KLEVER

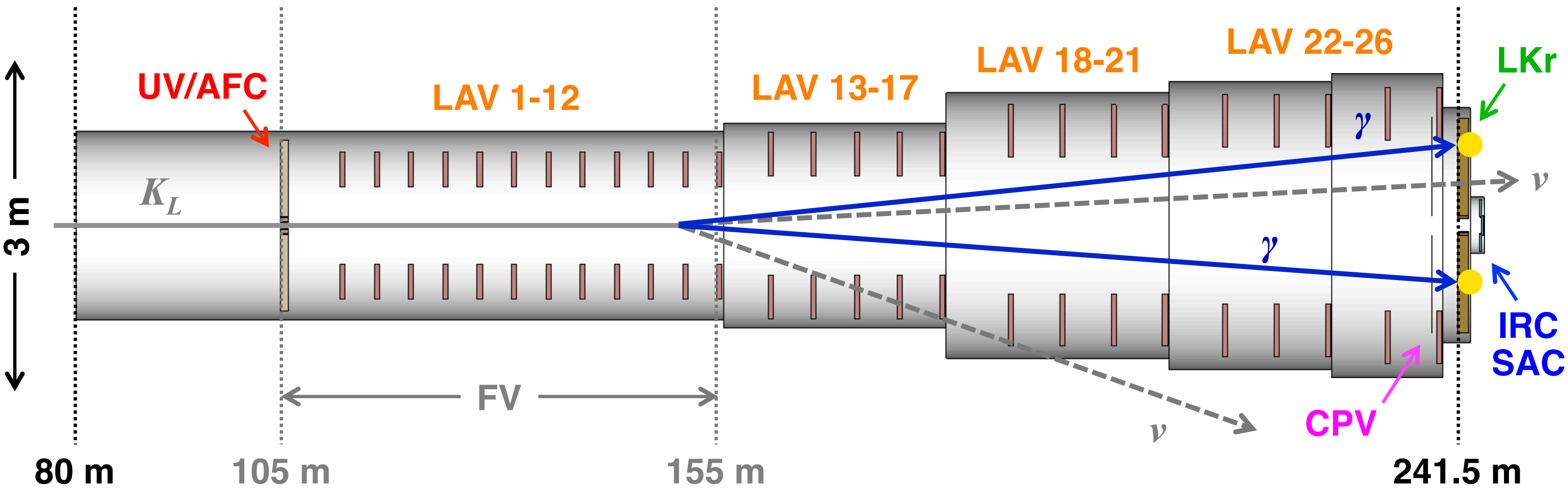
Ideas for PRIN 2017 projects for NA62

NA62-Italy meeting

Rome, 26 January 2018

Matthew Moulson

An experiment to measure $K_L \to \pi^0 \nu\bar{\nu}$ KLEVER



Main detector/veto systems:

UV/AFC	Upstream veto/active final collimator
LAV1-26	Large-angle vetoes (26 stations)
LKr	NA48 liquid krypton calorimeter
IRC/SAC	Small-angle vetoes
CPV	Charged particle veto

Survey of PRIN ideas

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PRIN funding (€800k) was used for the original KLEVER design study

- Could base a proposal on R&D for specific detector subsystems
- Presentation of propsal as follow-up to past PRIN project could be a value-added proposition

More than 1 PRIN proposal from NA62/KLEVER?

- Proposal by up to 6 Italian institutes
- INFN counts as 1 institute?
- CSN1 advice: < 4 sites, in order to avoid dispersion of resources
- Participation in PRIN projects is exclusive (1 project per person)

Possible PRIN hardware projects for KLEVER:

1. **Preshower**
2. **Charged-particle veto and tracking**
3. **Shashlyk calorimetry with longitudinal readout**
4. **Small-angle calorimeter and active final collimator**

PRIN ideas: Preshower

Why use a preshower?

- Redundancy for rejection for $K_L \to \pi^0\pi^0$
- Partial event reconstruction for calibration channels
- Sensitivity for exotics searches (ALP $\to \gamma\gamma$)
- Synergy with NA62:
  - Goal for PRIN project: develop prototype for NA62 Run 3 dedicated dump-mode running to allow ALP searches
  - Prototype constructed for 2021, for use in NA62 in 2024 or in KLEVER

A preshower has been discussed before:

- Ermanno, Massimo
  - Preshower performance dominated by MS in converter
  - ~10 m vertex resolution and ~10 MeV gg mass resolution
- Most background from even-paired events, thought not to be essential
- Require at least 1 conversion for signal events → cost in signal?
- Same complications as for adding tracking

PRIN ideas: Preshower

What changed?

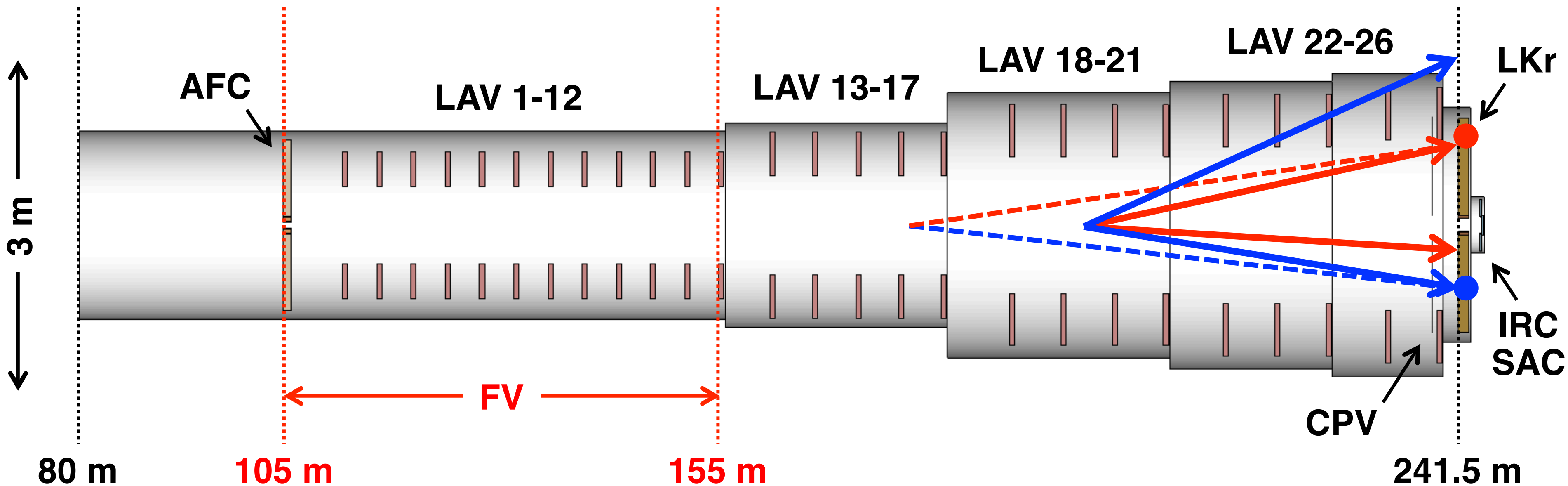
Initial studies performed before:

- upstream background included in simulation
- moving FV downstream to cope with L np0 background
- increase in number of events to reject with very poor vertex reconstruction

Design issues:

- 50% of pairs have at least 1 conversion events → enough to establish partial redundancy
- Place material as close as possible to LKr, so no energy from preshowering photons can escape
  - Integrated design with CPV?
- New technologies for tracking conversion products:
  - Multi-pattern gas detectors (i.e. micromegas): sx ~ 30 um
  - Innovative readout scheme to reduce data flow: data condensation on detector, only active cells read out (like GTK readout)

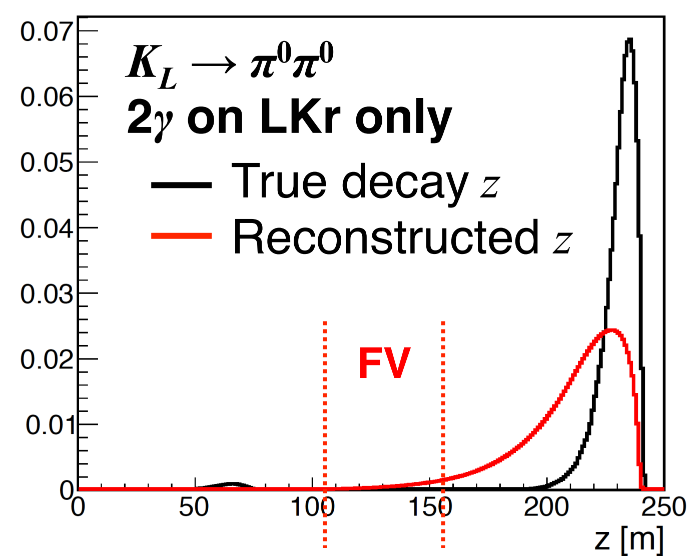
Detector layout for $K_L \to \pi^0 \nu\bar{\nu}$



Vacuum tank layout and FV similar to NA62

90-m distance from FV to LKr significantly helps background rejection

- Most $K_L \to \pi^0\pi^0$ decays with lost photons occur just upstream of the LKr
- "π^0s" from mispaired γs are mainly reconstructed downstream of FV



PRIN ideas: Preshower

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Preshower performance for KLEVER simulated with zOptical

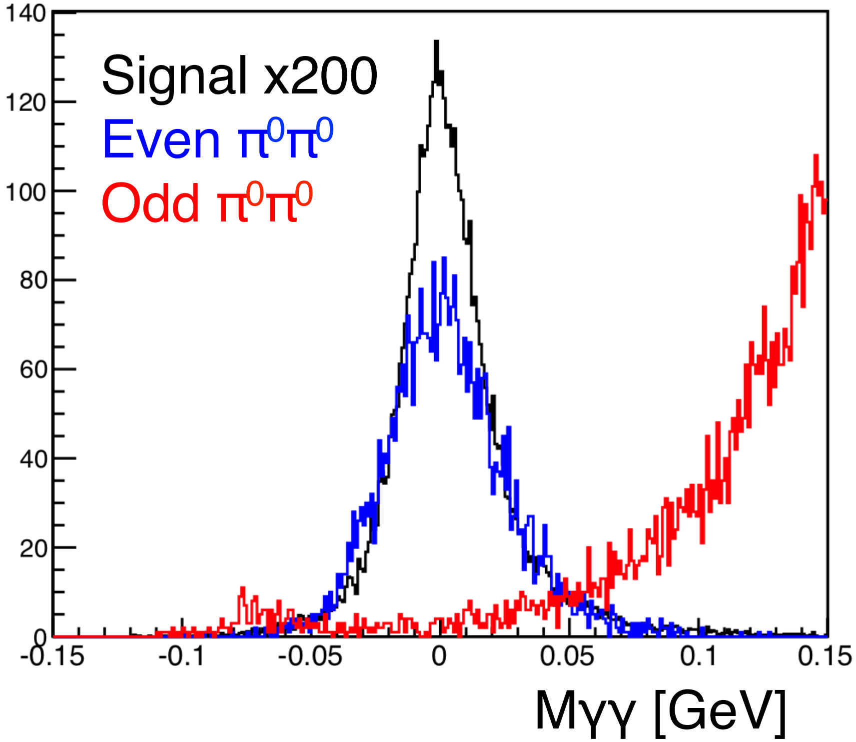
10M signal events + 1 year p0p0 background
- 8 mrad production angle
- FV 130 m < z < 170 m

Simulation details
- 0.5X0 radiator at z = 239.0 m
  - P(1 conv) = 33%, P(at least 1 conv) = 50%, P(2 conv) = 10%
- Tracking planes at z = 239.0 and z = 239.5 m
- 30 um spatial resolution on tracking planes
- Multiple scattering and pair production in converter only – not in tracking planes
- Assume e+ and e- share g energy equally and continue in forward direction

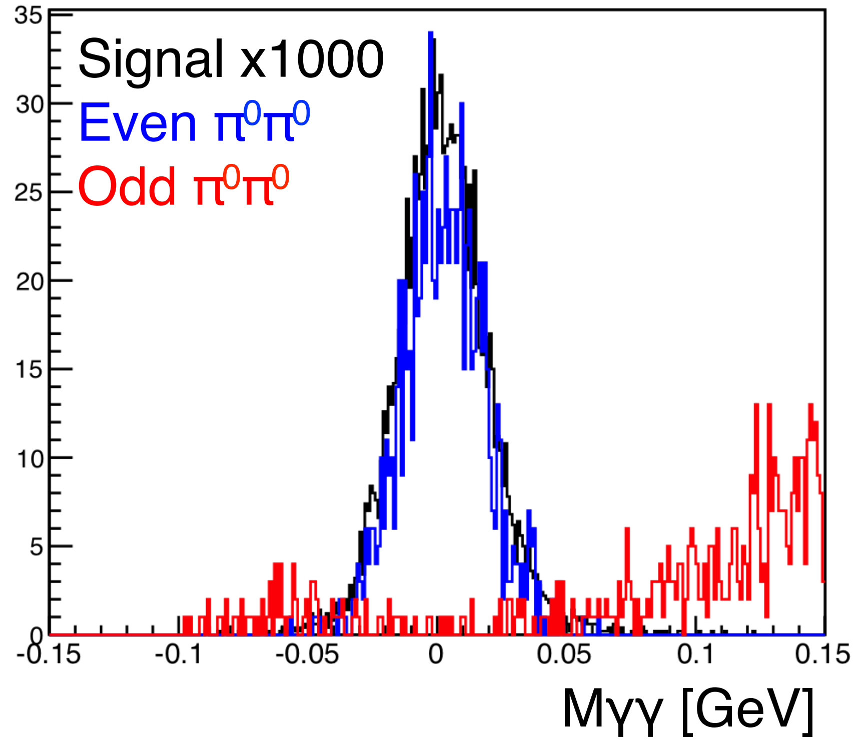
Vertex reconstruction
- 1 conversion: PCA on nominal beamline of photon momentum and nominal beamline
- 2 conversions: Midpoint of segment joining PCAs of each photon to the other
- Some flexibility in vertex reconstructon for 2-conversion case
  - Could use nominal beamline as a constraint
  - Needs to be explored

