L0 trigger for exotic decays

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Outline

Aim to exploit the flux of kaons and other mesons produced

@ NA62, possible tests for exotic NP scenarios; currently under study:

1. **heavy sterile neutrinos (a.k.a. heavy neutral leptons)**
2. **new-physics, U(1) vector bosons (a.k.a. dark photons)**
3. **rare pi0 decays**

L0-trigger strategy, general guideline:

1. **simple and low-rate**
2. **high-efficiency, but not necessarily "optimal" from the systematic point of view**

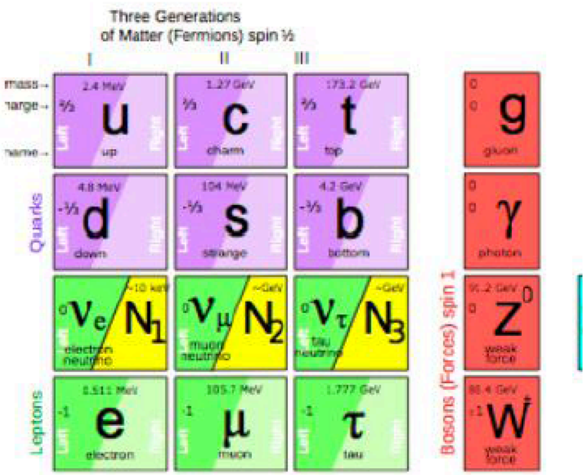
Will not spend time about rare π^0 decays:

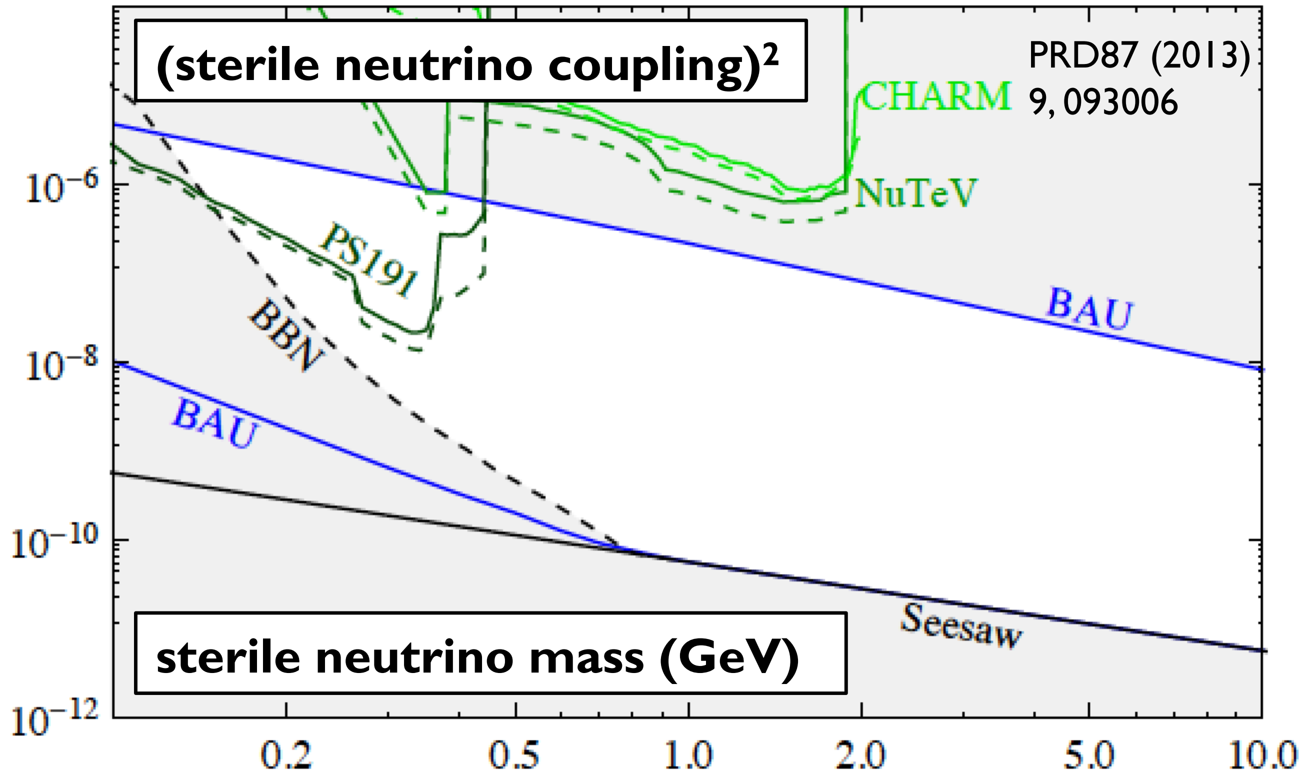
trigger strategy developed (see E. Minucci, T. Spadaro), awaiting for LKr-based complete trigger

Search for exclusive decays of sterile ν's

Motivations to search for heavy neutrinos (HN):

- Shaposhnikov et al.: can explain DM + BAU + low standard ν masses by adding 3 Maj HN's
- The minimal neutrino standard model is very predictive





Search for exclusive decays of sterile ν's

The experimental setup allows for a variety of complementary searches

- Model-independent, from $K\mu2$
- Search for exclusive decays after production

We considered the decay chains:

- $K \to \mu H_N$, $e H_N$, $H_N \to \mu\pi$, $e\pi$, with K from our selected beam
- $D_{(s)} \to \mu H_N$, $e H_N$, $H_N \to \mu\pi$, $e\pi$, with $D_{(s)}$ from the target
- $K^{+-} \to \mu H_N$, $e H_N$, $H_N \to \mu\pi$, $e\pi$, with K^{+-} from the target

Yield benefits from absence of helicity suppression, evaluated from:

- PYTHIA 8.1 for meson production at target + nominal attenuation (for K)
- GEANT4 simulation of kinematics
- Nominal intensity considered:
  - $1.1\ 10^{13}$ beam K's in 2 years
  - $1.1\ 10^{18}$ POT / year, 60% interacting

Example: D meson production

Simulate pp and pn hadroproduction cross sections for √s ~ 28 GeV

Literature: σ_{TOT} ~ 40 mbarn, s(cc-bar) ~ 40 μbarn → produce 0.7 x 10^{15} D-mesons / year

