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Development of a RICH detector for CBM

Christian Pauly, BU Wuppertal
for the
CBM collaboration

CBM-RICH group
GSI, Germany
Hochschule Esslingen, Germany
PNPI Gatchina, St. Petersburg, Russia
Pusan Natl. University, Korea
University Gießen, Germany
Bergische Universität Wuppertal, Germany

outline

- Introduction
  - CBM @ FAIR
  - RICH detector for electron identification
- RICH detector development
  - Some simulations
  - Photo detector, Photomultiplier evaluation
  - Wavelength shifter
  - Mirror evaluation
- Prototype tests
  - First proximity focusing tests 2009 / 2010
  - Full scale prototype test 2011
- Summary

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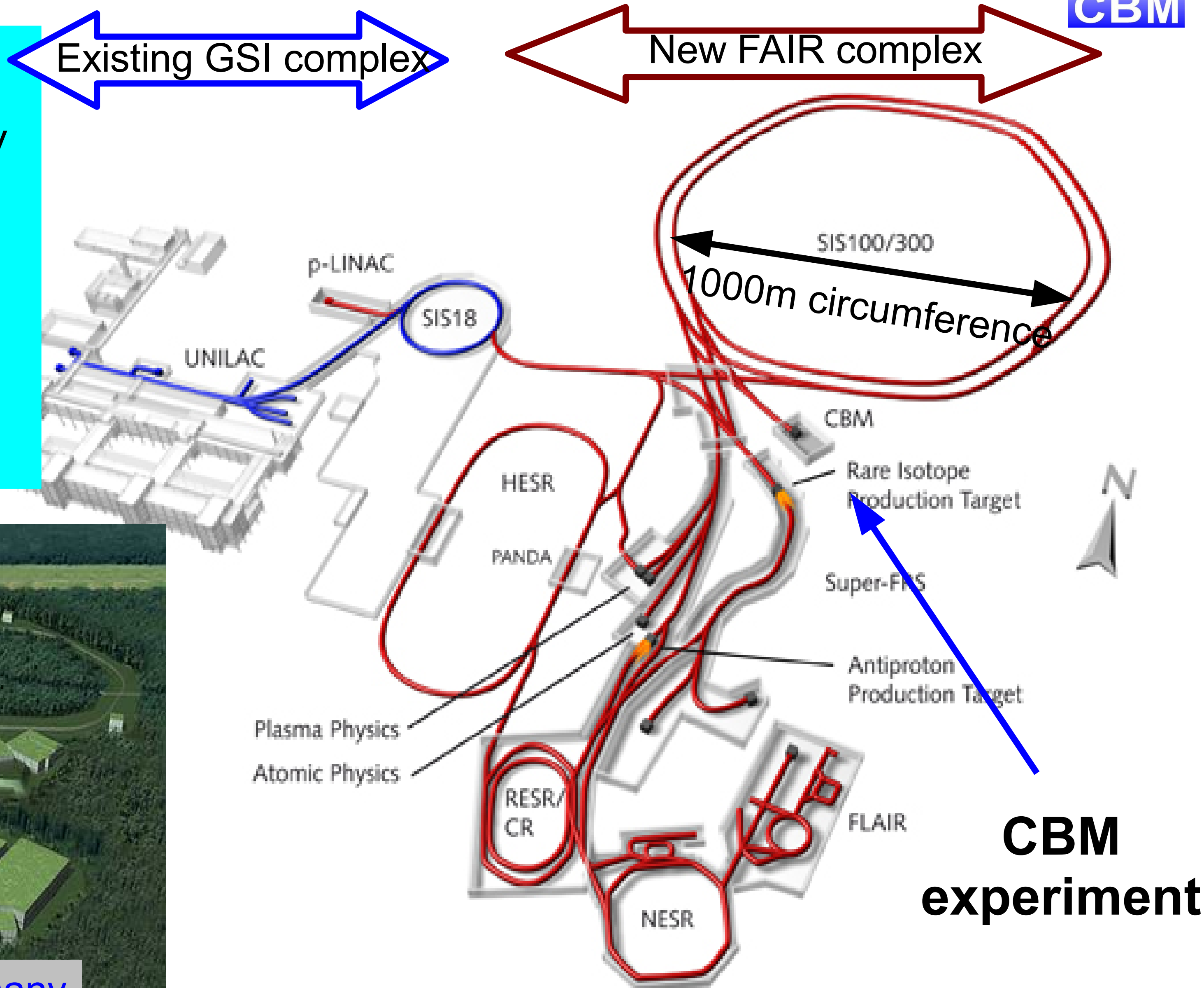
The FAIR complex at GSI

SIS100:
p beams : 2 – 30 GeV
Au beam : 2 – 15 AGeV
U beam(q=28+) : 10 AGeV
first beam : ~ 2016

SIS300: (later stage)
p beam : 2-90 GeV
Au beam : 2-35 AgeV
max intensity : 10^9 ions/s




GSI Darmstadt, Germany

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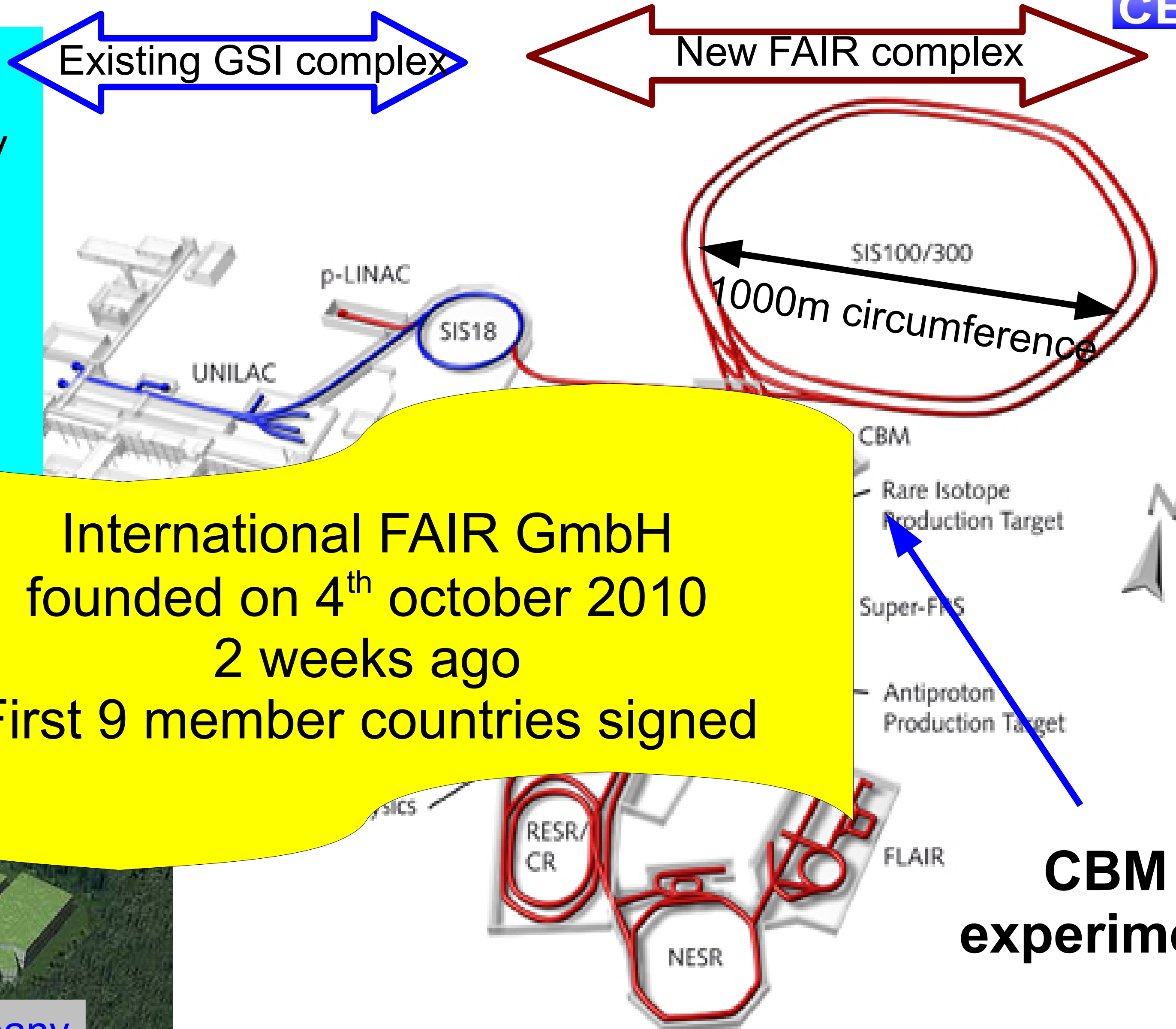


International FAIR GmbH
founded on 4^{th} october 2010
2 weeks ago
First 9 member countries signed

CBM experiment

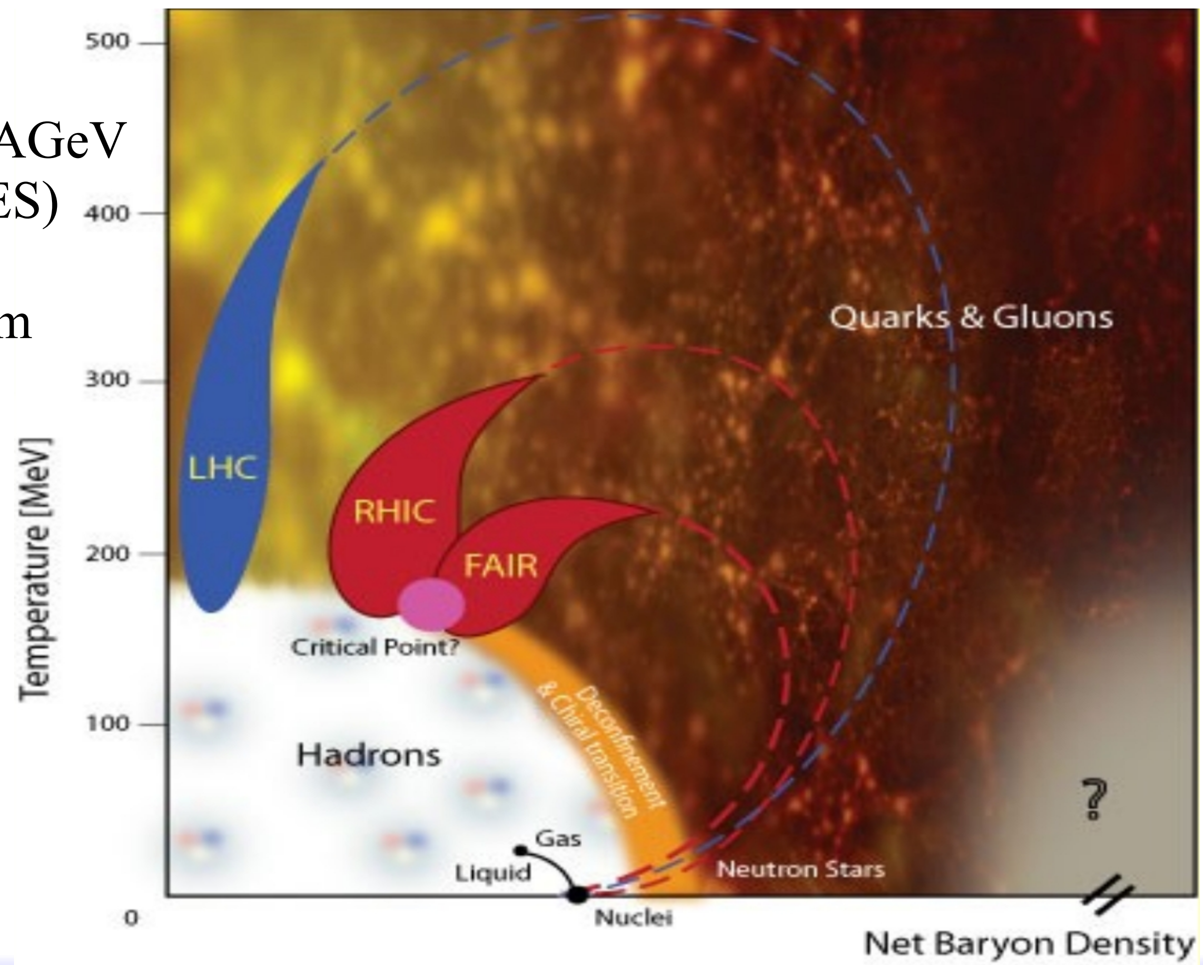
The CBM physics case

- Explore the landmarks of the QCD phase diagram at high net-baryon densities μ_b
  - First order phase transition
  - Chiral restoration at high baryon densities
  - **QCD critical endpoint**

- In Au-Au collisions from 2-45 AGeV
- starting in 2018 (CBM + HADES)

- Complementary physics program to RHIC, LHC

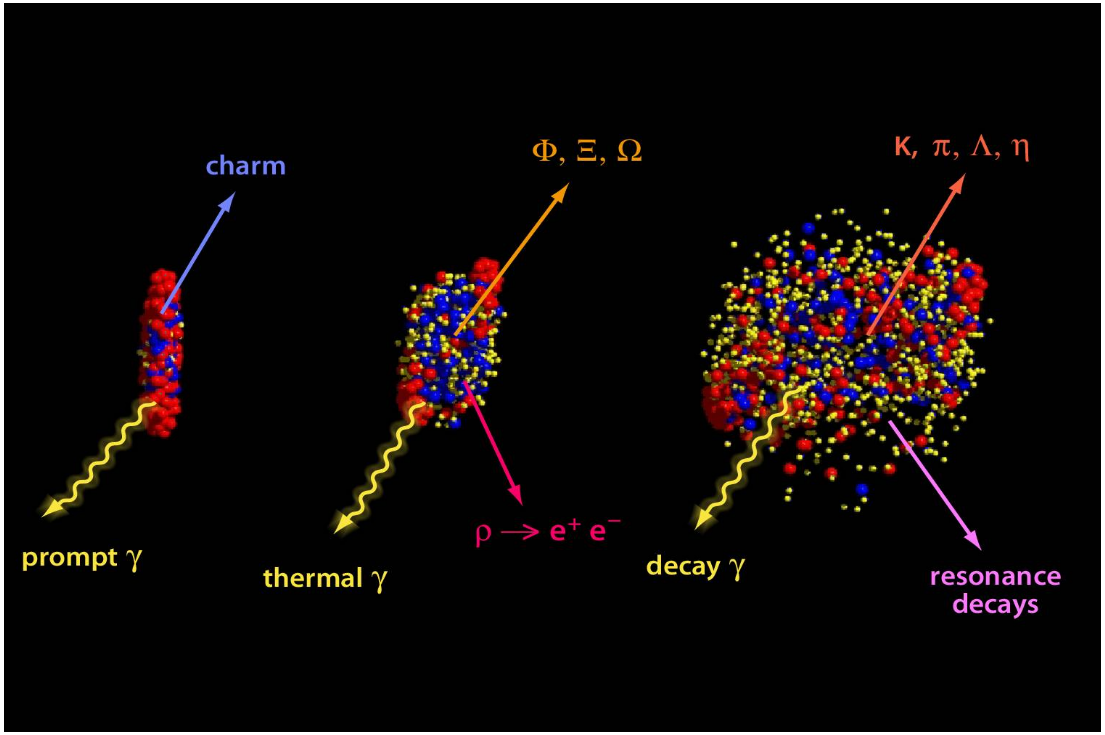
“CBM physics book”
Lecture Notes in Physics, Vol. 814
1st Edition, 2011, 960 p, Hardcover
ISBN: 978-3-642-13292-6



Probes of dense hadronic matter

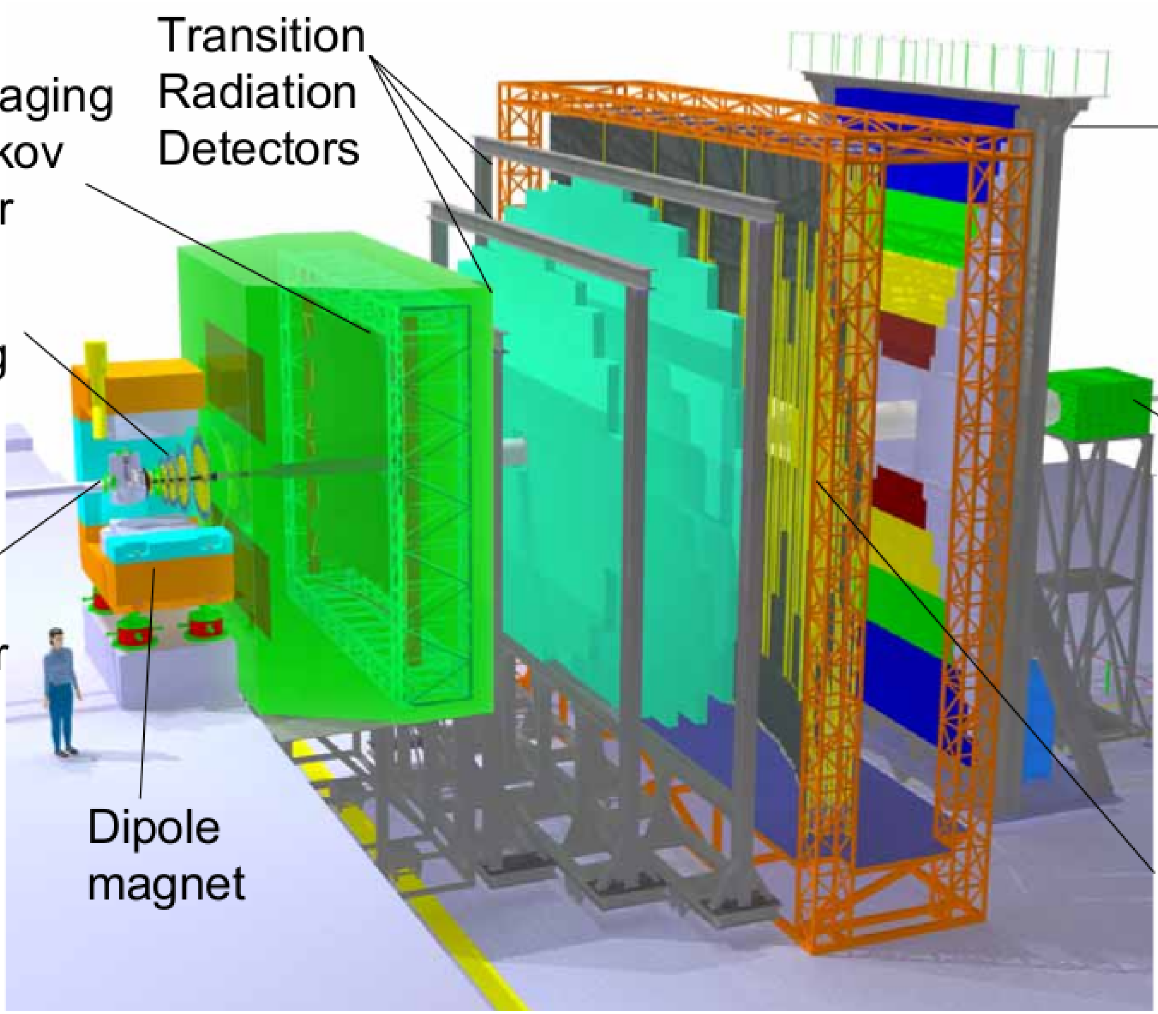
- CBM goal: measure the early, high density phase of the fire ball
- Unique approach → use dilepton probes
  - ρ, ω, Φ → $e^+ e^-$
  - J/Ψ, Ψ' → $e^+ e^-$
- Rare probes !
  Dilepton decays for ρ,σ,ω,
  suppressed by 4 orders mag:
  $1/\alpha^2 = (1/137)^2$

