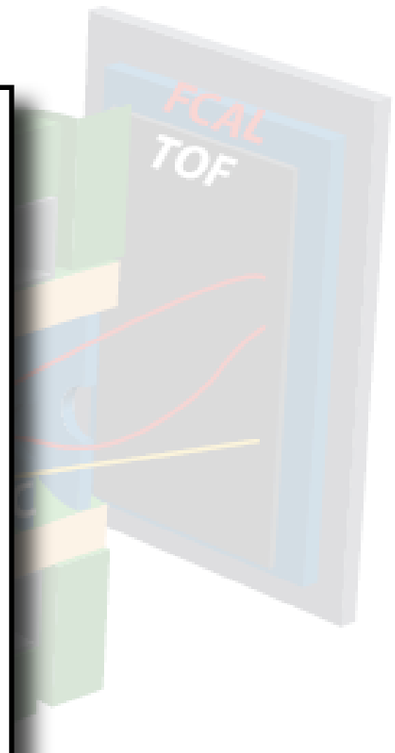
The GlueX Experiment (and its Context)

Ryan Mitchell
Indiana University
Hirschegg 2011
January 18, 2011



Overview of the GlueX Experiment

Use **9 GeV polarized photons** on a **proton target** to produce **hybrid mesons** with exotic J^{PC}:

- part of the JLab 12 GeV upgrade
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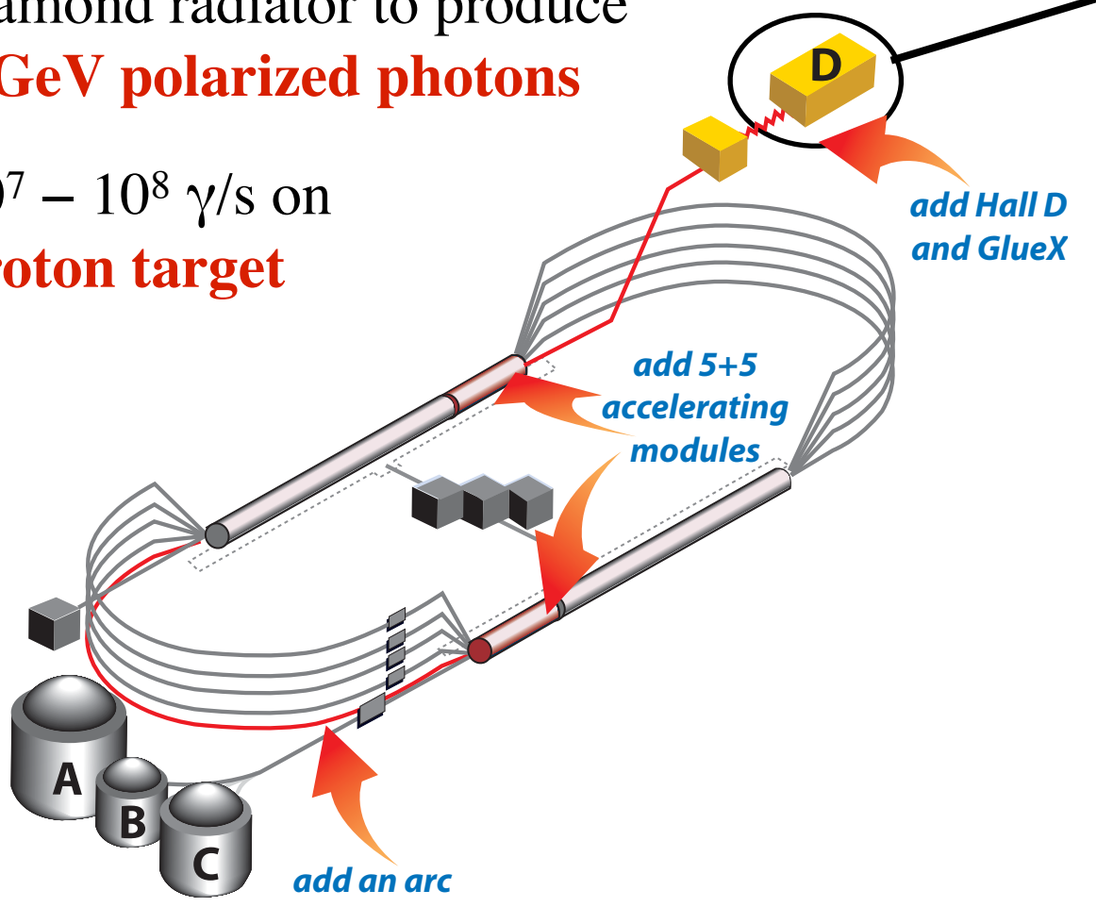
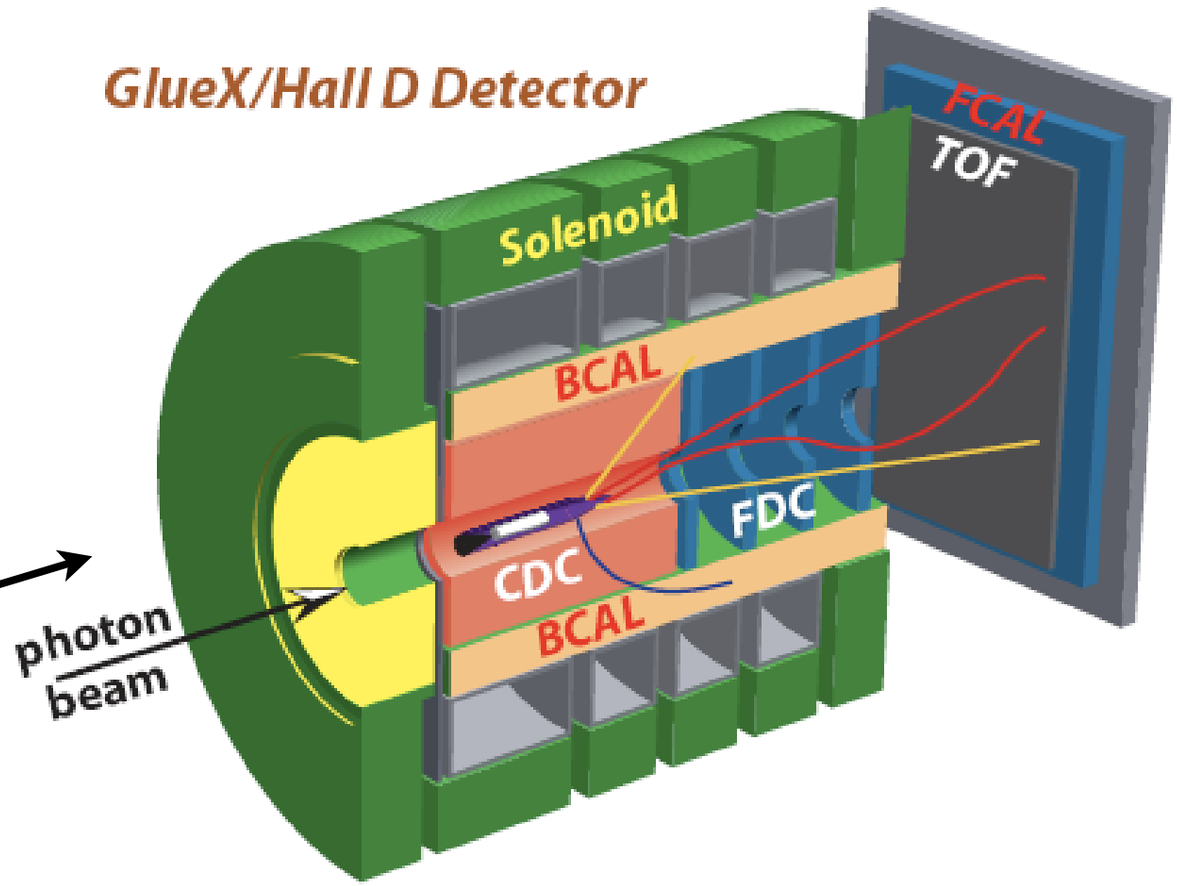
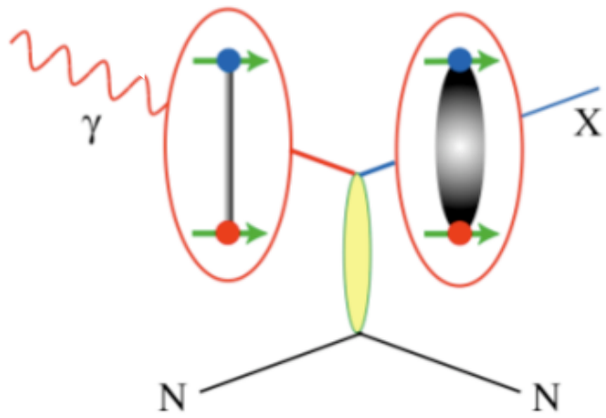




- produce **hybrid mesons** with exotic J^{PC}:



- use "amplitude analyses" to distinguish J^{PC}

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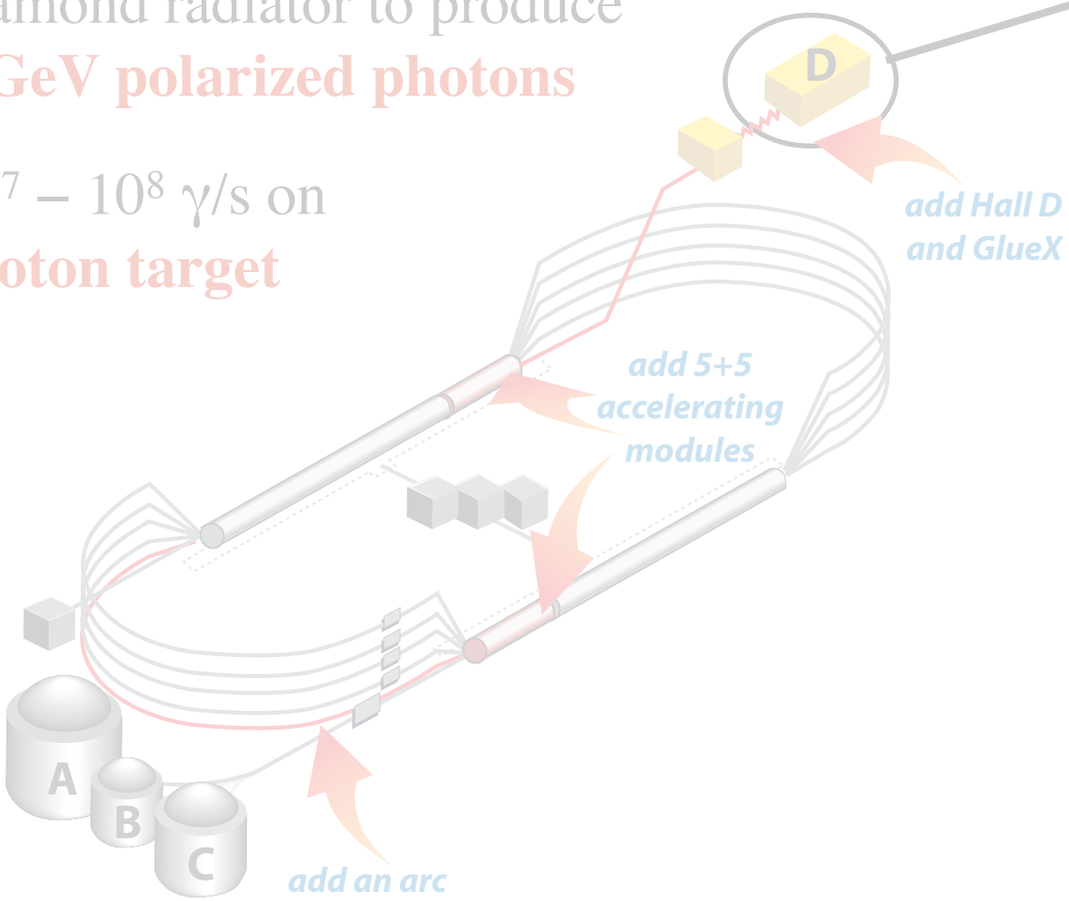

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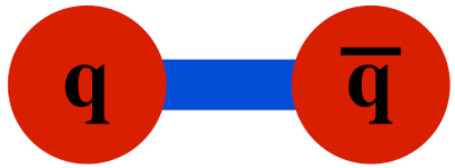
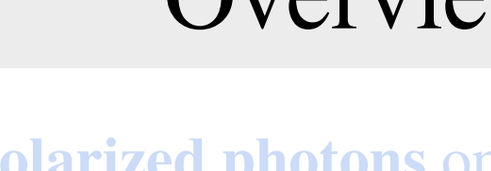
a "Quark Model" meson:



MESON

but hybrids are also predicted:



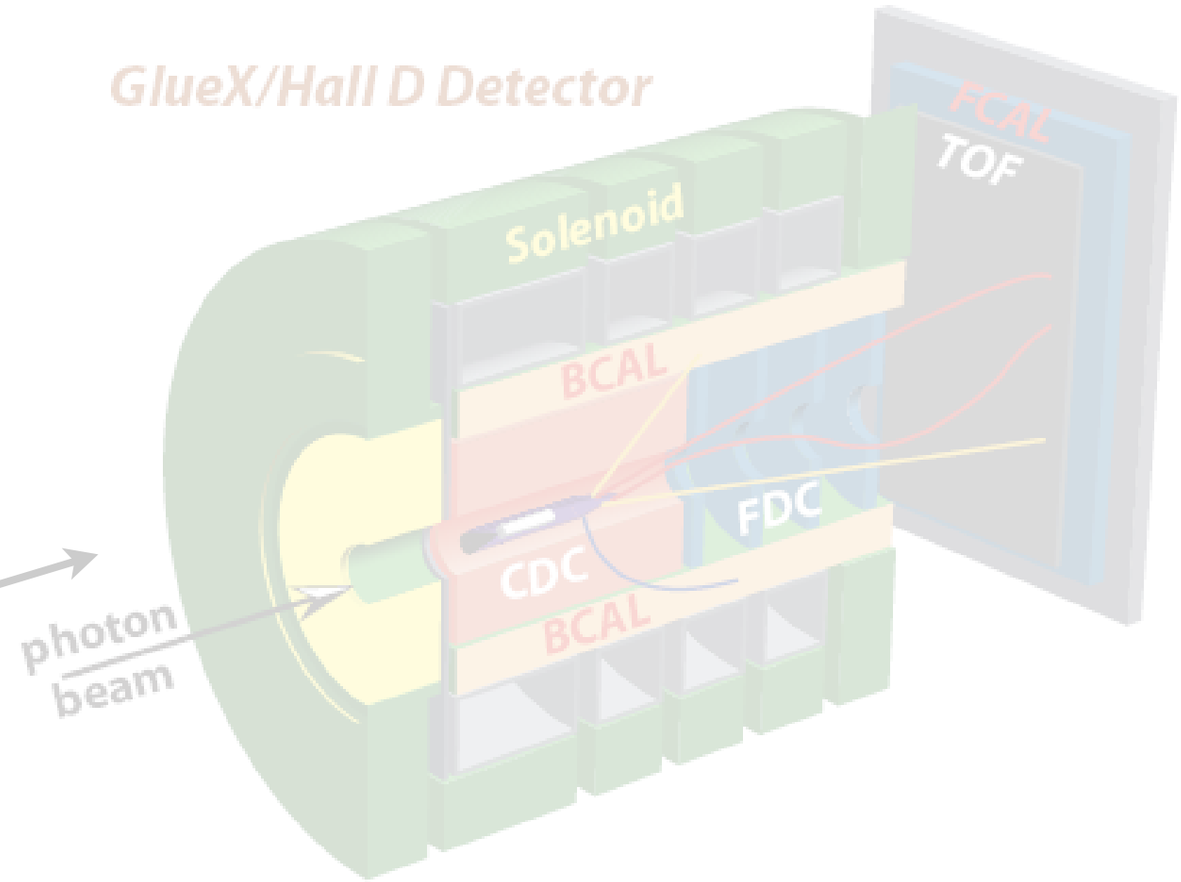
HYBRID MESON

and would shed light on

Gluonic eXcitations

add Hall D and GlueX

add an arc



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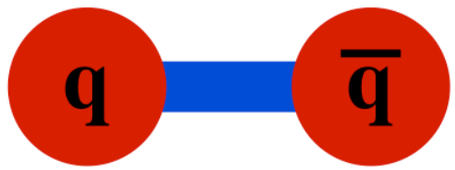

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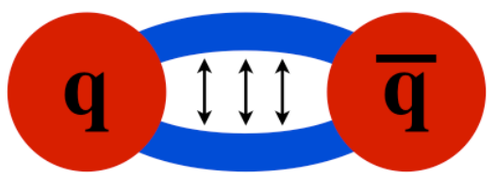

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must have "conventional" quantum numbers:

J^{PC} =			
	$\mathbf{0^{-+}}$	(η,π)	[S = 0; L = 0; J = 0]
	$\mathbf{0^{++}}$	(f_0,a_0)	[S = 1; L = 1; J = 0]
	$\mathbf{1^{++}}$	(f_1,a_1)	[S = 1; L = 1; J = 1]
	$\mathbf{1^{+-}}$	(h_1,b_1)	[S = 0; L = 1; J = 1]
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etc.

add Hall D
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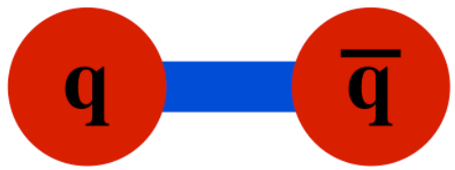

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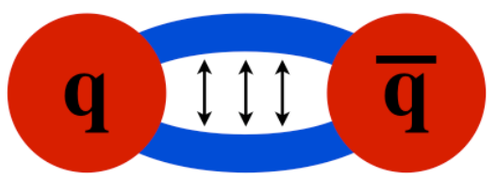

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etc.

- produce **hybrid mesons** with exotic J^{PC}:

can have "exotic" quantum numbers:

J^{PC} = $\mathbf{1^{-+}}$ (η_1,π_1) *(for example)*

⇒ ***unambiguous signature for a state beyond the quark model!***

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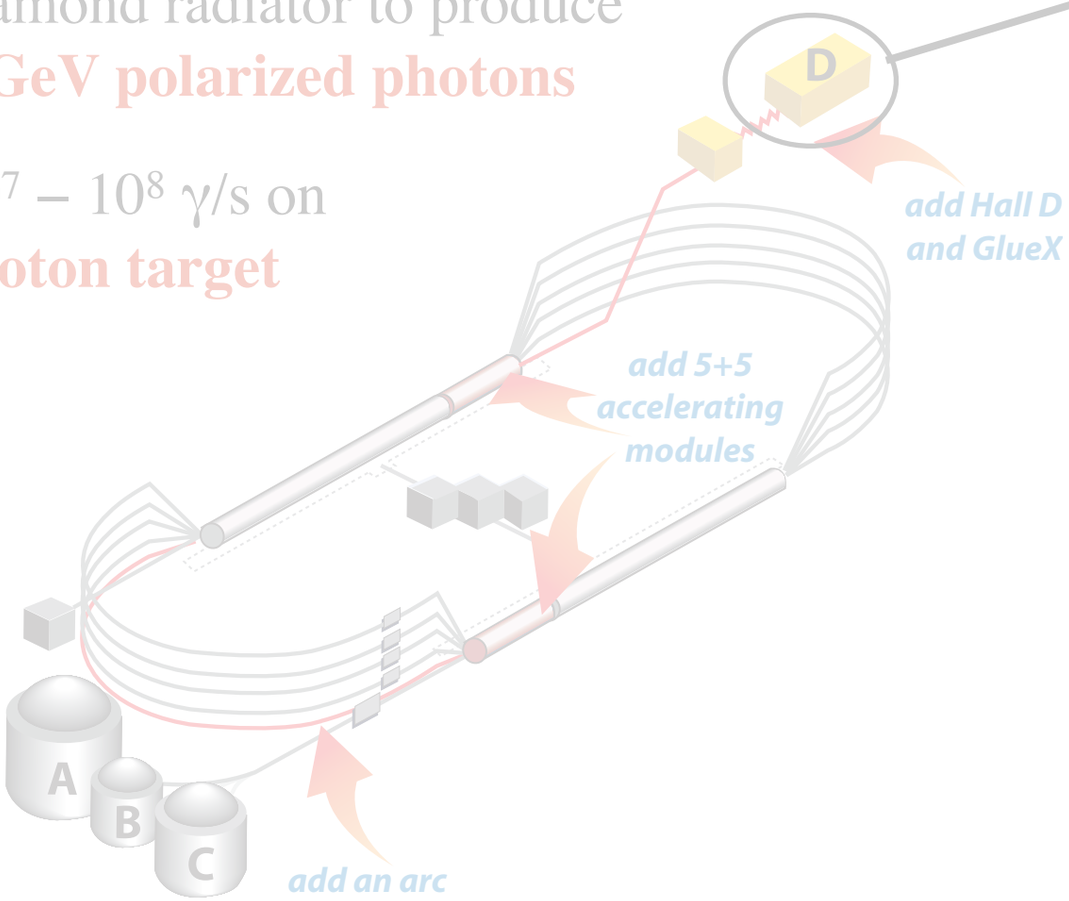

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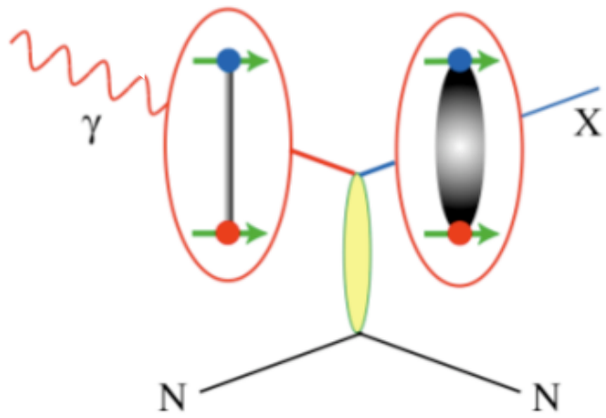

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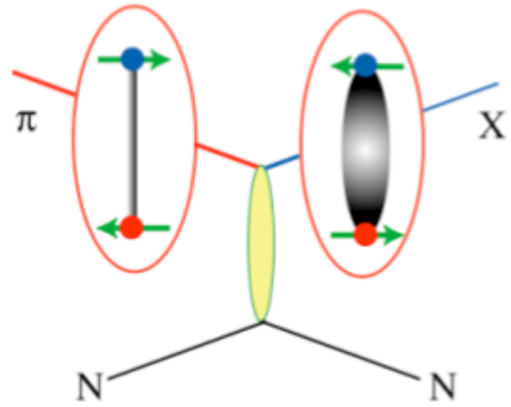
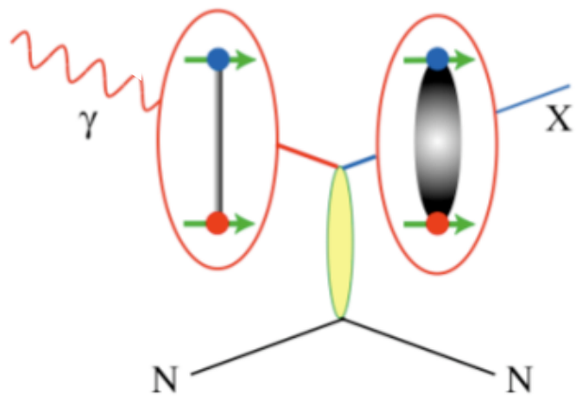
hybrid meson production

PION BEAM



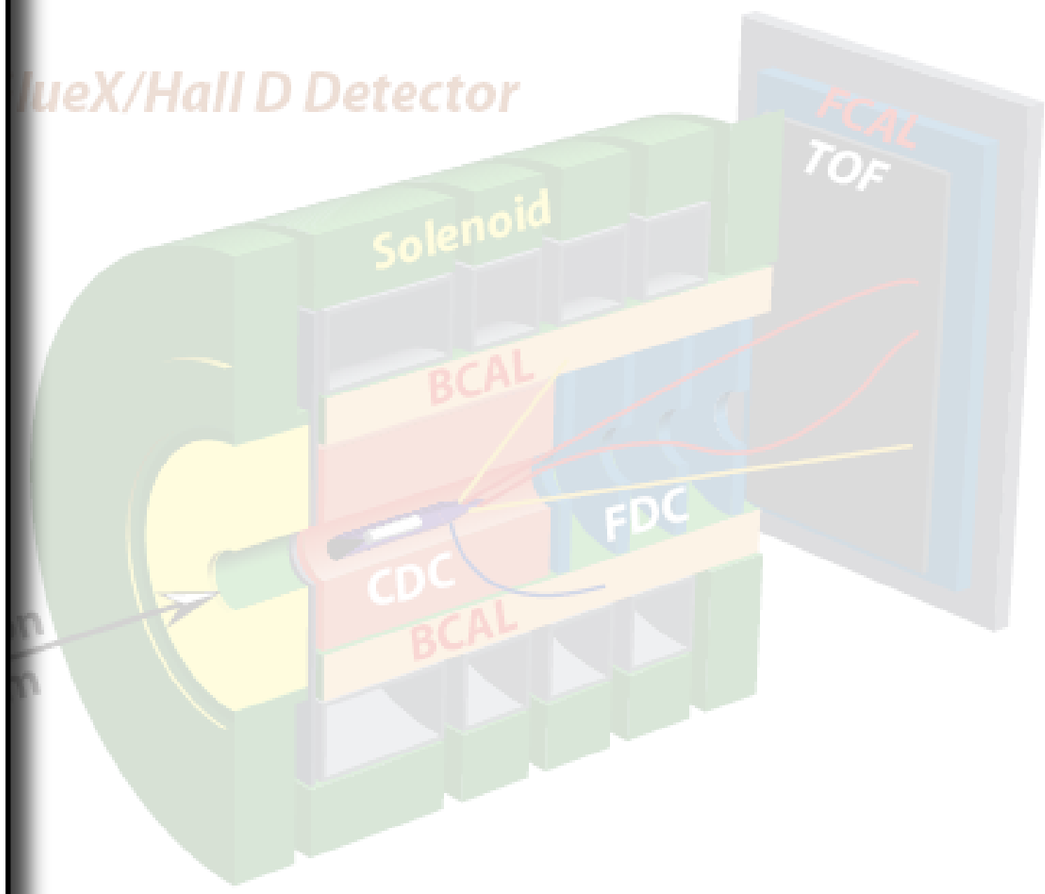
simplest S = 0 hybrids have $J^{PC} = 1^{++}$ or 1^{--}
(i.e. they mix with quark model states)

PHOTON BEAM



but simplest S = 1 hybrids can have $J^{PC} = 1^{-+}$
(i.e. they can be exotic)

⇒ photoproduction should be more favorable for exotic meson production?



