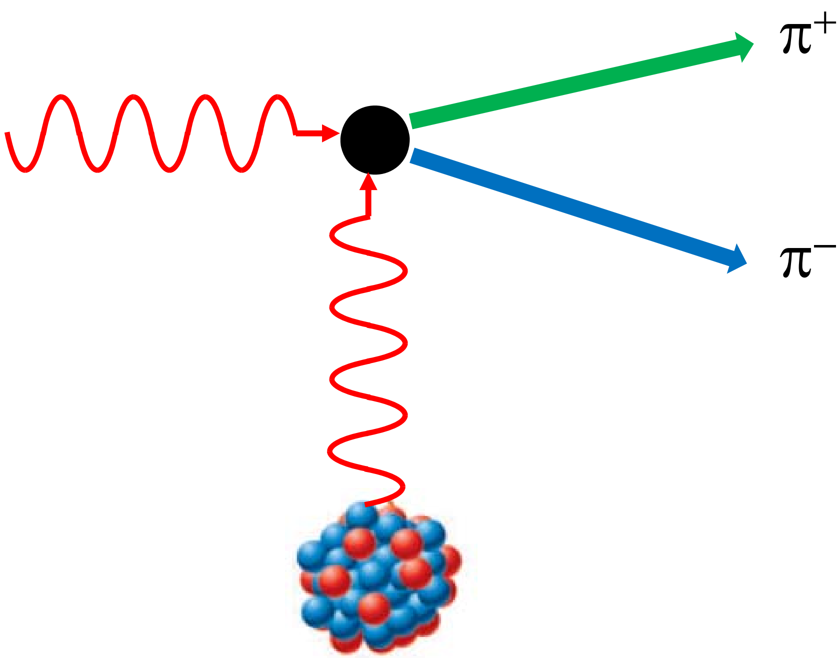
Measuring the Charged Pion Polarizability in the $\gamma\gamma\to\pi^+\pi^-$ Reaction

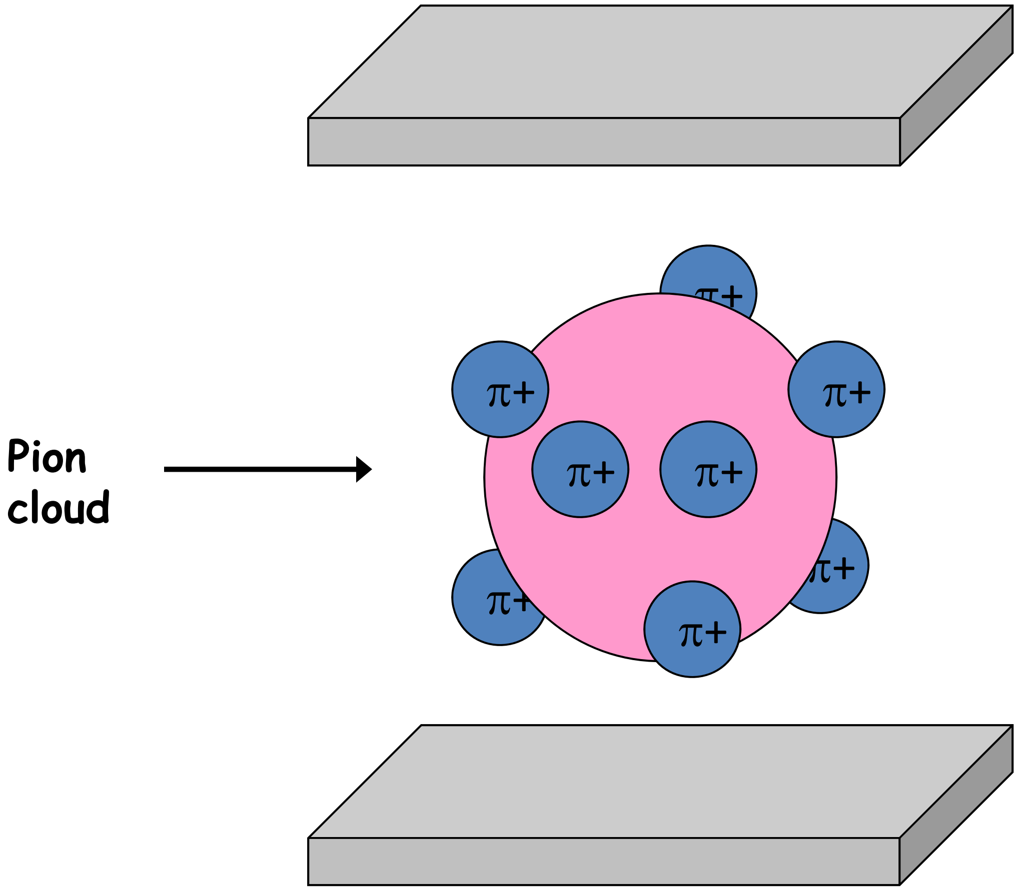
A proposal to the 40th Jefferson Lab Program Advisory Committee

Spokespersons: D. Lawrence, R. Miskimen, E. Smith



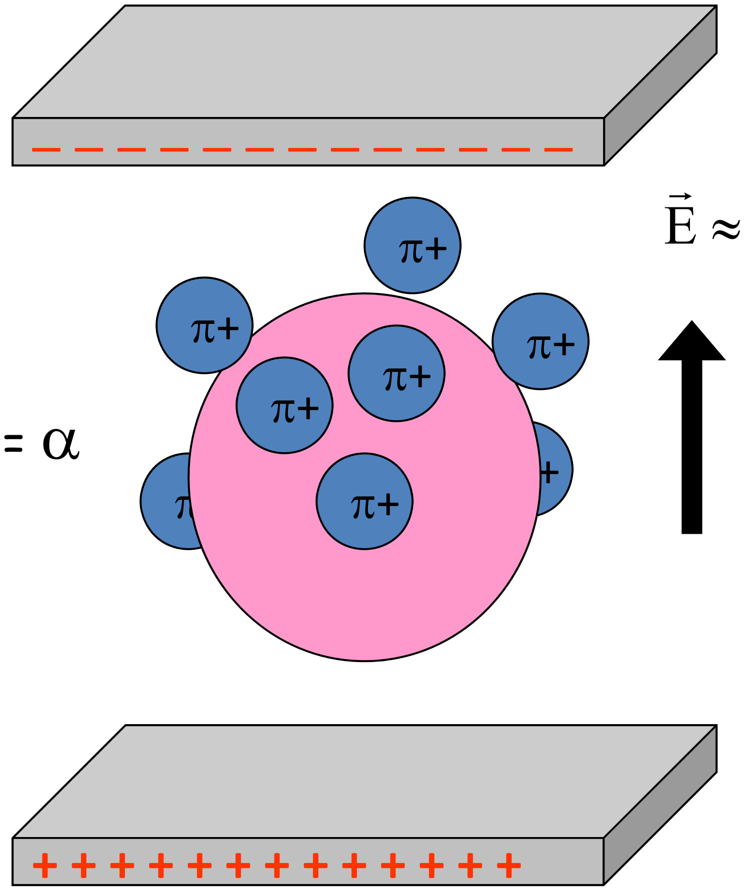
- Pion polarizability
- Experimental setup
- Backgrounds
- Muon detection system
- Analysis
- Projected results

Proton electric polarizability



Proton between charged parallel plates

Proton electric polarizability



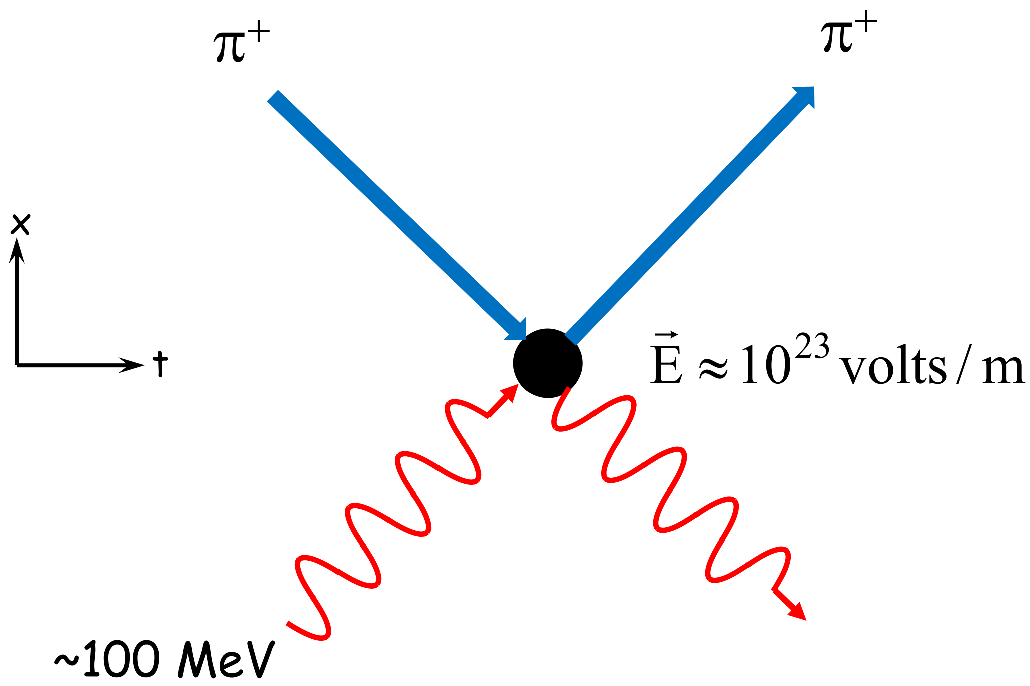
$$\vec{E} \approx \frac{100\text{MeV}}{1\text{fm}} = 10^{23}\,\text{volts}/\text{m}$$

Electric polarizability = α

$10^{-4} \times$ Volume

Proton between charged parallel plates

Compton Scattering and the E.M. polarizabilities

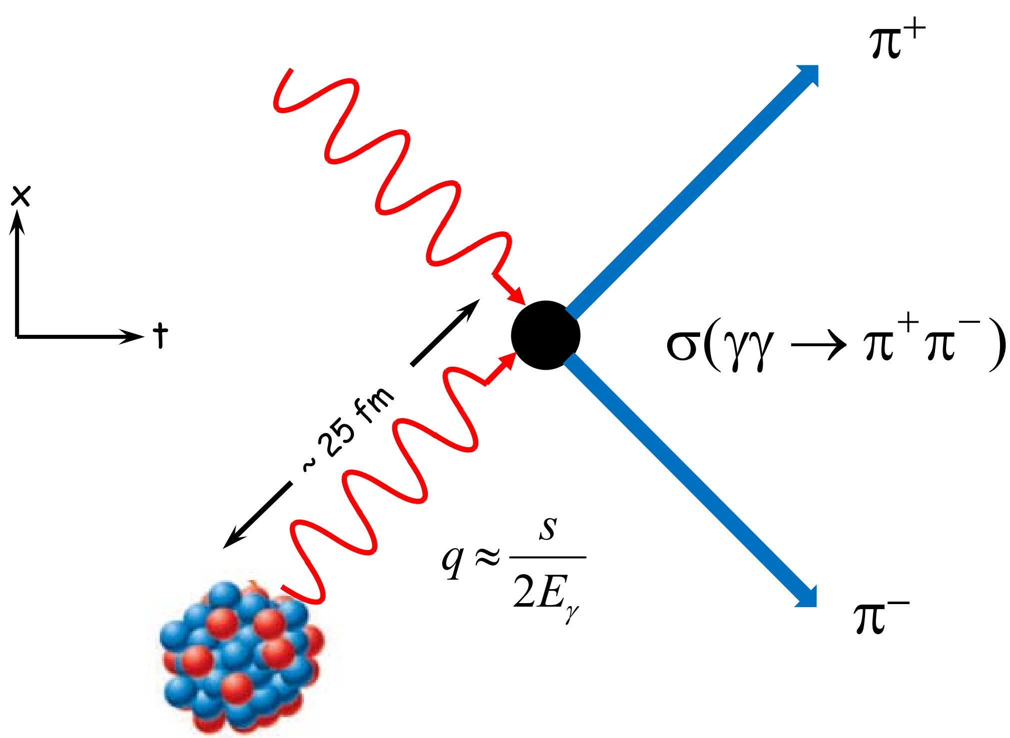


$$H = H_{Born}(e, \vec{\mu}) - 4\pi\left(\frac{1}{2}\alpha_{EM}\vec{E}^2 + \frac{1}{2}\beta_{EM}\vec{H}^2\right)$$

