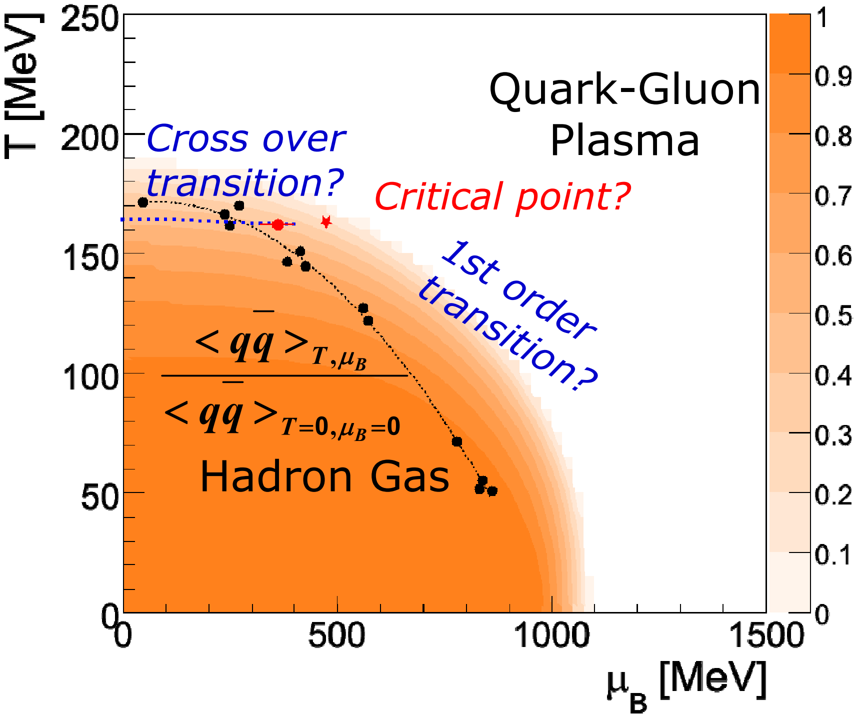
Status of the CBM experiment

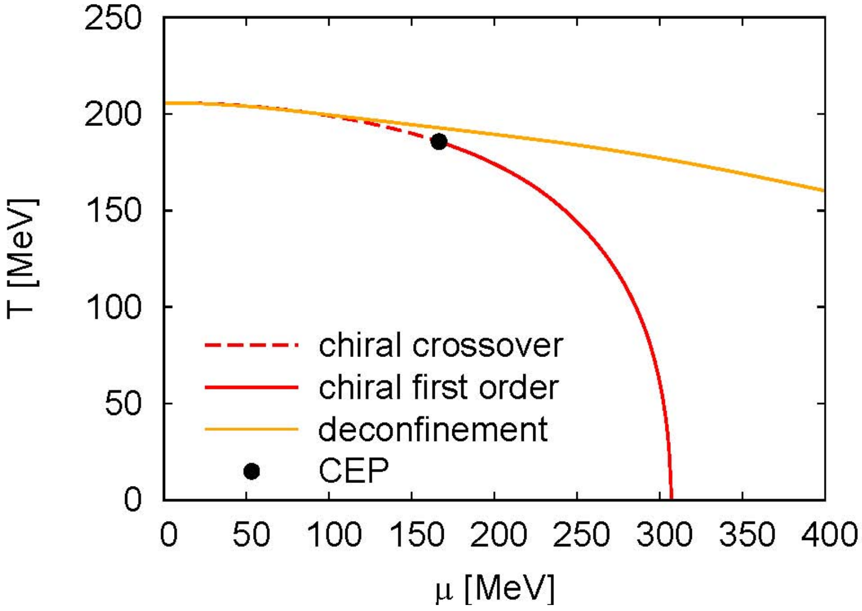
Claudia Höhne, GSI Darmstadt

Features of the phase diagramme

QCD inspired effective models predict rich structure of the phase diagramme at finite μ_B.

- Substantial depletion of the ciral condesate over almost the full lifetime of the fireball.
- Separation of the chiral from the deconfinement phase transition.
- 1st-order transition with a critical end point





Bernd-Jochen Schaefer, Jan M. Pawlowski, Jochen Wambach, priv. comm. and Phys. Rev. D. 76 074023

The Physics Program of CBM in total

Deconfinement phase transition at high ρ_B

- excitation function and flow of strangeness (K, Λ, Σ, Ξ, Ω)
- excitation function and flow of charm (J/ψ, ψ', D_0, $D^\pm$, Λ_c)
- melting of J/ψ and ψ'

QCD critical endpoint

- excitation function of event-by-event fluctuations (K/π,...)

The equation-of-state at high ρ_B

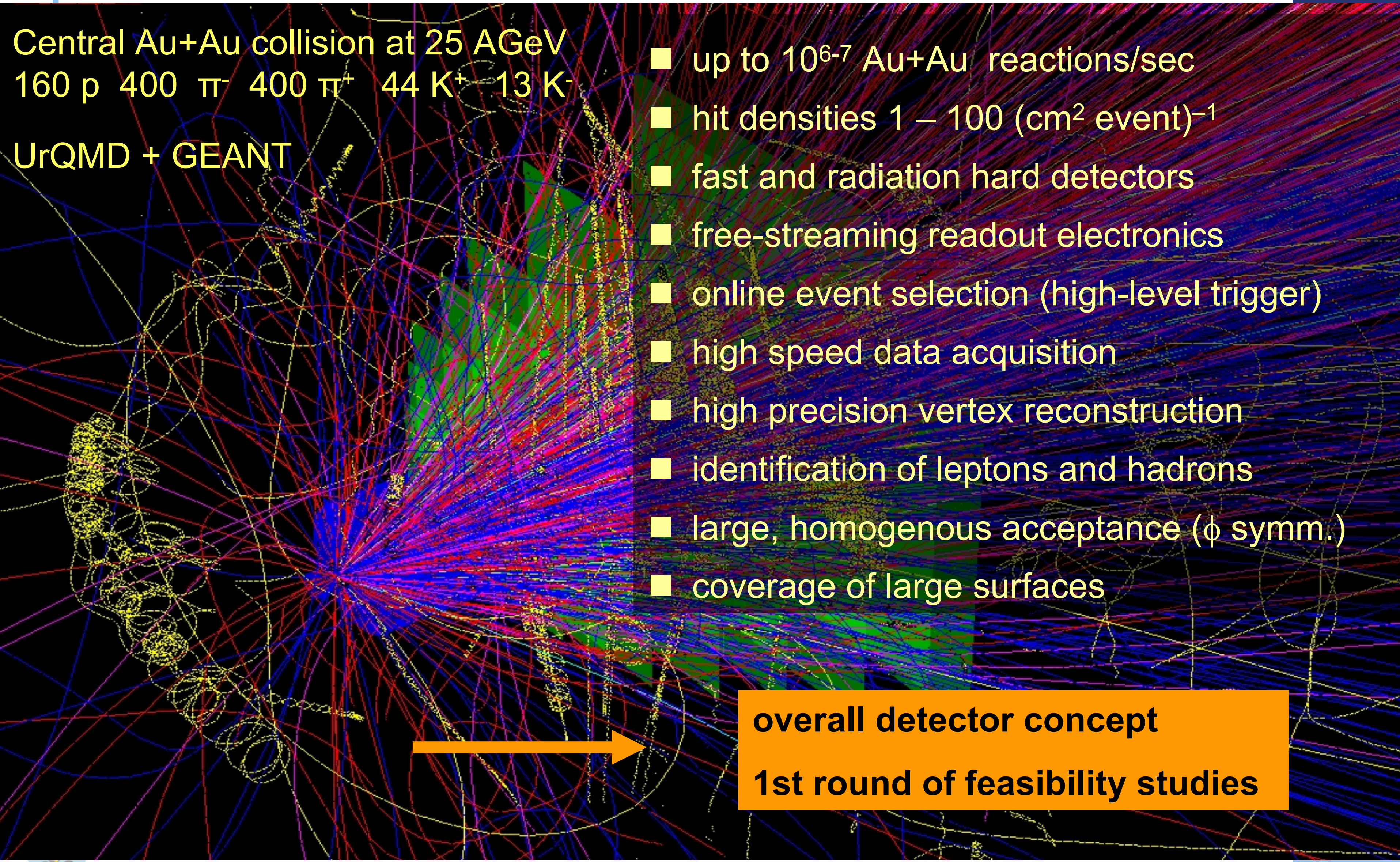
- collective flow of hadrons
- particle production at threshold energies (open charm?)

Onset of chiral symmetry restoration at high ρ_B

- in-medium modifications of hadrons ($\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$, D)

- Excitation functions of bulk and rare observables!
- Bulk observables with “unlimited” statistics
- Systematic studies of rare observables (charm, dileptons) with excellent statistics

Experimental challenges



Central Au+Au collision at 25 AGeV
160 p 400 π^- 400 π^+ 44 K^+ 13 K^-

UrQMD + GEANT

- up to $10^{6\text{-}7}$ Au+Au reactions/sec
- hit densities 1 – 100 $(\text{cm}^2\ \text{event})^{-1}$
- fast and radiation hard detectors
- free-streaming readout electronics
- online event selection (high-level trigger)
- high speed data acquisition
- high precision vertex reconstruction
- identification of leptons and hadrons
- large, homogenous acceptance (ϕ symm.)
- coverage of large surfaces

→ **overall detector concept**

1st round of feasibility studies

The CBM experiment

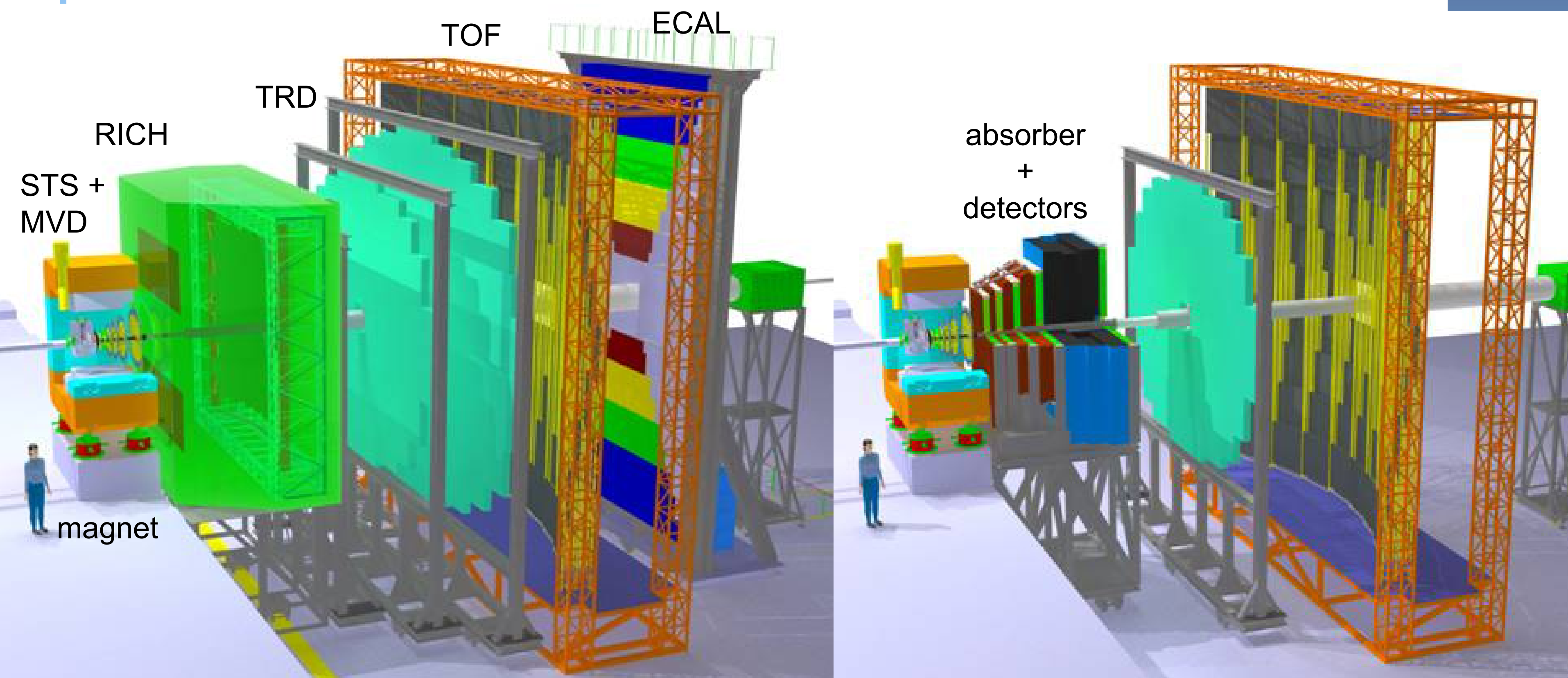
- tracking, momentum determination, vertex reconstruction: radiation hard silicon pixel/strip detectors (STS) in a magnetic dipole field

- hadron ID: TOF (& RICH)
- photons, π^0, η: ECAL

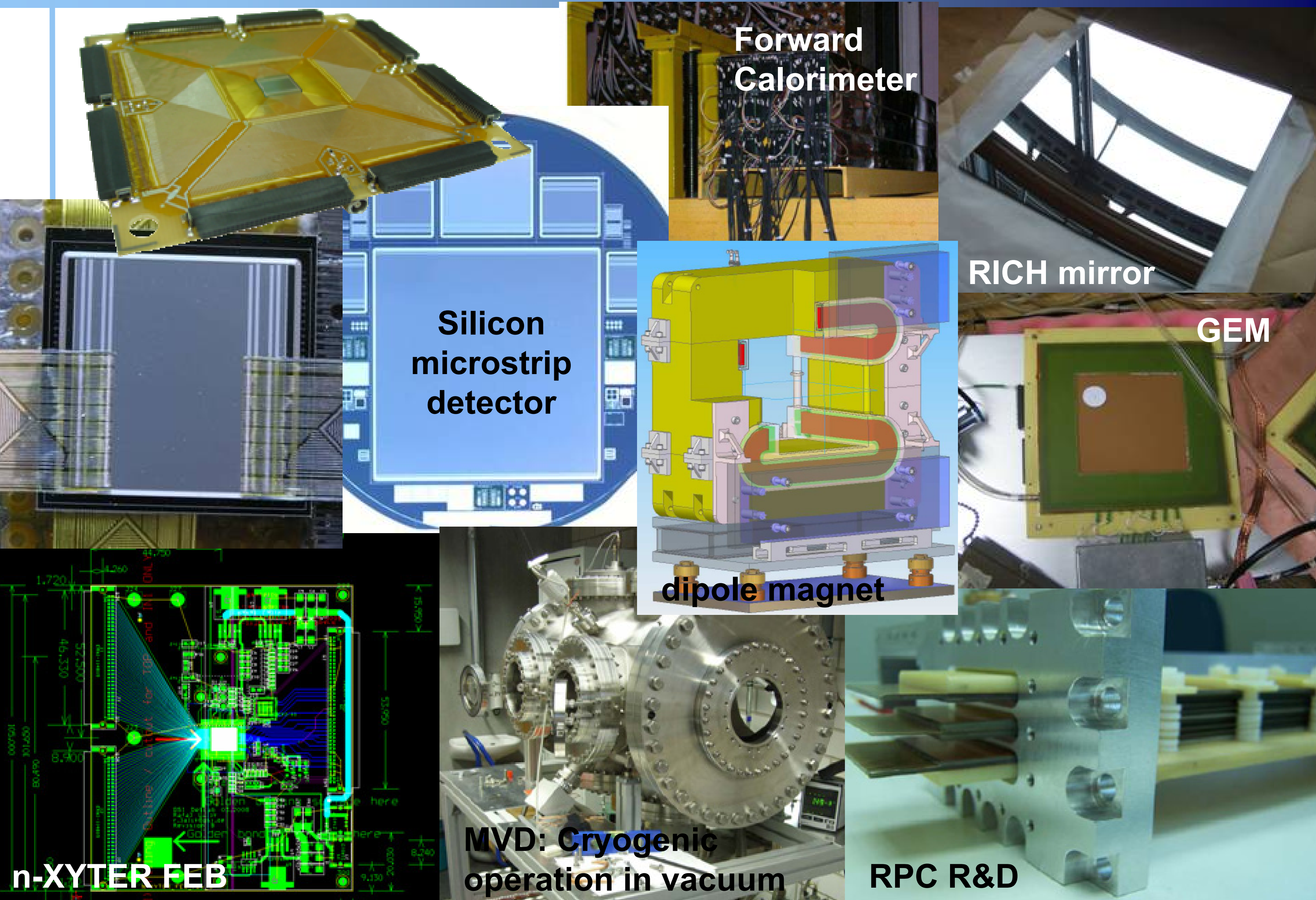
- PSD for event characterization
- high speed DAQ and trigger → **rare probes!**

- **electron ID**: RICH & TRD
  → π suppression $\geq 10^4$

- **muon ID**: absorber + detector layer sandwich
  → move out absorbers for hadron runs



CBM hardware R&D



Forward Calorimeter

RICH mirror

GEM

Silicon microstrip detector

dipole magnet

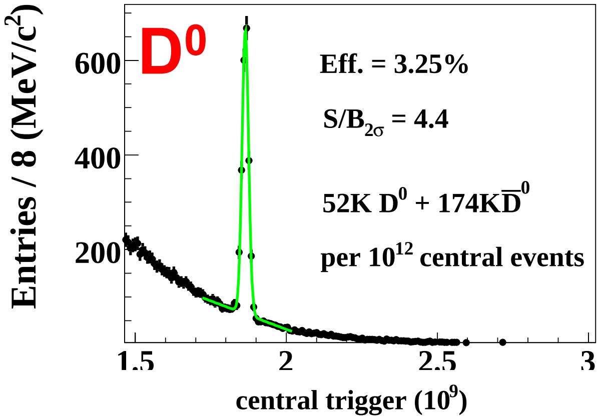
n-XYTER FEB

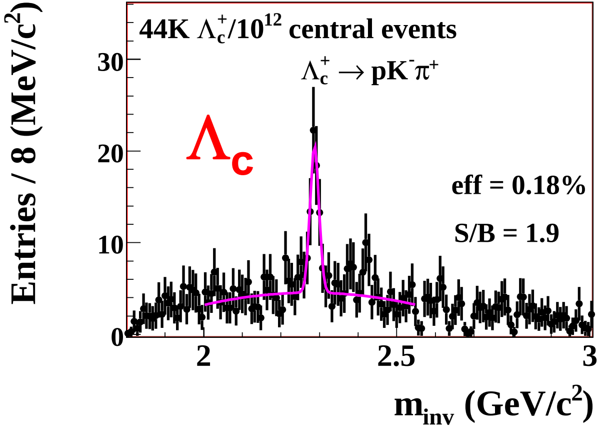
MVD: Cryogenic operation in vacuum

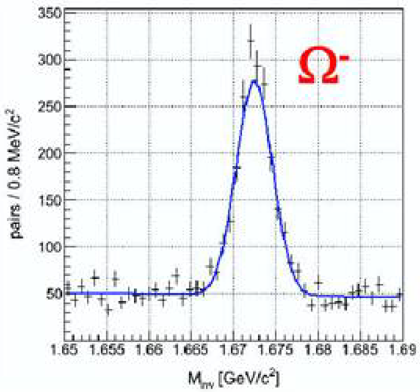
RPC R&D

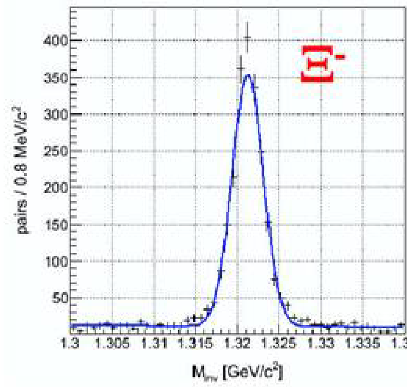
CBM feasibility studies

- feasibility studies performed for all major channels including event reconstruction and semirealistic detector setup



