Search for Hybrid Baryons with CLAS12 experimental setup

ECT* workshop

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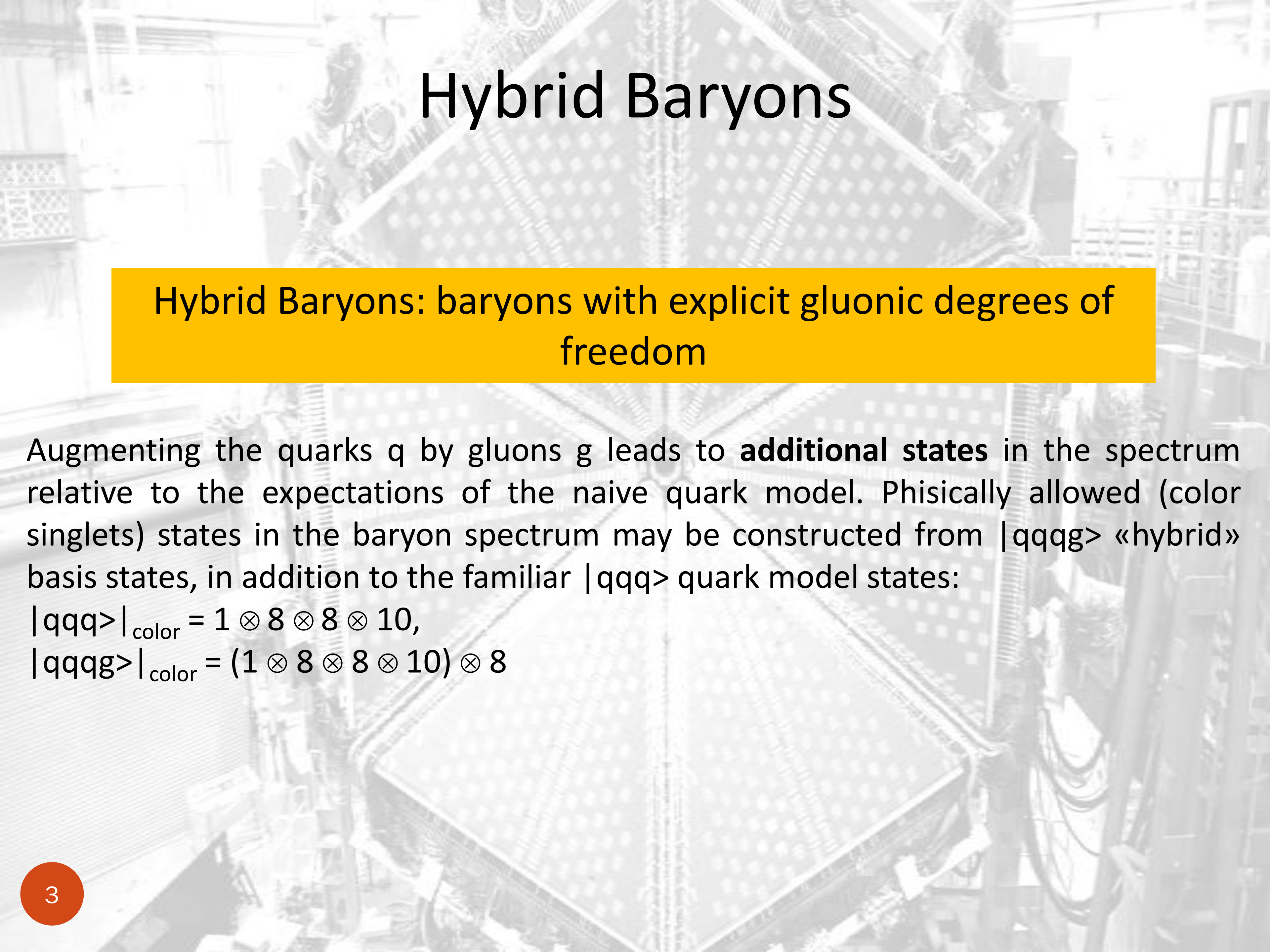
Outline

Physics motivation: Search of Hybrid Baryons contributions in the low Q^2 evolution of the cross section for $K^+\Lambda$ electro-production in CLAS12 → Endorsement of a Letter of Intent by the Program Advisory Committee, PAC43. In this LoI the role of the Forward Tagger (FT) experimental setup is crucial to cover the very low Q^2 kinematical regions.

- **FT Software**: Optimization the FT-Cal cluster reconstruction algorithm and the calibration procedure using the π^0 decay into two photons, and single photon events.
- **Simulation and fast mc reconstruction** of $K^+\Lambda$ electro-production events in CLAS12



Hybrid Baryons

Hybrid Baryons: baryons with explicit gluonic degrees of freedom

Augmenting the quarks q by gluons g leads to **additional states** in the spectrum relative to the expectations of the naive quark model. Phisically allowed (color singlets) states in the baryon spectrum may be constructed from |qqqg> «hybrid» basis states, in addition to the familiar |qqq> quark model states:

$|qqq>|_{color} = 1 \otimes 8 \otimes 8 \otimes 10,$

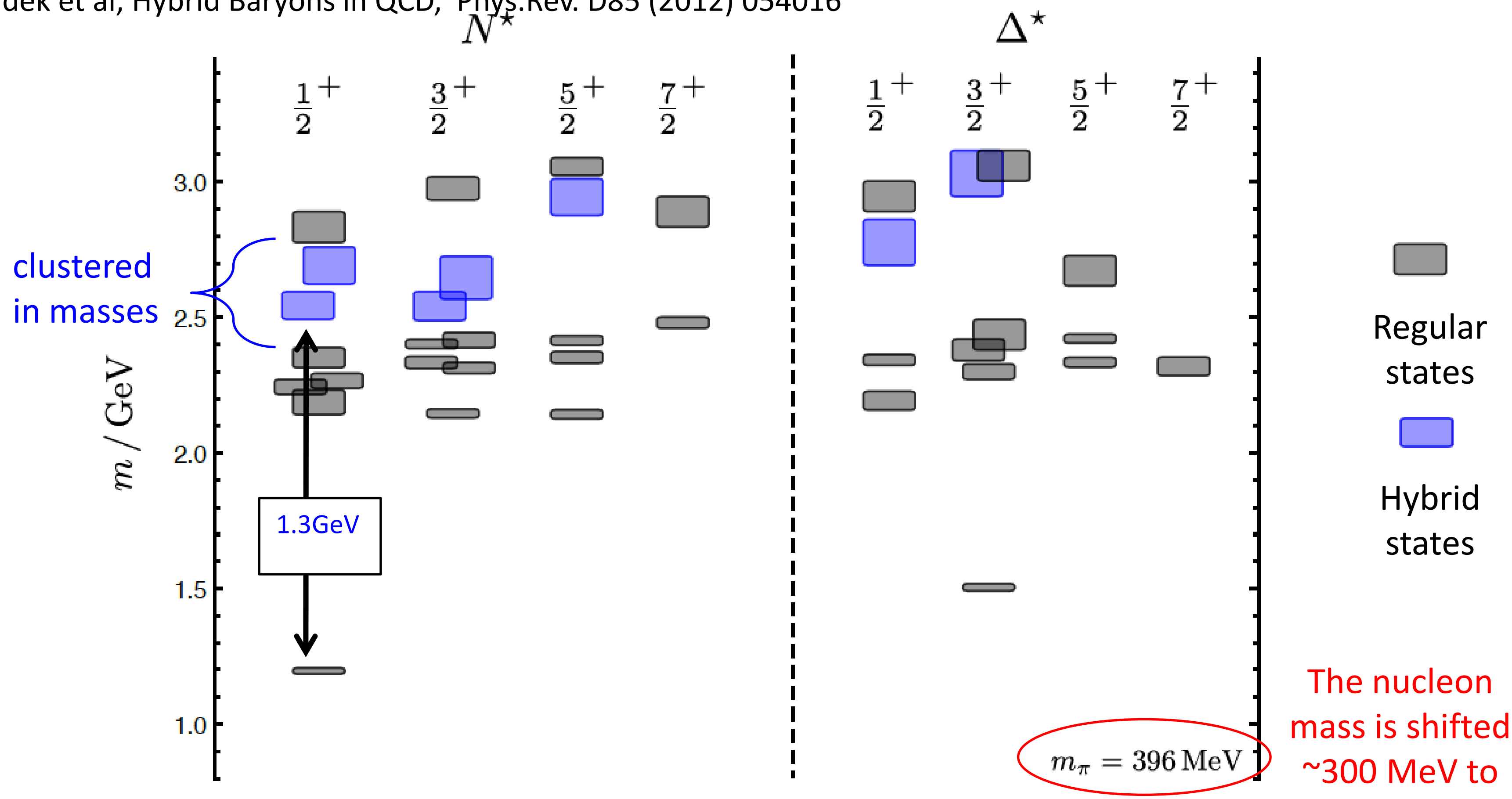
$|qqqg>|_{color} = (1 \otimes 8 \otimes 8 \otimes 10) \otimes 8$

Hybrid Baryons in LQCD

QCD allows for the existence of Hybrid Baryons.

LQCD predicts several hybrid baryons states.

J. Dudek et al, Hybrid Baryons in QCD, Phys.Rev. D85 (2012) 054016

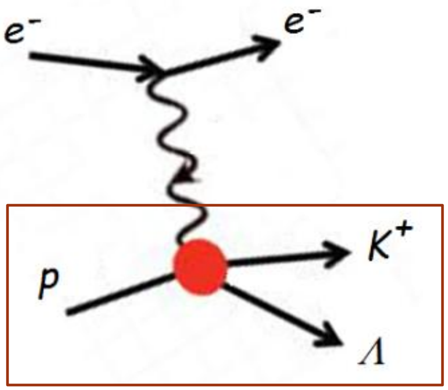


The nucleon mass is shifted ~300 MeV to higher masses

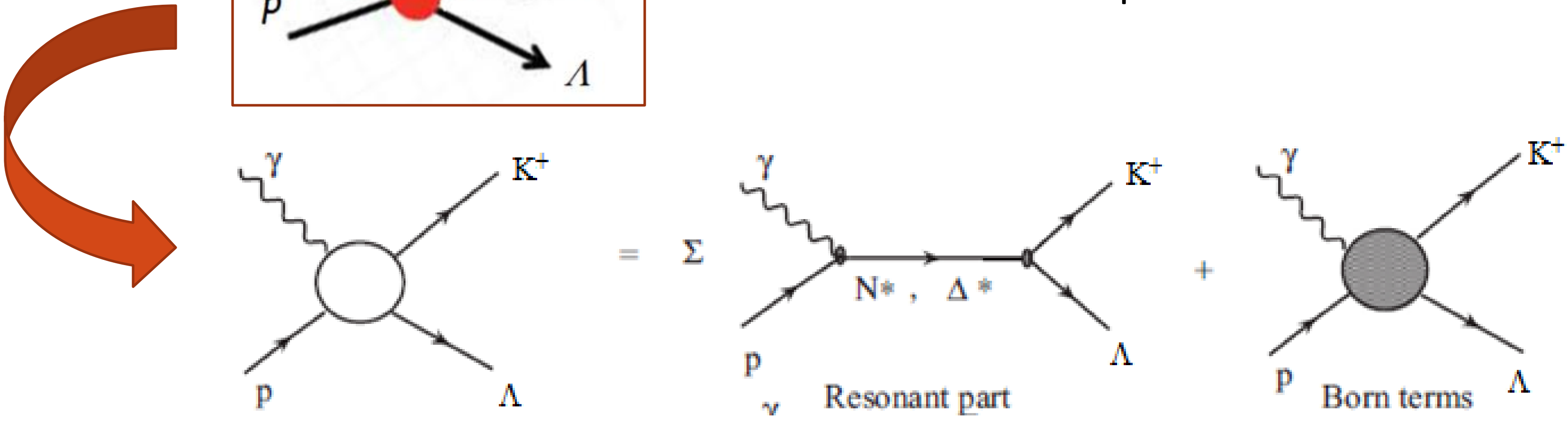
Differently from the case of hybrid mesons, hybrid baryons are predicted to have **same quantum numbers** of N* resonances

Separating Q^3G from Q^3 states: $A_{1/2,\,3/2}(Q^2)$ and $S_{1/2}(Q^2)$

Transverse elicity amplitude $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$ and longitudinal elicity amplitude $S_{1/2}(Q^2)$ allow to distinguish Q^3G from Q^3 states

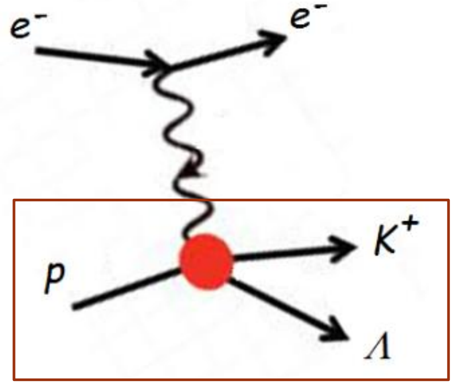


Electroexcitation via quasi-real photon exchange can be considered for practical purposes photo-production



V. I. Mokeev, CLAS Collaboration, PHYSICAL REVIEW C 86, 035203 (2012)

Separating Q^3G from Q^3 states: $A_{1/2,\,3/2}(Q^2)$ and $S_{1/2}(Q^2)$



Resonant contribution in the helicity rapresentation

Helicities of final state hadrons

Helicities of γ and p

N* helicity = $\lambda_\gamma - \lambda_p$

$$\langle \lambda_f | T_r | \lambda_\gamma \lambda_p \rangle = \sum_{N^*} \frac{\boxed{\langle \lambda_f | T_{dec} | \lambda_R \rangle} \boxed{\langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle}}{M_r^2 - W^2 - i\Gamma_r(W) M_r}$$

where

Resonance mass

Energy dependent total width

Invariant mass

The ***N**** **hadronic decay amplitudes** can be expanded in **partial waves** of total momentum *J*

$$\langle \lambda_f | T_{dec} | \lambda_R \rangle = \langle \lambda_f | T_{dec}^{J_r} | \lambda_R \rangle d_{\mu\nu}^{J_r}(\cos\theta^*) e^{i\mu\phi^*}$$

where

$$\langle \lambda_f | T_{dec}^{J_r} | \lambda_R \rangle = \frac{2\sqrt{2\pi}\sqrt{2J_r+1} M_r \sqrt{\Gamma_{\lambda_f}}}{\sqrt{\langle p_i^r \rangle}} \sqrt{\frac{\langle p_i^r \rangle}{\langle p_i \rangle}}$$

The **resonance electroexcitation amplitudes** can be related to the $\gamma_v NN^*$ electrocouplings $\mathbf{A_{1/2}}$, $\mathbf{A_{3/2}}$, and $\mathbf{S_{1/2}}$ for nucleons

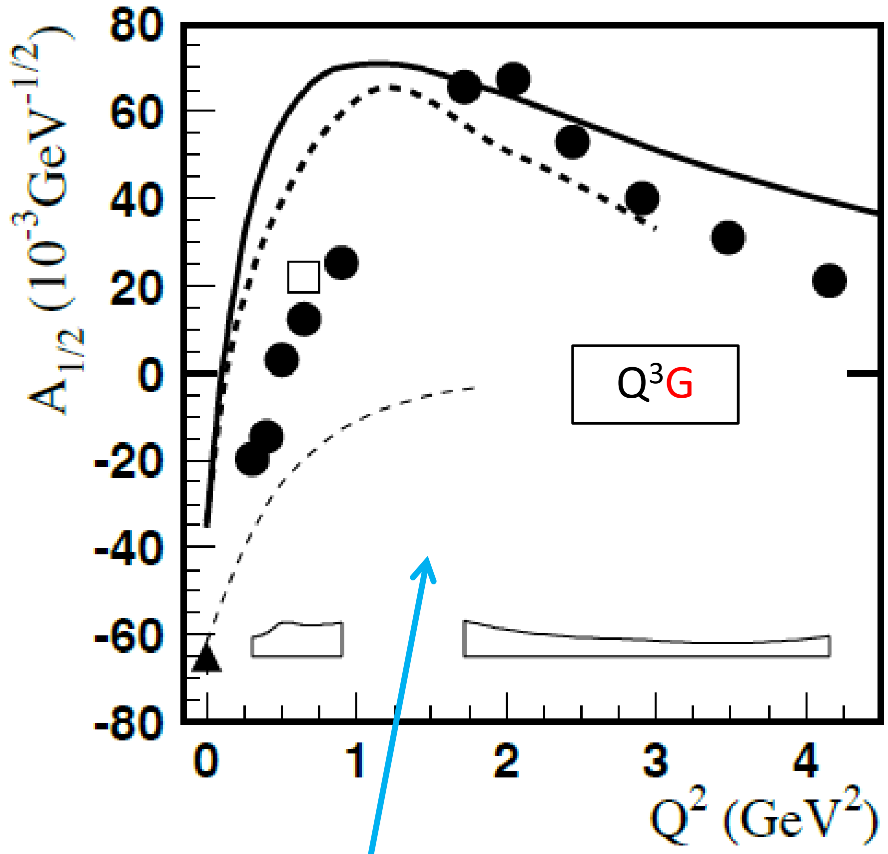
$$\langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle = \frac{W}{M_r} \sqrt{\frac{8 M_N M_r q_{\gamma_r}}{4\pi\alpha}} \sqrt{\frac{q_{\gamma_r}}{q_\gamma}} A_{1/2,3/2}(Q^2) \quad \text{with} \quad |\lambda_\gamma - \lambda_p| = \frac{1}{2}, \frac{3}{2} \text{ for transverse photons,}$$

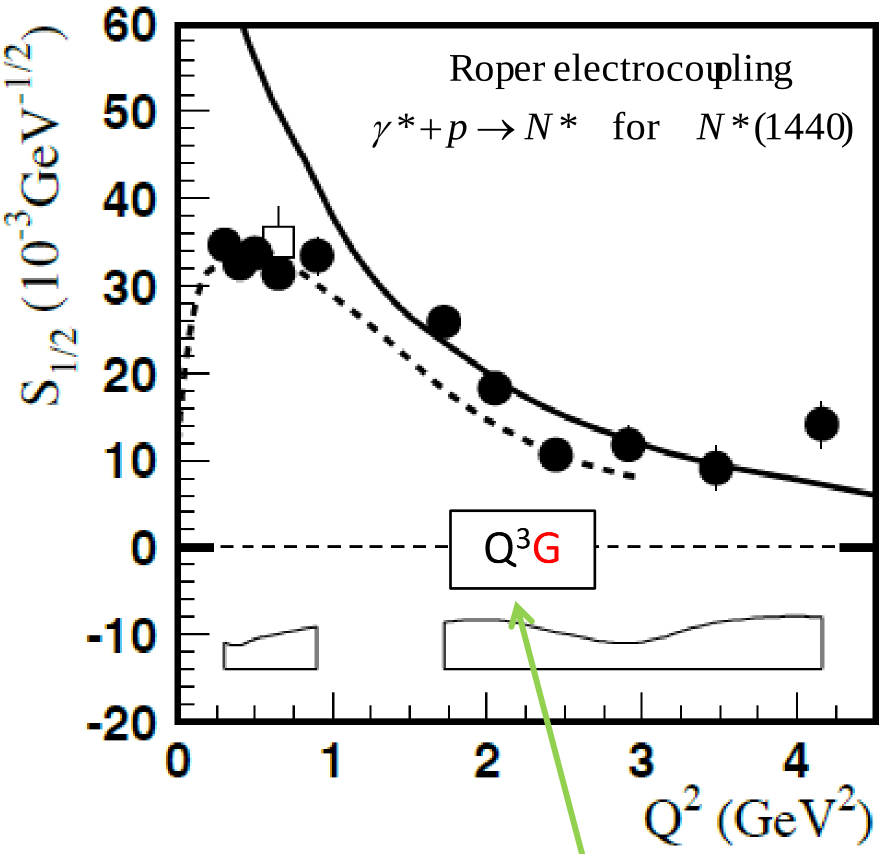
$$\langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle = \frac{W}{M_r} \sqrt{\frac{16 M_N M_r q_{\gamma_r}}{4\pi\alpha}} \sqrt{\frac{q_{\gamma_r}}{q_\gamma}} S_{1/2}(Q^2) \text{ for longitudinal photons}$$

V. I. Mokeev, CLAS Collaboration, PHYSICAL REVIEW C 86, 035203 (2012)

Separating Q^3G from Q^3 states

Transverse helicity amplitude $A_{1/2}(Q^2)$ and longitudinal helicity amplitude $S_{1/2}(Q^2)$ allow to distinguish Q^3G from Q^3 states





A drop of the transverse helicity amplitudes $A_{1/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure

A suppressed longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude

I. G. Aznauryan et al., CLAS Collaboration, PHYSICAL REVIEW C 80, 055203 (2009)

Signature

Based on available knowledge, the ***signature*** for hybrid baryons may consist of ***:***

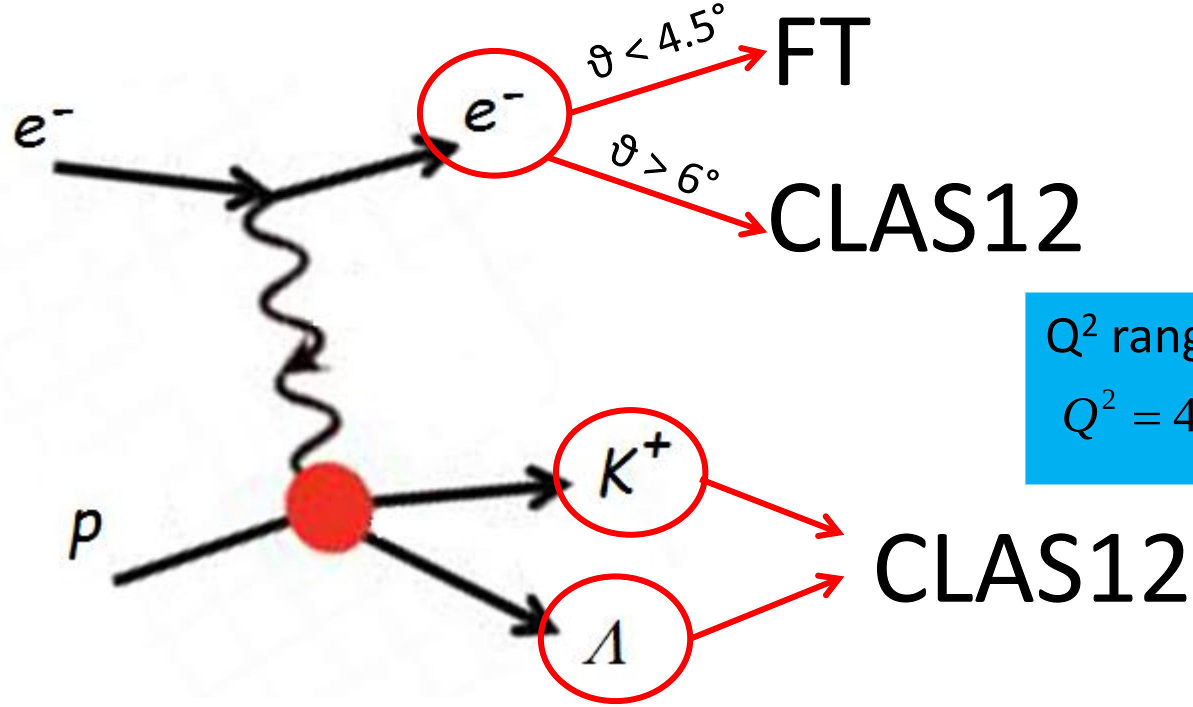
- Extra resonances with masses with $J^p=1/2^+$ from 1.8 GeV to 2.5 GeV and decays to Nππ or KY final states

- A drop of the transverse helicity amplitudes $A_{1/2}(Q^2)$ and $A_{3/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure

- A suppressed longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude

Experiment

Scattered electrons will be detected in Forward Tagger for angles from 2.5° to 4.5°. FT allows to probe the **crucial Q^2 range** where hybrid baryons may be identified due to their fast dropping $A_{1/2}(Q^2)$ amplitude and the suppression of the scalar $S_{1/2}$ (Q^2) amplitude.