Preshower mass reconstruction

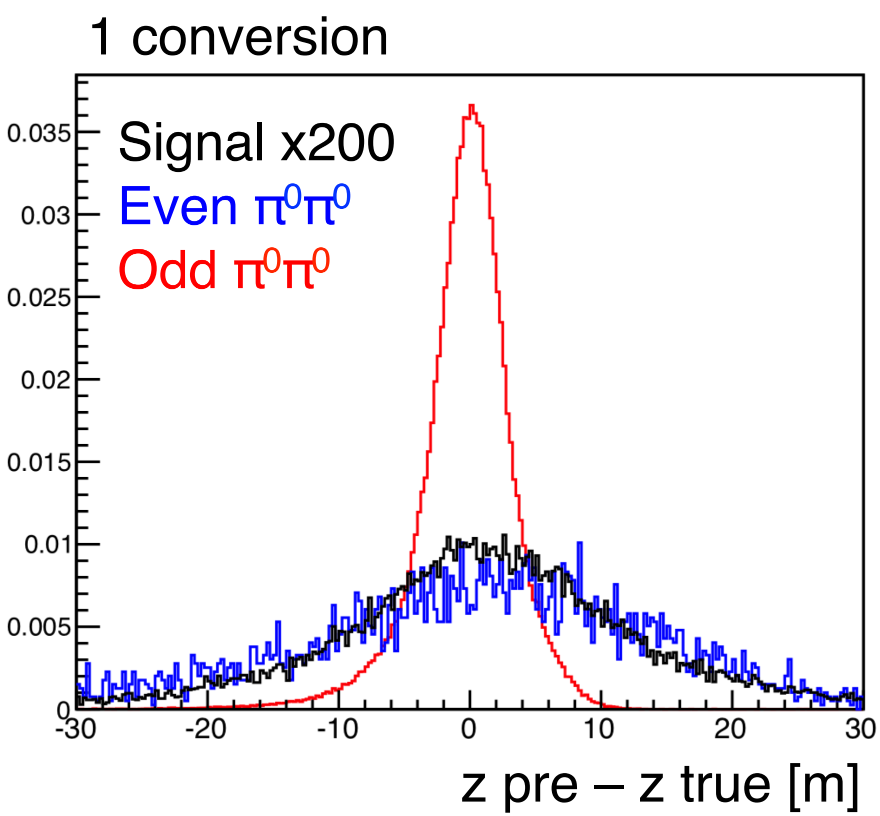
1 conversion

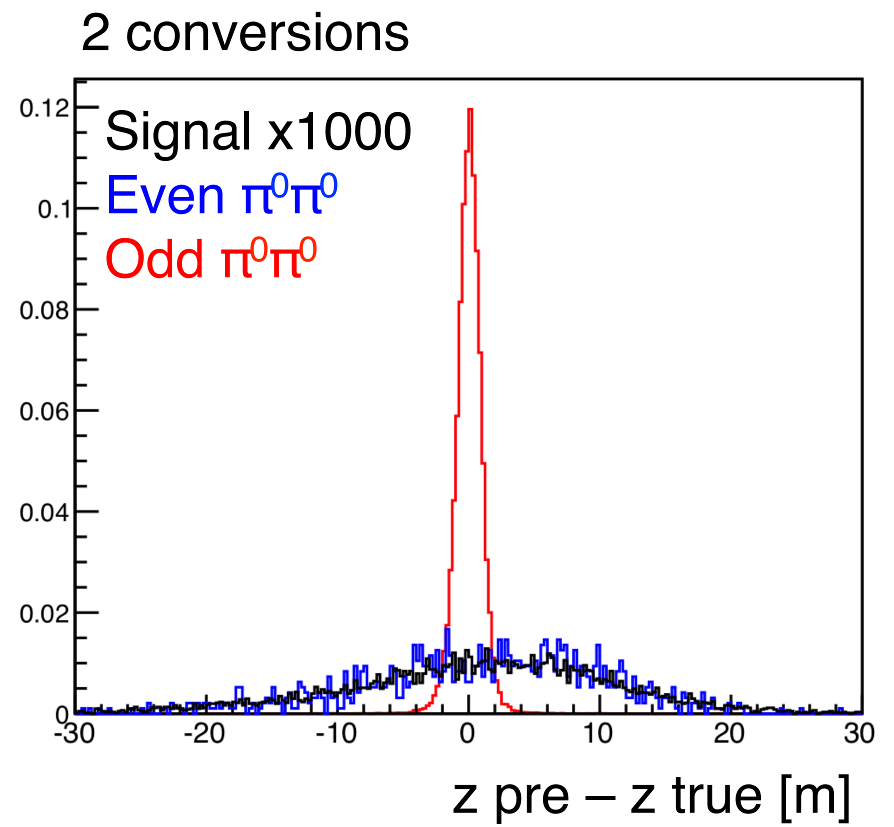


2 conversions

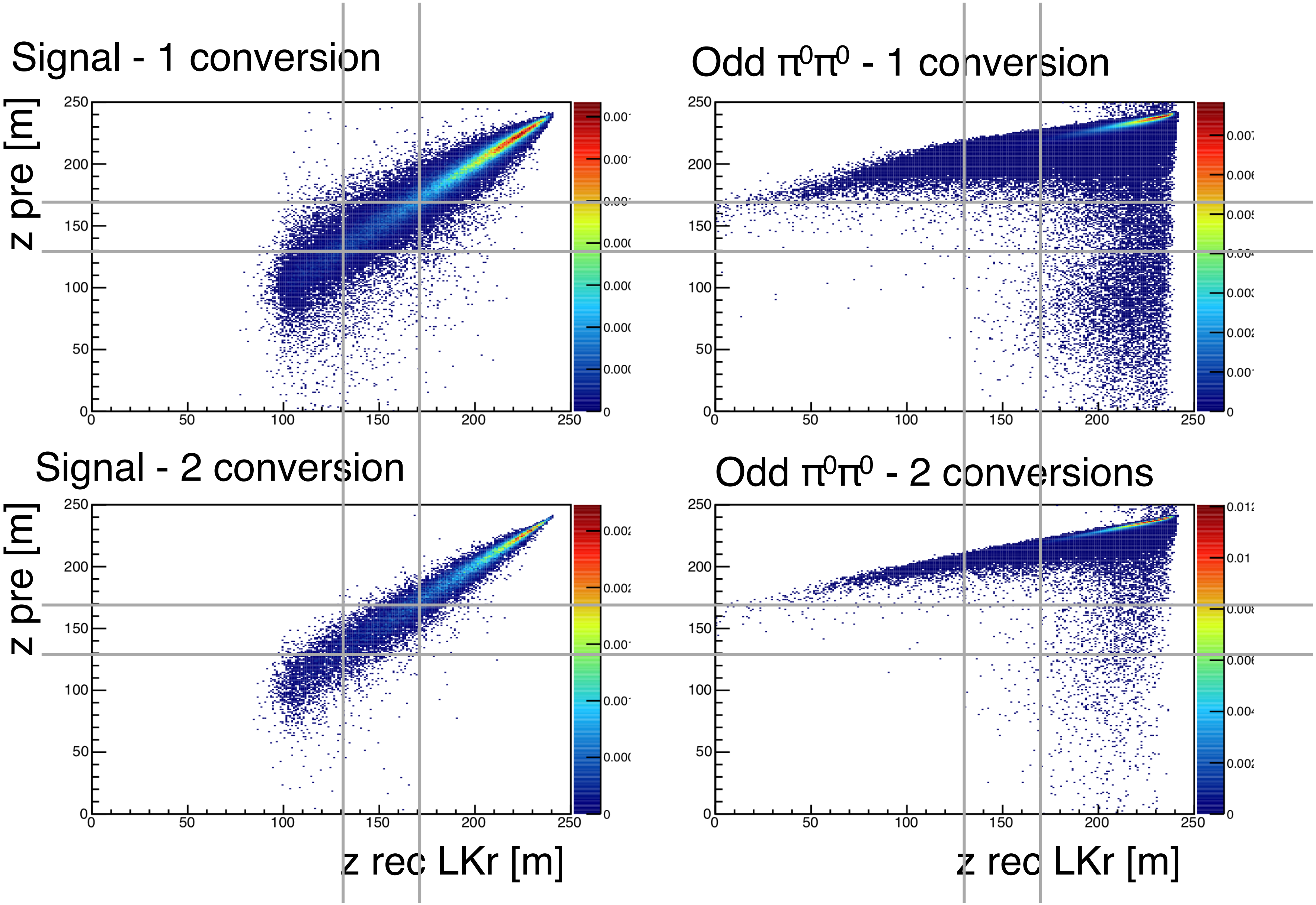


Preshower vertex reeconstruction





Preshower background rejection



PRIN ideas: CPV and tracking

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Charged-particle vetoes:

- Main challenge for CPV is to obtain high efficiency (>99.5%) from a scintillating tile type design while minimizing material burden
  - Multiple direct SiPM readout of scintillating tiles
  - Lightweight mechanical suspension (carbon-fiber fabric?)
- Commonalities with preshower project?
- Commonalities with NA62 upstream veto project (Gaia)?
- Develop and/or study impact of tracking system in this context?

Add a tracking system for charged particles?

Advantages

- Expand physics scope of experiment: $K_L \to \pi^0 \ell^+ \ell^-$, $K_L \to \ell^+ \ell^- \ell^+ \ell^-$, etc.
- Facilitate calibration and efficiency measurements

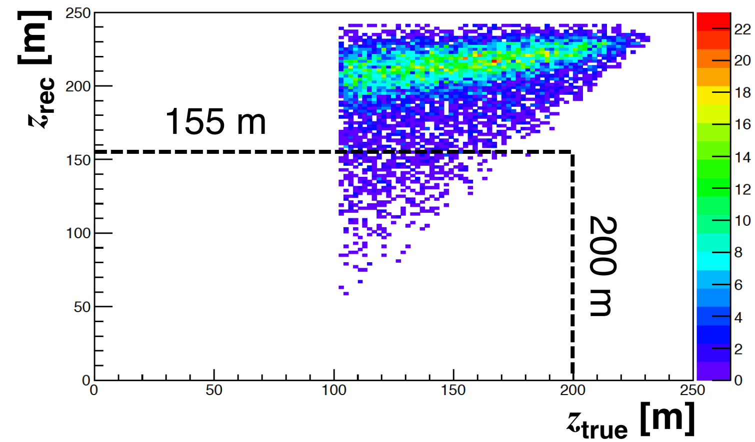
Issues

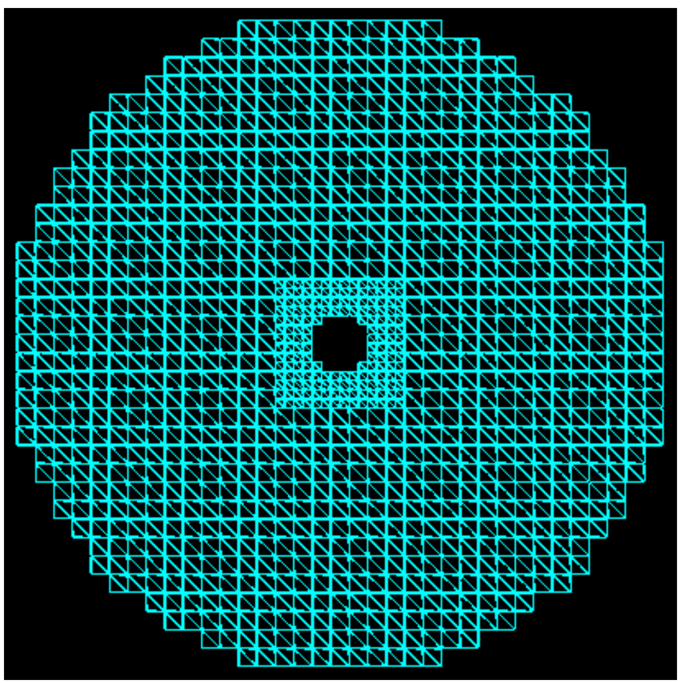
- Potential complications for $K_L \to \pi^0 \nu\nu$
  - Simulate impact of material budget on photon veto efficiency
  - Evaluate impact of magnet on photon veto coverage

Charged particle veto

$K_L \to \pi e \nu$ can emulate signal when both π and e deposit energy in LKr

- Fake π^0 vertexes from πe all reconstructed downstream of true decay
  - π^+ deposits only a fraction of its energy
- K_{e3} decays with "π^0" reconstructed in FV have $z_{\rm rec}$ < 200 m
  - All within the acceptance of the CPV





Using MC to add detail to design of CPV

Square scintillator tiles, 5-mm thick, supported on carbon fiber membrane

- 2 planes → 3% X_0

Tile geometry: 4x4 cm² or 8x8 cm²

- Smaller tiles near beam line
- Cracks staggered between planes
- 4 chamfered corners (45°) for direct SiPM coupling

PRIN ideas: Shashlyk calorimetry

Shashlyk calorimeters with longitudinal readout:

- Continued simulation studies and comparison with results obtained at Protvino and/or at Frascati BTF
- Design of upstream veto and/or main calorimeter
- Construction of prototypes to test with photon and neutral hadron beam in Run 3
- Possible interest from Birmingham if not addressed in PRIN

Development of new lead glasses (ADRIANO)?