Estimate confirmed using PYTHIA 8.1

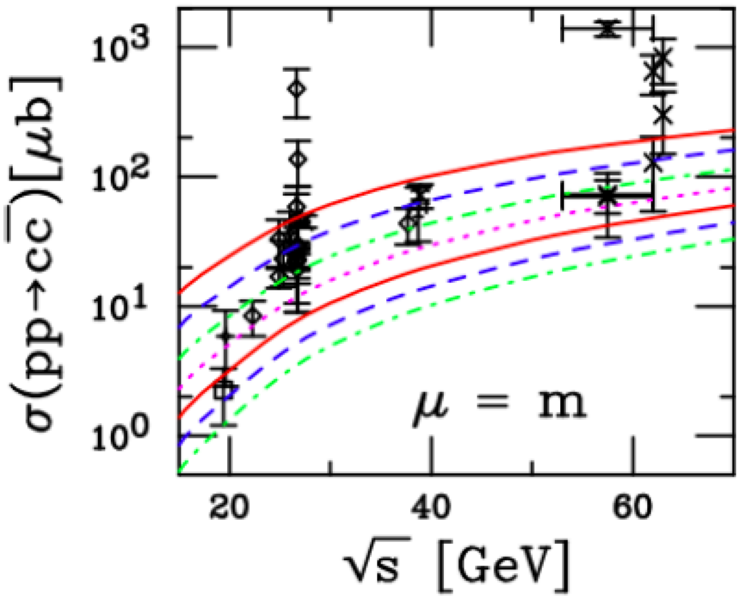
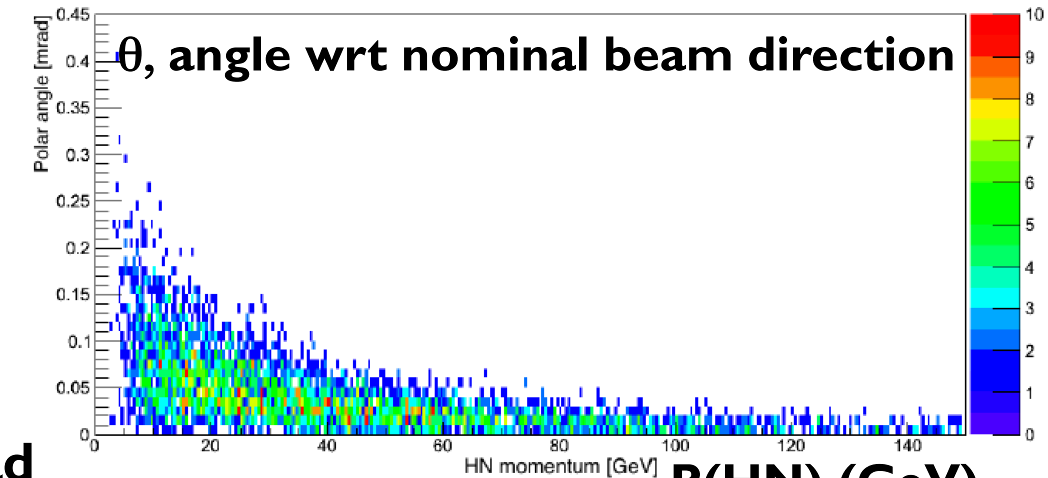


Figure 4.16: Total cc cross sections in pp interactions as a function of the charm quark mass. From top to bottom the curves are corresponding to Next-to-Leading order QCD calculations with charm masses of $m_c = 1.2, 1.3, 1.4, 1.5, 1.6, 1.7$, and 1.8 GeV, and for factorization and renormalization scales equal to the charm quark mass. The plot has been taken from Ref.[Vog08]

Angle-momentum correlation put into MC

E(H_N) up to 100 GeV, <θ> ~15 mrad



P(HN) (GeV)

Possible trigger for HN search

Experimental signature:

- **two oppositely charged tracks from a displaced vertex**
- **πe: minimum energy deposited in LKr, no MUV**
- **$\pi\mu$: minimum energy deposited in LKr (by the pion), MUV fired**

Subdetectors used: CHOD, RICH, LKr, MUV3

No cut based on subdetector correlation (as opposed to SIF proposal)

Trigger strategy will become trivial if CEDAR used in veto at L0

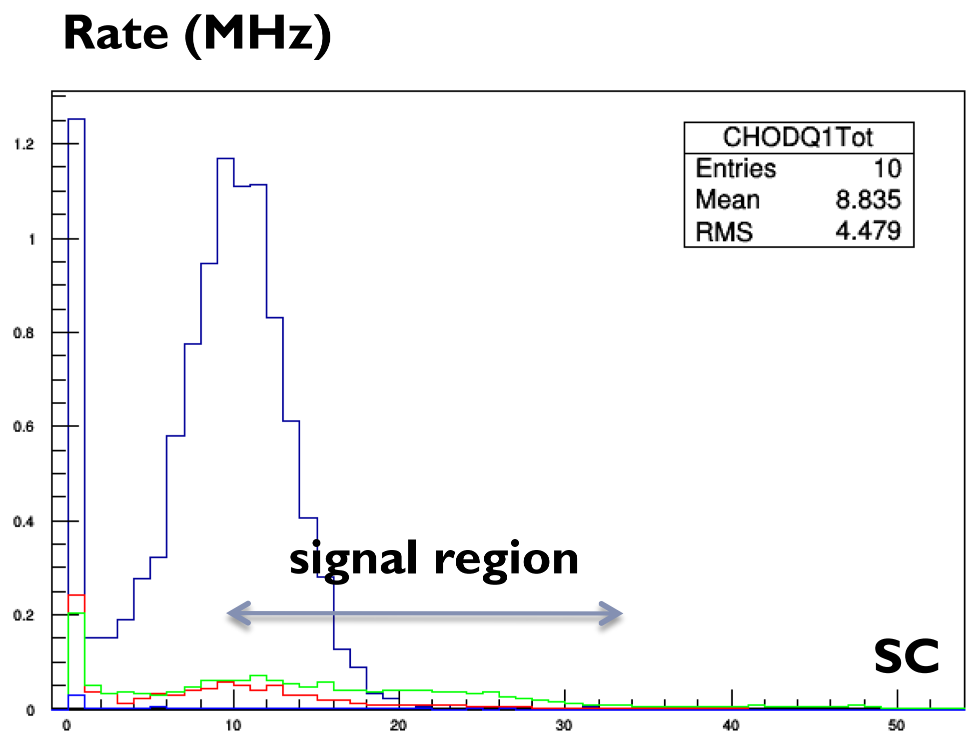
For background (rate estimate), used technology similar to Goudzovski/ Parkinson's NA62 note 14-07 (used MC production rev.329), except for:

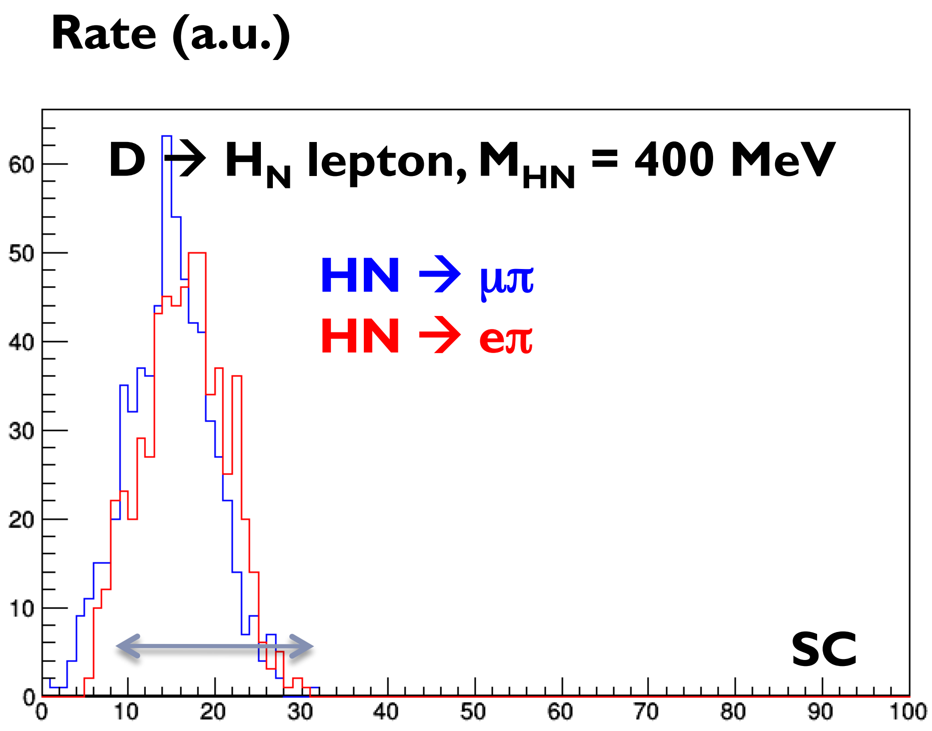
- **used official digitization**
- **considered all MUV3 channels, as opposed to masking innermost region**