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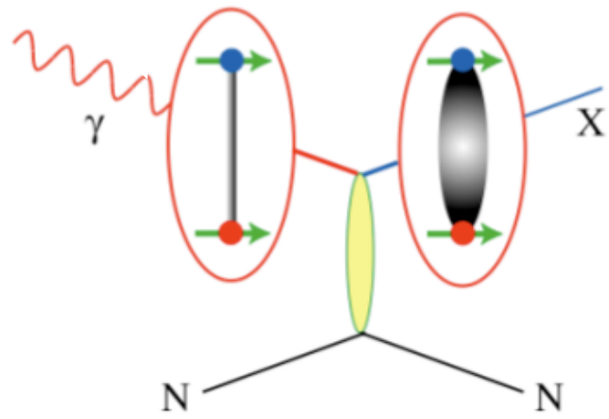

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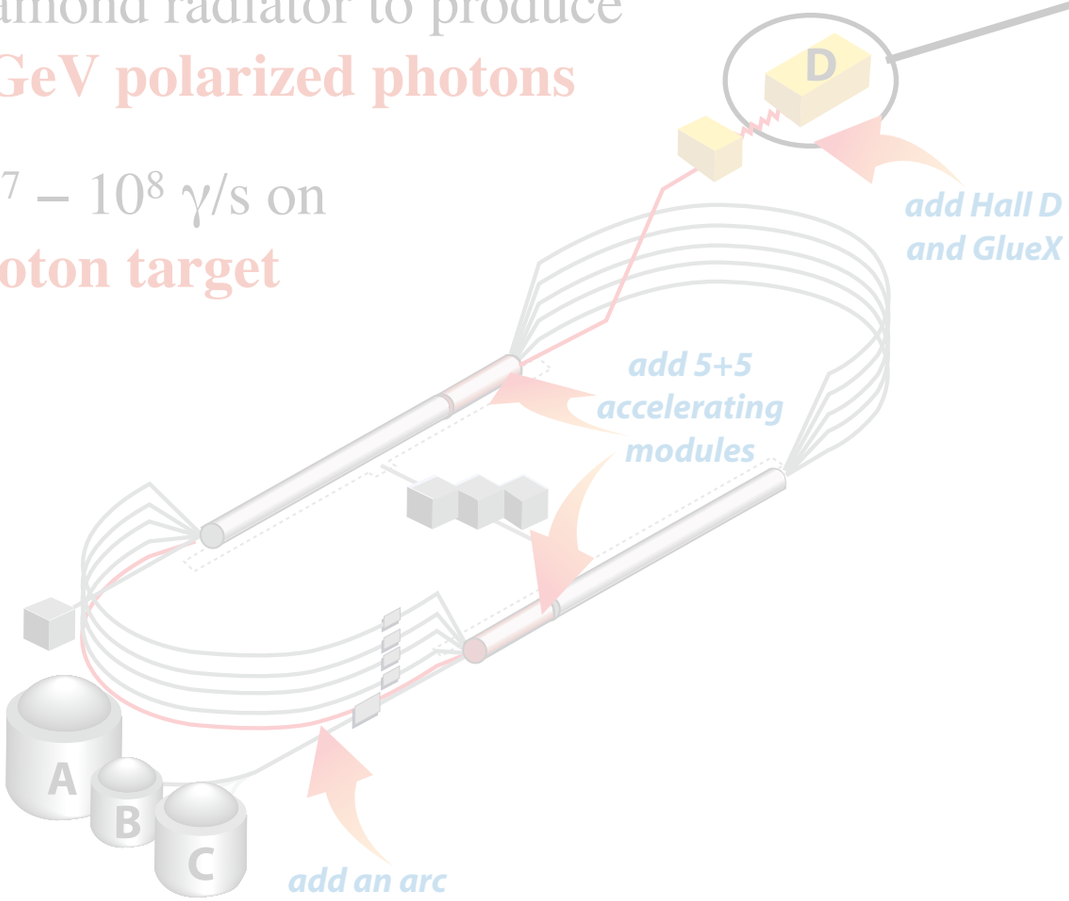

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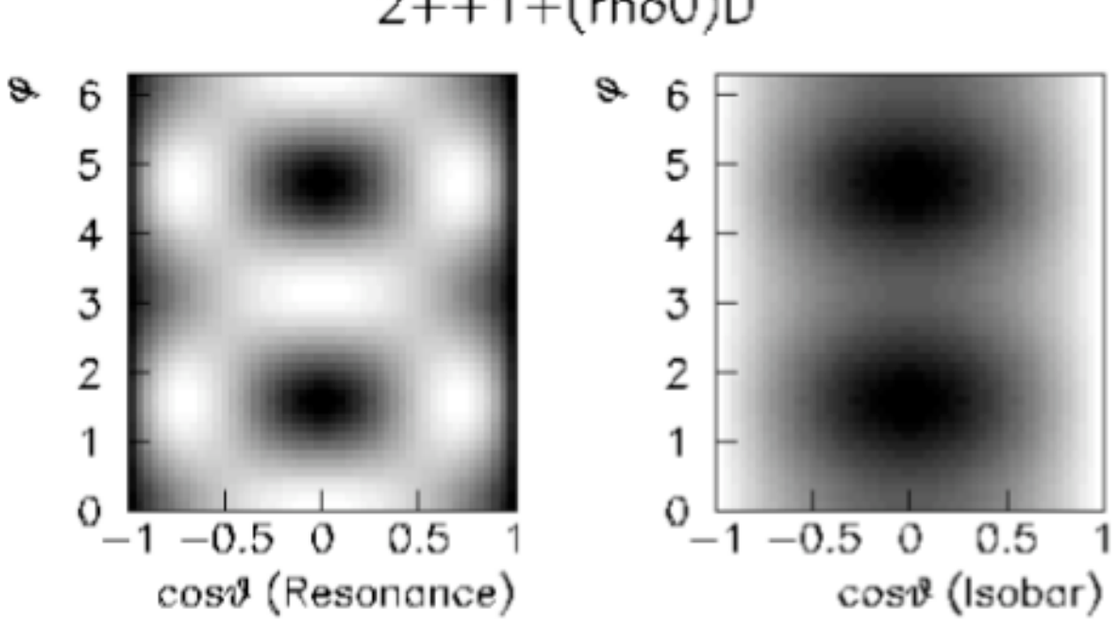
Overview of the GlueX Experiment

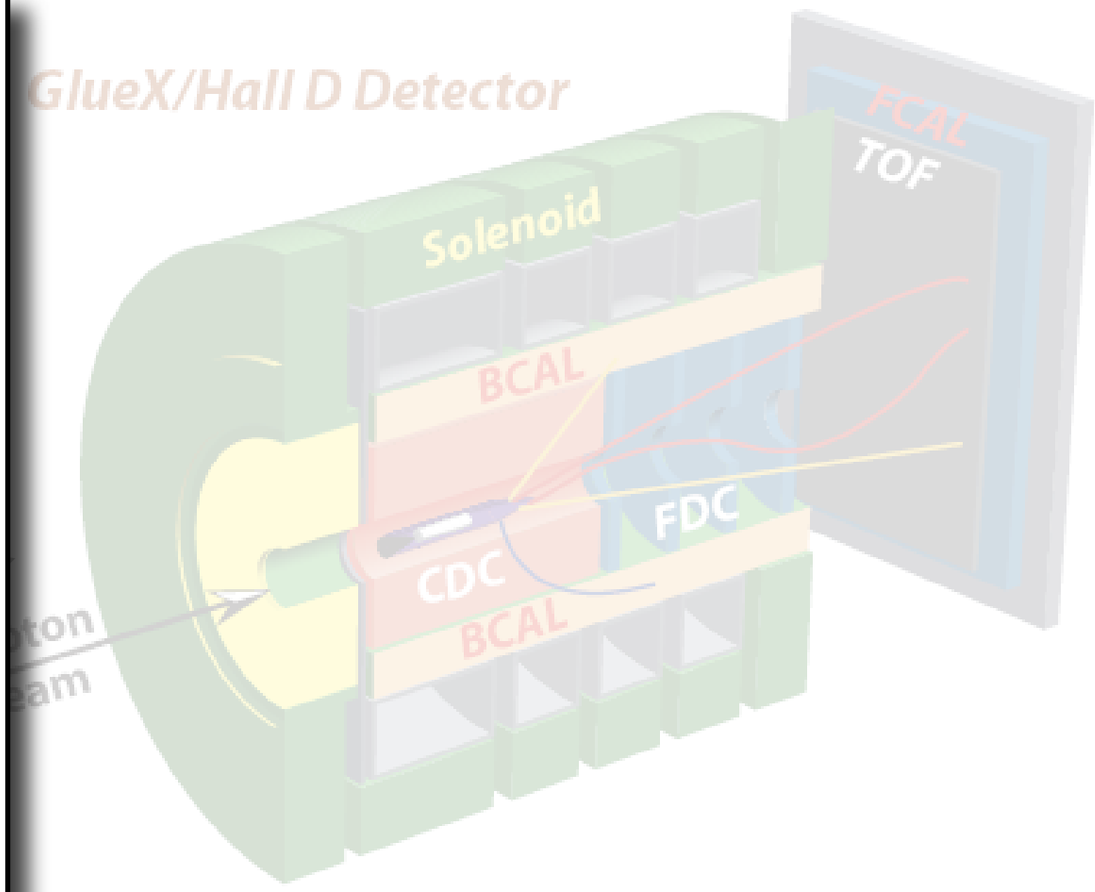
distinguish quantum numbers using angular distributions of decay products

for example:

$$\pi^- p \rightarrow X^- p \rightarrow \pi^+\pi^-\pi^- p$$

if X^- has $J^{PC} = 2^{++}$ and decays to $\varrho^0\pi^-$ in a D-wave, then you expect these angular distributions:





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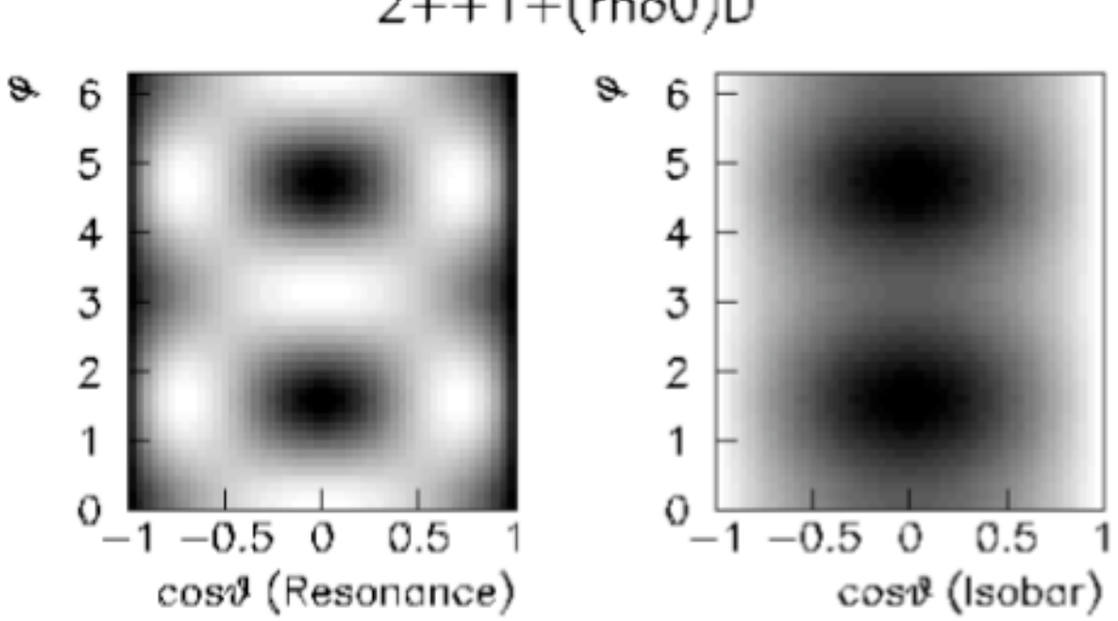

it's called an ***"amplitude analysis"*** because distributions are added on the amplitude level:

$$I(\Omega) = \sum_{\alpha} \left| \sum_{\beta} V_{\alpha,\beta} A_{\alpha,\beta}(\Omega) \right|^2$$

$A(\Omega)$ = Resonance Angles
× Isobar Angles
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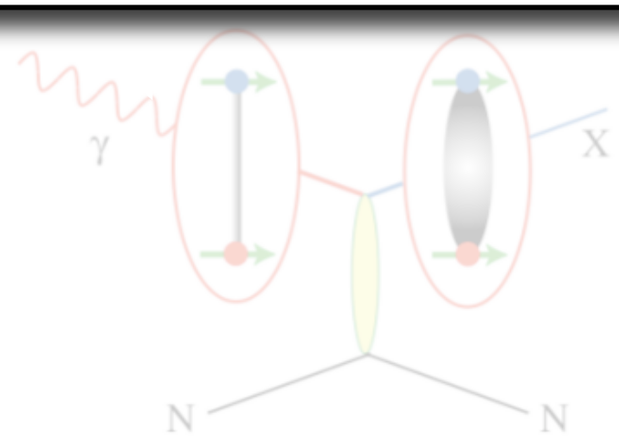
V are complex fit parameters



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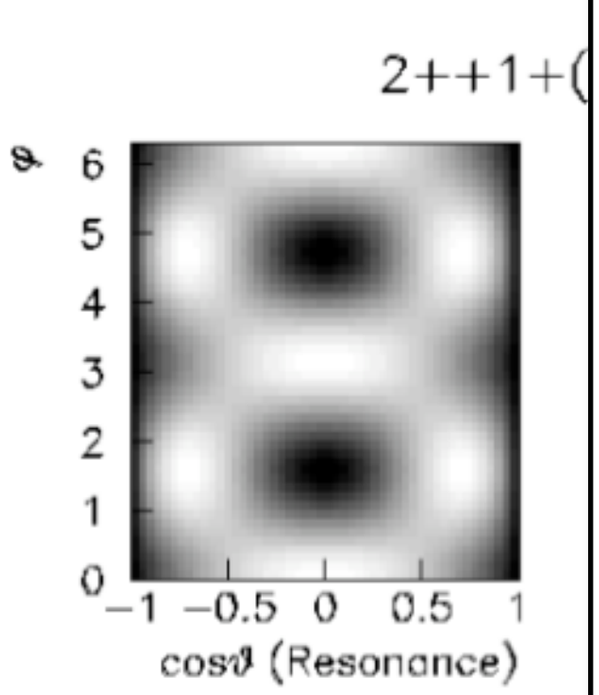
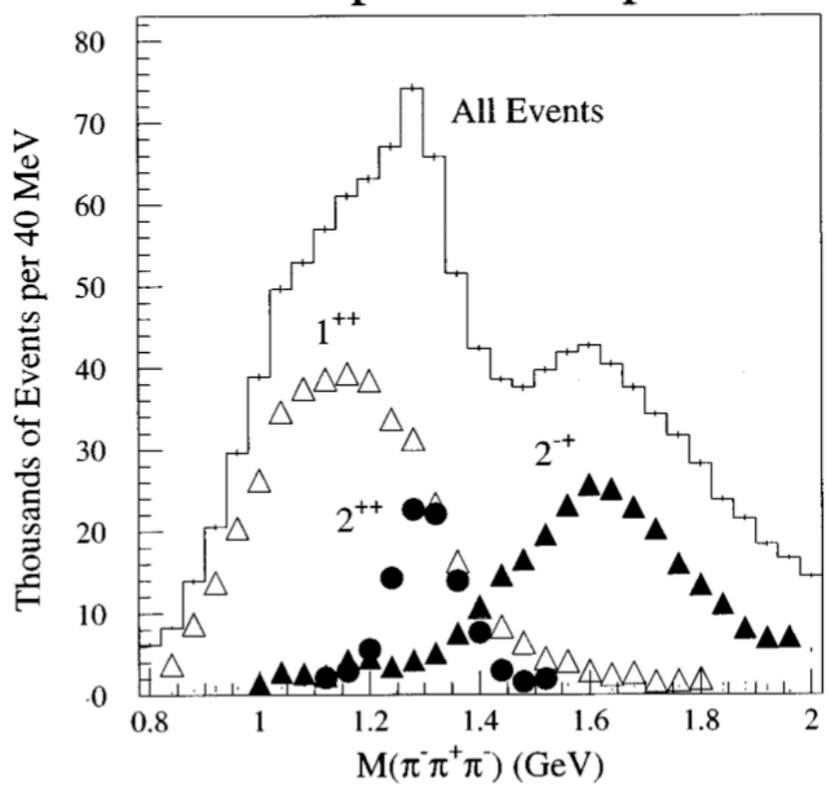


decomposition of 3π from E852



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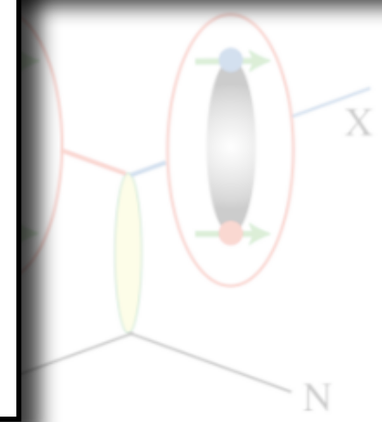

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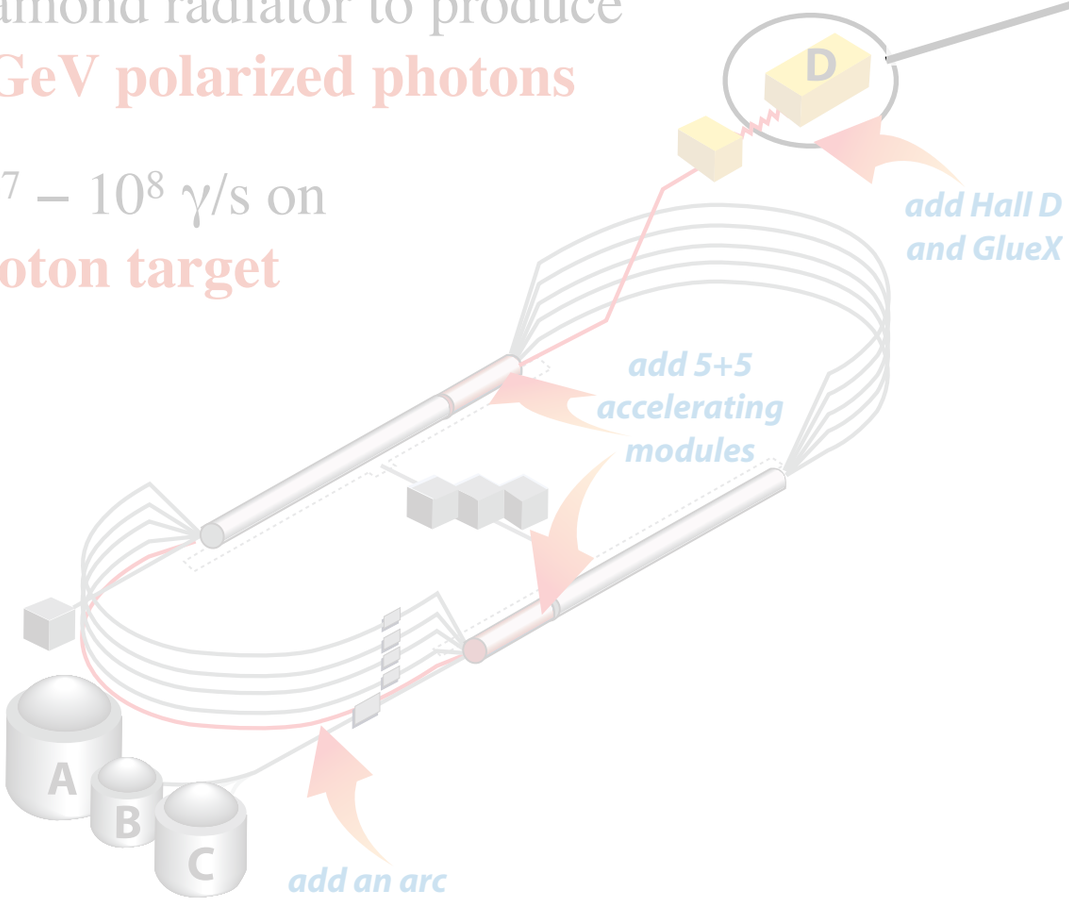

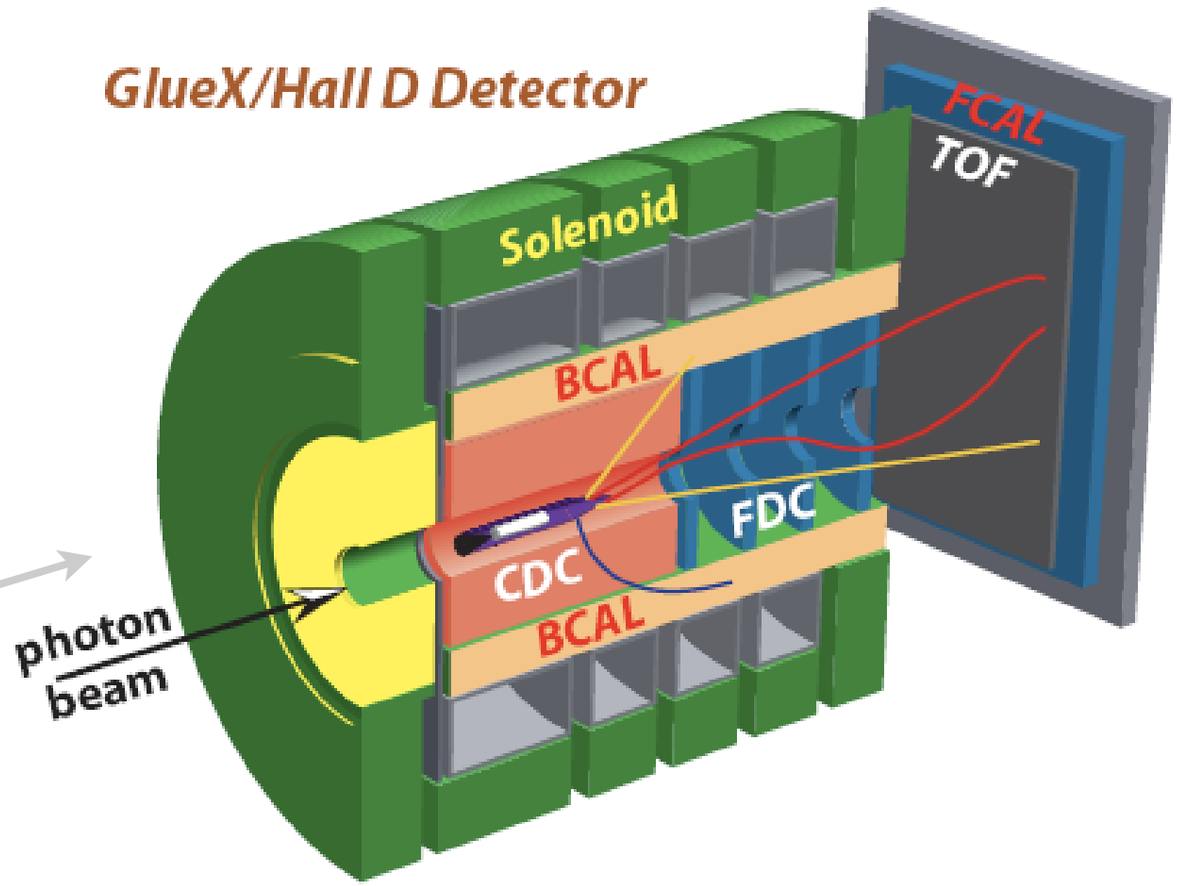

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Overview of the GlueX Experiment

the GlueX detector

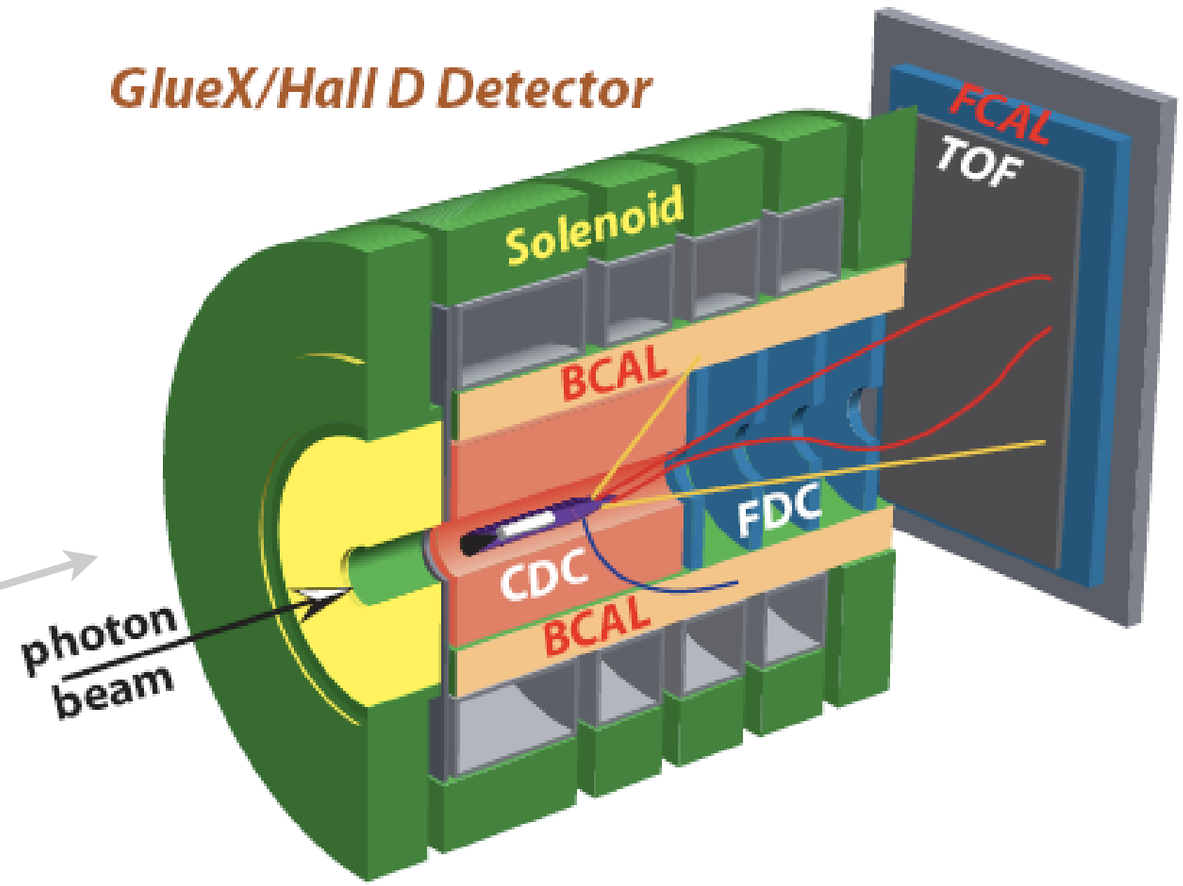
- designed to have:
  - uniform acceptance
  - good resolution
  - ability to handle "high" multiplicities (up to ~8 particles)

- tracking
  - Central Drift Chamber (**CDC**)
  - Forward Drift Chamber (**FDC**)
  - momentum resolution 1–3%

- calorimetry
  - Forward Calorimeter (**FCAL**)
  - Barrel Calorimeter (**BCAL**)
  - energy resolution ~6%/√E + 2%

- pid
  - Time of Flight (**TOF**)
  - timing from BCAL
  - dE/dx from tracking chambers
  - future Cerenkov Detector?

target



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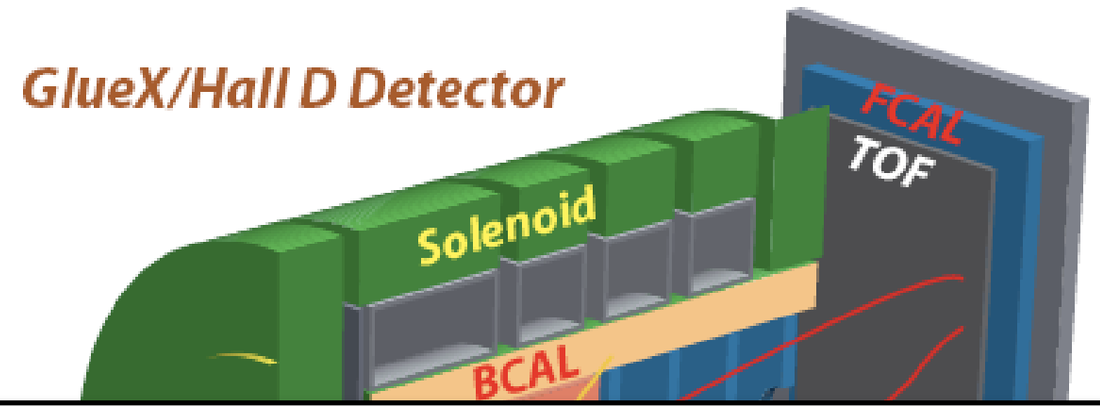
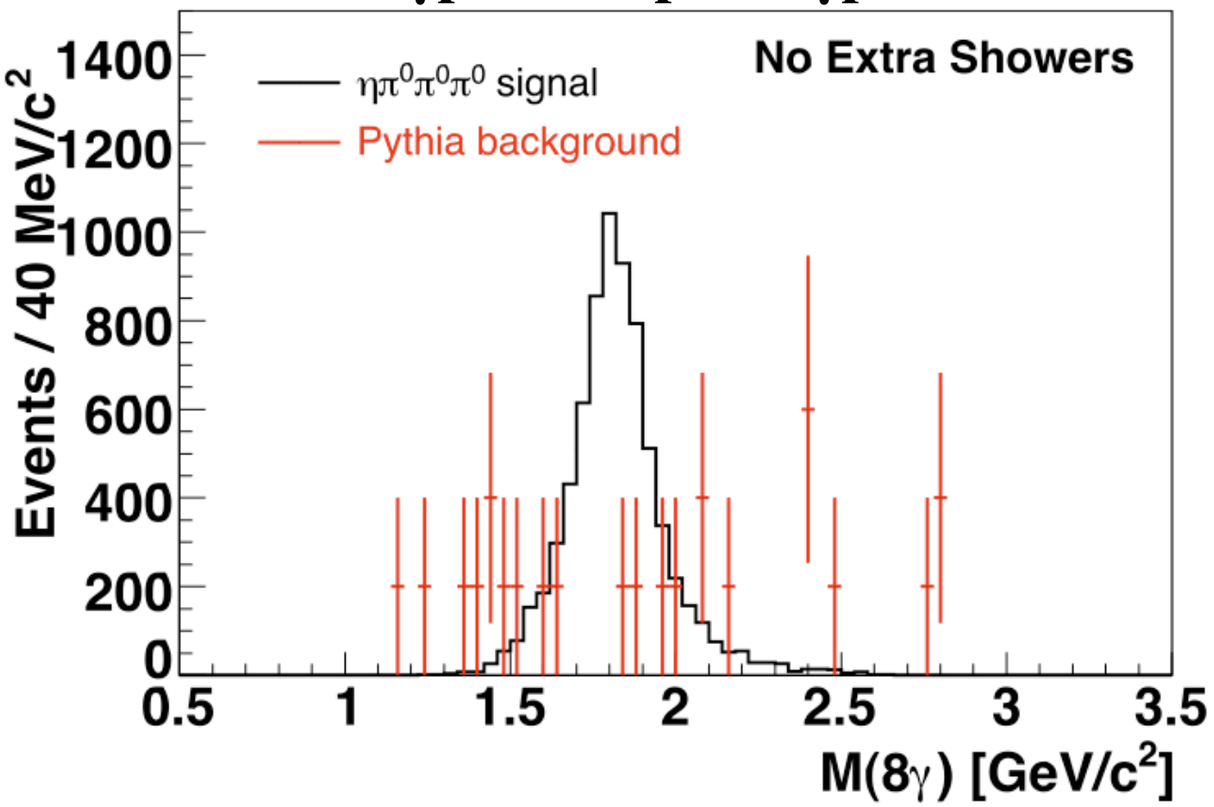


simulation of a *very* difficult channel

$\gamma p \rightarrow f_1 \pi^0 p \rightarrow 8\gamma p$



acceptance ≈ 8-10%

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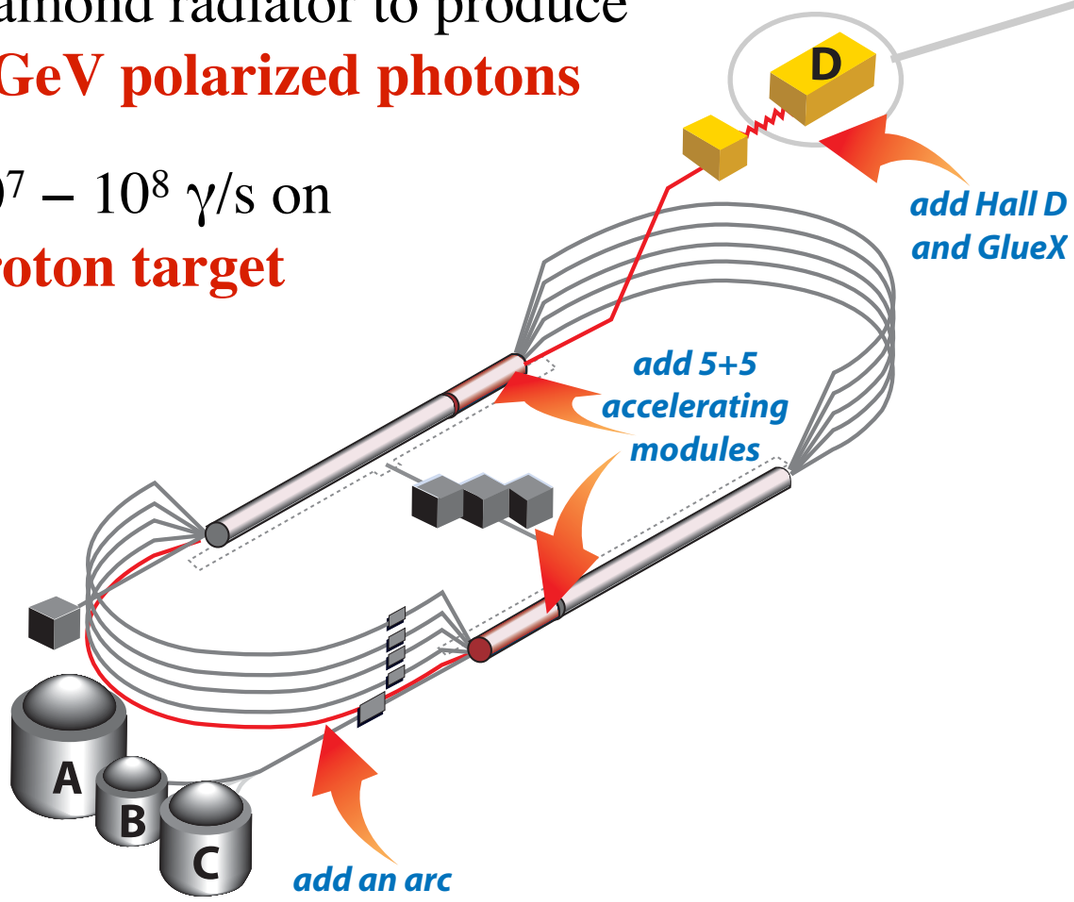

