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.

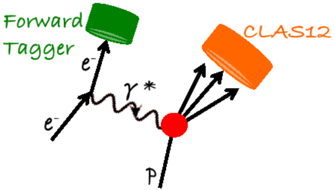
Goals:

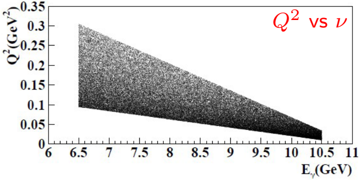
- Measure the light-quarks mesons spectrum in the mass range 1.0 - 3.0 GeV/c^2
- Determine masses and properties of rare $q\bar{q}$ states
- Search for **exotic mesons**

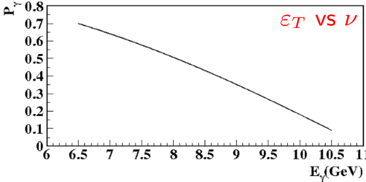
Low Q^2 electron scattering:

- 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)



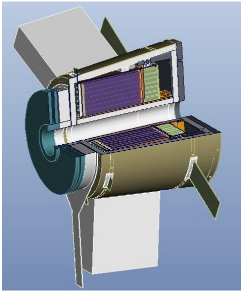




The Forward Tagger Facility

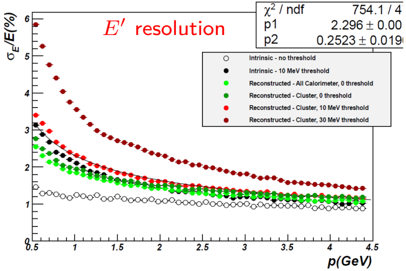
3 components:

- **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:

	Range
$E_{e'}$	0.5 - 4.5 GeV
$\theta_{e'}$	2.5^o - 4.5^o
$\phi_{e'}$	0° - 360°
E_γ	6.5 - 10.5 GeV
P_γ	70 - 10 %
Q^2	0.01 - 0.3 GeV^2 ($< Q^2 >$ 0.1 GeV^2)
W	3.6 - 4.5 GeV



Tagged low Q^2 electron-scattering: kinematics and rates

Kinematic variables:

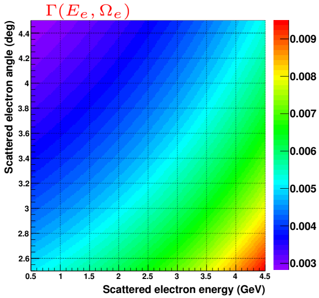
- $\nu = E - E'$
- $Q^2 = 4EE' \sin^2(\theta_e/2)$
- $W^2 = M^2 + 2M\nu - Q^2$

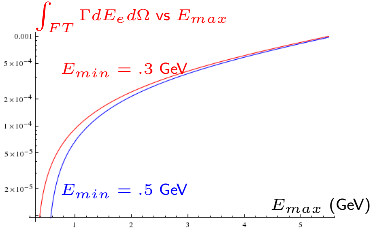
Virtual photon polarization:

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

Rates:

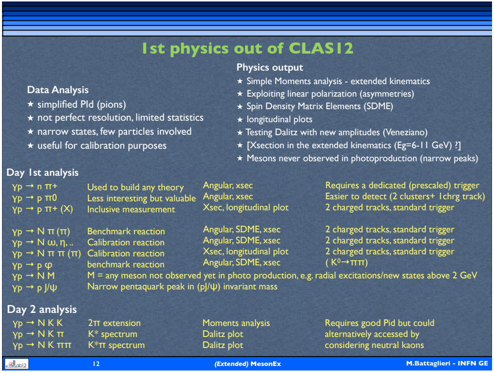
- Cross-section (low Q^2 limit, $\varepsilon_L = 0$):
  $\frac{d\sigma_e}{dE_e d\Omega_e dX} = \Gamma(E_e, \Omega_e) \cdot \frac{d\sigma_\gamma}{dX}$
- Virtual photon flux:
  $\Gamma(E_e, \Omega_e) = \frac{\alpha}{4\pi^2}\frac{E_e}{E_0}\frac{\nu}{Q^2}\left[\frac{(2E_0-\nu)^2}{\nu^2} + 1\right]$
- Total flux over FT-acceptance:
  $\Sigma \equiv \int \Gamma dE_e d\Omega_e = 7 \cdot 10^{-4}$