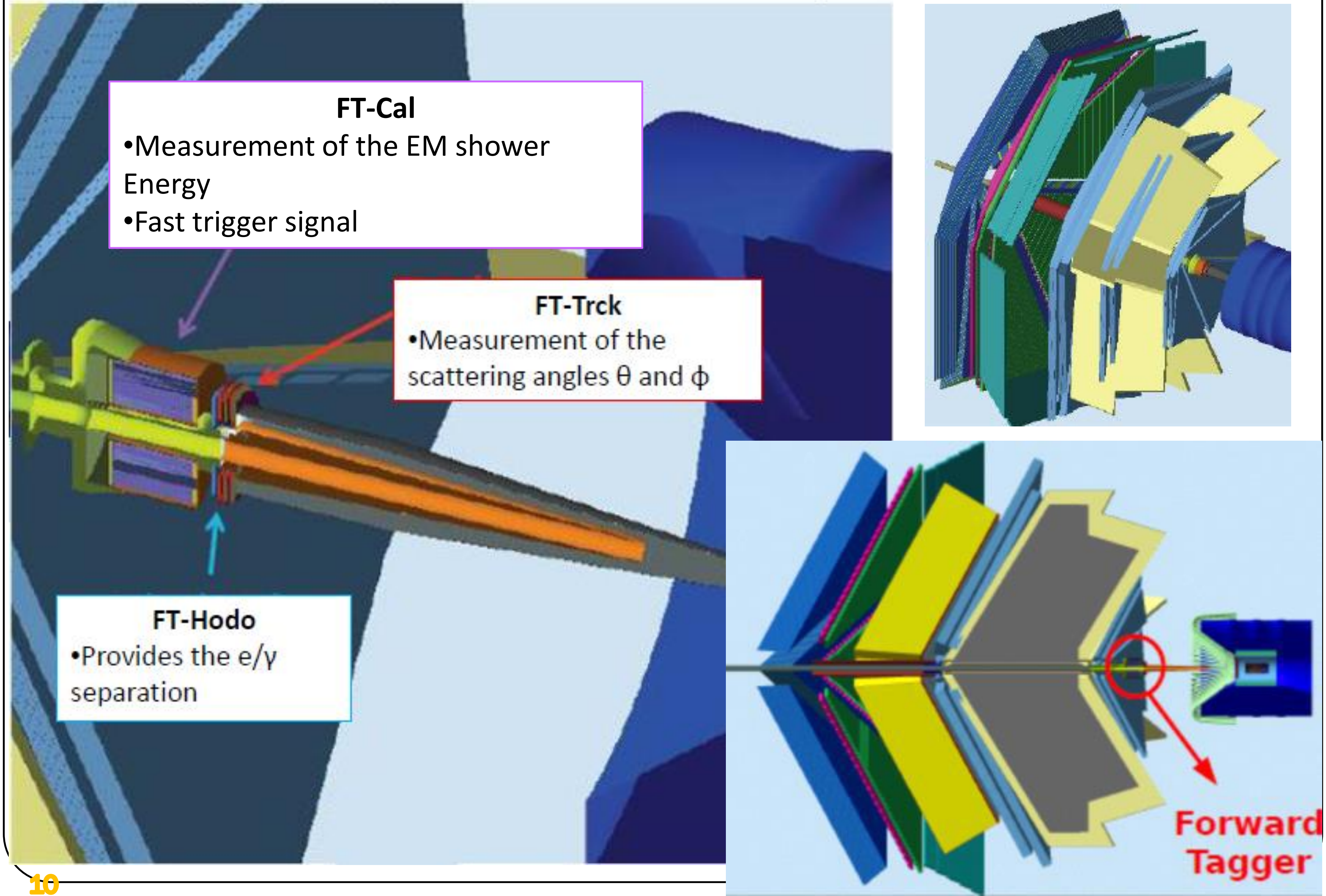


Q^2 range of interest: 0.05 - 2 GeV^2

$$Q^2 = 4E_{Beam}E_{e'}\sin^2\frac{\vartheta}{2} \quad \Rightarrow \quad \vartheta < 5°$$

Scattered electrons will be detected in the Forward Detector of CLAS12 for scattering angles greater than about 6°. Charged hadrons will be measured in the full range from 6° to 130°.

The Forward Tagger (FT): Experimental Setup



FT-Cal

- Measurement of the EM shower Energy
- Fast trigger signal

FT-Trck

- Measurement of the scattering angles θ and ϕ

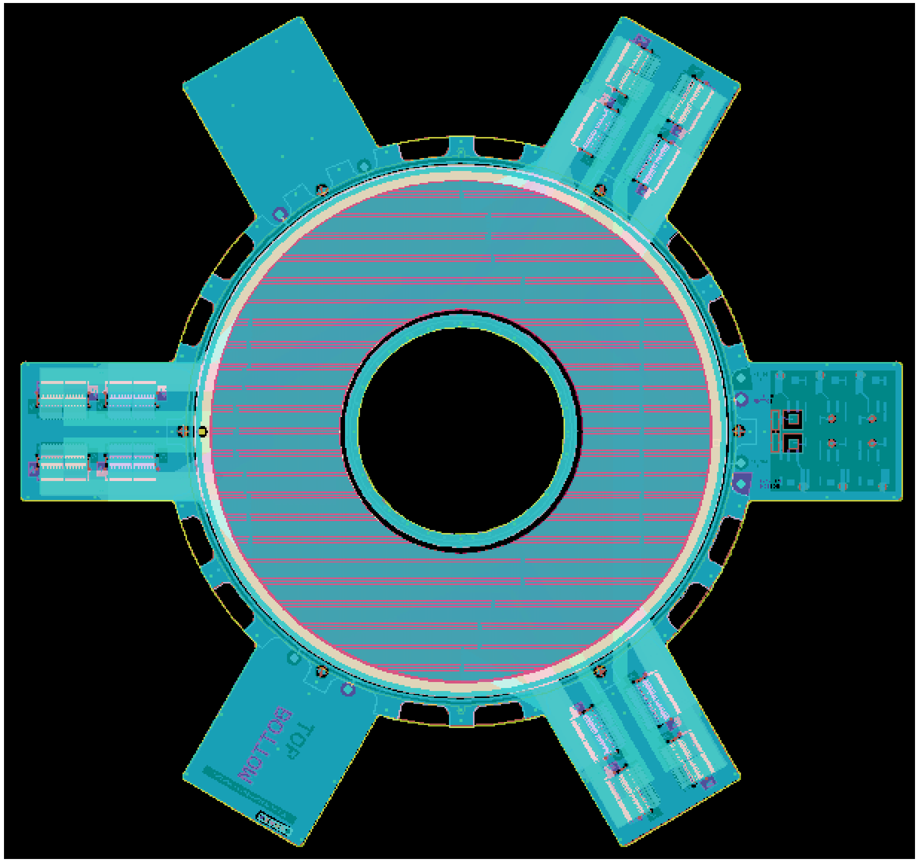
FT-Hodo

- Provides the e/γ separation

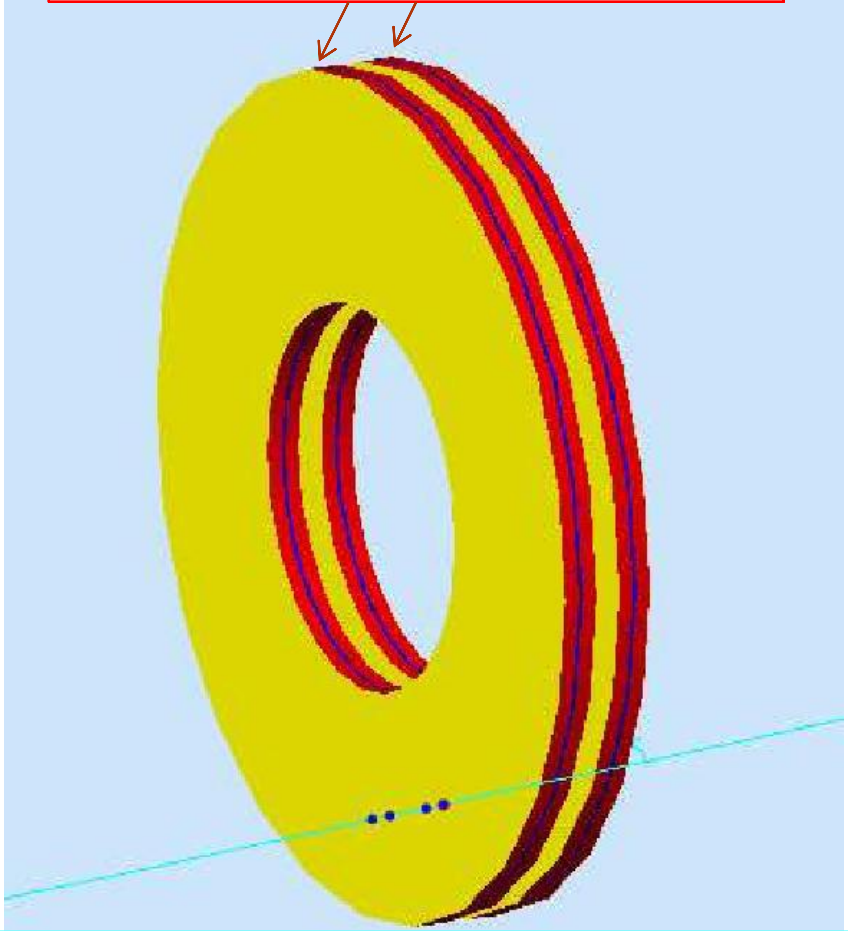
The Tracker (FT-Trck)

Micromegas detectors exploit the gas ionization process with charged particles to:

- Reconstruct the electron point of impact and path



Two layers of pairs of Micromegas detectors with strip readout

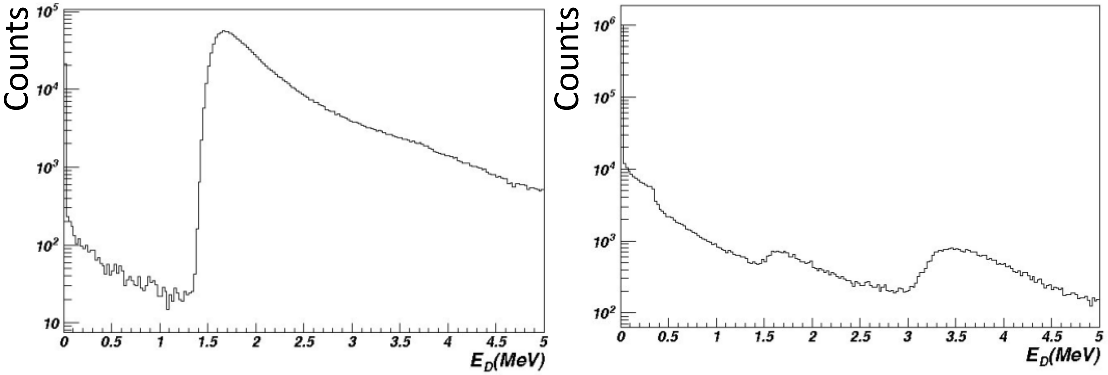


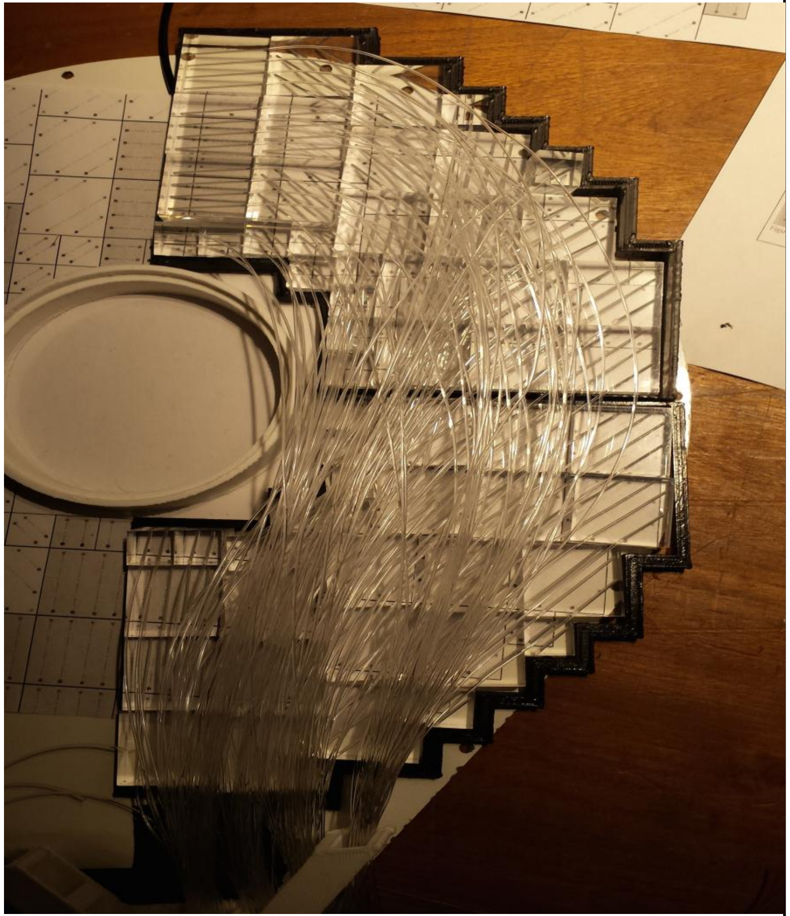
The strips of two different Micromegas in the same layer are orthogonal to produce a (x,y) couple

The Hodoscope (FT-Hodo)

E released in the hodoscope by an e^-

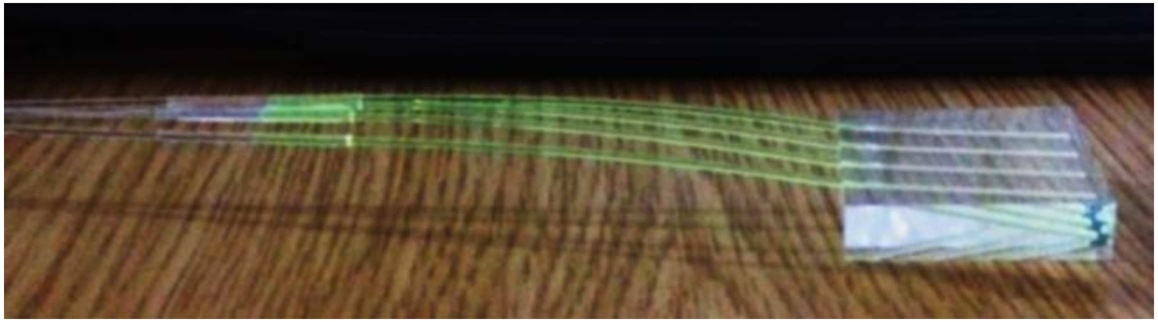
E released in the hodoscope by a γ





232 scintillator tiles, 752 fibers in total

Wavelength shifting (WLS) fibres

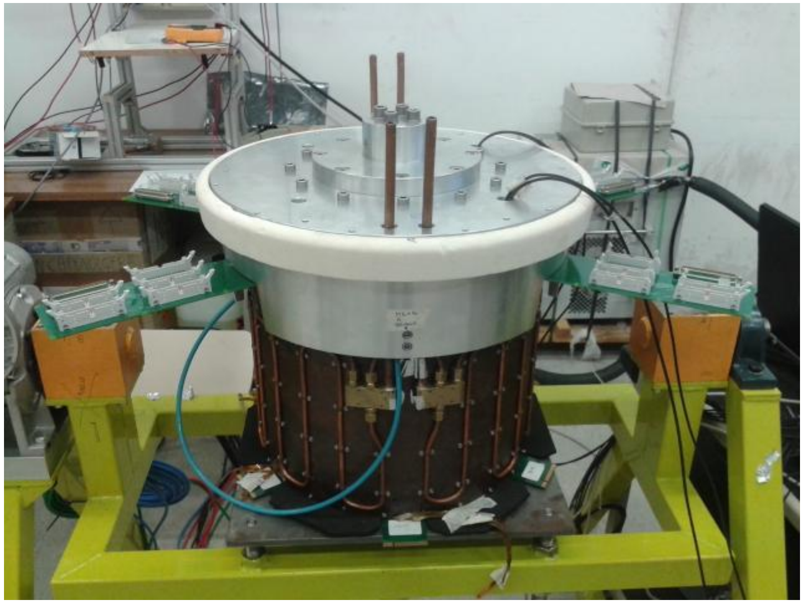


Two layers of plastic **scintillator tiles**

The Electromagnetic Calorimeter (FT-Cal)

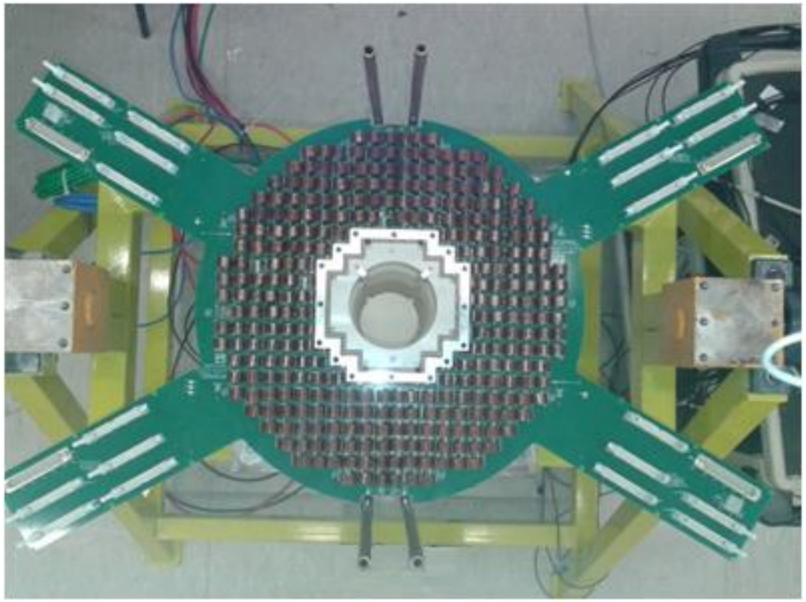
Requirements:

- High radiation hardness
- High light yield
- Small radiation length and Moliere radius
- Fast recovery time
- Good energy and time resolution



Modules of $PbWO_4$ scintillating crystals

Pros	Contra
•High density (8.28 g/cm^3) •Small radiation lenght (0.9 cm) •Very fast decay time (6.5 ns) •Very high radiation hardness	•Poor LY (fraction of % of the NaI one) (100-200 γ/MeV) •Temperature must be controlled to avoid variations in gain and noise



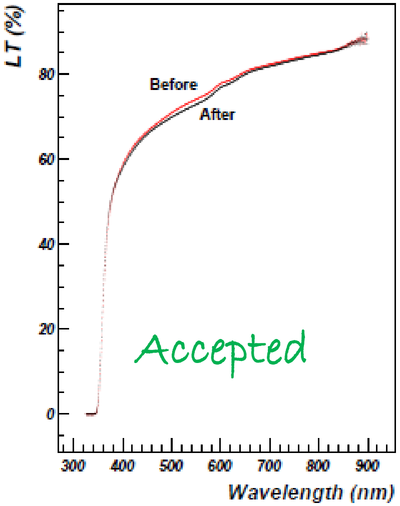
FT-Cal: PWO crystals

Modules of $PbWO_4$ scintillating crystals

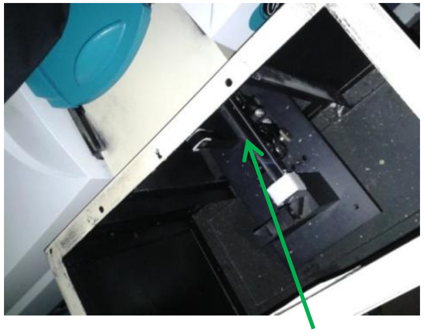
Pros	Contra
•High density (8.28 g/cm^3) •Small radiation lenght (0.9 cm) •Very fast decay time (6.5 ns) •Very high radiation hardness	•Poor LY (fraction of % of the NaI one) (100-200 γ/MeV) •Temperature must be controlled to avoid variations in gain and noise

Giessen measurements: employment of a **spectrophotometer** to perform hardness tests –LT before and after irradiation- on the **332 PWO crystals** that compose the FT calorimeter.