Trigger primitives: CHOD, RICH

EQ_N = coincidences in the 2 CHOD planes for exactly N quadrants

SC = number of RICH super-cells (8-fold) fired





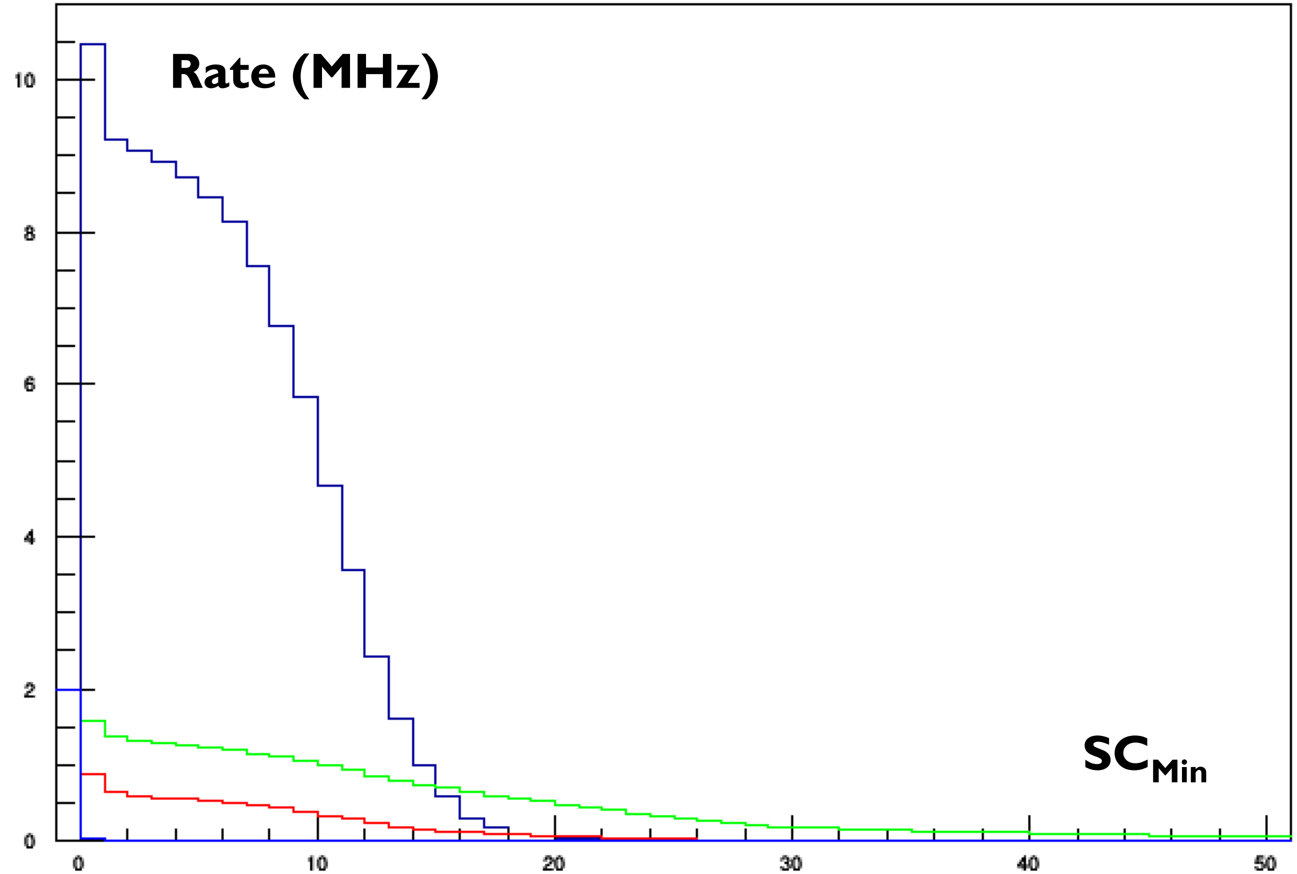
Background general figures: rate plots

Integrated rates when cutting such as SC > SC_{Min} (no cut on LKr energy):

EQ_1 = 10.4 MHz, EQ_2 = 0.88 MHz, EQ_3 + EQ_4 = 0.13 + 1.5 MHz

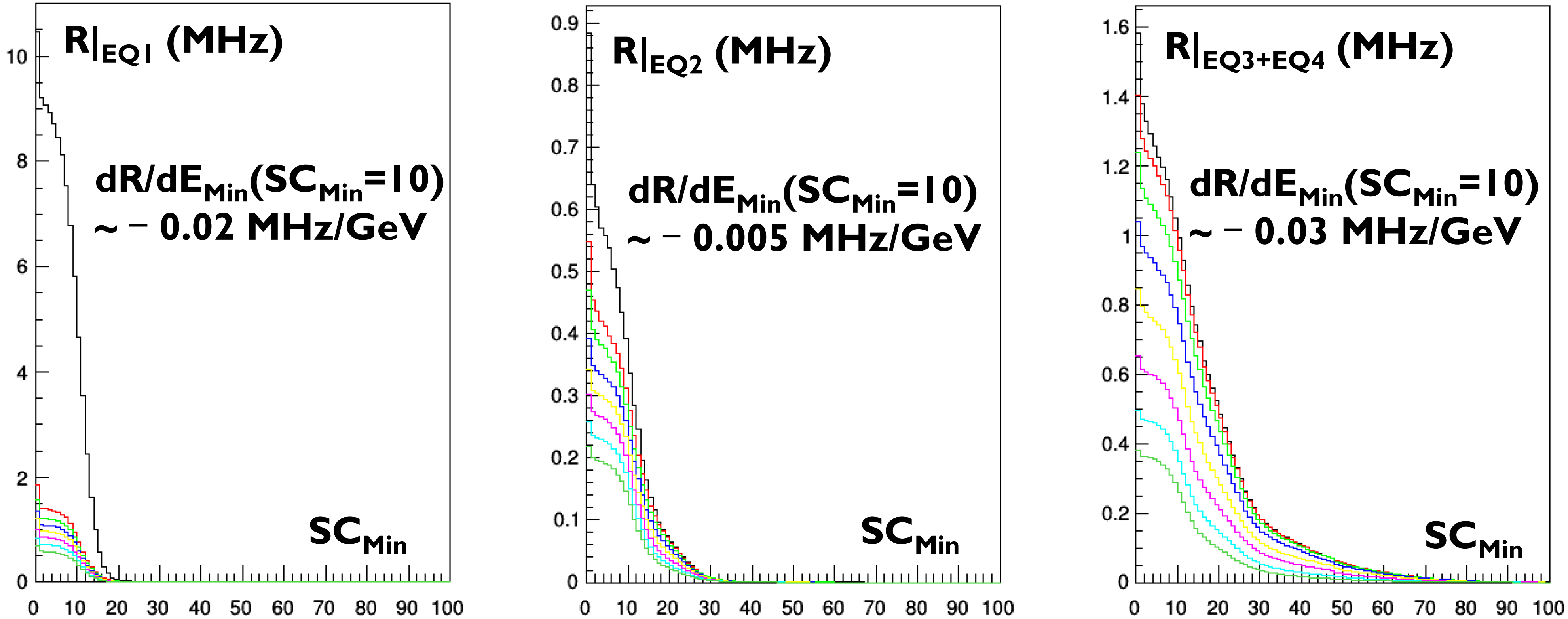
Good agreement with Evgueni's estimates for:

$Q_N = \mathrm{Sum}(EQ_j), j = N..4$



Background general figures: scaling

Integrated rates when cutting as SC > SC_{Min} for different cuts ELKr > E_{Min}

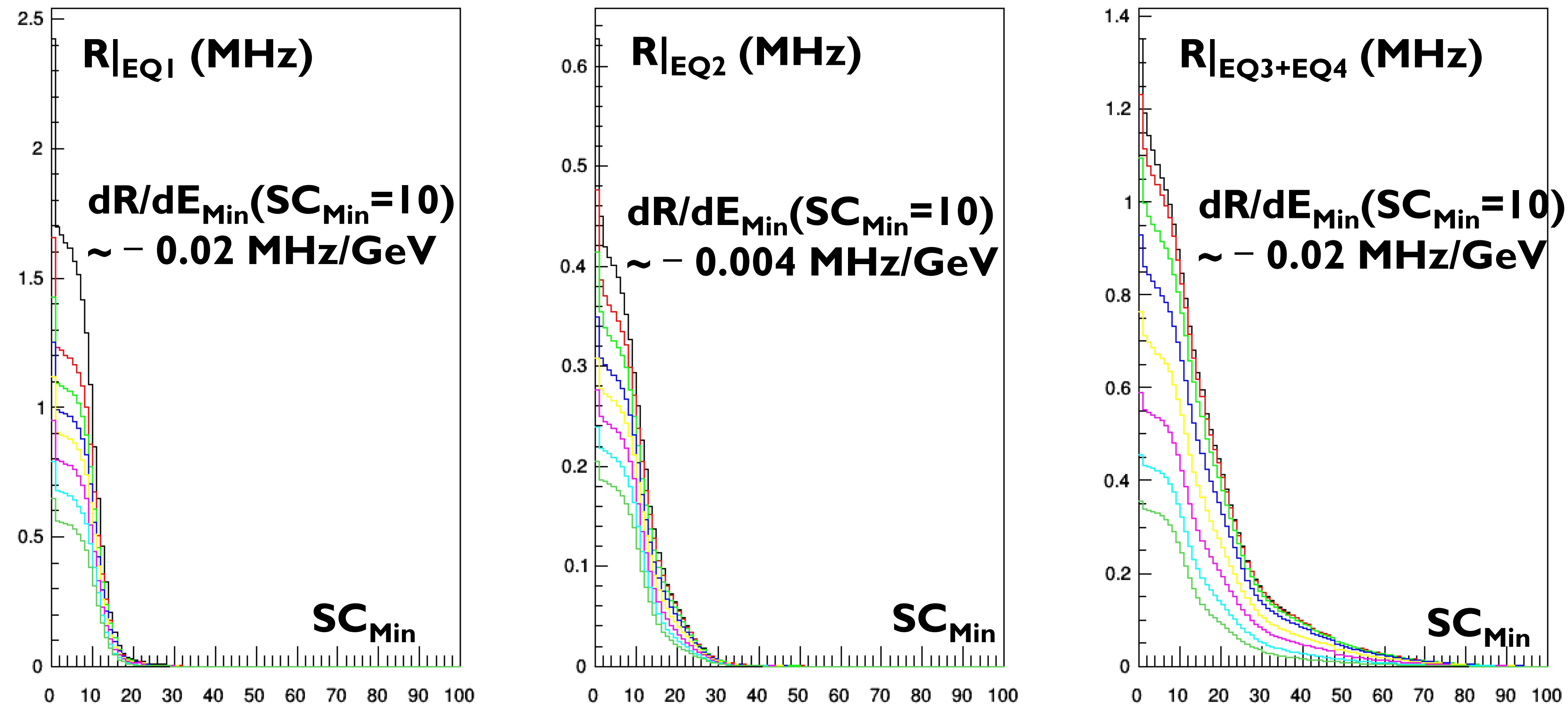


8 Cuts (in various colors) spanning 0 → 35 GeV in 5-GeV steps

Rate scales with E_{Min}, slope depending on EQ, constant to O(10%) for E > 5 GeV

Background general figures: scaling

Integrated rates for SC > SC_{Min} for different cuts ELKr > E_{Min}, MUV3 on



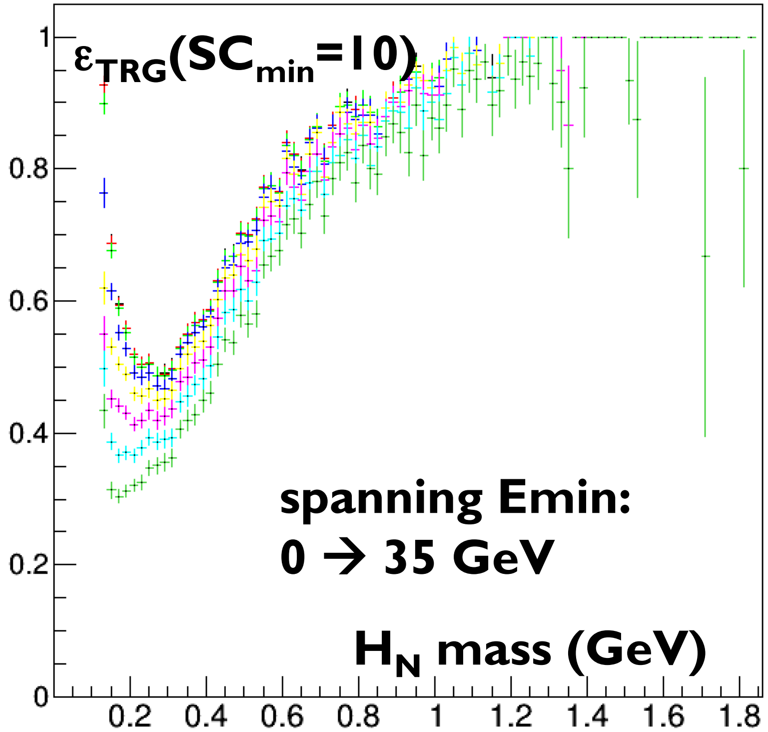
General comments:

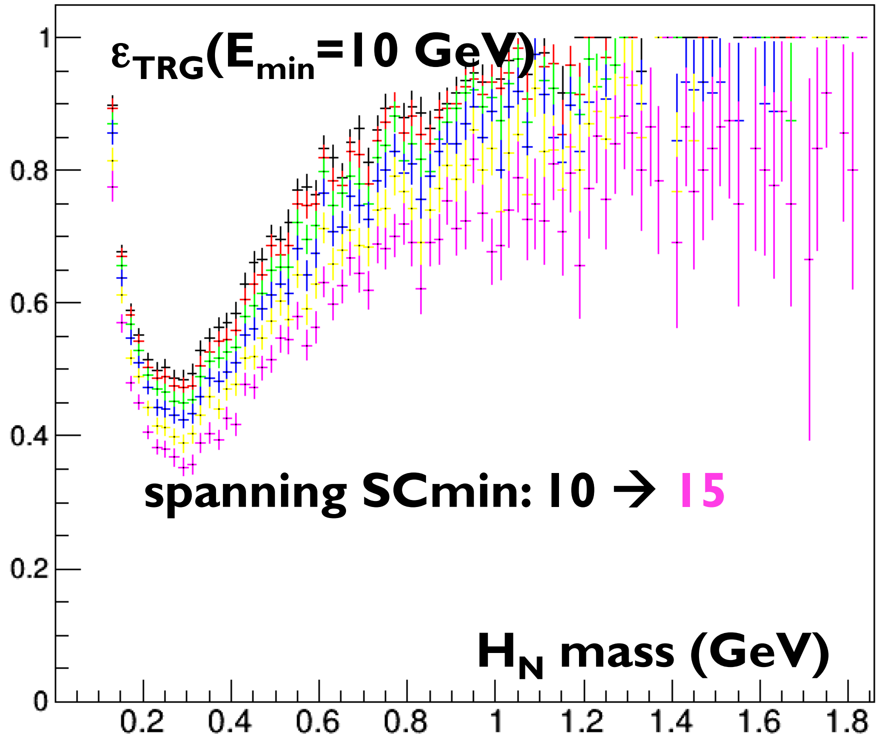
1. **observe a factor of ~2 between EQ_3+EQ_4 and EQ_2**
2. **a cut SC <~ 30 useful only for EQ_3+EQ_4, not much for EQ_2**

