π^0 transition form factor and search for dark photon

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EXCELLENCE IN SCIENCE

$K_{2\pi D}$ event selection

$K_{2\pi D}$ event selection (1)

- Data sample: **2003+2004 SCMP ee-split**.
- Trigger: **Q_2 × MBX (1VTX || 2VTX || 1TRK)**.
- Find the best 3-track vertex: least χ^2 among vertices with **$-18\text{m}<z_{vtx}<80\text{m}$**, **$|Q|=1$** and no common tracks with other vertices.
- Vertex fit quality: **$\chi^2<25$**.
- Inter-track distance in DCH1 plane: **$D_{DCH1}>6$ cm**.
- Track DCH times: **$|t_i|<25$ ns**; **$|t_i-t_j|<15$ ns**.
- Pion candidate: **$E/p<0.85$**; $e^\pm$ candidates: **$0.85<E/p<1.15$**.
- All tracks in LKr acceptance; **12 cm$<R_{track}<$100 cm** in DCH1,2,4.
- Track separations in LKr plane: **$R_{LKr}>15$ cm**.
- Track momenta: **3.3 GeV/c$<p_e<$60 GeV/c**; **5 GeV/c$<p_\pi<$60 GeV/c**.

[for the time being, **3.3 GeV/c** lower cut due to **3 GeV/c** cutoff for non-α,β-corrected momentum in the ee-filter algorithm]

$K_{2\pi D}$ event selection (2)

- Exactly 1 photon candidate LKr cluster:
  - ✓ separation from $\pi^\pm$ impact point: $R_{\gamma\pi}>50$ cm;
  - ✓ separation from $e^\pm$ impact points: $R_{\gamma e}>10$ cm;
  - ✓ separation from undeflected $e^\pm$ trajectories: $R_{\gamma e}>50$ cm;
  - ✓ LKr–DCH timing: $|t_\gamma - t_{vtx}|<10$ ns.
- The photon candidate is in LKr acceptance.
- Photon candidate $E_\gamma>3$ GeV, $D_{dead\text{-}cell}>2$ cm.
- Photon DCH1 intercept: $R_{DCH1}>13$ cm.
- Total momentum: $|p_{\pi ee\gamma}-60\ \mathrm{GeV}/c|<7$ GeV/c.
- Transverse momentum wrt z axis: $p_T^2<5\times10^{-4}\ (\mathrm{GeV}/c)^2$.
- $|M_{ee\gamma}-M_{\pi 0}|<8\ \mathrm{MeV}/c^2$.
- $475\ \mathrm{MeV}/c^2 < M_{\pi ee\gamma} < 510\ \mathrm{MeV}/c^2$.
- $M_{ee} > 10\ \mathrm{MeV}/c^2$ (no need for the upper limit).

Selection fully debugged: event-by-event comparisons with Michal and Nicolas with the 2007 data

MC samples (2003+2004)

[thanks to Nicolas Lurkin for integrating the Prague generator into CMC]

- $K^{\pm}\to\pi^{\pm}\pi^{0}_{D}(\gamma)$, KLOE IB generator,
  no radiative corrections to π^{0}_{D} (**835M** gen. events; data ×2)
  [mc.k2pigd.kloe.list]

- $K^{\pm}\to\pi^{\pm}\pi^{0}_{D}(\gamma)$, KLOE IB generator,
  Mikaelian-Smith radiative corrections to π^{0}_{D} (**835M** gen. events)
  [mc.k2pigd.kloe.pi0d.radcor.MS.list]

- $K^{\pm}\to\pi^{\pm}\pi^{0}_{D}(\gamma)$, KLOE IB generator,
  Prague radiative corrections to π^{0}_{D} (**835M** gen. events)
  [mc.k2pigd.kloe.pi0d.radcor.prague.list] **STANDARD**

- $K^{\pm}\to\pi^{0}_{D}\mu^{\pm}\nu(\gamma)$, KLOE IB generator,
  Prague radiative corrections to π^{0}_{D} (**418M** gen. events)
  [mc.km3gd.kloe.pi0d.radcor.prague.list] **STANDARD**

Prague vs MS radiative corrections comparison: 5 June 2014 talk

MC samples (2007)

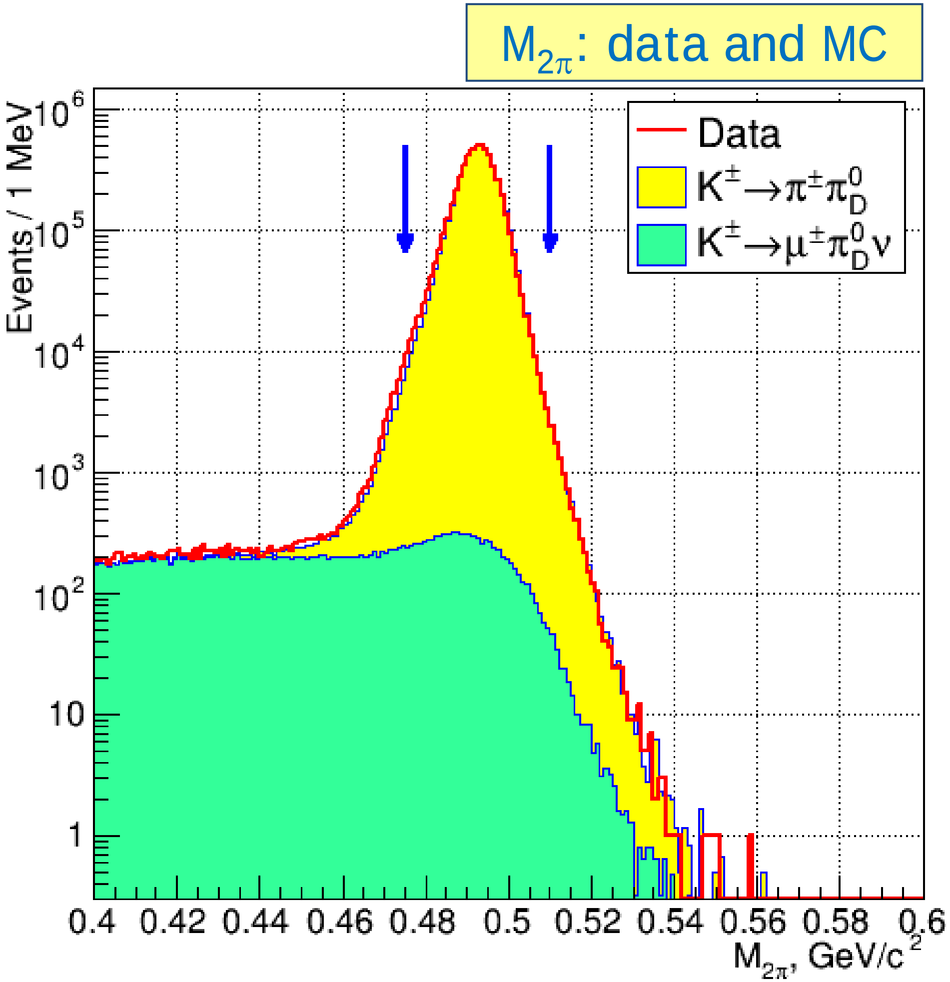
[thanks to Nicolas Lurkin for integrating the Prague generator into CMC]

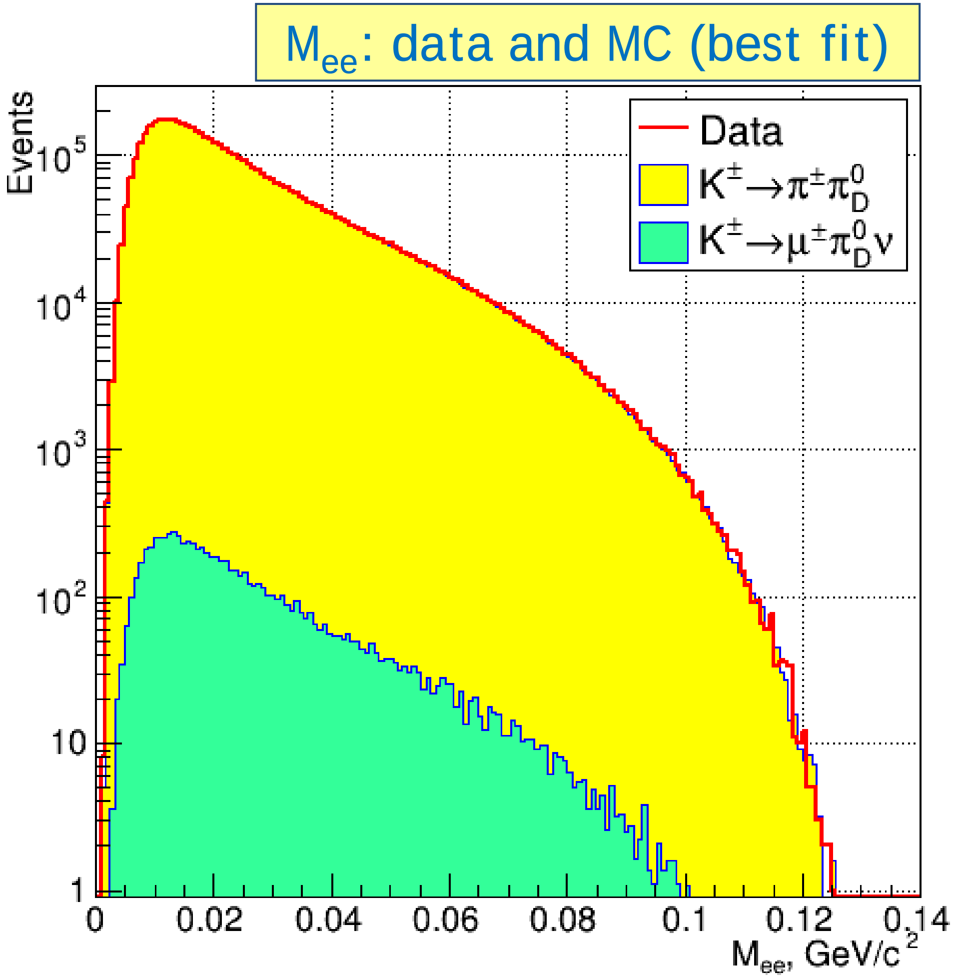
- **$K^{\pm}\to\pi^{\pm}\pi^{0}_{D}(\gamma)$**, KLOE IB generator,
  Mikaelian-Smith radiative corrections to π^{0}_{D} (**223M** gen. events)
  [mc.2007.k2pigd.kloe.pi0d.radcor.MS.list]

- **$K^{\pm}\to\pi^{\pm}\pi^{0}_{D}(\gamma)$**, KLOE IB generator,
  Prague radiative corrections to π^{0}_{D} (**447M** gen. events)
  [mc.2007.k2pigd.kloe.pi0d.radcor.prague.list]

- **$K^{\pm}\to\pi^{0}_{D}\mu^{\pm}\nu(\gamma)$**, KLOE IB generator,
  Prague radiative corrections to π^{0}_{D} (**119M** gen. events)
  [mc.2007.km3gd.kloe.pi0d.radcor.prague.list]

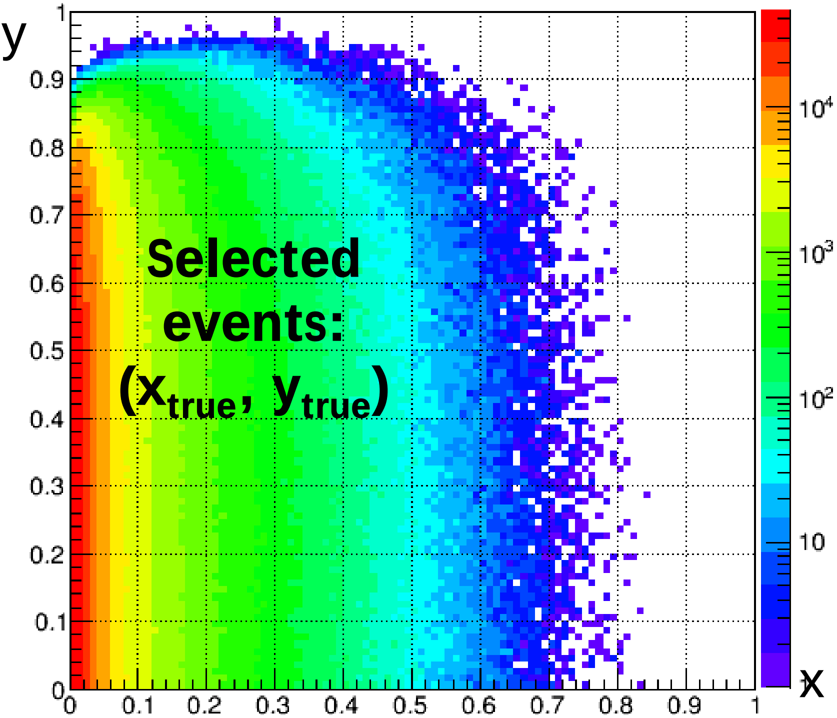
Data sample





Candidates: **$N(K_{2\pi D}, M_{ee}>10\,\text{MeV}/c^2)=4.687\times10^6$**, **$K_{\mu 3D}$** contribution: **0.15%**.

$K_{2\pi D}$ acceptance



Kinematic variables:

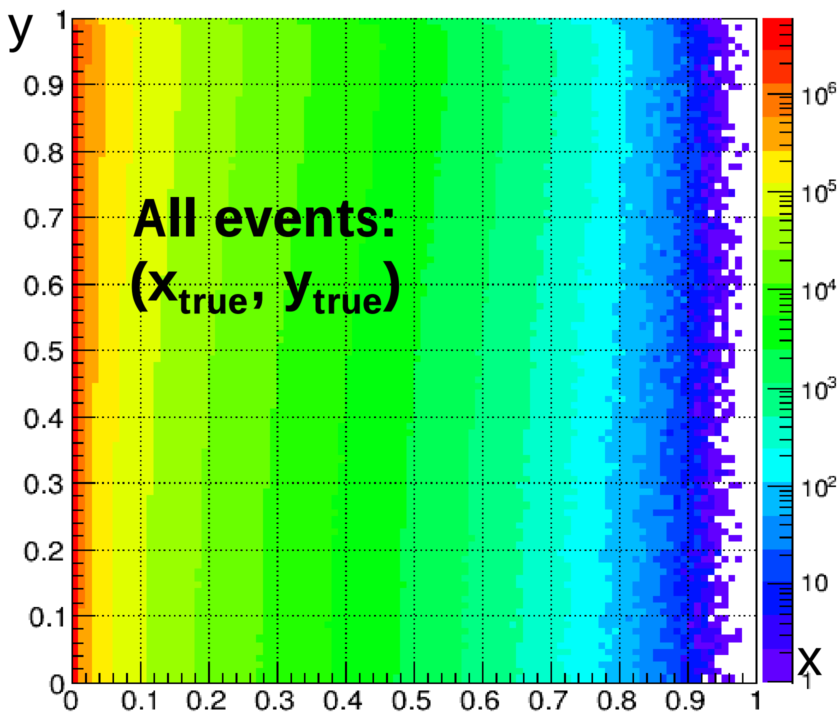
$x = (q_1+q_2)^2/m_\pi^2 = (m_{ee}/m_\pi)^2$

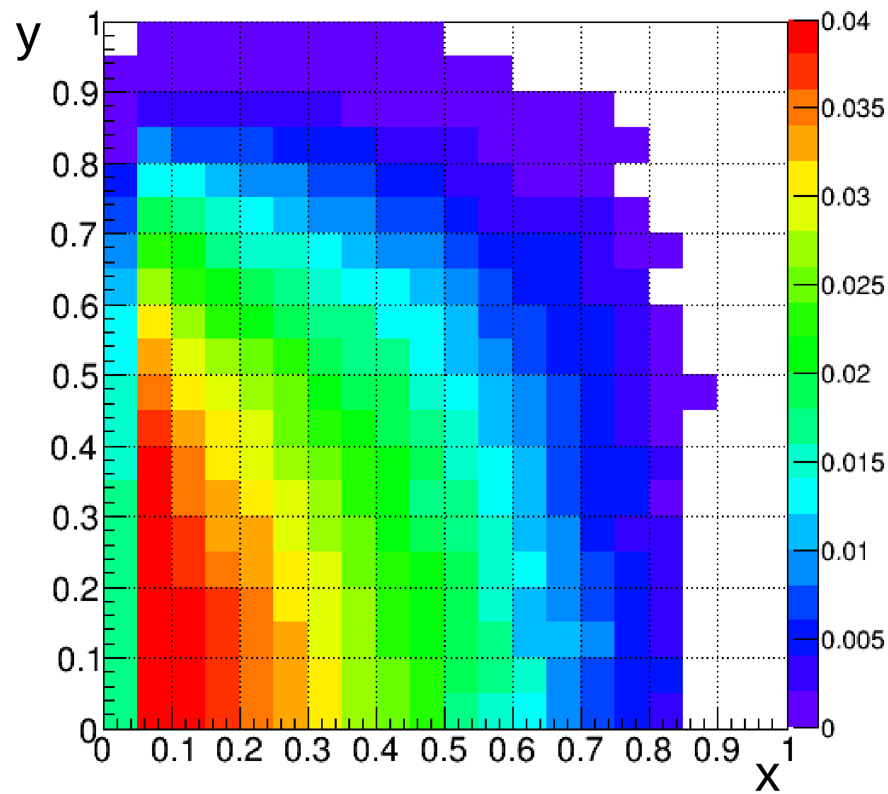
$y = 2p(q_1-q_2)/[m_\pi^2(1-x)] = 2(E_1-E_2)/[m_\pi(1-x)]$

Lowest-order differential decay rate:

$$\frac{1}{\Gamma_0}\frac{d^2\Gamma(\pi^0\to\gamma e^+e^-)}{dx\,dy} = \frac{\alpha}{\pi}\,|F(x)|^2\,\frac{(1-x)^3}{4x}\left(1+y^2+\frac{r^2}{x}\right)$$

$(r=2m_e/m_\pi)$





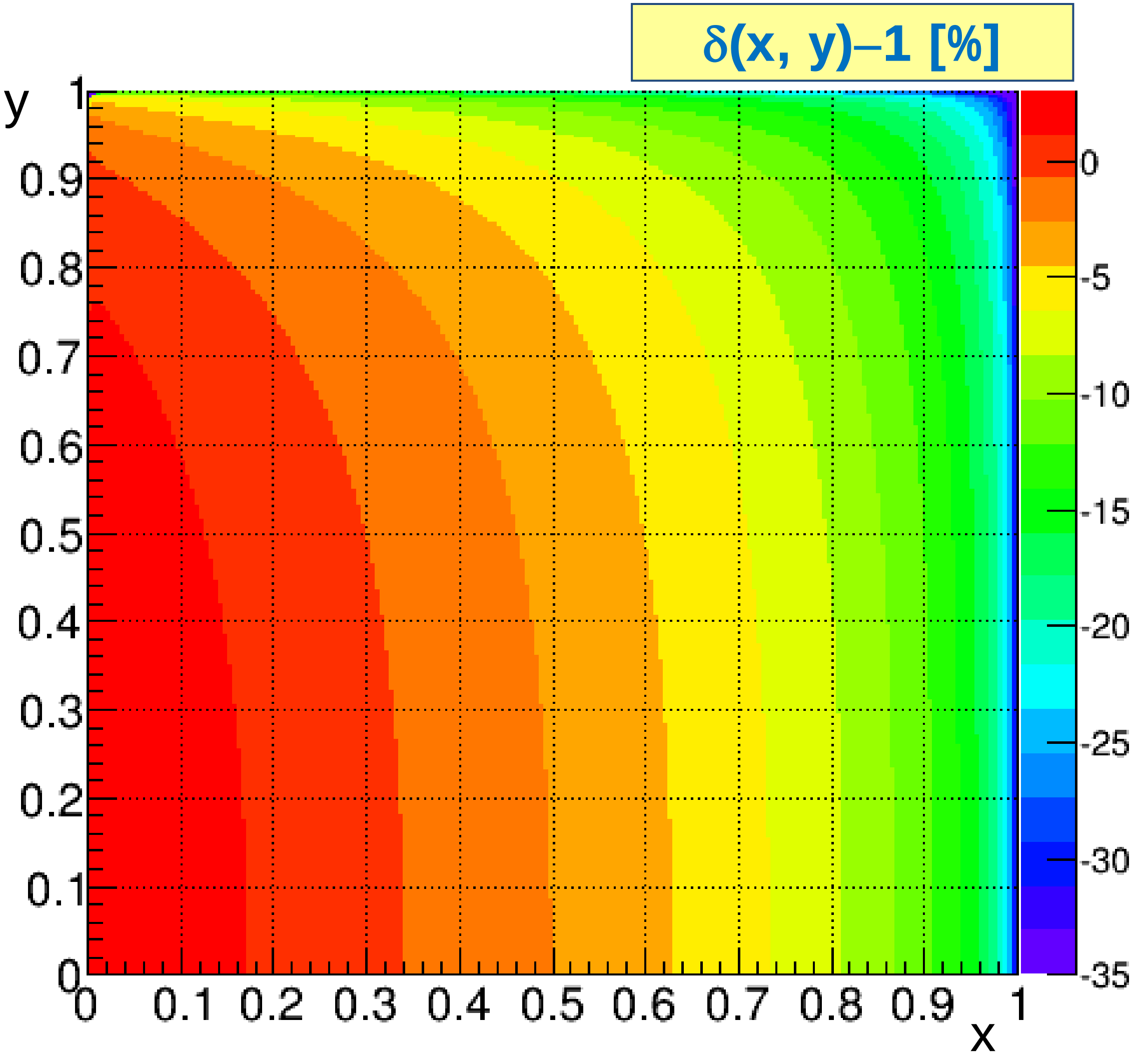
Radiative corrections to π^0_D

"Prague corrections" (T.Husek, K.Kampf, J.Novotný), to be published

$$\frac{d\Gamma}{dx\,dy} = \delta(x,y)\frac{d\Gamma^0}{dx\,dy}$$

The code to compute **δ(x,y)**
for any values of **(x,y)**
was developed by Tomas Husek.

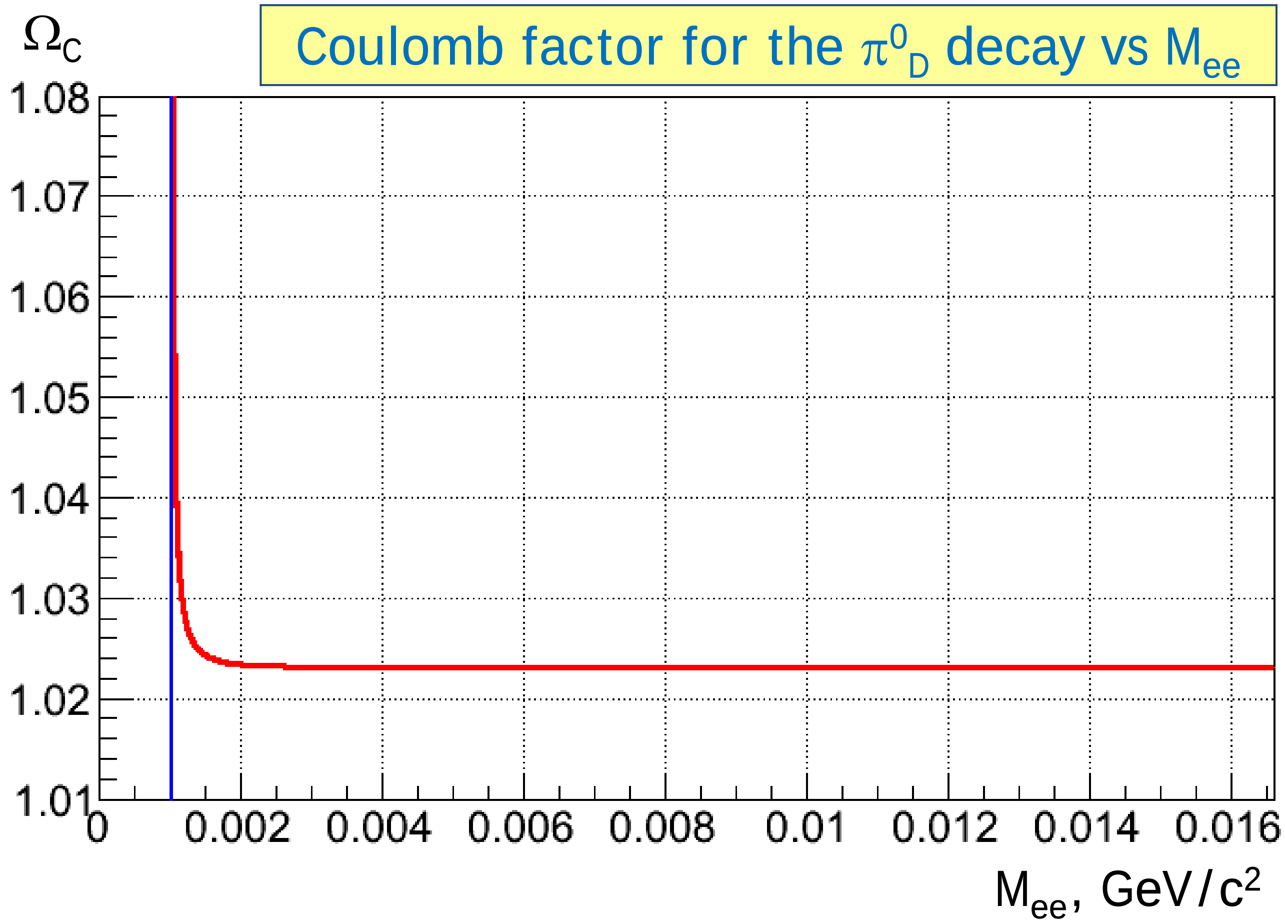
Available in NA62MC (public)
and CMC (private version,
implemented by Nicolas Lurkin).



