Search for New and Unusual Strangeonia in Photoproduction using CLAS

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  - Strangeonia
- Experiment
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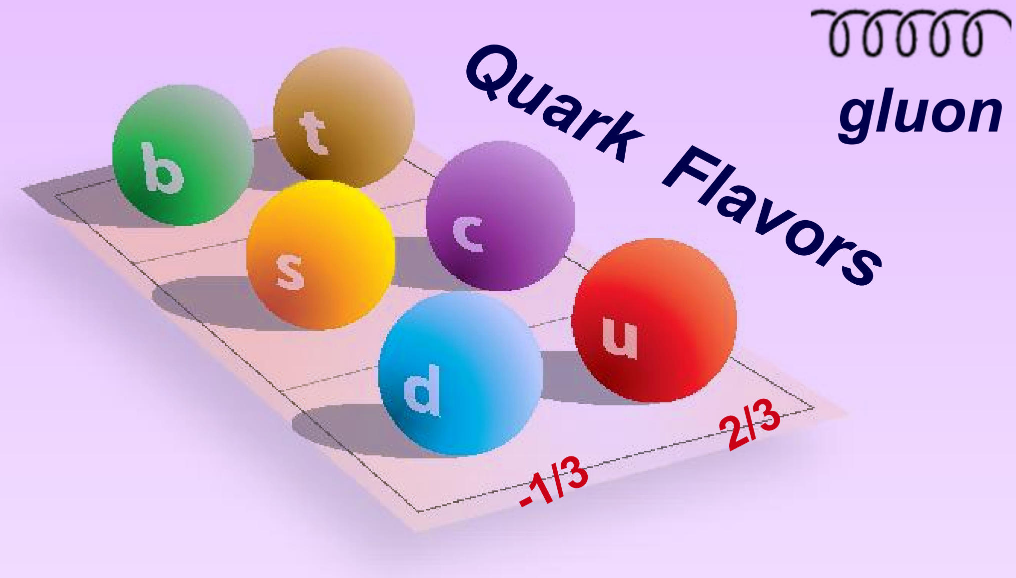
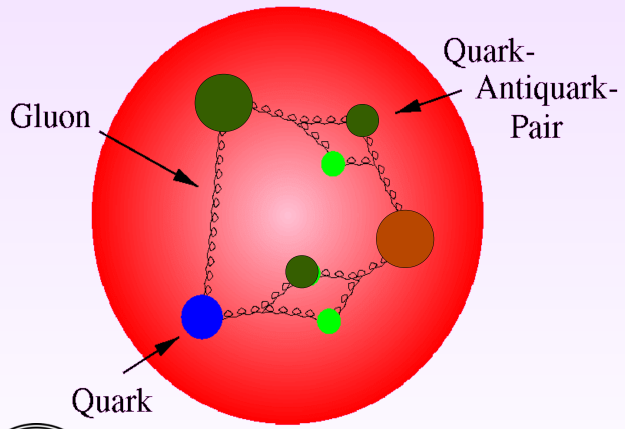
QCD



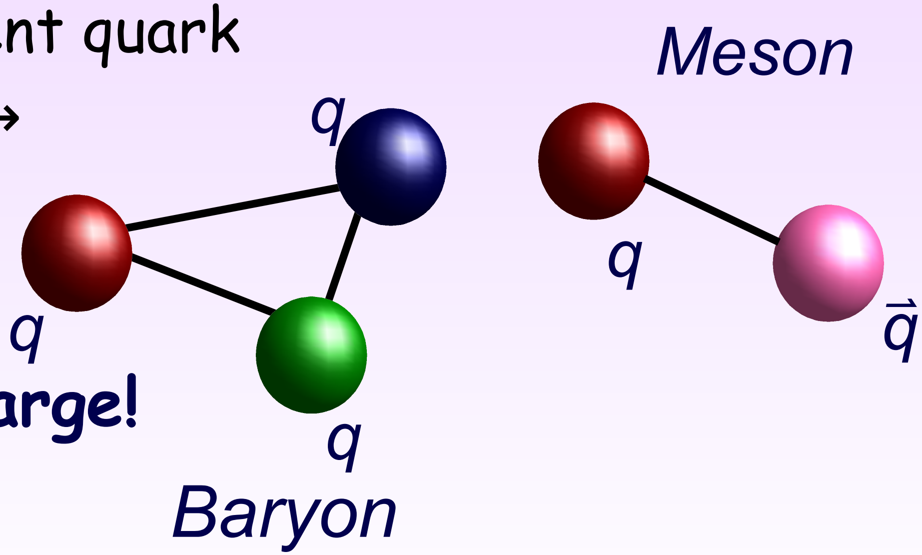
Quantum chromodynamics (QCD) is theory of the strong interaction (color force).

It describes the interactions of the quarks and gluons making up the hadron

QCD Picture



In constituent quark Model, →



Color charge!

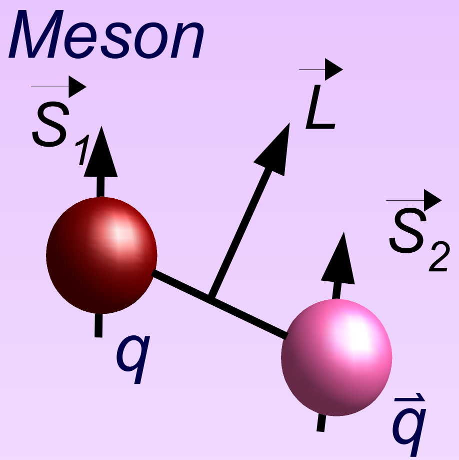
Quark Model and beyond

- Free quarks and gluons have not been observed in nature due to confinement

- QCD predicts exotic hadrons beyond the naive quark model [hybrids, glueballs and multi-quark states]

- Mapping of the meson spectra will help us identify exotic unconventional mesons and decays, to further our insight into soft (Non-perturbative) QCD

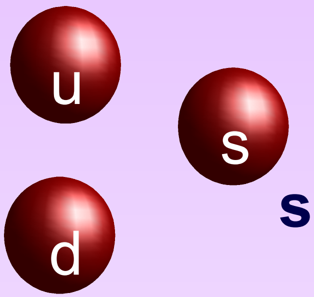
Meson Spectroscopy



$$\vec{J} = \vec{L} + \vec{S}$$

$$P = (-1)^{L+1}$$

$$C = (-1)^{L+S}$$



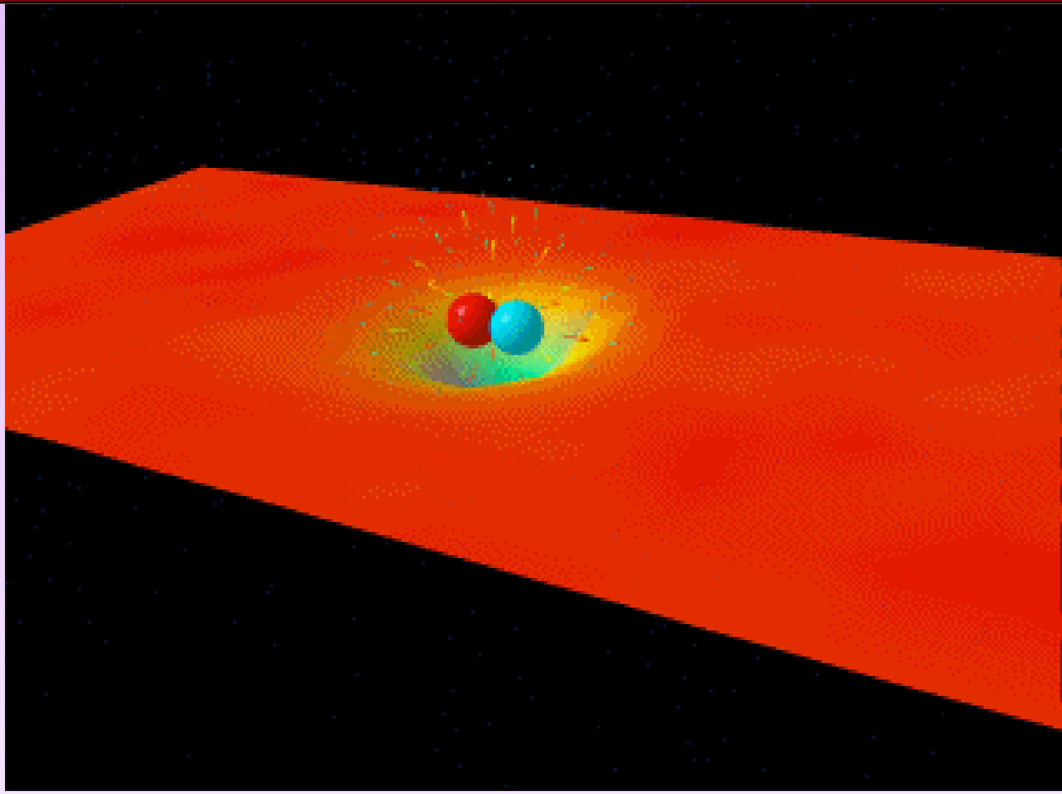
Light meson spectroscopy

$$J^{PC}\Big|_{allowed} = 0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 1^{++}, 2^{--}, \ldots\ .$$

$$J^{PC}\Big|_{exotic} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}, \ldots\ .$$

Flux-Tube Model

Lattice QCD inspired model that couples **gluonic** degrees of freedom with **quark** degrees of freedom



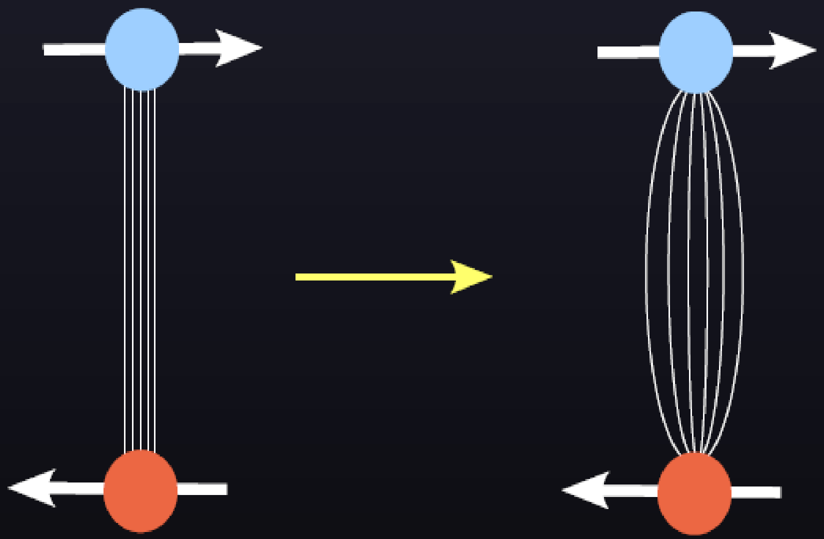
- The expulsion of the QCD vacuum from the region between a quark-antiquark pair. The tube joining the two quarks reveals the positions in space where the vacuum action is maximally expelled and corresponds to the famous "flux tube" of QCD.