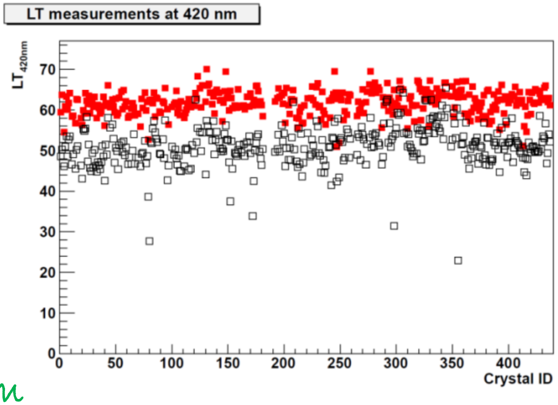
Rejected



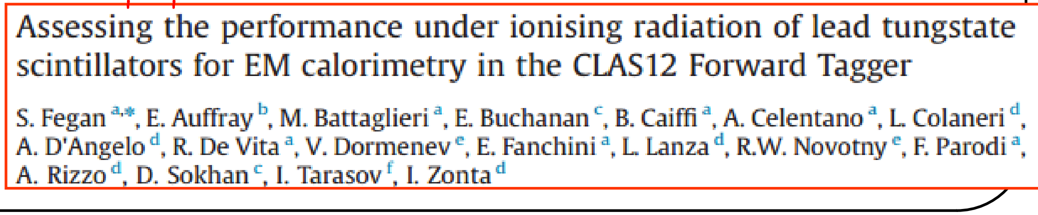
Accepted



SICCAS 20 cm $PbWO_4$



NIM paper:

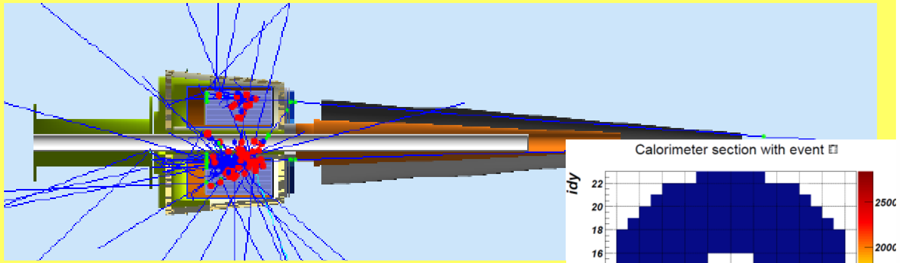


Assessing the performance under ionising radiation of lead tungstate scintillators for EM calorimetry in the CLAS12 Forward Tagger

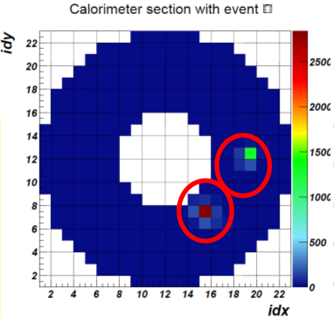
S. Fegan [a,*], E. Auffray [b], M. Battaglieri [a], E. Buchanan [c], B. Caiffi [a], A. Celentano [a], L. Colaneri [d], A. D'Angelo [d], R. De Vita [a], V. Dormenev [e], E. Fanchini [a], L. Lanza [d], R.W. Novotny [e], F. Parodi [a], A. Rizzo [d], D. Sokhan [c], I. Tarasov [f], I. Zonta [d]

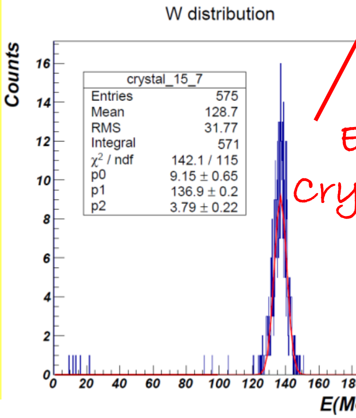
CLAS12 FT-Cal cluster reconstruction algorithm: Calibration using $\pi^0 \rightarrow \gamma\gamma$ process

- Generation of events with a $\pi^0 \rightarrow \gamma\gamma$ with GEMC (**GE**ant4 **M**onte**C**arlo)

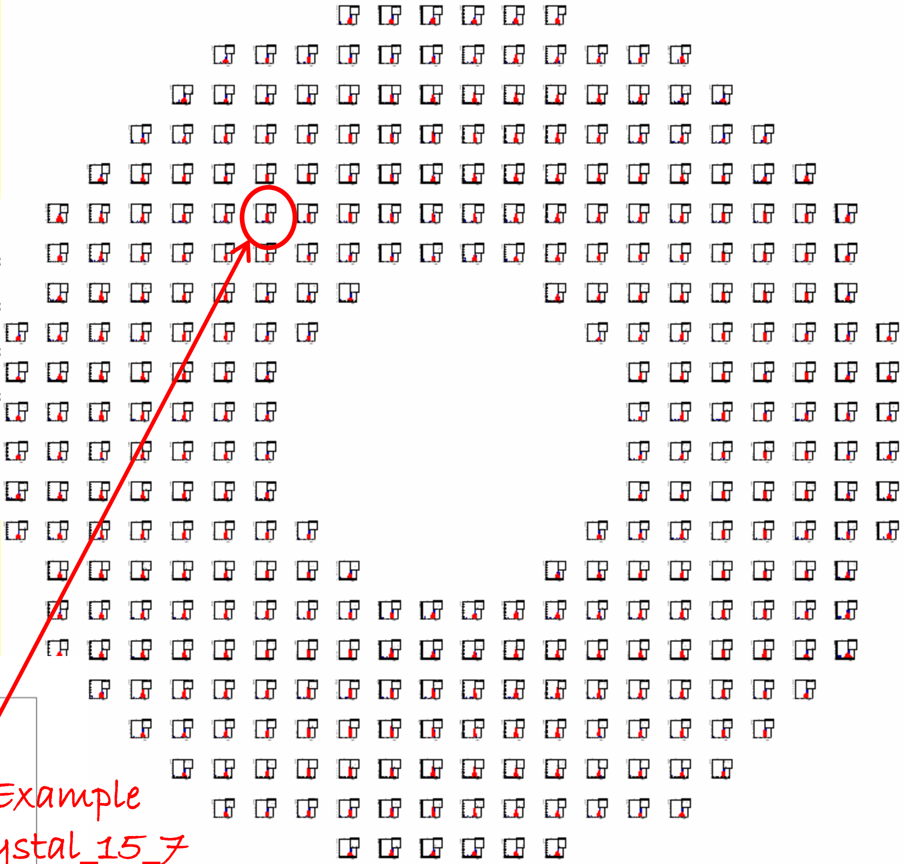


- Search for events with two photons using the flux detectors
- Identification of the clusters corresponding with the couple of photons:
  - Only hits having a minimum energy are considered
  - Reconstruction of the invariant mass of the two clusters: the invariant mass value is inserted in the histograms of the crystals that take part to the clusters
  - Gaussian fit





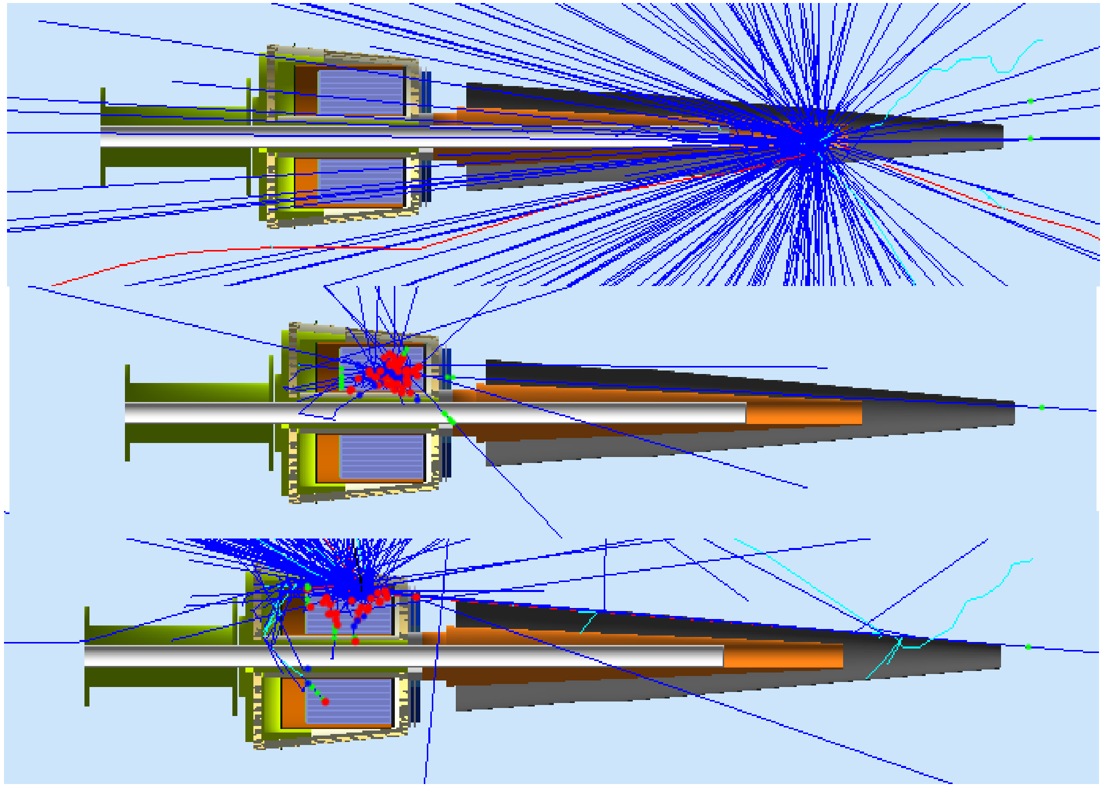
Distribution of the invariant mass of from each of the 332 PWO crystals



Example Crystal_15_7

Hits: events in a single crystal whose amplitude is more than a threshold fixed at 10 MeV
Clusters: sets of hits corresponding to electromagnetic showers in the calorimeter.

Energy corrections as a function of ϑ and E using single photon events



$\vartheta = 2.15°$

$\vartheta = 3.5°$

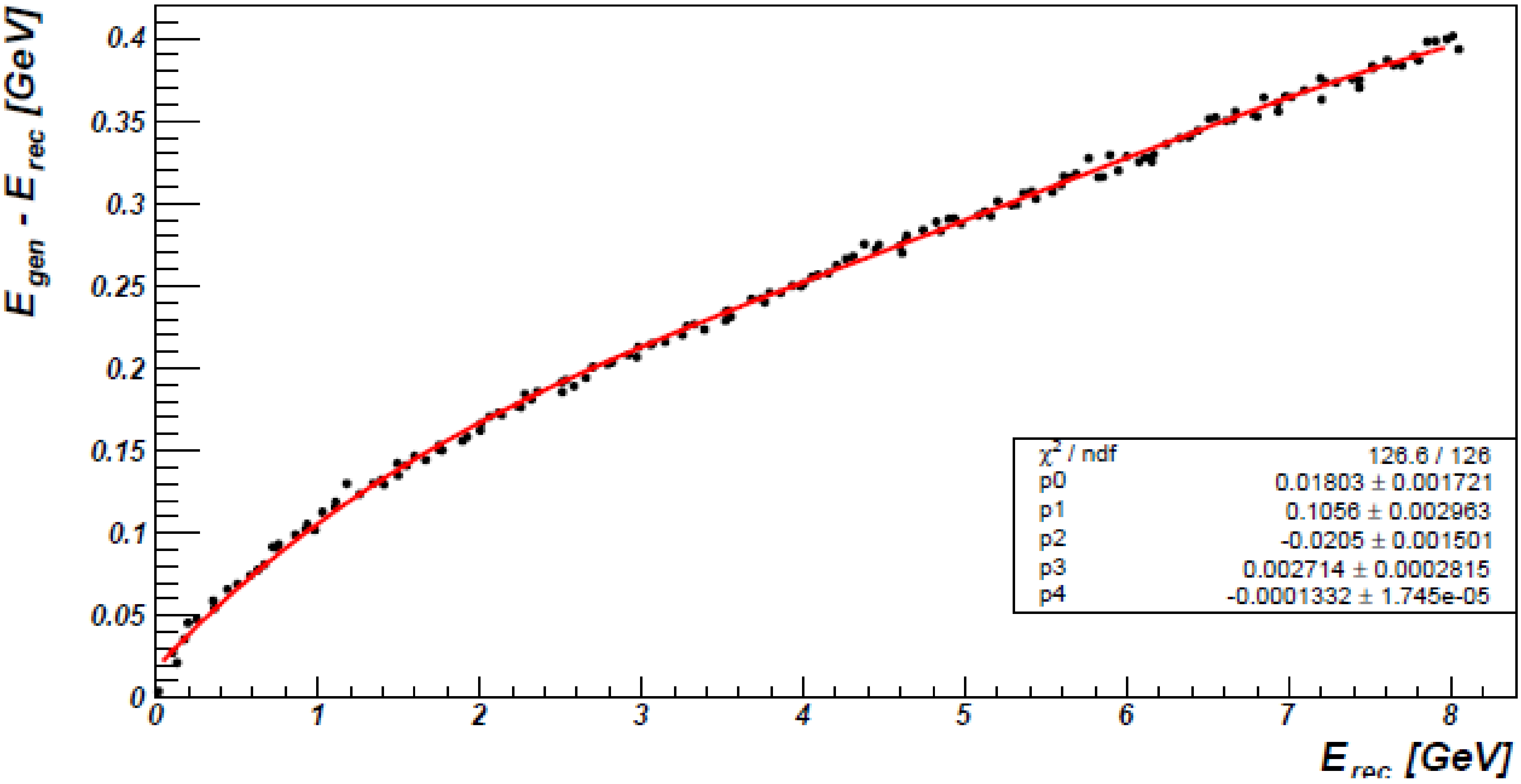
$\vartheta = 4.85°$

We expect a better reconstruction of cluster energy for intermediate values of ϑ ($2.5° < \vartheta < 4.5°$)

Simulation of single photon events have been performed using angles from 2.5° up to 4.5°, with steps of 0.2° and with photon energy 100 MeV < E_{gen} < 8 GeV

- Analysis procedure:
  - Generation of events with GEMC
  - Each event in the same .ev file is generated with random energy in the range [0.1, 8] GeV, and with ϑ fixed at 2.5°, 2.7°, 2.9°, ..., 4.5°
  - The algorithm reconstructs the energy for each event and divides events in energy bins on the basis of their energy
  - For each bin the difference between the reconstructed and the generated energies is displayed.
  - The distributions are fitted with gaussian functions whose means and sigmas are saved for the analysis
- The procedure is repeated for a new set of events characterized by a different ϑ

E_{gen}-E_{rec} vs E_{rec} , $\vartheta = 3.5°$



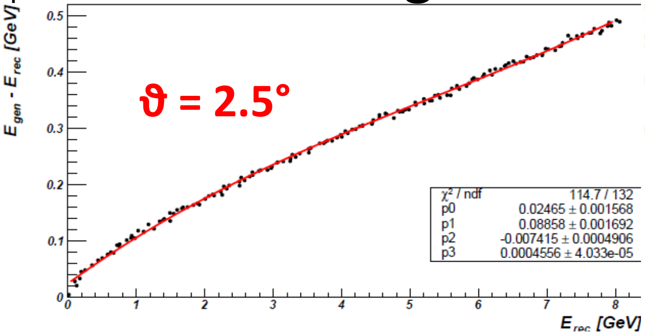
From these fits we can obtain the energy corrections to compensate the difference between E_{gen} - E_{rec}

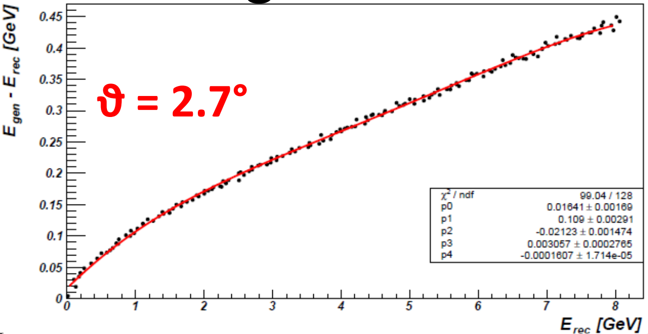
Reconstructed threshold

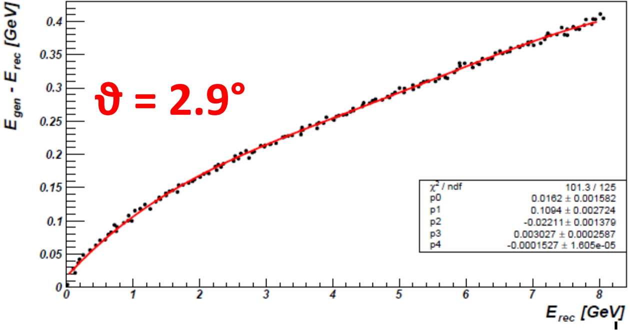
4° degree polynomium

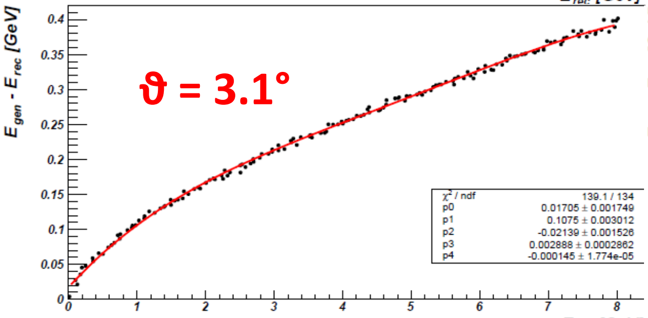
$f(x) = p_0 + p_1x + p_2x^2 + p_3x^3 + p_4x^4$

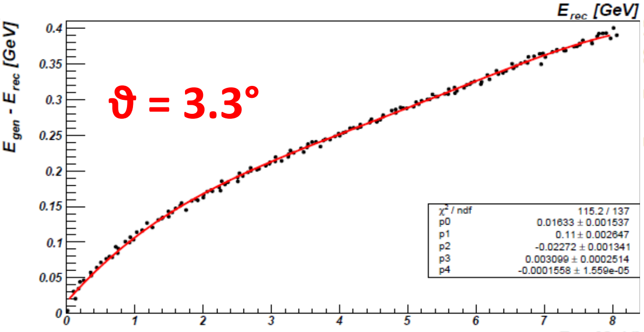
$E_{gen} – E_{rec}$ vs E_{gen} for all ϑ values