  → need high luminosity
  → reaction rate up to 10MHz
  → fast detector system
  → good particle ID
  → good pion suppression: 10^{-4}



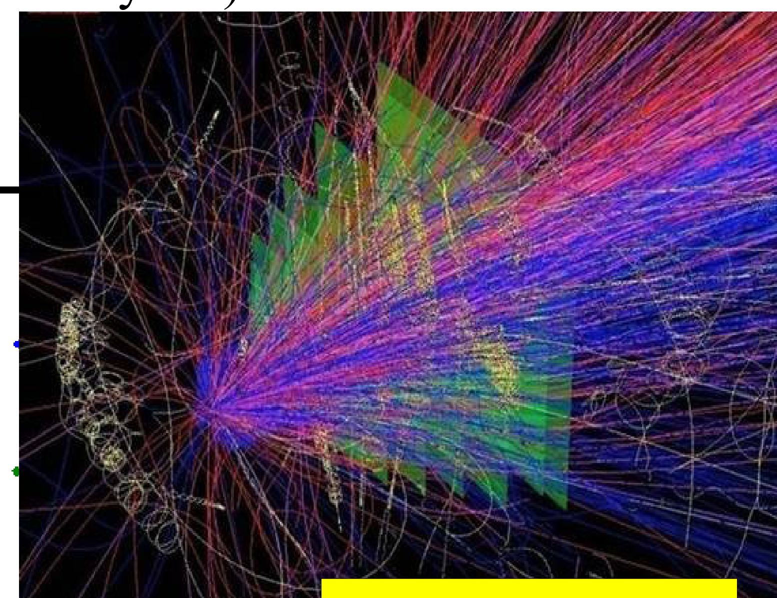
U – U collision at 23 AGeV, evolution in time

The CBM detector – electron setup

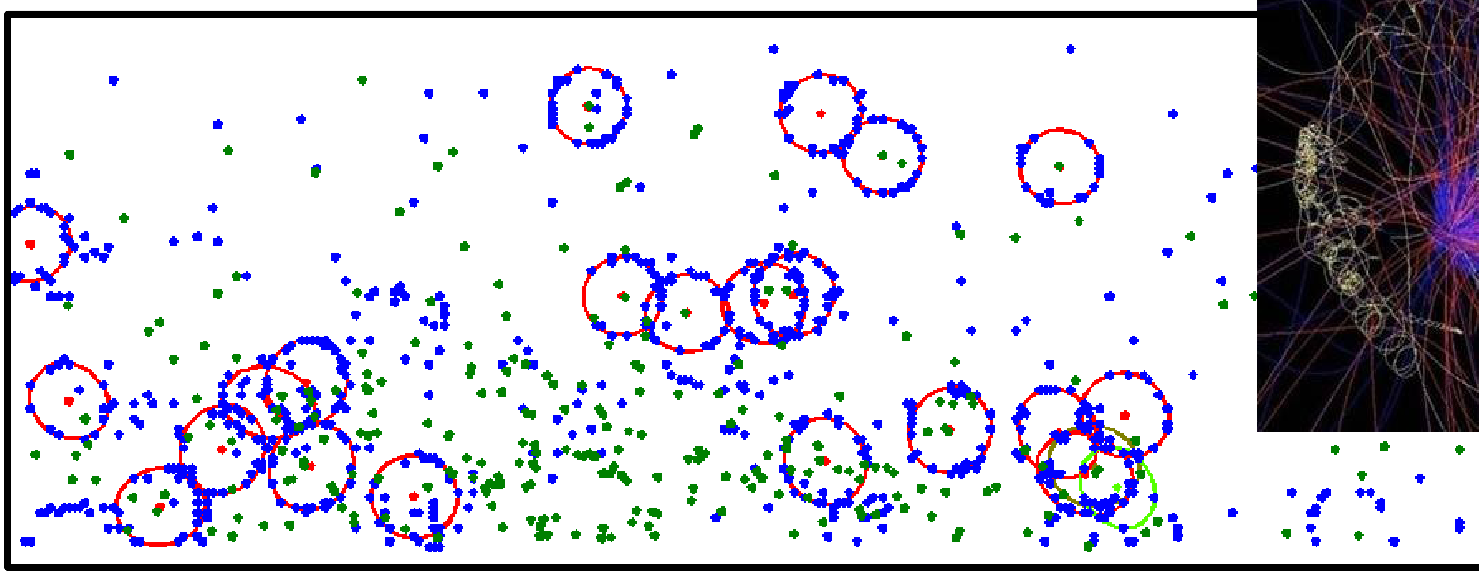


Challenges in Au+Au collisions

- RICH behind material budget of STS ➔ secondary e^+e^- , high ring density
- High track densities ➔ possible ring-track mismatching
- Interaction rate up to 10 MHz
- Radiation dose (< 3 kRad / year, < 3×10^{11} n-eq /cm^2 / year)



Event display showing 1/4 of photon detector:

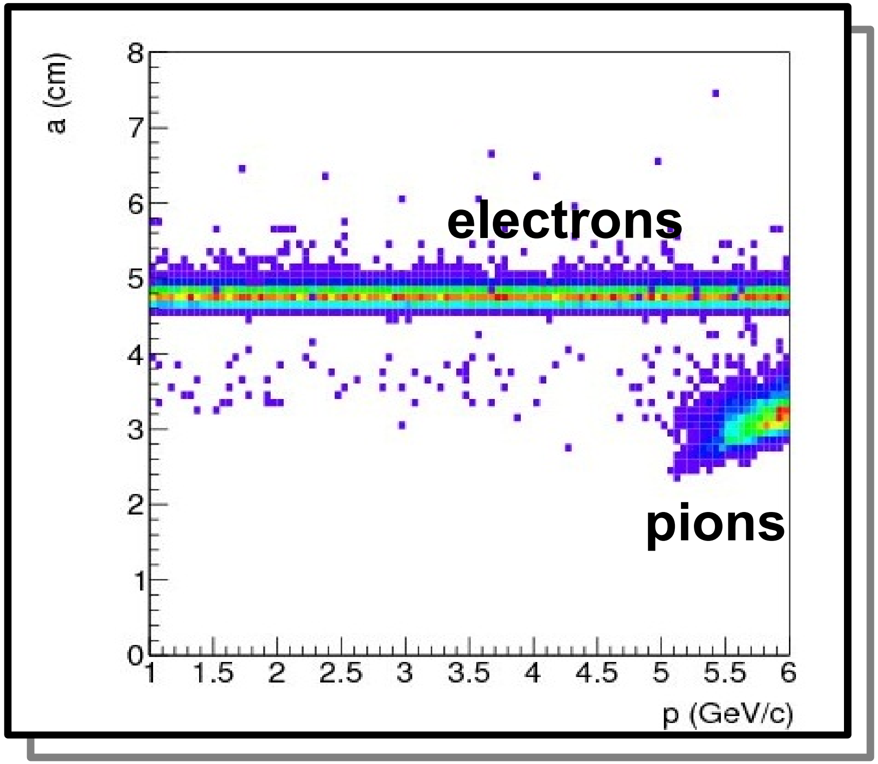


Green: track projections, blue: hits, red: ring fits

~100 rings per central Au+Au coll. at 25 GeV/nucl.

Simulations

- Full Geant detector simulation, ROOT-based analysis framework
- Ring-finding using localized Hough transformation
- Track matching: STS – RICH – TRD - TOF



Ring radius as funtion of momentum:
(pixel size : 5.8 x 5.8 mm^2)

21 hits / e^- ring (mean)
N_0 = 130-140 photons generated
Mirror thickness: ca 10% X_0

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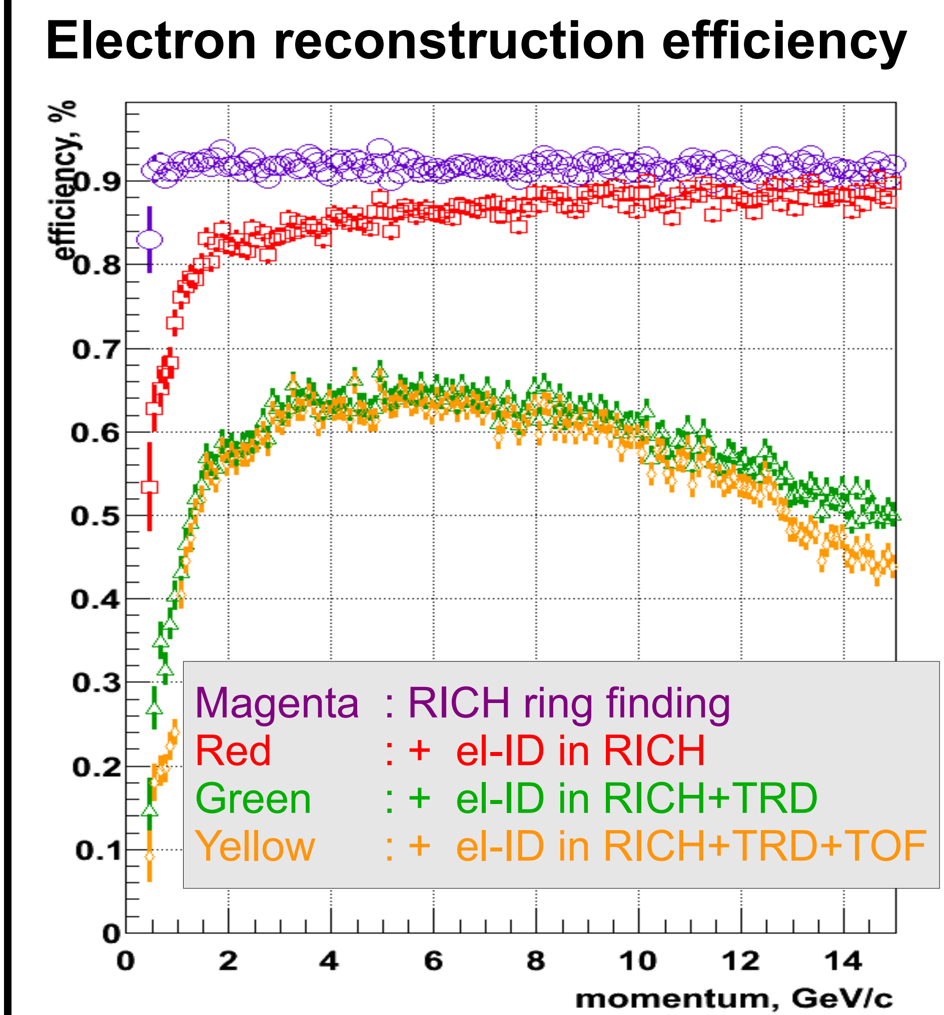
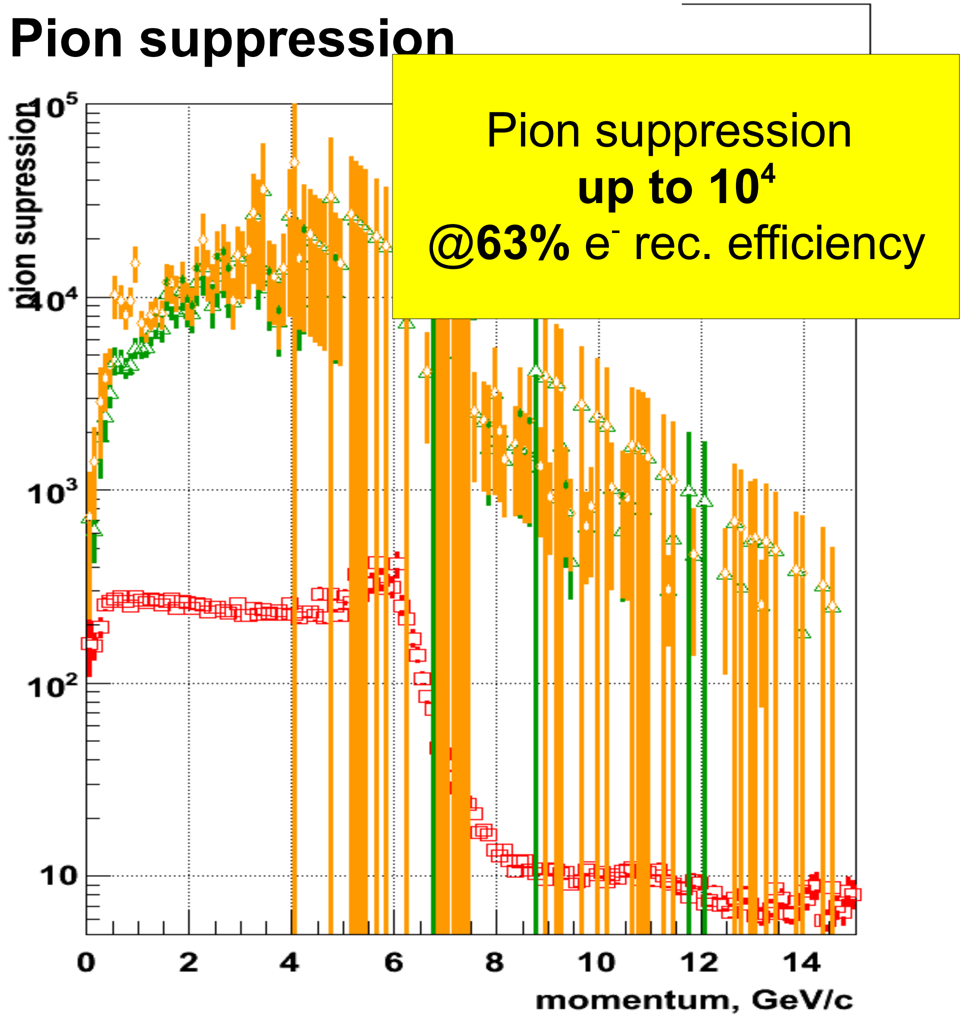
Simulations





The CBM RICH detector

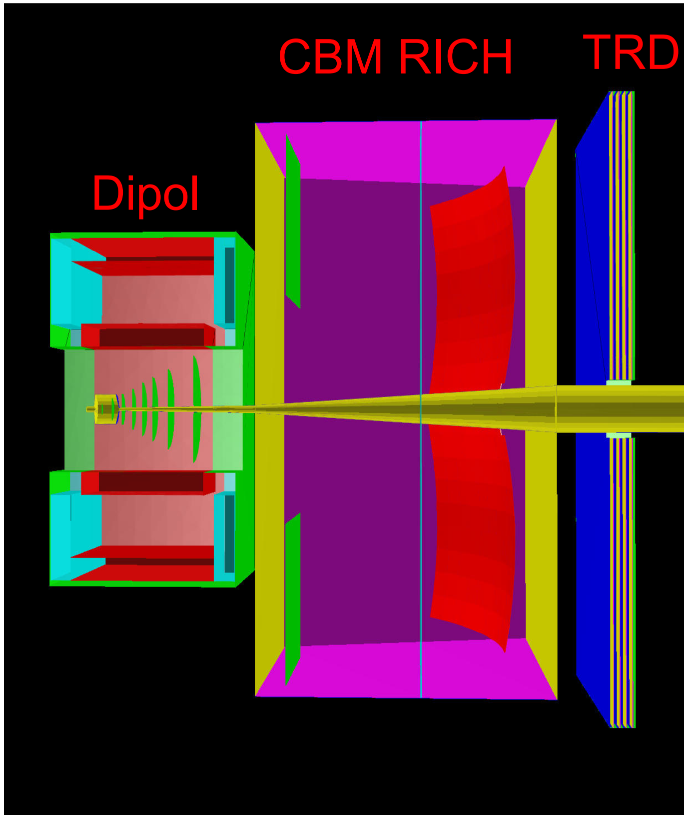
Aim: clean electron identification below 8 GeV/c
pion suppression 500-1000 from RICH alone, 10^4 together with TRD

concept:
CO_2 focusing gas RICH detector
rely on industry components as far as possible

Photodetector:
Hamamatsu H8500 MAPMT,
2.4 m^2, ca 900 pc, 55k channels
UV-transparent window, wavelength shifter ?
Super-Bialcali ???