A trigger for the HN → eπ decay

Strategy: ask EQ_2 and tune the minimum LKr energy + RICH SC min

Trigger efficiency evaluated vs the HN mass GIVEN the acceptance cuts





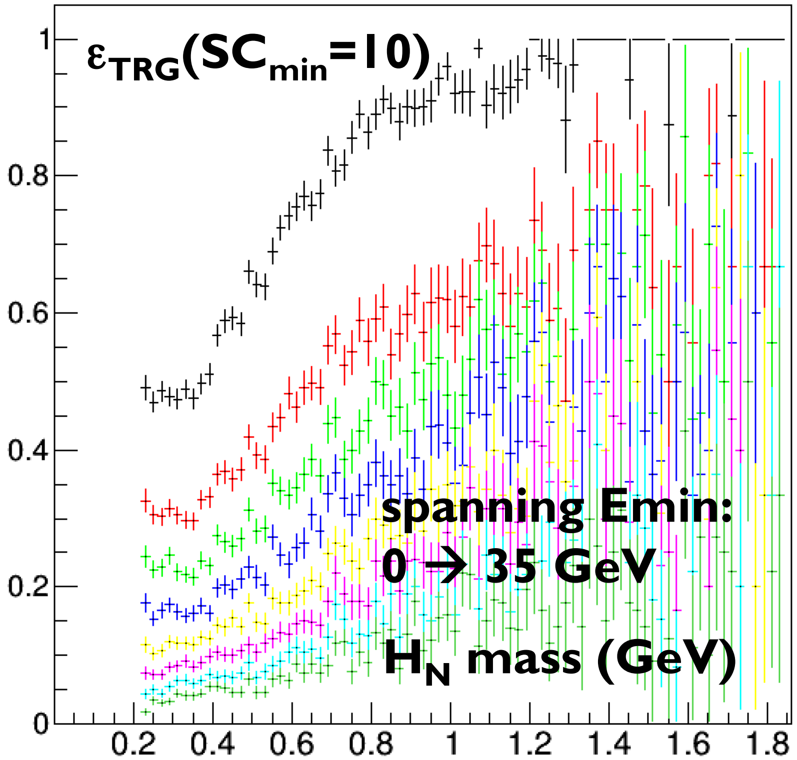
Comments:

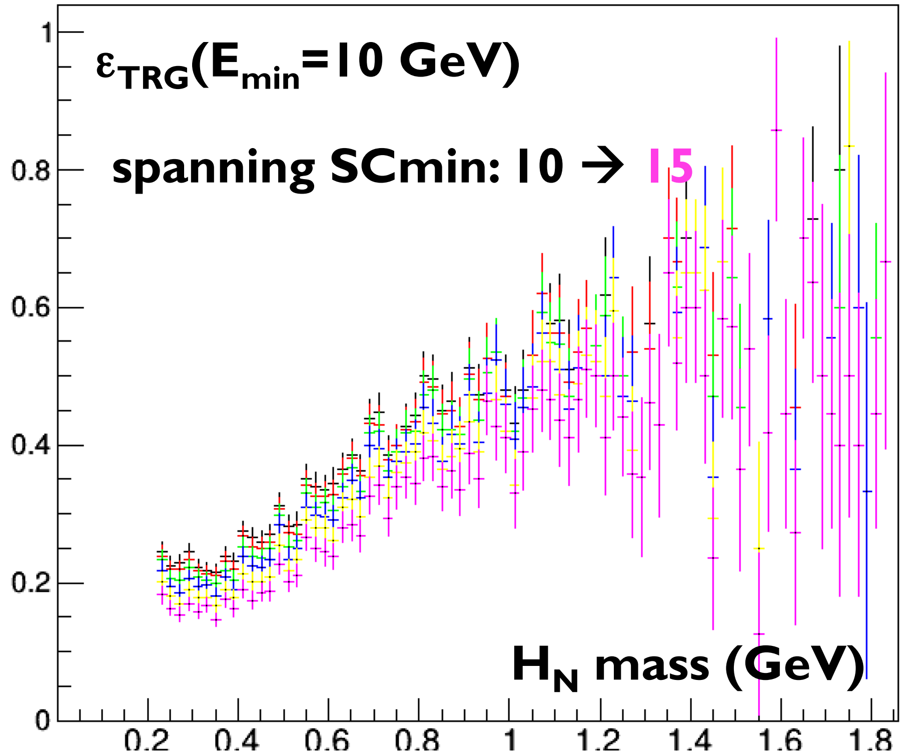
1. **high efficiency, e.g.: Rate(E_{min}=35 GeV, SC_{min}=13) < 50 KHz**
2. **behavior vs HN mass explained by production mechanism**

A trigger for the HN → μπ decay

Strategy: ask EQ_2 & MUV3, tune the minimum LKr energy + RICH SC_{min}

Trigger efficiency evaluated vs the HN mass GIVEN the acceptance cuts





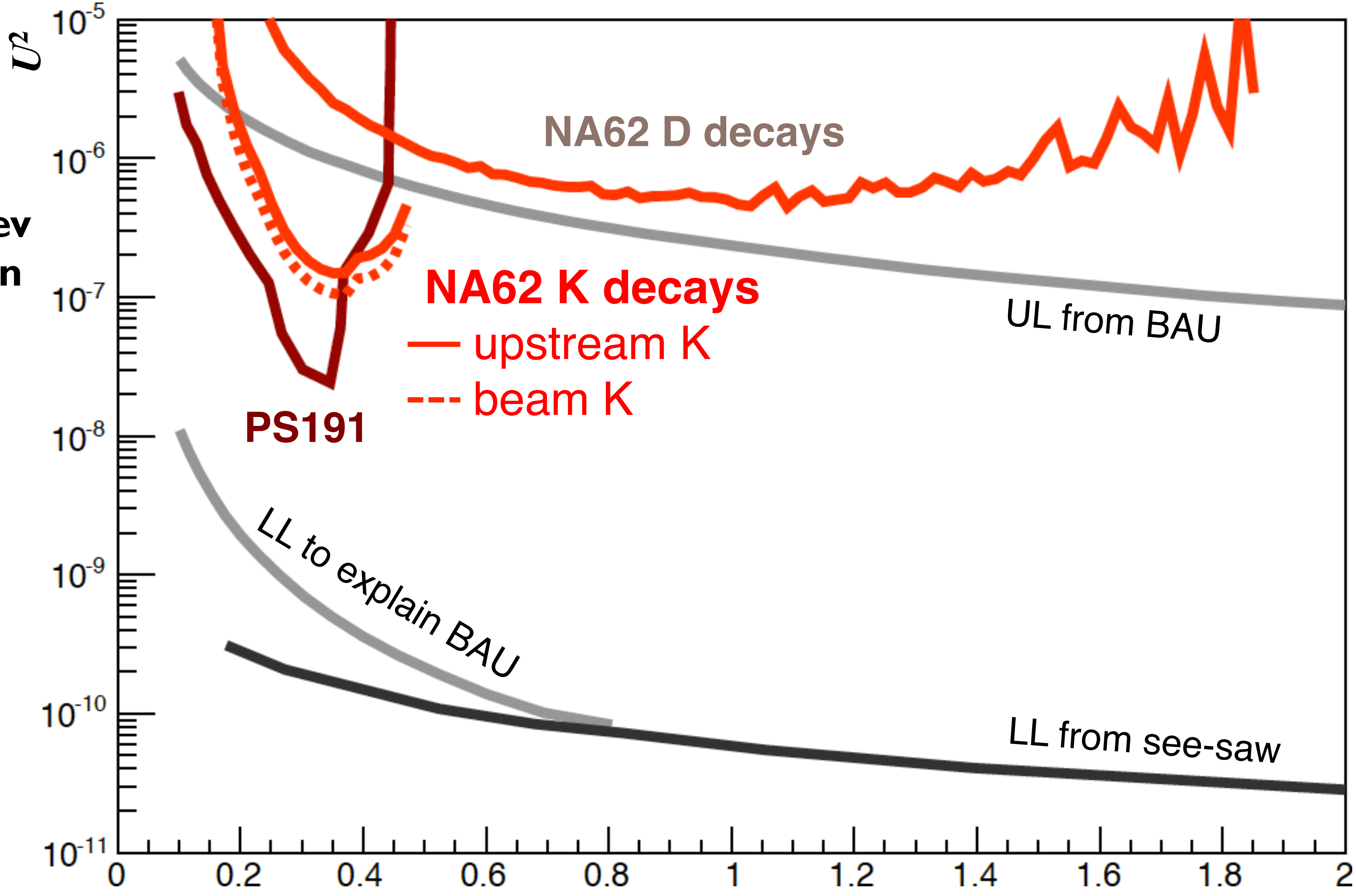
Comments:

1. **efficiency rapidly drops with E_{min}, better tuning on SC_{min}**
2. **Emin = 10 GeV to be pursued: ε ~ 30-40%, Rate ~ 100 KHz**

Sensitivity to HV, NA62 still improving on past experiments after trigger requests

Improving on CHARM, NuTev in the D-meson area

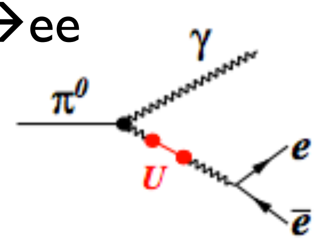
Slightly improving on PS191



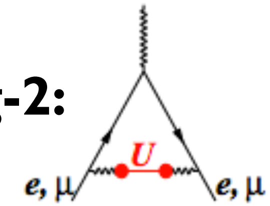
Additional search: exclusive U boson decays…

Presented at PANIC2014 in Hamburg last week…

Search for a U boson, dark-force mediator, from the chain $\pi^0 \to U\gamma$, $U \to ee$



U boson enters as NP contribution to muon g-2:



$$\Gamma_{U \to e^+e^-} = \frac{1}{3}\alpha\epsilon^2 M_U \sqrt{1 - \frac{4m_e^2}{M_U^2}}\left(1 + \frac{2m_e^2}{M_U^2}\right)$$

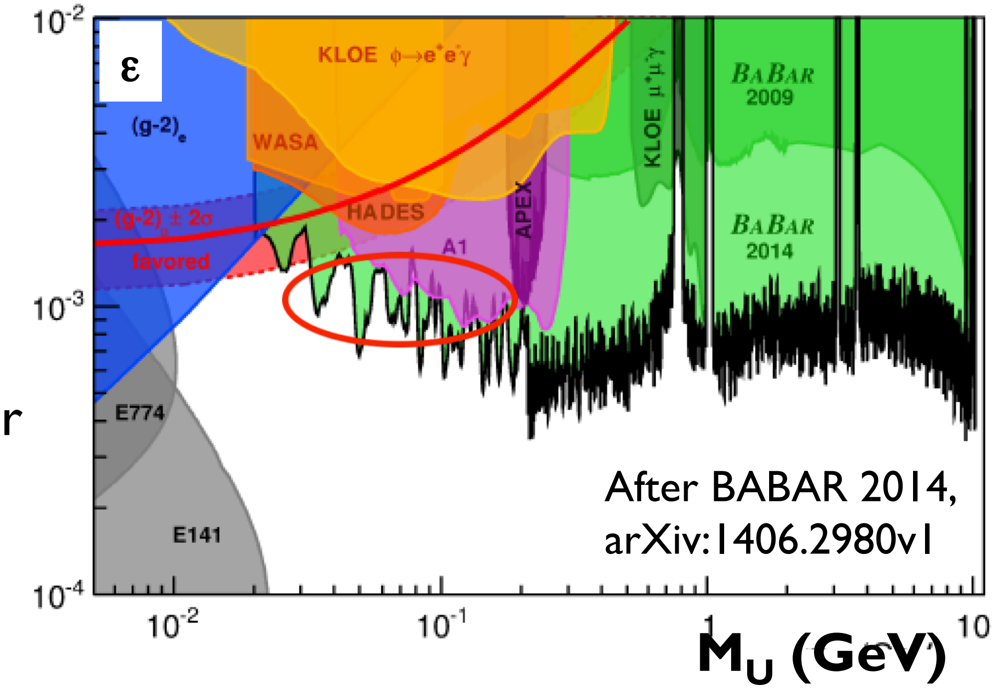
For $M_U < 2\,M\mu$, and effective coupling $\varepsilon \sim 10^{-3}$ width is ~ eV: U decay is prompt

Analysis in progress at NA48/2

At NA62: acquire w 3-track trigger + PID: rate sustainable, expect 10^8 candidates/year

e^+e^- invariant mass resolution ~ 1 MeV

Expect ~10^2 sensitivity improvement for $30 < M_U < 100$ MeV, up to $\varepsilon^2 \sim 10^{-6}$



After BABAR 2014, arXiv:1406.2980v1

… but changing perspective

Consider the "beam dump" accessible portion of the parameter space

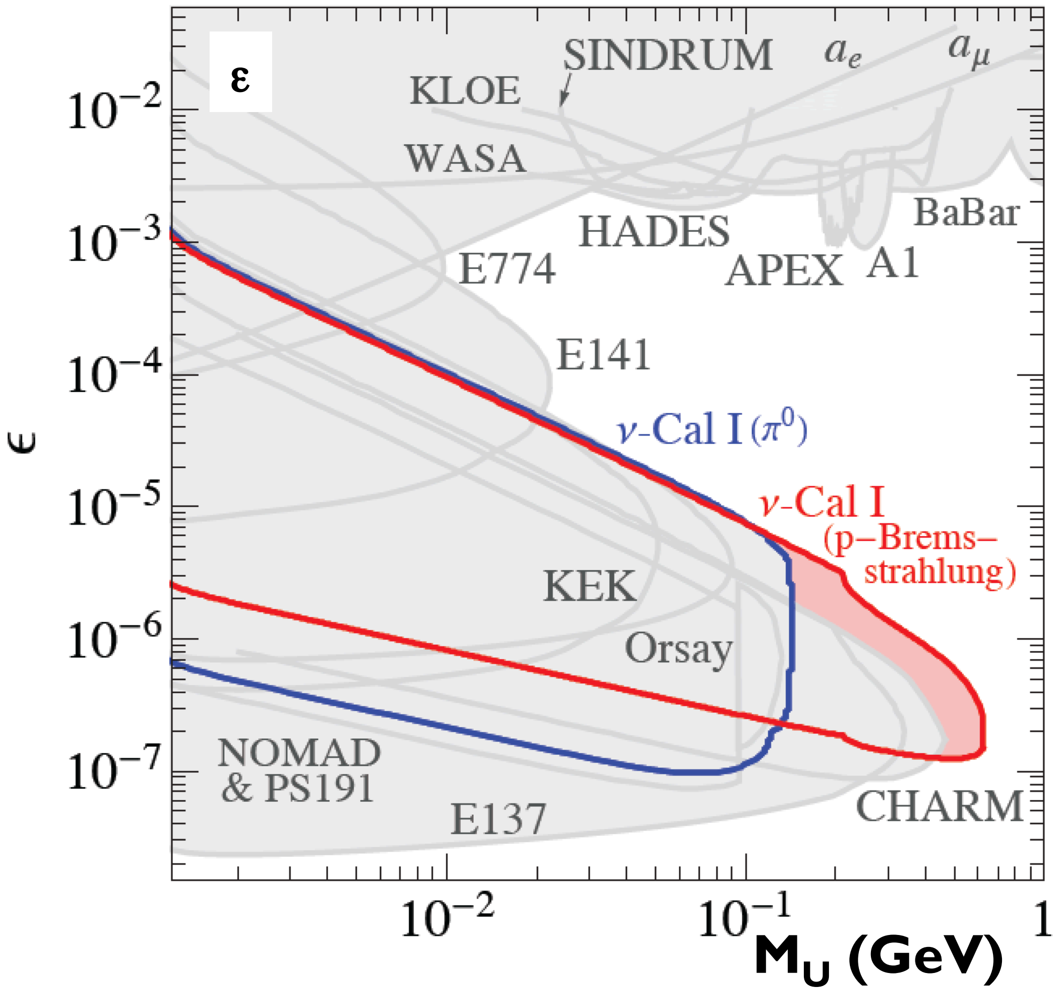
Blumlein, Brunner
arXiv:1311.3870v1

Very small couplings, O(10^{-6})