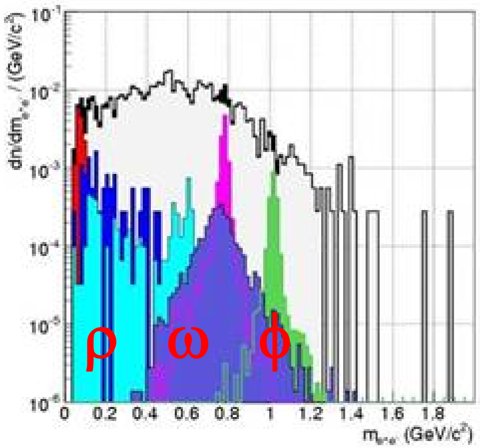


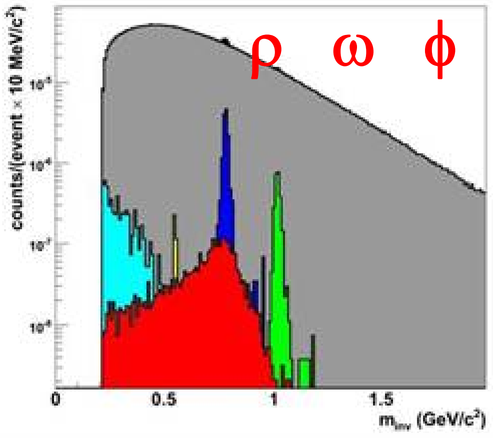


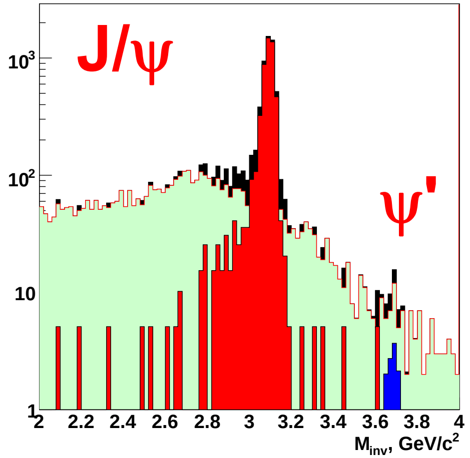


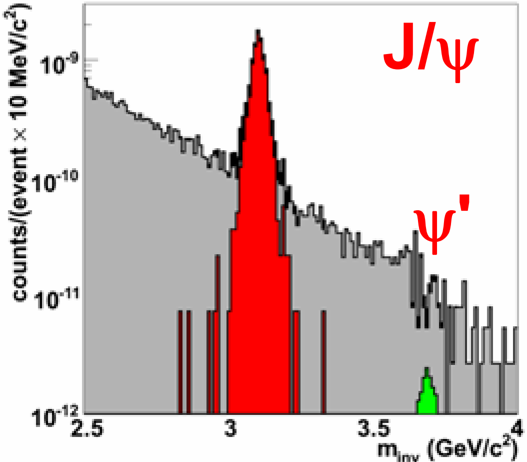
di-electrons

di-muons



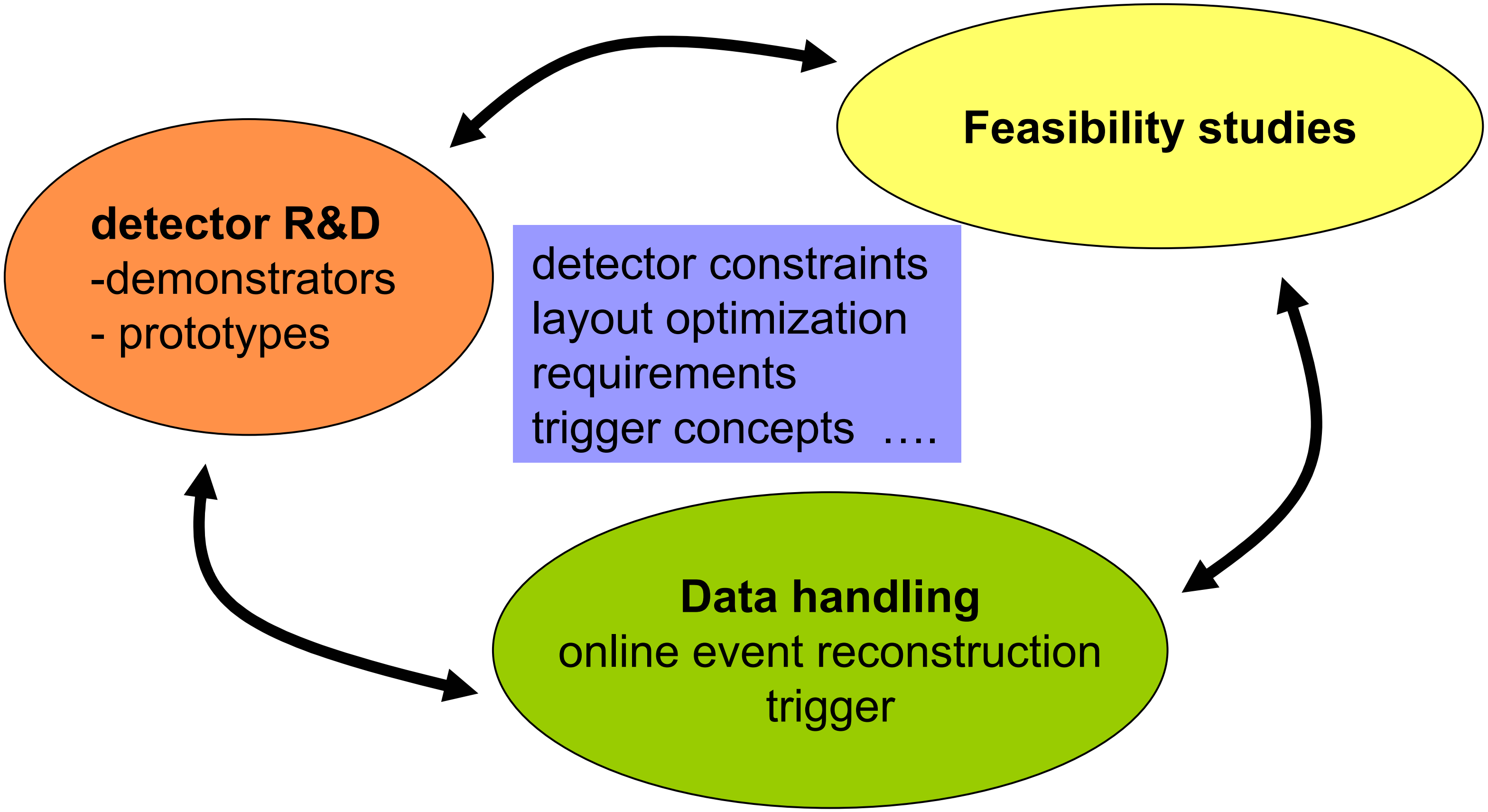






Outline

- overall detector concept ✓
- 1st round of feasibility studies ✓



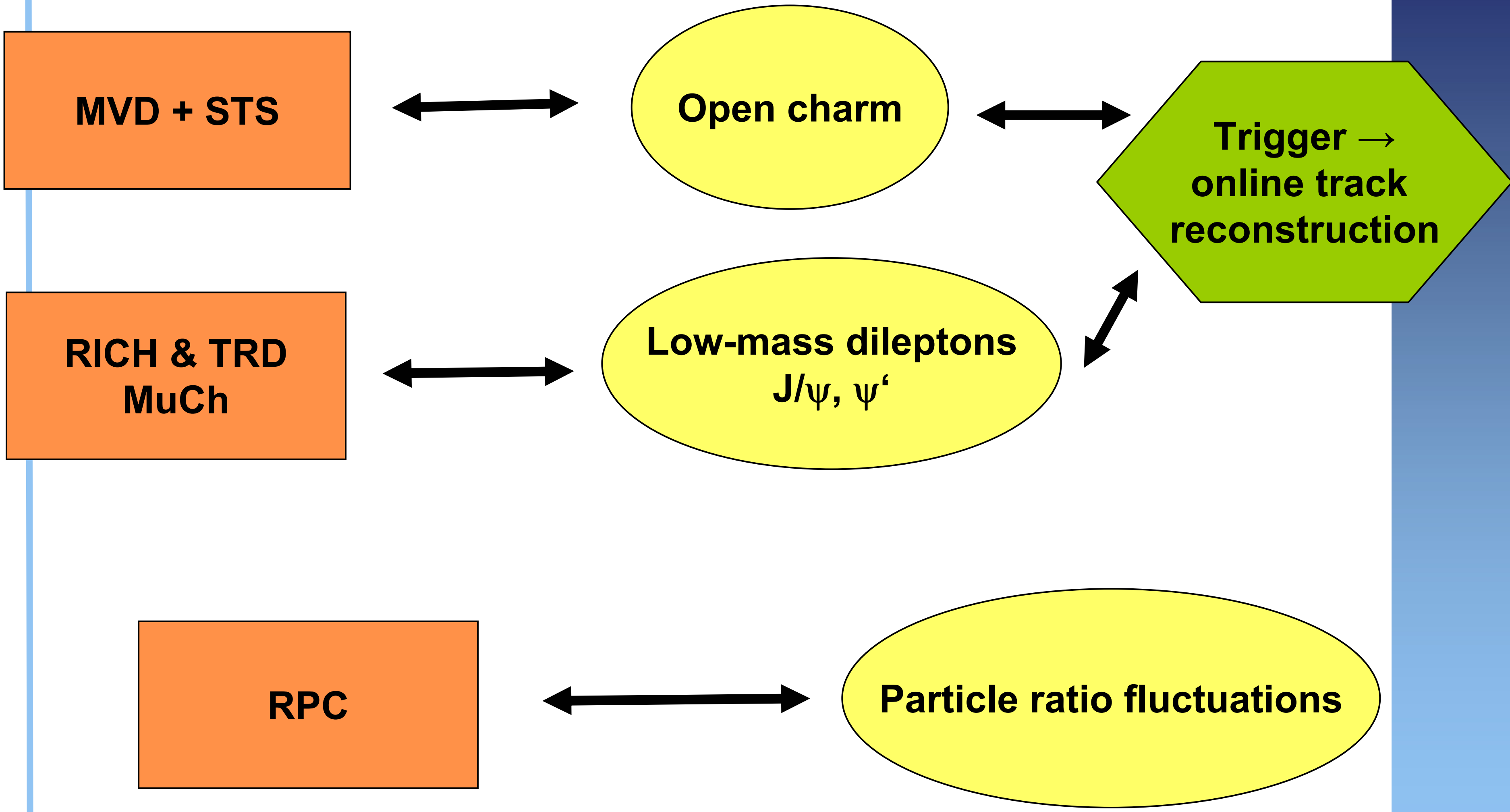
Feasibility studies

detector R&D
-demonstrators
- prototypes

detector constraints
layout optimization
requirements
trigger concepts ….

Data handling
online event reconstruction
trigger

Outline (II)



MVD + STS

Open charm

Trigger → online track reconstruction

RICH & TRD
MuCh

Low-mass dileptons
J/ψ, ψ'

RPC

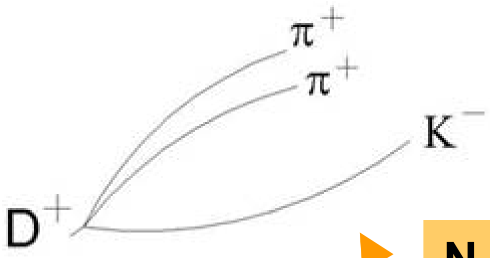
Particle ratio fluctuations

STS tracking – heart of CBM

Challenge: high track density: ≈ 600 charged particles in ± 25°

Task

- track reconstruction: 0.1 GeV/c < p ≤ 10-12 GeV/c Δp/p ~ 1% (p=1 GeV/c)
- primary and secondary vertex reconstruction (resolution ≤ 50 μm)
- V_0 track pattern recognition



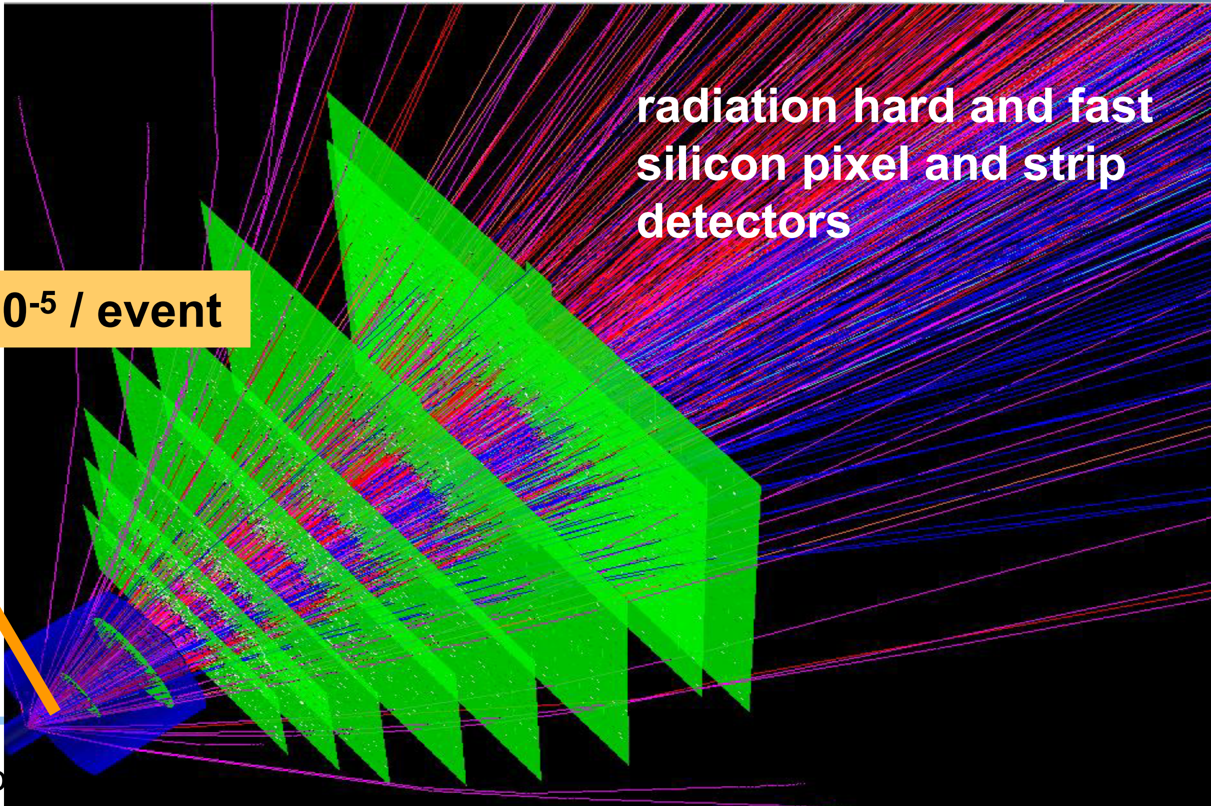
$c\tau = 312\ \mu m$

N ~ 10^{-5} / event

self triggered FEE

high speed DAQ and trigger

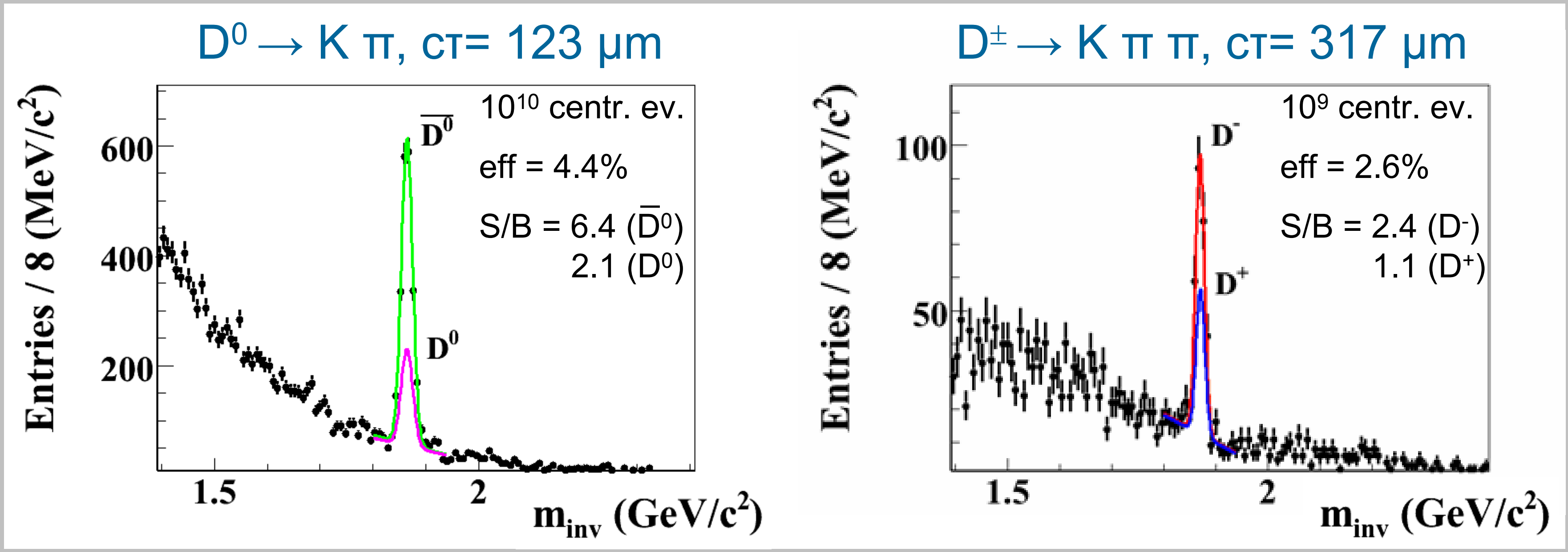
online track reconstruction!



radiation hard and fast silicon pixel and strip detectors

Open charm reconstruction

- STS: 8 stations double-sided Silicon micro-strip sensors (8 × 0.4% X_0)
- MVD: 2 stations MAPS pixel sensors (0.3% X_0, 0.5% X_0) at z = 5cm and 10cm
- no K and π identification, proton rejection via TOF



$D^0 \to K\pi$, cτ= 123 μm

10^{10} centr. ev.

eff = 4.4%

S/B = 6.4 ($\bar{D}^0$)
2.1 (D^0)

$D^\pm \to K\pi\pi$, cτ= 317 μm

10^9 centr. ev.

eff = 2.6%

S/B = 2.4 (D^-)
1.1 (D^+)

10^{12} minbias events: **~ 6.4k D^0 + 16k $\bar{D}^0$** and **19k D^+ + 42k D^-**

D meson reconstruction

- **important layout studies: MAPS position and thickness !**
- HSD: <D+> = 8 · 10^{-6}/ev (minbias Au+Au collisions, 25 AGeV)
- D+ → $K^-\pi^+\pi^+$ 9.2% BR
- 0.1 MHz interaction rate (MAPS readout time 10μs, small pile-up ok)
- 10^{12} minb events ~ 16 weeks running time (100% beam availability)

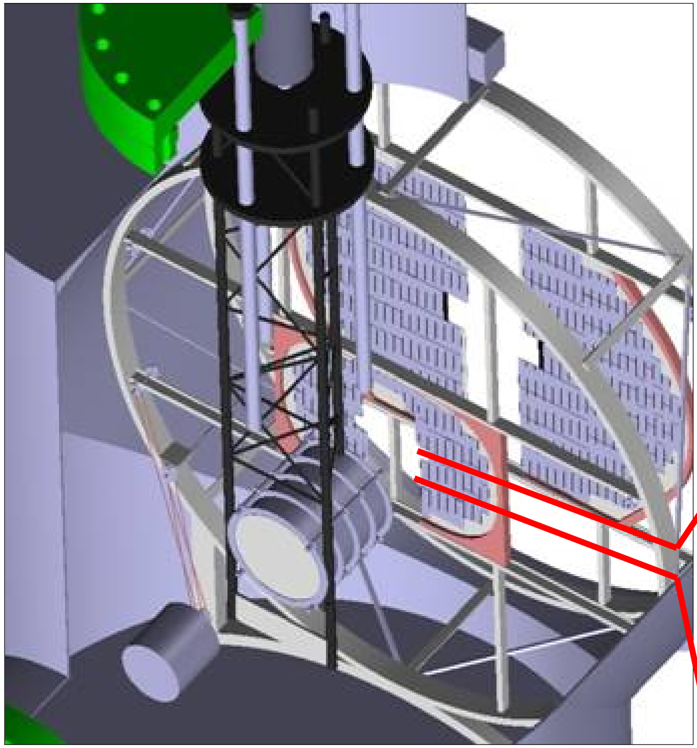
~10^{13} n_{eq}/cm^2 = lifetime of MAPS

1st MAPS thickness	Position of 1st MAPS *	D+ efficiency	D+ S/B (2σ)	D+ in 10^{12} ev.
150 μm	10 cm	4.2%	9	$31 \cdot 10^3$
500 μm	10 cm	1.05%	0.93	$8 \cdot 10^3$
300 μm	5 cm	2.6%	1.1	$19 \cdot 10^3$

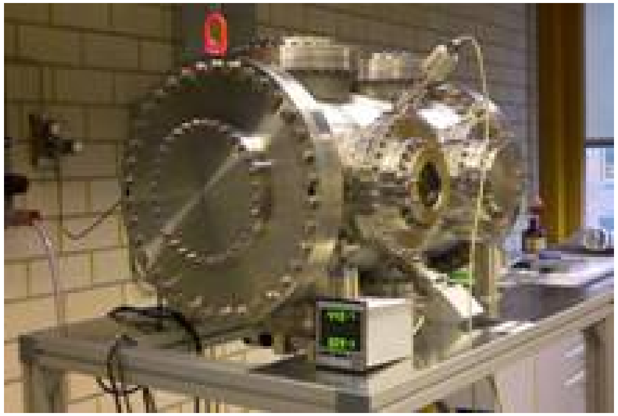
* 2nd MAPS, 500 μm Si equivalent, 10 cm (1st 5 cm) or 20 cm

Micro Vertex Detecor (MVD) Development

Artistic view of the MVD

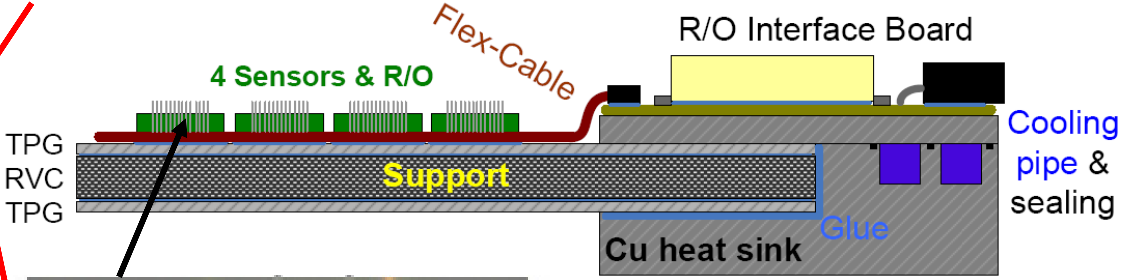


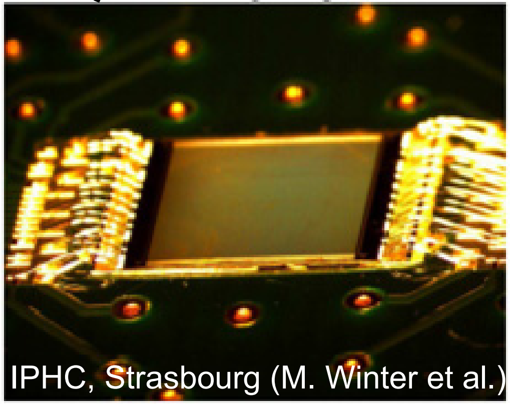
Monolithic **A**citive **P**ixel **S**ensors in commercial CMOS process $10\times10\ \mu m^2$ pixels fabricated, $\varepsilon > 99\%$, $\Delta x \sim 1.5 - 2.5\ \mu m$



MAPS demonstrator!

