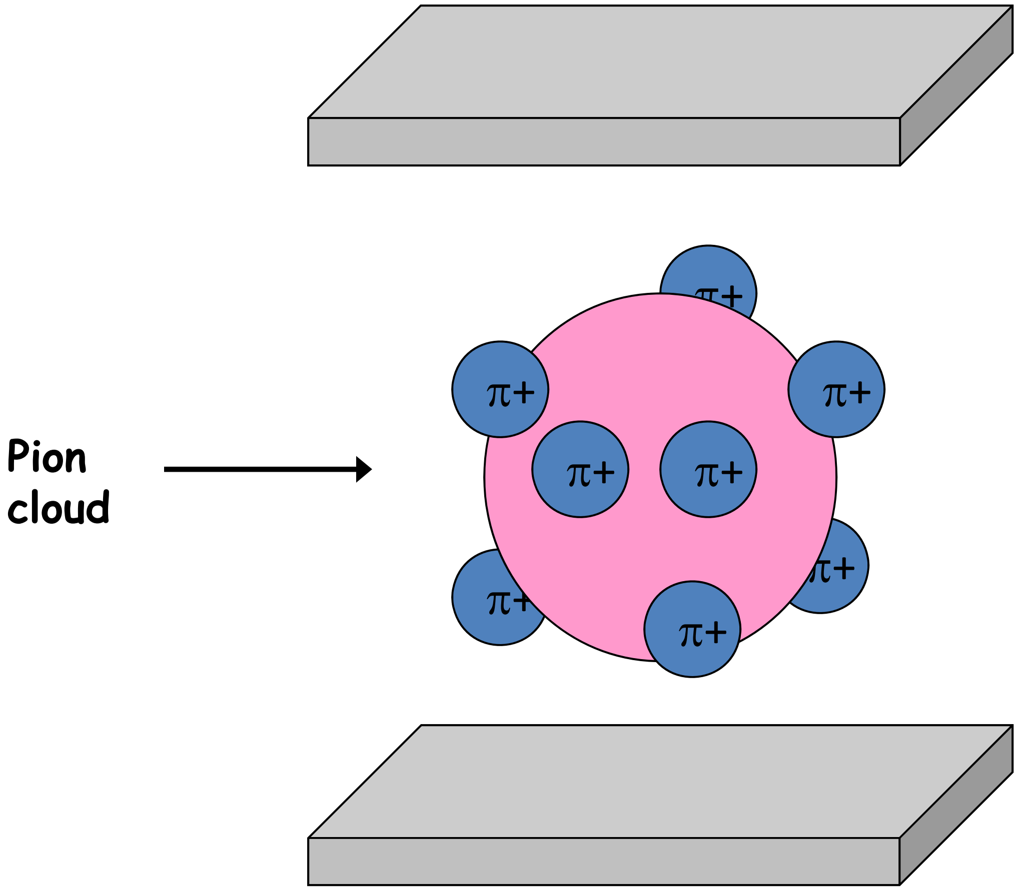
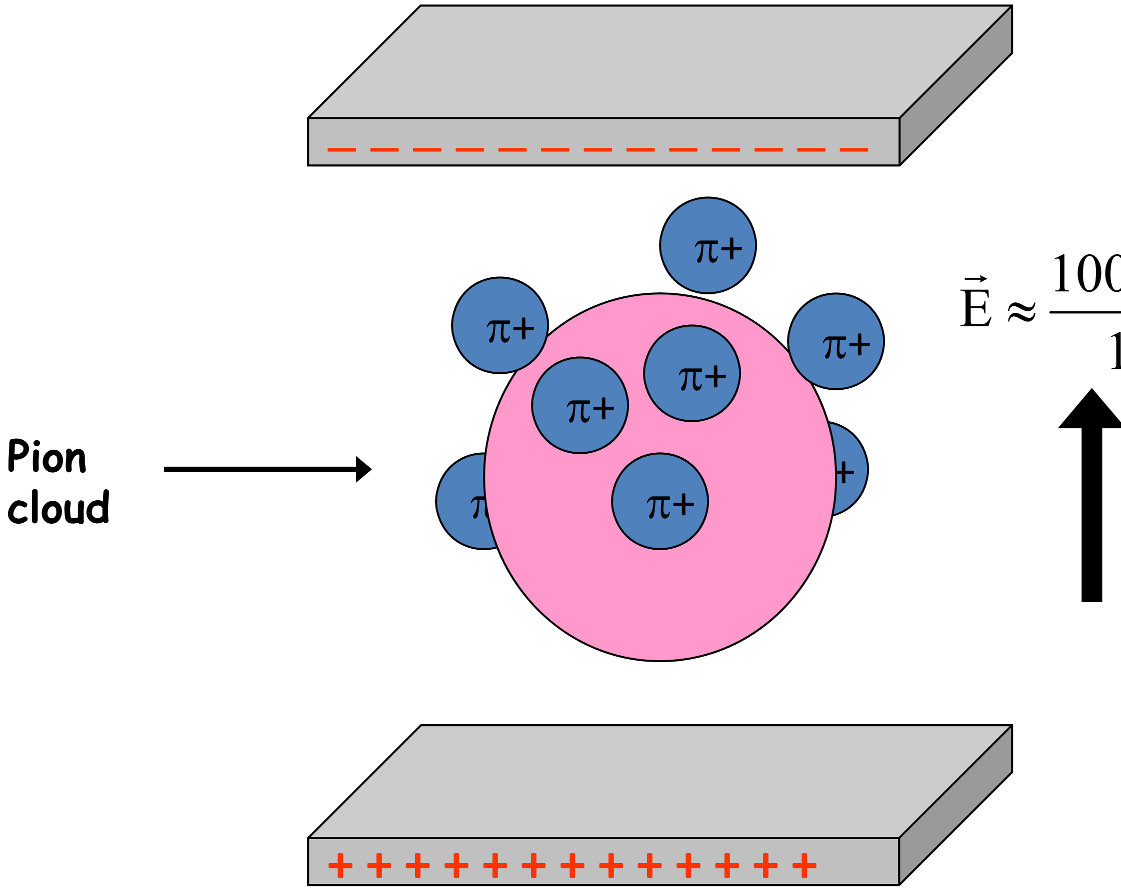
Proton electric polarizability



Electric polarizability: proton between charged parallel plates

Proton electric polarizability



$$\vec{E} \approx \frac{100\text{MeV}}{1\text{fm}} = 10^{23}\,\text{volts/m}$$

Electric polarizability: proton between charged parallel plates

Theory for pion polarizability: QCD expansion in powers of quark field operators

$$L_{QCD}(p^4) = L^{chiral-even}(p^4) + L^{chiral-odd}(p^4)$$

Charged pion polarizability

$$\alpha_\pi = -\beta_\pi = \frac{4\alpha}{m_\pi F_\pi^2}\left(L_9^r - L_{10}^r\right)$$

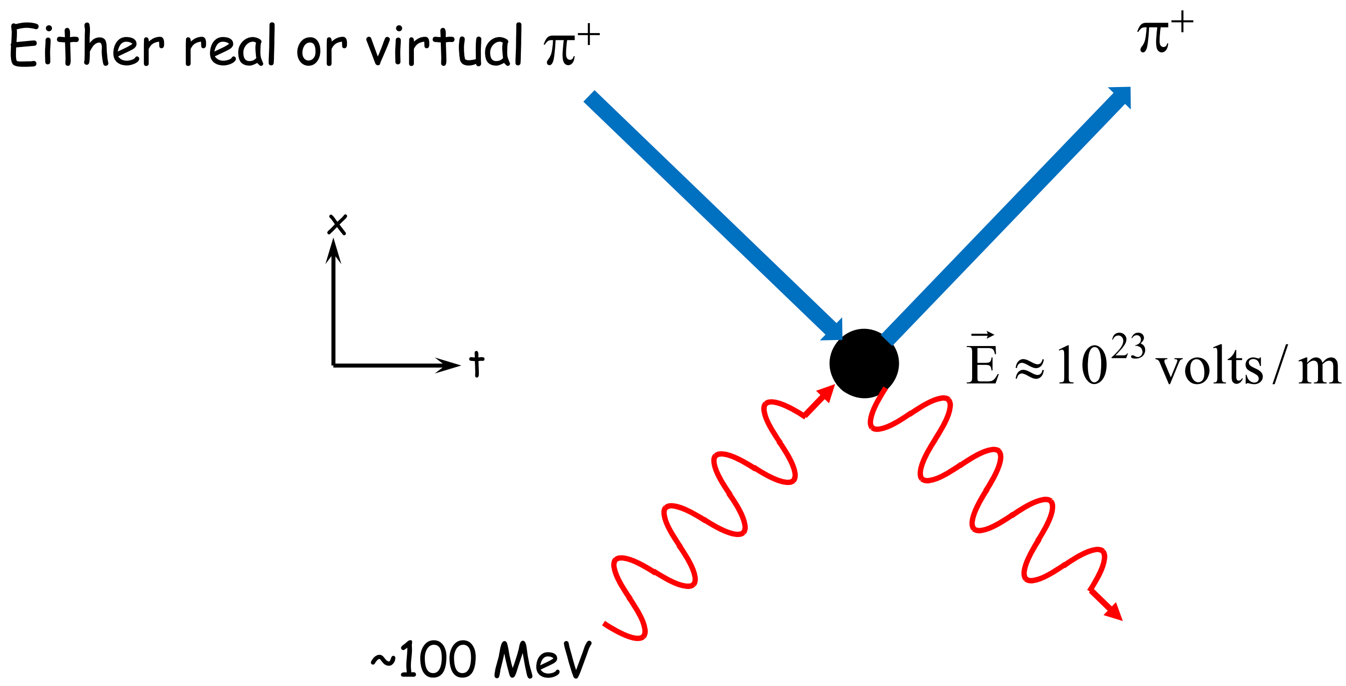
$$\pi^0 \to \gamma\gamma$$

$$A_{\gamma\gamma} = \frac{\alpha N_C}{3\pi F_\pi}$$

Primex result:

$\Gamma(\pi^0 \to \gamma\gamma) = 7.80$ eV $\pm$ 2.8%

Compton Scattering and the E.M. polarizabilities

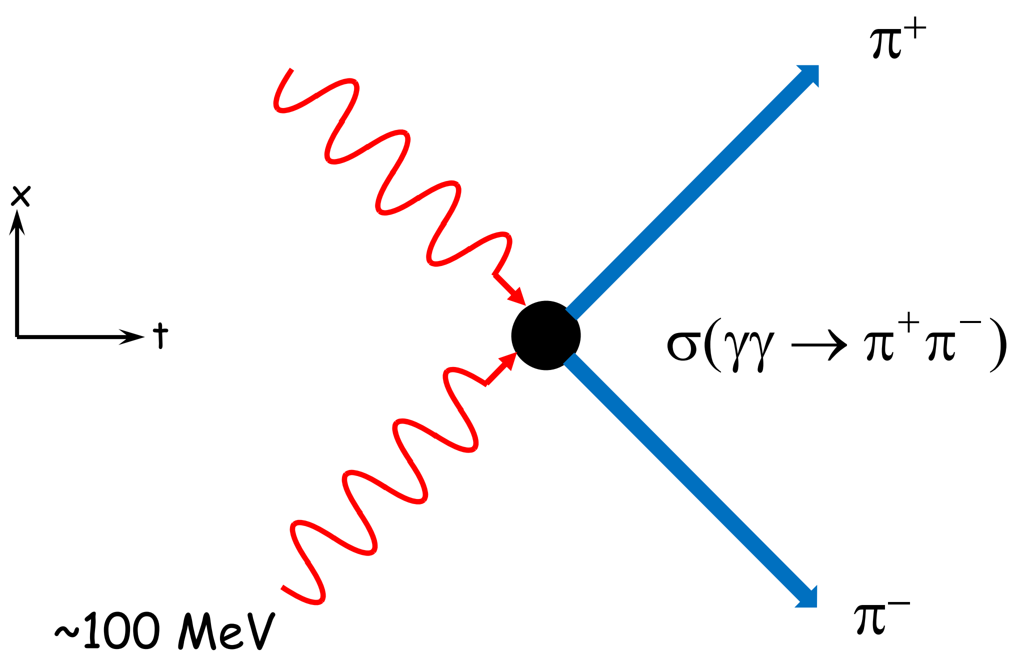


$$H = H_{Born}(e, \vec{\mu}) - 4\pi\left(\frac{1}{2}\alpha_{EM}\vec{E}^2 + \frac{1}{2}\beta_{EM}\vec{H}^2\right)$$

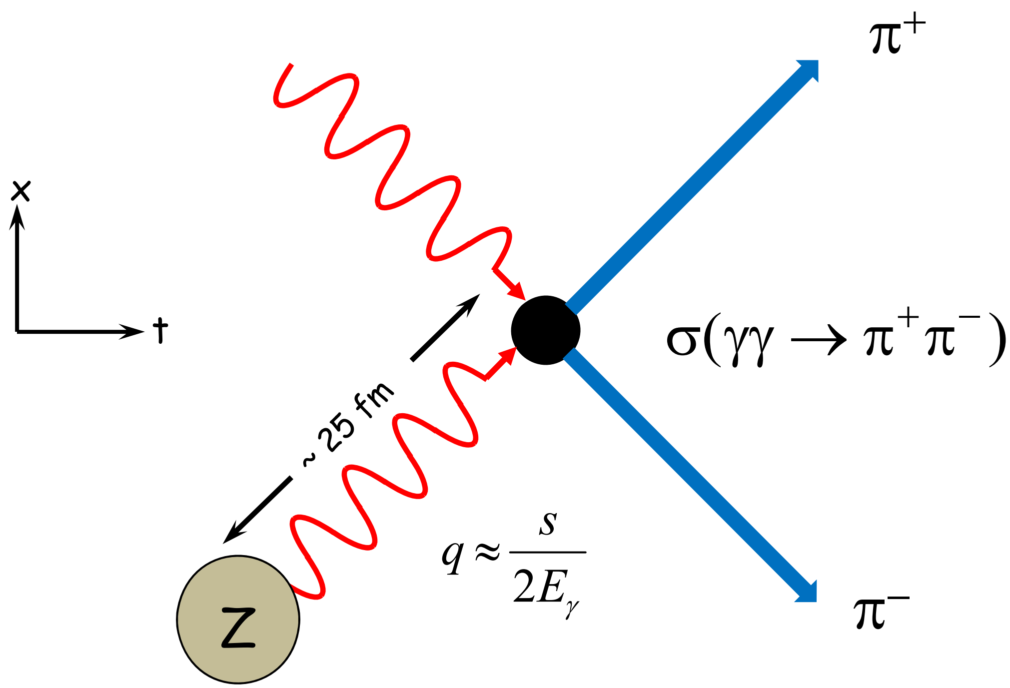
10%

Crossing symmetry ($x \leftrightarrow t$):

