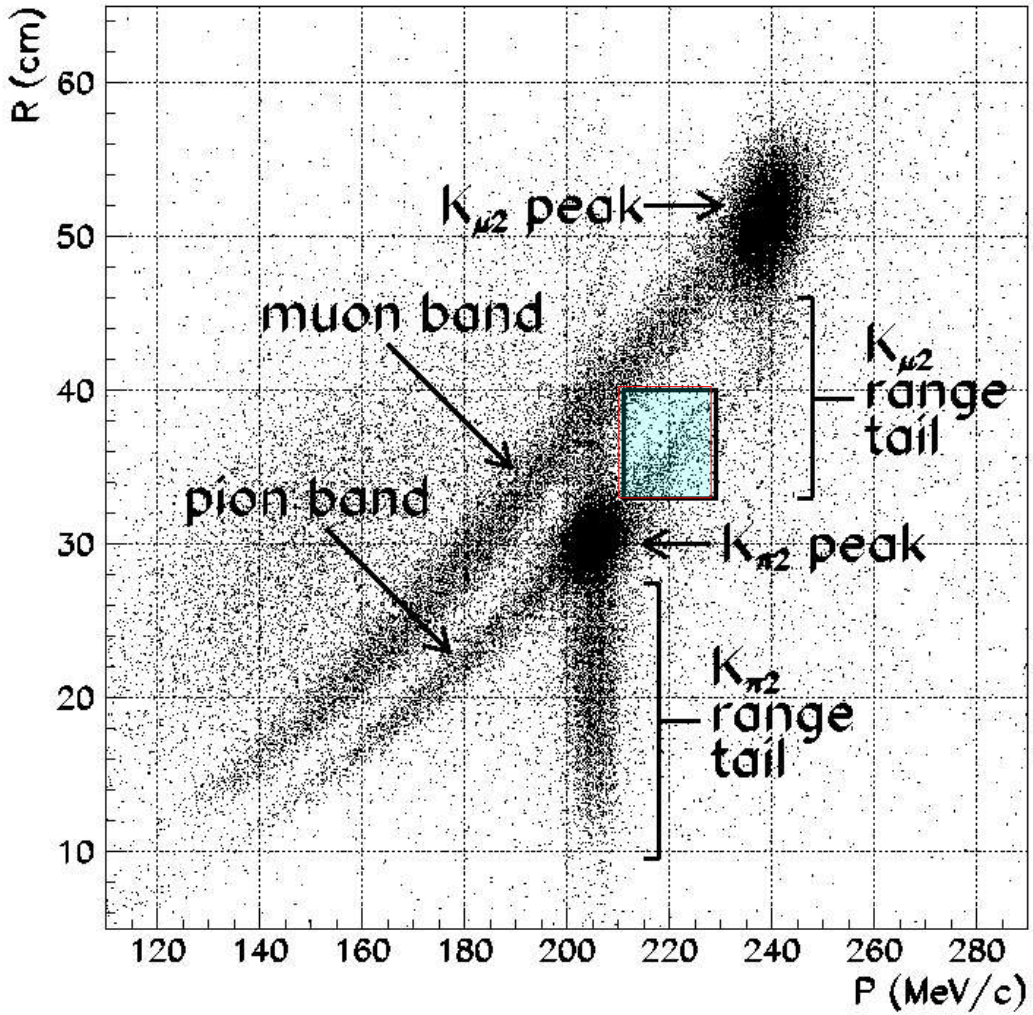
Estimating background from data in E949

Outline

- Introduction: Backgrounds to $K^+ \to \pi^+ \nu\bar{\nu}$ in E787/E949
- Background estimation, verification
  - Attempt to distill the important points for application to other experiments
- First thoughts on application to KOPIO

(Some remarks on trigger issues in E949 analysis. Save for the discussion?)

