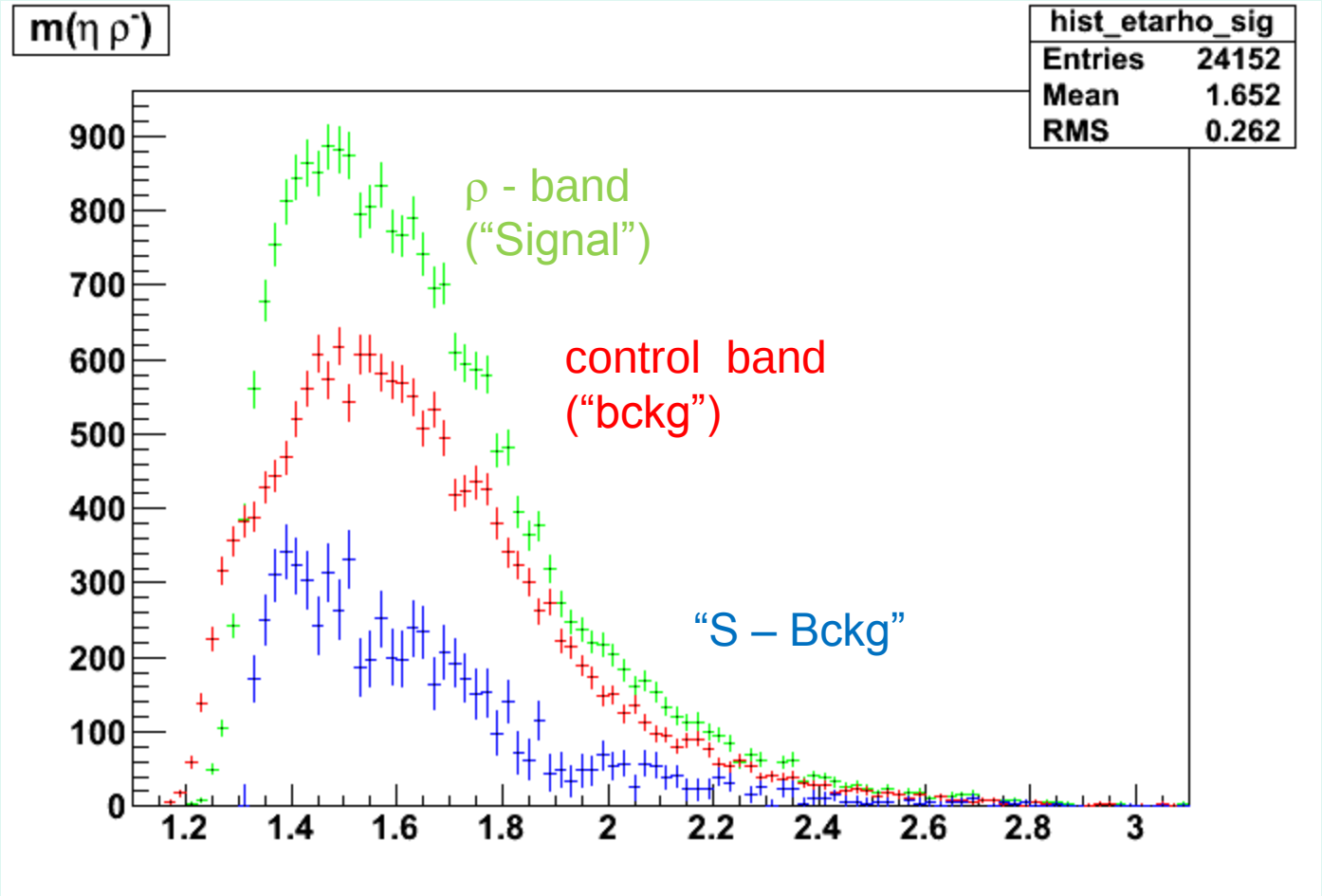
Backup slide: $\pi^- \pi^0$ system



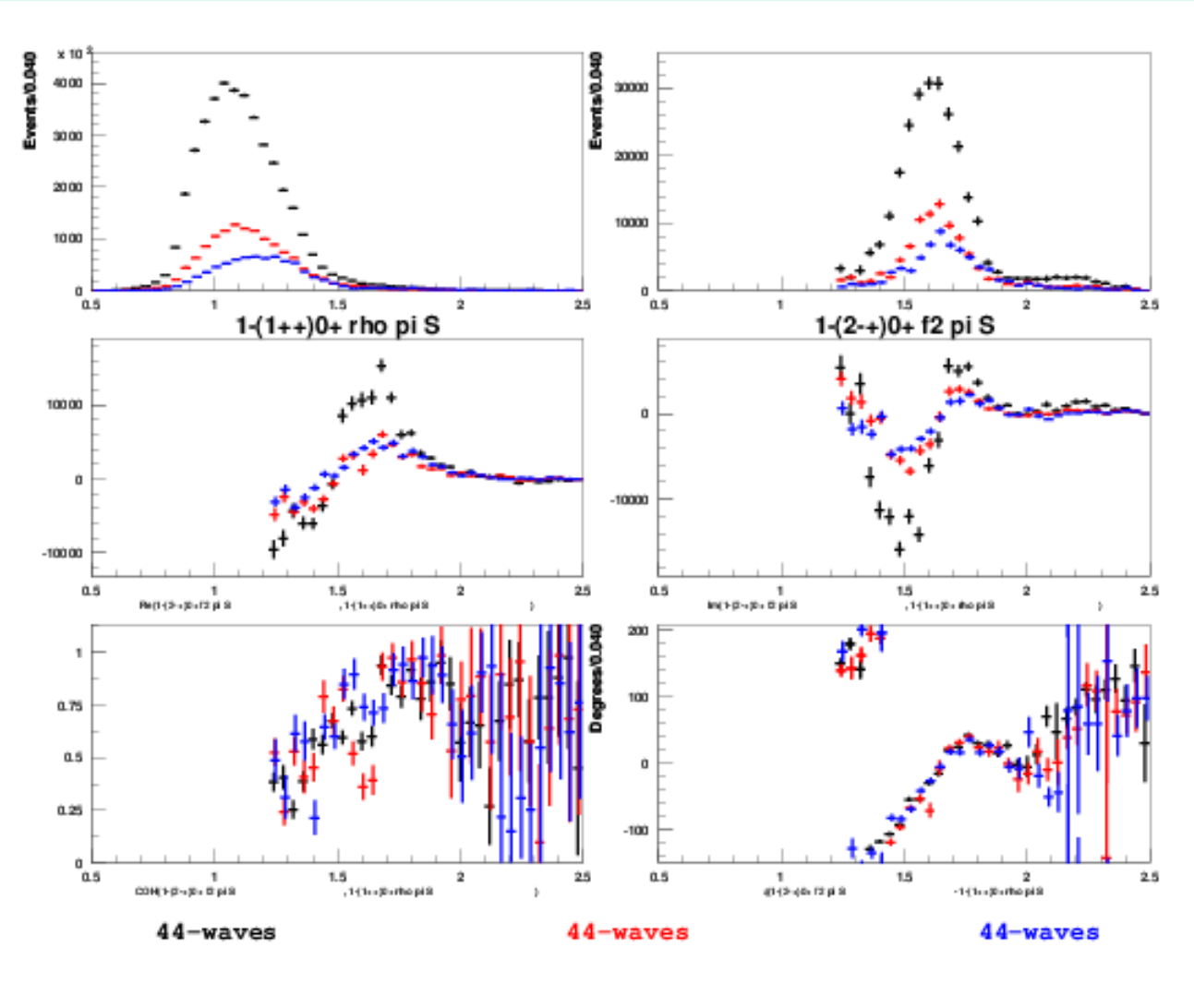
Backup slide: $\pi^- \eta$ system



Backup slide: $\pi^- \pi^0 \eta$ system



Backup slide: $\pi^- \pi^0 \pi^0$ system PWA



Backup slide: $\pi^- \pi^0 \pi^0$ PWA totals