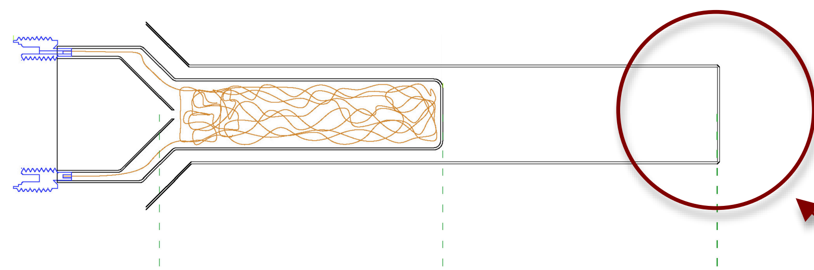
Subtracting EMPTY-cell backgrounds in conventional Histogram-based analyses

Mar 12'14

(Andy, with data replays by Tsuneo and Peng)



- ***periods 1-5 : cell 21a (silver) was the same as used in EMPTY runs***

  ⇨ ***normalize EMPTY up to the same flux as desired run period, using events reconstructed from the downstream KelF foil***

- ***what about data from the other 2 g14 target cells ?***

- ***different cells had differing amounts of aluminum,***
  while EMPTY data were all taken with cell 21a (silver) :

Cell #	< HD *length* > (cm)	< Al *region* > (cm)	< ρ(Al) > (gm/cc)	$< \rho^{Al}_{rel} >$ (relative to 21a)
21a (*silver*)	~ 4	6	0.0280	1
19b (*gold*)	5	6	0.0196	0.700
22b (*last*)	5	6	0.0268	0.957

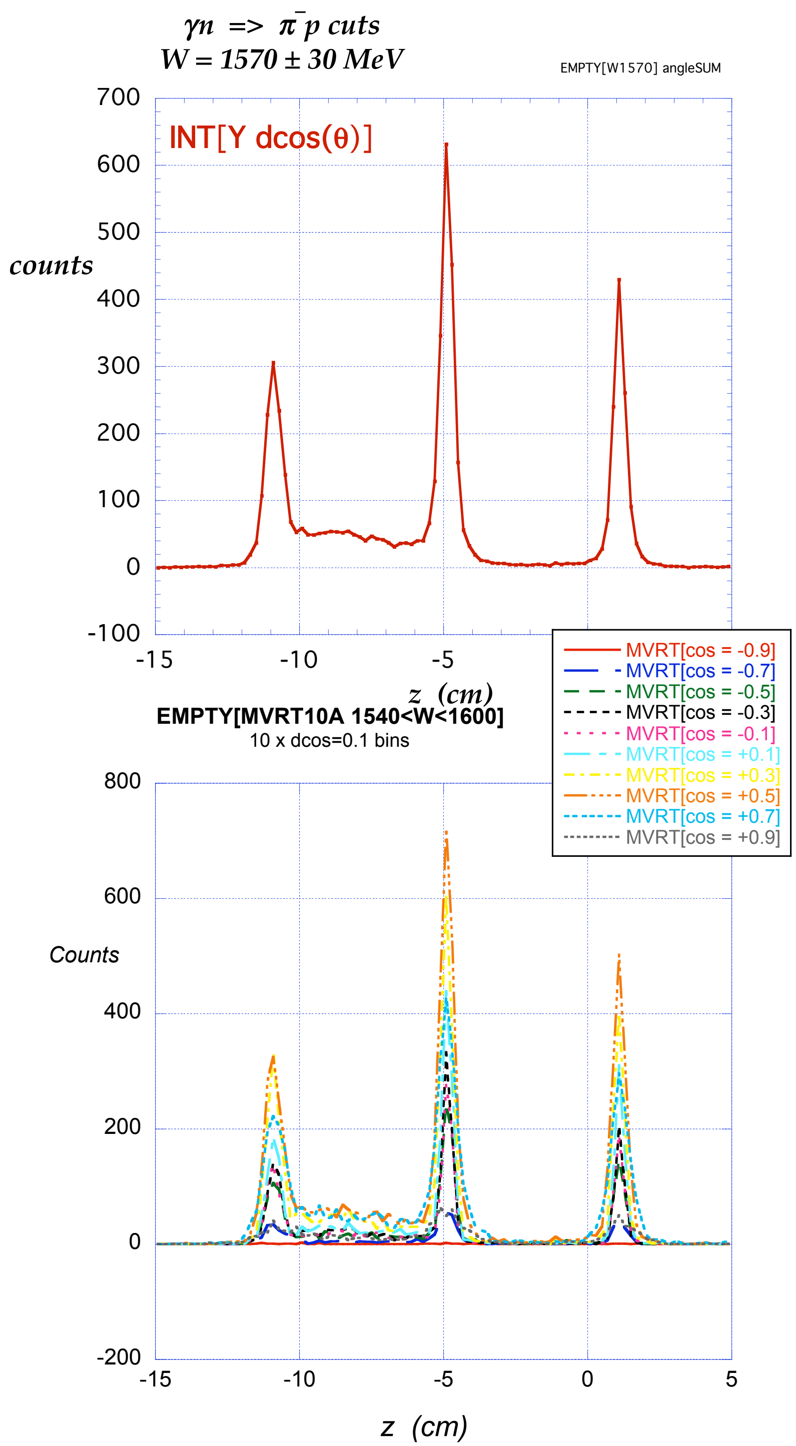
Test I: $\gamma n \rightarrow \pi^- p$

- ***examine EMPTY with $\pi^- p$ cuts from Tsuneo (PID, MM^2, coplanarity, 1 photon)***

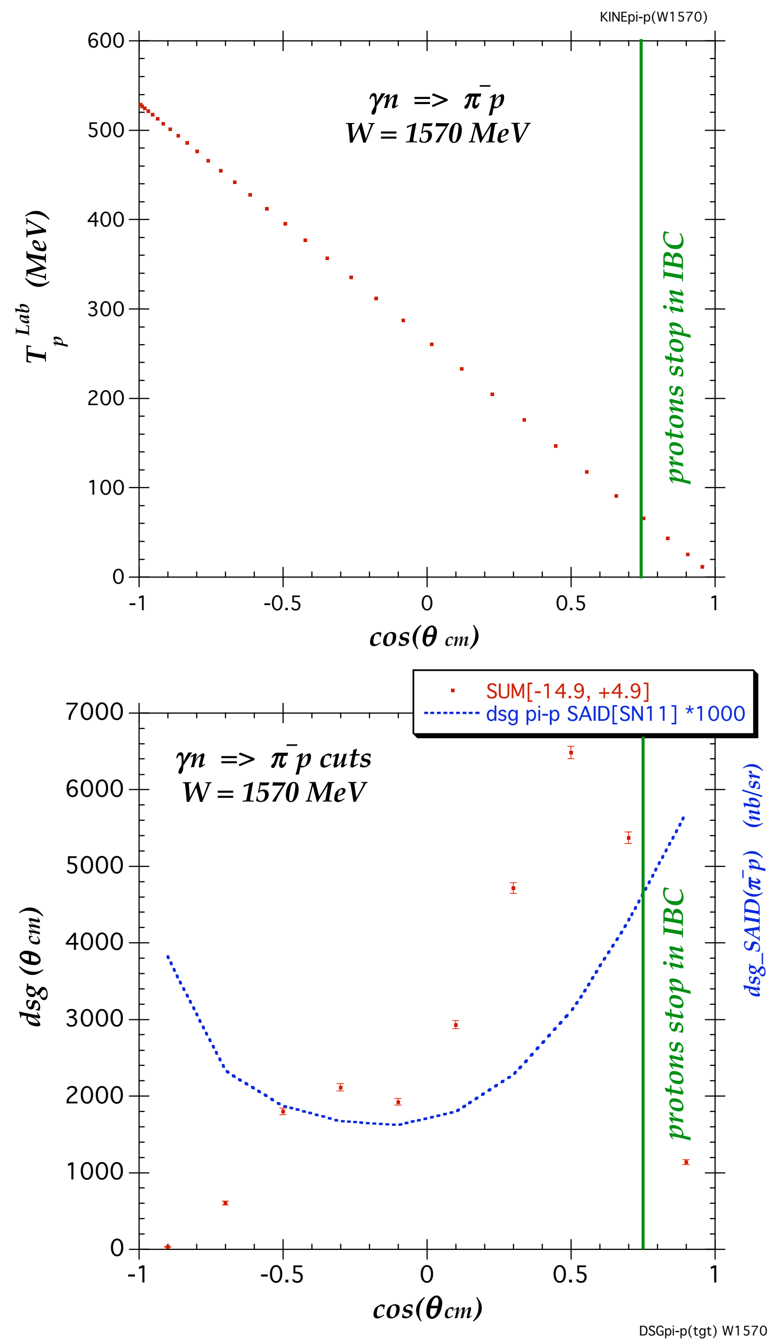
Q*: *is there a kinematic (angle, energy) dependence to the Alum/cell fraction ?
(conceivable from threshold effects)

⇔ ***examine $\pi^- p$ in the following ranges*:**

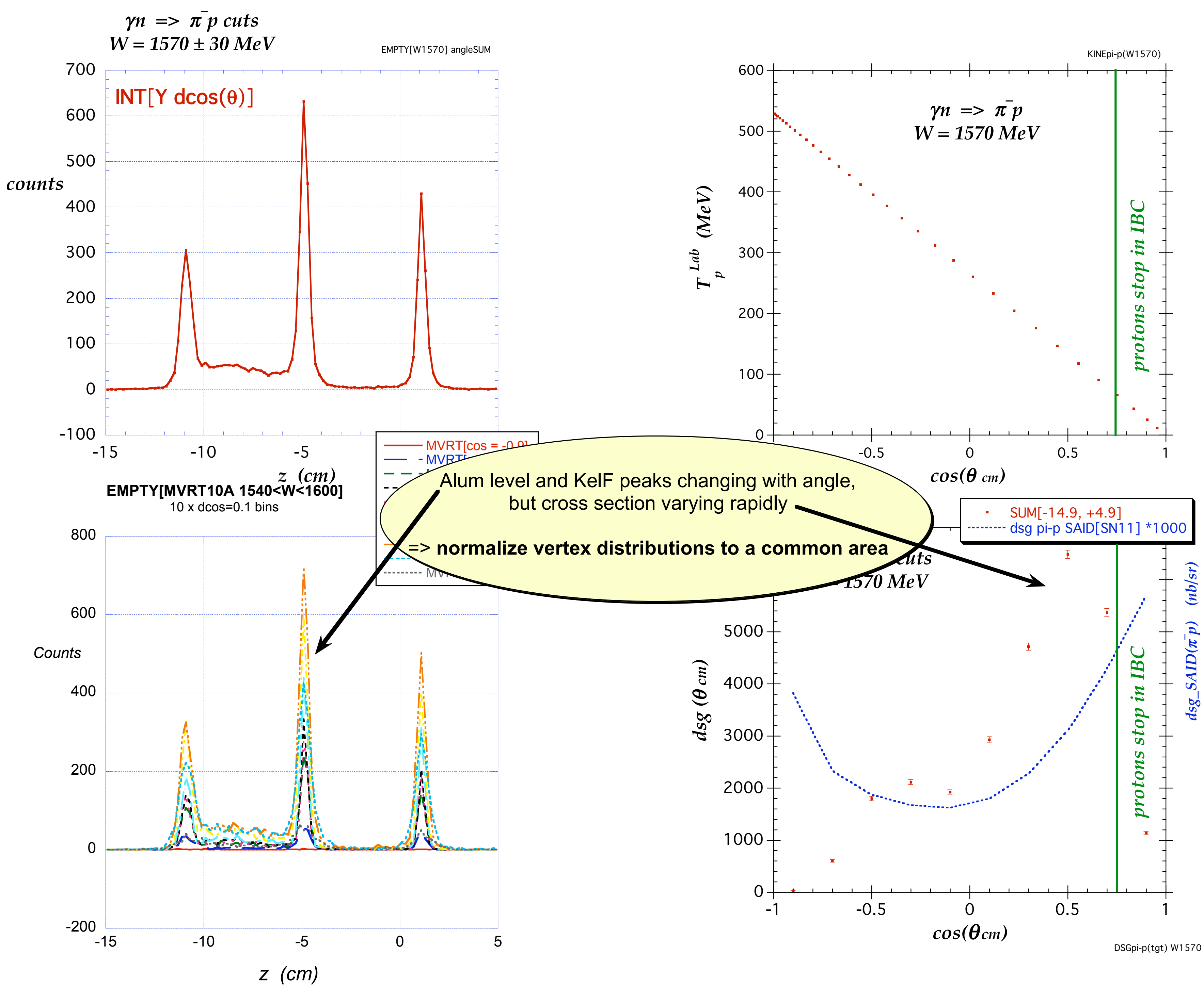
- $W = 1570$ [$1540 < W < 1600$]
- $W = 1970$ [$1920 < W < 2020$]
- $W = 2130$ [$2110 < W < 2150$]
- $W = 2220$ [$2200 < W < 2240$]