Backgrounds in E787/E949



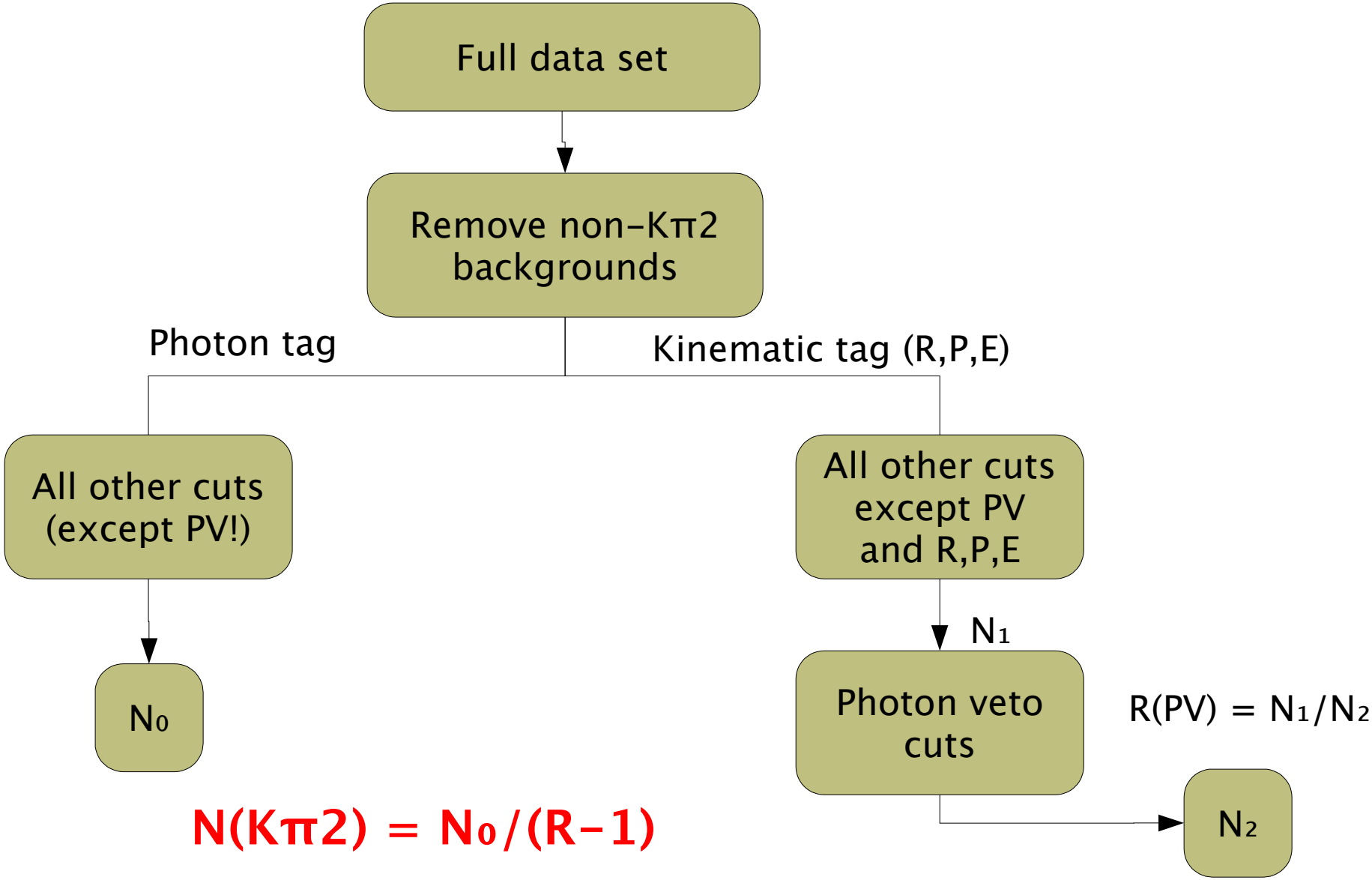
$K^+ \rightarrow \mu^+\nu(\gamma)$, $(\mu^+\pi^0\nu)$
- Wrong kinematics
- Mis-ID of μ as π
- (Photon(s) missed)

