A New Track Trigger for the Proton-Radius Measurement at COMPASS++/Amber

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Measurement of the Q^2 Spectrum at COMPASS

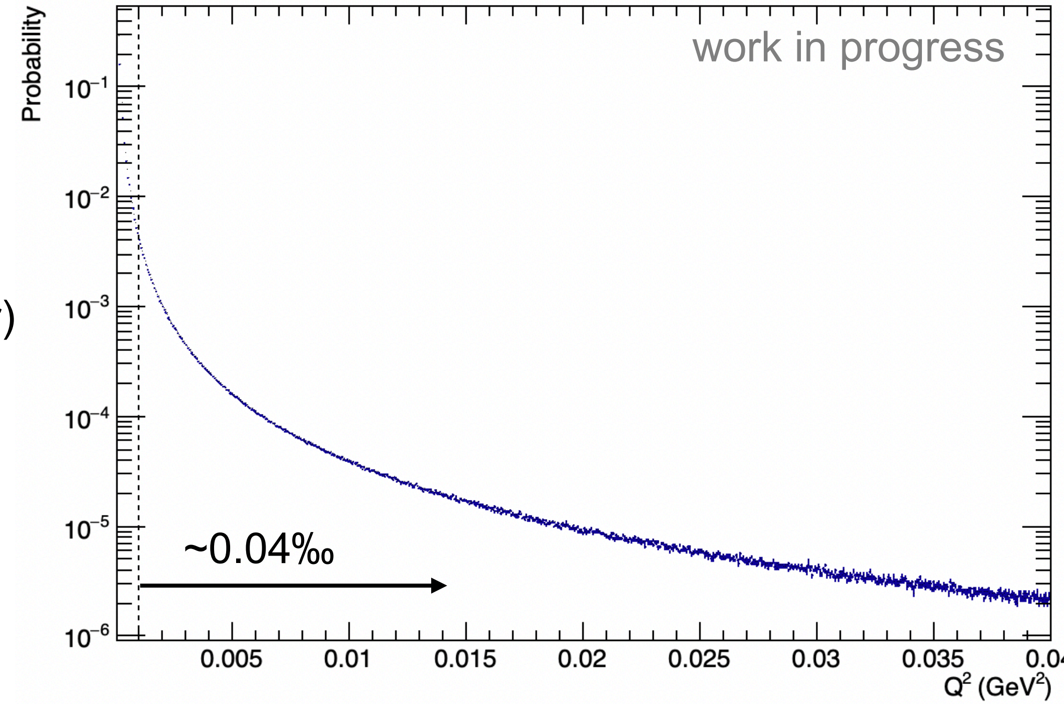
- high-intensity muon beam

  $$\phi_\mu \sim 2 \cdot 10^6\ /s \text{ - } 2 \cdot 10^7\ /s$$

- would correspond to data rates of
  3 GB/s – 20 GB/s (~7-50 PB per year)

- without trigger selection only
  ~0.04‰ interesting events
  (for $Q^2 > 10^{-3}$ GeV ^{2})

→ remove the "unscattered" muons with
a *kink trigger*



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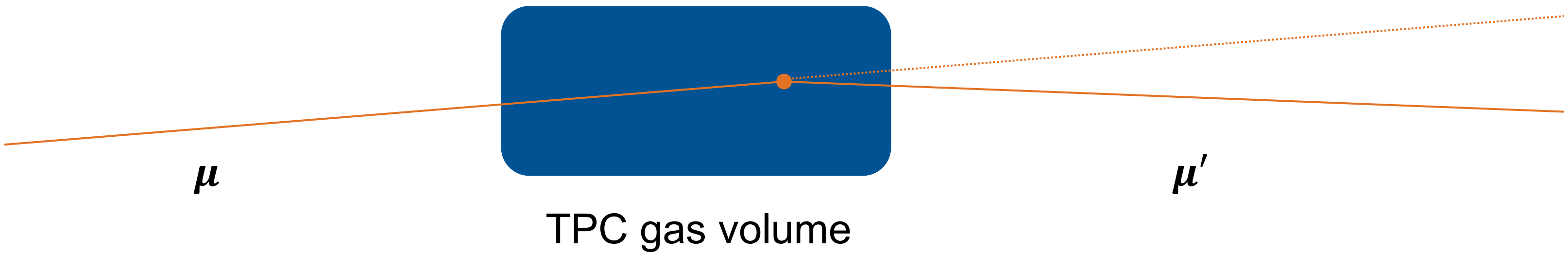
Triggering on Scattered Muons



Requirements

- reject unscattered muons below $Q^2 <$ *threshold (~ 10^{-4} – 10^{-3}* GeV ^{2}*)*
- high trigger efficiency for scattered muons with $Q^2 >$ *10^{-3}* GeV ^{2} (>90%)
- low material budget (source of multiple scattering)
- large active area (large beam profile)
- withstand high beam rate without pile up