– http://www.physics.adelaide.edu.au/cssm/research/lattice.htm

Flux-tube excitations

Pseudo-scalar Probe

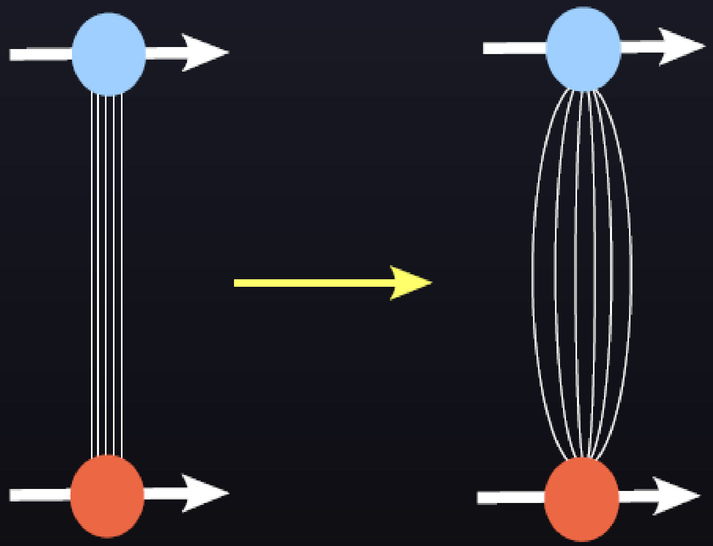
π–Beam



$$_{quarks}J^{PC} \otimes {}_{flux-tube}J^{PC} = 1^{--}, 1^{++}$$

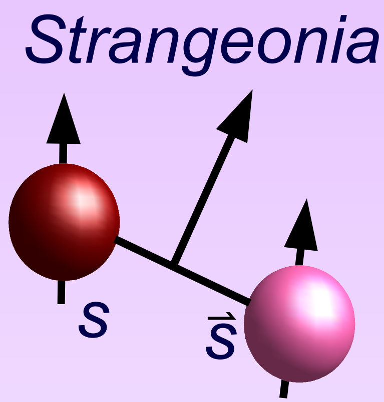
Vector Probe

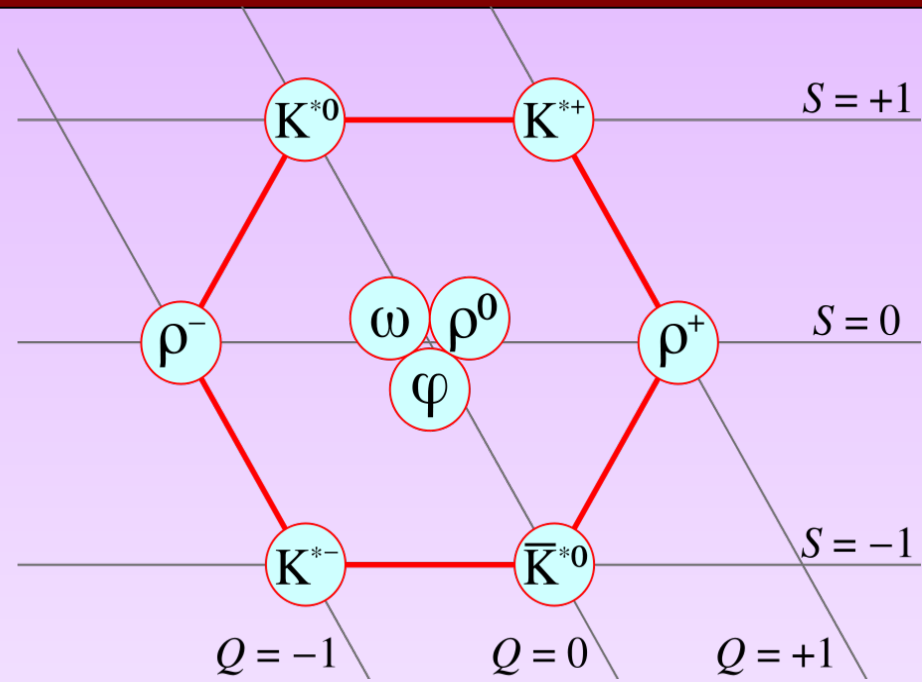
γ–Beam (or vector $s\bar{s}$)



$$_{quarks}J^{PC} \otimes {}_{flux-tube}J^{PC} = 0^{-+}, 1^{-+}, 2^{-+}, 0^{+-}, 1^{+-}, 2^{+-}$$

Strangeonia





- Of the **22** expected resonances, only **7** are well identified
  - η-η'
  - ϕ (1020)
  - h_1 (1386)
  - f_1 (1426)
  - f_2' (1525)
  - ϕ (1680)
  - ϕ_3 (1854)

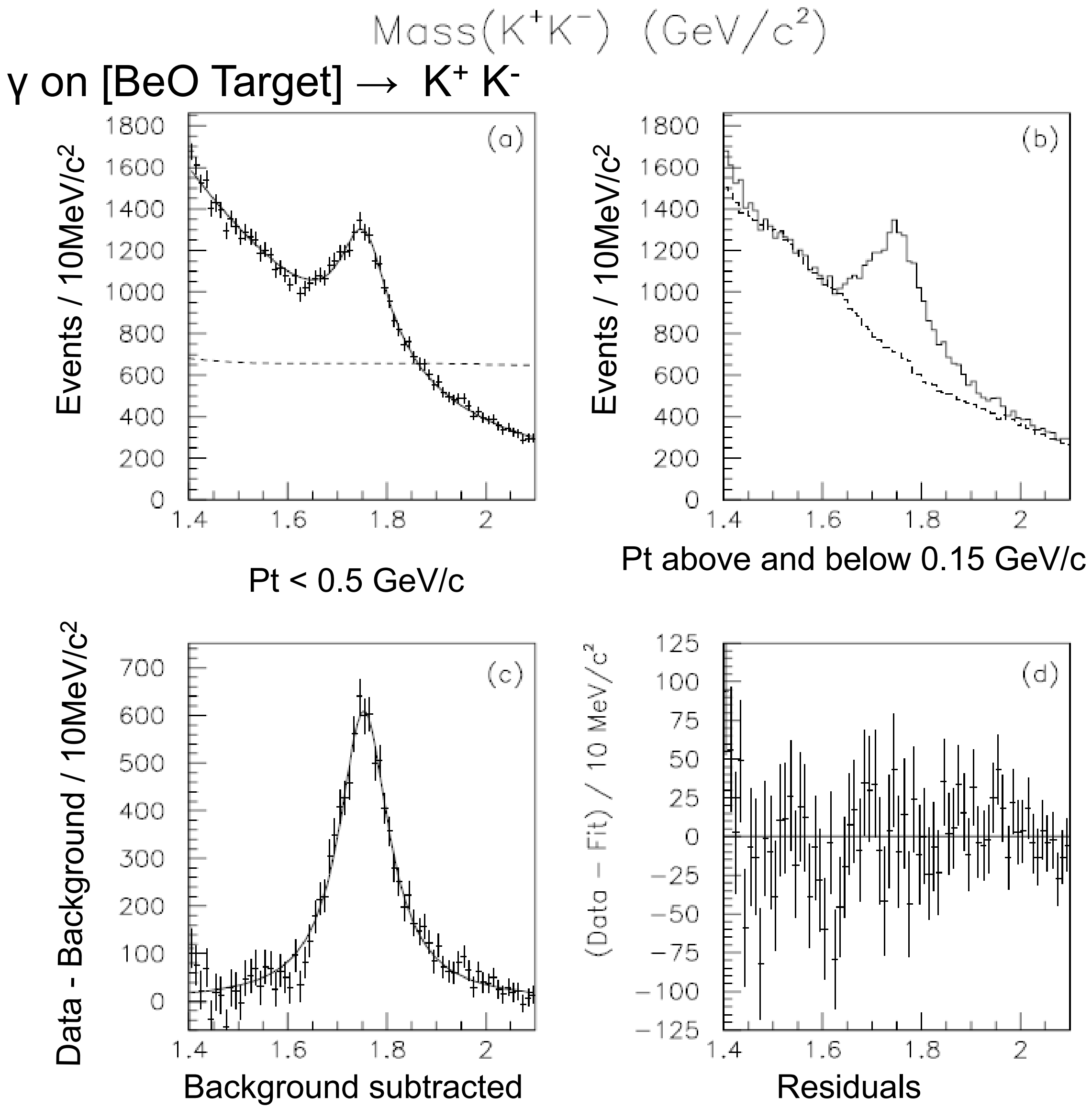
Why study Strangeonia?

- QCD is well tested at high mass meson states. Perturbative QCD, quarks essentially free ($\alpha_s << 1$). It works reasonably well in the charmonium sector and above.

- Perturbative QCD breaks down at the low mass scale. QCD is non-linear in this non-perturbative regime ($\alpha_s \sim 1$). We have to resort to specific hadronic models now.

- Because of the intermediate mass of the strange quarks, study of strangeonium states will serve as a bridge between short and large distance behavior of QCD confinement potential.

φ(1680)/φ(1750)



- e^+e^- production experiments observe the $\phi(1680)$
- $\phi(1750)$ is cited by PDG under $\phi(1680)$ with a note
- Focus experiment @ Fermilab has ~ 11,700 events for a resonance at $\phi(1750)$
- Exclusive $K^+ K^-$ events
- Cleanest way to look for this resonance is in the $\phi\eta$ decay

Proposed Analysis

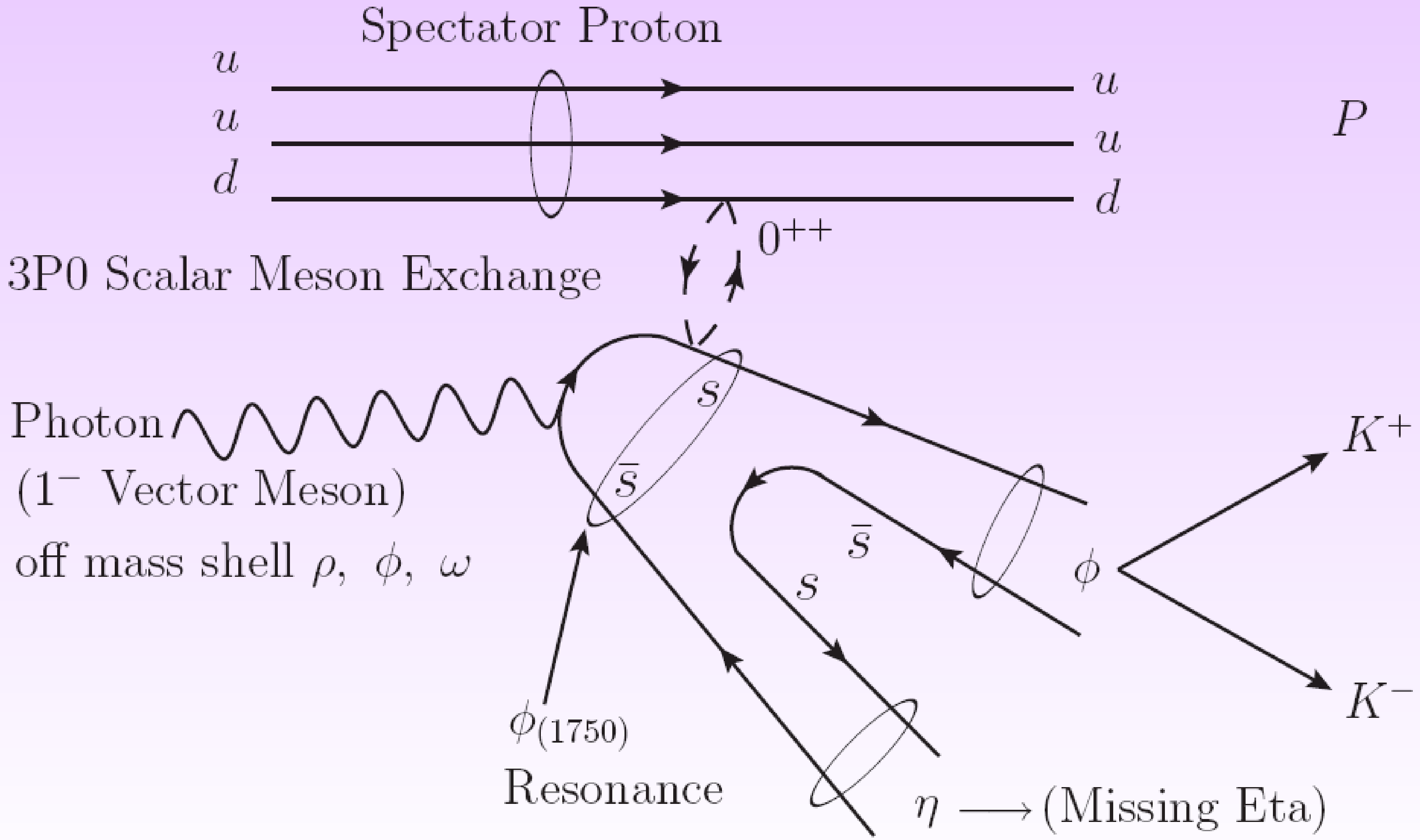
$$\gamma \; p \rightarrow p \; K^{+} \; K^{-} \; [x]$$