Mirror:
11.8 m^2, segmented (~100 rect. tiles)
glas mirror, <=6mm thickness
Al+MgF_2 reflective cover

Radiator:
CO_2: $\gamma_{thr} = 33$, $p_{\pi\text{-thr}} = 4.65$ GeV/c
ca 1.5m gas volume depth
2mbar overpresssure, dryed and cleaned



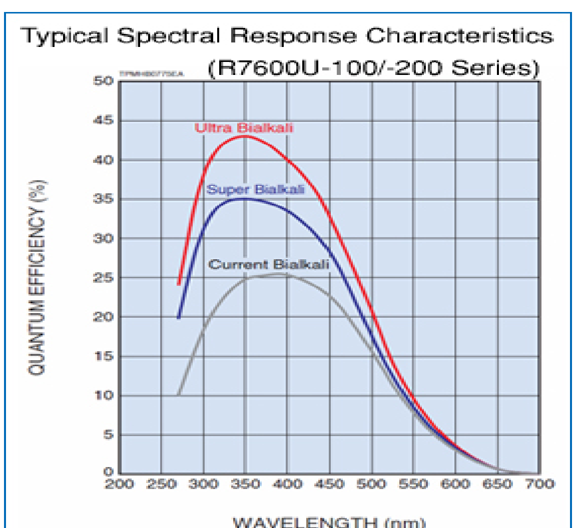
The photo detector

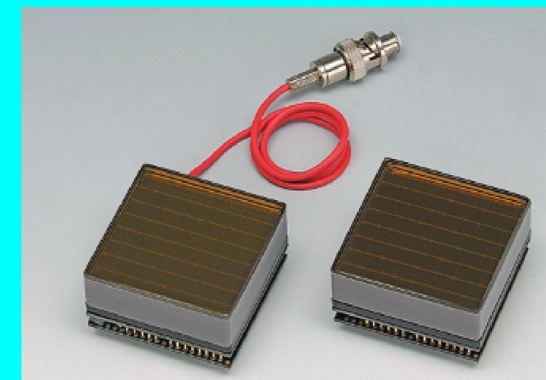
Working horse:

ca **900pc H8500C-03, Hamamatsu**
available with 8 and 12 stages
normal / Super-Bialcali (SBA)
SBA cathode only for 8-stage version

possible alternative: **R8900-103-M16**:

similar pixelsize,
available with SBA
16 channel, quarter size (26x26mm^2)
2-3 times more expensive
only ~80% effective area





H8500C-03:
12 stages, metal mash
52x52 mm^2
64 channels, 5.8x5.8 mm^2 pixel
89% effective area
gain: 1.5 x 10^6
time resolution: ~1 ns easily

UV-transparent glas window
normal BA cathode: max 24% q.e.

H10966-03:
8 stage version of H8500
gain: 3.3 x 10^5
SBA-cathode available: max 35% q.e.!

quantum efficiency measurements

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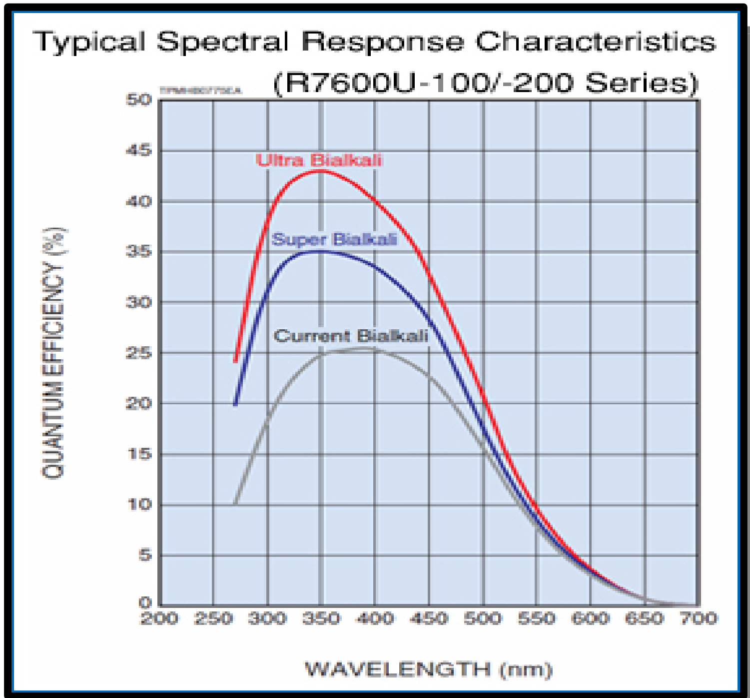
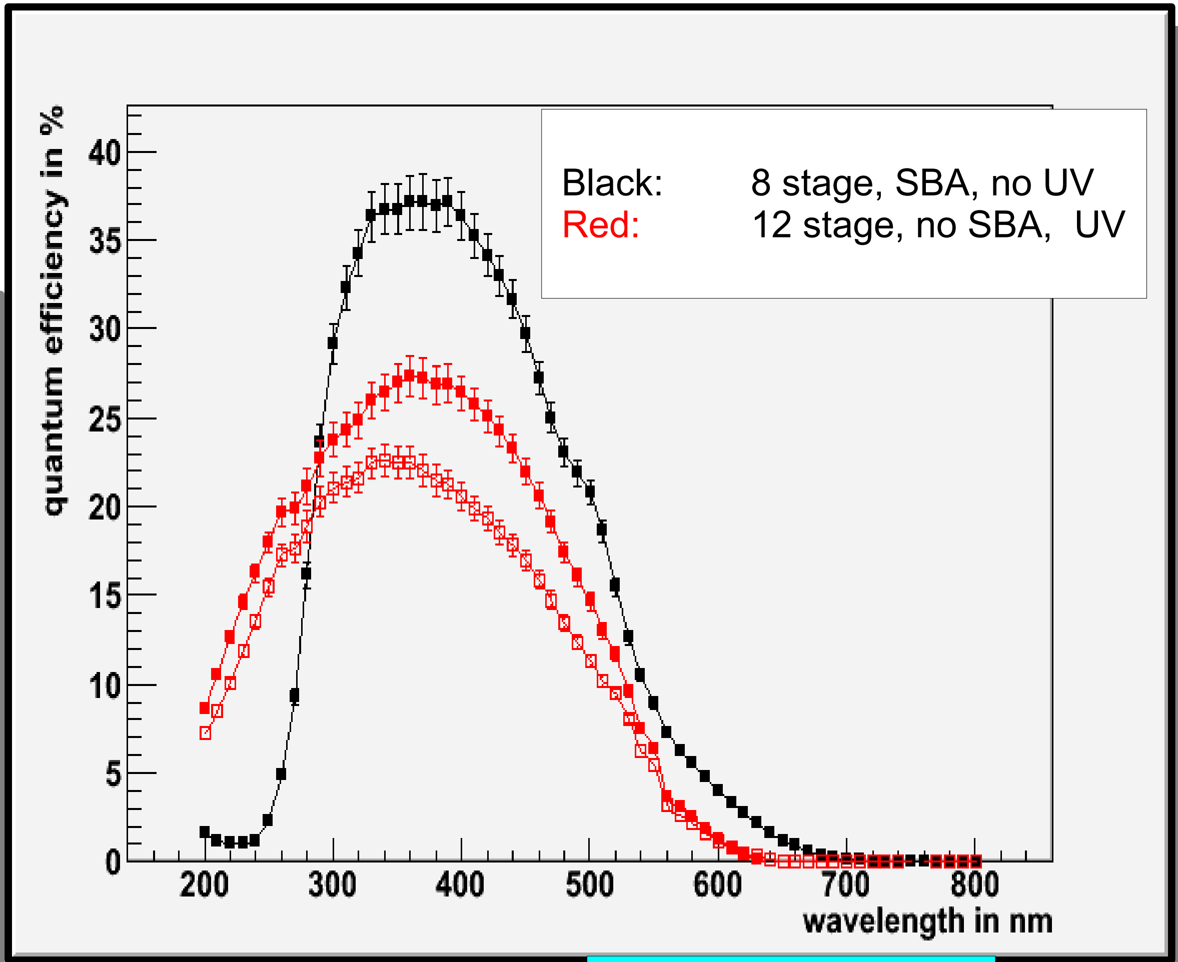
- Quantum efficiency measured using calibrated photo diode
- 3 test tubes:
  - 1x 8 stage, SBA-cathode, no UV-window
  - 2x 12 stage, normal cathode, UV-window

- Significant reflectivity on cathode window (10-20%)

Hamamatsu data sheet:





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R8900 ↔ H8500C (12 / 8 stage SBA)

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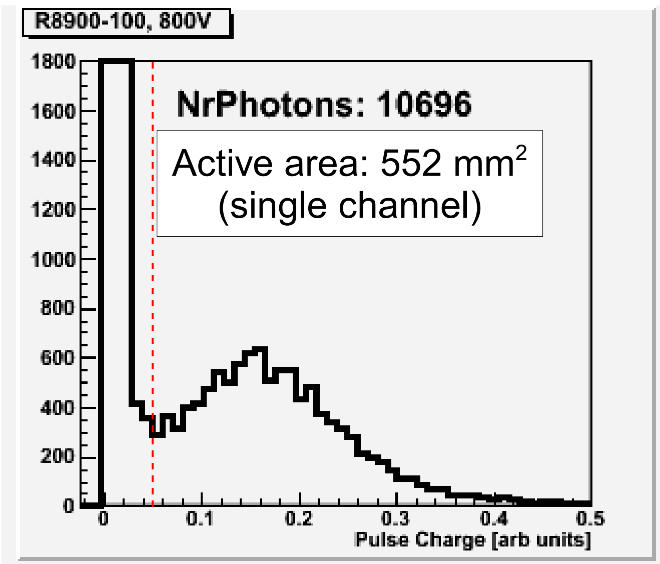
Direct comparison of single photon response
and photon yield for equal illumination

R8900 (1 channel version)

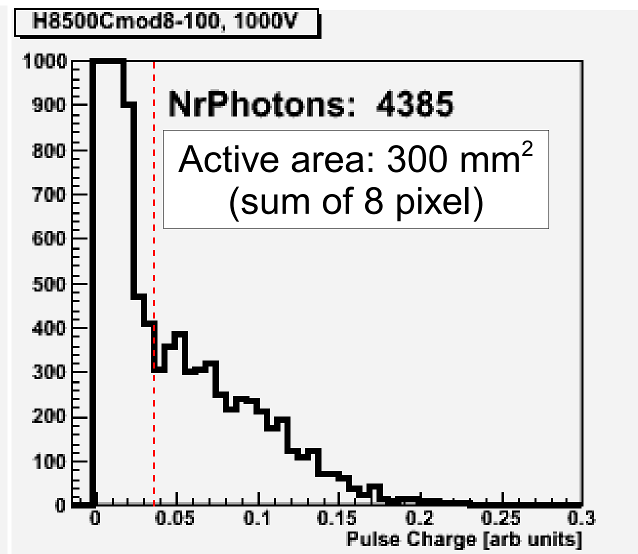
SBA-cathode
(q.e.@470nm : **28%**)



19.4 photons / mm²

× 80% geom=**15.5 ph/mm²**

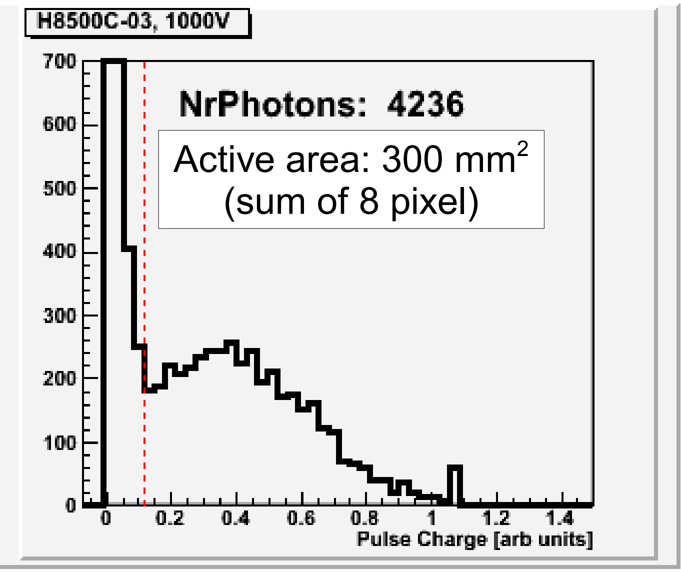
H8500
8-stages
SBA-cathode
(q.e.@470nm : **25%**)



14.6 photons / mm²

× 89% geom=**13.0 ph/mm²**

H8500
12-stages
normal cathode
(q.e.@470nm : **20%**)



14.1 photons / mm²

× 89% geom=**12.6 ph/mm²**

R8900 ↔ H8500C (12 / 8 stage SBA)

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CBM

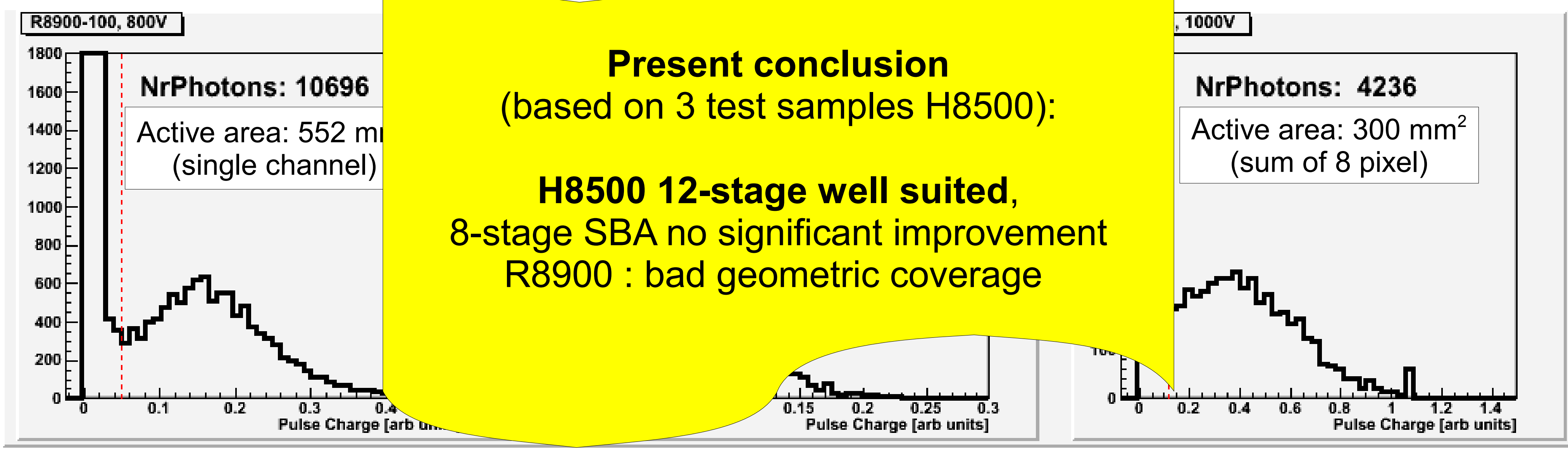
Direct comparison of single photon response
and photon yield for equal illumination

R8900 (1 channel version)

SBA-cathode
(q.e.@470nm : **28%**)

H8500
8-stages
SBA-ca
(q.e.