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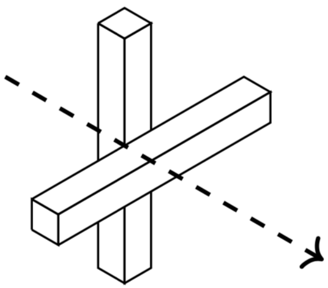
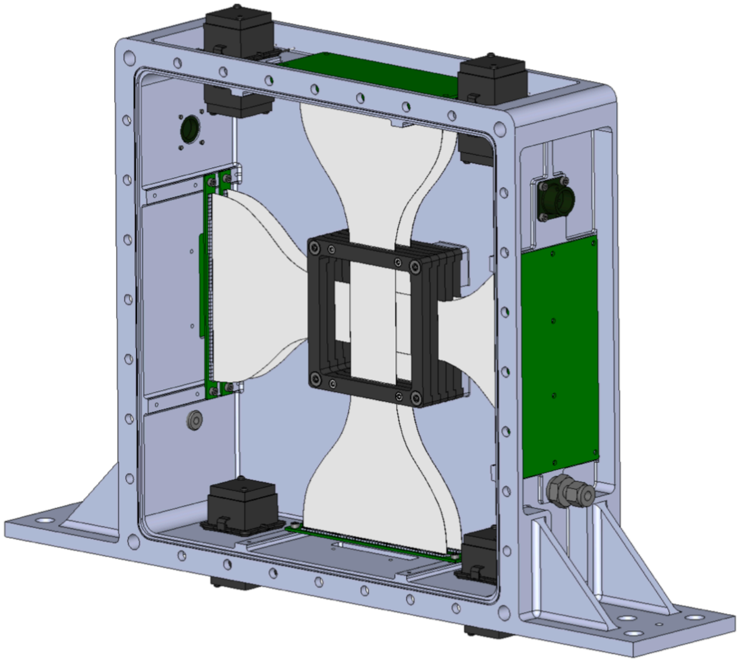
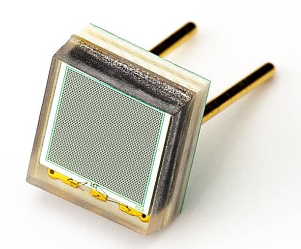
Fiber-Trigger Stations: Scintillating Plastic Fibers Coupled to Silicon Photomultipliers





Tracking Station

- layers of scintillating plastic fibers with alternating orientation
- 250 fibers per layer with 200 μm x 200 μm cross section and ~200 mm length
- 4 layers (2 oriented horizontally, 2 oriented vertically)
- relative shift of layers by 100 μm → 100 μm x 100 μm effective “pixel” size
- each fiber individually read out by two silicon photomultipliers (one on each end)



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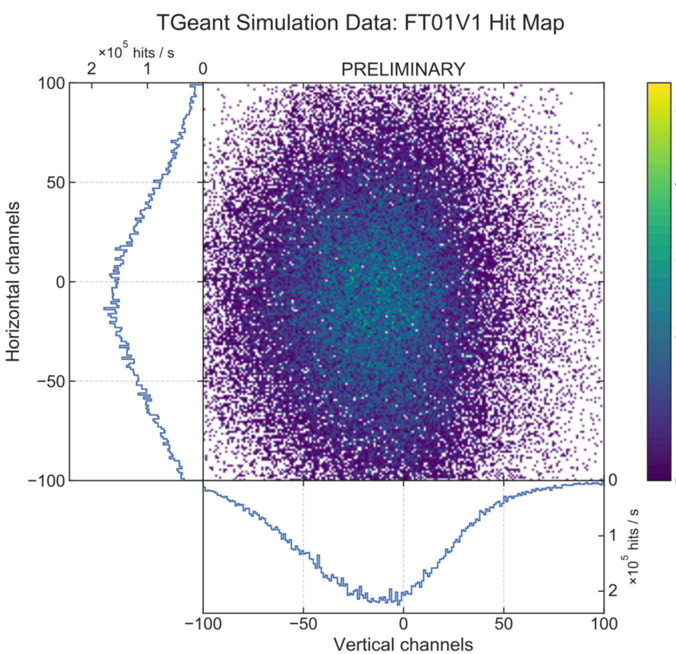
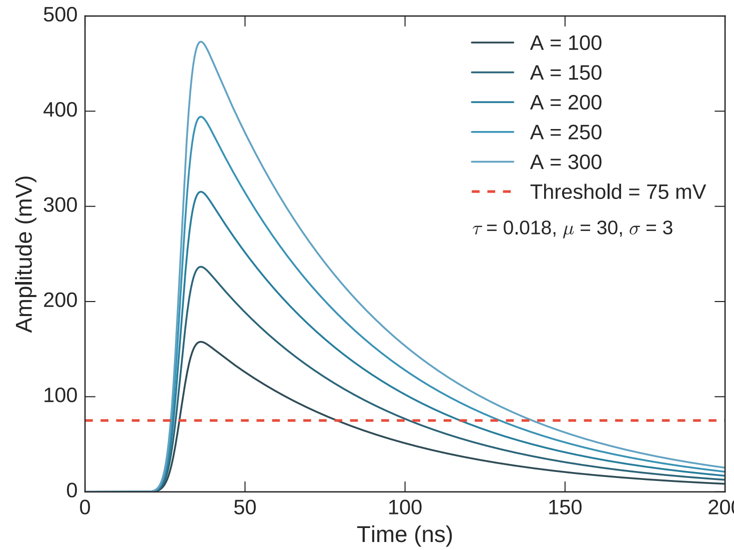
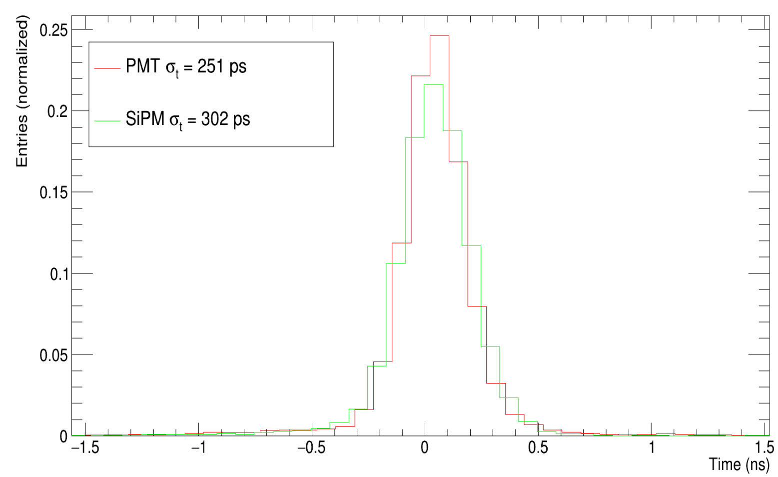
Fiber-Trigger Stations: Scintillating Plastic Fibers Coupled to Silicon Photomultipliers