$K^+ \rightarrow \pi^+\pi^0$
- Wrong kinematics
- π^0 missed

Scattered beam π
- Incoming π mis-id as K
- π fakes K-decay at rest (timing)
- K decay-in-flight mismeasured (timing)
- Two beam particles (segmentation)

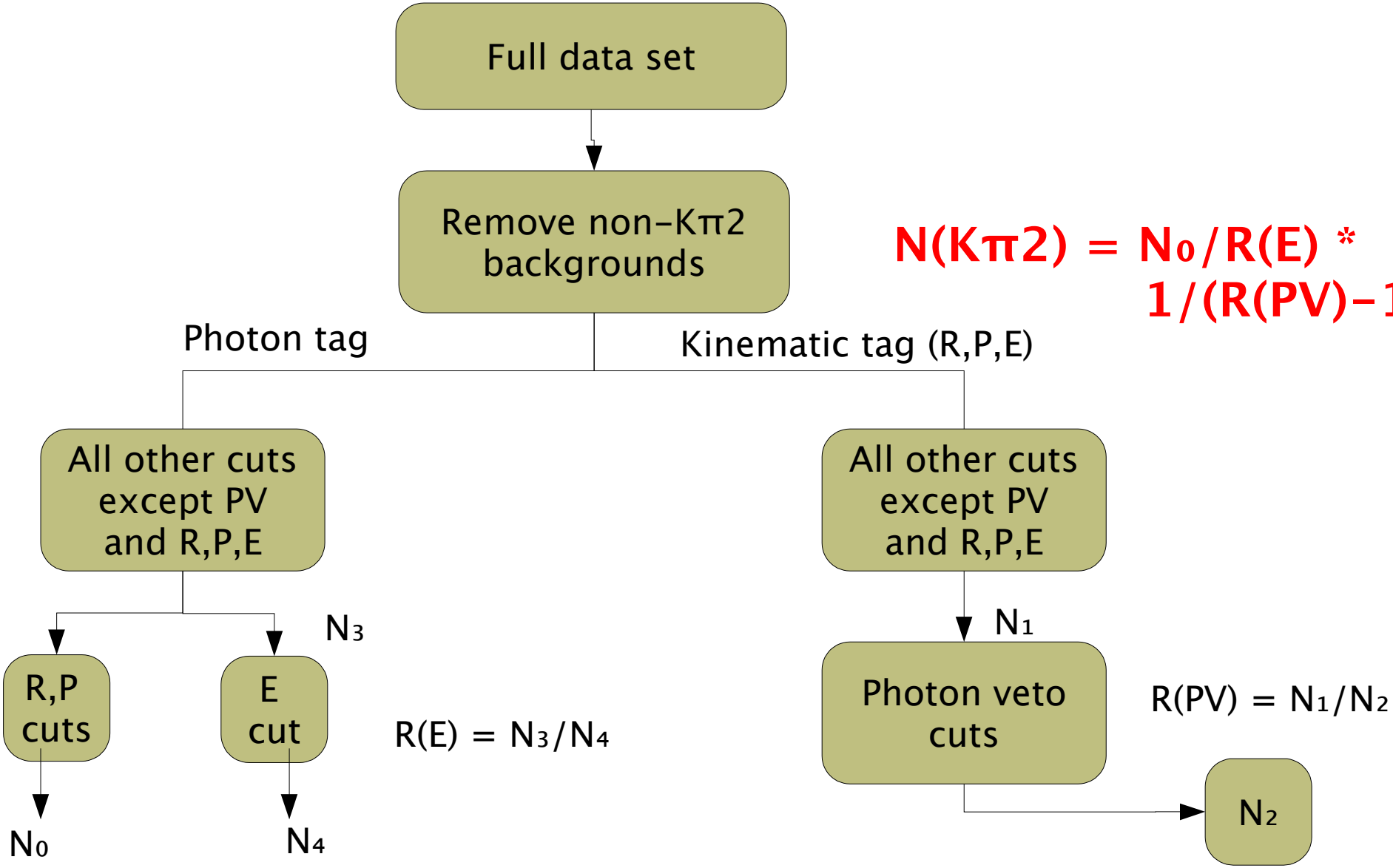
$K^+n \rightarrow K^0p$, $KL \rightarrow \pi^+l^-\nu$
- KL decays in K-stopping target
- Lepton missed
- No gap between K^+ and KL