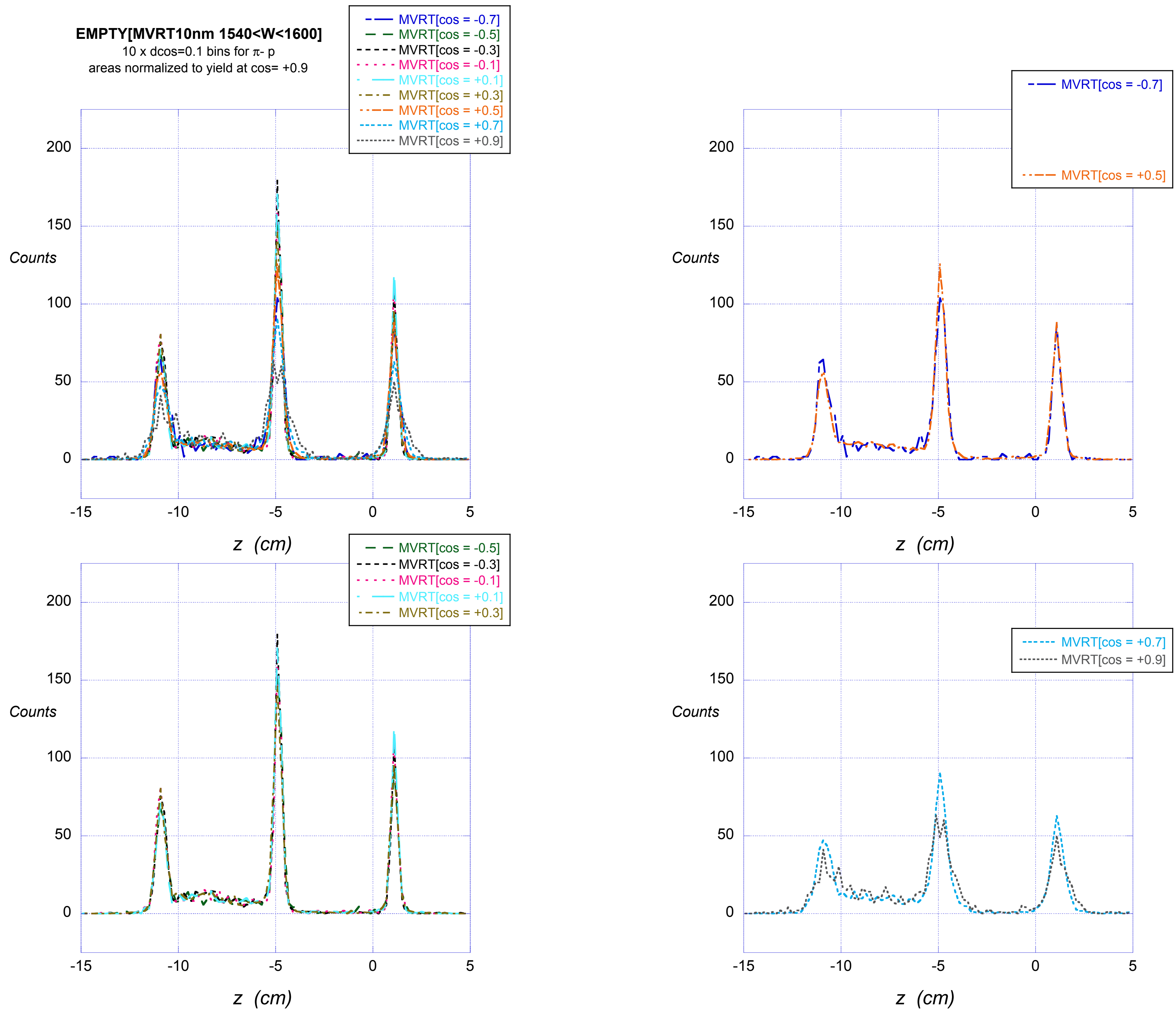


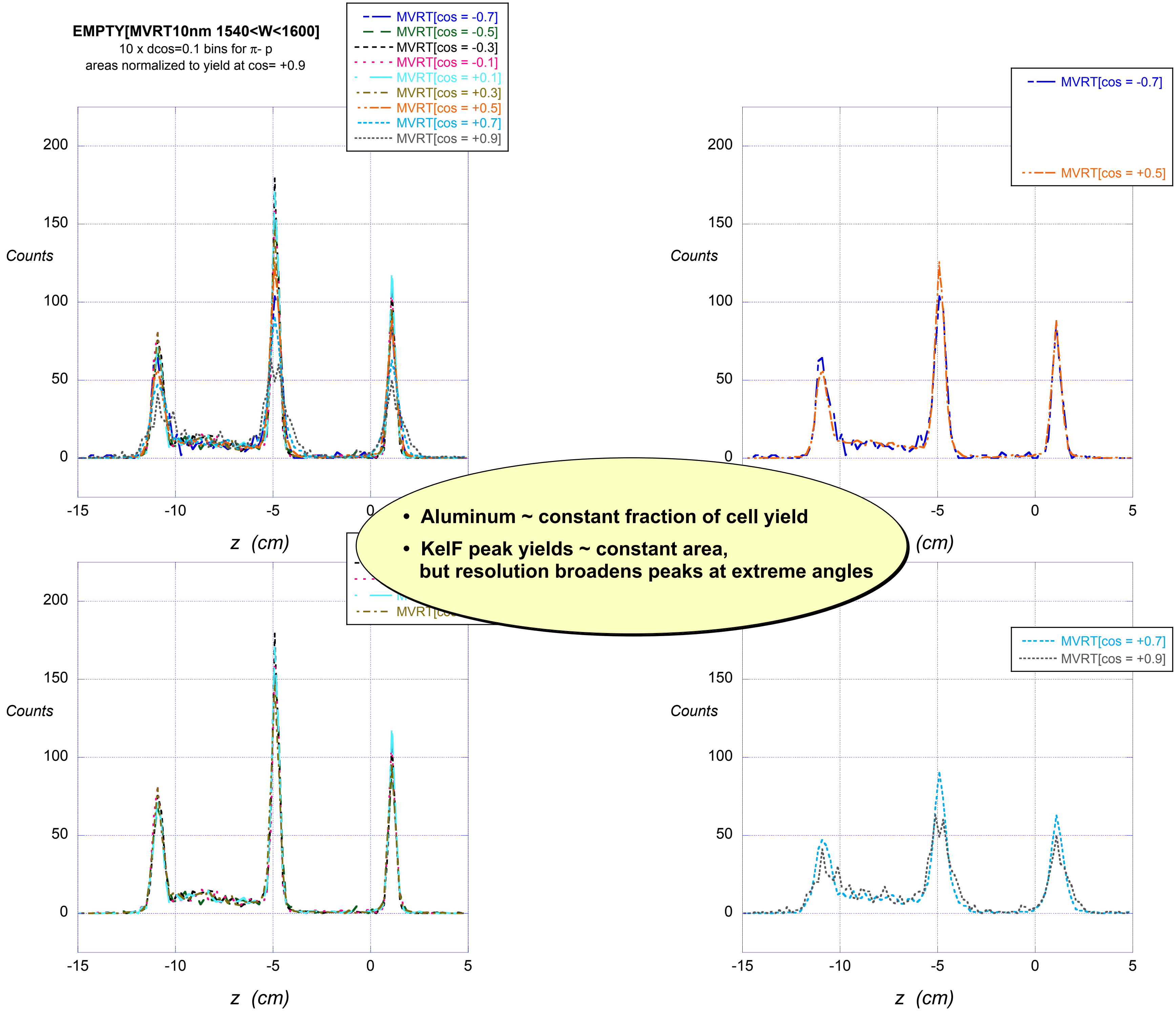
γn => π⁻p cuts
W = 1570 ± 30 MeV
EMPTY[W1570] angleSUM
INT[Y dcos(θ)]
counts
z (cm)
EMPTY[MVRT10A 1540<W<1600]
10 x dcos=0.1 bins
MVRT[cos = -0.9]
MVRT[cos = -0.7]
MVRT[cos = -0.5]
MVRT[cos = -0.3]
MVRT[cos = -0.1]
MVRT[cos = +0.1]
MVRT[cos = +0.3]
MVRT[cos = +0.5]
MVRT[cos = +0.7]
MVRT[cos = +0.9]
Counts
z (cm)



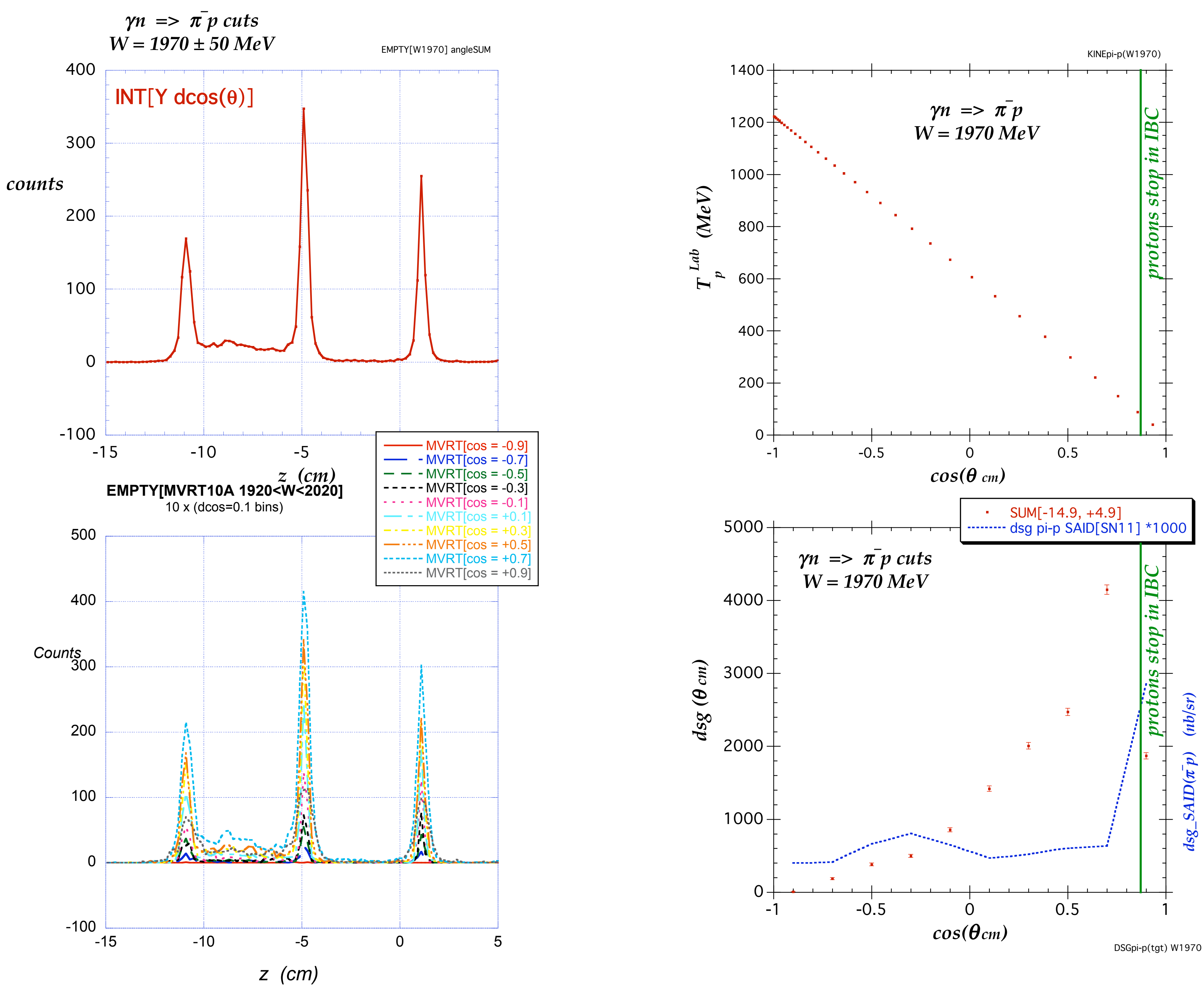
KINEpi-p(W1570)
γn => π⁻p
W = 1570 MeV
T_p^Lab (MeV)
protons stop in IBC
cos(θ cm)
SUM[-14.9, +4.9]
dsg pi-p SAID[SN11] *1000
γn => π⁻p cuts
W = 1570 MeV
dsg (θ cm)
dsg_SAID(π⁻p) (nb/sr)
protons stop in IBC
cos(θcm)
DSGpi-p(tgt) W1570