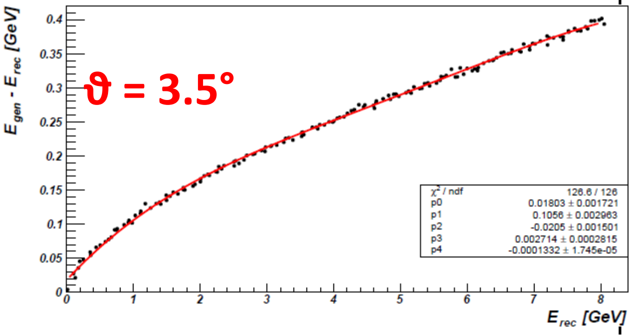


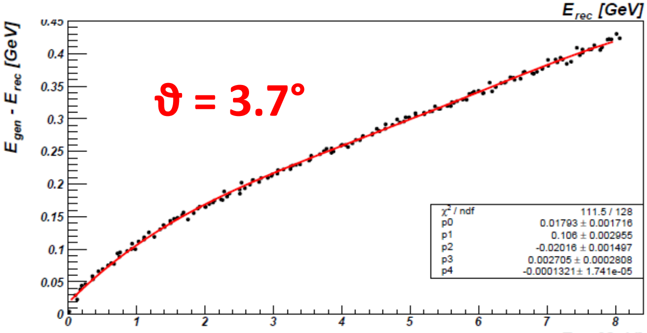


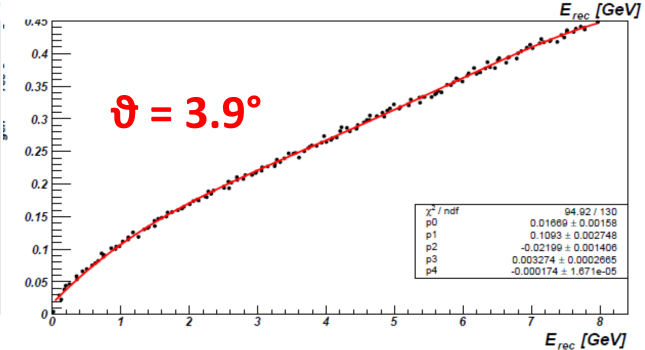


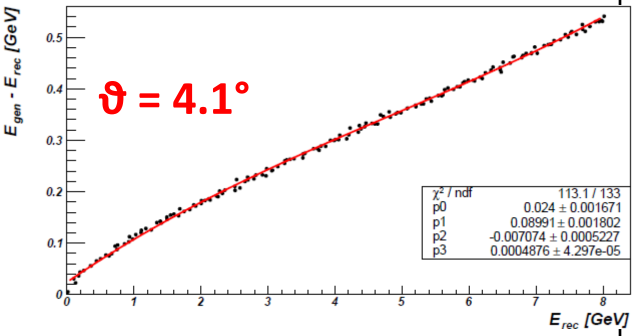


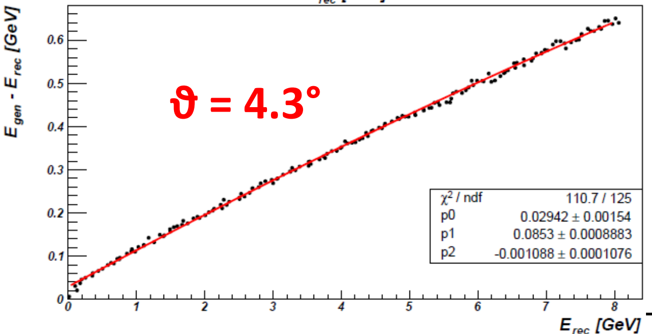


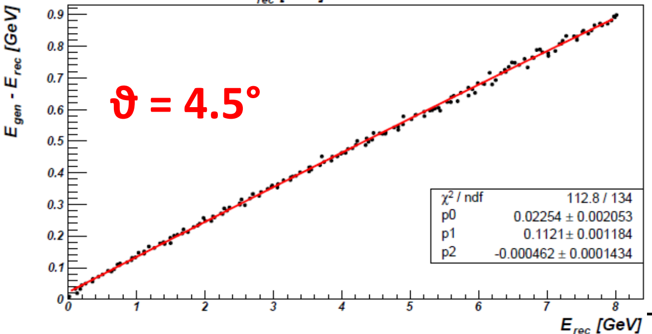












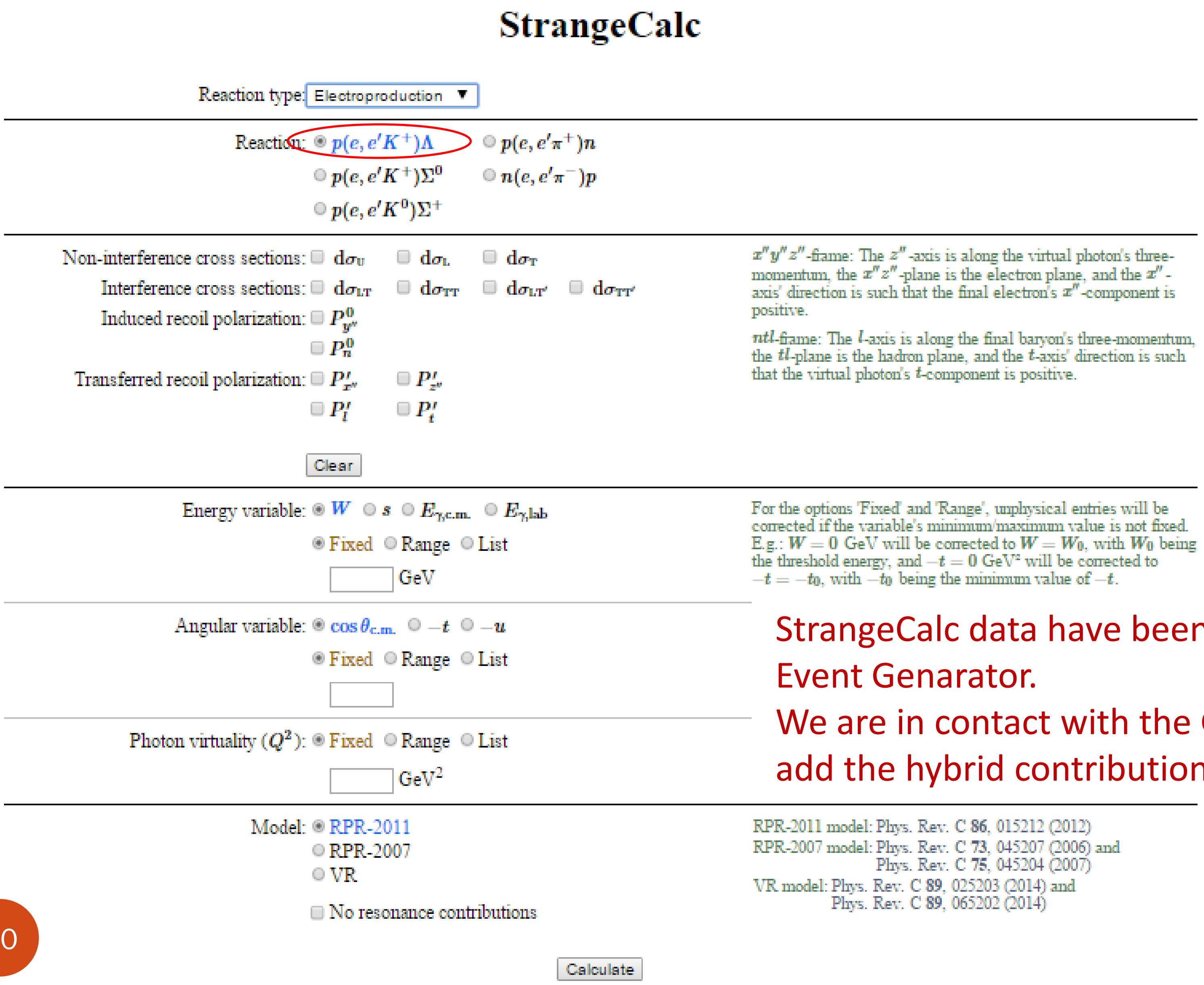
Simulation and fast mc reconstruction of $K^{+}\mathit{\Lambda}$ electro-production events in CLAS12 using the Gent RPR-2011 model

- Develop realistic event generator
- Simulation of *quasi-data* events including simplified experimental effects with FASTMC for channel

$$e + p \rightarrow e' + K^{+} + \Lambda$$

- Selection of trigger conditions
- Production of events with different run conditions to extract the better configuration.
- Conclusions

Available data on “Strange Calc” web site



StrangeCalc

Reaction type: Electroproduction ▼

Reaction: ● $p(e,e'K^+)\Lambda$ ○ $p(e,e'\pi^+)n$
○ $p(e,e'K^+)\Sigma^0$ ○ $n(e,e'\pi^-)p$
○ $p(e,e'K^0)\Sigma^+$

Non-interference cross sections: ☐ $d\sigma_U$ ☐ $d\sigma_L$ ☐ $d\sigma_T$
Interference cross sections: ☐ $d\sigma_{LT}$ ☐ $d\sigma_{TT}$ ☐ $d\sigma_{LT'}$ ☐ $d\sigma_{TT'}$
Induced recoil polarization: ☐ $P^0_{y''}$
☐ P^0_n
Transferred recoil polarization: ☐ $P'_{x''}$ ☐ $P'_{z''}$
☐ P'_l ☐ P'_t

$x''y''z''$-frame: The z''-axis is along the virtual photon's three-momentum, the $x''z''$-plane is the electron plane, and the x''-axis' direction is such that the final electron's x''-component is positive.

ntl-frame: The l-axis is along the final baryon's three-momentum, the tl-plane is the hadron plane, and the t-axis' direction is such that the virtual photon's t-component is positive.

Clear

Energy variable: ● W ○ s ○ $E_{\gamma,\text{c.m.}}$ ○ $E_{\gamma,\text{lab}}$
● Fixed ○ Range ○ List
GeV

For the options 'Fixed' and 'Range', unphysical entries will be corrected if the variable's minimum/maximum value is not fixed. E.g.: $W = 0$ GeV will be corrected to $W = W_0$, with W_0 being the threshold energy, and $-t = 0$ GeV² will be corrected to $-t = -t_0$, with $-t_0$ being the minimum value of $-t$.

Angular variable: ● $\cos\theta_{\text{c.m.}}$ ○ $-t$ ○ $-u$
● Fixed ○ Range ○ List

Photon virtuality (Q^2): ● Fixed ○ Range ○ List
GeV²

Model: ● RPR-2011
○ RPR-2007
○ VR

☐ No resonance contributions

RPR-2011 model: Phys. Rev. C **86**, 015212 (2012)
RPR-2007 model: Phys. Rev. C **73**, 045207 (2006) and Phys. Rev. C **75**, 045204 (2007)
VR model: Phys. Rev. C **89**, 025203 (2014) and Phys. Rev. C **89**, 065202 (2014)

Calculate

StrangeCalc data have been used for the Event Genarator.
We are in contact with the Gent group to add the hybrid contributions.

Trigger conditions and simulations

Step 1

Selection of trigger conditions for fastmc event generator:

- 1 electron in CLAS
- 1 charged particle in CLAS

Or

- 1 electron in FT
- 2 charged particles in CLAS

Charged particle: proton, π^-, k^+

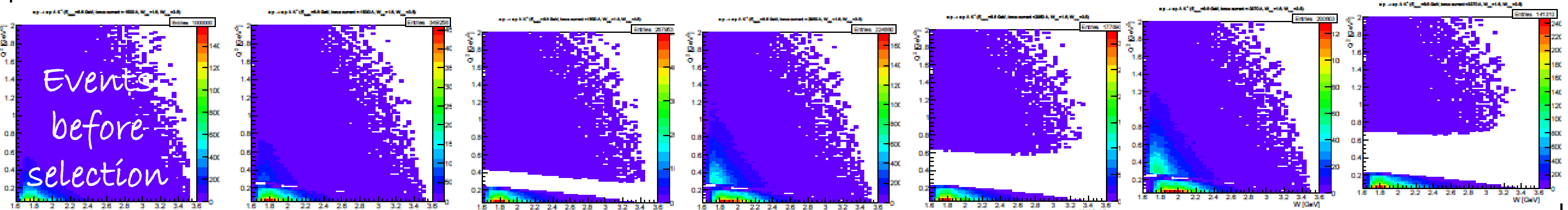
Step 2

Production of plots with the conditions:

- E_{beam}= 6.6 GeV, 8.8 GeV, 11 GeV
- Torus current = ±1500 A, ±2950 A, ±3370 A

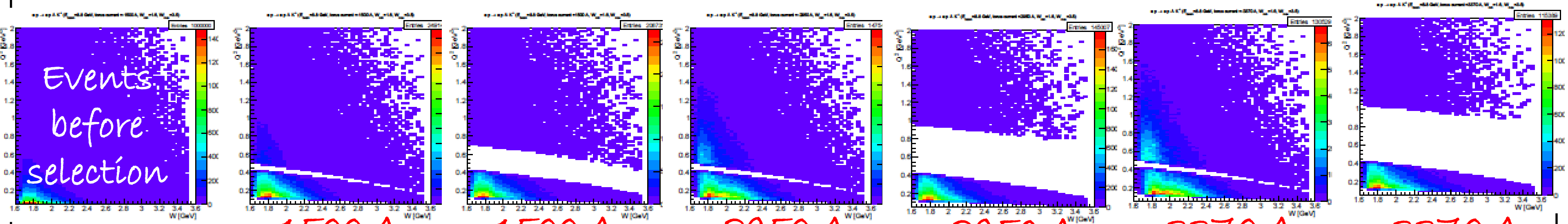
Q^2 vs W for different run conditions

E = 6.6 GeV



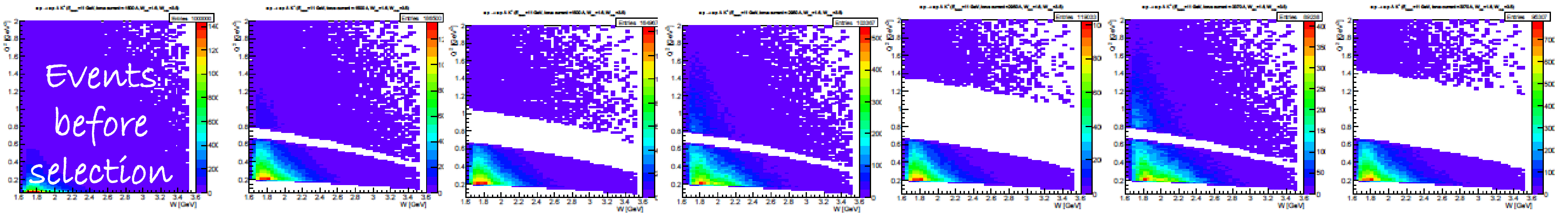
-1500 A
1500 A
-2950 A
2950 A
-3370 A
3370 A

E = 8.8 GeV



-1500 A
1500 A
-2950 A
2950 A
-3370 A
3370 A

E = 11 GeV

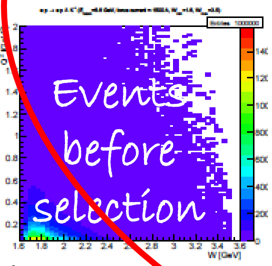


-1500 A
1500 A
-2950 A
2950 A
-3370 A
3370 A

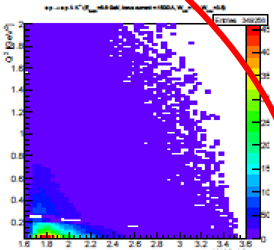
Q^2 vs W for different run conditions

E = 6.6 GeV

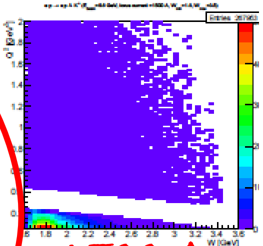
Best efficiency value



Events before selection



-1500 A



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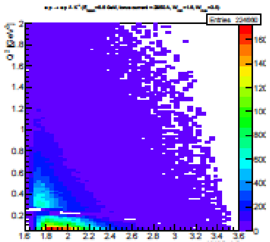
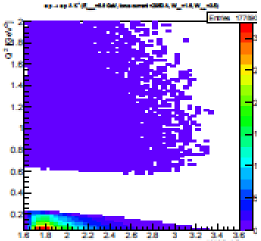


-2950 A



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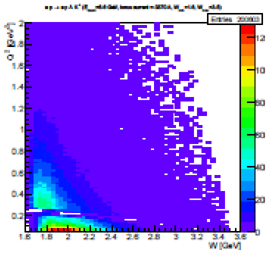
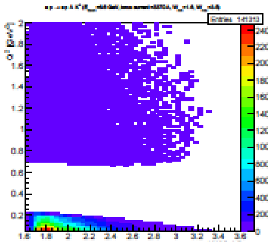


-3370 A



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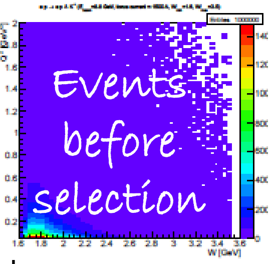
E = 8.8 GeV



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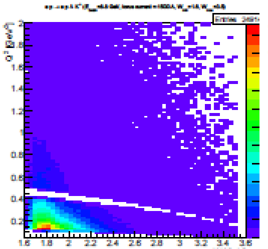

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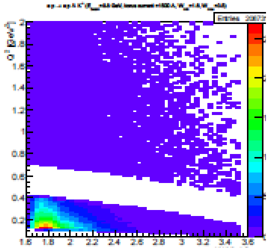

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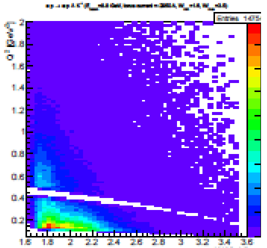

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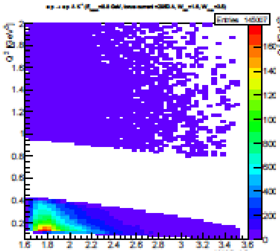

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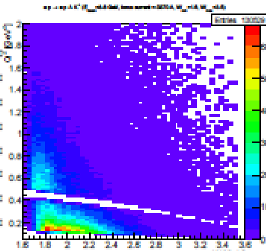

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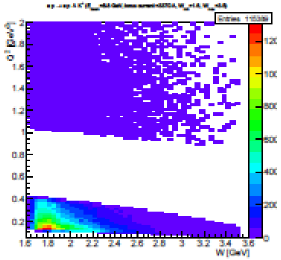

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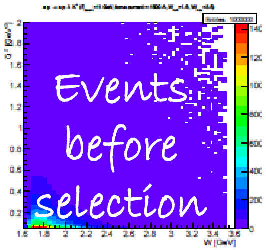
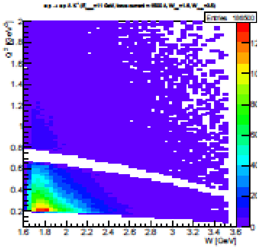
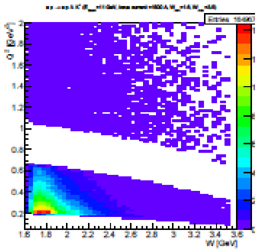
E = 11 GeV



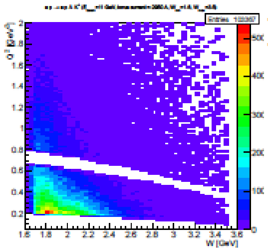
Events before selection



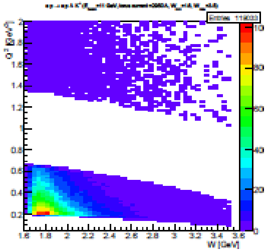
-1500 A



1500 A



-2950 A



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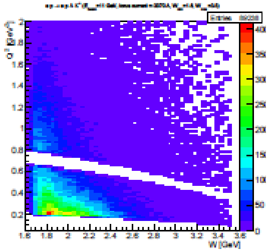

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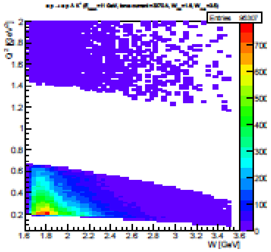
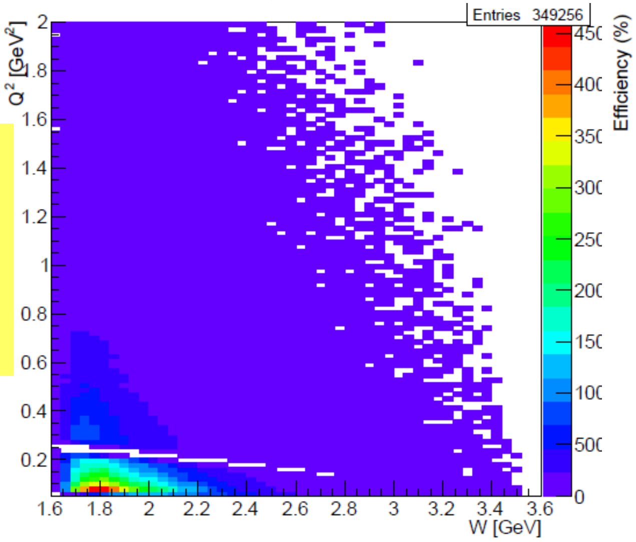