MesonEx trigger requirements

MesonEx has a **broad** physics program, aiming to measure multiple reactions, characterized by different **topologies** and **kinematics**



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

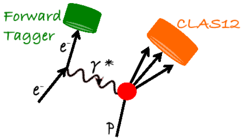
Critical points to consider for trigger design:

- Efficiency / uniformity (for the signal)
- Total rate (signal+background)
- Purity

MesonEx trigger overview

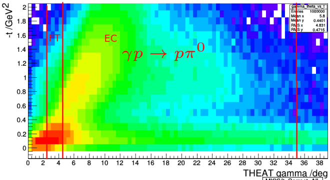
Starting point for MesonEx trigger design: CLAS hadron spectroscopy program experience (g11/g12)

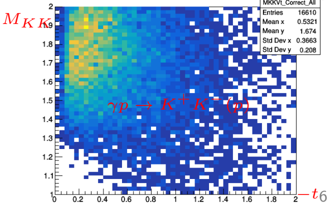
MesonEx primary trigger: coincidence between e^- detected in FT and N charged particles detected in CLAS12-FD (N: 2 or 3)



Individual reactions may require specific settings:

- $\gamma^* p \rightarrow p\pi^0$
    - Photons from π^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
    - ϕ acceptance very low for this topology
    - Need to include CLAS12-CD to recover ϕ by measuring all topologies





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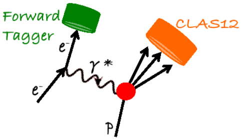
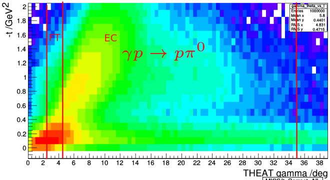
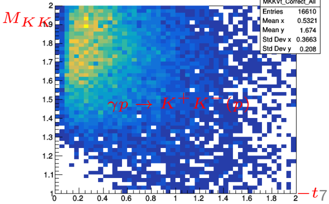


Higher priority in MesonEx trigger efforts: CLAS12-FD + FT implementation, validation, and commissioning.
Other algorithms have lower priority.





Trigger-rate estimates @ 10^{35} cm^{-2} s^{-1} (CLAS12-FD only, $N = 2$)

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

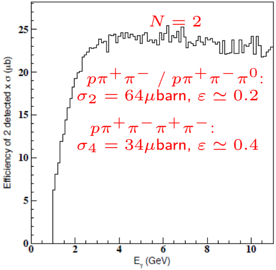
- $\sigma_\gamma^{TOT} \simeq 100\mu$barn
- $\sigma_\gamma^{TOT} \cdot \varepsilon \simeq 25\,\mu$barn (2 ch) / 9 μbarn (3 ch)
- $R_{signal} = \mathcal{L} \cdot \Sigma \cdot \sigma_\gamma^{Tot} \cdot \varepsilon$

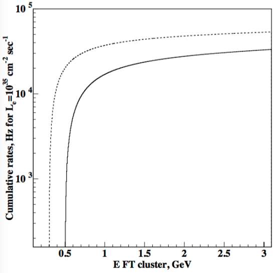
Background: random coincidence between FT and CLAS12-FD ($\Delta T = 50$ ns)

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

Summary table: (all rates in kHz) N=2

	FT	CLAS12-FD	Coinc.
Signal	1.6		
Bck	40 (el. tail) + 90 (EM)	125	1.6
Total	**3.3**		





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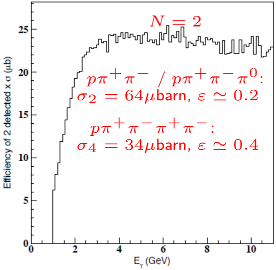
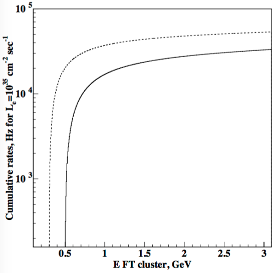
Summary table: (all rates in kHz) N=3

	FT	CLAS12-FD	Coinc.
Signal	0.6		
Bck	40 (el. tail) + 90 (EM)	33	0.5
Total	**1.0**		