Compton scattering ⬌ $\gamma\gamma \to \pi^+\pi^-$

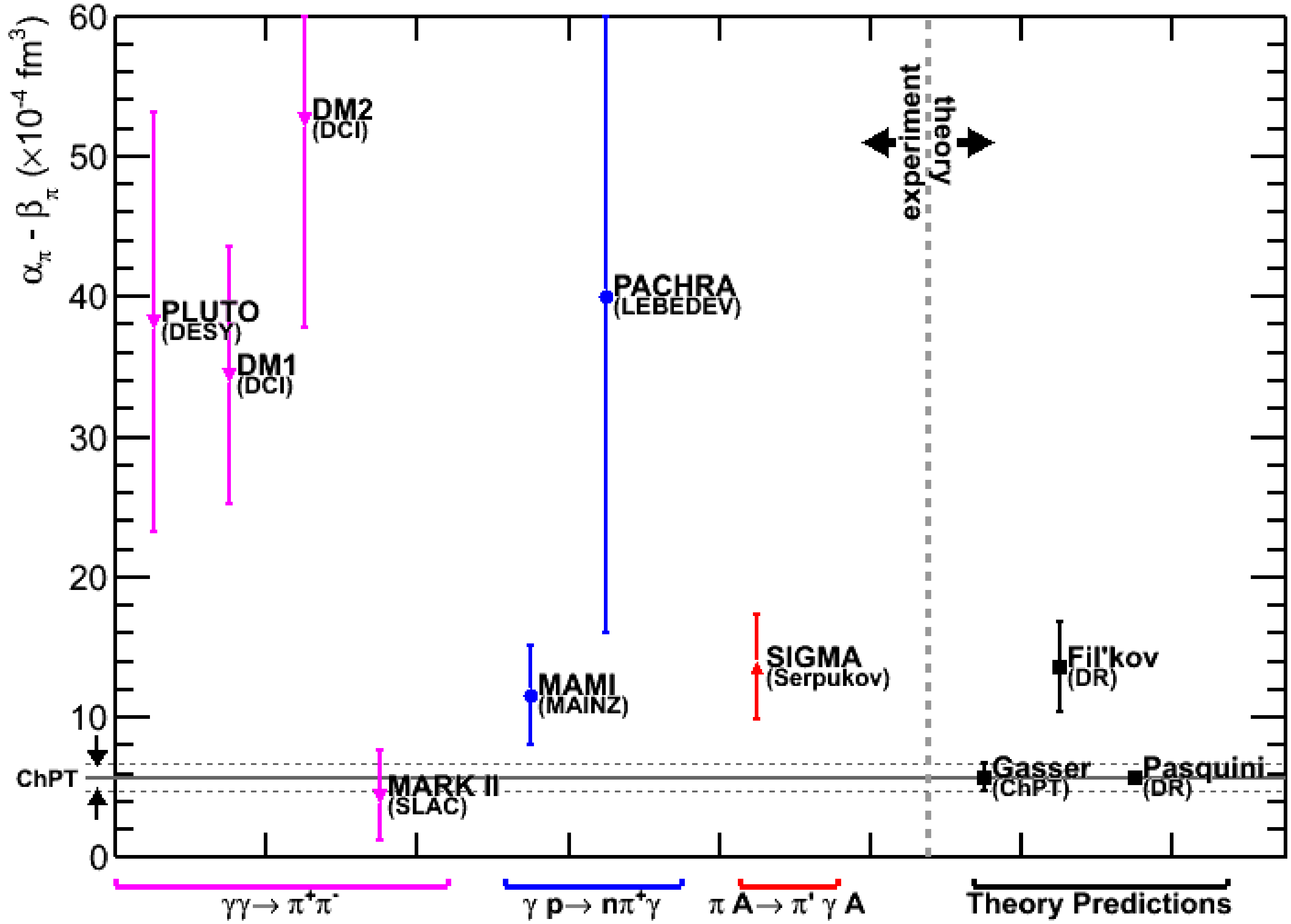


Primakoff process:
very low-t photoproduction $\gamma A \rightarrow \pi^+\pi^- A$

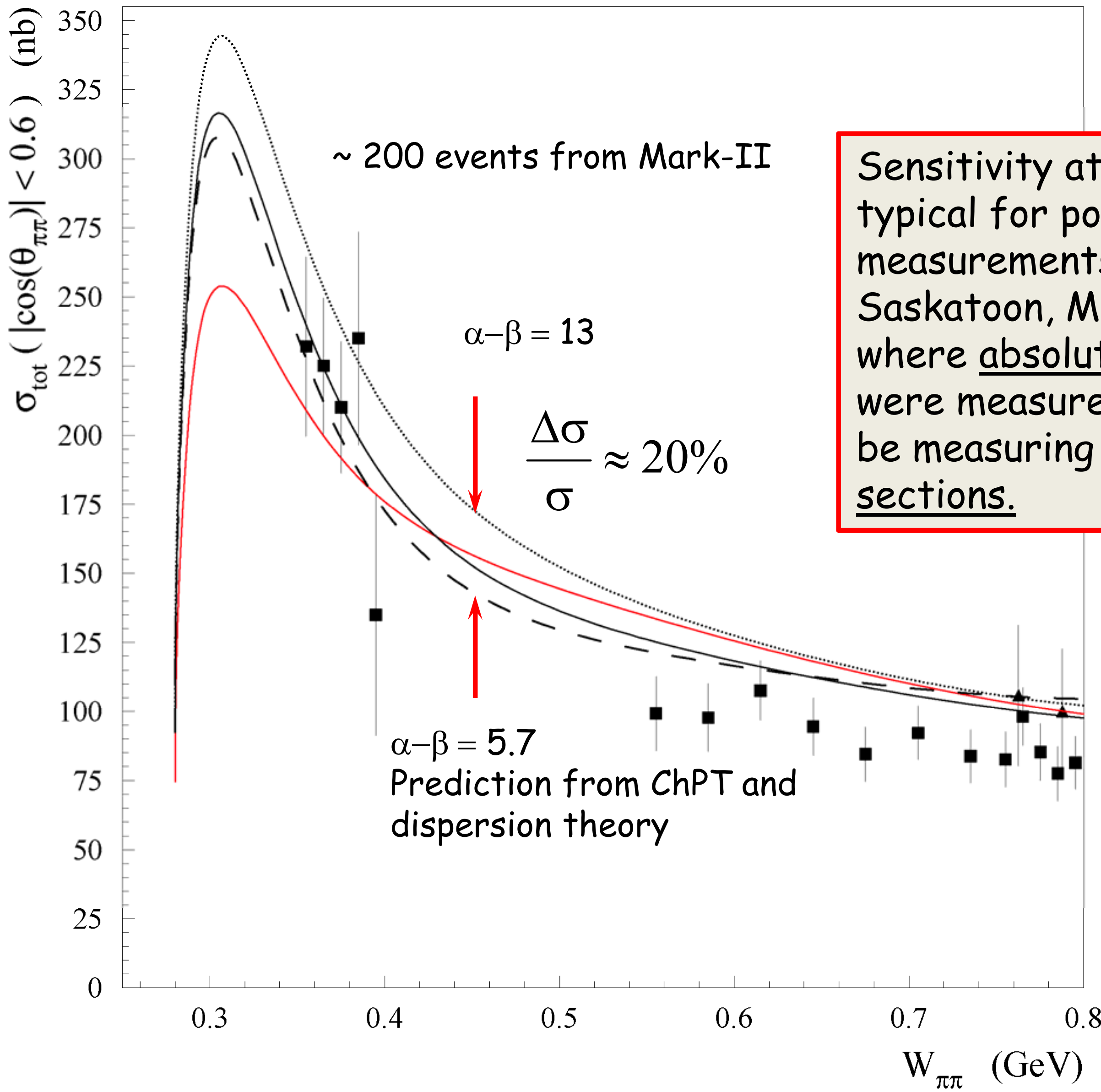


$$\frac{d^2\sigma_{\mathrm{Pr}\,imakoff}}{d\Omega dM} = \frac{2\alpha Z^2}{\pi^2}\frac{E_\gamma^4\beta^2}{M}\frac{\sin^2\theta}{Q^4}\left|F(Q^2)\right|^2\left(1+P_\gamma\cos 2\varphi_{\pi\pi}\right)\sigma(\gamma\gamma\rightarrow\pi\pi)$$

Pion Polarizability Measurements

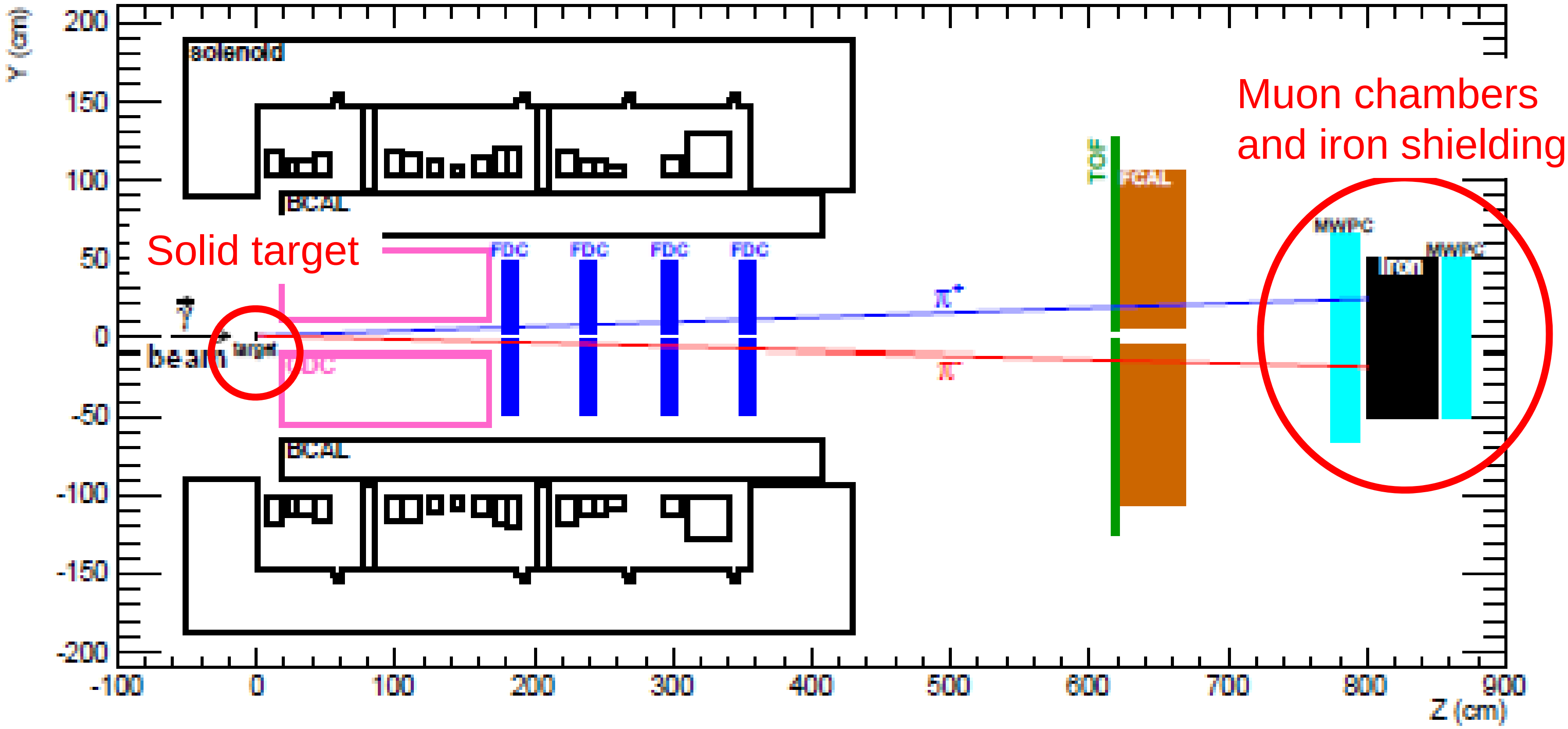


$\gamma\gamma \to \pi^+\pi^-$



Sensitivity at ~20% level is typical for polarizability measurements at Mainz, Saskatoon, MIT-Bates, and Lund, where <u>absolute cross sections</u> were measured. At JLab we will be measuring <u>relative cross sections.</u>

Proposed Detector Setup

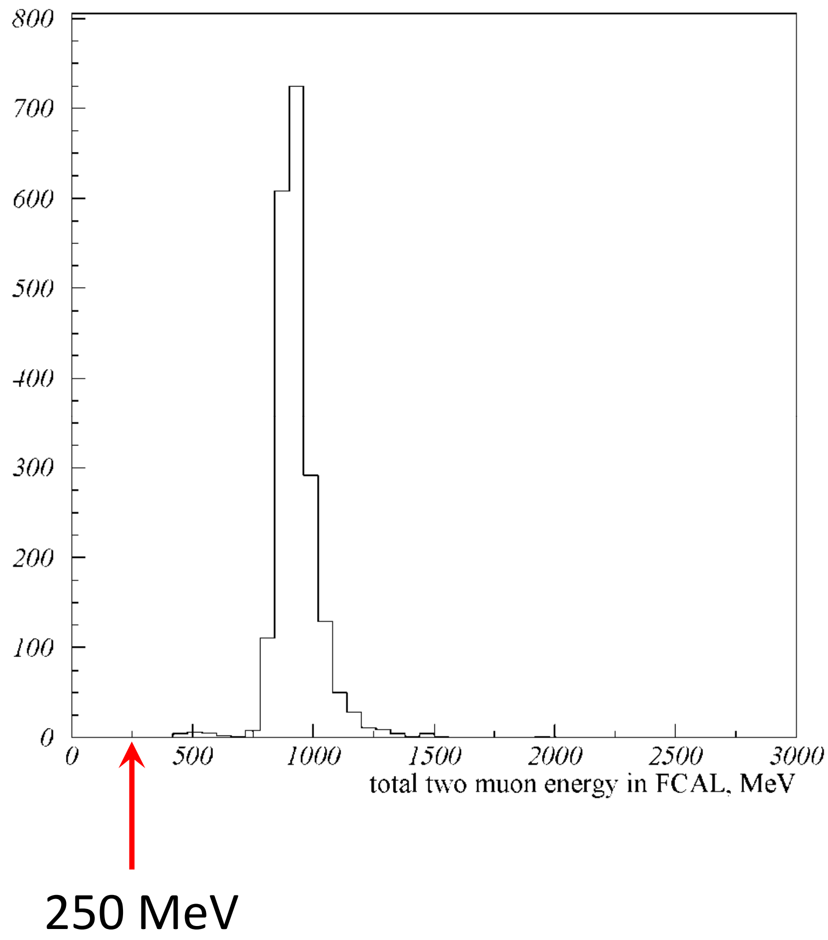


Electron energy	12.0 GeV	Peak polarization	76%
Electron current	50 nA on 20 μm diamond	Coherent/incoherent	0.32
Coherent peak	5.5-6.0 GeV	Target position	1 cm
Collimator	3.5 mm	Target	^{116}Sn, 5% RL