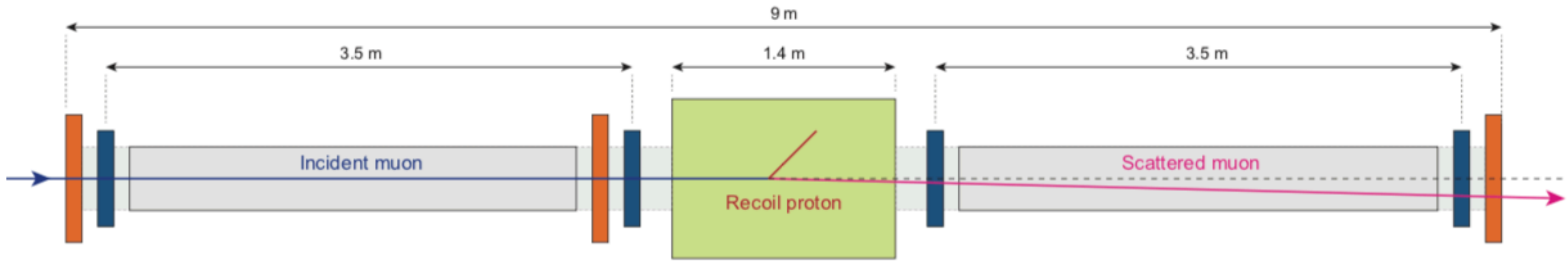
- ✓ low material budget (~4% contribution)
- ✓ very fast: organic scintillator ~ 2 ns
  SiPMs ~ 10 – 100 ns
- ✓ good single-channel time resolution
- ✓ no pile-up for expected beam settings







Identification of a Scattered Muon



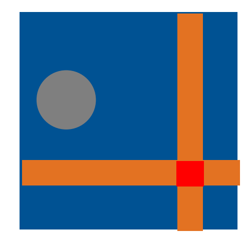
Trigger Station 1

Trigger Station 2

Trigger Station 3

- determines track parameters of incoming muon

straight-line extrapolation



- ✓ only one trigger station within the scattering-sensitive measurement regime (minimize multiple scattering)
- ✓ simple calculation for online triggering (FPGA based)
- low-Q^2 resolution limited by fiber cross-section