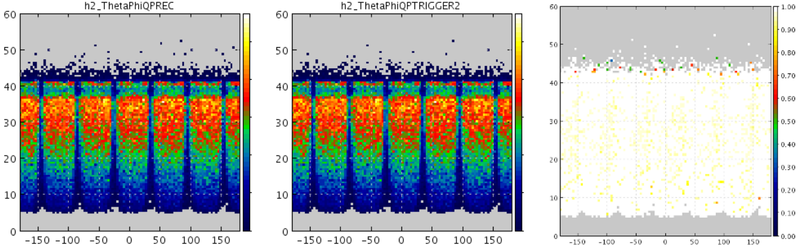


General strategy

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/π^+/π^-) in CLAS12-FD
  - Identify events with a well-reconstructed particle: $N_{rec}(p, \theta, \phi)$
  - Identify events **also** satisfying charged-particle trigger: $N_{rec}^{trig}(p, \theta, \phi)$
  - Determine trigger efficiency: $\varepsilon = N_{rec}^{trig}/N_{rec}$ → 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. $\gamma p \to p\pi^+\pi^-$)

Example: π^+, 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

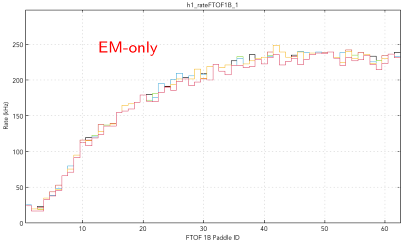
In order to evaluate the background rate in CLAS12-FD for the 50-ns time coincidence with FT, a "time-slice" approach was followed.

- When asking for $N \geq 2$ charged particles in CLAS12-FD, main contribution is from multi-hadrons production ($R_{CLAS12-FD} = 125$ 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 $R_{CLAS12-FD}$: multi-hadron + pile-up
  - G4 over-estimates hadron production: **results obtainer 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[1]:

- 1 MeV threshold on deposited energy
- Invidual 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:

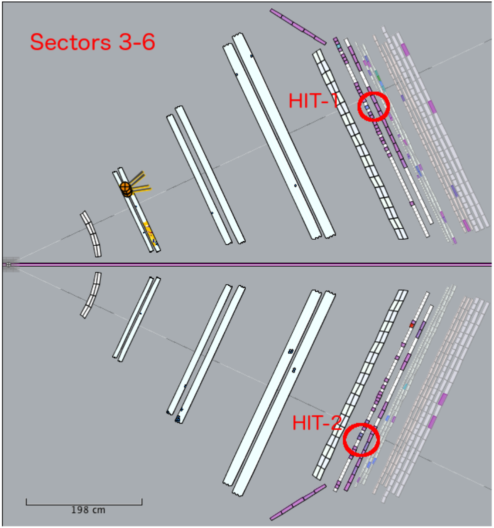
Phys. list	N			
	1	2 (any)	2 (diff.)	3
EM-only	5 MHz	870 kHz	720 kHz	111 kHz
Full	5.6 MHz	1.2 MHz	990 kHz	274 kHz

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 $N = 3$

[1] PCAL not yet considered - waiting for cluster time reconstruction

CLAS12-FD charged particles identification algorithm: FTOF only

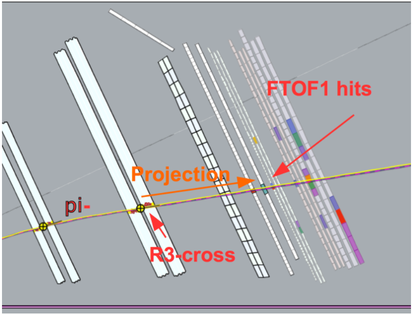
Example: EM phys. list only, event with 2 charged particles identified as FTOF1A/FTOF1B time coincidence and geometric match



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):