H8500
12-stages
mal cathode
.@470nm : **20%**)



Present conclusion
(based on 3 test samples H8500):

H8500 12-stage well suited,
8-stage SBA no significant improvement
R8900 : bad geometric coverage

19.4 photons / mm²
× 80% geom=**15.5 ph/mm²**

14.6 photons / mm²
× 89% geom=**13.0 ph/mm²**

14.1 photons / mm²
× 89% geom=**12.6 ph/mm²**

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H8500C in magnetic field

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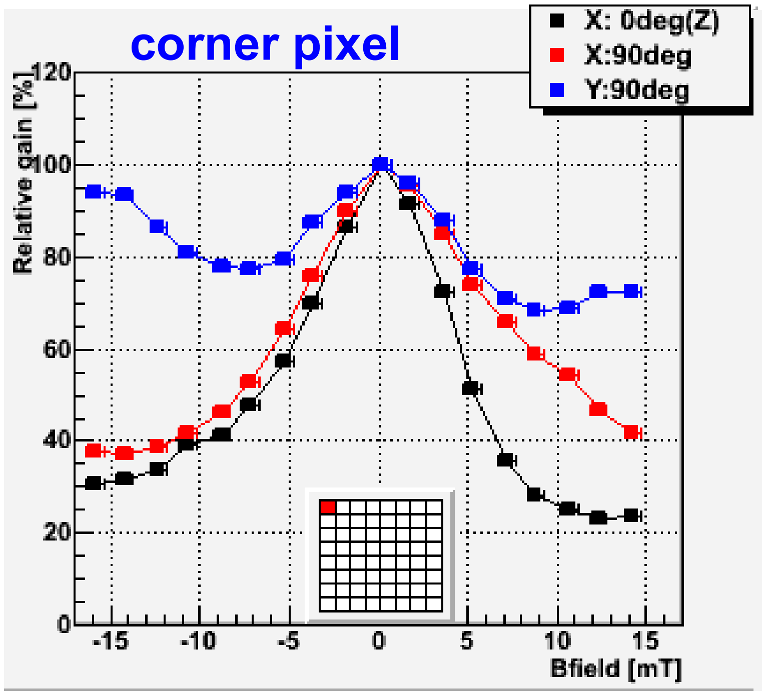
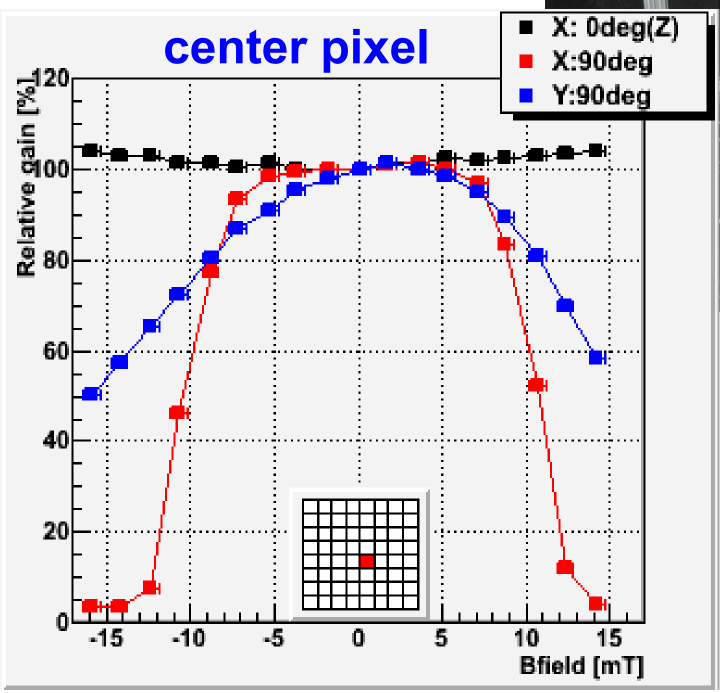
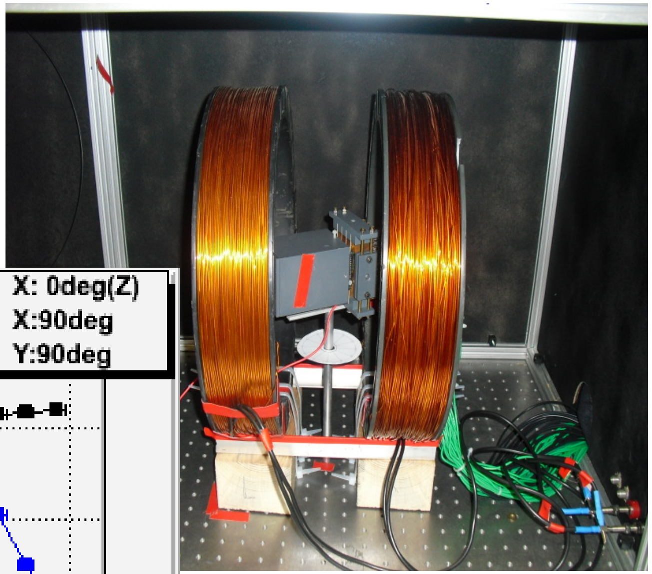
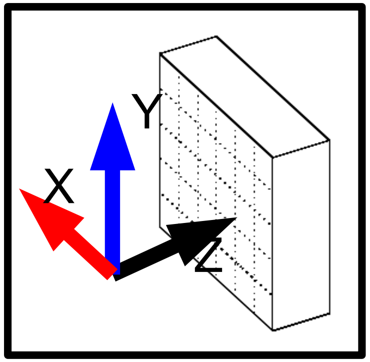
- CBM RICH situated close to Dipole magnet
- Magnetic field up to 25mT in camera region
- significant drop of gain / photon efficiency already for B>1mT
  - → need extensive shielding,
  - → shift of camera position









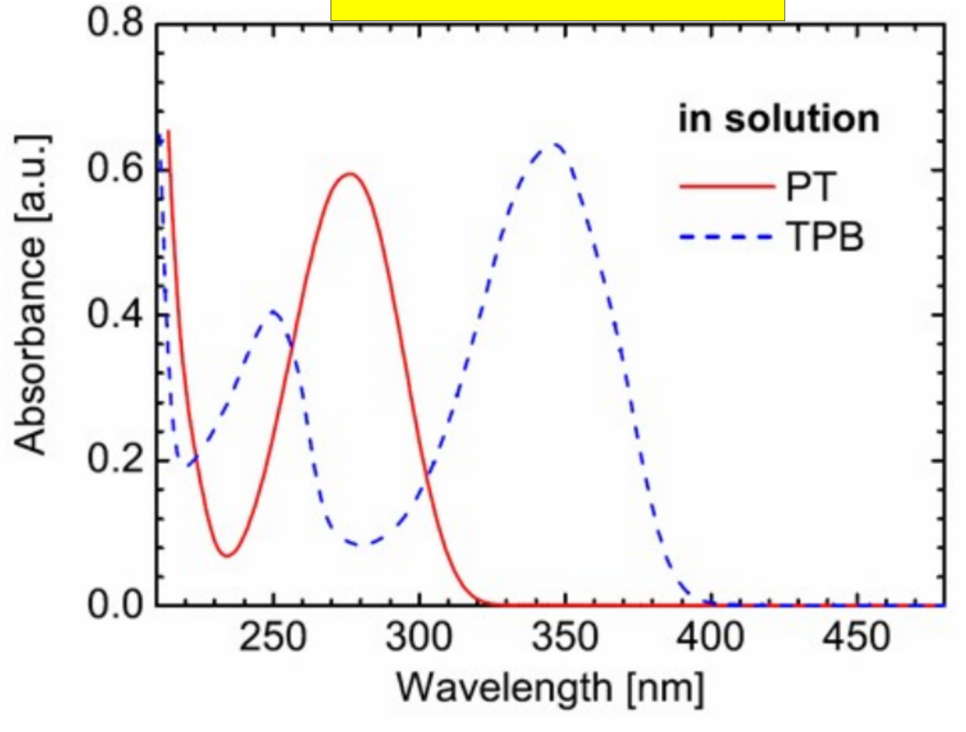
gain: 0-120%

B-field ± 15mT

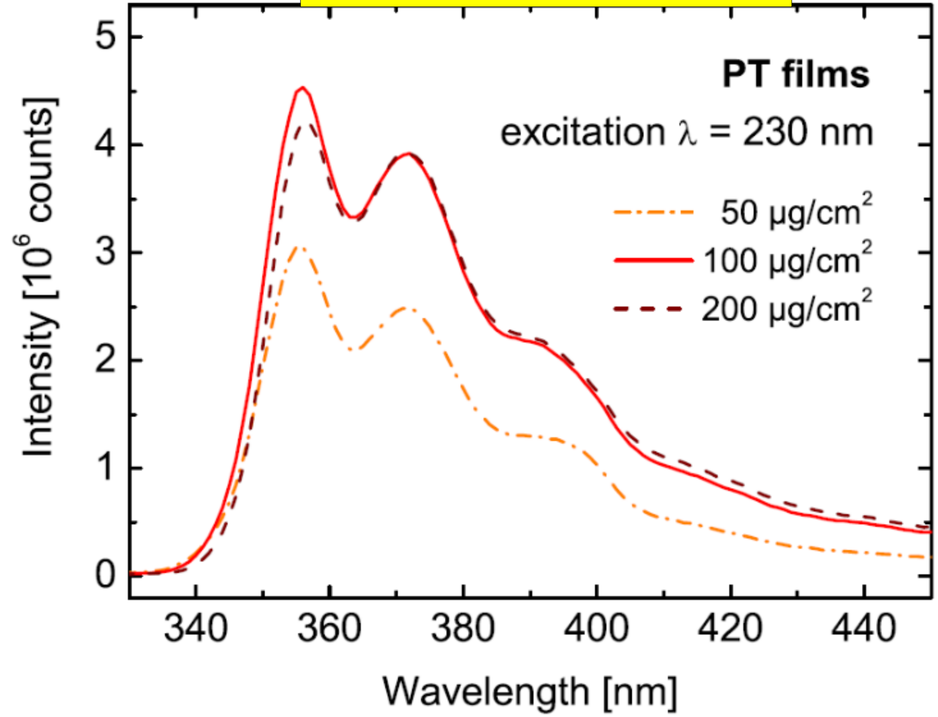
Wavelength shifter (WLS)

- Goal: increase photon efficiency in UV-range by using WLS film on PM window
- Tests with P-terphenyl (PT), Tetraphenyl Butadiene (TPB)

Absorption in UV



Reemittance in visible
excitation: 230nm



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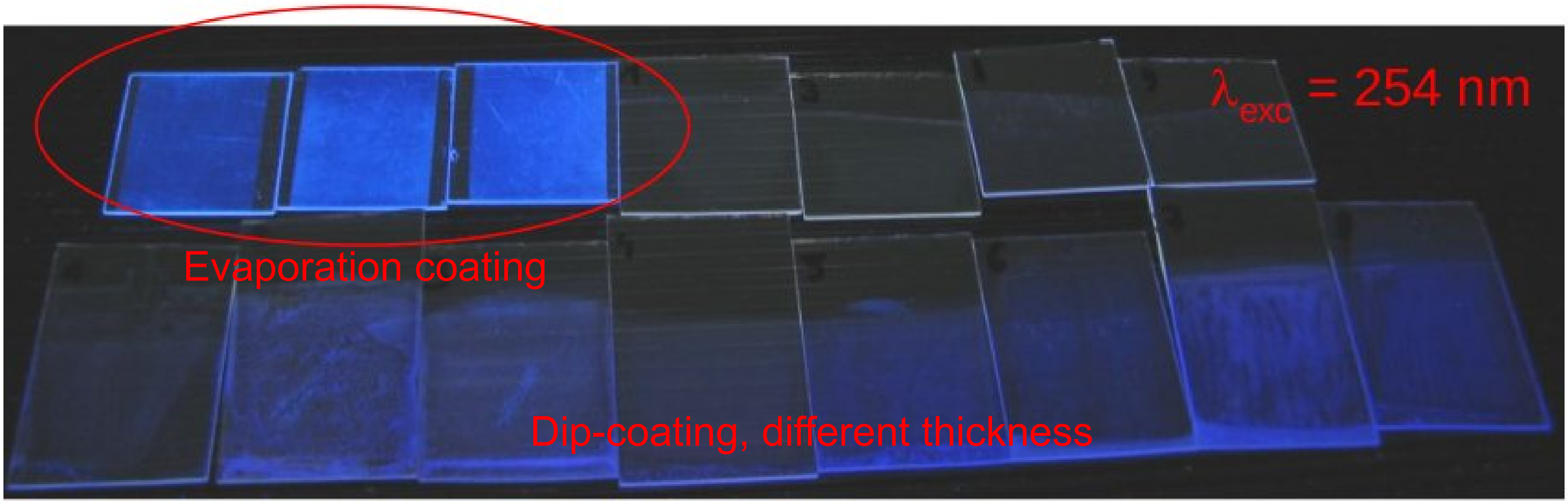

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WLS coating and quantum efficiency

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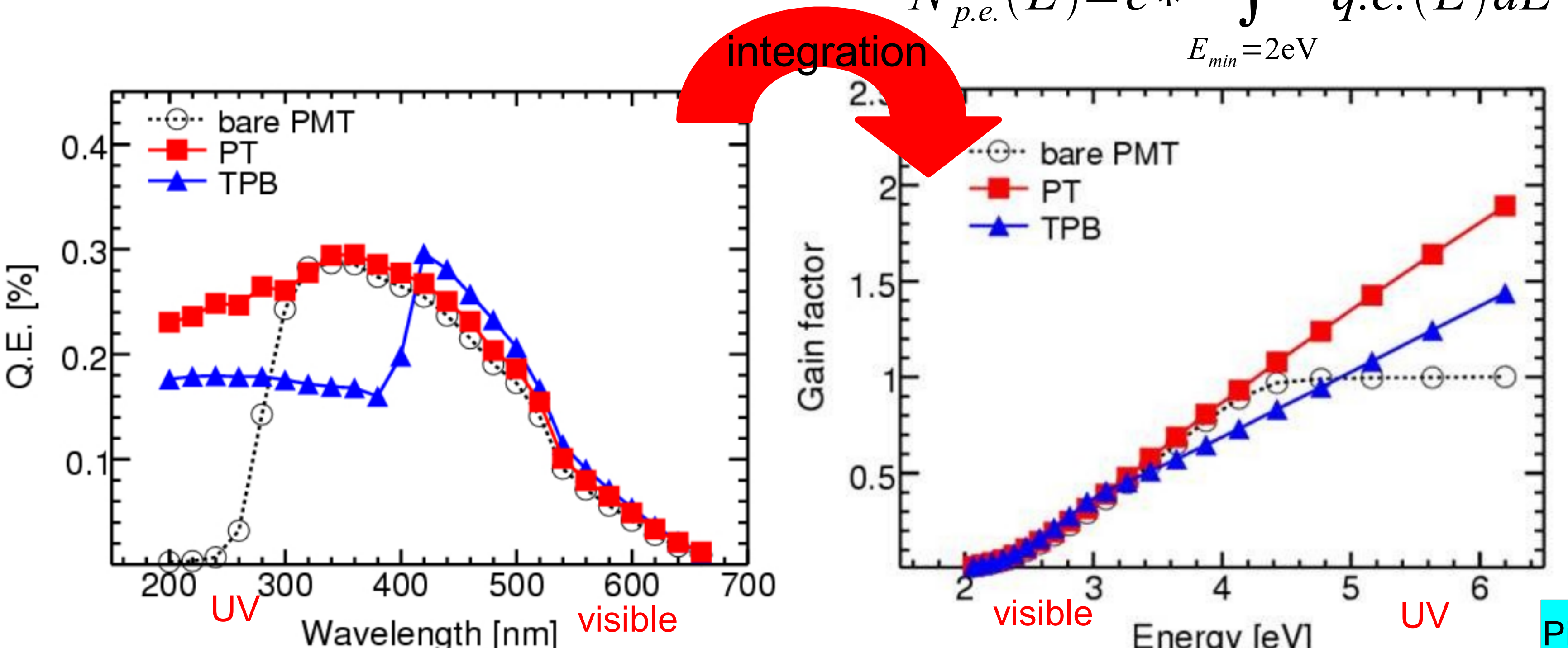
- First tests done with coated standard PMTs on standard borosilicate window (!)
- quantum efficiency significantly enhanced compared to uncoated PMTs

- Next step: study effect on H8500 with UV-window
  - loss of resolution due to isotropically retransmission (simulation: 2.3mm σ)
  - effect on time resolution (PT fluorescence decay time: ~1.1 ns)

$$N_{p.e.}(E) = c * \int_{E_{min}=2\text{eV}}^{E} q.e.(E)\, dE$$



gain ~1.7

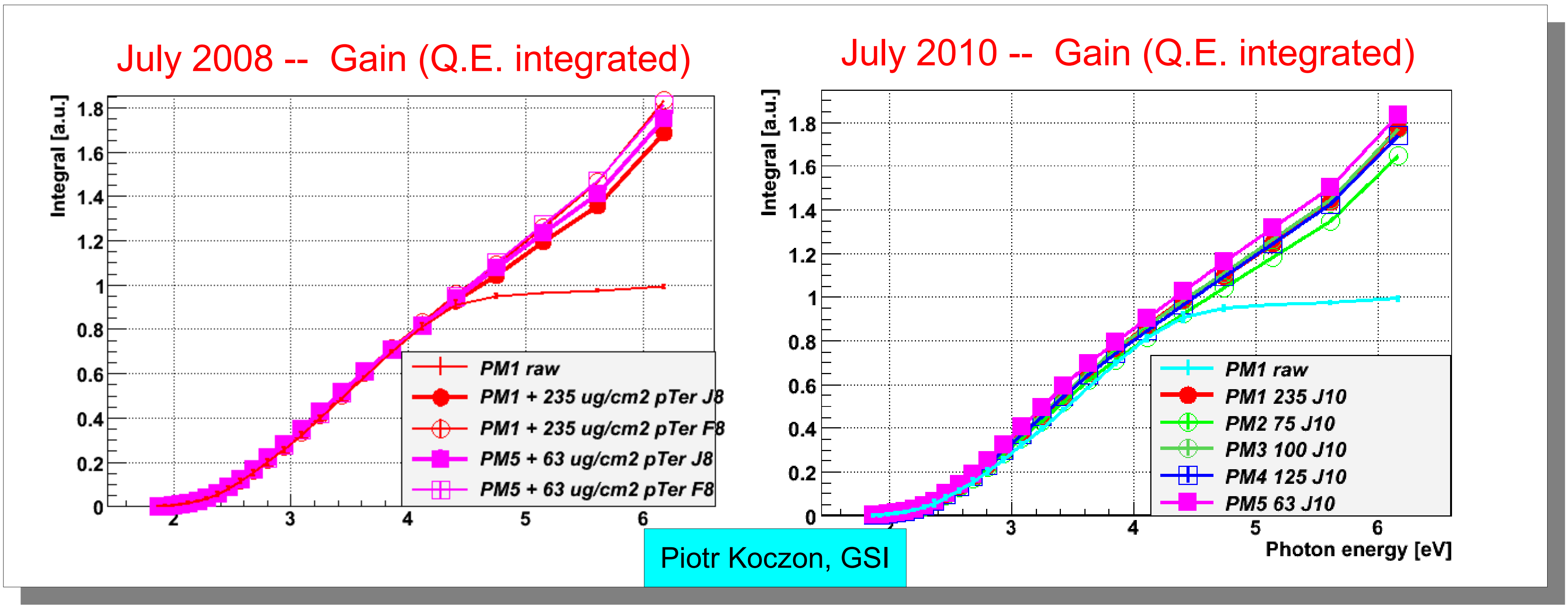
gain ~1.3

Piotr Koczon, GSI

WLS coating : aging in CO_2

Five coated PMs stored in CO_2 athmosphere for 2 years

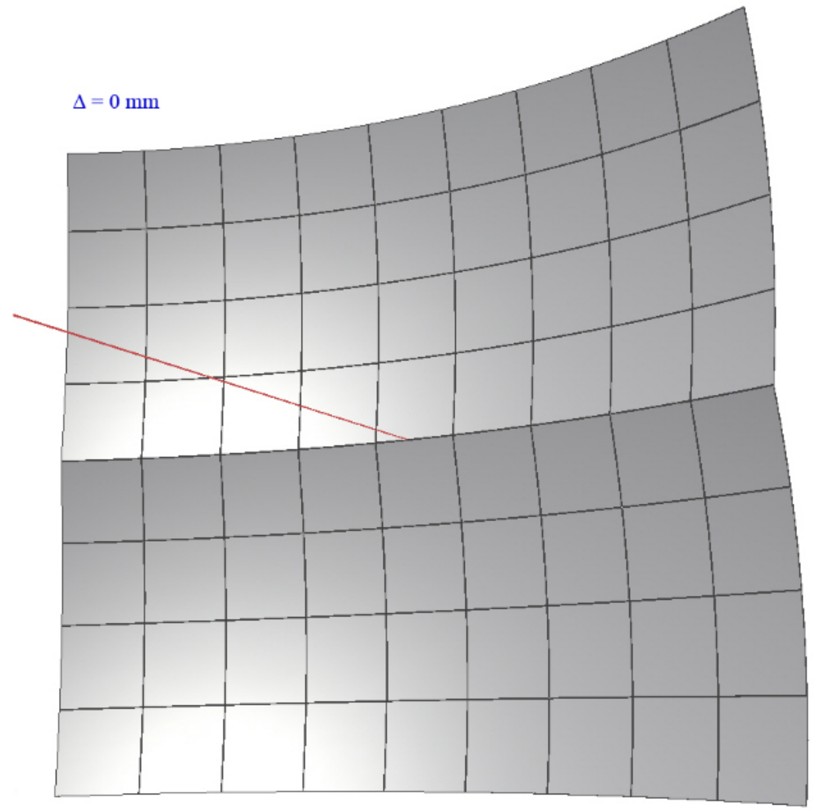
No significant ageing effects observed



Mirror studies

- Two mirror halfs with dimensions
  4 x 1.7 m^2 each
- Optimal dimensions of trapezoidal tiles approx. 40 x 40 mm^2,
  (will depend on manufacturer)
- ~80 separate mirror tiles