γn => π⁻p cuts
W = 1570 ± 30 MeV
EMPTY[W1570] angleSUM
INT[Y dcos(θ)]
counts
z (cm)
EMPTY[MVRT10A 1540<W<1600]
10 x dcos=0.1 bins
Counts
z (cm)
KINEpi-p(W1570)
γn => π⁻p
W = 1570 MeV
T_p^{Lab} (MeV)
protons stop in IBC
cos(θ cm)
Alum level and KelF peaks changing with angle,
but cross section varying rapidly
=> normalize vertex distributions to a common area
SUM[-14.9, +4.9]
dsg pi-p SAID[SN11] *1000
1570 MeV
dsg (θ cm)
dsg_SAID(π⁻p) (nb/sr)
protons stop in IBC
cos(θcm)
DSGpi-p(tgt) W1570

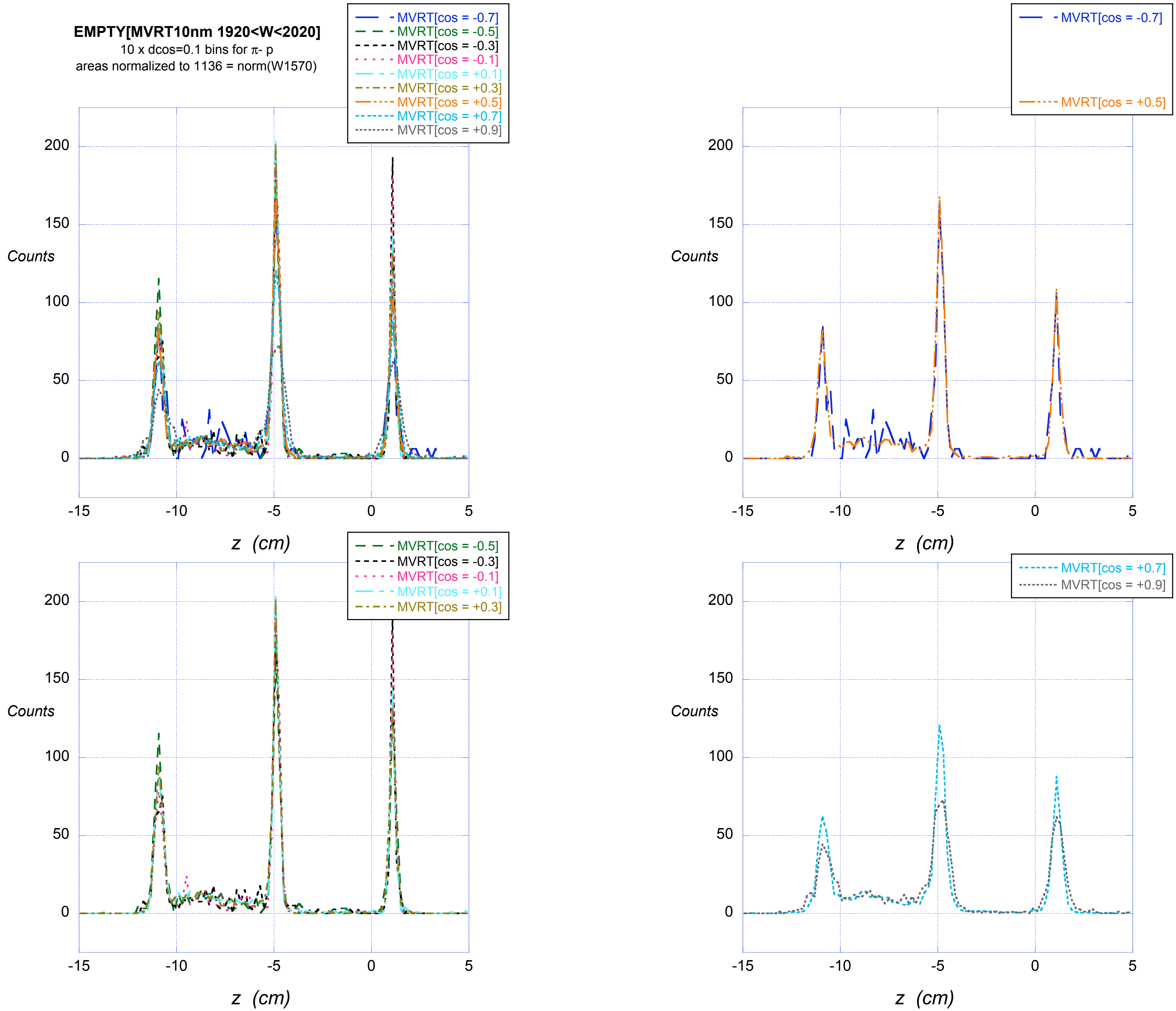

EMPTY[MVRT10nm 1540<W<1600]
10 x dcos=0.1 bins for π- p
areas normalized to yield at cos= +0.9
MVRT[cos = -0.7]
MVRT[cos = -0.5]
MVRT[cos = -0.3]
MVRT[cos = -0.1]
MVRT[cos = +0.1]
MVRT[cos = +0.3]
MVRT[cos = +0.5]
MVRT[cos = +0.7]
MVRT[cos = +0.9]
Counts
z (cm)
-15
-10
-5
0
5
0
50
100
150
200



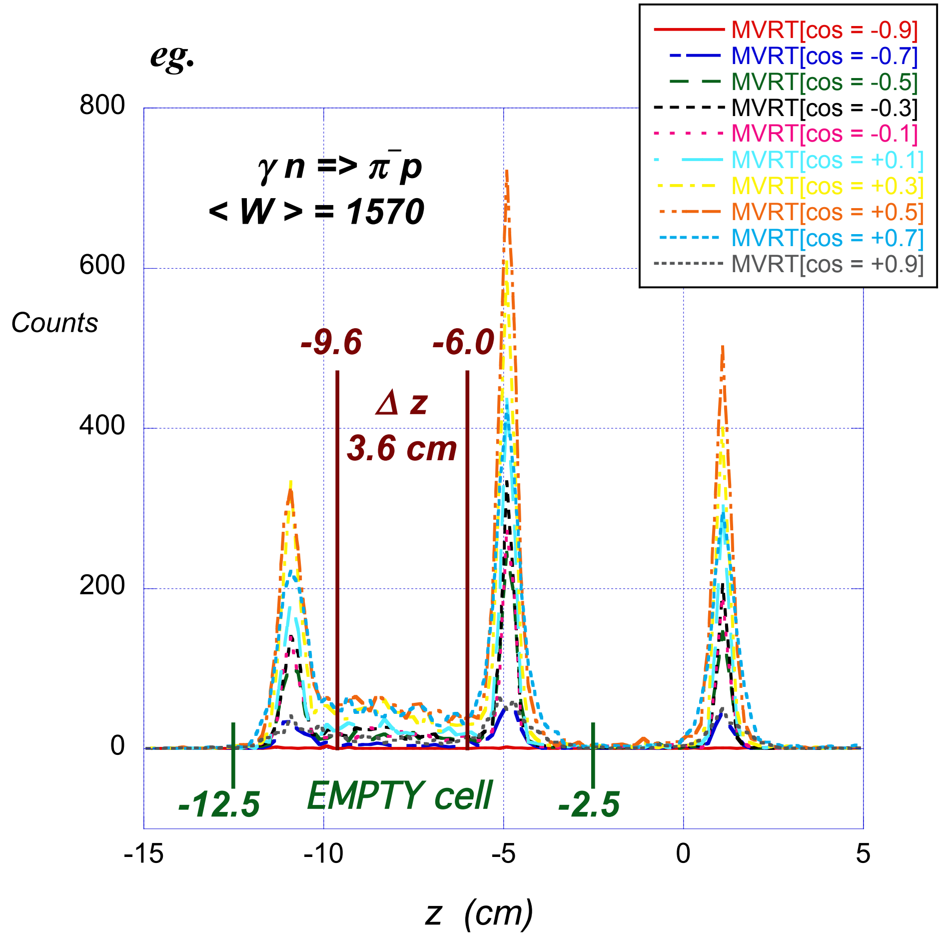
- **Aluminum ~ constant fraction of cell yield**
- **KelF peak yields ~ constant area, but resolution broadens peaks at extreme angles**

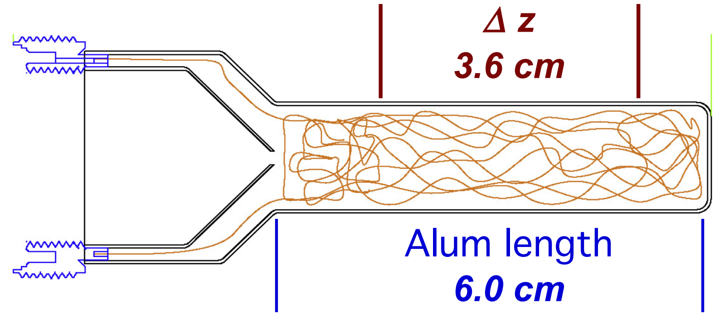


γn => π⁻p cuts
W = 1970 ± 50 MeV
EMPTY[W1970] angleSUM
INT[Y dcos(θ)]
counts
z (cm)
EMPTY[MVRT10A 1920<W<2020]
10 x (dcos=0.1 bins)
MVRT[cos = -0.9]
MVRT[cos = -0.7]
MVRT[cos = -0.5]
MVRT[cos = -0.3]
MVRT[cos = -0.1]
MVRT[cos = +0.1]
MVRT[cos = +0.3]
MVRT[cos = +0.5]
MVRT[cos = +0.7]
MVRT[cos = +0.9]
Counts
z (cm)
KINEpi-p(W1970)
γn => π⁻p
W = 1970 MeV
T_p^{Lab} (MeV)
protons stop in IBC
cos(θ cm)
SUM[-14.9, +4.9]
dsg pi-p SAID[SN11] *1000
γn => π⁻p cuts
W = 1970 MeV
dsg (θ cm)
protons stop in IBC
dsg_SAID(π⁻p) (nb/sr)
cos(θcm)
DSGpi-p(tgt) W1970


EMPTY[MVRT10nm 1920<W<2020]
10 x dcos=0.1 bins for π- p
areas normalized to 1136 = norm(W1570)
MVRT[cos = -0.7]
MVRT[cos = -0.5]
MVRT[cos = -0.3]
MVRT[cos = -0.1]
MVRT[cos = +0.1]
MVRT[cos = +0.3]
MVRT[cos = +0.5]
MVRT[cos = +0.7]
MVRT[cos = +0.9]
Counts
z (cm)

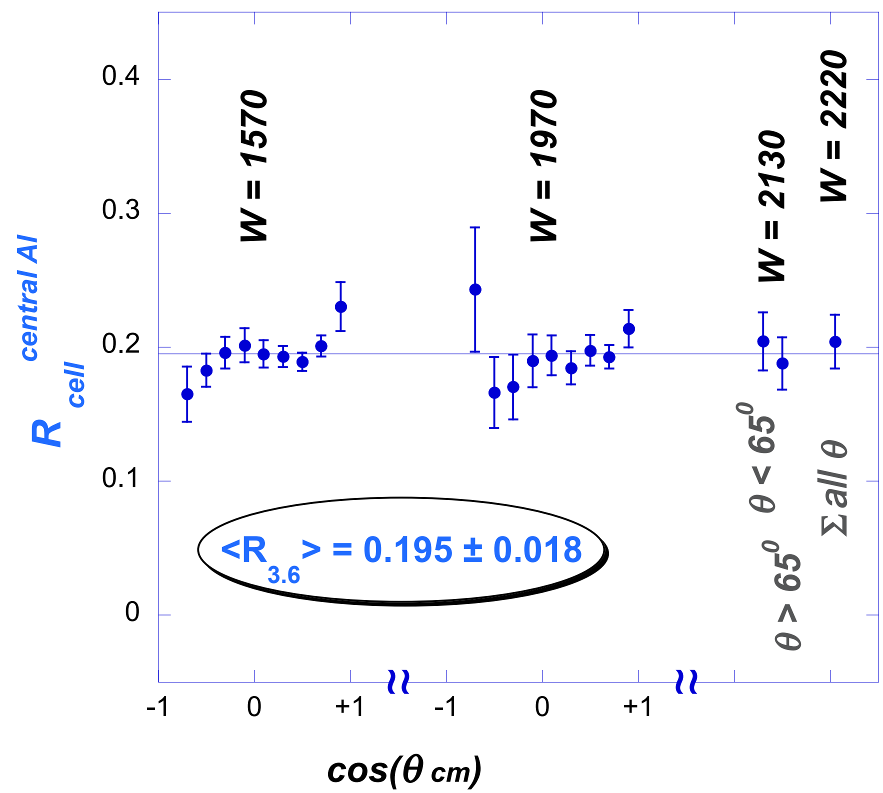
eg.