10%

Crossing symmetry (x ↔ t):

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



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

Low energy QCD and pion polarizability

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

Charged pion polarizability

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

P⁶ corrections are small

$$\alpha_\pi - \beta_\pi = (5.7 \pm 1.0) \times 10^{-4}\, fm^3$$

$$\alpha_\pi + \beta_\pi = (0.16 \pm 1.0) \times 10^{-4}\, fm^3$$

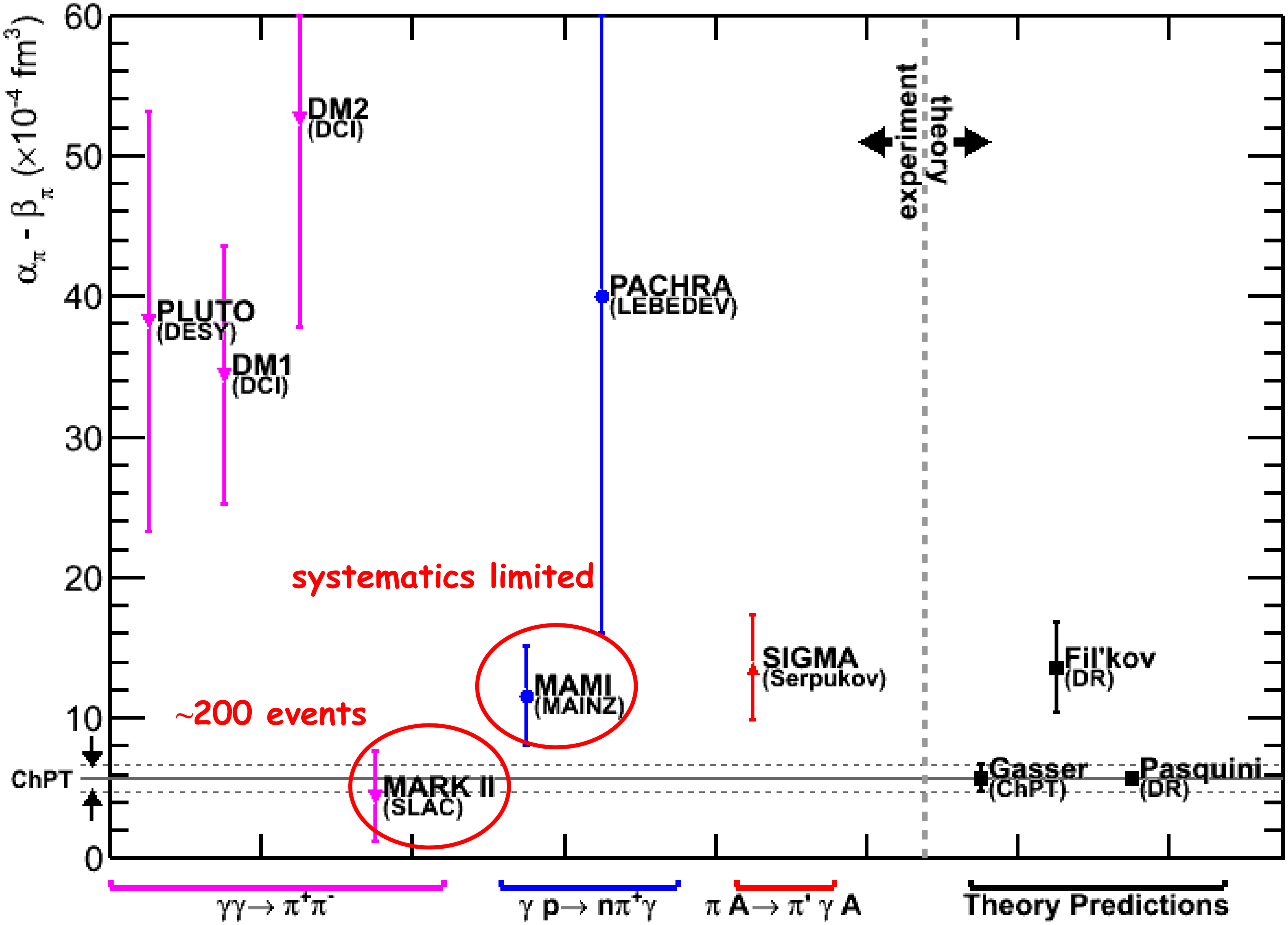
$$\pi^0 \to \gamma\gamma$$

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

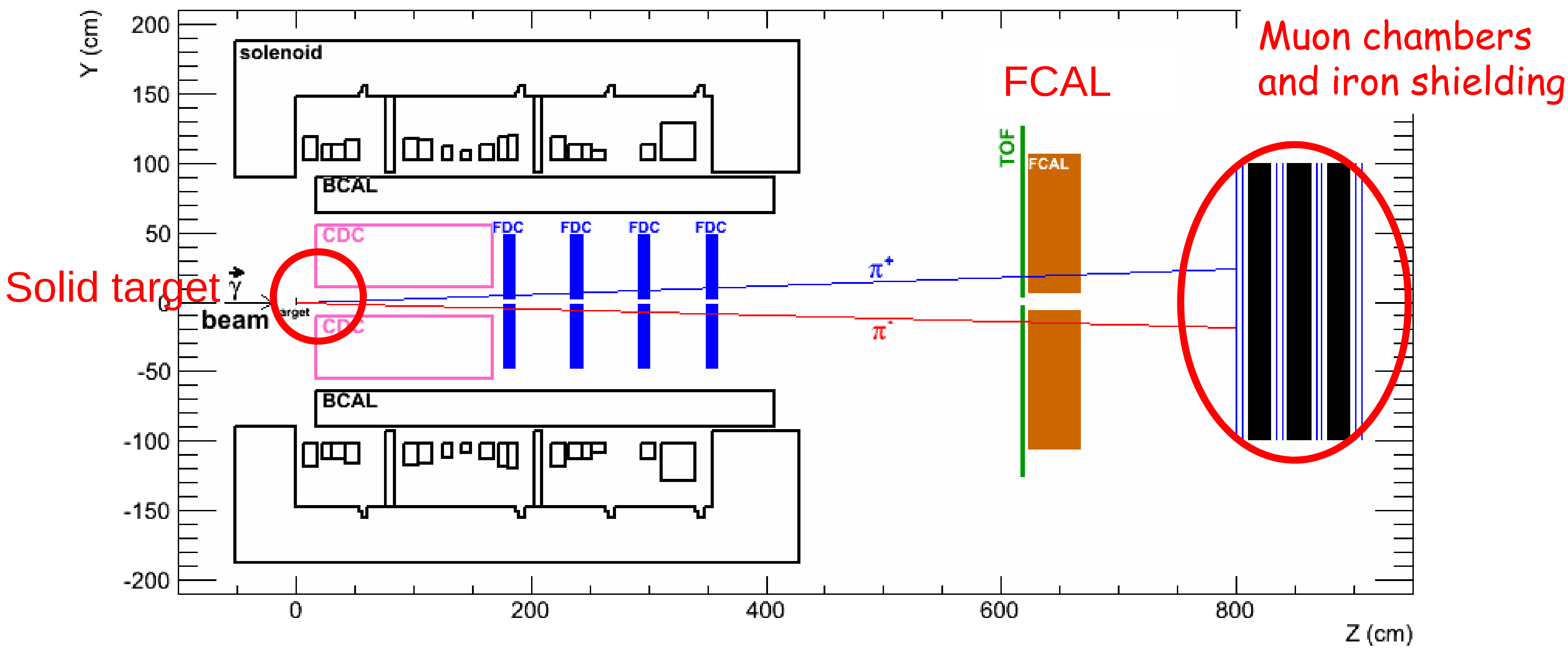
Primex result

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

Pion Polarizability Measurements



Proposed Detector Setup



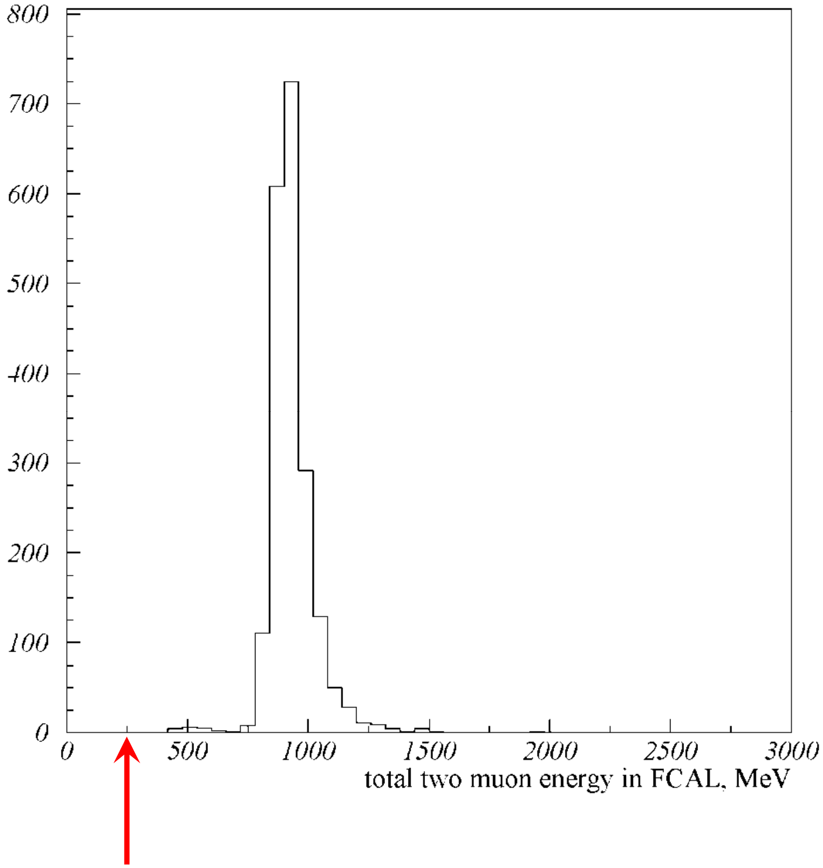
Micro-tagger moved from 9.0 GeV to 6.0 GeV to increase polarization from 44% to 76%, and ratio of coherent/incoherent Brem. from .068 to 0.32