Coulomb corrections to π^0_D

Well-known. Online: e.g. G.Isidori, EPJ C53 (2008) 567

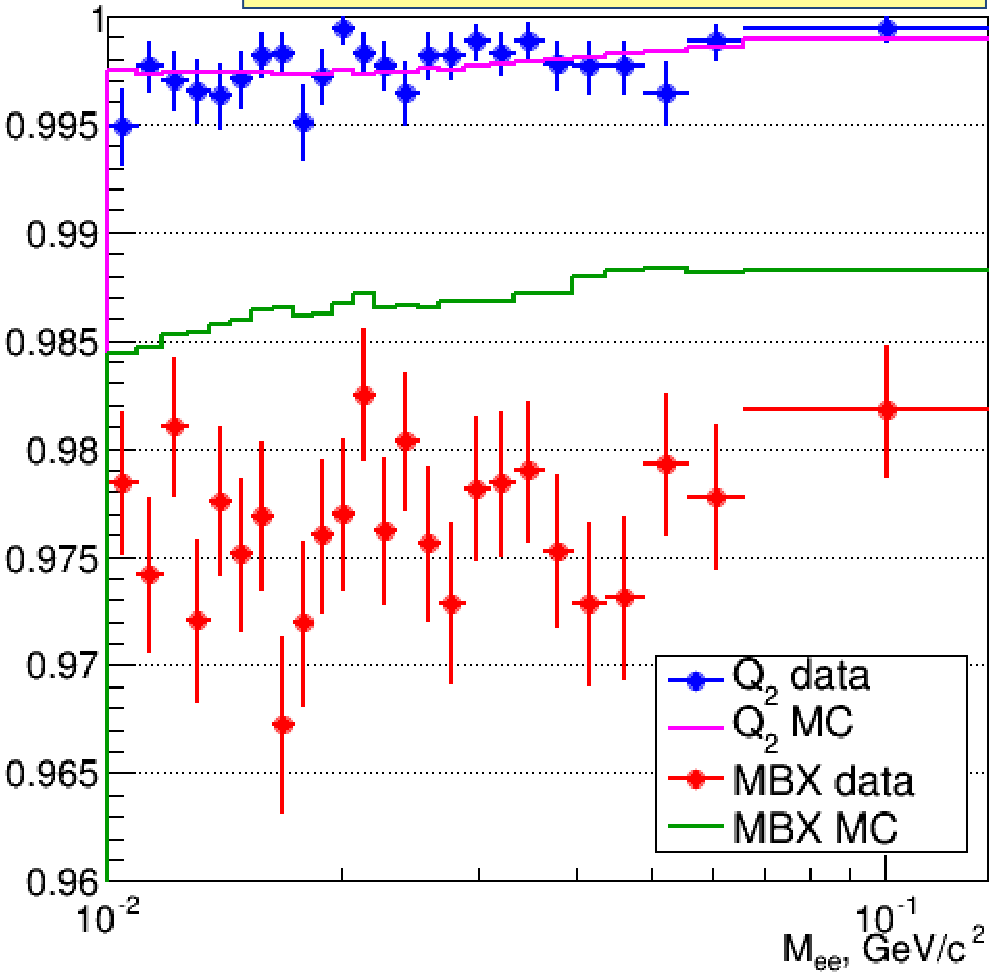
$$\Omega_C(s_{ij}) = \prod_{\{0<i<j\}} \frac{2\pi\alpha Q_i Q_j}{\beta_{ij}} \frac{1}{e^{\frac{2\pi\alpha Q_i Q_j}{\beta_{ij}}} - 1} \quad , \quad \beta_{ij} = \left[1 - \frac{4m_i^2 m_j^2}{(s_{ij} - m_i^2 - m_j^2)^2}\right]^{1/2}$$



... affects only very low **M_{ee}**, as expected: this correction is irrelevant for spectrum shape analysis.

Trigger efficiency correction

Trigger efficiencies vs M_{ee}
(within the signal M_{ee} region)



Measured trigger efficiencies used.
Simulated efficiencies presented for comparison only.

Corrections for trigger efficiencies:

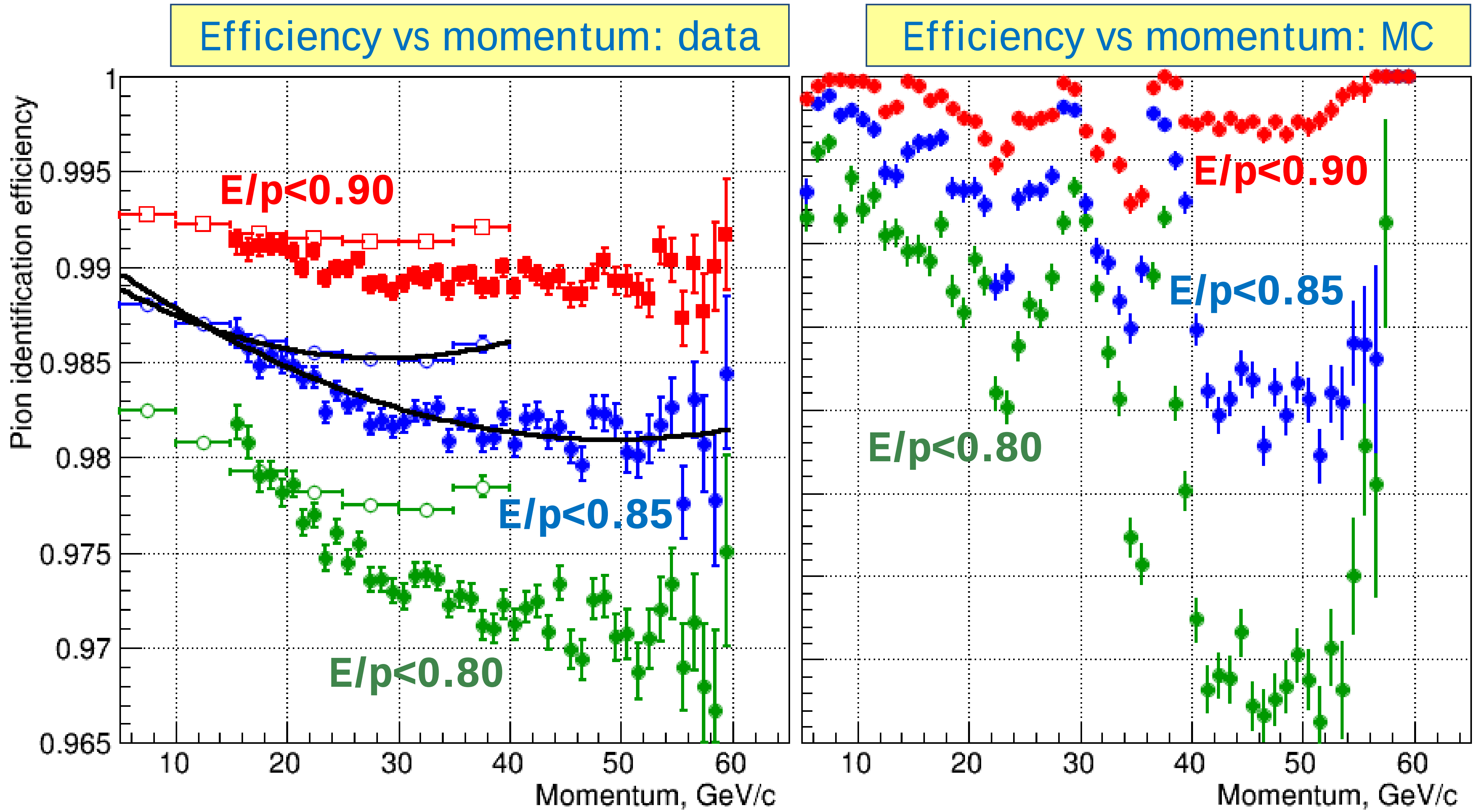
Δa_{Q2} **= (–0.33 ± 0.11$_{stat}$)×10^{-2}**;

Δa_{MBX} **= (–0.84 ± 0.44$_{stat}$)×10^{-2}**.

MBX bits

2VTX: **91.7%**; 1VTX: **4.1%**,
1TRK: **1.9%**, inefficient: **2.3%**.

Pion identification efficiency



○□ Karim's measurement ($K_{3\pi}$, 2003+04 data)

●■ Andreas's measurement ($K_{2\pi}$, 2007 data)

MC: pion identification

❖ If the pion **does not decay** upstream of the LKr, **match** a reconstructed track to the true pion.

1) For each reconstructed track, check consistency with the true pion:

$$\chi^2 = ((p-p_{true})/0.6\ \mathrm{GeV}/c)^2 + ((x-x_{true})/0.5\mathrm{mm})^2 + ((y-y_{true})/0.5\mathrm{mm})^2 + ((x'-x'_{true})/10^{-4})^2 + ((y'-y'_{true})/10^{-4})^2$$

(**p**: track momentum, **(x,y)**: coordinates in DCH1 plane; **(x',y')**: directional cosines; all normalized to measured resolutions)

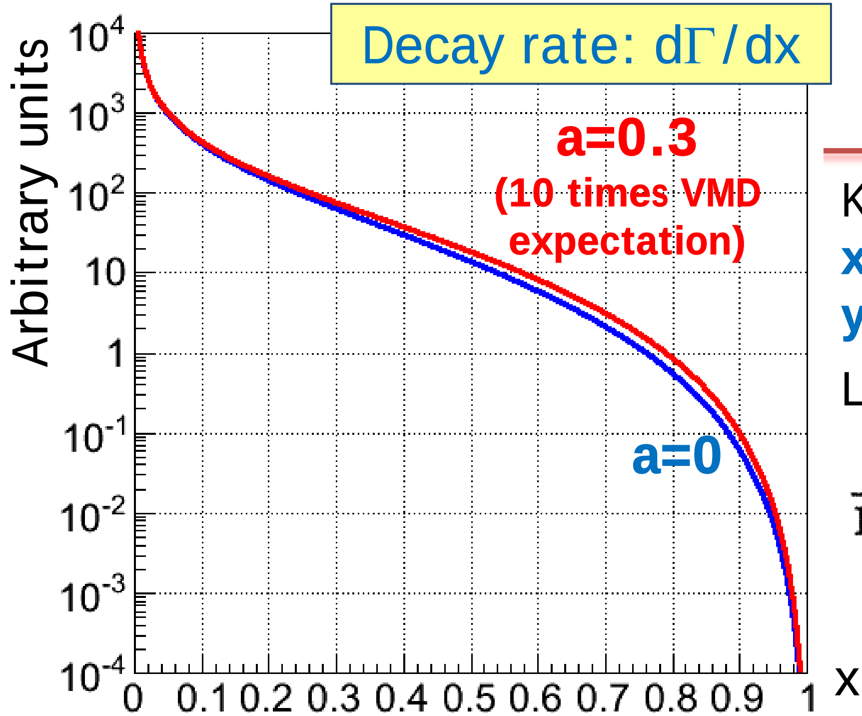
2) Track with **χ^2<100** is considered the **reconstructed pion**. Exactly one reconstructed pion is found in **>99%** of the cases.

❖ Reset **E/p** of the pion track (**E/p=0.1**) so it **passes the selection**.

❖ Momentum-dependent **weight applied** to the event, evaluated from polynomial fits to combined 2003+04+07 efficiency measurements.

Form factor slope measurement

π^0_D decay rate



Kinematic variables:

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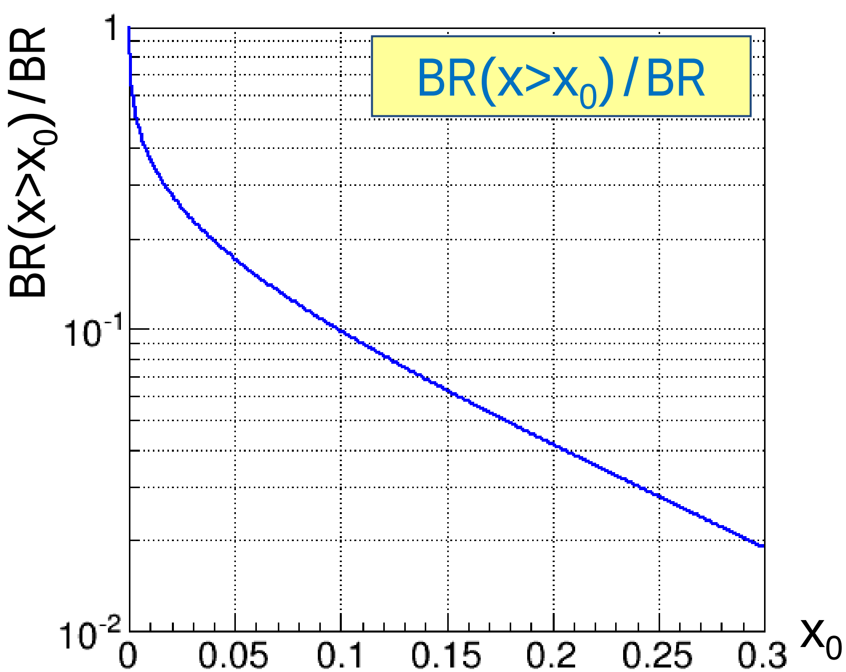
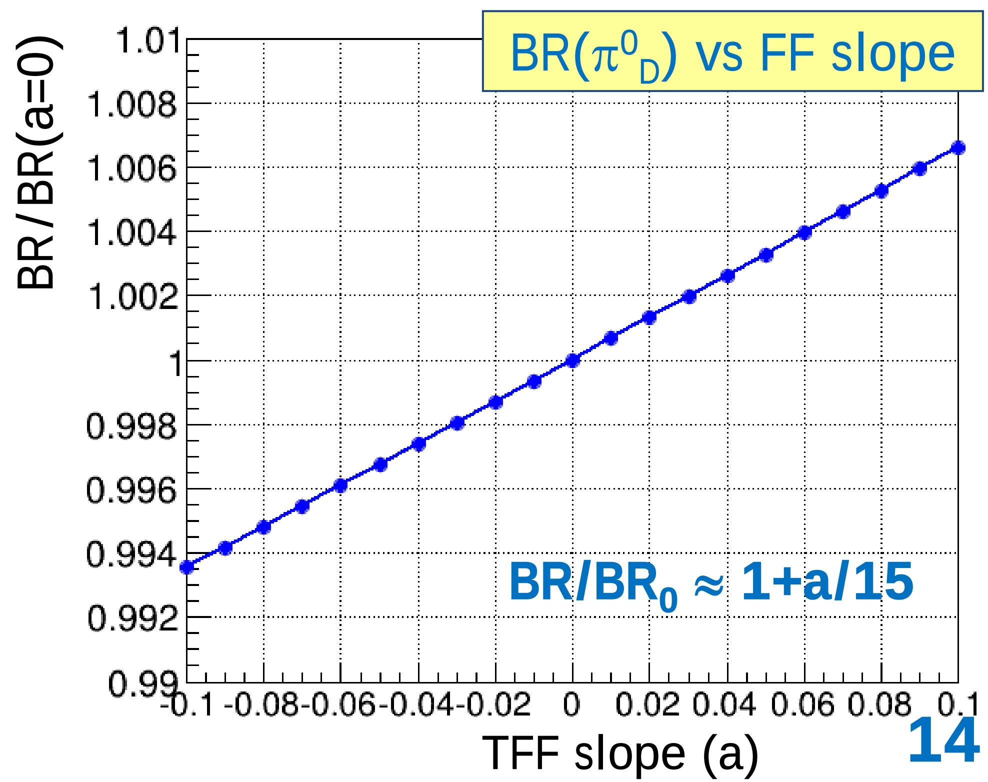
$y = 2p(q_1-q_2)/[m_\pi^2\,(1-x)] = 2(E_1-E_2)/[m_\pi(1-x)]$

Lowest-order differential decay rate:

$$\frac{1}{\Gamma_0}\frac{d^2\Gamma(\pi^0\to\gamma e^+e^-)}{dx\,dy} = \frac{\alpha}{\pi}\,|\mathbf{F(x)}|^2\,\frac{(1-x)^3}{4x}\left(1+y^2+\frac{r^2}{x}\right)$$

($r=2m_e/m_\pi$)





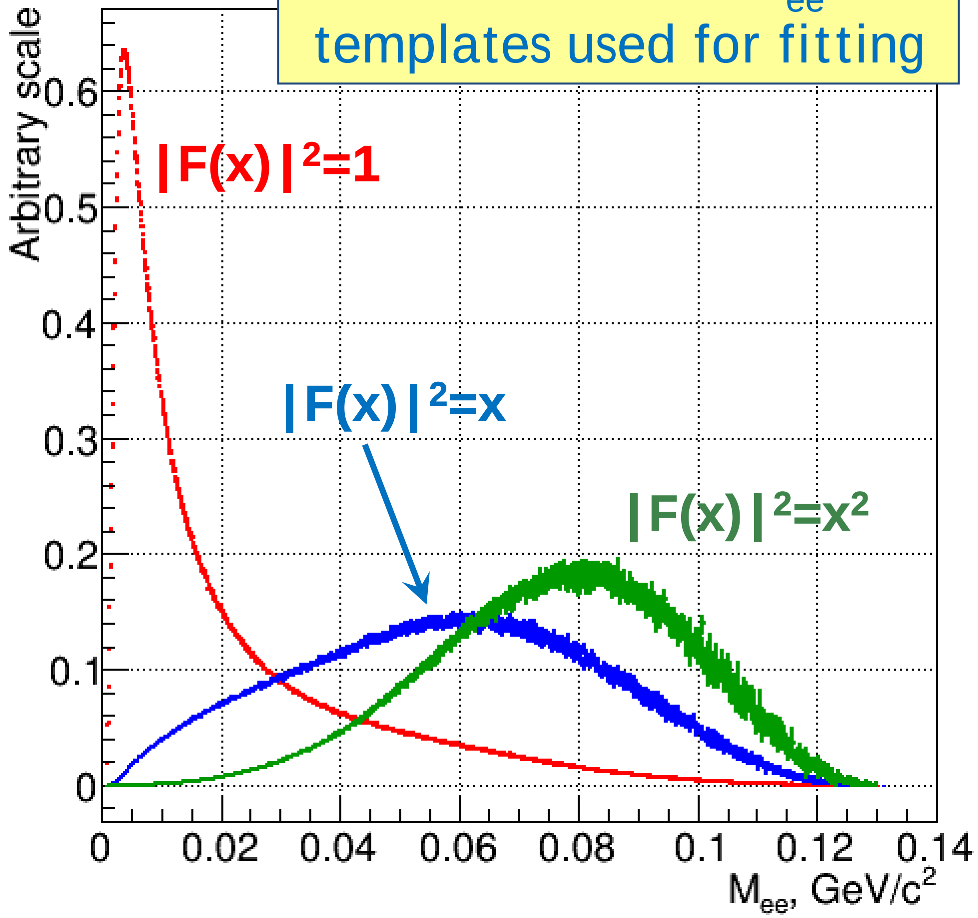
Fitting method

❖ Using re-weighting, build three independent MC templates with different (unphysical) form-factors: **$|F(x)|^2=1$**, **$|F(x)|^2=x$**, **$|F(x)|^2=x^2$**.

❖ Then **$|F(x)|^2=(1+ax)^2$** is a linear combination of the templates: any hypothesis on slope (**a**) is tested with the χ^2 method.

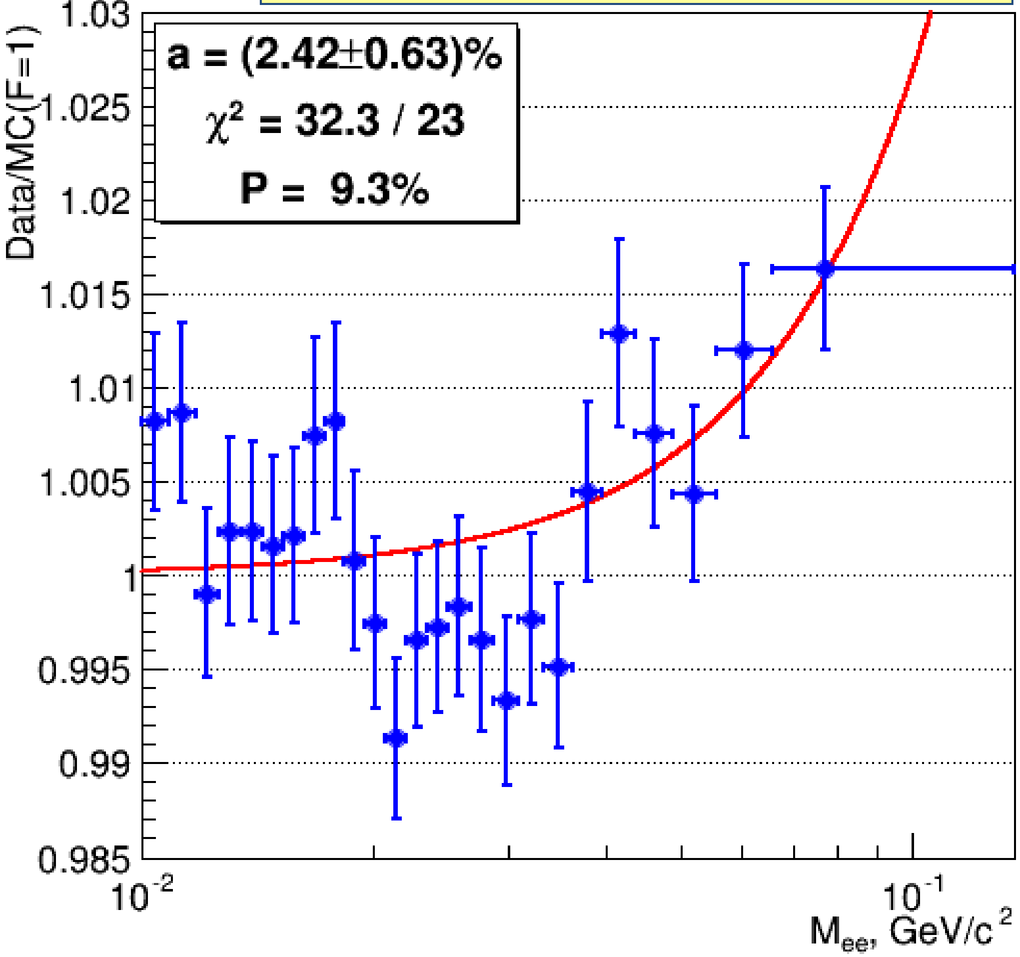
❖ The reconstructed **M_{ee}** spectra with small bin size are re-binned into (almost) equipopulous bins for the test.

Reconstructed M_{ee}: templates used for fitting



Fit result

Data divided by MC with a=0
and the fit result



- ❖ The fitting procedure does not involve the plotted ratio.
- ❖ This plot is for illustration of the result only, this is not a fit.
- ❖ The statistical uncertainty resulting from the fit procedure includes components from data, MC and trigger.

Systematic checks (assigned errors in red)

Spectrometer calibration

Variation of the analysis procedure	$\Delta a \times 10^2$
1. Spectrometer calibration (α,β corrections) OFF for MC	–1.28
2. Spectrometer calibration OFF for DATA	+1.40
3. Spectrometer calibration OFF for both DATA and MC	+0.07

LKr non-linearity correction

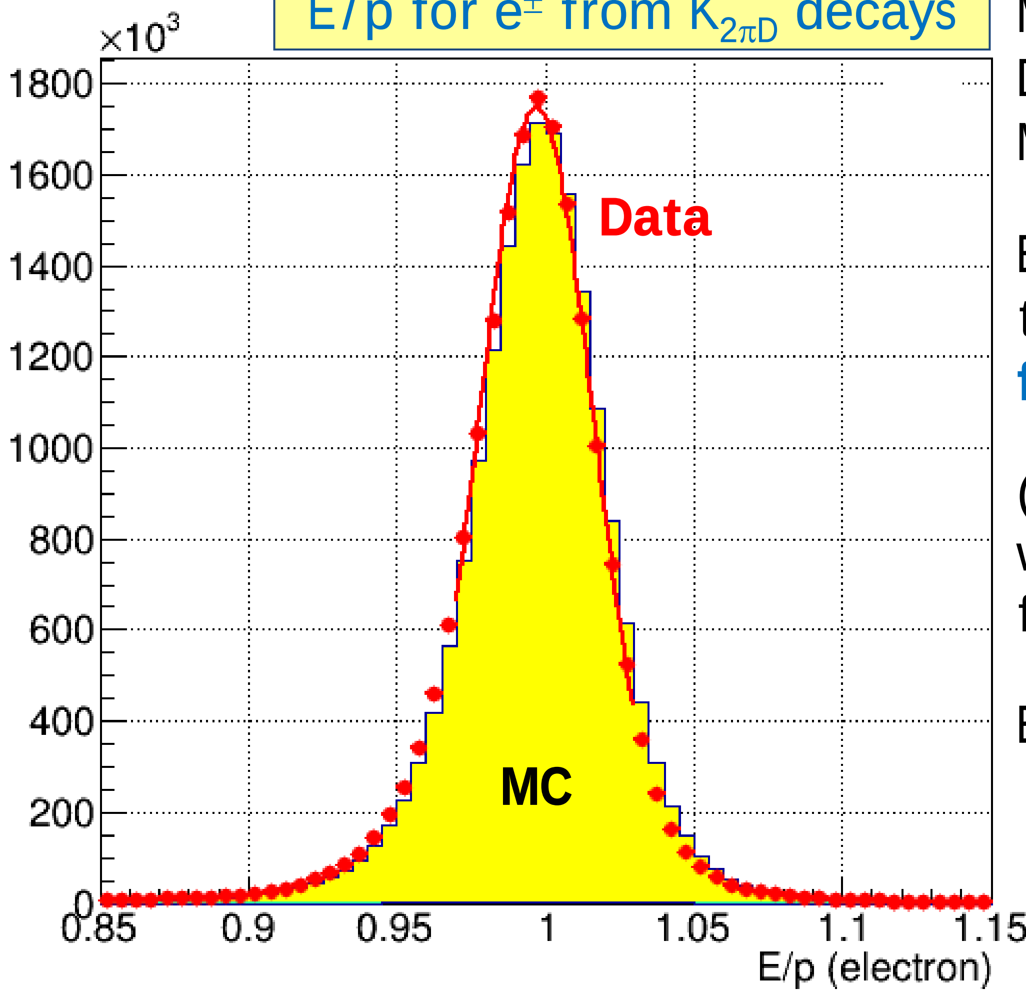
Variation of the analysis procedure	$\Delta a \times 10^2$
1. LKr non-linearity correction OFF for DATA	–0.69
2. LKr non-linearity correction with FLAG=2 for DATA	+0.56

Backgrounds

- $K_{\mu 3D}$ component (included into simulation): the result is unchanged if $K_{\mu 3D}$ neglected; $\Delta a = 0.002 \times 10^2$ (negligible) if $BR(K_{\mu 3D})$ increased by x10.
- Therefore can neglect e^+e^- pairs from all Dalitz decays ($K_{3\pi D}$, K_{l3D}, K_{l4D}).
- e^+e^- pairs not from π^0_D decays (with mis-ID): K_{e3D}, $K_{2\pi D}$ with $\pi^\pm \to e^\pm \nu$: can be estimated from same-sign ($e^\mp \gamma e^\pm e^\pm$) events.
- $K_{3\pi}$+accidental photon (with mis-ID and/or $\pi^\pm \to e^\pm \nu$): can be estimated from same-sign events x2.
- Subtracting SS from signal M_{ee} spectrum: $\Delta a = -0.002 \times 10^{-2}$ (negligible).