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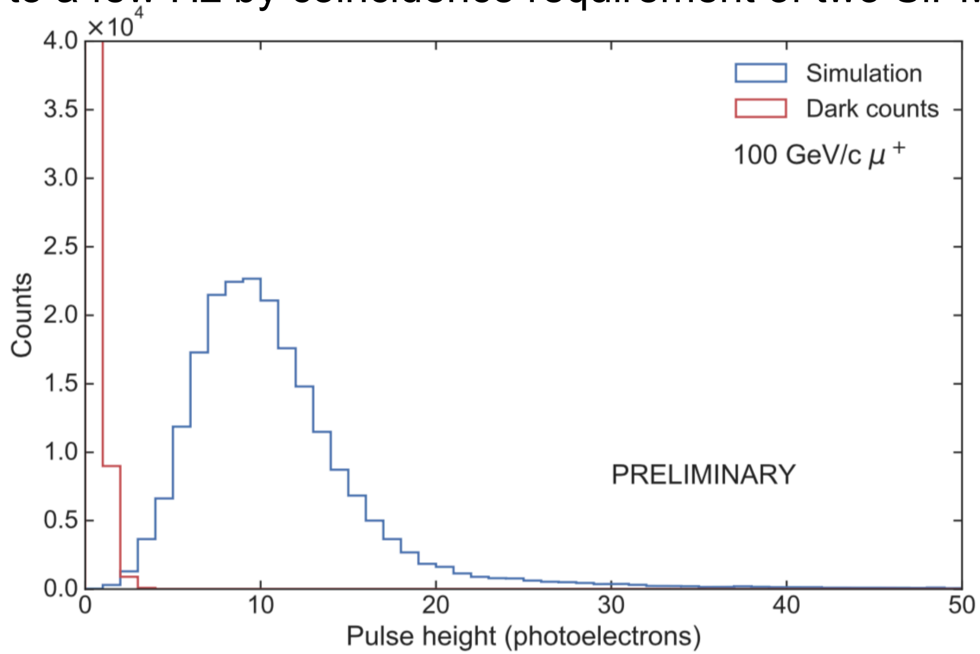
Challenge: Having a High Detection Efficiency for the Muon

- high-energy muons are nearly minimum-ionizing: ~40 keV energy deposition in fiber
- together with scintillation efficiency, photon transport, and detection efficiency of SiPMs we expect only ~10 photoelectrons (p.e.) in average (Poisson distributed)

- noise level of SiPMs ~10 kHz @ 2 p.e.

  →reduced to a few Hz by coincidence requirement of two SiPMs



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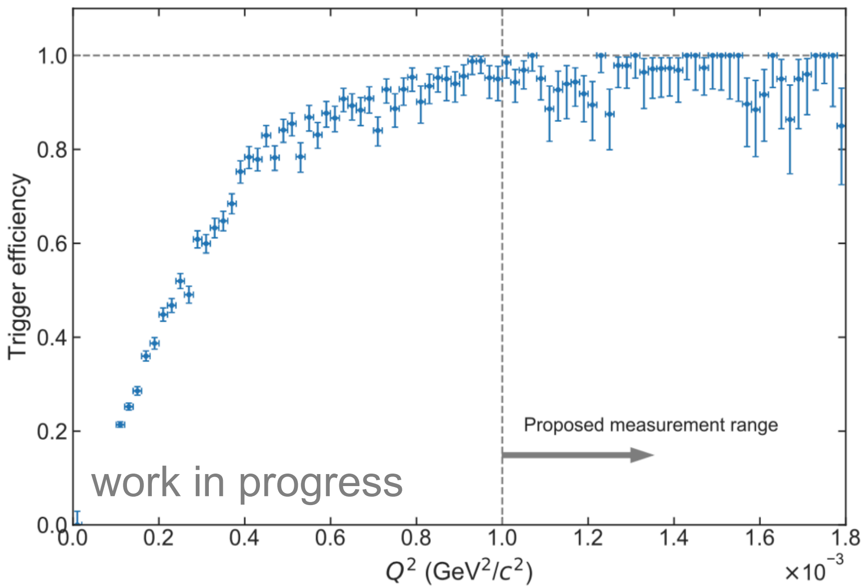
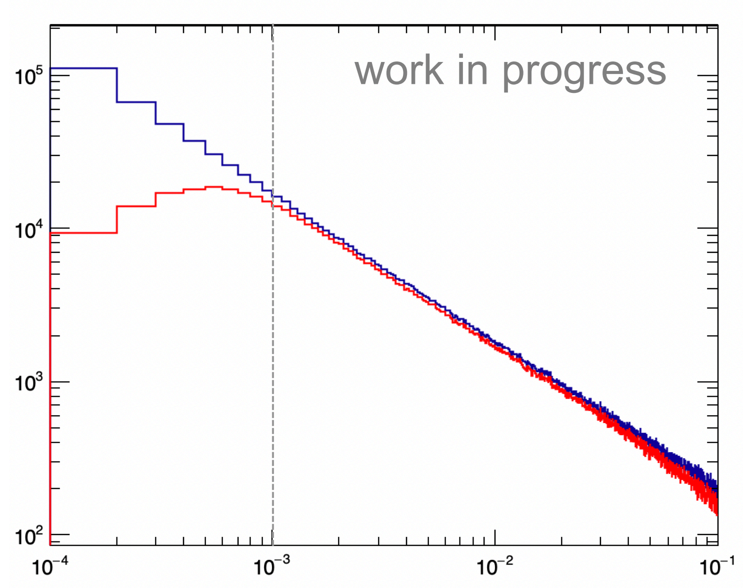
Simulation of Trigger Efficiency and Rejection Efficiency





- efficiency: 97% @ $Q^2 = 10^{-3}$ GeV^2
- rejection power: 96.5% @ $Q^2 < 10^{-3}$ GeV^2

Systematic Studies

- misalignment studies
- influence of mechanical tolerances (gaps between fibers, fiber-size variations, …)
- tune trigger threshold
- acceptance correction for measurement range
- investigate correlation between trigger efficiency and proton-radius parameters

Fitting Procedure: Markov-Chain Monte Carlo (MCMC) (Work in Progress!)