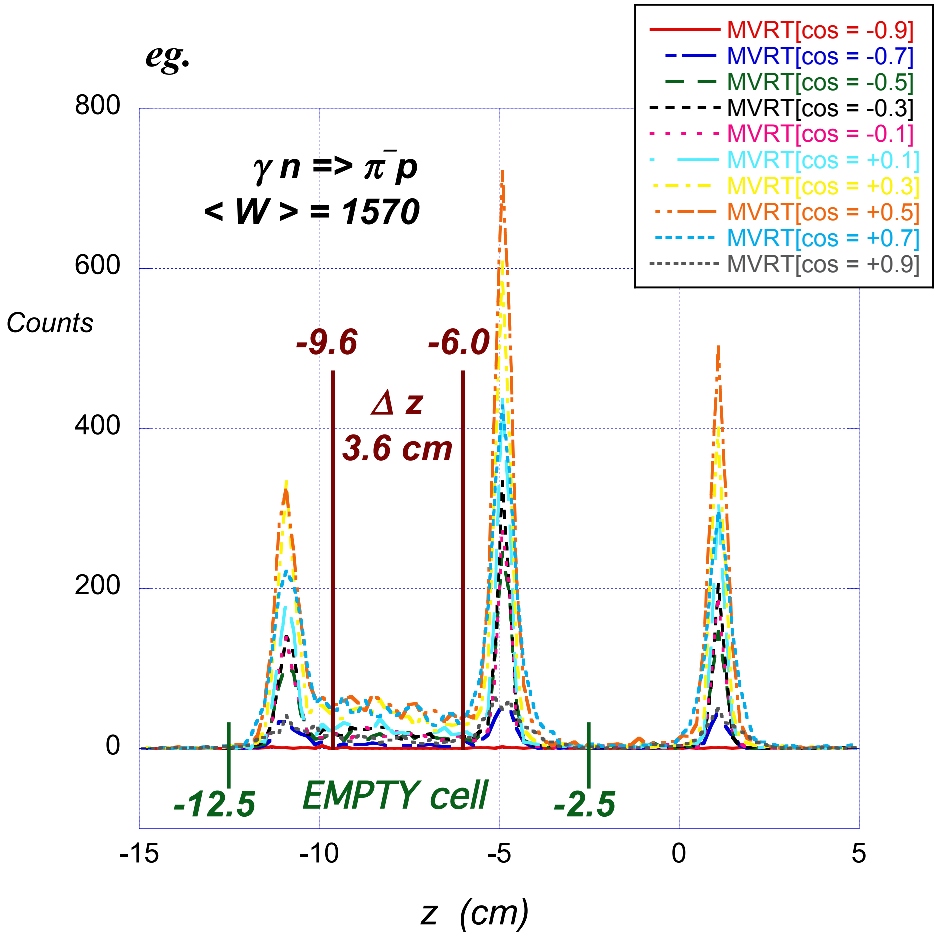


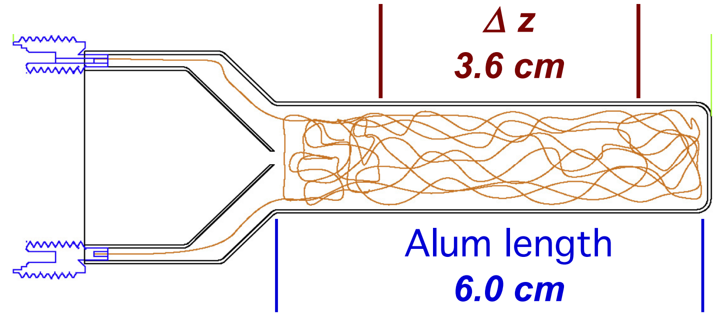
EMPTY Alum/cell ratio

3.6cm (-9.6<z<-6.0) **Aluminum** / **cell** (-12.5<z<-2.5)



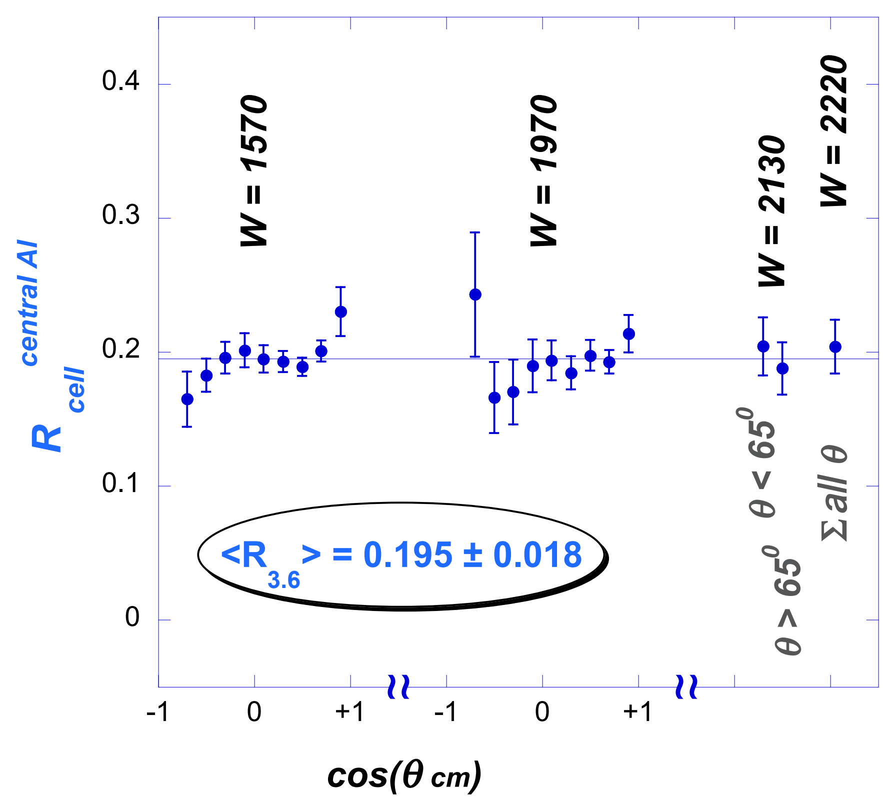
eg.





EMPTY Alum/cell ratio

***3.6**cm (-9.6<z<-6.0) **Aluminum** / **cell** (-12.5<z<-2.5)*



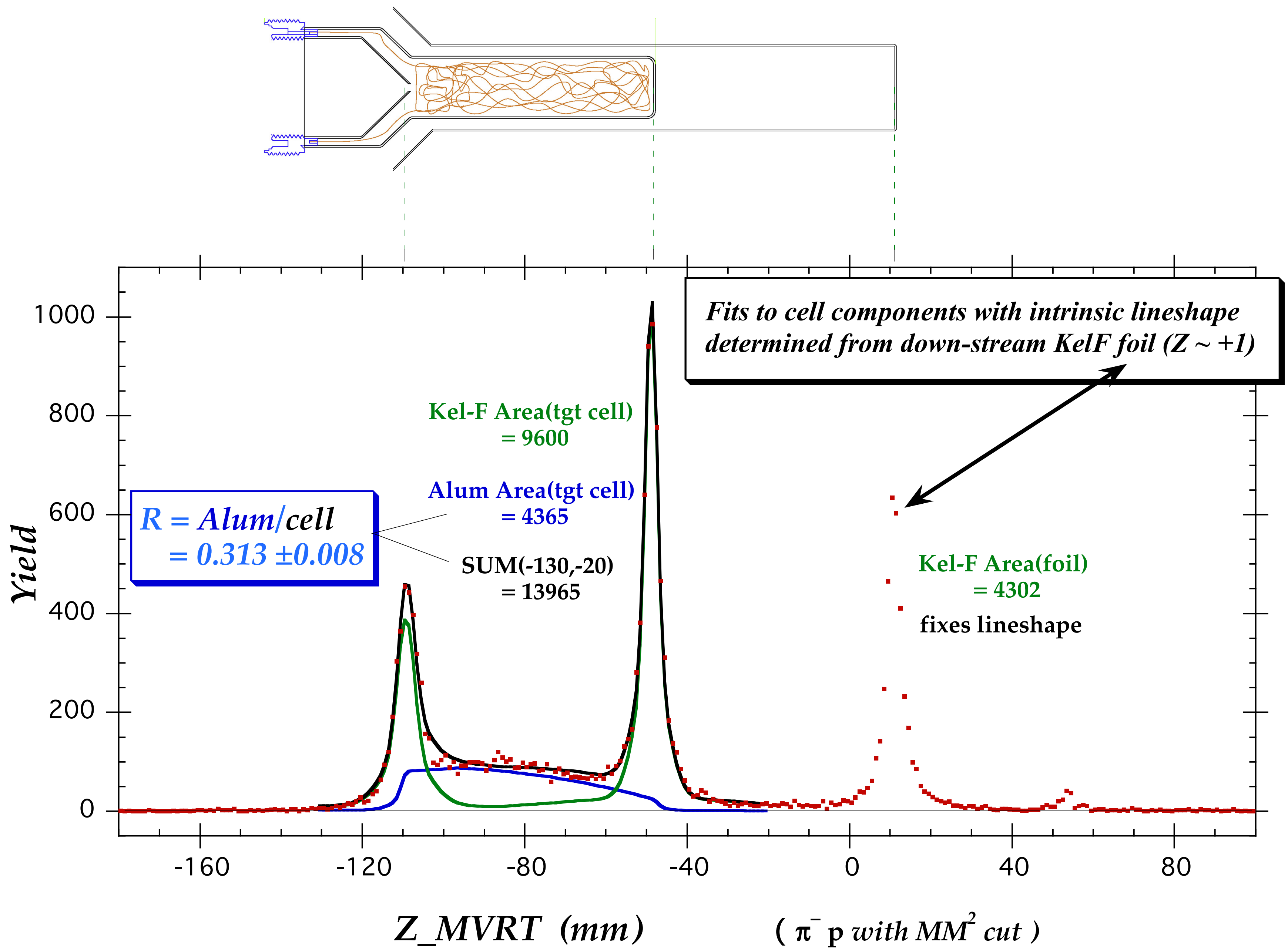
- *no obvious kinematic dependence*

=> $R = Alum/cell$

$= \langle R_{3.6} \rangle \times 6.0/3.6$

$= 0.325 \pm 0.030$

for comparison - fits with Dao from Sept'12: $\pi^- p$ [PID, MM^2, 0.9 < Eg < 2.1 GeV, all angles]



EMPTY–tgt summary w fits

Scaling EMPTY cell Yields:

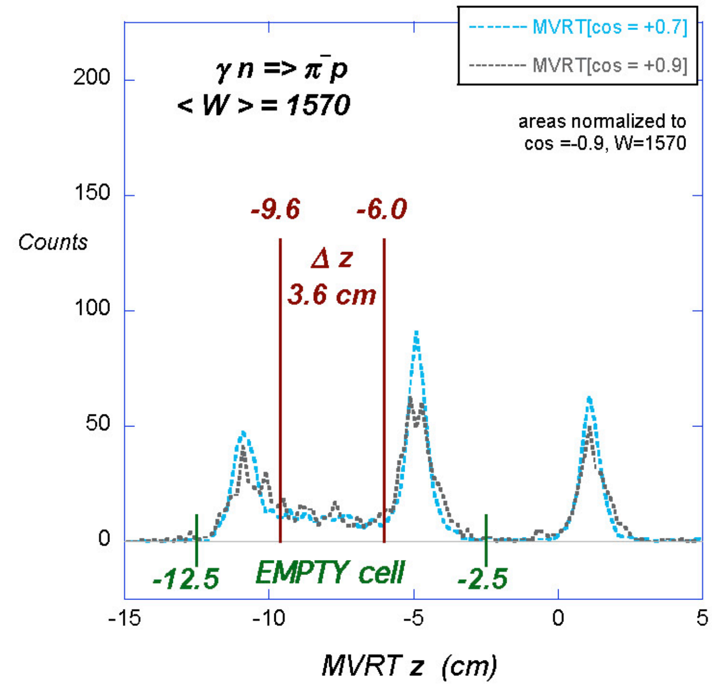
Cell #	< HD *length* > (cm)	< Al *region* > (cm)	< ρ(Al) > (gm/cc)	< ρ^{Al}_{rel} > (relative to 21a)
21a (*silver*)	~ 4	6	0.0280	1
19b (*gold*)	5	6	0.0196	0.700
22b (*last*)	5	6	0.0268	0.957

$$Y^{21a}_{cell}(empty) = \left[Y_{KelF}\right] + \left\{Y^{21a}_{Al}\right\}$$

$$\cong \left[Y^{21a}_{cell} - Y^{21a}_{Al}\right] + \left\{Y^{21a}_{cell} \cdot \frac{Y^{21a}_{Al}(\Delta z = 3.6)}{Y^{21a}_{cell}} \cdot \left(\frac{6}{3.6}\right)\right\}$$

$$= \left[Y^{21a}_{cell}\left(1 - R^{Al}_{3.6} \cdot \tfrac{5}{3}\right)\right] + \left\{Y^{21a}_{cell} \cdot R^{Al}_{3.6} \cdot \tfrac{5}{3}\right\}$$