- thickness
- readout speed
- radiation hardness

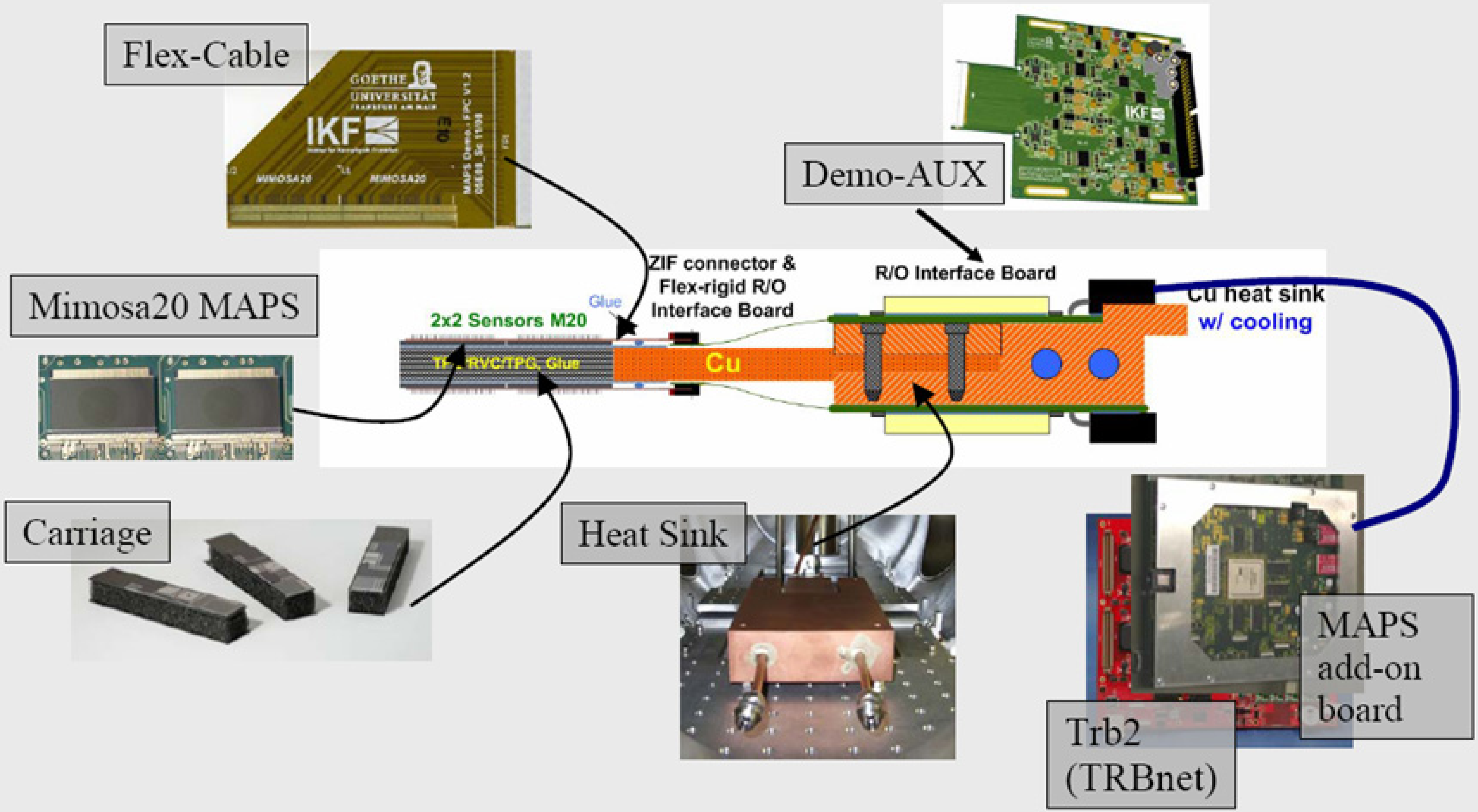




IPHC, Strasbourg (M. Winter et al.)

die thinned to 50 μm glued to support.

MAPS Demonstrator @ IKF Frankfurt



- all parts in house, under test or ordered
- demonstrator to be completed and tested until mid 2009!!
- in parallel: investigate zero suppression, setup analysis software

First in-beam experiments of Si strips!

GSI: Test beam line with 2.5 GeV protons

CBM pre-prototype detector systems with free-streaming read-out electronics

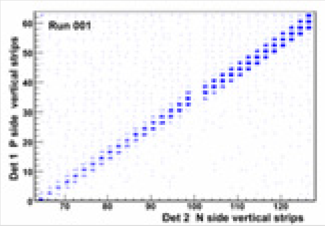
2 double-sided silicon microstrip detectors

2 GEM detectors

Front-end board with self-triggering n-XYTER chip

Readout controller

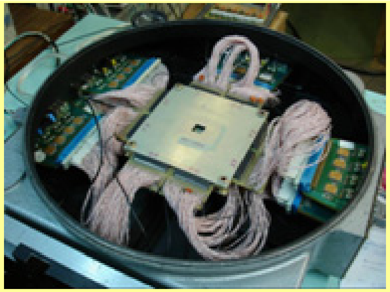
DAQ



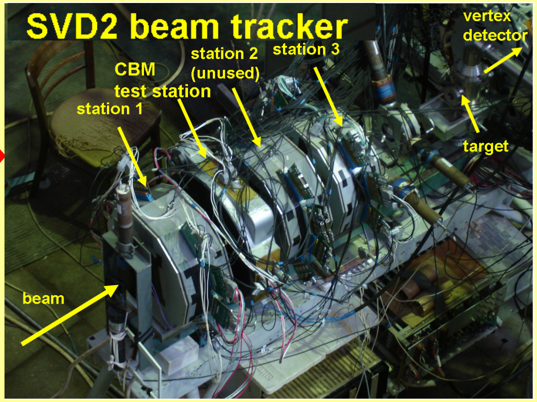
online/offline analysis (FAIRroot)

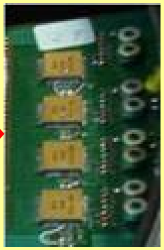
IHEP: SVD-2 experiment, 50 GeV protons

CBM demonstrator tracking station operated in the SVD-2 beam tracker



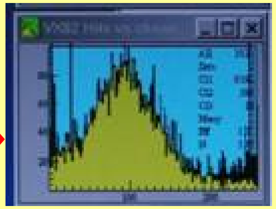
1 tracking station with a double-sided silicon microstrip detector





Readout board with Gassiplex chips

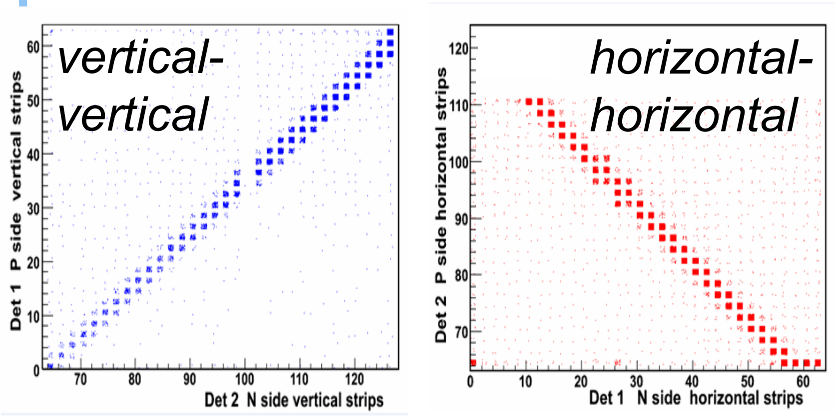
SVD-2 DAQ



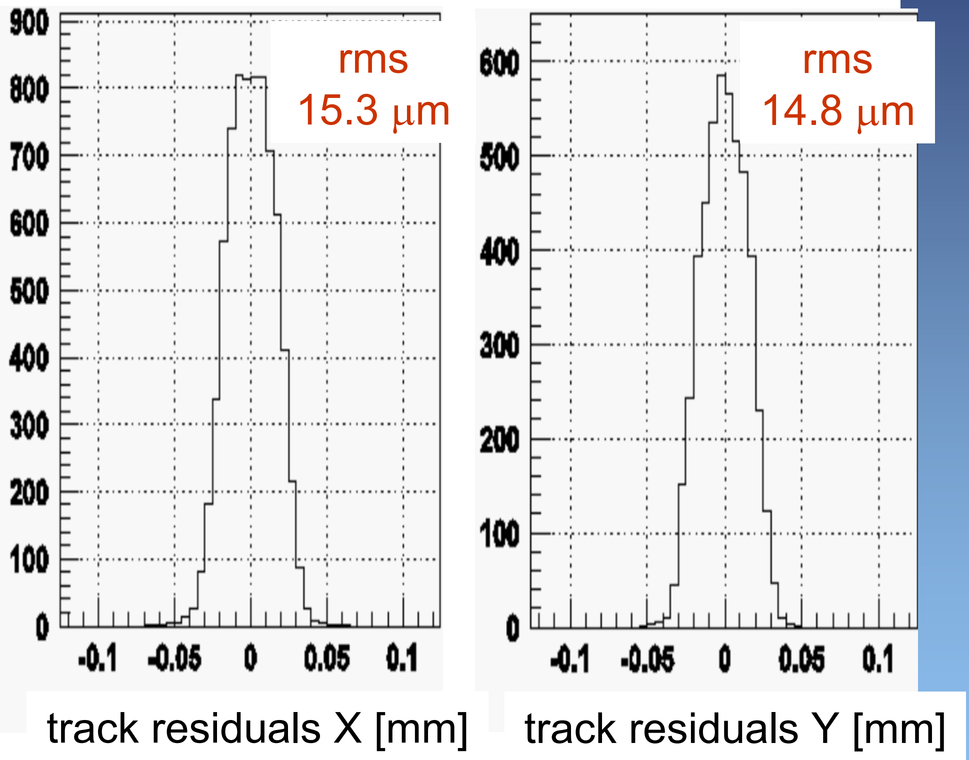
online/offline analysis

Results from in-beam experiments

correlation of fired strips



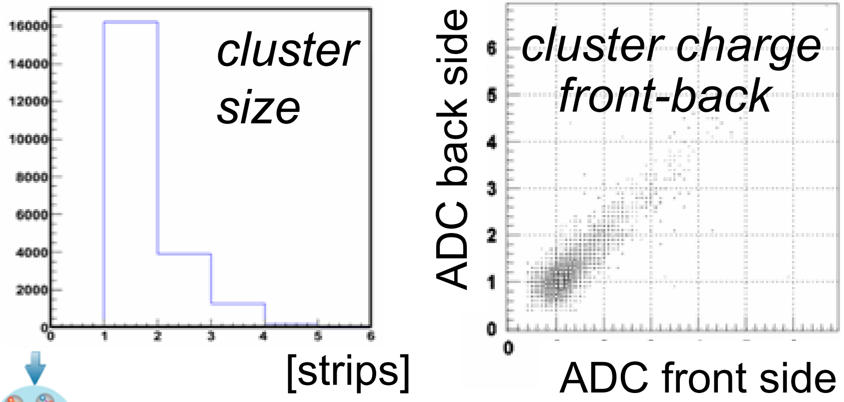
spatial resolution



corresponds to 50 μm strip pitch/√12

tracking efficiency ~ 100%

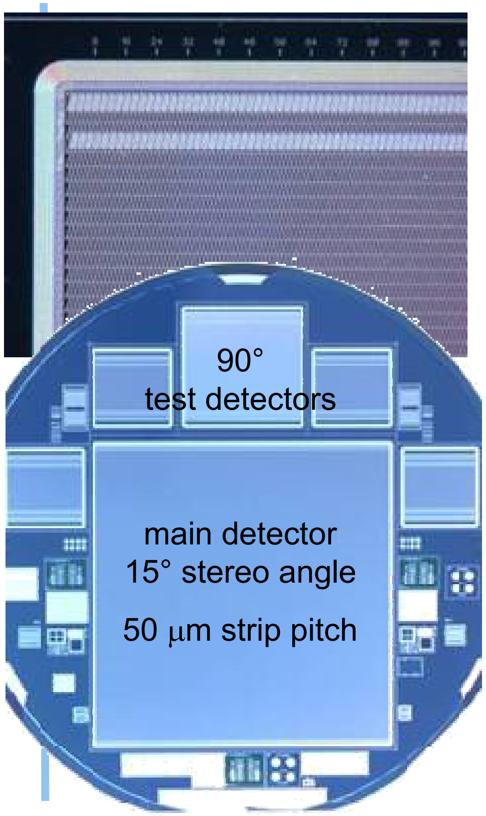
detector hits



R&D on radiation hard Si microstrip detectors

double-sided microstrip detectors

Prototype CBM01 – focus on STS system aspects, radiation soft

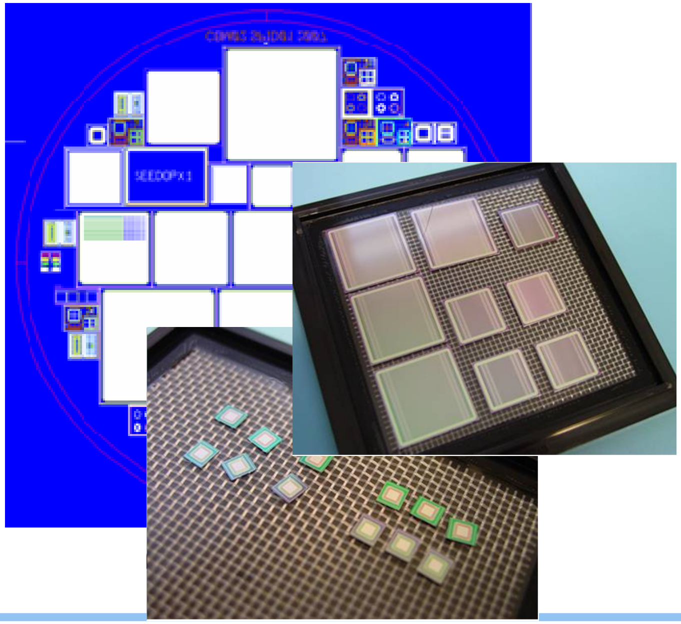


4" wafer, 285 µm Si

Neutron fluence through Silicon Tracking System up to 10^{15} n_{eq}/cm^2

in 6 years of operation

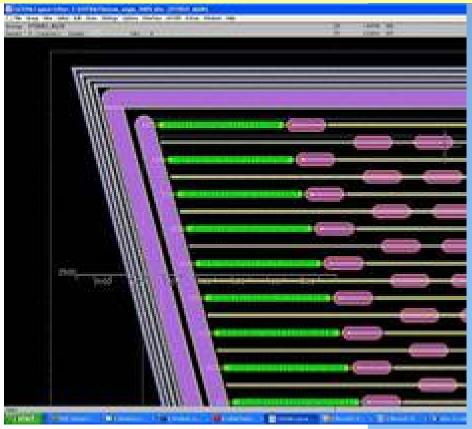
CBM02 – first prototype with radiation tolerant design



R&D activities:

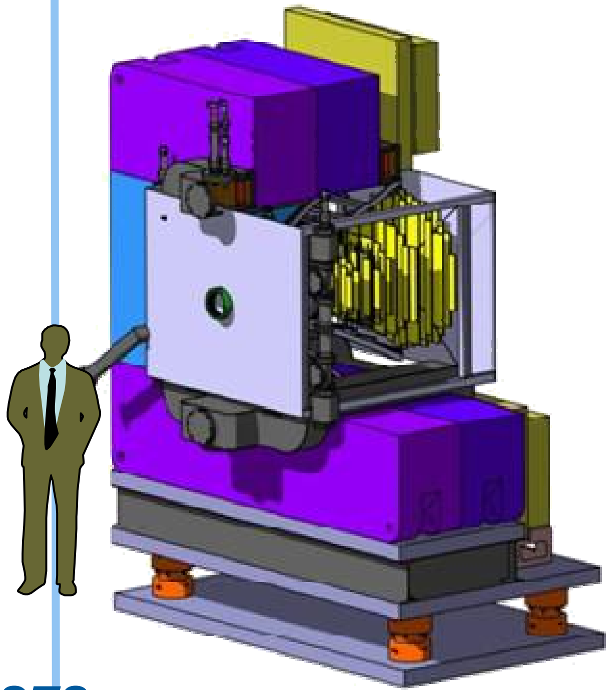
- **novel systematic 2D/3D device and process simulations (ISE-TCAD/Synopsis)**
- **irradiation tests**
- **fall back solution:**

radiation hard single-sided detectors

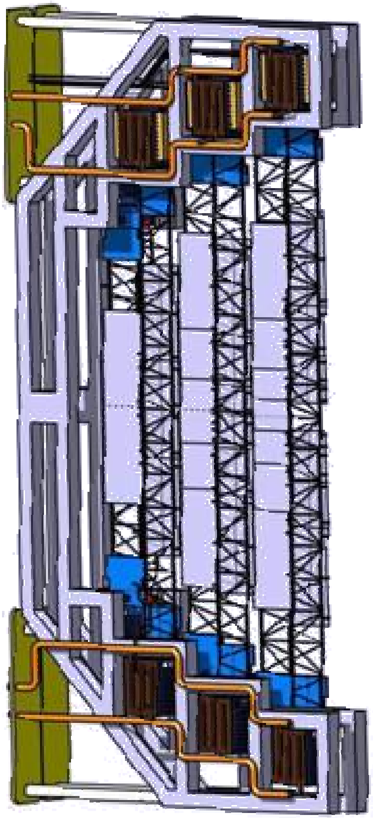


R&D on the Silicon Tracking System

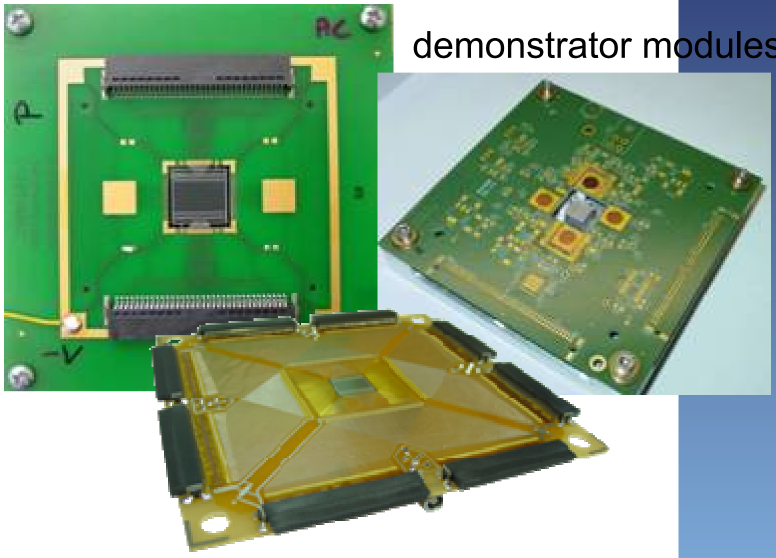
Challenge: *detector stations with ultra-low material budget*



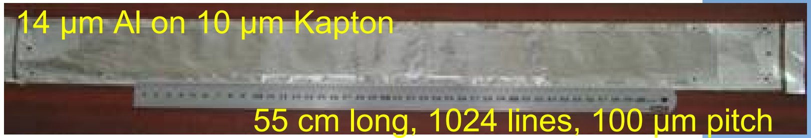
STS:
8 detectors stations
in thermal enclosure



Stations:
carbon enforced ladder structures
with peripheral read-out.



demonstrator modules



14 µm Al on 10 µm Kapton

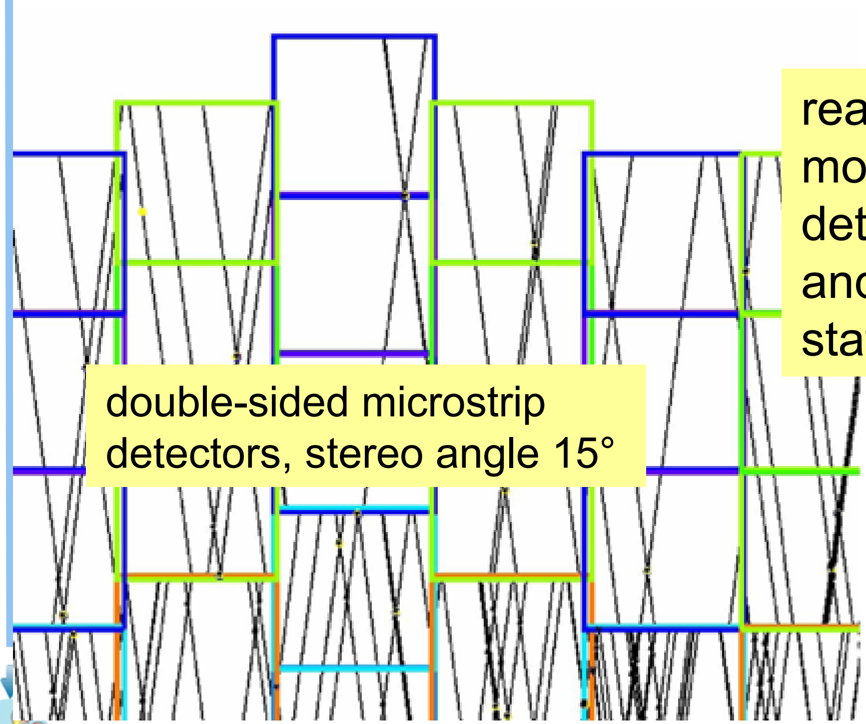
55 cm long, 1024 lines, 100 µm pitch

Ladders: sensors, bonded to ultra-thin long micro-cables, read-out electronics at periphery