- Bayesian probabilistic analysis method
- evaluate the full posterior-probability distribution (not only a point estimate)

$$p(\theta|D) = \frac{L(D|\theta) \cdot \pi(\theta)}{\int L(D|\theta')\pi(\theta')} \propto L(D|\theta) \cdot \pi(\theta)$$

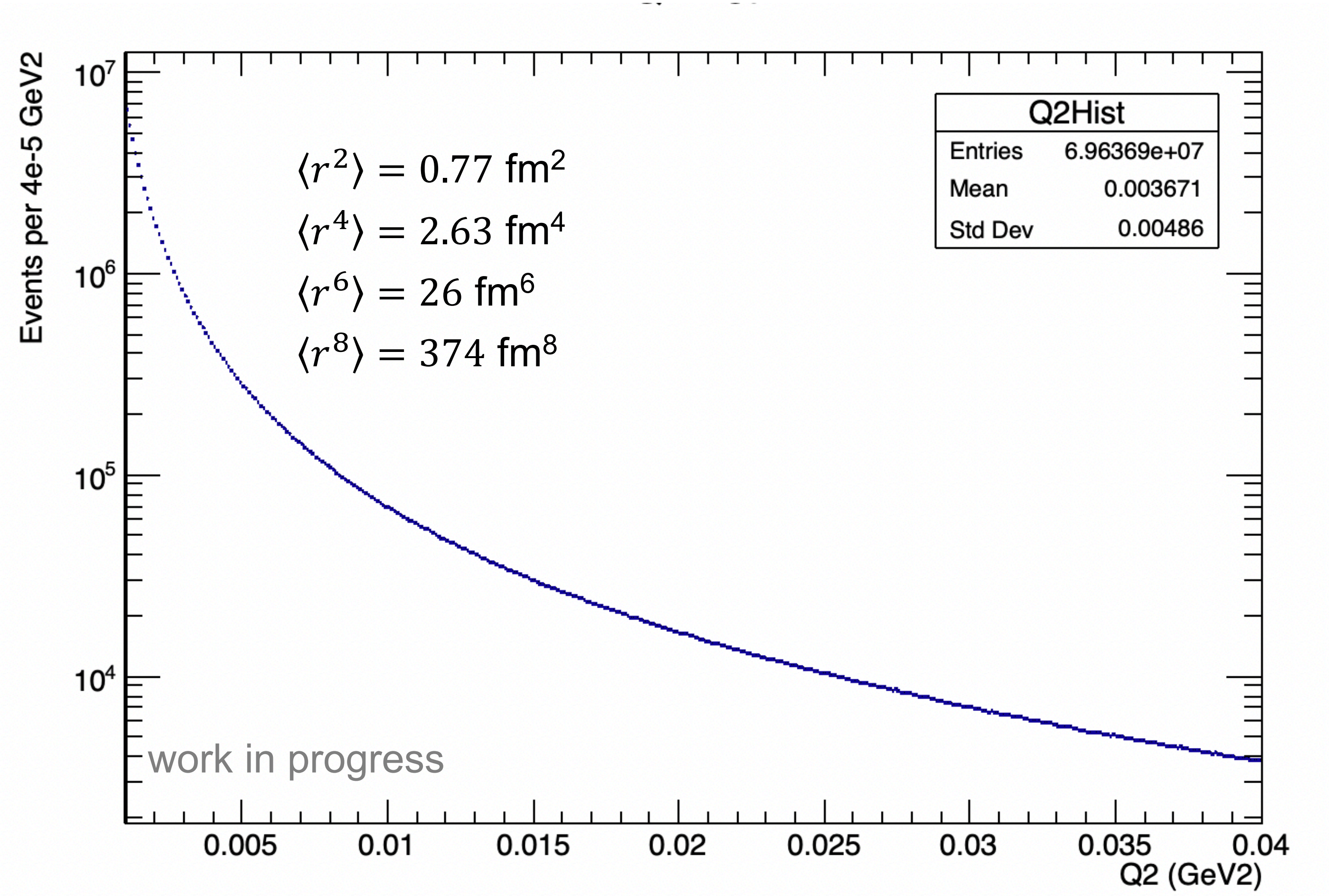
- update information on parameters given new data
- include acceptance corrections as nuisance parameters in the fit with informative priors
- marginalize out nuisance parameters
  → posterior-probability distribution of the target parameter (<r^2>)

$$p(\theta_0|D) = \int p(\theta_0, \theta_n|D)\, d\theta_n$$

- allows extended correlation studies between the parameters

implementation using the Bayesian Analysis toolkit (BAT) (Caldwell et al. http://www.mppmu.mpg.de/bat)