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

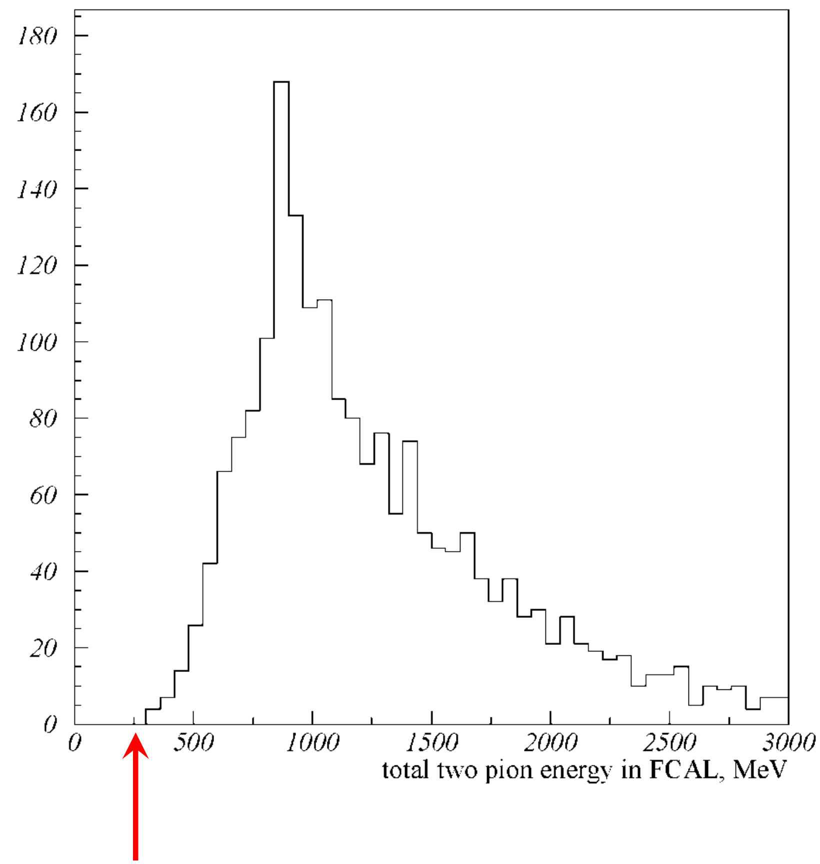
$E_{\mu 1} + E_{\mu 2} = 5.5$ GeV



250 MeV

Pion response in FCAL

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



250 MeV

Backgrounds: *PRIMEX can provide guidance on backgrounds*

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

   Calculations by T. Rodrigues

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

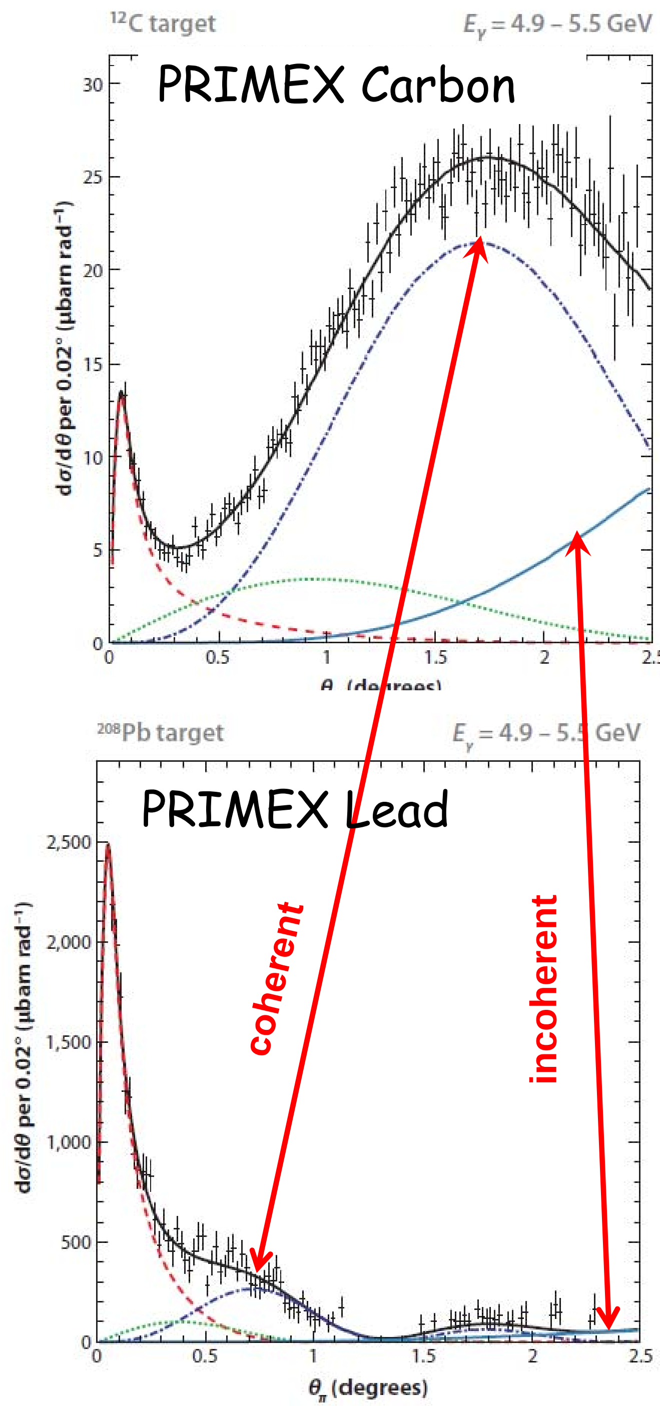
   Calculations by S. Gevorkyan

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

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

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

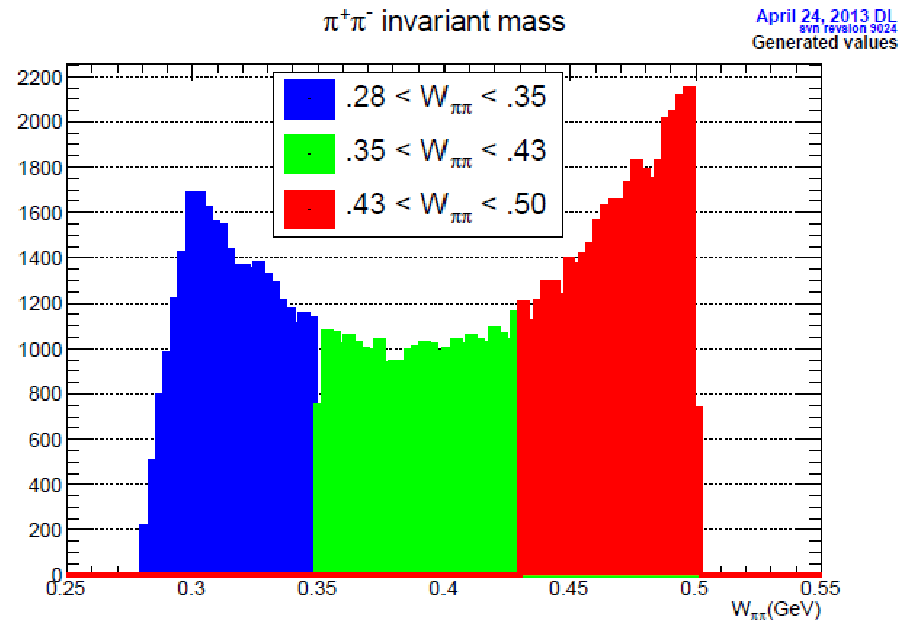
1. Incoherent $\gamma A \rightarrow \pi^+\pi^- X$

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

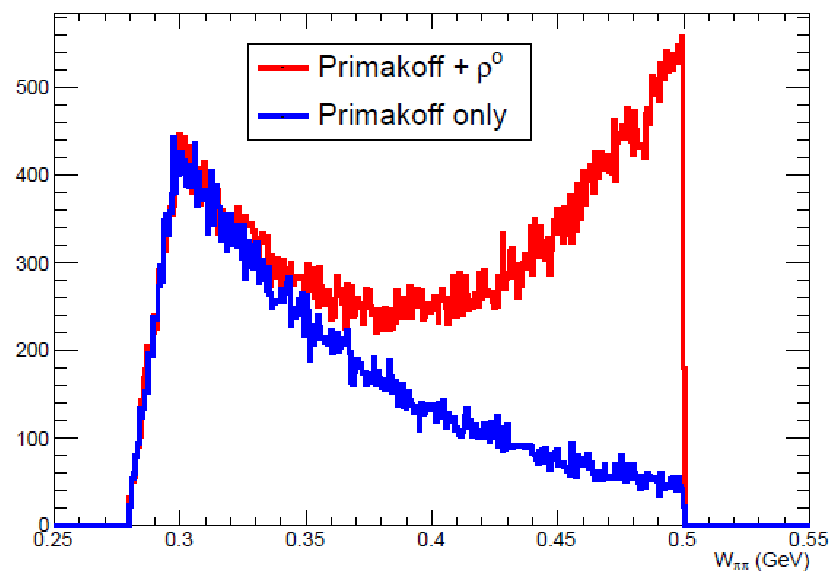
3. $\gamma A \rightarrow \rho^0 A$

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

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



W distribtution of $\pi\pi$ events



Backgrounds

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

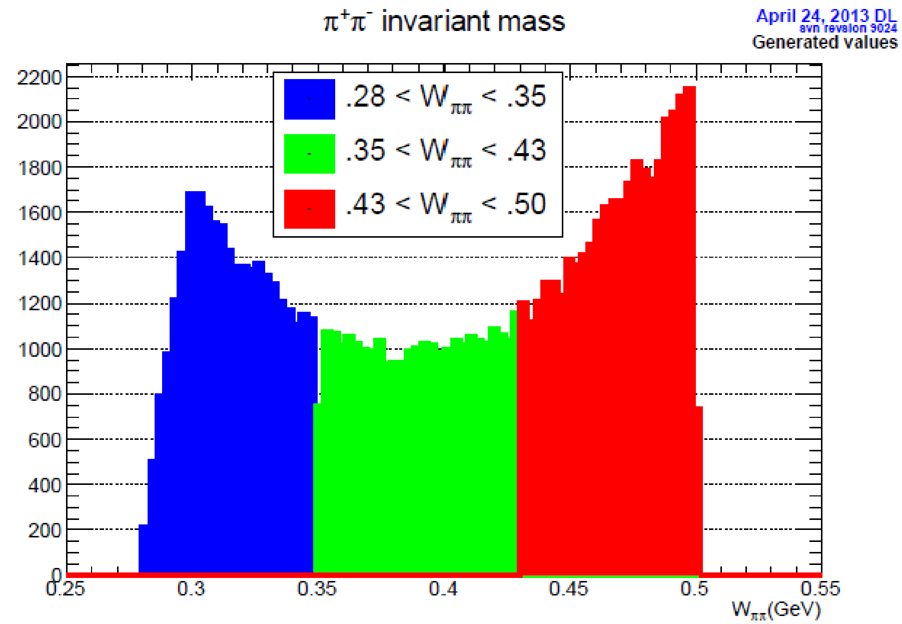
2. Coherent $\gamma A \rightarrow f_0(600)$