- I will analyse inclusive $p \; K^{+} \; K^{-}$ final state for exotica and strangeonia
- From g12 dataset 3 track events with an additional missing neutral particle will be selected
- From the invariant mass of $K^{+} \; K^{-}$, an intermediate φ meson will be identified
- This gives us access to φ η, φ π^0 and possibly φ ω states via missing mass using energy-momentum conservation
- φ(1680)/φ(1750) resonance will be investigated

Photoproduction

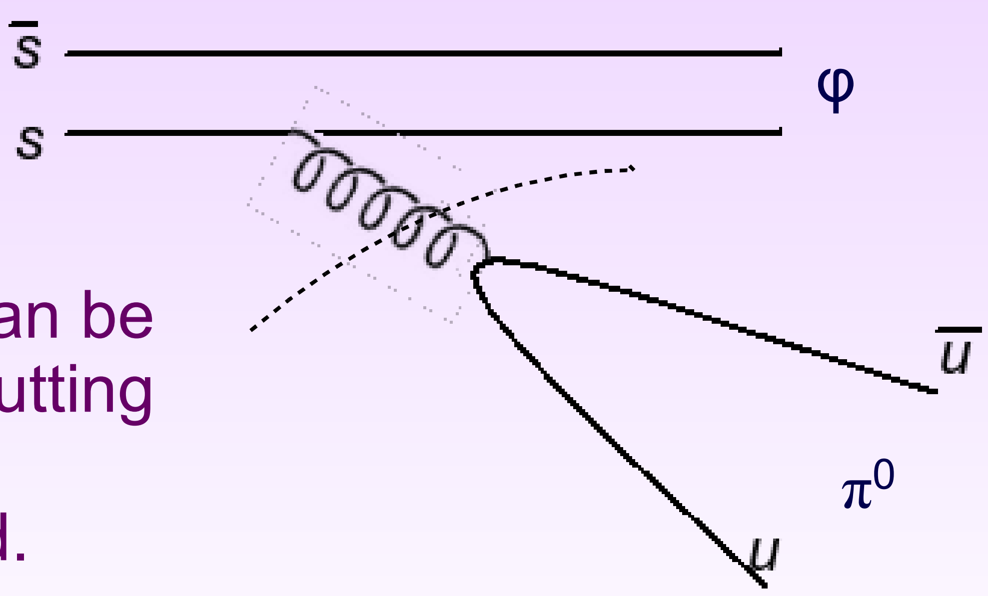
Vector Meson Dominance

Photon can be regarded as a superposition of vector mesons **(ρ, ω, ϕ)** with an important $s\bar{s}$ component.



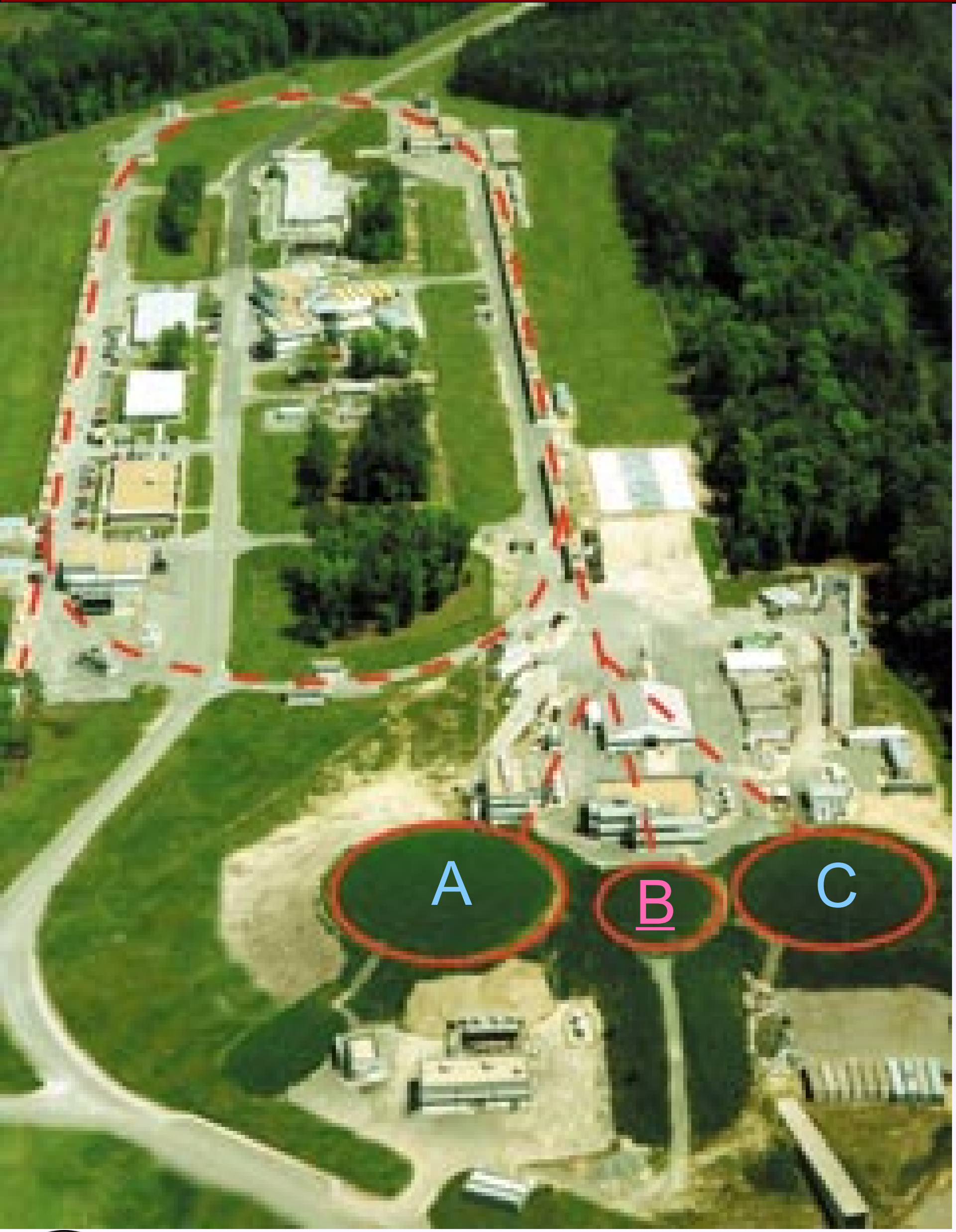
$\varphi \pi^0$ / $\varphi \omega$

- We expect to observe in the data, decays into states like $\varphi \pi^0$ and possibly $\varphi \omega$ which are OZI-suppressed and hence exotic
- This signals Physics beyond the conventional quark model.



* OZI rule: if two states can be completely separated by cutting across one gluon line the process is OZI-suppressed.

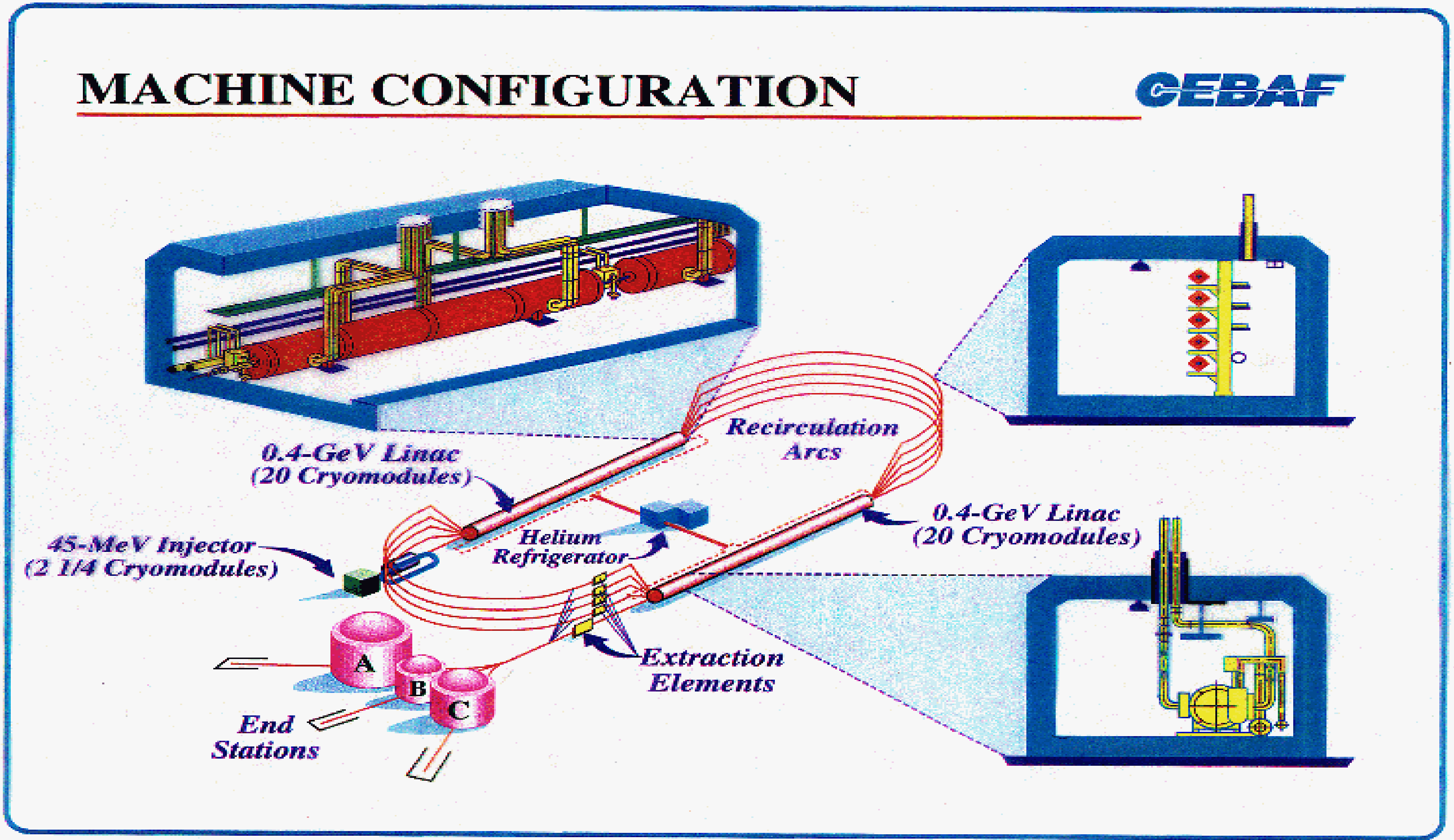
Jefferson Lab



CEBAF: Continuous Electron Beam Accelerator Facility @ Thomas Jefferson National Accelerator Facility, Newport News, Virginia.

- Operated for U.S. DOE by JSA, LLC.
- CEBAF delivers e^- beams to the 3 Halls. Polarised if requested. 5-pass beam. Energies up-to 6 GeV (1.2 x 5).
- Hall-B is the smallest experimental Hall with the largest detector "CLAS".

