The CLAS12-MesonEx trigger system

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The MesonEx (E12-12-005) experiment

Meson Spectroscopy program with quasi-real photons: low $Q^2$ electron scattering on a hydrogen target.

Goals:

- Measure the light-quarks mesons spectrum in the mass range 1.0 - 3.0 GeV/c$^2$
- Determine masses and properties of rare $qar{q}$ states
- Search for exotic mesons

Low $Q^2$ electron scattering:

- Provides a high-flux of high-energy, linearly polarized, quasi-real photons.
- Complementary and competitive to real photo-production
- Virtual photon kinematics and polarization determined event-by-event measuring scattered electron variables

Experimental technique: coincidence measurement between CLAS12 (final state hadrons) and Forward Tagger facility (low-angle scattered electron)
The Forward Tagger Facility

3 components:

- **Lead-tungstate calorimeter (FT-Cal):** measure the energy of scattered electrons with few % resolution.
- **Hodoscope (FT-Hodo):** distinguish photons from electrons.
- **Tracker (FT-Trck):** determine the electron scattering plane.

**Nominal design parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{e'}$</td>
<td>0.5 - 4.5 GeV</td>
</tr>
<tr>
<td>$\theta_{e'}$</td>
<td>2.5° - 4.5°</td>
</tr>
<tr>
<td>$\phi_{e'}$</td>
<td>0° - 360°</td>
</tr>
<tr>
<td>$E_\gamma$</td>
<td>6.5 - 10.5 GeV</td>
</tr>
<tr>
<td>$P_\gamma$</td>
<td>70 - 10 %</td>
</tr>
<tr>
<td>$Q^2$</td>
<td>0.01 - 0.3 GeV² ($&lt;Q^2&gt; 0.1$ GeV²)</td>
</tr>
<tr>
<td>$W$</td>
<td>3.6 - 4.5 GeV</td>
</tr>
</tbody>
</table>
Tagged low $Q^2$ electron-scattering: kinematics and rates

Kinematic variables:
- $\nu = E - E'$
- $Q^2 = 4EE' \sin^2(\theta_e/2)$
- $W^2 = M^2 + 2M\nu - Q^2$

Virtual photon polarization:
- $\varepsilon_T = [1 + 2\frac{Q^2+\nu^2}{Q^2} \tan^2(\theta_e/2)]^{-1}$
- $\varepsilon_L = \frac{Q^2}{\nu^2} \varepsilon_T$

Rates:
- Cross-section (low $Q^2$ limit, $\varepsilon_L = 0$):
  $$\frac{d\sigma_e}{dE_e d\Omega_e dX} = \Gamma(E_e, \Omega_e) \cdot \frac{d\sigma_\gamma}{dX}$$
- Virtual photon flux:
  $$\Gamma(E_e, \Omega_e) = \frac{\alpha}{4\pi^2} \frac{E_e}{E_0} \frac{\nu}{Q^2} \left[\frac{(2E_0-\nu)^2}{\nu^2} + 1\right]$$
- Total flux over FT-acceptance:
  $$\Sigma \equiv \int_{FT} \Gamma dE_e d\Omega_e = 7 \cdot 10^{-4}$$
MesonEx has a **broad** physics program, aiming to measure multiple reactions, characterized by different **topologies** and **kinematics**.

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**Trigger requirements**

**MesonEx**

### 1st physics out of CLAS12

**Data Analysis**
- Simplified Pid (pions)
- Not perfect resolution, limited statistics
- Narrow states, few particles involved
- Useful for calibration purposes

**Physics output**
- Simple Moments analysis - extended kinematics
- Exploiting linear polarization (asymmetries)
- Spin Density Matrix Elements (SDME)
- Longitudinal plots
- Testing Dalitz with new amplitudes (Veneziano)
- [Xsection in the extended kinematics (Eg=6-11 GeV)?]
- Mesons never observed in photoproduction (narrow peaks)

**Day 1st analysis**
- \( \gamma p \rightarrow n \pi^+ \)
- \( \gamma p \rightarrow p \pi^0 \)
- \( \gamma p \rightarrow p \pi^+ (X) \)
- \( \gamma p \rightarrow N \pi (\pi) \)
- \( \gamma p \rightarrow N \omega, \eta, .. \)
- \( \gamma p \rightarrow N \pi \pi (\pi) \)
- \( \gamma p \rightarrow p \phi \)

**Day 2 analysis**
- \( \gamma p \rightarrow N K K \)
- \( \gamma p \rightarrow N K \pi \)
- \( \gamma p \rightarrow N K \pi^\pm \)

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**Trigger system should be as open as possible**, to allow measurement of all reactions of interest (as opposite to standard CLAS12 electron trigge!)