Progress of simulation studies with the STS

<u>tracking:</u>

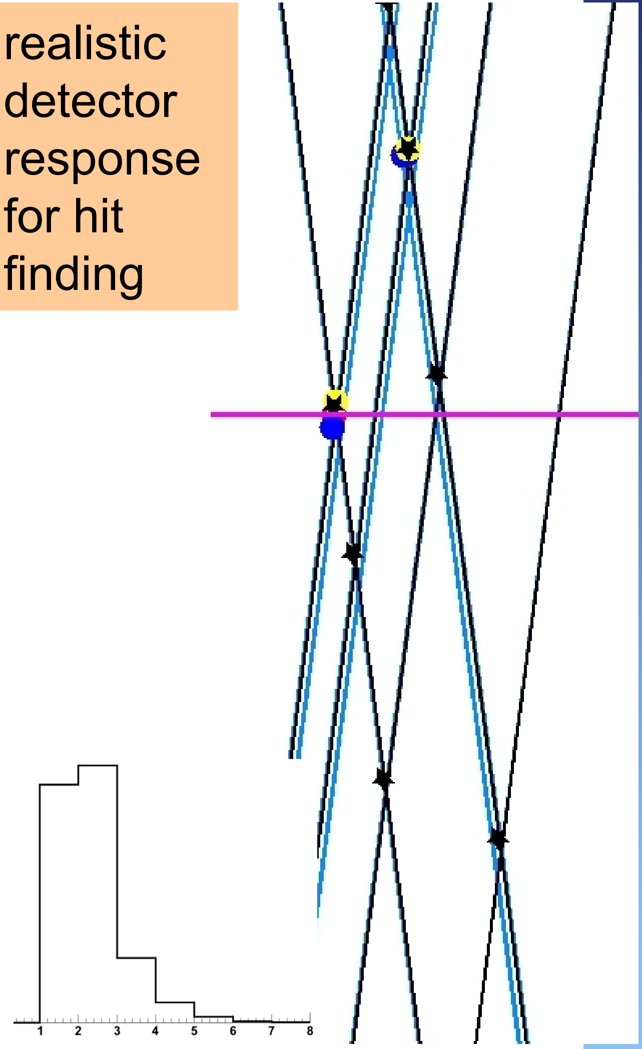
- efficiency **≤ 97%**
- momentum resolution **1.3%**



double-sided microstrip detectors, stereo angle 15°

realistic models of detectors and tracking stations

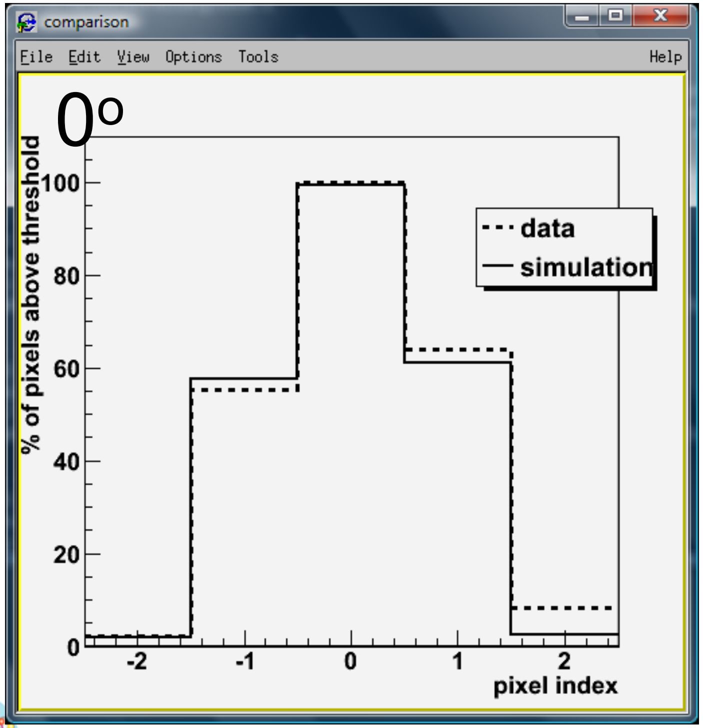
realistic detector response for hit finding

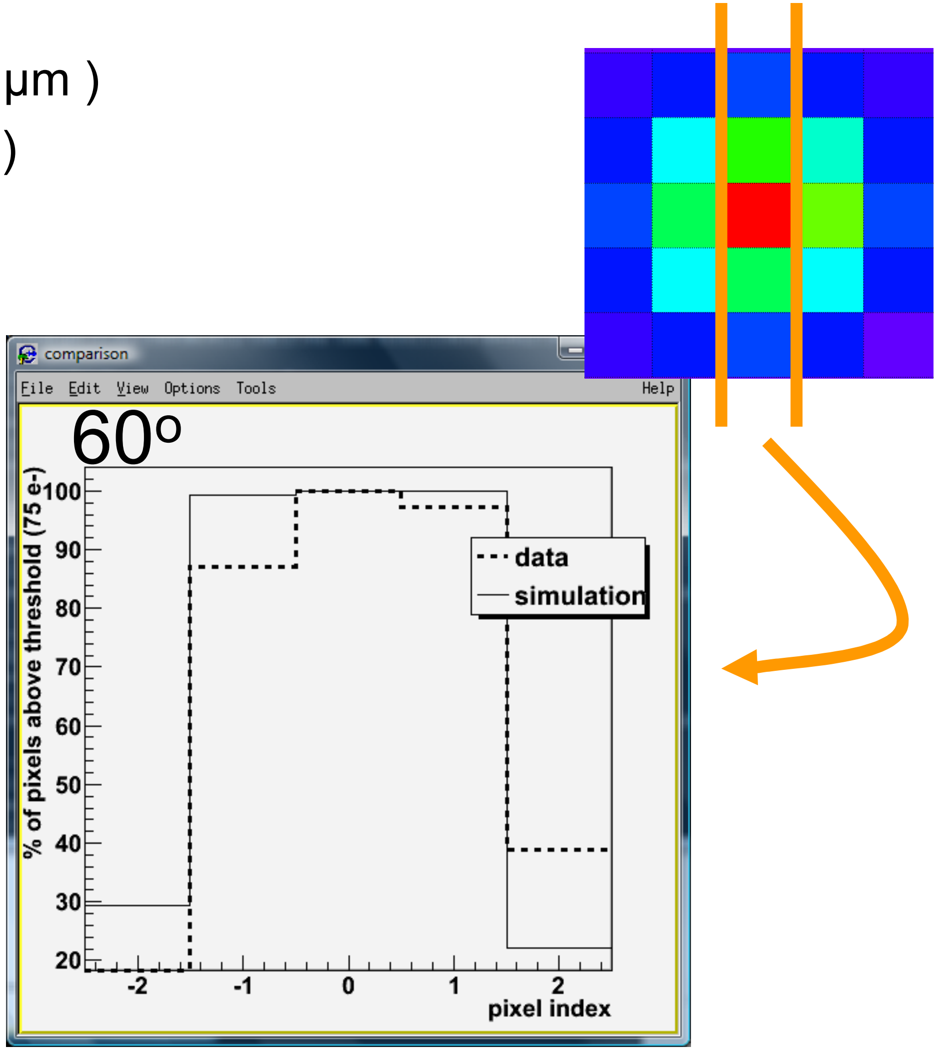


cluster size [strips]

Cluster shape & size modelling in the MVD

- Cluster shapes in MVD modeled, compared and adjusted to testbeam data (CERN, 120 GeV pions)
- MAPS sensor MIMOSA 17 (30 µm)
- Different incident angles (0°-80°)





Be prepared for exotica: multi-strange di-baryons

Signal: strange dibaryon

$(\Xi^0\Lambda)_b \rightarrow \Lambda\Lambda$ (cτ=3cm)

M= 10^{-6}, BR = 5%

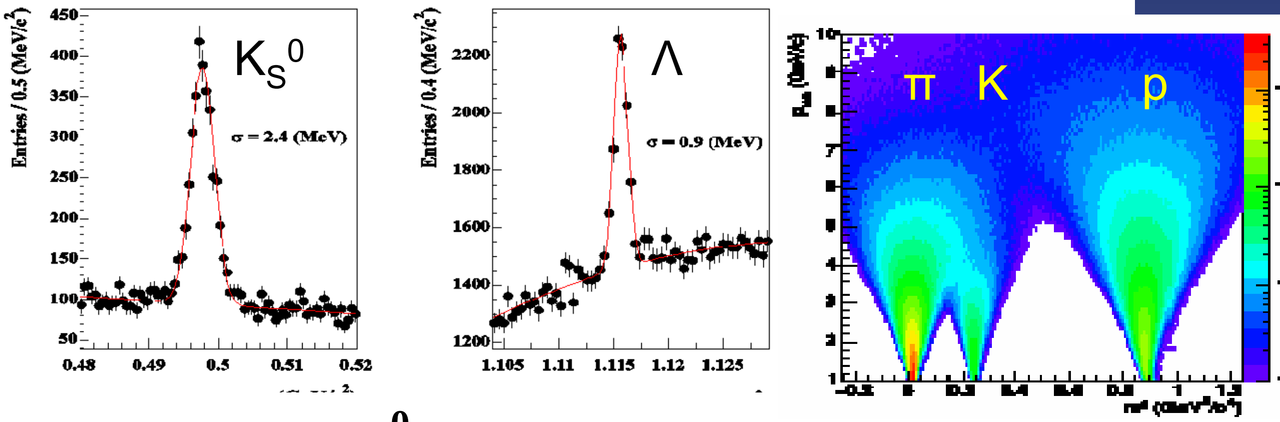
Background:

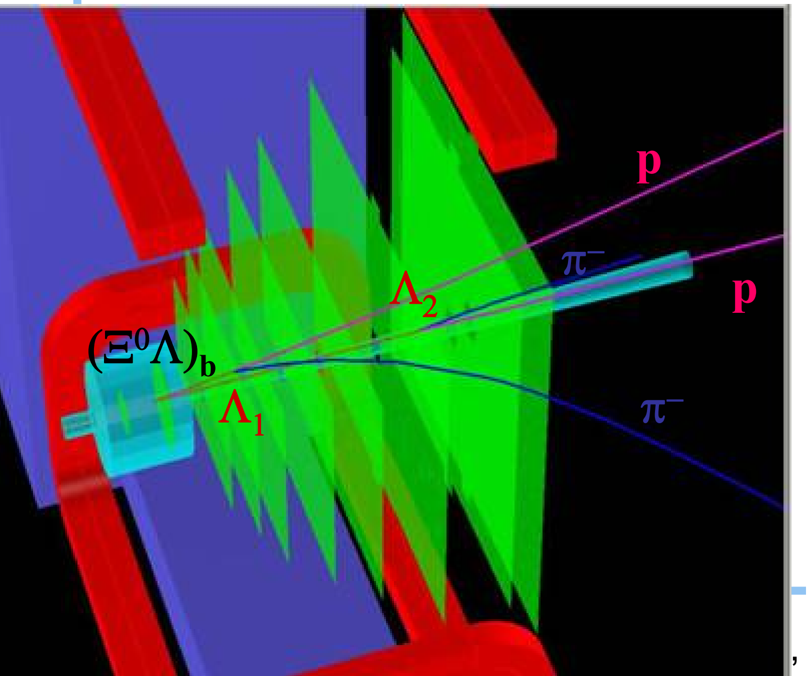
Au+Au @ 25 AGeV

32 Λ per central event

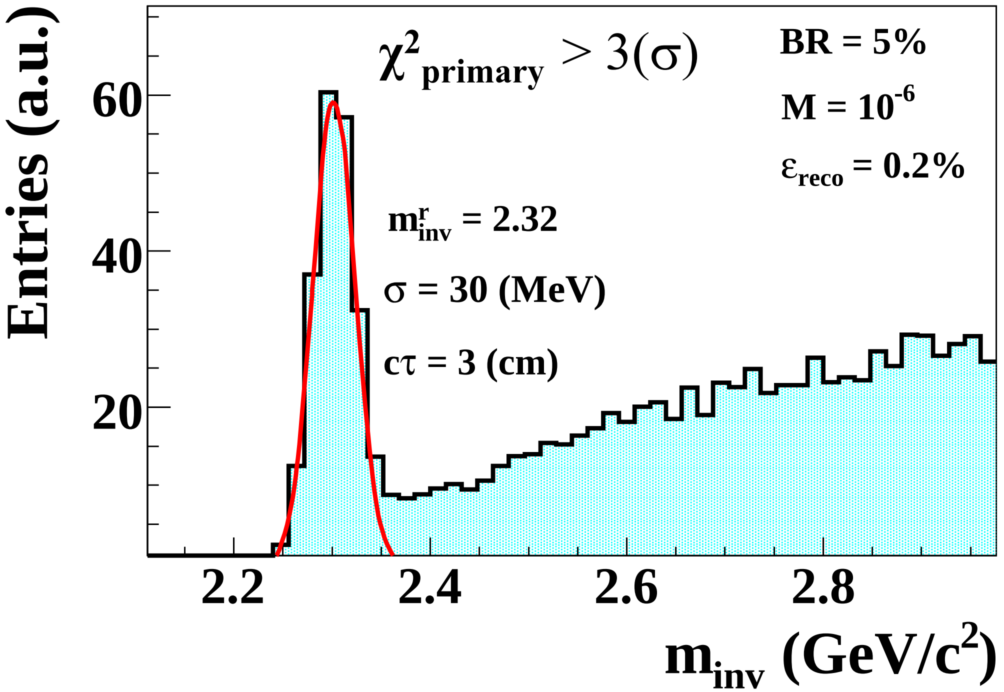
11 Λ reconstructable

Particle identification with CBM





$(\Xi^0\Lambda)_b \rightarrow \Lambda\Lambda$

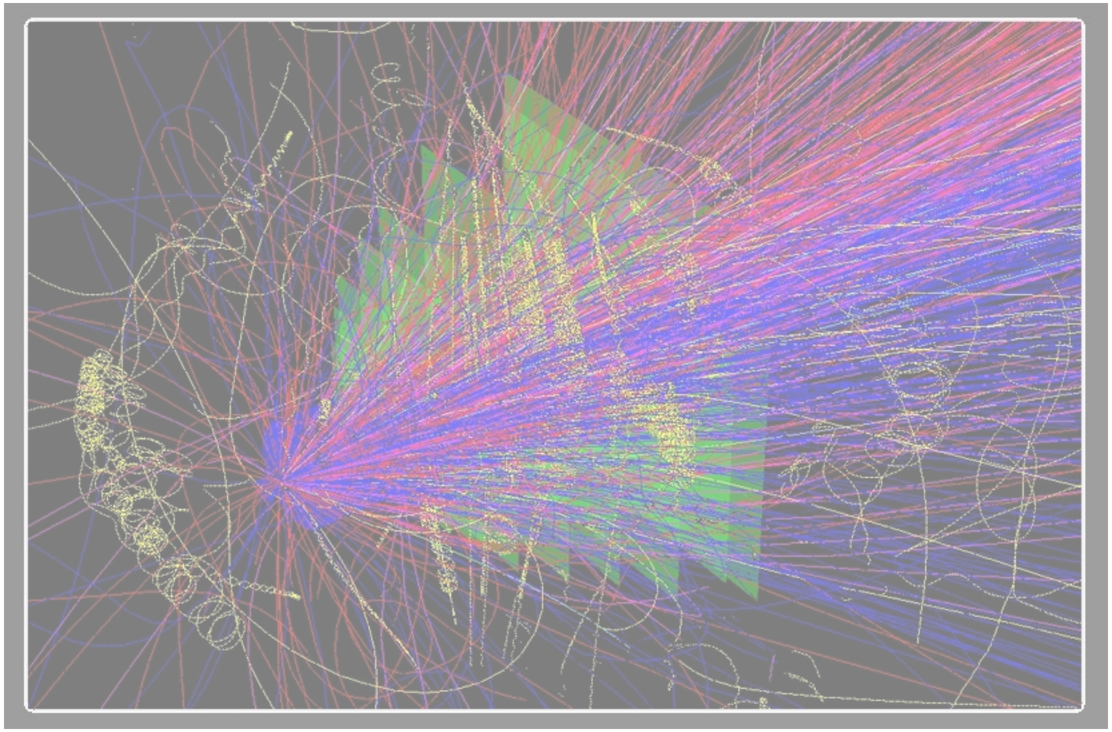


Fast track reconstruction

- J/ψ: up to ~$10^{8\text{-}9}$ tracks/s in the silicon tracker (1-10 MHz, ~100 tracks/ev.)
- D-mesons: ~10^{7} tracks/s (0.1 MHz)

→ **online event selection!**

→ **fast track reconstruction!**



Fast track reconstruction

- optimize code, port C++ routines to dedicated hardware
- parallel processing
- make use of manycore architectures of new generation graphics cards etc.
- **2015: few 1000 GPUs do the job!**

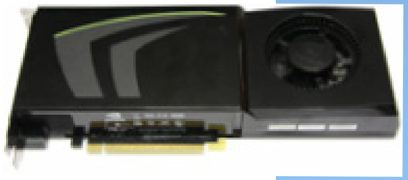
CPU
Intel: XXX-cores

Gaming
STI: Cell

GP CPU
Intel: Larrabee

OpenCL?

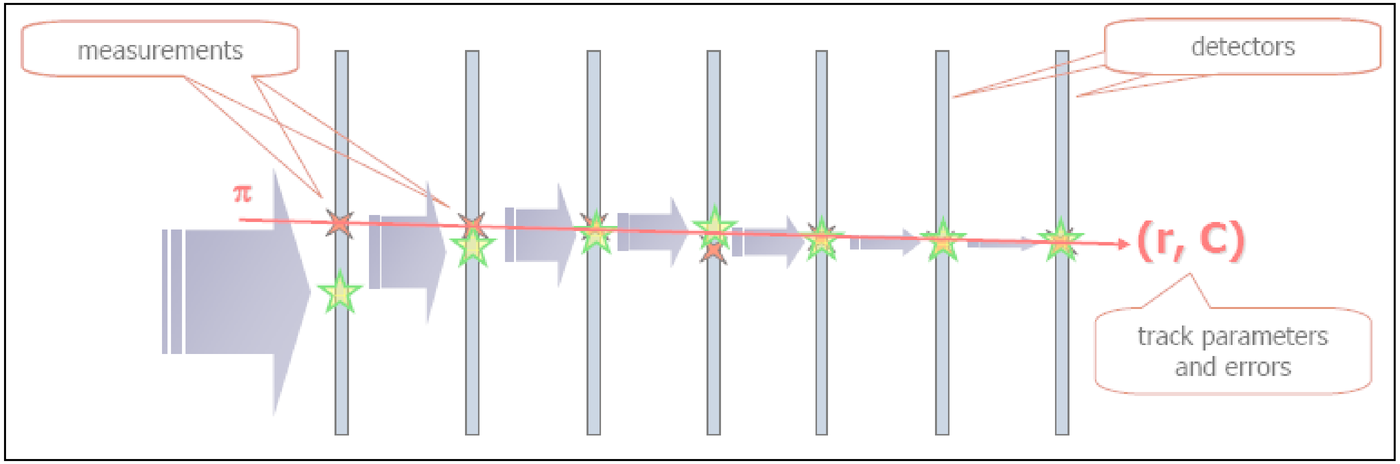
GP GPU
Nvidia: Tesla



CPU/GPU
AMD: Fusion

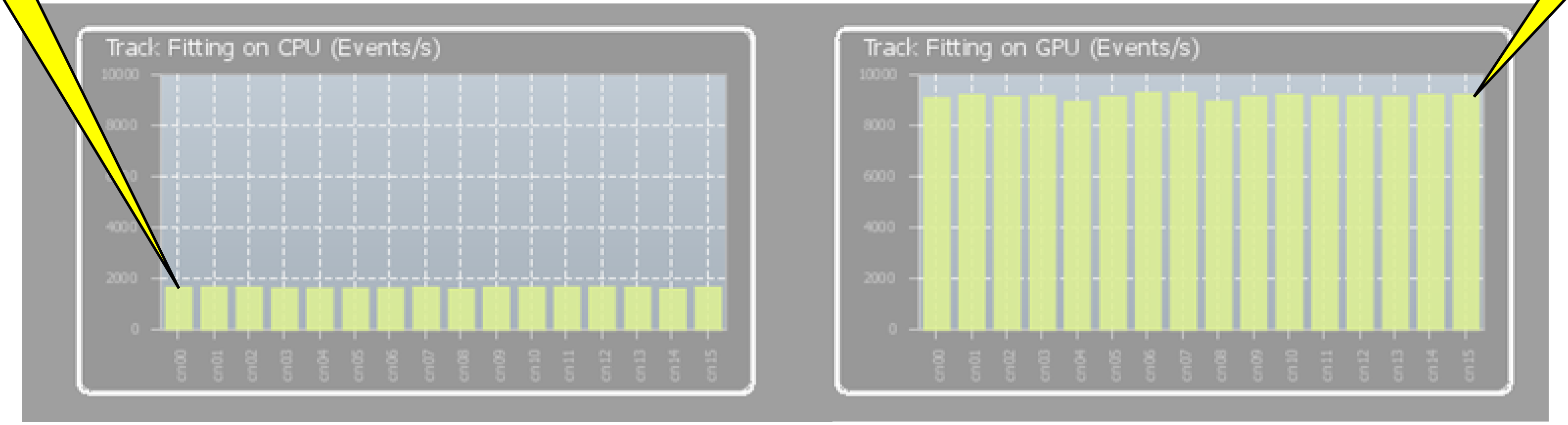
FPGA
Altera, ?