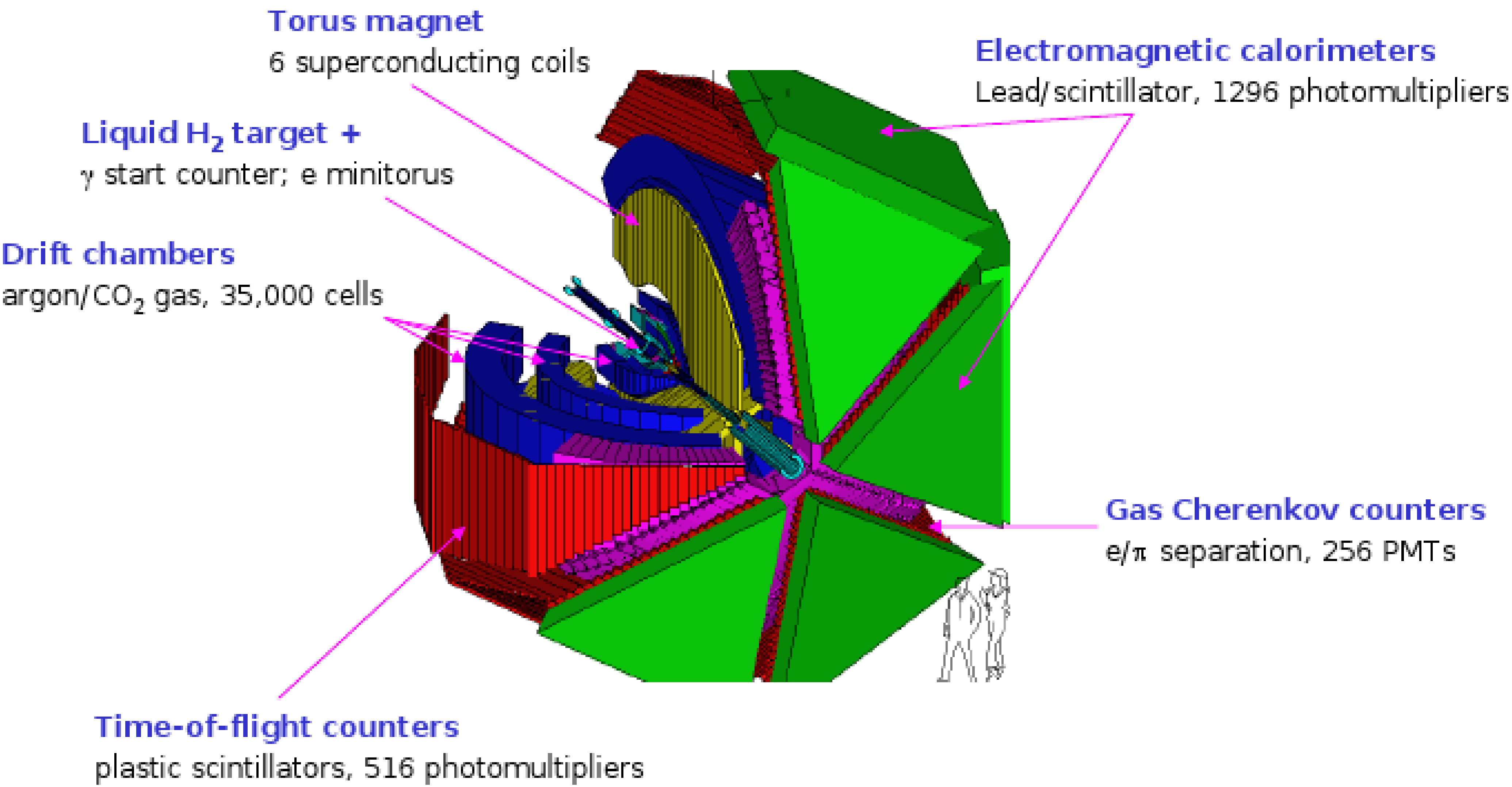
CEBAF



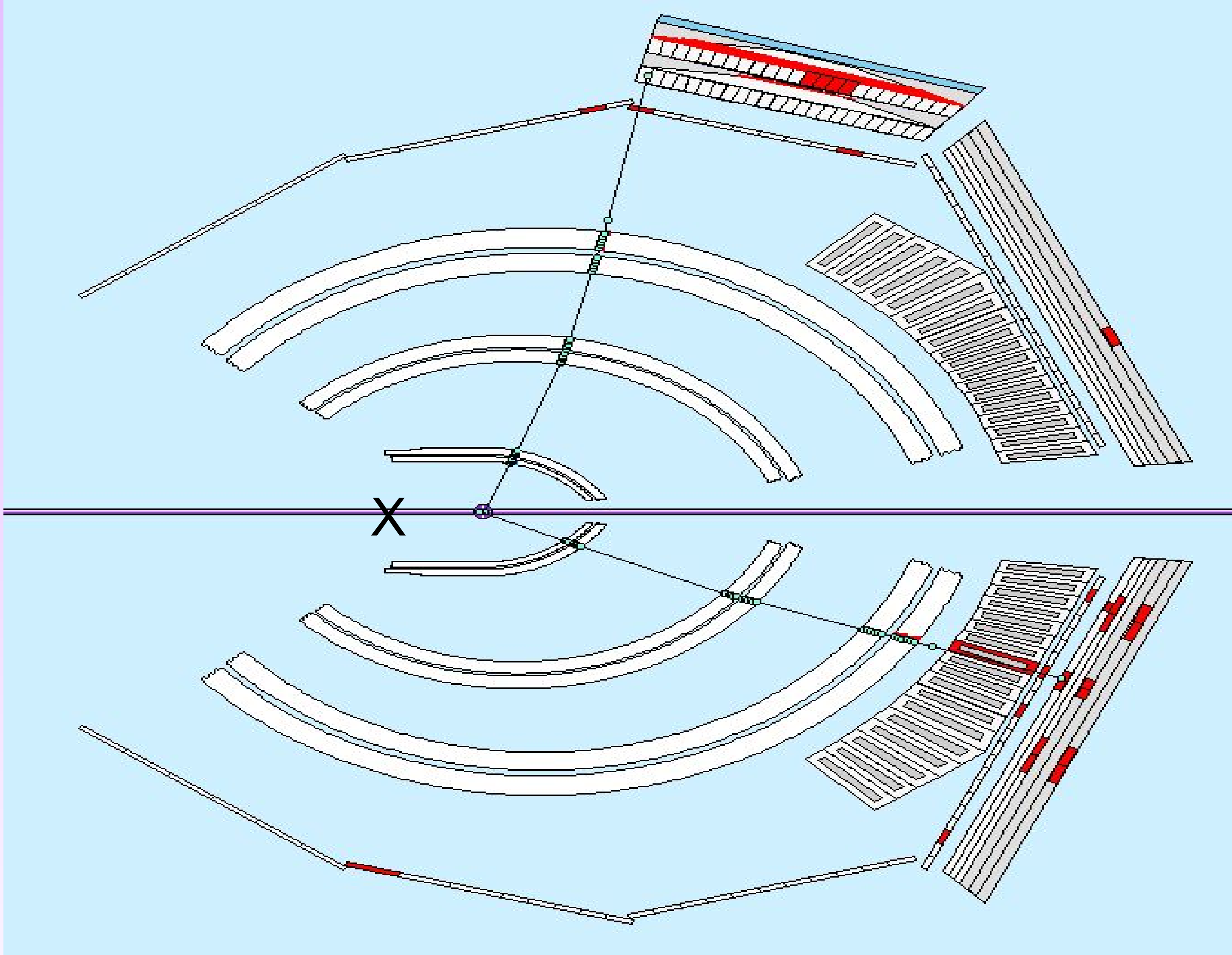
MACHINE CONFIGURATION
CEBAF
Recirculation Arcs
0.4-GeV Linac (20 Cryomodules)
45-MeV Injector (2 1/4 Cryomodules)
Helium Refrigerator
0.4-GeV Linac (20 Cryomodules)
Extraction Elements
A
B
C
End Stations

CLAS subsystems

CEBAF Large Acceptance Spectrometer

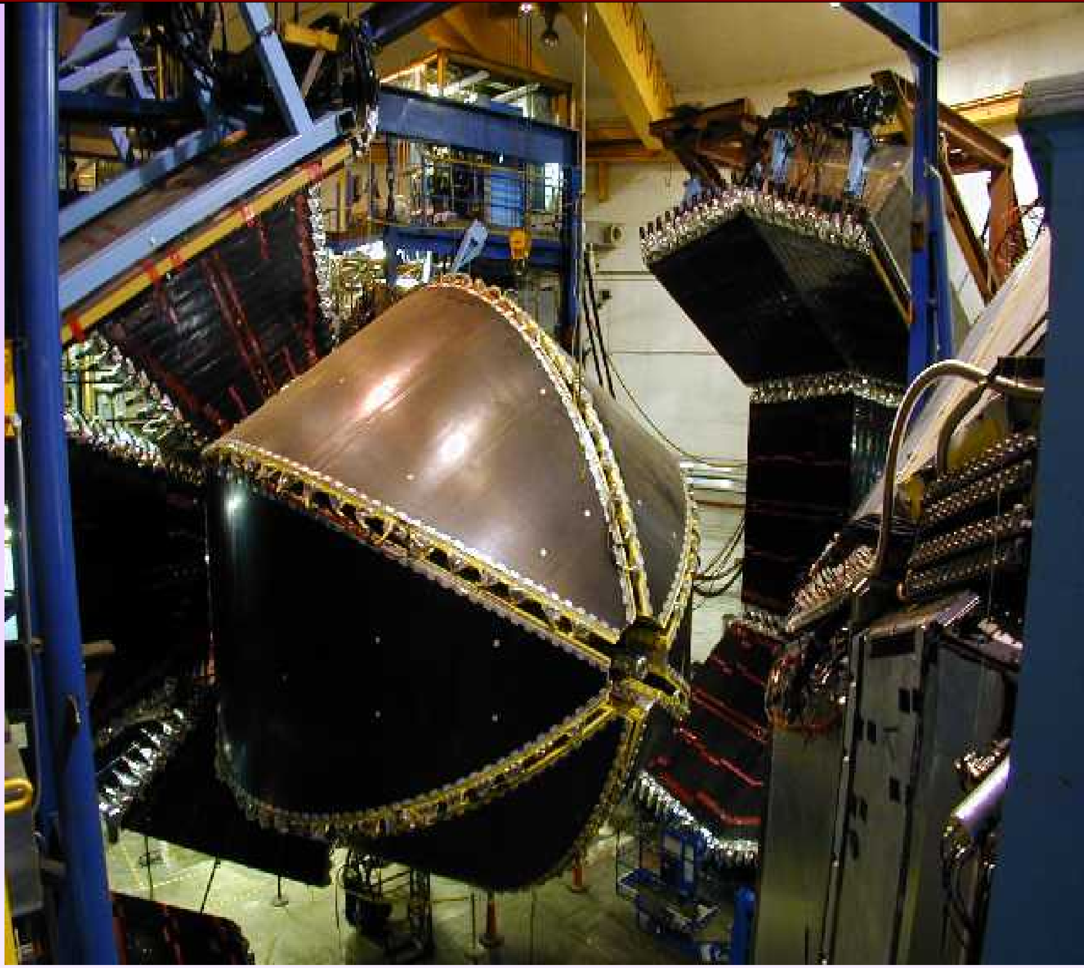


Tracking



- g12 used modified CLAS geometry to increase acceptance in the forward region for low t events.

CLAS



- Skeletal superconducting Toroidal Magnets for CLAS.
- CLAS detector during assembly.

g12 Data Summary

Commissioned : April 1, 2008 Completed : June 9, 2008

Production Triggers

- 44.2 Days of beam-time over 70 calendar days
- **Beam current ~ 60-65 *nA***, DC Occupancy ~ 3%
- **E^e = 5.71 *GeV***, DAQ Rate ~ 8 *KHz*
- 26.2 billion triggers, 68 pb^{-1} of data
  - 2 prong, No Level 2 Trigger, **$E^\gamma \geq$ 4.4 *GeV***
  - EC * CC
  - 3 prong with no MOR, etc.
- 1 billion triggers, 1.9 pb^{-1} of single sector data
- **126 *TB*** of raw data on tape

Calibrations

As part of my contribution to the experiment, I am responsible for calibrating the Tagger and the Start counter.

- Tagger tags the beam photon in CLAS with its energy and time using energy-momentum conservation for e^-.
- Start Counter helps find the right photon for the event as it is the closest of all detectors to the Target.