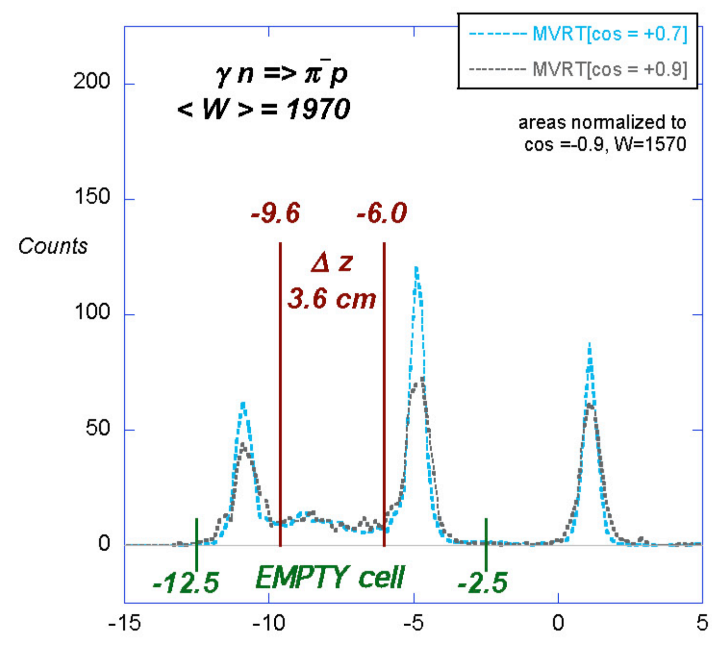
- *assuming Alum density ~ constant with length*



$$Y^{19b}_{cell}(gold) = \left[Y_{KelF}\right] + \left\{Y^{19b}_{Al}\right\}$$

$$= \left[Y^{21a}_{cell}\left(1 - R^{Al}_{3.6} \cdot \tfrac{5}{3}\right)\right] + \left\{Y^{21a}_{cell} \cdot R^{Al}_{3.6} \cdot \tfrac{5}{3} \times \rho^{Al}_{rel}\right\}$$

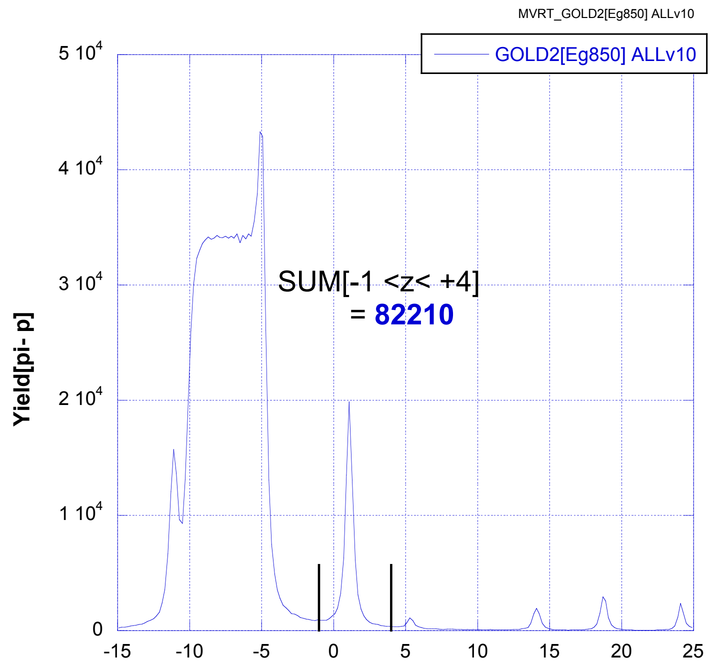
$$= Y^{21a}_{cell} \cdot \left\langle 1 - R^{Al}_{3.6} \cdot \tfrac{5}{3}(1 - \rho^{Al}_{rel})\right\rangle \quad = Y^{21a}_{cell} \cdot \langle 0.903 \rangle$$



Normalizing to the same flux

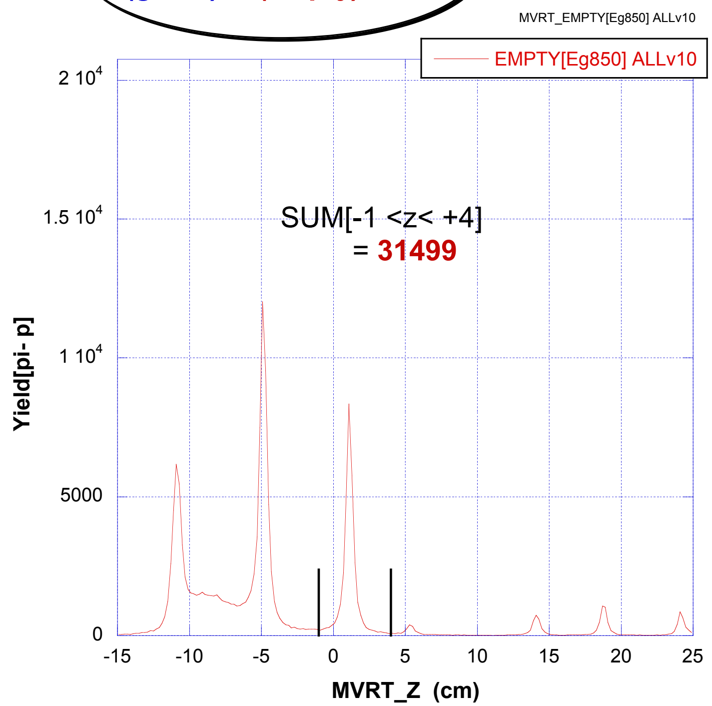
0.8 < Eγ < 0.9 GeV

(*both helicity states*)



***γ n** (p)* **=>** *π⁻* ***p** (p)*

Φ(gold2) / ***Φ(empty)*** **= *2.61***



(1) normalize *empty* to the same flux as *gold2* using KelF foil

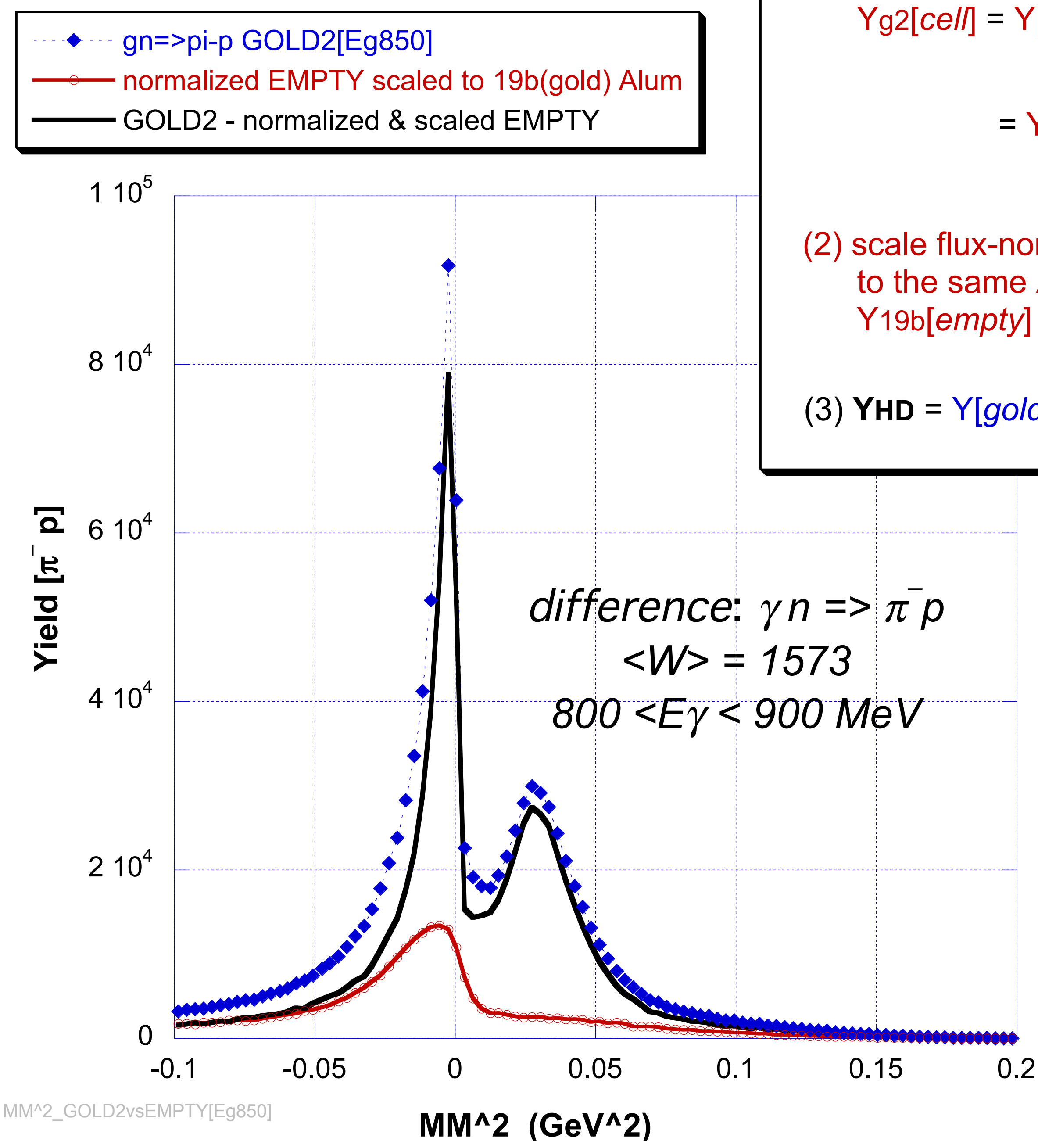
$$Y_{g2}[cell] = Y[empty] \times \frac{MVRT\,gold2[-1<z<+4]}{MVRT\,empty[-1<z<+4]}$$

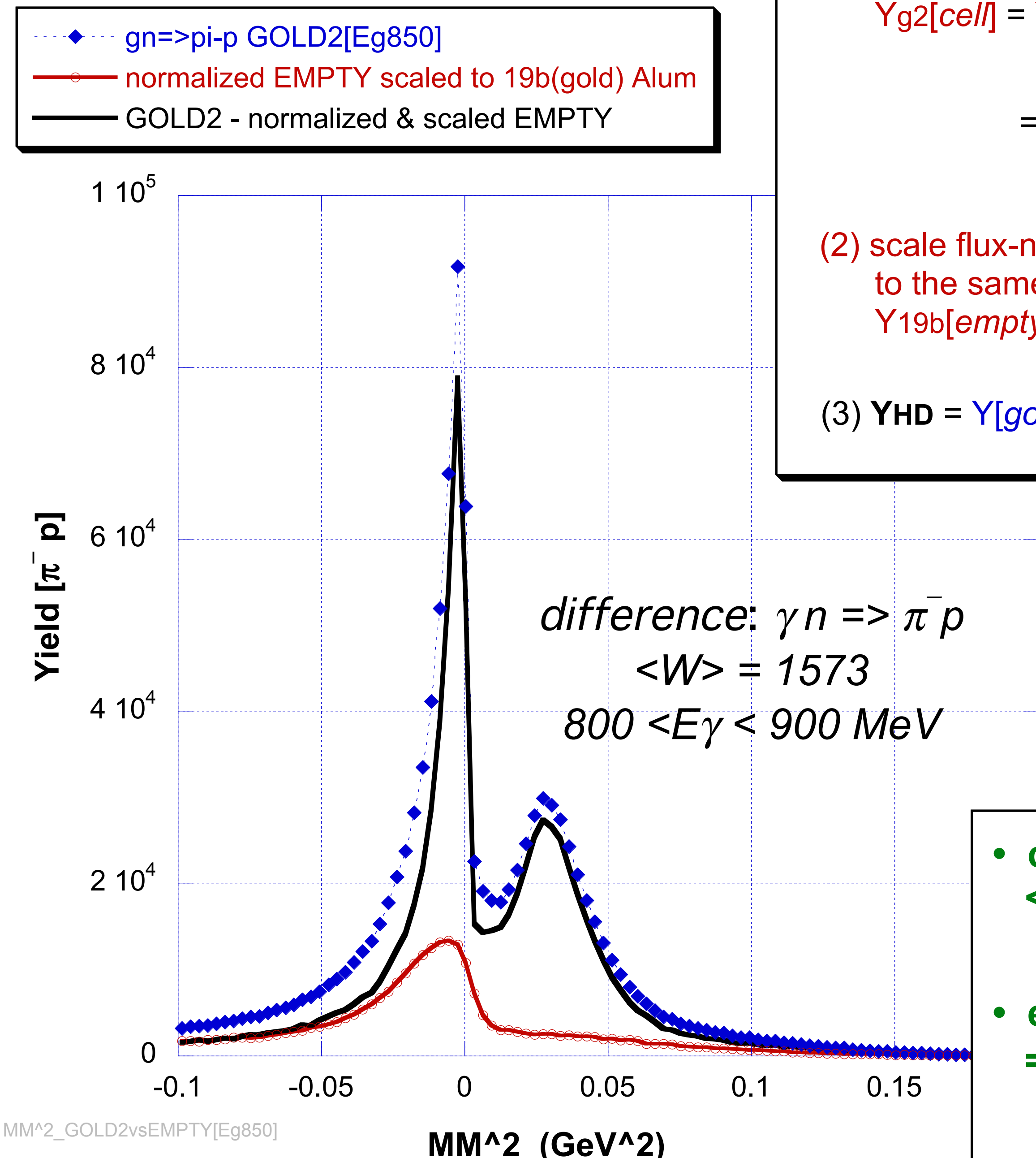
$$= Y[empty] \times \frac{82210}{31499} = Y[empty] \times (2.610)$$