"Dual-cut " technique. Example: Kπ2 background



$$N(K\pi 2) = N_0/(R-1)$$

Example of "higher order" variations



$$N(K\pi 2) = N_0/R(E) * 1/(R(PV)-1)$$

Comments on the dual-cut technique

- All background levels (except for CEX) in E949 are determined directly from the data
- Independence of the two cut sets is essential

Background	Cut 1	Cut 2
$K\pi 2$	R,P,E of π^+	π^0 veto
$K\mu 2$	P (R,E) of μ^+	$\pi \rightarrow \mu \rightarrow e$ decay sequence
$K\mu 2\gamma$	R vs P of μ^+ γ veto	$\pi \rightarrow \mu \rightarrow e$ decay sequence
$K\mu 3$	R vs P of μ^+ π^0 veto	$\pi \rightarrow \mu \rightarrow e$ decay sequence
Scattered beam pion	π id in beam hodoscope	$K \rightarrow \pi$ decay time
2 beam: K-K	2nd track in beam hodoscope, Target pattern and photon veto	2nd track in beam wire chambers or K Cerenkov counter
2 beam: K-π	2nd track in beam hodoscope, Target pattern and photon veto	2nd track in beam wire chambers or π Cerenkov counter

- Extensive check for correlations.
  - Direct check between the two cut sets, e.g. $\pi \rightarrow \mu \rightarrow e$ rejection as a function of Range due to higher rates in inner RS layers
    - Some correlations can be accounted for. In the above example, the final Range cut needs to be applied before measuring the $\pi \rightarrow \mu \rightarrow e$ rejection. Penalty is a loss of statistics in rejection measurement.

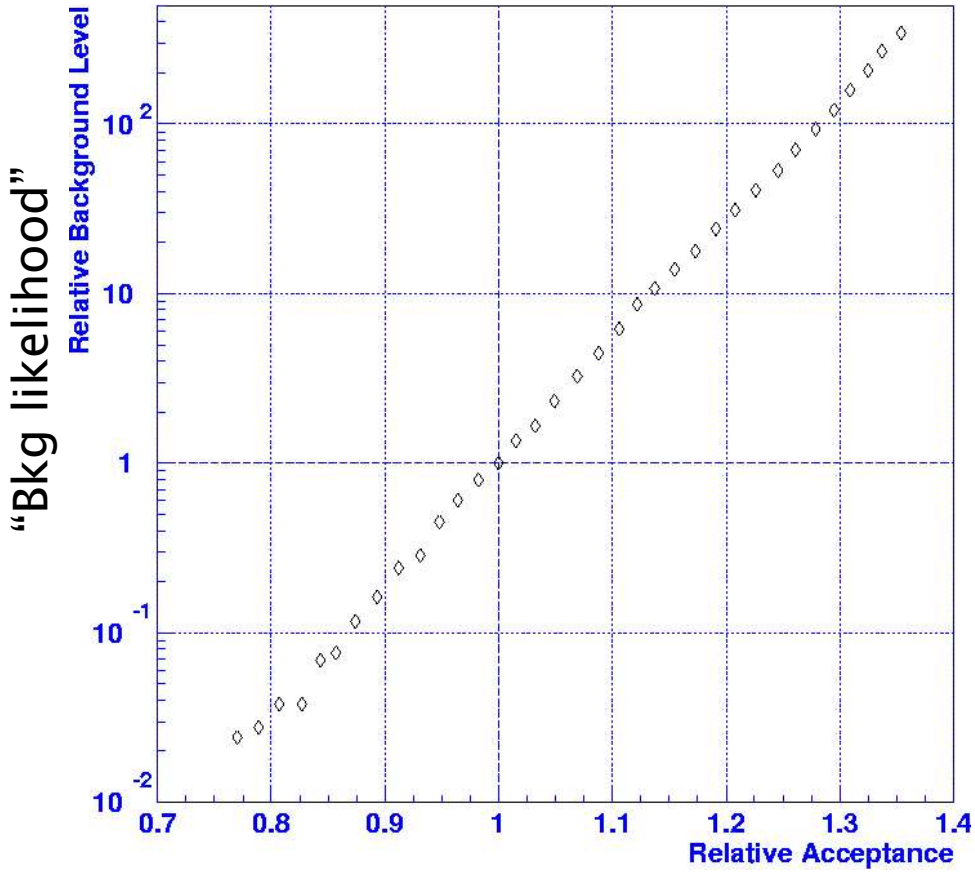
Comments (2)