Not the g-2-favourite region, which anyway has been almost ruled out

Long-lived U-bosons
Consider production at target, decay in the FV

Consider decays to ee, μμ
U-boson model: kinetic mixing



Meson production rates and meson modes

Hadroproduction of η, η', Φ, ρ: a total of 10^{18} with ratios 0.39/0.04/0.02/0.54

Produce U bosons from:

- **η → γ U**
- **η'→ γ U, π^0 U**
- **Φ, ρ→ π U, η U**

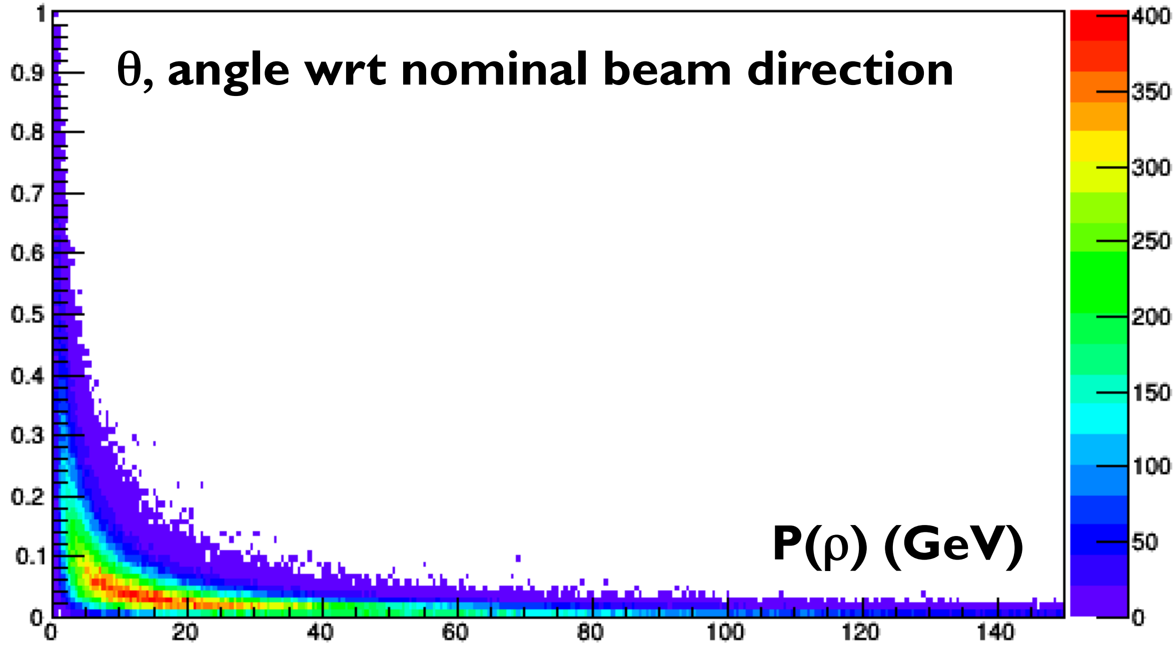
Scale from known BR's

Having γ in place of U:

- **account for U coupling**
- **correct for phase-space**

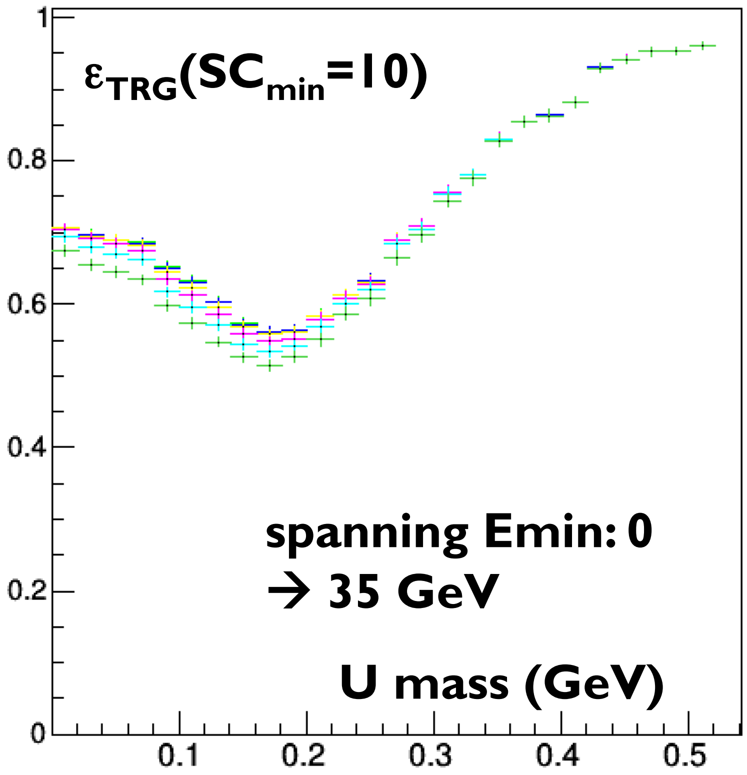
Put θ-P correlations in MC

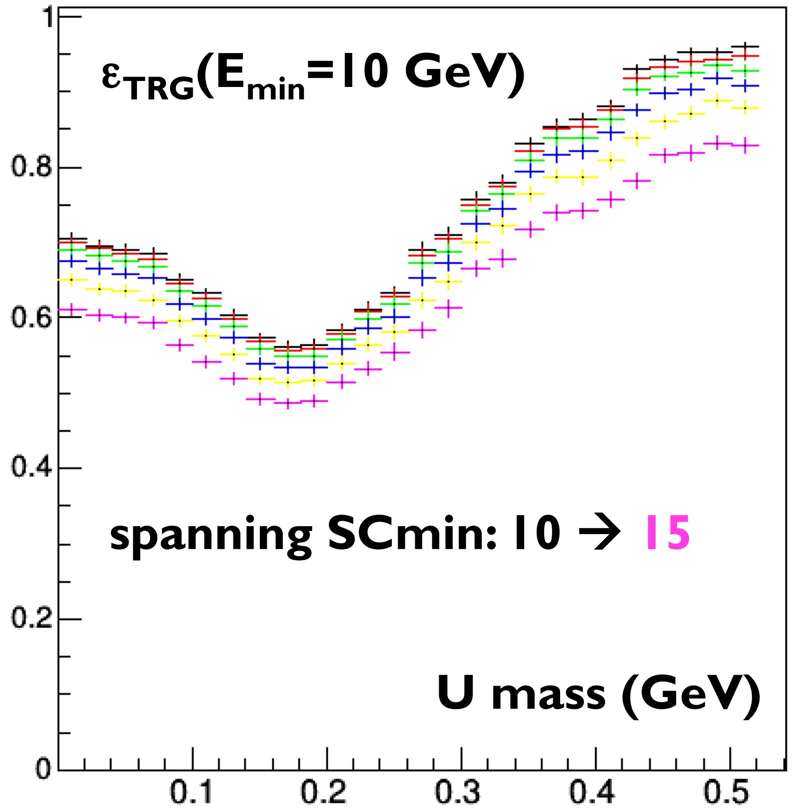
ρ^0 production from pp + pn



Trigger strategy for U decays, ee

U → ee: follow the previous reasoning, EQ2 & SC_{Min} & LKr(E_{min})