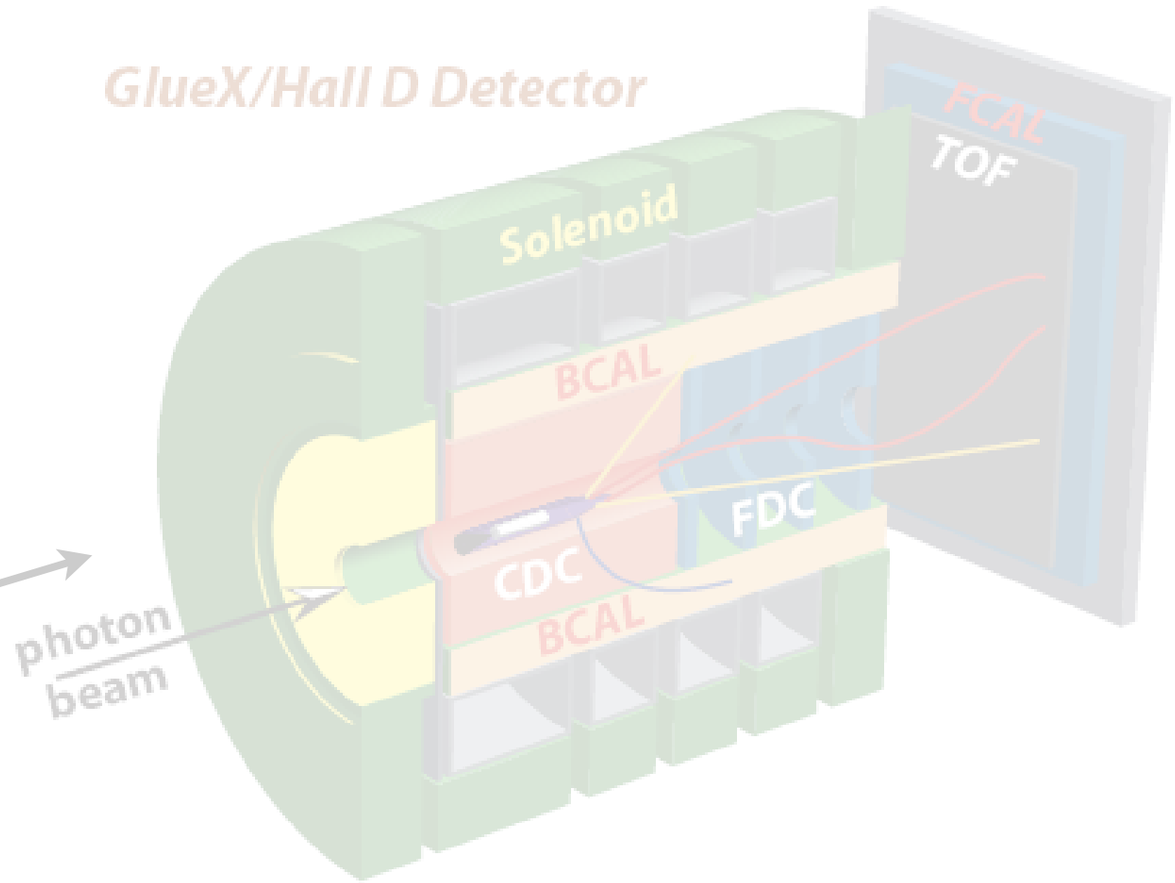

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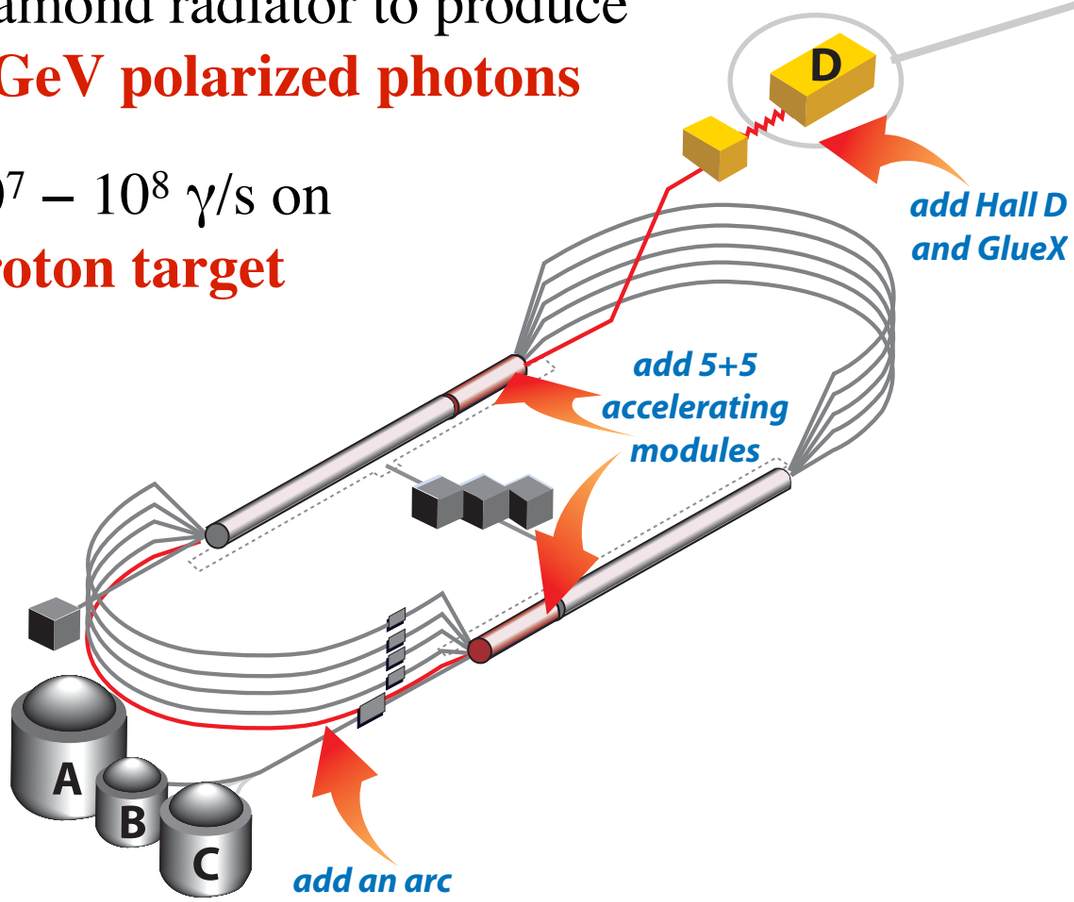

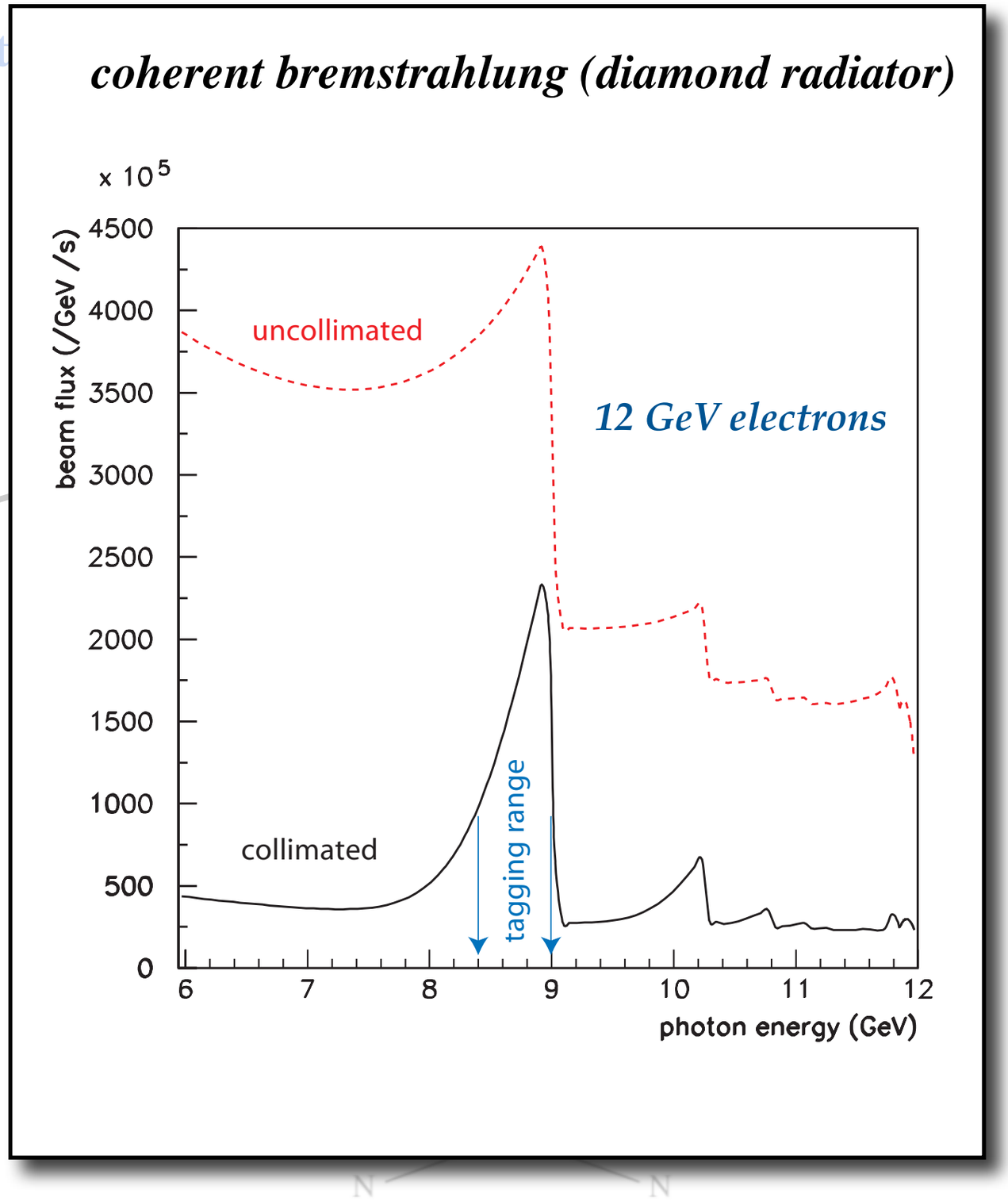

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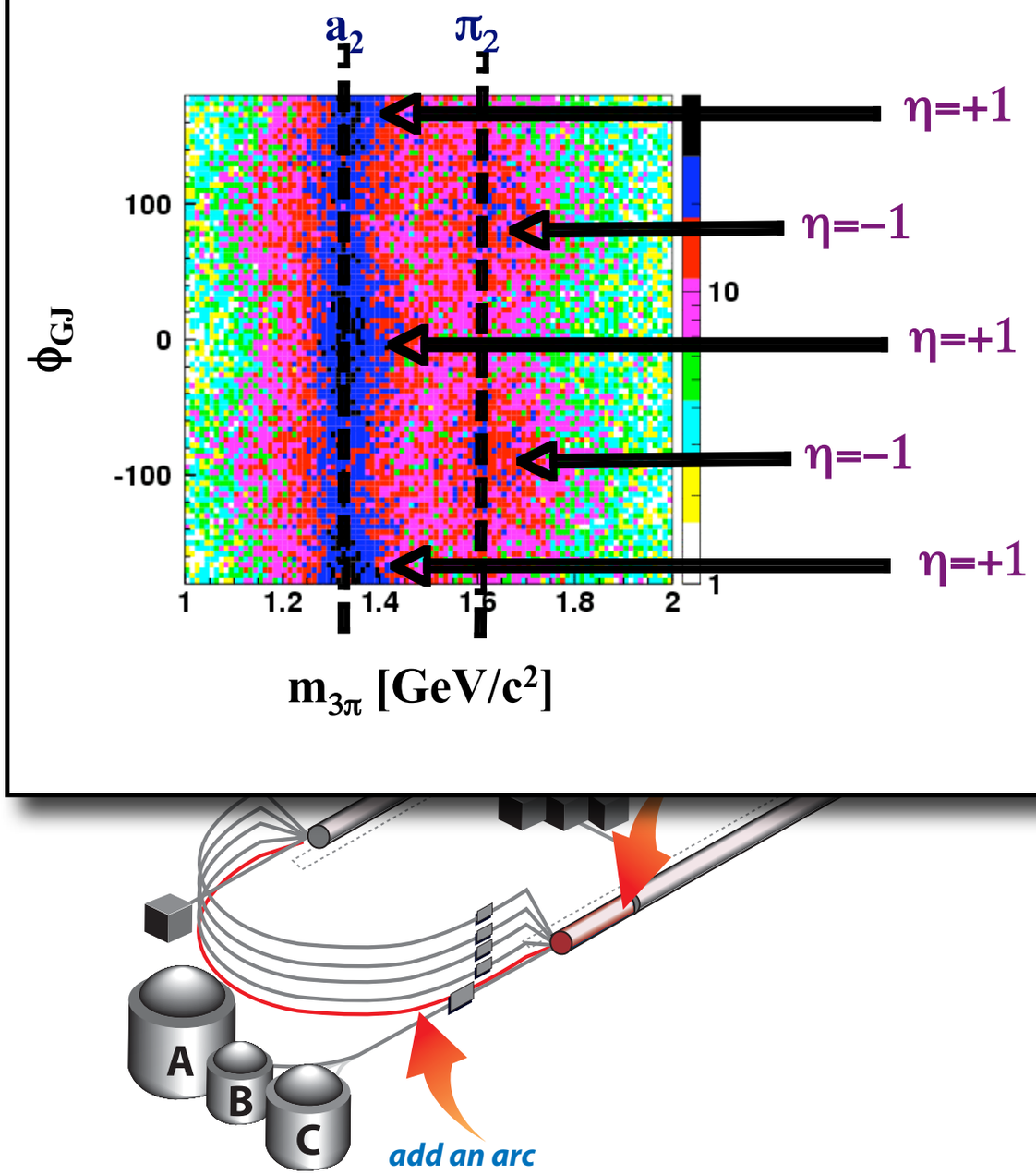
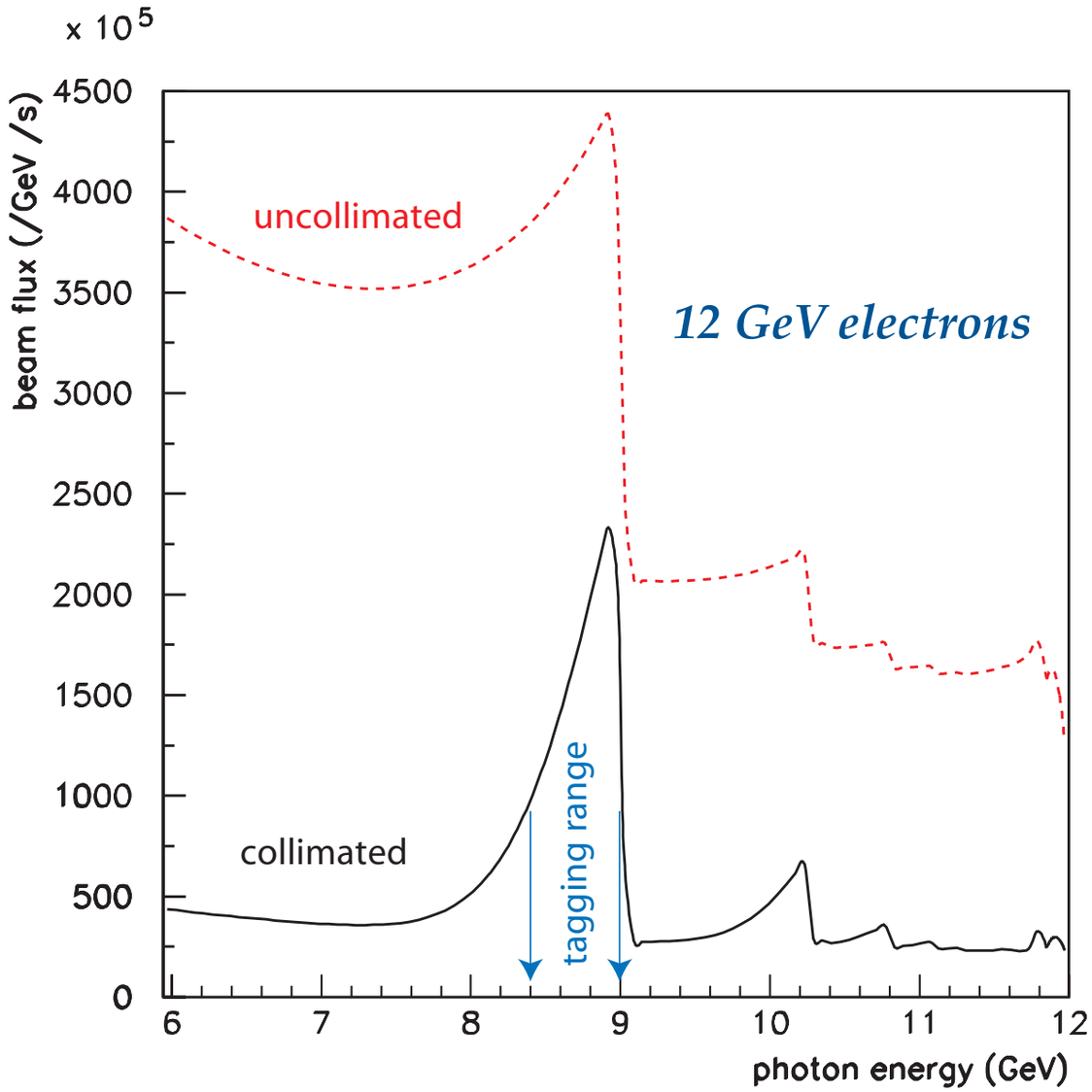
simulation of $\gamma p \to 3\pi n$ with linear polarization



coherent bremstrahlung (diamond radiator)



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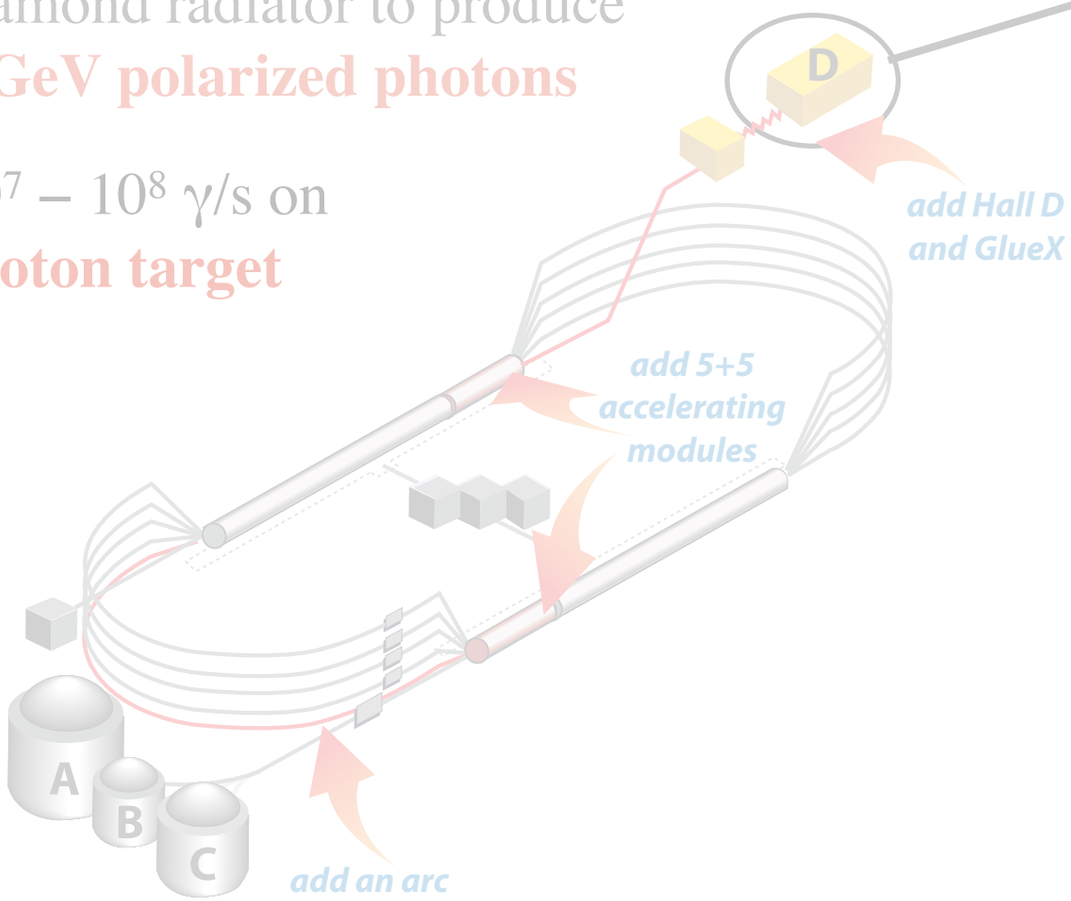

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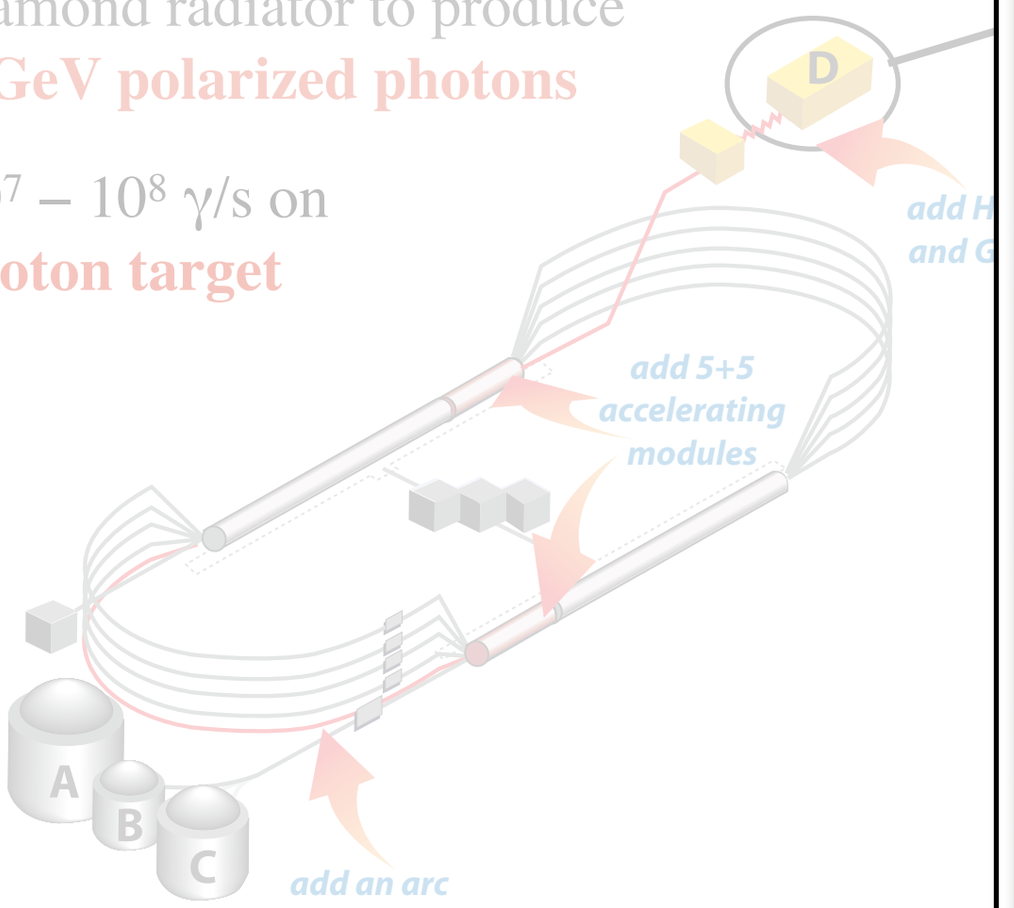
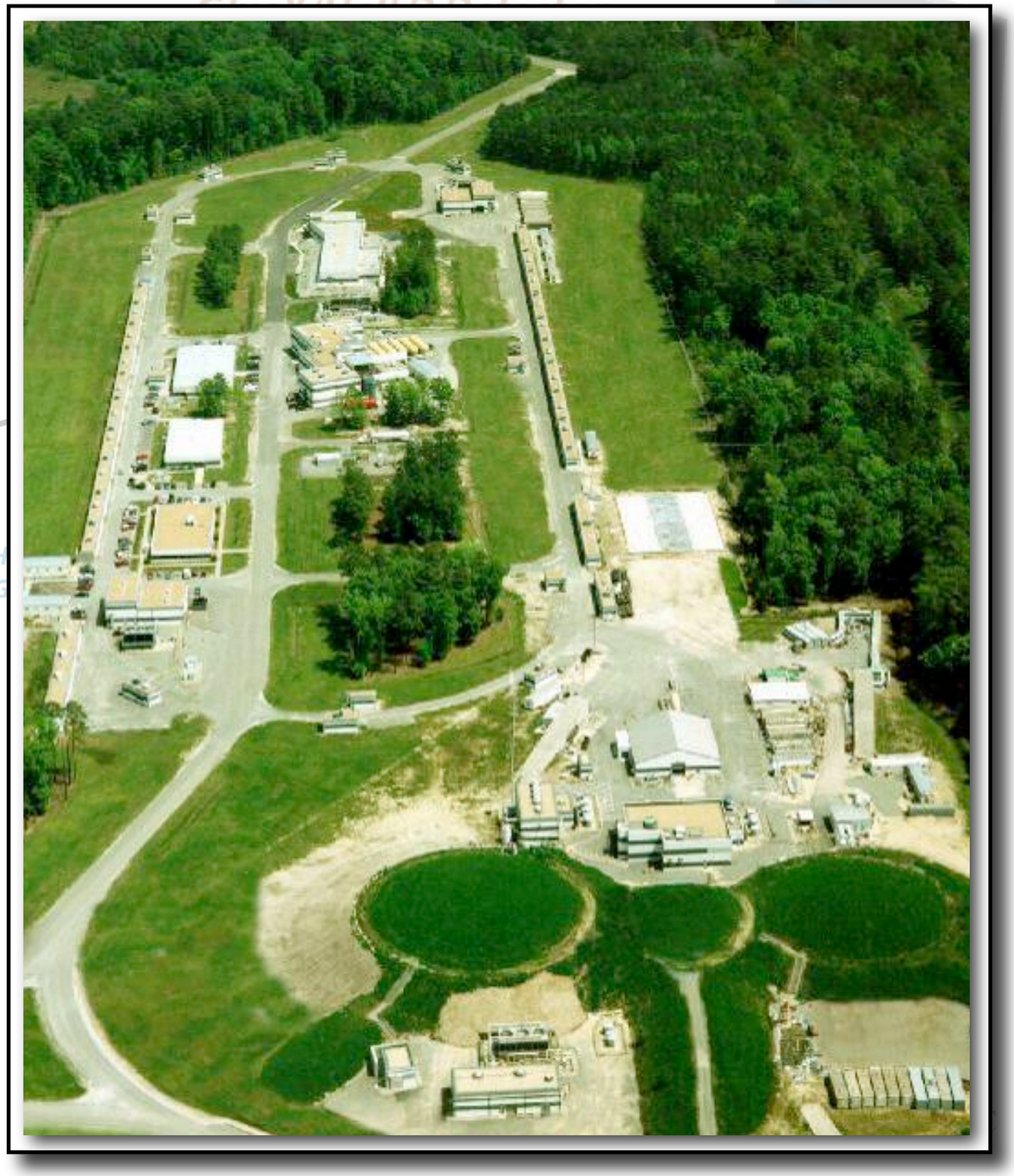
- $10^7 - 10^8$ γ/s on **proton target**