Example: Fitting Polynomial Function (up to Q^8) to Toy MC Data



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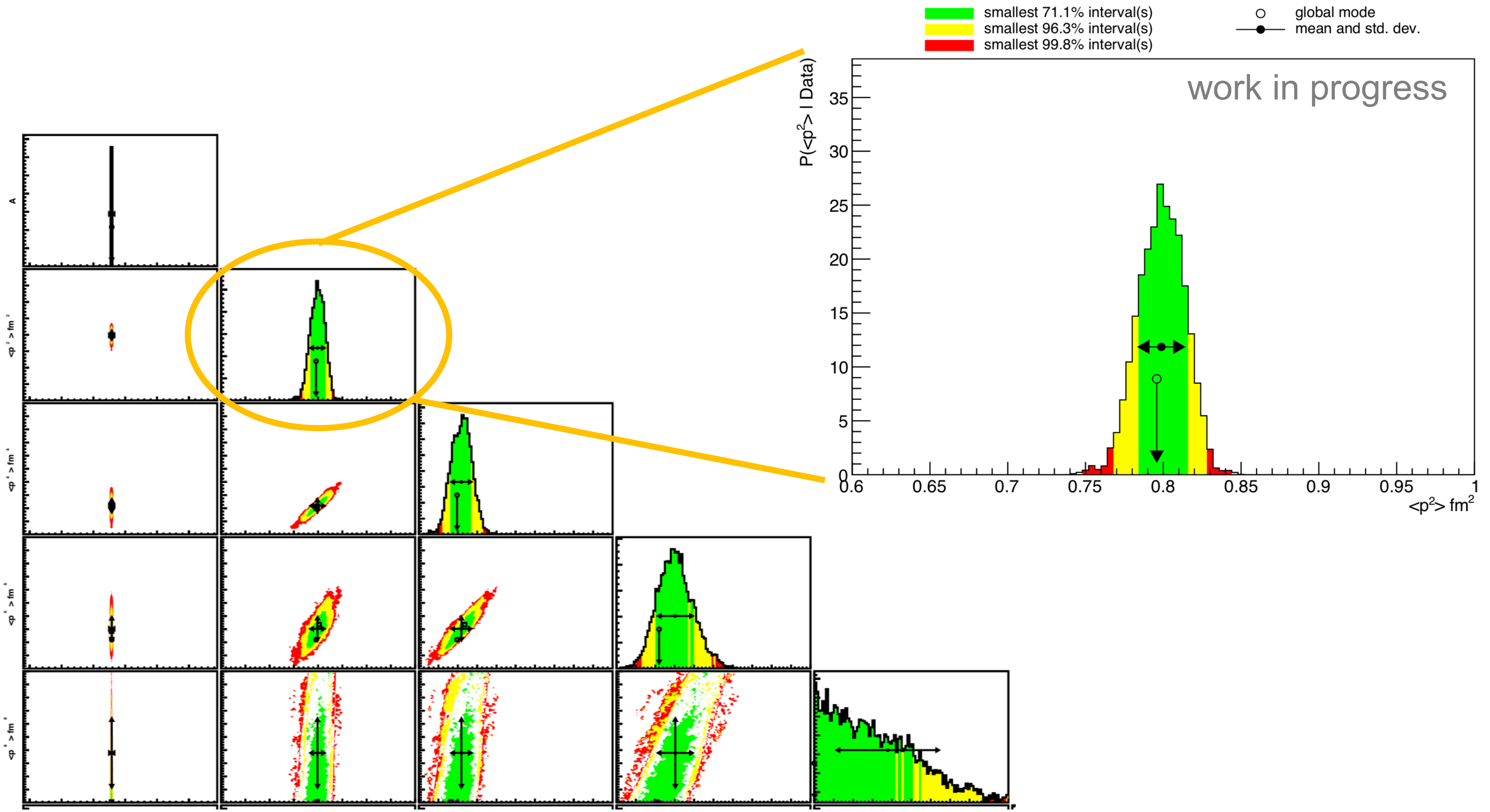