Suitability of LKr calorimeter

Study and confirm LKr performance with NA62 data

- Two-cluster resolution
- Photon detection efficiency
  - Effect of dead cells, etc.

In parallel with efforts by NA62

Explore possibilities to improve time resolution with faster readout

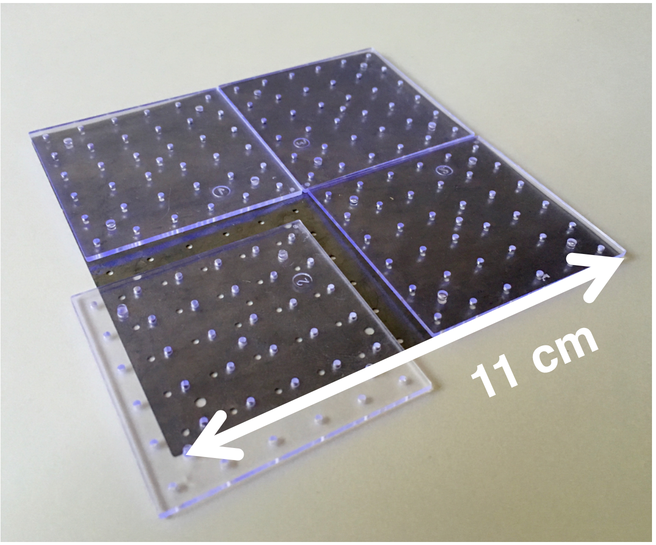
- Signal π^0 candidates all have $E_{\gamma\gamma}$ > 20 GeV

  σ_t = 2.5 ns/$\sqrt{E}$ (GeV) → 500 ps or better
- Needs improvement – SAC may have ~100 MHz accidental rate
- Simulating readout upgrades to estimate effect on time resolution:
  - Shorter shaping time, faster FADCs

Evaluate long-term reliability of LKr (2018 → 2030):

- Identify support systems needing replacement or upgrade
- Catalog of dead cells, prospects for repair

Shashlyk-based alternatives to LKr



Fine-sampling shashlyk based on PANDA forward EM calorimeter produced at Protvino

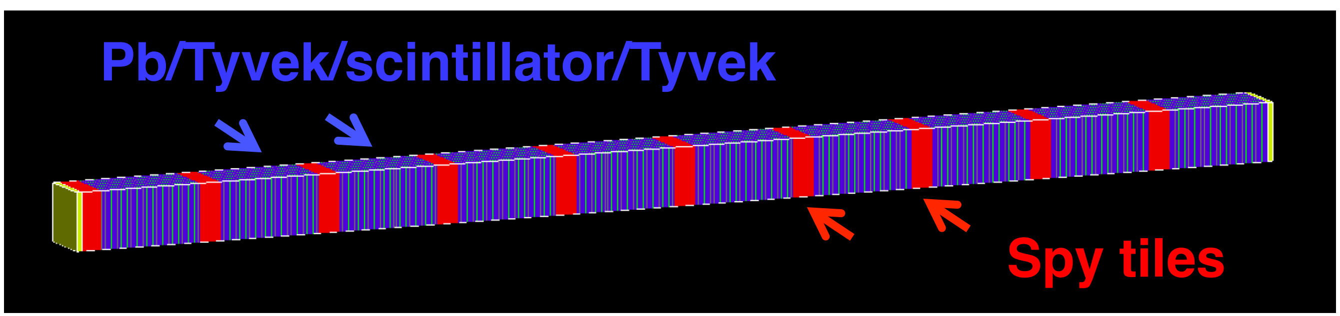
0.275 mm Pb + 1.5 mm scintillator

$\sigma_E/\sqrt{E}$ **~ 3%** $/\sqrt{E}$ (GeV)
σ_t **~ 72 ps** $/\sqrt{E}$ (GeV)
σ_x **~ 13 mm** $/\sqrt{E}$ (GeV)

} PANDA, KOPIO prototypes

New for KLEVER: Longitudinal shower information from spy tiles

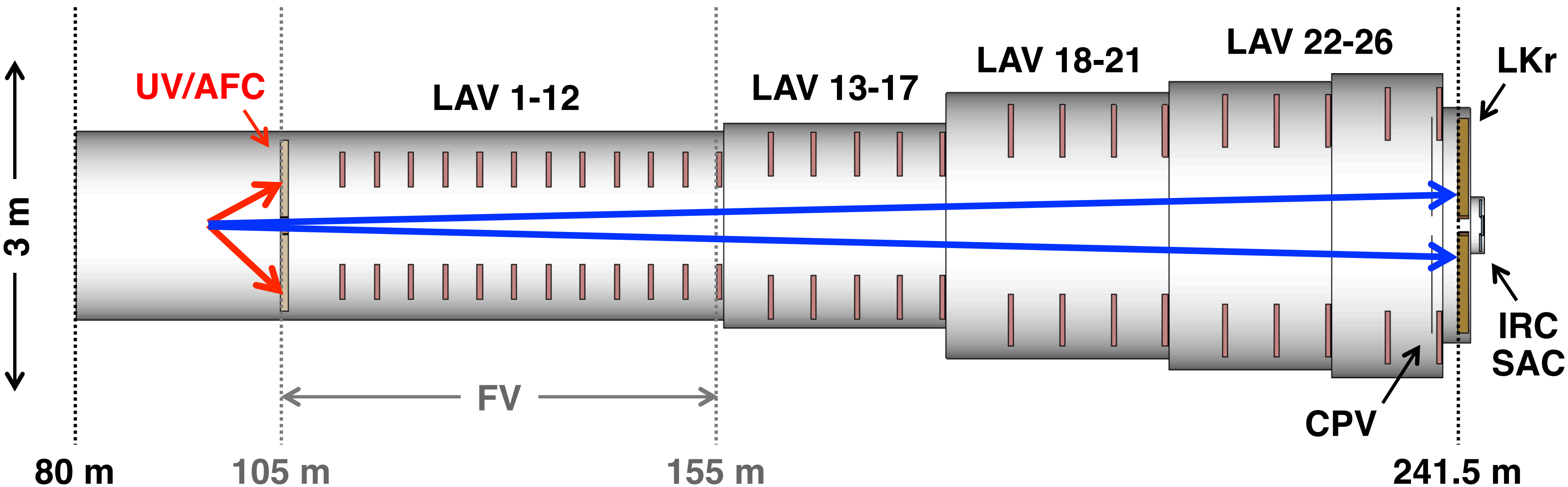
- PID information: identification of μ, π, n interactions
- Shower depth information: improved time resolution for EM showers