SIMD Kalman Filter Track Fit on Many-Core Systems



CPU 1600

GPU 9100



Type	Cores	Clock, GHz	Time/track, μs
Core 2	2	2.66	0.26
Core i7	4	3.2	0.1

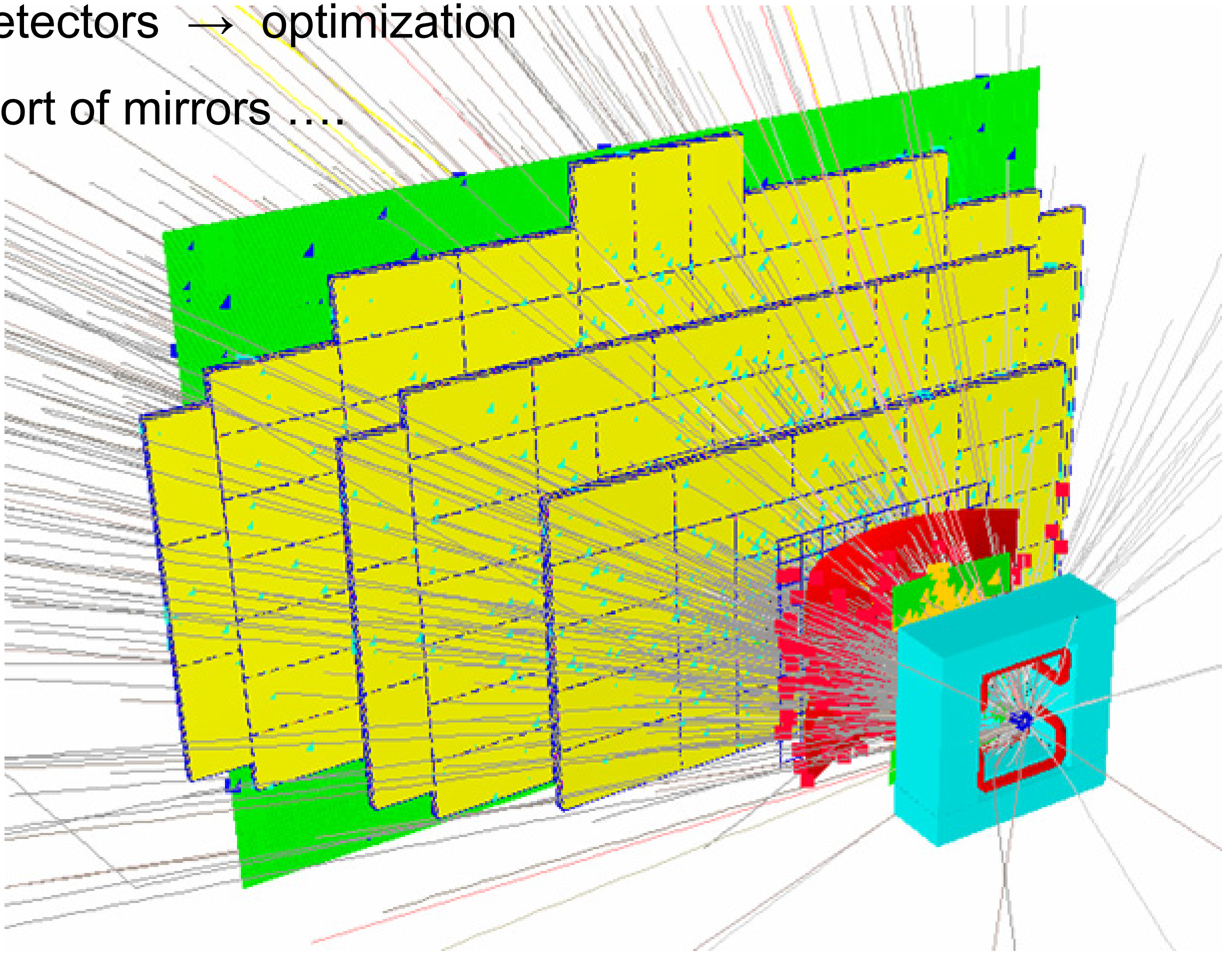
NVIDIA Unit	Clock, GHz	Throughput, 10^6 tr./s
8800 GTS 512	1.6	13.0
GTX 280	1.3	21.7

M. Bach, H. Bjerke, S. Gorbunov, I. Kisel, U. Kebschull, V. Lindenstruth, P. Post, R. Ratering

Detector layout & global track reconstruction

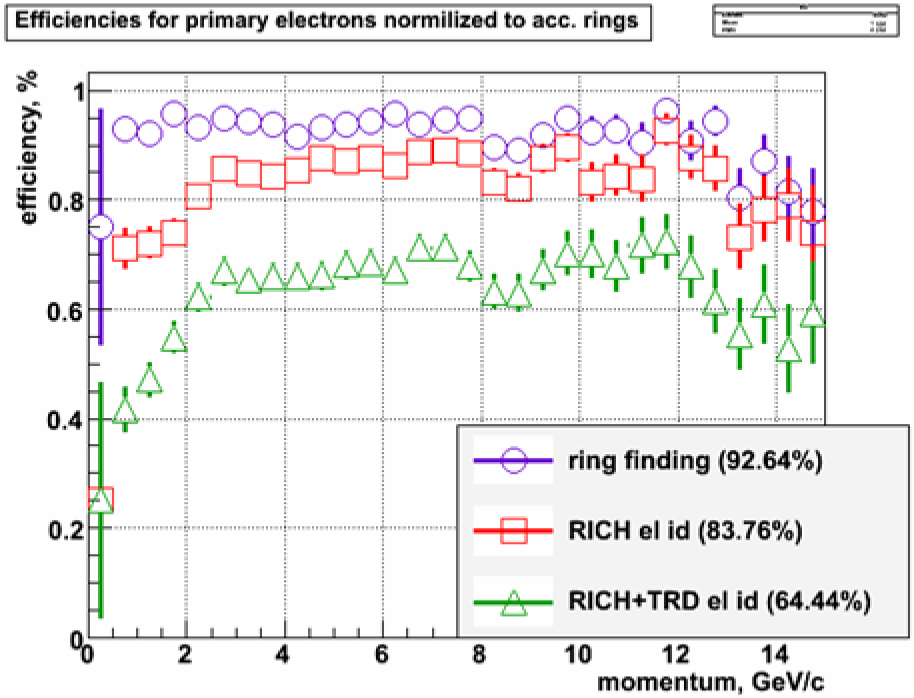
improved detector layout:

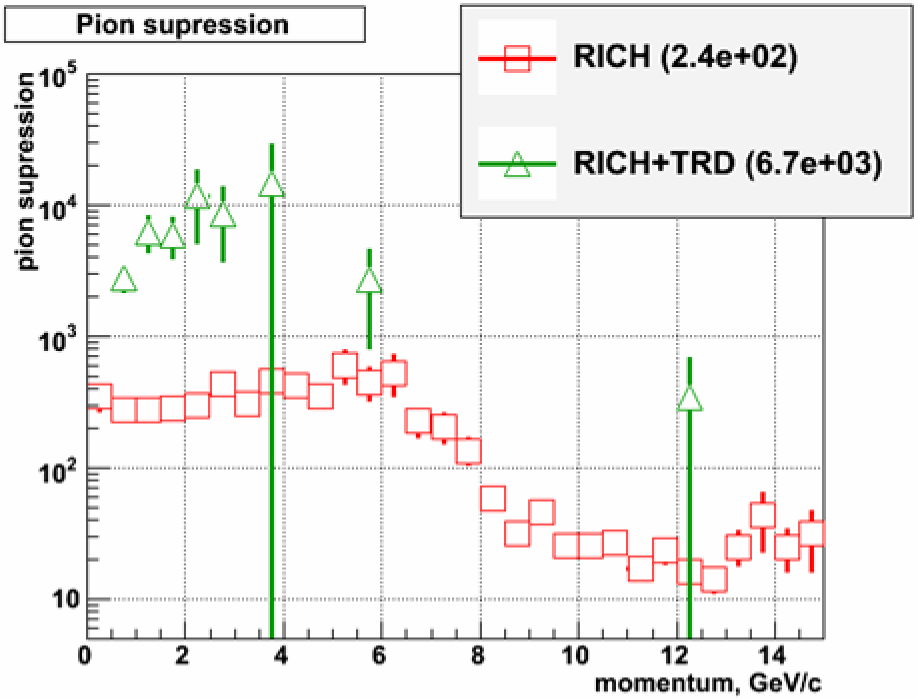
- modules with frames → study impact on efficiencies
- pad layout of detectors → optimization
- aluminum support of mirrors ….



RICH & TRD layout studies

- re-designed RICH detector: 6mm glass mirrors, aluminium support, CO$_2$ radiator, total length1.8 m
- segmented TRD layout including module frames
- STS module layout including ladders, cables …. : still adopt tracking!
- first tests and efficiency studies: 65% e-efficiency at (0.5 -1)·10^4 π-suppr. !

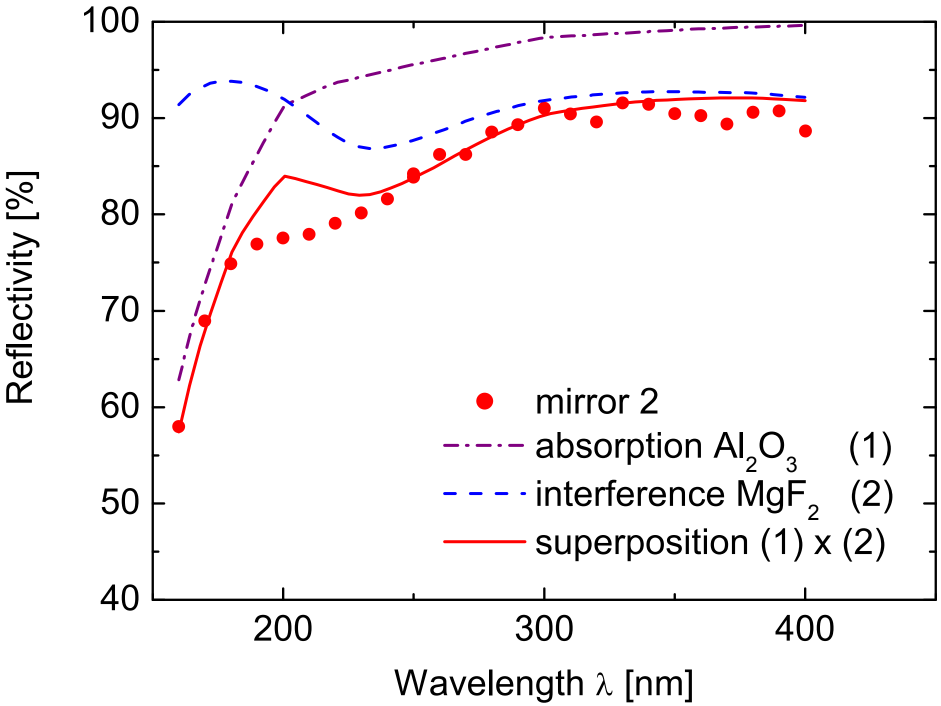




RICH mirror R&D

- find industry partner providing the glass substrate with good surface homogeneity **and** the coating (Al + MgF_2)
- 1st trial: FLABEG GmbH, Furth im Wald, Germany (R = 3.2 m, d = 6mm, Al+MgF_2 coating)
  - good reflectivity
  - surface inhomogeneities on cm scale

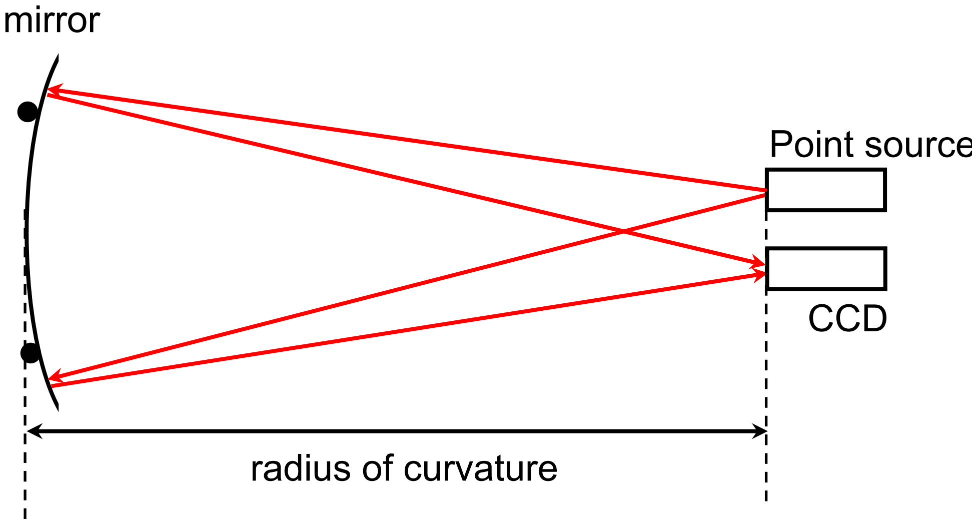
  → 2nd prototype from Compas, Czech Republic

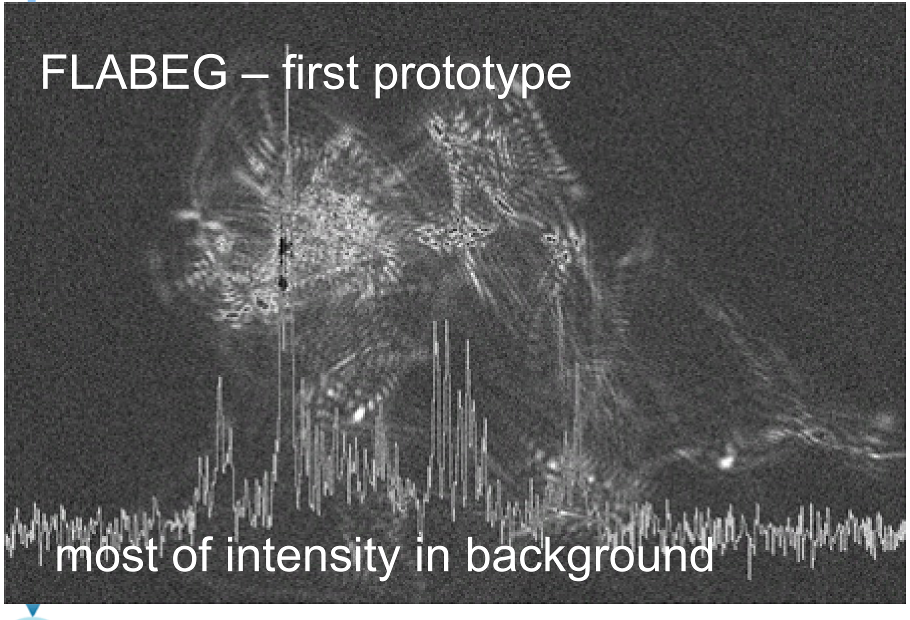


RICH mirror R&D

- measurement for radius of curvature, projection properties

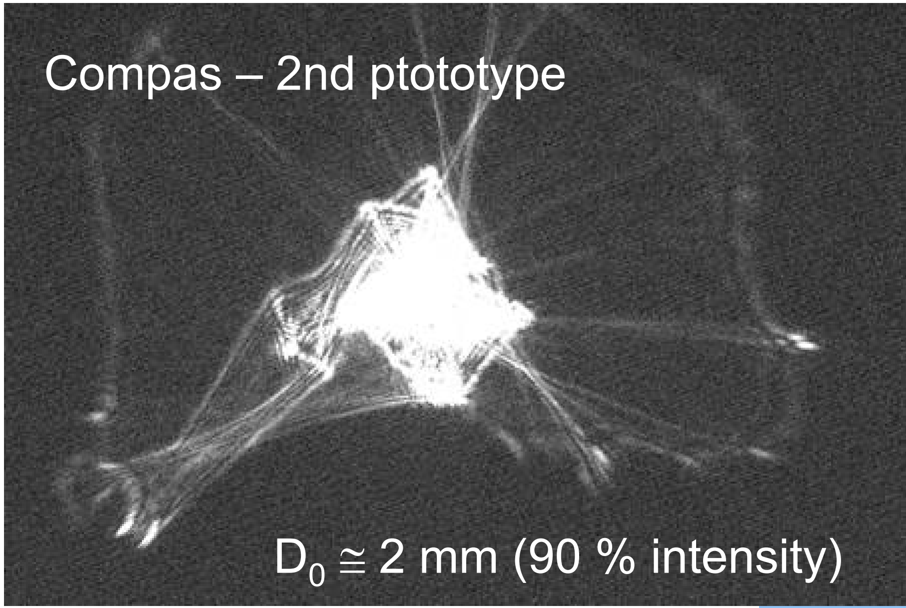
Mirror measurements in cooperation with CERN: A. Braem, C. d'Ambrosio





FLABEG – first prototype

most of intensity in background

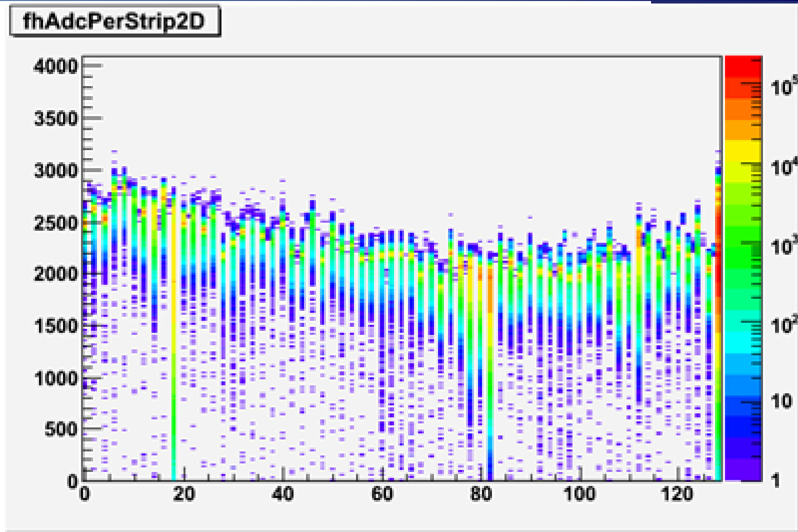


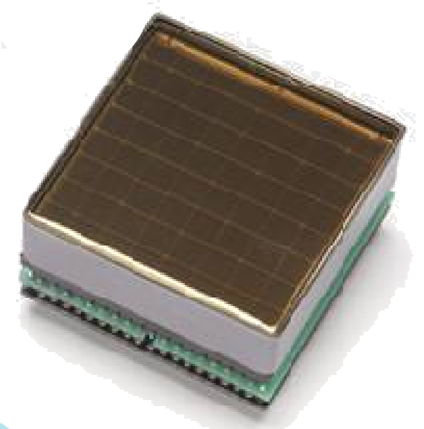
Compas – 2nd ptototype

$D_0 \cong 2$ mm (90 % intensity)

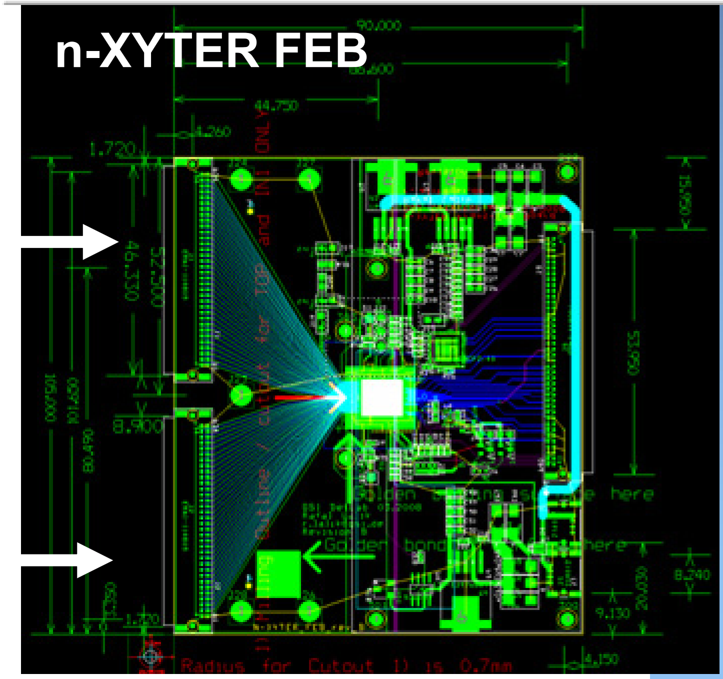
RICH Photodetector R&D

- Hamamatsu H8500 MAPMT (pixel size ~6x6 mm^2)
- readout with self triggered N-XYTER chip?
- collecting first first experiences





charge attenuator board



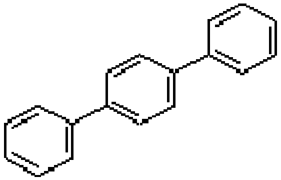
WLS films

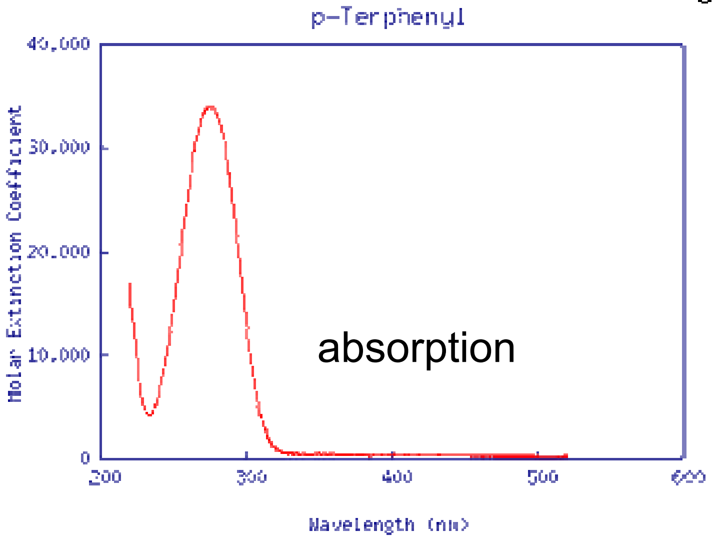
Wavelength shifting films – principle and application

- Organic molecules absorbing in the short (UV) wavelength region
- Strong fluorescence in visible region
- Application via evaporation, spin coating/ dip coating

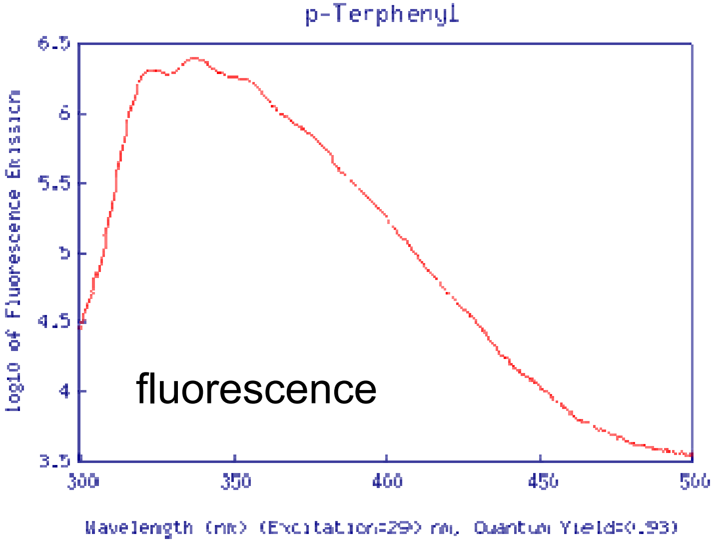
… many papers and investigations in the 70s: renewed interest!