3370 A

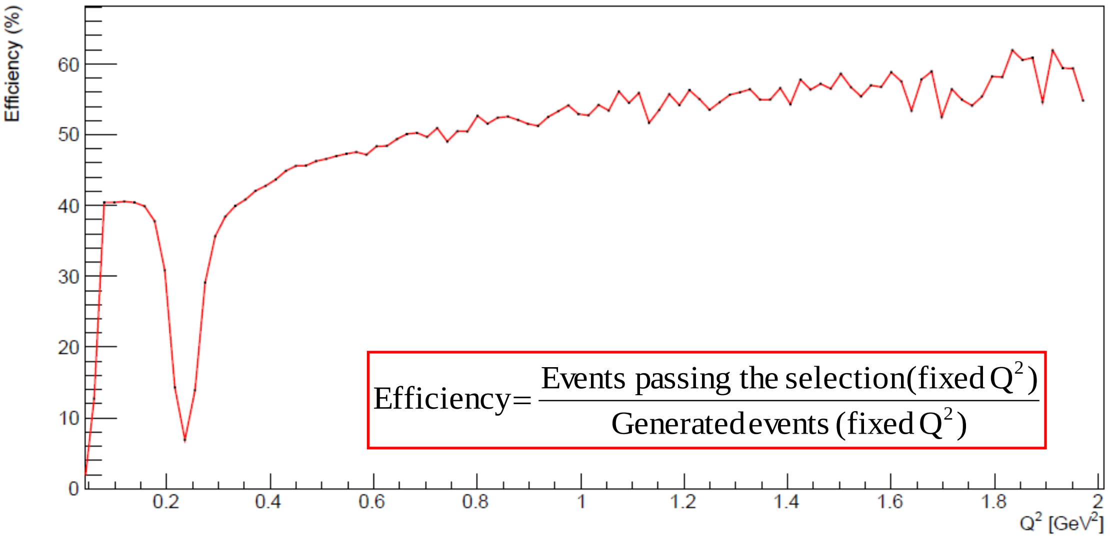
Covering the whole Q^2 range

E =
6.6 GeV
TorCur=
-1500 A

Q^2 vs W

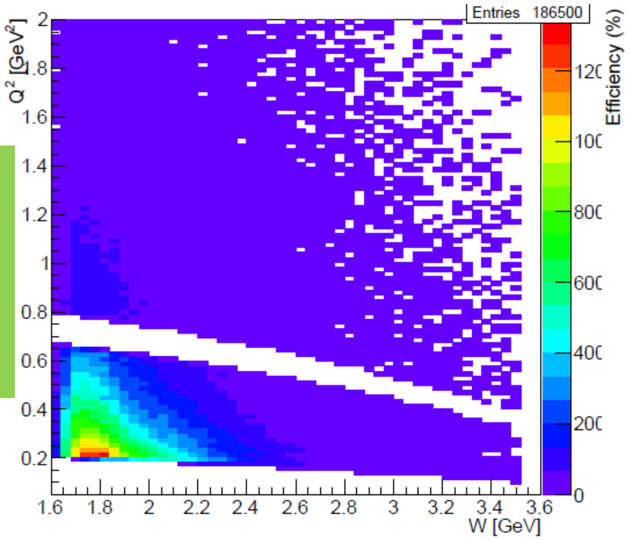


Efficiency curve

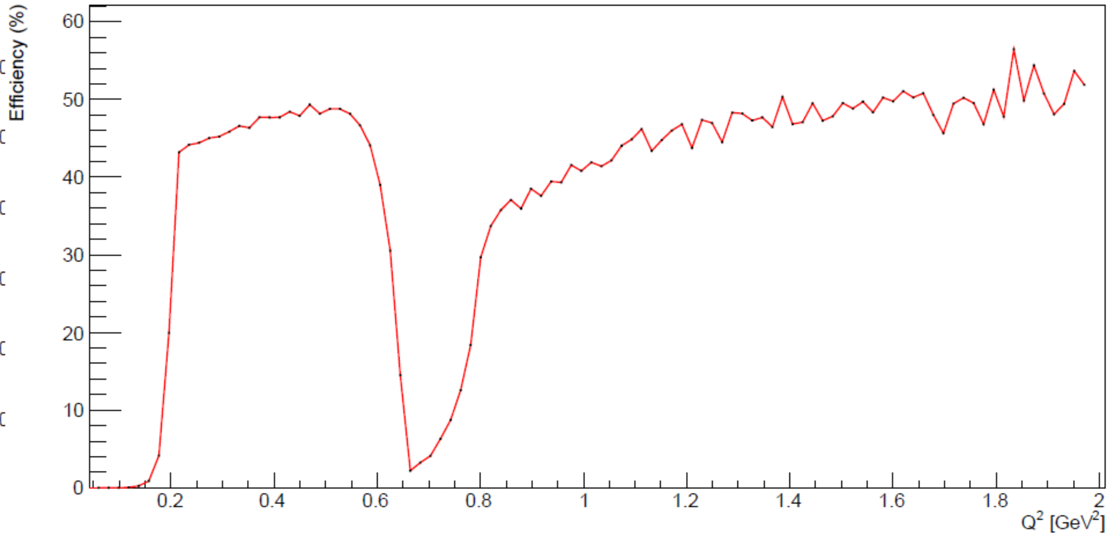


$$\text{Efficiency} = \frac{\text{Events passing the selection (fixed } Q^2)}{\text{Generated events (fixed } Q^2)}$$

E =
11 GeV
TorCur=
-1500 A



Complementary ranges

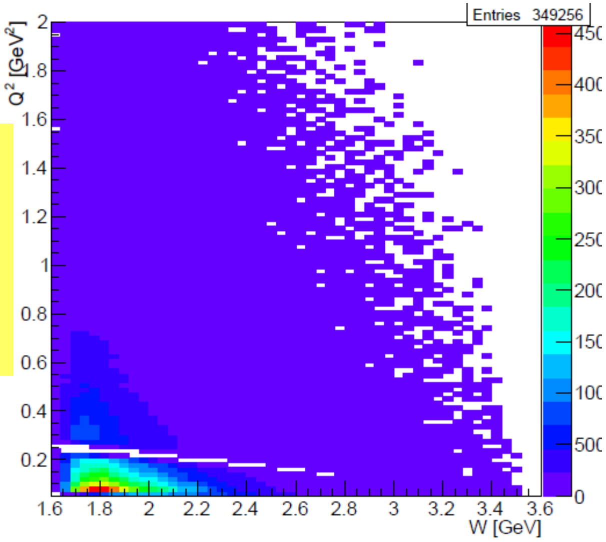


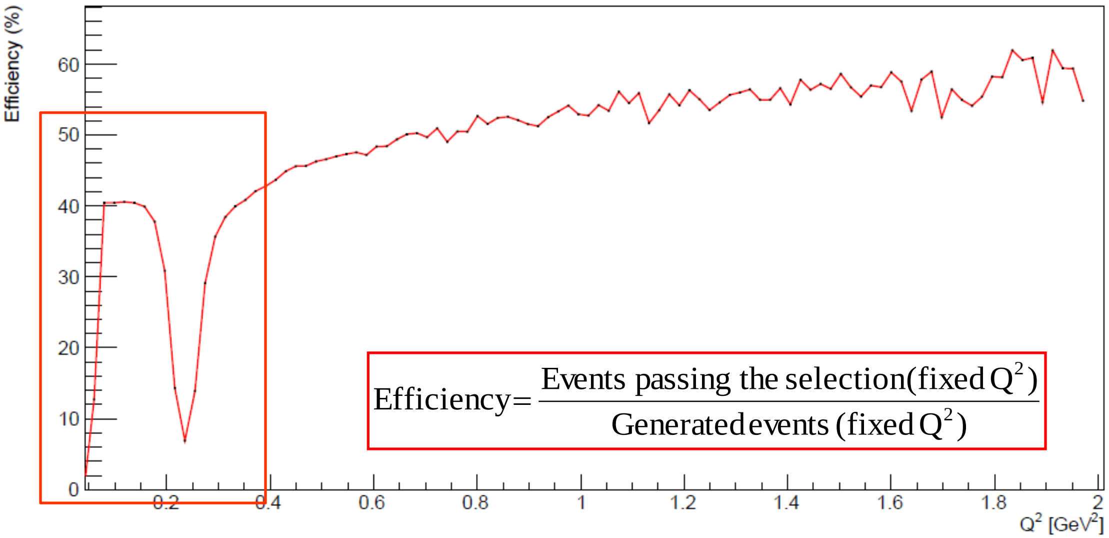
Covering the whole Q^2 range

Q^2 vs W

Efficiency curve

E =
6.6 GeV
TorCur=
-1500 A





$$\text{Efficiency} = \frac{\text{Events passing the selection(fixed } Q^2\text{)}}{\text{Generated events (fixed } Q^2\text{)}}$$

Complementary ranges

E =
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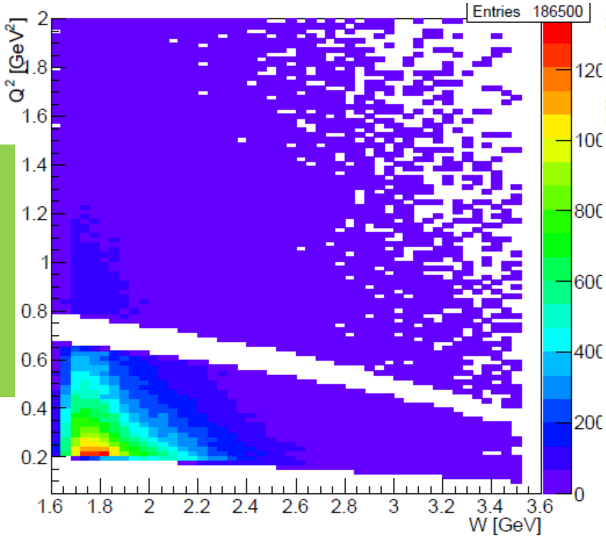
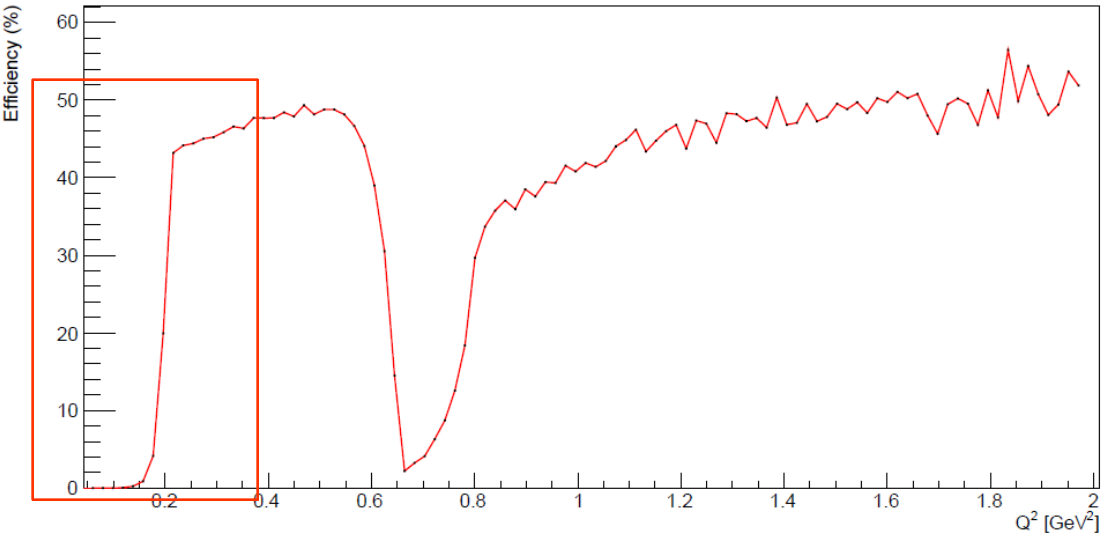
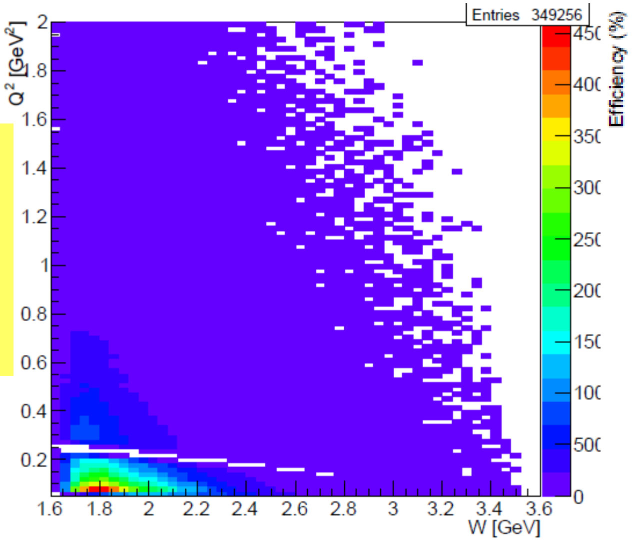




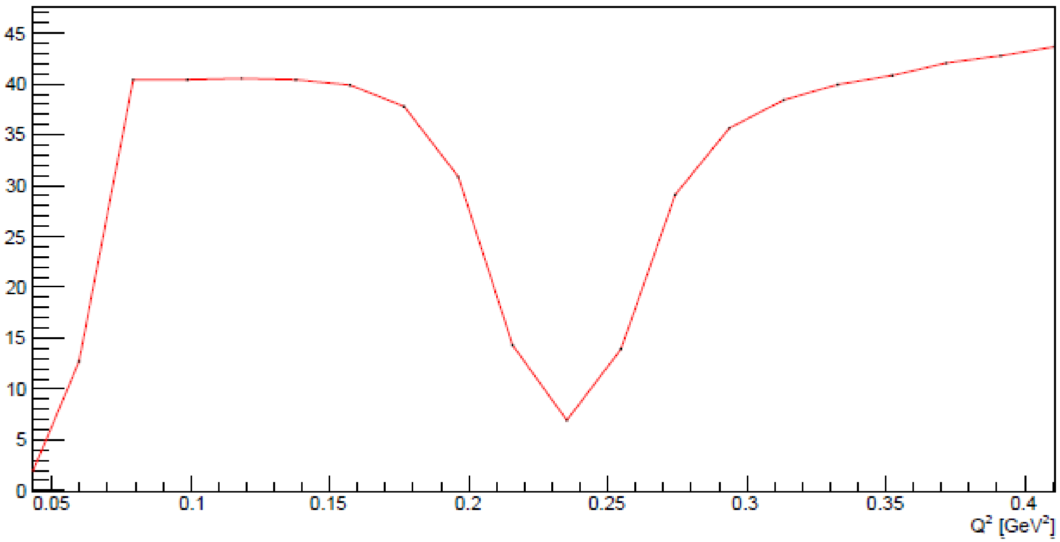
Covering the whole Q^2 range

Q^2 vs W

E =
6.6 GeV
TorCur=
-1500 A

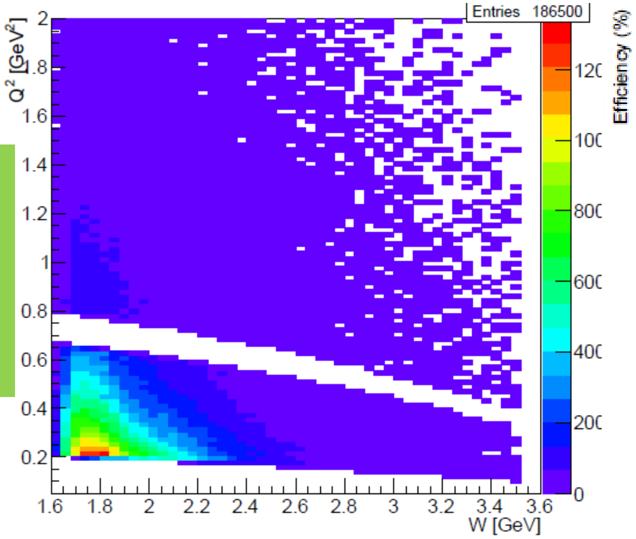


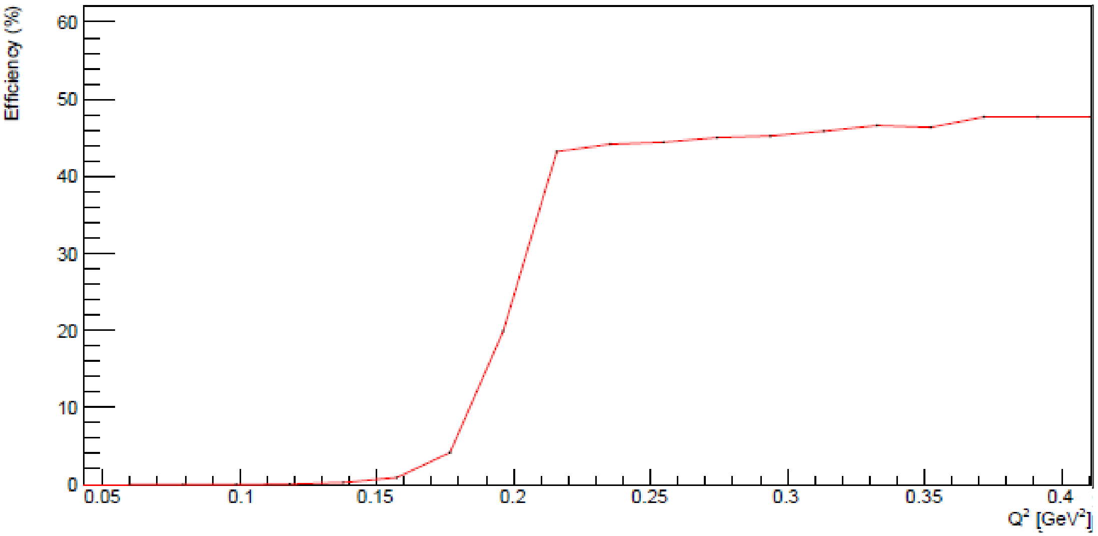
Efficiency curve



Complementary ranges

E =
11 GeV
TorCur=
-1500 A

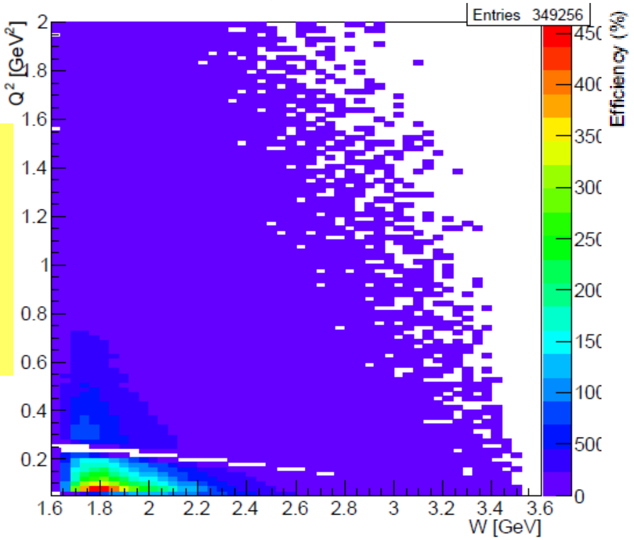




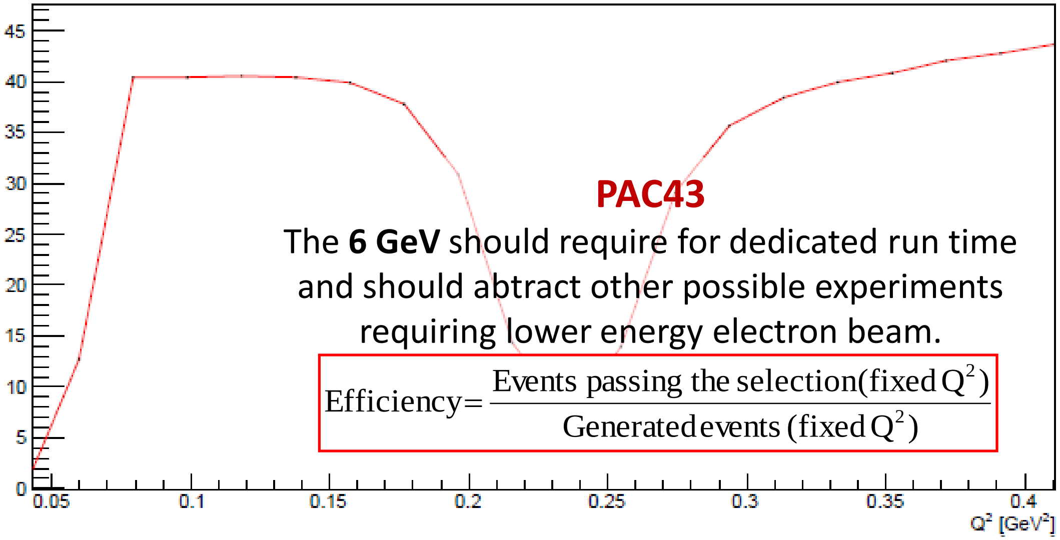
Covering the whole Q^2 range

Q^2 vs W

E =
6.6 GeV
TorCur=
-1500 A



Efficiency curve



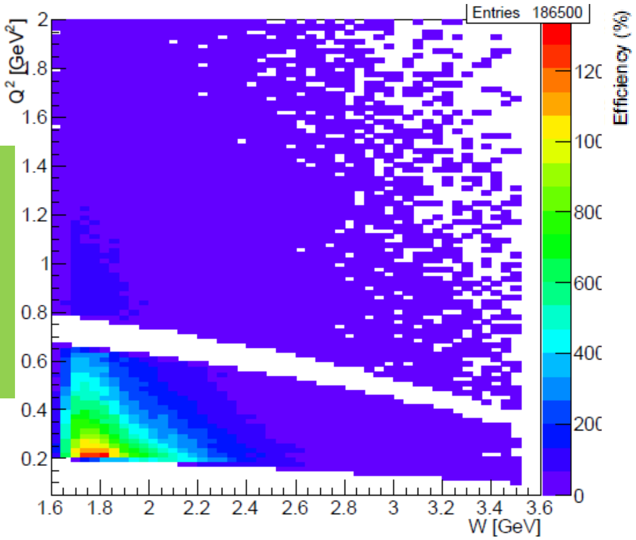
PAC43

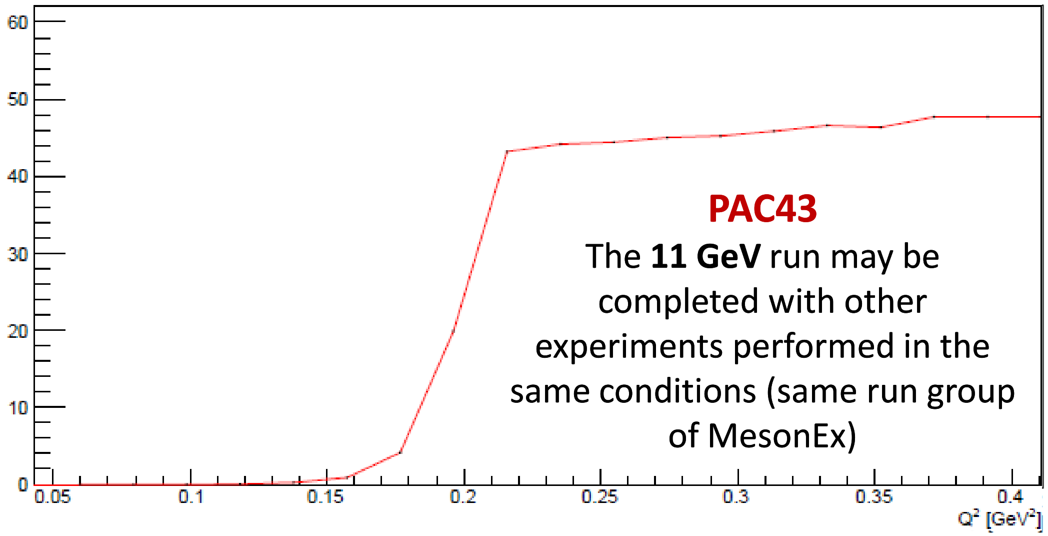
The **6 GeV** should require for dedicated run time and should abtract other possible experiments requiring lower energy electron beam.