Thicker spy tiles (5-20 mm) with independent WLS fiber readout

Simulation studies in progress (e.g., to choose spy tile thickness)

Vetoes for upstream K_L decays



- **25 m of vacuum upstream of final collimator**
  No obstruction for γs from decays with 80 m < z < 105 m
- **Upstream veto (UV):**
  Outer ring: Shashlyk calorimeter, Pb/scint in 1:5 ratio
  10 cm < r < 1 m → 1/3 of total rate
- **Active final collimator (AFC):**
  Inner ring: LYSO collar counter, 80 cm deep, shaped crystals
  4.2 cm < r < 10 cm → 2/3 of total rate

Vetoes for upstream K_L decays

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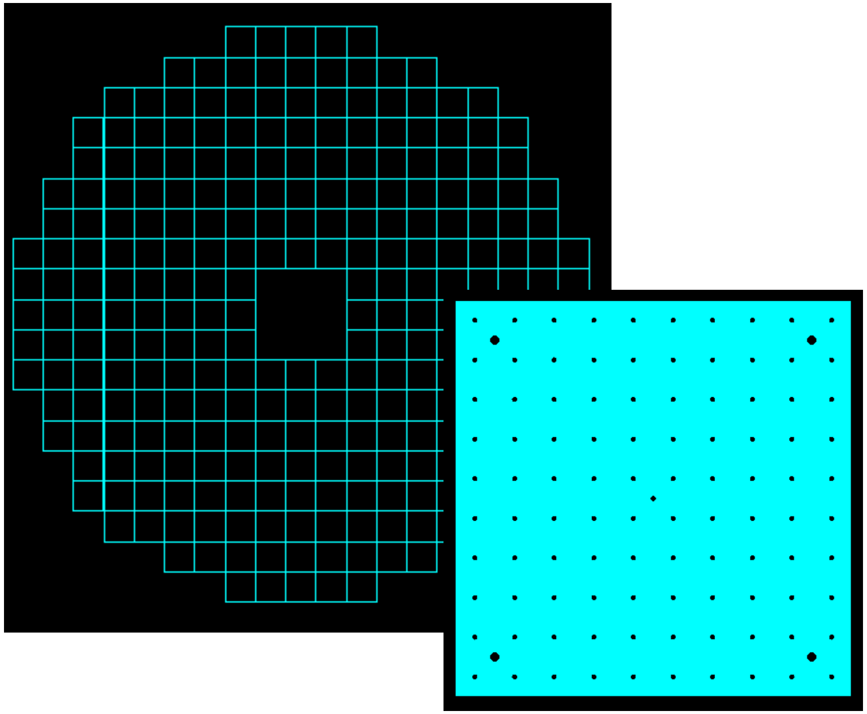
Rejects $K_L \to \pi^0\pi^0$ from upstream of final collimator (80 m < z < 105 m)

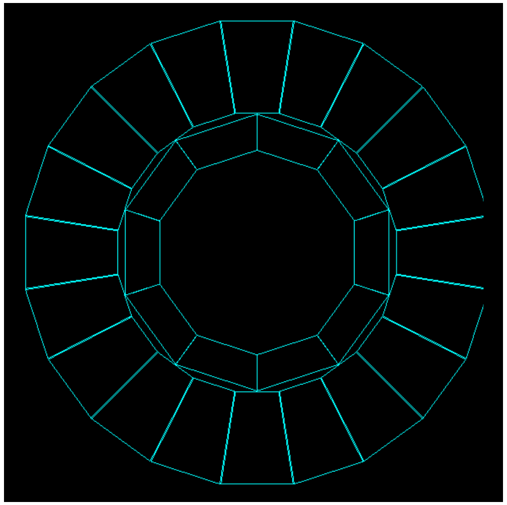
Upstream veto (UV):

- 10 cm < r < 1 m:
- Shashlyk calorimeter modules à la PANDA/KOPIO

As implemented in MC:



Active final collimator:



- 4.2 < r < 10 cm
- LYSO collar counter
- 80 cm long
- Internal collimating surfaces

- Intercepts halo particles from scattering on defining collimator or γ absorber
- Active detector → better rejection for π^0 from n interactions

Residual background from upstream $K_L \to \pi^0\pi^0$:

15 events/5 years

PRIN ideas: SAC and AFC

Small-angle calorimeter with crystal-metal absorber

- Simulation of coherent effects in crystals
- Analysis of test-beam data
- Design of calorimeter, including mechanics, Si-pad detectors, etc.
- Development of prototype to test in 2021

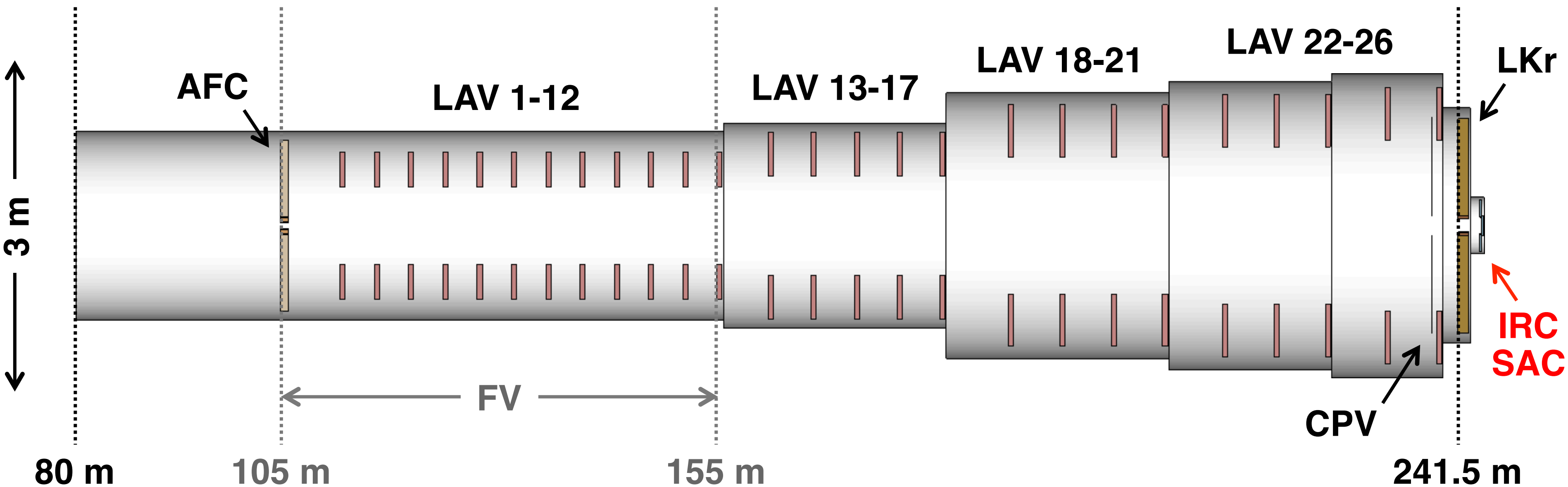
Active final collimator:

- Design and prototype to test with neutral hadron beam in Run 3

Status:

- Laura interested in proposing own PRIN project focused more generally on compact calorimetry for fixed target
  - KLEVER SAC could be a special case
- Mauro (La Sapienza) and Matteo talking with Laura to explore possible synergies/points in common

Small-angle photon vetoes



Small-angle photon veto systems (IRC, SAC)

- Reject high-energy γs from $K_L \to \pi^0\pi^0$ escaping through beam hole
- Must be insensitive as possible to 3 GHz of beam neutrons

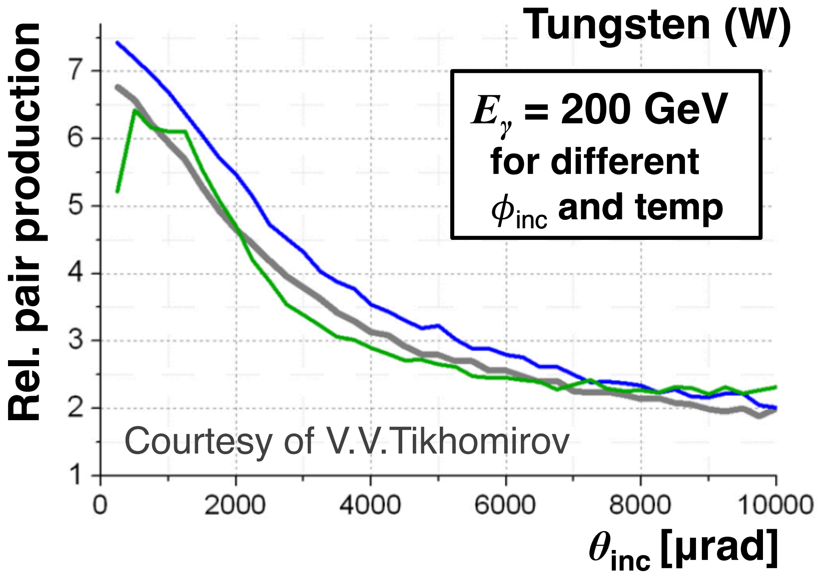
Beam comp.	Rate (MHz)	Req. $1-\varepsilon$
γ, $E > 5$ GeV	**230**	**10^{-2}**
γ, $E > 30$ GeV	**20**	**10^{-4}**
n	**3000**	**–**

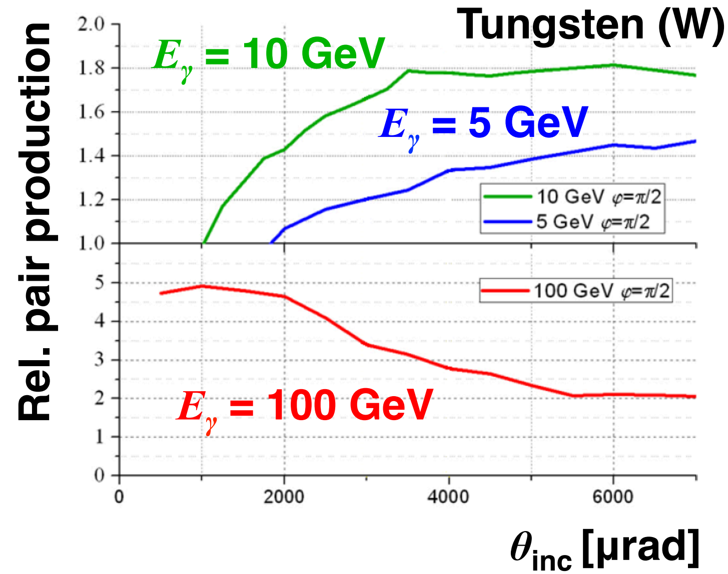
Baseline solution:

- Tungsten/silicon-pad sampling calorimeter with crystal metal absorber

Efficient γ conversion with crystals

Coherent effects in crystals enhance pair-conversion probability



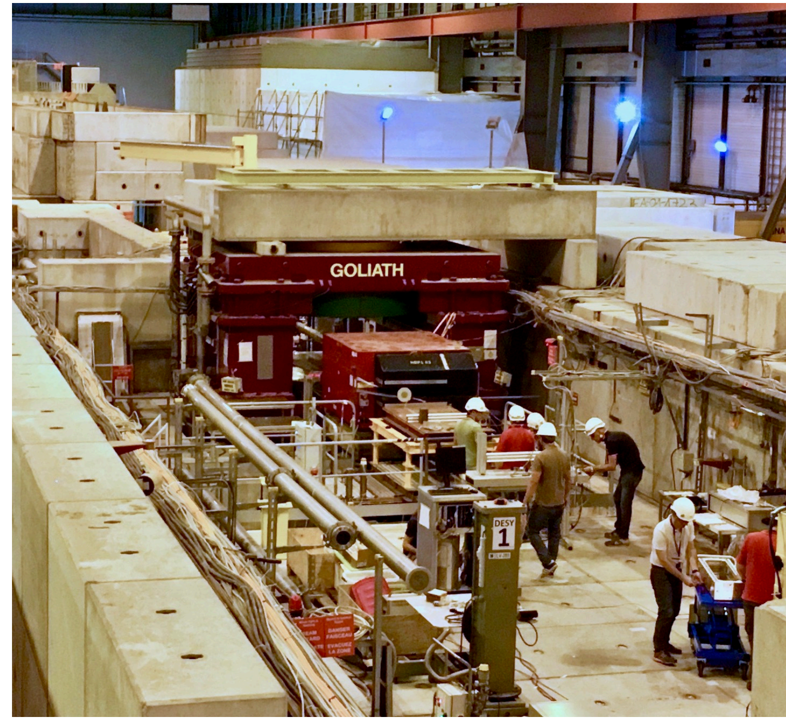


Use coherent effects to obtain a converter with large effective λ_{int}/X_0:

1. **Beam photon converter in dump collimator**
   Effective at converting beam γs while relatively transparent to K_L
2. **Absorber material for small-angle calorimeter (SAC)**
   Must be insensitive as possible to ~GHz of beam neutrons while efficiently vetoing high-energy γs from K_L decays

Beam test of $\gamma \to e^+e^-$ in crystals

KLEVER is collaborating with INFN groups with experience with coherent phenomena in crystals for test beam measurement of pair-production enhancement



July 2017 AXIAL data taking, H4 beamline
Run Coordinator: L. Bandiera

E. Bagli, L. Bandiera, V. Guidi, A. Mazzolari, M. Romangnoni, A. Sytov (Ferrara);
D. De Salvador (LNL);
V. Mascagna, M. Prest (Milano Bicocca);
E. Vallazza (Trieste).