Example: p-Terphenyl





absorption

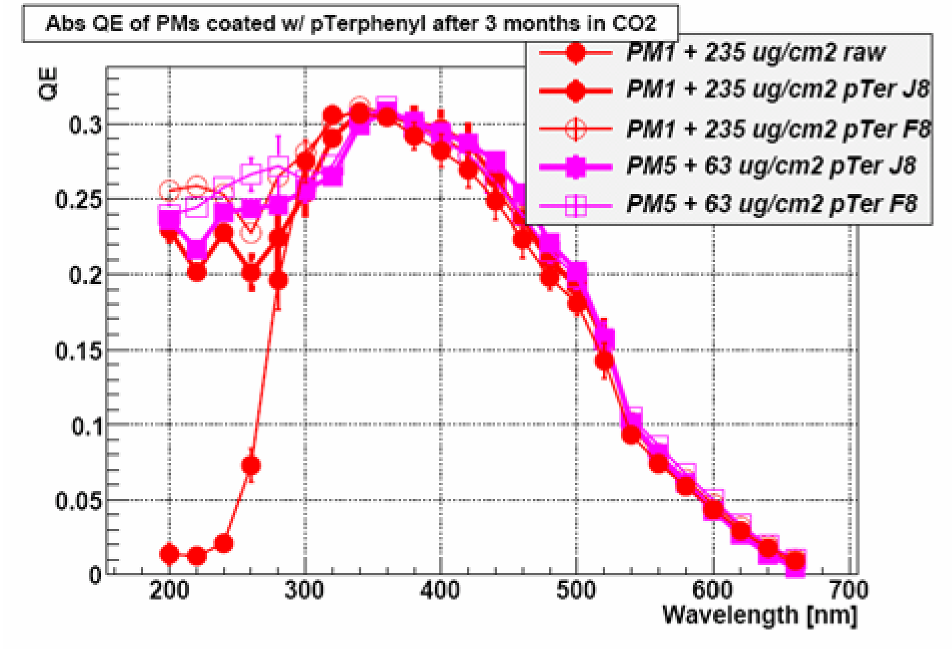


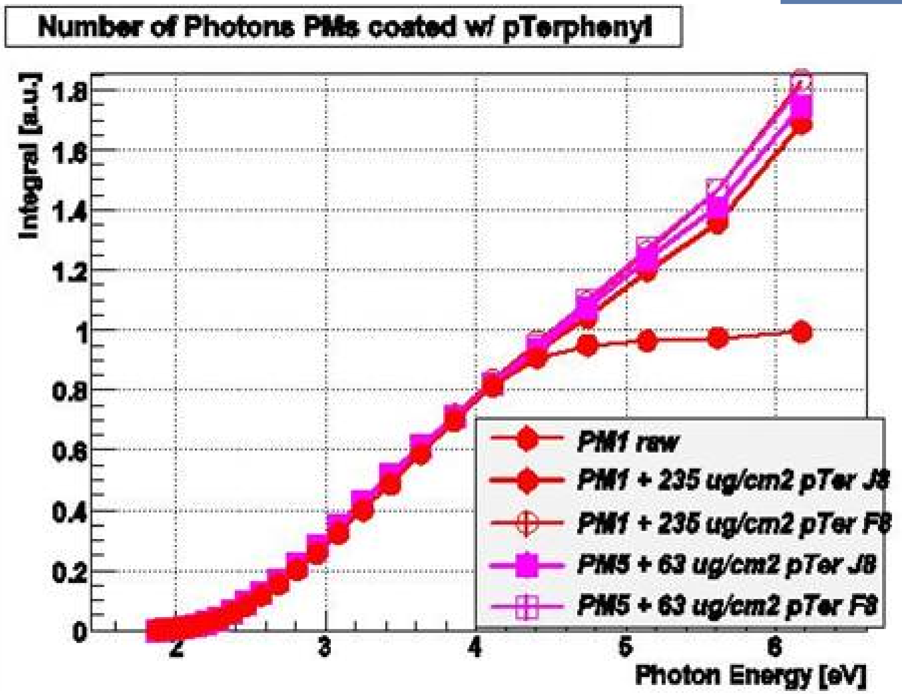
fluorescence

http://omlc.ogi.edu/spectra/PhotochemCAD/html/p-terphenyl.html

WLS films

- gain of factor ~1.8 in integrated photon number due to extended wavelength range down to 200nm
- **continue investigations: application technique, time response, crosstalk effects if used with MAPMT**

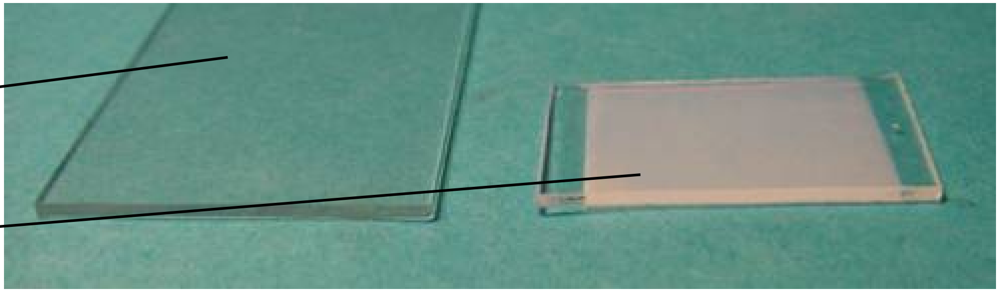




WLS films

- application technique alternative to evaporation: spin or dip coating

→ WLS layer scratch proove, less light diffusion



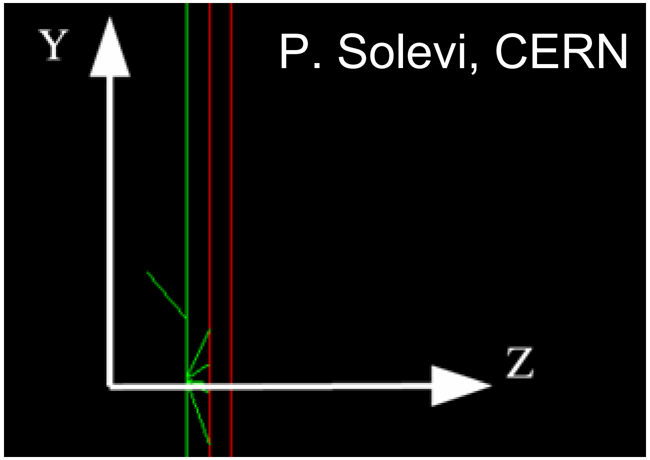
Dip-coated film, 6 cm/min

Evaporated film, 100 µg/cm^2

- simulations for spread of photons on photocathode after absorption and re-emission with WLS film

→ photons spread by 3mm (RMS)

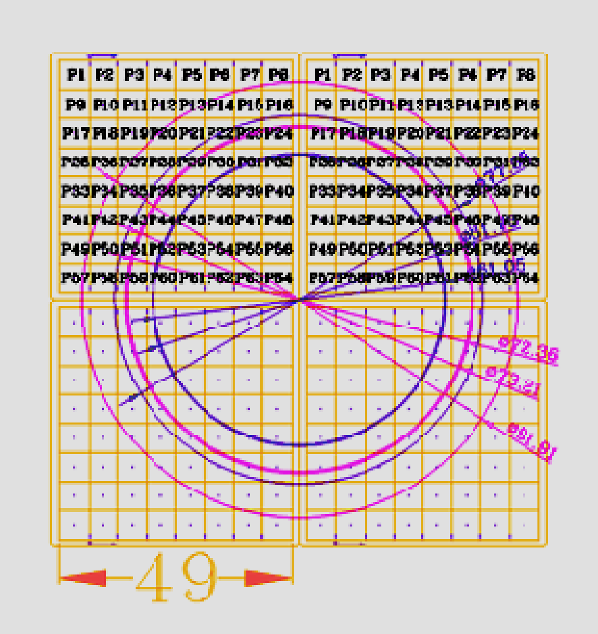
- H8500: appr. (6x6) mm^2 pixels

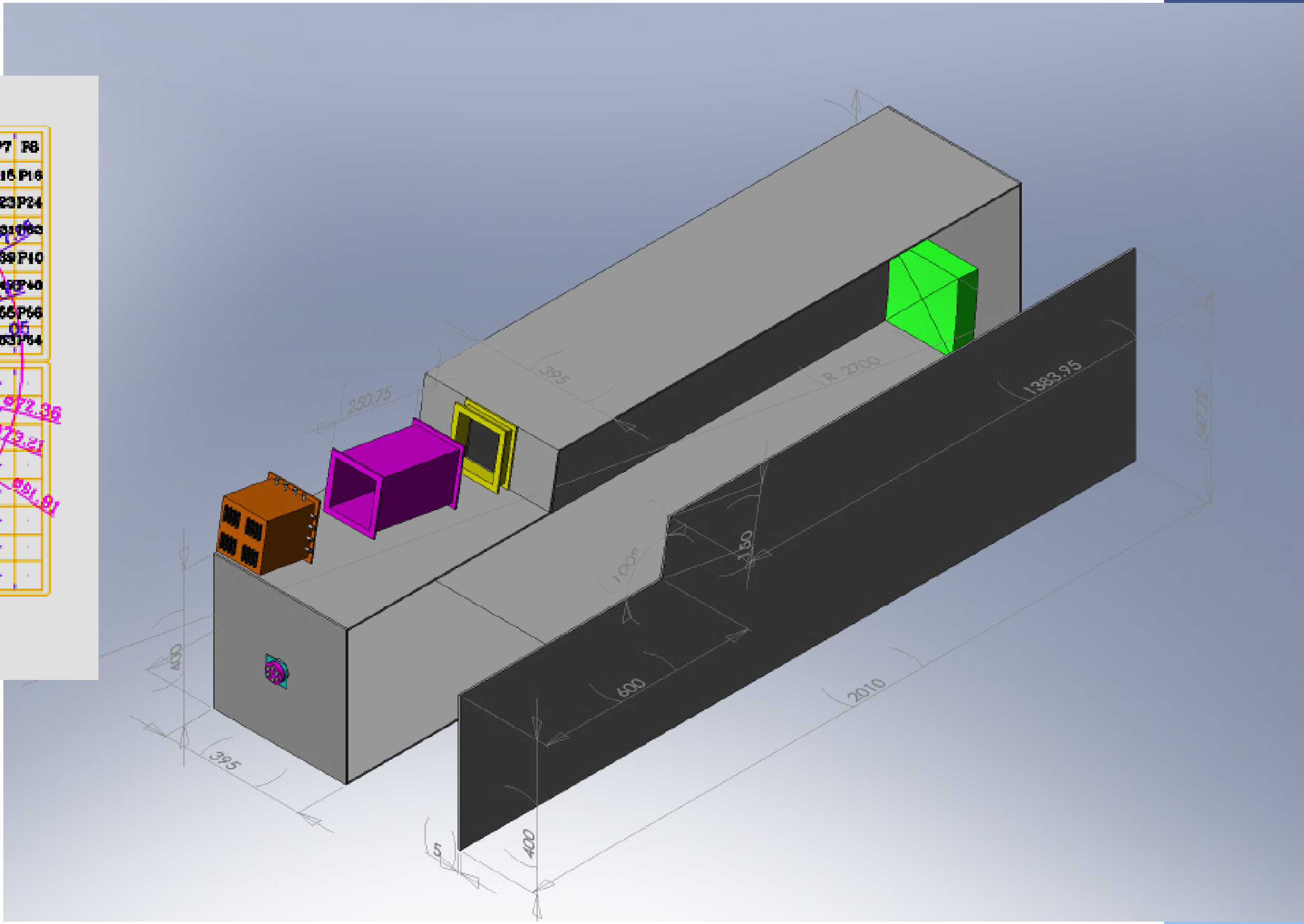


P. Solevi, CERN

RICH Prototype

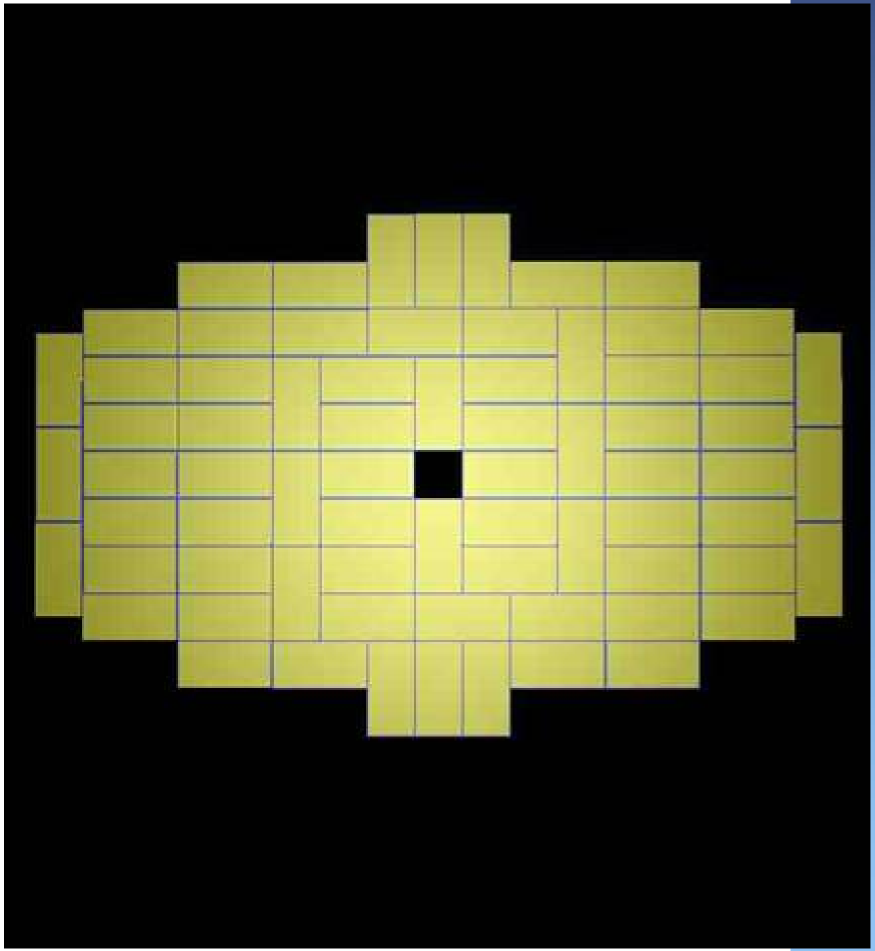
- **prepare small RICH prototype at Natl. University Pusan for test of components and verification of simulations**





TRD layout

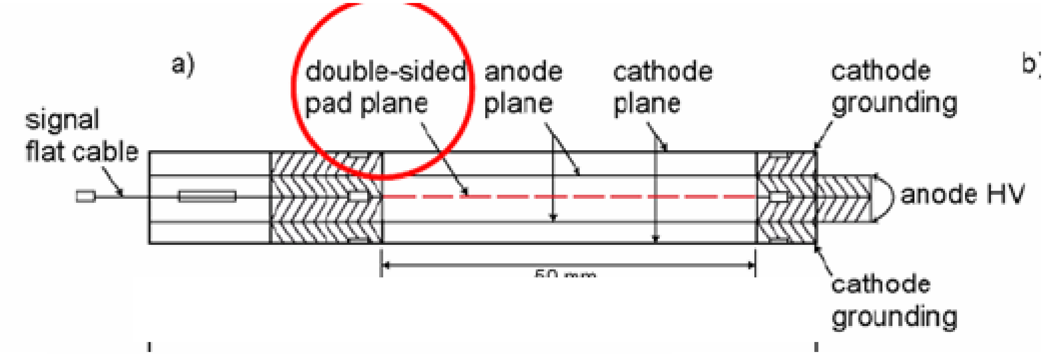
- ongoing work towards a realistic TRD design
- enlarge TR detection probability by
  - larger gas gap in outer regions (lower rates)
  - double gas layer with intermediate double sided pad plane in inner region (higher rates)

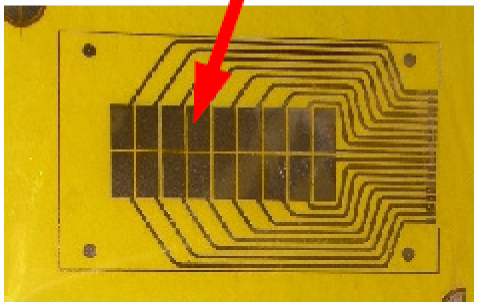


Real size TRD prototypes (double layer type)

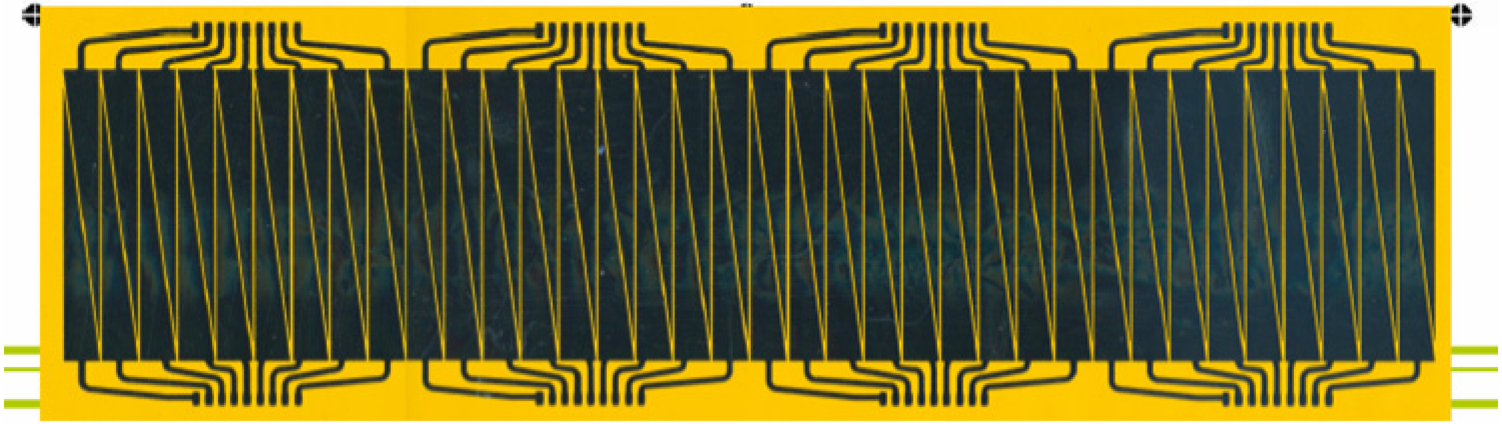
Münster-Bucharest development:

- enlarged TR photon detection probability due to larger gas gap



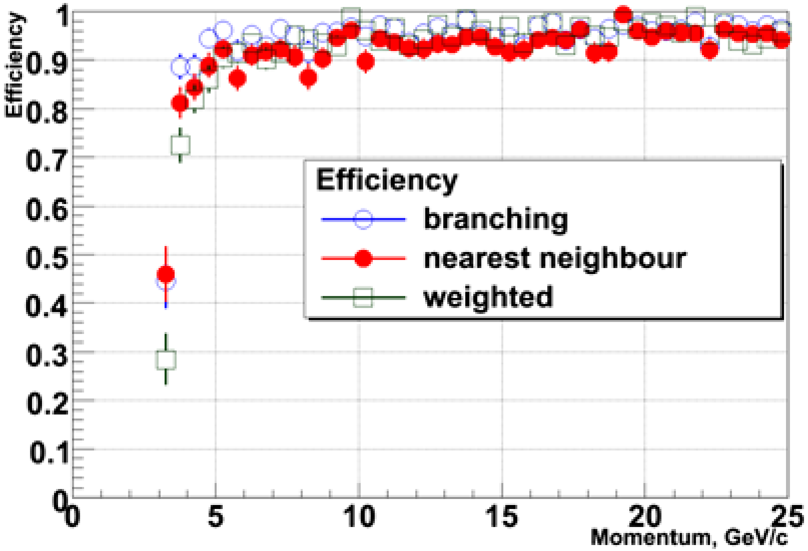


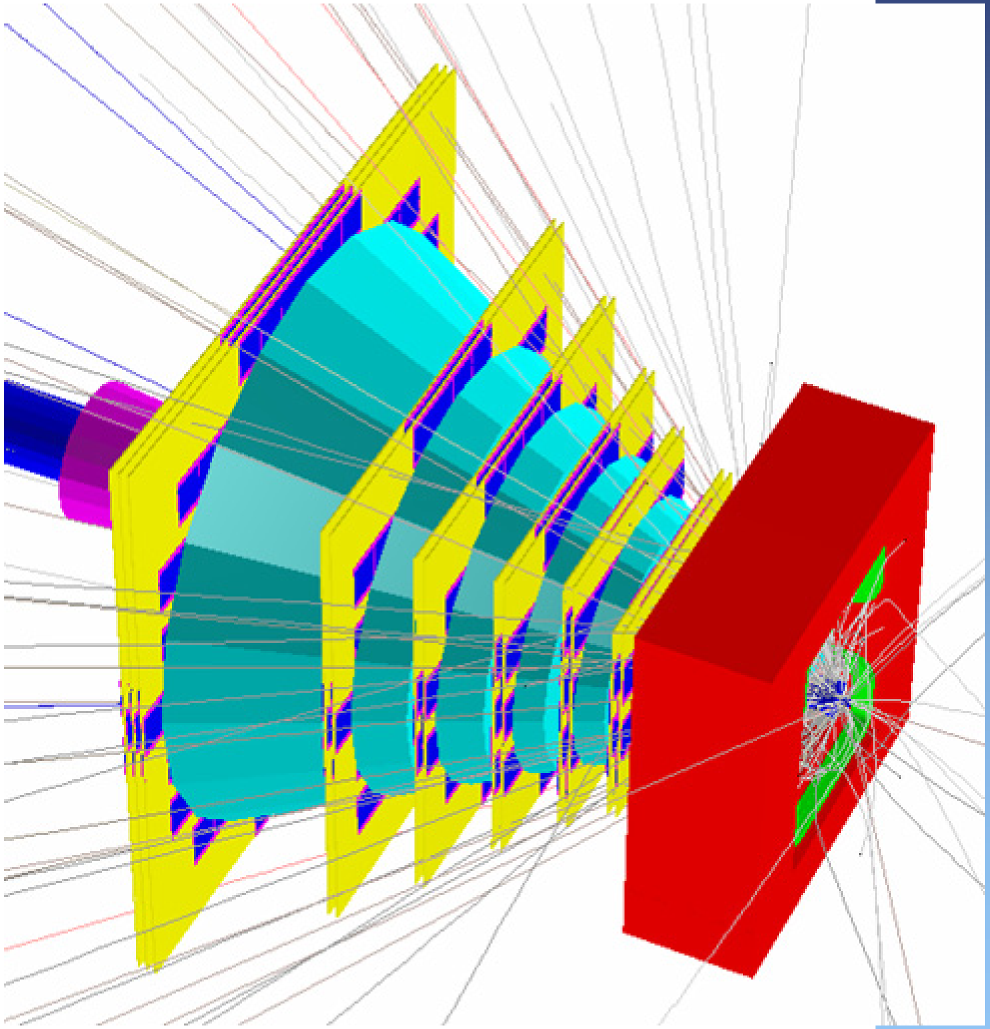
› 36 readout pads
› Total size: 80mm x 377.5mm