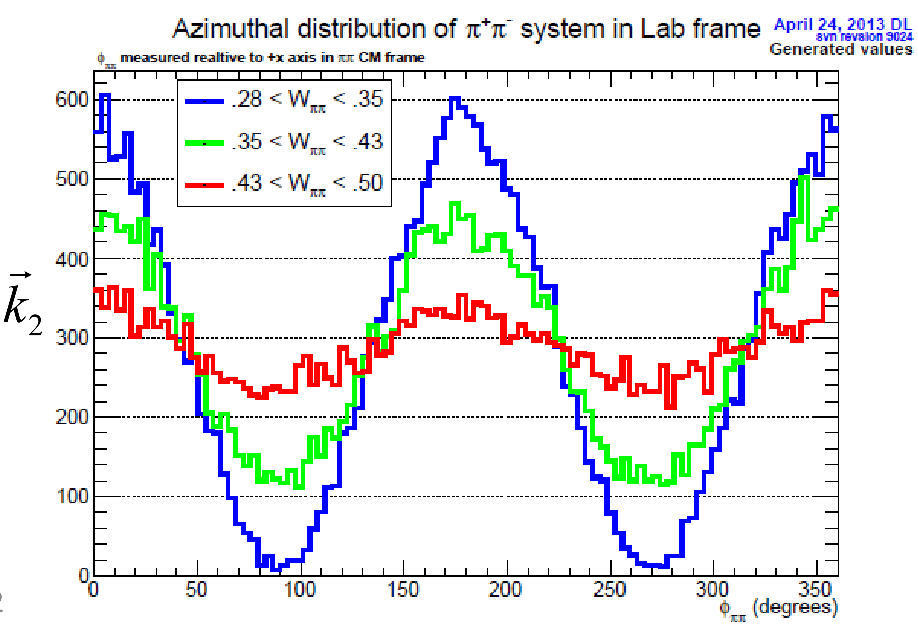
3. $\gamma A \rightarrow \rho^0 A$

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

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

Lab azimuthal distribution of $\vec{k}_1 + \vec{k}_2$ $(1+P_\gamma \cos 2\phi)$





Backgrounds

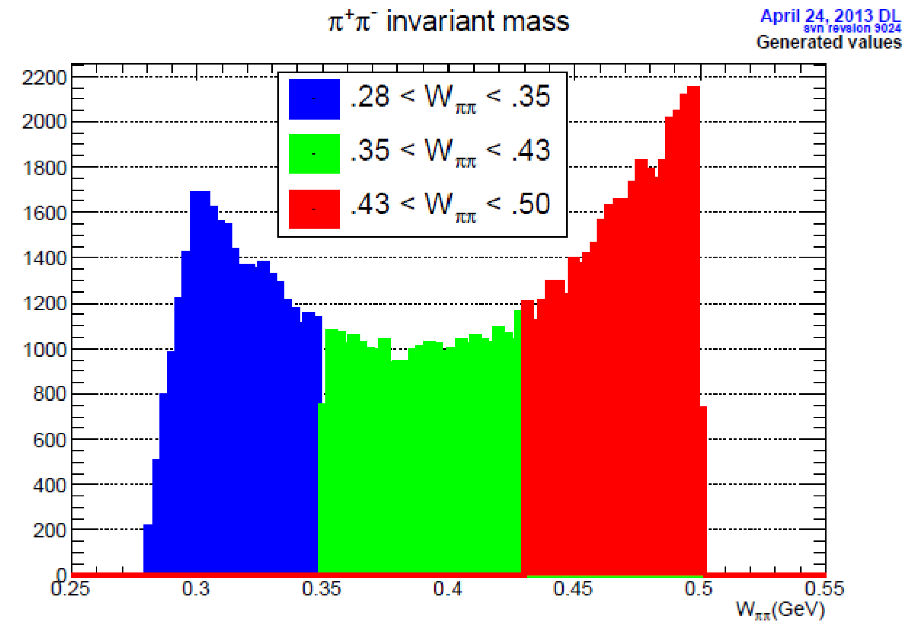
1. Incoherent $\gamma A \to \pi^+\pi^- X$

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

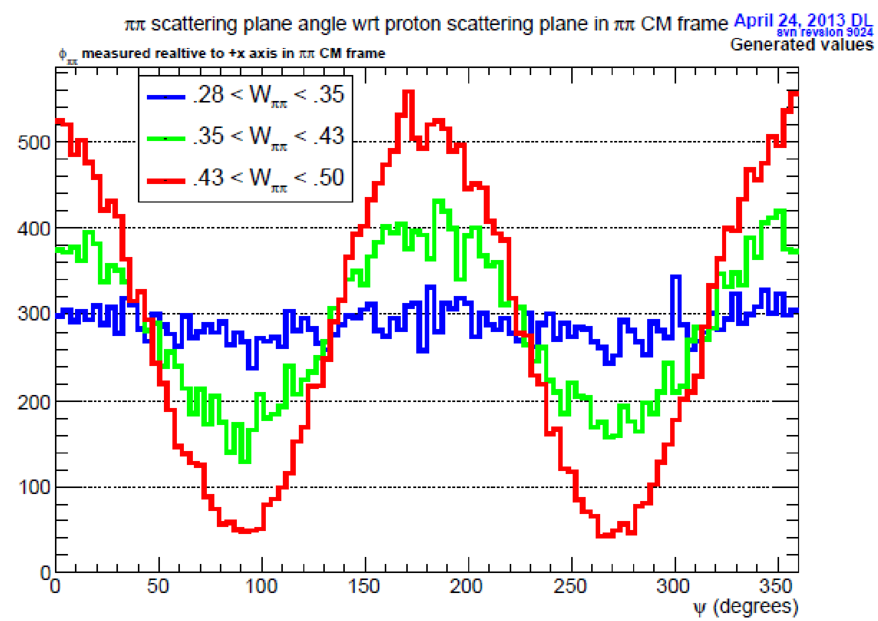
3. $\gamma A \to \rho^0 A$

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

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

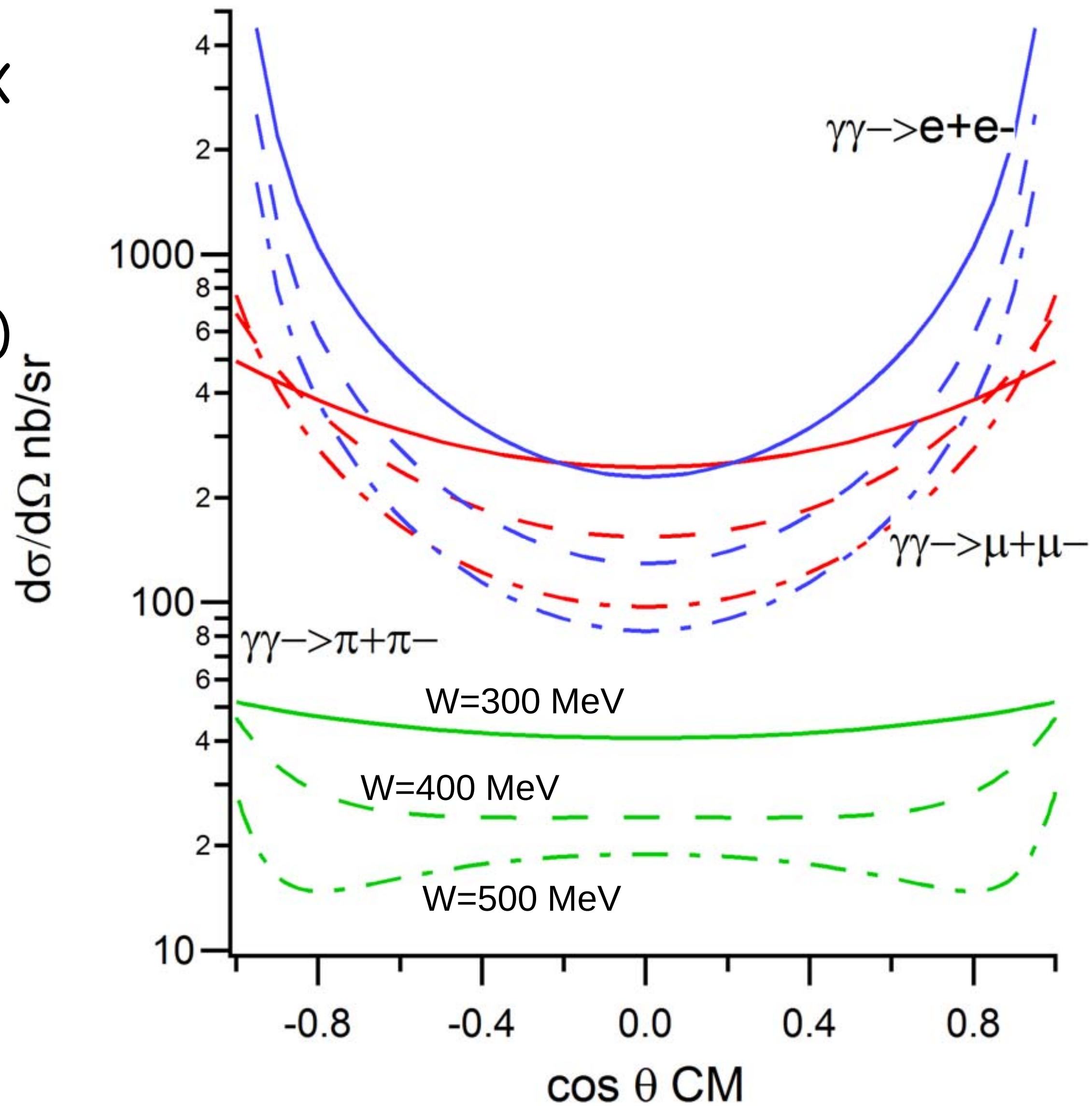


Azimuthal distribution of π^+ in helicity frame $(1+P_\gamma \cos 2\psi)$



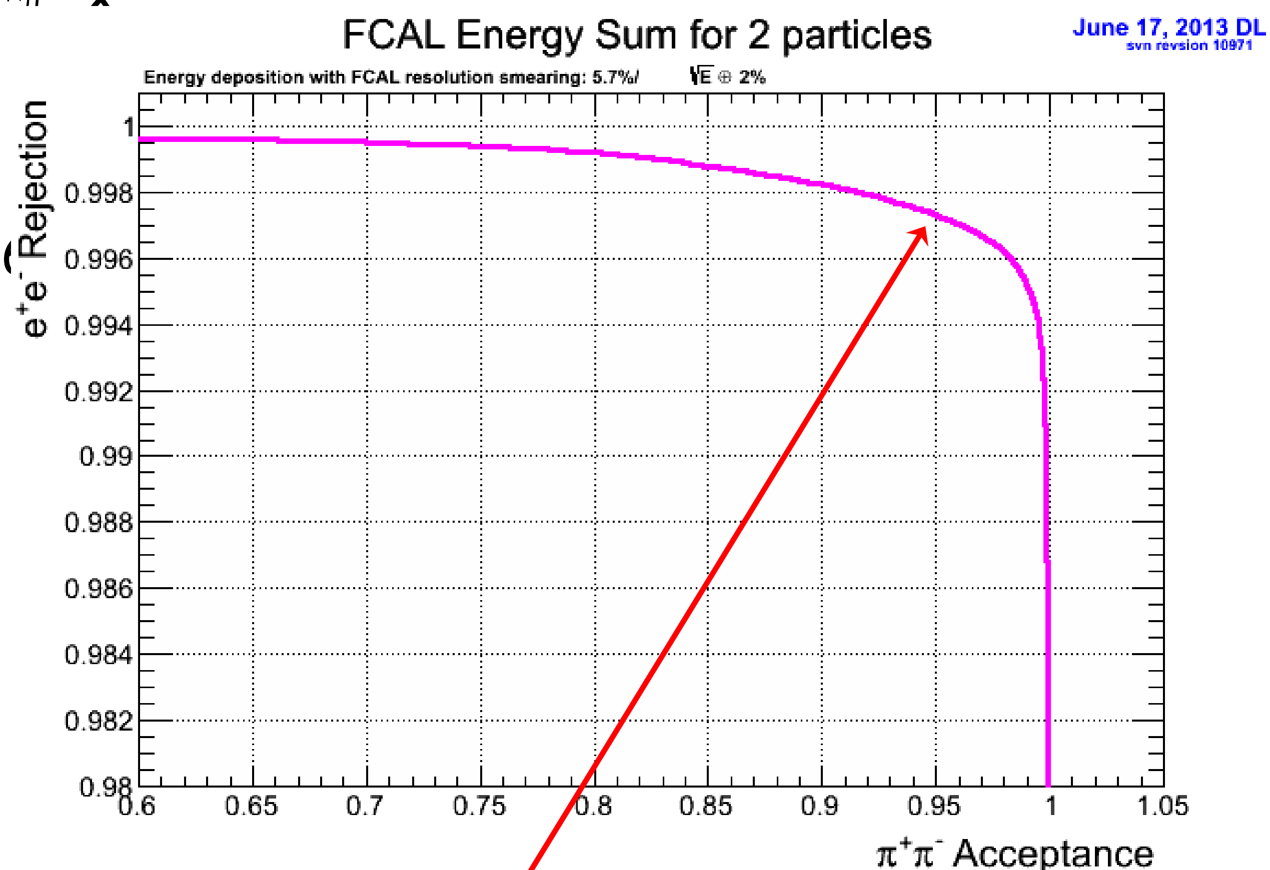
Backgrounds

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 $\gamma A \rightarrow \pi^{+}\pi^{-}$ X
2. Coherent $\gamma A \rightarrow$ f_0((
3. $\gamma A \rightarrow \rho^0$ A
4. $\gamma A \rightarrow e^{+}e^{-}$ A
5. $\gamma A \rightarrow \mu^{+}\mu^{-}$ A