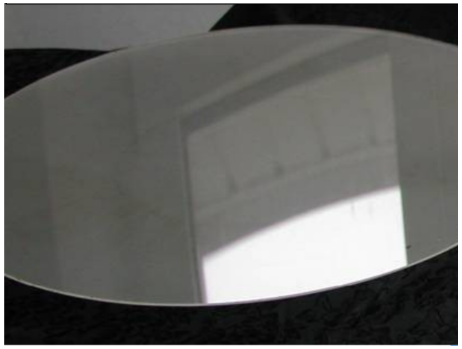
- Crucial parameters:
  - Reflectivity, UV-range
  - <=6mm glas thickness,
  - Al + MgF_2 coating
  - Radius of curvature : R_0=3m
  - Good surface quality, optical quality
    (-> D_0 parameter)



Mirror manufacturers

- **FLABEG GmbH, Germany:**
  2 samples, d = 6mm glas, R_0 = 3.2m
  size A=40 x 40 cm^2
  coating: Al(55 nm) + MgF_2(120nm)

- **Compas, Czech Republic:**
  d = 3mm and 6mm glas, R_0= 3m,
  3mm sample broken when cutting tiles
  size R=30cm
  coating: Al(80nm) + MgF_2 (30nm)



- **SLO – Olomouc, Czech Republic:**
  two prototypes ordered, delivery Nov 2010
  d = 6mm, R_0=3m
  size A = 40 x 40 cm^2

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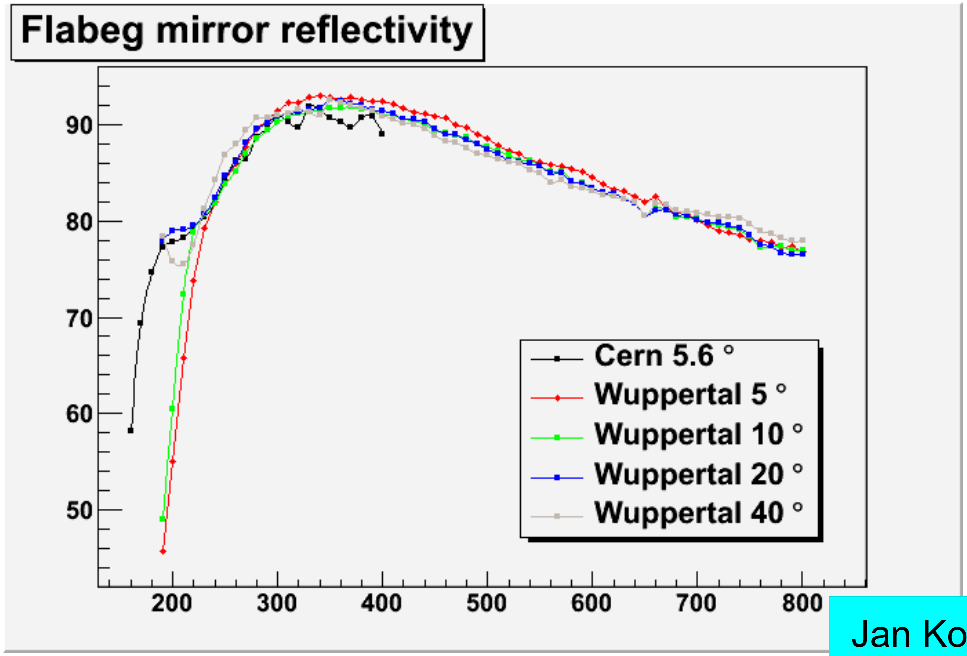
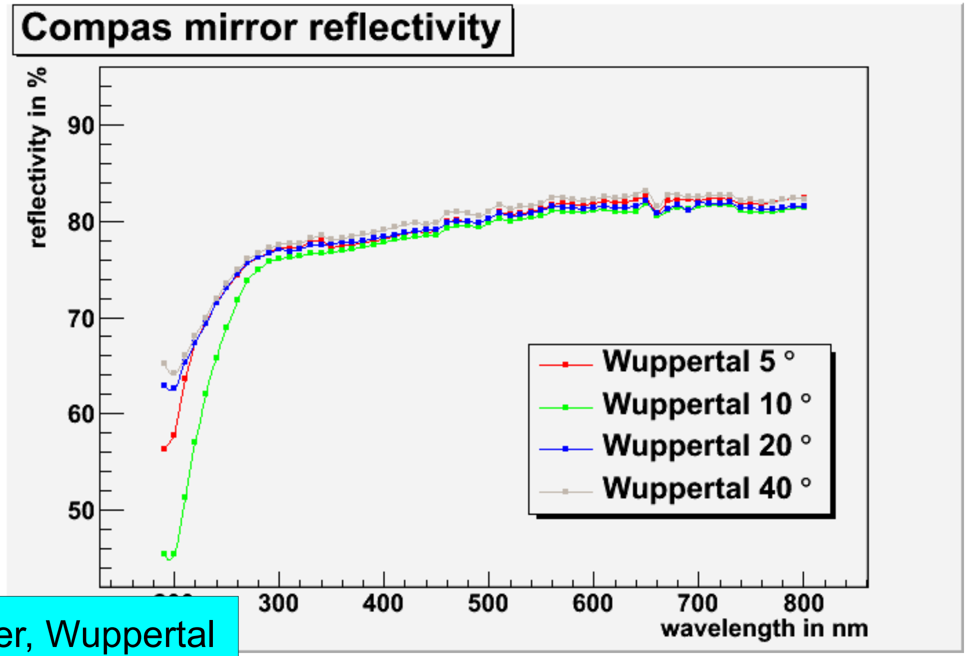
Comparison of mirror reflectivity

- Flabeg mirror shows better reflectivity, up to 92% @ 350nm
  Compas: maximum 80%, 78%@350nm
- Different incidence angles:
  Angular dependance of UV reflectivity due to interference in MgF_2 layer



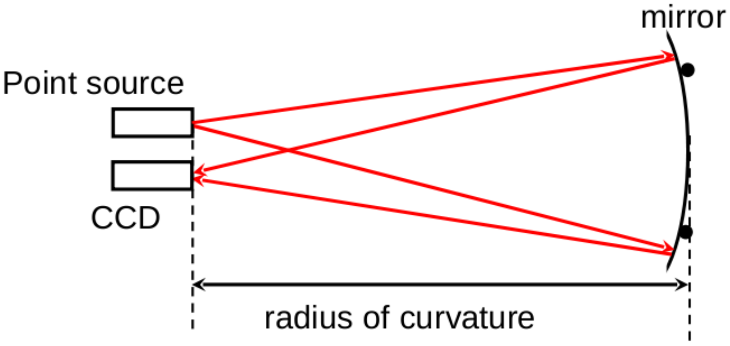


Jan Kopfer, Wuppertal

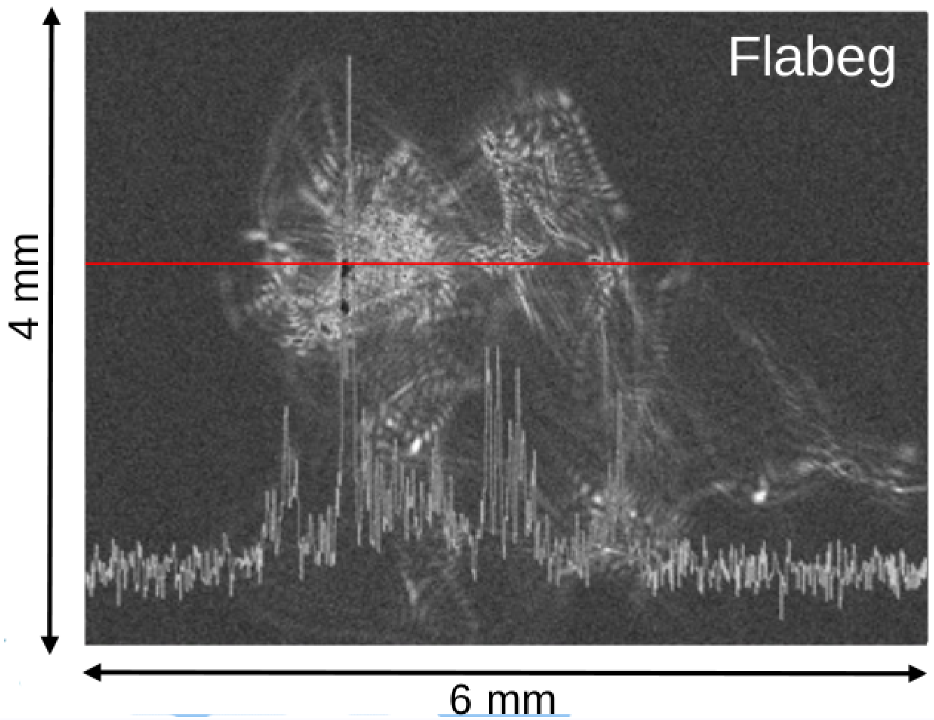
Comparison of optical quality

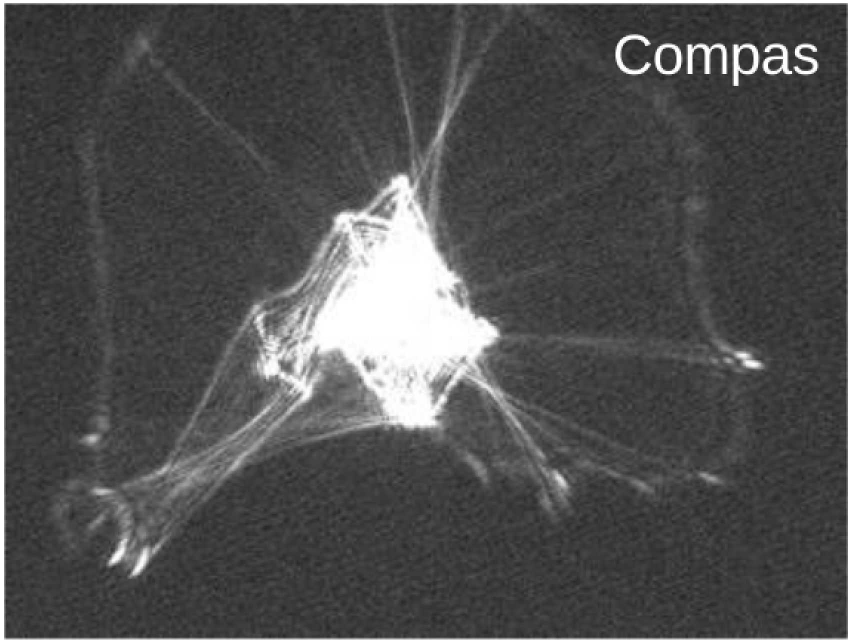
- D0 measures focal image-size of pointlike source in focal plane.

- **Flabeg mirror:** very broad image, most intensity in background
- **Compas:** $D_0 \sim 2.3$mm (95% intensity inside)



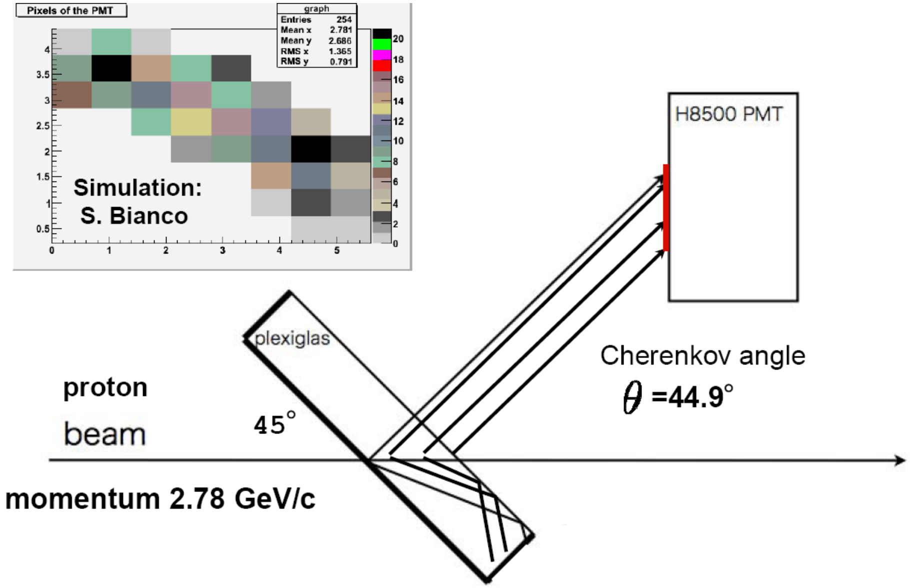
Carmelo D'Ambrosio, CERN

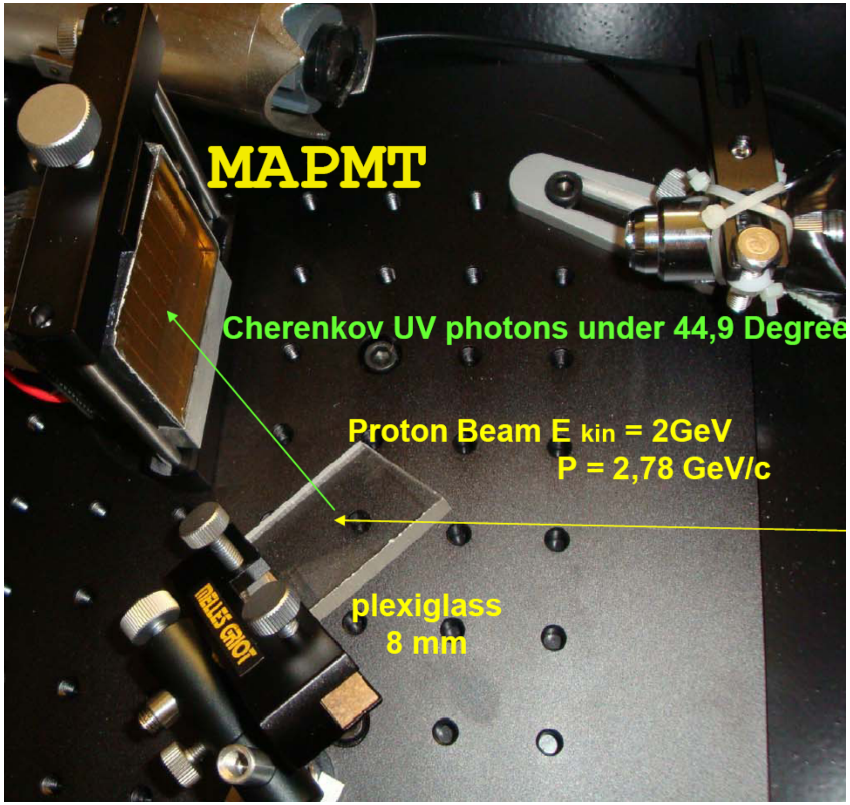




First Proximity focusing test 2009

- Feasibility test of photon counting
  using single H8500 MAPMT, CBM n-XYter readout electronics
- proton beam, p=2.78 GeV/c on plexiglass radiator @GSI, 2009
- Quarter cherencov ring expected
  $\theta_{\text{Cherenkov}} = 44.9$ deg





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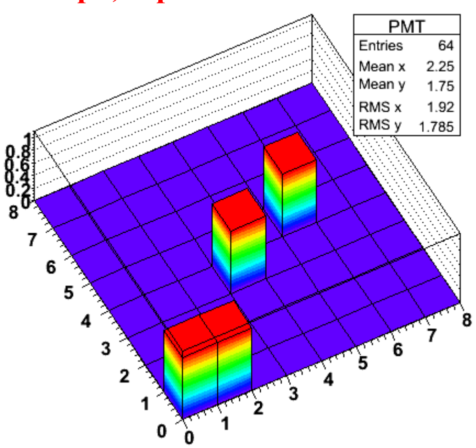
Promising results:

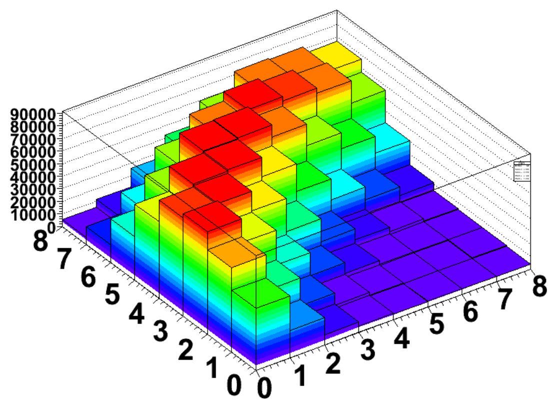
- Only analysis cut: time coincidence with beam counter
- produced Nr of photons: $N=\int_{390\,nm}^{800\,nm}\frac{1}{\lambda^2}\cdot d\lambda\cdot L\cdot 2\pi\alpha\cdot z^2\sin^2\theta_c=235{,}9$
- photon efficiency limited due to:
  - geometrical coverage (quarter ring)
  - Quantum efficiency folded with Cherencov spectrum (15%)
  - Light transmission plexiglas (80%)
  - Photon collection efficiency (80%)

3.5 photons/event

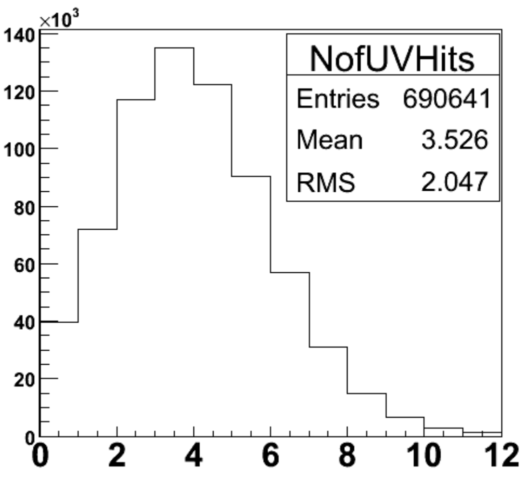
- $N_{ph,\,expected} = 3.6 \pm 0.7 \leftrightarrow N_{ph,\,measured} = 3.5$



Single event



Integrated over many events



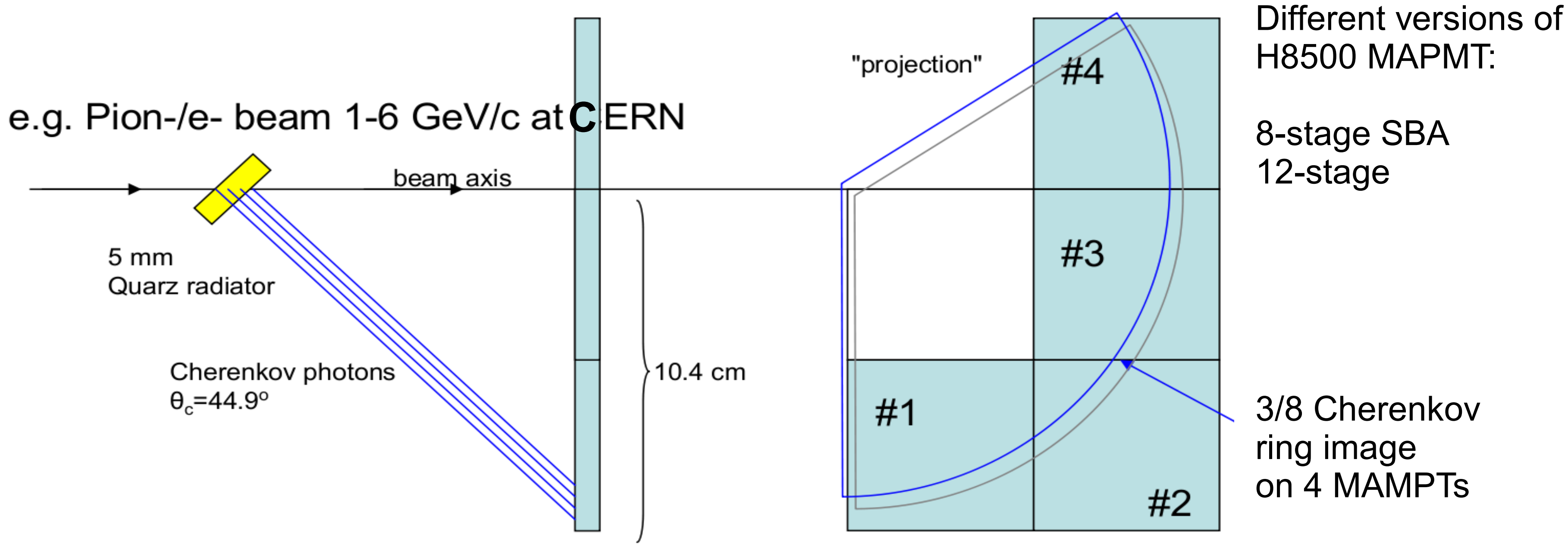
avg. photons / event

Jürgen Eschke, GSI

Second proximity focusing test, 2010

- Extend previous setup to parallel readout of 4 MAPMTs
- Use quartz glass radiator to keep UV photons
- Use mixed π / e^- beam at CERN-PS, T10   15. - 22. Nov 2010
- test full electronic readout chain:
  - 1 Readout Controller ROC
  - 2 n-XYter Front end Boards (FEB)

- Gather experience for full scale prototype test 2011



Full scale prototype test 2011

- "full scale" prototype to be tested at CERN-PS, T10 in autumn 2011
- Mixed e / π beam, 1-6 GeV/c, 1cm^2 beam spot
- Scalable to full CBM RICH

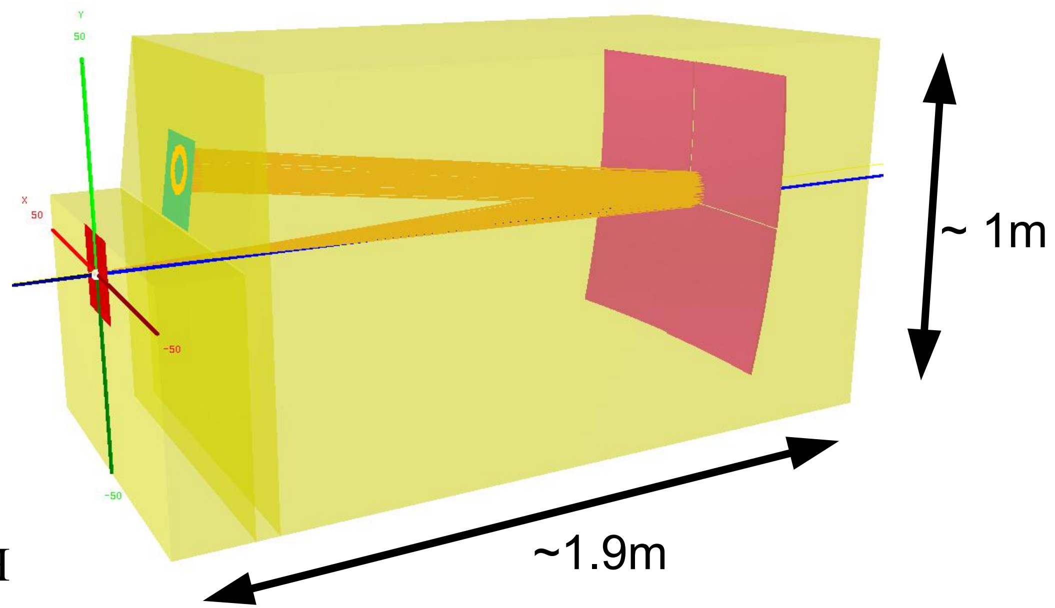
- Obtain firm performance data for CBM-RICH TDR in 2012

setup :

up to 4 mirror tiles 40x40 cm,
- test mirror mounts

4x4 = 16 MAPMTs H8500D
- Test scalable camera design

full gas system: (PNPI, Gatchina)
- control CO_2 pressure (2mbar)
- gas purification
- Temperature control
- later to be used for final CBM-RICH



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Prototype simulations:

- Geant3 simulation, including:
  - Mirror miss-alignment
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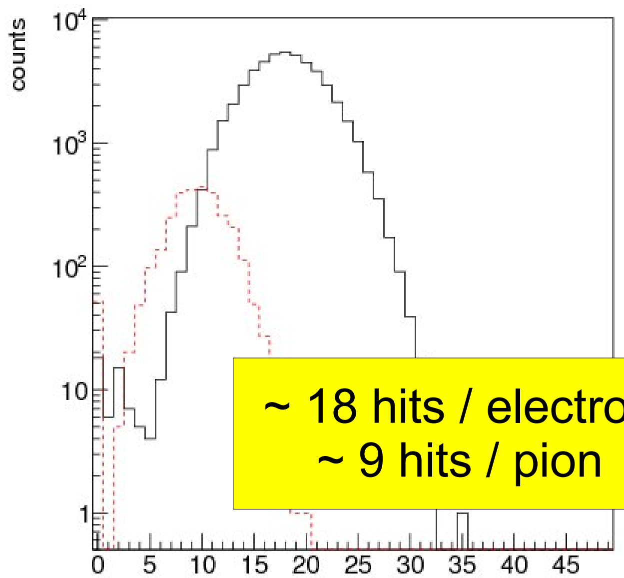
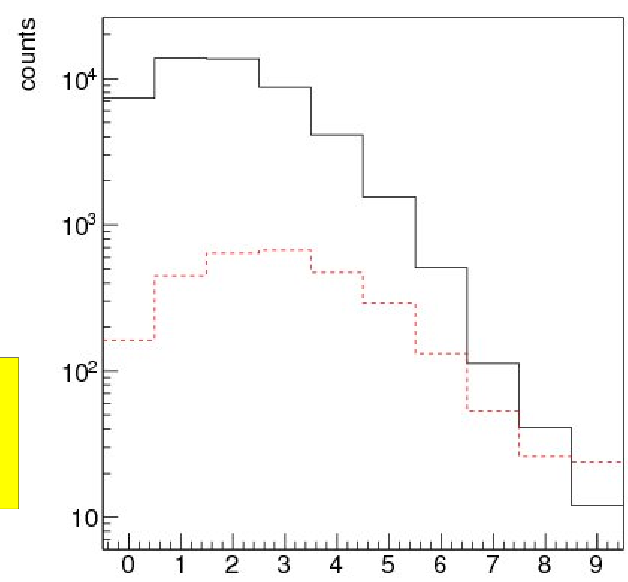
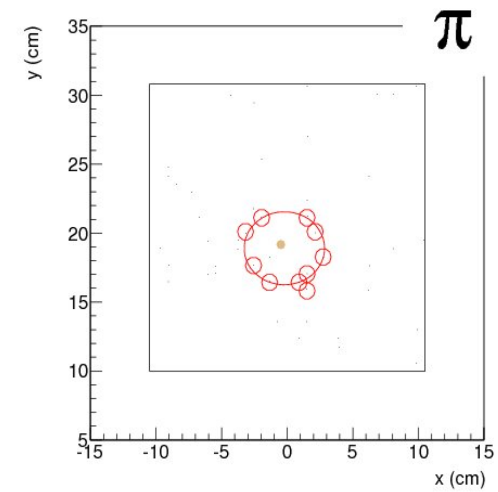


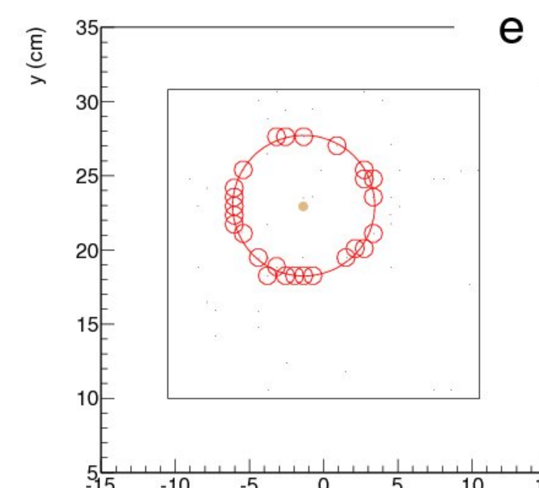
~ 18 hits / electron
~ 9 hits / pion

Nr true hits / ring



Nr fake hits / ring





D. Kresan, Gießen

summary

- CBM experiment at FAIR will offer uniqe approach to explore the QCD phase diagram at high baryon density using dilepton probes
- RICH detector is key component to provide good pion suppression, particle ID
- H8500 MaPMT shows good photon detection capabilities,
  no significant advantage of 8-stage SBA-version despite higher q.e.
- Magnetic field shielding is important issue
- Promising first tests with WLS-coating,
  further tests with UV-sensitive MAPMT
  Aging in CO_2 athmosphere is no issue
- Evaluation of different mirror manufacturers under way, no satisfying result yet
- Full-scale prototype test sheduled for autumn 2011
  obtain firm performance for CBM RICH Technical Design report in 2012

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The CBM collaboration

CBM

China:
Tsinghua Univ., Beijing
CCNU Wuhan
USTC Hefei

Croatia:
University of Split
RBI, Zagreb

Cyprus:
Nikosia Univ.

Czech Republic:
CAS, Rez
Techn. Univ. Prague

France:
IPHC Strasbourg

Germany:
Univ. Gießen *
Univ. Heidelberg, Phys. Inst.
Univ. HD, Kirchhoff Inst.
Univ. Frankfurt

Univ. Mannheim
Univ. Münster
FZ Rossendorf
GSI Darmstadt
Univ. Tübingen *
Univ. Wuppertal

Hungaria:
KFKI Budapest
Eötvös Univ. Budapest

India:
Aligarh Muslim Univ., Aligarh
IOP Bhubaneswar
Panjab Univ., Chandigarh
Gauhati Univ., Guwahati
Univ. Rajasthan, Jaipur
Univ. Jammu, Jammu
IIT Kharagpur
SAHA Kolkata
Univ Calcutta, Kolkata
VECC Kolkata

Univ. Kashmir, Srinagar
Banaras Hindu Univ., Varanasi

Korea:
Korea Univ. Seoul
Pusan National Univ.

Norway:
Univ. Bergen

Poland:
Krakow Univ.
Warsaw Univ.
Silesia Univ. Katowice
Nucl. Phys. Inst. Krakow

Portugal:
LIP Coimbra

Romania:
NIPNE Bucharest
Bucharest University

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
KRI, St. Petersburg
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP, Moscow State Univ.
St. Petersburg Polytec. U.
Kurchatov Inst. Moscow
LHE, JINR Dubna
LPP, JINR Dubna

Ukraine:
INR, Kiev
Shevchenko Univ. , Kiev

56 institutions, > 400 members

Split, Oct. 2009

Extra slides

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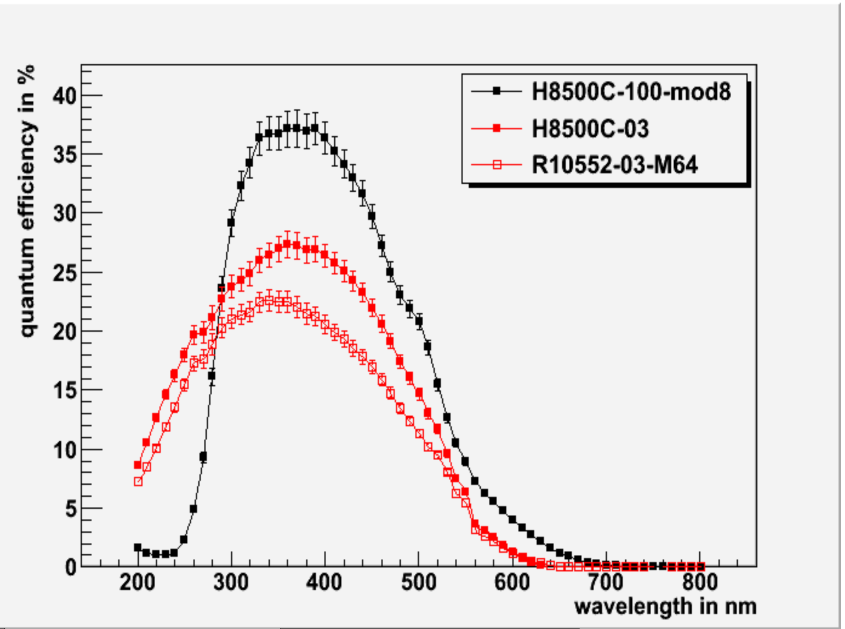
quantum efficiency measurements

CBM

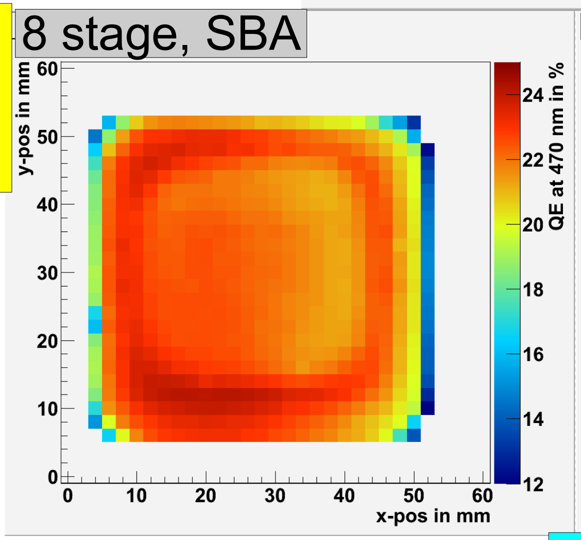
- 3 test samples:
  - 1x 8 stage, SBA-cathode, no UV-window
  - 2x 12 stage, normal cathode, UV-window