TRIGGER = FCAL, E_{th} = 250 MeV

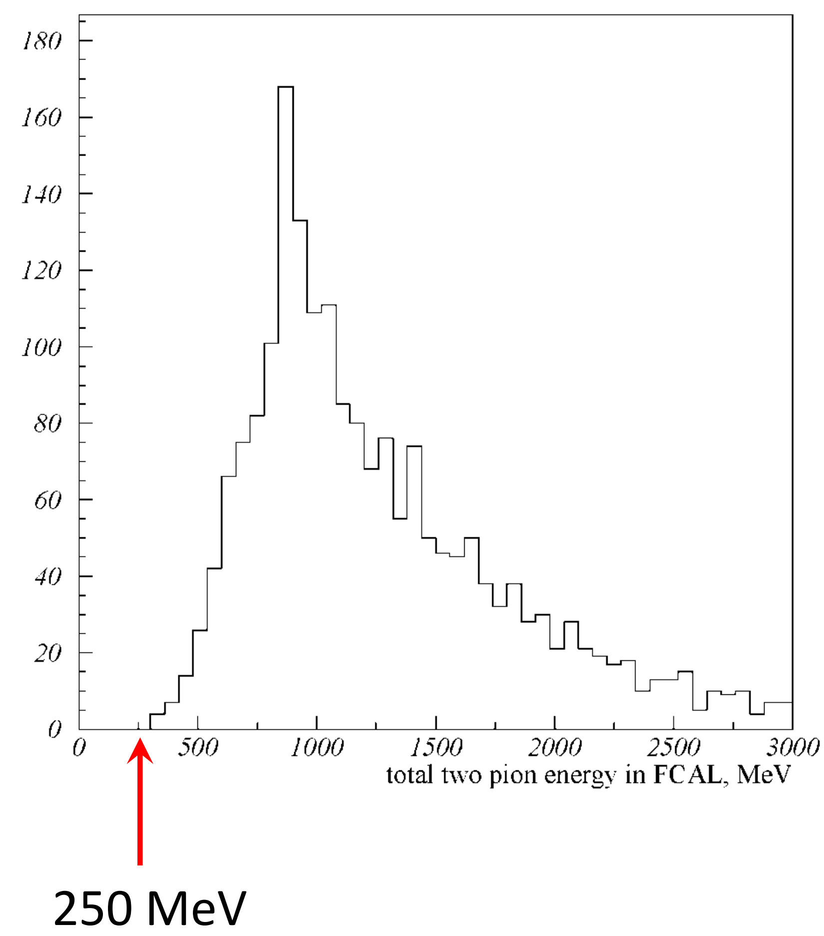
Muon response in FCAL

$E_{\mu 1} + E_{\mu 2}$ = 5.5 GeV



Pion response in FCAL

$E_{\pi 1} + E_{\pi 2}$ = 5.5 GeV



Backgrounds: *PRIMEX can provide guidance on backgrounds.*

1. Incoherent $\gamma A \rightarrow \pi^+\pi^-$ X

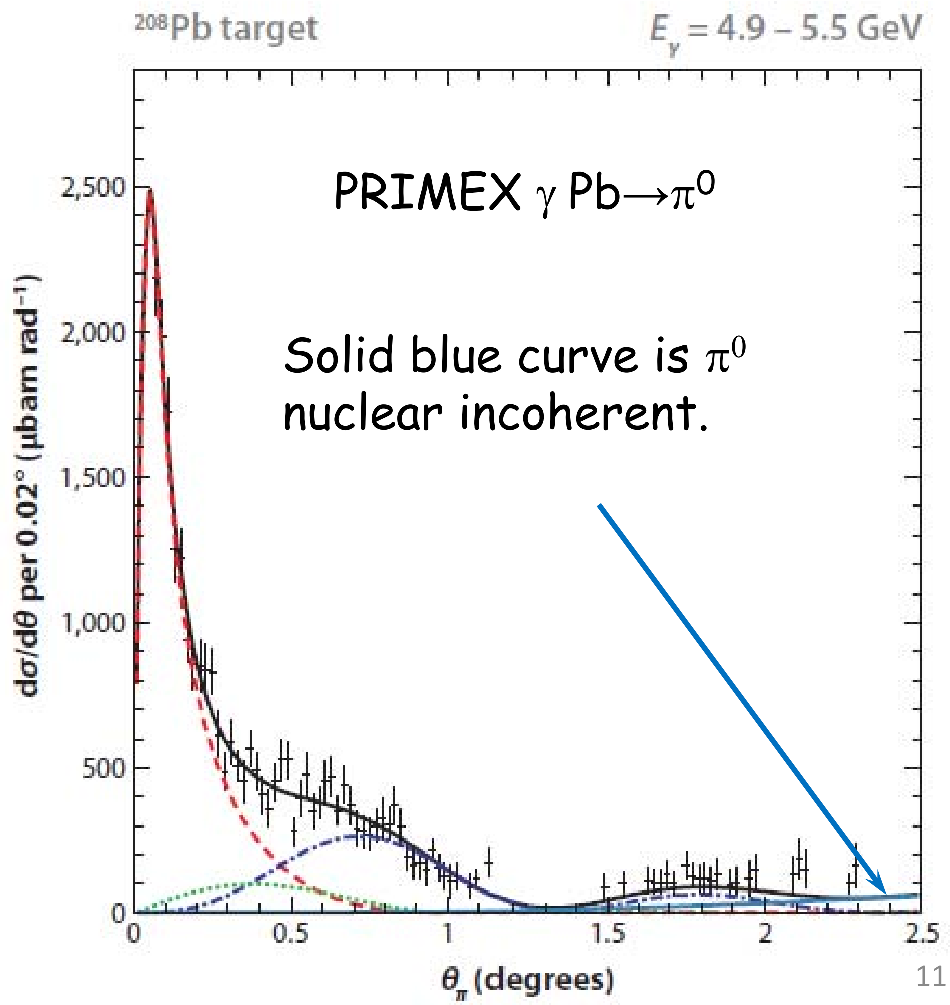
Calculations by T. Rodrigues

2. Coherent $\gamma A \rightarrow f_0(600)$

3. $\gamma A \rightarrow \rho^0$ A

4. $\gamma A \rightarrow e^+e-$ A

5. $\gamma A \rightarrow \mu^+\mu-$ A



Backgrounds: *PRIMEX can provide guidance on backgrounds.*

1. Incoherent $\gamma A \to \pi^+\pi^- X$

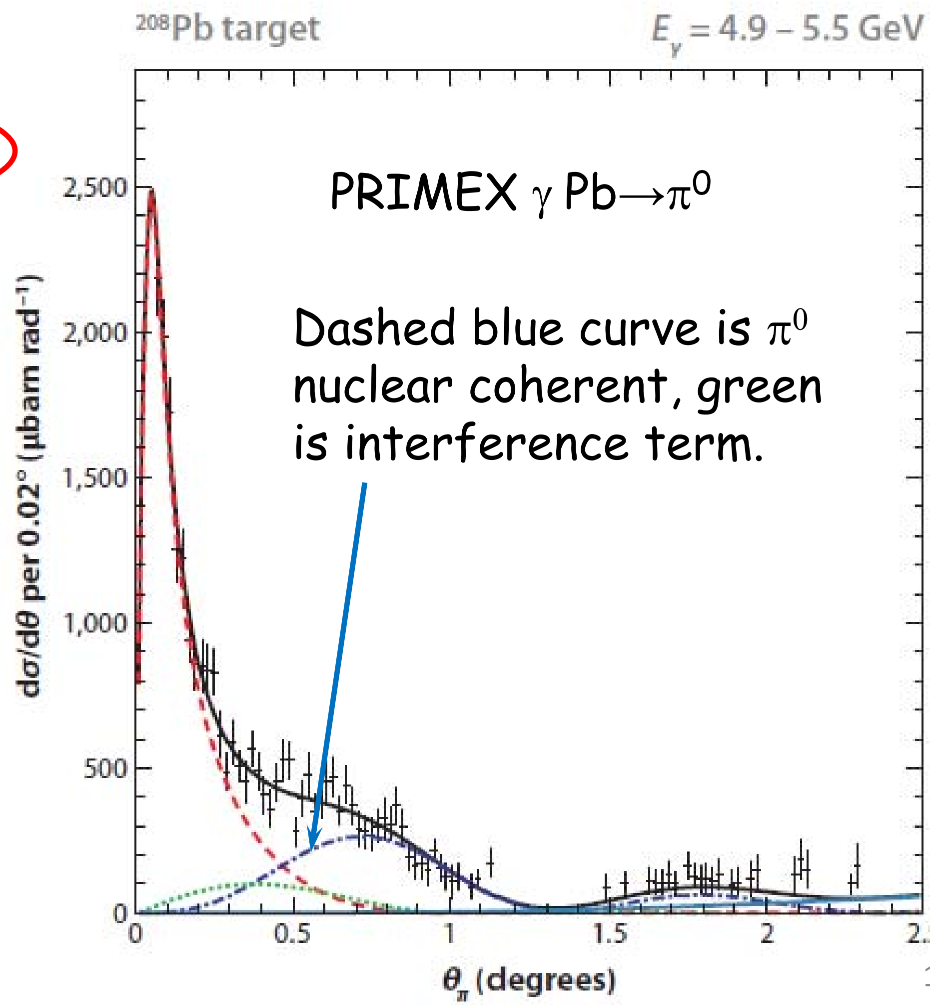
2. Coherent $\gamma A \to f_0(600)$

Calculations by S. Gevorkyan ,
$\gamma p \to \pi^0\pi^0$ from RadPhi as a constraint

3. $\gamma A \to \rho^0 A$

4. $\gamma A \to e^+e^- A$

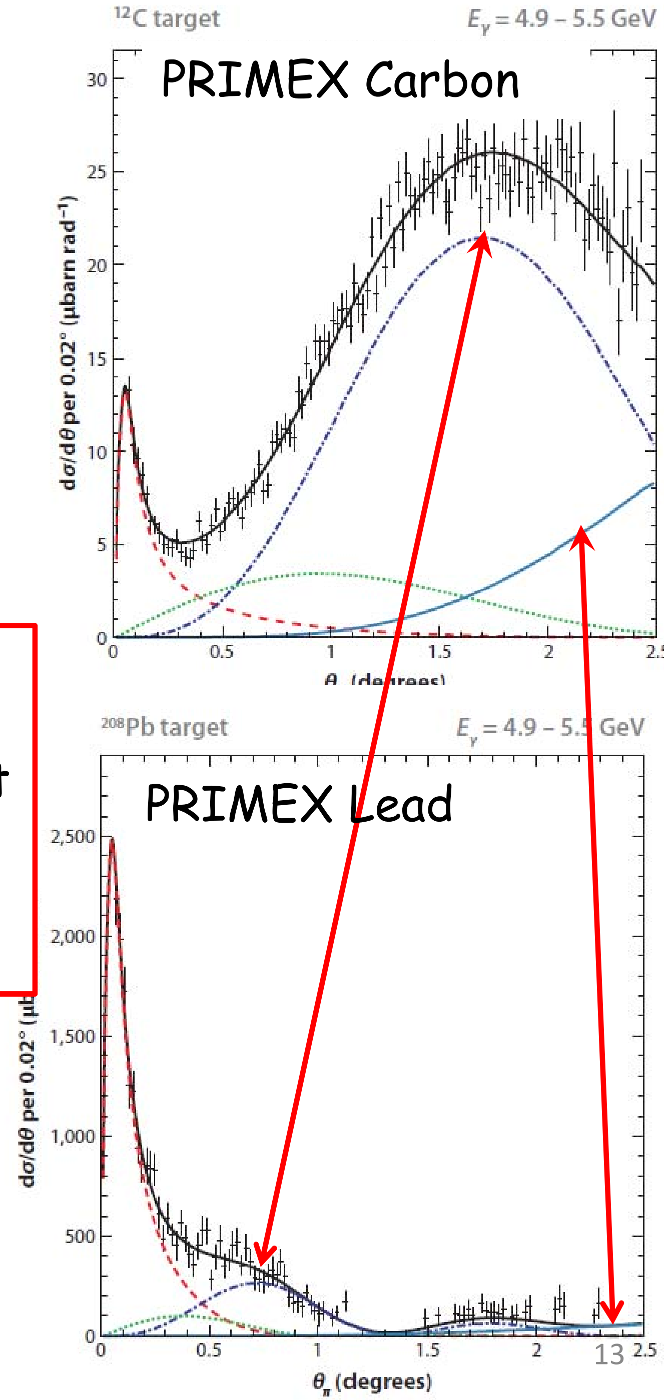
5. $\gamma A \to \mu^+\mu^- A$



Backgrounds

1. Incoherent $\gamma A \rightarrow \pi^+\pi^- X$
2. Coherent $\gamma A \rightarrow f_0(600)$
3. $\gamma A \rightarrow \rho^0 A$
4. $\gamma A \rightarrow e^+e^- A$
5. $\gamma A \rightarrow \mu^+\mu^- A$

The nucleus acts as a filter for incoherent and coherent backgrounds. The nuclear effect will be even more pronounced for a $\pi\pi$ final state