Tagger

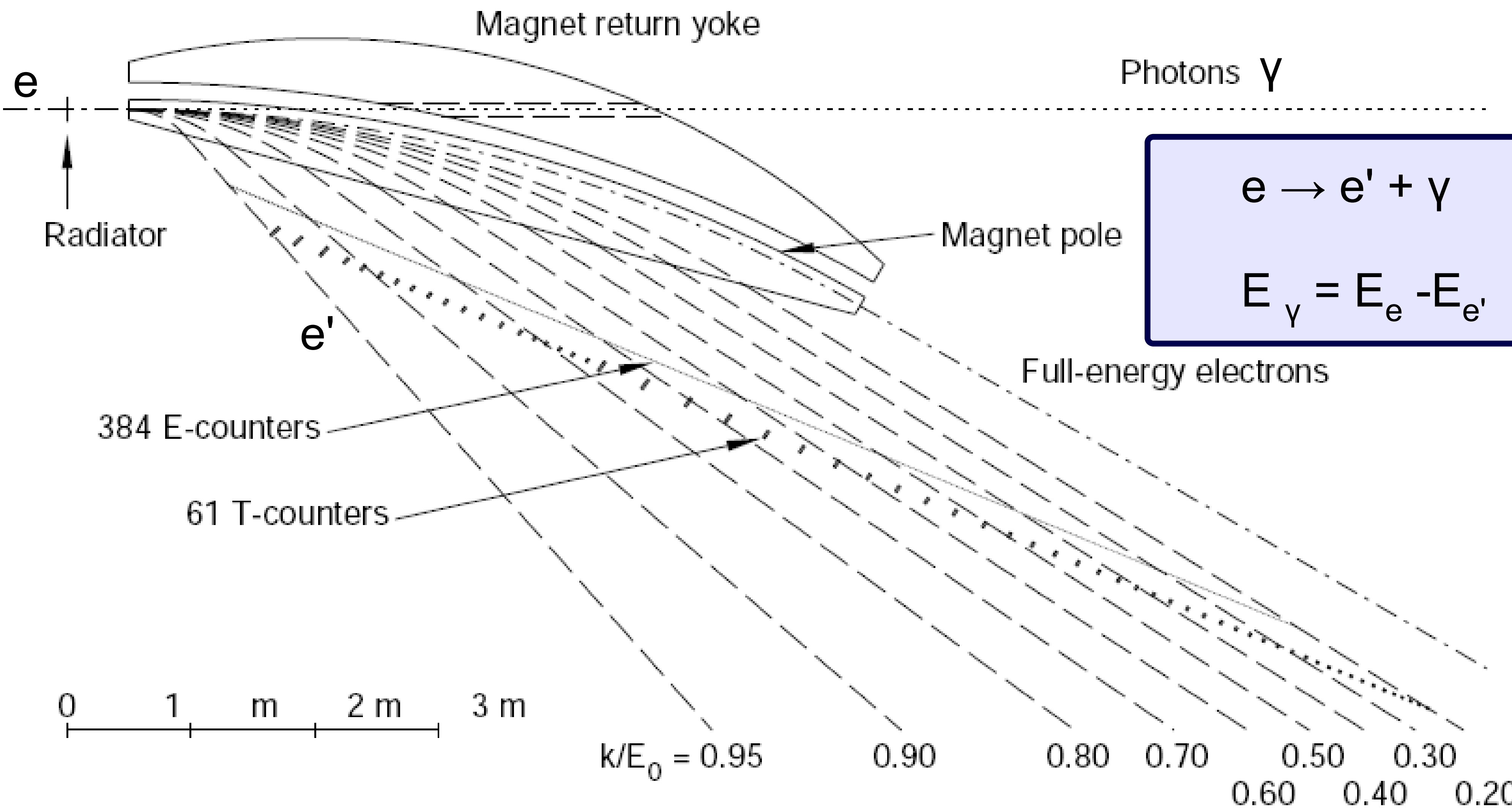
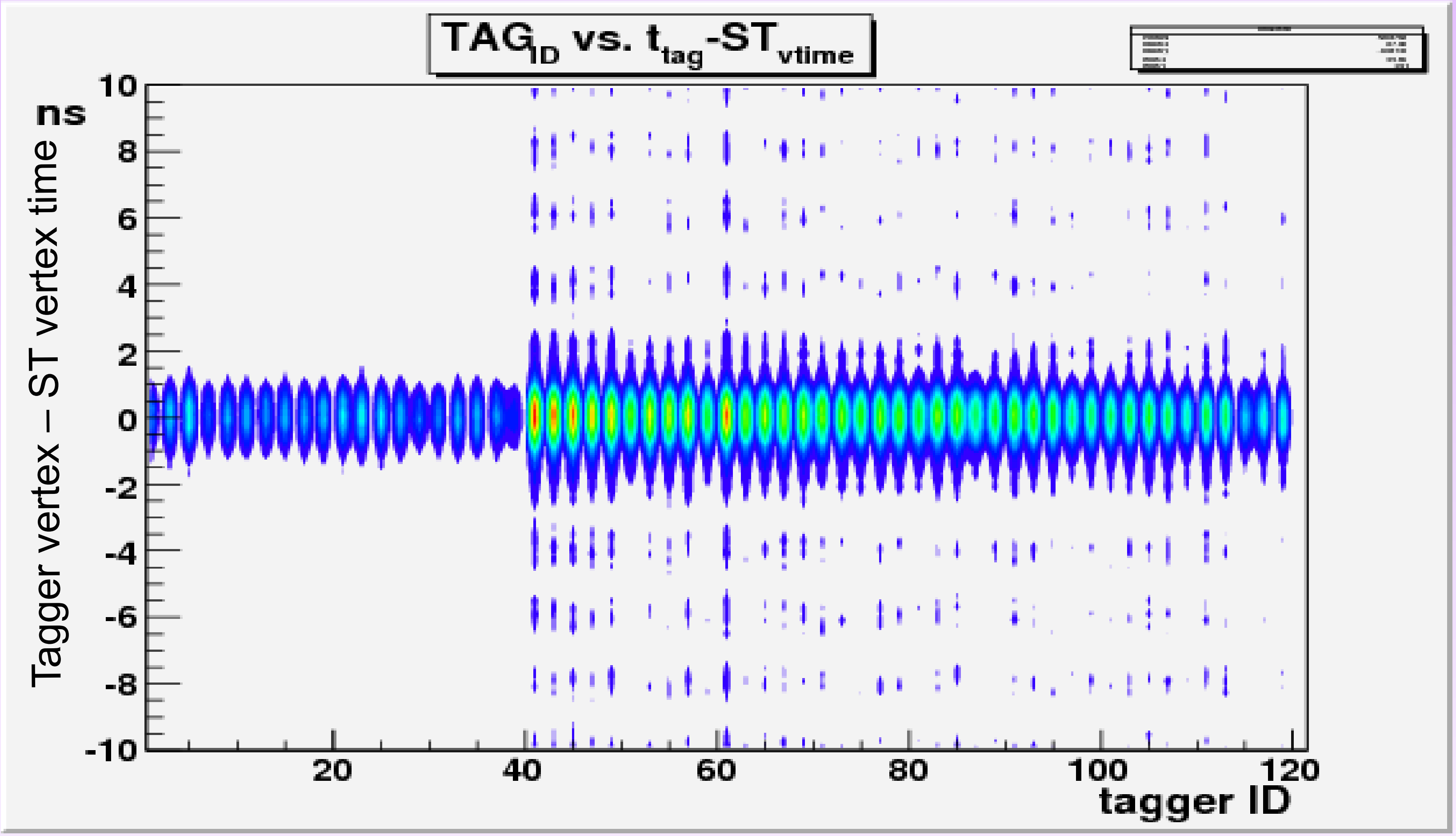


Fig. 23. Hall B photon-tagging system.

$e \rightarrow e' + \gamma$

$E_\gamma = E_e - E_{e'}$

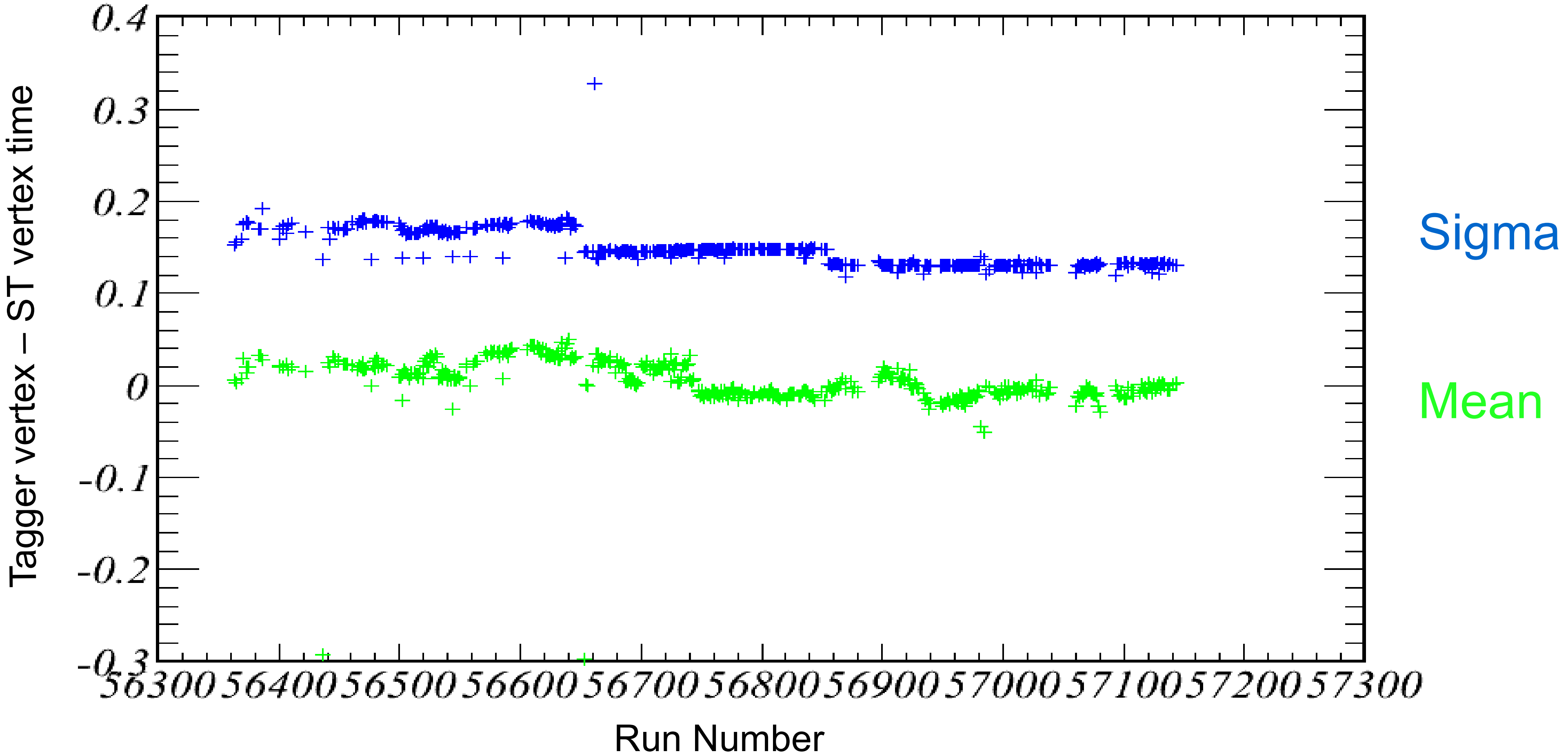
Tagger Calibration



Tagger Calibrations

- This plot shows that a hit in the start counter picks the right RF bucket. If timing for one of the counter was misaligned, it would show up here.