Overview of the GlueX Experiment

Use **9 GeV polarized photons** on a **proton target**
to produce **hybrid mesons** with exotic J^{PC}:

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- use "amplitude analyses" to distinguish J^{PC}

Overview of the GlueX Experiment

Use **9 GeV polarized photons** on a **proton target**
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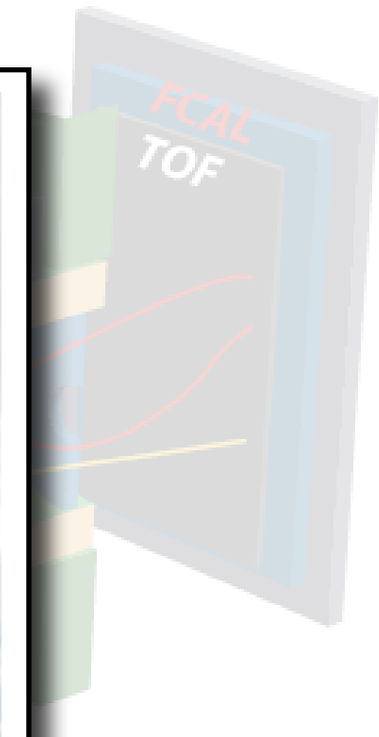
February, 2010



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Overview of the GlueX Experiment

Use **9 GeV polarized photons** on a **proton target**
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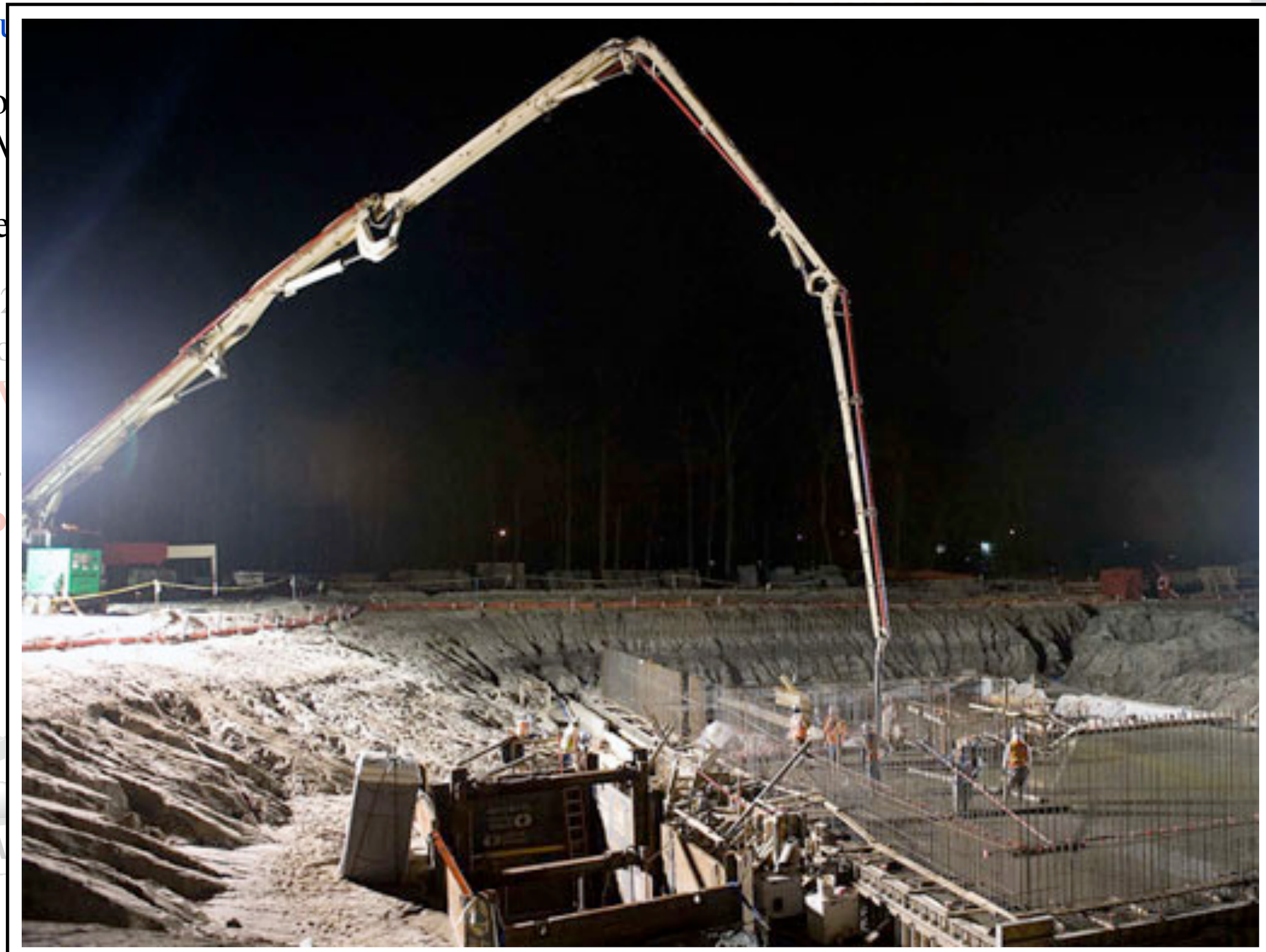

February, 2010

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Overview of the GlueX Experiment

Use **9 GeV polarized photons** on a **proton target**
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- use 12 Ge
  diamond r
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- $10^7 - 10^8$
  proton ta

September, 2010

Overview of the GlueX Experiment

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photos of 8 of 48 modules of the Barrel Calorimeter (lead and scintillating fibers)

Mod 05

Mod 06

Mod 07

Mod 08

Mod 09

Mod 10

Mod 11

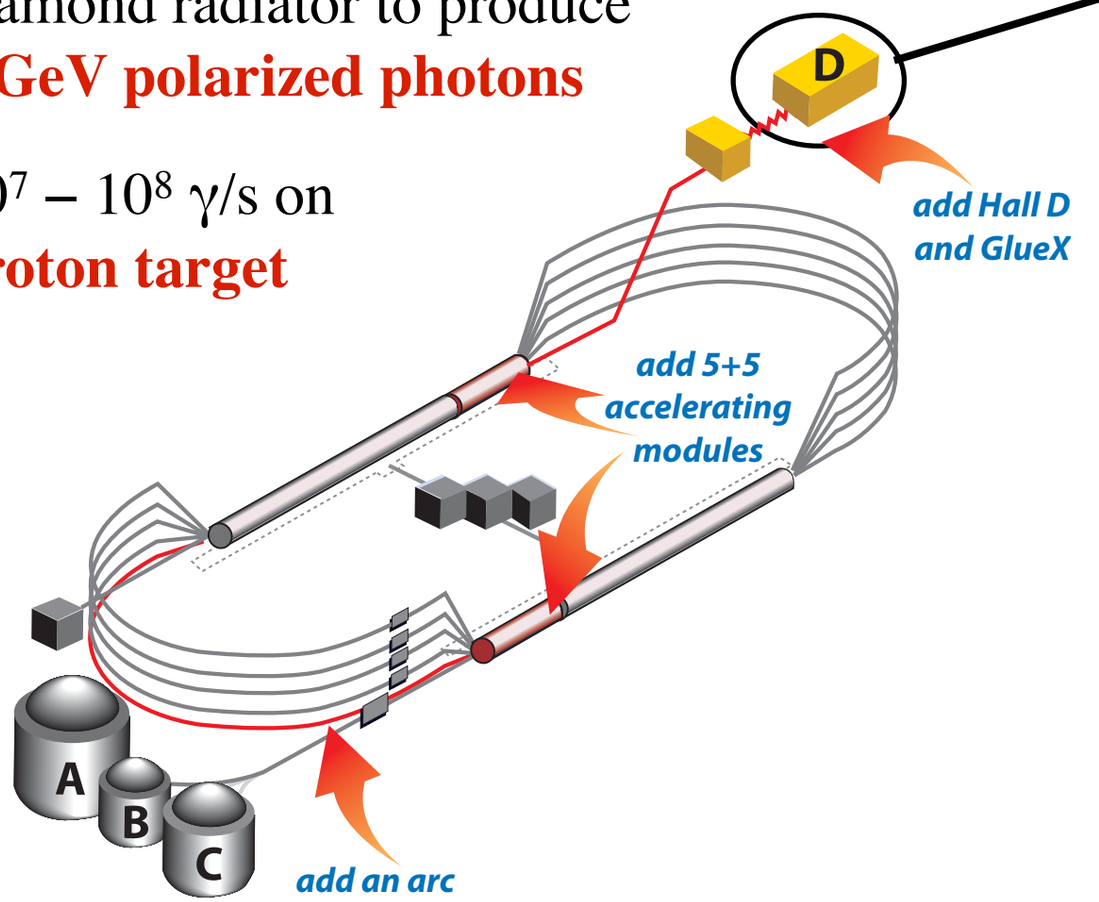
Mod 12

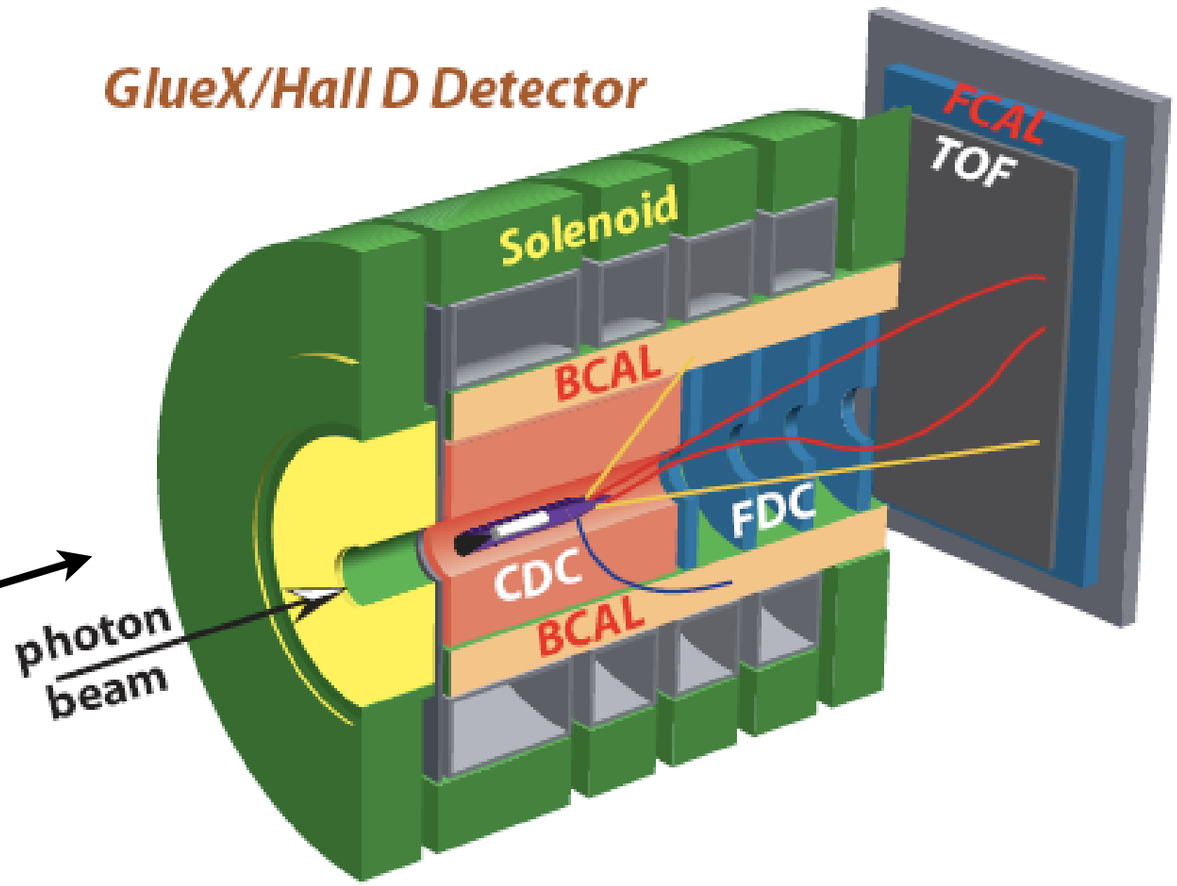
- use "amplitude analyses" to distinguish J^{PC}

Overview of the GlueX Experiment

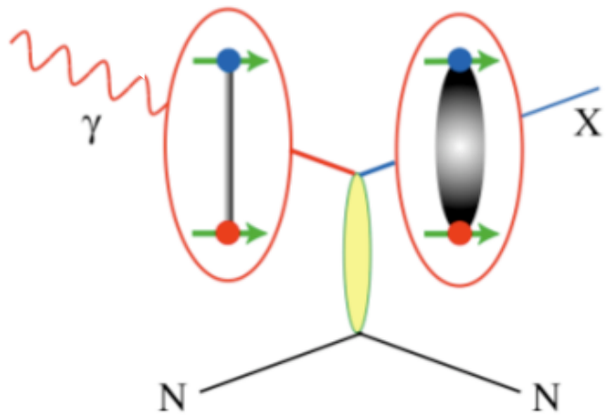
Use **9 GeV polarized photons** on a **proton target** to produce **hybrid mesons** with exotic J^{PC}:

- part of the JLab 12 GeV upgrade
  (in Newport News, Virginia)
- data expected in 2014
- use 12 GeV electrons and a diamond radiator to produce **9 GeV polarized photons**
- $10^7 - 10^8$ γ/s on **proton target**





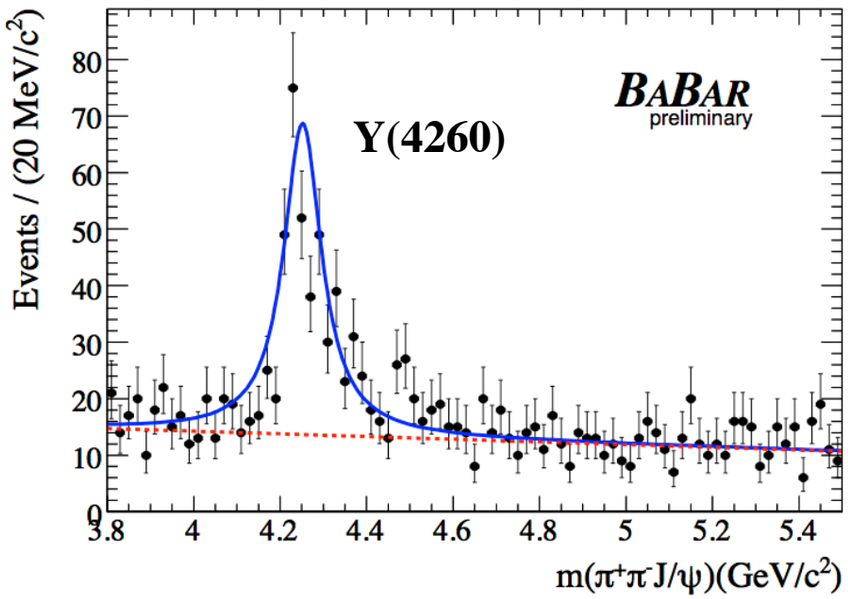
- produce **hybrid mesons** with exotic J^{PC}:



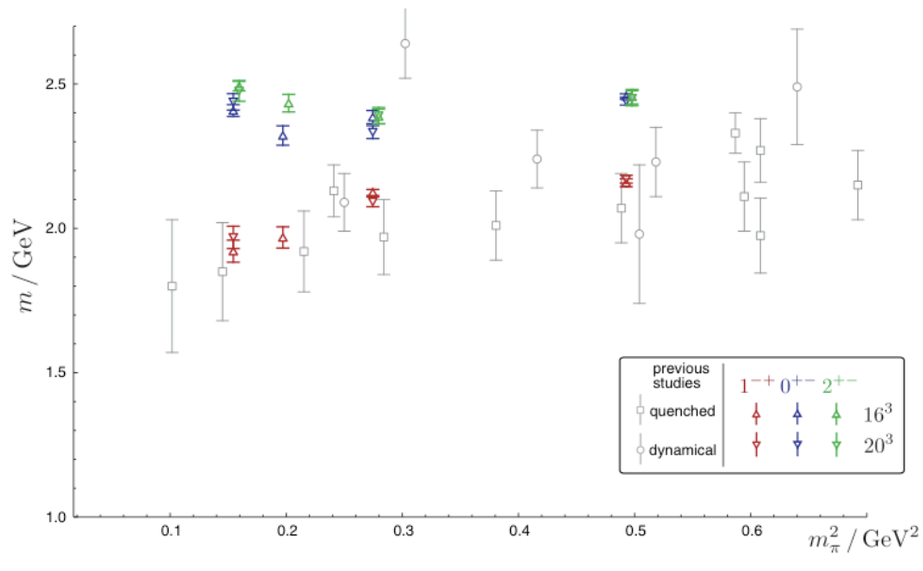
- use "amplitude analyses" to distinguish J^{PC}

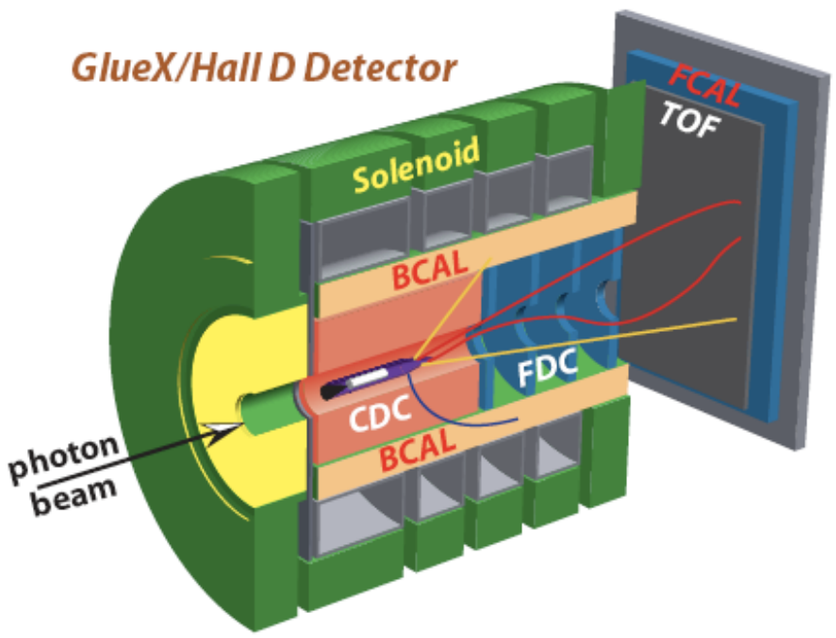
The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)

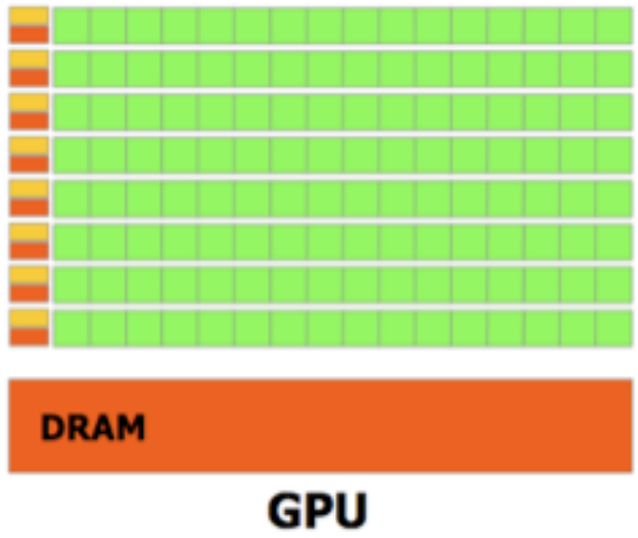


Theoretical Context
(advances in lattice QCD)



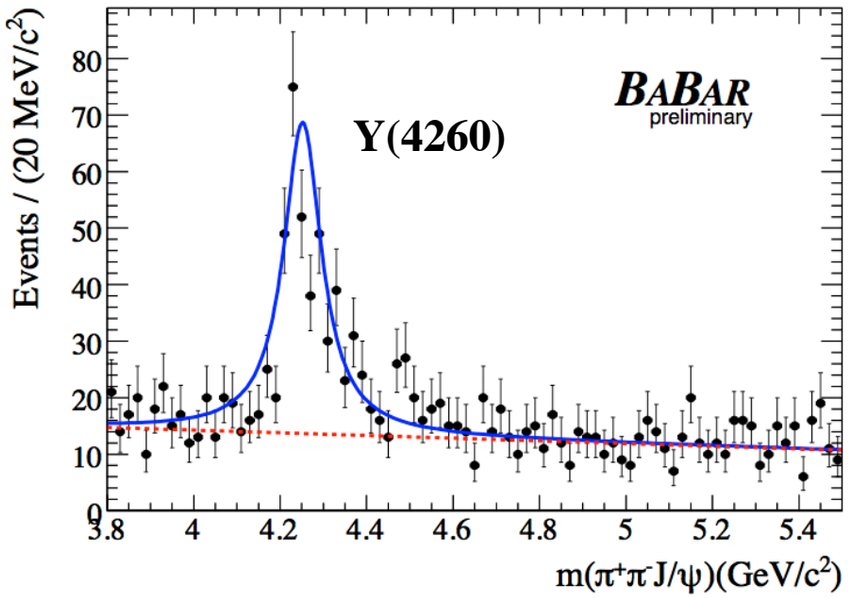


Technological Context
(advances in amplitude analysis)



The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)



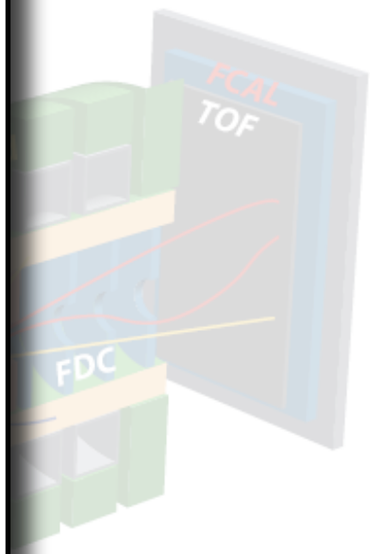
1. discovery of the **X, Y, Z states** in charmonium

2. mapping the **light quark vectors** with ISR

3. progress in searches for **exotic mesons**

Theoretical Context
(advances in lattice QCD)

Technological Context
(advances in amplitude analysis)

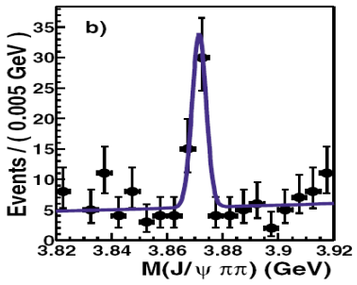


The Context of the GlueX Experiment

(some of) the X, Y, Z states of charmonium

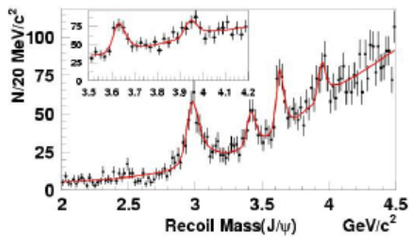
X(3872)

PRL 91, 262001 (2003)



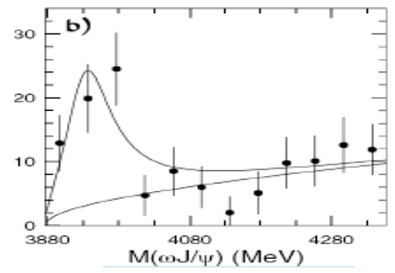
X(3940)

PRL 98, 082001 (2007)



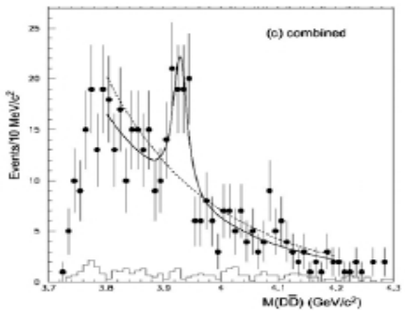
Y(3940)

PRL 94, 182002 (2005)



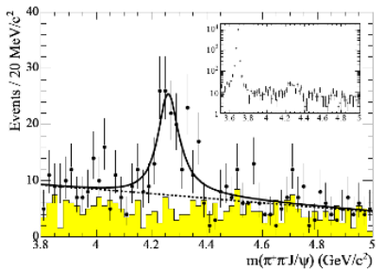
Z(3940)

PRL 96, 082003 (2006)



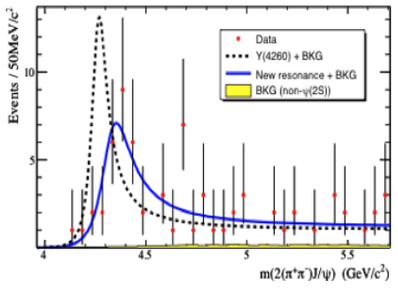
Y(4260)

PRL 95, 142001 (2005)



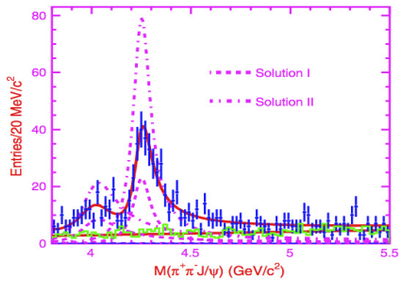
Y(4350)

PRL 98, 212001 (2007)



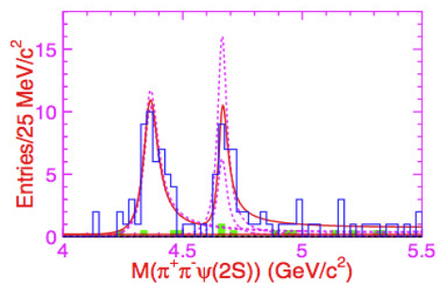
Y(4008)

PRL 99, 182004 (2007)



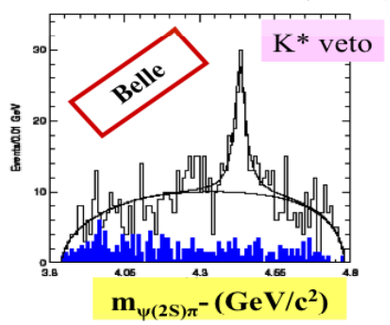
Y(4660)

PRL 99, 142002 (2007)



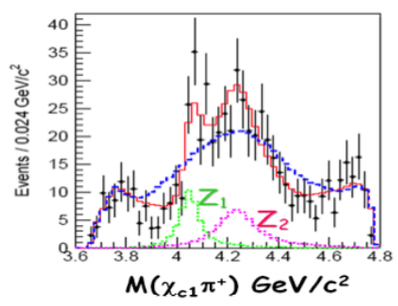
Z(4430)⁺

PRL 100, 142001 (2008)



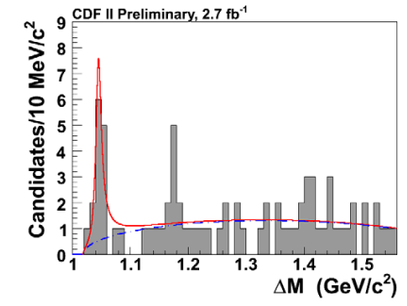
Z_1^+ and Z_2^+

PRD 78, 072004 (2008)



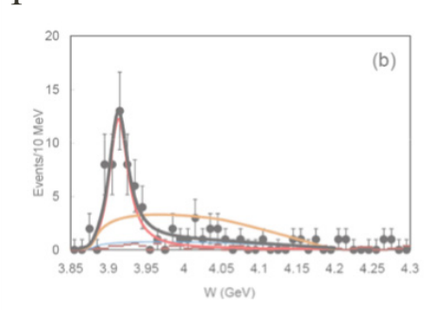
Y(4140)

arXiv:0903.2229



X(3915)

presented at CHARM09



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The Context of the GlueX Experiment

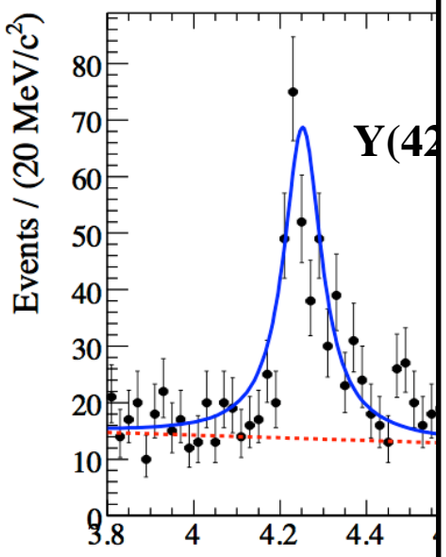
1. discovery of the **X, Y, Z states** in charmonium