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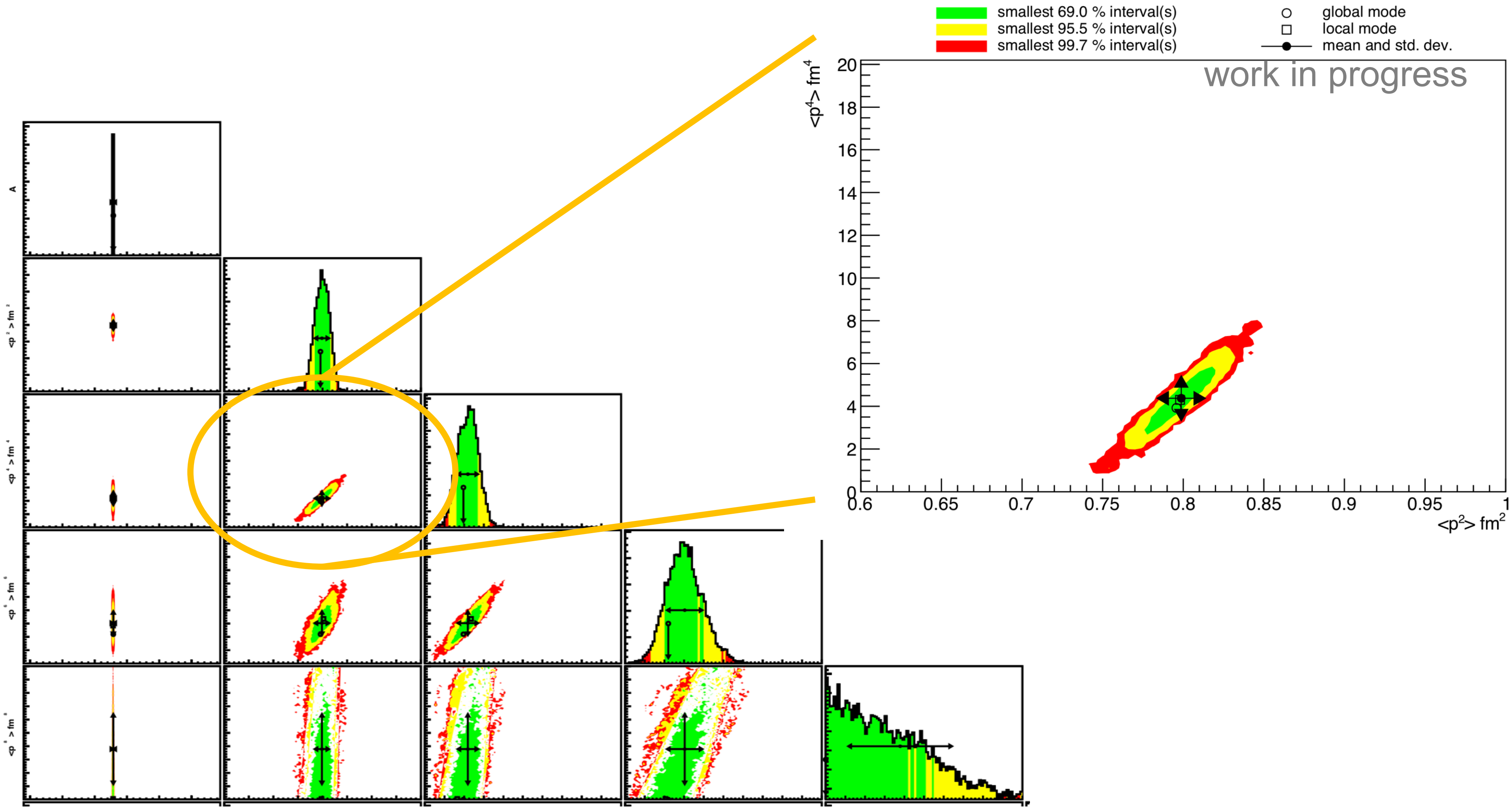

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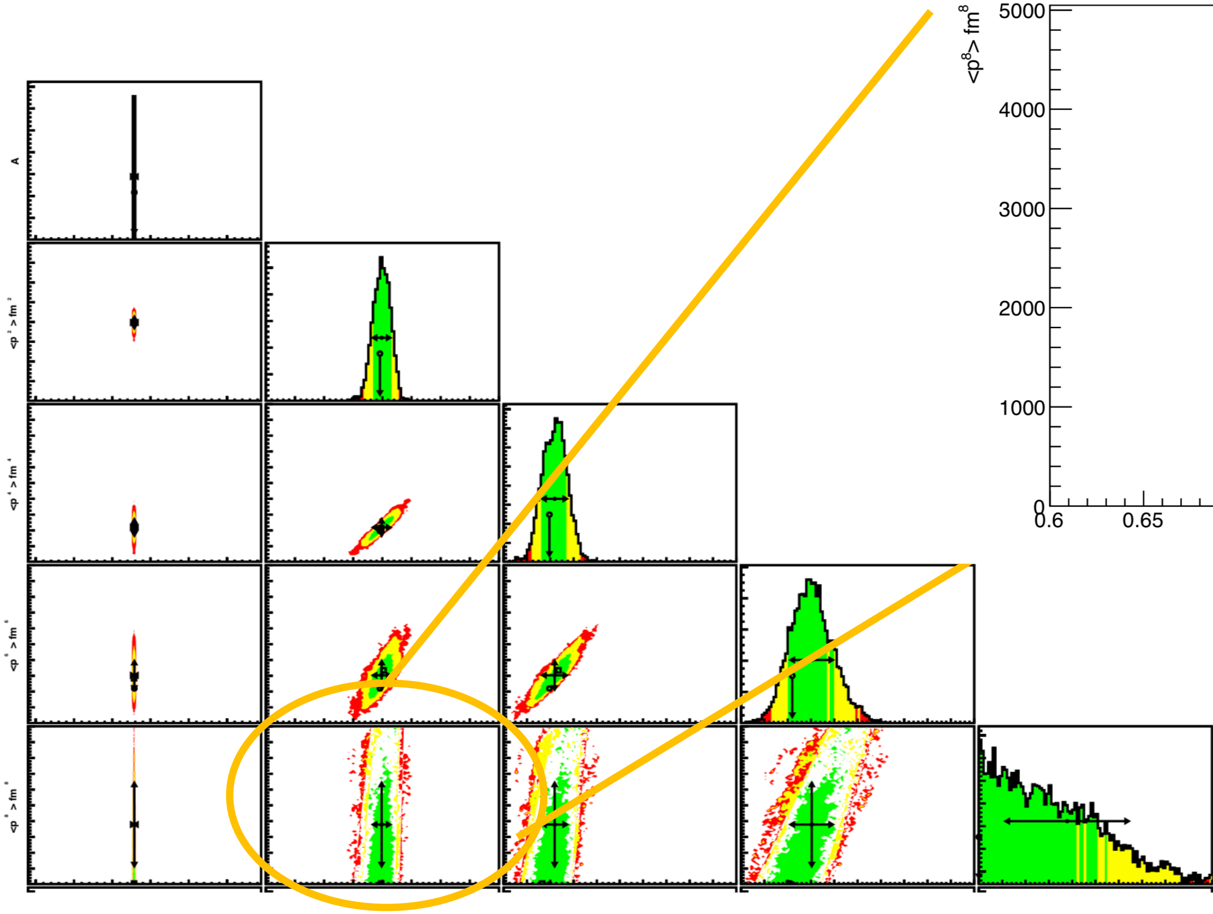