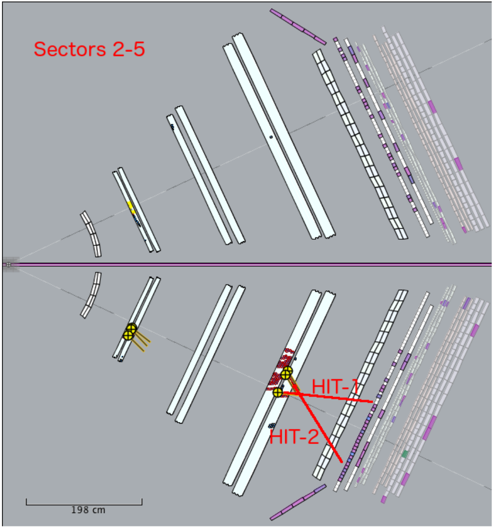
- Average trigger efficiency → next slide
- Rates in $\Delta T = 50$ ns time window:

Phys. list	N			
	1	2 (any)	2 (diff.)	3
EM-only	480 kHz	33 kHz	11 kHz	3 kHz
Full	1.9 MHz	423 kHz	244 kHz	109 kHz

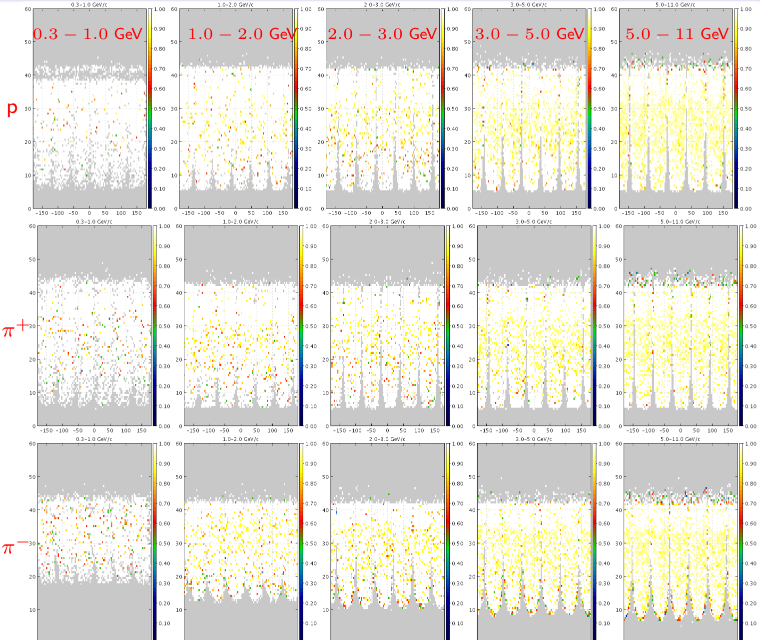
- EM-rate under control
- $N = 2$ hadron rate comparable with estimates

CLAS12-FD charged particles identification algorithm: FTOF-DC match

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



MesonEx trigger study with data

MesonEx trigger effort: study algorithms and develop tools and plans to commission hadronic trigger - evaluating the effect of implemenation 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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Work in progress to be ready for engineering run!!

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 trough 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 $N = 2$
  - Tipical 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

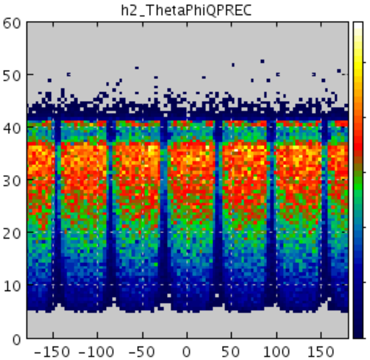
Backup slides

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. $\Delta P/P < 20\%$, $\Delta\theta < 10^\circ$, $\Delta\phi < 20^\circ$
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 tipically 2 entries, only one satisfying condition #1 above. However, FTOF hit associated with the non-matching one.



REC::Scintillator

index	pindex	detector	sector	component	energy	time	x	y	z
3	0	17	1	19	4.31960	176.28140	327.55264	-68.69802	602.86169

REC::Particle

	pid	px	py	pz	vx	vy	vz	charge
1	0	0.56855	-0.75559	1.30242	45.12827	33.95700	99.07033	1
2	0	5.12493	-0.29654	6.70572	6.08587E-4	-3.52144E-5	1.63532	1

MC::Particle

	pid	px	py	pz	vx	vy	vz	mass
1	2212	5.00138	-0.28512	6.53318	0.0	0.0	0.0	0.0

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