Backgrounds

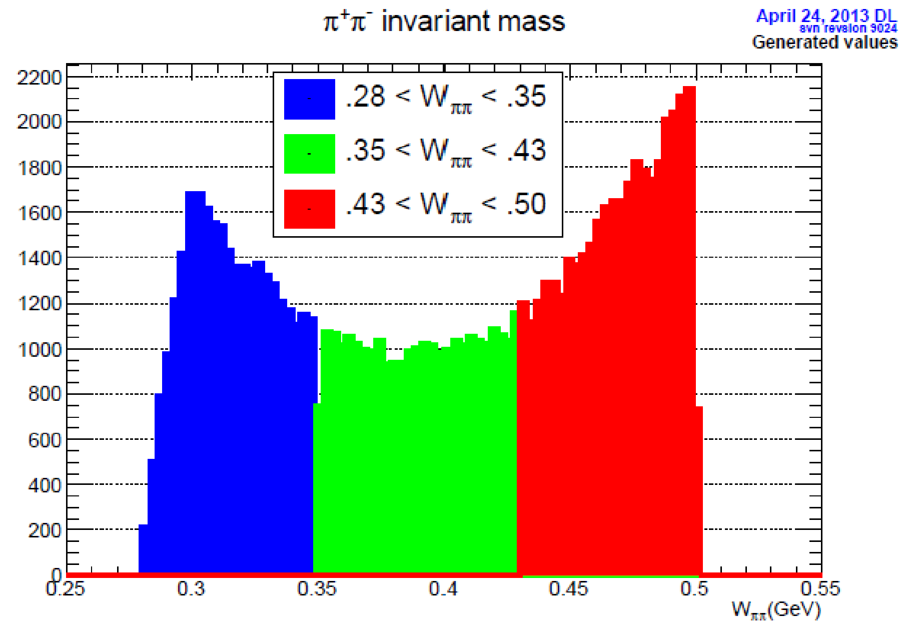
1. Incoherent $\gamma A \rightarrow \pi^+\pi^- X$

2. Coherent $\gamma A \rightarrow f_0(600)$

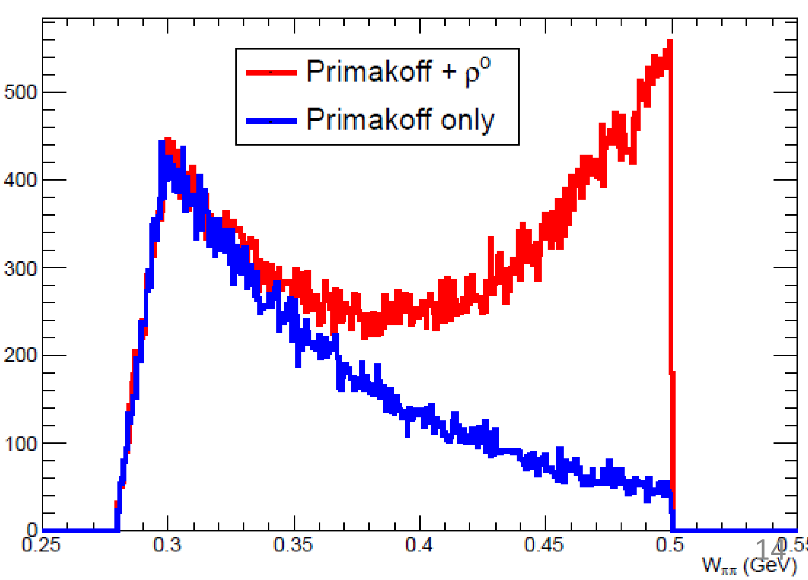
3. $\gamma A \rightarrow \rho^0 A$

4. $\gamma A \rightarrow e^+e^- A$

5. $\gamma A \rightarrow \mu^+\mu^- A$



W distribtution of $\pi\pi$ events



Backgrounds

1. Incoherent $\gamma A \to \pi^+\pi^- X$

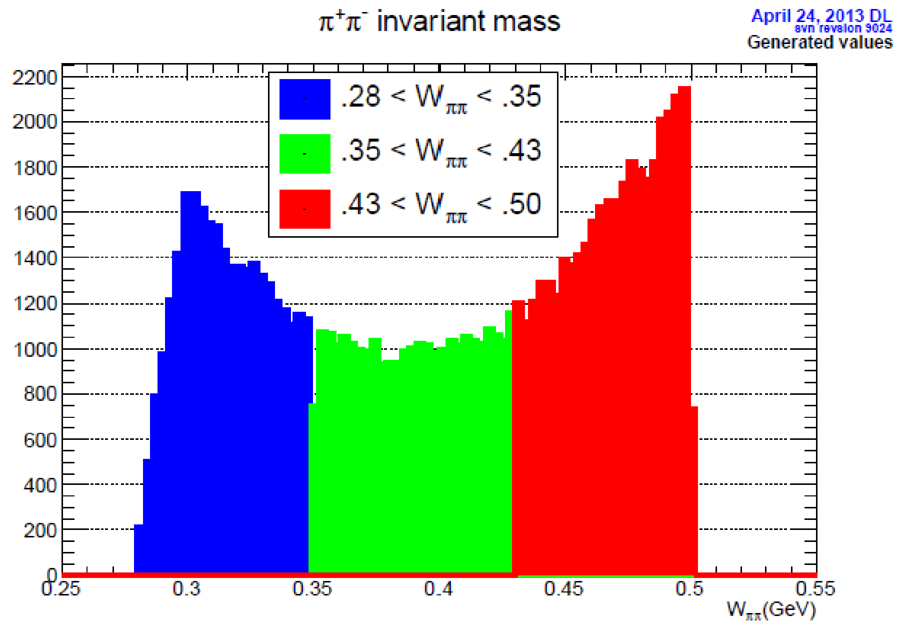
2. Coherent $\gamma A \to f_0(600)$

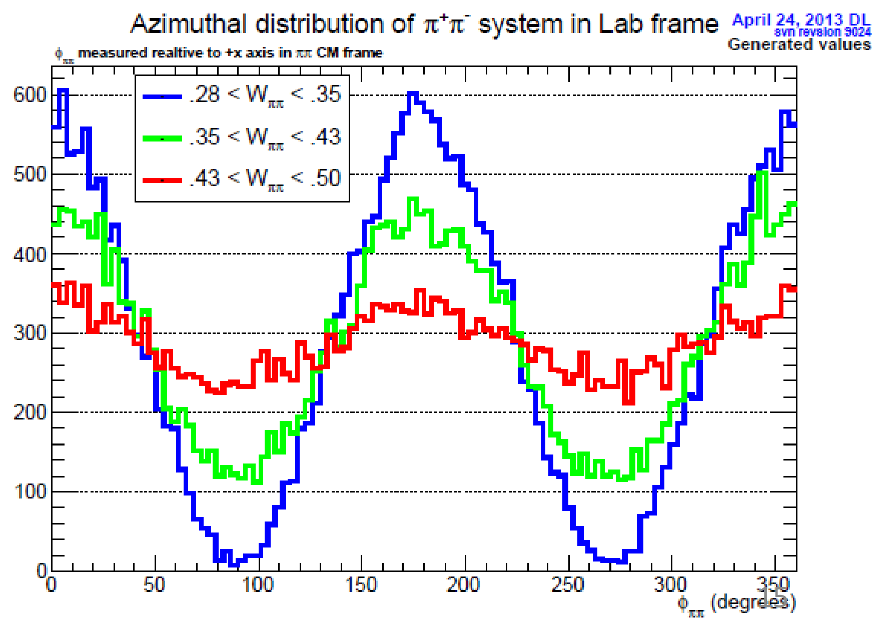
3. $\gamma A \to \rho^0 A$

4. $\gamma A \to e^+e^- A$

5. $\gamma A \to \mu^+\mu^- A$

Lab azimuthal distribution of $\pi\pi$ system $(1+P_\gamma \cos 2\phi)$





Backgrounds

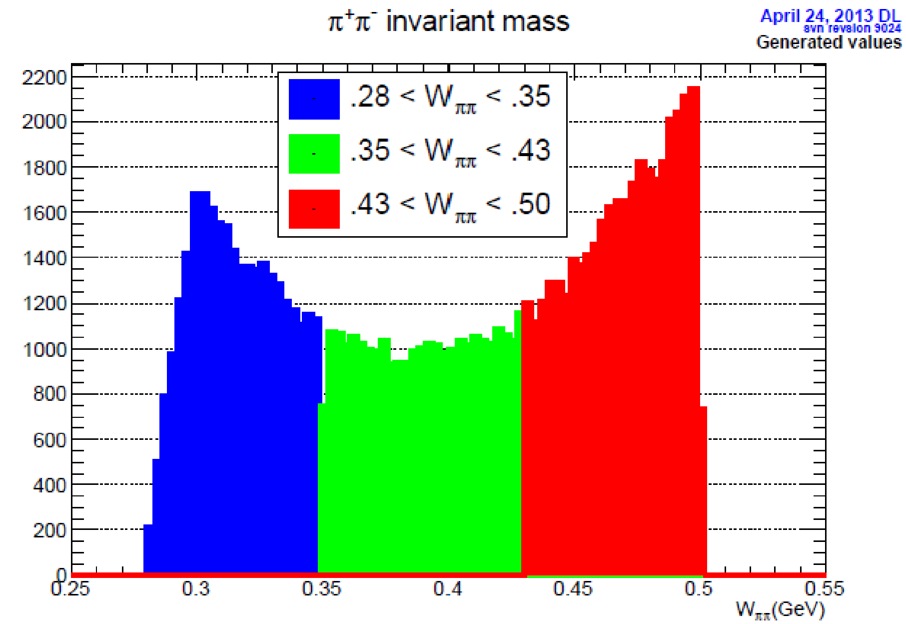
1. Incoherent $\gamma A \rightarrow \pi^+\pi^- X$

2. Coherent $\gamma A \rightarrow f_0(600)$

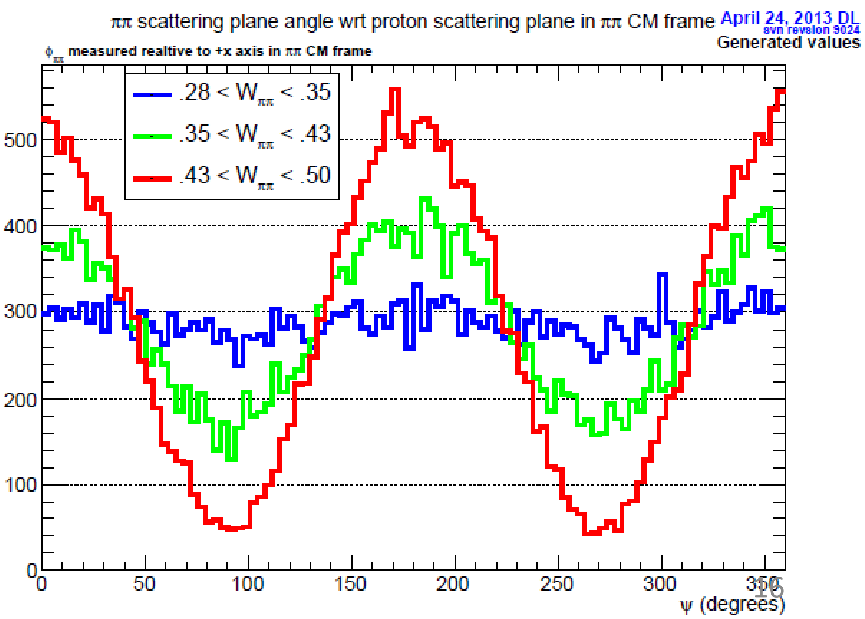
3. $\gamma A \rightarrow \rho^0 A$

4. $\gamma A \rightarrow e^+e- A$

5. $\gamma A \rightarrow \mu^+\mu- A$



Azimuthal distribution of π^+ in helicity frame $(1+P_\gamma \cos2\psi)$



Backgrounds

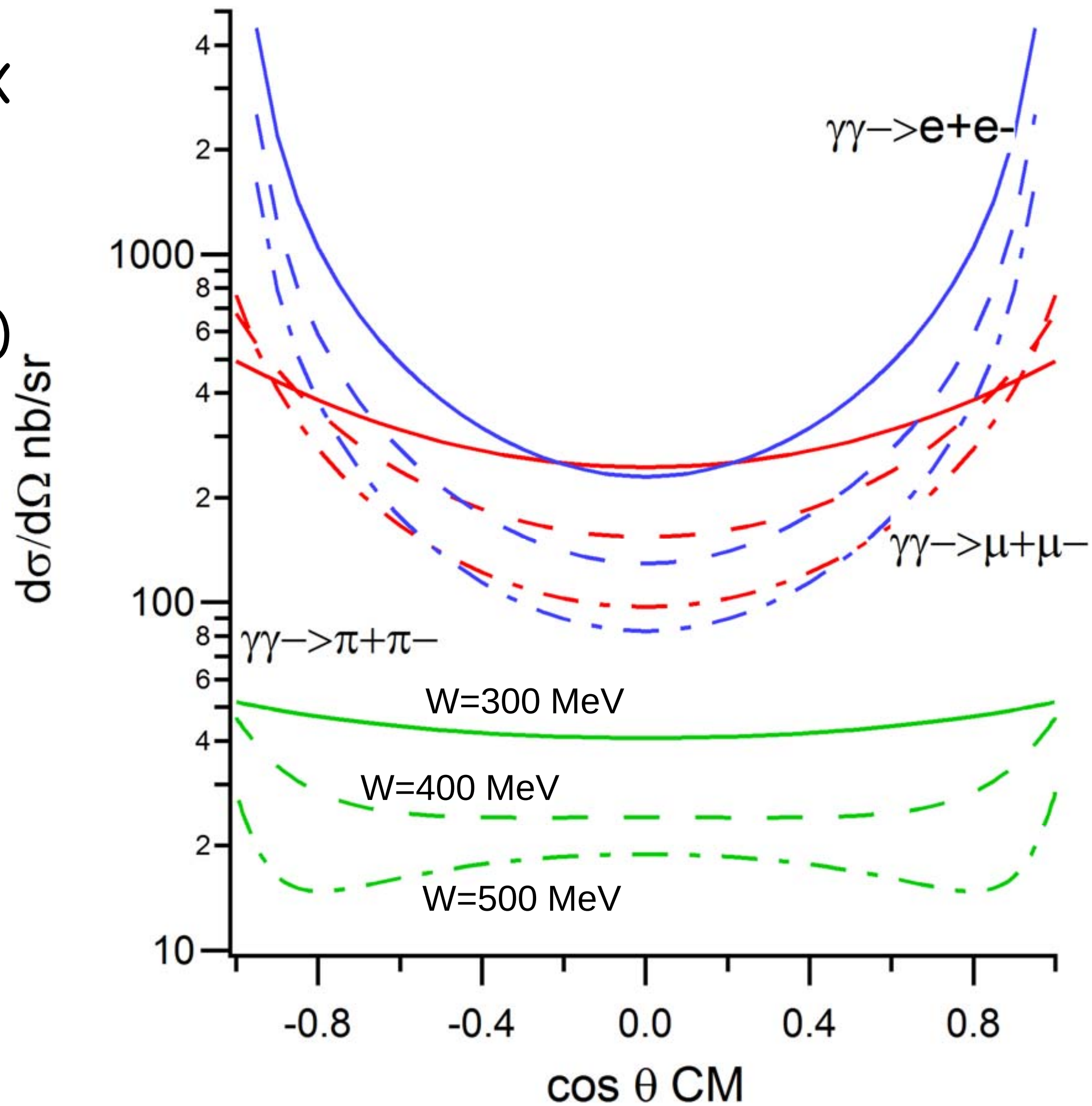
1. Incoherent $\gamma A \rightarrow \pi^+\pi^- X$