- Correlations, cont..
  - Study rejection power of each “branch” as a function of various variables; check partner cut for similar dependence. Again, can be taken into account with the penalty of statistics for rejection measurement.
  - Correlations induced by detector problems, reconstruction problems, etc
    - Apply cuts to remove the pathological cases.
- Ultimately, the absence of correlations is checked by predicting background levels outside (but near) the signal region and comparing with observation.

- As backgrounds become better understood, natural to go from fixed cuts analysis to likelihood analysis ⇒ tables of background and acceptance as a function of cut position

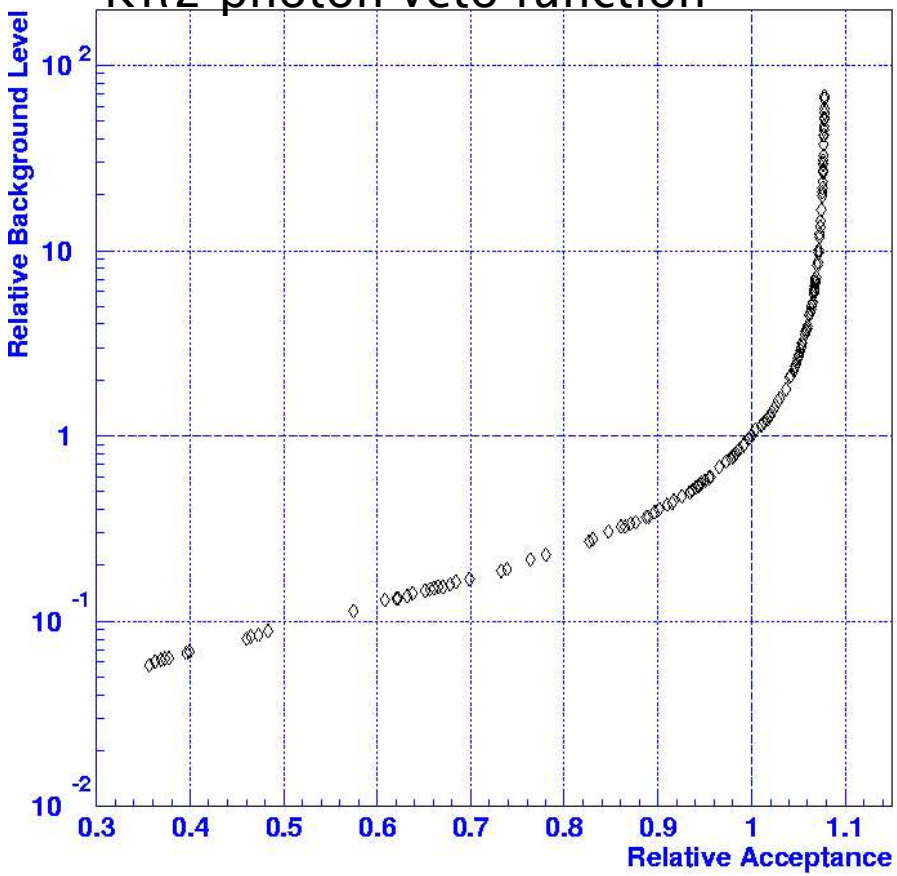
Examples of background functions

Kπ2 kinematic function (R,P,E)