0.997 $e^{+}e^{-}$ rejection at 95% $\pi^{+}\pi^{-}$ acceptance

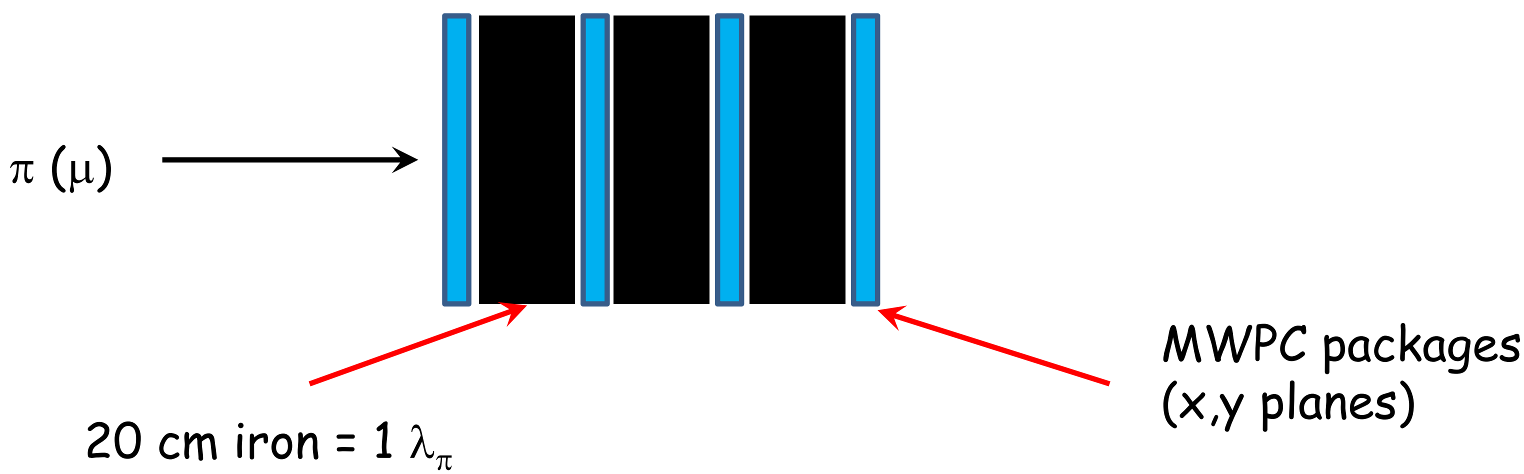
Muon detector design

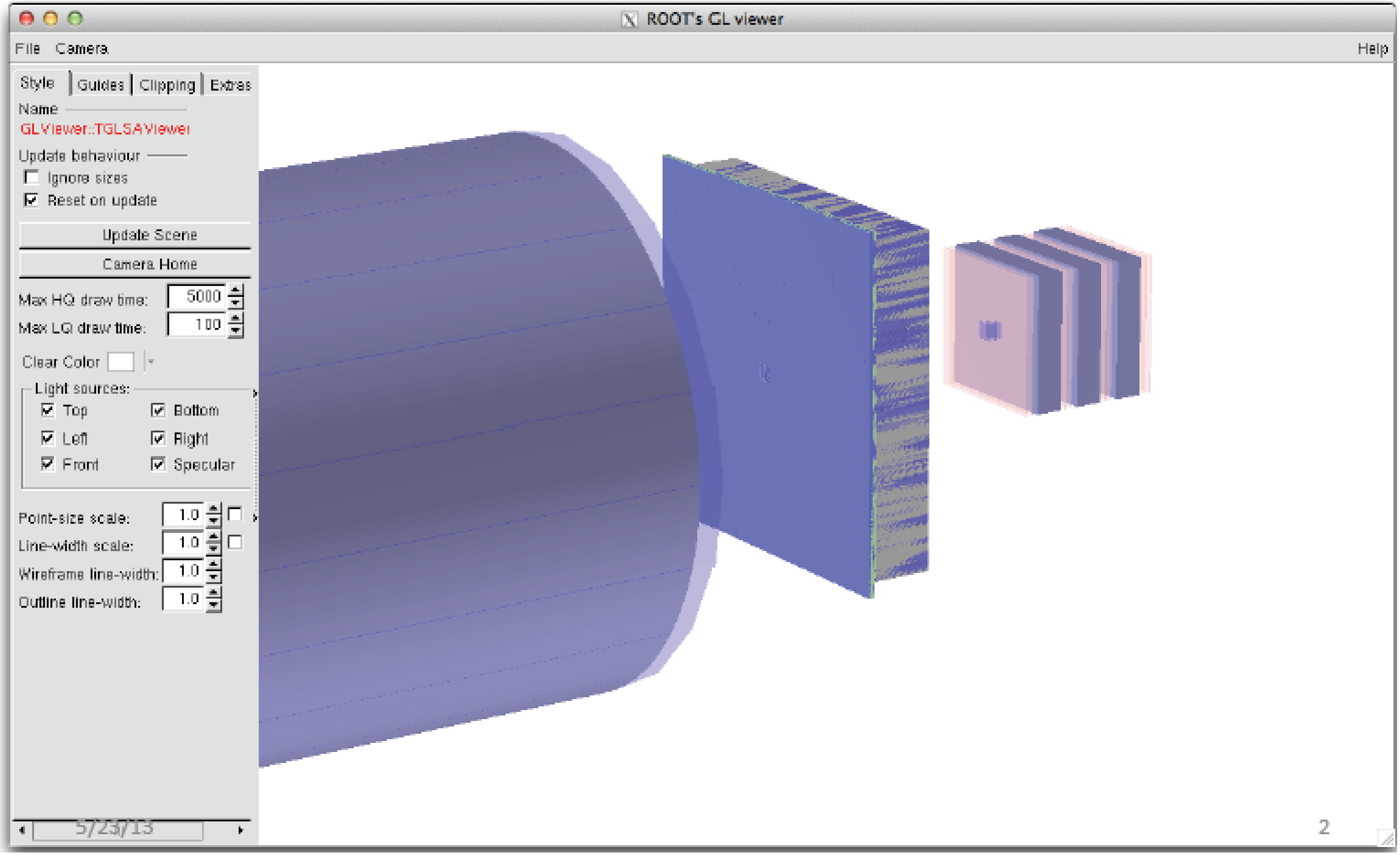
Muon detector:

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

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

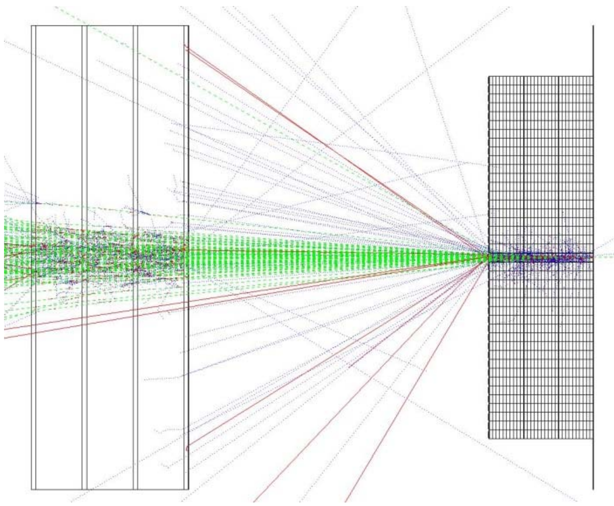
   iii. # hits in muon chambers

   iv. track depths in muon chambers

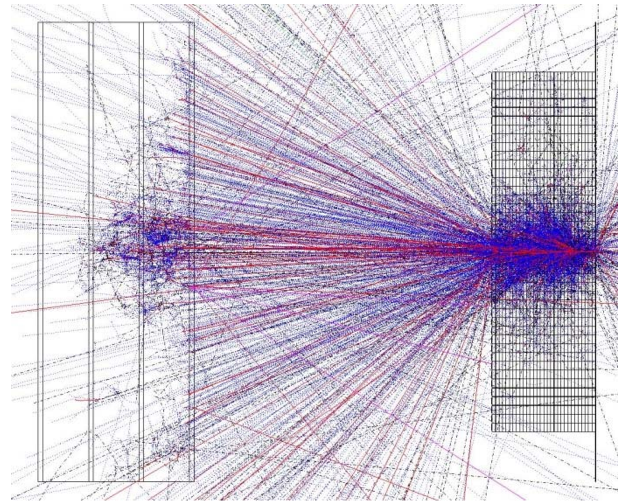
   v. x,y distribution of hits in muon chambers