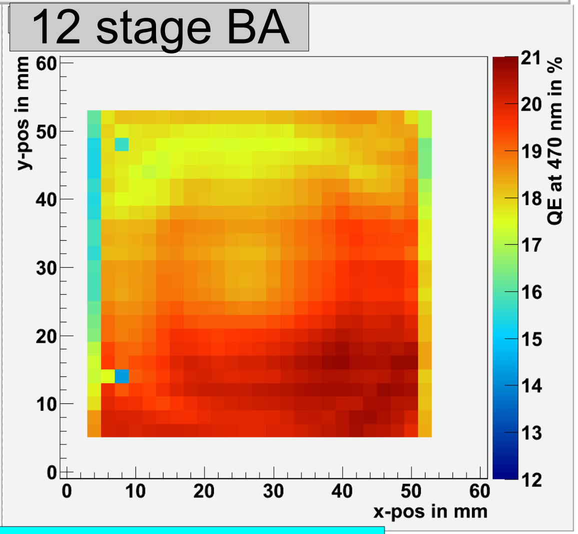
- Cathode inhomogeneity partly due to reflection on slightly concave window

- Significant reflectivity on cathode window (10-20%)



Surface scan using LED @470nm





Jan Kopfer, Wuppertal

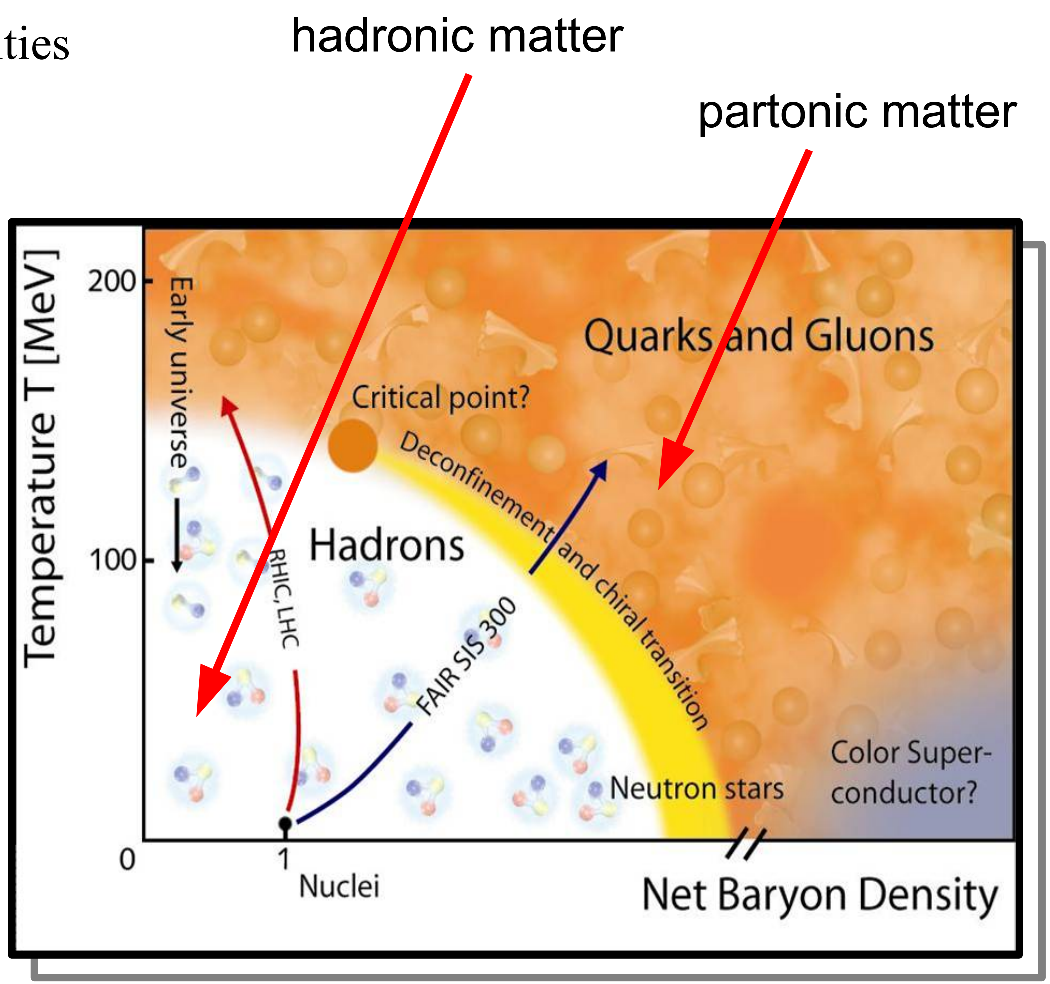
The CBM physics case

- Explore the landmarks of the QCD phase diagram at high net-baryon densities μ_b
  - First order phase transition
  - Chiral restoration at high baryon densities
  - QCD critical endpoint

- In Au-Au collisions from 2-45 AGeV
- starting in 2018 (CBM + HADES)

- Complementary physics program to RHIC, LHC

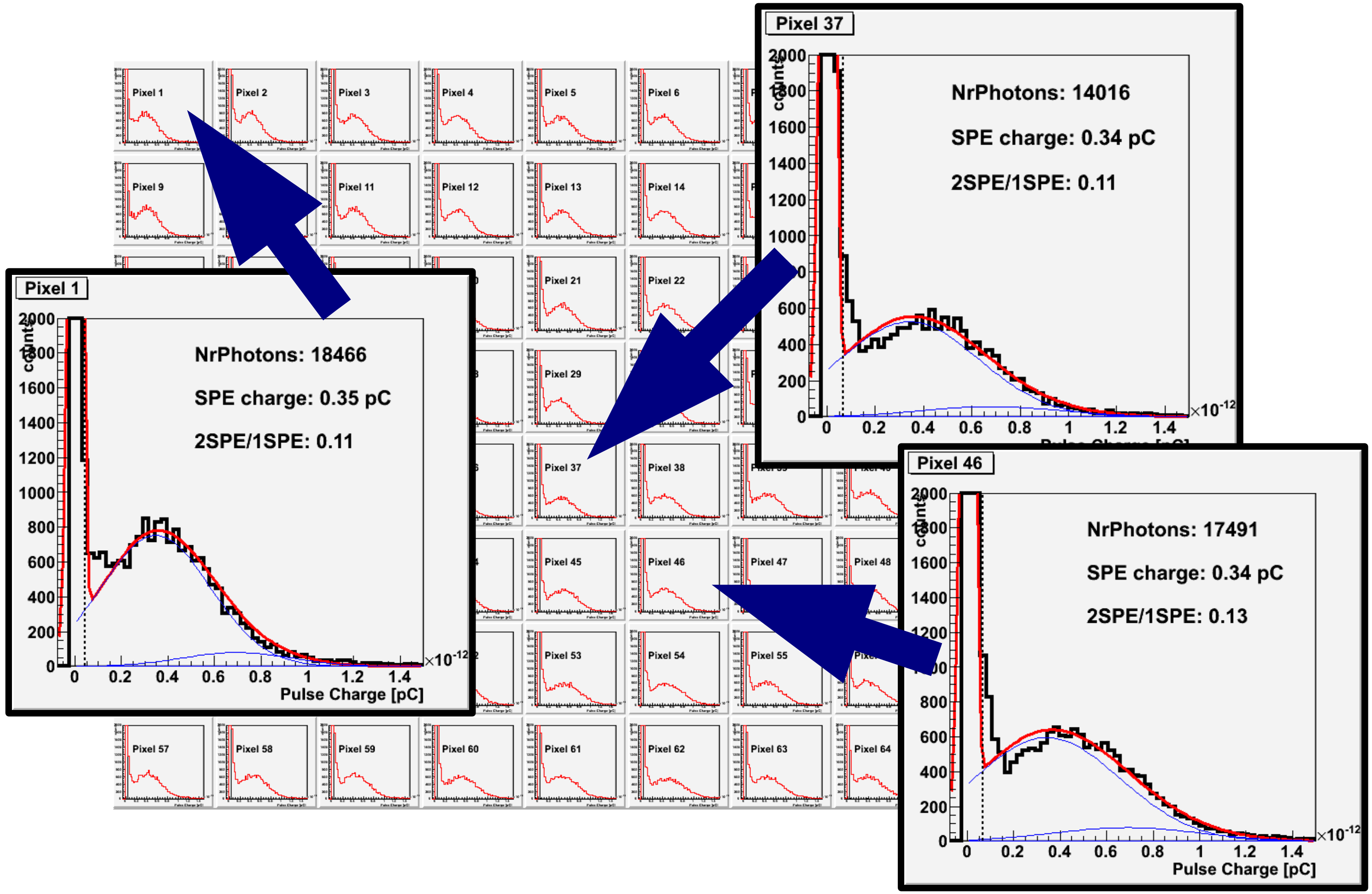
"CBM physics book"
Lecture Notes in Physics, Vol. 814
1st Edition, 2011, 960 p, Hardcover
ISBN: 978-3-642-13292-6



Single photon response 12-stage

12-stage H8500C:

- clear single-photon peak visible in each channel
- Peak/valley ratio ~ 1.3



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Single photon response 12-stage

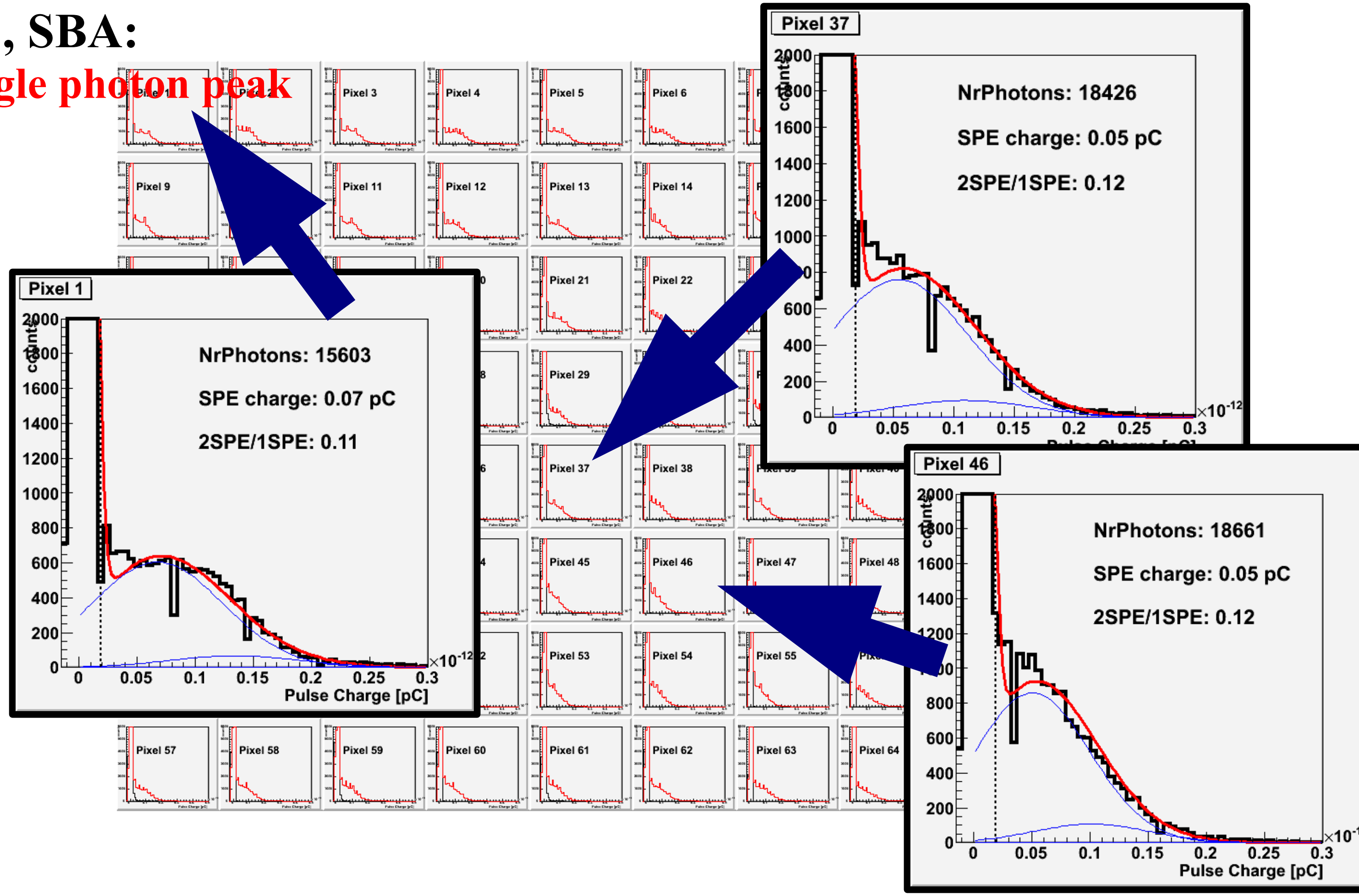
CBM

12-dynode H8500C:

- clear single-photon peak visible in each channel
- Peak/valley ratio ~ 1.3

8-dynode H8500C, SBA:

- No clear single photon peak



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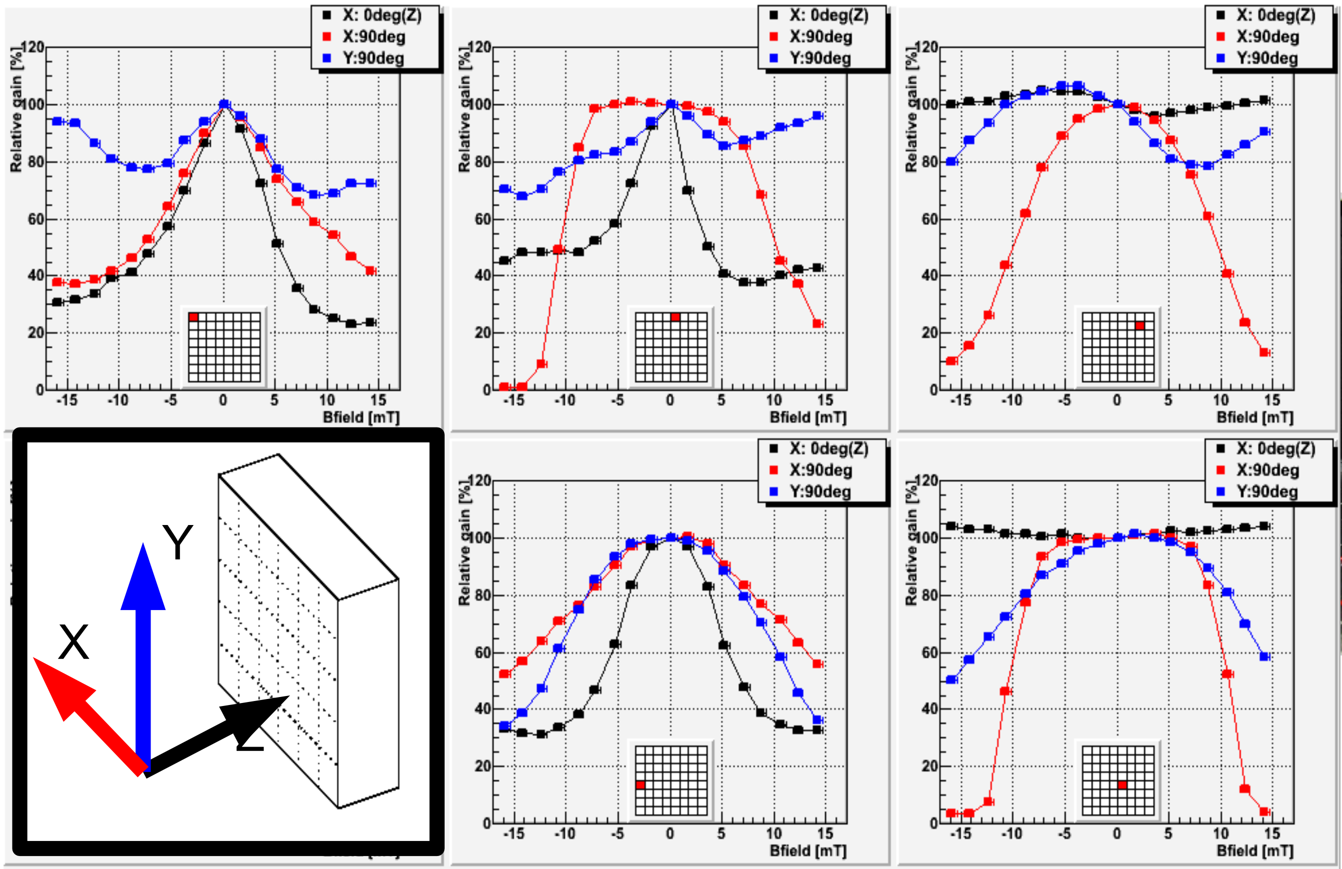
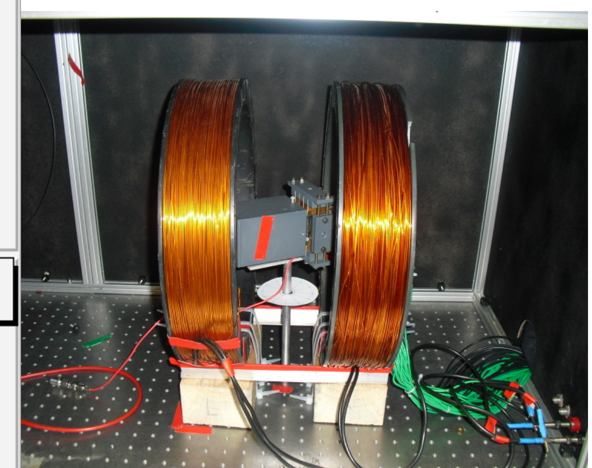
H8500C in magnetic field

- CBM RICH situated close to Dipole magnet
- Magnetic field up to 25mT in camera region
- Lab test shows: significant drop of gain / photon efficiency already for B>1mT