2. Coherent $\gamma A \rightarrow f_0(600)$

3. $\gamma A \rightarrow \rho^0 A$

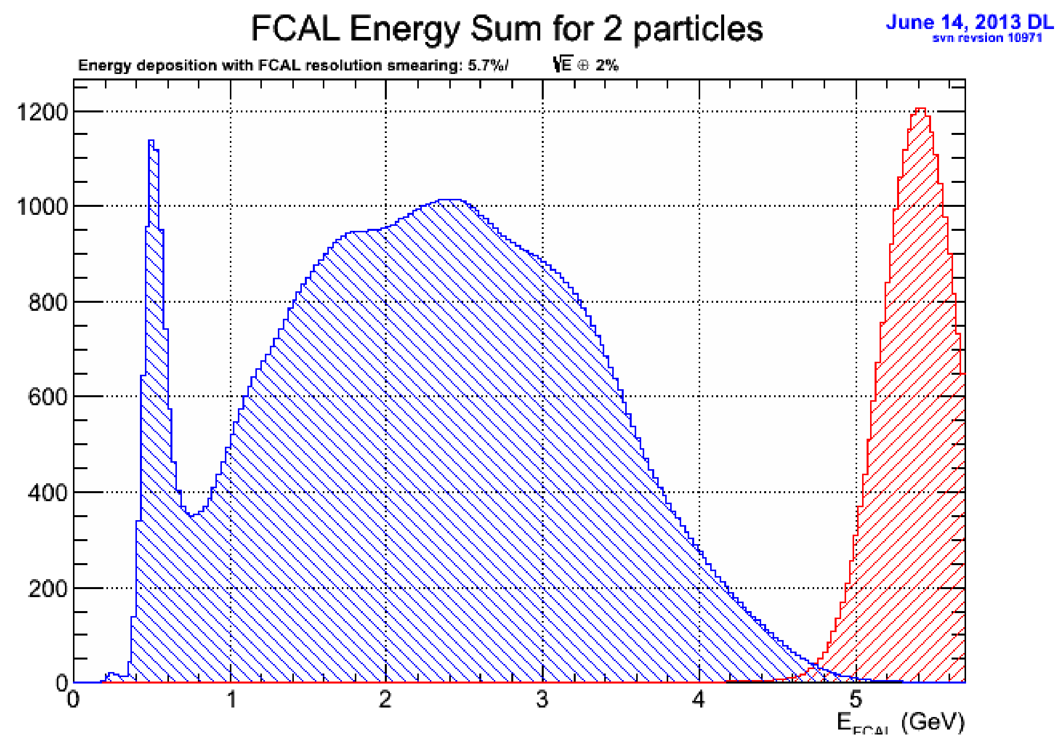
4. $\gamma A \rightarrow e^+e^- A$

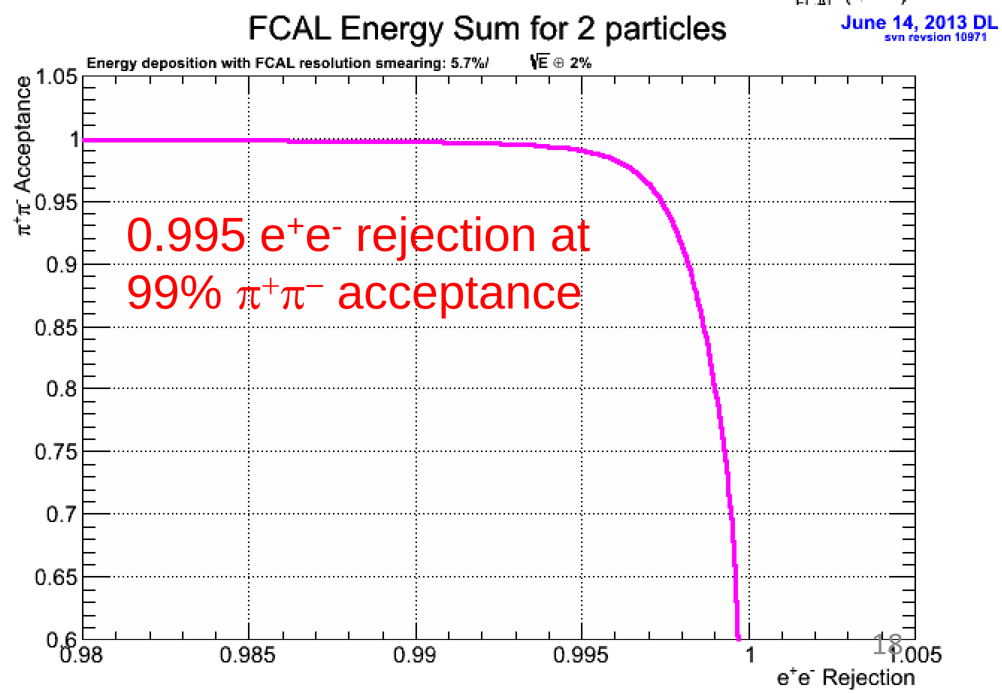
5. $\gamma A \rightarrow \mu^+\mu^- A$



Backgrounds

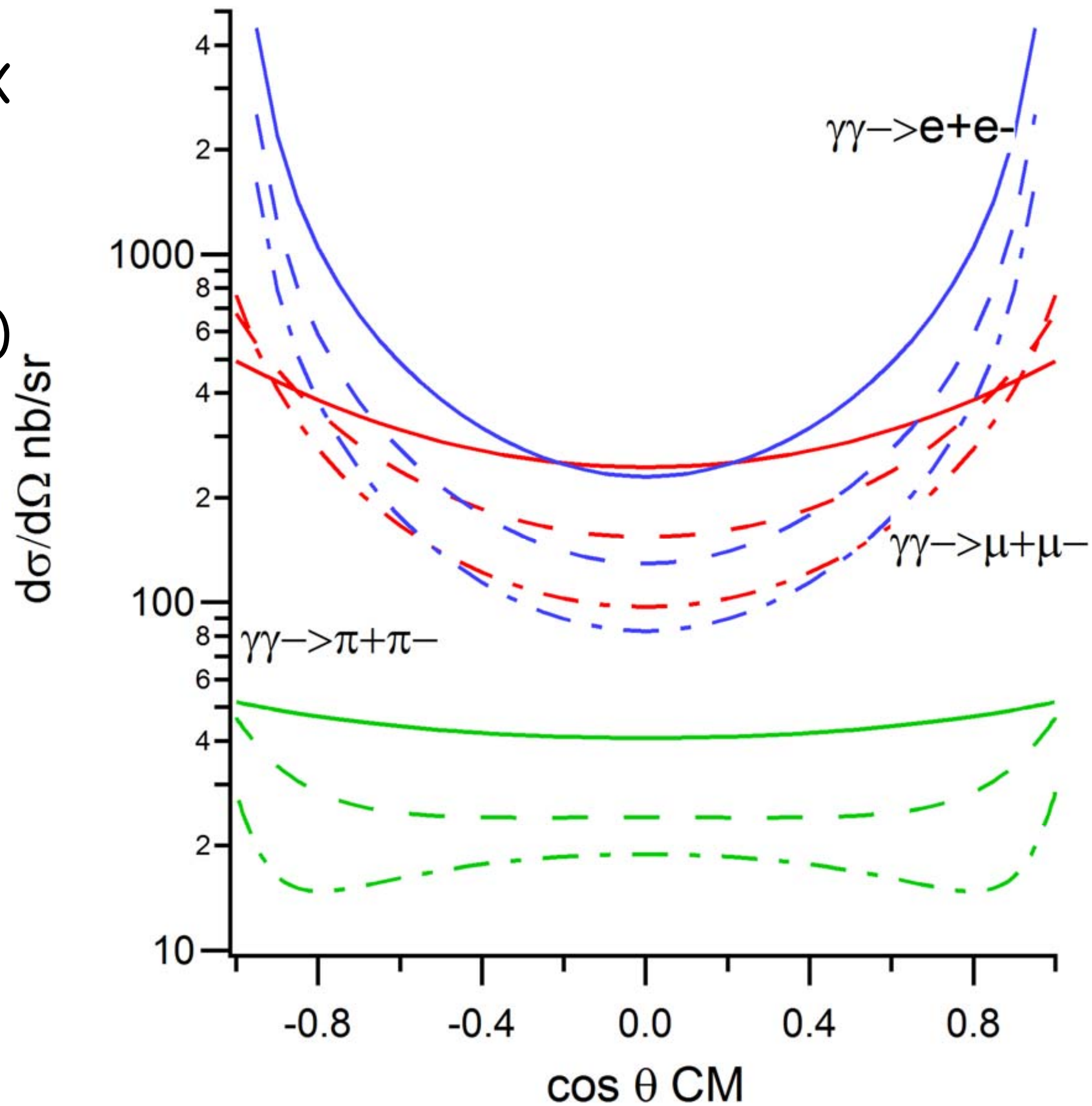
1. Incoherent $\gamma A \to \pi^+\pi^- X$
2. Coherent $\gamma A \to f_0(600)$
3. $\gamma A \to \rho^0 A$
4. $\gamma A \to e^+e^- A$
5. $\gamma A \to \mu^+\mu^- A$





Physics Backgrounds

1. Incoherent $\gamma A \rightarrow \pi^+\pi^- X$
2. Coherent $\gamma A \rightarrow f_0(600)$
3. $\gamma A \rightarrow \rho^0 A$
4. $\gamma A \rightarrow e^+e^- A$
5. $\gamma A \rightarrow \mu^+\mu^- A$