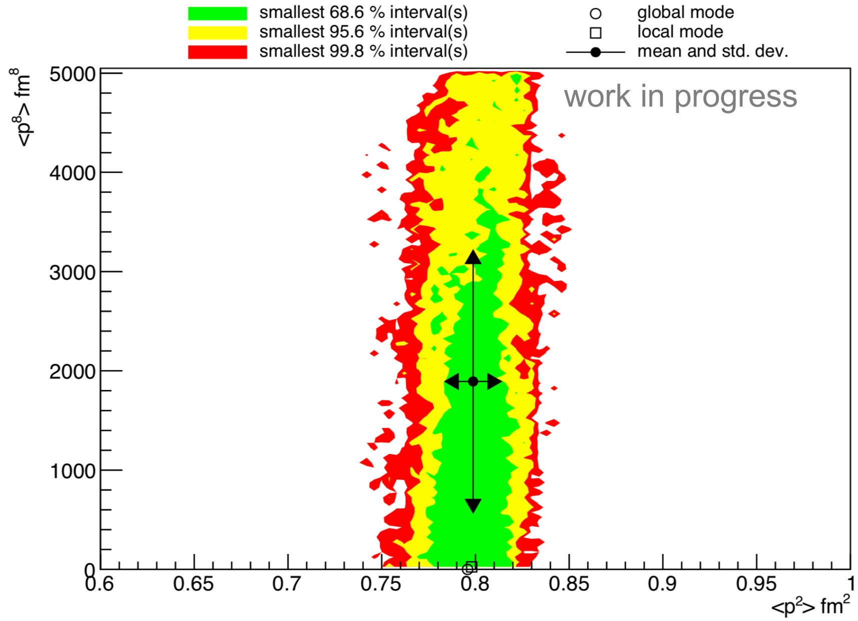

→ easily visualizable how a constraint on a nuisance parameter would influence the target parameter

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Quantifying Correlation

	A	$\langle p^2 \rangle$ fm^2	$\langle p^4 \rangle$ fm^4	$\langle p^6 \rangle$ fm^6	$\langle p^8 \rangle$ fm^8	$\sqrt{\langle p^2 \rangle}$ fm
A	+1	+0.87	+0.75	+0.57	+0.091	+0.87
$\langle p^2 \rangle$ fm^2	+0.87	+1	+0.94	+0.76	+0.16	+1
$\langle p^4 \rangle$ fm^4	+0.75	+0.94	+1	+0.91	+0.32	+0.94
$\langle p^6 \rangle$ fm^6	+0.57	+0.76	+0.91	+1	+0.67	+0.76
$\langle p^8 \rangle$ fm^8	+0.091	+0.16	+0.32	+0.67	+1	+0.16
$\sqrt{\langle p^2 \rangle}$ fm	+0.87	+1	+0.94	+0.76	+0.16	+1

work in progress

Next Steps & Conclusion

- Include acceptance correction in MCMC Fit Procedure
  - parametrize with uncertainties (a few nuisance parameters)
  - binned template from simulation (a few thousand nuisance parameters)

    → check correlation with proton radius

  - implement further acceptance corrections
    - vertex cuts
    - tracking uncertainties
    - recoil-kinematics reconstruction (muon in spectrometer & proton in TPC)

  - further systematic checks of fitting procedure with different parametrizations of form factor
  - fit-range dependence

  - build and test trigger stations in particle beam

Thank you for your attention!