(2) scale flux-normalized *EMPTY* (cell #21a) down to the same Alum as in the *GOLD* cell *(#19b)*

$$Y_{19b}[empty] = Y_{g2}[cell] \times (0.903)$$

(3) $\mathbf{Y_{HD}} = Y[gold] - Y_{19b}[empty]$





(1) normalize *empty* to the same flux as *gold2* using KelF foil

$$Y_{g2}[cell] = Y[empty] \times \frac{MVRT\,gold2[-1<z<+4]}{MVRT\,empty[-1<z<+4]}$$

$$= Y[empty] \times \frac{82210}{31499} = Y[empty] \times (2.610)$$

(2) scale flux-normalized *EMPTY* (cell #21a) down to the same Alum as in the *GOLD* cell *(#19b)*

$$Y_{19b}[empty] = Y_{g2}[cell] \times (0.903)$$

(3) $\mathbf{Y_{HD}} = Y[gold] - Y_{19b}[empty]$

- **cell contribution has a different shape**
  <=> binding differences in heavier nuclei
- **empty-subtracted MM^2 is narrower**
  => best to do empty subtraction before imposing final MM cuts

Test II

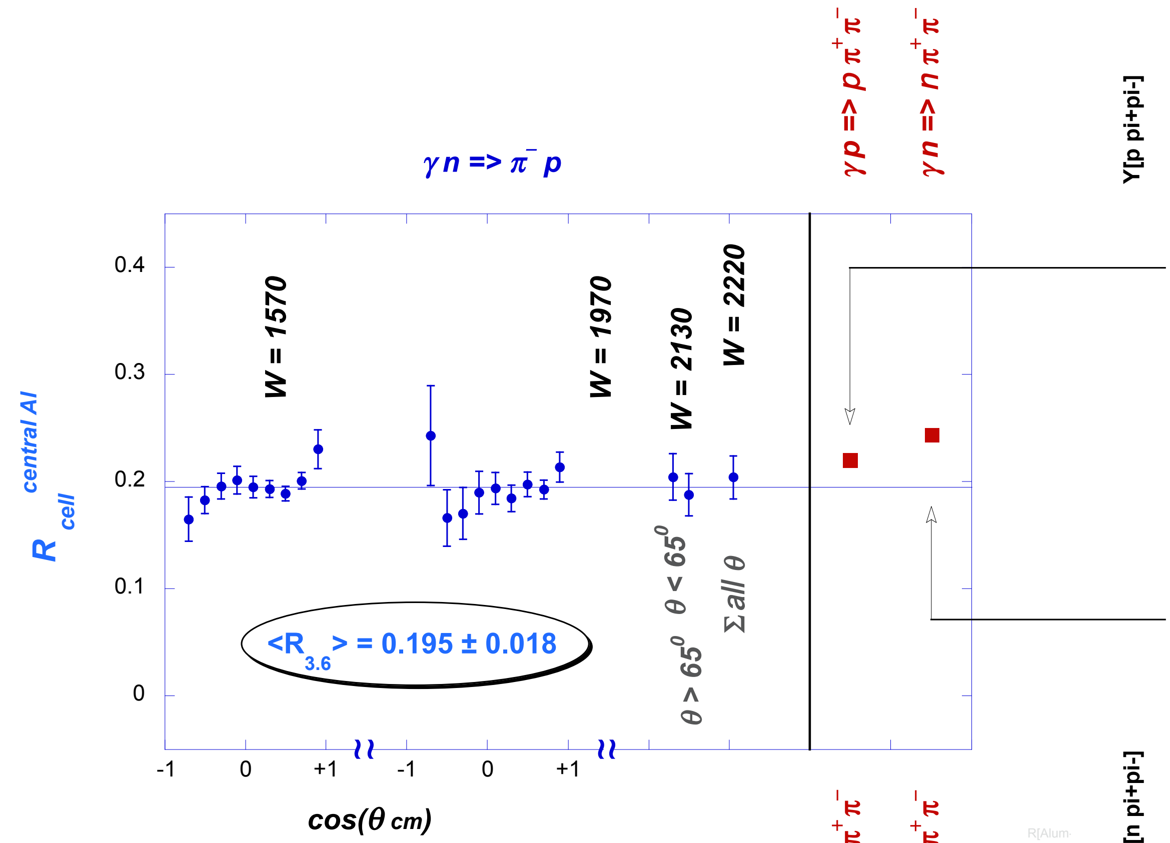
- $\gamma p \rightarrow p\ \pi^+\ \pi^-$
- $\gamma n \rightarrow n\ \pi^+\ \pi^-$

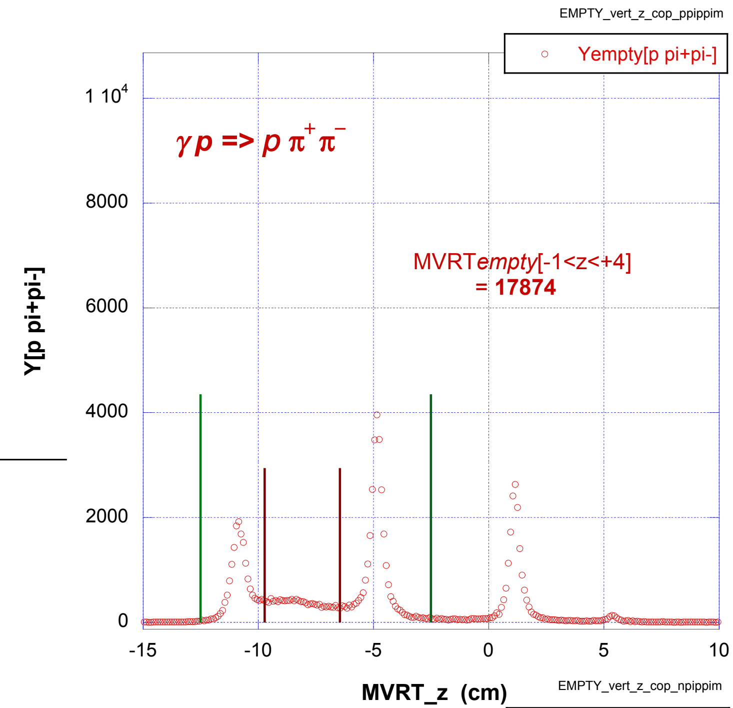
- ***g14 replays by Peng with cuts on PID, coplanarity, 1 photon***

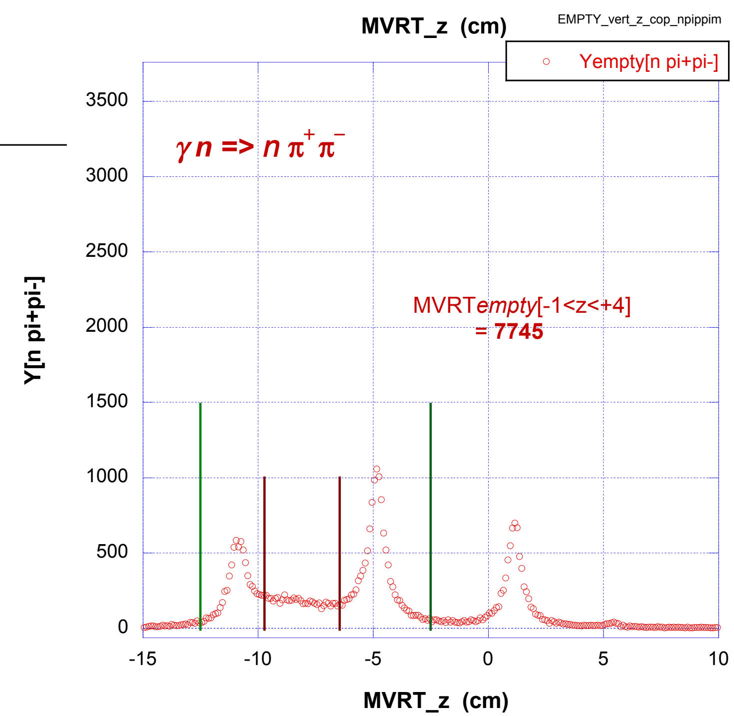
EMPTY Alum/cell ratio:

3.6**cm (-9.6<z<-6.0) **Aluminum

***cell** (-12.5<z<-2.5)*





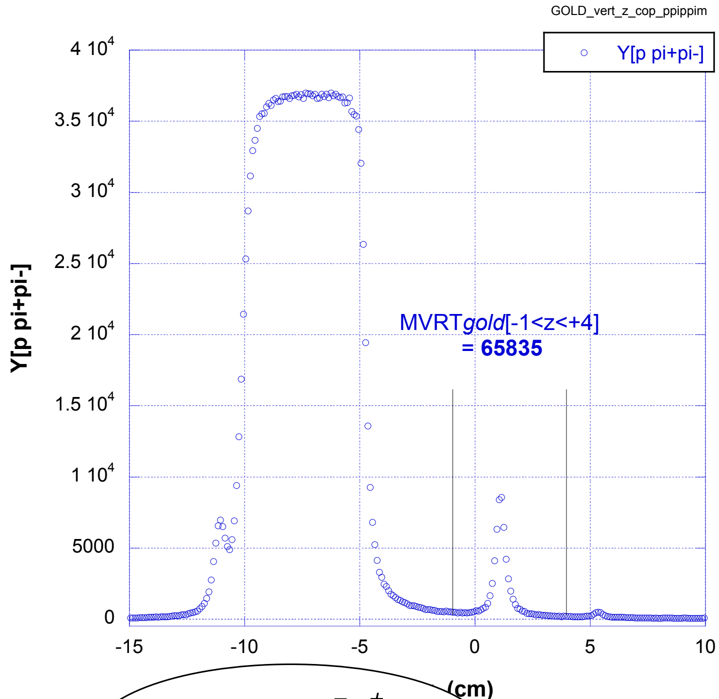


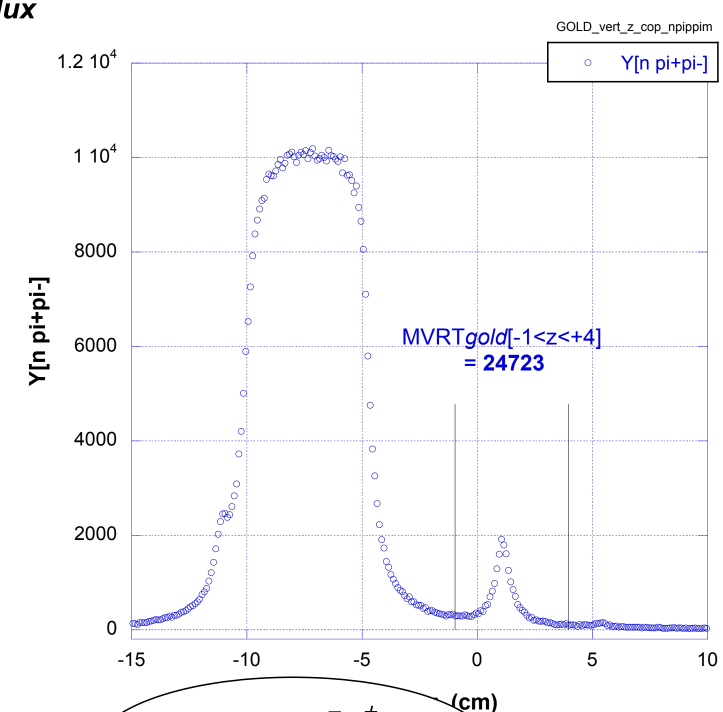
	$\gamma n \Rightarrow \pi^- p$	$\gamma p \Rightarrow p \pi^+ \pi^-$	$\gamma n \Rightarrow n \pi^+ \pi^-$
$\langle R_{3.6} \rangle$	0.20 ±0.02	0.22	0.25
R = $\langle R_{3.6} \rangle$ x 6.0 / 3.6	0.33 ±0.03	0.36	0.41
empty cell correction Y19b(*cell*) / Y21a(*cell*)	**0.90 ±0.01**	**0.89**	**0.88**