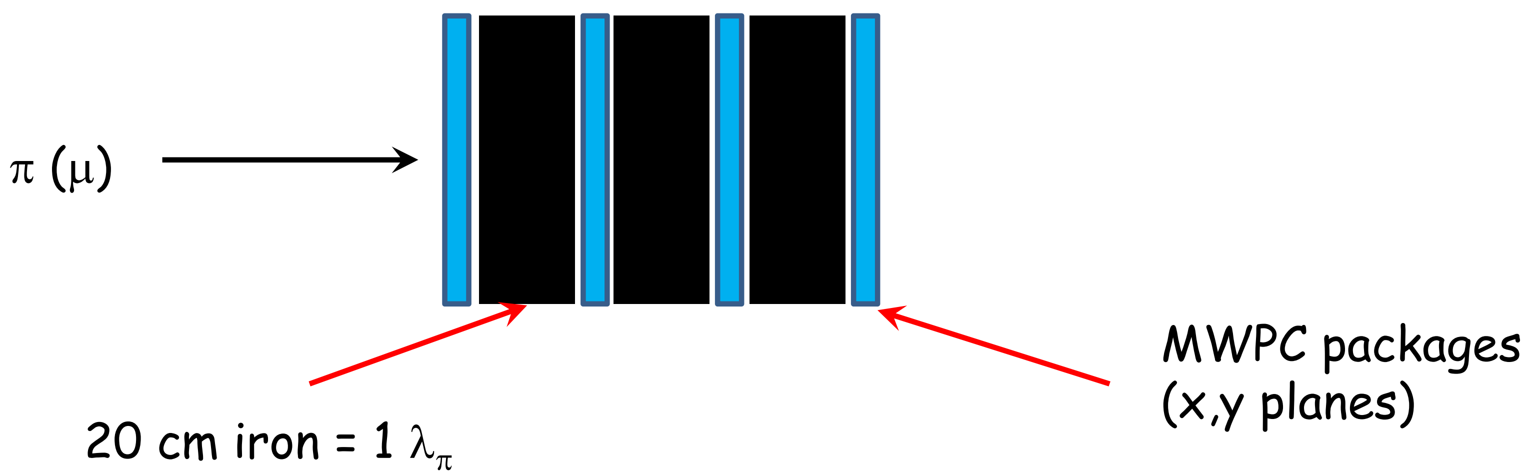
Muon detector design

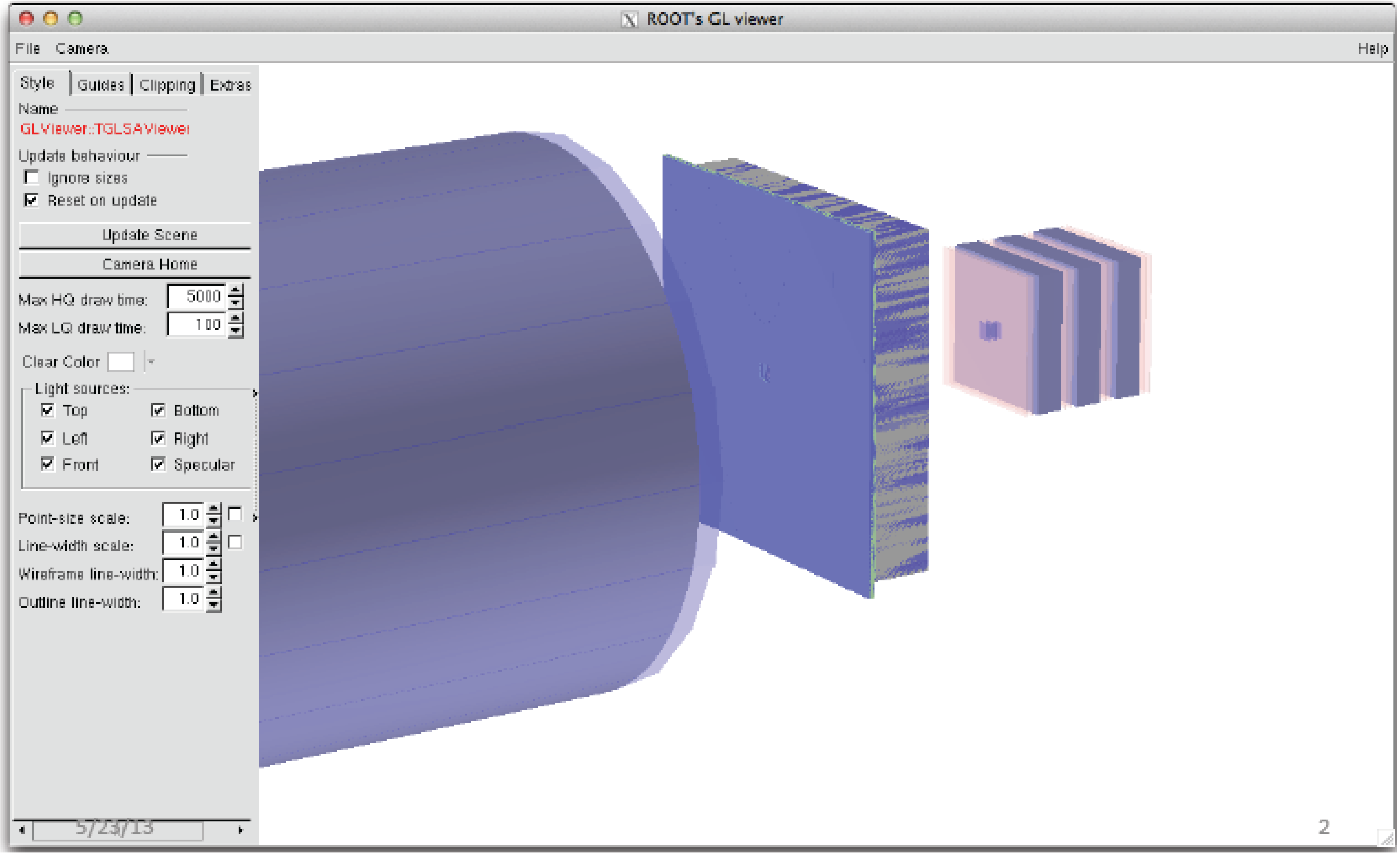
Concept:

Iron absorbers to initiate pion showers, followed by MWPC's to detect muons and shower products

Design work is in progress:

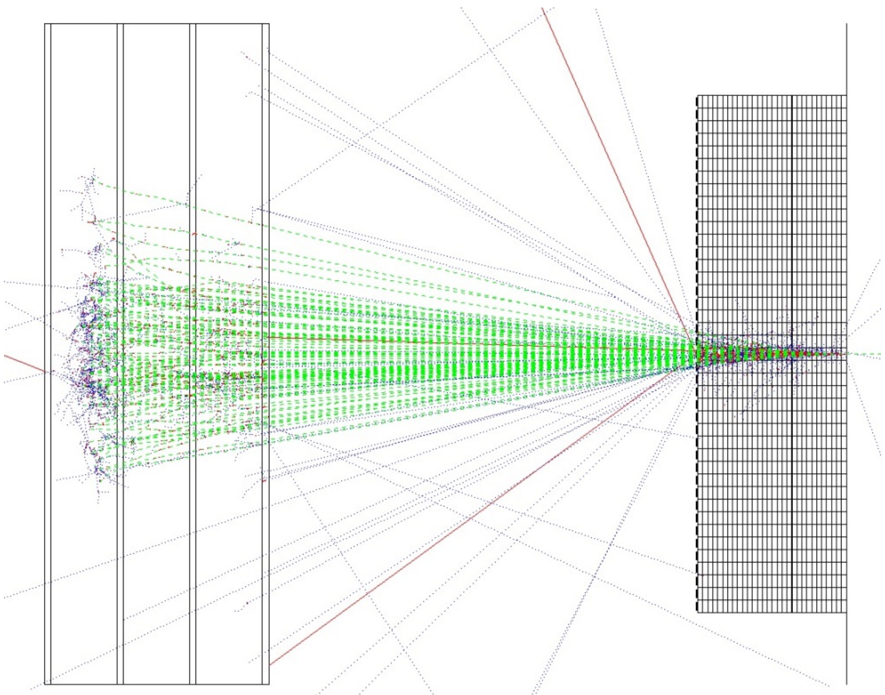
Developing Geant3 and Geant4 simulations of this geometery



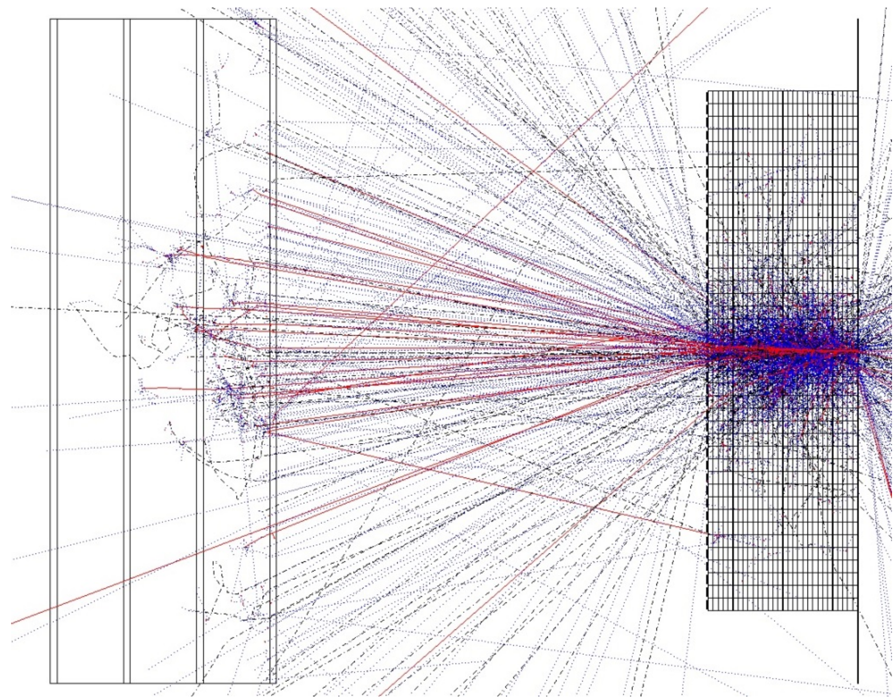

ROOT's GL viewer
File
Camera
Help
Style
Guides
Clipping
Extras
Name
GLViewer::TGLSAViewer
Update behaviour
Ignore sizes
Reset on update
Update Scene
Camera Home
Max HQ draw time:
5000
Max LQ draw time:
100
Clear Color
Light sources:
Top
Bottom
Left
Right
Front
Specular
Point-size scale:
1.0
Line-width scale:
1.0
Wireframe line-width:
1.0
Outline line-width:
1.0
5/23/13
2