**Critical points to consider for trigger design:**

- **Efficiency / uniformity** (for the signal)
- **Total rate** (signal+background)
- **Purity**
MesonEx trigger overview

Starting point for MesonEx trigger design: CLAS hadron spectroscopy program experience (g11/g12)

MesonEx primary trigger: coincidence between $e^-$ detected in FT and $N$ charged particles detected in CLAS12-FD ($N$: 2 or 3)

Individual reactions may require specific settings:

- $\gamma^* p \rightarrow p\pi^0$
  - Photons from $\pi^0$ decay mostly go in FT (low-t) / FT + EC (high-t)
  - FT-only / FT + EC neutral trigger required

- $\gamma^* p \rightarrow pK^+K^-$
  - Proton typically goes in CLAS12-CD, CLAS12-FD trigger mainly selects $K^+K^-(p)$ topology
  - $\phi$ acceptance very low for this topology
  - Need to include CLAS12-CD to recover $\phi$ by measuring all topologies
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Higher priority in MesonEx trigger efforts: CLAS12-FD + FT implementation, validation, and commissioning. Other algorithms have lower priority.
Trigger-rate estimates @ $10^{35} \text{ cm}^{-2} \text{ s}^{-1}$ (CLAS12-FD only, $N = 2$)

**Signal:** $e^-$ in FT $\otimes \geq 2$ charged particles in CLAS12-FD

- $\sigma^{TOT}_\gamma \simeq 100 \mu\text{barn}$
- $\sigma^{TOT}_\gamma \cdot \varepsilon \simeq 25 \mu\text{barn}$ (2 ch) / $9 \mu\text{barn}$ (3 ch)
- $R_{\text{signal}} = \mathcal{L} \cdot \Sigma \cdot \sigma^{TOT}_\gamma \cdot \varepsilon$

**Background:** random coincidence between FT and CLAS12-FD ($\Delta T = 50$ ns)

- FT: Elastic scatt. rad. tail, EM-backgrounds (Moller, Bremmstrahlung, ...)
- CLAS12-FD: hadrons production due to $\simeq 0^\circ$ scattered electrons. $\mathcal{L}_{\text{equiv}}$:
  - 2 ch: $5 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$, $E_{\gamma^*} > 1.5$ GeV
  - 3 ch: $3.7 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$, $E_{\gamma^*} > 3$ GeV

**Summary table:** (all rates in kHz)

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<td>Signal</td>
<td>1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bck</td>
<td>40 (el. tail) + 90 (EM)</td>
<td>125</td>
<td>1.6</td>
</tr>
<tr>
<td>Total</td>
<td>3.3</td>
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**Summary table:** (all rates in kHz) $N = 3$

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<td>33</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td>1.0</td>
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General strategy

Start by focusing on CLAS12-FD only and design charged-particles identification algorithm

- Evaluate single-particle trigger efficiency:
  - Generate and reconstruct events with 1 charged particle ($p/\pi^+/\pi^-$) in CLAS12-FD
  - Identify events with a well-reconstructed particle: $N_{\text{rec}}(p, \theta, \phi)$
  - Identify events also satisfying charged-particle trigger: $N_{\text{trig}}^{\text{rec}}(p, \theta, \phi)$
  - Determine trigger efficiency: $\varepsilon = N_{\text{trig}}^{\text{rec}}/N_{\text{rec}} \rightarrow$ ideally, in the kinematic regions where particles are tracked and reconstructed, trigger efficiency should be flat and close to 100%

- Evaluate foreseen background rate

- Study trigger effects for specific reactions (e.g. $\gamma p \rightarrow p\pi^+\pi^-$)

**Example:** $\pi^+$, torus 0.75 inbending, solenoid 0.8. Charged particle algorithm: any FTOF-1B / FTOF2 hit above 1 MeV. Plots show all momenta
Background rate evaluation

In order to evaluate the background rate in CLAS12-FD for the 50-ns time coincidence with FT, a “time-slice” approach was followed.

- When asking for $N \geq 2$ charged particles in CLAS12-FD, main contribution is from multi-hadrons production ($R_{CLAS_{12-FD}} = 125$ kHZ)
- There may be a sizeable contribution due to random coincidences due to pile-up, i.e. hits due to particles coming from different $e^-$ bunches
- Different topologies are possible: 2 hadrons / 1 hadron + 1 EM hit / ...  
- Total background rate is evaluated by simulating a 250 ns time window @ $10^{35}$ cm$^{-2}$ s$^{-1}$, and counting hits within a 50-ns time window starting at $T = 150$ ns

- Results are evaluated considering in GEMC full physics list / EM only physics list
  - Full physics list *already* includes multi-hadron production
  - Results are a G4 estimate of $R_{CLAS_{12-FD}}$: multi-hadron + pile-up
  - G4 over-estimates hadron production: *results obtained with full physics list should be considered as an upper limit only*
CLAS12-FD charged particles identification algorithm: FTOF only

CLAS12-FD charged particles identification algorithm development started from FTOF\textsuperscript{1}:

- 1 MeV threshold on deposited energy
- Individual paddles rate is too high to implement an CLAS-like trigger system (OR of all counters in a sector)
- FTOF1A-FTOF1B time coincidence (20 ns) and geometrical matching (50 cm) implemented
- No FTOF2 - loss in trigger acceptance

Results (torus -0.75, solenoid +0.8):

- Trigger efficiency \( \geq 90\% \)
- Rates in \( \Delta T = 50 \) ns time window:

<table>
<thead>
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<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>EM-only</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Full</td>
<td>5.6 MHz</td>
</tr>
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High rate source in EM case currently being investigated. If numbers are confirmed, these results show FTOF-only algorithm is not sufficient for \( N = 2 \) / critical for \( N = 3 \)

\textsuperscript{1}PCAL not yet considered - waiting for cluster time reconstruction
Example: EM phys. list only, event with 2 charged particles identified as FTOF1A/FTOF1B time coincidence and geometric match
CLAS12-FD charged particles identification algorithm: FTOF-DC match

Geometrical matching between R3-crosses and FTOF hits (panel 1B / panel 2). No time coincidence imposed between R3 crosses and FTOF hits in the 250-ns event time window

- For each sector, project hit-based R3 crosses to FTOF1B / FTOF2 planes in that sector
- Select hits from FTOF1B / FTOF2 above threshold
- Verify if, among all hits, there’s at least one in geometrical coincidence with the projected cross, within \( \Delta R = 50 \) cm (torus -0.75, solenoid +0.8):
  - Average trigger efficiency \( \rightarrow \) next slide
  - Rates in \( \Delta T = 50 \) ns time window:

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<td></td>
<td>1</td>
</tr>
<tr>
<td>EM-only</td>
<td>480 kHz</td>
</tr>
<tr>
<td>Full</td>
<td>1.9 MHz</td>
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- EM-rate under control
- \( N = 2 \) hadron rate comparable with estimates
Example: EM phys. list only, event with 2 charged particles identified each as one hit in FTOF1B/FTOF2 matched with R3 cross projection
FTOF-DC match: trigger efficiency

\[ p, p^+, p^- \]
MesonEx trigger study with data

MesonEx trigger effort: study algorithms and develop tools and plans to commission hadronic trigger - evaluating the effect of implementation choices (thresholds / coinc. window / ...) on the measured data

Possible procedure to study trigger uniformity with real data: similar to MC studies, with the (remarkable) difference related to the trigger bias itself.

For the $N = 2$ case:

- Select three-track events with given topology (e.g. $\pi^+\pi^- p$)
- Let $p_1, p_2, p_3$, be the trigger efficiency for each track - each depending on that particle kin. variables
- Number of measured events with all three-particles satisfying trigger condition: $N_{all} = p_1 p_2 p_3$
- Number of measured events with two (defined) particles (e.g. 2 and 3) satisfying trigger condition: $N_{two} = p_2 p_3$
- Trigger efficiency for particle 1: $\varepsilon_1 = N_{all} / N_{two} = p_1(p, \theta, \phi)$

This algorithm requires an efficient way to associate the trigger bit to a reconstructed particle.

Also identify possible “easily accessible” reaction channels to evaluate trigger effects on the physics
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Conclusions

- MesonEx broad physics program requires an open trigger to allow measurement of different reactions, with different kinematics and topologies

- **Primary MesonEx trigger:** coincidence between $e^-$ in FT and $N = 2/3$ charged particles in CLAS12-FD
  - Trigger rate estimate ($N = 2$): 1.7 kHz (signal) + 1.6 kHz (bck)
  - Full BG evaluation through MC (including pile-up effects) being performed, first results compatible with estimate (caveat with G4 hadrons production!)
  - Matching with DC information required to suppress EM rate required for $N = 2$
  - Typical trigger efficiency $\geq 90\%$

- MesonEx trigger efforts are focused on the implementation, commissioning, and validation of this algorithm
  - On-going discussion with trigger group to identify practical implementations
  - Development of algorithm and tools to commission trigger during engineering run with real data currently in progress
Backup slides
Single-particle efficiency: reconstructed particles

To identify events with a “well-reconstructed” particle and compute $N_{rec}(p, \theta, \phi)$, I check if in the bank REC:Particle there’s one entry satisfying following conditions:

1. $\frac{\Delta P}{P} < 20\%$, $\Delta \theta < 10^\circ$, $\Delta \phi < 20^\circ$
2. There’s a matching FTOF hit associated with the particle in REC:Scintillator

For events with $38^\circ < \theta < 40^\circ$, I see that REC:Particle has typically 2 entries, only one satisfying condition #1 above. However, FTOF hit associated with the non-matching one.

Effect currently being investigated. Trigger efficiency results not affected, since this simplify in the ratio $\varepsilon = \frac{N_{trg}}{N_{rec}(p, \theta, \phi)}$