$$\text{Efficiency}=\frac{\text{Events passing the selection(fixed } Q^2)}{\text{Generated events (fixed } Q^2)}$$

Complementary ranges

E =
11 GeV
TorCur=
-1500 A



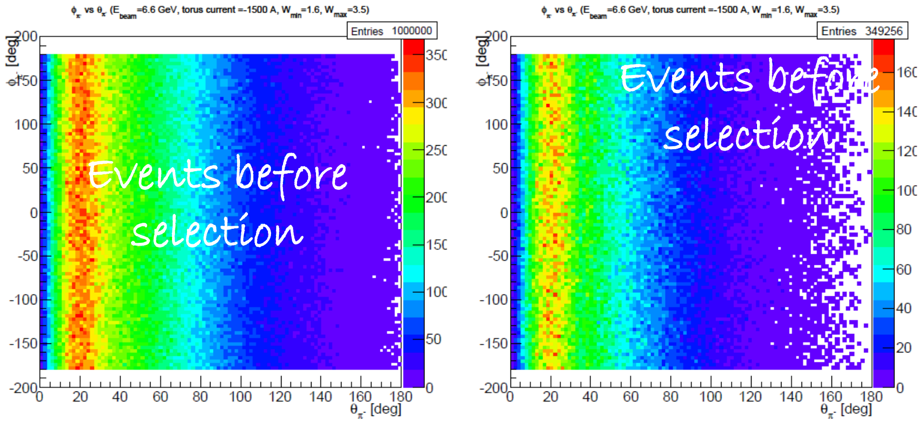


PAC43

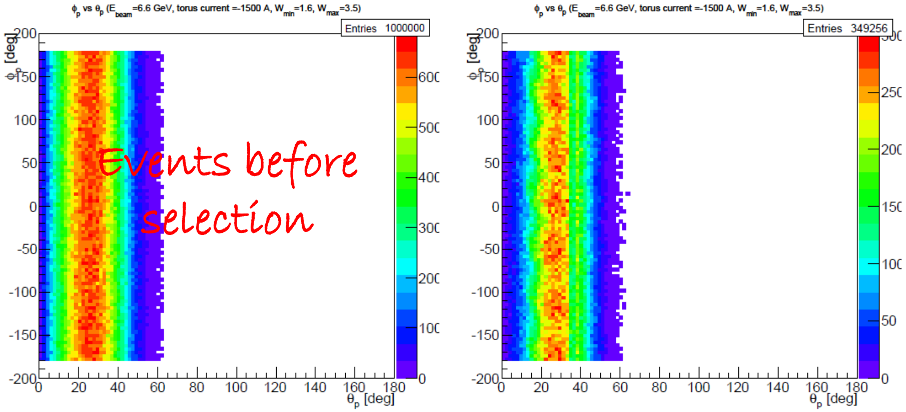
The **11 GeV** run may be completed with other experiments performed in the same conditions (same run group of MesonEx)

Results for run conditions: E_{beam}=6.6 GeV TorCur=-1500 A

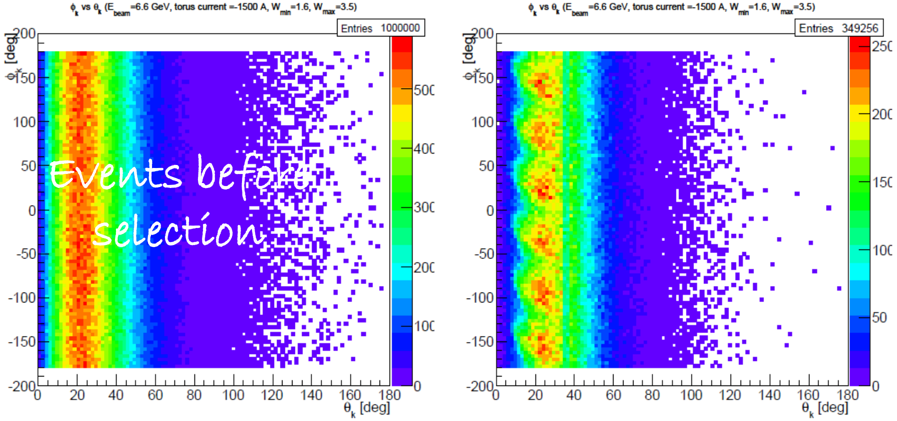
ϑ vs ϕ for proton



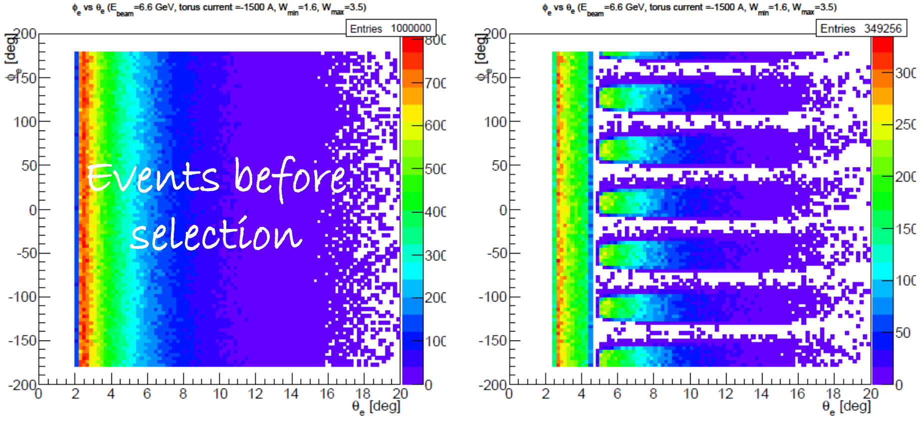
ϑ vs ϕ for kaon



ϑ vs ϕ for pion

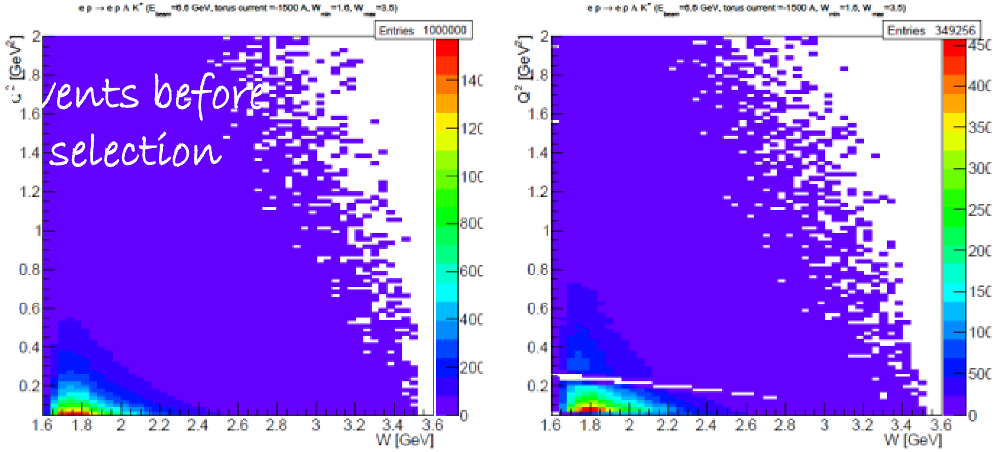


ϑ vs ϕ for electron



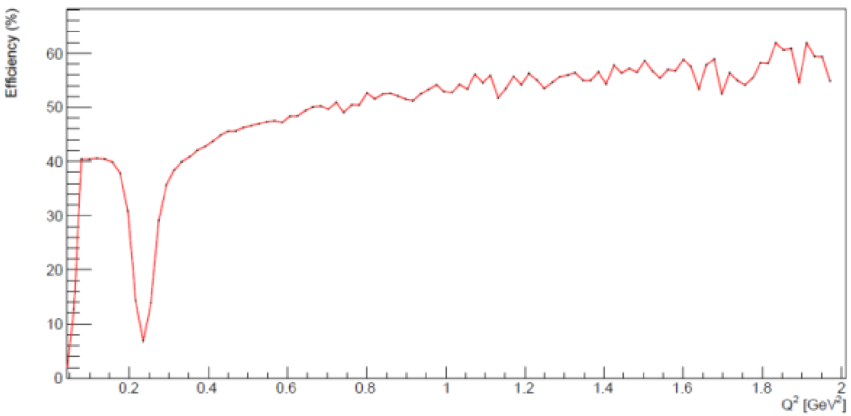
Results for run conditions: E_{beam}=6.6 GeV TorCur=-1500 A

Q^2 vs W

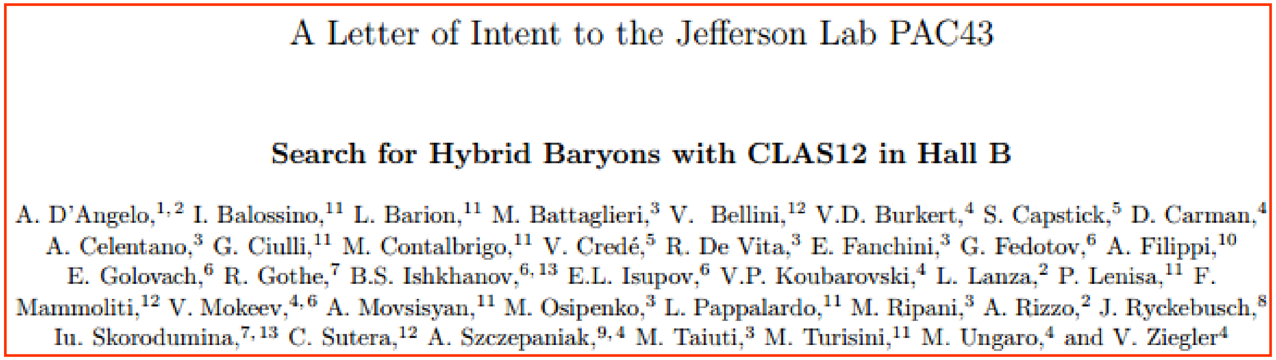


vents before selection

Efficiency curve



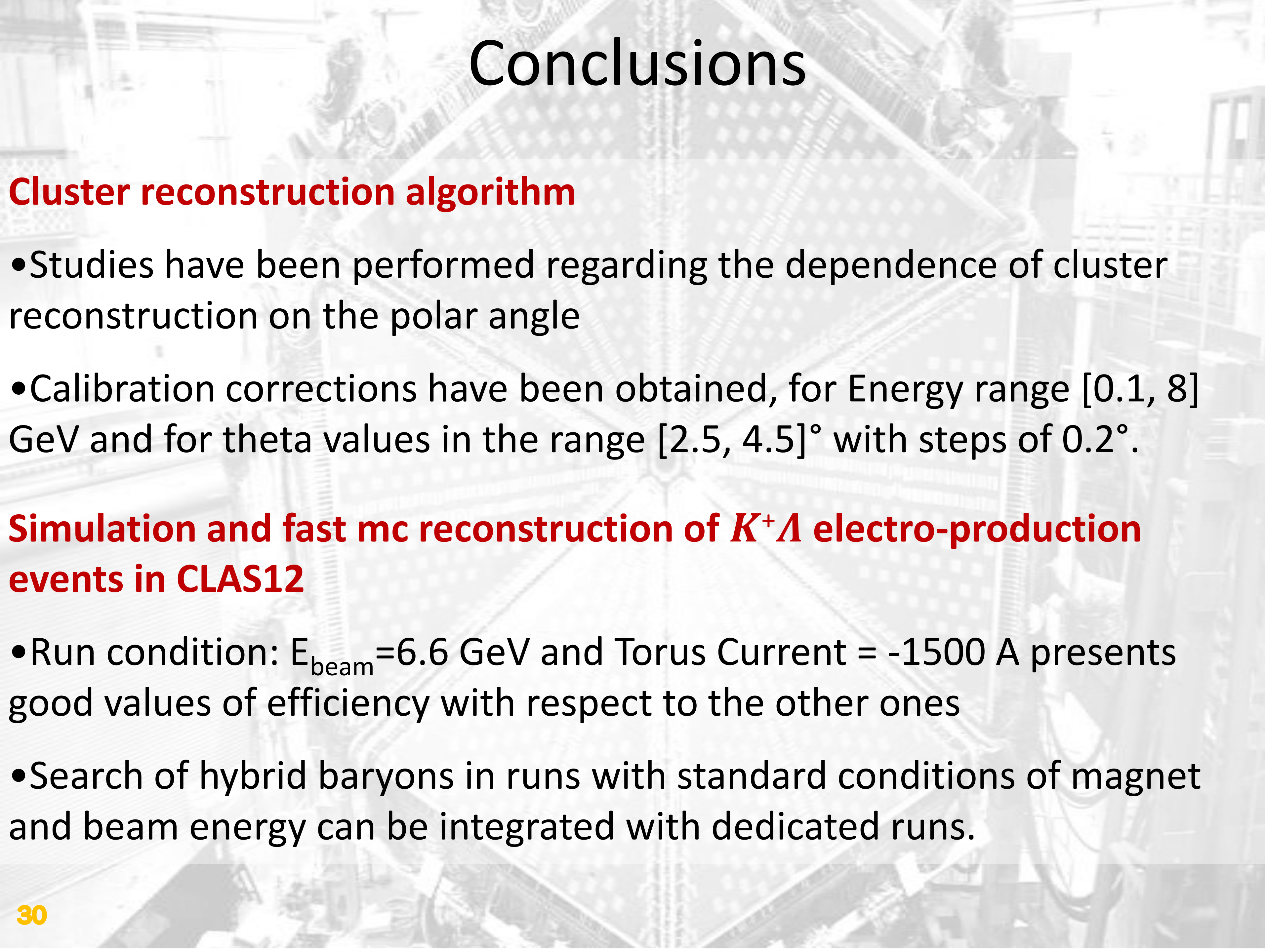
A Letter of Intent has been endorsed by the PAC43.



A Letter of Intent to the Jefferson Lab PAC43

Search for Hybrid Baryons with CLAS12 in Hall B

A. D'Angelo,[1,2] I. Balossino,[11] L. Barion,[11] M. Battaglieri,[3] V. Bellini,[12] V.D. Burkert,[4] S. Capstick,[5] D. Carman,[4] A. Celentano,[3] G. Ciulli,[11] M. Contalbrigo,[11] V. Credé,[5] R. De Vita,[3] E. Fanchini,[3] G. Fedotov,[6] A. Filippi,[10] E. Golovach,[6] R. Gothe,[7] B.S. Ishkhanov,[6,13] E.L. Isupov,[6] V.P. Koubarovski,[4] L. Lanza,[2] P. Lenisa,[11] F. Mammoliti,[12] V. Mokeev,[4,6] A. Movsisyan,[11] M. Osipenko,[3] L. Pappalardo,[11] M. Ripani,[3] A. Rizzo,[2] J. Ryckebusch,[8] Iu. Skorodumina,[7,13] C. Sutera,[12] A. Szczepaniak,[9,4] M. Taiuti,[3] M. Turisini,[11] M. Ungaro,[4] and V. Ziegler[4]



Conclusions

Cluster reconstruction algorithm

- Studies have been performed regarding the dependence of cluster reconstruction on the polar angle

- Calibration corrections have been obtained, for Energy range [0.1, 8] GeV and for theta values in the range [2.5, 4.5]° with steps of 0.2°.

Simulation and fast mc reconstruction of $K^+\Lambda$ electro-production events in CLAS12

- Run condition: E_{beam}=6.6 GeV and Torus Current = -1500 A presents good values of efficiency with respect to the other ones

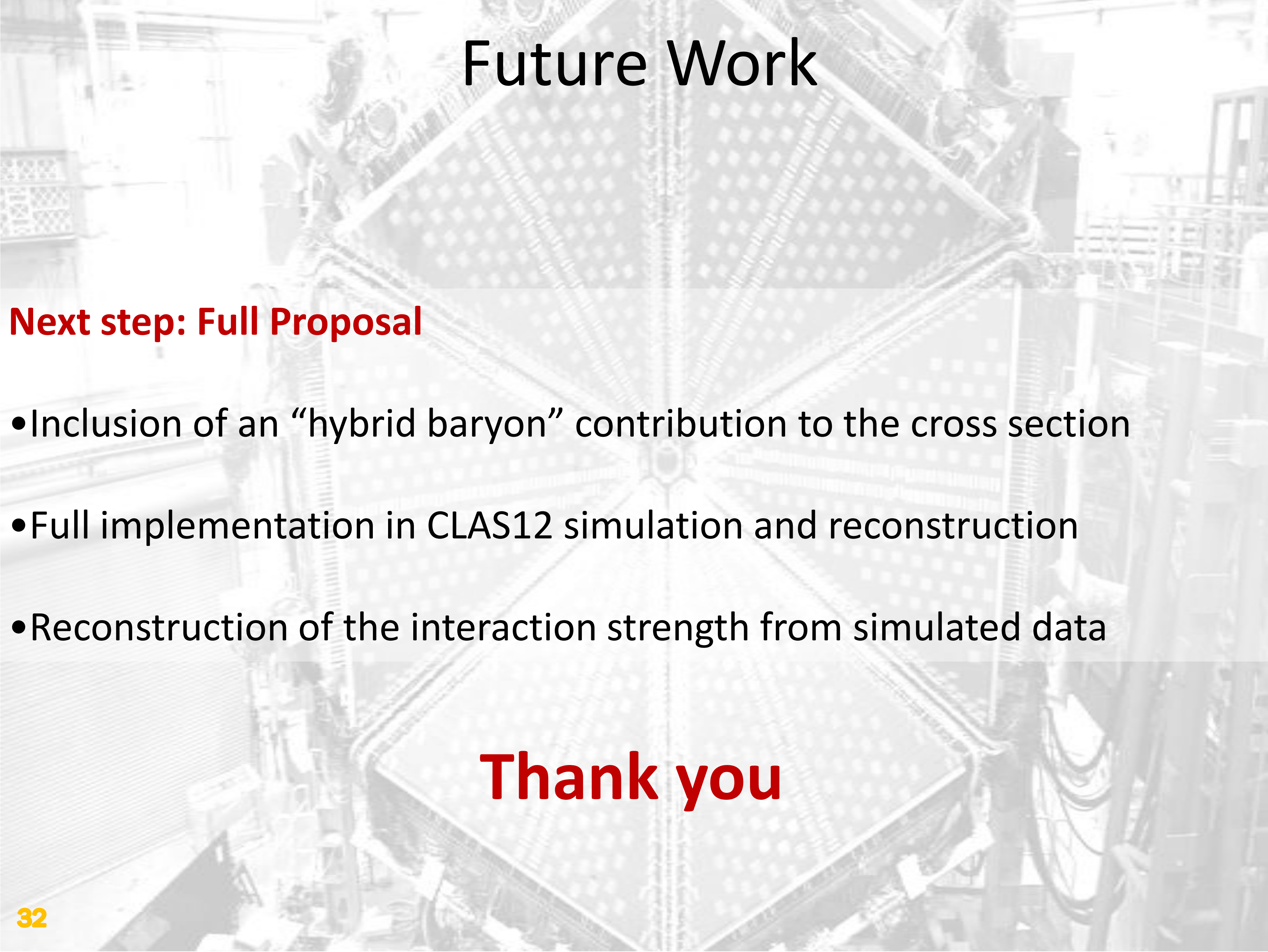
- Search of hybrid baryons in runs with standard conditions of magnet and beam energy can be integrated with dedicated runs.