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

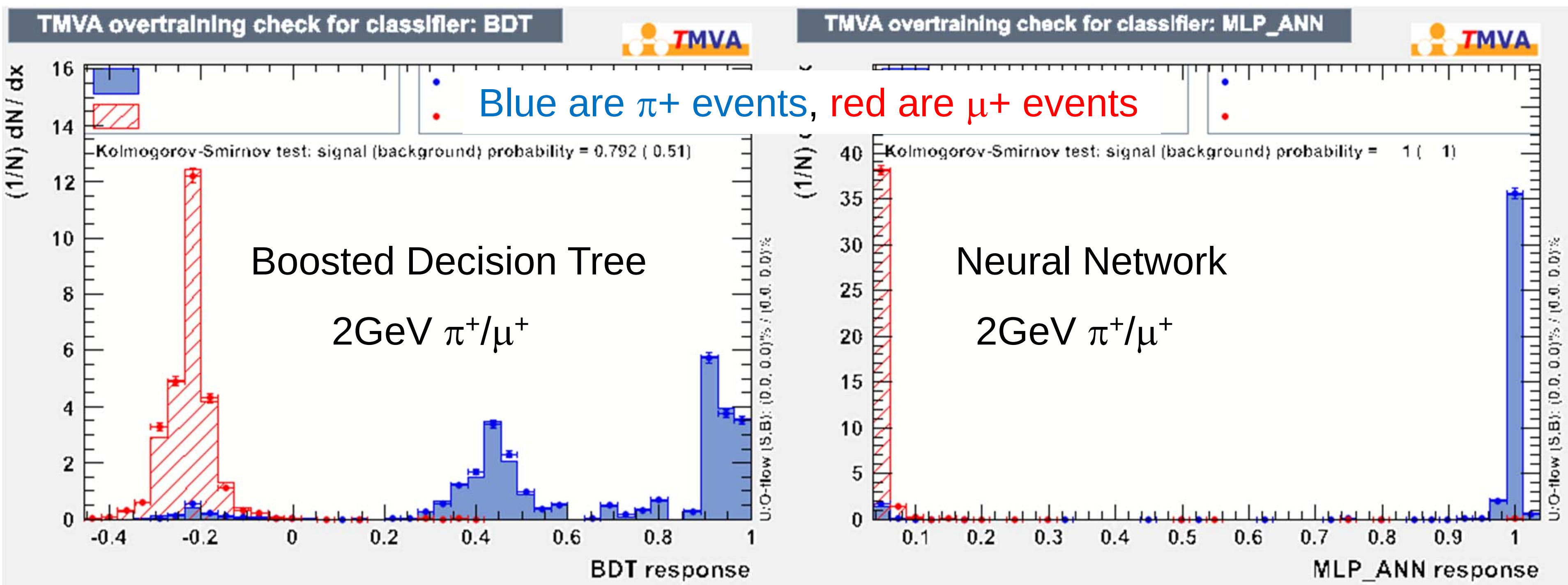
MVA Classification Examples



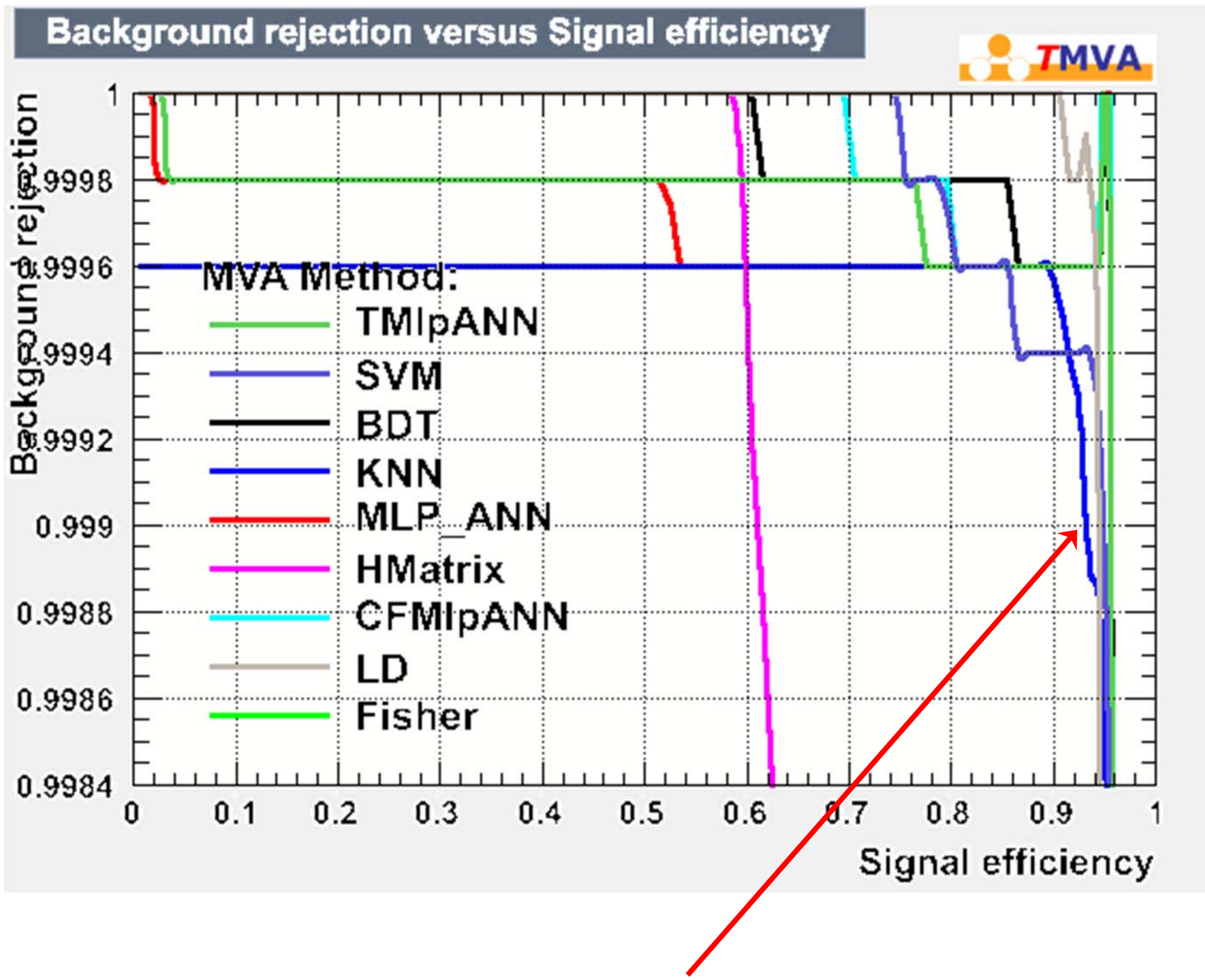
2 GeV muon



2 GeV pion



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



μ rejection at 0.999, π efficiency at 95%

Summary of the Muon System

- We conclude that a **particle ID system based on MWPCs and iron absorbers + FCAL** can deliver the $\pi/\mu/e$ 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.

Analysis

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**

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

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

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

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

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

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

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

Determine probabilities *f* with data and simulation

Analysis

3. Azimuthal fits to pion yields

Lab frame distribution of $\vec{k}_1 + \vec{k}_2$ $$N_{\pi\pi} = N_{\Pr imakoff}\left(1 + P_\gamma \cos 2\phi_{\pi\pi}\right) + N_\rho$$

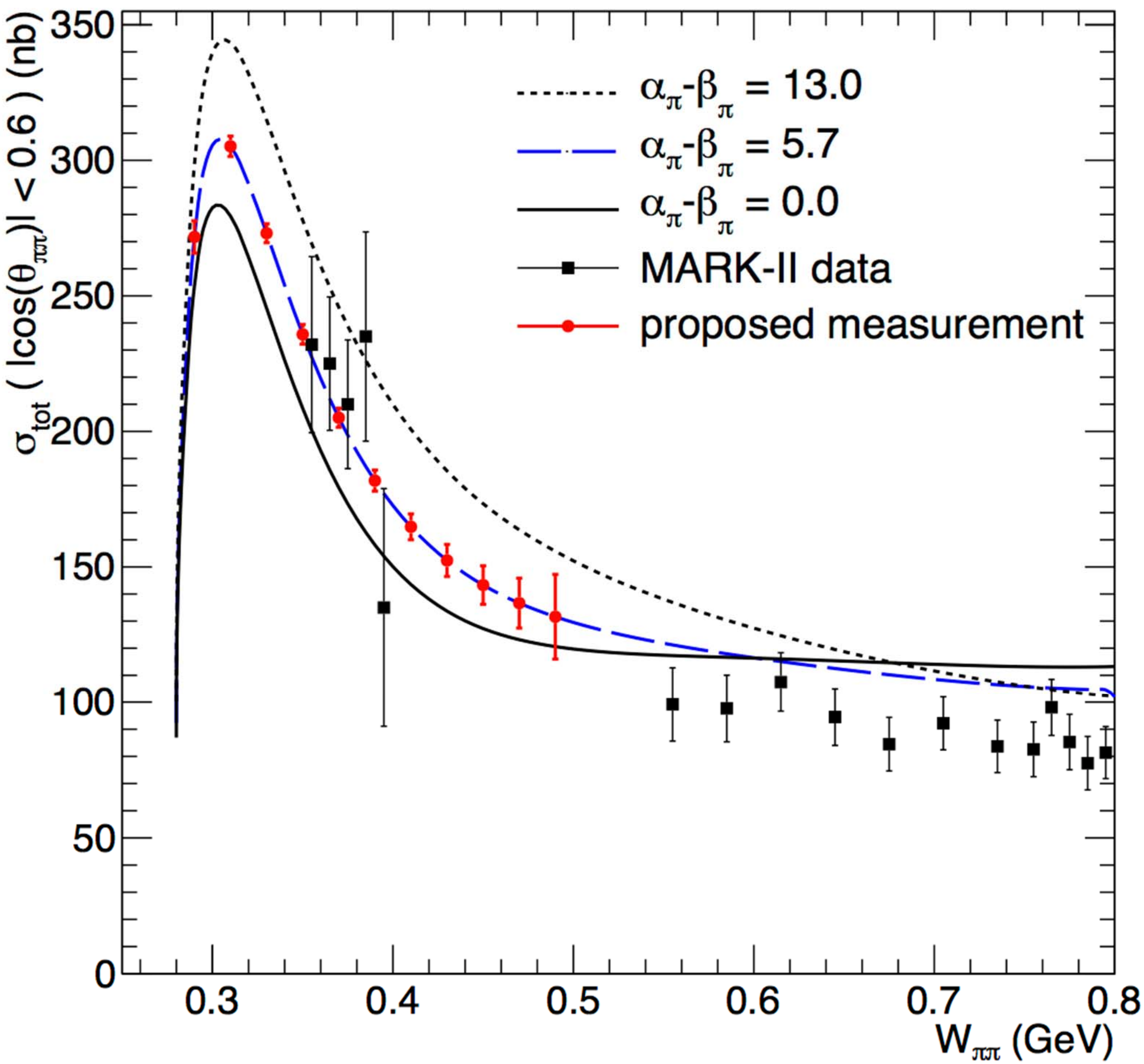
Helicity frame distribution of π^+ $$N_{\pi\pi} = N_\rho (1 + P_\gamma \cos 2\psi) + N_{\Pr imakoff}$$

4. Form ratio with muon yields

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

Corrections from unity	-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%	0.5%
$\mu\mu$ contamination	2%	0.5%
polarization	70%	0.5%
Strong form factor	4%	0.6%
Acceptance	0%	0.5%
Trigger	0%	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