Tagger run by run Calibration

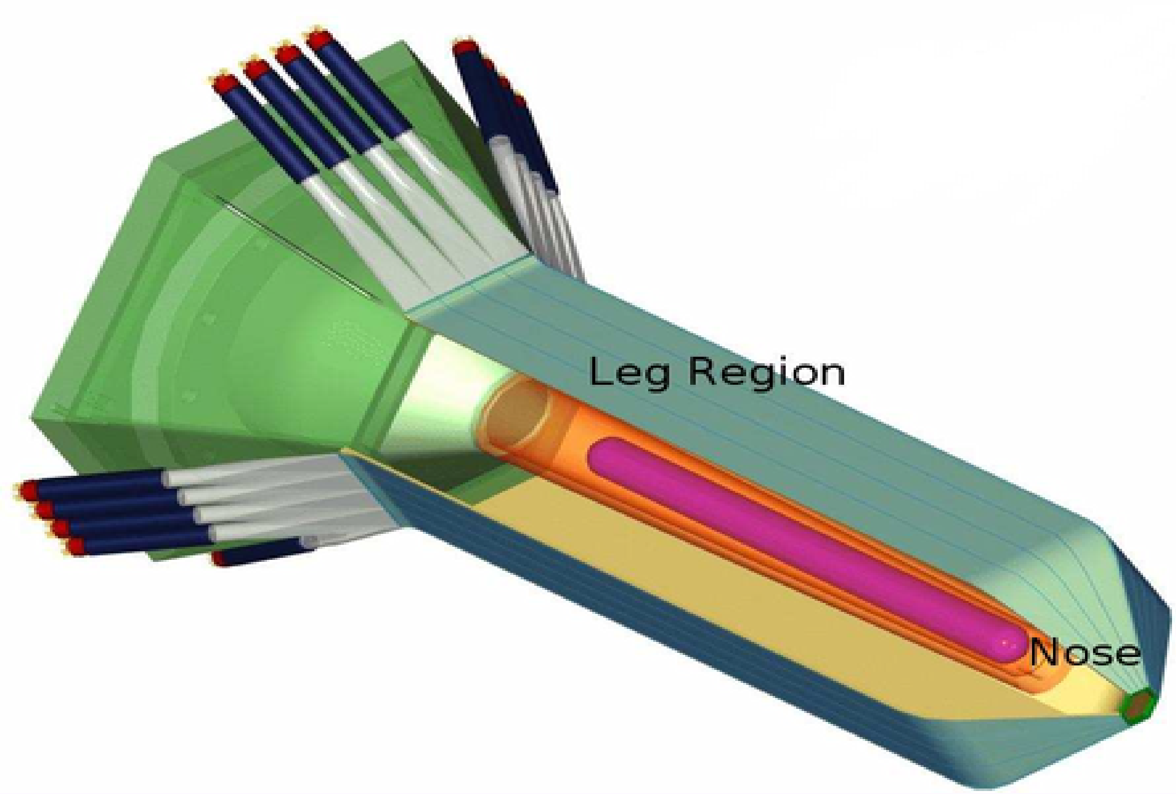


Tagger Calibrations

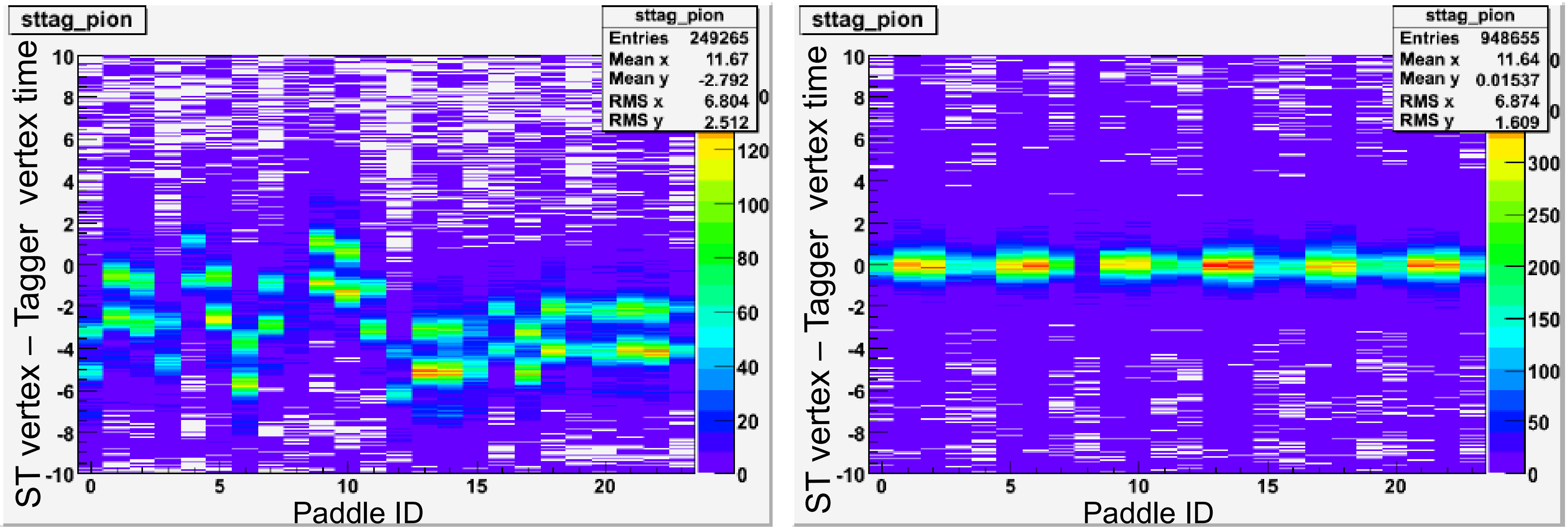
- Resolution remains more or less constant except for low current runs and runs after 56653 when we had a trigger change.

Start Counter

- Incorporates the independent sector based tracking of CLAS
- Covers the whole azimuthal (ϕ)
- g12 had ST pulled back from the center of CLAS to increase acceptance for low t, forward going particles
- ST is crucial for picking the right photon as well as Particle ID due to its proximity to the target



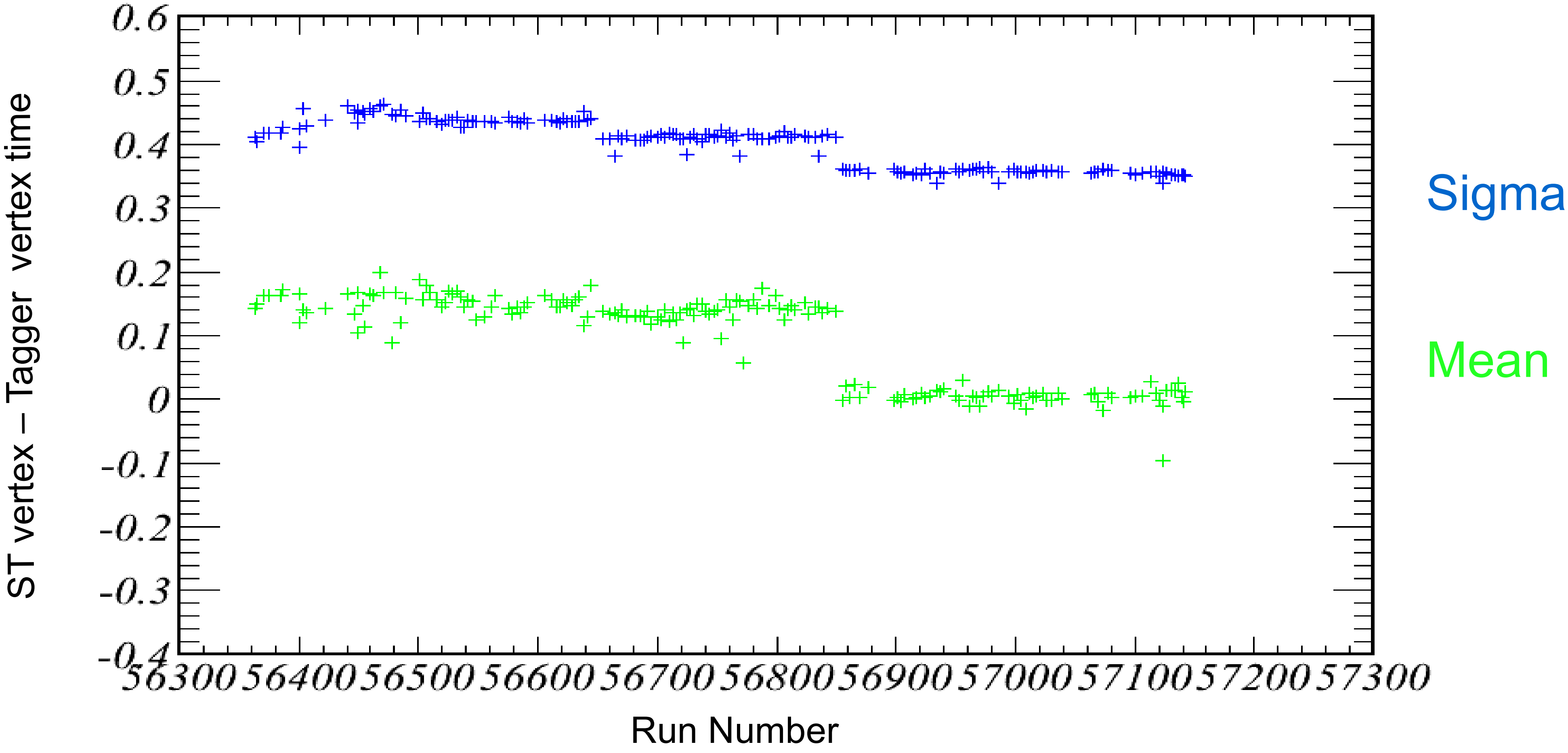
ST Alignment



(a) Before (b) After

- On the left is the plot of the time distribution of events in the 24 paddles before the iterative calibration process
- A month later with all paddles aligned and in time