Normalizing to the same flux

0.8 < Eγ < 2.2 GeV

166 < φ(R) - φ(ππ) < 195



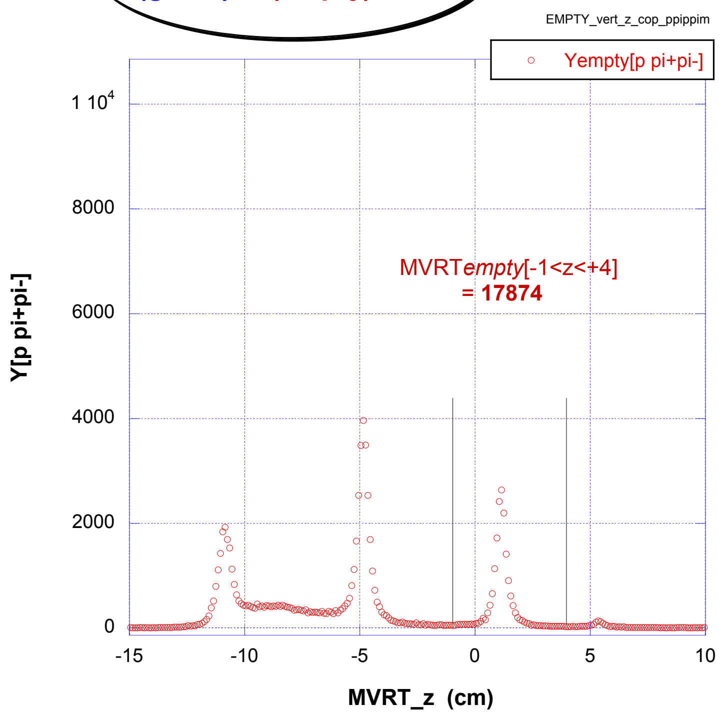


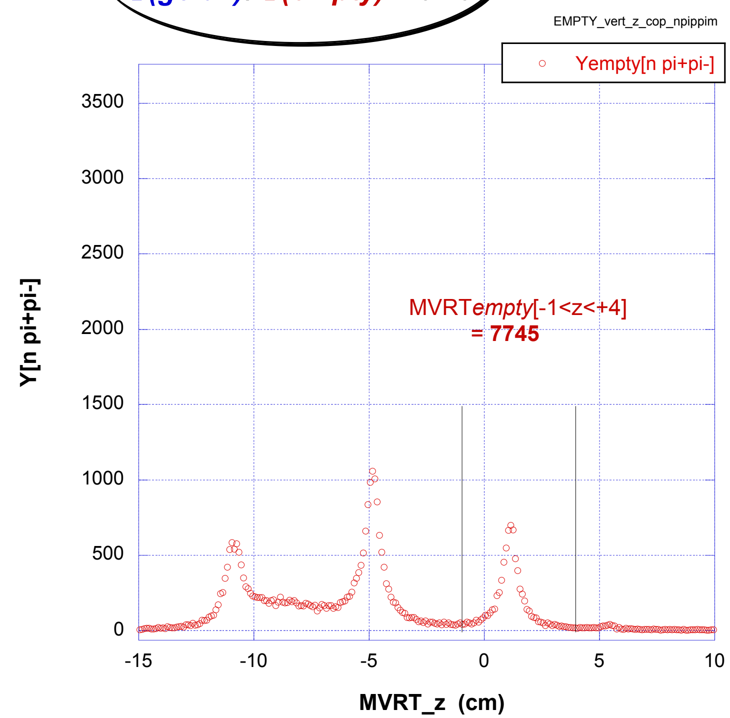
***γ p** (n) => **p** π^- π^+ (n)*

Φ(gold2)/Φ(empty) = 3.68

***γ n** (p) => **n** π^- π^+ (p)*

Φ(gold2)/Φ(empty) = 3.19



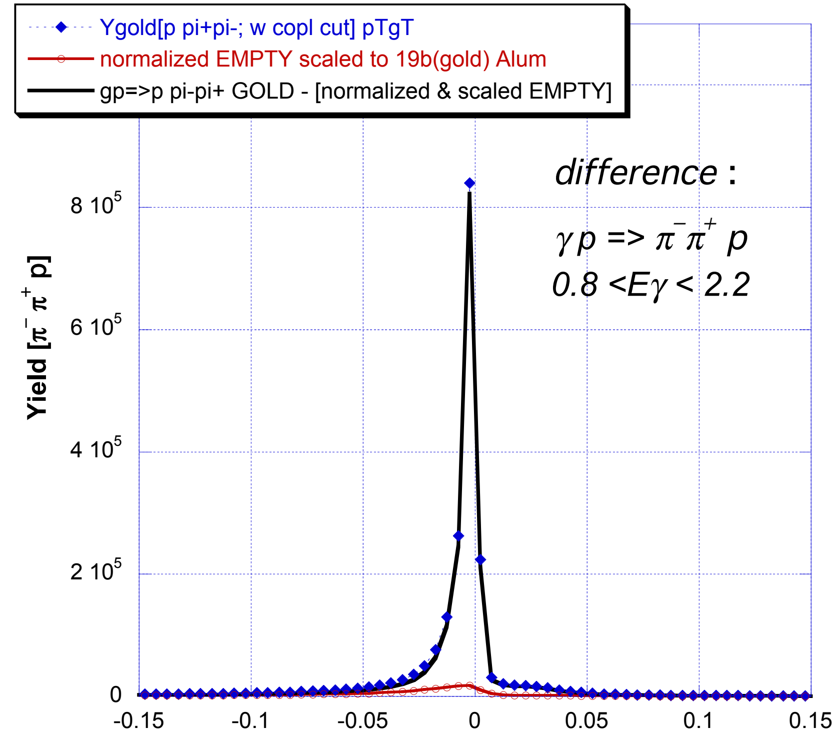


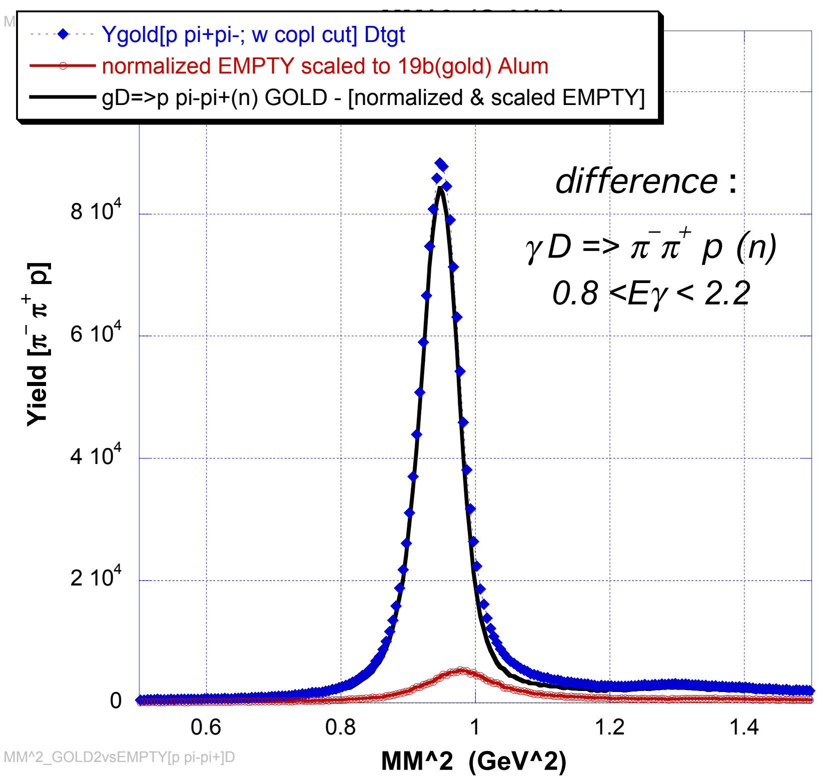
Q. Flux normalizations btw *gold2* and *EMPTYa* :

- **reaction events from downstream KelF foil in MVRT [-1 < z < +4] ⇔ Φ**
- **pass 0; v10; all files**

			Φ(*gold*) / Φ(*empty*)
•	$\gamma n \rightarrow \pi^- p$	(Tsuneo)	2.61
•	$\gamma p \rightarrow \pi^- \pi^+ p$	(Peng)	3.68
•	$\gamma n \rightarrow \pi^- \pi^+ n$	(Peng)	3.19

?





$\pi^+ \pi^-$ production form protons

MM^2 with normalized and scaled empty subtraction

(1) normalize *empty* to the same flux as *gold2* using KelF foil

$$Y_{g2}[cell] = Y[empty] \times \frac{MVRT_{gold2}[-1<z<+4]}{MVRT\,empty[-1<z<+4]}$$

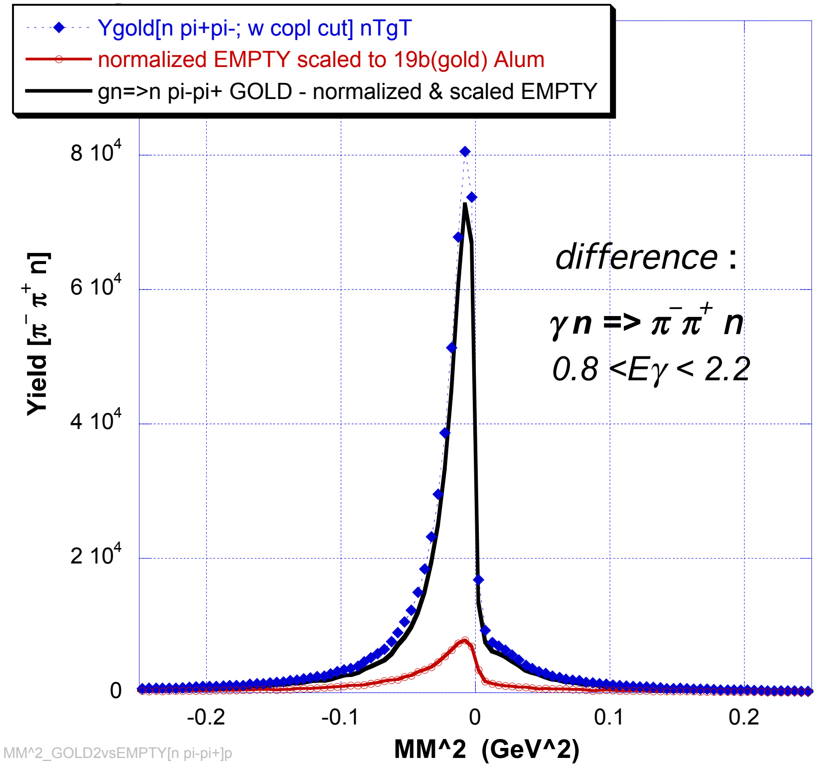
$$= Y[empty] \times \frac{65835}{17874} = Y[empty] \times (3.683)$$

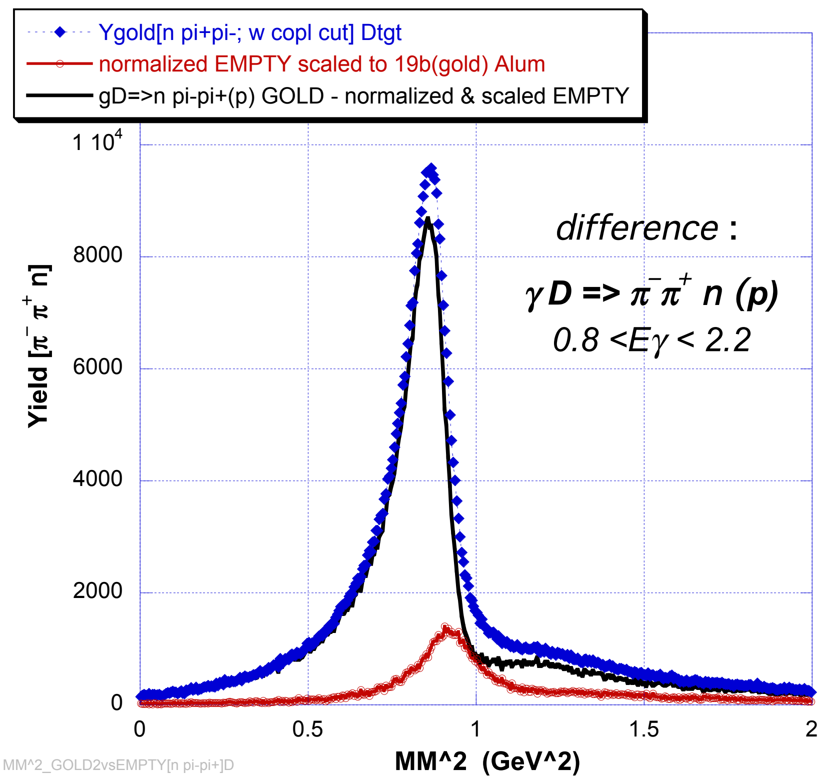
(2) scale flux-normalized *EMPTY* (cell #21a) down to the same Alum as in the *GOLD* cell *(#19b)*

$$Y_{19b}[empty] = Y_{g2}[cell] \times (0.89)$$

(3) **YHD** = Y[*gold*] – Y_{19b}[*empty*]