  → need extensive shielding

gain: 0-120%





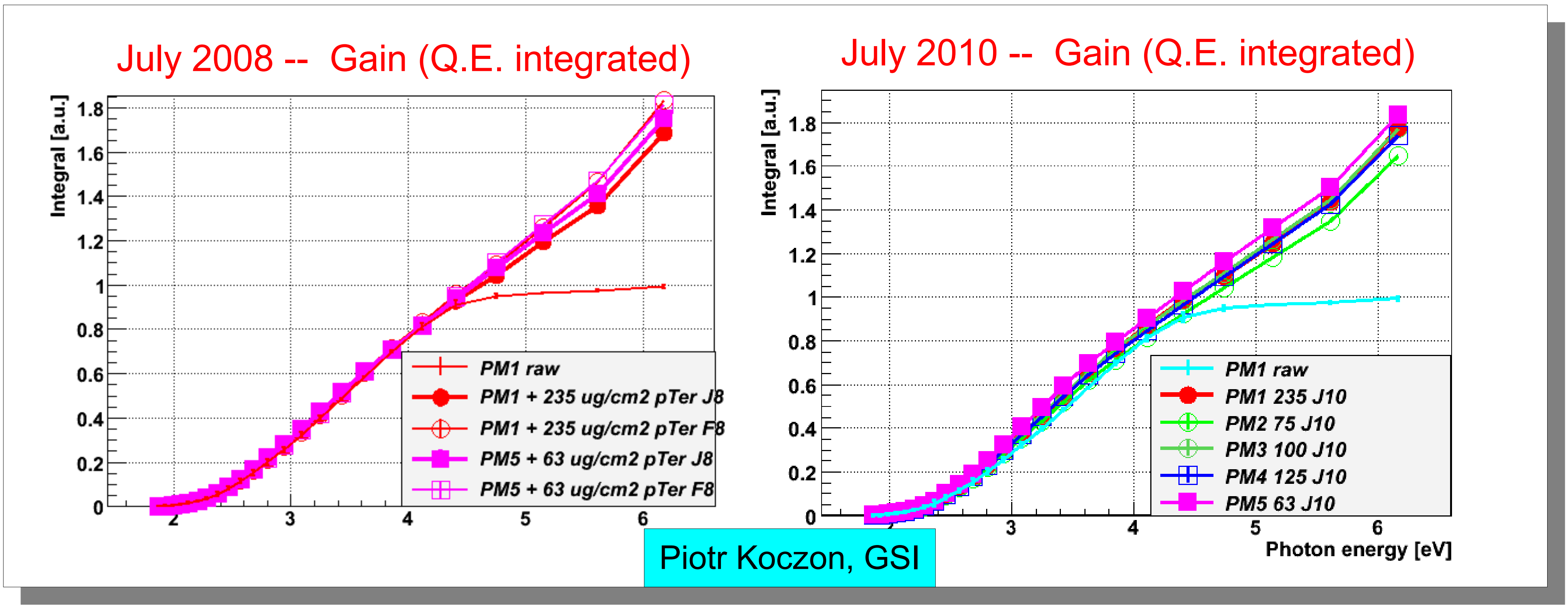
Different field orientations

B-field ± 15mT

WLS coating : aging in CO_2

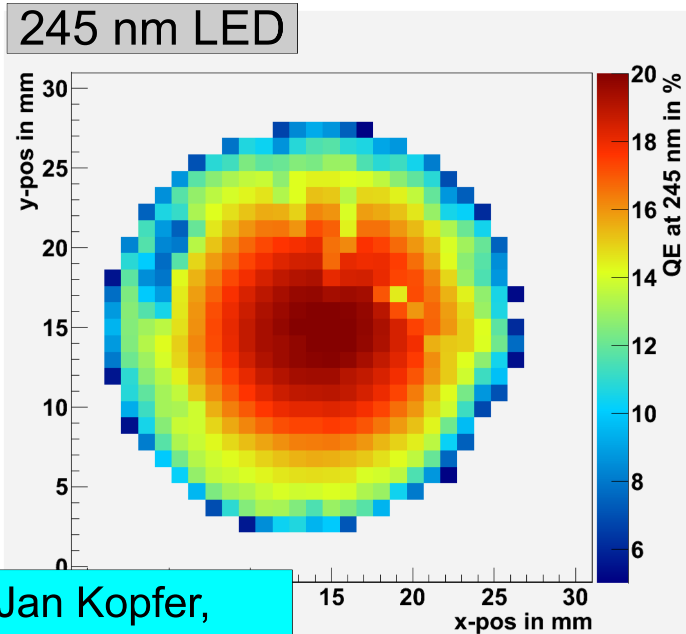
- Five coated PMs placed in CO_2 athmosphere after measurement 2008
- Stored in CO_2 athmosphere for 2 years to simulate influence of radiator gas
- Quantum efficiency measured again in 2010 using same instruments
  → **no significant deterioration of properties**

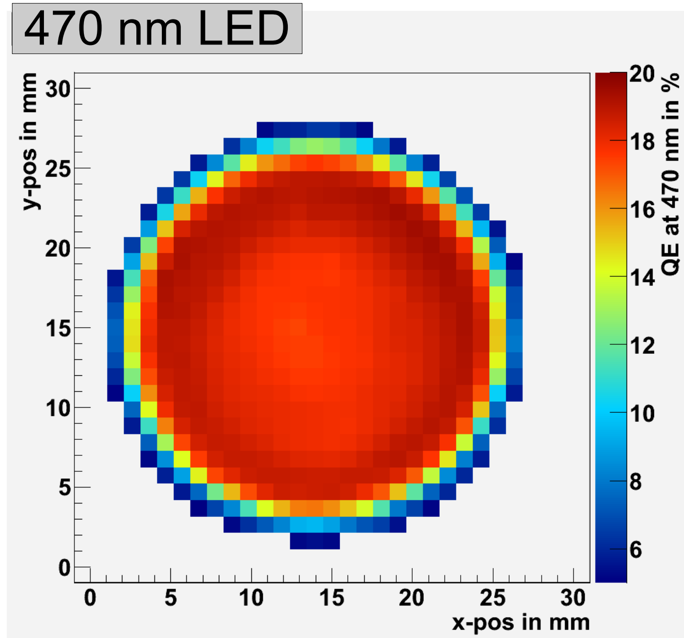
- Next step: check radiation hardness



WLS: deterioration of resolution

- Resolution will deteriorate due to isotropical reemittance
- GEANT4 simulation (P. Solevi, ETH Zürich):
  degradaton of pixel resolution from 1.7mm to 2.3mm sigma
  (Pixel size H8500: 5.8 x 5.8 mm)
- In line with quantum efficiency scans at different wave length:





Photonis XP3102
borosilicate glass
bialkali cathode,
WLS applied

Jan Kopfer,
BU Wuppertal

Comparison of mirror reflectivity

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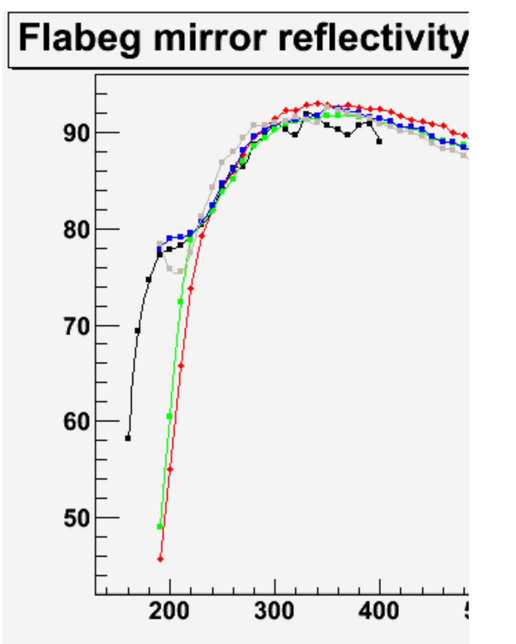
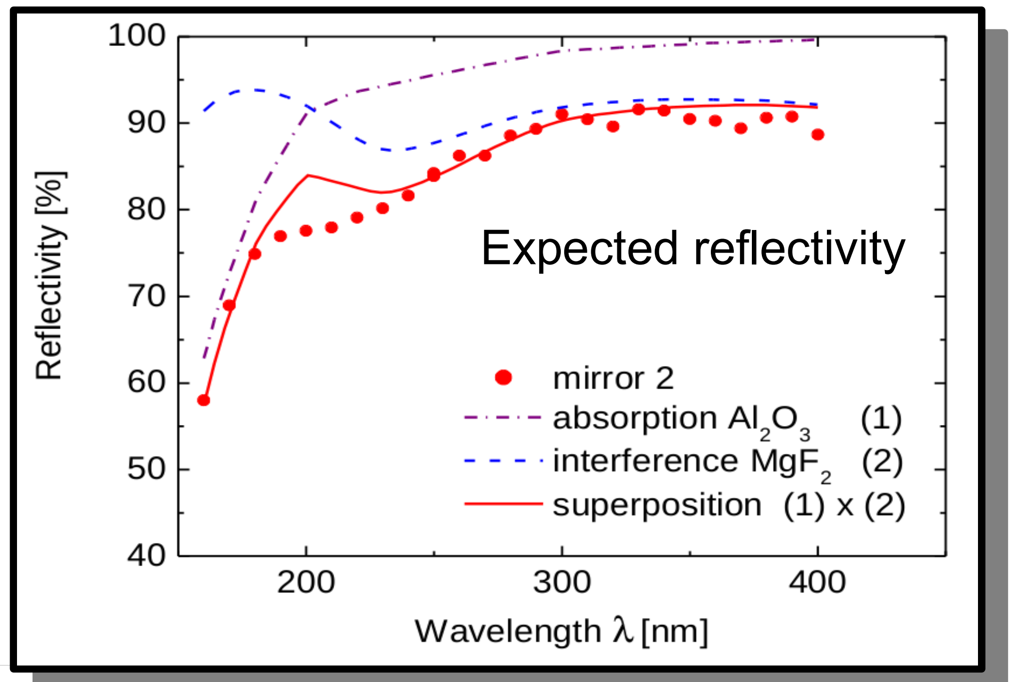
CBM

- Flabeg mirror shows better reflectivity, up to **92% @ 350nm**
  Compas: maximum **80%**, 78%@350nm
- Different incidence angles:
  Angular dependance of UV reflectivity due to interference in MgF_2 layer

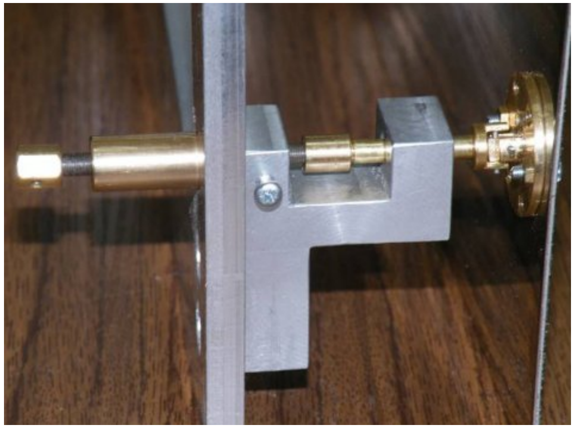
- Good understanding of Flabeg reflectivity in terms of absorption in Al_2O_3, interference in MgF_2

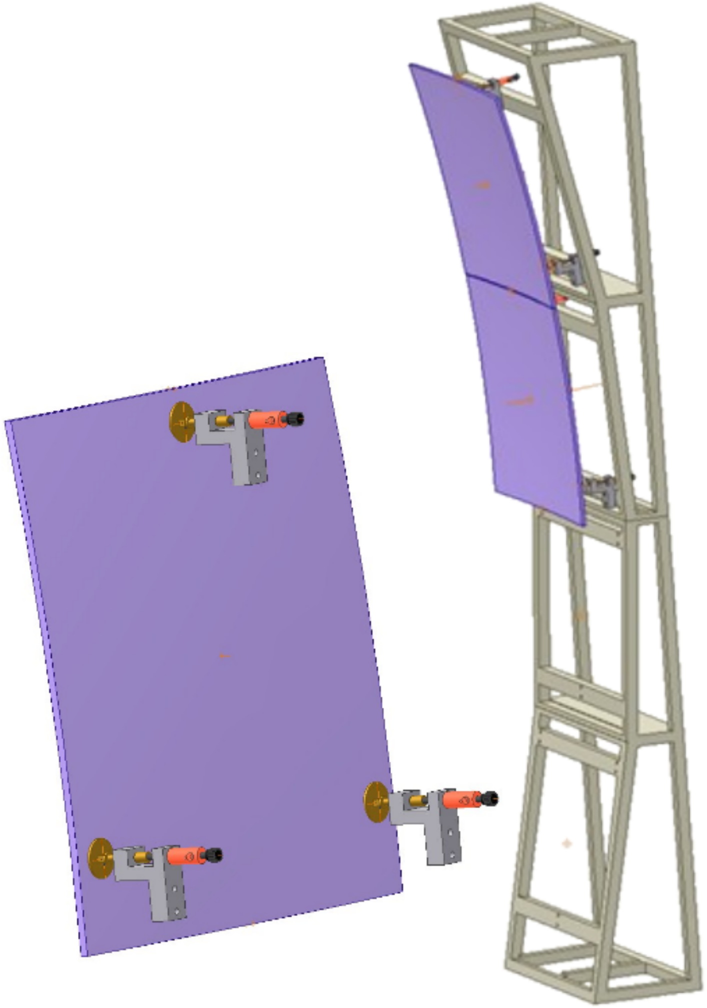




Mirror mounting

- Mechanical actuators for mirror mount developed at PNPI, St Petersburg
- Finite elemente simulation of mirror deformation, optimization of mount points
- Mount point location influence on D0: ~0.5mm





PNPI, Gatchina, RU

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Prototype simulations:

- Geant3 simulation, including:
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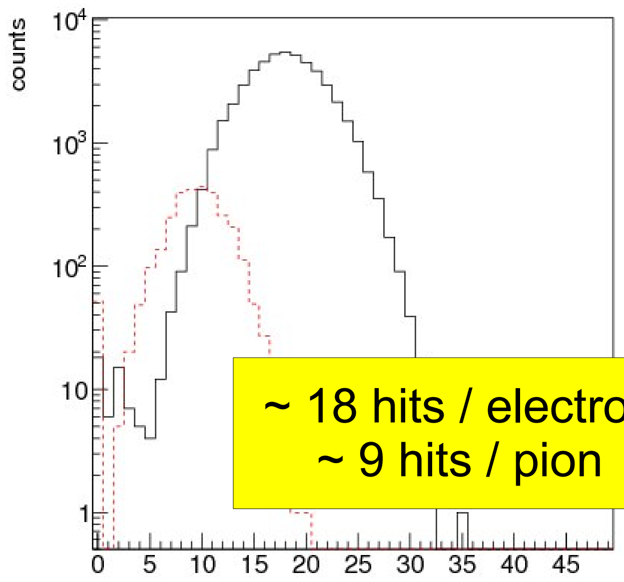

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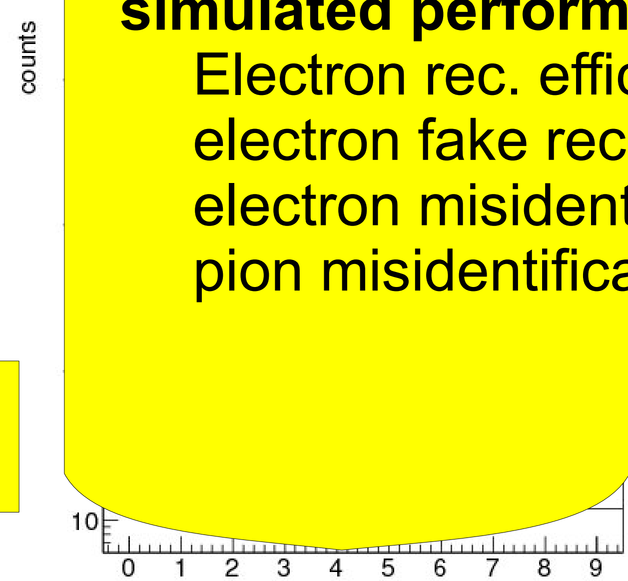

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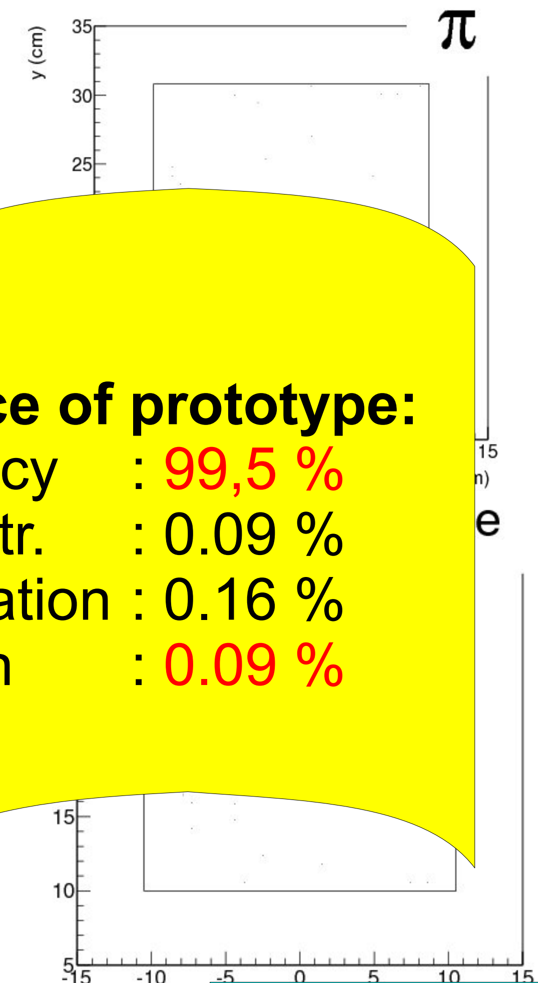

simulated performance of prototype:

Electron rec. efficiency	: 99,5 %
electron fake reconstr.	: 0.09 %
electron misidentification	: 0.16 %
pion misidentification	: 0.09 %

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