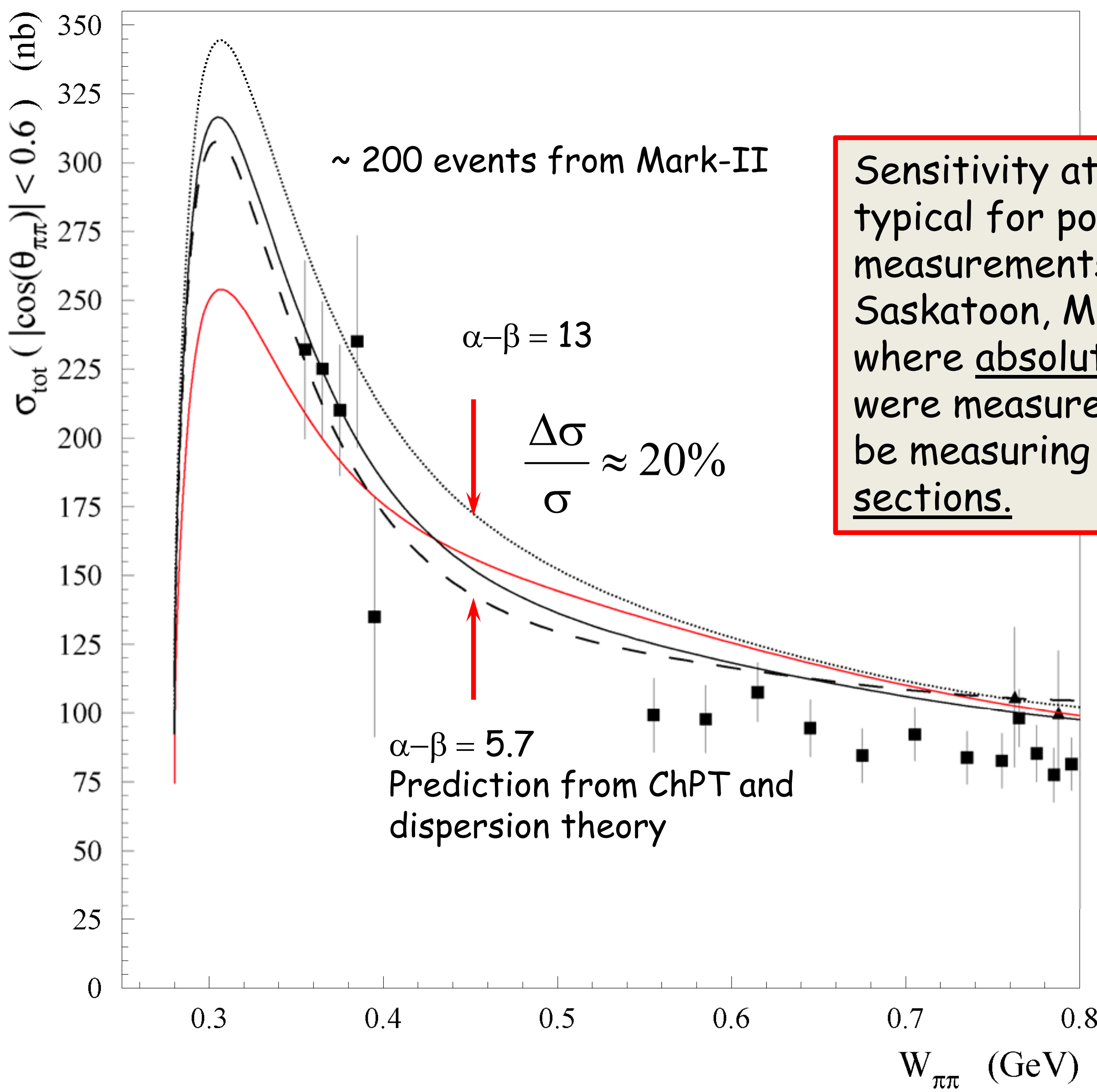
- The charged pion polarizability is predicted by $L_{QCD}(p^4)$. The NLO corrections to $\alpha-\beta$ are small.
- The charged pion polarizability ranks as one of the most important tests of low-energy QCD unresolved by experiment.
- We have proposed to measure the charged pion polarizability $\alpha-\beta$ 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.
- Changes to the standard GlueX setup:

i. muon counter/iron absorber system installed after FCAL, approx. 400 electronics channels

ii. solid target installed near the upstream end of the GlueX magnet.

iii. move the microtagger from 9.0 GeV to 6.0 GeV to increase photon polarization, and ratio of coherent/incoherent bremstrahlung.

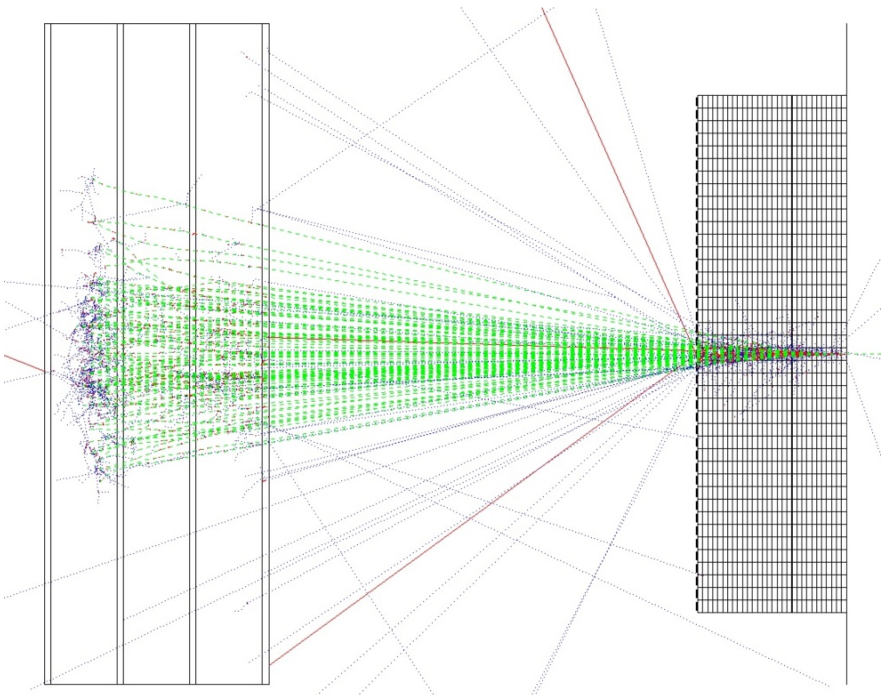
$$\gamma\gamma \rightarrow \pi^+\pi^-$$



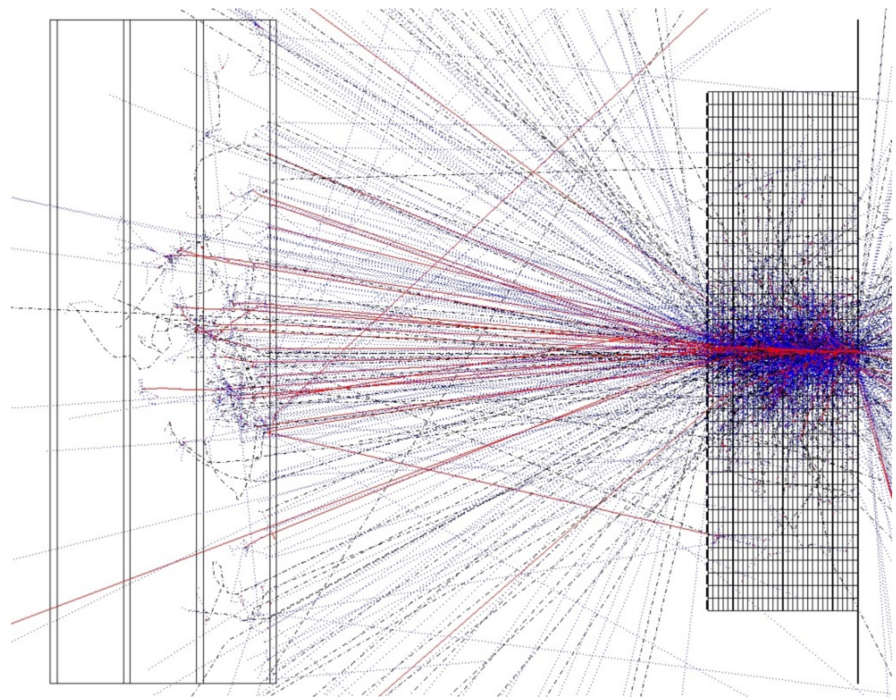
Sensitivity at ~20% level is typical for polarizability measurements at Mainz, Saskatoon, MIT-Bates, and Lund, where absolute cross sections were measured. At JLab we will be measuring relative cross sections.