Future Work

Next step: Full Proposal

- Inclusion of an “hybrid baryon” contribution to the cross section
- Full implementation in CLAS12 simulation and reconstruction
- Reconstruction of the interaction strength from simulated data

Future Work



Next step: Full Proposal

- Inclusion of an “hybrid baryon” contribution to the cross section
- Full implementation in CLAS12 simulation and reconstruction
- Reconstruction of the interaction strength from simulated data

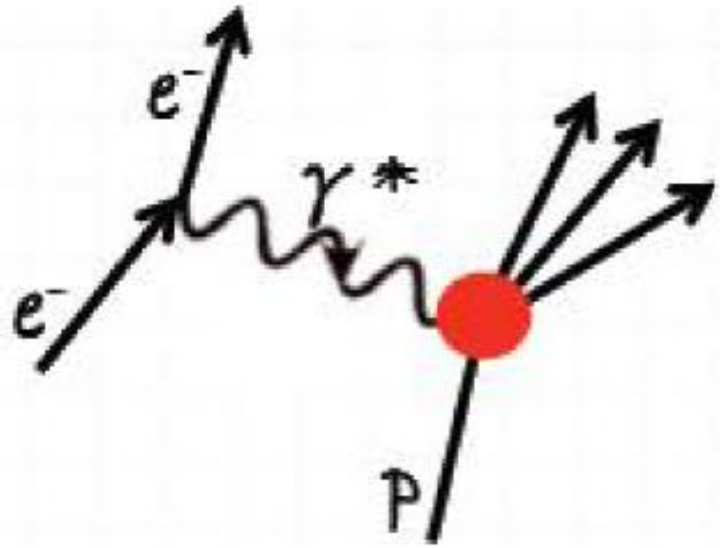
Thank you

Bibliography

- *CLAS12 Forward Tagger (FT) Technical Design Report*, The CLAS12 Collaboration
- *Draft CLAS-Note, An Inner Calorimeter for CLAS/DVCS experiments*, I. Bedlinskiy, et Al.
- *CLAS/DVCS Inner Calorimeter Calibration*, R. Niyazov , S. Stepanyan
- *A Letter of Intent to the Jefferson Lab PAC43, Search for Hybrid Baryons with CLAS12 in Hall B*, A. D'Angelo et al.
- J. Dudek et al., 2012
- V. Mokeev et al., 2012, *Experimental study of the P11(1440) and D13(1520) resonances from the CLAS data on* $ep \to e\pi^+\pi^- p$
- I. G. Aznauryan et al., CLAS Collaboration, PHYSICAL REVIEW C 80, 055203 (2009)
- [1] S. Capstick and B. D. Keister, Phys. Rev. D 51, 3598 (1995)
- [2] I. G. Aznauryan, Phys. Rev. C 76, 025212 (2007).
- [3] Z. P. Li, V. Burkert, and Zh. Li, Phys. Rev. D 46, 70 (1992).

The Forward Tagger (FT)

For $Q^2 \approx 0$ the exchanged virtual photon becomes for all practical purposes almost a real photon



$$Q^2=-q^2=-(p_e-p_{e'})^2= m_{\gamma^*}{}^2 c^4 = 2E_eE_{e'}+\cancel{m_e{}^2}+\cancel{m_{e'}{}^2}-2\mathbf{p_e}\mathbf{p_{e'}}=$$
$$=2(E_eE_{e'}-|\mathbf{p}_e||\mathbf{p}_{e'}|\cos\vartheta) = 2E_eE_{e'}(1-\cos\vartheta)$$

Where

$q=p_e-p_{e'}$

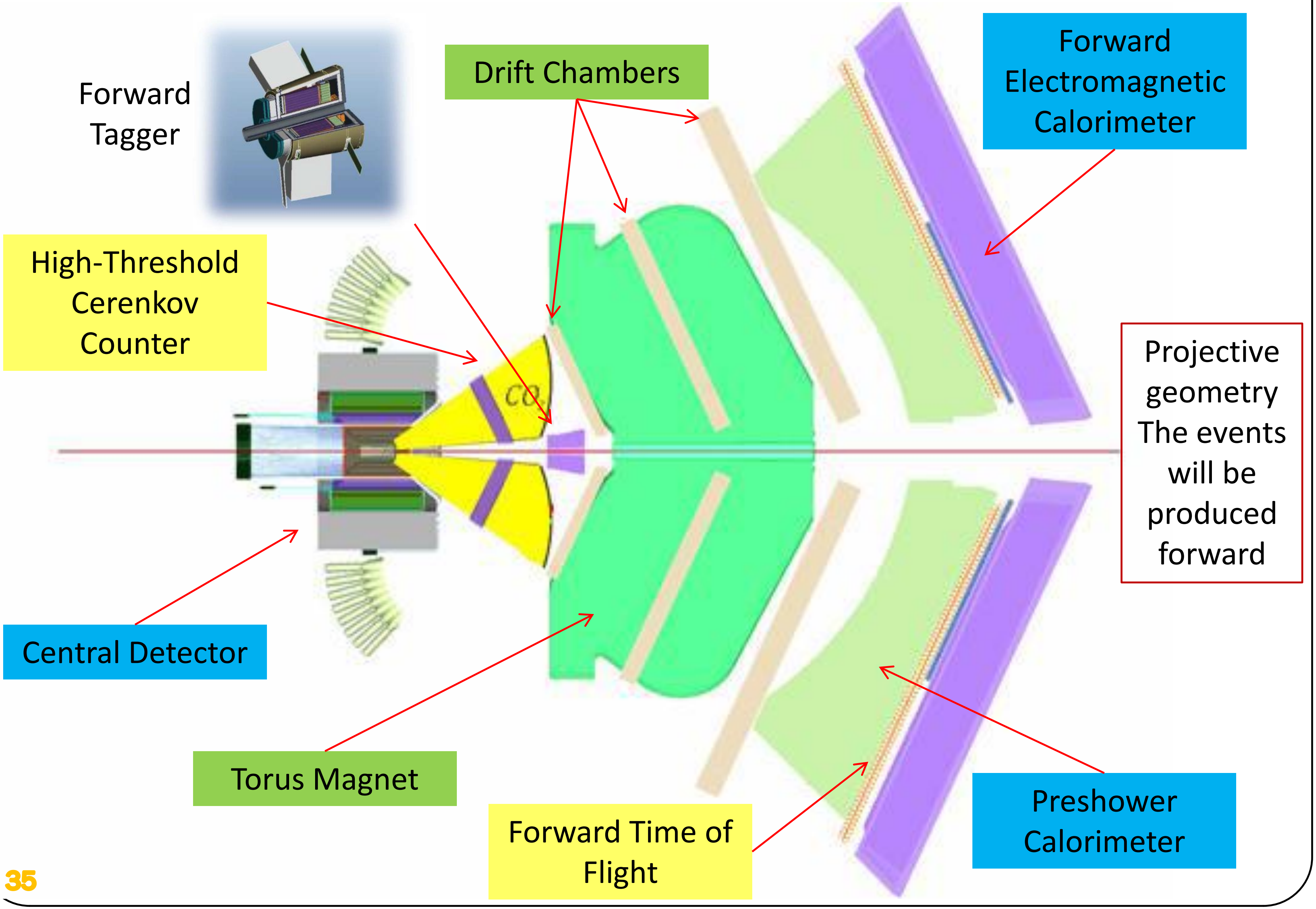
Using the prosthaphaeresis formula:

$$\boxed{Q^2 = 4E_{Beam}E_{e'}\sin^2\frac{\vartheta}{2}}$$

Where ϑ is the angle between the e and the e’ directions.

To select events where a quasi-real photon has been exchanged, electrons scattered with a small (ϑ<5°) must be detected and measured → **Forward Tagger** (FT) apparatus

Experimental setup: CLAS12



Forward Tagger

Drift Chambers

Forward Electromagnetic Calorimeter

High-Threshold Cerenkov Counter

Projective geometry
The events will be produced forward

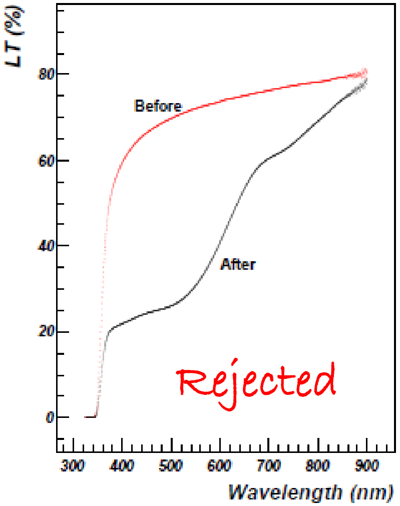
Central Detector

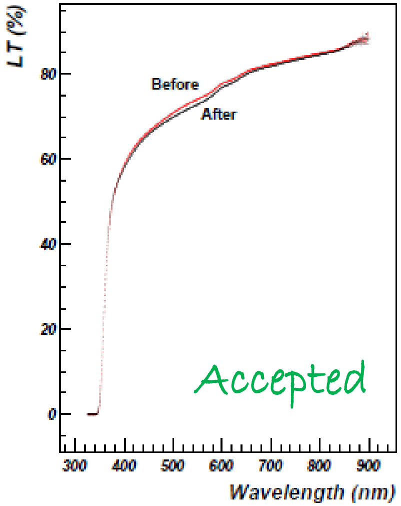
Torus Magnet

Forward Time of Flight

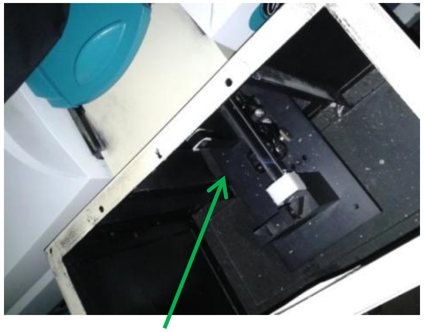
Preshower Calorimeter

Light Trasmission of PWO crystals for EM calorimetry in the CLAS12 FT





Giessen measurements: employment of a **spectrophotometer** to perform hardness tests – LT before and after irradiation- on the **332 PWO crystals** that compose the FT calorimeter.



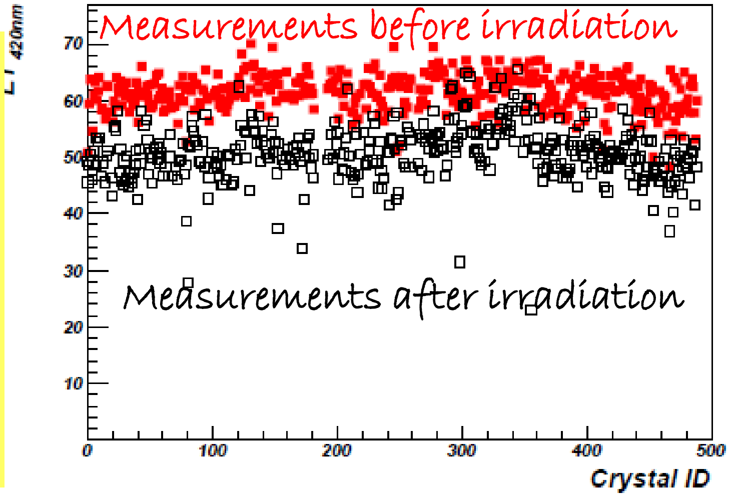
SICCAS 20 cm $PbWO_4$

For each of the **332 crystals**:

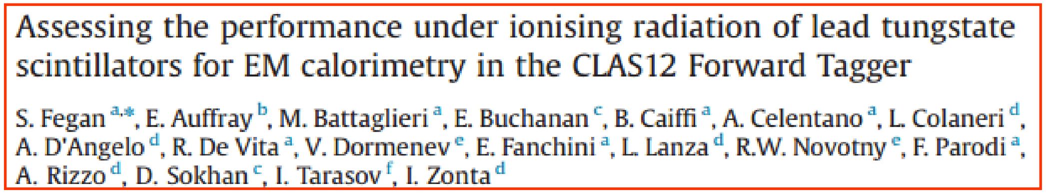
- Measurement in the spectrophotometer before irradiation
- Irradiation (dose of a month operations at CLAS12)
- 30 minutes in a dark environment for the fast component of the crystal's light transmission to occur
- Measurement in the spectrophotometer after irradiation
- Data analysis and evaluation of quality on the basis of

Absorption coefficient:

$$\Delta k = \frac{1}{lenght} \ln \frac{T_{before}}{T_{after}}$$



NIM paper:



Assessing the performance under ionising radiation of lead tungstate scintillators for EM calorimetry in the CLAS12 Forward Tagger

S. Fegan [a,*], E. Auffray [b], M. Battaglieri [a], E. Buchanan [c], B. Caiffi [a], A. Celentano [a], L. Colaneri [d], A. D'Angelo [d], R. De Vita [a], V. Dormenev [e], E. Fanchini [a], L. Lanza [d], R.W. Novotny [e], F. Parodi [a], A. Rizzo [d], D. Sokhan [c], I. Tarasov [f], I. Zonta [d]

Light Trasmission of PWO crystals for EM calorimetry in the CLAS12 FT

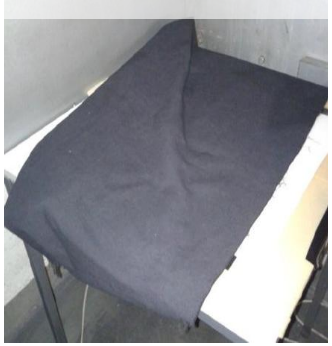
Giessen measurements: employment of a **spectrophotometer** to perform hardness tests –LT before and after irradiation- on the **332 PWO crystals** that compose the FT calorimeter.

Spectrophotometer

SICCAS 20 cm $PbWO_4$

Irradiation Chamber

Black Cloath

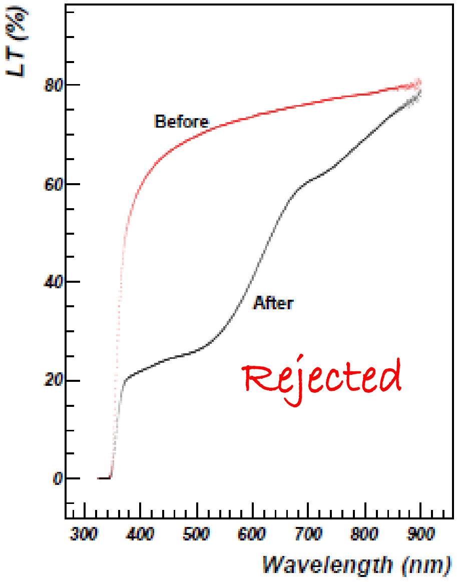


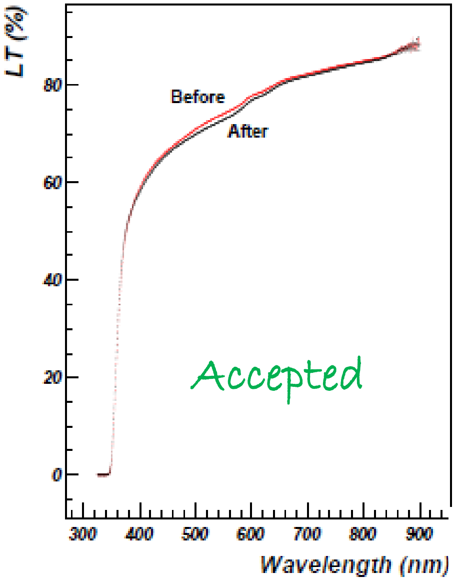
For each of the **332 crystals**:

- Measurement in the spectrophotometer before irradiation
- Irradiation (dose of a month operations at CLAS12)
- 30 minutes in a dark environment for the fast component of the crystal's light transmission to occur
- Measurement in the spectrophotometer after irradiation
- Data analysis and evaluation of quality on the basis of

Absorption coefficient: $\Delta k = \frac{1}{lenght} \ln \frac{T_{before}}{T_{after}}$

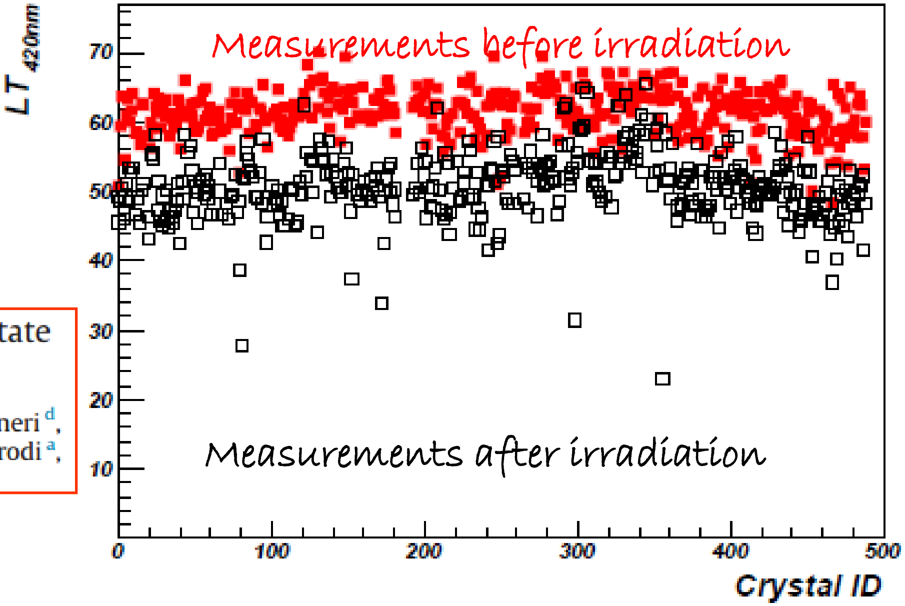
Light Trasmission of PWO crystals for EM calorimetry in the CLAS12 FT



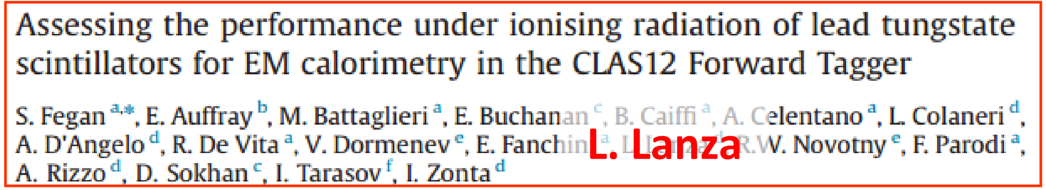


The absorption coefficient Δk[m^{-1}] quantifies the absorption

$$\Delta k = \frac{1}{lenght} \ln \frac{T_{before}}{T_{after}}$$



NIM paper, S. Fegan et al., Sec. A, volume 789, 21 July 2015, Pages 101-108



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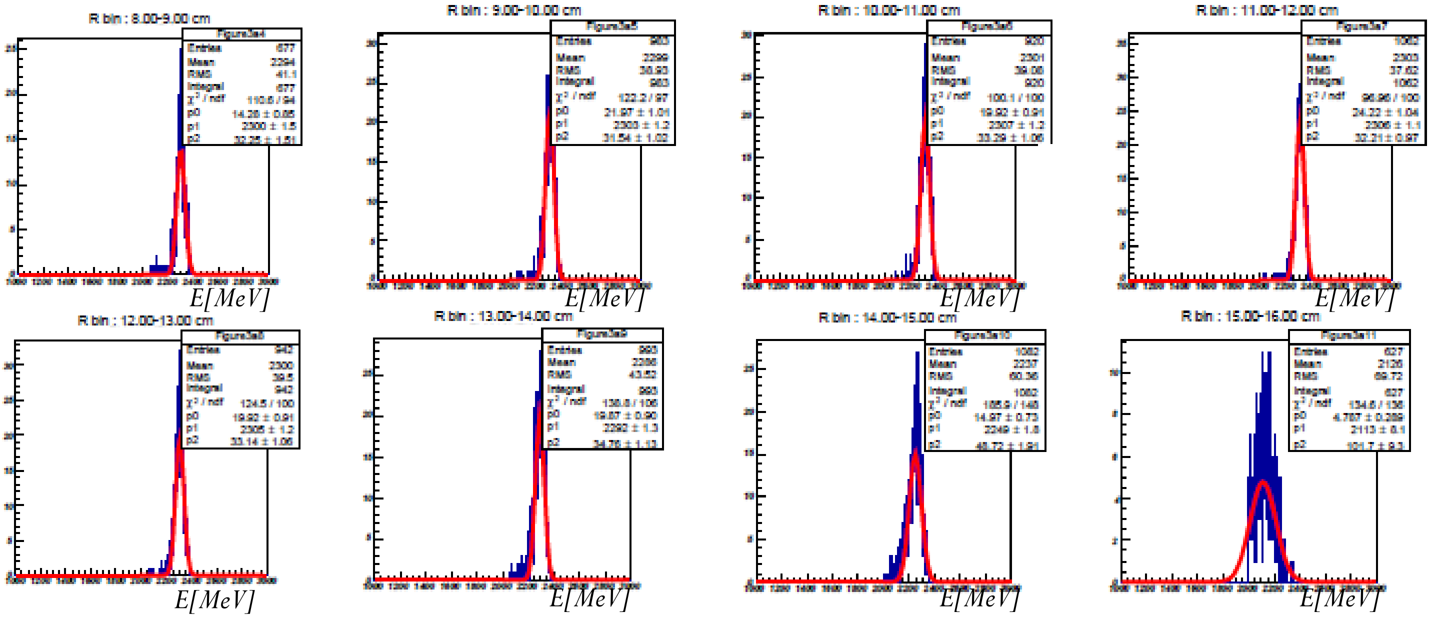
Single photon reconstruction