Test goals:

1. Observe $\gamma \to e^+e^-$ enhancement with a commercially available tungsten crystal
2. Measure spectrum of transmitted γ energy for a thick (~10 mm) crystal
3. Measure pair conversion vs. E_γ, θ_{inc} for $5 < E_\gamma < 150$ GeV
4. Obtain information to assist MC development for beam photon converter and SAC

Beam test of $\gamma \to e^+e^-$ in crystals

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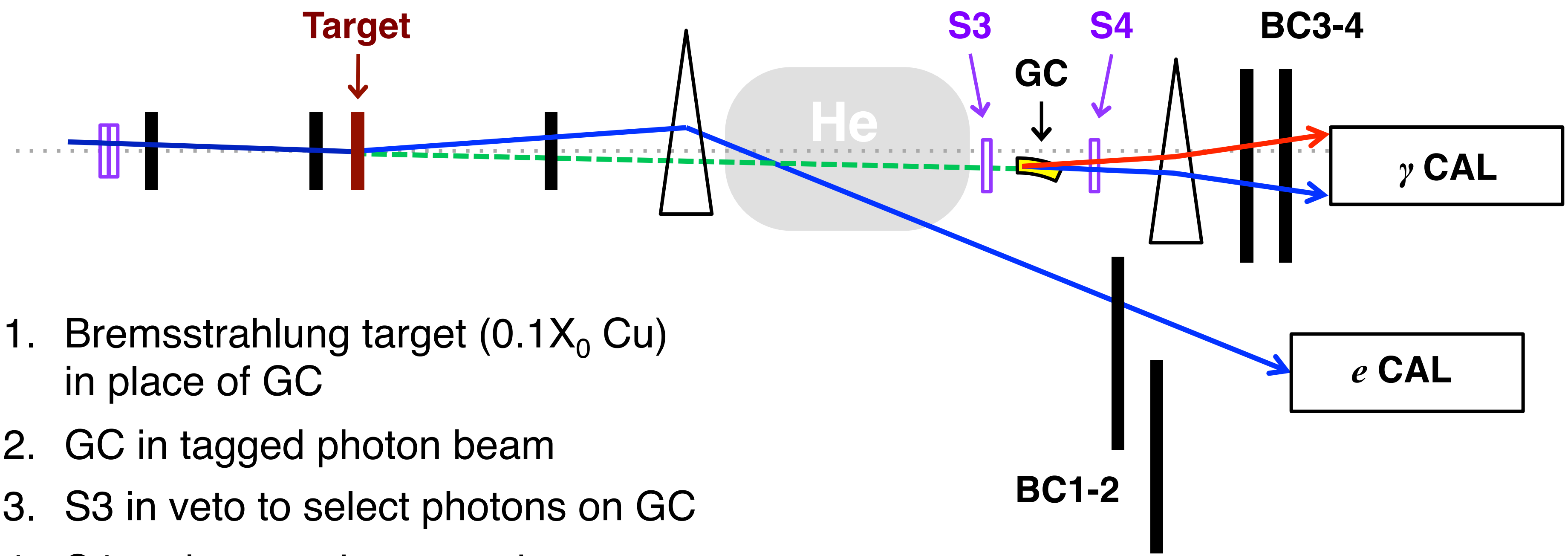
Tagged photon beam setup for H4 (or H2) test beam:



1. Bremsstrahlung target ($0.1X_0$ Cu) in place of GC
2. GC in tagged photon beam
3. S3 in veto to select photons on GC
4. S4 to detect pair conversions
5. BC1-2: 9.5×9.5 cm^2 Si detectors to extend coverage of tagging system
6. Analysis magnet and BC3-4 to assist in reconstruction of e^+e^- pairs
7. He bag to reduce multiple scattering

- **Nearly all detectors and DAQ system available for use from AXIAL**
- **INFN has approved funds for crystal samples, etc.**
- **1 week of beam requested in 2018**

$K_L \to \pi^0 \ell^+ \ell^-$

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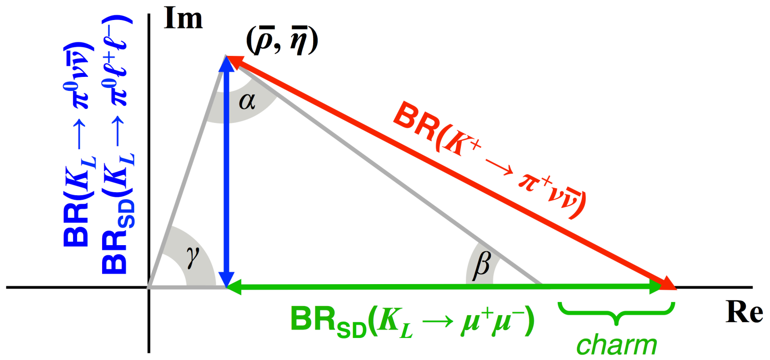
$K_L \to \pi^0 \ell^+ \ell^-$ vs $K \to \pi\nu\nu$:

- Somewhat larger theoretical uncertainties from long-distance physics
  - SD CPV amplitude: γ/Z exchange
  - LD CPC amplitude from 2γ exchange
  - LD indirect CPV amplitude: $K_L \to K_S$
- $K_L \to \pi^0 \ell^+ \ell^-$ can be used to explore helicity suppression in FCNC decays

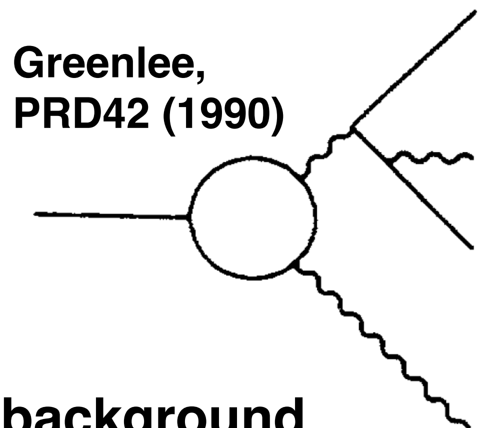


$K_L \to \pi^0 \ell^+ \ell^-$ CPV amplitude constrains UT in same way as $BR(K_L \to \pi^0 \nu\nu)$

Main background: $K_L \to \ell^+ \ell^- \gamma\gamma$

- Like $K_L \to \ell^+ \ell^- \gamma$ with hard bremsstrahlung

Greenlee, PRD42 (1990)



$BR(K_L \to e^+ e^- \gamma\gamma) = (6.0 \pm 0.3) \times 10^{-7}$ $E_\gamma^* > 5$ MeV

$BR(K_L \to \mu^+ \mu^- \gamma\gamma) = 10^{+8}_{-6} \times 10^{-9}$ $m_{\gamma\gamma} > 1$ MeV

$K_L \to \pi^0 e^+ e^-$ channel is plagued by $K_L \to e^+ e^- \gamma\gamma$ background

– Small acceptance because of tight cuts on Dalitz plot

$K_L \to \pi^0 \mu^+ \mu^-$ channel may be more tractable