"signal likelihood"

Kπ2 photon veto function



Comments (3)

New or hitherto unknown backgrounds?

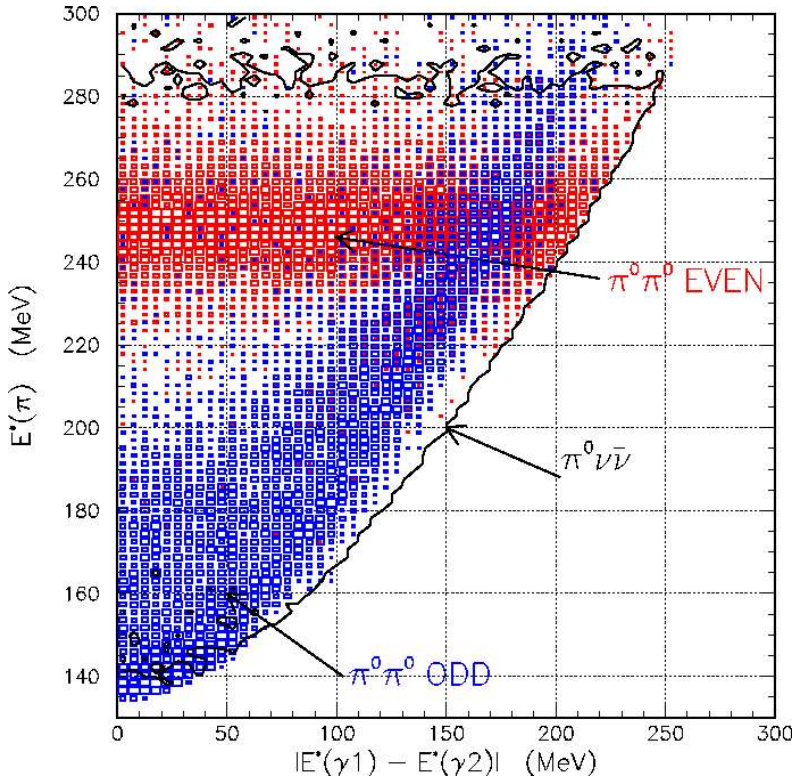
- New backgrounds near the signal region can show up as an apparent correlation between the dual cuts (even if the dual cuts are independent for the new background).
- Can also look “in the signal region” along a different axis, i.e. loosen a cut that has only acceptance loss for the known backgrounds, and check for anomalies