… towards a realistic MuCh detector layout

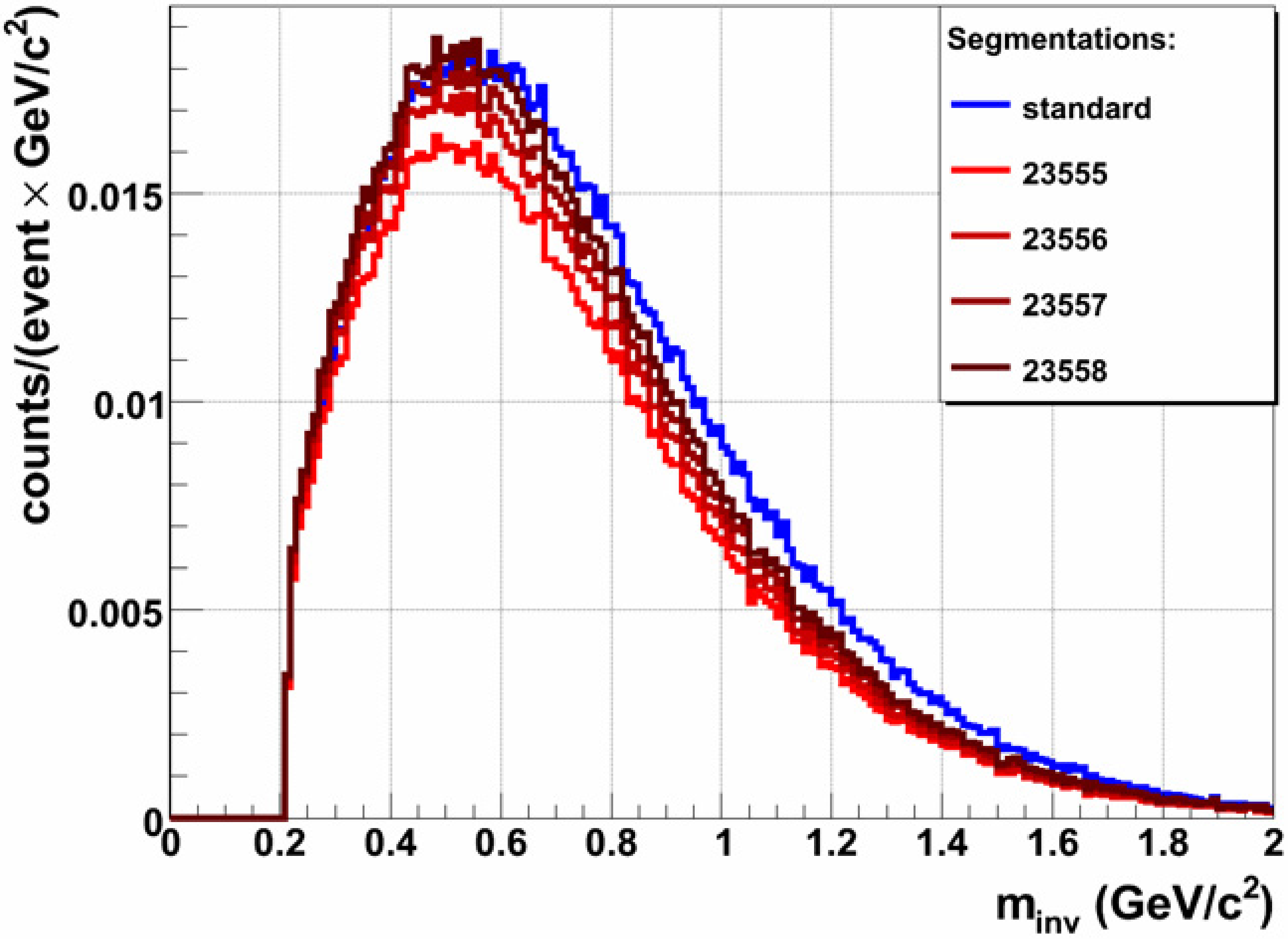
moduls, frames, pads,
overlapping sensors ….





MuCh detector optimization

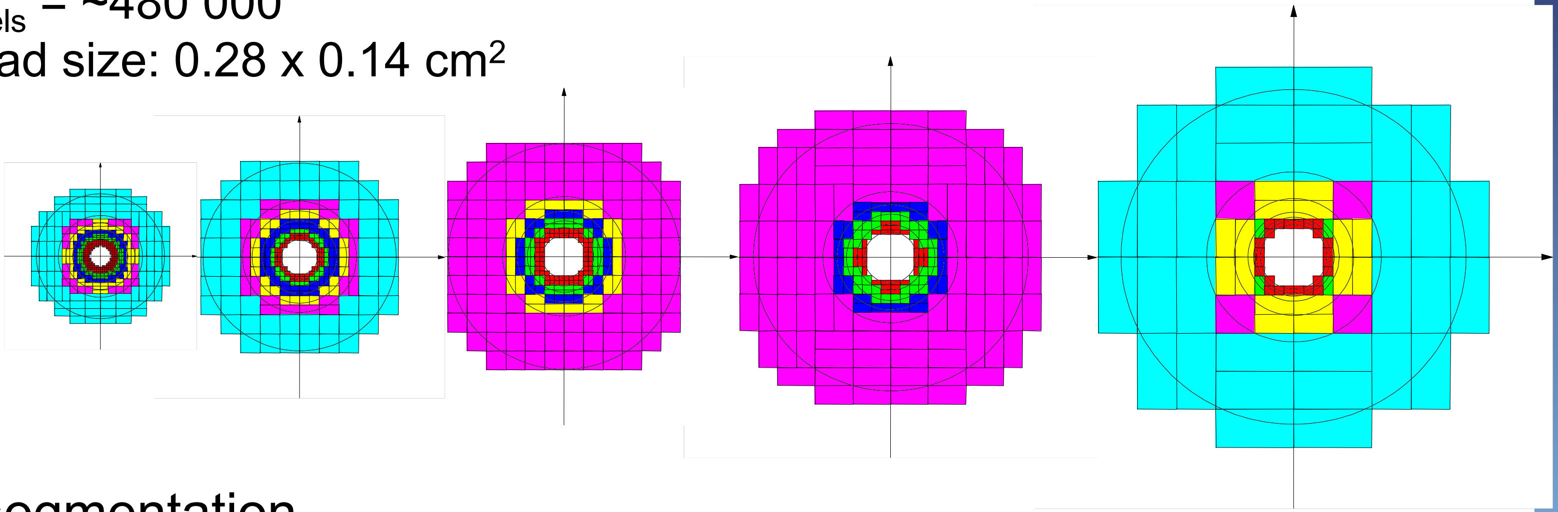
- systematic study of background distribution assuming different pad segmentation



Comparison of pad segmentation schemes

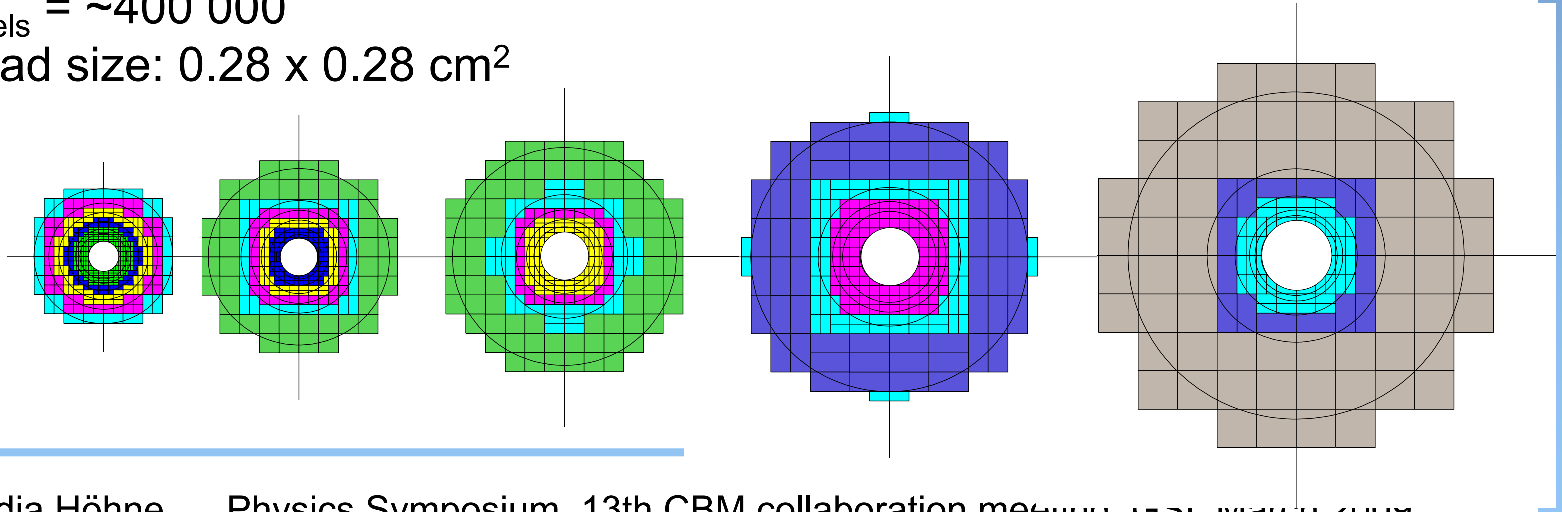
old segmentation

$N_{channels}$ = ~480 000
min. pad size: 0.28 x 0.14 cm^2



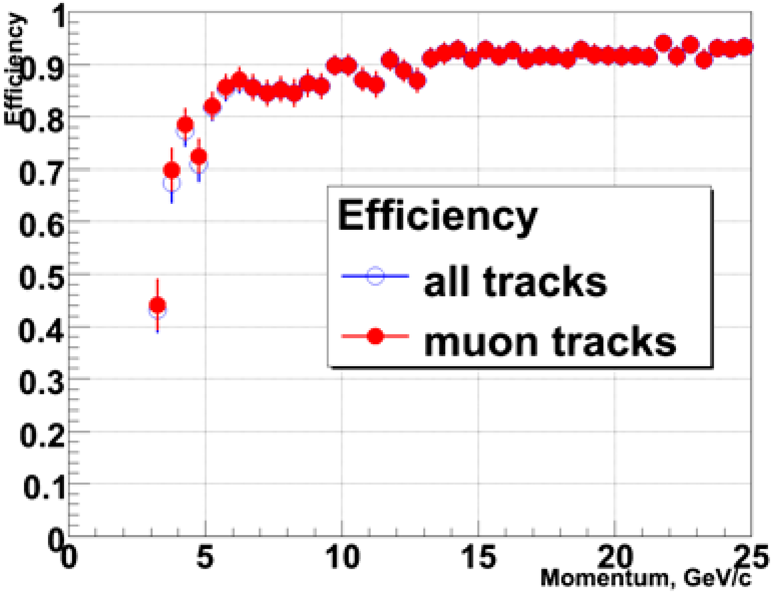
new segmentation

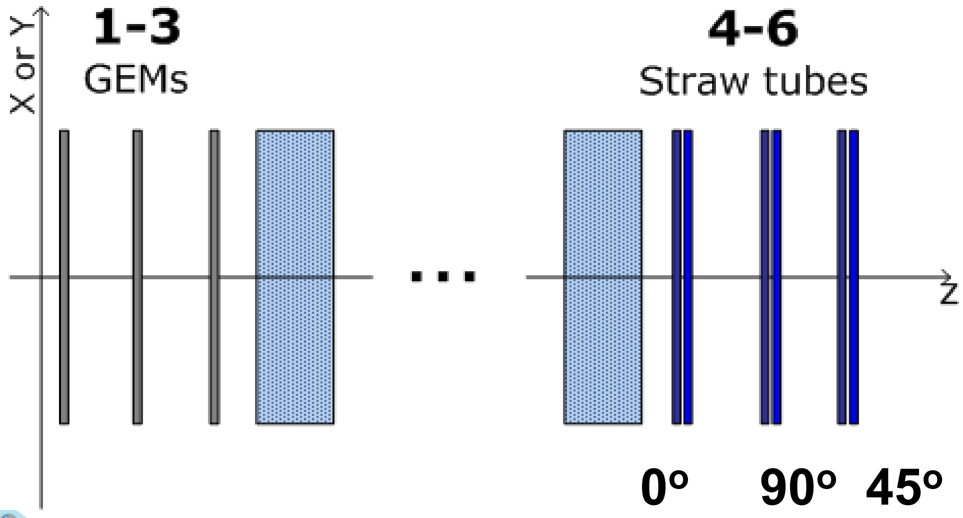
$N_{channels}$ = ~400 000
min. pad size: 0.28 x 0.28 cm^2

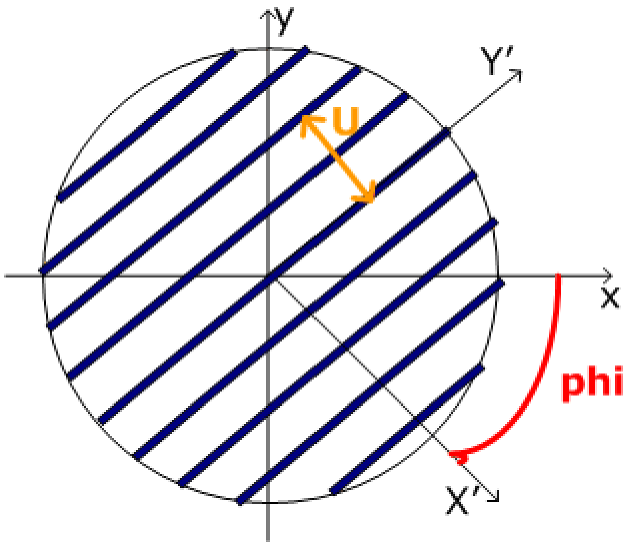


… towards a realistic MuCh layout

- first 3 detectors stations (high hit densities) GEMs
- later detector stations from straw tubes







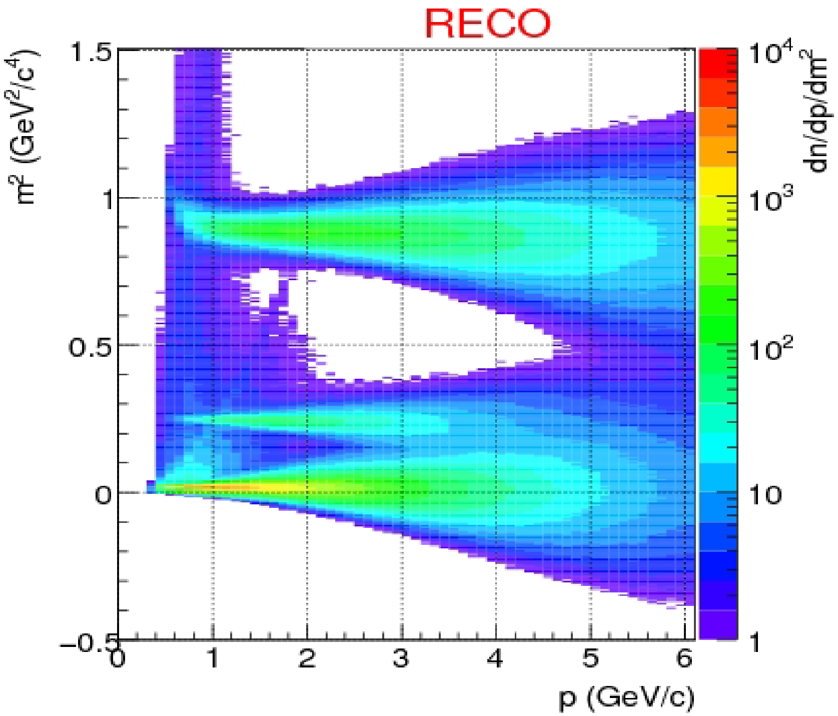
Hadron Identification

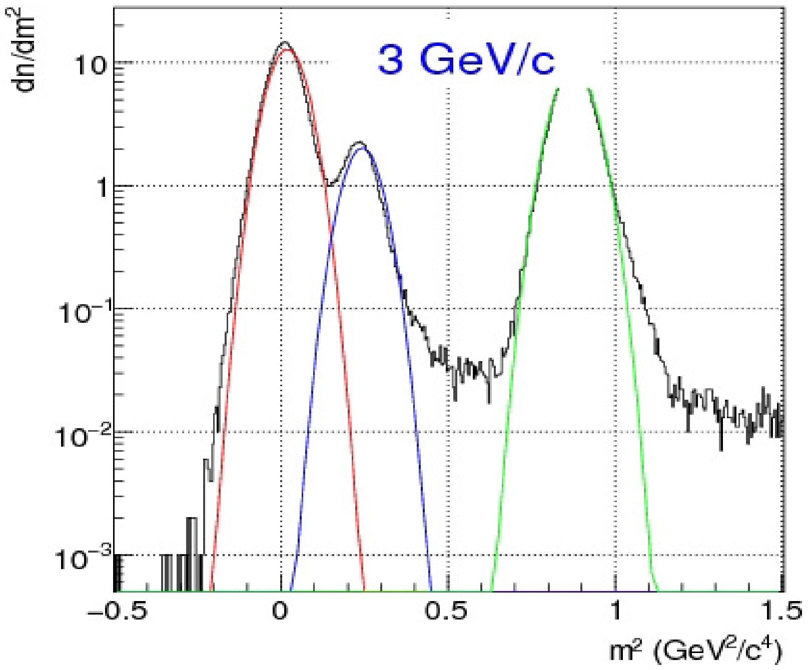
- hadrons will be identified by TOF (80 ps time resolution)

→ good kaon-pion separation up to 3.5 GeV/c (99% purity)

$$purity = \frac{N_K}{N_{all}} \cdot 100\%$$

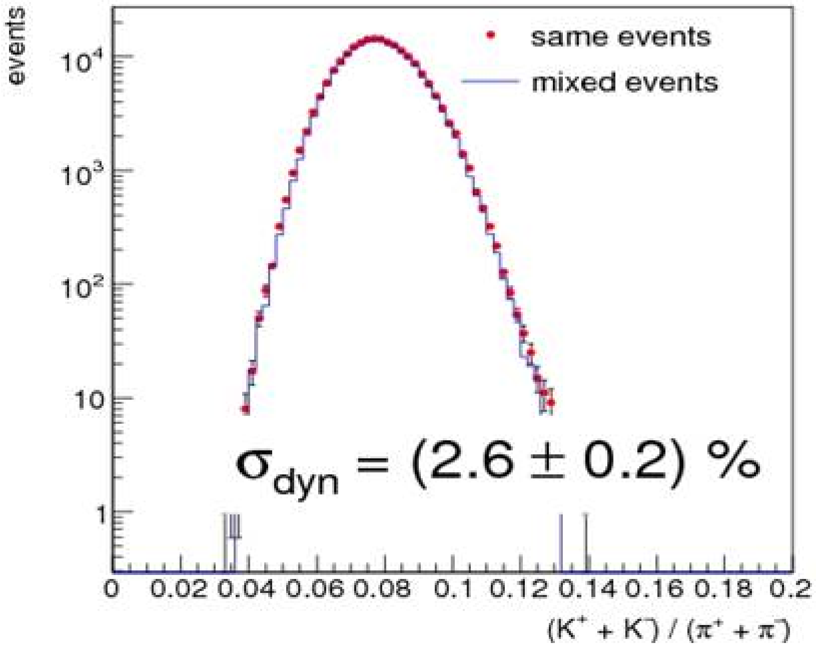
calculated for each momentum bin



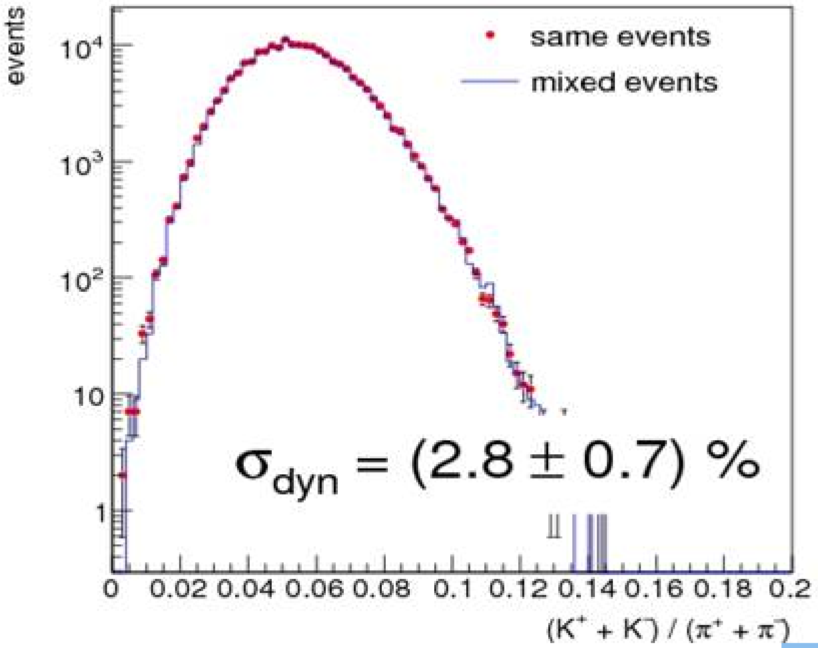


K/π Dynamical Fluctuations

- event-by-event K/π fluctuations from UrQMD
- no large acceptance bias (p < 5 GeV/c)