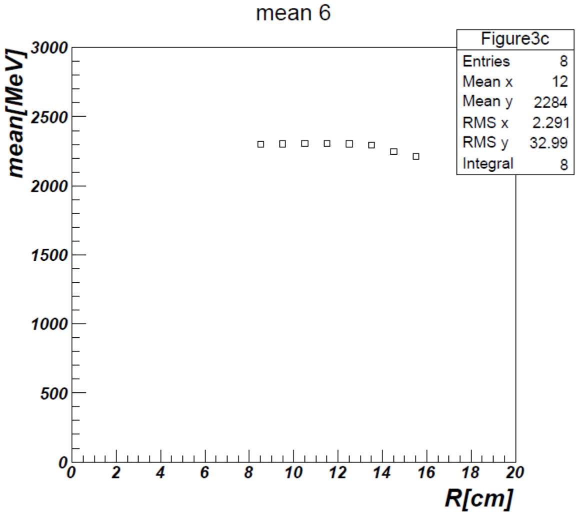
Reconstructed cluster energy slices for E_{gen}^{γ} = 2.5 GeV

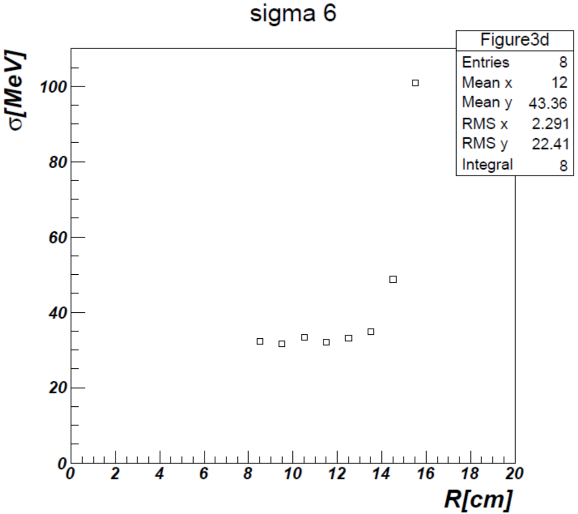


E_{clust} sliced with R bins and fitted with gaussian

mean

from the fit as a function of R

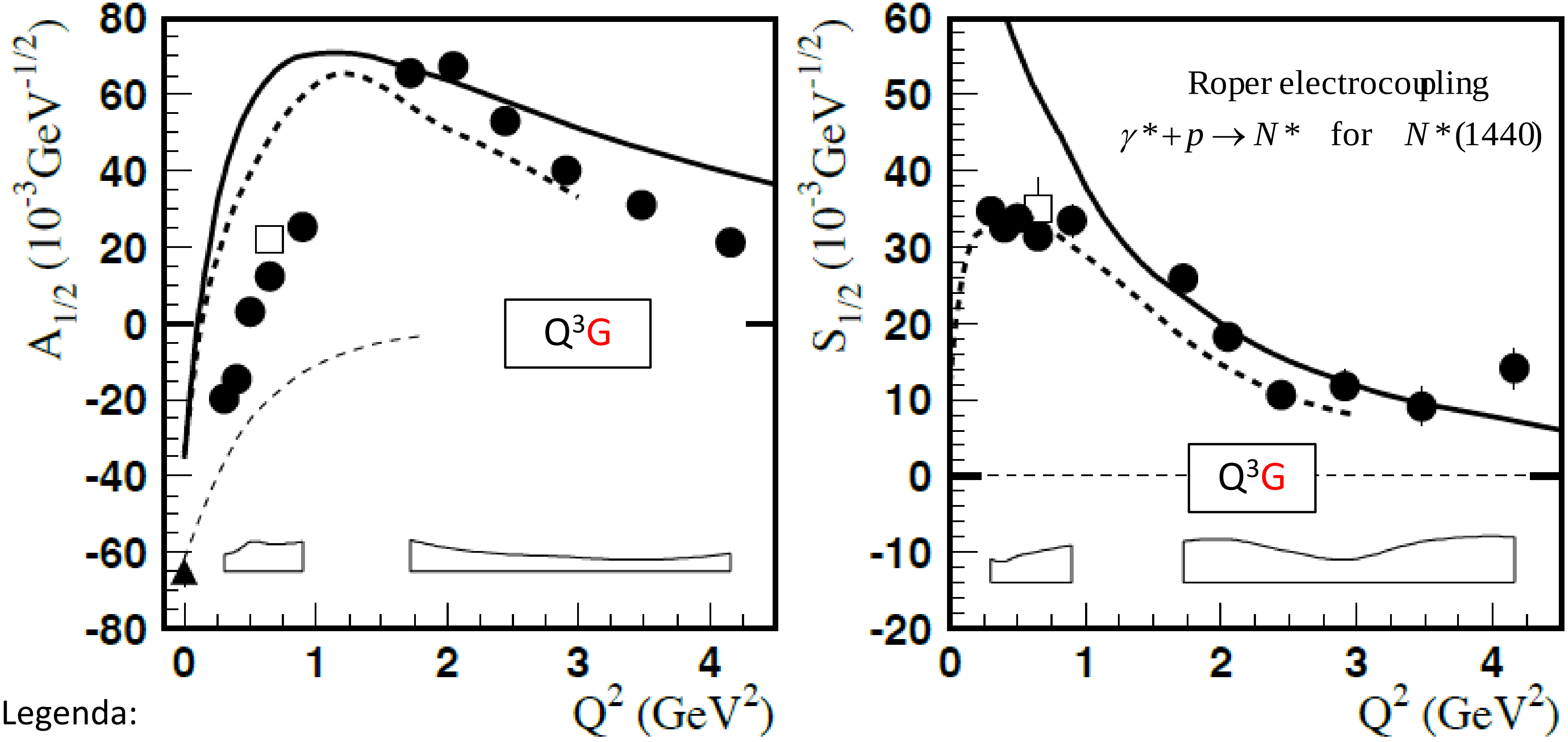




σ

from the fit as a function of R

Separating Q^{3}G from Q^3 states



Legenda:

● results from Table IX obtained from CLAS data in [I. G. Aznauryan et al., (2009)]

□ results of the combined analysis of CLAS single π and 2π electroproduction data

▲ at $Q^2 = 0$ is the RPP estimate

The bands show the model uncertainties.

----- ——— results obtained in the LF relativistic quark models assuming that N(1440)P_{11} is a first radial excitation of the 3q ground state: [1] (-----), [2] (———).

The thin dashed curves are obtained assuming that N(1440)P_{11} is a gluonic baryon excitation (q3G hybrid state) [3].

I. G. Aznauryan et al., CLAS Collaboration, PHYSICAL REVIEW C 80, 055203 (2009)

Separating Q^3G from Q^3 states: $A_{1/2}(Q^2)$ and $S_{1/2}(Q^2)$

The ***N**** **hadronic decay amplitudes** can be expanded in **partial waves** of total momentum *J*

$\nu = -\lambda_\Delta$

CM polar and azimuthal angles for the final K

$$\langle \lambda_f | T_{dec} | \lambda_R \rangle = \langle \lambda_f | T^{J_r}_{dec} | \lambda_R \rangle d^{J_r}_{\mu\nu}(\cos\theta^*) e^{i\mu\phi^*}$$

λ_R

where

N* spin

partial hadronic decay widths of the N* to kΛ final states f of helicity λ_f

Magnitudes of the three-momenta of the final K for the N* → KΛ decay, evaluated at W = M_r and at the running W, respectively, and averaged over the running mass of the unstable hadron in the intermediate state

$$\langle \lambda_f | T^{J_r}_{dec} | \lambda_R \rangle = \frac{2\sqrt{2\pi}\sqrt{2J_r+1}M_r\sqrt{\Gamma_{\lambda_f}}}{\sqrt{\langle p_i^r \rangle}}\sqrt{\frac{\langle p_{\mathrm{K}}^r \rangle}{\langle p_{\mathrm{K}} \rangle}}$$

The **resonance electroexcitation amplitudes** can be related to the $\gamma_v NN^*$ electrocouplings $\mathbf{A_{1/2}}$, $\mathbf{A_{3/2}}$, and $\mathbf{S_{1/2}}$ for nucleons

$$\langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle = \frac{W}{M_r}\sqrt{\frac{8M_N M_r q_{\gamma_r}}{4\pi\alpha}}\sqrt{\frac{q_{\gamma_r}}{q_\gamma}}A_{1/2,3/2}(Q^2) \quad \text{with} \quad |\lambda_\gamma - \lambda_p| = \frac{1}{2}, \frac{3}{2} \text{ for transverse photons,}$$

$$\langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle = \frac{W}{M_r}\sqrt{\frac{16M_N M_r q_{\gamma_r}}{4\pi\alpha}}\sqrt{\frac{q_{\gamma_r}}{q_\gamma}}S_{1/2}(Q^2) \text{ for longitudinal photons}$$

$q_{\gamma,r}$ is the three-momentum modulus of the photon at W = M_r in the CM frame

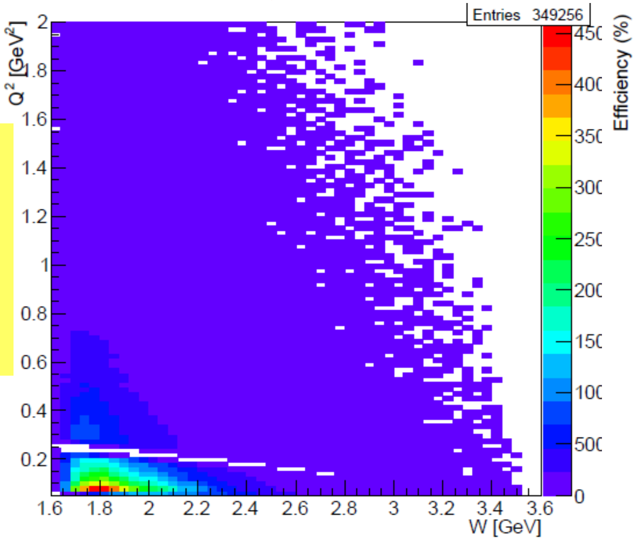
$$q_\gamma = \sqrt{Q^2 + E_\gamma^2}$$

CLAS Collaboration, PHYSICAL REVIEW C 86, 035203 (2012)

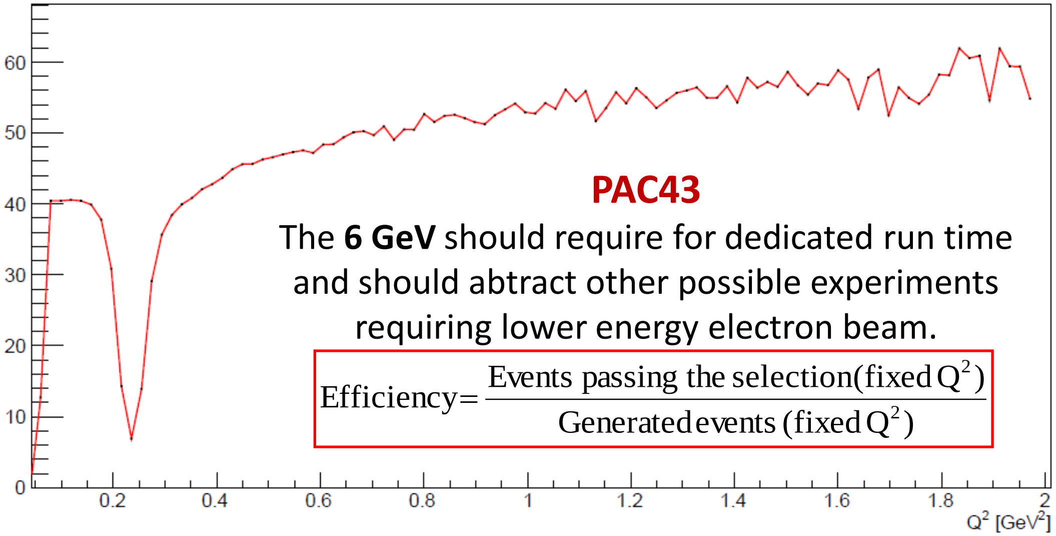
Covering the whole Q^2 range

Q^2 vs W

E =
6.6 GeV
TorCur=
-1500 A



Efficiency curve



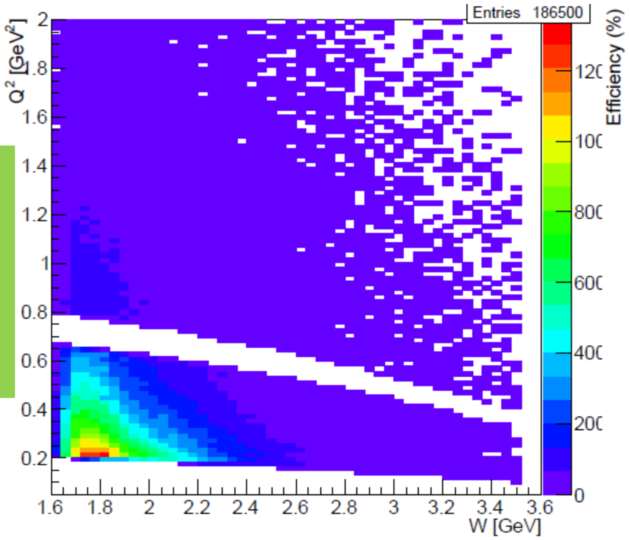
PAC43

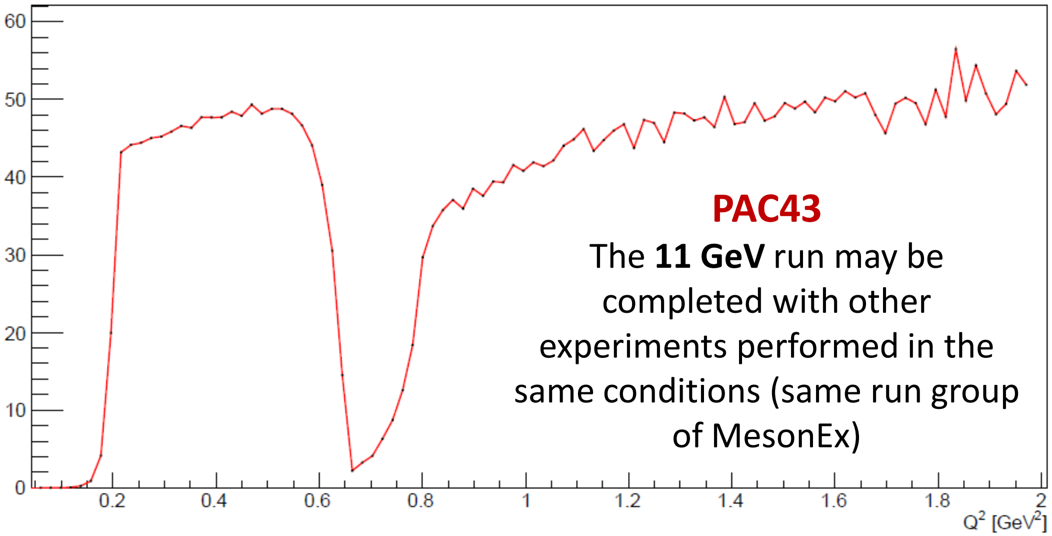
The **6 GeV** should require for dedicated run time and should abtract other possible experiments requiring lower energy electron beam.

$$\boxed{\text{Efficiency}=\frac{\text{Events passing the selection(fixed } Q^2)}{\text{Generated events (fixed } Q^2)}}$$

Complementary ranges

E =
11 GeV
TorCur=
-1500 A





PAC43

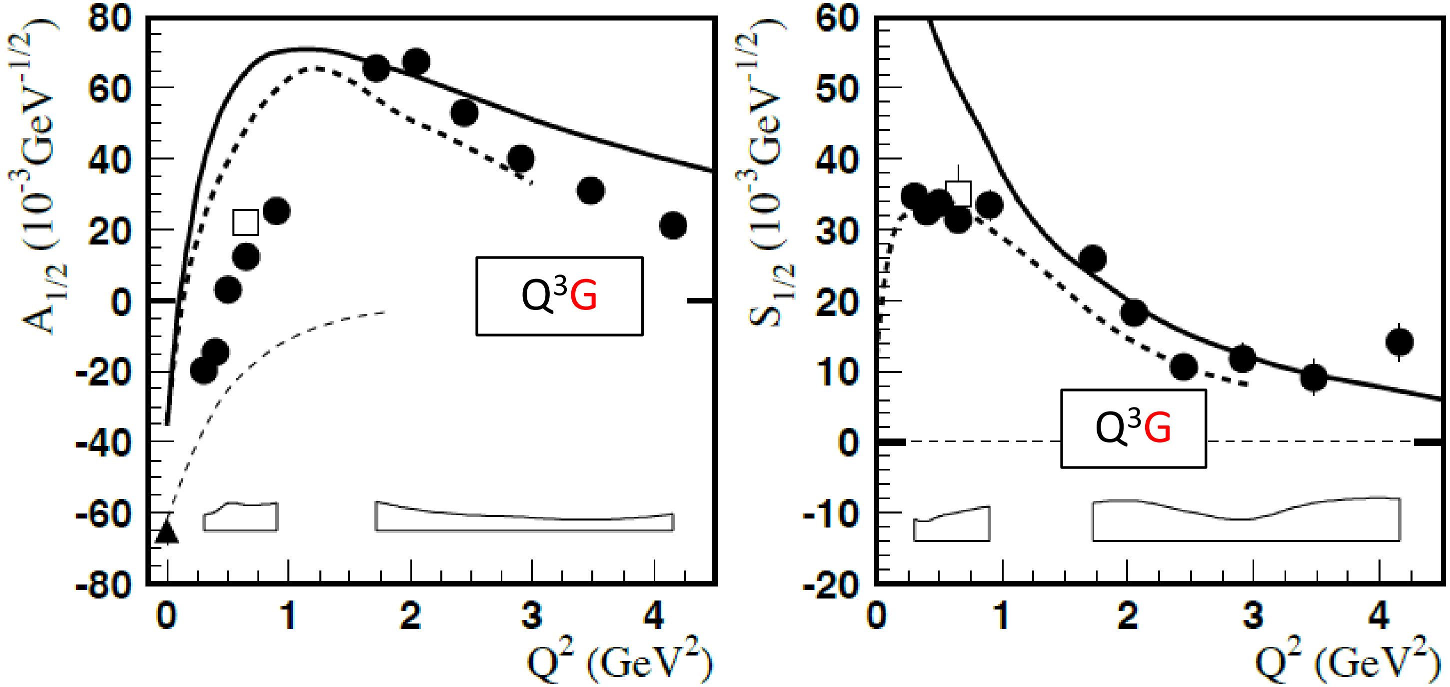
The **11 GeV** run may be completed with other experiments performed in the same conditions (same run group of MesonEx)

Separating Q^3G from Q^3 states

Transverse elicity amplitude $A_{1/2}(Q^2)$ and longitudinal elicity amplitude $S_{1/2}(Q^2)$ allow to distinguish Q^3G from Q^3 states

$$A^p_{1/2} = \begin{cases} -\frac{2\sqrt{2}}{9}\delta\sqrt{\pi/k_0}\mu_0\frac{k}{\gamma^2}e^{-k^2/6\alpha_h^2\gamma^2} & S^p_{1/2}(q^3)=0 \\ -\frac{\sqrt{2}}{9\sqrt{3}}\sqrt{\pi/k_0}\mu_0\frac{k}{\gamma^2}\frac{k^2}{\alpha^2\gamma^2}e & S^p_{1/2}(q^3)=-\frac{1}{3\sqrt{3}}\sqrt{2\pi/k_0}m_q\mu_p\frac{k^2}{\alpha^2}e^{-k^2/6\alpha^2} \end{cases} \quad \text{for} \quad \begin{matrix} |q^3G> \\ |q^3> \end{matrix}$$

Z.P. Li, V.B., Zh. Li, Phys.Rev. D46 (1992) 70



Helicity amplitudes for the γ *p → N(1440)P11 transition. The full circles are the results from Table IX obtained in this work from CLAS data (Tables I–IV). The bands show the model uncertainties. The open boxes are the results of the combined analysis of CLAS single π and 2π electroproduction data [42]. The full triangle at Q2 = 0 is the RPP estimate [20]. The thick curves correspond to the results obtained in the LF relativistic quark models assuming that N(1440)P11 is a first radial excitation of the 3q ground state: [15] (dashed), [19] (solid). The thin dashed curves are obtained assuming that N(1440)P11 is a gluonic baryon excitation (q3G hybrid state)