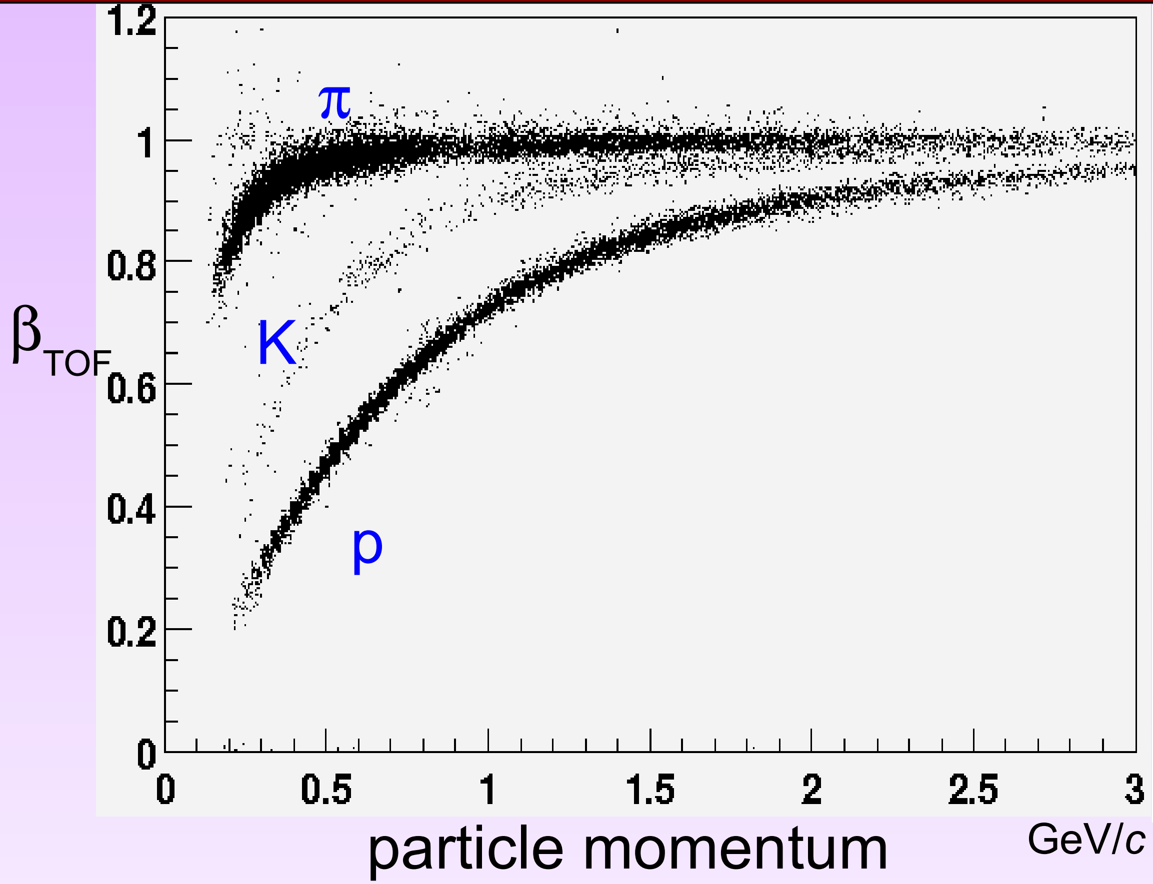
ST Run by Run Calibration

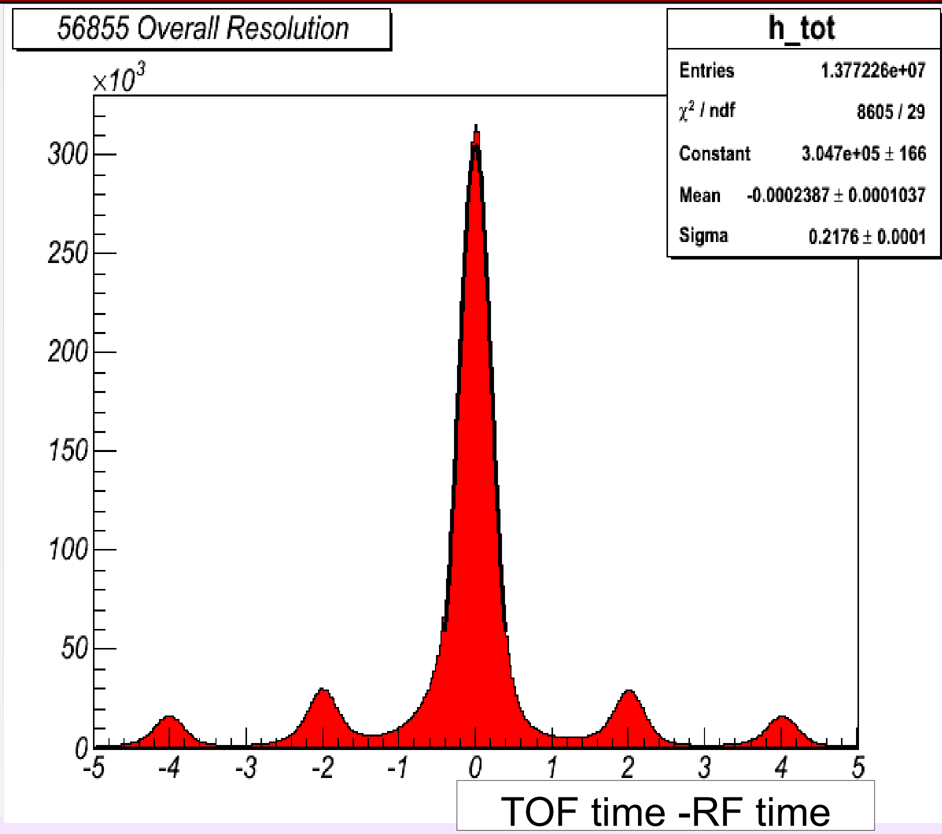


ST Resolution

- Resolution remains approx. constant through run-periods except for
- low current runs and runs after 56653 when we had a trigger change.

Particle ID using TOF





$$\beta = \frac{v}{c} = \frac{pathlength\ from\ event\ vertex\ to\ TOF}{Particle's\ flight\ time * \ c}$$

$$Mass = \frac{P}{\beta.\gamma(\beta)}$$

Preliminary Analysis

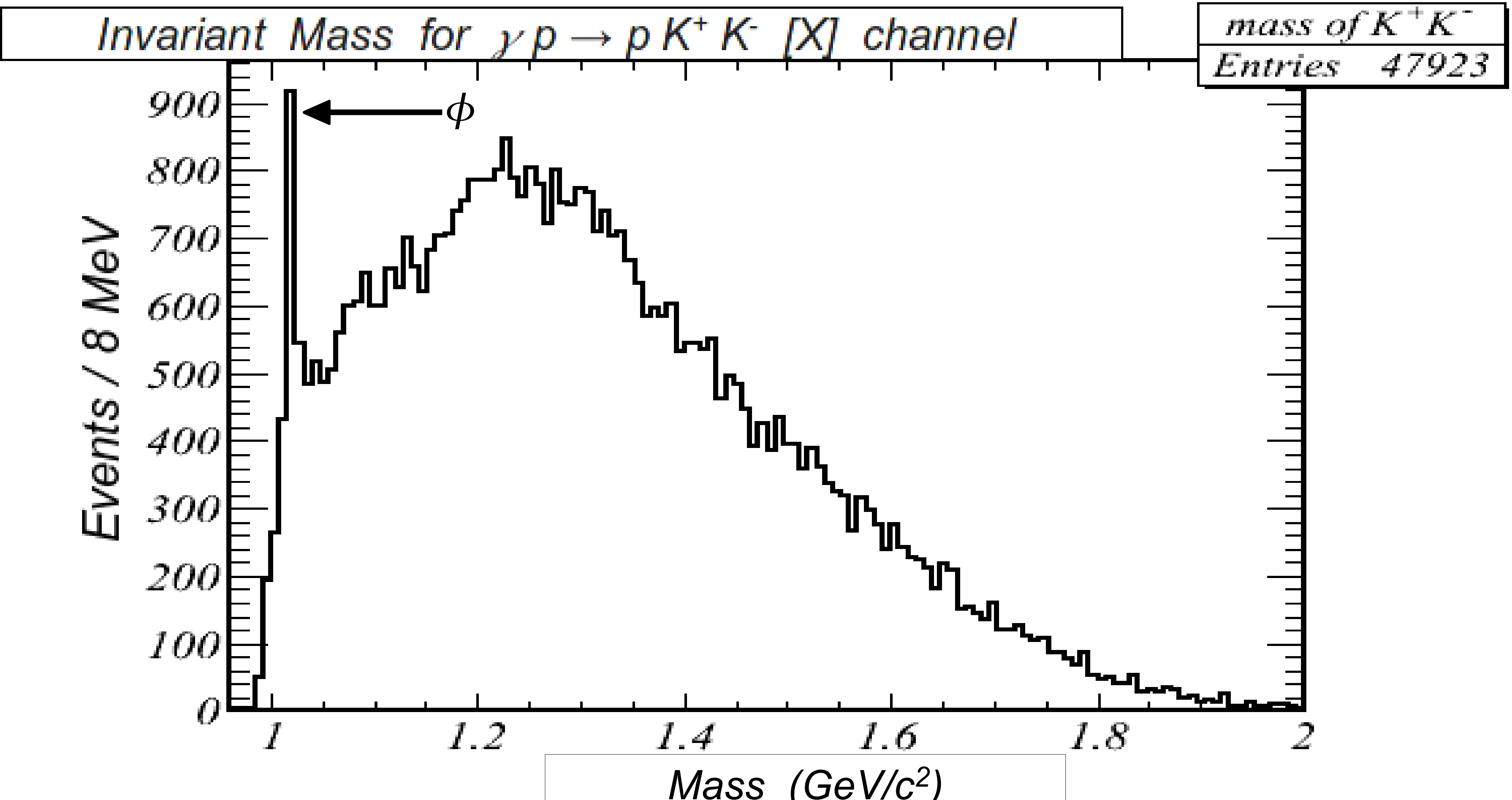
$$\gamma \; p \rightarrow p \; K^{+} \; K^{-} \; [x]$$

- Few % of g12 data was recently processed for physics and calibrations
- 3 track events with an additional missing neutral particle were selected
- From the invariant mass of $K^{+} \; K^{-}$, an intermediate φ meson was identified
- Missing mass in these inclusive events was calculated using energy-momentum conservation

Event Selection

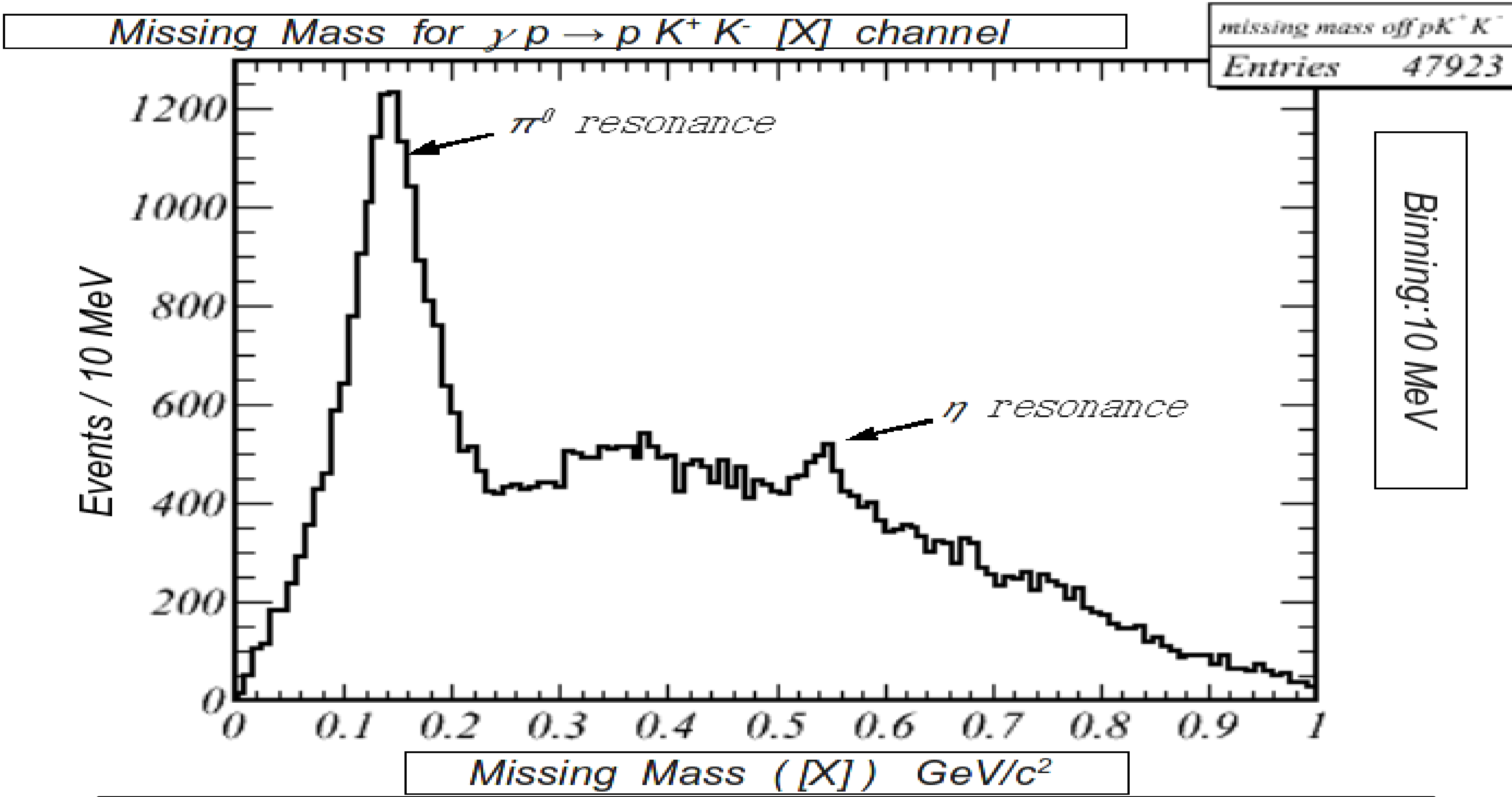
- **Data reconstruction → tracking → particle identification**
- **Select events with a proton, K^+ & K^-**
- **Apply cuts on the event such that**
  - Event vertex inside the target
  - Beam photon energy > 4.4 GeV
  - Time of the beam photon within ±1ns of a ST hit
  - Cuts on transverse missing momentum to identify peripheral meson production