Systematics: LKr energy scale

E/p for $e^{\pm}$ from $K_{2\pi D}$ decays



Mean reconstructed **E/p** values:

Data: $(E/p)_{mean} = 0.9972$.

MC: $(E/p)_{mean} = 0.9986$.

Energy scale correction applied to the data: photon energies scaled by **f=1.0014**.

(NB: the correction for the 2007 data was evaluated by Andreas separately for each LKr cell).

Effect of the correction:

$\Delta a = -0.02\times10^{-2}$.

The full size of the correction is conservatively considered as a systematic error.

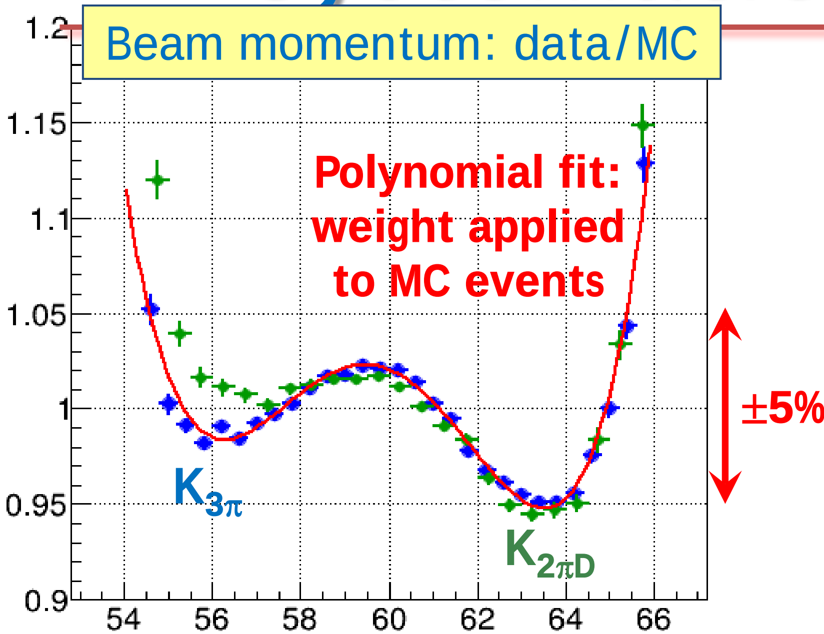
Systematics: accidentals

Standard selection: the best 3-track vertex,
i.e. least χ^2 among vertices with $-18\text{m}<z_{vtx}<80\text{m}$, $|Q|=1$
and no common tracks with other vertices.

Variation of the selection	$\Delta a\times10^2$
0. Standard vertex selection	$a=2.42$
1. Replace best vertex search with $N_{vtx}=1$	+0.08
2. $N_{vtx}=1$ and reject events with "extra tracks" = tracks not belonging to the vertex, $\lvert t-t_{vtx}\rvert<20\text{ns}$, $p<60$ GeV/c, closest approach to z axis: $-20\text{m}<z<90\text{m}$, CDA<10cm.	+0.13
3. Remove common tracks condition from best vertex search	–0.05
4. Remove $\lvert Q\rvert=1$ condition	–0.01
5. Remove z_{vtx} criteria	+0.01
6. Add $p_i<60$GeV/c condition	0
7. Add $p_{tot}<70$GeV/c condition	0

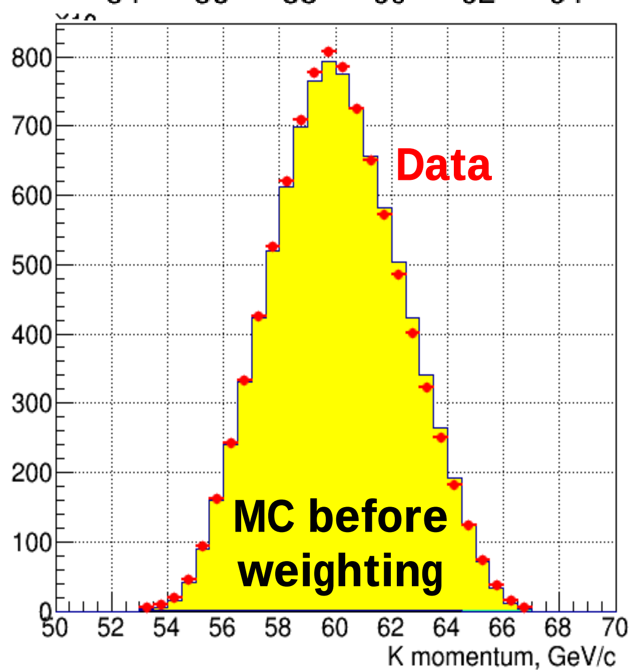
Assigned systematic uncertainty: $\delta a=0.13\times10^{-2}$.

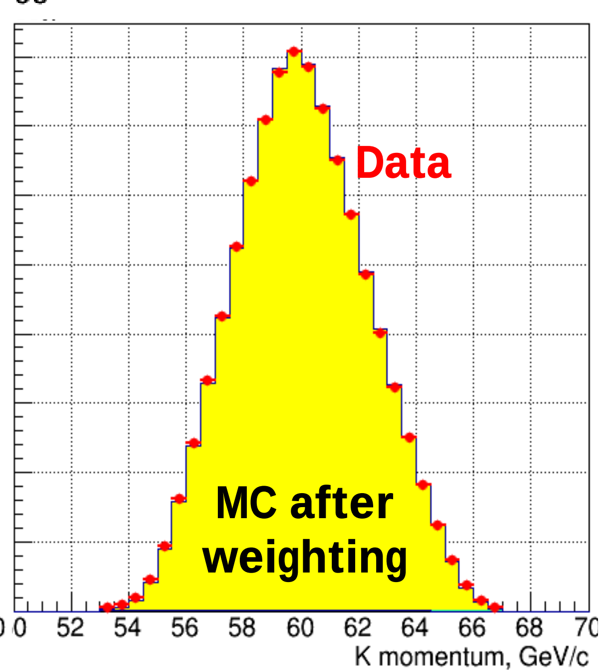
Systematics: beam momentum

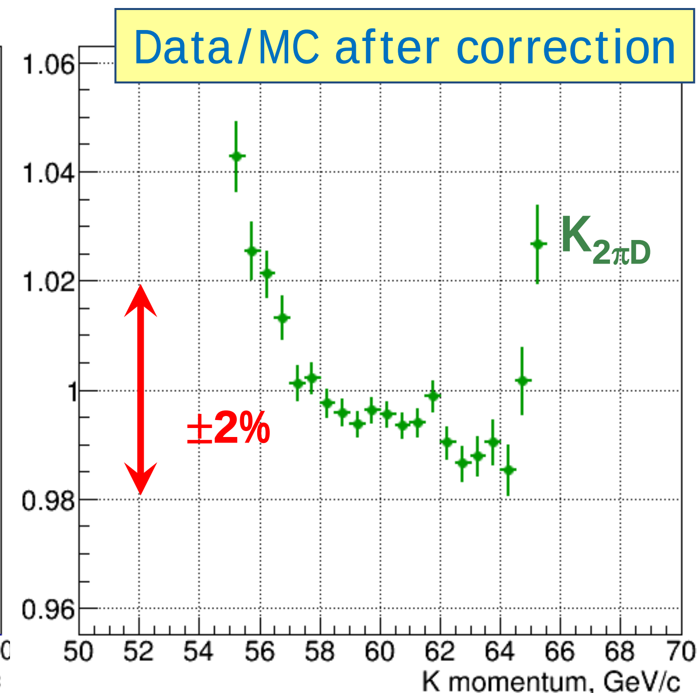


MC events weighted to provide first-order correction for spectrum shape.

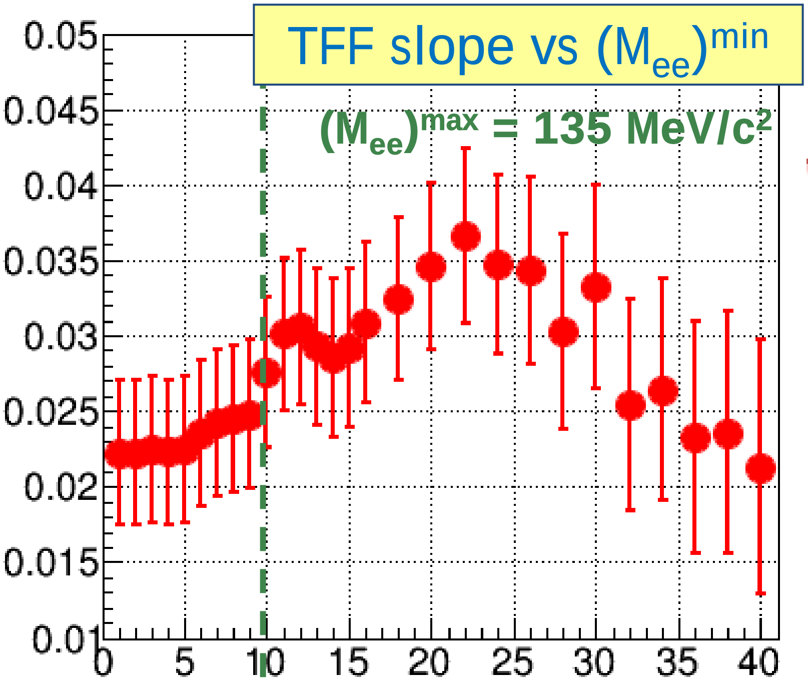
No effect on FF slope: **$|\Delta a|<0.01\times10^{-2}$**.
Further fine corrections not performed.

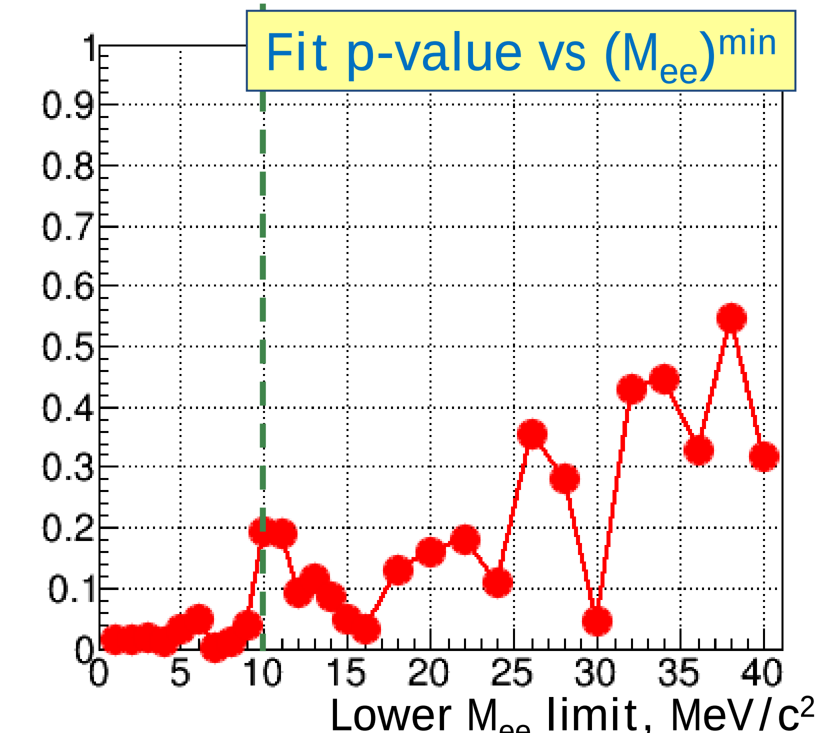


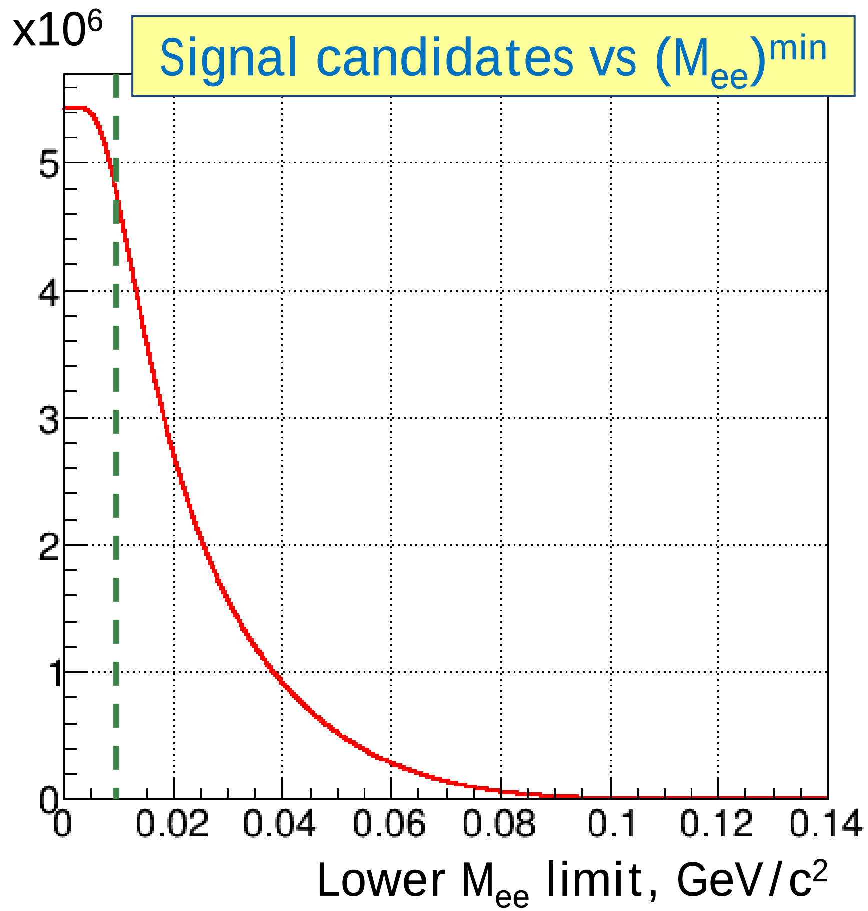




Lower M_{ee} limit

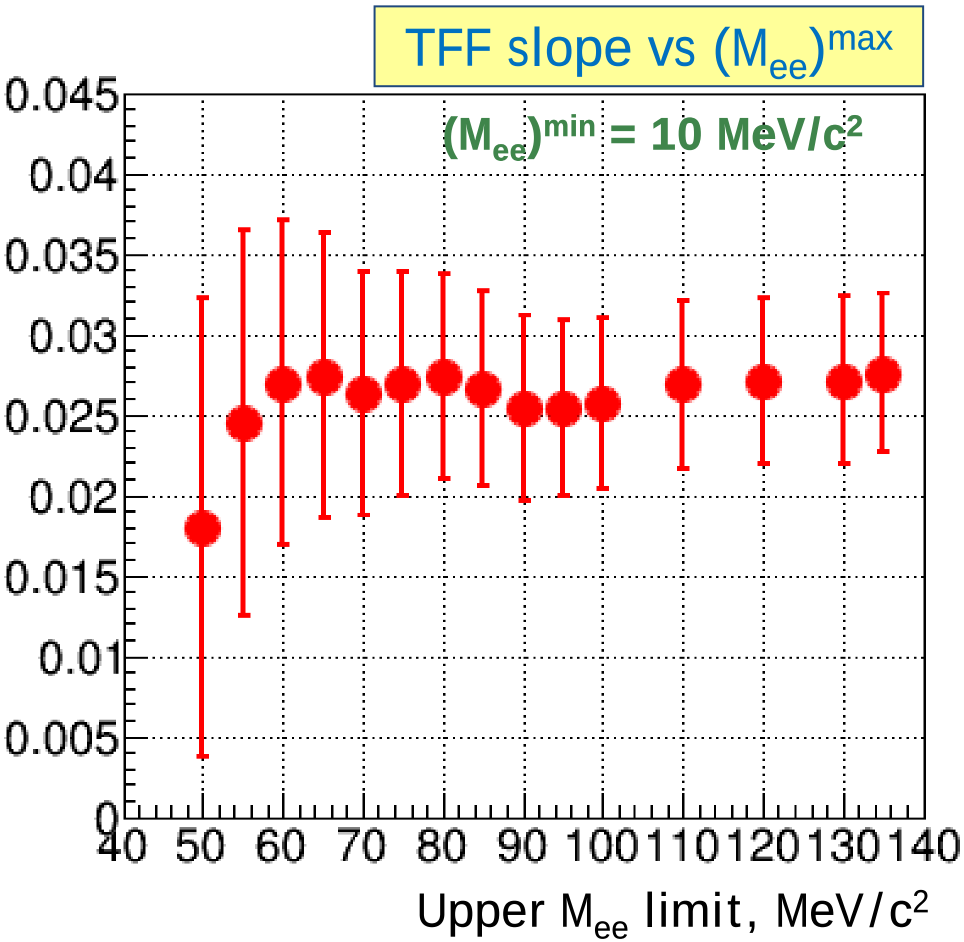


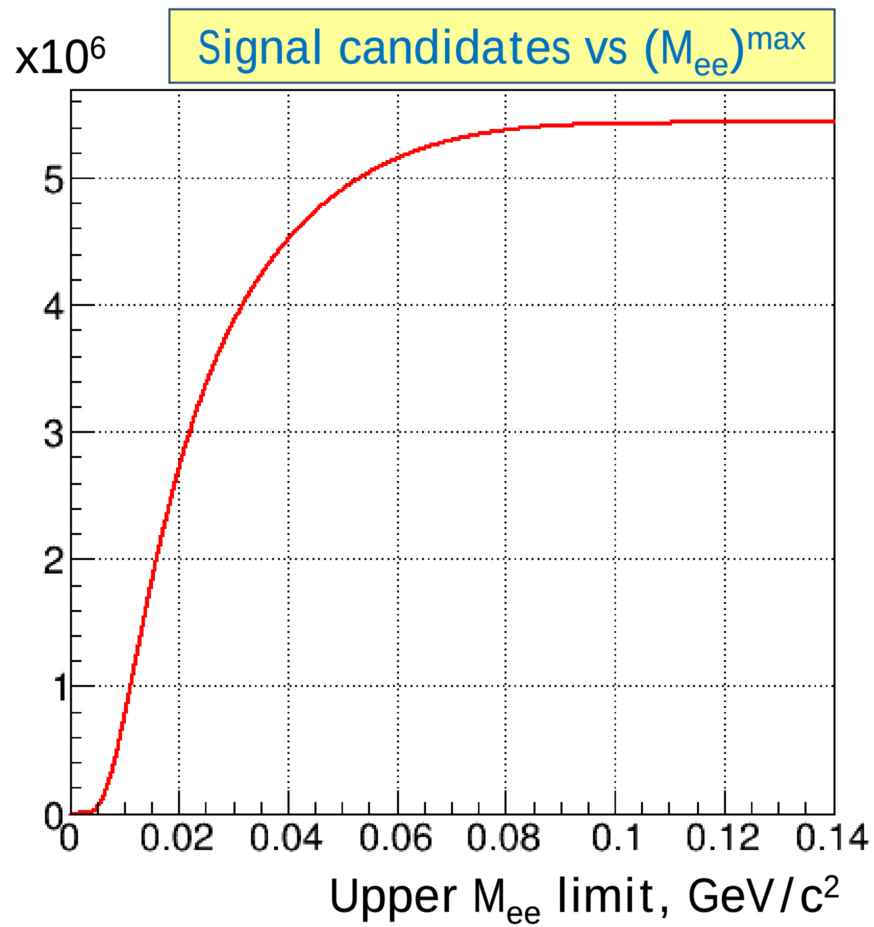




Statistical errors (data+MC+trigger) of the individual measurements are indicated

Upper M_{ee} limit

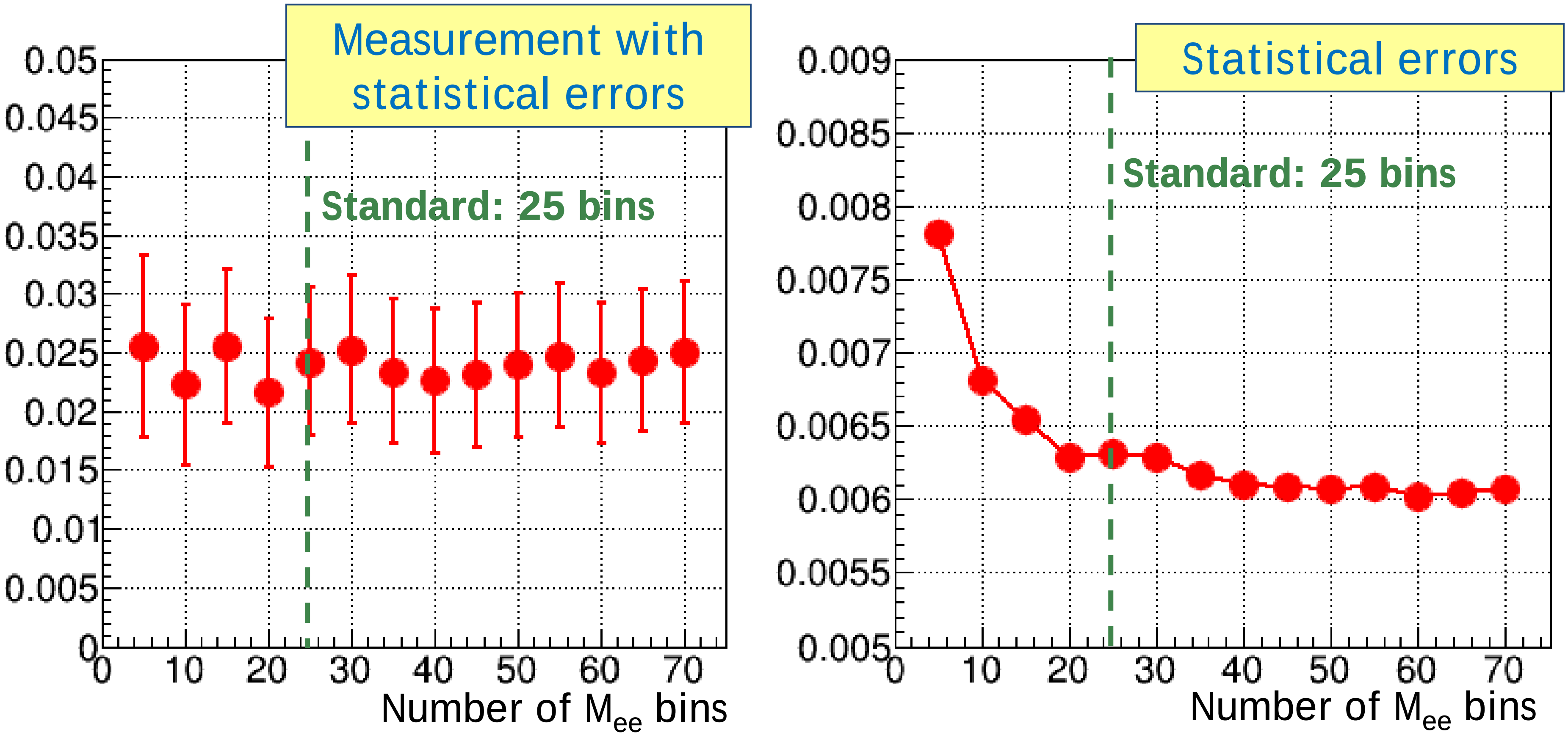




Statistical errors (data+MC+trigger)
of the individual measurements are indicated

Number of M_{ee} bins

(equipopulous bins in the range M_{ee} > 10 MeV/c^2)

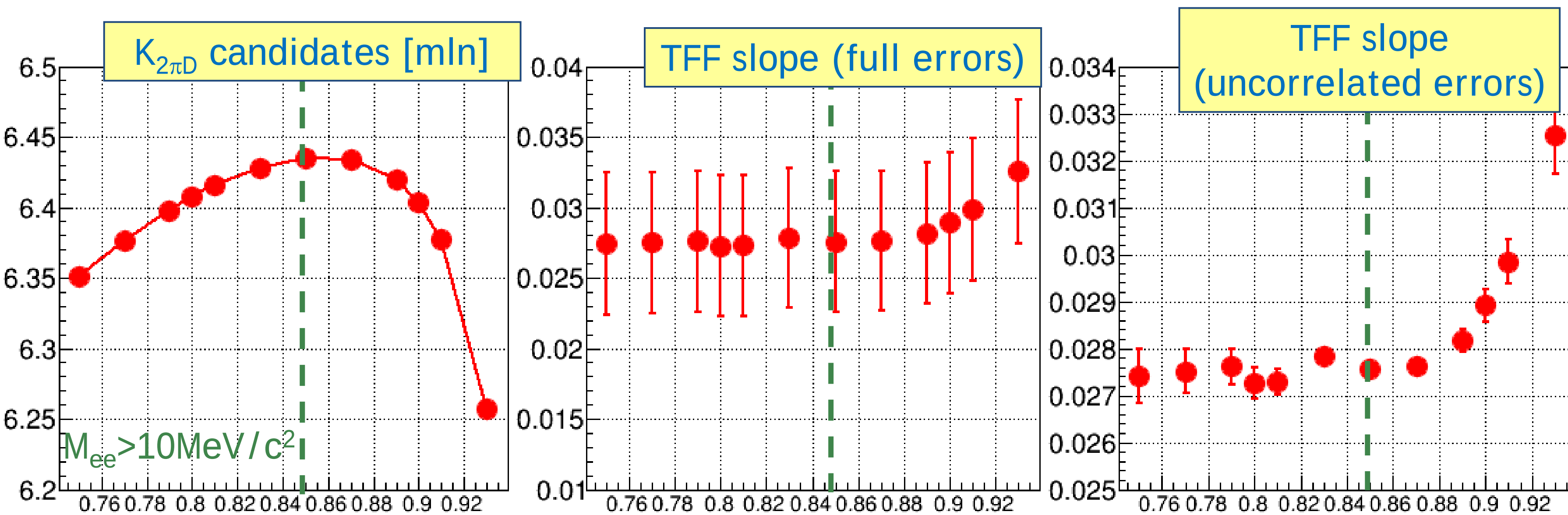


Statistical errors (data+MC+trigger) of the individual measurements are indicated

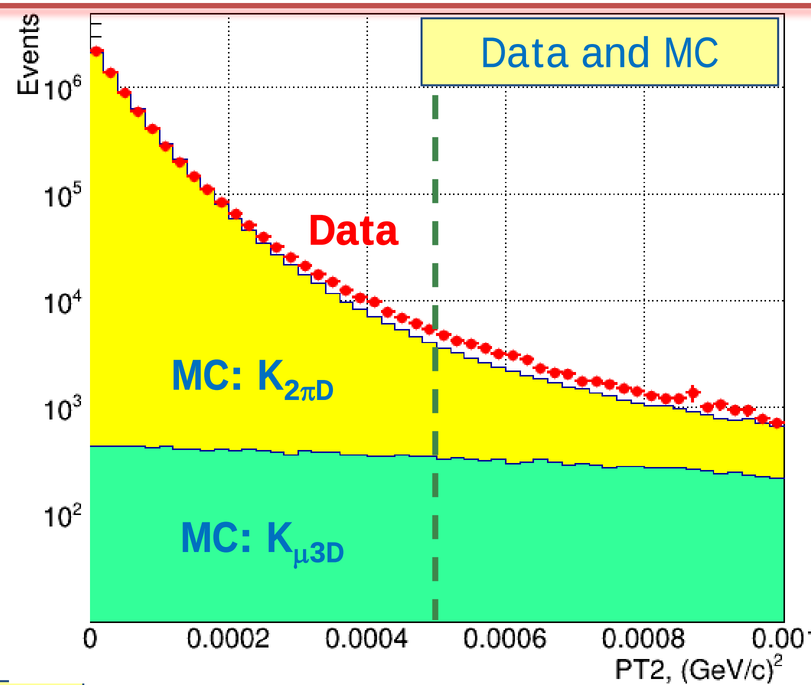
E/p cut scan

Pion definition:	**E/p<(E/p)$_0$**.
Electron definition:	**E/p>(E/p)$_0$**.
Standard selection:	**(E/p)$_0$=0.85**.