<= note larger MM^2 spread w D tgt





$\pi^+ \pi^-$ production form neutrons

MM^2 with normalized and scaled empty subtraction

(1) normalize *empty* to the same flux as *gold2* using KelF foil

$$Y_{g2}[cell] = Y[empty] \times \frac{MVRT_{gold2}[-1<z<+4]}{MVRT_{empty}[-1<z<+4]}$$

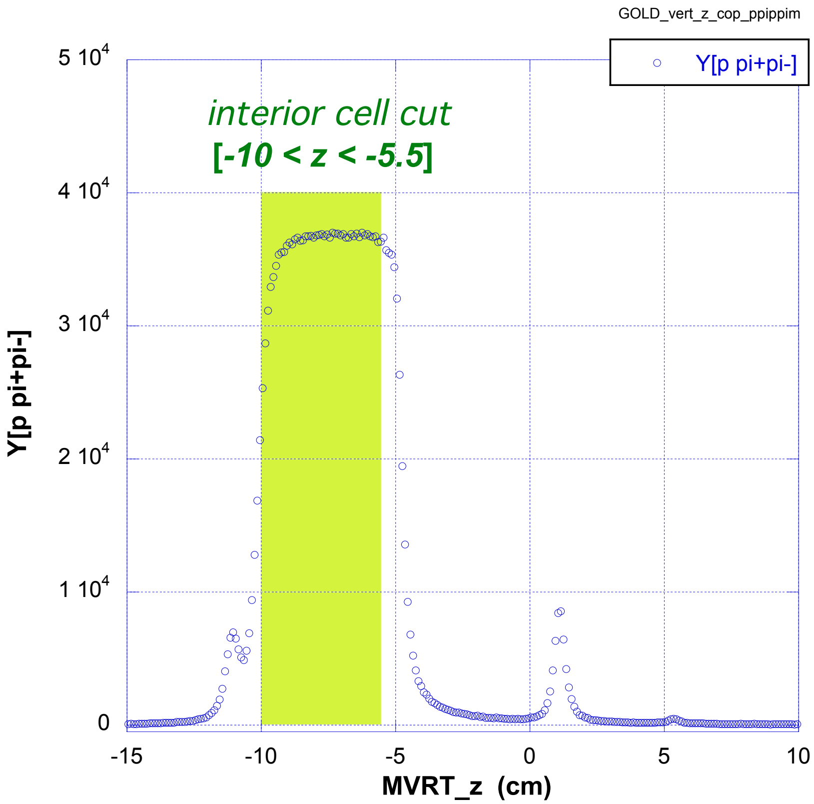
$$= Y[empty] \times \frac{24723}{7745} = Y[empty] \times (3.192)$$

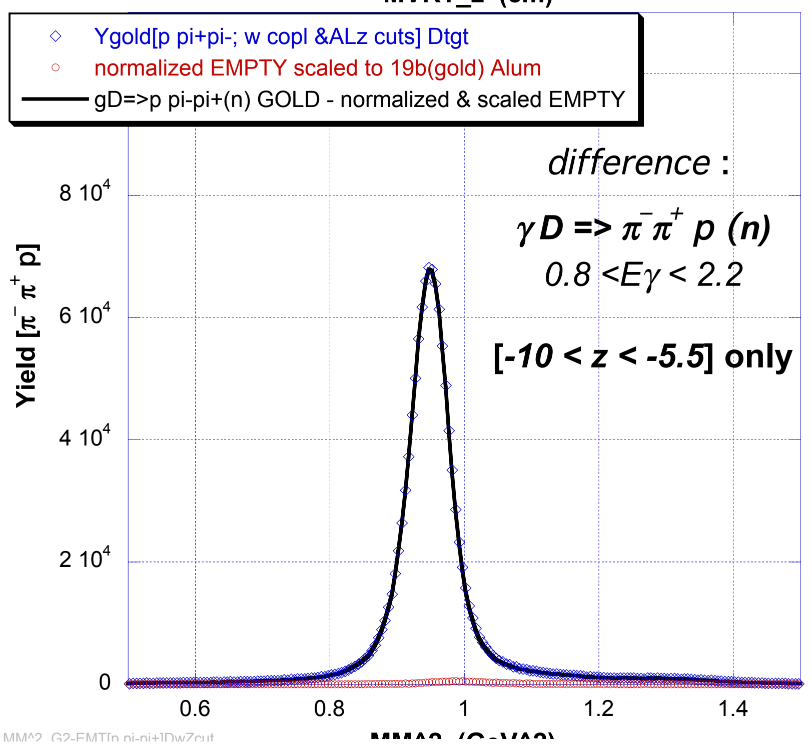
(2) scale flux-normalized *EMPTY* (cell #21a) down to the same Alum as in the *GOLD* cell *(#19b)*

$Y_{19b}[empty] = Y_{g2}[cell] \times (0.88)$

(3) **YHD** = $Y[gold] - Y_{19b}[empty]$

<= note larger MM^2 spread w D tgt





Alternate empty subtraction with interior cut

interior cell cut to remove KelF:
[-10 < z < -5.5]

(1) normalize *empty* to the same flux as *gold2* using KelF foil

$$Y_{g2}[cell] = Y[empty] \times \frac{MVRT_{gold2}[-1<z<+4]}{MVRT_{empty}[-1<z<+4]}$$

$$= Y[empty] \times \frac{65835}{17874} = Y[empty] \times (3.683)$$

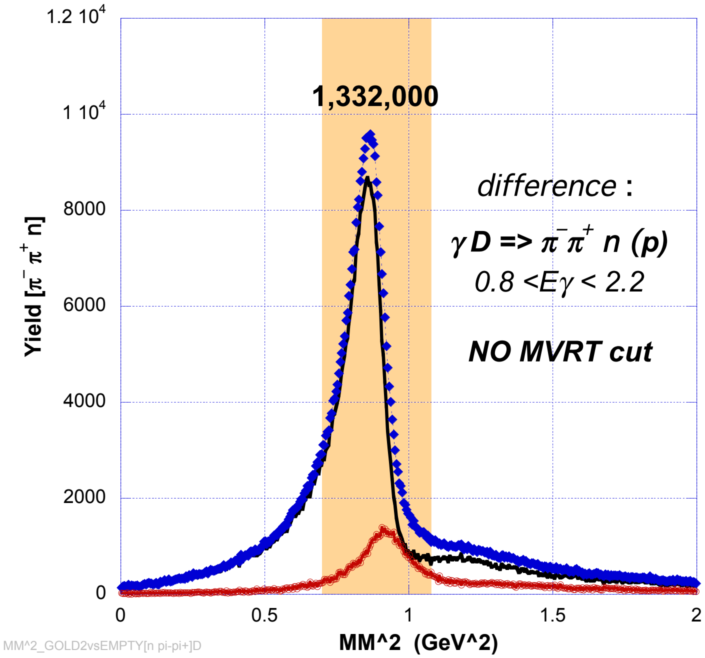
(2) scale flux-normalized *EMPTY* (cell #21a) down to the same Alum as in the *GOLD* cell *(#19b)*

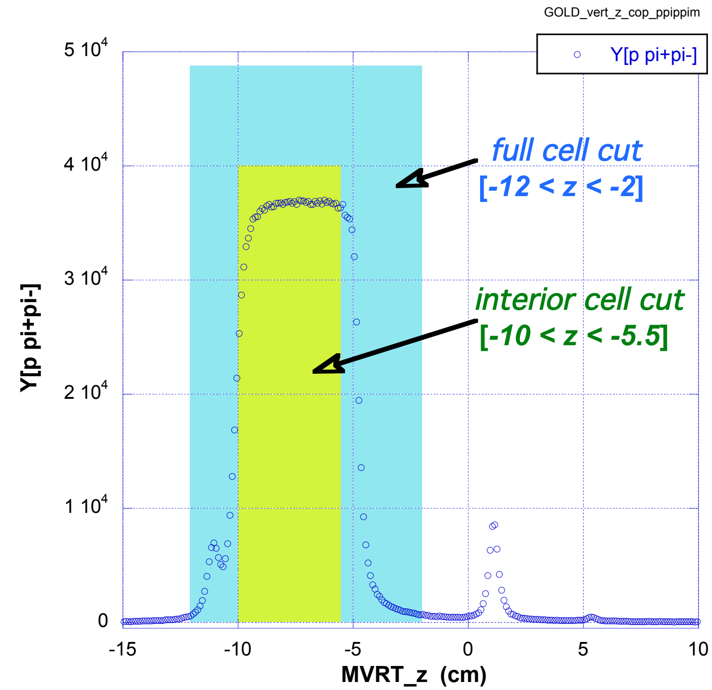
$$Y_{19b}[empty] = Y_{g2}[cell] \times (\mathbf{0.70})$$

(3) **YHD** = $Y[gold] - Y_{19b}[empty]$

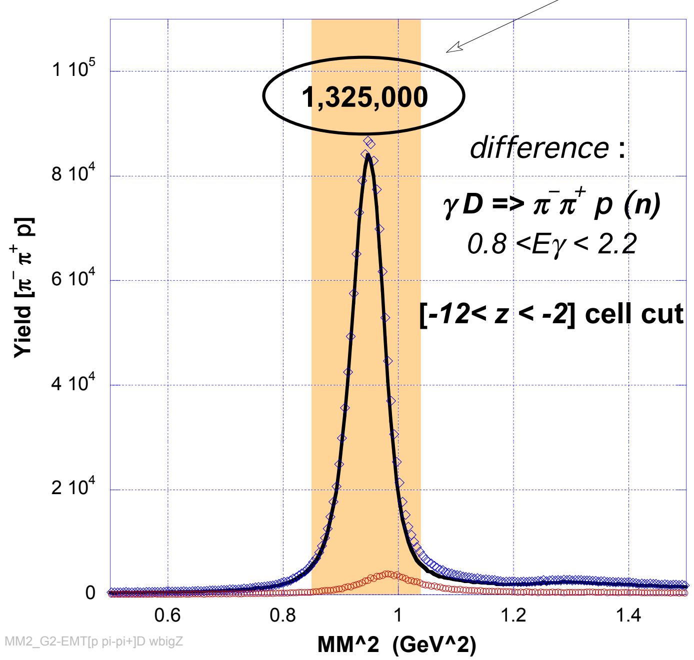
correct only for Aluminum

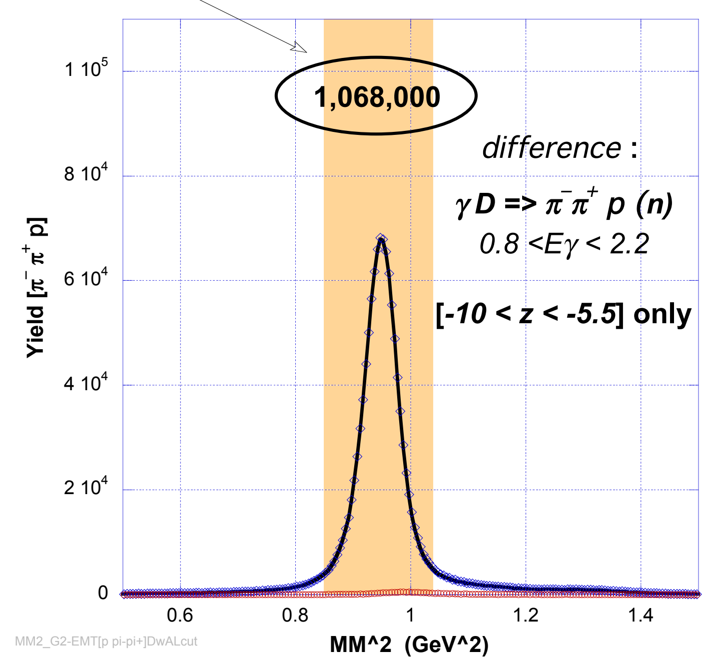
<= Aluminum yield is almost nothing





25% more statistics from full cell subtraction





Method I:

- flux normalize Gold and Empty
- impose a tight target cut to keep only interior of cell
- scale the normalized empty to correct for different Aluminum density (~ 0.7)
- subtract what little of the empty survives

Method II:

- flux normalize Gold and Empty
- scale this normalized empty to correct for different Aluminum content (~ 0.9)
- subtract the full cell (including KelF windows)
- impose a coarse target cell cut to remove downstream windows

$\Rightarrow$ ~ 25% more efficient (due to the limited reconstructed vertex resolution)