$\gamma\ p \rightarrow p\ K^+\ K^-\ [X]$



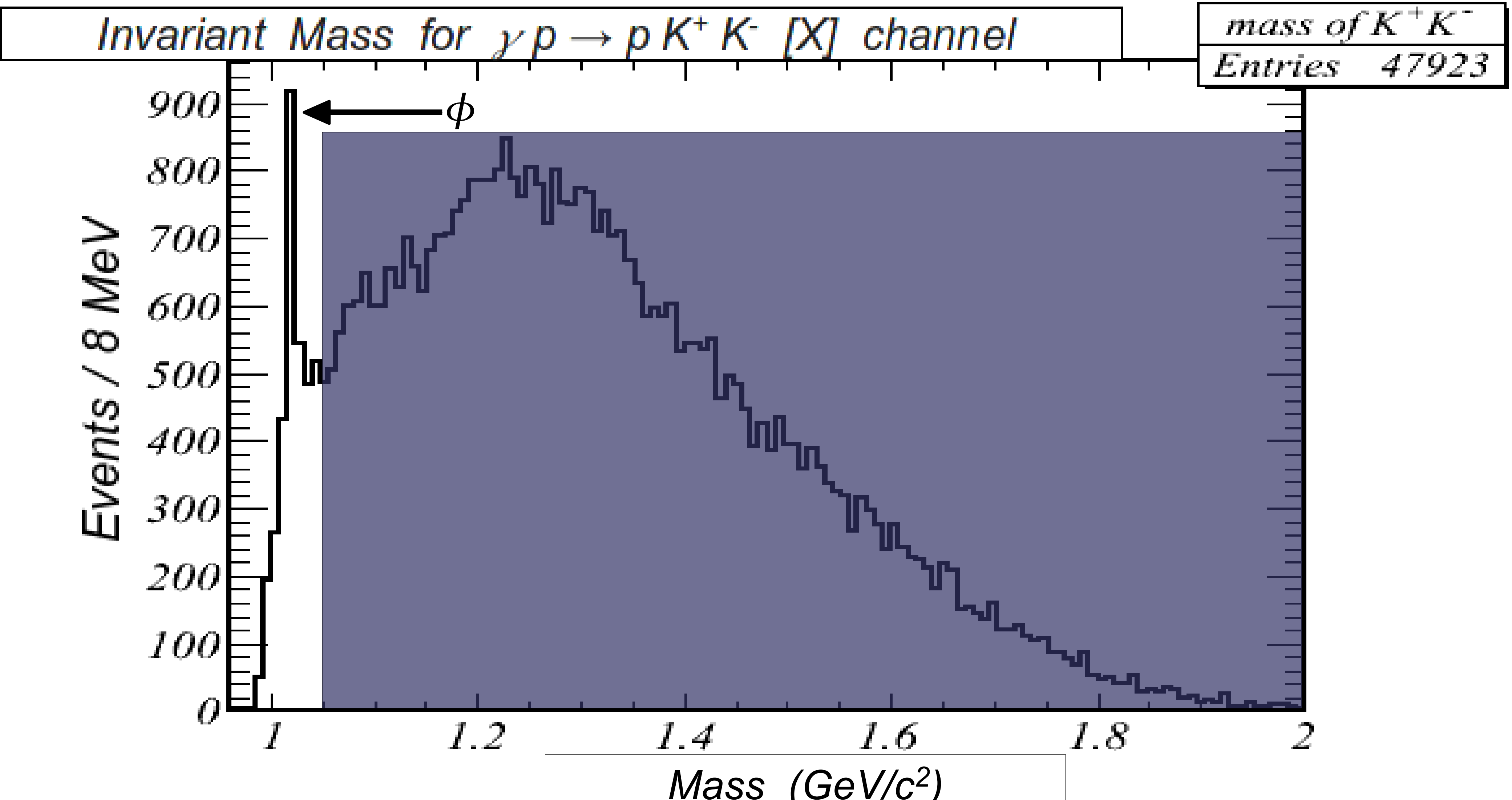
- Reconstructed Invariant Mass for K^+K^-
- Peak for the ϕ meson is visible

Missing mass for $\gamma \; p \rightarrow p \; K^+ \; K^- \; [X]$



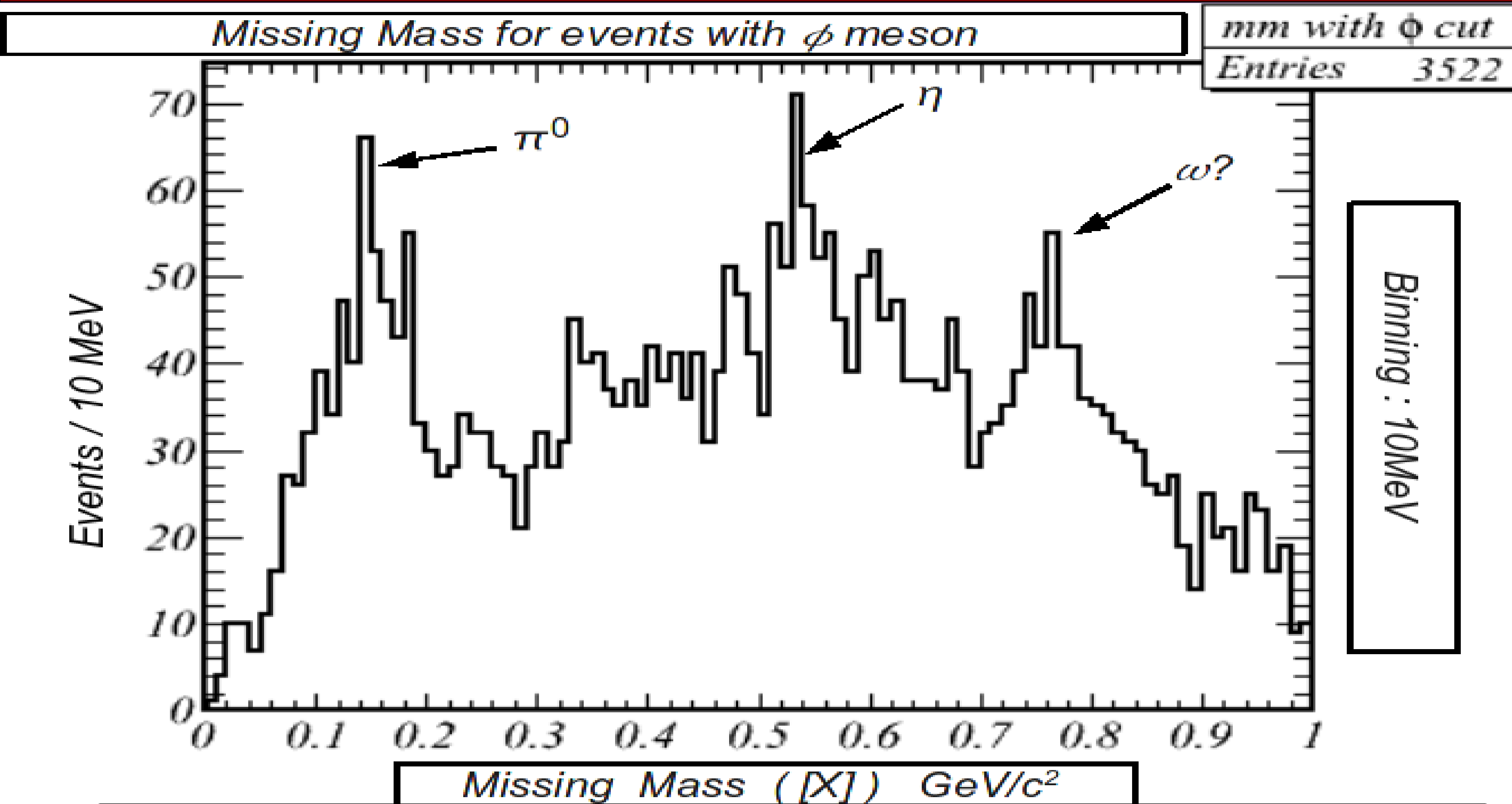
- Missing mass for final state p K^+ K^- [X]
- Peaks for η & π^0 mesons are visible

φ Events



- Reconstructed Invariant Mass for K^+K^-
- Peak for the ϕ meson is visible

Missing mass for $\gamma\ p \rightarrow p\ \varphi\ [X]$



- Missing mass for final state p K^+ K^- [X] in events identified with a ϕ.
- Peaks for η, π^0 and even ω mesons are visible.

Summary

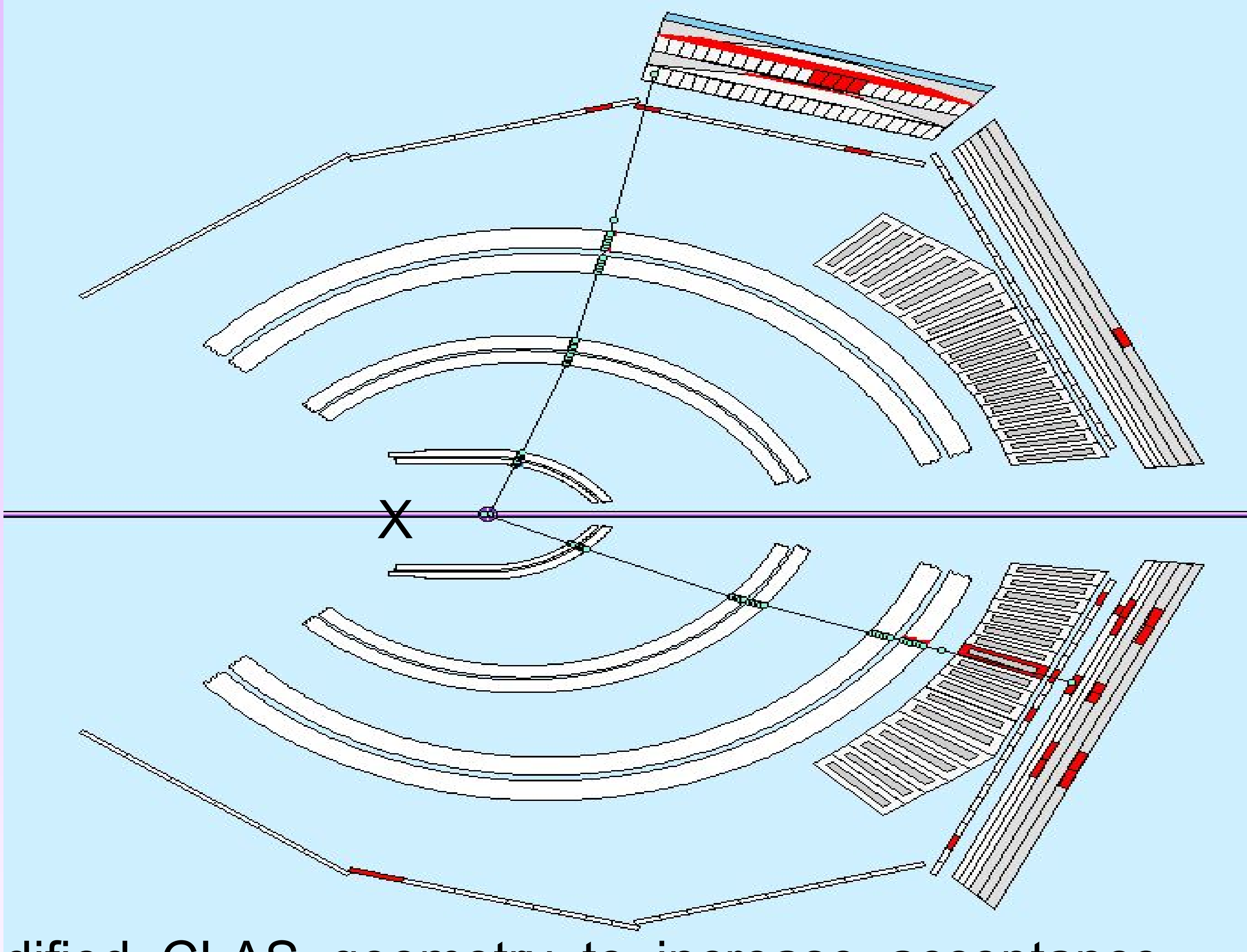
- Strangeonia is quite an interesting and important sector to look at. It will give us an insight into Non-perturbative QCD regime

- g12 has a huge dataset that will be soon calibrated, processed and available for analysis. Run by run calibration has been more or less stabilised

- From preliminary analysis, we see hints of decay states for strangeonia $\varphi\ \eta$ and exotics $\varphi\ \pi^0$ and $\varphi\ \omega$. Results look promising

Thank you!

Tracking



- g12 used modified CLAS geometry to increase acceptance in the forward region for low t events.

Search for Strangeonia in HyCLAS