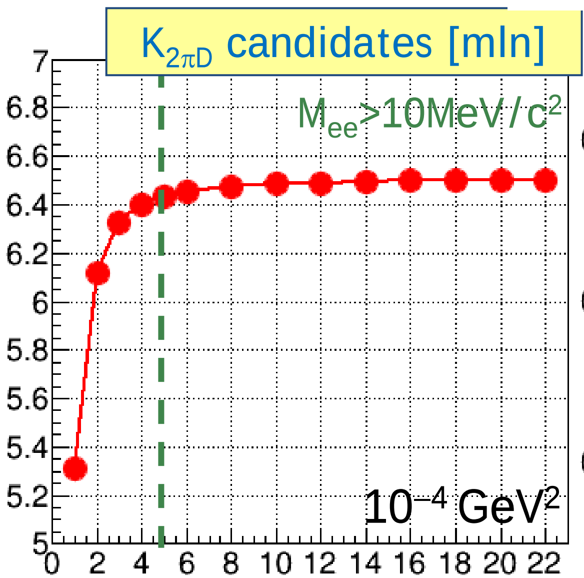
- ❖ MC selection takes into account the measured pion (but not electron) **E/p** distribution.
- ❖ If using reconstructed (not measured) pion **E/p**: variation of the result is negligible.
- ❖ Measurement is unbiased for low **(E/p)$_0$**, i.e. low negligible electron loss. Systematic uncertainty from stability at low **(E/p)$_0$**: **$\delta a = 0.03\times10^{-2}$**.



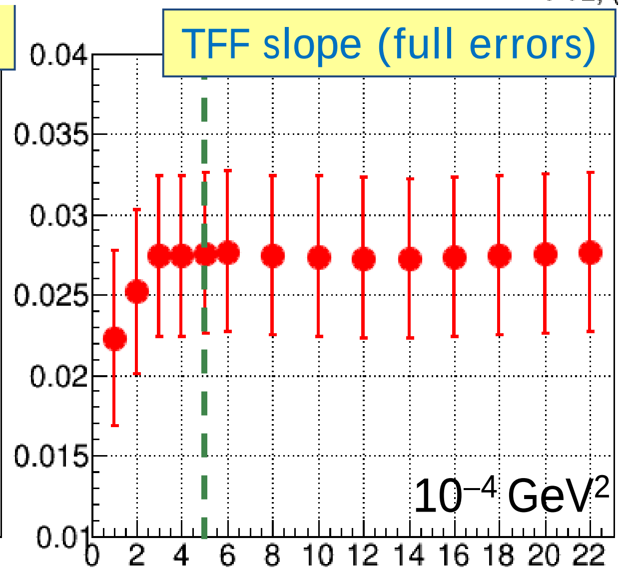
Maximum P_T^2



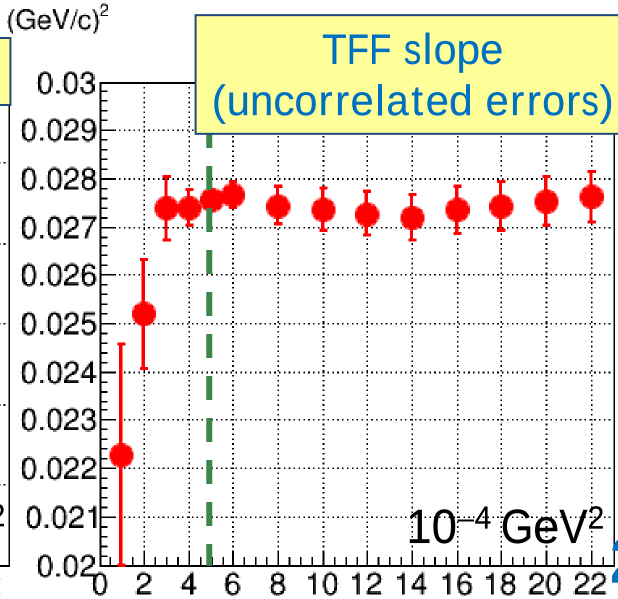
Data and MC
Events
10^6
10^5
10^4
10^3
10^2
Data
MC: $K_{2\pi D}$
MC: $K_{\mu 3D}$
0
0.0002
0.0004
0.0006
0.0008
0.001
PT2, $(GeV/c)^2$



$K_{2\pi D}$ candidates [mln]
M_{ee}>10MeV/c^2
10^{-4} GeV^2

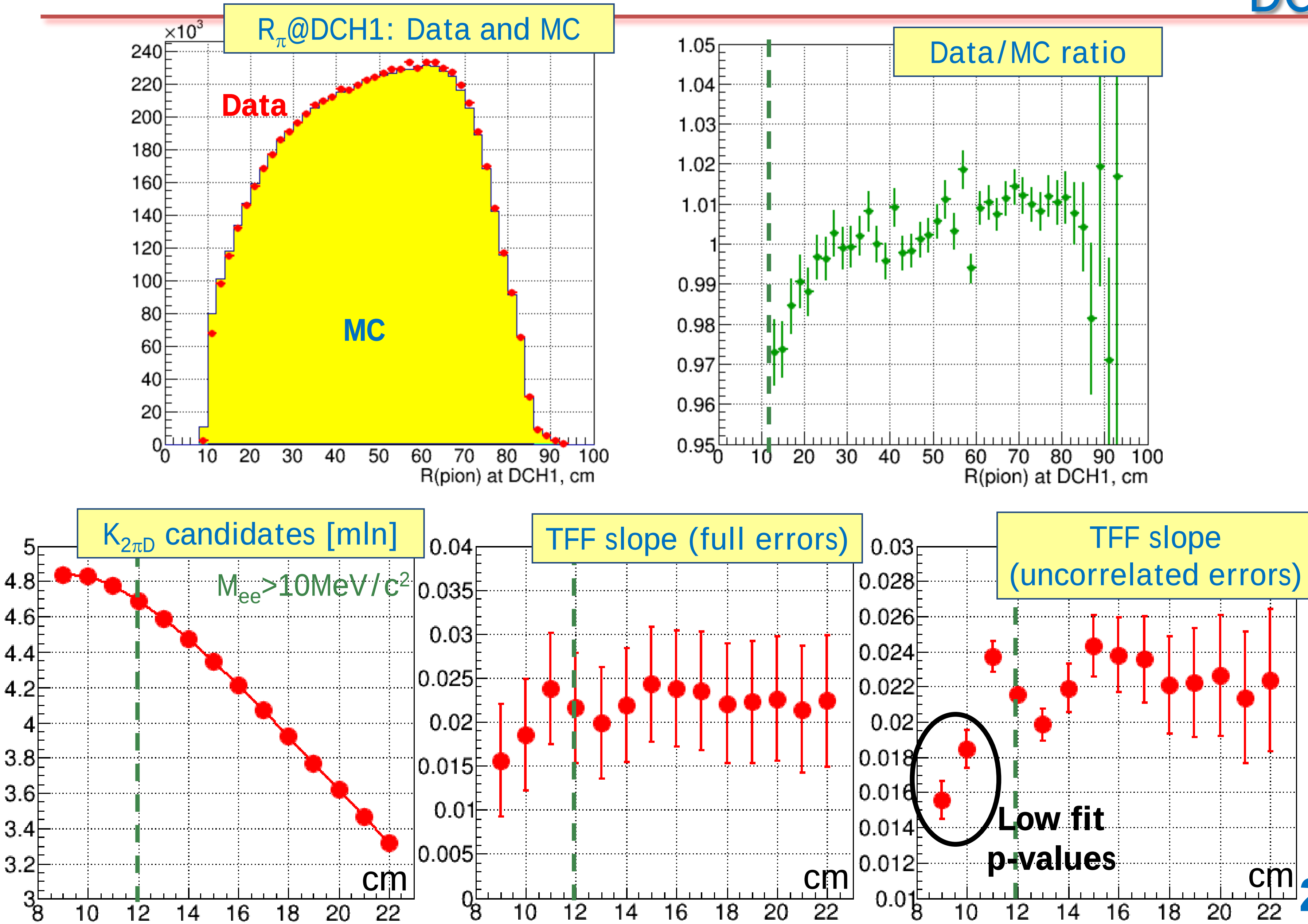


TFF slope (full errors)
10^{-4} GeV^2

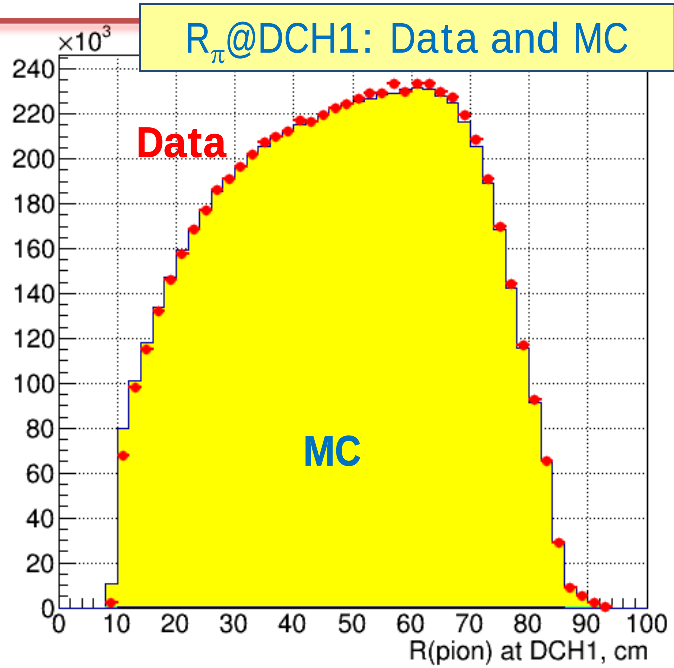


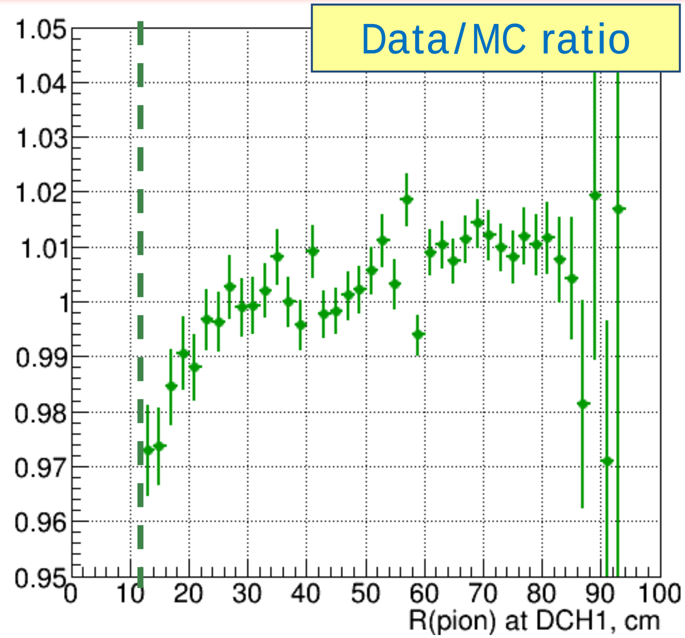
TFF slope
(uncorrelated errors)
10^{-4} GeV^2