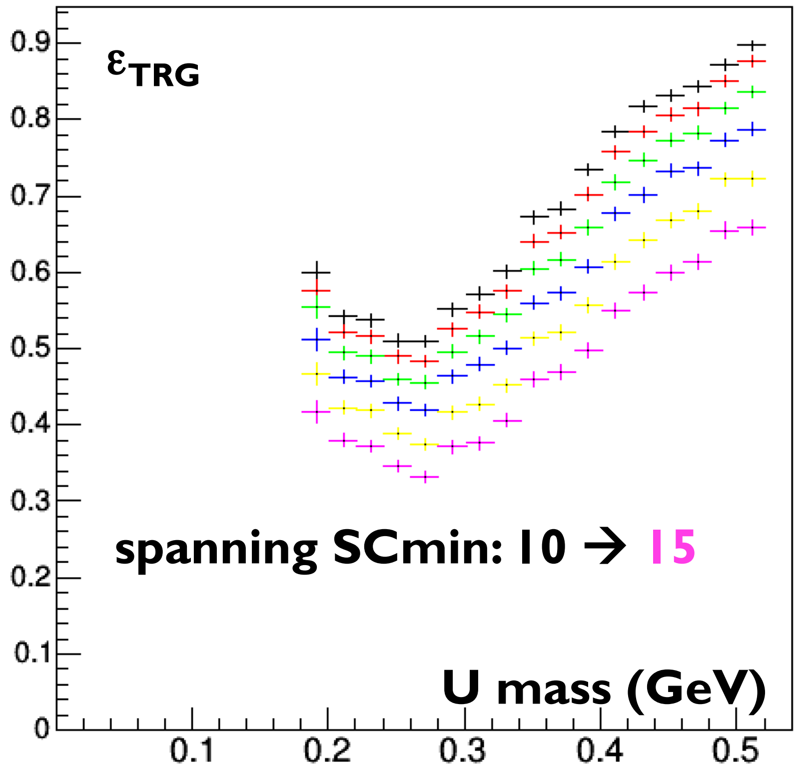


Comments:

1. **high efficiency, e.g.: Rate(E_{min}=35 GeV, SC_{min}=13) < 50 KHz**
2. **behavior vs U mass explained by production mechanism**

Trigger strategy for U decays, μμ

U → μμ: EQ2 & SC_{Min} & 2 MUV3 hits



Comments:

1. **high efficiency, e.g.: Rate(SC_{min}=10) < 50 KHz**
2. **behavior vs U mass explained by production mechanism**

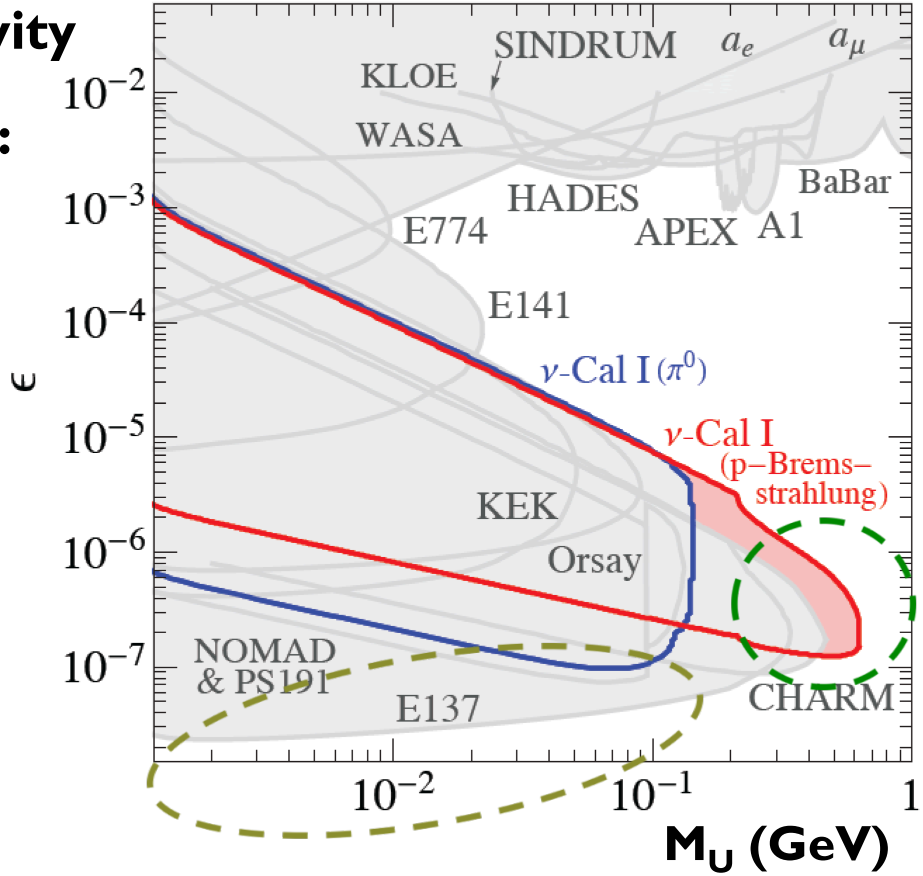
Expected sensitivity for U bosons

Really a first look to the U sensitivity

Possible to improve in the regions:

$\varepsilon \sim 10^{-8}$, $M_U \sim$ 10—100 MeV

$\varepsilon \sim 10^{-6}$, $M_U \sim$ 500 MeV



Comments:

1. **Will have to include U-strahlung production process**
2. **Possibly consider and simulate U hadronic decay modes**

Summary: L0 triggers for exotic searches

Reach ultimate sensitivities: maximize signal yield, even pay in systematics

Choice, to be validated after first data come: use EQ_2 in place of Q_2

Use RICH super cells, SC > SC_{Min}

Search for sterile neutrinos or U bosons with electron final states:

- **Good efficiency, allow tight cuts as ELKr > 35 GeV or more**
- **EQ_2 & E(35) & SC > 10, rate of background under control < 100 KHz**
- **No downscale should be needed**

Search for sterile neutrinos, $\mu\pi$ final state:

- **More delicate dependence for ELKr, allow 10 GeV cut at most**
- **EQ_2 & E(10) & SC > 10 & MUV3, Rate ~ 100 KHz (agrees with Note 14-07)**

Search for U bosons, $\mu\mu$ final state: safely use the di-muon trigger

Conclusion: future exotic analyses at NA62

The idea of studying sterile neutrino appearance and U bosons is promising and popular (both from the experimental and the theoretical points)

After having developed the necessary tools, i.e.,

- **PYTHIA simulation of meson production**
- **GEANT4 physics list including sterile neutrinos + dark photons**
- **Basic selection criteria for background rejection + viable trigger strategies**

I hope I have shown that:

- **provided the analysis of first data confirms the MC estimates, a fraction of the available bandwidth might be dedicated to exotic searches, to broaden the physics reach including motivated searches, obviously in parasitic mode with respect to the main NA62 goal**
- **electron + Tracks (not downscaled) might be a valid control sample for the main analysis: K $\rightarrow \pi\pi^0$, $\pi\pi^0\pi^0$, useful for tracking resolution and other studies**