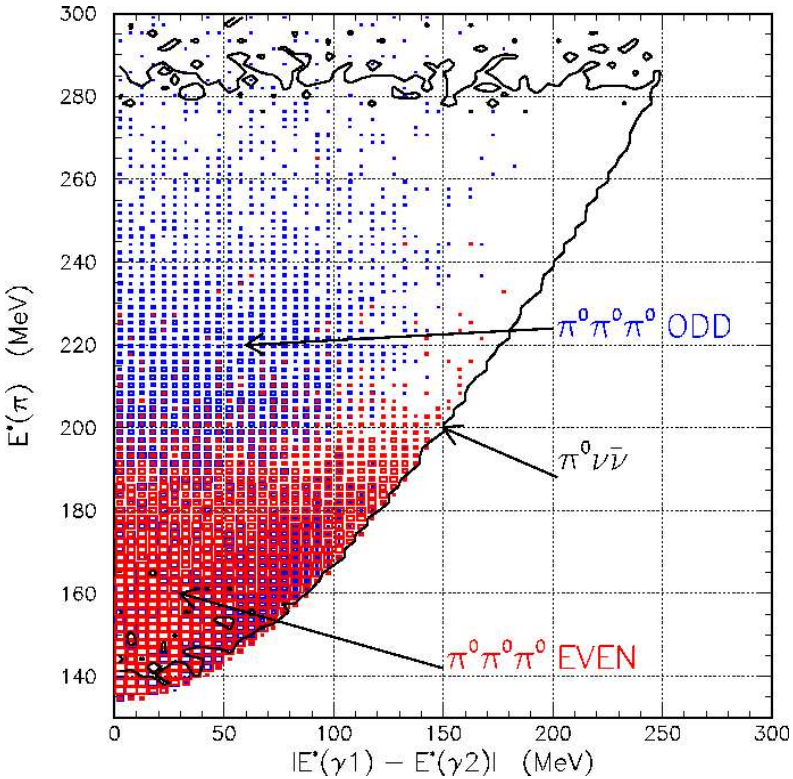
In practice, we look around the signal region along a “large” number of axes, comparing observations to expectations. Some care required, since with enough checks, random fluctuations can give rise to anomalies; however these can give hints for areas for further inspection.

Finally, after the box is opened, a detailed examination is made of the candidates. Again, with so many variables, we have to keep in mind the possibility of random fluctuations. Obviously candidates cannot be eliminated with this procedure since that violates the whole point of doing a blind analysis.