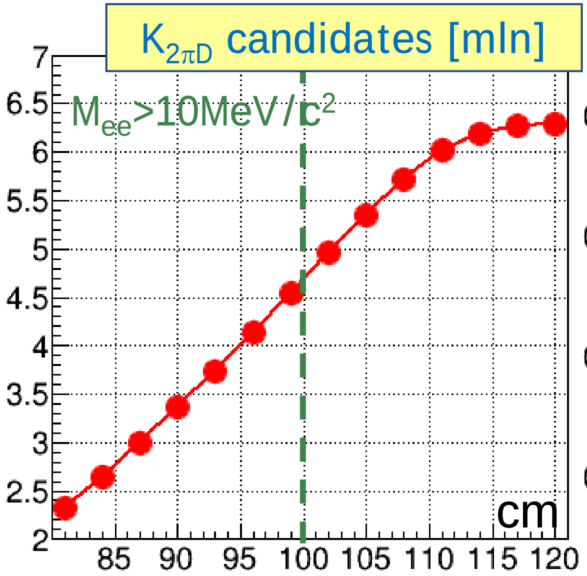
Tracks: minimum R_{DCH}

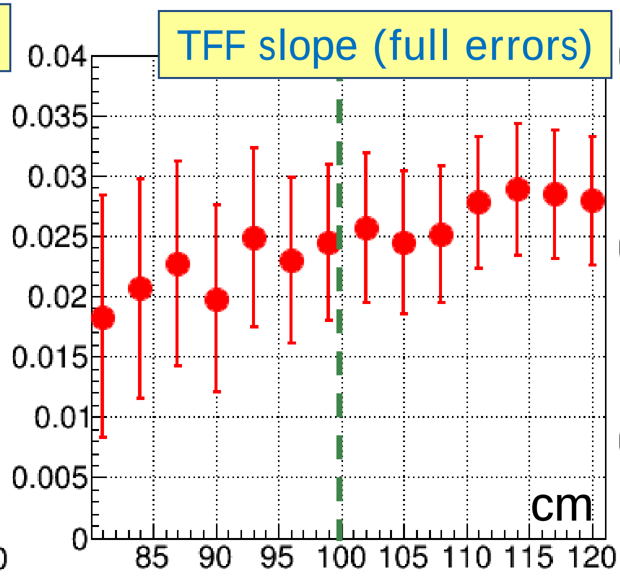


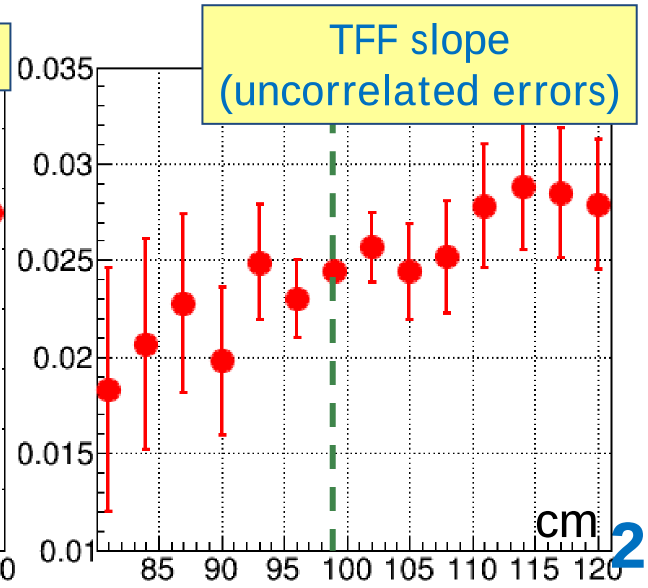
Tracks: maximum R_{DCH}



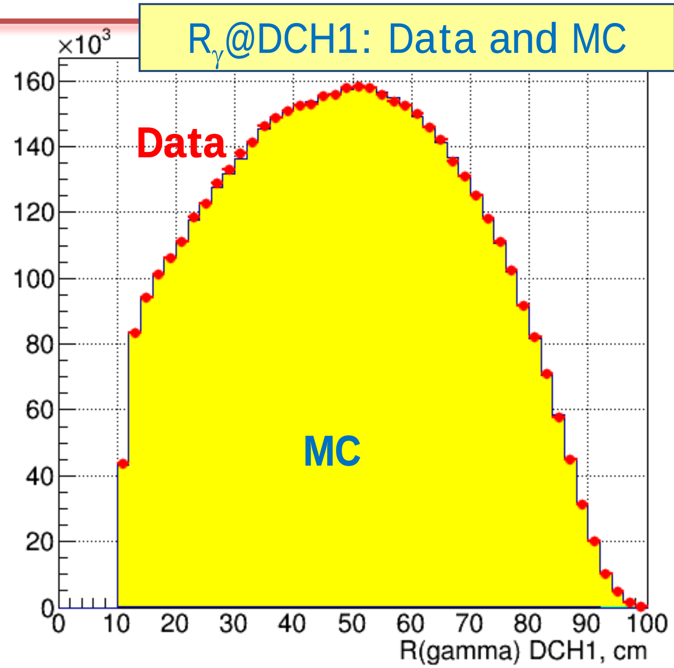


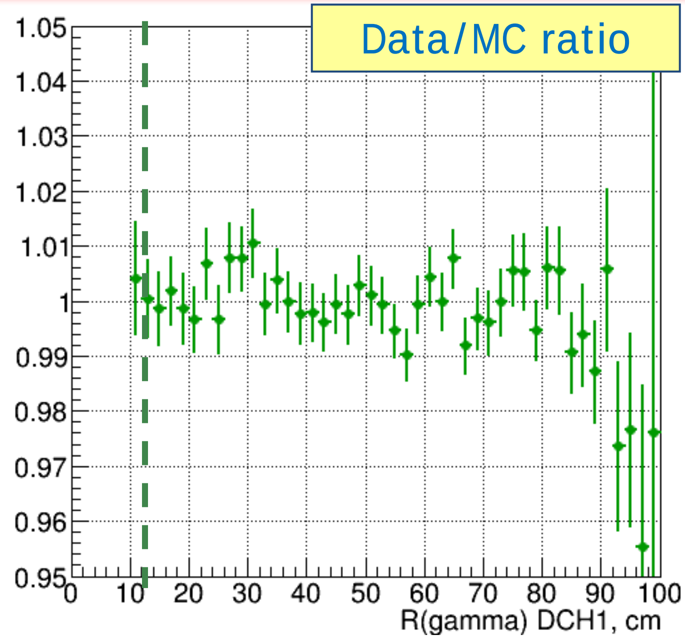


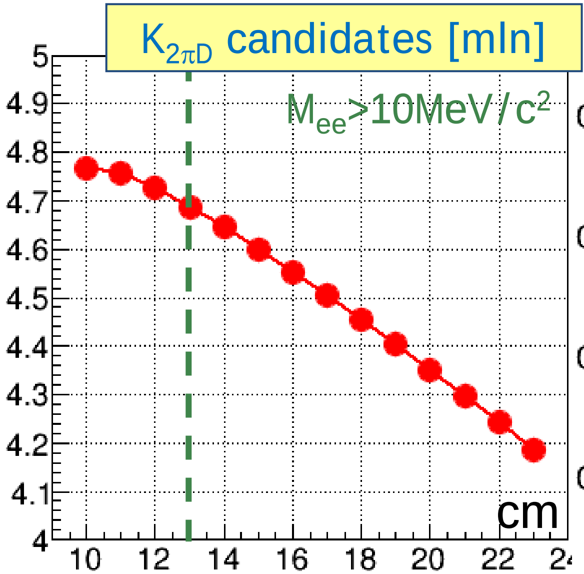


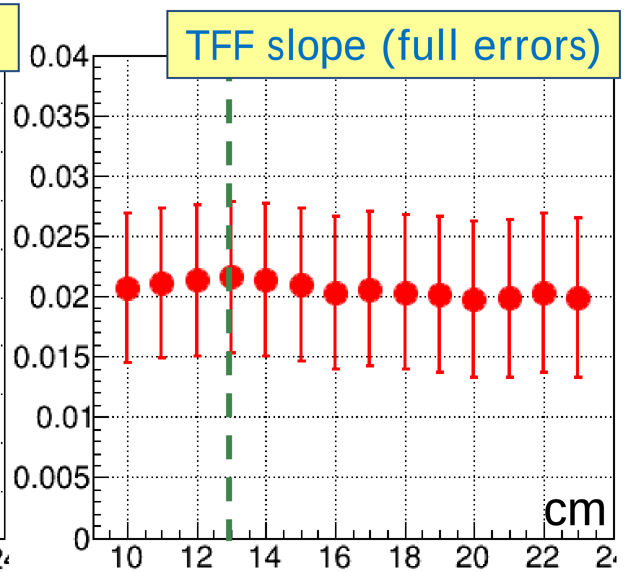


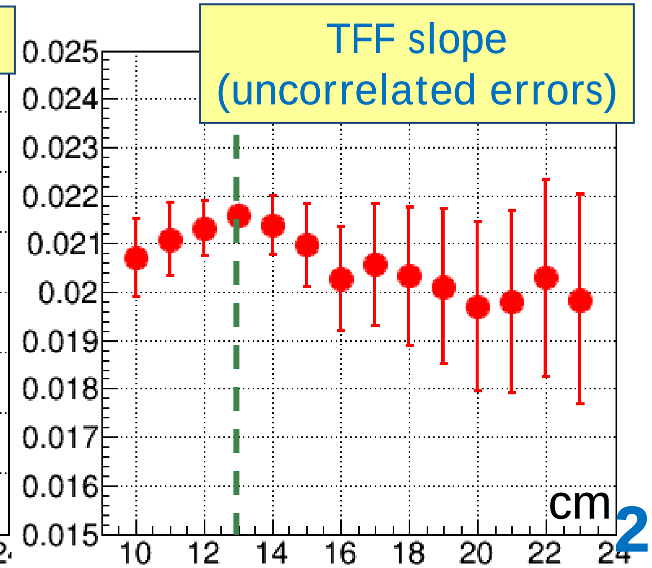
Photon: minimum R_{DCH1}



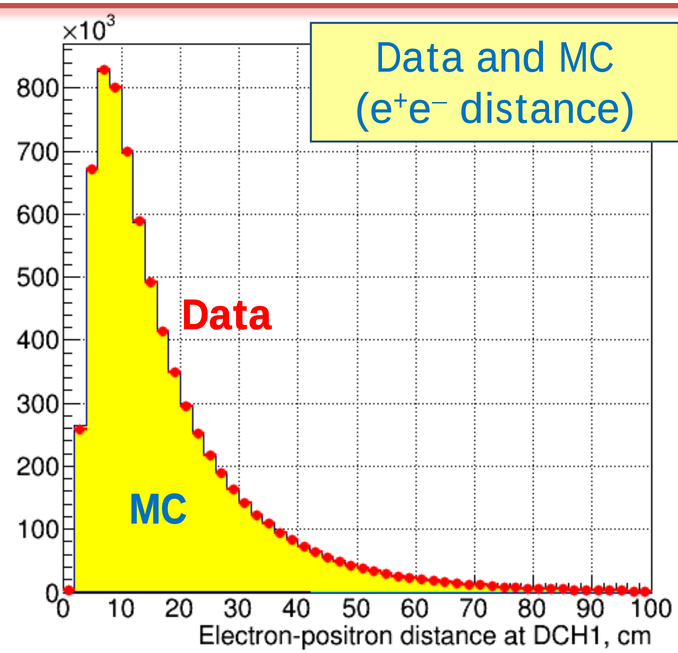


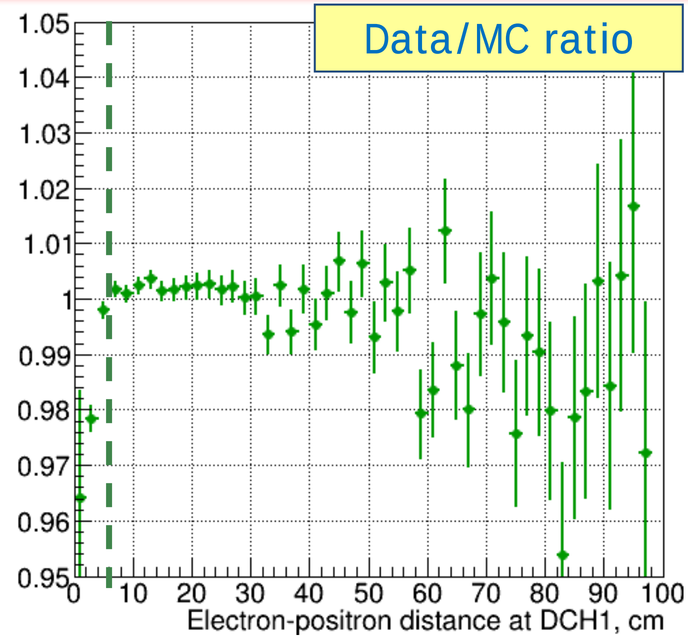




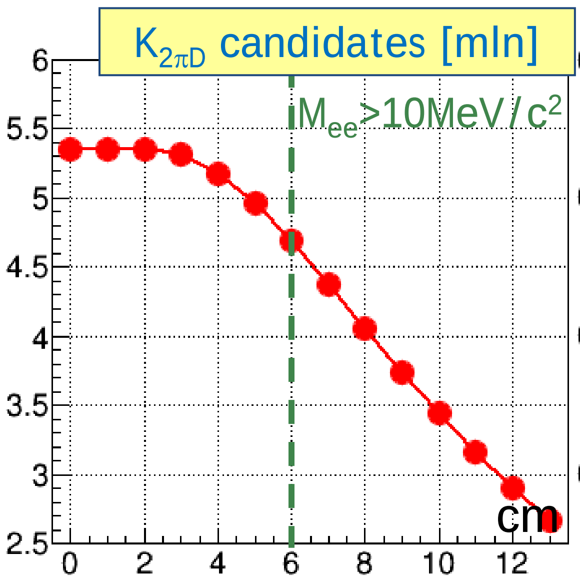


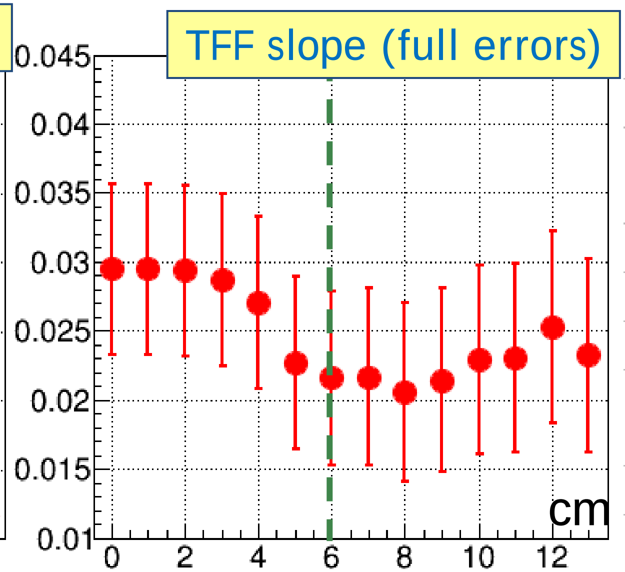
Inter-track distance in DCH1 plane

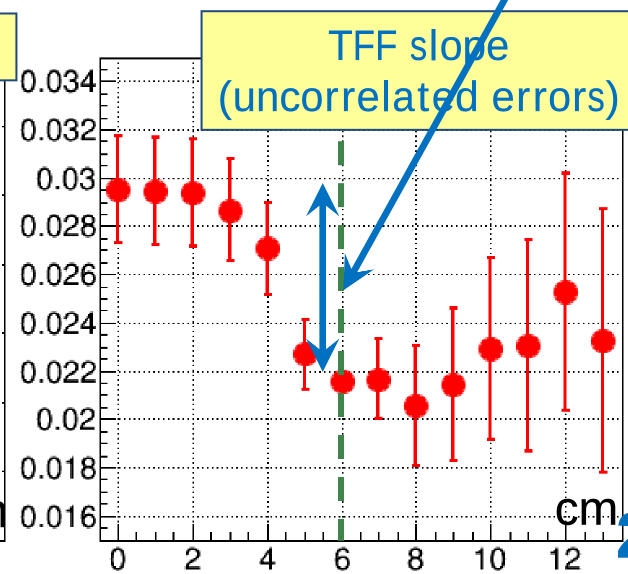




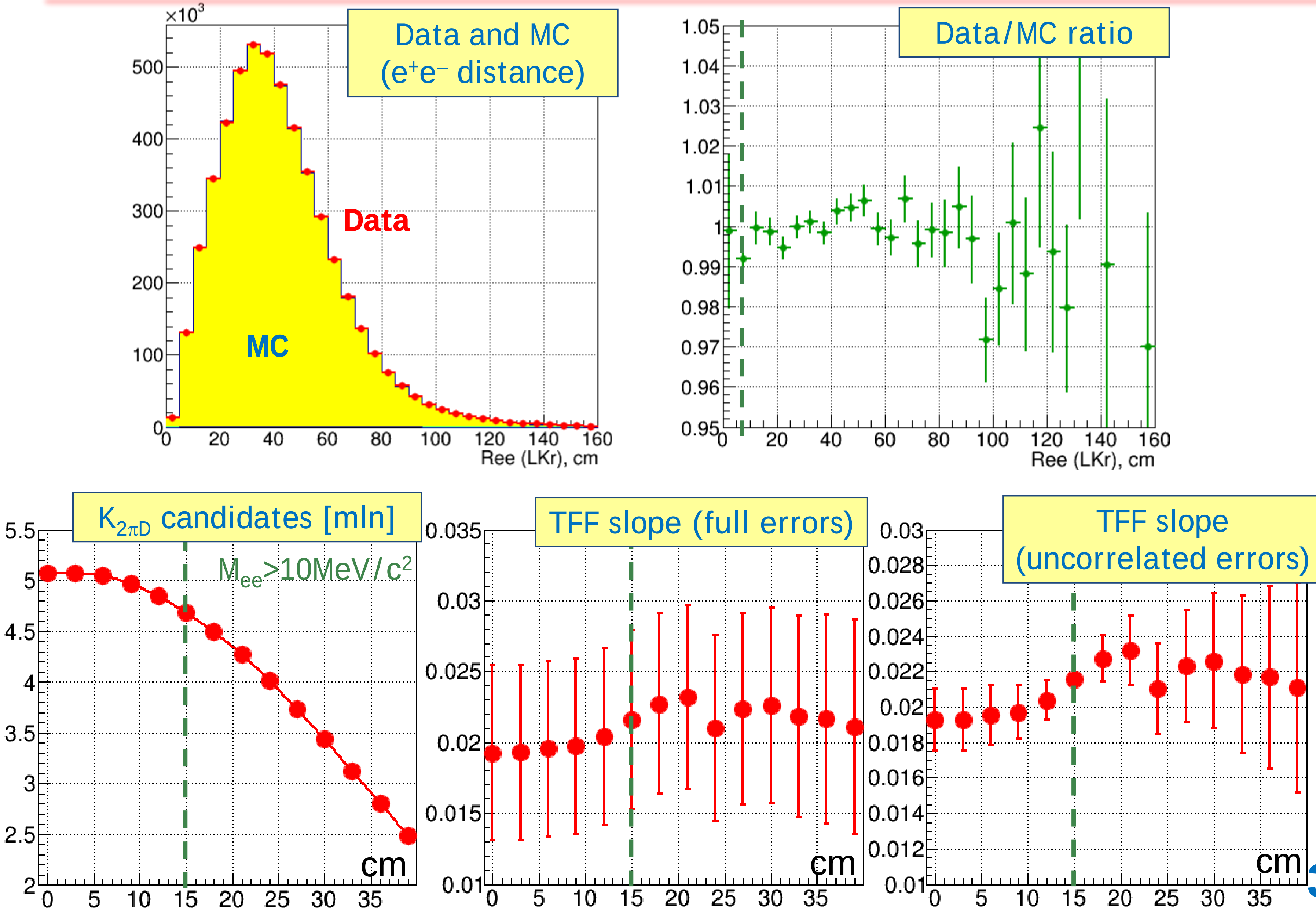
The largest non-understood effect: considered as a systematic uncertainty



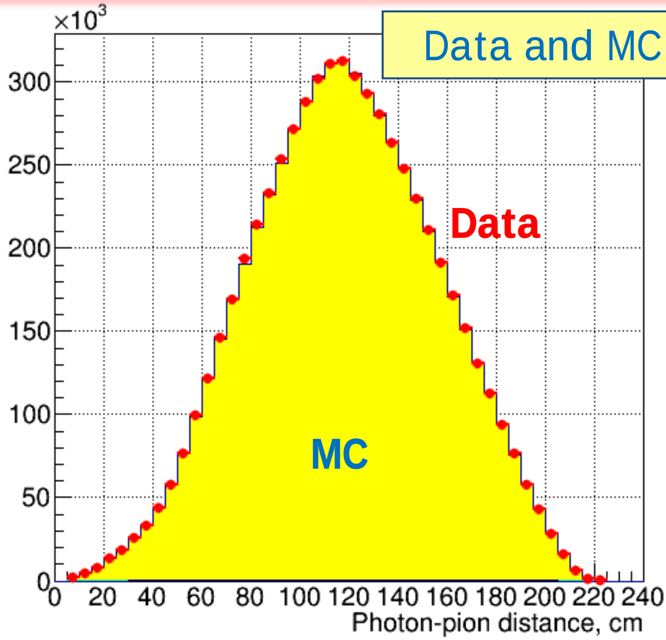




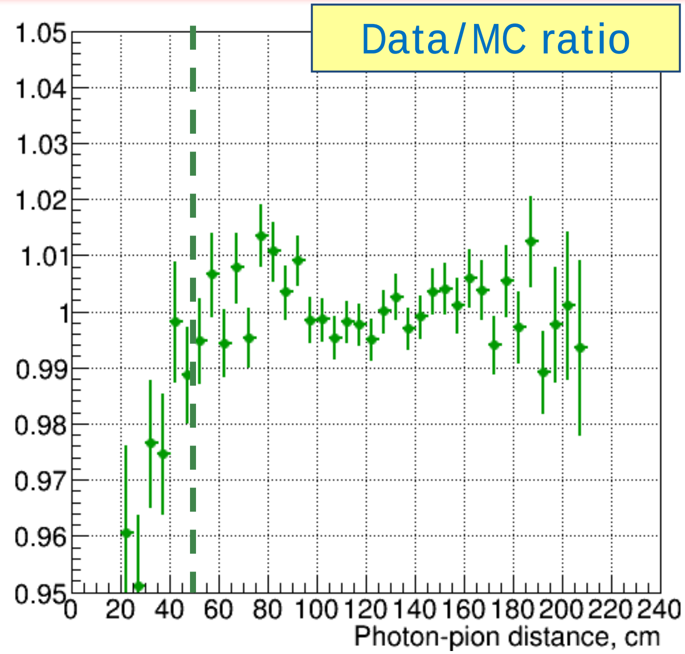
Inter-track distance in LKr plane



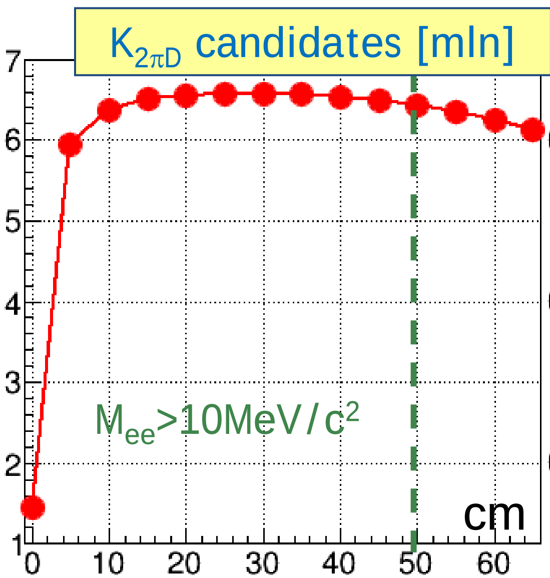
π–γ distance



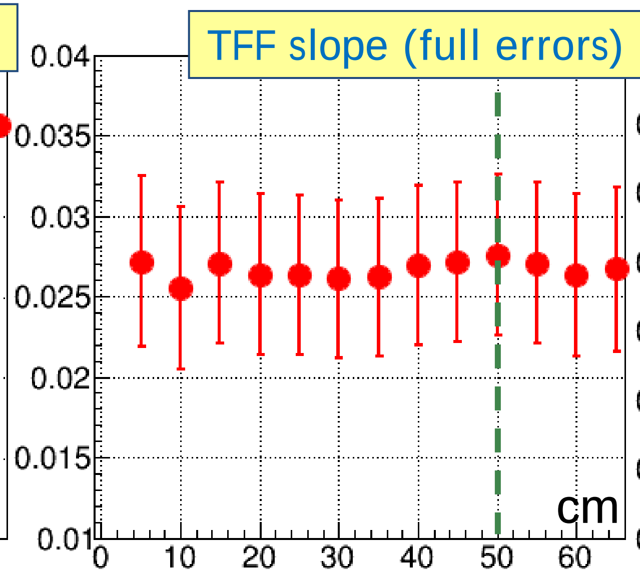
Data and MC
Data
MC
×10³
Photon-pion distance, cm



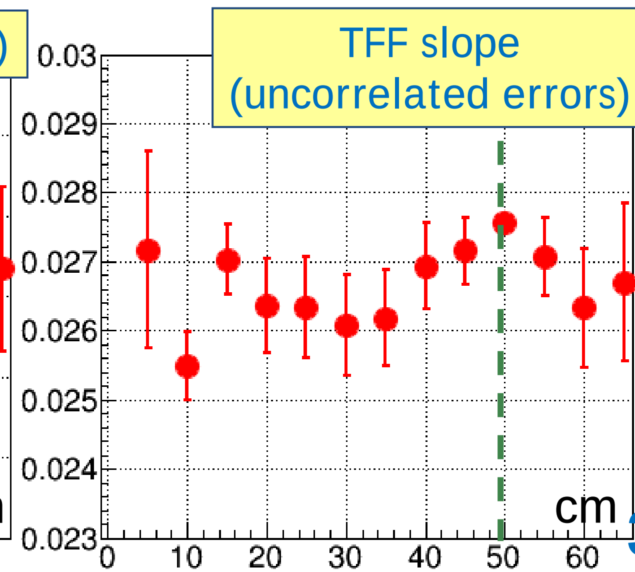
Data/MC ratio
Photon-pion distance, cm



K2πD candidates [mln]
Mee>10MeV/c²
cm

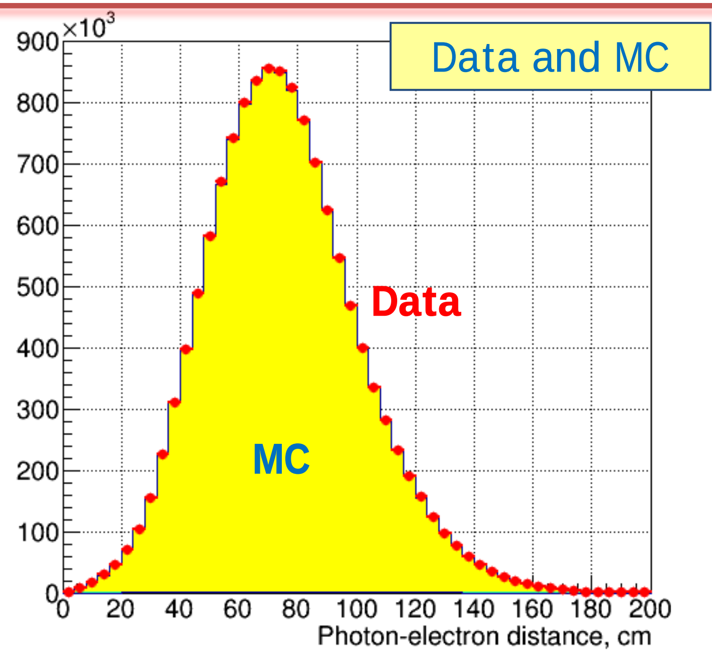


TFF slope (full errors)
cm

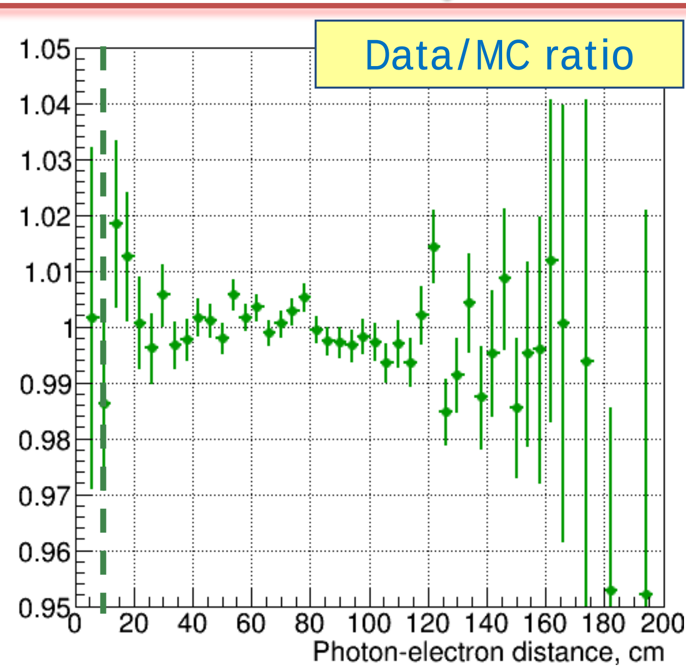


TFF slope
(uncorrelated errors)
cm

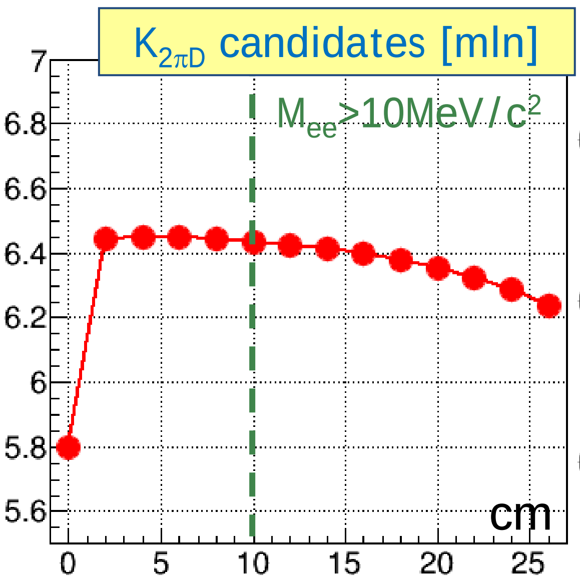
e–γ distance



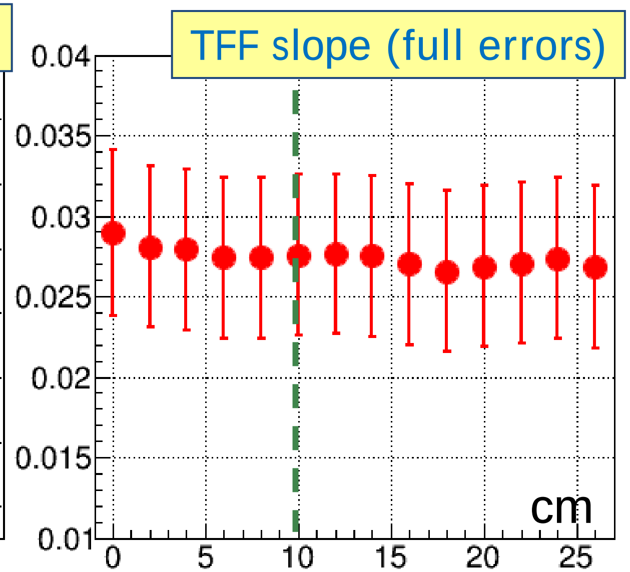
Data and MC
Data
MC
Photon-electron distance, cm



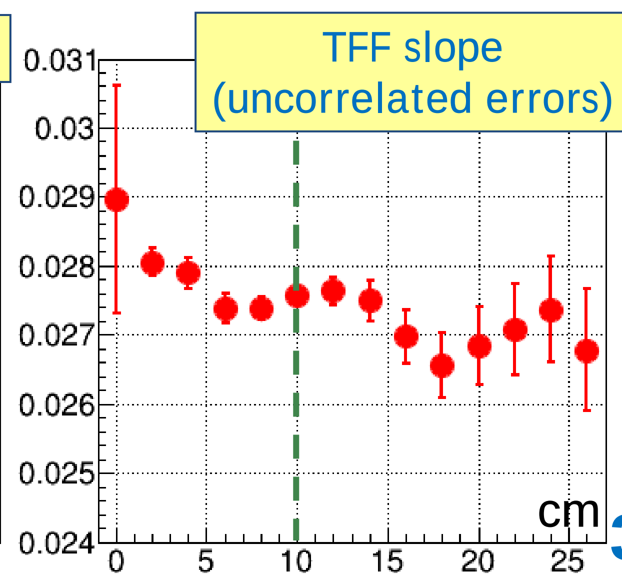
Data/MC ratio
Photon-electron distance, cm