2. mapping the **light quark vector** with ISR

3. progress in searche for **exotic mesons**

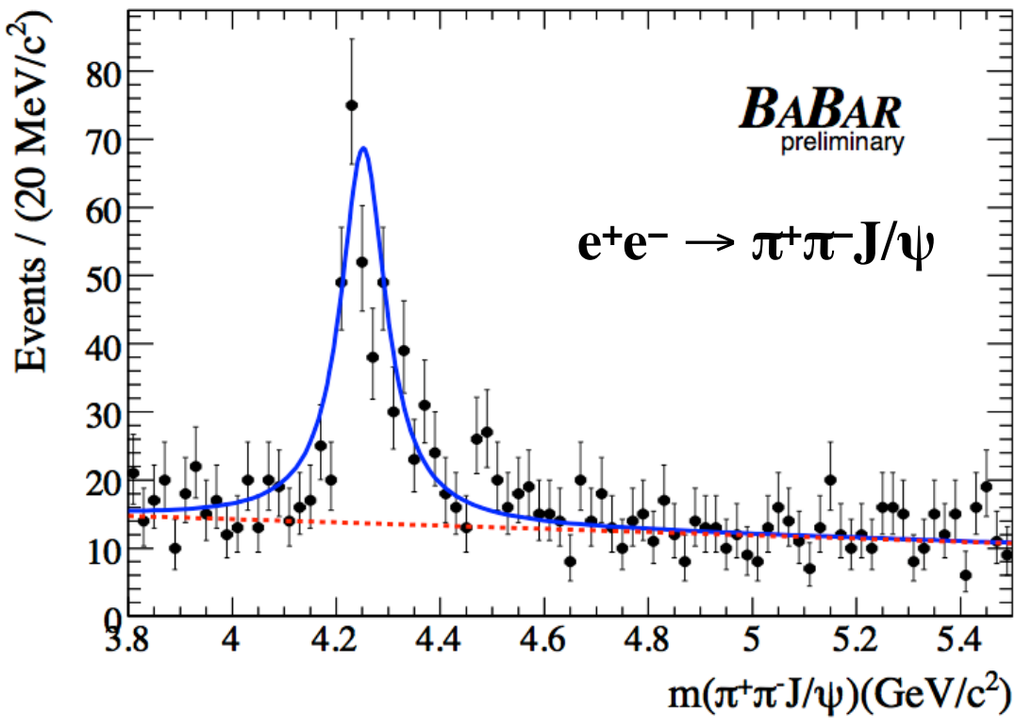
Experimen

(advances in

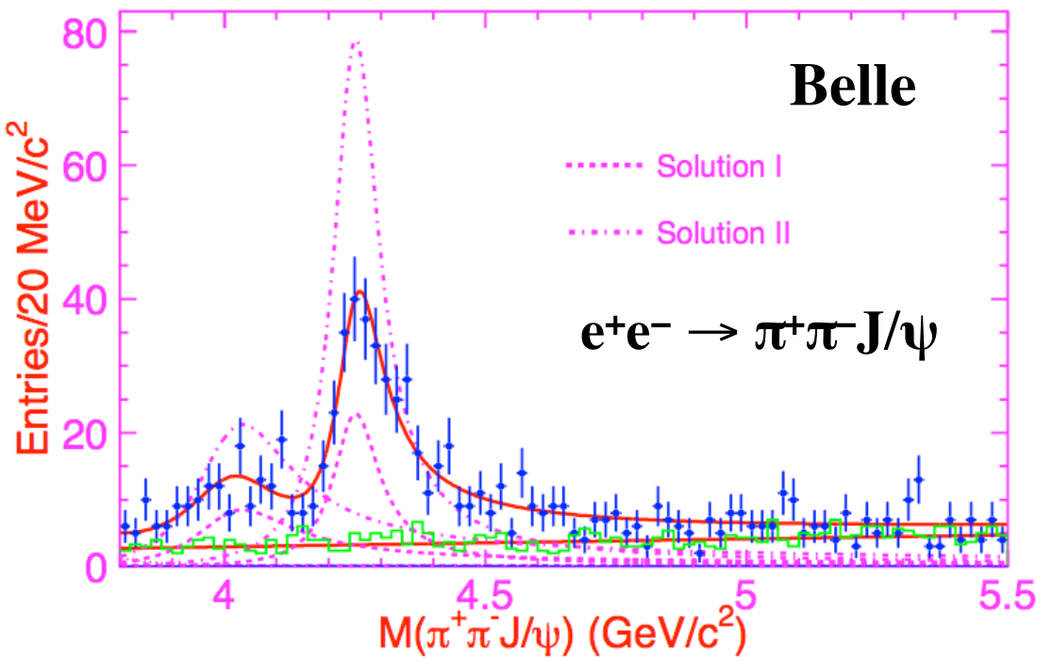


some properties of the Y(4260)

arXiv:0808.1543



PRL99, 182004 (2007)



- discovered by **BaBar** in $e^+e^- \to \pi^+\pi^- J/\psi$
- e^+e^- annihilation requires $J^{PC} = 1^{--}$
- confirmed by **CLEO** and **Belle**
- latest **BaBar** results:

$M = 4252 \pm 6\ ^{+2}_{-3}$ MeV

- no expected 1^{--} charmonium states in this region
- models predict 1^{--} hybrids between 4200 and 5000 MeV

Possible charmonium hybrid meson?

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Experimental
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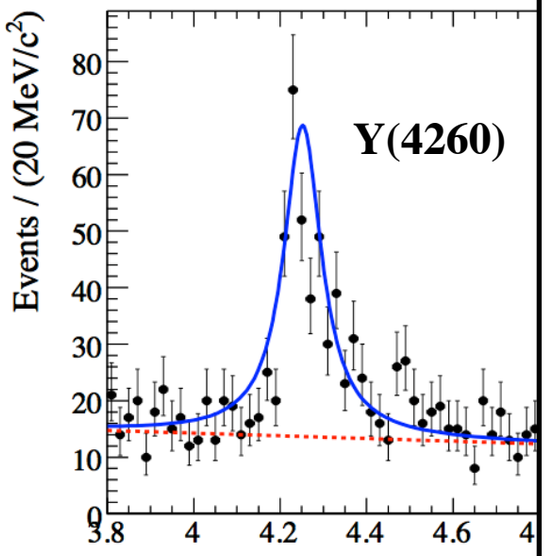
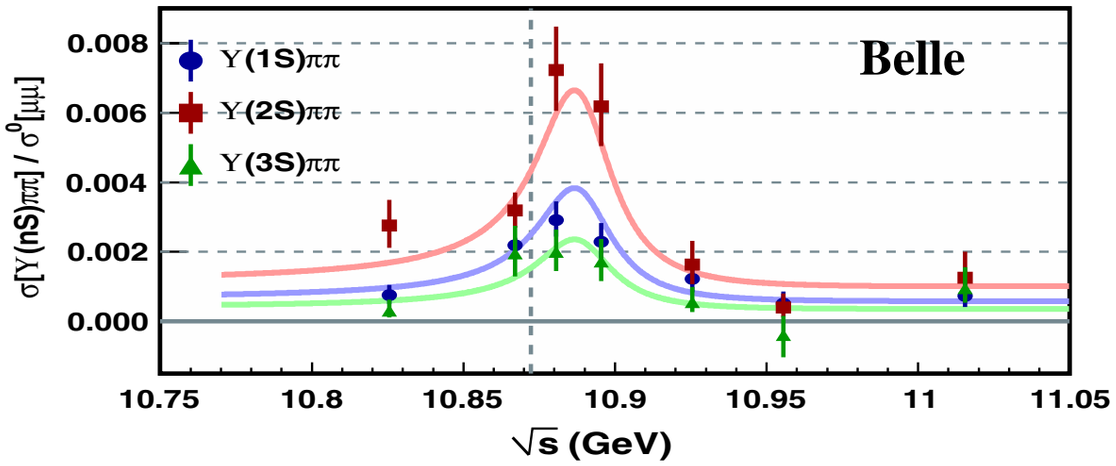


bottomonium and strangeonium partners of the Y(4260)?

$Y_b(10890)$?

- anomalously large $e^+e^- \to \pi\pi\Upsilon(1S)$ seen at 10890 MeV
- inconsistent with $\Upsilon(5S)$

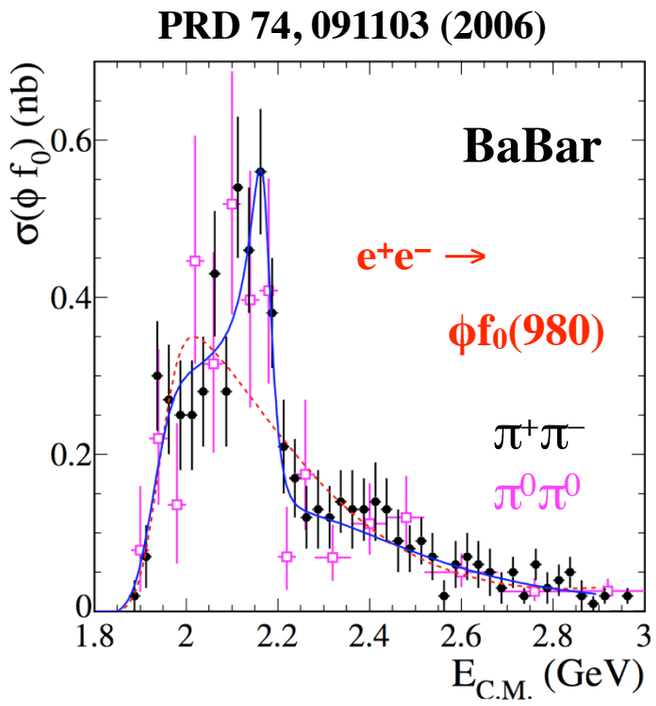
PRD 82, 091106(R) (2010)



$Y_s(2175)$?

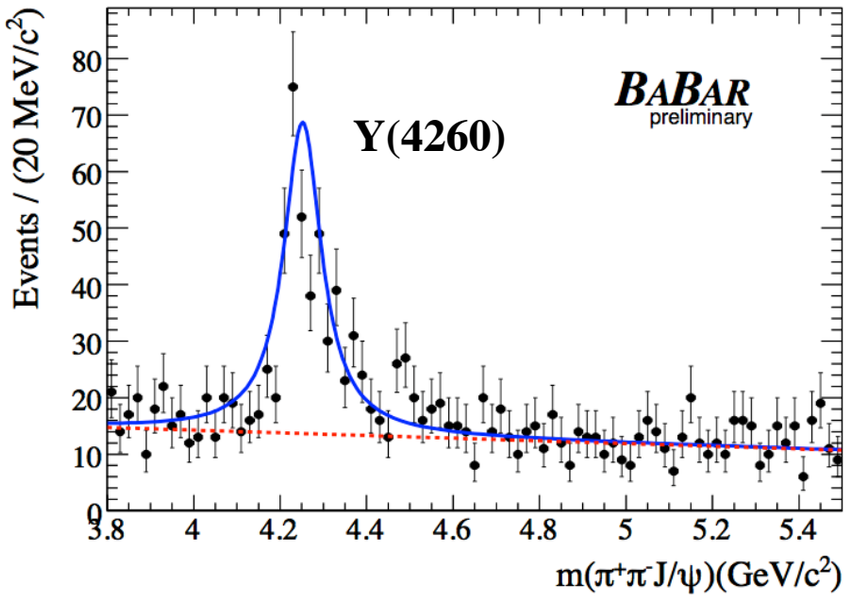
- peak at 2175 MeV in $e^+e^- \to \pi\pi\phi$
- consistent state seen by BES in $J/\psi \to \eta(\phi\pi\pi)$

PRD 74, 091103 (2006)



The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)



1. discovery of the **X, Y, Z states** in charmonium

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Theoretical Context
(advances in lattice QCD)

the charmonium renaissance and GlueX

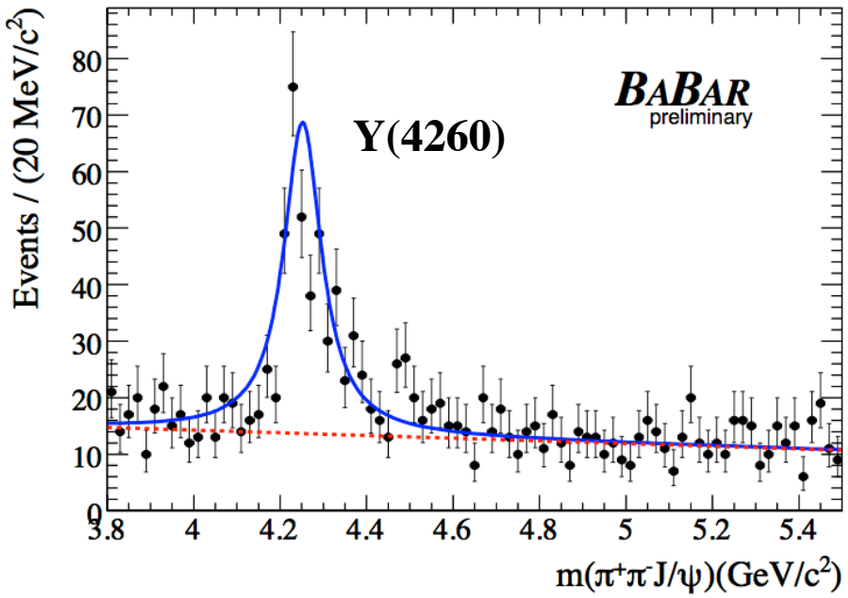
advantage of charmonium states:
clean, narrow, obvious states

disadvantage of charmonium states:
conventional J^{PC}

⇒ ***sets the stage for GlueX and exotic J^{PC}!***

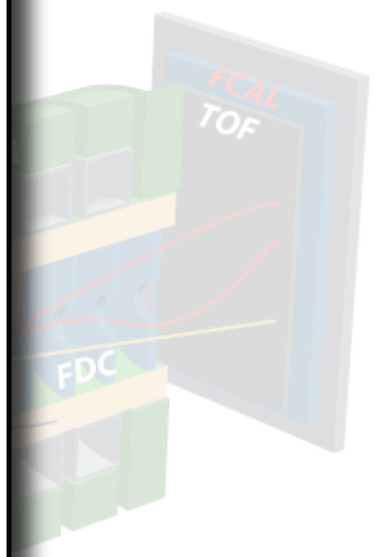
The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)



Theoretical Context
(advances in lattice QCD)

Technological Context
(advances in amplitude analysis)



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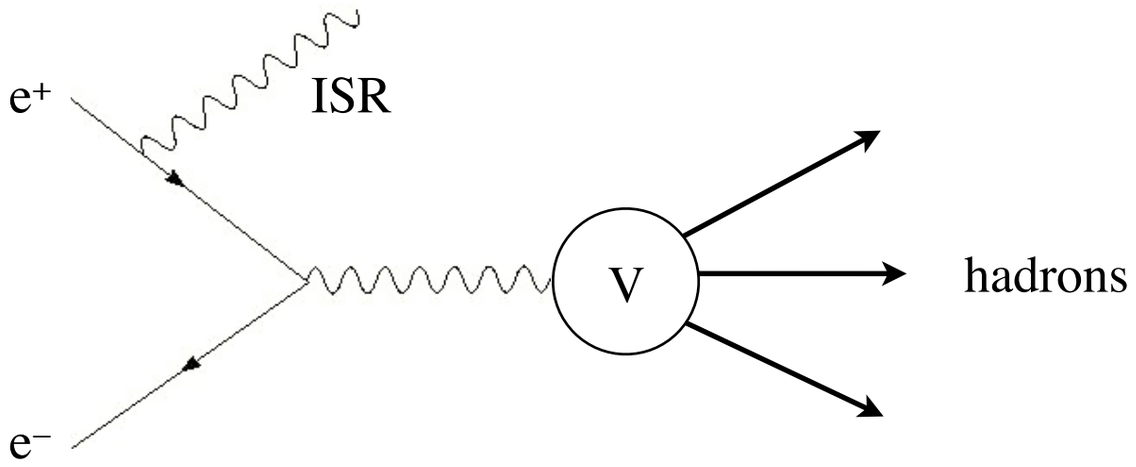
The Context of the GlueX Experiment

BaBar's program to measure R exclusively



$m(\pi^+\pi^- J/\psi)(GeV/c^2)$

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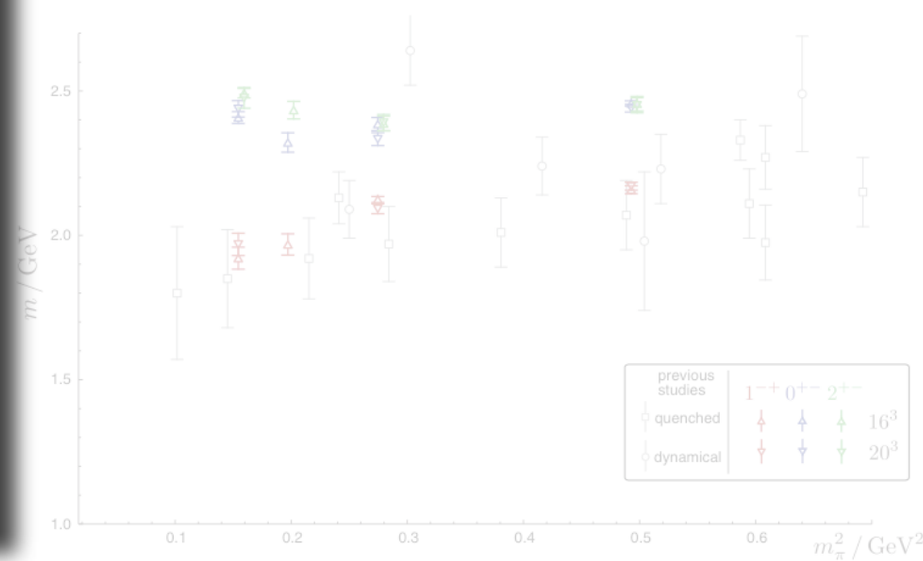
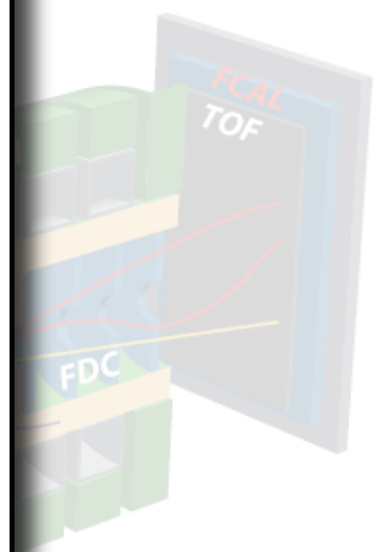
Theoretical Context
(advances in lattice QCD)



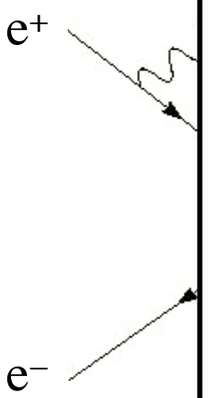


Technological Context
(advances in amplitude analysis)

The Context of the GlueX Experiment

BaBar's program to measure R exclusively

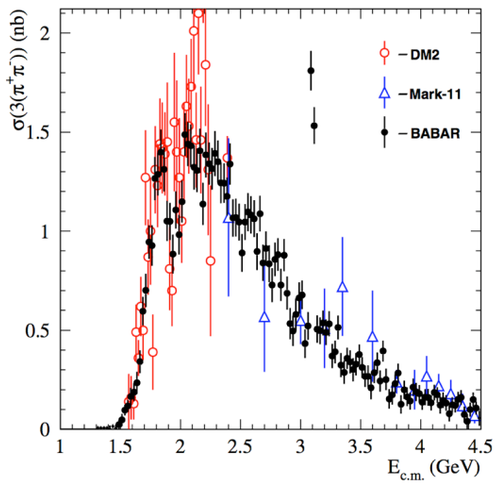
a collection of e^+e^- ISR plots from BaBar



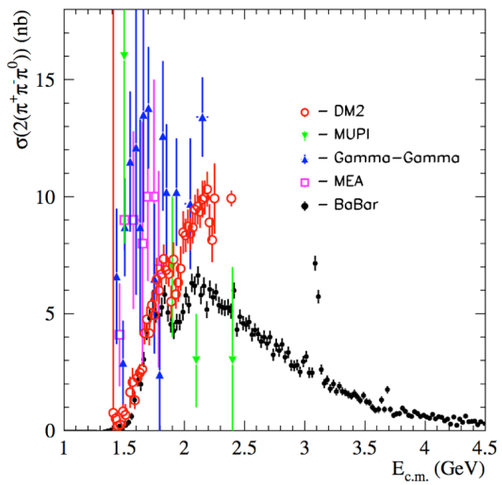
- **BaBar ISR**
- **Older Experiments**

PRD70,072004(2004)
PRD73,052003(2006)
PRD76,012008(2007)
PRD76,092005(2007)
PRD77,092002(2008)

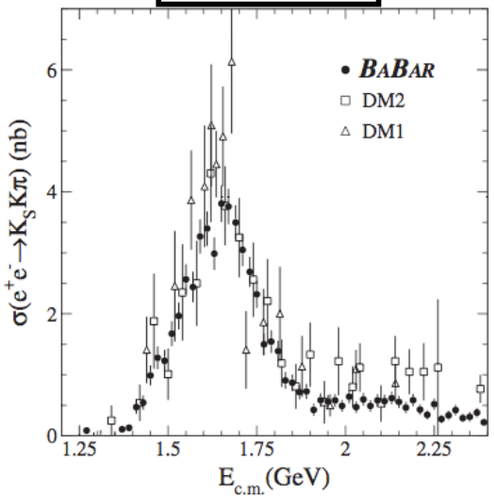
$\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$



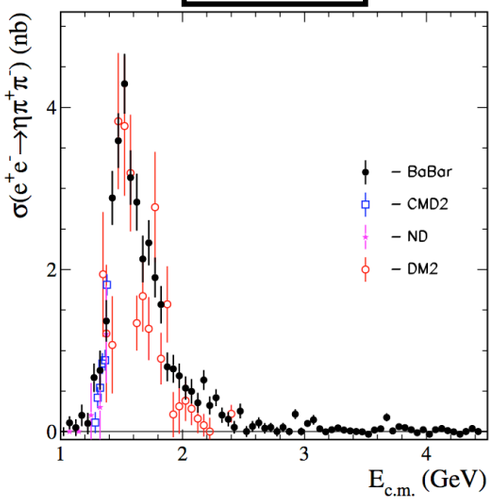
$\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$



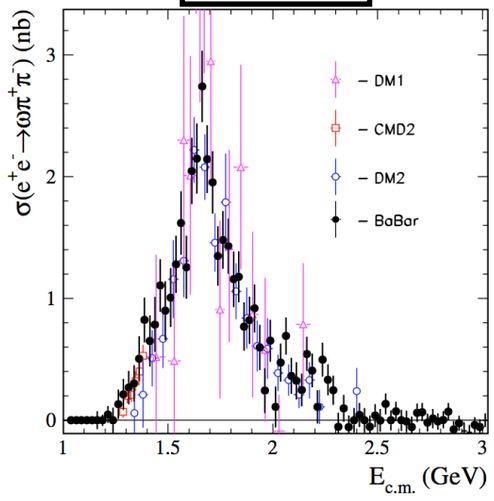
$K_S\,K^+\,\pi^-$



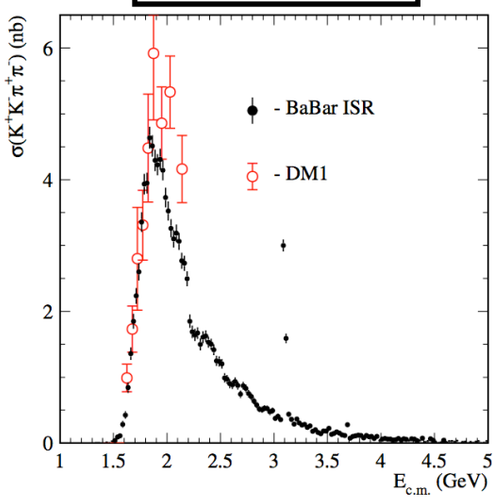
$\eta\,\pi^+\,\pi^-$



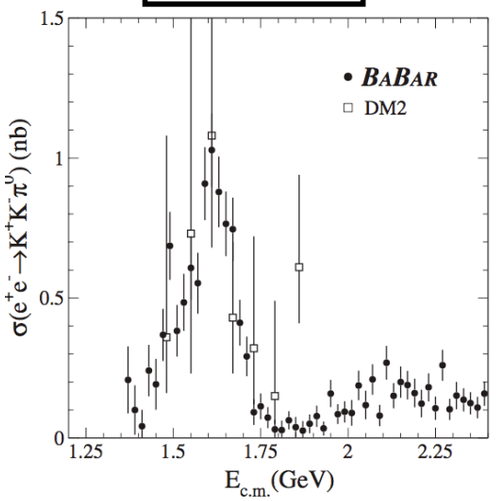
$\omega\,\pi^+\,\pi^-$



$K^+\,K^-\,\pi^+\,\pi^-$



$K^+\,K^-\,\pi^0$



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Theoretical Context
(advances in lattice QCD)

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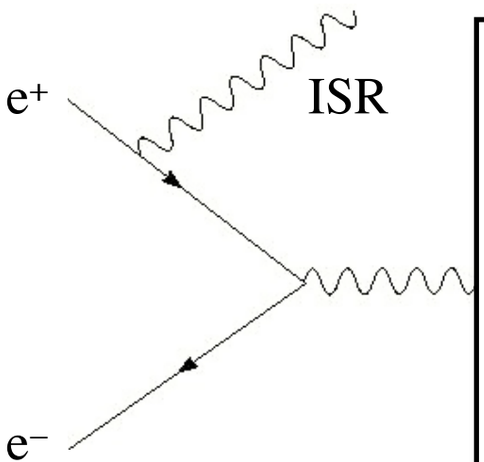
The Context of the GlueX Experiment

BaBar's program to measure R exclusively



1. discovery of the **X, Y, Z states** in charmonium

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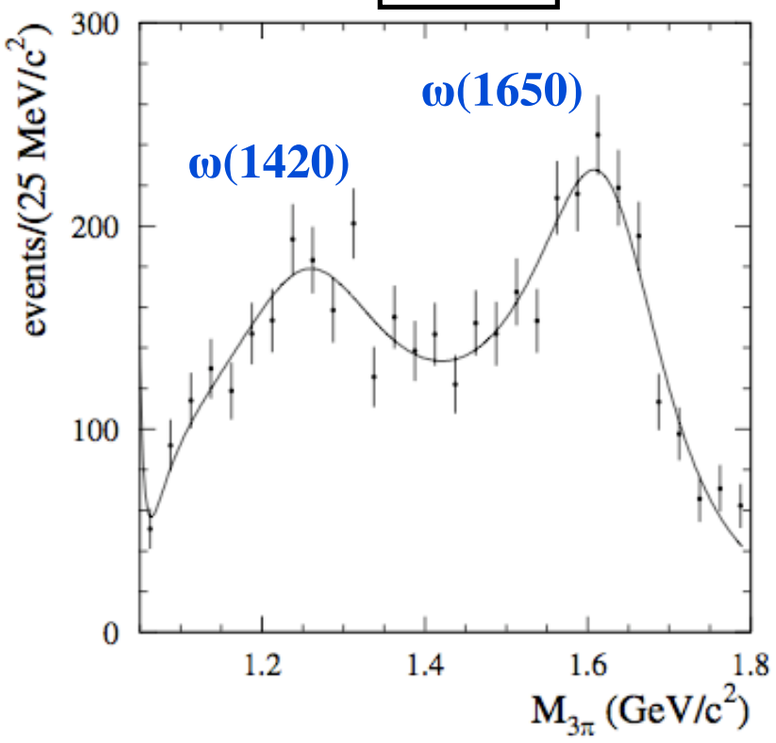
properties of light quark vector states

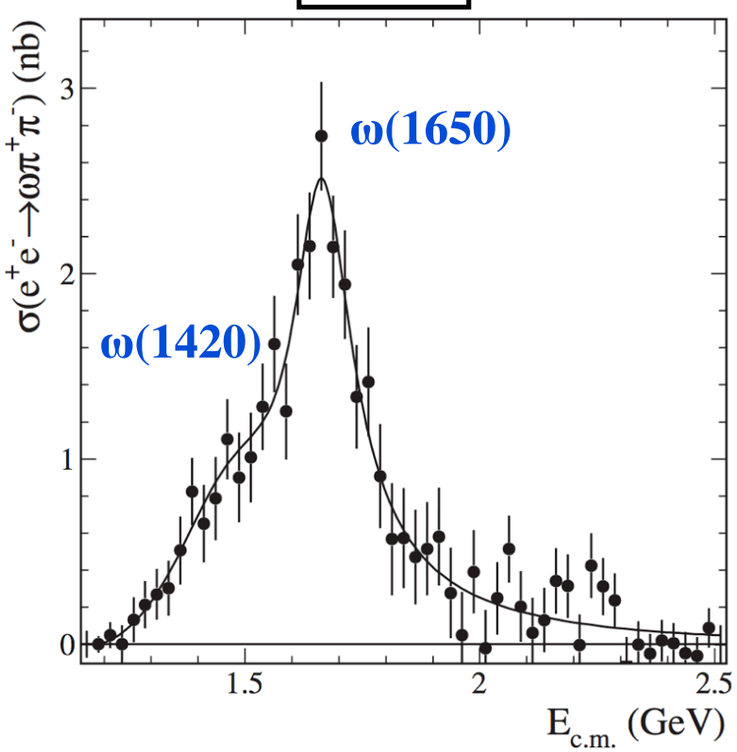
$\pi^+ \pi^+ \pi^0$



M(ω(1420)) = 1350 ± 20 ± 20 MeV/c²

M(ω(1650)) = 1660 ± 10 ± 2 MeV/c²

$\omega \pi^+ \pi^-$



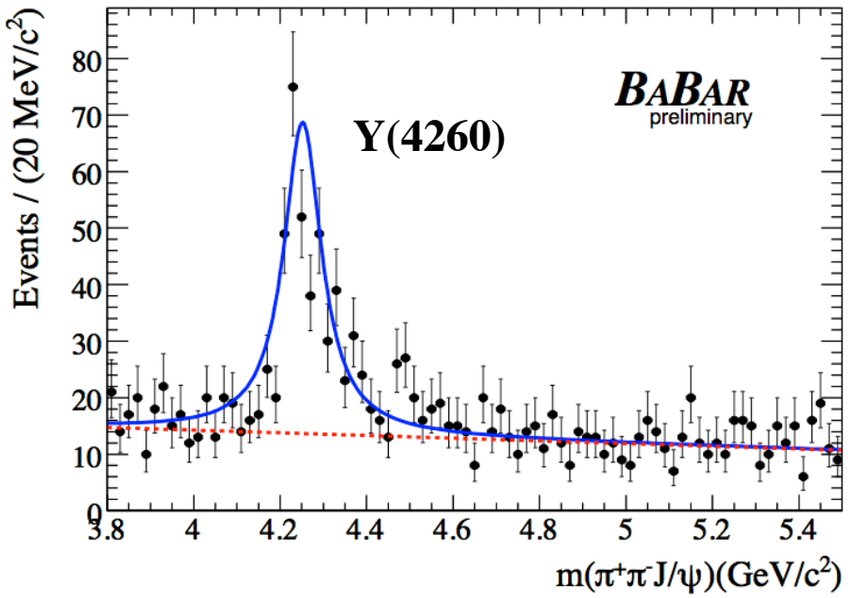
M(ω(1420)) = 1380 ± 20 ± 70 MeV/c²

M(ω(1650)) = 1667 ± 13 ± 6 MeV/c²

⇒ valuable input for GlueX

The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)