Geant3 Simulations

1 GeV muon



1 GeV pion

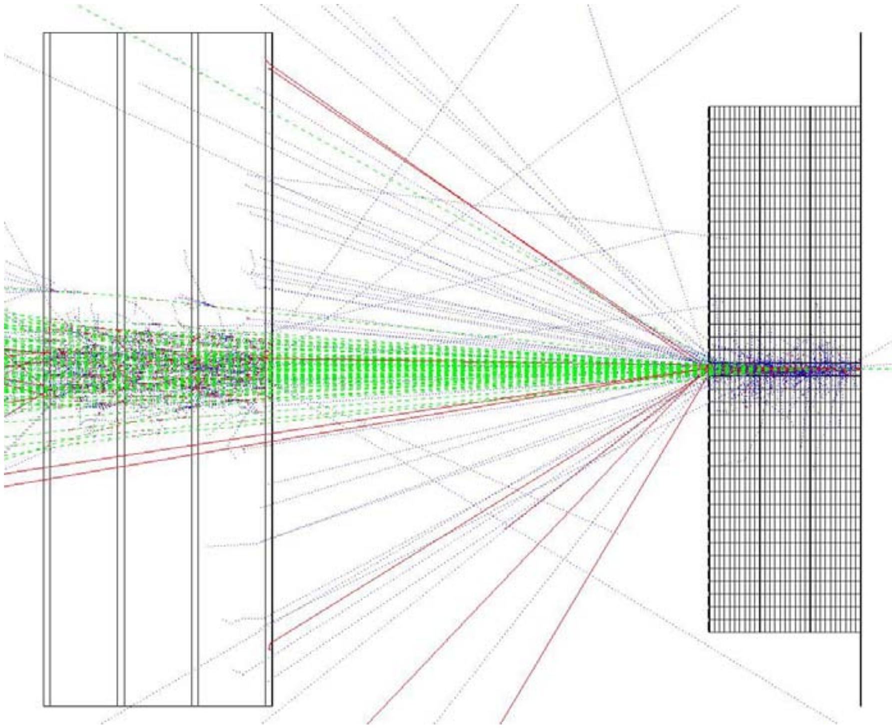


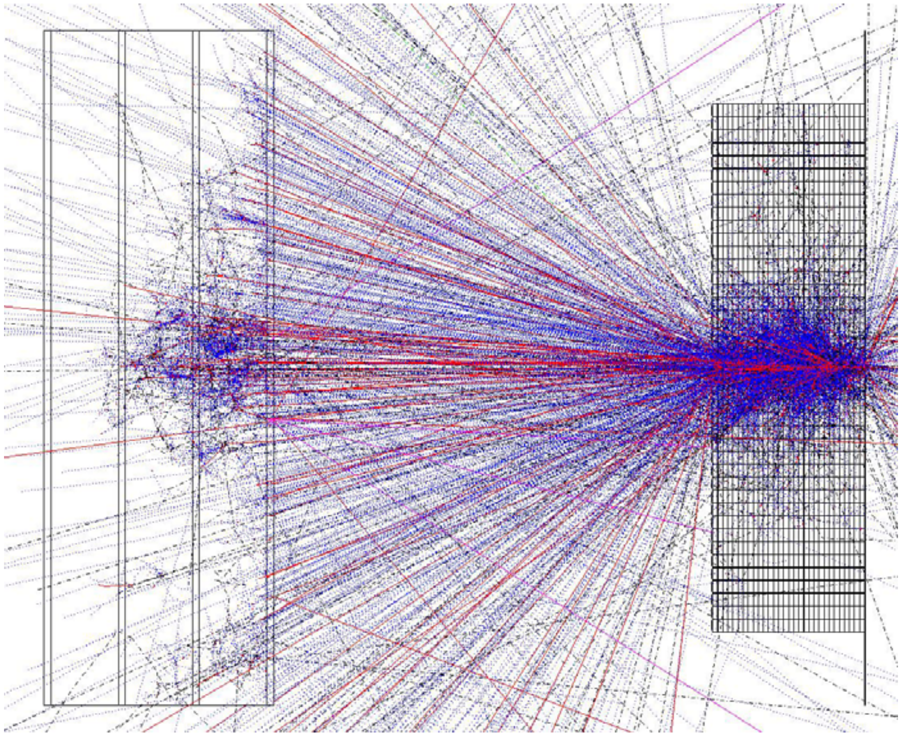
Muon detectors FCAL

Geant3 Simulations

2 GeV muon

2 GeV pion

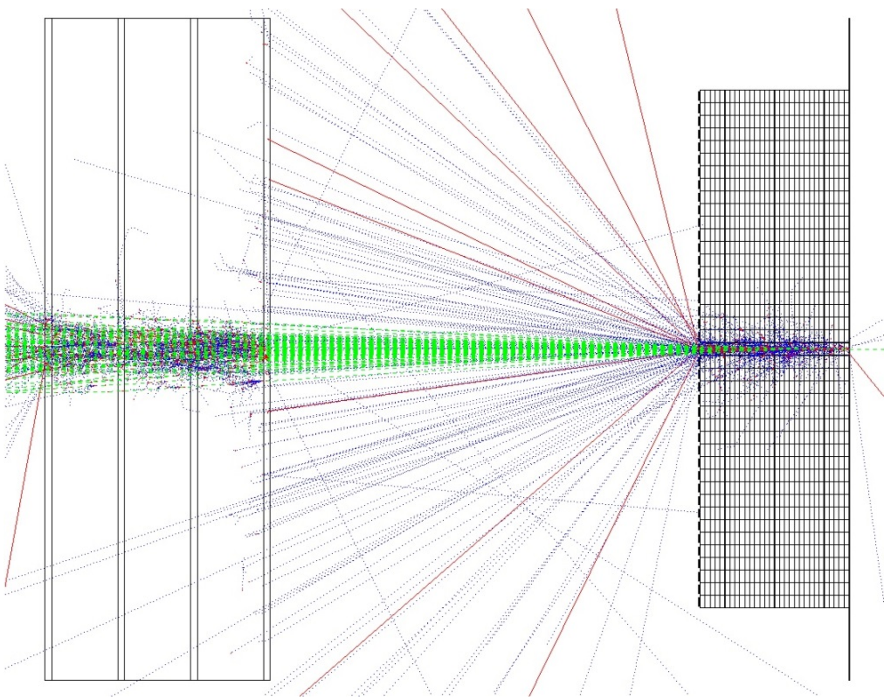




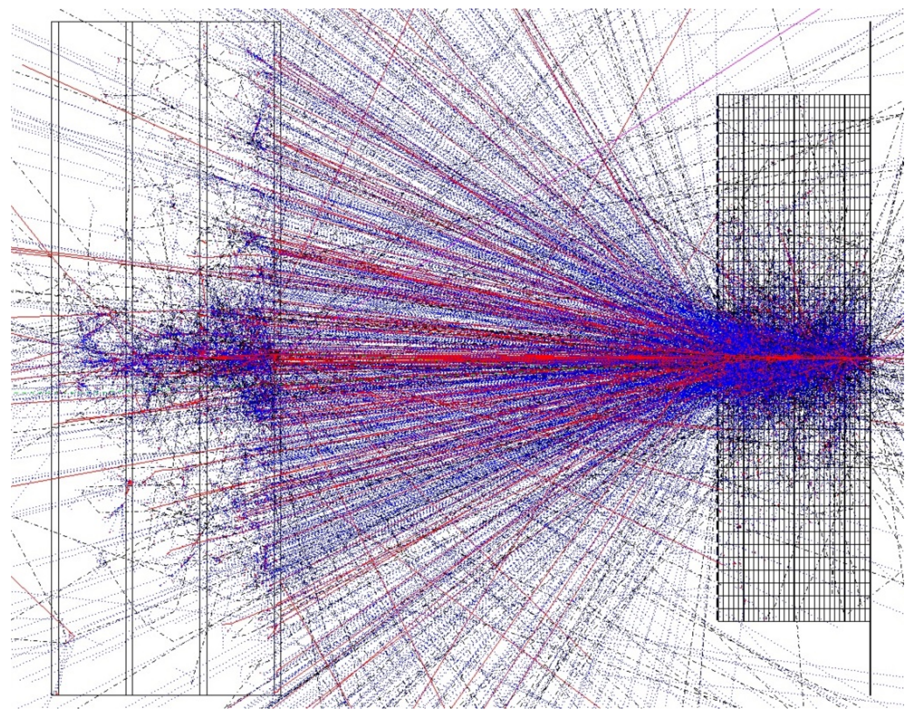
Muon detectors FCAL

Geant3 Simulations

3 GeV muon



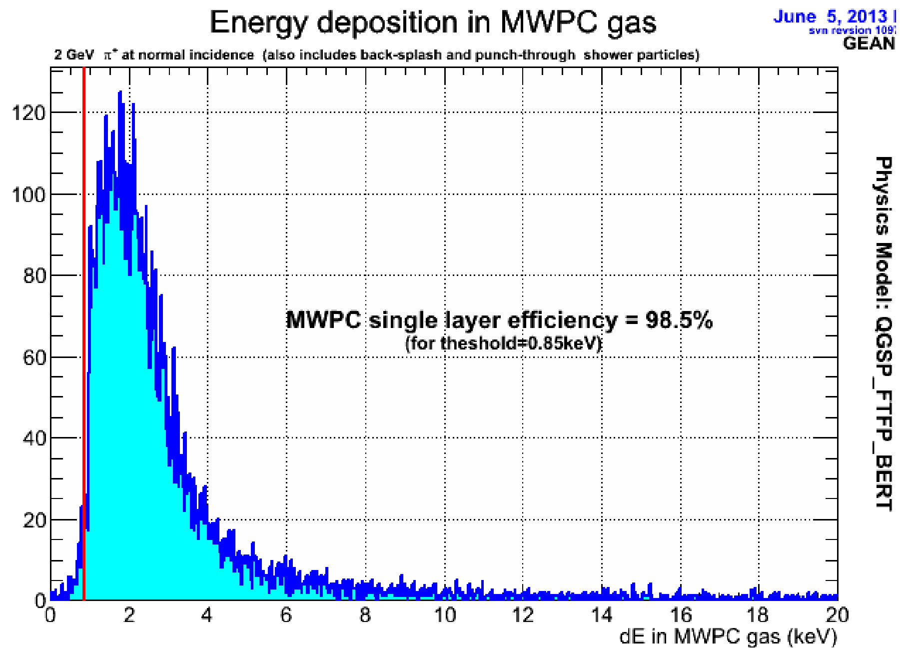
3 GeV pion



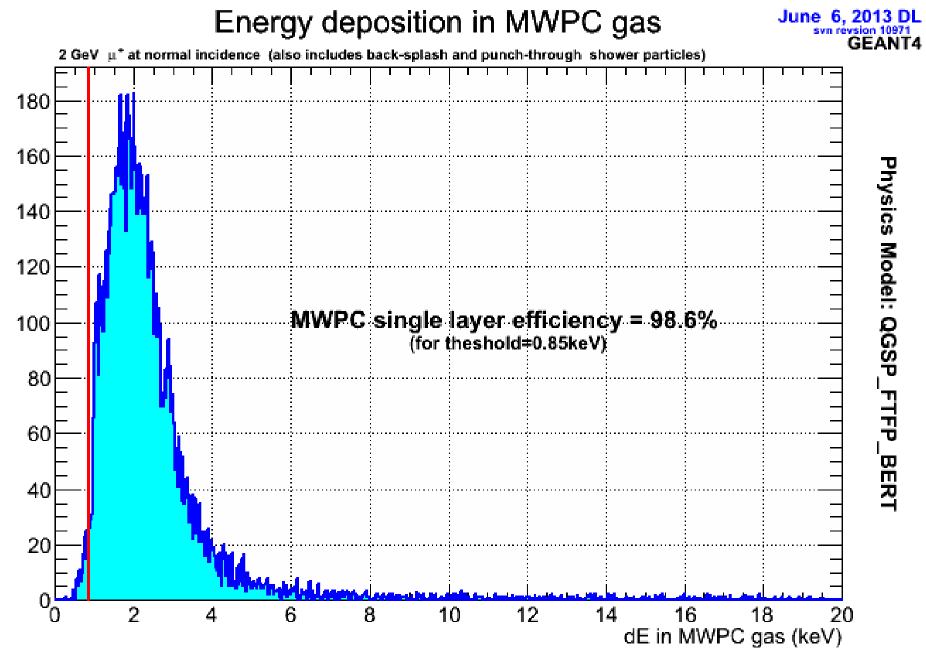
Muon detectors FCAL

Geant4 calculaton of dE/dx in the MWPCs

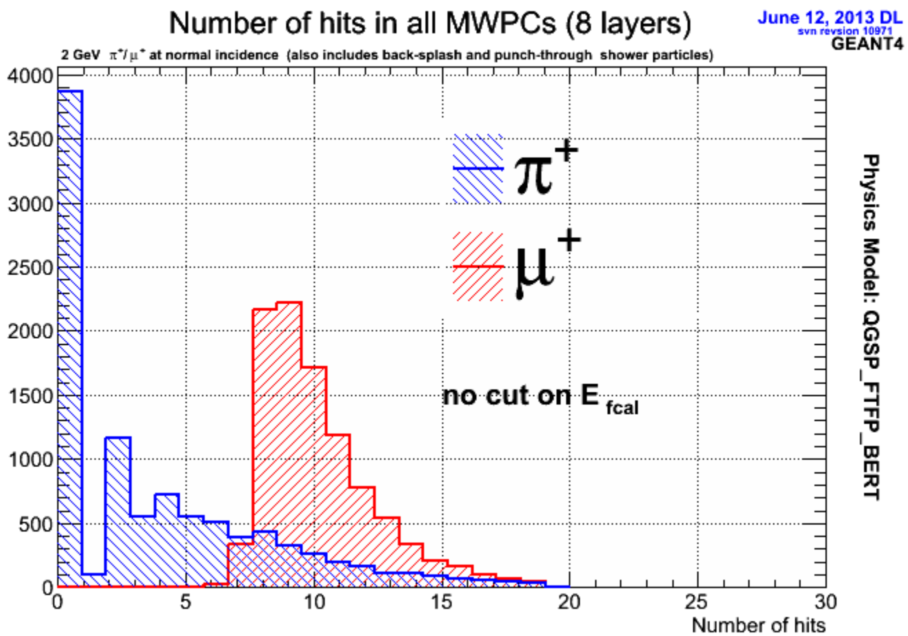
π^+

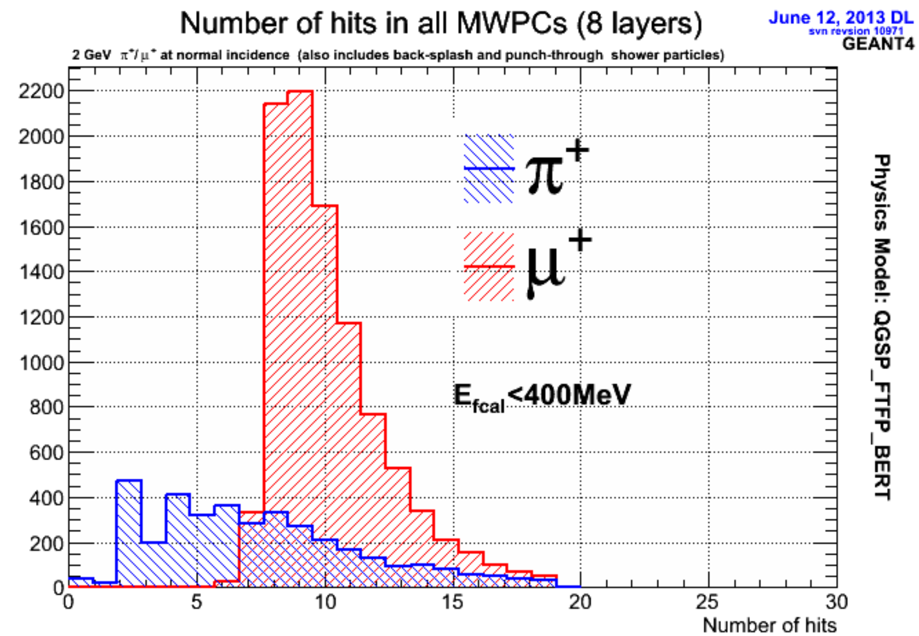


μ^+



Number of hits in all MWPCs (8 layers)





Pion showers tend to be absorbed in iron, not necessarily leading to many hits in MWPCs

Conclusion: may need more sampling layers

Particle ID Summary

- Can't base particle ID on a single variable. Need to combine all sources of information about the event:

  i. Particle momenta

  ii. Energy in FCAL

  iii. # hits in muon chambers

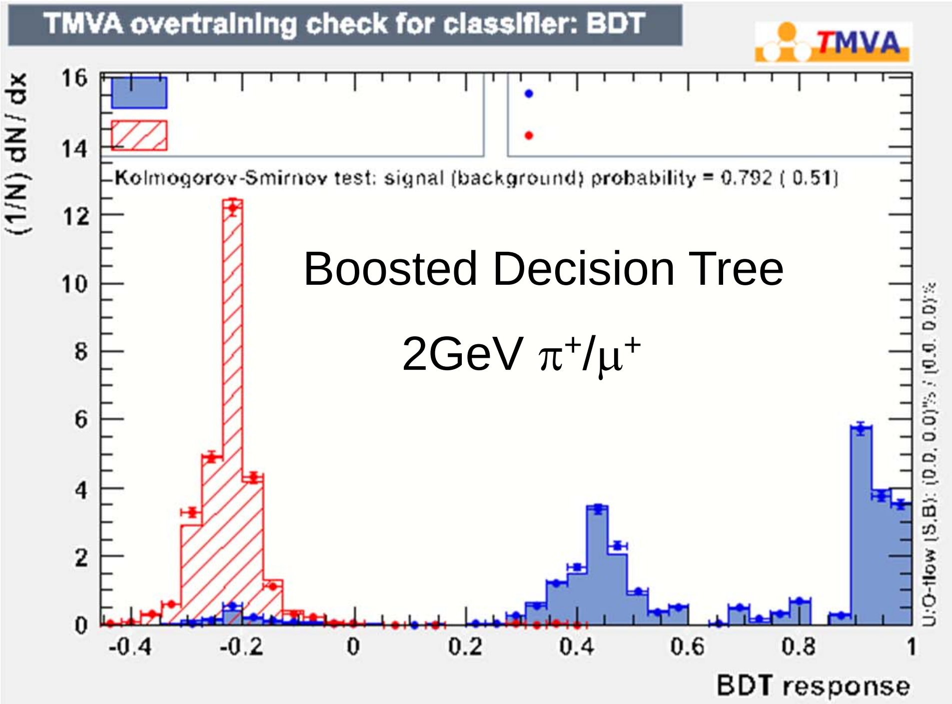
  iv. track depths in muon chambers

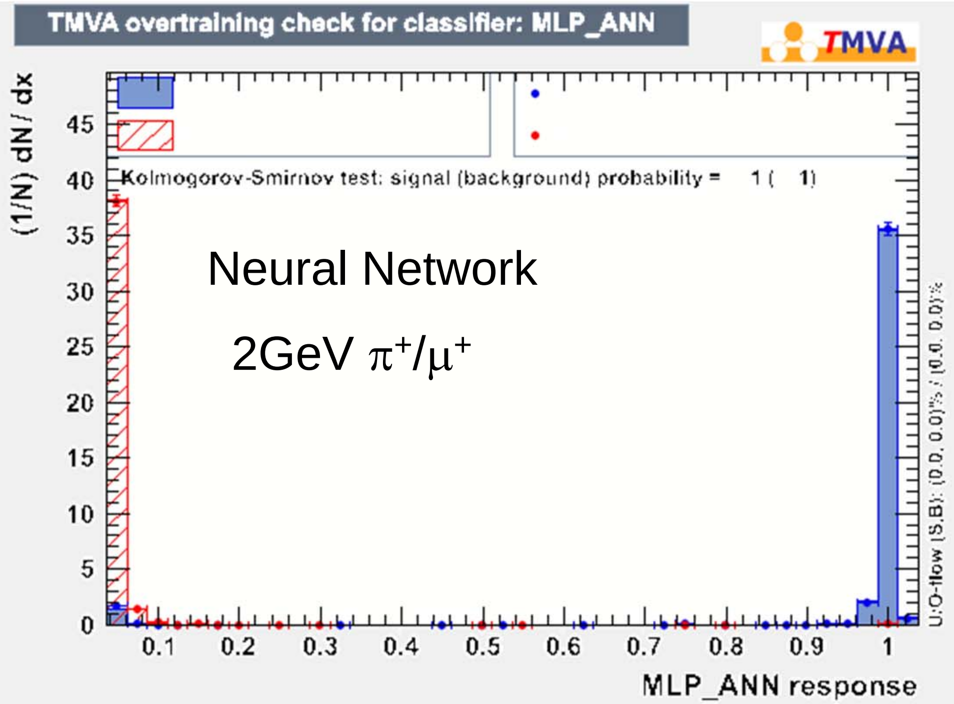
  v. x,y distribution of hits in muon chambers

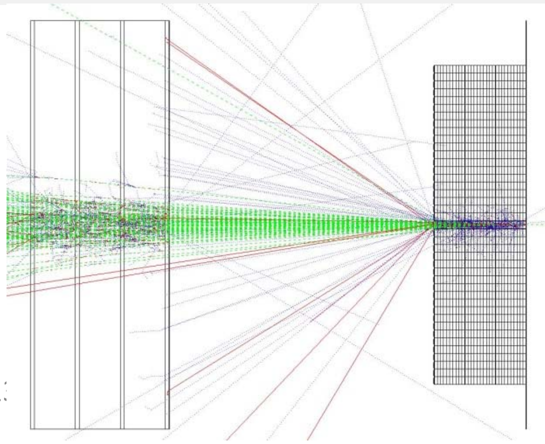
- Use Multi-Variate Analysis (MVA) to to map the point in N-dimensional space to a probability value that can be used to classify the type of event.