Geant3 Simulations

1 GeV muon



1 GeV pion

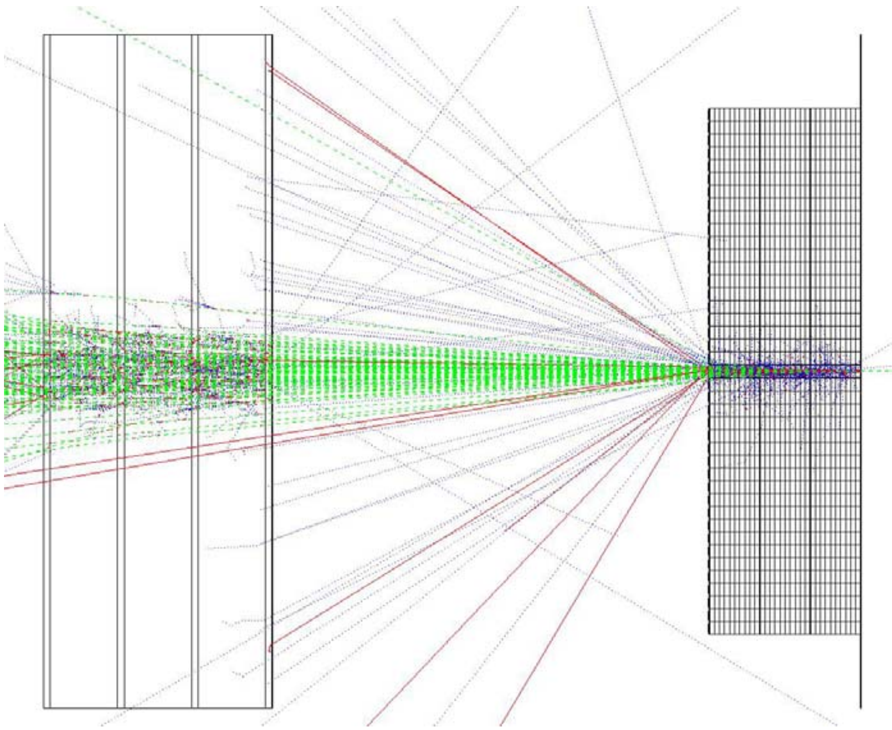


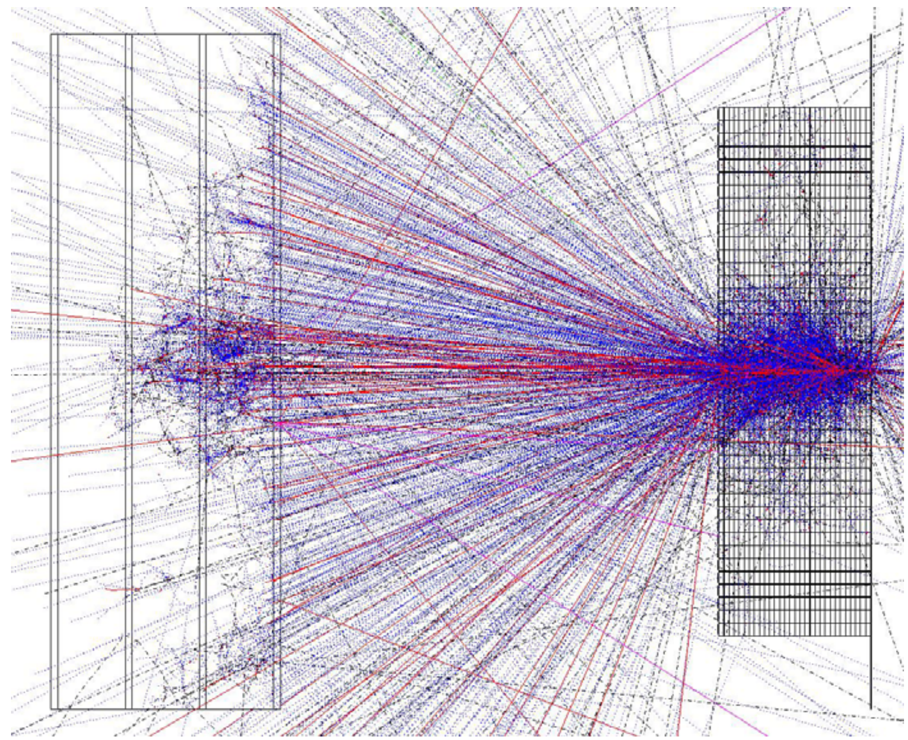
Muon detectors FCAL

Geant3 Simulations

2 GeV muon

2 GeV pion



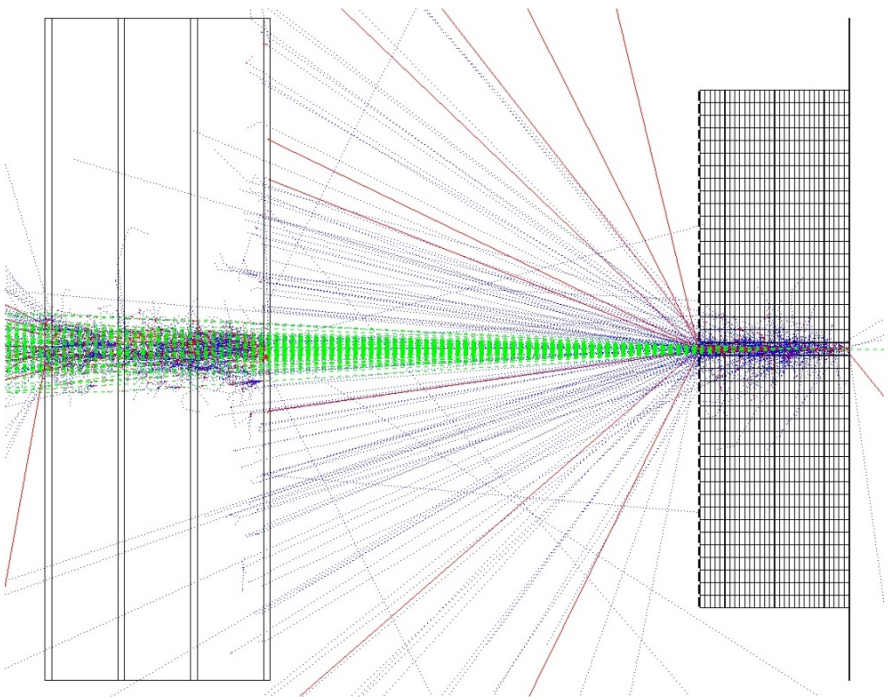


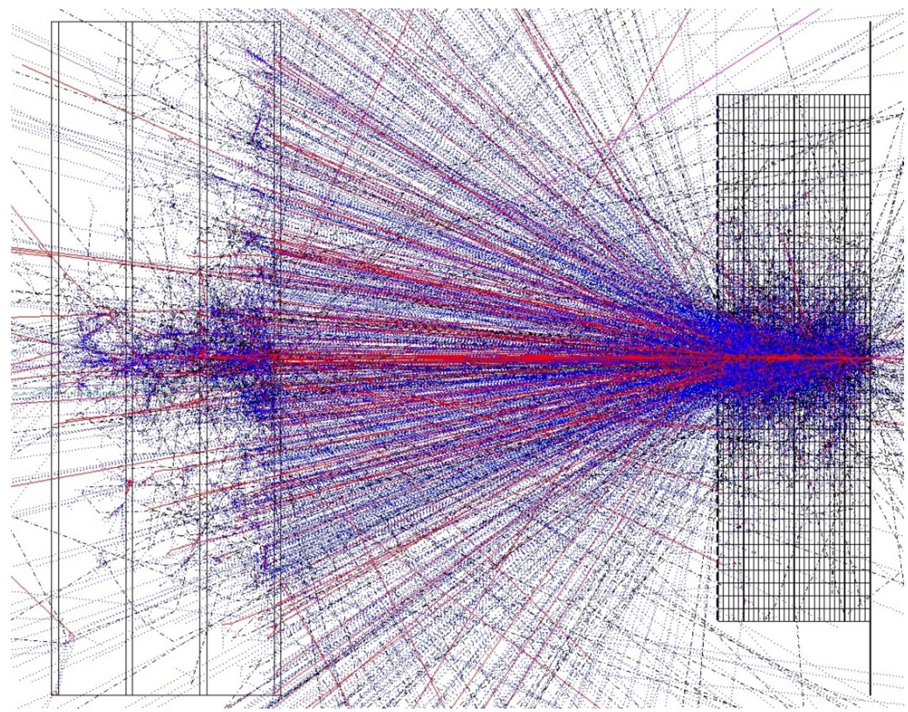
Muon detectors FCAL

Geant3 Simulations

3 GeV muon

3 GeV pion



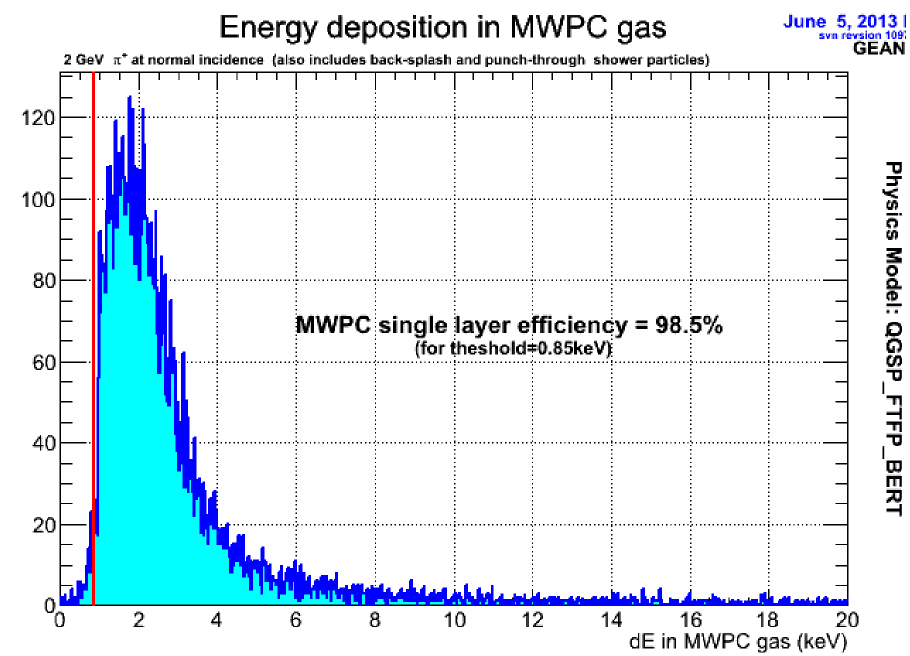


Muon detectors

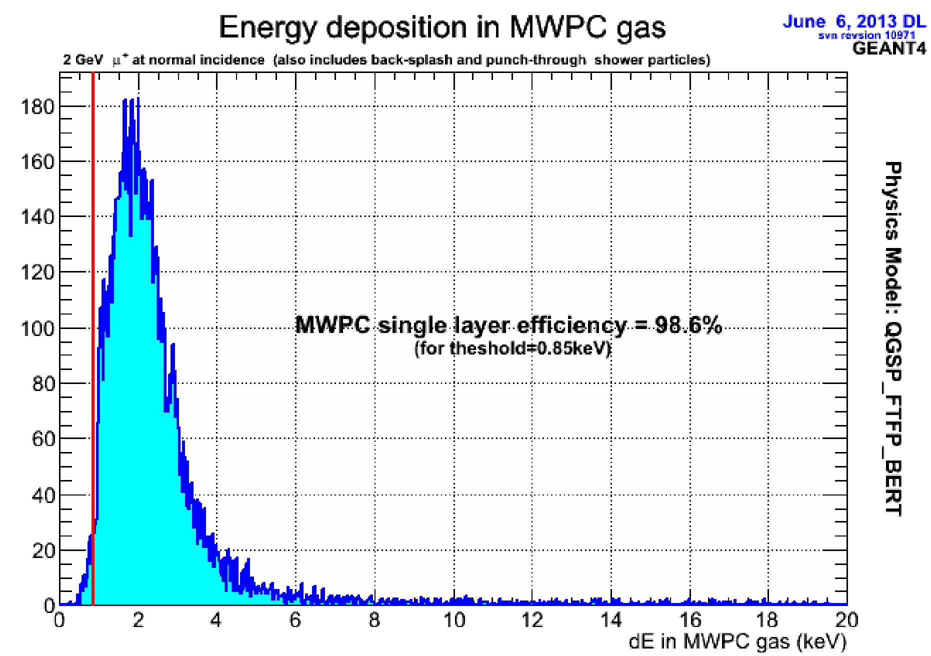
FCAL

Geant4 calculaton of dE/dx in the MWPCs

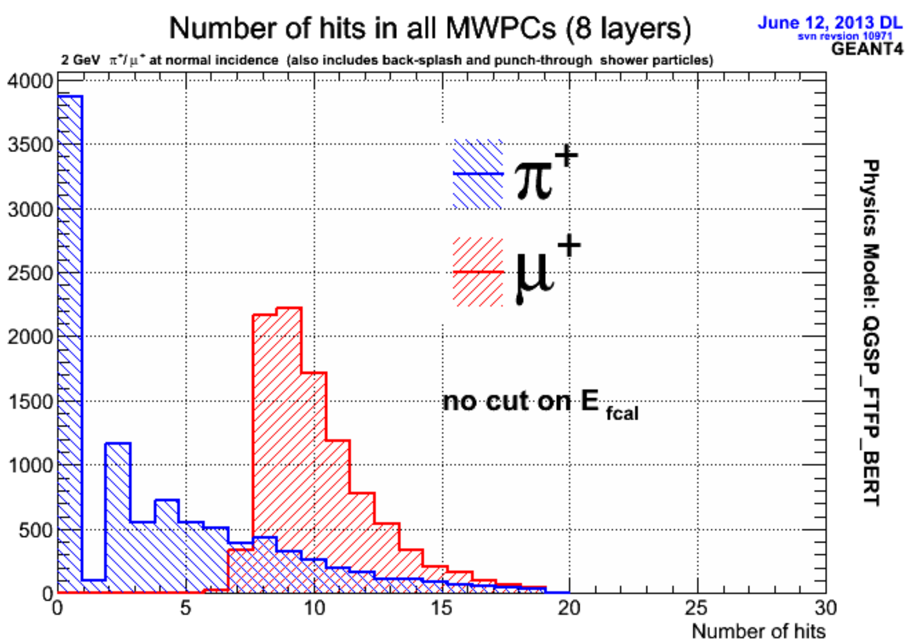
π^+

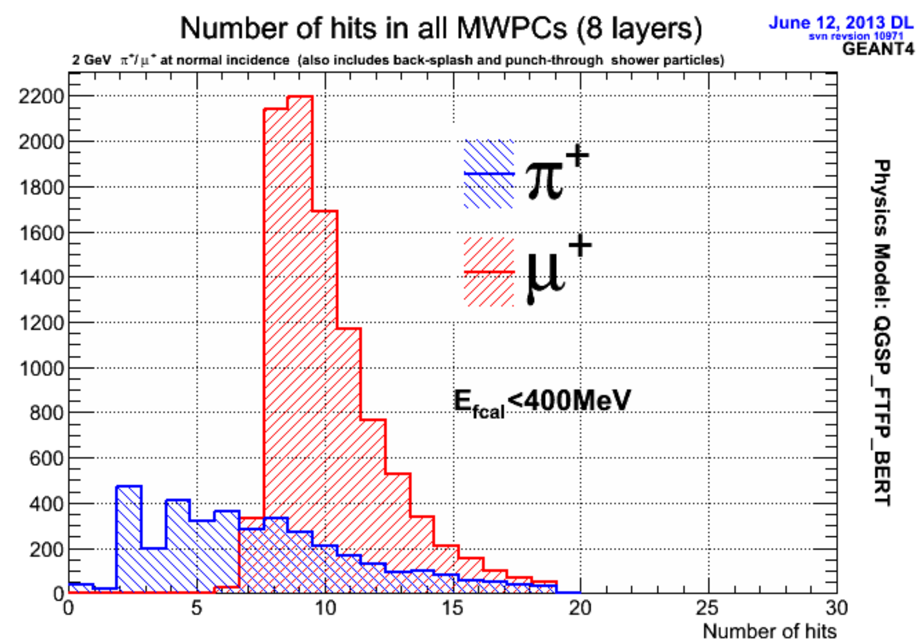


μ^+



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