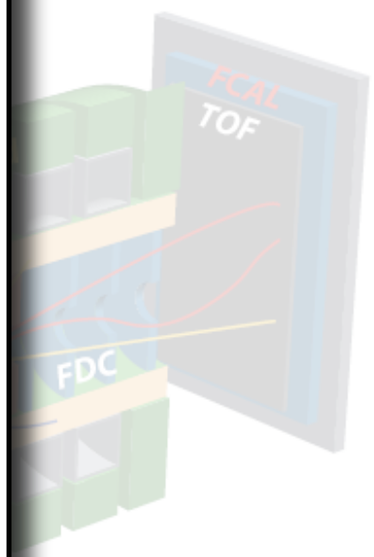
Theoretical Context
(advances in lattice QCD)

Technological Context
(advances in amplitude analysis)

1. discovery of the **X, Y, Z states** in charmonium

2. mapping the **light quark vectors** with ISR

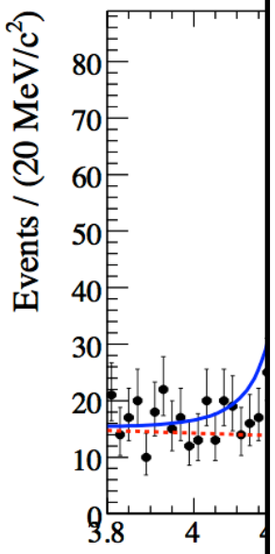
3. progress in searches for **exotic mesons**



The Context of the GlueX Experiment

Experimental Context

(advc



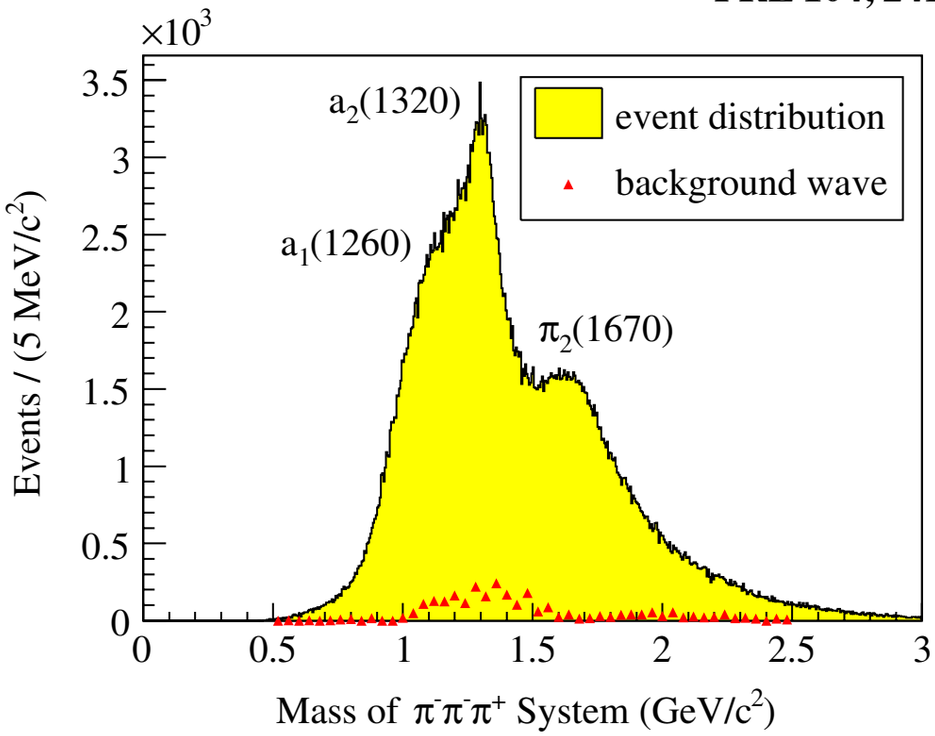
1. discovery o
   X, Y, Z stat
   in charmoni

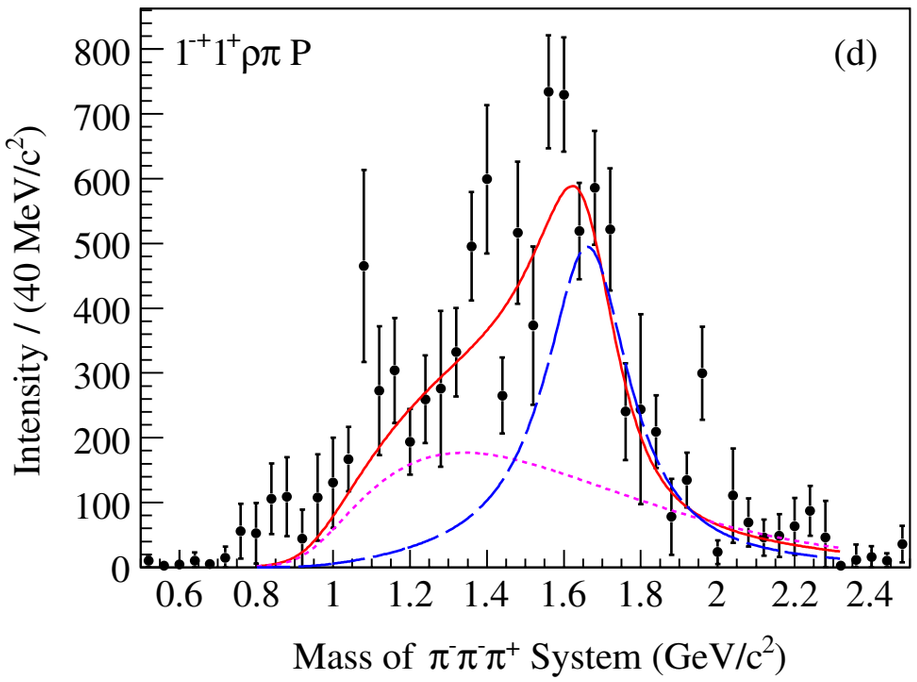
2. mapping the
   light quark
   with ISR

3. progress in searches for **exotic mesons**

analysis of $\pi^- Pb \to \pi^+\pi^-\pi^- Pb$ at COMPASS

PRL 104, 241803 (2010)





- indication of an exotic (1^{-+}) decaying to $\varrho\pi$ with phase motion
- a factor of ~11 smaller than $a_2(1320)$

The Context of the GlueX Experiment

Experimental Context

(ad

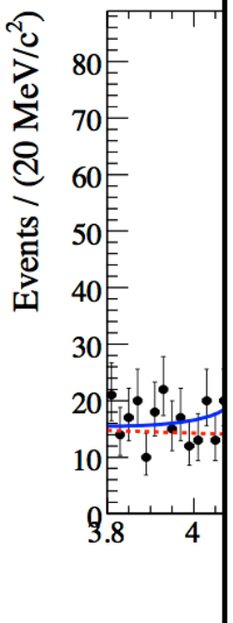
1. discovery
   X, Y, Z st
   in charmo

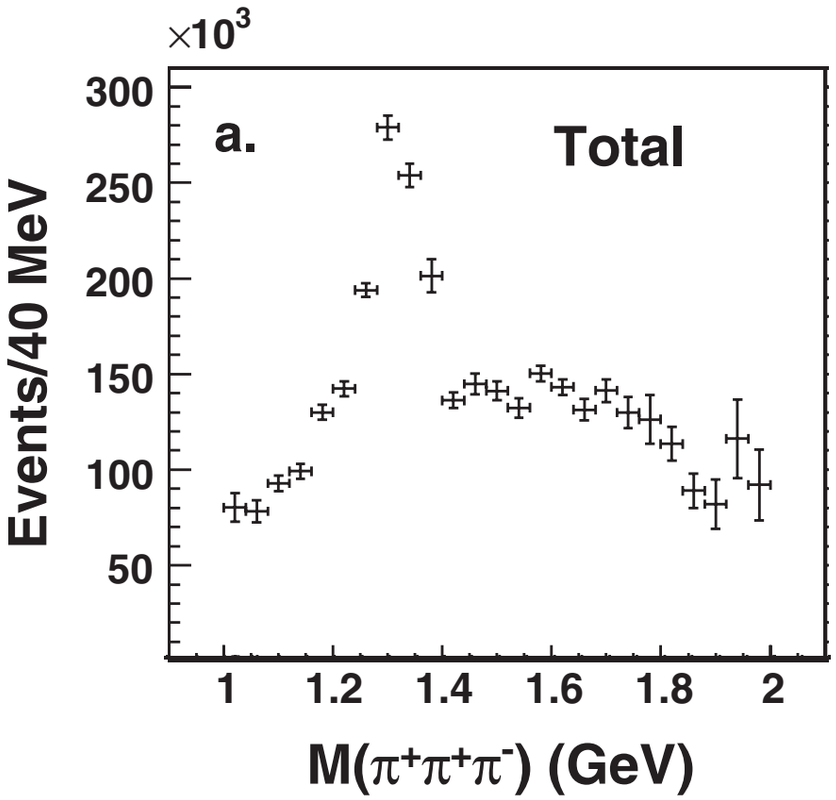
2. mapping t
   light quar
   with ISR

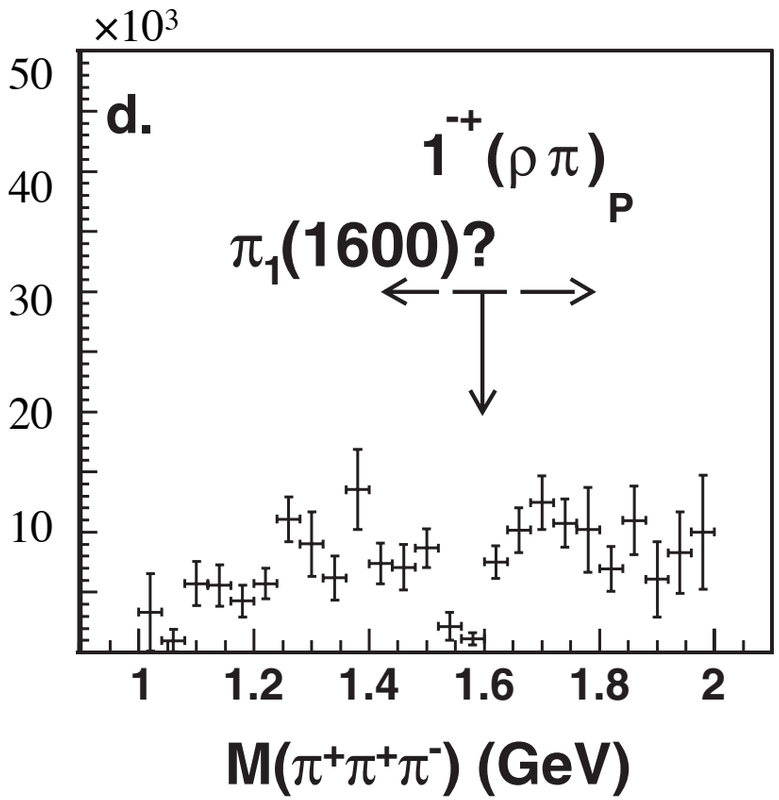
3. progress i
   for **exotic**

analysis of $\gamma p \to \pi^+\pi^+\pi^- n$ at CLAS

PRL 102, 102002 (2009)





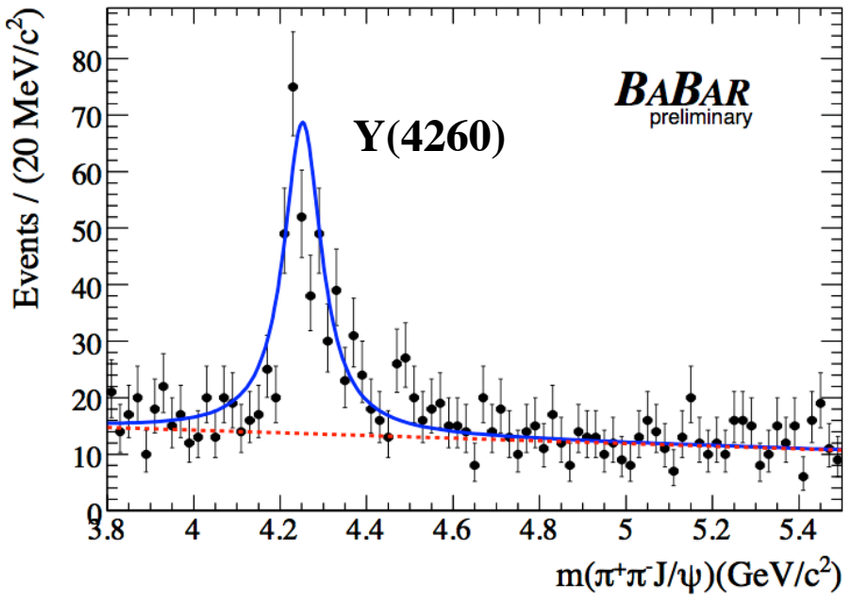


- no indication of the exotic decaying to ϱπ in photoproduction
- ratio of exotic to $a_2(1320)$ production (times BF's to ϱπ) is < 2% (95% CL)

⇒ ***dialogue between pion production and photoproduction has begun***

The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)



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(advances in lattice QCD)

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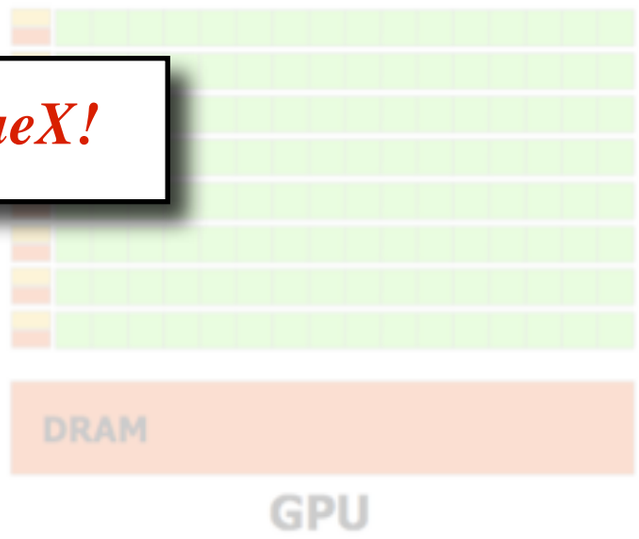
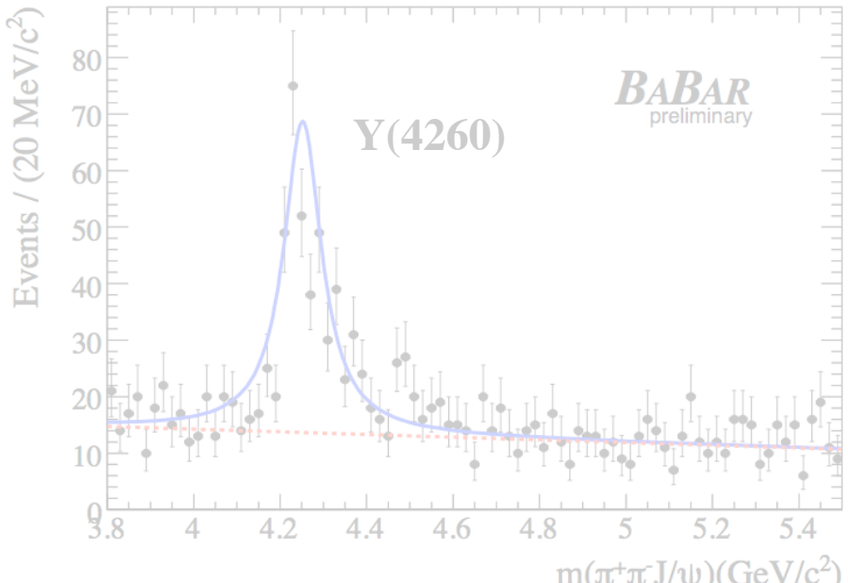


⇒ opportune timing for GlueX!

The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)



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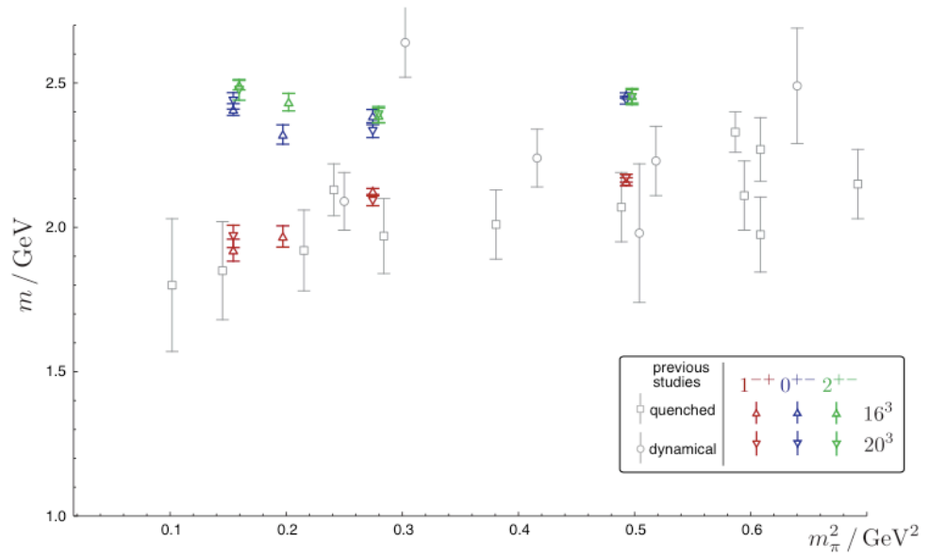

Technological Context
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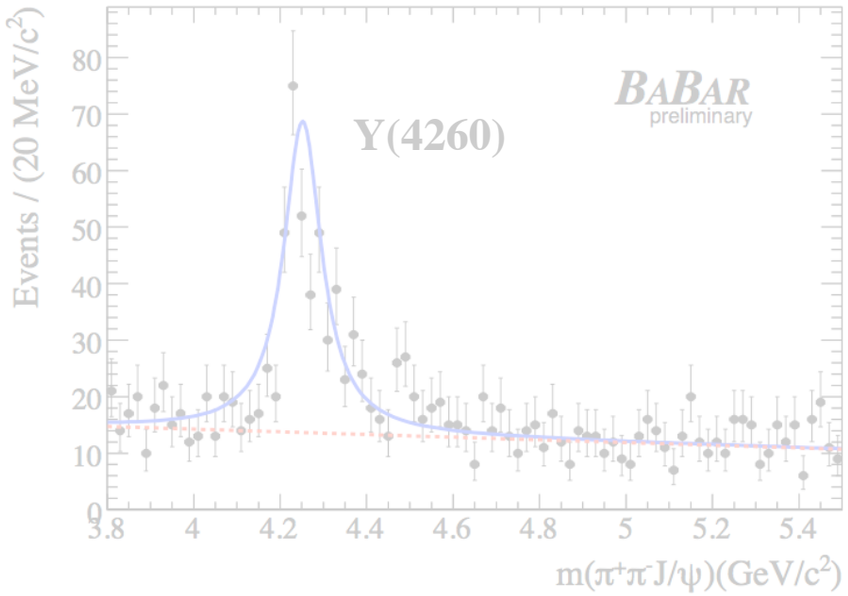
The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)



Theoretical Context
(advances in lattice QCD)

how does GlueX become a test of QCD?

1. QCD predicts mesons with exotic J^{PC}?
   (i.e. they should exist?)

2. QCD predicts they should be produced in photoproduction?
   (i.e. they should be produced?)

3. QCD predicts they have reasonable widths and decays?
   (i.e. they should be detected?)

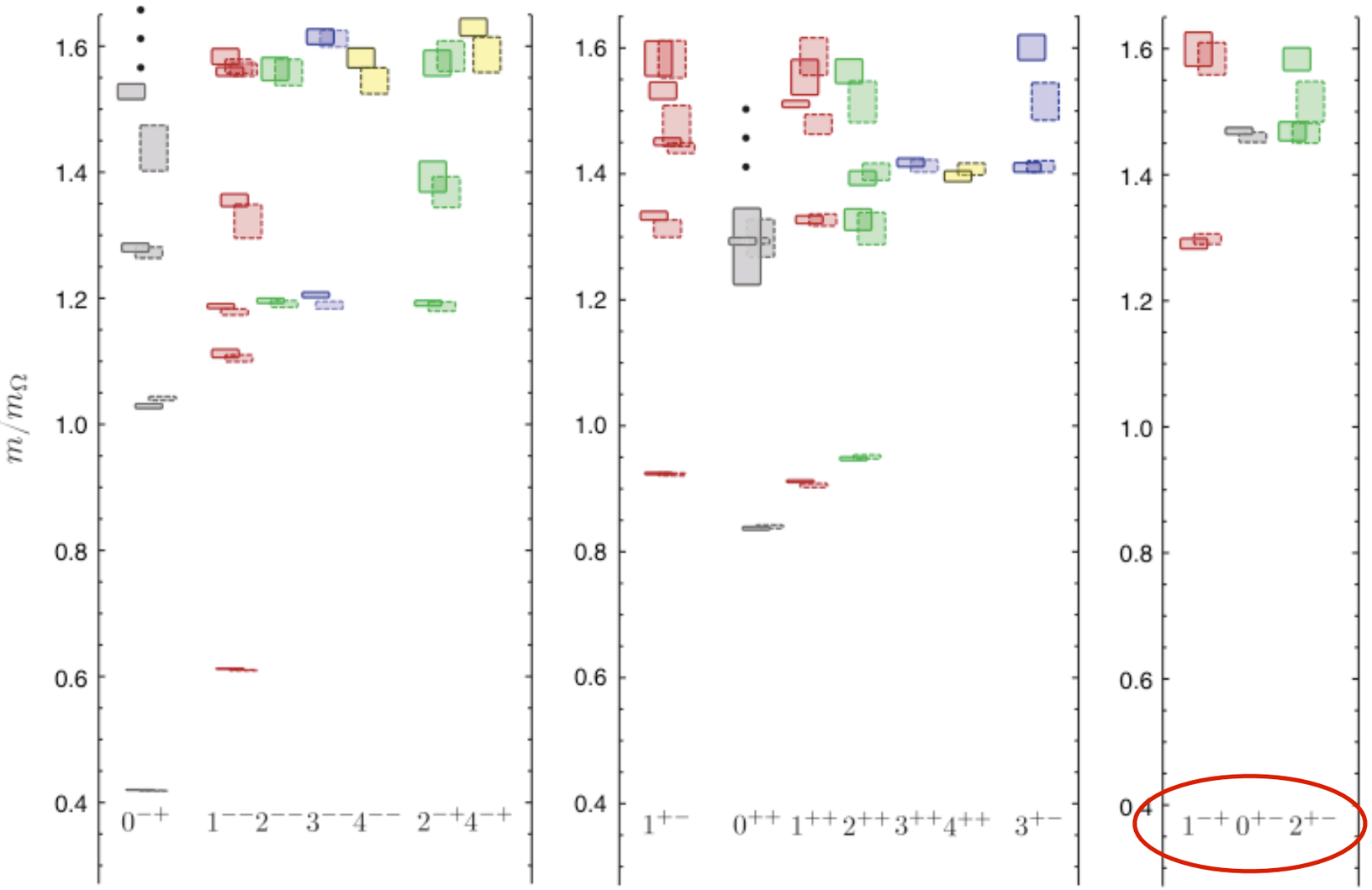
traditionally the domain of models, but lattice QCD is now being applied...

The Context of the GlueX Experiment

Experimental Context

light quark spectroscopy from lattice QCD

(unquenched, u,d,s quarks have the strange quark mass)



[The Hadron Spectrum Collaboration] PRD 82, 034508 (2010)

Theoretical Context

…ces in lattice QCD)

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…CD is now being applied…

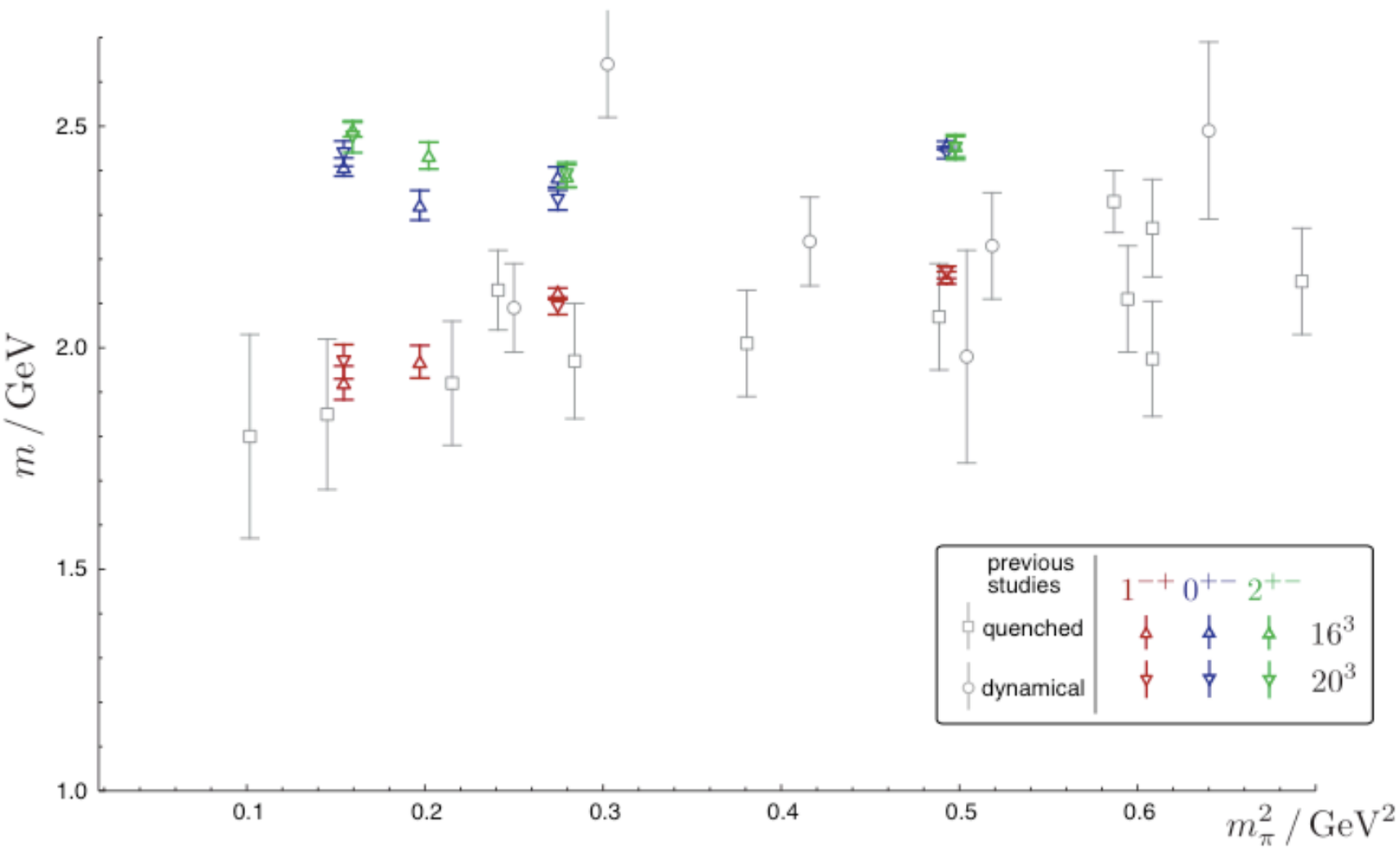
GPU

The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)

Theoretical Context
(advances in lattice QCD)

exotic meson spectroscopy from lattice QCD
(exotic meson mass as a function of pion mass)



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GPU

The Context of the GlueX Experiment

1. calculate radiative transitions in charmonium
(PRD 73, 074507 (2006))

2. extend to radiative transitions with exotic mesons (related to photoproduction)
(PRD 79, 094504 (2009))

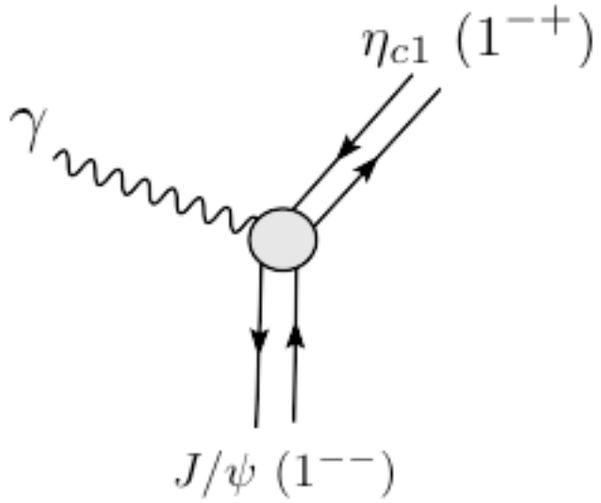
$\Gamma(\eta_{c1} \rightarrow \gamma J/\psi) =$

(115 ± 16) keV

is much larger than

$\Gamma(J/\psi \rightarrow \gamma \eta_c) =$

(2.51 ± 0.08) keV



looks promising!