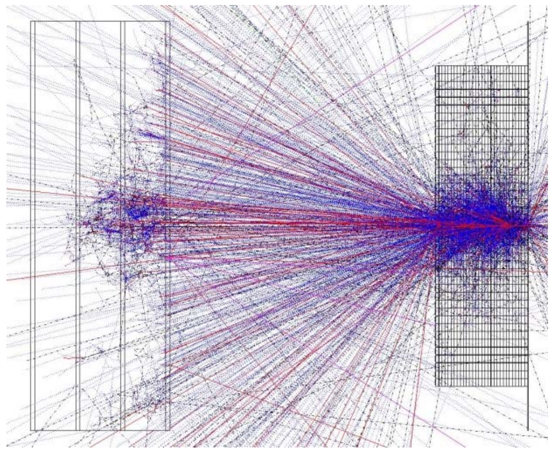
MVA Classification Examples

Blue are π+ events, red are μ+ events

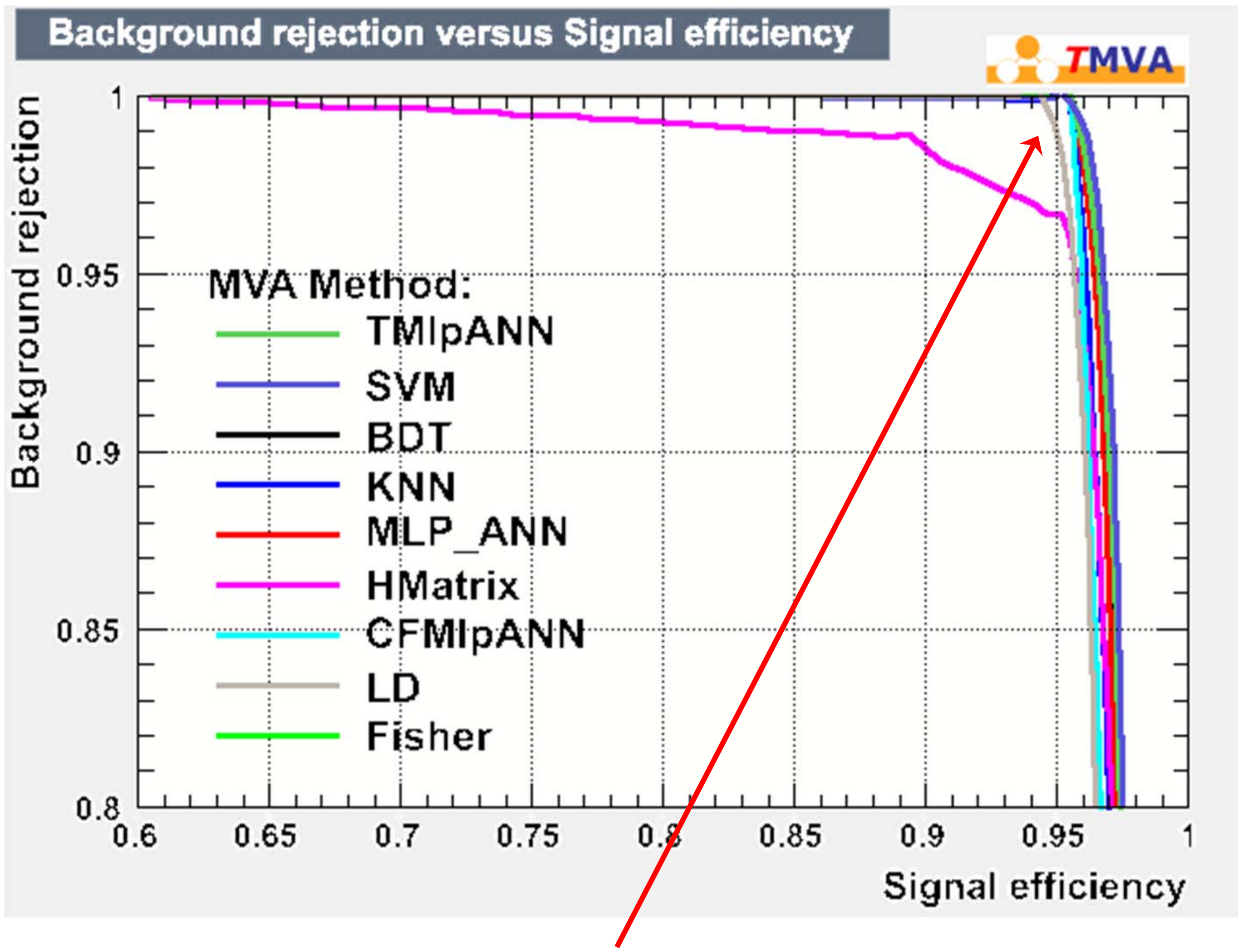








Multi-Variate Analysis for 2 GeV π+ and μ+



μ rejection at 0.998, π efficiency at 95%

Summary of the Muon System

- We conclude that a **muon system based on MWPCs and iron absorbers + FCAL** can deliver the π/μ/e separation required
- Need to optimize the size of the detector, the number of detector planes, the total iron thickness, and *neural net/boosted decision tree* algorithms
- Use MWPC's operating in proportional mode: cheap, relatively easy to construct, high eff. for MIP.
- Channel estimate: assume cell spacing = 4 cm, four MWPC packages with x, y planes, 2 x 2 m^2, = 400 total cells.
- Electronics readout: borrow 25 FADC' modules + ancillary electronics + crates. Need a relatively cheap preamp card on the MWPC's.

The Road to $\sigma_{\gamma\gamma\rightarrow\pi\pi}$

1. **Identify candidate events based on kinematic cuts**
   a) $E_1+E_2 = E_\gamma$
   b) $0.3 < W_{12} < 0.5$ GeV
   c) $\Theta_{12} < 0.6°$
   d) $\pi\pi$ = event with no identified muon
   e) $\mu\mu$ = event with at least one identified muon

2. **Subtract backgrounds from yields**

$$N_{\pi\pi} = N_{\pi\pi-candidate} - f_{bad-\mu\mu(\pi\pi)} N_{\mu\mu} + f_{bad-\pi\pi(\mu\mu)} N_{\pi\pi} - f_{bad-\pi\mu(\pi\pi)} f_{\pi\rightarrow\mu\nu} N_{\pi\pi}$$

$$N_{\mu\mu} = N_{\mu\mu-candidate} + f_{bad-\mu\mu(\pi\pi)} N_{\mu\mu} - f_{bad-\pi\pi(\mu\mu)} N_{\pi\pi} - f_{bad-\pi\mu(\mu\mu)} f_{\pi\rightarrow\mu\nu} N_{\pi\pi}$$

$f_{\pi\rightarrow\mu\nu}$ = probability for pion decay = 8%

$f_{bad-\pi\pi(\mu\mu)}$ = probability for $\pi\pi$ event to ID as $\mu\mu$ event $\sim$ 0.05

$f_{bad-\mu\mu(\pi\pi)}$ = probability for $\mu\mu$ event to ID as $\pi\pi$ event $\sim$ 0.002

$f_{bad-\pi\mu(\pi\pi)}$ = probability for $\pi\mu$ event to ID as $\pi\pi$ event $\sim$ 0.05

$f_{bad-\pi\mu(\mu\mu)}$ = probability for $\pi\mu$ event to ID as $\mu\mu$ event $\sim$ 1

The Road to $\sigma_{\gamma\gamma\to\pi\pi}$

3. **Azimuthal fits to pion yields**

$$N_{\pi\pi} = N_{\Pr imakoff}\left(1 + P_\gamma \cos 2\phi_{\pi\pi}\right) + N_\rho$$

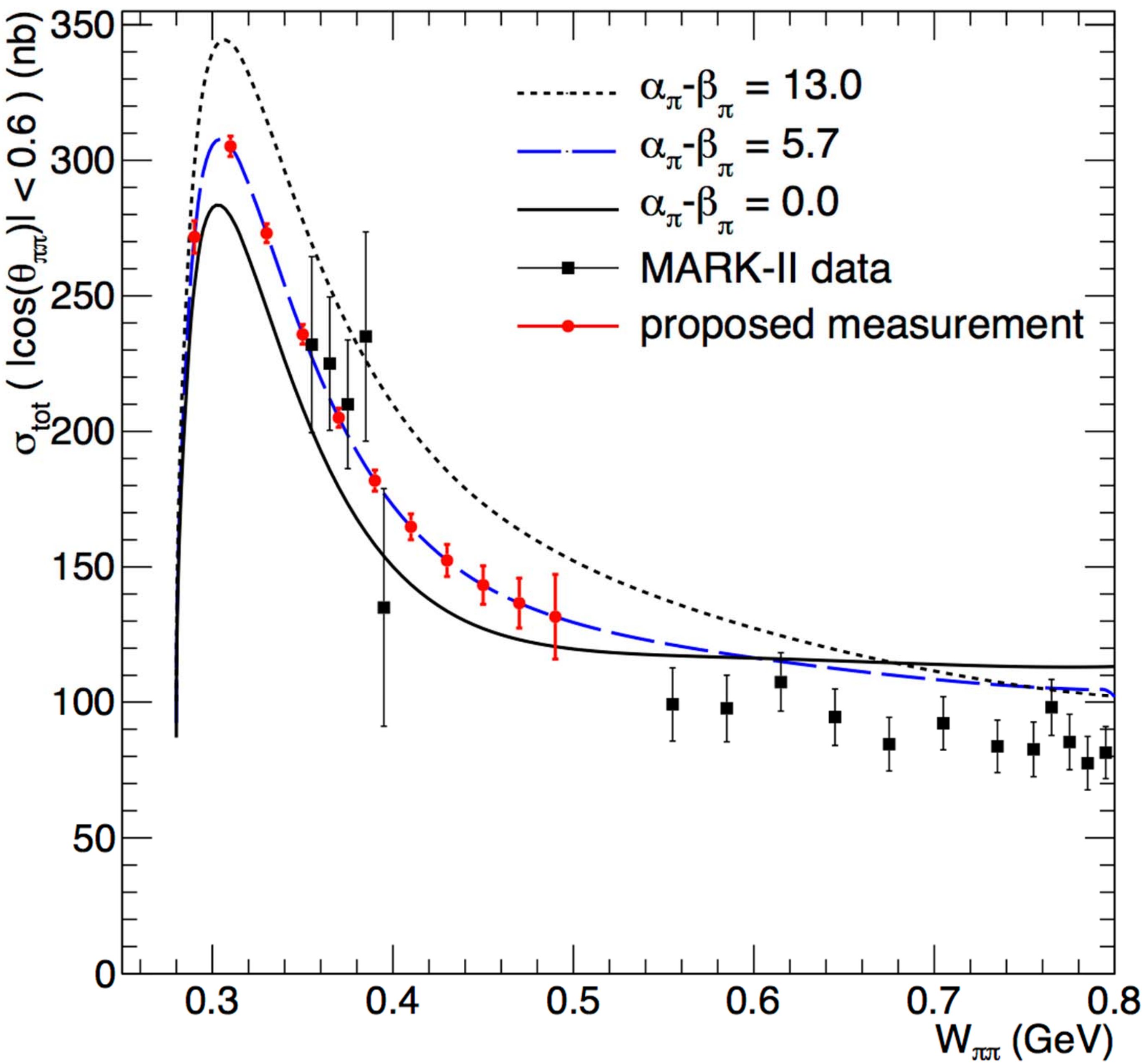
$$N_{\pi\pi} = N_\rho(1 + P_\gamma \cos 2\psi) + N_{\Pr imakoff}$$

4. **Form ratio with muon yields**

$$\frac{N_{\Pr imakoff}}{N_{\mu\mu}} = \left|\frac{F_{strong}(q^2)}{F_{EM}(q^2)}\right|^2 \frac{(FDC \cdot TOF)_{\pi\pi}}{(FDC \cdot TOF)_{\mu\mu}} \times \frac{Trig_{\pi\pi}}{Trig_{\mu\mu}} \times (1 - f_{\pi\to\mu\nu}) \frac{CoulCorr_{\pi\pi}}{CoulCorr_{\mu\mu}} \left[\frac{\sigma_{\gamma\gamma\to\pi\pi}}{\sigma_{\gamma\gamma\to\mu\mu}}\right]$$

-4% 0% 0% -8% +1%

$\gamma + \gamma \rightarrow \pi^+ + \pi^-$



Errors and correction factors	Correction factor	Uncertainty in correction
Overall statistical error		0.6%
$\pi\pi$ inefficiency	5%	.5%
$\mu\mu$ contamination	2%	.5%
$\pi\mu$ identified as $\pi\pi$	0.4%	small
$\pi\mu$ identified as $\mu\mu$	0.8%	small
polarization	70%	0.5%
Strong form factor	4%	0.6%
Acceptance		0.5%
Trigger		0.5%
Coulomb correction	1%	0.5%
Total error		1.5%
Projected error in $\alpha-\beta$		$\pm 0.6 \times 10^{-4}$ fm^3

Summary

- The charged pion polarizability has special status among hadron polarizabilities; the predicted value comes directly from $L_{QCD}(p^4)$. The NLO corrections to $\alpha-\beta$ are small.
- The charged pion polarizability ranks as one of the most important tests of low-energy QCD unresolved by experiment. The experimental value for $\alpha-\beta$ is poorly known.
- We have proposed to measure the charged pion polarizability $\alpha-\beta$ by measurement of $\gamma\gamma\rightarrow\pi^+\pi^-$ cross sections in the threshold region
- 20 days are requested for running, and 5 days for commissioning. The projected uncertainty in $\alpha-\beta$ is at the level of $\pm0.6\times10^{-4}$ fm^4, equal to the PDG error on the proton electric polarizability.
- The experiment will utilize a muon counter/iron absorber system installed after FCAL, and a solid target installed near the upstream end of the GlueX magnet. The number of additional electronics channels, approx. 400.