$K_{2\pi D}$ candidates [mln]
M_{ee}>10MeV/c^2
cm

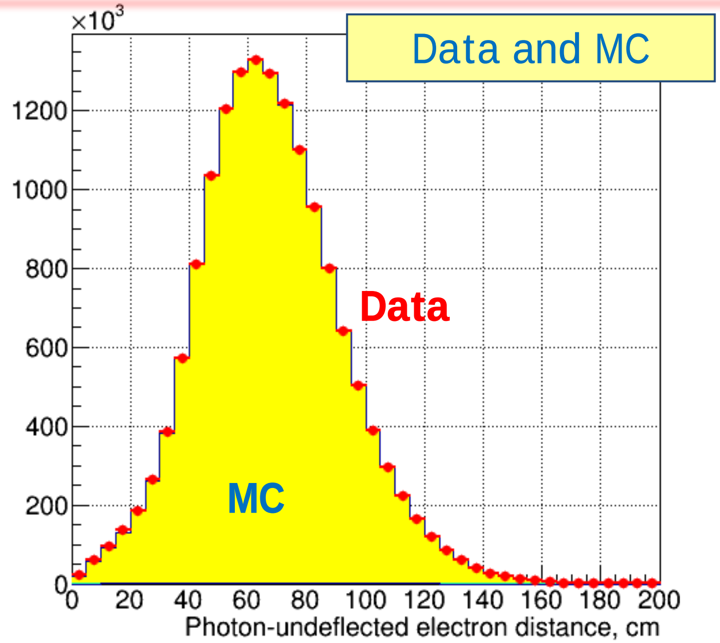


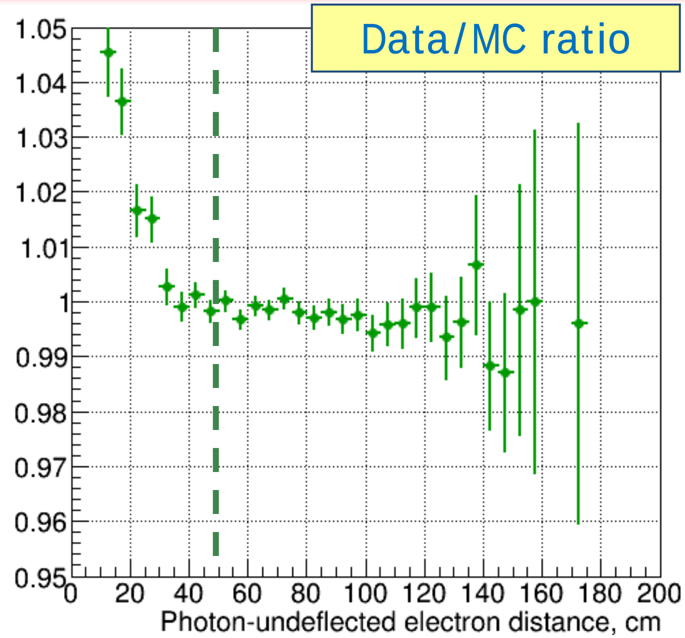
TFF slope (full errors)
cm

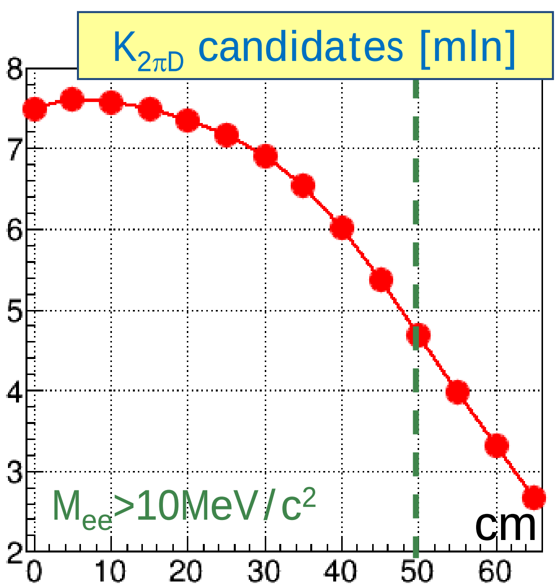


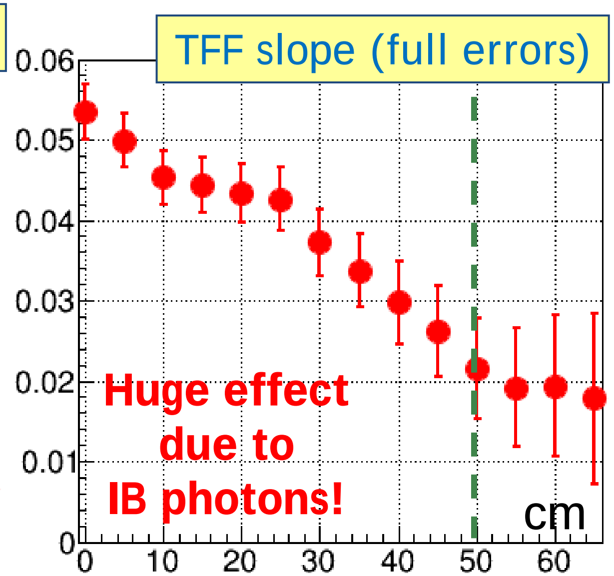
TFF slope
(uncorrelated errors)
cm

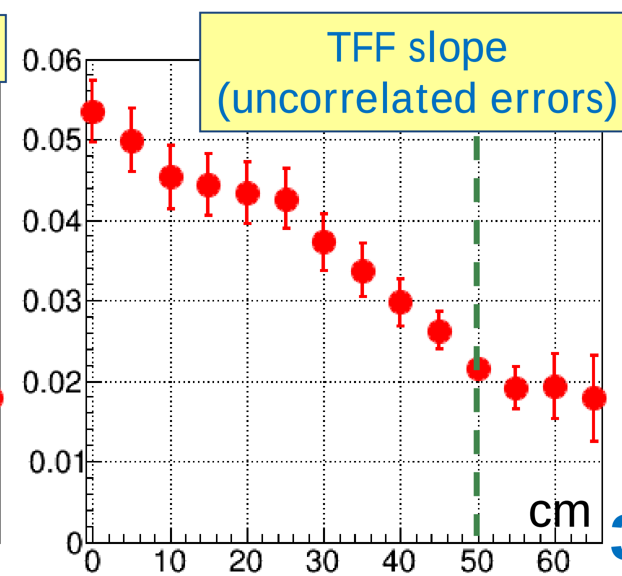
Undefl. trajectory: e–γ distance



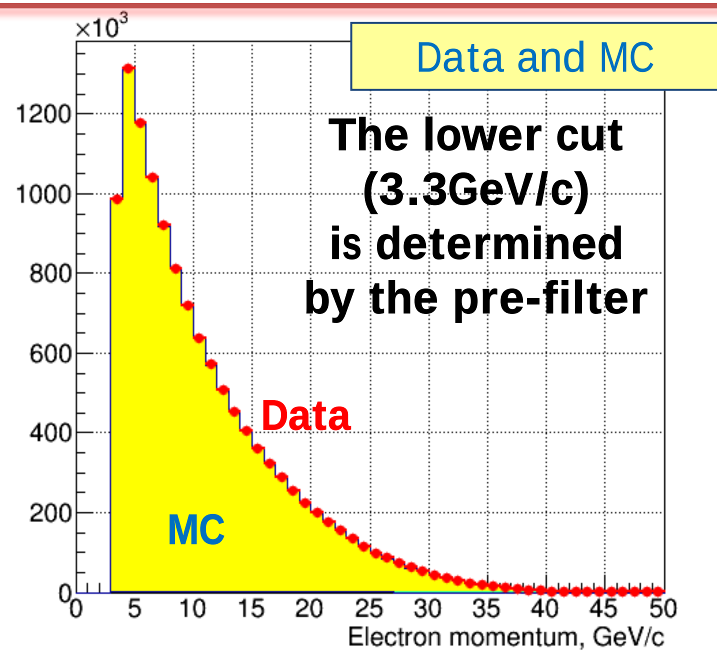


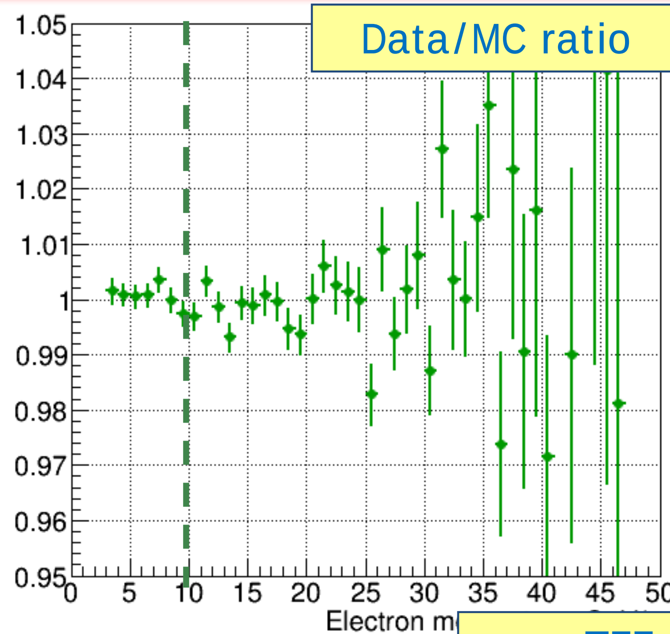


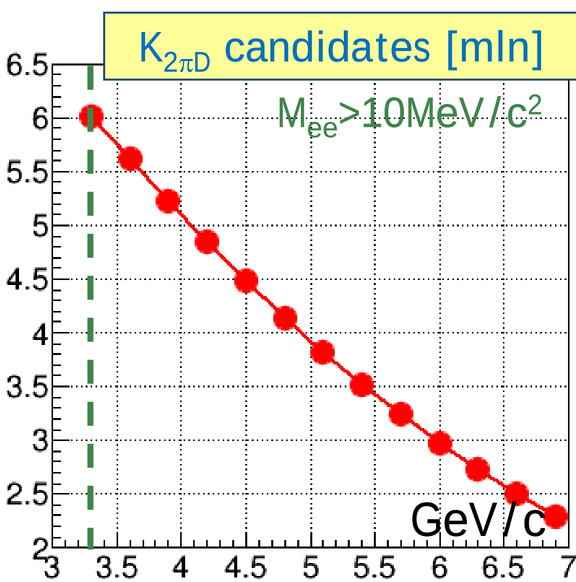


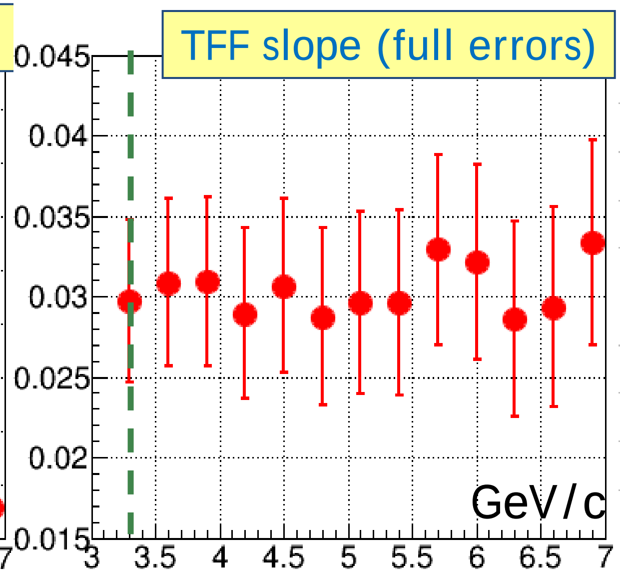


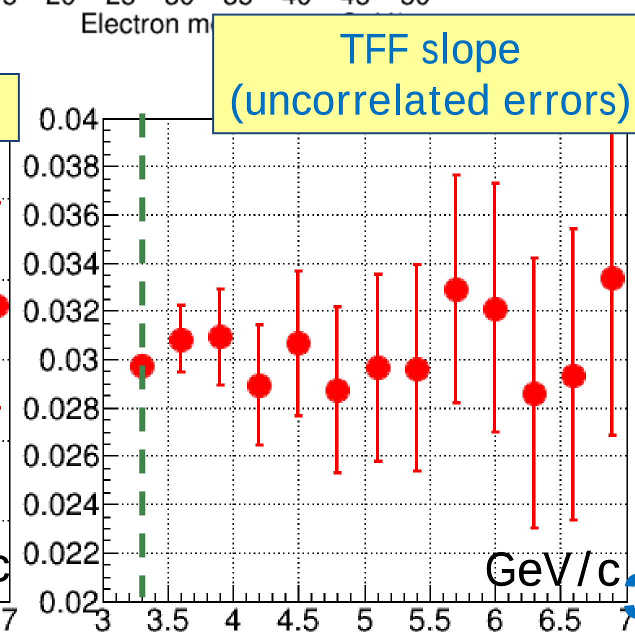
Minimum electron ($e^{\pm}$) momentum



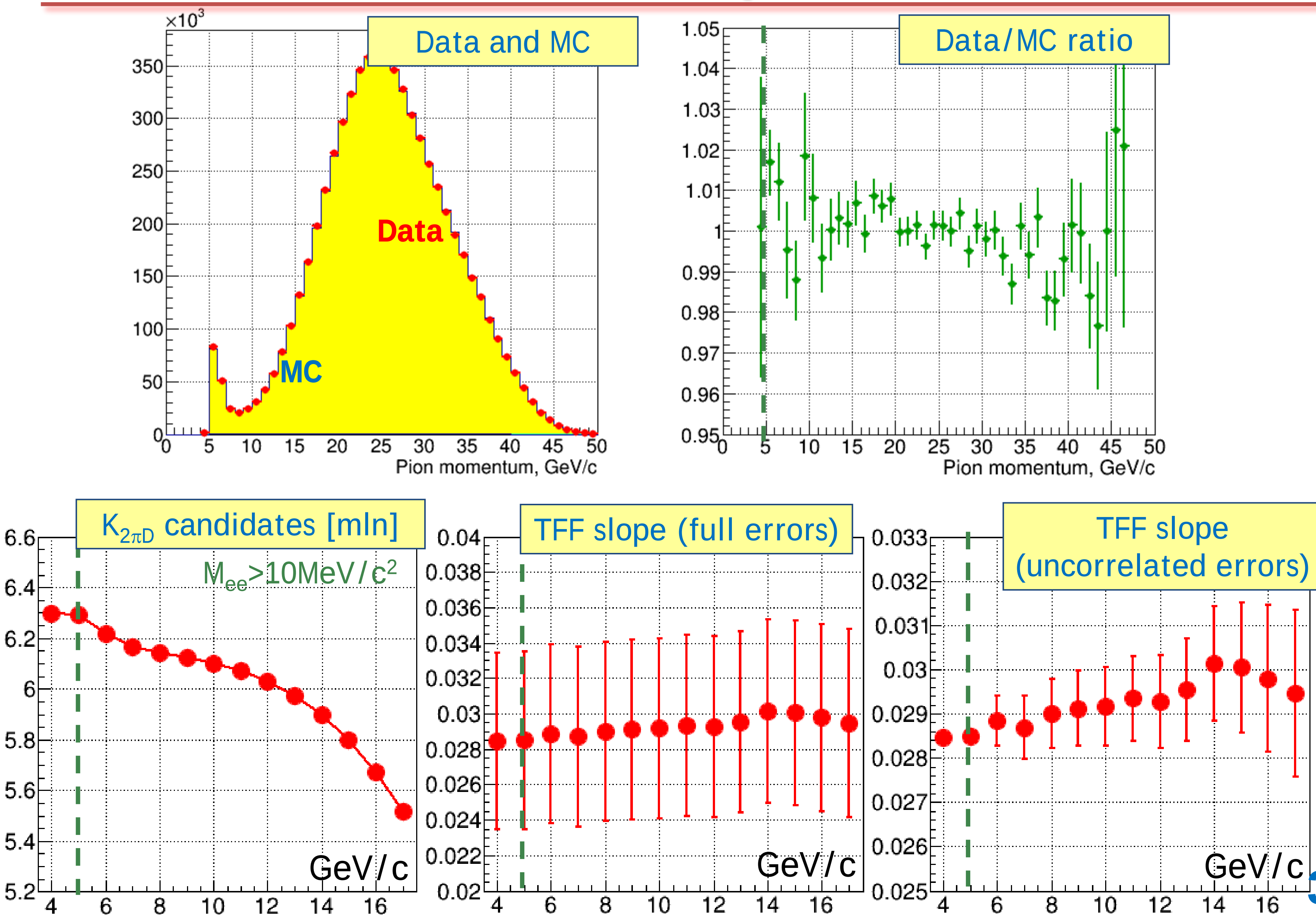




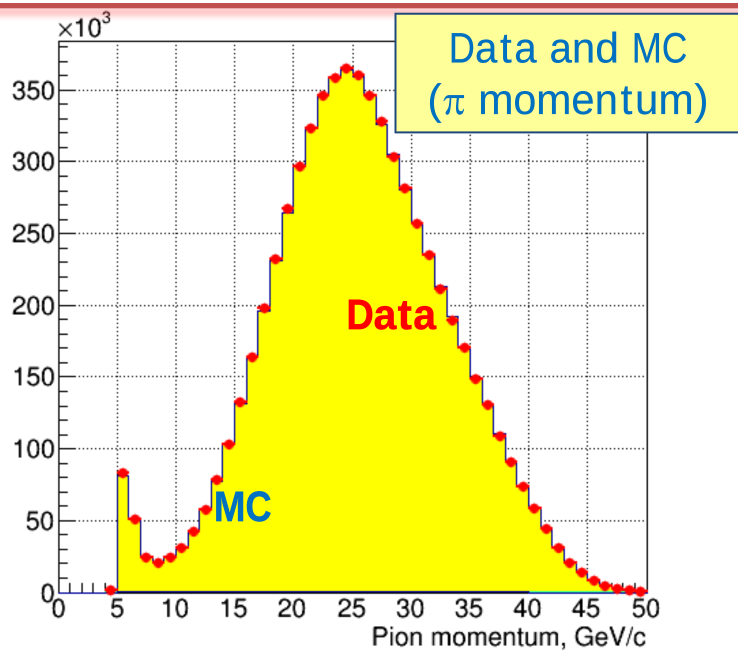


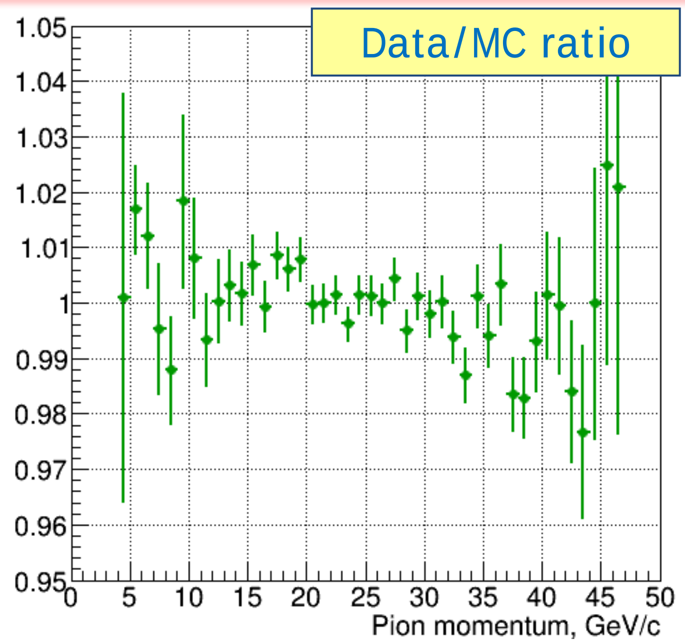


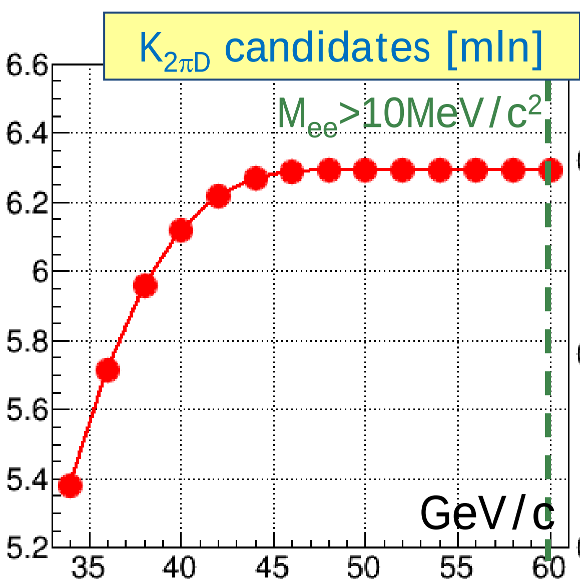
Minimum pion momentum

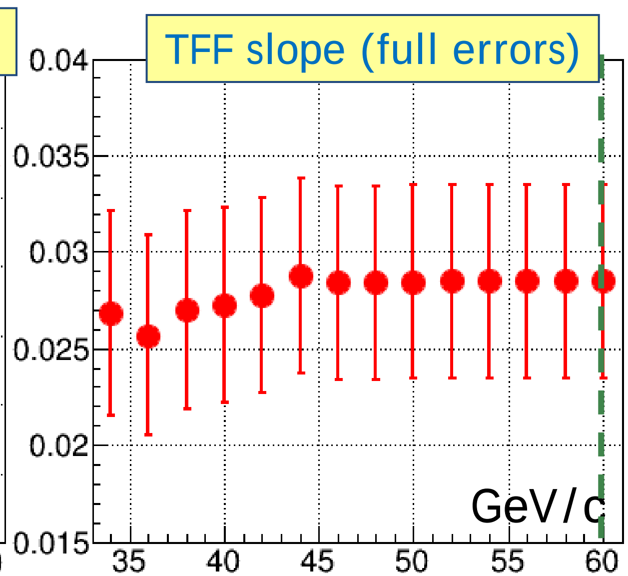


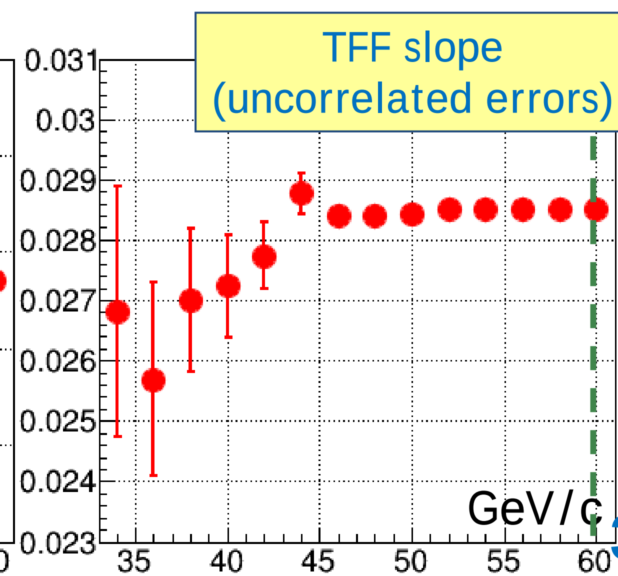
Maximum momentum



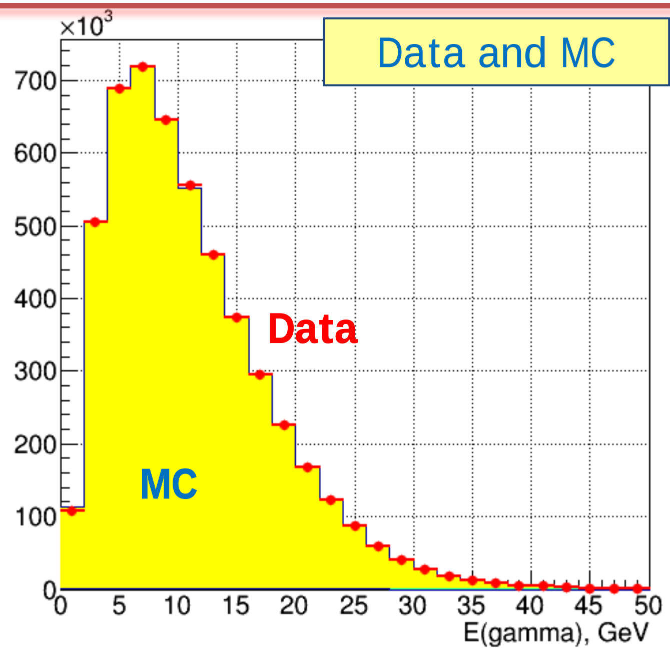


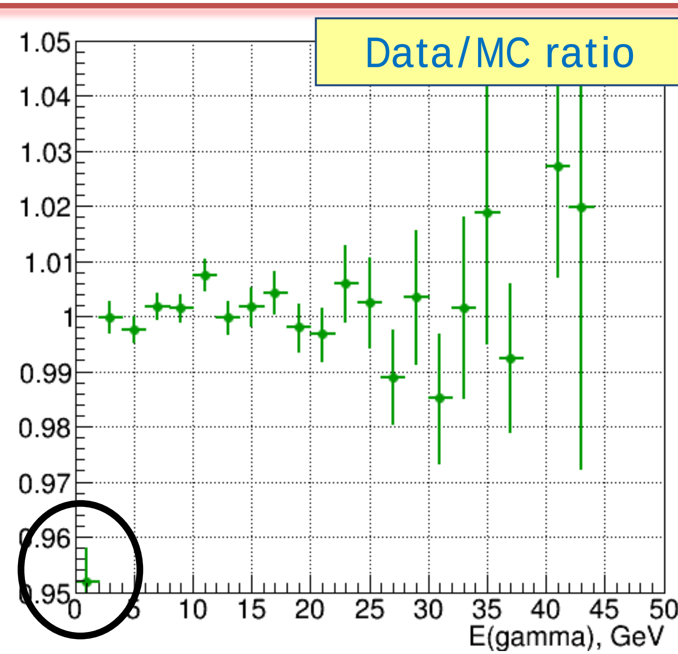


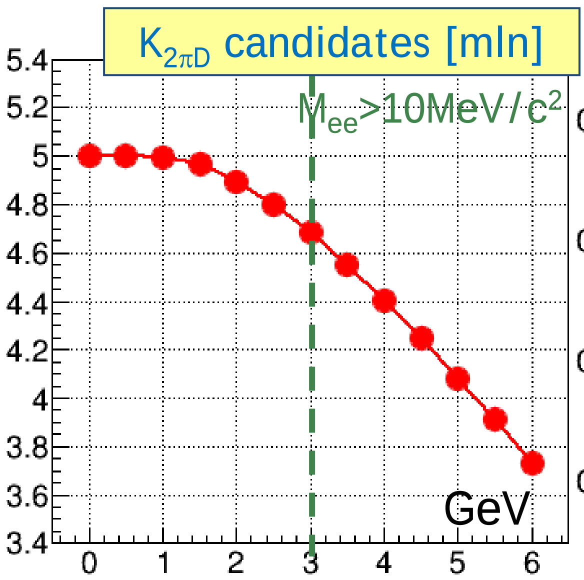


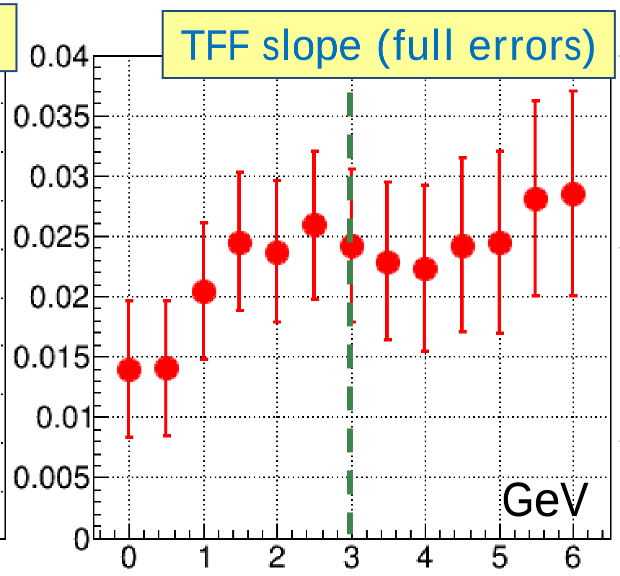


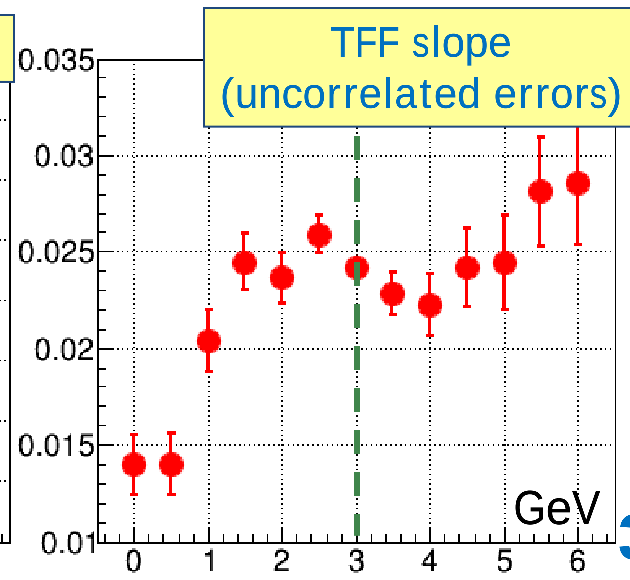
Photon energy



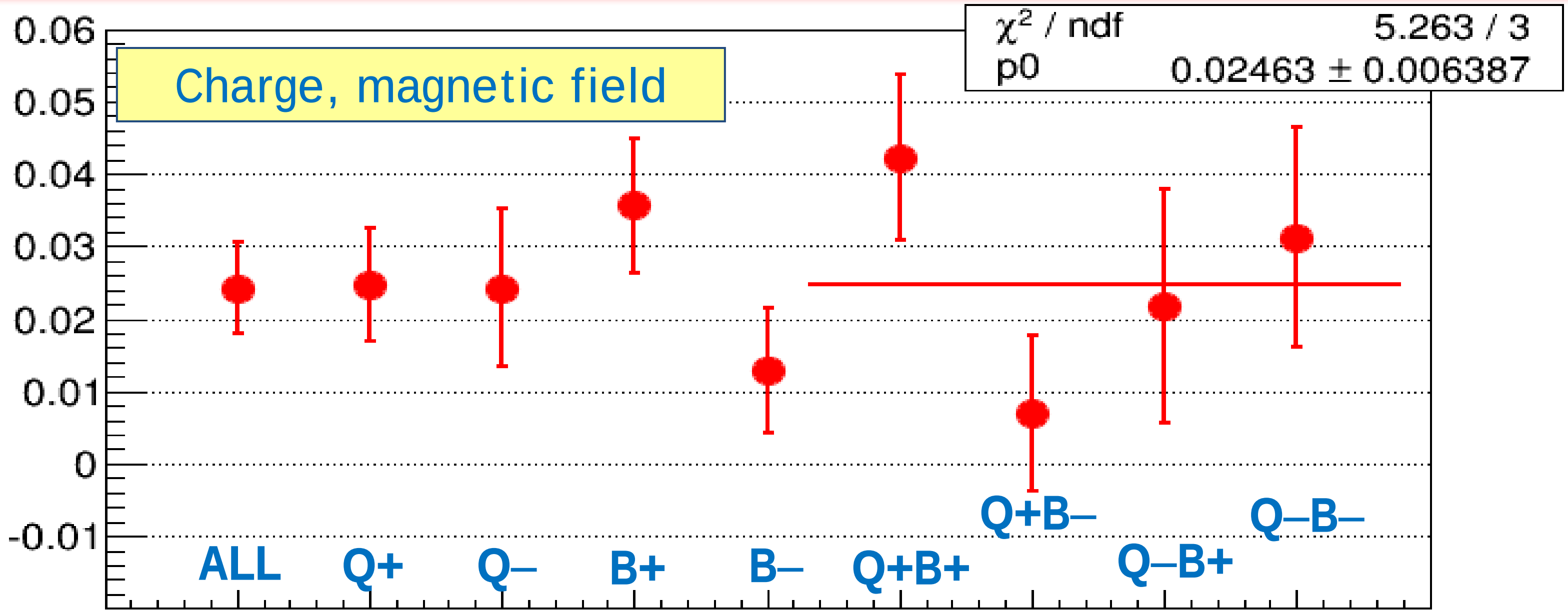


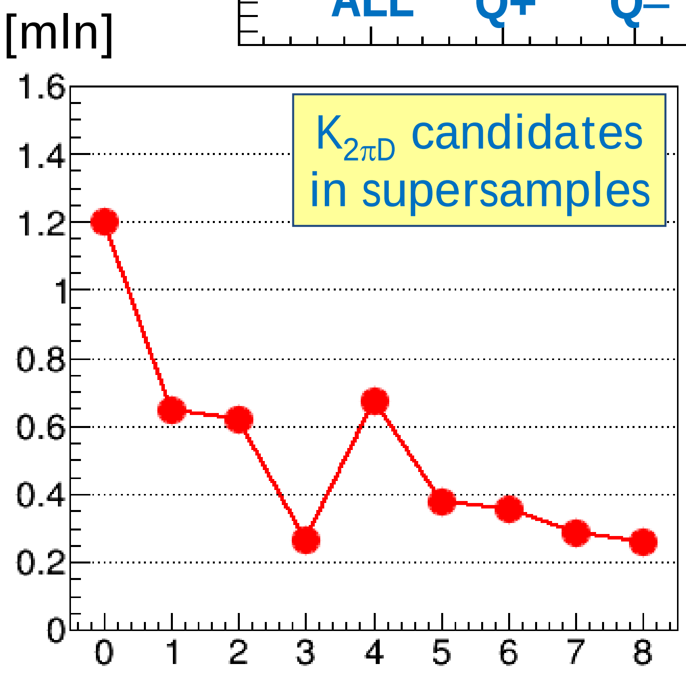


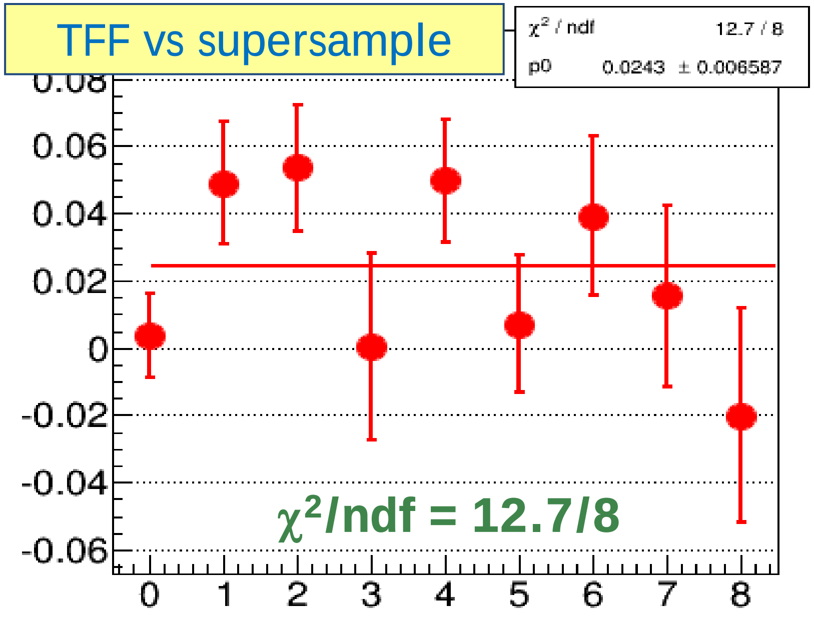




Kaon charge & magnetic field







TFF slope: error budget

Source	Correction $\Delta a \times 10^2$	Uncertainty $\delta a \times 10^2$
Statistical error		0.33
Trigger efficiency	–1.17	0.45
MC statistical error		0.29
Geometrical acceptance		0.79
Spectrometer calibration		0.07
LKr non-linearity		0.56
LKr energy scale	–0.02	0.02
Particle identification		0.03
Accidentals		0.13
Total		1.23

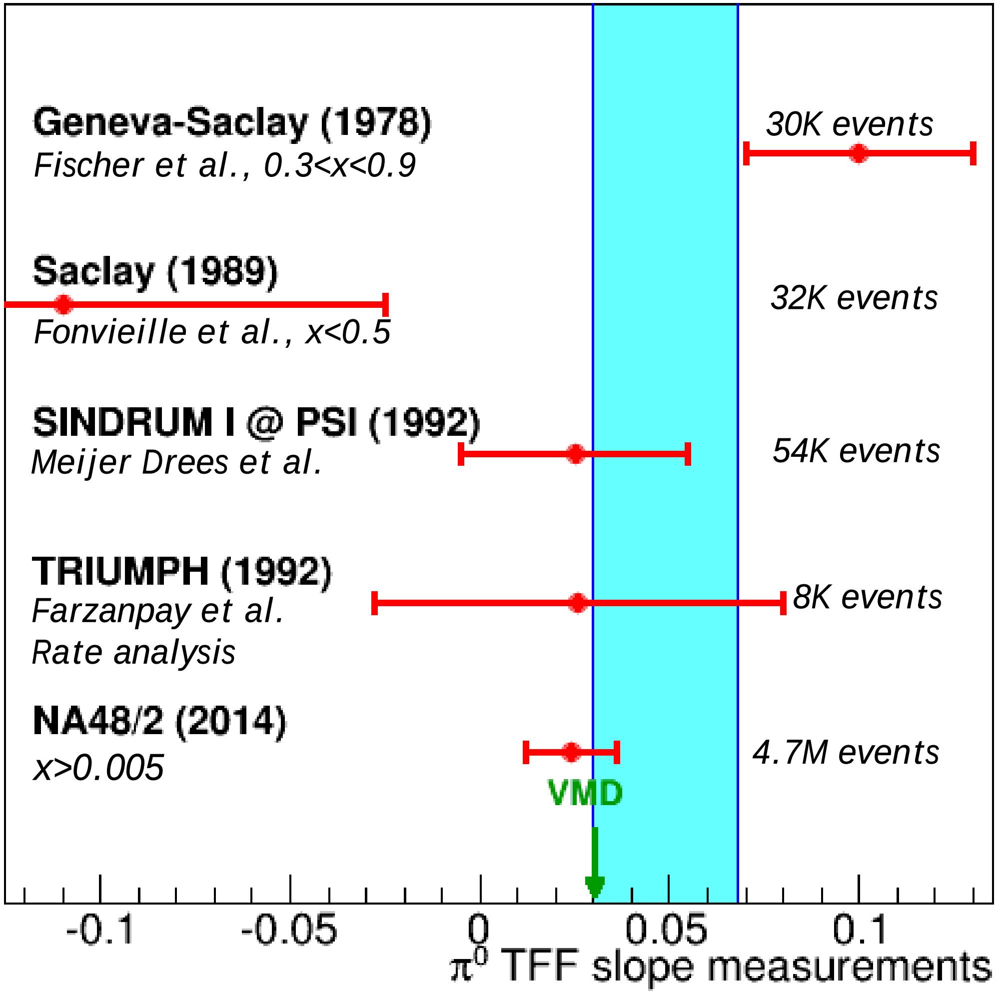
Preliminary result on the π^0 TFF slope:

$$a = (2.4 \pm 0.6_{stat} \pm 1.0_{syst}) \times 10^{-2} = (2.4 \pm 1.2) \times 10^{-2}$$

TFF slope: world data

Measurements with π^0_D decays since the Mikaelian-Smith paper (1972)

Slope measurements from π^0_D decays