3. extend to light quarks (in progress)

[The Hadron Spectrum Collaboration]

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(advances in lattice QCD)

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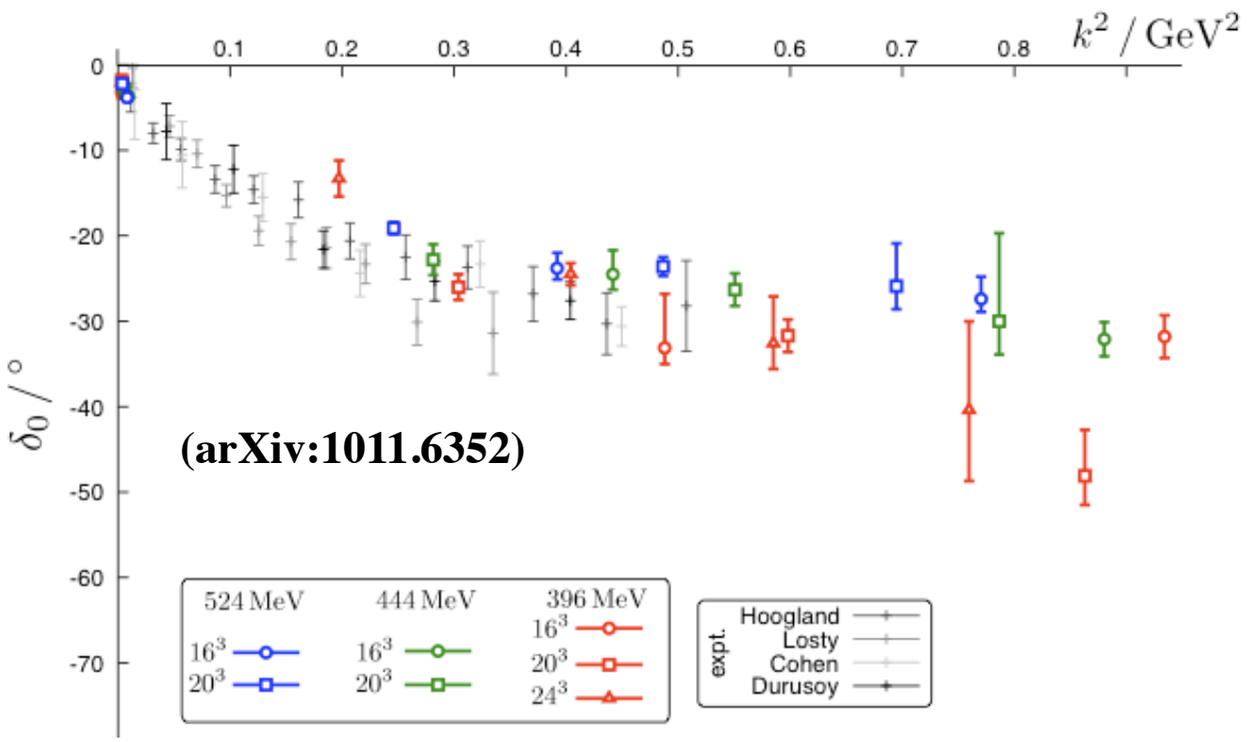
traditionally the domain of models, but lattice QCD is now being applied...

The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)

phase shift calculations in lattice QCD
($I = 2$ $\pi\pi \rightarrow \pi\pi$)



(widths and decays are difficult in lattice QCD)

[The Hadron Spectrum Collaboration]

Theoretical Context
(advances in lattice QCD)

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SOME PROGRESS

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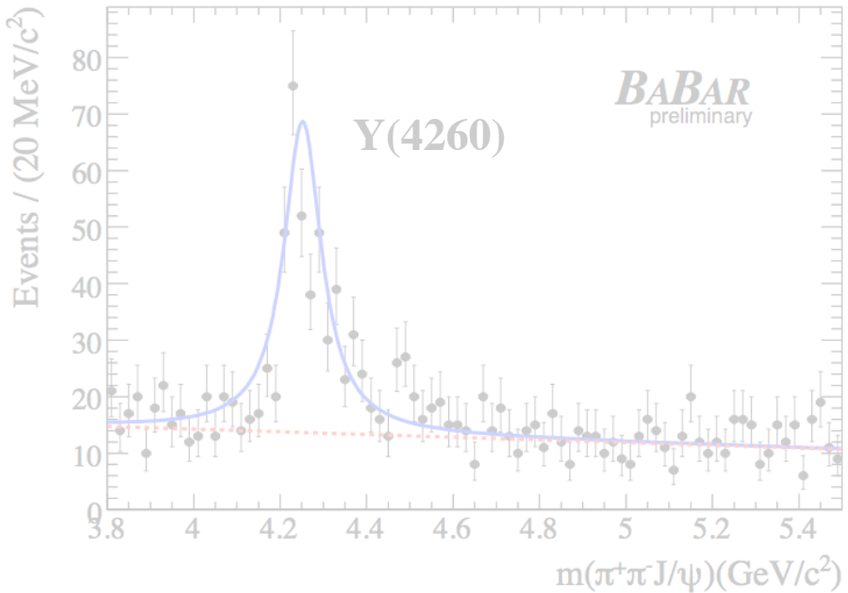
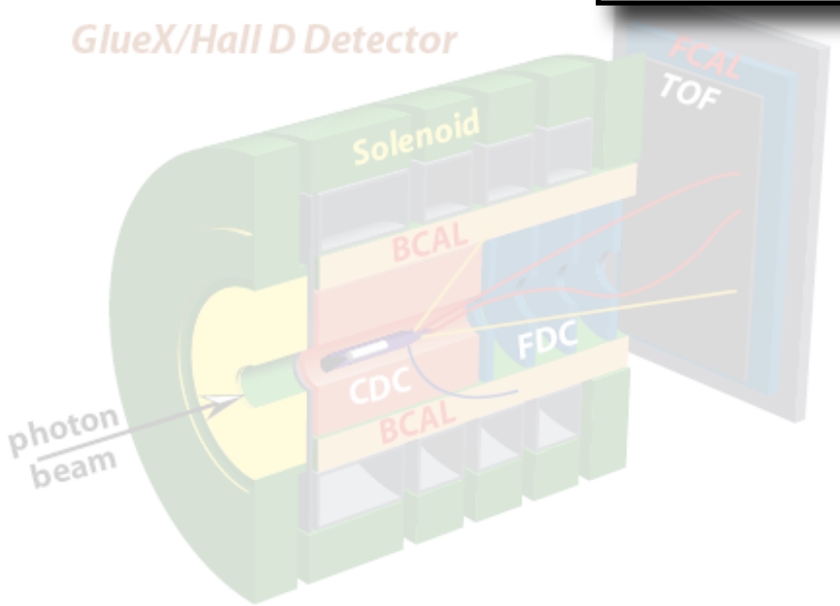
The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)



⇒ ***progress!***



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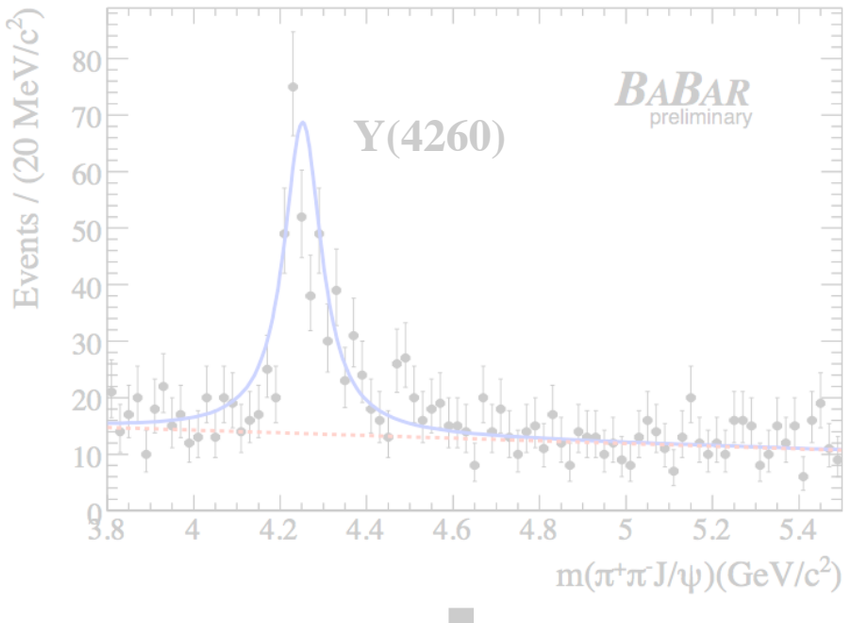
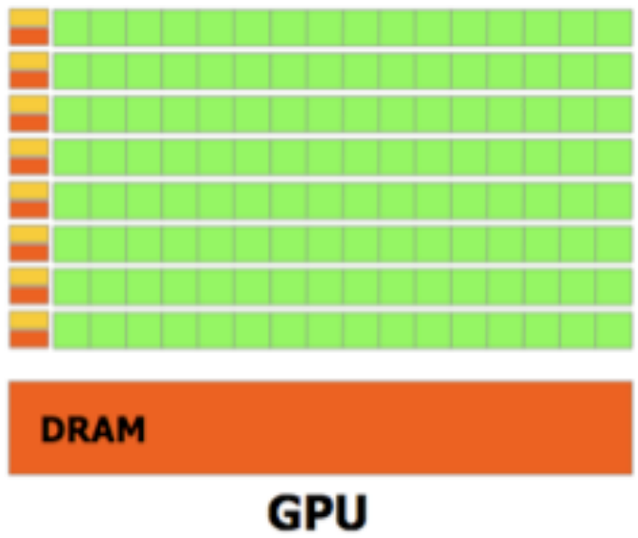
The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)



Theoretical Context
(advances in lattice QCD)

Technological Context
(advances in amplitude analysis)



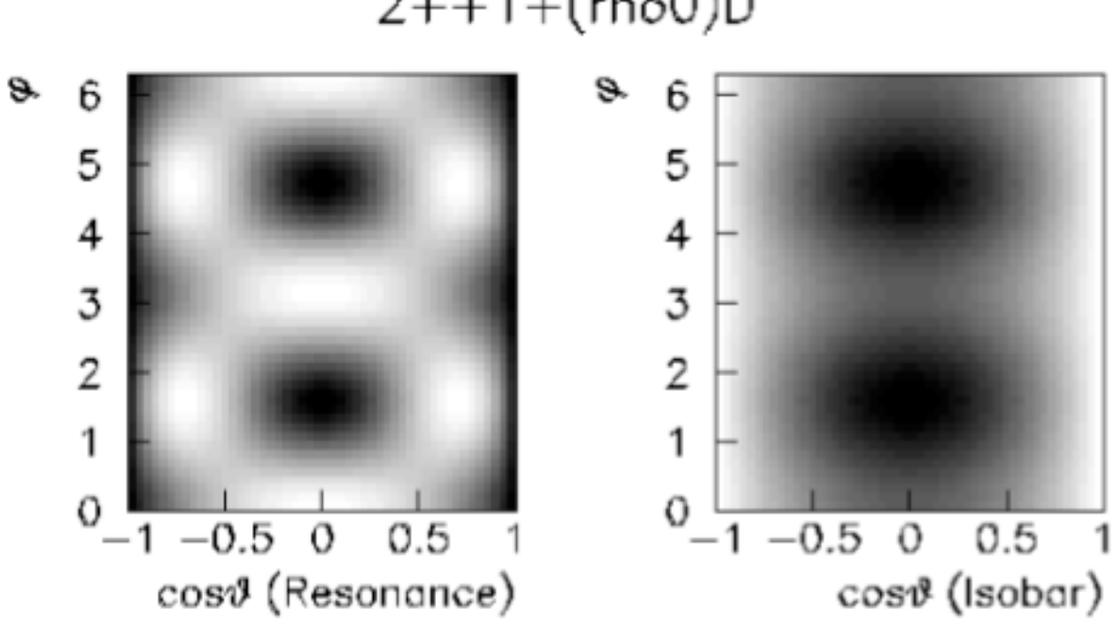
The Context of the GlueX Experiment

distinguish quantum numbers using angular distributions of decay products

for example:

$$\pi^- p \rightarrow X^- p \rightarrow \pi^+\pi^-\pi^- p$$

if X^- has $J^{PC} = 2^{++}$ and decays to $\varrho^0\pi^-$ in a D-wave, then you expect these angular distributions:



Theoretical Context

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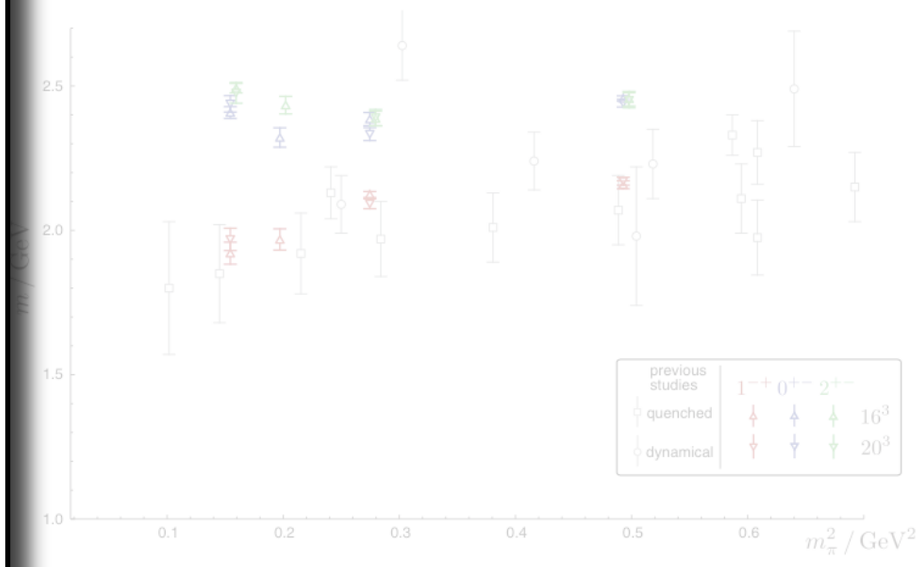
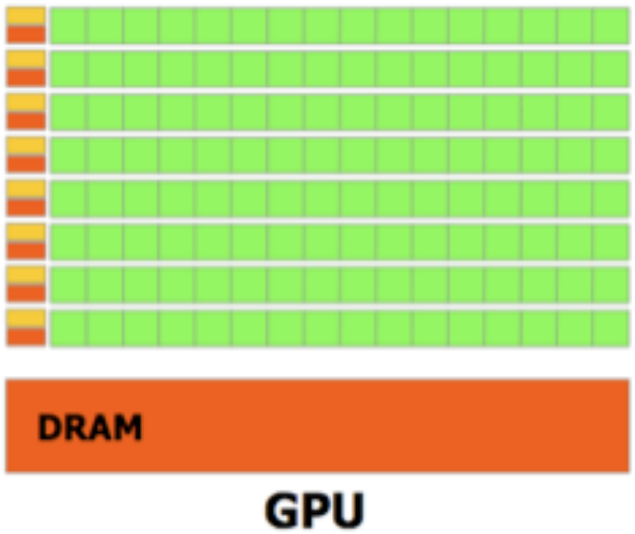


Technological Context

(advances in amplitude analysis)



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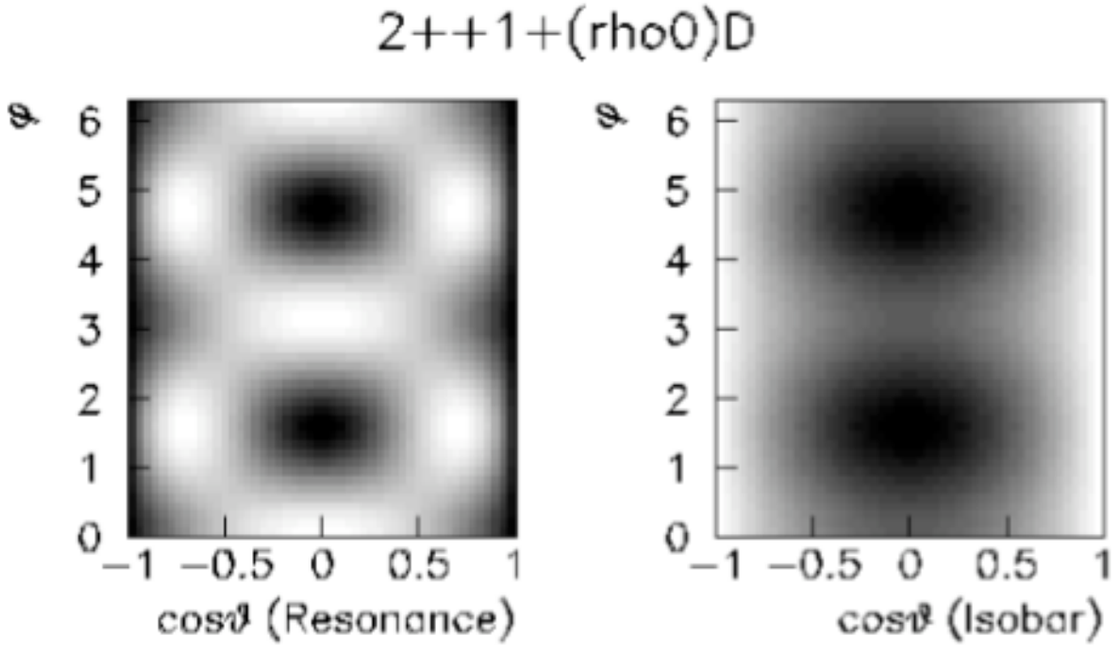
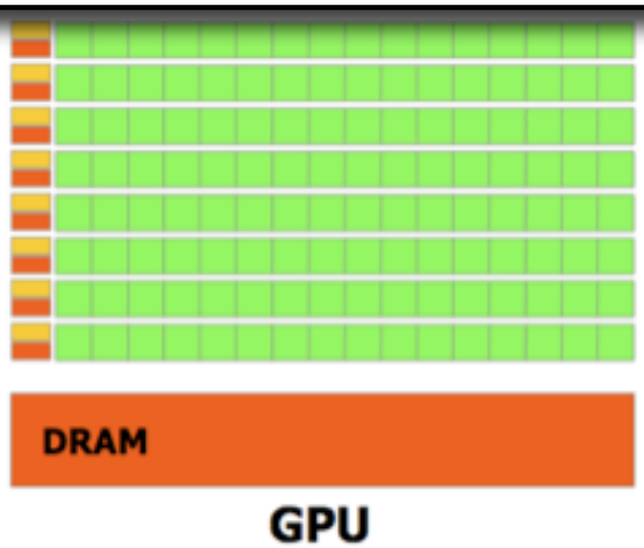


it's called an ***"amplitude analysis"*** because distributions are added on the amplitude level:

$$I(\Omega) = \sum_{\alpha} \left| \sum_{\beta} V_{\alpha,\beta} A_{\alpha,\beta}(\Omega) \right|^2$$

$A(\Omega)$ = Resonance Angles
× Isobar Angles
× Isobar Breit Wigner

V are complex fit parameters



The Context of the GlueX Experiment

fit I(Ω) (modified by detector acceptance) to data using an unbinned extended likelihood

the likelihood simplifies to two sums:

$$-2\ln(L) = -2\sum_{data}\ln(I(\Omega_i)) + 2\sum_{MC} I(\Omega_i)$$

doing an "amplitude analysis" means finding the V, or any free parameters within A, that minimize this function

ideal function for parallelization!

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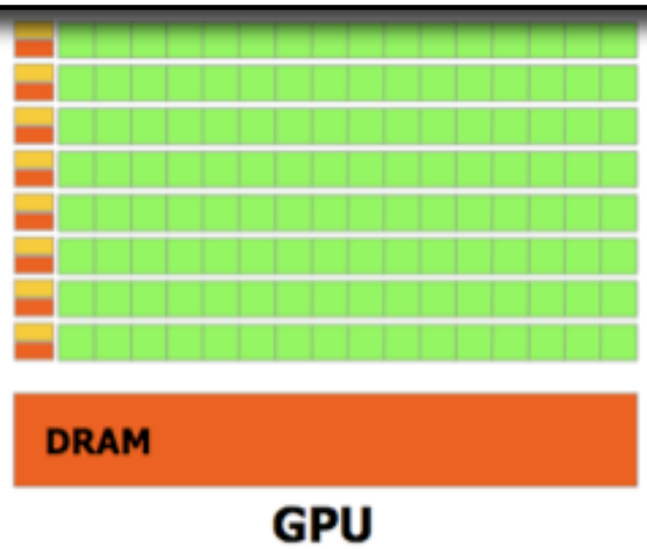

The Context of the Glue

Experimental Context

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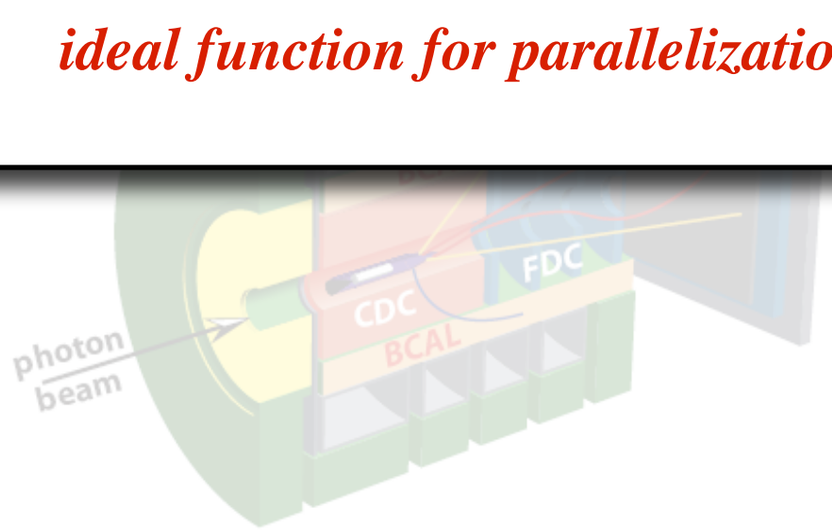


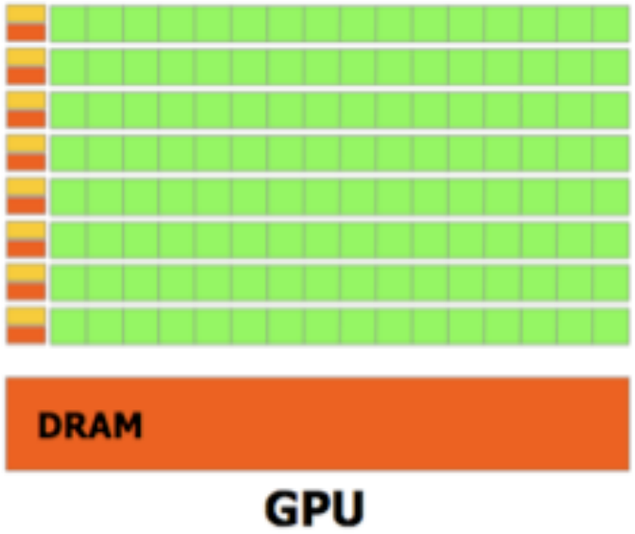
a progression of strategies

(NSF Physics at the Information Frontier Grant)

1. Open Science Grid
   - ✘ latencies, if you lose one node you lose the fit, etc.
2. Clusters of CPU's
   - ✘ good progress, but we can do better
3. Clusters of GPU's
   - ✓ revolutionary speed gains!

Technological Context

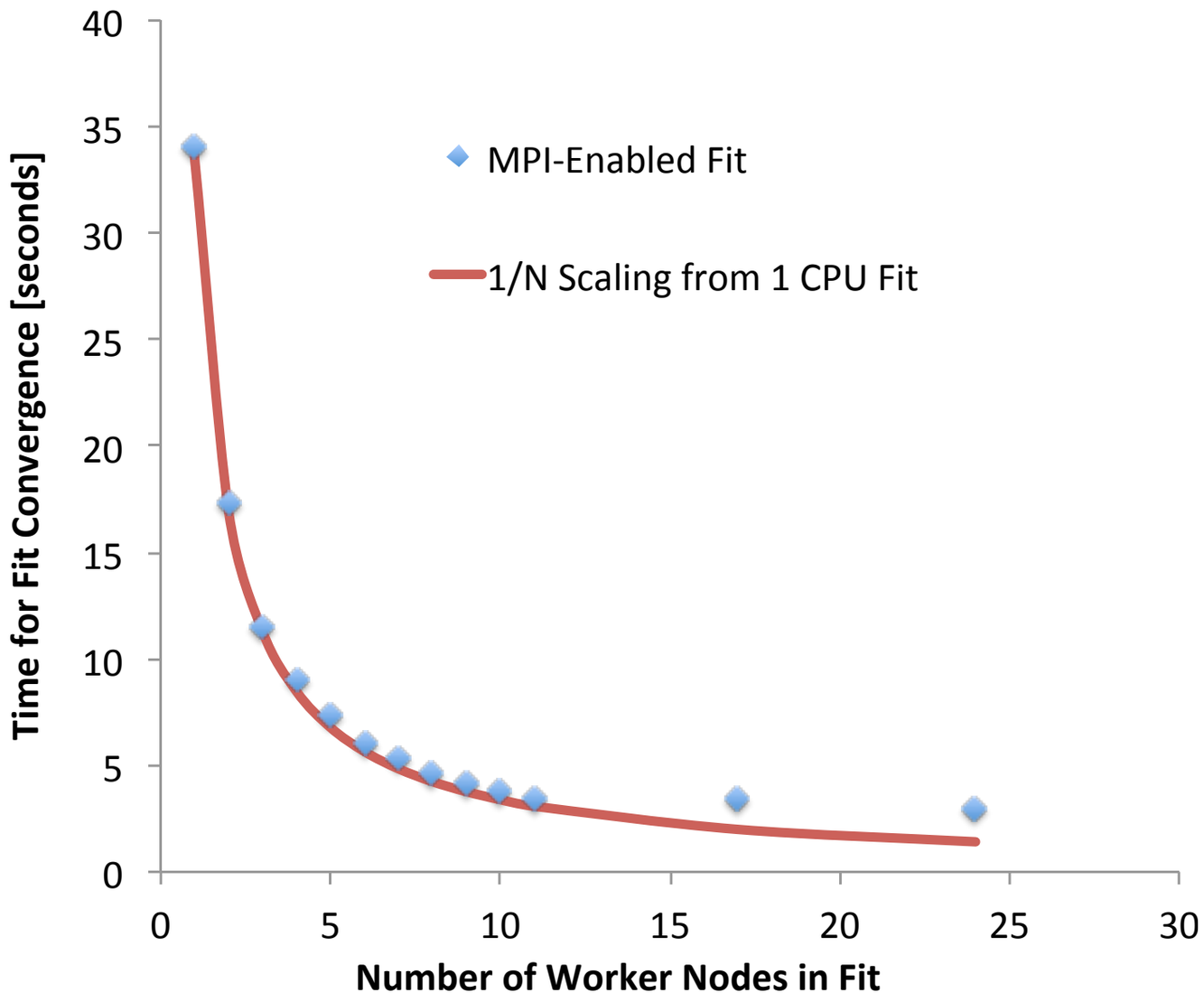
(advances in amplitude analysis)



The Context of the Glue

Experimental Context

sample fit to GlueX $\gamma p \rightarrow \pi^+\pi^+\pi^- n$ Monte Carlo



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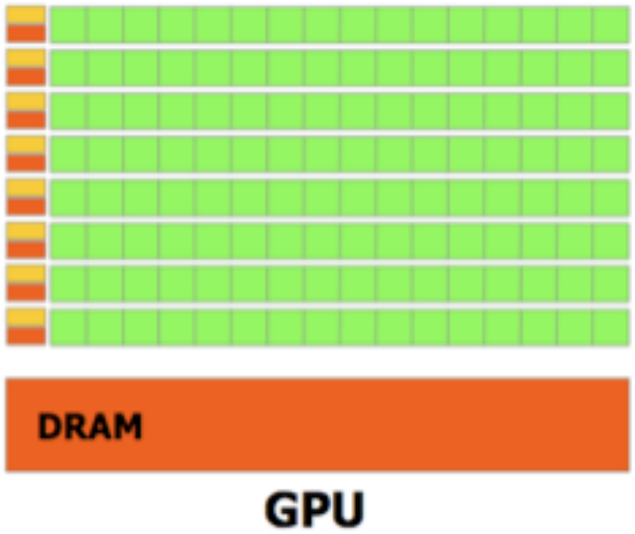
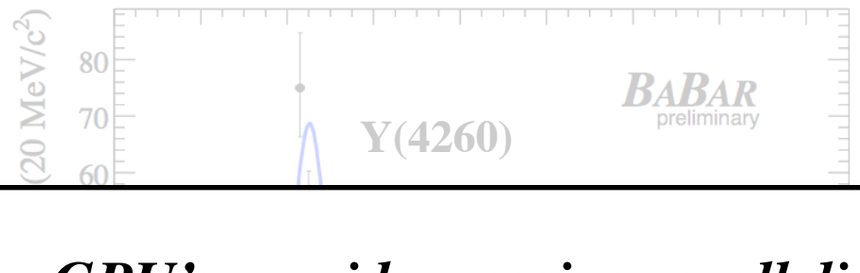
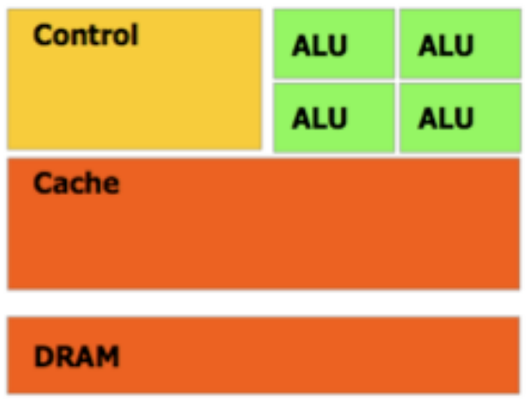