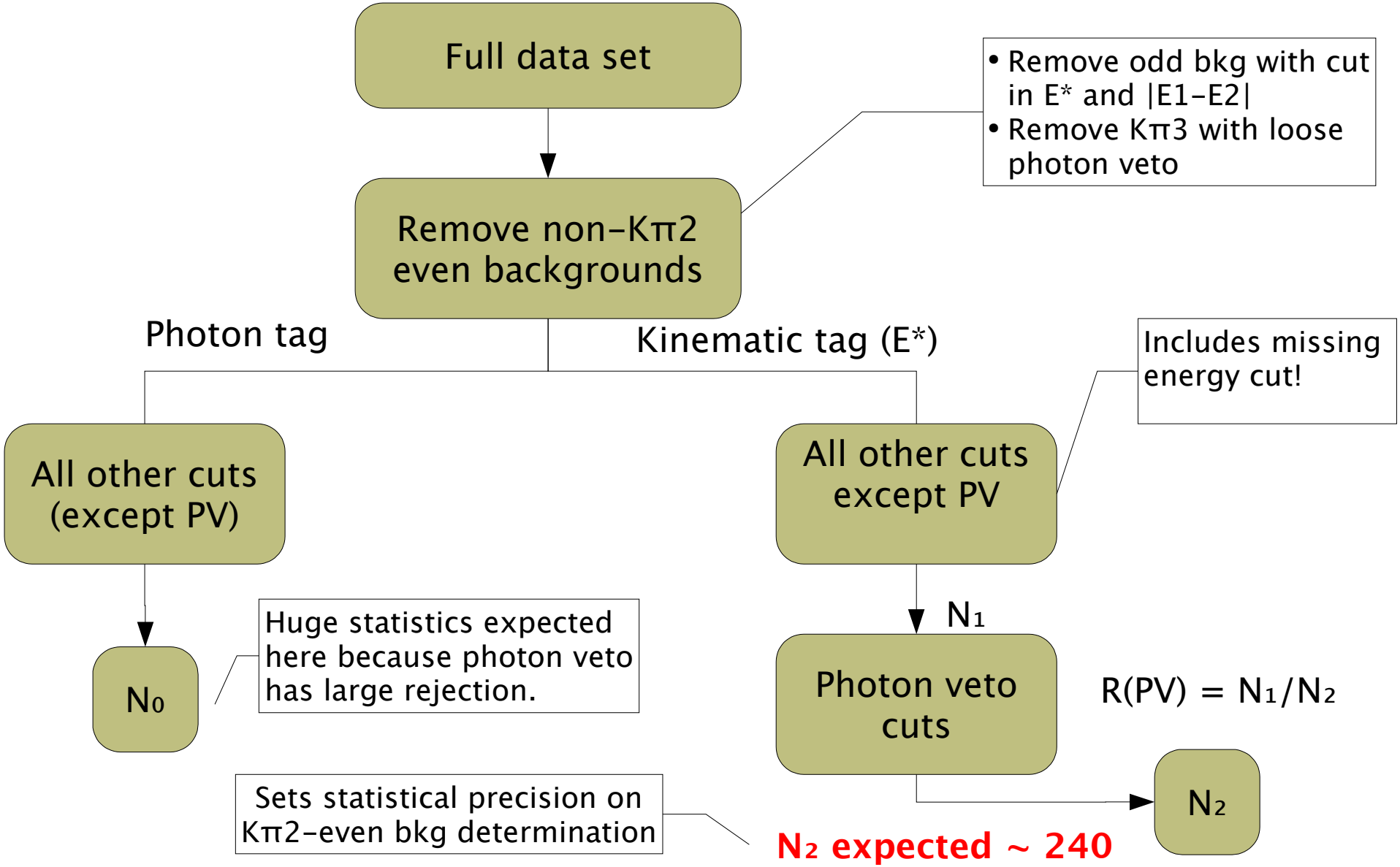
Application to KOPIO

Must keep in mind that E949 analysis technique developed over ~10 years. Extrapolation to KOPIO therefore has its limits. Nevertheless one strength of KOPIO is that it allows the dual-cut technique.





Kπ2 "even" background in KOPIO



Conclusion

All backgrounds (except CEX) in E949 are measured directly from the data.

Dual-cut technique

- Two cuts (with minimal correlation) for each background
- Allows high levels of rejection to be reached
- Allows the total rejection to be measured from the data

KOPIO expects to use the same techniques (at least for the major backgrounds)

A few remarks on trigger issues in E949 analysis

Triggers used in the $\pi\nu\bar{\nu}$ analysis:

- $\pi\nu\bar{\nu}$ trigger for background analysis and signal search
- For detector calibration and acceptance measurements:
  - $K\mu 2$
  - $K\pi 2$
  - π scattering
  - K entering stopping target

Typically ~300 evts/spill of which roughly 5-10% monitor triggers

Background rejection

The signal search and background analysis are made with a single dataset from the $\pi\nu\bar{\nu}$ trigger. There are no issues of mixing different trigger sets.

Dual-cut technique works best when each of the dual cuts has comparable rejection ***after the trigger***. Bkg estimates can suffer from statistics problems if the trigger is not balanced (e.g. cutting much harder on photon veto compared to kinematics). Was not really a problem in E787/E949.

Care needed on this point when the "higher-order variations" on the dual-cut technique are used. Need to be aware of possible trigger biases when splitting bkg analysis into products of more than 2 factors. Became an issue in E949. Details in thesis of T. Sekiguchi.

Acceptance

A number of different trigger sets are used for acceptance measurements:

- Kμ2: reconstruction cuts on beam and target, accidental losses
- Kπ2: target cuts that depend on energy loss in target
- π scattering: pion kinematic cuts (but not R,E,P box and trigger kinematic cuts), $\pi \rightarrow \mu \rightarrow e$ analysis
- Monte Carlo: solid angle, phase space (R,E,P box), trigger kinematic cuts (range cut), acceptance of π^+ stopping in Range Stack
- Kaon entering stopping target: effects of photostatistics and azimuthal gaps in trigger fiducial counters

Acceptance of kaon stopping in target: normalize BR(πνν) to BR(Kμ2)

Do not underestimate complexity of acceptance analysis.