For comparison with measurements in space-like region (CELLO, CLEO), the higher-order radiative correction to the π^0 decay due to two-photon exchange is

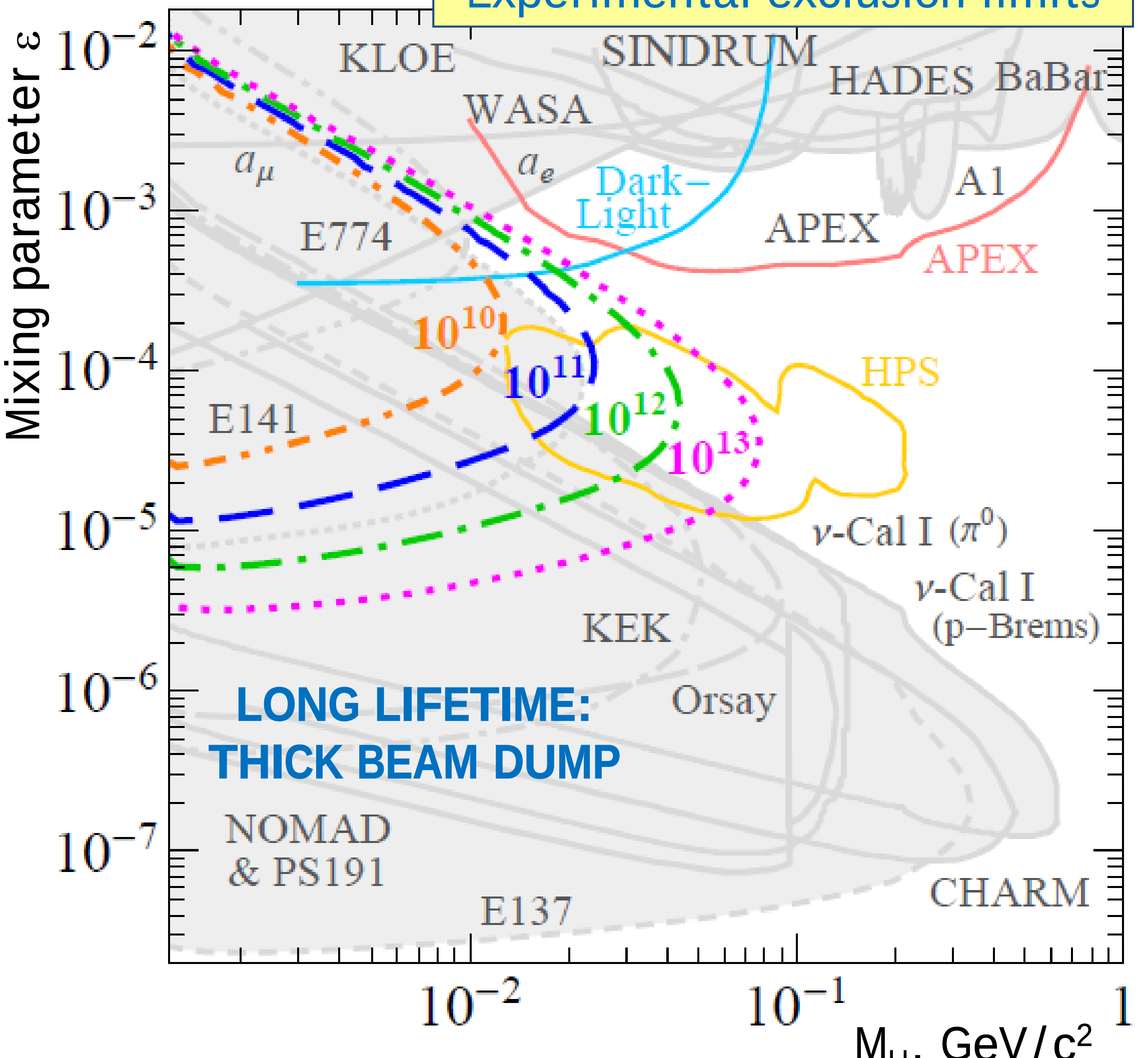
$\Delta a=+0.005$

[Kampf et al., EPJ C46 (2006) 191]

Search for the dark photon in π^0_D decay

DP parameter space

Experimental exclusion limits



Plot: S.Andreas et al., arXiv:1312.3309 (proposal for a new experiment at CERN)

A possible SM extension: a light vector boson (the **dark photon**, **A'** or **U**) mixing with the photon.

Possible search strategies for DP decaying to $\ell^+\ell^-$:

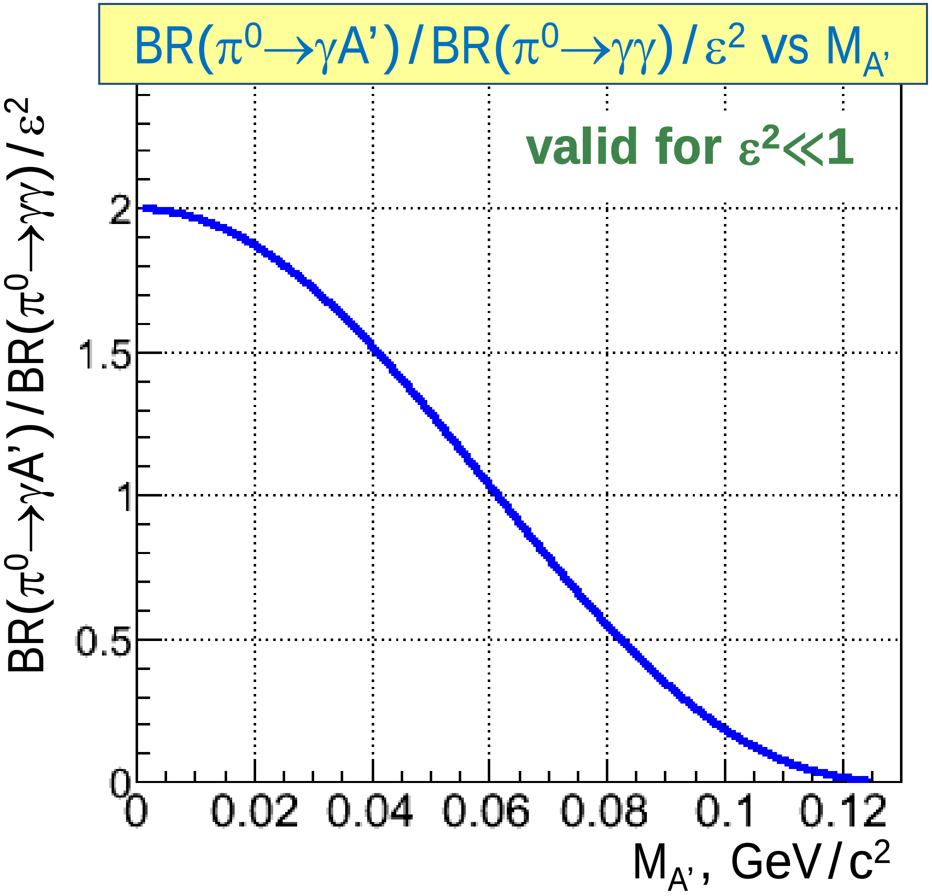
- meson decays (π^0, **K**, ϕ, …): KLOE, WASA;
- **$e^+e^-\to\gamma A'$** at colliders: KLOE, BaBar;
- fixed target electron-nucleus scattering **$eN\to eNA'$**, thin targets or beam dump: APEX@JLAB, A1@MAMI, …

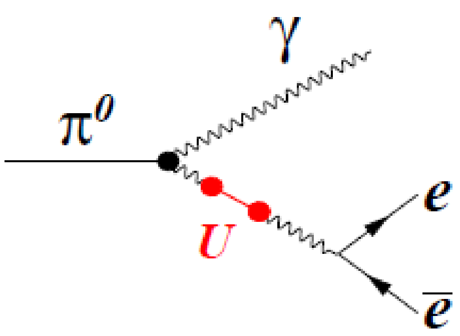
Coloured contours correspond to proposed future measurements. Several recent constraints missing.

Search via the $\pi^0 \to \gamma A'$ decay

Batell, Pospelov and Ritz, PRD80 (2009) 095024

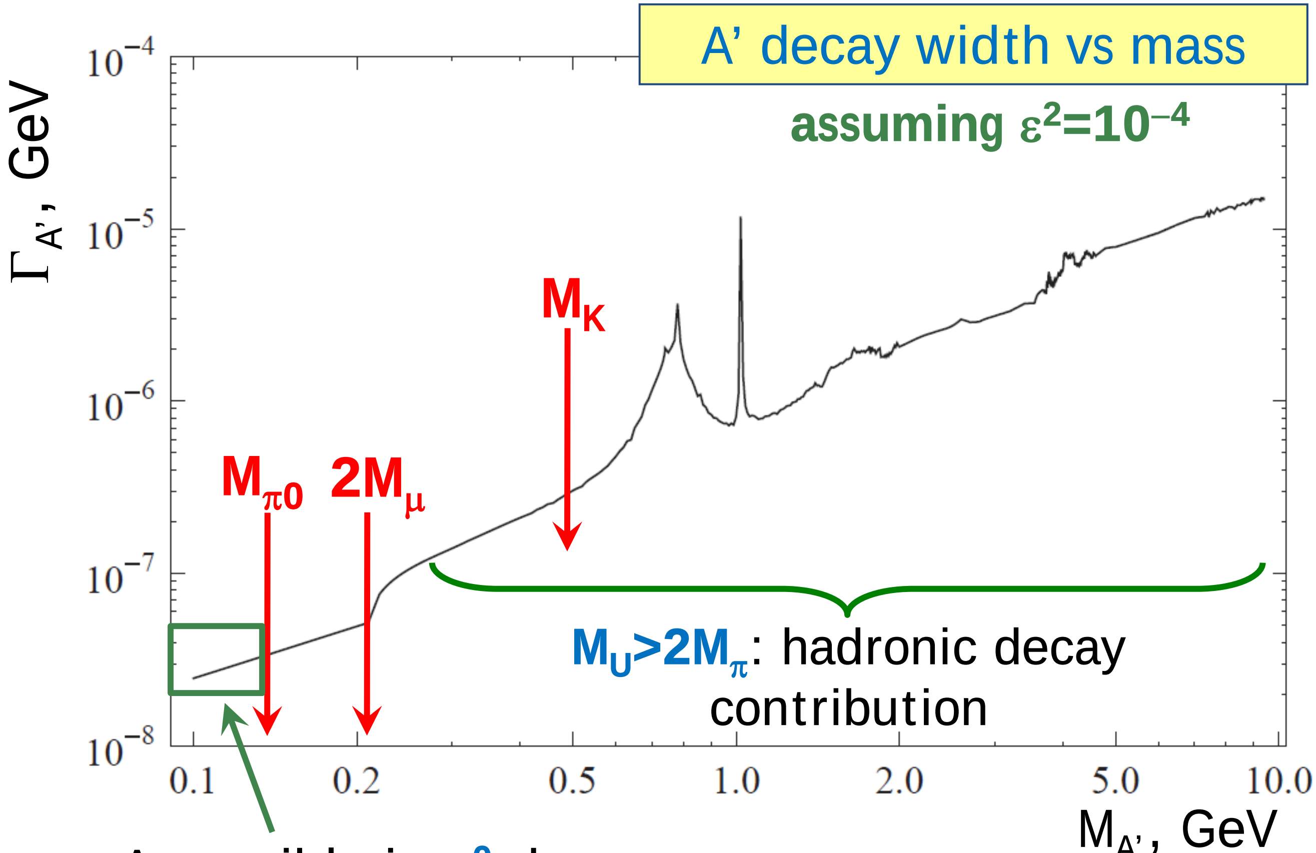
$$\frac{\mathcal{B}(\pi^0 \to \gamma U)}{\mathcal{B}(\pi^0 \to \gamma\gamma)} \approx 2\epsilon^2 |F(M_U^2)|^2 \left(1 - \frac{M_U^2}{M_\pi^2}\right)^3$$

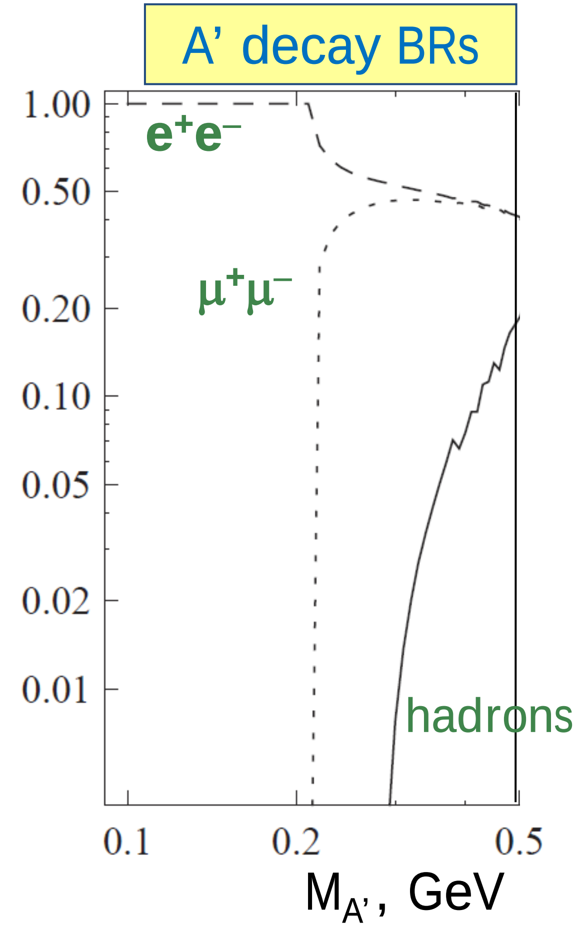




DP decays into SM fermions

Batell, Pospelov and Ritz, PRD79 (2009) 115008;
Andreas et al., arXiv:1312.3309





Accessible in π^0 decays:

$$\Gamma(A' \to e^+e^-) = \frac{\alpha}{3}\epsilon^2 M_{A'}\sqrt{1-\frac{4m_e^2}{M_{A'}^2}}\left(1+\frac{2m_e^2}{M_{A'}^2}\right) \approx \alpha\varepsilon^2 M_A/3$$

$BR(A'\to e^+e^-) = 1$ (unless decays into DM particles kinematically allowed)

DP lifetime

Decay width for $M_e \ll M_U < 2M_\mu$: $\Gamma_A \approx \alpha\varepsilon^2 M_A/3$, $BR(A' \to e^+e^-)=1$

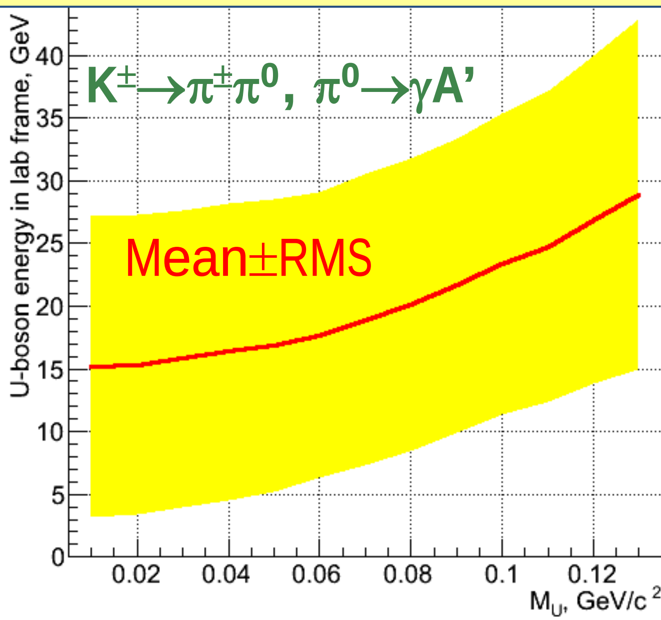
Batell, Pospelov and Ritz, PRD79 (2009) 115008

Proper lifetime:

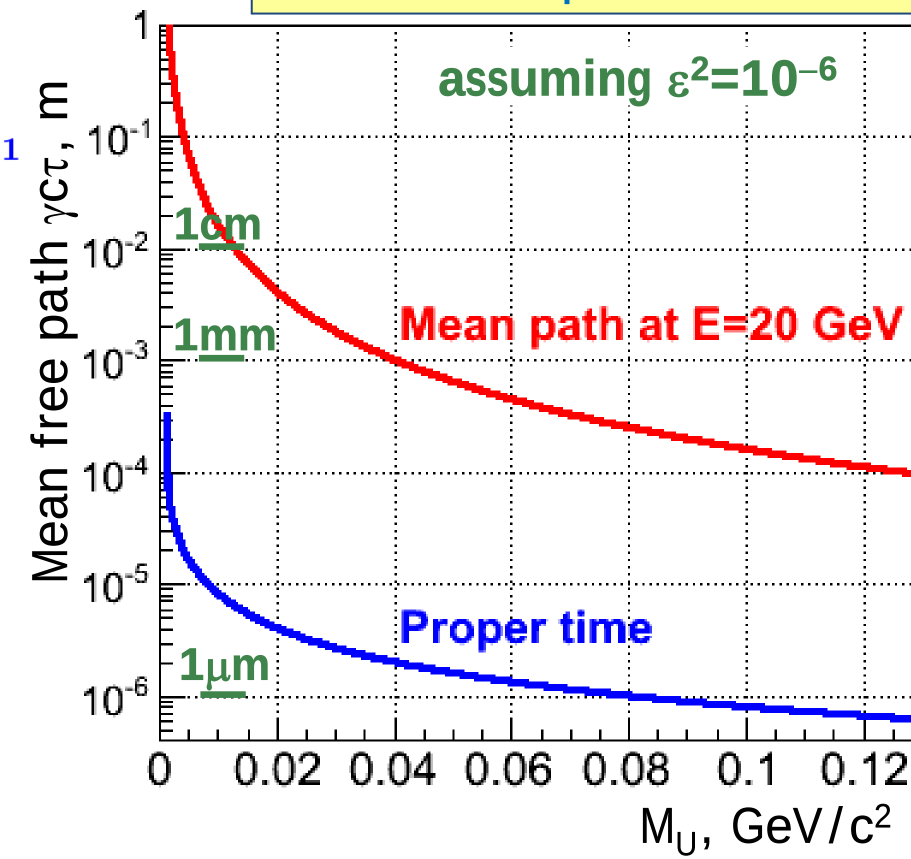
$$c\tau = \frac{\hbar c}{\Gamma_U} \approx 80\ \mathrm{nm} \times \frac{10^{-6}}{\epsilon^2} \times \left(\frac{M_U}{\mathrm{GeV}}\right)^{-1}$$

$$\tau = \frac{\hbar}{\Gamma_U} \approx 3 \times 10^{-16}\ \mathrm{s} \times \frac{10^{-6}}{\epsilon^2} \times \left(\frac{M_U}{\mathrm{GeV}}\right)^{-1}$$

DP energy in lab frame vs mass



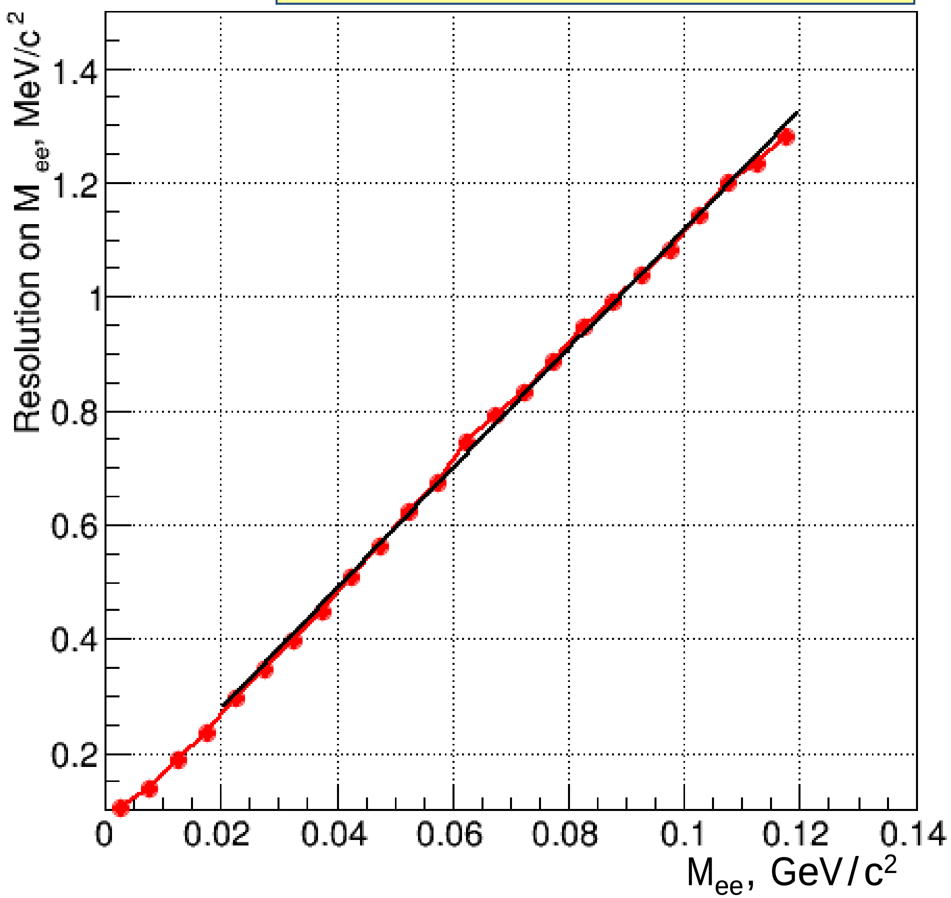
Mean free path vs mass



→ DP path can be neglected for $\varepsilon^2 > 10^{-7}$

DP mass resolution & acceptance

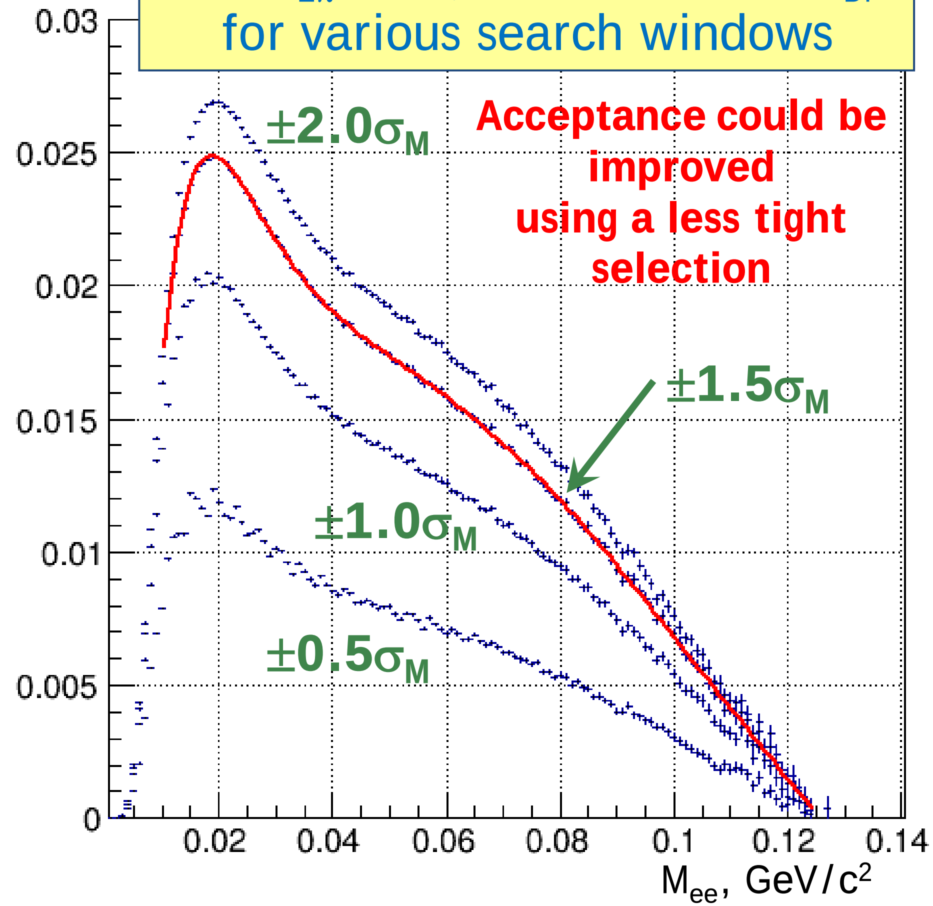
Resolution on M_{ee} vs M_{ee}



Linear fit to the resolution:

$\sigma_M(M_{ee}) = 0.0105M_{ee} + 0.067$ MeV

Acc($K_{2\pi}$, $\pi\to\gamma A'$, $A'\to e^+e^-$) vs M_{DP} for various search windows



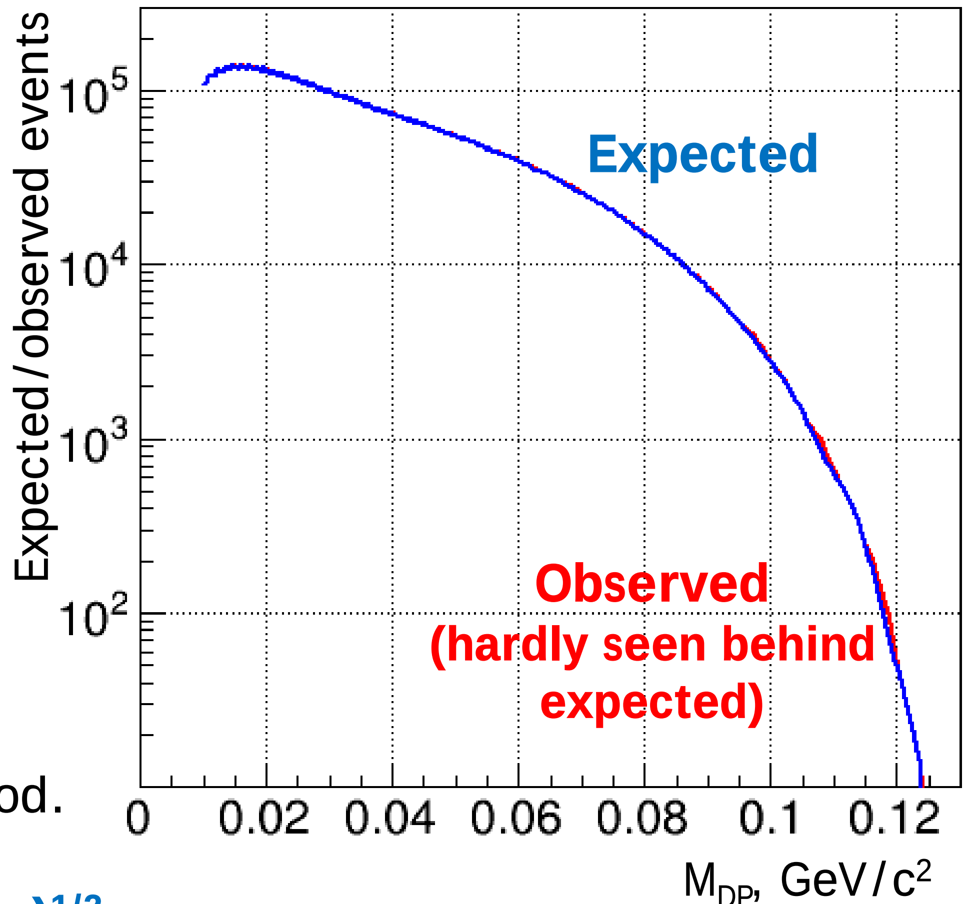
Acceptances for $\pm\alpha\sigma_M$ search windows are roughly **~ erf(α)**.

Modulation at low M_{ee} due to finite bin size.

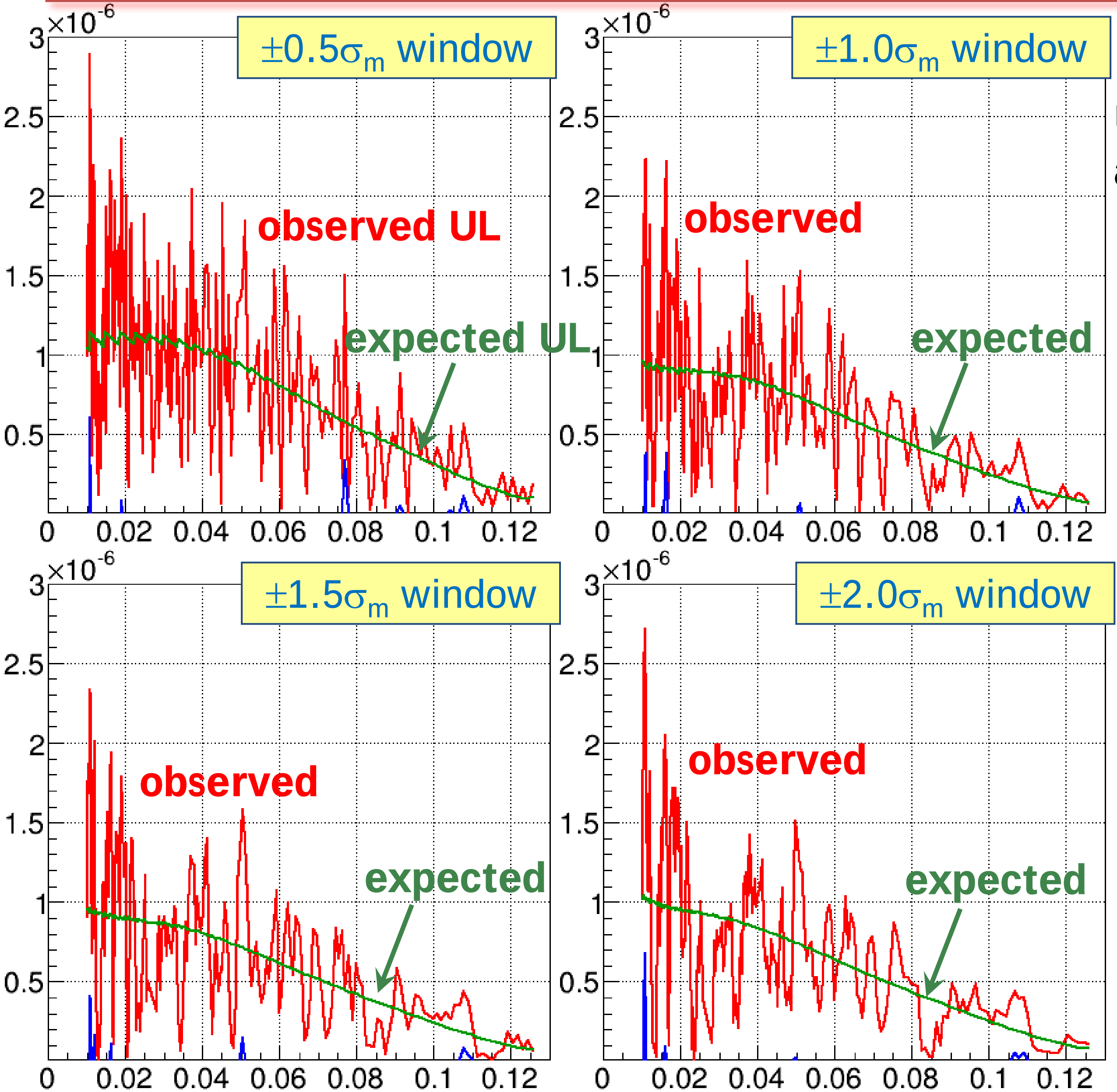
Search for the DP

- Scanned DP mass range: **10 MeV/c^2<M_{DP}<125 MeV/c^2**.
- Variable mass step: approximately **$0.5\sigma_M$**.
- Mass hypotheses tested: **398**.
- Expected background: from π^0_D TFF fit in the range **(9–130) MeV/c^2**.
- Sensitivity is determined by the fluctuation of the number of background (π^0_D) events.
- Upper and lower limits on N_{DP} are computed from $N_{expected}$, $N_{observed}$ and $\delta N_{observed}$ using the Rolke-Lopez method. Feldman-Cousins method is not applicable because $\delta N_{expected} \neq (N_{expected})^{1/2}$.

Numbers of expected and observed events in the signal mass window vs mass hypothesis



DP search window optimisation



Upper limits for **$BR(\pi^0 \to \gamma A')$** at **90% CL** for different mass search windows

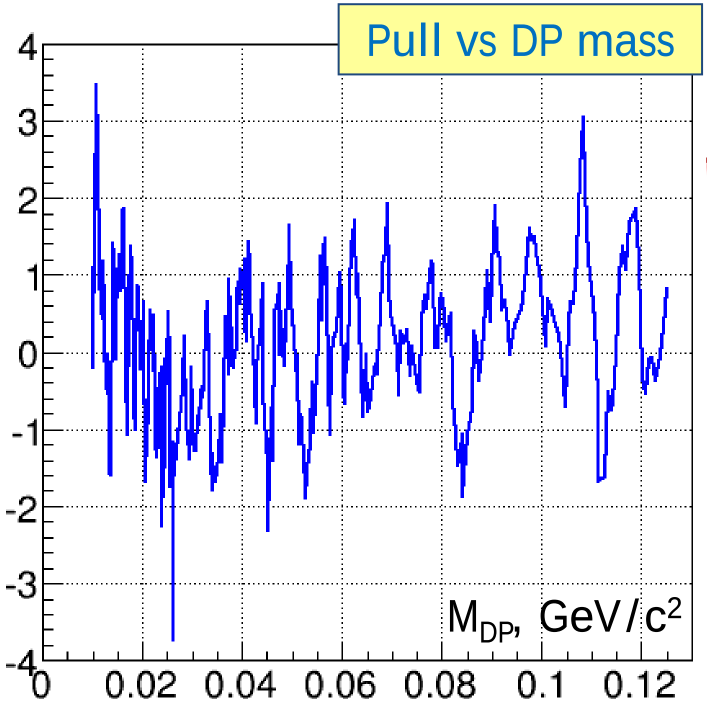
Competing effects: increasing acceptance vs larger background fluctuation.

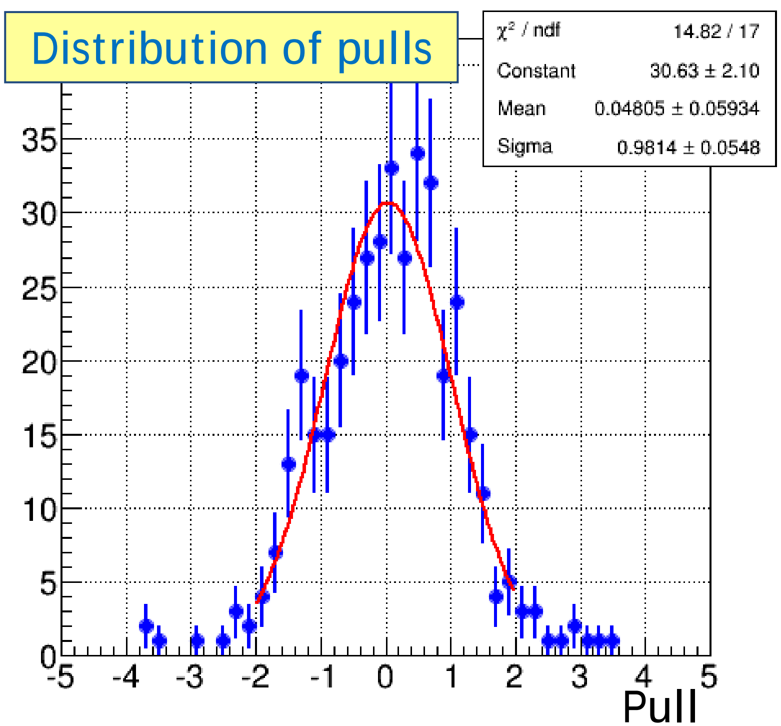
A broad UL minimum is observed at **1.0σ –1.5σ**, similarly to other searches.

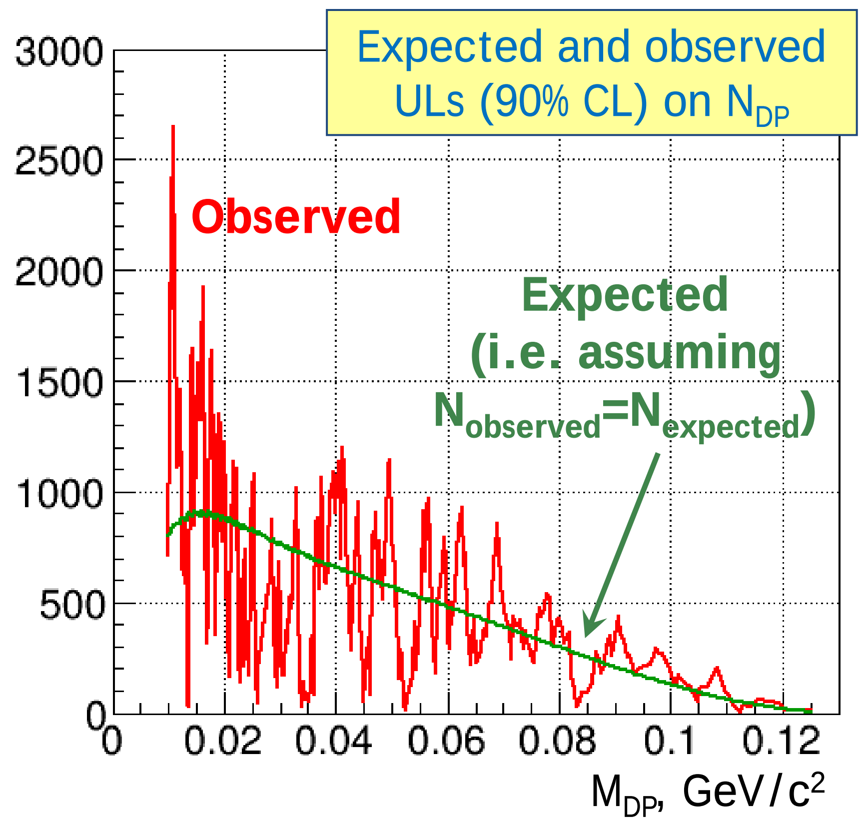
A search window width of $\pm 1.5\sigma_M$ is used.

Significance (pulls)

Pull: $P = N_{diff} / \delta N_{diff}$,
where $N_{diff} = N_{observed} - N_{expected}$.
Statistical, MC statistical and trigger efficiency uncertainties are propagated into $\delta N_{expected}$.

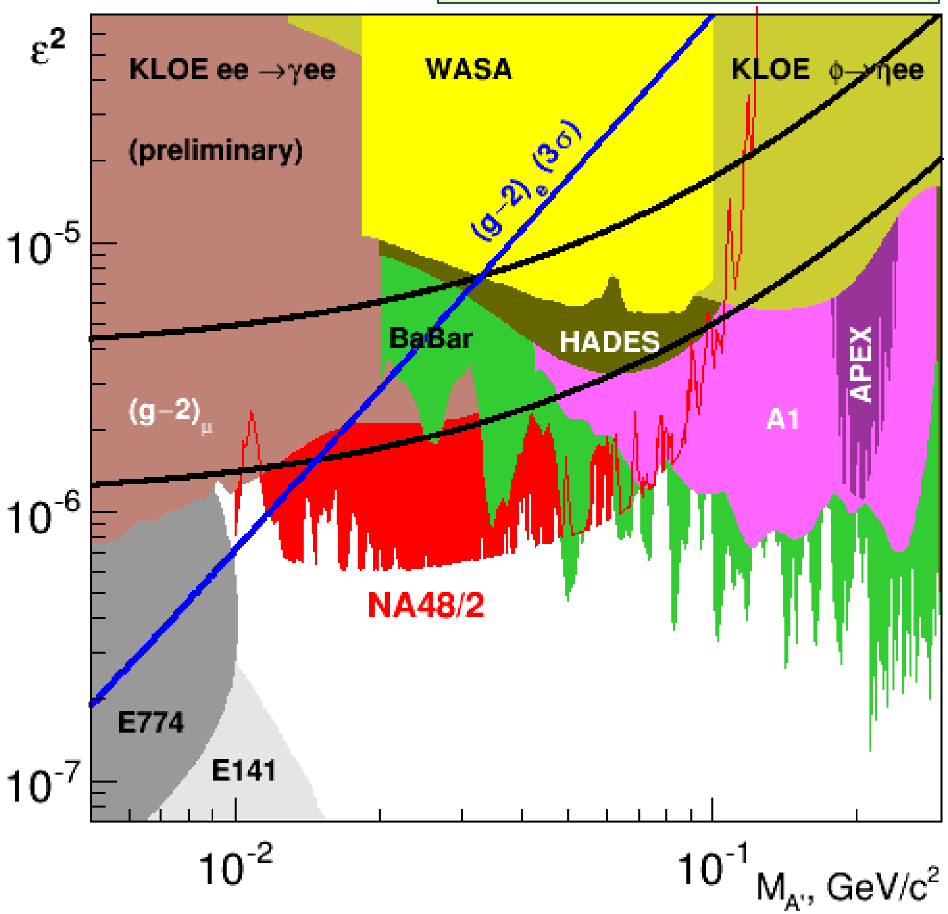






DP exclusion: summary

DP exclusion summary



- Our result improves the existing limits in the range **10–70 MeV/c²**.
- DP as the explanation for **$(g\text{–}2)_\mu$** is now ruled out.
- As APEX, we conservatively assume **$N_{observed}=N_{expected}$** in cases when **$N_{observed}<N_{expected}$**. Therefore there are no downward spikes.

Conclusions

- **Preliminary result** on the π^0 TFF slope is proposed for blessing:

$$a = (2.4 \pm 0.6_{stat} \pm 1.0_{syst}) \times 10^{-2}.$$

- The precision will be improved:
  - ✓ further optimisation of the selection to improve acceptance;
  - ✓ new di-electron split with removed **p_e=3 GeV/c** cutoff;
  - ✓ production of more MC samples;
  - ✓ optimisation of MC grouping into the 3 templates for the fit;
  - ✓ possibly alternative fitting method(s);
  - ✓ understandng the bremsstrahlung effect (try MC without external bremsstrahlung or PHOTOS corrections?)

- **Preliminary limits** on the DP produced in the $\pi^0 \to \gamma A'$ decay proposed for blessing: most stringent limits in the **10–70 MeV/c²** mass range.

- Improvements on TFF will lead to improvement of DP limits.