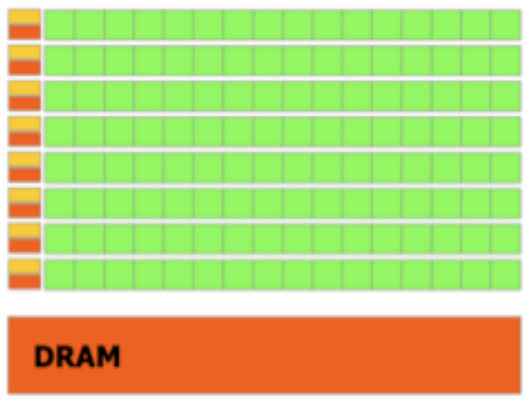
The Context of the Glue

Experimental Context
(advances in spectroscopy)



GPU's provide massive parallelization
(100's of computing cores)





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Technological Context
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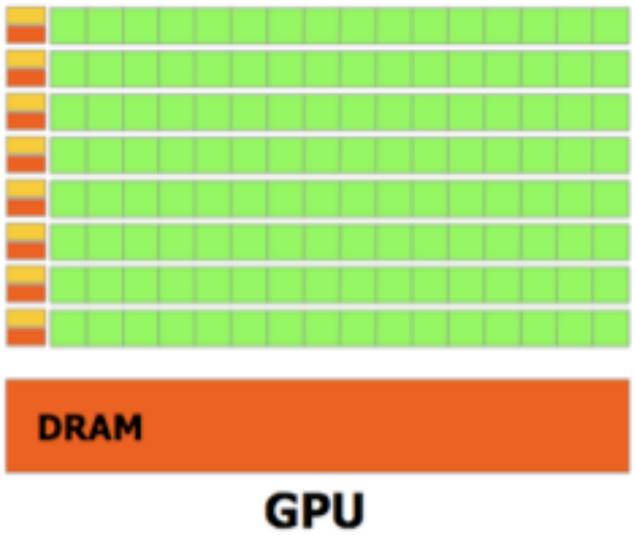
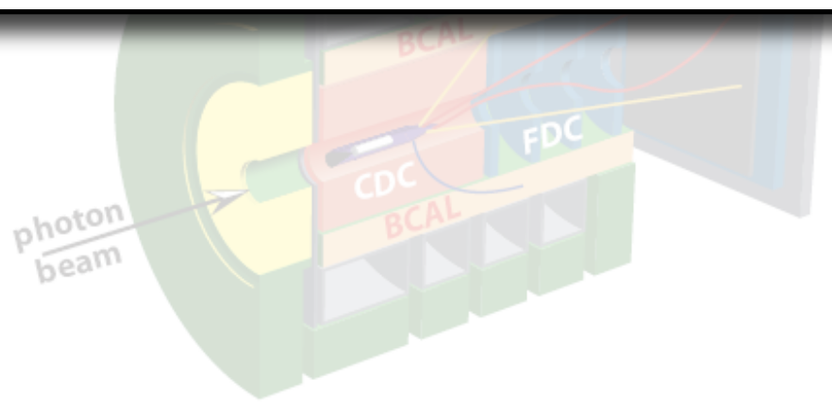
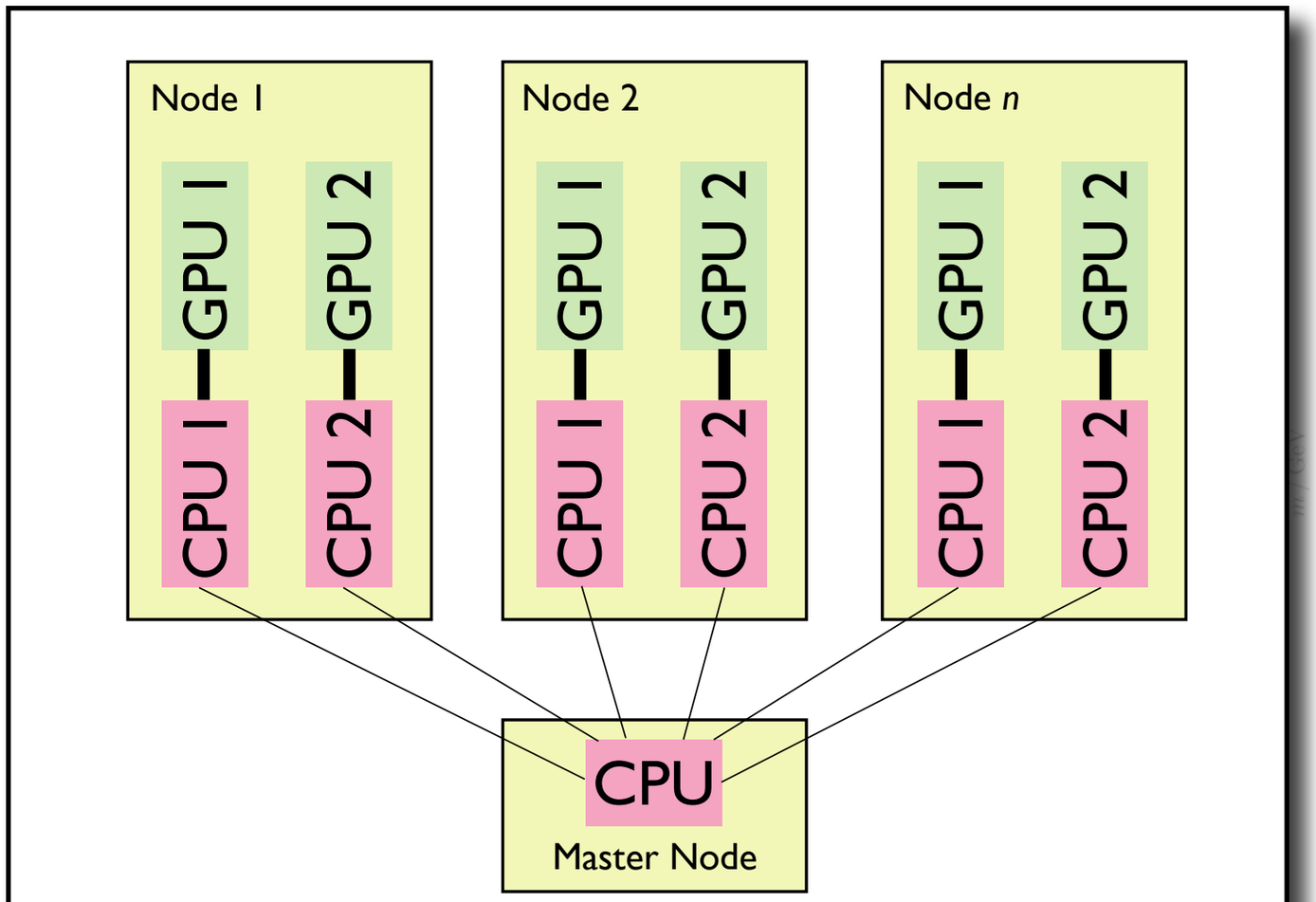




The Context of the Glue



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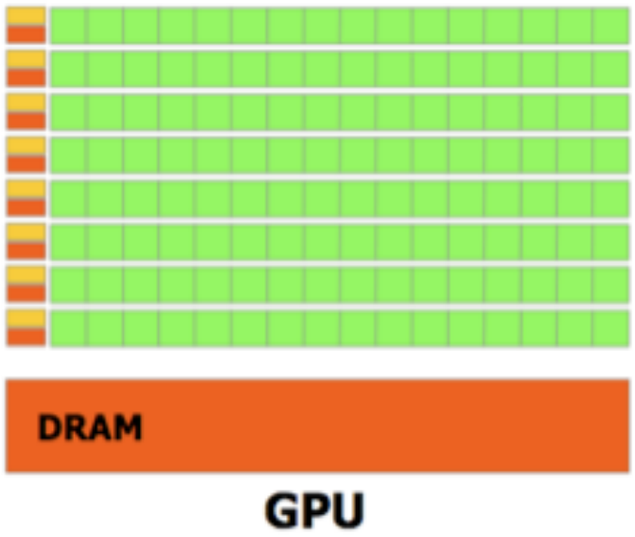
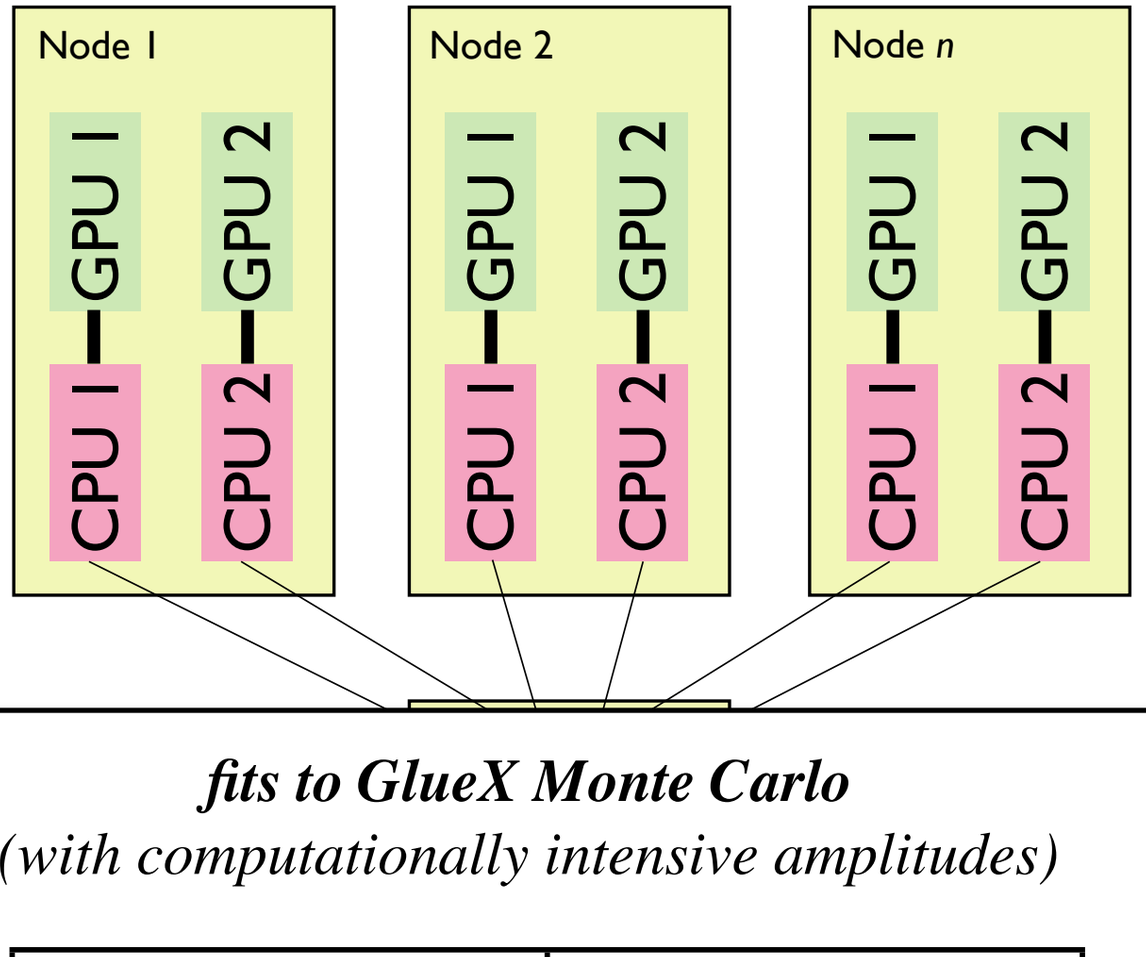


The Context of the GlueX Experiment



fits to GlueX Monte Carlo

(with computationally intensive amplitudes)

Fit Configuration	Time to Converge (seconds)
Single CPU	4855
Single CPU + 1 GPU	57
CPU Master + 4 (CPU + GPU)	16

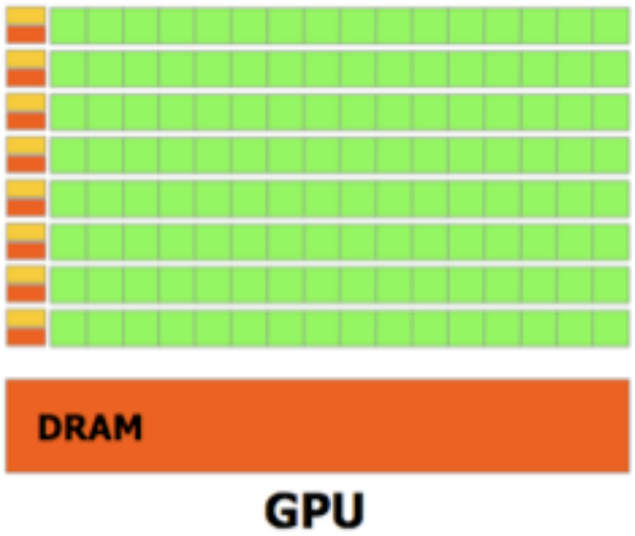
a progression of strategies

(NSF Physics at the Information Frontier Grant)

1. Open Science Grid
   - ✘ latencies, if you lose one node you lose the fit, etc.
2. Clusters of CPU's
   - ✘ good progress, but we can do better
3. Clusters of GPU's
   - ✓ revolutionary speed gains!

Technological Context

(advances in amplitude analysis)



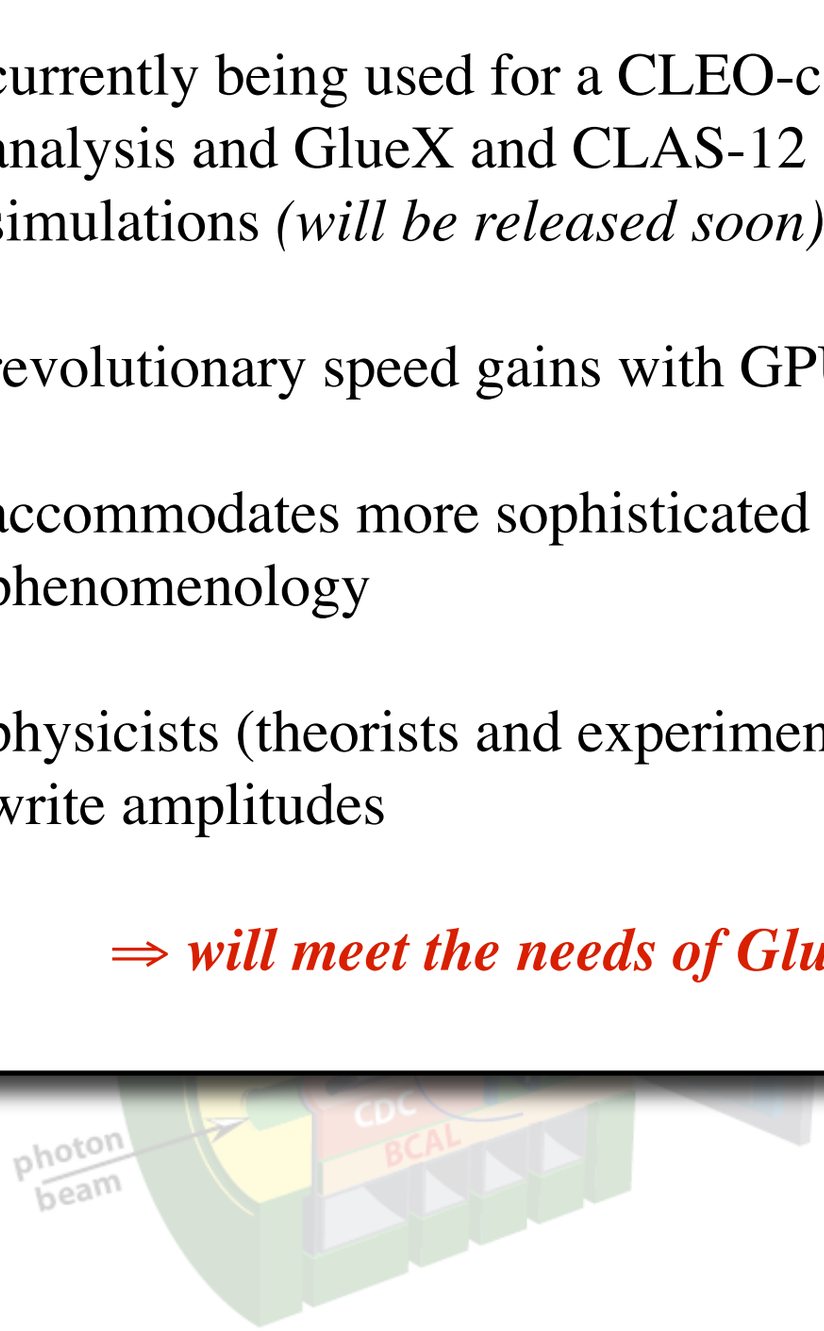
The Context of the GlueX Experiment

Experimental Context

amplitude analysis software (AmpTools)

- currently being used for a CLEO-c analysis and GlueX and CLAS-12 simulations *(will be released soon)*
- revolutionary speed gains with GPU's!
- accommodates more sophisticated phenomenology
- physicists (theorists and experimentalists) write amplitudes

⇒ ***will meet the needs of GlueX***



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Technological Context

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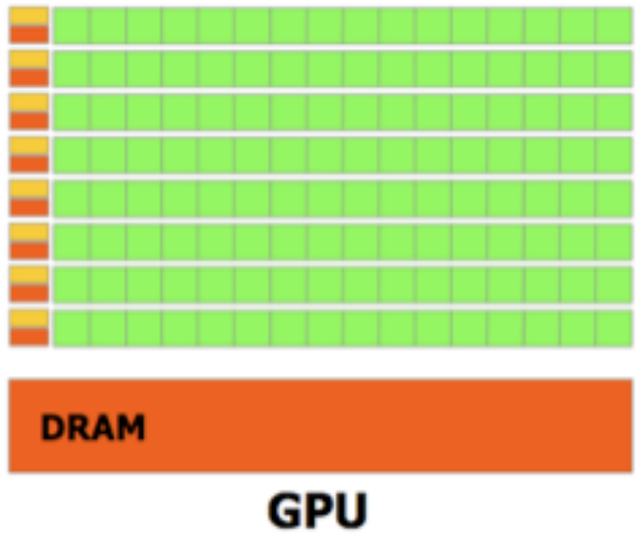
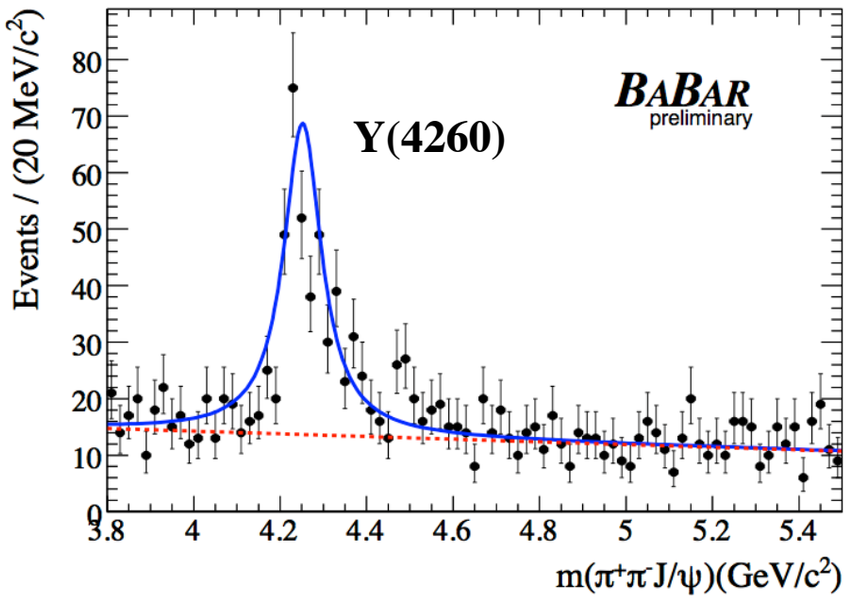
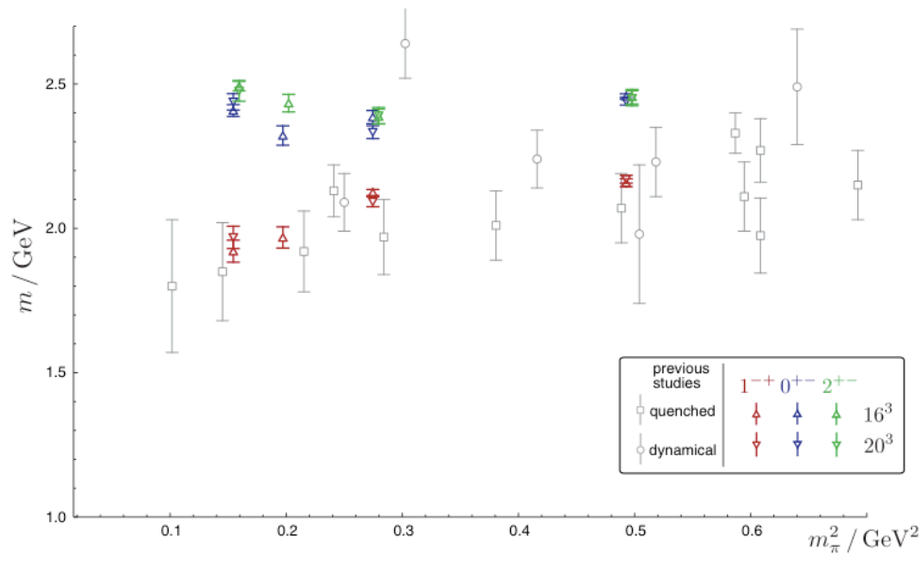


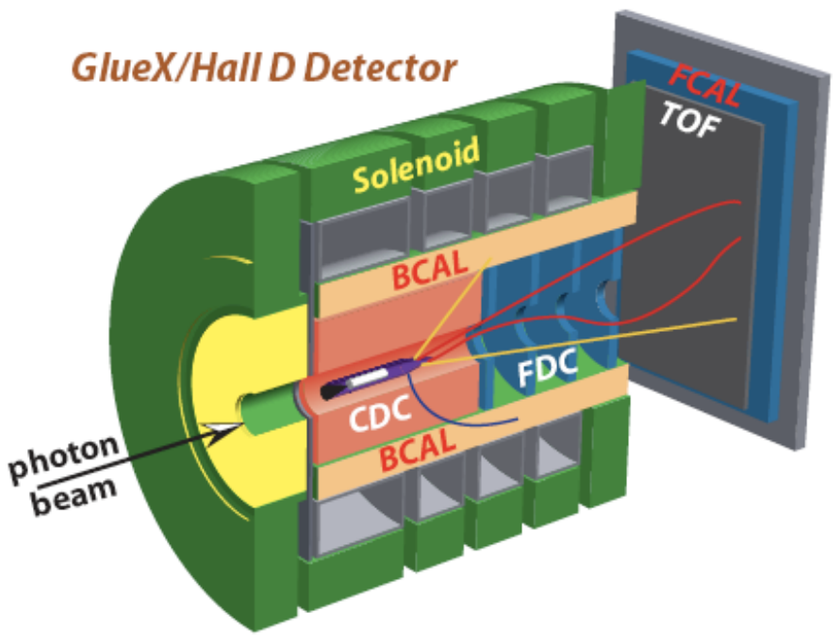
The Context of the GlueX Experiment

Experimental Context
(advances in spectroscopy)

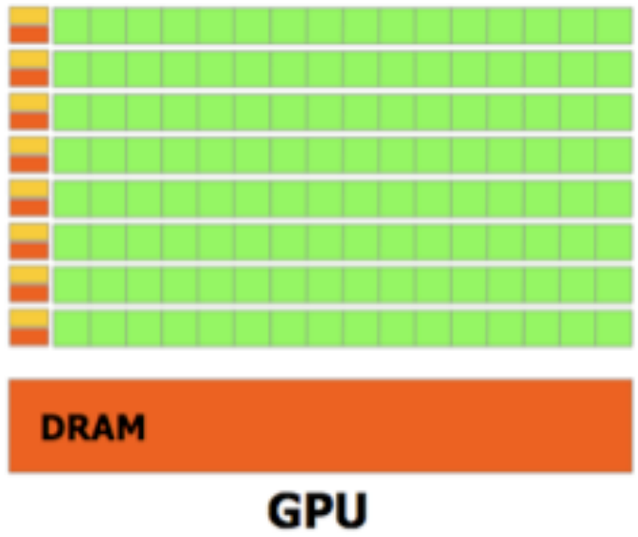


Theoretical Context
(advances in lattice QCD)

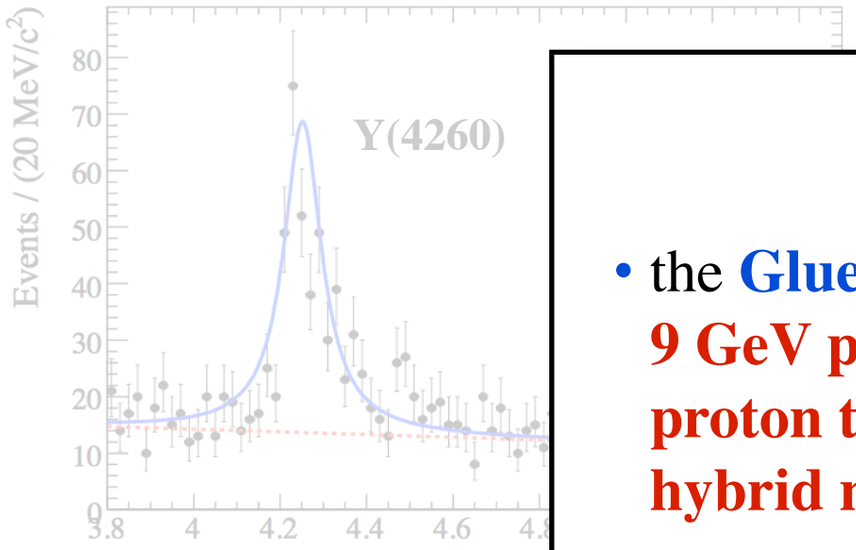




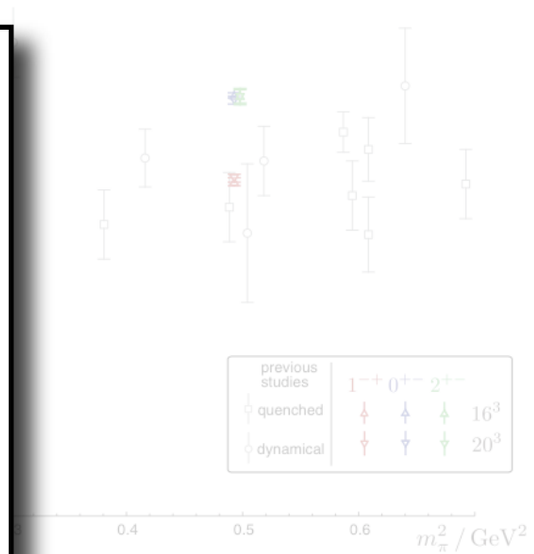
Technological Context
(advances in amplitude analysis)



Experimental Context
(advances in spectroscopy)

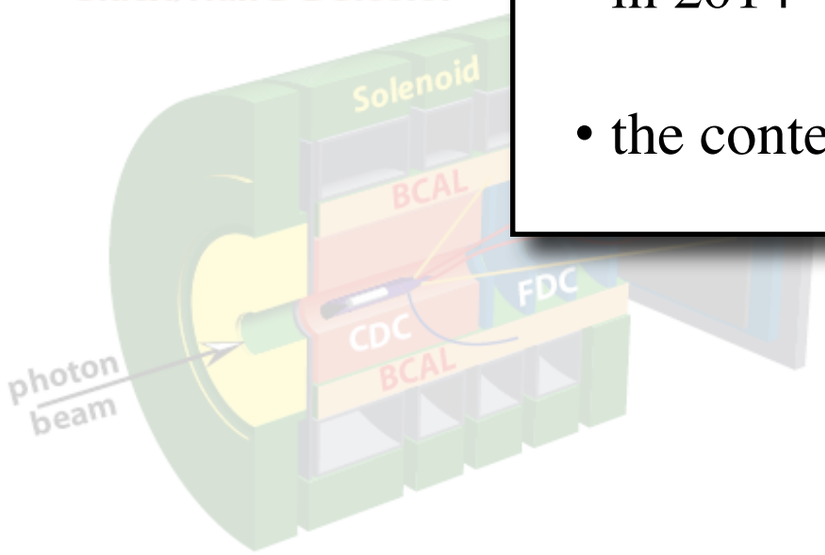


Theoretical Context
(advances in lattice QCD)



summary

- the **GlueX experiment** will use **9 GeV polarized photons** on a **proton target** to search for **hybrid mesons** with exotic J^{PC}
- construction has begun
- expecting first data/commissioning in 2014
- the context of GlueX is opportune!



gical Context
amplitude analysis)