UrQMD: 4π



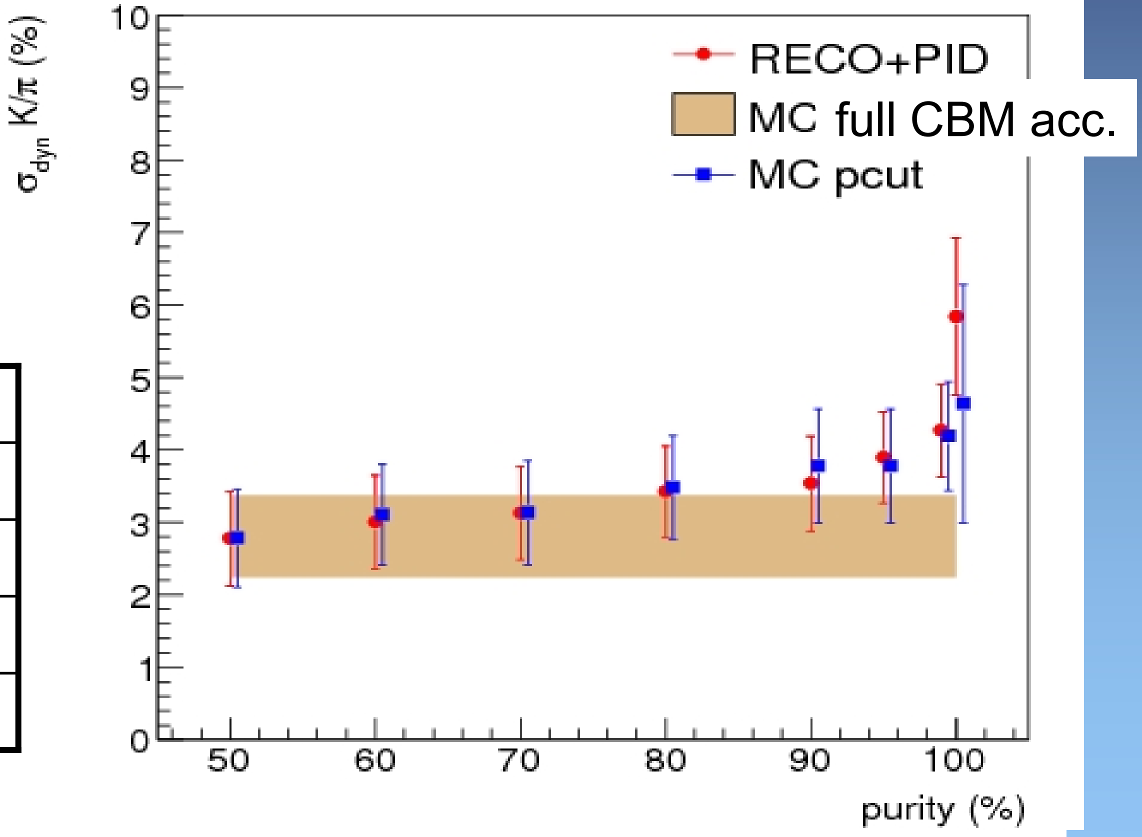
RECO + PID
50% purity (p < 5 GeV/c)

Purity Study

- purity restriction implies a momentum cut off for kaons
- acceptance effects fluctuation values: rise for lower p-cut off = higher purity of kaons

→ **80 ps time resolution!**

K purity	p-cut
50 %	5 GeV/c
90 %	4.2 GeV/c
99 %	3.5 GeV/c
100 %	2.2 GeV/c



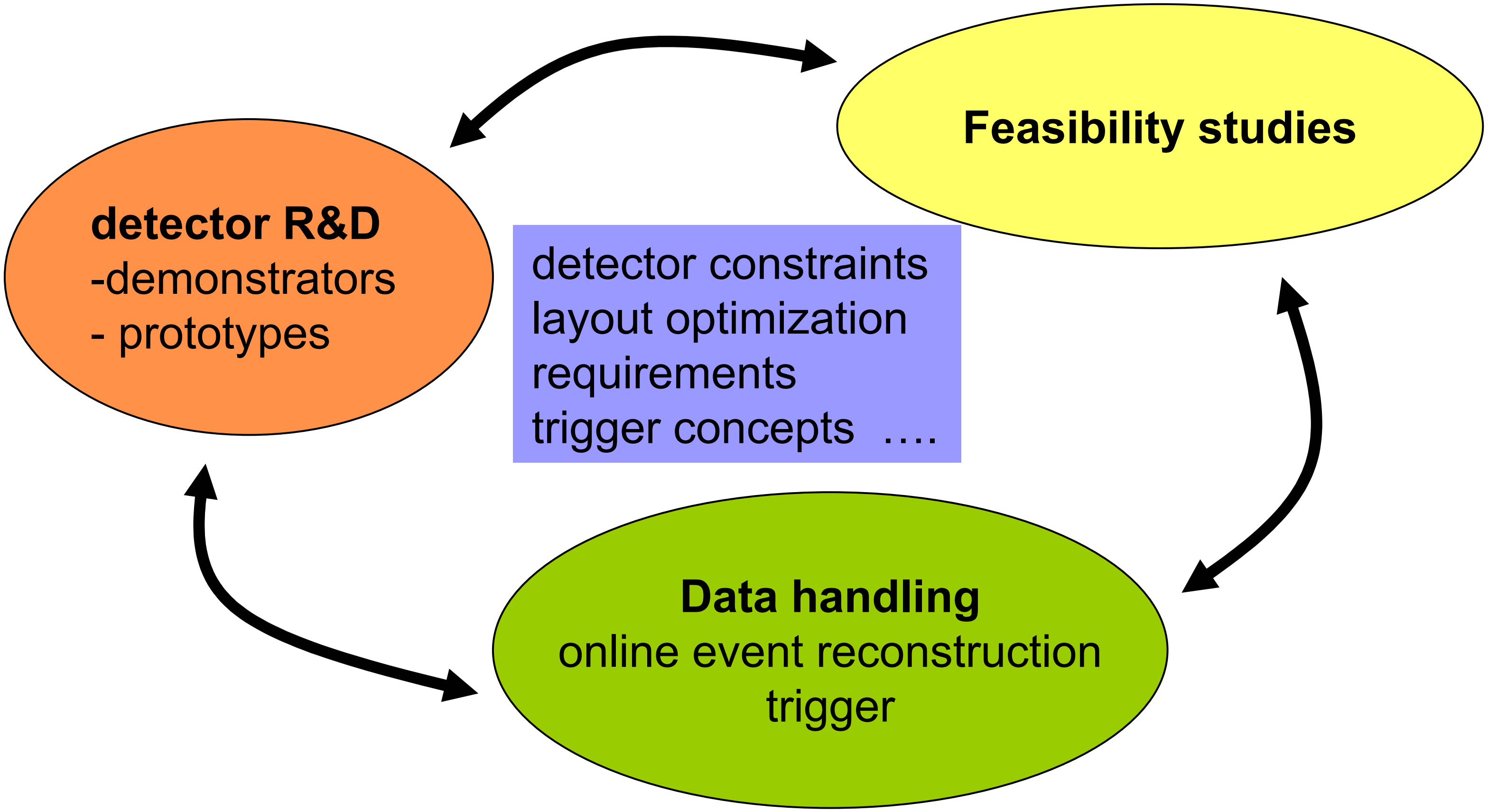
…. This was an incomplete overview ….

- GEM and straw tube R&D for MuCh
- RPC R&D
- ECAL – redesign with respect to phase space coverage, feasibility studies including advanced detector simulations: cluster shapes ….
- simulations on direct photon production, first studies on flow and reaction plabe resolution with the proposed PSD
- ….

For the presented R&D and simulation status I thank:
MVD – C. Müntz
STS – J. Heuser
RICH – M. Dürr, P. Koczon
TRD – M. Klein-Bösing
Fast tracking – I. Kisel
Simulations – C. Dritsa, A. Kiseleva, D. Kresan, A. Lebedev, S. Lebedev, I. Vassiliev

Summary

- overall detector concept ✓
- 1st round of feasibility studies ✓



Feasibility studies

detector R&D
-demonstrators
- prototypes

detector constraints
layout optimization
requirements
trigger concepts ….

Data handling
online event reconstruction
trigger

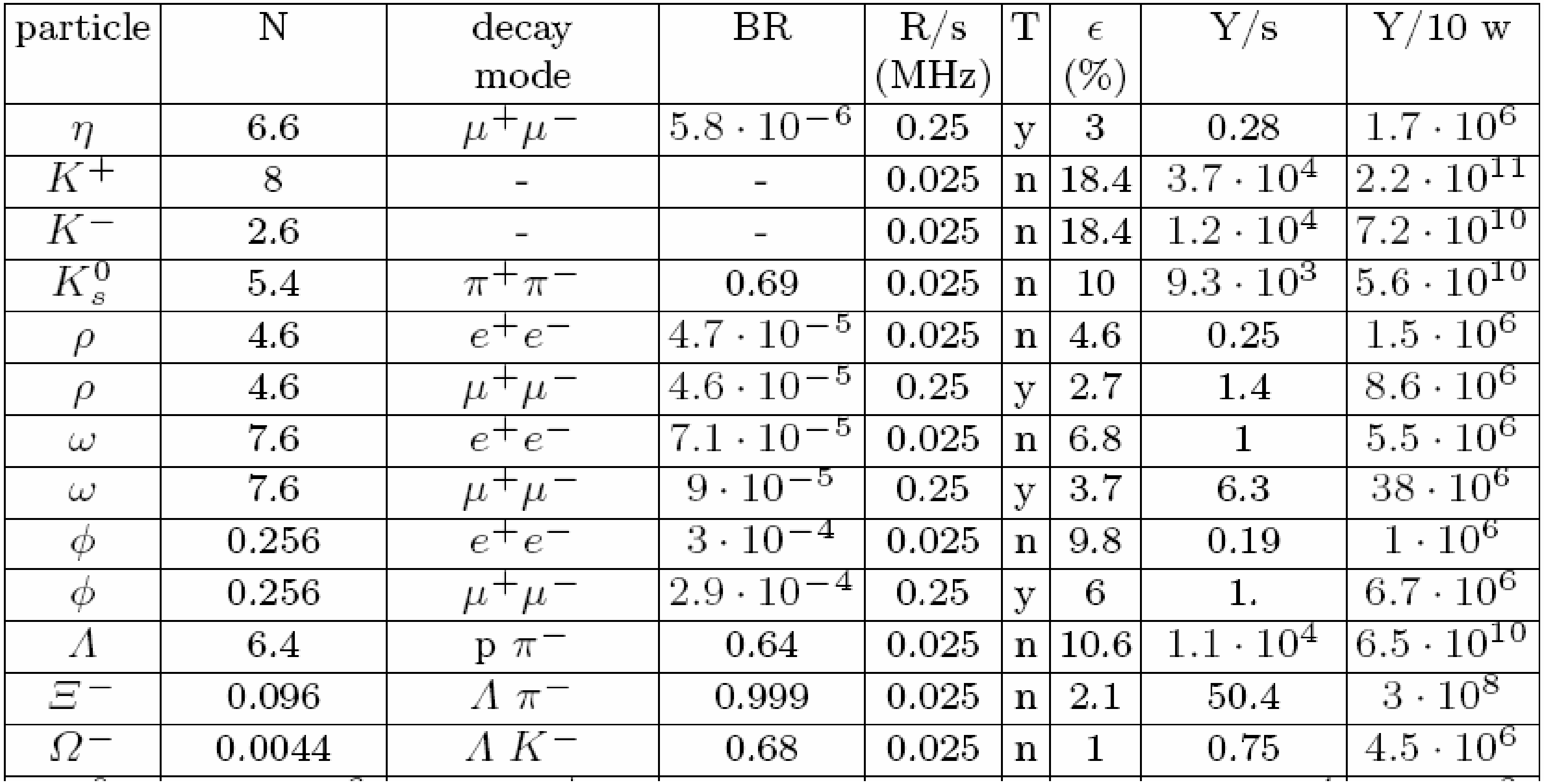
CBM collaboration

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. Heidelberg, Phys. Inst.
Univ. HD, Kirchhoff Inst.
Univ. Frankfurt
Univ. Mannheim
Univ. Münster
FZ Rossendorf
GSI Darmstadt
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
Kurchatov Inst. Moscow
LHE, JINR Dubna
LPP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk State Univ.
PNPI Gatchina
SINP, Moscow State Univ.
St. Petersburg Polytec. U.
Ukraine:
INR, Kiev
Shevchenko Univ. , Kiev

55 institutions, > 400 members

Dubna, Oct 2008

Expected particle yields



particle	N	decay mode	BR	R/s (MHz)	T	ϵ (%)	Y/s	Y/10 w
η	6.6	$\mu^+\mu^-$	$5.8 \cdot 10^{-6}$	0.25	y	3	0.28	$1.7 \cdot 10^6$
K^+	8	-	-	0.025	n	18.4	$3.7 \cdot 10^4$	$2.2 \cdot 10^{11}$
K^-	2.6	-	-	0.025	n	18.4	$1.2 \cdot 10^4$	$7.2 \cdot 10^{10}$
K_s^0	5.4	$\pi^+\pi^-$	0.69	0.025	n	10	$9.3 \cdot 10^3$	$5.6 \cdot 10^{10}$
ρ	4.6	e^+e^-	$4.7 \cdot 10^{-5}$	0.025	n	4.6	0.25	$1.5 \cdot 10^6$
ρ	4.6	$\mu^+\mu^-$	$4.6 \cdot 10^{-5}$	0.25	y	2.7	1.4	$8.6 \cdot 10^6$
ω	7.6	e^+e^-	$7.1 \cdot 10^{-5}$	0.025	n	6.8	1	$5.5 \cdot 10^6$
ω	7.6	$\mu^+\mu^-$	$9 \cdot 10^{-5}$	0.25	y	3.7	6.3	$38 \cdot 10^6$
ϕ	0.256	e^+e^-	$3 \cdot 10^{-4}$	0.025	n	9.8	0.19	$1 \cdot 10^6$
ϕ	0.256	$\mu^+\mu^-$	$2.9 \cdot 10^{-4}$	0.25	y	6	1.	$6.7 \cdot 10^6$
Λ	6.4	p π^-	0.64	0.025	n	10.6	$1.1 \cdot 10^4$	$6.5 \cdot 10^{10}$
Ξ^-	0.096	Λ π^-	0.999	0.025	n	2.1	50.4	$3 \cdot 10^8$
Ω^-	0.0044	Λ K^-	0.68	0.025	n	1	0.75	$4.5 \cdot 10^6$

$$Y/s = N \cdot BR \cdot \varepsilon \cdot R/s$$

Expected particle yields

particle	N	decay mode	BR	R/s (MHz)	T	ϵ (%)	Y/s	Y/10 w
D^0	$7.5 \cdot 10^{-6}$	$K^-\pi^+$	0.038	0.1	y	3.25	$8.5 \cdot 10^{-4}$	$5.1 \cdot 10^3$
D^0	$7.5 \cdot 10^{-6}$	$K^-\pi^+\pi^+\pi^-$	0.075	0.1	y	0.37	$2.1 \cdot 10^{-4}$	$1.3 \cdot 10^3$
D^0	$2.3 \cdot 10^{-5}$	$K^+\pi^-$	0.038	0.1	y	3.25	$2.6 \cdot 10^{-3}$	$1.6 \cdot 10^4$
D^+	$8 \cdot 10^{-6}$	$K^-\pi^+\pi^+$	0.092	0.1	y	4.2	$3.1 \cdot 10^{-3}$	$1.9 \cdot 10^4$
D^-	$1.8 \cdot 10^{-5}$	$K^+\pi^-\pi^-$	0.092	0.1	y	4.2	$7 \cdot 10^{-3}$	$4.2 \cdot 10^4$
D_s^+	$1.08 \cdot 10^{-6}$	$K^+K^-\pi^+$	0.053	0.1	y	1	$5.7 \cdot 10^{-5}$	$3.5 \cdot 10^2$
Λ_c	$4.9 \cdot 10^{-4}$	$pK^-\pi^+$	0.05	0.1	y	0.5	$1.2 \cdot 10^{-2}$	$7.4 \cdot 10^4$
J/ψ	$3.8 \cdot 10^{-6}$	e^+e^-	0.06	10	y	13	0.32	$1.9 \cdot 10^6$
ψ'	$5.1 \cdot 10^{-8}$	e^+e^-	$7.3 \cdot 10^{-3}$	10	y	14	$5.2 \cdot 10^{-4}$	$3.2 \cdot 10^3$
J/ψ	$3.8 \cdot 10^{-6}$	$\mu^+\mu^-$	0.06	10	y	16	0.36	$2.2 \cdot 10^6$
ψ'	$5.1 \cdot 10^{-8}$	$\mu^+\mu^-$	$7.3 \cdot 10^{-3}$	10	y	19	$7.1 \cdot 10^{-4}$	$4.3 \cdot 10^3$

$$Y/s = N \cdot BR \cdot \varepsilon \cdot R/s$$

Online event reconstruction and selection

Minimum bias Au+Au 25 AGeV:

2009: 50 ms/ min. bias event (1 CPU)
10^7 events/s
5 × 10^5 CPU

Transition to many-core & wide-SIMD systems:
CPU → GPU: today 1 TFlop/system (50 × today's CPU)
10^4 GPU

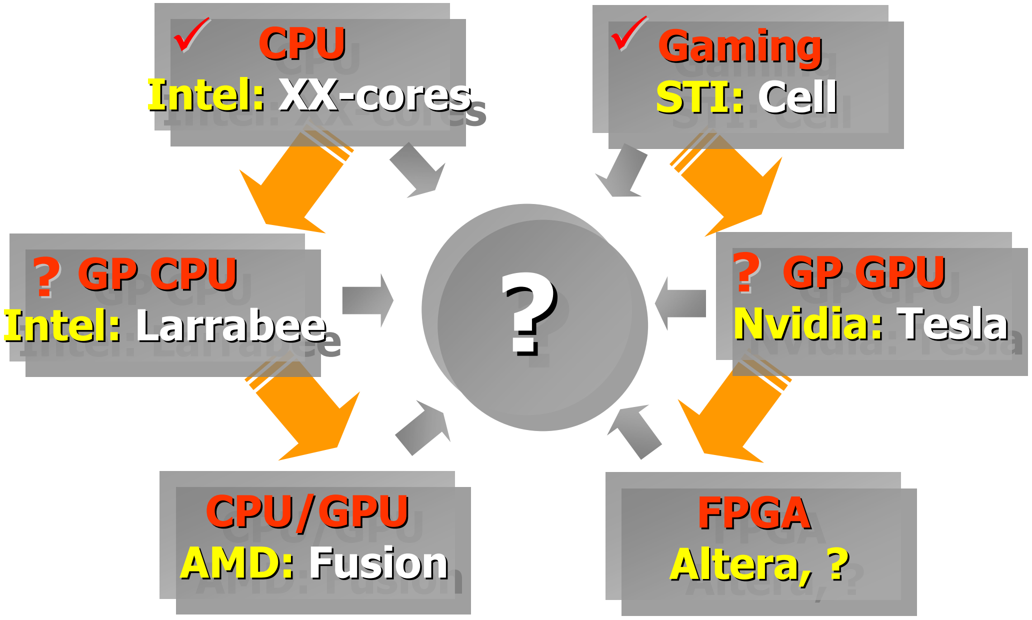
2015: with help of "Moore's Law" ⇒ **several 1000 GPU**

Physics cases:

1) $J/\psi \rightarrow e^+e^-$: min. bias events
2) Open charm: limited by MVD (10^5 – 10^6 events/s)
3) J/ψ with $\mu^+\mu^-$: pre-selection by MUCH (× 10^{-3})
4) ω, ϕ with $\mu^+\mu^-$: pre-selection by MUCH (× 10^{-1})

Many-core HPC

- High performance computing (HPC)
- Highest clock rate is reached
- Performance/power optimization
- Heterogeneous systems of many (>8) cores
- Similar programming languages (OpenCL, Ct and CUDA)
- We need a uniform approach to all CPU/GPU families



✓ **CPU**
Intel: XX-cores

✓ **Gaming**
STI: Cell

? **GP CPU**
Intel: Larrabee

?

? **GP GPU**
Nvidia: Tesla

CPU/GPU
AMD: Fusion

FPGA
Altera, ?

- On-line event selection
- Mathematical and computational optimization
- SIMDization of the algorithm (from scalars to vectors)
- MIMDization (multi-threads, many-cores)

RICH mirror R&D

- 2nd mirror prototype: Compas, Czech Republic (R = 3m, d = 3mm, Al+MgF_2 coating)
  - reflectivity ? – to be tested
  - good surface homegeneity